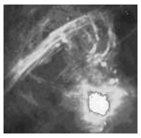
GCNEWS



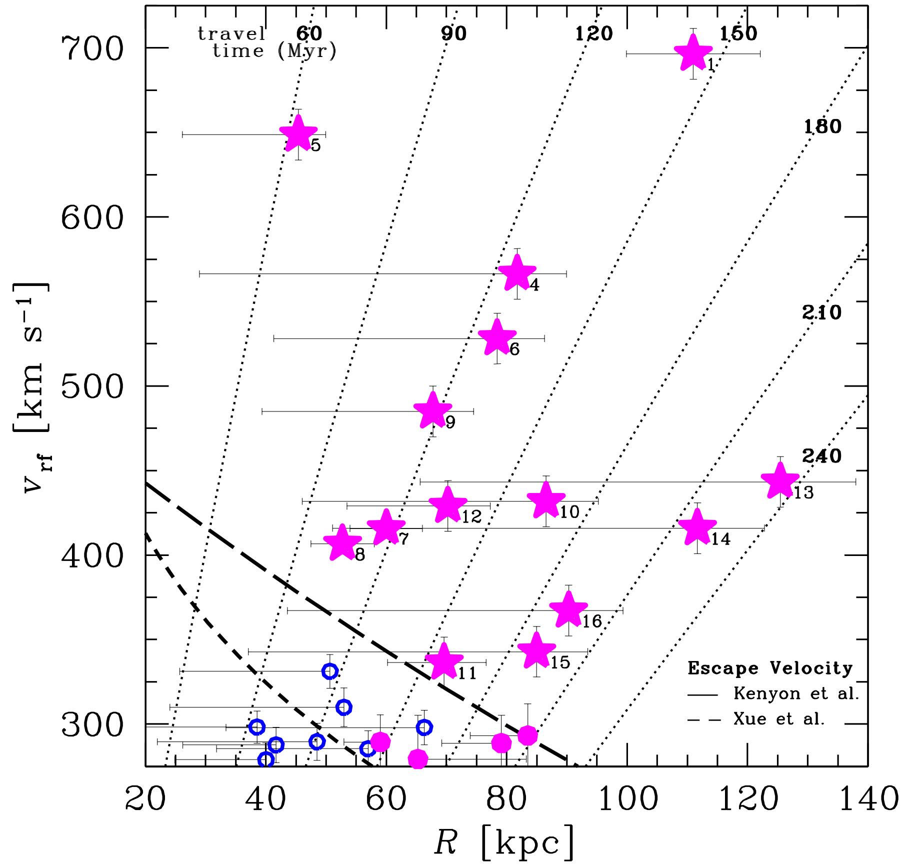
The Newsletter of Galactic Center Research

Cornelia Lang, Joseph Lazio, Sera Markoff, Masaaki Sakano, Rainer Schödel, Loránt Sjouwerman & Feng Yuan

Vol. 28 **2008 November**

email: gcnews@aoc.nrao.edu **http://www.aoc.nrao.edu/~gcnews/**

Hypervelocity Stars and the Galactic Center



The above image shows the distribution of the hypervelocity stars (HVSs), which are found in the survey by Brown et al. (2008), in the minimum rest-frame velocity vs. Galactocentric distance frame. Fourteen unbound HVSs (*solid stars*) have velocities and distances exceeding the Kenyon et al. (2008) escape velocity model (*long dashed line*), 4 possible HVSs (*dots*) are in excess of the Xue et al. (2008) escape velocity model (*dashed line*), whereas 8 possibly bound HVSs (*open circles*) are also indicated. For more details, see the invited article by Brown (The above figure is adopted from Fig. 3 in the article).

Table of Contents

In the News

Masaaki Sakano

GCNEWS Updates

Happy Autumn 2008 from the GC News Editors. This is our second issue this year and we are featuring an invited article entitled, "Hypervelocity stars and the Galactic Center". Hypervelocity stars (HVSs) are a class of stars that have an unusually high velocity, probably due to the fact that they are kicked off via three-body interaction with a massive black hole. The term 'HVS' was proposed by Hills (1988) as a theoretical concept. However, during the last three years, HVSs have been detected in our own Galaxy and possibly the LMC. The number of known HVSs is rapidly increasing. Warren R. Brown, one of the pioneers of the observational study of HVSs, summarises a recent survey of HVSs. They discovered over a dozen of solid HVS candidates, as well as a few more possible ones, and discusses its potential impact on the study of our Galactic Center region and more.

In this issue we have 64 abstracts submitted! Many thanks to all of these authors for sharing their work. Please note the variety and breadth of these abstracts — research on the GC is in a very vibrant phase, so make sure to look up some of these research results. Also, please continue to submit your recent publication information to GC News (including the link to `astro-ph`) and look for the email newsflashes to bring you news from our GC.

Finally we have great news for the GC community: the next GC workshop (GC2009) will be held in Shanghai, China on 19−23 October 2009. The workshop will be devoted to the presentation and discussion of observational and theoretical results on low-luminosity galactic nuclei. Studies of the Milky Way center and its surroundings will of course be emphasized at the conference. The chairs of the SOC, Feng Yuan and Daniel Wang, invite you to the conference, as announced in the next column. Please mark the date of the conference as well as the deadline of the early registration (1st June 2009), in your calendar. We'll see you all there!

Summary: *The Universe under the Microscope*

Several sessions of the workshop "The Universe under the Microscope - Astrophysics at High Angular Resolution" (21-25 April 2008, Bad Honnef, Germany) were dedicated to the nucleus of our own and those of other galaxies. Two sessions were focused exclusively on the GC: Session I - *Sagittarius A*: The inner accretion flow/outflow* and Session II - *The nuclear star cluster of the Milky Way.* Sessions related to external galactic nuclei were: Session V - *Black hole feeding from 1 kpc to the event horizon*, Session VI - *Nuclear star clusters and galaxy evolution*, and Session VIII - *Supermassive Black Holes and Microquasars.* Here we present a brief summary and highlight some important results and discussions.

Some of the talks can be found online at *http://www.astro.uni-koeln.de:8085/teaching_seminars /conferences/AHAR2008/* (follow the link to the Schedule, where some talks are linked to the corresponding files). The proceedings of *The Universe under the Microscope - Astrophysics at High Angular Resolution* will be published online by *Journal of Physics: Conference Series* in December 2008.

Sagittarius A*

The first simultaneous detection of the variable emission from Sgr A* in the near-infrared and at X-ray wavelengths occurred just a few years ago (Eckart et al., 2004, A&A). By now, coordinated multi-wavelength observations of the activity of Sgr A* have become a popular tool among the Sagittarius A* observers community. Several large teams are pursuing such campaigns, involving telescopes all across the globe and in space (e.g., Chandra, XMM, INTEGRAL, VLT, Keck, IRAM 30m, ATCA, CARMA). The X-ray to near-infrared connection has been studied in many flare events by now and can be fairly well modeled with synchrotron/synchrotron self-Compton processes. The connection between X-ray/NIR variability events and variability in the (sub-)mm regime has been less well studied until recently (mainly due to observational difficulties). Recent campaigns (2006 - 2008) have accumulated evidence, however, that NIR -flares appear to be accompanied by sub-mm flares lagging behind by about 90-100 min, This time lag is generally interpreted as being due to adiabatic expansion of the emitting plasma. It is not yet clear whether this expansion is accompanied by a large bulk motion, i.e. whether the plasma is ejected along a jet, or whether the expansion occurs rather within the accretion flow without plasma escaping the gravitational potential of Sgr A* (Talks by *Fred Baganoff*, *Andreas Eckart*, and *Stefan Gillessen*).

An issue that is still unresolved is the existence and role of quasi-periodic oscillations in the NIR lightcurves of Sgr A* flares. There is good evidence now that the NIR emission from Sgr A* is characterized by a red-noise-like process. This implies that the detected quasi-periodicities may simply be artifacts of the intrinsic power-spectrum, combined with short observing windows (*Tuan Do*). However, the physical causes of the red-noise are not understood. The inevitability of orbital motion in the accretion flow and the characteristics of certain flares with high modulation, partly observed in polarized light, lead other groups to claim that the quasi-periodic signals observed in some flare events are indeed connected to orbital motion of material near the last stable orbit of Sgr A* (*Andreas Eckart*). The dilemma is that it will be hard to claim statistical significance of detected quasi-periodicities – even if they are real – if the underlying process is indeed characterized by red-noise. Possibilities to resolve the current dead-lock are analyses of large data bases, new/more observations, and an understanding of what physical processes may underlie the red-noise.

Bozena Czerny from the Copernicus Astronomical Center in Warsaw, Poland, presented a low angular momentum flow model of the Sgr A* activity. The model can be located in a certain way between ADAF and Bondi Hoyle models. It predicts circularization of the accreted material at radii as small as a few, up to tens of Schwarzschild radii, high variability of the accretion flow, traces of QPO behavior, and leads to a flatter radio spectrum than spherical models or ADAFs. It is therefore an attractive theory to be applied to Sgr A* (and similar extremely sub-Eddington BHs in the Universe).

The nuclear star cluster of the Milky Way

Thibaut Paumard provided a review of the known facts and our understanding – and our gaps in this understanding – of star formation in the central 0.5 pc of the Milky Way. He discussed the various scenarios proposed to resolve the so-called "paradox of youth", i.e. the presence of massive, young stars in the immediate environment of the supermassive black hole.

A large number of the young, massive stars in the central parsec of the GC show coherent rotation. Levin & Beloborodov (2003, ApJ) found that many of them lie within a disk, the so-called clockwise rotating system (CWS). Genzel et al. (2003, ApJ) and Paumard et al. (2006, ApJ) claimed the discovery of a second disk of young stars, the so-called counter-clockwise system (CCWS). The existence of the CCWS is subject to intense discussion because evidence for its existence appears to be marginal.

Hendrik Bartko connected to Thibaut's talk and presented a statistical analysis of the distribution of the young massive stars. Testing against the hypothesis of an isotropic distribution, the distribution of a sample of 73 early-type stars was examined. With this method the CWS is found with a high significance ($> 10\,\sigma$) and 40 member stars, distributed at projected radii of 0.8" – 4.8" from Sgr A*. The CCWS is identified as well, although with a lower significance ($2 - 4\,\sigma$) and a smaller number of member stars (18), distributed at projected radii of 2.8" – 6.8" from Sgr A*.

Jessica Lu challenged the existence of the CCWS. She presented an analysis based on constraining individual orbital solutions for the same sample of 73 young stars, using the currently best data available (proper motions, radial velocities, limits on acceleration of the stars in the plane of the sky). This analysis confirms the existence of the CWS, but finds no evidence for the CCWS. Instead, it appears that about 50% of the young stars belong to the CWS, while the rest of the stars is distributed in a close to isotropic way.

Sergei Nayakshin presented models on how the young stars in the central 0.5 pc of the GC could have formed from a gaseous disk. They find that one or two massive, self-gravitating gaseous disks could indeed have resulted from a large angle collision of two massive clouds. The density of stars that form in the simulations of the gaseous disk(s) is consistent with the observationally derived surface density of the stars, $\Sigma_* \propto R^{-2}$.

Ladislav Subr presented a study on how the gaseous circum-nuclear disc (CND) may have warped an initially thin disk of stars in the central parsec of the GC. This model provides a possible explanation how all the young stars in the central 0.5 pc may have originated in a single thin disc.

Jörg-Uwe Pott presented the results of first interferometric observations of targets in the GC cluster. He presented detailed modeling of interferometric observations of the the strongly resolved, dust-enshrouded source IRS 3. Near-infrared interferometric observations of the brightest star in the central parsec, IRS 7, show large amounts of correlated flux on a 50 m baseline. Therefore, IRS 7 is appears to be a suitable calibration source for future interferometric observations of targets in the GC. Finally, Pott discussed current and near-future interferometric technology with respect to GC observations.

Andrea Stolte presented multi-epoch adaptive optics observations of the Arches cluster. From these observations she derived the 3D-velocity of the Arches cluster. The resulting limits on the orbit of the Arches cluster place strong constraints on its formation.

Koraljka Muzic talked about the discovery of a new group of co-moving stars. It is located $\sim$ 0.5" north of IRS 13E and $<$ 0.2 pc in projection from Sgr A* and has been termed the IRS 13N cluster. The stars in the co-moving IRS13 N-group are highly extincted and have therefore been suggested as very young stars in previous work (Eckart et al., 2004, ApJ). The finding on the common proper motion of these stars provides further evidence that IRS 13N may be a very young object.

In *Session V - Nuclear star clusters and galaxy evolution*, *Rainer Schödel* talked about the structure of the nuclear star cluster of the Milky Way. He presented proper motions for $\sim$ 6000 stars within 1 pc of Sagittarius A*. The new velocity data show that the Keplerian fall-off of the velocity dispersion due to the point mass of the central black hole is only clearly visible in the inner 0.3 pc (in projection). At greater projected distances, out to $R = 1$ pc, the velocity dispersion appears to be isotropic with a constant value of $100 \pm 1\,\mathrm{km\,s^{-1}}$. The data allow, for the first time, to detect the potential of the extended, stellar mass around Sgr A*. Modeling provides robust evidence for about $1 \times 10^6\,\mathrm{M_\odot}$ of mass in the central parsec, in addition to the mass of the black hole.

Further talks

Sheperd Doeleman reported on recent successful VLBI observations of Sagittarius A* at 1.3 mm. These observations lead to an intrinsic diameter of Sgr A* that is smaller than the apparent size of its event horizon. They provide evidence that the bulk of the emission may not be centered on the black hole. The results were recently published in *Nature*.

Further talks related to the GC and nearby galactic nuclei were:

- *Santiago García-Burillo* - Feeding and feedback in AGN
- *Cornelia Lang* - The magnetic environment in the central regions of nearby galaxies
- *Mamiko Sato* - Infalling gas onto the Galactic Center circumnuclear ring
- *Julia Scharwächter* - A high angular resolution study of the nuclear regions of QSO host galaxies with the NACO Simultaneous Differential Imager
- *Walter Jaffe* - Interferometric observations of NGC 1068 in the near-infrared
- *Daniel Rouan* - A close look at the BLR of NGC 7469
- *Dan Maoz* - The properties of LLAGN inferred from high resolution observations
- *Antxón Alberdi* - High resolution radio observations of nuclear and circumnuclear regions of LIRGs
- *Gabriele Giovannini* - VLBI observations of radio galaxies with a faint radio core
- *Makoto Kishimoto* - AGN accretion disks as spatially resolved by polarimetry. The presented results provide firm evidence for the standard accretion disk model in quasars and have been recently published in *Nature*.
- *Torsten Böker* - Properties of nuclear star clusters
- *Laura Ferrarese* - The relation between nuclear star clusters, supermassive black holes, and their host galaxies

Upcoming GC Meetings

GC Massive Stars and Magnetized ISM

AAS Special Session: 1/5/2009 10:00 - 11:30 AM

In the past few years, the central hundred parsecs of the Galaxy have been surveyed anew at a variety of wavelengths, notably with Spitzer, Chandra, HST, UKIDSS, and the VLA, all with considerably enhanced sensitivity and spatial resolution. These efforts have culminated this year with the emergence of a new large-scale HST/NICMOS survey of Paschen-alpha emission and a deep Chandra mosaic. All of this newly available information provides an exciting new vision of the population of massive young stars and star clusters, and on the dramatic effect that those stars have on the interstellar medium in terms of heating, ionization and dynamical shaping. The proposed special session would bring together investigators to discuss the timely issues that are emerging from the new views of the rich Galactic center region. These issues include: (1) the dominant mode of star formation in the central molecular zone, (2) the effect of the winds and radiation of massive stars on subsequent star formation in neighboring clouds, (3) the likely role of the strong Galactic center magnetic field in determining the morphology of HII regions and PDRs, and (4) the extent to which our Galactic nucleus serves as a template for understanding star formation activity in gas-rich galactic nuclei in general. In addition, the attendees would use the discussions to focus the scientific program for the next international symposium on the Galactic center, to be held in China in October 2009.

Organizer: Cornelia Lang, University of Iowa (cornelia-lang@uiowa.edu) See: http://aas.org/meetings/aas213/event_special_ss03.php

Getting to the Event Horizon: SgrA*

AAS Special Session: 1/5/2009 2:00 - 3:30 PM

SgrA*, the super massive black hole candidate at the Galactic Center, presents the nearest example of the AGN phenomenon, and the best opportunity to study black hole physics, accretion, and strong GR effects in detail. Within the past several years there has been a great deal of progress on modeling the innermost accretion regions of SgrA* with linear resolutions much less than the Schwarzschild radius. Recent 230GHz VLBI detections of SgrA* have angular resolutions that are beginning to constrain these models and, hence, fundamental black hole parameters. Multi-wavelength monitoring campaigns are refining models of flaring structures and setting expected size and time scales for variability. The goal of this special session is to bring together researchers in theory and observers across the spectrum to discuss the present and future prospects for pinning down the existence of a super massive black hole, and its characteristics. We also plan to address the issue of future technical advances that would significantly advance the field.

Organizer: Sheperd Doeleman, MIT-Haystack Observatory (dole@haystack.mit.edu) See: http://aas.org/meetings/aas213/event_special_ss04.php

GC09 in Shanghai !

The Galactic center: a window to the nuclear environment of disk galaxies

Time October 19-23, 2009

Early registration deadline June 1, 2009

Location Hope Hotel, Shanghai

Webpage `http://www.shao.ac.cn/gc2009/`

In the present Universe, the majority of supermassive black holes (SMBHs) in galactic nuclei are in a low-luminosity state. Understanding the physical nature of this state and its connection to the nuclear environment is central to the study of galaxy structure and evolution.

The Galactic Center Workshop 2009 will be devoted to the presentation and discussion of recent observational and theoretical results on low-luminosity galactic nuclei. In particular, the center of the Milky Way will be emphasized to give a close-up view of such a nucleus, resolving structures from scales of hundreds of parsecs down to a few milliparsecs, and thus to explore the implications for our understanding of other galactic nuclei. Developments in the study of low-luminosity galactic nuclei in nearby galaxies will also be highlighted to provide complementary perspectives — global and relatively unobscured — which are particularly important for investigating the relationship between nuclear activity and the galactic "ecosystem".

The workshop is aimed to address a range of scientific topics related to SMBHs and galactic nuclear environment, including:

- physics of the accretion flow around SMBHs
- star formation around SMBHs and in circumnuclear regions
- stellar dynamics around SMBHs
- population and distribution of compact objects around SMBHs
- stellar and gaseous contents in the nuclear and circumnuclear regions and the fueling of SMBHs
- SMBH feedback effects on the nuclear and circumnuclear environment
- interplay between stars and the interstellar medium
- magnetic field and its role in regulating the gas dynamics
- fundamental physics at the Galactic Center (e.g., dark matter radiation and GR effects)
- formation and evolution of SMBHs

In addition, we propose to have daily discussions and mini-debate sessions to focus on persistent issues facing GC studies and to raise new challenging questions. The preliminary plan is to solicit and post a set of issues to be discussed and debated so that interested individuals can get prepared.

Hypervelocity Stars and the Galactic Center
Warren R. Brown[1]

[1] Smithsonian Astrophysical Observatory, 60 Garden St, Cambridge, MA 02138, USA
wbrown@cfa.harvard.edu

1 Introduction

A massive black hole (MBH) will inevitably unbind stars from the Galaxy. Hills (1988) coined the term "hypervelocity star" (hereafter HVS) to describe a star ejected at $\sim$1000 km s^{-1} from a three-body interaction with a MBH. HVSs are a general consequence of MBHs in any galaxy (e.g. Sherwin et al., 2008), but the HVSs we can observe are the stars ejected from our own Galaxy.

Yu & Tremaine (2003) predict that Sgr A* ejects one HVS every $\sim 10^5$ yrs. Thus HVSs are rare: of the Galaxy's 10^{11} stars, there are only $\sim 10^3$ HVSs within 100 kpc of the Milky Way. Yet HVSs would be very interesting to find because HVSs provide unique constraints on the nature and environment of the central MBH.

In 2005 we reported the discovery of the first HVS: a 3 $M_\odot$ main sequence star traveling with a Galactic rest frame velocity of at least $+709 \pm 12$ km s^{-1}, more than twice the Milky Way's escape velocity at the star's distance of 110 kpc (Brown et al., 2005). This star cannot be explained by normal stellar interactions: the maximum ejection velocity from binary disruption mechanisms (Blaauw, 1961; Poveda et al., 1967) is limited to $\sim$300 km s^{-1} for 3 $M_\odot$ stars (Leonard & Duncan, 1988, 1990; Leonard, 1991, 1993; Tauris & Takens, 1998; Portegies Zwart, 2000; Davies et al., 2002; Gualandris et al., 2005). Thus a massive and compact object is needed to accelerate a 3 $M_\odot$ star to an unbound velocity.

There is overwhelming evidence for a $\sim 4 \times 10^6$ $M_\odot$ MBH in the dense stellar environment of the Galactic center (e.g. Schödel et al., 2003; Ghez et al., 2005). The three-body exchange mechanism that may explain S-stars orbiting the MBH (Gould & Quillen, 2003) is the same mechanism that may eject HVSs (Hills, 1988). In this picture, S-stars are the former companions of HVSs (Ginsburg & Loeb, 2006, 2007). Interestingly, the S-stars are main sequence B stars (Ghez et al., 2003; Eisenhauer et al., 2005; Martins et al., 2008), just like the observed HVSs described below.

In §2 we define HVSs in the context of unbound stars, and discuss how HVSs are made. In §3 we highlight recent HVS discoveries and discuss their nature. In §4 we explore the links between HVSs and the Galactic Center. We conclude in §5.

2 Theoretical Considerations

2.1 Defining an Hypervelocity Star

Following Hills (1988), we define HVSs by 1) their MBH origin and 2) their unbound velocities. An HVS ejected from the Milky Way travels on a nearly radial trajectory; the expected proper motion for a 50 kpc distant HVS is a few tenths of a milliarcsecond per year (Gnedin et al., 2005). Thus radial velocity directly measures most of an HVS's space motion. Deciding whether an HVS is unbound, however, requires knowledge of the star's location in the Galaxy.

Unfortunately, the Galactic potential is poorly constrained at distances > 50 kpc. Kenyon et al. (2008) discuss a form of the potential that, for the first time, fits the Milky Way mass distribution from 5 pc to 10^5 pc. Because the potential does not yield a formal escape velocity, they define unbound stars as having $v_{rf} > 200$ km s^{-1} at $R = 150$ kpc. This conservative definition yields a Galactic escape velocity of 360 km s^{-1} at 50 kpc and 260 km s^{-1} at 100 kpc. Xue et al. (2008), on the other hand, fit a halo potential model to the velocity dispersion of 2466 BHB stars located 5 kpc $< R <$ 60 kpc. The escape velocity resulting from the Xue et al. (2008) model is 290 km s^{-1} at 50 kpc and 190 km s^{-1} at 100 kpc.

2.2 Hyper-Runaways

Not all unbound stars are necessarily HVSs. Fast-moving pulsars, for example, are explained by supernova kicks (e.g. Arzoumanian et al., 2002). The star HD 271791 is the first example of an unbound "hyper-runaway" that was ejected from the outer disk, in the direction of Galactic rotation, when its former 55 $M_\odot$ binary companion exploded as a supernova (Heber et al., 2008; Przybilla et al., 2008a). Objects ejected in this manner are traditionally called runaways (Blaauw, 1961). The term runaway also includes stars dynamically ejected from binary-binary encounters (Poveda et al., 1967).

Runaway star ejection mechanisms share a common velocity constraint: the physical properties of binary stars. Theoretically, the maximum ejection velocity from disrupting a binary is the binary orbital velocity, a velocity that increases with the mass of the stars. The theoretical maximum velocity is not realizable, however, because compact binaries that are too tight will merge due to energy loss from tidal dissipation and Roche-lobe overflow (e.g. Vanbeveren et al., 1998). While it is possible for an hyper-runaway to be confused with an HVS in the absence of proper motions, we estimate that $\sim$3 $M_\odot$ HVSs ejected from the Galactic Center are $\sim$100 times more common than hyper-runaways of the same mass (Brown et al., 2008). Hyper-runaways are limited by the rarity of massive stars and the requirement to avoid merging the compact binary progenitor.

2.3 How to Make Hypervelocity Stars

HVSs attain extreme velocities because the gravitational potential energy of a MBH greatly exceeds the binding energy of a stellar binary. In Hill's mechanism, the gravitational tidal force of a single MBH disrupts an approaching binary. One star is captured on an eccentric orbit around the MBH and, by conservation of energy, the other star escapes with a final velocity equal to the geometric mean of the $\sim 10^4$ km s^{-1} infall velocity (S0-16 had a pericenter velocity of 12000 km s^{-1}, Ghez et al., 2005) and the $\sim 10^2$ km s^{-1} binary orbital velocity. A star traveling 10^3 km s^{-1} at 1 pc will exit the Galaxy at 100 kpc at 400-500 km s^{-1} (Kenyon et al., 2008).

Yu & Tremaine (2003) further develop Hill's analysis to include the case of a binary MBH. While an equal-mass binary MBH is ruled out in the Galactic Center (Reid & Brunthaler, 2004), theorists speculate that the massive star clusters in the Galactic Center may form intermediate mass black holes (IMBHs) in their cores. If such IMBHs exist, dynamical friction will cause them to in-spiral into the central MBH and eject HVSs along the way.

The properties of HVSs allow us to discriminate between the single MBH and binary MBH ejection mechanisms:

- *Velocity Distribution.* HVS ejection velocity depends weakly on the mass of the stellar binary $\propto (m_1 + m_2)^{1/3}$ for a single MBH (Hills, 1988), but there is no such dependence on stellar mass for a binary MBH (e.g. Sesana et al., 2007b).

- *Ejection Rate.* A binary MBH has a larger cross-section and may eject $\sim 10\times$ more HVSs than a single MBH (Yu & Tremaine, 2003).

- *Spatial Distribution.* A binary MBH preferentially ejects HVSs in its orbital plane, and thus produces a ring of HVSs around the sky (Gualandris et al., 2005; Levin, 2006; Sesana et al., 2006; Merritt, 2006).

- *Temporal Distribution.* As a binary MBH hardens and then merges, it will produce a distinctive burst of HVSs over $\sim 10^7$ yrs, during which HVS velocities will become systematically more energetic with time (Baumgardt et al., 2006; Sesana et al., 2006, 2007a).

- *Stellar Rotation Distribution.* HVSs ejected by a single MBH should be slow rotators, because stars in compact binaries have systematically lower $v \sin i$ due to tidal synchronization (Hansen, 2007). On the other hand, single stars spun up and ejected by a binary MBH should be fast rotators (Löckmann & Baumgardt, 2008).

HVSs may also be ejected by three-body interactions of single stars with stellar mass black holes clustered around the central MBH (O'Leary & Loeb, 2008). This mechanism predicts that the lowest-mass HVSs will have the highest velocities, in contrast to Hill's mechanism.

2.4 Dark Matter

One interesting theoretical application for HVSs is as probes of the Galactic dark matter potential (Gnedin et al., 2005; Yu & Madau, 2007; Wu et al., 2008). The dark matter paradigm makes specific predictions about the anisotropy of dark matter halos. Any deviation of an HVS's trajectory from the Galactic Center measures this anisotropy. Unlike tidal streams, HVSs integrate the Galactic potential out to very large distances. Interestingly, the Kenyon et al. (2008) potential suggests that HVSs may be much more sensitive to the bulge than to the halo. Moreover, the bulge potential acts as a high-pass filter: a star must be ejected at ~800 km/s to reach 1 kpc.

3 Observations of Hypervelocity Stars

3.1 New HVSs

Observers have identified a remarkable number of unbound HVSs in the past 3 years. Following the discovery of the first HVS (Brown et al., 2005), Hirsch et al. (2005) reported a helium-rich subluminous O star leaving the Galaxy with a rest-frame velocity of at least +717 km s^{-1}. Edelmann et al. (2005) reported an 9 $M_\odot$ main sequence B star with a Galactic rest frame velocity of at least +548 km s^{-1}, possibly ejected from the Large Magellanic Cloud (LMC).

Brown et al. designed a targeted HVS survey that has discovered 13-17 new HVSs, plus evidence for a similar number of bound HVSs ejected by the same mechanism (Brown et al., 2006a,b, 2007a,b, 2008). Briefly, our survey uses Sloan photometry to select HVS candidates with the colors of late B-type stars (Figure 1). B-type stars have lifetimes consistent with travel times from the Galactic Center but are not a normally expected Galactic halo population. We highlight the latest results of our survey below.

3.2 Velocity Distribution and Bound HVSs

Figure 2 plots the observed distribution of line-of-sight velocities, corrected to the Galactic rest-frame (see Brown et al., 2006b), for the B-type stars in our survey. The survey covers 7300 $\deg^2$ of sky, with a surface density of ~0.1 $\deg^{-2}$. The 731 survey stars with $|v_{rf}| < 275$ km s^{-1} have a -1 ± 4 km s^{-1} mean and a 106 ± 5 km s^{-1} dispersion, consistent with a normal stellar halo population.

Remarkably, we observe 26 stars with $v_{rf} > 275$ km s^{-1} and only 2 stars with $v_{rf} < -275$ km s^{-1}. The escape velocity of the Milky Way at 50 kpc is ~ 300 km s^{-1}, thus the 12 stars with $v_{rf} > 400$ km s^{-1} are clearly unbound (see also Figure 3). Ignoring the 12 unbound stars, there is less than a 10^{-5} probability of randomly drawing 14 stars with $275 < v_{rf} < 400$ km s^{-1} from the tail of a Gaussian distribution with the observed parameters. Thus the excess of positive velocity outliers $275 < v_{rf} < 400$ km s^{-1} appears significant at the 4-σ level.

The positive velocity outliers demonstrate a population of possibly bound HVSs (Brown et al., 2007a,b). HVS ejection mechanisms naturally produce a broad spectrum of ejection velocities (e.g. Sesana et al., 2007b). Simulations of HVS ejections from the Hills mechanism suggest there should be comparable numbers of unbound and bound HVSs with $v_{rf} > +275$ km s^{-1} in our survey volume (Bromley et al., 2006). We find 14 unbound HVSs and 12 possibly bound HVSs with $v_{rf} > +275$ km s^{-1}, in good agreement with model predictions.

3.3 The Nature of HVSs

The significant absence of stars falling back onto the Galaxy around -300 km s^{-1} demonstrates that HVSs are short-lived (Brown et al., 2007b; Kollmeier & Gould, 2007; Yu & Madau, 2007). If bound HVSs had main sequence lifetimes greater than ~1 Gyr, we would see them falling back onto the Galaxy, contrary to the observations. Given the color-selection of the HVS survey, the B-type HVSs must be 3-4 $M_\odot$ main sequence stars.

Follow-up observations have confirmed that four of the HVSs are main sequence stars: HVS1 is a slowly pulsating B variable (Fuentes et al., 2006), HVS3 is a 9 $M_\odot$ B star (Bonanos et al., 2008; Przybilla et al., 2008b), HVS7 is a 3.7 $M_\odot$ Bp star (Przybilla et al., 2008c), and HVS8 is a rapidly rotating B star (Lopez-Morales & Bonanos, 2008).

The identification of HVSs as main sequence stars is in stark contrast to the halo stars in our survey, which are, presumably, evolved 0.6-1 $M_\odot$ stars on the blue horizontal branch (BHB). BHB stars among the HVSs would be exciting, however, because unbound BHB stars would allow us to probe the low-mass regime of HVSs.

Interestingly, HVS12 was previously classified as a BHB star in the BHB samples of Sirko et al. (2004) and Xue et al. (2008). The existence of 1 ± 1 BHB stars among our 14 unbound HVSs is consistent with predictions from Galactic center ejection models (Kenyon et al., 2008). A single HVS among the 1170 Sirko et al. (2004) BHB stars and the 10224 Xue et al. (2008) BHB candidates also shows the immense dilution due to stars in the Galactic halo. Our HVS survey works because we target stars that are bluer and/or fainter than the bulk of halo BHB stars.

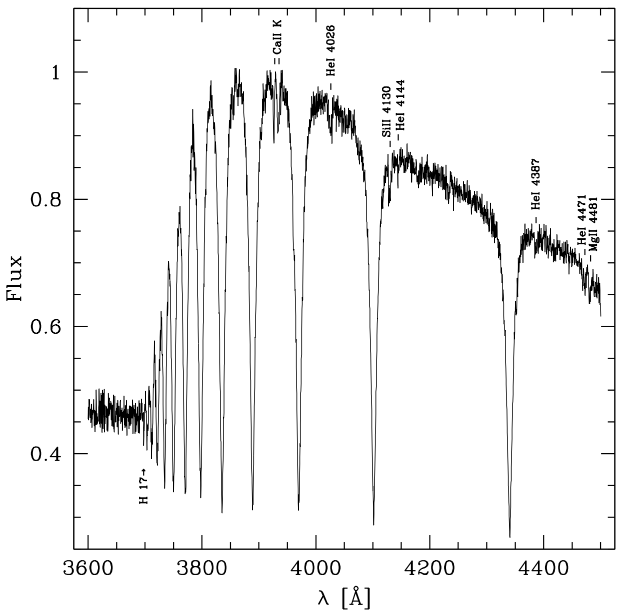


Figure 1 Summed HVS spectrum, created from the weighted average of our observations of HVS1 and HVS4 - HVS10, shifted to rest frame. The spectral type is that of a B8 - B9 star. The wavelength difference between the pair of Ca II K lines, one from the HVSs and one from the local interstellar medium that appears in the spectra of HVS8 and HVS9, visibly indicates the large space motion of the HVSs, $\Delta\lambda/\lambda \sim 550$ km s^{-1}.

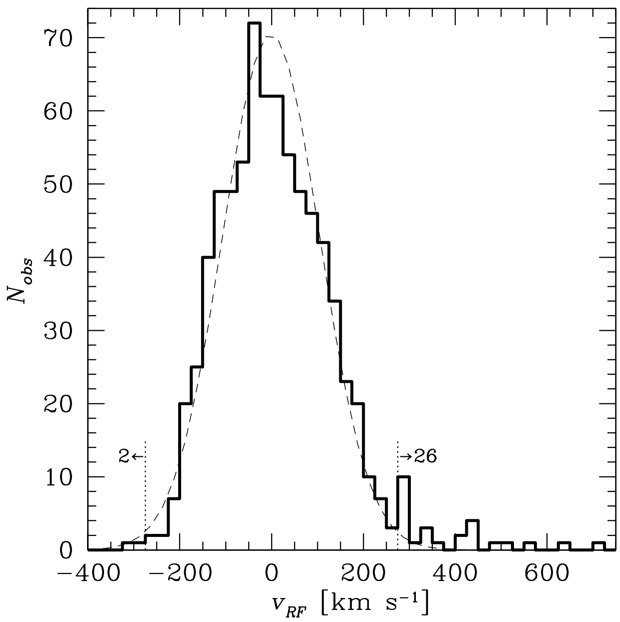


Figure 2 Observed radial velocity distribution, corrected to the Galactic rest-frame v_{rf}, for the 759 stars in our HVS survey. The best-fit Gaussian (*dashed line*) has dispersion 106 ± 5 km s^{-1}, excluding the 26 stars with $v_{rf} > +275$ km s^{-1}.

3.4 A Possible HVS from the Large Magellanic Cloud

HVS3, the unbound star very near the LMC on the sky, has received considerable attention. HVS3 is a 9 $M_\odot$ B star of half-solar abundance, a good match to the abundance of the LMC (Bonanos et al., 2008; Przybilla et al., 2008b). Stellar abundance may not be conclusive evidence of origin, however. A- and B-type stars exhibit 0.5 - 1 dex scatter in elemental abundances within a single cluster, due to gravitational settling and radiative levitation in the atmospheres of the stars (Varenne & Monier, 1999; Monier, 2005; Fossati et al., 2007; Gebran et al., 2008; Gebran & Monier, 2008). Yet because the 18 Myr lifetime of HVS3 is significantly shorter than its travel time from the Galactic Center, HVS3 may be the first evidence for a MBH in the LMC (Edelmann et al., 2005).

An LMC origin requires that HVS3 was ejected from the galaxy at ~ 1000 km s^{-1} (Przybilla et al., 2008b), a velocity that can possibly come from three-body interactions with an intermediate mass black hole in a massive star cluster (Gualandris & Portegies Zwart, 2007; Gvaramadze et al., 2008). Perets (2008) shows that the ejection rate of 9 $M_\odot$ stars, however, is four orders of magnitude too small for this explanation to be plausible. The alternative explanation is that HVS3 is a blue straggler, ejected by the Milky Way's MBH. Theorists argue that a single MBH or a binary MBH can eject a compact binary star as an HVS (Lu et al., 2007; Perets, 2008); the subsequent evolution of such a compact binary can result in mass-transfer and/or a merger that can possibly explain HVS3 (Perets, 2008). Proper motion measurements, underway now with the *Hubble Space Telescope*, will determine HVS3's origin.

4 Links to the Galactic Center

4.1 Ejection History

If Sgr A* ejects a steady fountain of HVSs from the Galactic Center, then the space density of HVSs goes as $\rho \propto R^{-2}$ (Brown et al., 2006a; Kollmeier & Gould, 2007; Kenyon et al., 2008). The volume sampled by a magnitude-limited survey is proportional to R^3. Thus, in the simplest picture, we expect the number of HVSs to have a linear dependence with R. Remarkably, the observed HVSs show just such a linear cumulative distribution (Brown et al., 2007b).

Figure 3 explores the history of stars interacting with Sgr A* in more detail. We calculate Galactic Center travel times (dotted lines) from the Kenyon et al. (2008) model, assuming the observed radial velocities are full space motions. HVS travel times span 60 - 240 Myr.

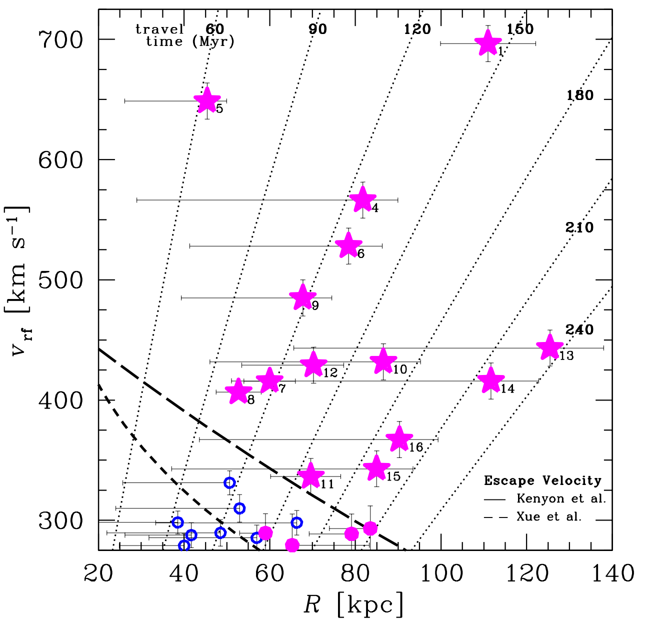


Figure 3 Minimum rest-frame velocity vs. Galactocentric distance R for stars in our HVS survey (Brown et al., 2008). 14 unbound HVSs (*solid stars*) have velocities and distances exceeding the Kenyon et al. (2008) escape velocity model (*long dashed line*). 4 possible HVSs (*dots*) are in excess of the Xue et al. (2008) escape velocity model (*dashed line*). 8 possibly bound HVSs (*open circles*) are also indicated. Errorbars show the span of physically possible distance if the HVSs are BHB stars. Isochrones of travel time from the Galactic center (*dotted lines*) are calculated using the potential model of Kenyon et al. (2008), assuming the observed minimum rest frame velocity v_{rf} is the full space motion of the stars.

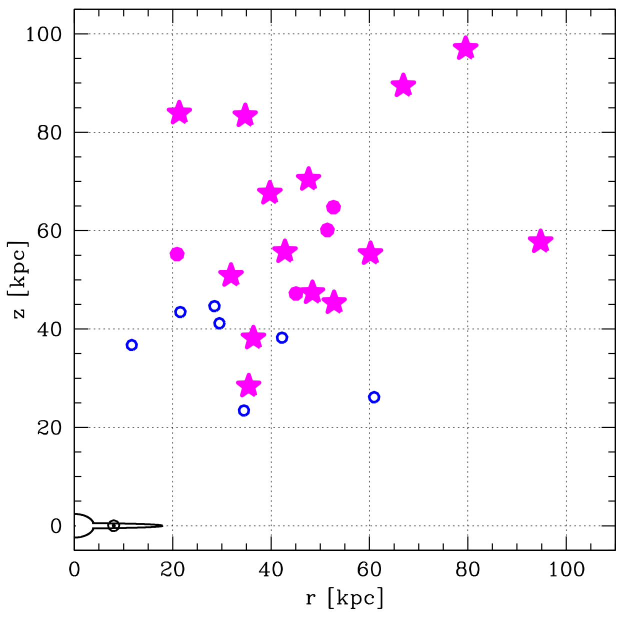


Figure 4 Location of our 14 HVSs (*stars*), the 4 possible HVSs (*dots*), and 8 possibly bound HVSs with $v_{rf} > 275$ km s^{-1} (*open circles*). z is the distance above the Galactic plane and r is the distance along the Galactic plane, such that $R = (r^2+z^2)^{-0.5}$. For reference, we sketch the Milky Way and the Sun at $(r, z) = (8, 0)$ kpc.

Statistically, the set of HVSs favor a continuous ejection process. In other words, there is no evidence that a massive star cluster or IMBH has in-spiraled into the Galactic Center in the past couple hundred Myr, or at least one that produced a coherent burst of HVSs. Given the small number statistics, we cannot rule out that the 5 HVSs near ∼120 Myr, for example, come from a single ejection event. However, the 5 HVSs near ∼120 Myr exhibit lower velocities at shorter travel times, in the opposite sense expected for ejections from an in-spiraling IMBH.

4.2 Stellar Population

Observed HVSs exit the Galaxy in ∼100 Myr and so they reflect the present stellar population near Sgr A*. In principle, we can constrain the parent mass function of HVSs by combining predictions of HVS rates with the observations. An HVS moving 500 km s^{-1} travels 100 kpc in 200 Myr, thus the Yu & Tremaine (2003) rate implies ∼2000 HVSs of all types to a depth of 100 kpc. Our magnitude-limited survey reaches the same depth over 1/6 of the sky, from which we infer 96 ± 20 unbound 3-4 $M_\odot$ HVSs within 100 kpc (Brown et al., 2007b). A Salpeter mass function (Salpeter, 1955), integrated over the mass range 0.2-100 $M_\odot$ and normalized to 2000 stars, contains ∼20 stars between 3 and 4 $M_\odot$.

Perets et al. (2007) argues that massive perturbers, such as giant molecular clouds, scatter stars into Sgr A*'s "loss cone" much more efficiently than 2-body scattering. As a result, the Galactic Center may eject HVSs at a

$\sim$10$\times$ greater rate than predicted by Yu & Tremaine (2003); in this case, the expected number of 3-4 $M_\odot$ HVSs in a Salpeter mass function increases to $\sim$200, in better agreement with observations.

The likelihood of finding low-mass HVSs depends sensitively on the mass function. If Sgr A* ejects stars with the present day mass function of the bulge, there is 1 unbound F-type HVS with $g' < 21.5$ per 50 deg^2 of sky (Kollmeier & Gould, 2007). In the Galactic Center, there is some indication that the stellar mass function is top heavy (Maness et al., 2007). A Salpeter mass function predicts an order-of-magnitude lower density of F-type HVSs, 1 per $\sim$500 deg^2 (Brown et al., 2007b). The ratio of high- to low-mass HVSs thus provides a sensitive measure of the stellar mass function near Sgr A*.

4.3 Binary Fraction

HVSs are also linked to the properties of binaries. In the disk, nearly all O and B stars are in binaries, and a third of such binaries are equal-mass twins (Kobulnicky & Fryer, 2007). It would be very interesting to know the multiplicity of stars in the Galactic Center, particularly the S-stars orbiting Sgr A*.

If HVSs are disrupted binaries, the former companions of HVSs are left on highly eccentric orbits around Sgr A* (Ginsburg & Loeb, 2006). The orbital properties of the S-stars are thus linked to HVSs leaving the Galaxy today. Stars with main sequence lifetimes $\gtrsim$200 Myr were present when the known HVSs were ejected from the Galactic Center.

5 Conclusion

HVSs are fascinating because their properties are linked to Sgr A* and the stellar environment of the Galactic Center. A statistical sample of HVSs can address: 1) the nature of the MBH ejection mechanism, 2) the in-fall history of stars onto Sgr A*, 3) the types of stars orbiting Sgr A*, and 4) a unique measurement the shape of the Galaxy's dark matter potential. The challenge to observers is to find new HVSs and strengthen the connection between HVSs and the Galactic Center.

Acknowledgements

Margaret Geller and Scott Kenyon are invaluable mentors and collaborators in this work. I also wish to acknowledge Ben Bromley and Michael Kurtz for their important contributions to our HVS program.

References

Arzoumanian, Z., Chernoff, D. F., & Cordes, J. M. 2002, ApJ, 568, 289
Baumgardt, H., Gualandris, A., & Portegies Zwart, S. 2006, MNRAS, 372, 174
Blaauw, A. 1961, Bull. Astron. Inst. Netherlands, 15, 265
Bonanos, A. Z., López-Morales, M., Hunter, I., & Ryans, R. S. I. 2008, ApJ, 675, L77
Bromley, B. C., Kenyon, S. J., Geller, M. J., Barcikowski, E., Brown, W. R., & Kurtz, M. J. 2006, ApJ, 653, 1194
Brown, W. R., Geller, M. J., & Kenyon, S. J. 2008, ArXiv:0808.2469
Brown, W. R., Geller, M. J., Kenyon, S. J., & Kurtz, M. J. 2005, ApJ, 622, L33
—. 2006a, ApJ, 640, L35
—. 2006b, ApJ, 647, 303
Brown, W. R., Geller, M. J., Kenyon, S. J., Kurtz, M. J., & Bromley, B. C. 2007a, ApJ, 660, 311
—. 2007b, ApJ, 671, 1708
Davies, M. B., King, A., & Ritter, H. 2002, MNRAS, 333, 463
Edelmann, H., Napiwotzki, R., Heber, U., Christlieb, N., & Reimers, D. 2005, ApJ, 634, L181
Eisenhauer, F. et al. 2005, ApJ, 628, 246
Fossati, L. et al. 2007, A&A, 476, 911
Fuentes, C. I., Stanek, K. Z., Gaudi, B. S., McLeod, B. A., Bogdanov, S., Hartman, J. D., Hickox, R. C., & Holman, M. J. 2006, ApJ, 636, L37
Gebran, M. & Monier, R. 2008, A&A, 483, 567

Gebran, M., Monier, R., & Richard, O. 2008, A&A, 479, 189
Ghez, A. M., Salim, S., Hornstein, S. D., Tanner, A., Lu, J. R., Morris, M., Becklin, E. E., & Duchene, G. 2005, ApJ, 620, 744
Ghez, A. M. et al. 2003, ApJ, 586, L127
Ginsburg, I. & Loeb, A. 2006, MNRAS, 368, 221
—. 2007, MNRAS, 376, 492
Gnedin, O. Y., Gould, A., Miralda-Escudé, J., & Zentner, A. R. 2005, ApJ, 634, 344
Gould, A. & Quillen, A. C. 2003, ApJ, 592, 935
Gualandris, A. & Portegies Zwart, S. 2007, MNRAS, 376, L29
Gualandris, A., Portegies Zwart, S. P., & Sipior, M. S. 2005, MNRAS, 363, 223
Gvaramadze, V. V., Gualandris, A., & Portegies Zwart, S. 2008, MNRAS, 385, 929
Hansen, B. M. S. 2007, ApJ, 671, L133
Heber, U., Edelmann, H., Napiwotzki, R., Altmann, M., & Scholz, R.-D. 2008, A&A, 483, L21
Hills, J. G. 1988, Nature, 331, 687
Hirsch, H. A., Heber, U., O'Toole, S. J., & Bresolin, F. 2005, A&A, 444, L61
Kenyon, S. J., Bromley, B. C., Geller, M. J., & Brown, W. R. 2008, ApJ, 680, 312
Kobulnicky, H. A. & Fryer, C. L. 2007, ApJ, 670, 747
Kollmeier, J. A. & Gould, A. 2007, ApJ, 664, 343
Leonard, P. J. T. 1991, AJ, 101, 562
Leonard, P. J. T. 1993, in ASP Conf. Ser. 45, Luminous High-Latitude Stars, ed. D. Sasselov, 360
Leonard, P. J. T. & Duncan, M. J. 1988, AJ, 96, 222
—. 1990, AJ, 99, 608
Levin, Y. 2006, ApJ, 653, 1203
Löckmann, U. & Baumgardt, H. 2008, MNRAS, 384, 323
Lopez-Morales, M. & Bonanos, A. Z. 2008, ArXiv:0802.2945
Lu, Y., Yu, Q., & Lin, D. N. C. 2007, ApJ, 666, L89
Maness, H. et al. 2007, ApJ, 669, 1024
Martins, F., Gillessen, S., Eisenhauer, F., Genzel, R., Ott, T., & Trippe, S. 2008, ApJ, 672, L119
Merritt, D. 2006, ApJ, 648, 976
Monier, R. 2005, A&A, 442, 563
O'Leary, R. M. & Loeb, A. 2008, MNRAS, 383, 86
Perets, H. B. 2008, ArXiv:0802.1004
Perets, H. B., Hopman, C., & Alexander, T. 2007, ApJ, 656, 709
Portegies Zwart, S. F. 2000, ApJ, 544, 437
Poveda, A., Ruiz, J., & Allen, C. 1967, Bol. Obs Tonantzintla Tacubaya, 4, 860
Przybilla, N., Nieva, M. F., Heber, U., & Butler, K. 2008a, ApJ, accepted
Przybilla, N., Nieva, M. F., Heber, U., Firnstein, M., Butler, K., Napiwotzki, R., & Edelmann, H. 2008b, A&A, 480, L37
Przybilla, N., Nieva, M. F., Tillich, A., Heber, U., Butler, K., & Brown, W. R. 2008c, A&A, accepted
Reid, M. J. & Brunthaler, A. 2004, ApJ, 616, 872
Salpeter, E. E. 1955, ApJ, 121, 161
Schödel, R., Ott, T., Genzel, R., Eckart, A., Mouawad, N., & Alexander, T. 2003, ApJ, 596, 1015
Sesana, A., Haardt, F., & Madau, P. 2006, ApJ, 651, 392
—. 2007a, ApJ, 660, 546
—. 2007b, MNRAS, 379, L45
Sherwin, B. D., Loeb, A., & O'Leary, R. M. 2008, MNRAS, 386, 1179
Sirko, E. et al. 2004, AJ, 127, 899
Tauris, T. M. & Takens, R. J. 1998, A&A, 330, 1047
Vanbeveren, D., De Loore, C., & Van Rensbergen, W. 1998, A&A Rev., 9, 63
Varenne, O. & Monier, R. 1999, A&A, 351, 247
Wu, X., Famaey, B., Gentile, G., Perets, H., & Zhao, H. 2008, MNRAS, 455
Xue, X. et al. 2008, ArXiv 0801.1232
Yu, Q. & Madau, P. 2007, MNRAS, 379, 1293
Yu, Q. & Tremaine, S. 2003, ApJ, 599, 1129

Abstracts

The distance to the Galactic Centre based on Population II Cepheids and RR Lyrae stars

M.A.T. Groenewegen [1] *A. Udalski* [2] *and G. Bono* [3,4]

(1) Instituut voor Sterrenkunde, Celestijnenlaan 200 D, B–3001 Leuven, Belgium
and Warsaw University Observatory, Aleje Ujazdowskie 4, PL-00-478, Warsaw, Poland and INAF Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monte Porzio Catone, Italy
and European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei Munchen, Germany

The distance to the Galactic Centre (GC) is of importance for the distance scale in the Universe. The value derived by Eisenhauer et al. (2005) of 7.62 ± 0.32 kpc based on the orbit of one star around the central black hole is shorter than most other distance estimates based on a variety of different methods. To establish an independent distance to the GC with high accuracy. To this end Population-II Cepheids are used that have been discovered in the OG-II and OG-III surveys. Thirty-nine Population-II Cepheids have been monitored with the SOFI infrared camera on 4 nights spanning 14 days, obtaining typically between 5 and 11 epochs of data. Light curves have been fitted using the known periods from the OGLE data to determine the mean K-band magnitude with an accuracy of 0.01-0.02 mag. It so happens that 37 RR Lyrae stars are in the field-of-view of the observations and mean K-band magnitudes are derived for this sample as well. After correction for reddening, the period-luminosity relation of Population-II Cepheids in the K-band is determined, and the derived slope of -2.24 ± 0.14 is consistent with the value derived by Matsunaga et al. (2006). Fixing the slope to their more accurate value results in a zero point, and implies a distance modulus to the GC of 14.51 ± 0.12, with an additional systematic uncertainty of 0.07 mag. Similarly, from the RR Lyrae K-band period-luminosity relation we derive a value of 14.48 ± 0.17 (random) ± 0.07 (syst.). The two independent determinations are averaged to find 14.50 ± 0.10 (random) ± 0.07 (syst.), or 7.94 ± 0.37 ± 0.26 kpc. The absolute magnitude scale of the adopted period-luminosity relations is tied to an LMC distance modulus of 18.50 ± 0.07.

Ref.: A&A accepted
Email: groen@ster.kuleuven.be
Eprint: 0801.2652

Cataclysmic Variables in Globular Clusters, the Galactic Center, and Local Space

Craig O. Heinke Ashley J. Ruiter Michael P. Muno Krzysztof Belczynski

(1) University of Virginia, Astronomy Dept., PO Box 400325, Charlottesville VA 22903 (2) Dept. of Astronomy, New Mexico State University, 1320 Frenger Mall, Las Cruces, NM 88003 (3) Space Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125 (4) Dept. of Astronomy, New Mexico State University, 1320 Frenger Mall, Las Cruces, NM 88003; Tombaugh Fellow

We compare the X-ray spectra and luminosities, in the 2-8 keV band, of known and suspected cataclysmic variables (CVs) in different environments, assessing the nature of these source populations. These objects include nearby CVs observed with ASCA; the Galactic Center X-ray source population identified by Muno et al.; and likely CVs identified in globular clusters. Both of the latter have been suggested to be dominated by magnetic CVs. We find that the brighter objects in both categories are likely to be magnetic CVs, but that the fainter objects are likely to include a substantial contribution from normal CVs. The strangely hard spectra observed from the Galactic Center sources reflect the high and variable extinction, which is significantly greater than the canonical 6×10^{22} cm^{-2} over much of the region, and the magnetic nature of many of the brightest CVs. The total numbers of faint Galactic Center sources are compatible with expectations of the numbers of CVs in this field.

Ref.: Proceedings of "A Population Explosion", R.
Email: coh5z@virginia.edu
Eprint: 0801.1279

Spectral imaging of the Sagittarius B2 region in multiple 3-mm molecular lines with the Mopra telescope

P. A. Jones[1], M. G. Burton[1], M. R. Cunningham[1], K. M. Menten[2], P. Schilke[2], A. Belloche[2], S. Leurini[3], J. Ott[4], A. J. Walsh[5]

[1] School of Physics, University of New South Wales, NSW 2052, Australia
[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[3] European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany
[4] National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA
[5] School of Maths, Physics and IT, James Cook University, Qld 4814, Australia

Using the Mopra telescope, we have undertaken a 3-mm spectral-line imaging survey of a 5 arcmin square area around Sgr B2. We covered almost the complete spectral the range from 81.7 to 113.5 GHz, with 2.2 MHz wide spectral channels or ~ 6 km s^{-1} and have observed 24 lines, with 0.033 MHz wide, or ~ 0.1 km s^{-1} channels. We discuss the distribution of around 50 lines, and present velocity-integrated emission images for 38 of the lines. In addition, we have detected around 120 more lines, mostly concentrated at the particularly spectral line-rich Sgr B2(N) source. There are significant differences in molecular emission, pointing to both abundance and excitation differences throughout the region. Seven distinct spatial locations are identified for the emitting species, including peaks near the prominent star forming cores of Sgr B2(N), (M) and (S) that are seen in IR-to-radio continuum images. The other features are a 'North Ridge' and a 'North Cloud' to the north of the Sgr B2 N-M-S cores, a 'South-East Peak' and a 'West Ridge'. The column density, as evident through $C^{18}O$, peaks at the Sgr B2(N) and (M) cores, where strong absorption is also evident in otherwise generally-bright lines such as HCO^+, HCN and HNC. Most molecules trace a ridge line to the west of the Sgr B2 N-M-S cores, wrapping around the cores and extending NE to the North Cloud. This is most clearly evident in the species HC_3N, CH_3CN, CH_3OH and OCS. They are found to be closer in distribution to the cooler dust traced by the sub-mm continuum than either the warmer dust seen in the mid-IR or to the radio continuum. The molecule CN, in contrast, is reasonably uniform over the entire region mapped, aside from strong absorption at the positions of the Sgr B2(N) and (M) cores.

Ref.: MNRAS, in press
Email: pjones@phys.unsw.edu.au
Eprint: 0712.0218

Hypervelocity Stars: From the Galactic Center to the Halo

Scott J. Kenyon(1), Benjamin C. Bromley(2), Margaret J. Geller(1), Warren R. Brown(1)

(1) Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge, MA 02138 (2) Department of Physics, University of Utah, 115 S 1400 E, Rm 201, Salt Lake City, UT 84112

Hypervelocity stars (HVS) traverse the Galaxy from the central black hole to the outer halo. We show that the Galactic potential within 200 pc acts as a high pass filter preventing low velocity HVS from reaching the halo. To trace the orbits of HVS throughout the Galaxy, we construct two forms of the potential which reasonably represent the observations in the range 5–10^5 pc, a simple spherically symmetric model and a bulge-disk-halo model. We use the Hills mechanism (disruption of binaries by the tidal field of the central black hole) to inject HVS into the Galaxy and compute the observable spatial and velocity distributions of HVS with masses in the range 0.6–4 $M_\odot$. These distributions reflect the mass function in the GC, properties of binaries in the GC, and aspects of stellar evolution and the injection mechanism. For 0.6–4 $M_\odot$main sequence stars, the fraction of unbound HVS and the asymmetry of the velocity distribution for their bound counterparts increases with stellar mass. The density profiles for unbound HVS decline with distance from the GC approximately as r^{-2} (but are steeper for the most massive stars which evolve off the main sequence during their travel time from the GC); the density profiles for the bound ejecta decline with distance approximately as r^{-3}. In a survey with limiting magnitude $V \leq 23$, the detectability of HVS (unbound or bound) increases with stellar mass.

Ref.: ApJ, submitted
Email: kenyon@cfa.harvard.edu
Eprint: 0801.3479

Tracing shocks and photodissociation in the Galactic center region

Sergio Martín(1), M.A. Requena-Torres(2), J. Martín-Pintado(3), R. Mauersberger(4)

(1) Harvard-Smithsonian Center for Astrophysics, 60 Garden St., 02138, Cambridge, MA, USA (2) Max-Plack-Institut für

Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany (3) Departamento de Astrofisíca Molecular e Infrarroja, Instituto de Estructura de la Materia, CSIC, Serrano 121, E-28006 Madrid, Spain (4) Instituto de Radioastronomía Milimétrica, Avenida Divina Pastora 7, Local 20, E-18012 Granada, Spain

We present a systematic study of the HNCO, $C^{18}O$, ^{13}CS, and $C^{34}S$ emission towards 13 selected molecular clouds in the Galactic center region The molecular emission in these positions are used as templates of the different physical and chemical processes claimed to be dominant in the circumnuclear molecular gas of galaxies. The relative abundance of HNCO shows a variation of more than a factor of 20 among the observed sources. The $HNCO/^{13}CS$ abundance ratio is highly contrasted (up to a factor of 30) between the shielded molecular clouds mostly affected by shocks, where HNCO is released to gas-phase from grain mantles, and those pervaded by an intense UV radiation field, where HNCO is photodissociated and CS production favored via ion reactions. We propose the relative HNCO to CS abundance ratio as a highly contrasted diagnostic tool to distinguish between the influence of shocks and/or the radiation field in the nuclear regions of galaxies and their relation to the evolutionary state of their nuclear star formation bursts.

Ref.: ApJ accepted
Email: smartin@cfa.harvard.edu

LMC origin of the hyper-velocity star HE 0437−5439. Beyond the supermassive black hole paradigm

N. Przybilla[1], M. F. Nieva[1], U. Heber[1], M. Firnstein[1], K. Butler[2], R. Napiwotzki[3], H. Edelmann[1]

(1) Dr. Remeis-Sternwarte Bamberg, Sternwartstr. 7, D-96049 Bamberg, Germany (2) Universitätssternwarte München, Scheinerstr. 1, D-81679 München, Germany (3) Centre for Astrophysics Research, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK

Hyper-velocity stars move so fast that only a supermassive black hole (SMBH) seems to be capable to accelerate them. Hence the Galactic centre (GC) is their only suggested place of origin. Edelmann et al. (2005) found the early B-type star HE 0437−5439 to be too short-lived to have reached its current position in the Galactic halo if ejected from the GC, except if being a blue straggler star. Its proximity to the Large Magellanic Cloud (LMC) suggested an origin from this galaxy. The chemical signatures of stars at the GC are significantly different from those in the LMC. Hence, an accurate measurement of the abundance pattern of HE 0437−5439 will yield a new tight constraint on the place of birth of this hyper-velocity star. High-resolution spectra obtained with UVES on the VLT are analysed using state-of-the-art non-LTE modelling techniques. We measured abundances of individual elements to very high accuracy in HE 0437−5439 as well as in two reference stars, from the LMC and the solar neighbourhood, respectively. The abundance pattern is not consistent at all with that observed in stars near the GC, ruling our an origin from the GC. However, there is a high degree of consistency with the LMC abundance pattern. Our abundance results cannot rule out an origin in the outskirts of the Galactic disk. However, we find the life time of HE 0437−5439 to be more than three times shorter than the time of flight to the edge of the disk, rendering a Galactic origin unlikely. Only one SMBH is known to be present in Galaxy and none in the LMC. Hence the exclusion of an GC origin challenges the SMBH paradigm. We conclude that there must be other mechanism(s) to accelerate stars to hyper-velocity speed than the SMBH. We draw attention to dynamical ejection from dense massive clusters, that has recently been proposed by Gvaramadze et al. (2008).

Ref.: A&A, accepted
Email: przybilla@sternwarte.uni-erlangen.de
http://www.sternwarte.uni-erlangen.de/~ai32/hvs.pdf

GBT Multiwavelength Survey of the Galactic Center Region

C. J. Law(1,2), F. Yusef-Zadeh(1), W. D. Cotton(3), and R. J. Maddalena(4)

(1) Department of Physics and Astronomy, Northwestern University, 2145 Sheriadan Road, Evanston, 60208 IL, USA (2) Astronomical Institute "Anton Pannekoek", University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, Netherlands (3) National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA (4) National Radio Astronomy Observatory, P.O. Box 2, Rt. 28/92, Green Bank, WV 24944, USA

We describe the results of a radio continuum survey of the central 4sdeg×1sdeg with the 100 m Green Bank Telescope (GBT) at wavelengths of 3.5, 6, 20, and 90 cm. The 3.5 and 6 cm surveys are the most sensitive and highest resolution single dish surveys made of the central degrees of our Galaxy. We present catalogs of compact and extended sources in

the central four degrees of our Galaxy, including detailed spectral index studies of all sources. The analysis covers star-forming regions such as Sgr B and Sgr C where we find evidence of a mixture of thermal and nonthermal emission. The analysis quantifies the relative contribution of thermal and nonthermal processes to the radio continuum flux density toward the GC region. In the central 4sdeg×1sdeg of the GC, the thermal and nonthermal flux fractions for all compact and diffuse sources are 28%/72% at 3.5 cm and 19%/81% at 6 cm. The total flux densities from these sources are 783 ± 52 Jy and 1063 ± 93 Jy at 3.5 and 6 cm, respectively, excluding the contribution of Galactic synchrotron emission.

Ref.: ApJS, July 2008 , in press
Email: caseyjlaw@gmail.com
Eprint: 0801.4294

Tracing intermediate-mass black holes in the Galactic Centre

U. Löckmann and H. Baumgardt

Argelander Institute for Astronomy, University of Bonn, Auf dem Hügel 71, 53121 Bonn, Germany

We have developed a new method for post-Newtonian, high-precision integration of stellar systems containing a super-massive black hole (SMBH), splitting the forces on a particle between a dominant central force and perturbations. We used this method to perform fully collisional N-body simulations of inspiralling intermediate-mass black holes (IMBHs) in the centre of the Milky Way. We considered stellar cusps of different power-law indices and analysed the effects of IMBHs of different masses, all starting from circular orbits at an initial distance of 0.1 pc. Our simulations show how IMBHs deplete the central cusp of stars, leaving behind a flatter cusp with slope consistent with what has recently been observed. If an additional IMBH spirals into such a flat cusp, it can take 50 Myr or longer to merge with the central SMBH, thus allowing for direct observation in the near future. The final merger of the two black holes involves gravitational wave radiation which may be observable with planned gravitational wave detectors. Furthermore, our simulations reveal detailed properties of the hyper-velocity stars (HVSs) created, and how generations of HVSs can be used to trace IMBHs in the Galactic centre. We find that significant rotation of HVSs (which would be evidence for an IMBH) can only be expected among very fast stars ($v > 1000$ km/s). Also, the probability of creating a hyper-velocity binary star is found to be very small.

Ref.: MNRAS, 384, 323-330, 2008
Email: uloeck@astro.uni-bonn.de
Eprint: 0711.1326
http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2966.2007.12699.x

Linearly and Circularly Polarized Emission in Sagittarius A*

Lei Huang(1,3), Siming Liu(4), Zhi-Qiang Shen(1,2), Mike J. Cai(5), Hui Li,(4) and Christopher L. Fryer(4)

(1) Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China (2) Joint Institute for Galaxy and Cosmology (JOINGC) of ShAO and USTC, Shanghai 200030, China (3) Graduate School of the Chinese Academy of Sciences, Beijing 100039, China (4) Los Alamos National Laboratory, Los Alamos, NM 87545 (5) Academia Sinica, Institute of Astronomy and Astrophysics, Taipei 106, Taiwan

We perform general relativistic ray-tracing calculations of the transfer of polarized synchrotron radiation through the relativistic accretion flow in Sagittarius (Sgr) A*. Based on a two-temperature magneto-rotational-instability (MRI) induced accretion mode, the birefringence effects are treated self-consistently. By fitting the spectrum and polarization of Sgr A* from millimeter to near-infrared bands, we are able to not only constrain the basic parameters related to the MRI and the electron heating rate, but also limit the orientation of the accretion torus. These constraints lead to unique polarimetric images, which may be compared with future millimeter and sub-millimeter VLBI observations. In combination with general relativistic MHD simulations, the model has the potential to test the MRI with observations of Sgr A*.

Ref.: ApJL, accepted Feb 2008
Email: muduri@shao.ac.cn
Eprint: 0802.3561
http://arxiv.org/pdf/0802.3561

IRS 13N: a new comoving group of sources at the Galactic Center

K. Muzic[1,2], R. Schödel[3], A. Eckart[1,2], L. Meyer[4], A. Zensus[2,1]

(1) I. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany
(2) Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany

(3) Instituto de Astrofísica de Andalucía, Camino Bajo de Hutor 50, 18008 Granada, Spain
(4) University of California, Division of Astronomy and Astrophysics, Los Angeles, CA 90095-4705

The Galactic Center IRS 13E cluster is located ~3.2" from SgrA*. It is an extremely dense stellar association containing several Wolf-Rayet and O-type stars, at least four of which show a common velocity. Only half an arcsecond north from IRS 13E there is a complex of extremely red sources, so-called IRS 13N. Their nature is still unclear. Based on the analysis of their colors, there are two main possibilities: (1) dust embedded sources older than few Myr, or (2) extremely young objects with ages less than 1Myr. We present the first proper motion measurements of IRS 13N members, and additionally give proper motions of four of IRS 13E stars resolved in the L'-band. The L'-band (3.8μm) observations have been carried out using the NACO adaptive optics system at the ESO VLT. Proper motions have been obtained by linear fitting of the stellar positions extracted by StarFinder as a function of time, weighted by positional uncertainties. We show that six of seven resolved northern sources show a common proper motion, thus revealing a new comoving group of stars in the central half parsec of the Milky Way. The common proper motions of IRS 13E and IRS 13N clusters are significantly ($>5\,\sigma$) different. We also performed a fitting of the positional data for those stars onto Keplerian orbits, assuming SgrA* as the center of the orbit. Our results favor the very young stars hypothesis.

Ref.: A&A, 2008, in press
Email: muzic@ph1.uni-koeln.de

On a Source of Systematic Error in Absolute Measurement of Galactocentric Distance from Solving for the Stellar Orbit Around Sgr A*

Igor' I. Nikiforov

(1) Sobolev Astronomical Institute, St. Petersburg State University, Universitetskij pr. 28, Staryj Peterhof, St. Petersburg 198504, Russia, nii@astro.spbu.ru

Eisenhauer et al. (2003, 2005) derived absolute (geometrical) estimates of the distance to the center of the Galaxy, R_0, from the star S2 orbit around Sgr A* on the assumption that the intrinsic velocity of Sgr A* is negligible. This assumption produces the source of systematic error in R_0 value owing to a probable motion of Sgr A* relative to the accepted velocity reference system which is arbitrary to some extent. Eisenhauer et al. justify neglecting all three spatial velocity components of Sgr A* mainly by low limits of Sgr A*'s proper motion of 20–60 km/s. In this brief paper, a simple analysis in the context of the Keplerian dynamics was used to demonstrate that neglect of even low (perhaps, formal) radial velocity of Sgr A* leads to a substantial systematic error in R_0: the same limits of 20–60 km/s result in R_0 errors of 1.3–5.6%, i.e., $(0.1\text{–}0.45)\times(R_0/8)$ kpc, for current S2 velocities. Similar values for Sgr A*'s tangential motion can multiply this systematic error in the case of S2 orbit by factor ≈1.5–1.9 in the limiting cases.

Ref.: Dynamics of Galaxies, Proceedings of the
Email: nii@dyna.astro.spbu.ru
Eprint: 0803.0825

Odin observations of the Galactic centre in the 118-GHz band. Upper limit to the O_2 abundance

Aa. Sandqvist[1], *B. Larsson*[1], *Å. Hjalmarson*[2], *P. Bergman*[2], *P. Bernath*[3], *U. Frisk*[4], *M. Olberg*[2], *L. Pagani*[5], *L.M. Ziurys*[6]

(1) Stockholm Observatory, AlbaNova University Center, SE-106 91 Stockholm, Sweden (2) Onsala Space Observatory, SE-439 92 Onsala, Sweden (3) Department of Chemistry, University of York, Heslington, York, YO10 5DD, UK (4) Swedish Space Corporation, P. O. Box 4207, SE-171 04 Solna, Sweden (5) LERMA & UMR8112 du CNRS, Observatoire de Paris, 61, FR-75014 Paris, France (6) Arizona Radio Observatory, Steward Observatory, University of Arizona, Tucson, AZ 85721, USA

The Odin satellite has been used to search for the 118.75-GHz line of molecular oxygen (O_2) in the Galactic centre. Odin observations were performed towards the Sgr A^* circumnuclear disk (CND), and the Sgr A +20 km s^{-1} and +50 km s^{-1} molecular clouds using the position-switching mode. Supplementary ground-based observations were carried out in the 2-mm band using the ARO Kitt Peak 12-m telescope to examine suspected SiC features. A strong emission line was found at 118.27 GHz, attributable to the $J = 13 - 12$ HC_3N line. Upper limits are presented for the 118.75-GHz O_2 $(1_1 - 1_0)$ ground transition line and for the 118.11-GHz $^3\Pi_2, J = 3 - 2$ ground state SiC line at the Galactic centre. Upper limits are also presented for the 487-GHz O_2 line in the Sgr A +50 km s^{-1} cloud and for the 157-GHz, $J = 4 - 3$, SiC line in the Sgr A +20 and +50

$\mathrm{km\,s^{-1}}$ clouds, as well as the CND. The CH_3OH line complex at 157.2 - 157.3 GHz has been detected in the +20 and +50 $\mathrm{km\,s^{-1}}$ clouds but not towards Sgr A^*/CND. A 3σ upper limit for the fractional abundance ratio of $[O_2]/[H_2]$ is found to be $X(O_2) \leq 1.2 \times 10^{-7}$ towards the Sgr A molecular belt region.

Ref.: A&A, in press
Email: aage@astro.su.se
Eprint: 0803.1726

Radial Velocities of Stars in the Galactic Center

Qingfeng Zhu(1), Rolf P. Kudritzki(2), Donald F. Figer(1), Francisco Najarro(3), David Merritt(4)

(1) Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623-5604 (2) Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822 (3) Insituto de Estructura de la Materia, Consejo Superior de Investigaciones Cientificas, Calle Serrano 121, 28006, Madrid, Spain (4) Department of Physics and Center for Computational Relativity and Gravitation, 85 Lomb Memorial Drive, Rochester, NY 14623-5604

We present results from K band slit scan observations of a 20"x20" region of the Galactic center (GC) in two separate epochs more than five years apart. The high resolution (R≥14,000) observations allow the most accurate radial velocity and acceleration measurements of the stars in the central parsec of the Galaxy. Detected stars can be divided into three groups based on the CO absorption band heads at 2.2935 μm and the He I lines at 2.0581 μm and 2.112, 2.113 μm: cool, narrow-line hot and broad-line hot. The radial velocities of the cool, late-type stars have approximately a symmetrical distribution with its center at ~-7.8±10.3 km s^{-1} and a standard deviation ~113.7±10.3 km s^{-1}. Although our statistics are dominated by the brightest stars, we estimate a central black hole mass of $3.9 \pm 1.1 \times 10^6$ solar masses, consistent with current estimates from complete orbits of individual stars. Our surface density profile and the velocity dispersion of the late type stars support the existence of a low density region at the Galactic center suggested by earlier observations. Many hot, early-type stars show radial velocity changes higher than maximum values allowed by pure circular orbital motions around a central massive object, suggesting that the motions of these stars greatly deviate from circular orbital motions around the Galactic center. The correlation between the radial velocities of the early type He I stars and their declination offsets from Sagittarius A* suggests that a systematic rotation is present for the early-type population. No figure rotation around the Galactic center for the late type stars is supported by the new observations.

Ref.: ApJ, July 2008, in press
Email: qxzpci@cis.rit.edu
Eprint: 0803.1826

A Wide-area VLA Continuum Survey near the Galactic Center at 6 and 20 cm Wavelengths

C. J. Law(1,2), F. Yusef-Zadeh(2), W. D. Cotton(3)

(1) Department of Physics and Astronomy, Northwestern University, Evanston, Illinois 60208, USA (2) stronomical Institute "Anton Pannekoek", University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands (3) National Radio Astronomy Observatory, Charlottesville, VA 22903, USA

We describe the results of a mJy-sensitivity, VLA survey of roughly 1 square degree near the Galactic center at 6 and 20 cm. Catalogs of compact and filamentary structures are given and compared to previous surveys of the region. Eight of the unusual, nonthermal radio filaments are detected in 6 cm polarized emission; three of these are the first such detections, confirming their nonthermal nature. This survey found emission from a filament at (l,b)=(359.1,0.75), or a projected distance from Sgr A* of 200 pc, greatly extending the latitude range observed with such features. There is also new evidence for spatial gradients in the 6/20 cm spectral indices of some filaments and we discuss models for these gradients. In studying compact sources, the combination of spectral index and polarization information allows us to identify pulsar candidates and compact HII regions in the survey. There is also some evidence that the flux measurements of compact sources may be affected by electron scattering from the interstellar medium in the central few hundred parsecs of the Galaxy.

Ref.: ApJS, August 2008 , in press
Email: caseyjlaw@gmail.com
Eprint: 0803.1412

Massive Star Formation in the Galactic Center

D. F. Figer et al.

Rochester Institute of Technology, Rochester, NY, USA

The Galactic center is a hotbed of star formation activity, containing the most massive star formation site and three of the most massive young star clusters in the Galaxy. Given such a rich environment, it contains more stars with initial masses above 100 $M_{\odot}$ than anywhere else in the Galaxy. This review concerns the young stellar population in the Galactic center, as it relates to massive star formation in the region. The sample includes stars in the three massive stellar clusters, the population of younger stars in the present sites of star formation, the stars surrounding the central black hole, and the bulk of the stars in the field population. The fossil record in the Galactic center suggests that the recently formed massive stars there are present-day examples of similar populations that must have been formed through star formation episodes stretching back to the time period when the Galaxy was forming.

Ref.:
Email: cmtpci@cis.rit.edu
Eprint: 0803.1619
http://arxiv.org/abs/0803.1619

Time Variability of the Neutral Iron Lines from the Sgr B2 Region and its Implication of a Past Outburst of Sgr A*

Tatsuya Inui, Katsuji Koyama, Hironori Matsumoto and Takeshi Go Tsuru

(1) Department of Physics, Graduate School of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502

We investigate long-term X-ray behaviors from the Sgr B2 complex using archival data of the X-ray satellites Suzaku, XMM-Newton, Chandra and ASCA. The observed region of the Sgr B2 complex includes two prominent spots in the Fe I K-α line at 6.40 keV, a giant molecular cloud M 0.66−0.02 known as the "Sgr B2 cloud" and an unusual X-ray source G 0.570−0.018. Although these 6.40 keV spots have spatial extensions of a few pc scale, the morphology and flux of the 6.40 keV line has been time variable for 10 years, in contrast to the constant flux of the Fe XXV-Kα line at 6.67 keV in the Galactic diffuse X-ray emission. This time variation is mostly due to M 0.66−0.02; the 6.40 keV line flux declined in 2001 and decreased to 60% in the time span 1994–2005. The other spot G 0.570−0.018 is found to be conspicuous only in the Chandra observation in 2000. From the long-term time variability ($\sim$10 years) of the Sgr B2 complex, we infer that the Galactic Center black hole Sgr A* was X-ray bright in the past 300 year and exhibited a time variability with a period of a few years.

Ref.: PASJ, 2008, accepted
Email: inuit@cr.scphys.kyoto-u.ac.jp

The Path to Buried Treasure: Paving the Way to the FLAMINGOS-2 Galactic Center Survey with IR and X-ray Observations

Reba M. Bandyopadhyay, Stephen S. Eikenberry, Curtis Dewitt Andrew J. Gosling Michael P. Muno and the F2GCS Team

(1) Dept. of Astronomy, University of Florida, Gainesville, FL 32611 (2) Dept. of Astrophysics, University of Oxford, Oxford OX1 3RH, UK (3) California Institute of Technology, Pasadena, CA 91125

I describe the IR and X-ray campaign we have undertaken to determine the nature of the faint discrete X-ray source population discovered by *Chandra*in the Galactic Center. These results will provide the input to the FLAMINGOS-2 Galactic Center Survey (F2GCS). With FLAMINGOS-2's multi-object IR spectrograph we will obtain 1000s of IR spectra of candidate X-ray source counterparts, allowing us to efficiently identify the nature of these sources, and thus dramatically increase the number of known X-ray binaries and CVs in the Milky Way.

Ref.: AIP Conf. Proc., 2008, in press
Email: reba@astro.ufl.edu
Eprint: 0803.2721

FLAMINGOS-2: A Near-IR Multi-Object Spectrometer Ideal for Surveying the Galactic Center

S. Nicholas Raines, Stephen S. Eikenberry, and Reba M. Bandyopadhyay

(1) University of Florida, Department of Astronomy, 211 Bryant Space Science Center, Gainesville, FL 32611

FLAMINGOS-2 (PI: S. Eikenberry) is a $5M facility-class near-infrared (1-2.5 μm) multi-object spectrometer and wide-field imager being built at the University of Florida for Gemini South. Here we highlight the capabilities of FLAMINGOS-2, as it will be an ideal instrument for surveying the accreting binary population in the Galactic Center.

Ref.: AIP Conf. Proc., 2008, in press
Email: reba@astro.ufl.edu

Eprint: 0803.3083

The FLAMINGOS-2 Galactic Center Survey

Stephen S. Eikenberry

(1) Department of Astronomy, University of Florida, 211 Bryant Space Science Center, Gainesville, 32611

Upon commissioning on Gemini South, FLAMINGOS-2 will be one of the most powerful wide-field near-infrared imagers and multi-object spectrographs ever built for use on 8-meter-class telescopes. In order to take best advantage of the strengths of FLAMINGOS-2 early in its life cycle, the instrument team has proposed to use 21 nights of Gemini guaranteed time in 3 surveys – the FLAMINGOS-2 Early Science Surveys (F2ESS). The F2ESS will encompass 3 corresponding science themes – the Galactic Center, galaxy evolution, and star formation. In this paper, I review the design performance and status of FLAMINGOS-2, and describe the planned FLAMINGOS-2 Galactic Center Survey.

Ref.: AIP Conf. Proc., 2008, in press
Email: reba@astro.ufl.edu
Eprint: 0803.3084

Non-uniform model for the synchrotron radiation of SgrA* and other low-luminosity galactic nuclei

V. I. Slysh

Astro Space Center, Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia

The model of a non-uniform source of synchrotron radiation with a power-law radial distribution of the magnetic field and relativistic-electron density along one- or two-sided jets is described. Non-relativistic jets with both constant cross sections (collimated jets) and the cross sections that are proportional to distance (conical jets) are considered. Formulas that can be used to determine source parameters from the spectral index, source size, and index of the relativistic-electron energy spectrum based on multi-frequency observations are obtained. In the case of a conical jet, these formulas coincide with the analogous formulas for a spherical source obtained by A.P.Marscher. Relations that can be used to estimate the magnetic-field strength from the brightness temperature in the self-absorbed region are also obtained. As examples, the non-uniform source model is applied to the compact radio sources at the centers of the Milky Way, SgrA*, and the low-luminosity galactic nuclei M81* and M87*, which are associated with supermassive black holes. The inner radius of the radiation region is determined. For SgrA*, this distance turns out to be comparable to the gravitational radius, smaller than the radius of the last stable orbit for non-rotating black hole, and consistent with the radius of the last stable orbit expected for a rotating black hole. The inner radii in M81* and M87* are $\sim 15\ R_S$, an order of magnitude larger then for SgrA*. Estimates of the magnetic field at the inner radius are 400 G for M81*, 0.65/5.3 kG for SgrA*, and 20/100 kG for M87*. These magnetic fields and the Blandford–Znajek model for the radiation of a rotating black hole are used to estimate the rotational speed of the black holes, which is in agreement with the characteristic variability time scales for these three objects. However, the accuracy of these estimates is modest, and is limited primarily by the accuracy of interferometric measurements at millimeter wavelengths.

Ref.: Astronomy reports, May 2008, in press
Email: vslysh@asc.rssi.ru

Limits on the Position Wander of Sgr A*

Mark J. Reid[1], Avery E. Broderick[1,2], Abraham Loeb[1], Mareki Honma[3], Andreas Brunthaler[4]

(1) Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
(2) Canadian Institute for Theoretical Astrophysics, 60 St. George Street, Toronto, ON Canada
(3) Mizusawa VERA Observatory, NAOJ, Mitaka, Tokyo 181-8588, Japan
(4) Max-Planck-Institute für Radioastronomie, 69 Auf dem Hügel, Bonn-53121, Germany

We present measurements with the VLBA of the variability in the centroid position of Sgr A* relative to a background quasar at 7mm wavelength. We find an average centroid wander of 71 ± 45
muas for time scales between 50 and 100 min and 113 ± 50
muas for timescales between 100 and 200 min, with no secular trend. These are sufficient to begin constraining the viability of the accretion hot-spot model for the radio variability of Sgr A*. It is possible to rule out hot spots with orbital radii above $15\,GM_{SgrA*}/c^2$ that contribute more than 30% of the total 7mm flux. However, closer or less luminous hot spots remain unconstrained. Since the fractional variability of Sgr A* during our observations was

$\sim 20\%$ on time scales of hours, the hot-spot model for Sgr A*'s radio variability remains consistent with these limits. Improved monitoring of Sgr A*'s centroid position has the potential to place significant constraints upon the existence and morphology of inhomogeneities in a supermassive black hole accretion flow.

Ref.: ApJ, in press
Email: reid@cfa.harvard.edu

Very Large Array Observations of Galactic Center OH 1720 MHz Masers in Sagittarius A East and in the Circumnuclear Disk

Loránt O. Sjouwerman(1) Ylva M. Pihlström(2)

(1) National Radio Astronomy Observatory, 1003 Lopezville Rd., Socorro, NM 87801, (2) Department of Physics and Astronomy, University of New Mexico, 800 Yale Boulevard NE, Albuquerque, NM 87131,

We present Very Large Array (VLA) radio interferometry observations of the 1720 MHz OH masers in the Galactic Center (GC). Most 1720 MHz OH masers arise in regions where the supernova remnant Sgr A East is interacting with the interstellar medium. The majority of the newly found 1720 MHz OH masers are located to the northeast, independently indicating and confirming an area of shock interaction with the +50 km/s molecular cloud (M-0.02-0.07) on the far side of Sgr A East. The previously known bright masers in the southeast are suggested to be the result of the interaction between two supernova remnants, instead of between Sgr A East and the surrounding molecular clouds as generally found elsewhere in the Galaxy. Together with masers north of the circumnuclear disk (CND) they outline an interaction on the near side of Sgr A East. In contrast to the interaction between the +50 km/s cloud and Sgr A East, OH absorption data do not support a direct interaction between the CND material and Sgr A East. We also present three new high-negative velocity masers, supporting a previous single detection. The location and velocities of the high-negative and high-positive velocity masers are consistent with being near the tangent points of, and physically located in the CND. We argue that the high velocity masers in the CND are pumped by dissipation between density clumps in the CND instead of a shock generated by the supernova remnant. That is, the CND masers are not coupled to the supernova remnant and are sustained independently.

Ref.: ApJ, accepted
Email: lsjouwer@nrao.edu
Eprint: 0804.0445

Spherical Accretion with Anisotropic Thermal Conduction

P. Sharma[1], E. Quataert[1], J. M. Stone[2]

(1) Astronomy Department and Theoretical Astrophysics Center, 601 Campbell Hall, University of California, Berkeley CA, 94720, USA (2) Department of Astrophysical Sciences, Peyton Hall, Ivy Lane, Princeton, NJ, 08544, USA

We study the effects of anisotropic thermal conduction on magnetized spherical accretion flows using global axisymmetric MHD simulations. In low collisionality plasmas, the Bondi spherical accretion solution is unstable to the magnetothermal instability (MTI). The MTI grows rapidly at large radii where the inflow is subsonic. For a weak initial field, the MTI saturates by creating a primarily radial magnetic field, i.e., by aligning the field lines with the background temperature gradient. The saturation is quasilinear in the sense that the magnetic field is amplified by a factor of $\sim 10-30$ independent of the initial field strength (for weak fields). In the saturated state, the conductive heat flux is much larger than the convective heat flux, and is comparable to the field-free (Spitzer) value (since the field lines are largely radial). The MTI by itself does not appreciably change the accretion rate $\dot{M}$ relative to the Bondi rate $\dot{M}_B$. However, the radial field lines created by the MTI are amplified by flux freezing as the plasma flows in to small radii. Oppositely directed field lines are brought together by the converging inflow, leading to significant resistive heating. When the magnetic energy density is comparable to the gravitational potential energy density, the plasma is heated to roughly the virial temperature; the mean inflow is highly subsonic; most of the energy released by accretion is transported to large radii by thermal conduction; and the accretion rate $\dot{M} \ll \dot{M}_B$. The predominantly radial magnetic field created by the MTI at large radii in spherical accretion flows may account for the stable Faraday rotation measure towards Sgr A* in the Galactic Center.

Ref.: MNRAS submitted
Email: psharma@astro.berkeley.edu
http://arxiv.org/abs/0804.1353

X-Ray Observations of the Sagittarius D HII Region toward the Galactic Center with Suzaku

Makoto Sawada(1), Masahiro Tsujimoto(2), Katsuji Koyama(1), Casey J. Law(3), Takeshi Go Tsuru(1), Yoshiaki Hyodo(1)

(1) Department of Physics, Graduate School of Science, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606-8502 (2) Department of Astronomy & Astrophysics, Pennsylvania State University, 525 Davey Laboratory, University Park, PA 16802, USA (3) Astronomical Institute "Anton Pannekoek", University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands

We present a Suzaku X-ray study of the Sagittarius D (Sgr D) HII region in the Galactic center region. Two $18' \times 18'$ images by the X-ray Imaging Spectrometer (XIS) encompass the entire Sgr D complex. Thanks to the low background, XIS discovered two diffuse sources with low surface brightness and obtained their high signal-to-noise ratio spectra. One is associated with the core of the Sgr D HII region, arising from the young stellar cluster. The other is a new object in the vicinity of the region. We also present 3.5 cm and 6.0 cm radio continuum maps of the new source using the 100 m Green Bank Telescope. We conclude that the source is a new supernova remnant (SNR; G1.2–0.0) based on: (1) the 0.9 ± 0.2 keV thermal X-ray spectrum with emission lines from highly ionized atoms; (2) the diffuse nature with an apparent extent of $\sim$10 pc at the Galactic center distance inferred from the X-ray absorption ($\sim 8.5 \times 10^{22}$ cm^{-2}); and (3) the nonthermal radio continuum spectral index (~ -0.5). Our discovery of an SNR in the Sgr D HII region leads to a revision of the view of this system, which had been considered to be a thermal HII region and its environment.

Ref.: PASJ, in press
Email: sawada@cr.scphys.kyoto-u.ac.jp
Eprint: 0805.2079
http://www-cr.scphys.kyoto-u.ac.jp/member/sawada/paper/ms_SuzakuSgrD.pdf

First VLTI infrared spectro-interferometry on GCIRS 7

J.-U. Pott(1,2,3), A. Eckart(3), A. Glindemann(4), S. Kraus(5), R. Schödel(6), A. M. Ghez(2), J. Woillez(1), G. Weigelt(5),

(1) W.M. Keck Observatory (WMKO), CARA, 65-1120 Mamalahoa Hwy., Kamuela, HI-96743, USA (2) University of California Los Angeles (UCLA), Department of Astronomy, 430 Portola Plaza, Los Angeles, CA 90095-1547, USA (3) I. Physikalisches Institut (PH1), University of Cologne, Zülpicher Str. 77, D-50937 Köln, Germany (4) European Southern Observatory (ESO), Karl-Schwarzschild Str. 2, D-85748 Garching bei München, Germany (5) Max-Planck-Institut für Radioastronomie (MPIfR), Auf dem Hügel 69, D-53121 Bonn, Germany (6) Instituto de Astrofísica de Andalucía (IAA), Camino Bajo de Huétor, 50, 18008 Granada, Spain

The massive black hole Sgr A* at the very center of the Galaxy, and its immediate stellar and non-stellar environment, have been studied in the past decade with increasing intensity and wavelength coverage, revealing surprising results. This research requires the highest angular resolution available to avoid source confusion and to study the physical properties of the objects. GCIRS 7 is the dominating star of the central cluster in the NIR, so it has been used as wavefront and astrometric reference. Our studies investigate, for the first time, its properties at 2 and 10 μm using the VLTI. We aim at analyzing the suitability of GCIRS 7 as an interferometric phase-reference for the upcoming generation of dual-field facilities at optical interferometers. VLTI-AMBER and MIDI instruments were used to spatially resolve GCIRS 7 and to measure the wavelength dependence of the visibility using the low spectral resolution mode ($\lambda/\Delta\lambda \approx 30$) and projected baseline lengths of about 50 m, resulting in an angular resolution of about 9 mas and 45 mas for the NIR and MIR, respectively. The first K-band fringe detection of a GC star suggests that GCIRS 7 could be marginally resolved at 2 micron, which would imply that the photosphere of the supergiant is enshrouded by a molecular and dusty envelope. At 10 μm, GCIRS 7 is strongly resolved with a visibility of approximately 0.2. The MIR is dominated by moderately warm (200 K), extended dust, mostly distributed outside of a radius of about 120 AU (15 mas) around the star. A deep 9.8 μm-silicate absorption in excess of the usual extinction law with respect to the NIR extinction has been found. Our VLTI observations show that interferometric NIR phase-referencing experiments with mas resolution using GCIRS 7 as phase reference appear to be feasible, but more such studies are required to definitely characterize the close environment around this star. The MIR data confirm recent findings of a relatively enhanced, interstellar 9.8 μm-silicate ab-

sorption with respect to the NIR extinction towards another star in the central arc-seconds, suggesting an unusual dust composition in that region. We demonstrate that the resolution and sensitivity of modern large-aperture optical telescope arrays is required to resolve the innermost environment of stars at the Galactic center.

Ref.: A&A, 2008, in press
Email: jpott@keck.hawaii.edu
Eprint: 0805.4408
http://planetquest.jpl.nasa.gov/Keck/keck_index.cfm

On the Formation of Compact Stellar Disks Around Sgr A*

Mark Wardle Farhad Yusef-Zadeh

(1) Department of Physics, Macquarie University, Sydney NSW 2109, Australia (2) Department of Physics & Astronomy, Northwestern University, Evanston, IL 60208, USA

The recent identification of one or two sub-parsec disks of young, massive stars orbiting the ~ 4
ee6
msol black hole Sgr A* has prompted an "in-situ" scenario for star formation in disks of gas formed from a cloud captured from the Galactic center environment. To date there has been no explanation given for the low angular momentum of the disks relative to clouds passing close to the center. Here we show that the partial accretion of extended Galactic center clouds, such as the 50 km s^{-1} giant molecular cloud, that temporarily engulf Sgr A* during their passage through the central region of the Galaxy provide a natural explanation for the angular momentum and surface density of the the observed stellar disks. The captured cloud material is gravitationally unstable and forms stars as it circularizes, potentially explaining the large eccentricity and range of inclinations of the observed stellar orbits. The application of this idea to the formation of the circumnuclear ring is also discussed.

Ref.: ApJ Letters, in press
Email: wardle@ics.mq.edu.au
Eprint: 0805.3274

Two extremely luminous WN stars in the Galactic center with circumstellar emission from dust and gas

A. Barniske, L. M. Oskinova, and W.-R. Hamann

(1) Potsdam University, Am Neuen Palais 10, Potsdam, 14469 Germany

The central region of our Galaxy contains a large population of young massive stars. These stars are concentrated in three large star clusters, as well as being scattered in the field. Strong ionizing radiation and stellar winds of massive stars are the essential feedback agents that determine the physics of the ISM in the Galactic center. The aim is to study relatively isolated massive WN-type stars in the Galactic center in order to explore their properties and their influence on the ISM. The K-band spectra of two WN stars in the Galactic center, WR 102ka and WR 102c, are exploited to infer the stellar parameters and to compute synthetic stellar spectra using the Potsdam Wolf-Rayet (PoWR) model atmosphere code. These models are combined with dust-shell models for analyzing the *Spitzer* IRS spectra of these objects. Archival IR images complement the interpretation. We report that WR 102ka and WR 102c are among the most luminous stars in the Milky Way. They critically influence their immediate environment by strong mass loss and intense UV radiation, and thus set the physical conditions for their compact circumstellar nebula. The mid-IR continua for both objects are dominated by dust emission. For the first time we report the presence of dust in the close vicinity of WN stars. Also for the first time, we have detected lines of pure-rotational transitions of molecular hydrogen in a massive-star nebula. A peony-shaped nebula around WR 102ka is resolved at 24μm by the *Spitzer* MIPS camera. We attribute the formation of this IR-bright nebula to the recent evolutionary history of WR 102ka.

Ref.: A&A 486/3, 2008, in press
Email: lida@astro.physik.uni-potsdam.de
http://www.spitzer.caltech.edu/Media/releases
/ssc2008-13/

The Galactic Center as a laboratory for extreme mass ratio gravitational wave source dynamics

Tal Alexander

(1) Weizmann Institute of Science

The massive Galactic black hole and the stars around it are a unique laboratory for studying how relaxation processes lead to close interactions of stars and compact remnants with the central massive black hole, in particular those leading to the emission of gravitational waves. I review new results on

the processes of strong mass segregation and loss-cone refilling by massive perturbers and resonant relaxation; describe observational evidence that these processes play a role in the Galactic Center and can be studied there; and discuss some of the implications for Extreme Mass Ration Inspiral event rates and their properties.

Ref.: Invited talk 2nd Kolkata conf. on BHs
Email: tal.alexander@weizmann.ac.il
Eprint: 0807.1929

Dynamical evolution of the young stars in the Galactic center

Hagai. B. Perets[1], Alessia Gualandris[2], David Merritt[2] and Tal Alexander[1]

(1) Benoziyo Center for Astrophysics, Weizmann Institute of Science and Center for Computational Relativity and Gravitation, Rochester Institute of Technology

Recent observations of the Galactic center revealed a nuclear disk of young OB stars near the massive black hole (MBH), in addition to many similar outlying stars with higher eccentricities and/or high inclinations relative to the disk (some of them possibly belonging to a second disk). In addition, observations show the existence of young B stars (the 'S-cluster') in an isotropic distribution in the close vicinity of the MBH ($<$ 0.04 pc). We use extended N-body simulations to probe the dynamical evolution of these two populations. We show that the stellar disk could have evolved to its currently observed state from a thin disk of stars formed in a gaseous disk, and that the dominant component in its evolution is the interaction with stars in the cusp around the MBH. We also show that the currently observed distribution of the S-stars could be consistent with a capture origin through 3-body binary-MBH interactions. In this scenario the stars are captured at highly eccentric orbits, but scattering by stellar black holes could change their eccentricity distribution to be consistent with current observations.

Ref.: Central Kiloparsec conference proceedings, 2008
Email: hagai.perets@weizmann.ac.il

Origin of the S Stars in the Galactic Center

Ulf Löckmann, Holger Baumgardt, and Pavel Kroupa

(1) Argelander-Institut für Astronomie, Universität Bonn, Auf dem Hügel 71, 53121 Bonn, Germany

Over the last 15 years, around a hundred very young stars have been observed in the central parsec of our Galaxy. While the presence of young stars forming one or two stellar disks at $\approx 0.1\,\mathrm{pc}$ from the supermassive black hole (SMBH) can be understood through star formation in accretion disks, the origin of the S stars observed a factor of 10 closer to the SMBH has remained a major puzzle. Here we show the S stars to be a natural consequence of dynamical interaction of two stellar disks at larger radii. Due to precession and Kozai interaction, individual stars achieve extremely high eccentricities at random orientation. Stellar binaries on such eccentric orbits are disrupted due to close passages near the SMBH, leaving behind a single S star on a much tighter orbit. The remaining star may be ejected from the vicinity of the SMBH, thus simultaneously providing an explanation for the observed hypervelocity stars in the Milky Way halo.

Ref.: ApJ Letters, August 2008, in press
Email: uloeck@astro.uni-bonn.de
Eprint: 0807.2239
http://www.journals.uchicago.edu/doi/ref/10.1086/591734

Interpretation of radio continuum and molecular line observations of Sgr B2: free-free and synchrotron emission, and implications for cosmic rays

R.J. Protheroe[1], J. Ott[2,3], R.D. Ekers[4], D.I. Jones[1,4], R.M. Crocker[5]

[1] Department of Physics, School of Chemistry & Physics, University of Adelaide, South Australia 5000, Australia.
[2] National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA 22903, USA
[3] California Institute of Technology, 1200 E. California Blvd., Caltech Astronomy, 105-24, Pasadena, CA, 91125, USA.
[4] Australia Telescope National Facility, CSIRO, P.O. BOX 76 Epping, NSW 1710, Australia.
[5] J.L. William Fellow, School of Physics, Monash University, Victoria, Australia.

Recent ammonia (1,1) inversion line data on the Galactic star forming region Sgr B2 show that the column density is consistent with a radial Gaussian density profile with a standard deviation of 2.75 pc. Deriving a formula for the virial mass of spherical Gaussian clouds, we obtain $M_{vir} = 1.9 \times 10^6$ $\mathrm{M}_\odot$ for Sgr B2. For this matter distribution, a reasonable magnetic field and an impinging flux of cosmic rays of solar neighbourhood intensity, we predict the expected synchrotron emission from the Sgr B2 giant molecular cloud due to secondary electrons and positrons resulting from cosmic ray interactions, including effects of losses due to pion production collisions during diffusive propagation into the cloud complex. We assemble radio continuum data at frequencies between 330 MHz and 230 GHz. From the spectral energy distribution the emission appears to be thermal at all frequencies. Before using these data to constrain the predicted synchrotron flux, we first model the spectrum as free-free emission from the known ultra compact HII regions plus emission from an envelope or wind with a radial density gradient, and obtain an excellent fit. We thus find the spectrum at all frequencies to be dominated by thermal emission, and this severely constrains the possible synchrotron emission by secondary electrons to quite low flux levels. The absence of a significant contribution by secondary electrons is almost certainly due to multi-GeV energy cosmic rays being unable to penetrate far into giant molecular clouds. This would also explain why 100 MeV–GeV gamma-rays (from neutral pion decay or bremsstrahlung by secondary electrons) were not observed from Sgr B2 by EGRET, while TeV energy gamma-rays were observed, being produced by higher energy cosmic rays which more readily penetrate giant molecular clouds.

Ref.: MNRAS in press
Email: rprother@physics.adelaide.edu.au
Eprint: arXiv:0807.0127

The Rotating Nuclear Star Cluster in NGC 4244

Anil C. Seth(1,2), Robert D. Blum(3), Nate Bastian(4), Nelson Caldwell(1), Victor P. Debattista(5)

(1) Harvard-Smithsonian Center for Astrophysics, 60 Garden Street Cambridge, MA 02138 (2) Center for Astrophysics Fellow (3) National Optical Astronomy Observatory, 950 North Cherry Avenue, Tucson, AZ, 85721 (4) Institute of Astronomy, University of Cambridge (5) Centre For Astrophysics, University of Central Lancashire, Preston PR1 2HE, UK

We present observations of the nuclear star cluster in the nearby edge-on spiral galaxy NGC 4244 using the Gemini Near-Infrared Integral Field Spectrograph (NIFS) with laser guide star adaptive optics. From a previous study of edge-on galaxies, this nuclear star cluster was found to be one of a sample of clusters that appear flattened along the plane of their host galaxies disks. Such clusters show evidence for multiple morphological components, with younger/bluer disk components and older/redder spheroidal components. Our new observations of NGC 4244 show clear rotation of 30 $\mathrm{km\,s^{-1}}$ within the central 10 pc ($0.5''$) of the cluster. The central velocity dispersion is found to be 28 ± 2 $\mathrm{km\,s^{-1}}$. The multiple stellar populations inferred from the optical colors and spectra are seen as variations in the CO line strength in the NIFS spectra. The rotation is clearly detected even in the older, more spheroidal stellar

Ref.: ApJ, November 2008, in press
Email: aseth@cfa.harvard.edu
Eprint: 0807.3044
http://xxx.lanl.gov/pdf/0807.3044v1

Milliarcsecond angular resolution of reddened stellar sources in the vicinity of the Galactic Center

A. Richichi(1), O. Fors(2,3), E. Mason(4), J. Stegmaier(1), T. Chandrasekhar(5)

(1) European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany (2) Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Martí i Franqués 1, 08028 Barcelona, Spain (3) Observatori Fabra, Camí de l'Observatori s/n, 08035 Barcelona, Spain (4) European Southern Observatory, Santiago, Chile (5) Physical Research Laboratory, 380009 Ahmedabad, India

For the first time, the lunar occultation technique has been employed on a very large telescope in the near-IR with the aim of achieving systematically milliarcsecond resolution on stellar sources. We have demonstrated the burst mode of the ISAAC instrument, using a fast read-out on a small area of the detector to record many tens of seconds of data at a time on fields of few squared arcseconds. We have used the opportunity to record a large number of LO events during a passage of the Moon close to the Galactic Center in March 2006. We have developed and employed for the first time a data pipeline for the treatment of LO data, including the automated estimation of the main data analysis parameters using a wavelet-based method, and the preliminary fitting and plotting of all light curves. We recorded 51 LO events over about four hours. Of these, 30 resulted of sufficient quality to enable a detailed fitting. We detected two binaries with sub-arcsecond projected separation and three stars with a marginally resolved angular diameter of about 2 milliarcseconds. Two more stars, which are cross-identified with SiO maser, were found to be resolved and in one case we could recover the brightness profile of the extended emission, which is well consistent with an optically thin shell. The remaining unresolved stars were used to characterize the performance of the method. The LO technique at a very large telescope is a powerful and efficient method to achieve angular resolution, sensitivity, and dynamic range that are among the best possible today with any technique. The selection of targets is naturally limited and LOs are fixed-time events, however each observation requires only a few minutes including overheads. As such, LOs are ideally suited to fill small gaps of idle time between standard observations.

Ref.: A&A, Jul 2008, in press
Email: octavi.fors@gmail.com
Eprint: 0807.2646

Milliarcsecond angular resolution of reddened stellar sources in the vicinity of the Galactic Center. II. Additional observations

A. Richichi(1), O. Fors(2,3), E. Mason(4)

(1) European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany (2) Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Martí i Franqués 1, 08028 Barcelona, Spain (3) Observatori Fabra, Camí de l'Observatori s/n, 08035 Barcelona, Spain (4) European Southern Observatory, Santiago, Chile

We present lunar occultation (LO) observations obtained in August 2006 with the recently demonstrated burst mode of the ISAAC instrument at the ESO VLT. The results presented here follow the previously reported observations carried out in March 2006 on a similar but unrelated set of sources. Interstellar extinction in the inner regions of the galactic bulge amounts to tens of magnitudes at visual wavelengths. As a consequence, the majority of sources in that area are poorly studied and large numbers of potentially interesting sources such as late-type giants with circumstellar shells, stellar masers, infrared stars, remain excluded from the typical investigations which are carried out in less problematic regions. Also undetected are a large numbers of binaries. By observing LO events in this region, we gain the means to investigate at least a selected number of sources with an unprecedented combination of sensitivity and angular resolution. The LO technique permits to achieve milliarcsecond resolution with a sensitivity of K≈12 mag at a very large telescope. We have used the opportunity of a favorable passage of the Moon over a crowded region in the general direction of the Galactic Center to observe 78 LO events of heavily reddened stellar sources. We have detected six new binary and one triple star, with typical projected separation of ≈ 0.″01. We have also detected the compact circumstellar emission around one maser and one central star of a planetary nebula. Additionally we have measured the diameter and/or circumstellar shell of two carbon stars and other IR sources. We have used the upper limits on the size of about 60 unresolved or marginally resolved sources to establish the performance of the method. In agreement with our previous result, we conclude that lunar occultations in fast read-out mode on a detector subwindow at an 8 m-class telescope can achieve an angular resolution close to 0.″001 with a sensitivity K≈ 12 mag.

Ref.: A&A, Jul 2008, in press
Email: octavi.fors@gmail.com
Eprint: 0807.2650

Absorption Line Survey of H_3^+ toward the Galactic Center Sources II. Eight Infrared Sources within 30 pc of the Galactic Center

Miwa Goto(1) T. Usuda(2) T. Nagata(3) T. R. Geballe(4) B. J. McCall(5) N. Indriolo(5) H. Suto(6) Th. Henning(1) C. P. Morong(7) Takeshi Oka

(1) Max-Planck-Institut für Astronomie (2) Subaru Telescope (3) Kyoto University (4) Gemini Observatory (5) University of Illinois at Urbana-Champaign (6) NAOJ (7) Max-Planck-Institut für Astronomie (8) University of Chicago

Infrared absorption lines of H_3^+, including the metastable $R(3,3)^l$ line, have been observed toward eight bright infrared sources associated with hot and massive stars located in and between the Galactic Center Cluster and the Quintuplet Cluster 30 pc to the east. The absorption lines with high velocity dispersion arise in the Galaxy's Central Molecular Zone (CMZ) as well as in foreground spiral arms. The temperature and density of the gas in the CMZ, as determined from the relative strengths of the H_3^+ lines, are T=200 – 300 K and $n \leq$50 – 200 cm^{-3}. The detection of high column densities of H_3^+ to-

ward all eight stars implies that this warm and diffuse gaseous environment is widespread in the CMZ. The products of the ionization rate and path length for these sight lines are 1000 and 10 times higher than in dense and diffuse clouds in the Galactic disk, respectively, indicating that the ionization rate, ζ, is not less than 10^{-15} s^{-1} and that L is at least on the order of 50 pc. The warm and diffuse gas is an important component of the CMZ, in addition to the three previously known gaseous environments: (1) cold molecular clouds observed by radio emission of CO and other molecules, (2) hot ($T = 10^4 - 10^6$ K) and highly ionized diffuse gas ($n_e = 10 - 100$ cm^{-3}) seen in radio recombination lines, far infrared atomic lines, and radio-wave scattering, and (3) ultra-hot ($T = 10^7 - 10^8$ K) X-ray emitting plasma. Its prevalence significantly changes the understanding of the environment of the CMZ. The sight line toward GC IRS 3 is unique in showing an additional H_3^+ absorption component, which is interpreted as due to either a cloud associated with circumnuclear disk or the "50 km s^{-1} cloud" known from radio observations. An infrared pumping scheme is examined as a mechanism to populate the (3,3) metastable level in this cloud.

Ref.: ApJ, accepted
Email: mgoto@mpia-hd.mpg.de
Eprint: 0807.4522

Discovery and Interpretation of an X-ray Period in the Galactic Center Source CXOGC J174536.1-285638

Valerie J. Mikles(1), Stephen S. Eikenberry(1), Reba M. Bandyopadhyay(1), Michael P. Muno(2)

(1) Department of Astronomy, University of Florida, Gainesville, FL 32611 (2) Space Radiation Laboratory, Caltech, Pasadena, CA 91125

We present X-ray and infrared observations of the X-ray source CXOGC J174536.1-285638. Previous observations suggest that this source may be an accreting binary with a high-mass donor (HMXB) or a colliding wind binary (CWB). Based on the *Chandra* and *XMM-Newton* light curve, we have found an apparent 189 ± 6 day periodicity with better than 99.997% confidence. We discuss several possible causes of this periodicity, including both orbital and superorbital interpretations. We explore in detail the possibility that the X-ray modulation is related to an orbital period and discuss the implications for two scenarios; one in which the variability is caused by obscuration of the X-ray source by a stellar wind, and the other in which it is caused by an eclipse of the X-ray source. We find that in the first case, CXOGC J174536.1-285638 is consistent with both CWB and HMXB interpretations, but in the second, CXOGC J174536.1-285638 is more likely a HMXB.

Ref.: ApJ, 2008, in press
Email: reba@astro.ufl.edu
Eprint: 0807.0657

Decaying Sterile Neutrinos as a Heating Source in the Milky Way Center

M. H. Chan and M. -C. Chu

Department of Physics and Institute of Theoretical Physics, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong, China

Recent Chandra and Newton observations indicate that there are two-temperature components ($T \sim 8$ keV, 0.8 keV) of the diffuse x-rays emitted from deep inside the center of Milky Way. We show that this can be explained by the existence of sterile neutrinos, which decay to emit photons that can be bound-free absorbed by the isothermal hot gas particles in the center of Milky Way. The model can account for a stable configuration of the two-temperature components hot gas naturally as well as the energy needed to maintain the ~ 8 keV temperature in the hot gas. The predicted sterile neutrino mass is between 16-18 keV.

Ref.: MNRAS in press
Email: mhchan@sun1.phy.cuhk.edu.hk
Eprint: 0806.1311

Binary formation and mass function variations in fragmenting discs with short cooling times

R.D. Alexander (1,2), P.J. Armitage (2,3) and J. Cuadra (3)

(1) Sterrewacht Leiden, Universiteit Leiden, Niels Bohrweg 2, 2300 RA, Leiden, the Netherlands (2) JILA, University of Colorado, Boulder, CO 80309-0440, USA (3) Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309-0391, USA

Accretion discs at sub-pc distances around supermassive black holes are likely to cool rapidly enough that self-gravity results in fragmentation. Here, we use high-resolution hydrodynamic simulations of a simplified disc model to study how the outcome of fragmentation depends upon numerical resolution

and cooling time, and to investigate the incidence of binary formation within fragmenting discs. We investigate a range of cooling times, from the relatively long cooling time-scales that are marginally unstable to fragmentation down to highly unstable cooling on a time-scale that is shorter than the local dynamical time. The characteristic mass of fragments decreases with reduced cooling time, though the effect is modest and dependent upon details of how rapidly bound clumps radiate. We observe a high incidence of capture binaries, though we are unable to determine their final orbits or probability of survival. The results suggest that faster cooling in the parent disc results in an increased binary fraction, and that a high primordial binary fraction may result from disc fragmentation. We discuss our results in terms of the young massive stars close to the Galactic Centre, and suggest that observations of some stellar binaries close to the Galactic Centre remain consistent with formation in a fragmenting accretion disc.

Ref.: MNRAS, in press
Email: rda@strw.leidenuniv.nl
Eprint: 0807.1731

Gas flow models in the Milky Way embedded bars

N. J. Rodriguez-Fernandez(1), F. Combes(2)

(1) IRAM, 300 rue de la Piscine, 38406 St. Martin d'Heres, France
(2) LERMA, Observatoire de Paris, 61 Av de l'Observatoire, 75014 Paris, France

The gas distribution and dynamics in the inner Galaxy present many unknowns as the origin of the asymmetry of the *lv*-diagram of the Central Molecular Zone (CMZ). On the other hand, there are recent evidences in the stellar component of the presence of a nuclear bar that could be slightly lopsided. Our goal is to characterize the nuclear bar observed in 2MASS maps and to study the gas dynamics in the inner Milky Way taking into account this secondary bar. We have derived a realistic mass distribution by fitting the 2MASS star counts map of Alard (2001) with a model including three components (disk, bulge and nuclear bar) and we have simulated the gas dynamics, in the deduced gravitational potential, using a sticky-particles code. Our simulations of the gas dynamics reproduce successfully the main characteristics of the Milky Way for a bulge orientation of $20\,\mathrm{deg} - 35\,\mathrm{deg}$ with respect to the Sun-Galactic Center (GC) line and a pattern speed of 30-40 km/s/kpc. In our models the Galactic Molecular Ring (GMR) is not an actual ring but the inner parts of the spiral arms, while the 3-kpc arm and its far side counterpart are lateral arms that contour the bar. Our simulations reproduce, for the first time, the parallelogram shape of the *lv*-diagram of the CMZ as the gas response to the nuclear bar. This bar should be oriented by an angle of $\sim 60\,\mathrm{deg} - 75\,\mathrm{deg}$ with respect to the Sun-GC line and its mass amounts to $(2-5.5)\,10^9\ M_\odot$. We show that the observed asymmetry of the CMZ cannot be due to lopsidedness of the nuclear bar as suggested by the 2MASS maps. We do not find clear evidences of lopsidedness in the stellar potential. We propose that the observed asymmetry of the central gas layer can be due to the infalling of gas into the CMZ in the *l=1.3*deg*-complex*.

Ref.: A&A in press
Email: rodrigue@iram.fr
Eprint: 0806.4252

Study of the Science Capabilities of PRIMA in the Galactic Center

H. Bartko(1), O. Pfuhl(1), F. Eisenhauer(1), R. Genzel(1,2), S. Gillessen(1), S. Rabien(1), R. Abuter(3), G. v. Belle(3), F. Delplancke(3), S. Menardi(3), J. Sahlmann(3,4)

(1) Max-Planck-Institute for Extraterrestrial Physics, Garching, Germany; (2) Department of Physics, University of California, Berkeley, USA; (3) ESO, Garching, Germany;
(4) Observatoire de Genève, Sauverny, Switzerland.

The Phase-Referenced Imaging and Microarcsecond Astrometry (PRIMA) facility is scheduled for installation in the Very Large Telescope Interferometer observatory in Paranal, Chile, in the second half of 2008. Its goal is to provide astrometric accuracy in the micro-arcsecond range. High precision astrometry can be applied to explore the dynamics of the dense stellar cluster. Especially models for the formation of stars near super massive black holes or the fast transfer of short-lived massive stars into the innermost parsec of our galaxy can be tested. By measuring the orbits of stars close to the massive black hole one can probe deviations from a Keplerian motion. Such deviations could be due to a swarm of dark, stellar mass objects that perturb the point mass solution. At the same time the orbits are affected by relativistic corrections which thus can be tested. The ultimate goal is to test the ef-

fects of general relativity in the strong gravitational field. The latter can be probed with the near infrared flares of SgrA* which are most likely due to accretion phenomena onto the black hole. We study the expected performance of PRIMA for astrometric measurements in the Galactic Center based on laboratory measurements and discuss possible observing strategies.

Ref.: SPIE 325
Email: hendrik.bartko@googlemail.com

The Mid-Infrared Colors of the Interstellar Medium and Extended Sources at the Galactic Center

R. G. Arendt(1,2), S. R. Stolovy(3), S. V. Ramírez(4), K. Sellgren(5), A. S. Cotera(6), C. J. Law(7,8), F. Yusef-Zadeh(7), H. A. Smith(9), D. Y. Gezari(10)

(1) CRESST/UMBC/GSFC (2) Science Systems and Applications, Inc. (3) Spitzer Science Center (4) IPAC, California Institute of Technology (5) Ohio State University (6) SETI Institute (7) Northwestern University (8) Astronomical Institute "Anton Pannekoek", University of Amsterdam (9) Harvard-Smithsonian Center for Astrophysics (10) NASA/Goddard Space Flight Center

A mid-infrared (3.6 – 8 μm) survey of the Galactic Center has been carried out with the IRAC instrument on the *Spitzer Space Telescope*. This survey covers the central $2^\circ \times 1\overset{\circ}{.}4$ ($\sim 280 \times 200$ pc) of the Galaxy. At 3.6 and 4.5 μm the emission is dominated by stellar sources, the fainter ones merging into an unresolved background. At 5.8 and 8 μm the stellar sources are fainter, and large–scale diffuse emission from the ISM of the Galaxy's central molecular zone becomes prominent. The survey reveals that the 8 to 5.8 μm color of the ISM emission is highly uniform across the surveyed region. This uniform color is consistent with a flat extinction law and emission from polycyclic aromatic hydrocarbons (PAHs). Models indicate that this broadband color should not be expected to change if the incident radiation field heating the dust and PAHs is $< 10^4$ times that of the solar neighborhood. The few regions with unusually red emission are areas where the PAHs are underabundant and the radiation field is locally strong enough to heat large dust grains to produce significant 8 μm emission. These red regions include compact H II regions, Sgr B1, and wider regions around the Arches and Quintuplet Clusters. In these regions the radiation field is $\gtrsim 10^4$ times that of the solar neighborhood. Other regions of very red emission indicate cases where thick dust clouds obscure deeply embedded objects or very early stages of star formation.

Ref.: ApJ, 2008, 682, 384
Email: sellgren@astronomy.ohio-state.edu
Eprint: 0804.4491

Comparison of 3.6 – 8.0 Micron *Spitzer*/IRAC Galactic Center Survey Point Sources with Chandra X–Ray Point Sources in the Central 40x40 Parsecs

R. G. Arendt(1,2), D. Y. Gezari(3), S. R. Stolovy(4), K. Sellgren(5), R. Smith(3), S. V. Ramírez(6), F. Yusef-Zadeh(7), C. J. Law(7,8), H. A. Smith(9), A. S. Cotera(10), S. H. Moseley(3)

(1) CRESST/UMBC/GSFC; (2) Science Systems and Applications, Inc. (3) NASA/Goddard Space Flight Center (4) Spitzer Science Center, California Institute of Technology (5) Ohio State University (6) IPAC, California Institute of Technology (7) Northwestern University (8) Sterrenkundig Instituut "Anton Pannekoek", Universiteit van Amsterdam (9) Harvard-Smithsonian Center for Astrophysics (10) SETI Institute

We have studied the correlation between 2357 Chandra X–ray point sources in a 40×40 parsec field and ~20,000 infrared sources we observed in the corresponding subset of our $2^\circ \times 1.4^\circ$ *Spitzer*/IRAC Galactic Center Survey at 3.6–8.0 μm, using various spatial and X–ray hardness thresholds. The correlation was determined for source separations of less than $0\overset{''}{.}5$, $1''$ or $2''$. Only the soft X–ray sources show any correlation with infrared point sources on these scales, and that correlation is very weak. The upper limit on hard X–ray sources that have infrared counterparts is $< 1.7\%$ (3σ). However, because of the confusion limit of the IR catalog, we only detect IR sources with absolute magnitudes ≤ 1. As a result, a stronger correlation with fainter sources cannot be ruled out. Only one compact infrared source, IRS 13, coincides with any of the dozen prominent X–ray emission features in the 3×3 parsec region centered on Sgr A*, and the diffuse X–ray and infrared emission around Sgr A* seems to be anti-correlated on a few-arcsecond scale. We compare our results with previous identifications of near–infrared companions to Chandra X–ray sources.

Ref.: ApJ, 2008, in press
Email: sellgren@astronomy.ohio-state.edu

Eprint: 0806.1880

Massive Star Formation in the Molecular Ring Orbiting the Black Hole at the Galactic Center

Yusef-Zadeh F.; Braatz J.; Wardle M.; Roberts D.

A ring of dense molecular gas extending 2-7 pc orbits the supermassive black hole Sgr A* at the center of our Galaxy. Using the Green Bank Telescope, we detected water maser lines and both narrow (0.35 km/s) and broad (30 - 50 km/s) methanol emission from the molecular ring. Two of the strongest methanol lines at 44 GHz are confirmed as masers by interferometric observations. These class I methanol masers are collisionally excited and are signatures of early phases of massive star formation in the disk of the Galaxy, suggesting that star formation in the molecular ring is in its early phase. Close inspection of the kinematics of the associated molecular clumps in the HCN (J=1−0) line reveals broad red-shifted wings indicative of disturbance by protostellar outflows from young (few times 10^4 yr), massive stars embedded in the clumps. The thermal methanol profile has a similar shape, with a narrow maser line superimposed on a broad, red-shifted wing. Additional evidence for the presence of young massive protostars is provided by shocked molecular hydrogen and a number of striking ionized and molecular linear filaments in the vicinity of methanol sources suggestive of 0.5-pc scale protostellar jets. Given that the circumnuclear molecular ring is kinematically unsettled and thus is likely be the result of a recent capture, the presence of both methanol emission and broad, red-shifted HCN emission suggests that star formation in the circumnuclear ring is in its infancy.

Ref.: ApJL in press
Email: zadeh@northwestern.edu
Eprint: arXiv:0807.1745

Exploring a New Population of Compact Objects: X-ray and IR Observations of the Galactic Centre

Reba M. Bandyopadhyay Andrew J. Gosling Stephen E. Eikenberry Michael P. Muno Katherine M. Blundell Philipp Podsiadlowski Valerie J. Mikles Curtis DeWitt

I describe the IR and X-ray observational campaign we have undertaken for the purpose of determining the nature of the faint discrete X-ray source population discovered by Chandra in the Galactic Center (GC). Data obtained for this project includes a deep Chandra survey of the Galactic Bulge; deep, high resolution IR imaging from VLT/ISAAC, CTIO/ISPI, and the UKIDSS Galactic Plane Survey (GPS); and IR spectroscopy from VLT/ISAAC and IRTF/SpeX. By cross-correlating the GC X-ray imaging from Chandra with our IR surveys, we identify candidate counterparts to the X-ray sources via astrometry. Using a detailed IR extinction map, we are deriving magnitudes and colors for all the candidates. Having thus established a target list, we will use the multi-object IR spectrograph FLAMINGOS-2 on Gemini-South to carry out a spectroscopic survey of the candidate counterparts, to search for emission line signatures which are a hallmark of accreting binaries. By determining the nature of these X-ray sources, this FLAMINGOS-2 Galactic Center Survey will have a dramatic impact on our knowledge of the Galactic accreting binary population.

Ref.: AIP, 2008, in press
Email: reba@astro.ufl.edu
Eprint: 0808.0519

Is there a Supermassive Black Hole at the Center of the Milky Way?

Mark J. Reid

(1) Harvard–Smithsonian Center for Astrophysics
60 Garden Street, Cambridge, MA 02138, USA
mreid@cfa.harvard.edu

This review outlines the observations that now provide an overwhelming scientific case that the center of our Milky Way Galaxy harbors a supermassive black hole. Observations at infrared wavelength trace stars that orbit about a common focal position and require a central mass (M) of $4 \times 10^6\ M_\odot$ within a radius of 100 AU. Orbital speeds have been observed to exceed 5,000 km s^{-1}. At the focal position there is an extremely compact radio source (Sgr A*), whose apparent size is near the Schwarzschild radius ($2GM/c^2$). This radio source is motionless at the ~ 1 km s^{-1} level at the dynamical center of the Galaxy. The mass density required by these observations is now approaching the ultimate limit of a supermassive black hole within the last stable orbit for matter near the event horizon.

Ref.: International Journal of Modern Physics D
Email: reid@cfa.harvard.edu
Eprint: 0808.2624

Low angular momentum flow model of Sgr A* activity

B. Czerny, M. Mościbrodzka

(1) Copernicus Astronomical Center, Bartycka 18, 00-716 Warsaw, Poland

Sgr A* is the closest massive black hole and can be observed with the highest angular resolution. Nevertheless, our current understanding of the accretion process in this source is very poor. The inflow is almost certainly of low radiative efficiency and it is accompanied by a strong outflow and the flow is strongly variable but the details of the dynamics are unknown. Even the amount of angular momentum in the flow is an open question. Here we argue that low angular momentum scenario is better suited to explain the flow variability. We present a new hybrid model which describes such a flow and consists of an outer spherically symmetric Bondi flow and an inner axially symmetric flow described through MHD simulations. The assumed angular momentum of the matter is low, i.e. the corresponding circularization radius in the equatorial plane of the flow is just above the innermost stable circular orbit in pseudo-Newtonian potential. We compare the radiation spectrum from such a flow to the broad band observational data for Sgr A*.

Ref.: Proceedings of AHAR2008 Conference, Bad Honeff
Email: bcz@camk.edu.pl

Stellar dynamical evidence against a cold disc origin for stars in the Galactic Centre

Jorge Cuadra[1], Philip J. Armitage[1,2], Richard D. Alexander[3,1]

Observations of massive stars within the central parsec of the Galaxy show that, while most stars orbit within a well-defined disc, a significant fraction have large eccentricities and / or inclinations with respect to the disc plane. Here, we investigate whether this dynamically hot component could have arisen via scattering from an initially cold disc – the expected initial condition if the stars formed from the fragmentation of an accretion disc. Using N-body methods, we evolve a variety of flat, cold, stellar systems, and study the effects of initial disc eccentricity, primordial binaries, very massive stars and intermediate mass black holes. We find, consistent with previous results, that a circular disc does not become eccentric enough unless there is a significant population of undetected 100–1000 $M_\odot$ objects. However, since fragmentation of an eccentric disc can readily yield eccentric stellar orbits, the strongest constraints come from inclinations. We show that *none* of our initial conditions yield the observed large inclinations, regardless of the initial disc eccentricity or the presence of massive objects. These results imply that the orbits of the young massive stars in the Galactic Centre are largely primordial, and that the stars are unlikely to have formed as a dynamically cold disc.

Ref.: MNRAS 388, 64L
Email: jcuadra@cervantes.colorado.edu
Eprint: 0804.3596
http://dx.doi.org/10.1111/j%2E1745-3933%2E2008%2E00500%2Ex

A Disk of Young Stars at the Galactic Center as Determined by Individual Stellar Orbits

J. R. Lu(1), A. M. Ghez(1,2), S. D. Hornstein(1,3), M. R. Morris(1), E. E. Becklin(1), K. Matthews(4)

(1) UCLA Department of Physics and Astronomy, Los Angeles, CA 90095-1562 (2) UCLA Institute of Geophysics and Planetary Physics, Los Angeles, CA 90095-1565 (3) Center for Astrophysics & Space Astronomy, Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309 (4) Caltech Optical Observatories, California Institute of Technology, MS 320-47, Pasadena, CA 91125

We present new proper motions from the 10 m Keck telescopes for a puzzling population of massive, young stars located within 3.″5 (0.14 pc) of the supermassive black hole at the Galactic Center. Our proper motion measurements have uncertainties of only 0.07 mas yr^{-1} (3 km s^{-1}), which is $\gtrsim$ 7 times better than previous proper motion measurements for these stars, and enables us to measure accelerations as low as 0.2 mas yr^{-2} (7 km s^{-1} yr^{-1}). Using these measurements, line-of-sight velocities from the literature, and 3D velocities for additional young stars in the central parsec, we constrain the true orbit of each individual star and directly test the hypothesis that the massive stars reside in two stellar disks as has been previously proposed. Analysis of the stellar orbits reveals only one of the previously proposed disks of young stars using a method that is capable of detecting disks containing at least 7 stars. The detected disk contains 50% of the young stars, is inclined by $\sim$ 115° from the plane of the sky, and is oriented at a position angle of $\sim 100^\circ$ East of North. Additionally, the on-disk and off-disk populations have similar K-band luminosity functions and radial distributions that decrease at larger projected radii as $\propto r^{-2}$. The disk has an out-of-the-disk velocity dispersion of 28 ± 6 km s^{-1}, which corresponds to a half-opening angle of $7^\circ \pm 2^\circ$, and several candidate disk members have eccentricities greater than 0.2. Our findings suggest that the young stars may have formed *in situ* but in a more complex geometry than a simple, thin circular disk.

Ref.: ApJ, accepted
Email: jlu@astro.ucla.edu
Eprint: 0808.3818

Timing and Spectral Study of AX J1745.6–2901 with Suzaku

Yoshiaki Hyodo (1), Yoshihiro Ueda (1), Takayuki Yuasa (2), Yoshitomo Maeda (3), Kazuo Makishima (2), and Katsuji Koyama (1),

(1) Department of Astronomy, Graduate School of Science, Kyoto University, Kita-shirakawa Oiwake-cho, Sakyo, Kyoto 606-8502 (2) Department of Physics, School of Science, the University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo 113-0033 (3) Institute of Space and Astronautical Science, 3-1-1, Yoshinodai, Sagamihara, Kanagawa, 229-8510

The eclipsing low-mass X-ray binary AXJ was observed with Suzaku in its outburst phase. Combining the Chandra observation made 1.5 month earlier than Suzaku, we determined the orbital period to be 30063.76 ± 0.14 s. We found deep flux dips prior to the eclipse phase of orbit. The X-ray spectrum of the persistent phase is described with a combination of a direct and a scattered-in by dust emissions. During the eclipse, the X-ray spectrum becomes only the dust scattering (scattered-in) component. The optical depth of the dust-scattering is ~ 10.5 at 1 keV. The direct component is composed of a blackbody likely from the neutron star surface and a disk-blackbody. No power-law component is found in the hard energy band up to 30 keV. A clear edge at ~ 7.1 keV in the deep dip spectrum indicates that the major portion of Fe in the absorber is neutral or at low ionization state. We discovered four narrow absorption lines near the K-shell transition energies of Fe XXV, Fe XXVI, and Ni XXVII. The absorption line features are well explained by the solar abundance gas in a bulk motion of $\sim 10^3$ km s^{-1}.

Ref.: PASJ, 2009, accepted
Email: hyodo@cr.scphys.kyoto-u.ac.jp

On the tidal evolution of the orbits of low-mass satellites around black holes

Andrej Cadez(1) and Massimo Calvani(2) and Uros Kostić(1)

(1) Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia (2) INAF - Astronomical Observatory of Padova, Vicolo Osservatorio 5, 35122 Padova, Italy

Low-mass satellites, like asteroids and comets, are expected to be present around the black hole at the Galactic center. We consider small bodies orbiting a black hole, and we study the evolution of their orbits due to tidal interaction with the black hole. In this paper we investigate the consequences of the existence of plunging orbits when a black hole is present. We are interested in finding the conditions that exist when capture occurs. Earlier analysis of the evolution of classical Keplerian orbits was extended to relativistic orbits around a Schwarzschild black hole. The main difference between the Keplerian and black hole cases is in the existence of plunging orbits. Orbital evolution, leading from bound to plunging orbits, goes through a "final" unstable circular orbit. On this orbit, tidal energy is released on a characteristic black hole timescale. This process may be relevant for explaining how small, compact clumps of material can be brought onto plunging orbits, where they may produce individual short duration accretion events. The available energy and the characteristic timescale are consistent with energy released and the timescale typical of Galactic flares.

Ref.: A&A 487 (2008) 527-532
Email: uros.kostic@fmf.uni-lj.si
http://astro.ago.uni-lj.si/bh/uploads/Main/aa_tidal.pdf

A 600 minute near-infrared lightcurve of Sagittarius A*

L. Meyer(1), T. Do(1), A. Ghez(1), M. R. Morris(1), G. Witzel(2), A. Eckart(2), G. Bélanger(3), R. Schödel(4)

(1) Department of Physics and Astronomy, University of California, Los Angeles, CA 90095-1547 (2) Universität zu Köln, Zülpicher Str. 77, 50937 Köln (3) ESA/ESAC, PO Box 78, 28691 Villanueva de la Cañada, Spain (4) Instituto de Astrofísica de Andalucía, Camino Bajo de Huétor 50, 18008 Granada, Spain

We present the longest, by a factor of two, near-infrared lightcurve from Sgr A* – the supermassive black hole in the Galactic center. Achieved by combining Keck and VLT data from one common night, which fortuitously had simultaneous Chandra and SMA data, this lightcurve is used to address two outstanding problems. First, a putative quasi-periodicity of ~20 min reported by groups using ESO's VLT is not confirmed by Keck observations. Second, while the infrared and mm-regimes are thought to be related based on reported time lags between lightcurves from the two wavelength domains, the reported time lag of 20 min inferred using the Keck data of this common VLT/Keck night only is at odds with the lag of ~ 100 min reported earlier. With our long lightcurve, we find that (i) the simultaneous 1.3 millimeter observations are in fact consistent with a ~ 100 min time lag, (ii) the different methods of NIR photometry used by the VLT and Keck groups lead to consistent results, (iii) the Lomb-Scargle periodogram of the whole NIR lightcurve is featureless and follows a power-law with slope -1.6, and (iv) scanning the lightcurve with a sliding window to look for a transient QPO phenomenon reveals for a certain part of the lightcurve a 25 min peak in the periodogram. Using Monte Carlo simulations and taking the number of trials into account, we find it to be insignificant.

Ref.: ApJL, accepted
Email: leo@astro.UCLA.EDU

Dark stars at the Galactic centre – the main sequence

Pat Scott[1], *Malcolm Fairbairn*[2,3] *and Joakim Edsjö*[1]

[1]Cosmology, Particle Astrophysics and String Theory, Department of Physics, Stockholm University & High Energy Astrophysics and Cosmology Centre (HEAC), AlbaNova University Centre, SE-106 91 Stockholm, Sweden
[2]Theory Division, CERN, CH-1211, Geneva 23, Switzerland
[3]Physics, Kings College London, Strand, London WC2R 2LS, UK

In regions of very high dark matter density such as the Galactic centre, the capture and annihilation of WIMP dark matter by stars has the potential to significantly alter their evolution. We describe the dark stellar evolution code DarkStars, and present a series of detailed grids of WIMP-influenced stellar models for main sequence stars. We describe the changes in stellar structure and main sequence evolution which occur as a function of the rate of energy injection by WIMPs, for masses of 0.3–2.0 $M_\odot$ and metallicities $Z = 0.0003$–0.02. We show what rates of energy injection can be obtained using realistic orbital parameters for stars at the Galactic centre, including detailed consideration of the velocity and density profiles of dark matter. Capture and annihilation rates are strongly boosted when stars follow elliptical rather than circular orbits. Dark stars are unlikely to exist on any circular orbits in the Milky Way. If there is a spike of dark matter induced by the supermassive black hole at the Galactic centre, solar-mass stars following orbits with periods as long as 50 years and eccentricities as low as 0.9 could be significantly affected. The observation of low-mass stars on such orbits would either provide a detection of WIMP dark matter, or place stringent limits on the combination of the WIMP mass, spin-dependent nuclear-scattering cross-section, halo density and velocity distribution near the Galactic centre. In some cases, the derived limits on the WIMP mass and spin-dependent nuclear-scattering cross-section would be of comparable sensitivity to current direct-detection experiments.

Ref.: arXiv:0809.1871
Email: pat@physto.se
http://arxiv.org/abs/0809.1871v1

Metallicity in the Galactic Center: The Quintuplet cluster

Francisco Najarro(1), Don F. Figer(2), D. John Hillier(3), T. R. Geballe(4), Rolf P. Kudritzki(5)

(1) Instituto de Estructura de la Materia, CSIC, Serrano 121, 29006 Madrid, Spain (2) Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623 (3) Department of Physics and Astronomy, University of Pittsburgh, 3941 O'Hara Street, Pittsburgh, PA 15260 (4) Gemini Observatory, Hilo, 670 N. A'ohoku Pl., HI 96720 (5) Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822

We present a measurement of metallicity in the Galactic center Quintuplet Cluster made using quantitative spectral analysis of two Luminous Blue Variables (LBVs). The analysis employs line-blanketed NLTE wind/atmosphere models fit to high-resolution near-infrared spectra containing lines of H, He I, Si II, Mg II, and Fe II. We are able to break the H/He ratio vs. mass-loss rate degeneracy found in other LBVs and to obtain robust estimates of the He content of both objects. Our results indicate solar iron abundance and roughly twice solar abundance in the α-elements. These results are discussed within the framework of recent measurements of oxygen and carbon composition in the nearby Arches Cluster and iron abundances in red giants and supergiants within the central 30 pc of the Galaxy. The relatively large enrichment of α-elements with respect to iron is consistent with a history of more nucleosynthesis in high mass stars than the Galactic disk.

Ref.: ApJ accepted
Email: najarro@damir.iem.csic.es
Eprint: 0809.3185

High-frequency VLBI observations of Sgr A* during a multi-frequency campaign in May 2007

R-S Lu[1,2], T P Krichbaum[1], A Eckart[2], S König[2,1], D Kunneriath[2,1], G Witzel[2], A Witzel[1] and J A Zensus[1]

(1) [1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany (2) [2] University of Cologne, I. Physikalisches Institut, Zülpicher Str. 77, D-50937 Köln, Germany

In May 2007 the compact radio source Sgr A* was observed in a global multi-frequency monitoring campaign, from radio to X-ray bands. Here we present and discuss first and preliminary results from polarization sensitive VLBA observations, which took place during May 14-25, 2007. Here, Sgr A* was observed in dual polarization on 10 consecutive days at 22, 43, and 86 GHz. We describe the VLBI experiments, our data analysis, monitoring program and show preliminary images obtained at the various frequencies. We discuss the data with special regard also to the short term variability.

Ref.:
Email: rslu@mpifr-bonn.mpg.de
http://arXiv.org/abs/0809.2463

Magnetic Field Configuration at the Galactic Center Investigated by Wide Field NearInfrared Polarimetry

Shogo Nishiyama(1,2), Motohide Tamura(2), Hirofumi Hatano(3), Saori Kanai(3), Mikio Kurita(3), Shuji Sato(3), Noriyuki Matsunaga(1), Tetsuya Nagata(1), Takahiro Nagayama(1), Ryo Kandori(2), Yasushi Nakajima(2), Nobuhiko Kusakabe(4), Yaeko Sato(4), James H. Hough(5), Koji Sugitani(6), and Haruyuki Okuda(7)

(1) Department of Astronomy, Kyoto University, Kyoto 606-8502, Japan (2)National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan (3) Department of Astrophysics, Nagoya University, Nagoya 464-8602, Japan (4) Department of Astronomical Sciences, Graduate University for Advanced Studies (Sokendai), Mitaka, Tokyo 181-8588, Japan (5) Centre for Astrophysics Research, University of Hertfordshire, Hatfield, Herts AL10 9AB, UK (6) Graduate School of Natural Sciences, Nagoya City University, Nagoya 467-8501, Japan (7) Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa 229-8510, Japan

We present a polarimetric map of a $20' \times 20'$ area toward the Galactic center. The polarization of point sources has been measured in the J, H, and K_S bands using the near-infrared polarimetric camera SIRPOL on the 1.4 m telescope IRSF. One percent or better accuracy of polarization degree is achieved for sources with $J < 14.5$, $H < 13.5$, and $K_S < 12.0$. Comparing the Stokes parameters between high extinction stars and relatively low extinction ones, we have obtained a polarization originating from magnetically aligned dust grains at the central region of our Galaxy of at most 1−2 kpc. The distribution of the position angles shows a peak at $\sim 20°$, nearly parallel to the Galactic plane, suggesting a toroidal magnetic configuration. The derived direction of the magnetic field is in good agreement with that obtained from far-infrared/submillimeter observations, which detect polarized thermal emission from dust in the molecular clouds at the Galactic center. Our results show that by subtracting foreground components, near-infrared polarimetry allows investigation of the magnetic field structure *at* the Galactic center.

Ref.: ApJ, accepted
Email: shogo@kusastro.kyoto-u.ac.jp
Eprint: 0809.3089
http://www.kusastro.kyoto-u.ac.jp/~shogo/papers/08NishiyamaMagFGC.pdf

Measuring Distance and Properties of the Milky Way's Central Supermassive Black Hole with Stellar Orbits

A. M. Ghez(1,2), S. Salim(1,4), N. N. Weinberg(3,5), J. R. Lu(1), T. Do(1), J. K. Dunn(1), K. Matthews(3), M. Morris(1), S. Yelda(1), E. E. Becklin(1), T. Kremenek(1), M. Milosavljevic(6), J. Naiman(1,7)

(1) UCLA Department of Physics and Astronomy, Los Angeles, CA 90095-1547 (2) UCLA Institute of Geophysics and Planetary Physics, Los Angeles, CA 90095-1565 (3) California Institute of Technology, Division of Mathematics, Physics and Astronomy, Pasadena, CA 91125 (4) NOAO, 950 N Cherry Ave, Tucson, AZ

85719 (5) University of California Berkeley, Department of Astronomy
Berkeley, CA 94720-3411 (6) University of Texas, Department of Astronomy, Austin, TX 78712 (7) UCSC, Department of Astronomy & Astrophysics, Santa Cruz, CA 95064

We report new precision measurements of the properties of our Galaxy's supermassive black hole. Based on astrometric (1995-2007) and radial velocity (2000-2007) measurements from the W. M. Keck 10-meter telescopes, a fully unconstrained Keplerian orbit for the short period star S0-2 provides values for the distance (R_0) of 8.0 ± 0.6 kpc, the enclosed mass (M_{bh}) of 4.1 ± 0.6 × $10^6 M_\odot$, and the black hole's radial velocity, which is consistent with zero with 30 km/s uncertainty. If the black hole is assumed to be at rest with respect to the Galaxy (e.g., has no massive companion to induce motion), we can further constrain the fit and obtain $R_0 = 8.4 \pm 0.4$ kpc and $M_{bh} = 4.5 \pm 0.4 \times 10^6 M_\odot$. More complex models constrain the extended dark mass distribution to be less than 3-4 × $10^5 M_\odot$ within 0.01 pc, ~100x higher than predictions from stellar and stellar remnant models. For all models, we identify transient astrometric shifts from source confusion (up to 5x the astrometric error) and the assumptions regarding the black hole's radial motion as previously unrecognized limitations on orbital accuracy and the usefulness of fainter stars. Future astrometric and RV observations will remedy these effects. Our estimates of R_0 and the Galaxy's local rotation speed, which it is derived from combining R_0 with the apparent proper motion of Sgr A*, ($\theta_0 = 229 \pm 18$ km s^{-1}), are compatible with measurements made using other methods. The increased black hole mass found in this study, compared to that determined using projected mass estimators, implies a longer period for the innermost stable orbit, longer resonant relaxation timescales for stars in the vicinity of the black hole and a better agreement with the M_{bh}-σ relation.

Ref.: ApJ, in press
Email: ghez@astro.ucla.edu
Eprint: 0808.2870

Using Millimeter VLBI to Constrain RIAF Models of Sagittarius A*

Vincent L. Fish, Avery E. Broderick, Sheperd S. Doeleman, & Abraham Loeb

The recent detection of Sagittarius A* at lambda = 1.3 mm on a baseline from Hawaii to Arizona demonstrates that millimeter wavelength very long baseline interferometry (VLBI) can now spatially resolve emission from the innermost accretion flow of the Galactic center region. Here, we investigate the ability of future millimeter VLBI arrays to constrain the spin and inclination of the putative black hole and the orientation of the accretion disk major axis within the context of radiatively inefficient accretion flow (RIAF) models. We examine the range of baseline visibility and closure amplitudes predicted by RIAF models to identify critical telescopes for determining the parameters of the Sgr A* black hole and accretion disk system. We find that baseline lengths near 3 gigalambda have the greatest power to distinguish amongst RIAF model parameters, and that it will be important to include either the Large Millimeter Telescope or a Chilean telescope in future VLBI arrays. Many RIAF models predict detectable fluxes on baselines between the continental United States and even a single 12 m-class dish in Chile. The extra information provided from closure amplitudes by a four-antenna array enhances the ability of VLBI to discriminate amongst models.

Ref.: ApJL, submitted
Email: vfish@franklin.haystack.mit.edu
Eprint: 0809.4489

GRAVITY: getting to the event horizon of Sgr A*

F. Eisenhauer, G. Perrin, W. Brandner, C. Straubmeier, A. Richichi, S. Gillessen, J.P. Berger, S. Hippler, A. Eckart, M. Schoeller, S. Rabien, F. Cassaing, R. Lenzen, M. Thiel, Y. Clenet, J.R. Ramos, S. Kellner, P. Fedou, H. Baumeister, R. Hofmann, E. Gendron, A. Boehm, H. Bartko, X. Haubois, R. Klein, K. Dodds-Eden, K. Houairi, F. Hormuth, A. Graeter, L. Jocou, V. Naranjo, R. Genzel, P. Kervella, T. Henning, N. Hamaus, S. Lacour, U. Neumann, M. Haug, F. Malbet, W. Laun, J. Kolmeder, T. Paumard, R.-R. Rohloff, O. Pfuhl, K. Perraut, J. Ziegleder, D. Rouan, G. Rousset

We present the second-generation VLTI instrument GRAVITY, which currently is in the preliminary design phase. GRAVITY is specifically designed to observe highly relativistic motions of matter close to the event horizon of Sgr A*, the massive black hole at center of the Milky Way. We have identified the key design features needed to achieve this goal and present the resulting instrument concept. It includes an integrated optics, 4-telescope, dual feed

beam combiner operated in a cryogenic vessel; near infrared wavefront sensing adaptive optics; fringe tracking on secondary sources within the field of view of the VLTI and a novel metrology concept. Simulations show that the planned design matches the scientific needs; in particular that 10 microarcsecond astrometry is feasible for a source with a magnitude of K=15 like Sgr A*, given the availability of suitable phase reference sources.

Ref.: proceedings
Email: eisenhau@mpe.mpg.de
Eprint: 0808.0063

Event-horizon-scale structure in the supermassive black hole candidate at the Galactic Centre

Doeleman, Sheperd S.; Weintroub, Jonathan; Rogers, Alan E. E.; Plambeck, Richard; Freund, Robert; Tilanus, Remo P. J.; Friberg, Per; Ziurys, Lucy M.; Moran, James M.; Corey, Brian; Young, Ken H.; Smythe, Daniel L.; Titus, Michael; Marrone, Daniel P.; Cappallo, Roger J.; Bock, Douglas C.-J.; Bower, Geoffrey C.; Chamberlin, Richard; Davis, Gary R.; Krichbaum, Thomas P.; Lamb, James; Maness, Holly; Niell, Arthur E.; Roy, Alan; Strittmatter, Peter; Werthimer, Daniel; Whitney, Alan R.; Woody, David

The cores of most galaxies are thought to harbour supermassive black holes, which power galactic nuclei by converting the gravitational energy of accreting matter into radiation. Sagittarius A* (SgrA*), the compact source of radio, infrared and X-ray emission at the centre of the Milky Way, is the closest example of this phenomenon, with an estimated black hole mass that is 4,000,000 times that of the Sun. A long-standing astronomical goal is to resolve structures in the innermost accretion flow surrounding SgrA*, where strong gravitational fields will distort the appearance of radiation emitted near the black hole. Radio observations at wavelengths of 3.5mm and 7mm have detected intrinsic structure in SgrA*, but the spatial resolution of observations at these wavelengths is limited by interstellar scattering. Here we report observations at a wavelength of 1.3mm that set a size of microarcseconds on the intrinsic diameter of SgrA*. This is less than the expected apparent size of the event horizon of the presumed black hole, suggesting that the bulk of SgrA* emission may not be centred on the black hole, but arises in the surrounding accretion flow.

Ref.: Nature, v455, p78, 2008
Email: dole@haystack.mit.edu

Modulated X-ray Emissivity near the Stress Edge in Sgr A*

M. Falanga (1), F. Melia (2), M. Prescher (2), G. Belanger (3), A. Goldwurm (1)

(1) CEA Saclay, DSM/IRFU/Service d'Astrophysique, 91191 Gif-sur-Yvette, France (2) Physics Department and Steward Observatory, The University of Arizona, Tucson, AZ 85721 (3) ESA/ESAC, Apartado 50727, 28080 Madrid, Spain

Sgr A* is thought to be the radiative manifestation of a 3.6x10E6 Msun supermassive black hole at the Galactic center. Its mm/sub-mm spectrum and its flare emission at IR and X-ray wavelengths may be produced within the inner ten Schwarzschild radii of a hot, magnetized Keplerian flow. The lightcurve produced in this region may exhibit quasi-periodic variability. We present ray-tracing simulations to determine the general-relativistically modulated X-ray luminosity expected from plasma coupled magnetically to the rest of the disk as it spirals inwards below the innermost stable circular orbit towards the "stress edge" in the case of a Schwarzschild metric. The resulting lightcurve exhibits a modulation similar to that observed during a recent X-ray flare from Sgr A*.

Ref.: Apj 679
Email: mfalanga@cea.fr

High accretion rates in magnetised Keplerian discs mediated by a Parker instability driven dynamo

Anders Johansen[1] *and Yuri Levin*[1]

(1) Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands

Hydromagnetic stresses in accretion discs have been the subject of intense theoretical research over the past one and a half decades. Most of the disc simulations have assumed a small initial magnetic field and studied the turbulence that arises from the magnetorotational instability. However, gaseous discs in galactic nuclei and in some binary systems are likely to have significant initial magnetisation. Motivated by this, we performed ideal magnetohydrodynamic simulations of strongly magnetised, vertically stratified discs in a Keplerian potential. Our initial equilibrium configuration, which has an azimuthal magnetic field in equipartion with thermal pressure,

is unstable to the Parker instability. This leads to the expelling of magnetic field arcs, anchored in the midplane of the disc, to around five scale heights from the midplane. Transition to turbulence happens primarily through magnetorotational instability in the resulting vertical fields, although magnetorotational shear instability in the unperturbed azimuthal field plays a significant role as well, especially in the midplane where buoyancy is weak. High magnetic and hydrodynamical stresses arise, yielding an effective α-value of around 0.1 in our highest resolution run. Azimuthal magnetic field expelled by magnetic buoyancy from the disc is continuously replenished by the stretching of a radial field created as gas parcels slide in the linear gravity field along inclined magnetic field lines. This dynamo process, where the bending of field lines by the Parker instability leads to re-creation of the azimuthal field, implies that highly magnetised discs are astrophysically viable and that they have high accretion rates.

Ref.: A&A, accepted
Email: ajohan@mail.strw.leidenuniv.nl
Eprint: 0808.3579
http://arxiv.org/abs/0808.3579

A near-IR variability study of the Galactic black hole: a red noise source with no detected periodicity

T. Do, A. M. Ghez, M. R. Morris, S. Yelda, L. Meyer, J. R. Lu S. D. Hornstein K. Matthews

(1) Physics and Astronomy Department, University of California, Los Angeles, CA 90095-1547 (2) Center for Astrophysics and Space Astronomy, Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO 80309 (3) California Institute of Technology, Pasadena, CA

We present the results of near-infrared (2 and 3 μm) monitoring of Sgr A*-IR with 1 min time sampling using the natural and laser guide star adaptive optics (LGS AO) system at the Keck II telescope. Sgr A*-IR was observed continuously for up to three hours on each of seven nights, between 2005 July and 2007 August. Sgr A*-IR is detected at all times and is continuously variable, with a median observed 2 μm flux density of 0.192 mJy, corresponding to 16.3 magnitude at K'. These observations allow us to investigate Nyquist sampled periods ranging from about 2 minutes to an hour. Using Monte Carlo simulations, we find that the variability of Sgr A* in this data set is consistent with models based on correlated noise with power spectra having frequency dependent power law slopes between 2.0 to 3.0, consistent with those reported for AGN light curves. Of particular interest are periods of $\sim$ 20 min, corresponding to a quasi-periodic signal claimed based upon previous near-infrared observations and interpreted as the orbit of a 'hot spot' at or near the last stable orbit of a spinning black hole. We find no significant periodicity at any time scale probed in these new observations for periodic signals. This study is sensitive to periodic signals with amplitudes greater than 20% of the maximum amplitude of the underlying red noise component for light curves with duration greater than $\sim$ 2 hours at a 98% confidence limit.

Ref.: ApJ, in press
Email: tdo@astro.ucla.edu
Eprint: 0810.0446

Simulation of Cosmic Ray propagation in the Galactic Centre Ridge in Accordance with Observed VHE γ-ray Emission

DIMITRAKOUDIS STAVROS[1], *MASTICHIADIS APOSTOLOS*[1], *GERANIOS ATHANASIOS*[2]

(1) University of Athens, Physics Department, Section of Astrophysics, Astronomy and Mechanics, Panepis-timioupoli 15771, Greece (2) University of Athens, Nuclear and Particle Physics Department, Panepistimioupoli 15771, Greece

Diffuse VHE γ radiation from the Galactic Centre ridge observed by the H.E.S.S. telescope has been convincingly linked with the propagation of recently accelerated cosmic rays that interact with molecular hydrogen clouds during their diffusion. Through a series of time-dependent simulations of that diffusion for different propagation parameters we have obtained the most probable values of the diffusion coefficient for the Galactic Centre region. Assuming that the diffusion coefficient is of the form $\kappa(E) = \kappa_0(E/E_0)^\delta$, then for different optimal combinations of κ_0 and δ its value is obtained for cosmic rays originating from a central point (possibly Sgr A East) 10 kyr ago.

Ref.: ICRC2007 proceedings
Email: sdimis@phys.uoa.gr
Eprint: 0807.4448

Kinematics of the old stellar population at the Galactic Center

S. Trippe[1] *and S. Gillessen*[1] *and O.E. Gerhard*[1] *and H. Bartko*[1] *and T.K. Fritz*[1] *and H.L. Maness*[3] *and F. Eisenhauer*[1] *and F. Martins*[2] *and T. Ott*[1] *and K. Dodds-Eden*[1] *and R. Genzel*[1,3]

(1) Max-Planck-Institut für extraterrestrische Physik, Giessenbachstras se 1, D-85748 Garching, Germany and GRAAL-CNRS, Université Montpellier II, Pl ace Eugène Bataillon, F-34090 Montpellier, France and University of Californi a, 94720 Berkeley, California, USA

We aim at a detailed description of the kinematic properties of the old (several Gyrs) late-type CO absorption star population among the Galactic Center (GC) cl uster stars. This cluster is composed of a central supermassive black hole (Sgr A*) and a self-gravitating system of stars. Understanding its kinematics thus of fers the opportunity to understand the dynamical interaction between a central p oint mass and the surrounding stars in general, especially in view of understand ing other galactic nuclei. We apply AO assisted near-infrared imaging and integral field spectroscopy using the instruments NAOS/CONICA and SINFONI at the VLT. We obtain proper motions fo r 5445 stars, 3D velocities for 664 stars, and acceleration limits (in the sky p lane) for 750 stars. Global kinematic properties are analyzed using velocity and velocity dispersion distributions, phase-space maps, two-point correlation func tions, and the Jeans equation. We detect for the first time significant cluster rotation in the sense of the ge neral Galactic rotation in proper motions. Out of the 3D velocity dispersion, we derive an improved statistical parallax for the GC of $R_0 = 8.07 \pm 0.32_{stat} \pm 0.13_{sys}$ *kpc*. The distribution of 3D stellar speeds can be app roximated by local Maxwellian distributions. Kinematic modelling provides de projected 3D kinematic parameters, including the mass profile of the cluster. We find an upper limit of 4% for the amplitude of fluctuations in the phase-space distribution of the cluster stars compared to a uniform, spherical model cluste r. Using upper limits on accelerations, we constrain the minimum line-of-sight d istances from the plane of Sgr A* of five stars located within the innermost few (projected) arcsec. The stars within 0.7" radius from the star group IRS13E do not co-move with this group, making it unlikely that IRS13E is the core of a su bstantial star cluster. Overall, the GC late-type cluster is well described as a uniform, isotropic, rotating, dynamically relaxed, phase-mixed system.

Ref.: A&A, Oct 2008, in press
Email: trippe@mpe.mpg.de
Eprint: 0810.1040

We are grateful to the National Radio Astronomy Observatory for providing access to the Internet. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Basic research in radio astronomy at the Naval Research Laboratory is supported by the Office of Naval Research.