

# Results from the Planet-Earth Building-Blocks Legacy e-MERLIN Survey (PEBBLeS) - how do the rocks start forming in discs?

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for the PEBBLeS team, key personnel:

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# *why use radio wavelengths, are you insane?!*

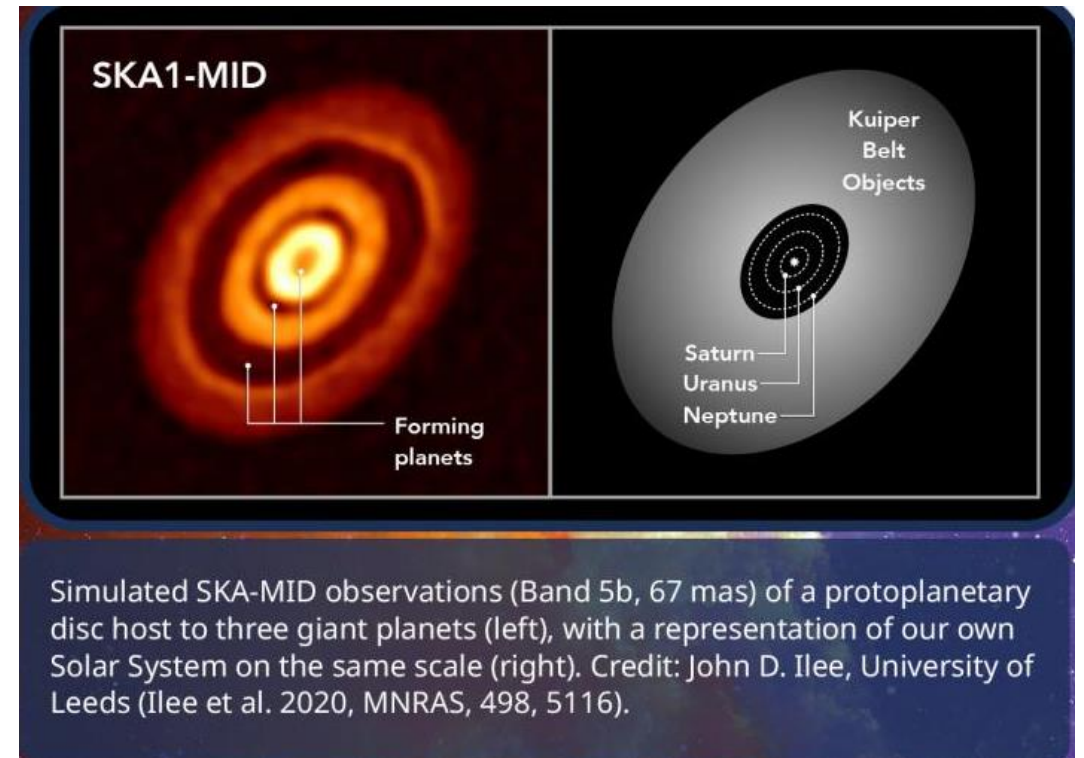
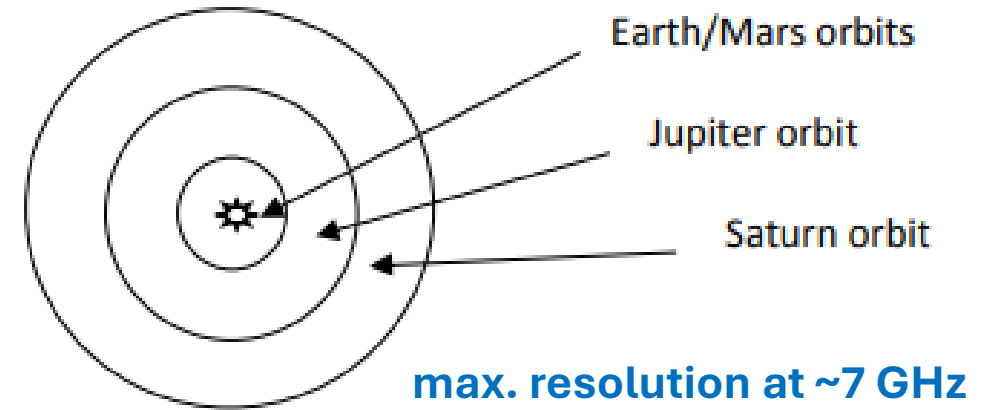
- dust spectrum  $F_\nu \propto \nu^2$  or steeper means  $\mu\text{Jy}$  fluxes from protoplanetary discs
- but unique to view the disc midplane (ALMA doesn't)
- shows grain radii  $\sim \lambda/2\pi$  are present (mini rocks!)
- superb resolution (to a few AU at  $\sim 100$  pc)





# hence: PEBBLeS

- approved for ~400h on e-MERLIN in 2017 (feasibility study 2009+)
  - main observing phase 2020/2021, finishing off HL Tau now
- unique resolution to separate pebbles growing where terrestrial planets are versus (present-day) orbits of Sun's giant planets
- northern-sky-counterpart / precursor-survey for #1 goal of “Cradle of Life” science with SKA



# survey design

- unbiased + flux-limited
  - young stars within 250 pc at northern Dec. (essentially Tau + Per)
  - $F_{\text{dust}} > 1$  mJy at  $\lambda \approx 9$  mm (from Disks@EVLA and VANDAM)
- 10 fields: 10 primary targets +  $\approx 20$  other discs in the fields

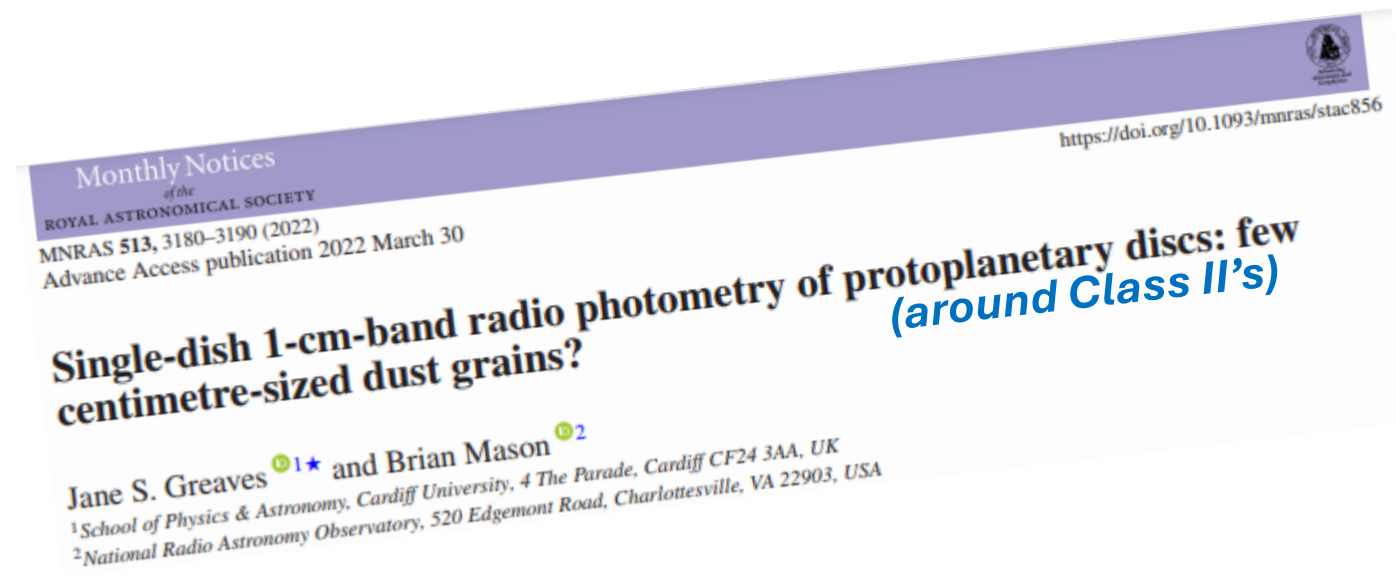
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Primary	other
DG Tau A	DG Tau B (53")
RY Tau	—
L1448C (Per-emb-26)	L1448C-S (Per-emb-42, 9"); L1448N/L1448IRS3B (Per-emb-33-A,B,C, 76"); L1448IRS3A (82"); L1448NW-A,B (97")
IRAS4A1 (Per-emb-12A)	IRAS4A2 (Per-emb-12B, 0.6"); IRAS4B (Per-emb-13, 35"); IRAS4B' (38"); IRAS4C (Per-emb-14, 47")
GV Tau S	GV Tau N (1")
Haro 6-13	—
IRAS 2A (Per-emb-27A)	IRAS 2A-VLA2 (Per-emb-27B, 0.6"); IRAS 2B-A (Per-emb-36-A, 31"); EDJ2009-183A (86"); SVS13C (102")
Per-emb-50	Per-emb-57 (96")
MWC 480	—
HL Tau	XZ Tau A,B (22"); LkH $\alpha$ 358 (37"); HH30 (V1213 Tau, 95")

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# how successful?

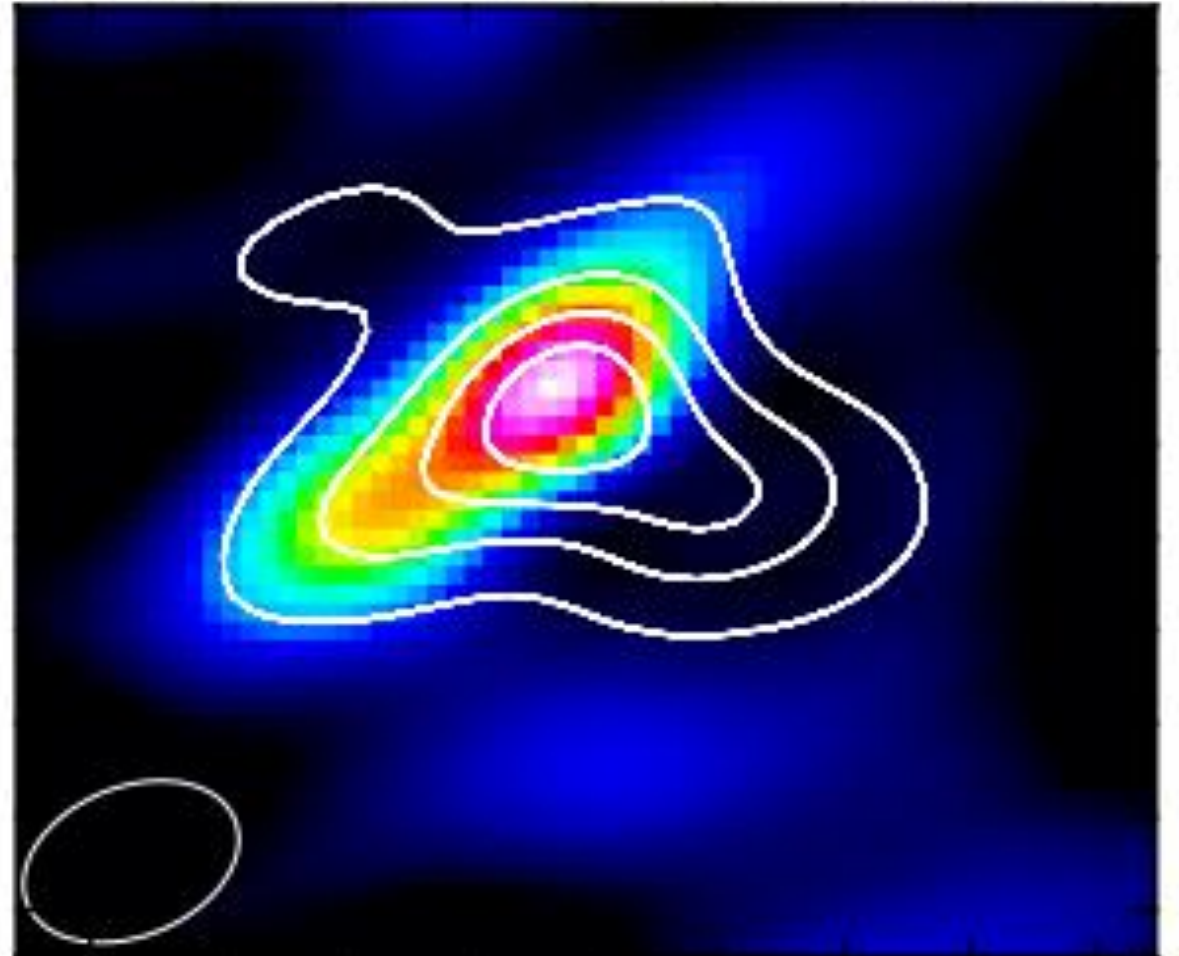
- compromise on resolution to get more sensitivity ( $\rightarrow$  rms  $\approx$  6  $\mu$ Jy/beam)
  - Jupiter and terrestrial planet orbits are all in the central beam
- dust discs are detected! (down to  $\sim$ 40  $\mu$ Jy - *wowzas*)
  - robust, use known orientations on sky
- survey is 50% processed – not finding many protostellar discs yet?
  - is growth phase short?
  - not all discs make pebbles?



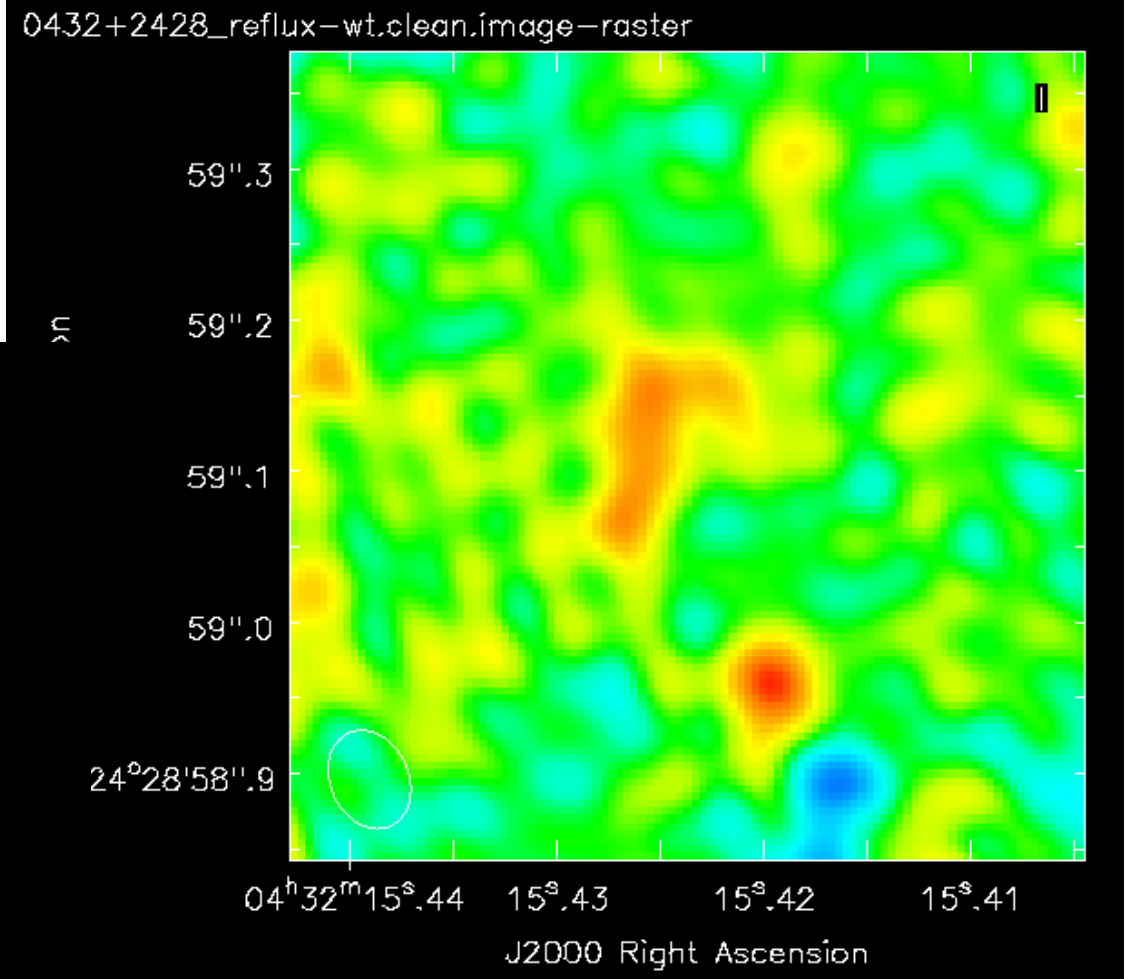
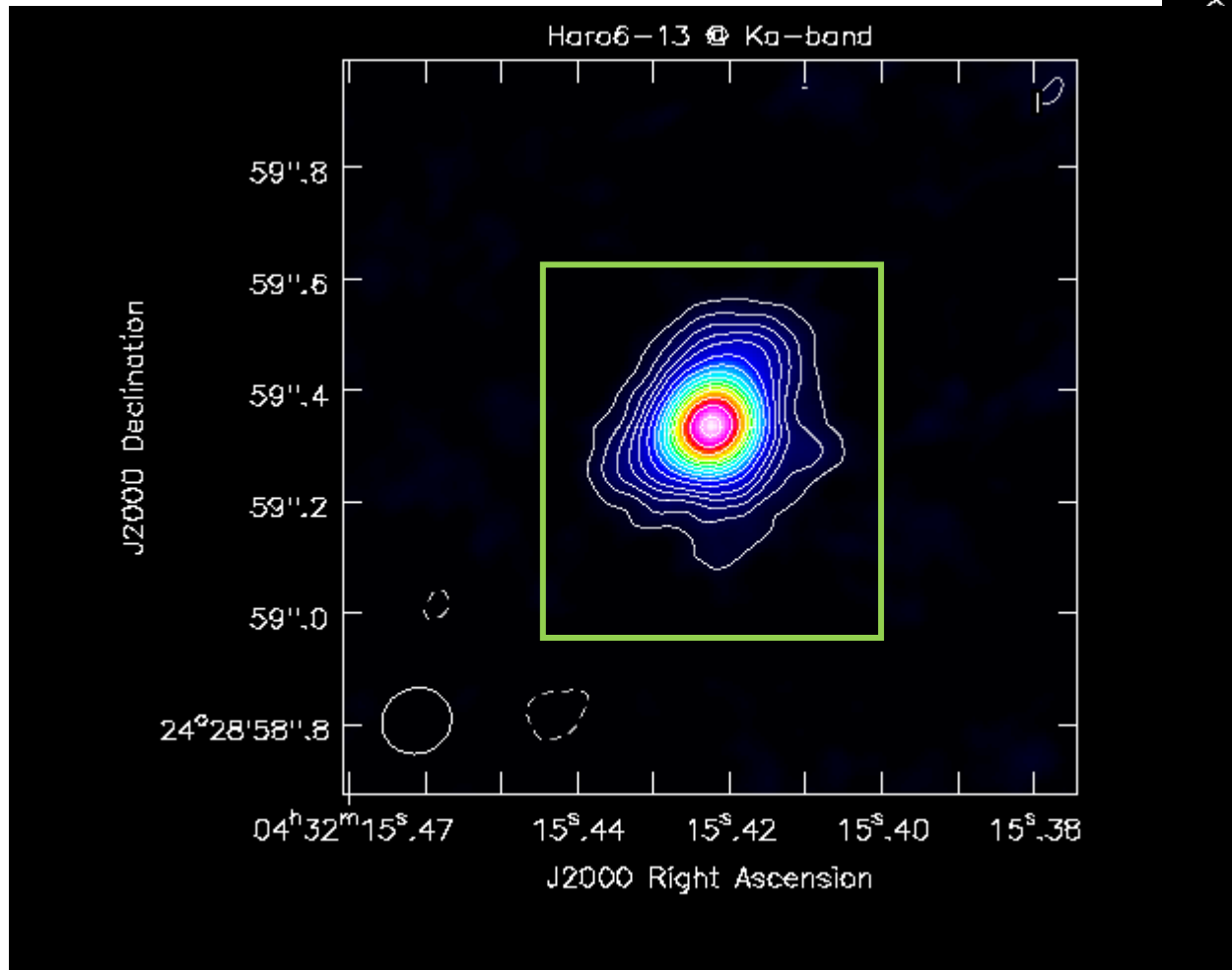
# DG Tau A

- $\lambda=4.5$  cm disc extends out to  $\sim 30$  AU from the star (Neptune-orbit-like scale)
  - continuous SED to this wavelength (requires some pebbles to be there)
- real (seen in 3 epochs) asymmetry with a flux peak SE of star
  - streaming instability?

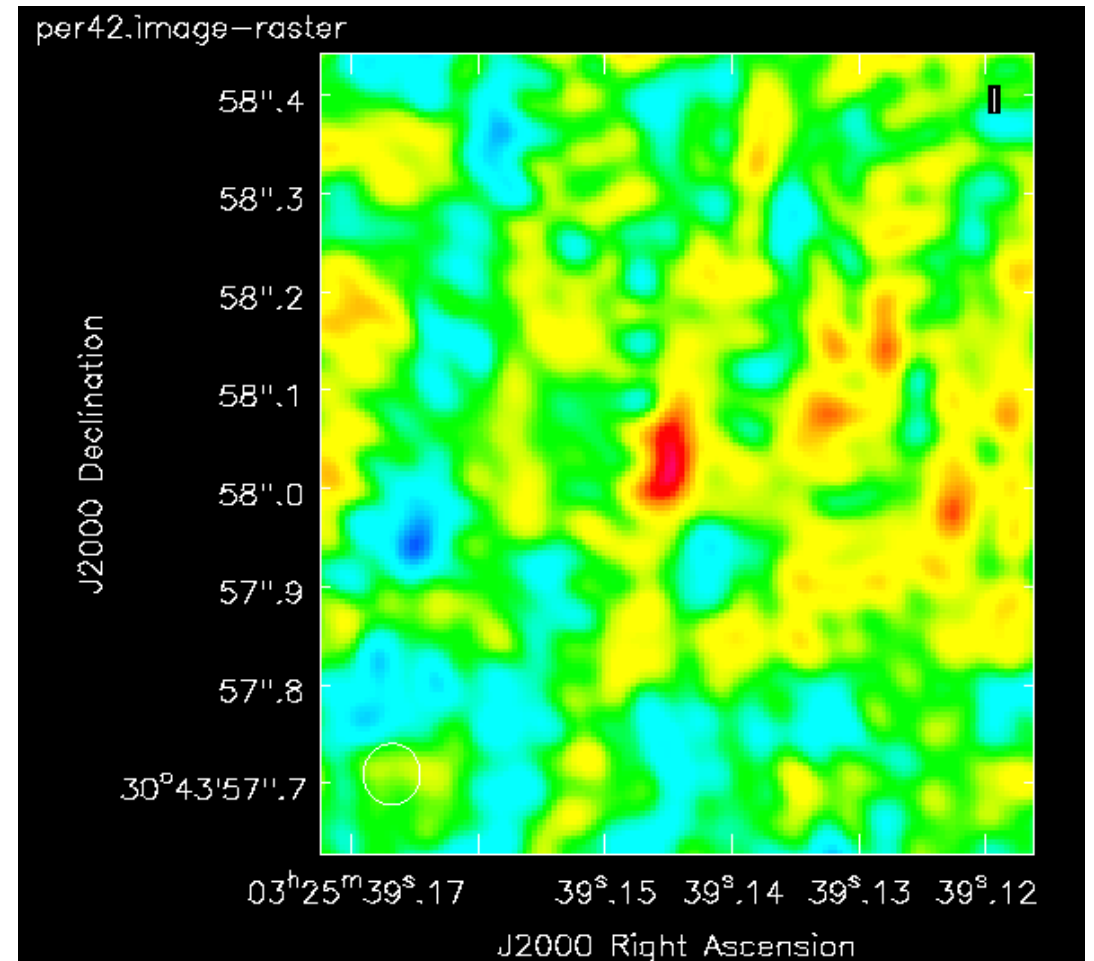
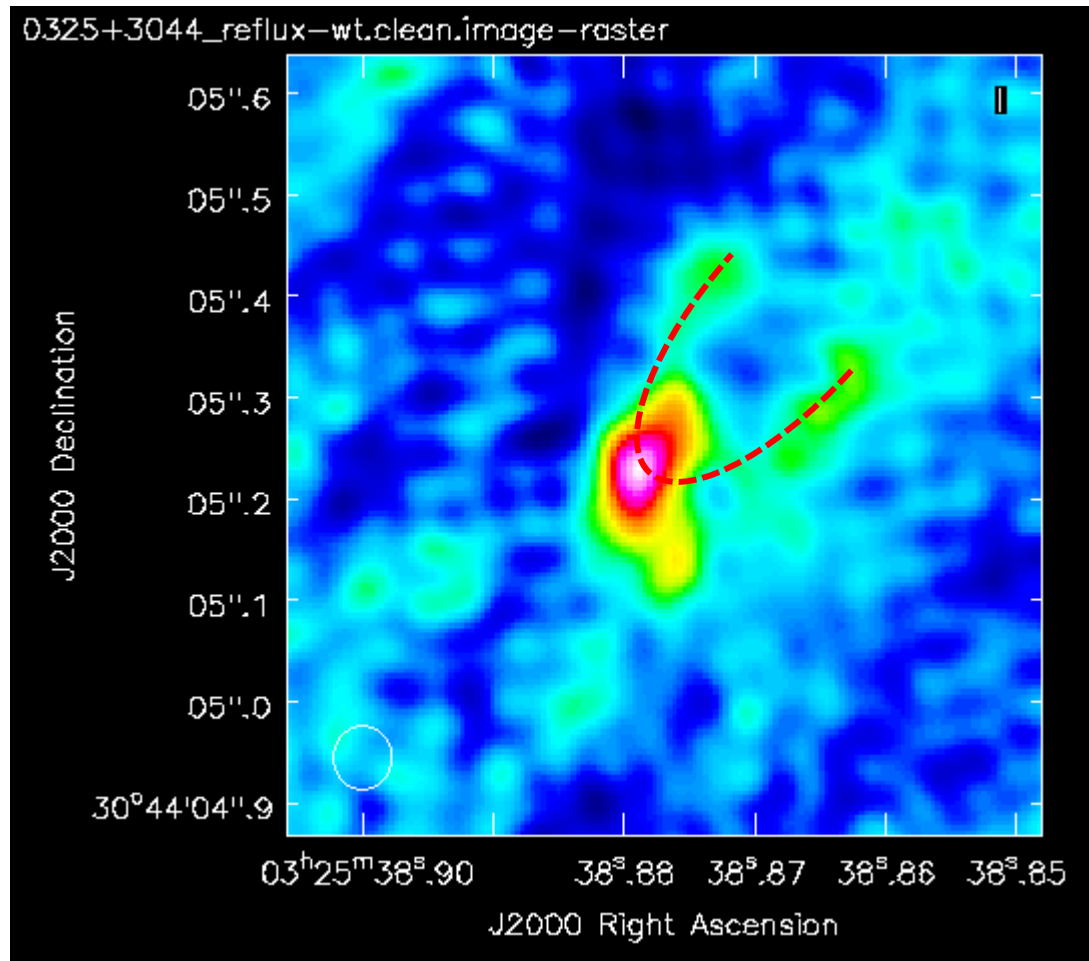
DG Tau @ C-band jets subtracted



# Haro 6-13



# L1448C-S



**primary, L1448C, shows emission mainly from the outflow – only the secondary shows a 4.5 cm dust disc**



# what's next

- PEBBLEs stats: any trends over  $\approx 30$  discs? [Greaves et al., in prep](#)
- planning for SKA (Key Science Projects to start  $\approx 2030$ )
- expand e-MERLIN even further! (up to 400 km baselines)

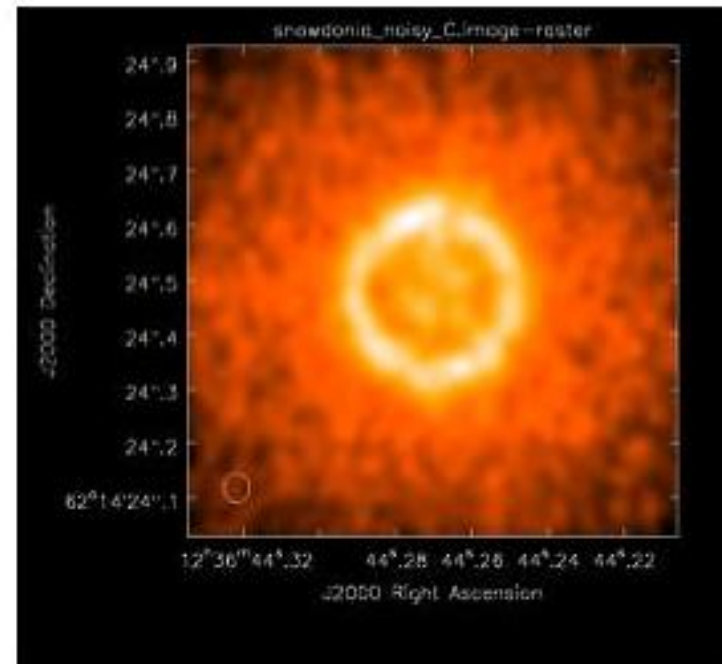
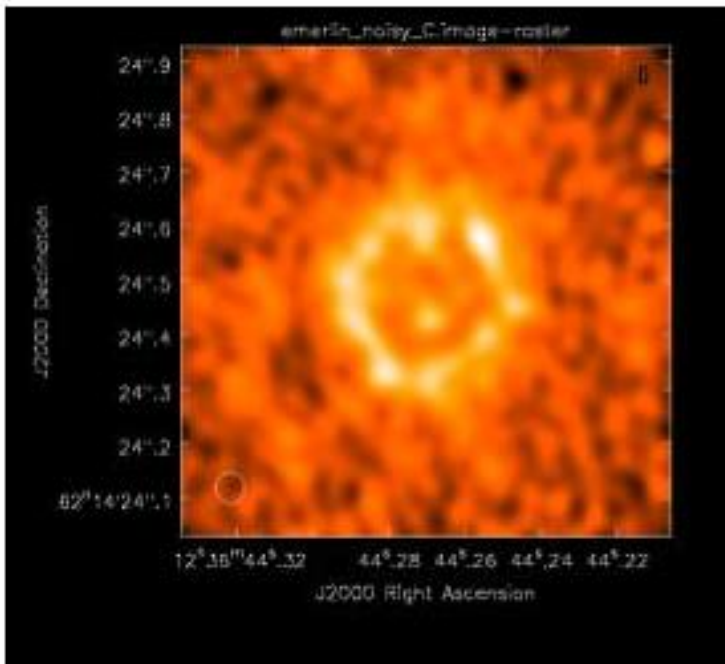


Figure 3: Comparison between the predicted view of the planetary disk at C-band (5.5 cm) using present e-MERLIN (left) and an upgraded array including an Antenna at Spaceport Snowdonia (right).