

Direct Imaging of Protoplanets: Where Simulations and Observations Meet

Iain Hammond

5th Phantom Workshop

15 February 2024



MONASH
University

exoALMA

Supervised by:

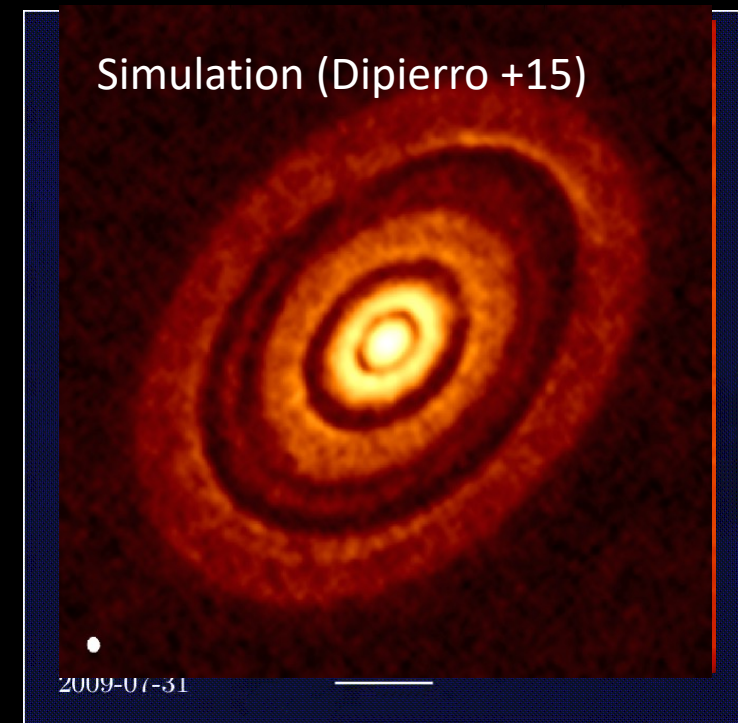
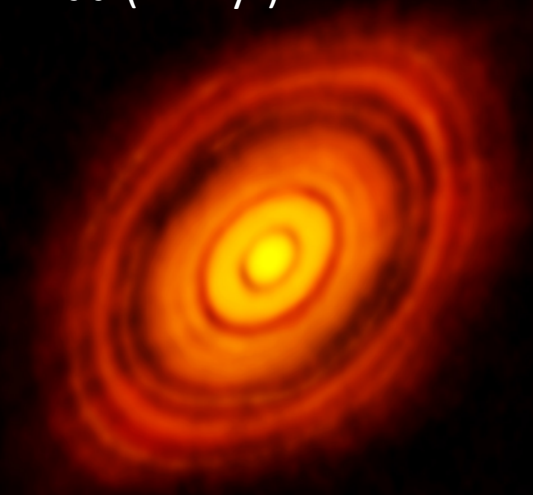
Daniel Price – Monash University

Valentin Christiaens - Université de Liège

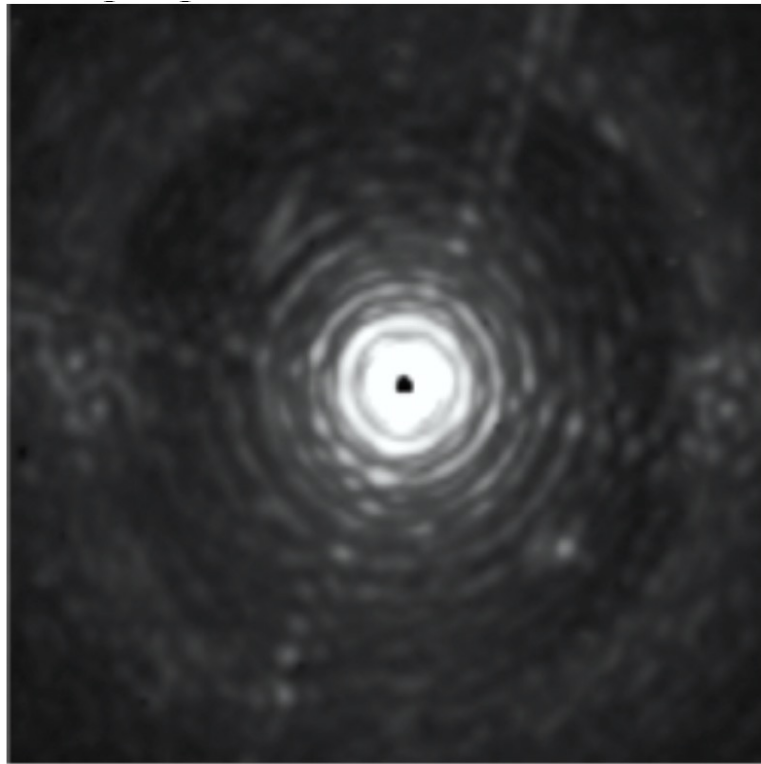
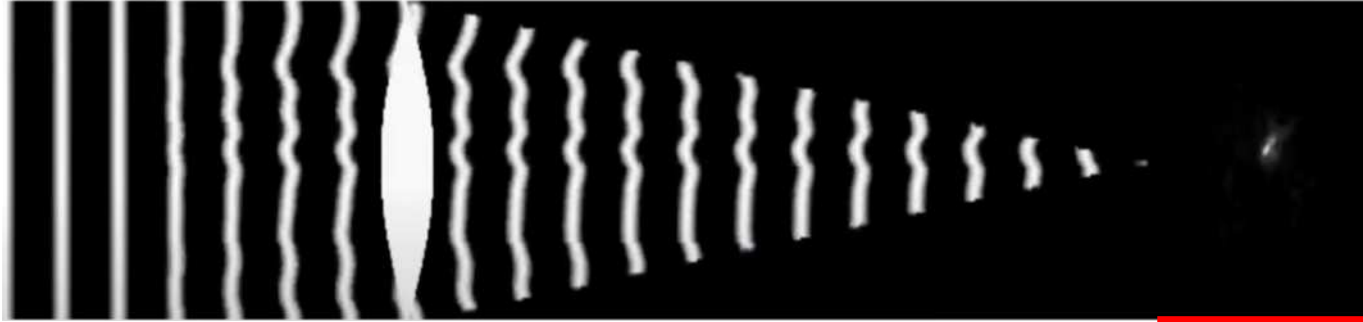
HL Tau (~1Myr)

Observational Planet Formation

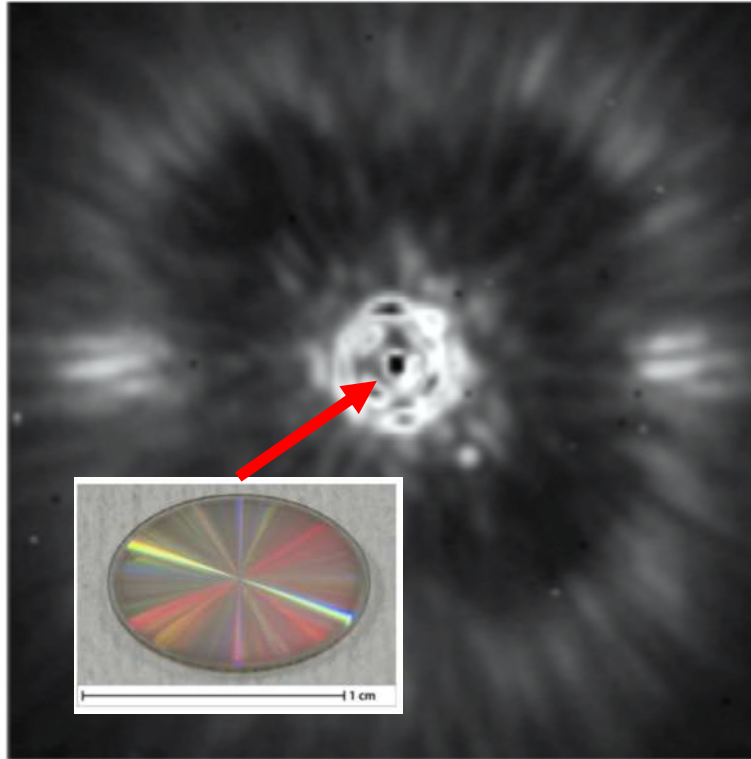
- Planets are most luminous during formation
- Directly imaged planets are young (0.1-10Myrs)
- Orbital constraints
- Theory predicts planets will carve observable gaps and excite spirals



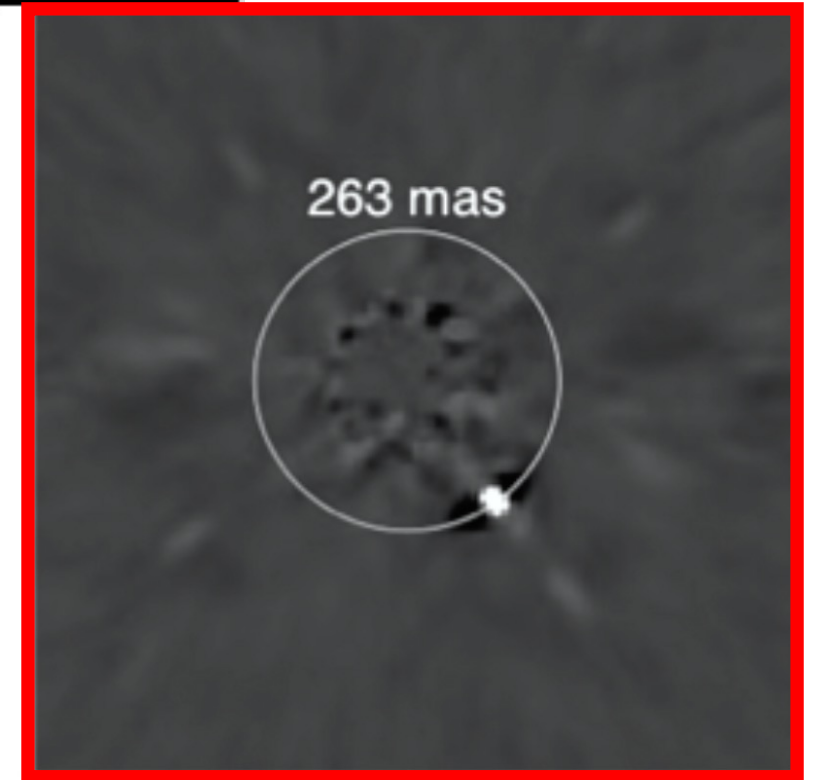
Pillars of high-contrast imaging



(extreme) Adaptive Optics



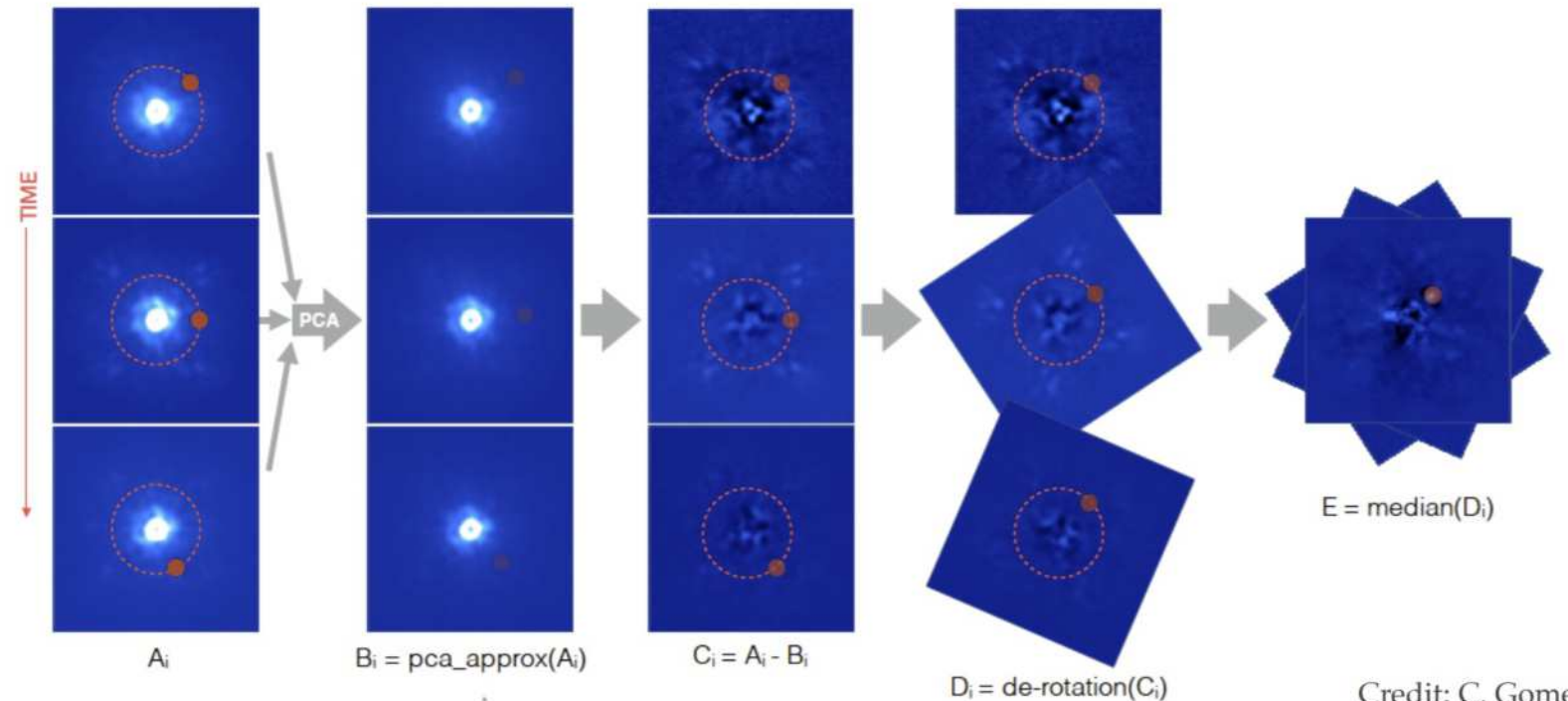
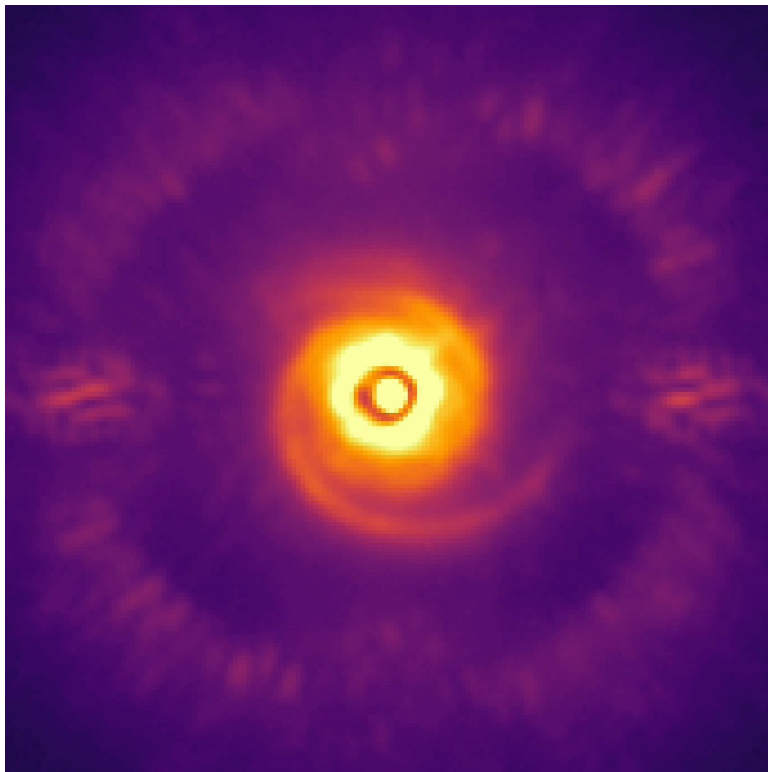
Coronagraphy



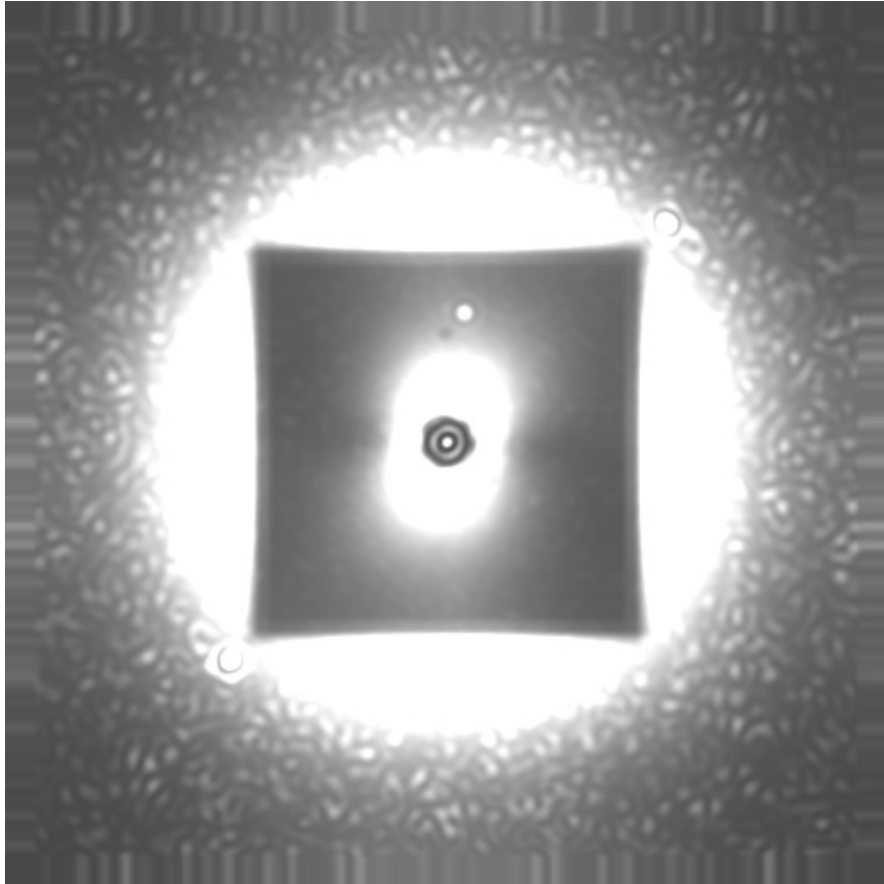
Strategy & post-processing

Angular Differential Imaging (ADI)

- Allow the field of view to rotate
- Point-sources and disc features will move
- Telescope and adaptive optics effects will remain static



Spectral Differential Imaging (SDI)

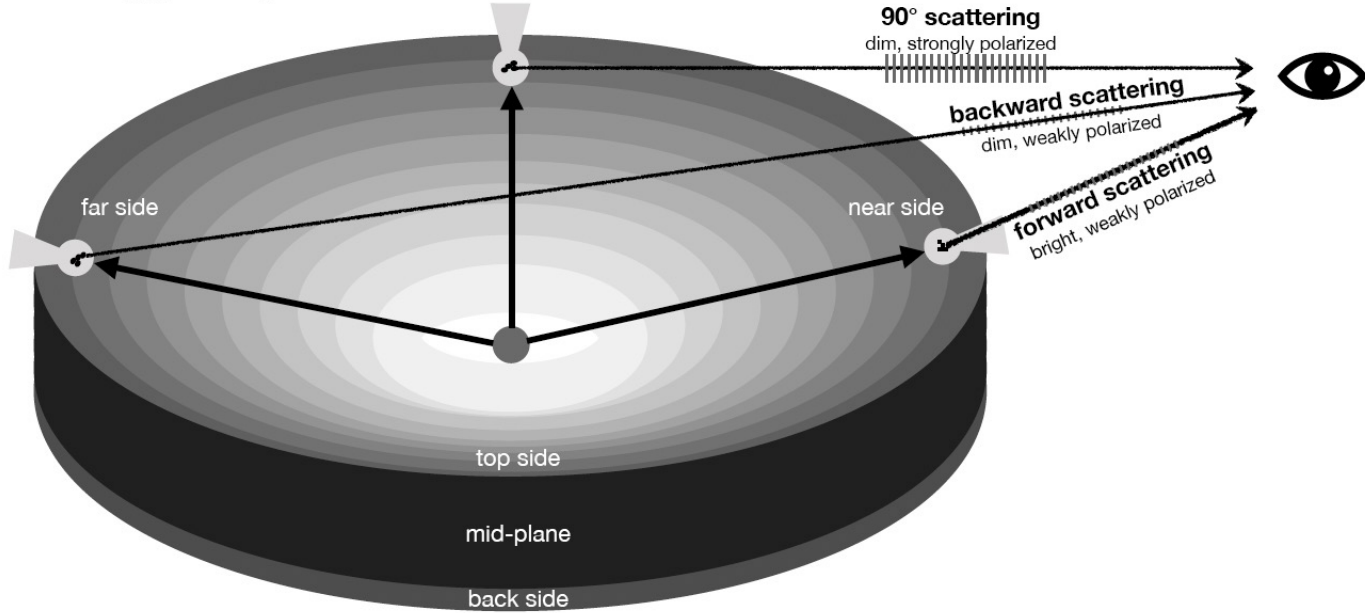


- Speckles expand radially with λ/D
- Point-sources and disc features remain fixed
- Changing wavelength = expanding speckles

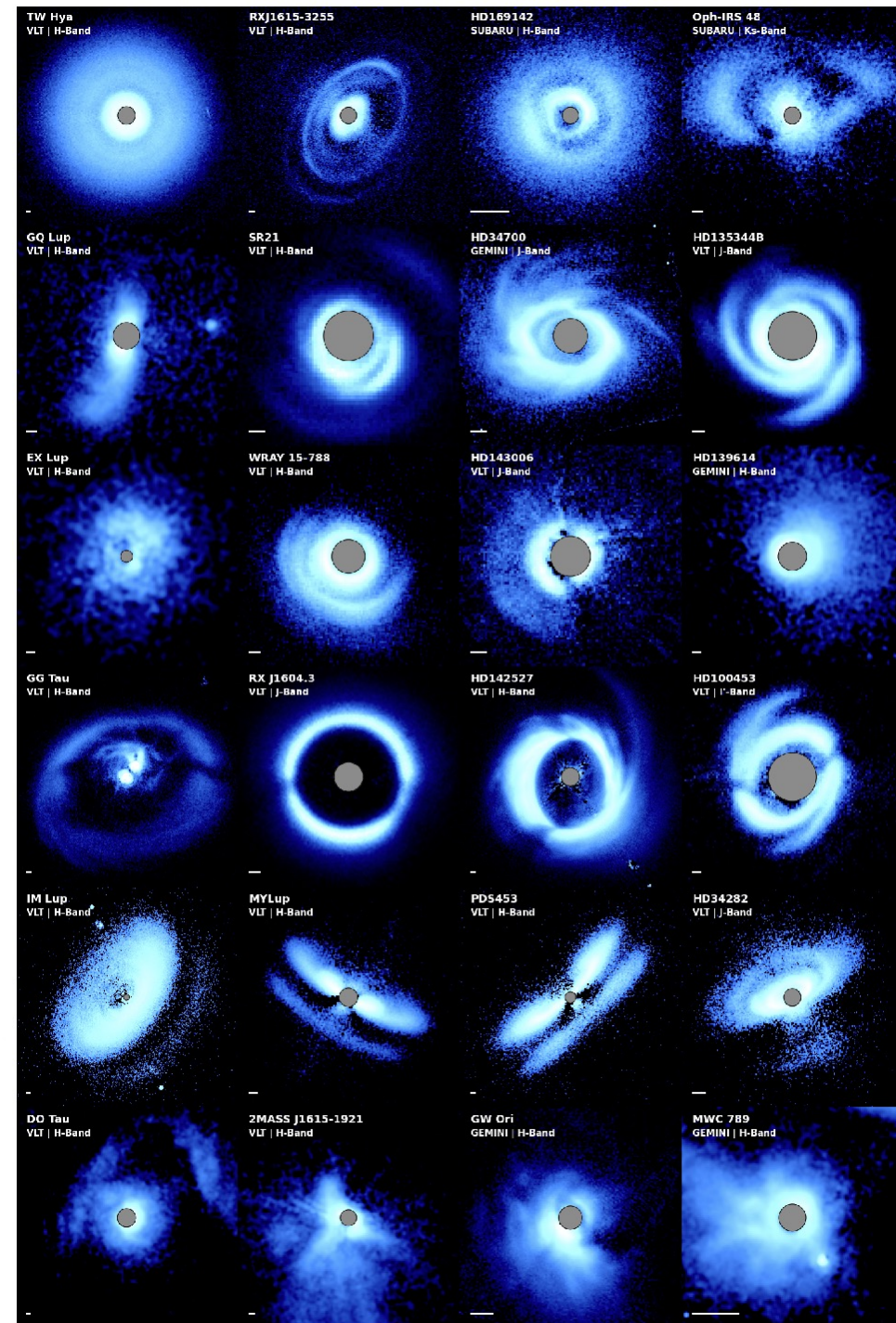
Credit: Bruce MacIntosh

Polarimetric Differential Imaging

Scattering geometry towards observer

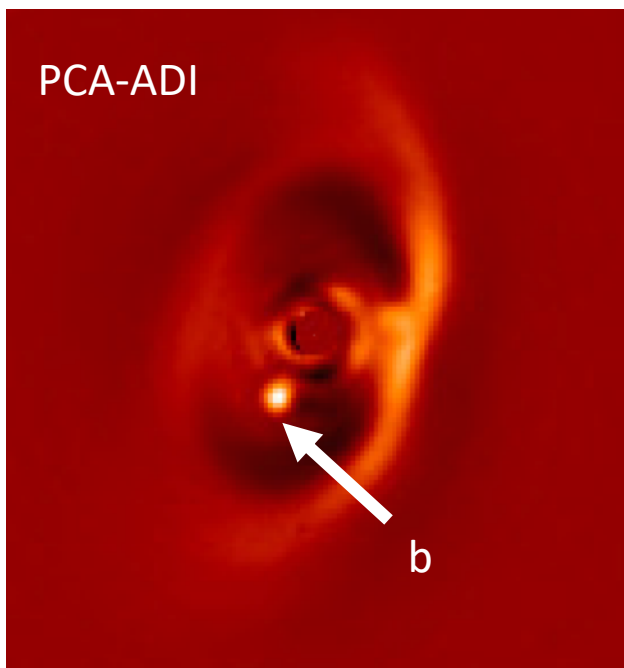


Benisty+22, PPVII



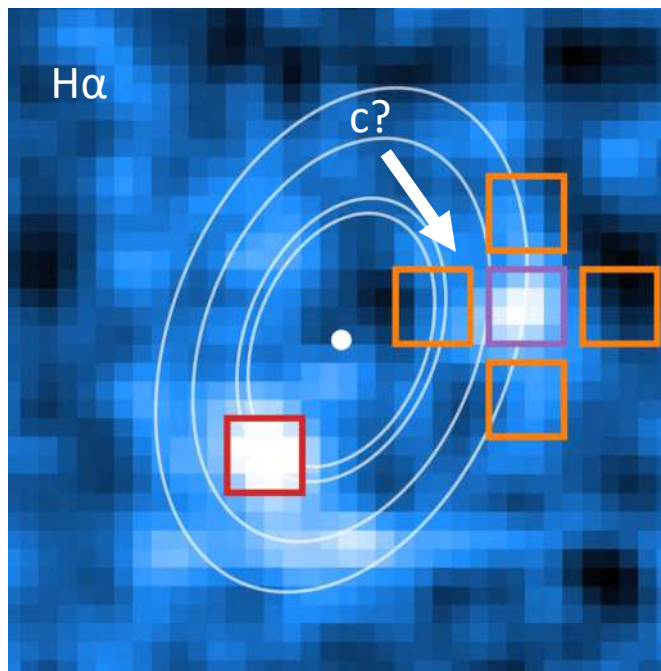
Direct Imaging of Young Planets – PDS 70 b

VLT/SPHERE



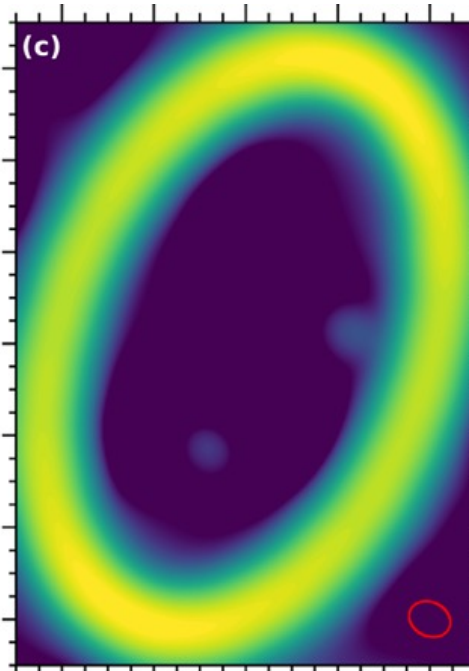
Muller+18

VLT/MUSE



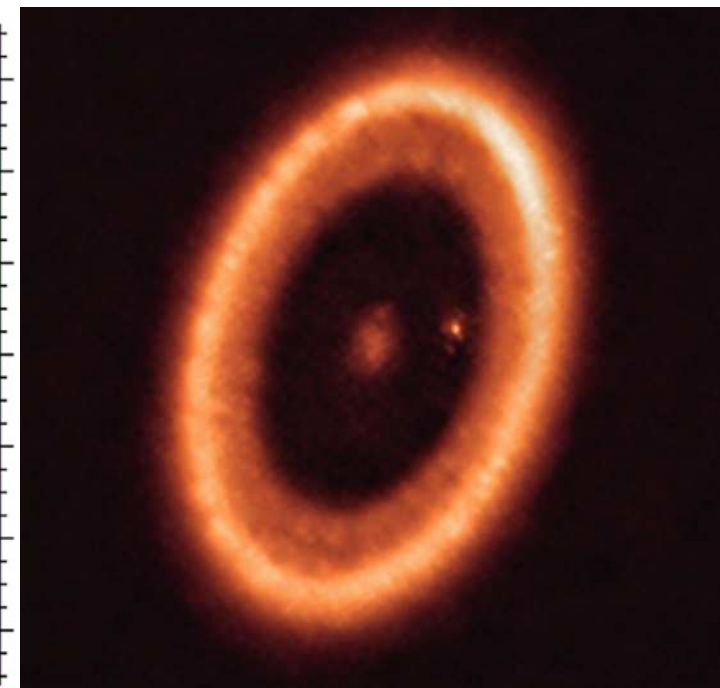
Haffert+19

Simulation



Bae+19

ALMA



Benisty+21

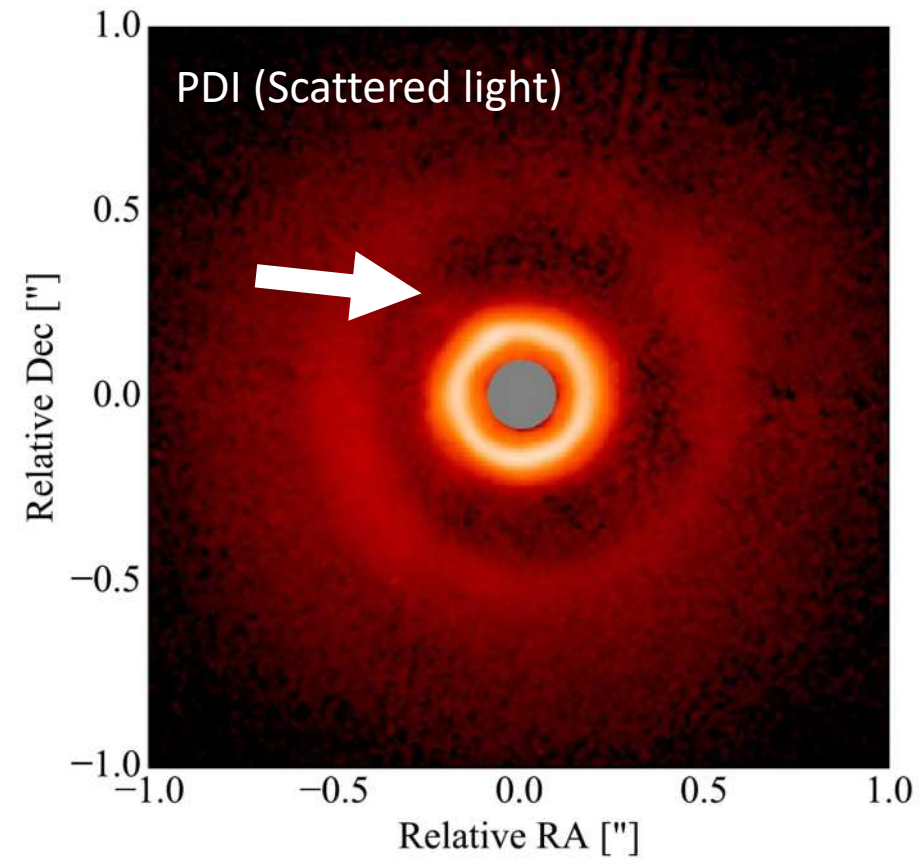
HD 169142

1.8 Msun

6 Myrs

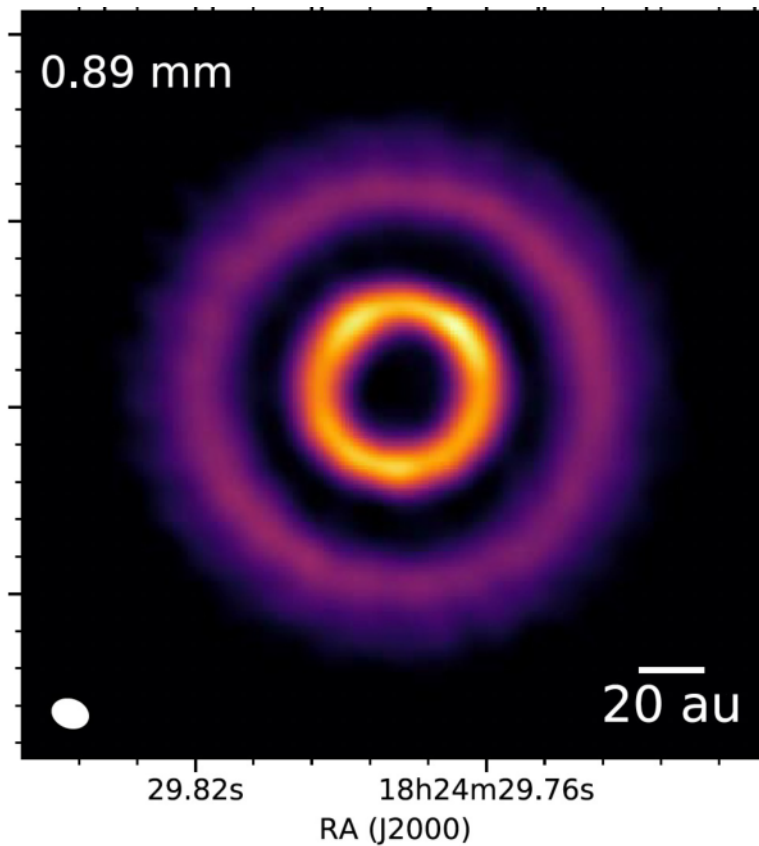
114 pc

VLT/SPHERE



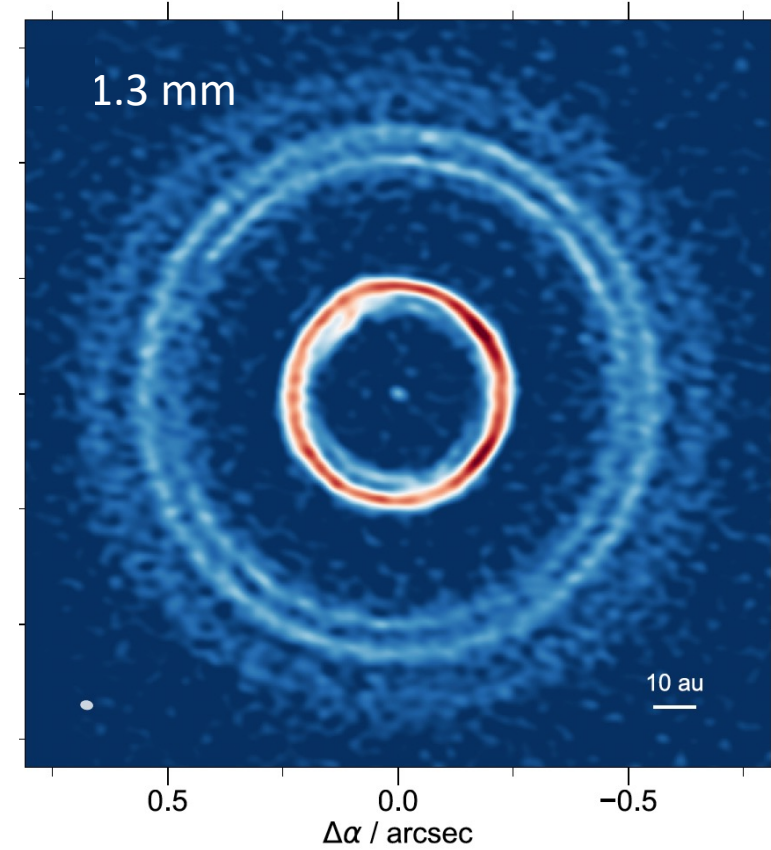
Pohl+17

ALMA



Macías+19

ALMA



Perez+19

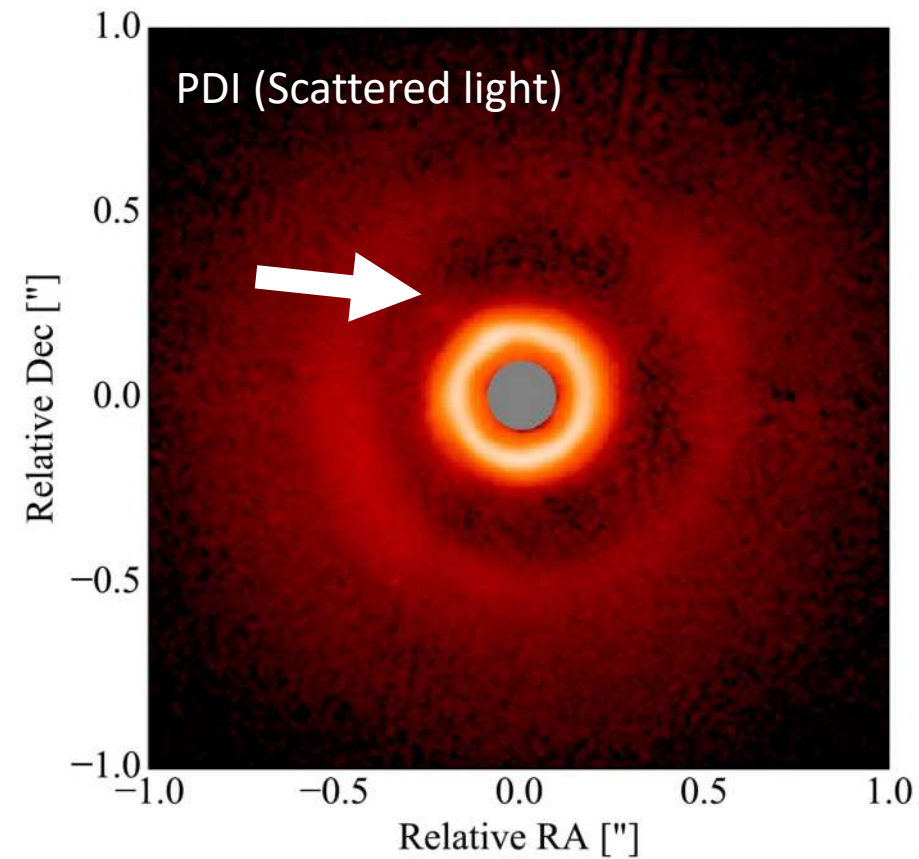
HD 169142

1.8 Msun

6 Myrs

114 pc

VLT/SPHERE



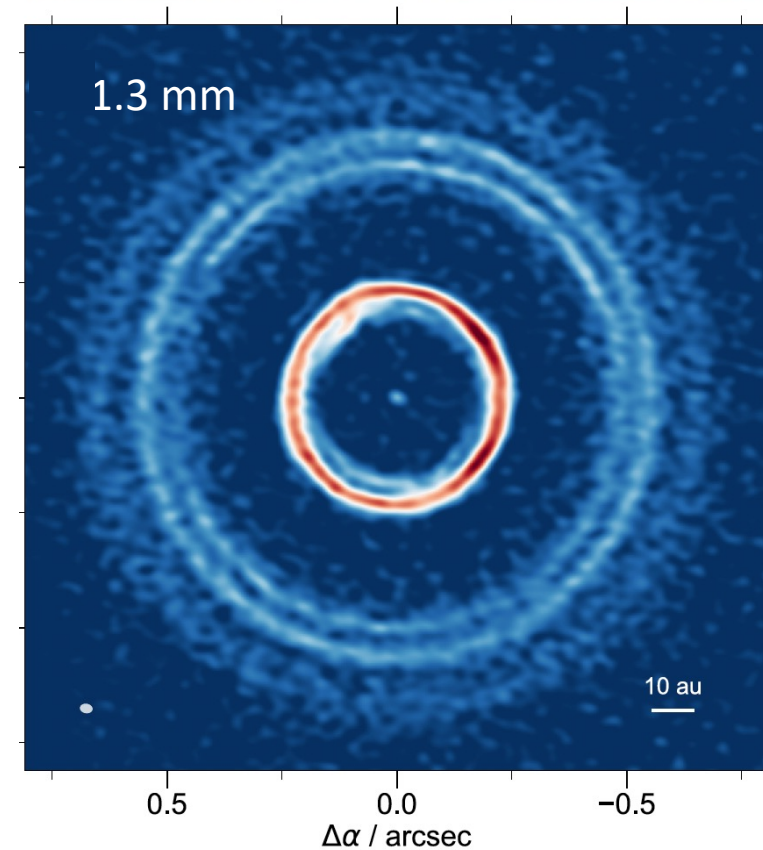
Pohl+17

Simulation (x2 planets)



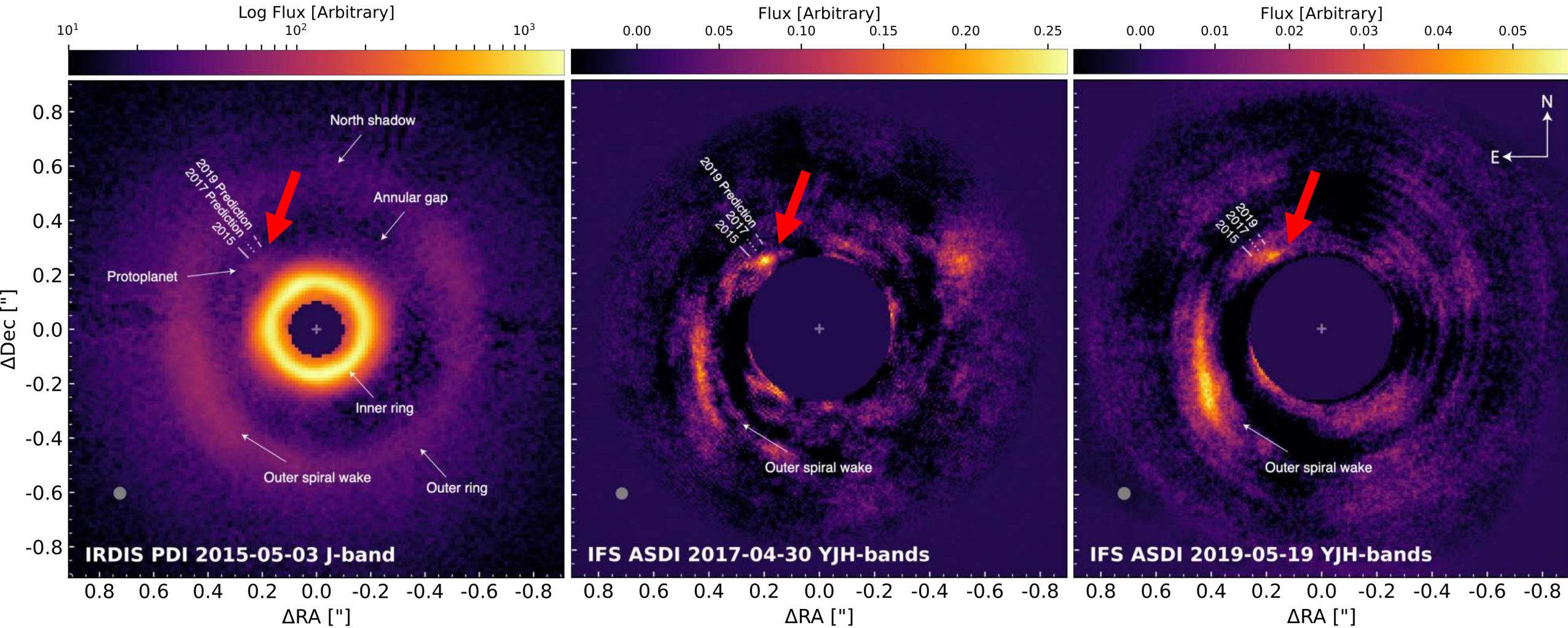
Toci+20

ALMA



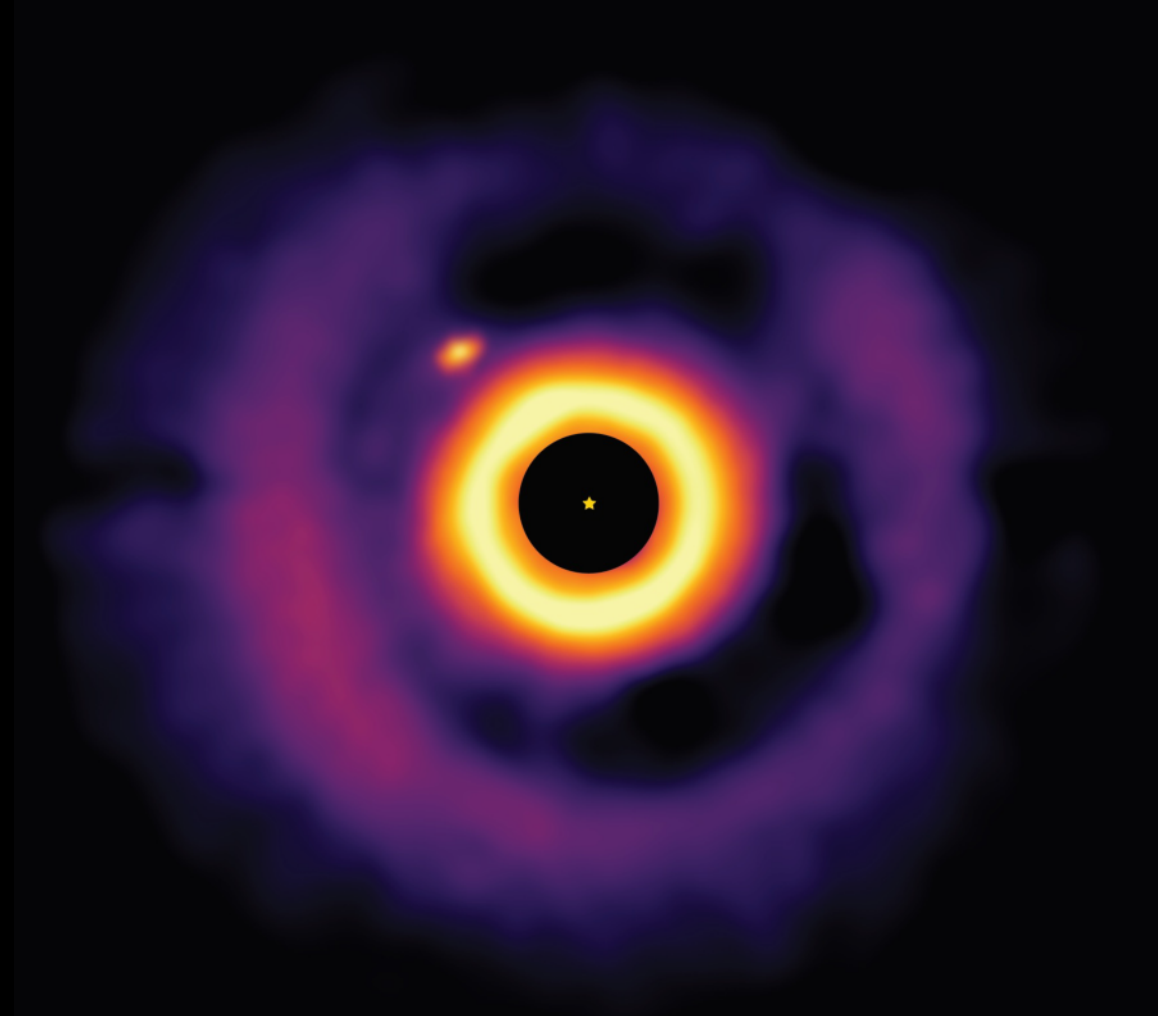
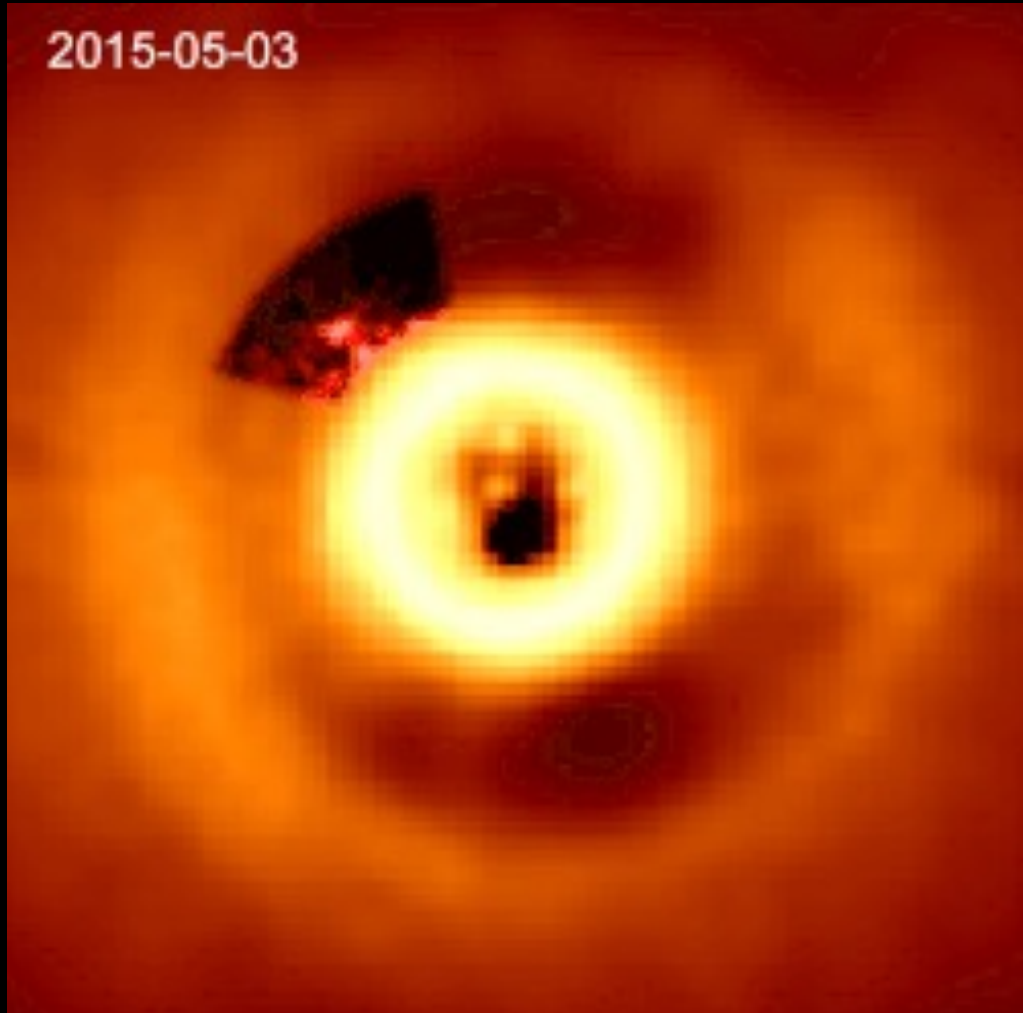
Perez+19

HD 169142 b



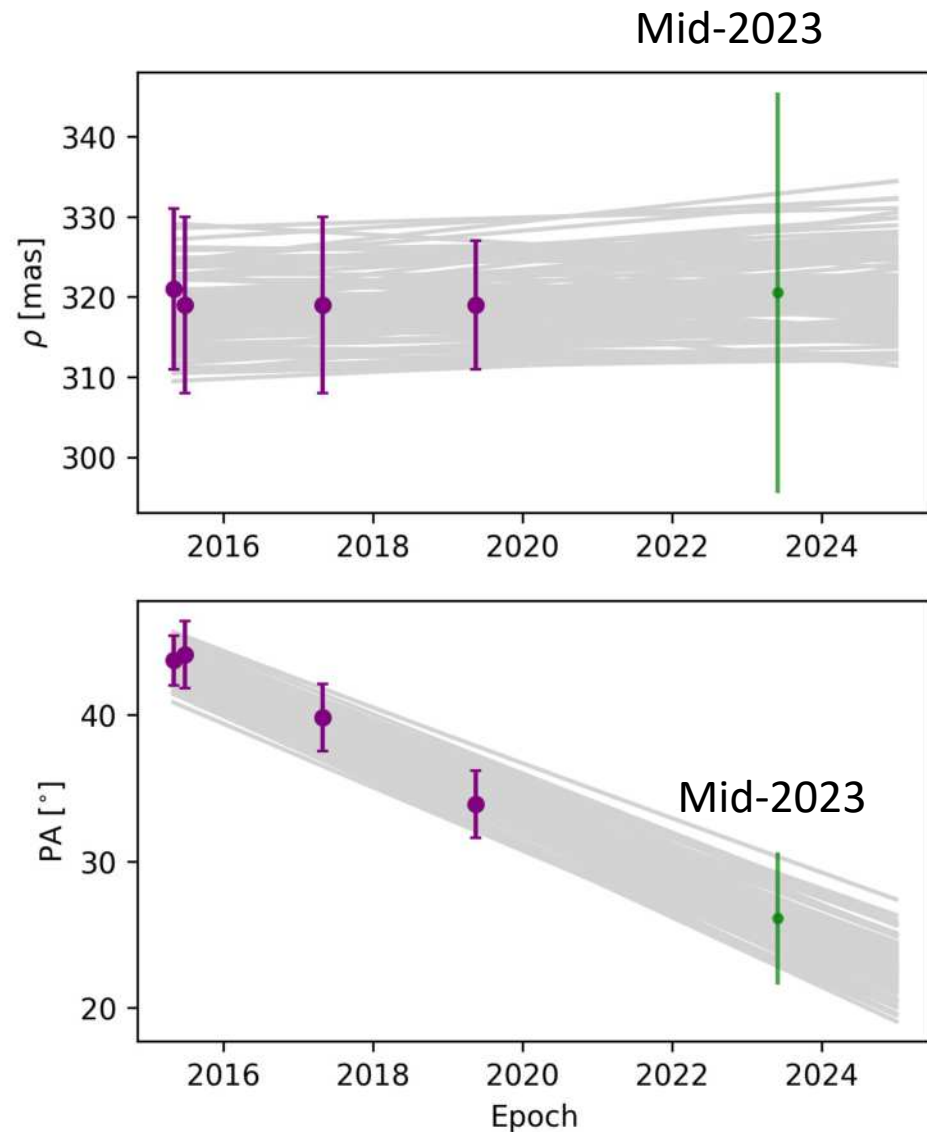
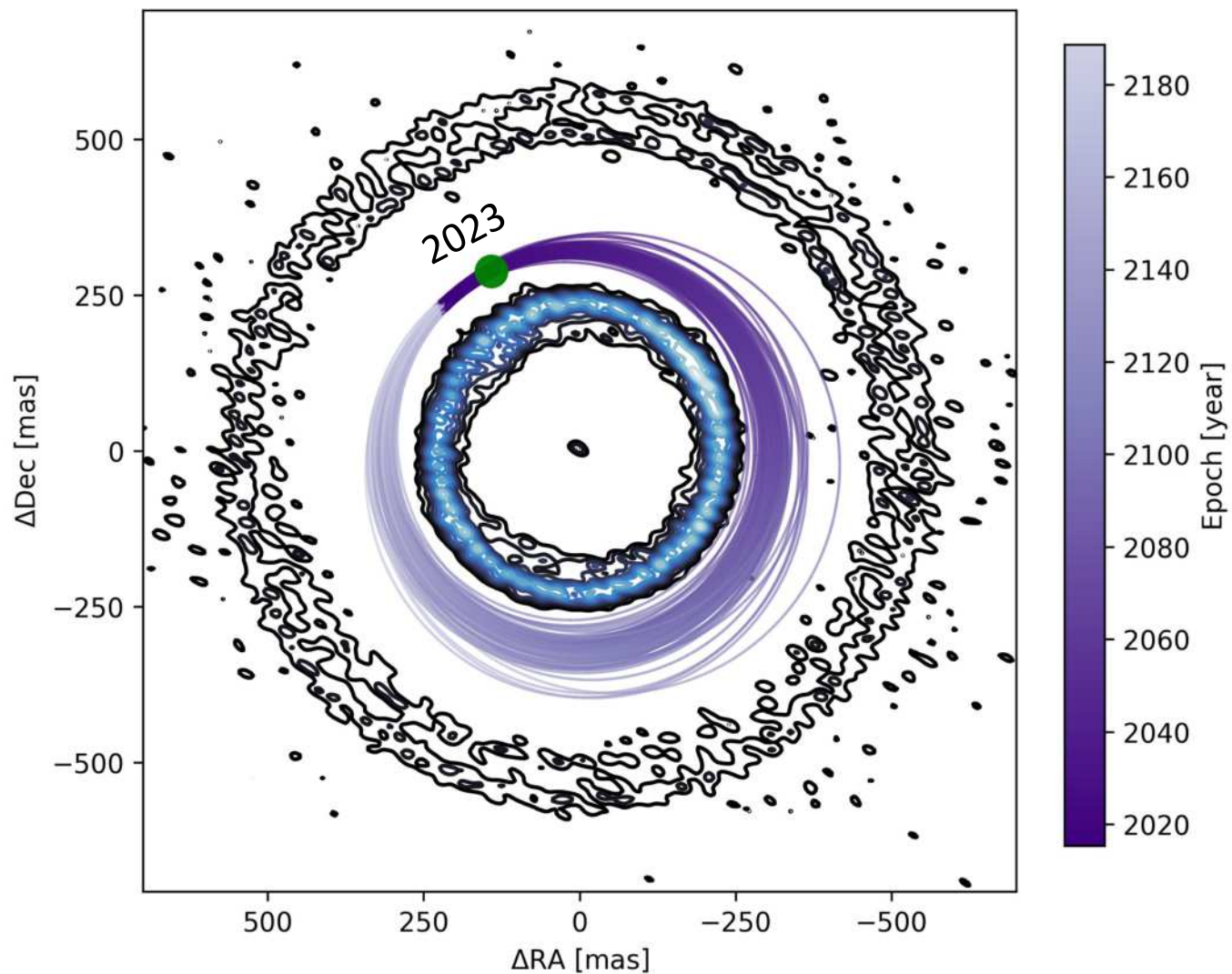
A compact near-IR source moving at Keplerian velocity in a gap exciting a spiral arm (Hammond+23)

HD 169142 b – a directly imaged protoplanet



https://en.wikipedia.org/wiki/HD_169142

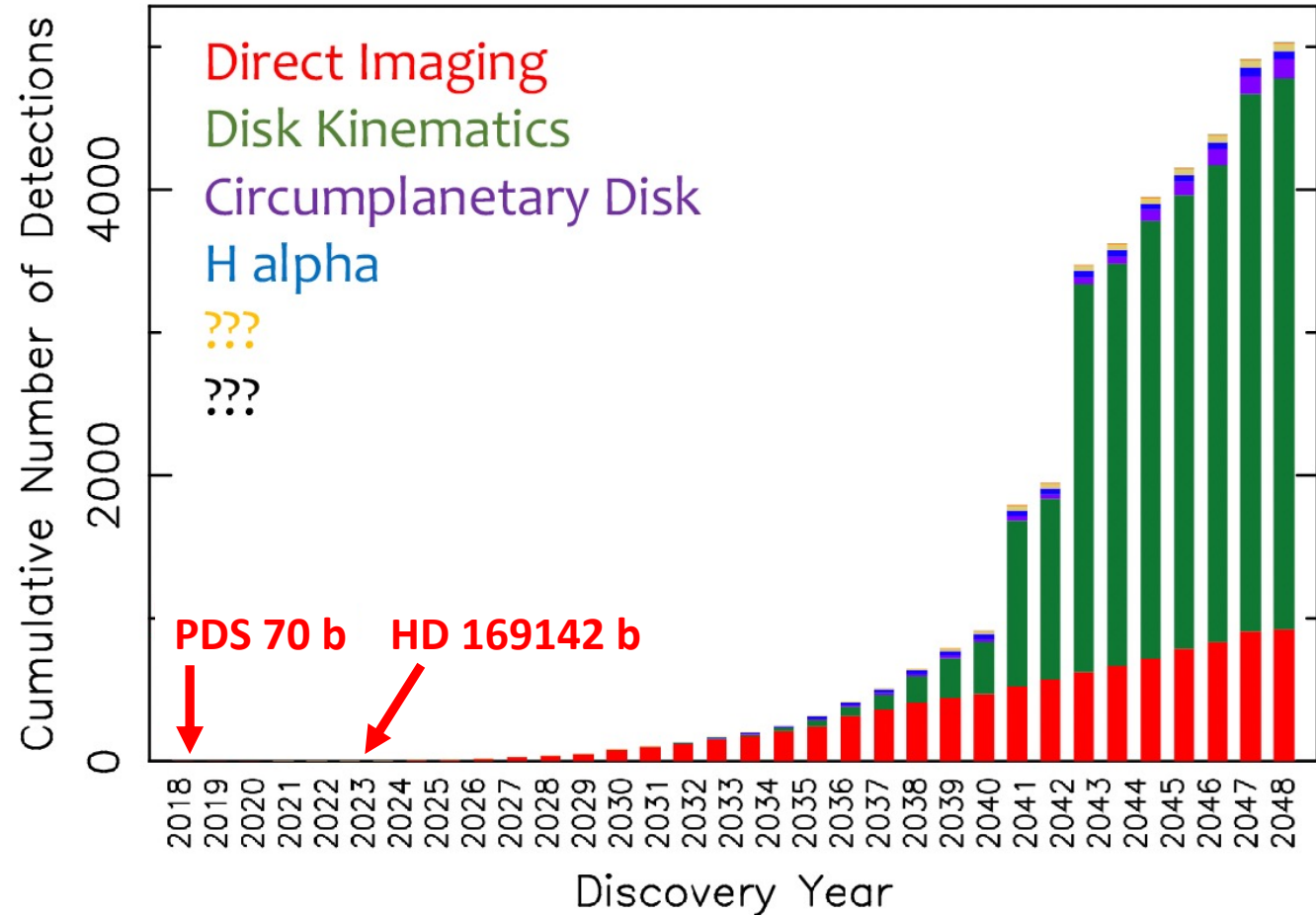
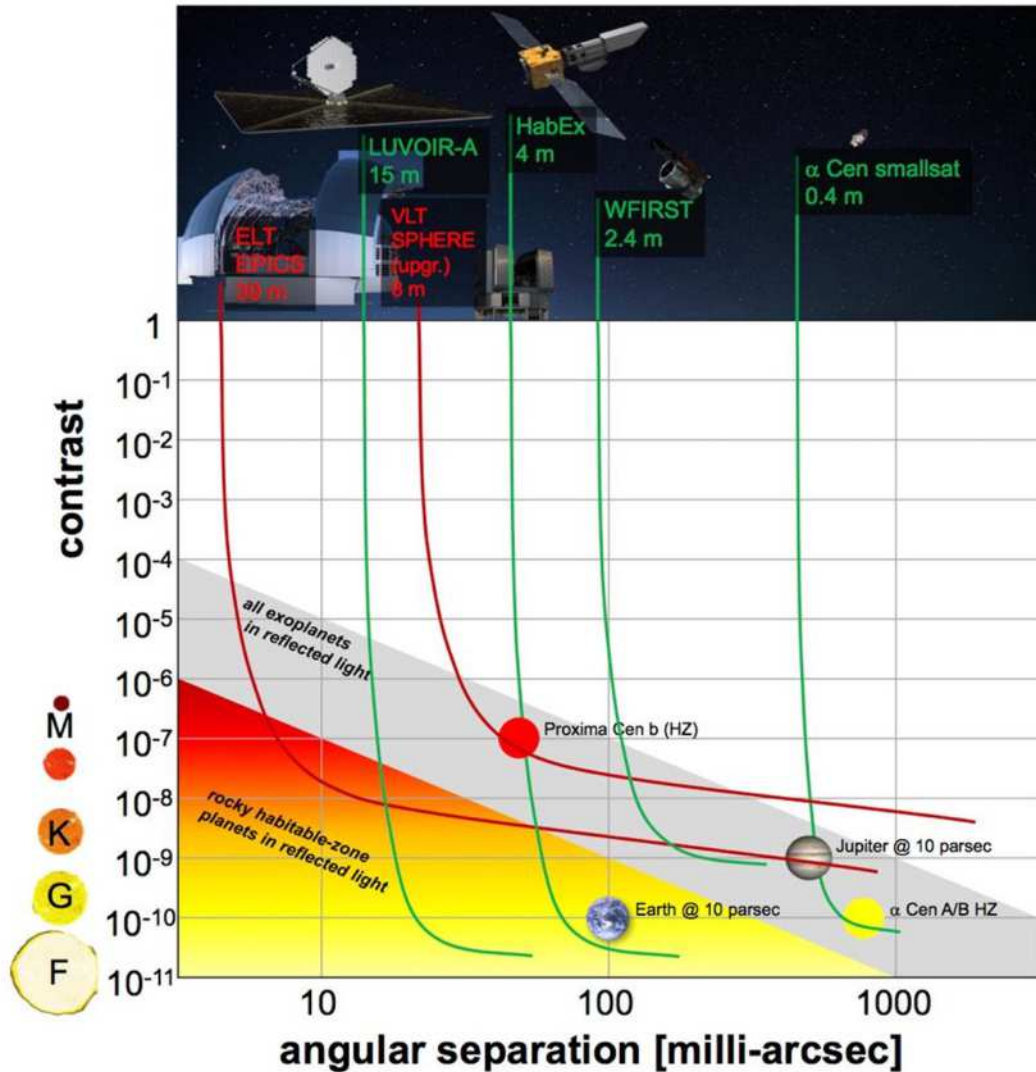
<https://exoplanetarchive.ipac.caltech.edu/overview/HD169142>



Remarkably close to a circular orbit (37 au)

Looking Ahead

ESA Voyage 2050



(credit: Jaehan Bae)

Summary

- Signatures of protoplanets are everywhere
- Planets form fast, possibly before the protoplanetary disc phase
- High-contrast imagers have to work in parallel with ALMA
- Simulations help us interpret our observations

