School of Physics & Astronomy
FACULTY OF MATHEMATICS & PHYSICAL SCIENCES

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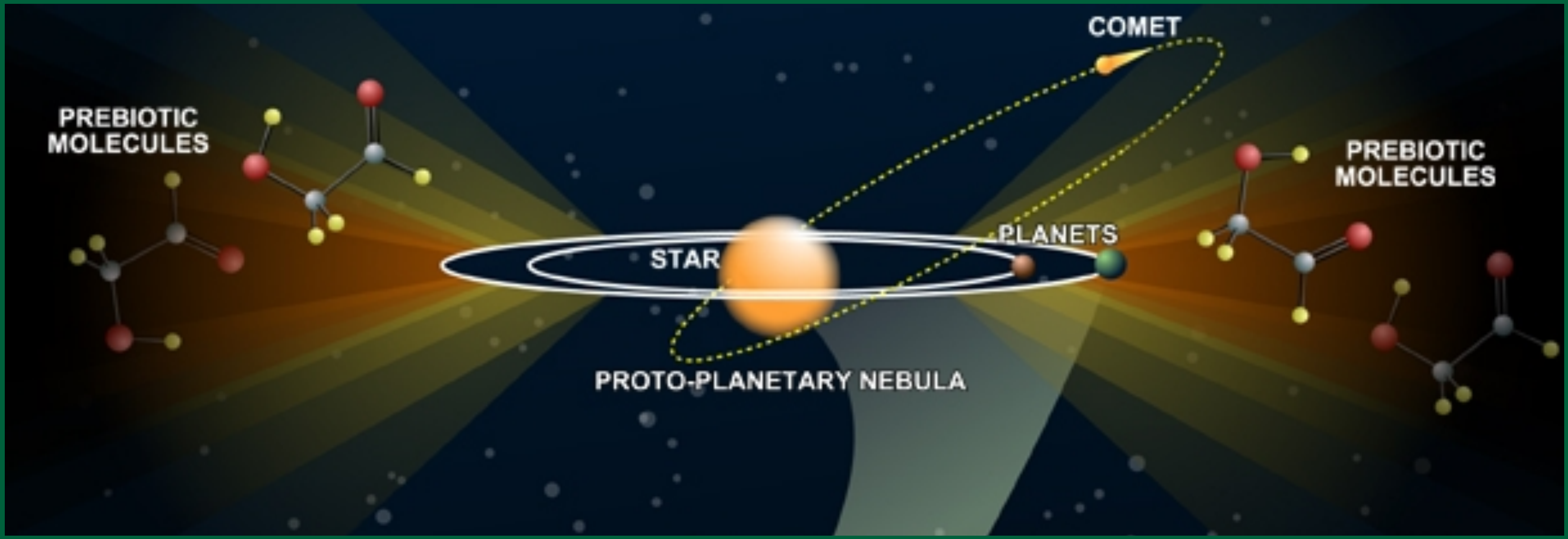
Cradle of Life Key Science Projects

CoL Members Present:

Melvin Hoare, Philippe Zarka, Andrew Siemion, Ian Morrison, Doug Johnstone, Jaime Pineda



The Big Questions

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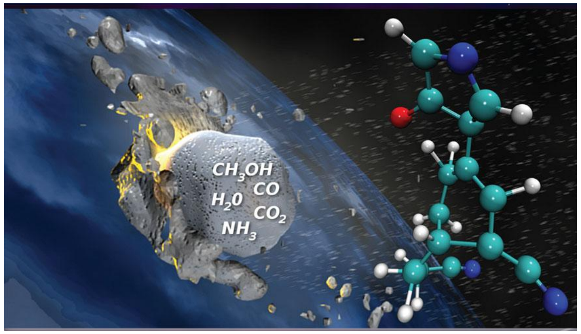
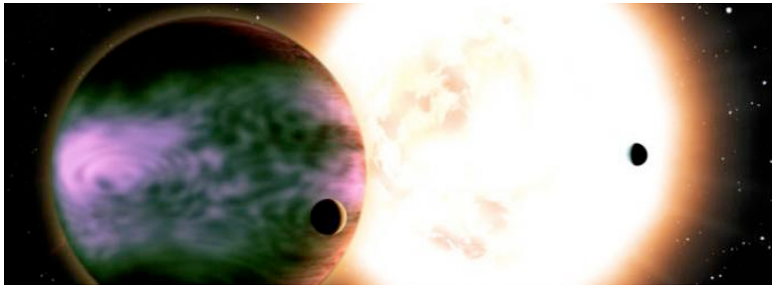
- How do Earth-like planets form?



- How did life originate?

- What are exo-planets like?



- Is there intelligent life out there?

Proposed Key Science Projects

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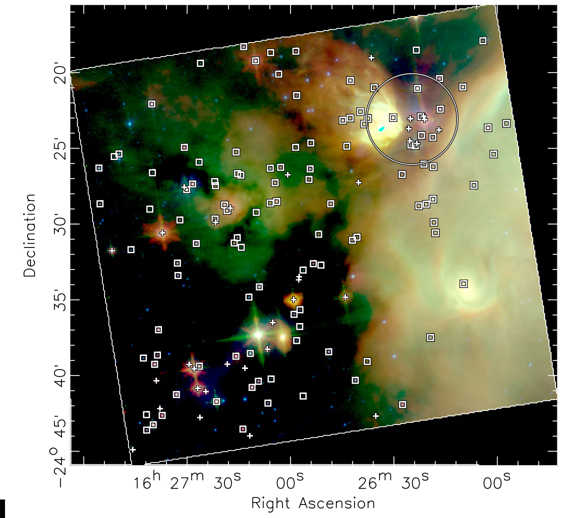
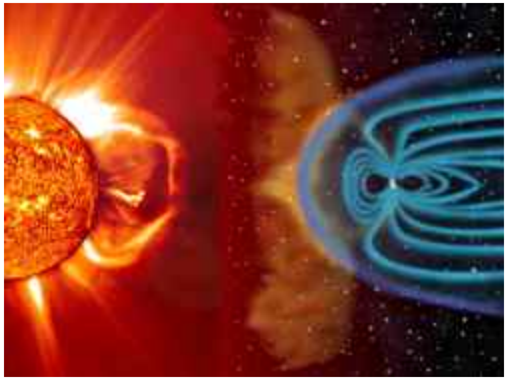
- Young Cluster Deep Field



- Characterization of exo-planets



- SETI search

Young Cluster Deep Field

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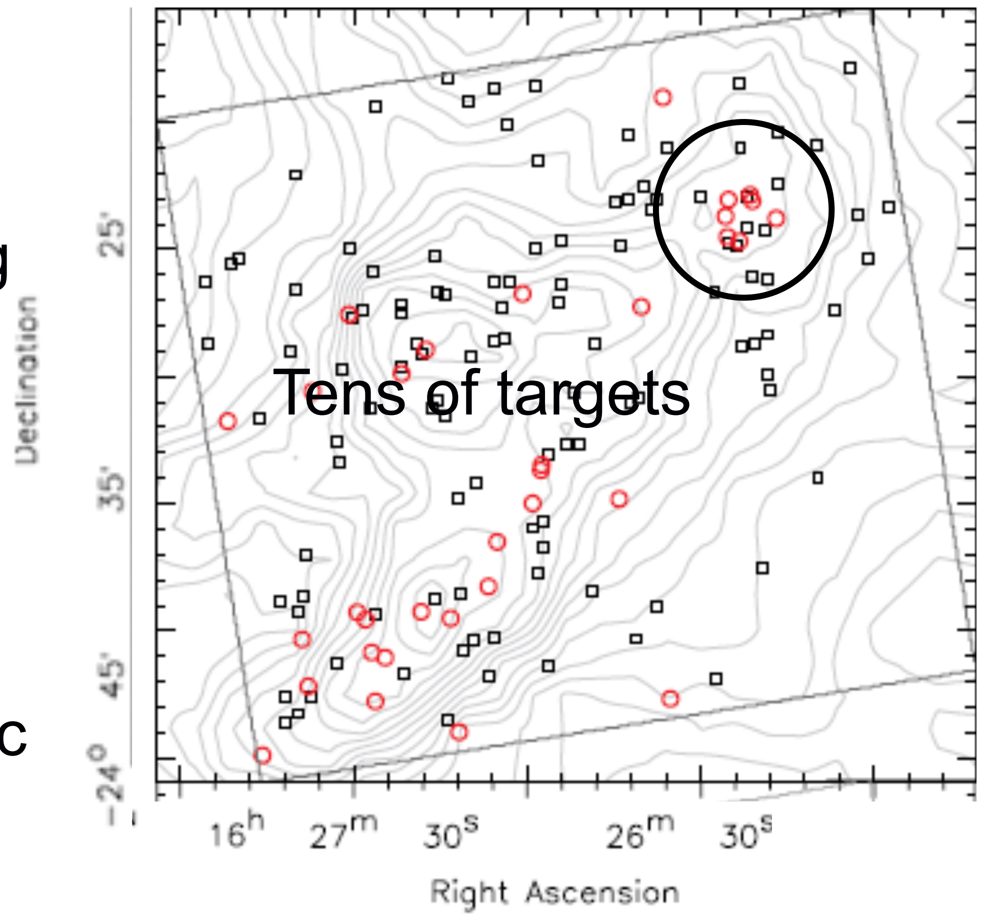
- Primary science driver: grain growth in proto-planetary discs
- ~ 1000 hour single pointing with SKA1-Mid
- Top end of band 5:

  8.8 – 13.8 GHz continuum
- 40 mas resolution equivalent to 5 au at 125 pc



Cm-wave data are vital

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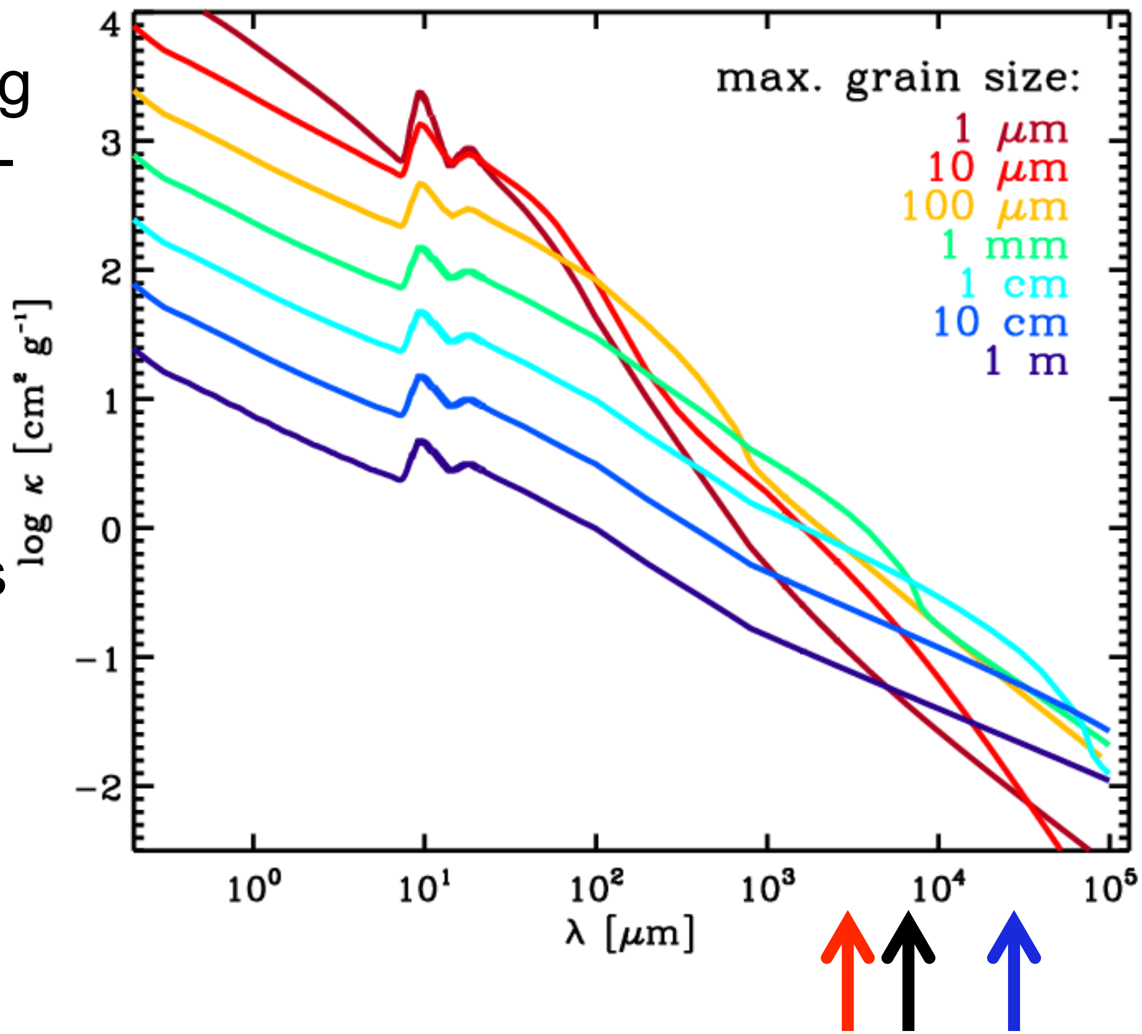
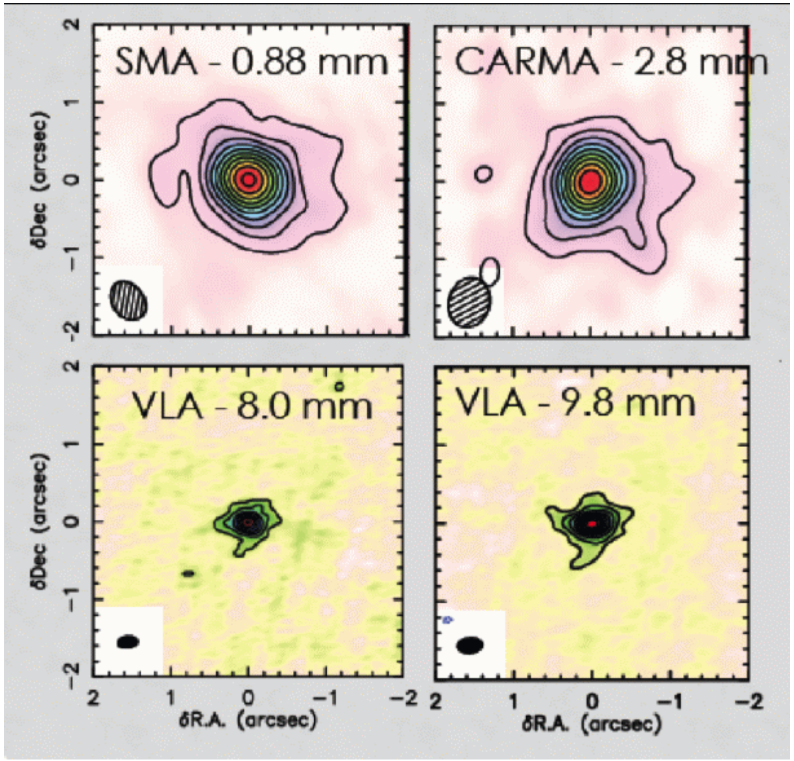
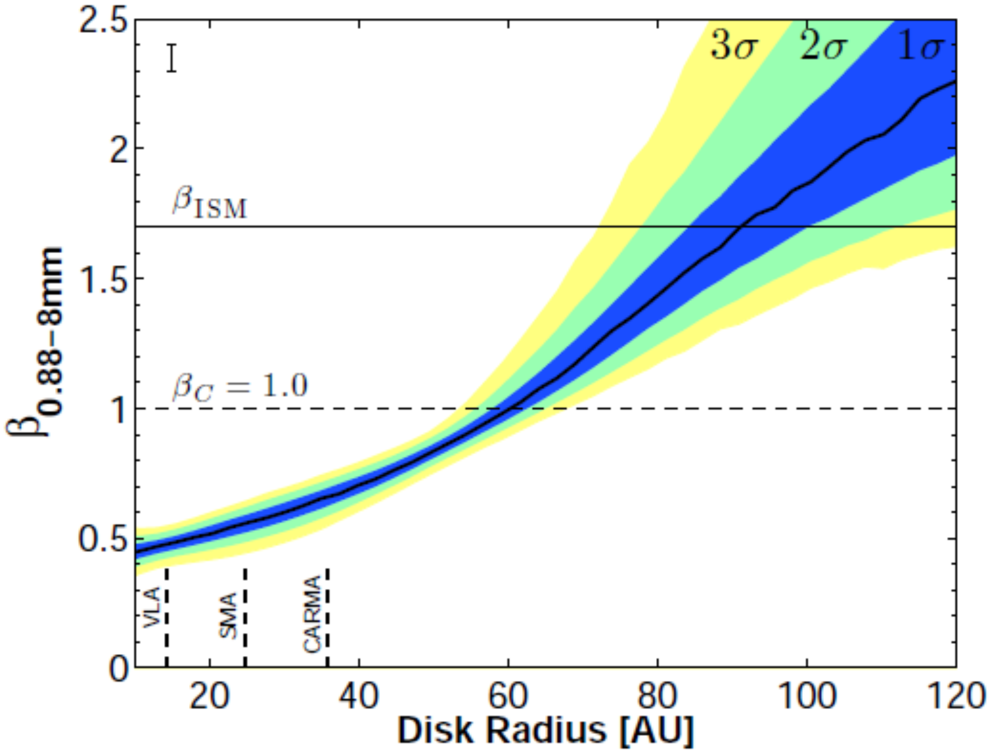
- Difficulty in growing grains through cm-sized regime
- Need cm-wave observations to probe cm-sized grains, emission is weak
- Map out the spectral index



Matching 40 mas beam

State-of-the-art





Shallow spectral index indicates grain growth in AS209
(Pérez et al. 2012)

Inside the snow line with SKA1

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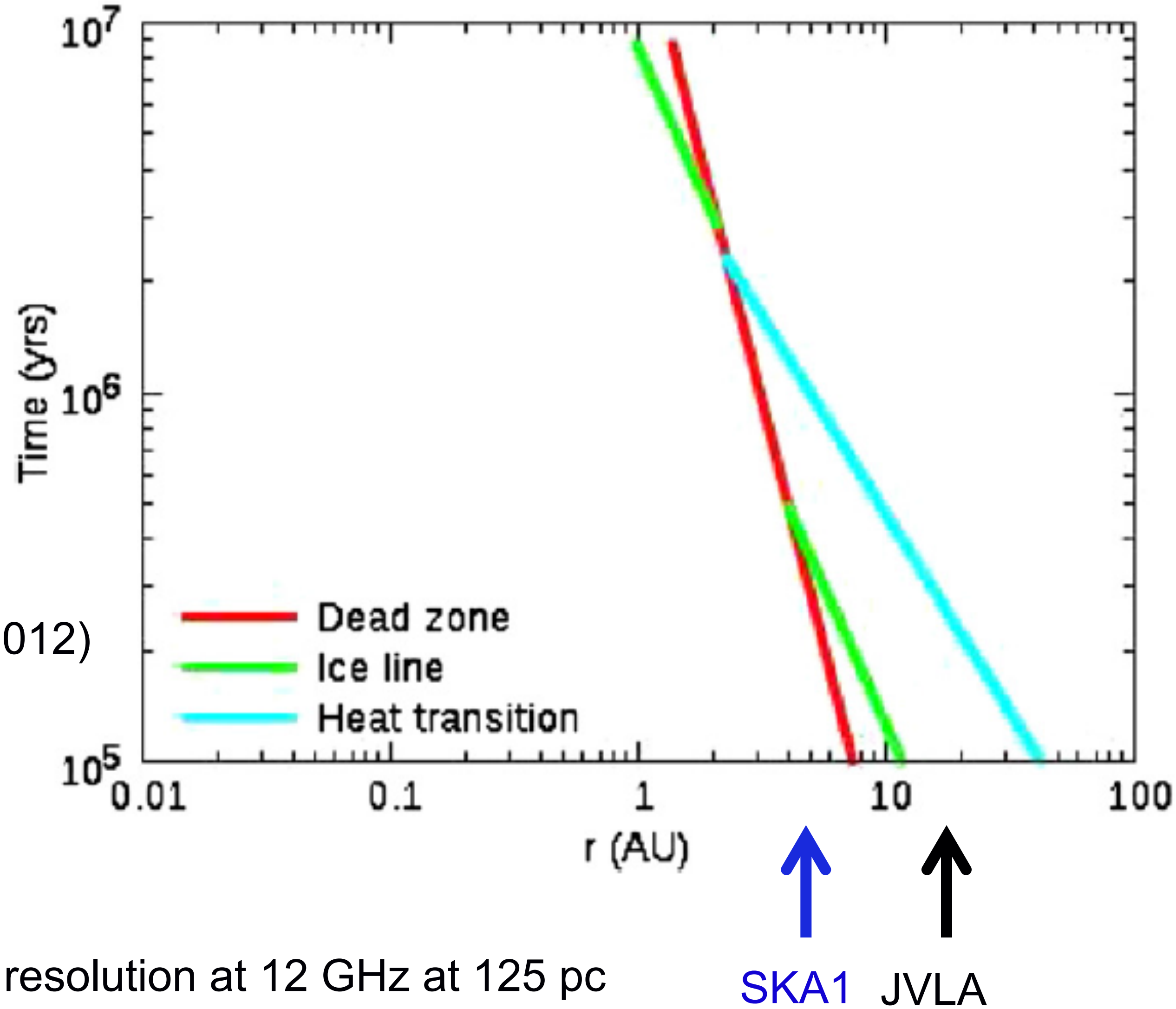
- Need 'dust traps' to help grains grow
- E.g. the water ice/snow line

Hasegawa & Pudritz (2012)



Spatial resolution at 12 GHz at 125 pc

Proto-planetary disc simulations

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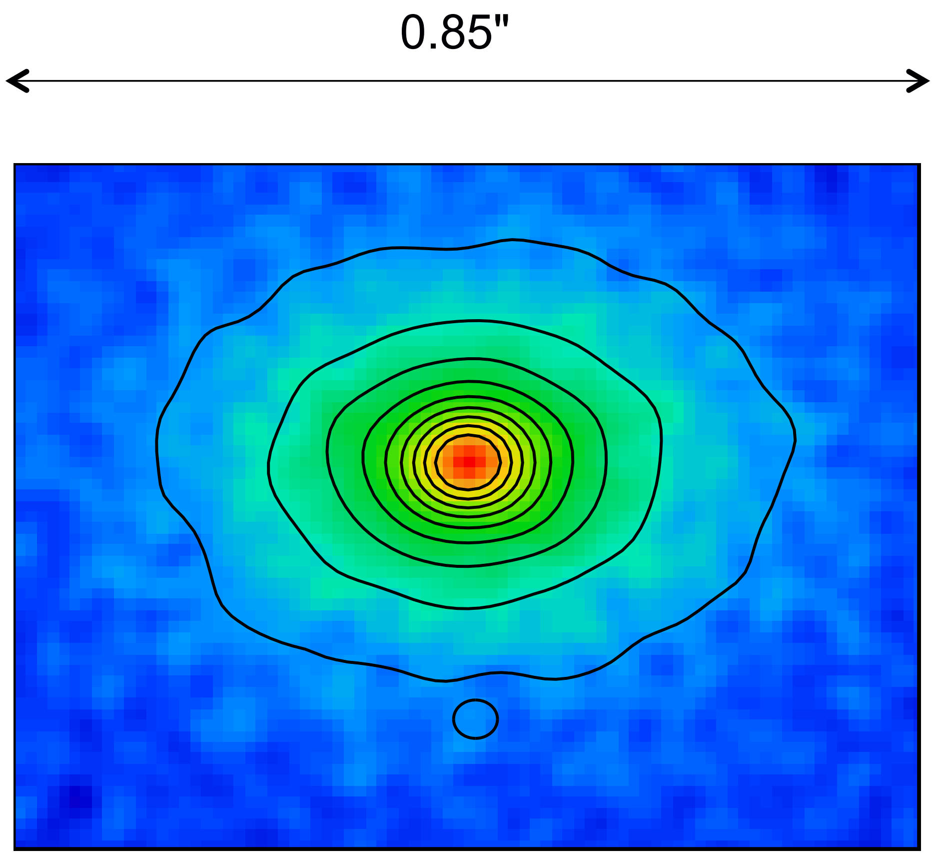
- Disc simulation from Laura Perez based on Isella et al. (2009)
- 1 $M_\odot$ star with MMSN 0.01 $M_\odot$ disk inclined at 45°
- Distance of 125 pc
- 35 x 40 mas beam at 11.3 GHz
- 1000 hr integration imaged with uniform weighted SKA1-Mid configuration

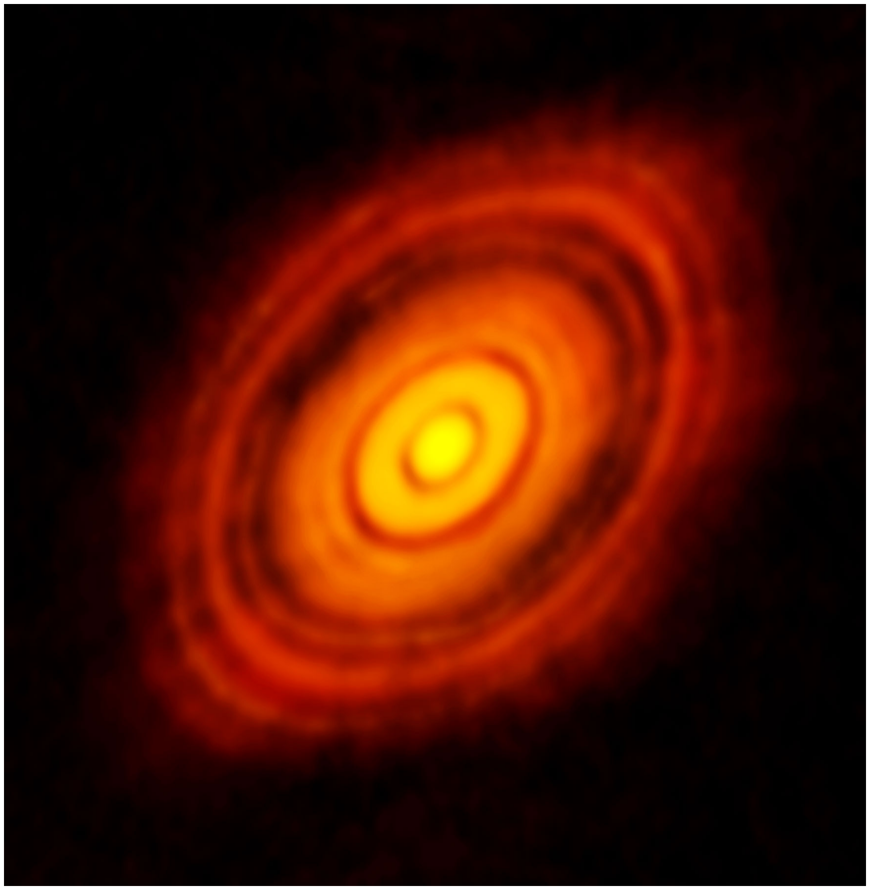


11.3 GHz intensity

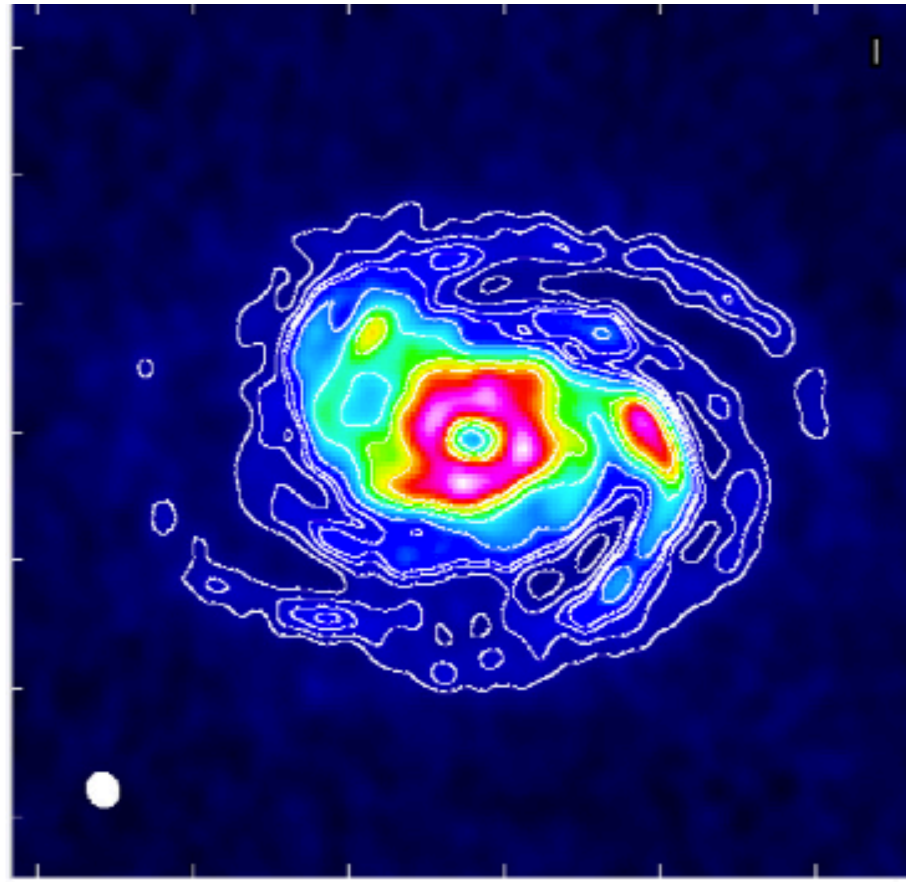
Peak 4.0 μJy/beam T_b=30 K

Noise 0.07 μJy/beam T_b=0.5 K

Disc Structure



ALMA:
HL Tau 1.3 mm at 35 mas resolution



Simulated self-gravitating disc:
7 mm emission at 7.5 au resolution

Additional science aims

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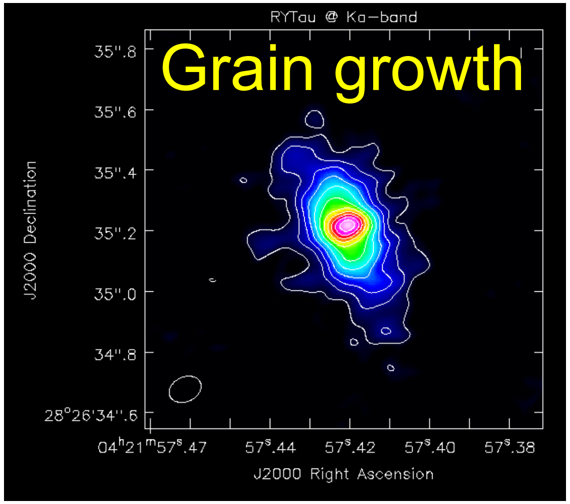
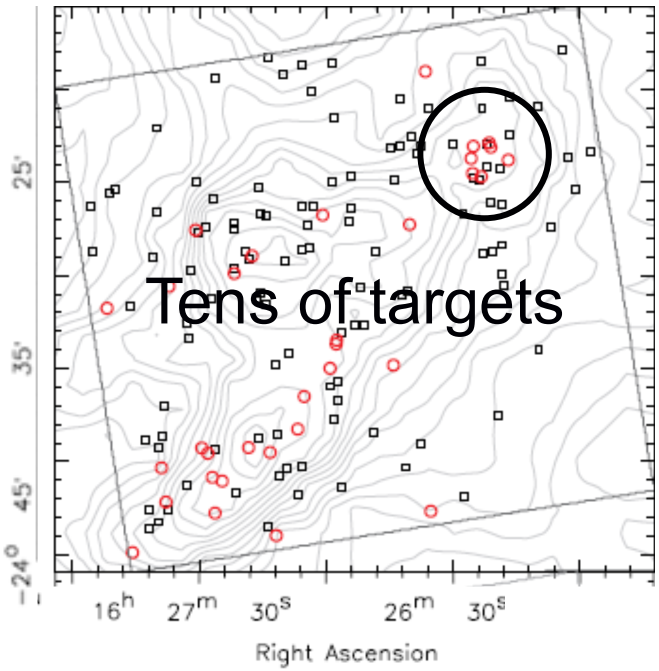
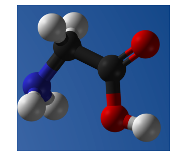
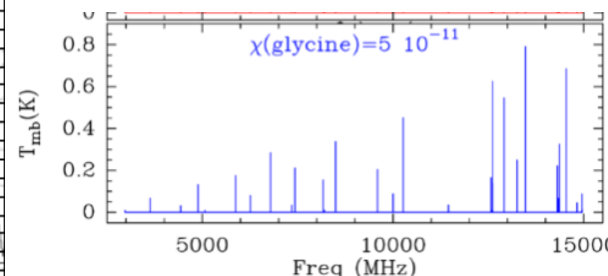
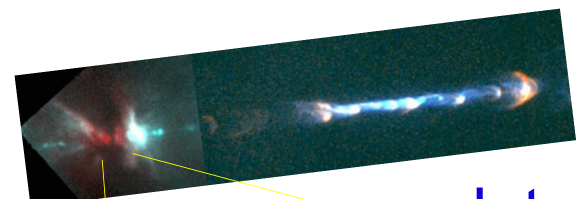




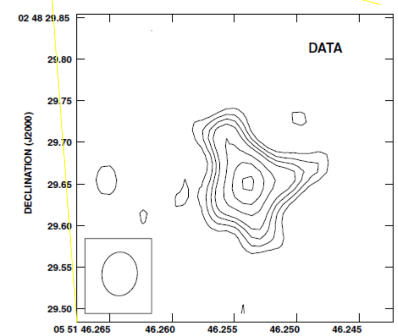
Pre-biotic molecules



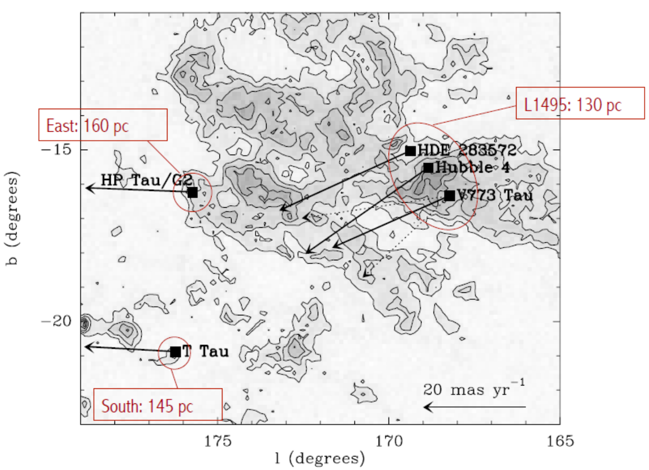


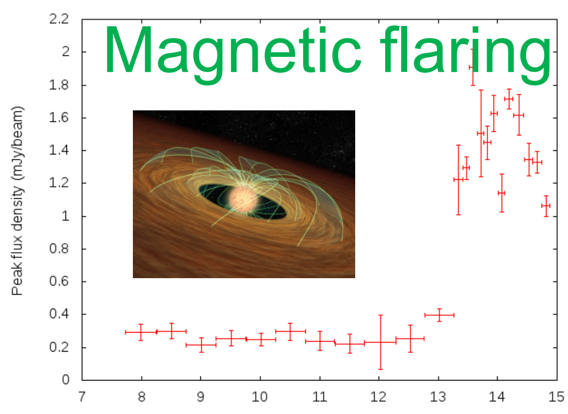


Jets



6D tomography





Cross-KSP Talks for young cluster

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- Our Galaxy – magnetic fields via polarization in jets and discs
    - (Melvin, Wouter, ...)
- Our Galaxy - continuum and recombination lines from jets
    - (Melvin, Mark, ...)
- Our Galaxy – pre-stellar core pre-biotic molecule KSP?
    - (Jaime, Doug, Jill, Sergio ...)
- Transients - time variability of radio jets and flares
    - (Melvin, Leonardo, Michael, ...)
- VLBI - tomography of young cluster
    - (Melvin, Hiroshi, Zolt, ...)

Exo-planet characterization

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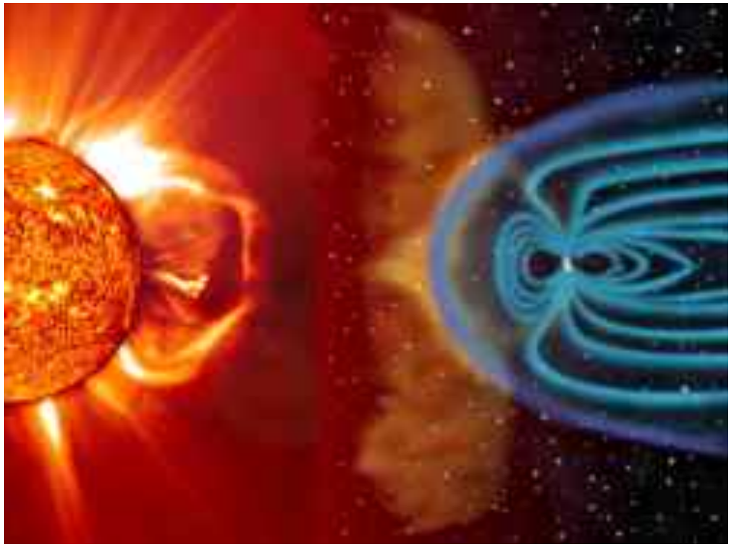
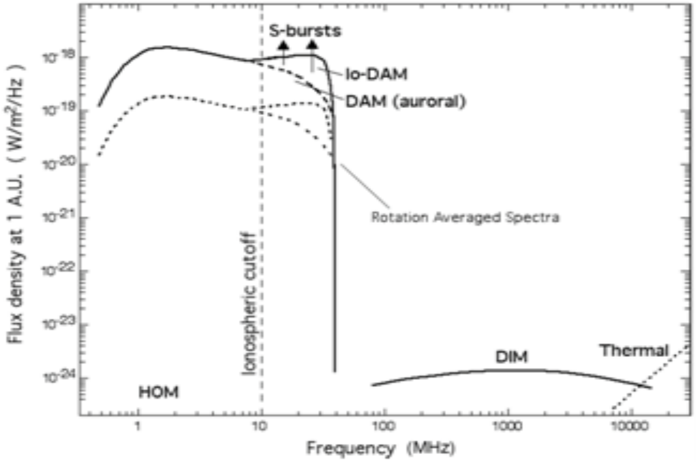
- SKA1-Low multi-beam imaging search for bursts of electron cyclotron maser emission from aurorae
- ~1 sec integrations at 1 MHz resolution over whole BW using full array
- Non-imaging follow-up?
- Targeted observations – e.g. known exoplanets
- Expand to include all nearby stars?





Solar system planets

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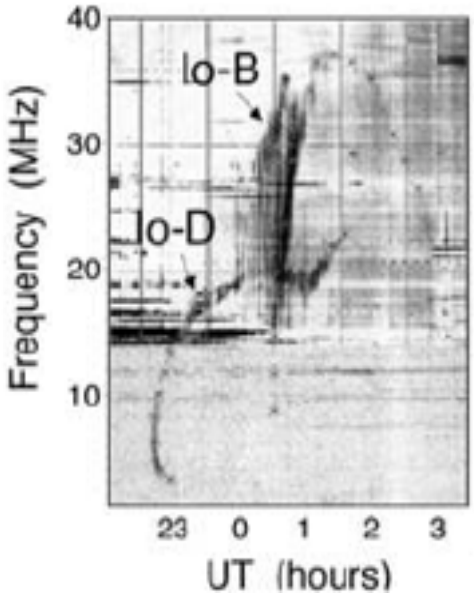

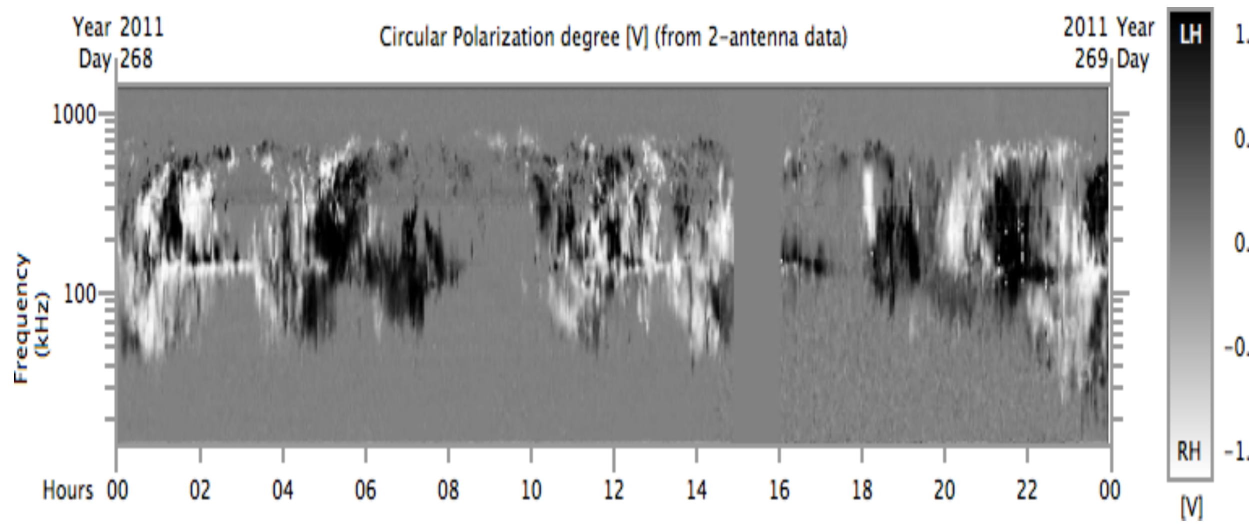

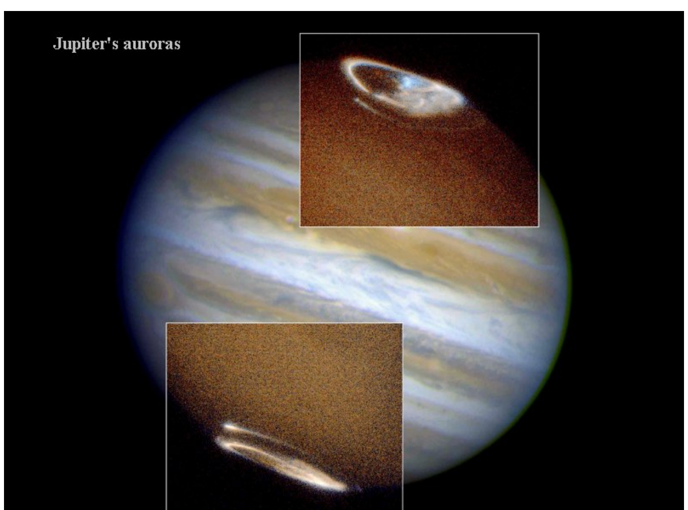

Exo-planet properties

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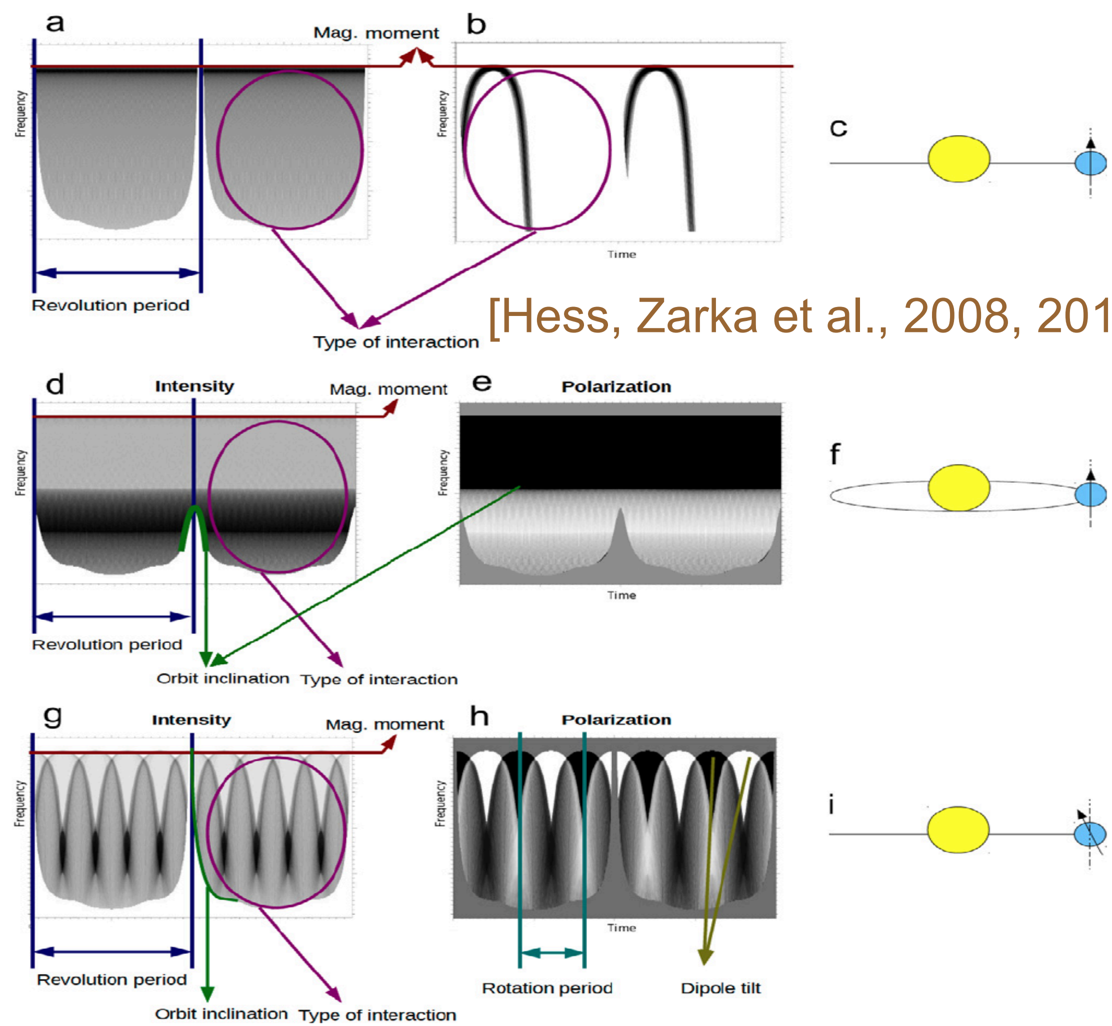
- Planetary magnetic field strength – planetary interior
- Planetary rotation period
- Type of interaction
- Orbit inclination
- Tilt of magnetic axis
- Exo-moons?

Model dynamic spectra (Hess, Zarka et al., 2008, 2011)



[Hess, Zarka et al., 2008, 2011]

State-of-the-art

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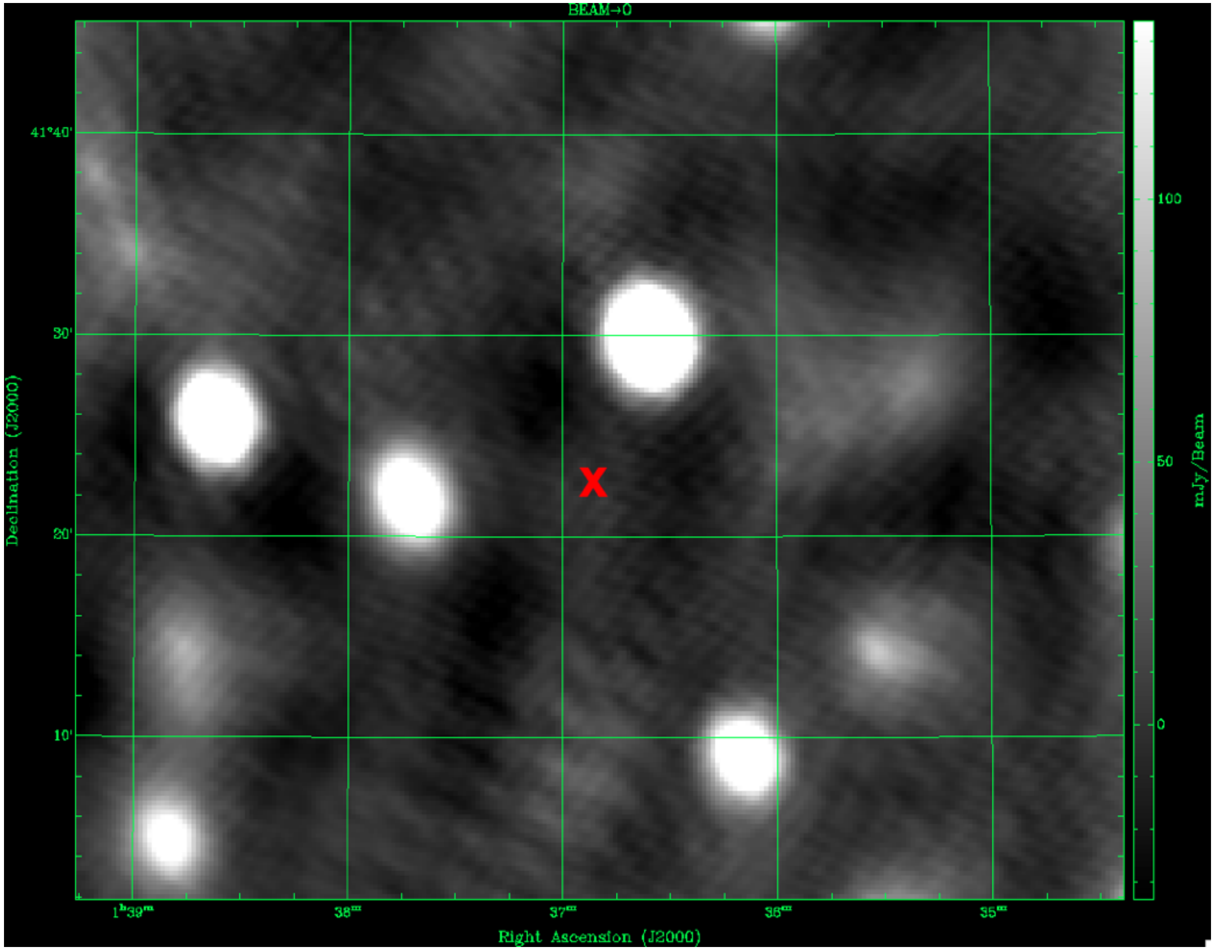
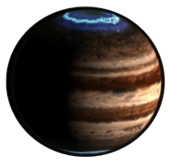
- LOFAR observations of Upsilon Andromedae at 59 ±3 MHz, 3 hour integration
- Clean image, baselines ≤ 5 kλ, resolution ~ 40", noise ~ 8 mJy, no detection

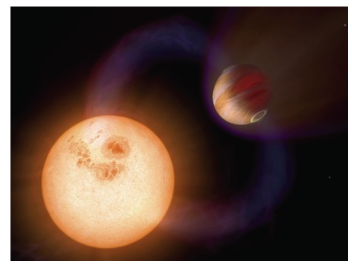


Common mechanisms & scaling law?

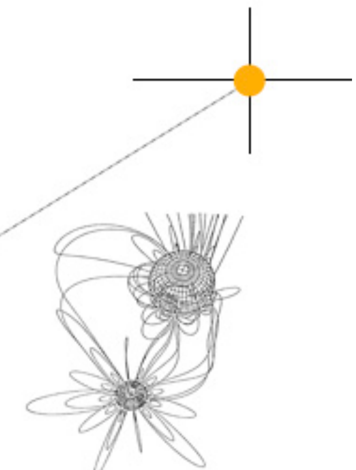
Solar System Planets & Planet-Satellite Interactions

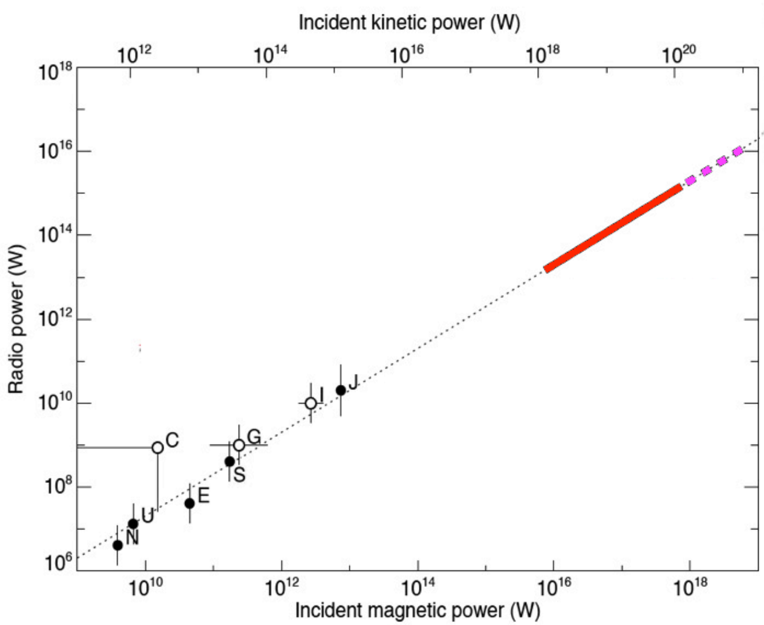


Star-Exo-planet Interactions



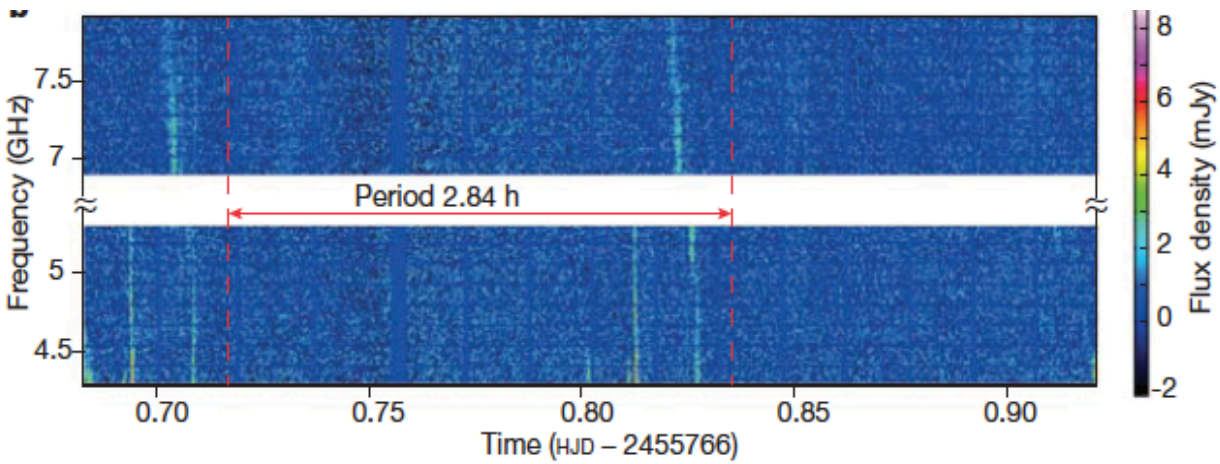
Magnetic binaries

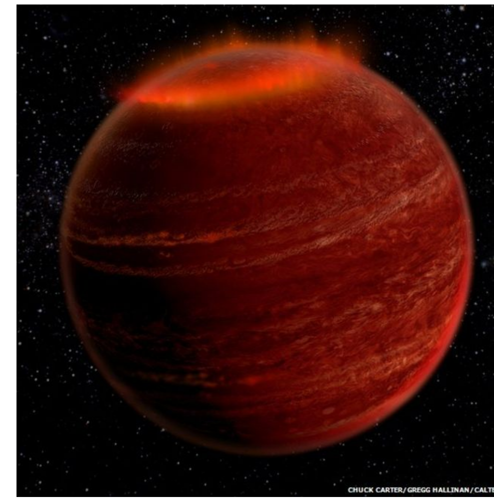




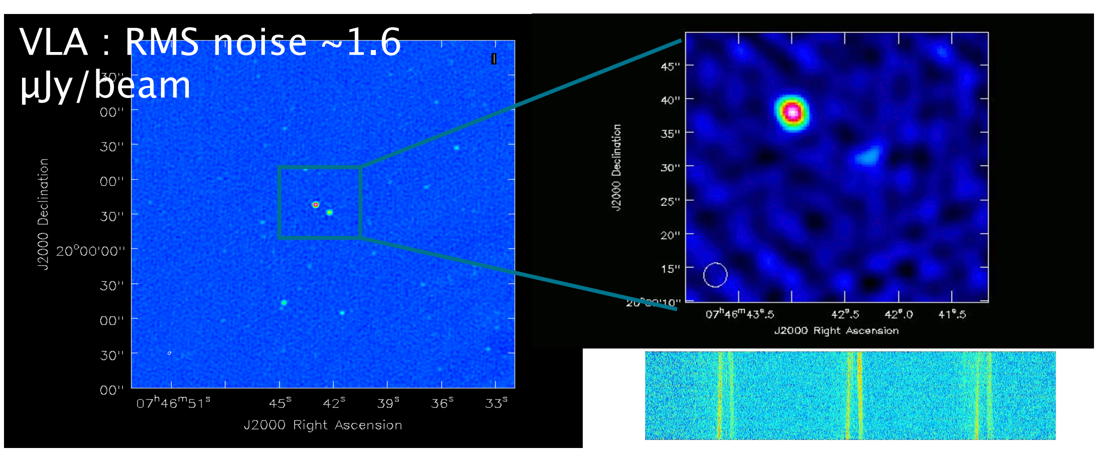
[Zarka et al., 2001 ; Zarka, 2007, 2010]

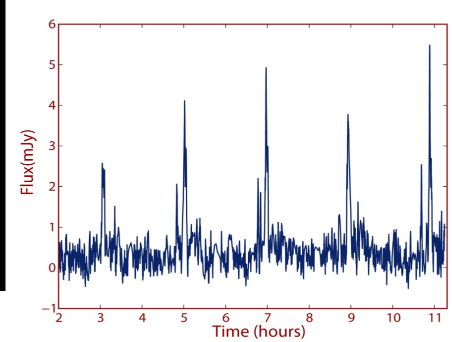
Low-mass stars/Brown Dwarfs





[Hallinan et al., 2015]





[Hallinan et al., 2007, 2008]

Extend to SKA1-Mid?

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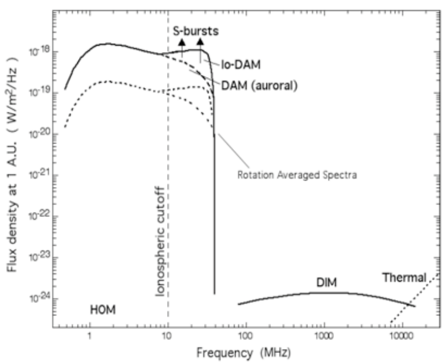
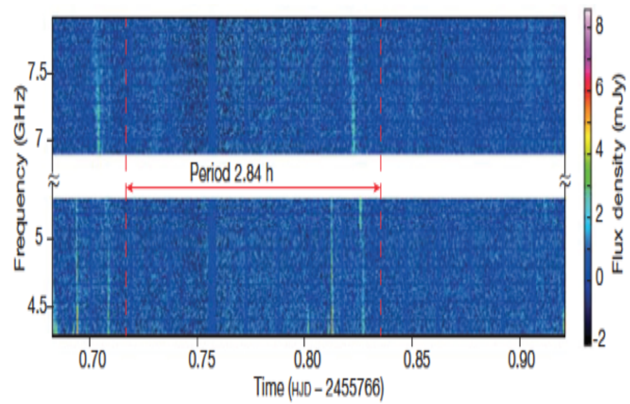
Exoplanets



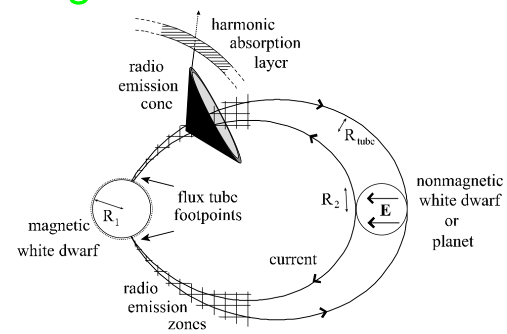
[Zarka, 2004]

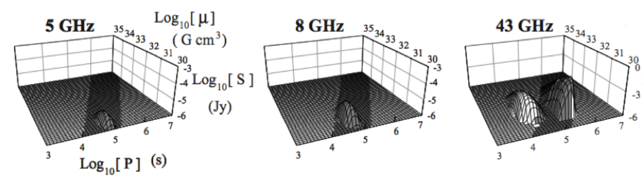
Low mass / cool stars, SPI



[Hallinan et al., 2007,2008,2015]

WD-Planet systems,
Magnetic Binaries





[Willes & Wu, 2004, 2005]

10s - 100s MHz

10s MHz ? - several GHz

10s MHz ? - 10s GHz

SKA-Low

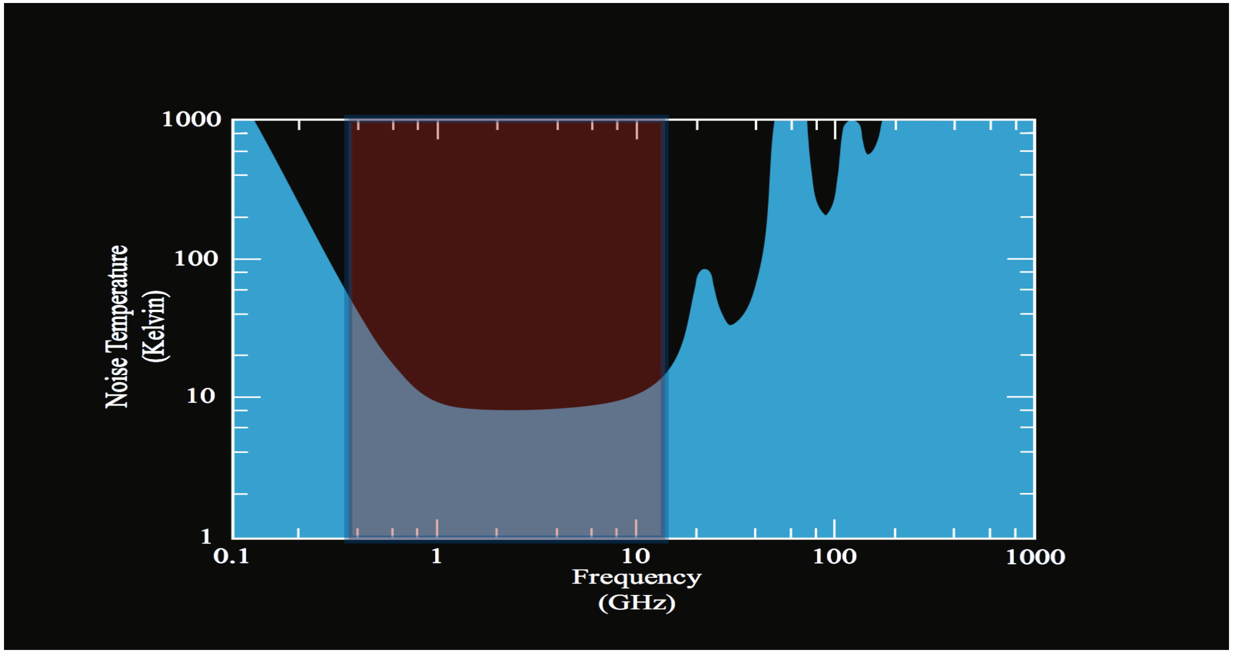
SKA-Mid

Cross-KSP Talks for exo-planets

- Cradle of Life – target only known exo-planet systems in era of GAIA/TESS/RV,…or…?
- Our Galaxy - extend to brown dwarfs, low-mass stars, white dwarfs, all nearby stars? Monitor stellar flares followed by auroral interaction on companion
  - (Philippe, Grazia, ...)
- Transients – methodologies, imaging/non-imaging, commensality
  - (Philippe, ...)
- EoR – commensal with/compliment EoR?
  - (Philippe, Leon, ...)

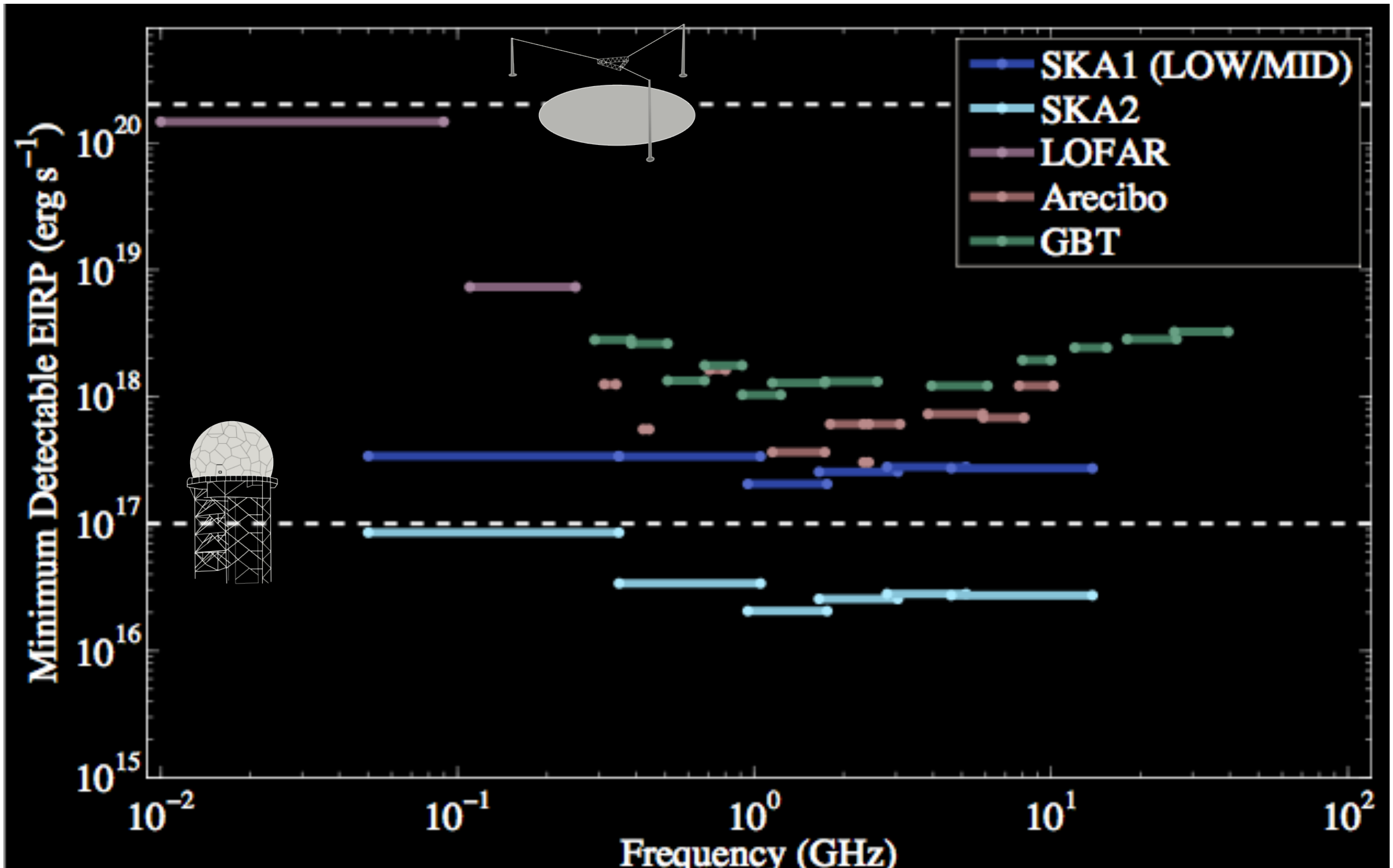
SETI

- **Commensal** survey of order of a million objects
- ~10 min integrations
- Cover whole of the SKA1 bandwidth at ~0.1 Hz resolution, i.e. using Low and Mid



Detection Limits

For an Extraterrestrial Transmitter @ 25 pc ($t_{integration}$ = 10 min, SNR = 15)



State-of-the-art

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- Most thorough targeted SETI search previously conducted: Project Phoenix: 1000 stars over 1-3 GHz to a luminosity limit of ~ 2 x 10^{19} ergs/sec.
- SKA1: In a five year commensal campaign, could survey <u>every star</u> within 70 pc to a luminosity limit an order of magnitude fainter, ~ 2 x 10^{18} ergs/sec over a larger band.

Potential SETI Approaches

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SETI Surveys	**Pros:** Least anthropocentric bias - makes no assumptions about locations, habitable zones, etc… **Cons:** computationally expensive (SKA2), especially for interferometers and large ranges of parameters.
Targeted SETI	**Pros:** Can conduct a sensitive search over a wide range of signal parameters. **Cons:** Differing opinions on what constitutes a "good" SETI target.
Data-mining SETI	**Pros:** The data are already there, and often well characterized already. **Cons:** Low sensitivity to "traditional" signal types, usually incoherent searches only.

Potential Targets

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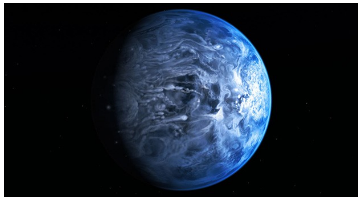
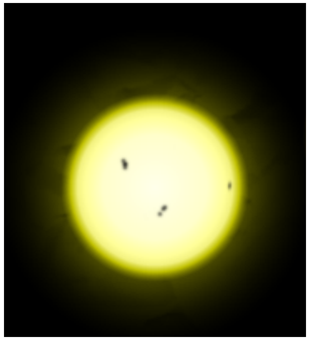
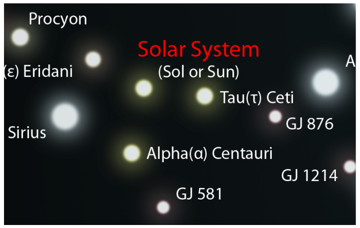


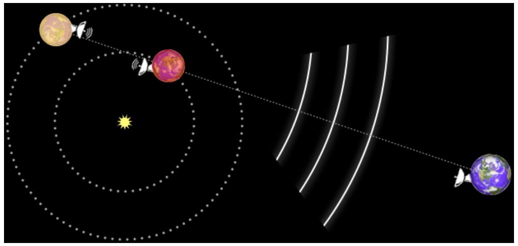
Known Earth-like Exoplanets or Solar System-like Exoplanet Systems



Sun-like Stars



Nearby Stars



Serendipitous Alignments, e.g. multiple exoplanets in a single system along a line of sight to the Earth, *"eavesdropping SETI"*

Cross-KSP Talks for SETI

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- Cradle of Life – common targets with exo-planet KSP on SKA1-Low
  - (Andrew, Ian, Philippe)
- Transients - commensality with searching all SKA1 observations for SETI signals
  - (Andrew, Ian, ...)

Major issues at this meeting

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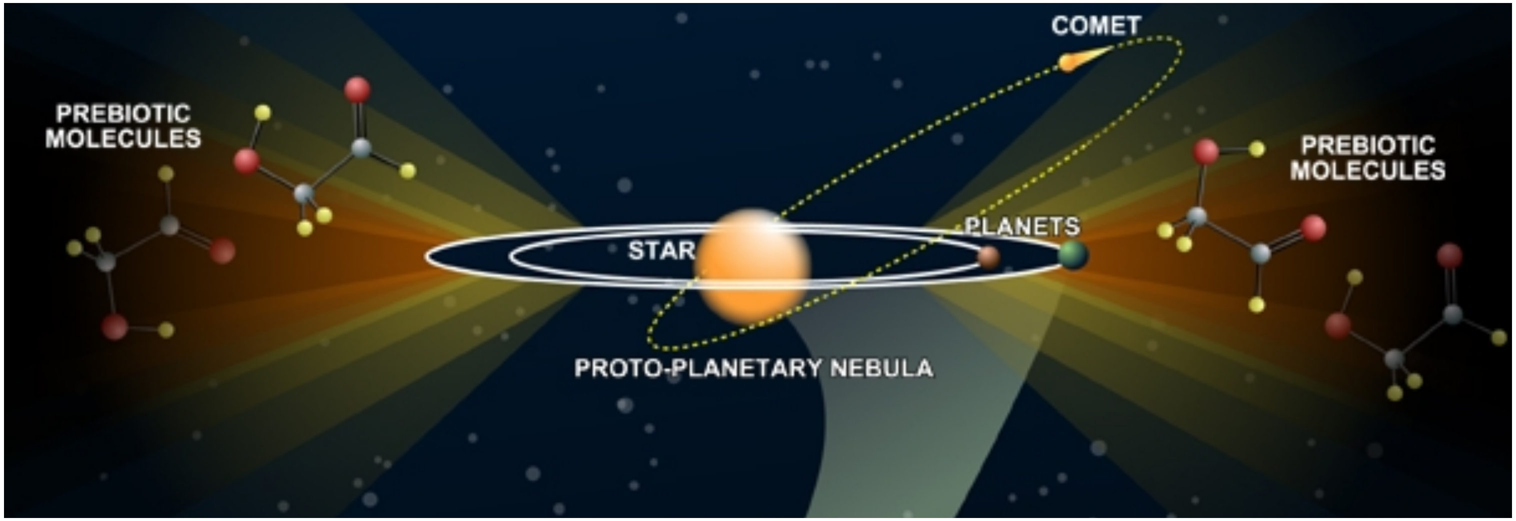
- Young cluster deep field – work up the KSP case, add science scope, explore target field, JVLA pilot
- Exo-planet characterization – extent and scope of joint KSP with stellar community, commensality
- SETI – commensal KSP philosophy, methodology, scope of targets, scope for hardware sharing



Example

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- We can observe all stars within 100 pc in order to study: exoplanets, stellar flares and SETI
- Do you want 3 separate KSPs that would have to be linked in some way since they are all observing the same targets?
- Or do you want 1 KSP on nearby star science?