Scientific Highlights of GRAVITY/VLT

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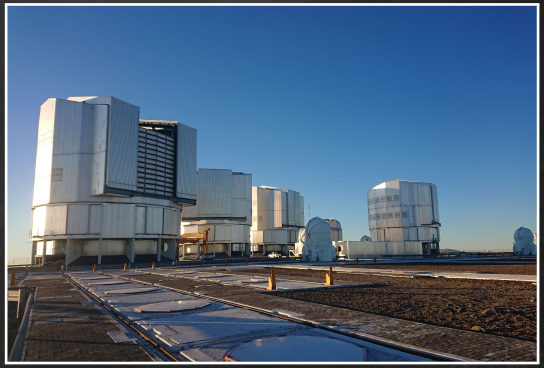
ORIGINS Excellence Cluster, MPE

FERO 10, Toulouse, 01. April 2022

People behind (and in front of) GRAVITY/VLT

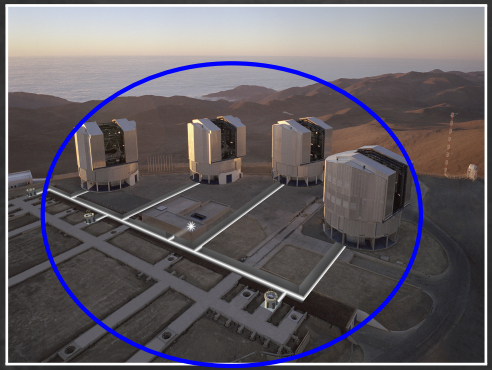
What is GRAVITY/VLT?

Cerro Paranal from La Residencia (2019)



The Very Large Telescope (VLT, 2019).
UTs: 8.2m & ATs: 1.8m

What is GRAVITY/VLT?



(ESO)

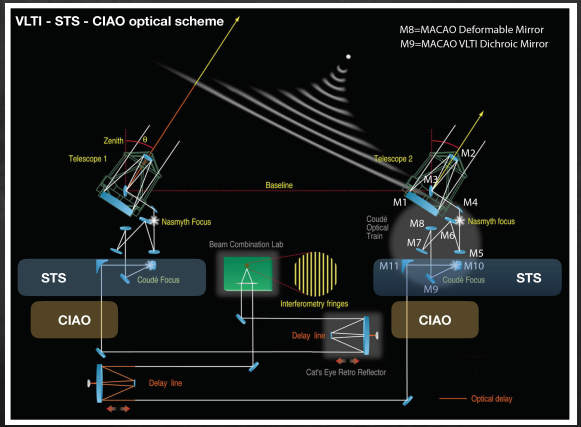
IR interferometer at the VLT.

GRAVITY is a beam combiner.

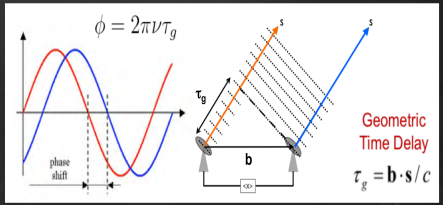
Combines light of 4 telescopes. Spatial resolution $R = 1.22\frac{\lambda}{D}$ of an equivalent telescope of D = 130 m, for the K-band, λ = 2.0 - 2.4 μm, i.e. about 3 mas.

How does GRAVITY/VLT work?

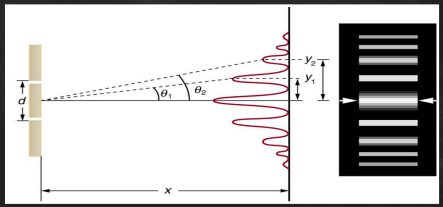
Interferometry: fringe contrast (= visibility) & phase (shift)



(ESO)



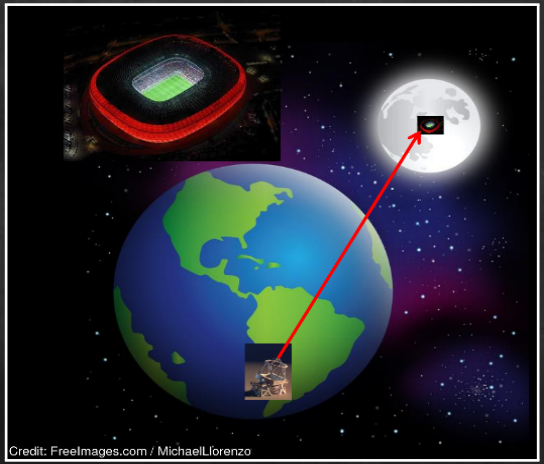
(MPIfR/Klöckner)



(MIT)

How does GRAVITY/VLT work?

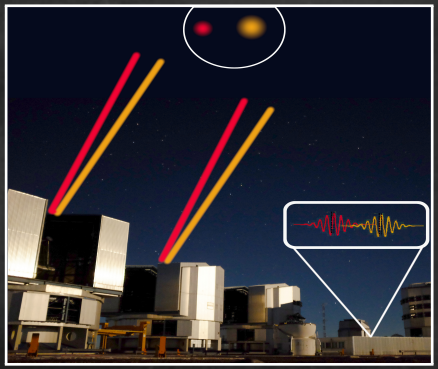
Requirements: resolve orbit of the star S2 - on the Moon, resolve size of a football field.



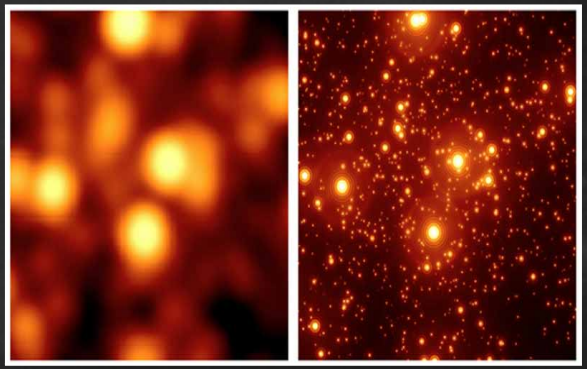
GRAVITY: could see a 1 Euro coin in a football field on the Moon!

How does GRAVITY/VLT work?

Fringe Tracking (FT) & Adaptive Optics (AO): enhance CONTRAST & RESOLUTION
→ stabilise fringes + correct atmospheric distortions!



phase referencing with FT star

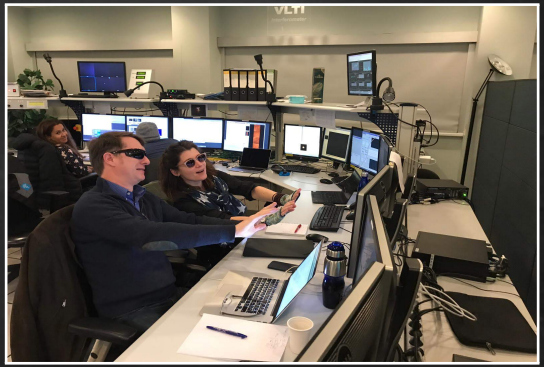


AO with natural guide star

How does GRAVITY/VLT work?

People in the VLTI Control Room

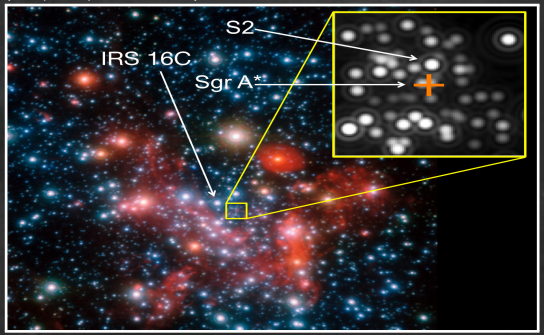
when Frank Eisenhauer is teaching (2017)



when $\mathrm{Sgr\ A}^*$is active (2019)

Probing gravity in the Galactic Centre

(ESO/MPE/Gillessen et al)



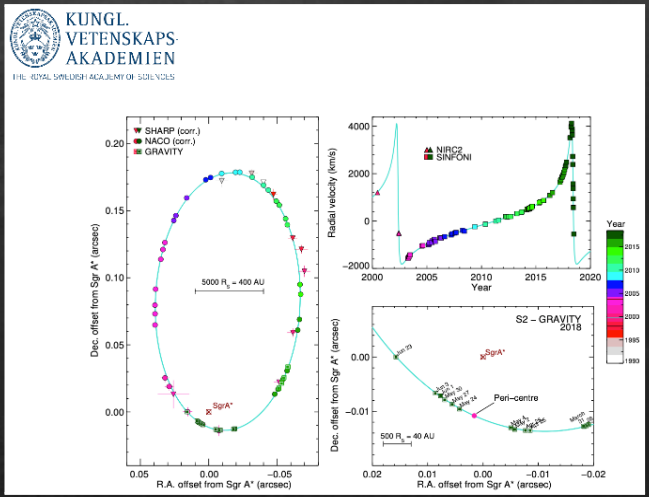
(NASA/CXC/Amherst College/Haggard et al)

- ⋆ S-stars: nuclear star cluster with semi-major ax. $sma \approx 100 - 800$ mas
- ⋆ Sgr A*: biggest BH in the sky - apparent size $d \approx 53\,\mu$as for $a_* = 0$,
  → shows variability (flaring)

"...uncovering the darkest secrets"

Nobel Prize in Physics 2020

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES



1. GRAVITY in the Galactic Centre

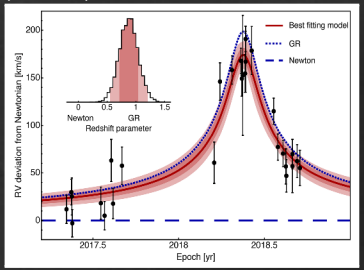
(ESO/GRAVITY Col. 2018)

$M_0 = 4.261 \pm 0.012 \times 10^6\ M_\odot$

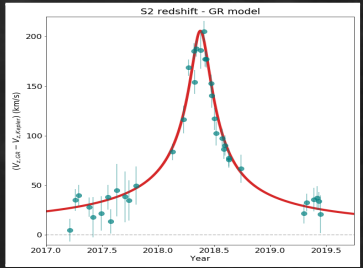
$R_0 = 8.248 \pm 0.009$ kpc

Gravitational redshift

(Do+ 2019)



(GRAVITY Col. 2018a, 2019, 2020)



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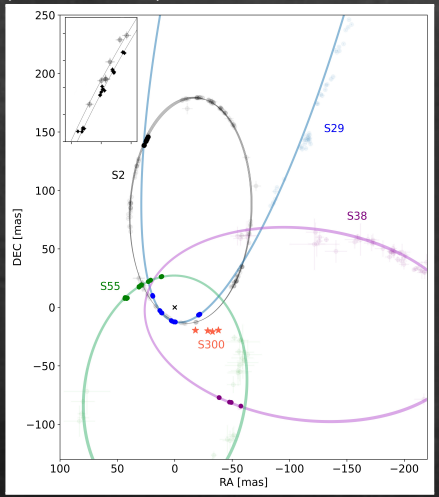
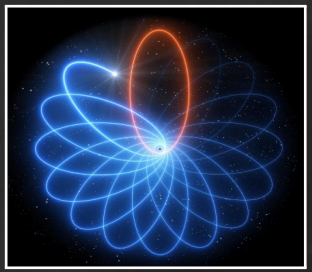
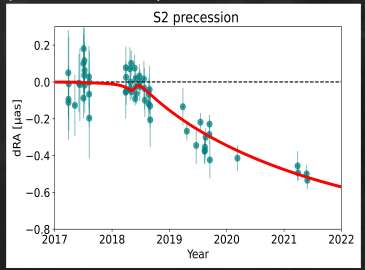
(GRAVITY Col. 2021)



Schwarzschild precession



(GRAVITY Col. 2021)



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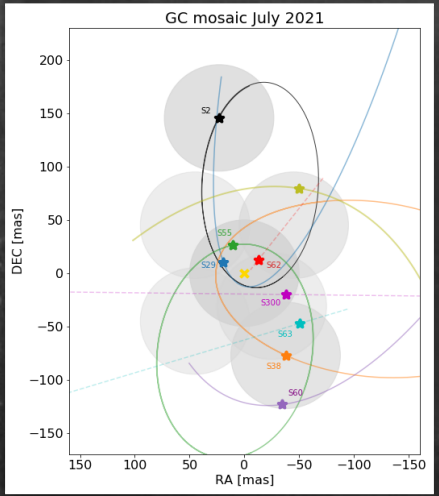
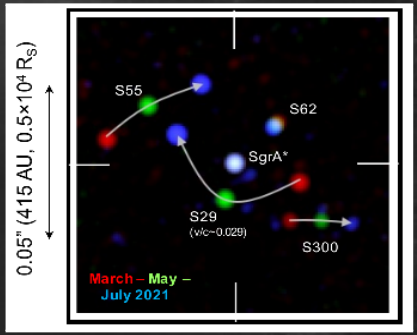


More stars:
constrain dark mass
among S-stars

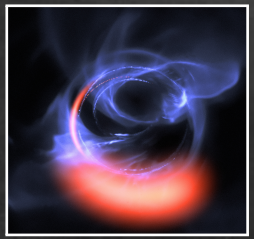
- ⋆ S29 closer at peri
- ⋆ S55 shorter period
- ⋆ S300 fast & faint (mK = 19.5)



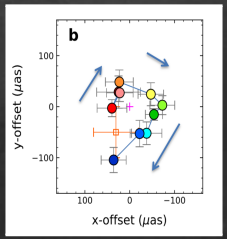
(GRAVITY Col., 2021,2022)

S300: linear motion (so far)
Search continues!

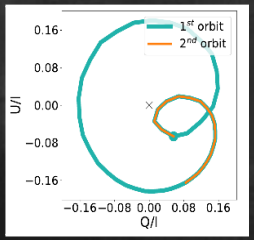
1. GRAVITY in the Galactic Centre



(ESO/Dexter)



(GRAVITY Col., 2018b)

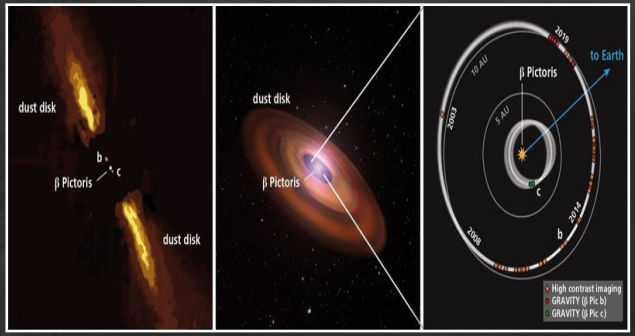


(Jimenez+, 2021)

- ⋆ Flares are recurrent bursts of radiations in the IR & X-ray
- ⋆ models: inefficient flow with hot spot, mag. reconnection (MAD?)

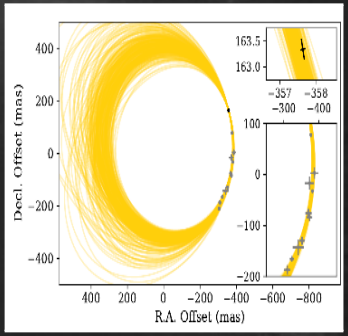
- ⋆ Why is this interesting?
  - variability ~ 30-60 min corresponds to near ISCO (strong gravity regime)!
- ⋆ Variability over the whole spectrum
- ⋆ Polarised

2. With GRAVITY... to new worlds



(GRAVITY Col. 2019a)

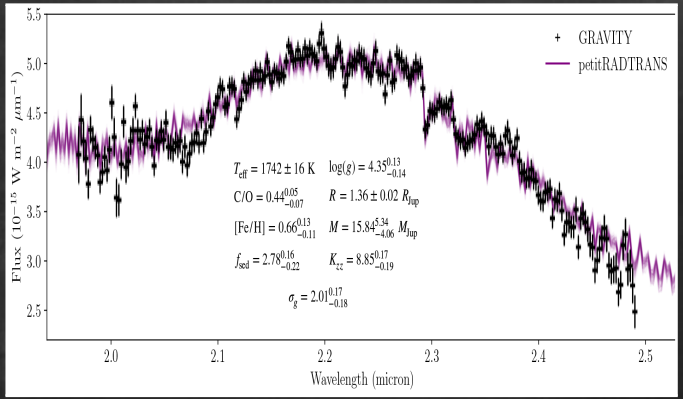
direct observation of young/hot exo-Jupiter in β Pic b



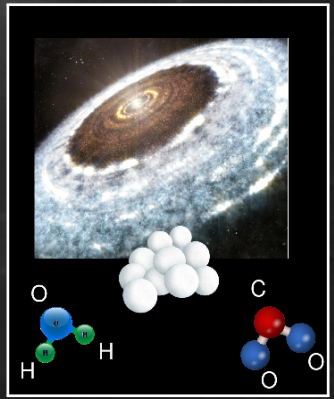
(GRAVITY Col. 2019b)

HR8977 e, one of 4 planets, still warm - star young!

2. With GRAVITY... to new worlds



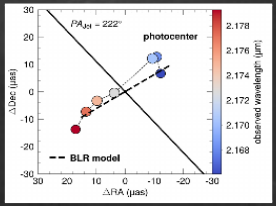
(GRAVITY Col. 2019a)



first interferometric IR spectrum of exo-planet β Pic b

planet formation: ice vs dust; high mass and low C/O ratio → core-accretion with strong (icy) planetesimal enrichment

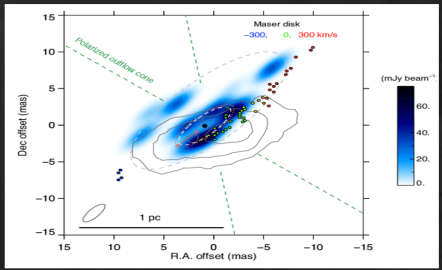
3. With GRAVITY... to other Galaxies



(Sturm+ 2018)

Ionized gas in the broad line region (BLR) of quasar 3C 273 associated to a rotating disc
direct measurement of SMBH mass: $3 \times 10^8\ M_\odot$

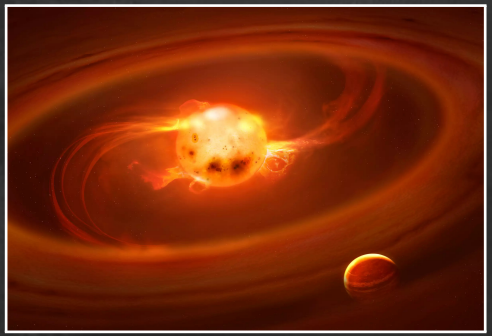
AGN NGC 1068:
hottest maser dust belongs not to geometrically and optically thick torus but to the inner rim of a thin gas & dust disc (dust sublimation region)



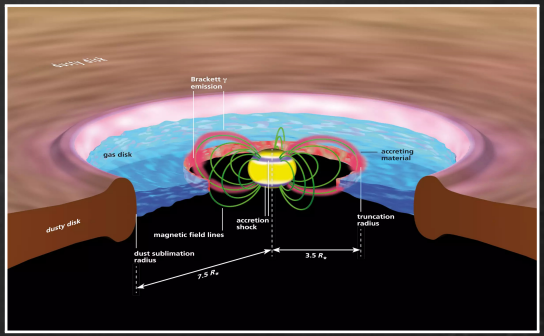
(GRAVITY Col. 2020)

4. GRAVITY and young stellar objects

Star's magnetic field directs material from accretion disc onto its surface



size of magnetospheric accretion (A.M. Garlick)



(MPIA graphics/GRAVITY Col. 2020)

5. GRAVITY... sees stars

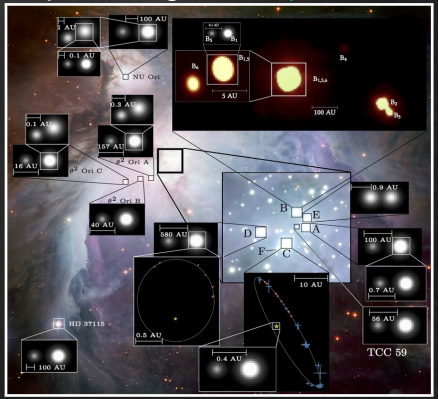
gas morphology in binaries, e.g. η Car and SS433 (HMXB!)

(ESO/G. Weigelt)

(ESO/Dong+ 2019)

two images of a microlensed source star TCP J0507+2447 ← measure angular Einstein radius

majority of massive stars in Orion Trapezium region multiple stars



(GRAVITY Col. 2018)

The future of GRAVITY

Now:

In 3 years:

The future of GRAVITY

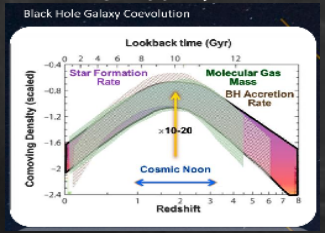
- ⋆ 2022: off-axis fringe tracking (G-wide)
- ⋆ 2024: Natural Guide Star extreme-AO
- ⋆ 2025: Laser Guide Star mode

- ⋆ Performance gain: $\mathrm{mK} = 22$,
  nearly anywhere in the galactic plane

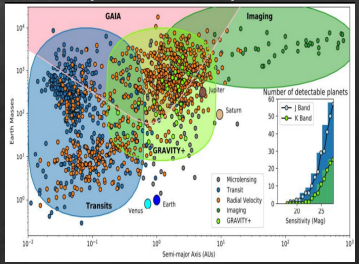
The future of GRAVITY

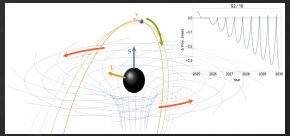
BBHs

AGN at z > 1



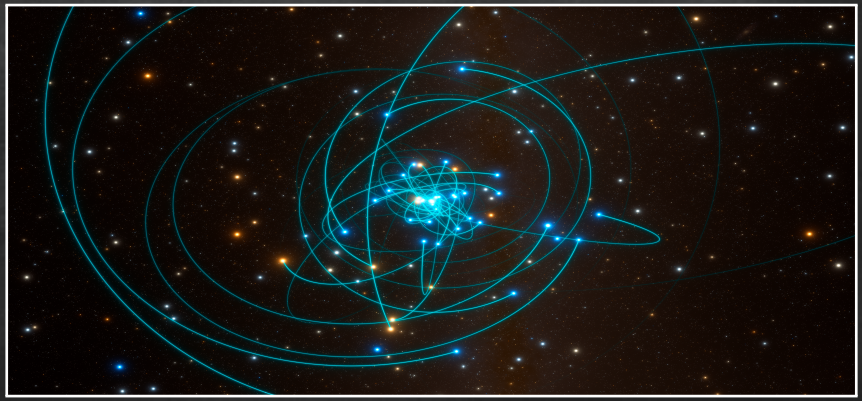
Hot Jupiters → Super-Earths





- XRBs
- Search for "S2/10" → spin of $\mathrm{Sgr\ A^*}$

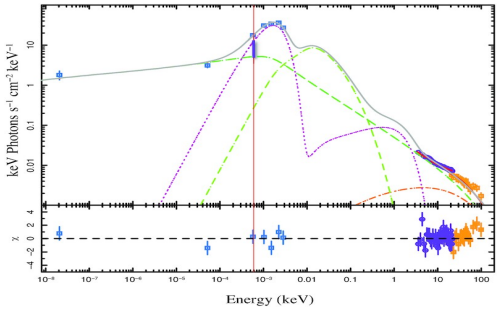
The end



(ESO)

Supplement: GRAVITY and X-ray binaries

Figure 2. An example simultaneous, broad-band spectrum from GRO J1655−40 in the hard state, from Migliari et al. ...



Mon Not R Astron Soc, Volume 495, Issue 1, June 2020, Pages 525–535, https://doi.org/10.1093/mnras/staa1193