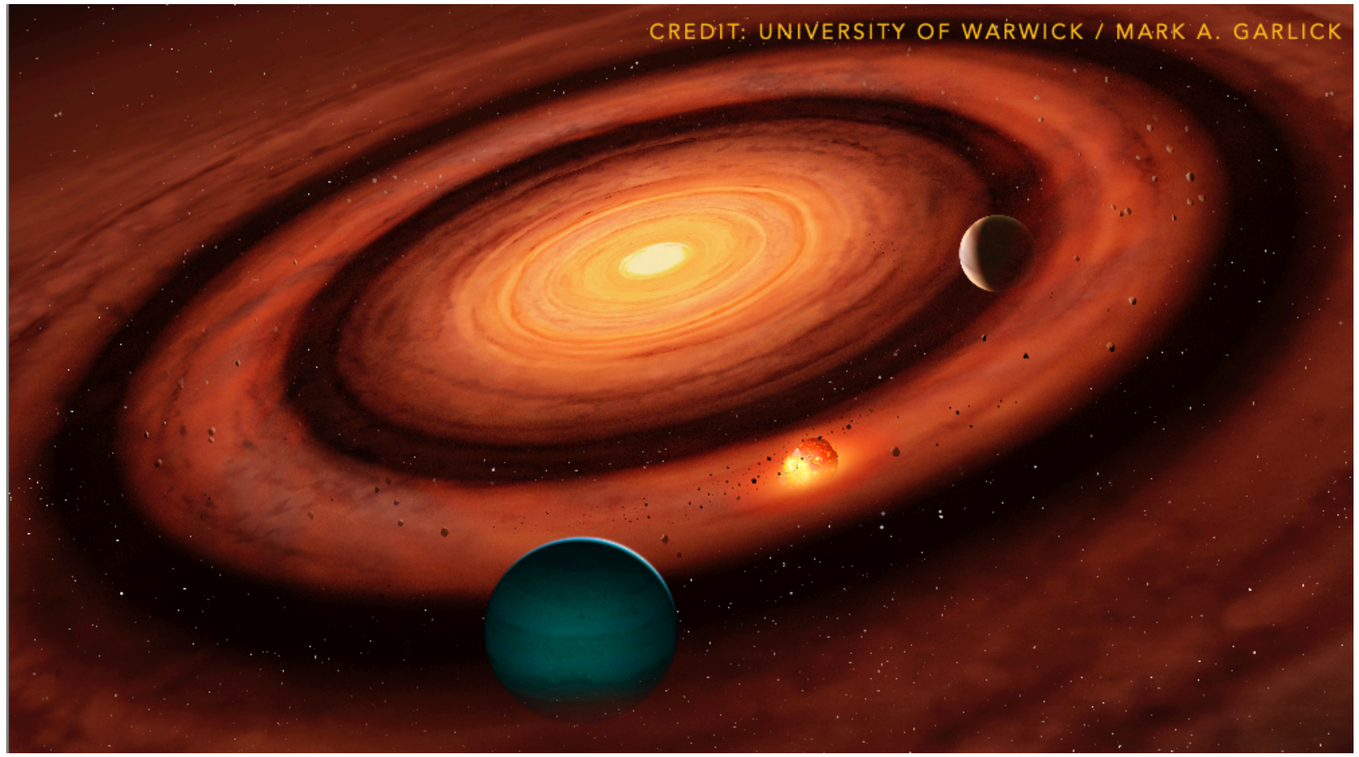
Sandwiched Planet Formation in Action.

Preliminary results



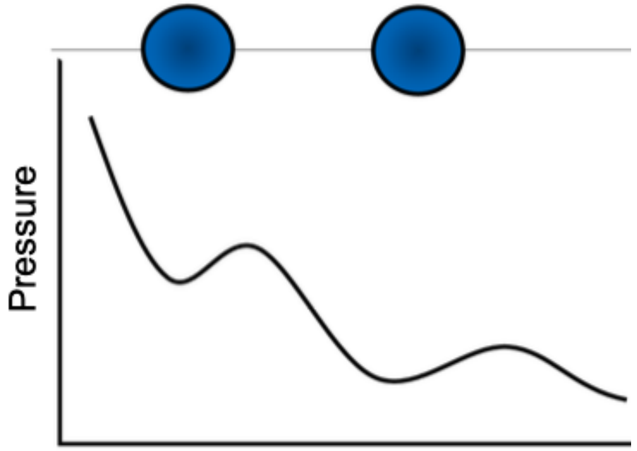
Maria de Juan Ovelar,
Farzana Meru, Paola Pinilla,
Amena Faruqi, and Michiel Min

UKI Discs Meeting, September 2024

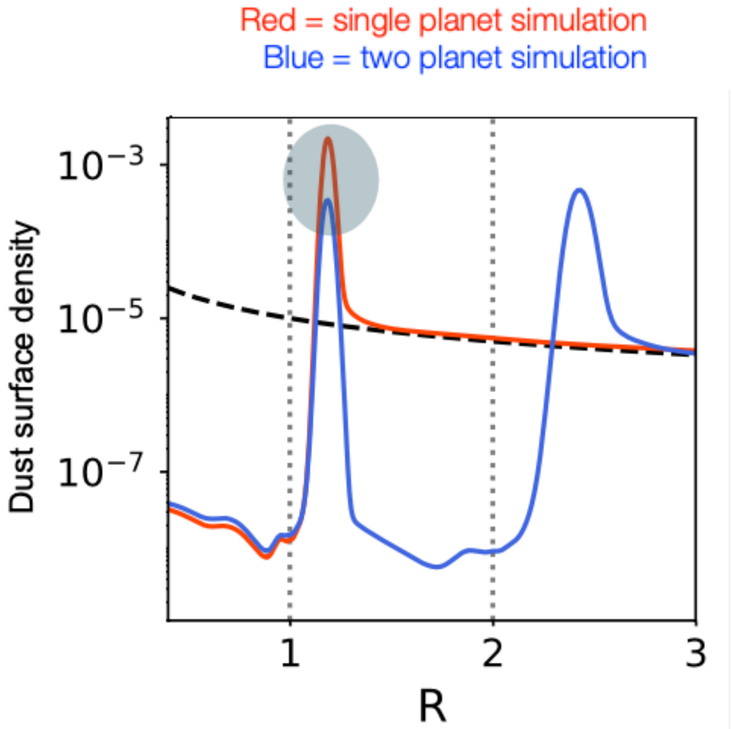
Sandwiched Planet Formation

Pritchard, Meru et al. 2024

- When 2 planets are present, they create two rings in the disc by creating dust traps (Pinilla et al. 2012b)
- The mass of dust in the inner ring is depleted
- Less amount of solids available to form planets -> resulting bodies will be restricted in mass



Pritchard, et al. 2024



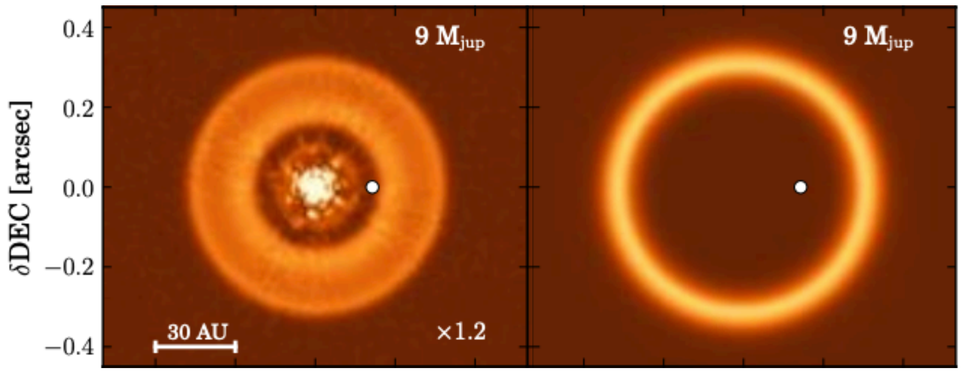
Sandwiched Planet Formation

Background

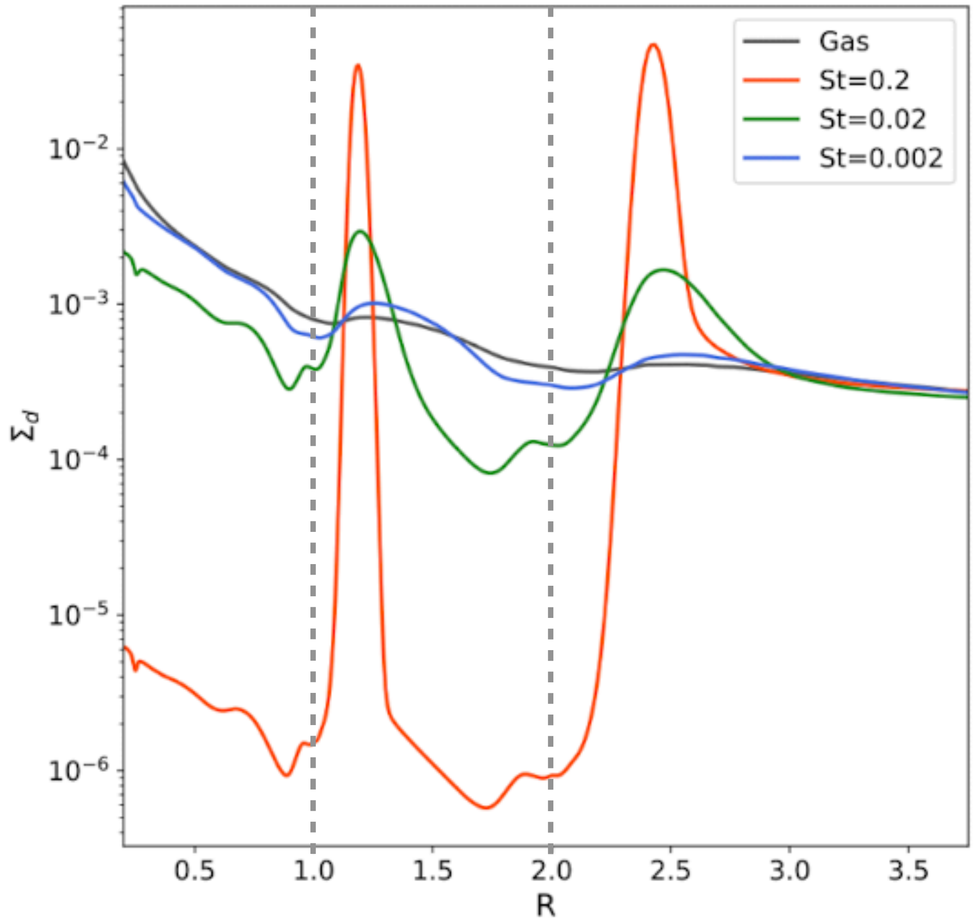
- These traps affect different dust grain sizes differently

-> Observations at different wavelengths will be affected!

0.65um (Pol. Int.) 850um



de Juan Ovelar et al. 2013



Pritchard, et al. 2024

Sandwiched Planet Formation

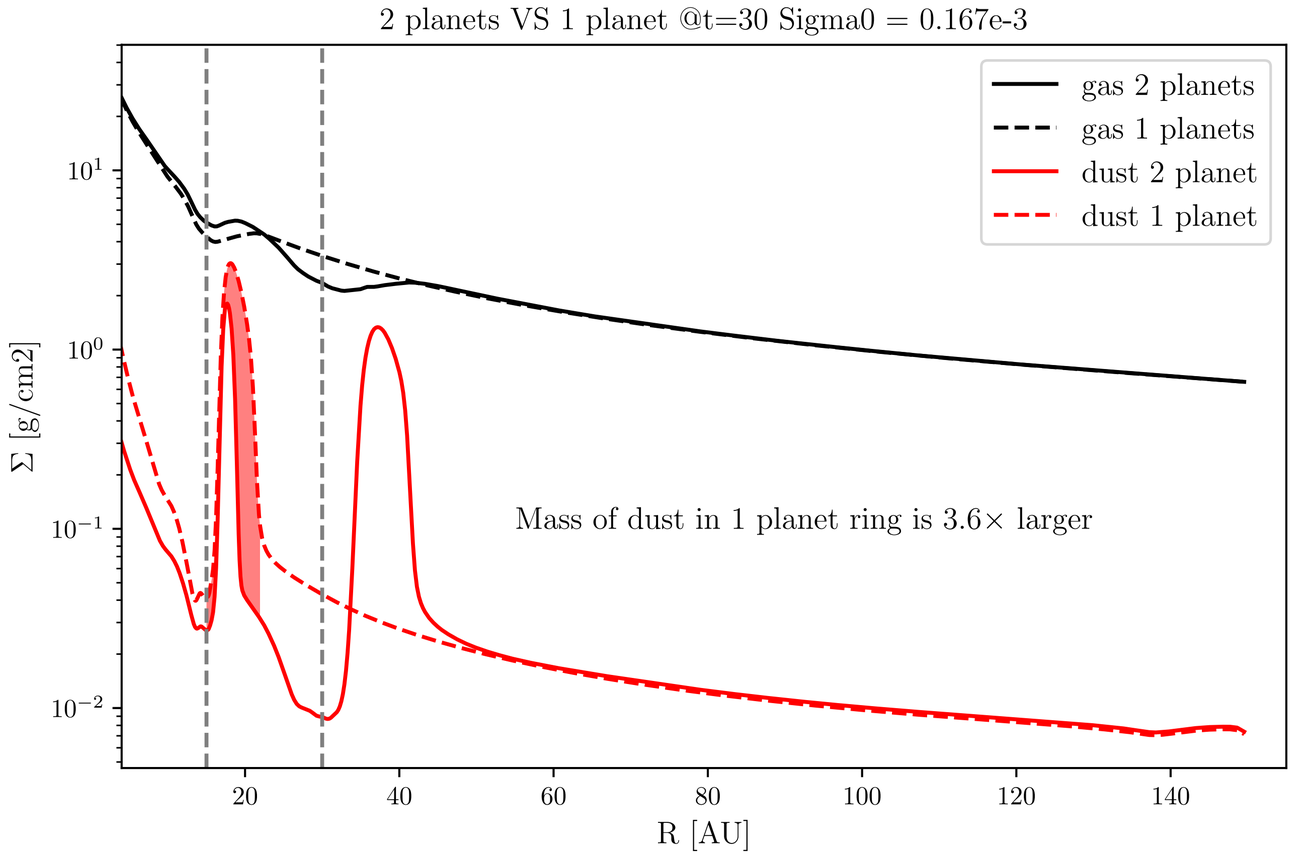
This work: observational signatures of SPF De Juan Ovelar et al. in prep.

- Hydrodynamical simulation of gas and dust grain sized species ranging from 1um to 1cm (FARGO 3D Multi-fluid).
- Radiative transfer simulation to create images of the discs at different wavelengths (MCMax).

Sandwiched Planet Formation

This work: observational signatures of SPF

- 0.01M_{Sun} disc with two 20,35 M_{Earth} planets at 15,30 AU
- x3.6 less mass available in the innermost ring



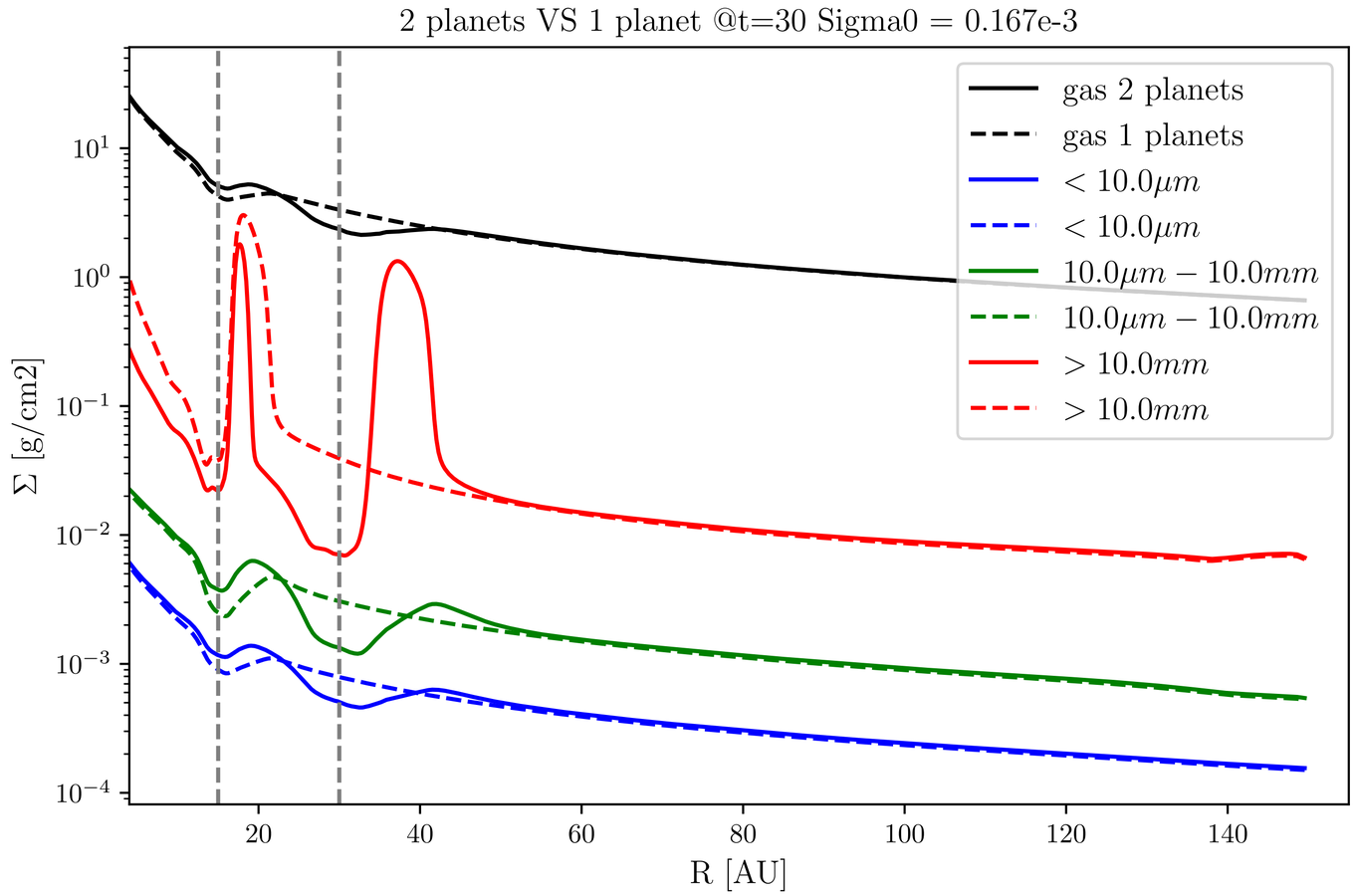
De Juan Ovelar et al. in prep.

Sandwiched Planet Formation

This work: observational signatures of SPF

ALSO:

- Large dust grains are depleted in the inner ring while smaller grains are able to reach it
- The outermost ring is mostly populated with large grains

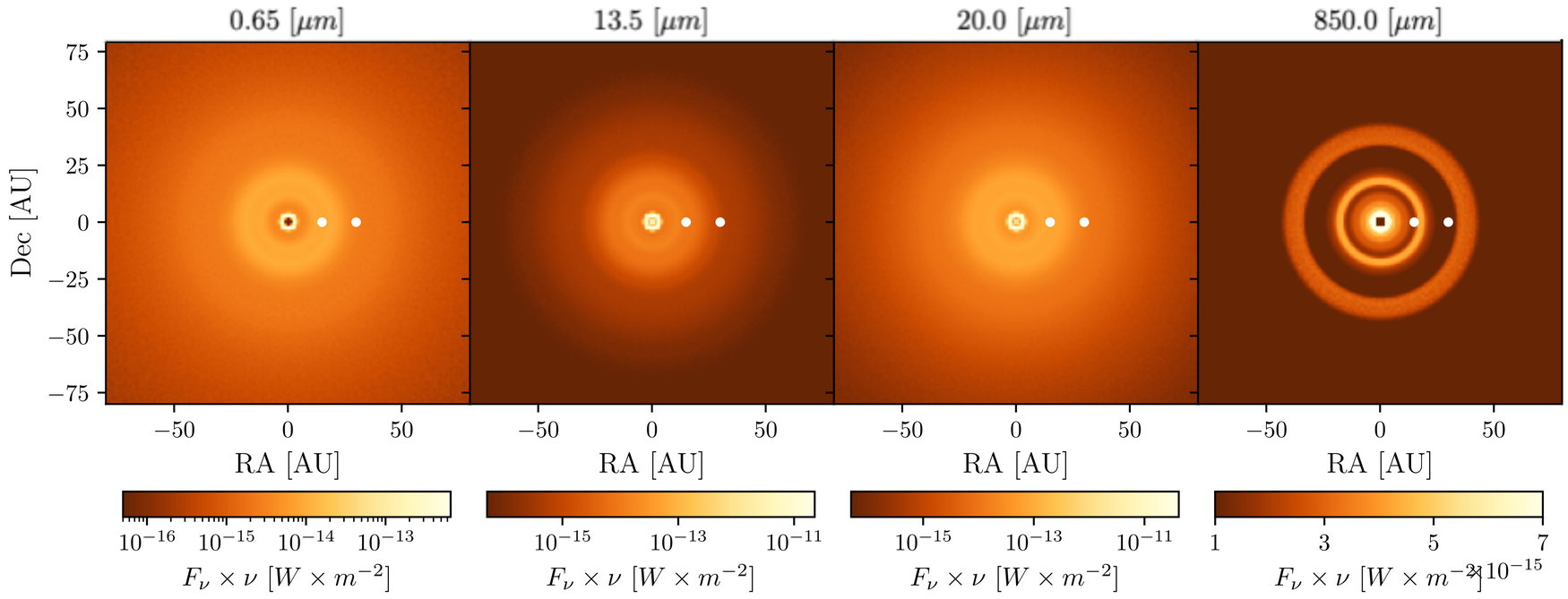


De Juan Ovelar et al. in prep.

Sandwiched Planet Formation

This work: observational signatures of SPF

SPHERE (Pol. Int.) METIS/JWST ALMA

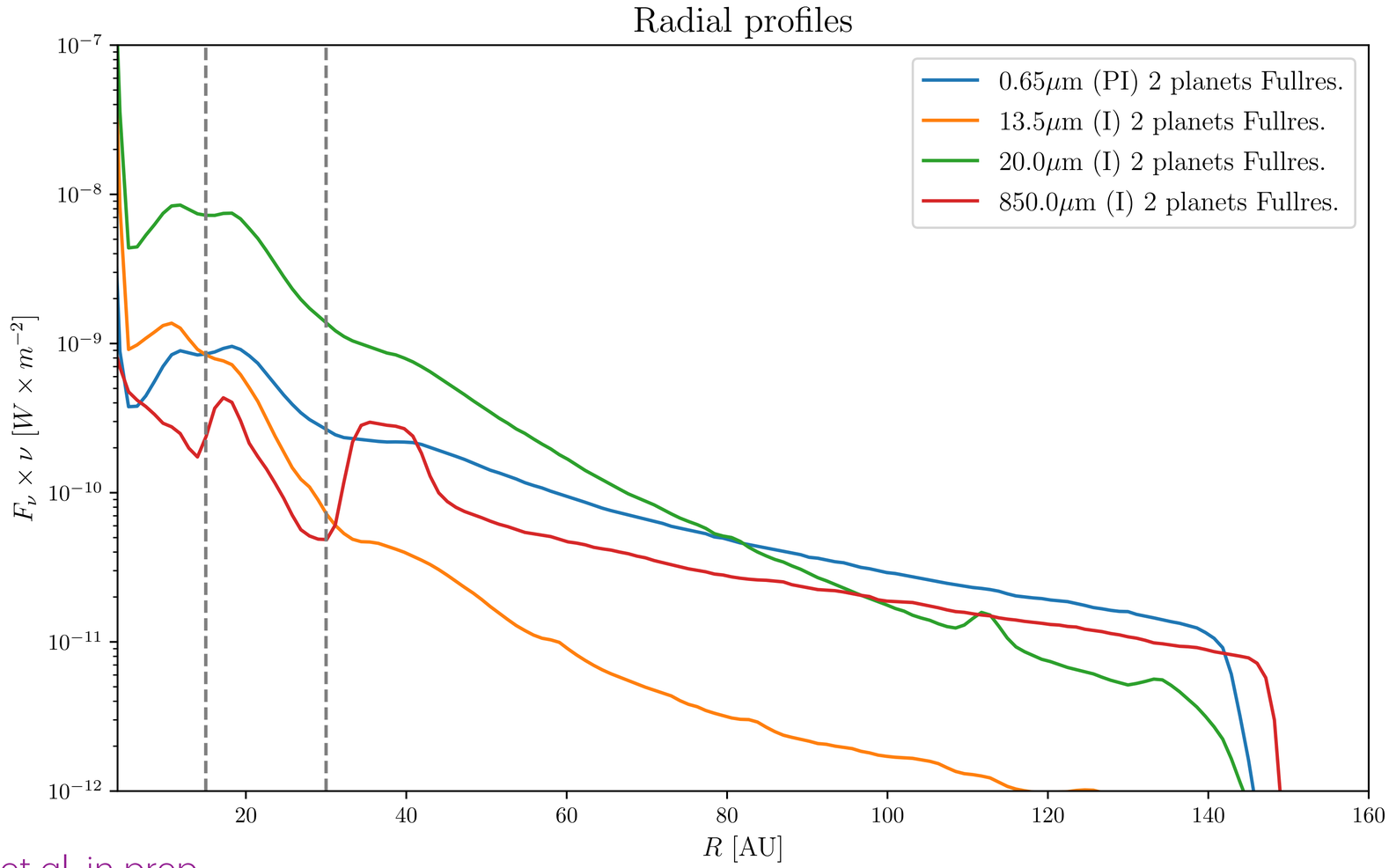


micron-sized dust grains → mm-cm dust grains

De Juan Ovelar et al. in prep.

Sandwiched Planet Formation

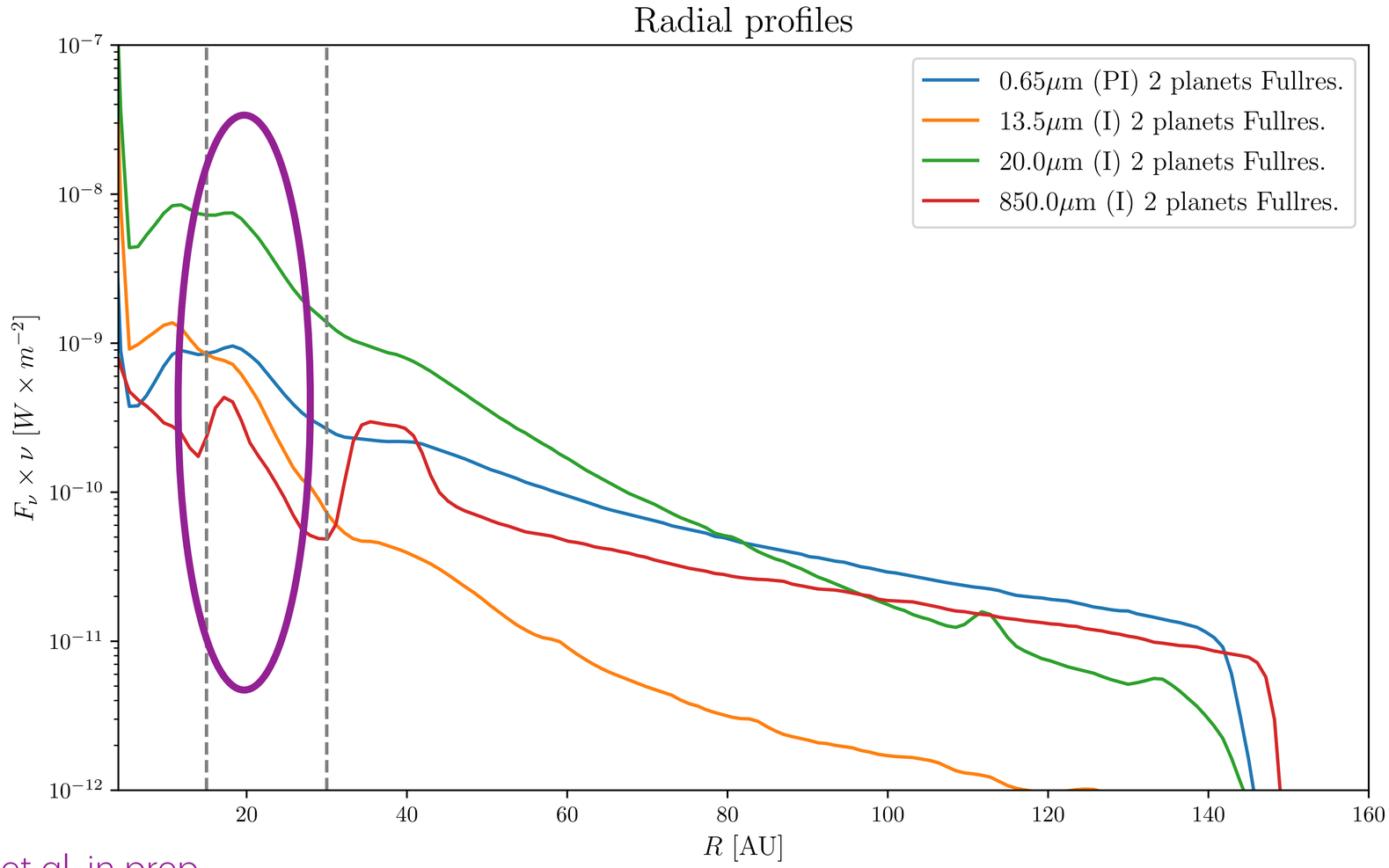
This work: observational signatures of SPF



De Juan Ovelar et al. in prep.

Sandwiched Planet Formation

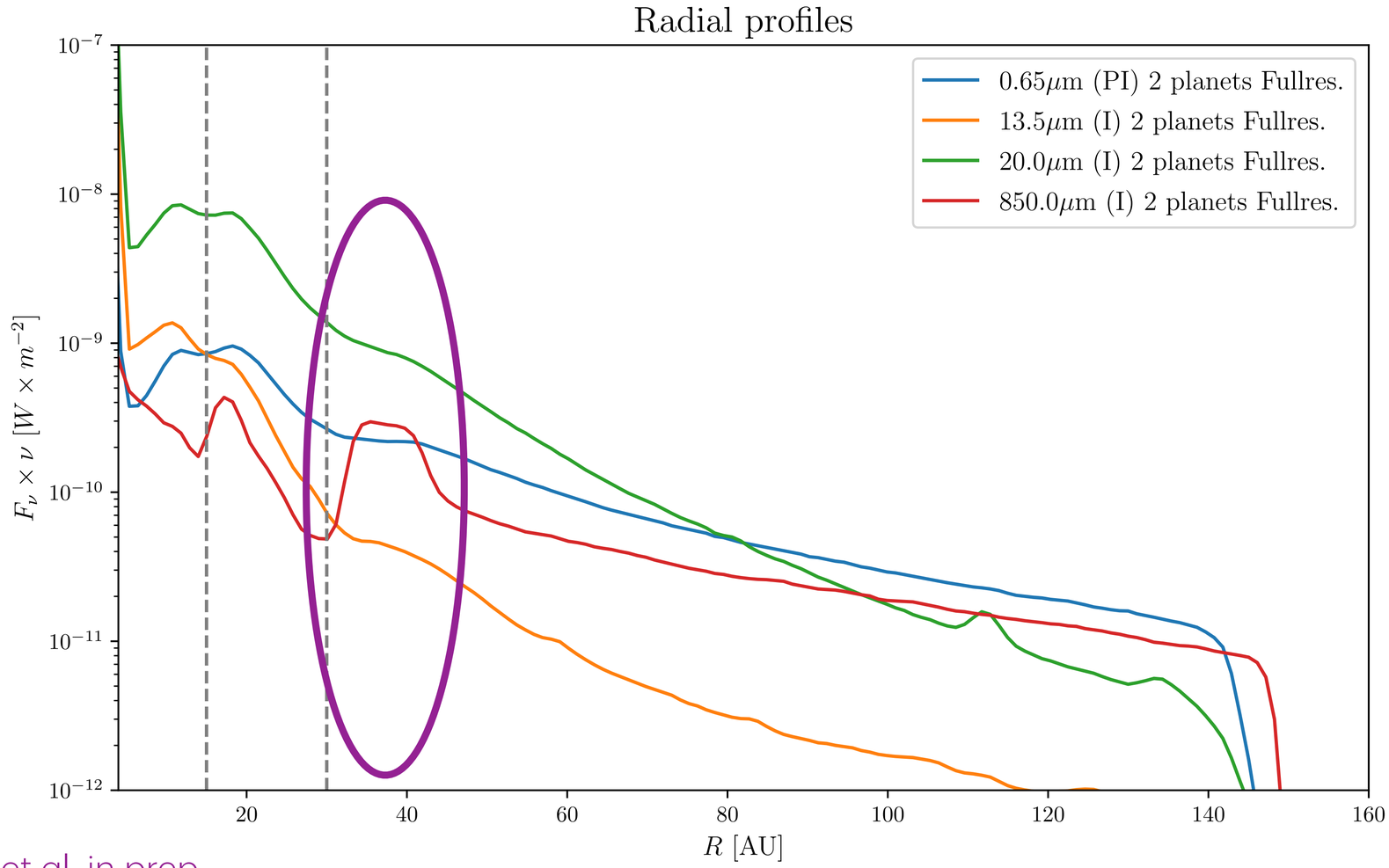
This work: observational signatures of SPF



De Juan Ovelar et al. in prep.

Sandwiched Planet Formation

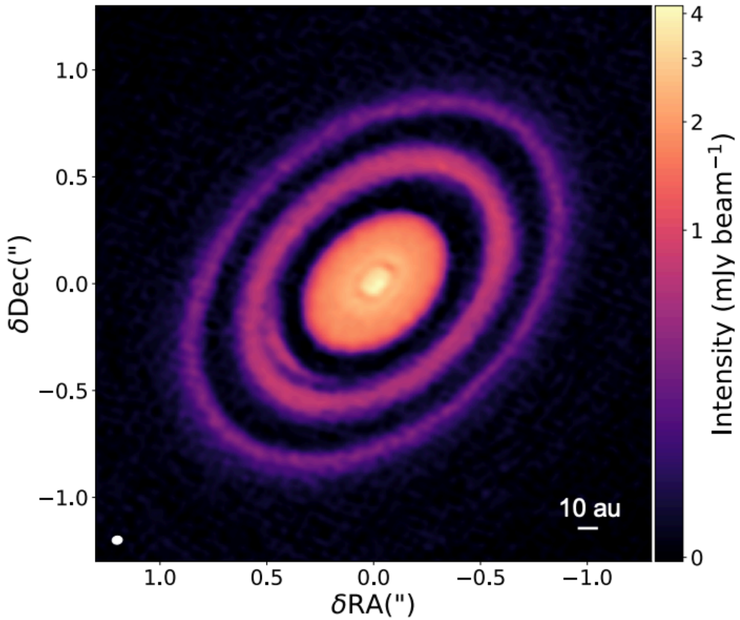
This work: observational signatures of SPF



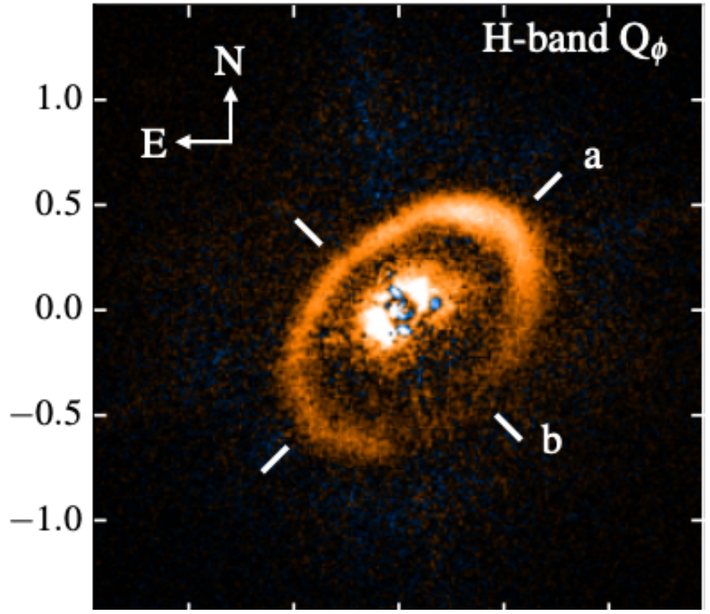
De Juan Ovelar et al. in prep.

HD 163296

observational signatures of SPF



Isella et al. 2018



Muro-Arena et al. 2018

- Is SPF taking place in the innermost ring of HD 163296?

Dust modeling of the combined ALMA and SPHERE datasets of HD163296

Is HD163296 really a Meeus group II disk?

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Received / Accepted

ABSTRACT

Context. Multi-wavelength observations are indispensable in studying disk geometry and dust evolution processes in protoplanetary disks.
Aims. We aimed to construct a 3-dimensional model of HD 163296 capable of reproducing simultaneously new observations of the disk surface in scattered light with the SPHERE instrument and thermal emission continuum observations of the disk midplane with ALMA. We want to determine why the SED of HD 163296 is intermediary between the otherwise well-separated group I and group II Herbig stars.
Methods. The disk was modelled using the Monte Carlo radiative transfer code *MCMax3D*. The radial dust surface density profile was modelled after the ALMA observations, while the polarized scattered light observations were used to constrain the inclination of the inner disk component and turbulence and grain growth in the outer disk.
Results. While three rings are observed in the disk midplane in millimeter thermal emission at ~80, 124 and 200 AU, only the innermost of these is observed in polarized scattered light, indicating a lack of small dust grains on the surface of the outer disk. We provide two models capable of explaining this difference. The first model uses increased settling in the outer disk as a mechanism to bring the small dust grains on the surface of the disk closer to the midplane, and into the shadow cast by the first ring. The second model uses depletion of the smallest dust grains in the outer disk as a mechanism for decreasing the optical depth at optical and NIR wavelengths. In the region outside the fragmentation-dominated regime, such depletion is expected from state-of-the-art dust evolution models. We studied the effect of creating an artificial inner cavity in our models, and conclude that HD 163296 might be a precursor to typical group I sources.

The Astrophysical Journal Letters, 959:L15 (10pp), 2023 December 20 https://doi.org/10.3847/2041-8213/ad0c54

Observing Planetesimal Formation under Streaming Instability in the Rings of HD 163296

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Abstract

We introduce a new technique to determine the gas turbulence and surface density in bright disk rings, under the assumption that dust growth is limited by turbulent fragmentation at the ring center. We benchmark this prescription in HD 163296, showing that our measurements are consistent with available turbulence upper limits and agree with independent estimates of the gas surface density within a factor of 2. We combine our results with literature measurements of the dust surface density and grain size to determine the dust-to-gas ratio and Stokes number in the 67 and 100 au rings. Our estimates suggest that particle clumping is taking place under the effect of streaming instability (SI) in the 100 au ring. Even though in the presence of external isotropic turbulence this process might be hindered, we provide evidence that turbulence is nonisotropic in both rings and likely originates from mechanisms (such as ambipolar diffusion) that could ease particle clumping under SI. Finally, we determine the mass accretion rate under the assumption that the disk is in steady state and turbulence regulates angular momentum transport. Our results are in tension with spectroscopic measurements and suggest that other mechanisms might be responsible for accretion, in qualitative agreement with the detection of a magnetocentrifugal wind in this system. Applying our method to larger samples can be used to statistically assess if SI is a viable mechanism to form planetesimals in bright rings.

Unified Astronomy Thesaurus concepts: CO line emission (262); Dust continuum emission (412); Gas-to-dust ratio (638); Planet formation (1241); Planetary cores (1247); Planetesimals (1259); Protoplanetary disks (1300); Submillimeter astronomy (1647)

Next Steps

observational signatures of SPF

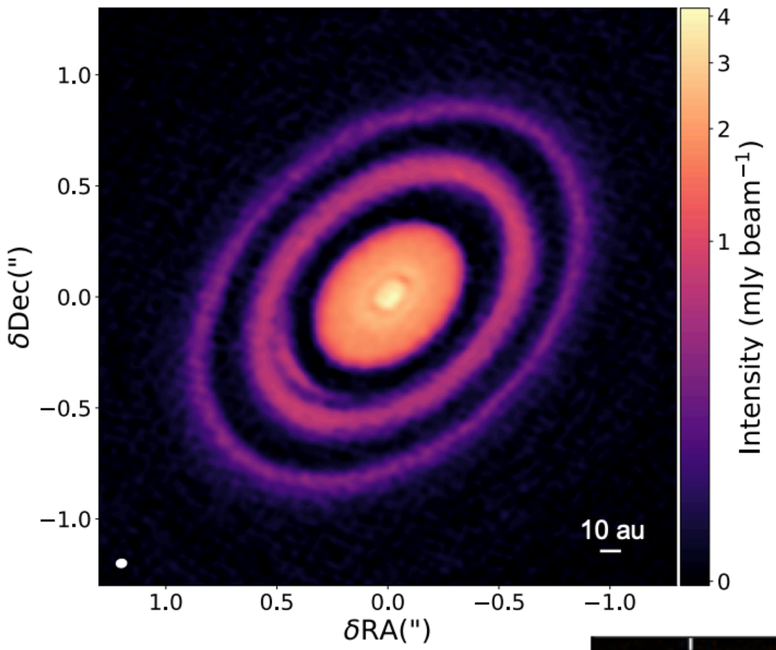
- Grid of models varying disc parameters and outer planet mass (MSc. student Mateusz Potrikus)
- Including the effect of dust evolution in these rings (see Amena Faruqi's talk next)
- Exploring the millimetre band range of ALMA -> narrowing of the ring trend? Spectral index analysis, etc...
- Exploring shadowing effects
- Synthetic observations using instrument simulators to establish what can be measured with current facilities

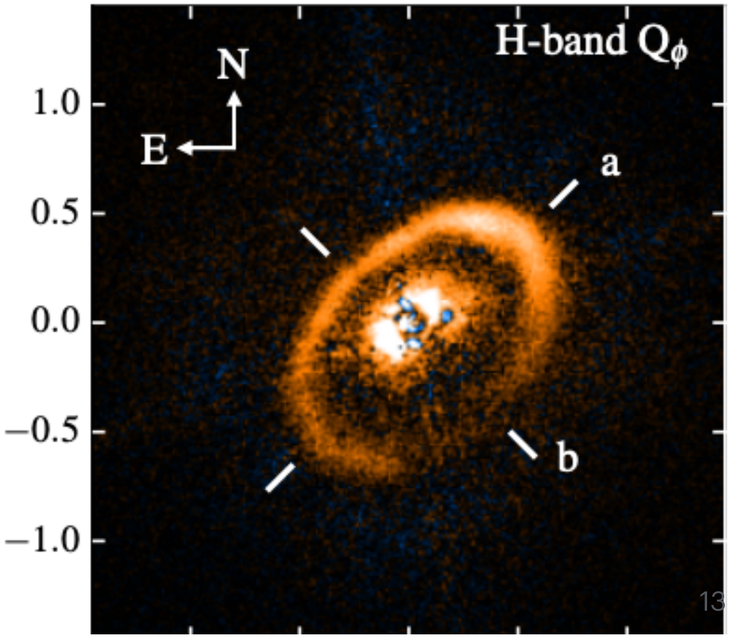
Ideas welcome!

Conclusions

observational signatures of SPF

- Sandwiched Planet Formation could explain observations where multiple rings are clearly detected in sub-mm imaging observations but not at shorter wavelengths.
- HD 163296 is an exceptional target to test this theory.
- Multi-wavelength observations are key to understand planet formation processes in PPDs





Thank you!