PlanetS
National Centre of Competence in Research

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Young planets embedded in circumstellar disks

Sascha P. Quanz (ETH Zurich)

Resolving planet formation in the era of ALMA and extreme AO, Santiago, May 16-20, 2016

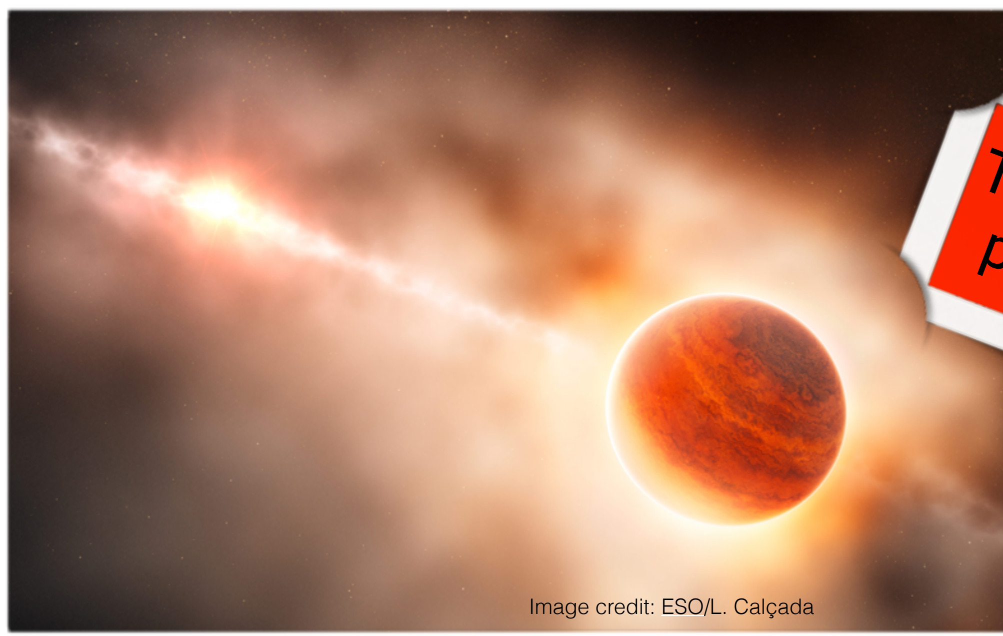


Image credit: ESO/L. Calçada

The observer's perspective!

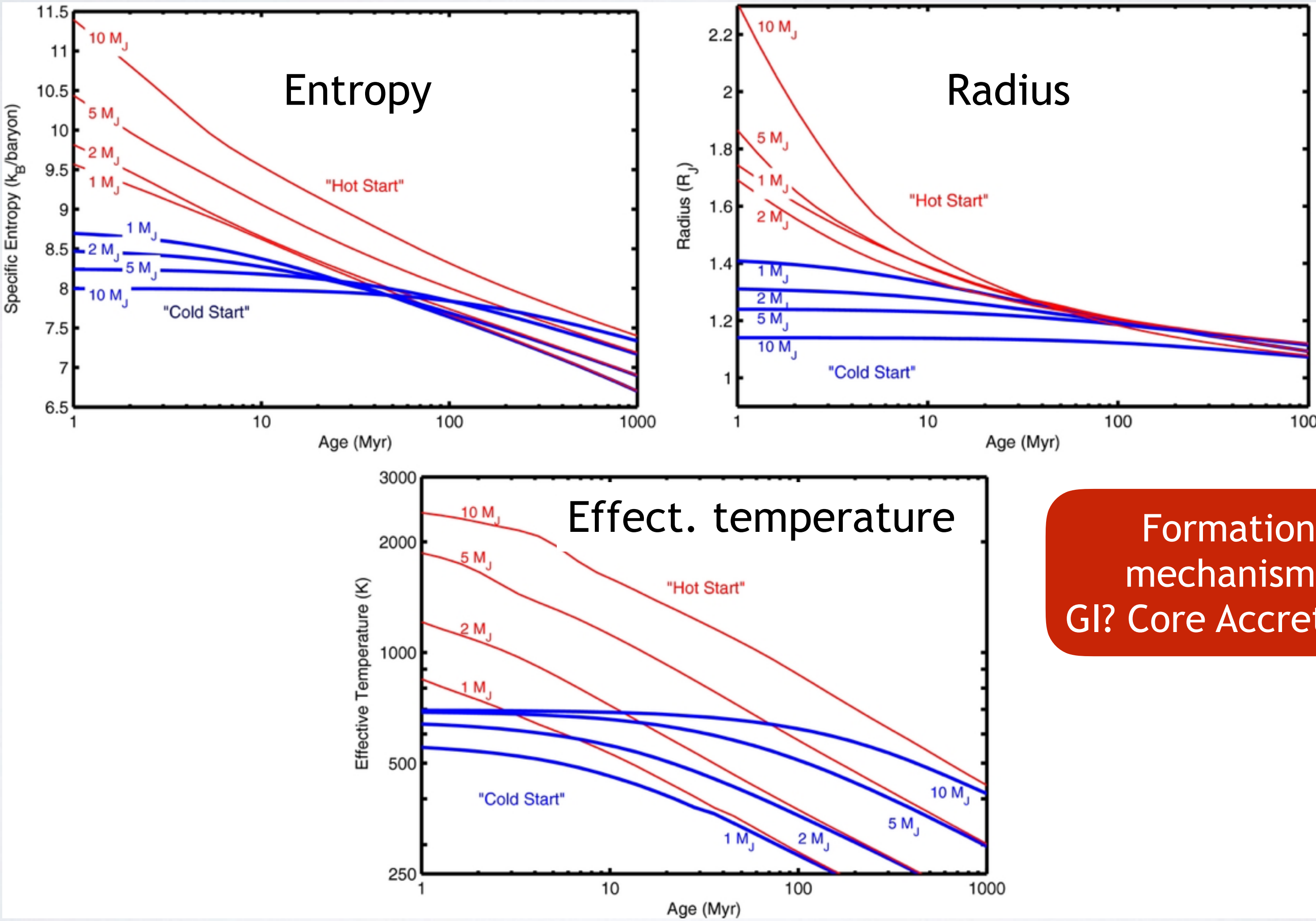
FNSNF
Swiss National Science Foundation

The National Centres of Competence in Research (NCCR)
are a research instrument of the Swiss National Science Foundation

Where and how do (gas giant) planets form?

The physical processes involved in planet formation are largely unconstrained

Predictions from evolutionary models for gas giant planets

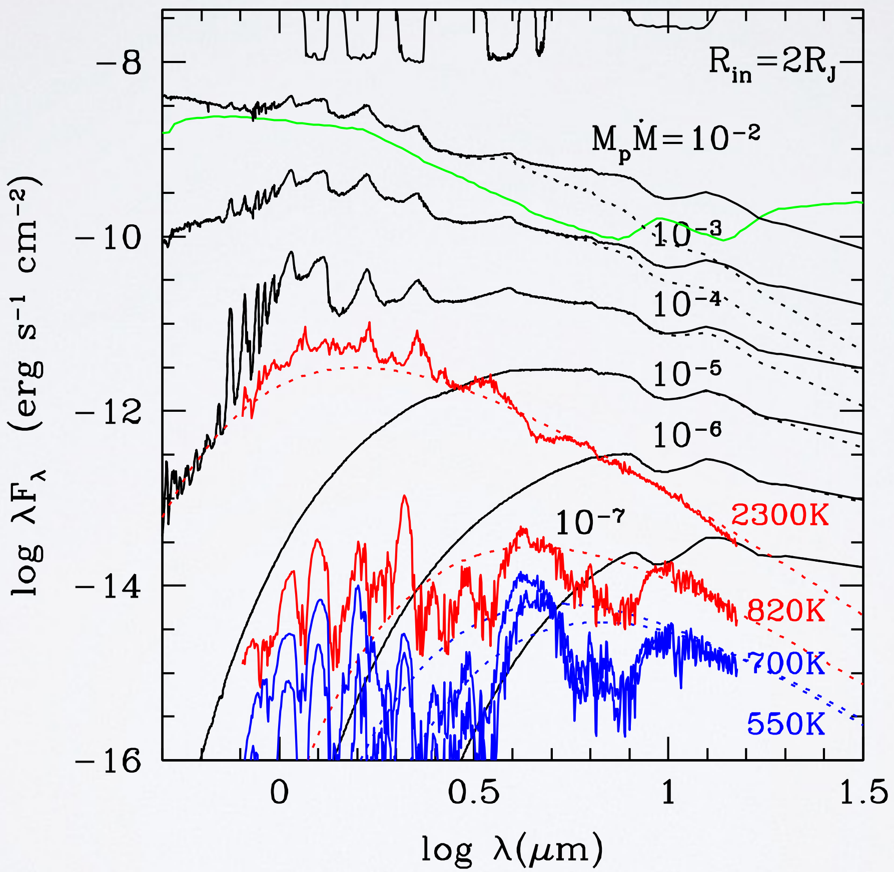


Formation mechanism:
GI? Core Accretion?

Spiegel & Burrows 2012 (see also, e.g., Marley et al. 2007)

The properties of the suspected circumplanetary disks are also unknown

Predictions for combined SEDs: young planets + circumplanetary disks



'Classical' ad-hoc analytical accretion disk models!

See following talks on CPDs and predicted properties!

Zhu 2015 (cf. Eisner 2015)

…and of course everything is connected

Hydrodynamic simulations of a forming gas giant

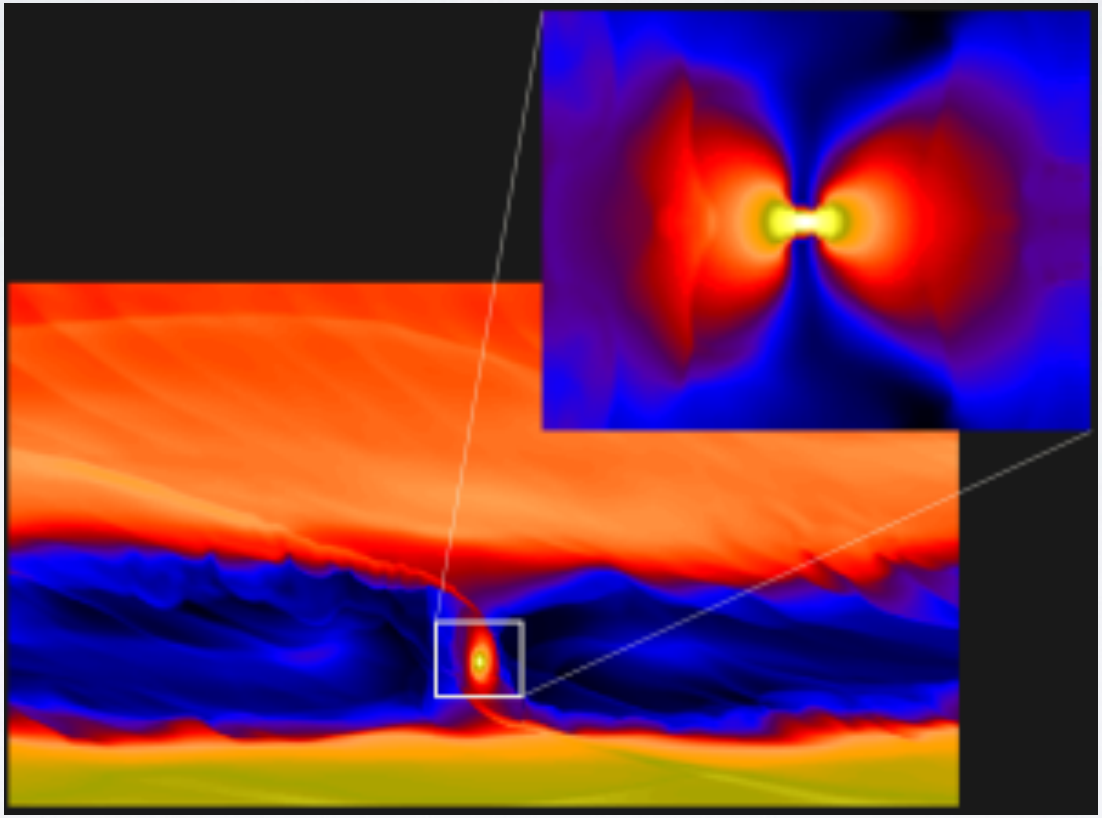
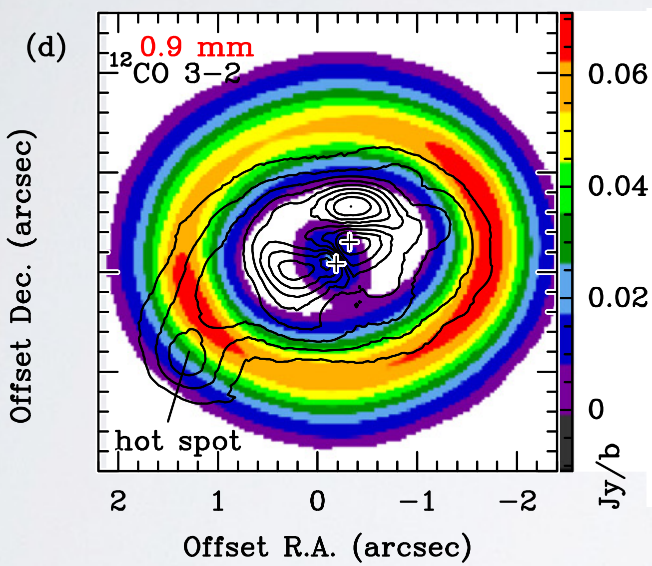


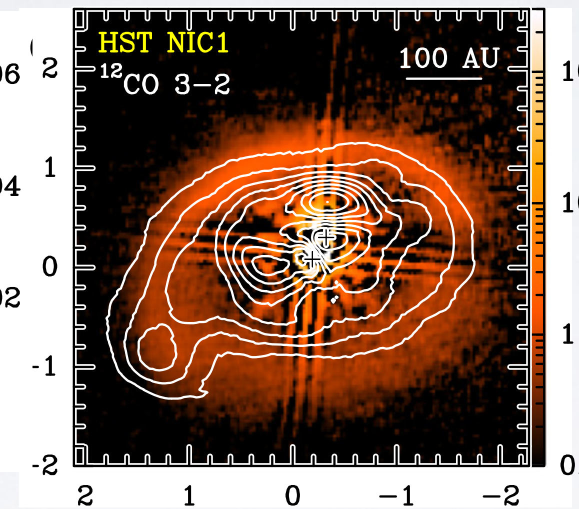
Image courtesy: Judit Szulagyi

So, you probably want to **empirically** measure L_{planet} & L_{CPD} and local circumstellar disk properties

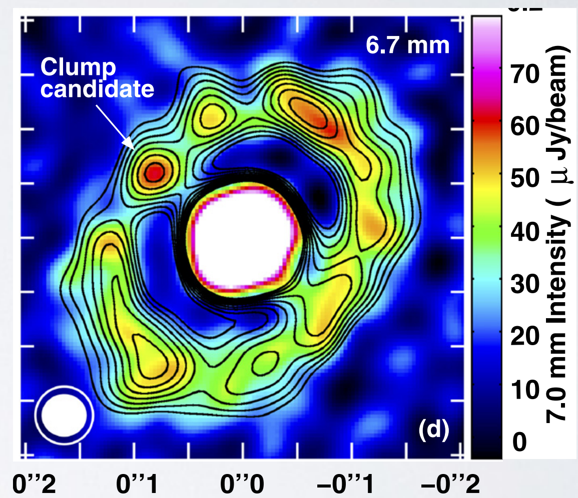
I will not really talk about these two interesting objects…

GG Tau





HL Tau



See talk by Mario Flock and Poster by Emmanuel Di Folco

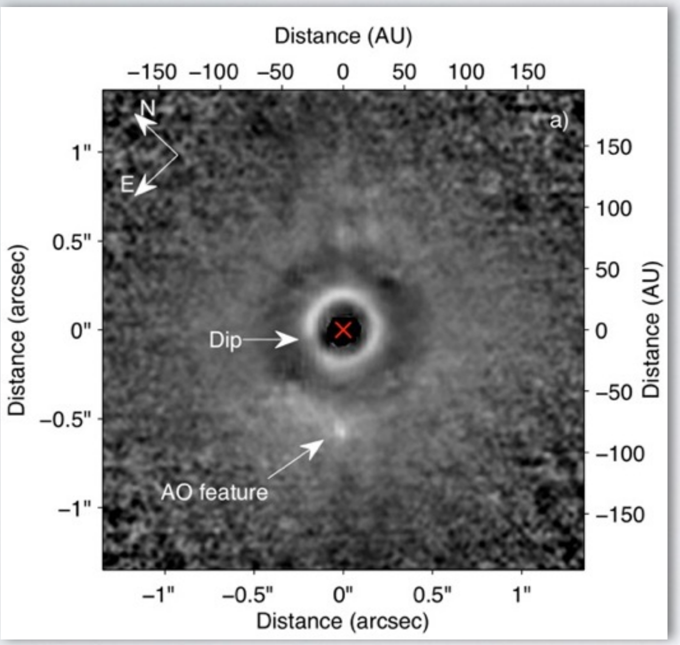
Tang et al. 2016; Carrasco-González et al. 2016

…but rather about these three

	HD 169142	LkCa 15	HD 100546
Sp. Type	A7-A9 IV	K5V	B9Vne
Mass	~1.6 M_{Sun}	~1 M_{Sun}	~2.4 M_{Sun}
Distance	~150 pc	~145 pc	~100 pc
Age	3-12 Myr	~2 Myr	5-10 Myr
Transition Disk?	✓	✓	✓
Accretion?	✓	✓	✓
>1 planets?	✓	✓	✓

The planet candidates around HD169142

1.6 micron polarized light image
NACO PDI

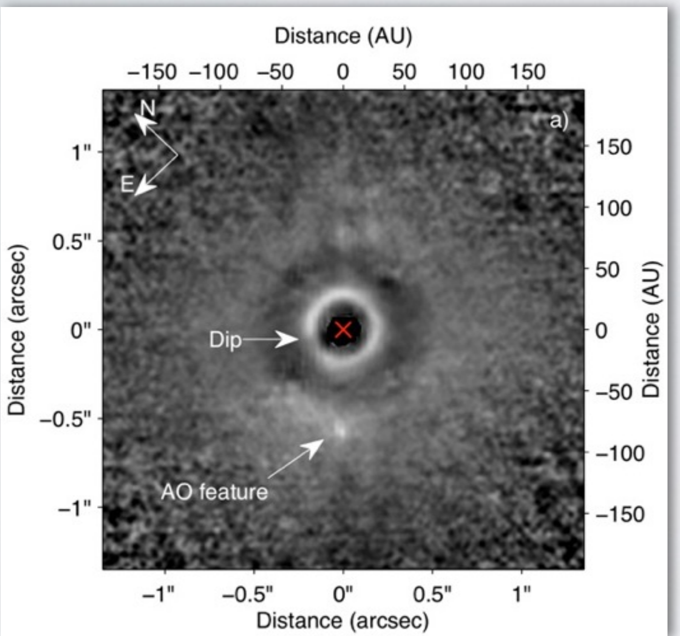


- Inner cavity <25 AU
- Annular gap ~40-70 AU

Quanz et al. 2013b (see, also Momose et al. 2015); Osorio et al. 2014

The planet candidates around HD169142

1.6 micron polarized light image
NACO PDI



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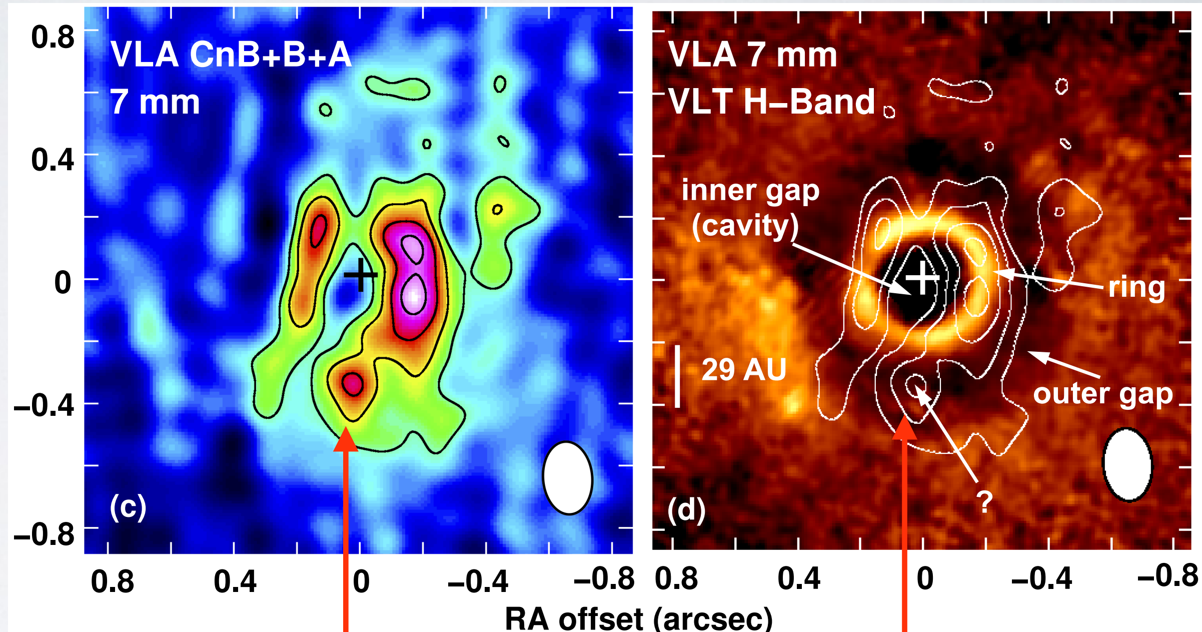
7 mm VLA data

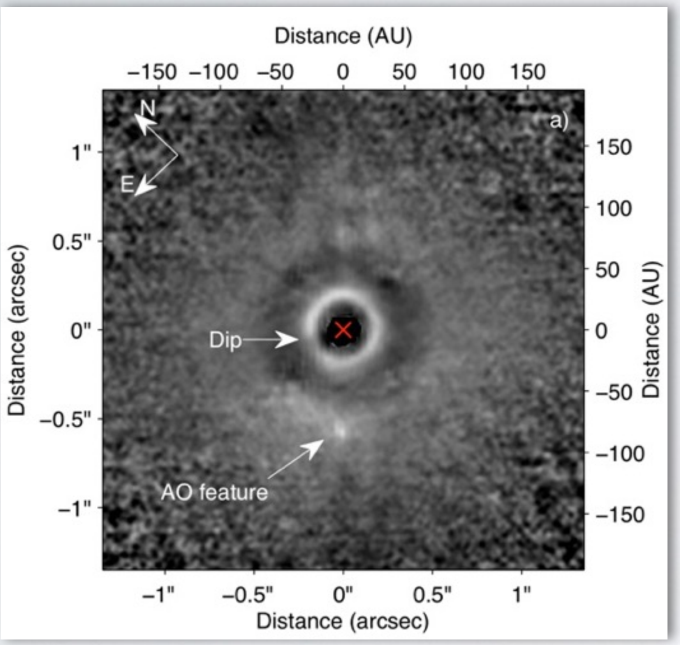


- ~5 sigma 'overdensity' inside the cavity ~50 AU

Quanz et al. 2013b (see, also Momose et al. 2015); Osorio et al. 2014

The planet candidates around HD169142

1.6 micron polarized light image
NACO PDI



- Inner cavity <25 AU
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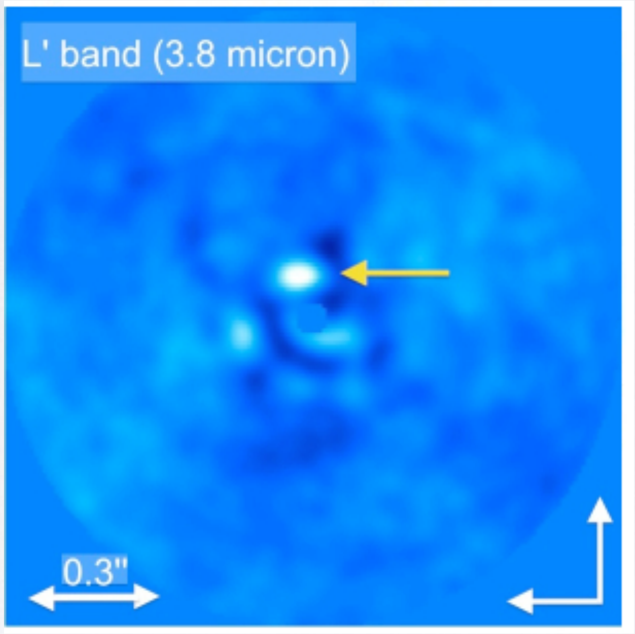
3.8 micron high contrast image
NACO ADI

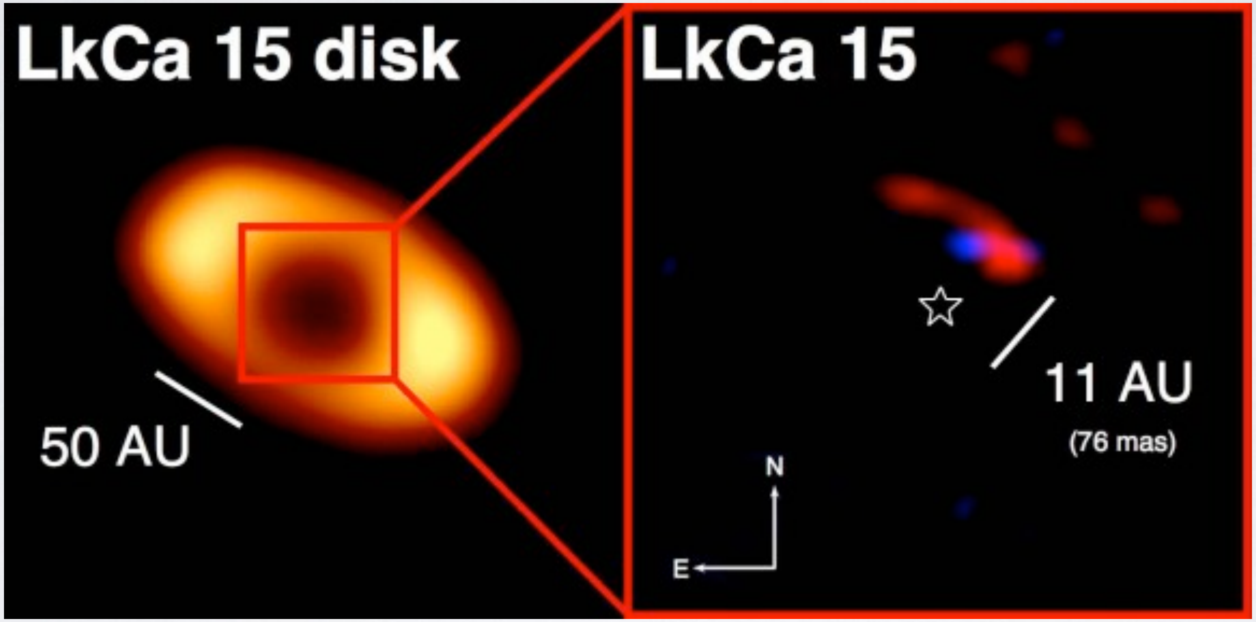


- 3.8 micron point source at ~20-23 AU (inside cavity)
- Not (yet) detected at shorter wavelengths (more data coming soon)

Quanz et al. 2013b; Reggiani, Quanz et al. 2014; Biller et al. 2015

The planet candidates around LkCa 15

SMA 850 micron + Keck aperture masking (2.3 and 3.8 micron)

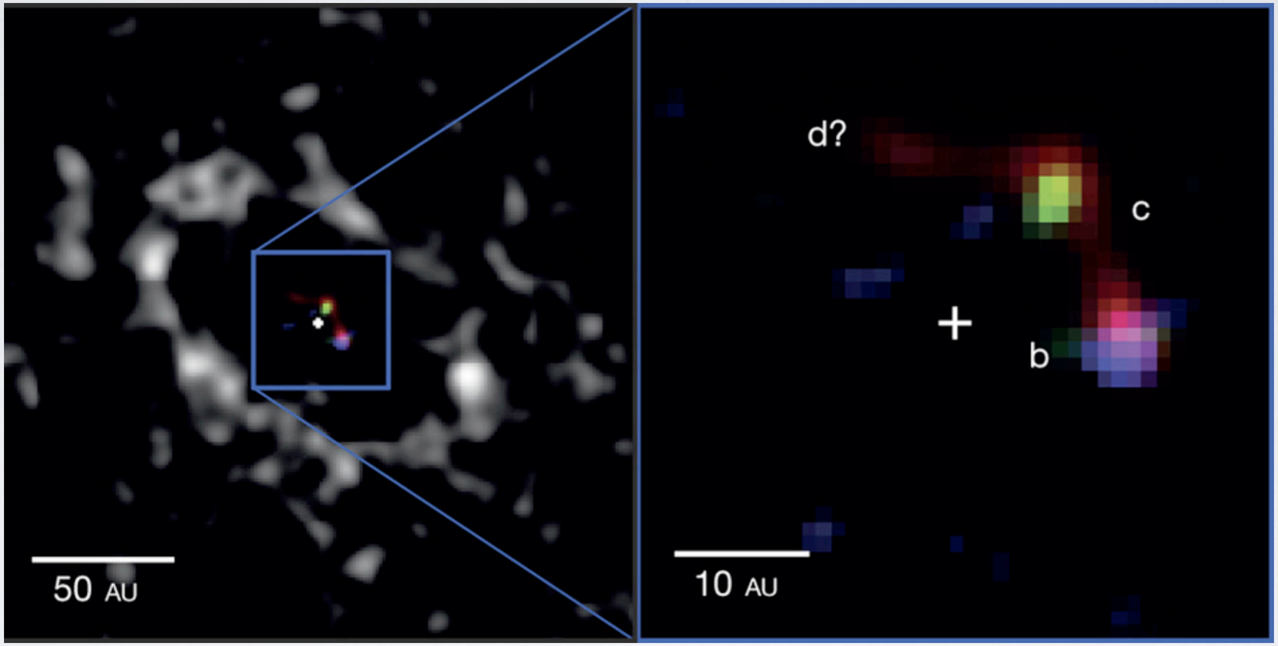


- Dust cavity R~40-50 AU (also in scattered light)
- Companion candidate in the cavity at ~11 AU

Kraus & Ireland 2012; Andrews et al. 2011

The planet candidates around LkCa 15

VLA 7mm + LMIRCam aperture masking (2.3 / 3.8 micron)
+ MagAO (H_alpha)



- Multiple sources compatible with orbital motion from discovery paper
- One component shows H-alpha excess emission
(potential tracer of ongoing accretion)

See also talk by
Steph Sallum

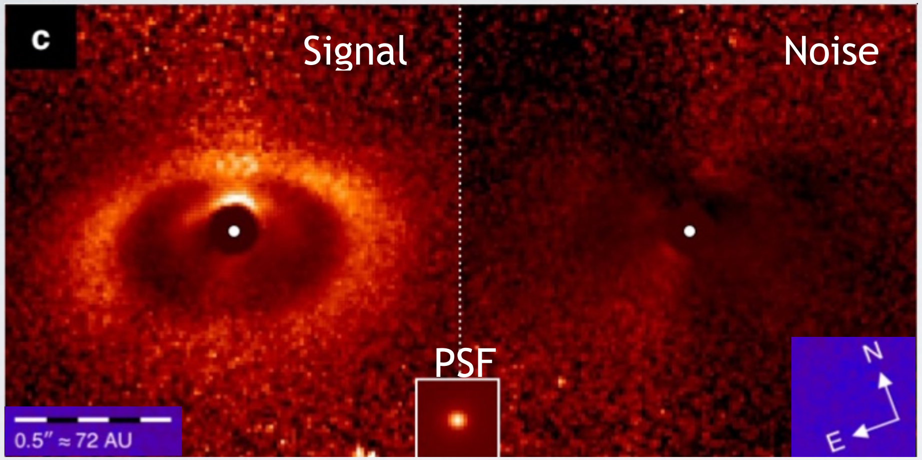
Isella et al. 2014; Sallum et al. 2015

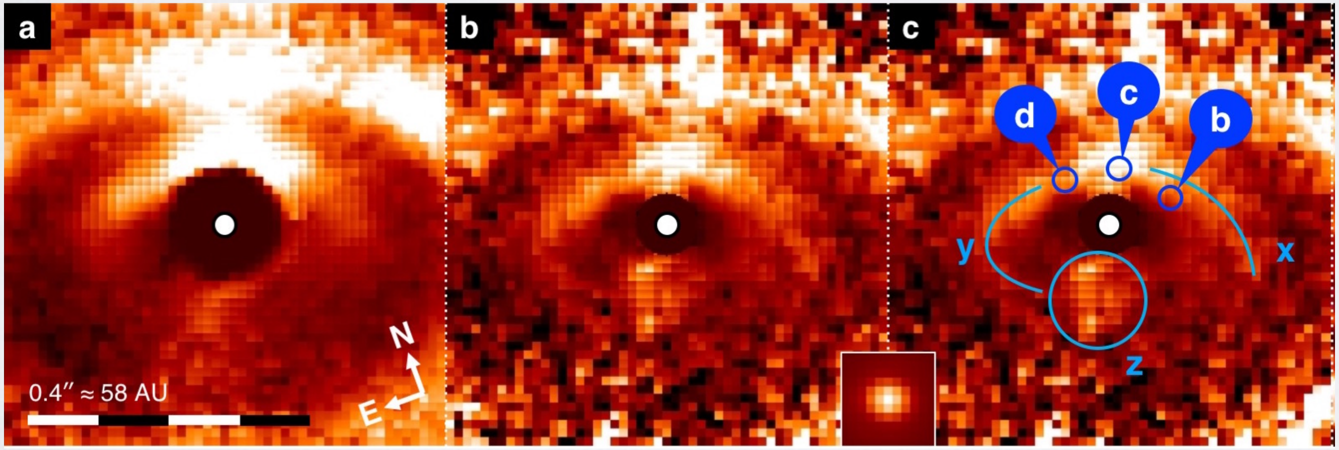
The planet candidates around LkCa 15

New data from SPHERE GTO program

See also talk by Claudio Caceres Steph Sallum

SPHERE polarized light J-band



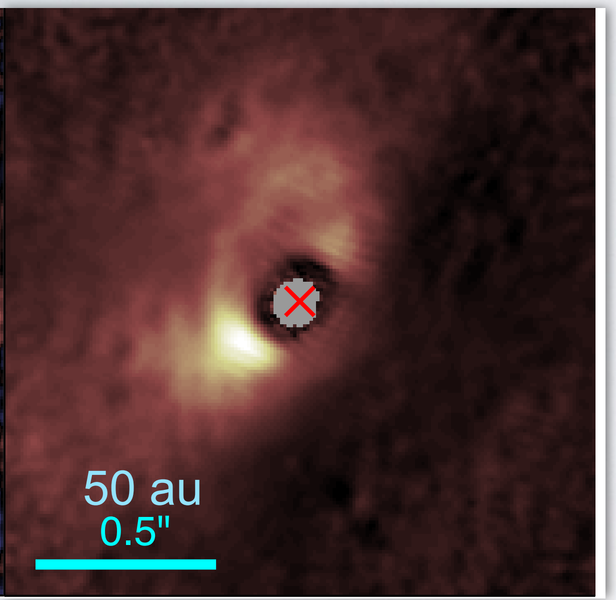


- There is small dust inside the disk cavity and scattered light from the inner disk

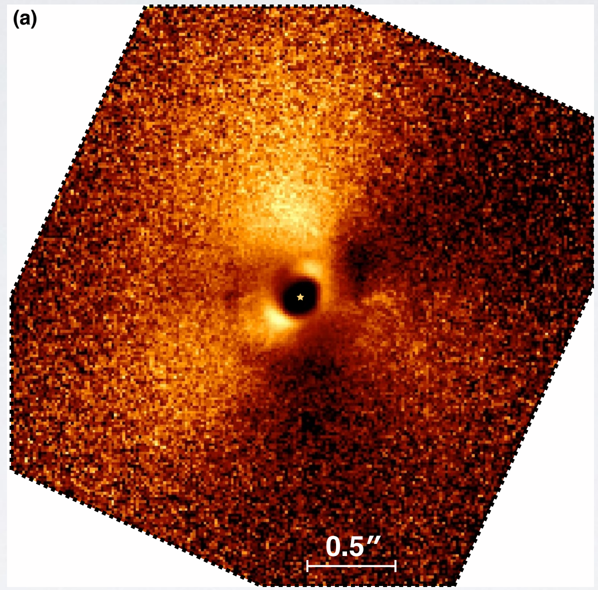
Thalmann et al. 2011, 2014, 2015, in prep.

The planet candidates around HD100546

1.6 micron polarized light image (VLT/NACO)



0.6 micron polarized light image (VLT/SPHERE)



See also talk by Elena Sissa

- Inner cavity <14 AU
- Brightness asymmetry

Avenhaus, Quanz et al. 2014; Quanz et al. 2011; Garufi, Quanz et al. 2016

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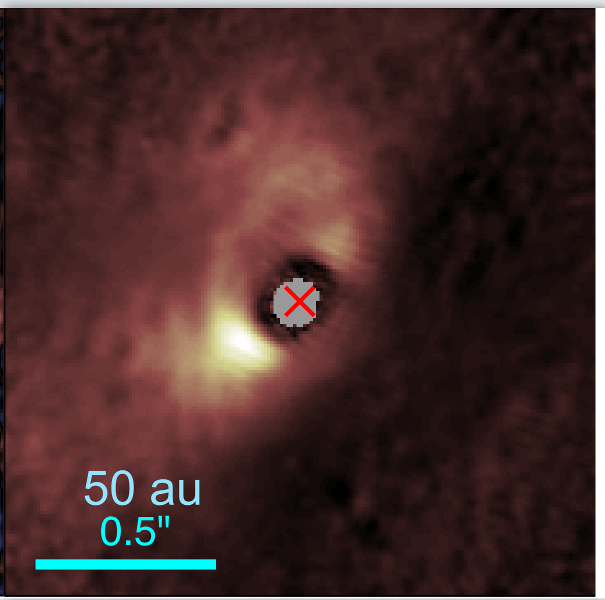
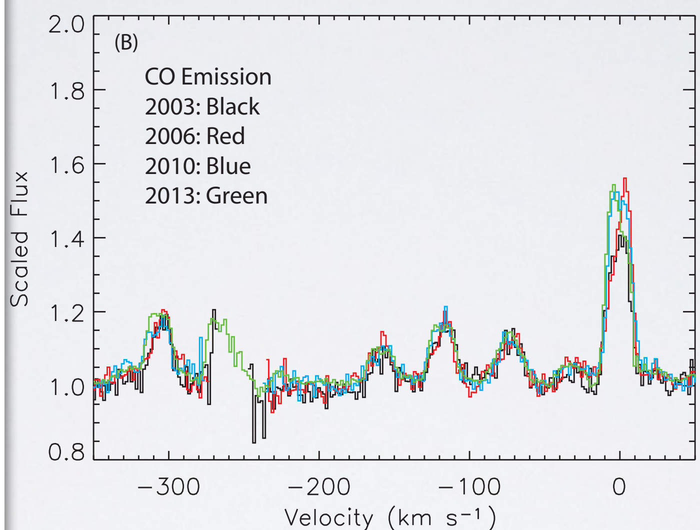
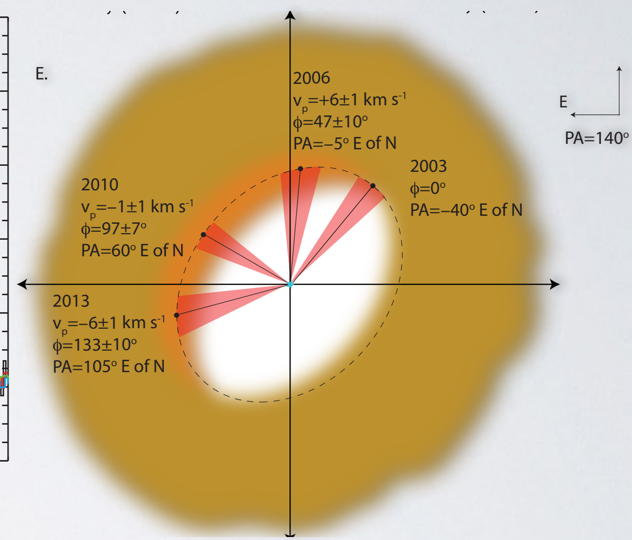


- Inner cavity <14 AU
- Brightness asymmetry

High dispersed 4.6 micron spectroscopy





- Fundamental CO ro-vibrational lines
- Hot-band lines static
- v=1-0 P26 line varies

- Spectro-astrometric signal consistent with orbiting body at ~10-12 AU

Avenhaus, Quanz et al. 2014; Quanz et al. 2011; Brittain et al. 2013, 2014

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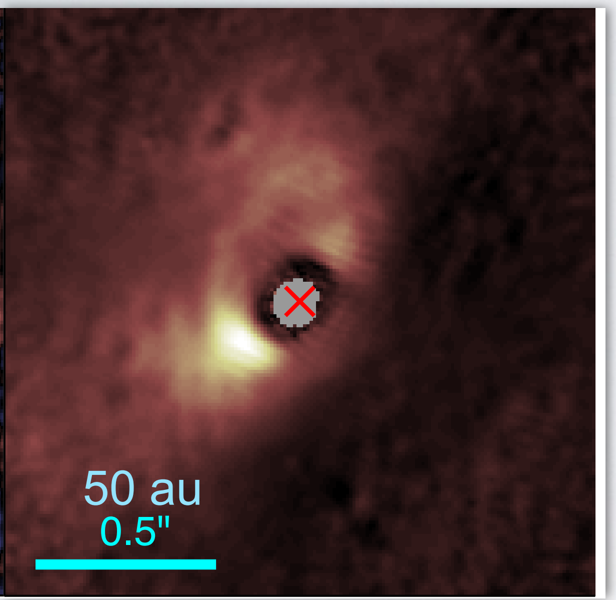
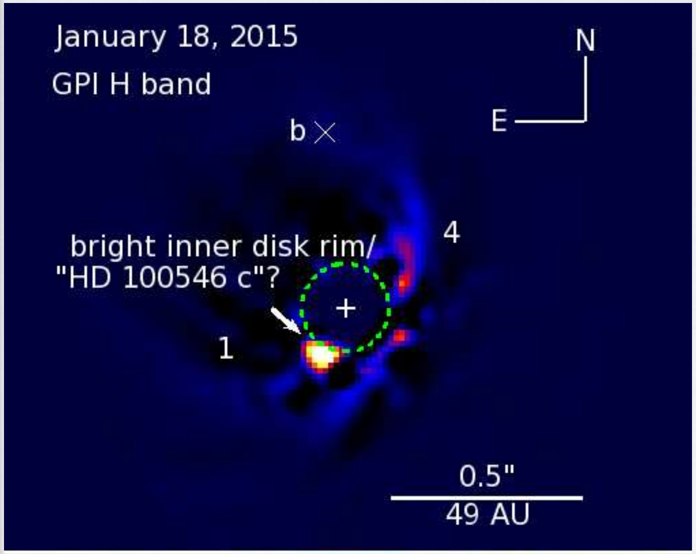
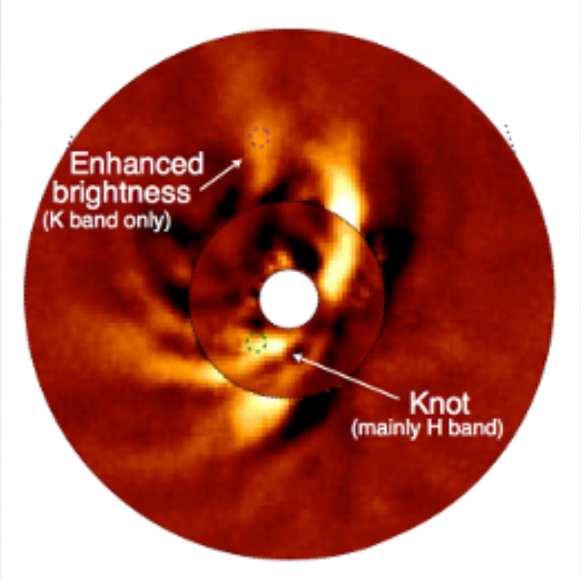


- Inner cavity <14 AU
- Brightness asymmetry

High contrast imaging with GPI and SPHERE



- GPI ADI imaging H band



- SPHERE ADI imaging in H and K band

See also talk by Elena Sissa

Avenhaus, Quanz et al. 2014; Quanz et al. 2011; Currie et al. 2015; Garufi, Quanz et al. 2016
Other 'indirect evidence': Bouwman et al. 2001; Acke & van den Ancker 2006; Mulders et al. 2013

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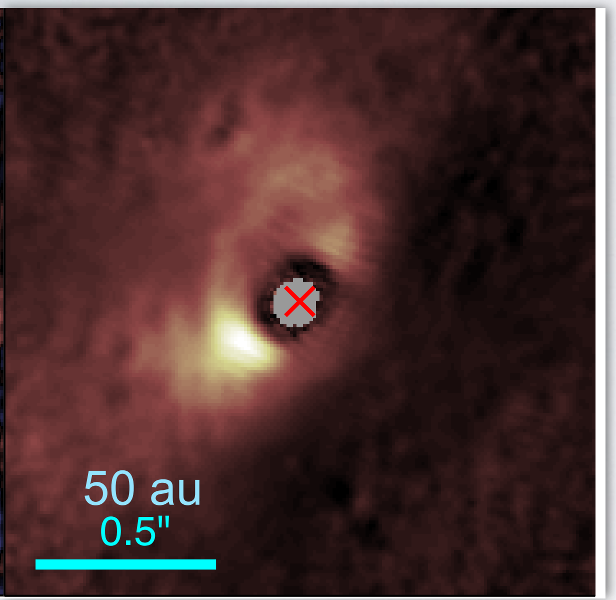

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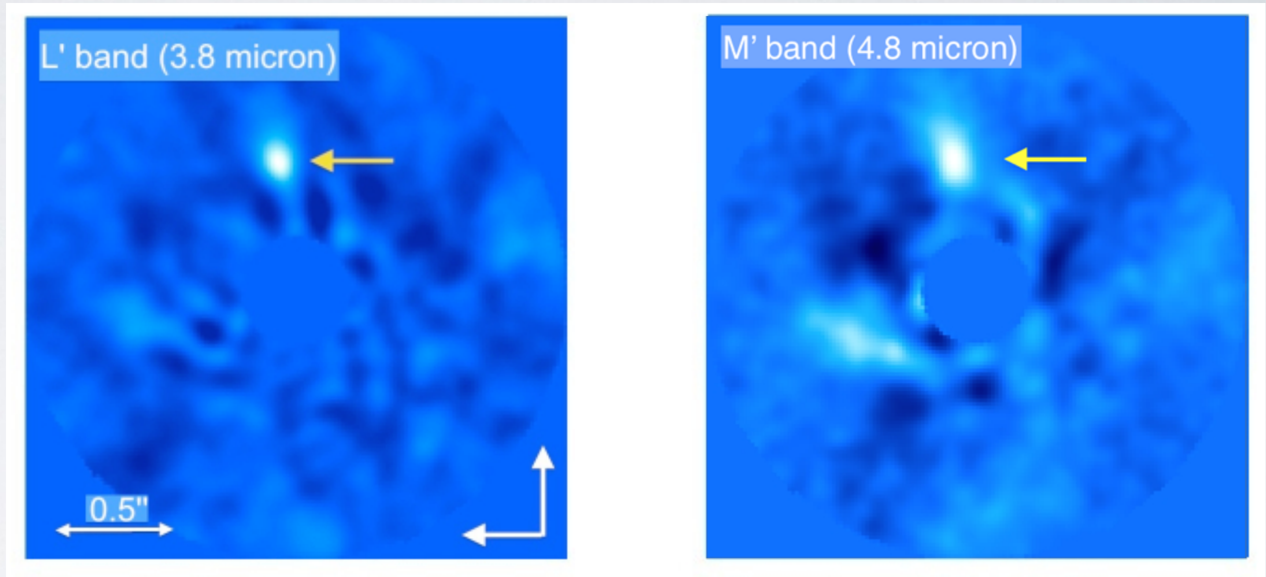

- Point source + plus extended emission at ~52 AU
- Very red H, L', M' colors

Avenhaus, Quanz et al. 2014; Quanz et al. 2011, 2013a, 2015; cf. Currie et al. 2014

The planet candidates around HD100546

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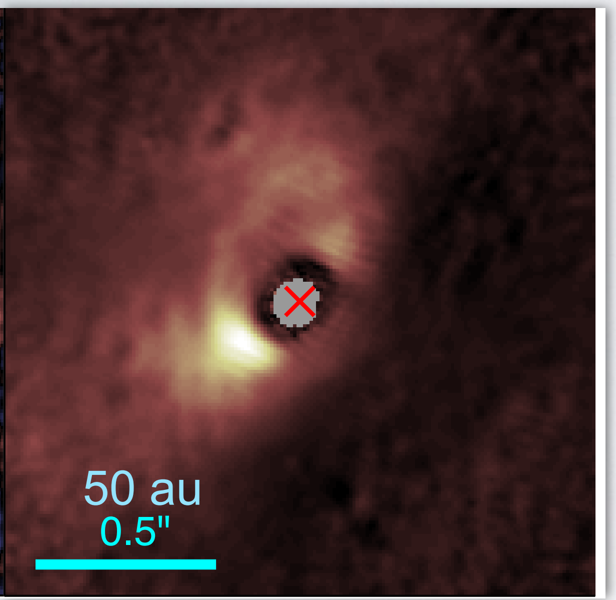

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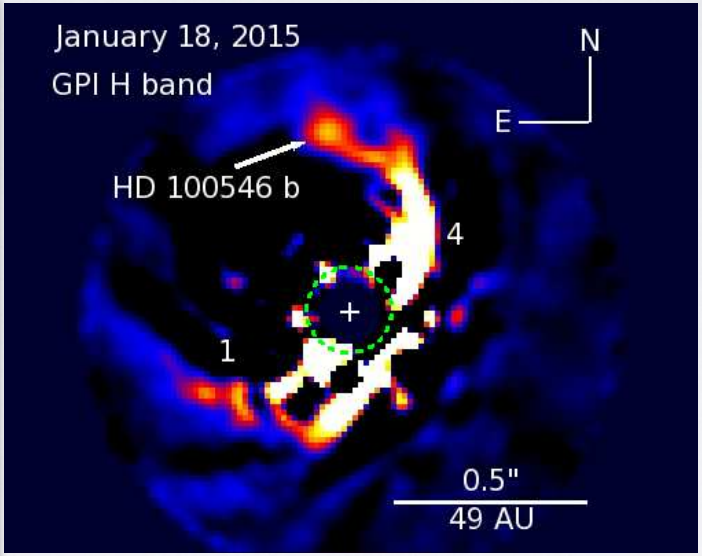

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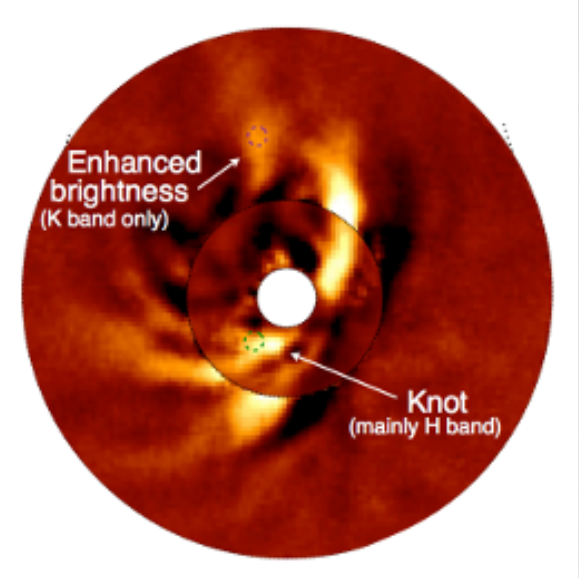

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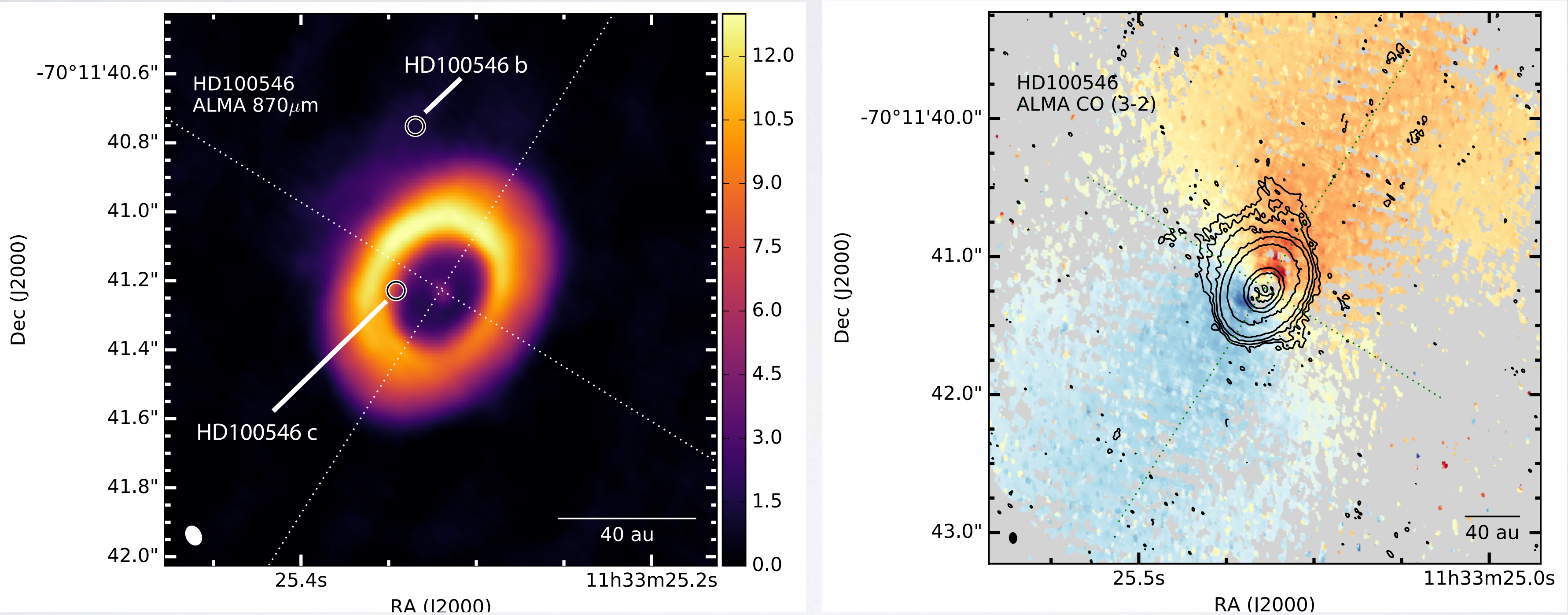
The planet candidates around HD100546

New data from ALMA cycle 3

ALMA cycle 3 data (345 GHz)



Pineda et al., in prep.

The planet candidates around HD100546

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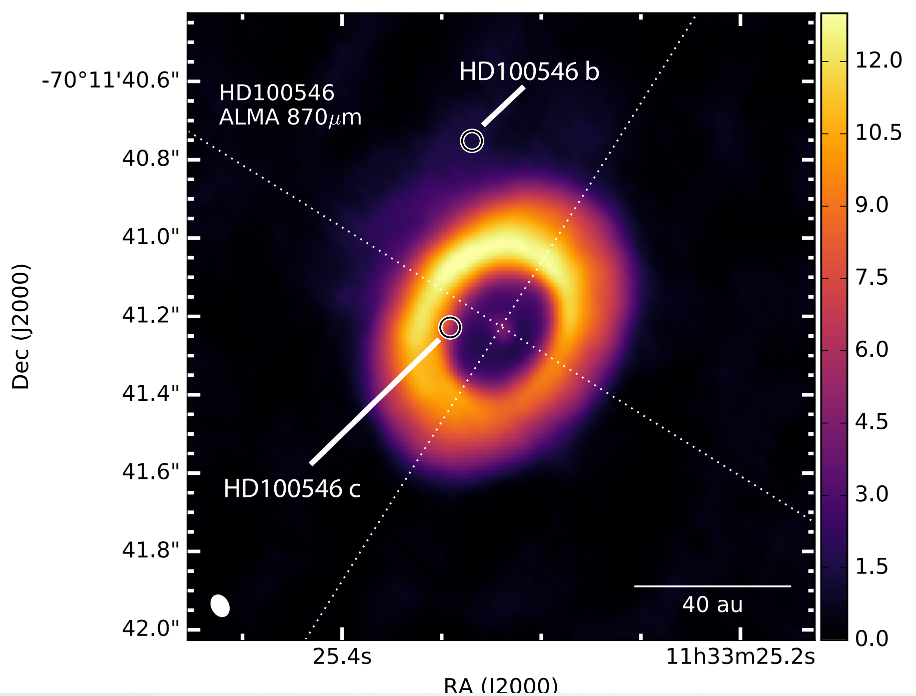
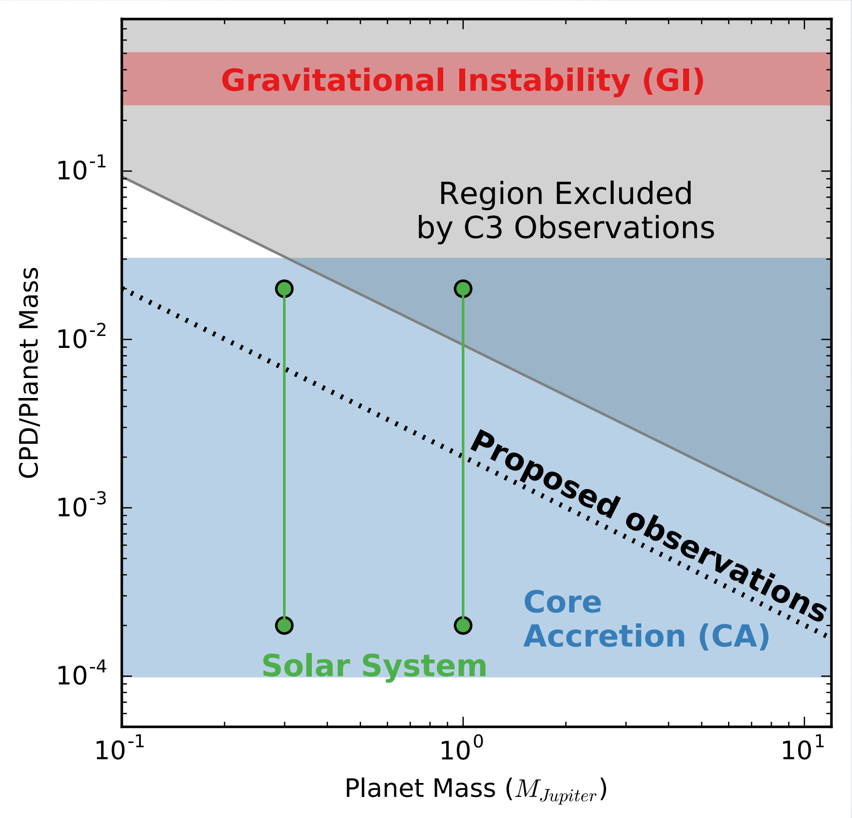




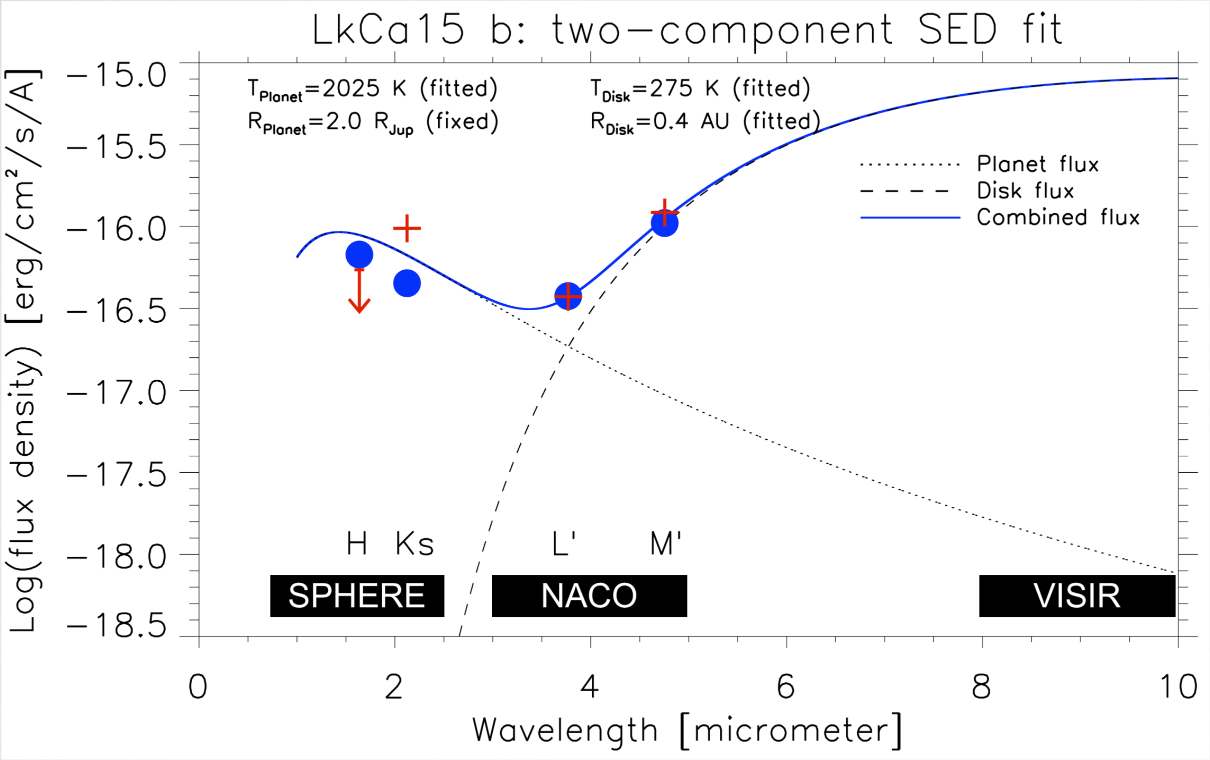
Pineda et al., in prep.

How do we link the data to the questions?

Compile 'simple' SEDs of planet+disk systems and compare

Caution - very simplistic!

LkCa 15 b - SED fitting



Data from Sallum et al. 2015; Ireland & Kraus 2014

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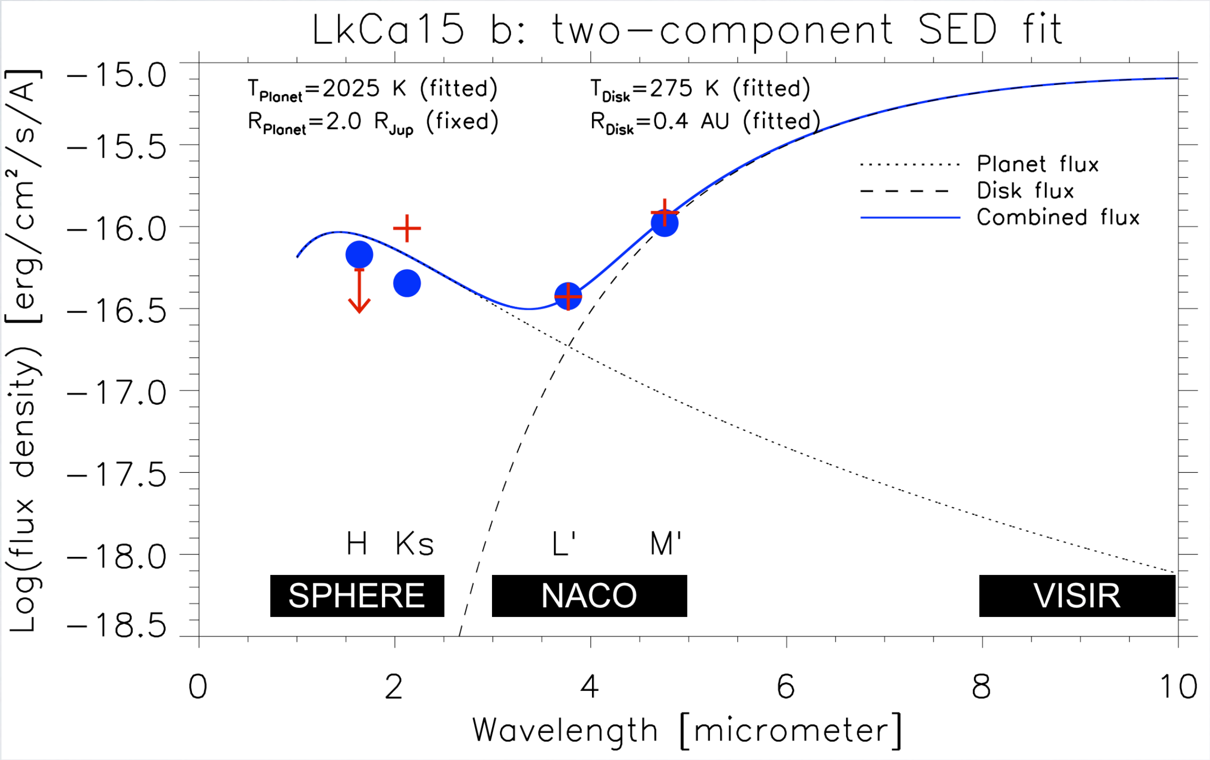

T and L of the planet ($L \sim 6 \times 10^{-4}\ L_{Sun}$) ->'hot'-start conditions

Assuming $R_{CPD} \sim 0.3\ R_{Hill}$ -> $M \sim 1.8\ M_{Jupiter}$

L_{CPD} comparable to accreting CPDs with of 10^{-6} - $10^{-5}\ M_{Jupiter}^2 yr^{-1}$ comparable to what was estimated from Halpha

Data from Sallum et al. 2015; Ireland & Kraus 2014

Compile 'simple' SEDs of planet+disk systems and compare

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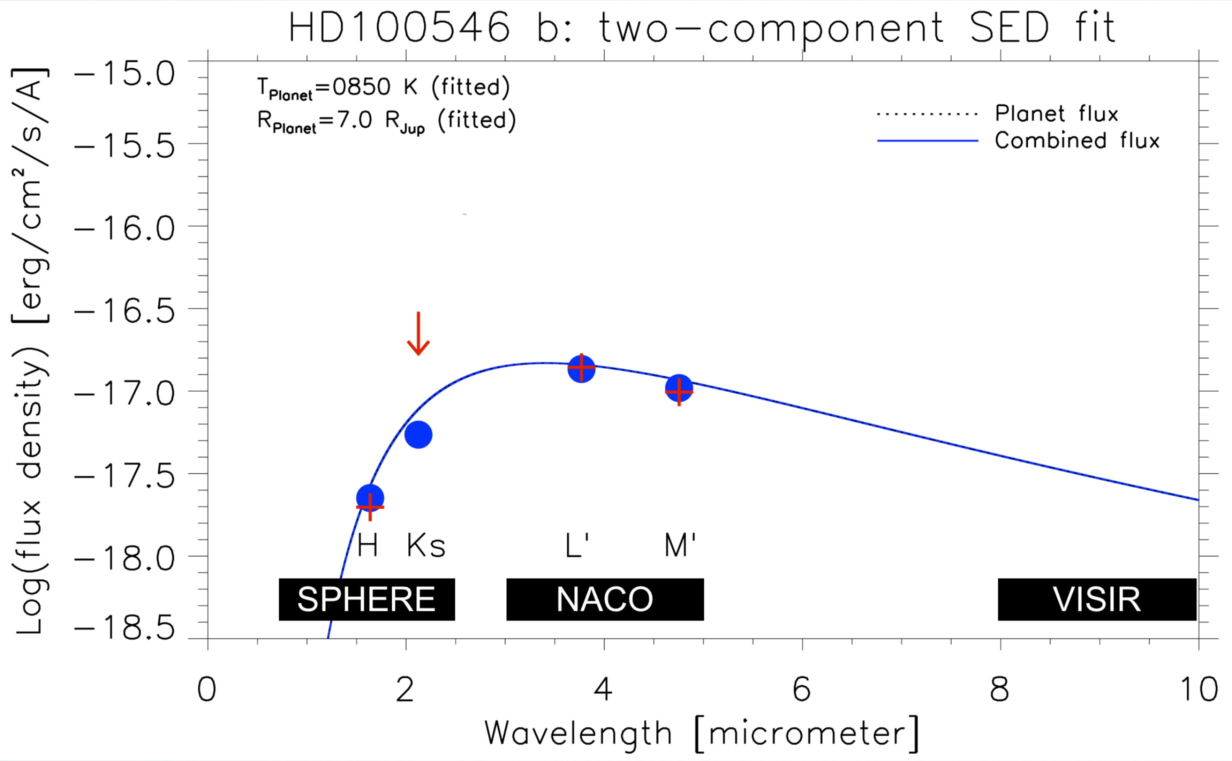
HD100546 b - SED fitting



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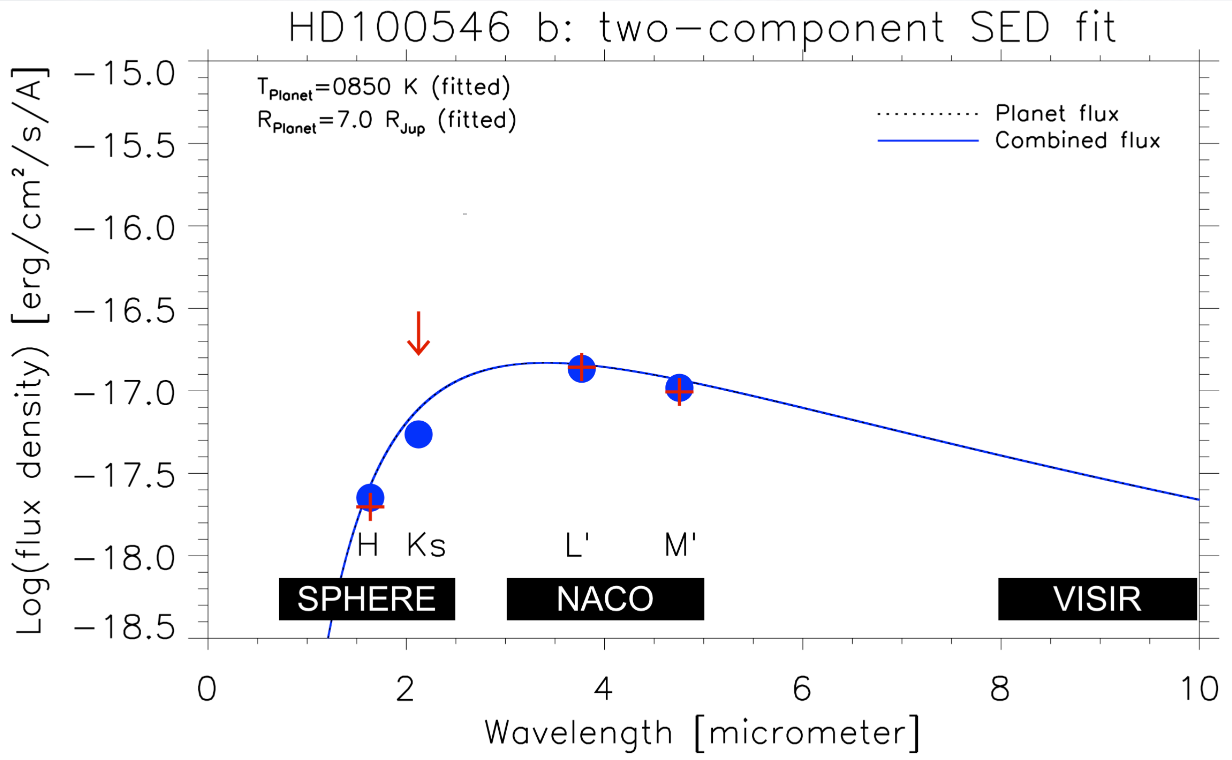

Effective radius and T are 7 $R_{Jupiter}$ and ~850 K

Luminosity ~$2x10^{-4}$ L_{Sun}

One component only? Younger stage, still deeper embedded?

Data from Quanz et al. 2015; Currie et al. 2015; Mordasini et al. 2012

Compile 'simple' SEDs of planet+disk systems and compare

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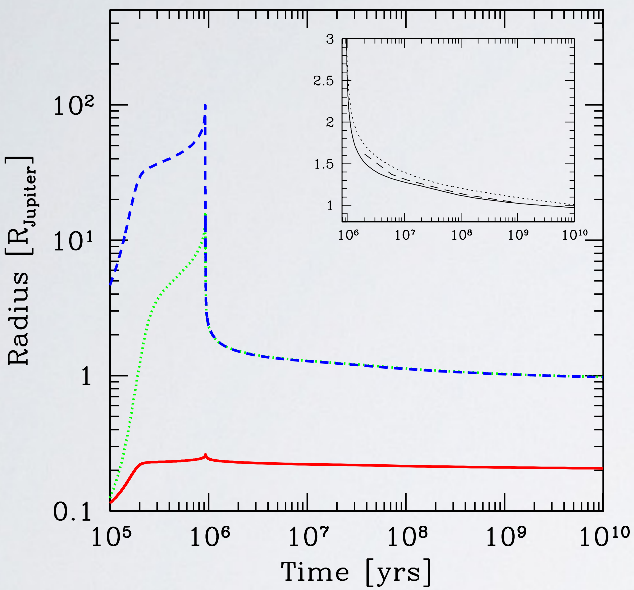
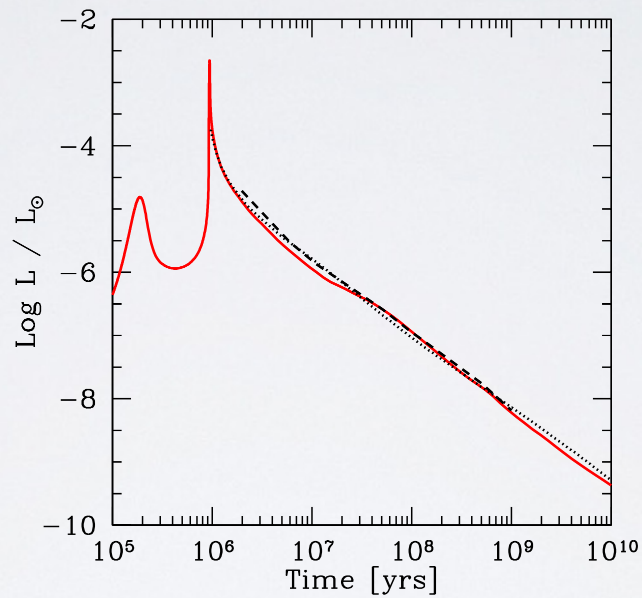
Models describing the formation of Jupiter





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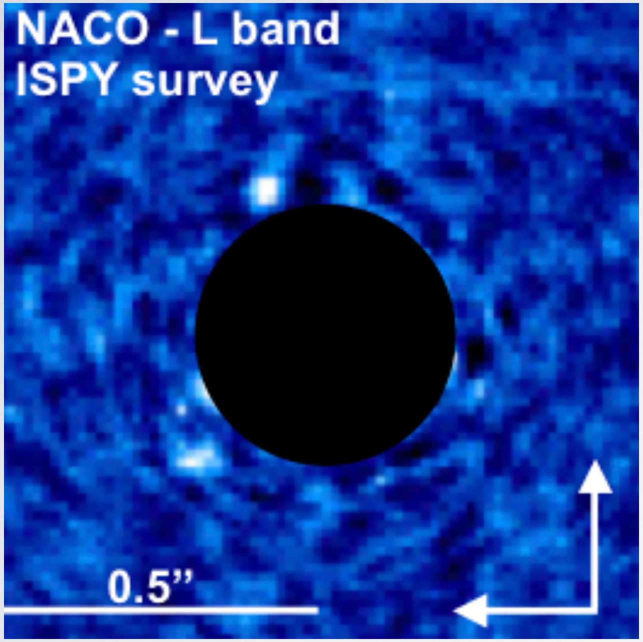
Mordasini et al. 2012

What’s next?

Find more objects…and get more data…

A VLT/NACO L band survey



~30 nights of GTO observations
to search for planets in disks

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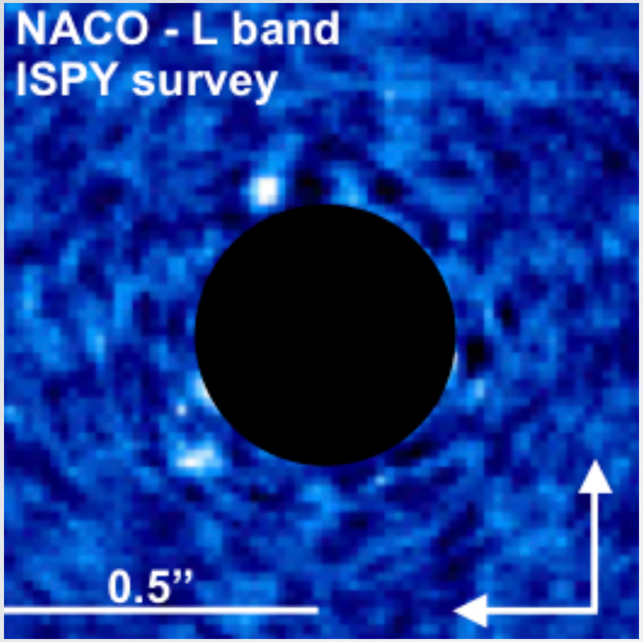
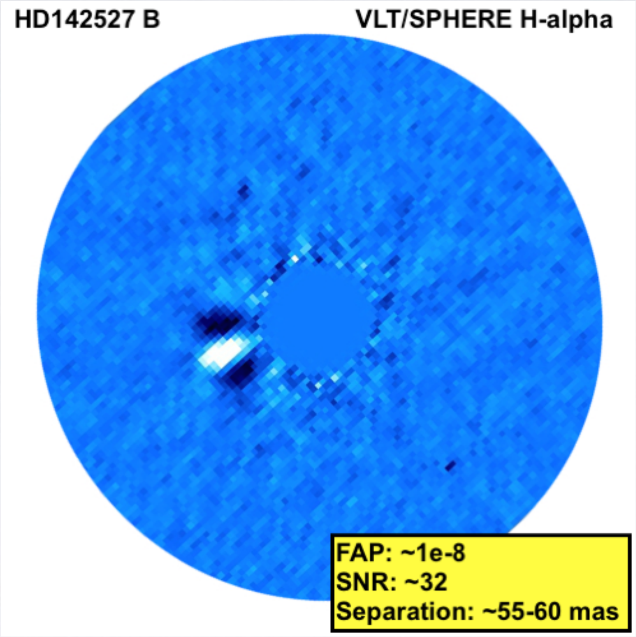


~30 nights of GTO observations to search for planets in disks

H_alpha with VLT/SPHERE



New data from SPHERE GTO program

Find more objects…and get more data…

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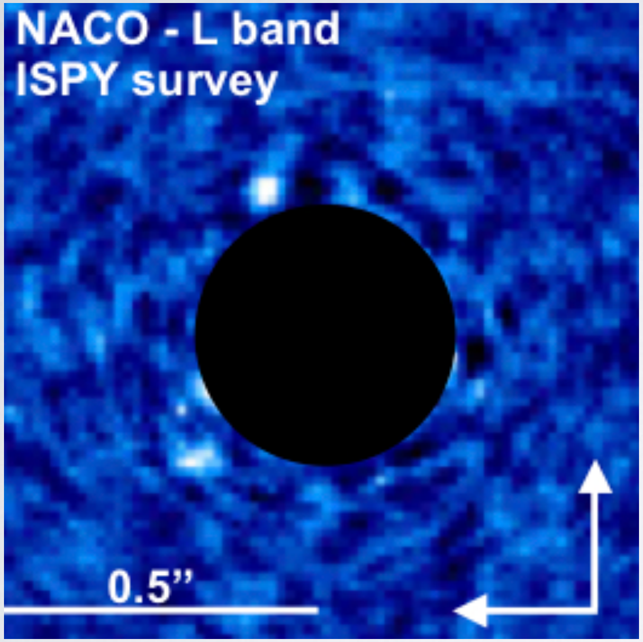

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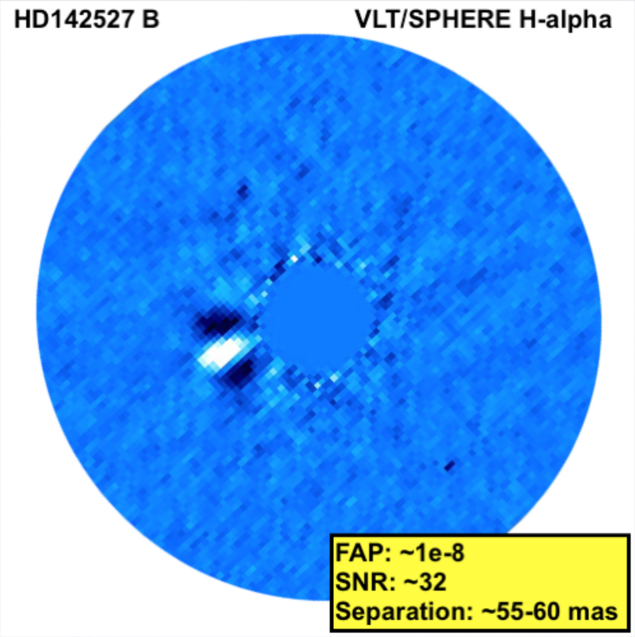
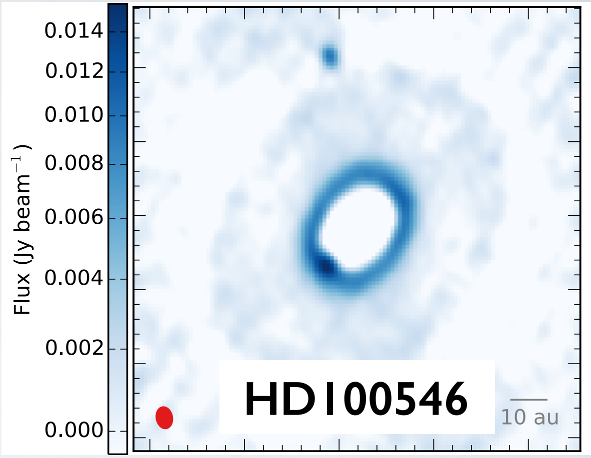
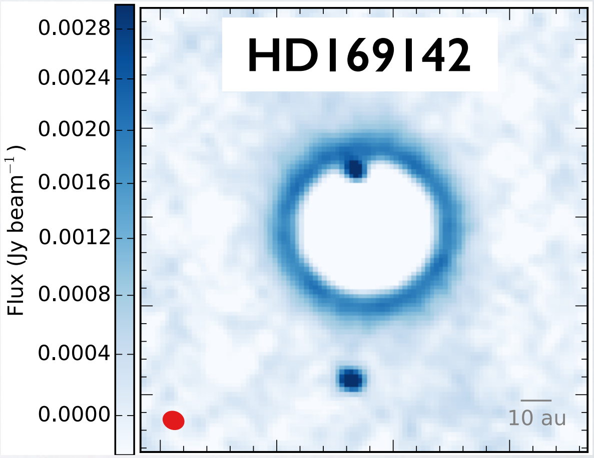


New data from SPHERE GTO program

ALMA data on "prime targets"





Take home messages

For at least three young stars we have direct observational evidence that young planets might orbit in their disks

If these are indeed forming giant planets then they are located between ~10-50 AU, i.e., at rather large separations

Detected objects have very red IR colors indicating the possible existence of warm circumplanetary material; one objects shows signs of accretion

More data, coming from ongoing ALMA and high-contrast imaging campaigns, will help us to characterize the SEDs of planet+disk systems

These objects allow us to constrain planet formation models with empirical data