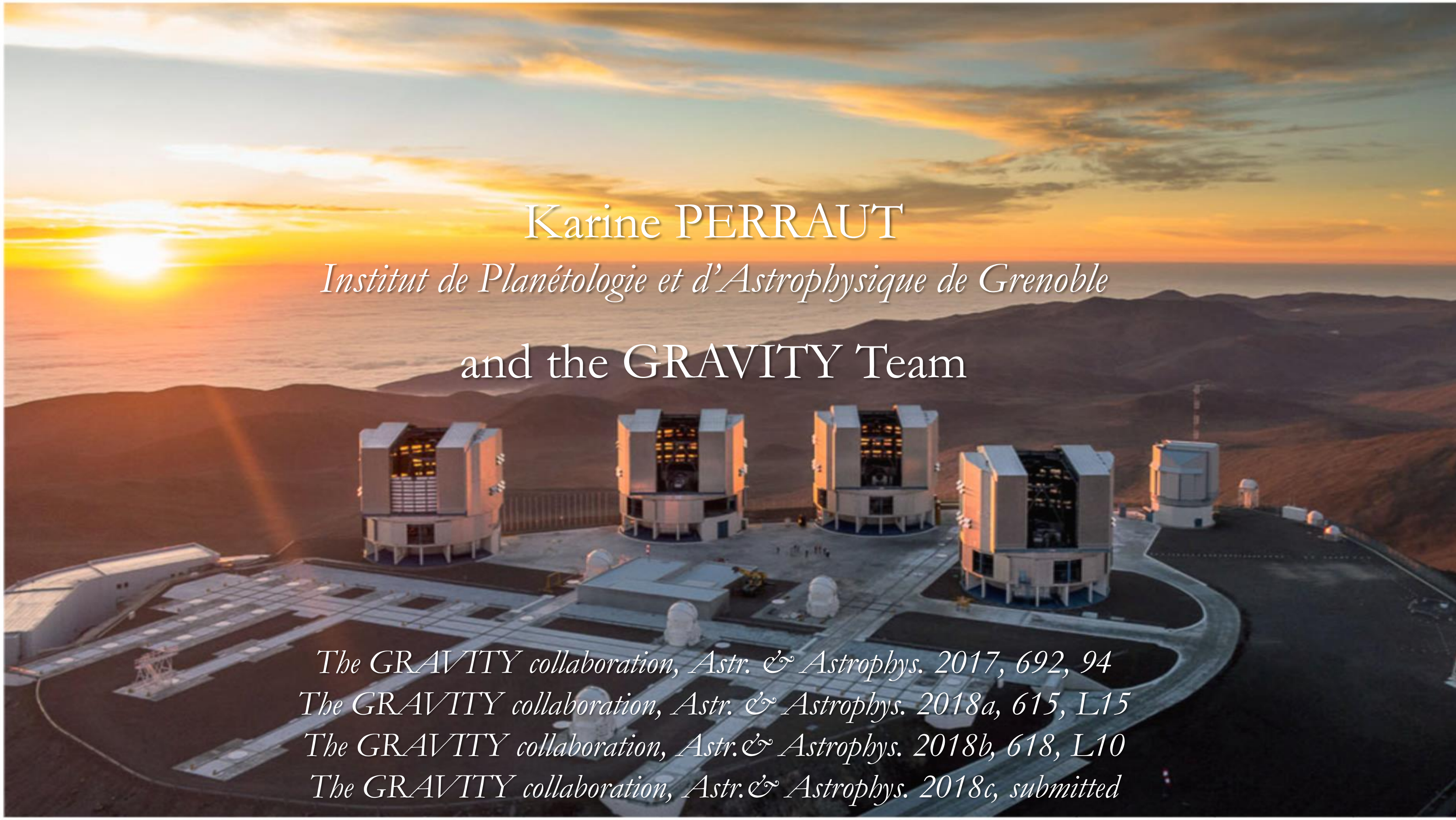
Le Centre Galactique vu par l'instrument GRAVITY du VLTI



Karine PERRAUT

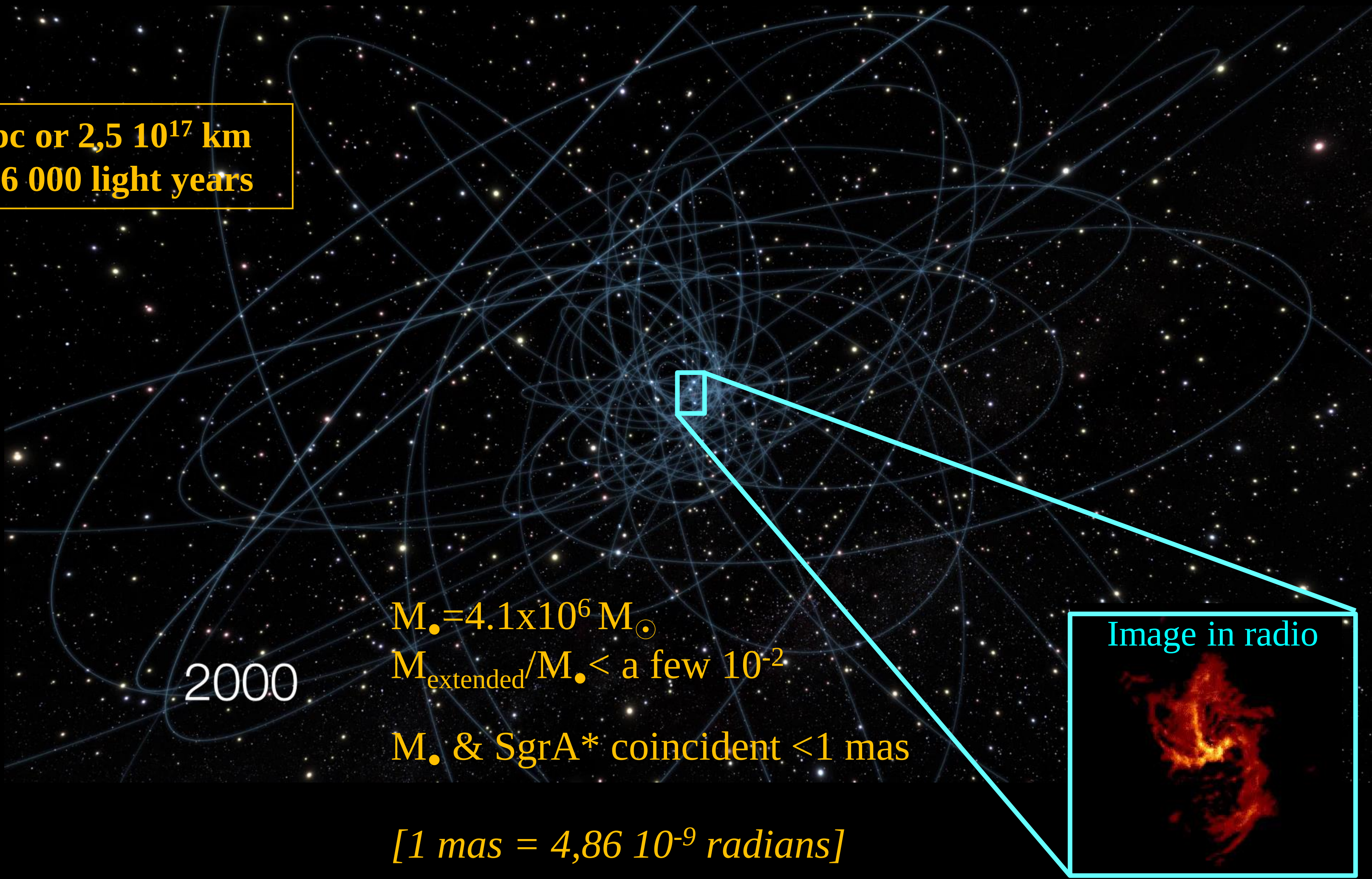
Institut de Planétologie et d'Astrophysique de Grenoble

and the GRAVITY Team

The GRAVITY collaboration, Astr. & Astrophys. 2017, 692, 94
The GRAVITY collaboration, Astr. & Astrophys. 2018a, 615, L15
The GRAVITY collaboration, Astr.& Astrophys. 2018b, 618, L10
The GRAVITY collaboration, Astr.& Astrophys. 2018c, submitted

Testing the Massive Black Hole Paradigm from Stellar Orbits in the Galactic Center

8 kpc or 2,5 10^{17} km
or 26 000 light years



$M_\bullet = 4.1\text{x}10^6\ M_\odot$
$M_{extended}/M_\bullet <$ a few 10^{-2}

$M_\bullet$ & SgrA* coincident <1 mas

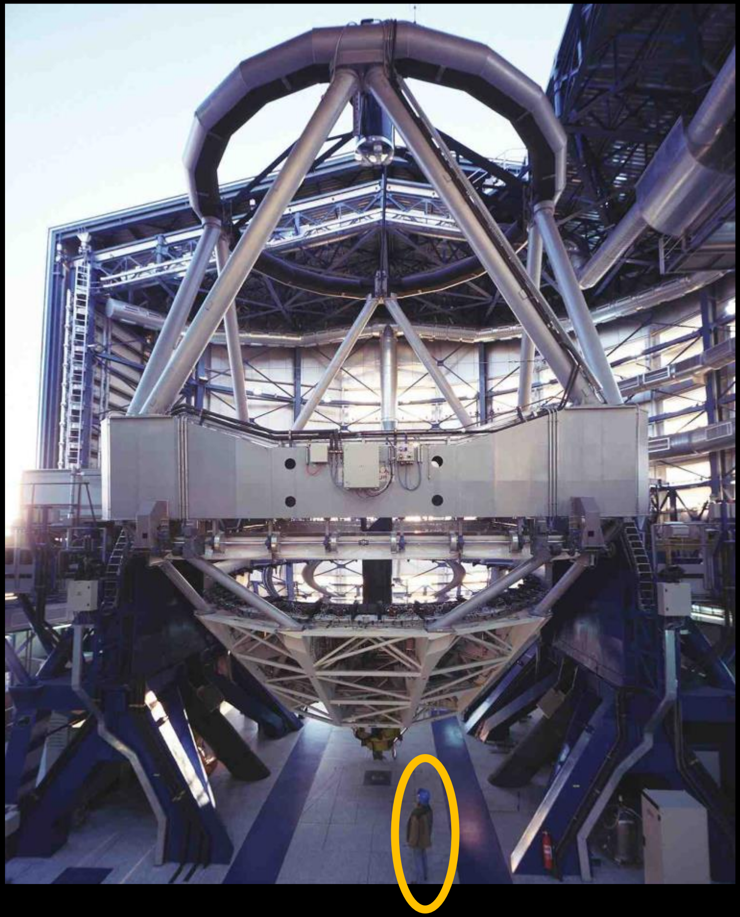
[1 mas = 4,86 10^{-9} radians]

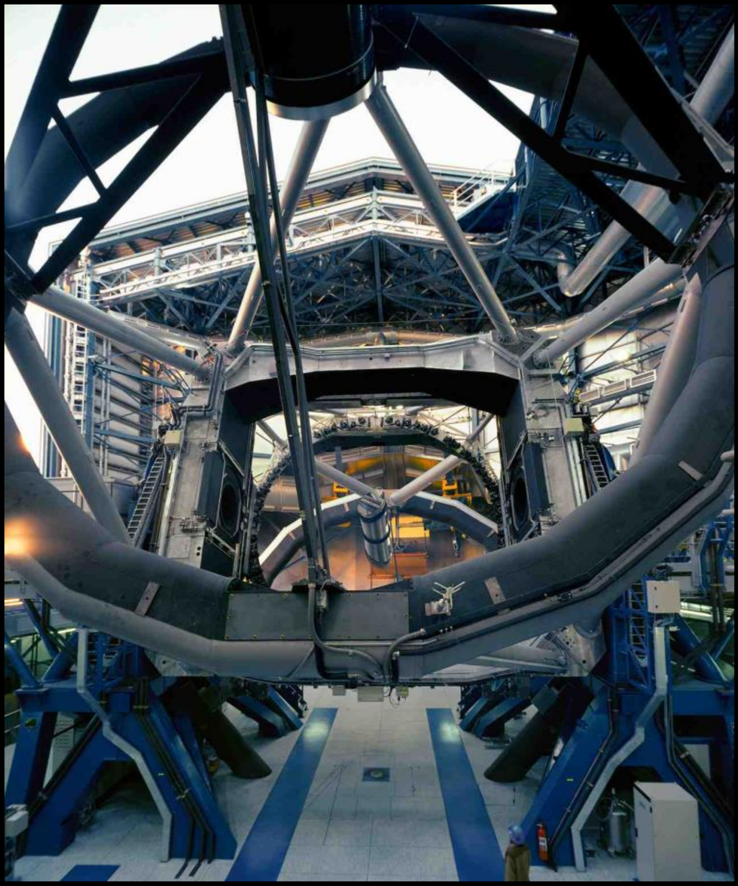
Schödel +02, +03, Ghez et al. +03, +08, Eisenhauer +03, +05, Gillessen +09a,b, +17, Meyer +12, Chatzopoulos +15, Fritz +17, Plewa +16


A Quest of 3 Decades
Imaging
NACO
Spectrometry
SHARP @ NTT
SINFONI
PARSEC
λ = [2.0 ; 2.5 μm]
GRAVITY
The ESO Very Large Telescope

The VLT, *Very Large Telescope*
Cerro Paranal, Chile

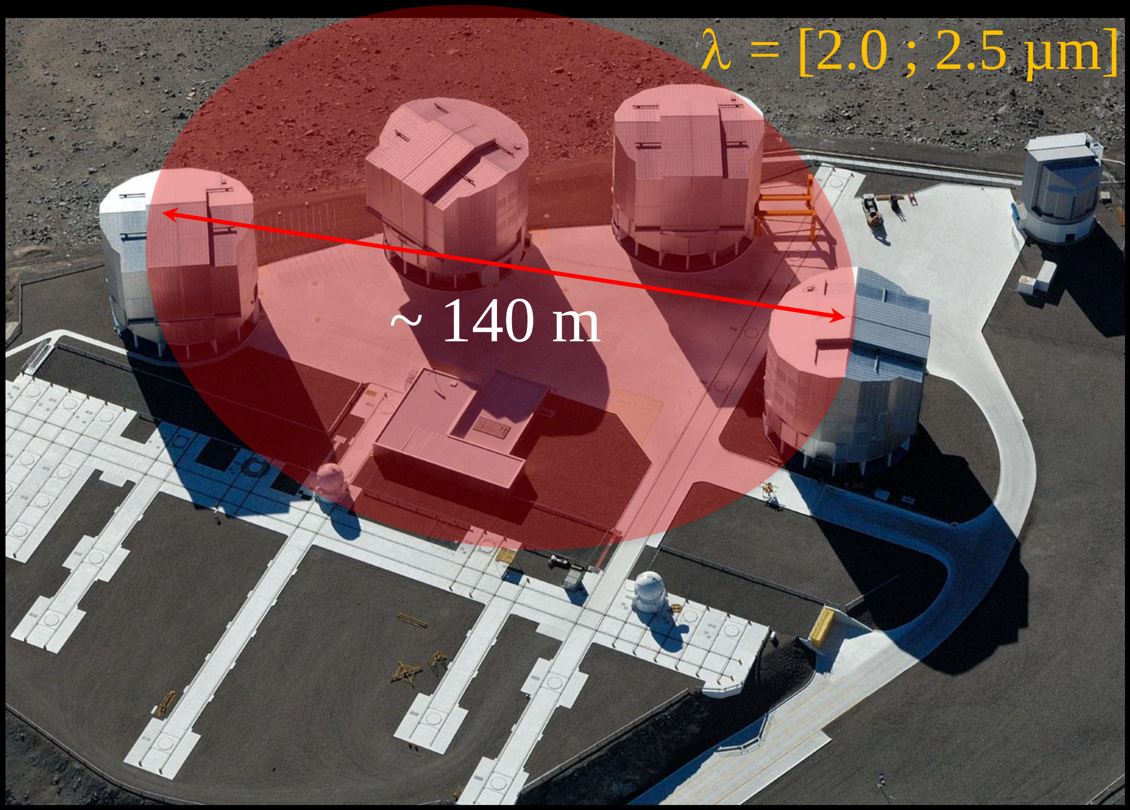
One of the 8.20-m telescopes of the VLT





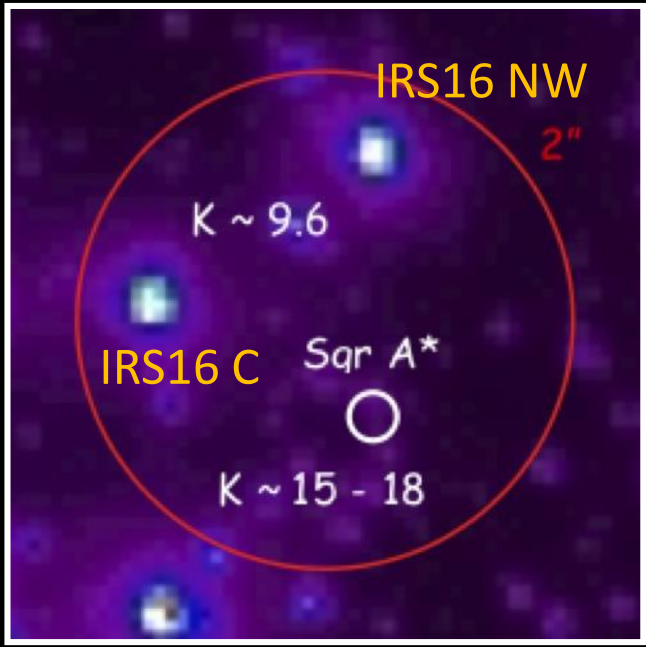
GRAVITY has combined 4 telescopes since 2016

Interferometry
to synthetize a giant mirror of 140 m



Angular resolution of 3.5 mas @ 2.2 µm

Astrometry
with 2 reference stars



Accuracy ~ a few 10µas


MPE
Max-Planck-Institut für
extraterrestrische Physik

Detection of the gravitational redshift in the orbit of the star S2 near the Galactic centre massive black hole

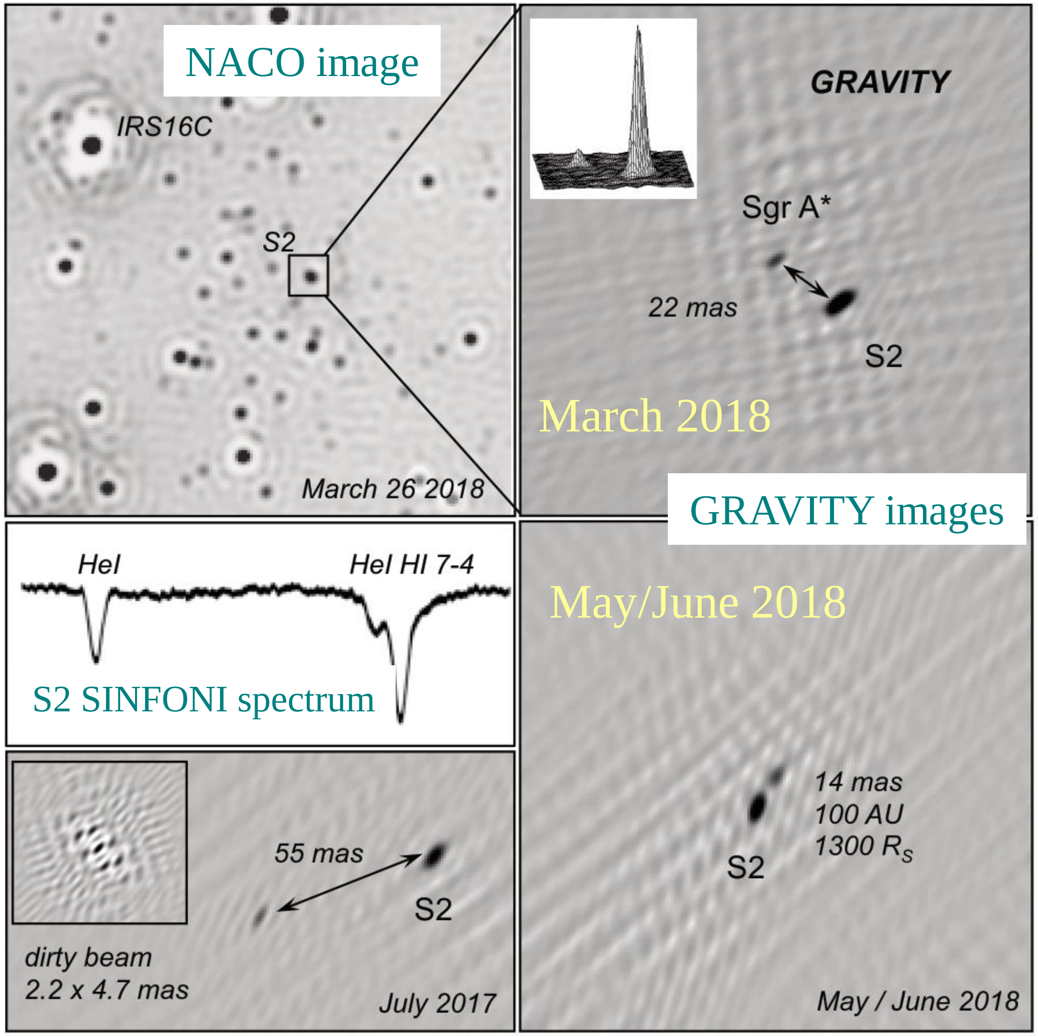
GRAVITY Collaboration*: R. Abuter[8], A. Amorim[6,14], N. Anugu[7], M. Bauböck[1], M. Benisty[5], J.P. Berger[5,8], N. Blind[10], H. Bonnet[8], W. Brandner[3], A. Buron[1], C. Collin[2], F. Chapron[2], Y. Clénet[2], V. Coudé du Foresto[2], P.T. de Zeeuw[12,1], C. Deen[1], F. Delplancke-Ströbele[8], R. Dembet[8,2], J. Dexter[1], G. Duvert[5], A. Eckart[4,11], F. Eisenhauer[1], G. Finger[8], N.M. Förster Schreiber[1], P. Fédou[2], P. Garcia[7,14], R. Garcia Lopez[3], F. Gao[1], E. Gendron R. Genzel[1,13], S. Gillessen[1], P. Gordo[6,14], M. Habibi[1], X. Haubois[9], M. Haug[8], F. Haußmann[1], Th. Henning[3], S. Hippler[3], M. Horrobin[4], Z. Hubert[2,3], N. Hubin[8], A. Jimenez Rosales[1], L. Jochum[8], L. Jocou[5], A. Kaufer[9], S. Kellner[11], S. Kendrew[3], P. Kervella[2], Y. Kok[1], M. Kulas[3], S. Lacour[2], V. Lapeyrère[2], B. Lazareff[5], J.-B. Le Bouquin[5], P. Léna[2], M. Lippa[1], R. Lenzen[3], A. Mérand[8], E. Müller[8,3], U. Neumann[3], T. Ott[1], L. Palanca[9], T. Paumard[2], L. Pasquini[8], K. Perraut[5], G. Perrin[2], O. Pfuhl[1], P.M. Plewa[1], S. Rabien[1], A. Ramírez[9], J. Ramos[3], C. Rau[1], G. Rodríguez-Coira[2], R.-R. Rohloff[3], G. Rousset[2], J. Sanchez-Bermudez[9,3], S. Scheithauer[3], M. Schöller[8] N. Schuler[9], J. Spyromilio[8], O. Straub[2], C. Straubmeier[4], E. Sturm[1], L.J. Tacconi[1], K.R.W. Tristram[9], F. Vincent[2], S. von Fellenberg[1], I. Wank[4], I. Waisberg[1], F. Widmann[1], E. Wieprecht[1], M. Wiest[4], E. Wiezorrek[1], J. Woillez[8], S. Yazici[1,4], D. Ziegler[2], and G. Zins[9]

(Affiliations can be found after the references)

This paper is dedicated to Tal Alexander, who passed away about a week before the pericentre approach of S2

Revised version following feedback from the language editor, July 3, 2018

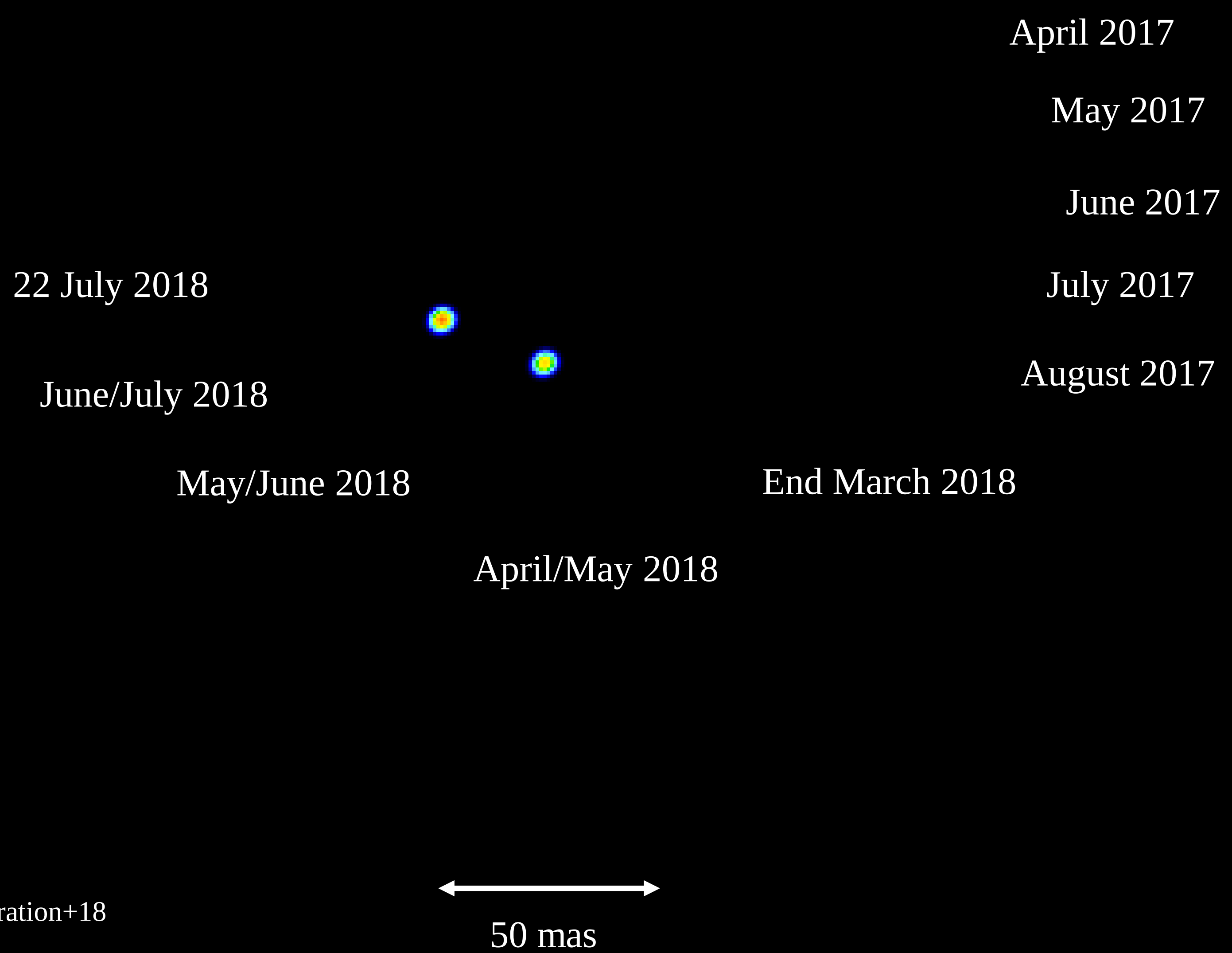
Precision Measurements of S2 Orbit with GRAVITY, SINFONI & NACO



GRAVITY collaboration+18, A&A, 615, L15

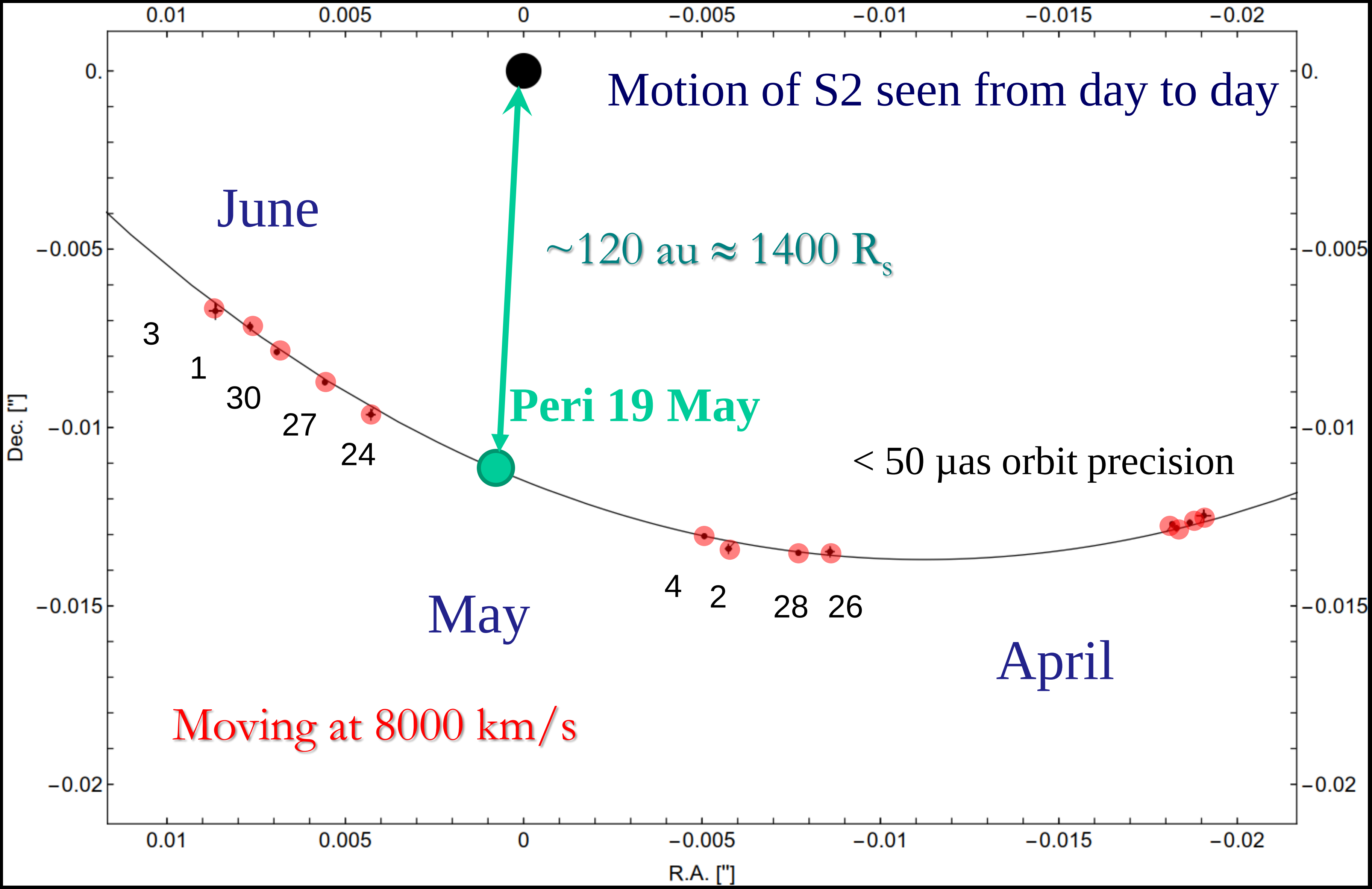
1 mas = 4,86 10-9 radians

Routine Faint Milli-arcsec Imaging with GRAVITY



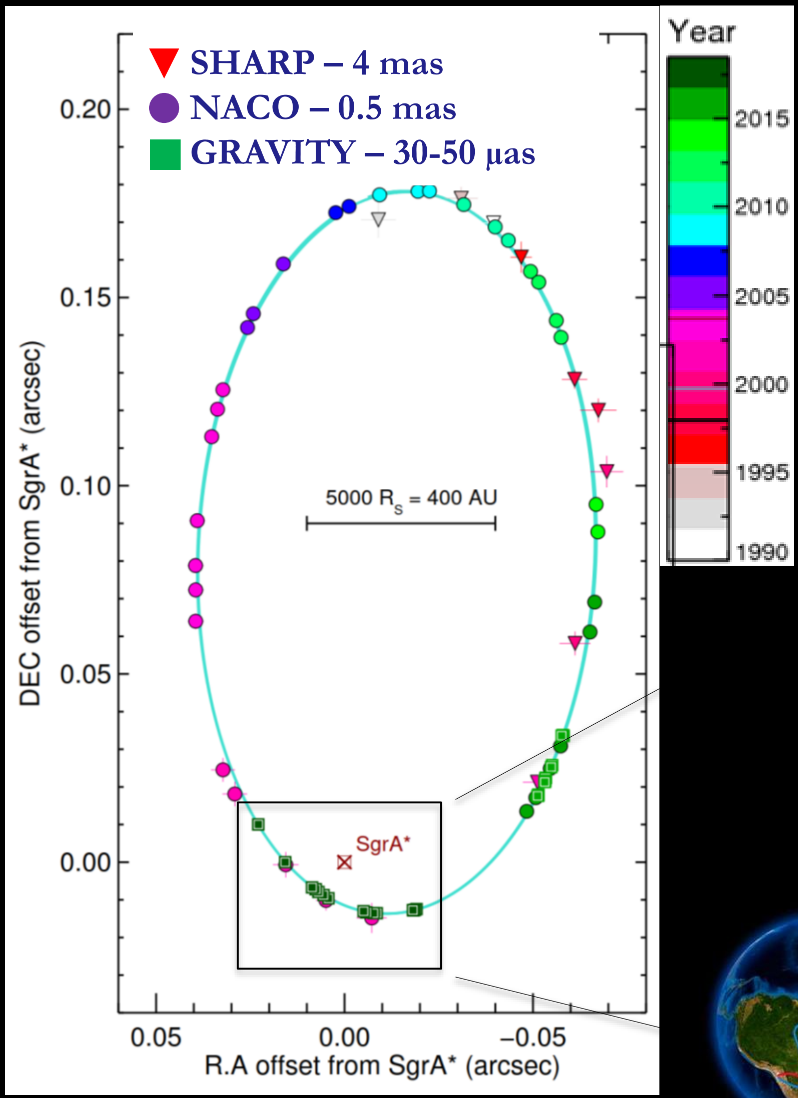
GRAVITY collaboration+18

S2 Passing Peri – 19 May 2018

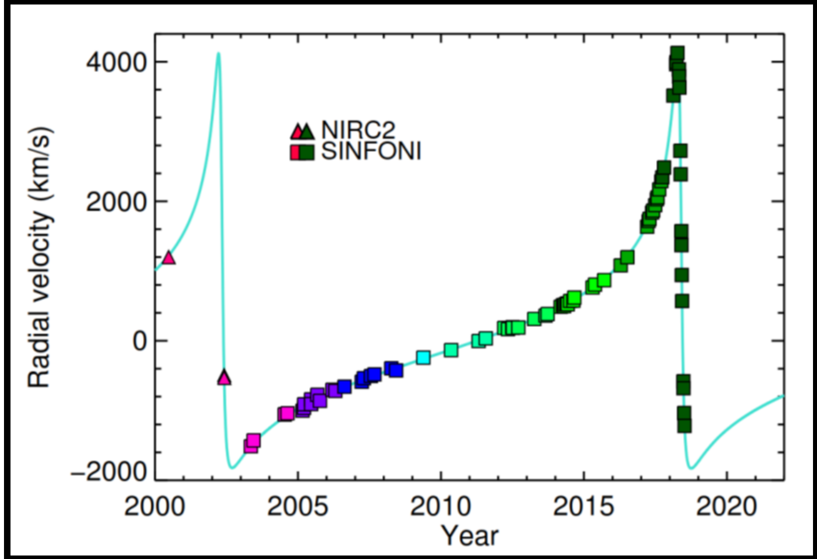


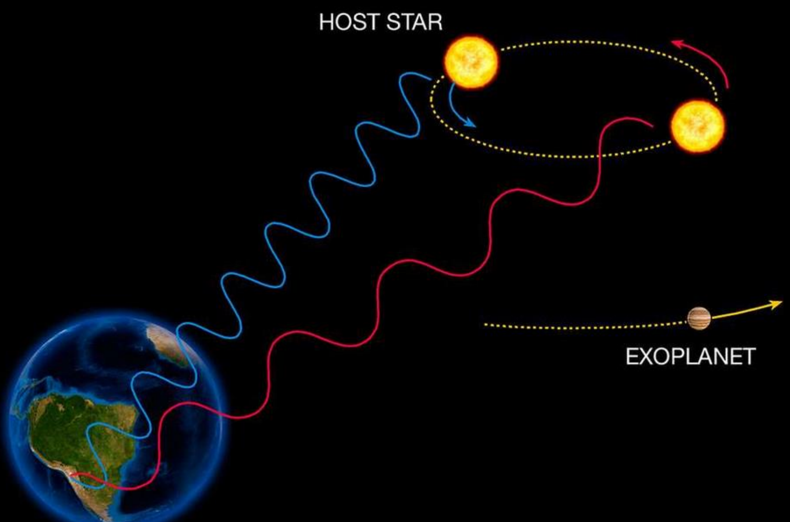
Look for Gravitational Redshift in S2's Orbit

Orbit



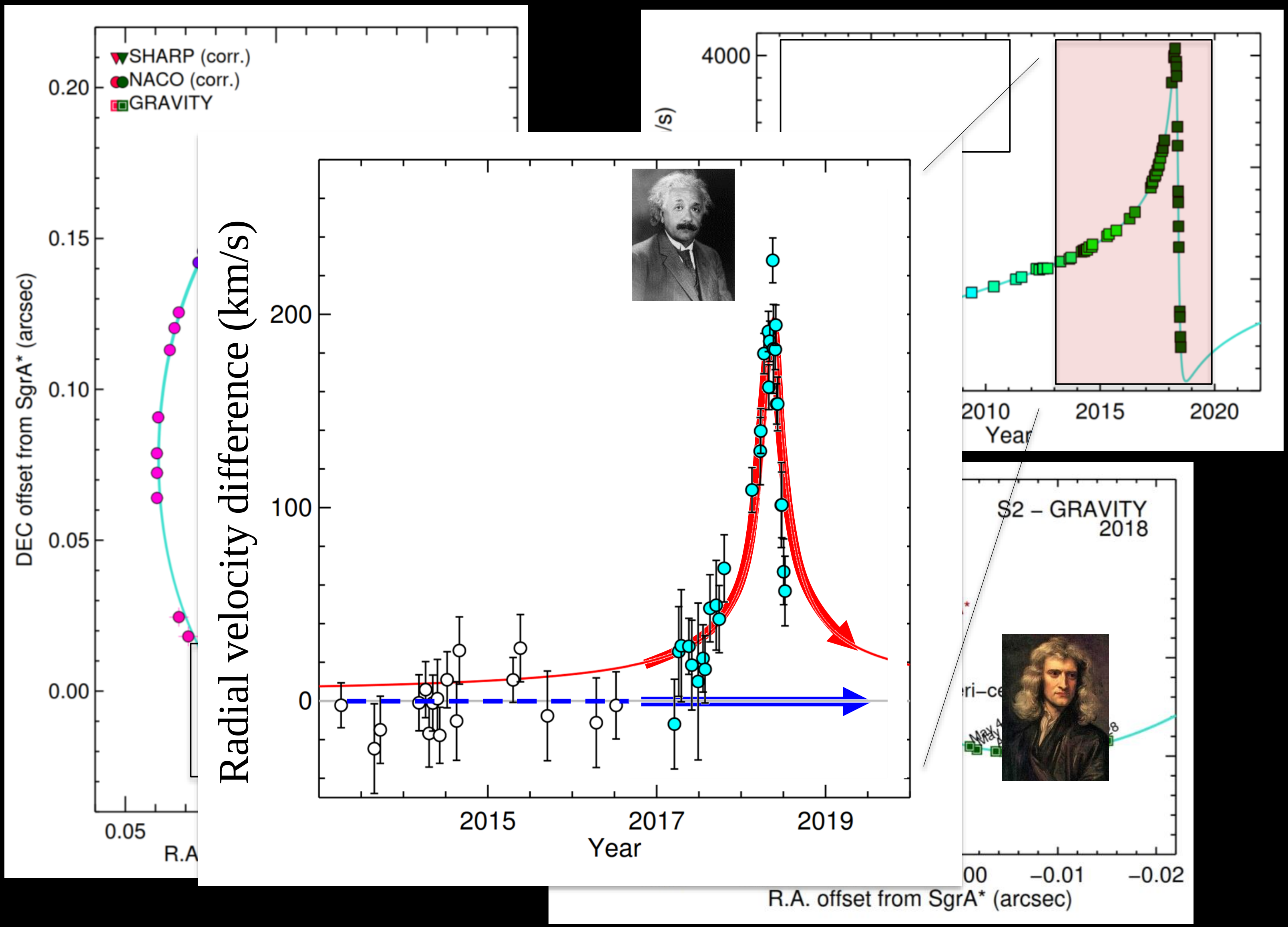
Radial velocities



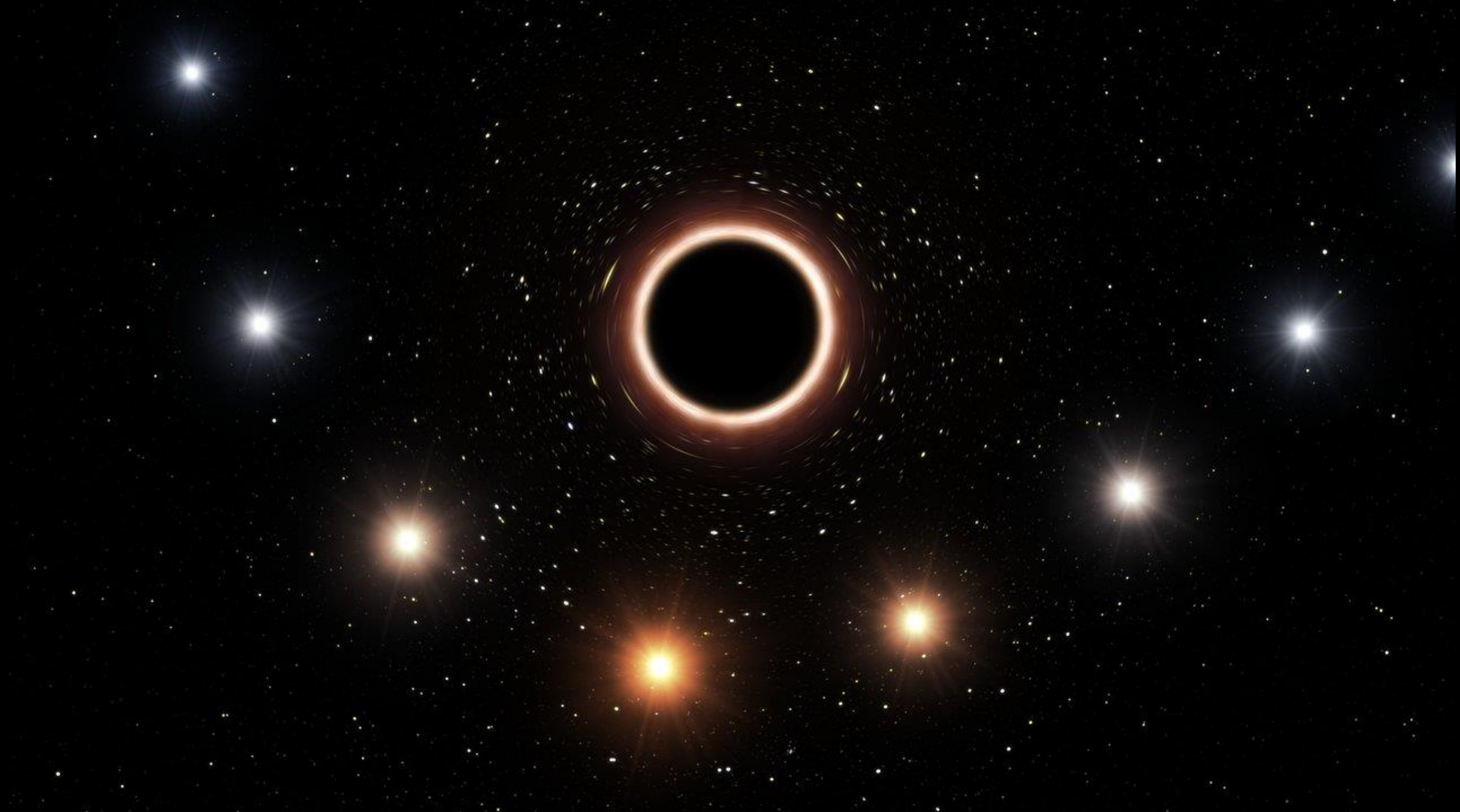


GRAVITY collaboration+18a, A&A, 615, L15

Look for Gravitational Redshift in S2's Orbit



Gravitational Redshift in S2's Orbit



Light stretched to longer wavelengths by the very strong gravitational field of the black hole.

Change in wavelength agrees precisely with that predicted by Einstein's GR theory.

First observation of this deviation in the motion of a star around a supermassive black hole.

Detection of orbital motions near SgrA*s ISCO

Detection of Orbital Motions Near the Last Stable Circular Orbit of the Massive Black Hole SgrA*

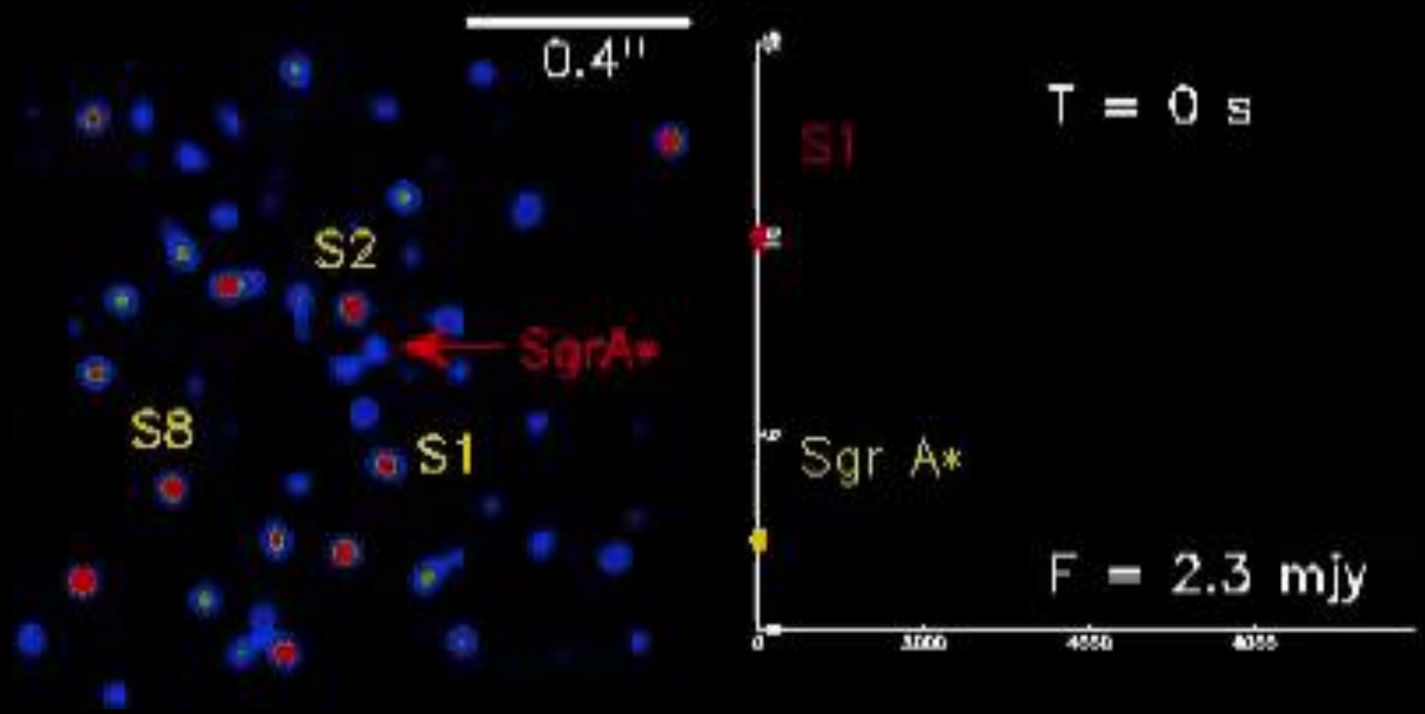
GRAVITY Collaboration*: R. Abuter[8], A. Amorim[6,14], M. Bauböck[1], J.P. Berger[5], H. Bonnet[8], W. Brandner[3], Y. Clénet[2], V. Coudé du Foresto[2], P.T. de Zeeuw[10,1], C. Deen[1], F. Delplancke-Ströbele[8], J. Dexter[1], G. Duvert[5], A. Eckart[4,13], F. Eisenhauer[1], N.M. Förster Schreiber[1], P. Garcia[7,14], F. Gao[1], E. Gendron[2], R. Genzel[1,11], S. Gillessen[1], M. Habibi[1], X. Haubois[9], Th. Henning[3], S. Hippler[3], M. Horrobin[4], A. Huber[3], N. Hubin[8], A. Jimenez Rosales[1], L. Jochum[8], L. Jocou[5], A. Kaufer[9], P. Kervella[2], S. Lacour[2,1], V. Lapeyrère[2], B. Lazareff[5], J.-B. Le Bouquin[5], P. Léna[2], M. Lippa[1], T. Ott[1], J. Panduro[3], L. Pasquini[8], T. Paumard[2], K. Perraut[5], G. Perrin[2], O. Pfuhl[1], P.M. Plewa[1], S. Rabien[1], G. Rodrígues-Coira[2], G. Rousset[2], M. Schöller[8], J. Spyromilio[8], A. Sternberg[12], O. Straub[2], C. Straubmeier[4], E. Sturm[1], L.J. Tacconi[1], K.R.W. Tristram[9], F. Vincent[2], S. von Fellenberg[1], I. Waisberg[1], F. Widmann[1], E. Wieprecht[1], E. Wiezorrek[1], J. Woillez[8], and S. Yazici[1,4]

(Affiliations can be found after the references)

Draft Sept 19, 2018 (sgr_20180918_v07)

Baganoff +2001, Genzel et al. 2003, Ghez et al. 2004, Do et al. 2008, Dodds-Eden et al. 2009, 2010, Ponti et al. 2017, Witzel et al. 2018, Broderick & Loeb 2006, Hamaus et al. 2009, Markoff et al. 2001, Yuan et al. 2004, Moscibrodzka et al. 2015, Dexter et al. 2013, Doeleman et al. 2008, Broderick et al. 2011, Johnson et al. 2017

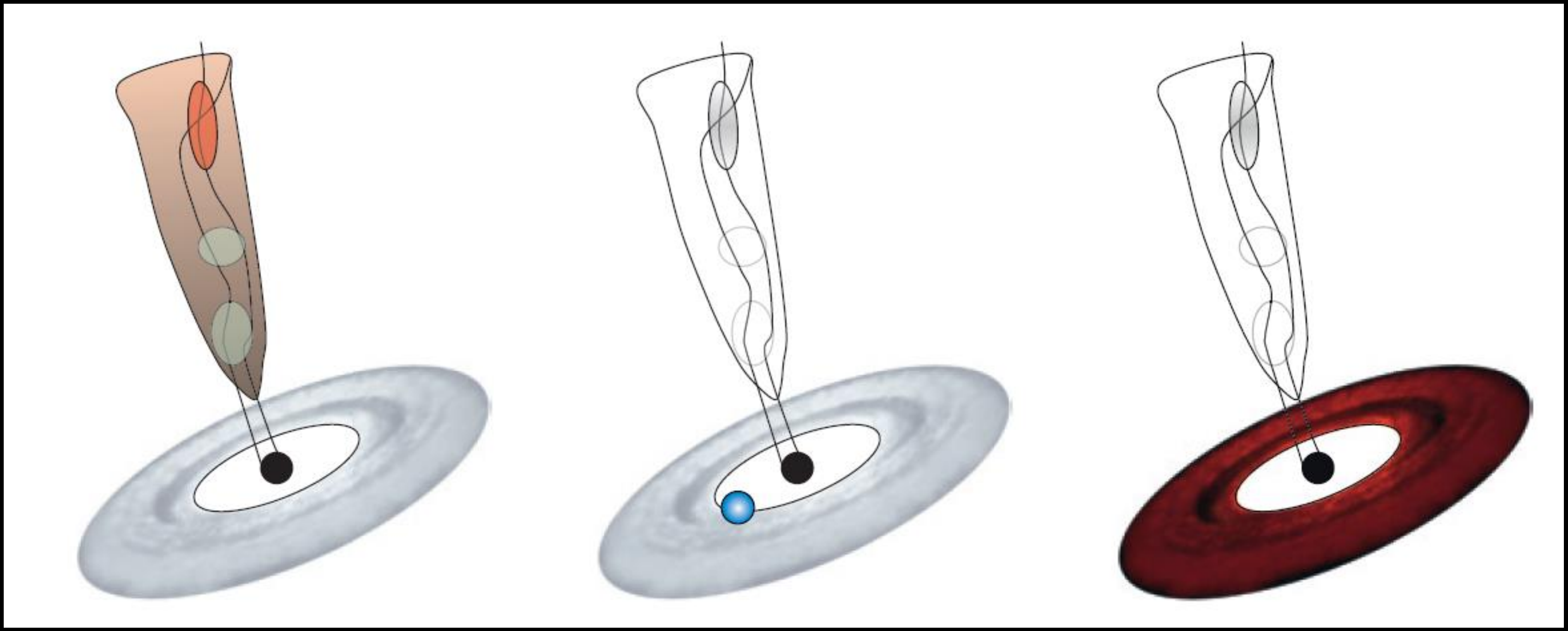
Looking at the flares in the near-infrared



In addition to the radio emission, variable X and infrared emission appears as « flares » several times per day during 1-2 hours.

The flares originate from transiently heated electrons of the inner accretion and outflow region but their origin is still matter of debate.

Different flare models



Material blobs ejected in a jet

Hot spot on the closest stable orbit

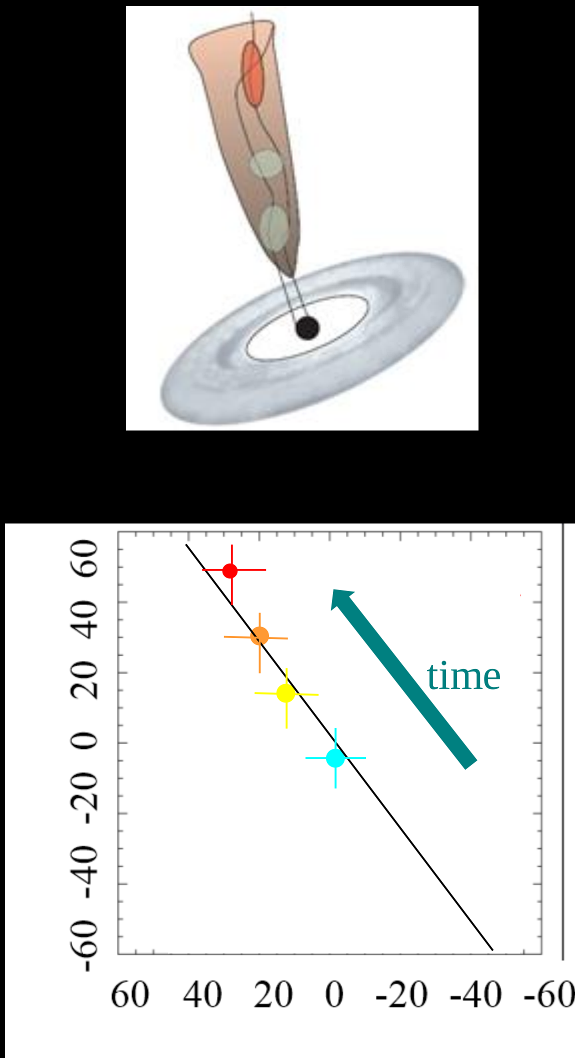
Statistical fluctuations in the accretion flow

Similar to AGN jets

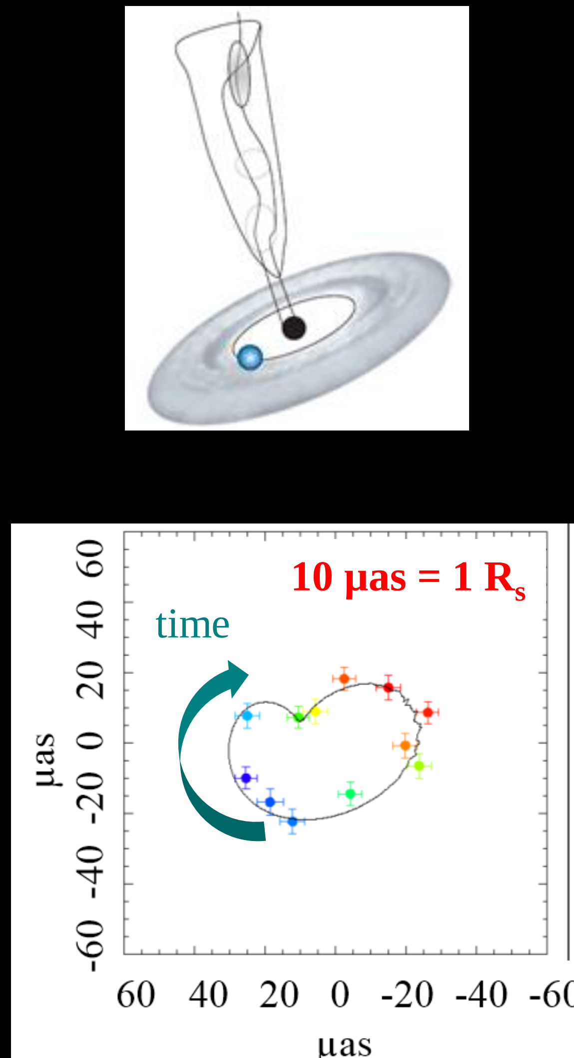
Consistent with the light curve in the near-infrared and the polarization changes

Consistent with the long-term variations of the light curve

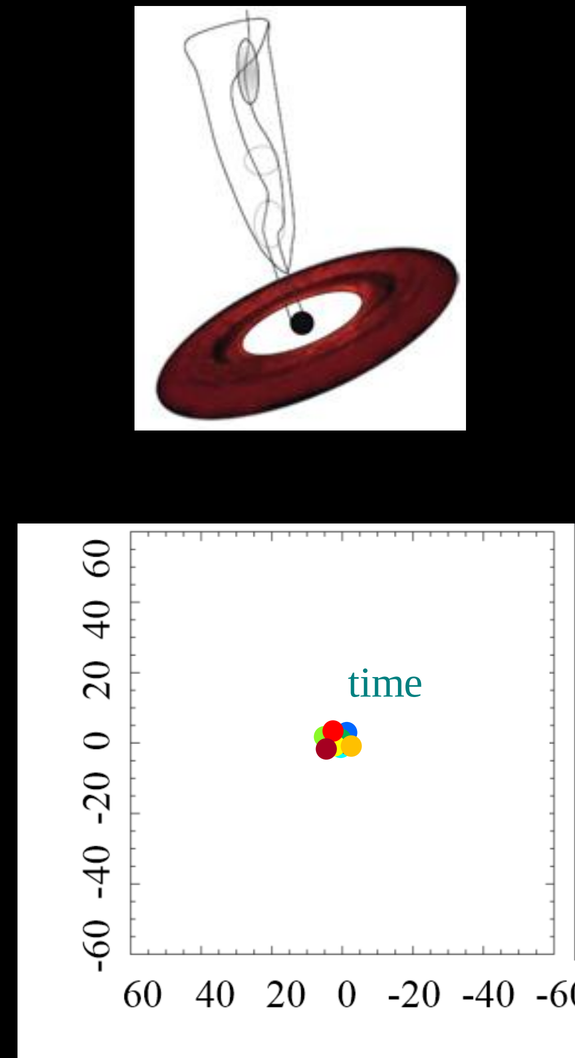
On-sky centroid positions



Jet

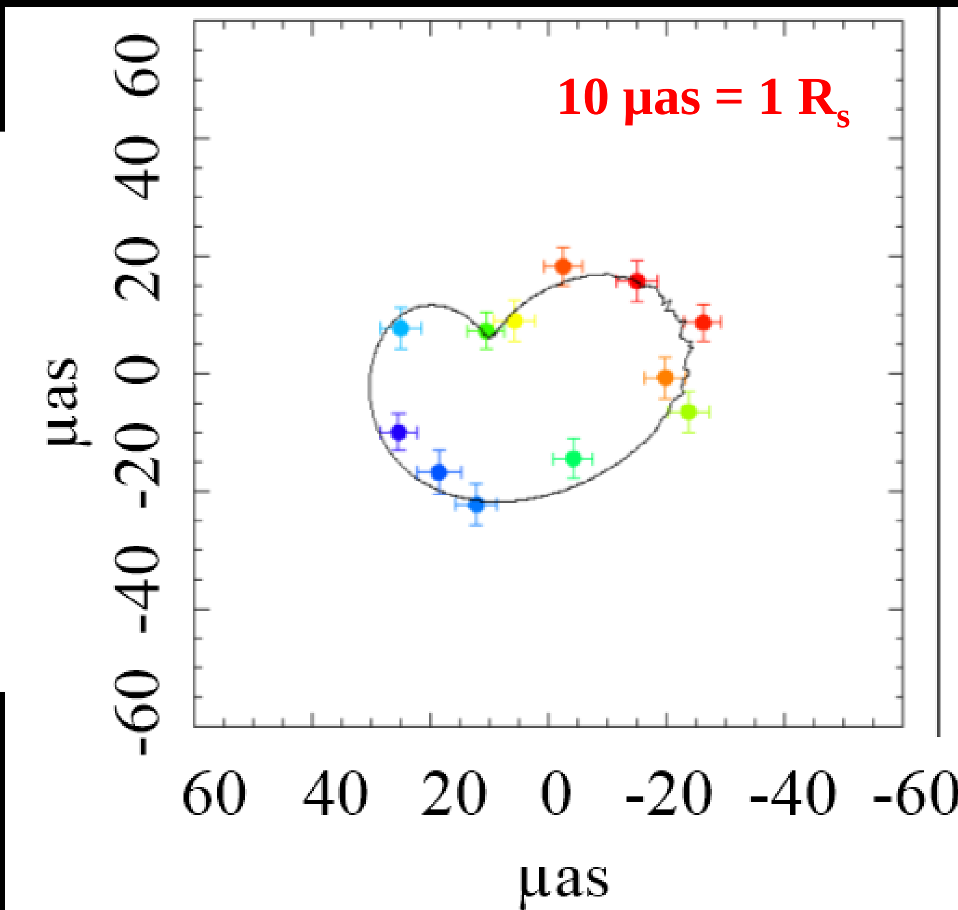


Hot spot model

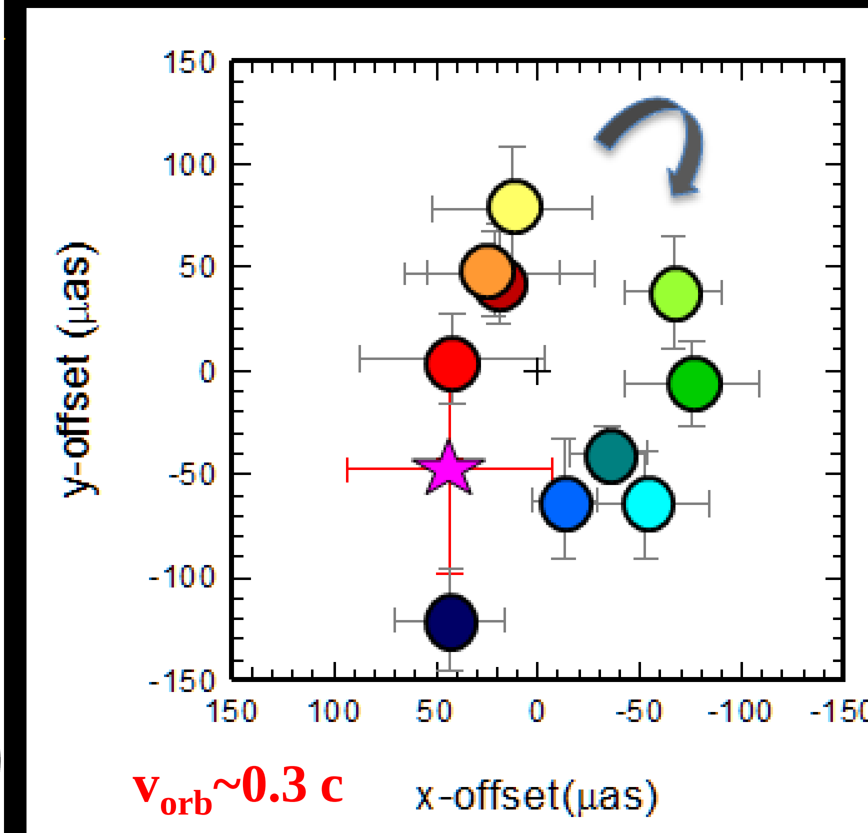


Statistical fluctuations

Centroid positions measured with GRAVITY



Positions recorded with GRAVITY

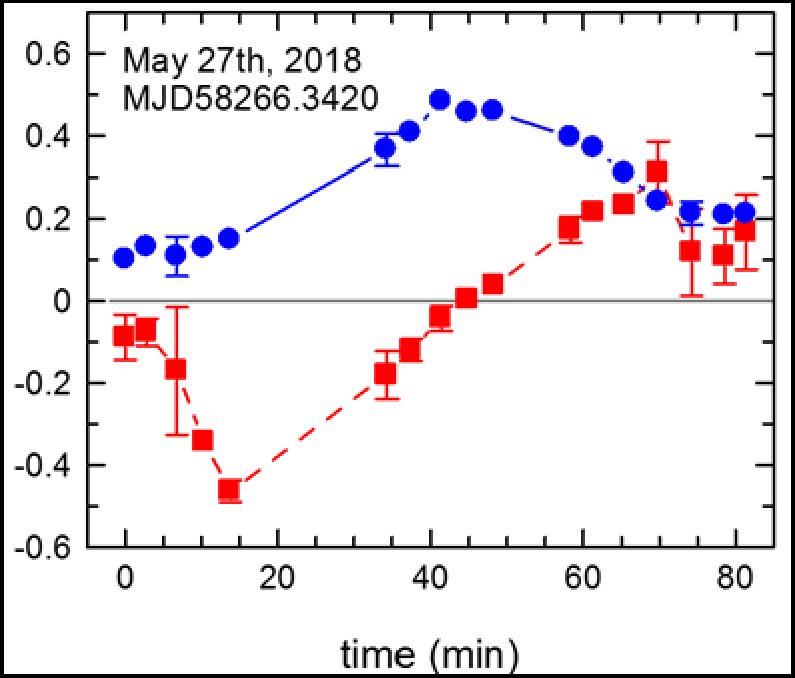


GRAVITY measurements
July 22nd, 2018

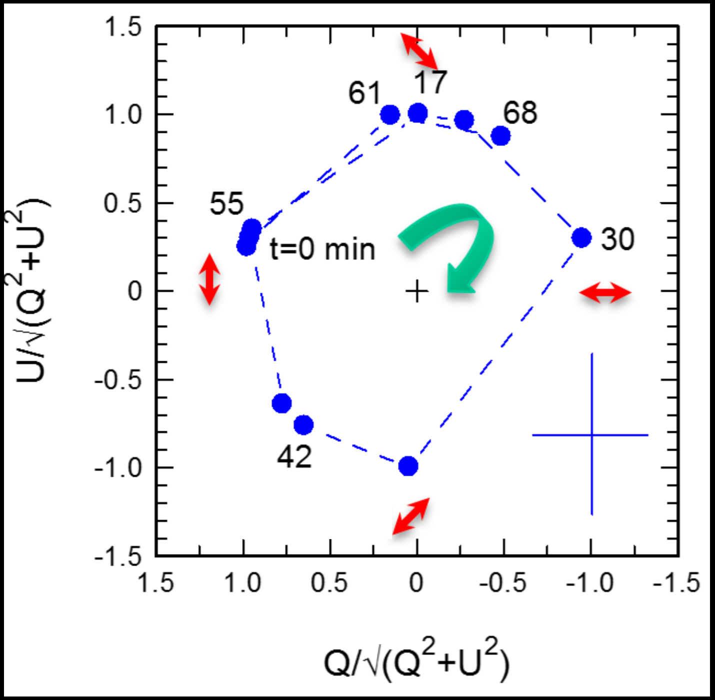
⇒ Consistent with the hot spot model

GRAVITY detection of polarization loops

Total flux **Flux in linear polarization**
(normalized to S2 flux)



Polarization loop with time

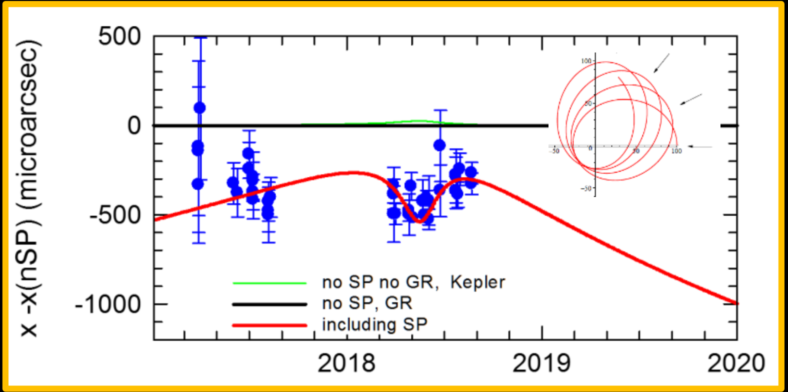


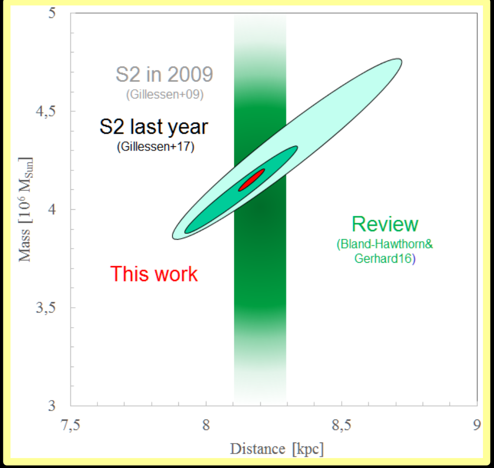
Several flare observations are consistent with the same parameters

⇒ Provide information on inclination (low), magnetic field (poloidal), …

Conclusion and perspectives

- Sgr A*:
  - The « largest » black hole we can study
  - A unique lab to study GR
- GRAVITY:
  - Fantastic instrument to do that
  - Very complementary to other diagnosis
  - Application to AGN





Next steps starting in March 2019:

- Look for other stars around SgrA*, closest than S2
- Look at new flares
- Look for higher order effects (Schwarzschild precession, Lense-Thirring effects) to better constrain the black hole parameters and physics

Mass = $4.144_{0.023} \times 10^6$ (6×10^{-3} precision)
Distance = 8174_{20} pc (2×10^{-3})