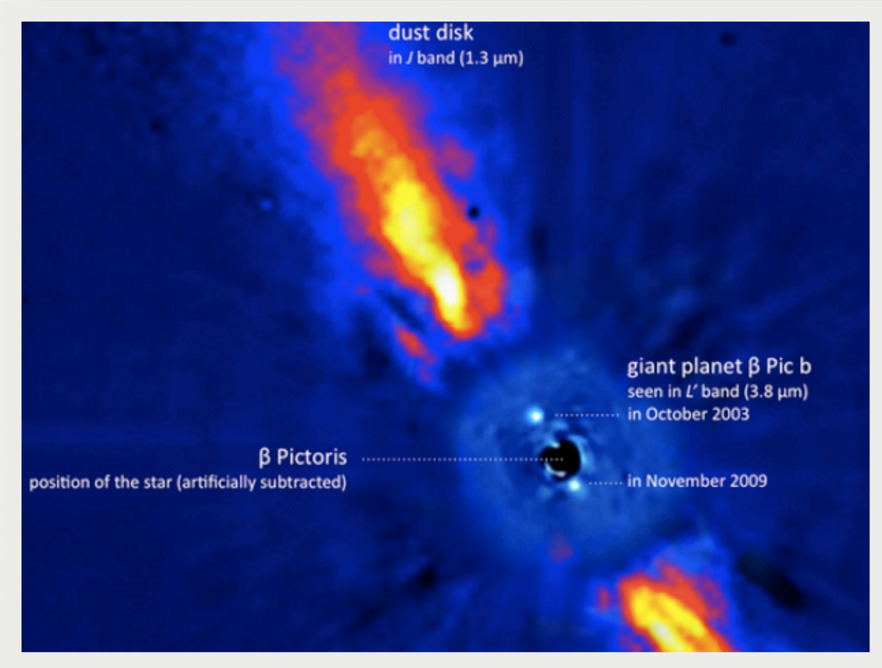
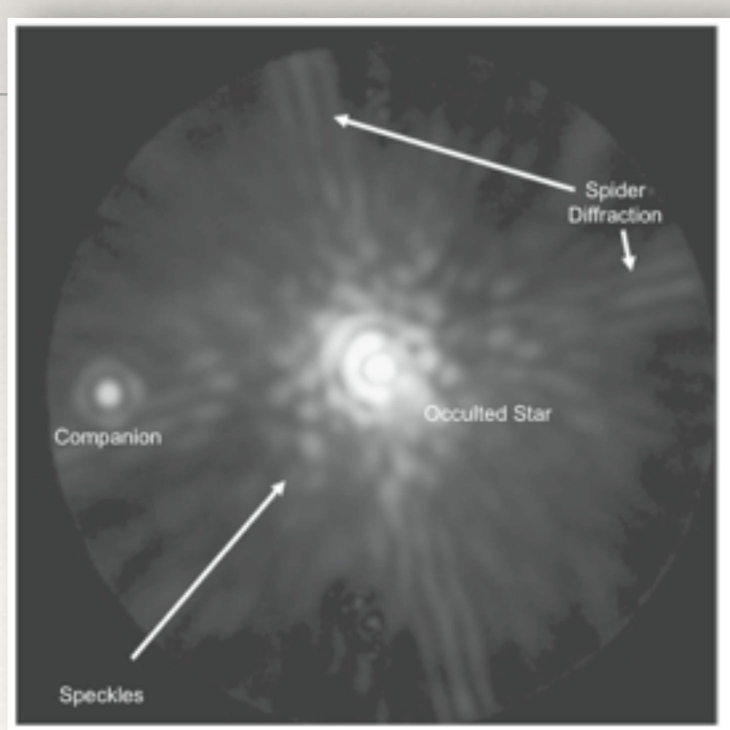


R. Claudi - INAF - Astronomical Observatory of Padova

DIRECT IMAGING OF EXTRASOLAR PLANETS

VII: RESULTS and PERSPECTIVES



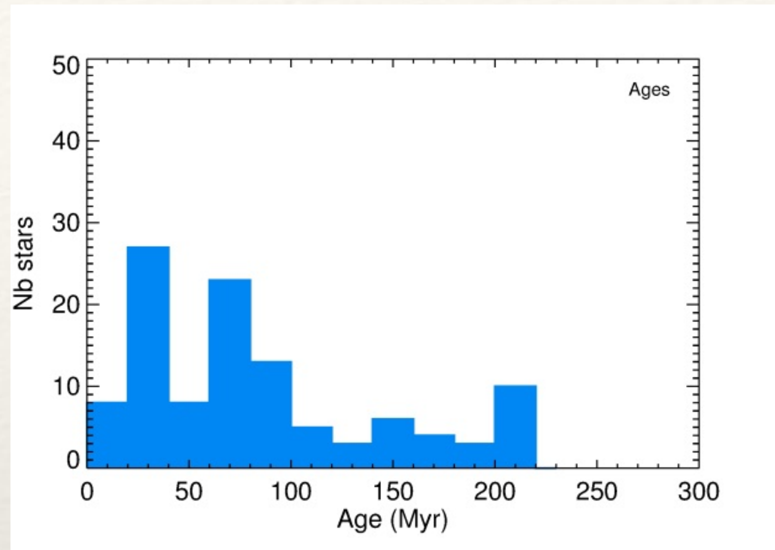
1st ADVANCED SCHOOL OF EXOPLANETARY SCIENCE
METHODS OF DETECTING EXOPLANETS
MAY 25-29, 2015 - VIETRI SUL MARE (SA)

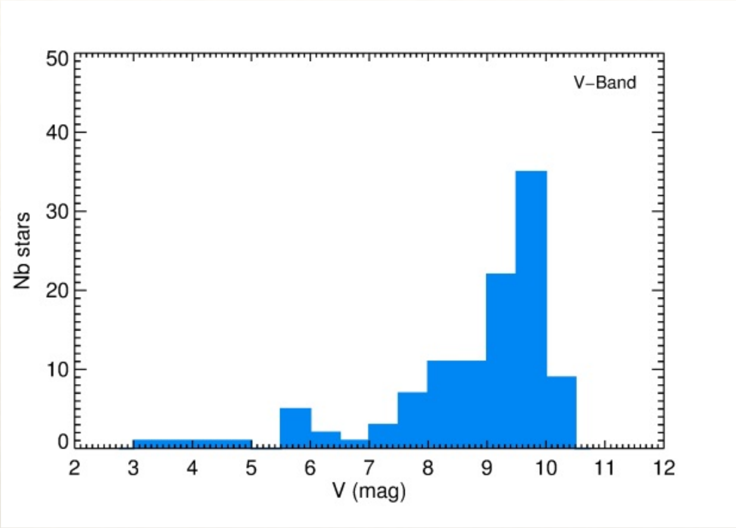
Updated Results and Perspectives

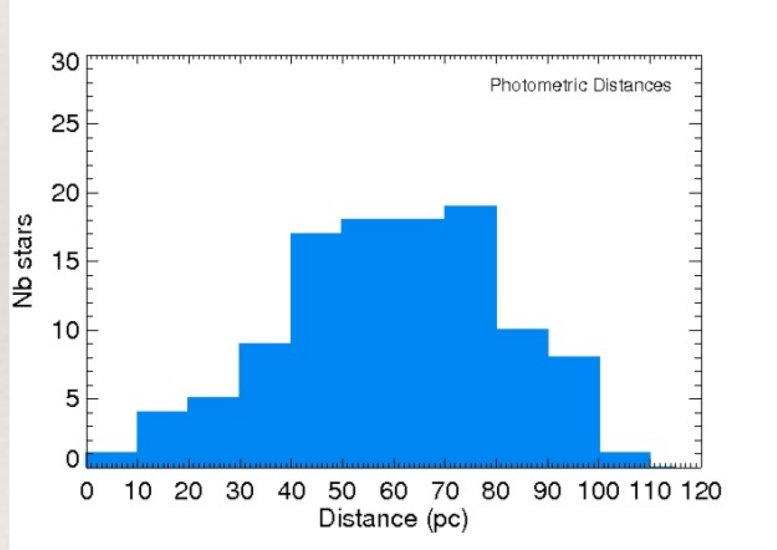
Optimized Samples

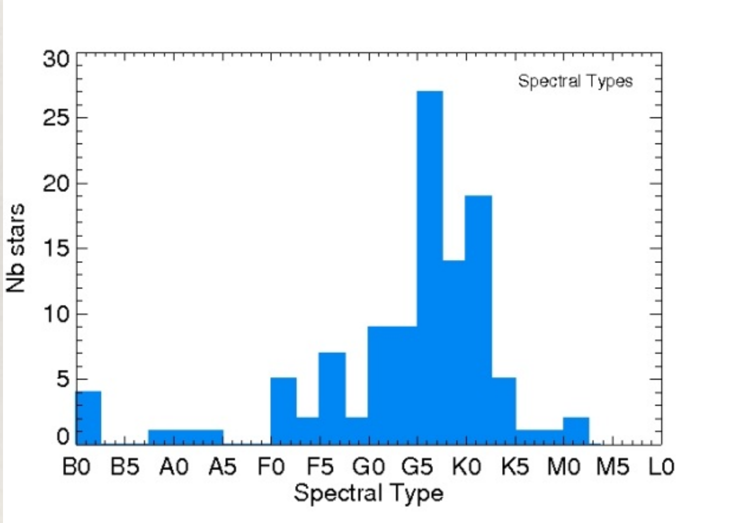
Young, nearby stars

- Age < 200 Myr
  - . Young, nearby associations
- Distance < 100 pc
  - access small sma,
  - enhanced sensitivity
- Spectral Types: AFGKM
  - . AF: More massive EGPs?
  - . M: favorable contrast
- V-band < 10.0 – 12.0
  - . AO-Full Performance limitation



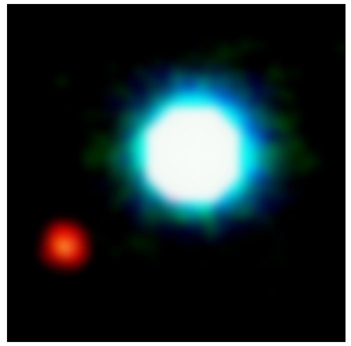




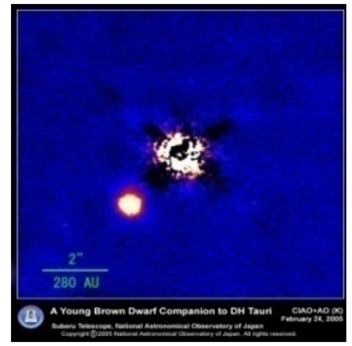


Family's Portrait

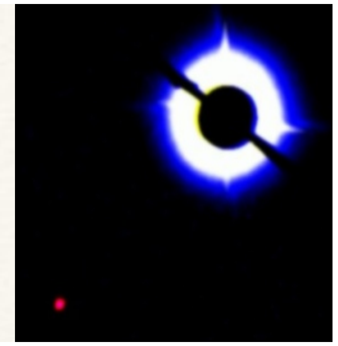
2M1207



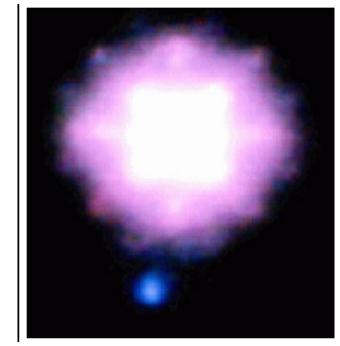
DH Tau



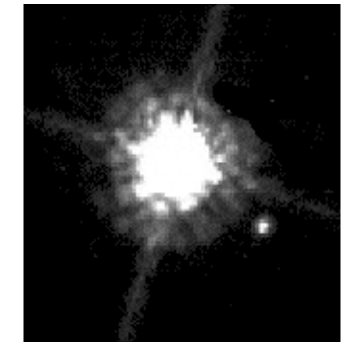
AB Pic



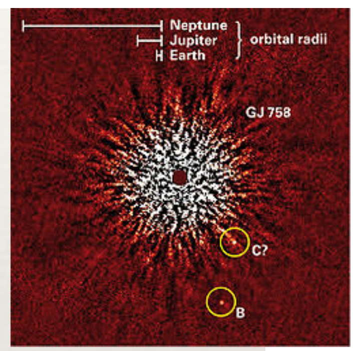
SCR1845



CHXR 73

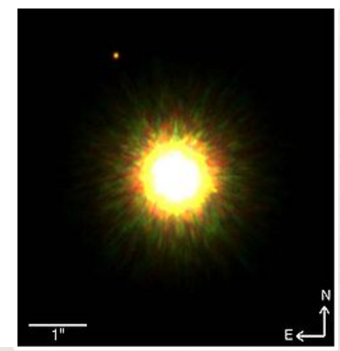


GJ 758

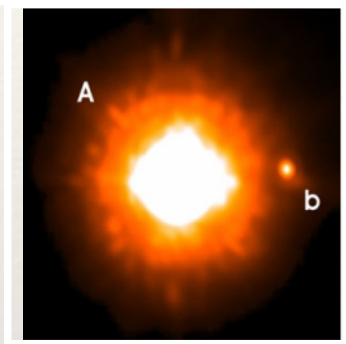


CT Cha

1RXJS609



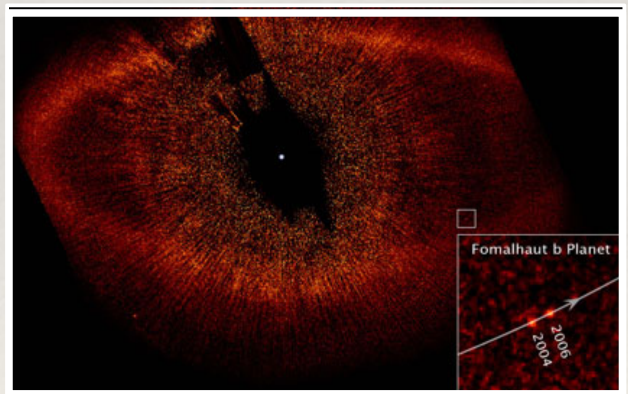
GQ Lup



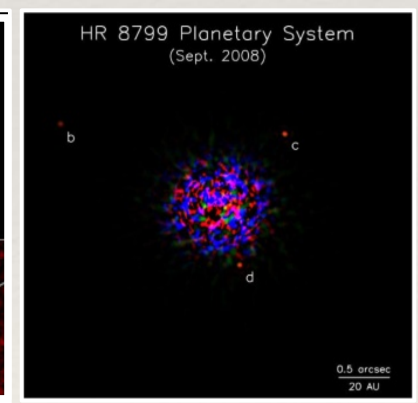
✱ **Wide** orbit **PMCs**:

- low mass KM stars
- q = 0.02 – 0.2 or Δ > 200 AU

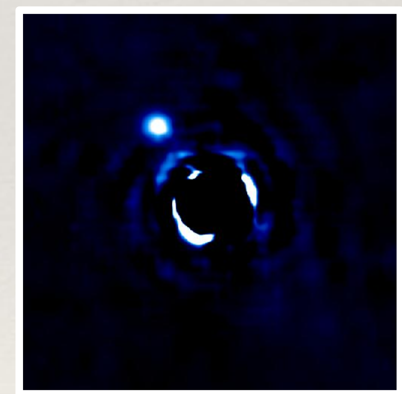
Fomalhaut



Hr8799



Beta Pic

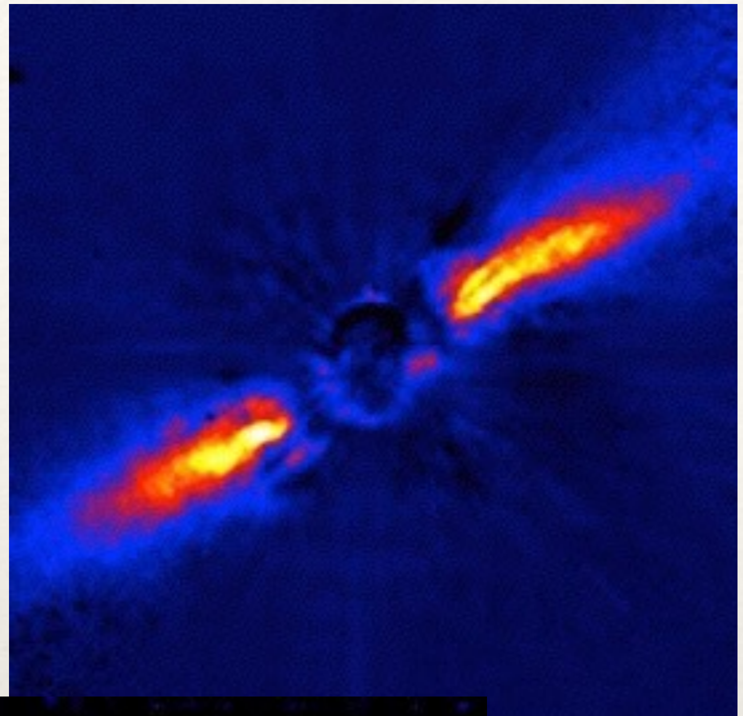


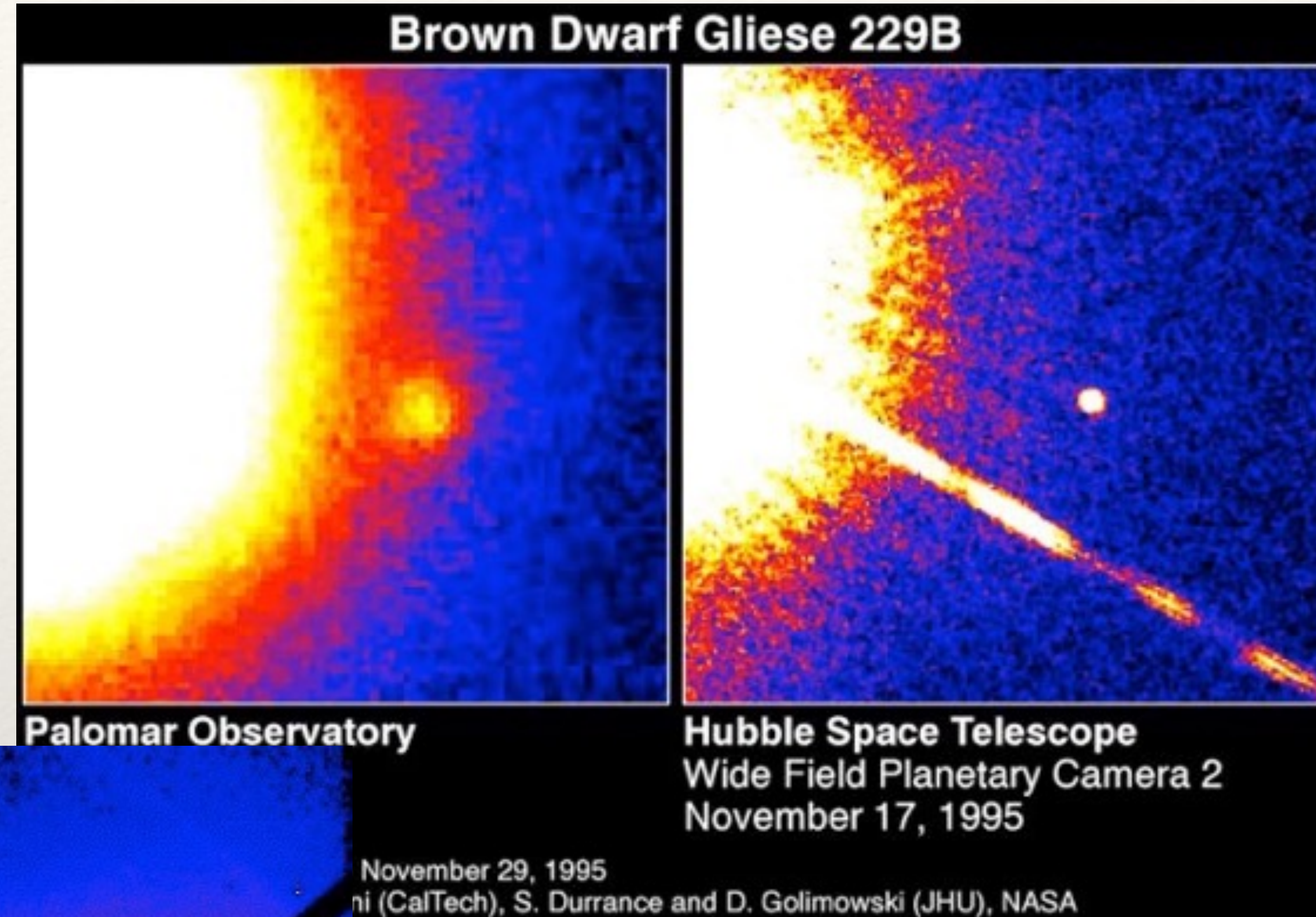
✱ Closer **PMCs**:

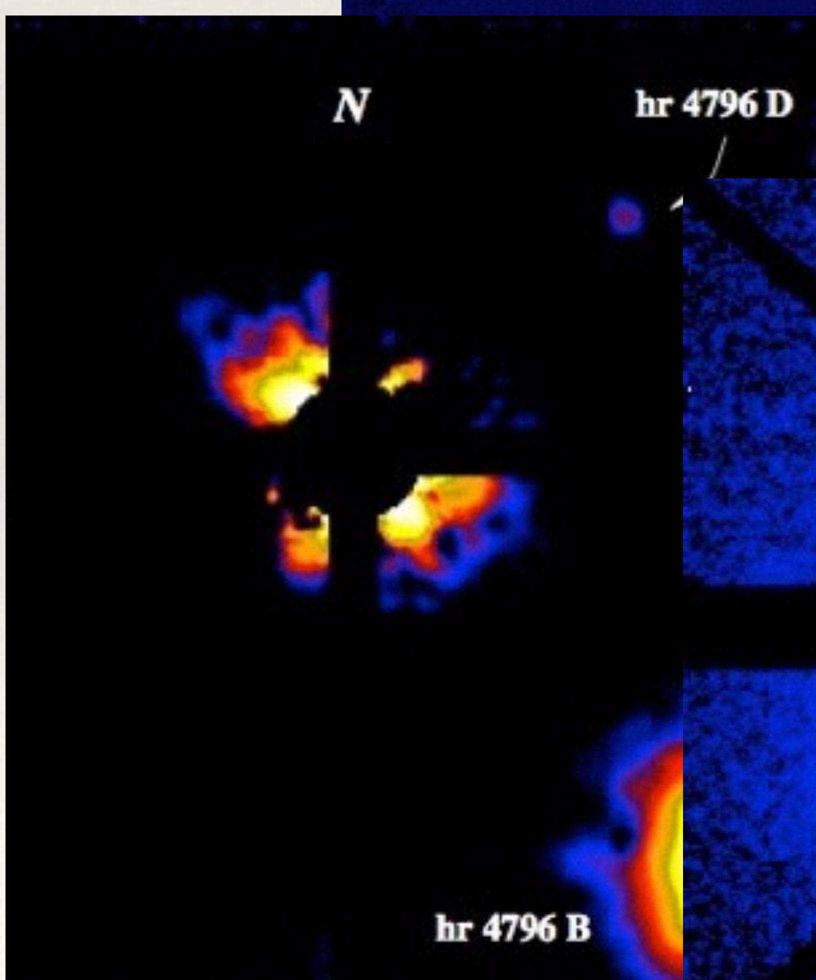
- A4V-A5V massive primaries
- q < 0.005 ; Δ = 8 - 120 AU
- CS Disk signatures

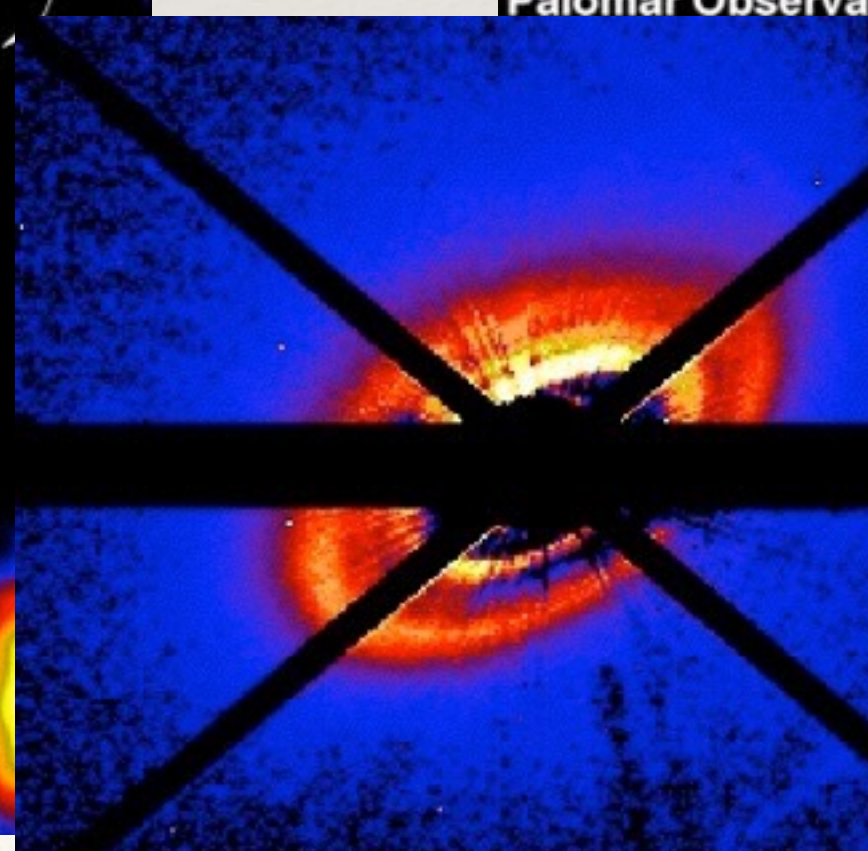
Ref: Chauvin et al. 04; Itoh et al. 05; Chauvin et al. 05; Biller et al. 05; Luhman et al. 06; Thalmann et al. 09; Lafrenière et al. 08; Neuhauser et al. 05; Schmidt et al. 09; Lagrange et al. 10; Kalas et al. 08; Marois et al. 08,10...

Years 1990 -2000



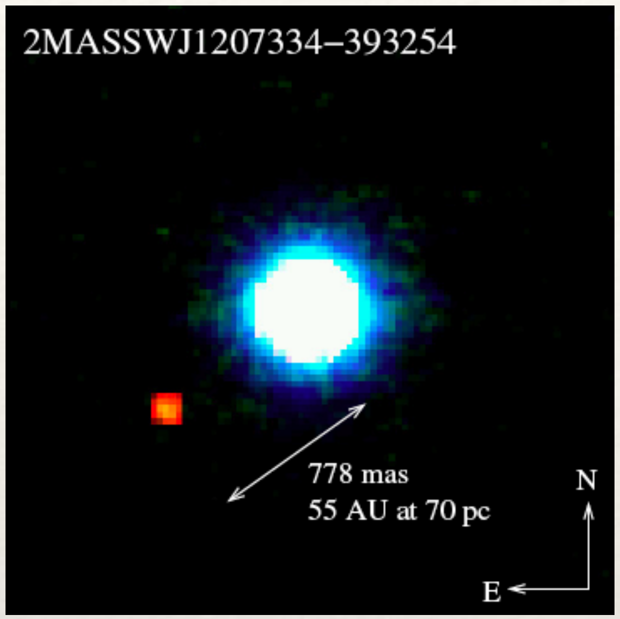


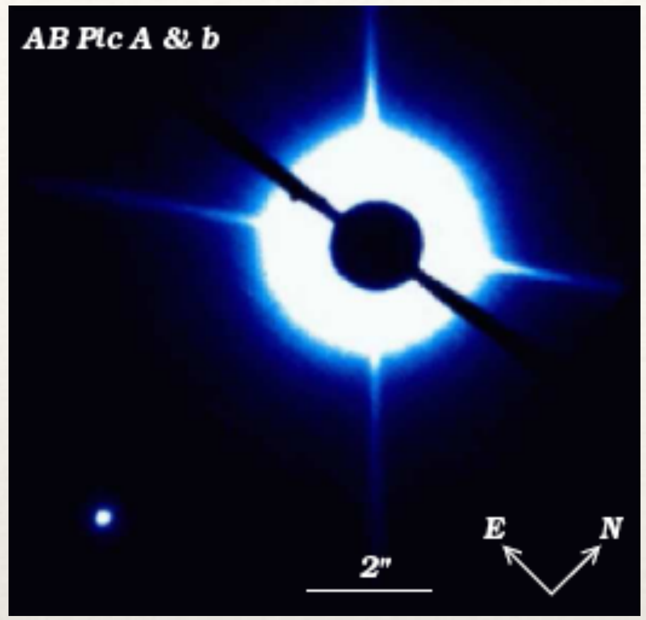


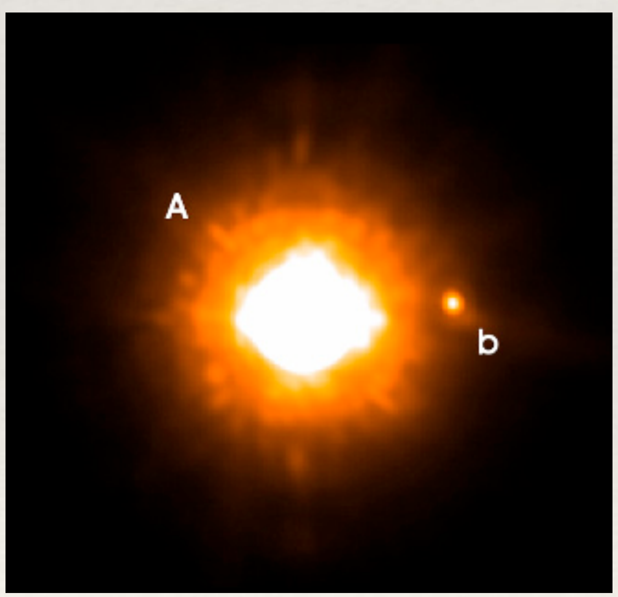


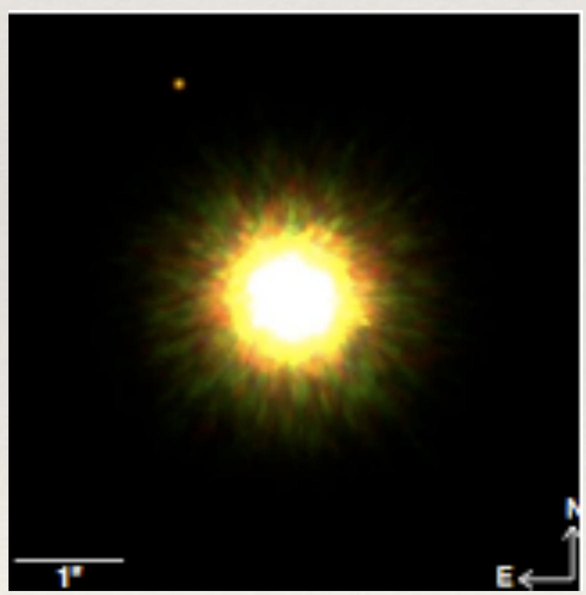
… mainly Disks and Brown dwarfs …

First results







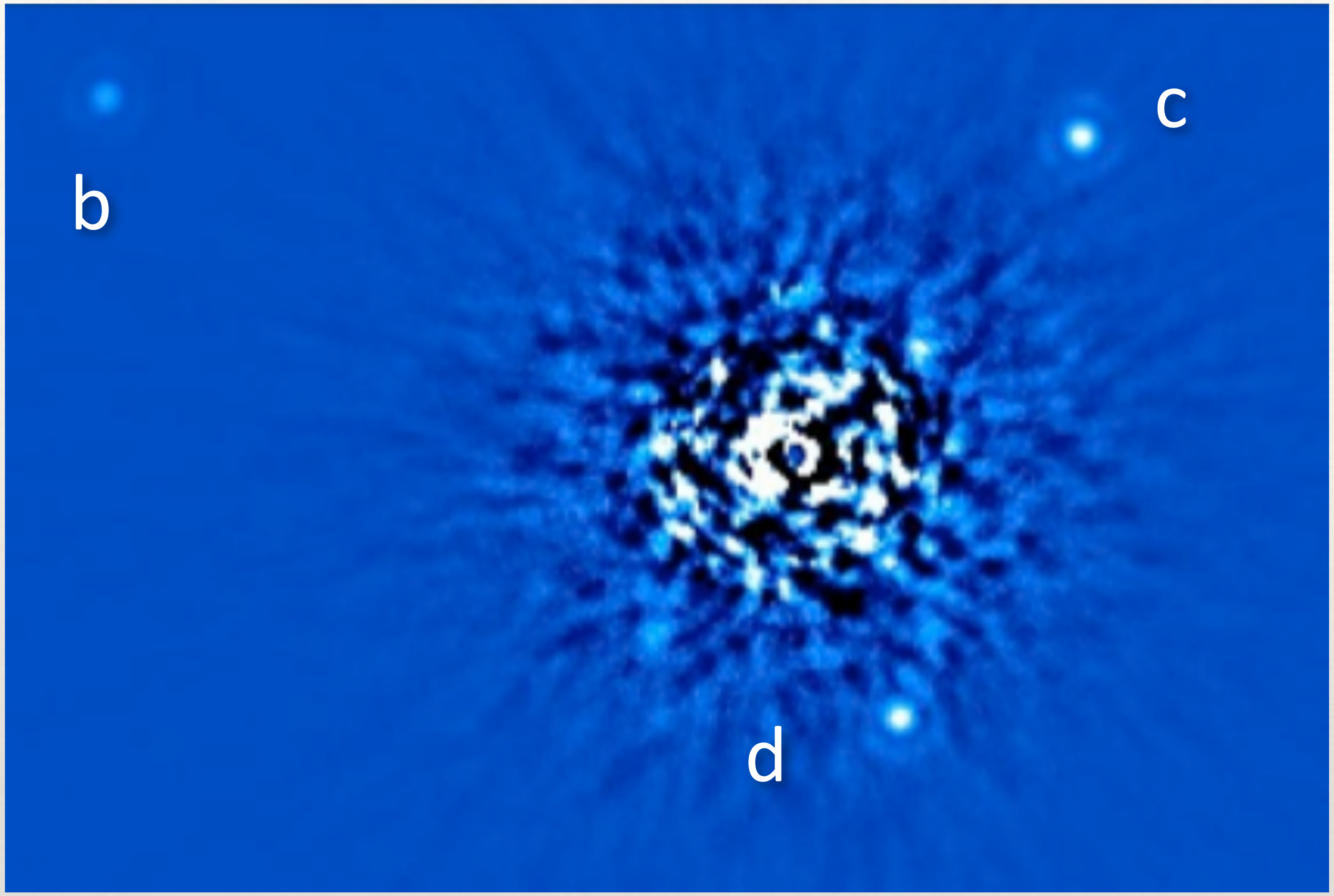


name	Mass (M_J)	Dist (AU)
2M 1207 b	5	46
GQ Lup b	17	100
AB Pic b	14	248
CHRX 73 b	12	210
HN Peg b	16	795
DH Tau b	12	330
RSX 1609 b	8	330

Favourable Conditions:

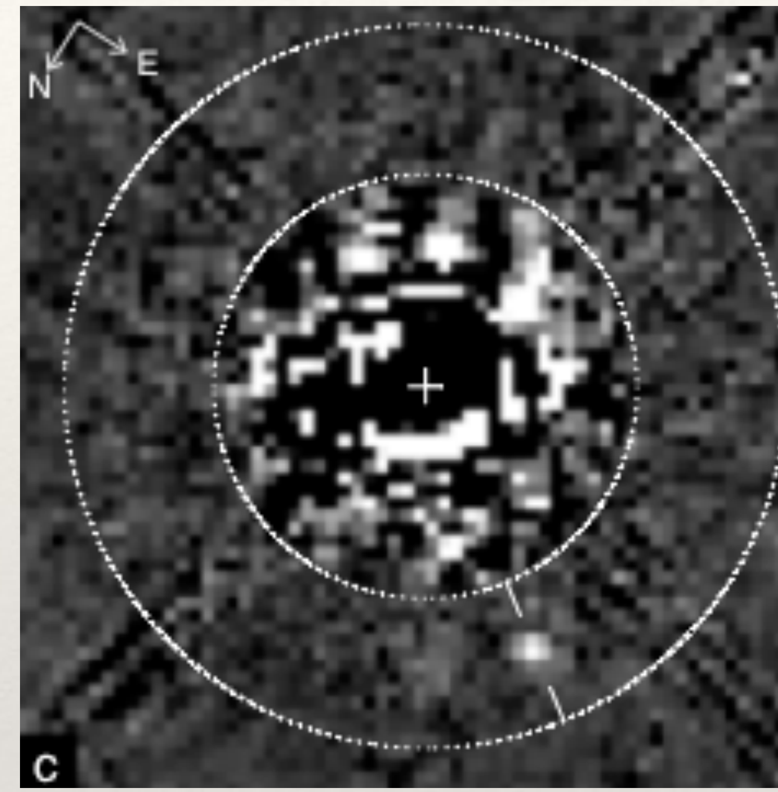
- ☑ Small Mass Ratio
- ☑ Fainter Contrast
- ☑ Young Age (brighter companion)
- ☑ Large angular sepration

HR 8799



Marois et al, 2008

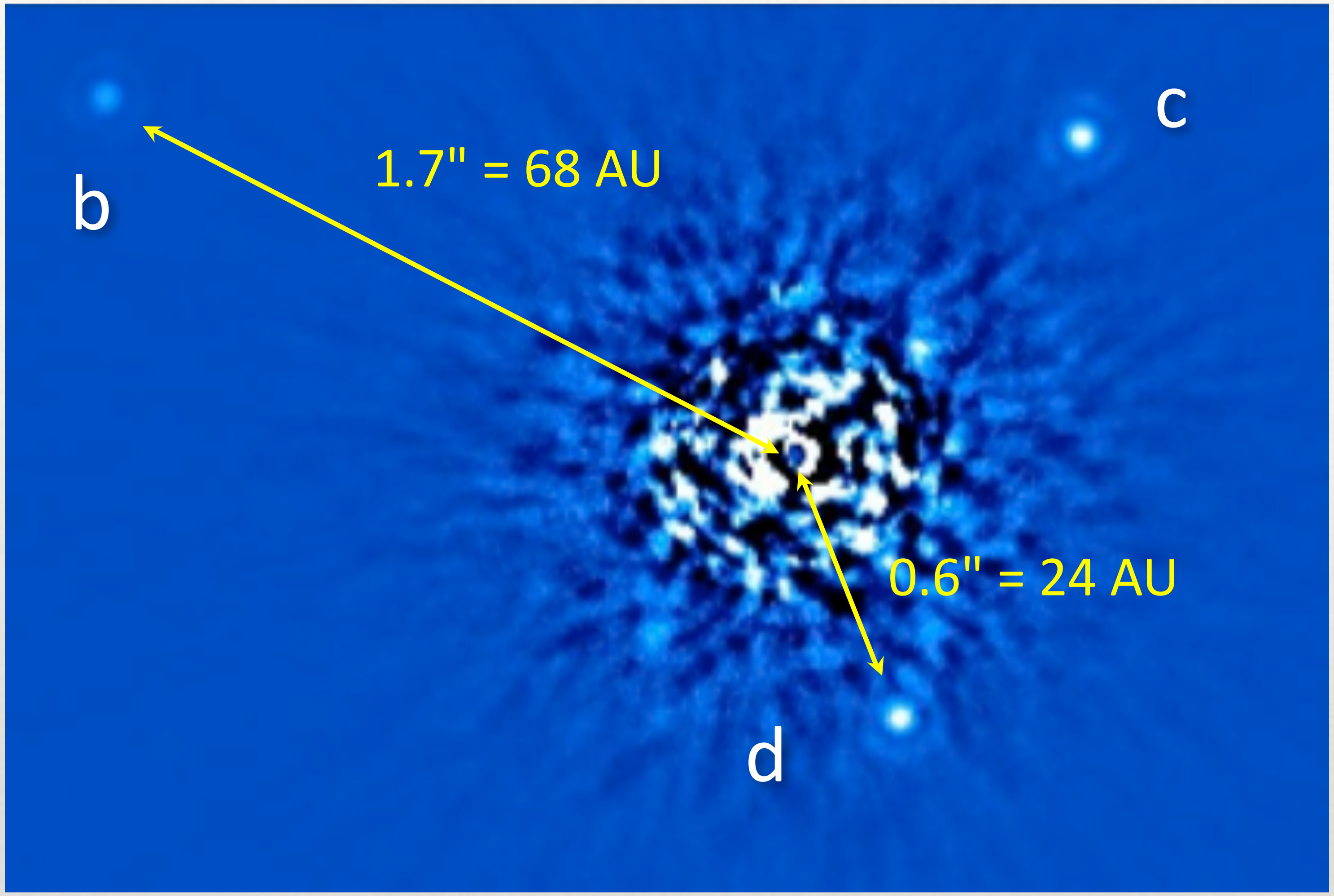
HST/NICMOS de 1998



Lafreniere et al, 2009

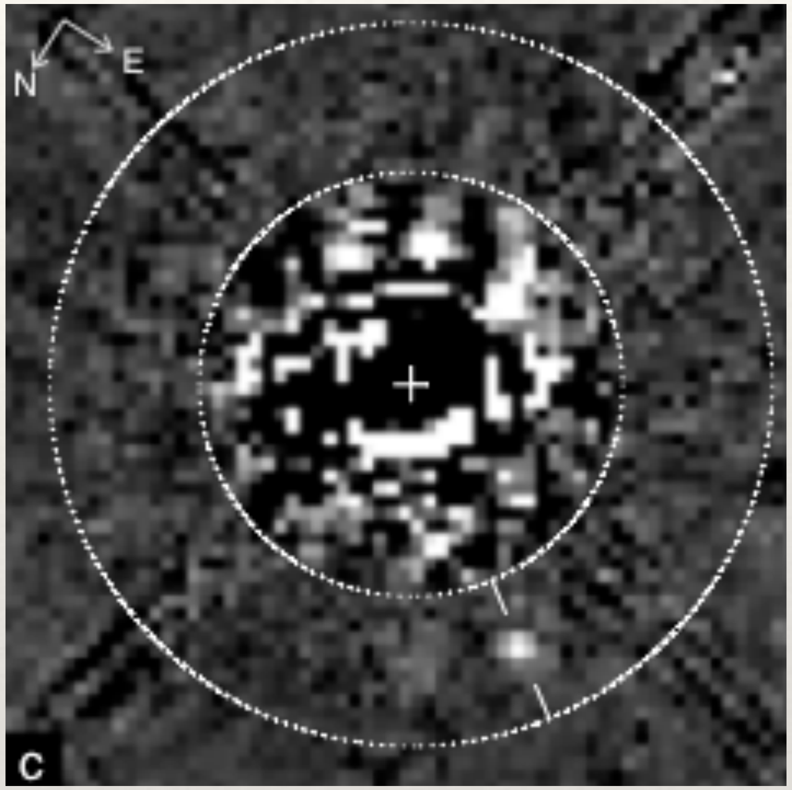
HR8799 : 30 Myr
masses : 7, 10, 10, 10 $M_{Jupiter}$
distance : 16, 24, 38, 68 AU

HR 8799



Marois et al, 2008

HST/NICMOS de 1998



Lafreniere et al, 2009

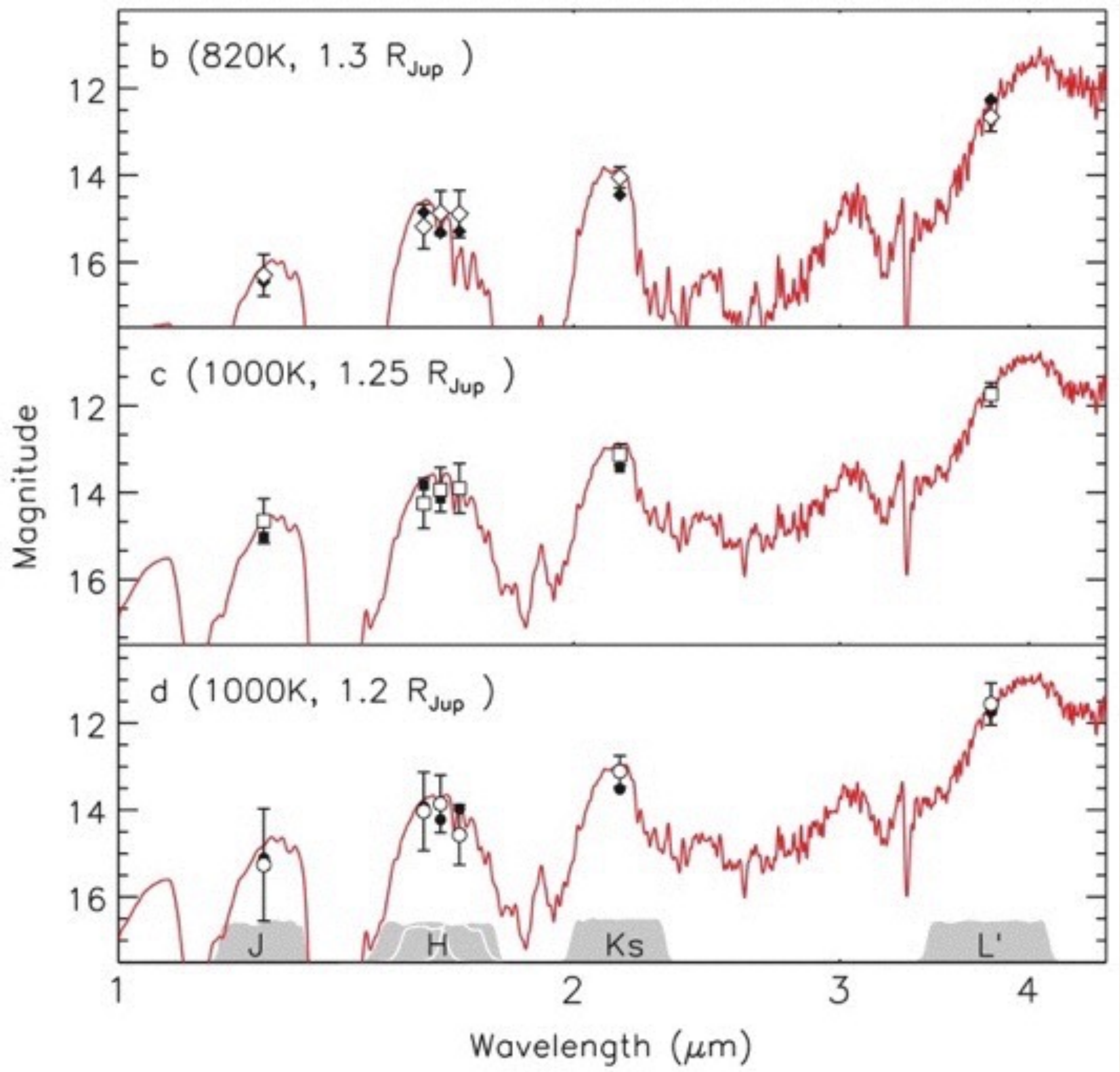
HR8799 : 30 Myr

masses : 7, 10, 10, 10 $M_{Jupiter}$

distance : 16, 24, 38, 68 AU

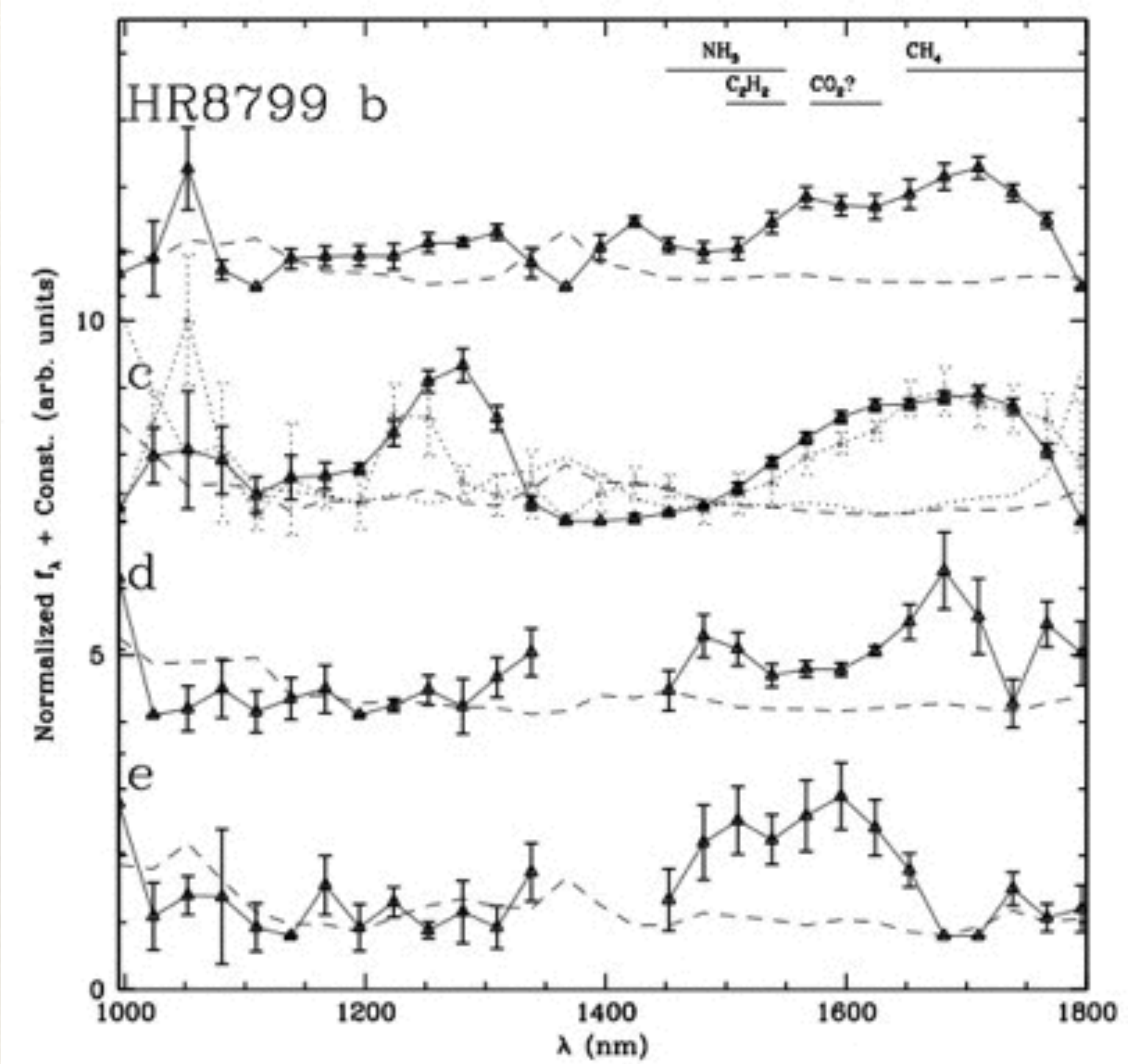
HR 8799

Photometry



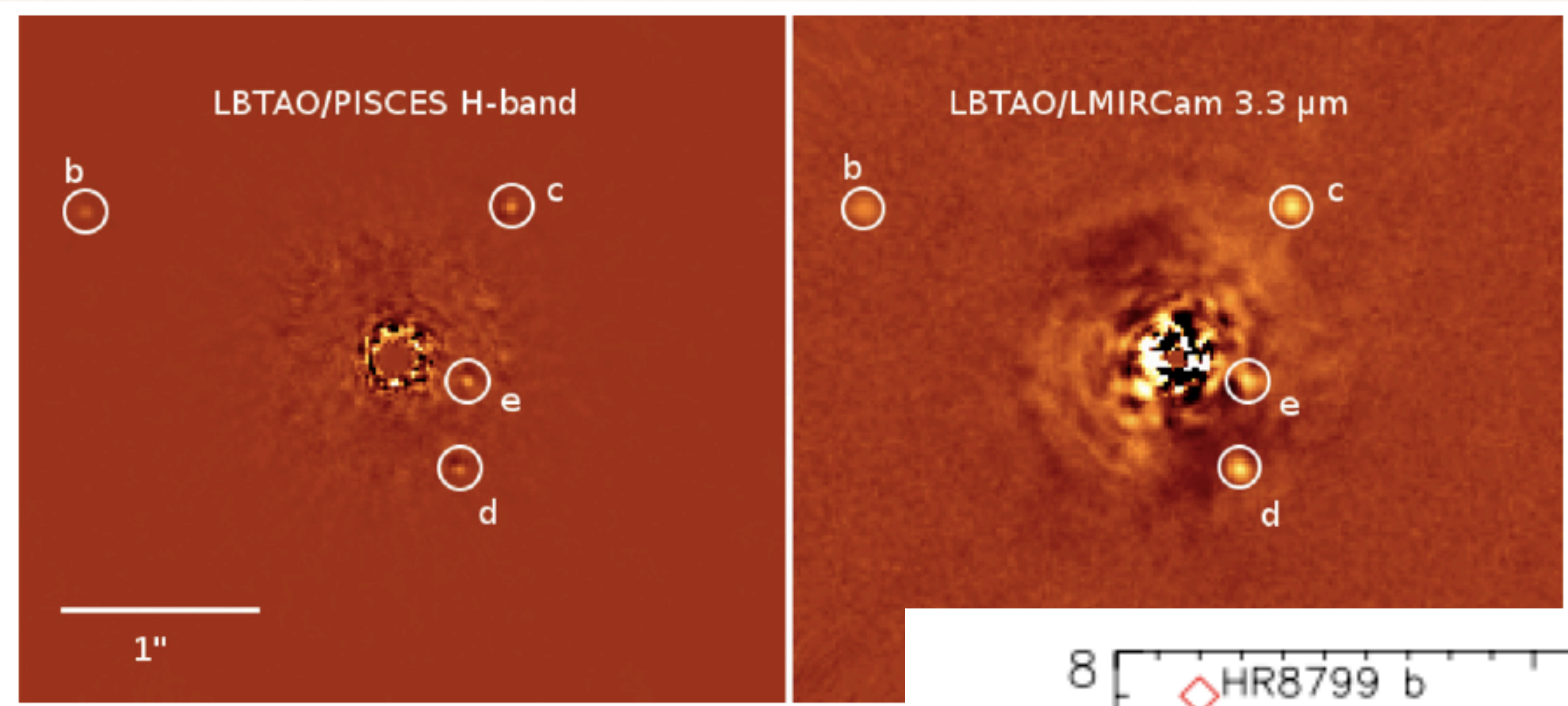
Marois et al, 2008

Low Resolution Spectroscopy

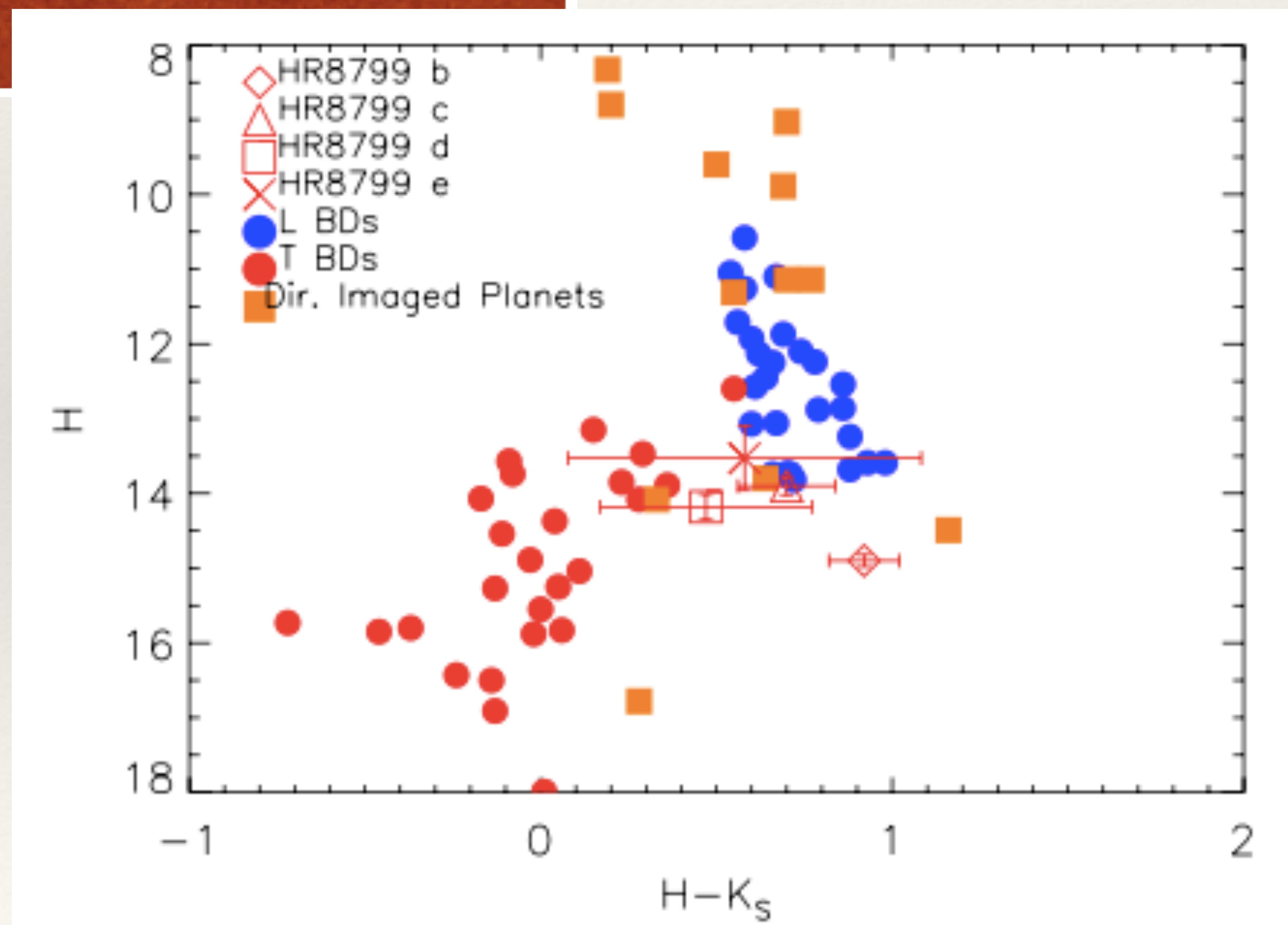


HR8799 bcde: Oppenheimer et al. 2013

HR 8799

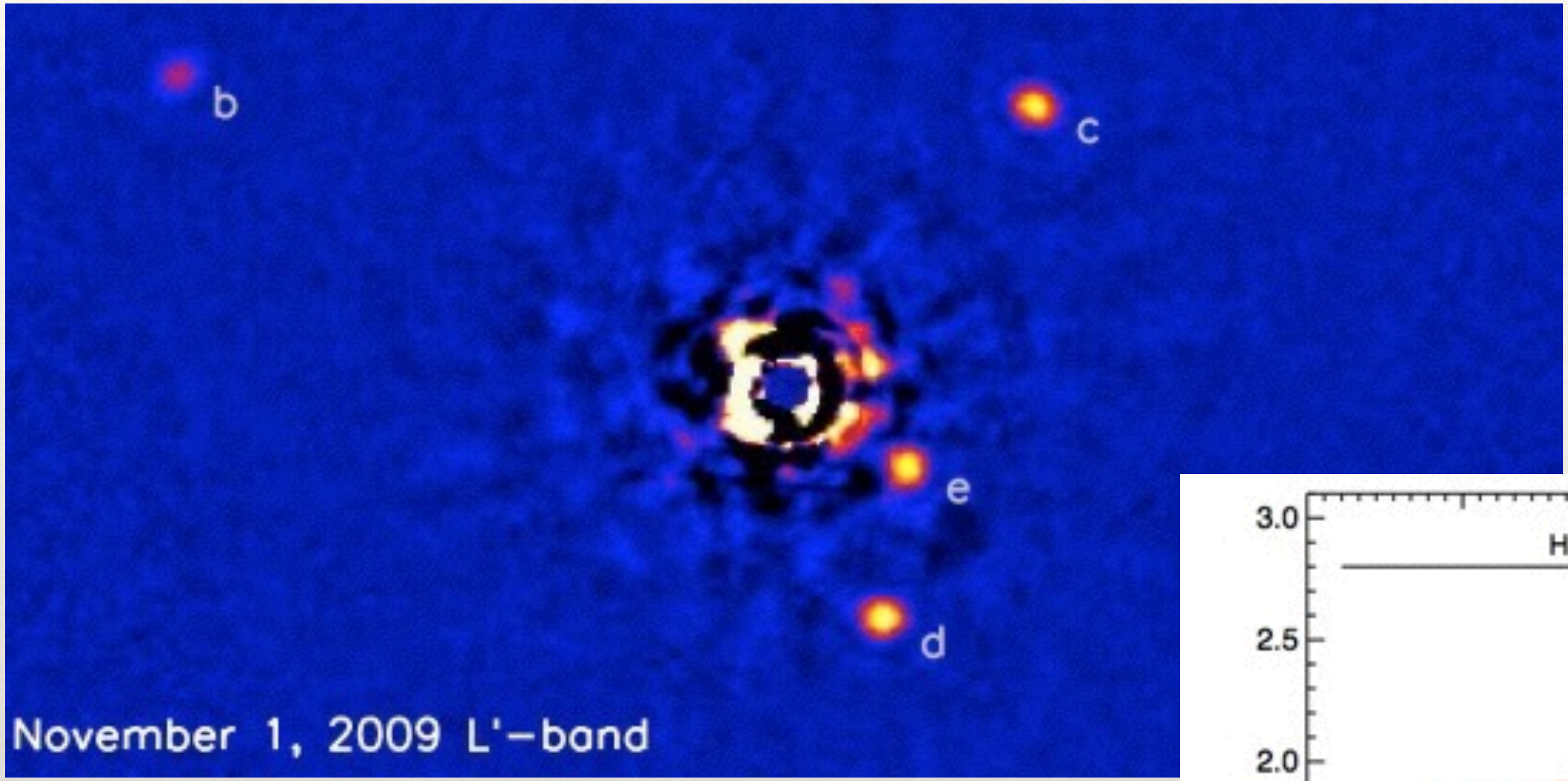


Skemer et al., 2013



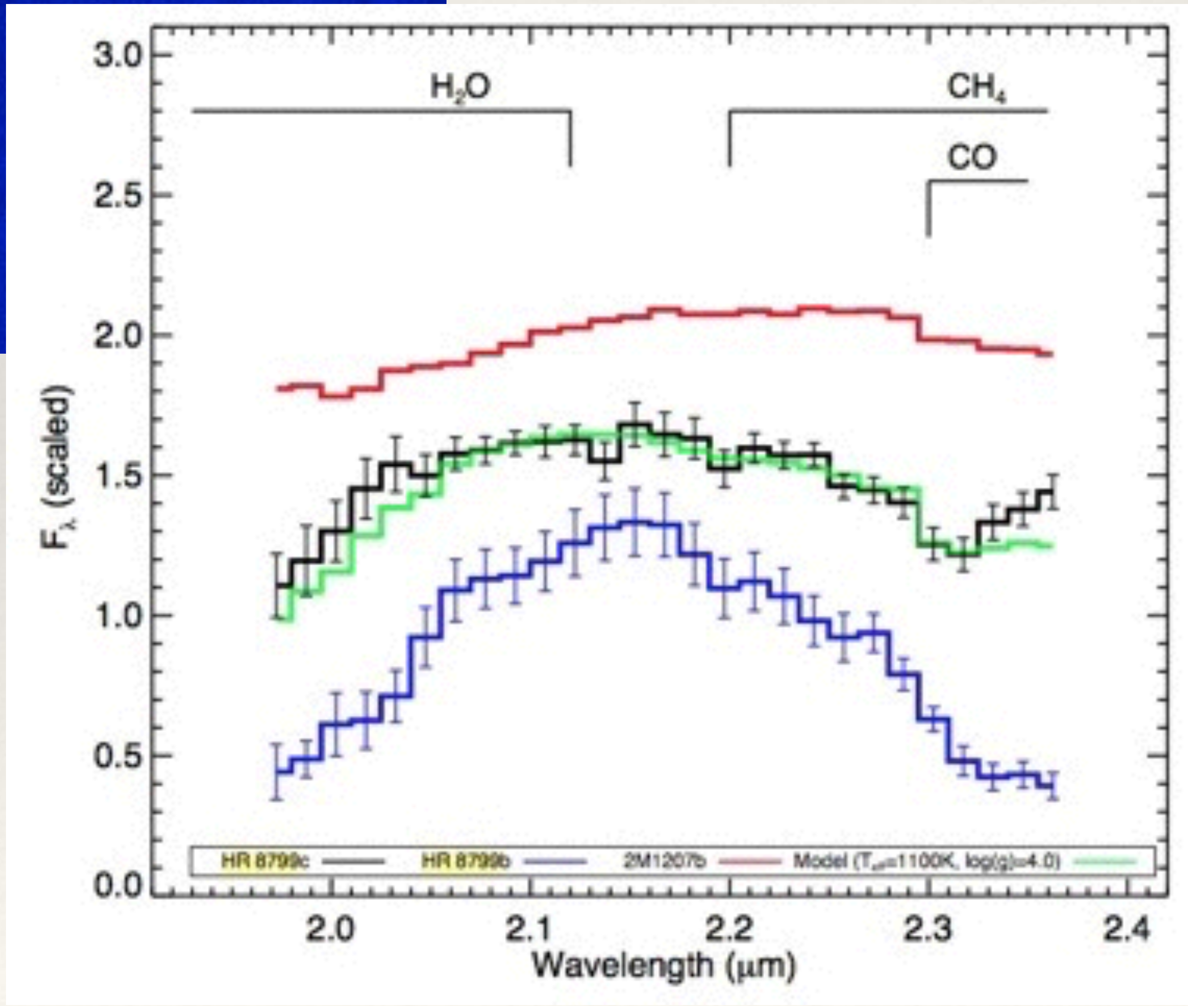
Esposito et al., 2013

HR 8799

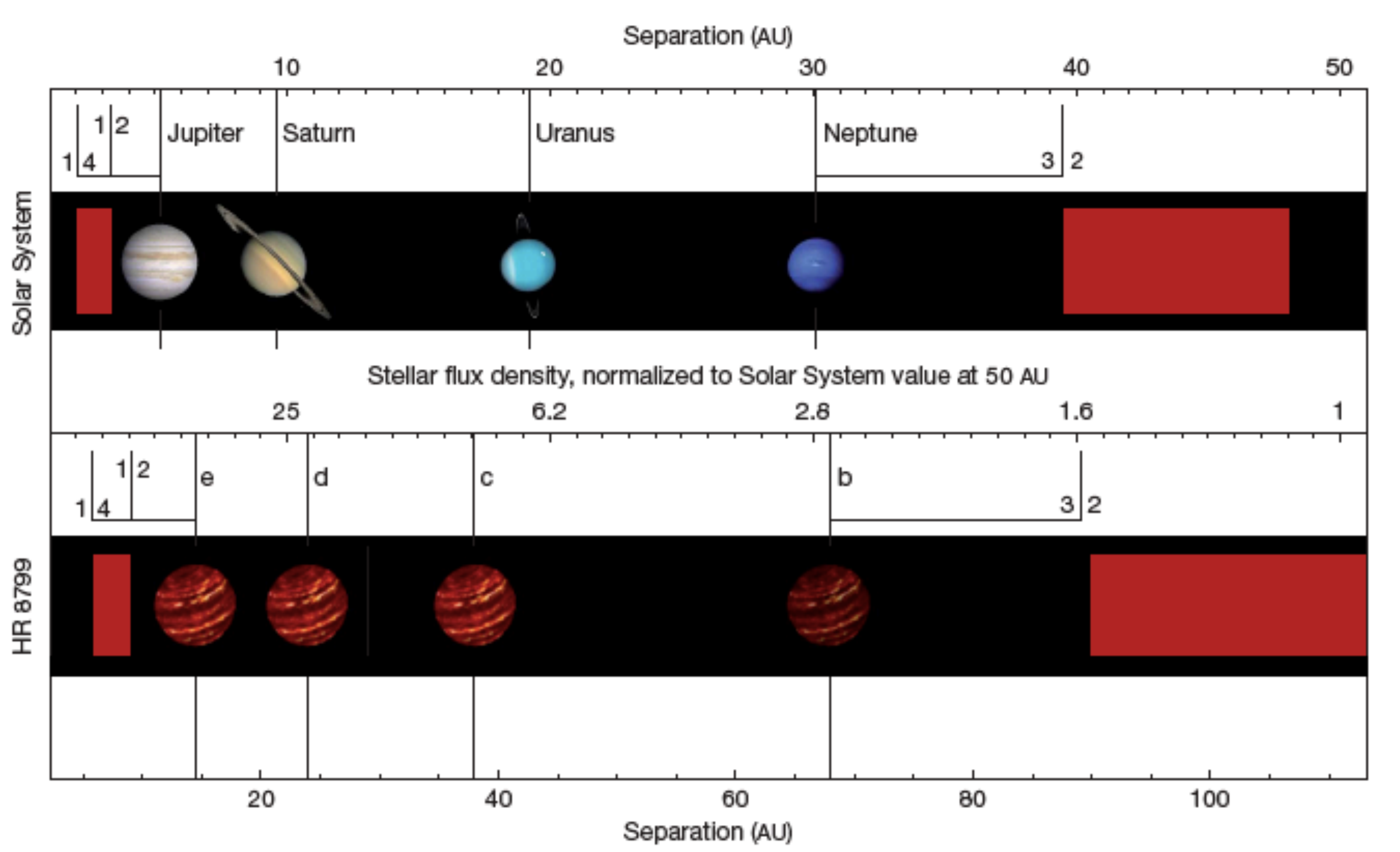


Marois et al, 2010, Keck

HR8799 bc: Konopacky et al. 2013

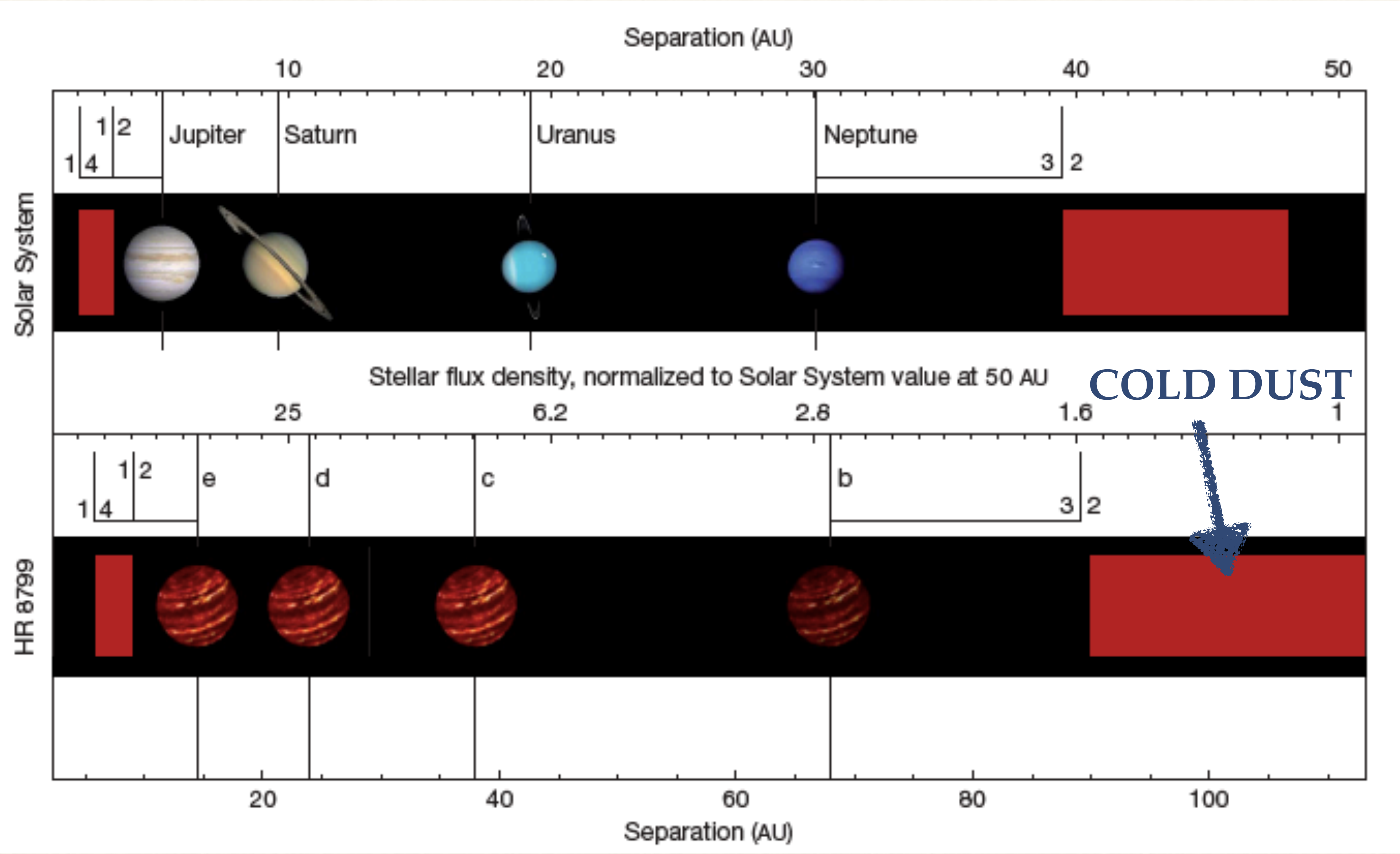


HR 8799



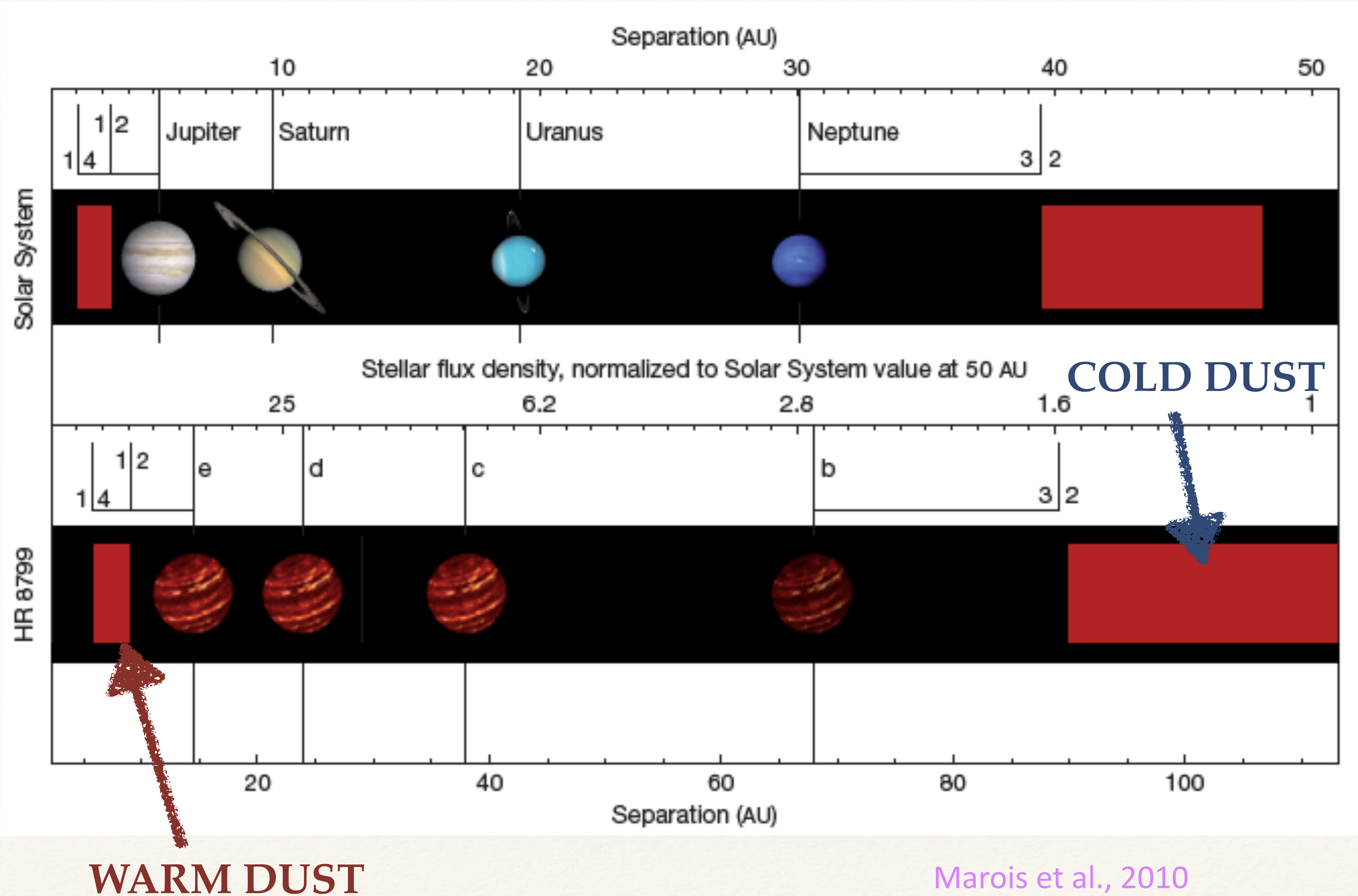
Marois et al., 2010

HR 8799



Marois et al., 2010

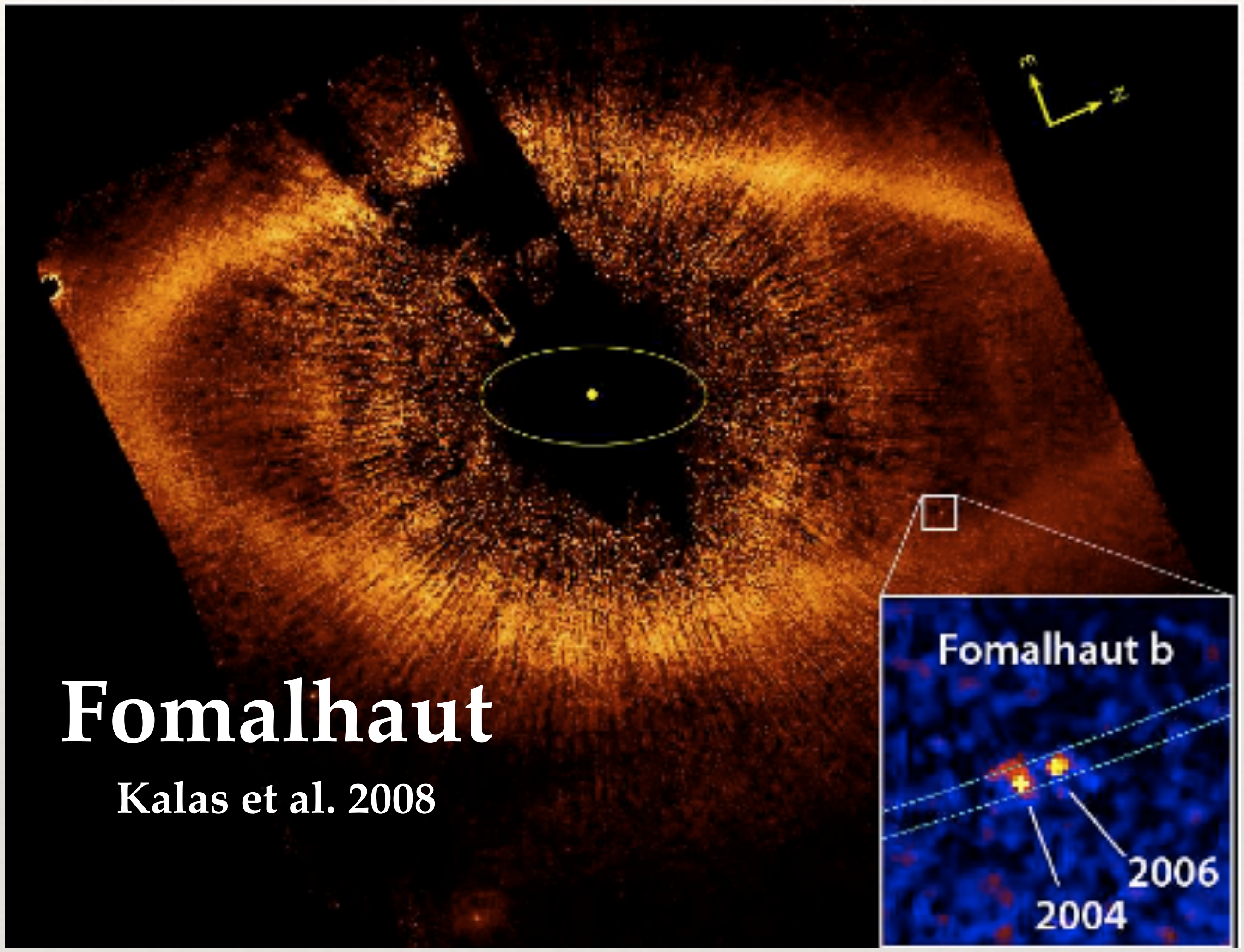
HR 8799

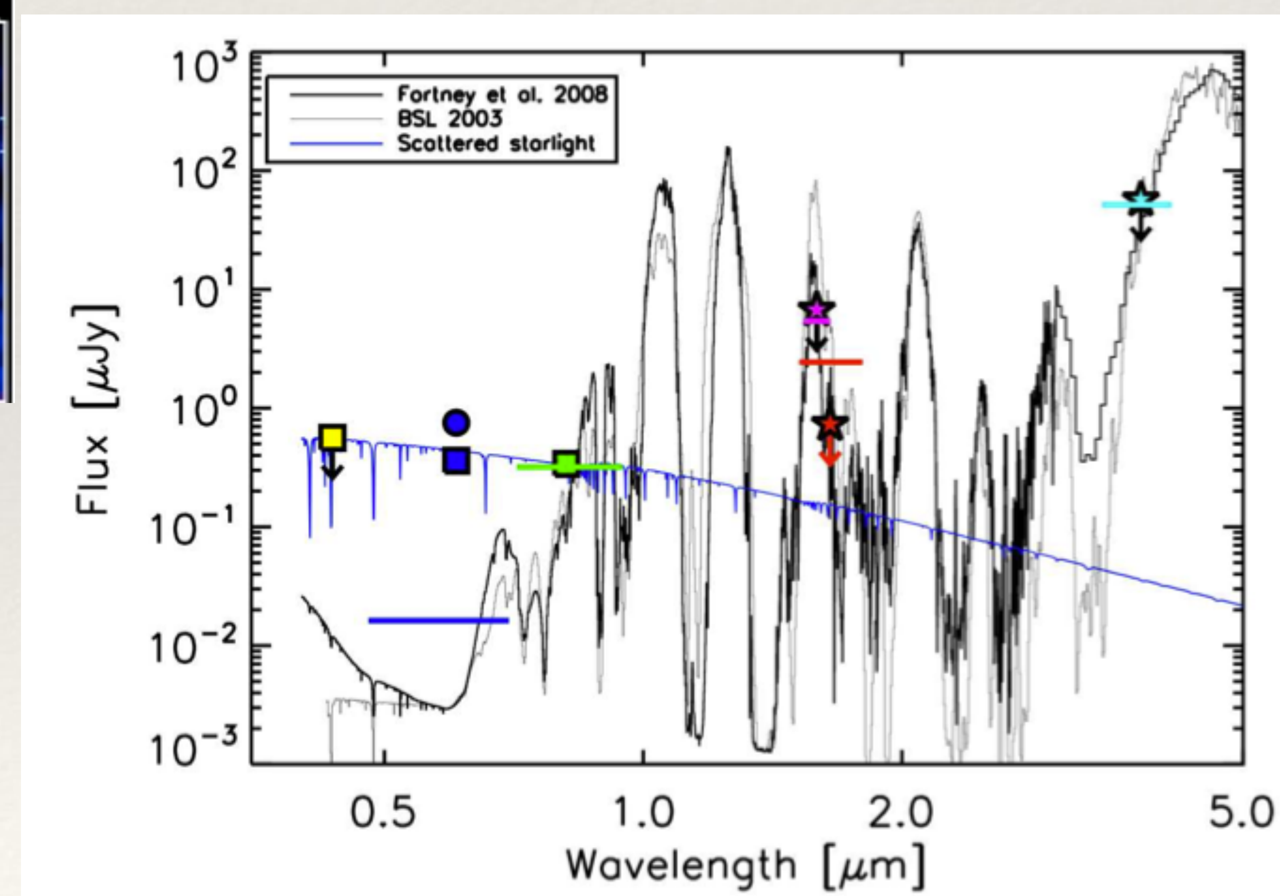


Marois et al., 2010

FOMHALAUT

- Fomalhaut b : 400 Myr
- Suspected the presence of the planet due to the disk morphology
- Limit mass > 3 M_J
- separation : 120 AU: formation ? migration ?

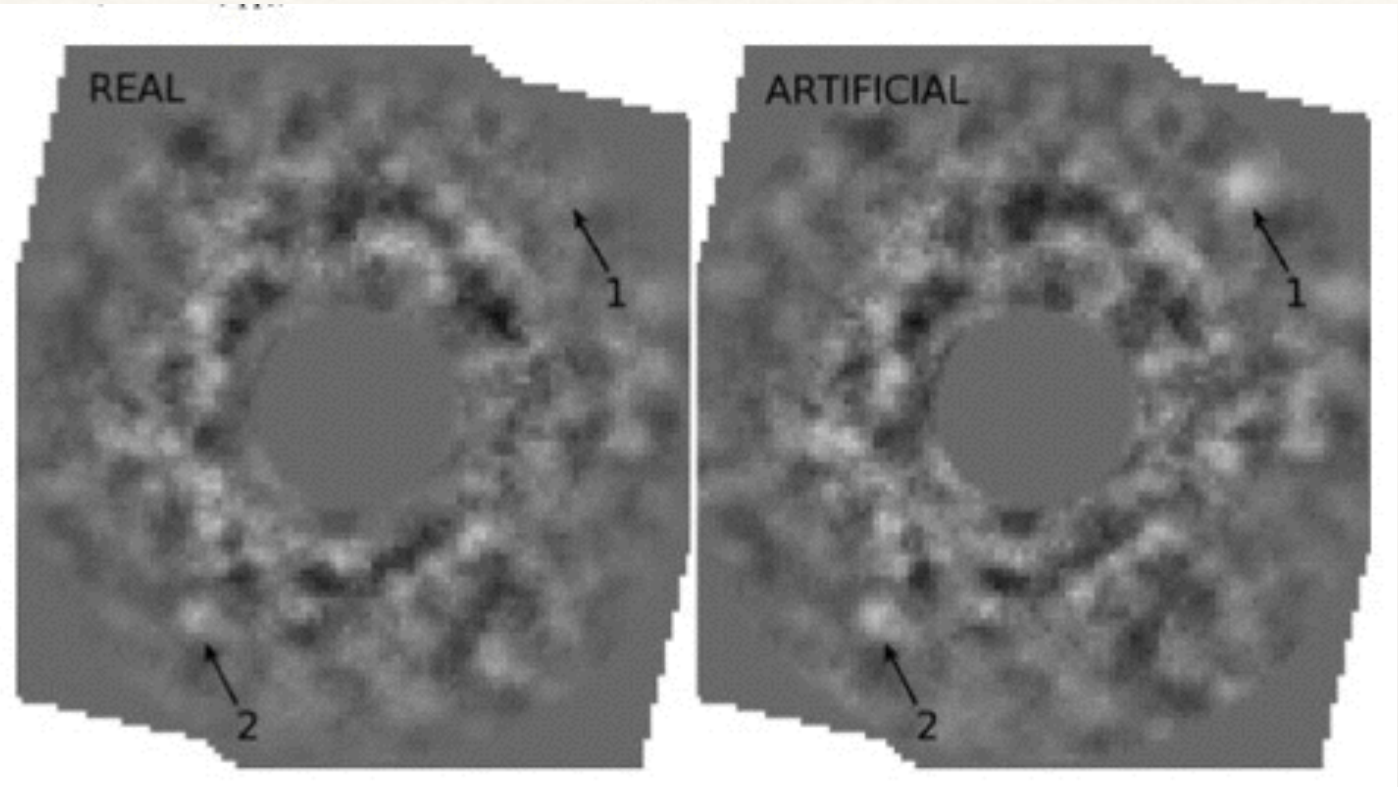


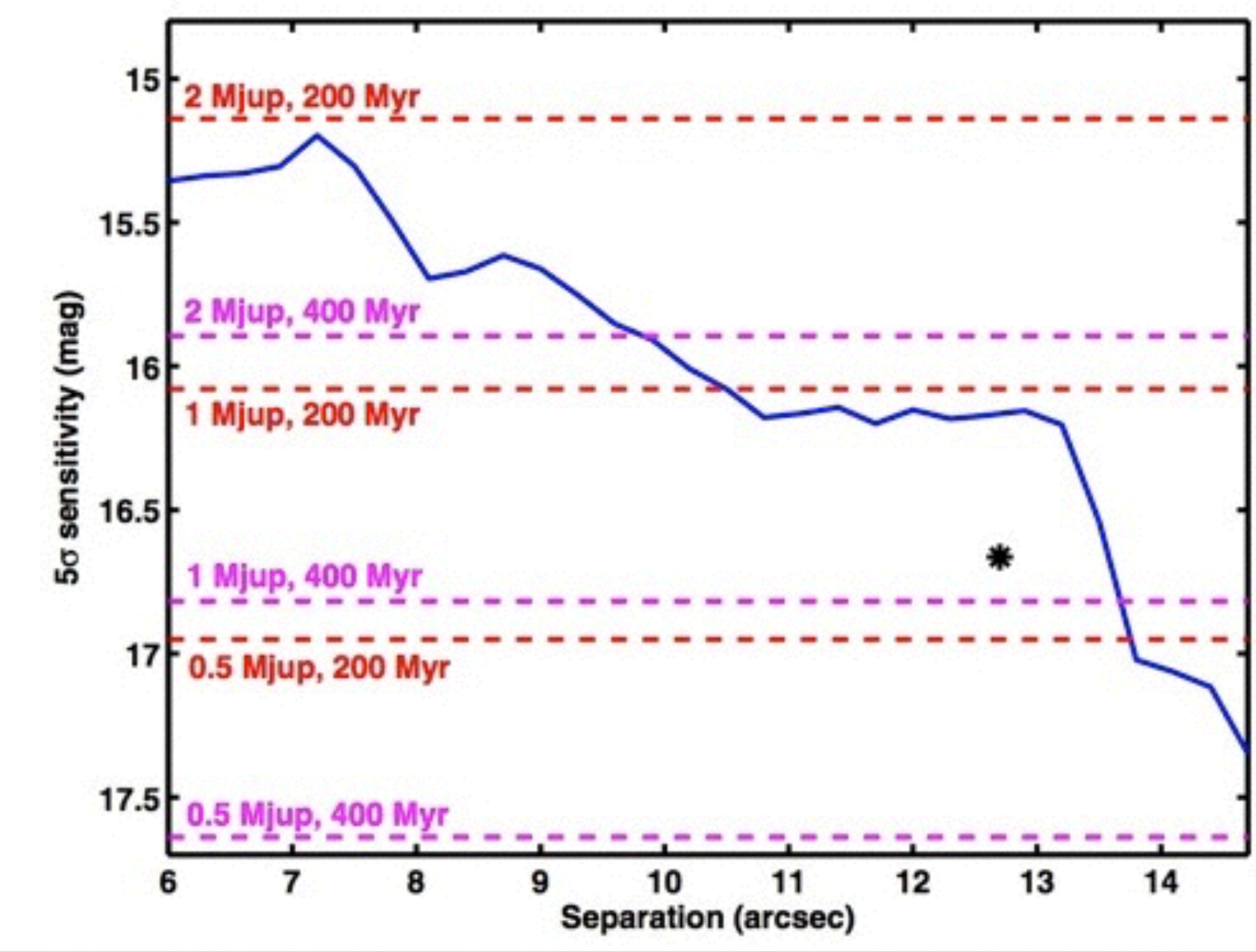


The planet discovered in the visible was not observed in the IR

FOMHALAUT

No detection with Spitzer at 4.5 μm
Janson et al., 2010

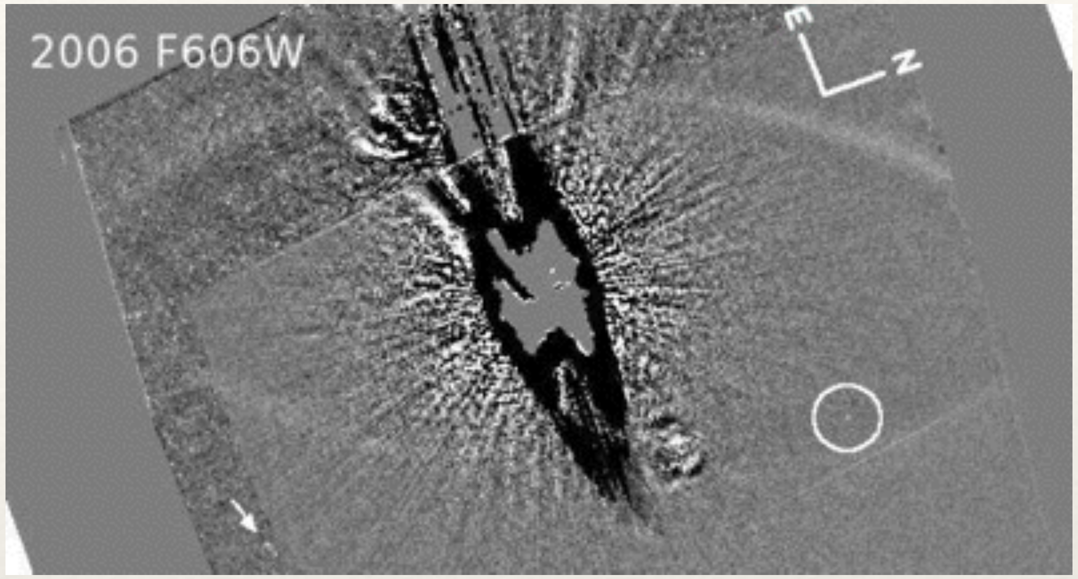


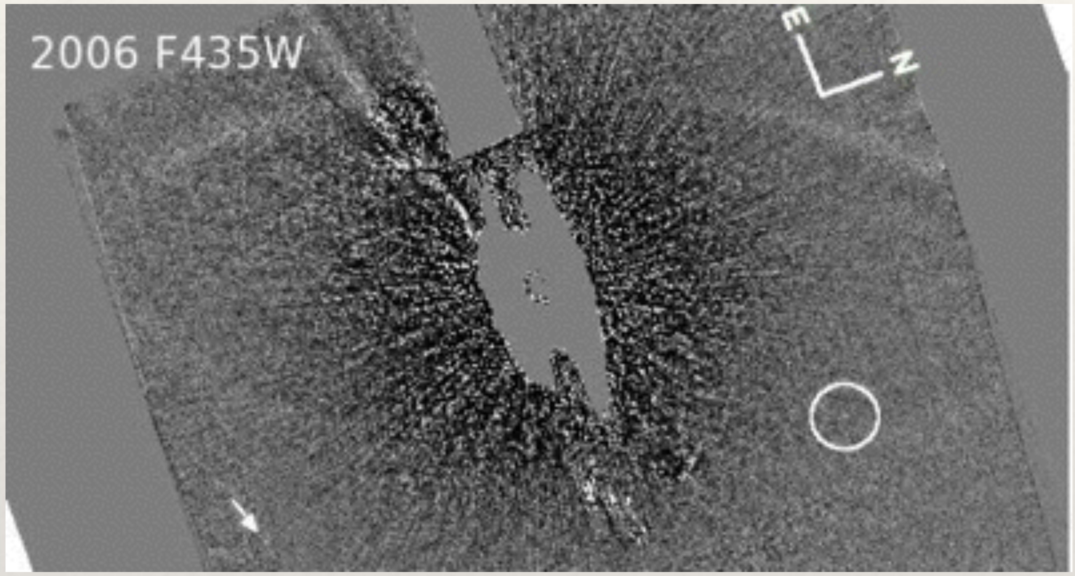


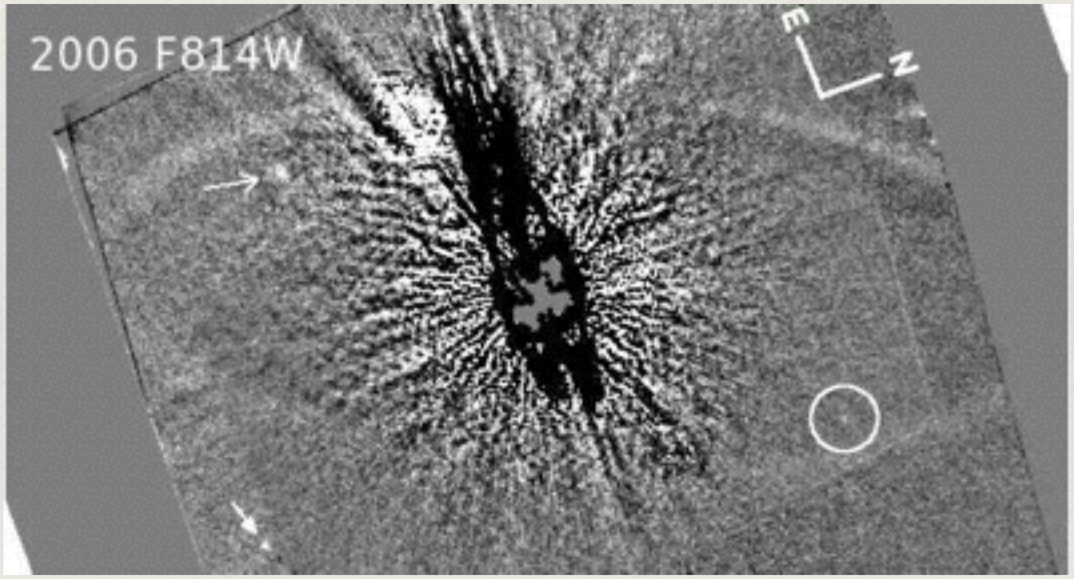
Transitory optically thin cloud

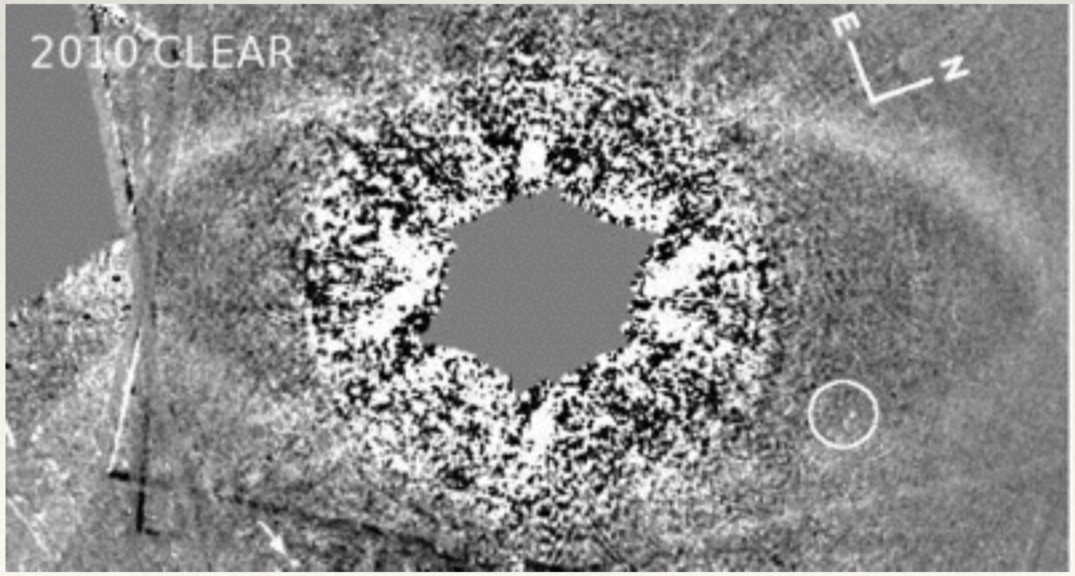
FOMHALAUT

Re-detection in 2012 in independent way by Garlicher



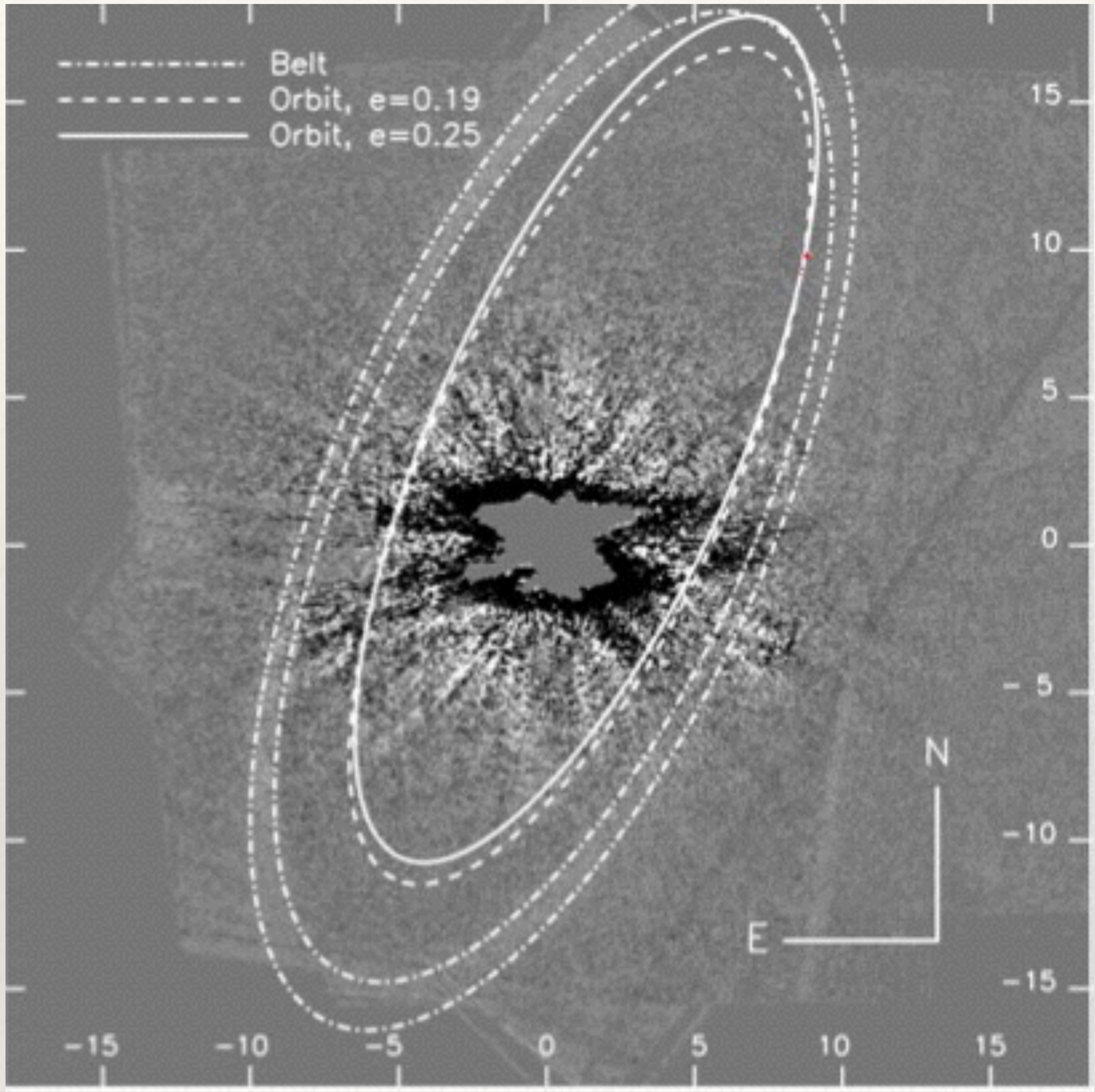




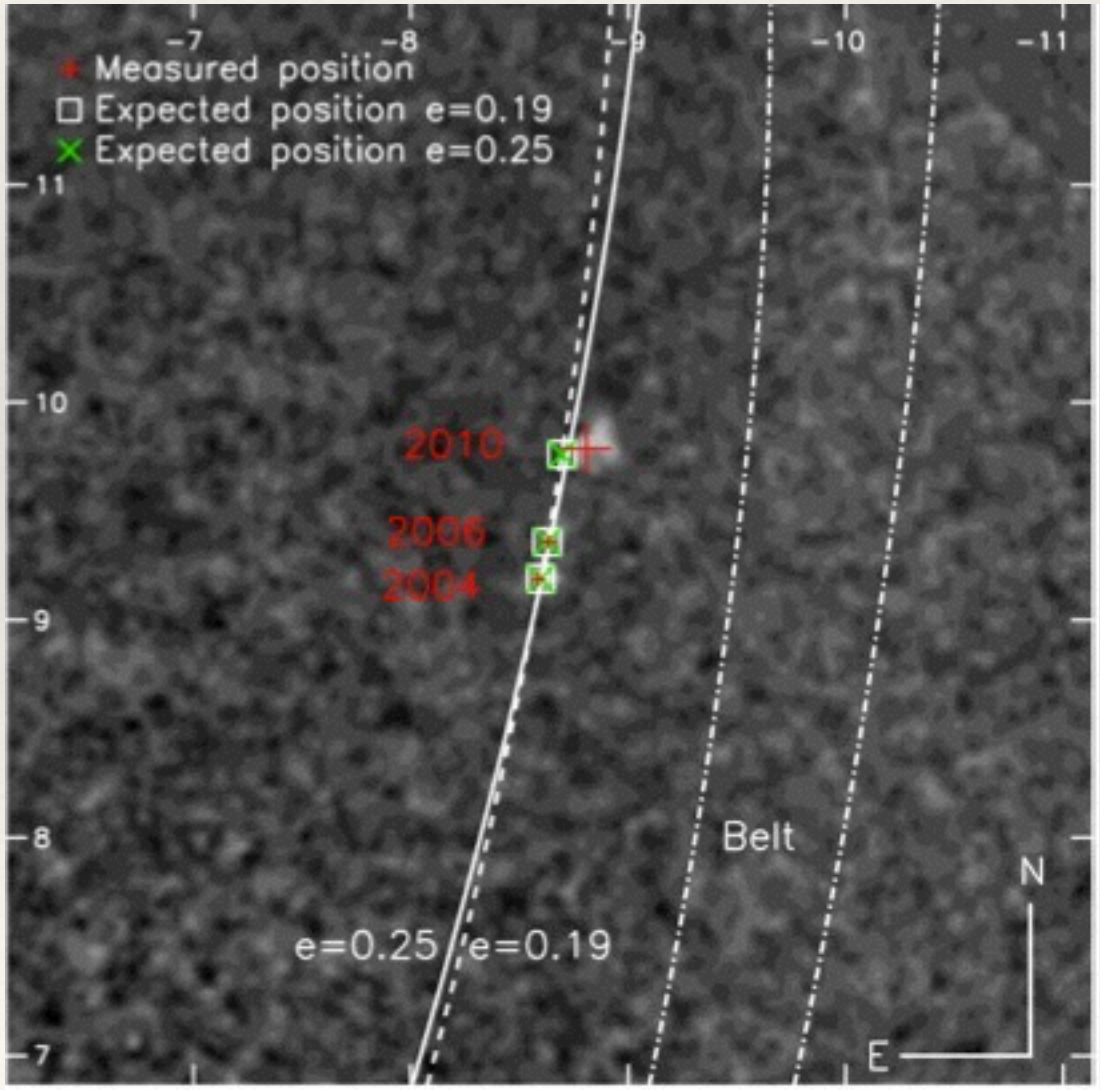


Galicher et al, 2012

FOMHALAUT

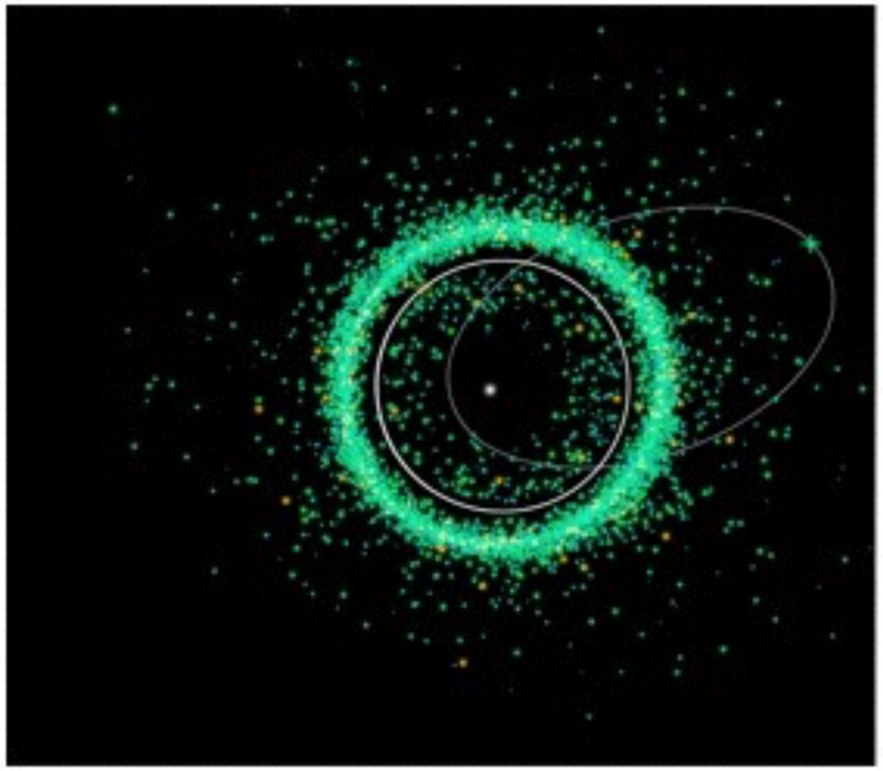


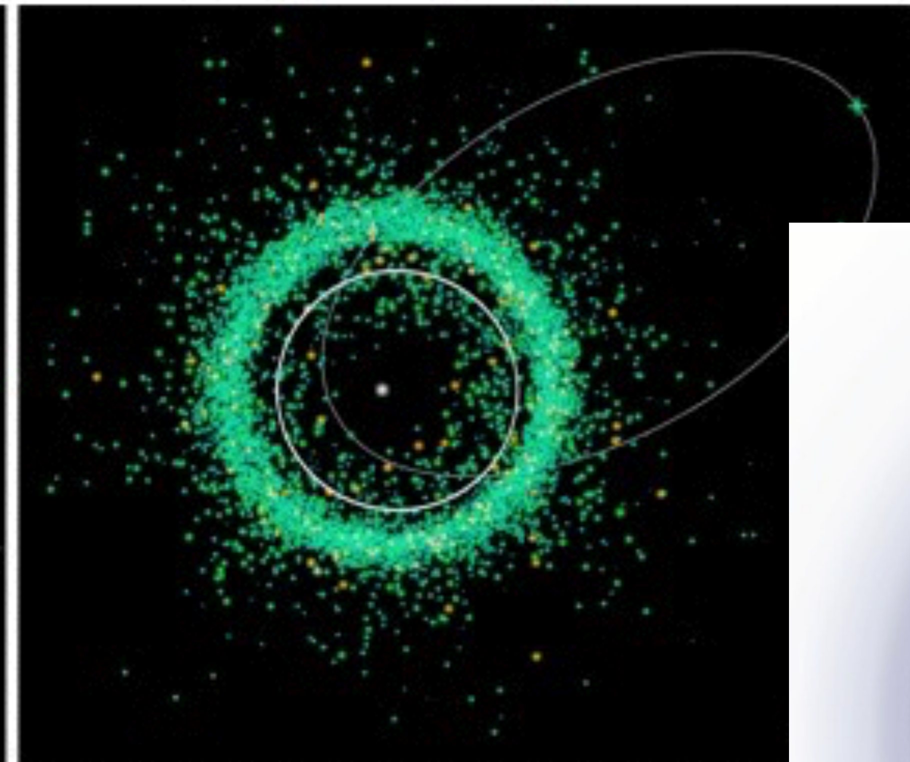
Galicher et al, 2012

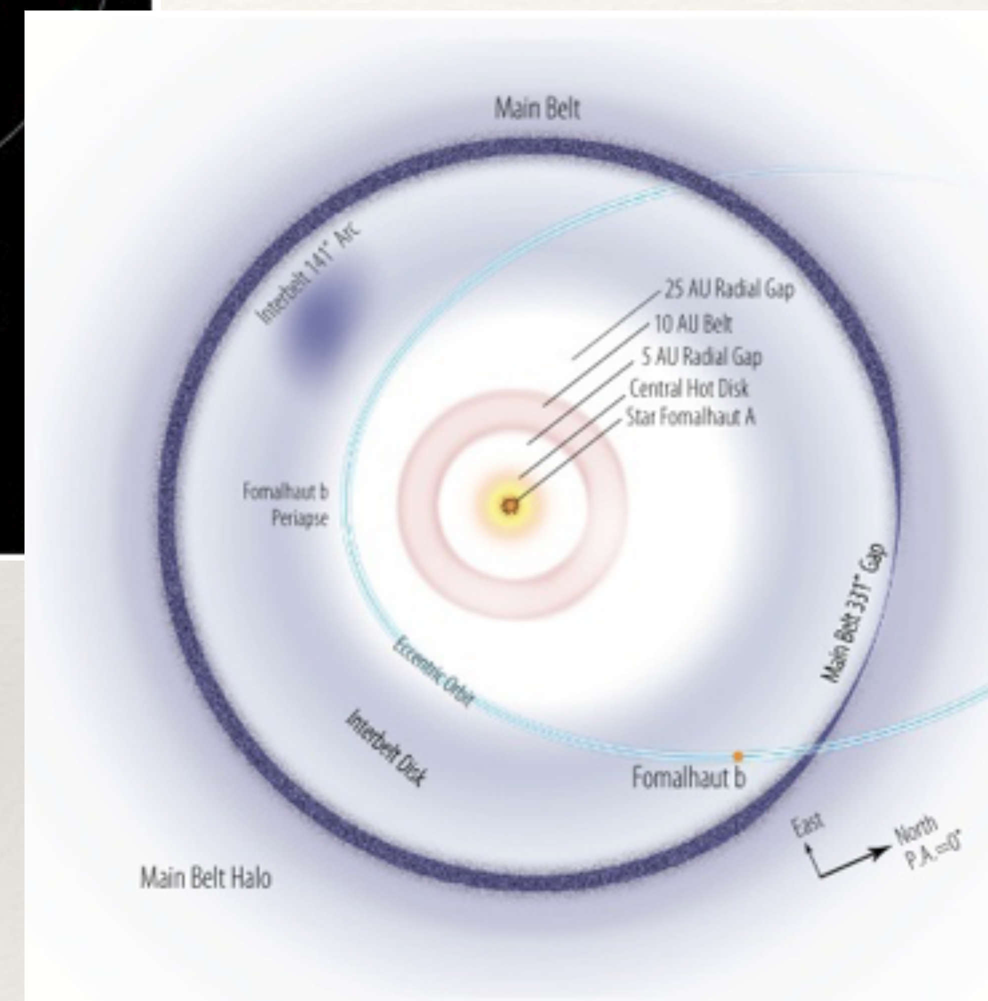


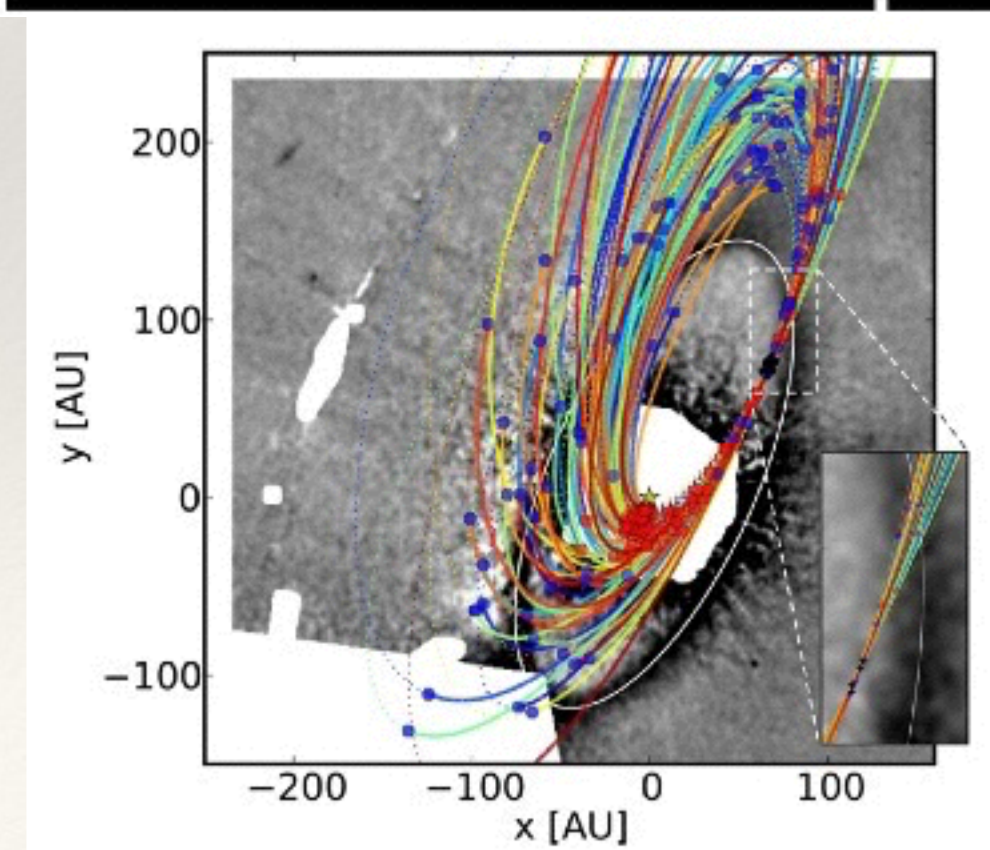
FOMHALAUT

Kalas et al, 2013



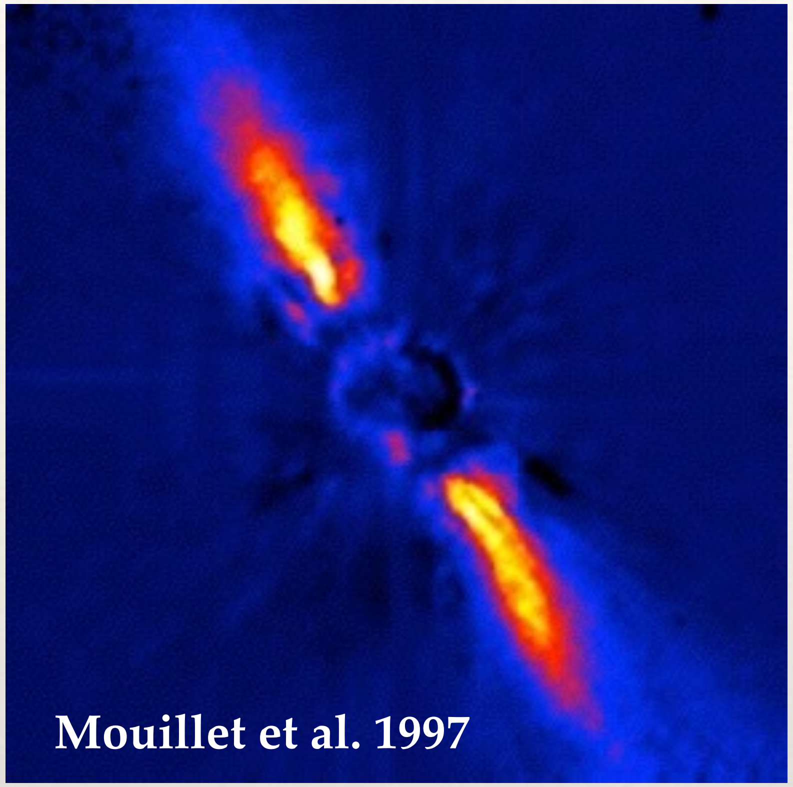


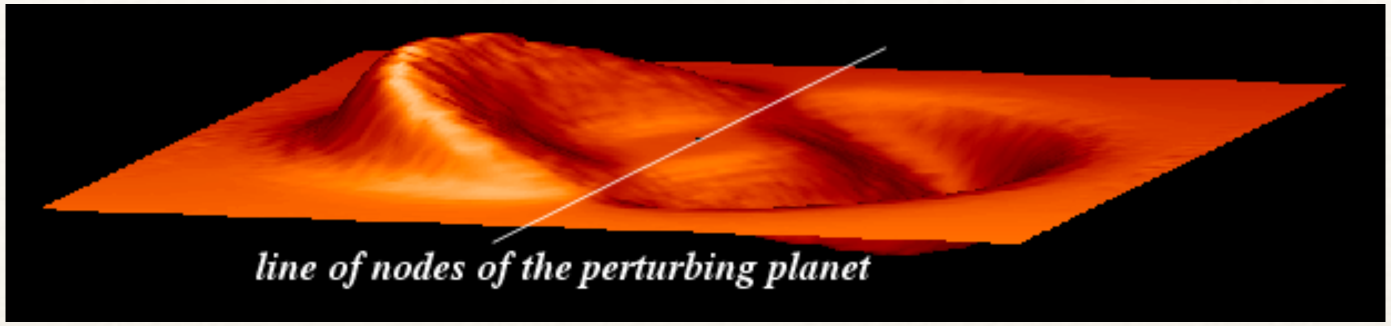




Eccentric Orbit:
is it an other planet (Fomhalaut c) to explain the shape of the disk?
Fomhalaut b: a dwarf planet surrounded by satellites -> Collisions -> Diffuse Light

Beta Pic b



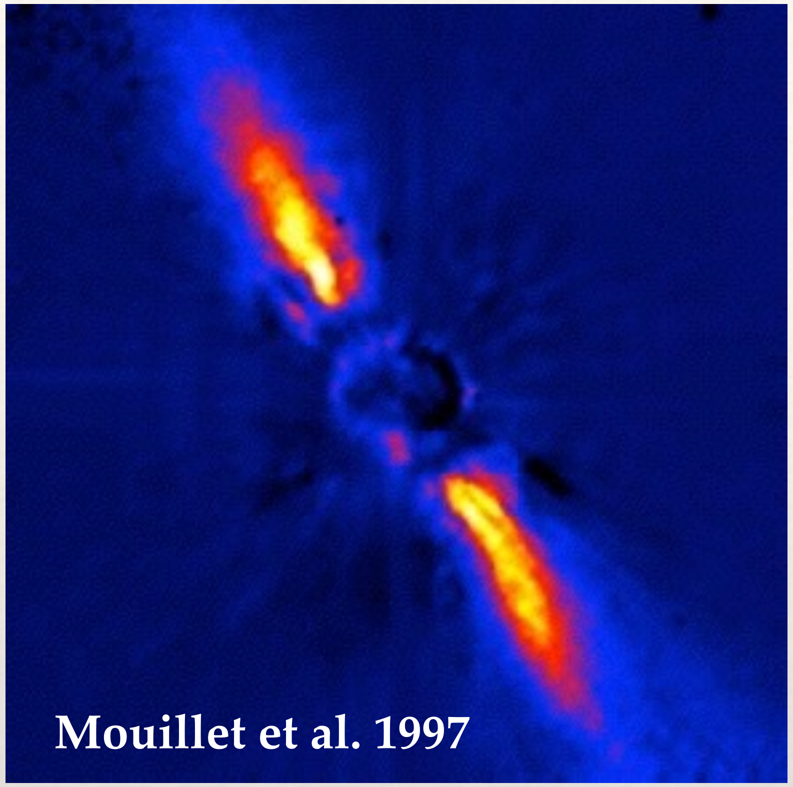


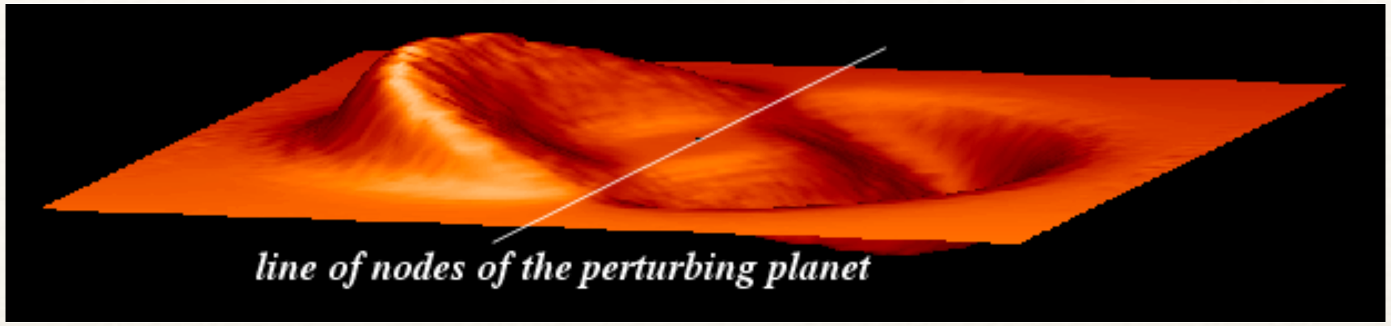
Disk Torsion
=> Planet prediction :

~10 M_J at ~10 UA

Lagrange et al, 2009 (NACO)

Beta Pic b





Disk Torsion
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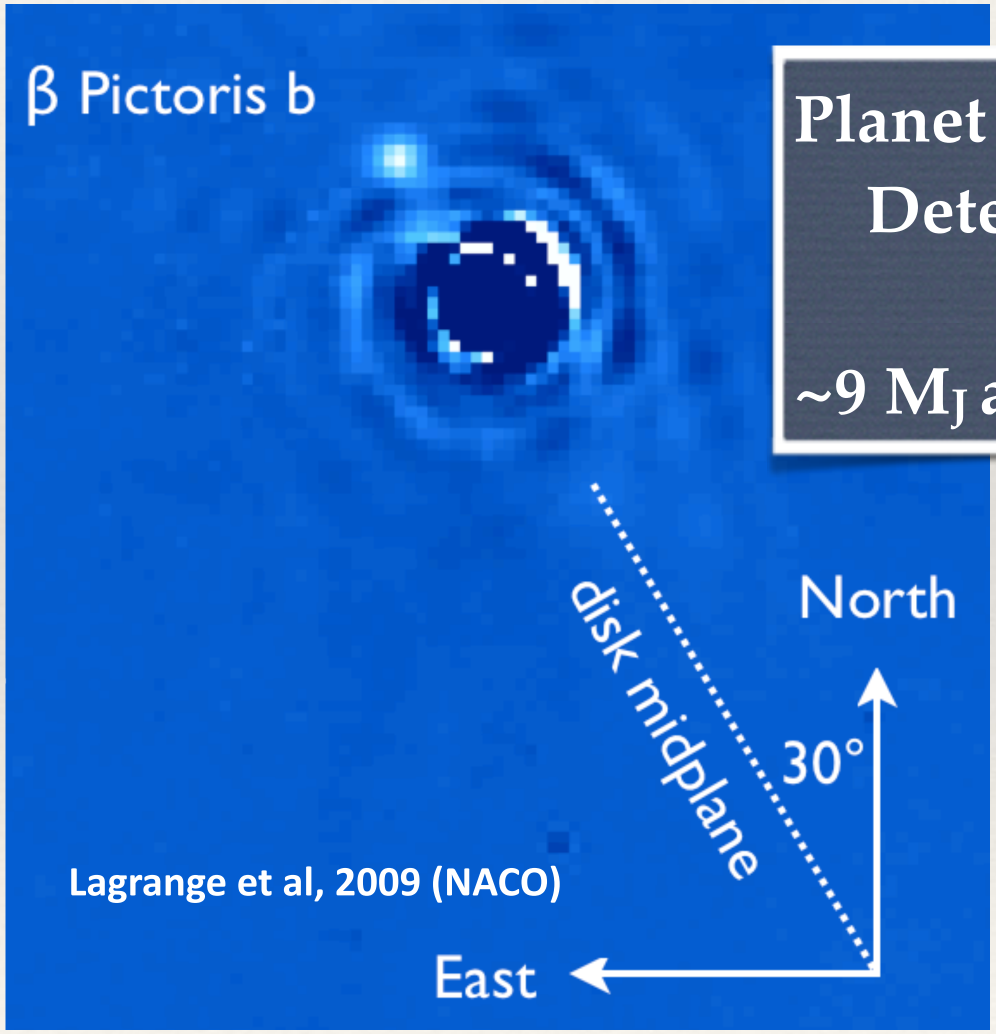


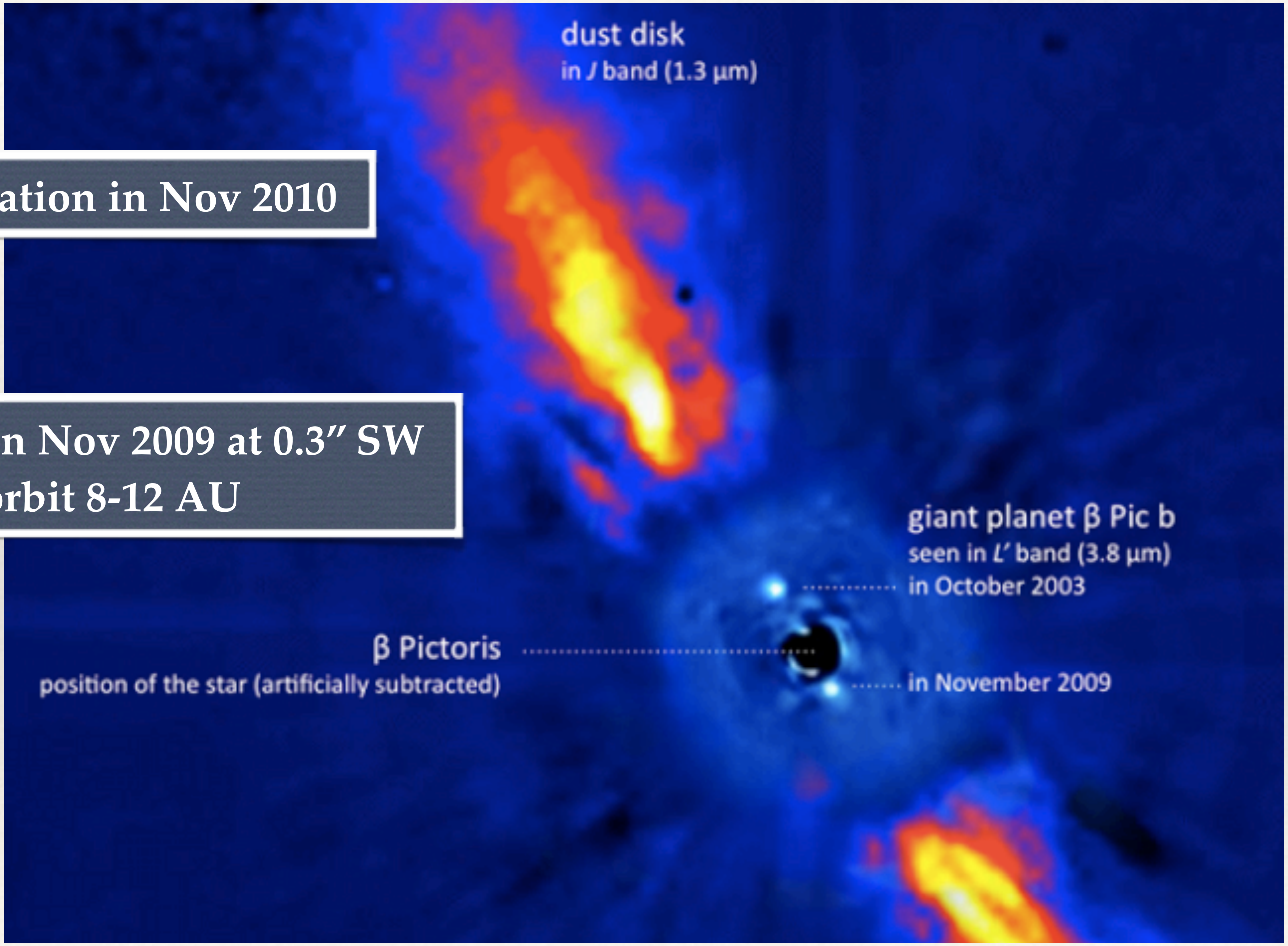
Planet Candidate
Detection in 2009

~9 M_J at ~8 UA

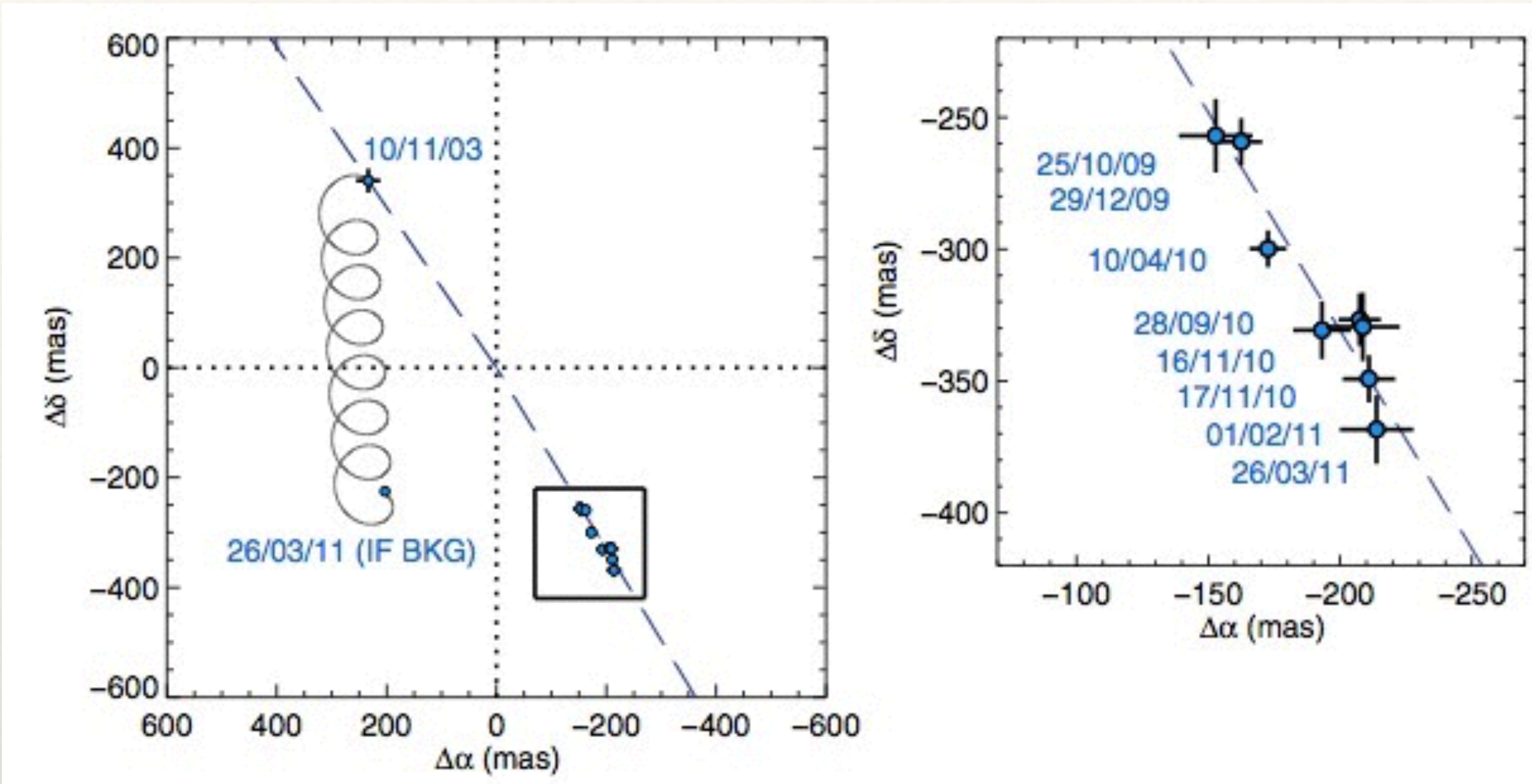
Beta Pic b

Definitive confirmation in Nov 2010

planet redetected in Nov 2009 at 0.3″ SW with a confirmed orbit 8-12 AU

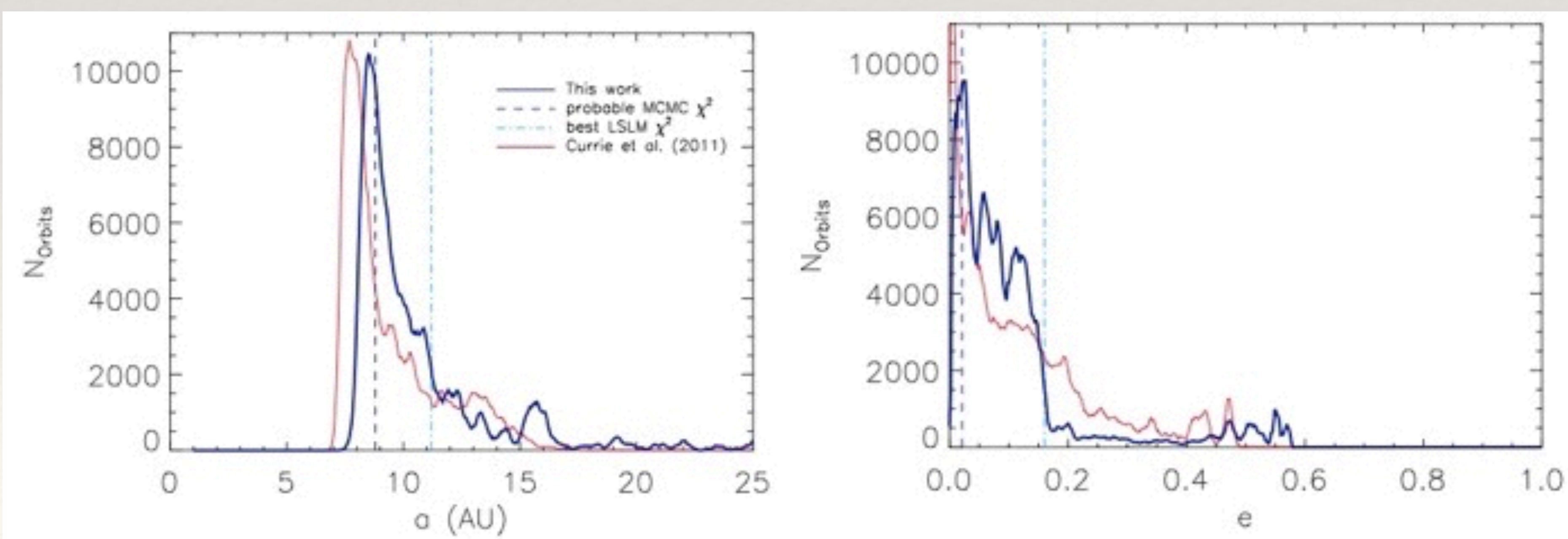


Beta Pic b

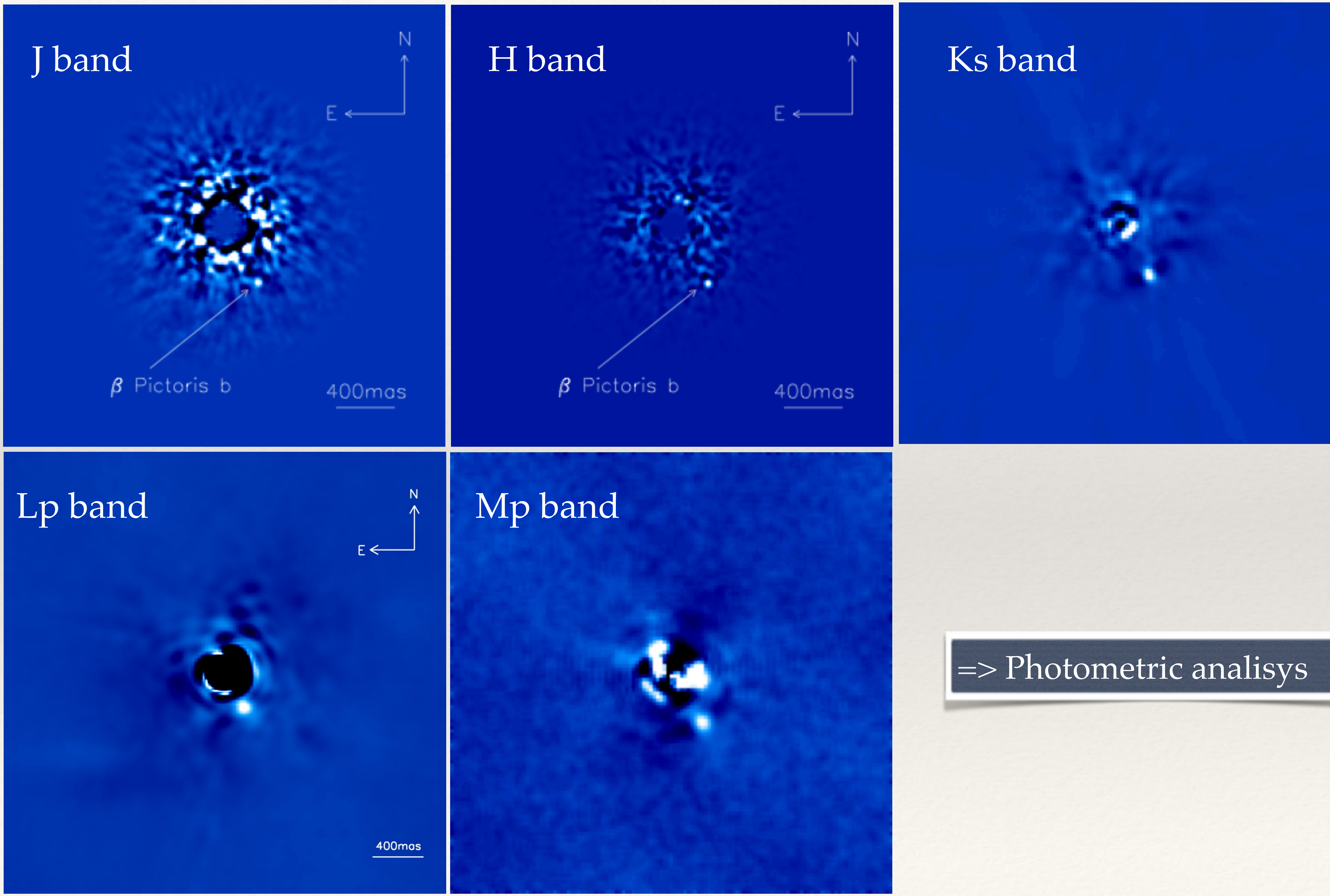


Chauvin et al, 2012

Orbit Determination (MCMC) confirmed at a = 8-9 AU



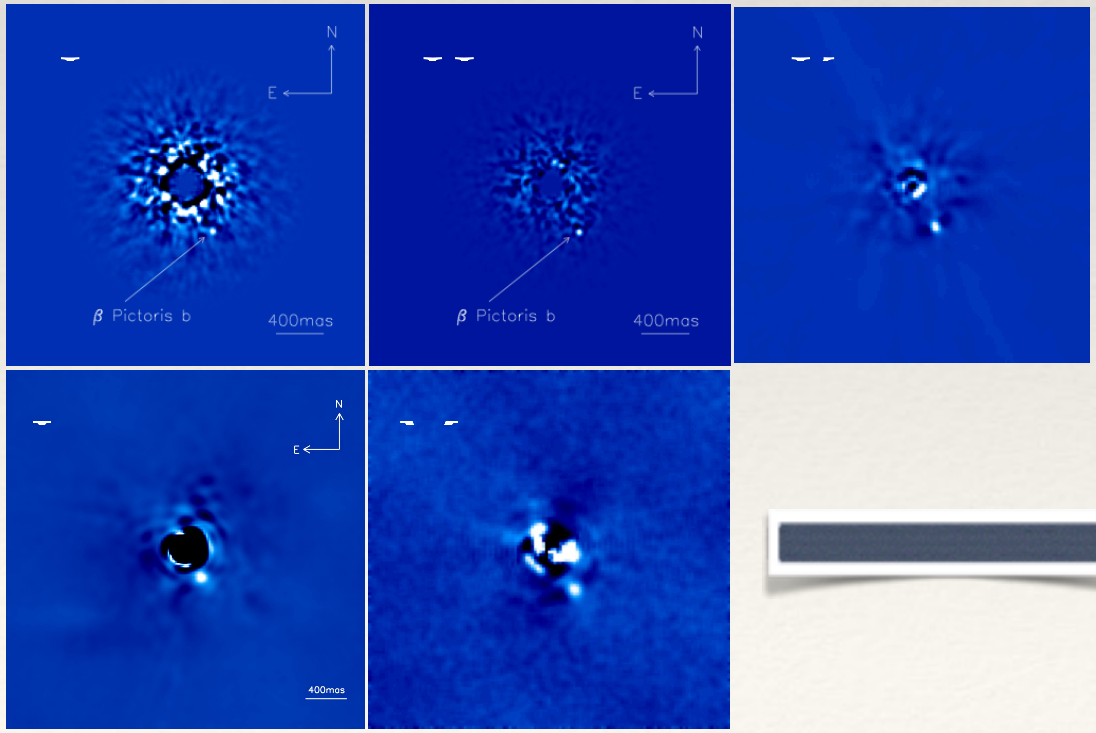
Beta Pic b

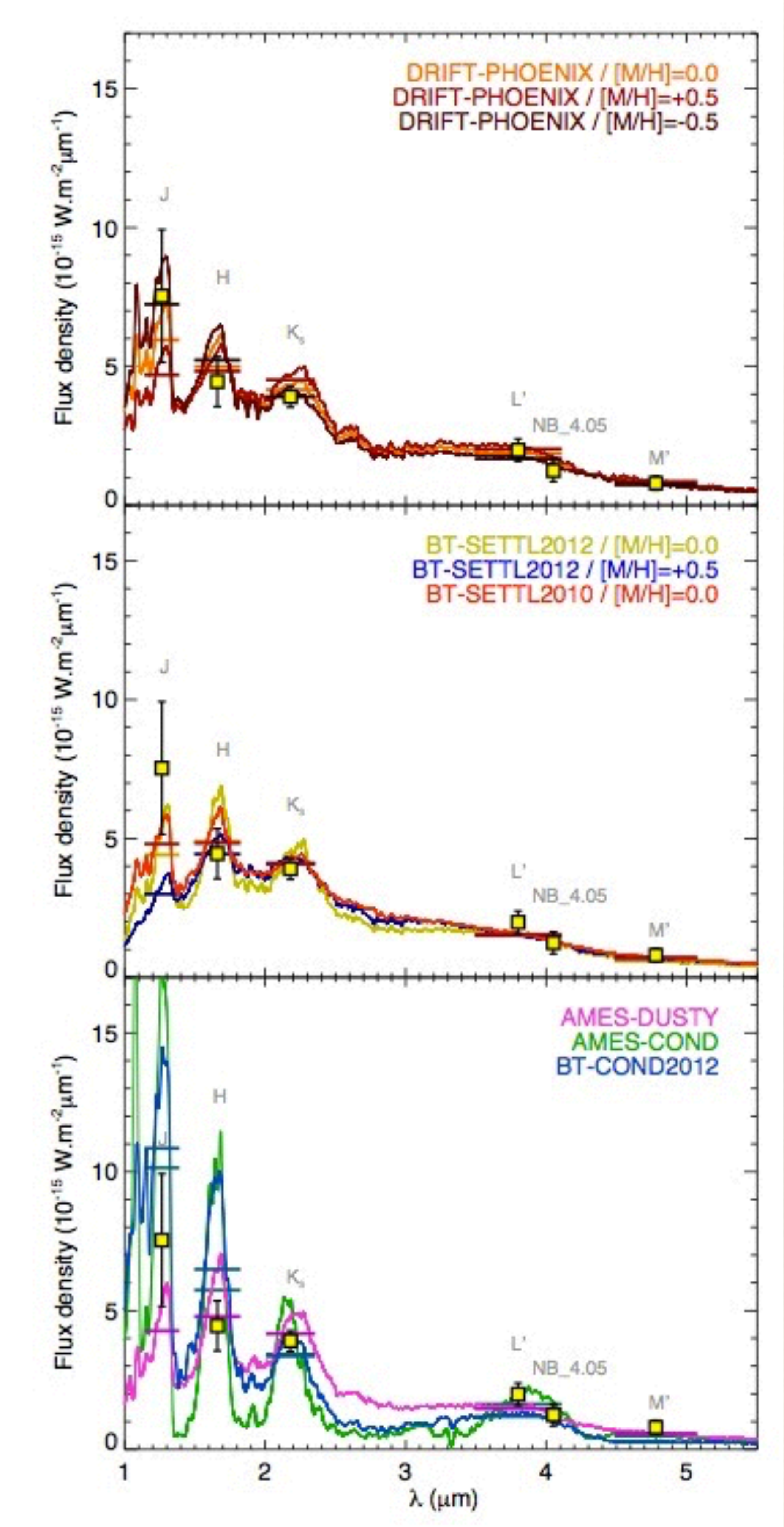


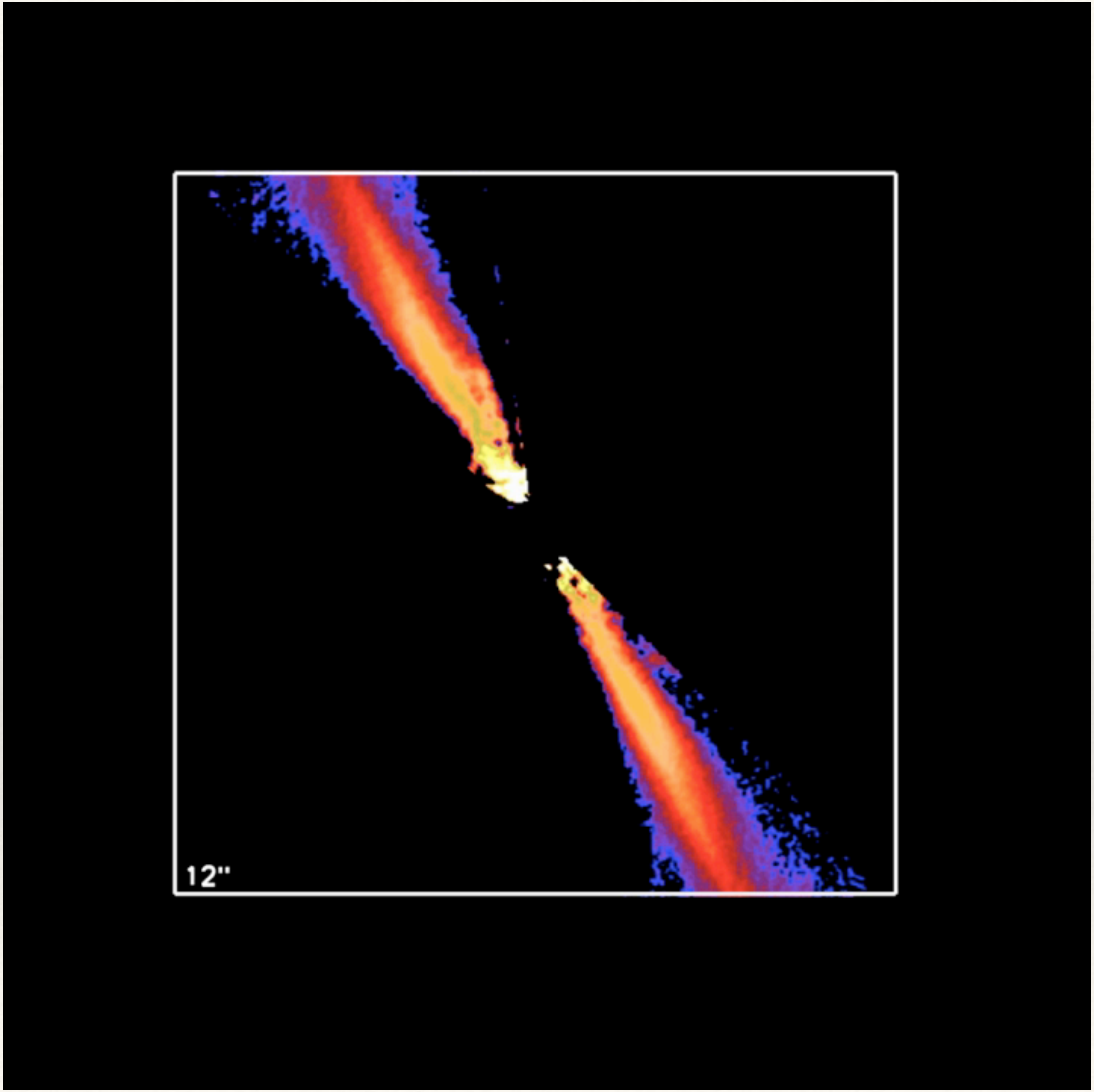
=> Photometric analisys

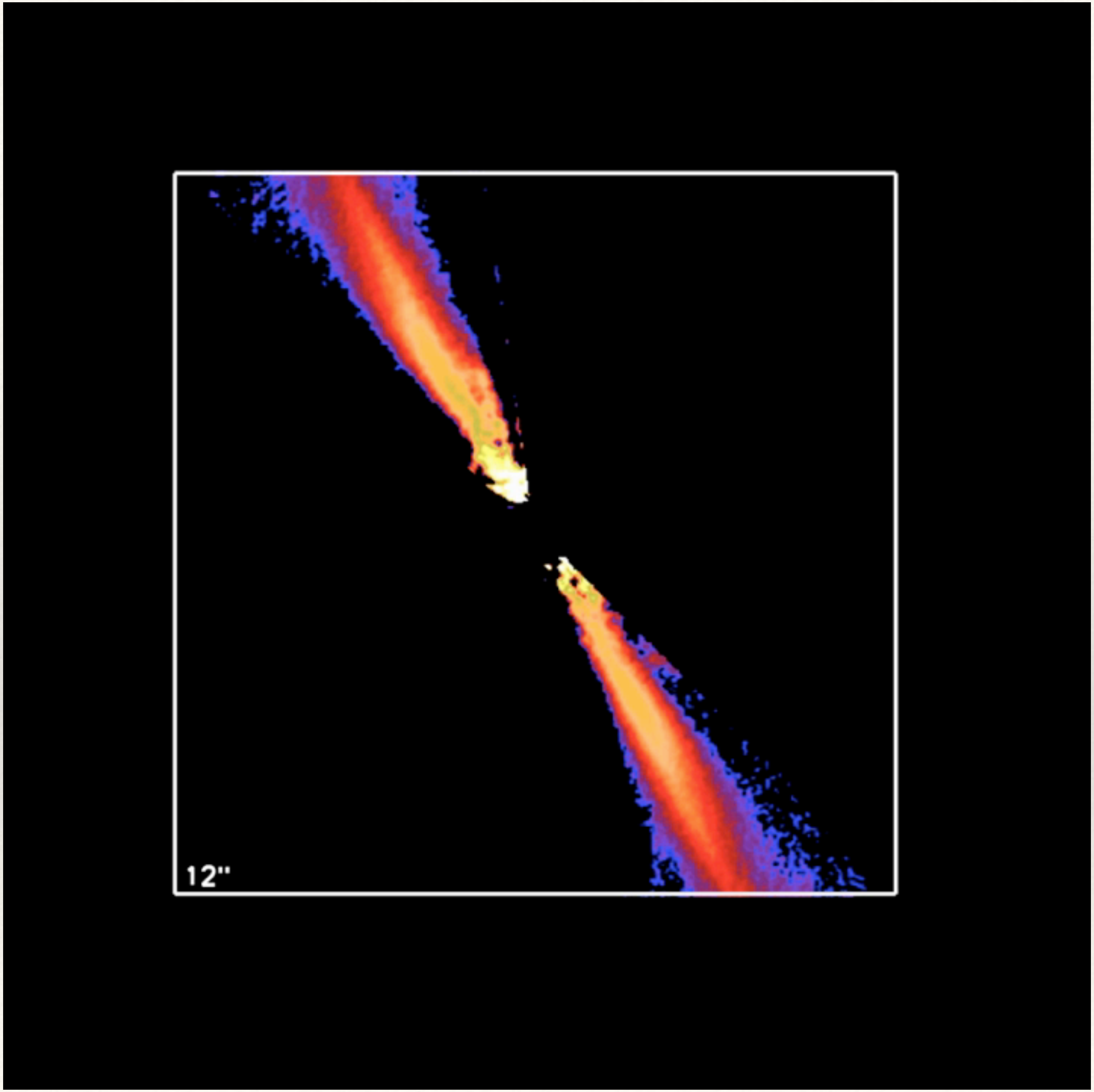
Beta Pic b

Temperature determination With models: 1700 K

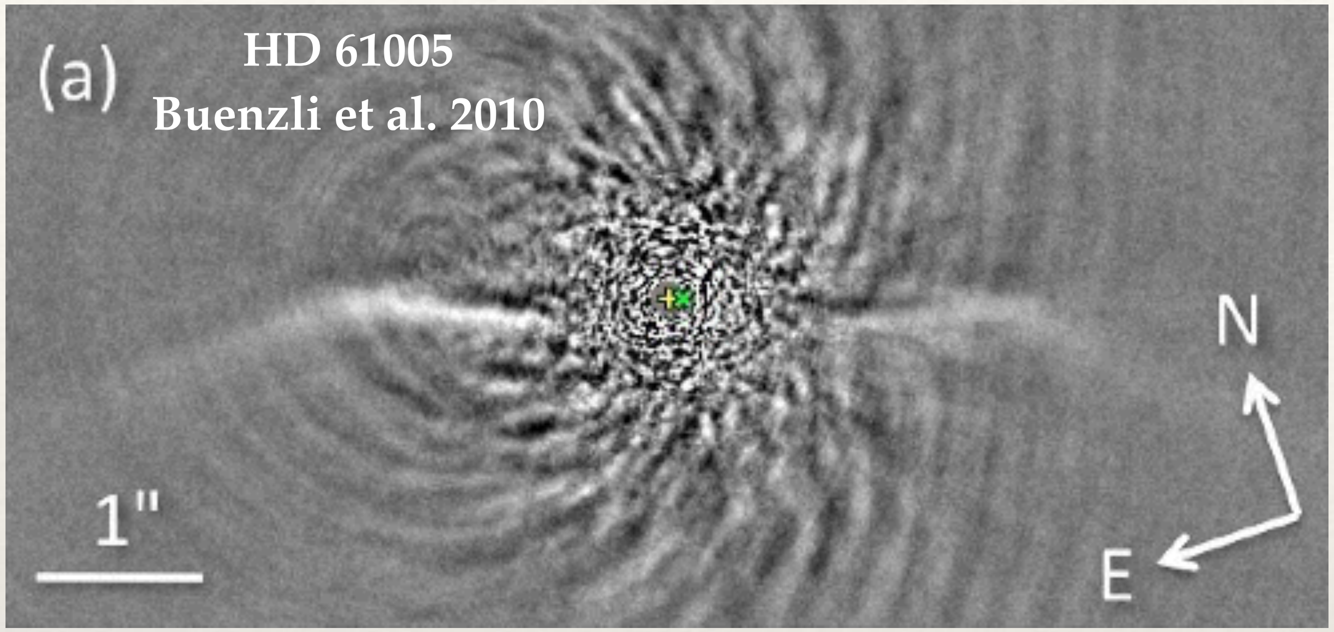


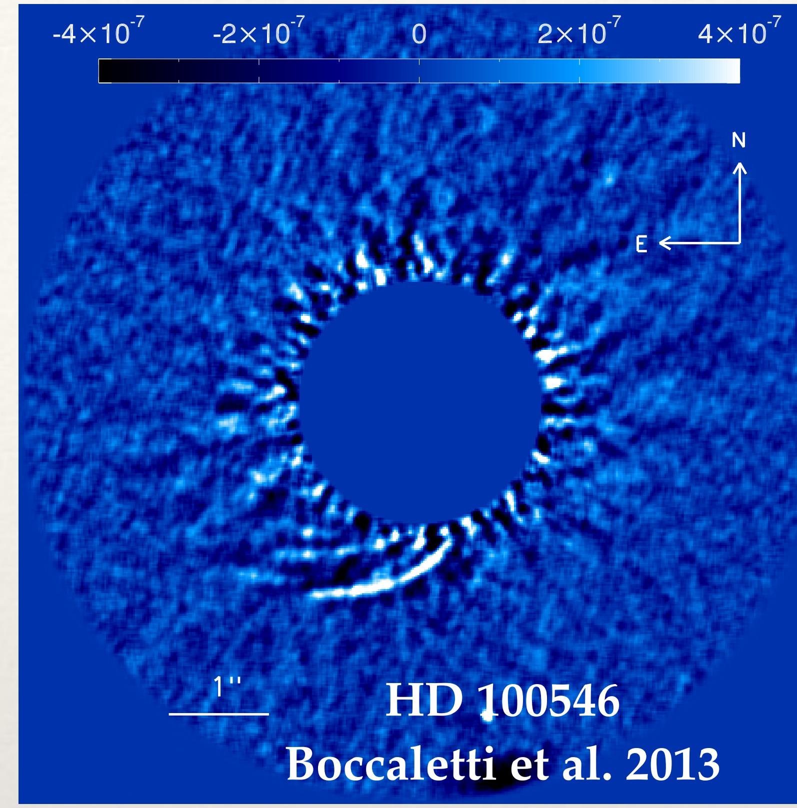


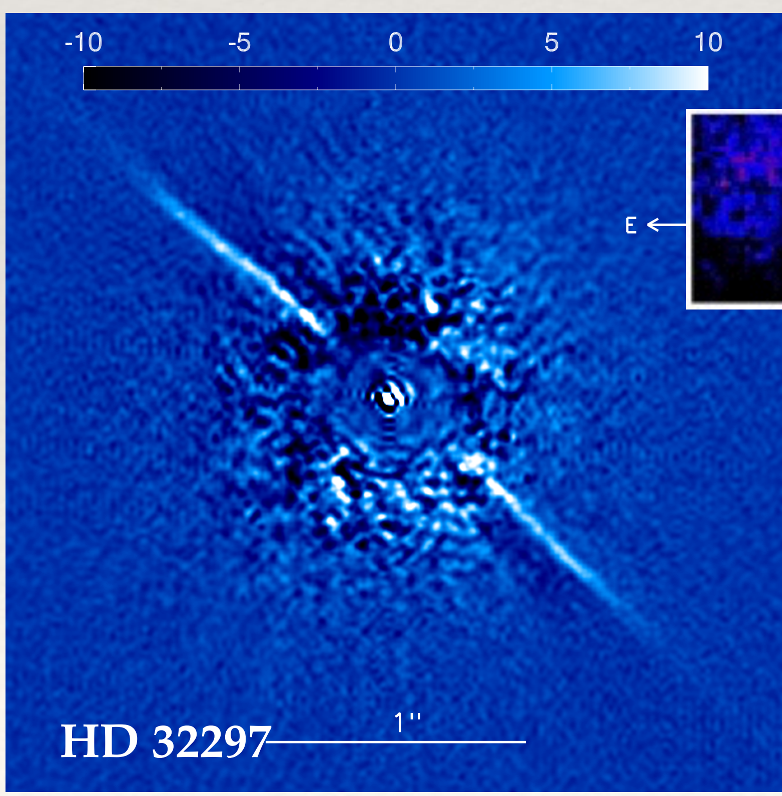

12''


12"

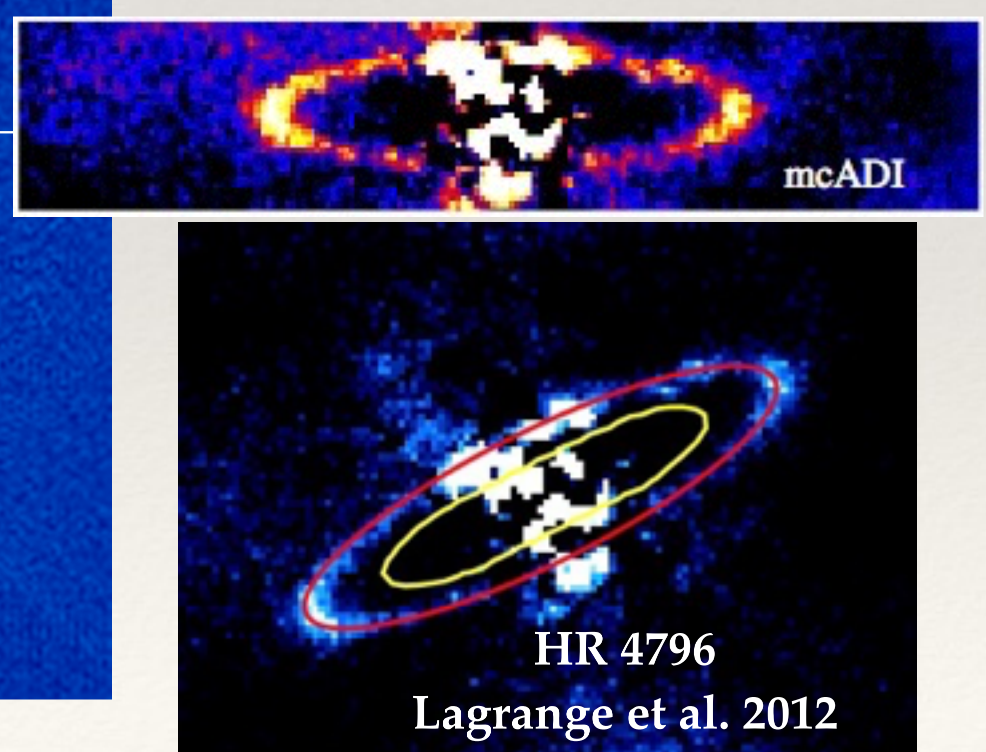
SIGNPOSTs

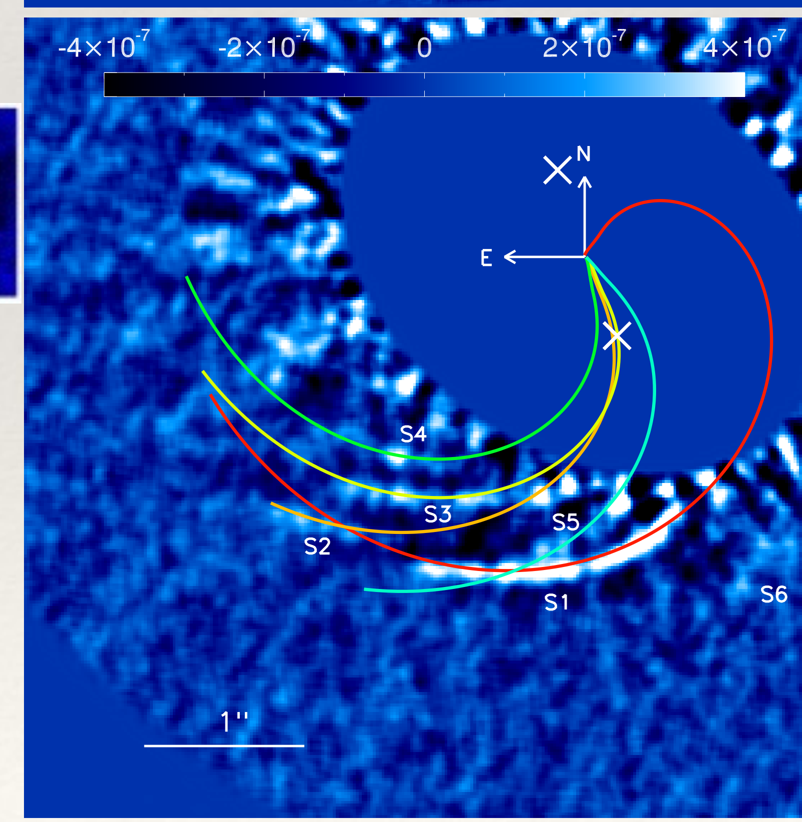




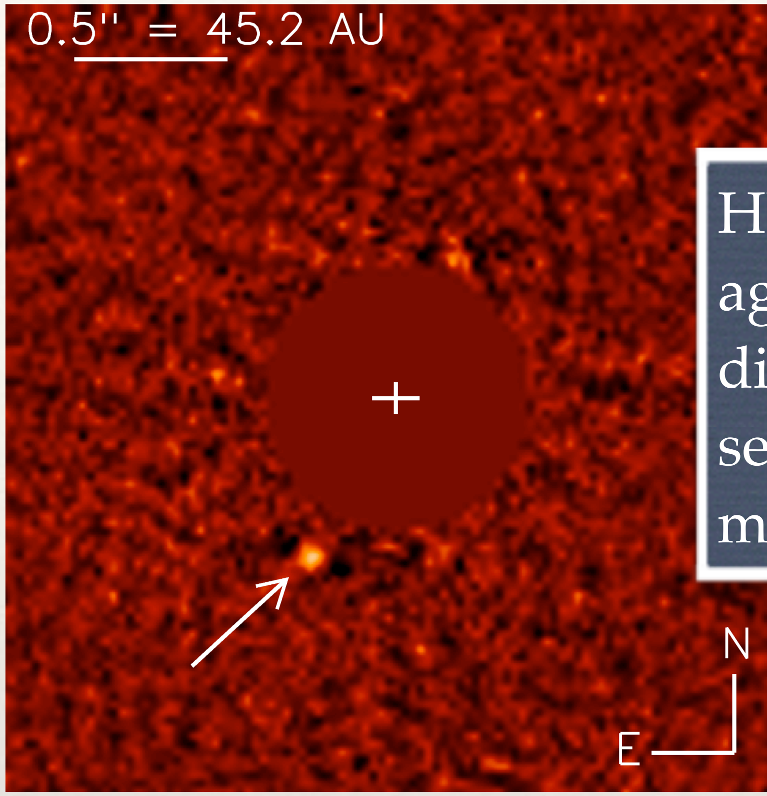


$$\delta a \,/\, a = 1.3(Mp/Ms)^{2/7}$$

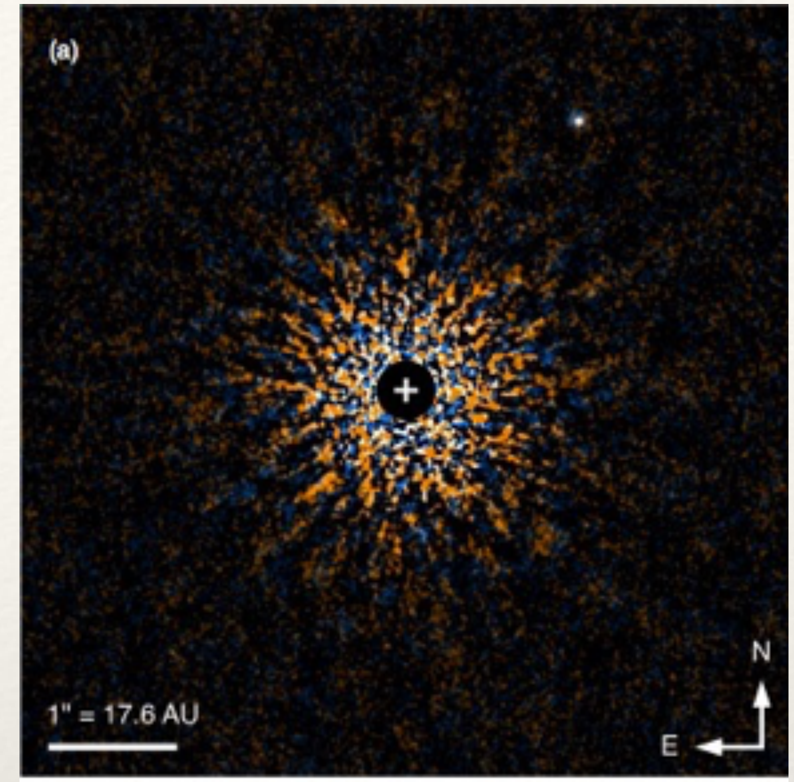




Others Planets

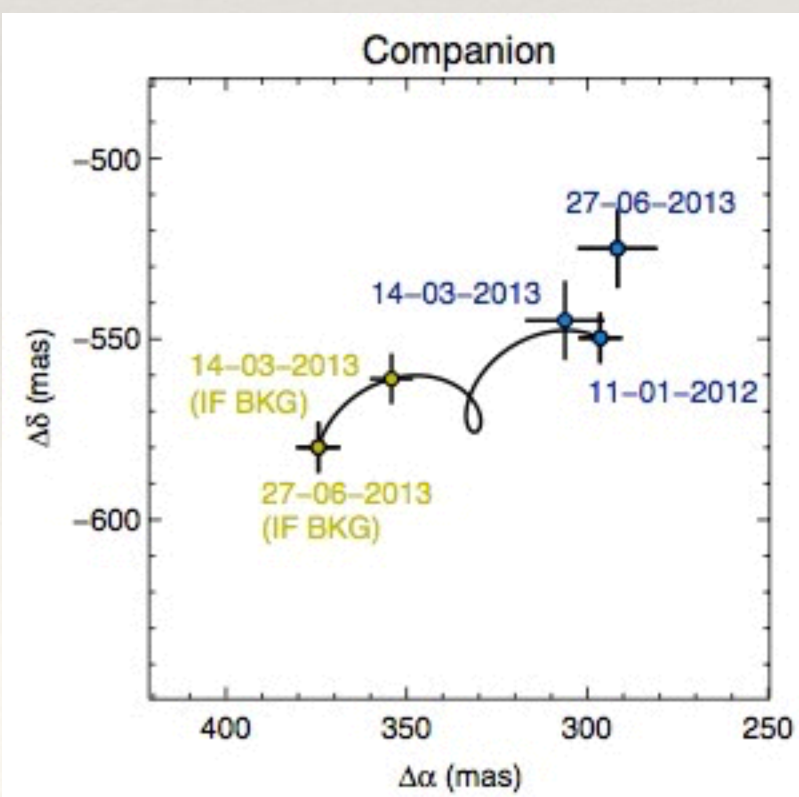


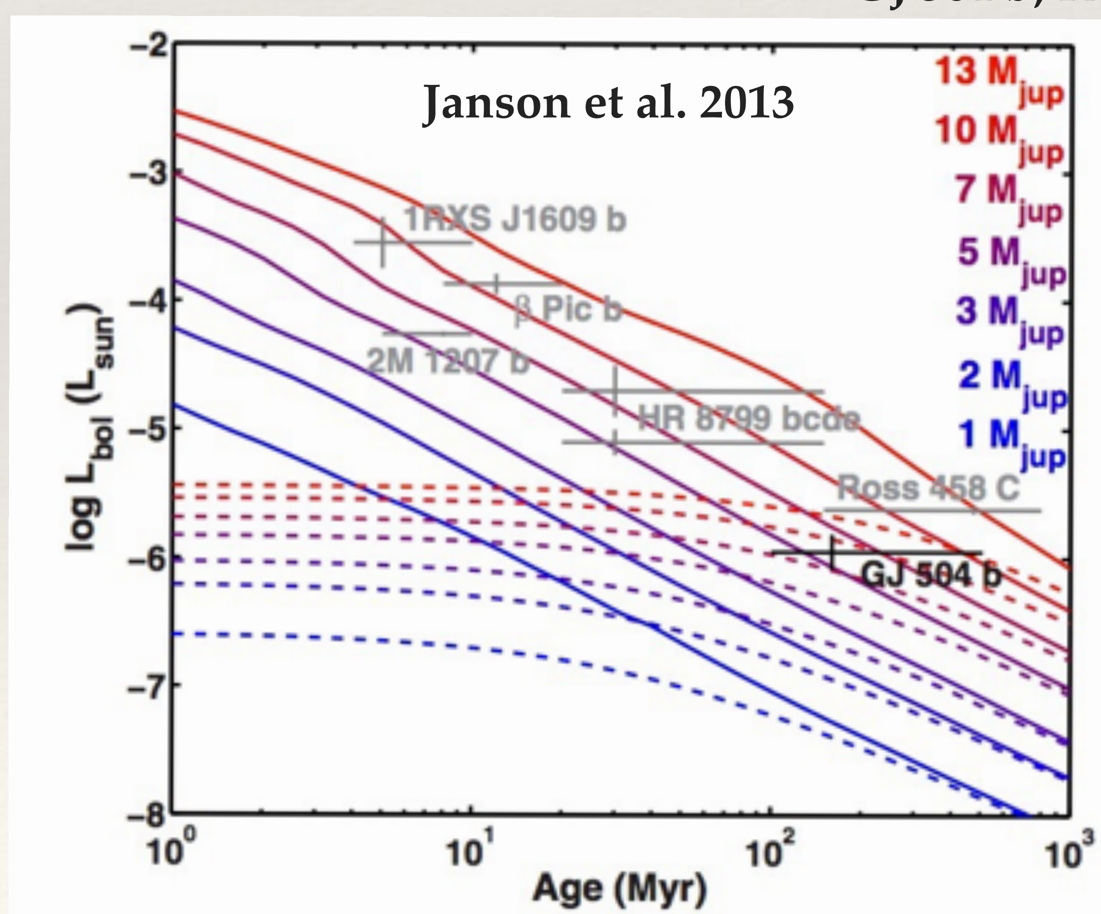
HD 95048
age = 17 Myr
dist = 90 pc
sep = 56 AU
mass = 5 Mj



GJ 504 b, Kuzuhara et al. 2013

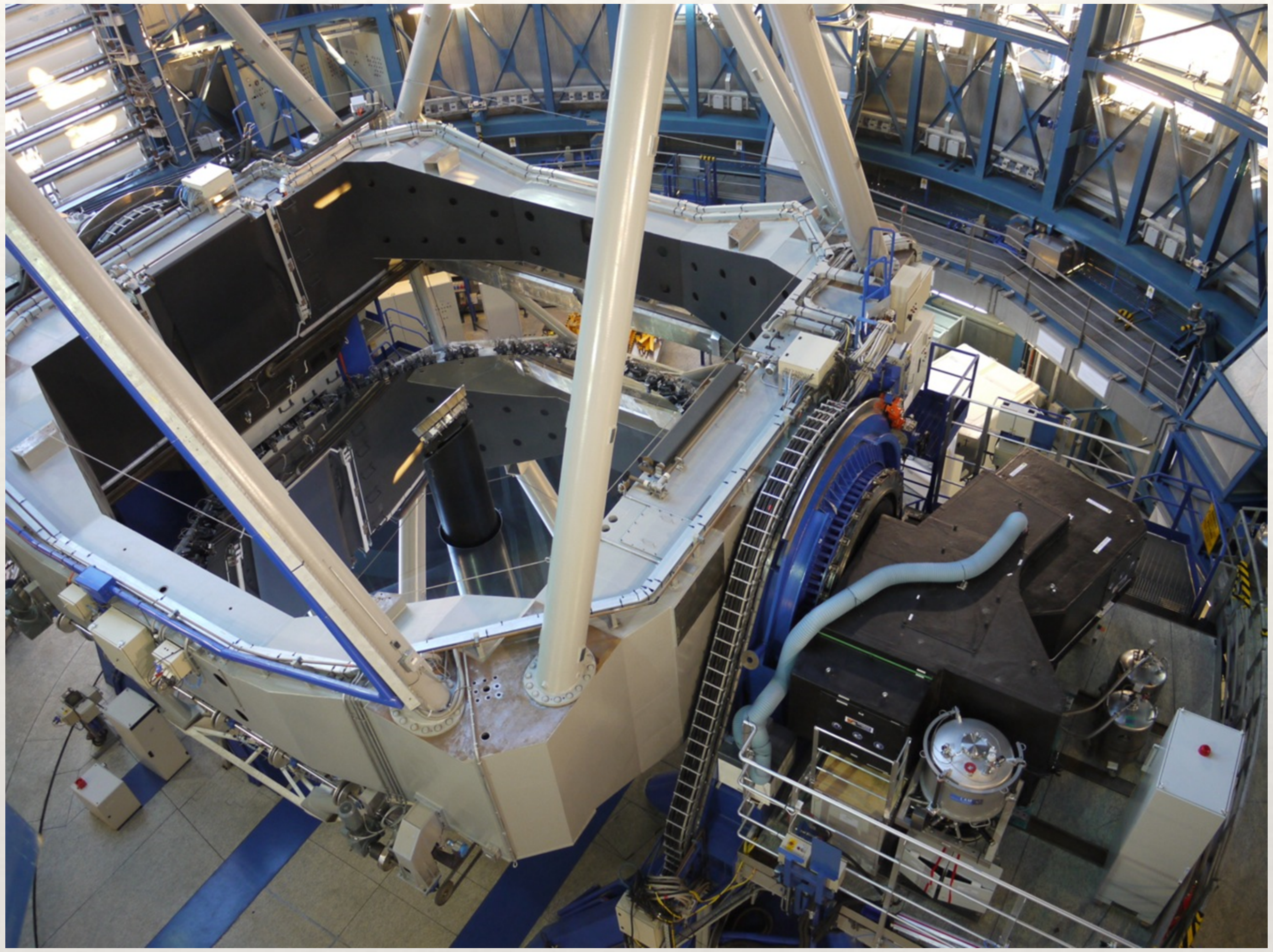
HD 95086 b, Rameau et al. 2013a,b



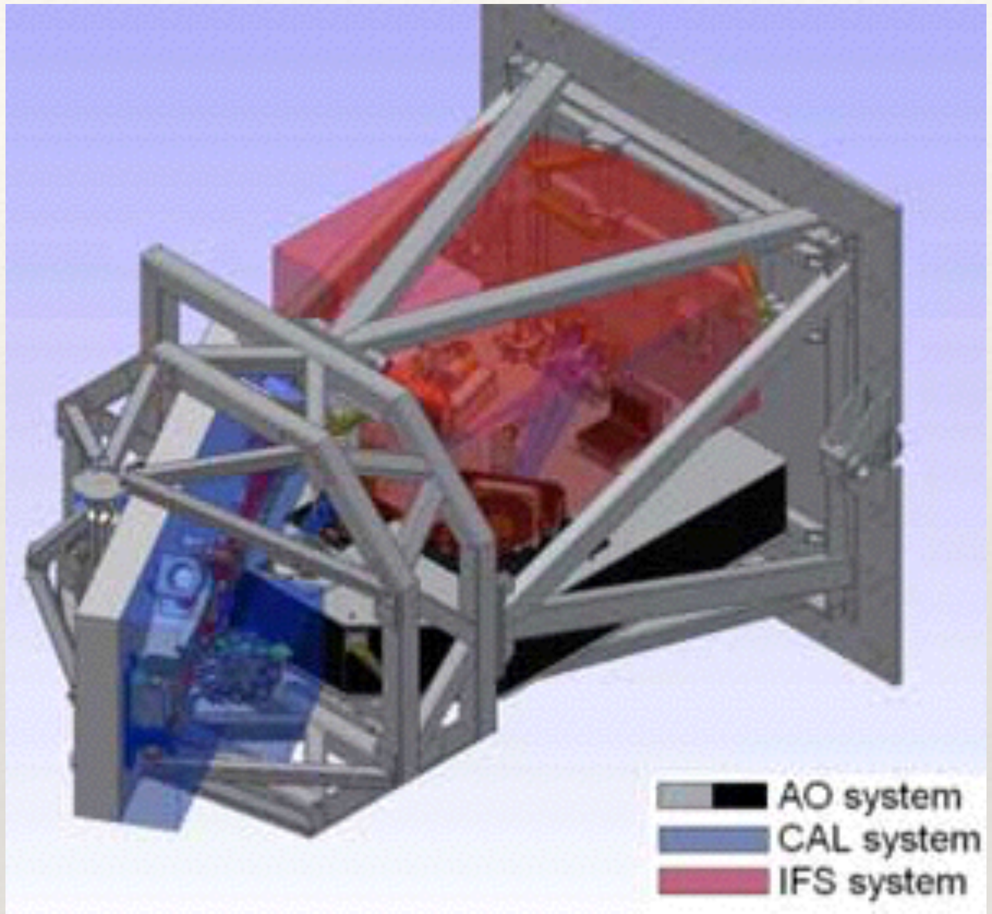


GJ 504
age = 160 Myr
dist = 17.5 pc
sep = 43 AU
mass = 4 Mj

2014 - ....



SPHERE



GPI

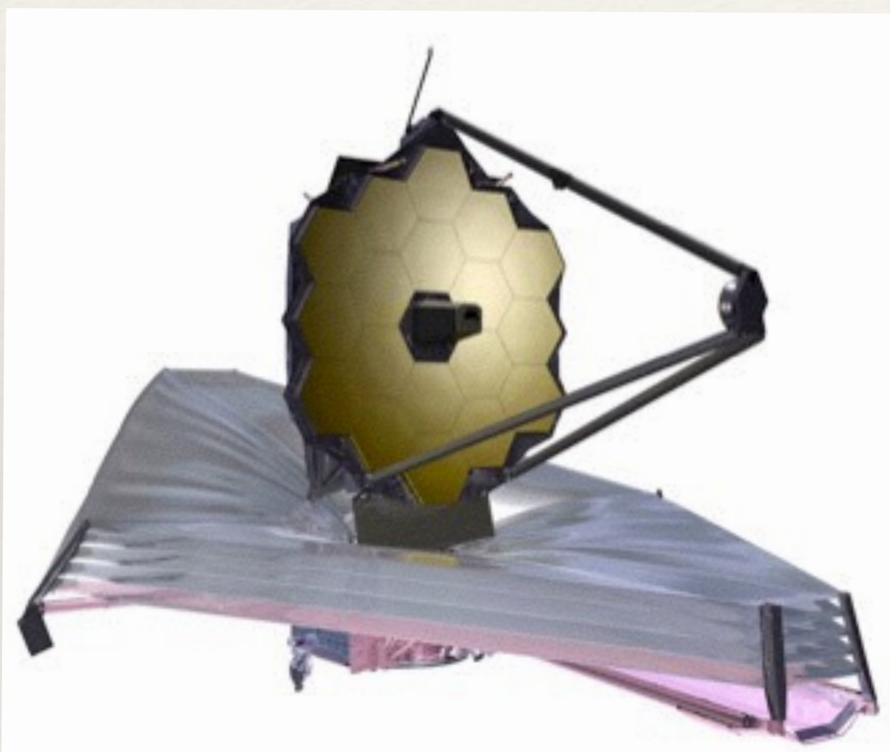
We are waiting for more exciting results

Single aperture planet imagers of the next future

- Ground based 8m telescopes (2013-)
  - Hi-Ciao (Subaru)
  - SPHERE (VLT)
  - GPI (Gemini) (http://gpi.berkeley.edu/)
- JWST (2018-)
  - <5 µm: NIRCAM/TFI (http://ircamera.as.arizona.edu/nircam/)
  - >5 µm: MIRI (http://www.roe.ac.uk/ukatc/consortium/miri/index.html)
- 1.5 m class space coronagraphs (??)
  - PECO: Guyon et al. 2008, SPIE, 7010, 70101Y
  - EPIC: Clampin et al. 2006, SPIE, 6265, 62651B; Lyon et al. 2008, SPIE, 7010, 101045
  - ACCESS: Trauger et al. 2008, SPIE, 7010, 701029
  - SEE-COAST: http://luth7.obspm.fr/SEE-COAST/SEE-COAST.html
- ELT Instruments (>2020-)
  - NIR: EPICS (E-ELT), PFI (TMT), HRCAM (GMT)
  - MIR: METIS (E-ELT: Brandl et al. 2008, SPIE), MIRES (TMT), MIISE (GMT)

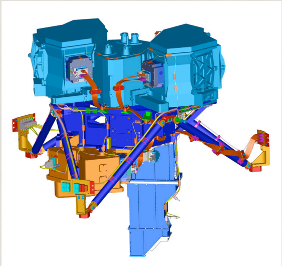
JWST

~~2015~~ --> 2018



NIRCAM

MIRI



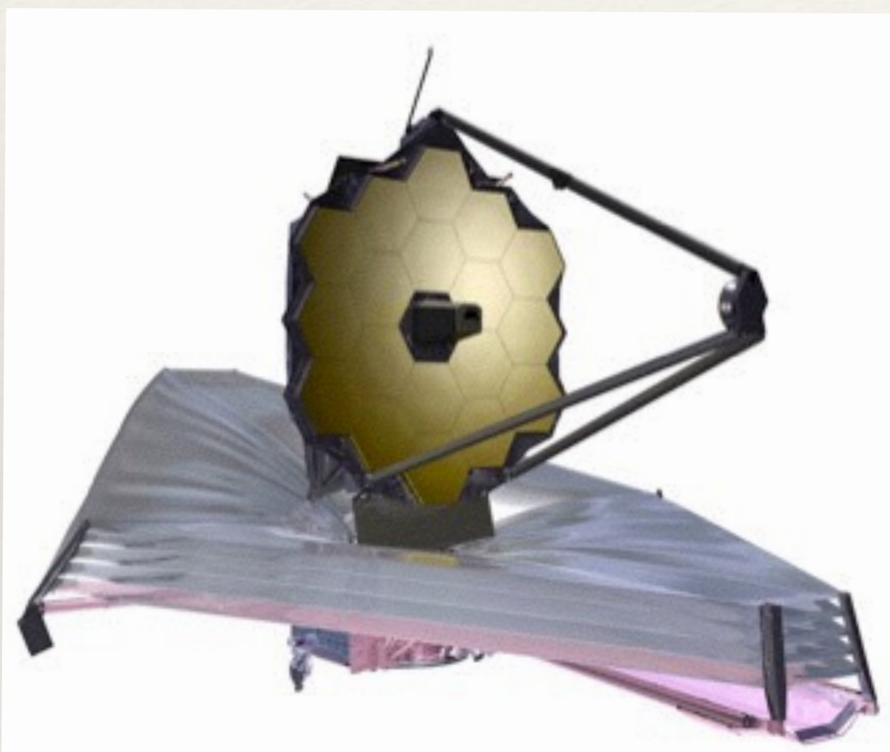
NIRISS

JWST

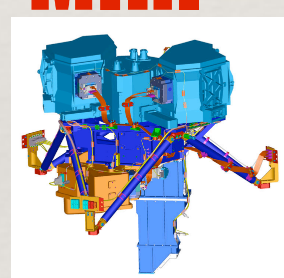
~~2015~~ --> 2018

NIRCAM

US
0.6 - 5 mm
coronographie + spectro transit



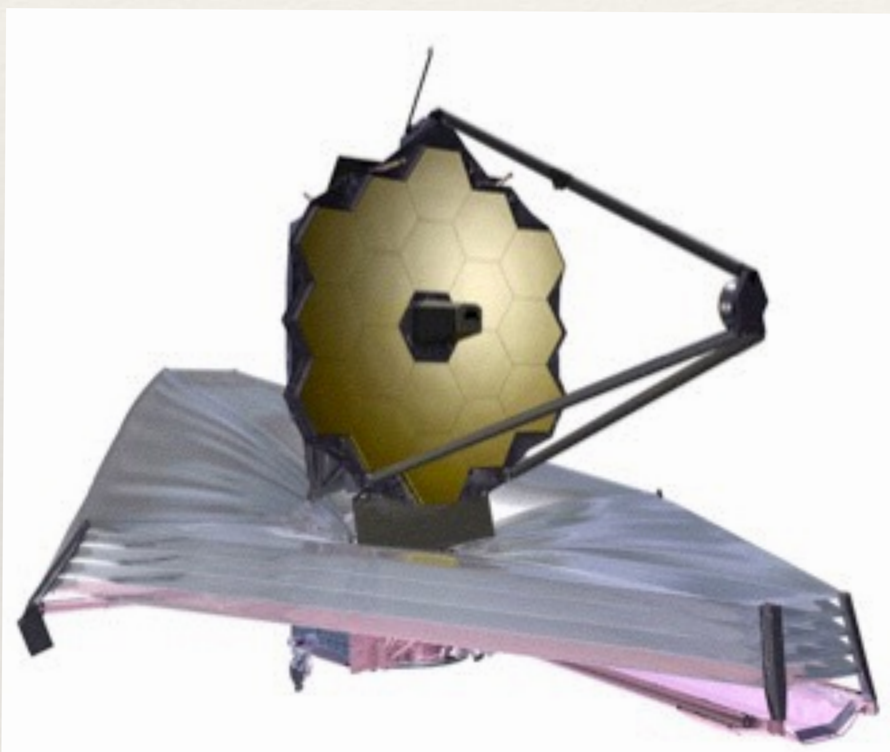
MIRI



NIRISS

JWST

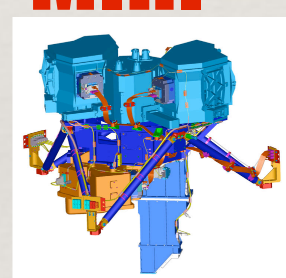
~~2015~~ --> 2018



NIRCAM

US
0.6 - 5 mm
coronographie + spectro transit

MIRI

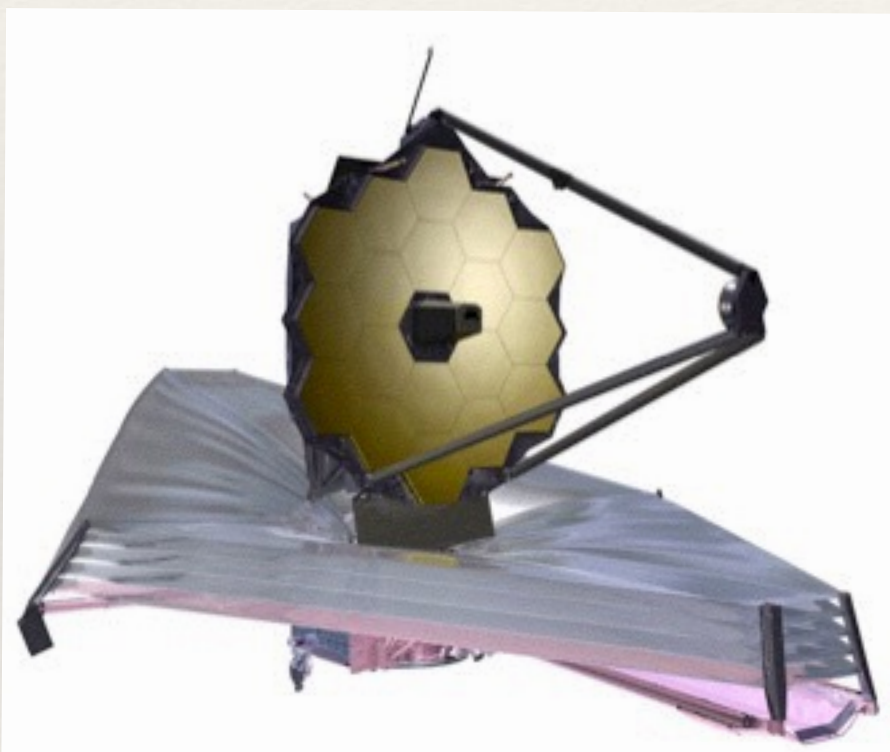


Europe/US
5 - 28 mm
coronographie + spectro transit

NIRISS

JWST

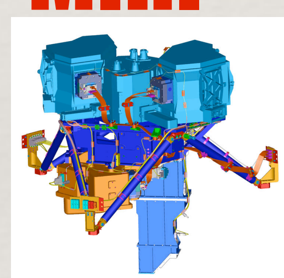
~~2015~~ --> 2018



NIRCAM

US
0.6 - 5 mm
coronographie + spectro transit

MIRI



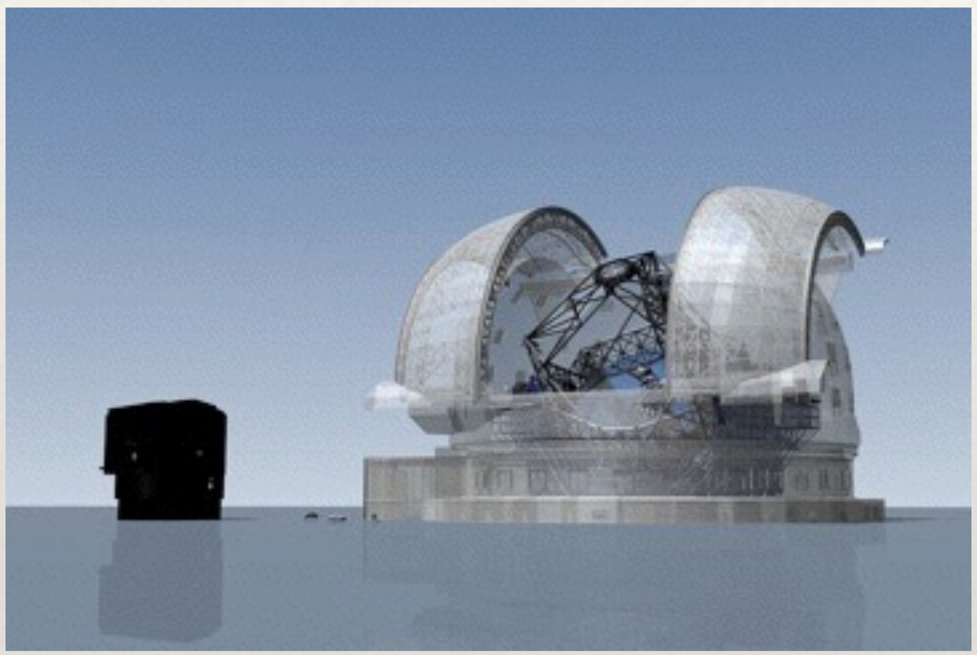
Europe/US
5 - 28 mm
coronographie + spectro transit

NIRISS

Canada
1 - 5 mm
coronographie + spectro transit

> 2020

TOWARDS :
- Earths and Super Earths detection
- Characterization of old Giant and Super Earths

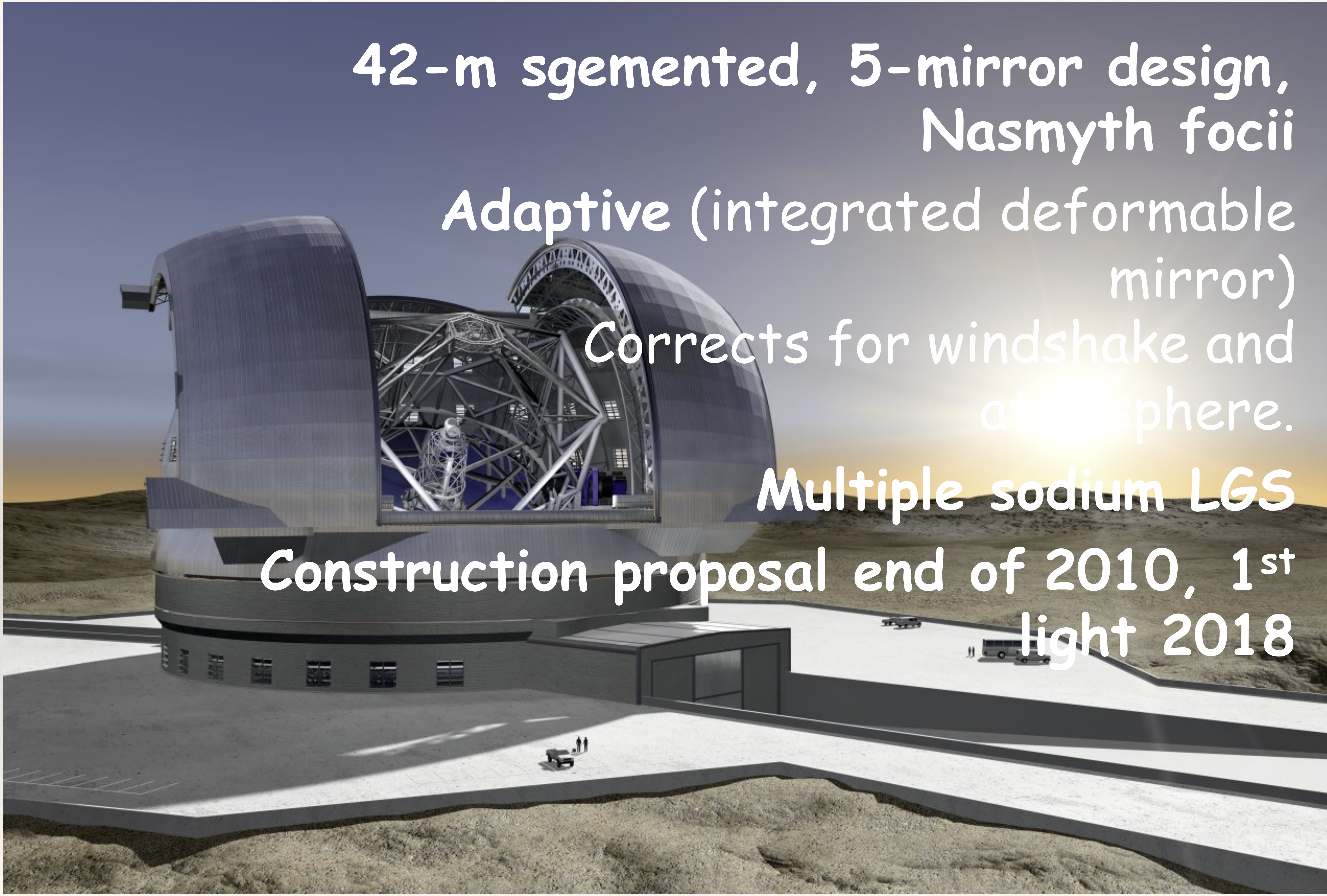


E-ELT
- HARMONI: Integral Field Spectrograph
MICADO: imager NIR
- METIS: imager/spectrograph MIR
- CODEX: High Resolution Visible spectrograph
- EPICS: High contrast Imager

3 Projects :

- **TMT** (Thirty Meter Telescope, US), 30m - Hawaii
- **GMT** (Giant Magellan Telescope, US), 25m - Chili
- **E-ELT** (European Extremely Large Telescope), 42m - Chili

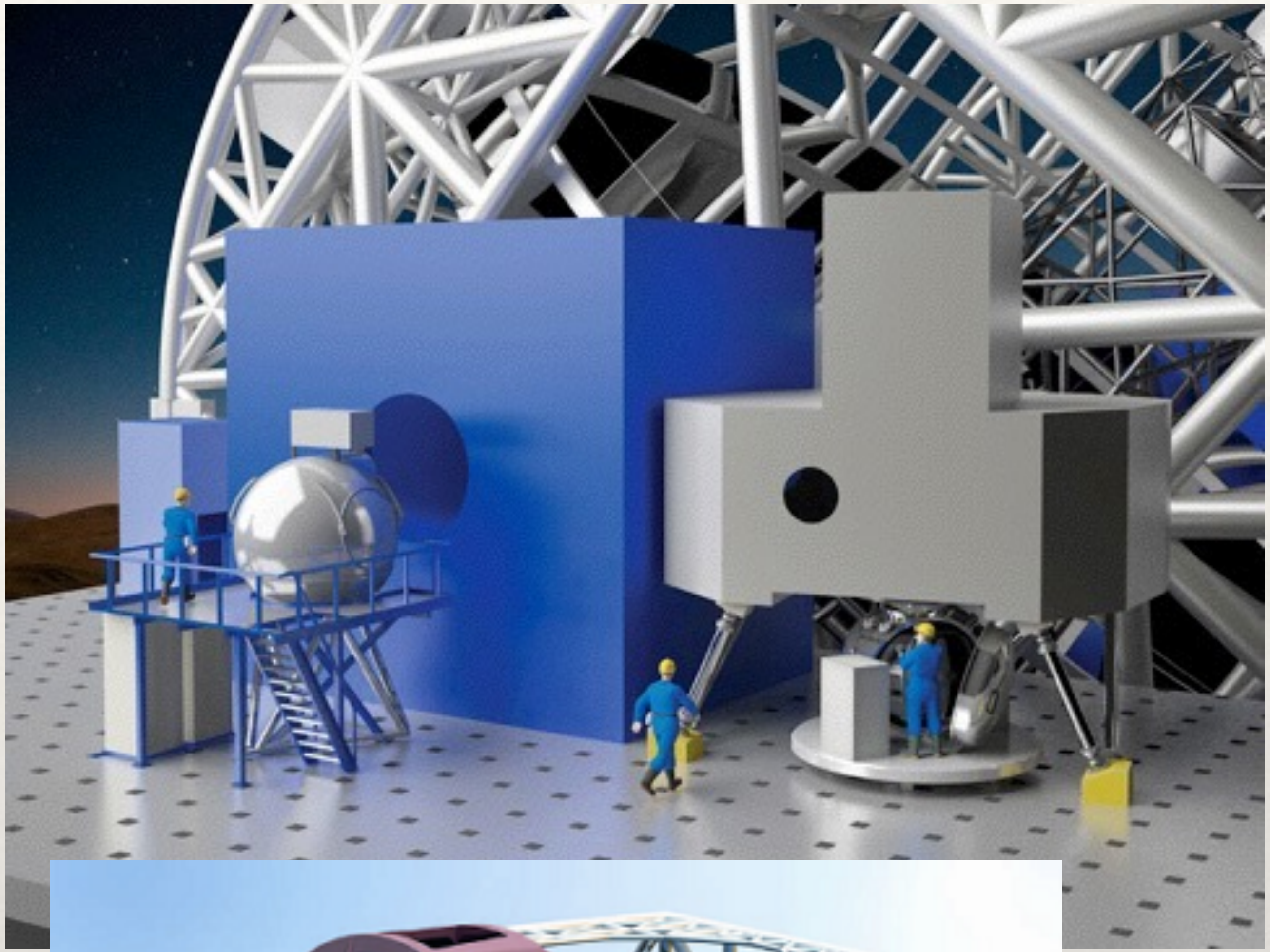
TMT
- HROS: High Resolution Visible spectrograph
- NIRES: Echelle Spectrograph NIR
- PFI: High contrast Imager

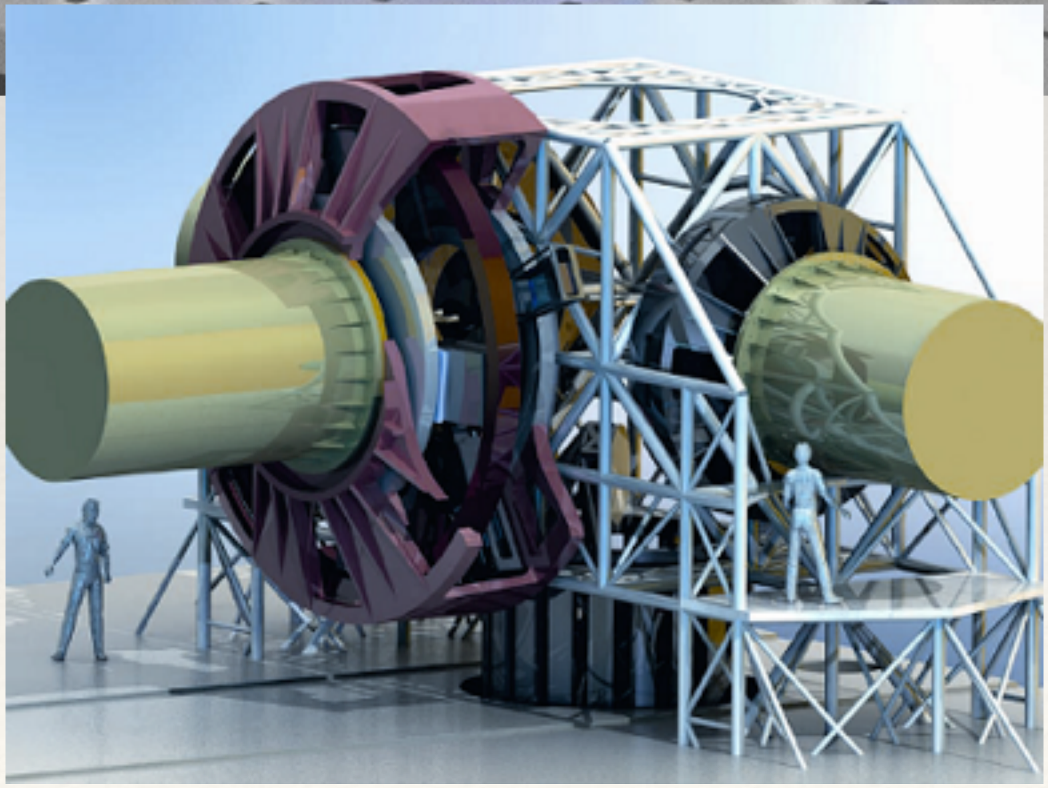

42-m sgemented, 5-mirror design, Nasmyth focii
Adaptive (integrated deformable mirror)
Corrects for windshake and atmosphere.
Multiple sodium LGS
Construction proposal end of 2010, 1st light 2018


140 M
120 M
100 M
80 M
60 M
40 M
20 M
Credits: Markus Kasper

E-ELT Instrumentation

- 2 First Light Instrumentation (2022) :
  - NIR Camera
  - NIR IFS
- MIR camera and spectrograph (METIS)
- multi objects Spectrograph / High Resolution spectrograph
- (EPCS) Exoplanets

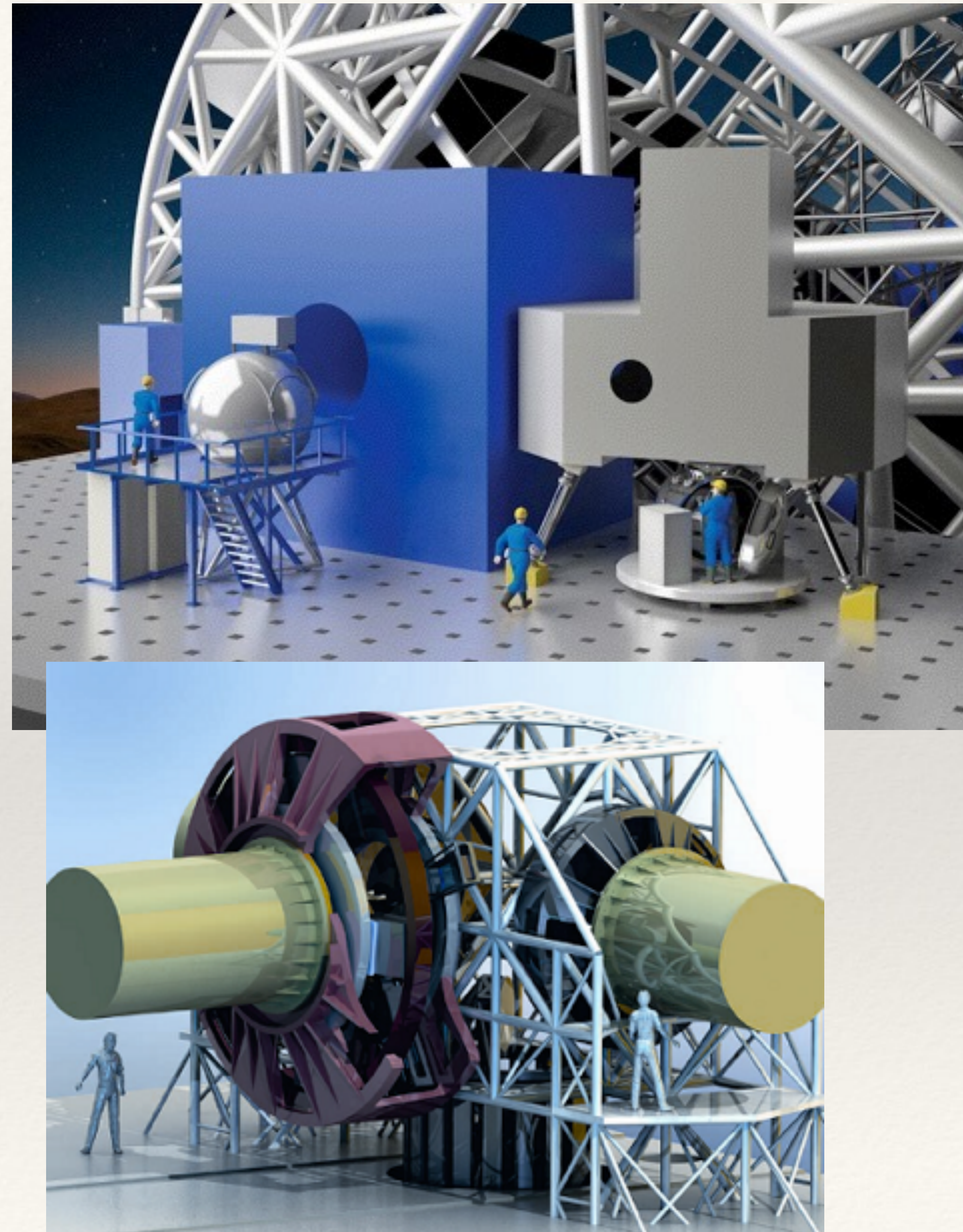




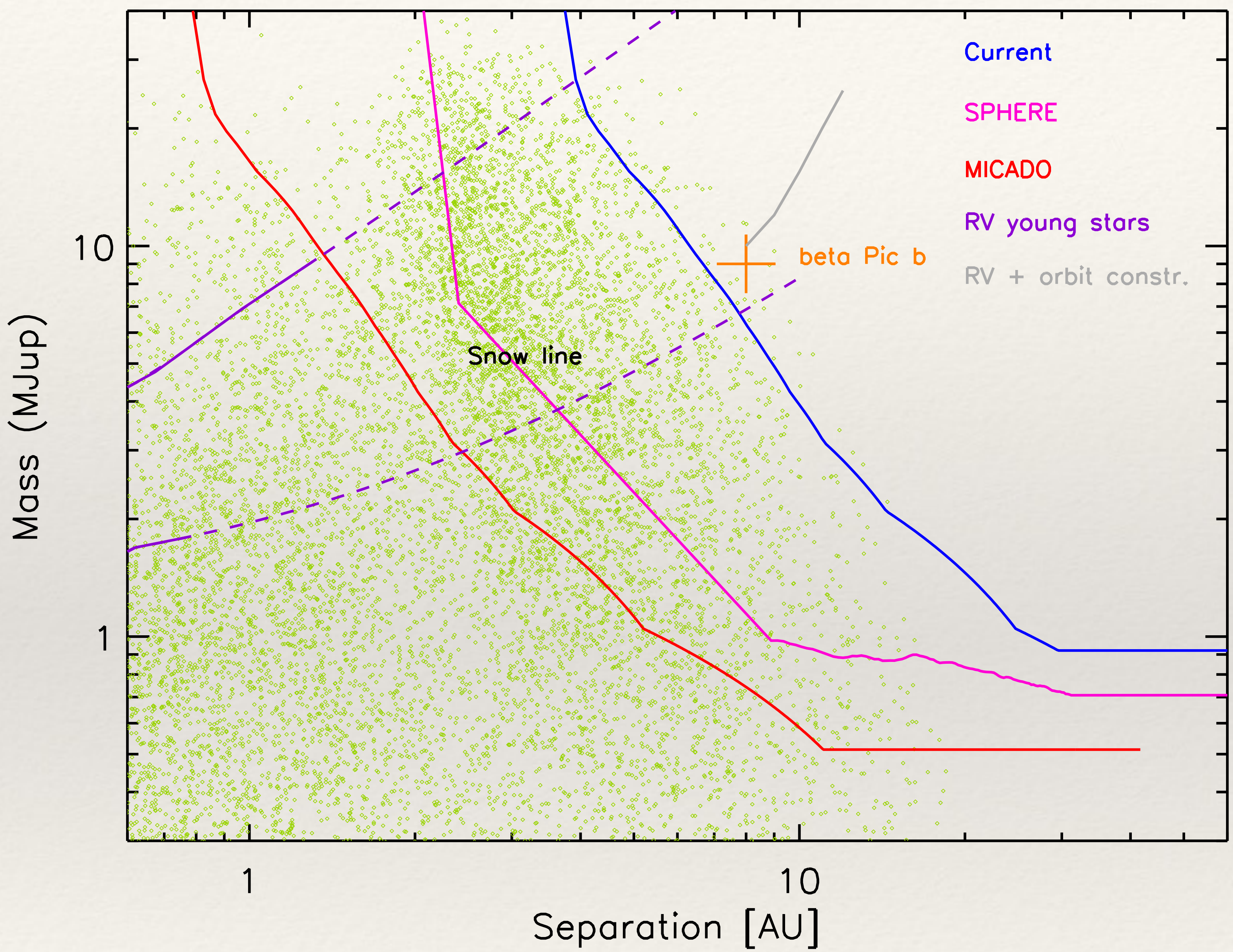
E-ELT Instrumentation

- 2 First Light Instrumentation (2022) :
  - NIR Camera
  - NIR IFS
- MIR camera and spectrograph (METIS)
- multi objects Spectrograph / High Resolution spectrograph
- (EPCS) Exoplanets

Most of the instruments will be equipped with :
- Adaptive Optics
- Laser stars



MICADO/HARMONY



Angular Resolution @ 2μm
= 10 mas

MICADO:

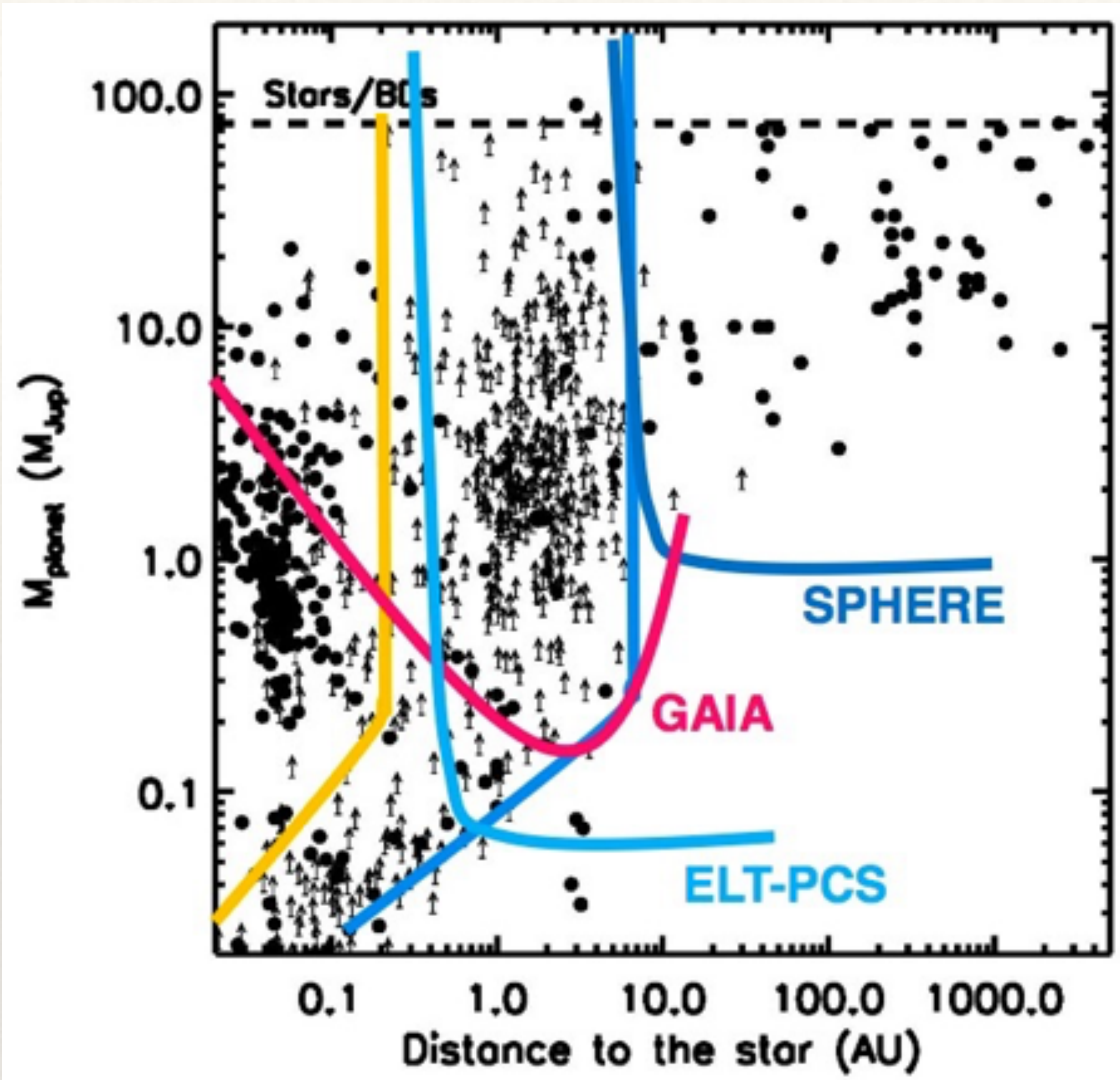
imager => survey

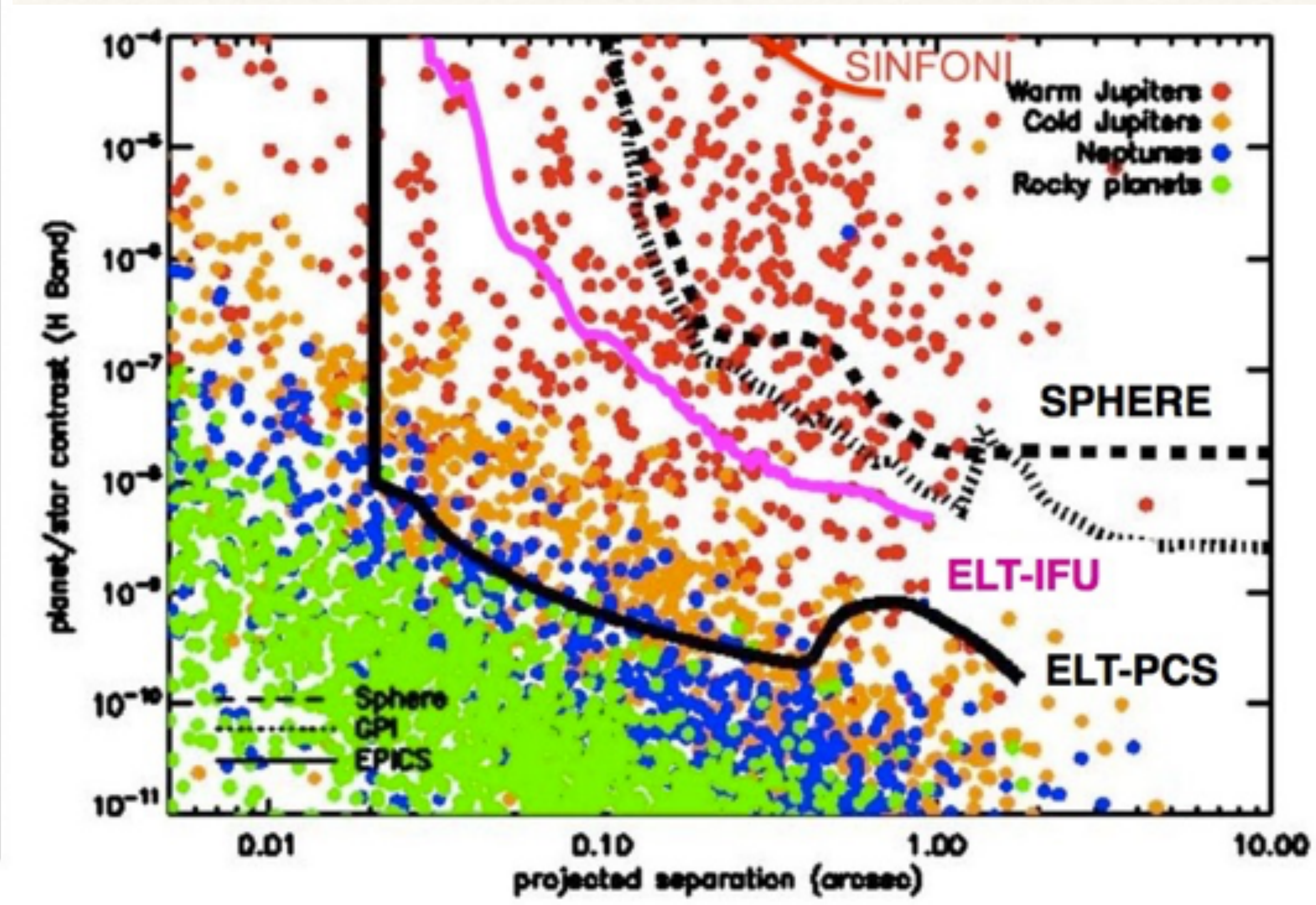
HARMONI:

- faint Fields
- High Resolution
=> Characterization of object discovered by SPHERE / GPI

beta Pic - 10 Myr - 20 pc

EPICS/ PCS

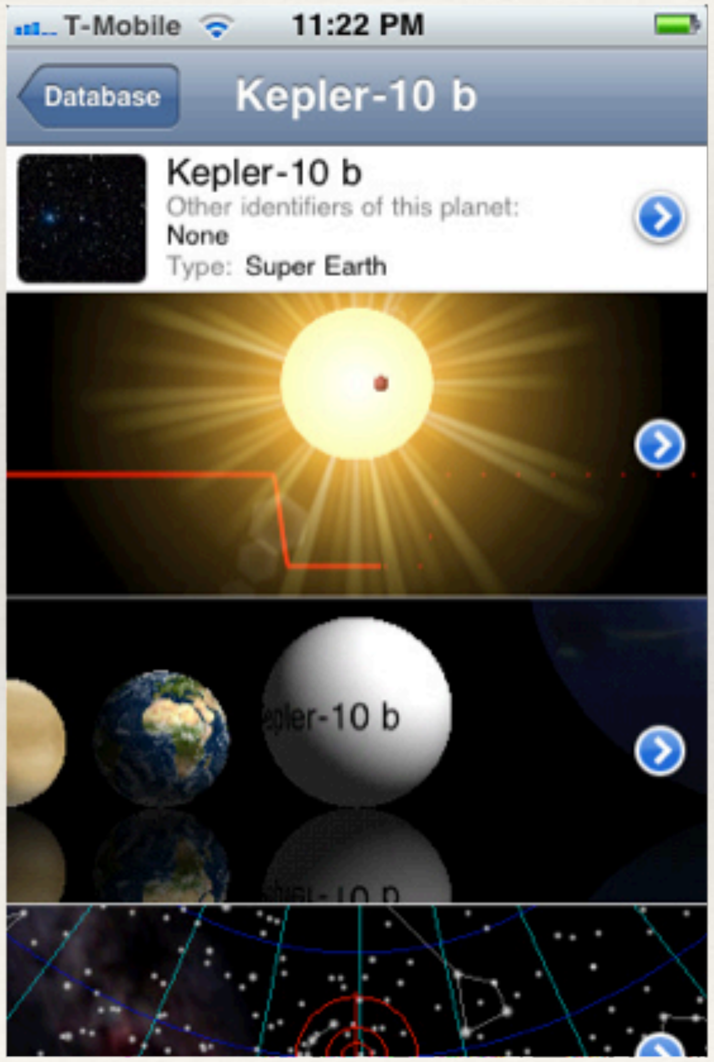




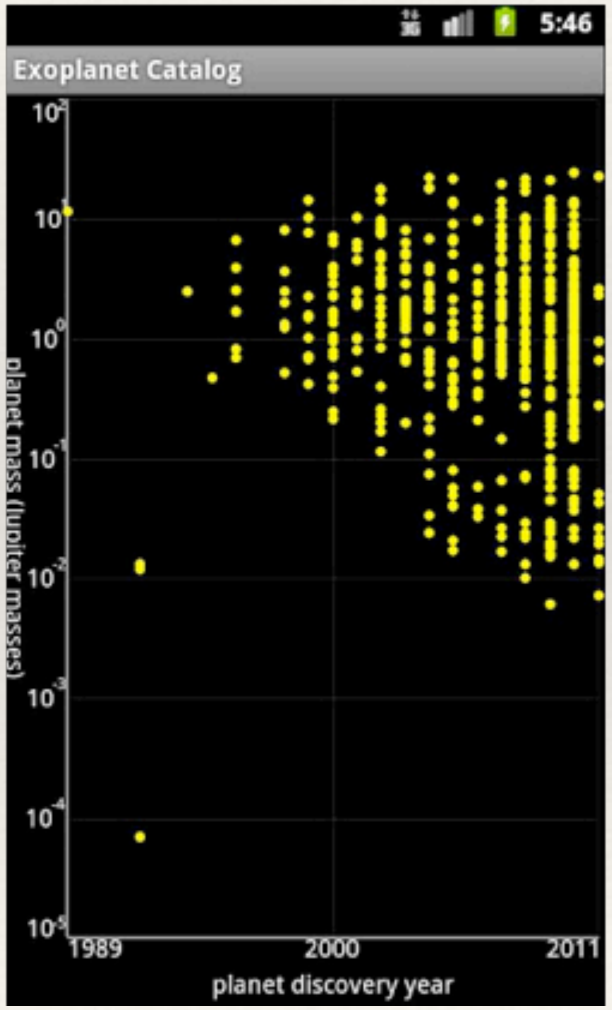
Brightness ratio at distance: [mas]	30	100	300	Limiting stellar Magnitude I band:
Science Case 1	10^{-6}	10^{-6}	10^{-6}	**9 (goal: 10)**
Science Case 2		**$2\ 10^{-9}$ (goal 10^{-9})**	**10^{-9} (goal 4 10^{-10})**	7 (goal: 8)
Science Case 3	**10^{-8}**	**10^{-9}**	10^{-8}	7 (goal: 8)
Science Case 4	$2\ 10^{-9}$ (goal 10^{-9})	10^{-9} (goal 4 10^{-10})	5 10^{-10} (goal 2 10^{-10})	5 (goal: 6)

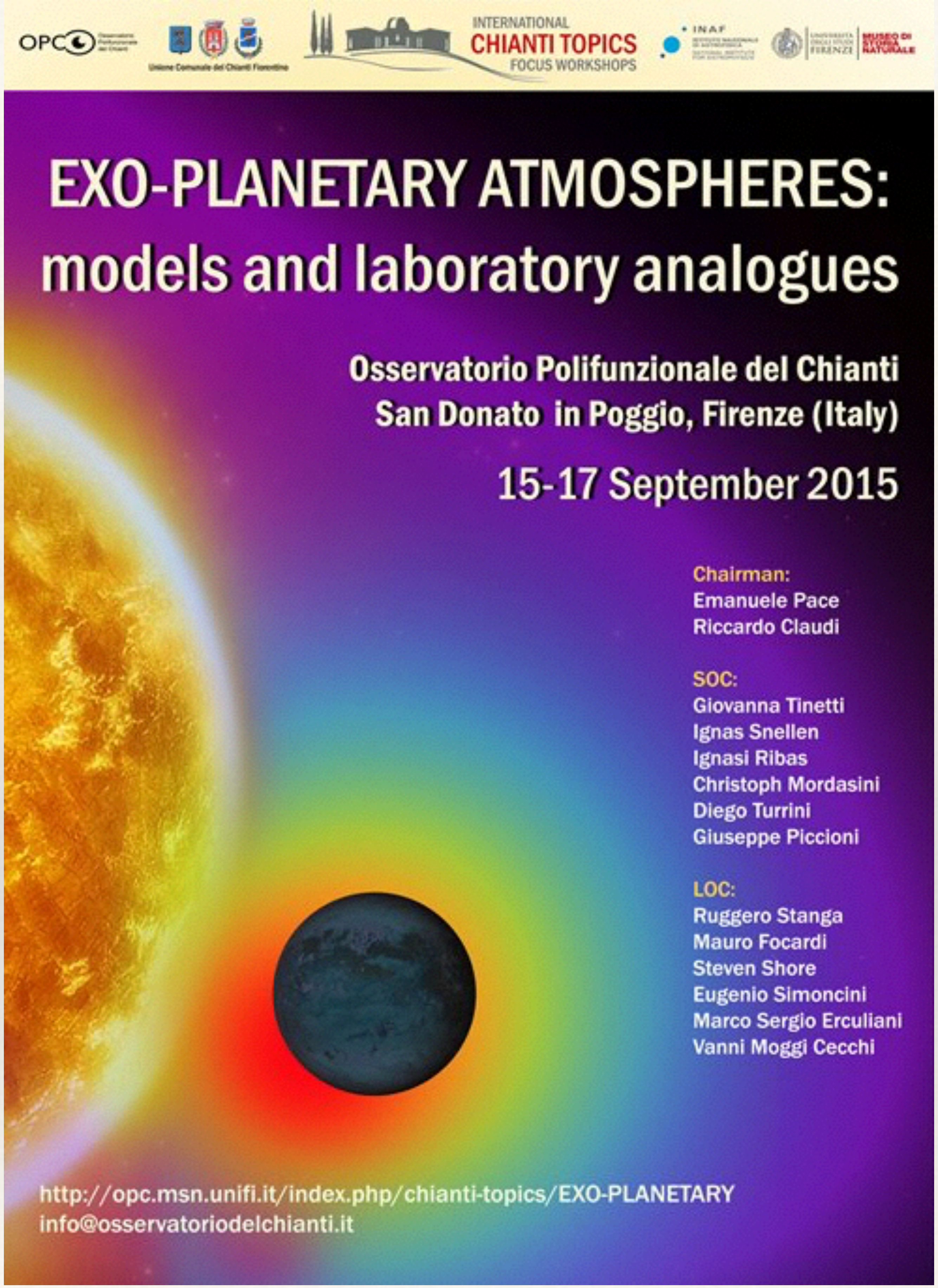
Stay Tuned ...

Exoplanet
(Hanno Rein)



Exoplanet Catalog
(Eric Gumtow)




INTERNATIONAL
CHIANTI TOPICS
FOCUS WORKSHOPS
EXO-PLANETARY ATMOSPHERES:
models and laboratory analogues
Osservatorio Polifunzionale del Chianti
San Donato in Poggio, Firenze (Italy)
15-17 September 2015
Chairman:
Emanuele Pace
Riccardo Claudi
SOC:
Giovanna Tinetti
Ignas Snellen
Ignasi Ribas
Christoph Mordasini
Diego Turrini
Giuseppe Piccioni
LOC:
Ruggero Stanga
Mauro Focardi
Steven Shore
Eugenio Simoncini
Marco Sergio Erculiani
Vanni Moggi Cecchi
http://opc.msn.unifi.it/index.php/chianti-topics/EXO-PLANETARY
info@osservatoriodelchianti.it