

Optical interferometry from the Moon

Astrophysics at very high angular resolution



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Overview

- **Science**

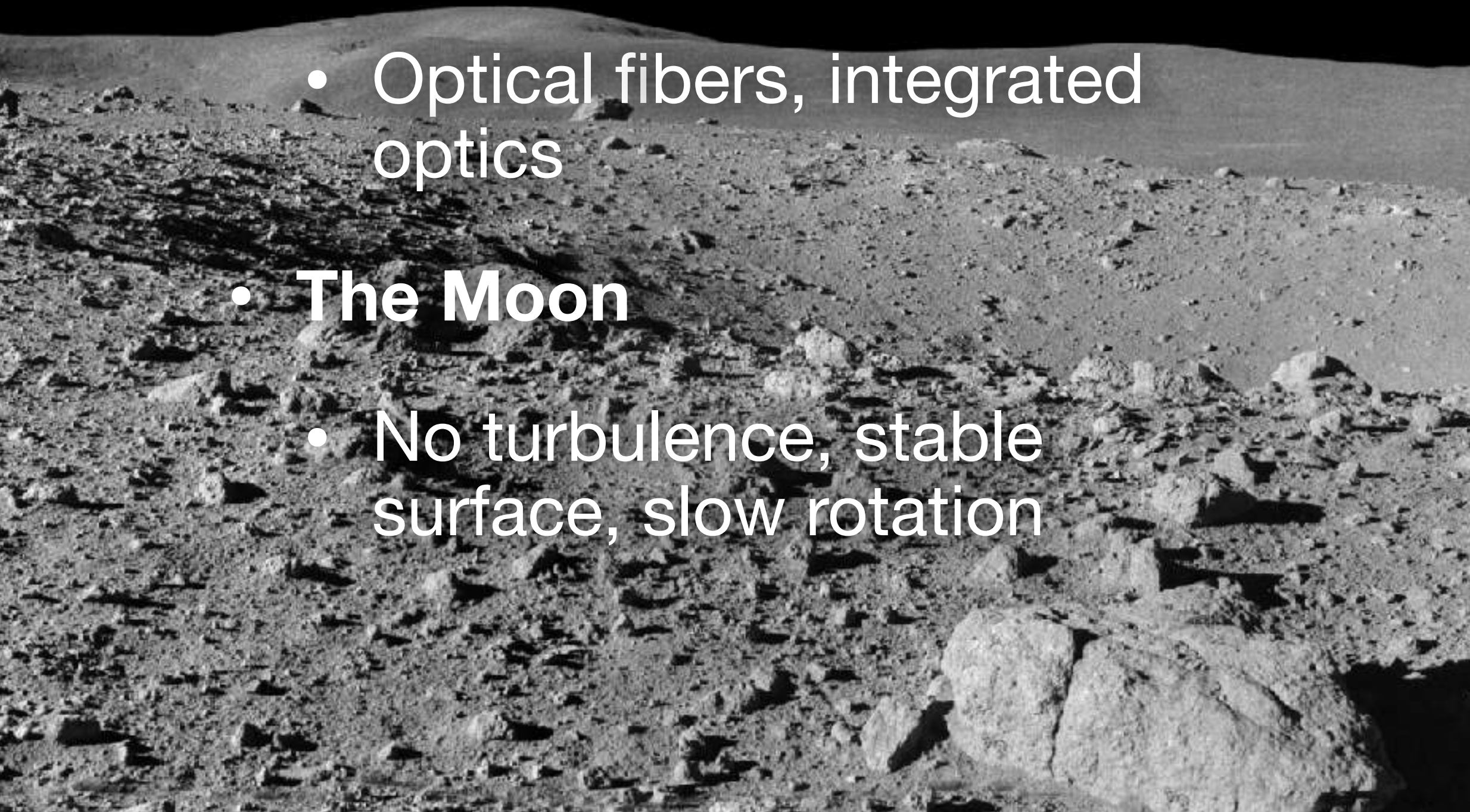
- Black hole Sgr A*, Quasar 3C 273, Exoplanets

- **Technology**

- Optical fibers, integrated optics

- **The Moon**

- No turbulence, stable surface, slow rotation





GRAVITY

LESIA l'Observatoire de Paris | PSL

Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique



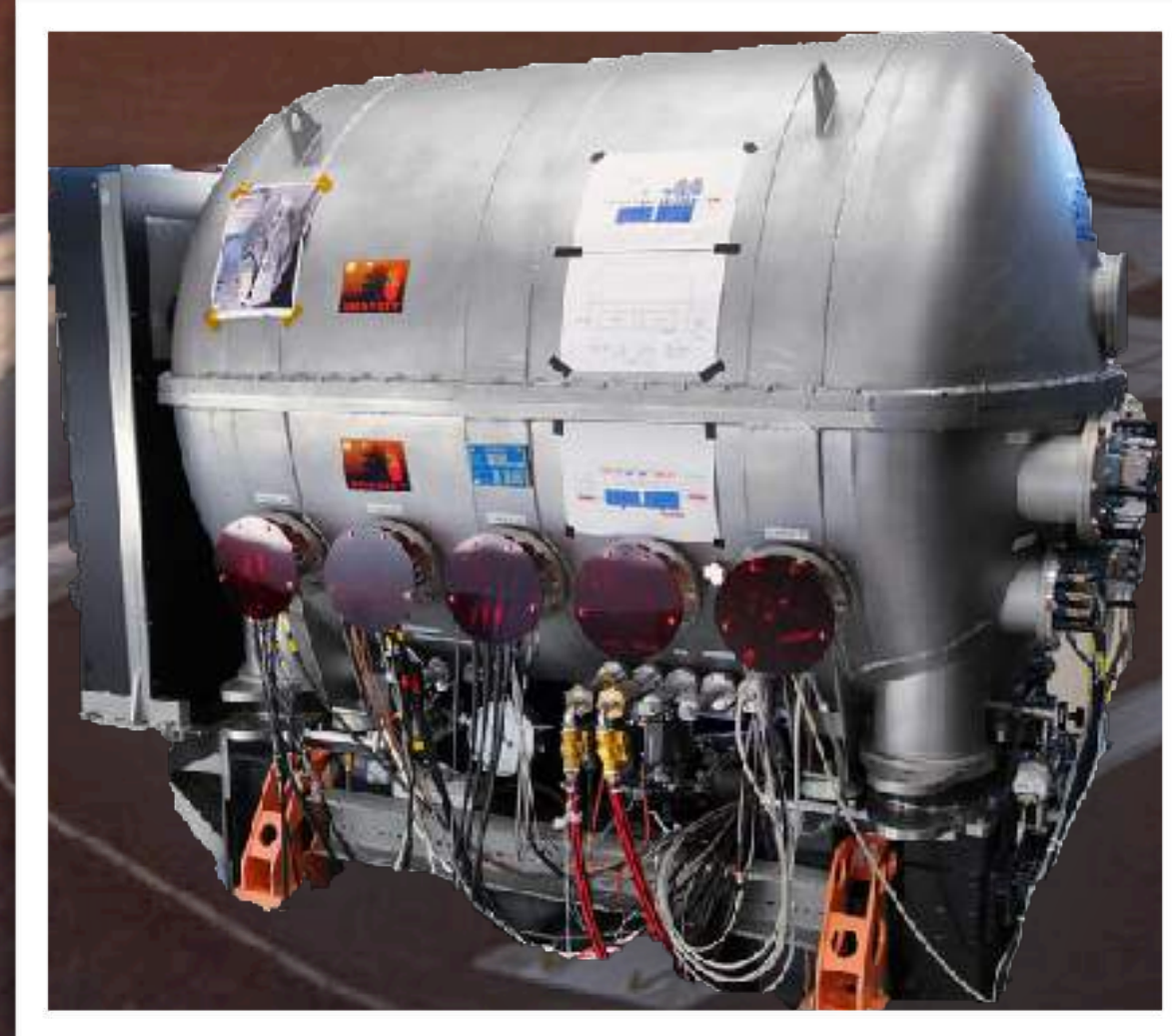
Institut de Planétologie et d'Astrophysique de Grenoble

and on GRAVITY+

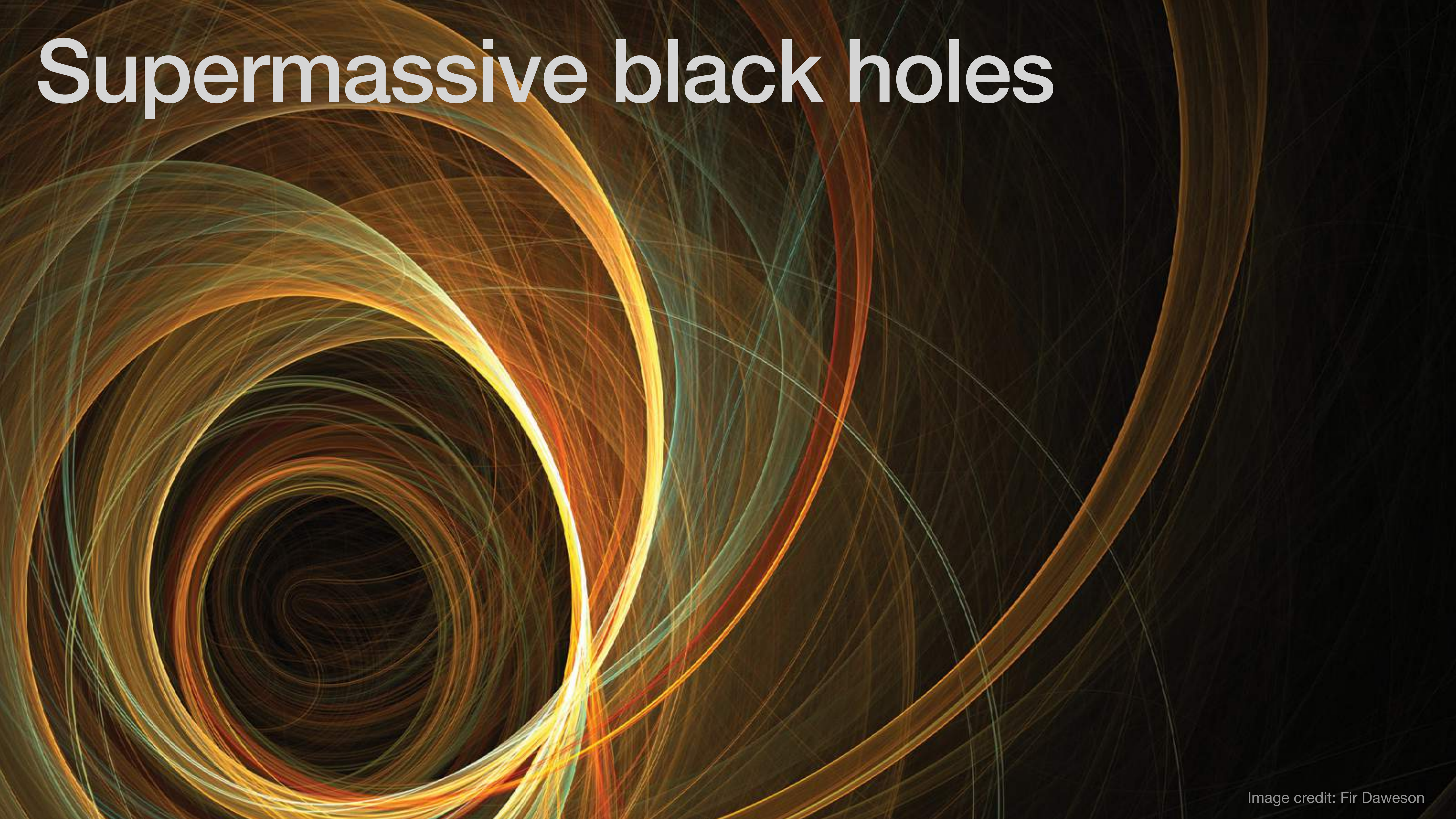
OBSERVATOIRE DE LA CÔTE D'AZUR
UNIVERSITÉ CÔTE D'AZUR



Centre de Recherche Astrophysique de Lyon

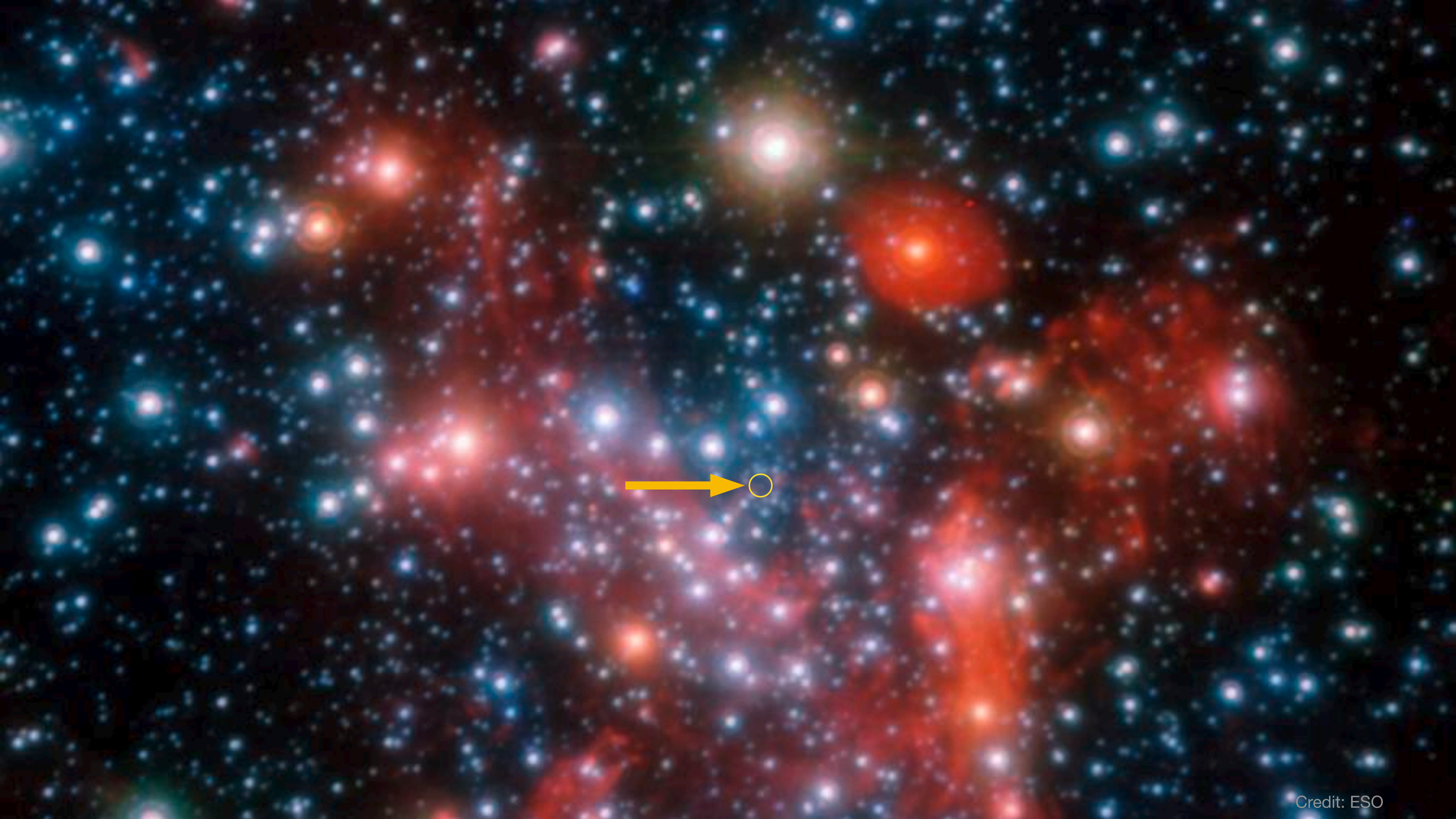


Supermassive black holes









Orbit of S2 around Sgr A*

- 4 million solar mass BH
- Nobel prize 2020

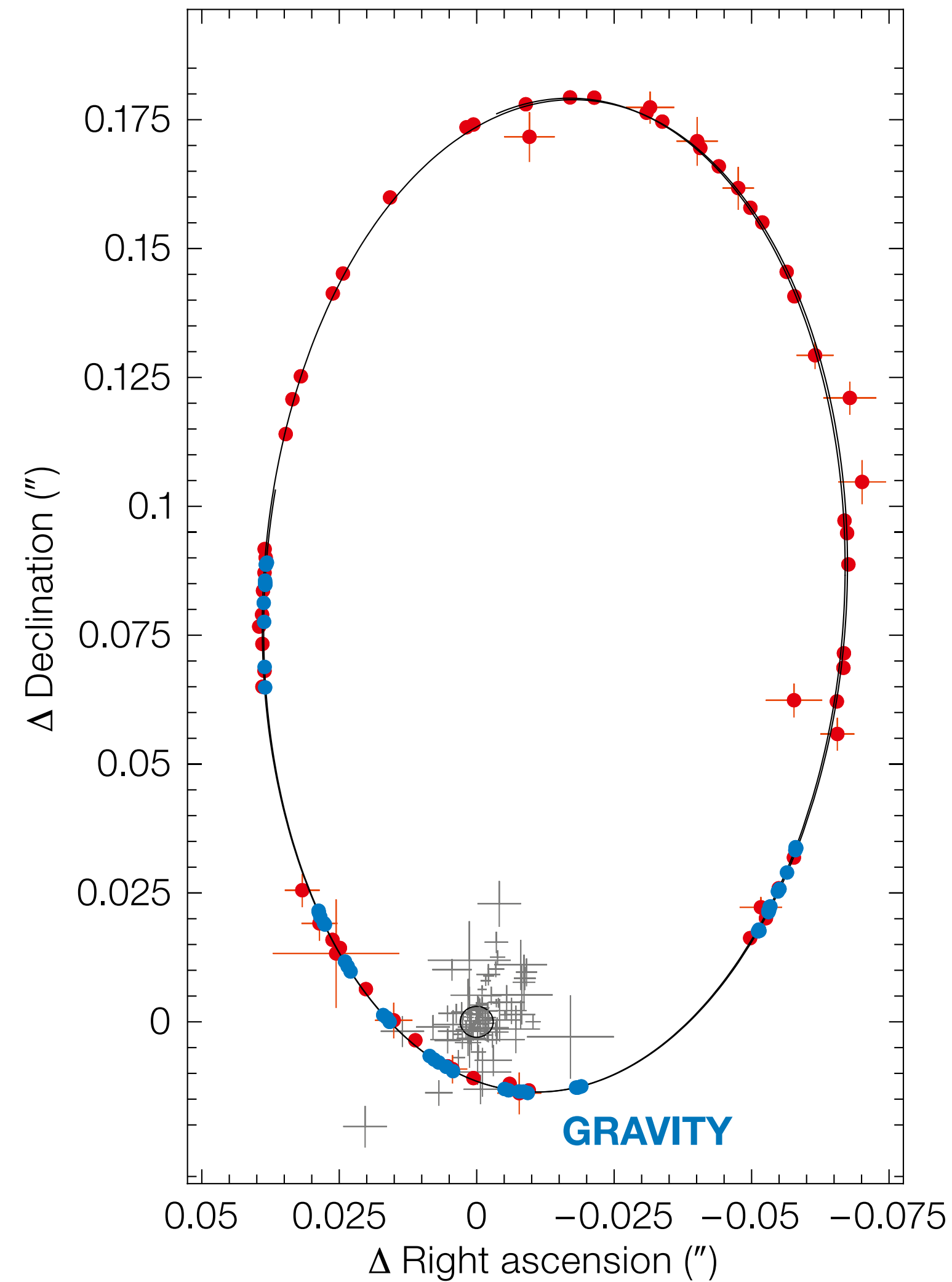
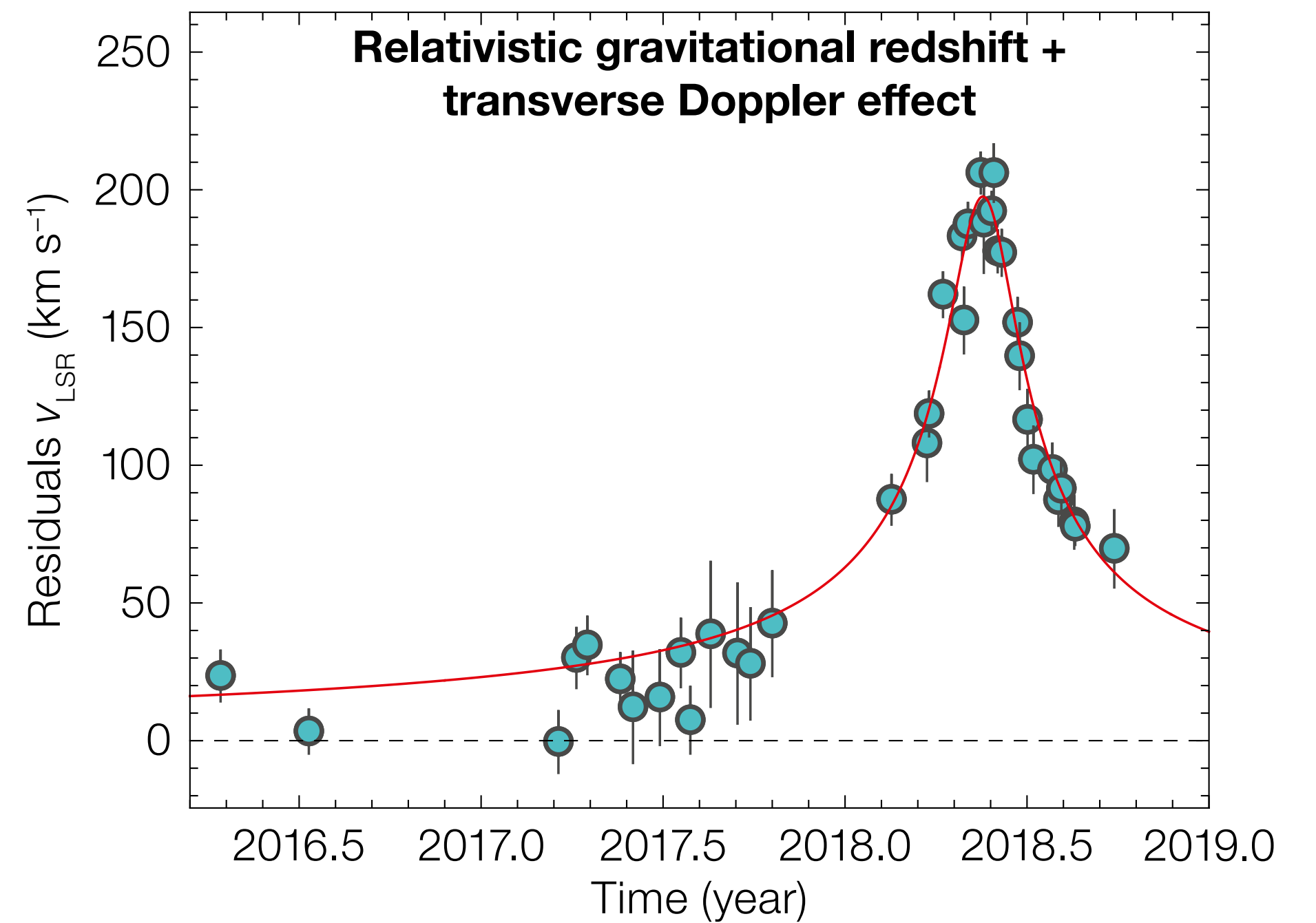
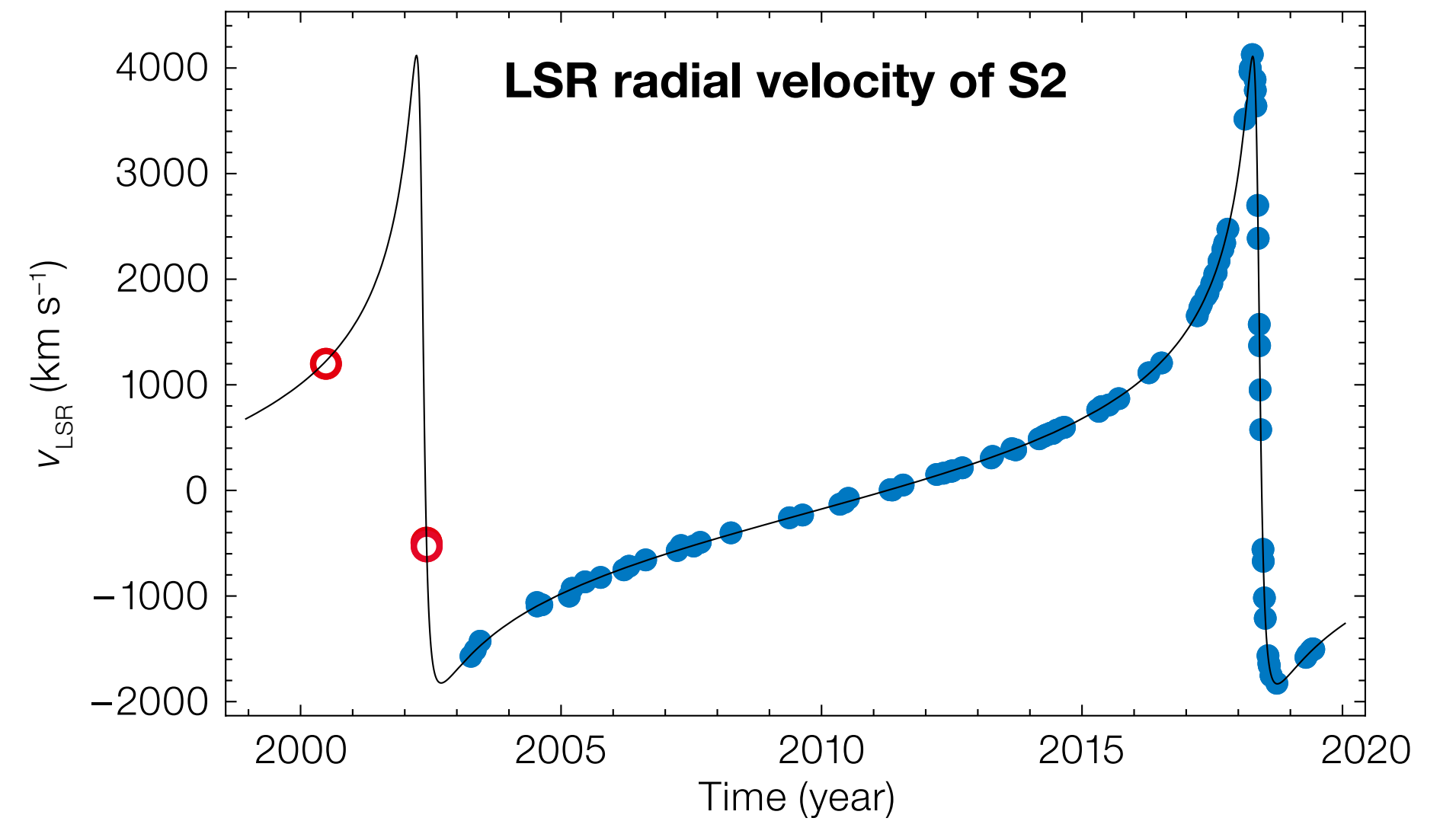
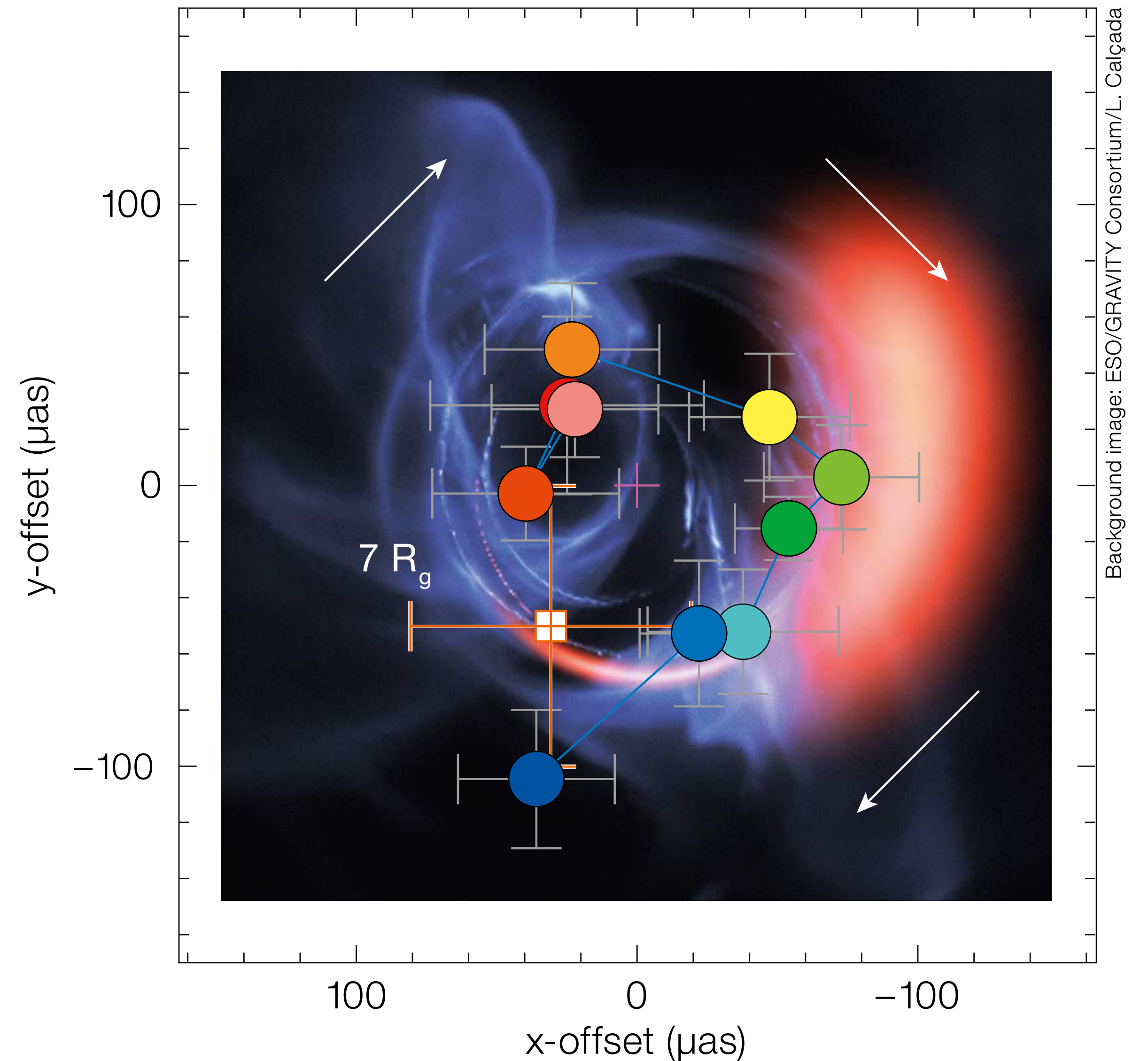


Figure 2. Orbit of S2. Astrometric data from GRAVITY (blue), NACO and SHARP (red). The black ellipse is the best-fit orbit and the black circle shows the position of Sgr A*. Flare positions are marked by grey crosses. Top right: S2 radial velocity (along our line of sight) measured over more than one orbit. Bottom right: The combined gravitational redshift and relativistic transverse Doppler effect manifest in an excess in the radial velocity of 200 km s^{-1} .

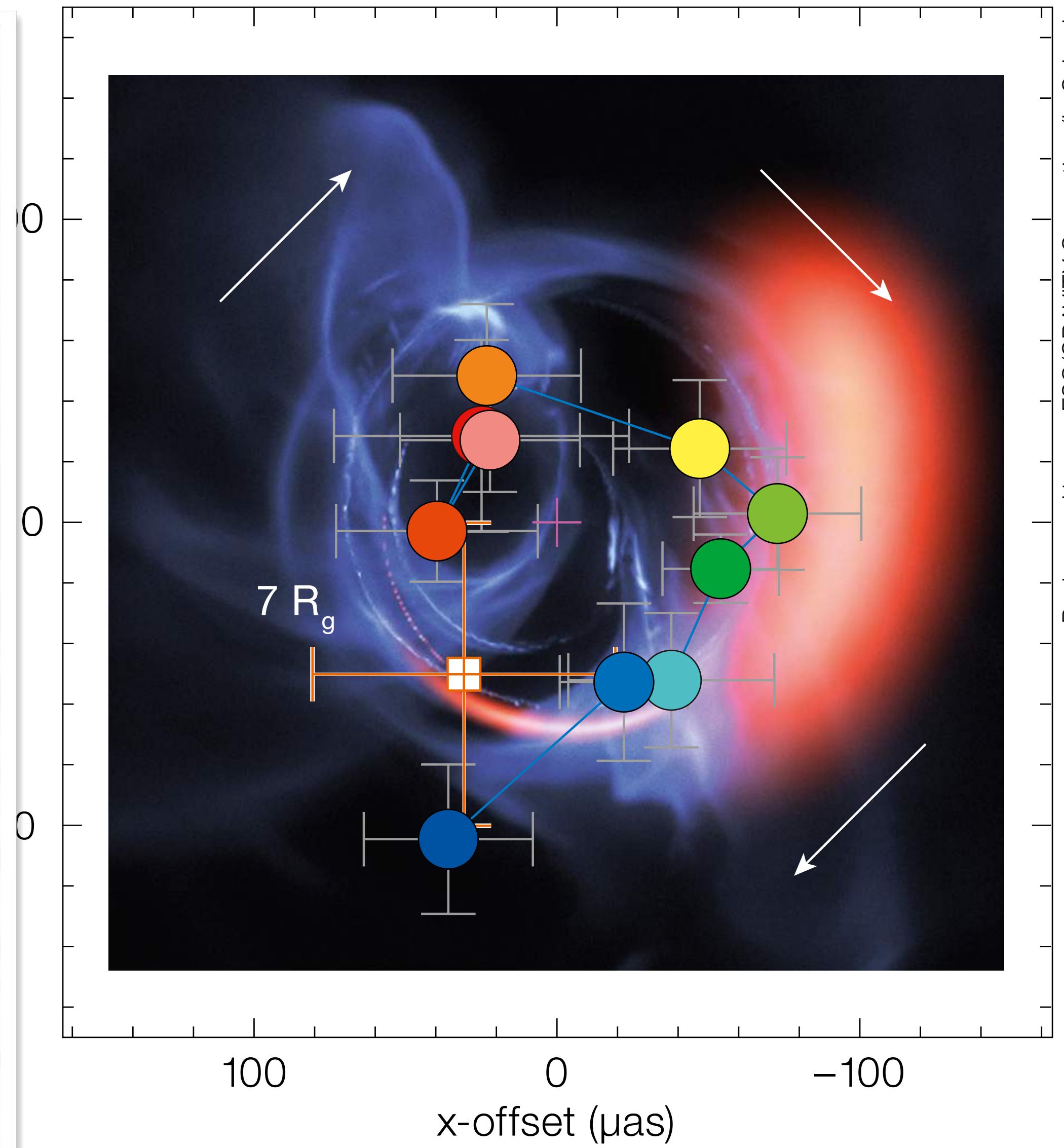


Accretion on Sgr A*

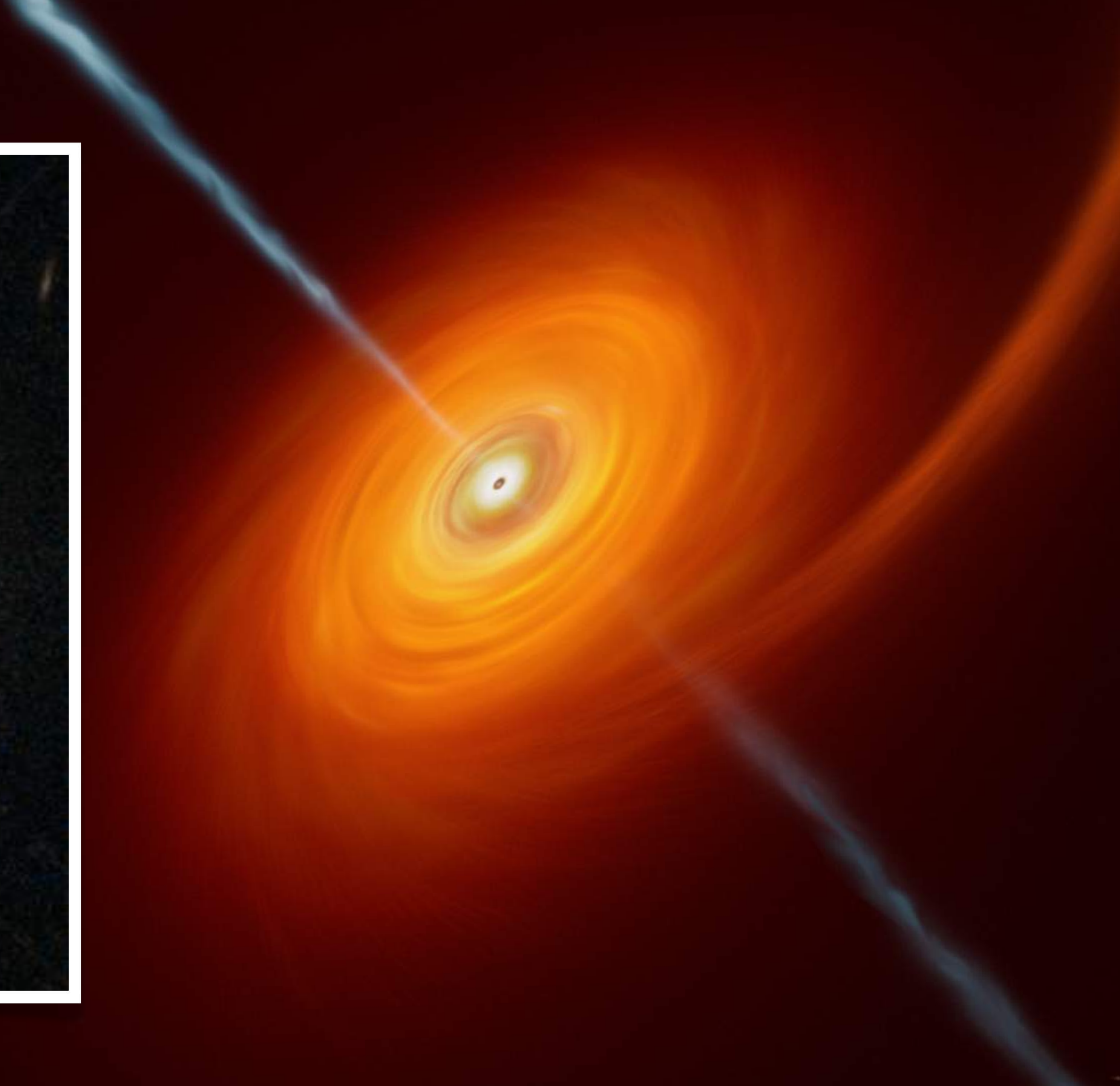
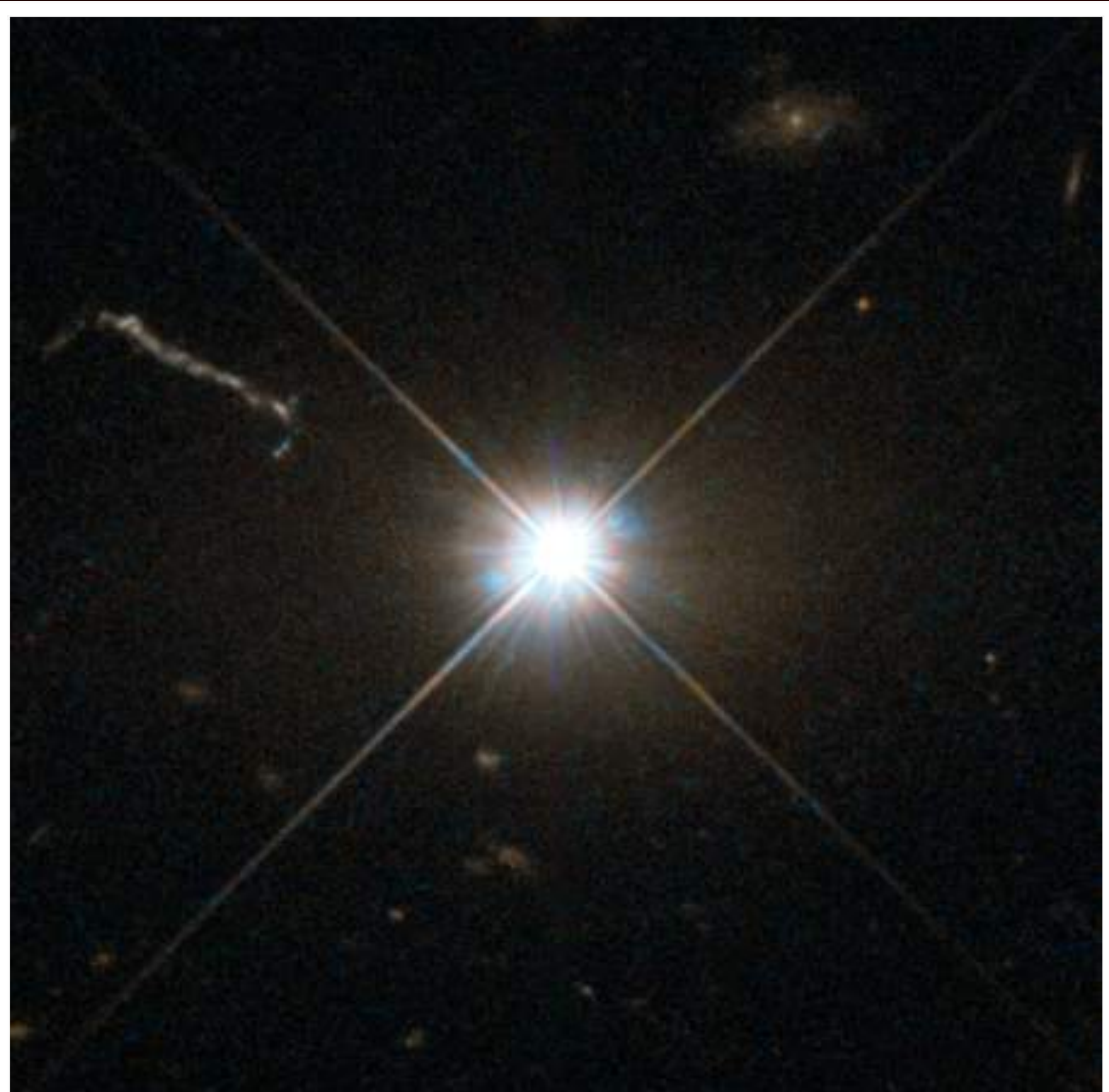
- Projected orbit of the flare recorded on 22 July 2018
- 30-minute duration



A

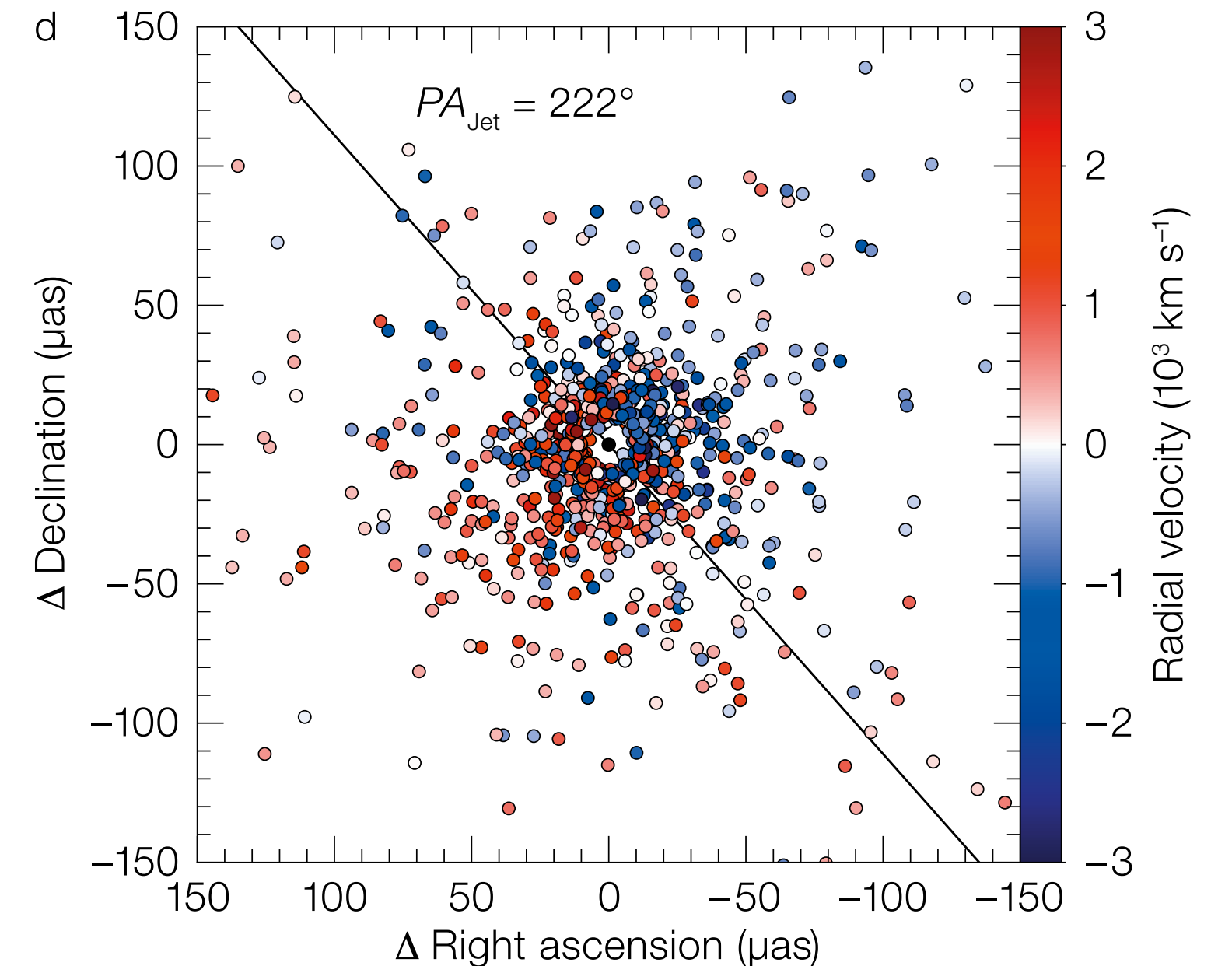
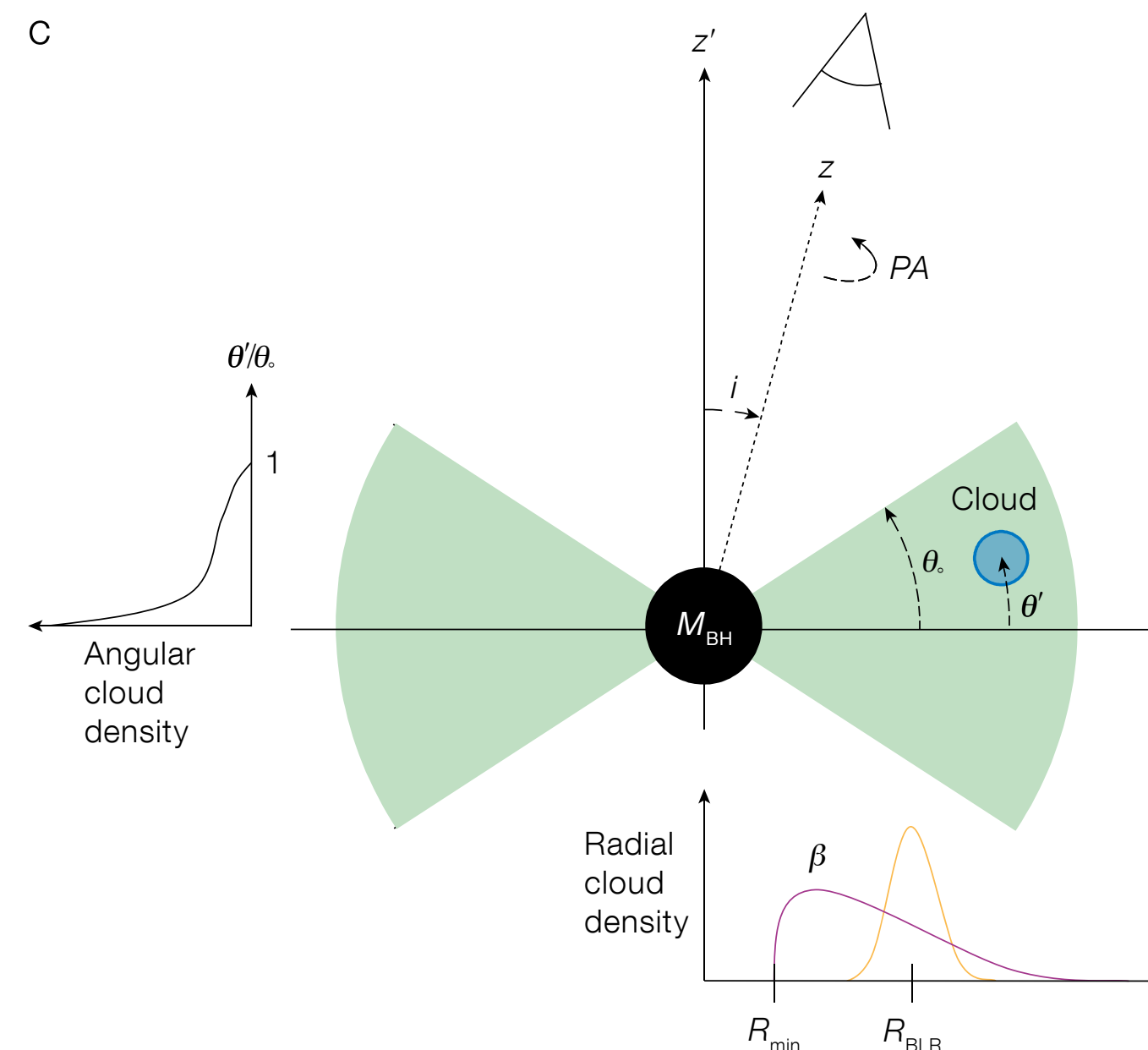
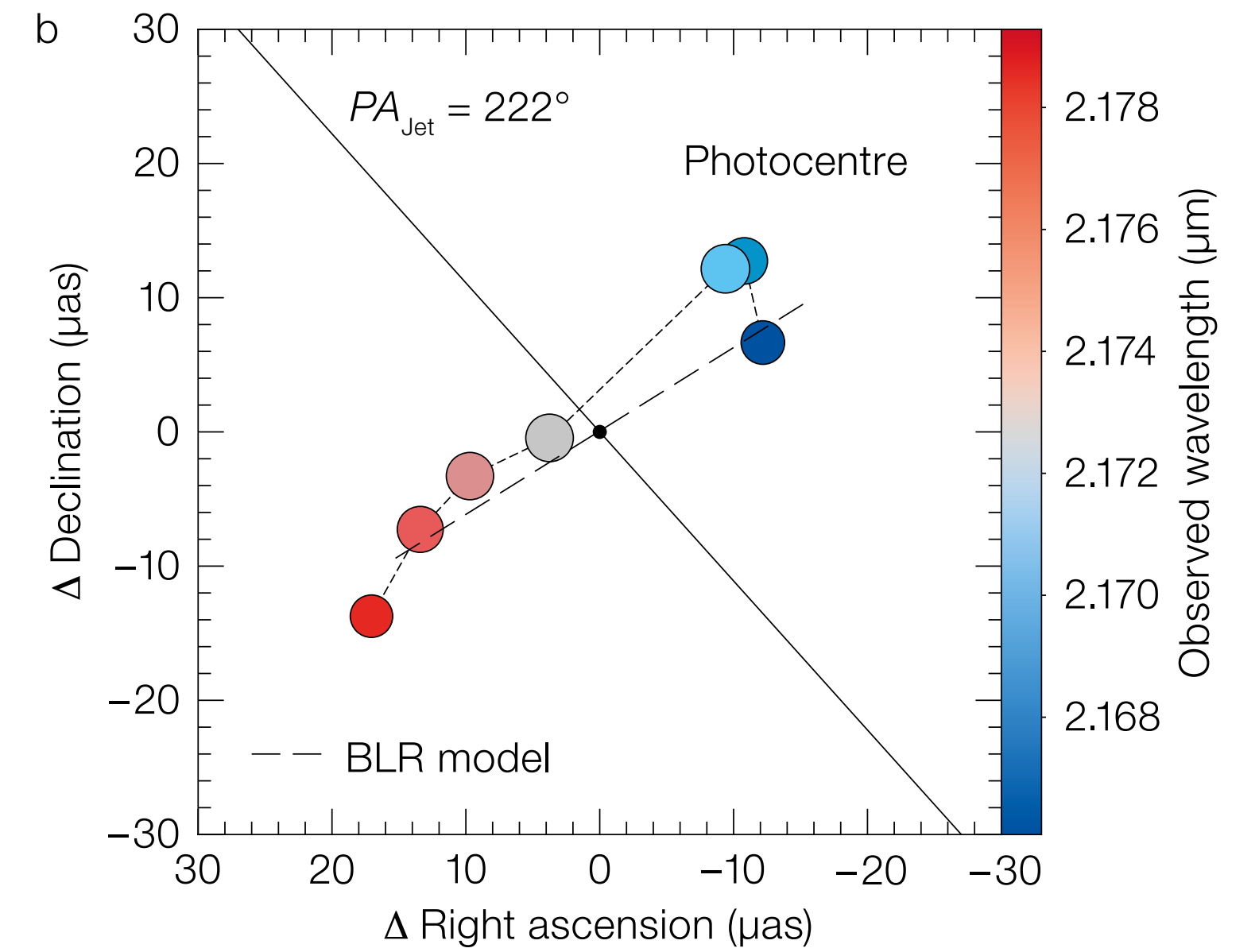
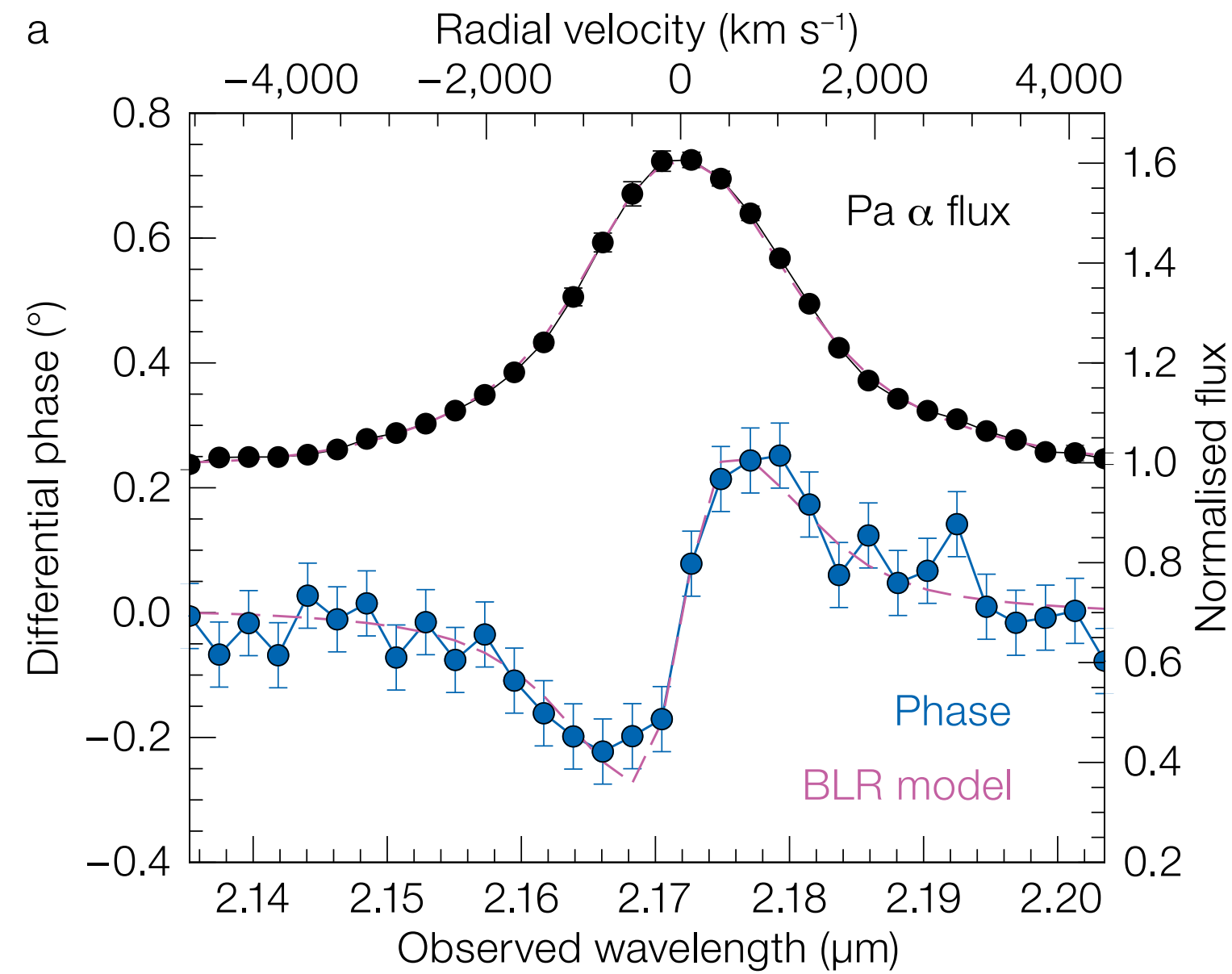


Quasar 3C 273



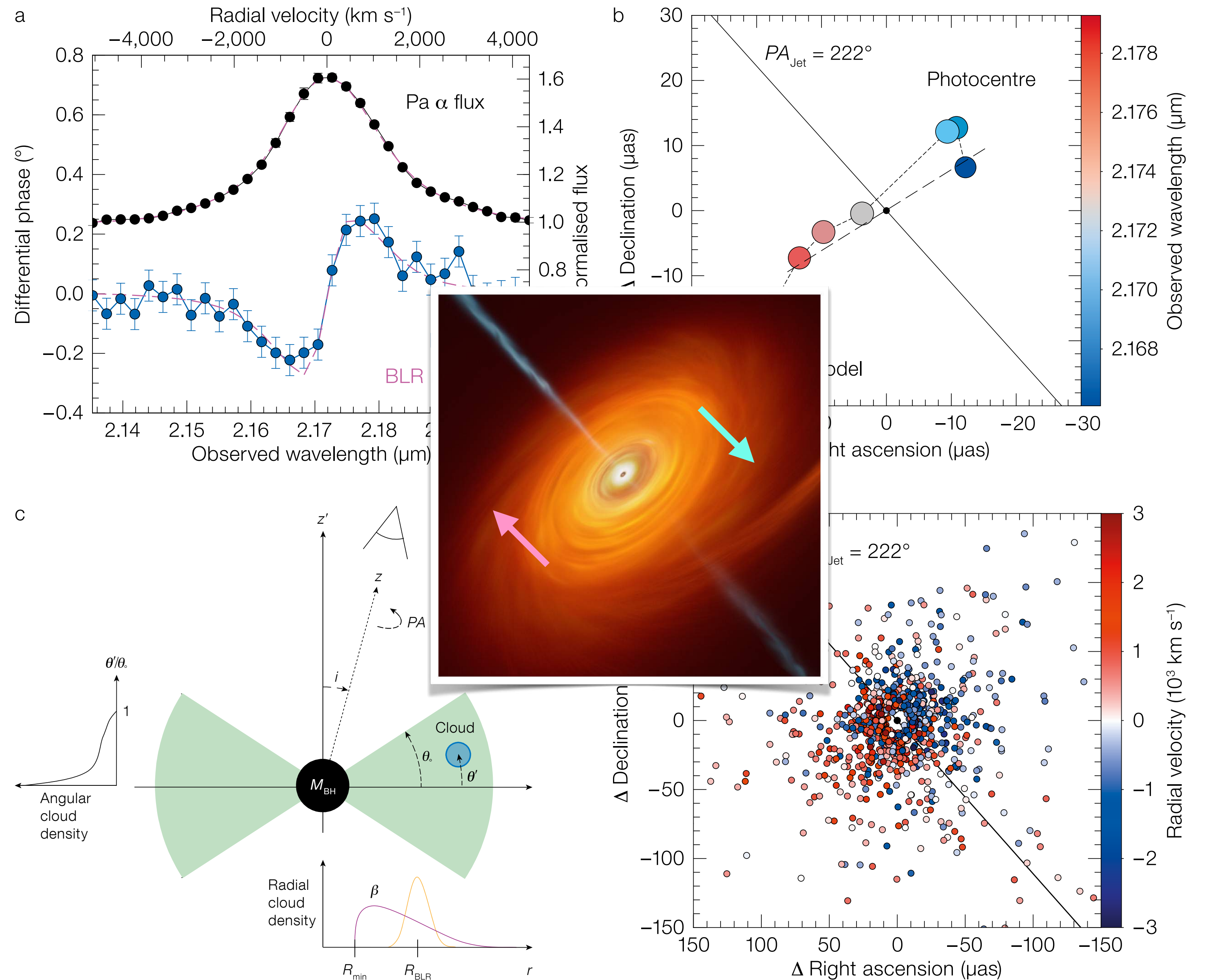
Quasar 3C 273

- 40 μas photocenter displacement in spectral line
- Dynamics of the material close to the BH (broad line region)
- 300 million solar mass BH



Quasar 3C 273

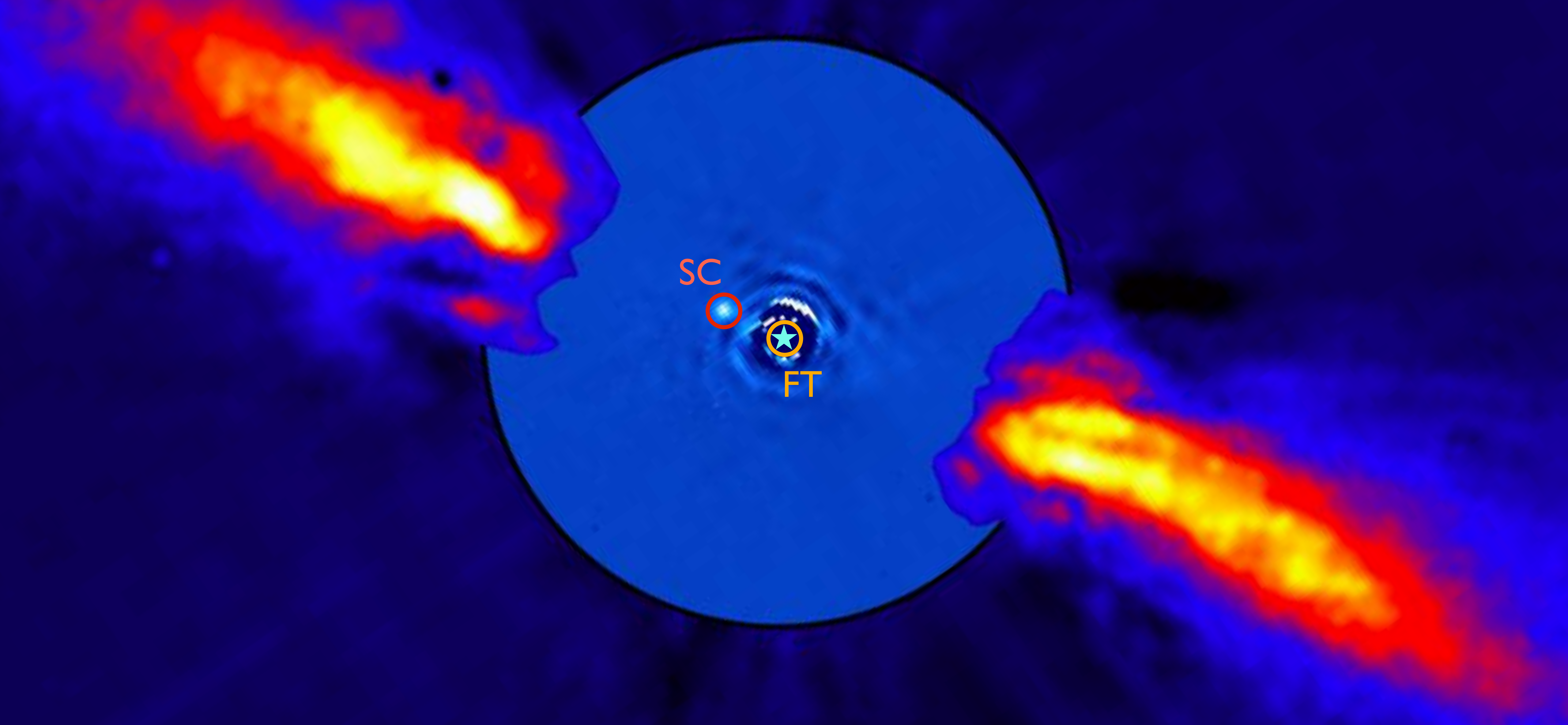
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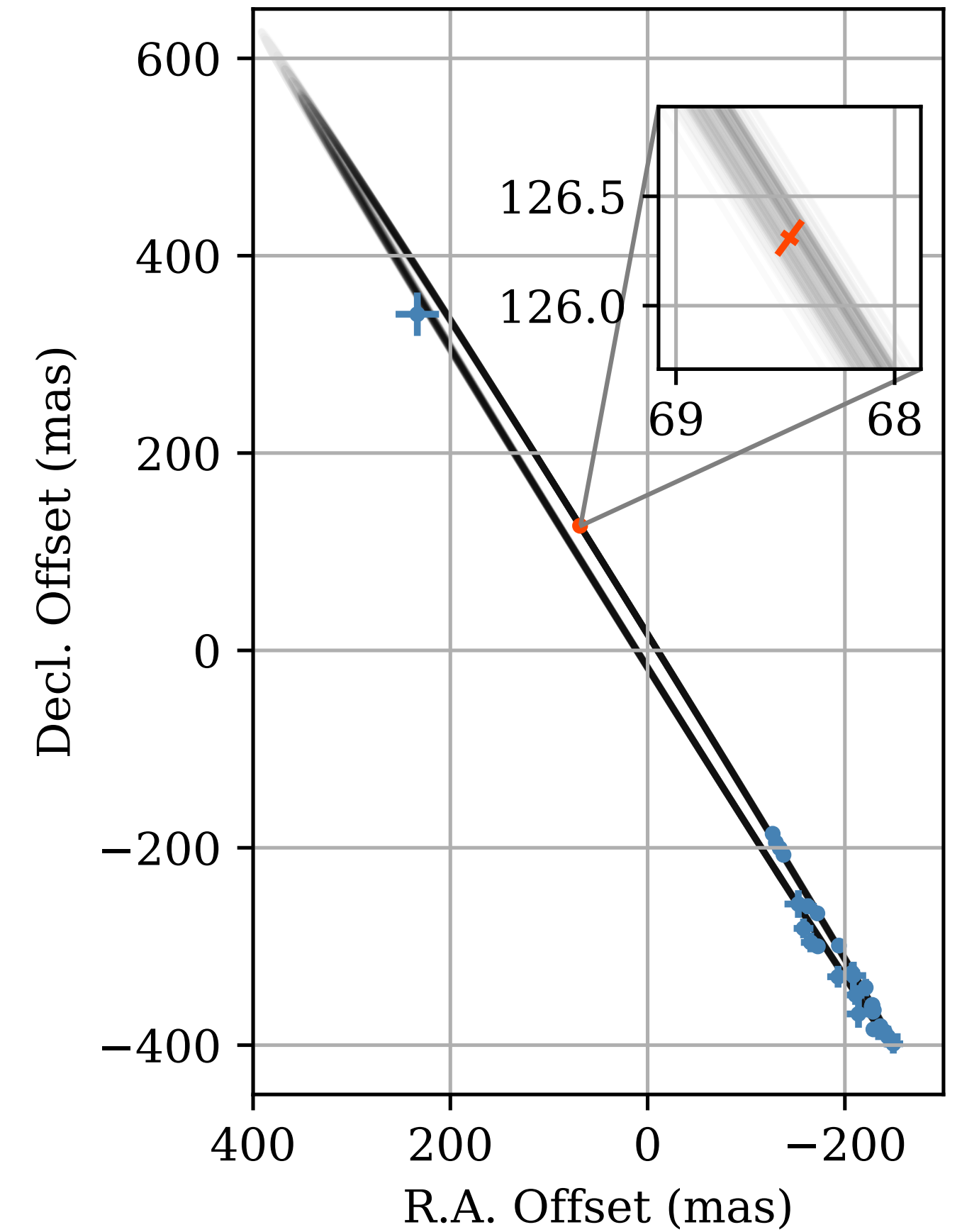
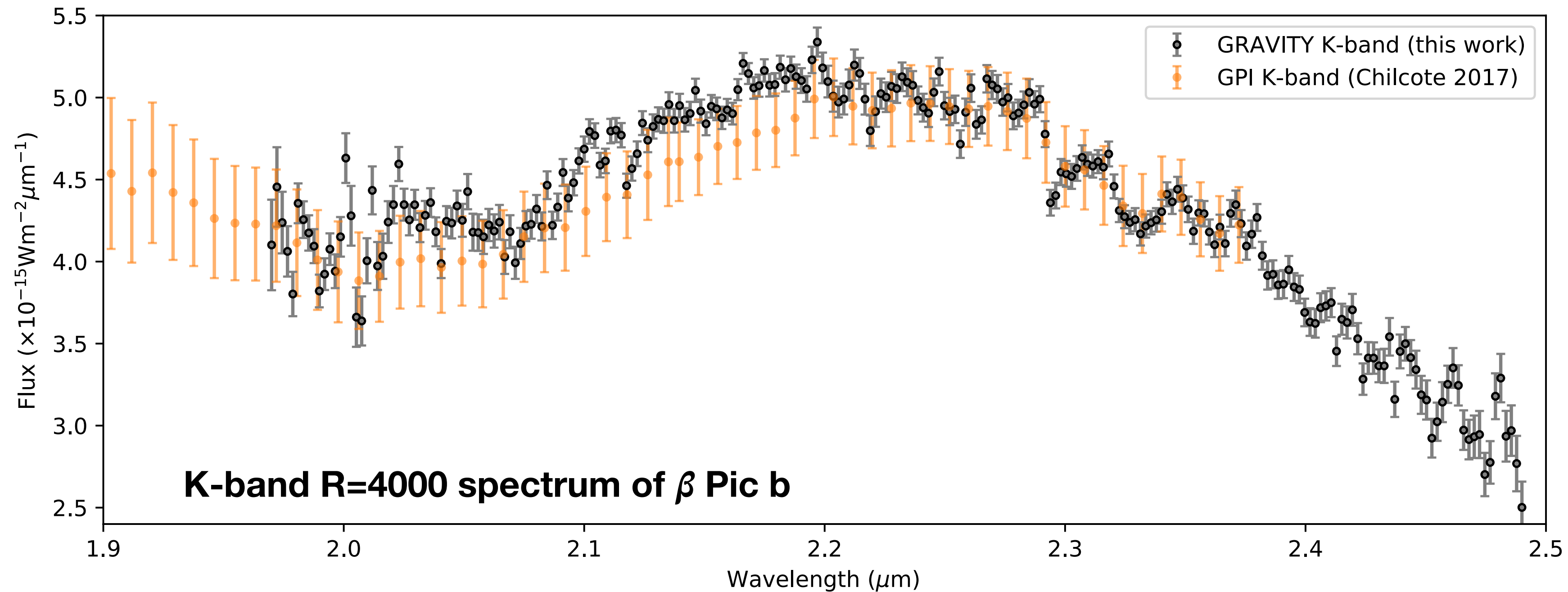
Exoplanets

β Pictoris and GRAVITY



β Pictoris b and GRAVITY

- Astrometric accuracy of GRAVITY position $\sim 70 \mu\text{as}$ from 1.5 hour of VLTI with 4 UTs

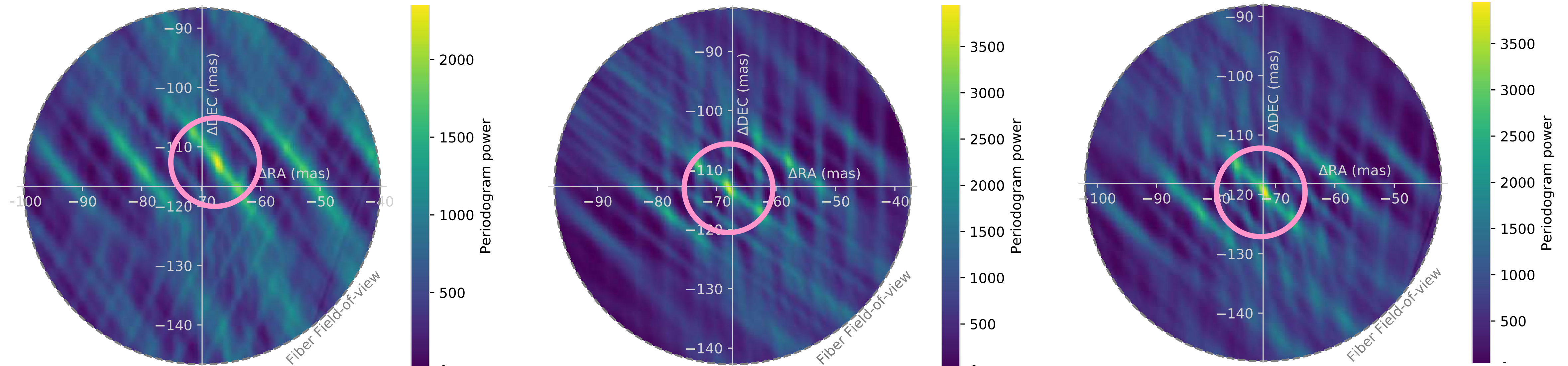


β Pictoris c

9 February 2020

11 February 2020

7 March 2020



- First interferometric detection of a radial velocity planet
- Relative astrometry to $\sim 200 \mu\text{as}$
- Detection of the *perturbation* of the orbit of b from planet c (3x closer to the star)

Technology



Optical delay

Telescope 1

Telescope 2

Light collection

Beam transportation

Optical delay cancellation

Nasmyth Focus

Nasmyth focus

Coudé Focus

Coudé Focus

Interferometric Laboratory

Coudé Optical Train

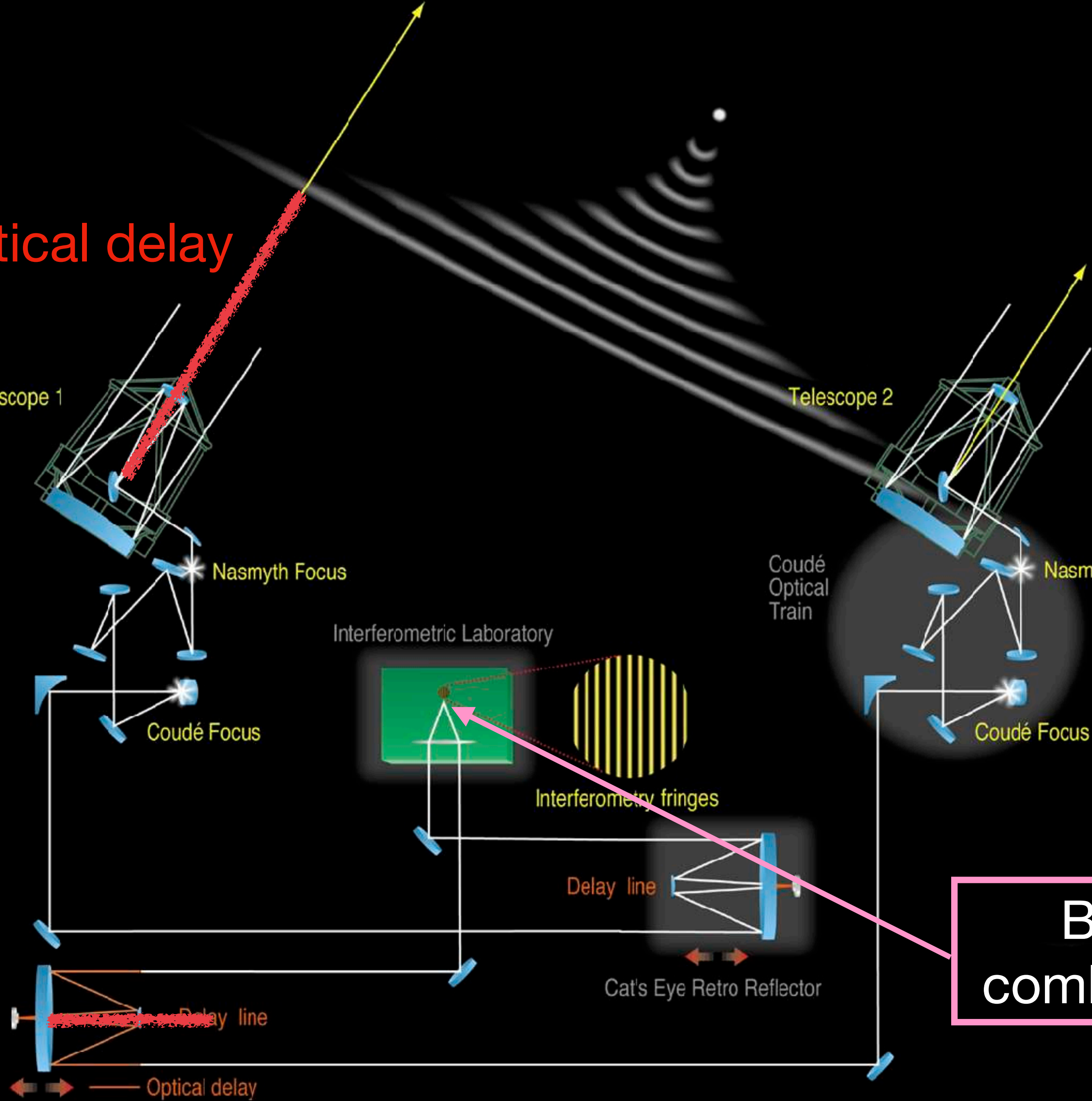
Interferometry fringes

Delay line

Cat's Eye Retro Reflector

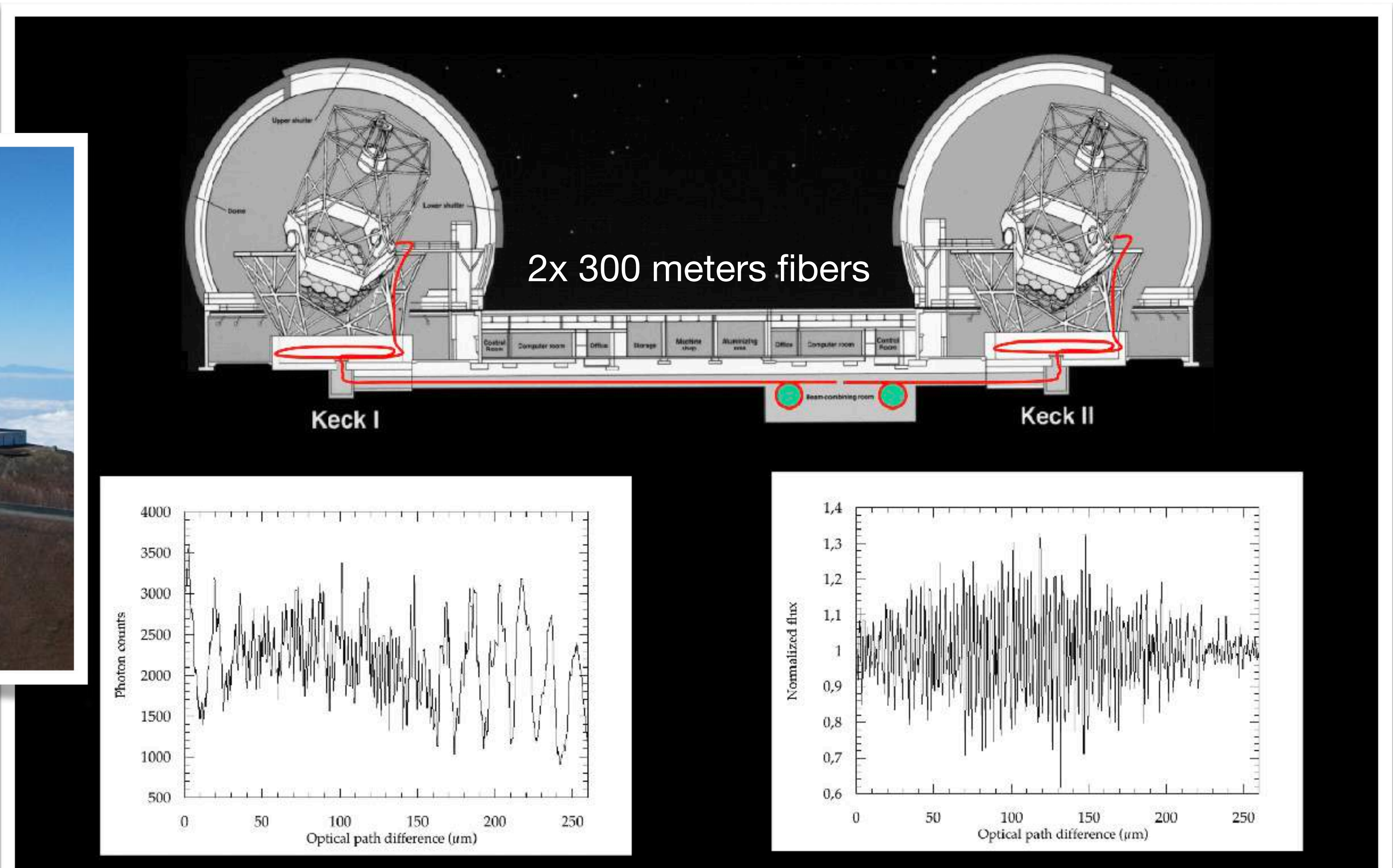
Beam combination

Optical delay



Beam transportation by optical fibers

The OHANA experiment





Optical delay cancellation



Typical 3 hour observation:

~ **30 meters delay** at VLT1

~ **1 meter delay** on the Moon

6 mm pure fibered delay lines
in operation in GRAVITY

10 to 1000m delay in fibers
plausible with R&D

Polarization controlled using
rotators in GRAVITY

Integrated optics beam combiner

GRAVITY's heart

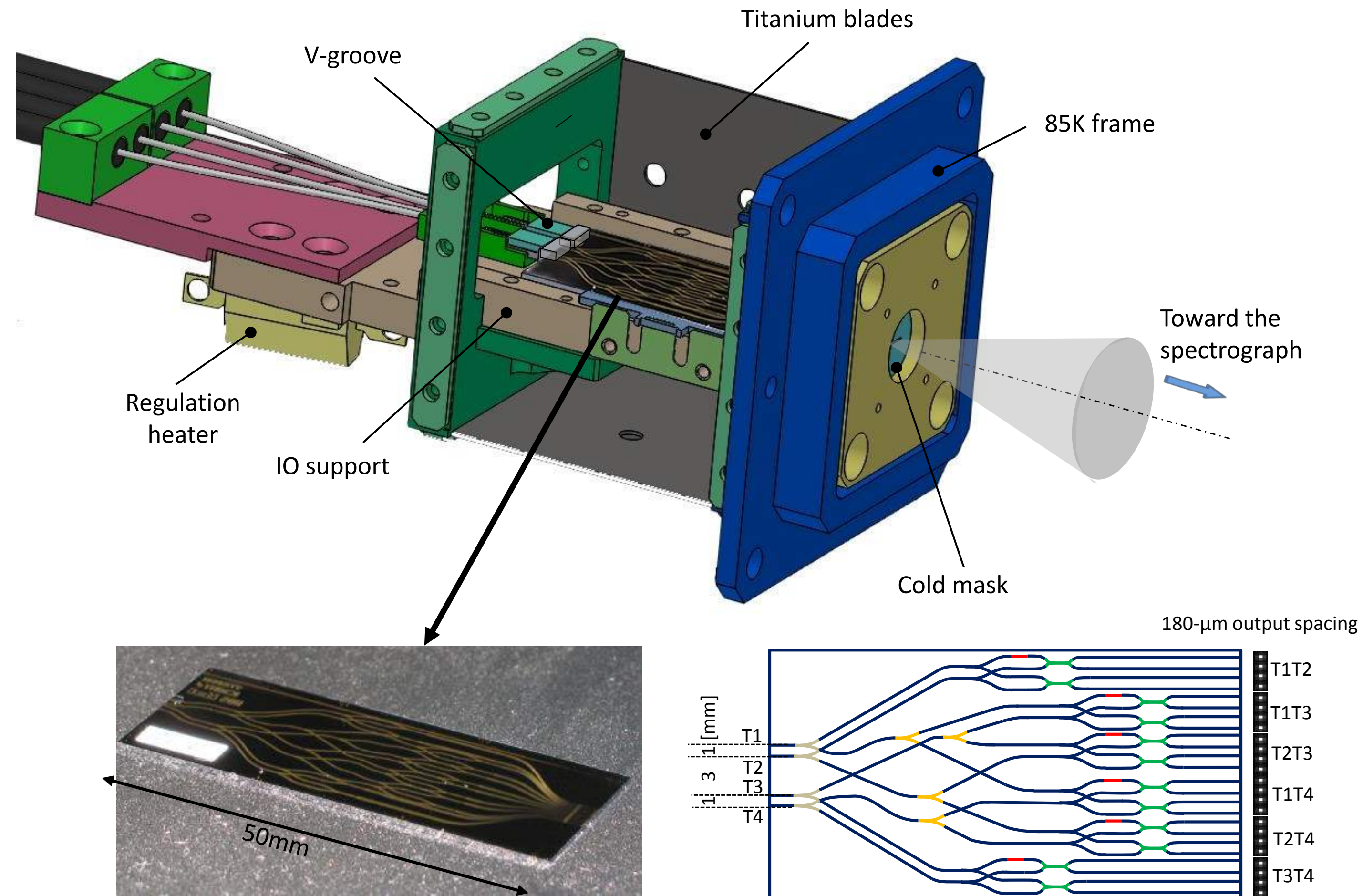


Fig. 3. Description of the IO assembly. *Top:* mechanical mount including the IO beam combiner and the fibre array. *Bottom:* photograph of an IO beam combiner manufactured by silica-on-silicon etching (*left*) and scheme of the beam combiner principle (*right*): 66/33 couplers (in red), Y-junctions (in grey), achromatic $\pi/2$ -phase shifters (in light blue), and 50/50 couplers (in green). See text for details.

The Moon: a dream environment for interferometry

- **No turbulence !** + all wavelengths are accessible
- **Stability of the surface** is a decisive advantage compared to free flying space telescope constellations
- **Slow sidereal rotation period of 27 days:** optical delay variation is slow and easier to track with short and compact modulators +14 days long continuous nights

- **Examples of sciences cases:**

- Galactic nuclei at high redshift with milliarcsecond angular resolution
- Surface and close environment of stars at high spatial and spectral resolution
- High-resolution spectroscopy of exoplanets at visible and infrared wavelengths
- Wide-angle microarcsecond differential astrometry of faint objects (binary compact objects, exoplanetary systems, exomoons...)



Summary

- Long-baseline optical interferometry is a **mature technique** with broad applicability in astrophysics. The expertise is available in France and in Europe.
- Possible **modular design** of an interferometric array, with flexible telescope usage in interferometric and single aperture modes (e.g., VLT/VLTI)
- (Sub-)milliarcsecond **angular resolution** at optical and infrared wavelengths
- **Game-changing benefits** of operation from the Moon surface: no atmosphere, stable surface, slow rotation