GCNEWS

The Newsletter of Galactic Center Research

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2006: The Year of the GC Meetings

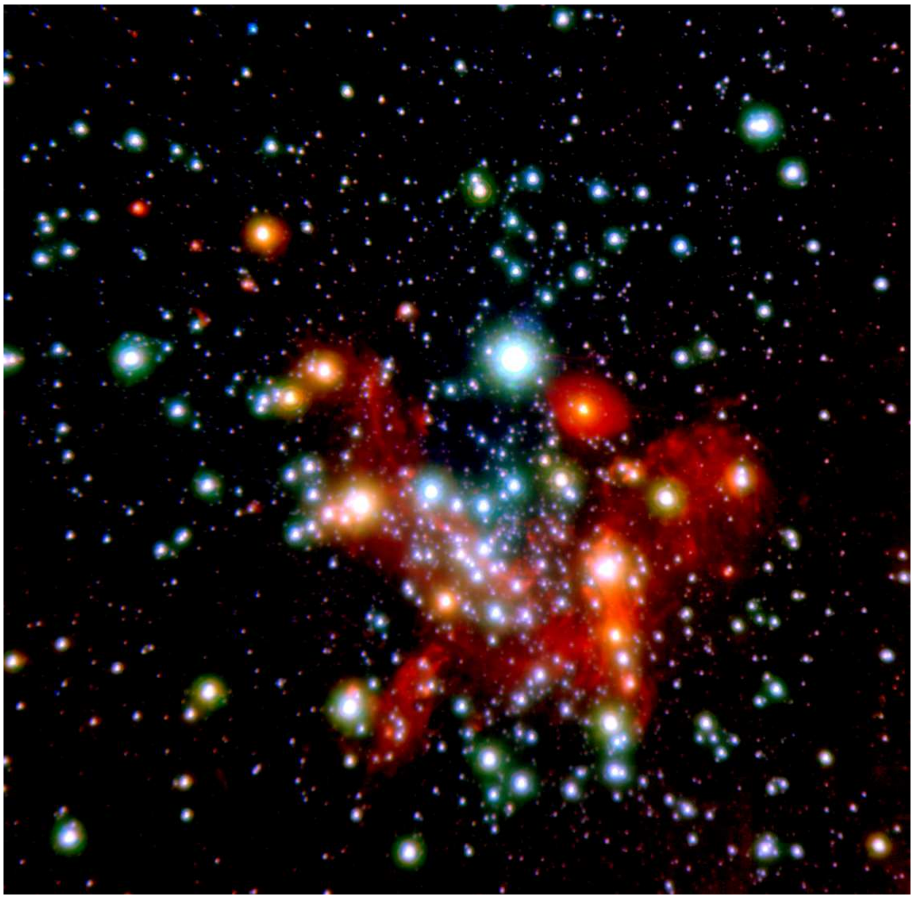

Figure 1 NIR View of the GC with NAOS/CONICA at the ESO VLT. The image has been composed using an image with the L' (3.8 μm) broad-band filter and two images with narrow band filters centered at 2.36 μm and 2.18 μm. All observations were obtained in July 2004 with the NACO adaptive optics system/NIR camera at unit telescope 4 (Yepun) of the ESO VLT observatory on Paranal, Chile. The field-of-view is approximately $30'' \times 30''$ or 1.1pc$\times$1.1pc. *Image credit: R. Schödel, University of Cologne.*

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In the News

Robin Herrnstein

Things are certainly moving fast in the GC community. This rapid pace is clearly evidenced by the TWENTY SIX **(!)** new GC abstracts included in this month's newsletter. With all of this progress, it is certainly time for GC-ers to get together and discuss our results face-to-face. Luckily, 2006 is starting to look like the "Year of the GC Meetings," with four GC-related meetings occuring next summer. We have full announcements of all four of these meetings in the following section of this newsletter. In particular, it is time to dust off your GC-caps and prepare for that once-every-4-year ritual: the Galactic Center Workshop! GC2006 will be held in Bad Honnef, Germany next June. So get to work polishing up your theories and reducing your data, and don't forget to register for next summer's conferences!

Upcoming GC Meetings

Galactic Center Workshop 2006

From the Center of the Milky Way to Nearby Low-Luminosity Galactic Nuclei

18-22 April 2006, Bad Honnef, Germany

The Galactic Center Workshop 2006 will be devoted to the presentation and discussion of the most recent observational and theoretical results on the center of the Milky Way and on other low-luminosity galactic nuclei in the local neighborhood. It will continue the tradition of the previous Galactic Center (GC) workshops, 1998 in Tucson, Arizona, and 2002 in Kona, Hawaii. While the main emphasis of the workshop will be clearly set on the center of the Milky Way, as a new feature in GC 2006, there will be a widening of the perspective to include other nearby low-luminosity galactic nuclei as well. This will serve to apply the detailed knowledge that has been gathered so far on the center of our own Galaxy to other systems as well as to place the center of the Milky Way into the broader context of quiescent/low-luminosity galactic nuclei. The latter will be especially important for topics such as accretion and emission mechanisms of highly under-luminous central black holes or the role and mechanisms of massive star formation in galactic nuclei.

GC 2006 is going to take place from 18-22 April 2006, with 17 April and 23 April as arrival and departure dates. Location of the conference is the Physikzentrum Bad Honnef. The Physikzentrum Bad Honnef has been serving as the main meeting point of the German Physical Society (DPG) since 1976. It offers a secluded setting for research conferences, seminars, and workshops. The mansion housing the Physikzentrum is located in the small town of Bad Honnef, at the foot of the Siebengebirge ("the Seven Hills") on the right bank of the Rhine river south of Bonn, about 40 km south of Koeln. Due to the limited capacity of the conference center in Bad Honnef and in order to provide a good atmosphere for discussions and scientific exchange, there will be a hard upper limit of 120 participants.

Registration:

Due to the limited number of participants, the following procedure has been adopted for registration: There is an obligatory pre-registration open from November 15 until December 31. At pre-registration, potential participants provide information on whether they would like to present a talk or a poster, together with a preliminary short abstract (there is also an option for "no presentation"). Based on this information, the SOC/LOC will select presentations relevant to the topic of the workshop. Accepted participants will be forwarded a link with the instructions for final registration and payment of the confrence fee until January 31. A secondary criterion for acceptance will be the time point of registration, therefore early registration is recommended. Please be also aware that due to the time constraints of the workshop also the final decision on the form of the presentation will be taken by the SOC/LOC.

For registration as well as further and more detailed information, please visit http://www.ph1.uni-koeln.de/GC06/ or contact us at gc2006@ph1.uni-koeln.de

Mapping the Galaxy and Nearby Galaxies

26-30 June 2006, Ishigaki Island, Okinawa, Japan

The symposium will focus on "mapping" the interstellar media and other components in galactic disks, bulges, halos, and central regions of galaxies. Thanks to recent progress in observations using radio interferometers and optical/infrared telescopes in ground and space, our knowledge on structures of our Galaxy and nearby galaxies has been growing for the last decade. Yet we do not fully understand the physics behind the observational results, and a number of questions still remain : What is the origin of spiral structure?; How should the global star formation rate be determined?; What causes the differences between our Galaxy and other nearby galaxies?; What differentiates galaxies with starburst/AGN activity from normal galaxies?

In the next decade, we will have next-generation instruments, such as ALMA, JWST, TMT, OWL, SPICA, etc.. With these telescopes, complete multi-wavelength data at high resolution will become available on the structures in our Galaxy and nearby galaxies. It is therefore good timing to have a comprehensive discussion on what has been learned so far, what are the major outstanding issues, and how we can physically understand them.

Recent numerical modeling of galaxies is much more realistic; such modeling has become an essential tool in understanding and testing physical interpretations of observational results. In this sense, this symposium is also an excellent occasion for observers and theorists to exchange results.

The symposium will cover the following topics, mainly focusing on mapping observations and related observational and theoretical studies.
(1) Our Galaxy – mass distribution (spiral arms, stellar bar and halo), global and local ISM, supermassive black holes and its environment at the center
(2) Central part of nearby galaxies – ISM around starbursts, AGNs, fueling mechanism
(3) Nearby Galaxies – molecular gas distribution and star formation, gas dynamics, origin of starburst
(4) Galactic environment and evolution – formation of our Galaxy, environmental effect on galactic morphology, origin of supermassive blackholes
(5) The Nature of the Dark Matter component and its effects on the internal structures of galaxies

This symposium is also planned in celebration of Professor Yoshiaki Sofue's 63th birthday and his retirement from the University of Tokyo. Although Prof. Sofue has worked mainly in the field of radio astronomy, the subjects in this conference reflect the wide range of research in which he has been active in over the past four decades.

For more information, see http://www.ioa.s.u-tokyo.ac.jp/galaxy2006/

Physics and Astrophysics of Supermassive Black-Holes

9-14 July 2006, Santa Fe, New Mexico

In the past, they were recognized as the most destructive force in nature. Now, following a cascade of astonishing discoveries, supermassive black holes have undergone a dramatic shift in paradigm. Astronomers are finding out that these objects may have been critical to the formation of structure in the early universe, spawning bursts of star formation, planets, and even life itself. They may have contributed as much as half of all the radiation produced after the Big Bang, and at least 300 million of them may now be lurking through the vast expanses of the observable cosmos. The most accessible among them appears to be lurking at the Center of our own Galaxy.

This meeting will bring together astronomers, astrophysicists, and general relativistis now working at the forefront of supermassive black hole research with the goal of furthering our understanding of the formation and evolution of these intriguing objects.

For more information, see http://qso.lanl.gov/meetings/meet2006/index.html

The 26th General Assembly of the International Astronomical Union

14-25 August 2006, Prague, Czech Republic

Next year's IAU meeting will see a number of discussions on the Galactic Center:

Invited Discourse 4: Reinhard Genzel: "The power of new experimental techniques in astronomy: Zooming in on the black hole in the Center of the Milky Way"

Symposium 238: "Black Holes: from Stars to Galaxies – across the Range of Masses" will have a session on the Galactic Center

Also, there will be a meeting of Division VII: The Galactic System that will focus on the Galactic Center and other nearby galactic nuclei.

For more information, see http://www.astronomy2006.com/

Abstracts

A Radio Transient 0.1 pc from Sagittarius A*

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We report the discovery of a transient radio source 2.7 arcsec (0.1 pc projected distance) South of the Galactic Center massive black hole, Sagittarius A*. The source flared with a peak of at least 80 mJy in March 2004. The source was resolved by the Very Large Array into two components with a separation of ~ 0.7 arcsec and characteristic sizes of ~ 0.2 arcsec. The two components of the source faded with a power-law index of 1.1 ± 0.1. We detect an upper limit to the proper motion of the Eastern component of $\sim 3 \times 10^3$ km s^{-1} relative to Sgr A*. We detect a proper motion of $\sim 10^4$ km s^{-1} for the Western component relative to Sgr A*. The transient was also detected at X-ray wavelengths with the Chandra X-ray Observatory and the XMM-Newton telescope and given the designation CXOGC J174540.0-290031. The X-ray source falls in between the two radio components. The maximum luminosity of the X-ray source is $\sim 10^{36}$ erg s^{-1}, significantly sub-Eddington. The radio jet flux density predicted by the X-ray/radio correlation for X-ray binaries is orders of magnitude less than the measured flux density. We conclude that the radio transient is the result of a bipolar jet originating in a single impulsive event from the X-ray source and interacting with the dense interstellar medium of the Galactic Center.

Ref.: 2005, *ApJ*, 633, 218
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Stellar Winds and Embedded Star Formation in the Galactic Center Quintuplet and Arches Clusters: Multifrequency Radio Observations

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A multi-frequency, multi-configuration study has been made of the compact radio sources in the Galactic Center Quintuplet and Arches stellar clusters using the Very Large Array. Ten radio sources have been detected in the Quintuplet cluster. The majority of these radio sources have rising spectral indices and are positionally coincident with young massive stars that are known to have powerful stellar winds. We conclude that the three most compact of these sources are produced by stellar wind emission; thus, mass-loss rates can be derived and have an average value of 3×10^{-5} $M_\odot$ yr^{-1}. The remainder of the sources are likely to be a combination of stellar wind emission and free-free emission from surrounding ionized gas. In three cases, the radio sources have no stellar counterpart and the radio emission is thought to arise from compact or ultra-compact H II regions. If so, these sources would be the first detections of embedded massive stars to be discovered in the Galactic center clusters. The radio nebula associated with the Pistol star resembles the nebula surrounding the LBV star η Carina and may be related to the stellar wind of the Pistol star. Ten compact radio sources are detected in the Arches cluster and are interpreted to be stellar wind sources, consistent with previous findings. Several of the sources show moderate variability (10-30%) in their flux density, possibly related to a nonthermal component in the wind emission. A number of radio sources in both clusters have X-ray counterparts, which have been interpreted to be the shocked, colliding winds of massive binary systems.

Ref.: 2005, *AJ*, 130, 2185
Email: cornelia-lang@uiowa.edu
Eprint: astro-ph/0508178

Hot and Diffuse Clouds near the Galactic Center Probed by Metastable H_3^+

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We have observed a vast amount of high temperature ($T \sim 250$ K) and low density ($n \sim 100$ cm^{-3}) gas with a large velocity dispersion in the central 200 pc of the Galactic center (the Central Molecular Zone; CMZ) that has not previously been reported. We used the infrared spectrum of H_3^+ which is a sensitive probe of low density molecular gas. The observed large column density of H_3^+ in the $(J, K) = (3, 3)$ metastable rotational level (361 K above the lowest (1, 1) level) gives evidence for high temperature, and the observed small column density in the (2, 2) level (210 K below (3, 3)), gives evidence for low density. This remarkable non-thermal rotational distribution is caused for a low density gas by the fact that the spontaneous emission from the (3, 3) level is rigorously forbidden by the selection rules while that for the $(2, 2) \rightarrow (1, 1)$ transition has a short lifetime of 27 days, corresponding to a low critical density of ~ 200 cm^{-3}. Observed H_3^+ spectrum toward the brightest infrared source GCS 3-2, one of the Quintuplet Stars, has been analyzed in detail. Of the observed total H_3^+ column density of 4.3×10^{15} cm^{-2}, approximately 3.1×10^{15} cm^{-2} with high velocity dispersion is inferred to be in the CMZ while 1.2×10^{15} cm^{-2} is in the intervening spiral arms. Almost all of H_3^+ in the CMZ are in diffuse clouds with high temperature. About a half of the gas has a velocity of ~ -100 km s^{-1} indicating that it is associated with the 180 pc Expanding Molecular Ring which approximately forms the boundary of the CMZ. The other half with lower velocities of ~ -50 km s^{-1} and ~ 0 km s^{-1} is thought to be closer to the Galactic center. CO does not exist much in those clouds. The non-thermal rotational distribution of H_3^+ has also been observed toward 7 other infrared sources within 40 pc of the Galactic center indicating that the hot and diffuse gas is ubiquitous in the CMZ. The spectrum toward GC IRS 3 near Sgr A* shows presence of the hot and diffuse gas in the "50 km s^{-1} cloud", the complex of giant molecular clouds which plays a central role in the discussion of Sgr A* and its environment. The hot and diffuse gas has not been observed toward any of the dense and diffuse clouds in the Galactic disk where we have observed large column densities of H_3^+ had been observed. The large observed H_3^+ column density suggests an ionization rate in the CMZ which is an on the order of magnitude higher than in the diffuse interstellar medium in the Galactic disk if the C/H ratio is indeed as high as reported. Also the fact that the observed H_3^+ in the CMZ are almost all in diffuse clouds, along with the reported relatively low visual extinctions ($A_V \sim 25$ - 40) and mass estimated from radio observations of molecules, indicate that dense clouds are more sparse than previously thought and the reported volume filling factor (f ≥ 0.1) is an overestimate by at least an order of magnitude.

Ref.: 2005, *ApJ*, 632, 882
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Stellar Processes Near the Massive Black Hole in the Galactic Center

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A massive black hole resides in the center of most, perhaps all galaxies. The one in the center of our home galaxy, the Milky Way, provides a uniquely accessible laboratory for studying in detail the connections and interactions between a massive black hole and the stellar system in which it grows; for investigating the effects of extreme density, velocity and tidal fields on stars; and for using stars to probe the central dark mass and to probe post-Newtonian gravity in the weak- and strong-field limits. Recent results, open questions and future prospects are reviewed in the wider context of the theoretical framework and physical processes that underlie them.

Ref.: invited review, Physics Reports, 2005, in press
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Eprint: astro-ph/0508106

X-raying the super star clusters in the Galactic center

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The Galactic center harbors some of the most massive star clusters known in the Galaxy: the Arches and the Quintuplet. Based on the Chandra observations of these clusters (PI: Wang) which recently became public, I discuss the X-ray emission from the massive stars in these clusters. Confirming the general trend for Wolf-Rayet (WR) stars being X-ray dim, none of them is detected in the Quintuplet cluster. The most massive star known in the Galaxy, the Pistol star, is also not detected, invoking questions regarding the proposed binary nature of this object. X-ray emission in the Arches cluster is dominated by three stellar point sources. All three sources as well as the cluster's diffuse radiation show strong emission at 6.4–6.7 keV, indicating the presence of fluorescenting cool material. The Arches point sources may be identified as colliding wind binaries, albeit other possibilities cannot be ruled out.

Ref.: JENAM 2005 conf. proc.
Email: lida@astro.physik.uni-potsdam.de
Eprint: astro-ph/0507693
http://www.astro.physik.uni-potsdam.de/~ftp/oskinova/x-ray_ssc.ps

VLT L-band mapping of the Galactic Center IRS 3-IRS 13 region. Evidence for new Wolf-Rayet type stars

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This paper presents L-band ISAAC and NAOS/CONICA (VLT) spectroscopic observations of the IRS 3-IRS 13 Galactic Center region. The ISAAC data allowed us to build the first spectroscopic data cube of the region in the L-band domain. Using the L-band spectrum of the extinction along the line of sight towards the GC derived in a previous paper (Moultaka et al. 2004), it was also possible to correct the cube for the foreground extinction. Maps of the water ice and hydrocarbon absorption line strength were then derived. These maps are important diagnostics of the interstellar and circumstellar medium because water ices are observed in molecular clouds while hydrocarbons are usually good tracers of the diffuse ISM. These maps support our previous results that the absorption features most probably occur in the local Galactic center medium and can be associated with the individual sources. Moreover, turbulence seems to affect the studied region of the minispiral, which appears like a mixture of a dense and diffuse medium. Comparison of the concentrations of ice and hydrocarbon absorptions around IRS 13E, IRS 6E, and IRS 2, with similar concentrations at the location of the extended continuum emission around IRS 3, suggests that these sources might present outflows interacting with the surrounding ISM. It was also possible to derive Brα and Pfγ emission line maps. The results suggest that the physical conditions of the ISM are not uniform in the observed region of the minispiral especially at the edges of the minicavity. The emission line maps allowed us to find three sources with broad lines corresponding to an FWHM deconvolved line width of about 1100 km/s and moving towards us with a radial velocity of about –300km/s. These sources are most probably new Wolf-Rayet type stars located in projection to the north and west of IRS 3. Their derived radial velocities and proper motions show that only two of them might belong to the two rotating disks of young stars reported by Genzel et al. (2003) and Levin & Beloborodov (2003). Previously, NAOS/CONICA (NACO) data allowed us to resolve the IRS13E3 region into two components E3N, and E3c (Eckart et al. 2004). The new spectroscopic NACO data show that E3c is a good candidate for a Wolf-Rayet type star. In addition, three sources (η, ζ, and γ) out of the eight very red sources located in the IRS13N complex also presented in Eckart et al. (2004) have been resolved spectroscopically with NACO. The spectra presented in this paper show that the red colors of the sources are probably due to extended dust emission.

Ref.: 2005, *A&A*, 443, 163
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Eprint: astro-ph/0507161

Magnetic-Reconnection and Current-Sheet Model for the Radio Arc and Threads in the Galactic Center

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We propose a new mechanism to explain the radio Arc and threads in the Galactic Center by current sheets produced by local magnetic shears due to interaction of a moving cloud and the vertical field based on three-dimensional magneto-hydrodynamical simulations. Magnetic reconnetion and acceleration of cosmic-ray electrons in the current sheet will result in high contrast of radio emissivity inside and outside the Arc and threads.

Ref.: 2005, *PASJ*, 57, 39
Email: sofue@ioa.s.u-tokyo.ac.jp
Eprint: astro-ph/0507568

Three-body encounters in the Galactic centre: the origin of the hypervelocity star SDSS J090745.0+024507

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Hills (1988) predicted that runaway stars could be accelerated to velocities larger than 1000km s^{-1} by dynamical encounters with the supermassive black hole (SMBH) in the Galactic center. The recently discovered hypervelocity star SDSS J090745.0+024507 (hereafter HVS) is escaping the Galaxy at high speed and could be the first object in this class. With the measured radial velocity and the estimated distance to the HVS, we trace back its trajectory in the Galactic potential. Assuming it was ejected from the center, we find that a ~ 2 mas yr^{-1} proper motion is necessary for the star to have come within a few parsecs of the SMBH. We perform three-body scattering experiments to constrain the progenitor encounter which accelerated the HVS. As proposed by Yu & Tremaine (2003), we consider the tidal disruption of binary systems by the SMBH and the encounter between a star and a binary black hole, as well as an alternative scenario involving intermediate mass black holes. We find that the tidal disruption of a stellar binary ejects stars with a larger velocity compared to the encounter between a single star and a binary black hole, but has a somewhat smaller ejection rate due to the greater availability of single stars.

Ref.: 2005, *MNRAS*, 363, 223
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Eprint: astro-ph/0507365

A Hot Helium Plasma in the Galactic Center Region

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Recent X-ray observations by the space mission Chandra confirmed the astonishing evidence for a diffuse, hot, thermal plasma at a temperature of $\sim 9 \times 10^7$ K ($\sim$ 8 keV) found by previous surveys to extend over a few hundred parsecs in the Galactic Centre region. This plasma coexists with the usual components of the interstellar medium such as cold molecular clouds and a soft (0.8 keV) component produced by supernova remnants, and its origin remains uncertain. First, simple calculations using a mean sound speed for a hydrogen-dominated plasma have suggested that it should not be gravitationally bound, and thus requires a huge energy source to heat it in less than the escape time. Second, an astrophysical mechanism must be found to generate such a high temperature. No known source has been identified to fulfill both requirements. Here we address the energetics problem and show that the hot component could actually be a gravitationally confined helium plasma. We illustrate the new prospects this opens by discussing the origin of this gas, and by suggesting possible heating mechanisms.

Ref.: 2005, *ApJ*, 631, 53
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A New Radio Detection of the Bursting Source GCRT J1745–3009

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GCRT J1745–3009 is a transient bursting radio source located in the direction of the Galactic center, discovered in 330 MHz VLA observations from 2002 September 30–October 1 by Hyman et al. We have searched for bursting activity from GCRT J1745–3009 in nearly all of the available 330 MHz VLA observations of the Galactic center since 1989 as well as in 2003 GMRT observations. We report a new radio detection of the source in 330 MHz GMRT data taken on 2003 September 28. A single ∼0.5 Jy burst was detected, approximately 3× weaker than the five bursts detected in 2002. Due to the sparse sampling of the 2003 observation, only the decay portion of a single burst was detected. We present additional evidence indicating that this burst is an isolated one, but we cannot completely rule out additional undetected bursts that may have occured with the same ∼77 min. periodicity observed in 2002 or with a different periodicity. Assuming the peak emission was detected, the decay time of the burst, ∼2 min, is consistent with that determined for the 2002 bursts. Based on the total time for which we have observations, we estimate that the source has a duty cycle of roughly 10%.

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Email: shyman@sbc.edu
Eprint: astro-ph/0508264

CH 3 GHz Observations of the Galactic Center

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A 3 × 3 map of the Galactic Center was made at 9′ resolution and 10′ spacing in the CH $^2\Pi_{1/2}$, J=1/2, F=1-1 transition at 3335 MHz. The CH emission shows a velocity extent that is nearly that of the CO(1-0) line, but the CH line profiles differ markedly from the CO. The 3335 MHz CH transition primarily traces low-density molecular gas and our observations indicate that the mass of this component within ∼ 30 pc of the Galactic Center is ∼ 9 × 10^6 $M_\odot$. The CO-H_2 conversion factor obtained for the low-density gas in the mapped region is greater than that thought to apply to the dense molecular gas at the Galactic Center. In addition to tracing the low-density molecular gas at the Galactic Center, the CH spectra show evidence of emission from molecular clouds along the line of sight both in the foreground and background. The scale height of these clouds ranges from 27 - 109 pc, consistent with previous work based on observations of molecular clouds in the inner Galaxy.

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Repeated X-ray Flaring Activity in Sagittarius A*

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Investigating the spectral and temporal characteristics of the X-rays coming from Sagittarius A* (Sgr A*) is essential to our development of a more complete understanding of the emission mechanisms in this supermassive black hole located at the center of our Galaxy. Several X-ray flares with varying durations and spectral features have already been observed from this object. Here we present the results of two long XMM observations of the Galactic nucleus carried out in 2004, for a total exposure time of nearly 500 ks. During these observations we detected two flares from Sgr A* with peak 2–10 keV luminosities about 40 times ($L_X \sim 9 \times 10^{34}$ erg/s) above the quiescent luminosity: one on 2004 March 31 and another on 2004 August 31. The first flare lasted about 2.5 ks and the second about 5 ks. The combined fit on the Epic spectra yield photon indeces of about 1.5 and 1.9 for the first and second flare respectively. This hard photon index strongly suggests the presence of an important population of non-thermal electrons during the event and supports the view that the majority of flaring events tend to be hard and not very luminous.

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A Persistent High-energy Flux from the Heart of the Milky Way: Integral's view of the Galactic Center

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Highly sensitive imaging observations of the Galactic center (GC) at high energies with an angular resolution of order 10 arcminutes, is a very recent development in the field of high-energy astrophysics. The Ibis/Isgri imager on the Integral observatory detected for the first time a hard X-ray source, IGR, located within 1 arcminute of Sagittarius A* (Sgr A*) over the energy range 20–100 keV. Here we present the results of a detailed analysis of approximately 7×10^6 s of observations of the GC obtained since the launch of Integral in October 2002. Two years and an effective exposure of 4.7×10^6 s have allowed us to obtain more stringent positional constraints on this high-energy source and to construct its spectrum in the range 20–400 keV. Furthermore, by combining the Isgri spectrum with the total X-ray spectrum corresponding to the same physical region around Sgr A* from XMM data, and collected during part of the gamma-ray observations, we constructed and present the first accurate wide band high-energy spectrum for the central arcminutes of the Galaxy. Our complete and updated analysis of the emission properties of the Integral source shows that it is faint but persistent with no variability above 3 σ, contrary to what was alluded to in our first paper. This result, in conjunction with the spectral characteristics of the soft and hard X-ray emission from this region, suggests that the source is most likely not point-like but, rather, that it is a compact, yet diffuse, non-thermal emission region. The centroid of IGR is estimated to be R.A. = $17^h45^m42^s.5$, decl. = $-28°59'28''$ (J2000), offset by 1' from the radio position of Sgr A* and with a positional uncertainty of 1'. Its 20–400 keV luminosity at 8 kpc is $L = (5.37 \pm 0.21) \times 10^{35}$ erg/s. A 3 σ upper limit on the flux at the electron-positron annihilation energy of 511 keV from the direction of Sgr A* is set at 1.9×10^{-4} ph cm^{-2} s^{-1}. Very recently, the Hess collaboration presented the detection of a source of $\sim$ TeV gamma-rays also located within an arcminute of Sgr A*. We present arguments in favor of an interpretation according to which the photons detected by Integral and Hess arise from the same compact region of diffuse emission near the central black hole and that the supernova remnant Sgr A East could play an important role as a contributor of very high-energy gamma-rays to the overall spectrum from this region. There is also evidence for hard emission from a region located between the central black hole and the radio Arc near l $\sim 0.1°$ along the Galactic plane and known to contain giant molecular clouds.

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The First Laser Guide Star Adaptive Optics Observations of the Galactic Center: Sgr A*'s Infrared Color and the Extended Red Emission in its Vicinity

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We present the first Laser Guide Star Adaptive Optics (LGS-AO) observations of the Galactic center. LGS-AO has dramatically improved the quality and robustness with which high angular resolution infrared images of the Galactic center can be obtained with the W. M. Keck II 10-meter telescope. Specifically, Strehl ratios of 0.7 and 0.3 at L'[3.8 μm] and K'[2.1 μm], respectively, are achieved in these LGS-AO images; these are at least a factor of two higher and a factor of four to five more stable against atmospheric fluctuations than the Strehl ratios delivered thus far with the Keck Natural Guide Star AO system on the Galactic center. Furthermore, these observations are the first that cover a large area ($76'' \times 76''$) surrounding the central black hole at diffraction-limited resolution for an 8-10 meter class telescope. During our observations, the infrared counterpart to the central supermassive black hole, Sgr A*-IR, showed significant infrared intensity variations, with observed L' magnitudes ranging from 12.6 to 14.5 mag and a decrease in flux density of a factor of two over an 8 minute interval. The faintest end of our L' detections, 1.3 mJy (dereddened), is the lowest level of emission yet observed for this source by a factor of 3. No significant variation in the location of SgrA*-IR is detected as a function of either wavelength or intensity. Previous claims of such positional variations are easily attributable to a nearby ($0\overset{''}{.}09$ or 720 AU, projected), extended, very red source, which we suggest arises from a locally heated dust feature. Near a peak in its intensity, we obtained the first measurement of SgrA*-IR's K'-L' color; its K'-L' of 3.0 ± 0.2 mag (observed) or 1.4 ± 0.2 (dereddened) corresponds to an intrinsic spectral index of $\alpha = -0.5 \pm 0.3$ for $F_\nu \sim \nu^\alpha$. This is significantly bluer than other recent infrared measurements from the literature, which suggest $\alpha = -4 \pm 1$. Because our measurement was taken at a time when Sgr A* was ~6 times brighter in the infrared than the other measurements, we posit that the spectral index of the emission arising from the vicinity of our Galaxy's central black hole may depend on the strength of the flare, with stronger flares giving rise to a higher fraction of high energy electrons in the emitting region.

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Probing Post-Newtonian Gravity near the Galactic Black Hole with Stellar Doppler Measurements

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Stars closely approaching the massive black hole in the center of the Galaxy provide a unique opportunity to probe post-Newtonian physics in a yet unexplored regime of celestial mechanics. Recent advances in infrared stellar spectroscopy allow the precise measurement of stellar Doppler shift curves and thereby the detection of β^2 post-Newtonian effects (gravitational redshift in the black hole's potential and the transverse Doppler shift). We formulate a detection procedure in terms of a simplified post-Newtonian parametrization. We then use simulations to show that these effects can be decisively detected with existing instruments after about a decade of observations. We find that neglecting these effects can lead to statistically significant systematic errors in the derived black hole mass and distance.

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The XMM-Newton/Chandra monitoring campaign on the Galactic center region

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We present the first results of our X-ray monitoring campaign on a 1.7 square degree region centered on Sgr A* using the X-ray satellites XMM-Newton and Chandra. The purpose of this campaign is to monitor the X-ray behavior (below 10 keV) of X-ray sources (both persistent and transient) which are too faint to be detected by monitoring instruments aboard satellites currently in orbit (e.g., Rossi X-ray Timing Explorer; INTEGRAL). Our first monitoring observations (using the HRC-I aboard Chandra) were obtained on June 5, 2005. Most of the sources detected could be identified with foreground sources, such as X-ray active stars. In addition we detected two persistent X-ray binaries (1E 1743.1-2843; 1A 1742-294), two faint X-ray transients (GRS 1741.9-2843; XMM J174457-2850.3), as well as a possible new transient source at a luminosity of a few times 10^{34} erg s^{-1}. We report on the X-ray results on these systems and on the non detection of the transients in follow-up radio data using the Very Large Array. We discuss how our monitoring campaign can help to improve our understanding of the different types of X-ray transients (i.e., the very faint ones).

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Structure and Dynamics at the Central 10 Parsecs of the Galaxy

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The Galactic center influences the current nature as well as the formation, the evolution and the future fate of the Milky Way. The Galactic nucleus stands for the galactic nuclei of other galaxies and provides an opportunity to study the environment around a super-massive black hole (SMBH) at high spatial resolution. The central 10 pc of the Galaxy, the Sgr A region, contains several principal components; the SMBH candidate (Sgr A*), the Central cluster, the circum-nuclear disk (CND), Sgr A West, a powerful supernova-like remnant (Sgr A East), and surrounding molecular clouds. Developing a consistent picture of the interactions between these components will improve our understanding of the Galaxy and the nature of galactic nuclei in general. Previous studies on the spatial and dynamical relationships between the various objects are mostly based on indirect and qualitative evidence and leave many unsolved questions, which need more robust evidence. Molecular hydrogen (H_2) emission has been used as an excellent tracer and diagnostic for interactions between dense molecular clouds and hot, powerful sources. We observed the H_2 $1-0$ $S(1)$ ($\lambda = 2.1218\mu$m) and H_2 $2-1$ $S(1)$ ($\lambda = 2.2477\mu$m) emission line spectra from the interaction regions between Sgr A East, the CND, and the surrounding molecular clouds. Using the long-slit Cooled Grating Spectrometer 4 (CGS4) with an echelle grating at the 3.8 m United Kingdom Infrared Telescope (UKIRT) on Mauna Kea, we scanned 56 positions in the interaction regions. We reduced 2-D spectral images using IRAF and analyzed a 3-D data cube using MIRIAD. The data cube has the H_2 information both in space (with a resolution of $\sim 2''$) and in velocity (with a resolution of ~ 18 $km\ s^{-1}$). The H_2 $1-0$ $S(1)$ data cube was directly compared with the NH_3(3,3) data cube from McGary, Coil, & Ho (2001, ApJ, 559, 326) to investigate the gas kinematics. Based on the H_2 $1-0$ $S(1)$ and $2-1$ $S(1)$ line intensities and gas kinematics, we concluded that the H_2 excitation can be explained by

two mechanisms; a combination of fluorescence and C-shocks in very strong magnetic fields, or a mixture of slow C-shocks and fast J-shocks. We estimated shock velocities ($\sim$ 100 $km\ s^{-1}$) of Sgr A East by comparing H_2 line profiles with those of NH_3. From the distribution of the shocked H_2 emission, we determined the interacting boundary of Sgr A East in projection as an ellipse with the center at $\sim$ 1.5 pc offset from Sgr A* and the dimension of 10.8 pc $\times$ 7.6 pc. We also determined the positional relationship between Sgr A East and the molecular clouds along the line-of-sight and suggested a revised model for the 3-D structure of the central 10 pc. From the estimated shock velocities, we deduced the initial explosion energy (0.2–4×10^{53} ergs) of Sgr A East. This extremely large energy excludes the hypothesis of a single, typical, supernova (SN) for the origin of Sgr A East. We examined other hypotheses (tidal disruption of a star by the SMBH, multiple supernovae, and a hypernova) and we concluded that a hypernova (collapsar or microquasar) is the most probable origin of Sgr A East. Based on the energy, we investigated the influences of the Sgr A East-like explosions (hypernovae) and normal SNe on the mass inflow to the Galactic nucleus. We suggest a scenario that the continuous mass inflow into the Galactic nucleus makes it active by igniting the SMBH or stimulating a starburst every $\sim 10^8$ yr, but each active phase continues only $< 10^7$ yr since a large number of SNe resulting from newly born massive stars cease the mass supply soon. The Galactic nucleus is likely to spend only about 1/10 of its life in active. As for the recent history of the central 10 pc, the mass inflow restarted several 10^6 yr ago after a quiescent phase for $\sim 10^8$ yr. In its usual schedule, the Galactic nucleus would continue its activity for a few 10^6 yr more from now before a huge number of SNe occur. However, the active phase was unexpectedly ceased $\sim 10^4$ yr ago, by Sgr A East.

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A dual emission mechanism in Sgr A*/L′?

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We have collected in 2004 adaptive optics corrected L′ images of the Galactic Center region with NAOS-CONICA at VLT. A strong variability was observed as well as a correlation between the photocenter positions and fluxes of the L′-band counterpart of Sgr A*. It is interpreted as the combined emission of a point-like flaring source at the position of Sgr A*/IR itself and an extended dust structure, 75 mas south west of Sgr A*/IR, which we name Sgr A*-f. We examine the different possible mechanisms to explain this dual Sgr A* L′ emission and conclude it is likely a flaring emission associated to energetic events in the close environment of the black hole plus a quiescent emission resulting from the collision of Sgr A*-f by a jet from Sgr A*.

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Spectral analysis of the Galactic e^+e^- annihilation emission

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We present a spectral analysis of the e^+e^- annihilation emission from the Galactic Centre region based on the first year of measurements made with the spectrometer SPI of the INTEGRAL mission. We have found that the annihilation spectrum can be modelled by the sum of a narrow and a broad 511 keV line plus an ortho-positronium continuum. The broad line is detected (significance 3.2σ) with a flux of $(0.35 \pm 0.11) \times 10^{-3}$ photons s^{-1} cm^{-2}. The measured width of 5.4 ± 1.2 keV FWHM is in agreement with the expected broadening of 511 keV photons emitted in the annihilation of positroniums that are formed by the charge exchange process of slowing down positrons with hydrogen atoms. The flux of the narrow line is $(0.72 \pm 0.12) \times 10^{-3}$ photons s^{-1} cm^{-2} and its width is 1.3 ± 0.4 keV FWHM. The measured ortho-positronium continuum flux yields

a fraction of positronium of (96.7±2.2)%. To derive in what phase of the interstellar medium positrons annihilate, we have fitted annihilation models calculated for each phase to the data. We have found that 49^{+2}_{-23} % of the annihilation emission comes from the warm neutral phase and 51^{+3}_{-2}% from the warm ionized phase. While we may not exclude that less than 23% of the emission might come from cold gas, we have constrained the fraction of annihilation emission from molecular clouds and hot gas to be less than 8% and 0.5%, respectively. We have compared our knowledge of the interstellar medium in the bulge (size, density, and filling factor of each phase) and the propagation of positrons with our results and found that they are in good agreement if the sources are diffusively distributed and if the initial kinetic energy of positrons is lower than a few MeV. Despite its large filling factor, the lack of annihilation emission from the hot gas is due to its low density, which allows positrons to escape this phase.

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Imaging Optically-Thin Hot Spots Near the Black Hole Horizon of Sgr A* at Radio and Near Infrared Wavelengths

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Sub milli-arcsecond astrometry and imaging of the black hole Sgr A* at the Galactic centre may become possible in the near future at infrared and submillimetre wavelengths. Motivated by observations of short-term infrared and X-ray variability of Sgr A*, in a previous paper we computed the expected images and light curves, including polarization, associated with an compact emission region orbiting the central black hole. We extend this work, using a more realistic hot-spot model and including the effects of opacity in the underlying accretion flow. We find that at infrared wavelengths the qualitative features identified by our earlier work are present, namely it is possible to extract the black hole mass and spin from spot images and light curves of the observed flux and polarization. At radio wavelengths, disk opacity produces significant departures from the infrared behaviour, but there are still generic signatures of the black hole properties. Detailed comparison of these results with future data can be used to test general relativity and to improve existing models for the accretion flow in the immediate vicinity of the black hole.

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Frequency-Dependent Shift in the Image Centroid of the Black Hole at the Galactic Center as a Test of General Relativity

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The inferred black hole in the Galactic center spans the largest angle on the sky among all known black holes. Forthcoming observational programs plan to localize or potentially resolve the image of Sgr A* to an exquisite precision, comparable to the scale of the black hole horizon. Here we show that the location of the image centroid of Sgr A* should depend on observing frequency because of relativistic and radiative transfer effects. The same effects introduce a generic dependence of the source polarization on frequency. Future detection of the predicted centroid shift and the polarization dependence on frequency can be used to determine the unknown black hole spin and verify the validity of General Relativity.

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Imaging Bright Spots in the Accretion Flow Near the Black Hole Horizon of Sgr A*

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Images from the vicinity of the black hole horizon at the Galactic centre (Sgr A*) could be obtained in the near future with a Very Large Baseline Array of sub-millimetre telescopes. The recently observed short-term infrared and X-ray variability of the emission from Sgr A* implies that the accretion flow near the black hole is clumpy or unsteady. We calculate the appearance of a compact emission region (bright spot) in a circular orbit around a spinning black hole as a function of orbital radius and orientation. We find that the mass and spin of the black hole can be extracted from their generic signatures on the spot image as well as on the light curves of its observed flux and polarization. The strong-field distortion remains noticeable even when the spot image is smoothed over the expected $\sim 20\mu as$ resolution of future sub-millimetre observations.

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An Infrared Imaging Survey of the Faint Chandra Sources near the Galactic Centre

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We present near-IR imaging of a sample of the faint, hard X-ray sources discovered in the 2001 Chandra ACIS-I survey towards the Galactic Centre (GC) (Wang et al. 2002). These ~800 discrete sources represent an important and previously undetected population within the Galaxy. From our VLT observations of 77 X-ray sources, we identify candidate K-band counterparts to 75% of the Chandra sources in our sample. The near-IR magnitudes and colours of the majority of candidate counterparts are consistent with highly reddened stars, indicating that most of the Chandra sources are likely to be accreting binaries at or near the GC

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Stochastic Electron Acceleration During the NIR and X-ray Flares in Sagittarius A*

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Recent near-IR (NIR) and X-ray observations of Sagittarius A*'s spectrum have yielded several strong constraints on the transient energizing mechanism, justifying a re-examination of the stochastic acceleration model proposed previously for these events. We here demonstrate that the new results are fully consistent with the acceleration of electrons via the transit-time damping process. But more importantly, these new NIR and X-ray flares now can constrain the source size, the gas density, the magnetic field, and the wave energy density in the turbulent plasma. Future simultaneous multi-wavelength observations with good spectral information will, in addition, allow us to study their temporal evolution, which will eventually lead to an accurate determination of the behavior of the plasma just minutes prior to its absorption by the black hole.

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Constraining the Nature of the Galactic Center X-ray Source Population

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We searched for infrared counterparts to the cluster of X-ray point sources discovered by Chandra in the Galactic Center Region (GCR). While the sources could be white dwarfs, neutron stars, or black holes accreting from stellar companions, their X-ray properties are consistent with magnetic

Cataclysmic Variables, or High Mass X-ray Binaries (HMXB) at low accretion-rates. A direct way to decide between these possibilities and hence between alternative formation scenarios is to measure or constrain the luminosity distribution of the companions. Using infrared (J, H, K, Brγ) imaging, we searched for counterparts corresponding to typical HMXB secondaries: spectral type B0V with K<15 at the GCR. We found no significant excess of bright stars in Chandra error circles, indicating that HMXBs are not the dominant X-ray source population, and account for fewer than 10% of the hardest X-ray sources.

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Simultaneous Multi-Wavelength Observations of Sgr A*

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We observed Sgr A* using the Very Large Array (VLA) and the Giant Metrewave Radio Telescope (GMRT) at multiple cm and mm wavelengths on 17 June 2003. The measured flux densities of Sgr A*, together with those obtained from the Submillimeter Array (SMA) and the Keck II 10 m telescope on the same date, are used to construct a simultaneous spectrum of Sgr A* from 90 cm to 3.8 μm. The simultaneous spectrum shows a spectral break at about 3.6 cm, a possible signature of synchrotron self-absorption of the strong radio outburst which occurred near epoch 17 July 2003. At 90 cm, the flux density of Sgr A* is 0.22 ± 0.06 Jy, suggesting a sharp decrease in flux density at wavelengths longer than 47 cm. The spectrum at long cm wavelengths appears to be consistent with free-free absorption by a screen of ionized gas with a cutoff $\sim$100 cm. This cutoff wavelength appears to be three times longer than that of $\sim$30 cm suggested by Davies, Walsh & Booth based on observations in 1974 and 1975. Our analysis suggests that the flux densities of Sgr A* at wavelengths longer than 30 cm could be attenuated and modulated by stellar winds from massive stars close to Sgr A*.

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Announcements

New Book: The Black Hole at the Center of the Milky Way

by Andreas Eckart, Rainer Schödel, and Christian Straubmeier

Imperial College Press, London
284 pages, 36 figures, 9 tables
ISBN 1-86094-567-8
Price: US $68/41 British Pounds

The intention of this book is to provide the reader with a concise summary of some central aspects of the rapidly developing field of Galactic Center research. It provides a review of a selection of fundamental instrumental techniques, observational findings, and astrophysical results that are relevant for the Galactic Center. Overall, the book concentrates on aspects that deal with the nuclear stellar cluster in the central parsec and the compact radio source Sagittarius A* at its center rather than the more extended components and large scale phenomena. For further details the reader is referred to the actual scientific articles and reviews in the corresponding sections.

Most prominently, the book highlights observational techniques and especially image processing aspects. We have also put a high weight on a detailed presentation of the most recent work carried out in the near-infrared wavelength regime. All of these aspects had not yet been discussed in a unified manner in any available reference. A list of abbreviations, a number of useful quantities, a bibliography comprising of more than 400 publications up to the editorial deadline in July 2004, and maps of the Galactic Center stellar cluster "for daily use" are included in this book.

Fur further information, please see www.ph1.uni-koeln.de/~gcbook

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