SKA and the Cradle of Life
Formation of Planets and Search for Extraterrestrial Life

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With much help from Izaskun Jimenez-Serra
Cradle of Life Science Themes

1) How do rocky planets form?

2) How did life originate?

3) What are exoplanets like?

4) SETI project
SKA Big Questions

- **The Cradle of Life & Astrobiology**
  - How do planets form? Are we alone?
- **Strong-field Tests of Gravity with Pulsars and Black Holes**
  - Was Einstein right with General Relativity?
- **The Origin and Evolution of Cosmic Magnetism**
  - What is the role of magnetism in galaxy evolution and the structure of the cosmic web?
- **Galaxy Evolution probed by Neutral Hydrogen**
  - How do normal galaxies form and grow?
- **The Transient Radio Sky**
  - What are Fast Radio Bursts? What haven’t we discovered?
- **Galaxy Evolution probed in the Radio Continuum**
  - What is the star-formation history of normal galaxies?
- **Cosmology & Dark Energy**
  - What is dark matter? What is the large-scale structure of the Universe?
- **Cosmic Dawn and the Epoch of Reionization**
  - How and when did the first stars and galaxies form?
How Do Rocky Planets Form?

- Formation of rocky cores of planets via grain growth and settling
How Do Rocky Planets Form?

- Formation of rocky cores of planets via grain growth and settling

\[ \kappa_\nu \propto \nu^{1.5} \]

Testi et al. 2014

Hoare et al. 2015

SKA covers the right \( \lambda \)'s to probe cm-sized grains
How Do Rocky Planets Form?

- Flattening of the spectral index has been observed in discs.

Dust traps help overcome grain growth barriers ➔ ‘spiral density waves’

How Do Rocky Planets Form?

- Using SKA to observe continuum emission for dust in discs

**Column Density** $N(H_2)$ (Hall+2017; Ilee+2007)

SPH simulation
Gravitationally Unstable Disk (Run2 from Hall+2017)

$M_{\text{disk}} = 0.25 \; M_\odot$

$M_*=1 \; M_\odot$

$t = 4100 \; \text{yrs}$

50 au
How Do Rocky Planets Form?

- Using SKA to observe continuum emission for dust in discs

**SPH simulation**
Gravitationally Unstable Disk (Run2 from Hall+2017)

\[ M_{\text{disk}} = 0.25 \, M_\odot \]
\[ M_\ast = 1 \, M_\odot \]

distance = 100 pc

1000 hr integration

Peak = 19 \mu Jy/beam (T_b=115 K)
Noise = 0.07 \mu Jy/beam (T_b=0.4 K)

**SKA-Mid Band 5 (64 dishes)**

Credit: D. Quenard, C. Hall, J. Ilee

Witnessing the formation of planets
How Do Rocky Planets Form?

- Using SKA to observe continuum emission for dust in discs

Credit: D. Quenard, C. Hall, J. Ilee

MAPPING OF $\beta$ ACROSS THE SNOW LINE OF WATER

ALMA 1.3 mm

@12 GHz

40 mas beam

Tobin+2016

50 au
How Did Life Originate?

- From the ISM to the Origin of Life

Molecular clouds (Pre-stellar Cores)

Planetary systems

Protoplanetary disks

Complex Organics (COMs)

How complex can organic chemistry become in the ISM and disc? Pre-biotic species!!

Exploring the Universe with the world’s largest radio telescope
How Did Life Originate?

- Complex Organic Molecules (COMs) … in Space

COMs are carbon-based compounds with >6 atoms

(Herbst & van Dishoeck 2009)
How Did Life Originate?

- Complex Organic Molecules (COMs) … in Space

*Prebiotic COMs: species believed to be involved in the processes leading to the origin of life*

Glycolaldehyde
(CH₂OHCHO)

Formamide
(NH₂CHO)

Amino Acetonitrile
(NH₂CH₂CN)

Simplest naturally occurring amide containing all elements needed for the synthesis of bio-molecules (*Saladino+12,15*)
How Did Life Originate?

- Formamide undetected in discs: SKA will be a pre-biotic COM detector

Simulations of $\text{NH}_2\text{CHO}$ (gas & solid) in the disk

SPH simulation (Hall+2017; Ilee+2007) +
chemistry of $\text{NH}_2\text{CHO}$ (Quenard+2018a)

Gas-phase $\text{NH}_2\text{CHO}$ (Quenard+2018b)
How Did Life Originate?

- Formamide undetected in disks: SKA as a pre-biotic COM detector

Simulations of NH$_2$CHO
*(gas & solid)* in the disk

SPH simulation *(Hall+2017; Ilee+2007)*

+ chemistry of NH$_2$CHO *(Quenard+2018a)*

Distance = 100 pc
1000 hr integration

Peak = 87 µJy/beam ($T_b = 530$ K)
Noise = 7 µJy/beam ($T_b = 40$ K)

Gas-phase NH$_2$CHO with SKA1

$t = 4100$ yrs

40 mas beam

NH$_2$CHO transition at 13.489 GHz

Credit: D. Quenard, C. Hall, J. Ilee
How Did Life Originate?

• Detection of pre-biotic COMs will be Challenging

Problems:
• High spectral line densities at mm/sub-mm λ’s ⇒ Line blending/confusion!!
• Broad linewidths (a few to some km s⁻¹) ⇒ Line identification problematic

interferometry reduces linewidths

cm λ’s are cleaner

SKA
What are Exoplanets like?

- Planet dynamos $\rightarrow$ large-scale $B_{\text{mag}}$ $\rightarrow$ magnetospheres
  - Magnetospheres may be key for habitability of planets ...
- Low-frequency ($\sim$50 MHz) bursts seen from Jovian planets
  - Cyclotron-Maser Instability Emission (CMI)
What are Exoplanets like?

- Planet dynamos $\Rightarrow$ large-scale $B_{\text{mag}}$ $\Rightarrow$ magnetospheres
What are Exoplanets like?

- Planet dynamos $\Rightarrow$ large-scale $B_{mag}$ $\Rightarrow$ magnetospheres

What can we learn??

- Magnetic field strength: planet interior structure
- Tilt of magnetic axis
- Rotation and revolution periods
- Orbit inclination
- Stellar wind activity
- Presence of exo-moons?
What are Exoplanets like?

- Planet dynamos $\Rightarrow$ large-scale $B_{mag} \Rightarrow$ magnetospheres

![Graph showing Flux Density (Jy) vs Frequency (MHz) with SKA1-LOW sensitivity improved by a factor $\sim$8, a Jupiter-like planet could be detected to $\sim$10 pc, and $\sim$200 known stars and $\sim$35 known exo-planets within this volume.]

SKA Cradle of Life
Searching for Extraterrestrial Life

Exploring the Universe with the world’s largest radio telescope
Searching for Extraterrestrial Life

- Known Technology Detection Limits ...

\( t_{\text{integration}} = 60 \text{ min}, \ SNR = 12 \)

- **SKA1**: high-power airport radars detectable for \( >10^4 \) stars

- **SKA2**: low-power TV and radio stations detectable for a few nearest stars

Siemion et al. 2015

Exploring the Universe with the world's largest radio telescope
Cradle of Life Key Science Projects

KSP 1) Young Stellar Cluster Deep Field - Mapping $\beta$ across snow lines

- Oph A star-forming cluster: 2/3 Class 0, 7 Class I, 12 Class II
- 1000 hours in SKA1-Mid (Band 5, @12 GHz)
- Angular resolution ~ 40 mas, i.e. 5 au at 125 pc

- Additional Science: Pre-biotic COMs, Jets, 6D Tomography, Magnetic Flaring

KSP 2) Stars, Planets and Civilizations

- Key Obs # 1 (SKA1-LOW): All sources within 25 pc ➔ 2500 hours
- Key Obs # 2 (SKA1-LOW): Selected sample (>25 pc) ➔ 1500 hours
- Key Ob # 3 (SKA1-LOW): Search for low Galactic latitudes ➔ 833 hours

- High commensality with SWGs “Our Galaxy”, “Epoch of Reionization”, “Cosmology” and “Transients”
The Cradle of Life Working Group

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+ 33 associate members from 15 countries
Cradle of Life Science Themes

1) How do rocky planets form?

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SQUARE KILOMETRE ARRAY
Exploring the Universe with the world’s largest radio telescope