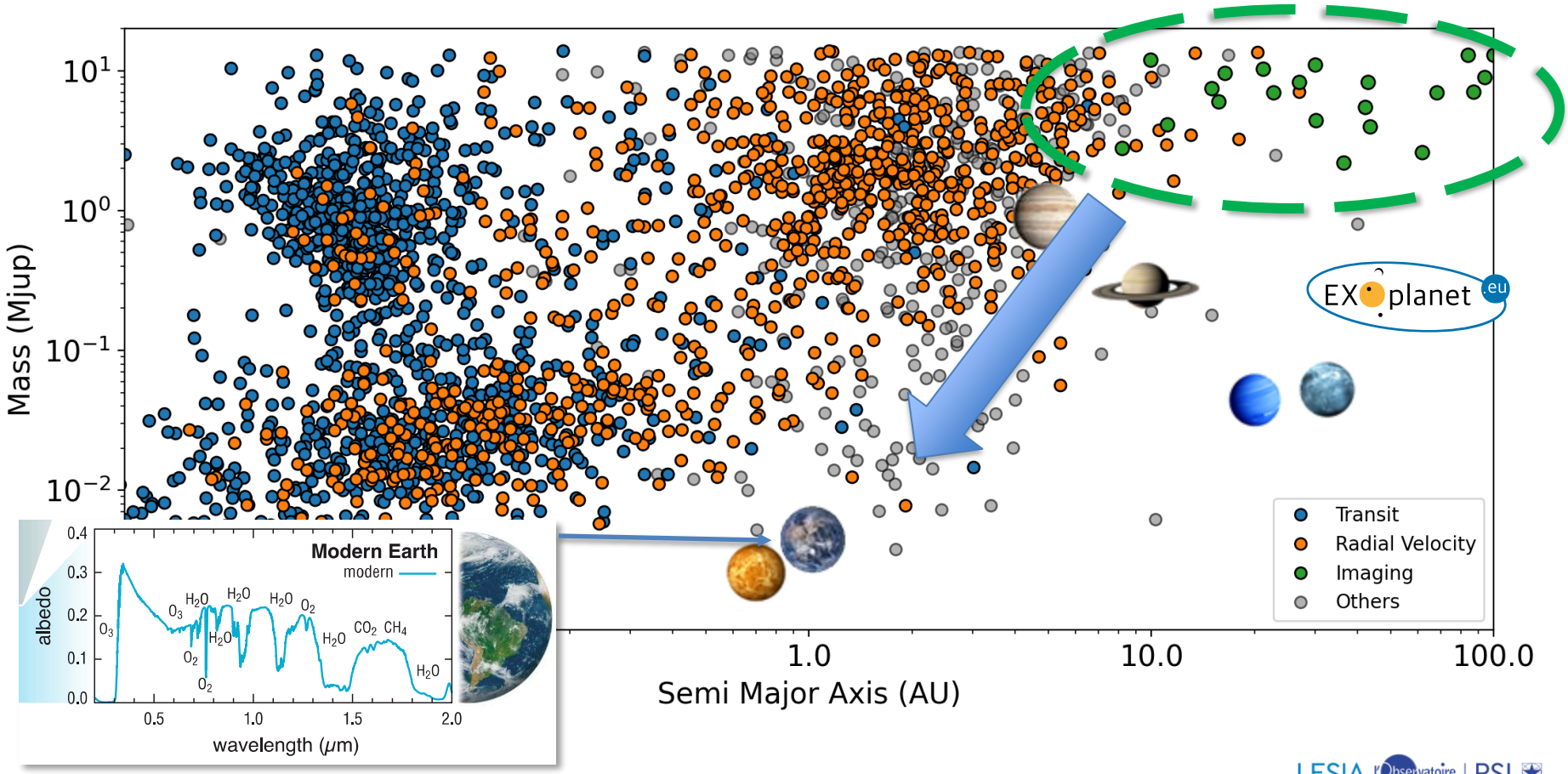
ExoGRAVITY

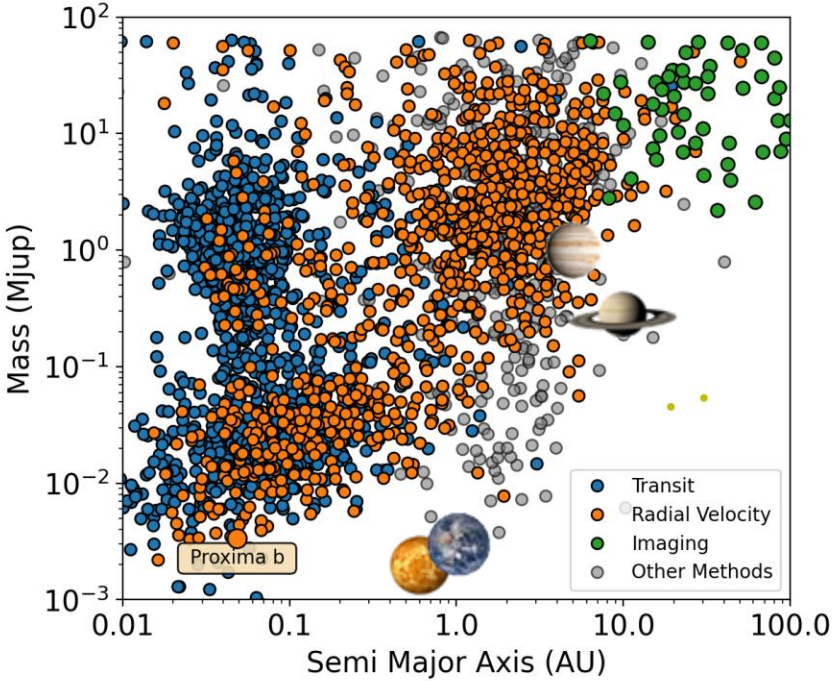
A supersharp view of Exoplanets with GRAVITY

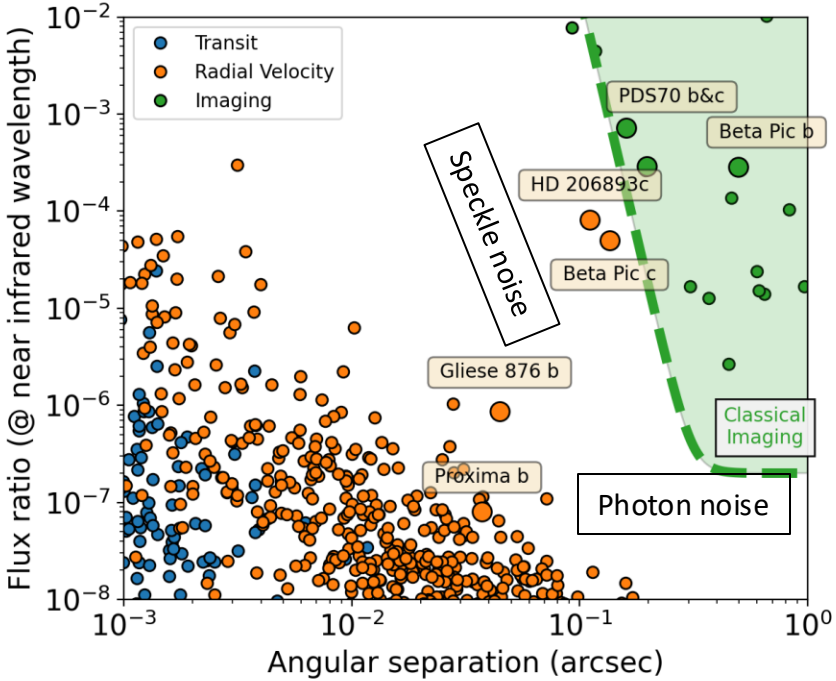
ESO · LAM Laboratoire d'Astrophysique de Marseille · University of Cambridge · MPE · Space Telescope Science Institute, Operated for NASA by AURA · Universiteit Leiden · Universidade de Coimbra · IPAG · Johns Hopkins University · Liège université · Caltech · University of Michigan · Stockholm University · ETH zürich · Monash University · U.Porto Feup Engenharia · Universität Hamburg · Australian National University · l'Observatoire de Paris – LESIA

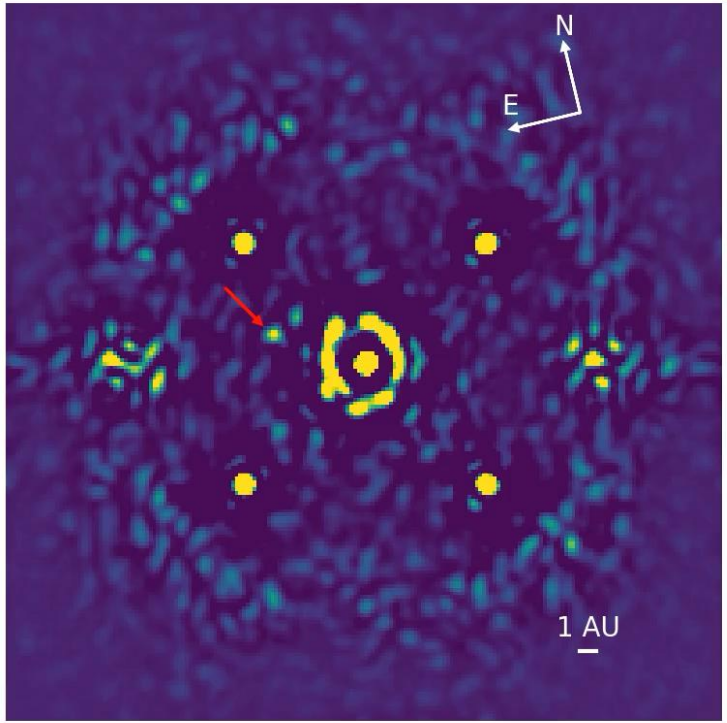
GRAVITY Collaboration

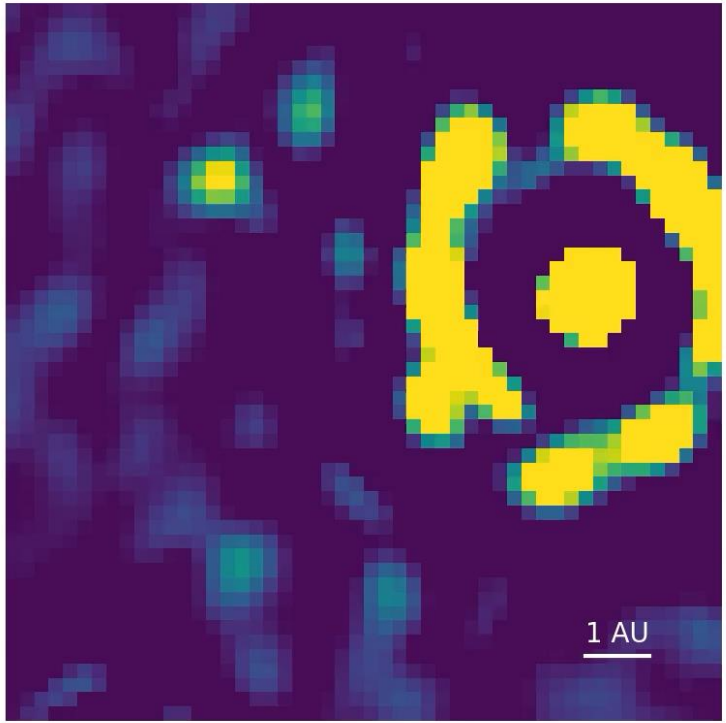
LAGRANGE
CRAL
LESIA l'Observatoire de Paris | PSL
IPAG
Institut de Planétologie et d'Astrophysique de Grenoble
centra
ESO
GRAVITY+
Collaboration
and growing
MPE
Max-Planck-Institut für Astronomie
UNIVERSITY OF Southampton
KU LEUVEN
Universität zu Köln

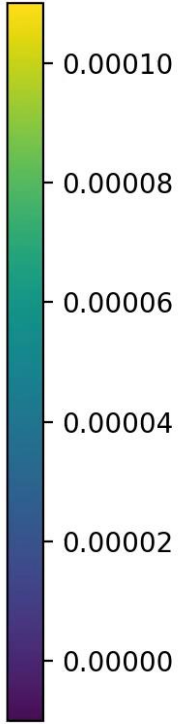

Mass (Mjup)
10^{1}
10^{0}
10^{-1}
10^{-2}
Semi Major Axis (AU)
1.0
10.0
100.0
Transit
Radial Velocity
Imaging
Others
EXOplanet.eu
Modern Earth
modern
albedo
0.4
0.3
0.2
0.1
0.0
O_3
H_2O
O_2
CO_2
CH_4
0.5
1.0
1.5
2.0
wavelength (μm)


Mass (Mjup)
Semi Major Axis (AU)
Transit
Radial Velocity
Imaging
Other Methods
Proxima b


Flux ratio (@ near infrared wavelength)
Angular separation (arcsec)
Transit
Radial Velocity
Imaging
PDS70 b&c
Beta Pic b
HD 206893c
Beta Pic c
Speckle noise
Gliese 876 b
Classical Imaging
Proxima b
Photon noise

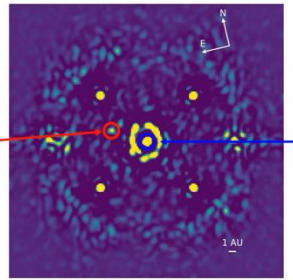




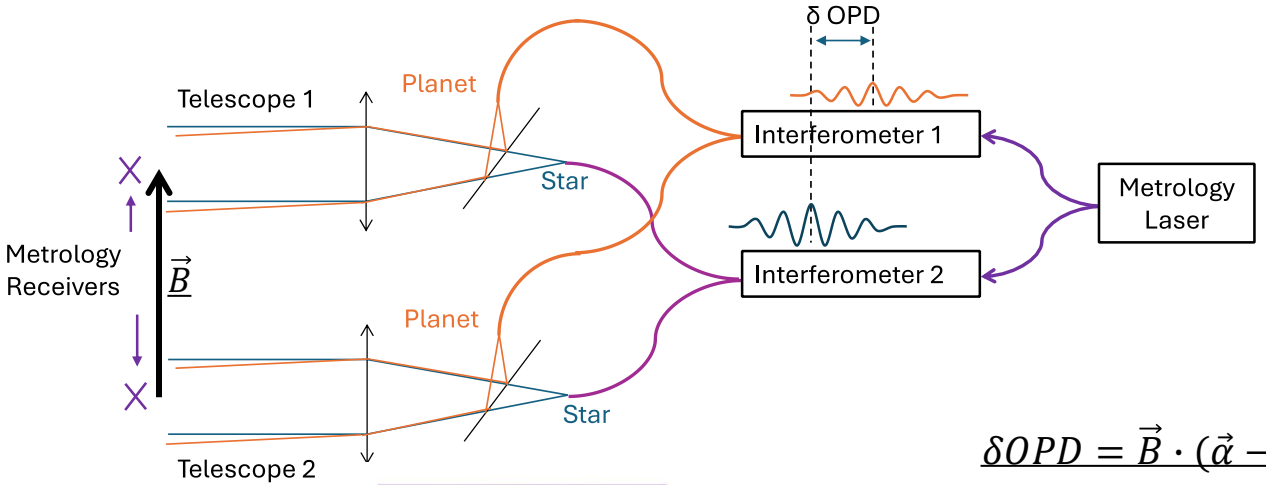


SPHERE observation of Beta pictoris b (Lagrange et al. 2020)

Single mode fiber on planet

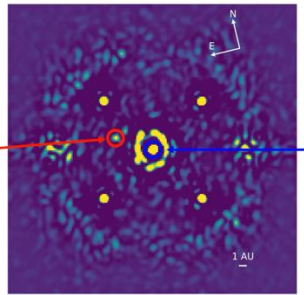


Single mode fiber on star



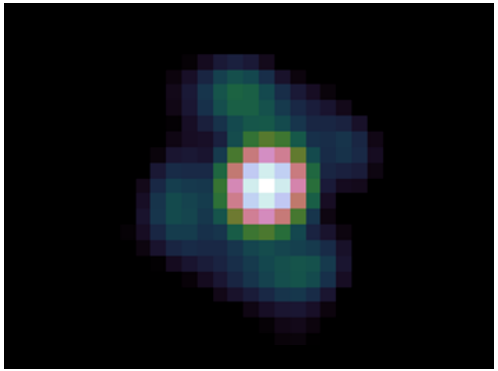
$$\delta OPD = \vec{B} \cdot (\vec{\alpha} - \vec{\beta})$$

Single mode fiber on planet



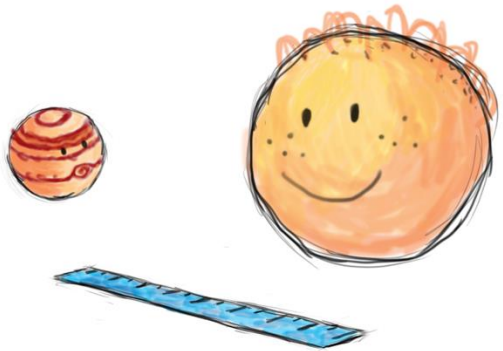
Single mode fiber on star

Astrometry



Spatial Resolution

$\sim \lambda/D$



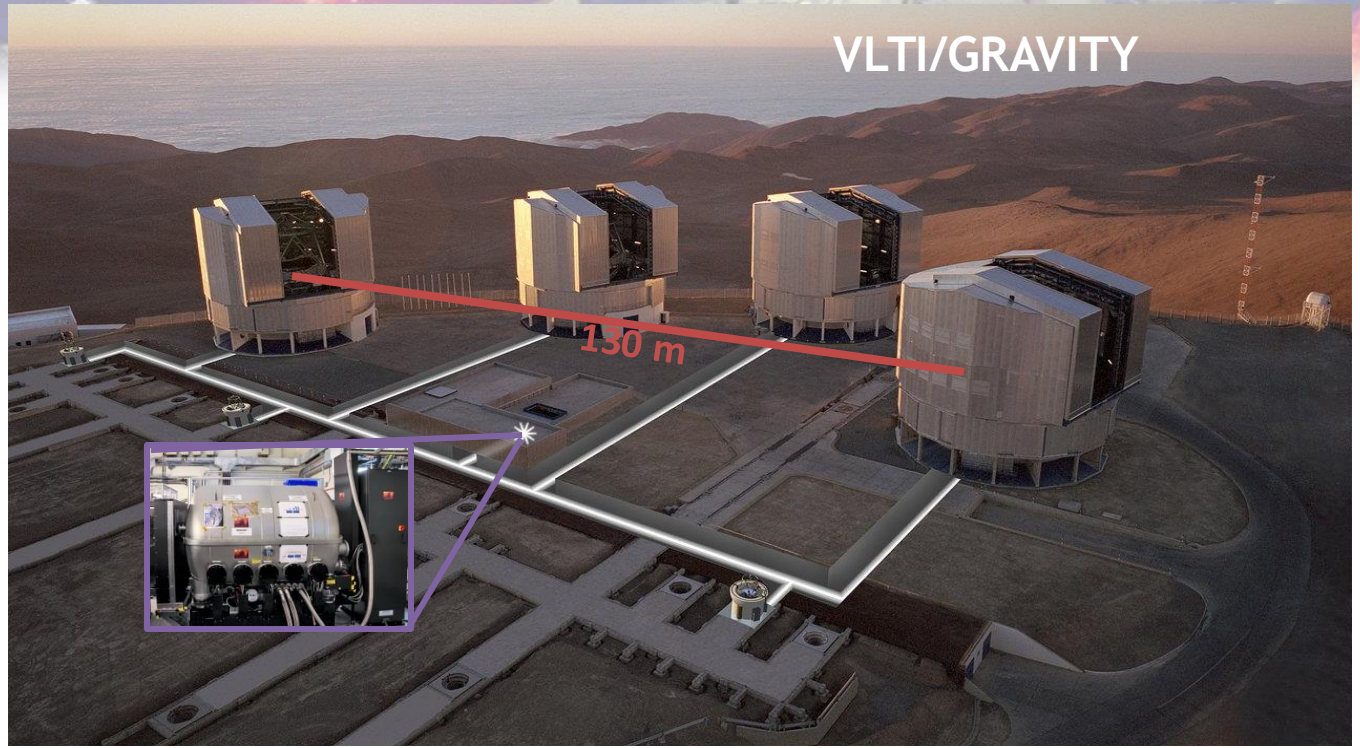
Astrometric Precision

$\sim \frac{(\lambda/D)}{SNR}$

For 8 m telescope observing at 2 µm:

~50 mas

~1 mas



Spatial Resolution

$\sim \lambda/2B$

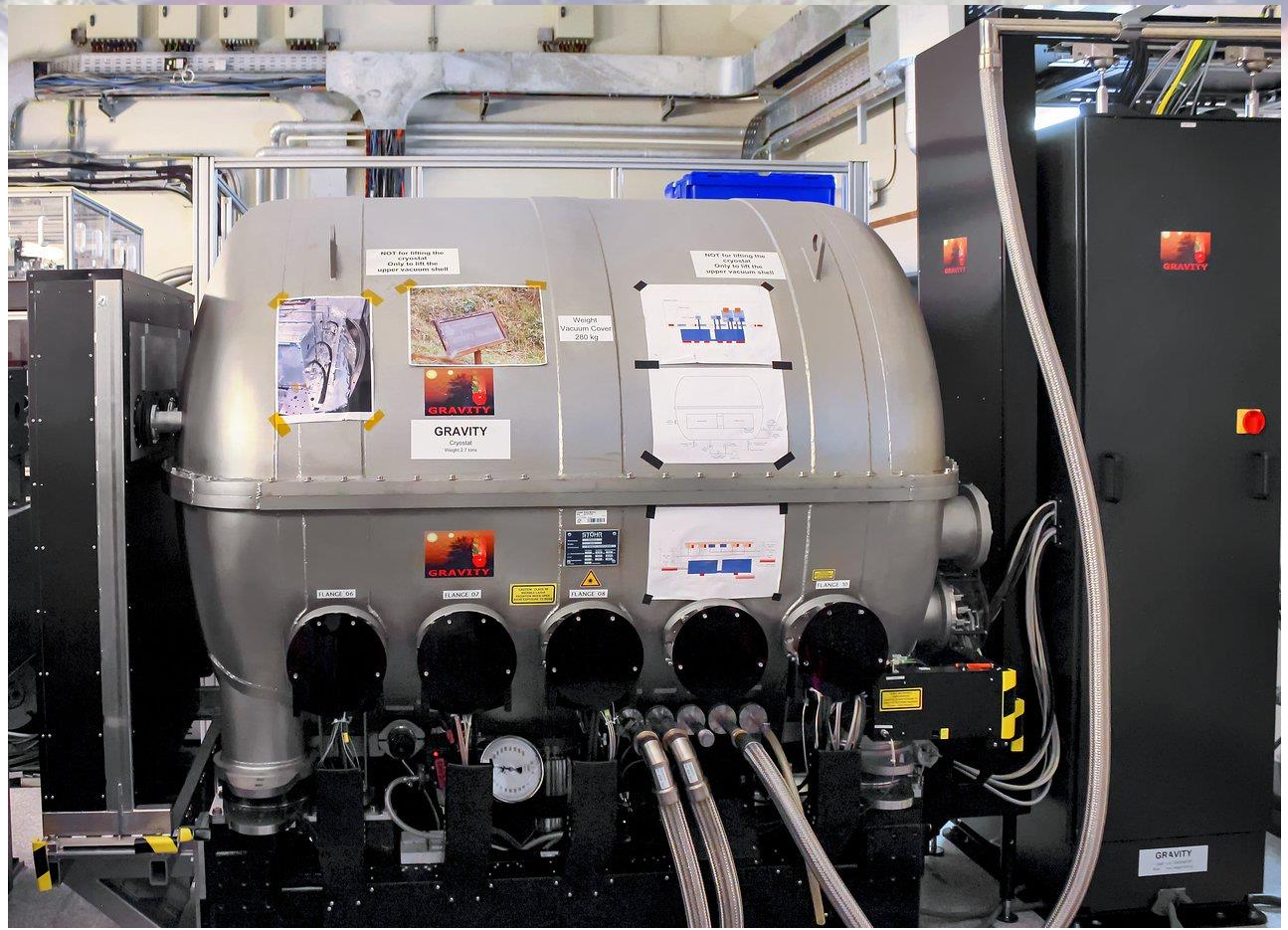
Astrometric Precision

$\sim \frac{(\lambda/2B)}{SNR}$

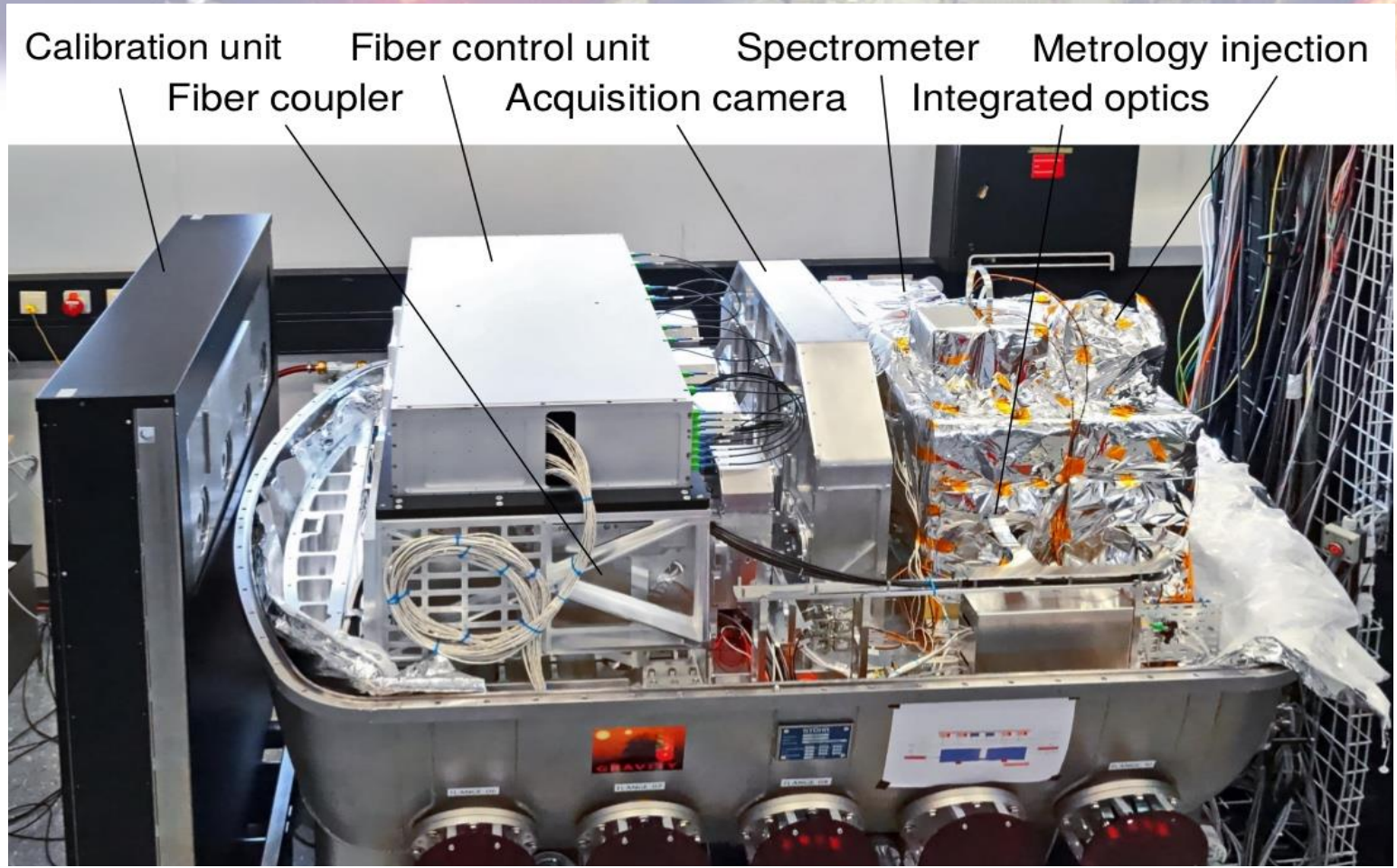
For 130 m baseline observing at 2 µm:

~1.5 mas

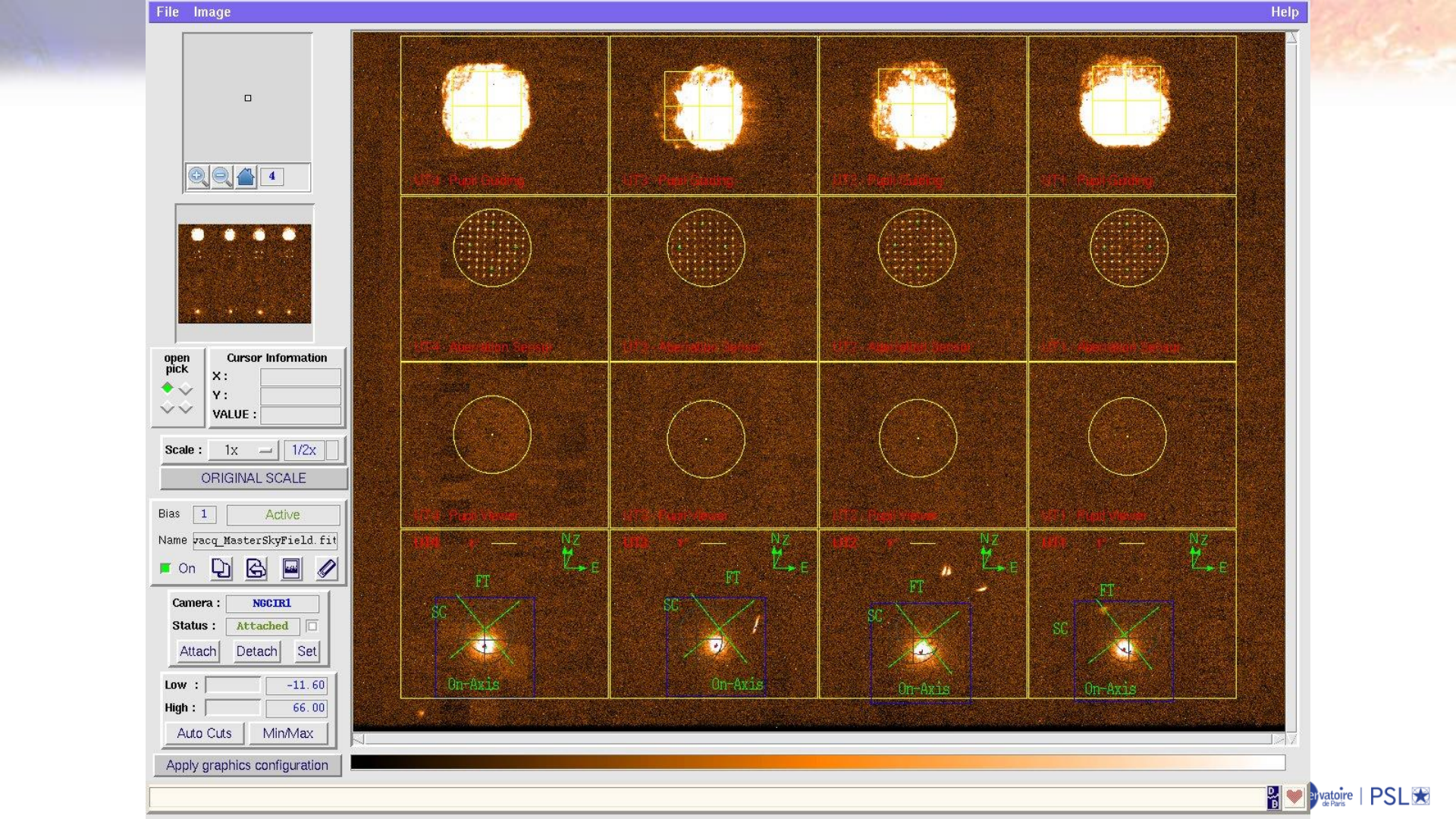
~40 µas



The GRAVITY instrument



Haug, Thiel, Hausmann & the GRAVITY


File
Image
Help
4
open pick
Cursor Information
X :
Y :
VALUE :
Scale :
1x
1/2x
ORIGINAL SCALE
Bias
1
Active
Name
vacq_MasterSkyField.fit
On
Camera :
NGCIR1
Status :
Attached
Attach
Detach
Set
Low :
-11.60
High :
66.00
Auto Cuts
Min/Max
Apply graphics configuration
UT4 - Pupil Guiding
UT3 - Pupil Guiding
UT2 - Pupil Guiding
UT1 - Pupil Guiding
UT4 - Aberration Sensor
UT3 - Aberration Sensor
UT2 - Aberration Sensor
UT1 - Aberration Sensor
UT4 - Pupil Viewer
UT3 - Pupil Viewer
UT2 - Pupil Viewer
UT1 - Pupil Viewer
UT4
UT3
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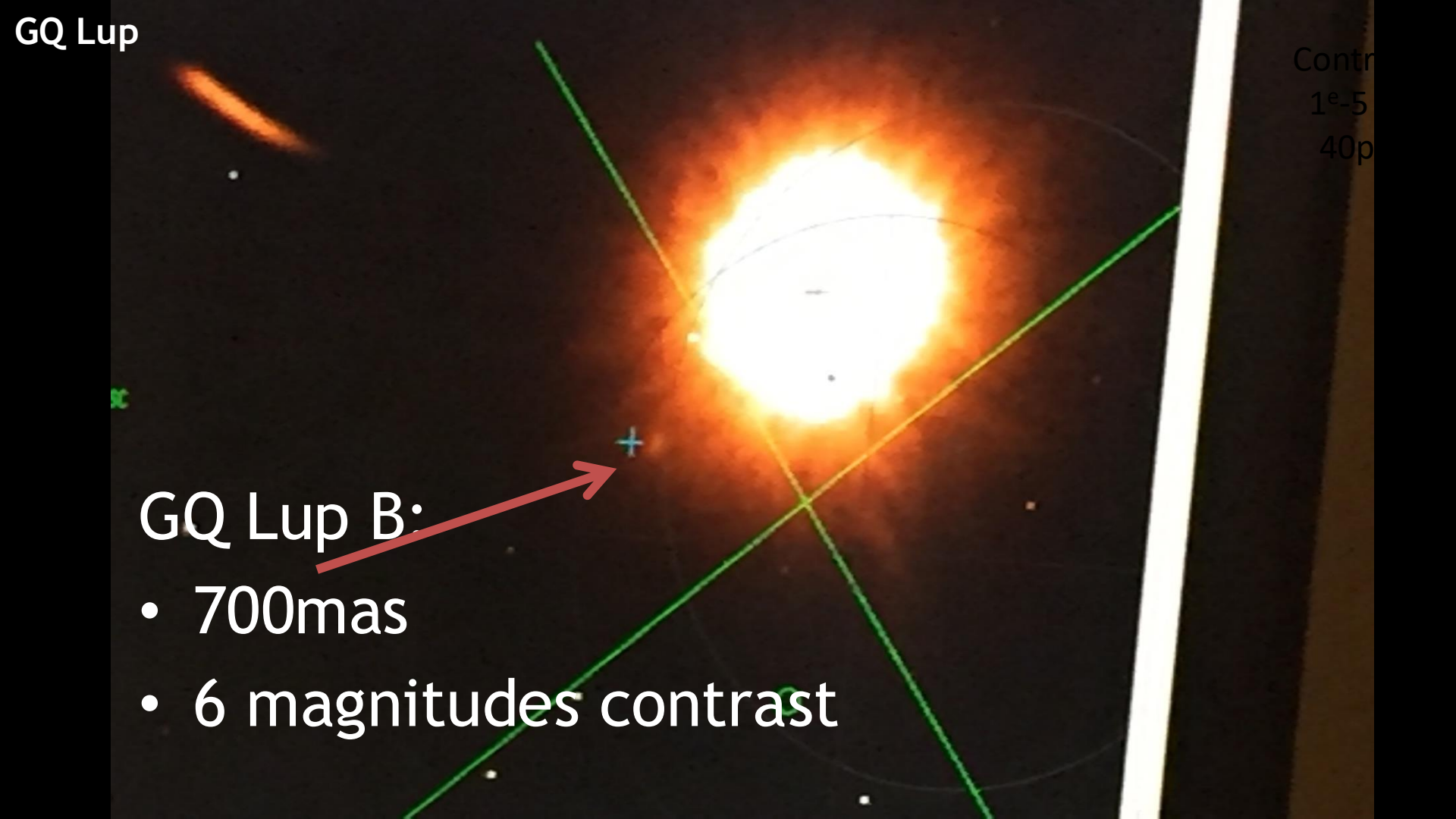
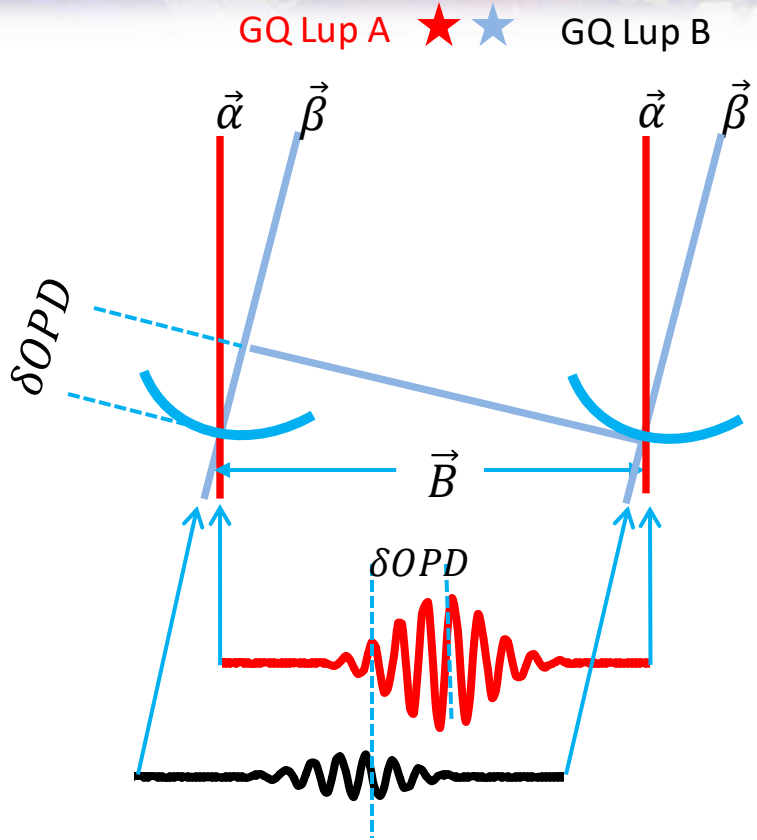
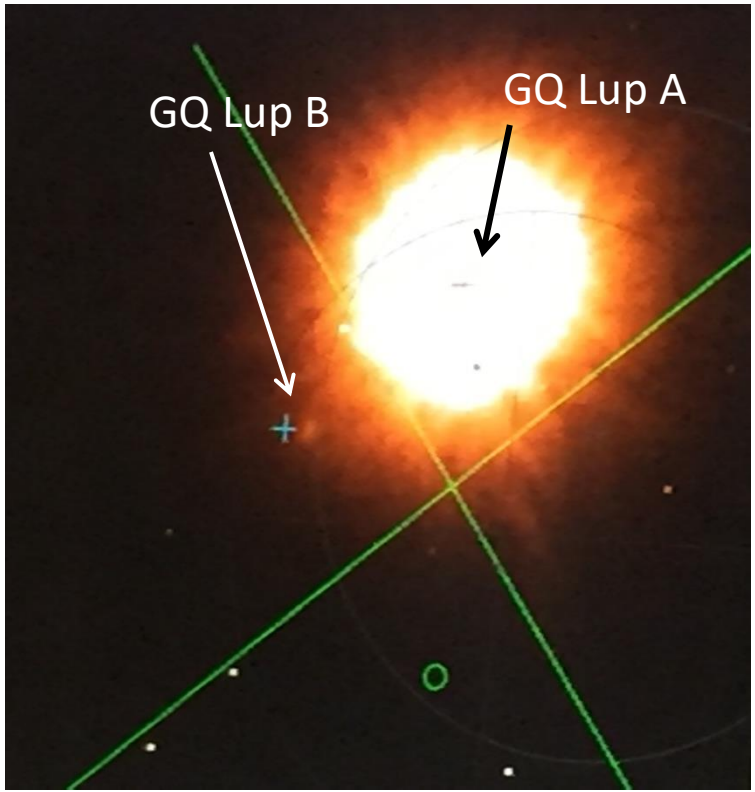
N
Z
E
FT
SC
On-Axis


GQ Lup
Contr
1e-5
40p
GQ Lup B:
• 700mas
• 6 magnitudes contrast



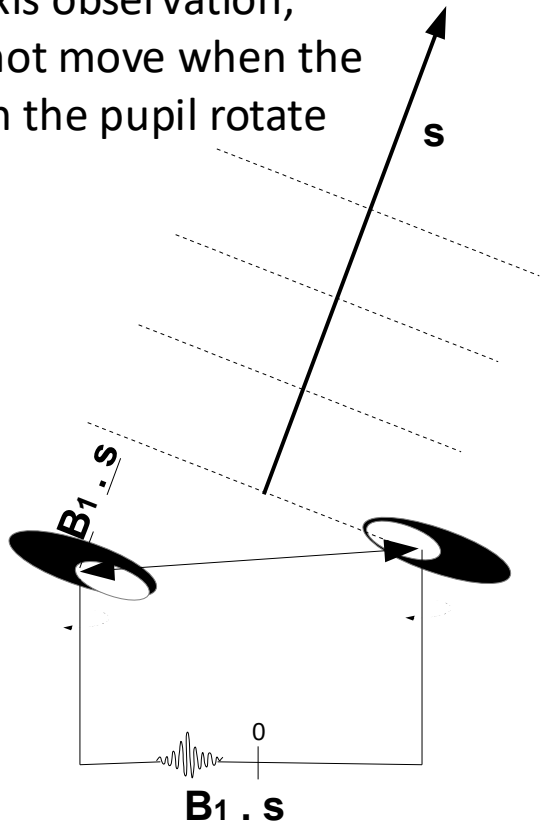


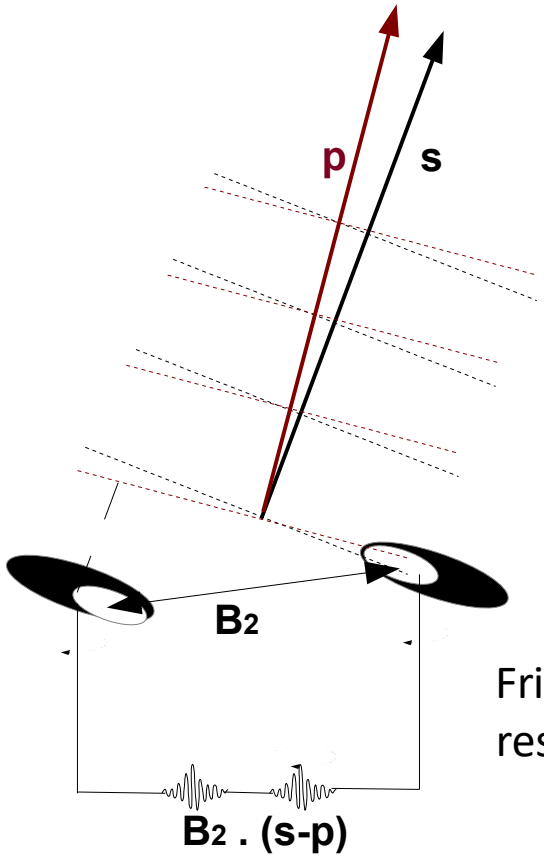
5 nm ← $\delta OPD = \vec{B} \cdot (\vec{\alpha} - \vec{\beta})$ → 10 µas

500 µm

The baseline paradox:

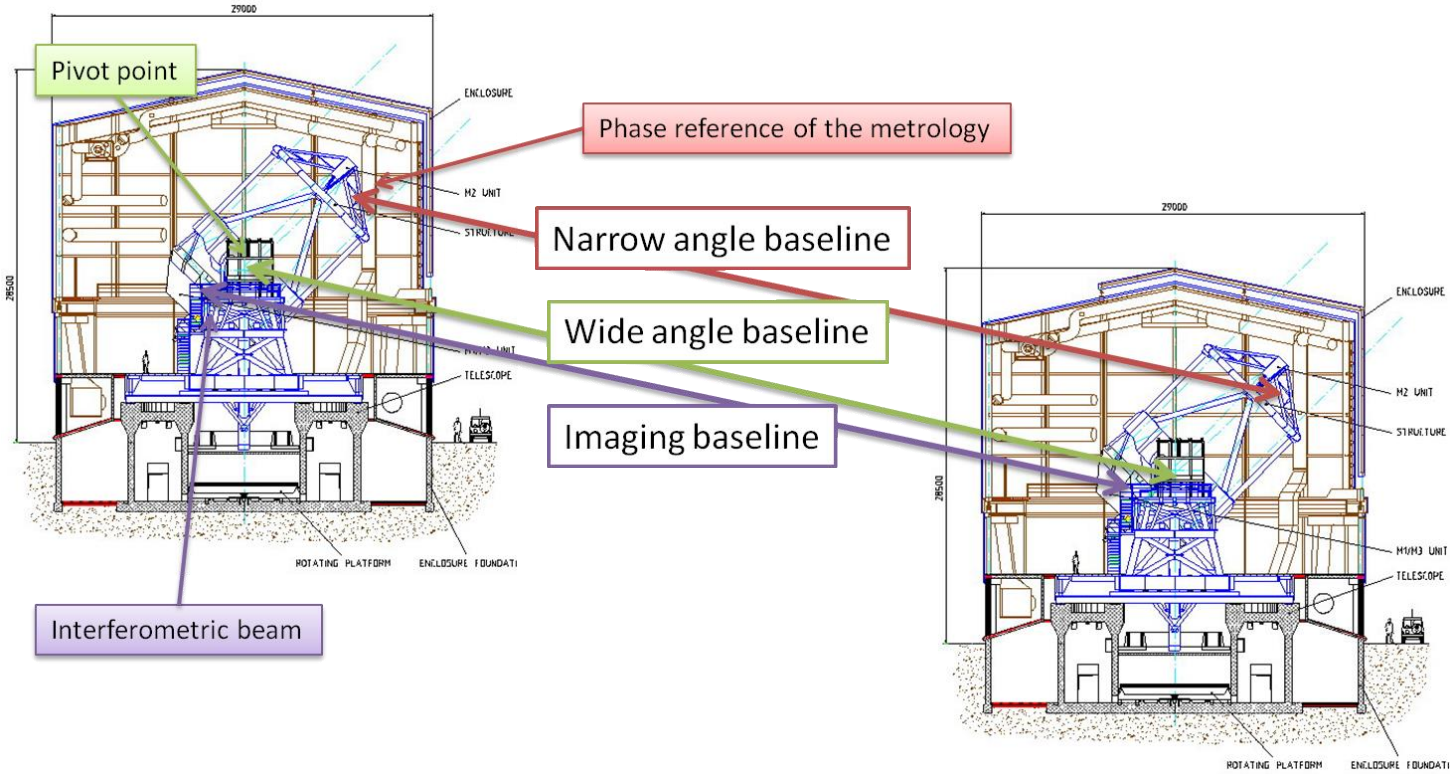
For an on-axis observation,
Fringes do not move when the apperture in the pupil rotate





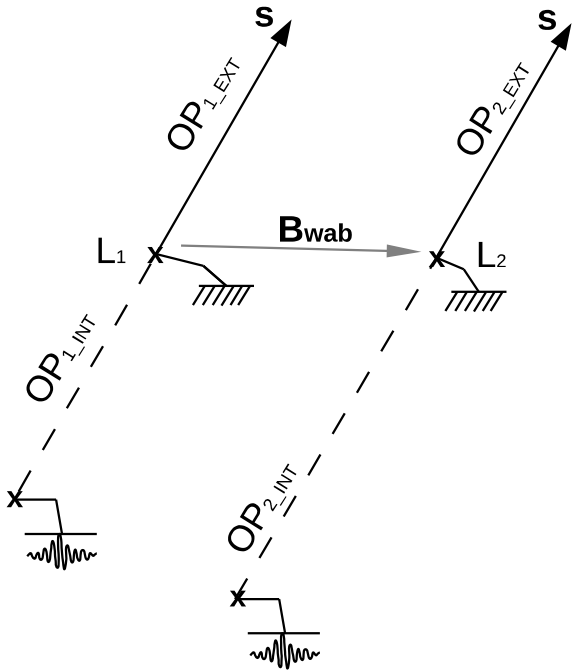
For a relative observation,
Fringes do move with respect to each other

We solved the baseline paradox by introducing 3 baselines, and a metrology



Woillez & Lacour, 2013

We solved the baseline paradox by introducing 3 baselines, and a metrology



A&A 567, A75 (2014)
DOI: 10.1051/0004-6361/201423940
© ESO 2014

Astronomy & Astrophysics

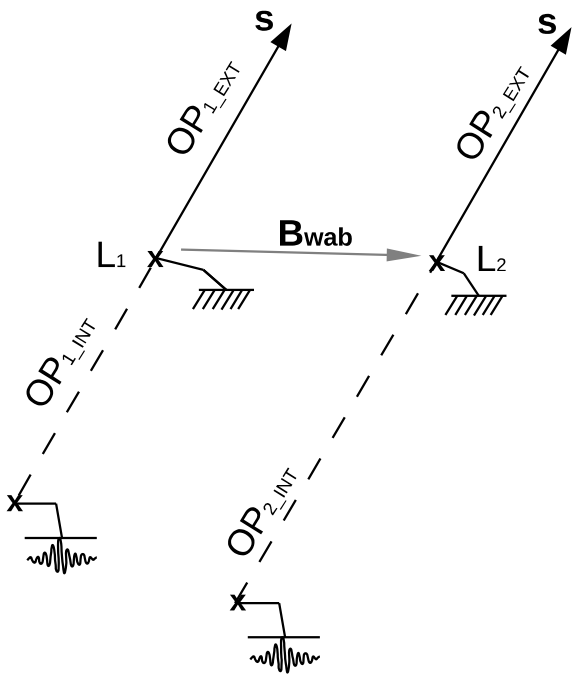
Reaching micro-arcsecond astrometry with long baseline optical interferometry

Application to the GRAVITY instrument

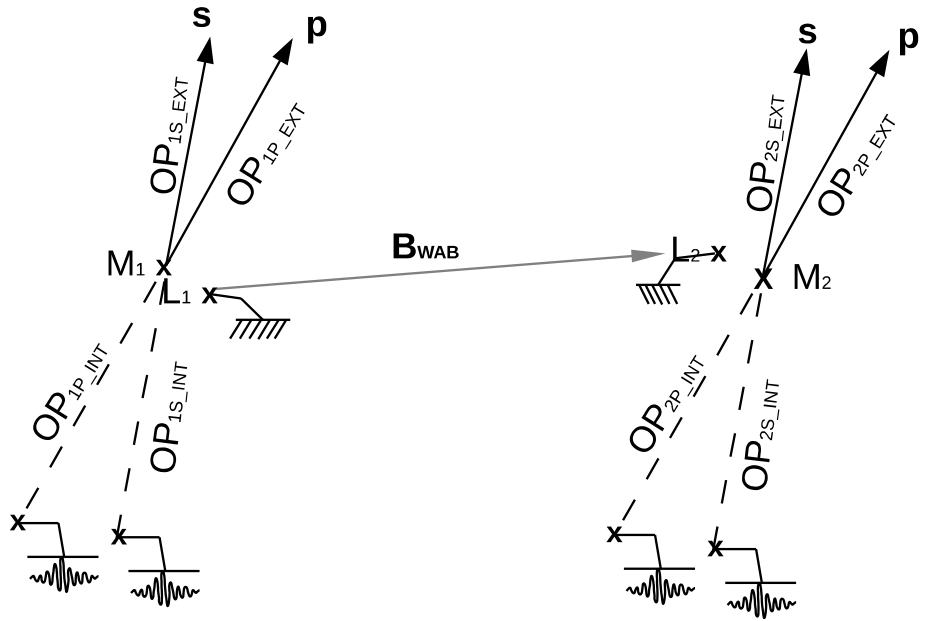
S. Lacour[1], F. Eisenhauer[2], S. Gillessen[2], O. Pfuhl[2], J. Woillez[3], H. Bonnet[3], G. Perrin[1], B. Lazareff[4], S. Rabien[2], V. Lapeyrère[1], Y. Clénet[1], P. Kervella[1], and Y. Kok[2]

The wide angle baseline, and the pivot point

We solved the baseline paradox by introducing 3 baselines, and a metrology

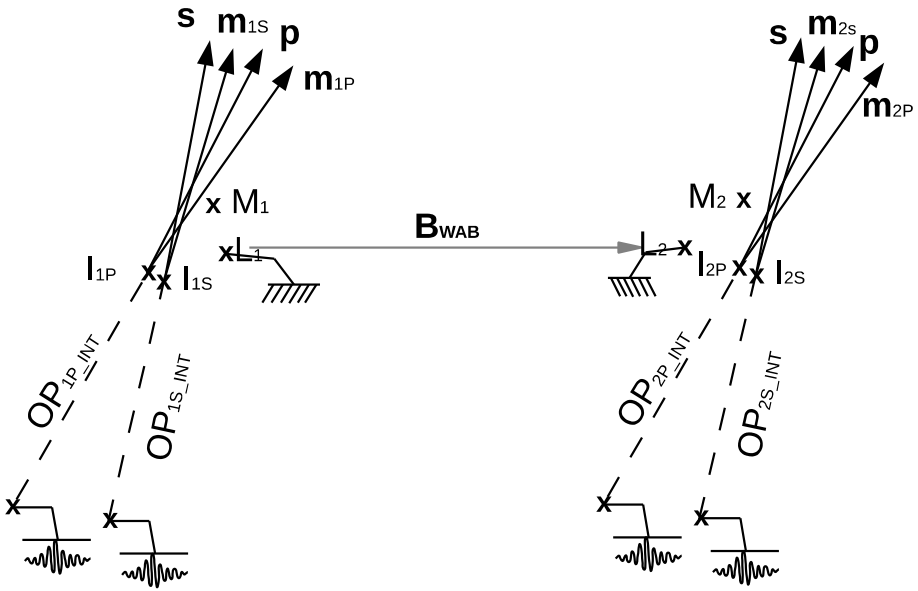


The wide angle baseline, and the pivot point



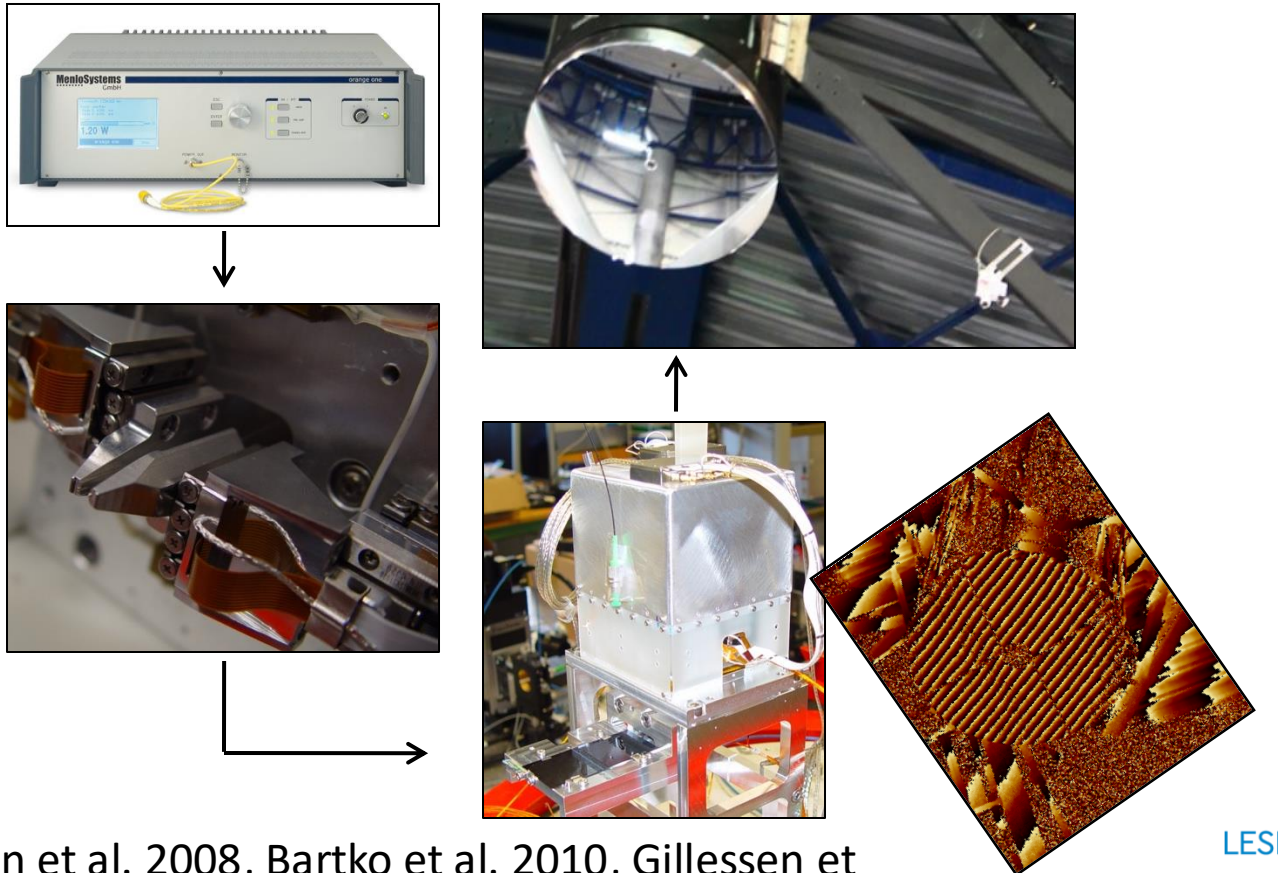
The narrow angle baseline, and the metrology end

We solved the baseline paradox by introducing 3 baselines, and a metrology



The imaging baseline, and the metrology propagation direction

GRAVITY Laser Metrology

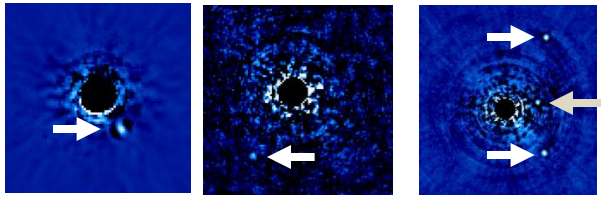


Rabien et al. 2008, Bartko et al. 2010, Gillessen et

ExoGRAVITY

14 VLTI nights (56 UT nights)
over 2 years (3 with Covid)

10 high-contrast exoplanets

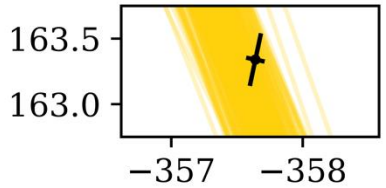


Beta Pictoris, 51 Eri, HR8799, …

1

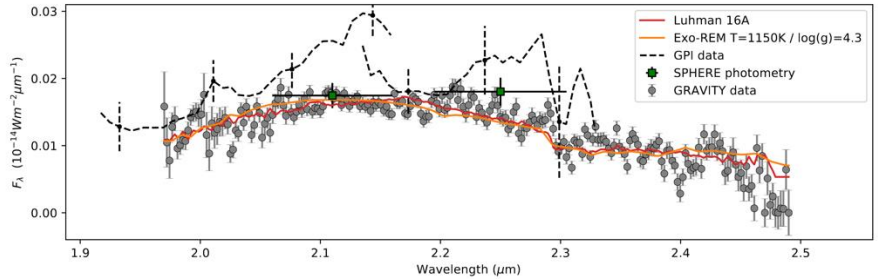
GRAVITY Collaboration et al. 2019:

10-100 µas astrometric monitoring



2

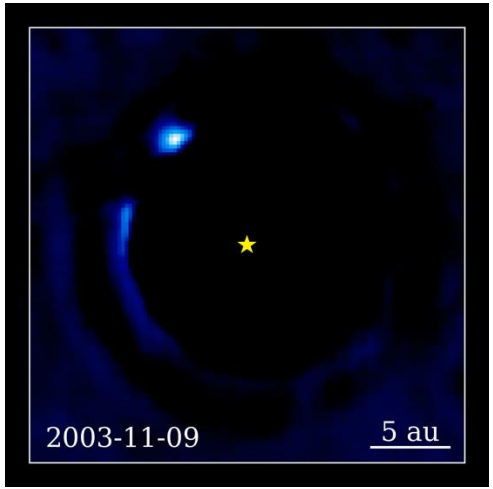
R~500 K-band Spectral Library



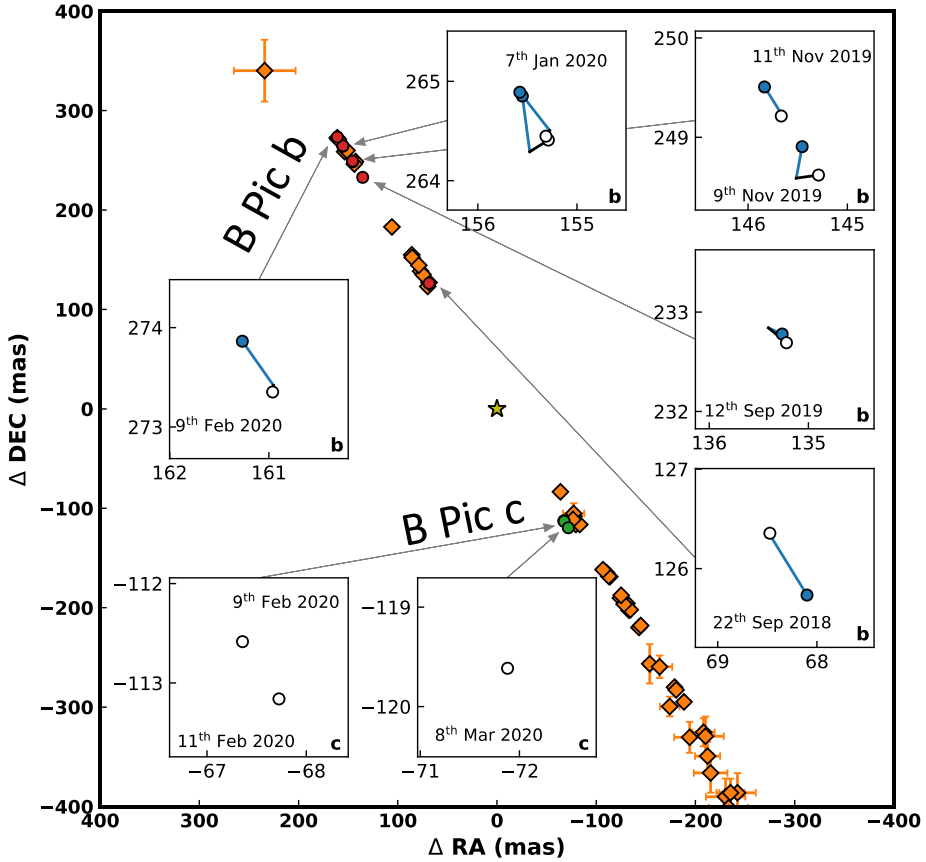
P104 P105 P106 P107 P108 P109

ESIA | Observatoire de Paris | PSL

Beta Pictoris & planet-planet interaction

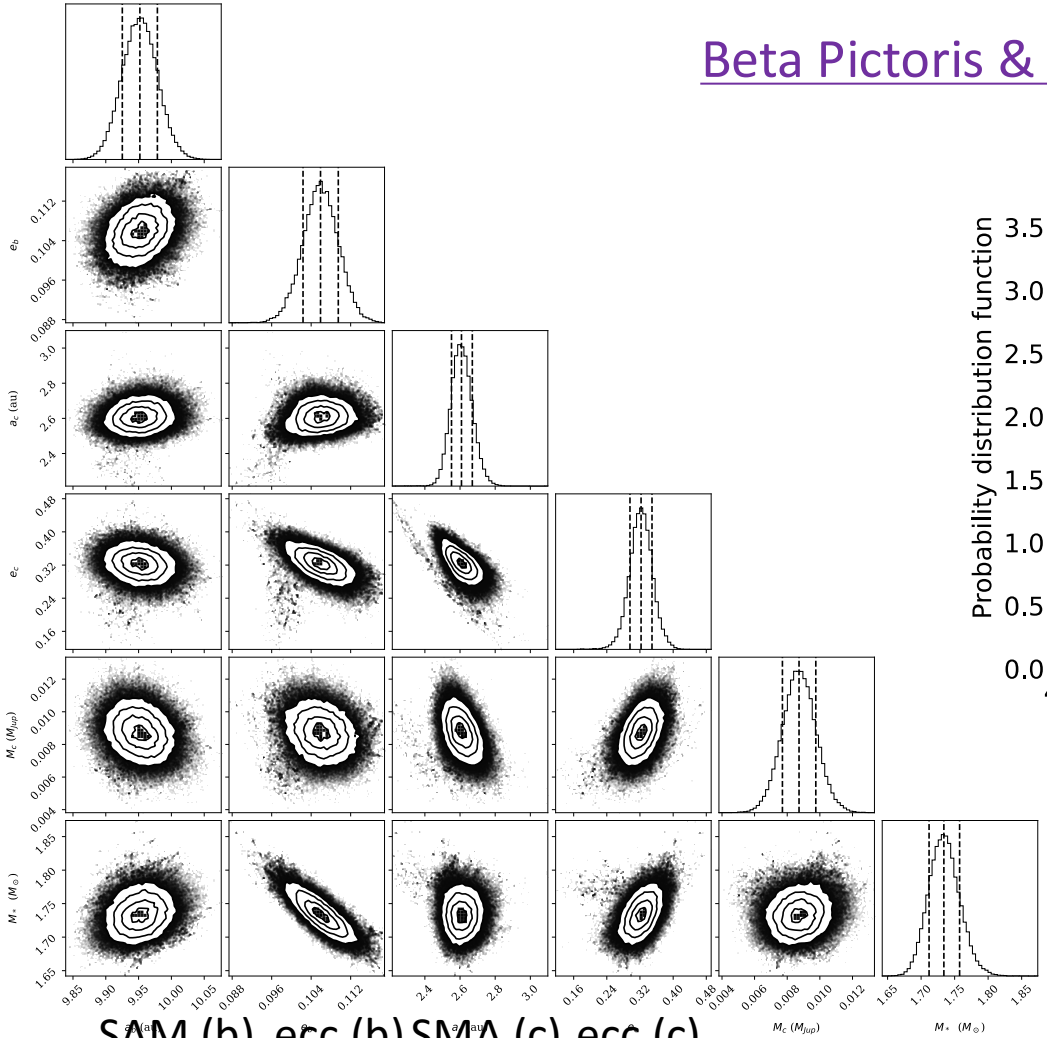


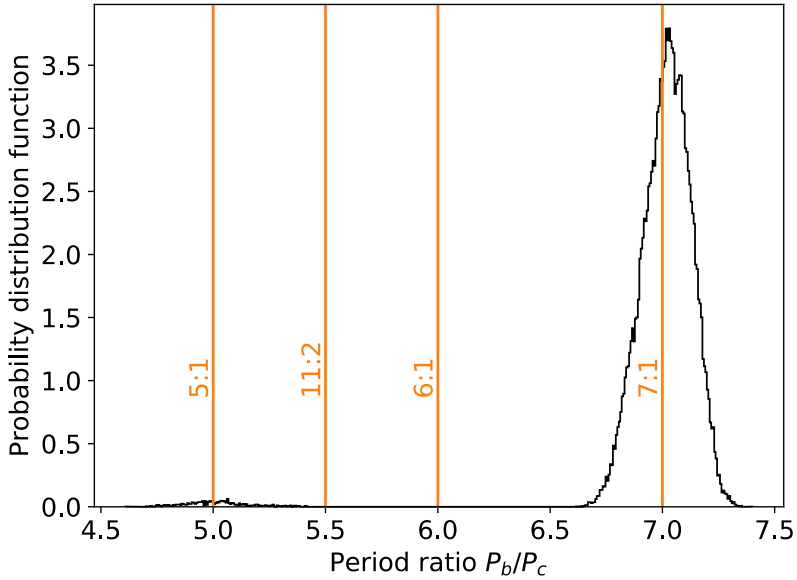
Credit: Jason Wang (Northwestern)/Gemini Planet Imager Exoplanet Survey



Lagrange et al. 2020
Nowak et al. 2020

Beta Pictoris & planet-planet interaction

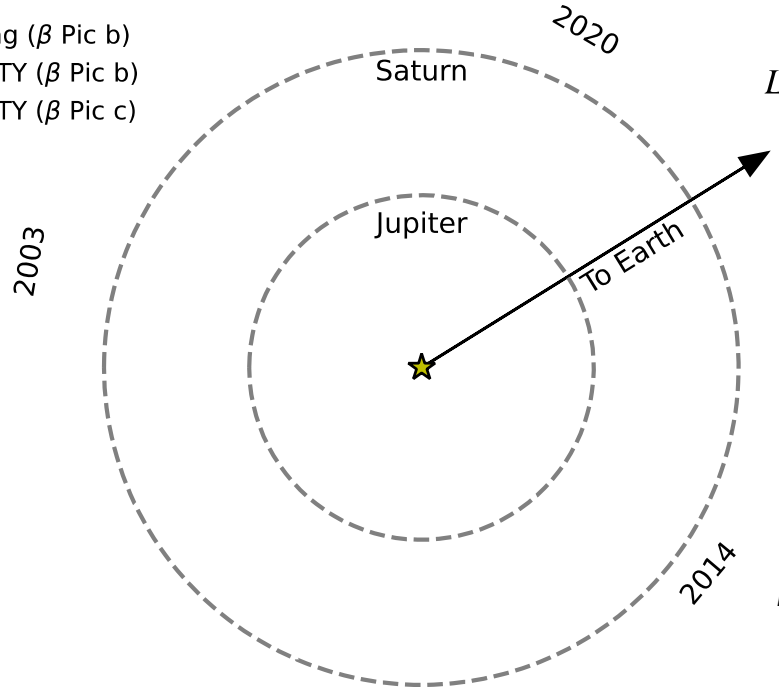




Lacour et al. 2021

Beta Pictoris & Jacobi coordinates

Imaging (β Pic b)
GRAVITY (β Pic b)
GRAVITY (β Pic c)



3-bodies Lagrangian:

$$L = \frac{1}{2}(m_\star \dot{\boldsymbol{x}}_\star^{\,2} + m_b \dot{\boldsymbol{x}}_b^{\,2} + m_c \dot{\boldsymbol{x}}_c^{\,2}) + \frac{G m_\star m_b}{|\boldsymbol{x}_b - \boldsymbol{x}_\star|} + \frac{G m_\star m_c}{|\boldsymbol{x}_c - \boldsymbol{x}_\star|} + \frac{G m_b m_c}{|\boldsymbol{x}_c - \boldsymbol{x}_b|},$$

$$\boldsymbol{q} = \boldsymbol{x}_c - \boldsymbol{x}_\star$$

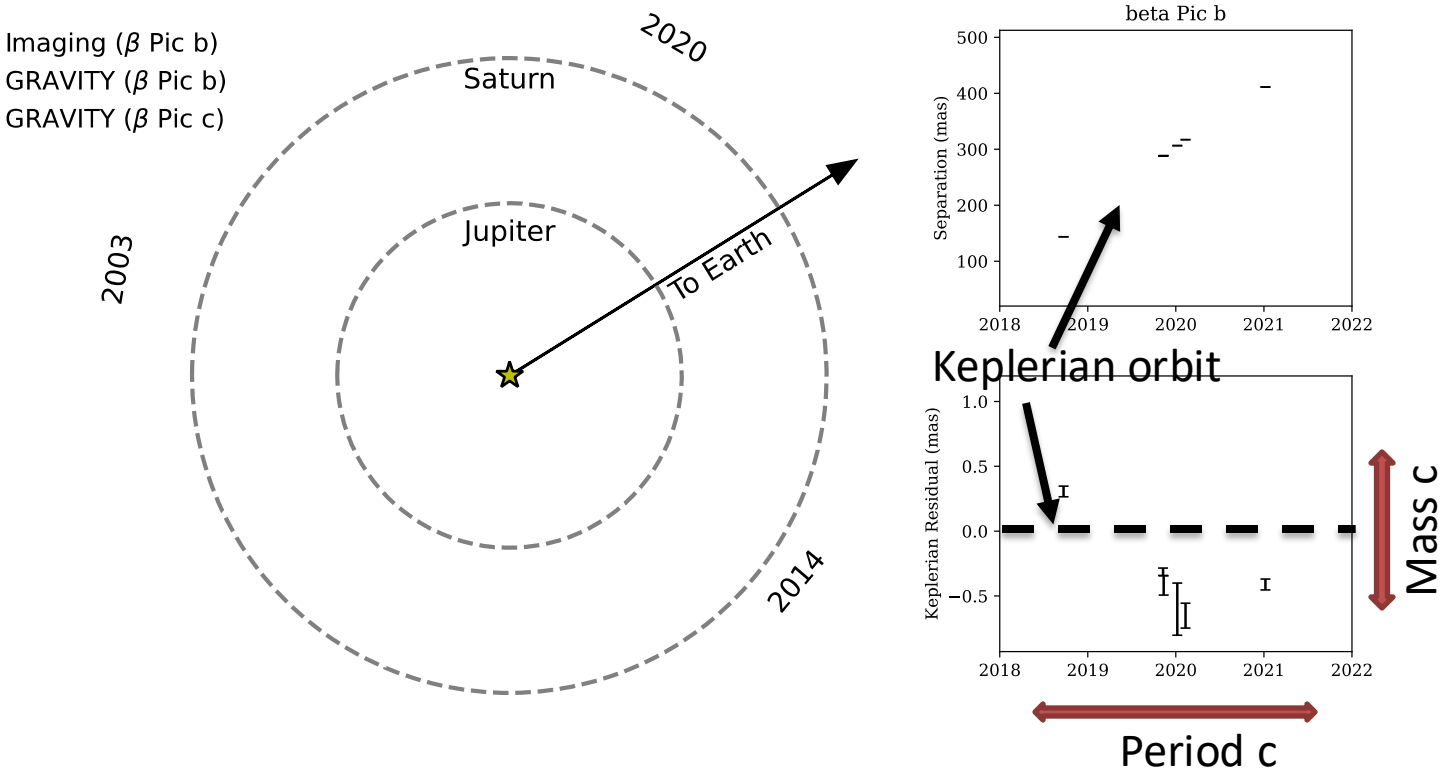
$$\boldsymbol{Q} = \boldsymbol{x}_b - (m_\star \boldsymbol{x}_\star + m_c \boldsymbol{x}_c)\nu^{-1}$$

$$\nu = m_\star + m_c$$

2 2-bodies Lagrangian (!) if $|Q| \gg |q|$:

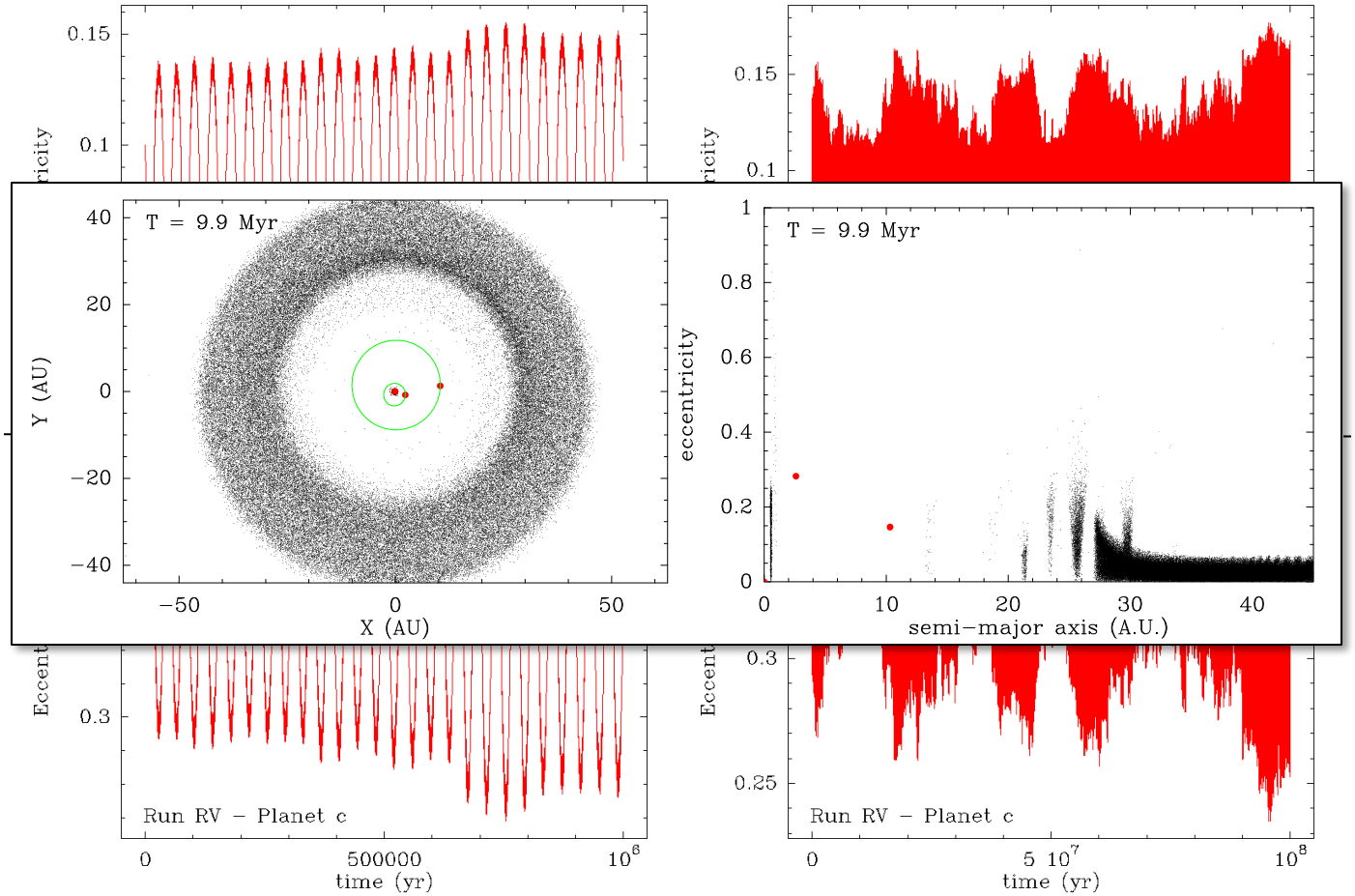
$$L = \frac{1}{2}\left(\mu_{\boldsymbol{q}} \dot{\boldsymbol{q}}^2 + \mu_{\boldsymbol{Q}} \dot{\boldsymbol{Q}}^2\right) + \frac{G m_{\boldsymbol{q}} m_c}{|\boldsymbol{q}|} + \frac{G m_b \mu_{\boldsymbol{Q}}}{|\boldsymbol{Q}|}.$$

Beta Pictoris & Jacobi coordinates



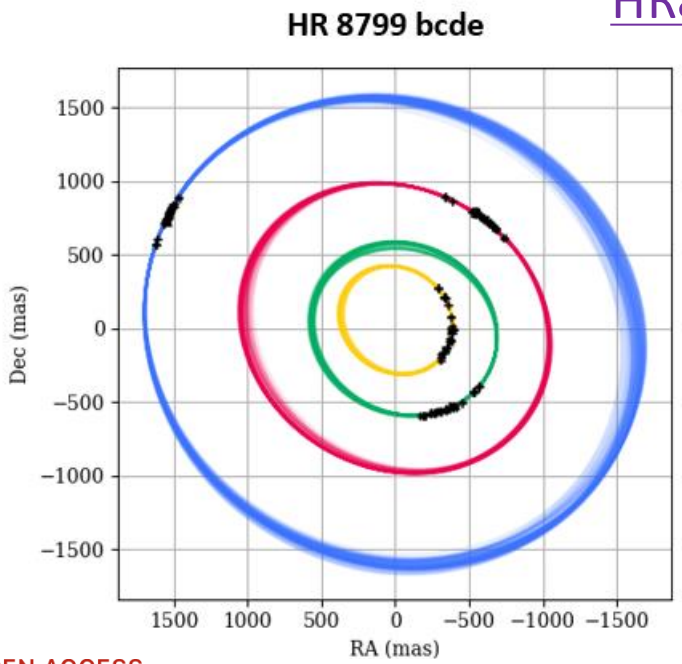
$$9.15^{+1.08}_{-1.06}\ M_{\mathrm{Jup}}$$

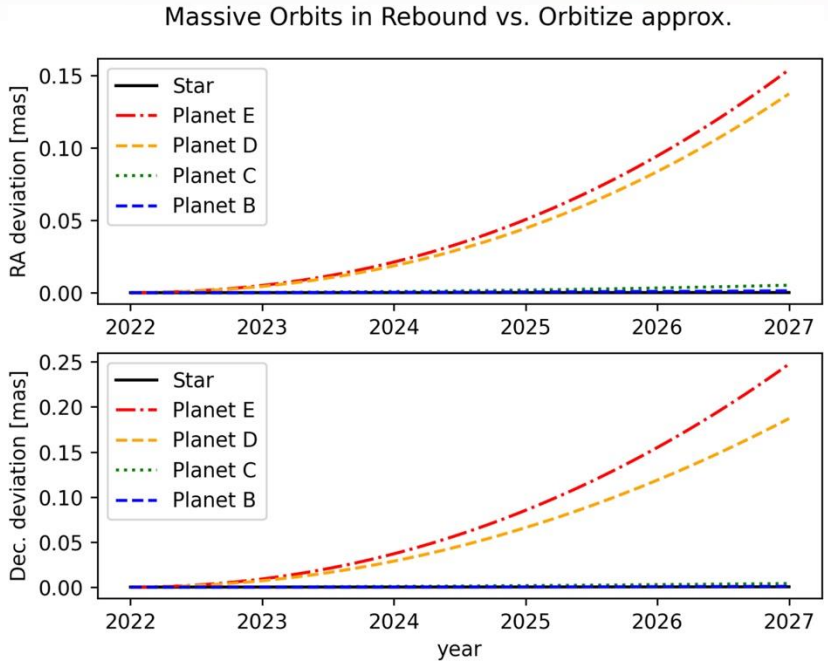
Beta Pictoris & N-body interaction



Beust et al. (2024)

HR8799 & N-body interactions





OPEN ACCESS

N-body Interactions will be Detectable in the HR-8799 System within 5 yr with VLTI-GRAVITY

Sofia Covarrubias[1,2], Sarah Blunt[2,3,4], and Jason J. Wang[2,4,5]

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Research Notes of the AAS, Volume 6, Number 3

Citation Sofia Covarrubias *et al* 2022 *Res. Notes AAS* **6** 66

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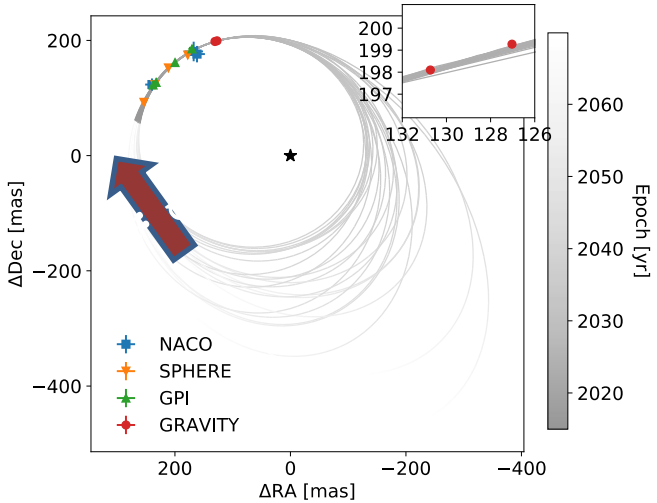
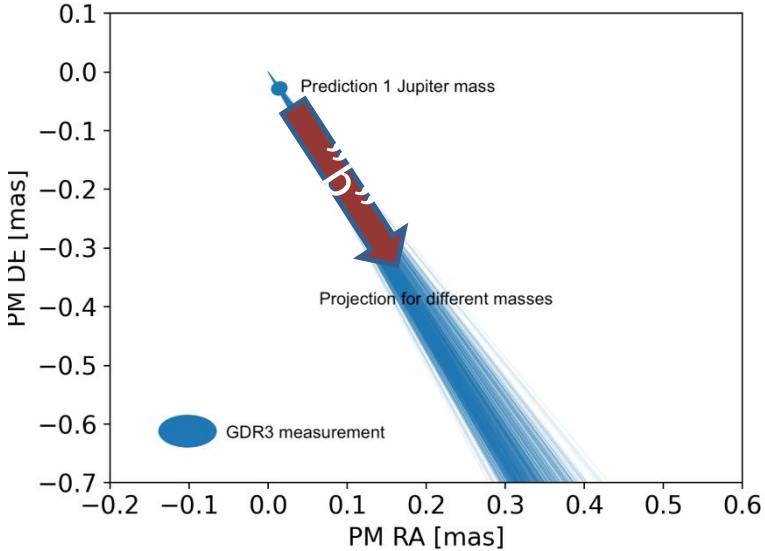
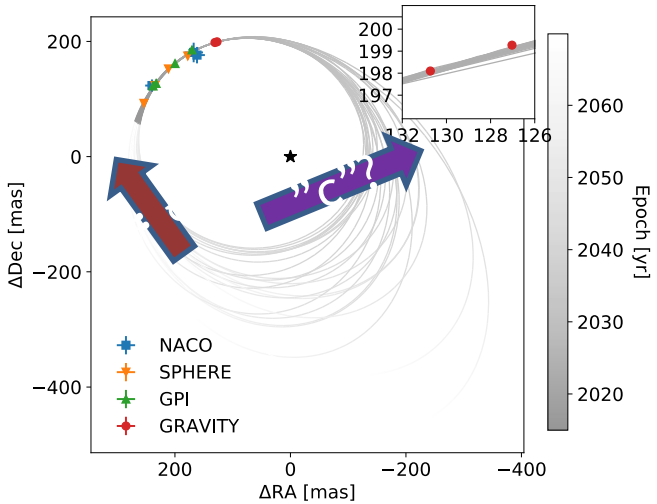
HD209086 and GAIA/Hipparcos

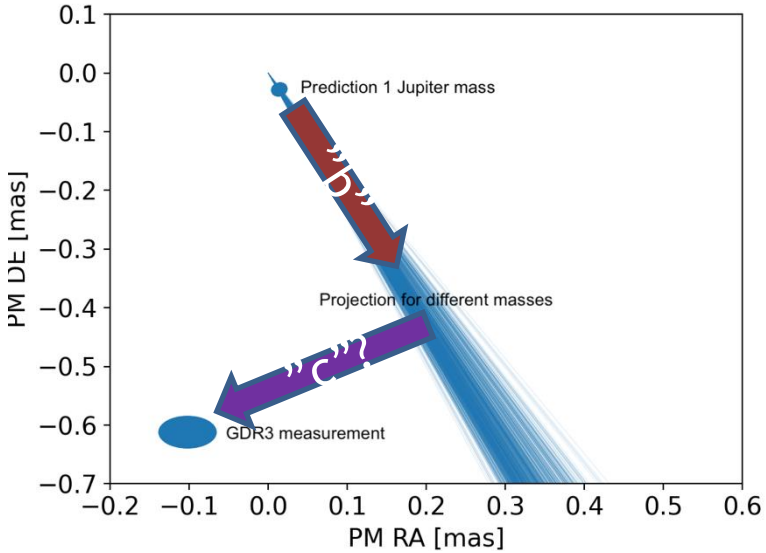




Grandjean+2019, Kammerer+ 2021, Kervella+ 2022

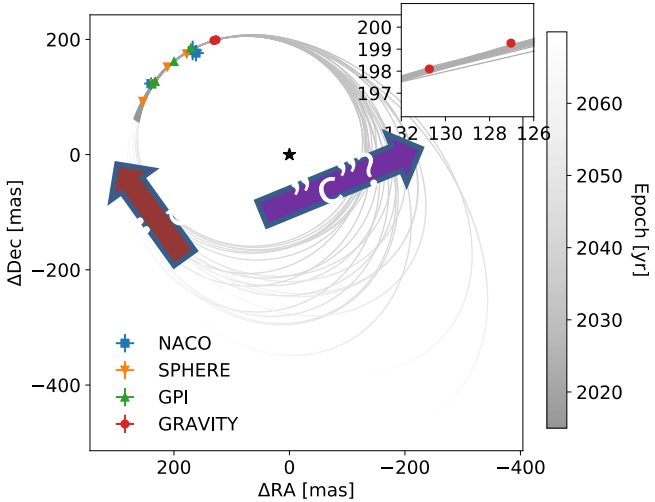
HD209086 and GAIA/Hipparcos

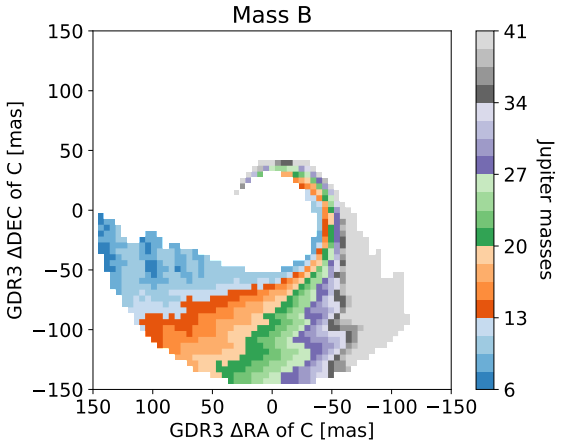


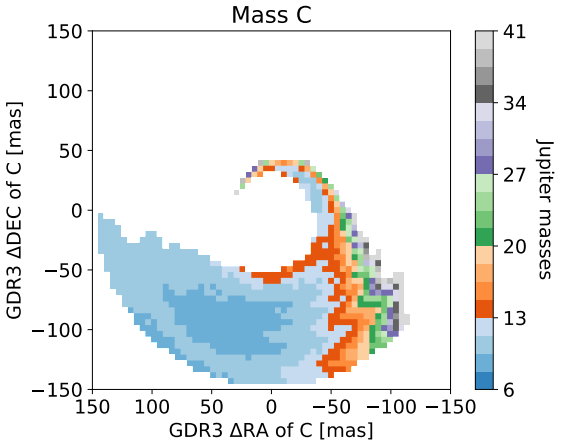


Grandjean+2019, Kammerer+ 2021, Kervella+ 2022

HD209086 and GAIA/Hipparcos



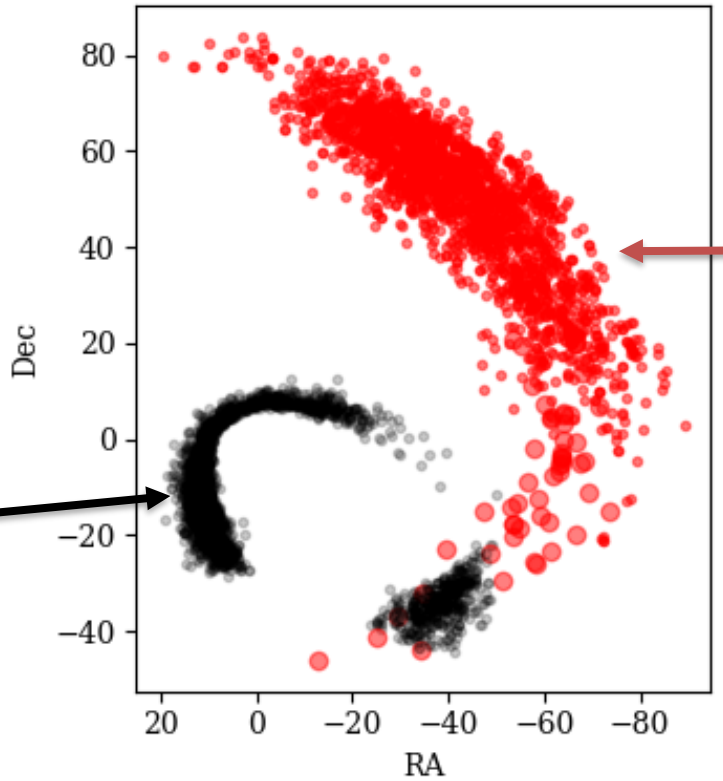




Kammerer+ 2021

The search of an inner planet with GRAVITY

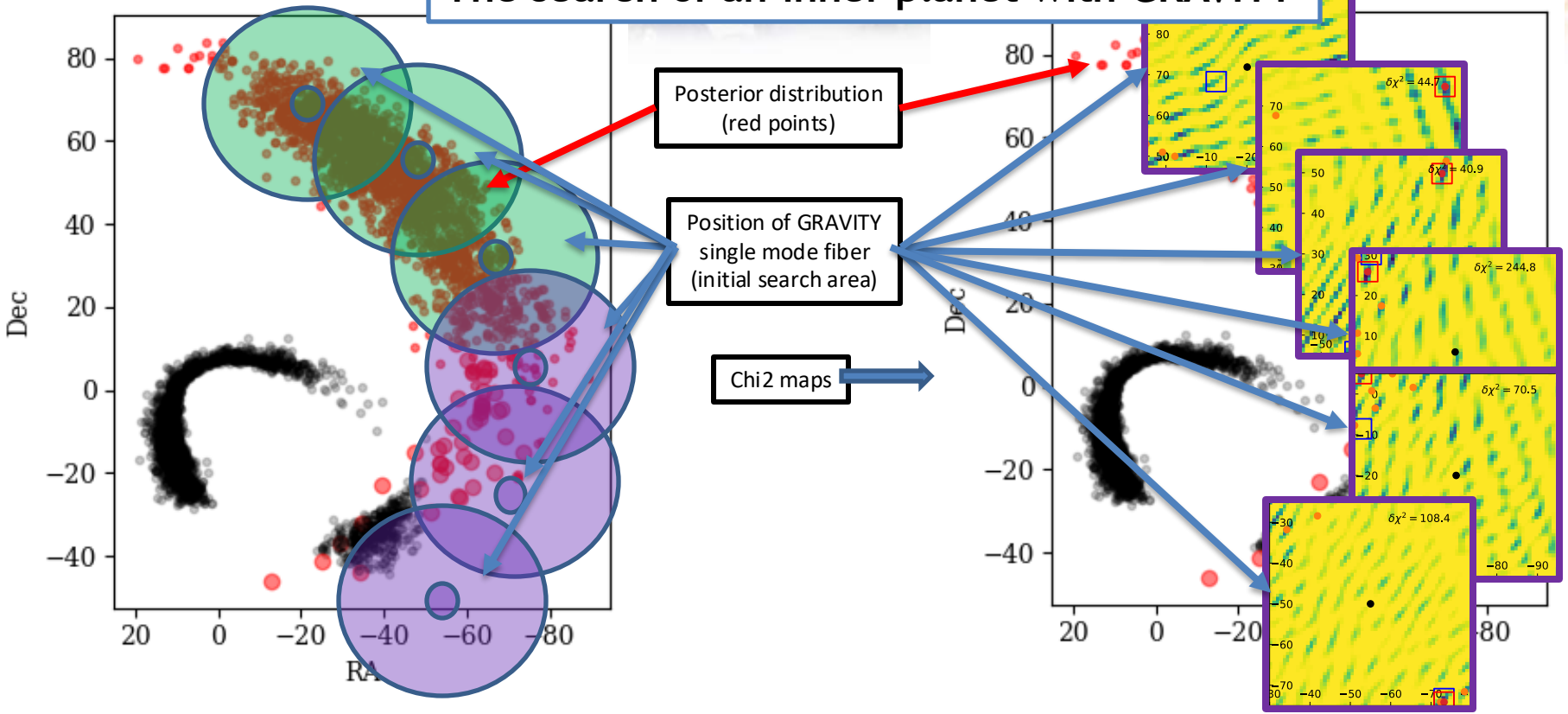
Using orbits of B
+ RVs (GrandJean et al. & +)
+ Gaia DR3:



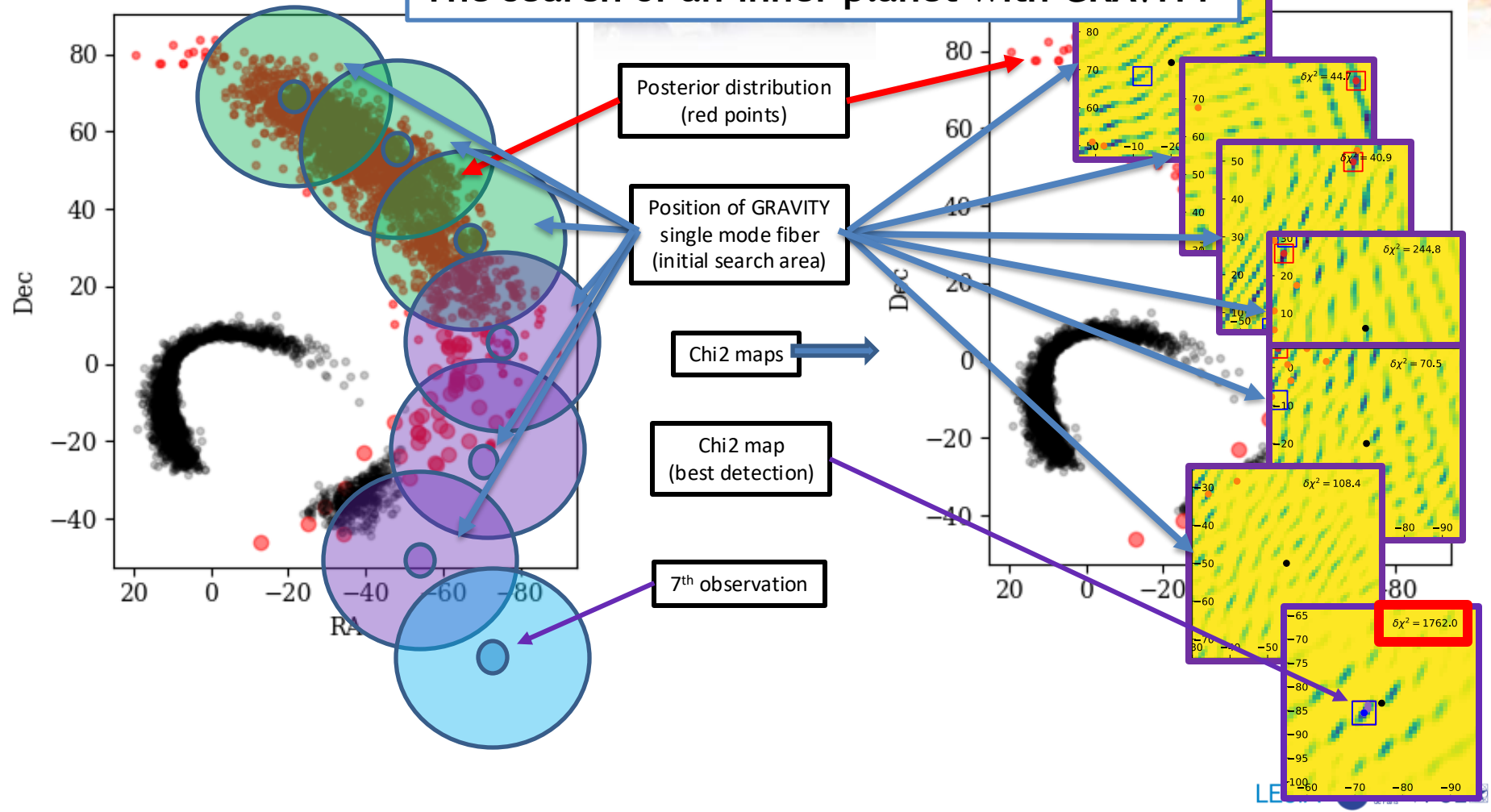
2.5 au, 15 Mjup in red

2 au, 35 Mjup in black

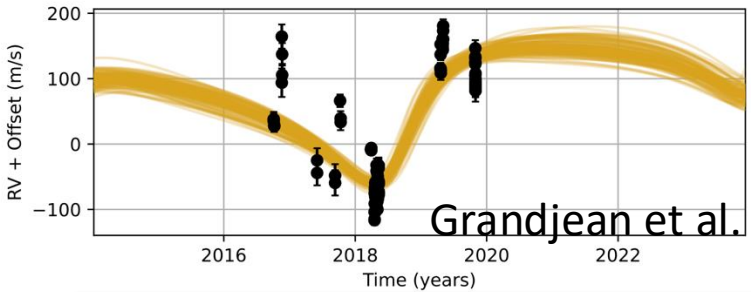
The search of an inner planet with GRAVITY

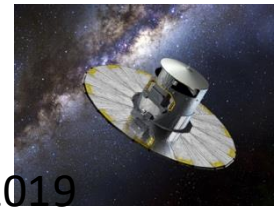


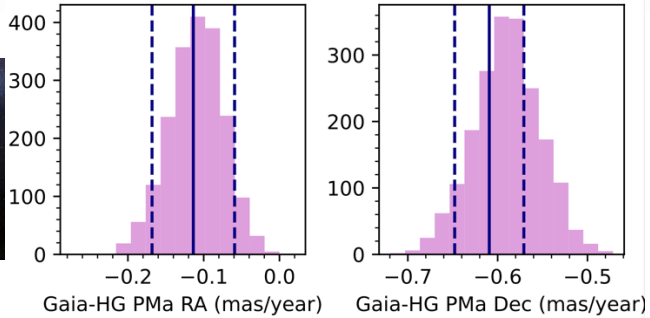
The search of an inner planet with GRAVITY



HD209086 and GAIA/Hipparcos



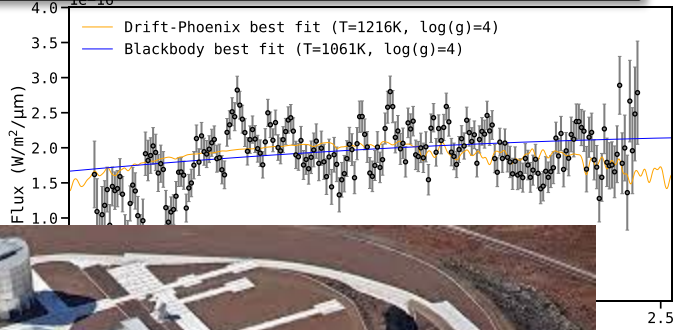


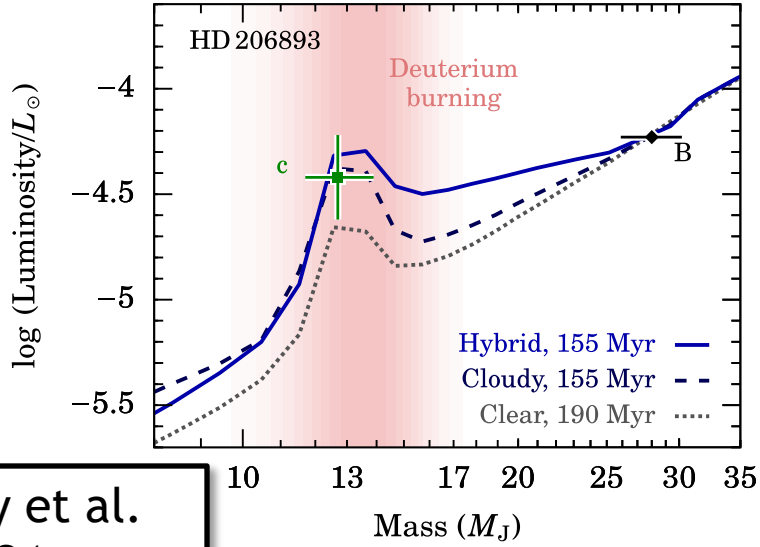


Harps: radial velocity ==> detection + mass

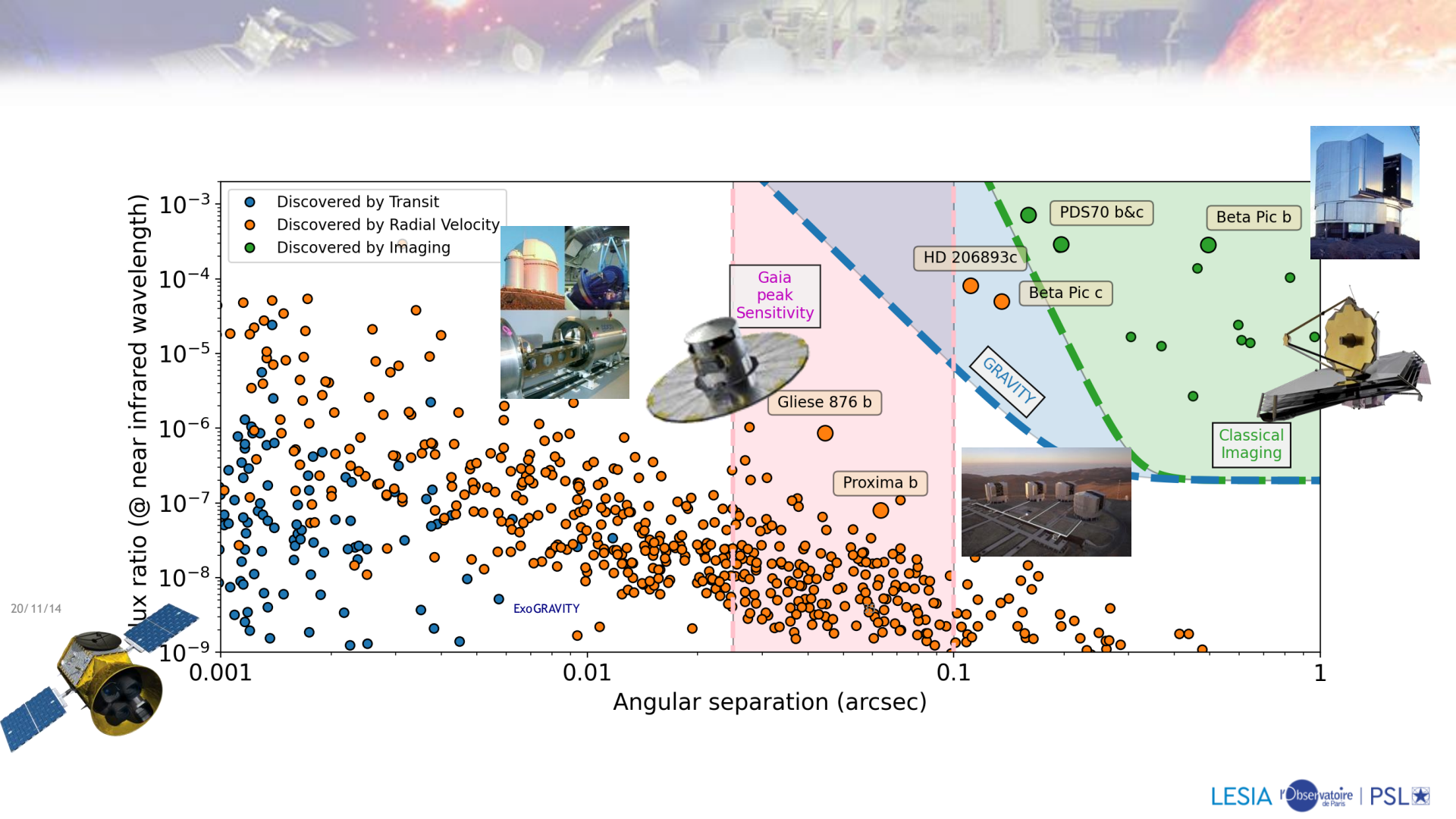
Gaia: proper motion anomaly ==> mass

GRAVITY: spectrum ==> luminosity. The star is too bright!



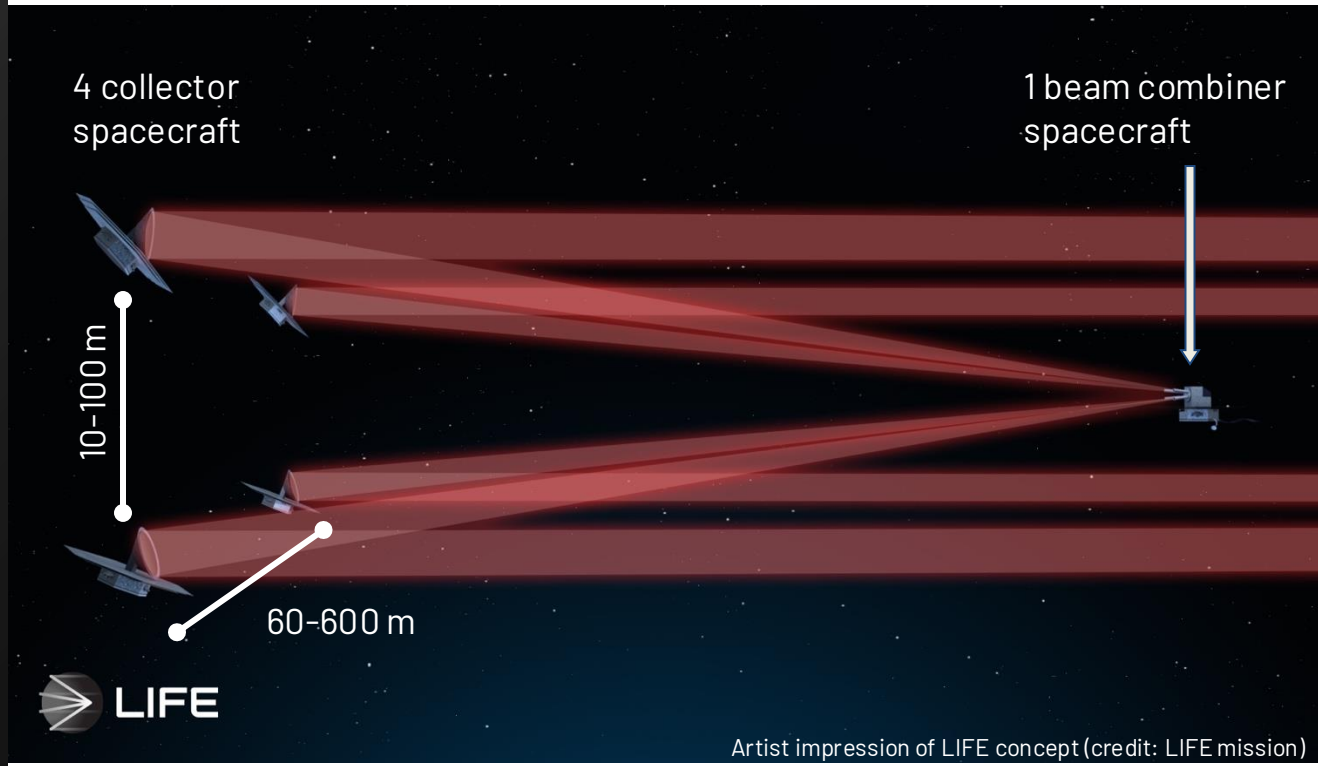


Hinkley et al.


Discovered by Transit
Discovered by Radial Velocity
Discovered by Imaging
Gaia peak Sensitivity
GRAVITY
Gliese 876 b
Proxima b
HD 206893c
Beta Pic c
PDS70 b&c
Beta Pic b
Classical Imaging
ExoGRAVITY
Flux ratio (@ near infrared wavelength)
Angular separation (arcsec)
0.001
0.01
0.1
1
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}

The LIFE mission

- LIFE is a space-based formation-flying nulling interferometer
- It consists of 4 collector spacecraft in a rectangular array and a central beam combiner spacecraft above the array
- All collectors point to the same target and send their light to the combiner where the light is analyzed
- The separation between the collectors can be freely adjusted to optimize the performance for each nearby star
- Like JWST, LIFE will be in an orbit around Lagrange Point 2
- The mission lifetime will be 5-6 years
- LIFE covers the mid-infrared wavelength range between ~6-16 µm (requirement) / ~4-18.5 µm (goal) with a spectral resolution of $R = \lambda/\delta\lambda \sim 100$



Artist impression of LIFE concept (credit: LIFE mission)