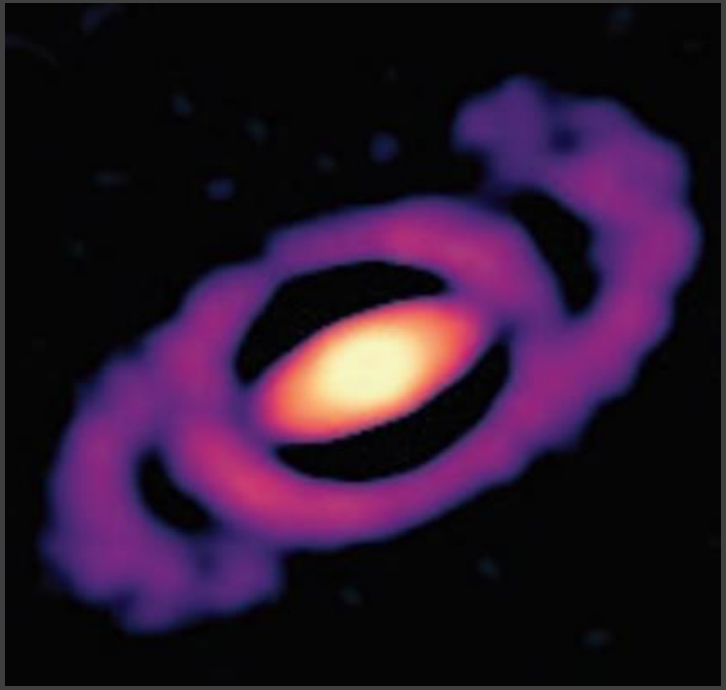
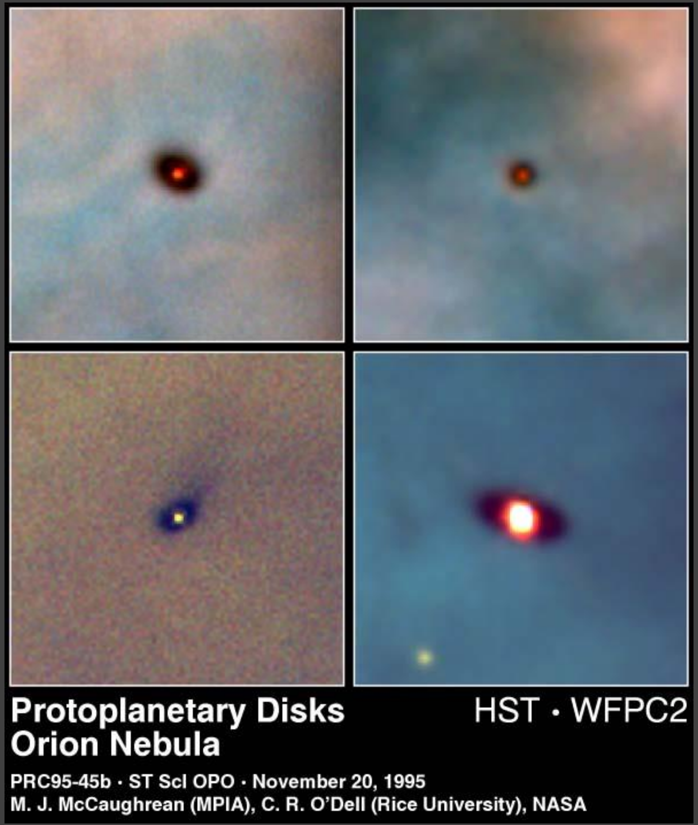
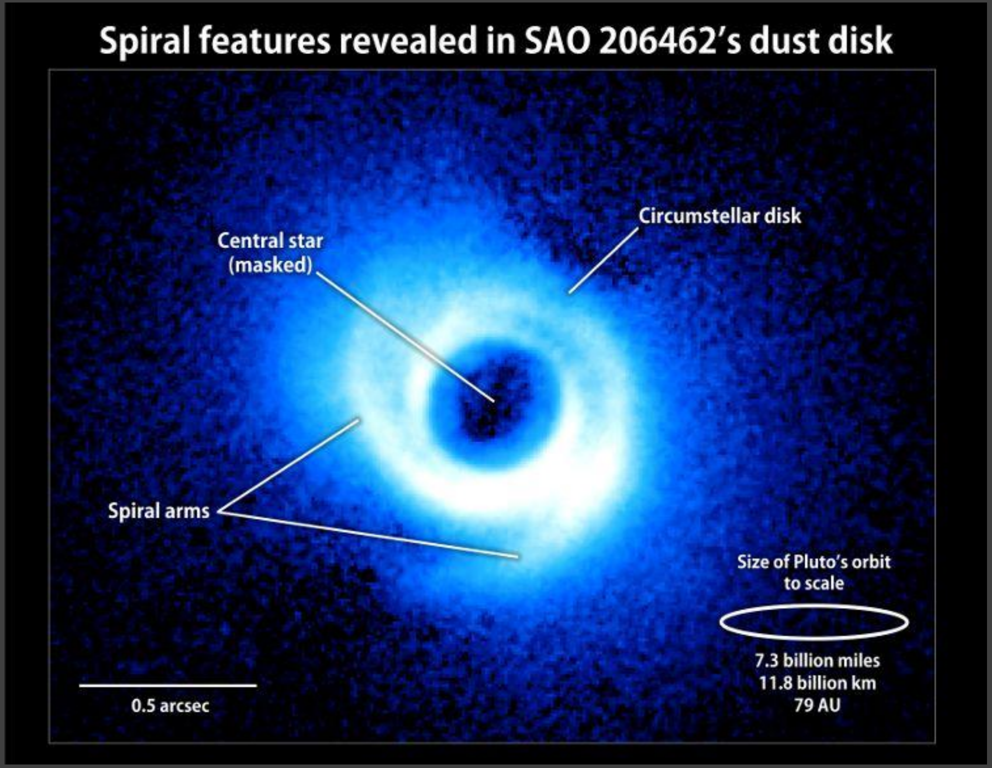


Young planetary systems

SERGEI POPOV

Protoplanetary discs





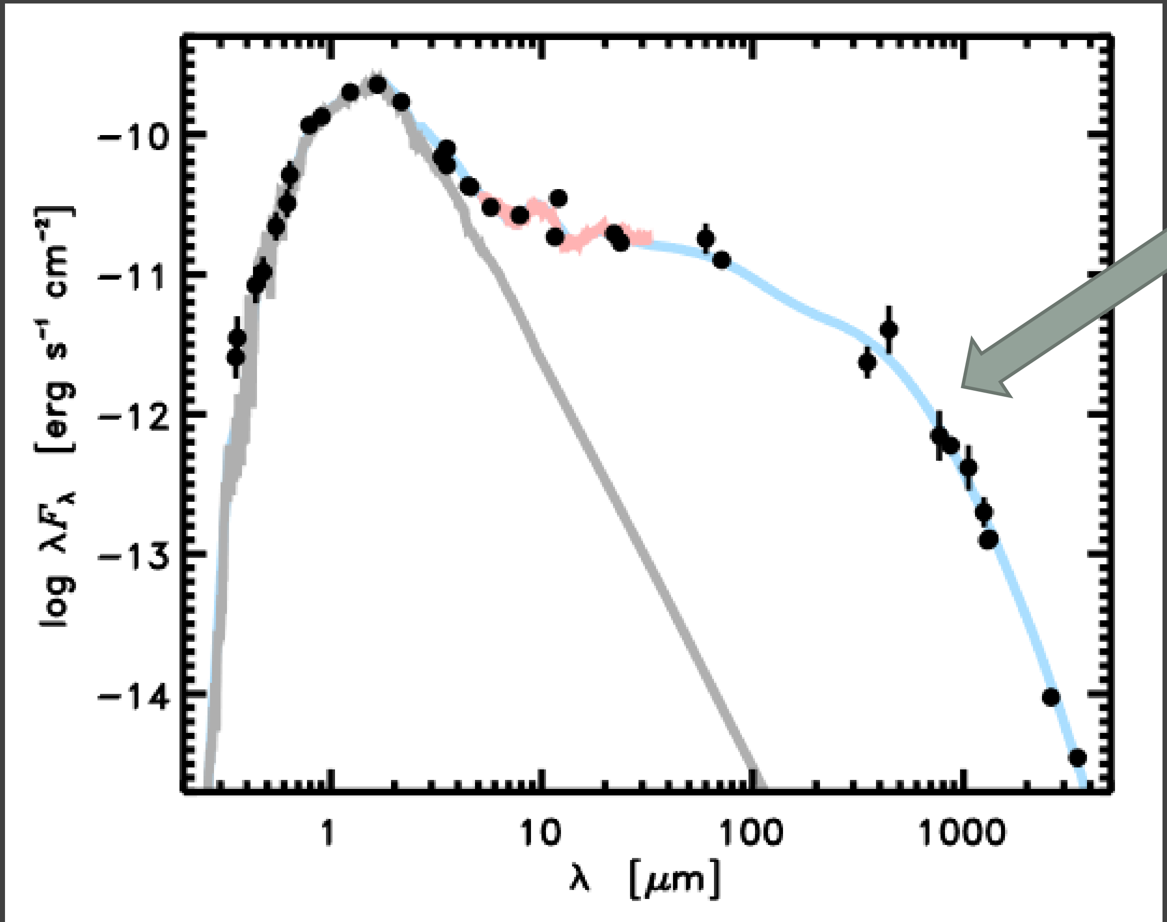
https://online.science.psu.edu/astro140_sp201314wd001/node/7717
http://news.softpedia.com/news/Exoplanets-Can-Form-Spiral-in-Stellar-Protoplanetary-Disks-228792.shtml

Dusty discs

HST observations

Disc is visible edge-on.

Discs and stars



Optically thin disc.
Allows to determine dust mass.

$$M_{\rm dust} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_{\rm dust})},$$

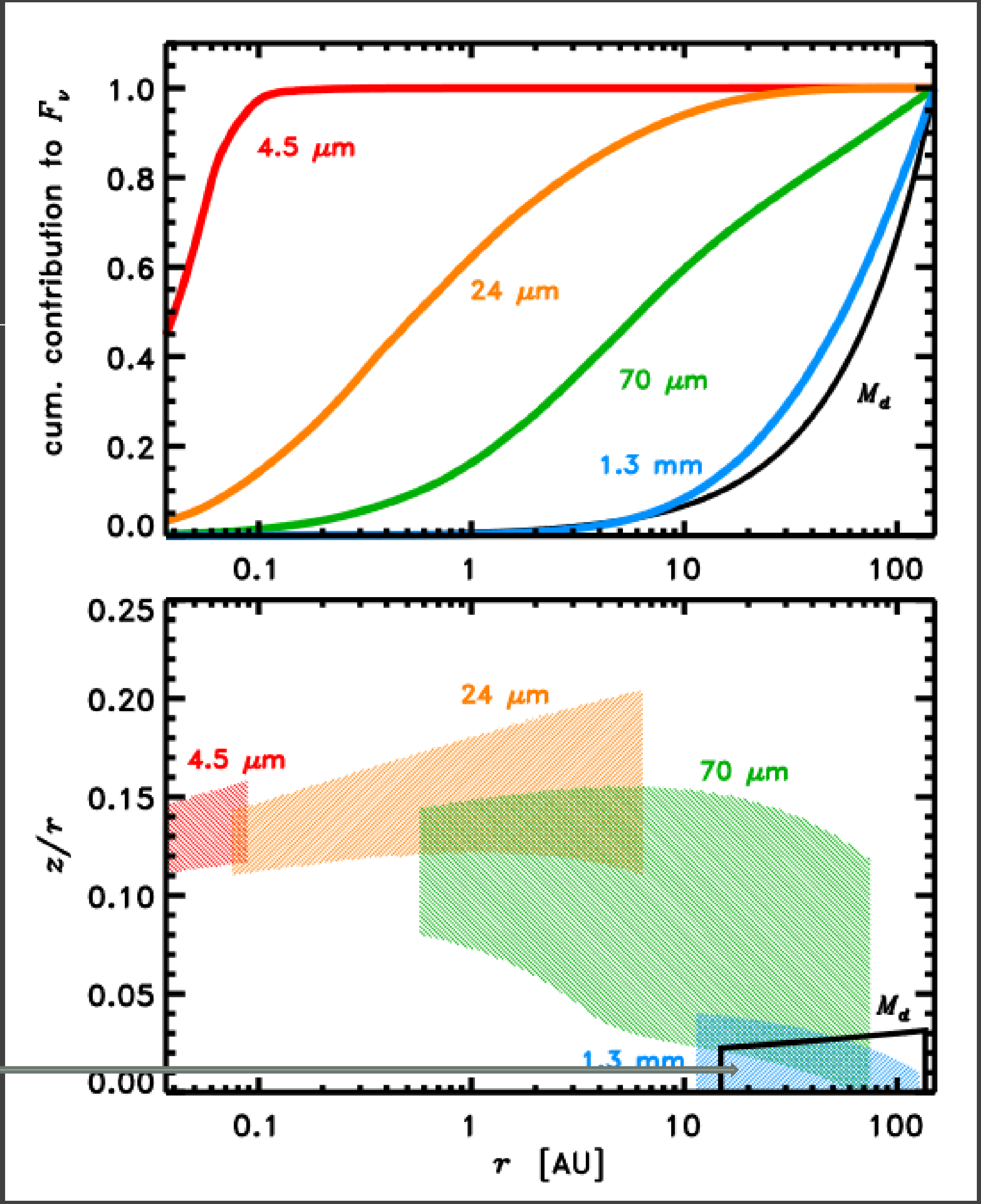
See 1807.09631
about different methods
of dust mass determination

$$M_{\rm dust} \propto M_{\rm star}^{1.8}.$$

1507.04758

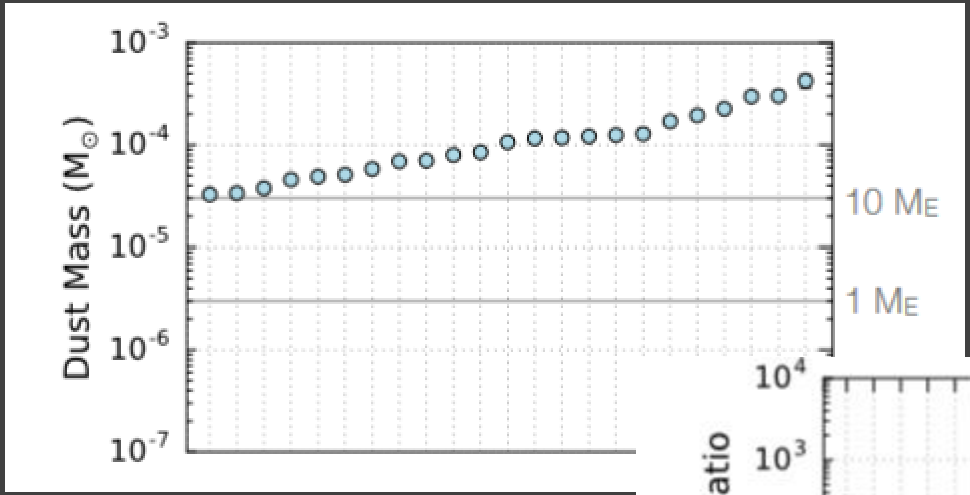
Dust in the disc

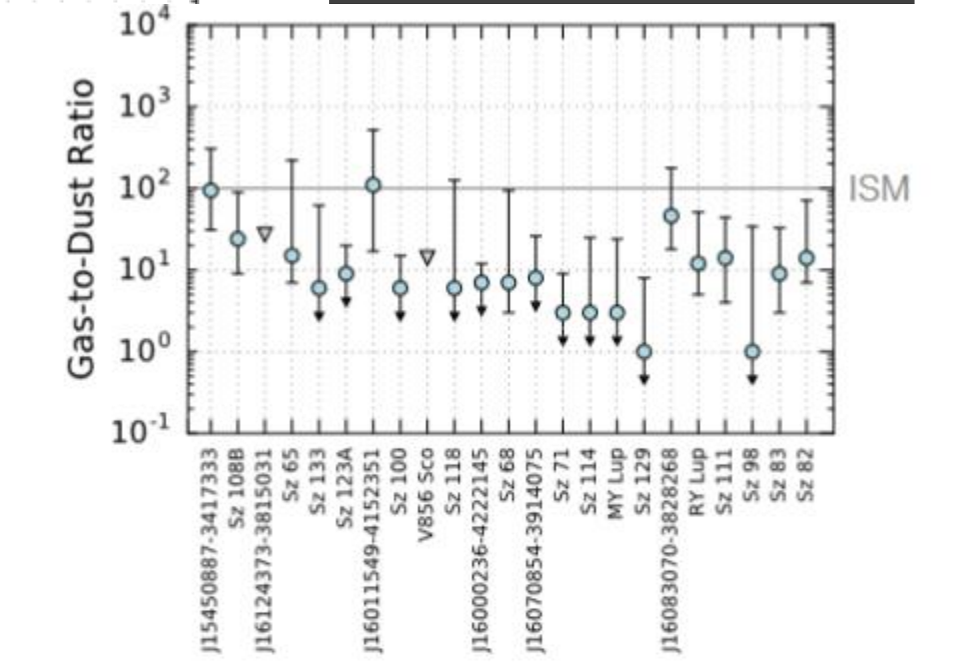
Observations in different wavelengths allow to probe different parts of the disc and determine dust mass and distribution.

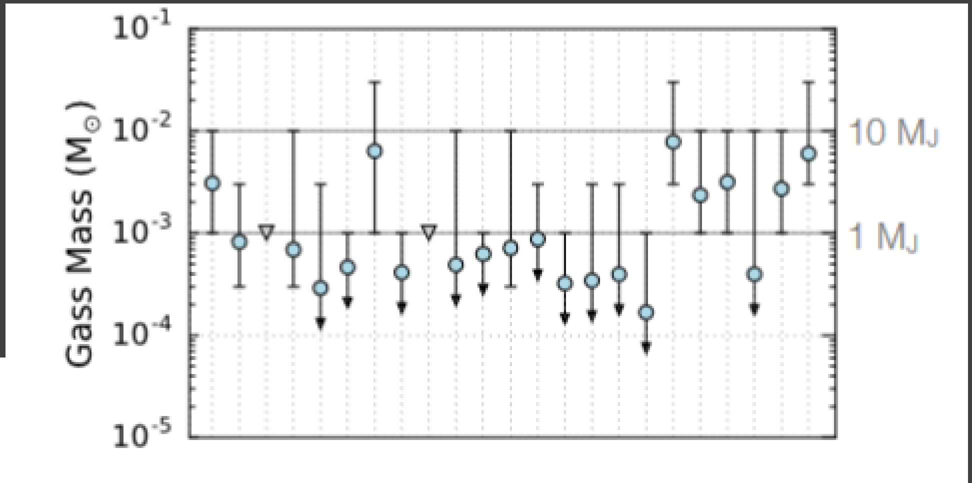


80% of dust

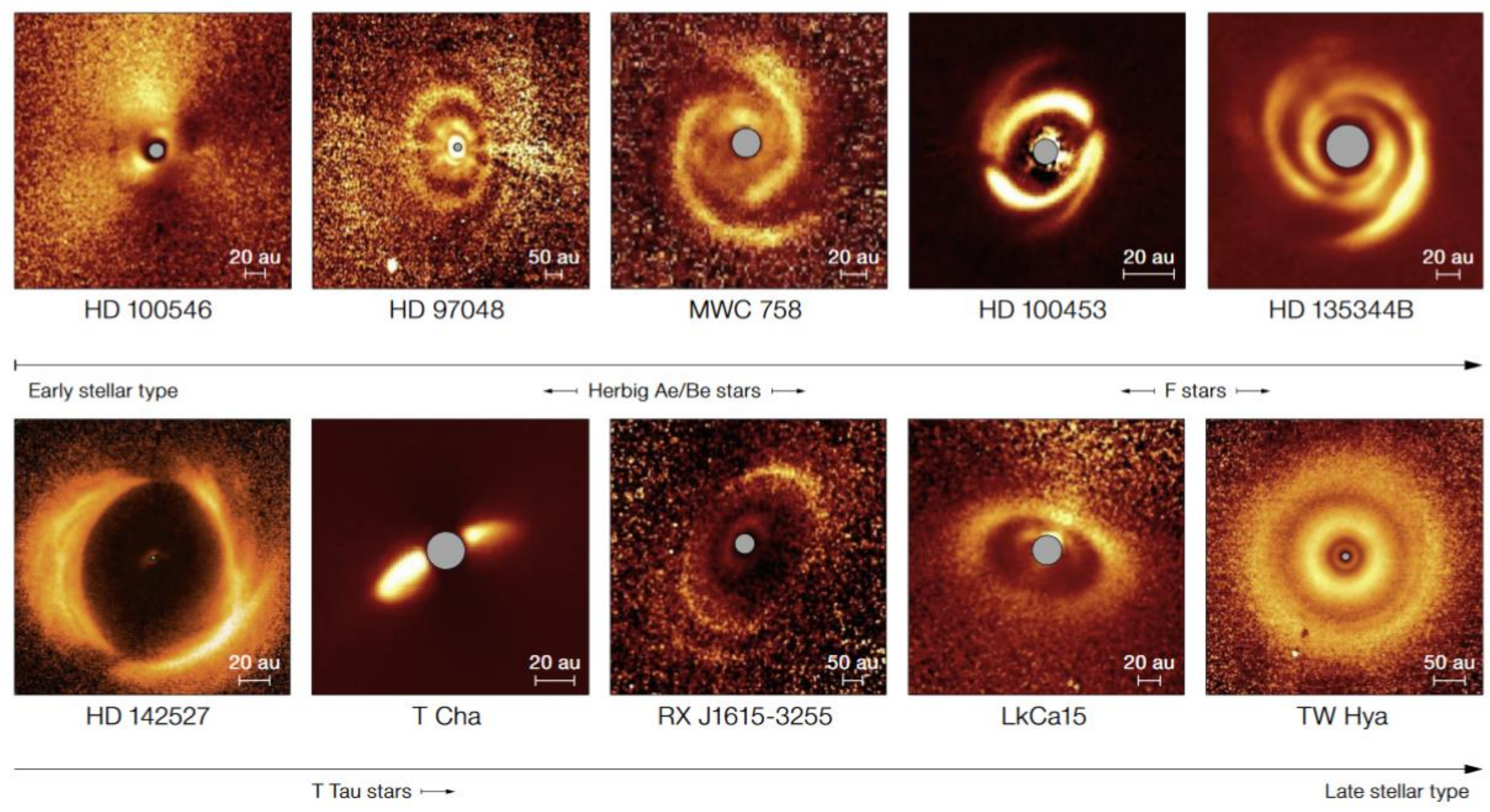
Disc mass: gas + dust







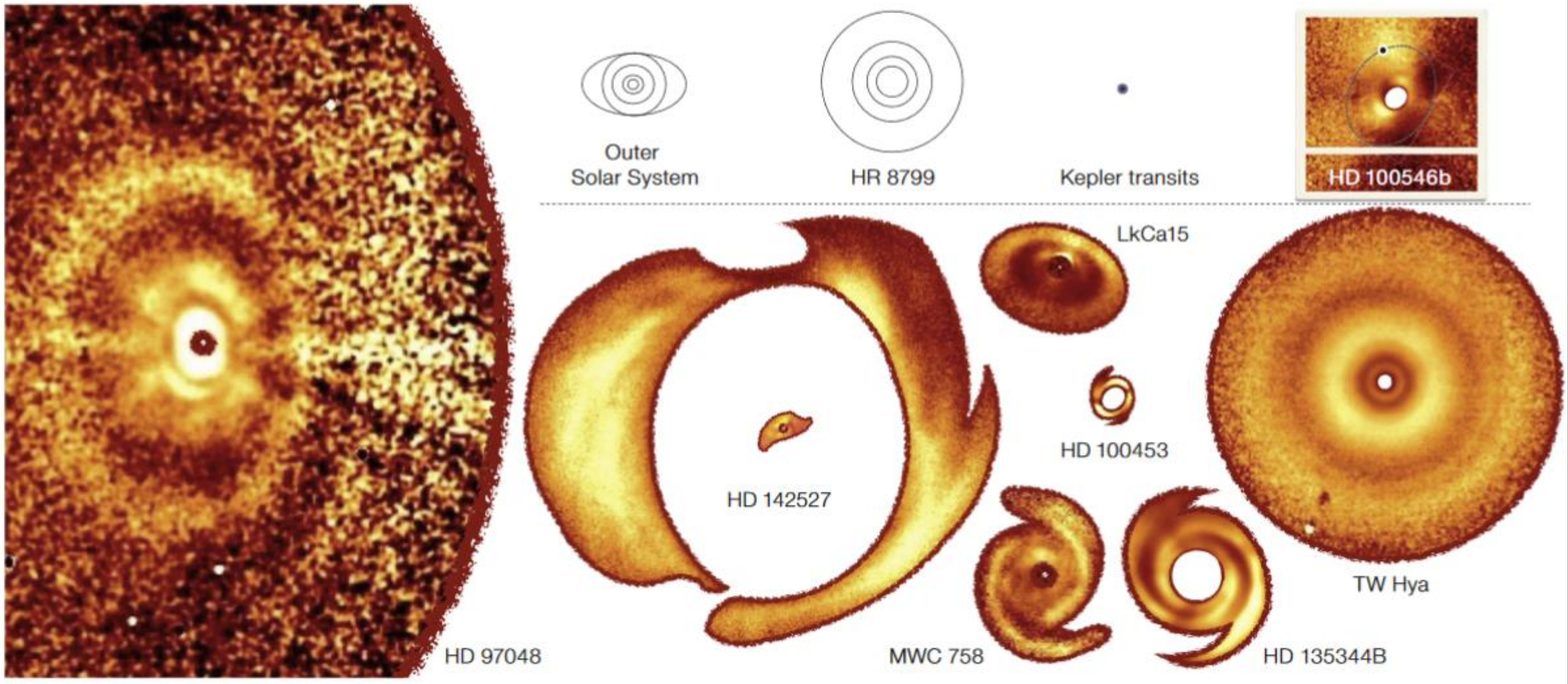
VLT/SPHERE



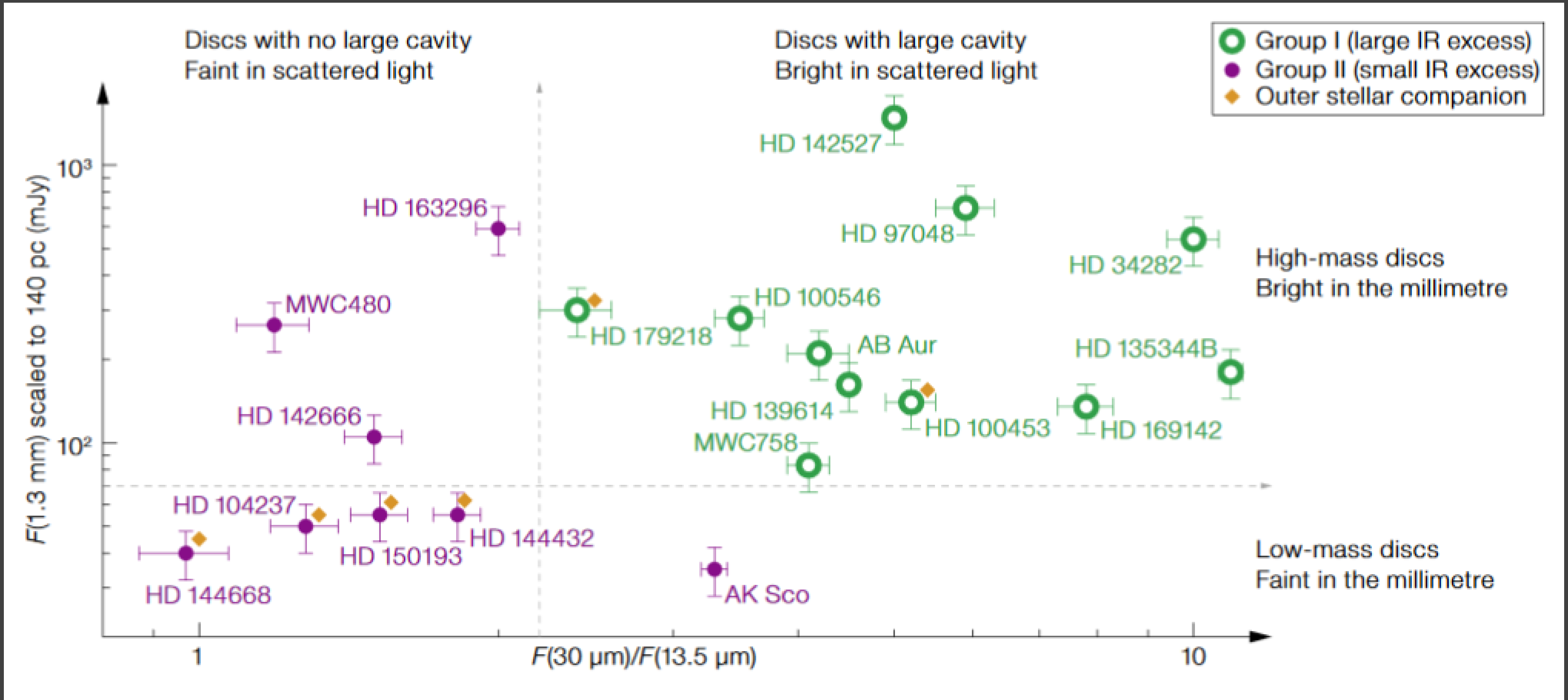
0.5-2.3 micrometers

1710.02795

PDI images are sensitive to micron-sized dust grains at the disc surface

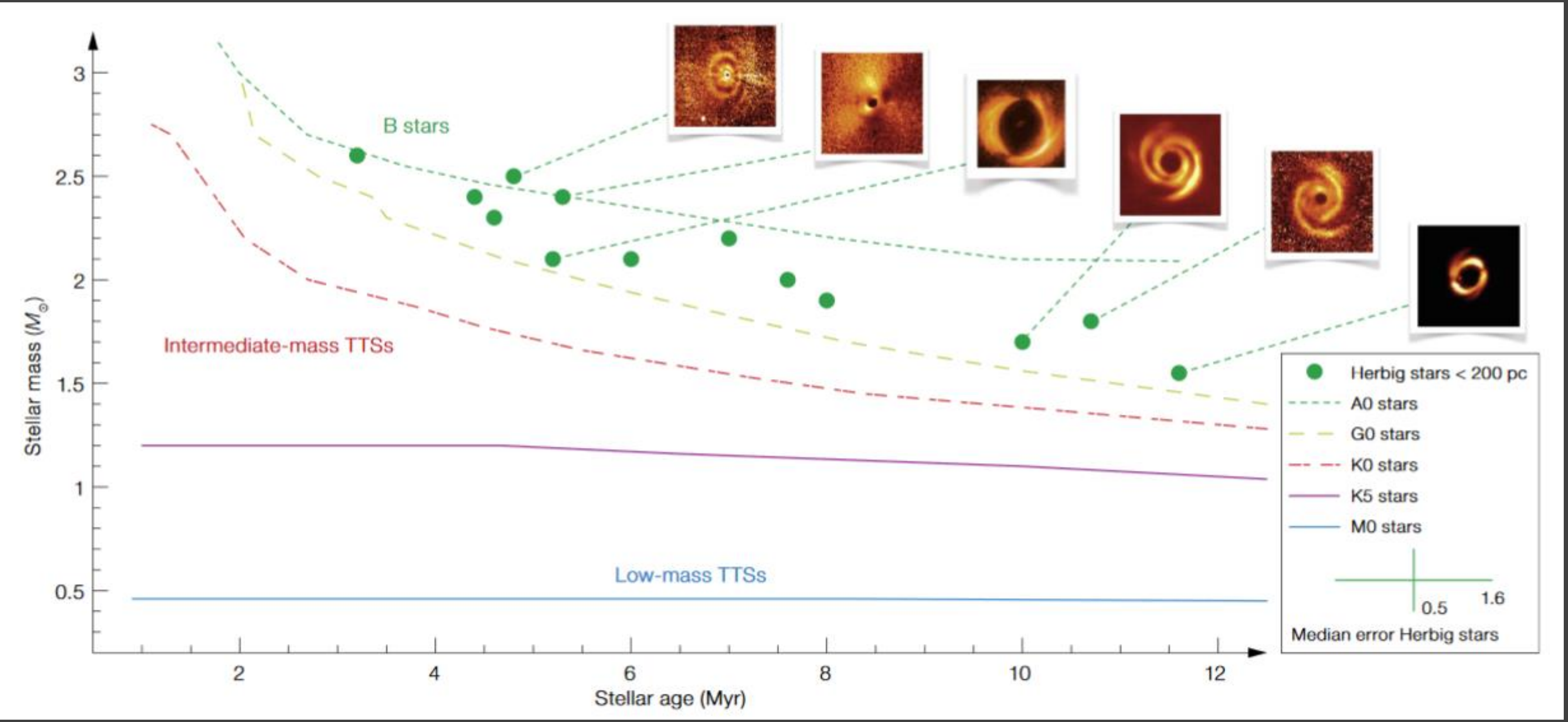

Outer
Solar System
HR 8799
Kepler transits
HD 100546b
LkCa15
HD 142527
HD 100453
TW Hya
HD 97048
MWC 758
HD 135344B

Different discs

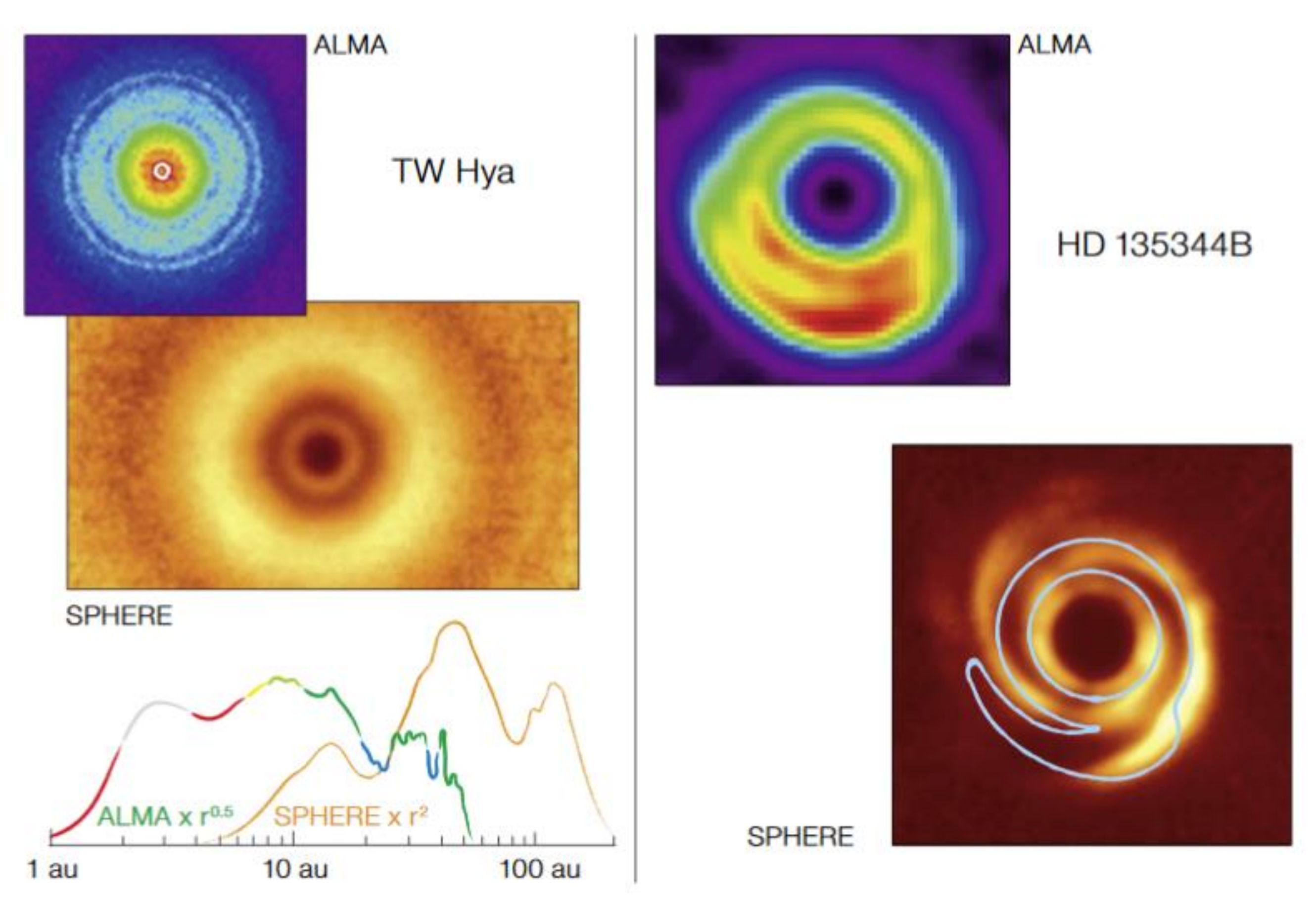


1710.02795

Disc evolution

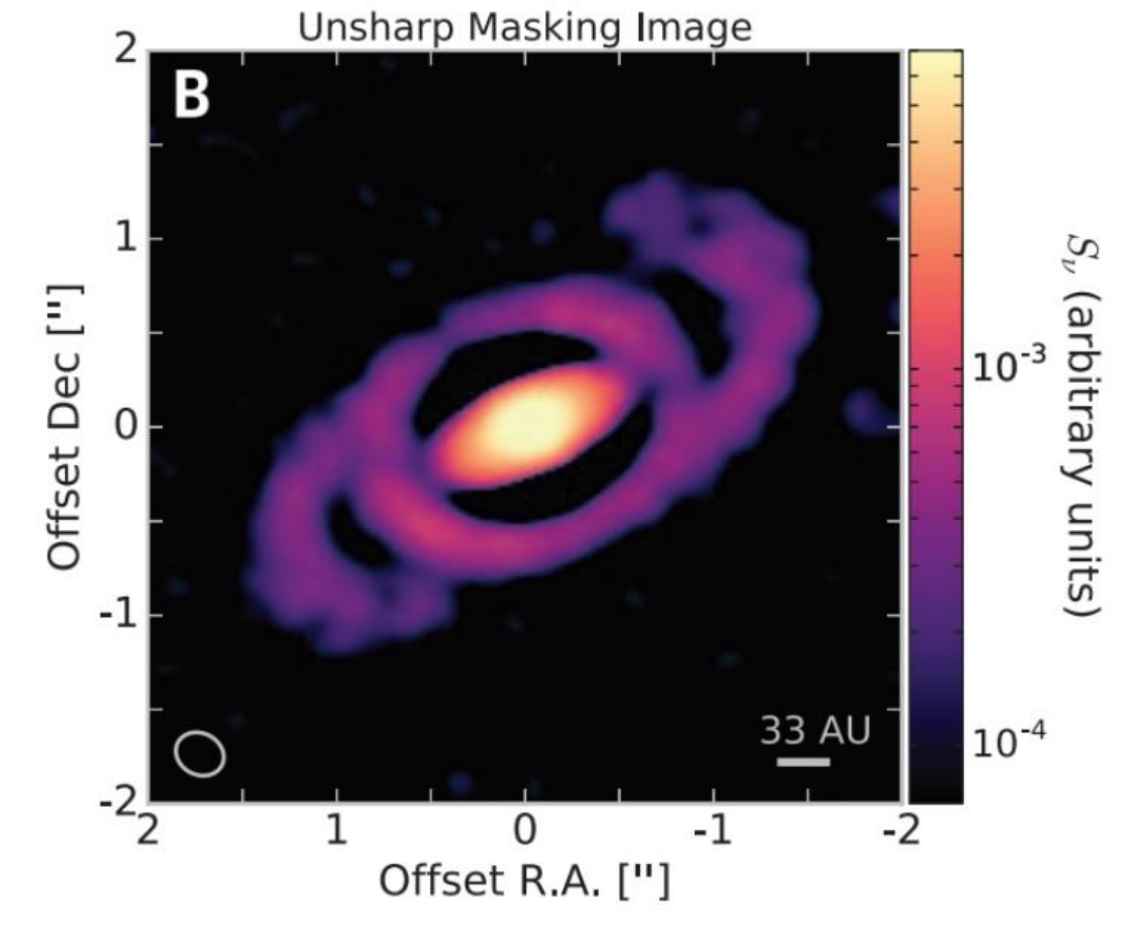


Different wavelengths – different dust



SPHERE – micron grains
ALMA – larger grains

Disc around Elias 2-27



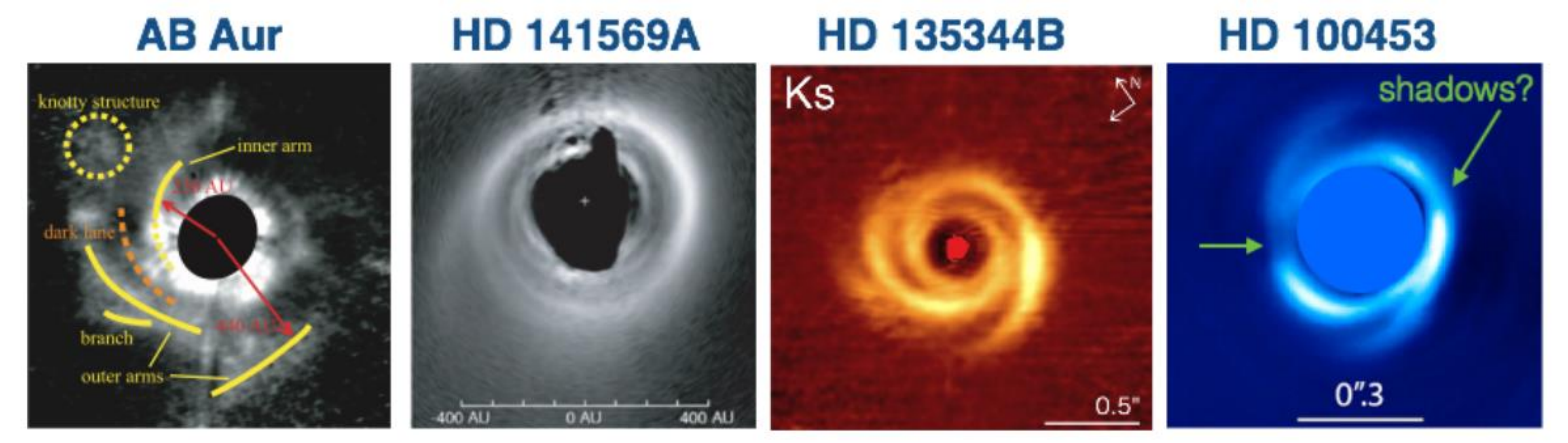
Spiral structure around Elias 2-27
Obtained by ALMA

The star has mass ~0.5 M_{solar},
but a very massive disc (>0.1M_{solar}) around.

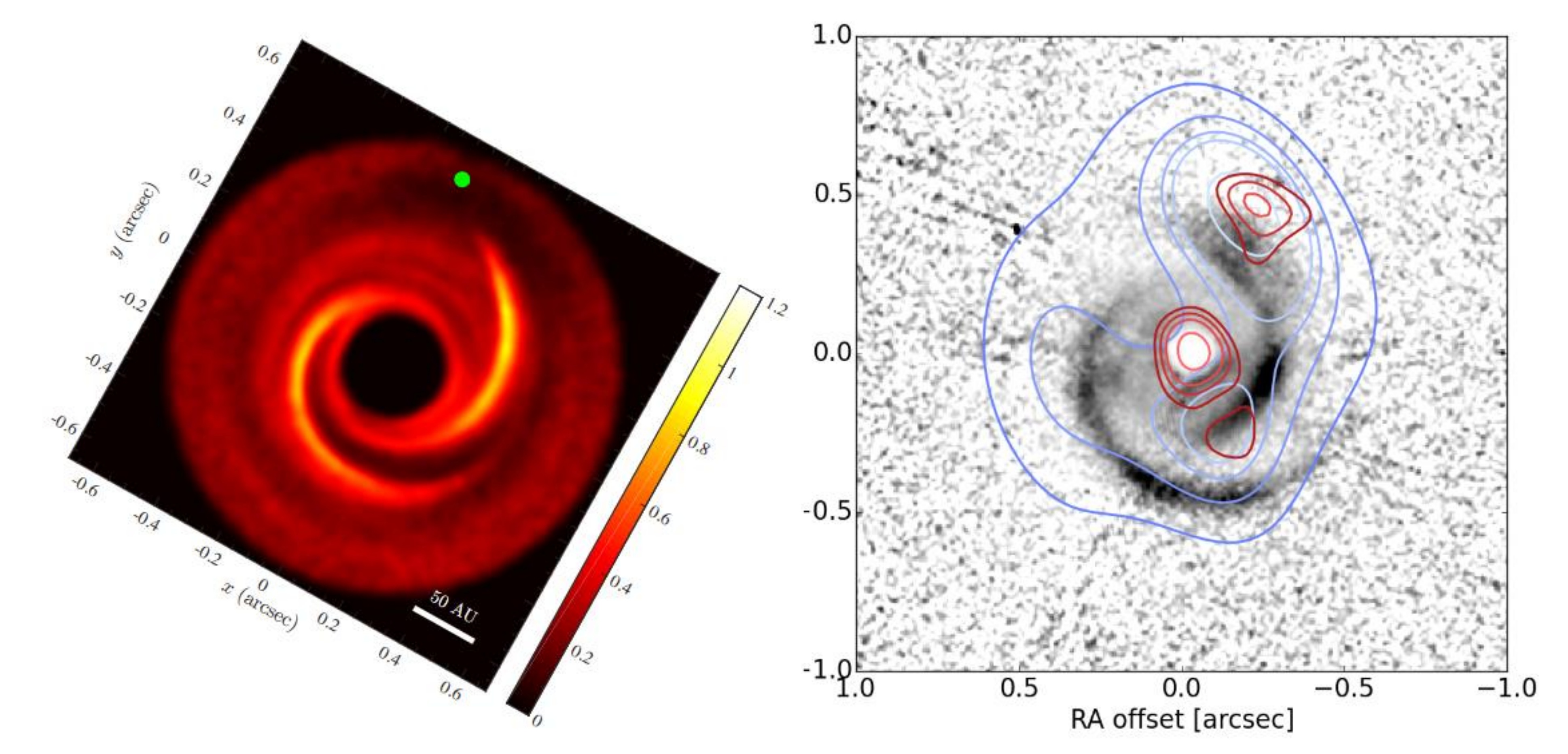
It is important that at distance >10 AU
the disc is transparent for 1.3 mm emission.
So, the spiral patter is related to the matter
also in the disc midplane.

Perez et al. 2016 (1610.05139), taken from the review 1703.08560

Gallery of spirals



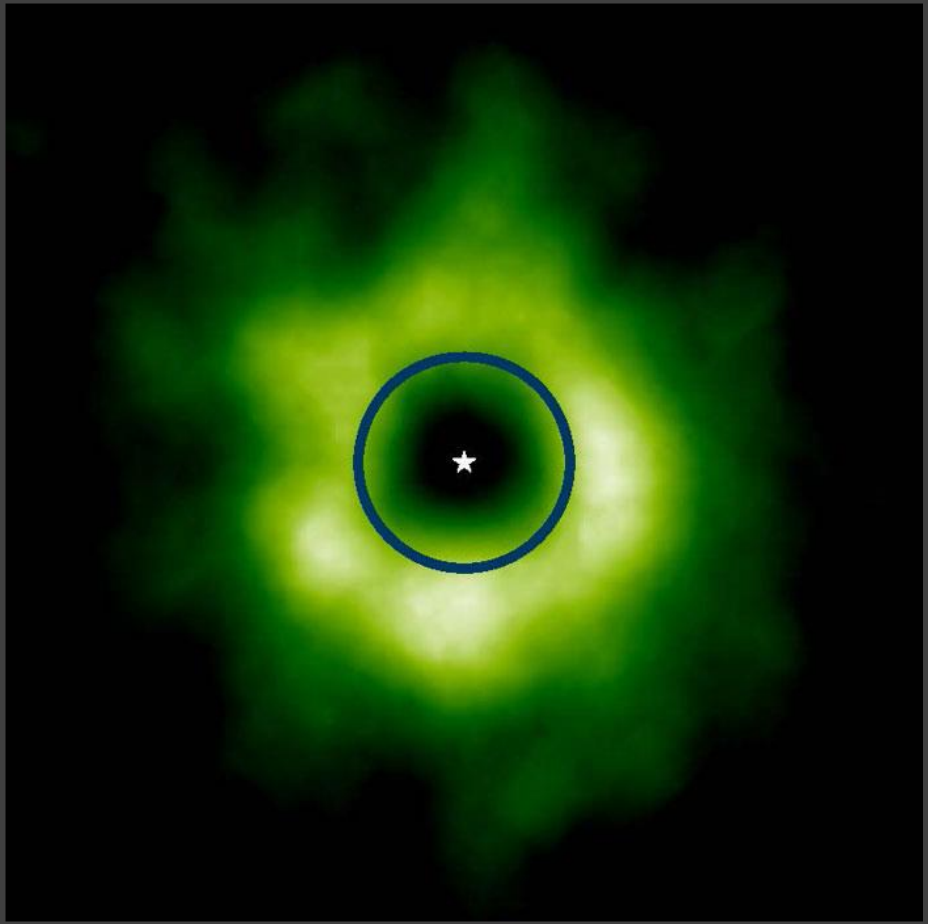
Spirals: model and observations

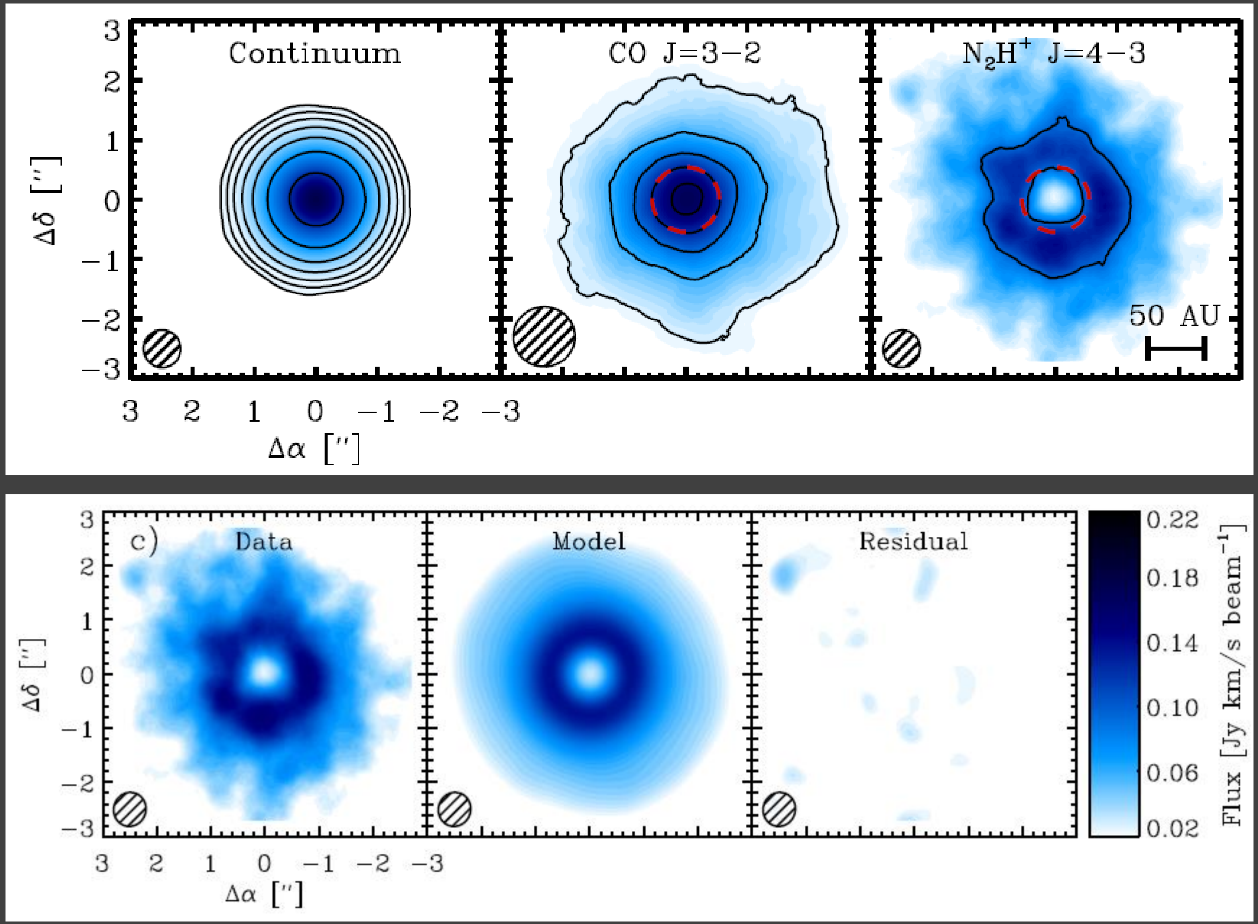


MWC 758
Left: model
Right: VLA+ALMA+SPHERE

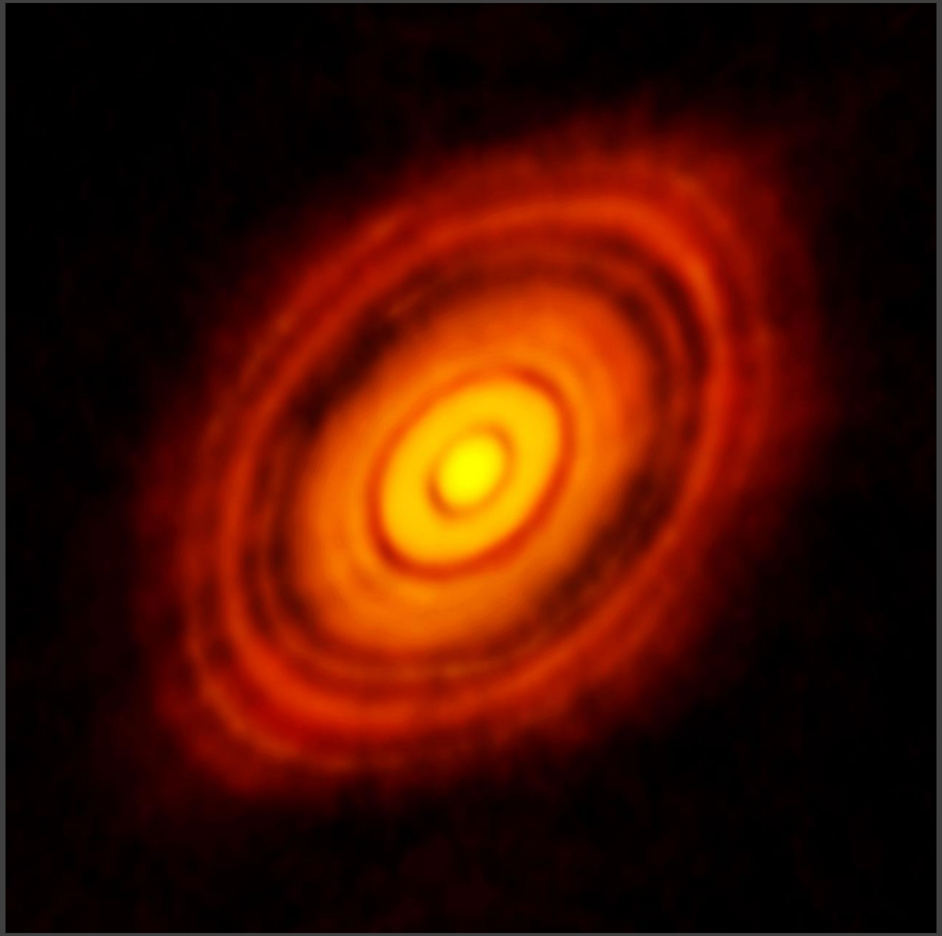
TW Hydra

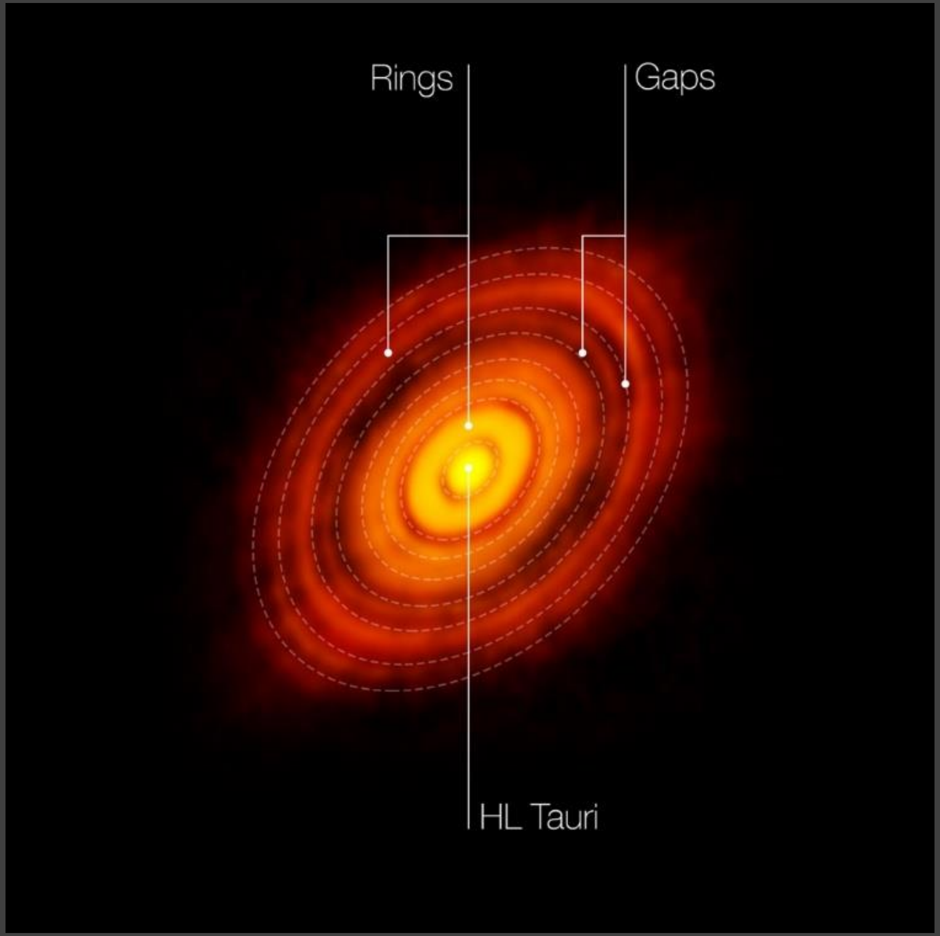
N_2H^+ visible only if CO is frozen out





Protoplanetary disc of HL Tau



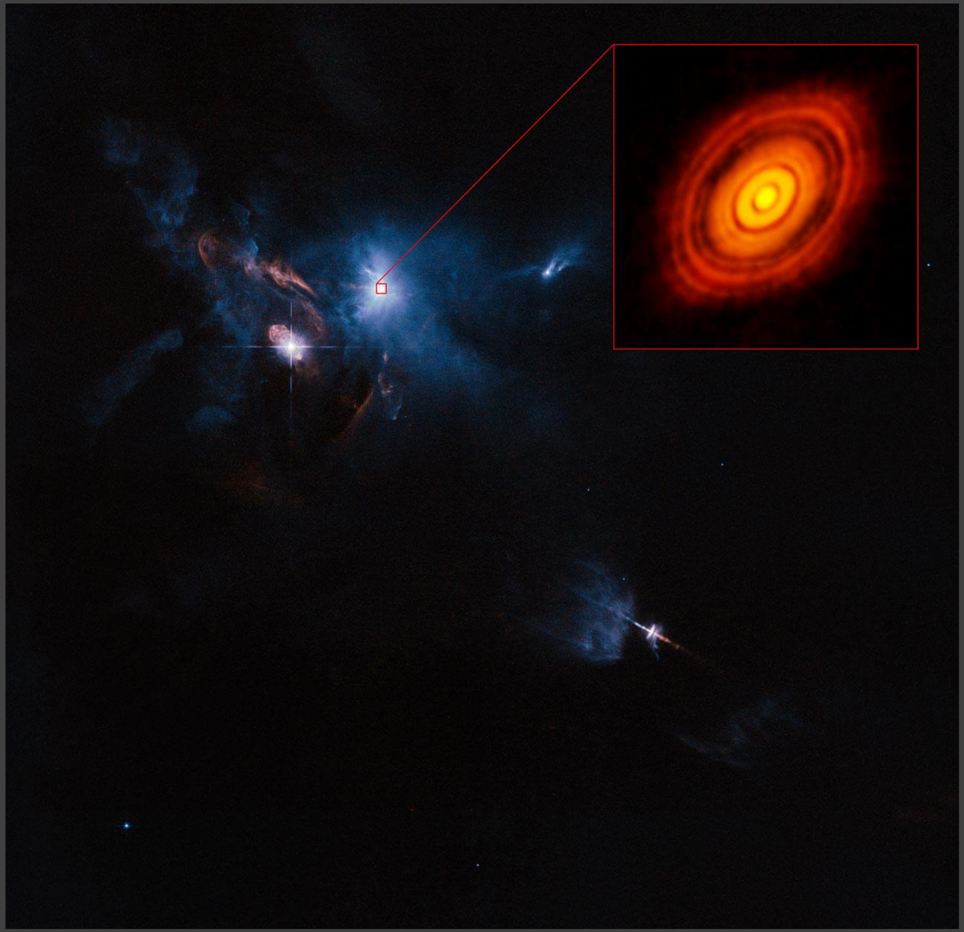


140 pc
Massive disc
Jet
Age <1-2 Myrs

http://www.eso.org/public/images/eso1436a/

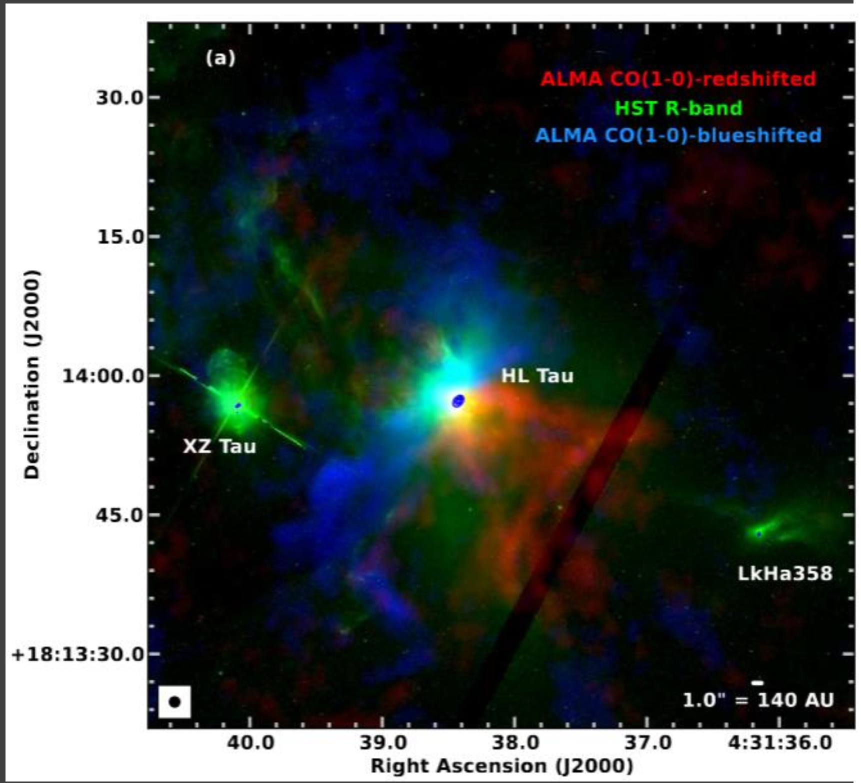
Where stars are born

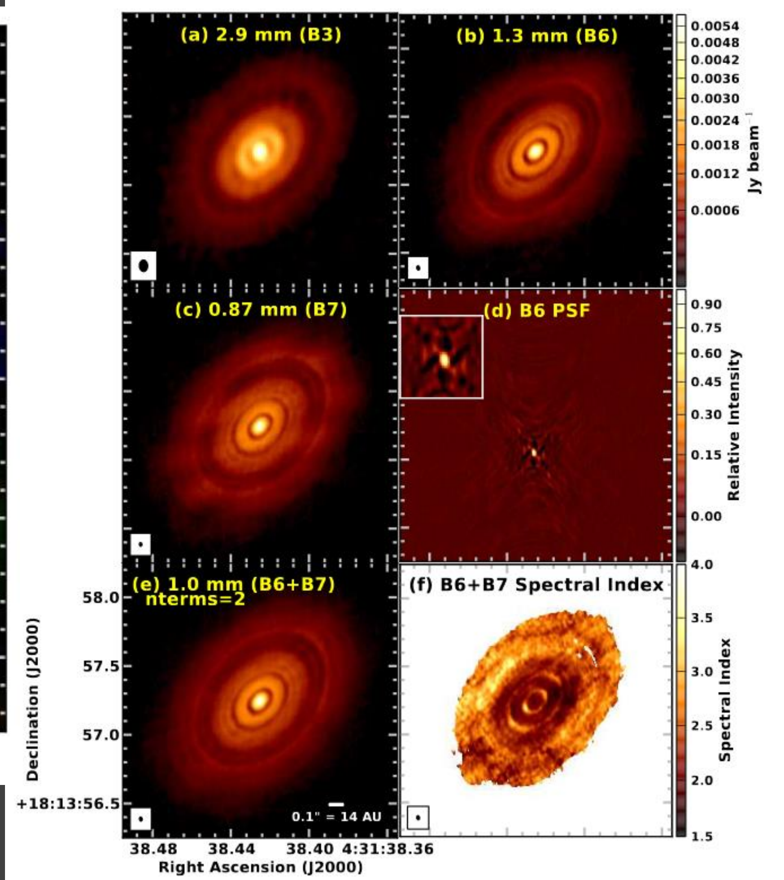
http://www.eso.org/public/images/eso1436b/



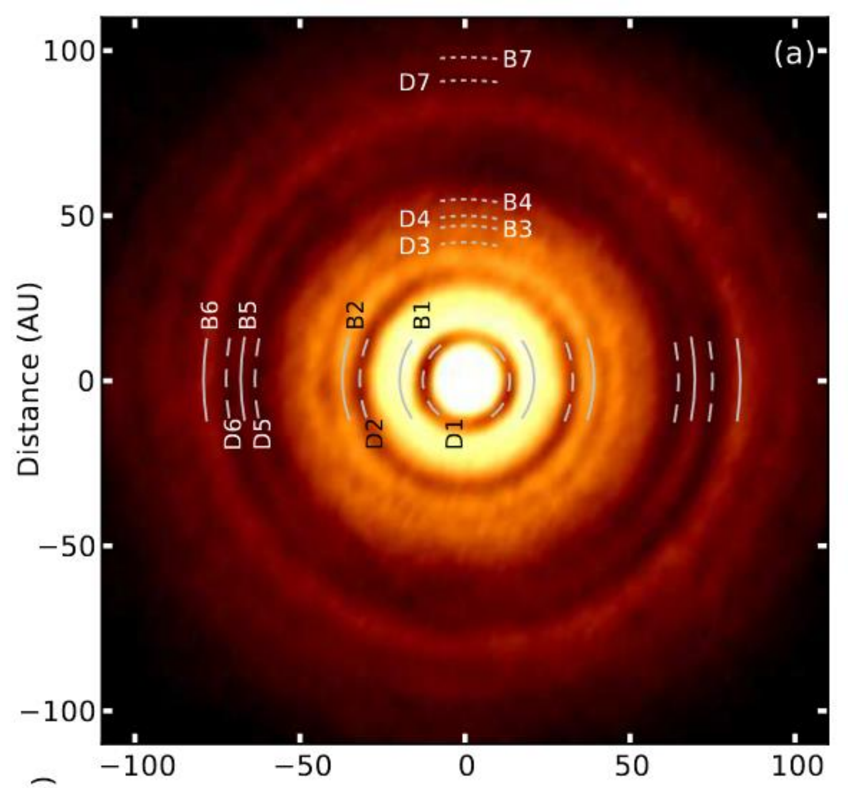
https://public.nrao.edu/AlmaExtras/

More details on the disc of HL Tau

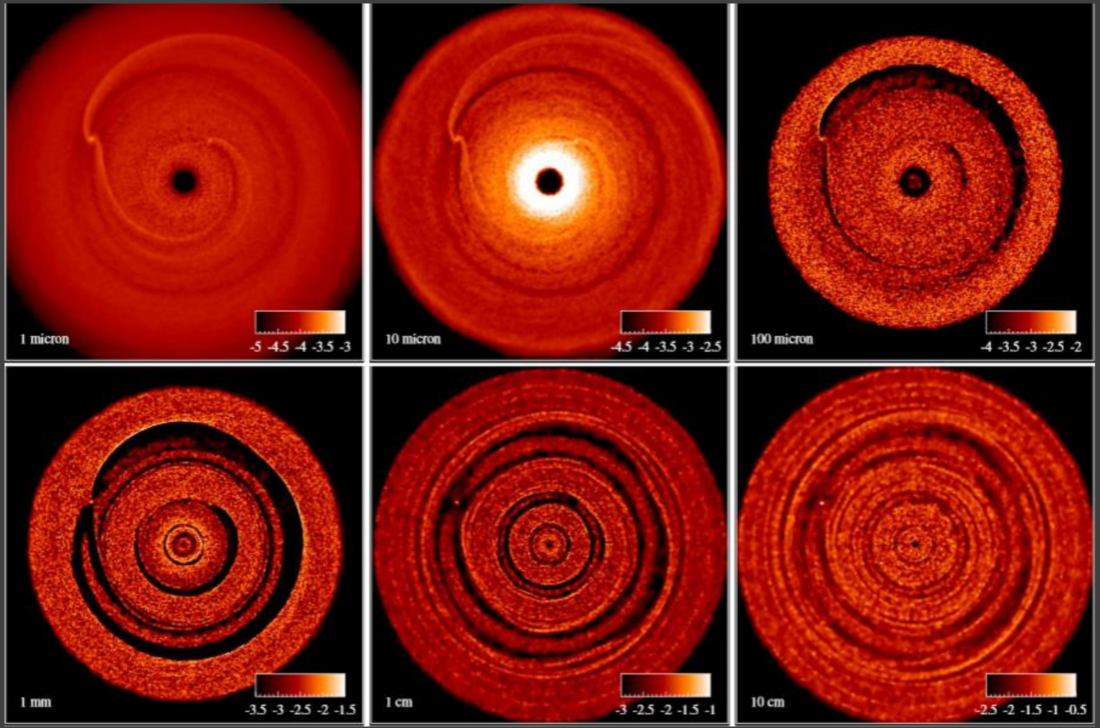




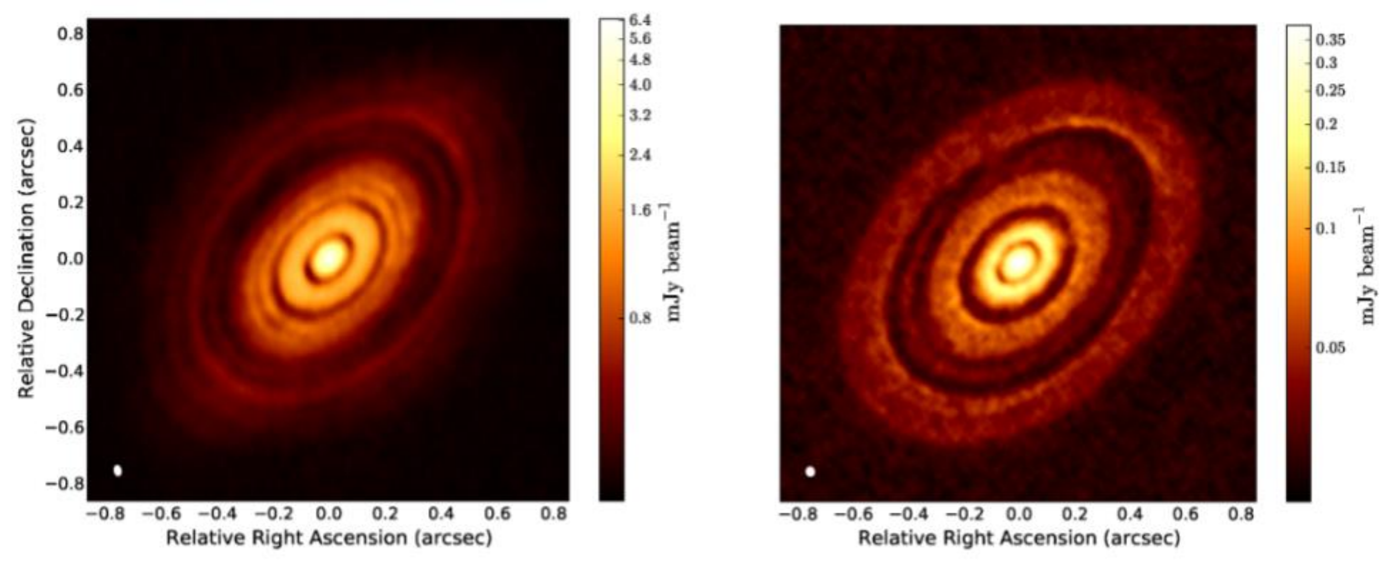
Some rings are in resonance with each other.



Modeling of the HL Tau disc



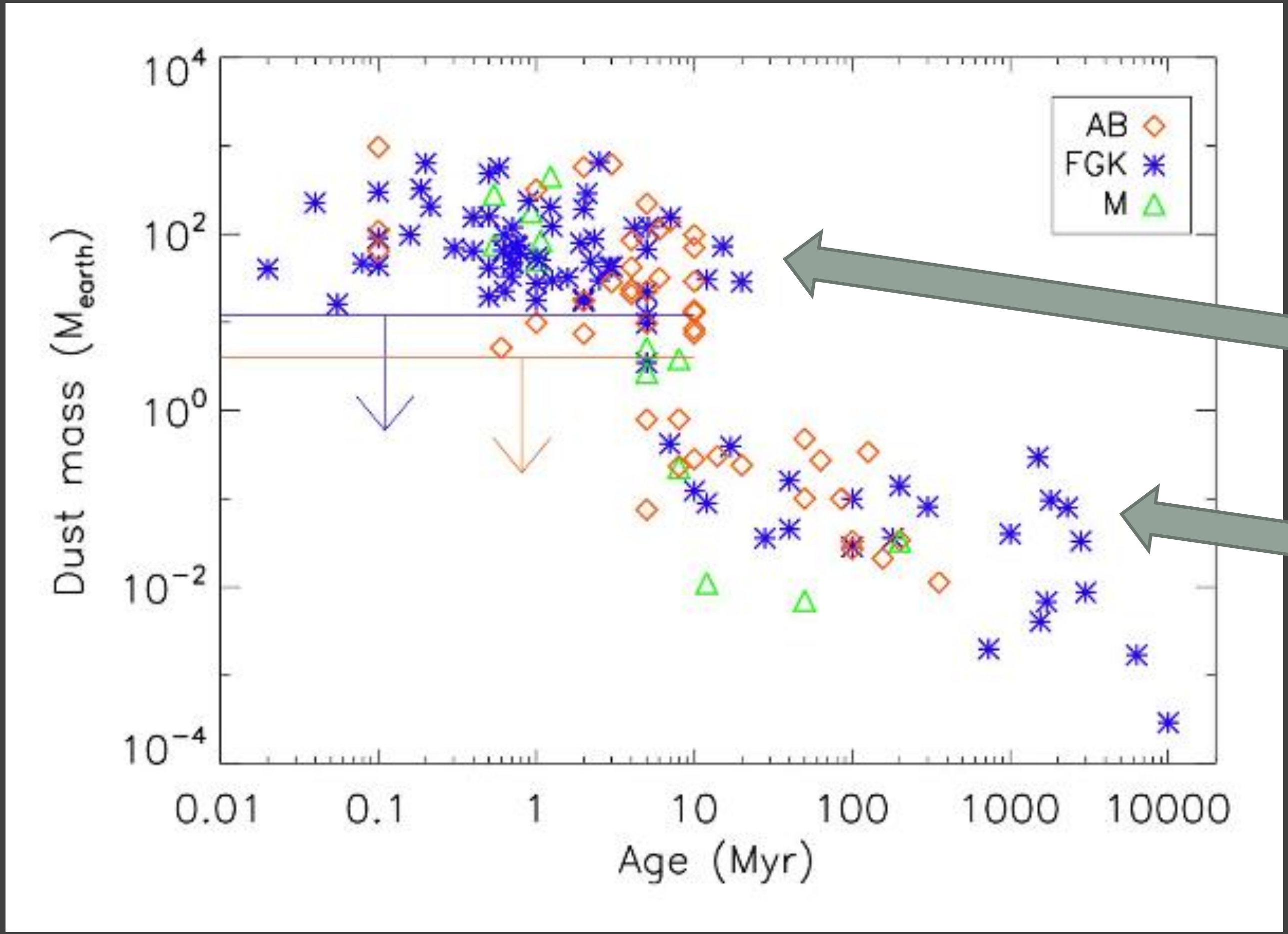
Three planets with masses from 0.2 up to 0.55 Jupiter mass



Observations

Modeling

Evolution of the dust mass in discs

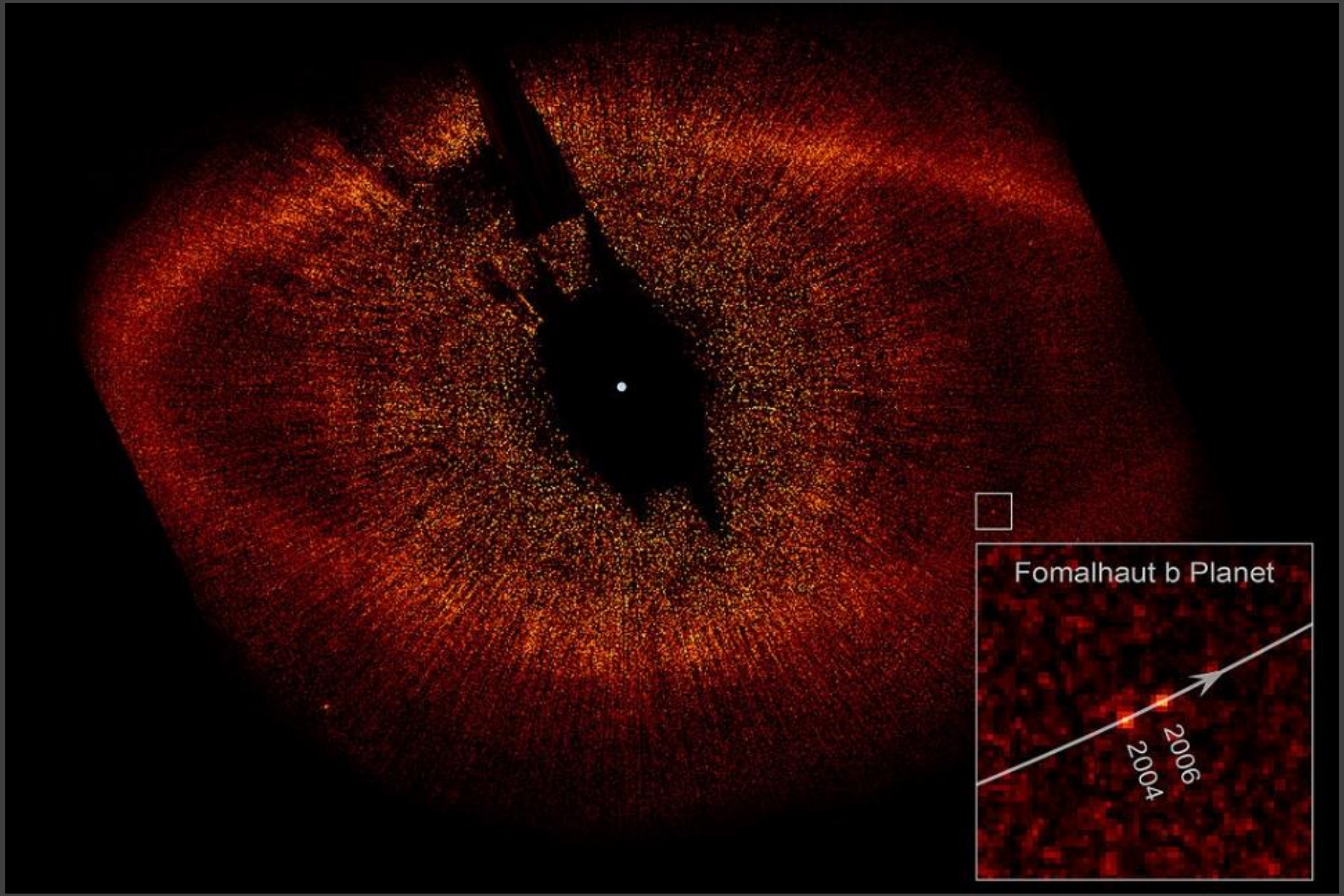


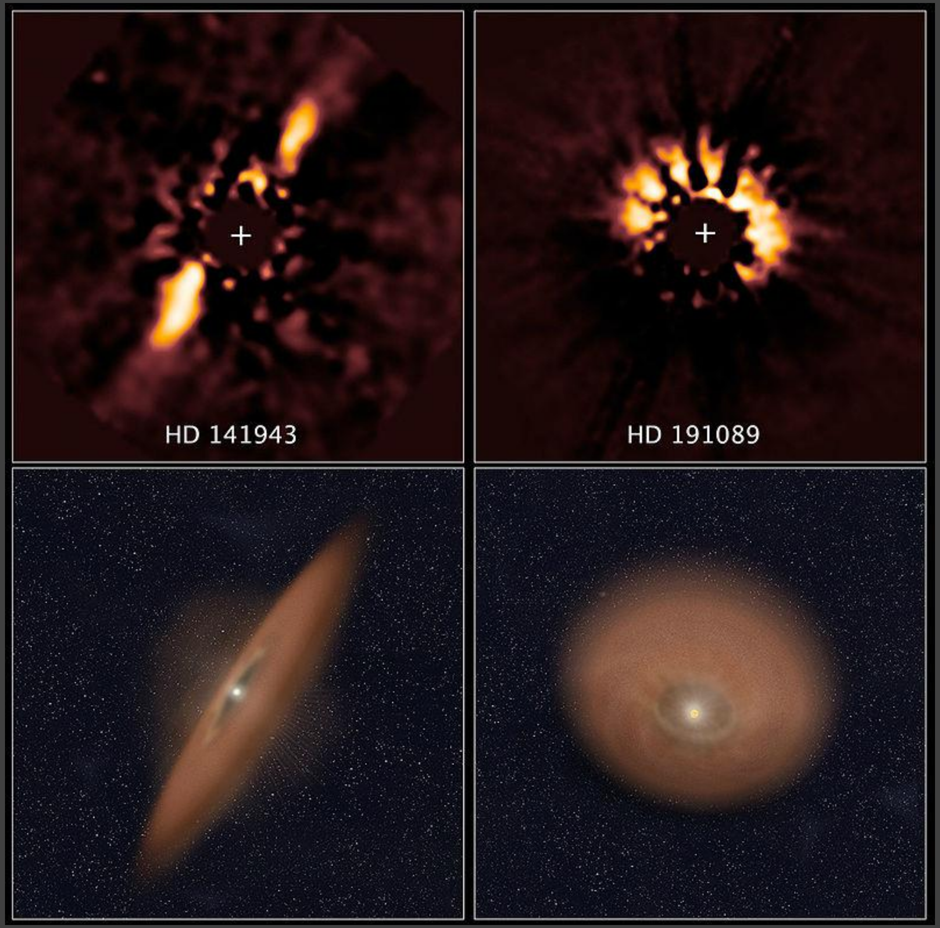
Protoplanetary discs

Debris discs

Panic et al. 2013, taken from the review 1703.08560

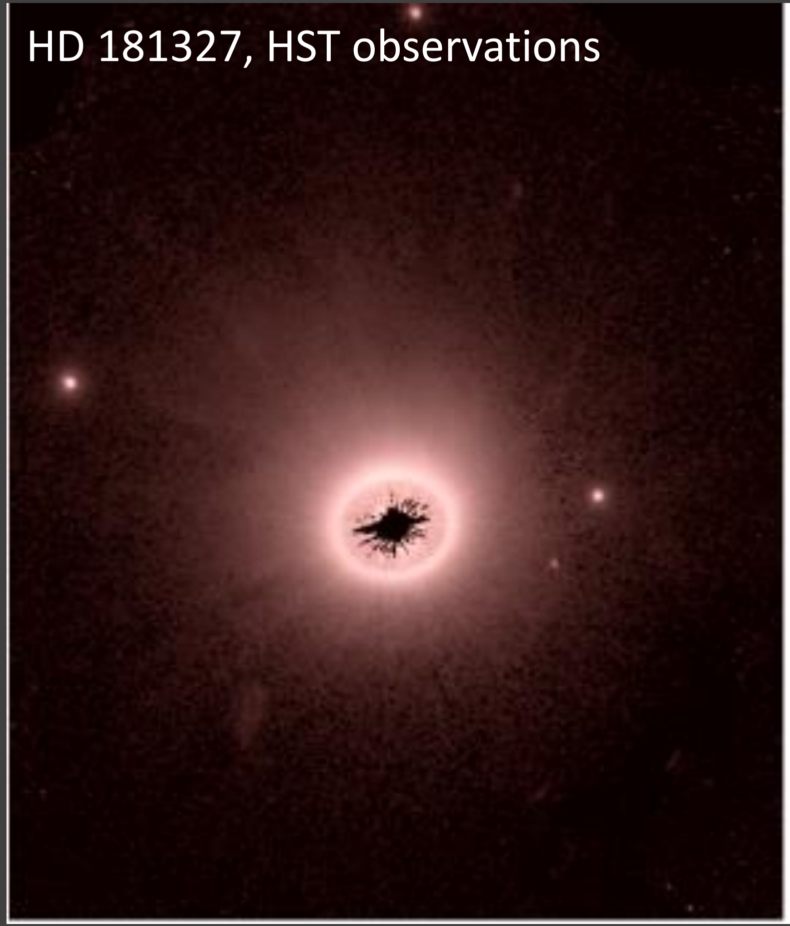
Debris discs

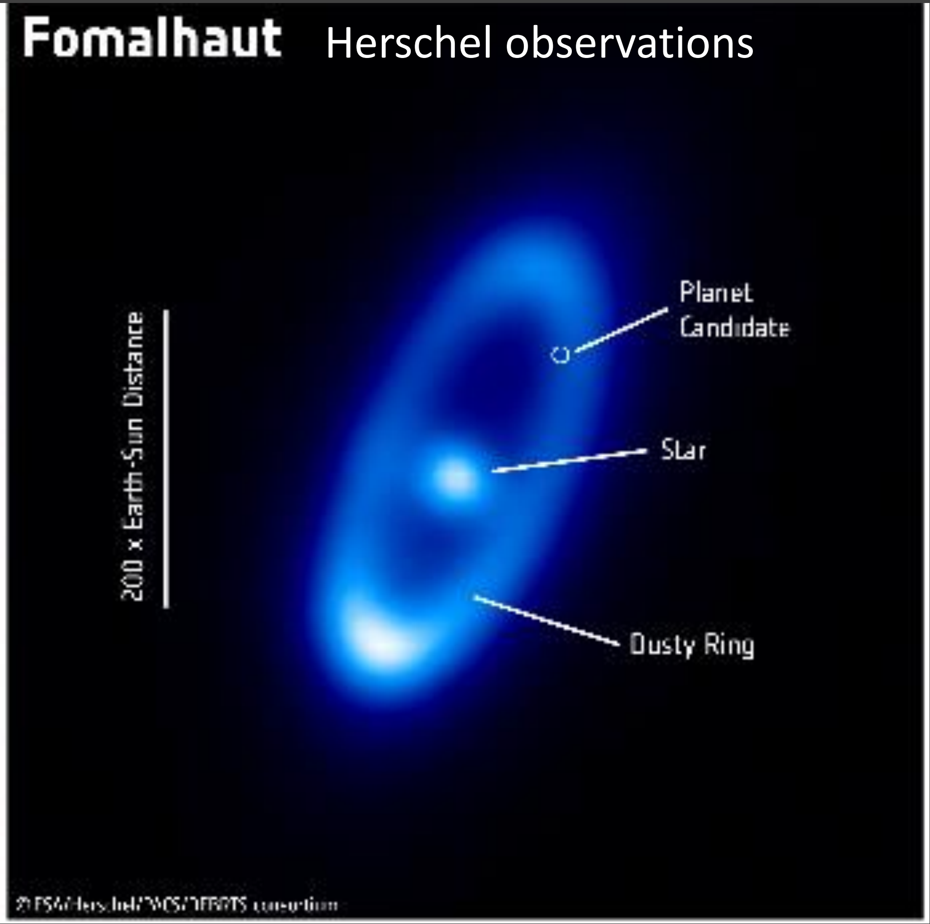




See a review in 1802.04313, 1804.08636

Two debris disc examples



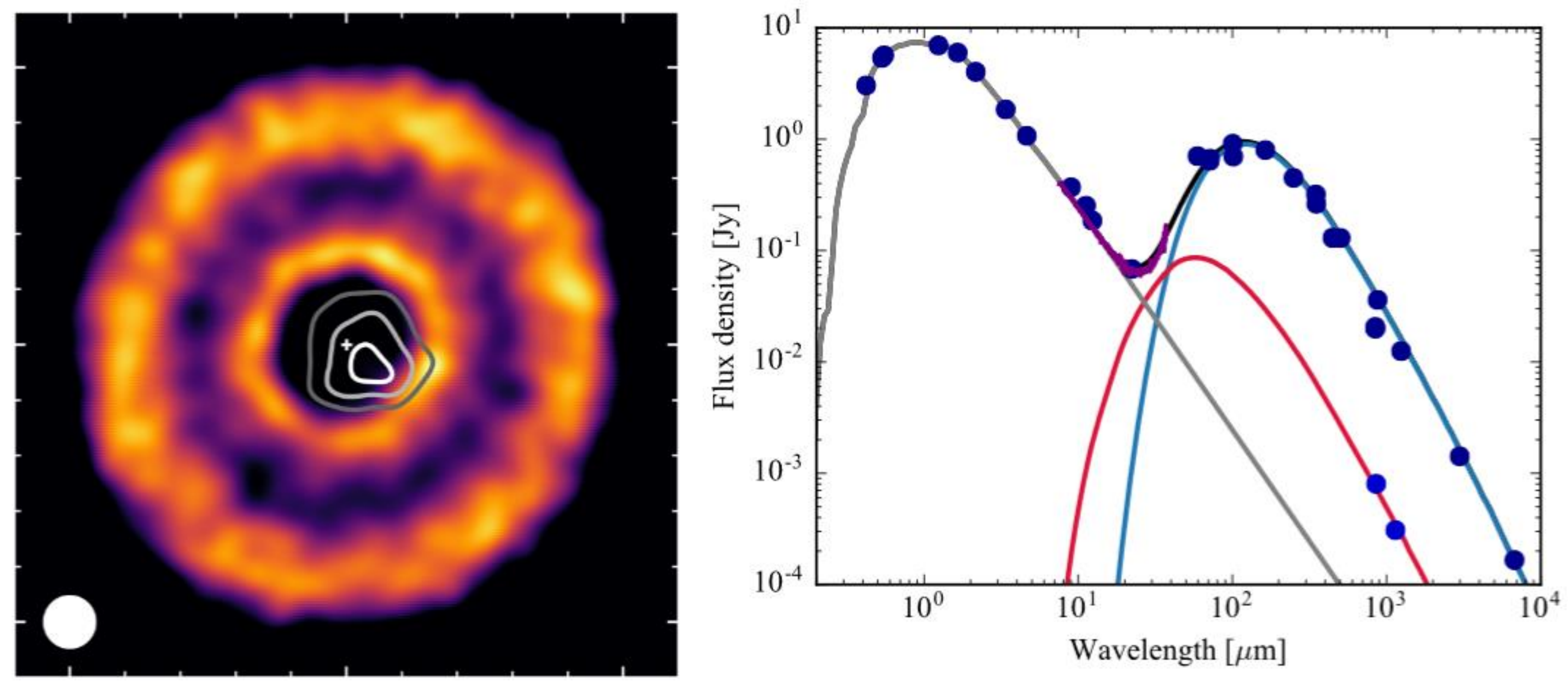


Hundreds of debris discs are known.

taken from the review 1703.08560

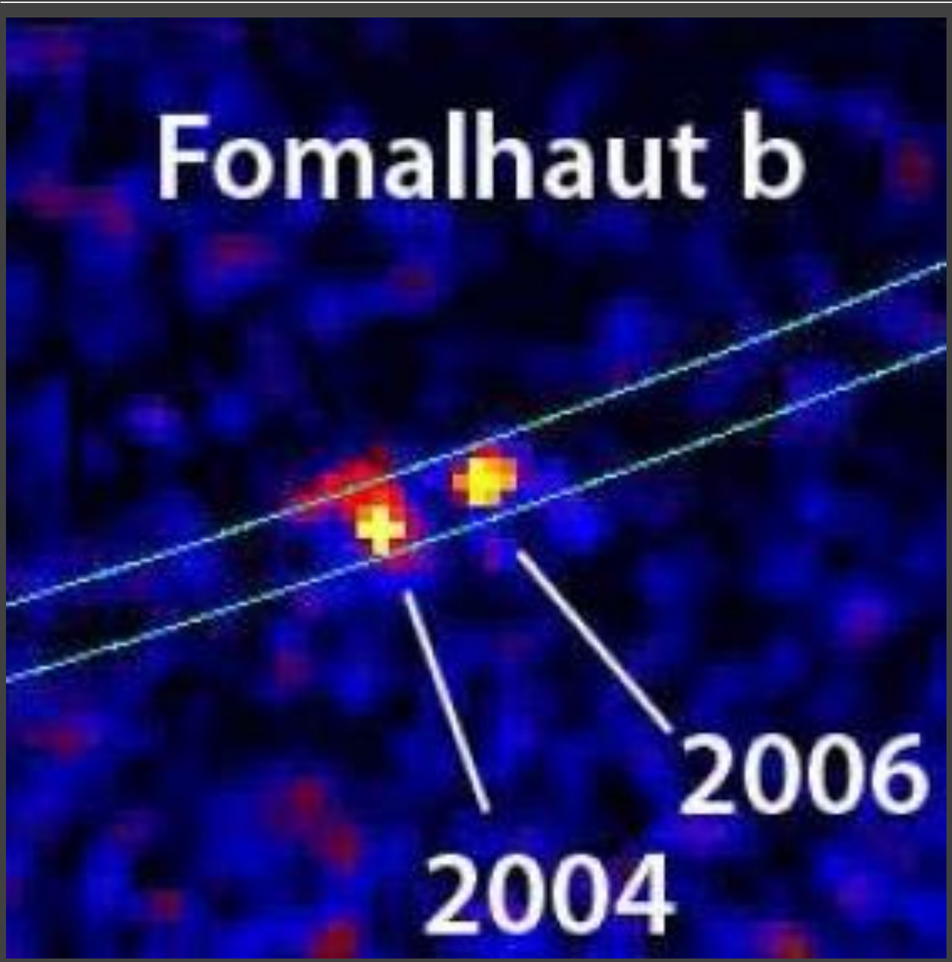
HD107146. ALMA observations

1804.08636



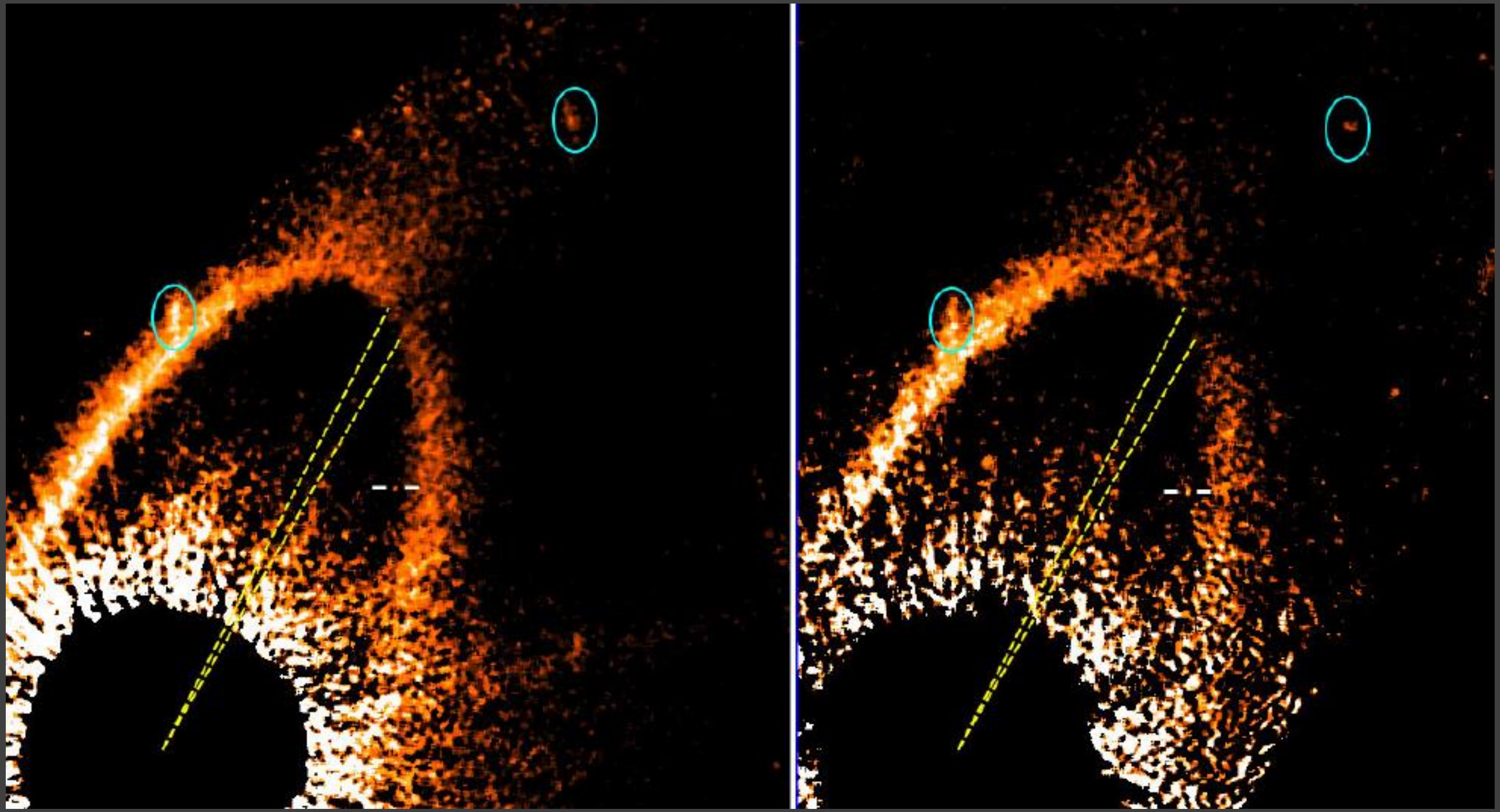
Debris disks are the dust disks found around ~20% of nearby main sequence stars in far-IR surveys.

Fomalhaut b



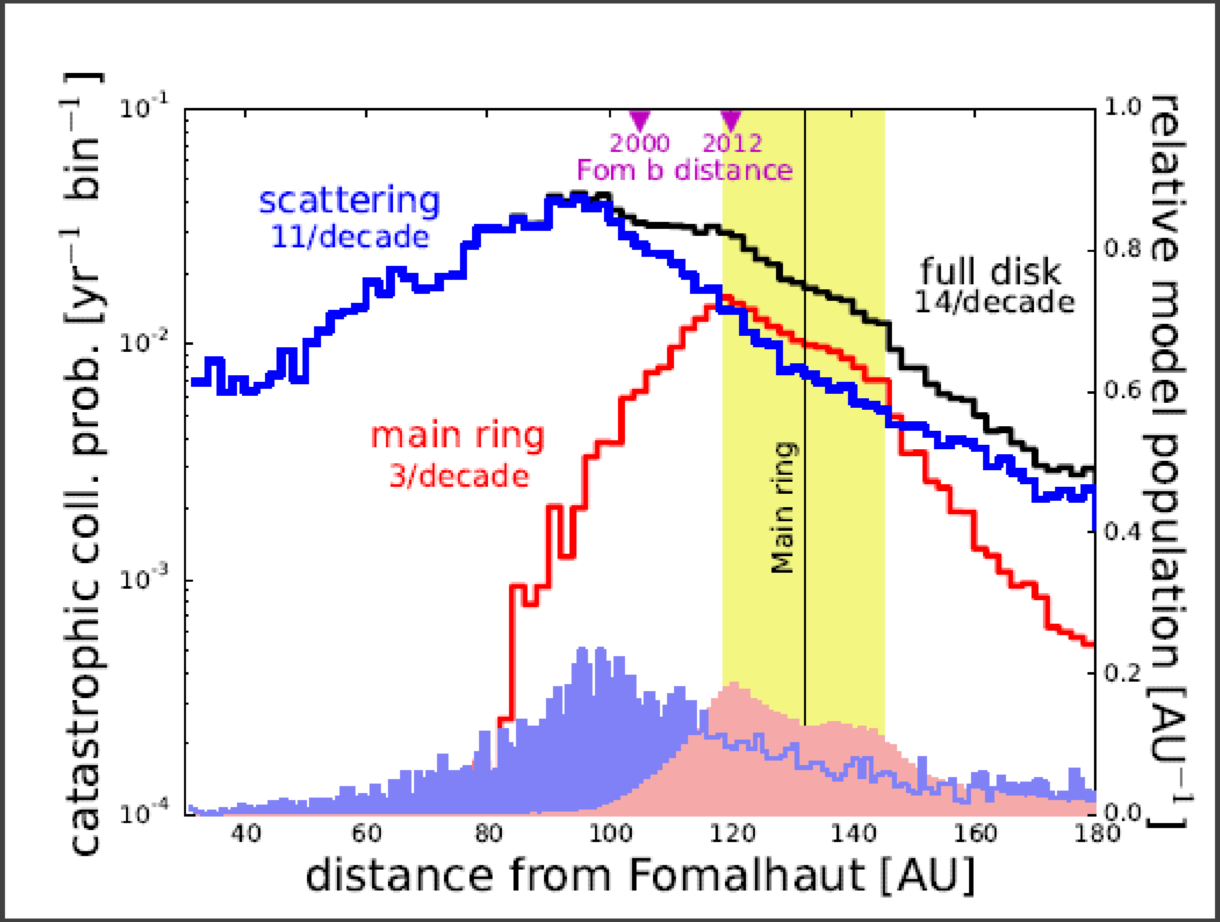
115 AU from the star

Is Fomalhaut b a real planet?



A planet or not a planet?
This is the question!

Result of a recent collision?

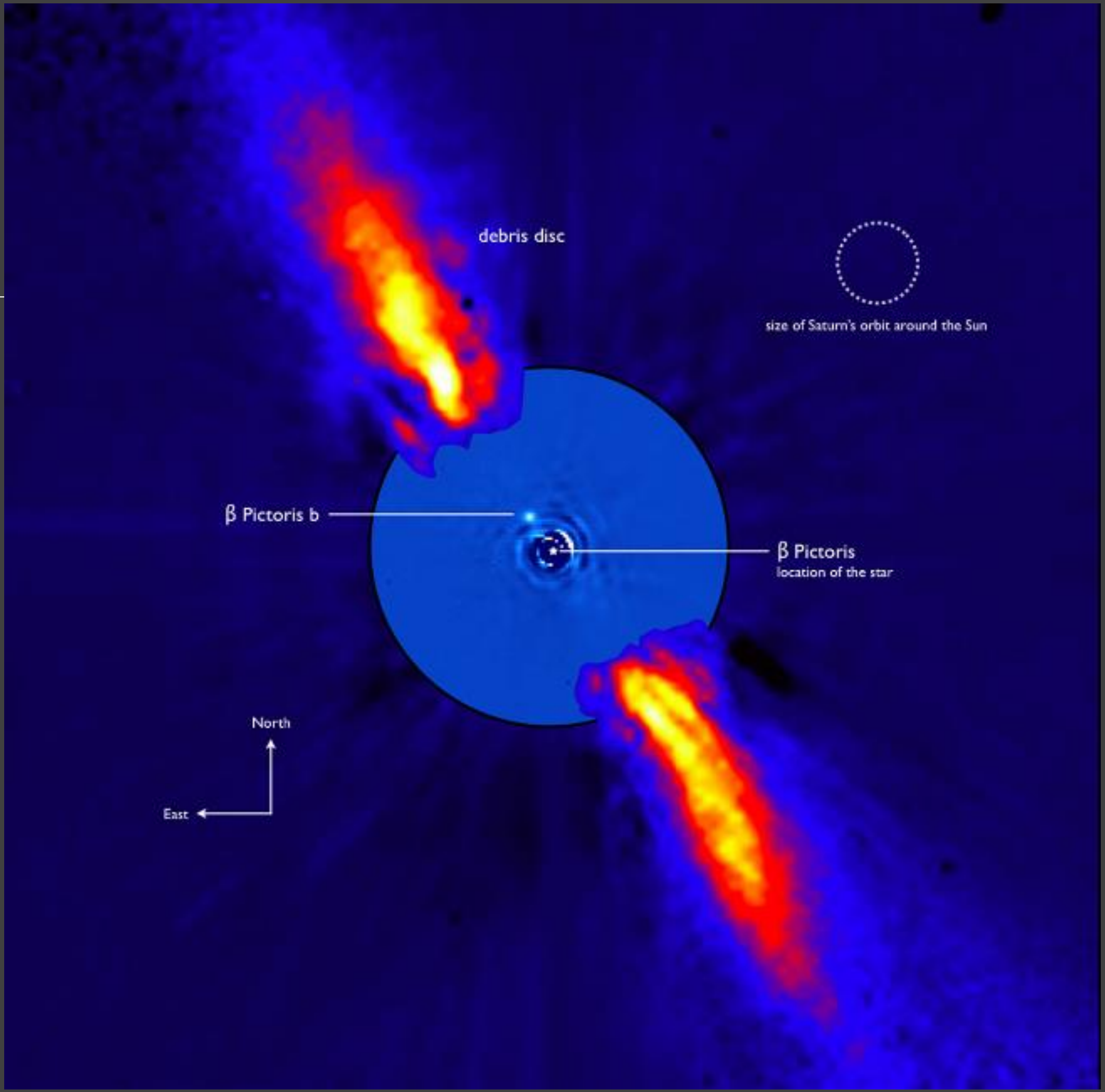


The object is situated in the region where collisions are very probable.

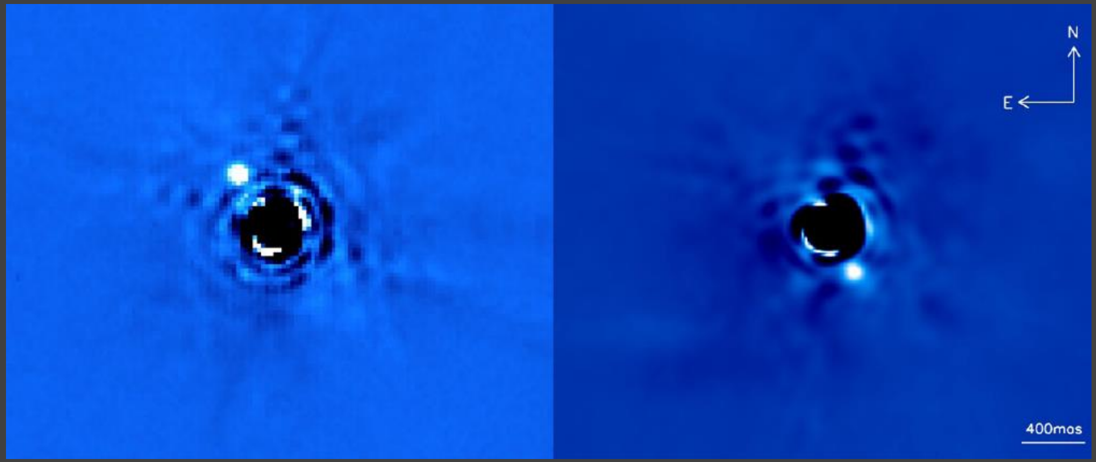
Two bodies with ~100 km size might be enough.

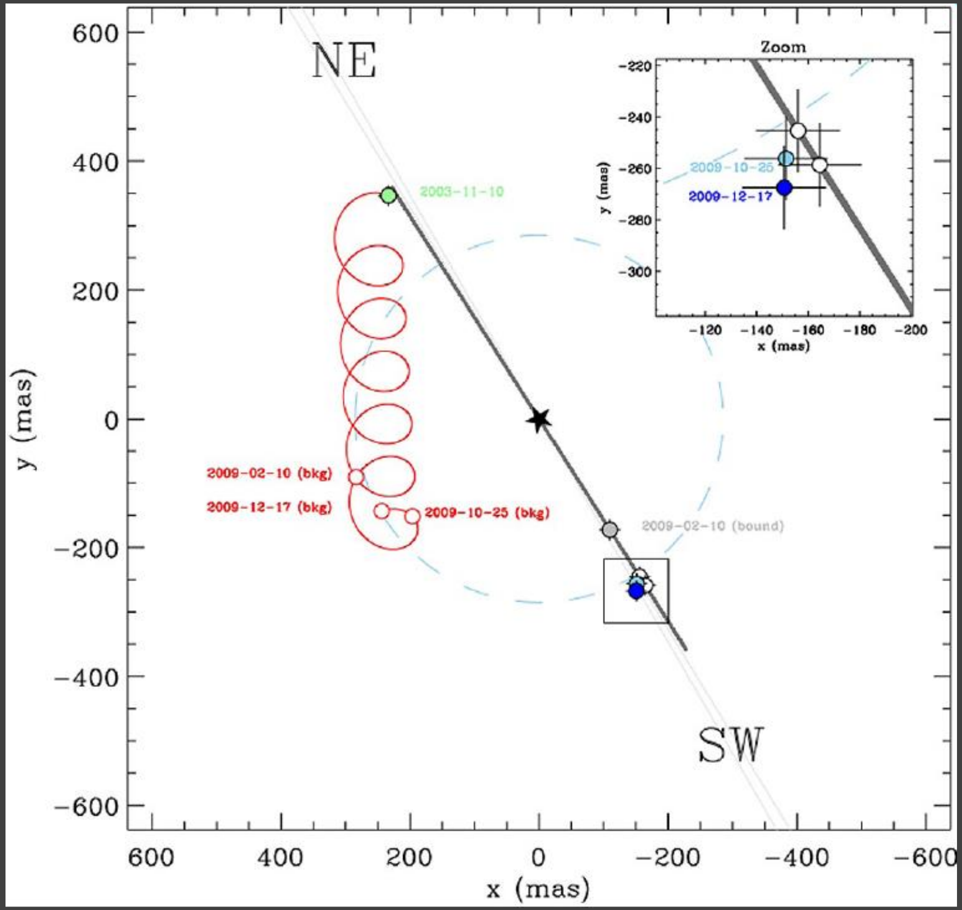
Beta Pictoris

Composite image obtained
by two instruments



Beta Pictoris





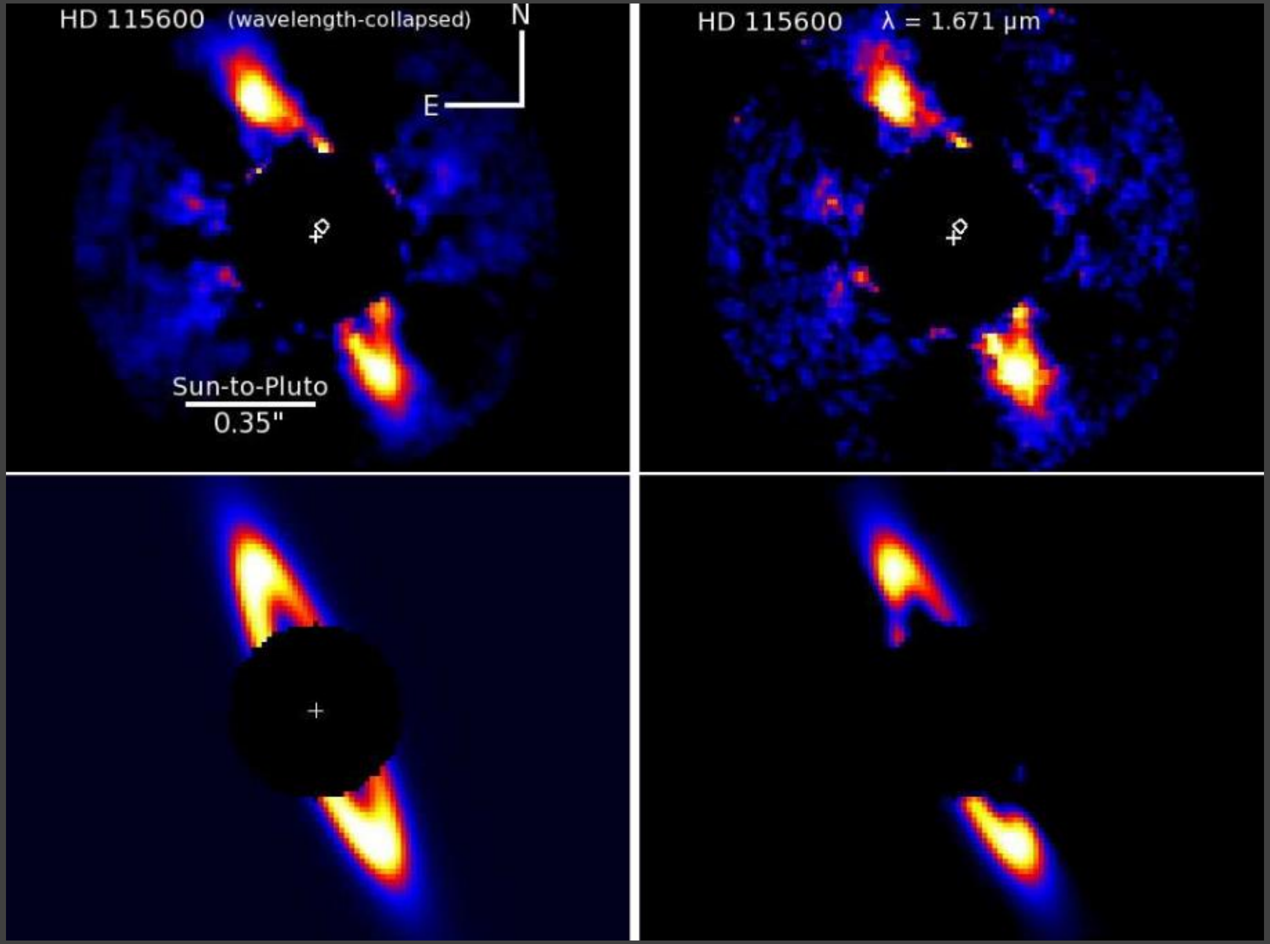
Age ~10 Myr
Distance ~ 9 AU

Young Kuiper belt-like debris disc

HD 115600
110 pc
15 Myrs
1.4 solar mass star

Gemini planet imager

Size of the disc 48 AU



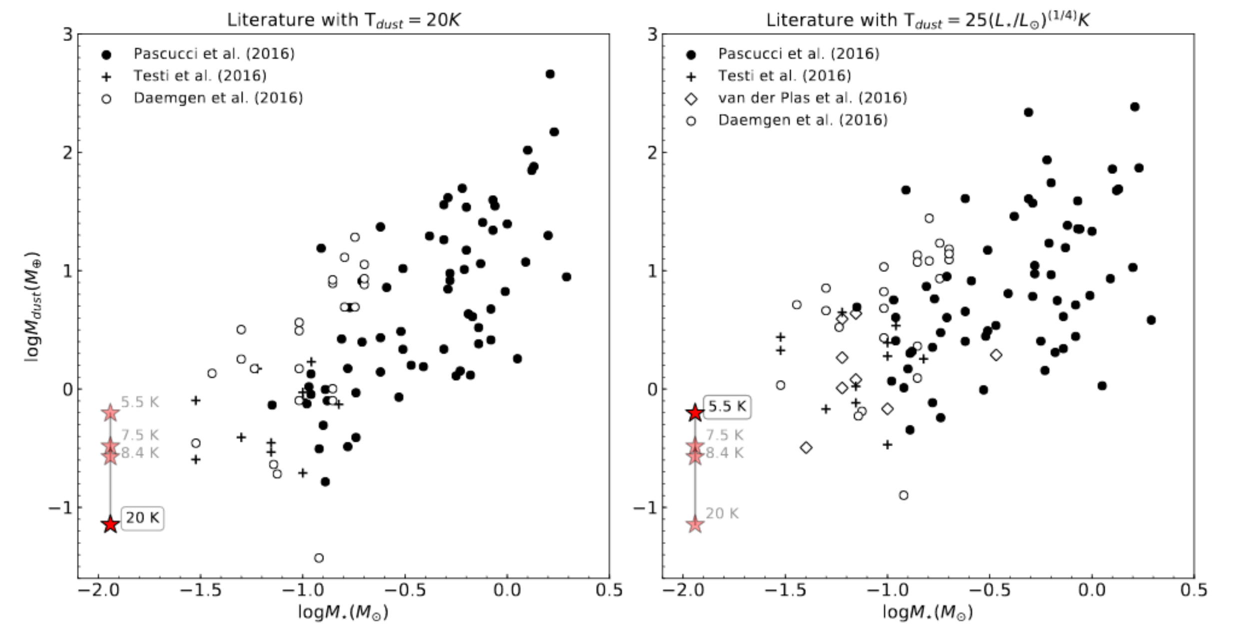
Disc around planetary mass object

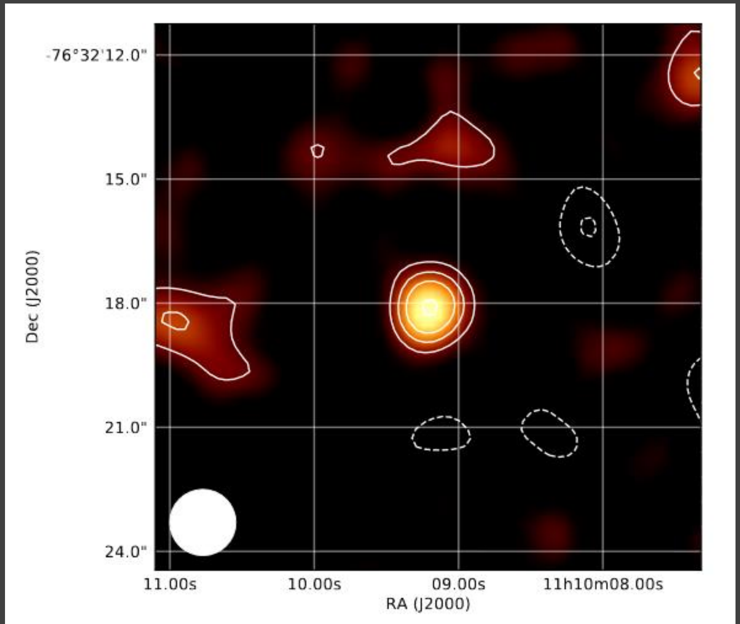
OTS44 is one of only four free-floating planets known to have a disc.
Mass ~12 $M_{jupiter}$

IR excess seen by Spitzer and Herschel

ALMA observations

$M_{dus}t$ ~0.07-0.7 M_{Earth}



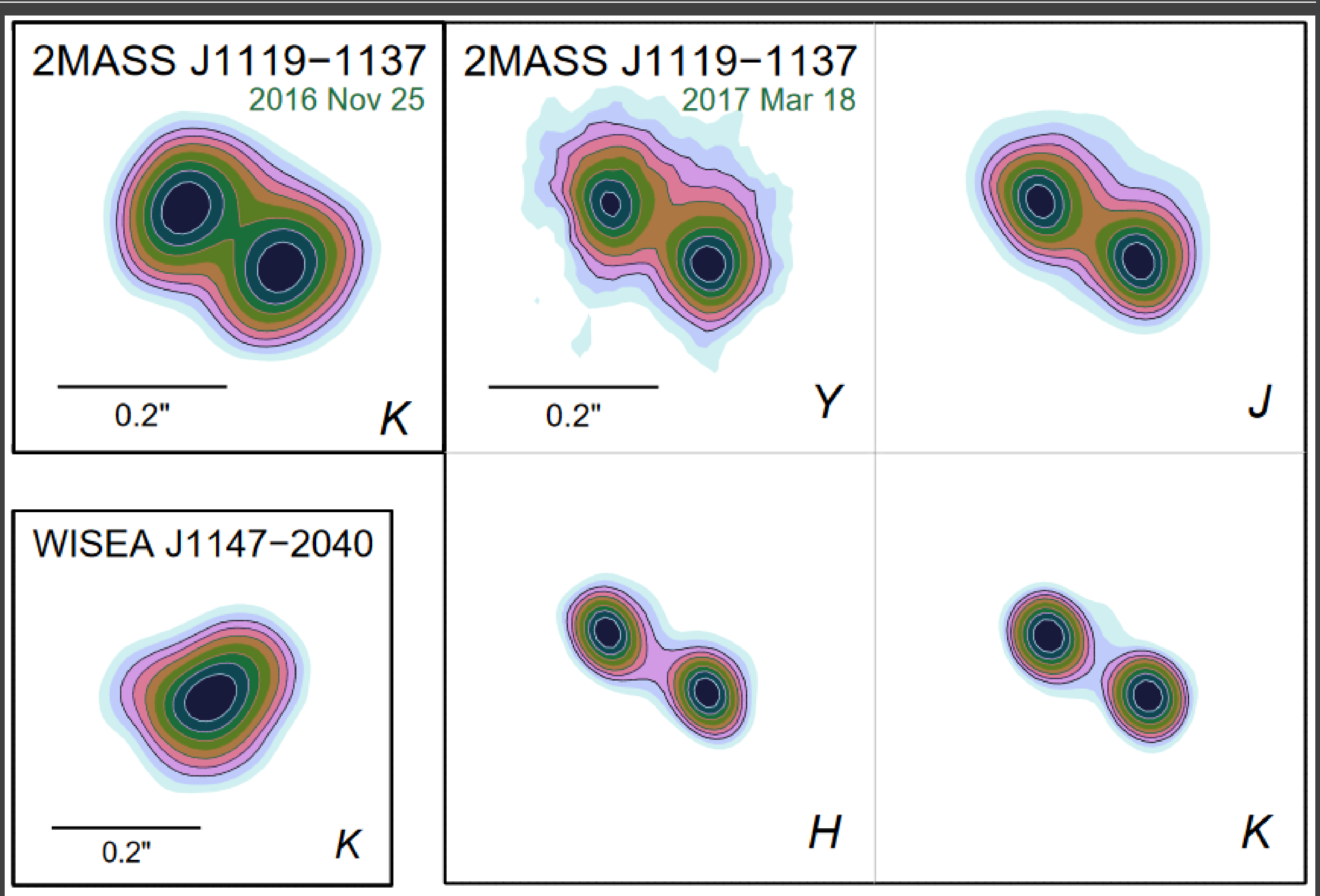


A brown dwarf is a pair of planets

2MASS J11193254−1137466

Age ~10 Myr
20-30 pc

M ~ 3-5 $M_{jupiter}$
Orbital period ~50-150 yrs
3-5 AU



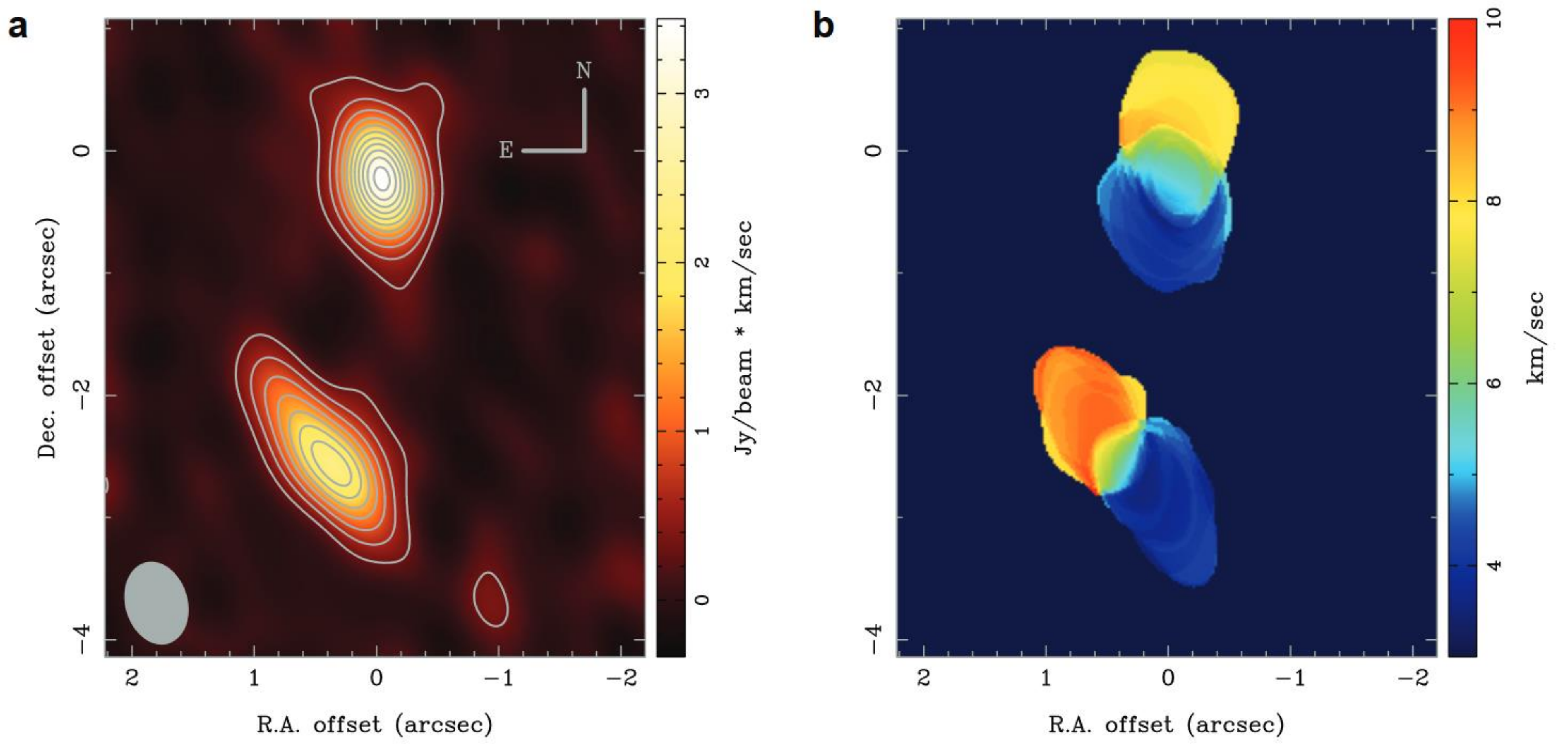
Protoplanetary discs in a binary system

HK Tau
161 pc

1-4 Myr

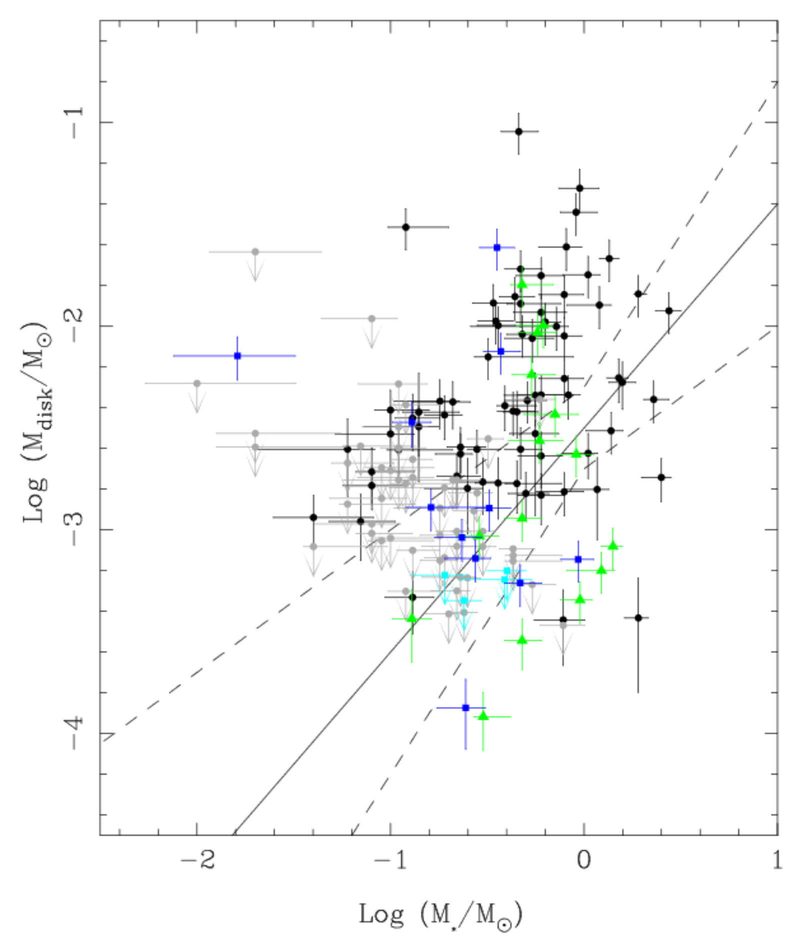
386 AU binary

ALMA observations



Statistics of circumstellar discs in binaries

17 binary systems
100-1400 AU
ALMA observations



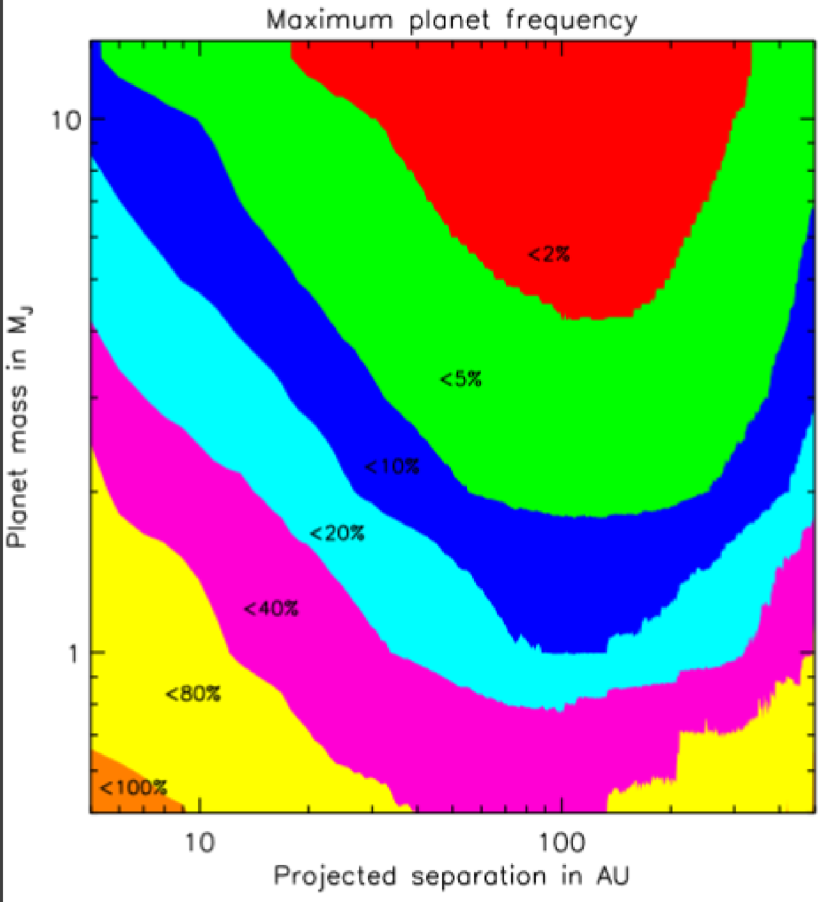
Green triangles – primaries;
Squares – secondaries
(dark blue – detected,
light blue – non-detected);
black dots – single stars
from other studies of the Tauris;
grey dods – single non-detections.

Secondary discs in two cases are brighter than discs around primaries.

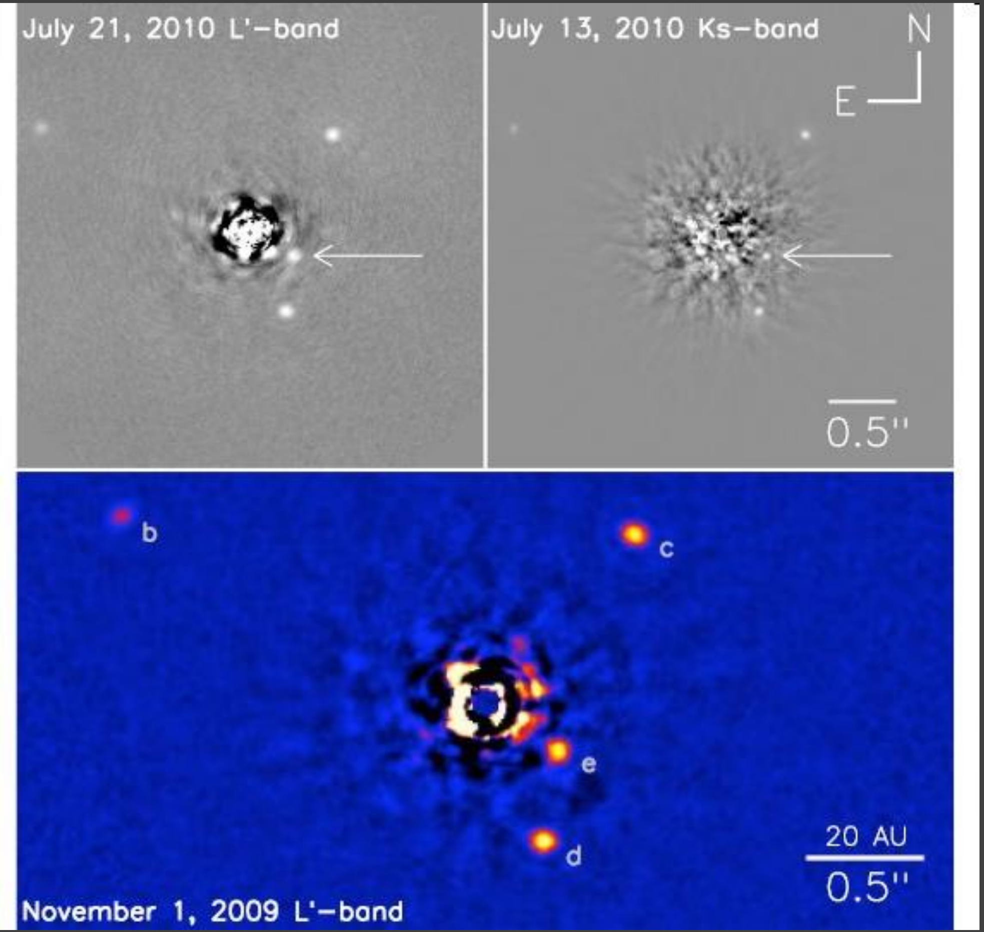
Direct imaging of planets

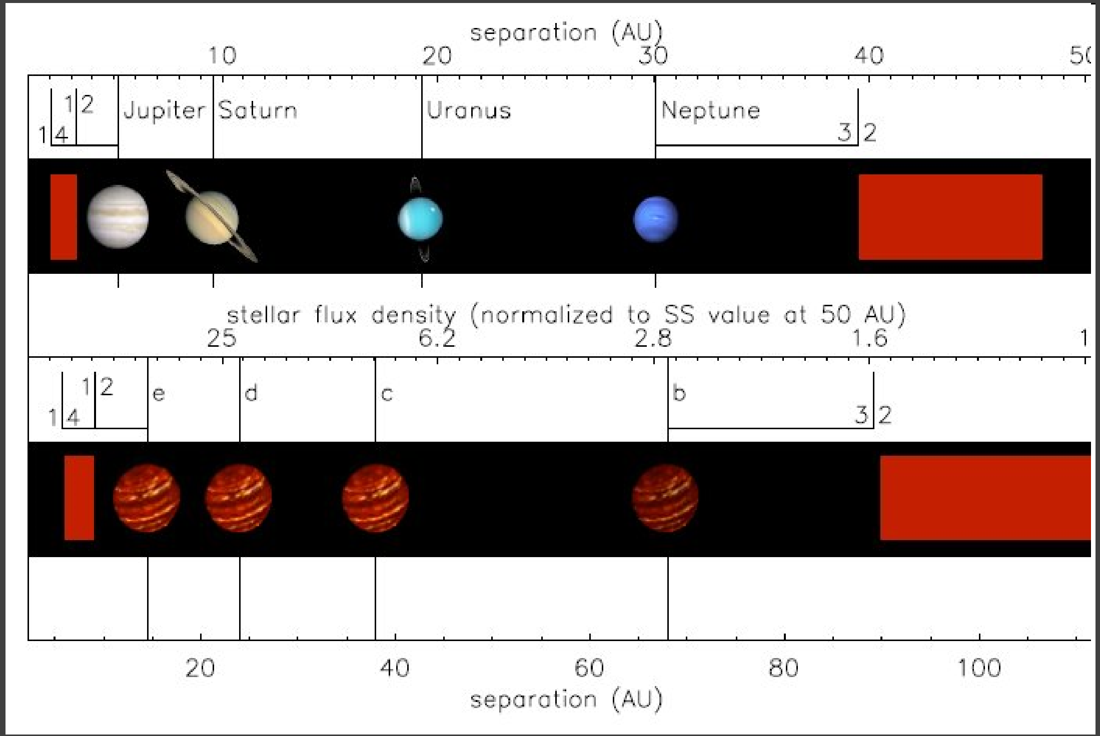
Recent survey with direct imaging resulted in an estimate that ~few percent of star have a planet 0.5-14 Mjup at 20-300 AU.

HR8799 system and several brown dwarfs were found



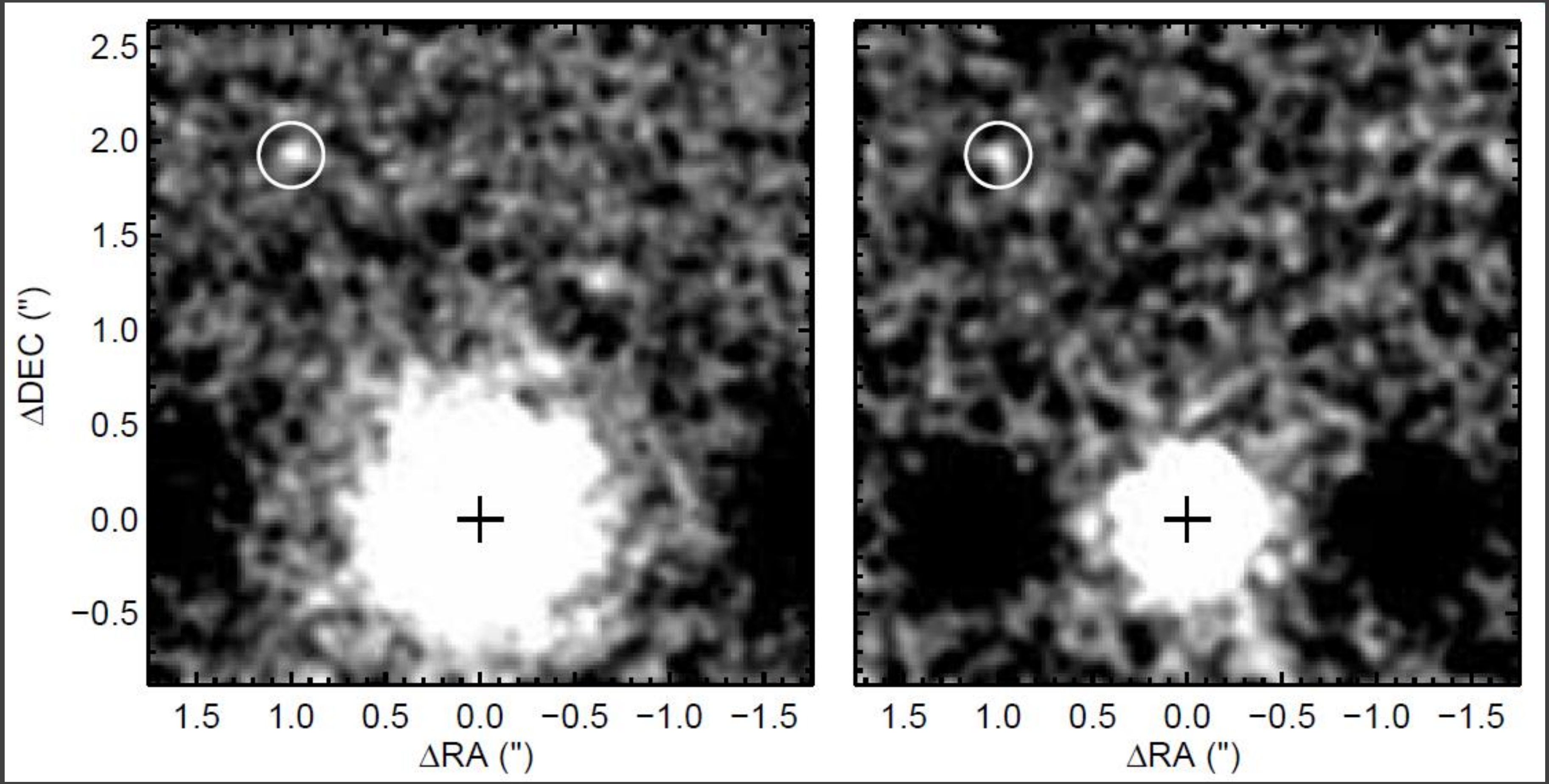
HR 8799





Keck II
Structure similar to the Solar system, but if expanded by factor 2

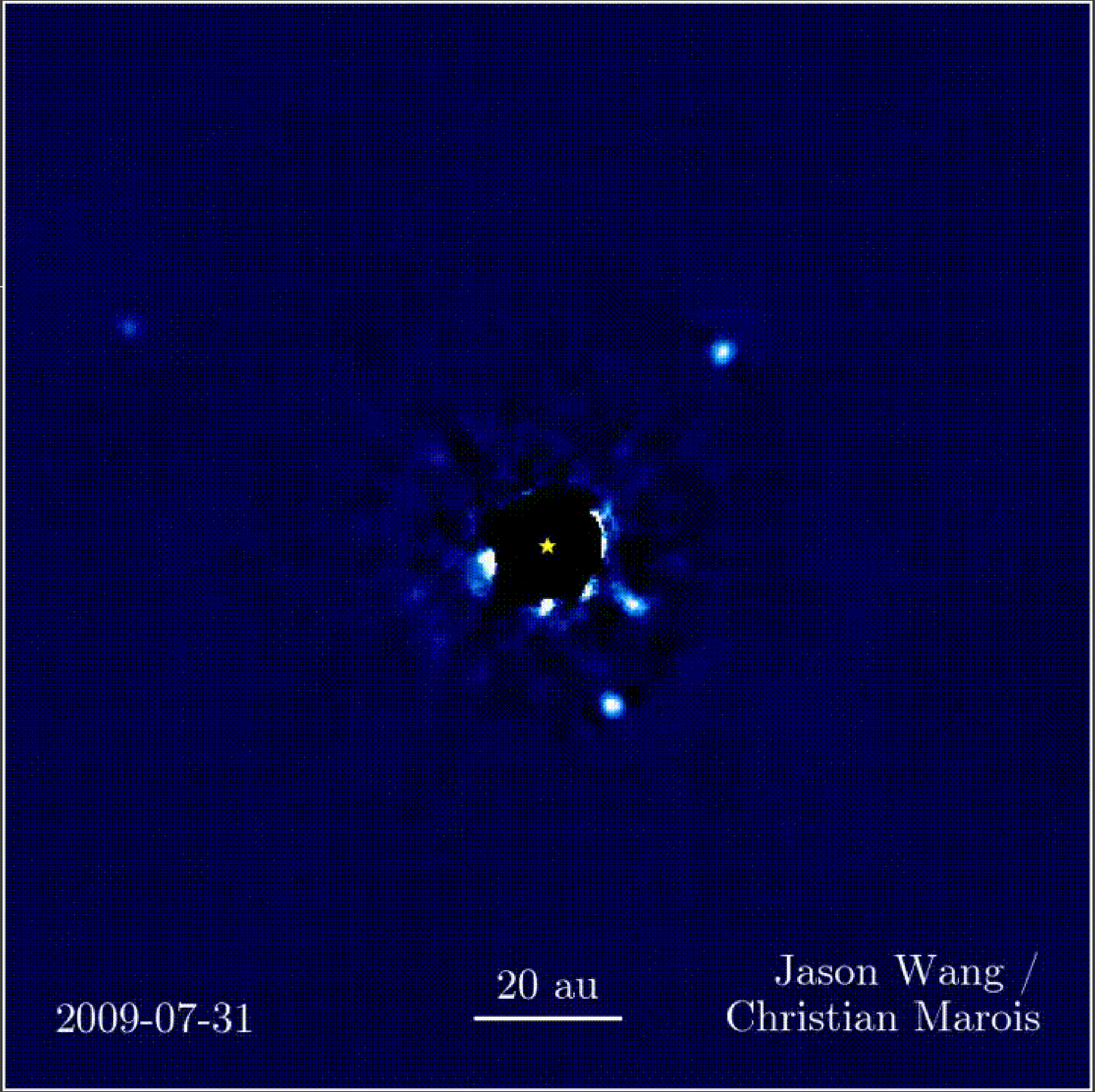
Young star 1RXS J160929.1-210524



Gemini North

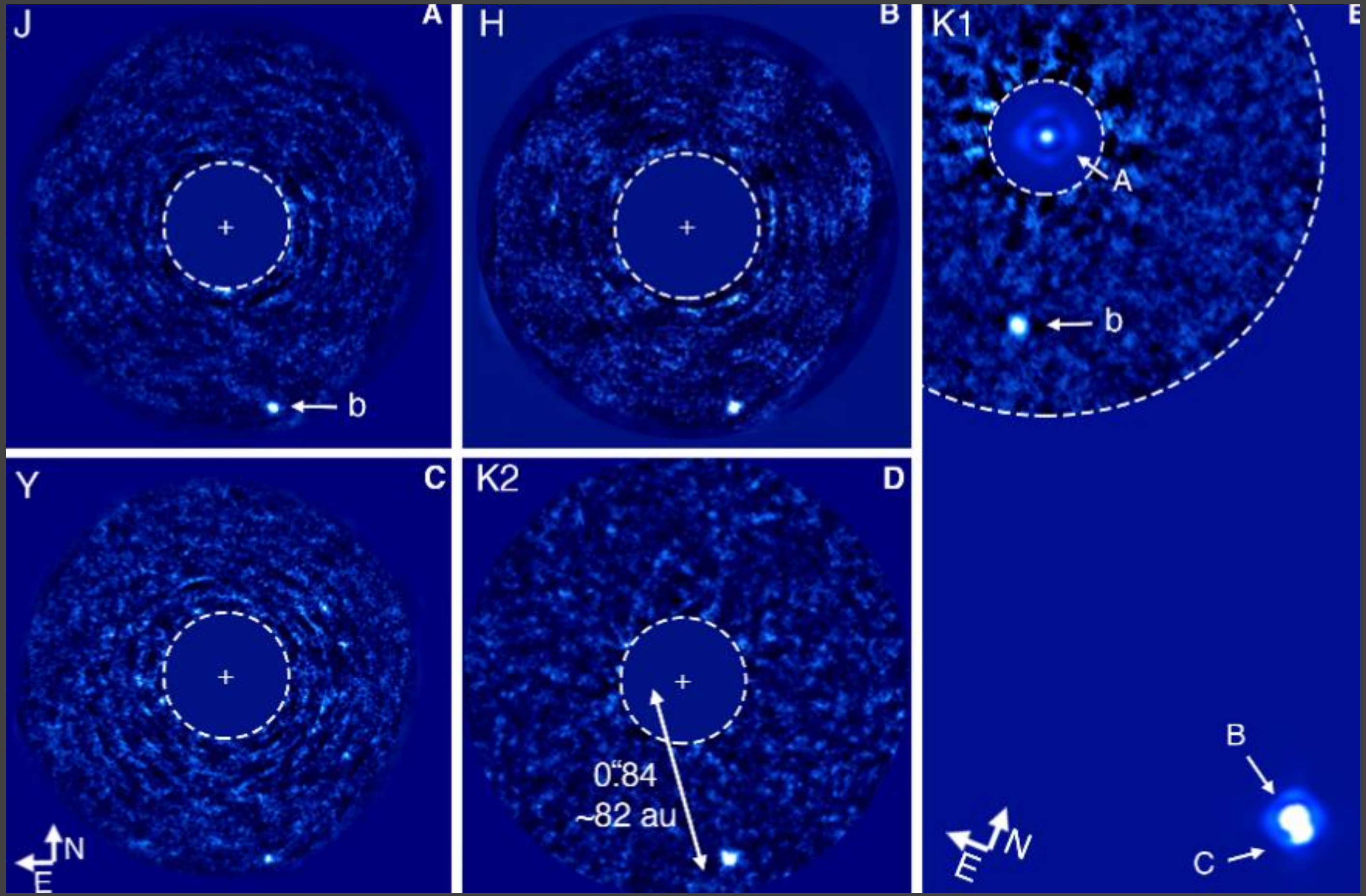
1006.3070

HR 8799

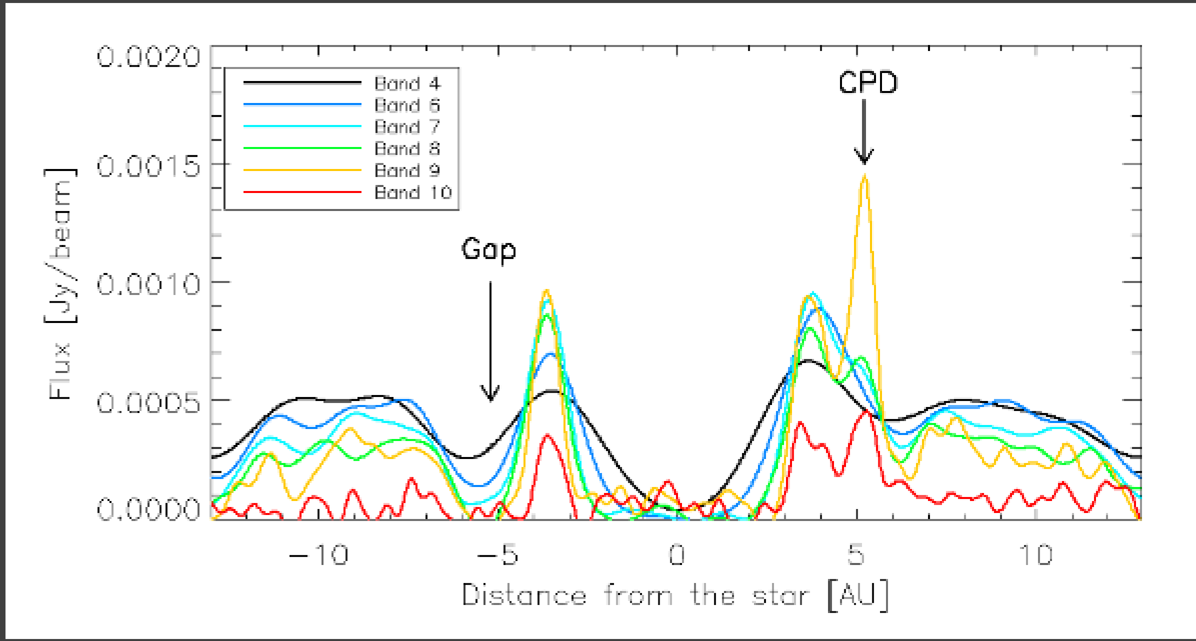


Planet in a triple system

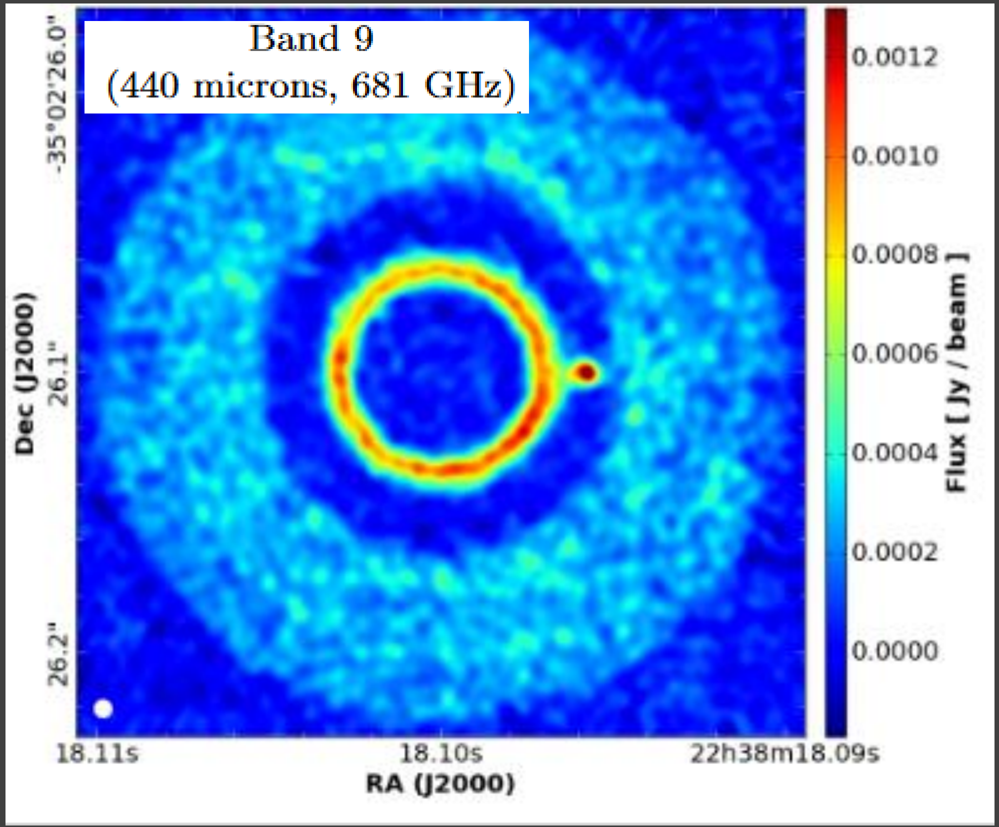
Young planet ~16 Myr.
Observed by VLT
Orbit might be unstable.



Circumplanetary discs (mock simulations)

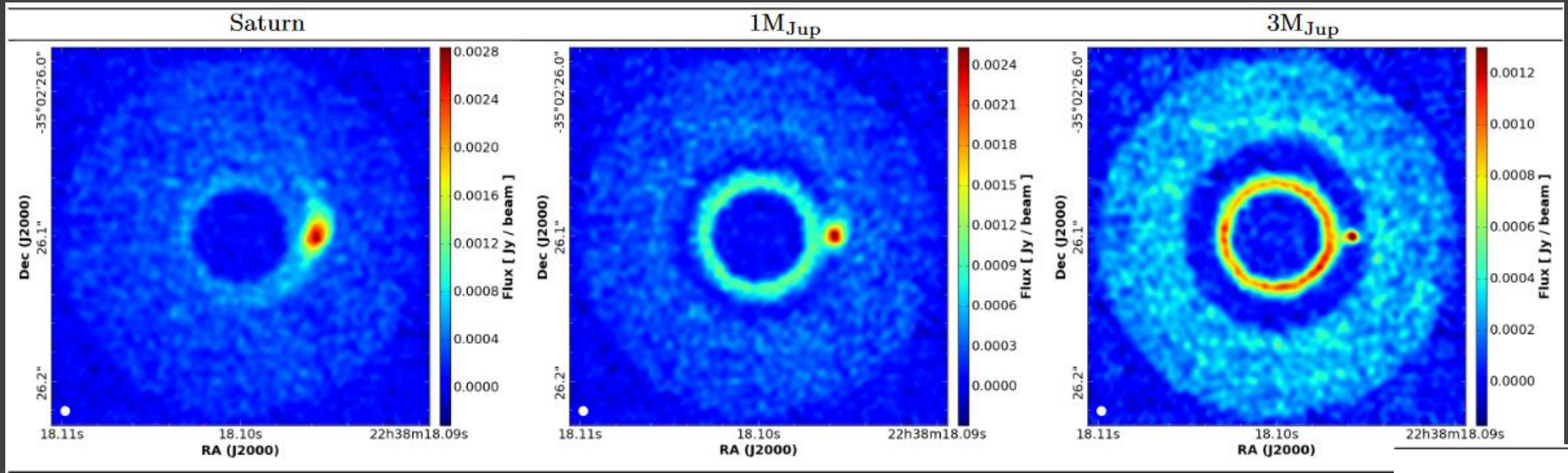


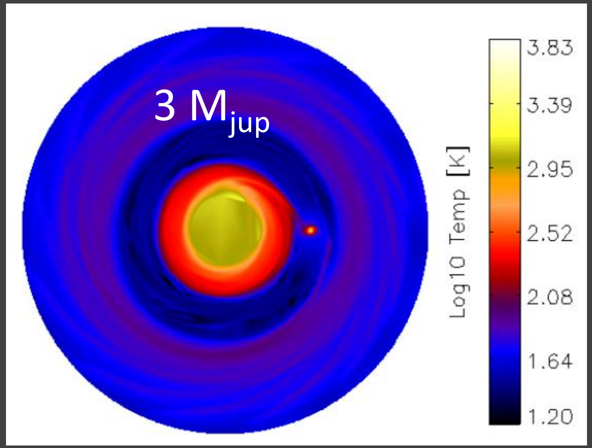
Size of a circumplanetary disc is about ½ of the Hill sphere.
Thus, it can be hardly resolved by ALMA, but can be detected.

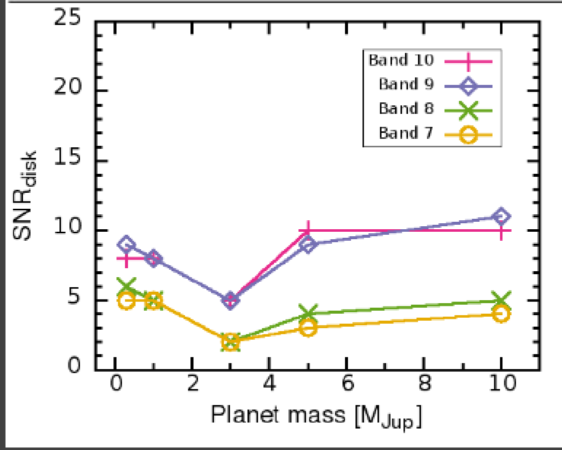


3 Jupiter masses
5 hours of observations
Better visible at shorter wavelengths
Gap opening is important
Planet temperature 4000K (age ~1 Myr)

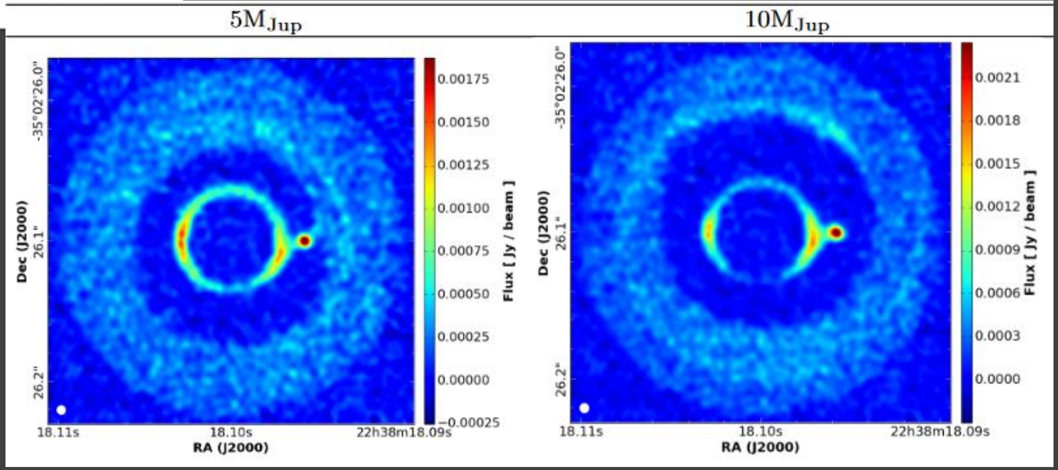
Dependence on the planet mass







Light planets, like Saturn, can also be detected.



Literature

arxiv:1507.04758 Observations of Solids in Protoplanetary Disks

arxiv:1703.08560 Circumstellar discs: What will be next?

arXiv: 1804.08636, 1802.04313 Debris discs

arxiv:1602.06523 Resolved observations of transition disks

arxiv:1607.08239 The International Deep Planet Survey II:
The frequency of directly imaged giant exoplanets with stellar mass

arXiv:1801.07721 Population synthesis of protostellar discs