Imaging protoplanets

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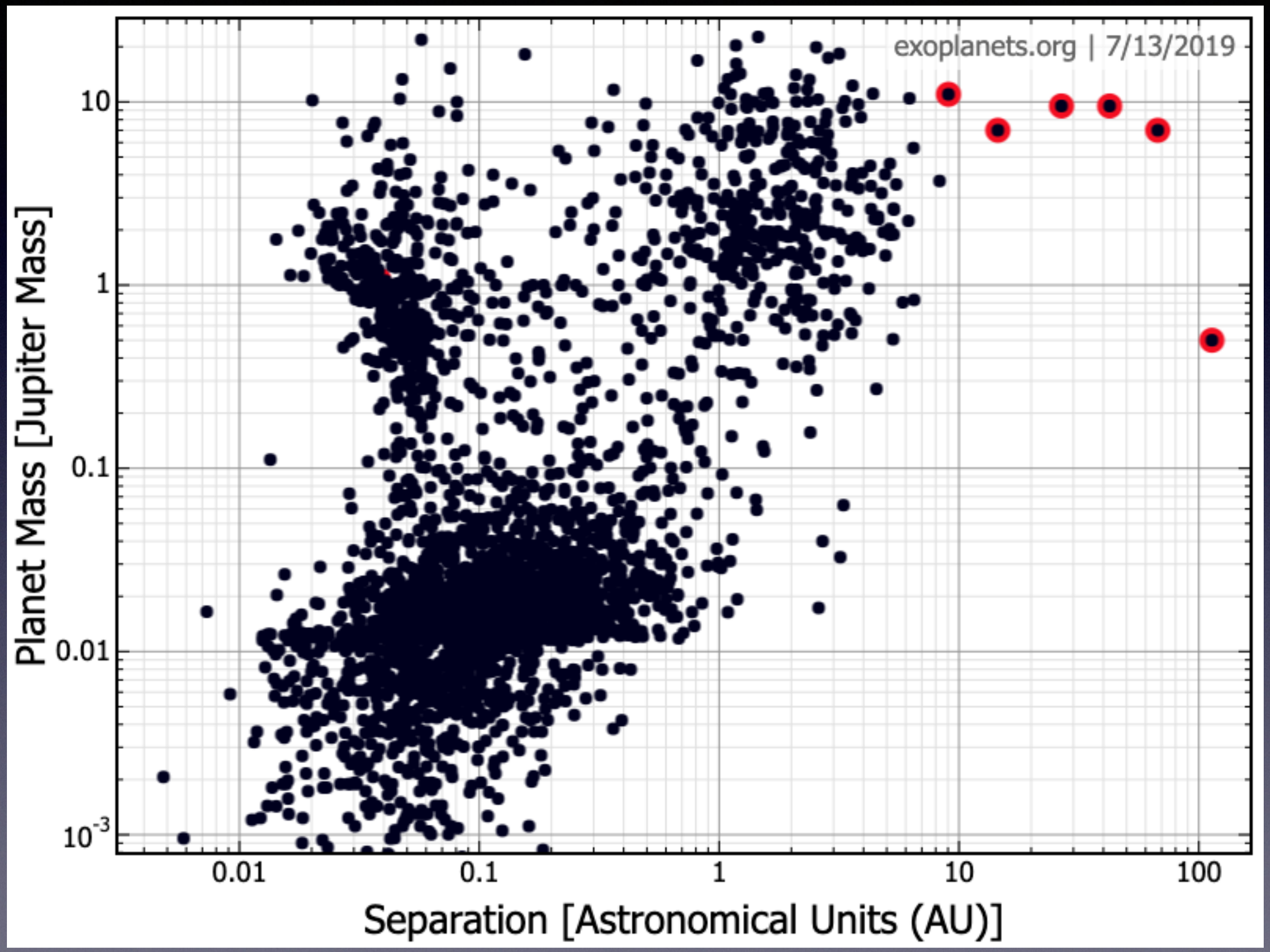
GREAT BARRIERS IN PLANET FORMATION, PALM COVE 2019

"Disks are so cool, they have different shapes, spirals, gaps, planets are just boring PSFs!"

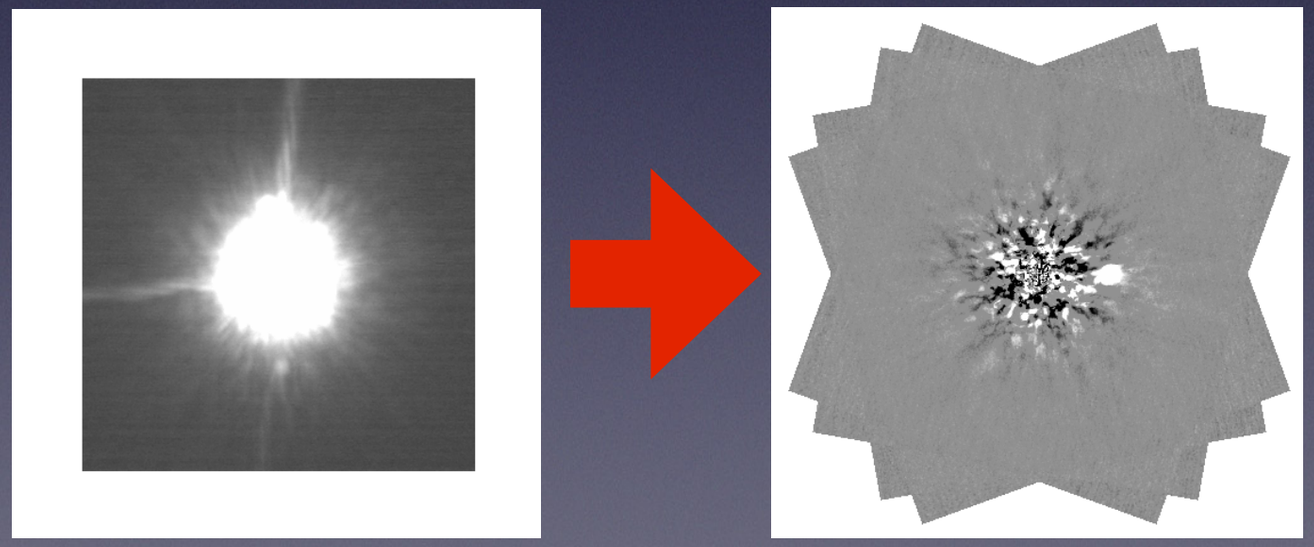
Jos de Boer

Direct imaging

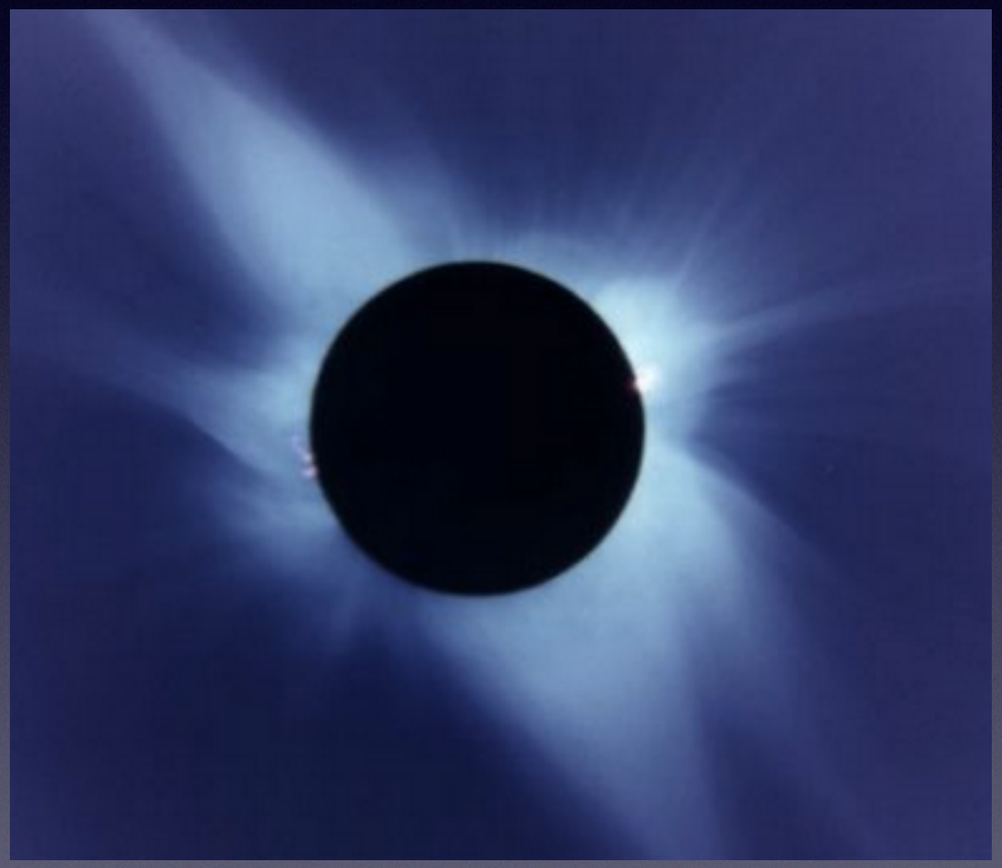


Direct imaging

Adaptive Optics

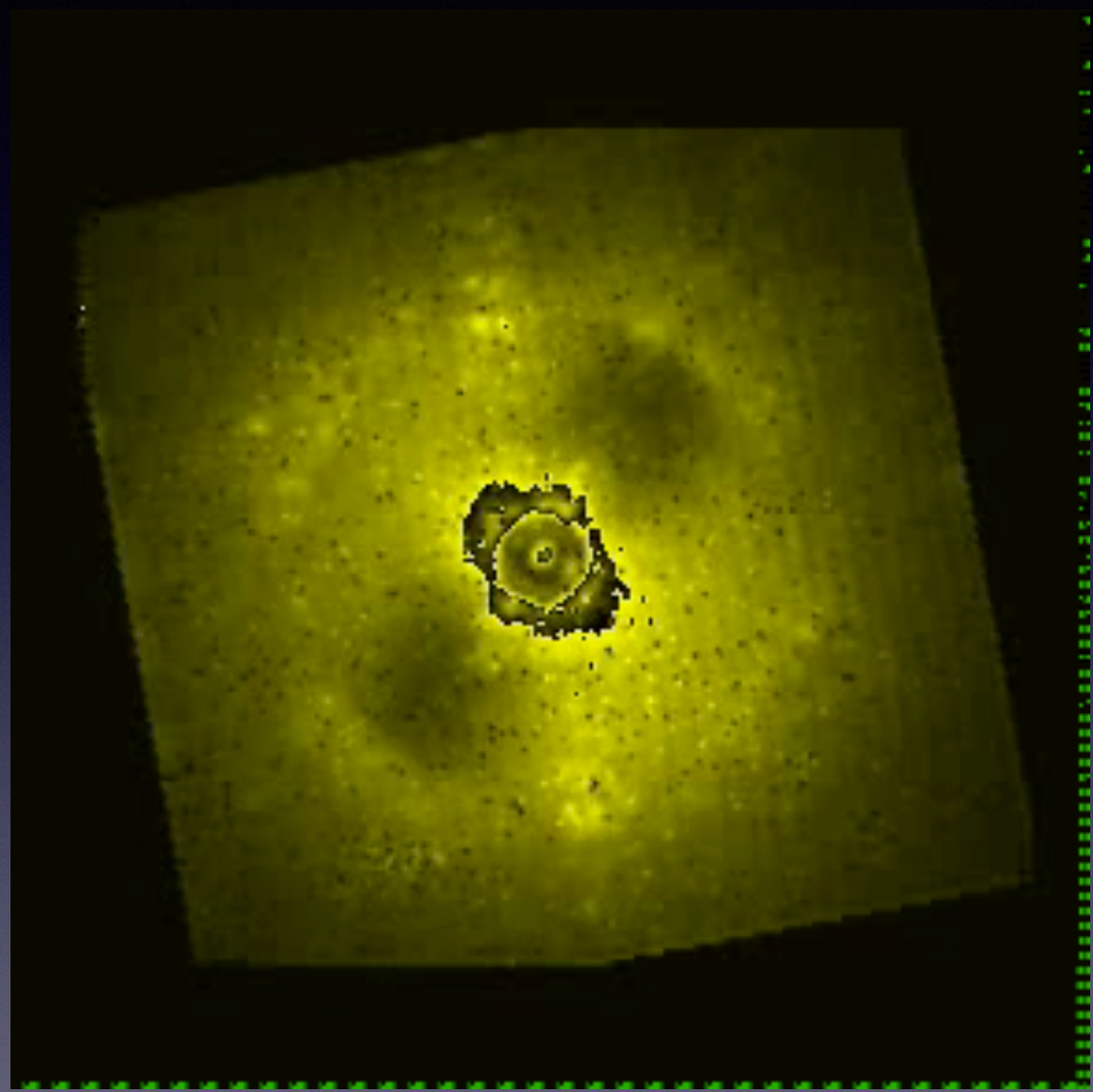


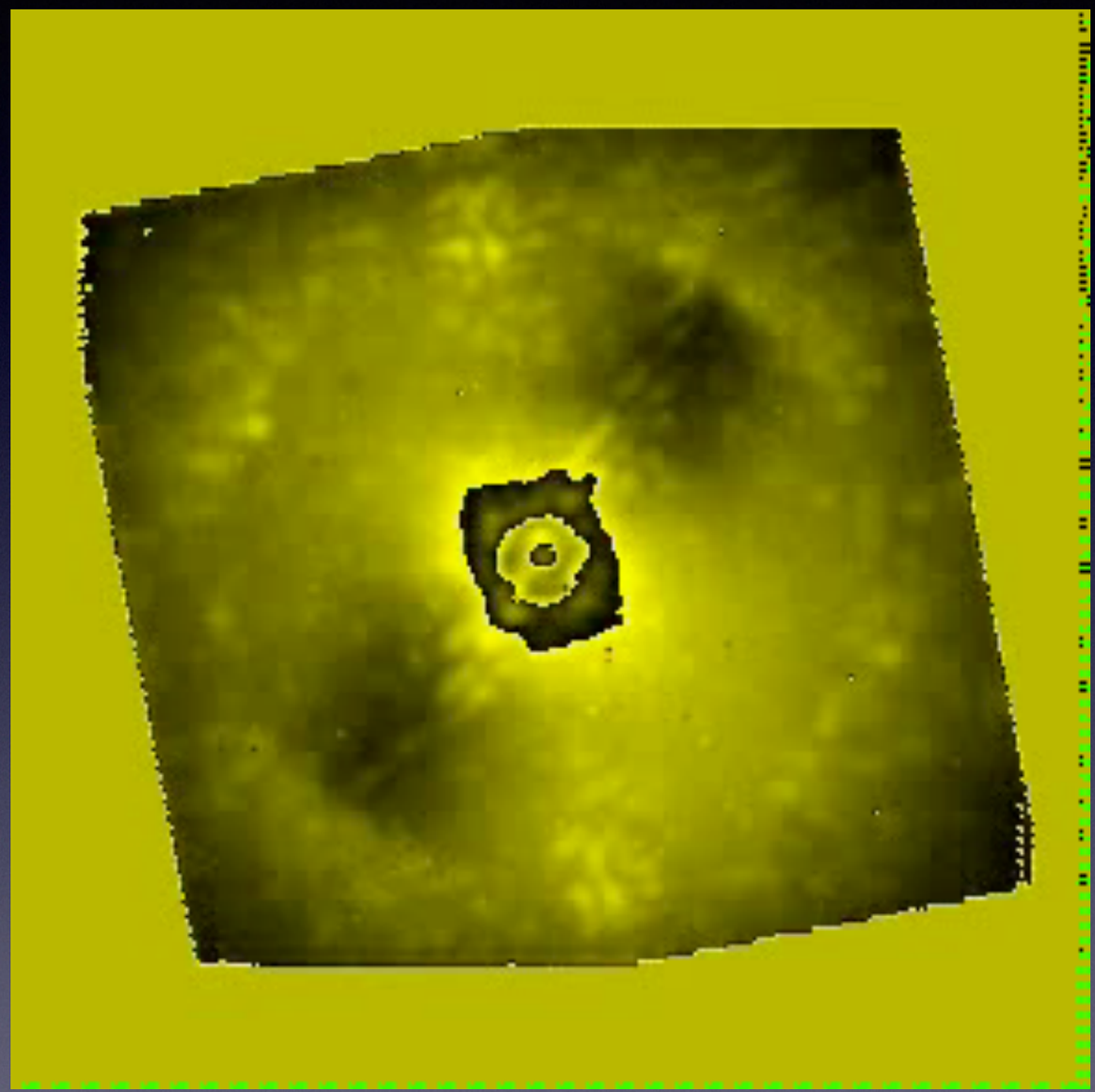
Post-processing



Coronagraph

Speckle pattern





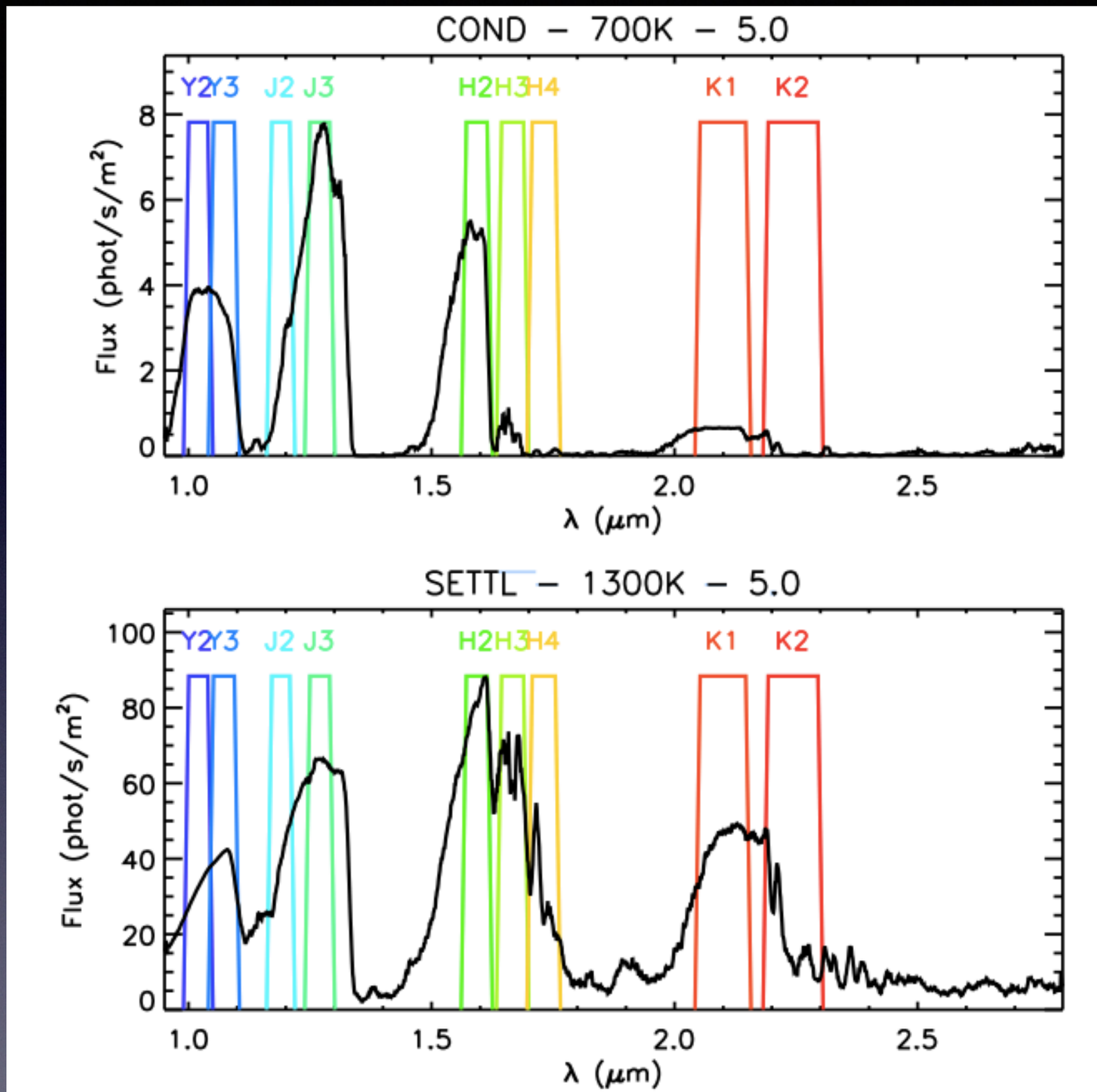
λ

HD 1160

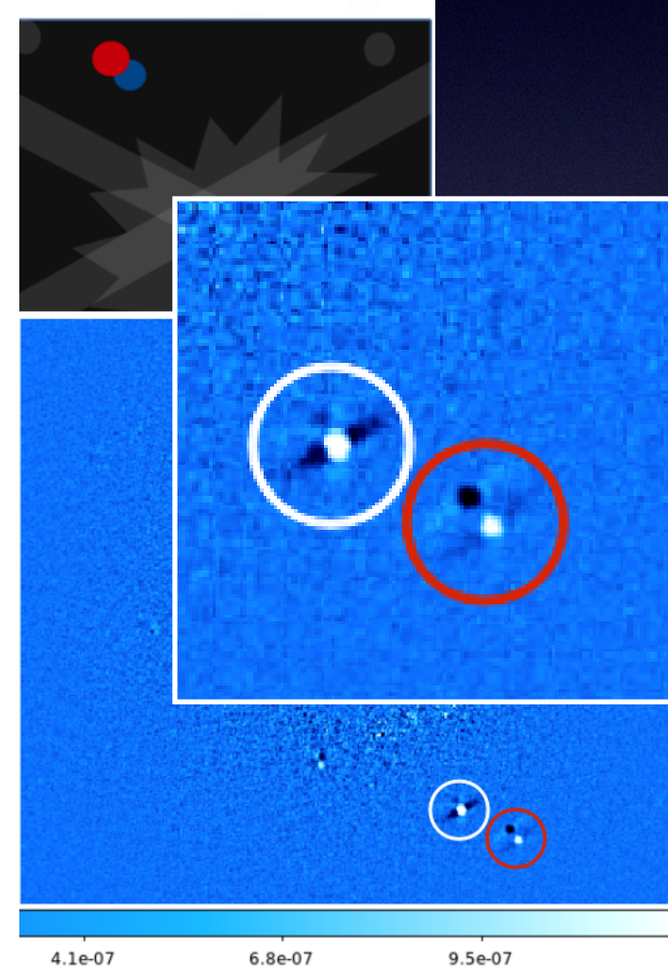
angle

Courtesy of R. Gratton

ial Imaging



Vigan A., phD thesis

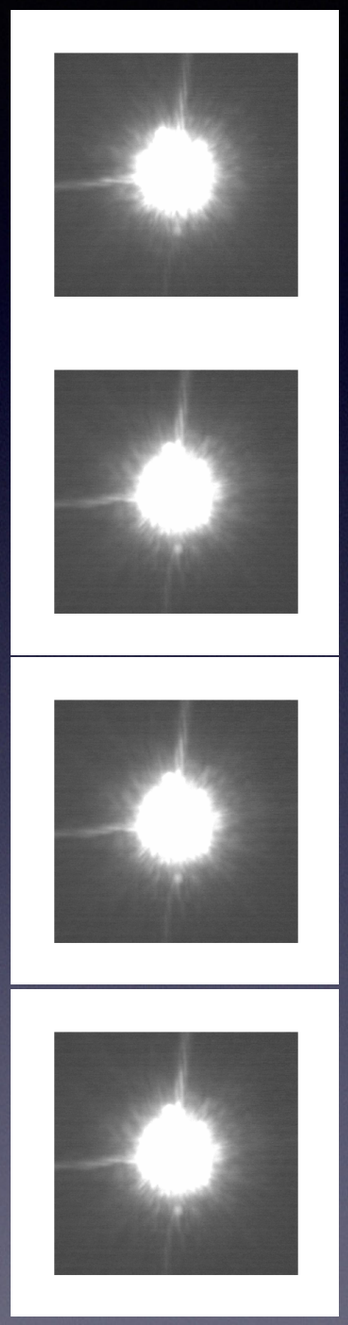


aled!

Vigan+2016

Angular Differential Imaging

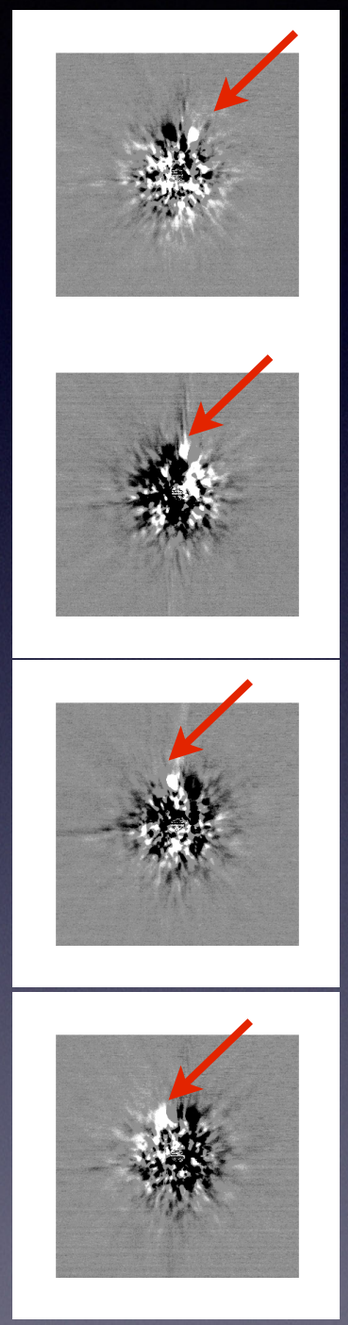
Courtesy of A. Vigan



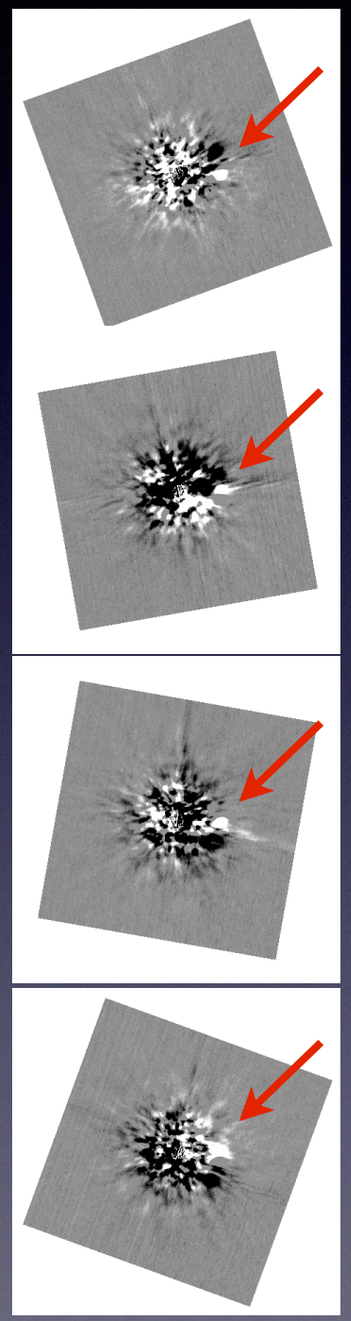
A_i

FOV rotation

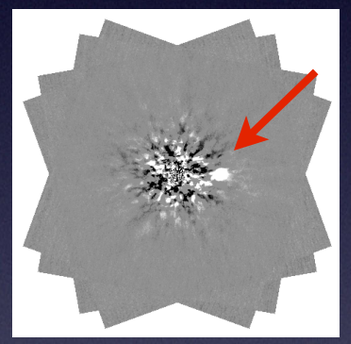
$B = \mathrm{median}(A_i)$



$C_i = A_i - B$



$D_i = \mathrm{derot}(C_i)$

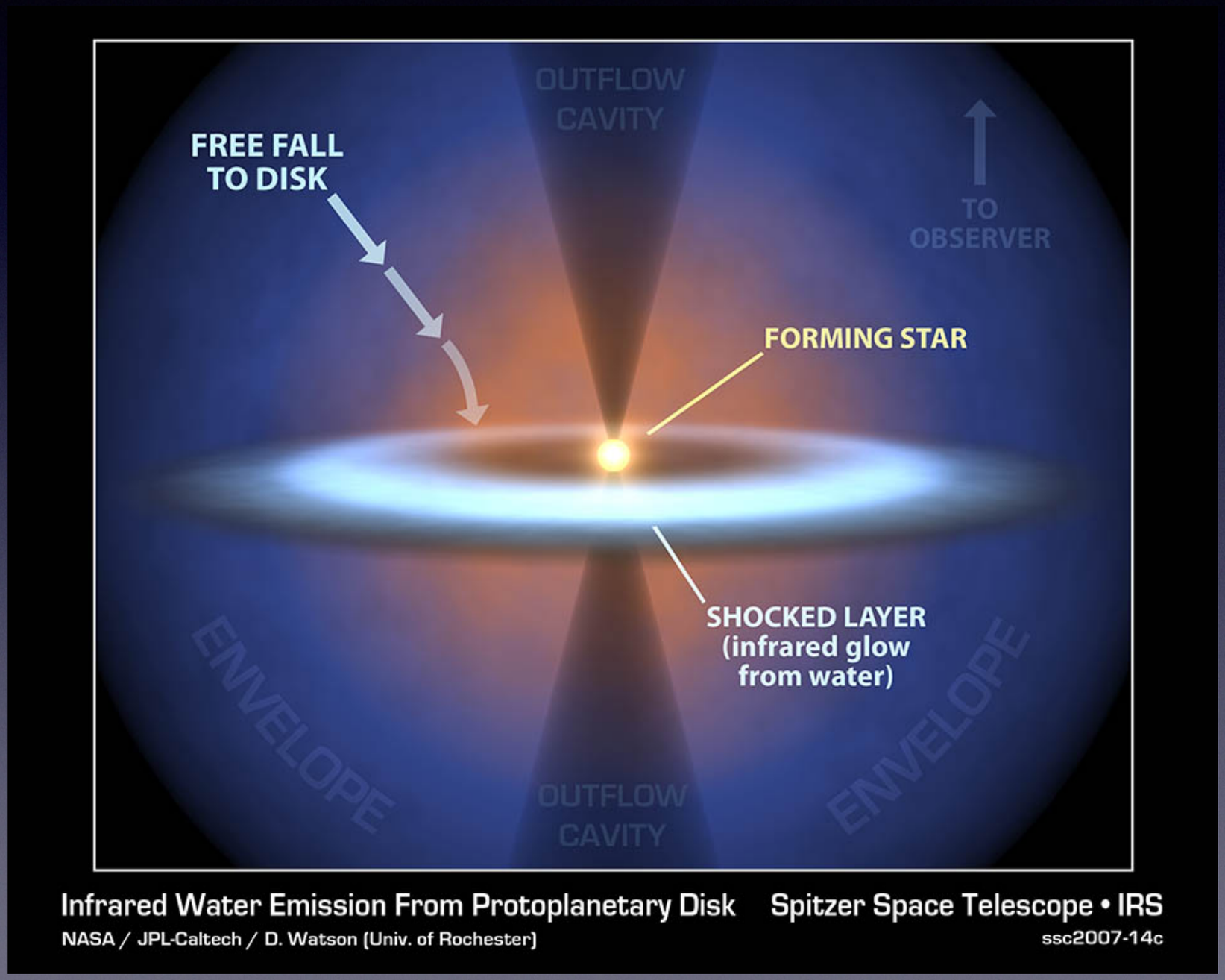


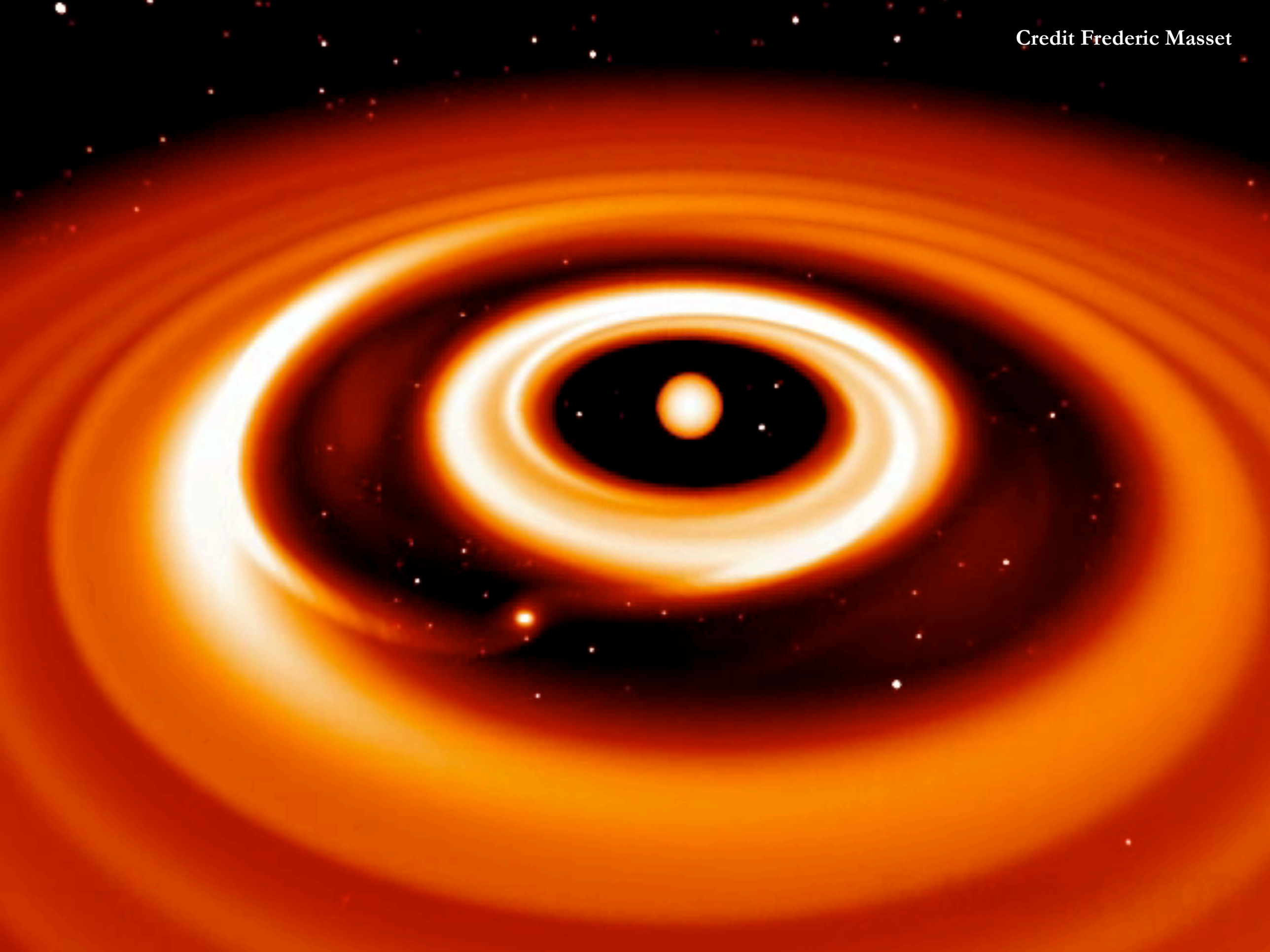
$E = \mathrm{median}(D_i)$

altazimutal telescopes

Protoplanet

- Planet-to-be
- Still accreting
- Rescaled FUor

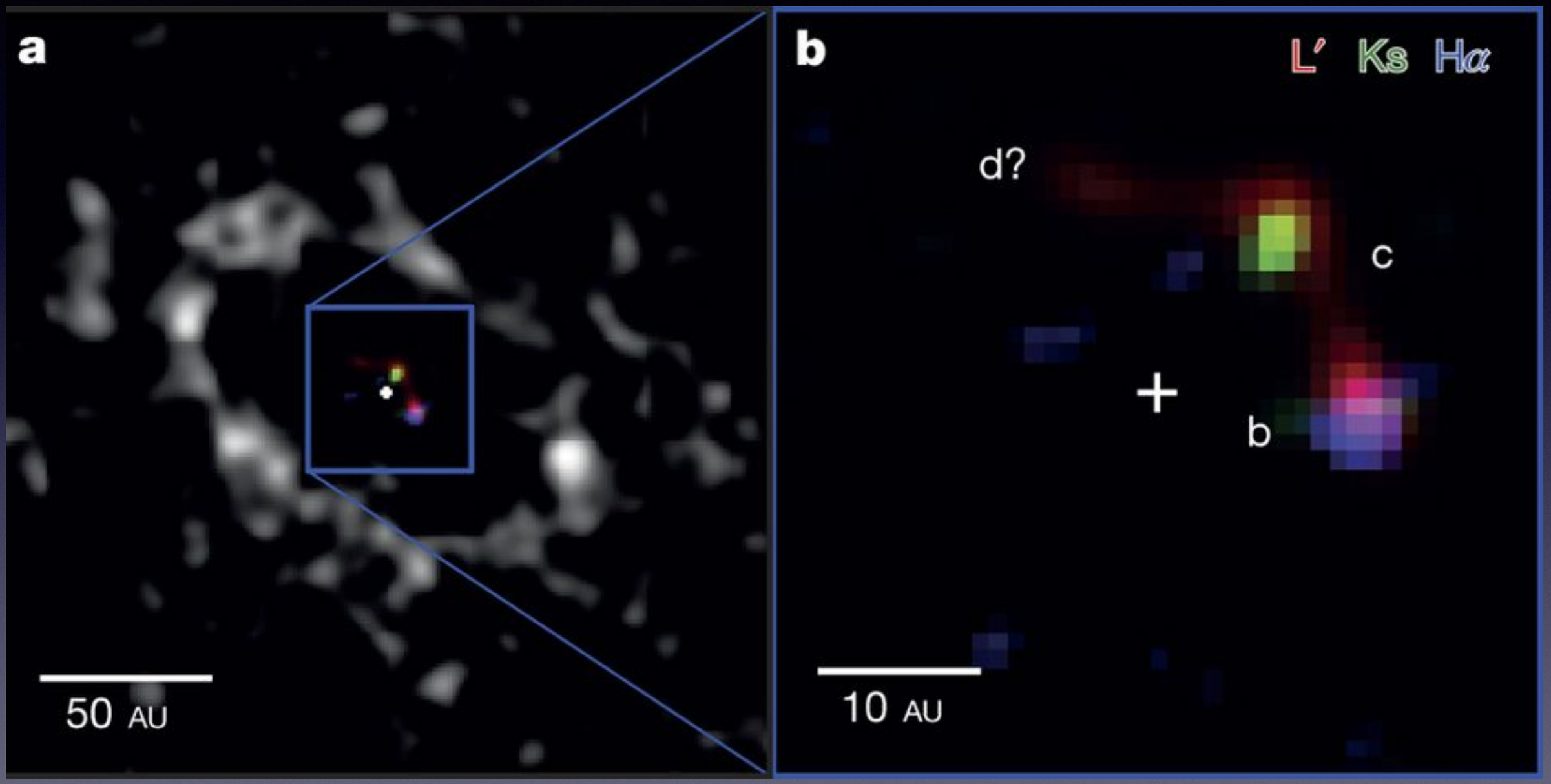



Credit Frederic Masset

Imaging protoplanets

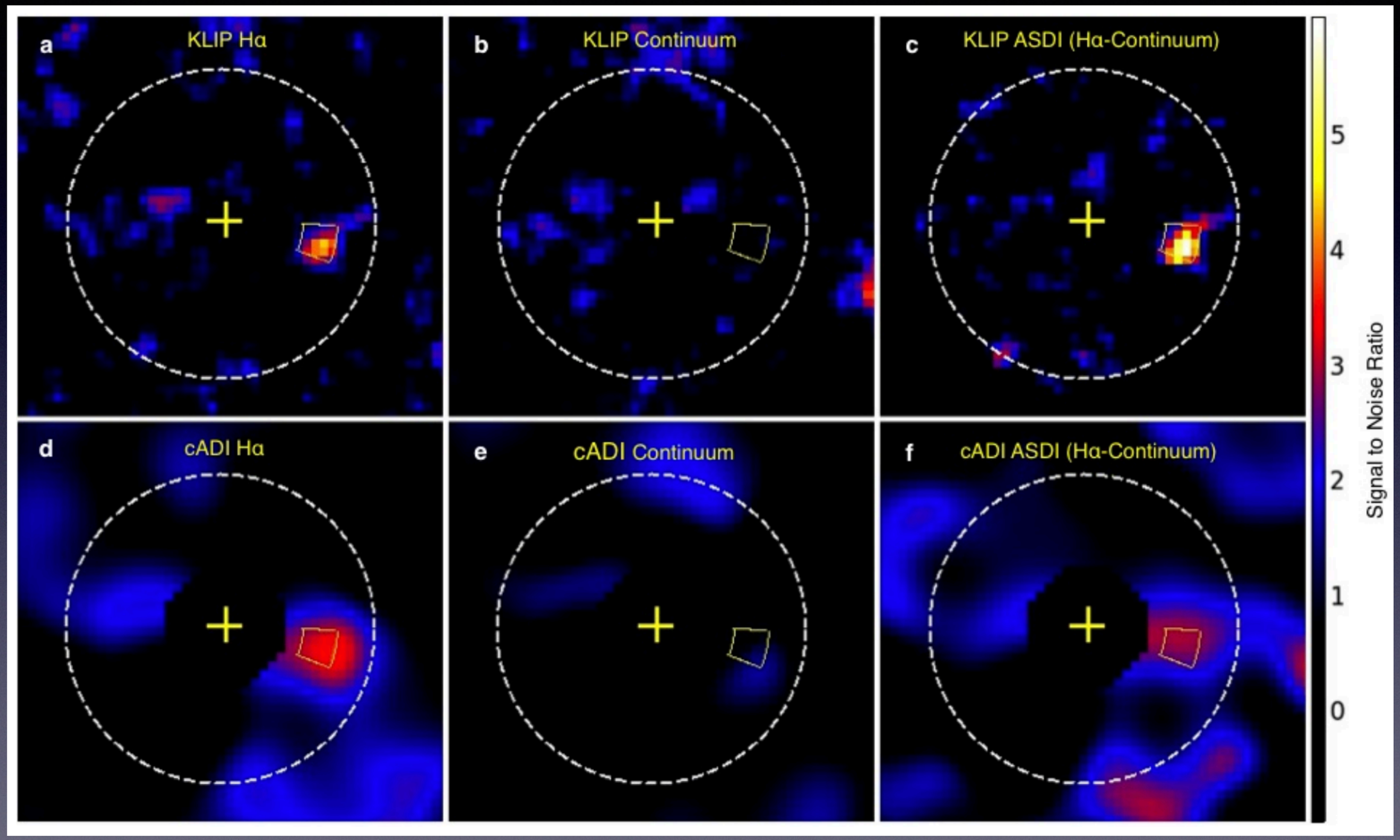
- Accretion indicators: Hα, Paschen β
- NIR counterpart
- Interferometry (CPD)

First detection: LkCa 15b



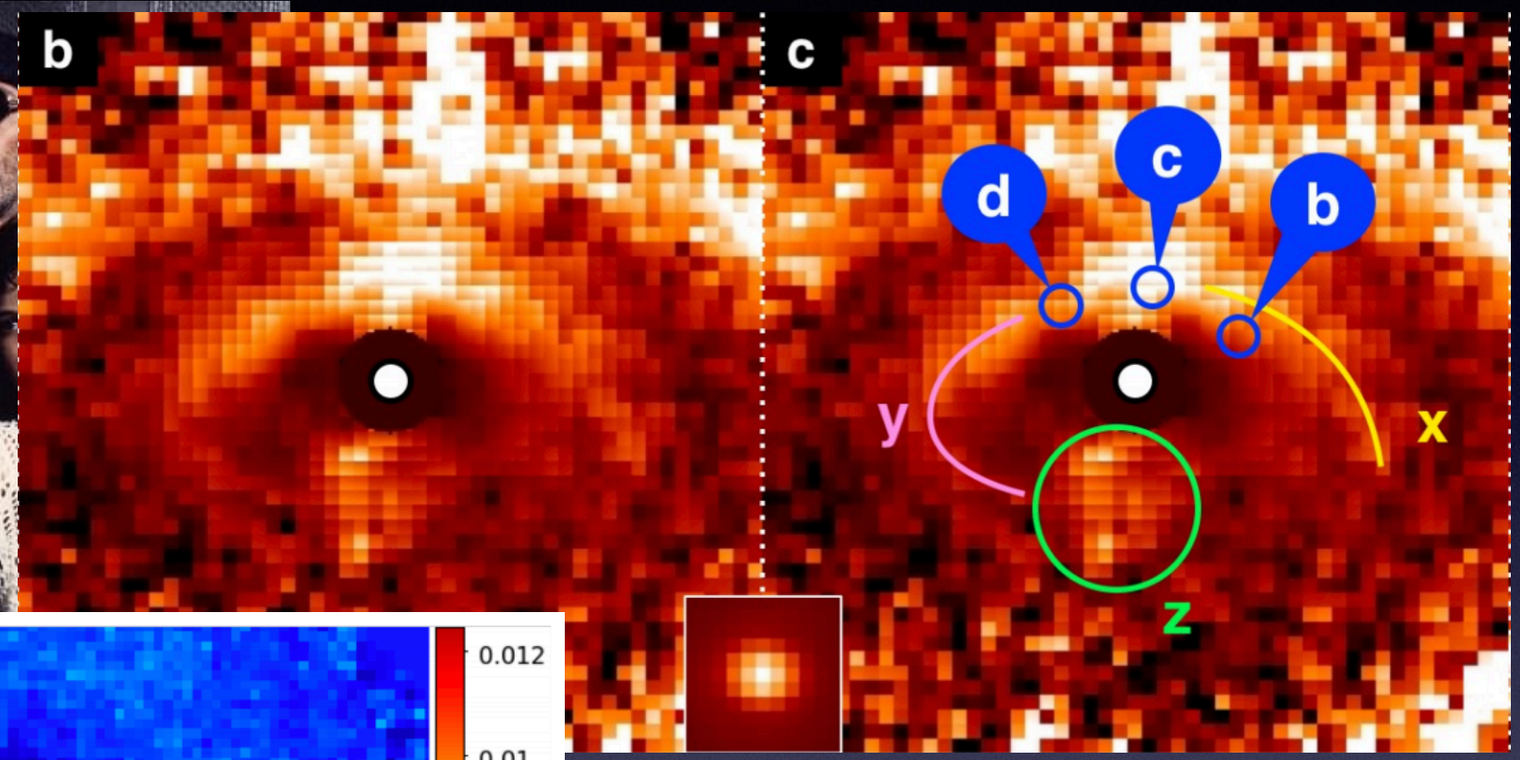
Sallum+15

Hα detection

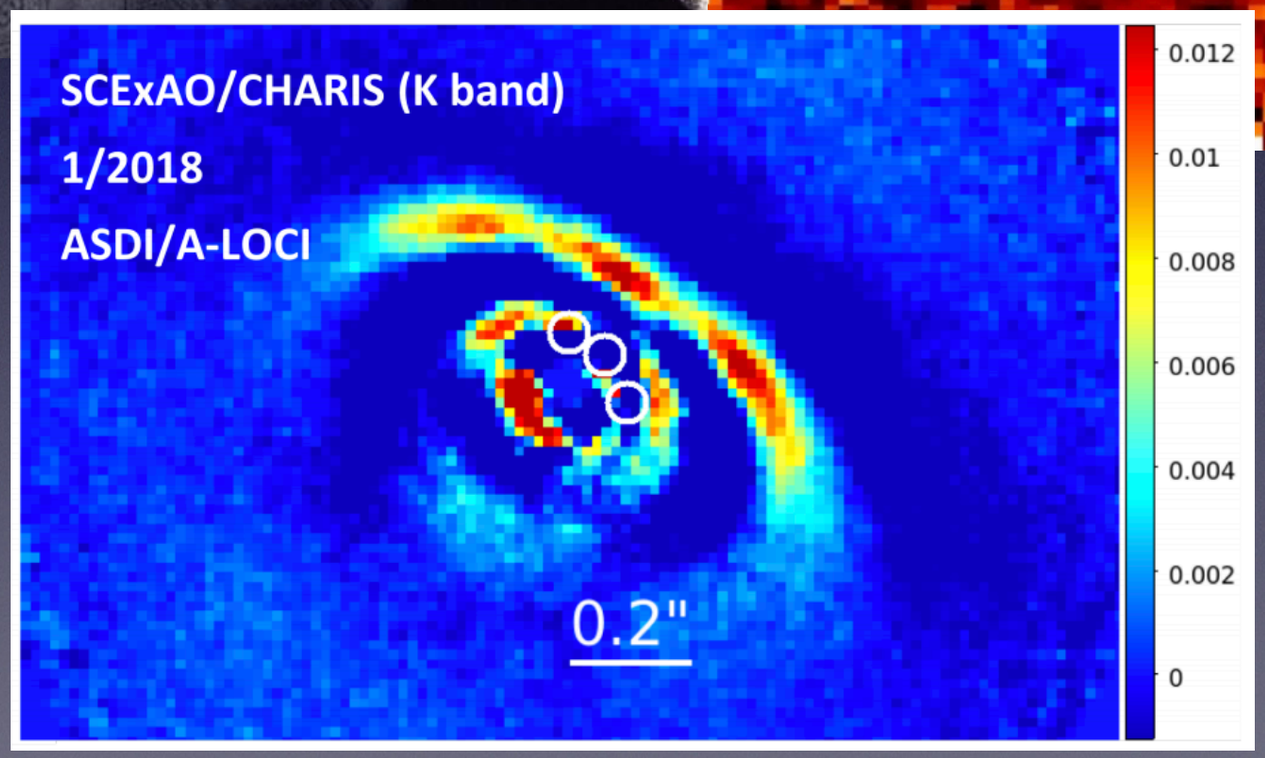


Sallum+15

(Proto)planet killers

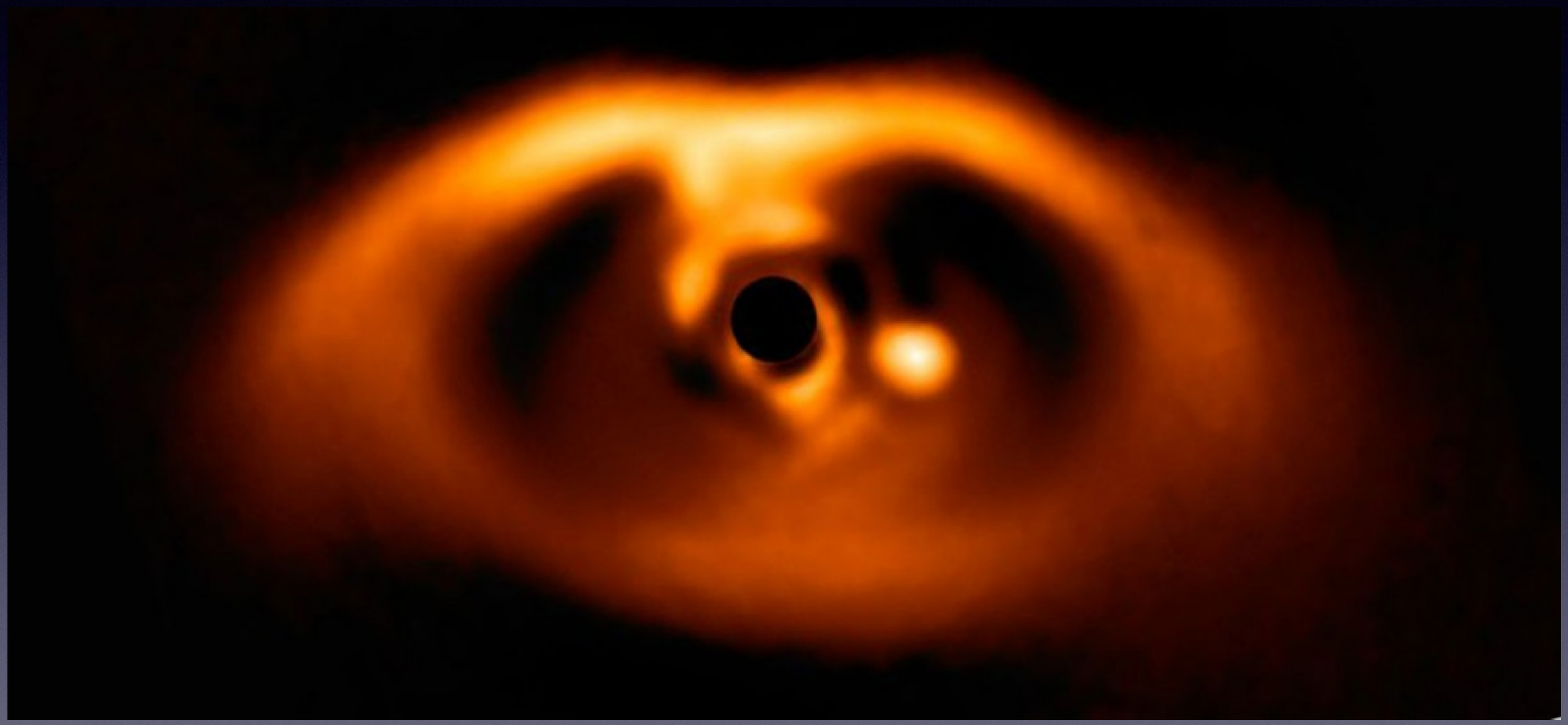


Thalmann+16



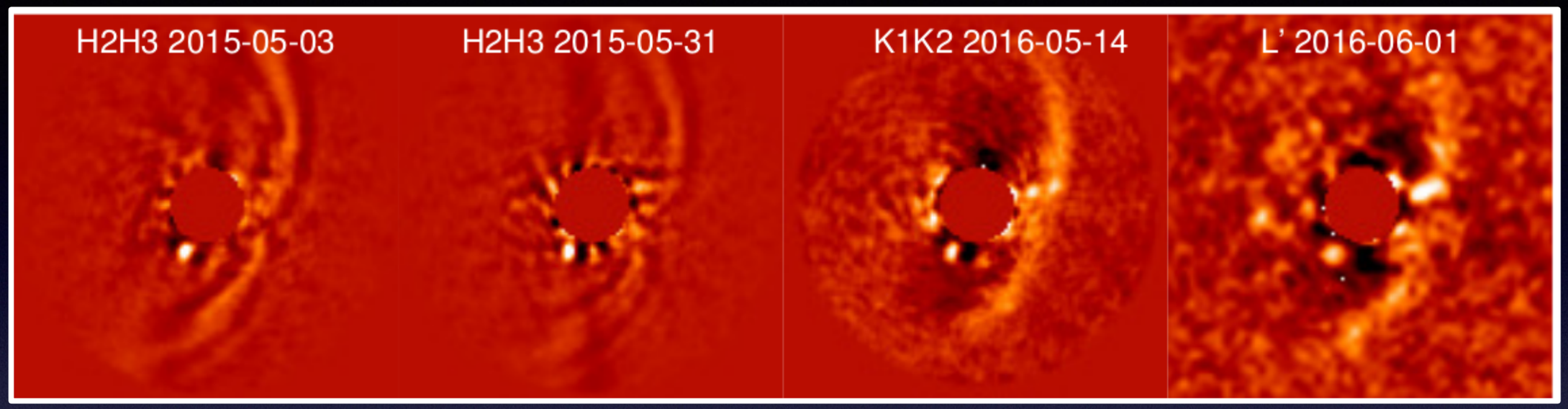
Currie+19

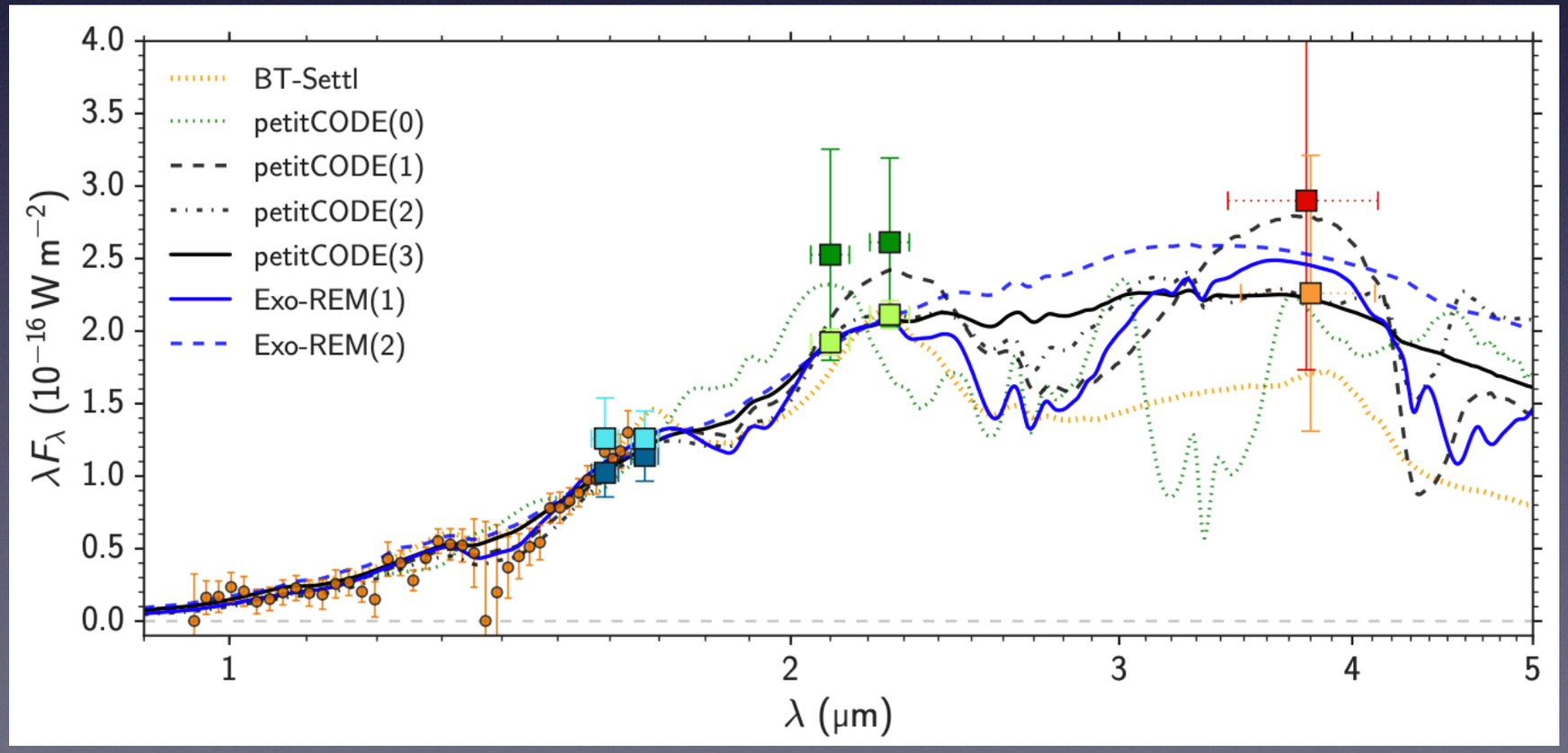
PDS 70



Keppler+18, Müller+18

PDS 70b

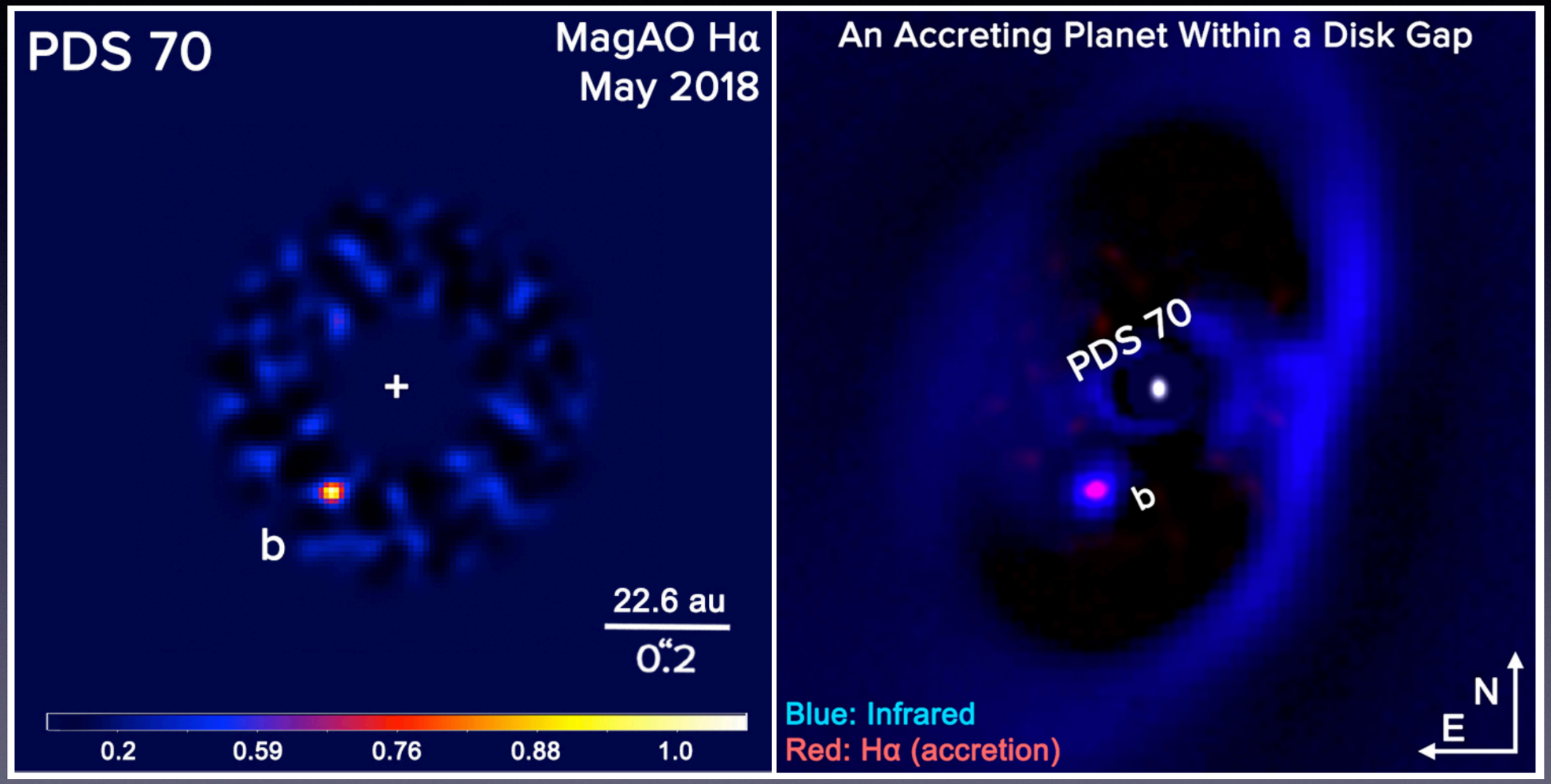




Separation = 200 mas (25 au)
ΔH2 = 9.2 ± 0.2 mag
Mass = 5-10 M_{Jup}
Teff = 800 – 1100 K
IRDIS H2, H3, K1 and K2 + NaCo L'

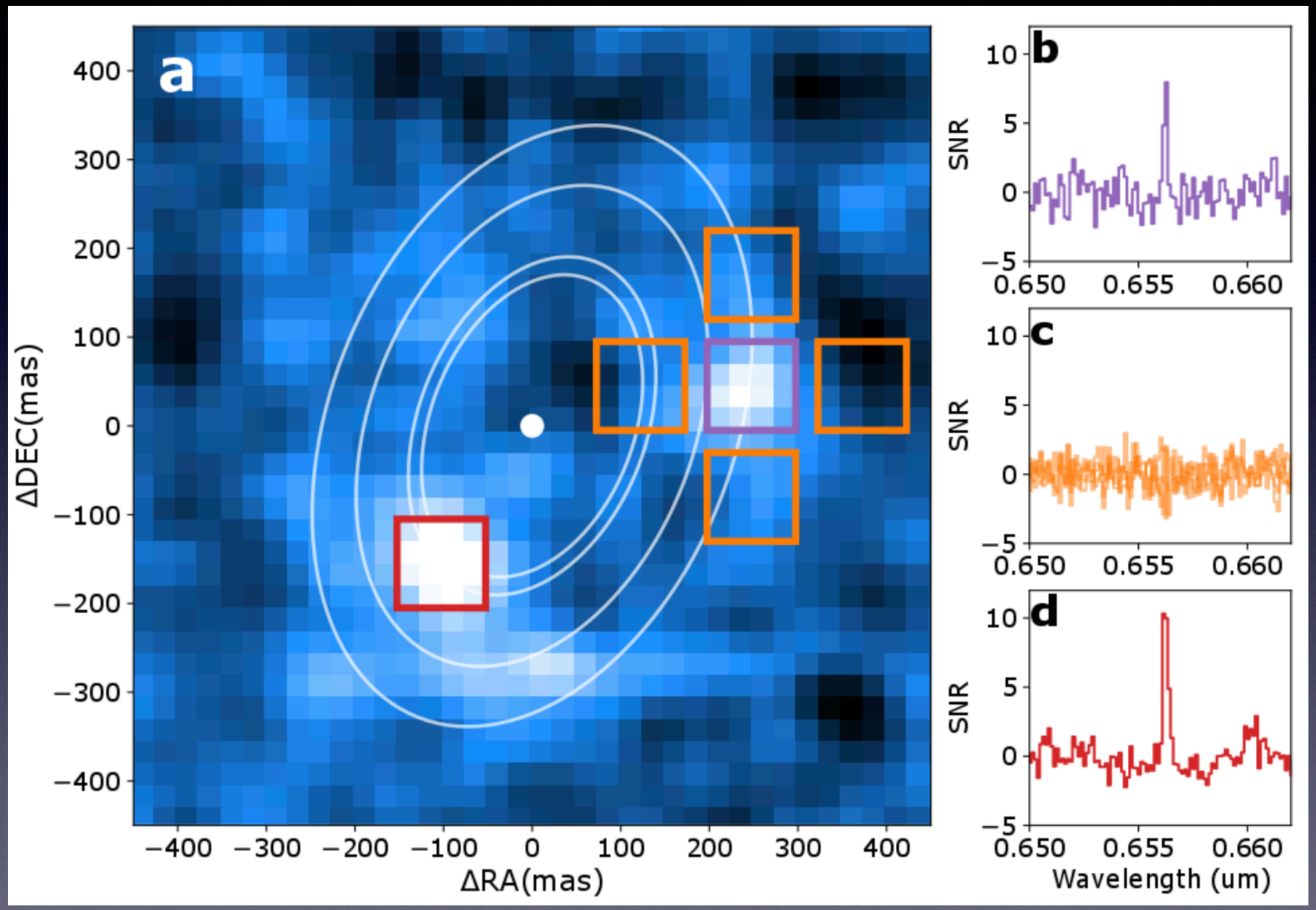
Keppler+18, Müller+18

PDS 70b is accreting!



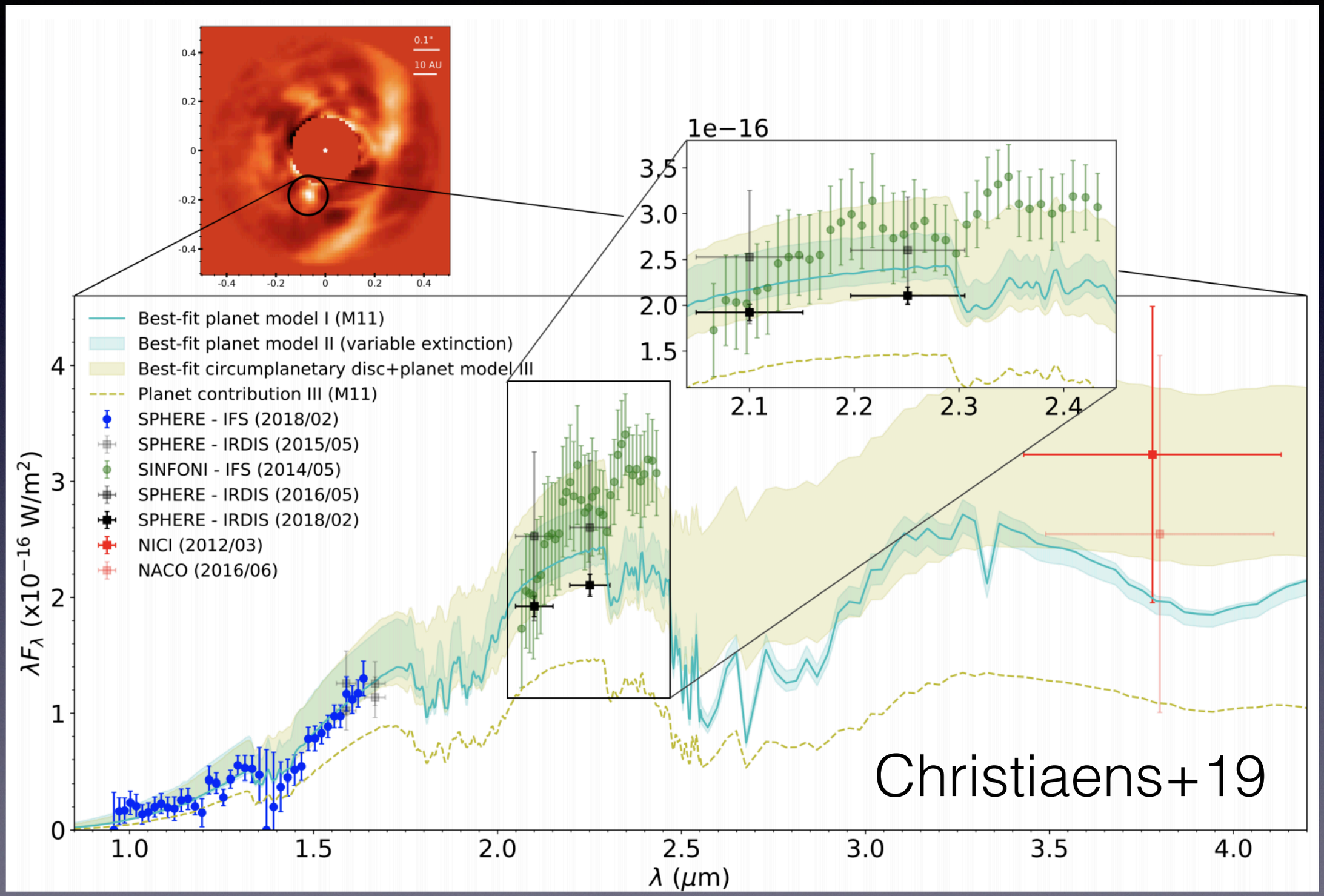
Wagner+18

PDS 70 b&c

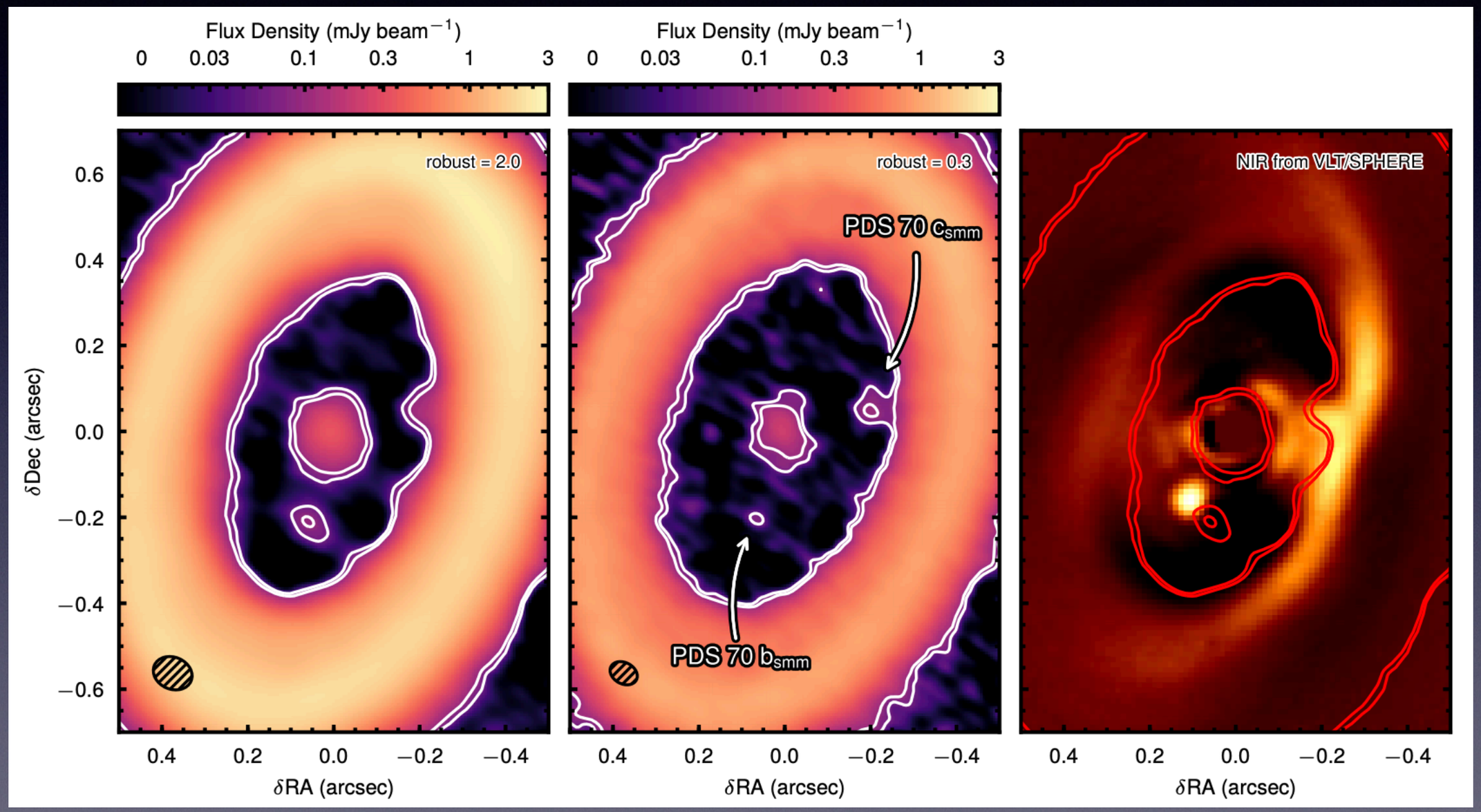


Haffert+19

PDS 70b CPD


0.1"
10 AU
1e−16
Best-fit planet model I (M11)
Best-fit planet model II (variable extinction)
Best-fit circumplanetary disc+planet model III
Planet contribution III (M11)
SPHERE - IFS (2018/02)
SPHERE - IRDIS (2015/05)
SINFONI - IFS (2014/05)
SPHERE - IRDIS (2016/05)
SPHERE - IRDIS (2018/02)
NICI (2012/03)
NACO (2016/06)
λF_λ (x10^{-16} W/m^2)
λ (μm)
Christiaens+19

PDS70



Isella+19

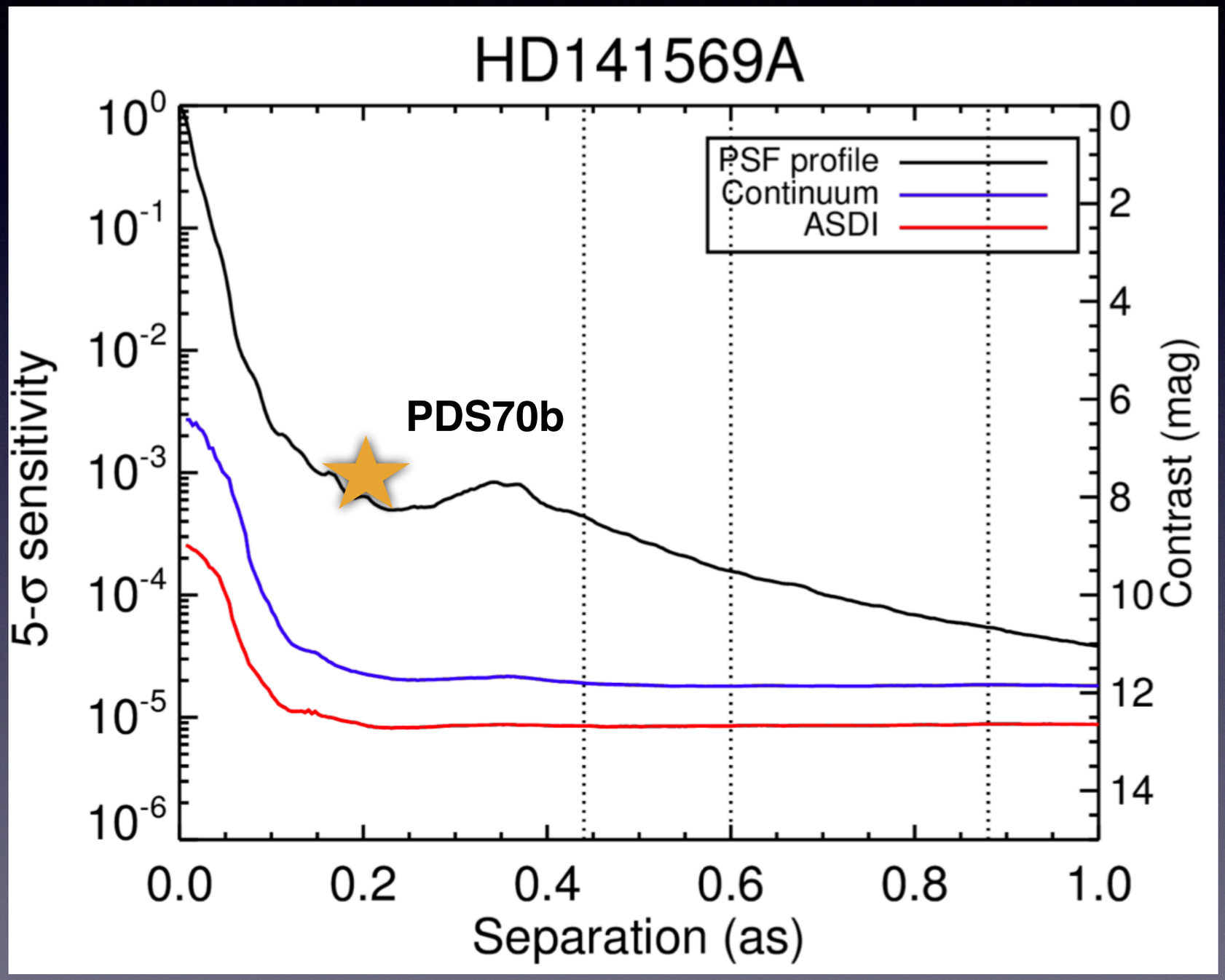
Survey of nearby TDs

Name	Sp. Type	d (pc)	Age (Myr)	Planet formation/presence indicators
MWC 758*	A8Ve	160	1.5[a]	Spiral arms, possibly shaped by a ~ 10 M_{Jup} companion at 160 au
HD 135344 B*	F8V	136	8[b]	Possible planet induced features
HD 142527*	F6III	157	5[c]	Accreting stellar companion
HD 100546	B9V	110	5[d]	Spirals, protoplanet candidates, bar-like structure
HD 98800 B	K5	47	7–10[e]	Gap up to 0.″13
AK Sco	Ae	141	10–20[f]	Two spiral arms
V4046 Sgr AB	K5V	72	10–20[g]	Rings at 14, 29, and 40 au
HD 169142	B5V	114	3–12[h]	Gap at 23 au
DoAr 44	K3	146	7[i]	Gap from 5 to 32 au, a rescaled version of HD 142527
HD 97048	A0V	185	2–3[j]	Gaps at 34, 79, 140 au, and 179 au and 4 rings
HD 141569 A	A0Ve	106	5[k]	Ringlets at 47 au, 64 au and 93 au
UX Tau A	K2Ve	140	1[l]	Gap at 0.″4
HD 100453	A9Ve	104	10[m]	Gap up to 0.″18
PDS 66	K1Ve	86	17[n]	Gap up to 0.″17

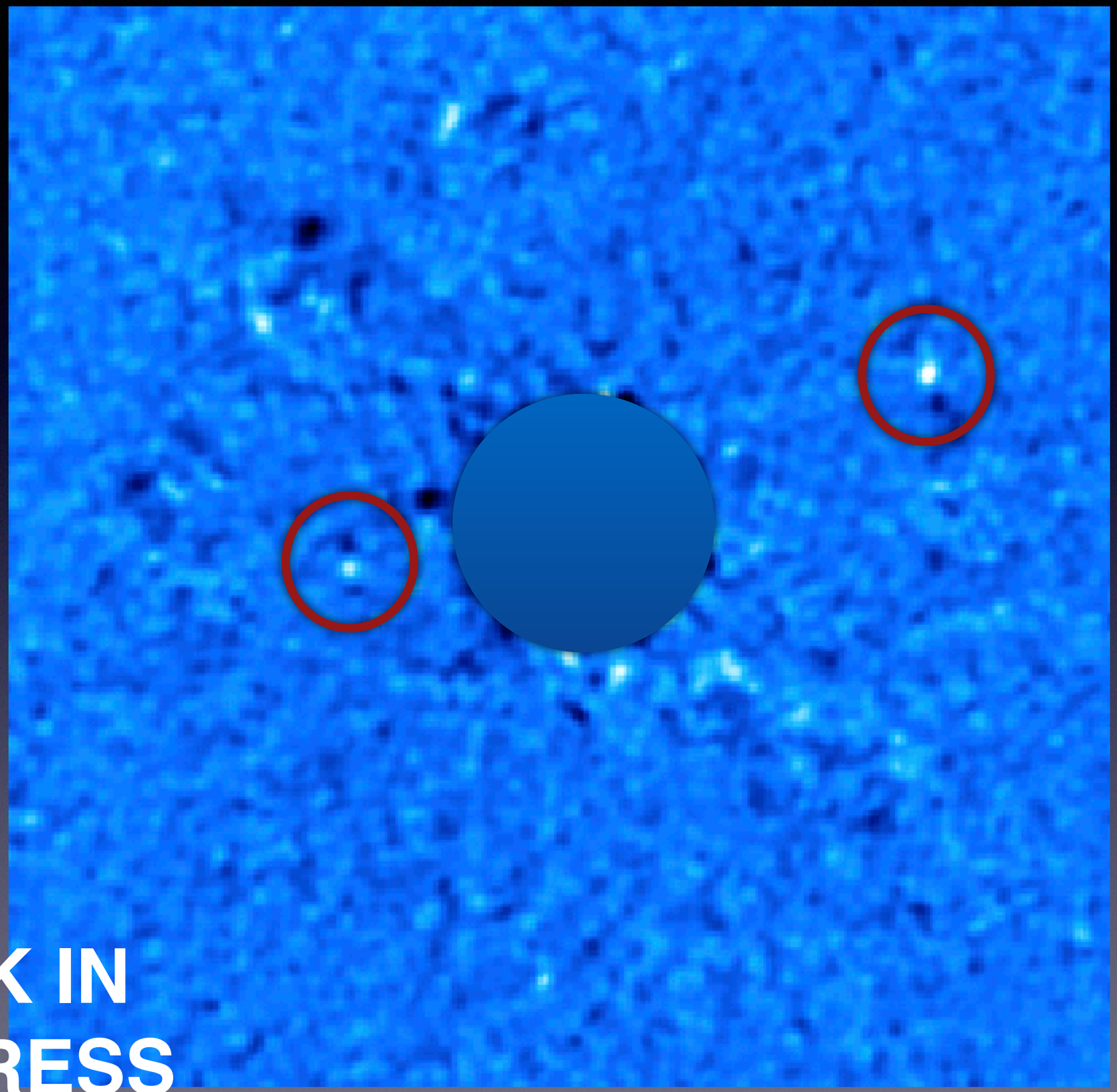
Zurlo+in prep.

SEE ALSO
CUGNO'S TALK

Contrast curves



Zurlo+in prep.



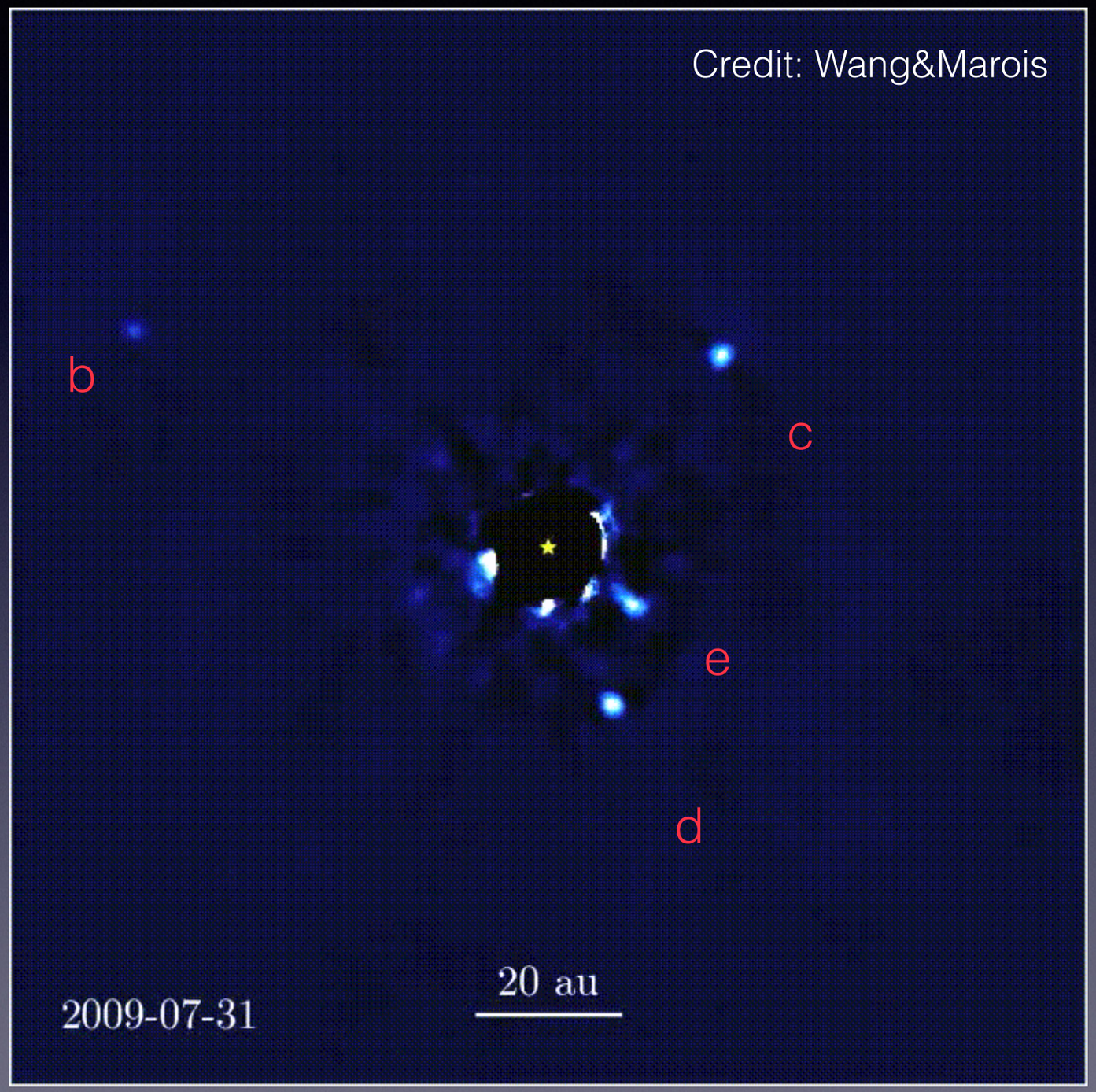
WORK IN PROGRESS

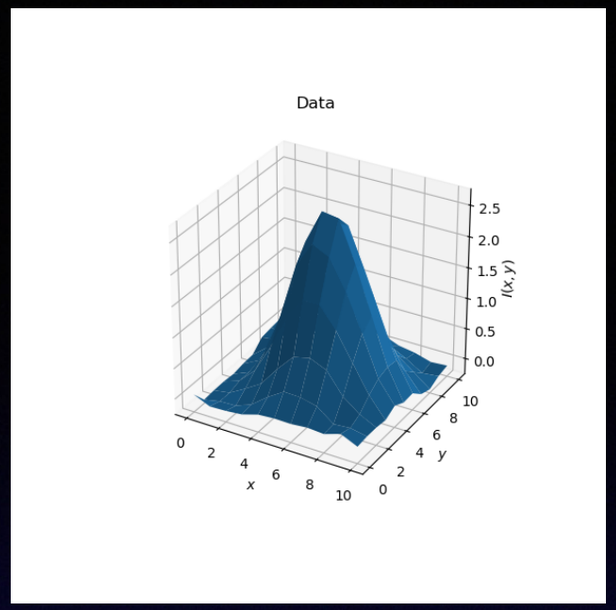
HR8799

Cecilia Lazzoni

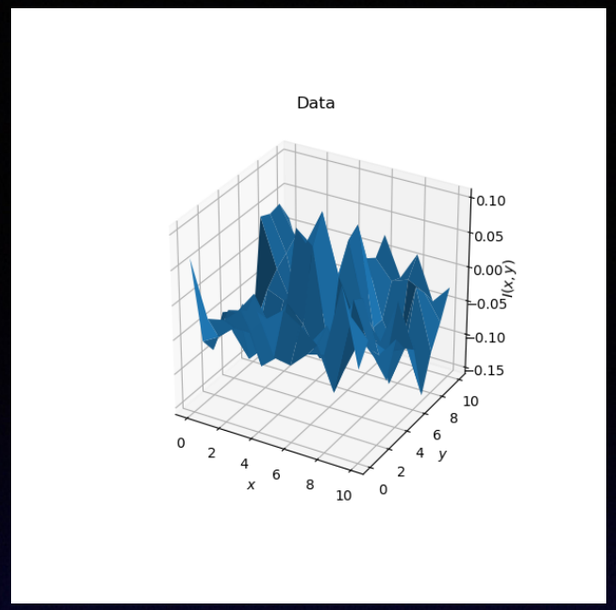
Four giant planets with masses in the range [5,10] M_J at semi-major axes of 67.9 (b), 38.0 (c), 24.5 (d), and 14.5 (e) au

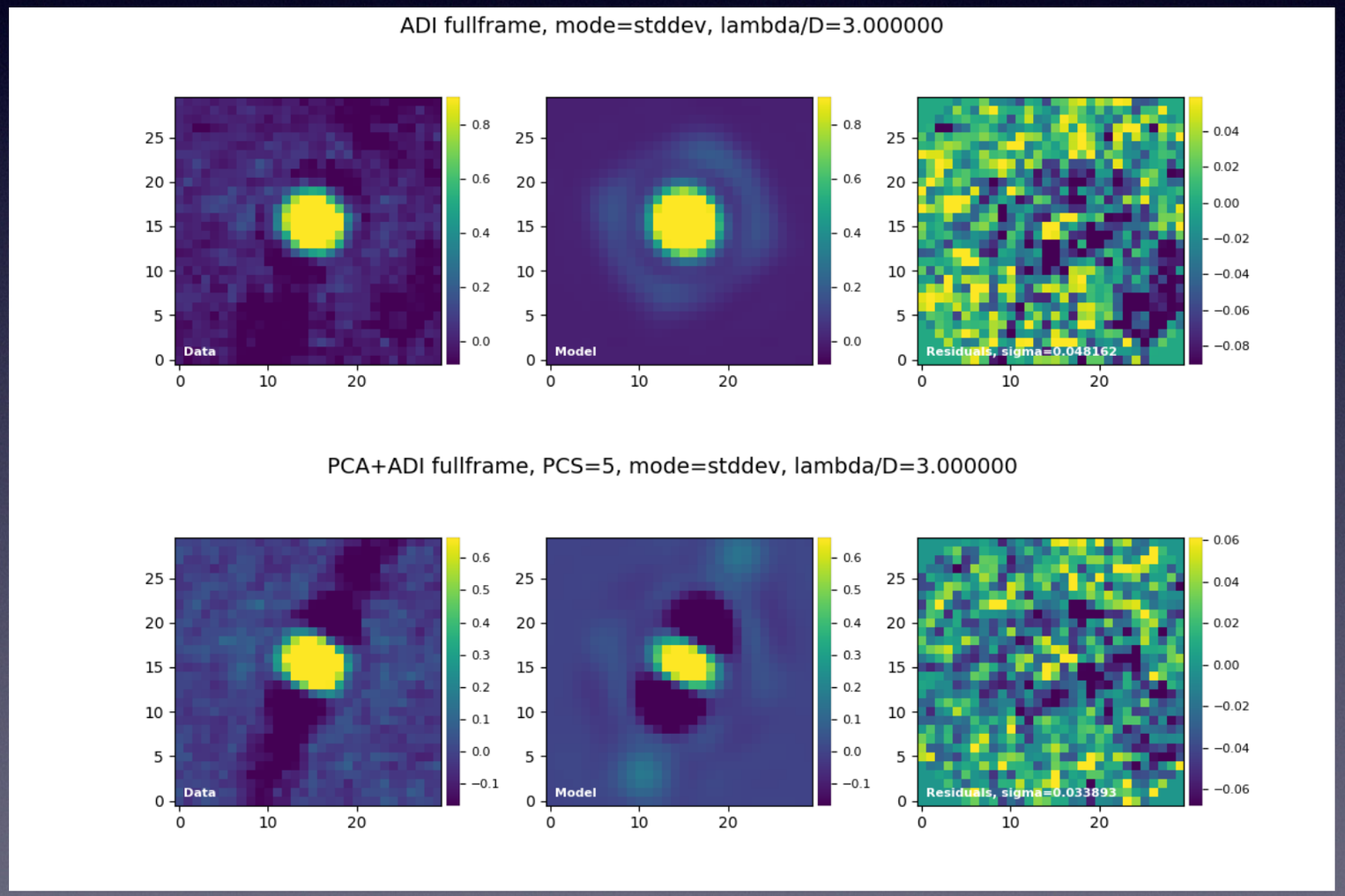
Marois+2005,2008





HR8799 b





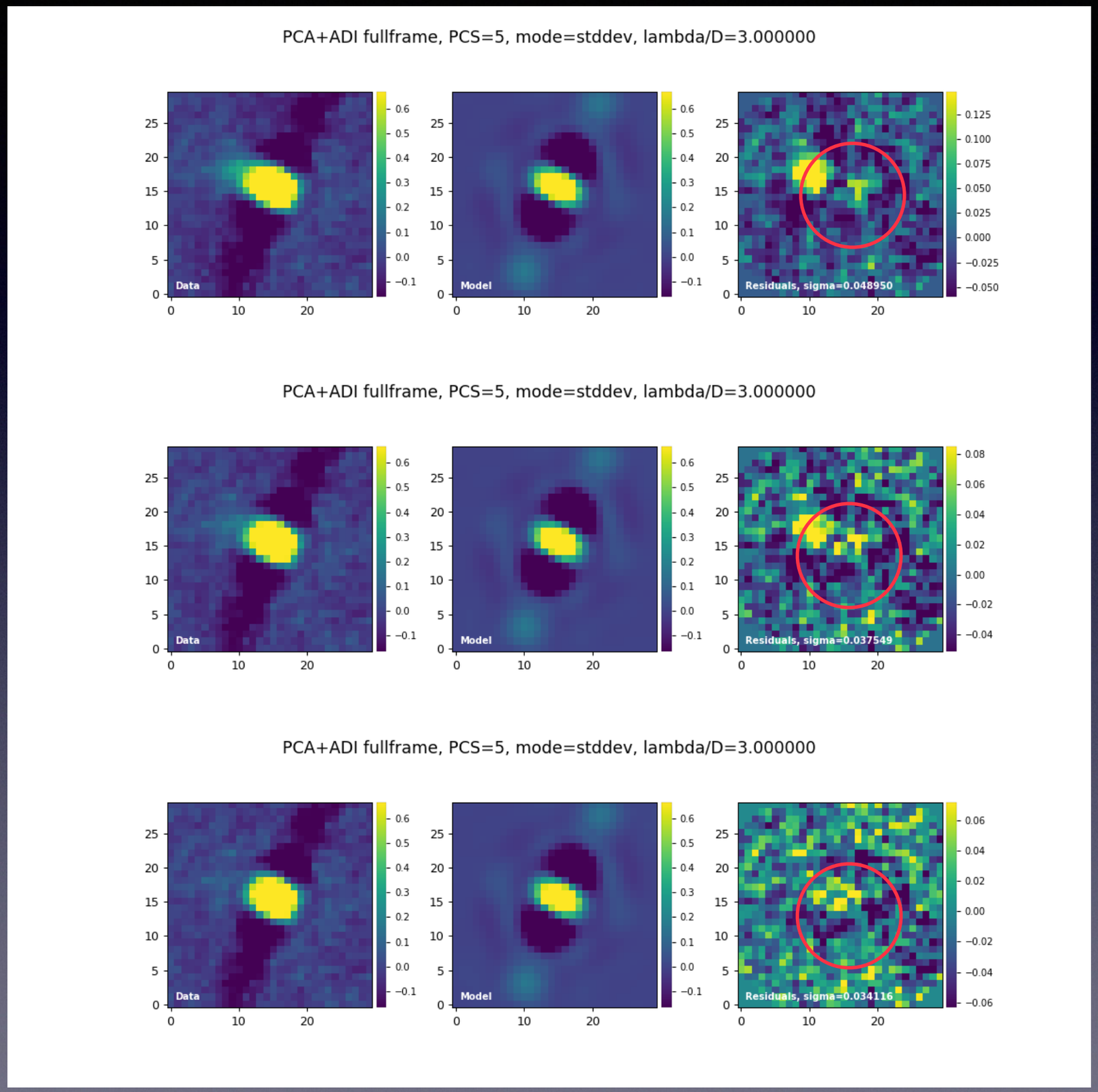
Lazzoni+in prep.

Fake moon

f/5

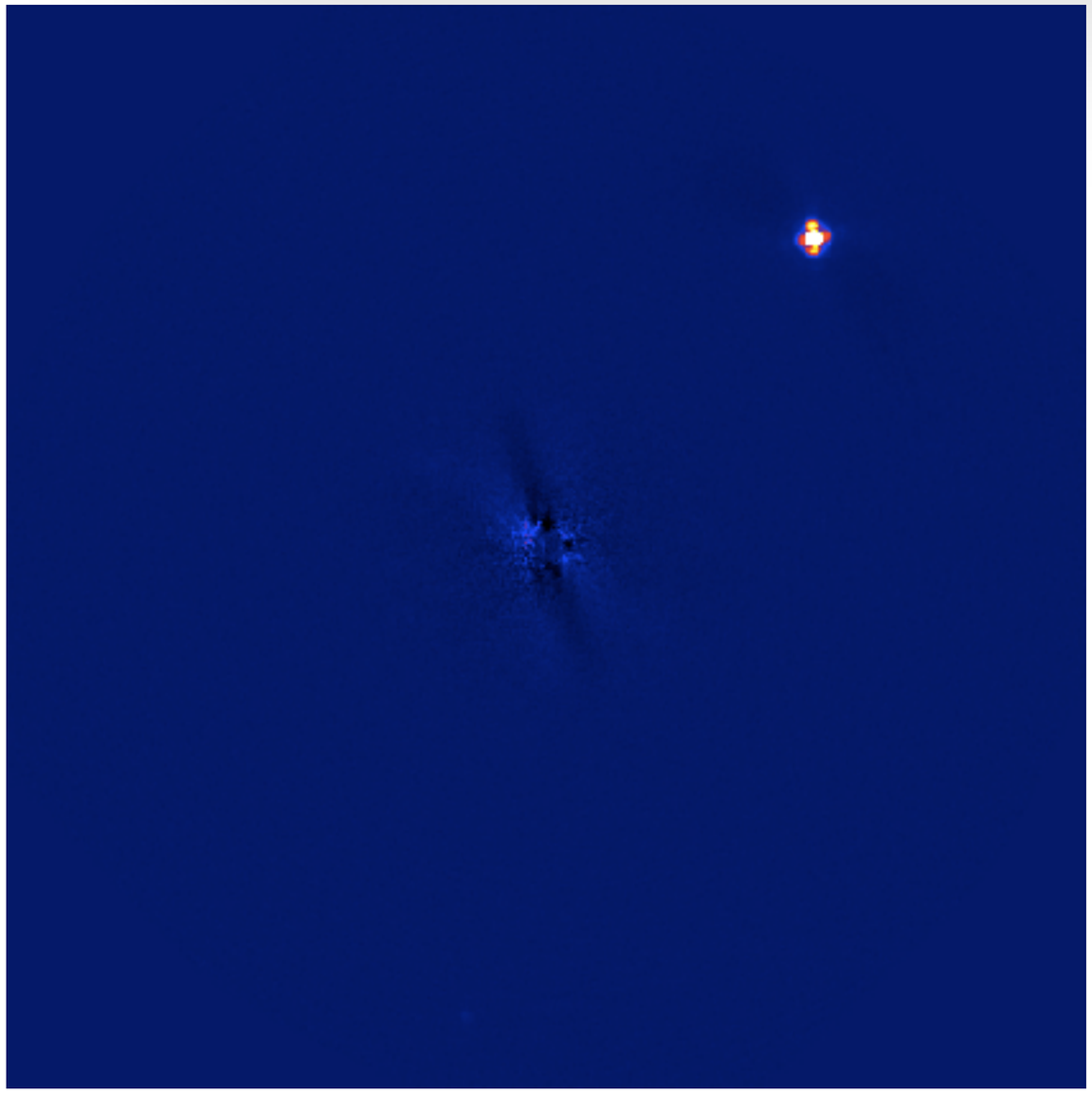
f/10

f/50

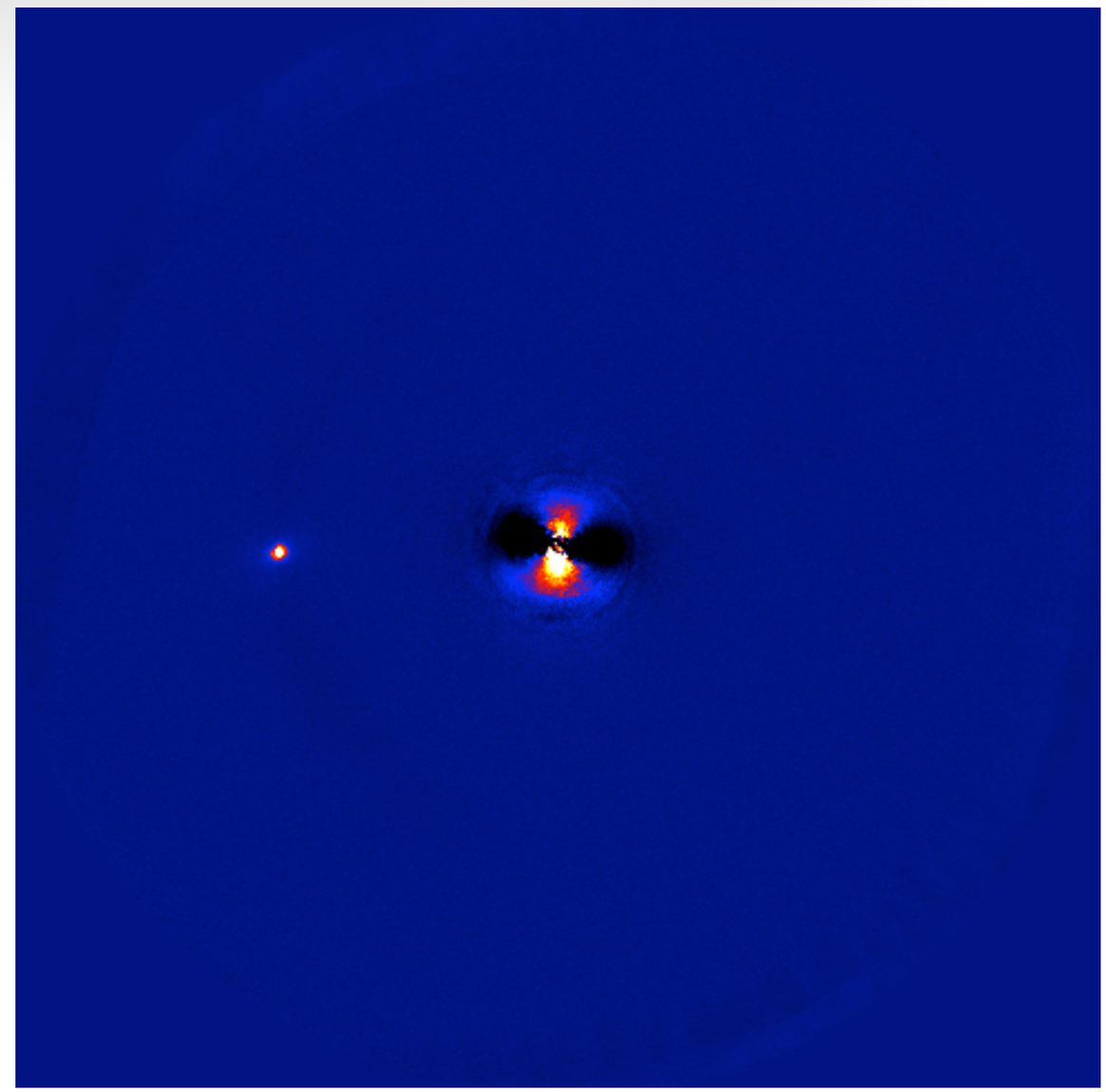


Lazzoni+in prep.

BDs with candidates



BD1

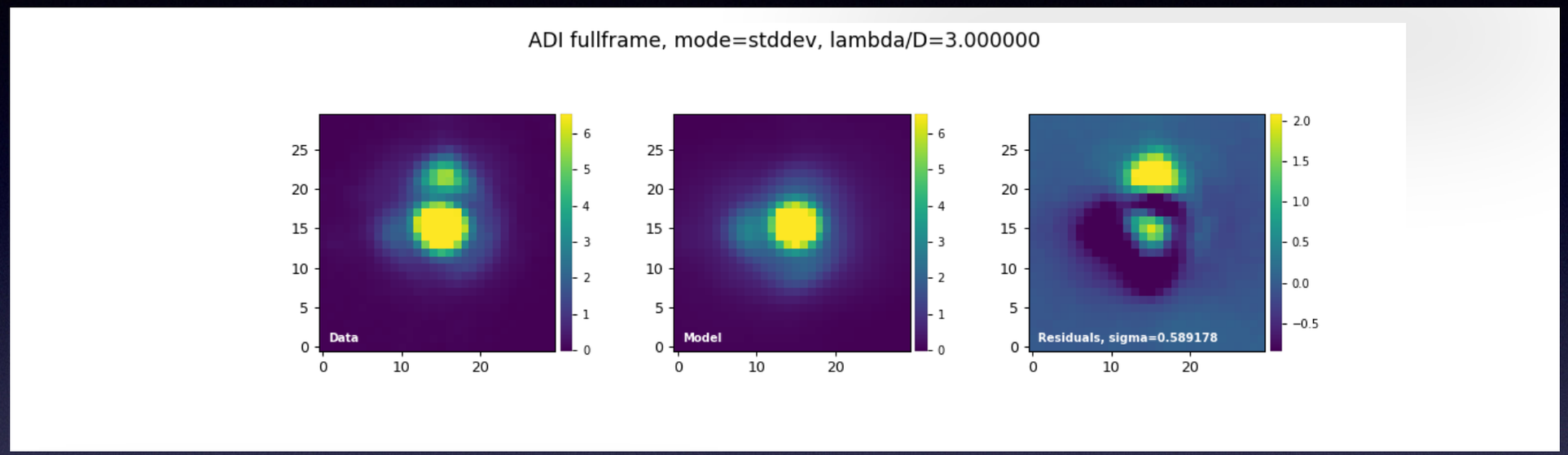


BD2

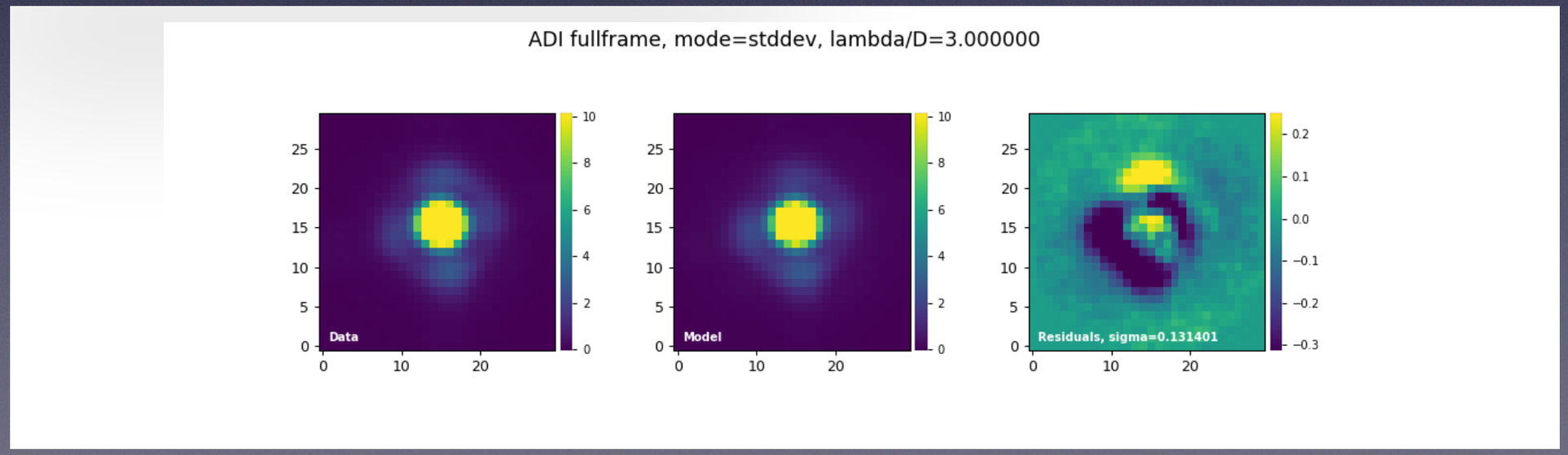
Lazzoni+in prep.

BD1 residuals

First epoch

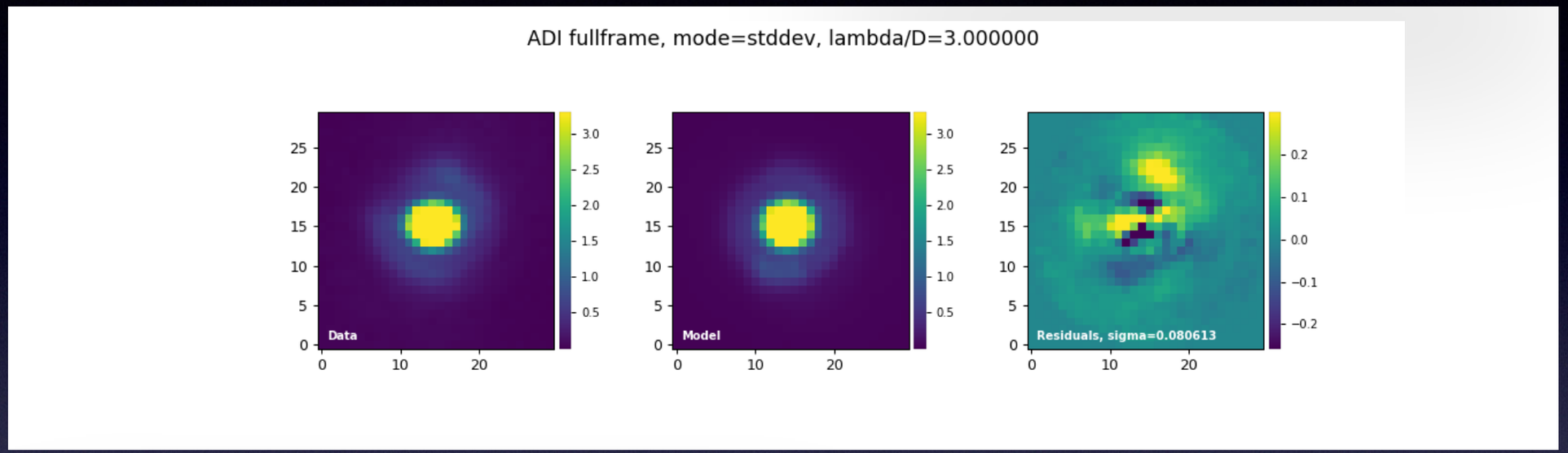


Second epoch

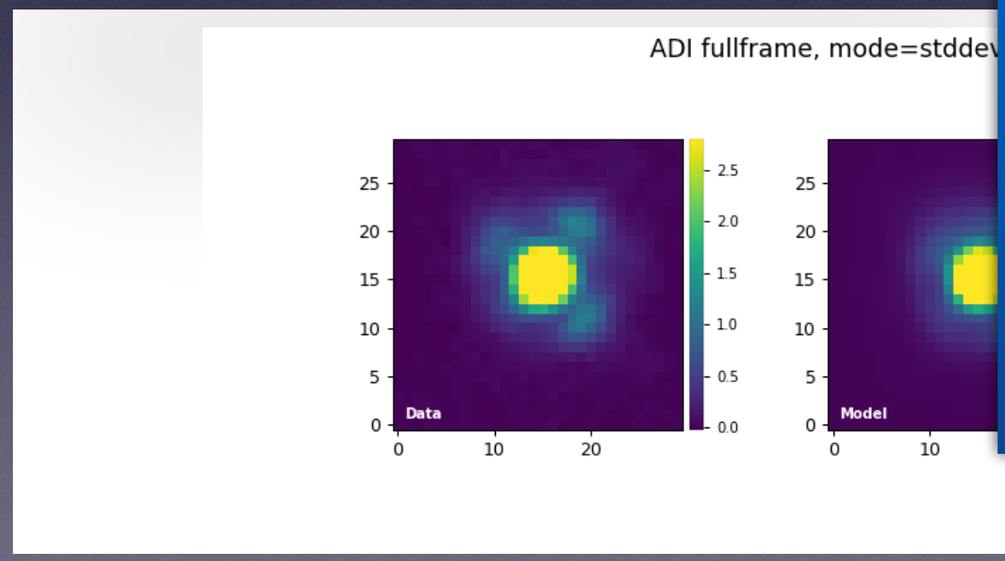


BD2 residuals

First epoch



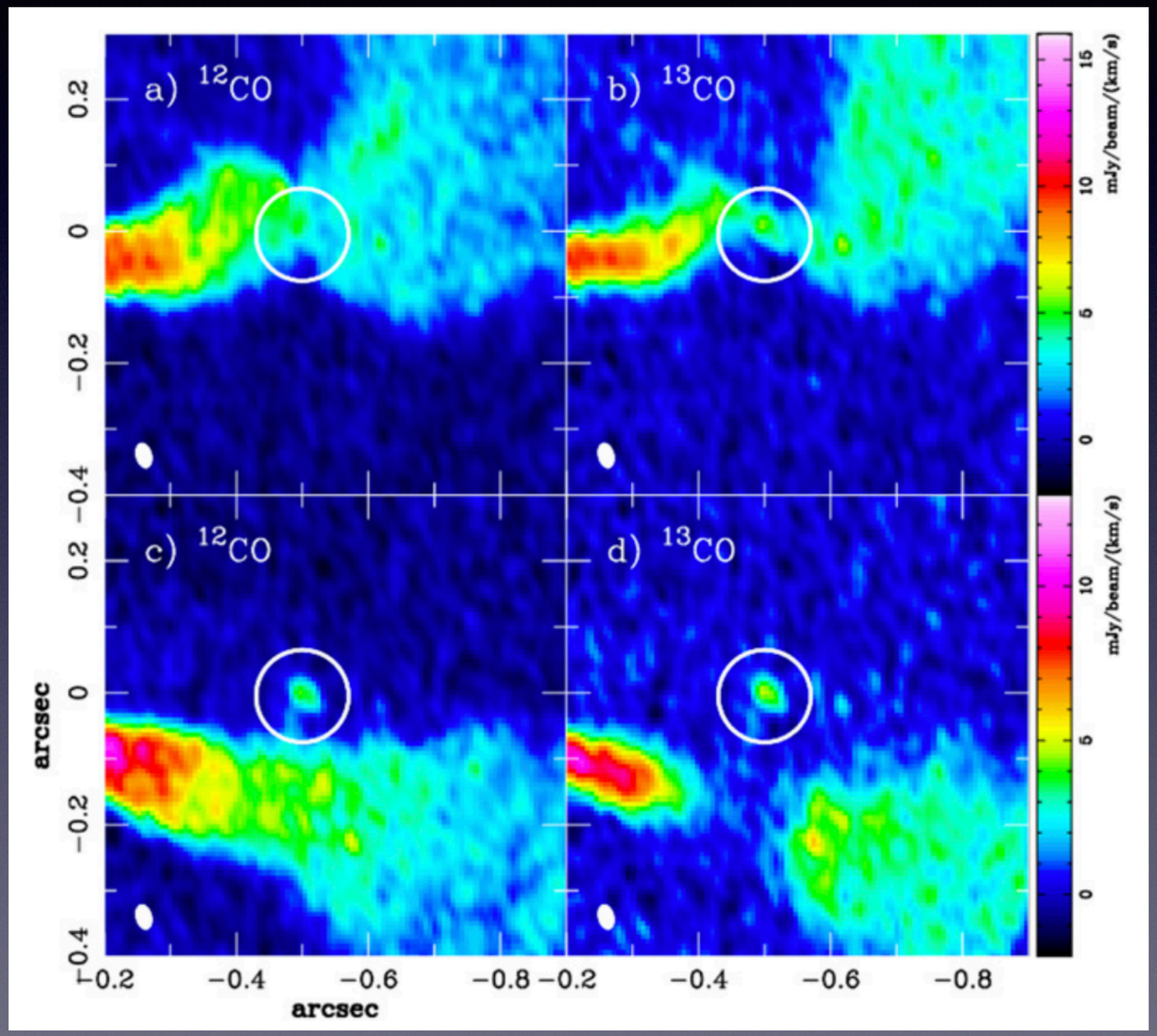
Second epoch



Follow-up observations granted with LBT & VLT

STAY TUNED!

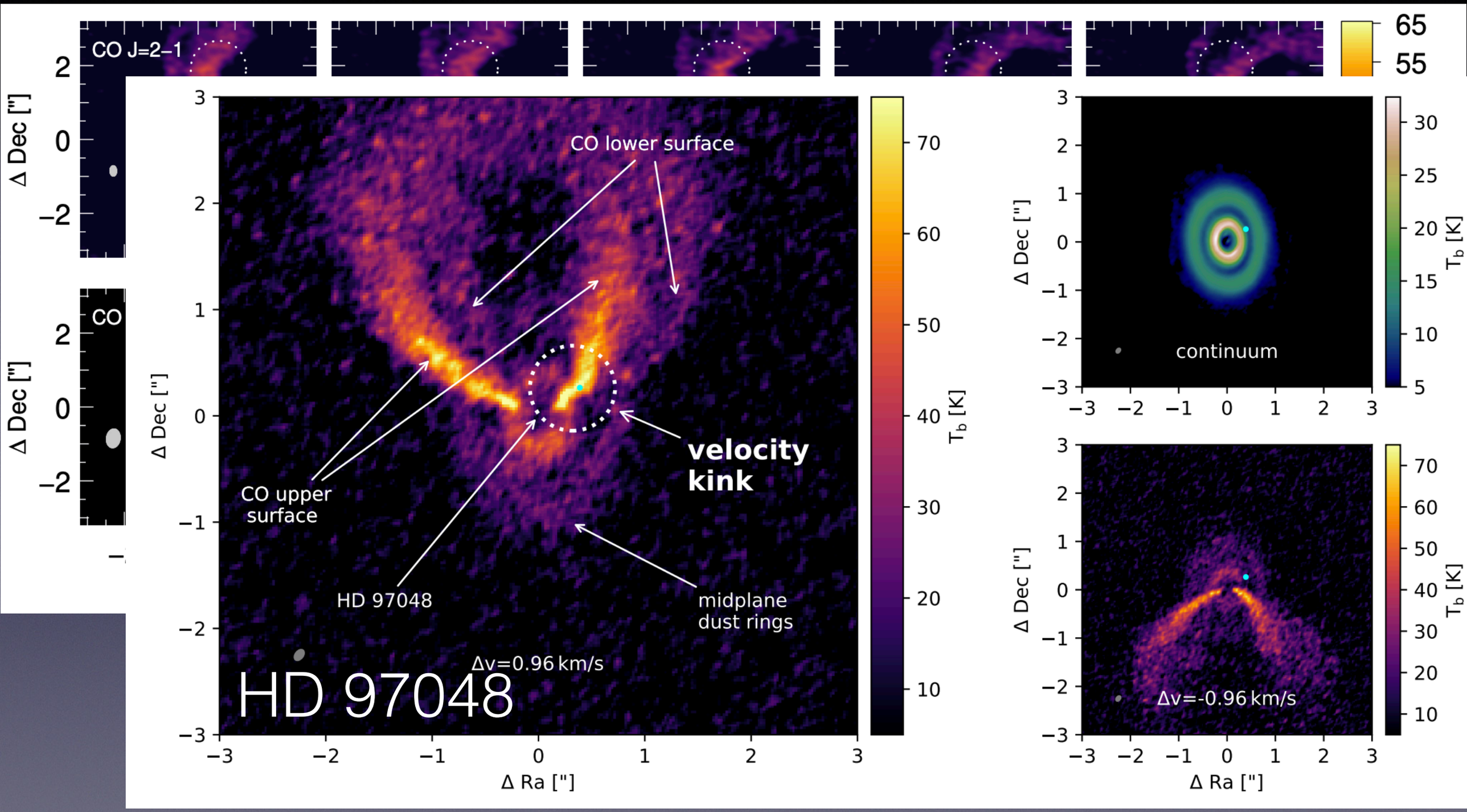
Gas kinematics



Perez+15

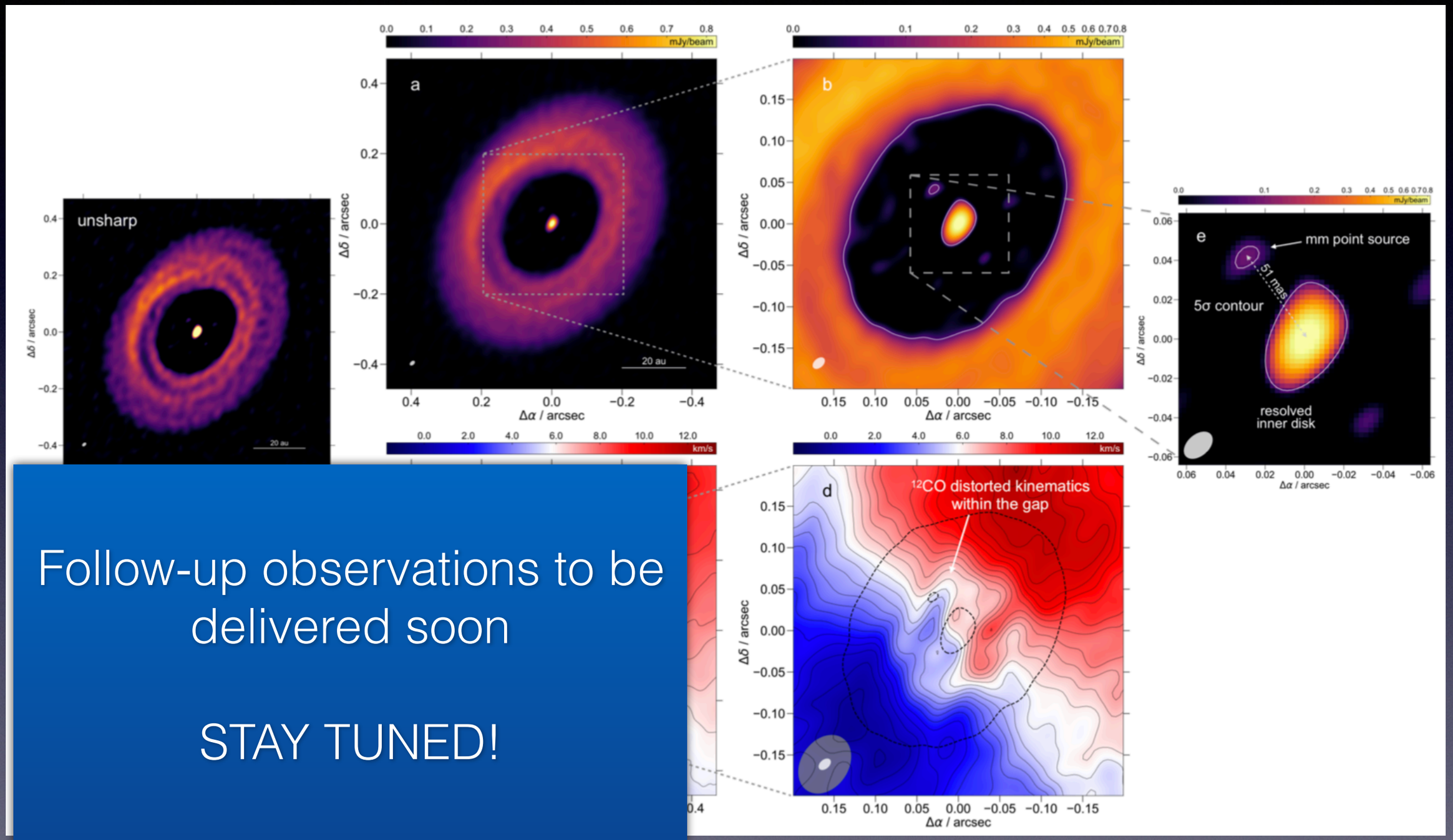
HD163296

Pinte+18



Pinte+19

HD 100546



Follow-up observations to be delivered soon

STAY TUNED!

Perez+subm.

Take-away points

- Imaging protoplanets is possible today thanks to 8m-class telescopes and interferometry
- The only confirmed and solid detections are the two protoplanets around the star PDS 70, both of them are accreting
- We have possible satellite candidates around two BD companions, which can question how planets form
- Interferometry can give hints on the presence of CPDs