GCNEWS

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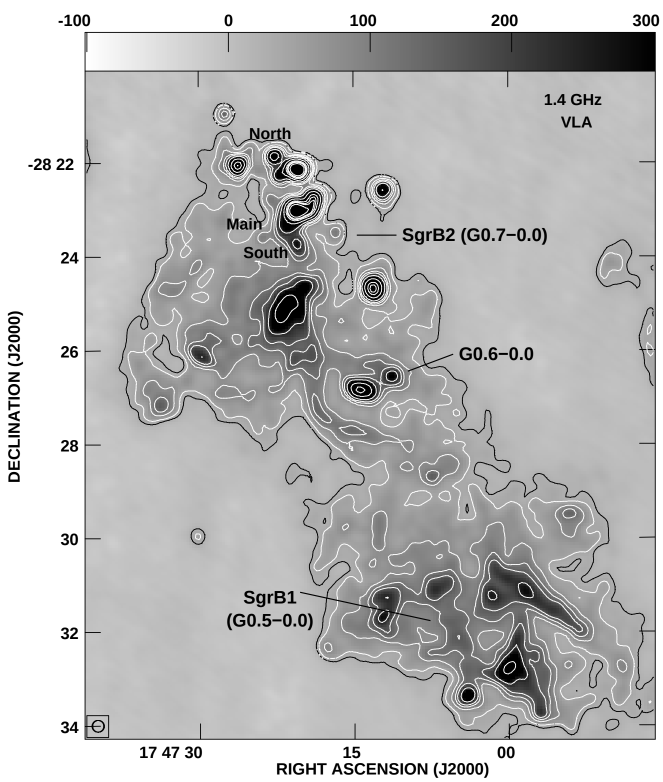
Non-thermal Emission in Sagittarius B?



The above image shows a VLA 1.4 GHz continuum image of the SgrB1 and B2 region from Lang et al. (2003) and Lang et al. *in prep.*. The image has a spatial resolution of 15″ × 15″ and shows the compact and filamentary-like structures. The Sgr B complex has long been known as one of the most massive star-forming complexes in the Galaxy, with primarily thermal emission (HII regions, stellar winds) being traced in the radio. Several recent studies have suggested that there is also a non-thermal component to this complex. For more details, see invited article by Lang, Palmer & Goss (Figure courtesy C. Lang)

Table of Contents

In the News

Cornelia Lang

GCNEWS Updates

Happy New Year 2008 from the editors at GC News! We apologize for the long delay in getting this GC News issue out to you. In the meantime, we hope that you have been keeping up with GC research via the email newsflashes. We plan to bring you three issues of GC News during 2008, with science articles in every other issue.

This issue features an invited article on the nature of the radio emission in the Sagittarius B (Sgr B) complex in the Galactic center region A number of papers were published in 2007 on the nature of the radio emission in the Sgr B complex, motivated in part by H.E.S.S. detections of high-energy radiation arising from this region. Several of these papers present evidence for a component of non-thermal radio emission found in the Sgr B complex. Here, Lang, Palmer & Goss, in their invited article, review these papers and offer their own insight into the nature of the radio emission arising from Sgr B.

Rainer Schödel would also like to bring attention to a meeting he is helping to organize in Bad Honnef, Germany in a few months. This meeting will focus on new frontiers in observational astrophysics and a number of sessions will be devoted to the center of our Milky Way as well as the centers of nearby galaxies. Please see the announcement in the next column for registration, which is open until the end of this month.

In this issue we have a whopping 52 abstracts submitted (partly due to the long delay in the publication of this GC News issue). 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!

Upcoming GC Meetings

The Universe under the Microscope - Astrophysics at High Angular Resolution
Dates: 21-25 April 2008
Location: Physikzentrum Bad Honnef, Germany
Web: https://www.ph1.uni-koeln.de/AHAR08

High angular resolution techniques at infrared and centimeter to millimeter wavelengths have become of ever increasing importance for astrophysical research in the past decade. These new techniques will enable us to address issues such as directly measuring the properties of exoplanets, imaging the surfaces of stars, examining stellar dynamics in extremely dense cluster cores, disentangling the processes at the bottom of black hole accretion flows in the jet launching region, or testing general relativity in the strong gravity regime near the event horizon of supermassive black holes. This conference aims at an interdisciplinary approach by bringing together astrophysicists from the three great branches of the field, instrumentation, observation, and theory, to discuss the current state of research and the possibilities offered by the next-generation instruments.

Note: There will be multiple sessions of interest to Our Galaxy's Central regions as well as the centers of nearby galaxies, i.e., "Sagittarius A*: Physics of the inner accretion flow/outflow", "The nuclear star cluster of the Milky Way", "The central 100s of parsecs of galaxies: Black hole feeding from 1 kpc to the event horizon and Nuclear star clusters". See conference webpage for more details.

Non-thermal Emission in Sagittarius B?

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Introduction: The Sgr B Region

The radio spectrum of the Galactic Center (GC) has been a longstanding and complicated problem for astronomers. The GC radio source was slowly recognized to be a complex of individual sources embedded in diffuse Galactic background emission. One of the first images to resolve the Sagittarius B (Sgr B) complex from the other major GC sources was made by Cooper & Price (1964) using the 210-foot telescope in Parkes, Australia at 3 GHz (6.7′ spatial resolution). Cooper & Price (1964) were the first to suggest that the Sgr B source is an optically-thick thermal source based on a spectral index measurement between 3 and 8 GHz (Drake 1959a,b) that had large uncertainties. The Sgr B region is now understood to be one of the most complex star-forming regions in the Galaxy. Located at $\sim$105 pc in projection from Sgr A*, the Sgr B giant molecular cloud has a total mass of 8-20 x 10^6 $M_\odot$ (Tsuboi et al. 1999). Therefore, many interstellar molecules have been detected for the first time in the Sgr B cloud. Most studies of Sgr B have been carried out in the far-infrared and radio regimes because this region of the Galaxy is highly obscured (by up to 50 magnitudes) at visible wavelengths.

Sgr B2 (G0.7-0.0; to the North) and Sgr B1 (G0.5-0.0; to the South) are both strong radio continuum sources and have been well-studied on fine scales ($\sim$1″ or better) with interferometric observations. In higher frequency radio observations ($\nu > 1.4$ GHz), Sgr B2 dominates due to the numerous ultra-compact, optically-thick HII regions (Benson & Johnston 1984; Gaume & Claussen 1990).

Sgr B2 is well-known for its incredibly high densities ($> 10^5$ cm^{-3}) in both ionized and molecular gas (Huttemeister et al. 1993; De Pree et al. 1998). The Sgr B2 complex has three bright cores - Sgr B2 "Main", "North" and "South". Sgr B2 shows radio emission over a factor of 6000 in size scale, from <1″ (ultra-compact HII regions) to the 10′ extent of diffuse emission along the complex. The highest resolution radio study of Sgr B2 was made at 43 GHz with the Very Large Array (VLA)[1] radio telescope with an angular resolution of $\sim$64 milli-arcseconds (600 AU at the GC distance of 8 kpc) in Sgr B2 Main which revealed more than 20 ultra-compact HII regions and stellar wind sources alone (De Pree et al. 1998). In addition, the range of observed emission measures in the ionized gas are from 1×10^4 to 1×10^9 pc cm^{-6}. Radio recombination line studies at numerous frequencies have helped cement the thermal nature of many of the individual radio components in the Sgr B complex (e.g., Mehringer et al. 1993). The radio emission arising from the Sgr B1 complex indicates that this region is a more highly evolved star-forming region with numerous filamentary and shell-like ionized structures (Mehringer et al. 1992). This paper also shows that the radio sources known as G0.6-0.0 are thought to physically connect Sgr B1 and Sgr B2, based on gas velocities and morphology.

Recent Papers and Our Motivation

Two recent papers on Sgr B complex have addressed the nature of the radio emission arising from this region, and have argued that there is a non-thermal component (Crocker et al. 2007 and Hollis et al. 2007). Because Sgr B is one of the most active regions of star formation in the Galaxy, containing more than 60 HII regions, it would not be surprising to find an embedded supernova remnant or two. However, because the preponderance of evidence for the last four decades has indicated that the Sgr B complex is a thermal radio source, claims of non-thermal emission deserve close scrutiny.

One of the main motivations for looking for non-thermal emission has come from high-energy investigations of this region. Using HESS, Aharonian et al. (1996) have made a detection of diffuse γ-ray flux between 0.2-20 TeV (1 TeV = 10^{12} eV) from the Galactic center (GC) region, distributed along the Galactic plane. In addition, a separate HESS measurement of the γ-ray flux and spectrum in a $0.5^\circ\times0.5^\circ$ region was centered on the SgrB molecular cloud. After removal of several bright point-like sources, the diffuse flux is believed to be correlated with the density of molecular gas (H_2) in the GC region, which has been imaged in the CS (J=1-0) line transition (Tsuboi et al. 1999).

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

One possible origin of the high-energy radiation is the collision between cosmic ray protons and the ambient, dense molecular gas in the GC. Crocker et al. (2007) predict the radio synchrotron spectrum from their broadband (radio to γ-ray) emission models and compare their results to the measured radio spectrum of this region. Crocker et al. (2007) base their radio spectrum of this region primarily on low-frequency data at 327 and 843 MHz (see below for a description). They determine that the radio spectrum of Sgr B is non-thermal in nature, with a measured excess of non-thermal emission. Finally, Hollis et al. (2007) present a study of the continuum temperature of Sgr B2 based on GBT spectral line observations. They argue that there is a non-thermal component in Sgr B2 on size scales of $\sim 143''$ at 1.4 GHz with an optically-thin spectral index of $\alpha = -0.7$.

In this paper, a discussion of the measurements used to derive the spectral index of radio emission in the above papers follows. In addition, a high-resolution 1.4 GHz image of the GC region is presented and used for comparison to the two recent results on the non-thermal emission in Sgr B.

Radio Observations of the Sgr B Region at Low Frequencies

Figure 1 shows a 1.4 GHz VLA image of the Sgr B region of the GC. This image was made using the DnC and CnB array configurations as part of an HI absorption study toward the central 250 pc of the Galaxy (e.g., Lang et al. (2003) and Lang et al. *in prep.*). In order to cover this large region, 5 fields were mosaicked together using the miriad task *mosmem*. The integration time was 8 hours for the set of five fields in each configuration (i.e., approximately 2.5 hours on each field) which resulted in an rms of 10 mJy beam^{-1}. The zero level in this image is within 1σ (10 mJy) of zero, and the image has also been corrected for the variable system temperature with frequency in the presence of HI emission. This mosaic is one of the highest-resolution images of the more extended structures in the complex GC region, with excellent sensitivity to both point-like and diffuse features. In this paper, this image is used to determine the flux density of the Sgr B complex and to help constrain the radio spectrum of Sgr B.

Based on data at 327 and 843 MHz, Crocker et al. (2007) determine that the radio emission arising from the Sgr B region is non-thermal. At 327 MHz, Crocker et al. (2007) use data from Brogan et al. (2003) smoothed from the original resolution of $120'' \times 60''$ to $252''$. They measure the integrated flux density in two regions: (1) the field of view of the HESS detection, which is a large region of $0.5^\circ \times 0.5^\circ$ size centered on Sgr B and (2) a smaller region containing primarily the bright radio emission associated with Sgr B1 and B2 radio sources. For the large region, they measure the flux density to be 45 ± 10 Jy, and for the smaller region they measure 25 Jy. At 843 MHz (using an image from SUMSS; Bock et al. 1999), a two sigma detection of 20 ± 10 Jy for the $0.5^\circ \times 0.5^\circ$ region is obtained by Crocker et al. (2007). They also attempt to measure the flux density at 74 MHz in an image from Brogan et al. (2003), but they can not obtain a result for the flux density of this region. It is likely that the spectrum derived by Crocker et al. (2007) is not reliable due primarily to the poorly-determined flux density at 327 MHz, coupled with the poor signal-to-noise of the 843 MHz data. At 327 MHz, there are large distortions in the image due to missing flux and confusion from SgrA West and East. It is not possible to obtain an accurate flux density over a region as large as $\sim 0.5^\circ \times 0.5^\circ$.

We suggest that a more reliable radio spectrum can be determined by using VLA data at two frequencies (1.4 GHz and 327 MHz) with matched *(u,v)* coverage. Data from Brogan et al. (2003) were used at 327 MHz and at 1.4 GHz from Lang et al. (2003; also presented above). The flux densities were obtained over a region which includes the radio emission associated with Sgr B1 and B2 (up to an angular size of $\sim 0.3^\circ$), with careful consideration of the problems of the displacement of the zero level. At both frequencies, good signal-to-noise determinations are possible. We have used the AIPS task *IRING* to determine the flux in concentric rings. The total cumulative flux density can then be determined as a function of radius. The total flux density at 1.4 GHz over a region that includes both Sgr B1 and B2 is 83 ± 7 Jy with a radius of $500''$ ($8.3'$). For Sgr B1 and B2 individually, we determine separate flux densities at 1.4 GHz of 35 ± 5 Jy and 49 ± 6 Jy. At 327 MHz, we determine a flux density of 37 ± 7 Jy for Sgr B over a region of the same region used at 1.4 GHz.

In Table 1 we summarize the flux density determinations from this paper and compare these with Crocker et al. (2007) and previous VLA measurements. The agreement with Mehringer et al. (1993) is encouraging (see Table 1). Our results, which have high signal-to-noise and matched *(u,v)* coverage, provide good evidence that the flux density of the Sgr B complex *increases* from 327 MHz to 1.4 GHz, in contrast to the conclusion of Crocker et al. (2007). The current data are in good agreement with previous independent VLA studies (see Table 1 and Mehringer et al. 1992, 1993).

A likely explanation of the radio spectrum of Sgr B we derive (i.e., thermal) is the large halo of size $10' \times 5'$ first described by Mehringer et al. (1993). This halo represents a "transition" region from HII gas optically thick at 327 MHz becoming optically thin at the higher frequencies. In order to provide a crude estimate of the physical

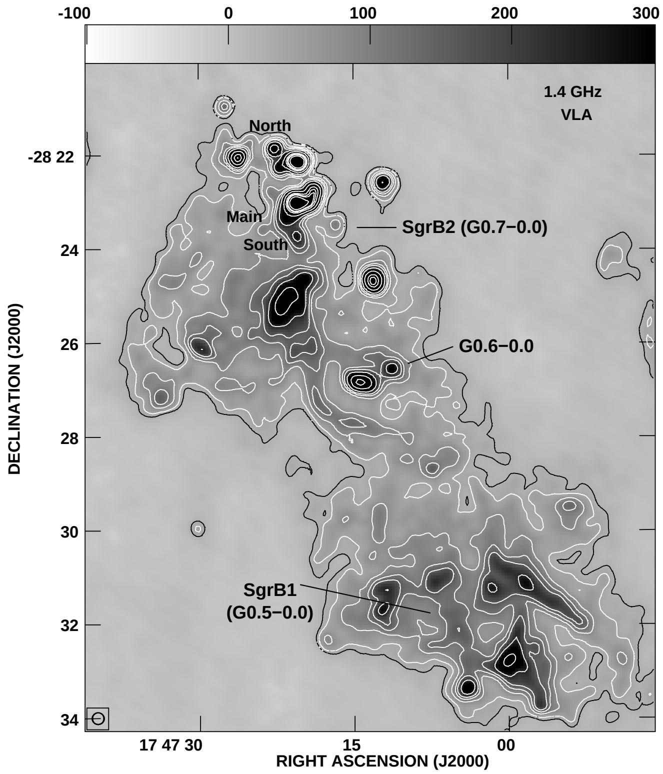

Figure 1: VLA 1.4 GHz continuum image of the SgrB1 and B2 region from Lang et al. (2003) and Lang et al. ***in prep.*****. The image has a spatial resolution of 15″ × 15″ and an rms level of 10 mJy beam^{-1}. Contours are at levels of 3, 5,10, 15, 20, 30, 50, 90, 100, and 125 times the rms level.**

parameters of the halo, we estimate that ∼50% of the emission at 1.4 GHz arises from the halo. This estimate is derived by summing all the compact components in Figure 1 (∼40 Jy) and subtracting this from the total flux density of ∼83 Jy (see Table 1) to obtain a flux density of ∼40 Jy. For a source of radius ∼15 pc, the emission measure is $1{\times}10^5$ pc^{-6}, with an rms electron density of 60 cm^{-3}. The implied opacity in the continuum at 327 MHz is then $\tau{\sim}0.3$ for a source of this size. Thus, the ratio of flux densities from 1.4 GHz to 327 MHz for the entire Sgr B complex is 2.2 and not the ratio for a source that is completely optically thick at both frequencies (which would be 21). This small ratio of flux densities (∼2) is likely due to a very gradual turnover in the spectrum at these frequencies because of the wide range of emission measures across the Sgr B complex.

Continuum Temperature of Sgr B2

Hollis et al. (2007) noted that the Green Bank Telescope (GBT) continuum antenna temperature toward Sgr B2 is linear on a log-log plot. From this straightforward result, they carried out an analysis suggesting that the bulk of the emission from this direction is non-thermal and can be associated with a source of size 143" at 1 GHz, with a source size decreasing with frequency as $\nu^{-0.52}$. We examine their methods and results, and suggest some problems in their analysis. We address two points: the effect of source structure on the measured continuum temperature and the estimates of source size from archival VLA observations.

At their lowest frequency (1.35 GHz), the FWHM of the GBT beam is 9.1′, while at their highest frequency (47.68 GHz) the FWHM is 16″. Within a FWHM of 9.1′, more than 100 components in the Sgr B2 complex are detected in high resolution images. The majority of these components are known to be thermal both because of their radio continuum spectra and because of the presence of recombination lines (Gaume & Claussen 1990, Mehringer et al. 1992, 1993). Emission measures of these components have a very wide range of values. Because the GBT beam scales as ν^{-1}, these components will contribute differently to the measured flux density due to their relative positions and to the changes in opacities because of the scaling of τ as $\sim \nu^{-2.1}$. Therefore, the apparent non-thermal spectral index (α=-0.7) of the continuum temperature measured with the GBT by Hollis et al. (2007) may be due to integrating over the large number of components in Sgr B2. The opacities change with frequency and the contribution of each compact source varies systematically as the GBT beam size changes with frequency.

If the flux density of a point source were independent of frequency, then the procedure of Hollis et al. (2007) would yield a spectral index of zero. For an extended source (size >> than the GBT beam), the measured flux density would scale as the beam area, i.e. as ν^{-2}. The measured flux density is proportional to the quantities plotted in Figures 1a, 1b, and 2a of Hollis et al. (2007) (with minor corrections for efficiencies). In their equation (3), a structure correction ($1+ \theta_s^2/\theta_b^2$) is introduced to compensate for the resolution of the source. This correction would remove the ν^{-2} dependence that results from the beam area when $\theta_s^2/\theta_b^2 >> 1$.

It is useful to demonstrate the effect of integration over a complex distribution. The 1.4 GHz image shown in Figure 1 is multiplied by the GBT beam pattern (approximated by a Gaussian with the same FWHM and positioned at the Hollis et al. (2007) pointing center) and summed to obtain the total flux density "observed". This method can be carried out at a number of frequencies. This procedure then shows that an apparent spectral index can be caused by structure alone. If the flux density is plotted on a log-log plot against frequency, the result is linear with a slope of -1.07 (+/- 0.05). This result may be compared with Hollis et al. Fig 1b of the continuum antenna temperature which has a slope of -1.06. In view of the complicated structure of the source shown in the Sgr B2 complex in Figure 1, the approximation used by Hollis et al. to make the structure correction is clearly questionable. However, if we ignore this misgiving and the Hollis et al. (2007) structure correction were made, the slope would become -0.82 ± 0.08. This value may be compared with Figure 2b of Hollis et al. (2007) in which the slope is given as -0.7. While this is not a simulation because we use data at only one frequency, this demonstration convinces us that the effect of structure cannot be ignored when trying to interpret the GBT continuum temperature. In our opinion, the apparent non-thermal spectrum reported by Hollis et al. (2007) is an effect of source structure alone.

In addition, estimates of source size obtained by heavily tapering VLA data are not realistic. The most compact VLA configurations were used in all of the archival observations analyzed. The shortest spacings (measured in wavelengths) increase with frequency so that the largest angular scale observable decreases with increasing frequency. Therefore it is not surprising that the apparent source size decreases with increasing frequency. Typically, if VLA data has been tapered so that the beam size is increased by more than a factor of two to four, the imaging quality is too poor to be useful. Hollis et al. (2007) acknowledge that this effect may cause an unknown systematic uncertainty.

In summary, the apparent non-thermal power law slope for the Sgr B2 continuum temperature observed by the GBT is likely determined by source structure and provides limited information about the physical processes in the Sgr B region.

Conclusions

In this paper, we have summarized two recent papers which point out possible non-thermal radio emission arising from the Sgr B region. We also present a high-resolution and sensitive image of the Sgr B region at 1.4 GHz. Using this image and a matched-array 327 MHz VLA image, we derive a thermal spectrum for the Sgr B complex and suggest that the radio emission is a mixture of optically thin and optically thick emission over the frequency range discussed here (255 MHz to 1.4 GHz). In addition, we show that the the apparent non-thermal power law slope for the Sgr B2 continuum temperature observed by the GBT is likely determined by source structure and provides limited information about the physical processes in the Sgr B region. While the structure Sgr B region is complex and furthermore confused by the Galactic background, there does not appear to be substantial evidence for a non-thermal component of Sgr B2.

A more complete version of this paper will be submitted to *astro-ph*.

The authors would like to thank Roland Crocker, Mike Hollis, and Farhad Yusef-Zadeh for their comments on this article.

Table 1. Radio Flux Density of the Sgr B Complex

Frequency (GHz)	VLA Array(s)	Spatial Resolution	Sgr B (Jy)	Sgr B1 (Jy)	Sgr B2 (Jy)	Reference
1.4	DnC,CnB	$15'' \times 15''$	83±7	35±5	49±6*	This paper
1.4	D,C	$26'' \times 15''$	75	26	39*	Mehringer et al. (1993)
0.843	−−		20±10**	−−	−−	Crocker et al. (2007)‡
0.327	C,D	$60'' \times 120''$	37±7	−−	17±4	This paper†
0.327	C,D	$252'' \times 252''$	45±10**	−−	−−	Crocker et al. (2007)†

*Sgr B2 region includes emission from the G0.6-0.0 complex.

**Flux density is for the HESS large region of size $0.5^\circ \times 0.5^\circ$.

†Data from Brogan et al. (2003).

‡Data from Bock et al. (1999).

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Abstracts

Variable accretion and emission from the stellar winds in the Galactic centre

Jorge Cuadra, Sergei Nayakshin, Fabrice Martins

We present numerical simulations of stellar wind dynamics in the central parsec of the Galactic centre. We are particularly interested in accretion of gas on to Sgr A*, the super-massive black hole. Unlike our previous efforts, here we use the state of the art observational data on orbits and wind properties of individual wind-producing stars. Since wind velocities were revised upwards and non-zero eccentricities were considered, our new simulations show fewer clumps of cold gas and no conspicuous disc-like structure. The accretion flow circularisation radius is roughly unchaged, $\sim$ 5000 Schwarzschild radii. The accretion rate is dominated by a few close 'slow wind stars' ($v_w \leq 750\,\mathrm{km\ s}^{-1}$), and is consistent with the Bondi estimate, but variable on time-scales of tens to hundreds of years. This variability is due to the stochastic in-fall of cold clumps, as in earlier simulations, and to the eccentric orbits of stars. The present models fail to explain the higher luminosity of Sgr A* a few hundred years ago implied by *Integral* observations, but we argue that the accretion of a cold clump with a small impact parameter could have caused it. Finally, we show the possibility of constraining the total mass-loss rate of the 'slow wind stars' using near infra-red observations of gas in the central few arcseconds.

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http://www.arxiv.org/ps/0705.0769

General Relativistic Flux Modulations from Disk Instabilities in Sagittarius A*

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Near-IR and X-ray flares have been detected from the supermassive black hole Sgr A* at the center of our Galaxy with a (quasi)-period of $\sim 17 - 20$ minutes, suggesting an emission region only a few Schwarzschild radii above the event horizon. The latest X-ray flare, detected with *XMM-Newton*, is notable for its detailed lightcurve, yielding not only the highest quality period thus far, but also important structure reflecting the geometry of the emitting region. Recent MHD simulations of Sgr A*'s disk have demonstrated the growth of a Rossby wave instability, that enhances the accretion rate for several hours, possibly accounting for the observed flares. In this *Letter*, we carry out ray-tracing calculations in a Schwarzschild metric to determine as accurately as possible the lightcurve produced by general relativistic effects during such a disruption. We find that the Rossby wave induced spiral pattern in the disk is an excellent fit to the data, implying a disk inclination angle of $\approx 77°$. Note, however, that if this association is correct, the observed period is not due to the underlying Keplerian motion but, rather, to the pattern speed. The favorable comparison between the observed and simulated lightcurves provides important additional evidence that the flares are produced in Sgr A*'s inner disk.

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The Nature of Linearly Polarized Millimeter and Sub-millimeter Emission in Sagittarius A*

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The linearly polarized millimeter and sub-millimeter emission in Sagittarius A* is produced within 10 Schwarzschild radii of the supermassive black hole at the Galactic Center. We show that

the millimeter emission likely originates from a hot accretion disk, where electrons are heated efficiently by turbulent plasma waves. The observed flux density and polarization requires that the disk have an inclination angle of $\sim 45°$ and its rotation axis be aligned with the major axis of the intrinsic polarization. The disk also needs to be strongly magnetized with a magnetic field energy density comparable to the thermal energy density of the gas. The high flux density and hard spectrum of the submillimeter (< 1 mm) emission, on the other hand, suggest that it is emitted from small emission regions and therefore associated with flare events occurring either in coronas of the disk or within the last stable orbit. Simultaneous spectrum and polarization measurements will be able to test the model.

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Gamma Rays from the Galactic Centre

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Recent results from the HESS gamma ray telescope have shown the presence of both a diffuse, extended, flux of gamma rays above ∼0.4 TeV and discrete sources in and near the Galactic Centre. Here, we put forward a possible explanation in terms of the diffusion of cosmic ray protons from a succession of supernova remnants (SNR) in the SgrA* region of the Galaxy plus a contribution from SNR in the rest of the Galactic Centre Region, to be called the Galactic Centre Ridge (GCR). Protons are favoured over electrons because the mG magnetic fields in the Region will attenuate energetic electrons severely. Prominent features are the need for 'anomalous diffusion' of the protons in the whole region and the adoption of low efficiency for SNR acceleration in the high density regions. The latter is related by us to the well-known low 'cosmic ray gradient' in the Galaxy. A corroborating feature is the close correlation of inferred cosmic ray intensity with the smoothed intensity of 5 GHz radio radiation. We attribute this to the presence of the SNR in the GCR.

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Eprint: arXiv:0705.2333

Massive perturbers and the efficient merger of binary massive black holes

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We show that dynamical relaxation in the aftermath of a galactic merger, and the ensuing formation of a binary massive black hole (MBH), are dominated by massive perturbers (MPs), such as giant molecular clouds or clusters. MPs accelerate relaxation by orders of magnitude relative to 2-body stellar relaxation alone, and efficiently scatter stars into the binary MBH's orbit. The 3-body star–binary MBH interactions shrink the binary MBH to the point where energy loss from the emission of gravitational waves (GW) leads to rapid coalescence. We take into account the decreased efficiency of the star-binary MBH interaction due to acceleration in the galactic potential, and show that the observed MP abundances in galactic nuclei imply binary MBH coalescence times shorter than the Hubble time. These events are observable by their strong GW emission. MPs thus increase the cosmic rate of these GW events, increase the mass deficit in the stellar core, lead to the ejection of hyper-velocity stars, and suppress the formation of triple MBH systems and the resulting ejection of MBHs into intergalactic space.

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Masers as Probes of Massive Star Formation in the Nuclear Disk

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OH(1720 MHz) and methanol masers are now recognized to be excellent probes of the interactions of supernova remnants with molecular clouds and tracers of massive star formation, respectively. To better understand the nature of star formation activity in the central region of the Galaxy, we have used these two classes of masers combined with the IRAC and MIPS data to study prominent sites of ongoing star formation in the nuclear disk. The nuclear disk is characterized by massive GMCs with elevated gas temperatures, compared to their dust temperatures. We note an association between methanol masers and a class of mid-infrared "green sources". These highly embedded YSOs show enhanced 4.5micron emission due to excited molecular lines. The distribution of methanol masers and supernova remnants suggest a low efficiency of star formation (with the exception of Sgr B2), which we believe is due to an enhanced flux of cosmic ray electrons impacting molecular clouds in the nuclear disk. We also highlight the importance of cosmic rays in their ability to heat molecular clouds, and thus increase the gas temperature.

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Email: zadeh@northwestern.edu
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A Constant Spectral Index for Sagittarius A* During Infrared/X-ray Intensity Variations

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We report the first time-series of broadband infrared color measurements of Sgr A*, the variable emission source associated with the supermassive black hole at the Galactic Center. Using the laser and natural guide star adaptive optics systems on the Keck II telescope, we imaged Sgr A* in multiple near-infrared broadband filters with a typical cycle time of ∼3 min during 4 observing runs (2005–2006), two of which were simultaneous with Chandra X-ray measurements. In spite of the large range of dereddened flux densities for Sgr A* (2 to 30 mJy), all of our near-infrared measurements are consistent with a constant spectral index of α = -0.6 ± 0.2 ($F_\nu \propto \nu^\alpha$). Furthermore, this value is consistent with the spectral indices observed at X-ray wavelengths during nearly all outbursts; which is consistent with the synchrotron self-Compton model for the production of the X-ray emission. During the coordinated observations, one infrared outburst occurs ≤36 min after a possibly associated X-ray outburst, while several similar infrared outbursts show no elevated X-ray emission. A variable X-ray to IR ratio and constant infrared spectral index challenge the notion that the infrared and X-ray emission are connected to the same electrons. We, therefore, posit that the population of electrons responsible for both the IR and X-ray emission are generated by an acceleration mechanism that leaves the bulk of the electron energy distribution responsible for the infrared emission unchanged, but has a variable high-energy cutoff. Occasionally a tail of electrons $\gtrsim$ 1 GeV is generated, and it is this high-energy tail that gives rise to the X-ray outbursts. One possible explanation for this type of variation is from the turbulence induced by a magnetorotational instability, in which the outer scale length of the turbulence varies and changes the high-energy cutoff.

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http://casa.colorado.edu/ hornstei/sgracolor.pdf

A search for possible anisotropies of cosmic rays with $0.1 < E < 10$ EeV in the region of the Galactic Centre

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We present updated results for anisotropy searches in the direction of the Galactic Center (GC) at energies in the ranges: $0.1 < E < 1$ EeV and $1 < E < 10$ EeV. We use data from the Pierre Auger Observatory up to March, 2007. Present analyzes are therefore based on a substantially larger data set than our previous published results. A limit on the flux coming from a hypothetical point-like neutron source at the GC for $1 < E < 10$ EeV was imposed, and searches for extended excesses were also performed.

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Email: emoura@cbpf.br
Eprint: arXiv:0706.2669

Radio Synchrotron Emission from Secondary Leptons in the Vicinity of Sgr A*

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A point-like source of TeV gamma-rays has recently been seen towards the Galactic center by HESS and other air Cerenkov telescopes. In recent work (Ballantyne et al. 2007), we demonstrated that these gamma-rays can be attributed to high-energy protons that (i) are accelerated close to the event horizon of the central black hole, Sgr A*, (ii) diffuse out to pc scales, and (iii) finally interact to produce gamma-rays. The same hadronic collision processes will necessarily lead to the creation of electrons and positrons. Here we calculate the synchrotron emissivity of these secondary leptons in the same magnetic field configuration through which the initiating protons have been propagated in our model. We compare this emission with the observed GHz radio spectrum of the inner few pc region which we have assembled from archival data and new measurements we have made with the Australia Telescope Compact Array. We find that our model predicts secondary synchrotron emission with a steep slope consistent with the observations but with an overall normalization that is too large by a factor of 2. If we further constrain our theoretical gamma-ray curve to obey the implicit EGRET upper limit on emission from this region we predict radio emission that is consistent with observations, i.e., the hadronic model of gamma ray emission can, simultaneously and without fine-tuning, also explain essentially all the diffuse radio emission detected from the inner few pc of the Galaxy.

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Eprint: arXiv:0706.3429

Faraday Rotation in Global Accretion Disk Simulations: Implications for Sgr A*

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We calculate Faraday rotation in global axisymmetric magnetohydrodynamic simulations of geometrically thick accretion flows. These calculations are motivated by the measured rotation measure (RM) of $\approx -6 \times 10^5$ rad m^{-2} from Sgr A* in the Galactic center, which appears to have been stable over the past $\approx$ 7 years. In our numerical simulations, the quasi-steady state structure of the accretion flow, and the RM it produces, depends on the initial magnetic field threading the accreting material. In spite of this dependence, we can draw several robust conclusions about Faraday rotation produced by geometrically thick accretion disks: i) the time averaged RM does not depend that sensitively on the viewing angle through the accretion flow, but the stability of the RM can. Equatorial viewing angles show significant variability in RM (including sign reversals), while polar viewing angles are relatively stable if there is a large scale magnetic field threading the disk at large radii. ii) Most of the RM is produced at small radii for polar viewing angles while all radii contribute significantly near the midplane of the disk. Our simulations confirm previous analytic arguments that the accretion rate onto Sgr A* must satisfy $\dot{M}_{in} \ll \dot{M}_{Bondi} \sim 10^{-5}$ in order to not over-produce the measured RM. We argue that the steady RM $\approx -6 \times 10^5$ rad m^{-2} from Sgr A* has two plausible explanations: 1) it is produced at ~ 100 Schwarzschild radii, requires $\dot{M}_{in} \approx 3 \times 10^{-8} M_\odot$ yr^{-1}, and we view the flow at an angle of $\sim 30°$ relative to the rotation axis of the disk; in our simulations, the variation in RM across a finite-sized source is sufficient to depolarize the emission below ≈ 100 GHz, consistent with observations. 2) Alternatively, the RM may be produced in the relatively spherical inflowing plasma near the circularization radius at $\sim 10^3 - 10^4$ Schwarzschild radii, with the magnetic field perhaps amplified by the magnetothermal instability. Time variability studies of the RM can distinguish between these two possibilities.

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Email: psharma@astro.berkeley.edu
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Surveys of the Galactic Center and the Nature of the Galactic Center Lobe

Casey Law

The Galactic center (GC) is a dense and chaotic region filled with unusual sources, such as intense star forming regions, dense star clusters, nonthermal radio filaments, and a massive black hole. The proximity of the GC region makes it an ideal place to study the unusual processes that tend to manifest themselves in Galactic nuclei. This thesis uses single-dish and interferometric radio continuum, radio recombination line, polarized radio continuum, and mid-IR observations to study the wide variety of physical processes seen in the GC region on physical scales from 0.1 to 100 parsecs. These observations provide one of the most sensitive and complete studies of the cm-wavelength continuum emission in the central 500 parsecs. I also study the distribution of radio spectral index and polarized emission from nonthermal radio filaments, which can constrain their origin and the structure of the magnetic field in the GC region. The presence of massive star clusters and a massive black hole suggest that starburst and AGN phenomena can manifest themselves in our Galaxy. This thesis explores this possibility by studying a 150-pc-tall, shell-like structure called the Galactic center lobe (GCL). Our multiwavelength observations of the central few hundred parsecs of the Galaxy examine the spectral index, dust emission, polarized continuum emission, and ionized gas throughout the GCL. I find strong evidence supporting the idea that the GCL is a true three-dimensional shell located in the GC region with nested layers of ionized, magnetized, and mid-IR–emitting components. I compare the physical conditions of the GCL to proposed models for its origin and find best agreement with starburst outflows seen in other galaxies, yet consistent with the currently observed pressure and star formation rate in the central tens of parsecs of our Galaxy.

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Email: claw@science.uva.nl
Eprint: arXiv:0705.0114

Cosmic-Ray Heating of Molecular Gas in the Nuclear Disk: Low Star Formation Efficiency

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Understanding the processes occurring in the nuclear disk of our Galaxy is interesting in its own right, as part of the Milky Way Galaxy, but also because it is the closest galactic nucleus. It has been more than two decades since it was recognized that the general phenomenon of higher gas temperature in the inner few hundred parsecs by comparison with local clouds in the disk of the Galaxy. This is one of the least understood characteristics of giant molecular clouds having a much higher gas temperature than dust temperature in the inner few degrees of the Galactic center. We propose that an enhanced flux of cosmic-ray electrons, as evidenced recently by a number of studies, are responsible for directly heating the gas clouds in the nuclear disk, elevating the temperature of molecular gas ($\sim$ 75K) above the dust temperature ($\sim$ 20K). In addition we report the detection of nonthermal radio emission from Sgr B2-F based on low-frequency GMRT and VLA observations. The higher ionization fraction and thermal energy due to the impact of nonthermal electrons in star forming sites have important implications in slowing down star formation in the nuclear disk of our galaxy and nuclei of galaxies.

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A Complete Survey of the Central Molecular Zone in NH_3

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We present a map of the major part of the central molecular zone (CMZ) of simultaneous observations in the NH_3 (J, K) = (1,1) and (2,2) lines using the Kagoshima 6-m telescope. The mapped area is $-1.000 \leq l \leq 1.625$, $-0.375 \leq b \leq +0.250$. The kinetic temperatures derived from the (2,2) to (1,1) intensity ratios are 20–80 K or exceed 80 K. The gases corresponding to temperature of 20–80 K and $\geq$ 80 K contain 75% and 25% of the total NH_3 flux, respectively. These temperatures indicate that the dense molecular gas in the CMZ is dominated by gas that is warmer than the majority of the dust present there. A comparison with the CO survey by Sawada shows that the NH_3 emitting region is surrounded by a high pressure region on the l-v plane. Although NH_3 emission traces dense gas, it is not extended into a high pressure region. Therefore, the high pressure region is less dense and has to be hotter. This indicates that the molecular cloud complex in the Galactic center region has a "core" of dense and warm clouds which are traced by the NH_3 emission, and an "envelope" of less dense and hotter gas clouds. Besides heating by ambipolar diffusion, the hot plasma gas emitting the X-ray emission may heat the hot "envelope".

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Email: nagayama@astro.sci.kagoshima-u.ac.jp
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On the origin of kinematic distribution of the sub-parsec young stars in the Galactic center

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Observations indicate the presence of a massive black hole in the Galactic center. Within a half-parsec from the Galactic center, there is a population of coeval young stars which appear to reside in a coherent disk. Surrounding this dynamically-cool stellar system, there is a population of stars with a similar age and much larger eccentricities and inclinations relative to the disk. We propose a hypothesis for the origin of this dynamical dichotomy. Without specifying any specific mechanism, we consider the possibility that both stellar populations were formed within a disk some 6±2 Myr ago. But this orderly structure was dynamically perturbed outside-in by an intruding object with a mass $\sim 10^4 M_\odot$, which may be an intermediate-mass black hole or a dark stellar cluster hosting an intermediate-mass black hole. We suggest that the perturber migrated inward to $\sim 0.15 - 0.3pc$ from the Galactic center as a consequence of orbital decay under the action of dynamical friction. Along the way, it captured many stars in the outer disk region into its mean-motion resonance, forced them to migrate with it, closely encountered with them, and induced the growth of their eccentricity and inclination. But stars in the inner regions of the disk retain their initial coplanar structure. Quantitatively, a perturber on a low-inclination or overhead orbit to the disk plane can reproduce the observed kinematic structure of these young stars. But this process is unlikely to produce the controversial two-disk structure. We predict that some of the inclined and eccentric stars surrounding the disk may have similar Galactocentric semimajor axis. Future precision determination of their kinematic distribution of these stars will not only provide a test for this hypothesis but also evidences for the presence of an intermediate-mass black hole or a dark cluster at the immediate proximity of the massive black hole at the Galactic center.

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The Origin of the Arches Stellar Cluster Mass Function

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We investigate the time evolution of the mass distribution of pre- stellar cores (PSCs) and their transition to the initial stellar mass function (IMF) in the central parts of a molecular cloud (MC) under the assumption that the coalescence of cores is important. Our aim is to explain the observed shallow IMF in dense stellar clusters such as the Arches cluster. The initial distributions of PSCs at various distances from the MC center are those of gravitationally unstable cores resulting from the gravo-turbulent fragmentation of the MC. As time evolves, there is a competition between the PSCs rates of coalescence and collapse. Whenever the local rate of collapse is larger than the rate of coalescence in a given mass bin, cores are collapsed into stars. With appropriate parameters, we find that the coalescence-collapse model reproduces very well all the observed characteristics of the Arches stellar cluster IMF; Namely, the slopes at high and low mass ends and the peculiar bump observed at $\sim 5 - 6\ M_\odot$. Our results suggest that today's IMF of the Arches cluster is very similar to the primordial one and is prior to the dynamical effects of mass segregation becoming important.

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Chemical Abundances of Luminous Cool Stars in the Galactic Center from High-Resolution Infrared Spectroscopy

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We present chemical abundances in a sample of luminous cool stars located within 30 pc of the Galactic Center. Abundances of carbon, nitrogen, oxygen, calcium, and iron were derived from high-resolution infrared spectra in the H- and K-bands. The abundance results indicate that both [O/Fe] and [Ca/Fe] are enhanced respectively by averages of +0.2 and +0.3 dex, relative to either the Sun or the Milky Way disk at near solar Fe abundances. The Galactic Center stars show a nearly uniform and nearly solar iron abundance. The mean value of A(Fe) = 7.59 ± 0.06 agrees well with previous work. The total range in Fe abundance among Galactic Center stars, 0.16 dex, is significantly narrower than the iron abundance distributions found in the literature for the older bulge population. Our snapshot of the current-day Fe abundance within 30 pc of the Galactic Center samples stars with an age less than 1 Gyr; a larger sample in time (or space) may find a wider spread in abundances.

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Hypervelocity binary stars: smoking gun of massive binary black holes

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The hypervelocity stars recently found in the Galactic halo are expelled from the Galactic center through interactions between binary stars and the central massive black hole or between single stars and a hypothetical massive binary black hole. In this paper, we demonstrate that binary stars can be ejected out of the Galactic center with velocities up to 10^3km s^{-1}, while preserving their integrity, through interactions with a massive binary black hole. Binary stars are unlikely to attain such high velocities via scattering by a single massive black hole or through any other mechanisms. Based on the above theoretical prediction, we propose a search for binary systems among the hypervelocity stars. Discovery of hypervelocity binary stars, even one, is a definitive evidence of the existence of a massive binary black hole in the Galactic center.

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Evidence for a Long-Standing Top-Heavy IMF in the Central Parsec of the Galaxy

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We classify 329 late-type giants within 1 parsec of Sgr A*, using the adaptive optics integral field spectrometer SINFONI on the VLT. These observations represent the deepest spectroscopic data set so far obtained for the Galactic Center, reaching a 50% completeness threshold at the approximate magnitude of the helium-burning red clump ($K_S \sim 15.5$ mag.). Combining our spectroscopic results with NaCo H and K_S photometry, we construct an observed Hertzsprung-Russell diagram, which we quantitatively compare to theoretical distributions of various star formation histories of the inner Galaxy, using a χ^2 analysis. Our best-fit model corresponds to continuous star formation over the last 12 Gyr with a top-heavy initial mass function (IMF). The similarity of this IMF to the IMF observed for the most recent epoch of star formation is intriguing and perhaps suggests a connection between recent star formation and the stars formed throughout the history

of the Galactic Center.

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Measuring the kinetic power of AGN in the radio mode

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We have studied the relationship among nuclear radio and X-ray power, Bondi rate and the kinetic luminosity of sub-Eddington active galactic nuclear (AGN) jets, as estimated from the *pdV* work done to inflate the cavities and bubbles observed in the hot X-ray emitting atmospheres of their host galaxies and clusters. Besides the recently discovered correlation between jet kinetic and Bondi power, we show that a clear correlation exists also between Eddington-scaled kinetic power and bolometric luminosity, given by: $\log(L_{kin}/L_{Edd}) = (0.49 \pm 0.07)\log(L_{bol}/L_{Edd}) - (0.78 \pm 0.36)$. The measured slope suggests that these objects are in a radiatively inefficient accretion mode, and has been used to put stringent constraints on the properties of the accretion flow. Interestingly, we found no statistically significant correlations between Bondi power and bolometric AGN luminosity, apart from that induced by their common dependence on L_{kin}, thus confirming the idea that most of the accretion power emerges from these systems in kinetic form. We have then analyzed the relation between kinetic power and radio core luminosity. Combining the measures of jet power with estimators of the un-beamed radio flux of the jet cores as, for example, the so-called 'fundamental plane' of active black holes, we are able to determine, in a statistical sense, both the probability distribution of the mean jets Lorentz factor, that peaks at $\Gamma_m \sim 7$, and the *intrinsic* relationship between kinetic and radio core luminosity (and thus the jet radiative efficiency), that we estimate as: $\log L_{kin} = (0.81 \pm 0.11)\log L_R + 11.9^{+4.1}_{-4.4}$, in good agreement with theoretical predictions of synchrotron jet models. With the aid of these findings, quantitative assessments of kinetic feedback from supermassive black holes in the radio mode (i.e. at low dimensionless accretion rates) will be possible based on accurate determinations of the central engine properties alone, such as mass, radio core and/or X-ray luminosity. As an example, we suggest that Sgr A* may follow the same correlations of radio mode AGN, based on its observed radiative output as well as on estimates of the accretion rate both at the Bondi radius and in the inner flow. If this is the case, the supermassive black hole in the Galactic center is the source of $\sim 5 \times 10^{38}$ ergs s^{-1} of mechanical power, equivalent to about 1.5 supernovae every 10^5 years.

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Eprint: arXiv:0707.3356v1

Apoastron Shift Constraints on Dark Matter Distribution at the Galactic Center

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The existence of dark matter (DM) at scales of few pc down to $\simeq 10^{-5}$ pc around the centers of galaxies and in particular in the Galactic Center region has been considered in the literature. Under the assumption that such a DM clump, principally constituted by non-baryonic matter (like WIMPs) does exist at the center of our galaxy, the study of the γ-ray emission from the Galactic Center region allows us to constrain both the mass and the size of this DM sphere. Further constraints on the DM distribution parameters may be derived by observations of bright infrared stars around the Galactic Center. Hall and Gondolo used estimates of the enclosed mass obtained in various ways and tabulated by Ghez et al. Moreover, if a DM cusp does exist around the Galactic Center it could modify the trajectories of stars moving around it in a sensible way depending on the DM mass distribution. Here, we discuss the constraints that can be obtained with the orbit analysis of stars (as S2 and S16) moving inside the DM concentration with present and next generations of large telescopes. In particular, consideration of the S2 star apoastron shift may allow improving limits on the DM mass and size.

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A Study of Stellar Photometric Variability Within the Central 4 pc of the Galactic Center with Infrared Image Subtraction

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We present a catalog of 110 variable stars within 1' of Sgr A* based on image subtraction of near-infrared (H and K) photometry. Our images were obtained over 133 nights from 2000–2002 in H-band and over 134 nights from 2001–2002 in K-band; the typical FWHM is 1.4". We match the catalog to other near-infrared, X-ray, and radio (i.e., maser) data, and we discuss some of the more interesting objects. The catalog includes 14 periodic sources, several known long-period variables and three new LPV candidates. We associate IRS 10* with OH, SiO, and H2O masers and a bright X-ray point source; this analysis suggests IRS 10* is an AGB star with an accreting companion. Among the approximately 90 newly discovered sources are a probable cataclysmic variable, a potential edge-on contact 84 day period eclipsing binary, and a possible 41 day period pulsating variable.

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Eprint: astro-ph/0703769

Stellar Relaxation Processes Near the Galactic Massive Black Hole

Tal Alexander

The massive black hole (MBH) in the Galactic Center and the stars around it form a unique stellar dynamics laboratory for studying how relaxation processes affect the distribution of stars and compact remnants and lead to close interactions between them and the MBH. Recent theoretical studies suggest that processes beyond "minimal" two-body relaxation may operate and even dominate relaxation and its consequences in the Galactic Center. I describe loss-cone refilling by massive perturbers, strong mass segregation and resonant relaxation; review observational evidence that these processes play a role in the Galactic Center and discuss some cosmic implications for the rates of gravitational wave emission events from compact remnants inspiraling into MBHs, and the coalescence timescales of binary MBHs.

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Spitzer IRS Observations of the Galactic Center: Shocked Gas in the Radio Arc Bubble

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We present *Spitzer* IRS spectra (R $\sim$ 600, 10 $-$ 38 μm) of 38 positions in the Galactic Center (GC), all at the same Galactic longitude and spanning $\pm 0.3^\circ$ in latitude. Our positions include the Arches Cluster, the Arched Filaments, regions near the Quintuplet Cluster, the "Bubble" lying along the same line-of-sight as the molecular cloud G0.11$-$0.11, and the diffuse interstellar gas along the line-of-sight at higher Galactic latitudes. From measurements of the [O IV], [Ne II], [Ne III], [Si II], [S III], [S IV], [Fe II], [Fe III], and H_2 S(0), S(1), and S(2) lines we determine the gas excitation and ionic abundance ratios. The Ne/H and S/H abundance ratios are ~ 1.6 times that of the Orion Nebula. The main source of excitation is photoionization, with the Arches Cluster ionizing the Arched Filaments and the Quintuplet Cluster ionizing the gas nearby and at lower Galactic latitudes including the far side of the Bubble. In addition, strong shocks ionize gas to O^{+3} and destroy dust grains, releasing iron into the gas phase (Fe/H$\sim 1.3 \times 10^{-6}$ in the Arched Filaments and Fe/H$\sim 8.8 \times 10^{-6}$ in the Bubble). The shock effects are particularly noticeable in the center of the Bubble, but O^{+3} is present in all positions. We suggest that the shocks are due to the winds from the Quintuplet Cluster Wolf-Rayet stars. On the other hand, the H_2 line ratios can be explained with multi-component models of warm molecular gas in photodissociation regions without the need for H_2 production in shocks.

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GRO J1744-28, search for the counterpart: infrared photometry and spectroscopy

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Using VLT/ISAAC, we have detected 2 candidate counterparts to the bursting pulsar GRO J1744, one bright and one faint, both within the X-ray error circles found using *XMM-Newton* and *Chandra*. In determining the spectral types of the counterparts we applied 3 different extinction corrections; one for an all-sky value, one for a Galactic Bulge value and one for a local value. We find that the local value, with an extinction law of $\alpha = 3.23 \pm 0.01$ is the only correction that results in colours and magnitudes for both the bright and faint counterparts that are consistent with a small range of spectral types, and in the case of the bright counterpart are also consistent with the spectroscopic identification. Photometry of the fainter candidate then indicates it is a K7/M0 V star at a distance of $3.75 \pm 1\, kpc$. Such a star would require a very low inclination angle ($i < 9°$) to satisfy the mass-function constraints; however this source cannot be excluded as the counterpart without follow-up spectroscopy to detect emission signatures of accretion. Photometry and spectroscopy of the bright candidate indicate that it is most likely a G/K III star. The spectrum does not show emission, a known indicator of accretion. The bright star's magnitudes are in agreement with the constraints placed on the probable counterpart for an evolved star that has had its envelope stripped. The mass-function indicates the most likely counterpart has $M < 0.3$ for an inclination of $i \geq 15°$; a stripped giant, or a main sequence M3+ V star would be consistent with this mass-function constraint. In both cases mass-transfer, if present, will be by wind-accretion as the counterpart will not fill its Roche lobe given the observed orbital period. In this case, the derived magnetic field strength of 2.4×10^{11} G is sufficient to inhibit accretion of captured material by the propeller effect, hence the quiescent state of the system.

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Email: ajgosling@gmail.com
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Do flares in Sagittarius A* reflect the last stage of tidal capture?

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In recent years the case for the presence of $3 - 4 \times 10^6 M_\odot$ black hole in our Galactic Centre has gained strength from results of stellar dynamics observations and from the detection of several rapid X-ray and IR flares observed in the Sagittarius A* from 2000 to 2004. Here we explore the idea that such flares are produced when the central black hole tidaly captures and disrupts a small body - e.g. a comet or an asteroid.

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On the orientation of the Sagittarius A* system

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The near-infrared emission from the black hole at the Galactic center (Sgr A*) has unique properties. The most striking feature is a suggestive periodic sub-structure that has been observed in a couple of flares so far. Using near-infrared polarimetric observations and modelling the quasi-periodicity in terms of an orbiting blob, we try to constrain the three dimensional orientation of the Sgr A* system. We report on so far unpublished polarimetric data from 2003. They support the observations of a roughly constant mean polarization angle of $\sim 60° \pm 20°$ from 2004 – 2006. Prior investigations of the 2006 data are deepened. In particular, the blob model fits are evaluated such that constraints on the position angle of Sgr A* can be derived. Confidence contours in the position – inclination angle plane are derived.

On a 3σ level the position angle of the equatorial plane normal is in the range $\sim 60^\circ - 108^\circ$ (east of north) in combination with a large inclination angle. This agrees well with recent independent work in which radio spectral/morphological properties of Sgr A* and X-ray observations, respectively, have been used. However, the quality of the presently available data and the uncertainties in our model bring some ambiguity to our conclusions.

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The Variability of Polarized Radiation from Sgr A*

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Sgr A* is variable at radio and submillimeter wavelengths on hourly time scales showing time delays between the peaks of flare emission as well as linearly polarized emission at millimeter and sub-mm wavelengths. To determine the polarization characteristics of this variable source at radio frequencies, we present VLA observations of Sgr A* and report the detection of polarized emission at a level of 0.77±0.01% and 0.2±0.01% at 43 and 22 GHz, respectively. The change in the time averaged polarization angle between 22 and 43 GHz corresponds to a RM of $-2.5\pm0.6 \times 10^3$ rad m^{-2} with no phase wrapping (or $\sim 5 \times 10^4$ rad m^2 with 2π phase wrap). We also note a rise and fall time scale of $1.5 - 2$ hours in the total polarized intensity. The light curves of the degree of linearly polarized emission suggests a a correlation with the variability of the total intensity at 43 GHz. The available polarization data at radio and sub-mm wavelengths suggest that the rotation measure decreases with decreasing frequency. This frequency dependence, and observed changes in polarization angle during flare events, may be caused by the reduction in rotation measure associated with the expansion of synchrotron-emitting blobs.

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http://arxiv.org/abs/0708.3492

Hypervelocity Stars III. The Space Density and Ejection History of Main Sequence Stars from the Galactic Center

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We report the discovery of 3 new unbound hypervelocity stars (HVSs), stars traveling with such extreme velocities that dynamical ejection from a massive black hole (MBH) is their only suggested origin. We also detect a population of possibly bound HVSs. The significant asymmetry we observe in the velocity distribution – we find 26 stars with $v_{rf} > 275$ km s^{-1} and 1 star with $v_{rf} < -275$ km s^{-1} – shows that the HVSs must be short-lived, probably 3 - 4 M$_\odot$ main sequence stars. Any population of hypervelocity post-main sequence stars should contain stars falling back onto the Galaxy, contrary to the observations. The spatial distribution of HVSs also supports the main sequence interpretation: longer-lived 3 M$_\odot$ HVSs fill our survey volume; shorter-lived 4 M$_\odot$ HVSs are missing at faint magnitudes. We infer that there are 96 ± 10 HVSs of mass 3 - 4 M$_\odot$ within $R < 100$ kpc, possibly enough HVSs to constrain ejection mechanisms and potential models. Depending on the mass function of HVSs, we predict that SEGUE may find up to 5 - 15 new HVSs. The travel times of our HVSs favor a continuous ejection process, although a ~120 Myr-old burst of HVSs is also allowed.

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Suzaku Detection of Extended/Diffuse Hard X-Ray Emission from the Galactic Center

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Five on-plane regions within ±0∘.8 of the Galactic center were observed with the Hard X-ray Detector (HXD) and the X-ray Imaging Spectrometer (XIS) onboard Suzaku. From all regions, significant hard X-ray emission was detected with HXD-PIN up to 40 keV, in addition to the extended plasma emission which is dominant in the XIS band. The hard X-ray signals are inferred to come primarily from a spatially extended source, rather than from a small number of bright discrete objects. Contributions to the HXD data from catalogued X-ray sources, typically brighter than 1 mCrab, were estimated and removed using information from Suzaku and other satellites. Even after this removal, the hard X-ray signals remained significant, exhibiting a typical 12–40 keV surface brightness of 4×10^{-10} $ergcm^{-2}$ s^{-1} deg^{-2} and power-law-like spectra with a photon index of 1.8. Combined fittings to the XIS and HXD-PIN spectra confirm that a separate hard tail component is superposed onto the hot thermal emission, confirming a previous report based on the XIS data. Over the 5–40 keV band, the hard tail is spectrally approximated by a power law of photon index ~ 2, but better by those with somewhat convex shapes. Possible origins of the extended hard X-ray emission are discussed.

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Email: yuasa@amalthea.phys.s.u-tokyo.ac.jp
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Implementing Few-Body Algorithmic Regularization with Post-Newtonian Terms

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We discuss the implementation of a new regular algorithm for simulation of the gravitational few-body problem. The algorithm uses components from earlier methods, including the chain structure, the logarithmic Hamiltonian, and the time-transformed leapfrog. The code can be used for the normal N-body problem, as well as for problems with softened potentials and/or with velocity-dependent external perturbations, including post-Newtonian terms, which we include up to order PN2.5. Arbitarily extreme mass ratios are allowed. Coordinate transformations are not used and thus the algorithm is somewhat simpler than many earlier regularized schemes. We present the results of performance tests, then use our algorithm to integrate the orbits of the S stars around the Milky Way supermassive black hole for one million years, including PN2.5 terms and an intermediate-mass black hole. The three S stars with shortest periods are observed to escape from the system after a few hundred thousand years.

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The Galactic center, the largest oxygen bearing organic molecule repository

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We present the first detection of complex aldehydes and isomers in three typical molecular clouds located within 200 pc of the center of our Galaxy. We find very large abundances of these complex organic molecules (COMs) in the central molecular zone (CMZ), which we attribute to the ejection of COMs from grain mantles by shocks. The relative abundances of the different COMs with respect to that of CH_3OH are strikingly similar for the three sources, located in very different environments in the CMZ. The similar relative abundances point toward a unique grain mantle composition in the CMZ. Studying the Galactic center clouds and objects in the Galactic disk having large abundances of COMs, we find that more saturated molecules are more abundant than the non-saturated ones. We also find differences between the relative abundance between COMs in the CMZ and the Galactic disk, suggesting different chemical histories of the grain mantles between the two regions in the Galaxy for the complex aldehydes. Different possibilities for the grain chemistry on the icy mantles in the GC clouds

are briefly discussed. Cosmic rays can play an important role in the grain chemistry. With these new detections, the molecular clouds in the Galactic center appear to be one of the best laboratories for studying the formation of COMs in the Galaxy.

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Point Sources from a *Spitzer* IRAC Survey of the Galactic Center

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We have obtained *Spitzer*/IRAC observations of the central $2.0^\circ \times 1.4^\circ (\sim 280 \times 200$ pc) of the Galaxy at 3.6μm–8.0μm. A point source catalog of 1,065,565 objects is presented. The catalog includes magnitudes for the point sources at 3.6, 4.5, 5.8, and 8.0μm, as well as JHK_s photometry from 2MASS. The point source catalog is confusion limited with average limits of 12.4, 12.1, 11.7, and 11.2 magnitudes for [3.6], [4.5], [5.8], and [8.0], respectively. We find that the confusion limits are spatially variable because of stellar surface density, background surface brightness level, and extinction variations across the survey region. The overall distribution of point source density with Galactic latitude and longitude is essentially constant, but structure does appear when sources of different magnitude ranges are selected. Bright stars show a steep decreasing gradient with Galactic latitude, and a slow decreasing gradient with Galactic longitude, with a peak at the position of the Galactic center. From IRAC color-magnitude and color-color diagrams, we conclude that most of the point sources in our catalog have IRAC magnitudes and colors characteristic of red giant and AGB stars.

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Star formation in accretion discs : from the Galactic Center to Active Galactic Nuclei

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Keplerian accretion discs around massive black holes (MBHs) are gravitationally unstable beyond a few hundredths of parsec and should collapse to form stars. It was indeed shown recently that an accretion/star formation episode took place a few millions years ago in the Galactic Center (GC). This raises the question of how the disc can survive in AGN and quasars and continue to transport matter towards the black hole.We study the accretion/star formation process in quasars and AGN, with one aim in mind, to show that a spectrum similar to the observed one can be produced by the disc. We compute models of stationary accretion discs, both continuous and clumpy. Continuous discs must be maintained in a state of marginal stability so that the rate of star formation remains modest and the disc is not immediately destroyed. The disc then requires an additional heating and an additional transport of angular momentum. In clumpy discs the momentum transport is provided by cloud interactions.Non-viscous heating can be provided by stellar illumination, but in the case of continuous discs, even momentum transport by supernovae is insufficient to sustain a marginal state, except at the very periphery of the disc. In clumpy discs it is possible to account for the required accretion rate through interactions between clouds, but this model is unsatisfactory as its parameters are tightly constrained without any physical justification. So finally one must appeal to non-stationary discs with intermittent accretion episodes like those that occurred in the GC, but such a model is probably not applicable to luminous high redshift quasars neither to radio-loud quasars.

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Flares from spiral waves by lensing and time-delay amplification?

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Episodically accreting black holes are thought to produce flares when a chunk of particles is accelerated to high velocity near the black hole horizon.

This also seems to be the case of Sagittarius A* in the Galactic Center, where the broad-band radiation is produced, likely via the synchrotron self-Compton mechanism. It has been proposed that strong-field gravitational lensing magnifies the flares. The effect of lensing is generally weak and requires a fine-tuned geometrical arrangement, which occurs with only a low probability. However, there are several aspects that make Sagittarius A* a promising target to reveal strong gravity effects. Unlike type II (obscured) active galaxies, chances are that a flare is detected at high inclination, which would be favourable for lensing. Time delays can then significantly influence the observed flare duration and the form of light-curve profiles. Here we discuss an idea that the impact of lensing amplification should be considerably enhanced when the shape of the flaring clump is appropriately elongated in the form of a spiral wave or a narrow filament, rather than a simple (circular) spot which we employed previously within the phenomenological 'orbiting spot model'. By parameterizing the emission region in terms of the spiral shape and contrast, we are able to extend the spot model to more complicated sources. In the case of spirals, we notice a possibility that more photons reach a distant observer at the same moment because of interplay between lensing and light-travel time. The effect is not symmetrical with respect to leading versus trailing spirals, so in principle the source geometry can be constrained. In spite of this, the spot model seems to provide entirely adequate framework to study the currently available data.

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Getting a kick out of the stellar disk(s) in the galactic center

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Recent observations of the Galactic center revealed a nuclear disk of young OB stars, 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). Binaries in such nuclear disks, if they exist in non-negligible fractions, could have a major role in the evolution of the disks through binary heating of this stellar system. We suggest that interactions with/in binaries may explain some (or all) of the observed outlying young stars in the Galactic center. Such stars could have been formed in a disk, and later on kicked out from it through binary related interactions, similar to ejection of high velocity runaway OB stars in young clusters throughout the galaxy.

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Three-Dimensional Observations of H_2 Emission around Sgr A East - I. Structure in the Central 10 Parsecs of Our Galaxy

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We have obtained velocity-resolved spectra of the $H_2 1-0S(1)(\lambda = 2.1218\mu$m) emission line at $2''$ angular resolution (or ~ 0.08 pc spatial resolution) in four regions within the central 10 pc of the Galaxy where the supernova-like remnant Sgr A East is colliding with molecular clouds. To investigate the kinematic, physical, and positional relationships between the important gaseous components in the center, we compared the H_2 data cube with previously published NH_3 data. The projected interaction-boundary of Sgr A East is determined to be an ellipse with its center offset ~ 1.5 pc from Sgr A* and dimensions of 10.8 pc $\times$ 7.6 pc. This H_2 boundary is larger than the synchrotron emission shell but consistent with the dust ring which is believed to trace the shock front of Sgr A East. Since Sgr A East is driving shocks into its nearby molecular clouds, we can determine their positional relationships using the shock directions as indicators. As a result, we suggest a revised model for the three-dimensional structure of the central 10 pc. The actual contact between Sgr A East and all of the surrounding molecular material, including the circum-nuclear disk and the southern streamer, makes the hypothesis of infall into the nucleus and feeding of Sgr A* very likely.

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Email: soojongpak@gmail.com
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Simultaneous H.E.S.S. and Chandra observations of Sgr A* during an X-ray flare

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The rapidly varying non-thermal X-ray emission observed from Sgr A* points to particle acceleration taking place close to the supermassive black hole. The TeV γ-ray source HESS J1745−290 is coincident with Sgr A* and may be closely related to the X-ray emission. Simultaneous X-ray and TeV observations are required to elucidate the relationship between these two objects. Here we report on joint H.E.S.S./Chandra observations in July 2005, during which an X-ray flare was detected. Despite a factor > 10 increase in the X-ray flux of Sgr A*, no evidence is found for an increase in the TeV γ-ray flux. We find that an increase of the γ-ray flux of a factor 2 or greater can be excluded at a confidence level of 99%. This finding disfavours scenarios in which the bulk of the γ-ray emission observed is produced close to Sgr A*.

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Email: j.a.hinton@leeds.ac.uk

Low angular momentum accretion flow model of Sgr A* activity

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Sgr A* is a source of strongly variable emission in several energy bands. It is generally agreed that this emission comes from the material surrounding the black hole which is either falling in or flowing out. The activity must be driven by accretion but the character of accretion flow in this object is an open question. We suggest that the inflow is dominated by the relatively low angular momentum material originating in one of the nearby group of stars. Such material flows in directly towards the black hole up to the distance of order of ten Schwarzschild radii or less, where it hits the angular momentum barrier which leads naturally to a flow variability. We study both the analytical and the numerical solutions for the flow dynamics, and we analyze the radiation spectra in both cases using the Monte Carlo code to simulate the synchrotron, bremsstrahlung and the Compton scattering. Our model roughly reproduces the broad band spectrum of Sgr A* and its variability if we allow for a small fraction of energy to be converted to non-thermal population of electrons. It is also consistent (for a range of viewing angles) with the strong constraints on the amount of circumnuclear material imposed by the measurements of the Faraday rotation.

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Self-gravitating fragmentation of eccentric accretion disks

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We consider the effects of eccentricity on the fragmentation of gravitationally unstable accretion disks, using numerical hydrodynamics. We find that eccentricity does not affect the overall stability of the disk against fragmentation, but significantly alters the manner in which such fragments accrete gas. Variable tidal forces around an eccentric orbit slow the accretion process, and suppress the formation of weakly-bound clumps. The "stellar" mass function resulting from the fragmentation of an eccentric disk is found to have a significantly higher characteristic mass than that from a corresponding circular disk. We discuss our results in terms of the disk(s) of massive stars at $\simeq 0.1$pc from the Galactic Center, and find that the fragmentation of an eccentric accretion disk, due to gravitational instability, is a viable mechanism for the formation of these systems.

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On the nature of the fast moving star S2 in the Galactic Center

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We analyze the properties of the star S2 orbiting the supermassive black hole at the center of the Galaxy. A high quality SINFONI H and K band spectrum obtained from coadding 23.5 hours of observation between 2004 and 2007 reveals that S2 is an early B dwarf (B0–2.5V). Using model atmospheres, we constrain its stellar and wind properties. We show that S2 is a genuine massive star, and not the core of a stripped giant star as sometimes speculated to resolve the problem of star formation so close to the supermassive black hole. We give an upper limit on its mass loss rate, and show that it is He enriched, possibly because of the presence of a magnetic field.

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The most massive stars in the Arches cluster

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We study a sample composed of 28 of the brightest stars in the Arches cluster. Our aim is to constrain their stellar and wind properties and to establish their nature and evolutionary status. We analyze K-band spectra obtained with the integral field spectrograph SINFONI on the VLT. Atmosphere models computed with the code CMFGEN are used to deri ve the effective temperatures, luminosities, stellar abundances, mass loss rates and wind terminal velocities. We find that the stars in our sample are either H-rich WN7–9 stars (WN7–9h) or supergiants, where two are classified as OIf^+. All stars are 2–4 Myr old. There is marginal evidence for a younger age among the most massive stars. The WN7–9h stars reach luminosities as high as $2 \times 10^6 L_\odot$, con sistent with initial masses of $\sim$ 120 Msun. They are still quite H-rich, but show both N enhancement and C depletion. They are thus identified as core H-burning objects showing products of the CNO equilibrium on their surface. Their progenitors are most likely supergiants of spectral types earlier than O4–6 and initial masses > 60 Msun. Their winds follow a well-defined modified wind momentum – luminosity relation (WLR): this is a strong indication that they are radiatively driven. Stellar abundances tend to favor a slightly super-solar metallicity, at least for the lightest metals. We note, however, that the evolutionary models seem to under-predict the degree of N enrichment.

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The enigma of GCIRS 3

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GCIRS 3 is the most prominent MIR-source in the central parsec of the Galaxy. NIR spectroscopy failed to solve the enigma of its nature. The properties and peculiarities of extreme individual objects of the central stellar cluster contribute to our knowledge of star and dust formation close to a supermassive black hole. We initiated an unprecedented interferometric experiment to understand the nature of GCIRS 3 and investigate its properties as spectroscopic and interferometric reference star at 10 μm. VLT/VISIR imaging separates a compact source from diffuse, surrounding emission. The VLTI/MIDI instrument was used to measure spectroscopically resolved visibility moduli at an angular resolution of $\sim$ 10 mas of that compact 10 μm source, still unresolved by a single VLT. Recent NIR/MIR photometry data were added to enable simple SED- and full radiative transfer-modeling of the data. The luminosity and size estimates show that IRS 3 is probably a cool carbon star enshrouded by a complex dust

distribution. Blackbody temperatures were derived. The coinciding interpretation of single telescope and interferometric data confirm dust emission from several different spatial scales. The interferometric data resolve the inner rim of dust formation. Despite observed deep silicate absorption towards GCIRS 3 we favor a carbon rich circumstellar dust shell. The silicate absorption most probably takes place in the outer diffuse dust, which is mostly ignored by MIDI measurements, but well observable in complementary VLT/VISIR data. This indicates physically and chemically distinct conditions of the local dust, changing with the distance to GCIRS 3. We have demonstrated that optical long baseline interferometry at infrared wavelengths is an indispensable tool to investigate sources at the Galactic Center. Our findings suggest further studies of the composition of interstellar dust and the shape of the 10 μm silicate feature at this outstanding region.

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The proper motion of the Arches cluster with Keck Laser-Guide Star Adaptive Optics

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We present the first measurement of the proper motion of the young, compact Arches cluster near the Galactic center from near-infrared adaptive optics (AO) data taken with the recently commissioned laser-guide star (LGS) at the Keck 10-m telescope. The excellent astrometric accuracy achieved with LGS-AO provides the basis for a detailed comparison with VLT/NAOS-CONICA data taken 4.3 years earlier. Over the 4.3 year baseline, a spatial displacement of the Arches cluster with respect to the field population is measured to be 24.0 ± 2.2 mas, corresponding to a proper motion of 5.6 ± 0.5 mas/yr or 212 ± 29 km/s at a distance of 8 kpc. In combination with the known line-of-sight velocity of the cluster, we derive a 3D space motion of 232 ± 30 km/s of the Arches relative to the field. The large proper motion of the Arches cannot be explained with any of the closed orbital families observed in gas clouds in the bar potential of the inner Galaxy, but would be consistent with the Arches being on a transitional trajectory between x1 and x2 orbits. We investigate a cloud-cloud collision as the possible origin for the Arches cluster. The integration of the cluster orbit in the potential of the inner Galaxy suggests that the cluster passes within 10 pc of the supermassive black hole only if its true GC distance is very close to its projected distance. A contribution of young stars from the Arches cluster to the young stellar population in the inner few parsecs of the GC thus appears increasingly unlikely. The measurement of the 3D velocity and orbital analysis provides the first observational evidence that Arches-like clusters do not spiral into the GC. This confirms that no progenitor clusters to the nuclear cluster are observed at the present epoch.

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A Time-Variable X-Ray Echo: Indications of a Past Flare of the Galactic-Center Black Hole

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A time-variability study of the neutral iron line flux at 6.40 keV in the Sgr B2 region from data of Suzaku and Chandra is presented. The highly ionized iron line at 6.68 keV is due to Galactic Center Diffuse X-rays (GCDX), and is thus time invariable. By comparing the 6.68 keV and 6.40 keV line fluxes, we found that the 6.40 keV flux from the Sgr B2 complex region is time variable; particularly the giant molecular cloud M 0.66−0.02, known as "Sgr B2 cloud" is highly variable. The variability of the 6.40 keV line in intensity and spatial distribution strongly supports the scenario that the molecular clouds in the Sgr B2 region are X-ray Reflection Nebulae irradiated by the Galactic Center (GC) black hole Sgr A*.

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X-Ray Observations of the Galactic Center with Suzaku

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We report on the diffuse X-ray emissions from the Galactic center (GCDX) observed with the X-ray Imaging Spectrometer (XIS) on board the Suzaku satellite. The highly accurate energy calibrations and extremely low background of the XIS provide many new facts on the GCDX. These are (1) the origin of the 6.7/7.0 keV lines is collisional excitation in hot plasma, (2) new SNR and super-bubble candidates are found, (3) most of the 6.4 keV line is fluorescence by X-rays, and (4) time variability of the 6.4 keV line is found from the Sgr B2 complex.

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Constraints on jet-driven disk accretion in Sagittarius A*

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We revisit theoretical and observational constraints on geometrically-thin disk accretion in Sagittarius A* (Sgr A*). We show that the combined effects of mass outflows and electron energization in the hot part of the accretion flow can deflate the inflowing gas from a geometrically-thick structure. This allows the gas to cool and even thermalize on an inflow timescale. As a result, a compact, relatively cool disk may form at small radii. We show that magnetic coupling between the relativistic disk and a steady-state jet results in a disk that is less luminous than a standard relativistic disk accreting at the same rate. This relaxes the observational constraints on thin-disk accretion in Sgr A* (and by implication, other Low-Luminosity Active Galactic Nulcei, LLAGN). We find typical cold gas accretion rates of a few $\times\, 10^{-9} M_{\odot}\, yr^{-1}$. We also find that the predicted modified disk emission is compatible with existing near-infrared (NIR) observations of Sgr A* in its quiescent state provided that the disk inclination angle is 87° and that the jet extracts more than 75% of the accretion power.

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Suzaku X-Ray Spectroscopy of a Peculiar Hot Star in the Galactic Center Region

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We present the results of a Suzaku study of a bright point-like source in the 6.7 keV intensity map of the Galactic center region. We detected an intense Fe XXV 6.7 keV line with an equivalent width of ~ 1 keV as well as emission lines of highly ionized Ar and Ca from a spectrum obtained by the X-ray Imaging Spectrometer. The overall spectrum is described very well by a heavily absorbed ($\sim 2{\times}10^{23}$ cm^{-2}) thin thermal plasma model with a temperature of 3.8 ± 0.6 keV and a luminosity of $\sim 3{\times}10^{34}$ erg s^{-1} (2.0–8.0 keV) at 8 kpc. The absorption, temperature, luminosity, and the 6.7 keV line intensity were confirmed with the archived XMM-Newton data. The source has a very red ($J - K_s = 8.2$ mag) infrared spectral energy distribution (SED), which was fitted by a blackbody emission of ~ 1000 K attenuated by a visual extinction of ~ 31 mag. The high plasma temperature and the large X-ray luminosity are consistent with a wind-wind colliding Wolf-Rayet binary. The similarity of the SED to those of the eponymous Quintuplet cluster members suggests that the source is a WC-type source.

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Dynamical and evolutionary constraints on the nature and origin of hypervelocity stars

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In recent years several hypervelocity stars (HVSs) have been observed in the halo of our Galaxy. Such stars are thought to be ejected through dynamical interactions near the massive black hole (MBH) in the Galactic center. Three scenarios have been suggested for their ejection; binary disruption by a MBH, scattering by inspiraling IMBH and scattering by stellar BHs close to MBH. These scenarios involve different stellar populations in the Galactic center. Here we use observations of the Galactic center stellar population, dynamical and evolutionary arguments to constrain the nature and origin of HVSs. We show that the IMBH inspiral scenario requires too many (10^3) main sequence B stars to exist close to the MBH ($<$ 0.01 pc) at the time of inspiral, where current observations show (10) such stars. Scattering by SBHs is also not likely to be consistent with the observed population of B stars in the Galactic center, although this scenario can still be compatible with observations under extreme conditions. The binary disruption scenario is still consistent with current observations. In addition we show that due to the conditions close to the MBH most binary star systems are not expected to survive for long in this region. Consequently, unique stellar populations that require long evolution in binaries are not expected to be ejected as HVSs in the BHs scattering mechanisms (this may also be related to to the recently observed asymmetry in the velocity distribution of HVSs). Furthermore, it is shown that recently suggested signatures for HVSs origin such as hypervelocity binaries and slow rotating HVSs may be much weaker than suggested and require large statistics.

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Massive Star Formation Near Sgr A* and Bimodal Star Formation in the Nuclear Disk

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The history of star formation in the strong gravitational potential of the Galactic center has been of much interest, recently. We propose that the sub-parsec-scale disk of massive stars orbiting the massive black hole at the Galactic center can be interpreted in terms of partial accretion of extended Galactic center clouds, such as the 50 km/s molecular cloud, as these clouds envelop Sgr A* on their passage through the inner Galactic center. The loss of angular momentum of the captured cloud material by self-interaction subsequent to gravitationally focusing by Sgr A* naturally creates a compact gaseous disk of material close to Sgr A* in which star formation takes place. On a larger scale the formation of massive clusters such as the Arches and Quintuplet clusters or on-going massive star formation such as Sgr B2 could also be triggered by cloud-cloud collisions due to gravitational focusing in the deep potential of the central bulge. Unlike the violent and high-pressure environment of clustered star formation triggered by cloud-cloud collision, there are also isolated pockets of star formation and quiescent dense clouds. These sites suggest an inefficient, slow mode of star formation. We propose enhanced cosmic rays in the nuclear disk may be responsible for inhibiting the process of star formation in this region. In particular, we argue that the enhanced ionization rate due to the impact of cosmic-ray particles is responsible for lowering the efficiency of on-going star formation in the nuclear disk of our Galaxy. The higher ionization fraction and higher thermal energy due to the impact of these electrons may also reduce MHD wave damping which contributes to the persistence of the high velocity dispersion of the molecular gas in the nuclear disk.

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Simultaneous Chandra, CSO and VLA Observations of Sgr A*: The Nature of Flaring Activity

Yusef-Zadeh, F., Wardle, M.; Heinke, C.; Dowell, C. D.; Roberts, D., Baganoff, F. K. and Bower, G. C.

Sgr A*, the massive black hole at the center of the Galaxy, varies in radio through X-ray emission on hourly time scales. The flare activity is thought to arise from the innermost region of an accretion flow onto Sgr A*. We present simultaneous light curves of Sgr A* in radio, sub-mm and X-rays that show a possible time delay of 110±17 minutes between X-ray and 850 μm suggesting that the sub-mm flare emission is optically thick. At radio wavelengths, we detect time lags of of $20.4 \pm 6.8, 30 \pm 12$ and 20±6 minutes between the flare peaks observed at 13 and 7 mm in three different epochs using the VLA. Linear polarization of 1±0.2% and 0.7±0.1% is detected at 7 and 13 mm, respectively, when averaged over the entire observation on 2006 July 17. A simple picture of an expanding bubble of synchrotron emitting hot plasma can explain the time delay between various wavelengths, the asymmetric shape of the light curves, and the observed polarization of the flare emission at 43 and 22 GHz. The derived physical quantities that characterize the flare emission give the blob expansion speed of $\mathrm{v}_{exp} \sim 0.003 - 0.1$c, magnetic field of B∼10-70 Gauss and particle spectral index p∼1-2. These parameters suggest that the expanding gas can not escape from Sgr A* unless it has a large bulk motion.

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An X-ray, IR, and Submillimeter Flare of Sagittarius A*

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Energetic flares are observed in the Galactic supermassive black hole Sagittarius A* from radio to X-ray wavelengths. On a few occasions, simultaneous flares have been detected in IR and X-ray observations, but clear counterparts at longer wavelengths have not been seen. We present a flare observed over several hours on July 17, 2006 with the Chandra X-ray Observatory, the Keck II telescope, the Caltech Submillimeter Observatory, and the Submillimeter Array. All telescopes observed strong flare events, but the submillimeter peak is found to occur nearly 100 minutes after the X-ray peak. Submillimeter polarization data show a polarization signature in the excess flare emission, increasing from 9% to 17% fractional polarization as the flare passes through its peak, consistent with a transition from optically thick to thin synchrotron emission. The temporal and spectral behavior of the flare requires that the energetic electrons responsible for the emission cool faster than expected from their radiative output. This is consistent with adiabatic cooling in an expanding emission region, with X-rays produced through self-Compton scattering. We also present the submillimeter detection of an IR flare on July 31, 2005, which showed a larger peak IR flux and similar submillimeter flux but did not have measurable X-ray emission. This flare also shows a delay between the IR peak and submillimeter peak, although it is significantly shorter. The submillimeter lag and the variable ratio of IR and X-ray luminosities are related through a synchrotron and self-Compton model.

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Infall and Outflow of Molecular Gas in Sgr B2

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Observations of two H_2CO ($3_{03} - 2_{02}$ and $3_{21} - 2_{20}$) lines and continuum emission at 1.3 mm towards Sgr B2(N) and Sgr B2(M) have been carried out with the SMA. The mosaic maps of Sgr B2(N) and Sgr B2(M) in both continuum and lines show a complex distribution of dust and molecular gas in both clumps and filaments surrounding the compact star formation cores. We have observed a decelerating outflow originated from the Sgr B2(M) core, showing that both the red-shifted and blue-shifted outflow components have a common terminal velocity. This terminal velocity is 58 ± 2 km s^{-1}. It provides an excellent method in determination of the systematic velocity of the molecular cloud. The SMA observations have also shown that a large fraction of absorption against the two continuum cores is red-shifted with respect to the systematic velocities of Sgr B2(N) and Sgr B2(M), respectively, suggesting that the majority of the dense molecular gas is flowing into the two major cores where massive stars have been formed. We have solved the radiative transfer in a multi-level system with LVG approximation. The observed H_2CO line intensities and their ratios can be adequately fitted with this model for the most of the gas components. However, the line intensities between the higher energy level transition H_2CO ($3_{21} - 2_{20}$) and the lower energy level transition H_2CO ($3_{03} - 2_{02}$) is reversed in the red-shifted outflow region of Sgr B2(M), suggesting the presence of inversion in population between the ground levels in the two K ladders (K_{-1}= 0 and 2). The possibility of weak maser processes for the H_2CO emission in Sgr B2(M) is discussed.

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