Following the G2 Gas Cloud towards the Galactic Centre

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A gas cloud was detected within half an arcsecond of Sagittarius A* in 2011 in *L′*-band and subsequently in line emission of H and He. The emitting cloud can be traced back in time to 2002 and is in an orbit with a pericentre very close to the central massive black hole at the Galactic Centre. Named G2, the cloud is passing the pericentre from mid-2013 to probably mid-2014 and is being intensively monitored by many facilities. An update on the progress of G2 is reported, based on recent VLT observations with SINFONI.

The region around the compact radio source Sagittarius A*, the site of the massive black hole (BH) at the centre of the Milky Way, is of intense observational interest. Although the black hole is very underluminous in comparison with active galactic nuclei in distant galaxies, it presents a unique opportunity to study in detail the effects of strong gravity in the vicinity of a black hole. The advent of adaptive optics has enabled the astrometry of tens of stars in the central arcsecond to be followed over a period of 21 years to date and their orbits to be solved. The star with the most diagnostic power is a bright (*K* = 14 mag) short-period star, labelled S2, which has a period of 16 years and underwent a pericentre passage in 2002 (Genzel et al., 2010), with its next pericentre approach in 2018. Solving for the orbital elements of these stars around the BH enabled the mass of the central black hole (4.3×10^6 $M_\odot$), and the distance to the Galactic Centre (8.3 kpc) to be well constrained (Gillessen et al., 2009).

The 3D orbits of the stars in orbit around the BH at the Galactic Centre (GC) require both astrometric and kinematic observations. Astrometric orbits of the GC cluster stars (the S stars; Gillessen et al., 2009) have been the province of speckle imaging and adaptive optics (AO) imaging, beginning with the SHARP 1 camera on the New Technology Telescope (NTT) and, since 2002, with the Very Large Telescope (VLT) NACO instrument (see Genzel et al. [2010] for a review) and with NIRC2 at the Keck Telescope (e.g., Ghez et al., 2008). The line-of-sight velocities of these stars have been mainly measured with AO-assisted integral field unit (IFU) spectrographs, such as SINFONI at the VLT and OSIRIS at Keck. The S-stars orbit Sgr A* on randomly oriented orbits. Further out, a population of massive, luminous stars orbit in a disc inclined to the line of sight. Frequent observations during the GC season (March to October for ground-based telescopes) have enabled the orbits of more stars to be refined over the years.

During the 2011 campaign a new moving object was detected, initially in *L′*-band (3.8 μm), but not in *K*-band, suggesting it was a source cooler than a star. Examination of SINFONI H+K grating spectra showed in addition emission lines of Brackett-γ (2.17 μm) and He I (2.06 μm) enabling its radial velocity to be measured (Gillessen et al. [2012] and ESO Release 1151[1]). It was christened G2 by Burkert et al. (2012), as the second gaseous cloud after the one found by Clénet et al. (2005) in the near vicinity of the GC.

The G2 gas cloud

Careful examination of imaging data prior to 2011 revealed that G2 could be detected in NACO *L′*-band AO images back to 2002 and that its proper motion was 42 milliarcseconds per year, or 1700 km/s at the distance of the GC (Gillessen et al., 2012). The properties of G2 were distinct from that of the stars orbiting the GC: line emission, continuum undetected in *H*- and *K*-bands, but continuum detections in *L′*-band and the *M*-band (4.7 μm); these properties are those expected of a dusty gas cloud. The ratio of the He I and H I emission lines is also similar to that of photoionised gas, further strengthening evidence for the gaseous nature of G2. Knowing where to extract the spectrum of G2 from its orbit allowed the radial velocities to be measured from the emission lines, including on SINFONI datacubes back to 2004, and the velocities were found to be increasing from 1250 km/s in 2008 to 1650 km/s in 2011 (Gillessen et al., 2012).

From the astrometry and radial velocities of G2 over this time period, the orbit was tightly constrained to be highly eccentric and the cloud was falling towards Sgr A* — and being tidally disrupted. From the initial orbital elements, a pericentre passage within 3000 Schwarzschild radii (R_s) of Sgr A* was estimated. The implications for black hole studies were profound: G2 would probe the accretion flow around the BH and even perhaps feed matter into the BH. The event might be observable in a variety of bands from the radio up to the X-ray regime. G2 thus became the subject of intense observational study covering most of the electromagnetic spectrum and with ground- and space-based telescopes.

The evolution of G2 was followed up in 2012 with a further NACO image and deep SINFONI observations (Gillessen et al., 2013a). The progress of G2 towards Sgr A* over the period 2008–2013 is shown in Figure 1. The addition of new velocity data showed further acceleration of G2 as it approached the GC, an even larger eccentricity for the orbit of 0.966 and a smaller pericentre distance of 2200 R_s. Although the emission lines were becoming broader, the flux of G2 in the Brackett-γ line remained similar to the value at earlier epochs. The date of pericentre passage was estimated as September 2013, allowing strategic observing proposals to be planned[2,3].

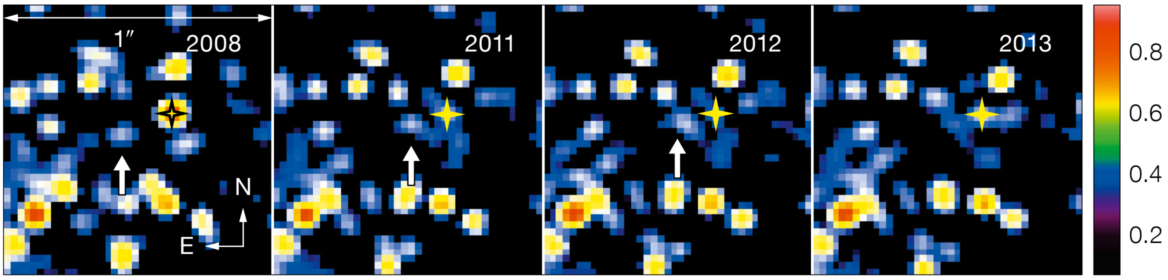

Figure 1. The progress of G2 in its course towards the Galactic Centre, Sgr A*, is shown in this sequence of restored NACO L'-band images over the period 2008 to 2013 (c.f., Gillessen et al. [2013a], Figure 1). The position of G2 is arrowed and the position of Sgr A* is shown by a cross.

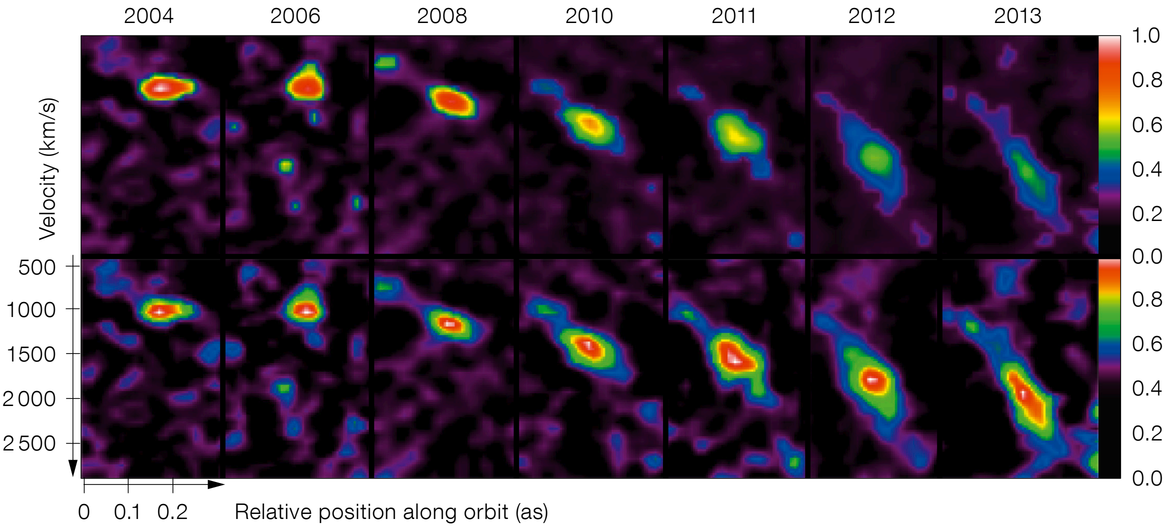

Figure 2. The evolution in the appearance of G2 in position–velocity diagrams extracted from SINFONI datasets is shown in two different scalings: upper row scaled to equal total luminosity; lower row scaled to identical peak luminosities. The increasing tidal shear with time is apparent (see Gillessen et al., 2013b).

2013 VLT campaign

NACO imaging in L'-band did not convincingly reveal the 2013 position of G2, on account of confusion. However very deep SINFONI data were obtained early in the 2013 GC season, in April: 24.4 hours of observational data, of which only 21% were rejected for lower Strehl ratios, made this the deepest integral field exposure of the Sgr A* region ever (Gillessen et al. [2013b] and ESO Release 1332[4]). On account of the high velocity of the G2 emission, the Paschen-α line (1.88 μm) could also be detected, shifted out of the strongest absorption of the Earth's atmosphere. Careful examination of earlier epochs revealed more detections of G2 in other datasets, enabling a total of 15 radial velocity measurements since 2004. Figure 2 shows a montage of the position velocity diagrams of G2 over this period: the evolution of a tidal shear on the knot emission is evident.

These observations are becoming more challenging as the cloud already presents low contrast emission against the diffuse emission from the whole GC region and the emission line of G2 is becoming broader as it is sheared by the gravitational field of the BH (Figure 2). Knowing the position from the astrometry, and the availability of IFU data, the spectrum can be extracted with a curved slit; by co-adding the three emission lines (two H lines, Brackett-γ and Paschen-α, and the He I line) a full position–velocity diagram along the orbit (Figure 3) reveals that emission is also detected with a blueshift of 3000 km/s, consistent with some gas having already undergone pericentre passage (Gillessen et al., 2013b). Thus the pericentre passage is an extended event of at least a year's duration with the bright head of G2 still before pericentre excursion in these observations.

Nature of G2

Although the recent SINFONI observations clearly reveal the course of G2 around the BH, there is still contention as to the nature of the cloud itself. A range of explanations, from the circumstellar shell of a low mass (T-Tauri) star or protoplanetary disc, a nova outburst, a stellar wind collision event, an instability in the gas of the Sgr A* accretion flow, have been advanced (see Gillessen et al., 2013a; also Phifer et al., 2013, Scoville & Burkert, 2013). In either case, it is clear that the observed phenomenology is that of a gas cloud being disrupted, and efforts to find a star inside have failed (Phifer et al., 2013). Also the 2013 VLT data are more consistent with a pure gas cloud model. A clue might be that G2 seems to be related to the disc of O and Wolf–Rayet stars that orbit the BH at radii larger than 1 arcsecond. As the pericentre passage begins to disrupt G2, the available options will be narrowed down. So far there is no evidence for hydrodynamic effects between the gas and BH at the Galactic Centre, but when the gas is at around 2000 R_s, interaction between G2 and the BH may become observable, both in X-ray and as a distortion from the, so-far, Keplerian orbit. The intense observing campaign this year and next year will be of unique interest for this first "experiment" with strong gravity and the infall of matter onto a massive BH.

References

Burkert, A. et al. 2012, ApJ, 750, 58
Clénet, Y. et al. 2005, A&A, 439, L9
Genzel, R., Eisenhauer, F. & Gillessen, S. 2010, Rev. Mod. Phys., 82, 3121
Ghez, A. M. et al. 2008, ApJ, 689, 1044
Gillessen, S. et al. 2009, ApJ, 692, 1075
Gillessen, S. et al. 2013a, ApJ, 763, 78
Gillessen, S. et al. 2013b, ApJ, in press, arXiv:1306.1374G
Phifer, K. et al. 2013, arXiv:1304.5280P
Scoville, N., Burkert, A. 2013, ApJ, 768, 108

Links

[1] ESO Release 1151: http://www.eso.org/public/news/eso1332/
[2] MPE Galactic Centre pages: http://www.mpe.mpg.de/ir/GC
[3] Gas cloud Wiki: https://wiki.mpe.mpg.de/gascloud/FrontPage
[4] ESO Release 1332: http://www.eso.org/public/news/eso1332/

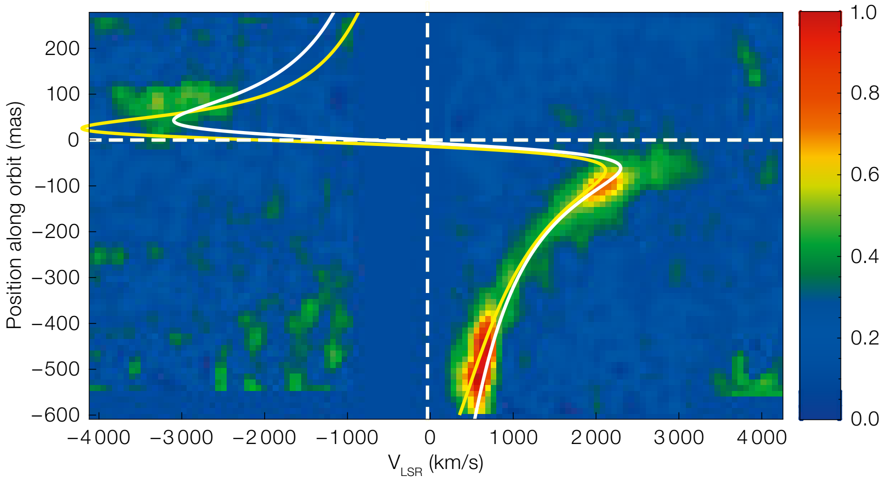

Figure 3. The full depth of the velocity–position diagram of G2 is revealed from the 24.4-hour 2013 SINFONI observation by extraction of the spectrum along the (curved) orbit path (from Gillessen et al., 2013b). The yellow line depicts the *L′*-band orbit which differs slightly from the Brackett-γ one (white line).

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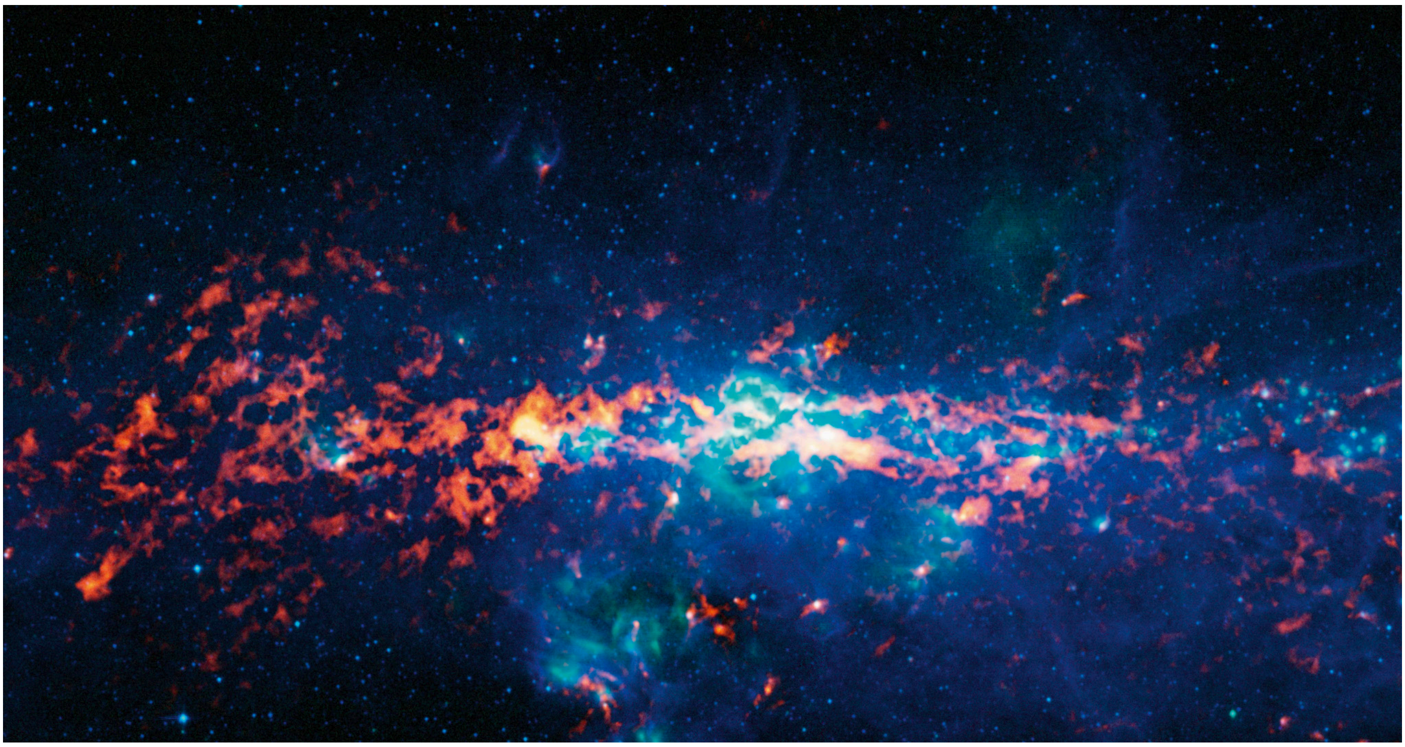

A composite submillimetre and infrared image of the Sagittarius B2 region towards the Milky Way Galactic Centre. APEX ATLASGAL submillimetre-wavelength data are shown in red and are overlaid on mid-infrared images from the Midcourse Space Experiment (MSX) in green and blue. Sagittarius B2 is the bright orange-red region to the left of image centre. More details in Release eso0924.