GO science with the WFIRST CGI

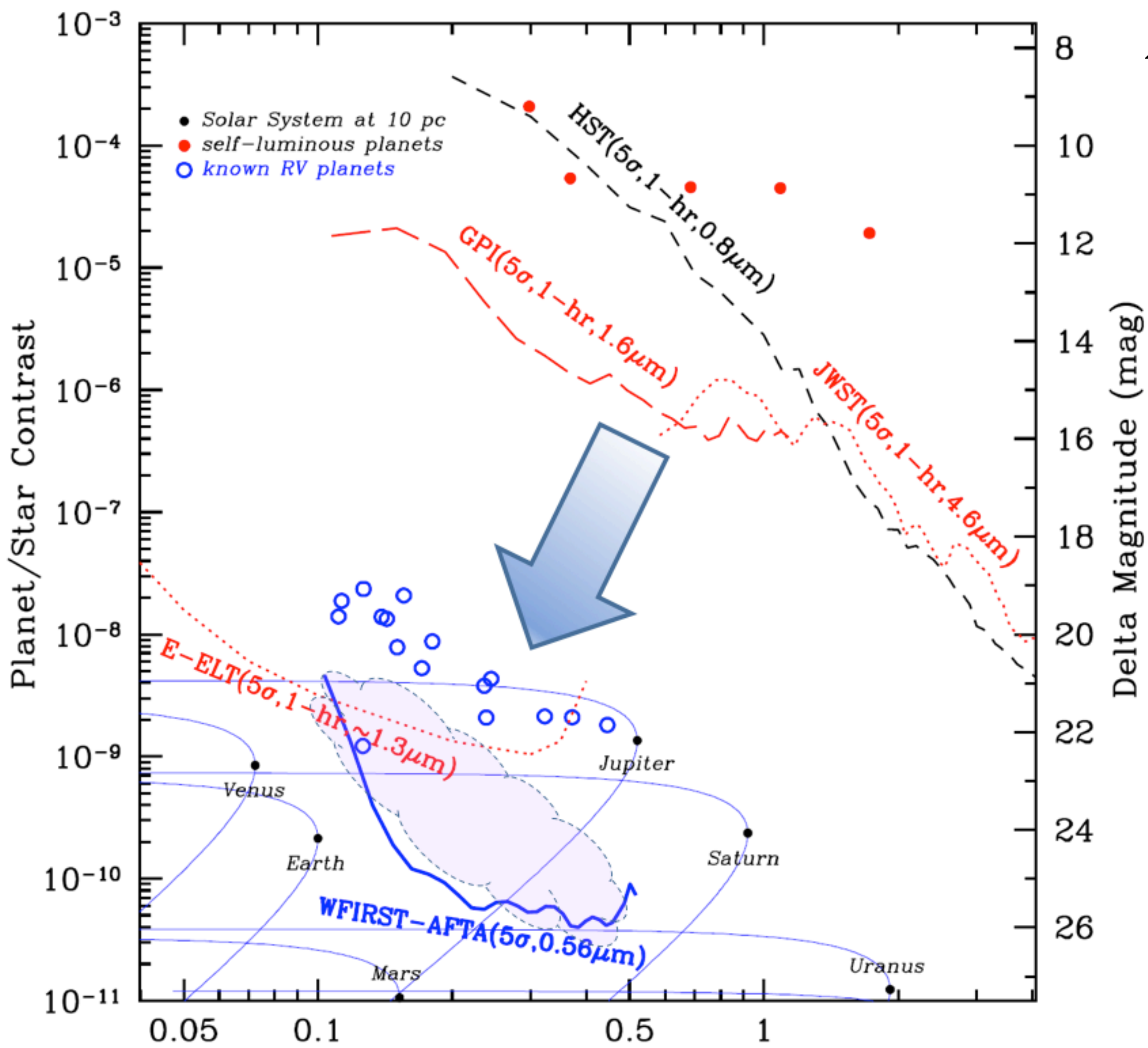
Laurent Pueyo (STScI)

Community Astrophysics with WFIRST:

Guest Observer and Archival Science.

March 1 st 2016

Parameter space for WFIRST CGI GO science



Compelling science in the uncharted yet unchallenging real estate:

- Science that does not drive the mission requirements.
- Territory only partially covered by ELT circa 2025.
- Synergies with other facilities. Science building upon recent results.

Uncharted yet unchallenging does not mean boring.

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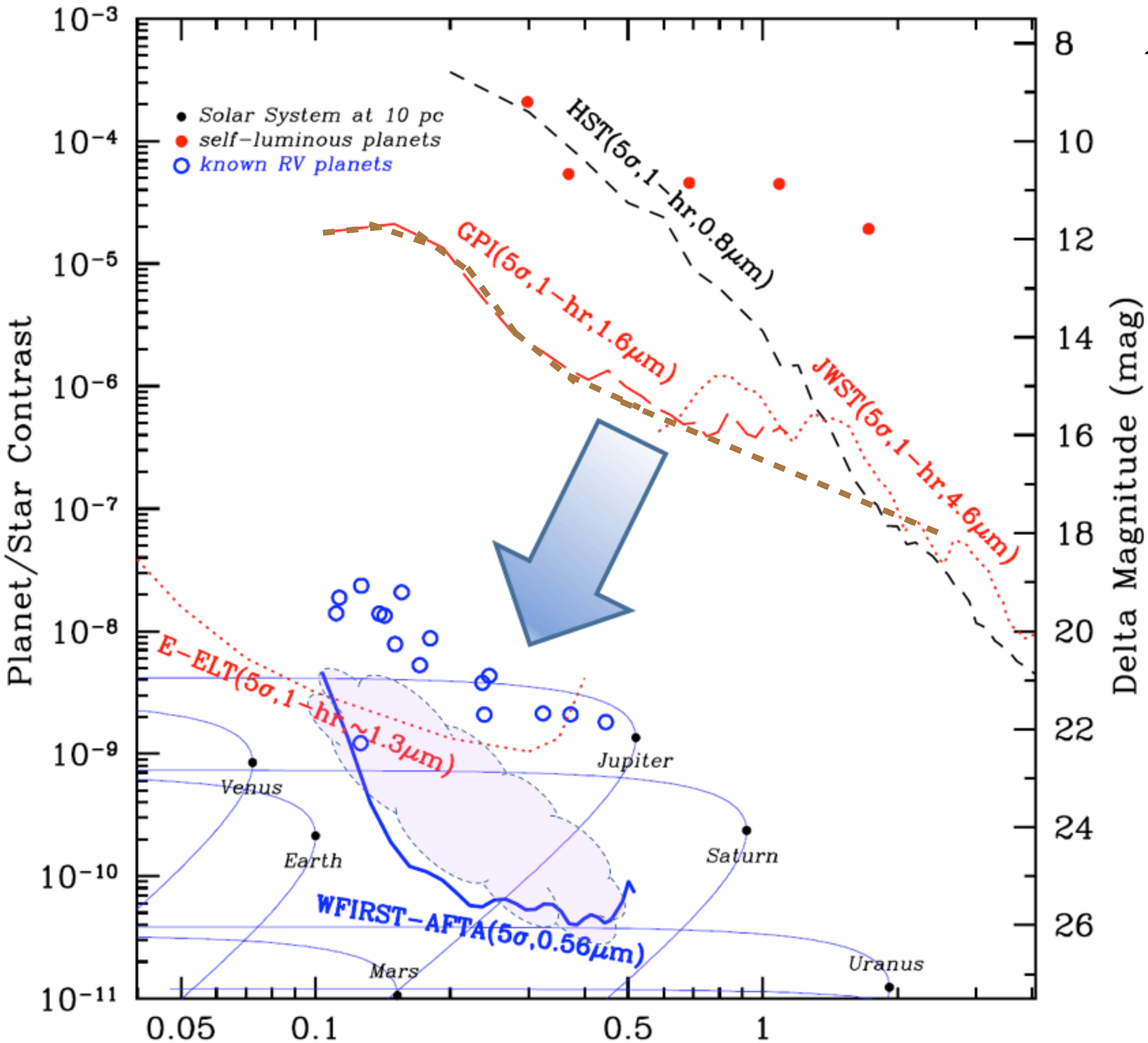

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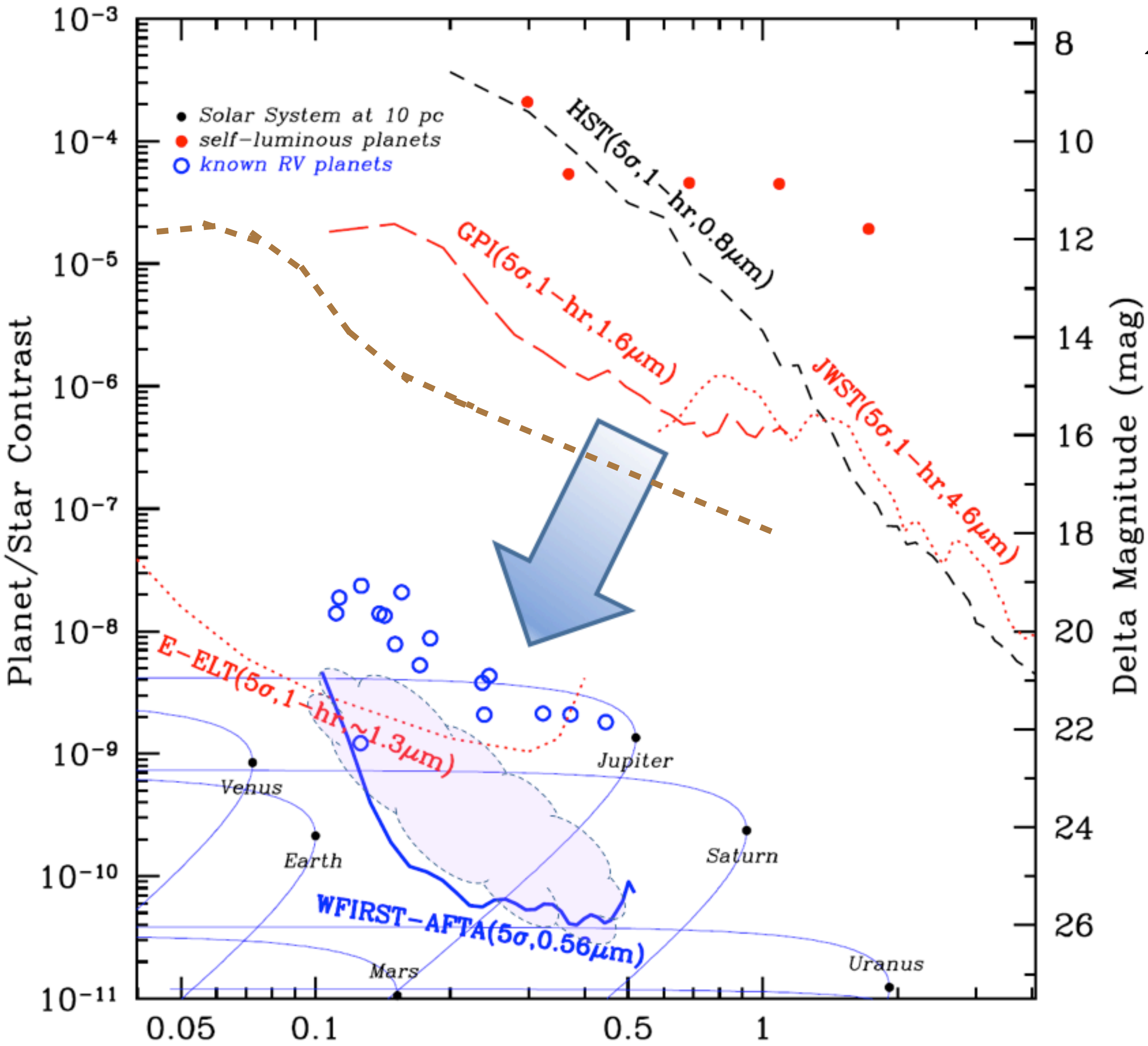

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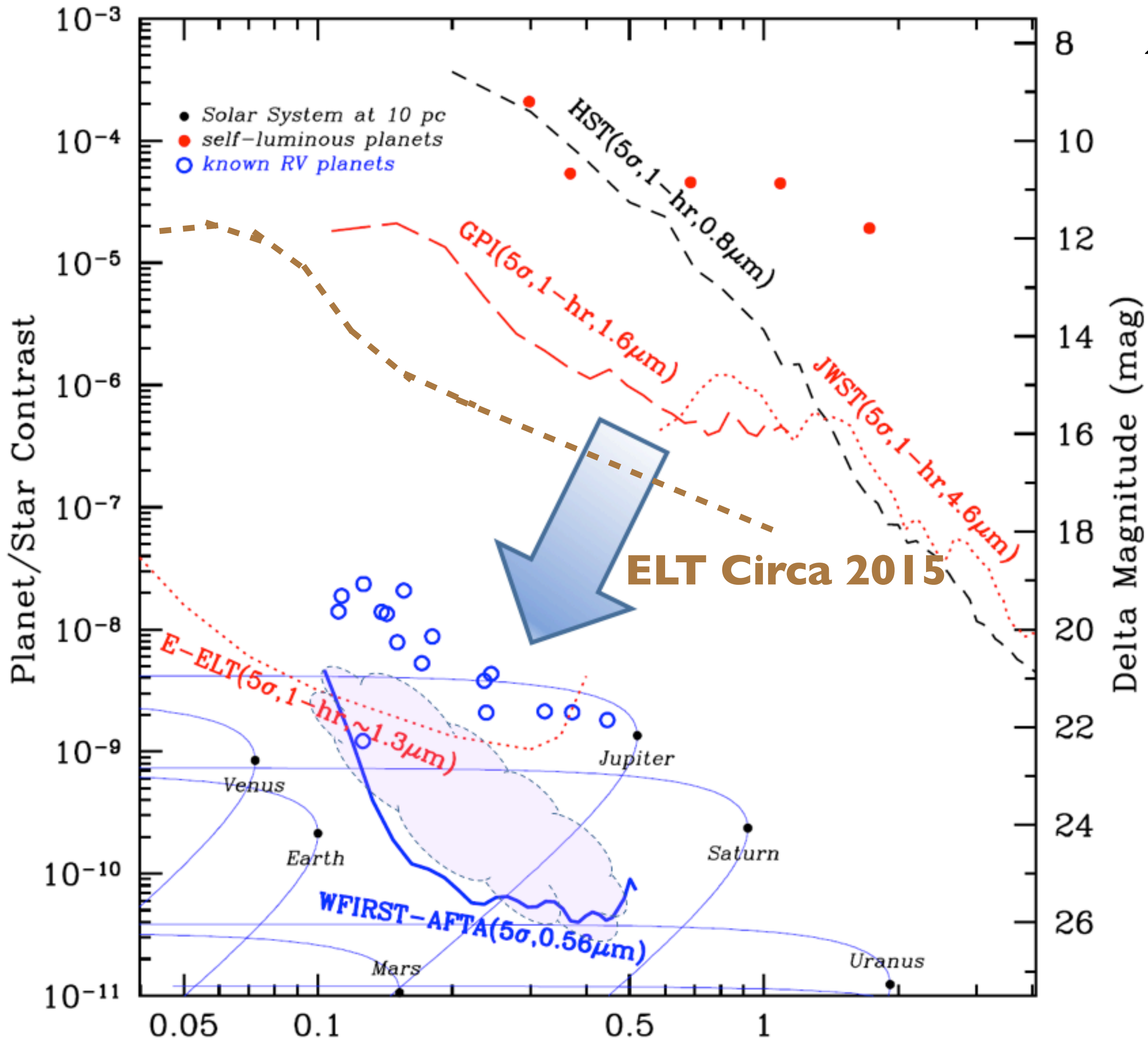

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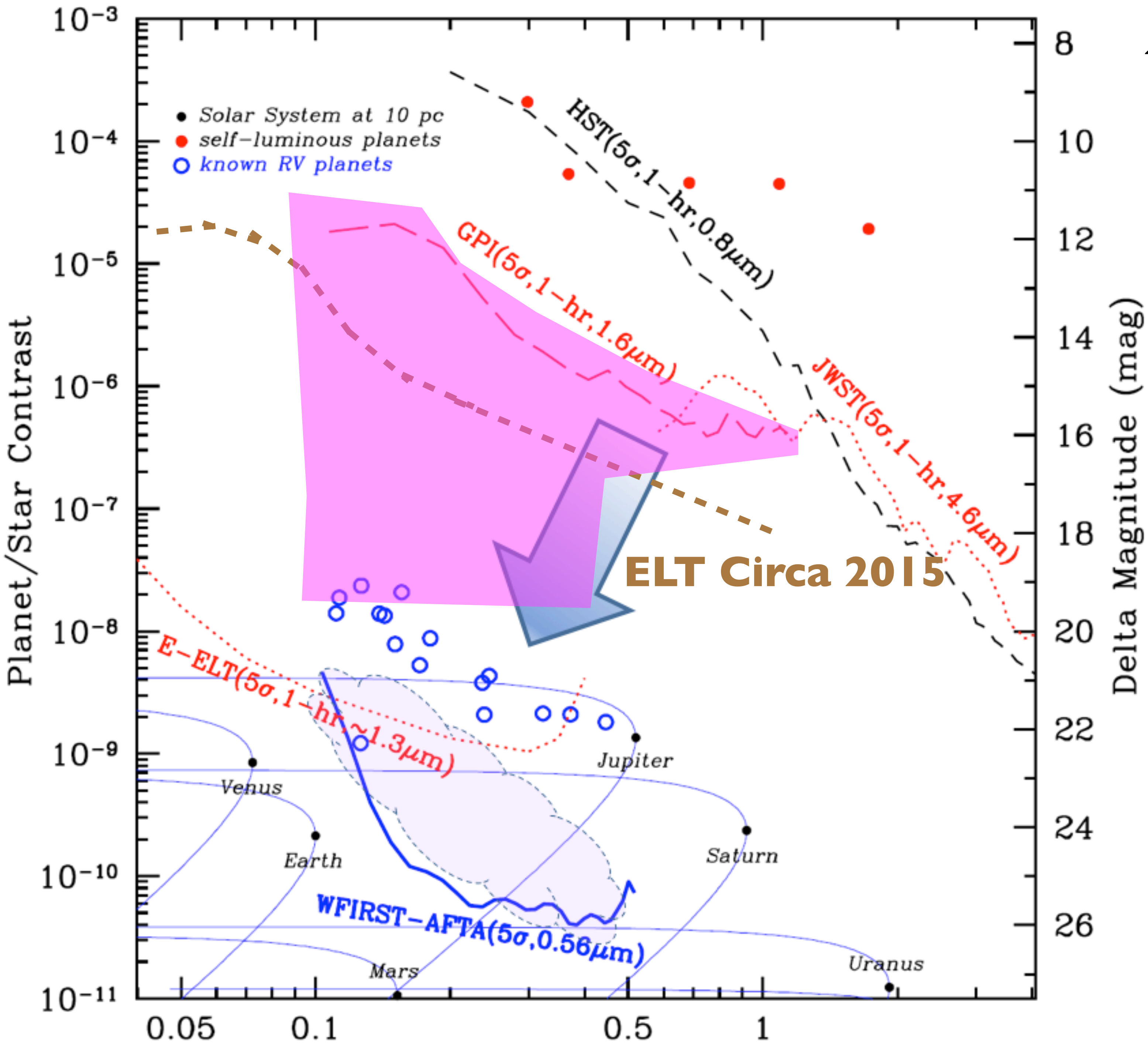

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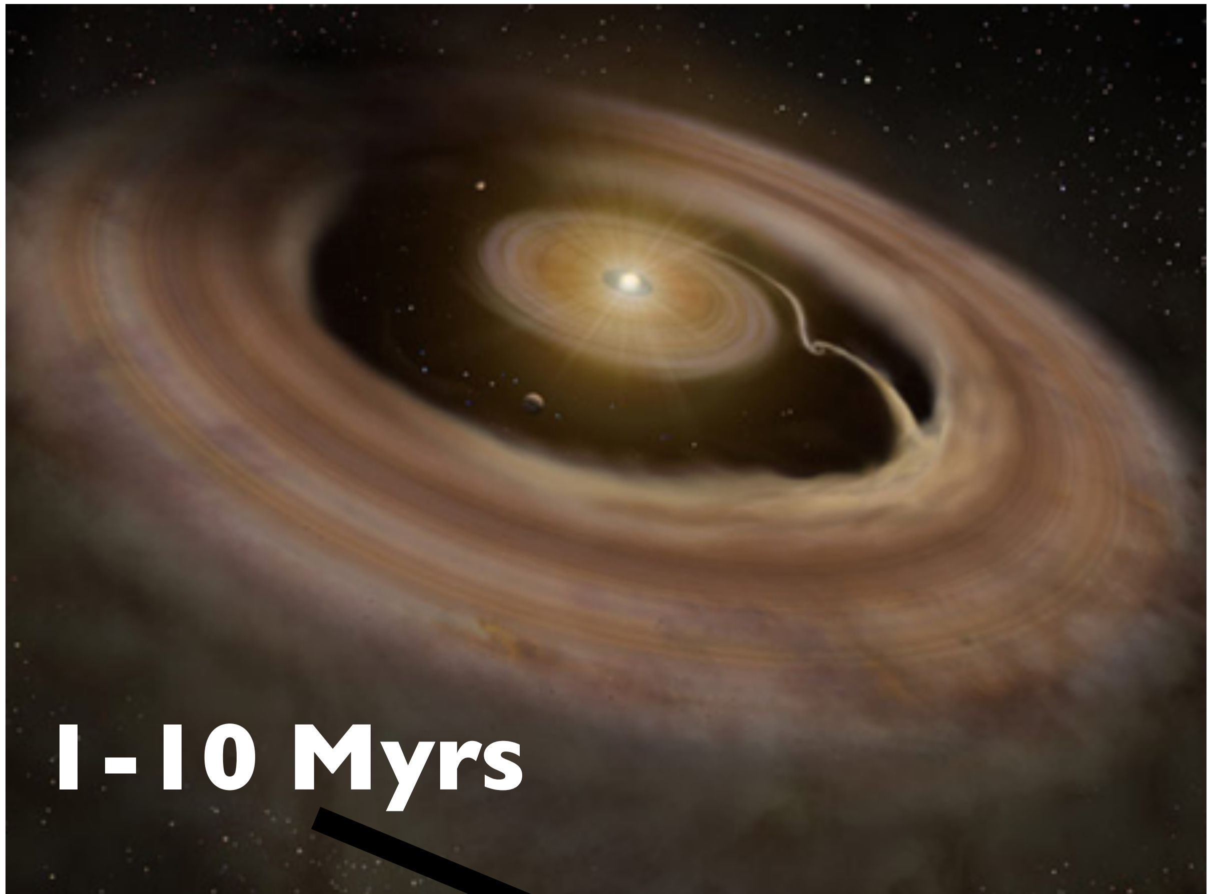

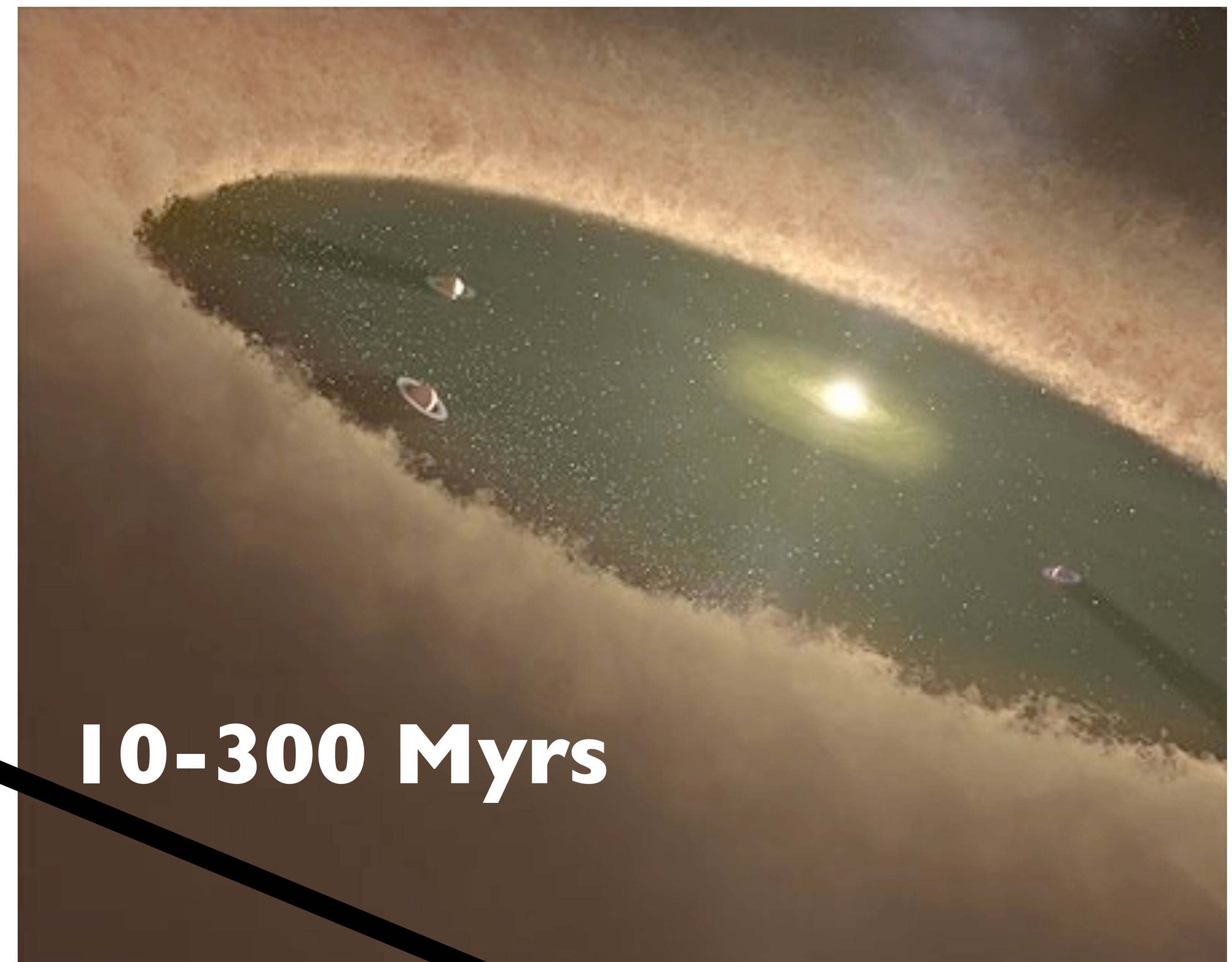

5 Gyrs

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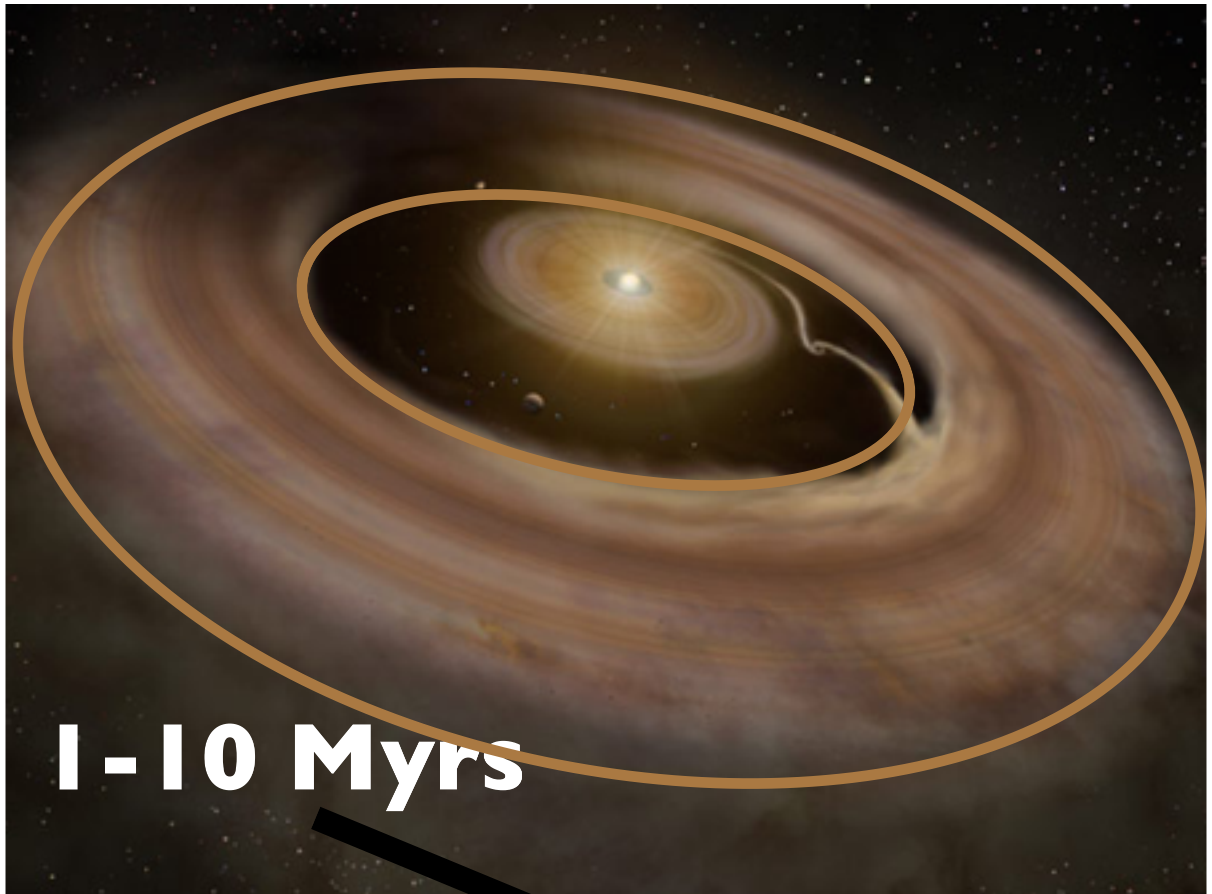
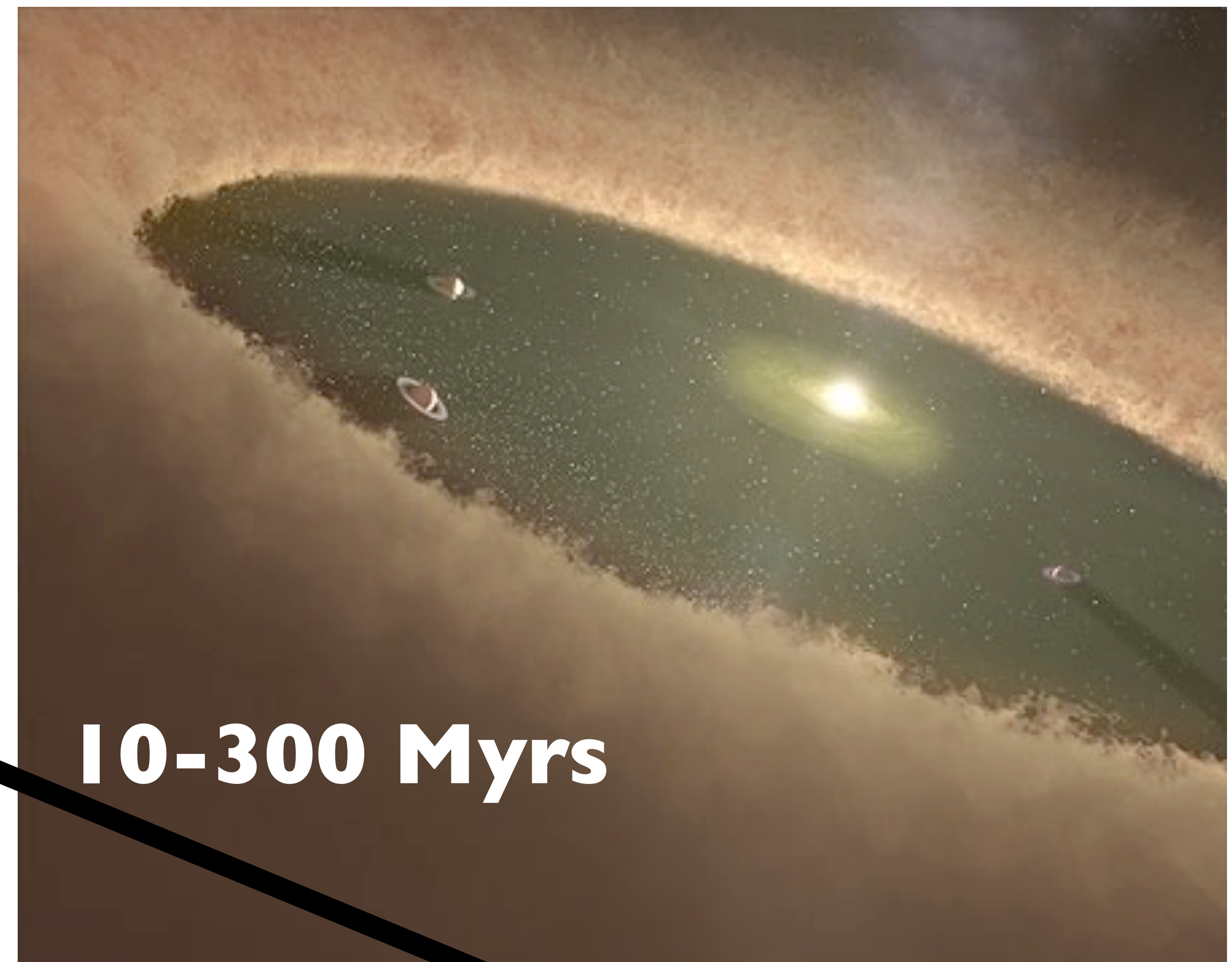


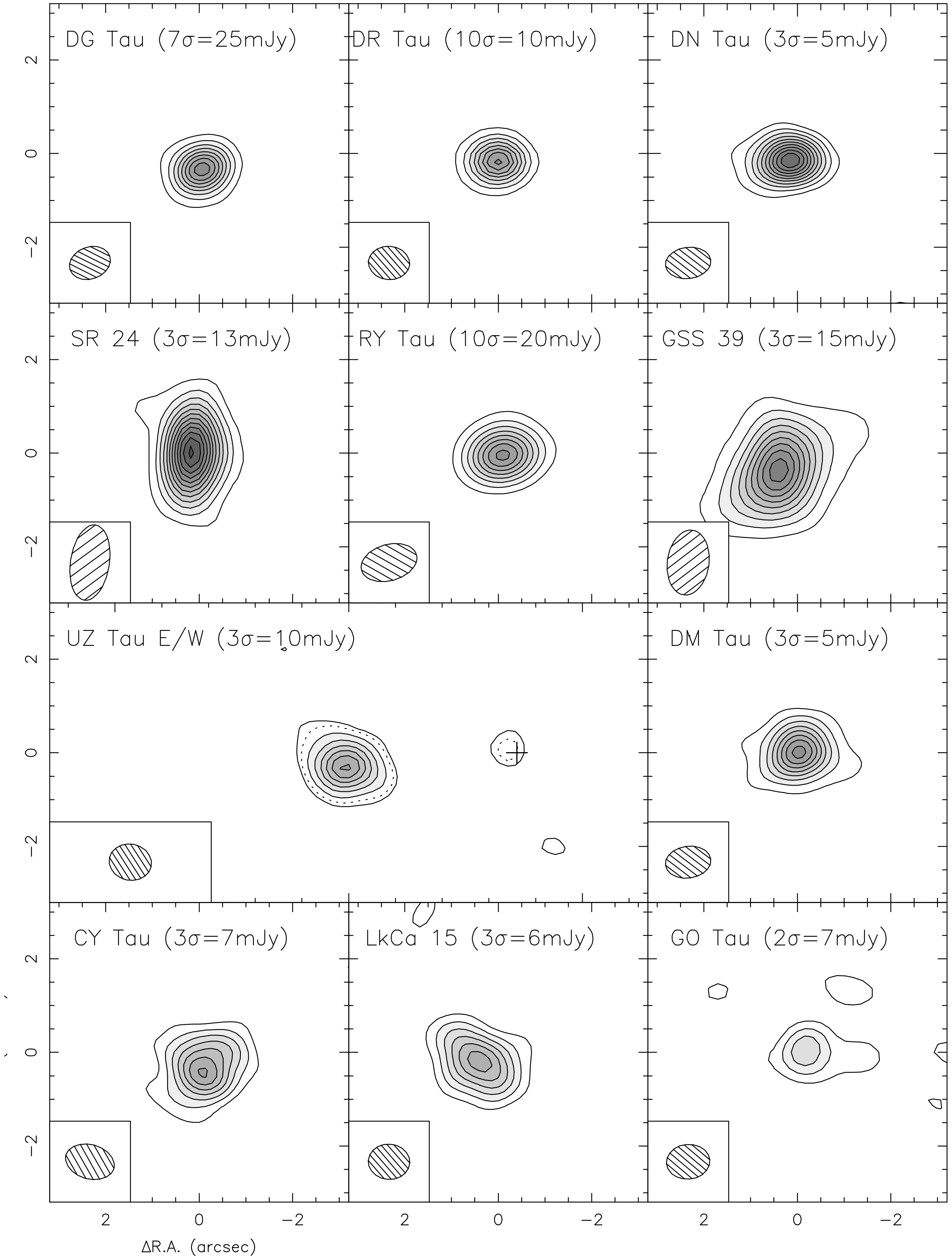


1. Proto-planetary disks
and their interaction with exoplanets

5 Gyrs

Proto-planetary disks: a mm portrait gallery.

Isella et al. (2009)



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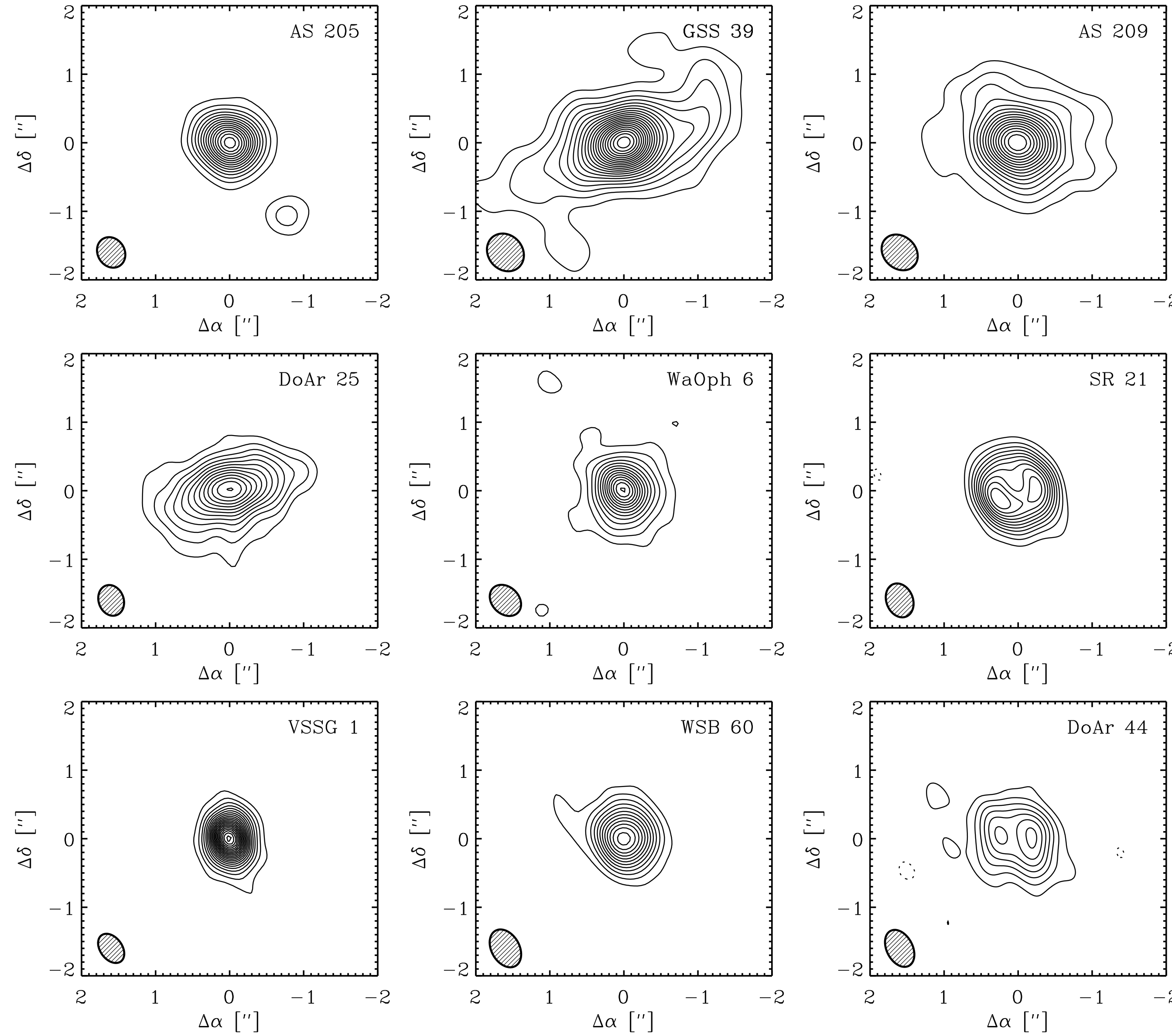

Tracing the location of the mm dust and molecular gas with mm observations. ALMA

Proto-planetary disks: a mm portrait gallery.

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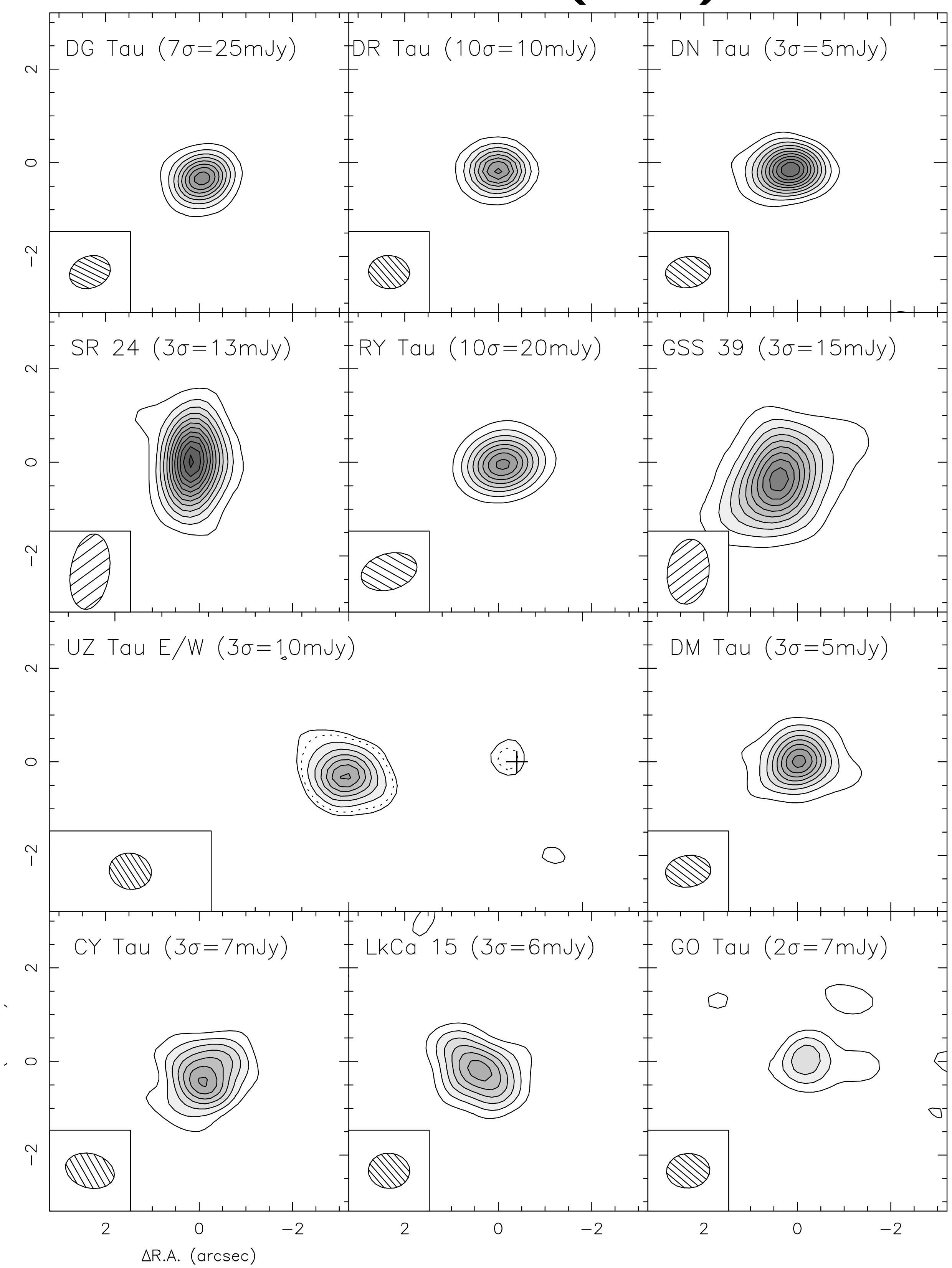

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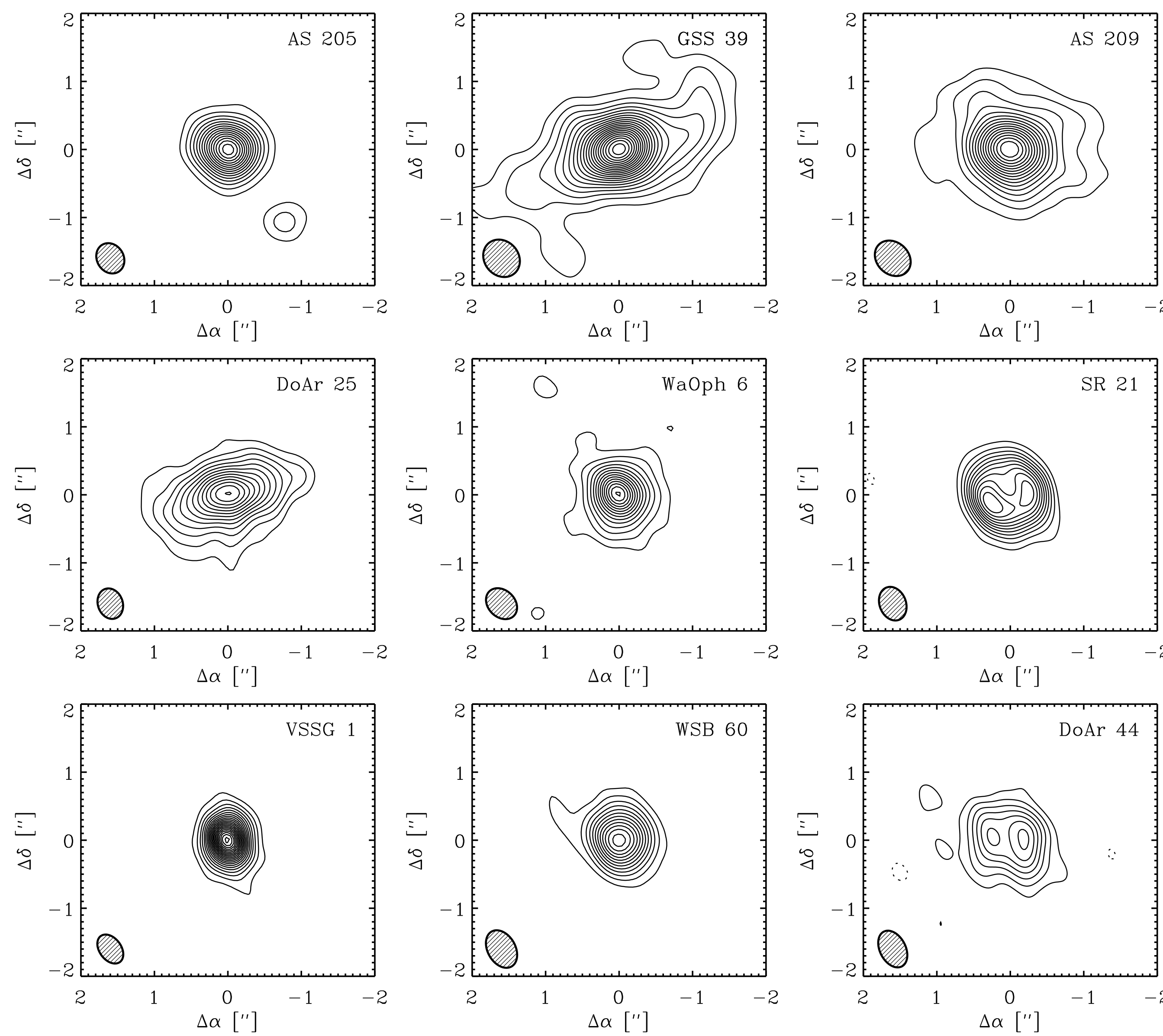

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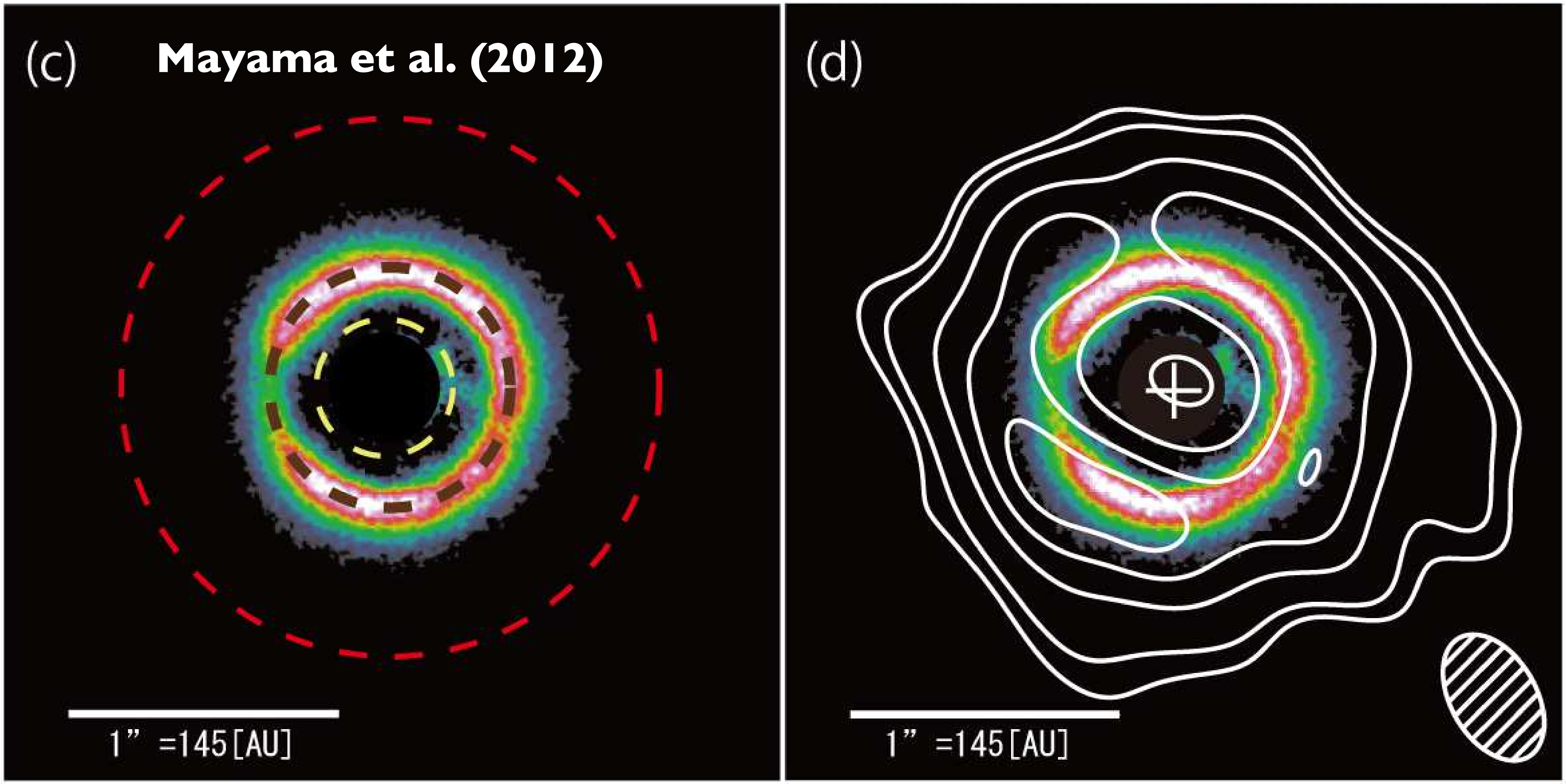
ALMA+scattered light imaging complementarity



- gap in mm dust does not correspond to gap in micron dust.
- apparent motion of the dip in the disk.

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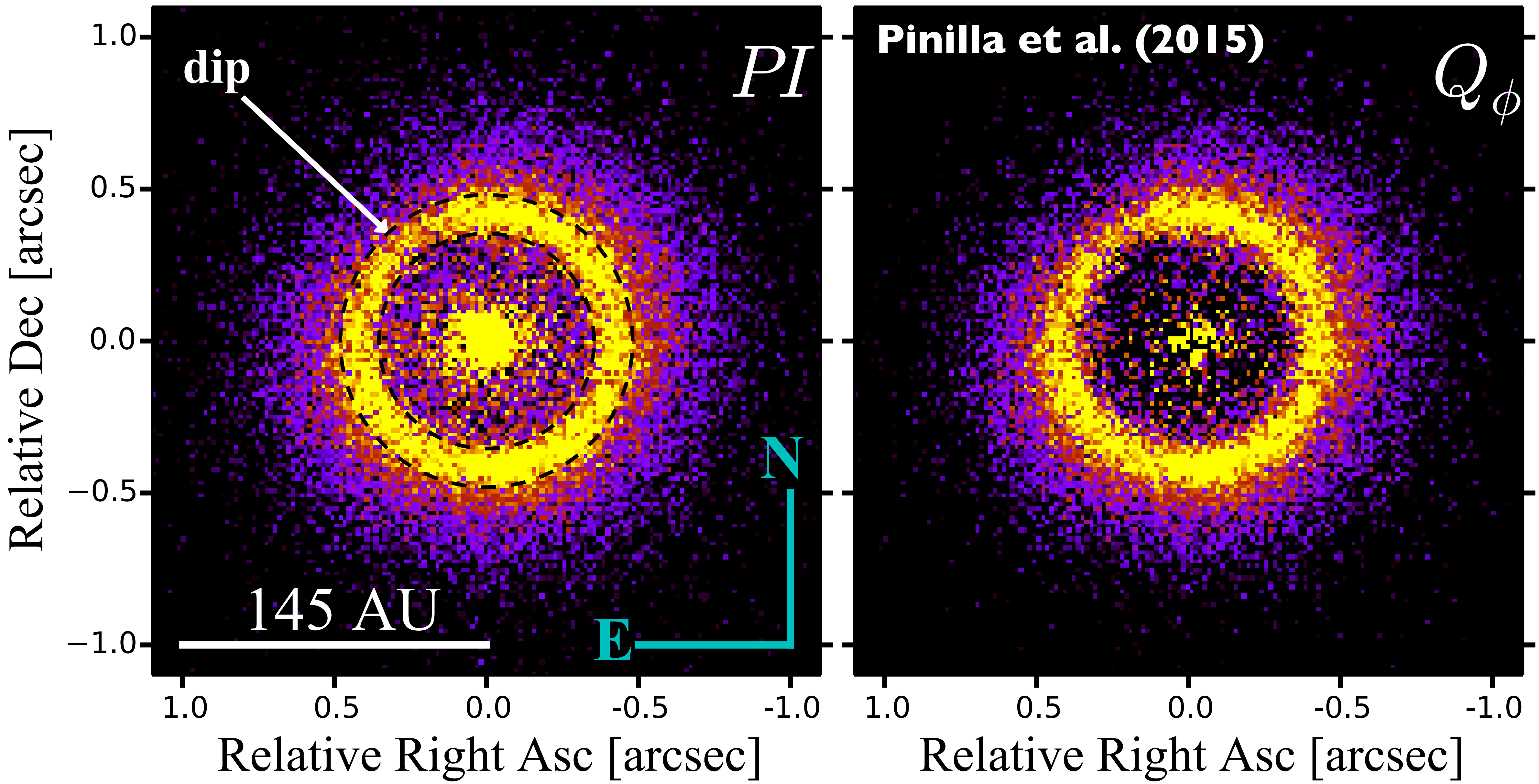

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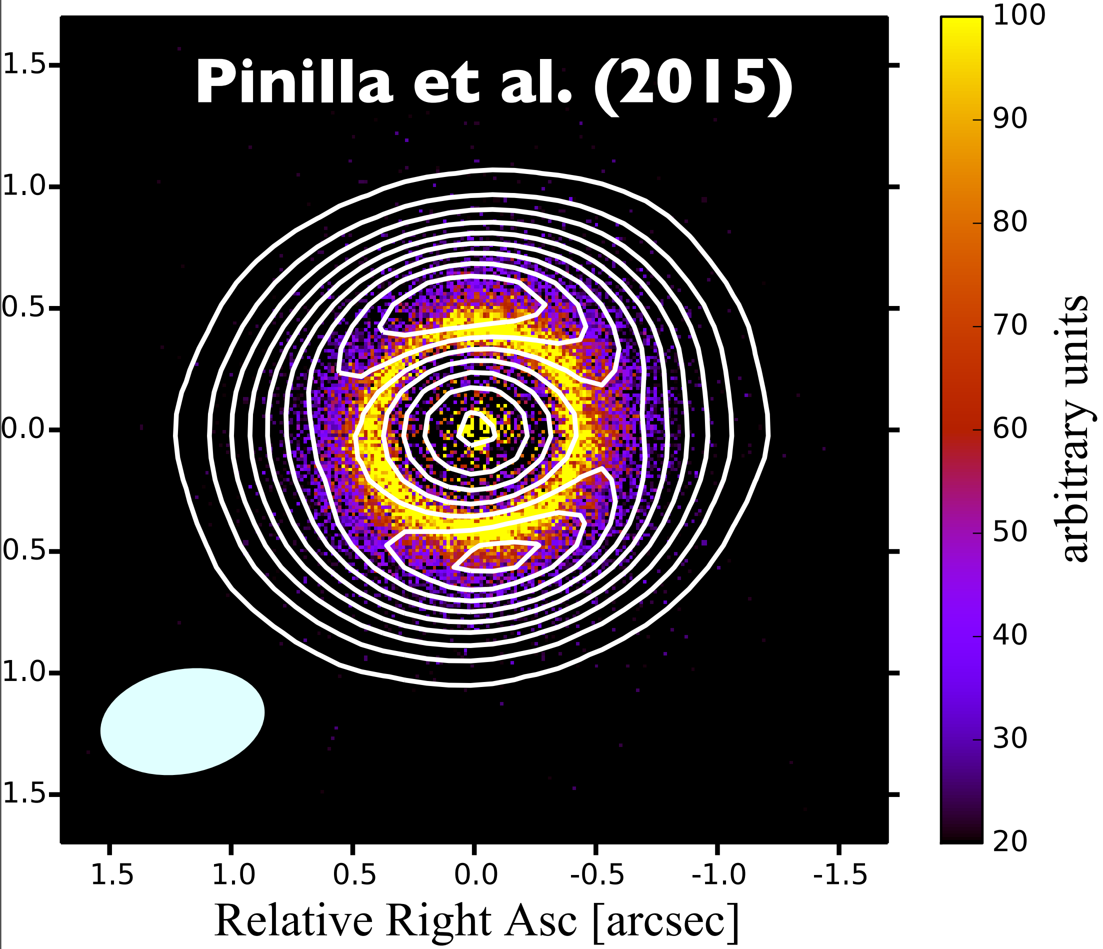

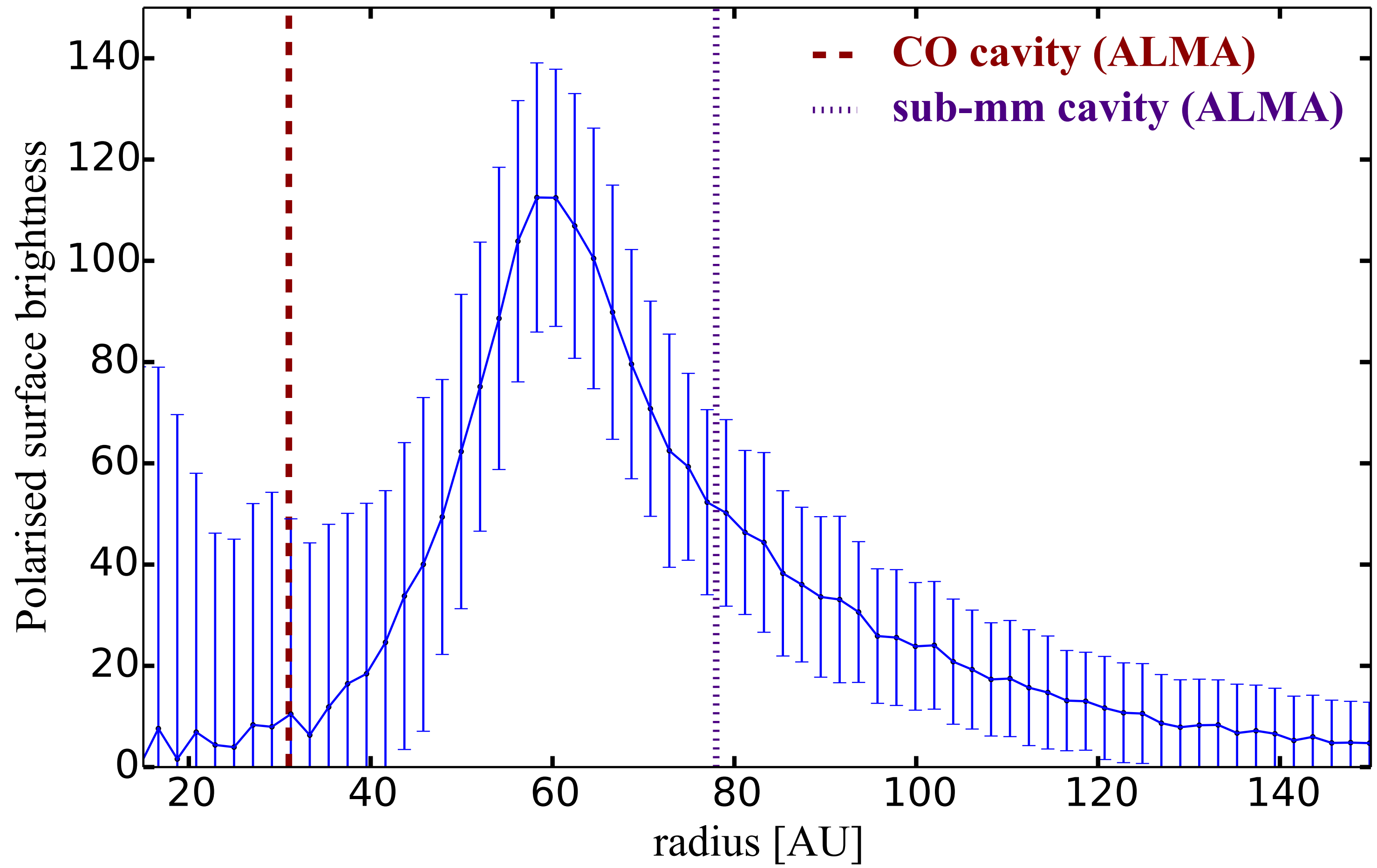

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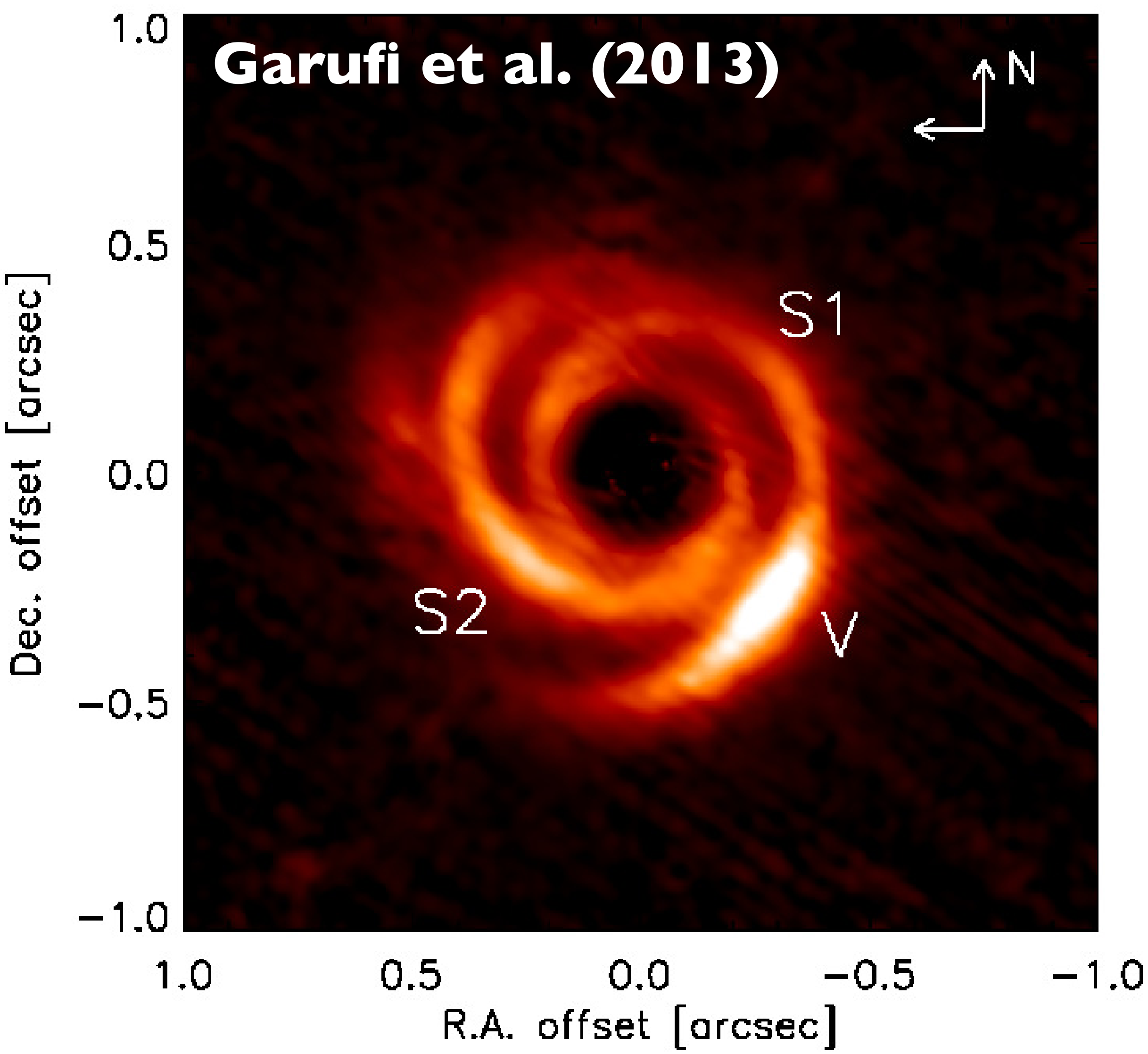

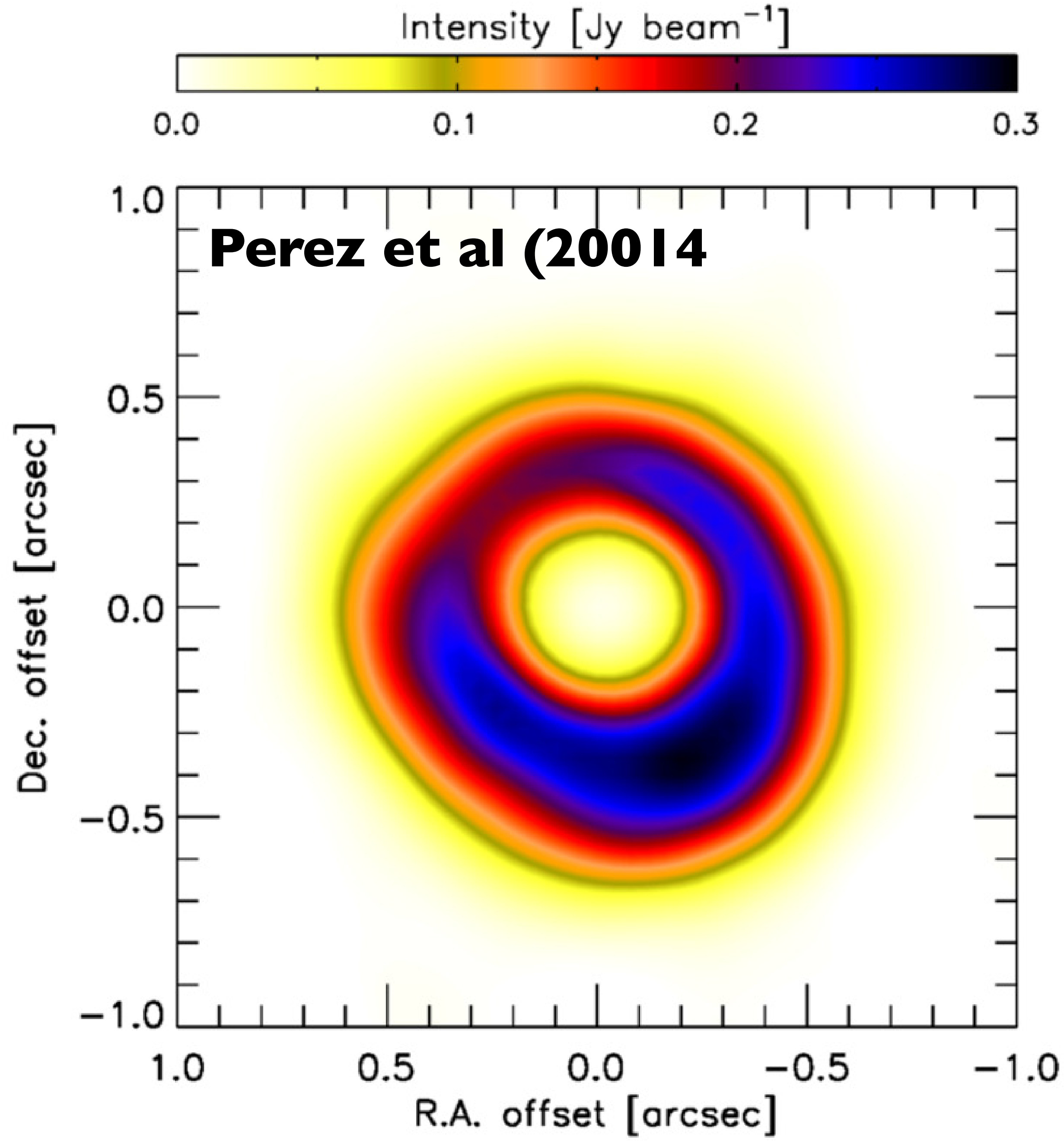

- Hypothetical planet excites spiral arms, carves a gap.
- Local pressure bump forms a vortex which traps mm particles.
- Vortex responsible for bright spot in SW spiral.
- Motion of the SW arm can pinpoint where the planet is.

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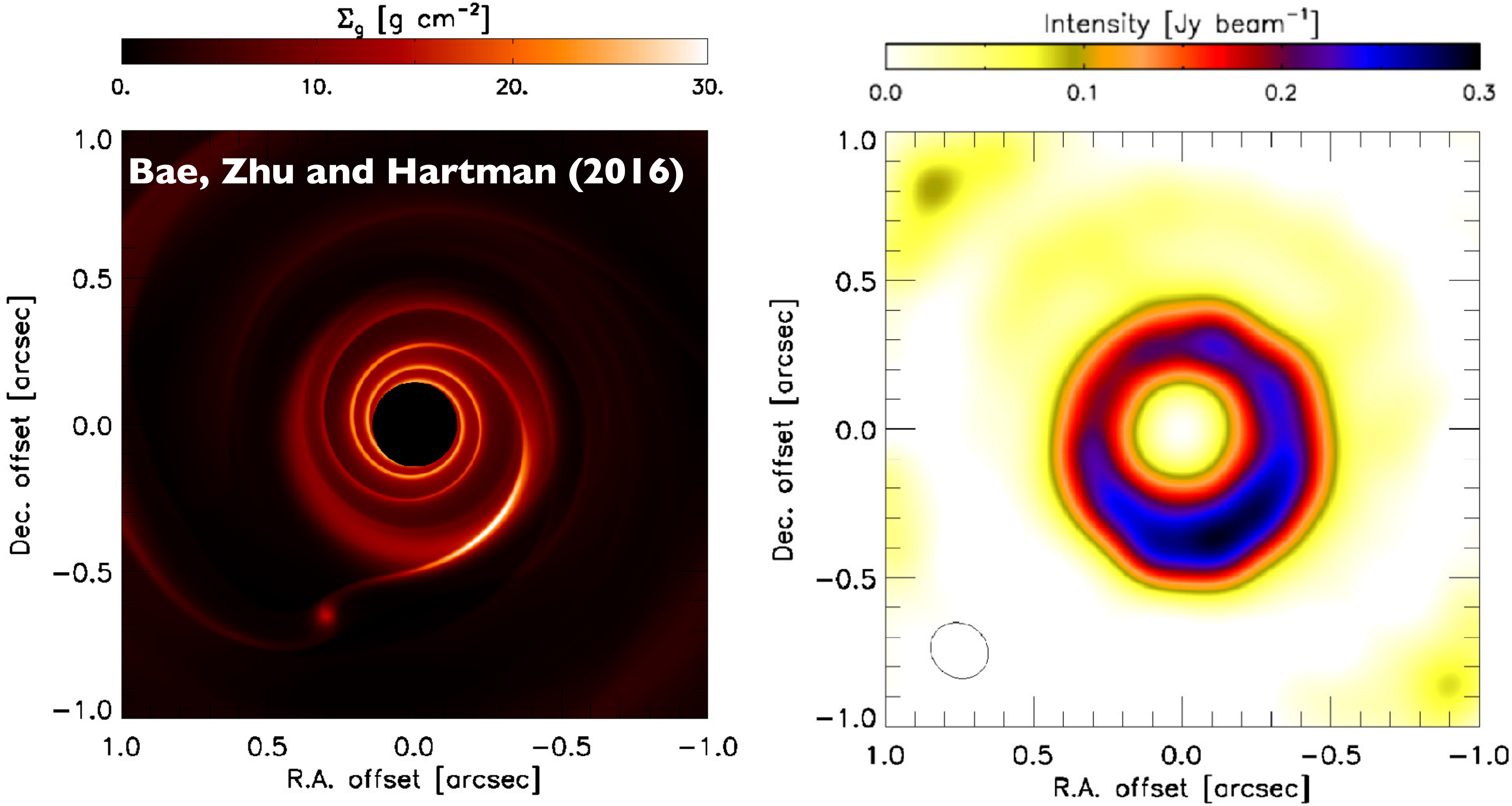

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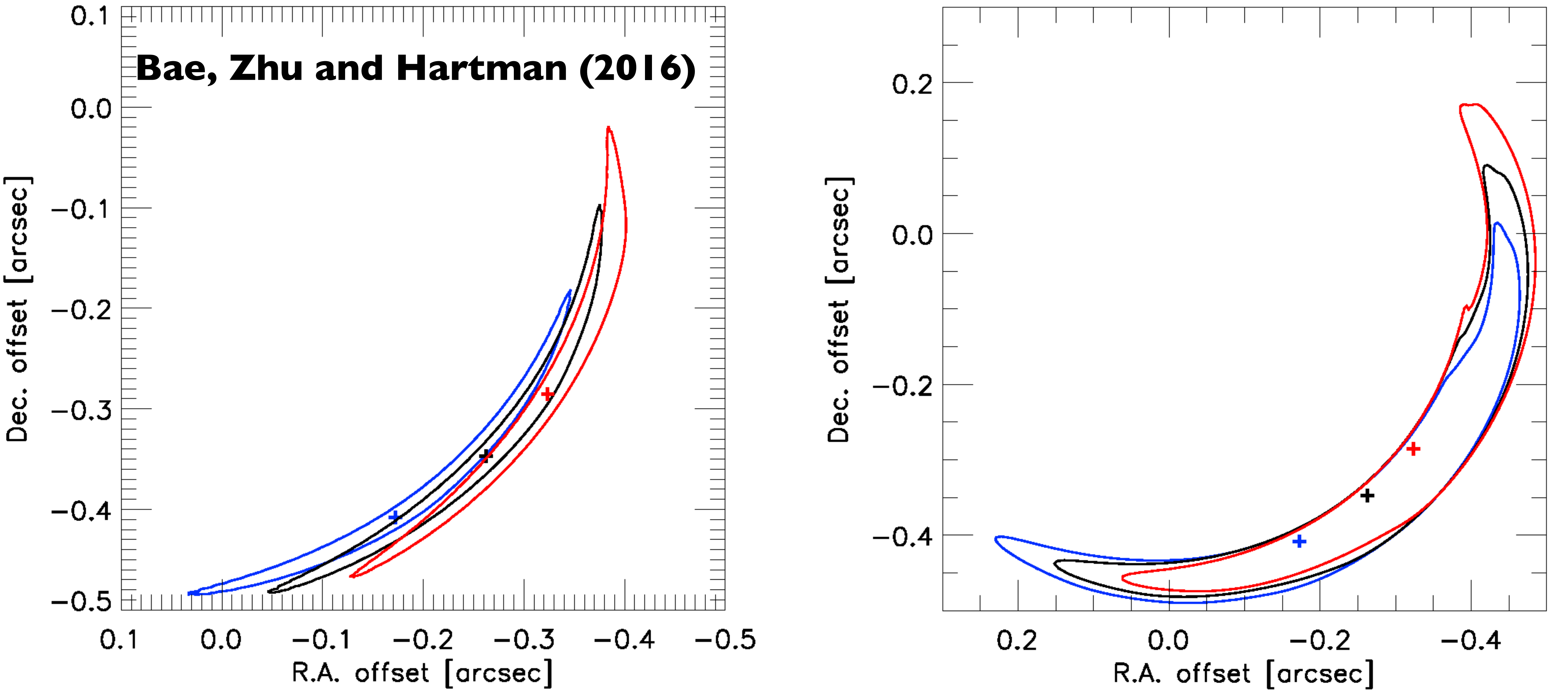

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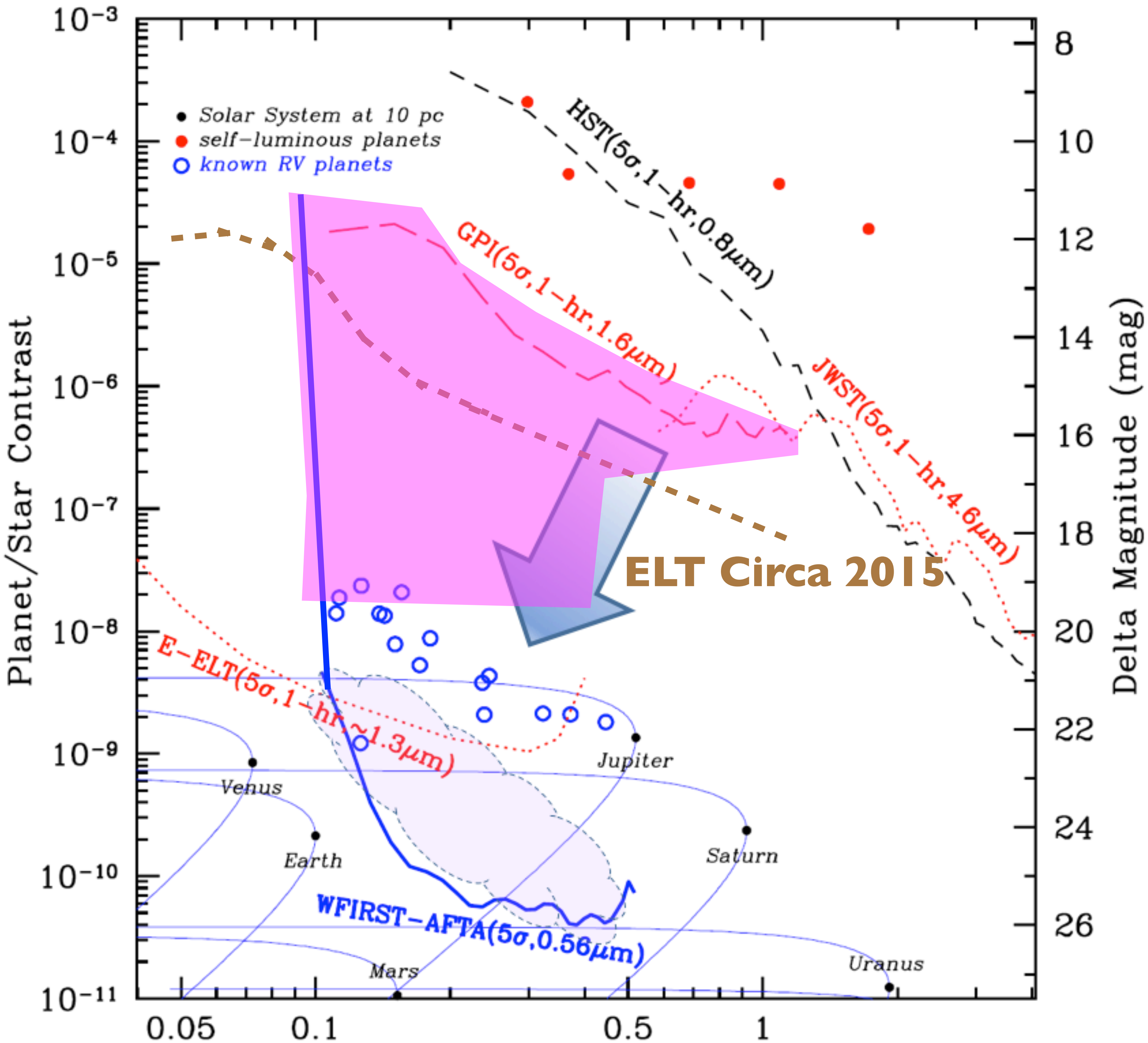

1. Proto-planetary disks and their interaction with exoplanets:

- Angular resolution is key. Contrast is not challenging.
- How much of this can be done from the ground now?

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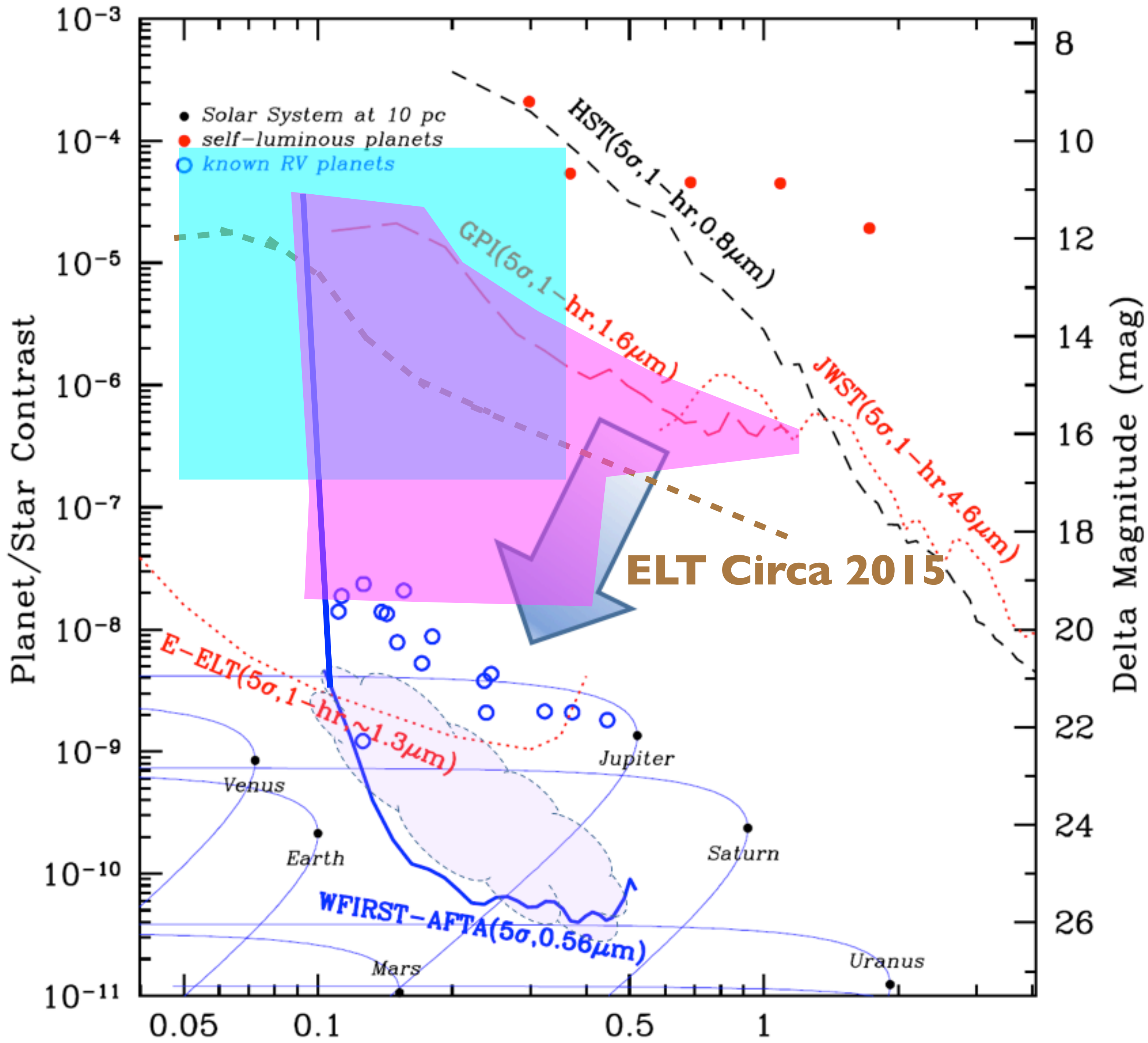

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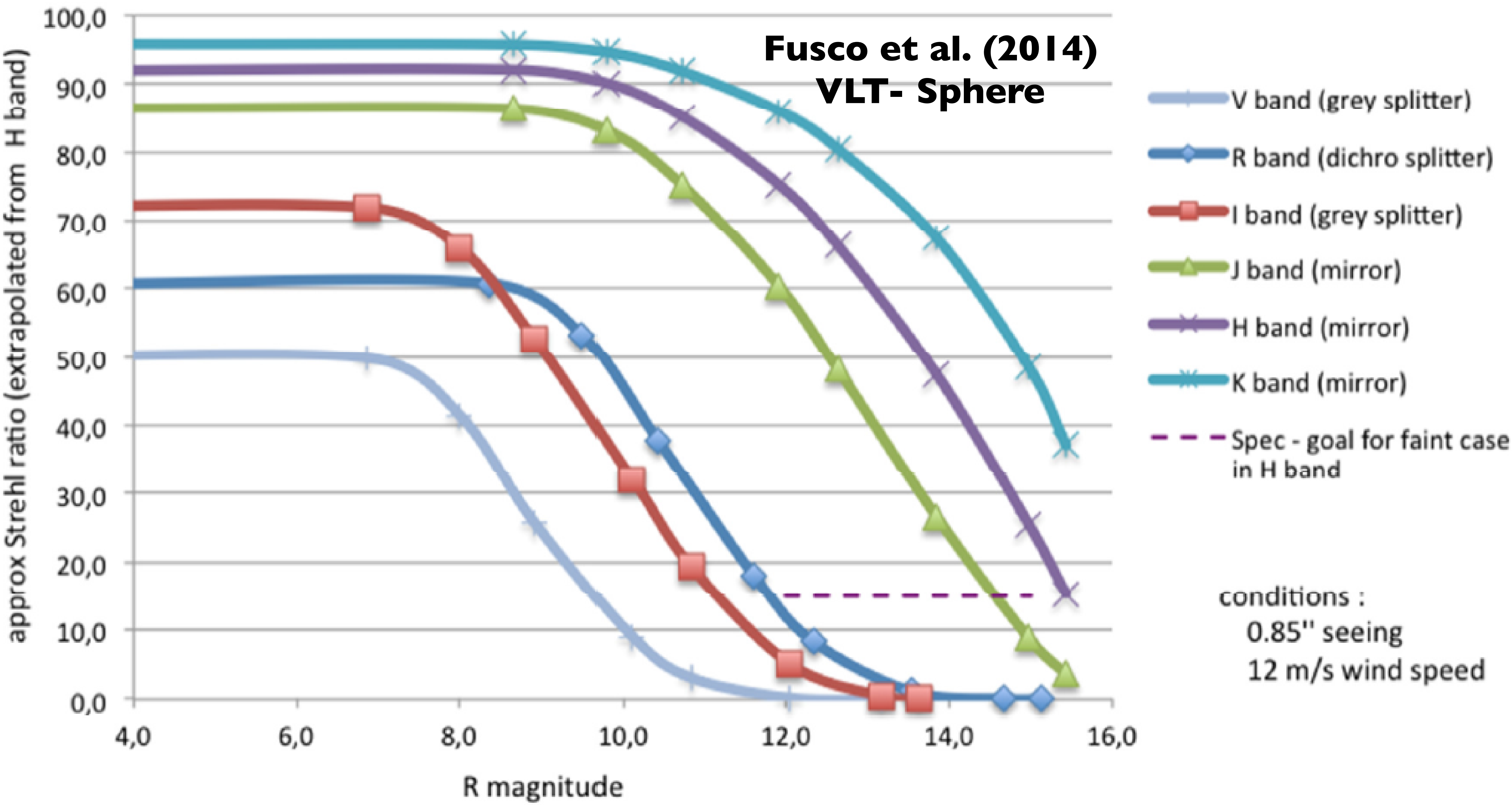
Performances of Adaptive Optics systems



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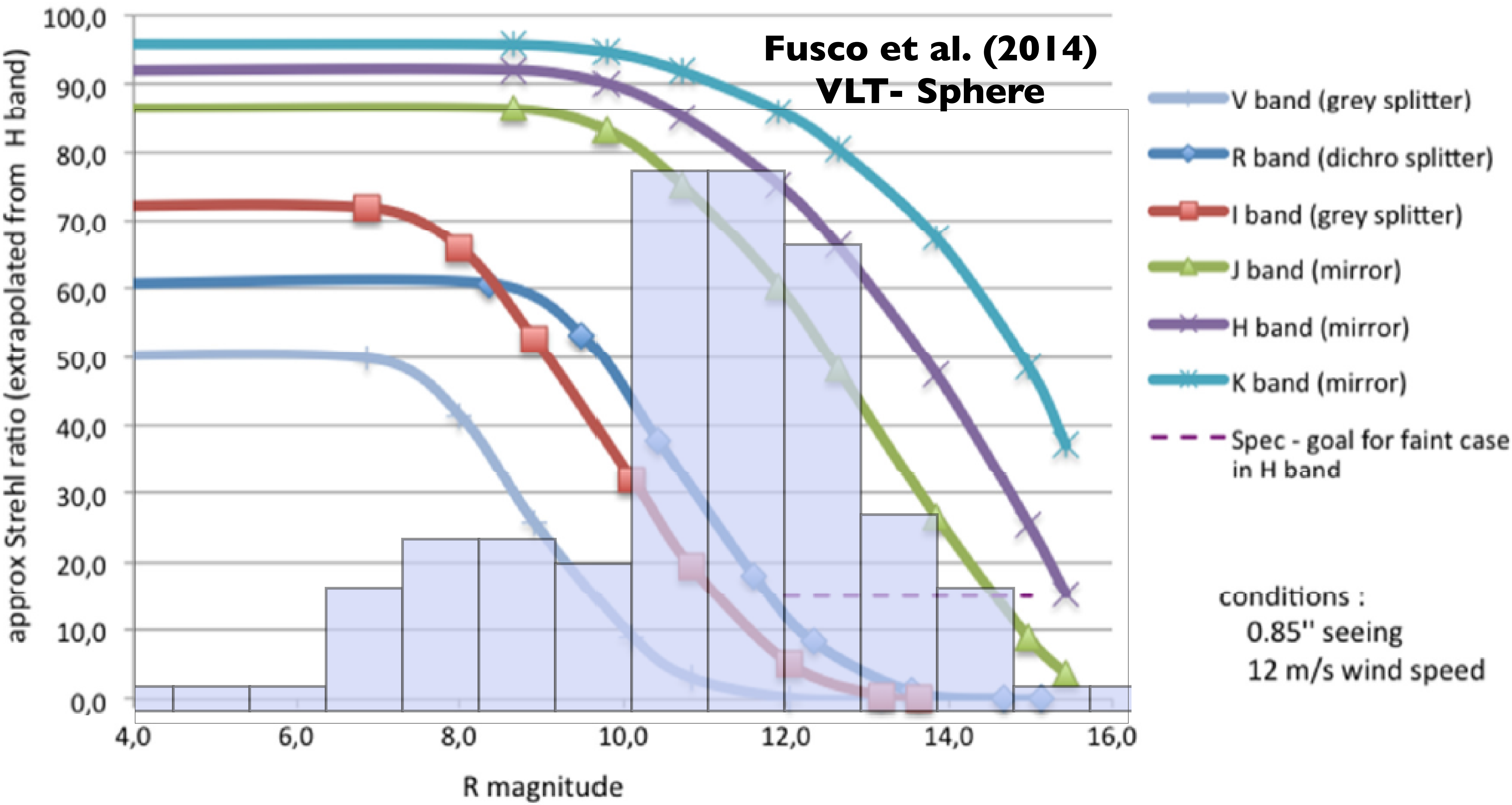

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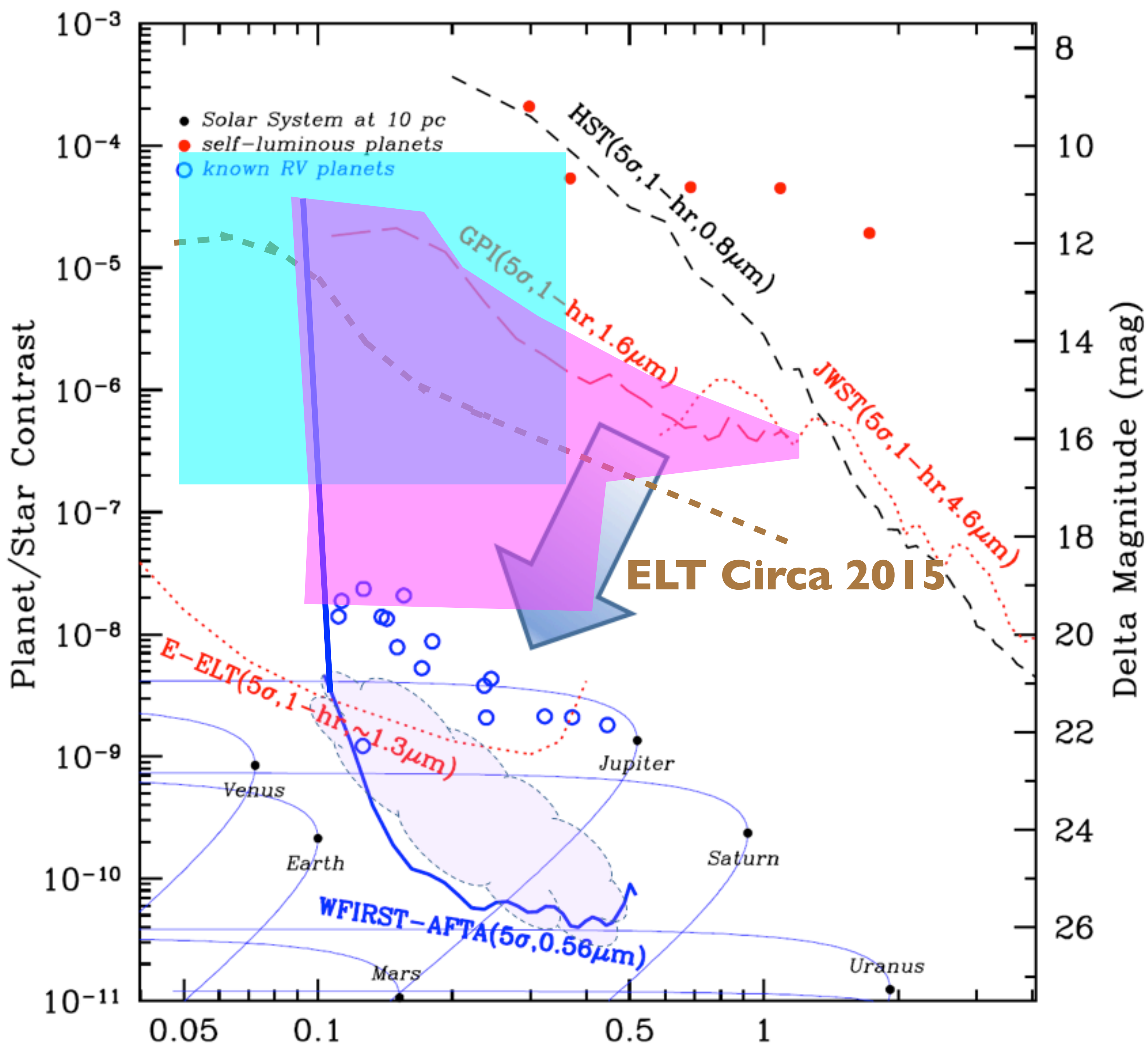
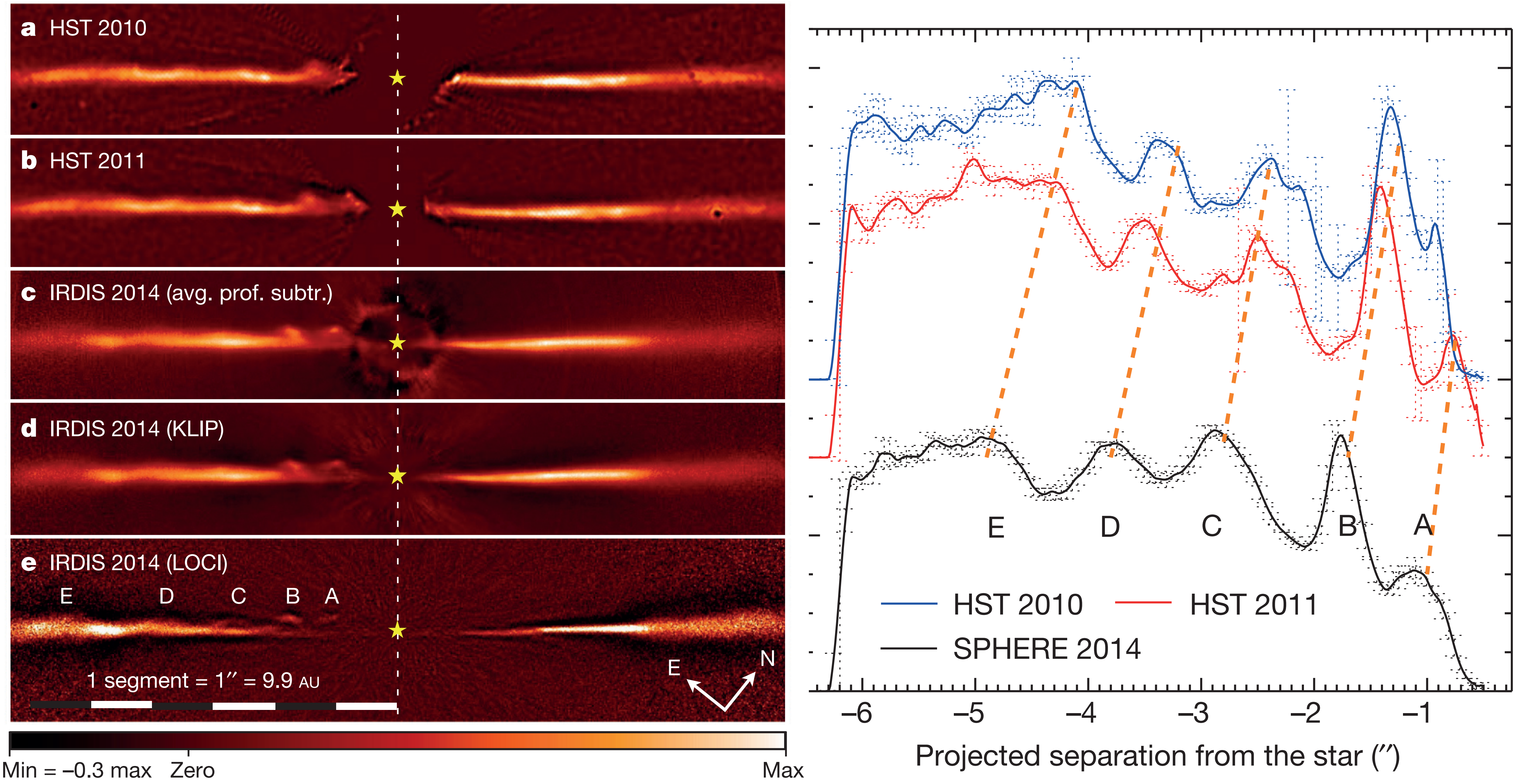


1. Proto-planetary disks and their interaction with exoplanets:

- Angular resolution is key. Contrast is not challenging.
- Current AO systems will only observe archetypal systems.
- WFIRST and/or ETLs will observe the bulk of these systems.

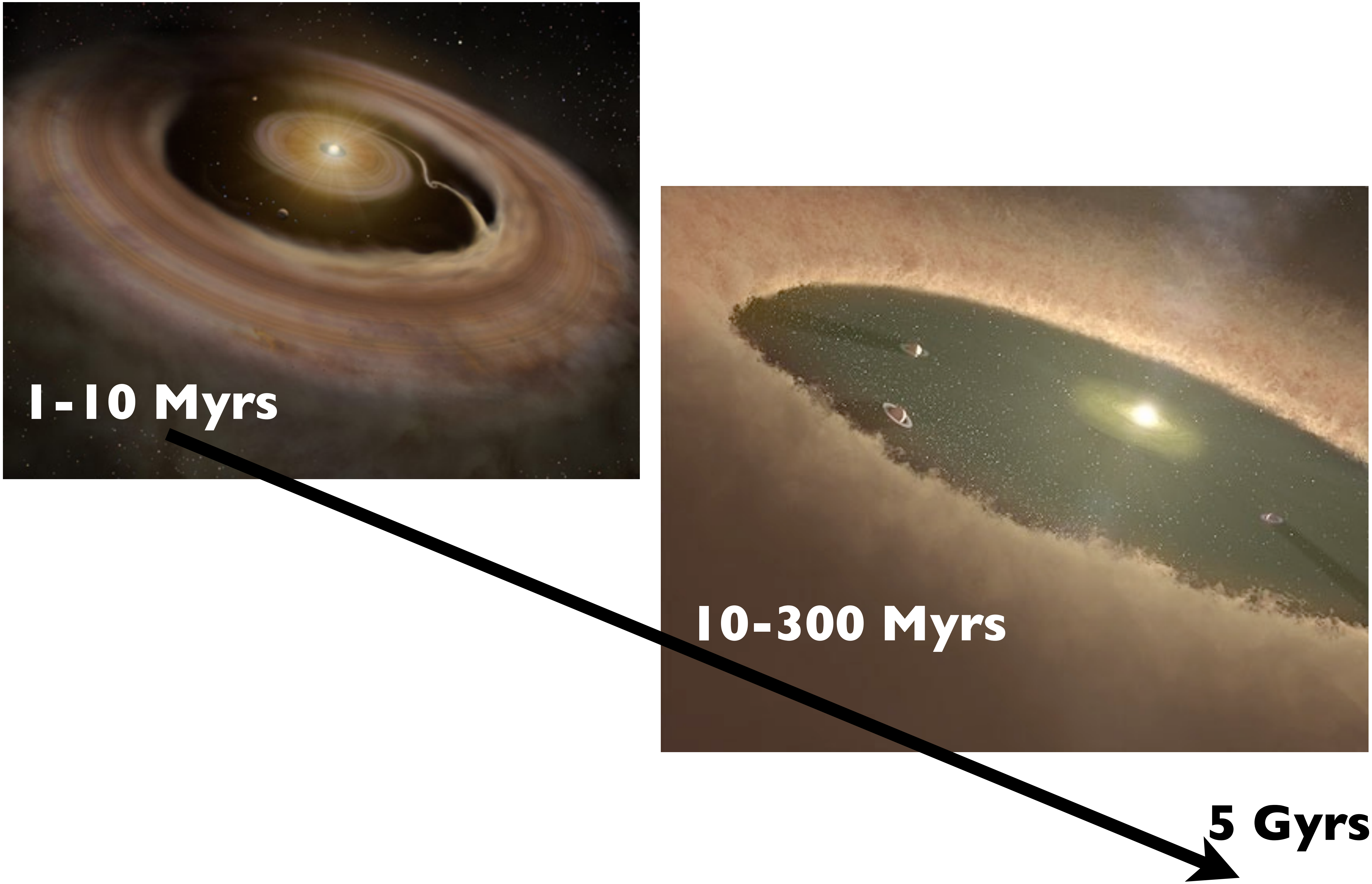
Given the timescales associated with planet disk interaction every observation is precious.

Archival data for time series observations



Boccaletti et al. (2015): VLT-SPHERE + HST-STIS

Context: formation and evolution of planetary systems



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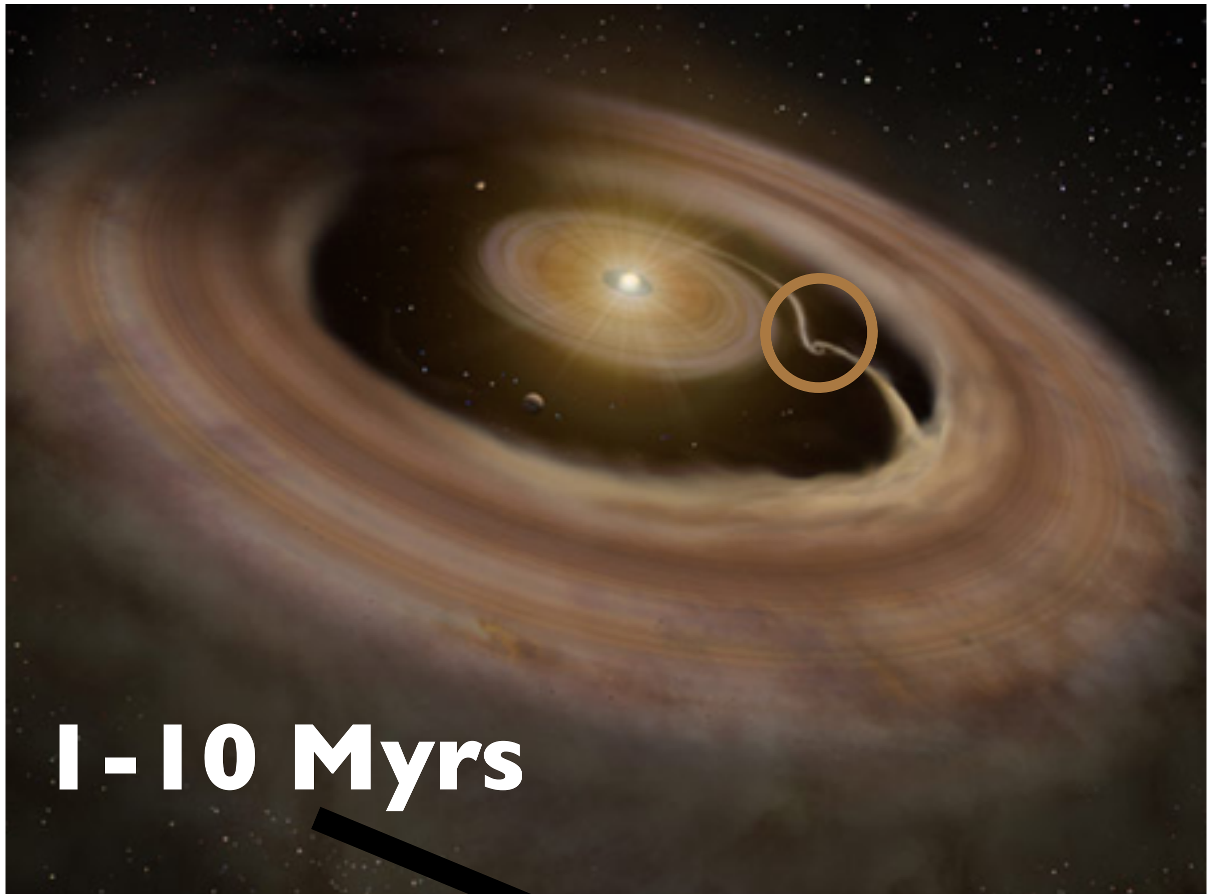
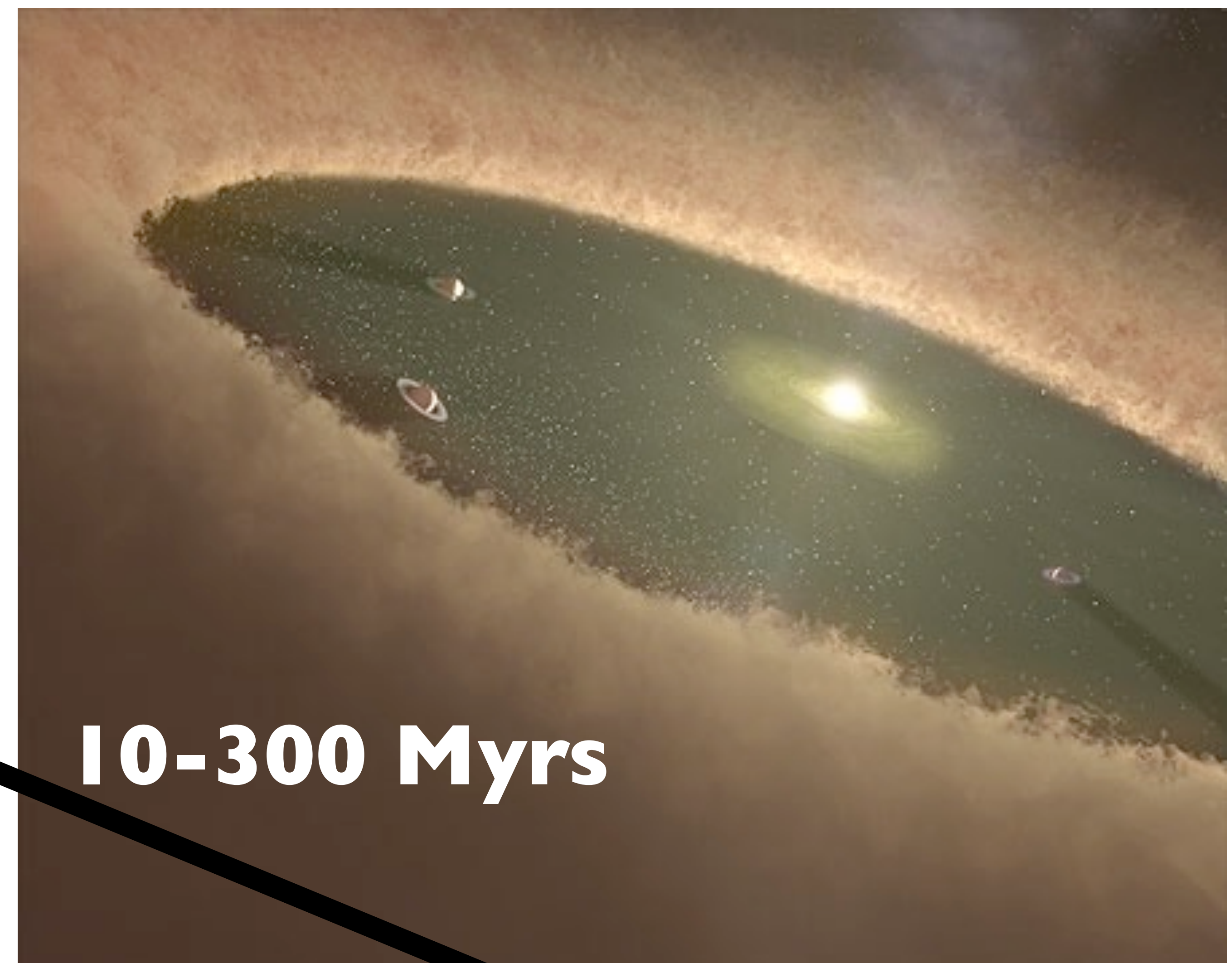
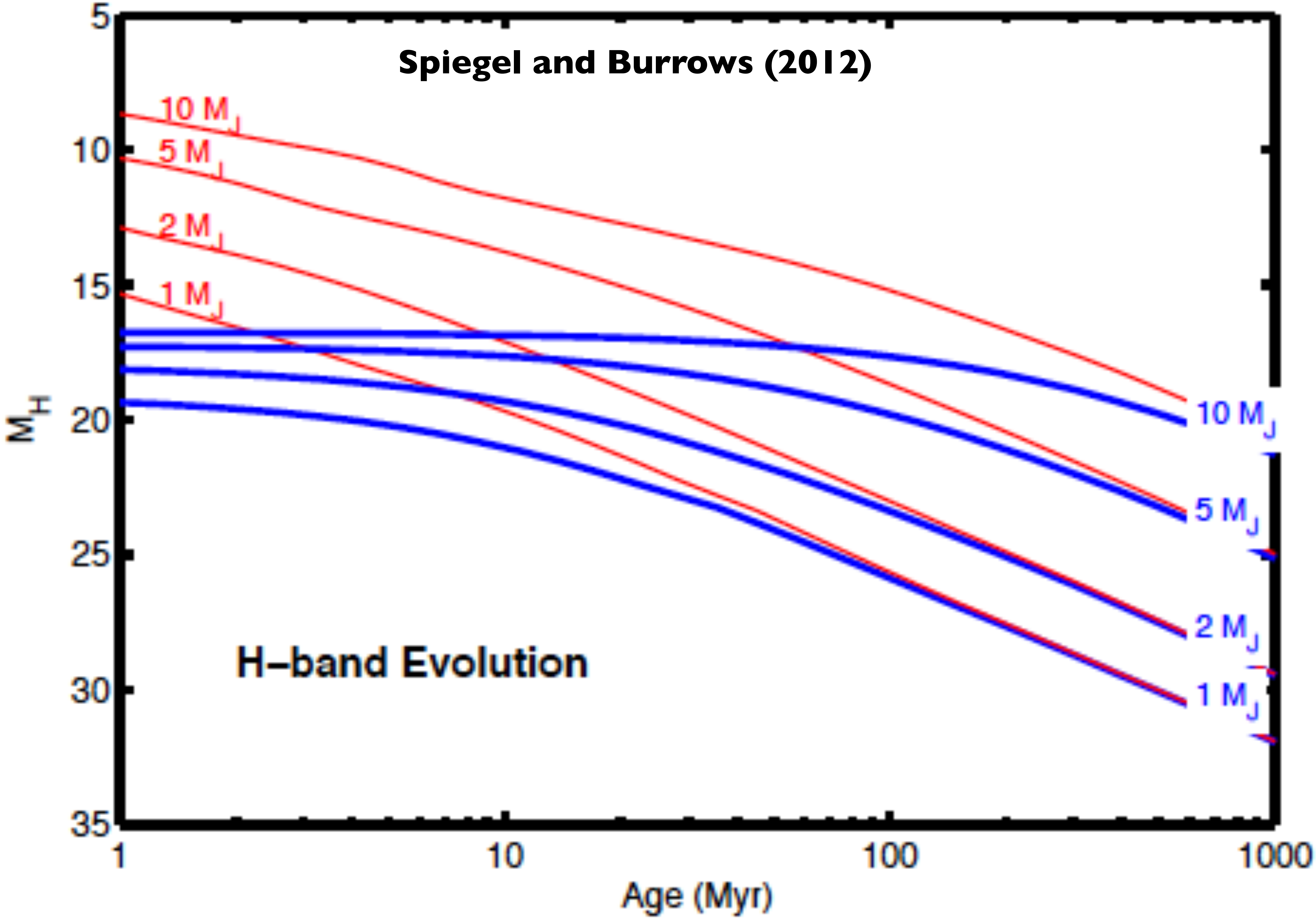




5 Gyrs

2. Proto-planets and interactions with their disk

What do proto-planets look like?



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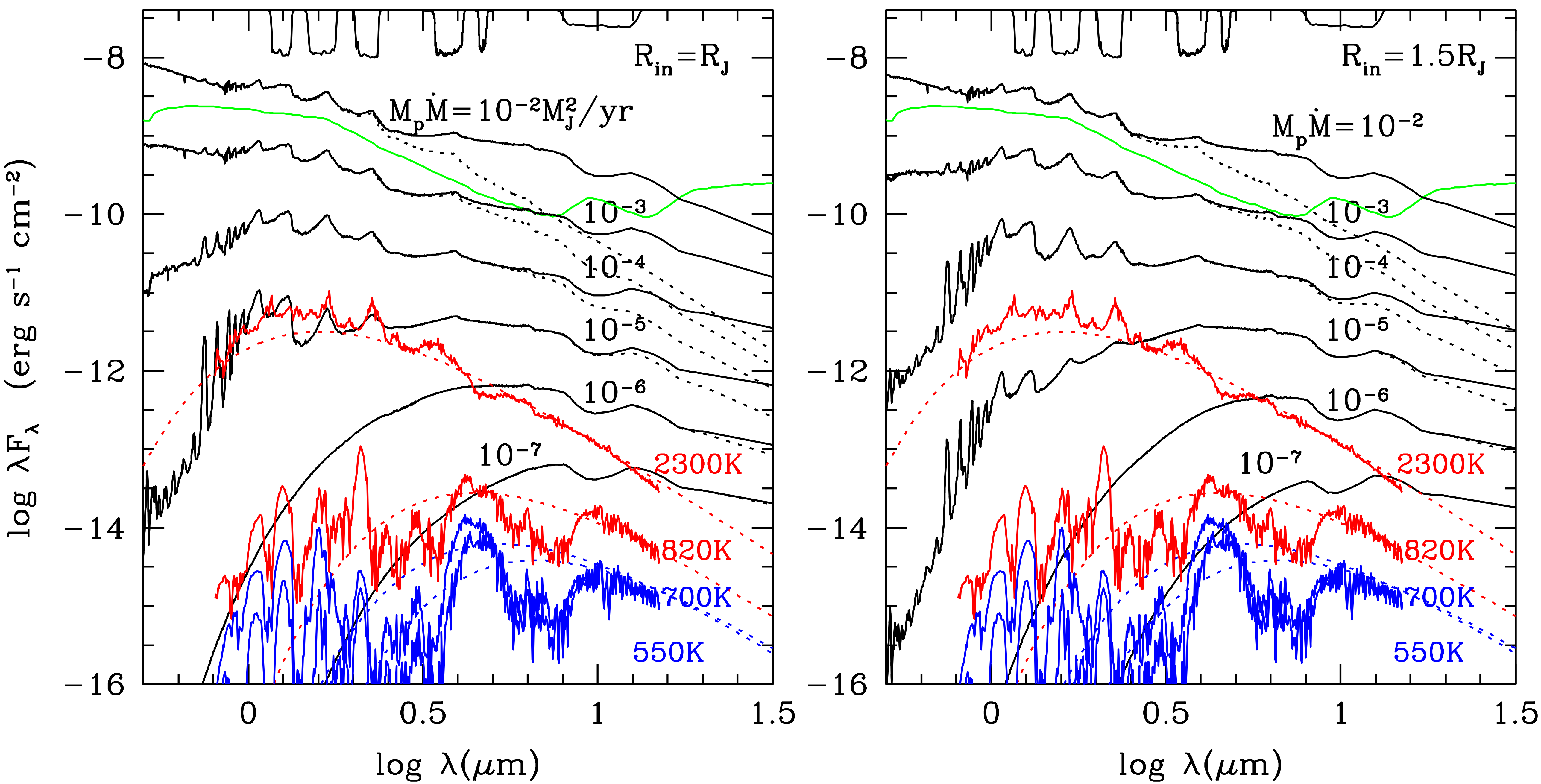

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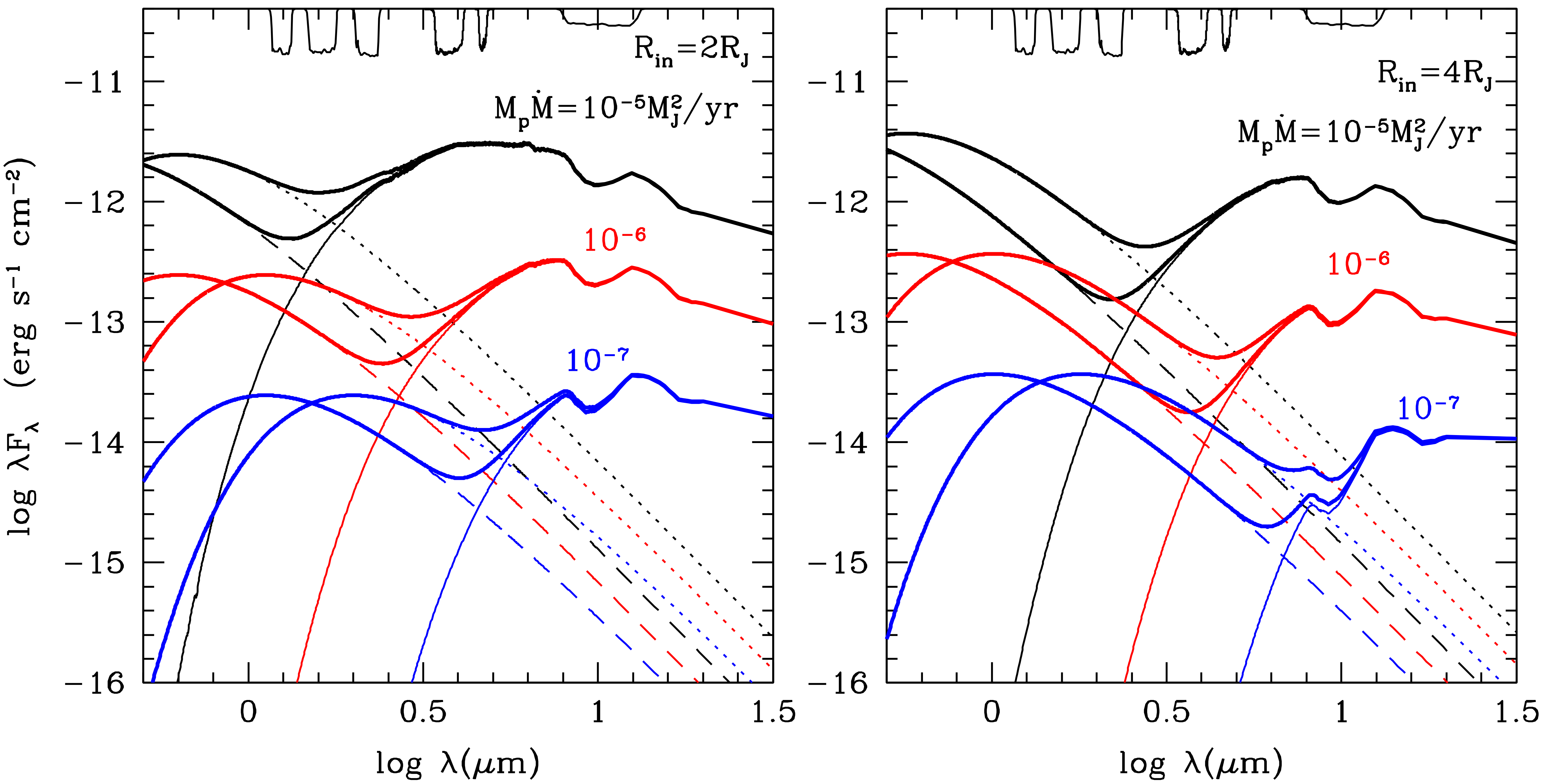
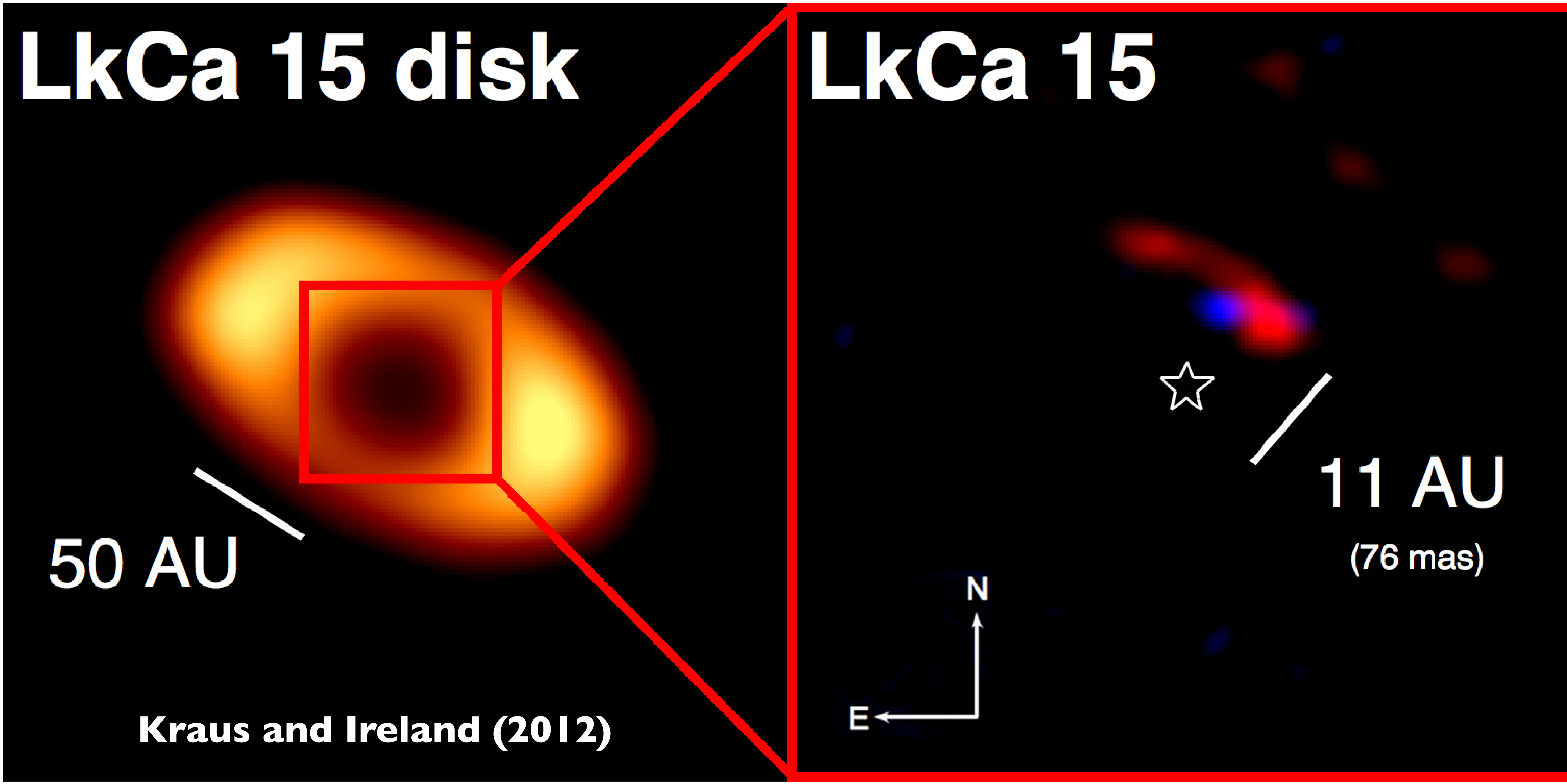


Example of LKCa15



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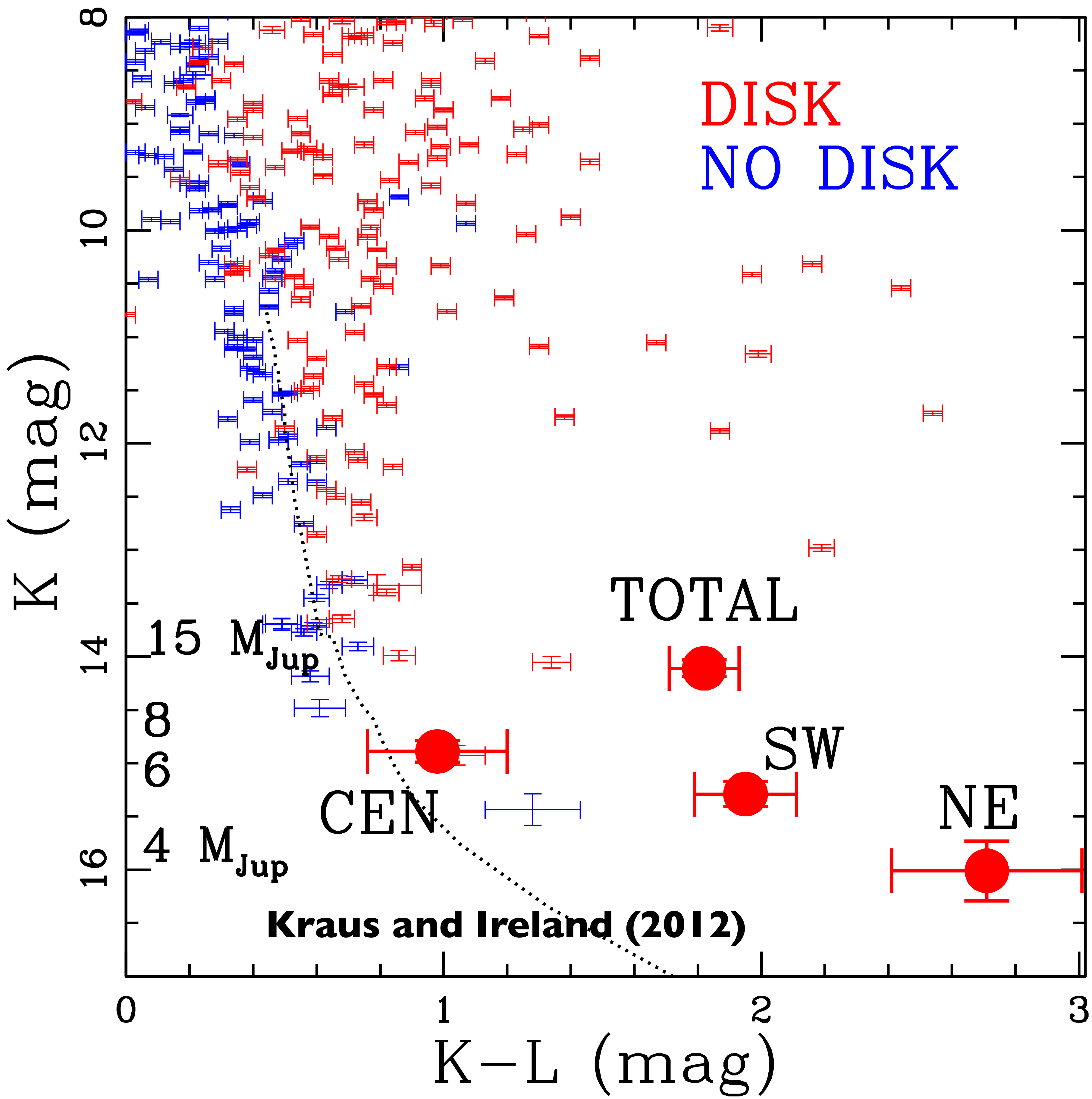

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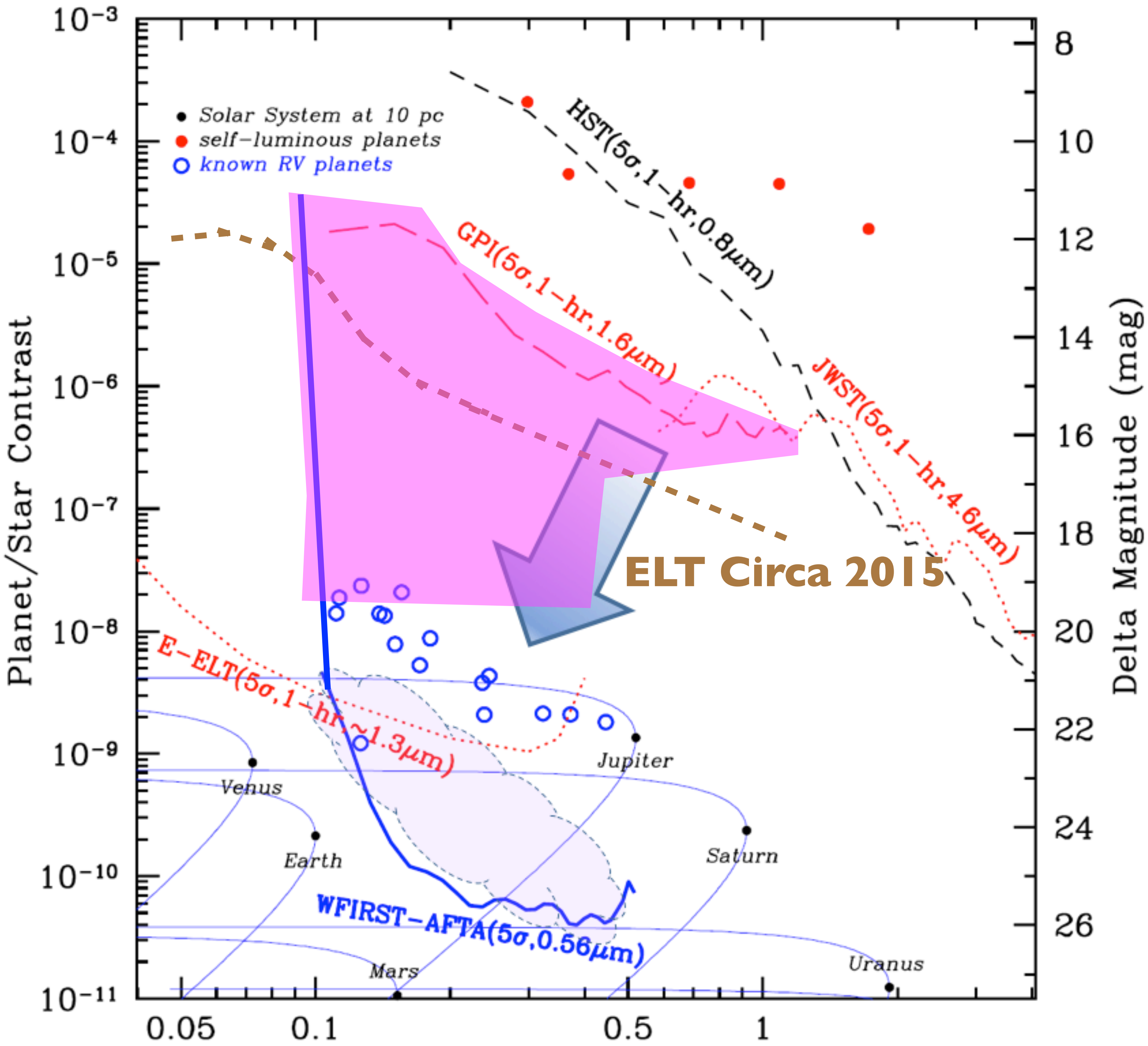

2. Proto-planets and interactions with their disk

- Proto-planets are bright. Contrast is not challenging.
- IR observations are key to characterize dust.
- Angular resolution is key. Can JWST get to the proto-planets within small cavities?

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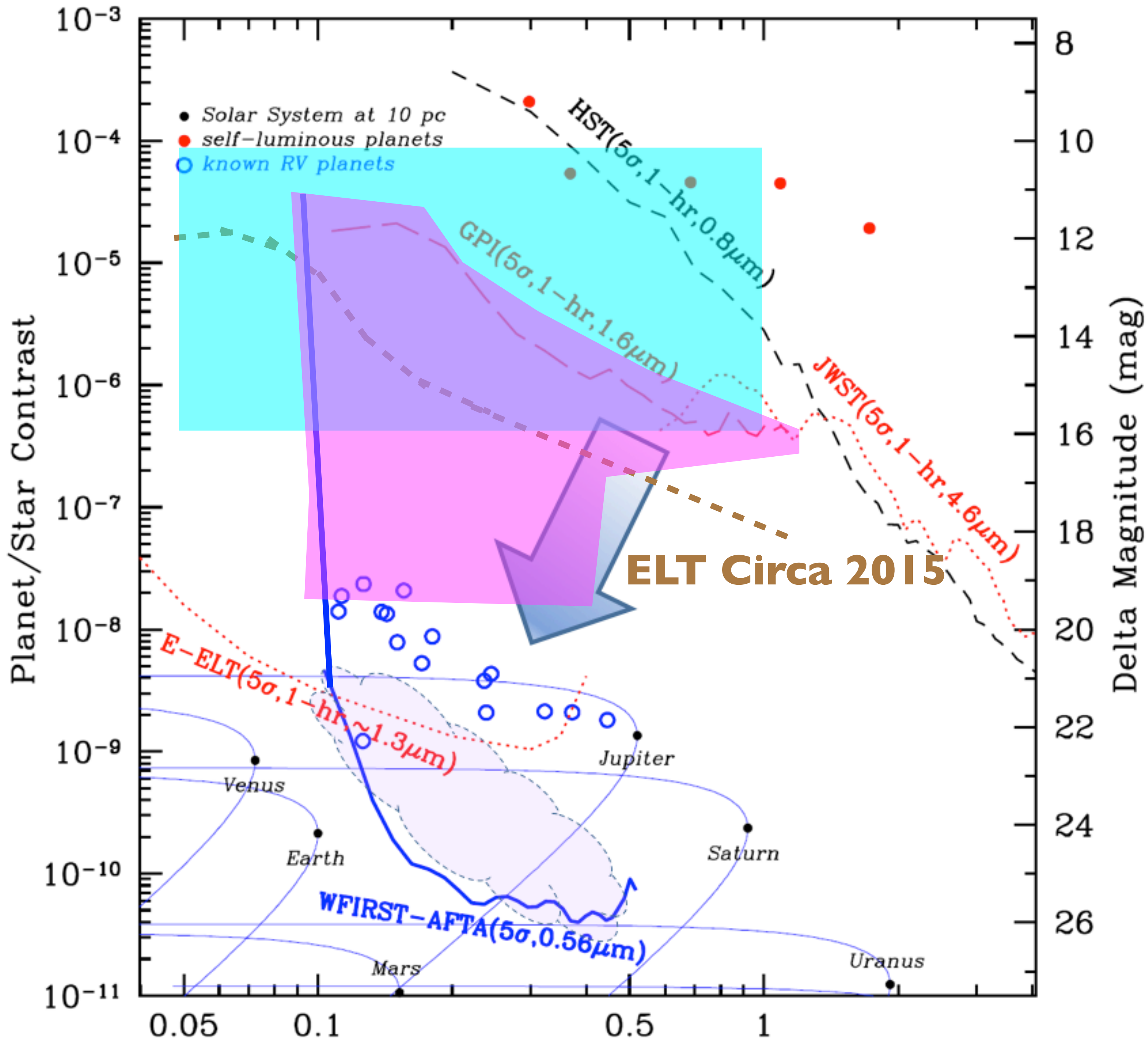

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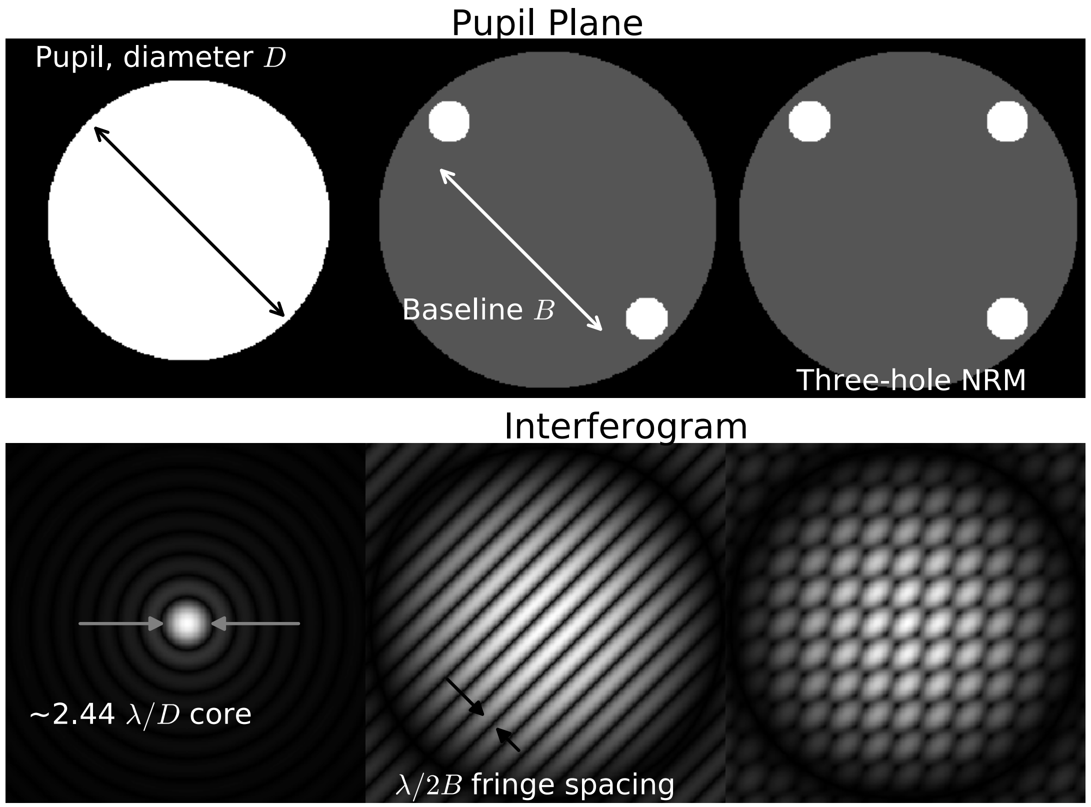
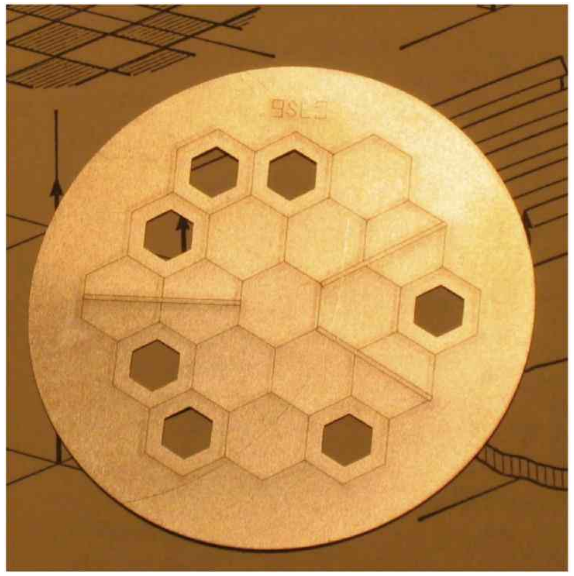
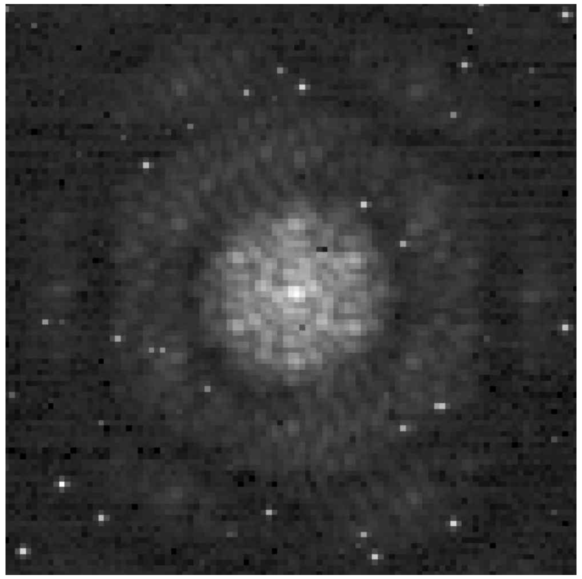
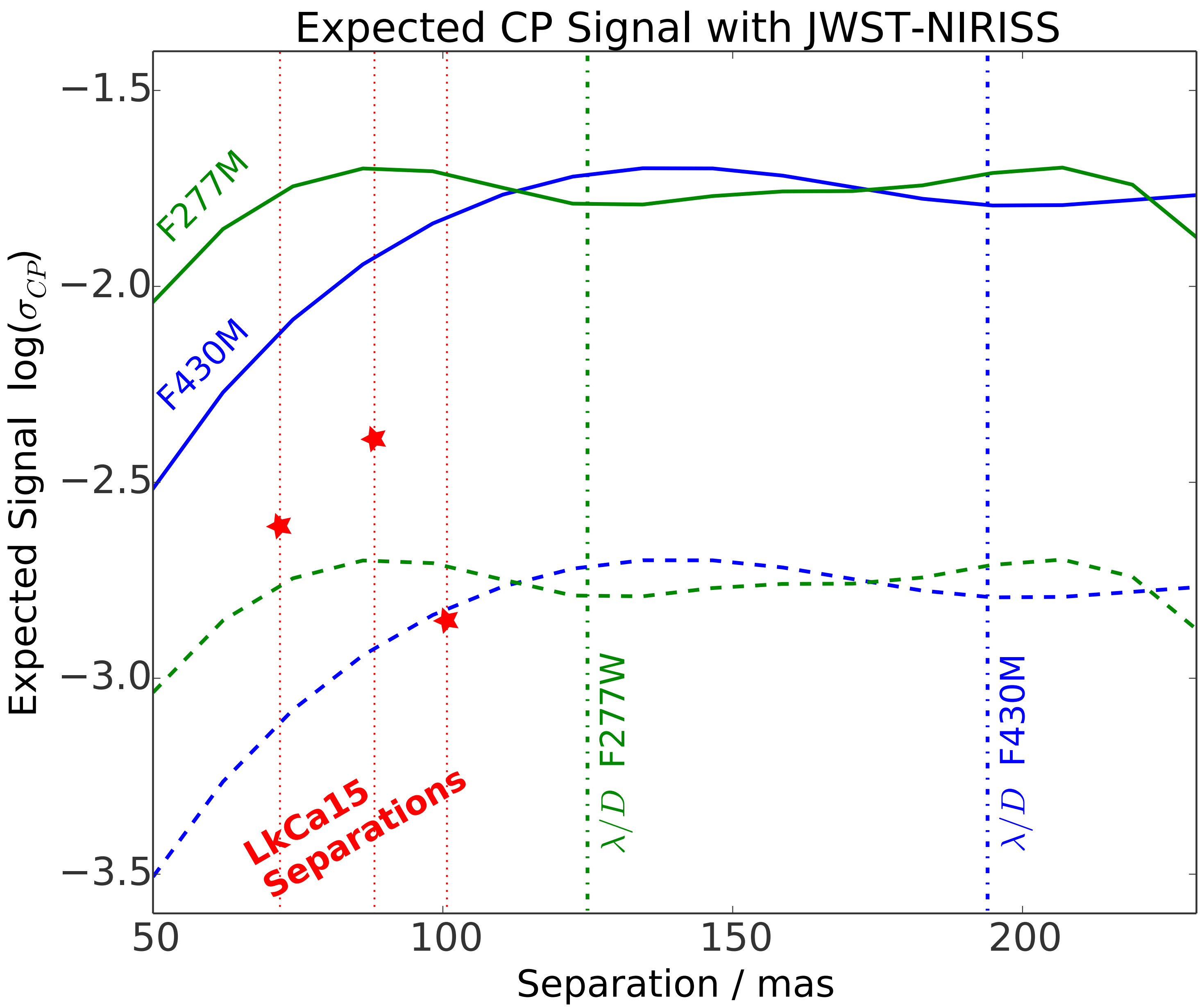
Proto-planets with JWST: using the AMI mode







Greenbaum, Pueyo et al. (2014)



JWST will find proto-planets in the near IR.

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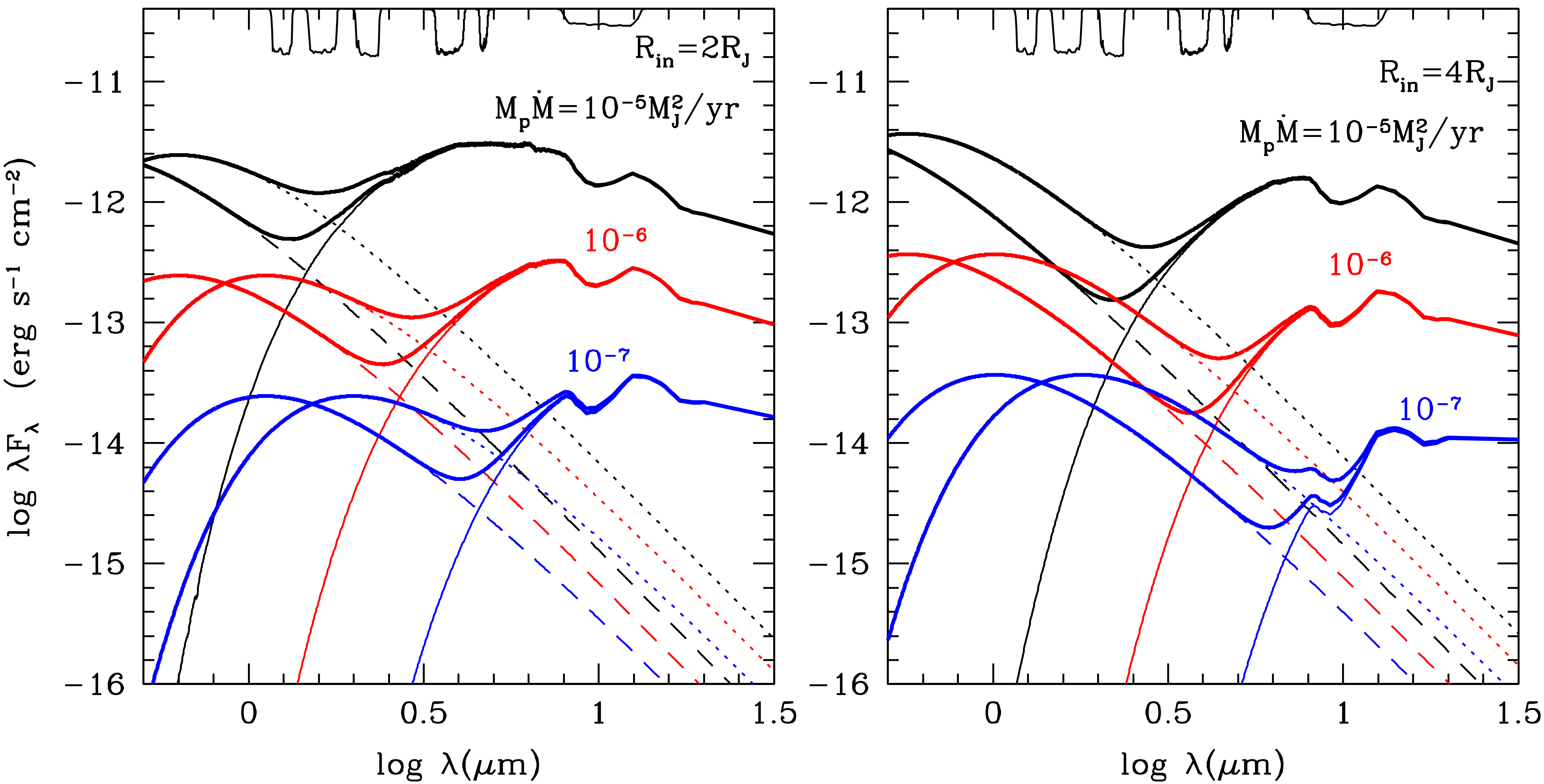

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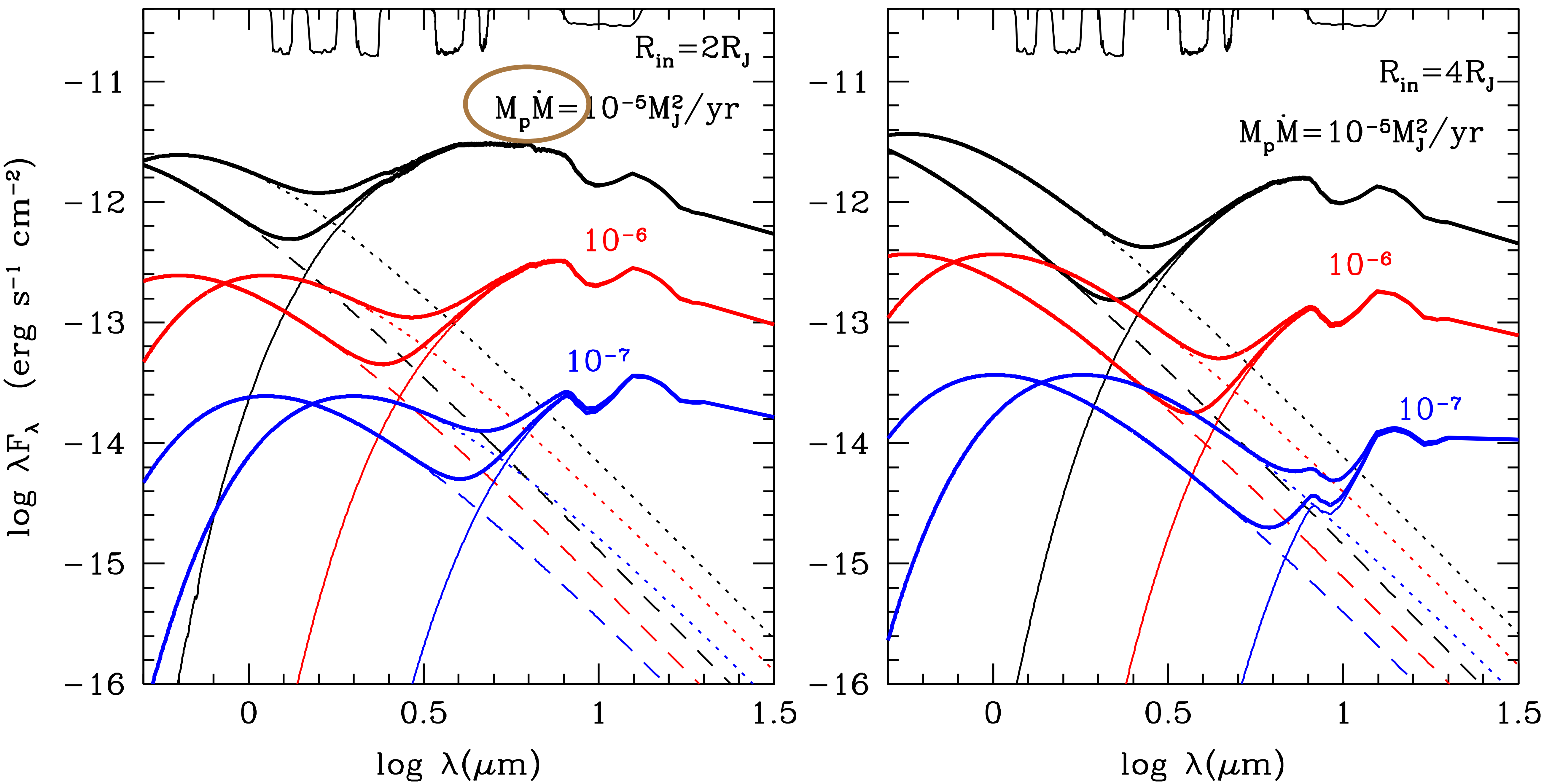
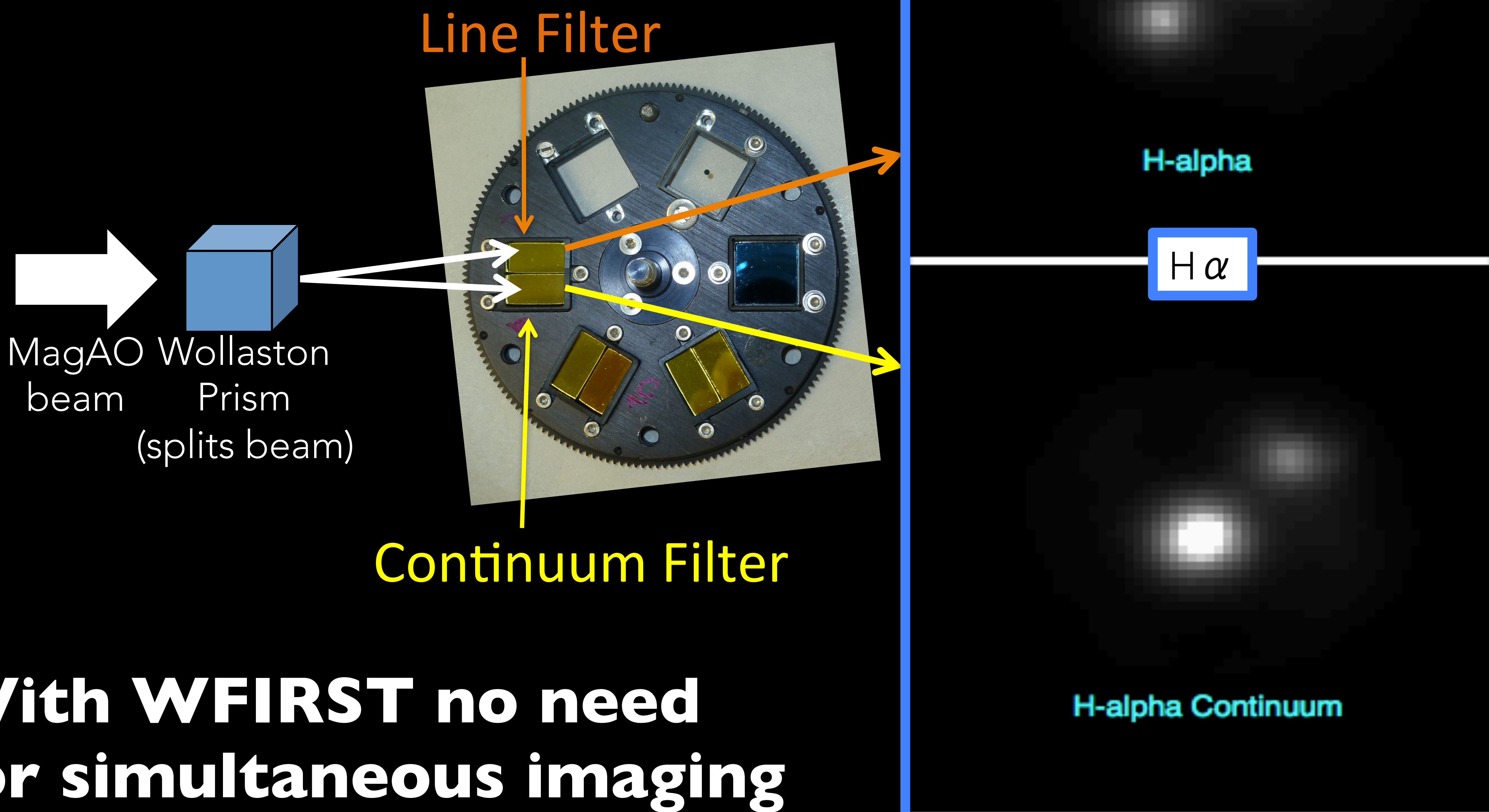


Key observable: Mp x dM/dt

Measuring accretion on a proto-planet

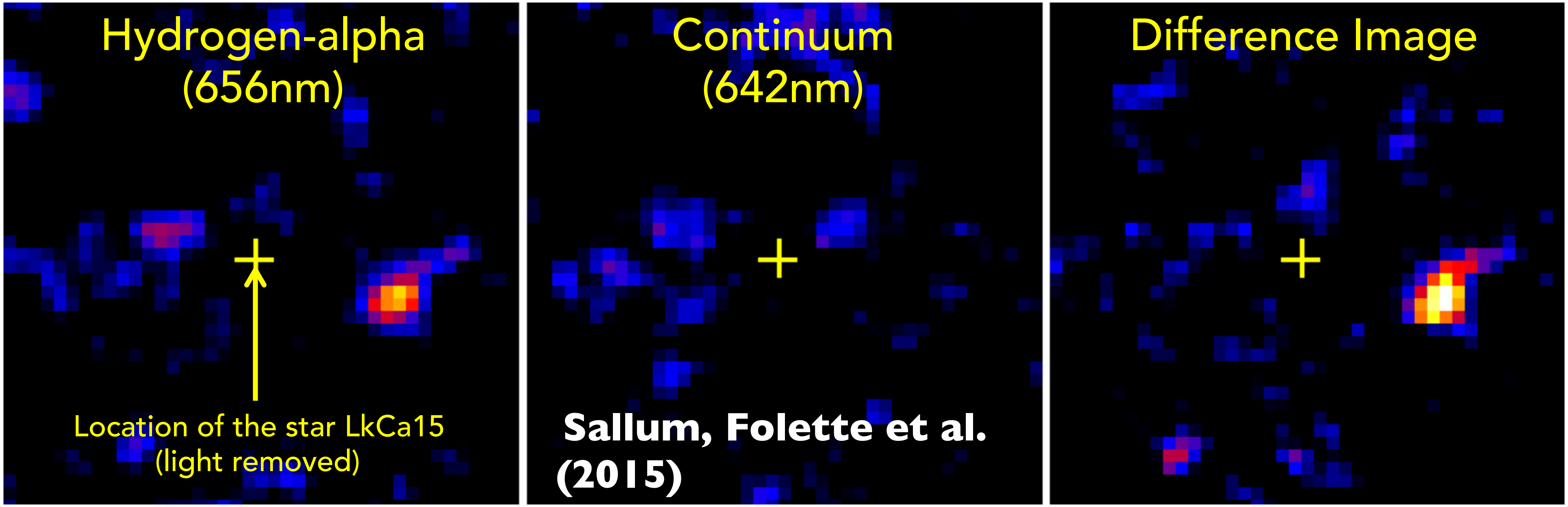
Spectra Differential Imaging
Coutersy of K. Folette

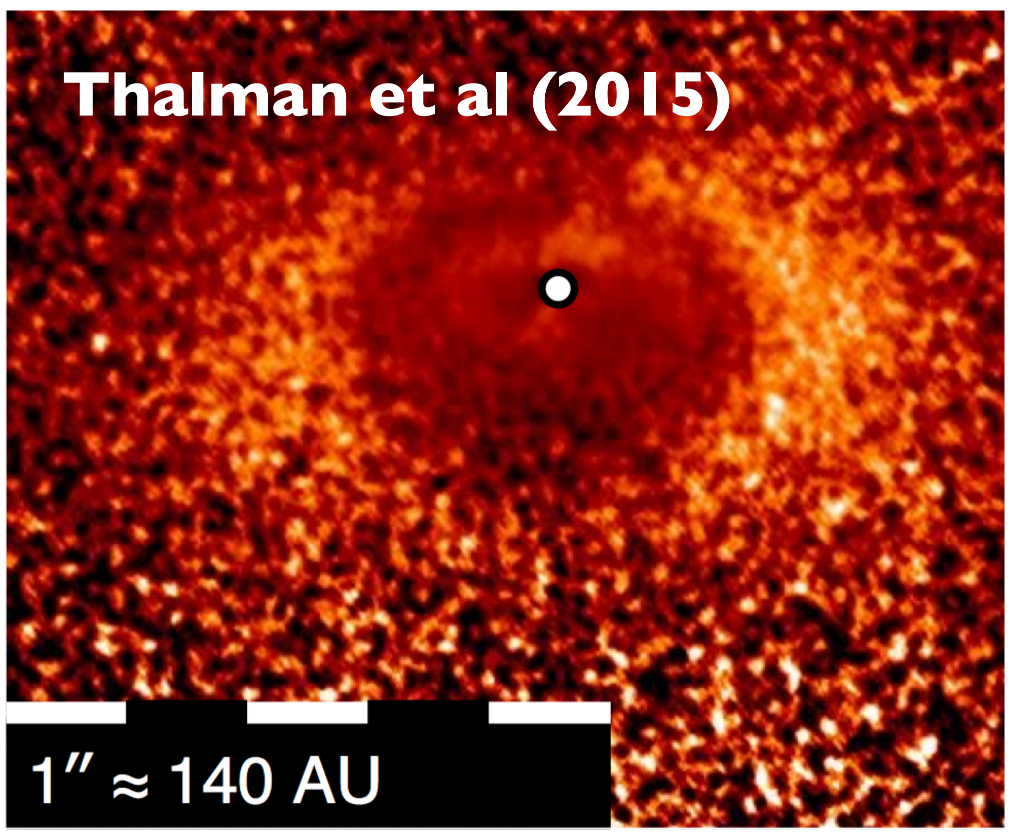
Close at al. (2013)



With WFIRST no need for simultaneous imaging

H-alpha: proxy for accretion rate





- Accreting proto-planet.
- Contrast 8x10^-3.
- Need continuum to measure dM/dt.

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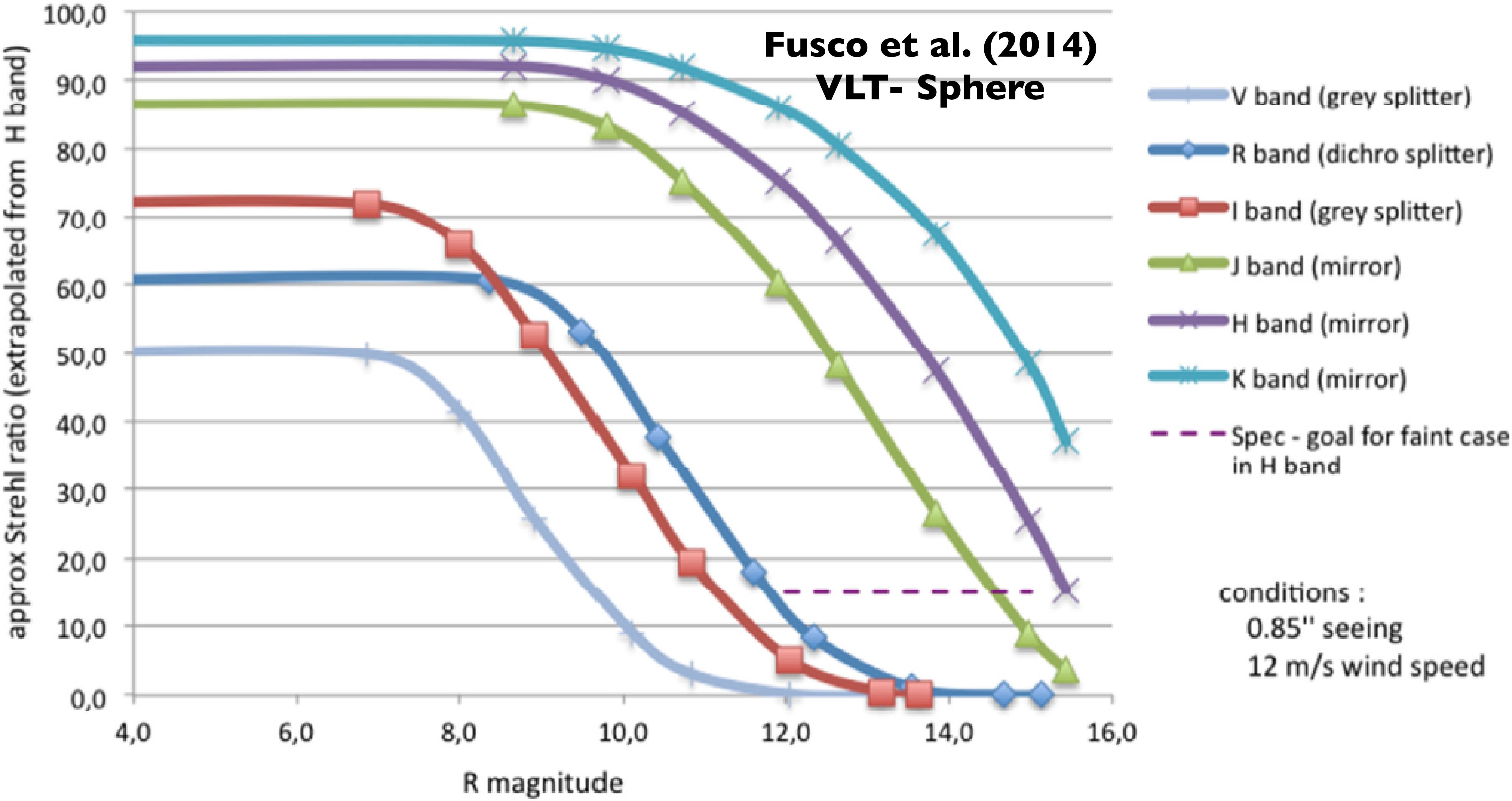

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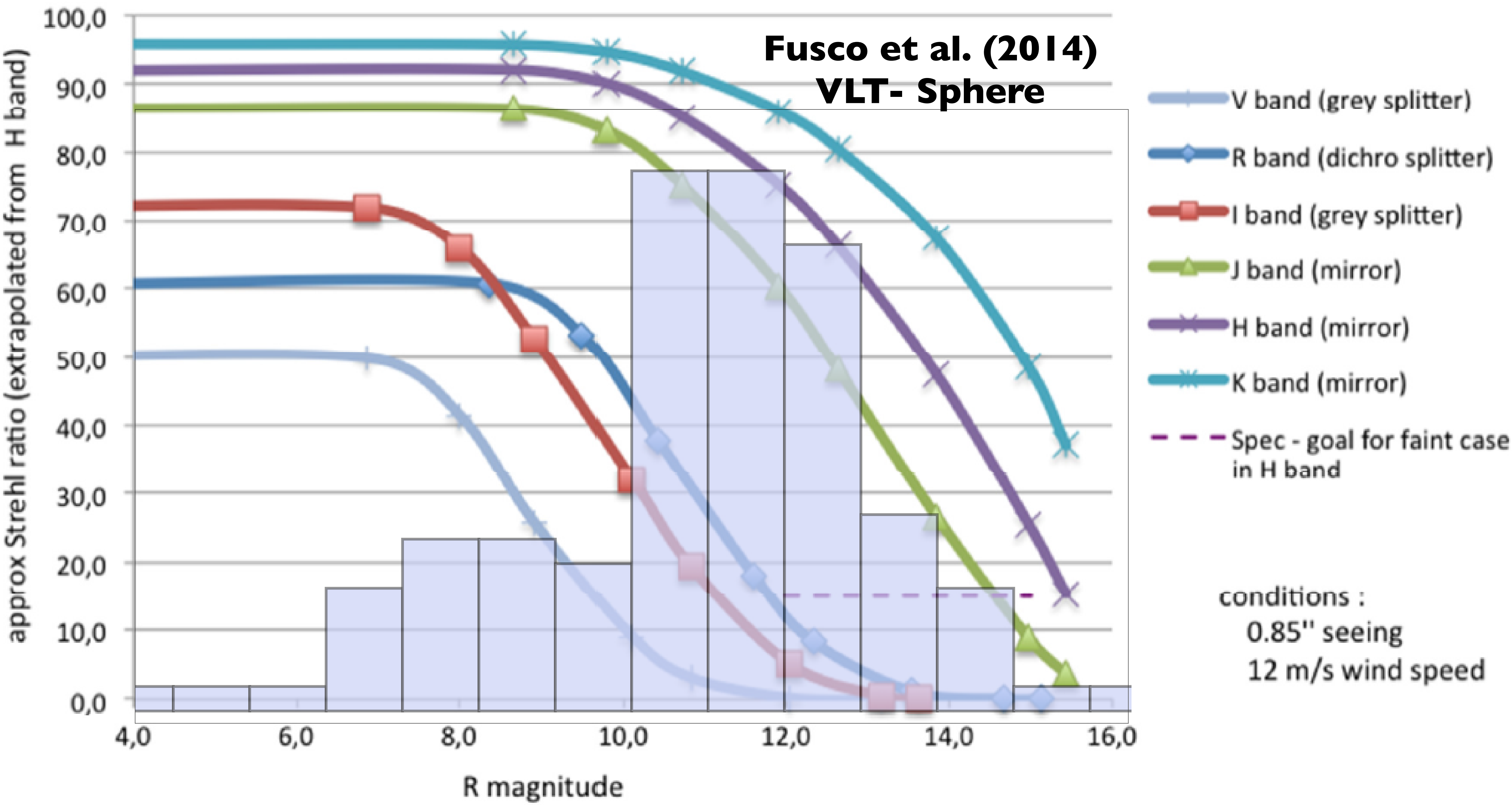

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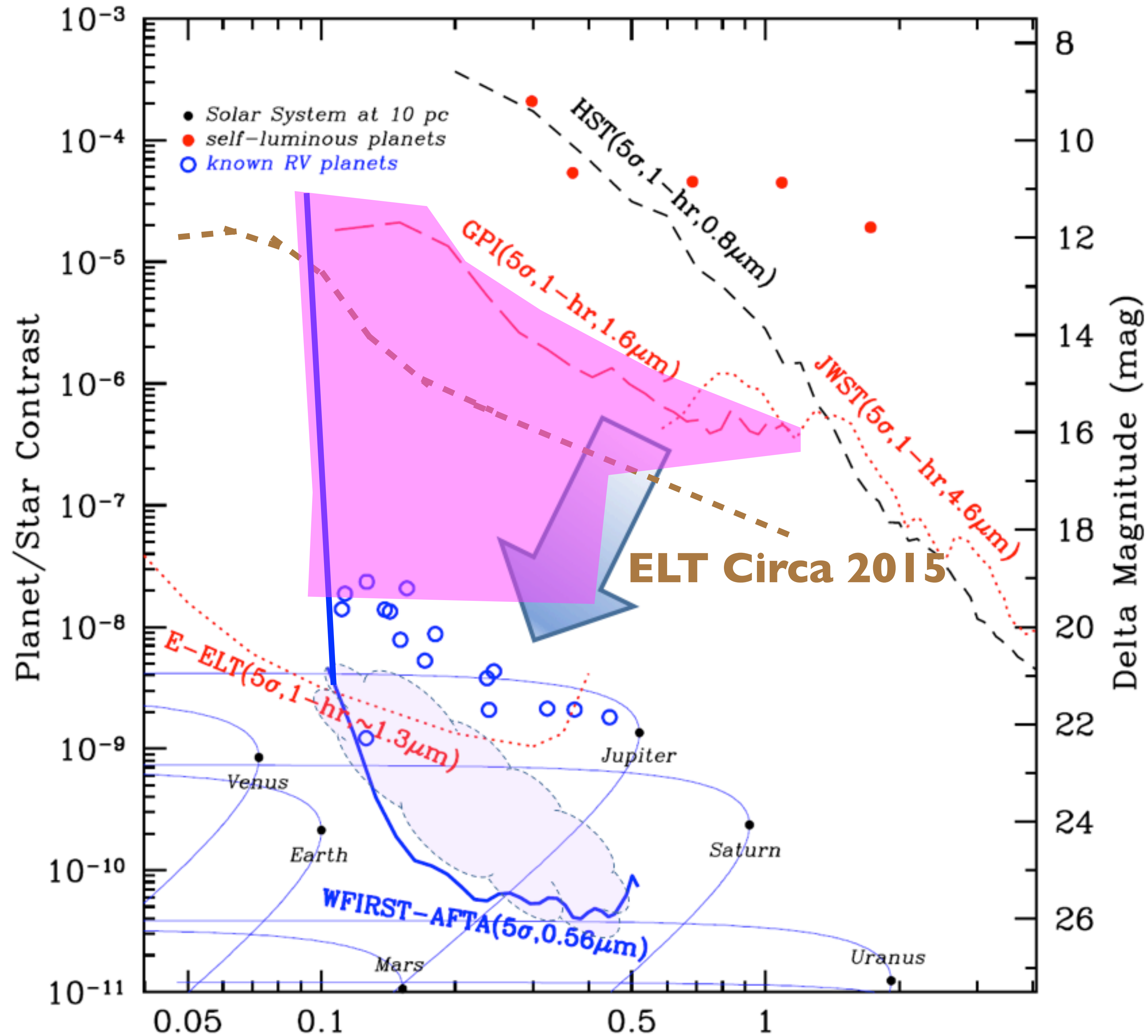

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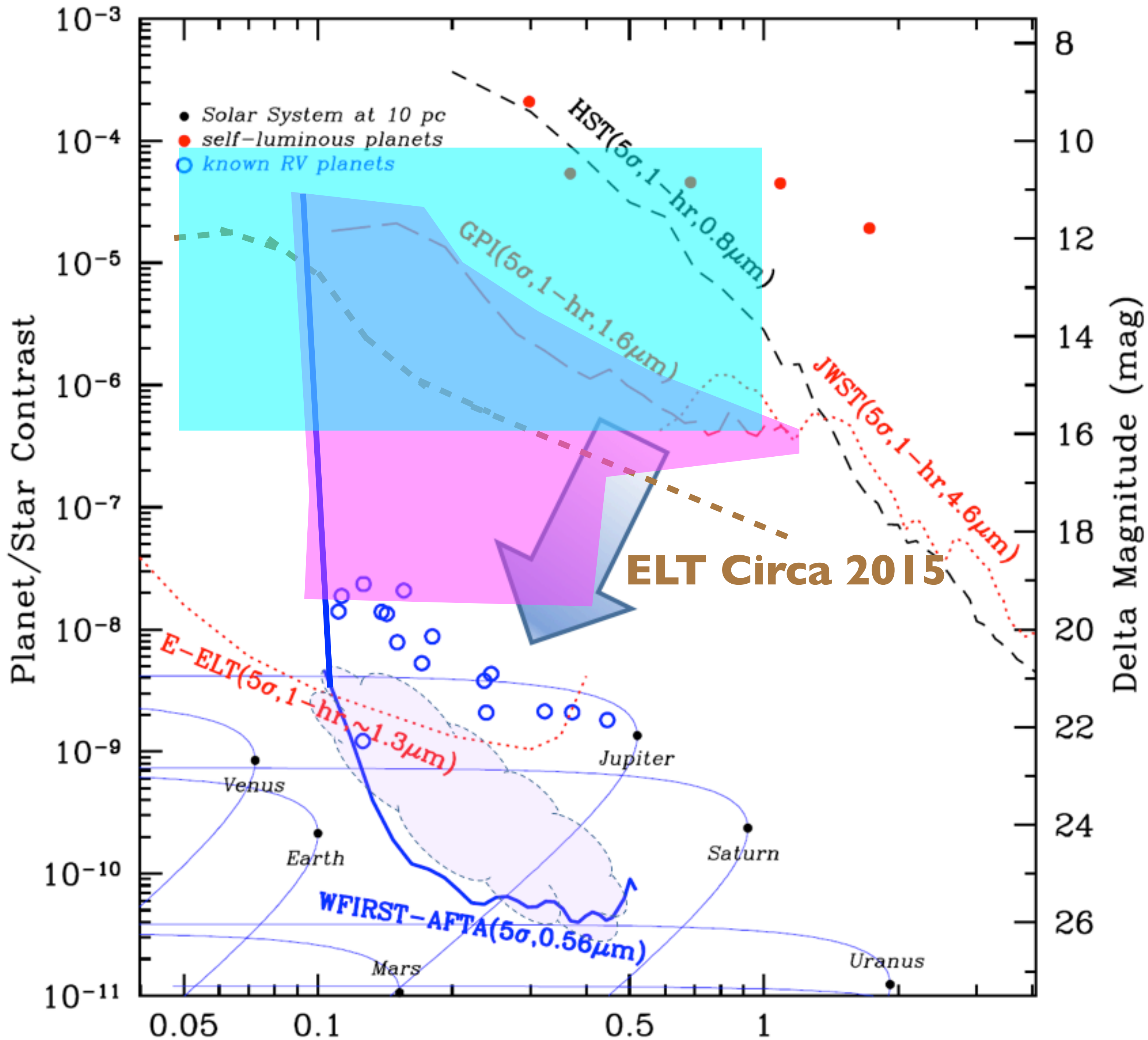

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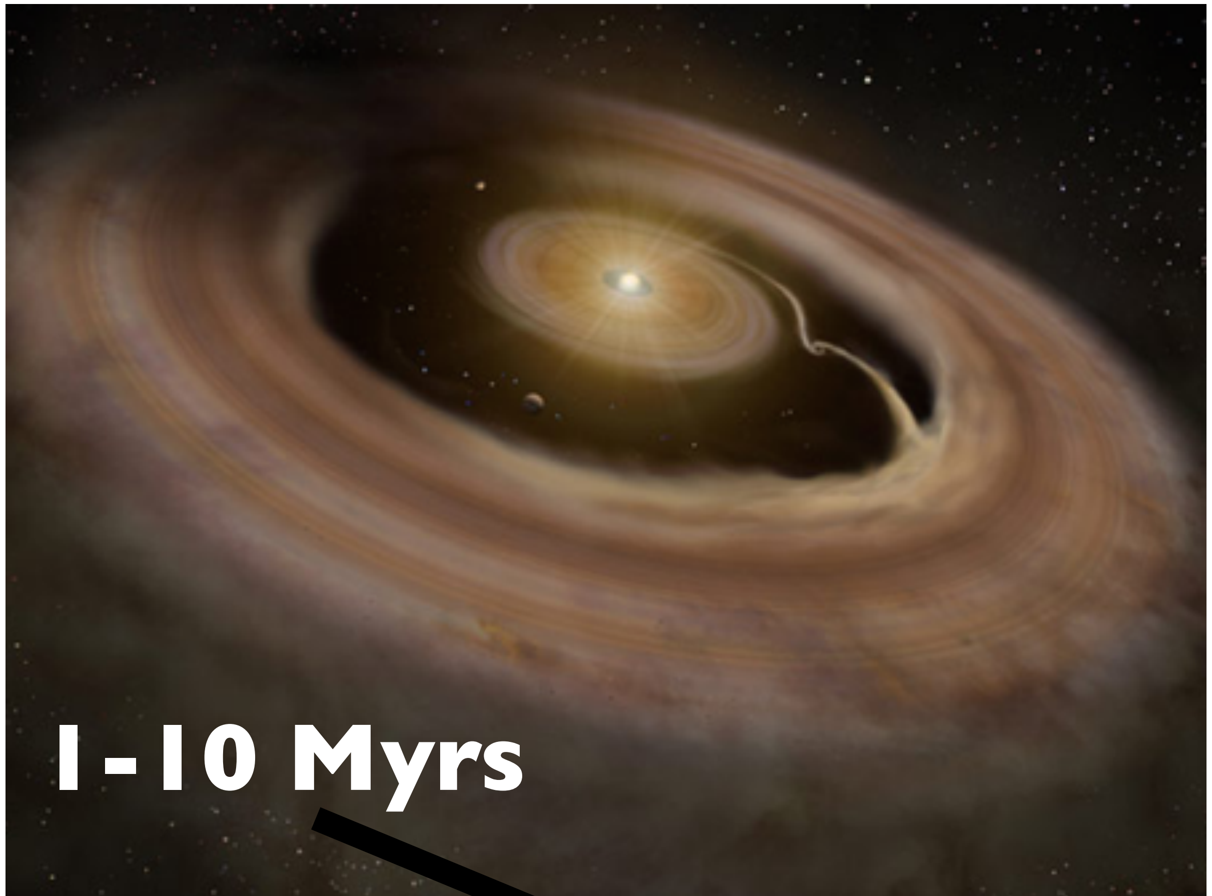

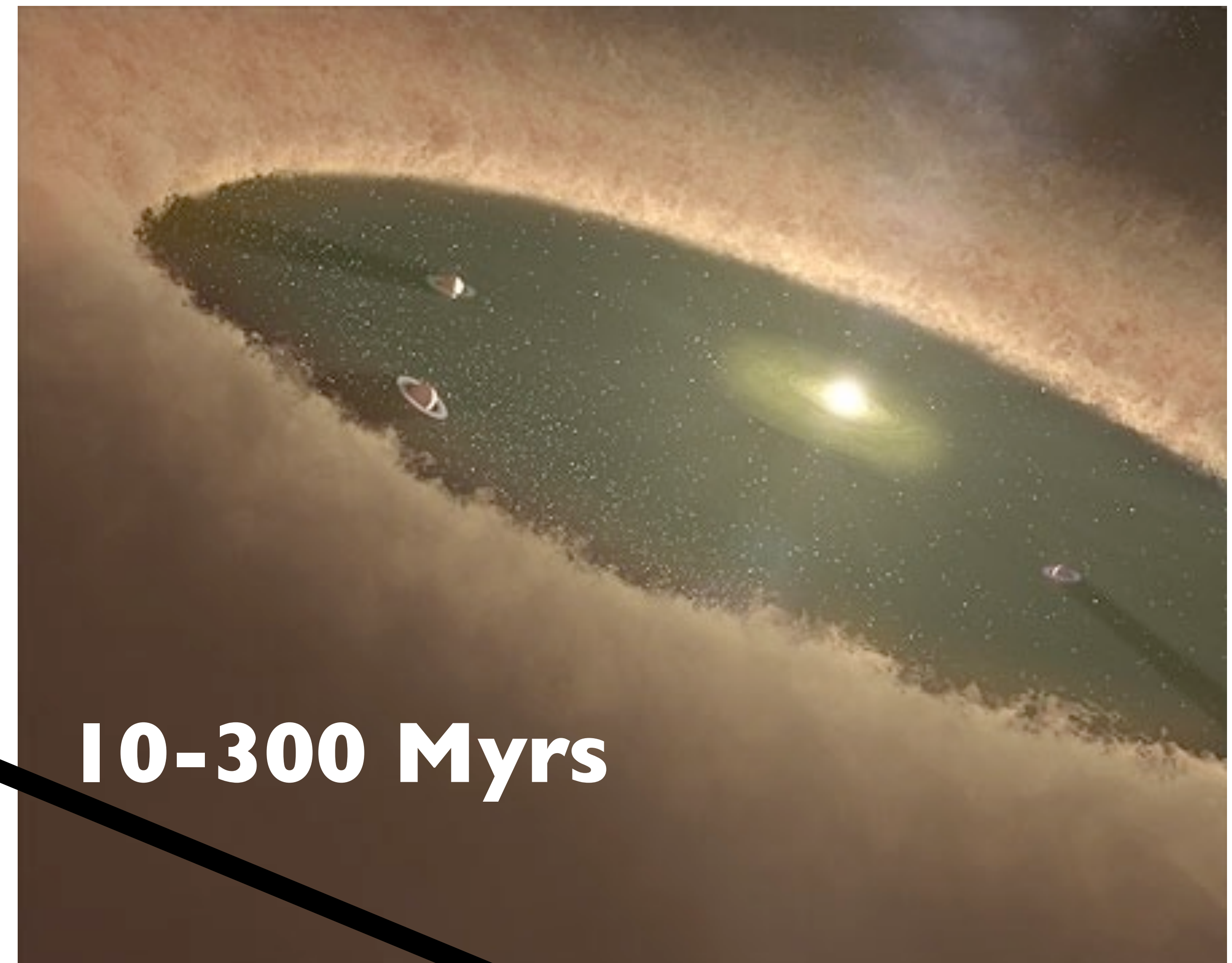

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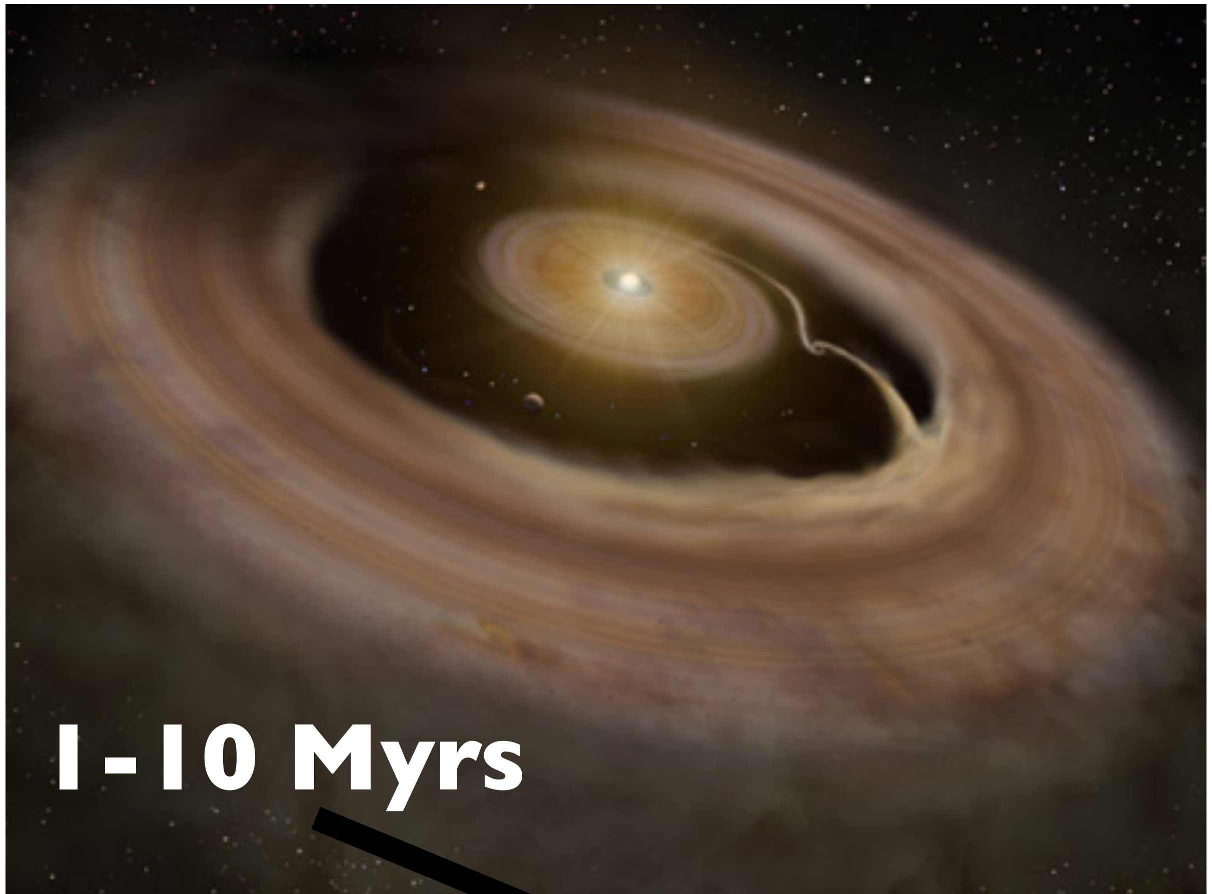
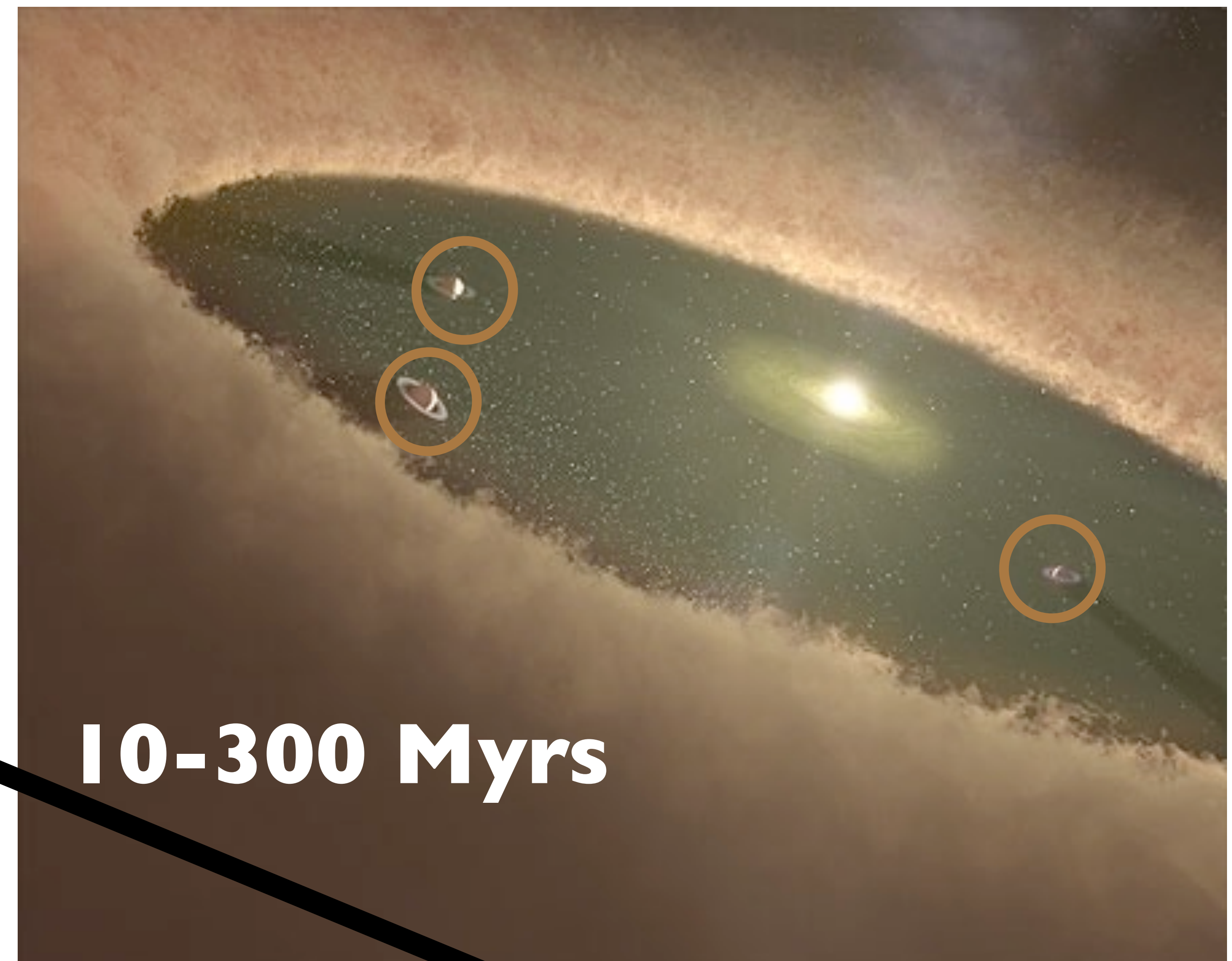
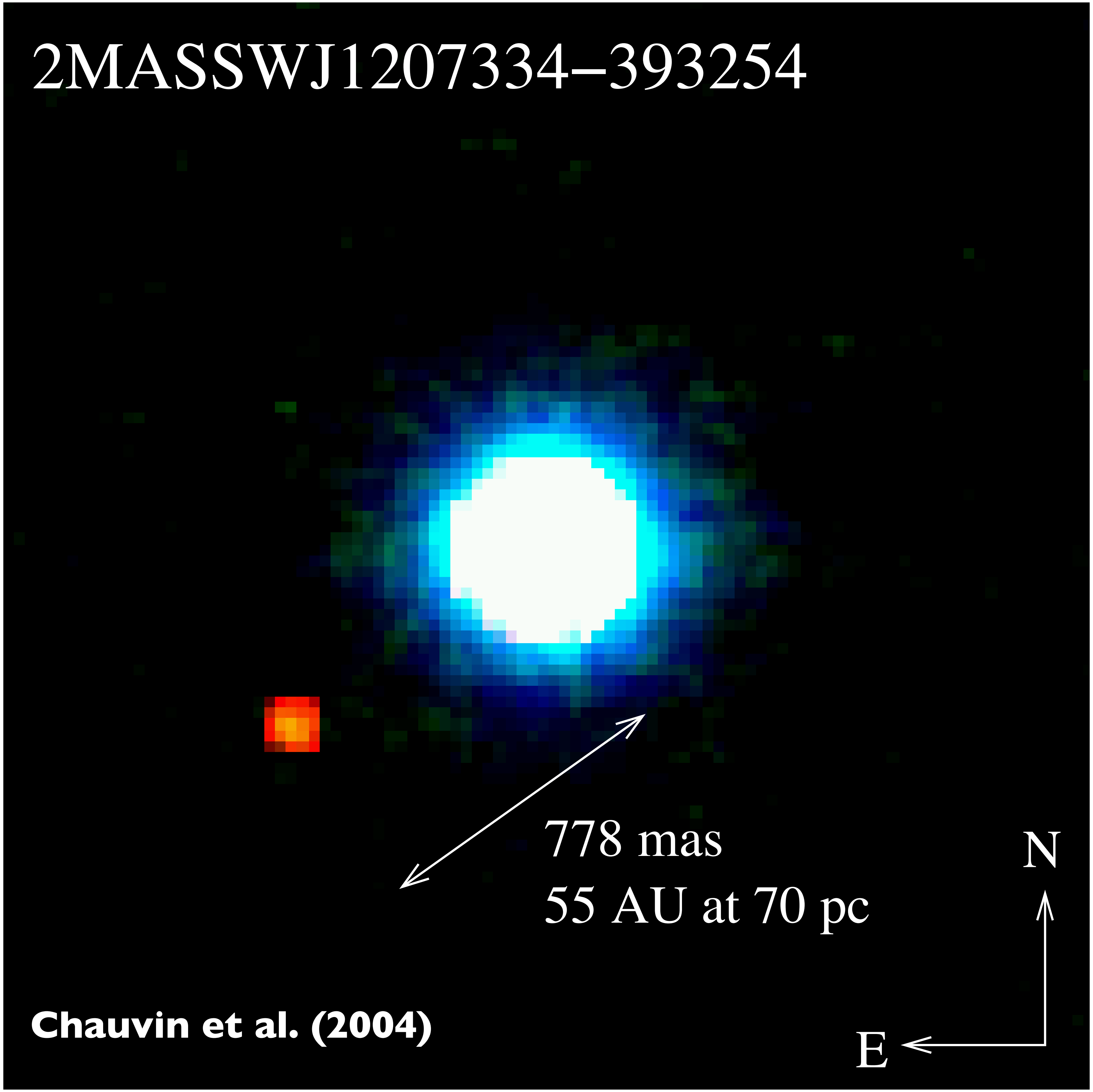




3. Adolescent-planets
and their atmospheres

5 Gyrs

Historical perspective on Extreme AO systems



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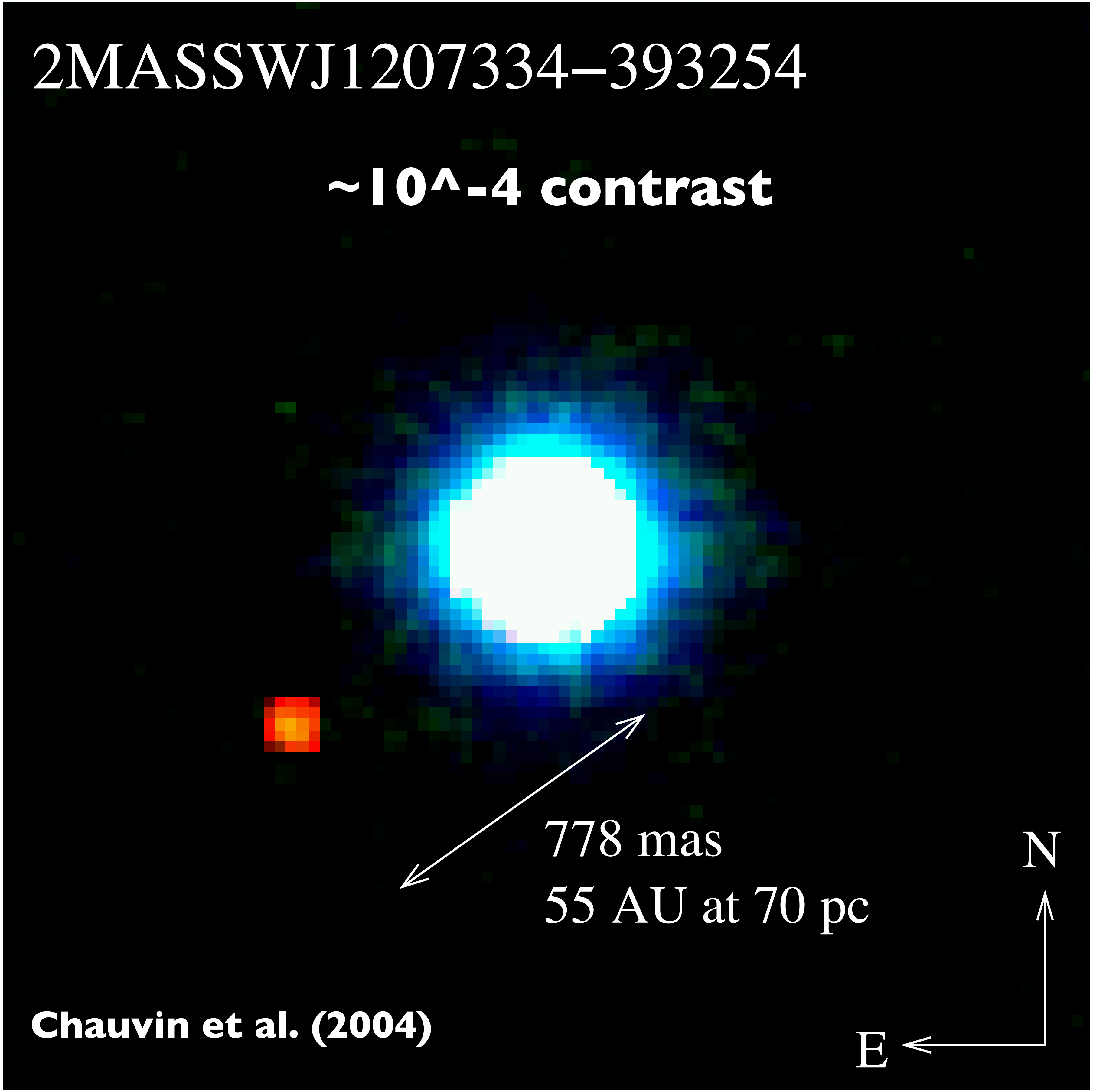

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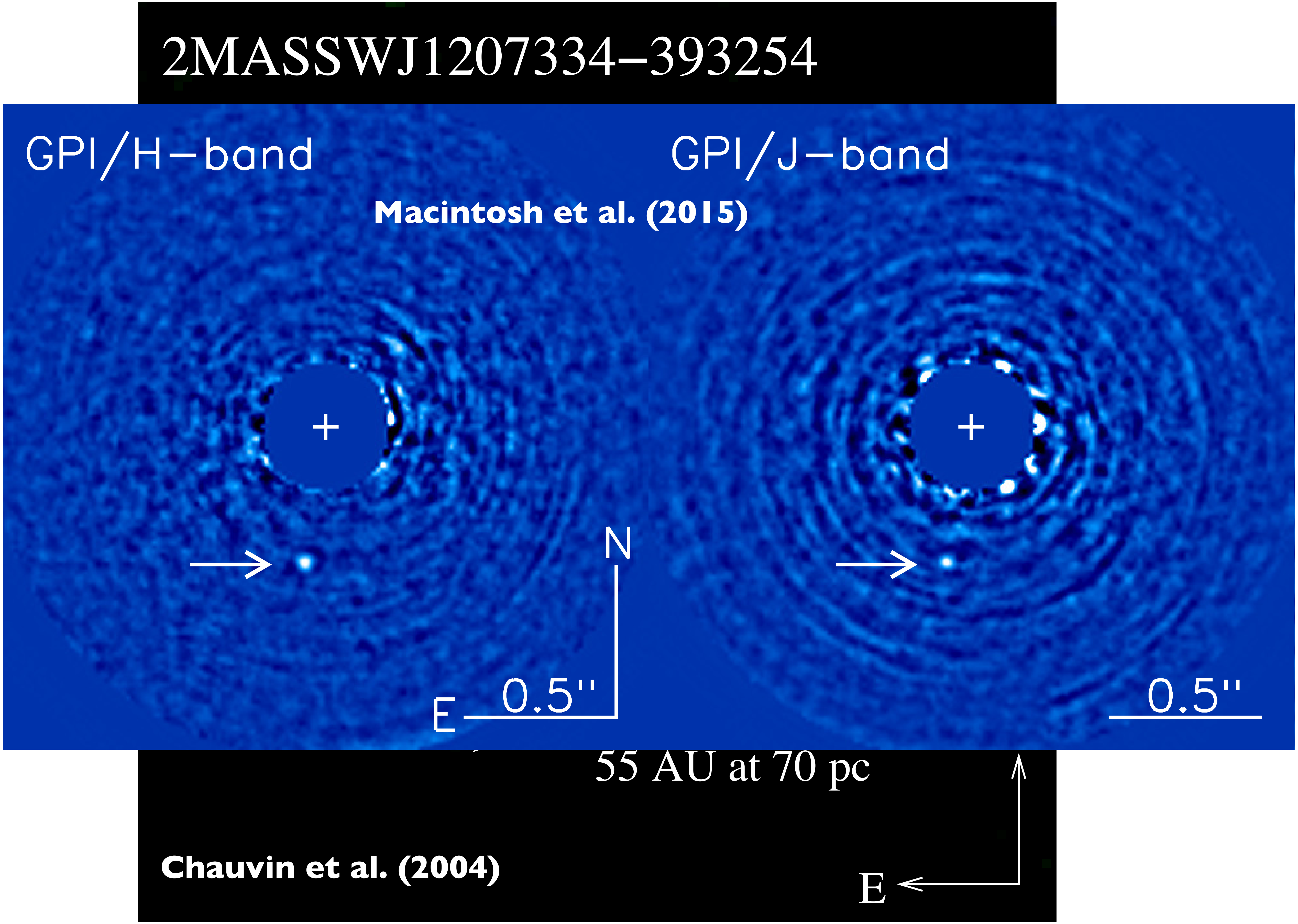

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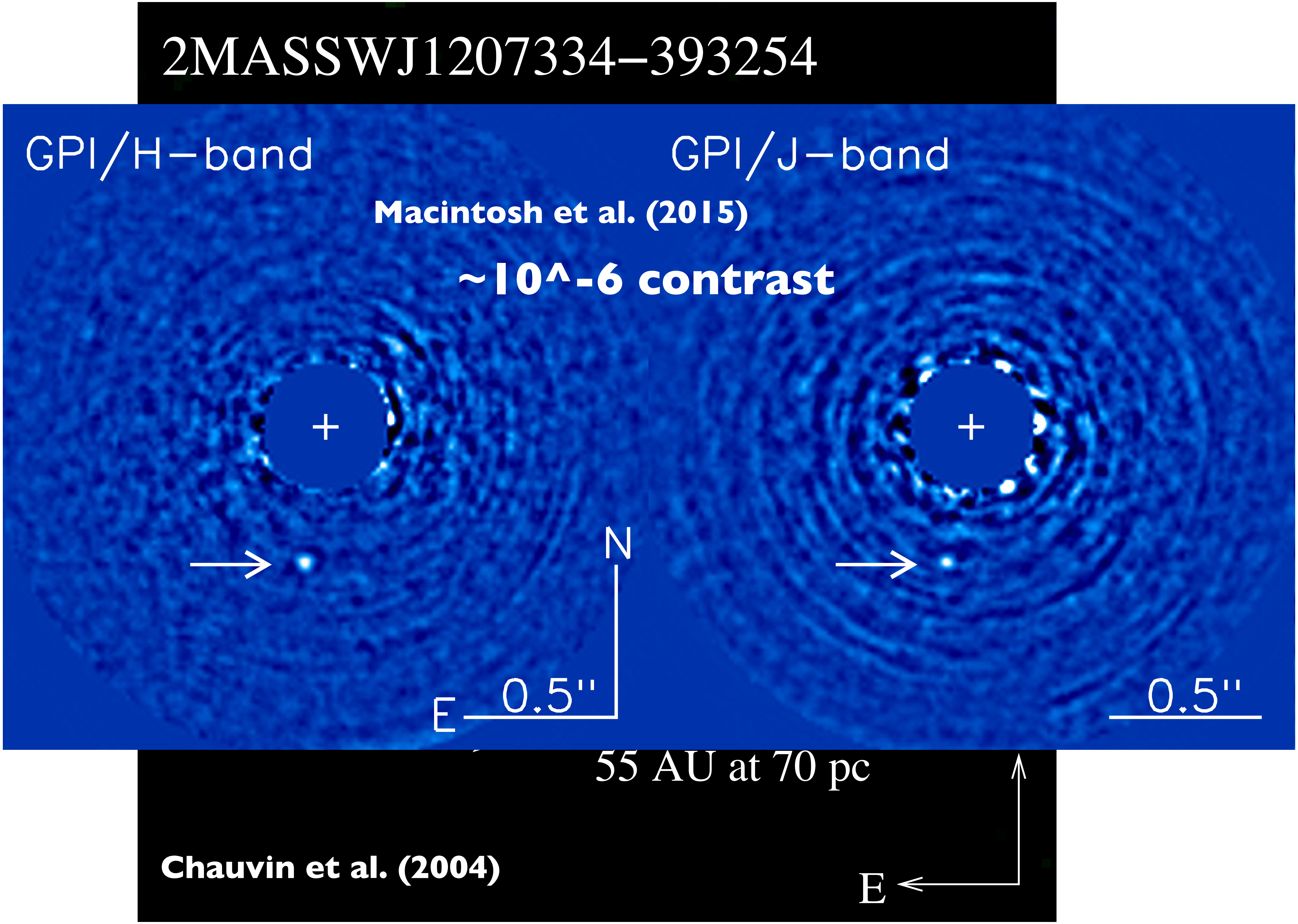
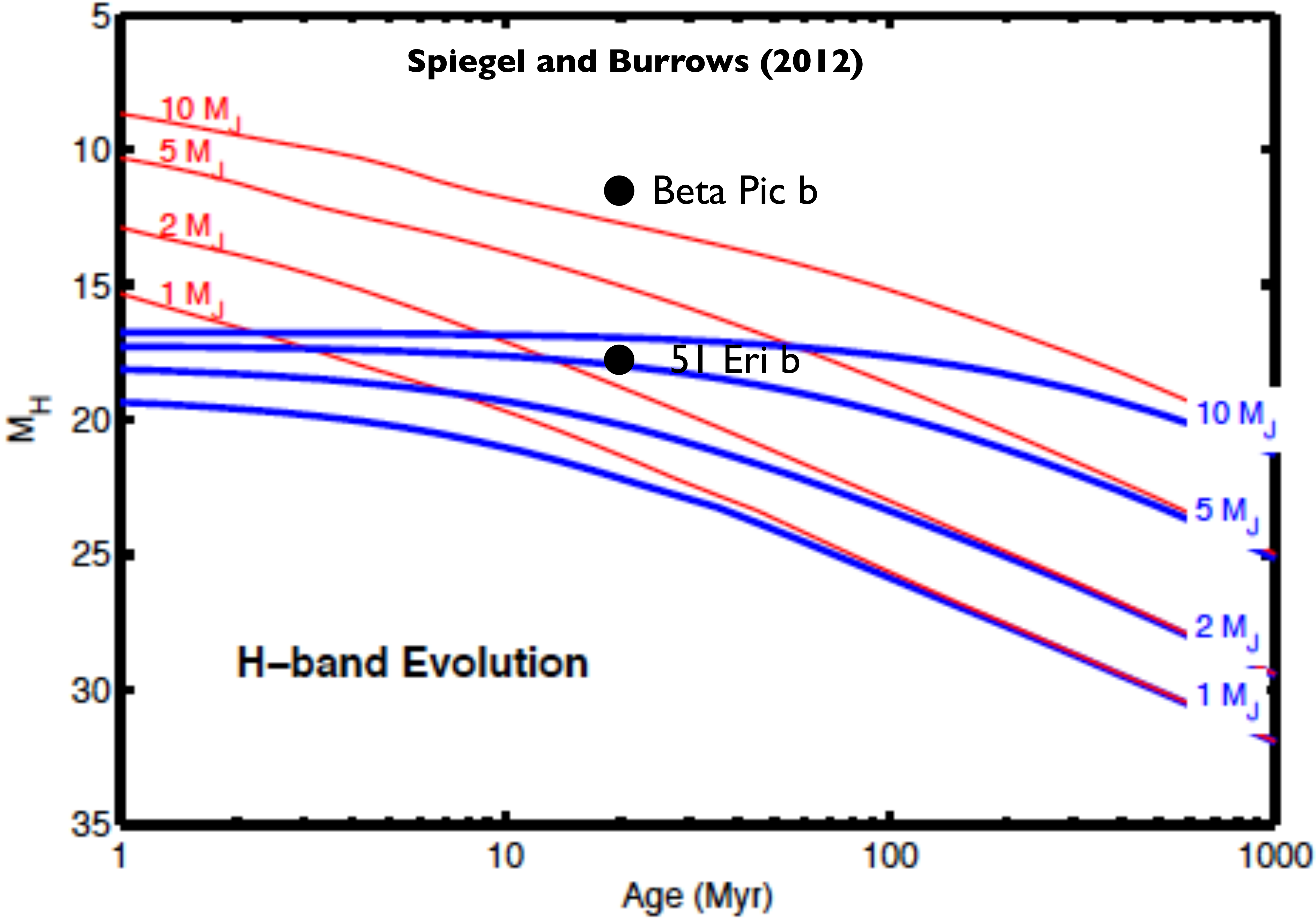


51 Eri b, first cold start candidate



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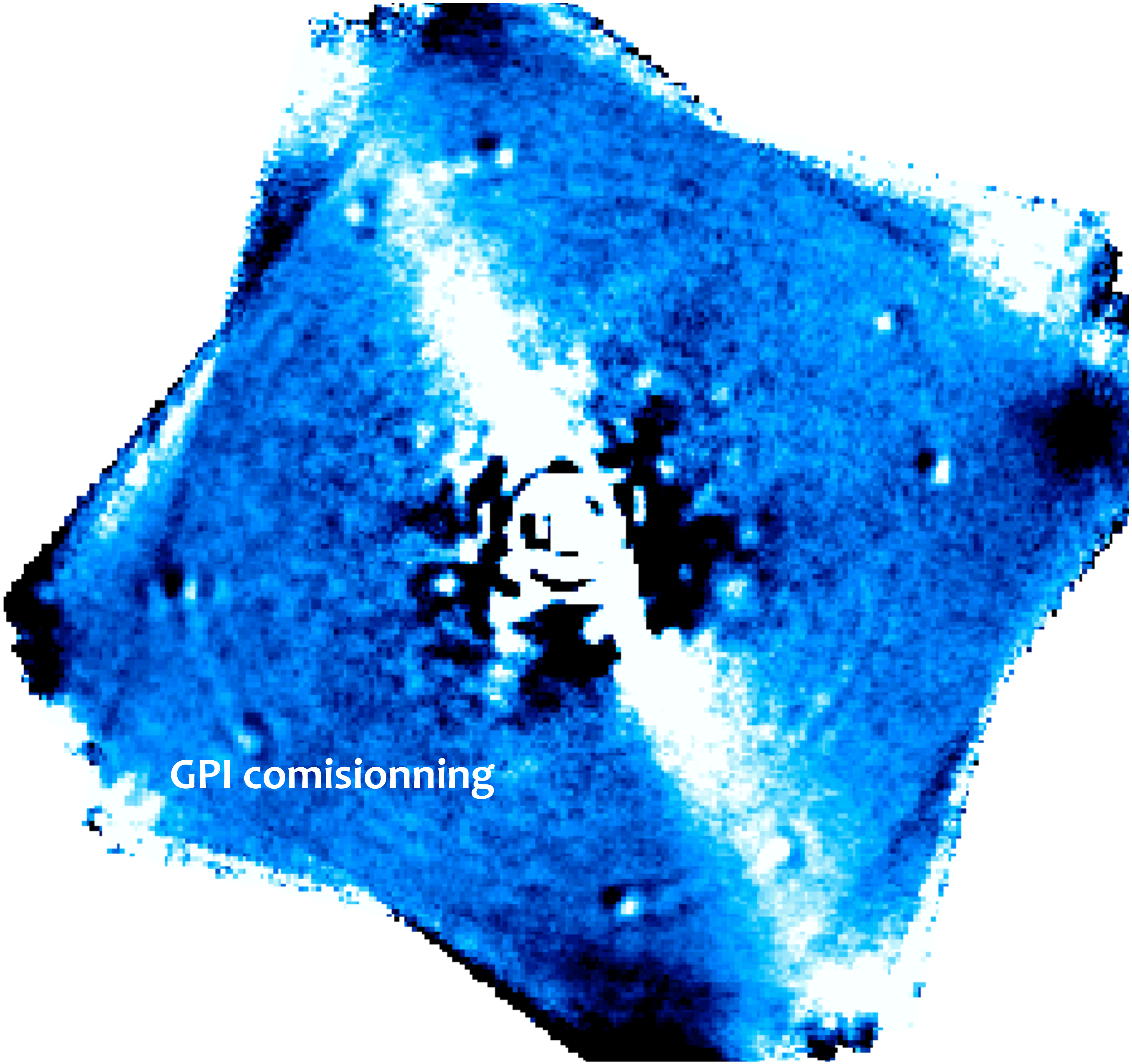

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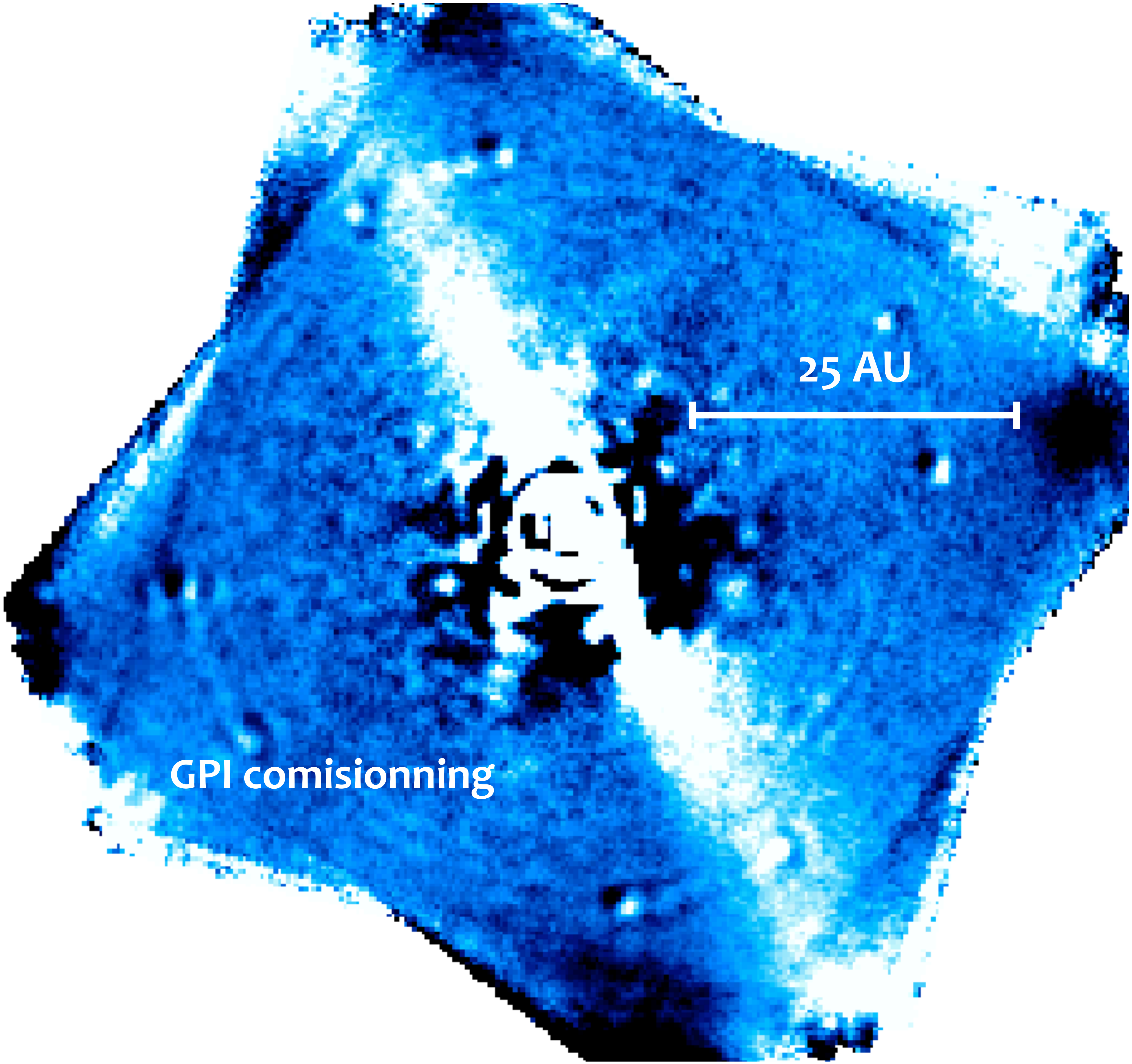

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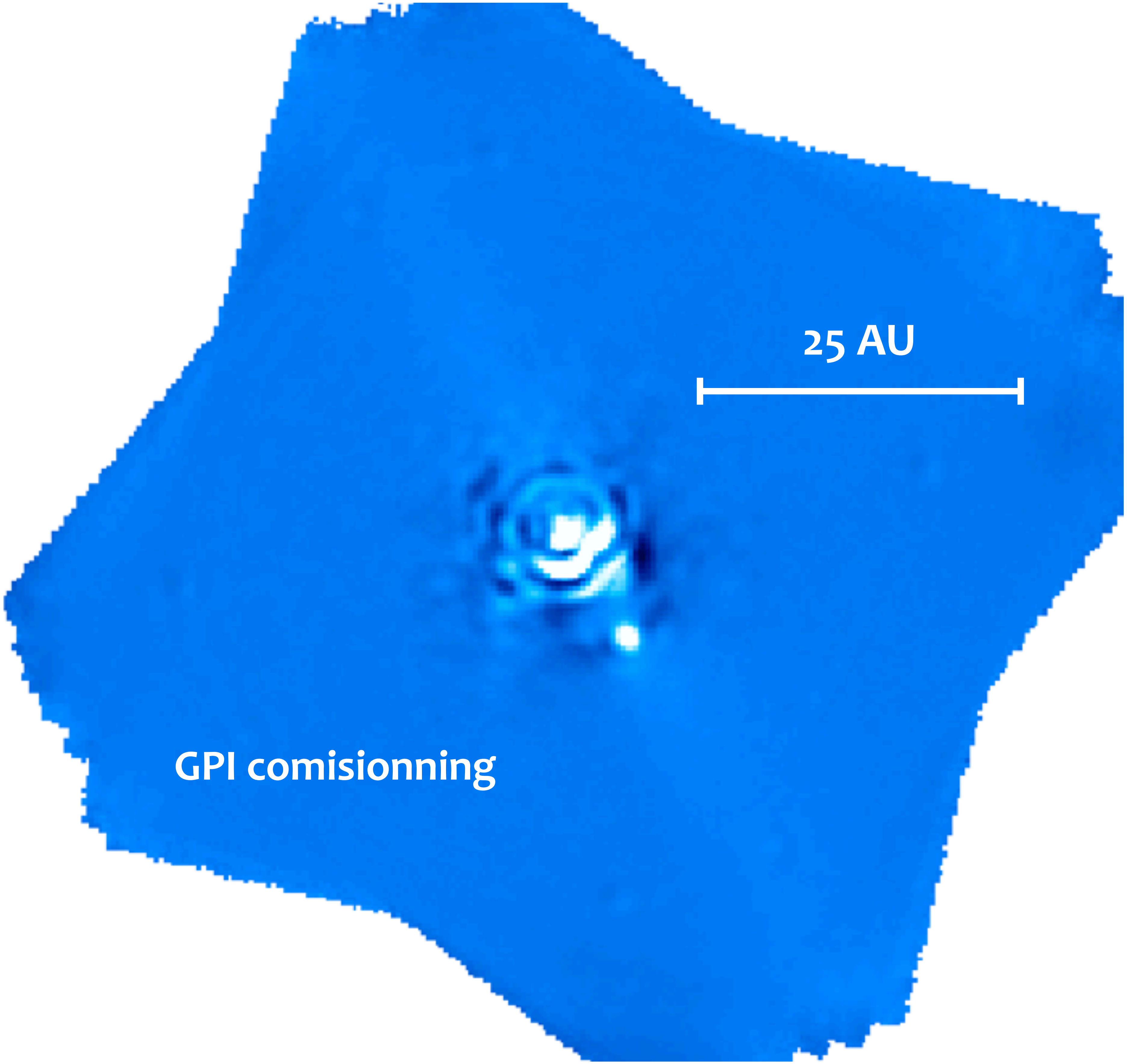

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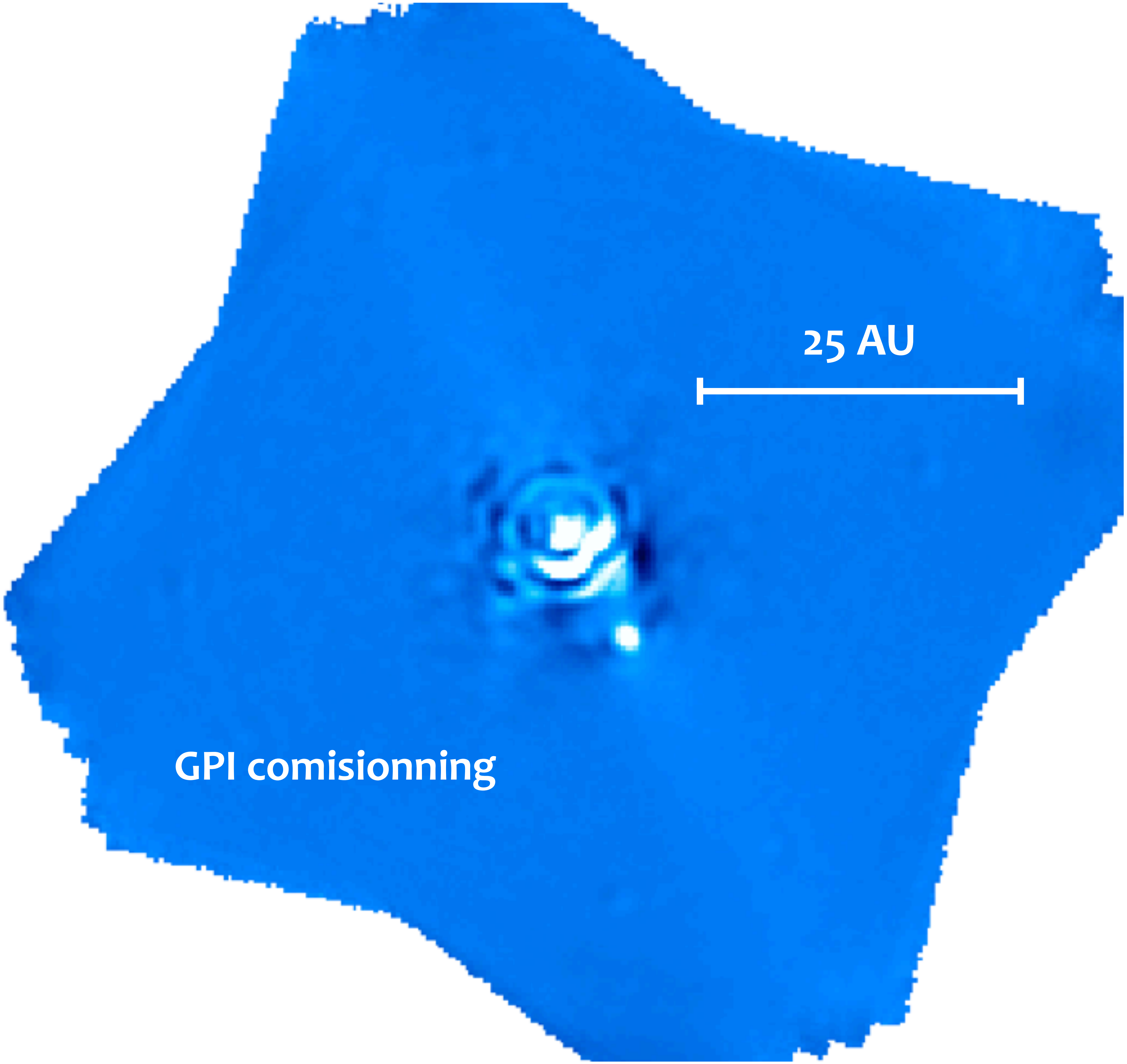
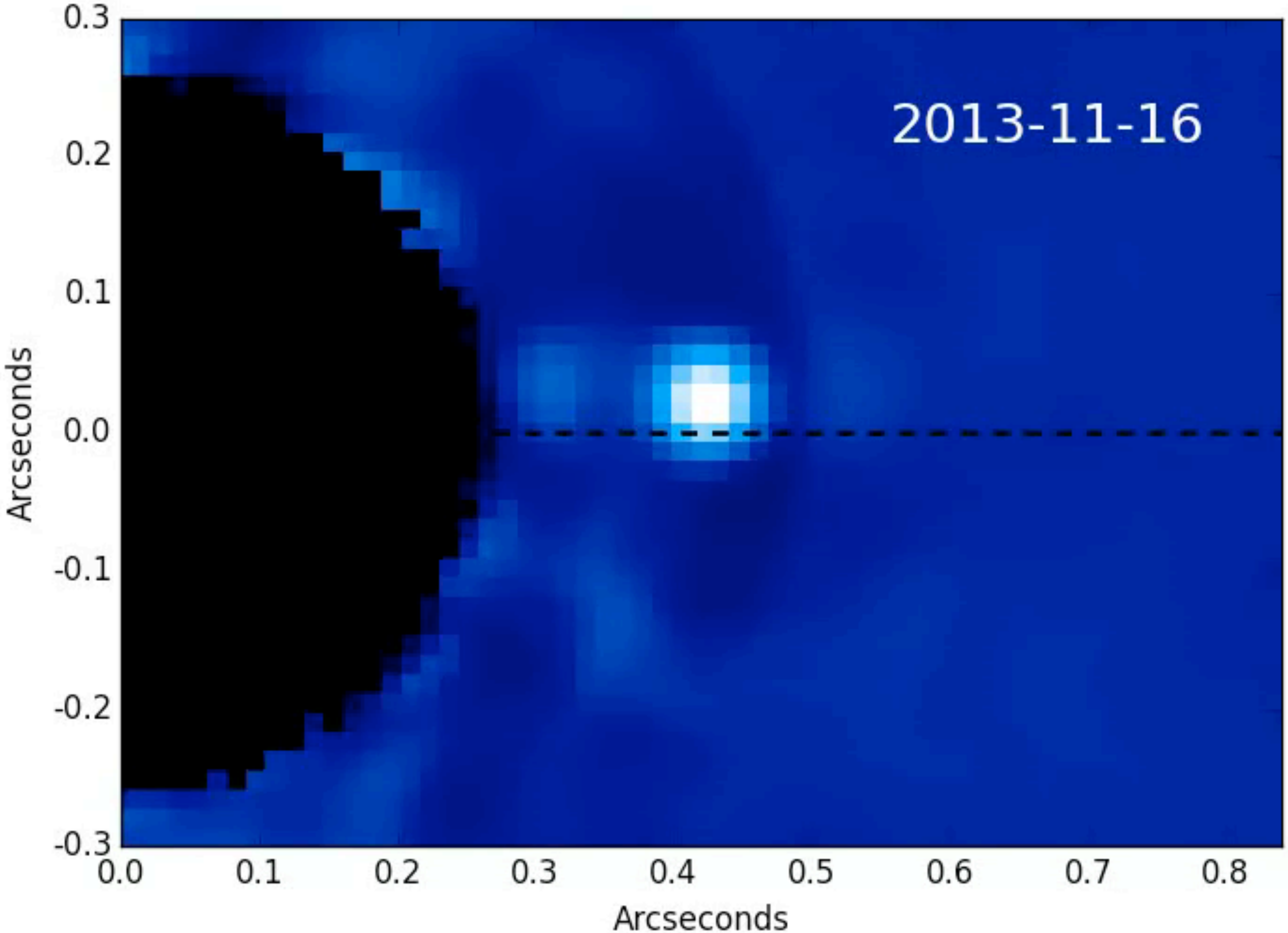
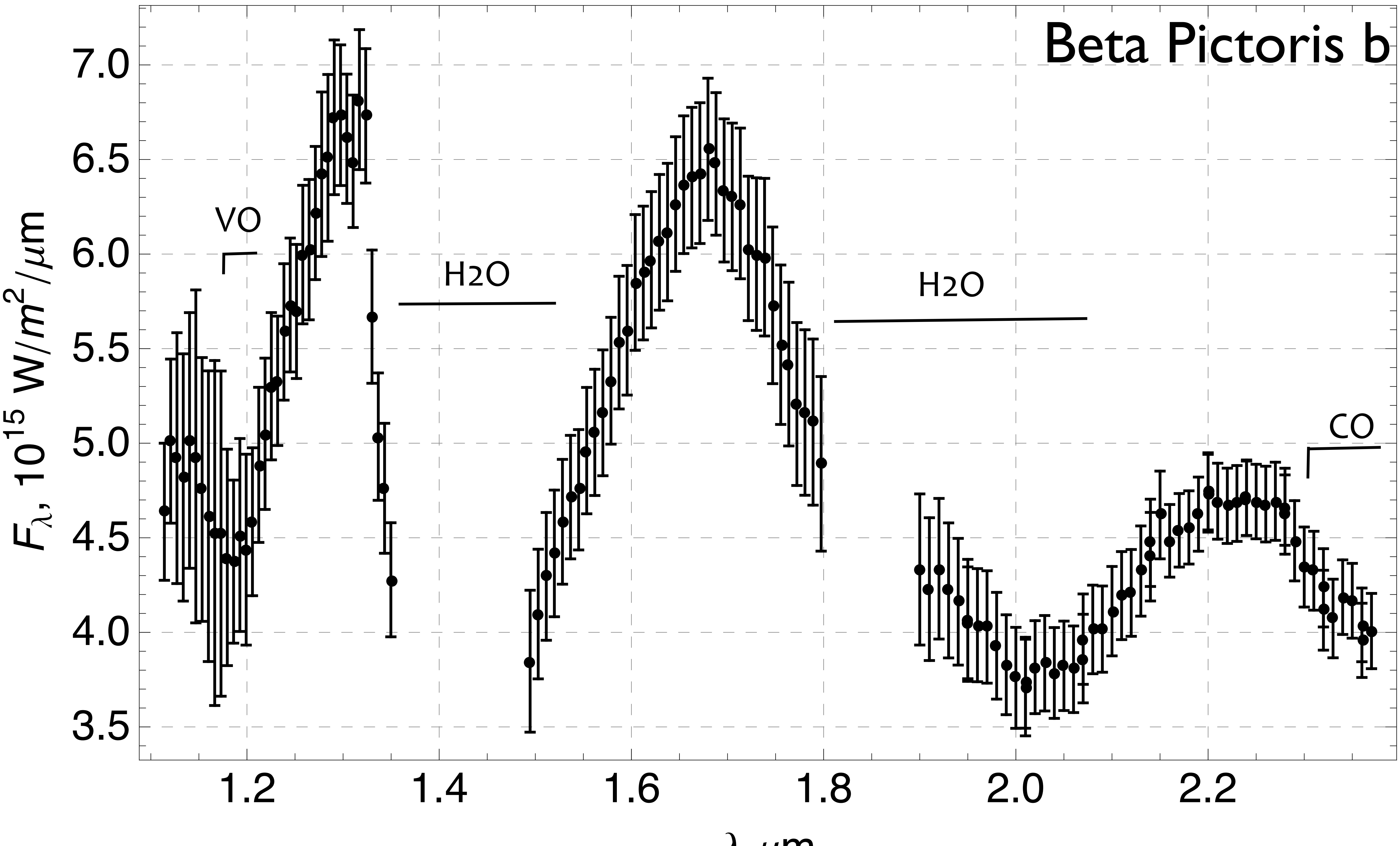


The orbit of Beta Pictoris b



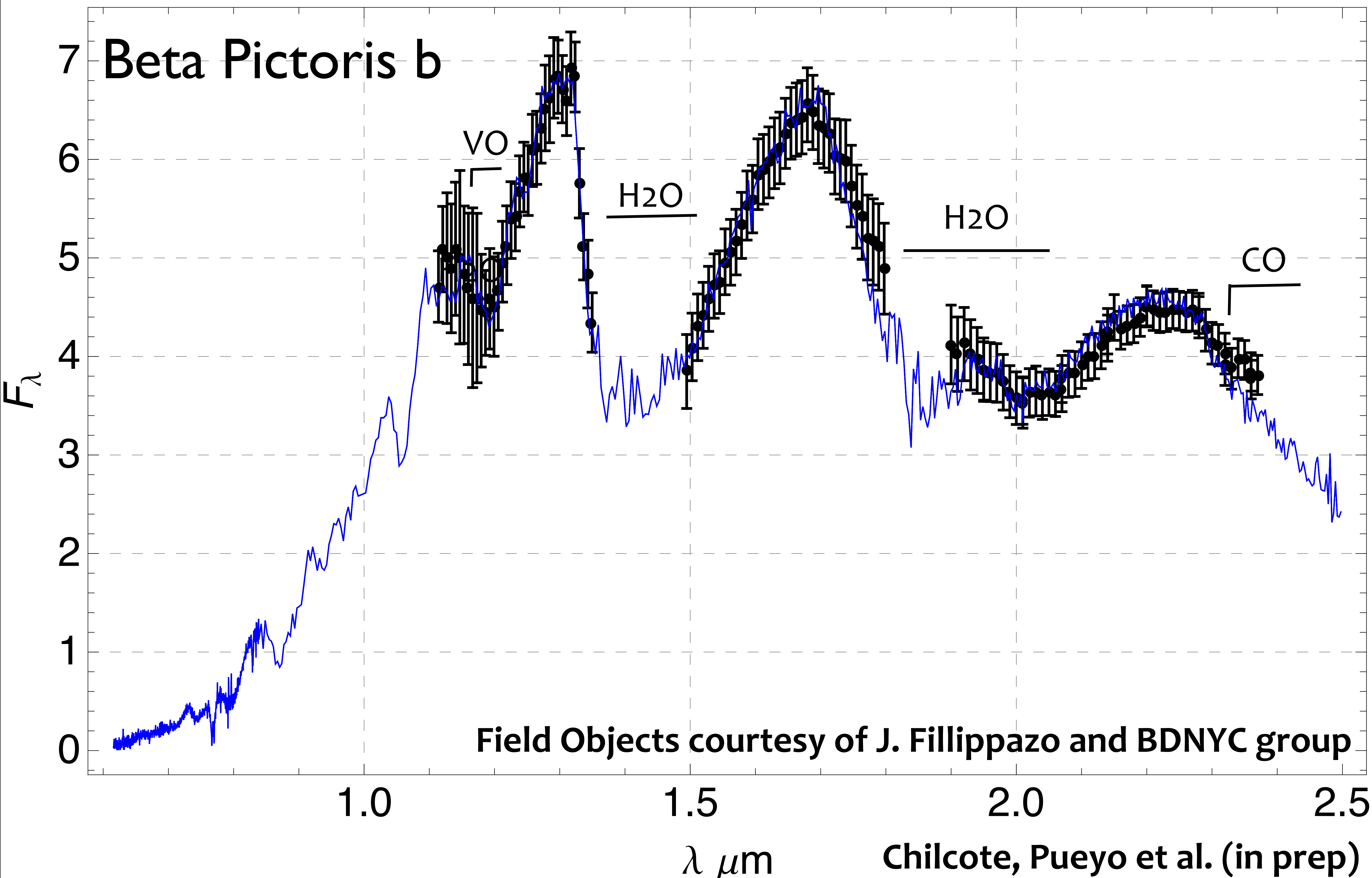
Millar-Blanchaer, et al. (2015)

GPI spectrum of Beta Pictoris b



Chilcote, Pueyo et al. (in prep)

Brown Dwarfs: empirical sample for context



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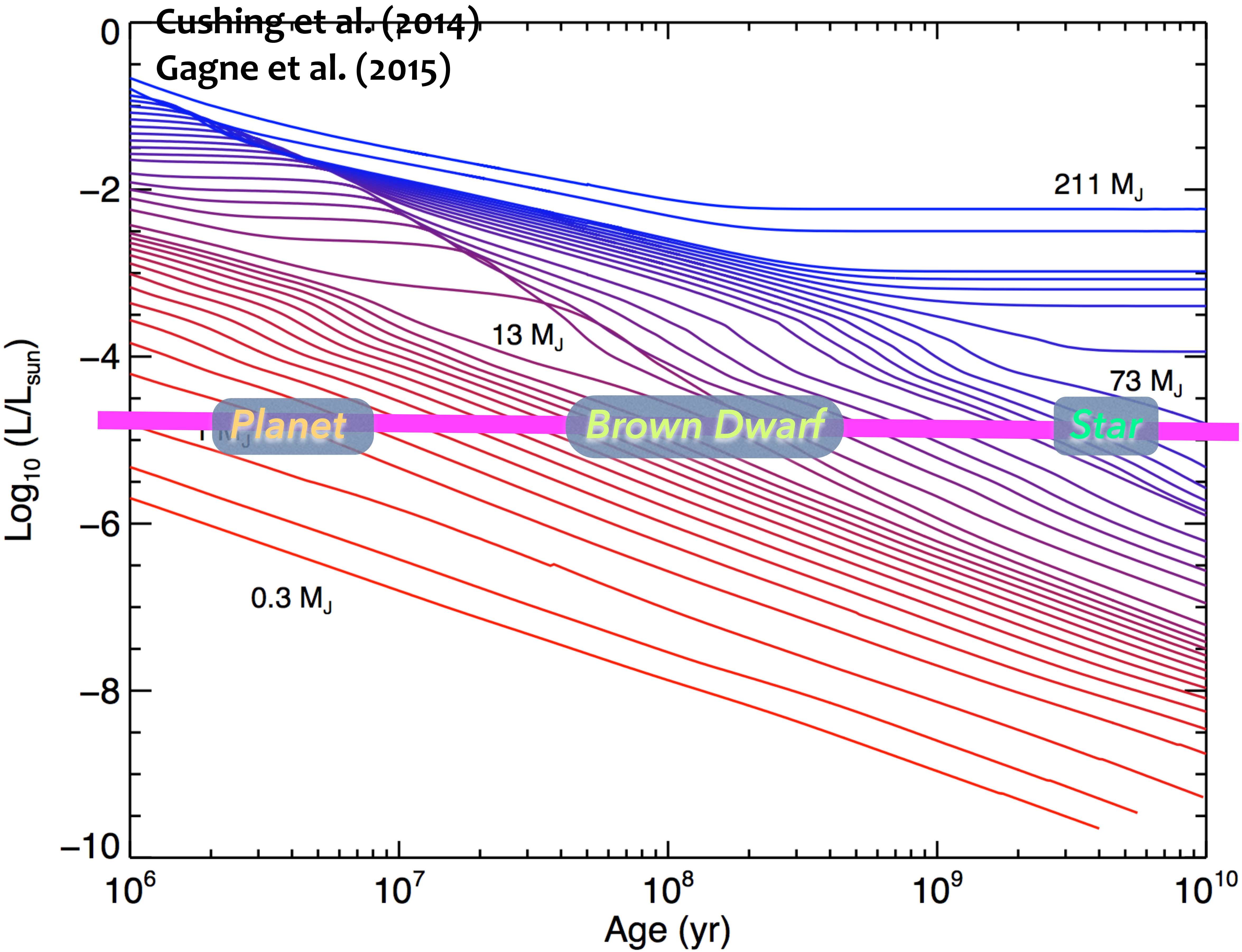

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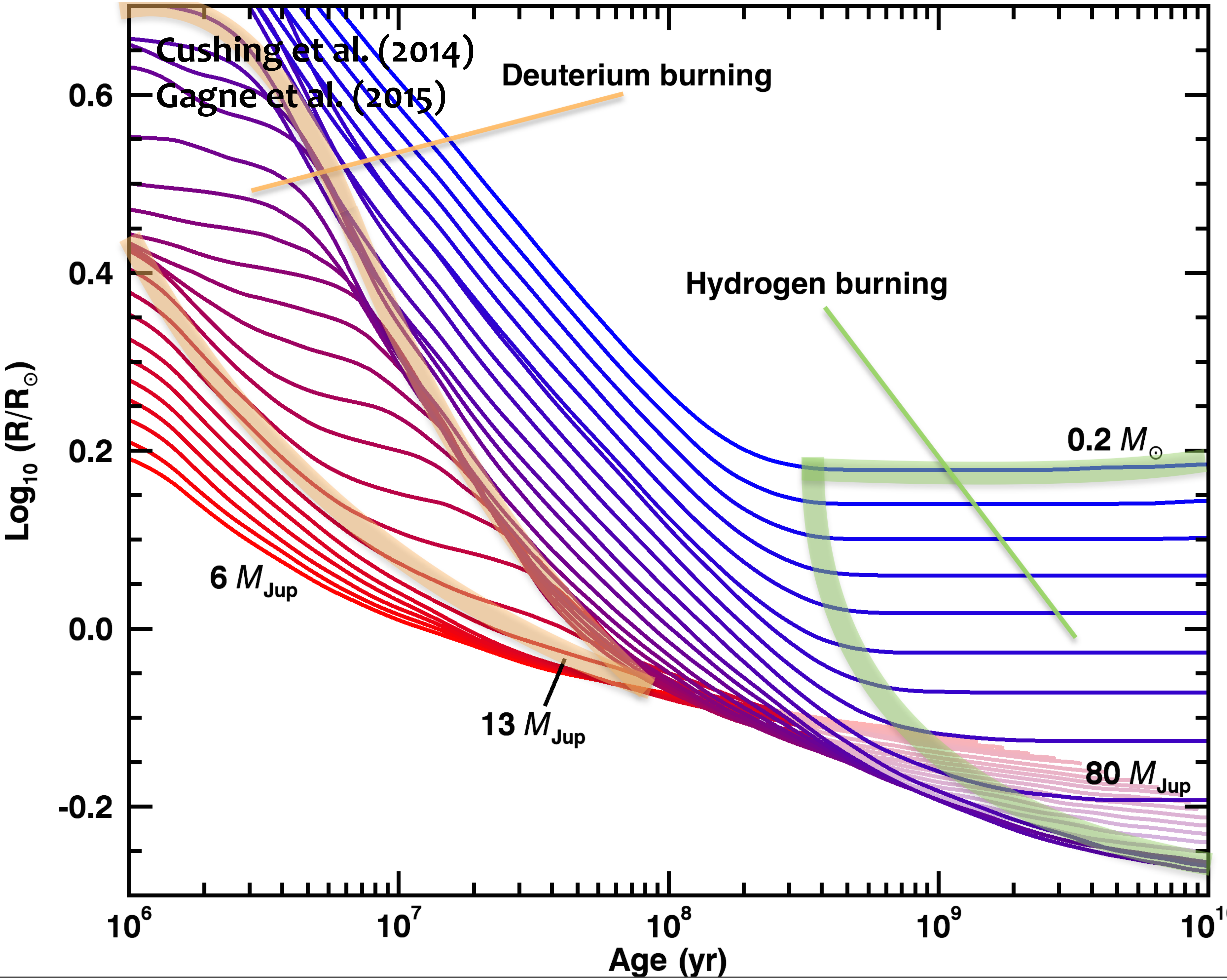

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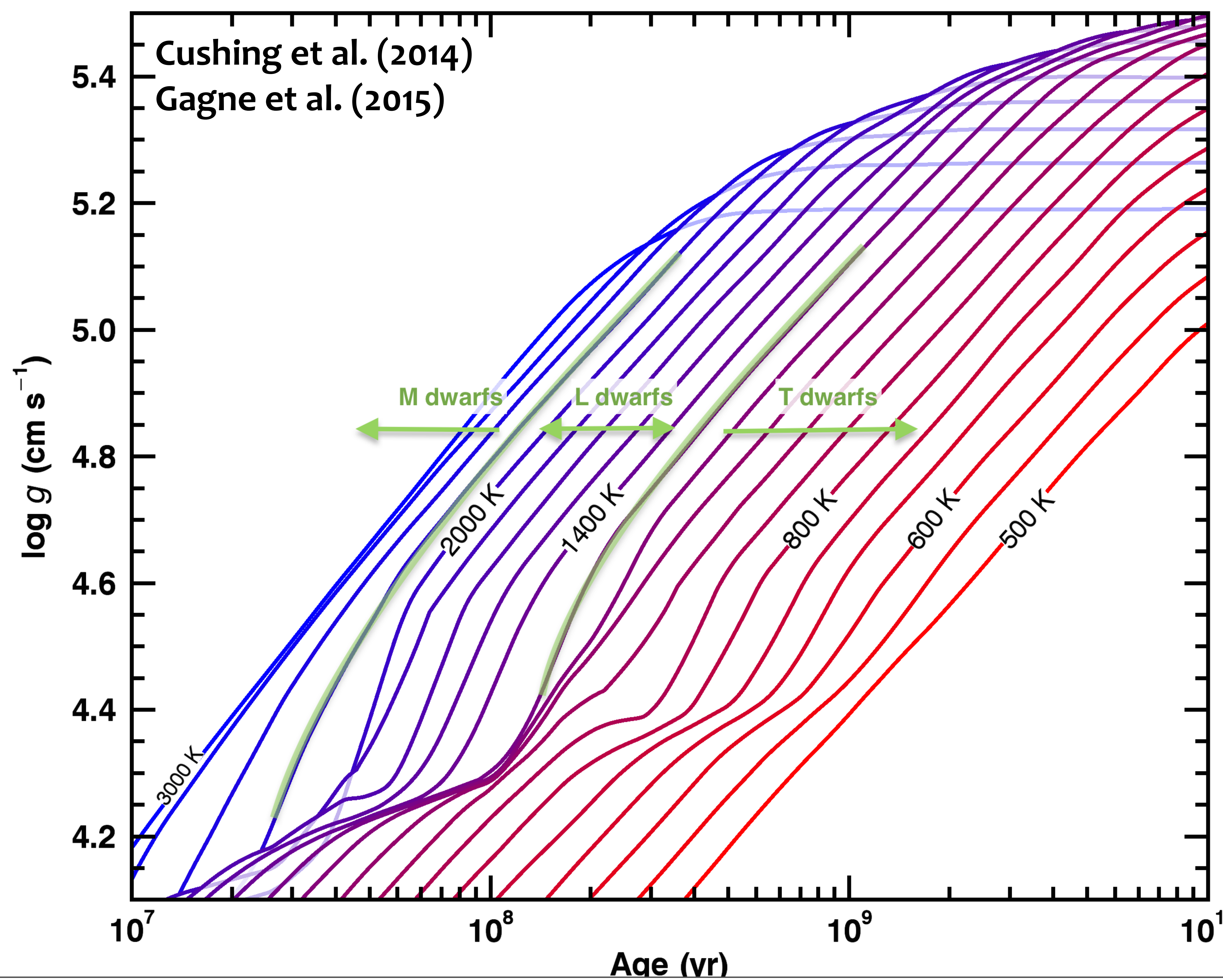

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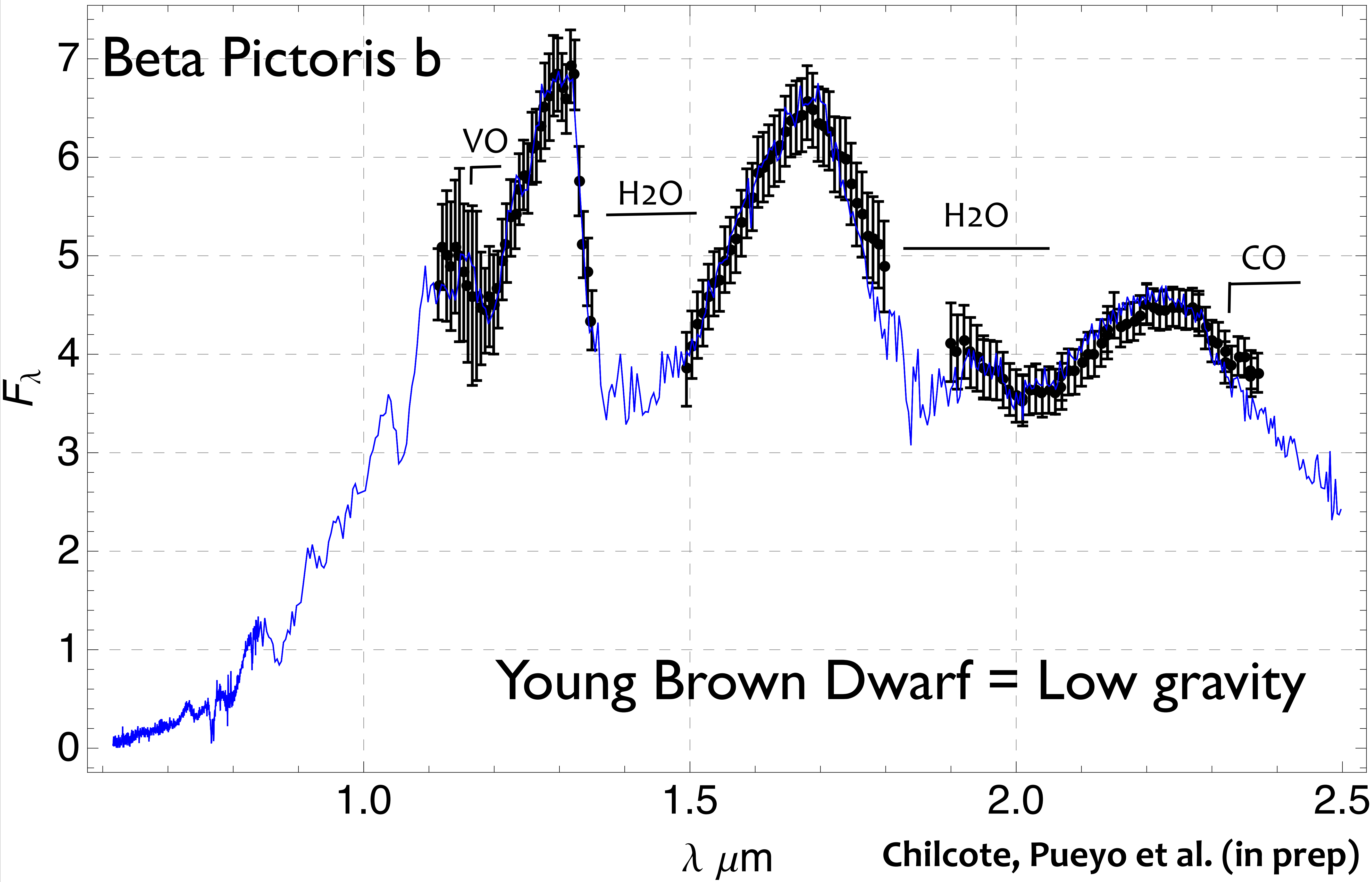

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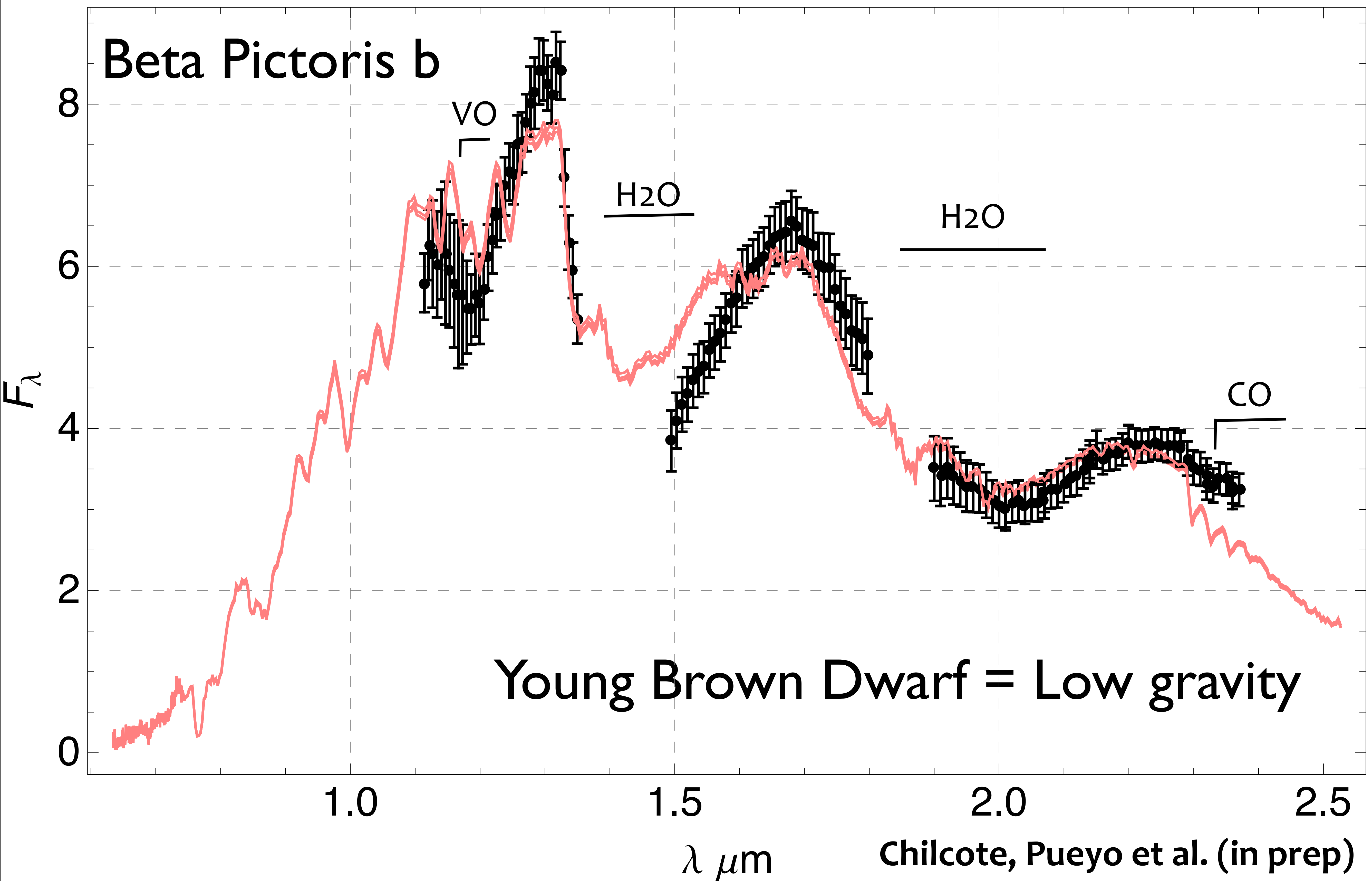

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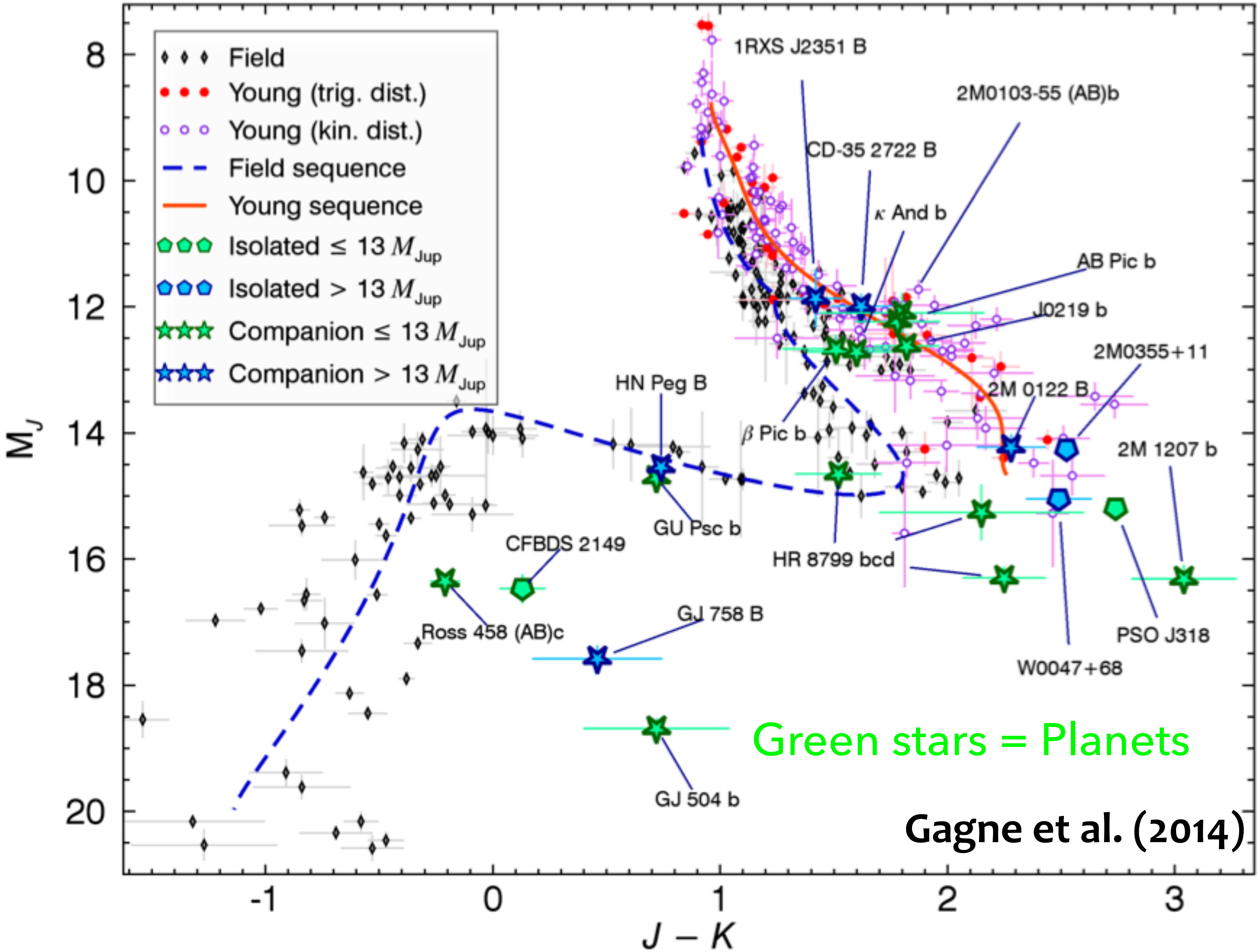
How do we find low gravity brown dwarfs?



Fainter end of the low gravity sequence incomplete. **WFIRST-WFI will address this.**

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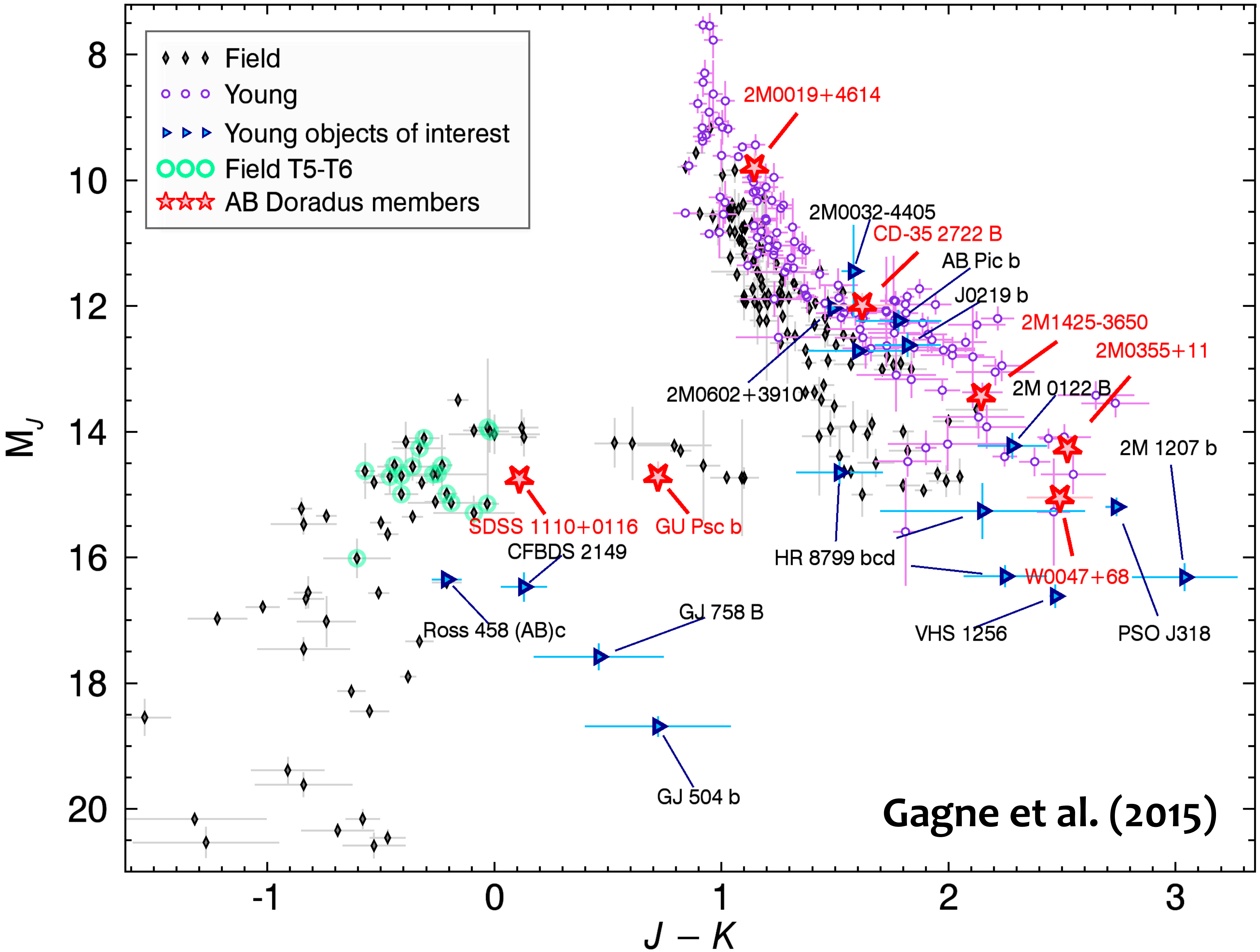

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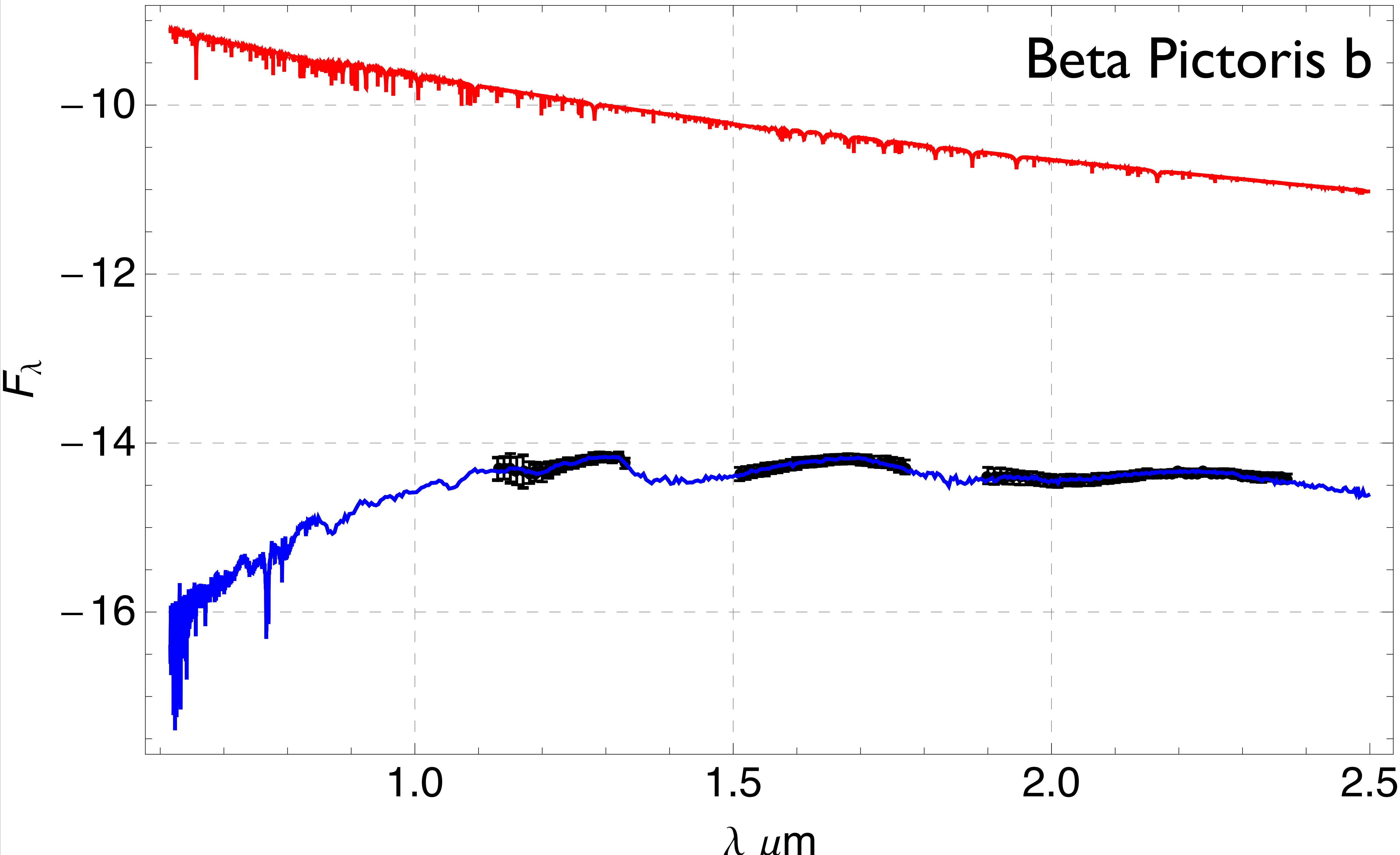

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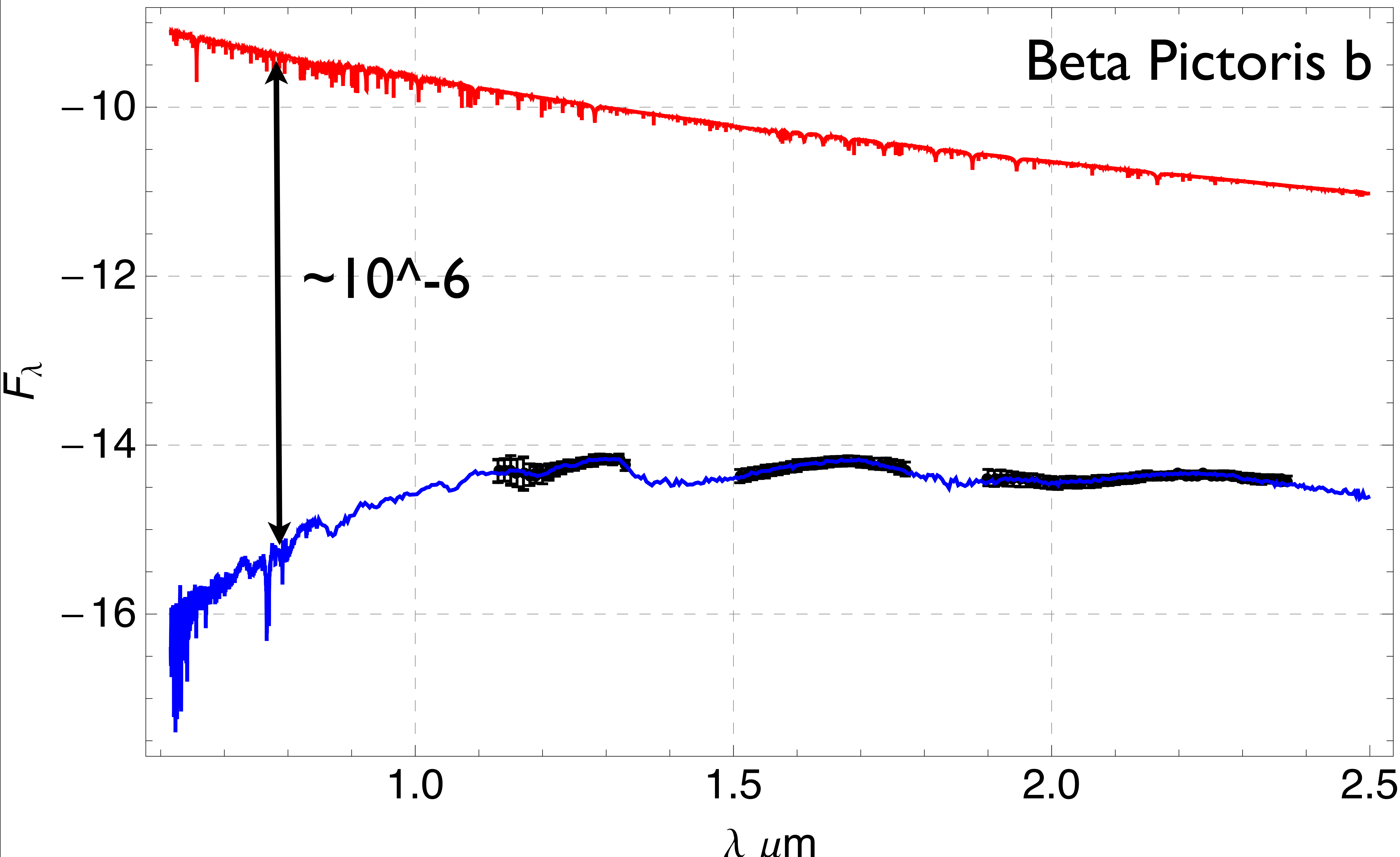

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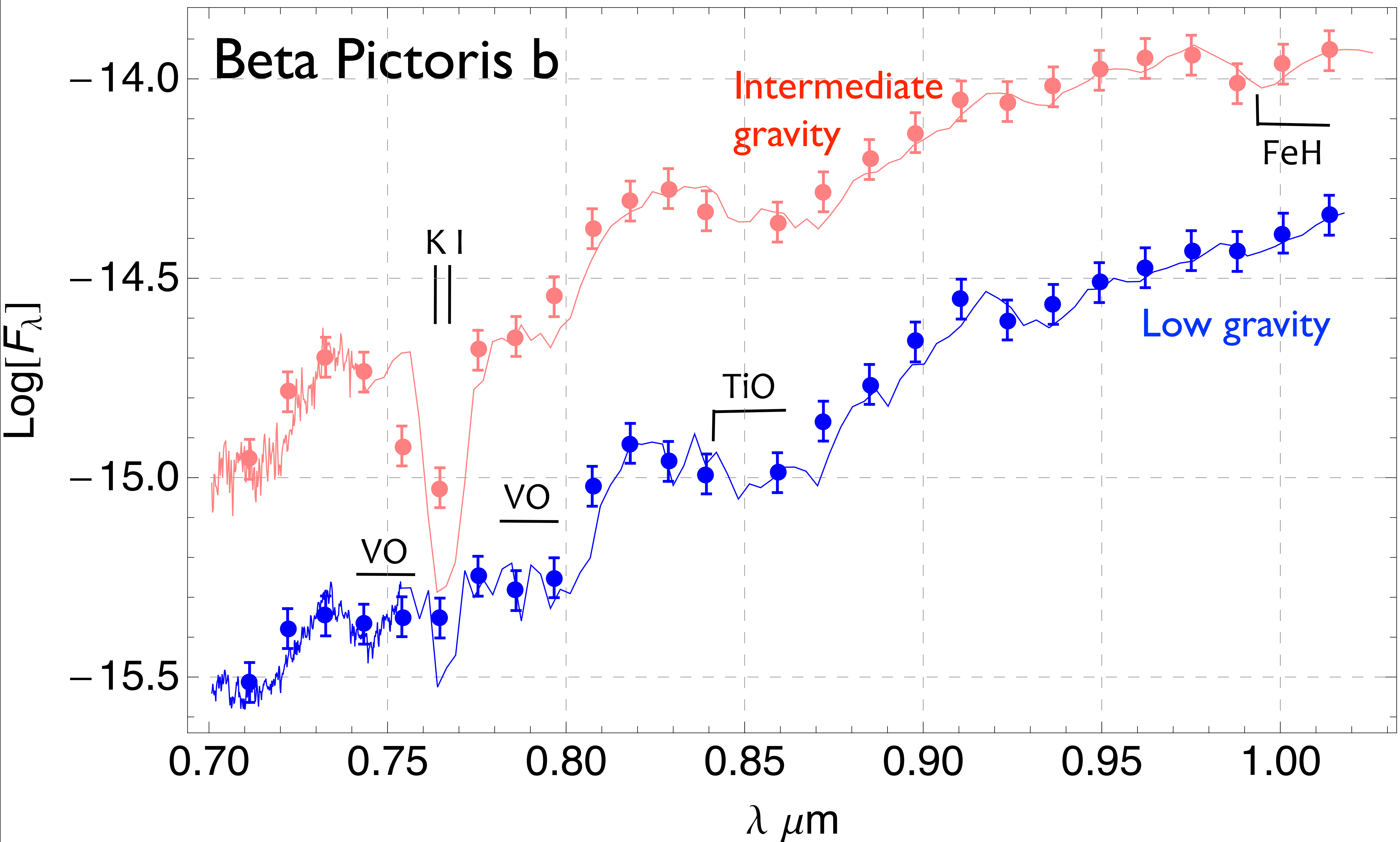
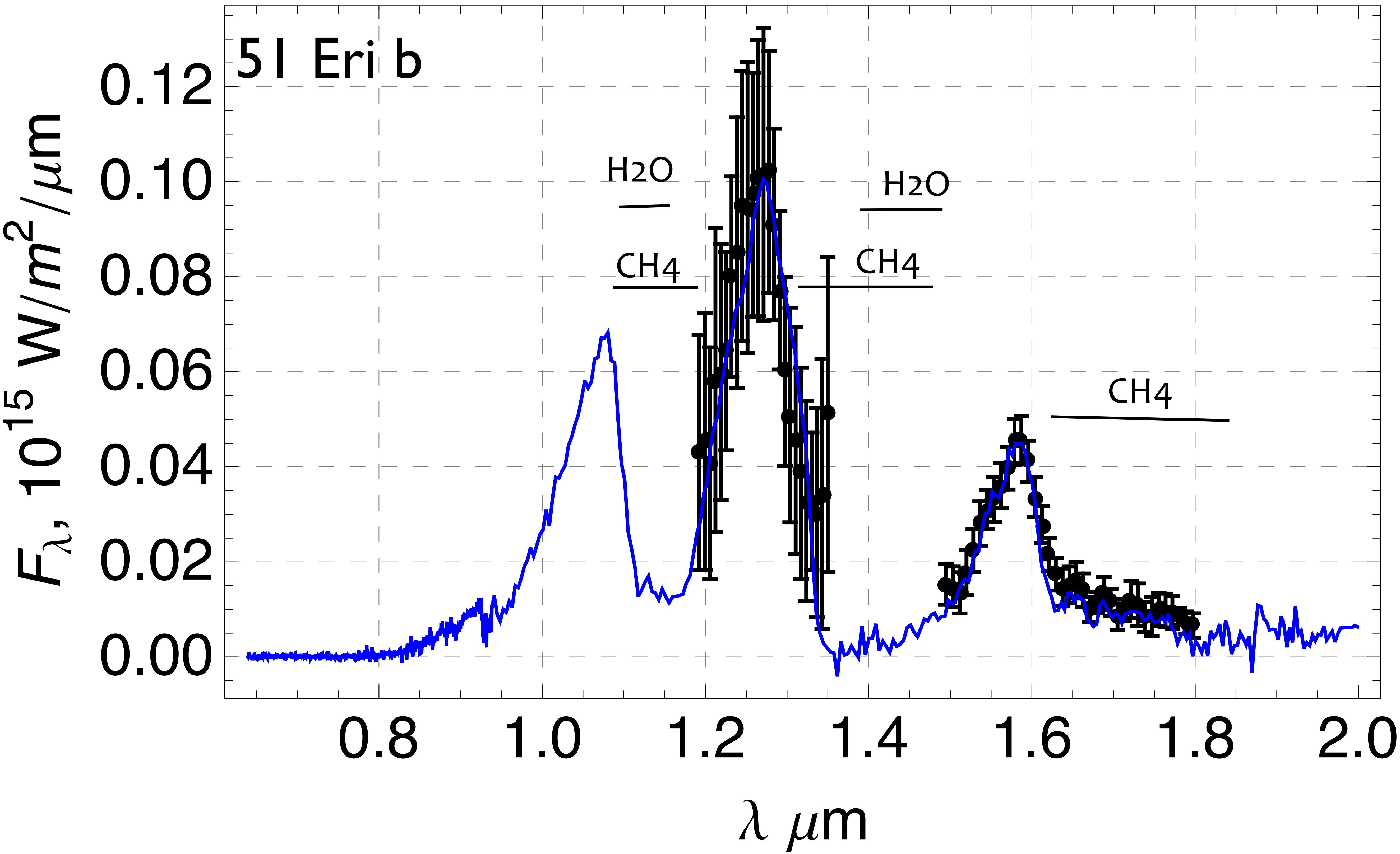
We can learn more about these plantes with WFIRST



Visible spectrum: estimates of gravity and metallicity

Brown Dwarfs: empirical sample for context



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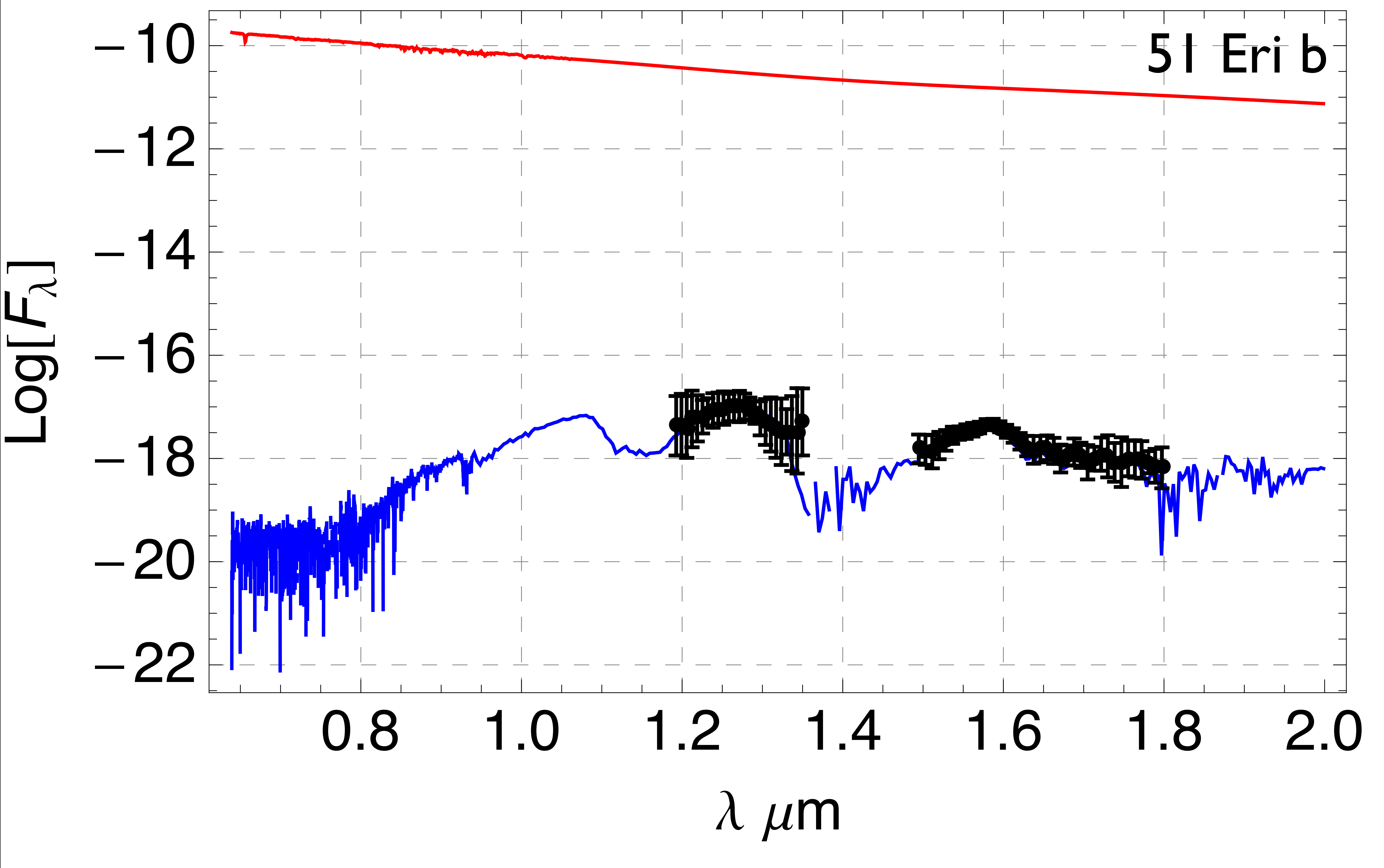

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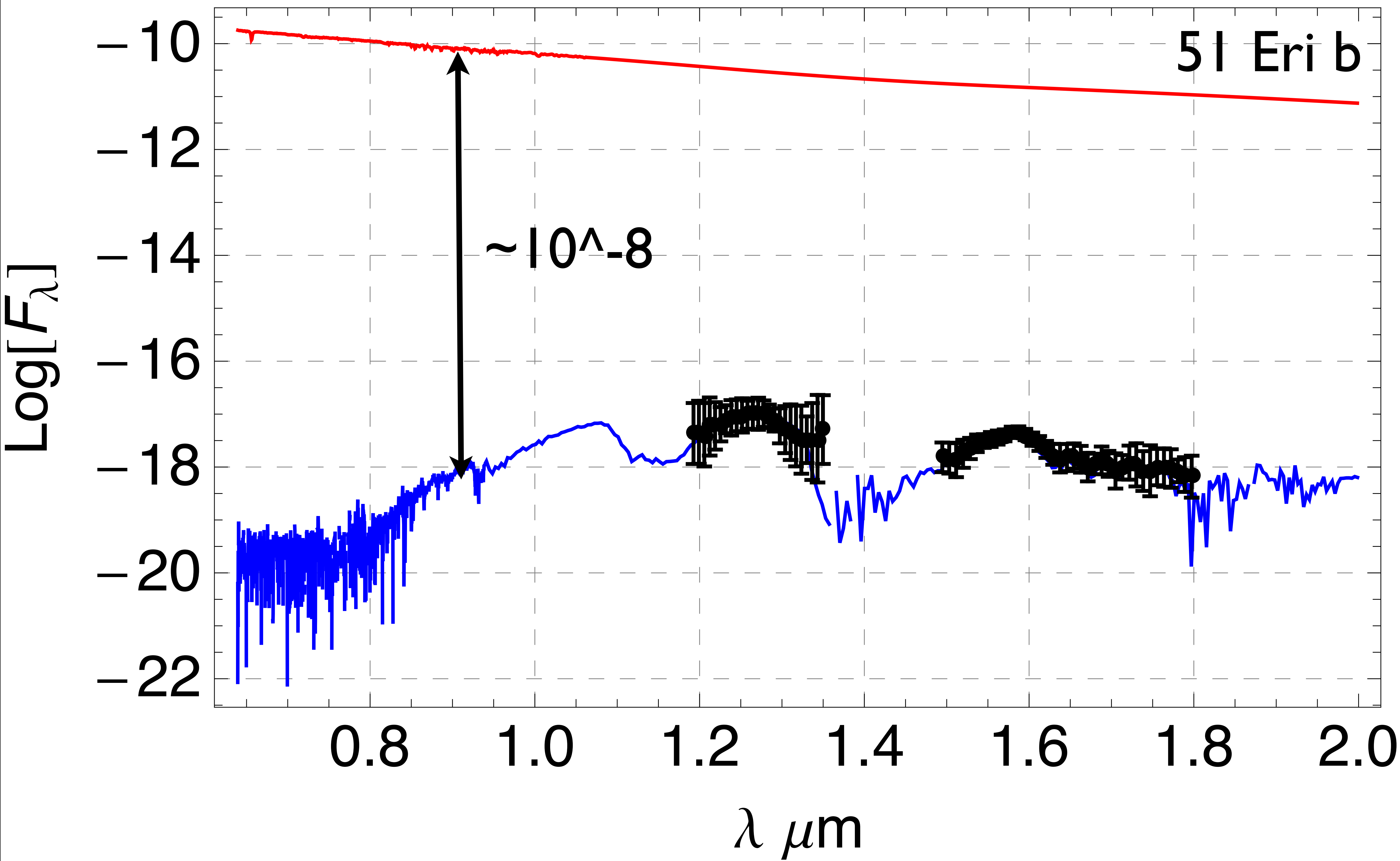

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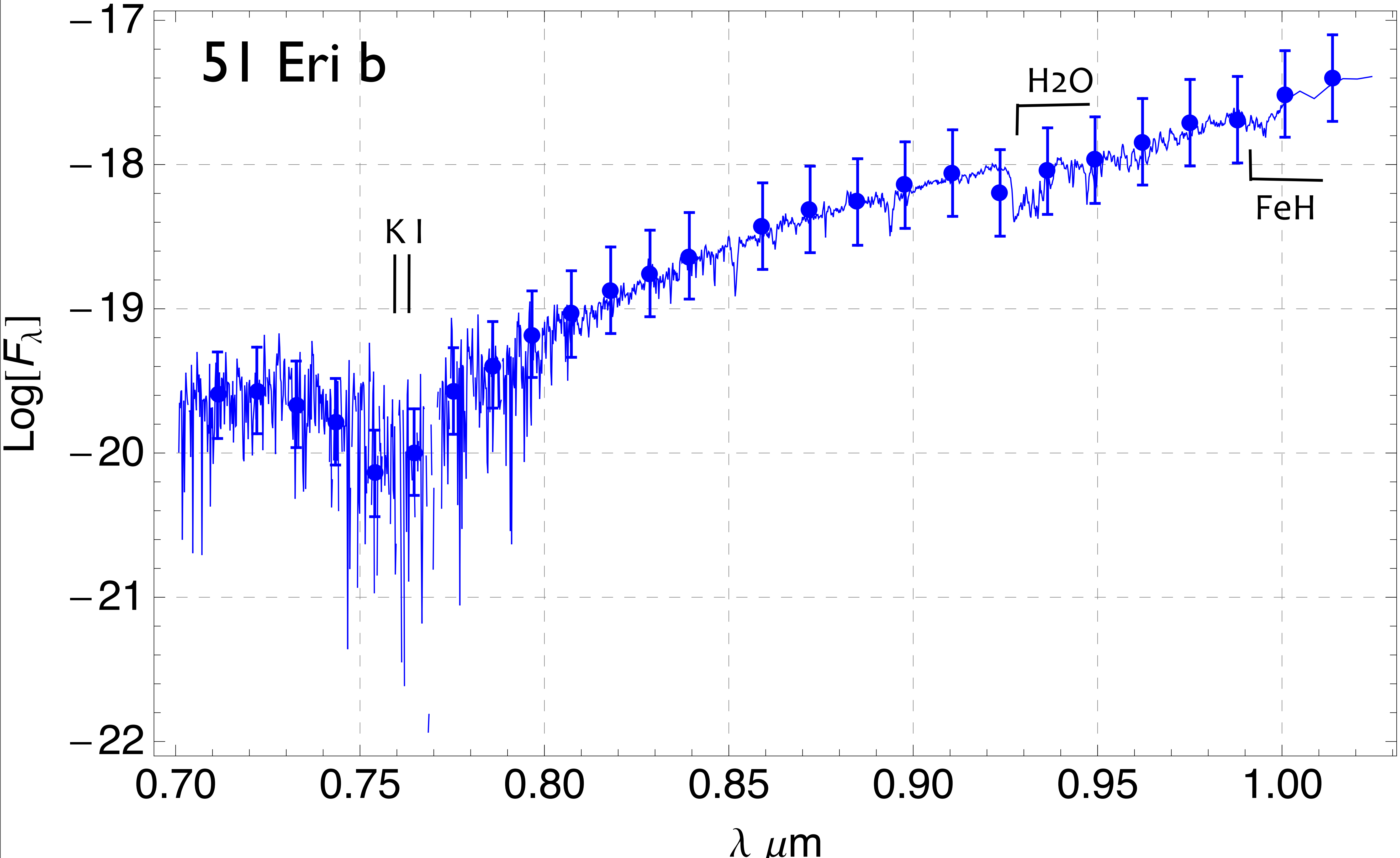

No low g counterpart: WFIRST-WFI will identify many.

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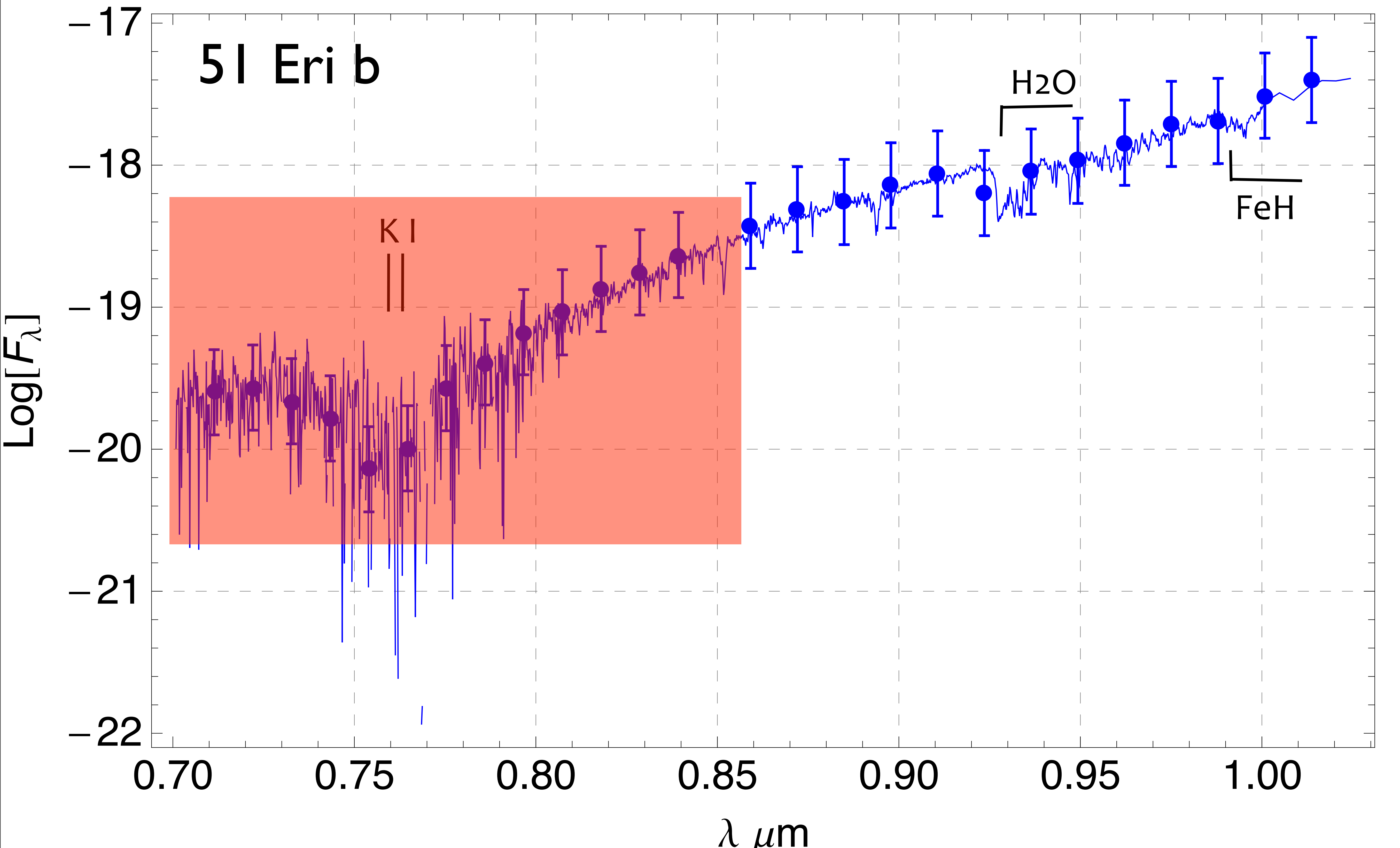

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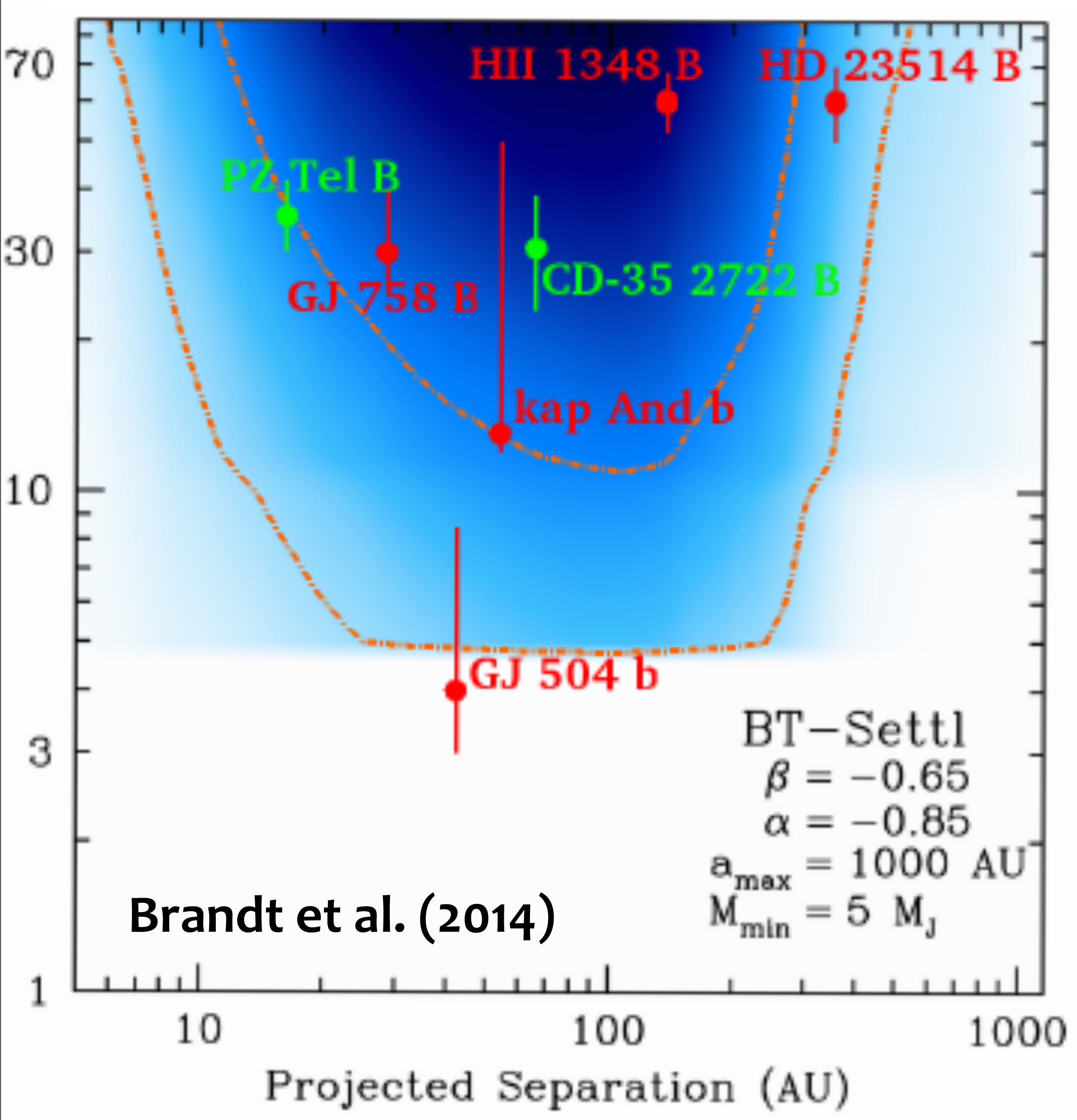
Low frequency of self-luminous exo-planets



Exo-planet/BD companion at large separations are rare:

- Either they are hiding close in/deeper.
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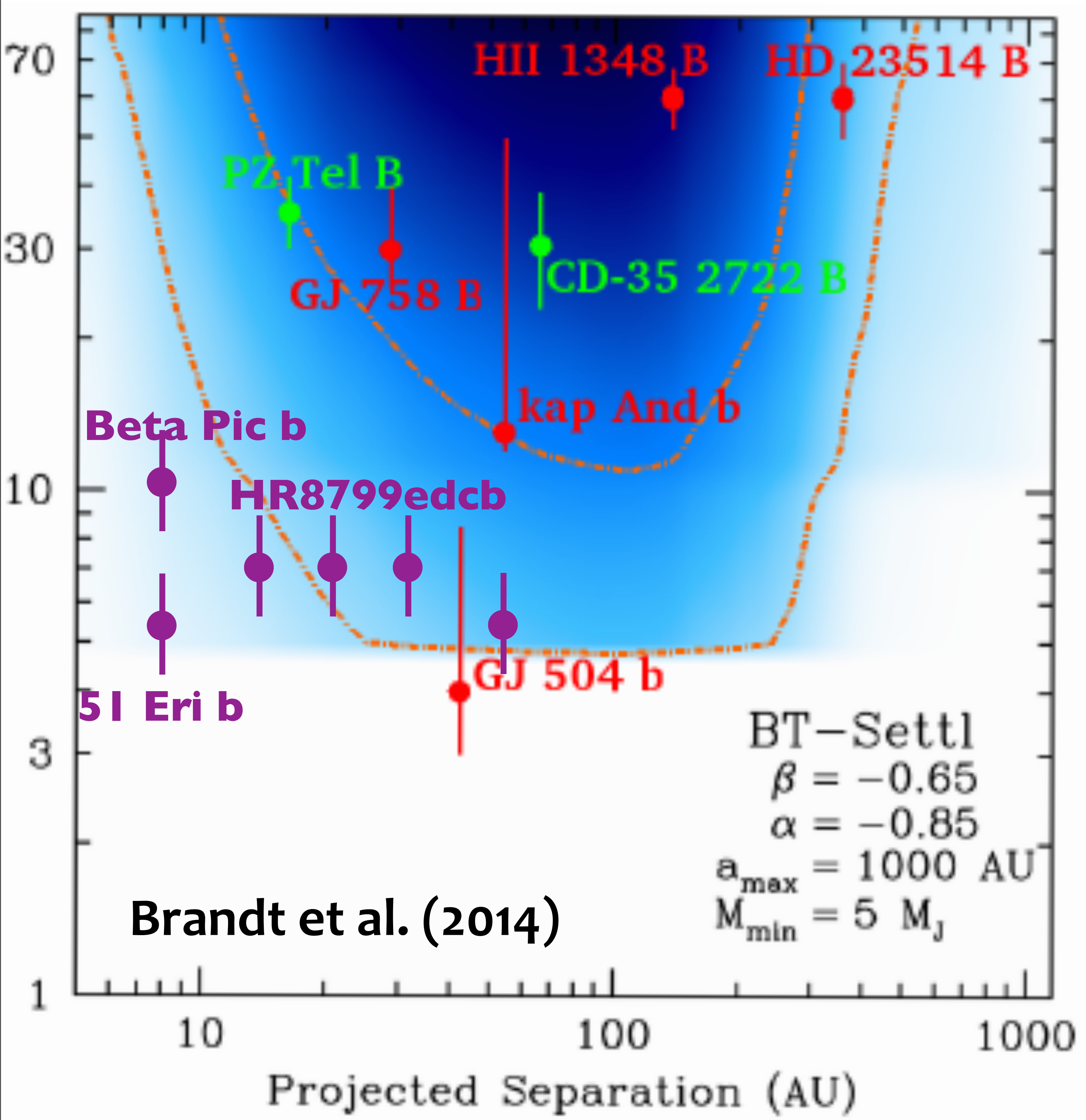

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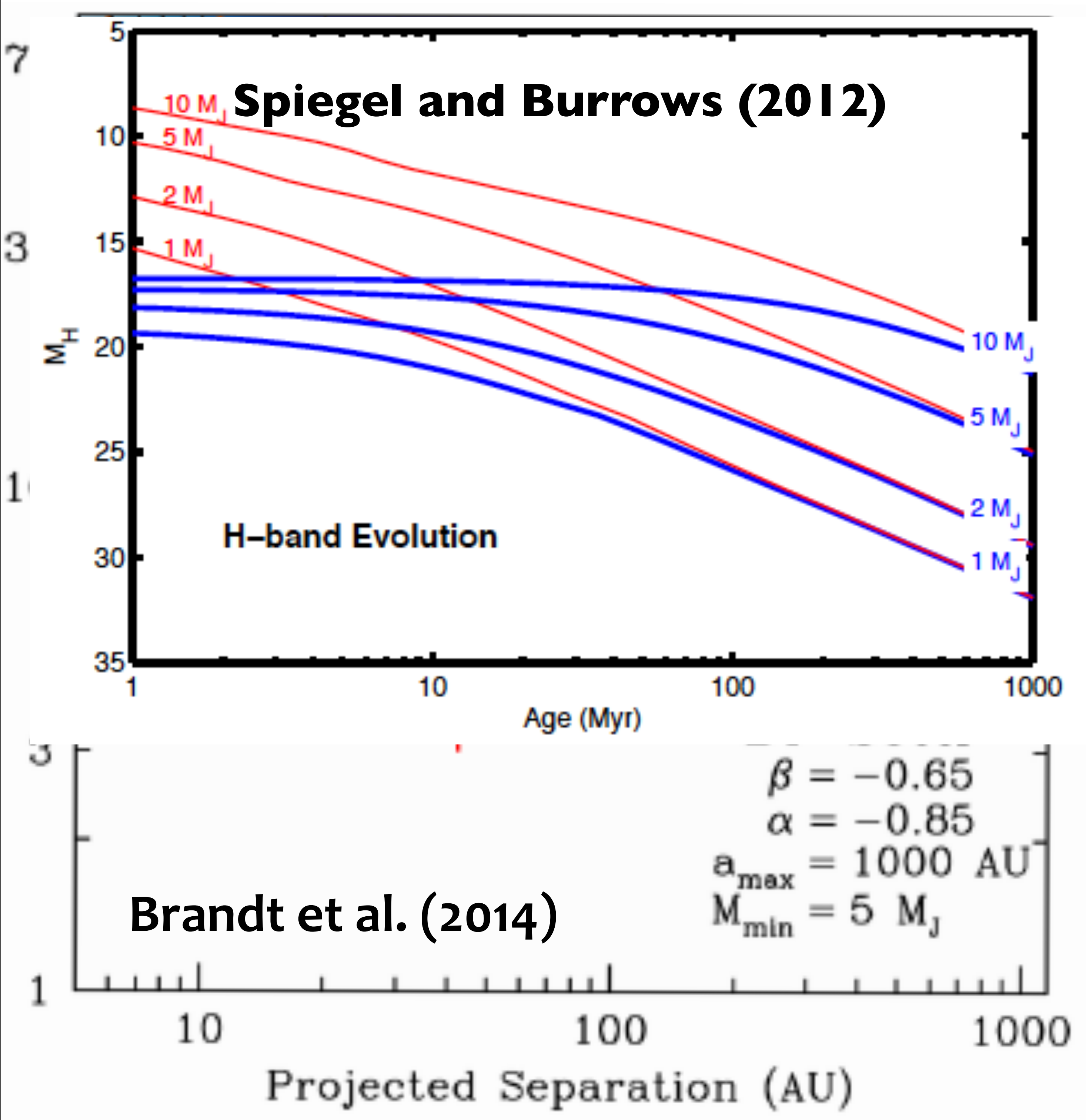

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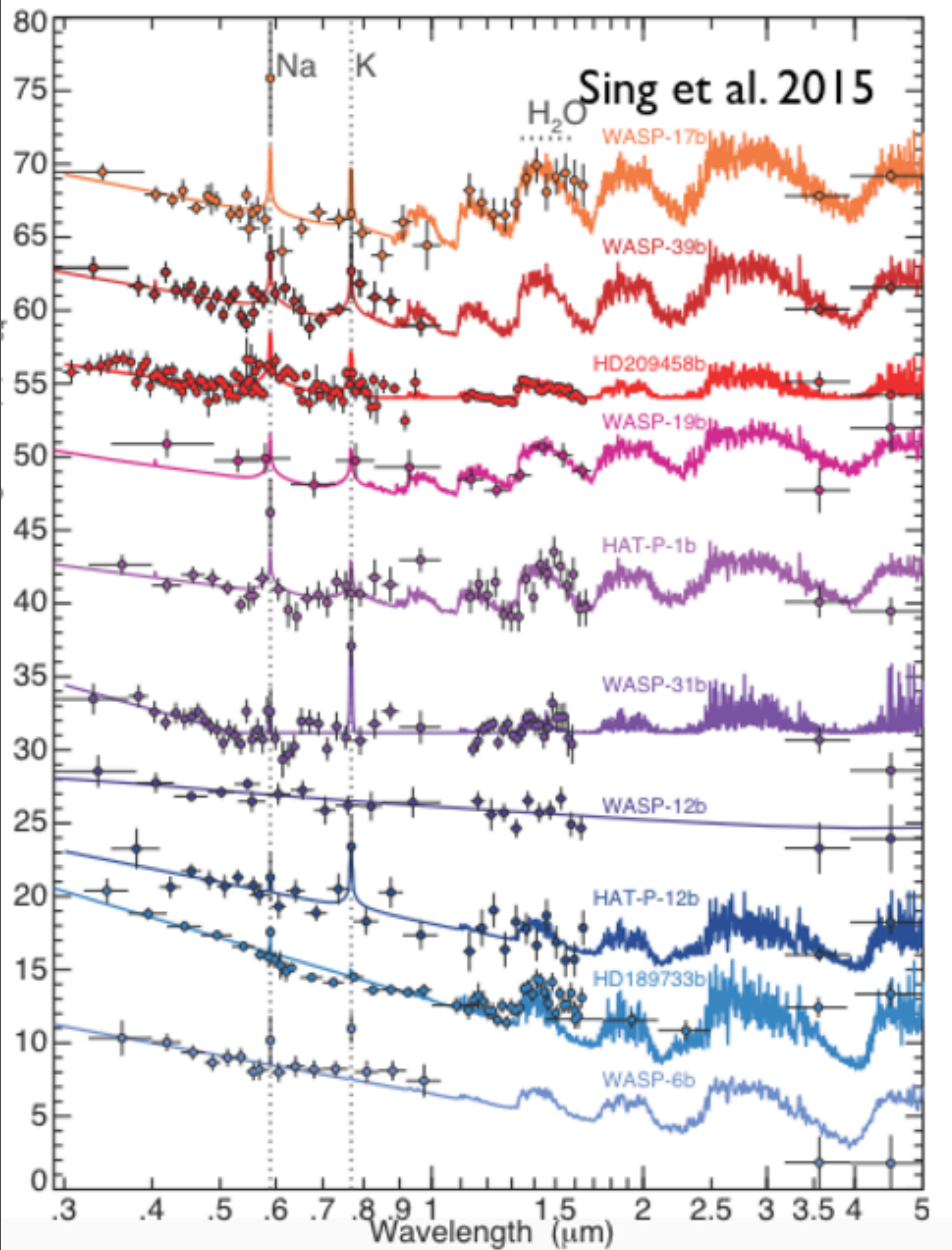
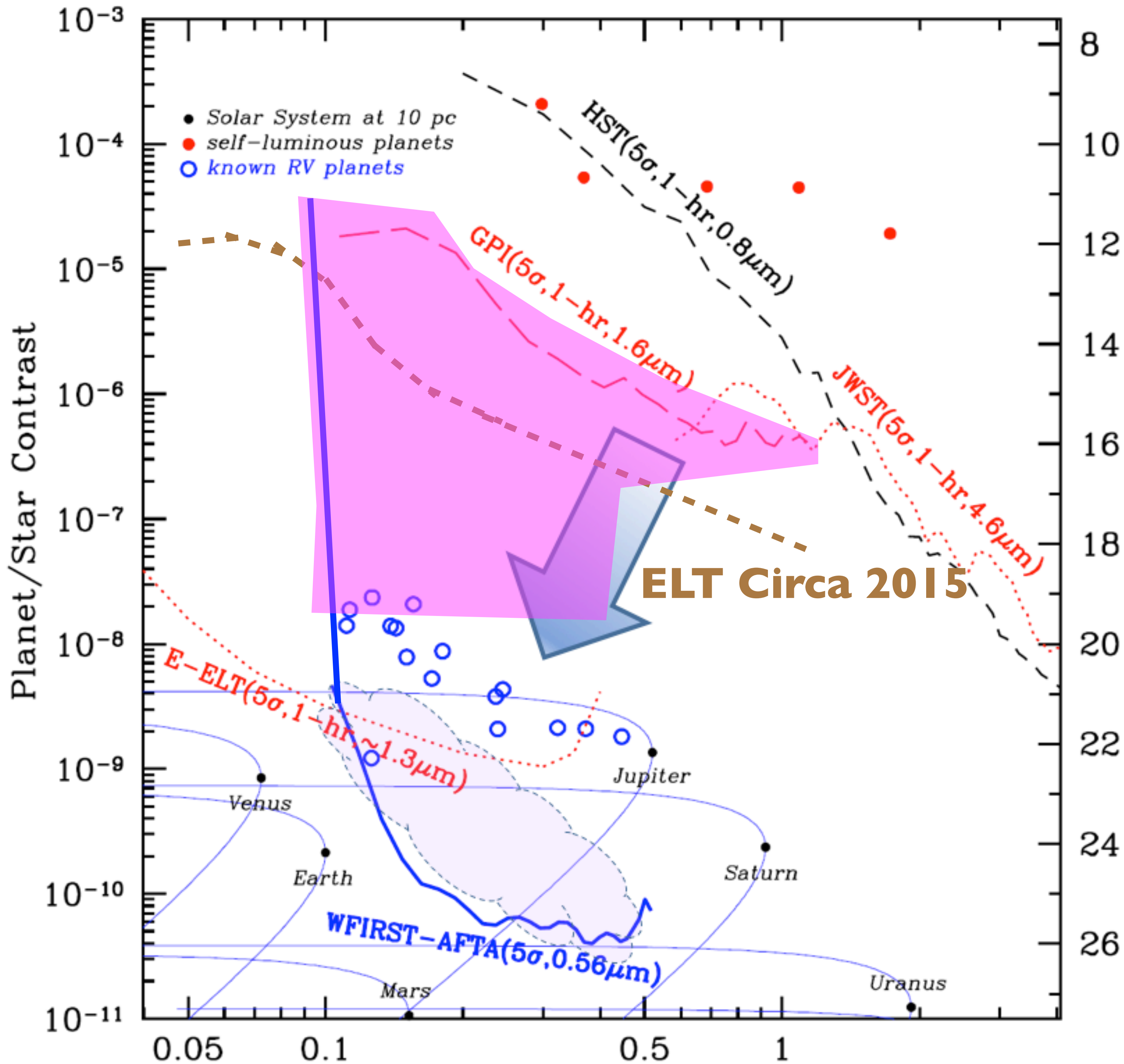
Atmospheric composition as a proxy of formation history



- Planet metallicity vs host star metallicity.
- Planet metallicity as a function of separation.
- Molecular abundances in the context of their corresponding ice lines in the primordial disk.
- Impact of incident stellar flux.

Parameter space for WFIRST CGI GO science



3. Adolescent-planets

and their atmospheres

- Visible contrast ranges 2-3 orders of magnitude. Most of the are "easy".

- **WFIRST-CGI optical spectrum will be a key element to undertand their atmopshere an their formation history,**

Synergies with the WFI will help identify the empirical reference sample to study these atmospheres.

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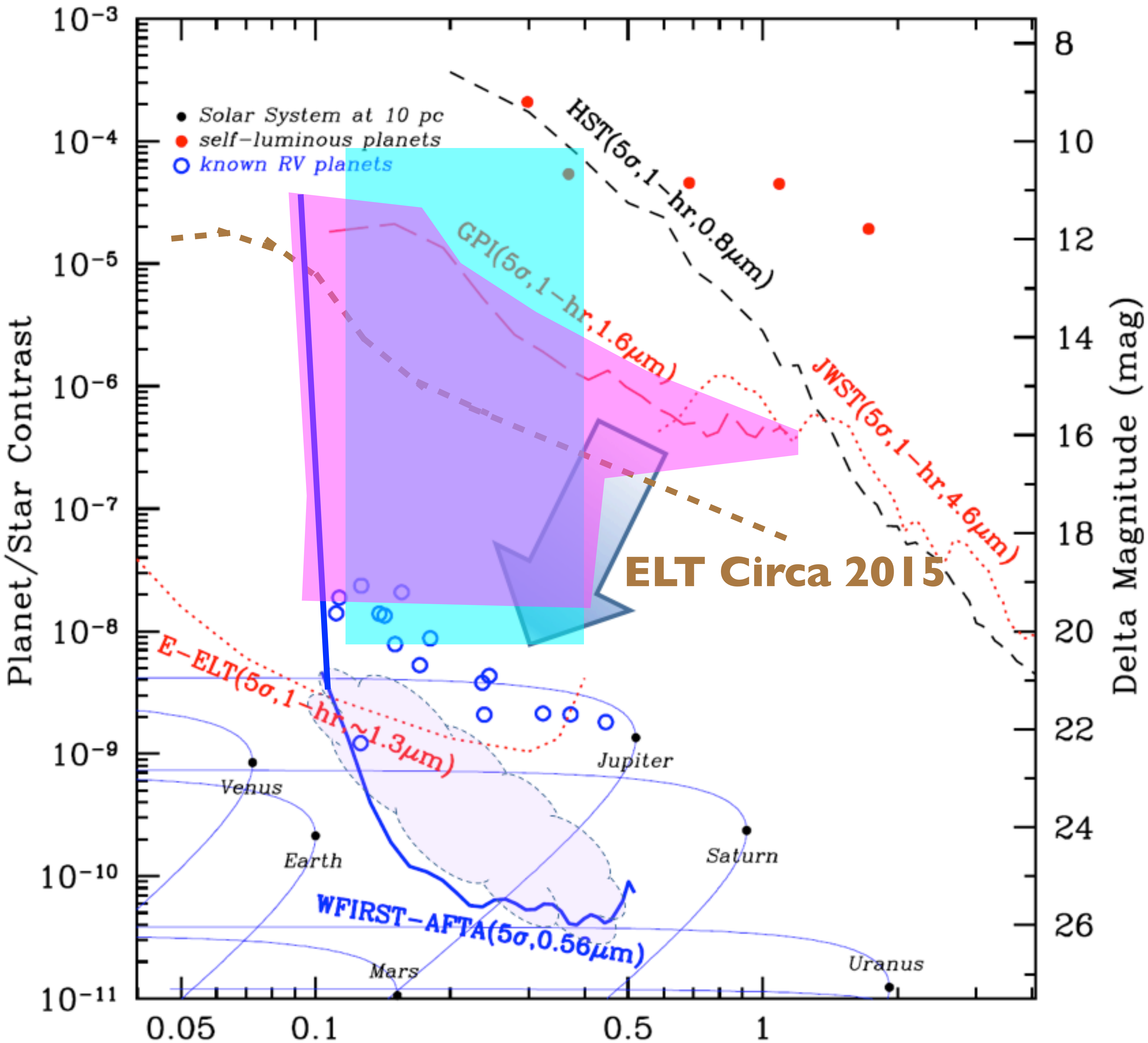

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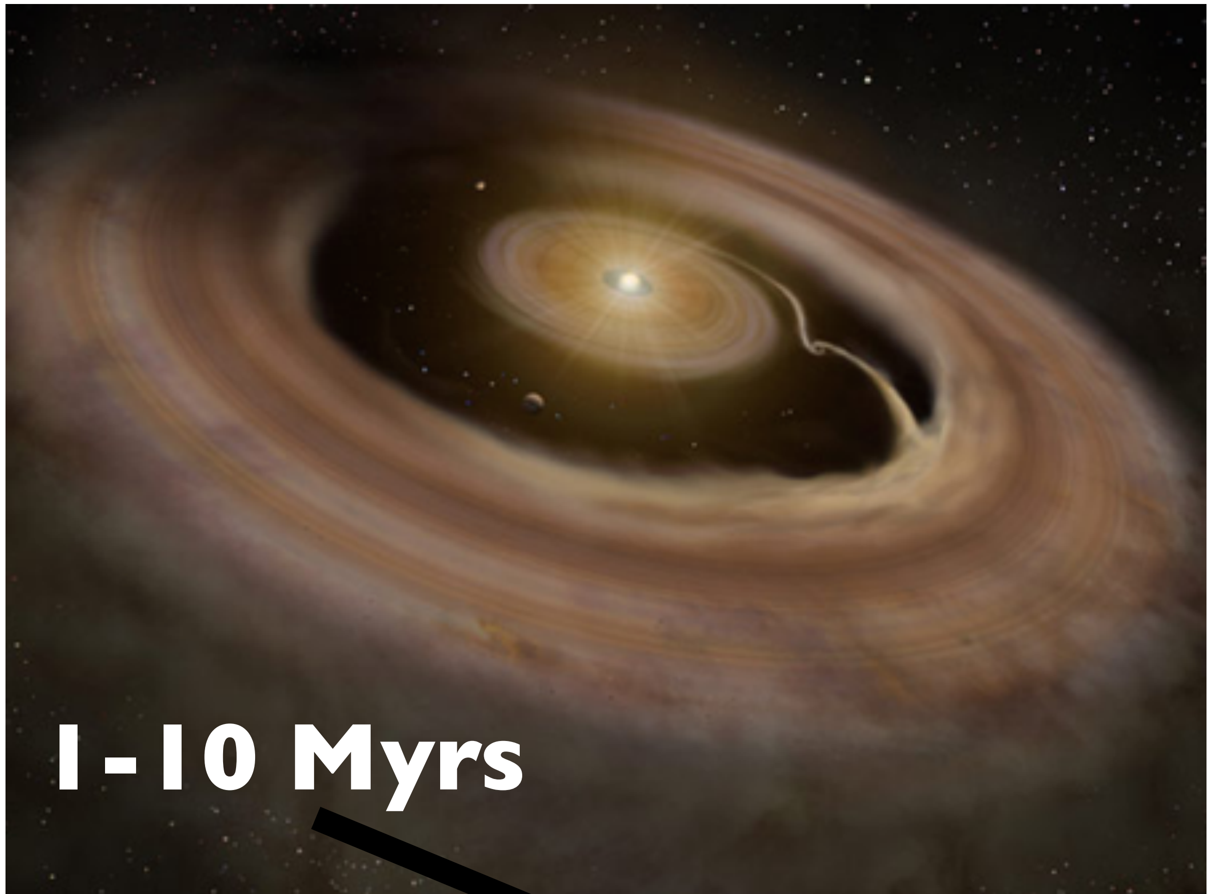

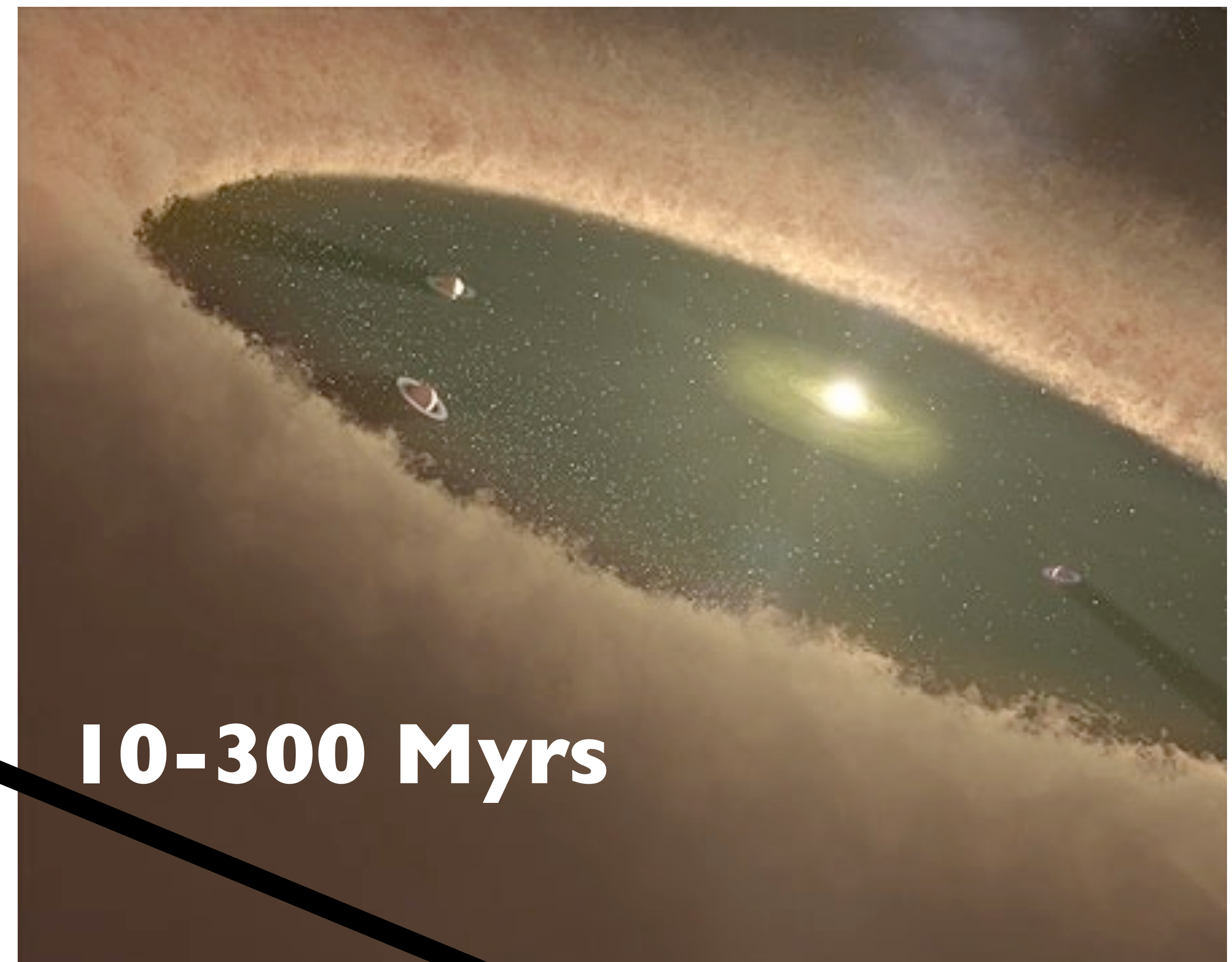

5 Gyrs

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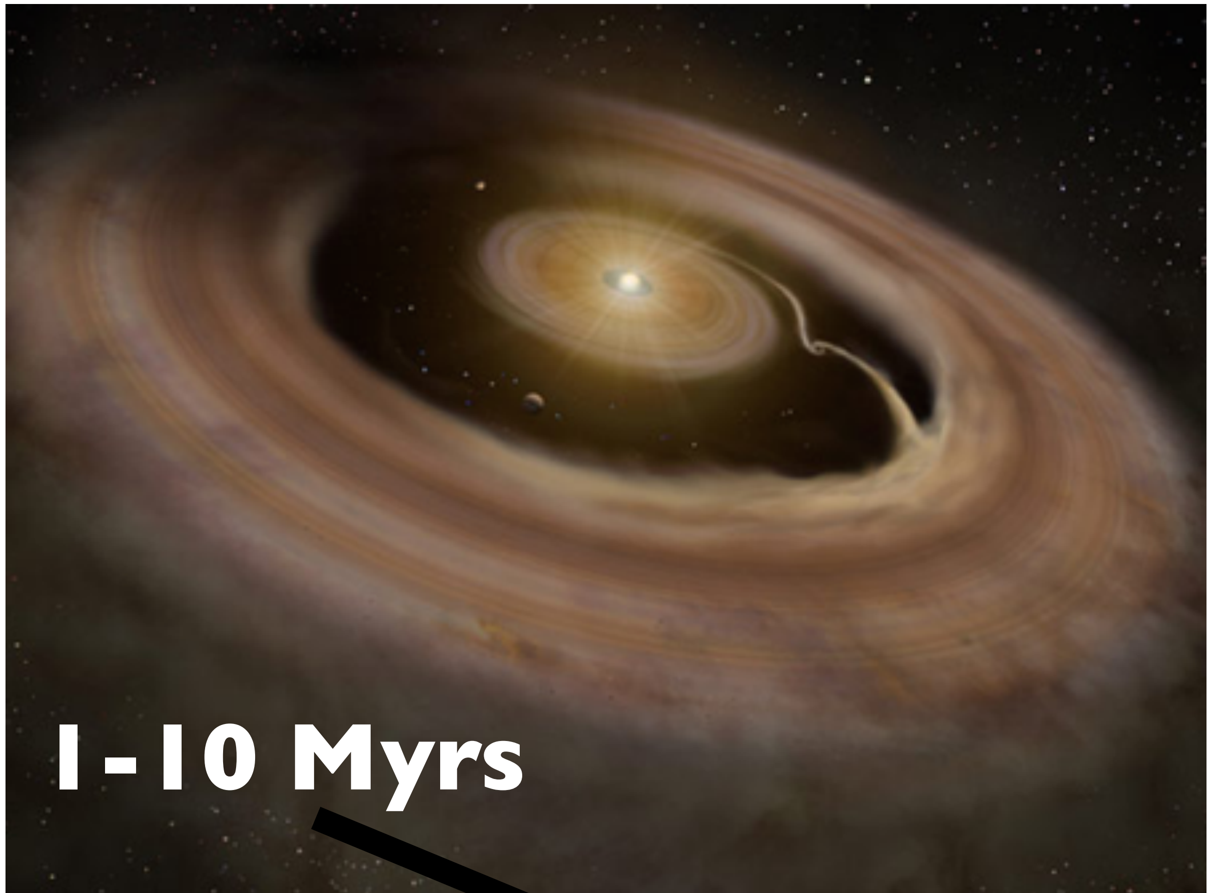

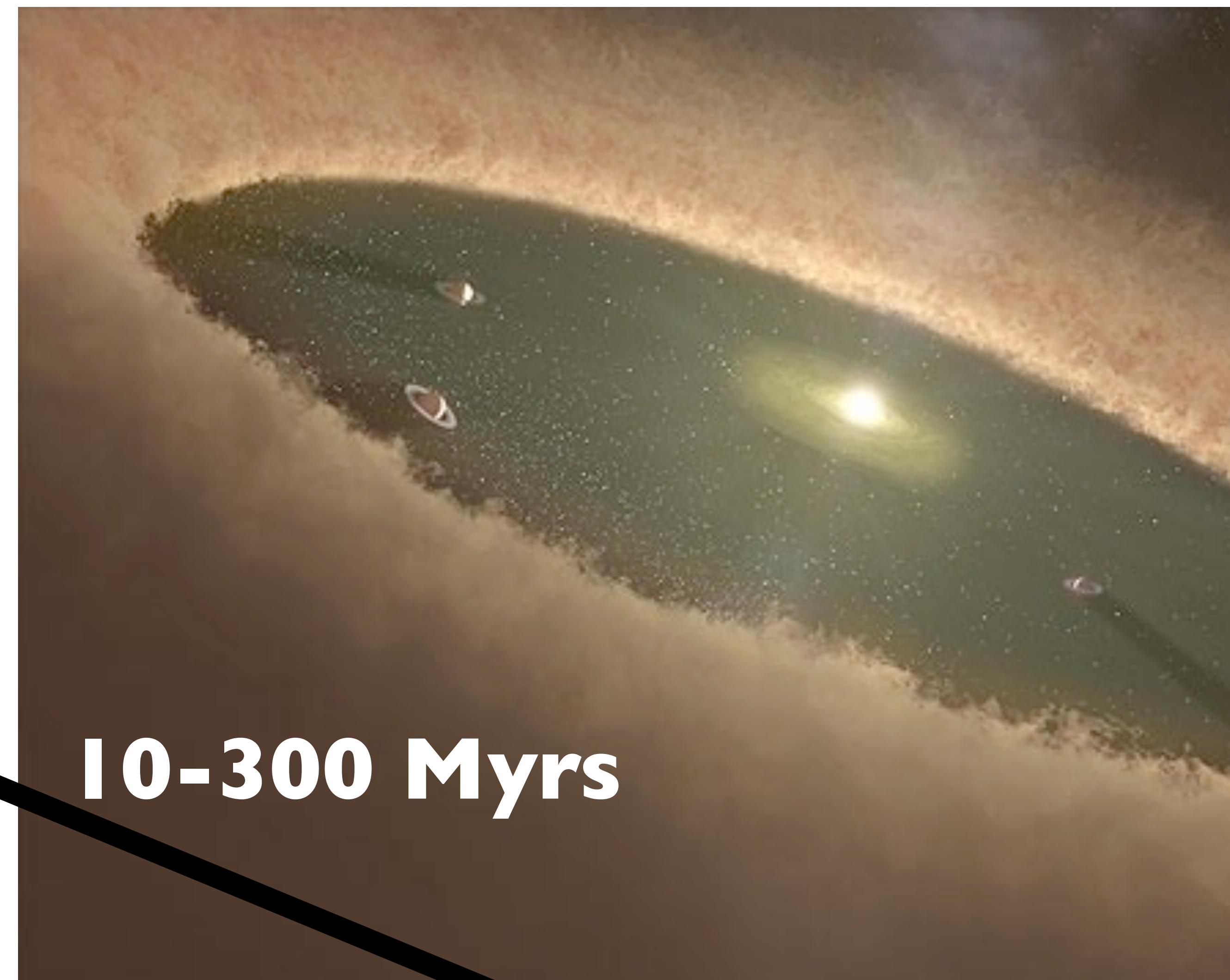

4. Debris disks

and their scattering properties

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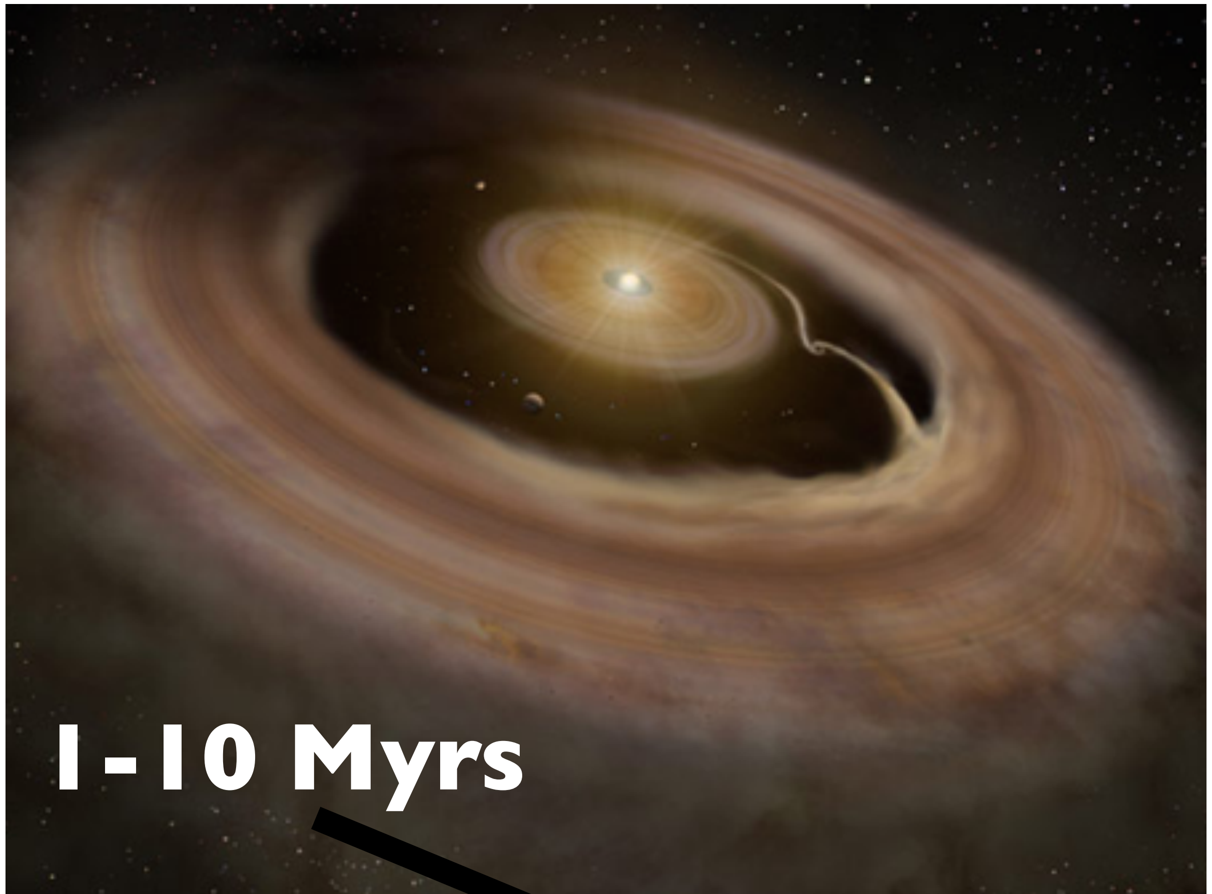

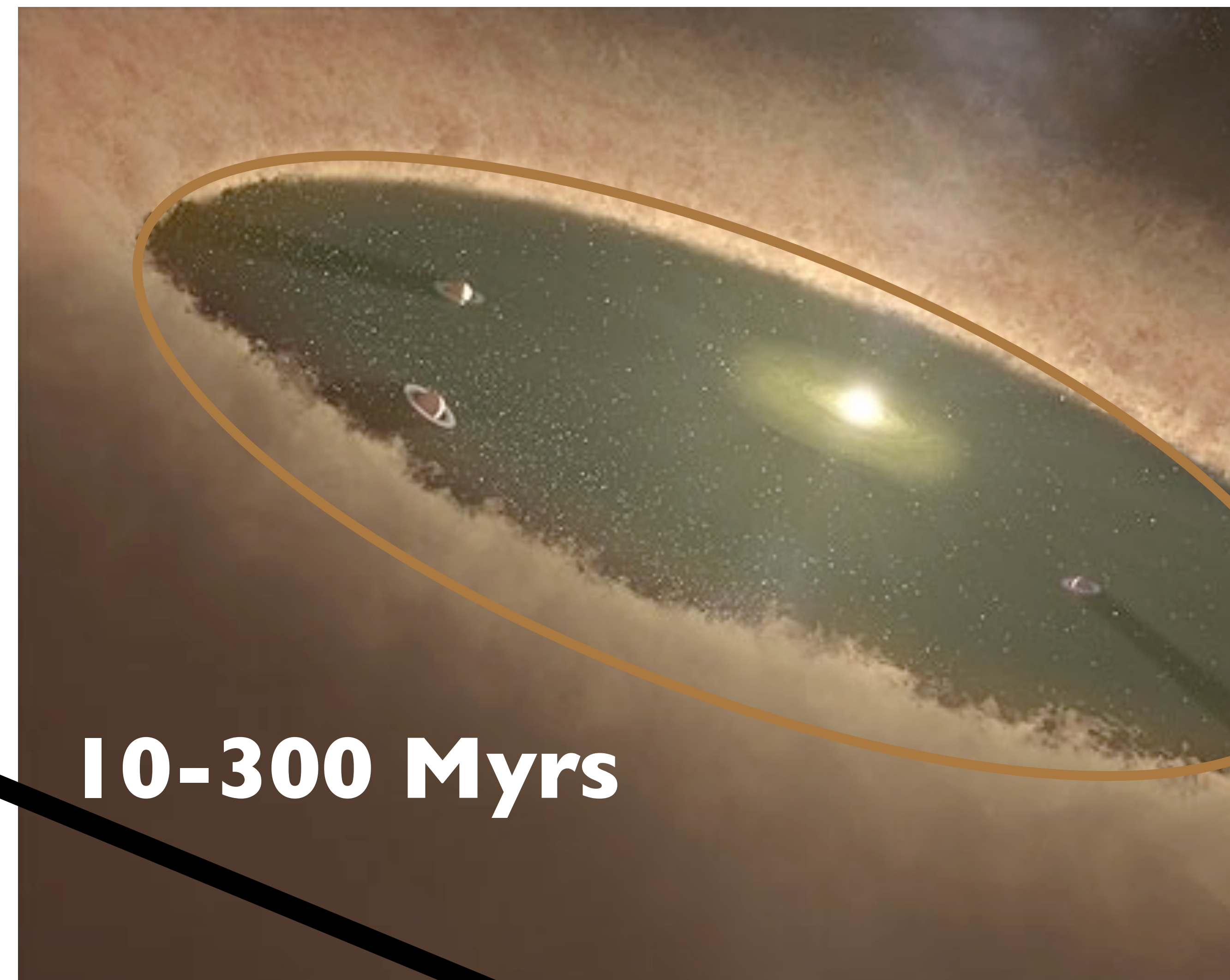

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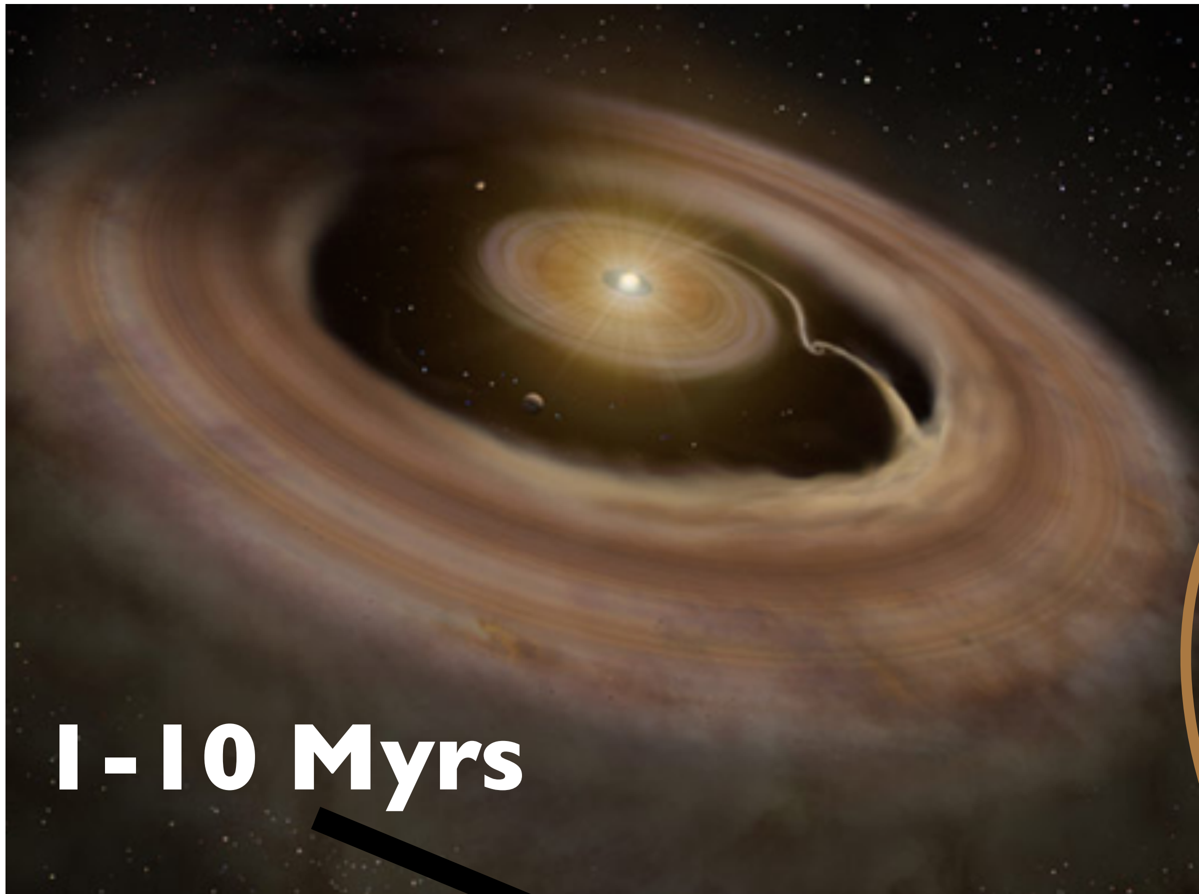

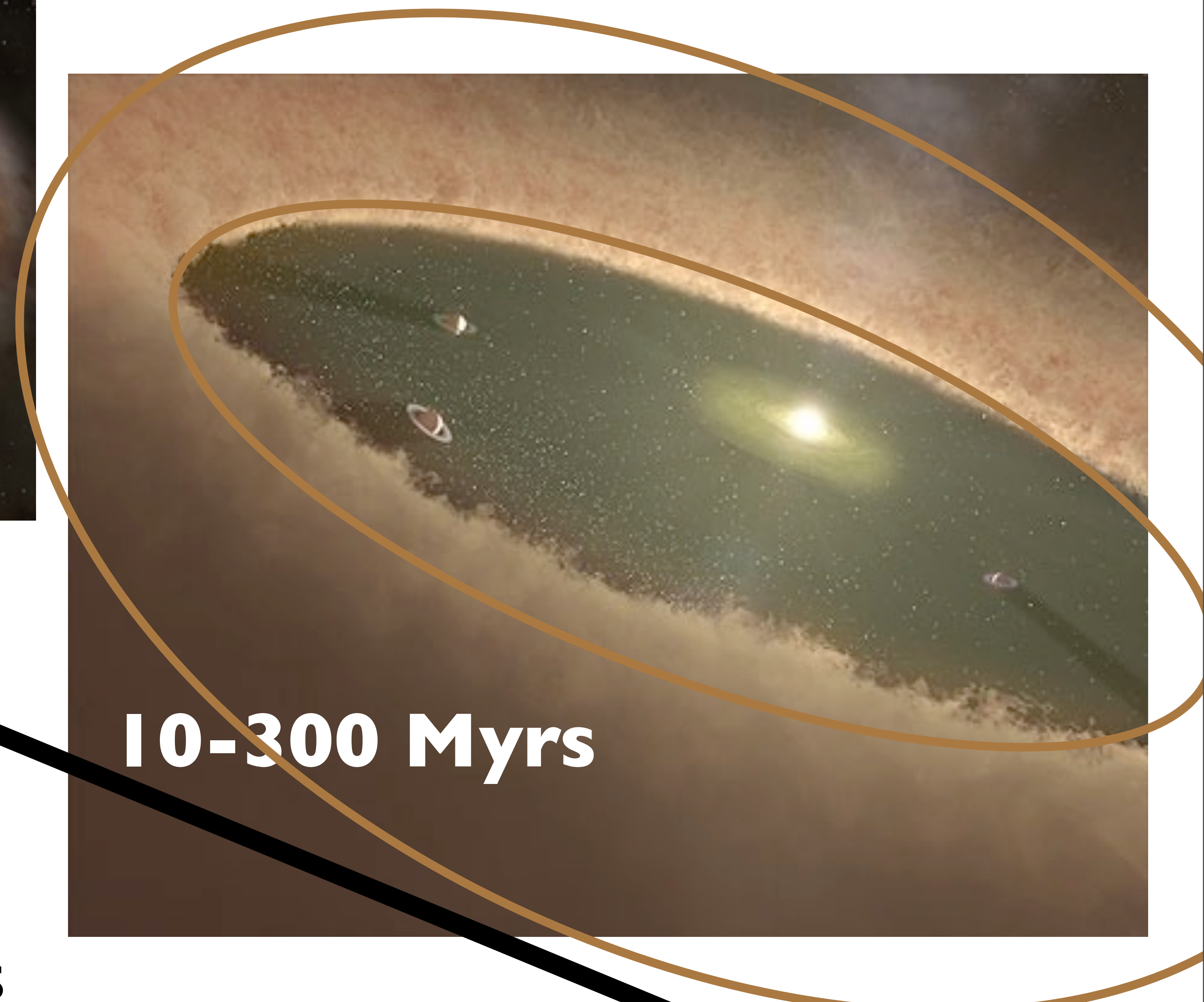

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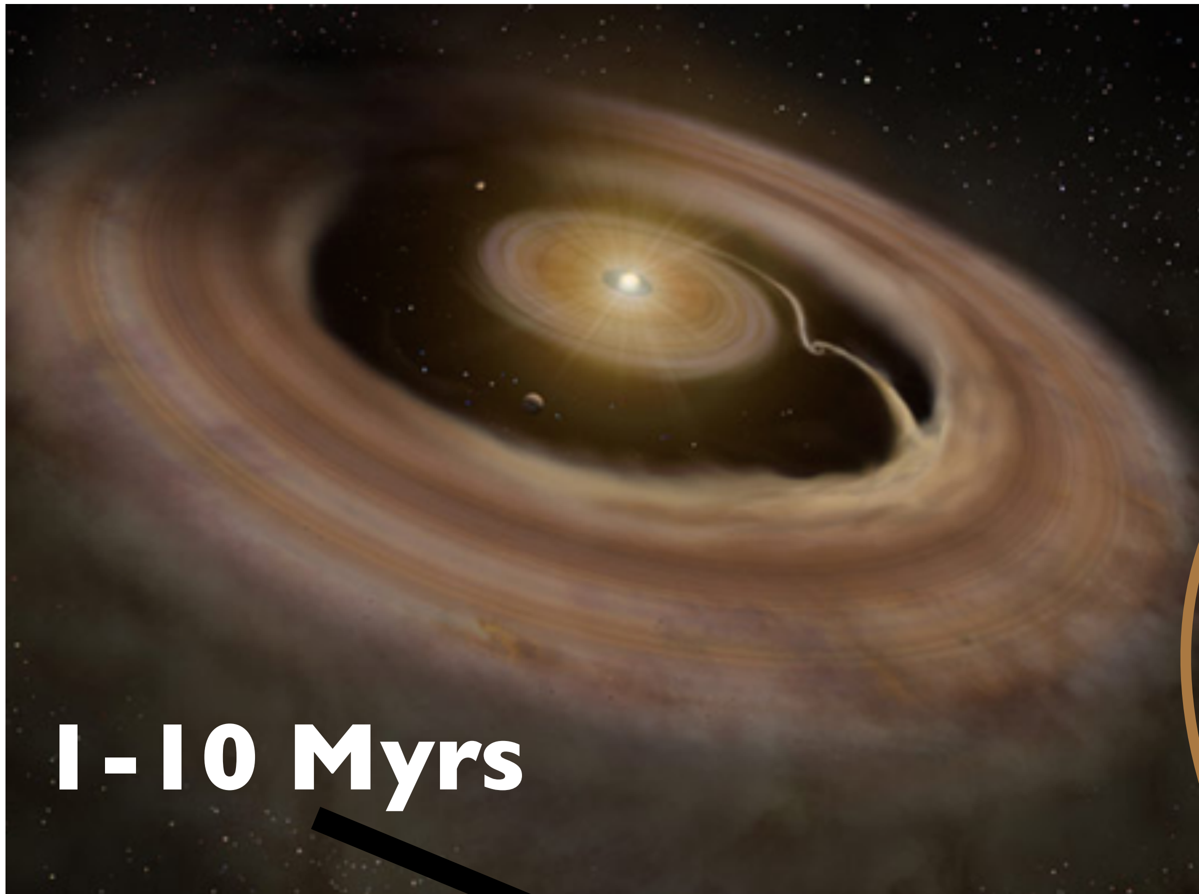

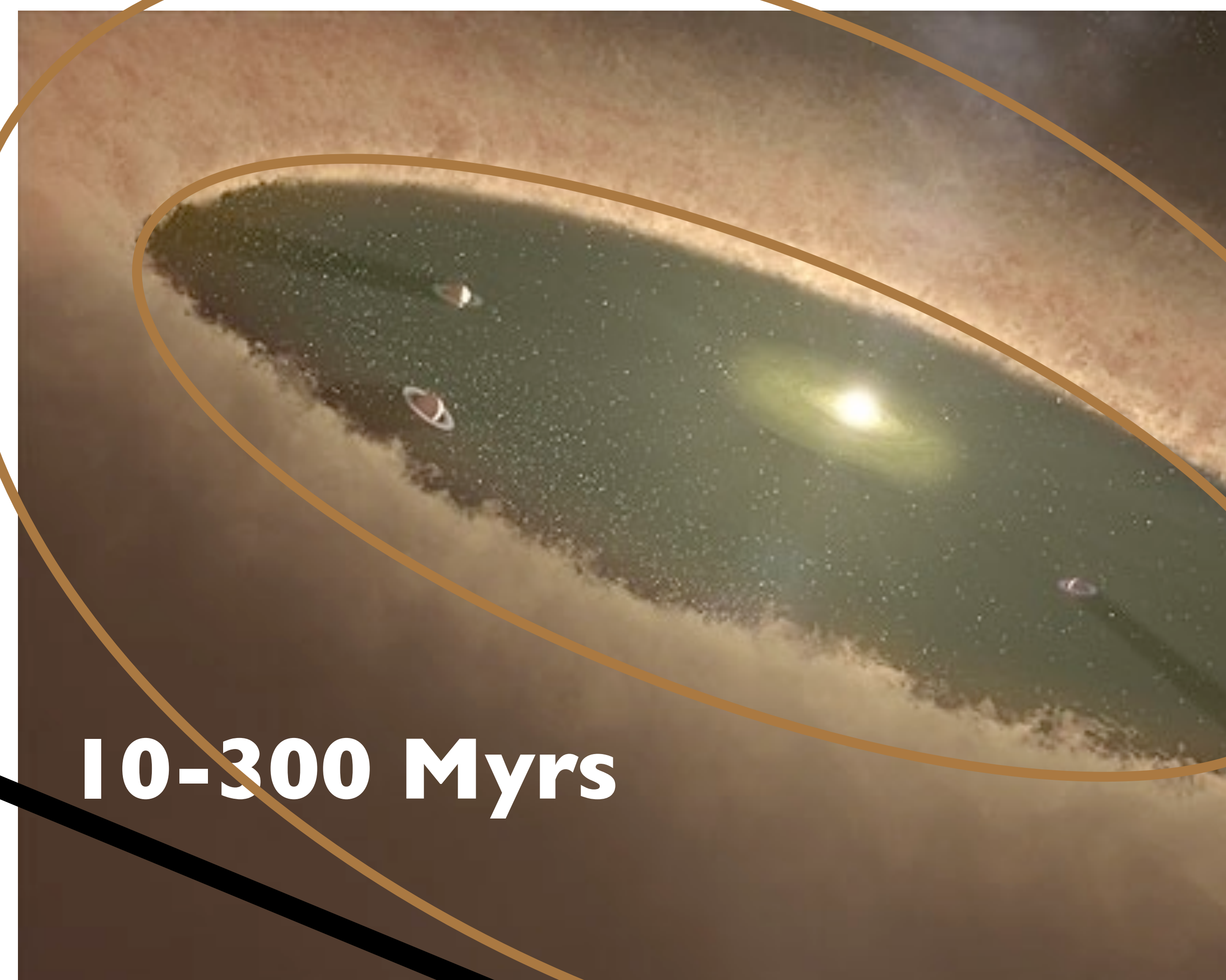

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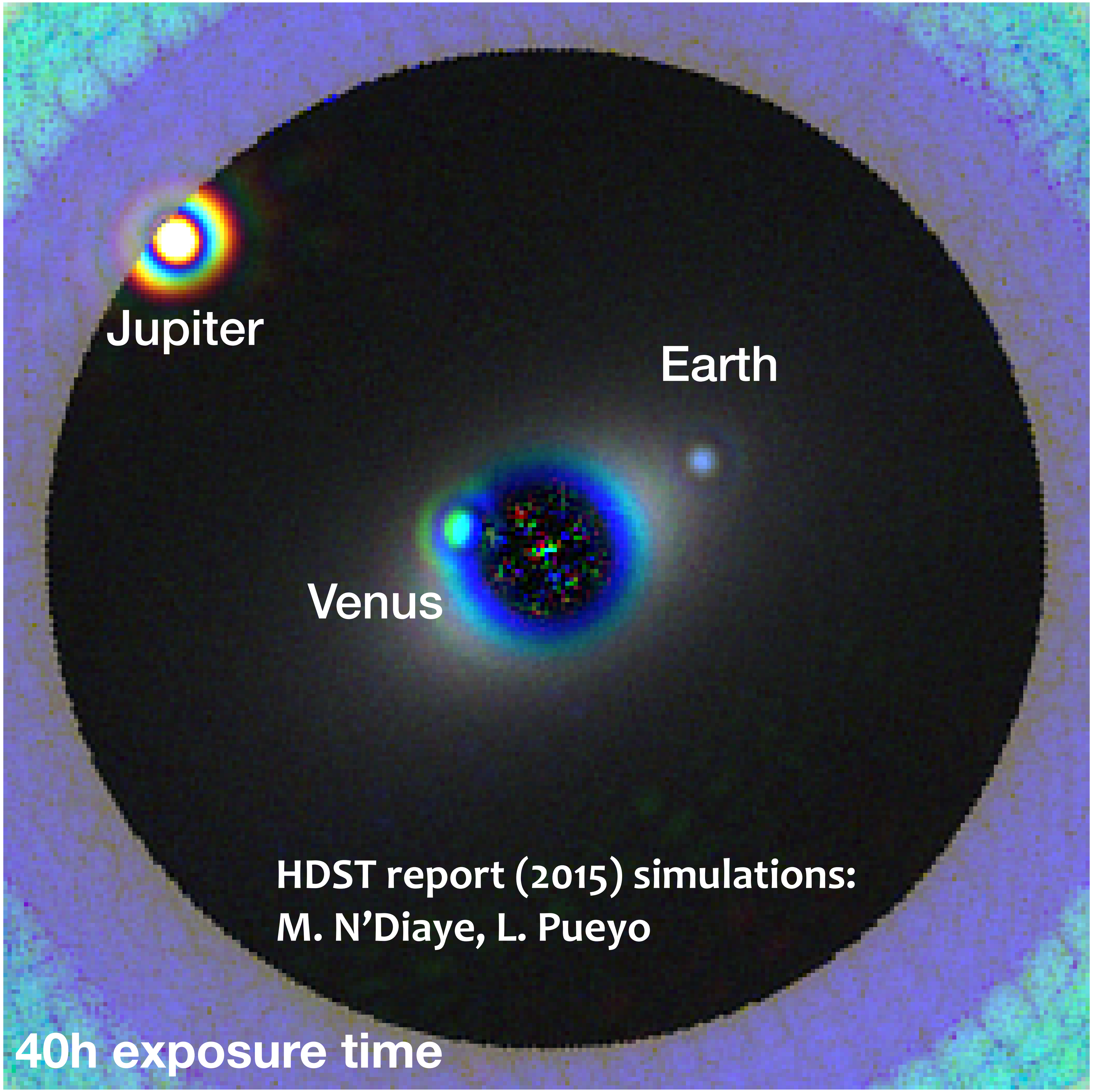
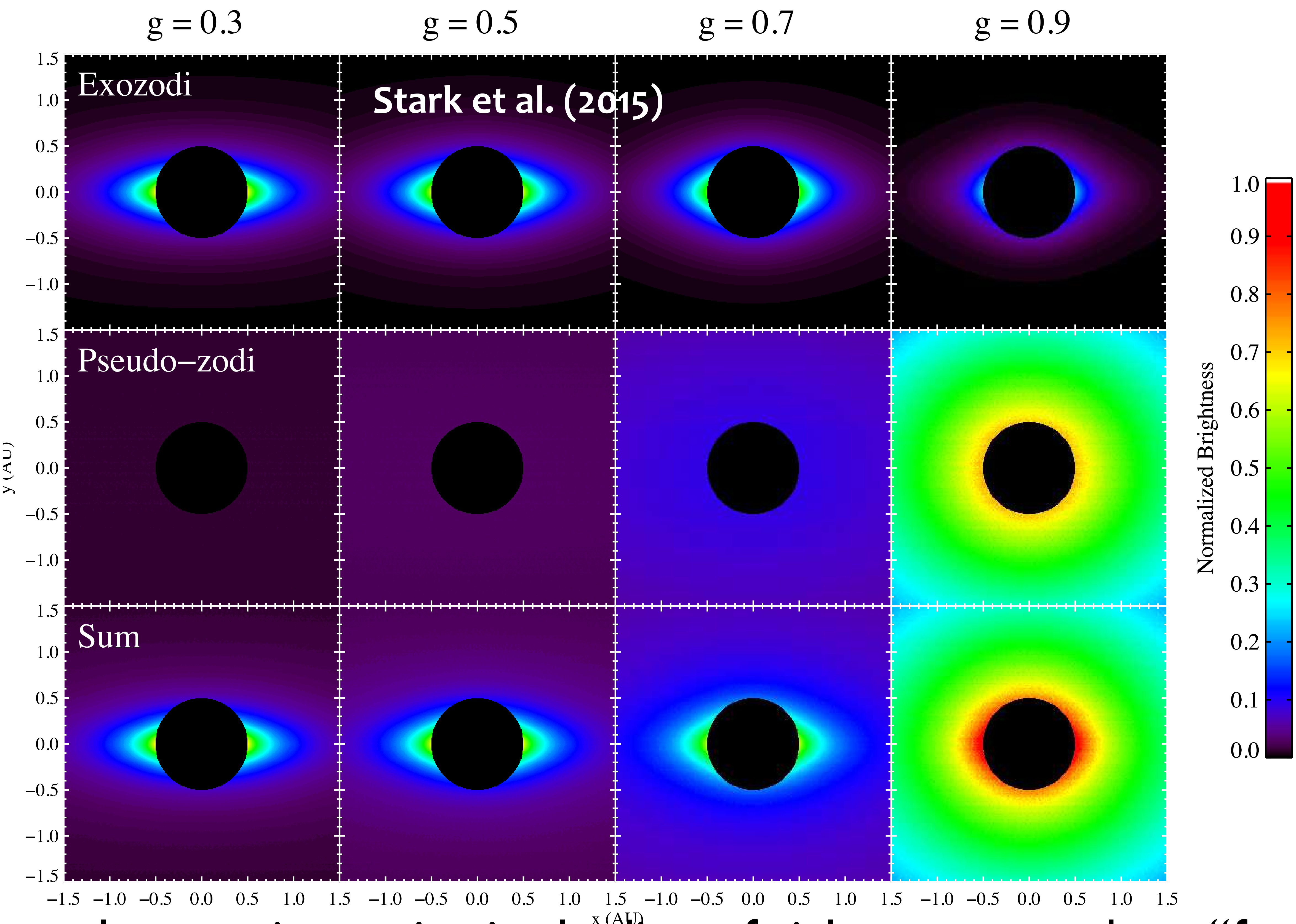
See G. Bryden Talk

Importance of dust for exo earth imaging missions

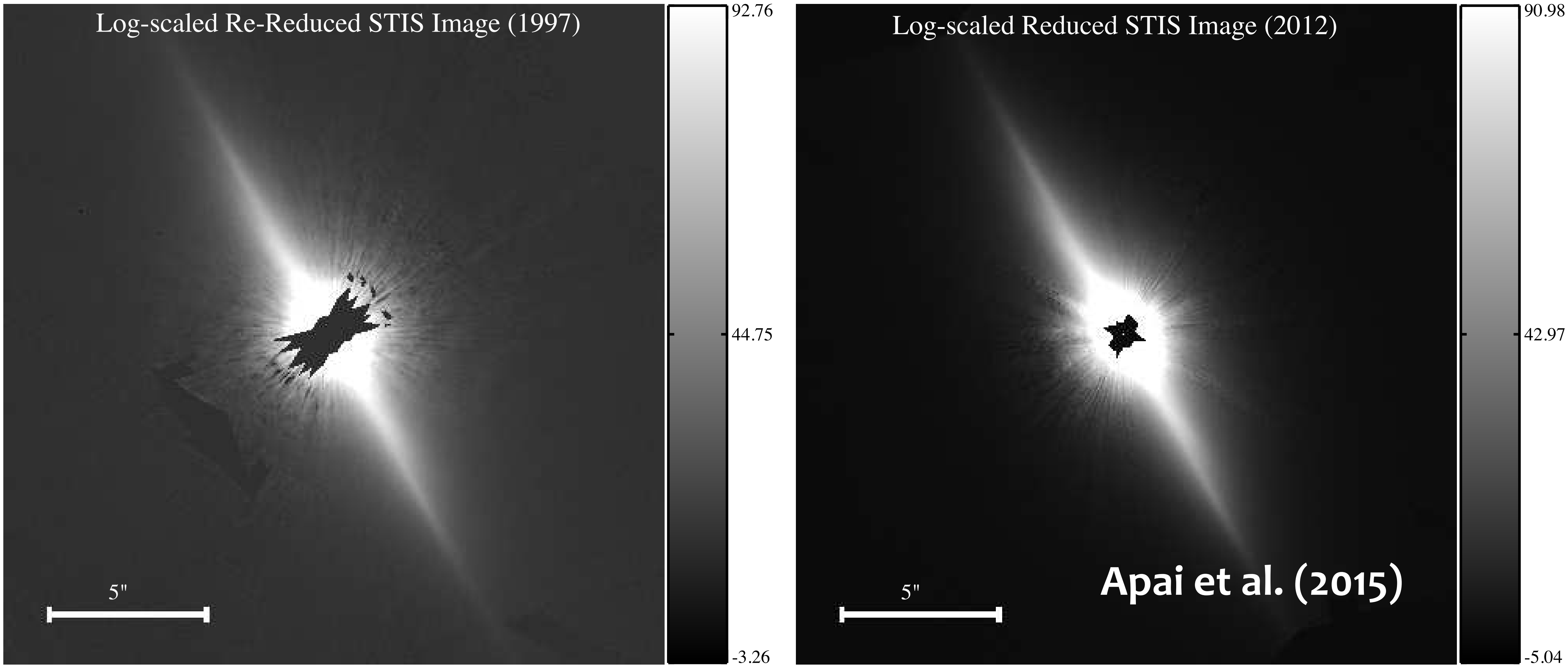


The pseudo zodi problem:



Forward scattering grains in the line of sight masquerade as "face on" zodi in an edge on system

This is not just a theoretical construction.



The disk around Beta Pictoris is very forward scattering

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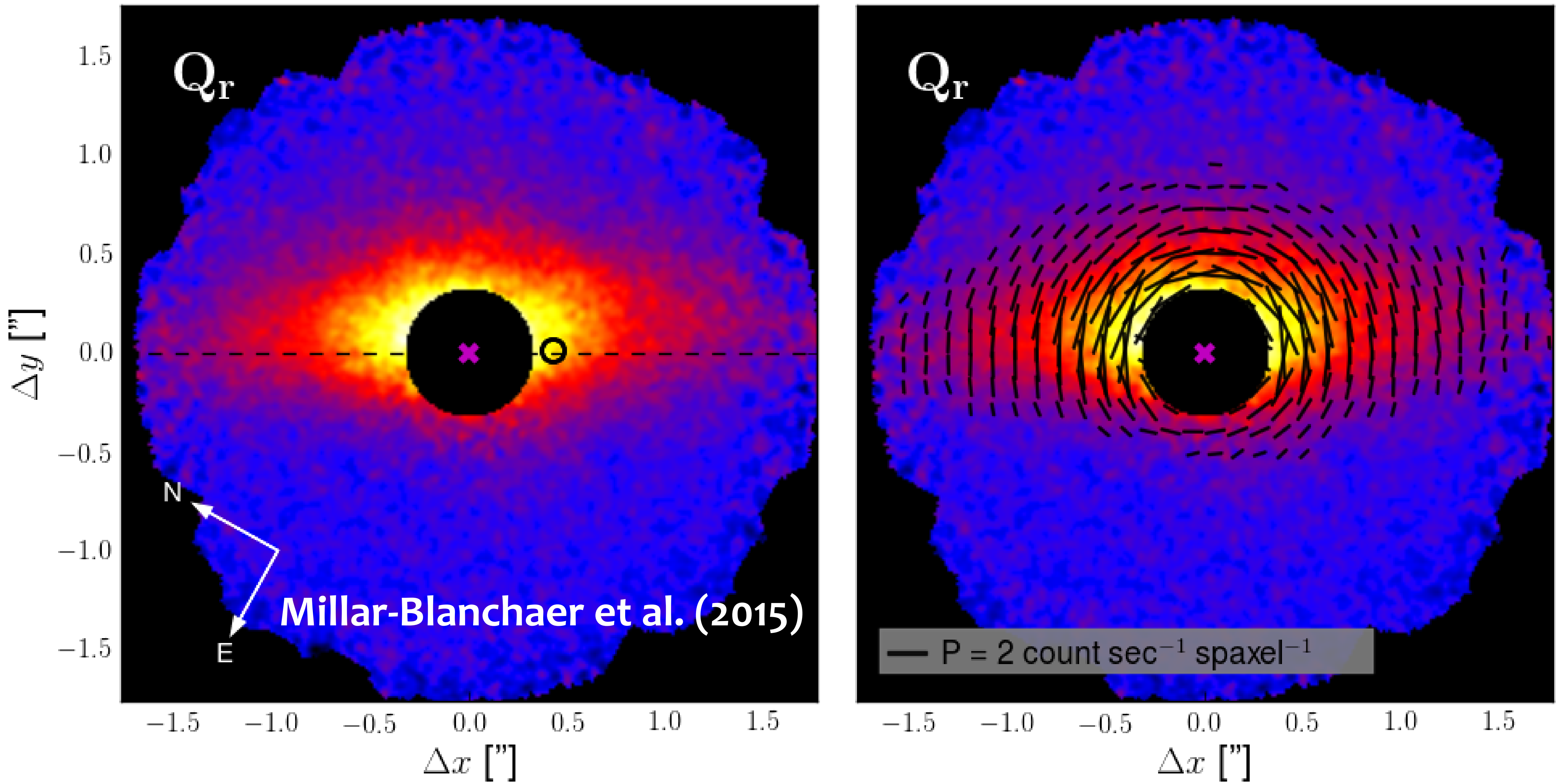

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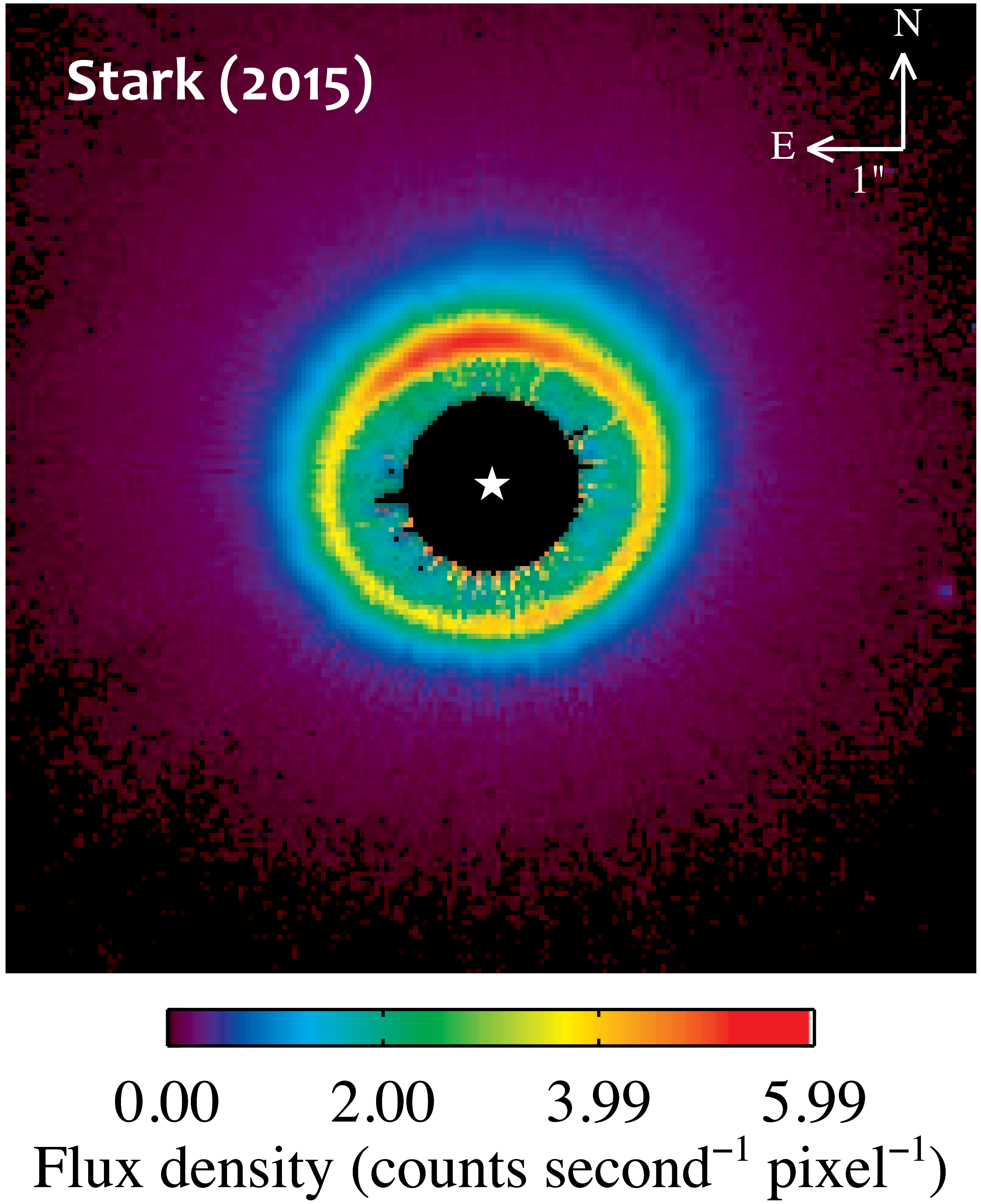
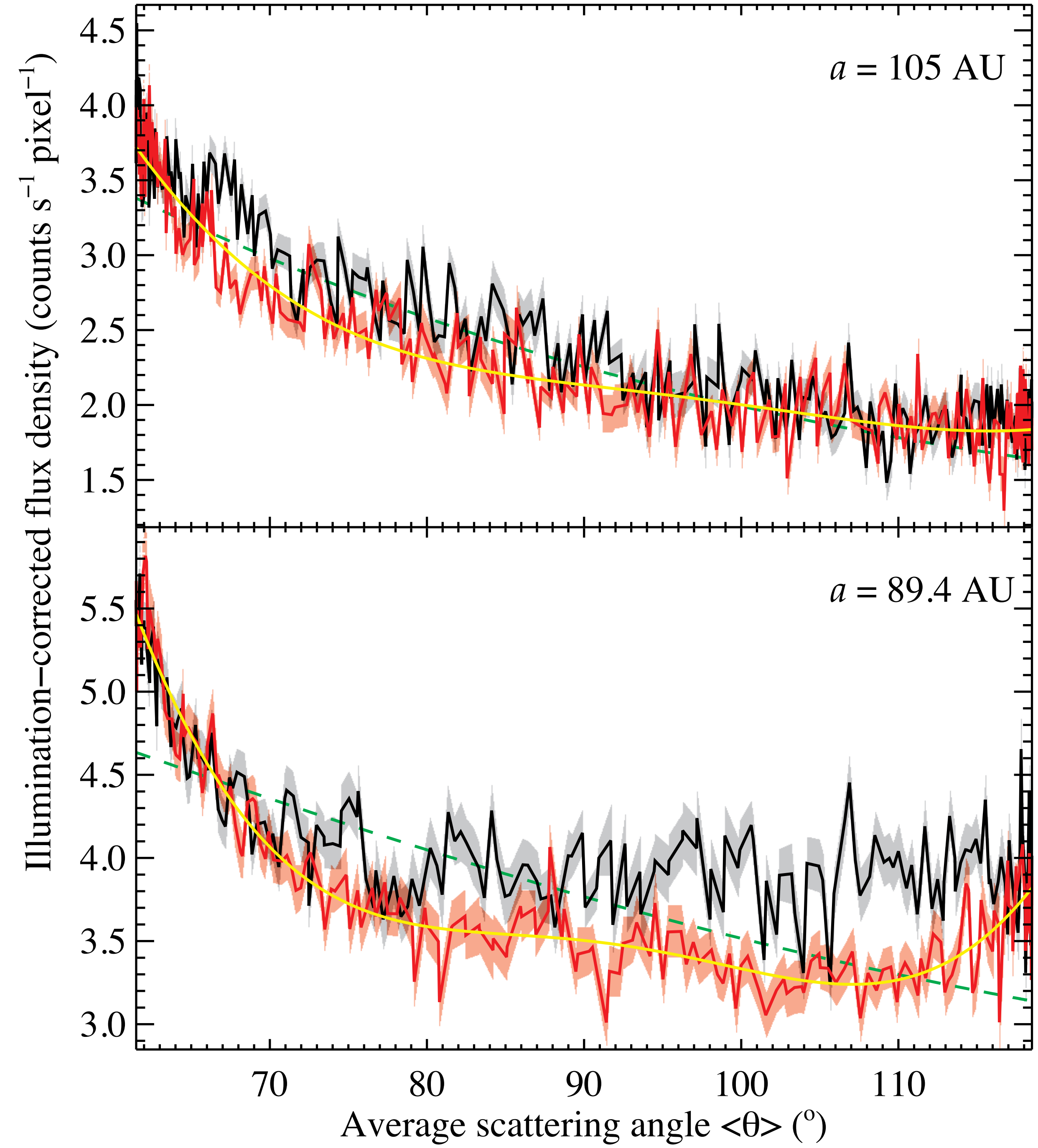
Measurements of scattering phase function





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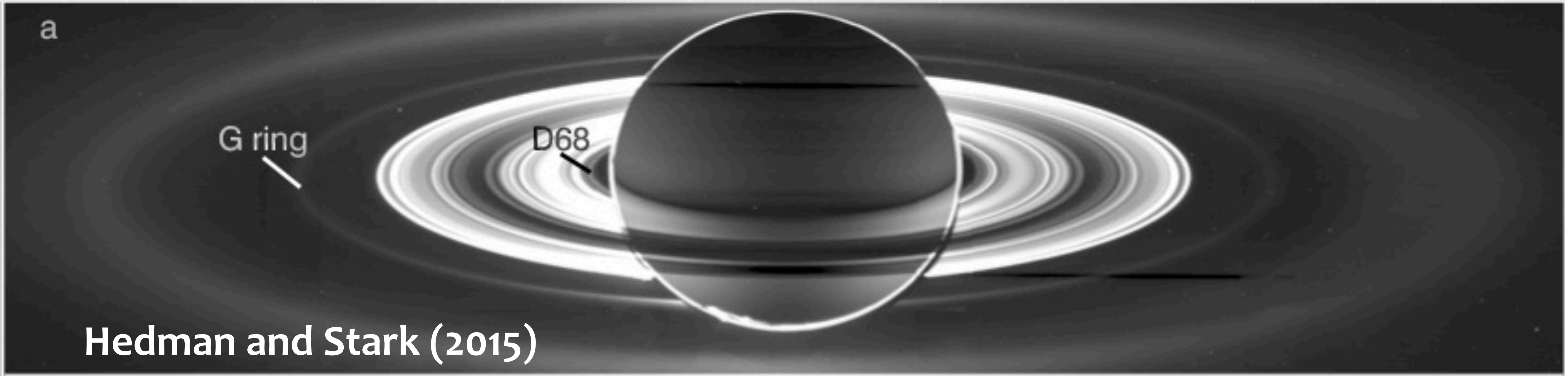

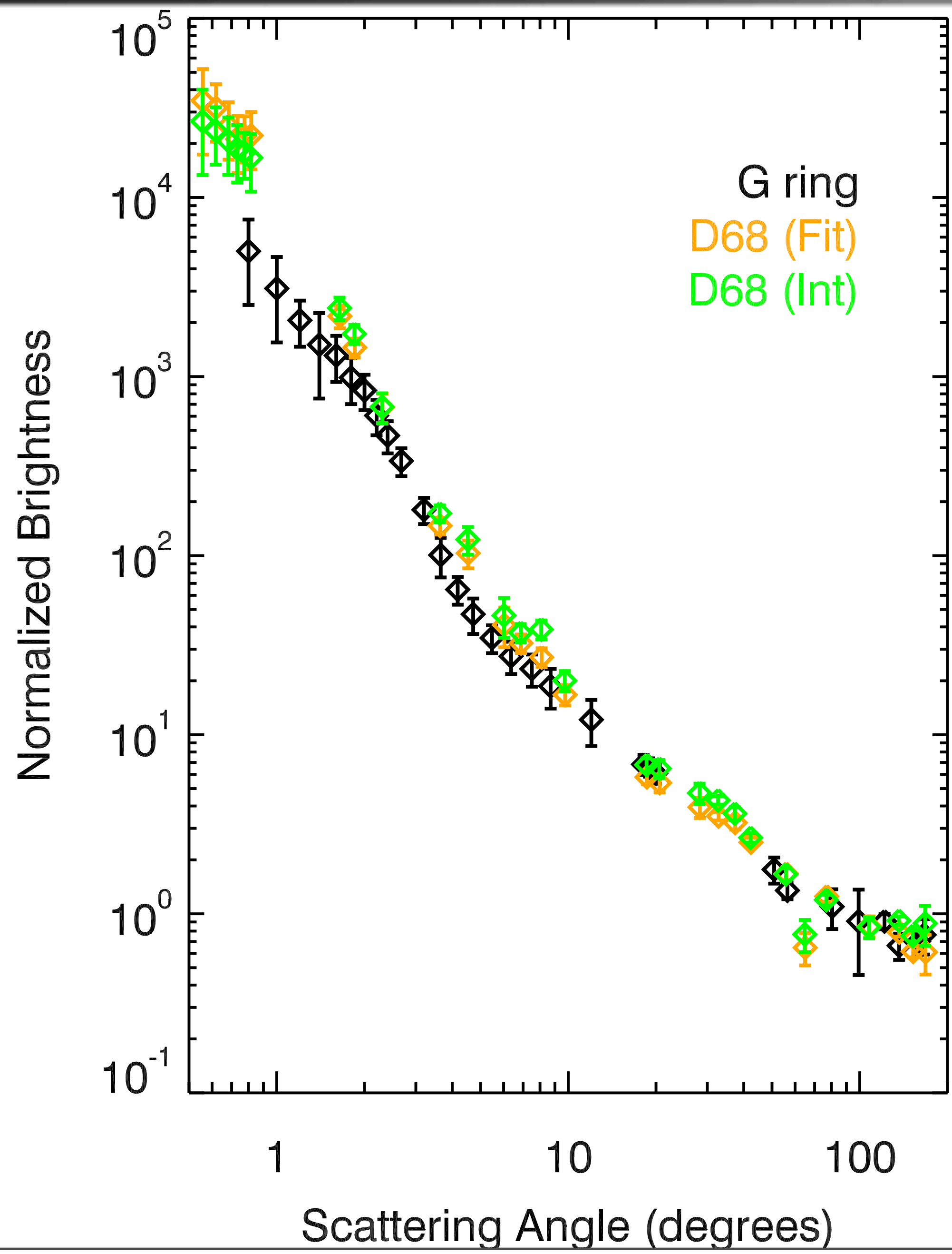

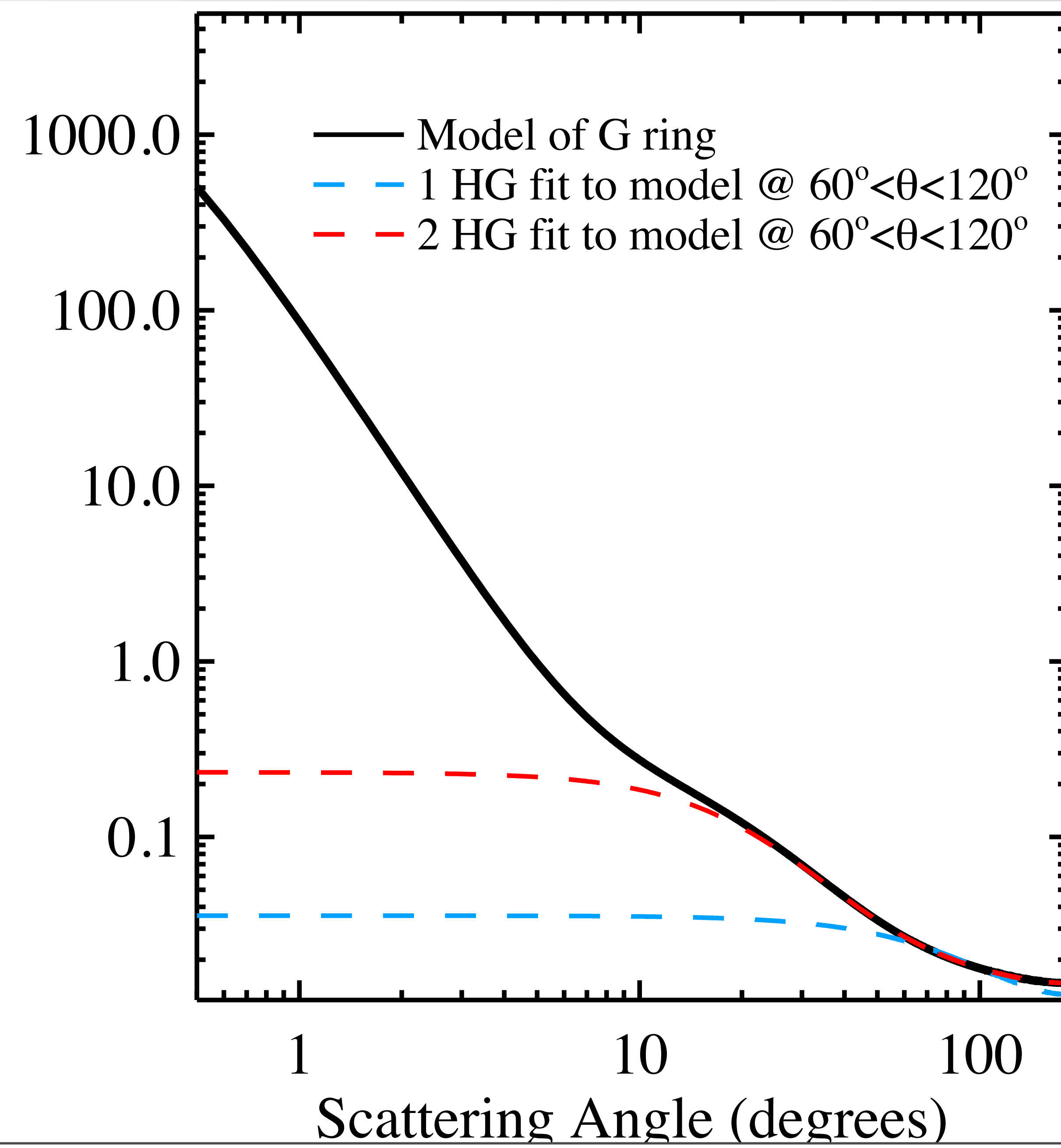

Scattering phase function cannot be measured for angles from 0 to 180 on a single system.

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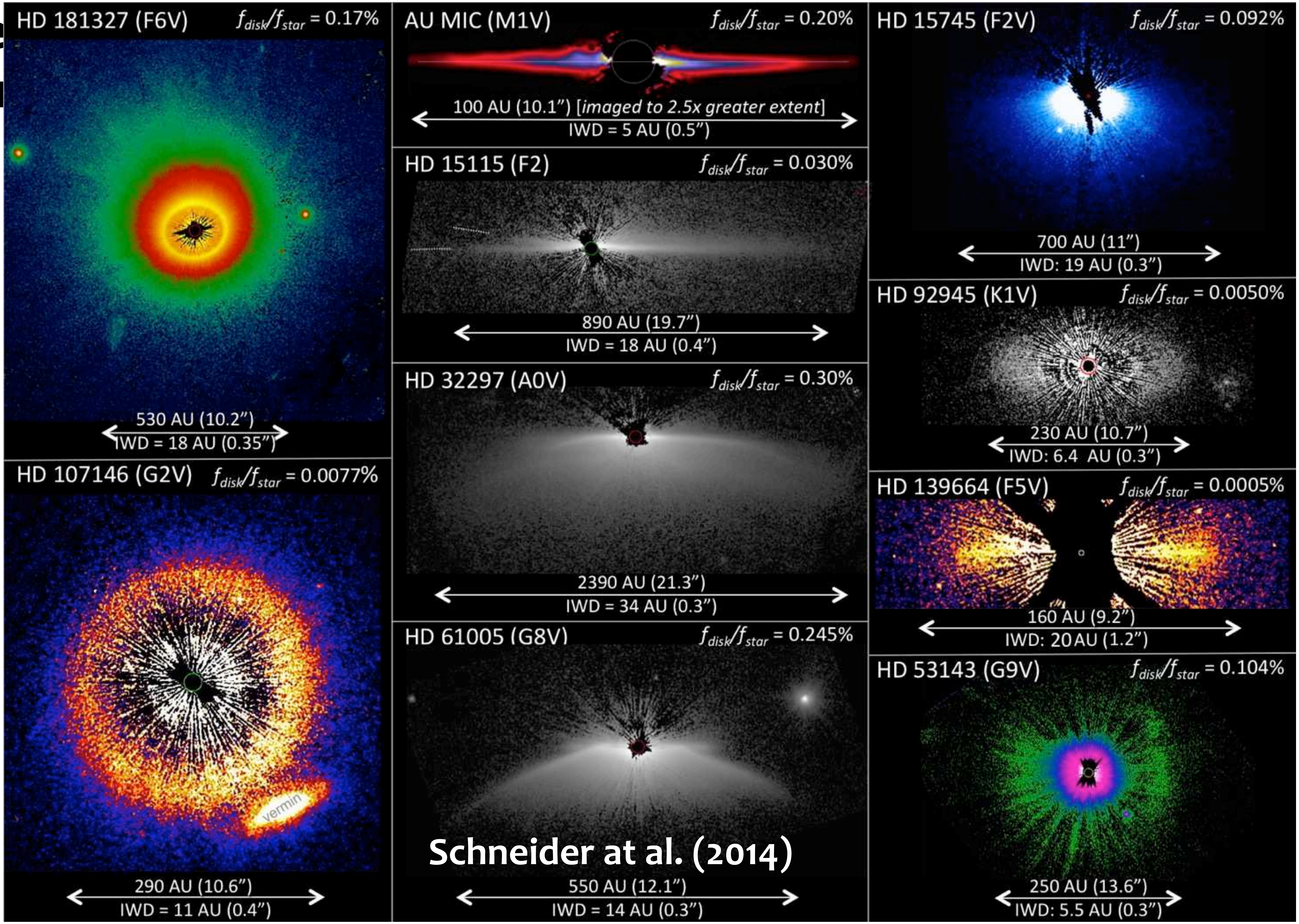

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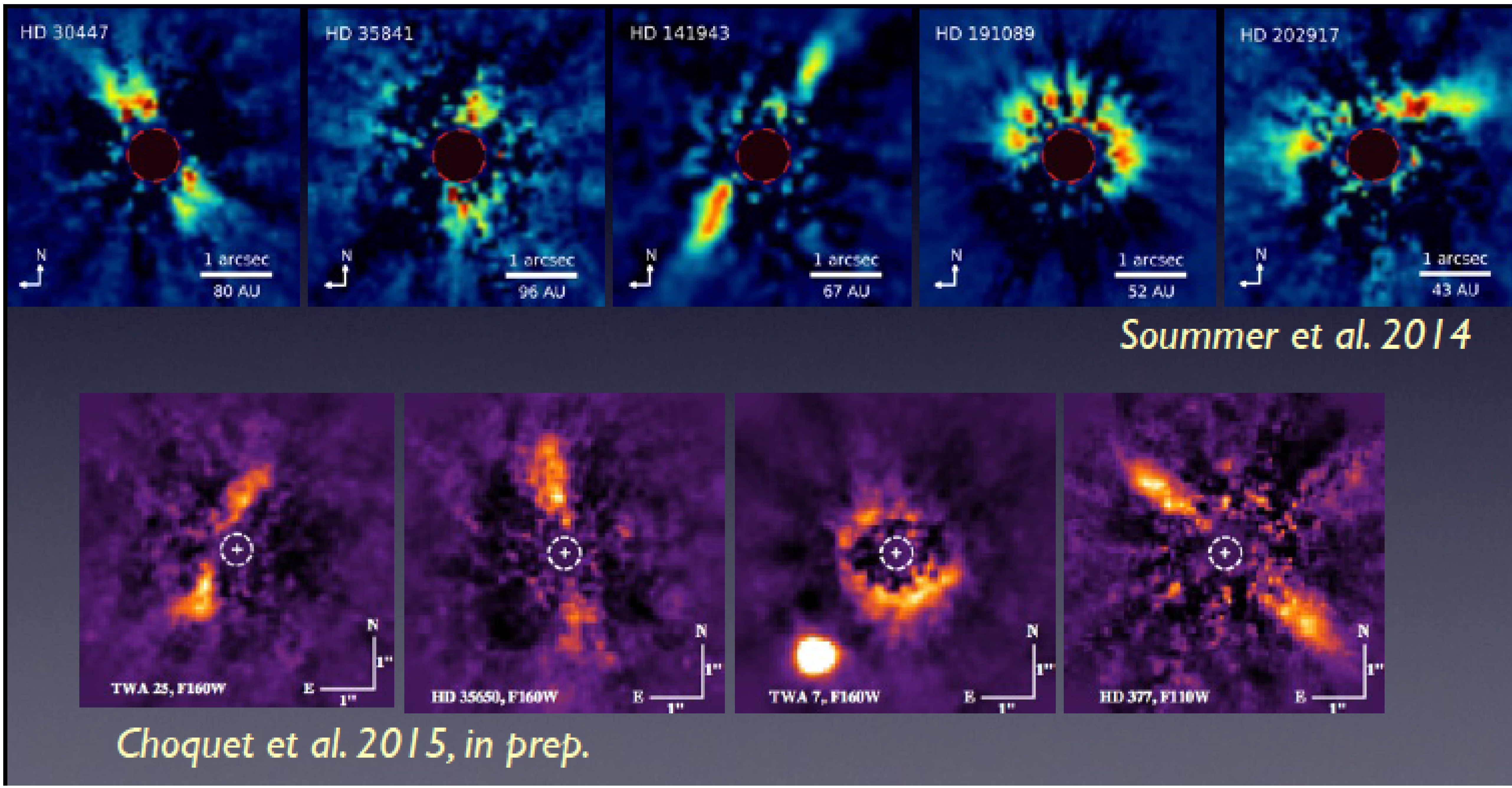

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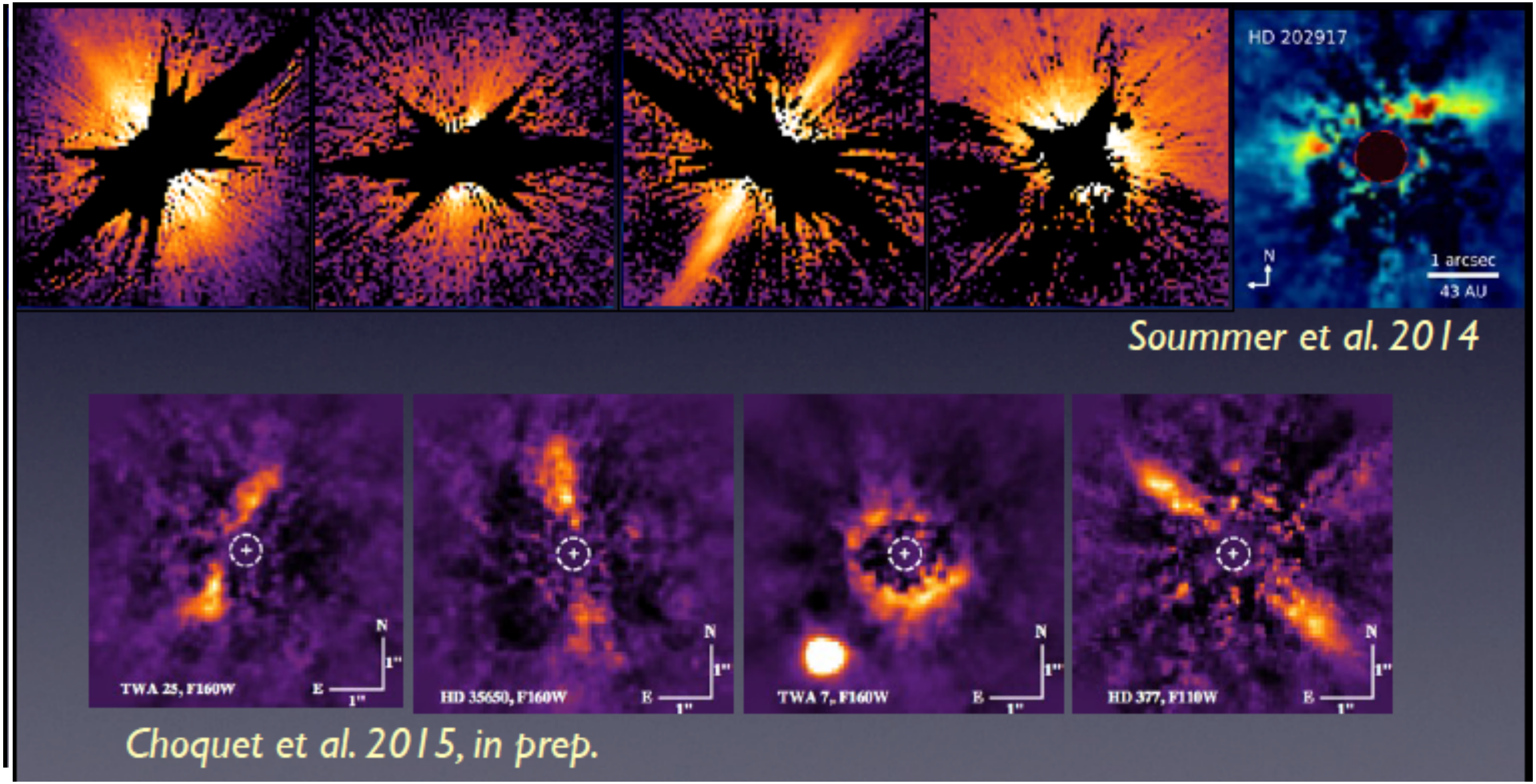
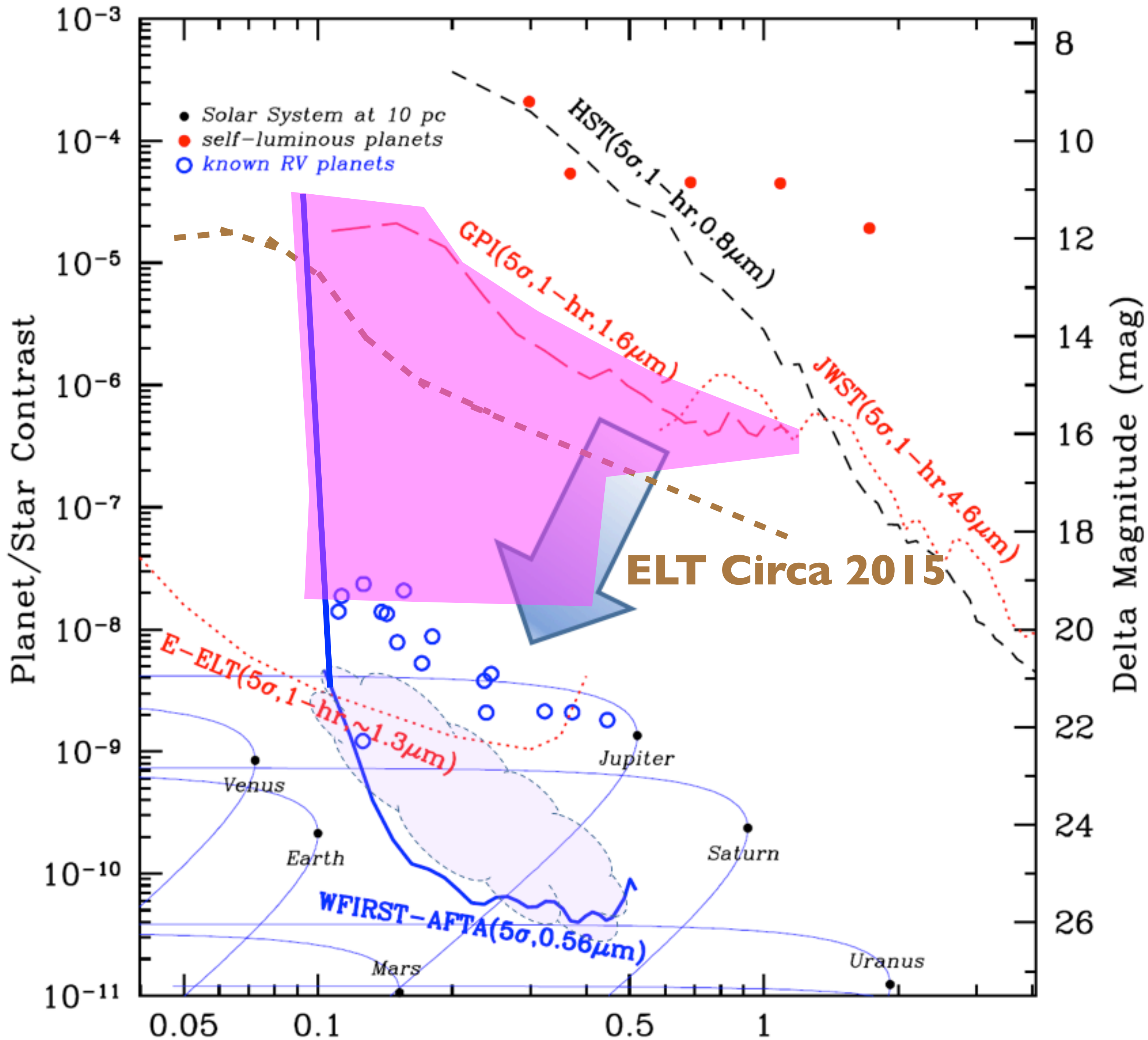


Parameter space for WFIRST CGI GO science



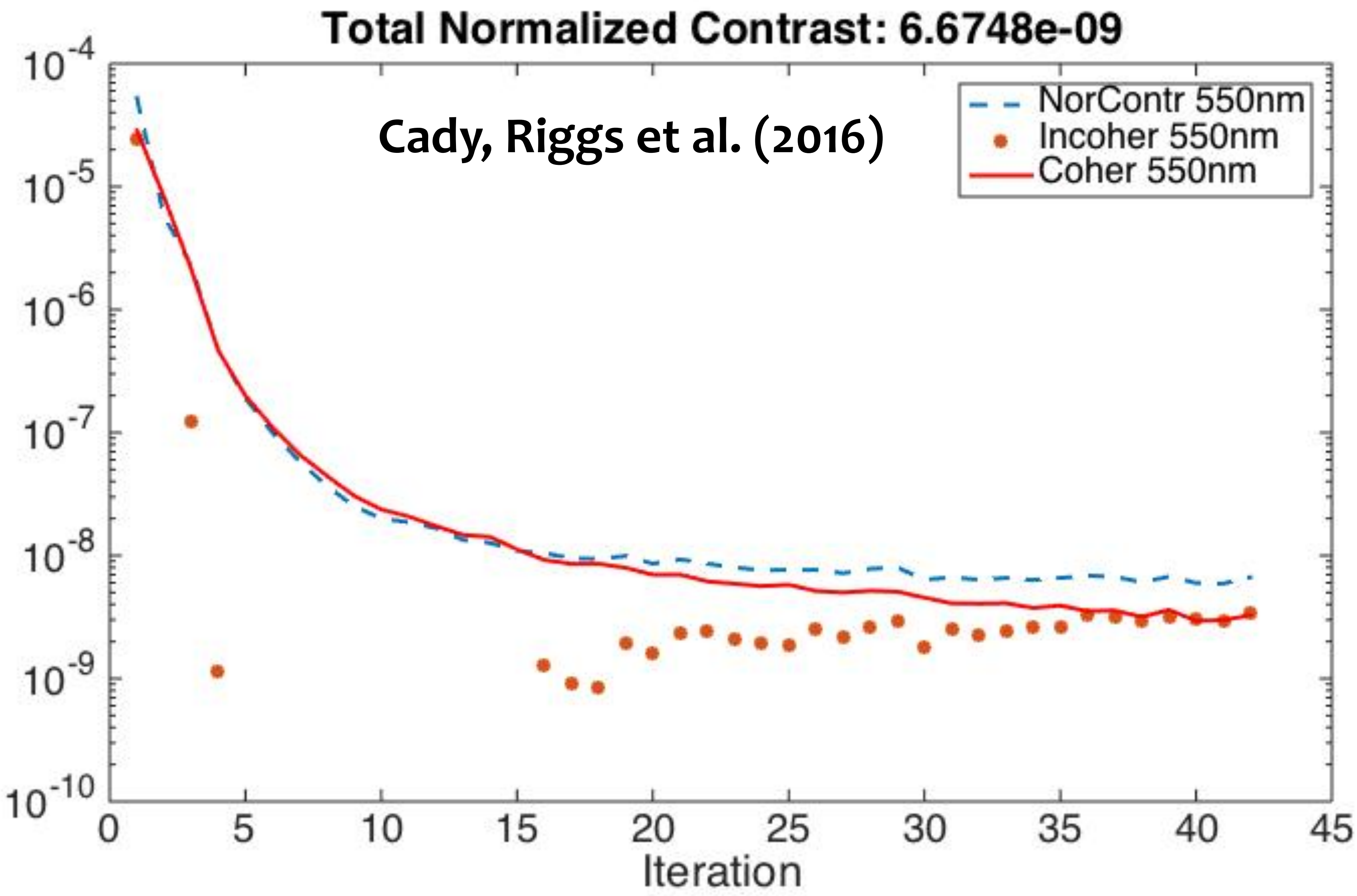
4. Debris disks

and their scattering properties

- Measurements of the scattering properties of dust at all possible inclinations.
- Take advantage of the polarization split in the CGI imager.
- Important consequences for the planning of future missions.

What does this mean for the CGI instrument:

- Maybe H alpha filter?
- Maybe larger field of view in the imaging channel?



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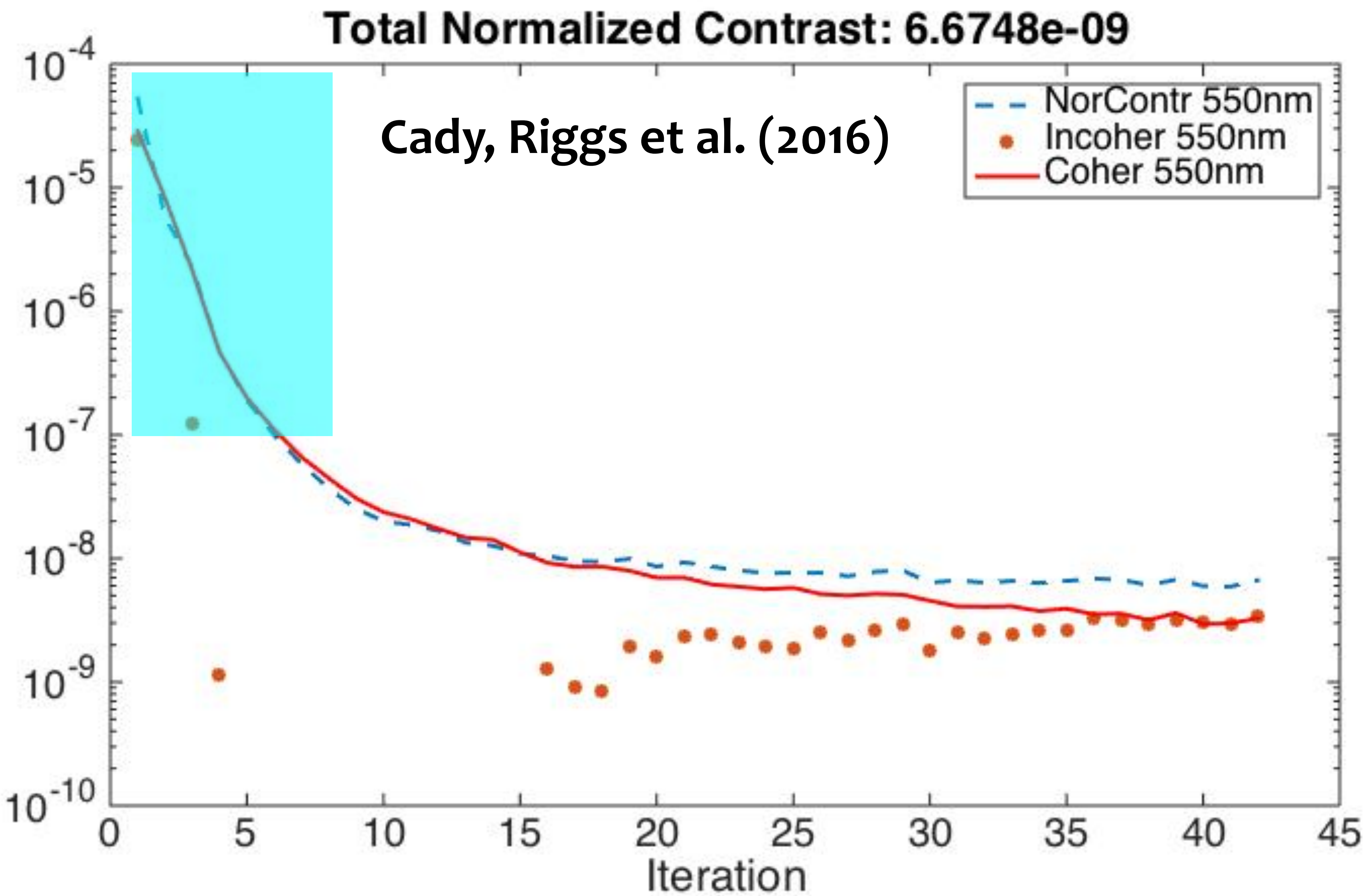

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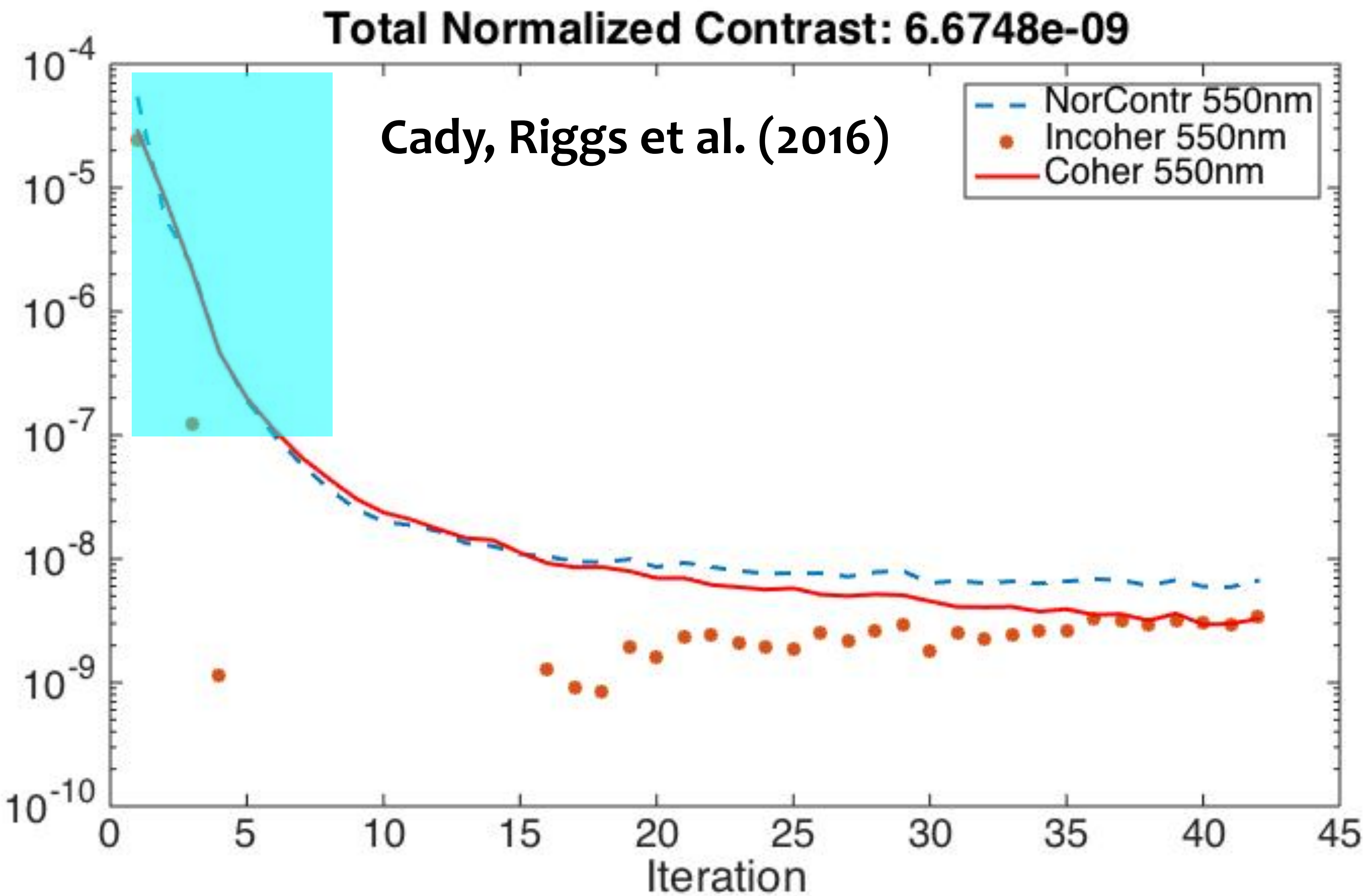
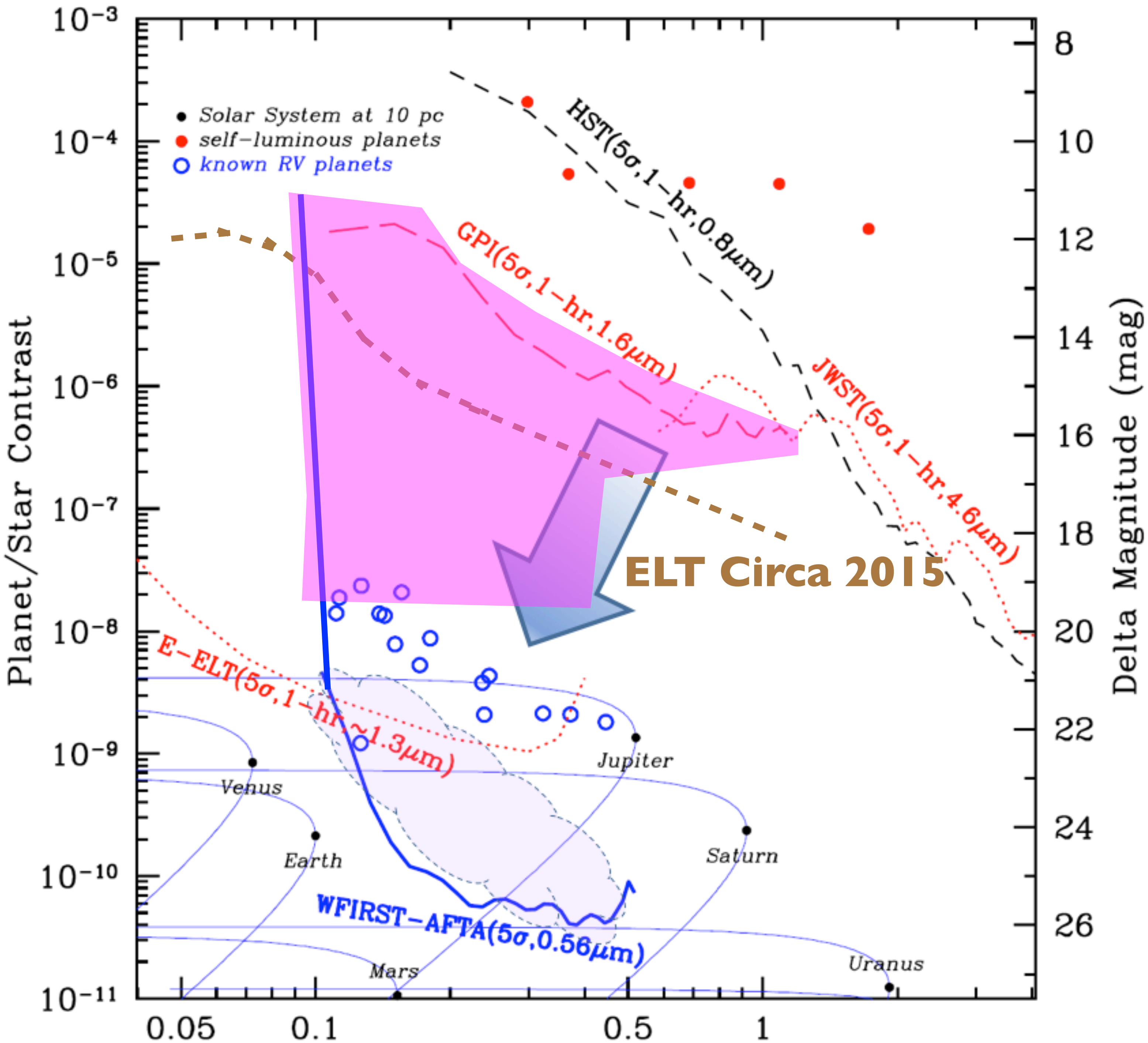


- **Science at a contrast 1-2 orders of magnitude more gentle than the requirements.**
- **Implication on timing of GO observations**

Parameter space for WFIRST CGI GO science



1. Proto-planetary disks and their interaction with exoplanets.
2. Proto-planets and interactions with their disk.
3. Adolescent-planets and their atmospheres.
4. Debris disks and their grains.

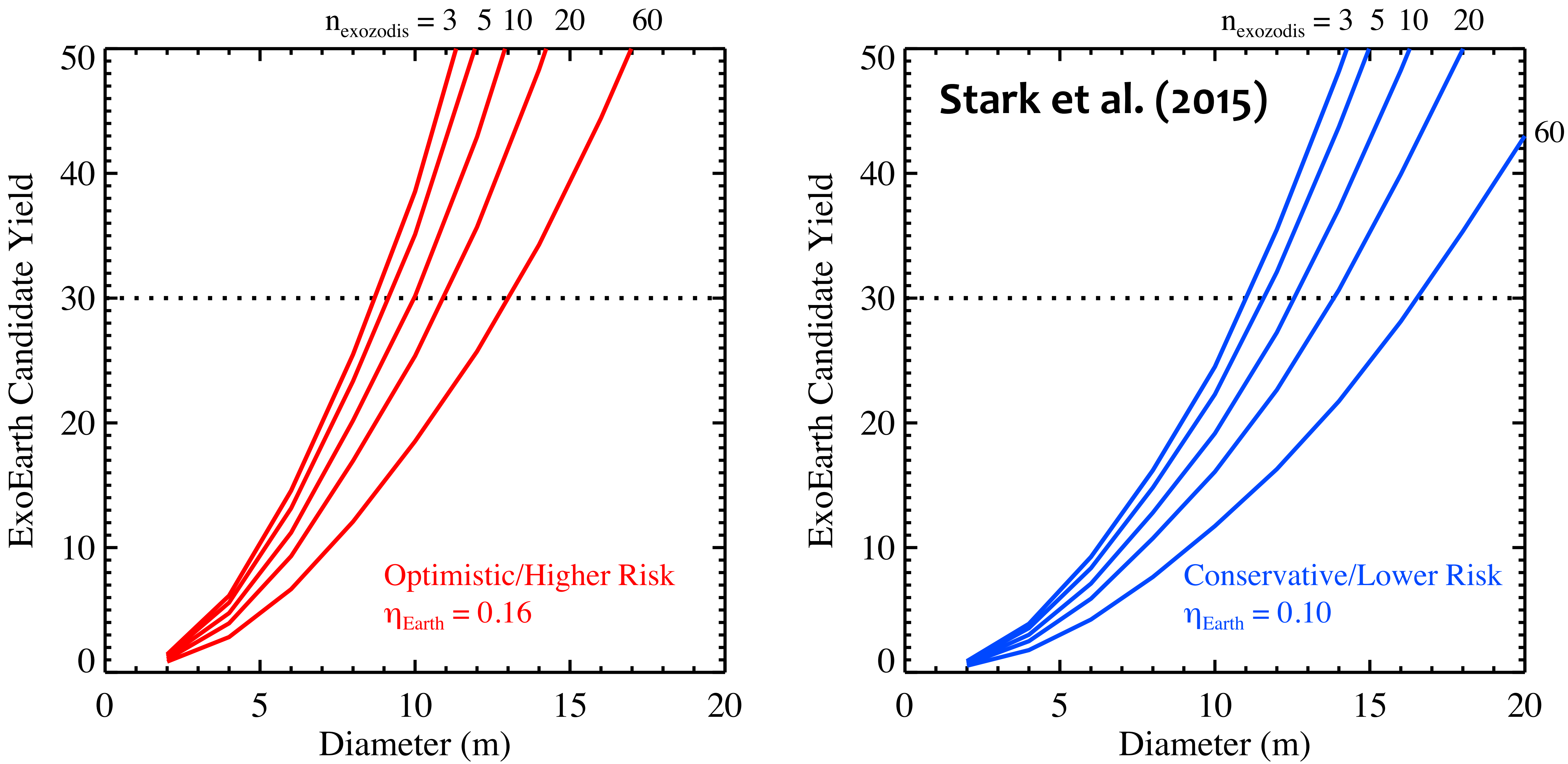
- **Plenty of exciting science with the WFIRST-CGI**
- **Synergies with JWST, ALMA, ELTs.**

High-Contrast Imaging from Space Workshop.
STScI
Nov 14-16 th 2016

Many astrophysical observations require the imaging of faint objects or nebulosity next to point sources such as stars and unresolved active galactic nuclei. To achieve these observations, several high-contrast imaging techniques have been developed to suppress light from the central bright source in optical through mid-IR wavelengths. The operation of telescopes in space has opened new frontiers in high contrast imaging due to their relative stability and location above the Earth's atmosphere. The astronomical community is using knowledge gained from current space- and ground-based facilities to plan for future high contrast imaging missions in the next decade. In this workshop, we will explore the legacy of existing space-based high contrast imaging from the Hubble and Spitzer Space Telescopes and investigate how existing scientific observations and coronagraphic techniques may be applied for future observations with the James Webb Space Telescope and the Wide-Field Infrared Survey Telescope to image exoplanets, debris disks, protoplanetary disks, AGN, Solar System objects, and other astronomical objects.

Back up

Importance of dust for future earth-imaging missions



The zodi-level is a key input to exo-earth experimental design.

Where is the zodi coming from?

Dust grains at 1 AU (LBTI)

x

Geometric Albedo (?)

x

Scattering phase function (??)

=

halo in images of solar system analogs.

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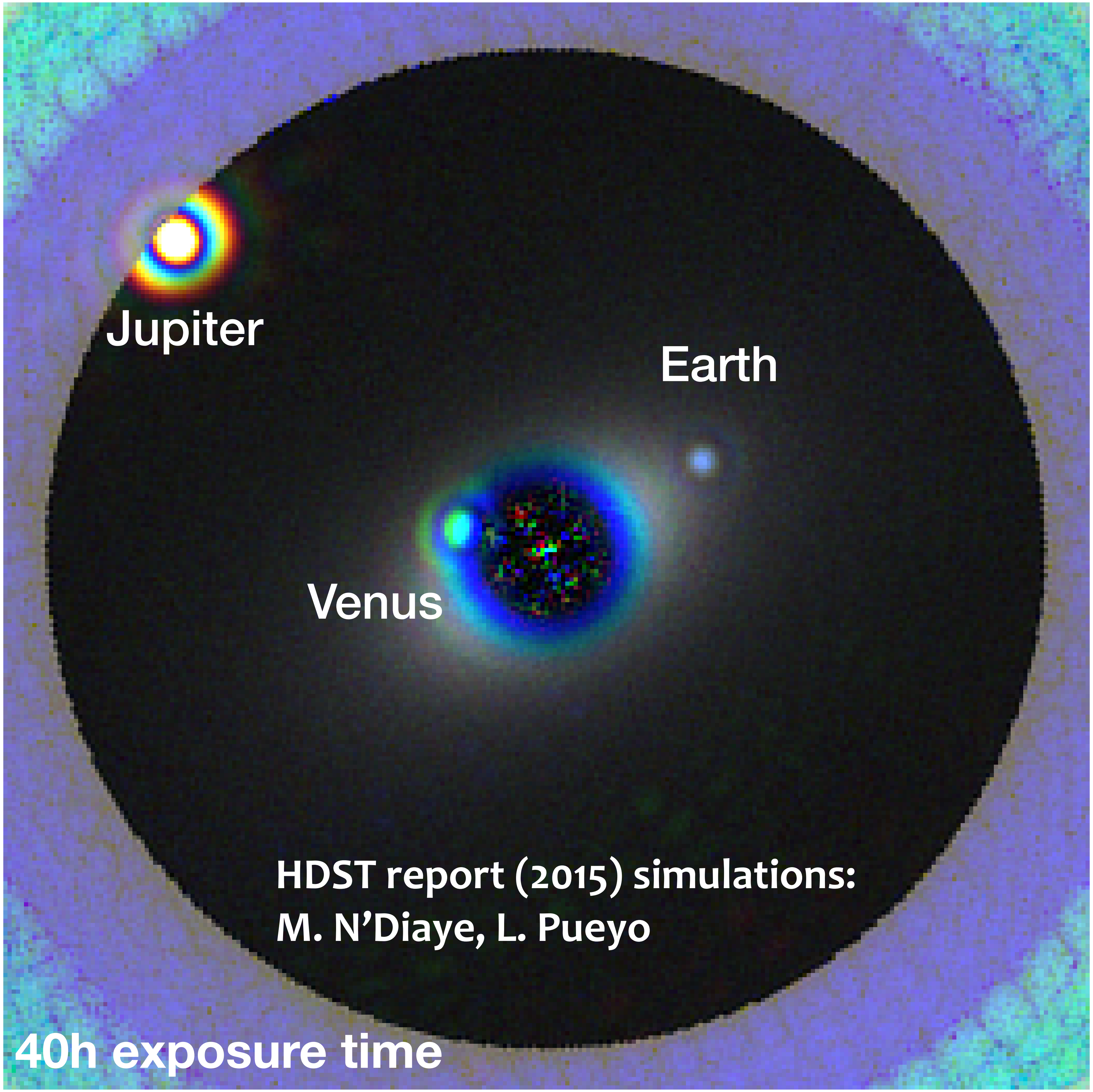

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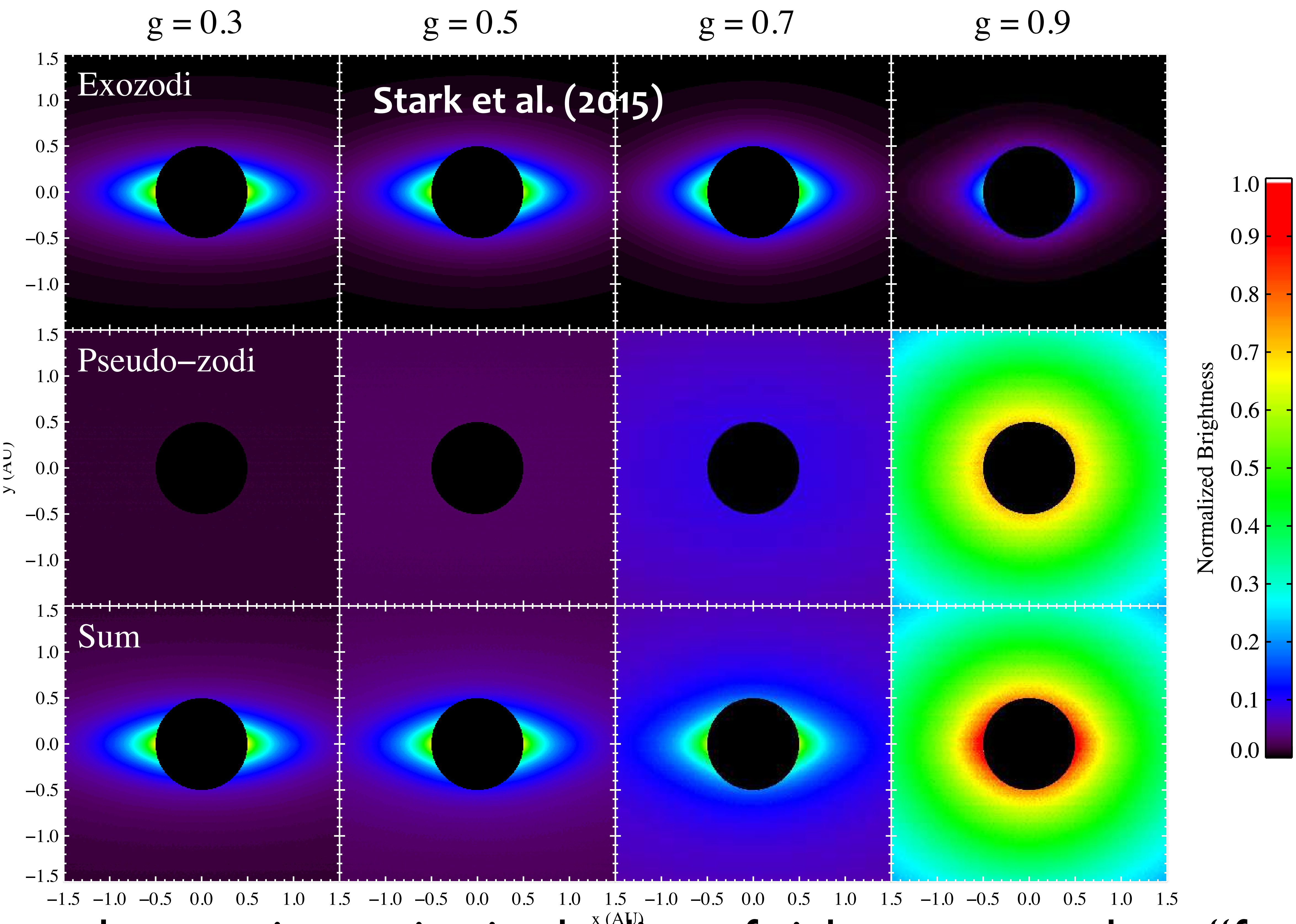
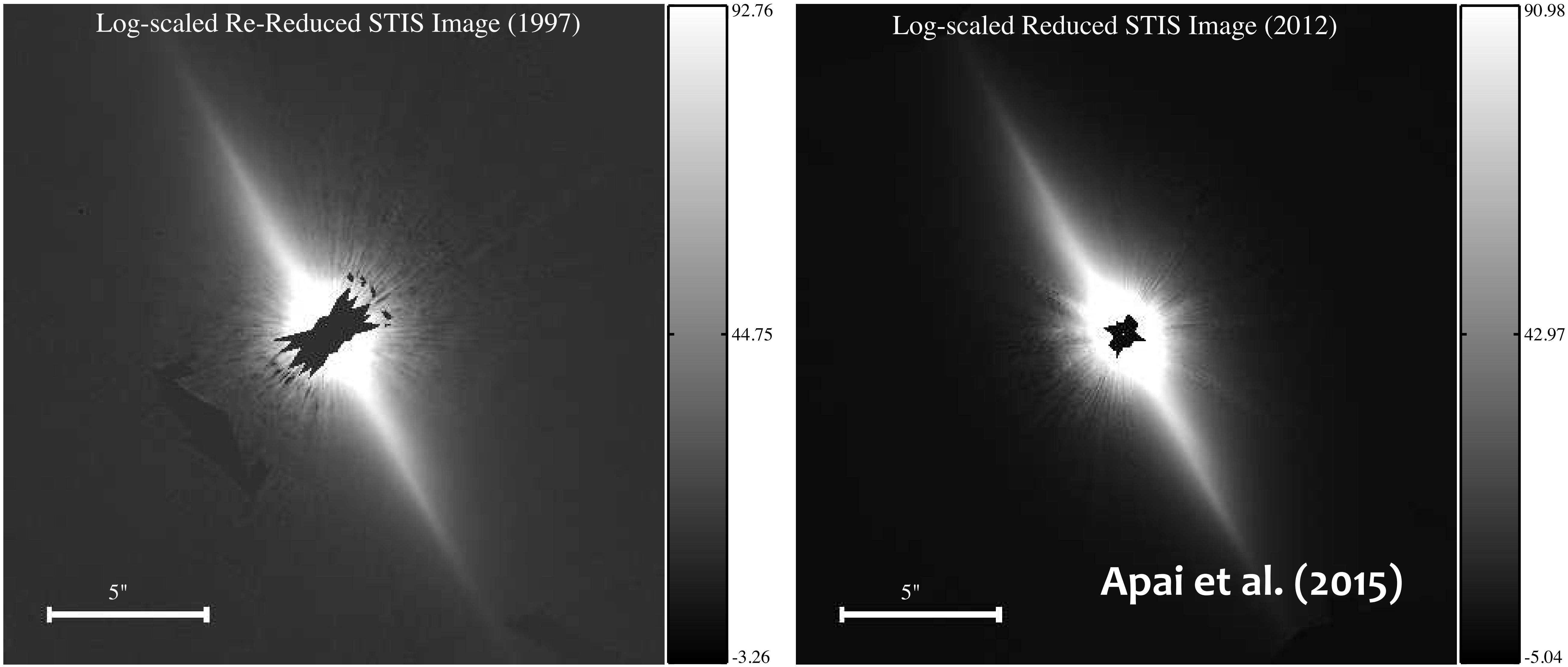


Forward scattering grains in the line of sight masquerade as “face on” zodi in an edge on system

This is not just a theoretical construction.



The disk around Beta Pictoris is very forward scattering

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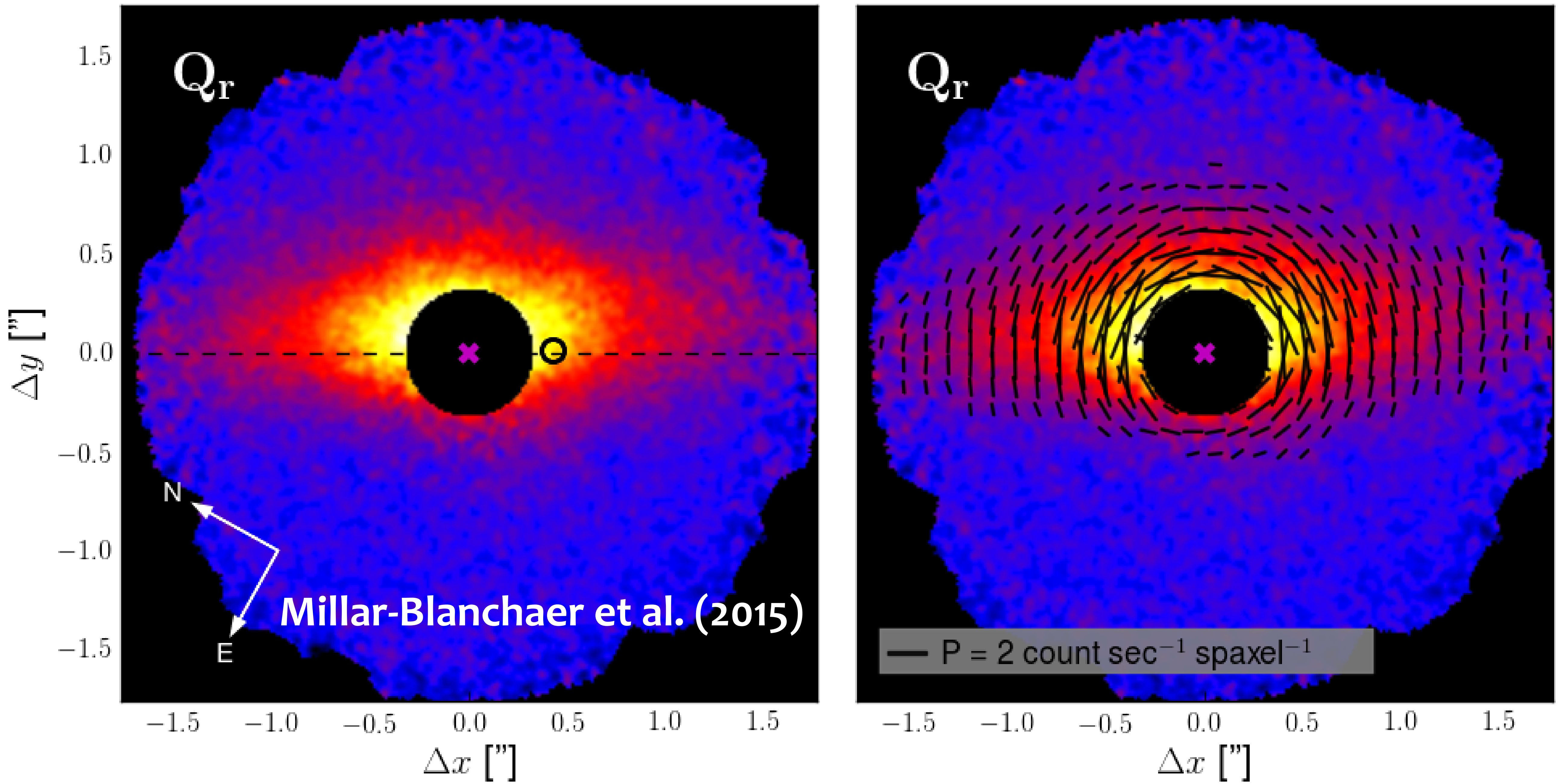

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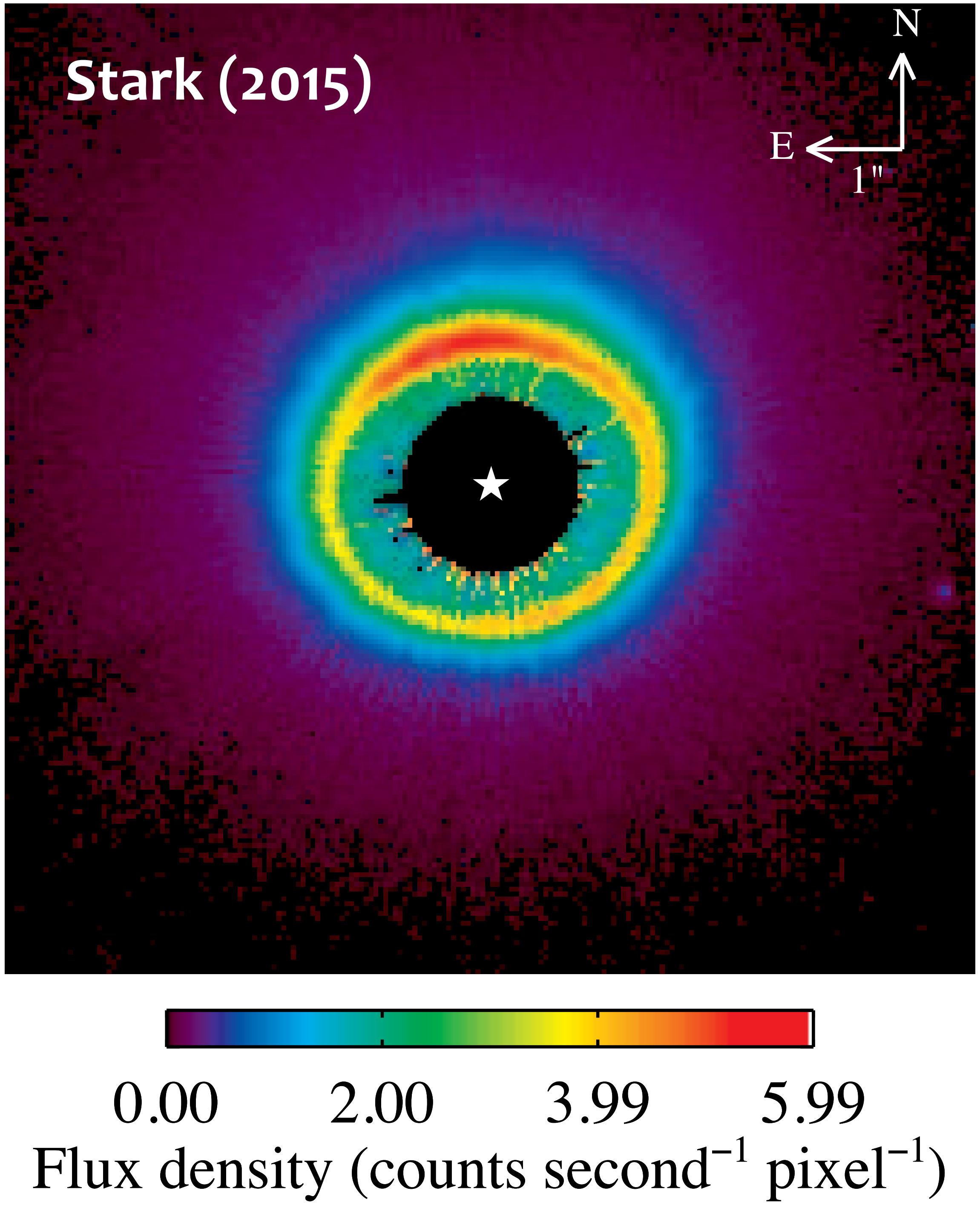
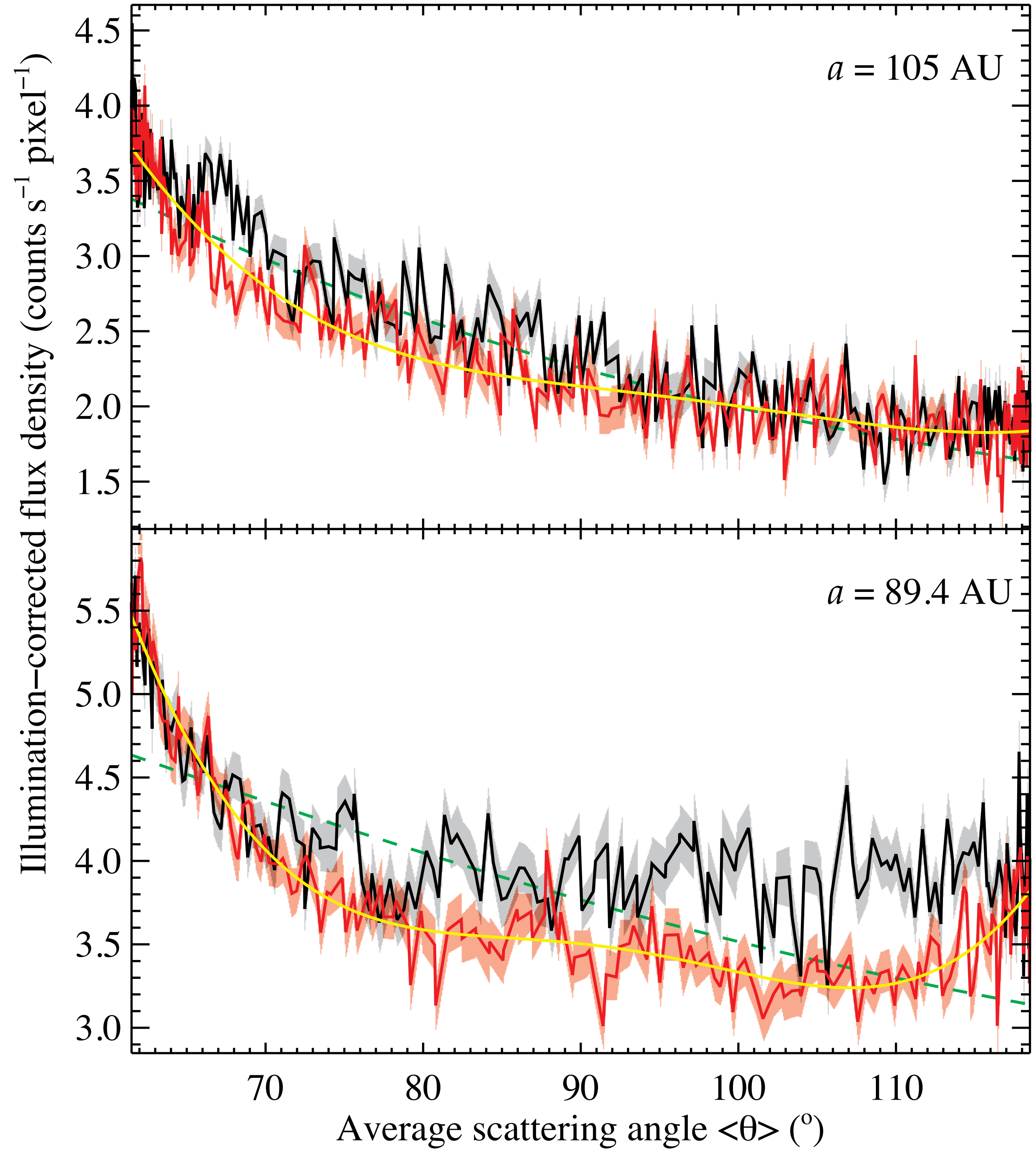
Measurements of scattering phase function





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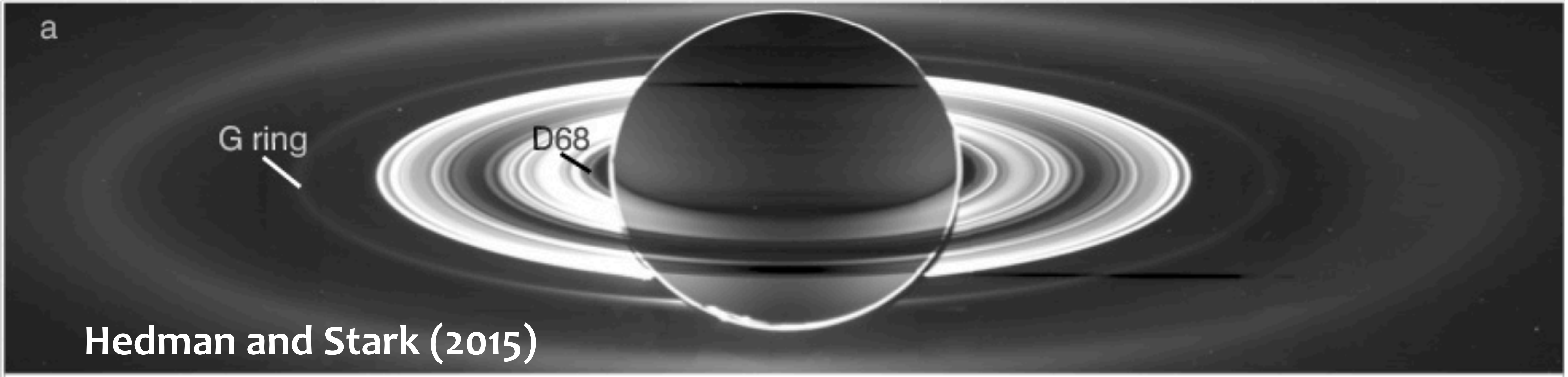

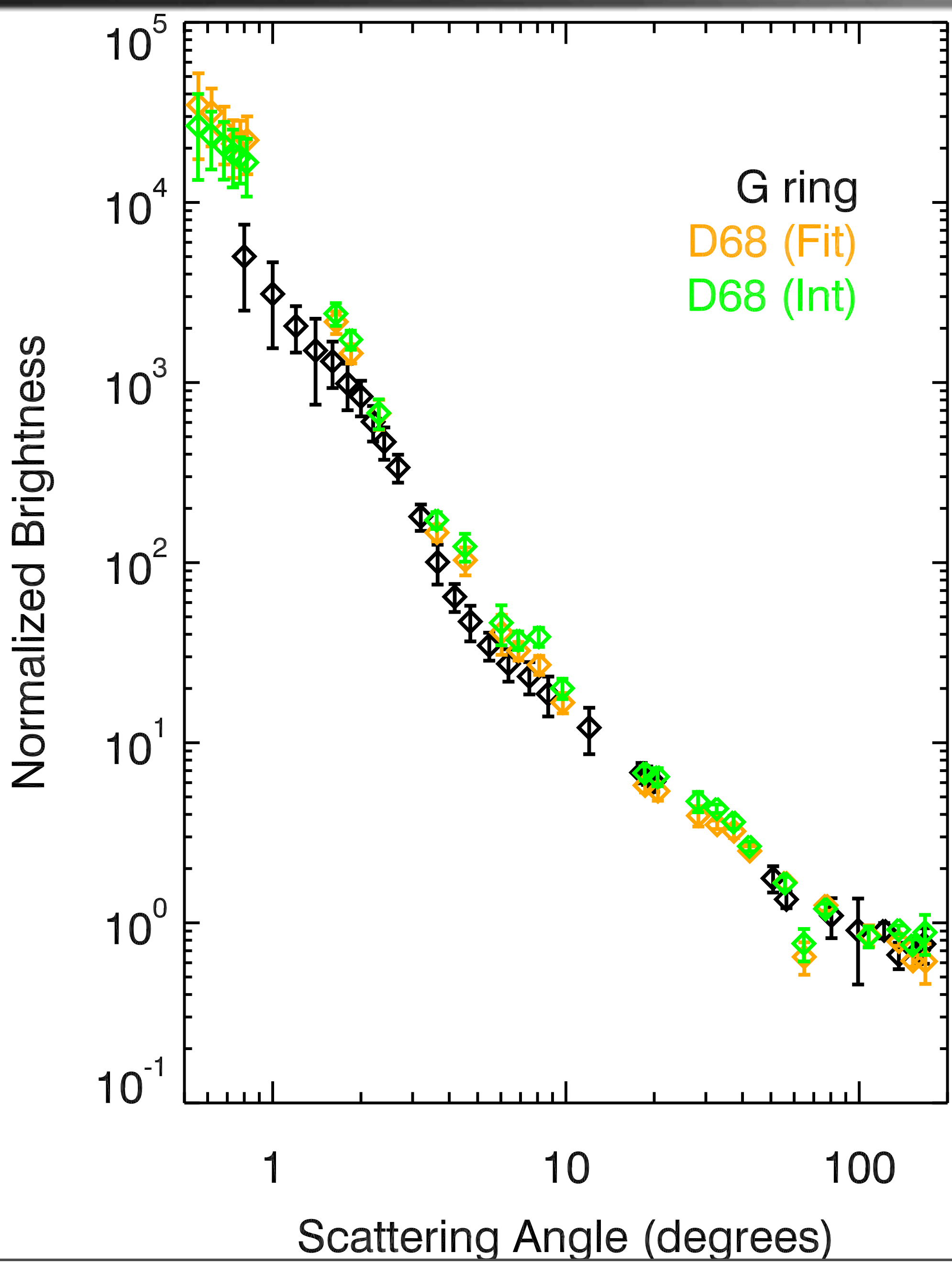

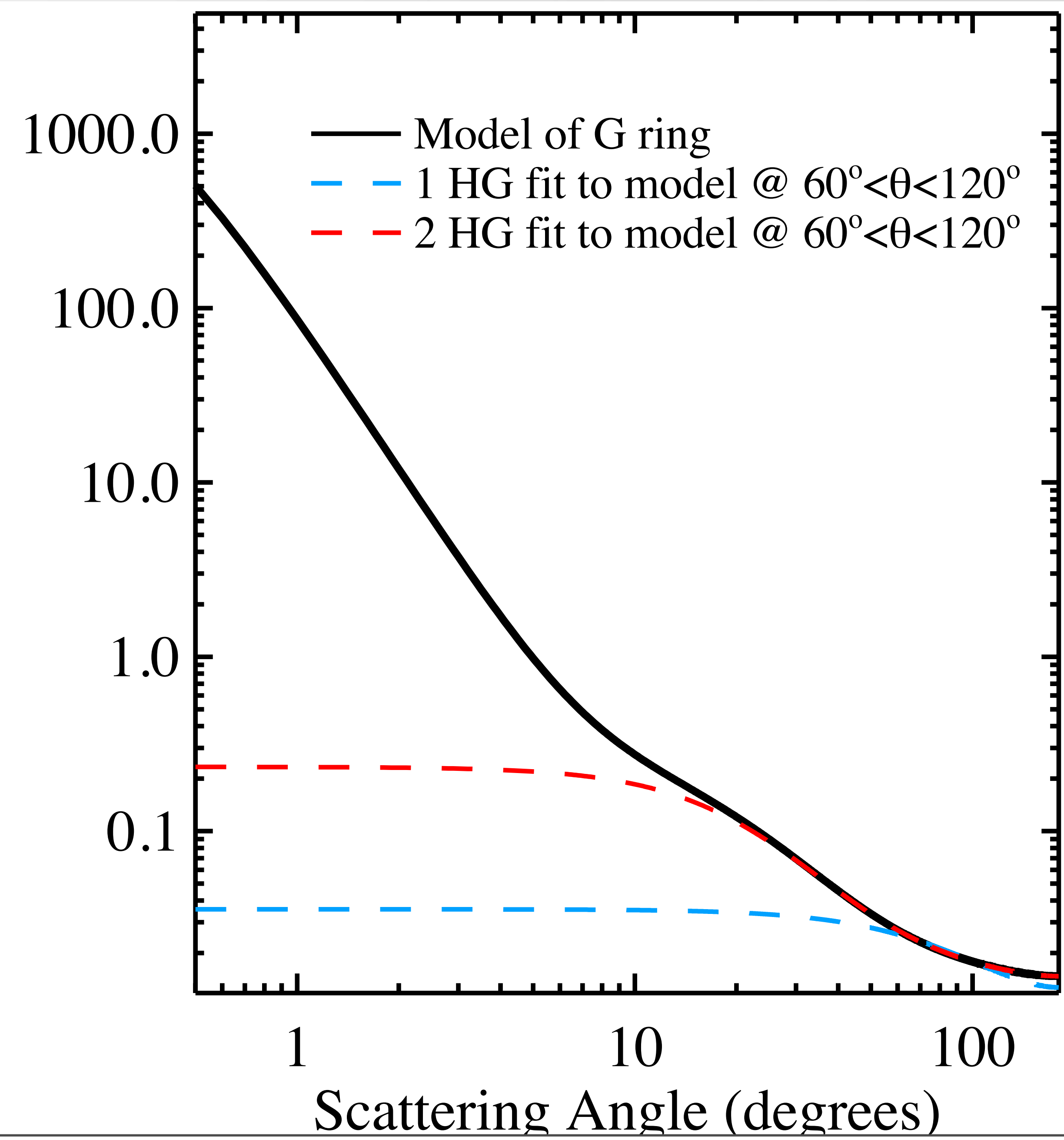

Scattering phase function cannot be measured for angles from 0 to 180 on a single system.

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Next step is to get a large sample of debris disks at various inclinations.

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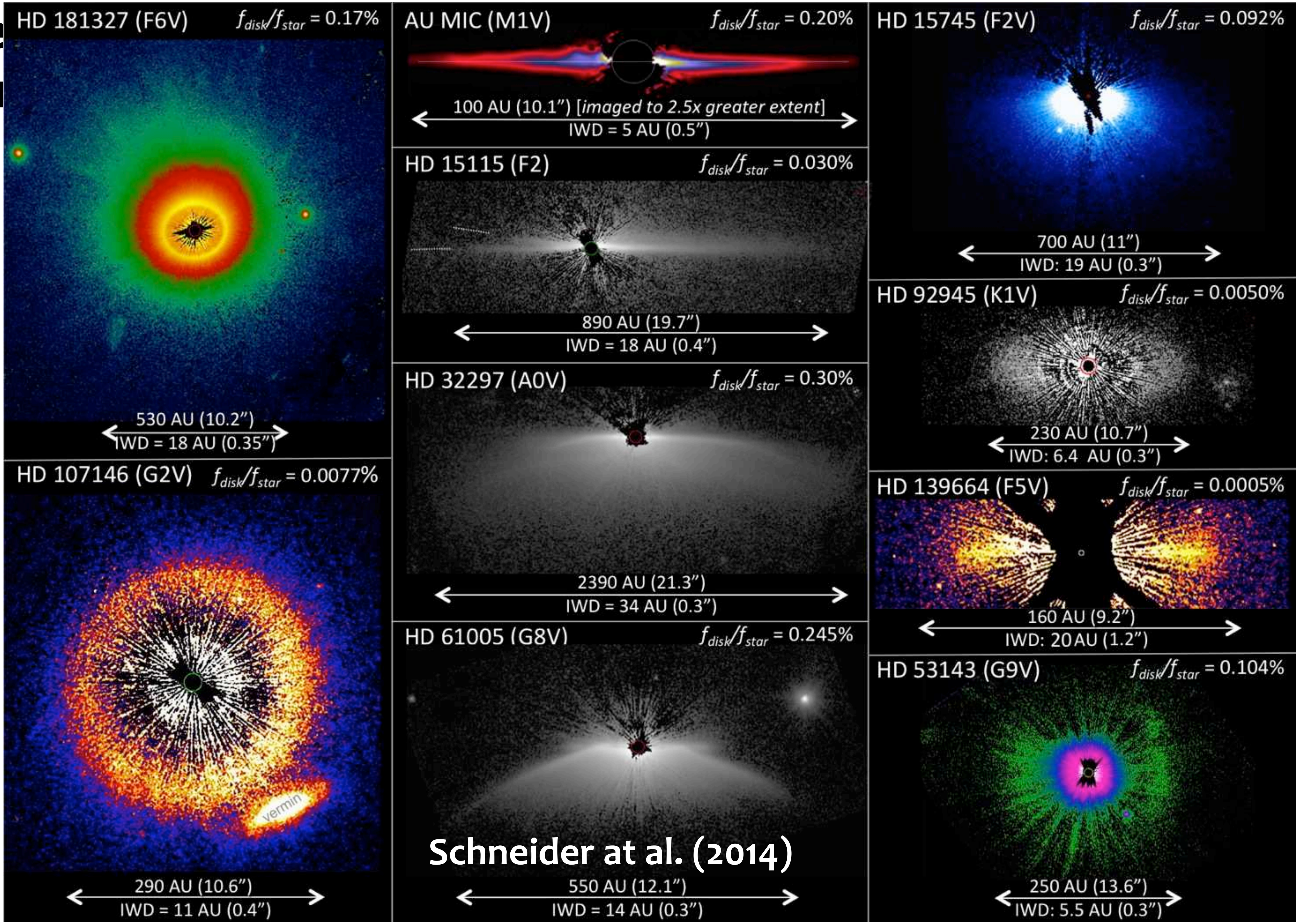

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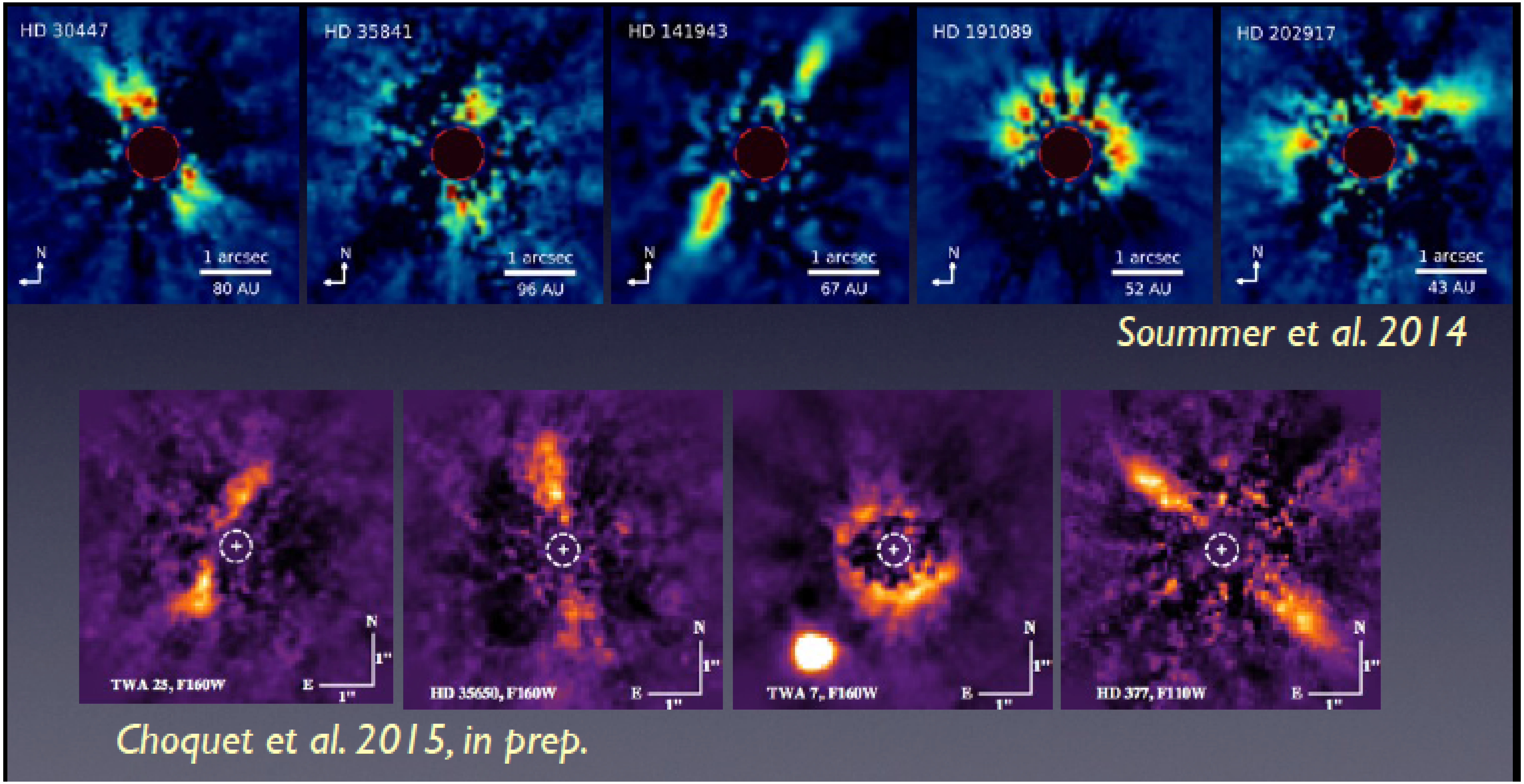

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