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PEBBLES: Proto-planetary discs with eMERLIN and SKA

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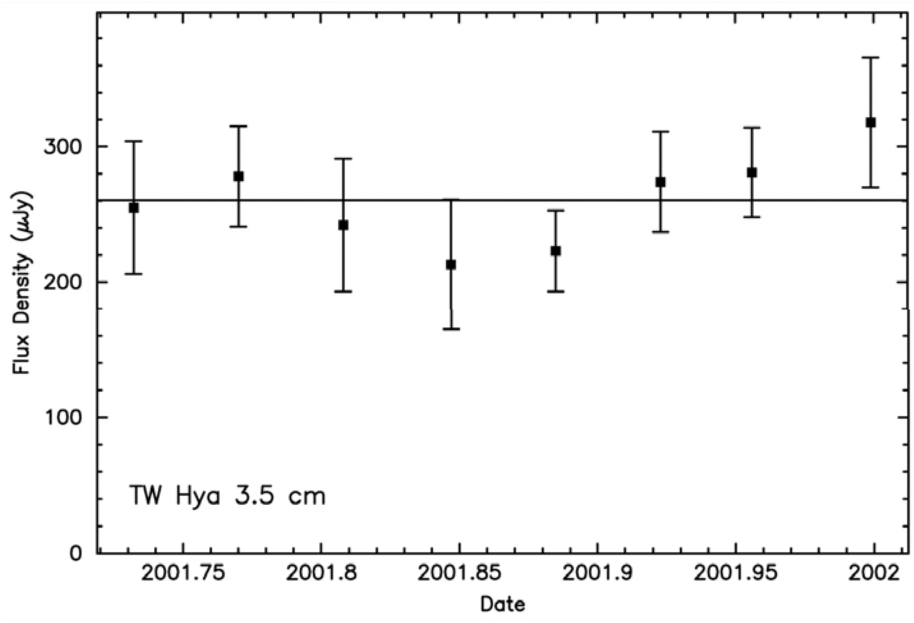
grain emission

- simply 'blackbody' continuum from rock particles
  - e.g. peaks at 10 microns for ~300 K temperature at Earth's orbit, but a long ν^2 tail
    - discovered at 3.5 cm for grains orbiting TW Hya, by accident! (Wilner et al. 2005)



why study it?

- traces super-sized grains
  - particles are actually greybodies: emit wavelengths larger than their size inefficiently
  - so cm-flux means pebble sized bodies exist
- this is about halfway from sub-micron ISM dust to 1000-km+ regime of planets
  - a critical growth stage as mm-sized aggregates tend to shatter in collisions
  - hence shows the onwards path to planets is possible

high resolution

- with VLA+Pie-Town at 1.3 cm, for HL Tau at 140 pc, achieved ~10 AU resolution for the first time
  - i.e. Jupiter's orbit
- see large dust out to ~30 AU … and a bonus candidate proto-planet!!

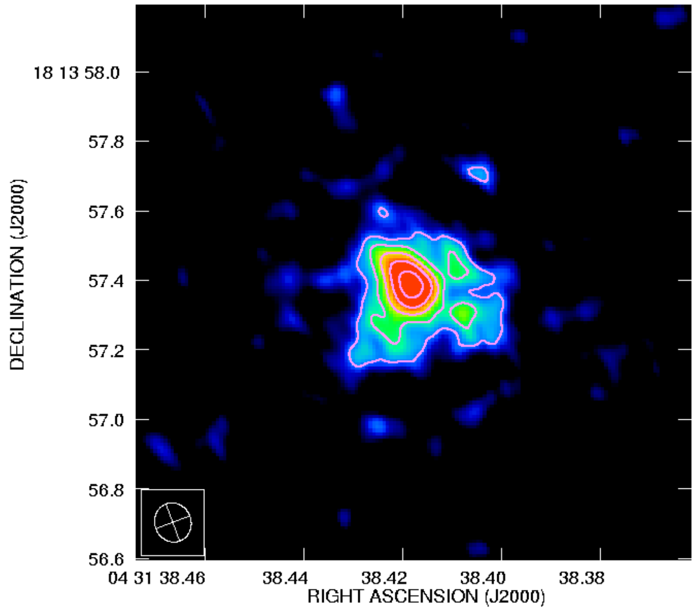


Figure 1: HL Tau disk at 1.3 cm with a resolution equivalent to Jupiter's orbit (size of central unresolved peak). NE/SW features are bases of the jets and NW, SE lobes are the ends of an inclined disk extending to ~Neptune's orbit. The marginally resolved candidate proto-planet at 55 AU is to the NW (upper right).

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- if there's one of these, there should be more!
- hence PEBBLES,
  - Planet Earth Building Blocks: a Legacy eMERLIN Survey
  - 5 cm continuum imaging of 13 fields
- aims to be complete for
  - northern star formation regions at <250 pc
  - with a mass-limited cut at >= 2.5 MMSN
  - 40 mas resolution = resolve terrestrial and gas giant formation zones

the team

- PI Jane Greaves, and

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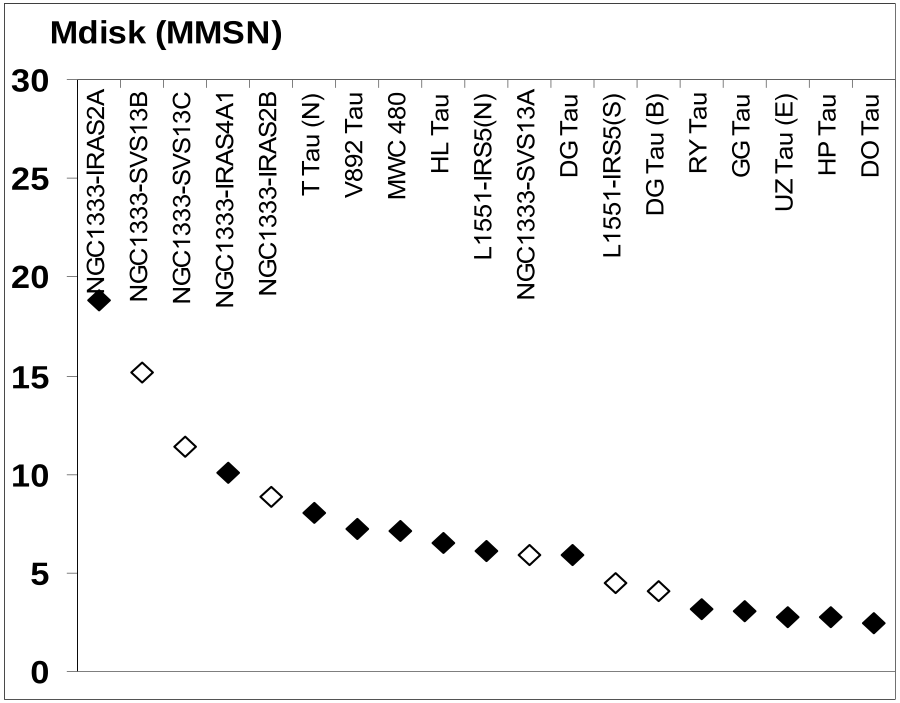
PEBBLES

science goals

- which of these candidate planet-forming discs are actually forming pebbles?
  – stars 0.1-7 Myr old (SED classes 0-II), spectral types A to M, singles/multiples...
- where does this growth occur within the discs?
  – inside/outside the snowline?
- what mass reservoir is there is dust
  – is it actually clumping into proto-planets?

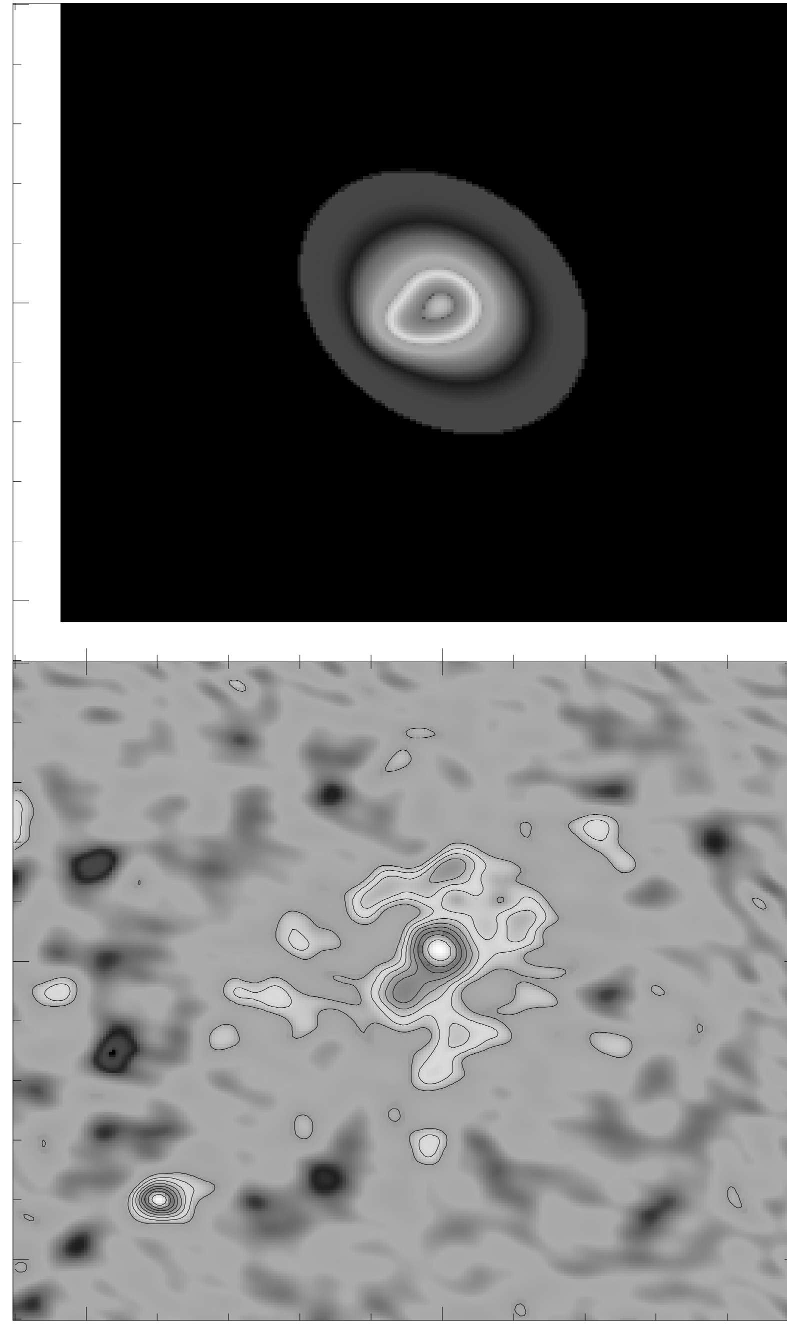
targets

Mass-ordered plot of the 19 target disks in PEBBLES, from 2.5-19 MMSN. Targets have 3mm-1.3cm data already indicating some dust growth. Unfilled symbols are disks lying in the same eMERLIN field as a brighter object.



simulations

Model $r^{-1.5}$-profile disk and predicted eMERLIN image at 5 cm, from simulation at PEBBLES bandwidth and depth plus reduction with correct baseline weighting (60 mas restoring beam). Total flux is 150 microJy (~10 MMSN at 140 pc). The simulation clearly shows the inner disk to 7 AU (50 mas) and a proto-planet at 13 AU. Images: 500 mas across.



survey status

- prototyping study approved for 6 tracks (2 fields)
- main challenges are broad bandwidth and mini-mosaics of clustered discs
  - need the Lovell: depth is critical
  - wide band can give spectal index map & help pinpoint dust

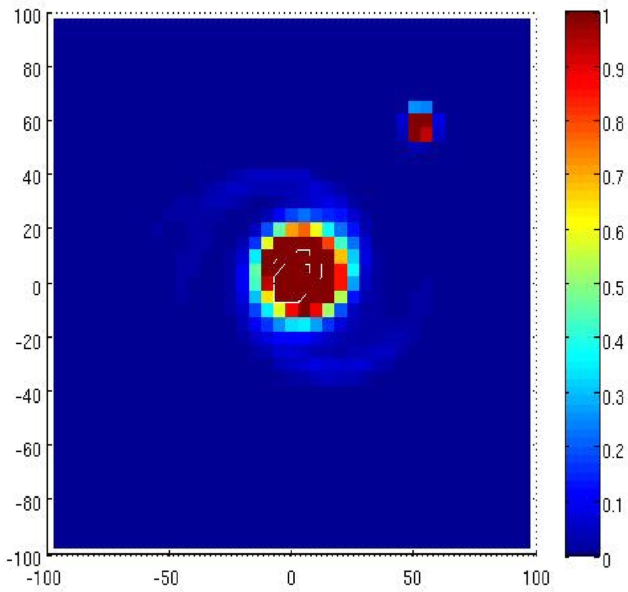
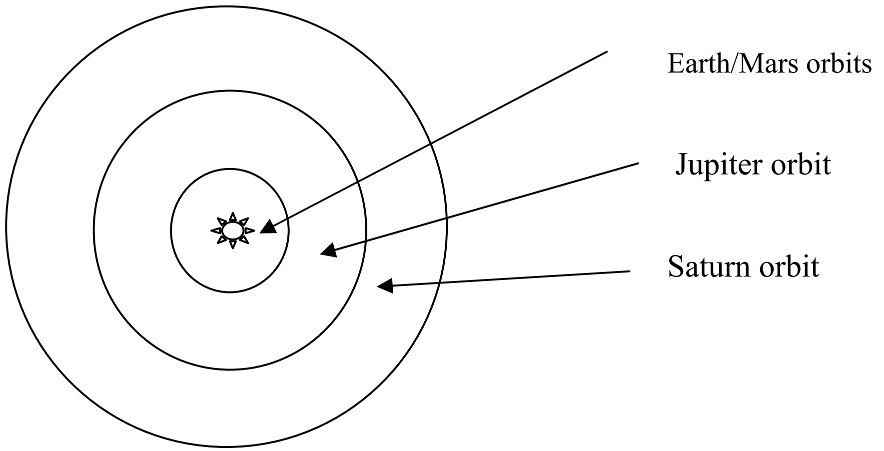


Figure 6. Radio map of the HL Tau disk simulation (Rice, in prep.) showing the overdensity (proto-planet) in the upper right corner and the spiral density waves in the inner disk. The x,y axes are in AU and the pixel size is the 5 AU resolution of eMERLIN at 5 cm. The flux scale is relative; HL Tau b is expected to be ~5 μJy at 5 cm and the accretion (Hill) sphere would be just resolved.

forward look

- PEBBLES can tell us if there are signs of planet formation, and roughly where... *what if we could see an Earth forming??*
    - PEBBLES can (only just) separate the formation zones of terrestrial and gas giant planets

Figure 7. Sketch of face-on disk seen at 140 pc, with annuli of width equal to the eMERLIN 5 cm resolution. For the furthest disks at ~220 pc (i.e. in NGC 1333), Saturn would appear in the same annulus as Jupiter.



why SKA?

- small dust mass spread out in a disc, plus faint emission in the greybody radio tail, makes this science very challenging!
- SKA will be unique for sensitivity and angular resolution at the right wavelengths
  - imaging structures and mapping spectral index unambiguously show growth of large grains in discs and compact protoplanets
    - *chance to see an Earth forming, in the Habitable Zone, before any other technology that can image exo-Earths (DARWIN, etc.) ???*

the dream experiment

- look for Earth-analogues forming in southern star clusters ~10-50 Myr old
    - the era up to our last major (Moon-forming) impact
  - the beta Pic, TW Hya, AB Dor, Tuc/Hor groups, at ~20-60 pc
- for the longest SKA baselines of 3000 km and observing at 5 GHz, resolution = 4 mas
  - at 40 pc, 40 beams around the Earth's orbit at 1 AU (in the Habitable Zone)
    - this is somewhat overkill so plan for 1000 km baselines to start with, 13 beams around orbit

the dream experiment

- forming the Sun's terrestrial planets takes ~ 5 M_{Earth} of rocky material spread over 0.5-4.5 AU
    - Raymond et al. (2009)
  - for a surface density profile of $r^{-1.5}$, a beam at 1 AU includes 0.05 M_{Earth} of rocks
  > flux at 5 GHz is 300 nJy/beam
- for rms ~100 nJy beam in 1 hour, 3 sigma detection in every beam (on average)
    - for A/T = 10,000 m^2/K and 1 GHz bandwidth
  - NB!! fainter as much of mass locked into planetesimals… but brighter if clumped

SKA drivers

- for this science,
  - high sensitivity!
    - lots of collecting area and wide bandwidth
  - must have long baselines
  - need frequencies towards high end
    - grain opacity worse at low frequencies
    - many low frequency background sources
      - it may be that ~20 GHz is optimum, cf. HL Tau


the future…
American Museum of Natural History