Jane Greaves, Cardiff

proto-planetary discs

– viewing the PEBBLeS*

***Planet Earth Building Blocks: the Legacy eMERLIN Survey**

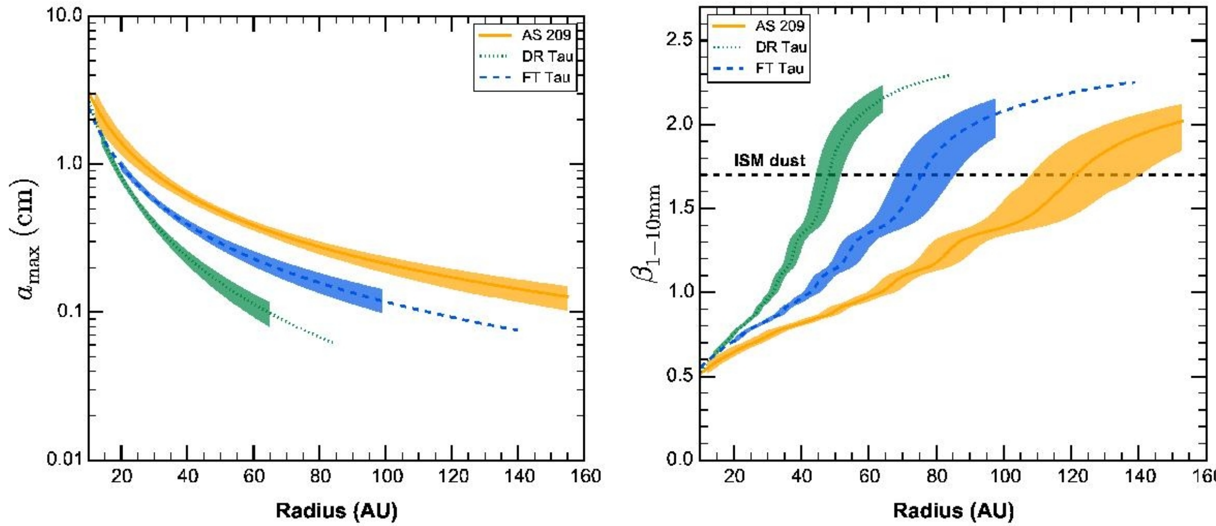
some context

- **plausible that all stars have a planet(ary system)**
  - natural consequence of star formation process

- **next advances: *habitable* planets**
  - Earth-like mass, orbit, composition?
- **hence research priorities:**
  - birth sites and migration of exo-Earths
  - accretion stages (oceans, atmosphere….)
  - influences of other planets in the system

blahblahALMAblahblah...

- **millimetre observations of dust discs are not always the most insightful**
  - inner disc likely optically thick at ~1 mm
  - grains producing mm-emission rather ubiquitous

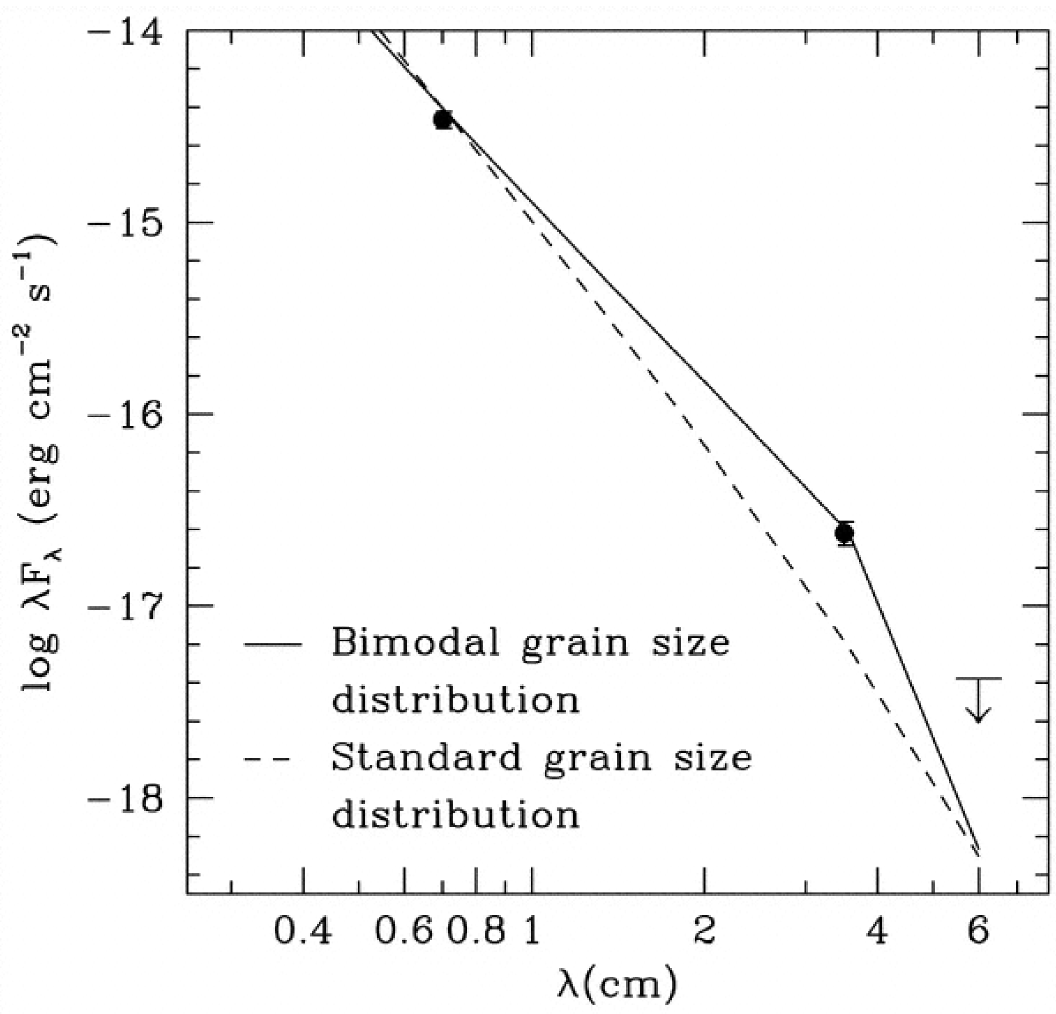


Tazzari et al. 2016
CARMA, EVLA

- **where do grains go on to form planetesimals?**

radio emission from grains

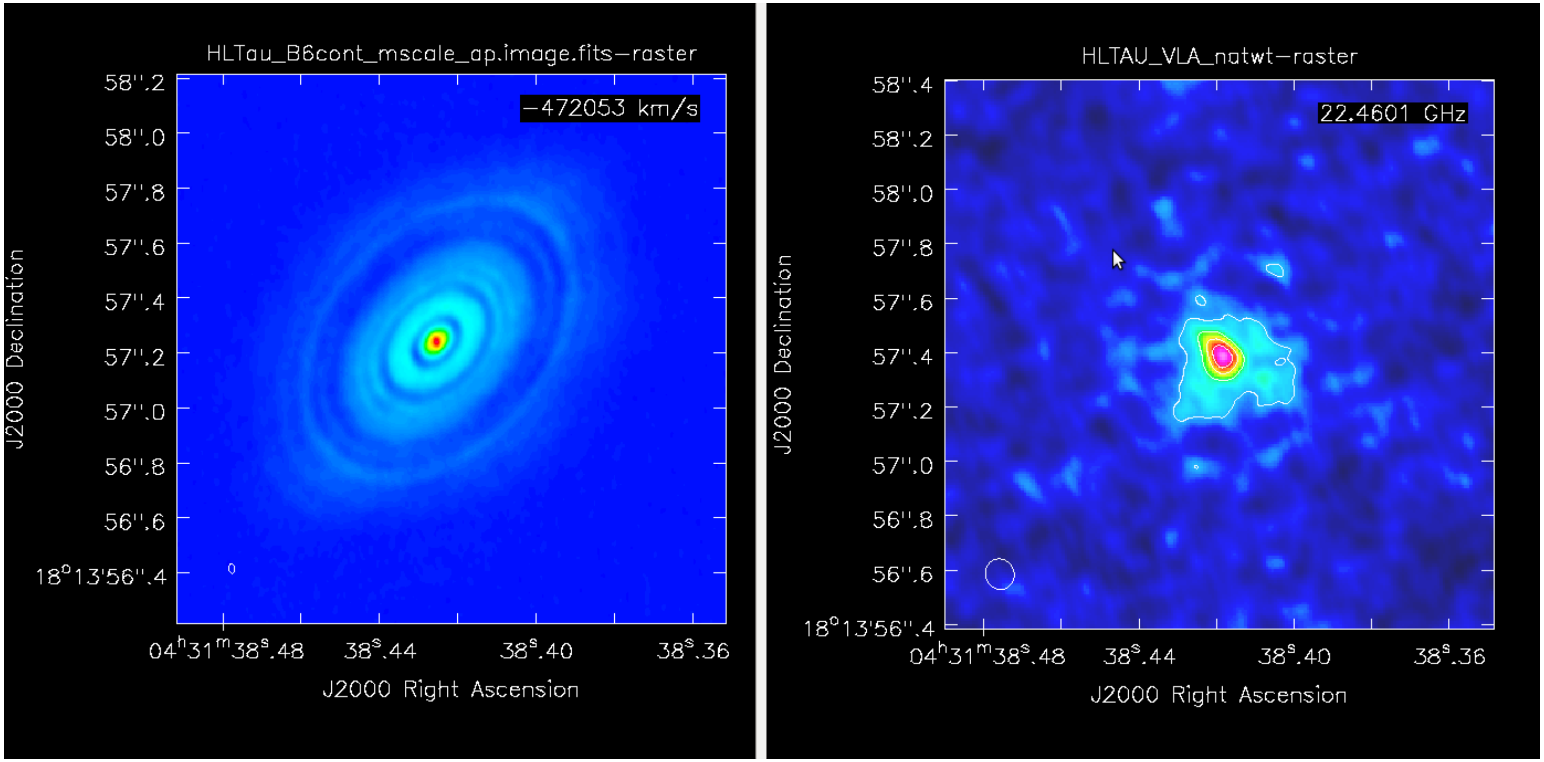
- **high angular resolution view isolating dust particles large enough to be cm-emitters**
  - shows where the 'millimetre barrier' is overcome
- ***not* easy!**



Wilner et al. 2005, VLA

radio emission from protoplanets

- **possibility of seeing dust being accreted into planetary cores**



HL Tau: ALMA 233 GHz; VLA 22.5 GHz (Greaves, Richards, Rice & Muxlow 2008)

PEBBLeS

- **prototyping observations approved in 2009**
  - 2 fields x 36 hours each, in C-band
- **full survey aim: ~20 stars in ~12 fields**
  - to few-Earth-mass sensitivity
  - involving ~30 scientists from 7+ countries
    - obs/theory/exp't view of planet formation

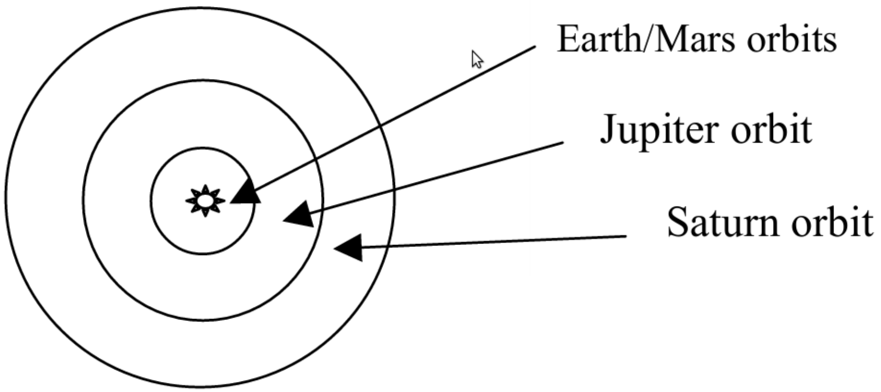
Table 1: Distribution of flux density among planet-forming zones of disks in the survey, assuming they have smooth r^{-1} surface density profiles and are seen face-on; the 40-mas-wide annuli contain 6, 12… beams. For clusters at 140 and 220 pc, the range of disk masses is 2.5-8 and 6-19 MMSN, respectively (Figure 3). An $r^{-1.5}$ disk would be more centrally peaked while inclined disks have higher flux per beam.

distance	annulus (orbital zone)	effective radius (AU)	T_{dust} (K)	M_{ring} (M_{Earth})	F_{beam} (5cm) (µJy/beam)	rms (5cm) (µJy/beam)	S/N_{beam}
140 pc (Taurus)	Earth/Mars	1.5	280	25-80	15-50	1.3	12-35
	Jupiter	5.5	140	50-150	2.5-8	1.3	2-6
	Saturn	11	100	50-150	1-3	1.3	(0.7-2.5)
220 pc (NGC 1333)	Earth/Mars	2	220	100-300	20-60	1.3	15-45
	Jupiter/Saturn	9	110	200-600	4-10	1.3	3-8

PEBBLeS

- **prototyping observations approved in 2009**
  - 2 fields x 36 hours each, in C-band
- **full survey aim: ~20 stars in ~12 fields**
  - to few-Earth-mass sensitivity
  - involving ~30 scientists from 7+ countries
    - obs/theory/exp't view of planet formation

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.



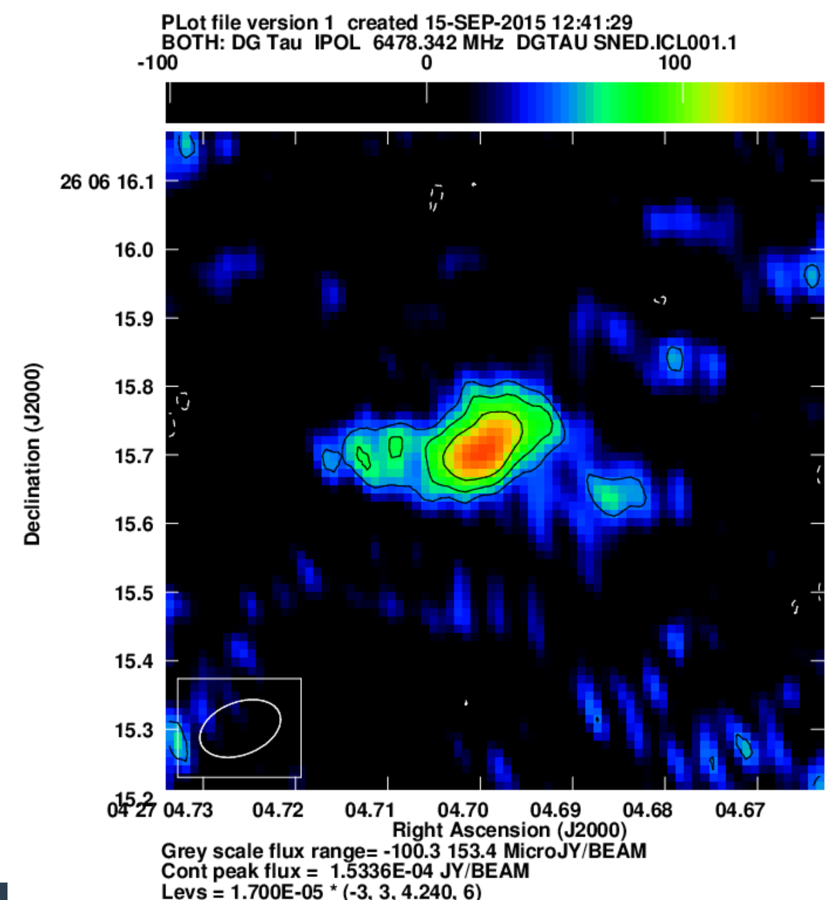
PEBBLeS

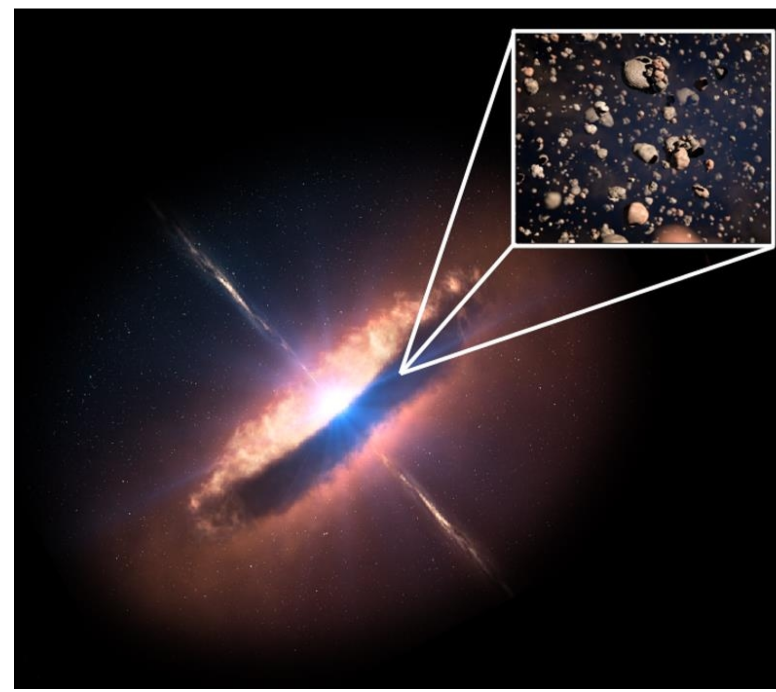
- **pushing eMERLIN limits:**
  - new C-band receivers, full bandwidth, Lovell
    - 3 tracks per field for detection at few-μJy level
- **moving from commissioning to prototyping stage**
  - but! other advances mean we can zoom in on the Habitable Zone (2 AU resolution, at K-band)
- **lots of parallel development**
  - better theory in grain physics … completed 1cm survey (Disks@EVLA)… pdra starting at Cardiff

commissioning results

- **no fields done at full spec yet, but DG Tau has turned out substantially brighter than expected :-)**

data reduction: Anita Richards
+ Emily Drabek-Maunder



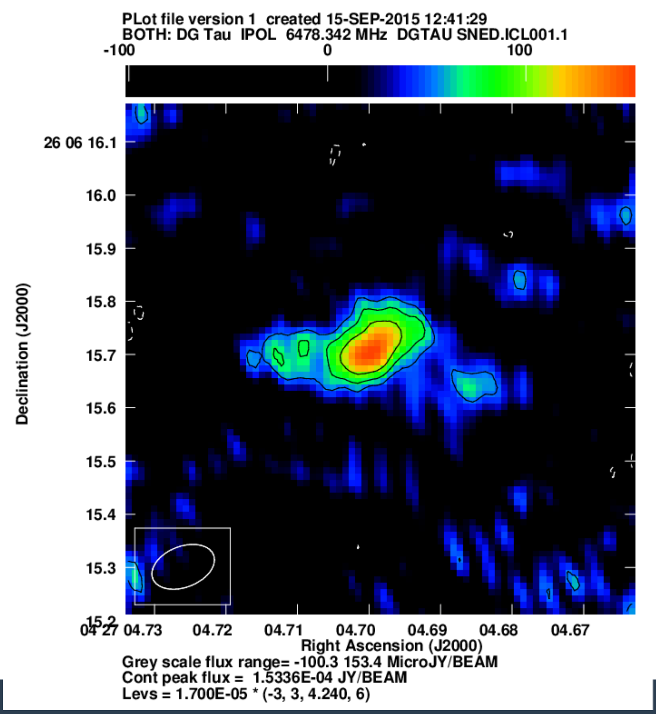


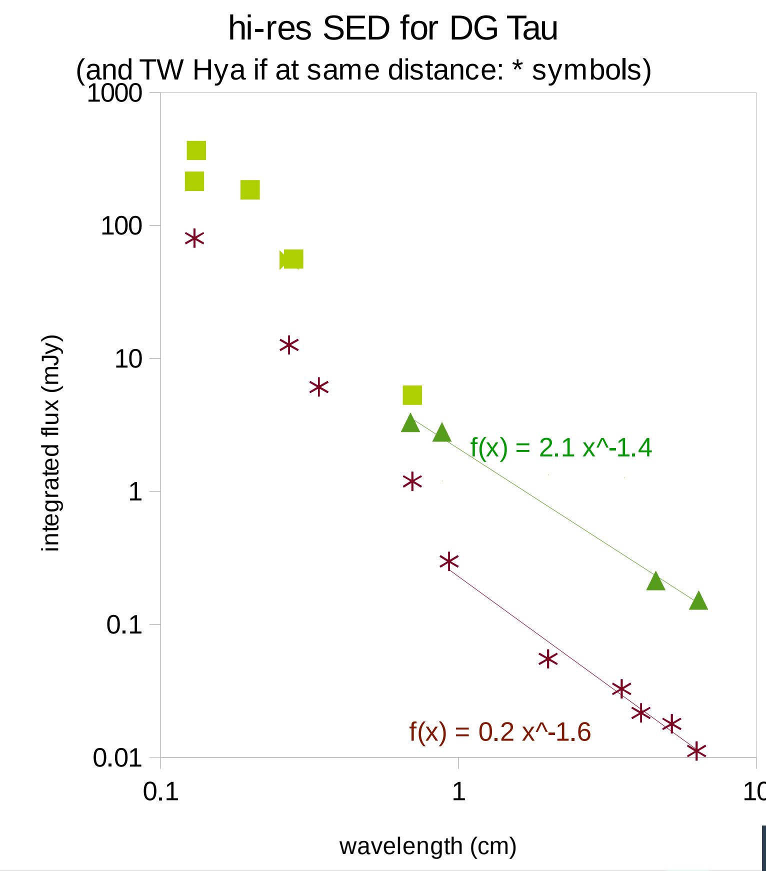
https://www.ras.org.uk/news-and-press/2656-astronomers-see-pebbles-poised-to-make-planets

commissioning results

- **DG Tau's disc appears to be a 'super TW Hya'**
  - still isolating possible jet, disc-wind signals
    - benefiting from Jets Legacy

(extra C-band from Ainsworth et al. 2013)





updating the science goals

- **from a census of discs:**
  - when do planets form?
    - e.g. in relation to the volatile-rich early disc
  - forming in-situ, versus migration
    - where does a planet's raw material come from?
    - do planets interact dynamically?
  - where does planet formation succeed, and why?
    - i.e. the physics of growing solid bodies (sticking, fragmentation, drift...)

eMERLIN for pebble science

- **a head start on SKA1-MID science - this is the top priority objective in the Cradle of Life goal**

  (... and it is hit quite hard by re-baselining options)

- **eMERLIN, unlike other facilities, offers:**
  - long baselines (even better with Goonhilly)
  - good frequencies (higher is better: $F_{dust} \sim \nu^{2+}$)
  - sensitivity – really critical!
    - PEBBLeS has a flux limit of a few times the 'minimum mass solar nebula' – but Earths could be built from lower-mass discs