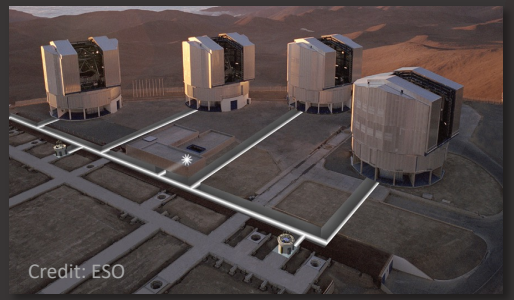
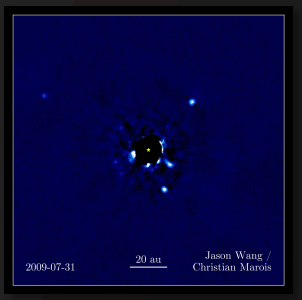


VLTI @ Paranal

Direct characterization of and search for gas giant exoplanets with near-infrared long-baseline interferometry



HR 8799

The ExoGRAVITY team:

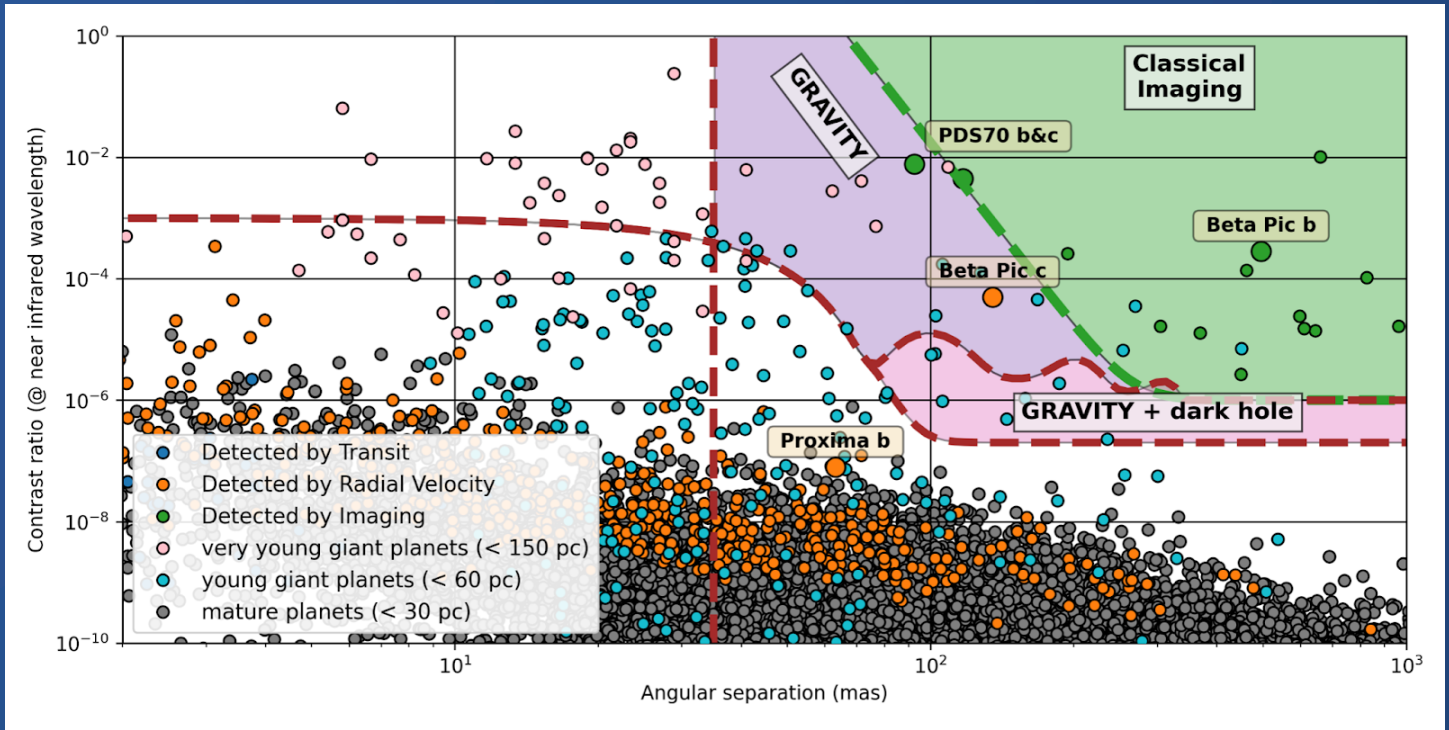
R. Abuter, A. Amorim, R. Asensio-Torres, W. Balmer, M. Baubock, M. Benisty, J.P. Berger, H. Beust, A. Boccaletti, M. Bonnefoy, H. Bonnet, G. Bourdarot, W. Brandner, F. Cantalloube, B. Charnay, E. Choquet, V. Christiaens, Y. Clénet, V. Coudé du Foresto, A. Cridland, P.T. de Zeeuw, R. Dembet, J. Dexter , A. Drescher, G. Duvert, A. Eckart, F. Eisenhauer, F. Gao, P. Garcia, R. Garcia Lopez, T. Gardner, E. Gendron, R. Genzel, S. Gillessen, J. Girard, A. Greenbaum, X. Haubois, G. Heissel, T. Henning, S. Hinkley , S. Hippler, M. Horrobin, M. Houllé, Z. Hubert, A. Jiménez-Rosales, L. Jocou, J. Kammerer, P. Kervella, M. Keppler, L. Kreidberg, M. Kulikauskas, S. Lacour, A.-M. Lagrange, L. Lasi , V. Lapeyrère, J.-B. Le Bouquin, P. Léna, A. Mérand, A.-L. Maire, P. Mollière, J. Monnier, M. Nowak, D. Mouillet, A. Muller, E. Nasedkin, T. Ott, G. Otten, D. Oré , T. Paumard, C. Paladini, K. Perraut, G. Perrin, L. Pueyo, O. Pfuhl, J. Rameau, L. Rodet, G. Rodriguez-Coira, G. Rousset, P. Rubini, S. Scheithauer, J. Shangguan, J. Stadler, O. Straub, C. Straubmeier, T. Stolker, E. Sturm, L.J. Tacconi, E.F. van Dishoeck, A. Vigan, F. Vincent, S.D. von Fellenberg, J. Wang, K. Ward-Duong , F. Widmann, E. Wieprecht, E. Wiezorrek, J. Woillez, and The GRAVITY Collaboration

ExoGRAVITY

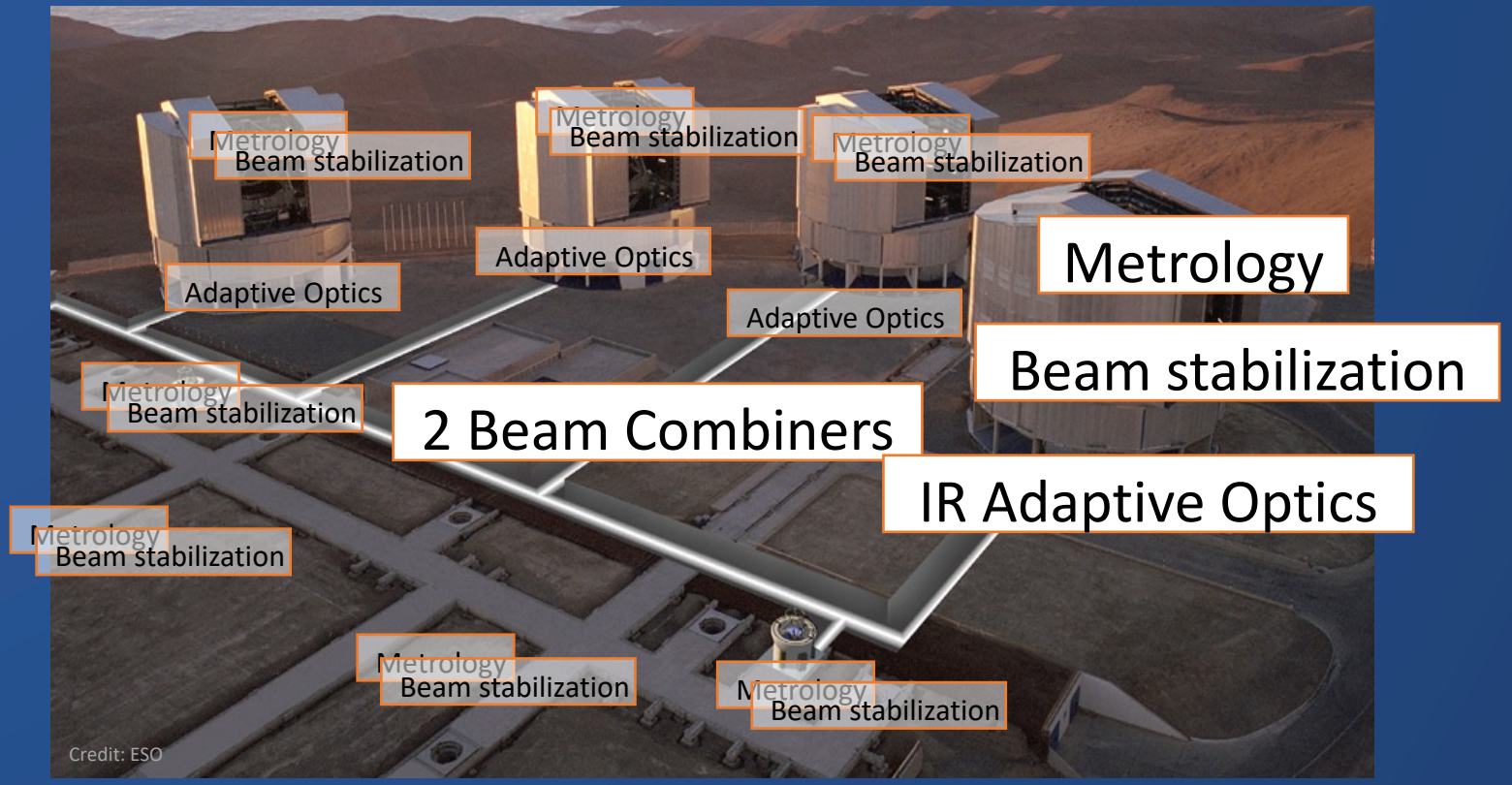
Jens Kammerer

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

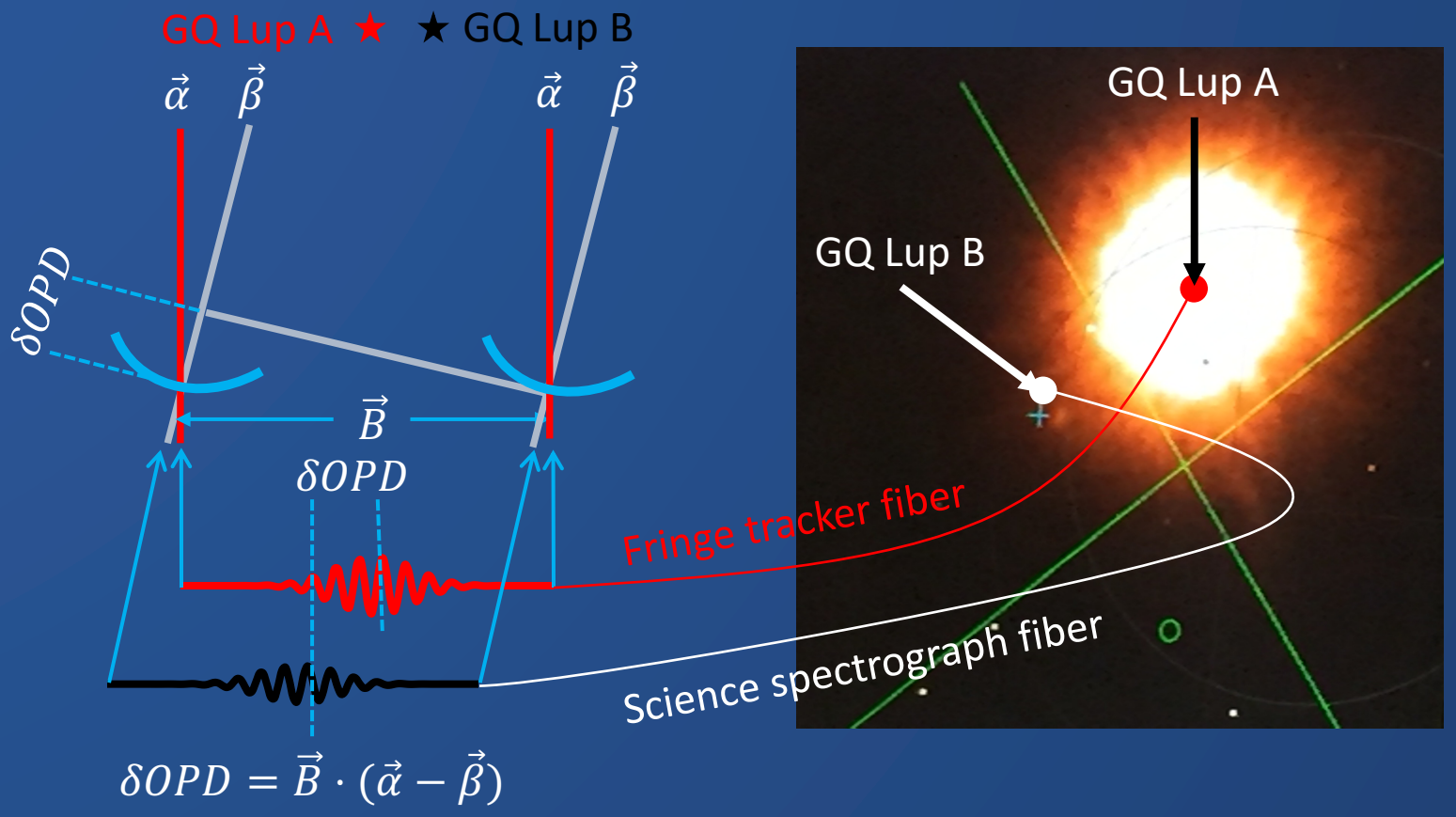
The unique power of GRAVITY



How it works

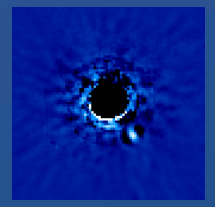

Metrology
Beam stabilization
Metrology
Beam stabilization
Metrology
Beam stabilization
Adaptive Optics
Adaptive Optics
Adaptive Optics
Metrology
Beam stabilization
Metrology
Beam stabilization
Metrology
Beam stabilization
Metrology
Beam stabilization
Credit: ESO
Metrology
Beam stabilization
2 Beam Combiners
IR Adaptive Optics

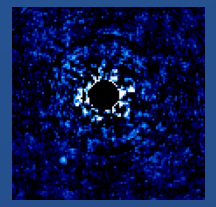
How it works

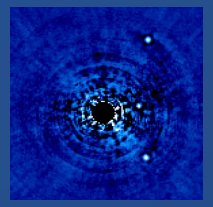

GQ Lup A ★
★ GQ Lup B
$\vec{\alpha}$
$\vec{\beta}$
$\vec{\alpha}$
$\vec{\beta}$
δOPD
$\vec{B}$
δOPD
Fringe tracker fiber
Science spectrograph fiber
GQ Lup A
GQ Lup B
$\delta OPD = \vec{B} \cdot (\vec{\alpha} - \vec{\beta})$

What it does

- ExoGRAVITY Large Program
  - 14 VLTI nights (56 UT nights)
  - Distributed over 3 years
  - 10 high-contrast gas giant planets

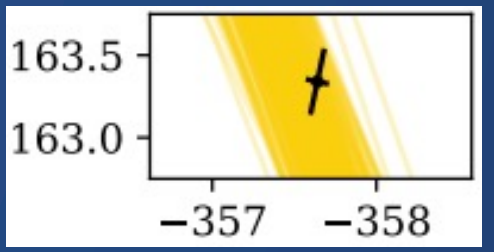

β Pic


51 Eri


HR 8799

etc...

1. ~100 µas astrometry (here HR 8799 e)



GRAVITY Collaboration et al. 2019

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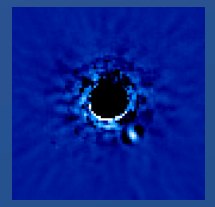
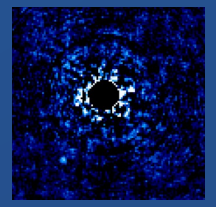

β Pic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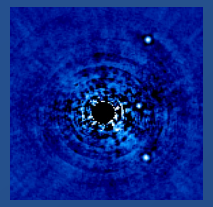
HR 8799

etc...

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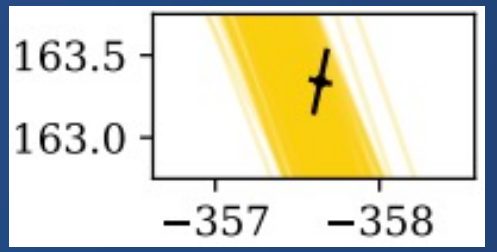
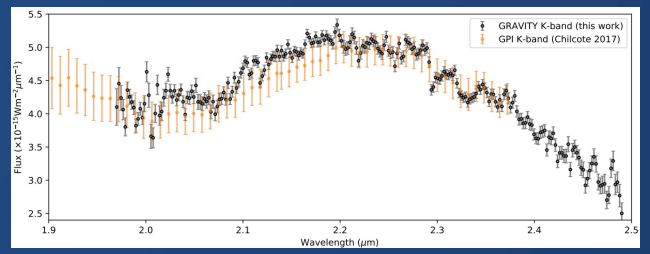


GRAVITY Collaboration et al. 2019

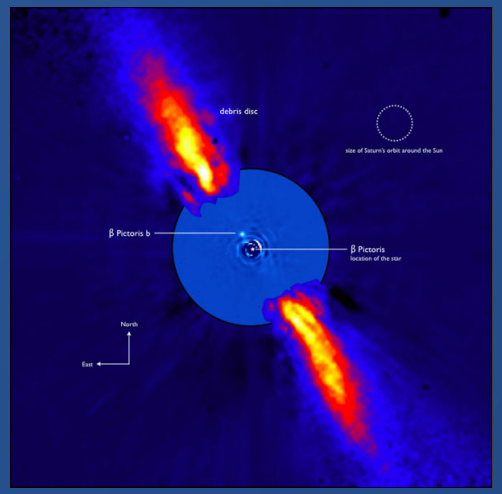
2. R ~ 500 K-band spectra (here HR 8799 e)



GRAVITY Collaboration et al. 2020

β Pic

- First direct detection of a radial velocity planet (thanks to Anne-Marie Lagrange et al.)



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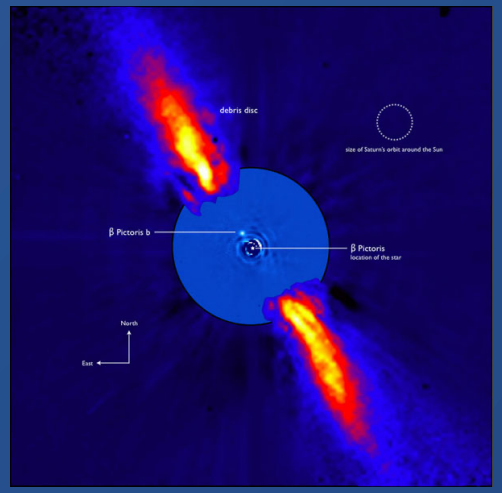
Article | Published: 19 August 2019

Evidence for an additional planet in the β Pictoris system

A.-M. Lagrange ✉, Nadège Meunier, Pascal Rubini, Miriam Keppler, Franck Galland, Eric Chapellier, Eric Michel, Luis Balona, Hervé Beust, Tristan Guillot, Antoine Grandjean, Simon Borgniet, Djamel Mékarnia, Paul Anthony Wilson, Flavien Kiefer, Mickael Bonnefoy, Jorge Lillo-Box, Blake Pantoja, Matias Jones, Daniela Paz Iglesias, Laetitia Rodet, Matias Diaz, Abner Zapata, Lyu Abe & François-Xavier Schmider

Nature Astronomy **3**, 1135–1142 (2019) | Cite this article



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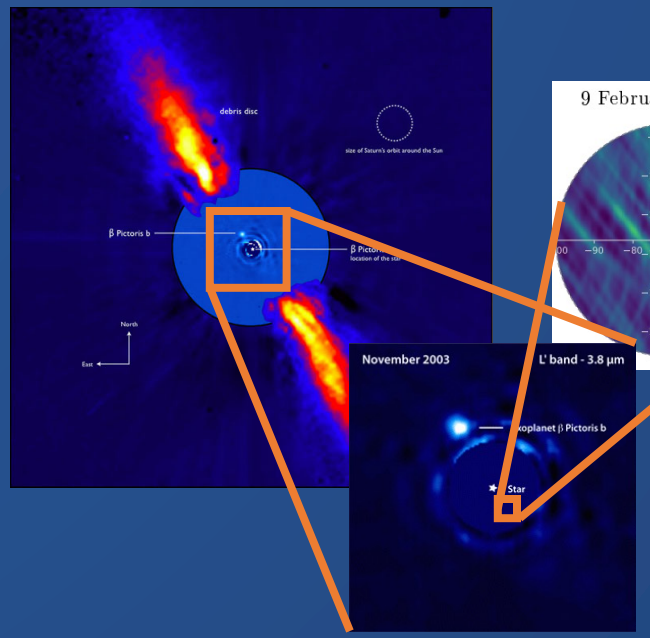
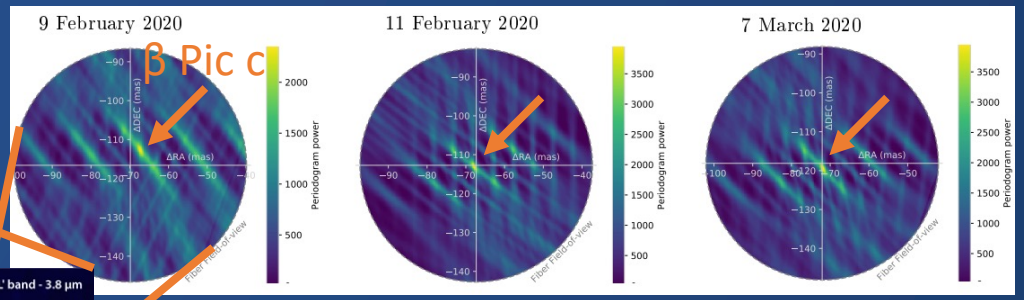
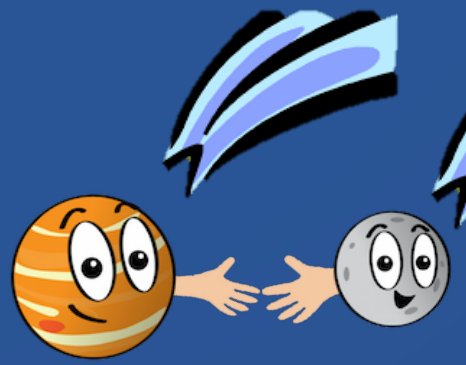


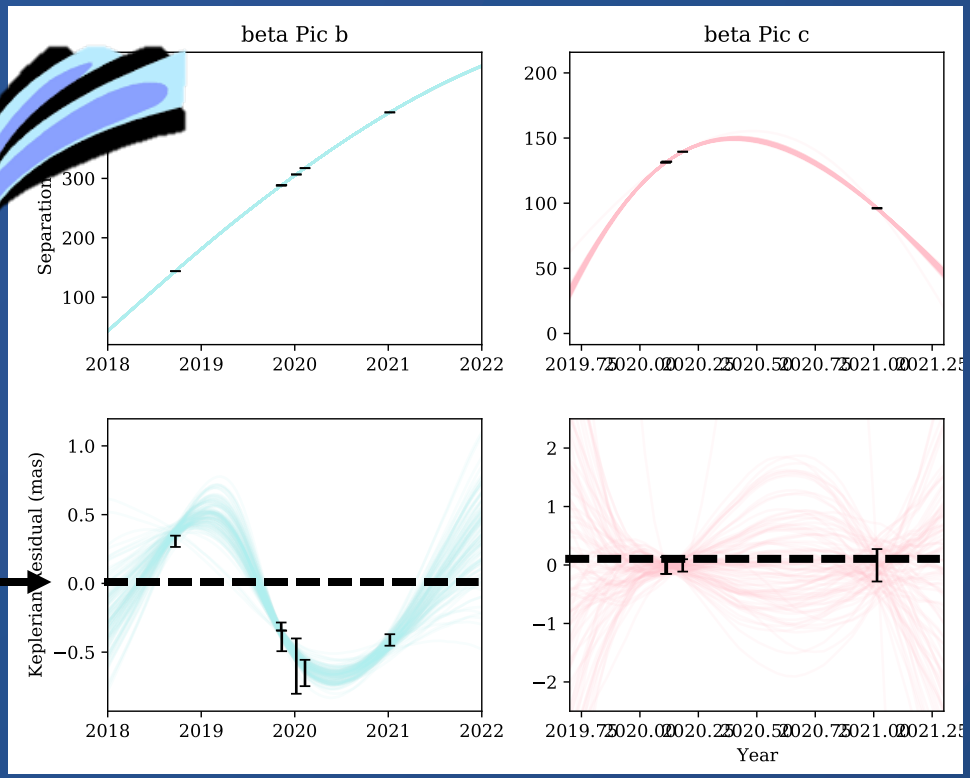


Nowak et al. 2020

β Pic

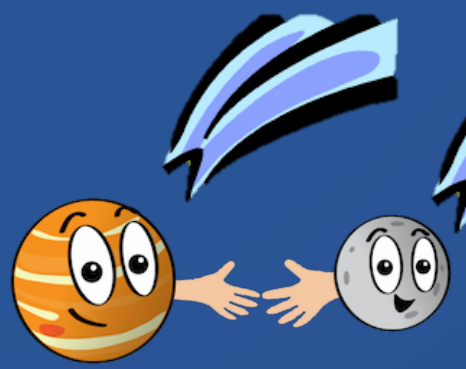


Keplerian orbit

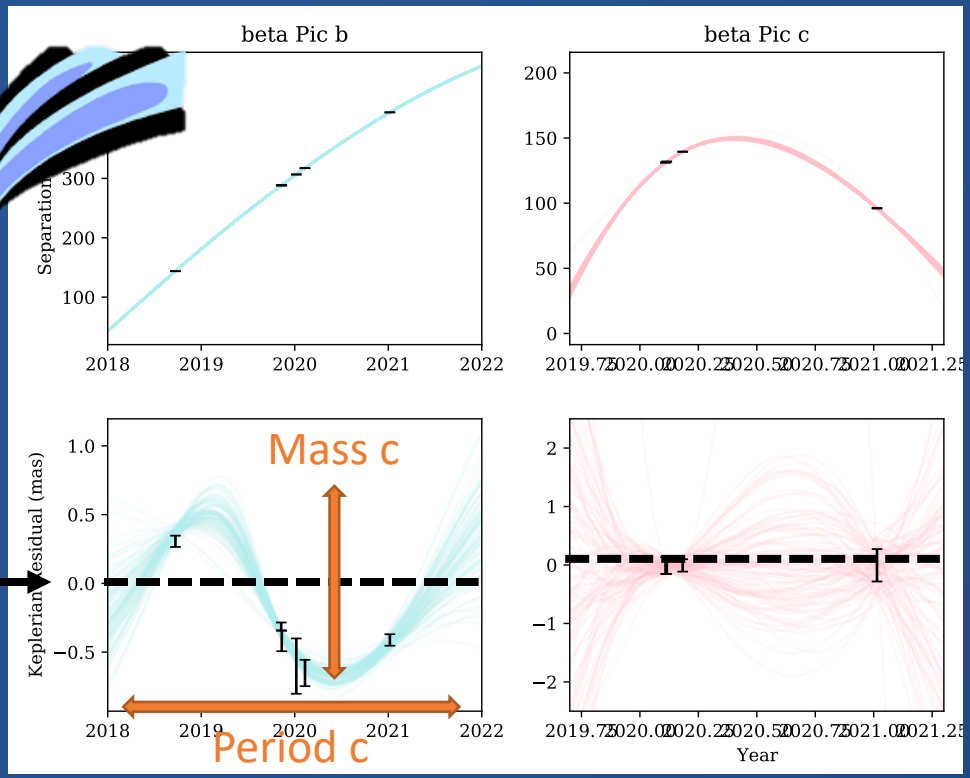


Lacour et al. 2021

β Pic

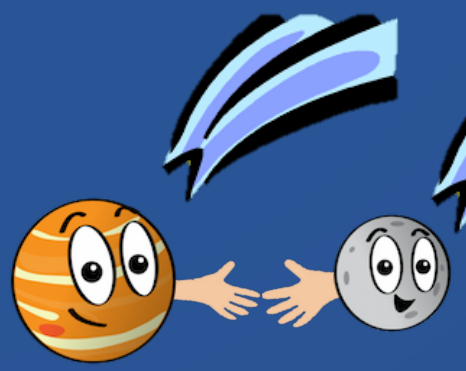


Keplerian orbit

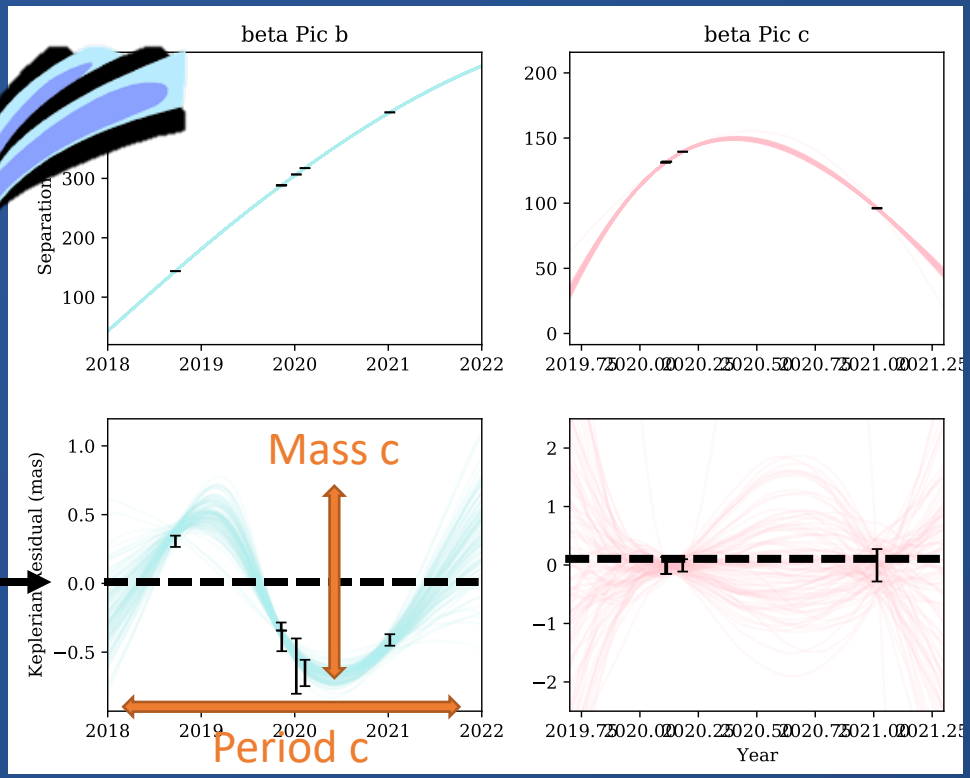


Lacour et al. 2021

β Pic



Keplerian orbit



Lacour et al. 2021

Combining GRAVITY astrometry with RV data:

$$M_b = 11.90^{+2.93}_{-3.04}\ M_{\rm Jup}$$
$$M_c = 8.89^{+0.75}_{-0.75}\ M_{\rm Jup}$$

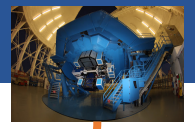
Independent mass constraints that can be compared to evolutionary models to constrain formation scenario

Nowak et al. 2020

HD 206893

GRAVITY SPHERE GPI





~15 M_{Jup}

Grandjean et al. 2019

15-30 M_{Jup}

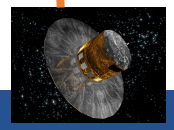
Milli et al. 2017
Delorme et al. 2017
Kammerer et al. 2021

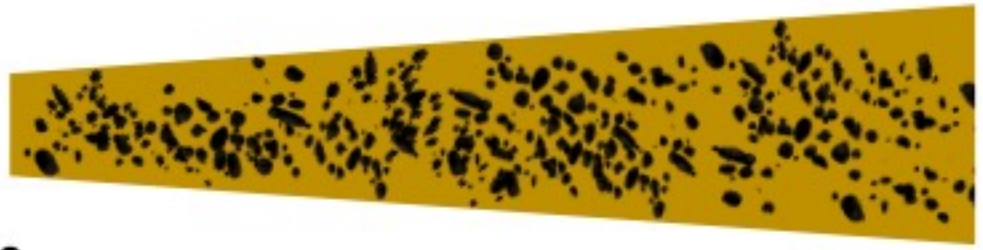
~2 au

10 au

~250 mas


HARPS


Gaia



30 au

27 au disk gap

0.9 M_{Jup} candidate

74 au

Marino et al. 2020

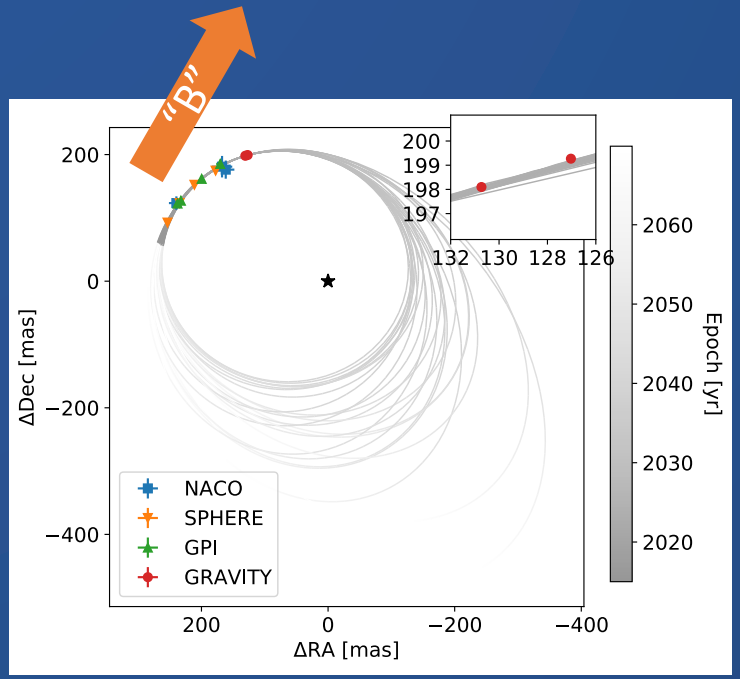

ALMA

(disk extends to 180 au) →

Credit: Kim Ward-Duong

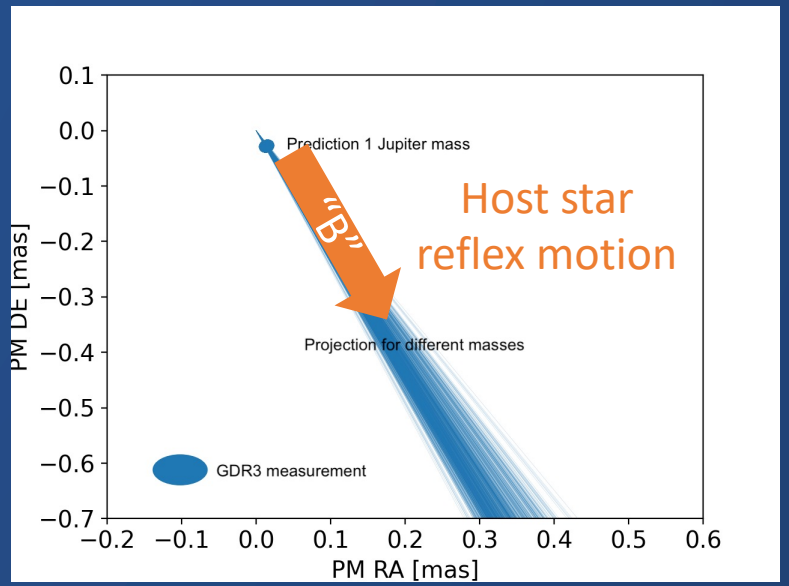
HD 206893

Orbit of “B” companion



Kammerer et al. 2021

Gaia proper motion anomaly



Grandjean et al. 2019, Kammerer et al. 2021, Kervella et al. 2022

HD 206893

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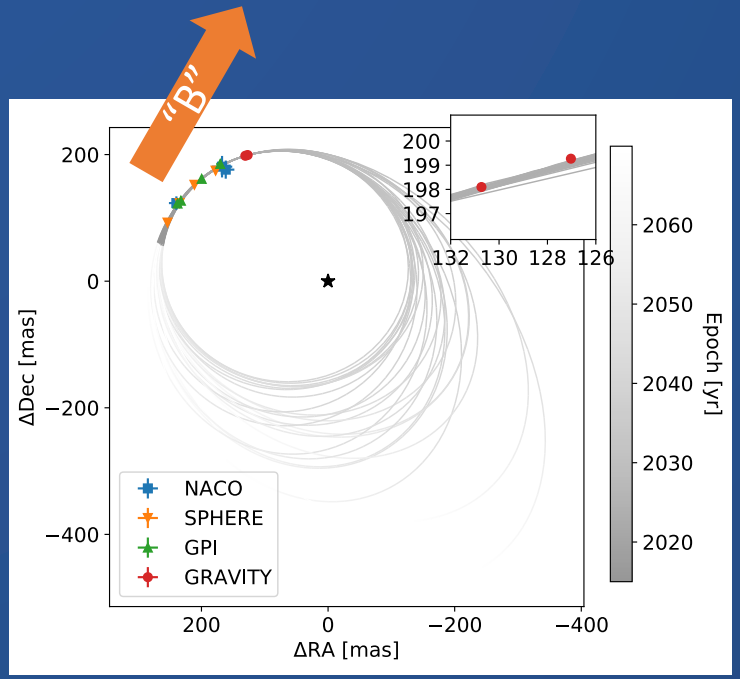

Kammerer et al. 2021

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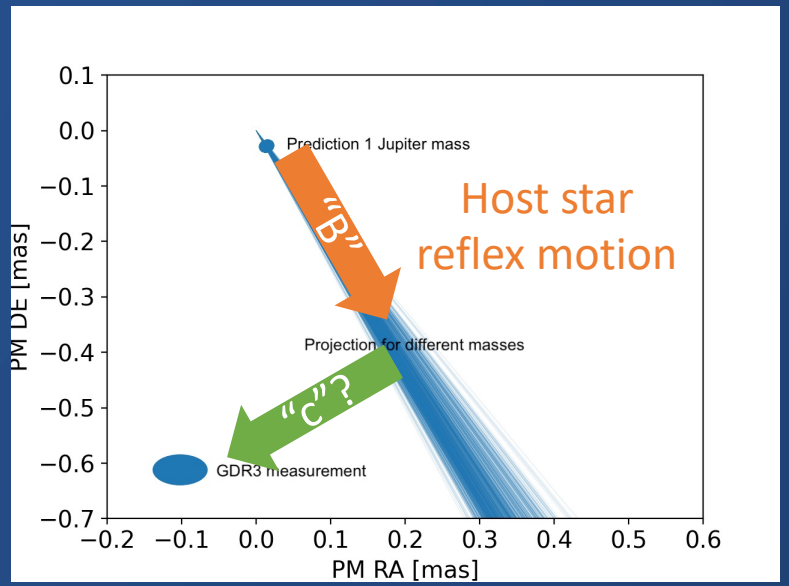


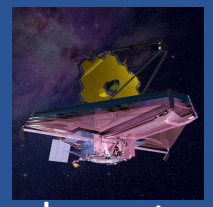
Grandjean et al. 2019, Kammerer et al. 2021, Kervella et al. 2022

Not sensitive to “d” companion because too long orbital period

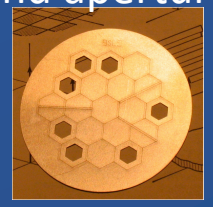
JWST

- 2 JWST Aperture Masking Interferometry programs

Credit: NASA



JWST and aperture mask



Credit: Sivaramakrishnan

Gives access to small separations (70-400 mas)

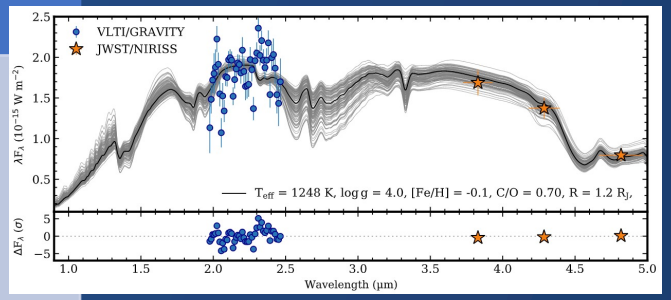
HD 206893

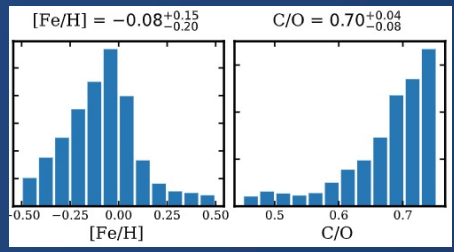
- GO 1843
- PI Kammerer
- Cloud composition & origin

β Pic

- GO 2297
- PI Stolker
- Formation signatures

Combine GRAVITY + JWST…





…get Fe/H and C/O constraints