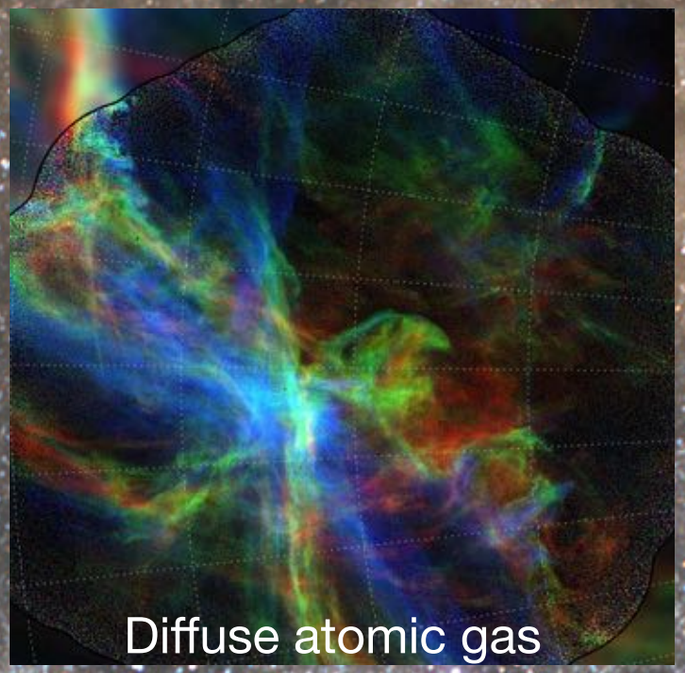
The Galactic interstellar medium in the radio: prospects for the SKA

Marta I.R. Alves (Radboud University Nijmegen, Netherlands)
&
The French ISM SKA community

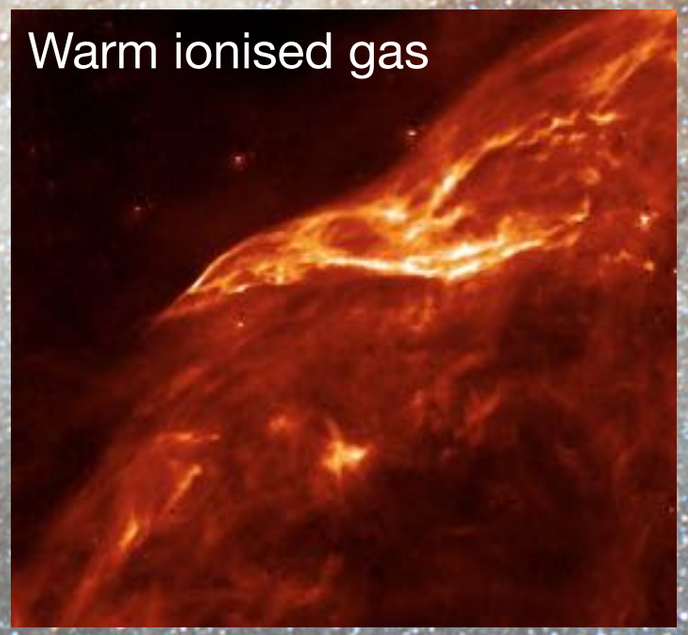
SF2A — 5 July 2018 — Bordeaux

Interstellar medium in galaxies

Gas & dust
Magnetic fields
Cosmic rays


Diffuse atomic gas


Molecular gas


Warm ionised gas

The central part of the Milky Way in the visible (ESO)

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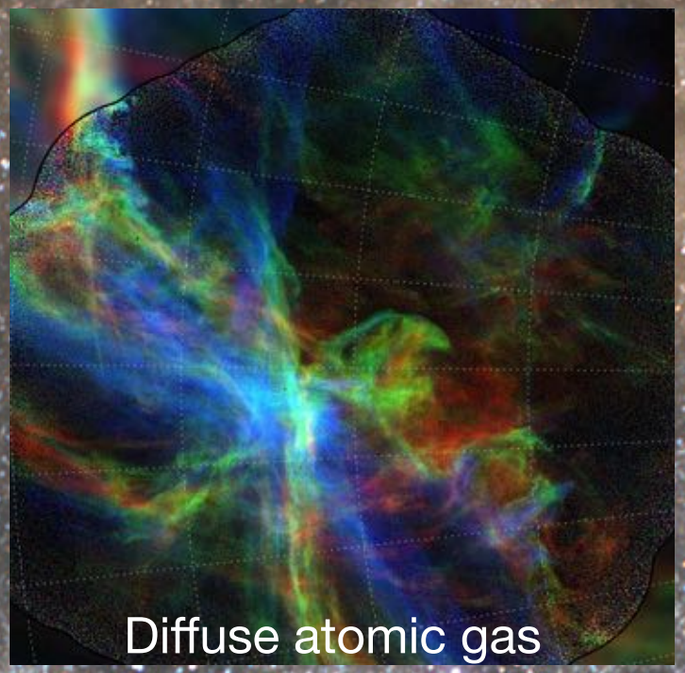
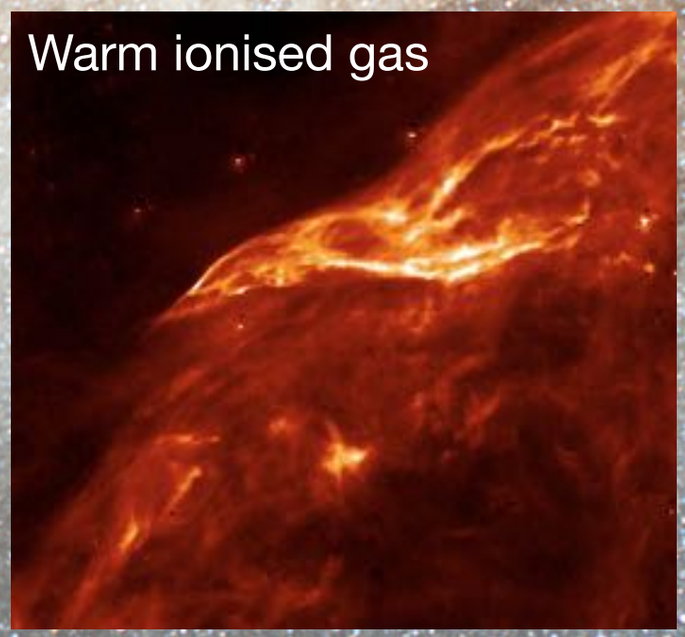

Diffuse atomic gas


Star formation


Molecular gas

Gravity
Heating and cooling
Chemistry
Stellar feedback
Turbulence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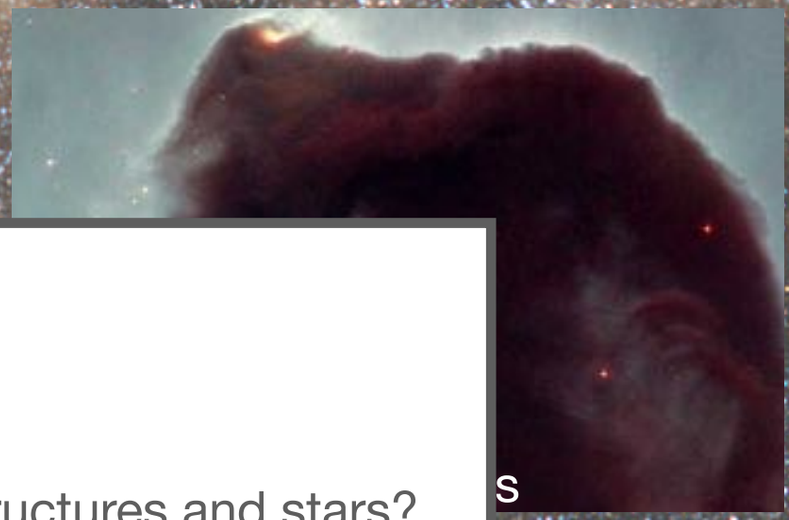

- How do cold dense structures form from the diffuse ISM?
- How do stars drive turbulence and energy into the ISM?
- What is the role of the magnetic field in the formation of structures and stars?
- How do dust grains and molecules evolve in the ISM?

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Heating and cooling
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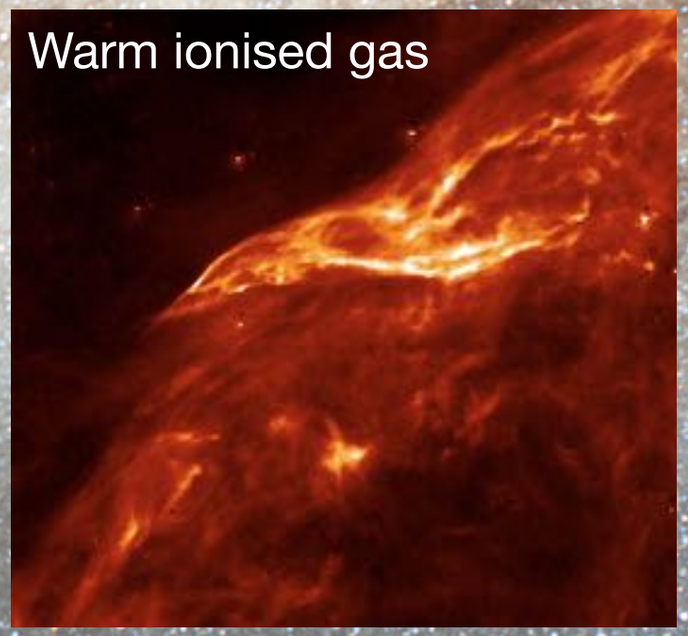

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SKA brings this all together

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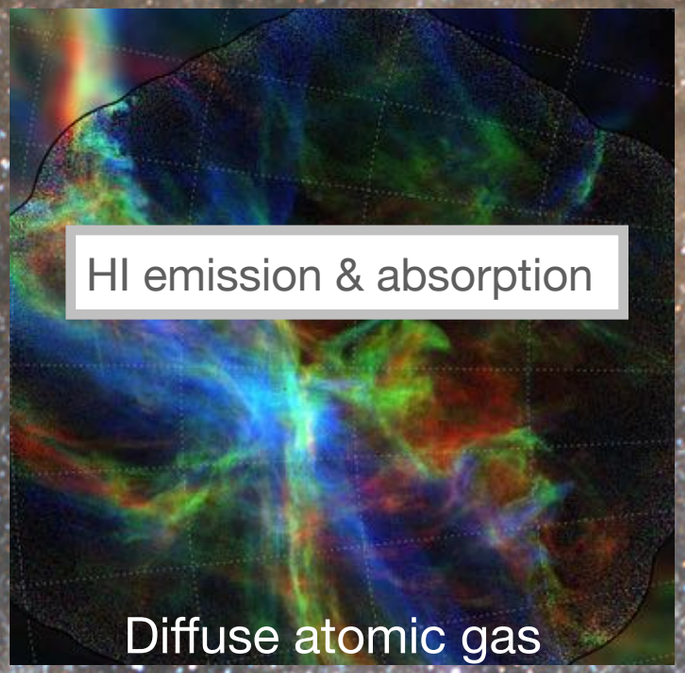

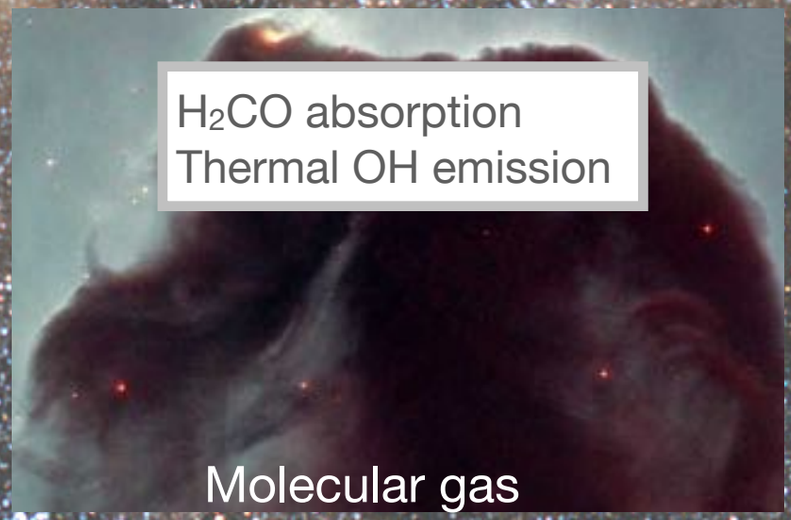

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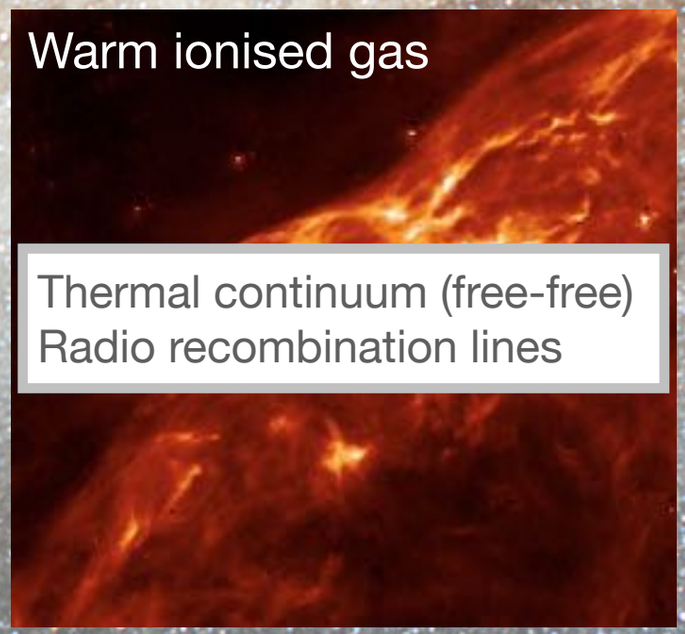

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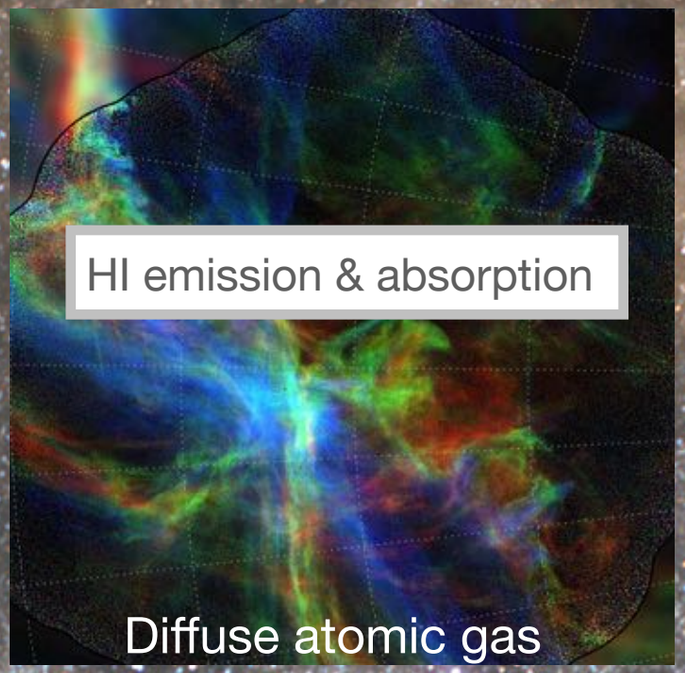

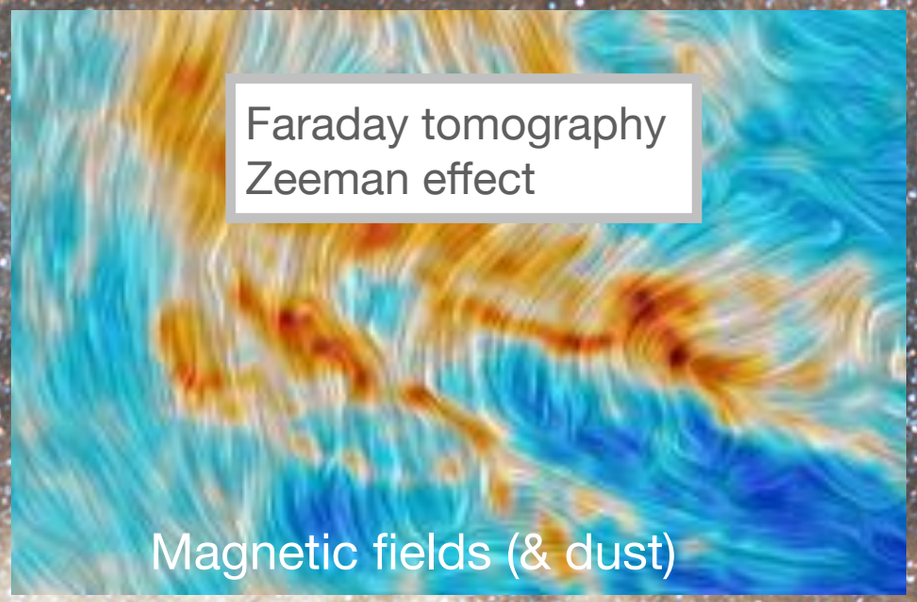

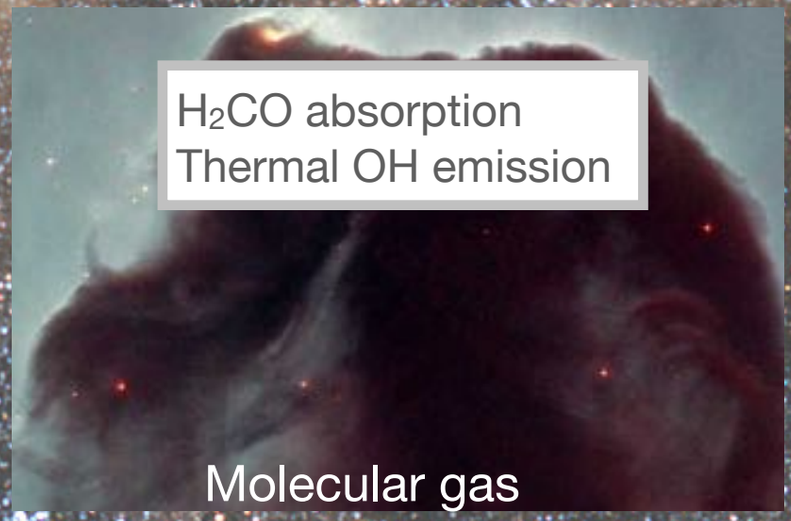

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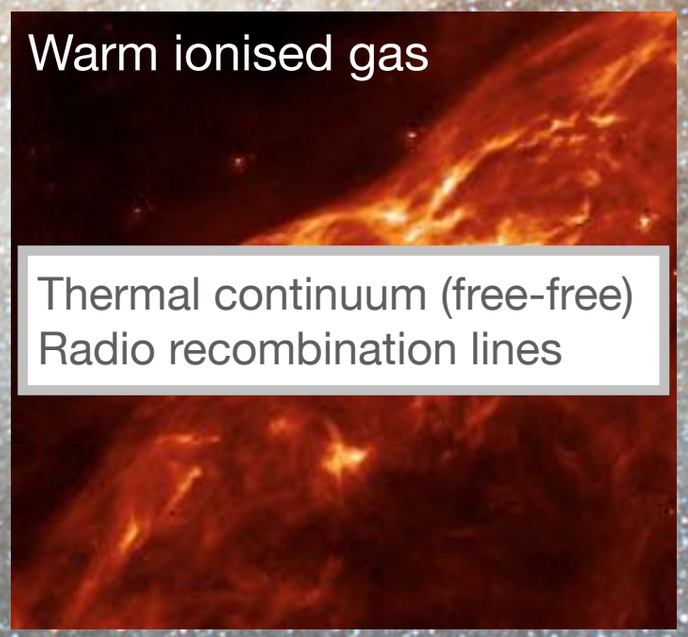


The central part of the Milky Way in the visible (ESO)

SKA: a unique machine to study the ISM

- **Frequency coverage (50 MHz — 15 GHz)**

  HI, OH, H_2CO, radio recombination lines (H, He, C), complex molecules (COMs — glycine?), continuum (free-free, synchrotron, anomalous microwave emission, dust)

  Pulsar dispersion measures, rotation measures

  Faraday tomography, Zeeman effect (HI, OH, CH, radio recombination lines)

- **Angular resolution** (25%better/4 times the resolution of LOFAR/JVLA)

  Small-scale structures: disks, filaments, shocks, dissipative structures

  Astrophysics of other galaxies

- **Sensitivity** (8/5 times more sensitive than LOFAR/JVLA)

  Small-scale structure, faint line emission, Galactic halo, external galaxies

- **Mapping speed** (135/60 times faster than LOFAR/JVLA)

  Multi-scale/multi-phase physics

Interstellar medium science with the SKA: French community

Galactic Astronomy — 40 scientists from 12 institutes

1. The nearby interstellar medium
2. Turbulent cascade
3. The formation of cold atomic structures
4. Molecular complexity in cold cores and hot corinos
5. Interstellar dust
6. Faraday tomography
7. Magnetic fields in star forming regions: Zeeman effect of RRLs
8. Jets, outflows, and young stellar objects
9. Supernova remnants
10. Pulsar census and probe of the interstellar medium
11. Distance determination

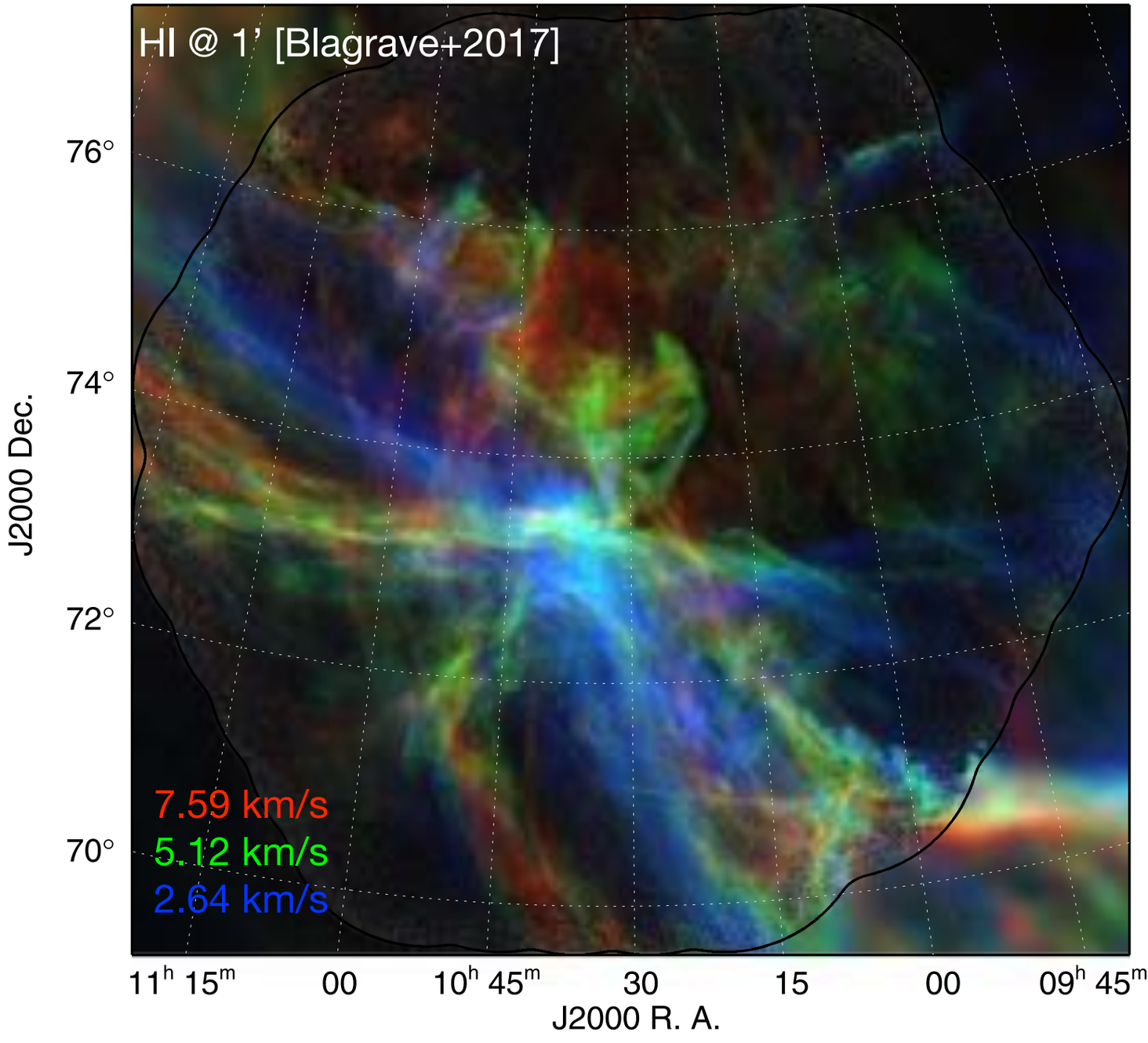
Gas phase transition

How do cold dense structures form from the warm and diffuse phase?
And how do they evolve into the molecular (star-forming) phase?

Cold & warm neutral medium (CNM & WNM)
T~ 20 — 200 K vs. T ~ 10^4 K

Transition: Thermal instability [Field 1965]

Need to estimate the amount and properties (temperature, cloud density, velocity) of gas over a large range of physical conditions.



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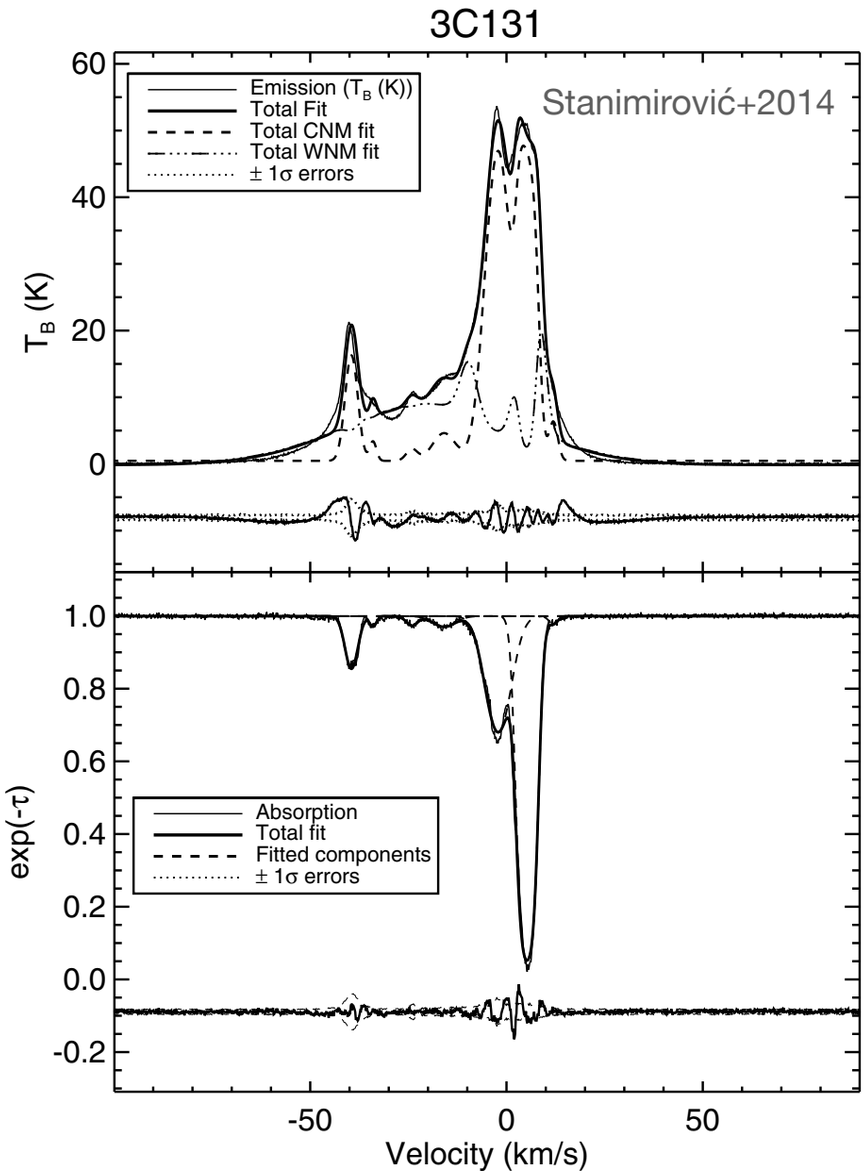
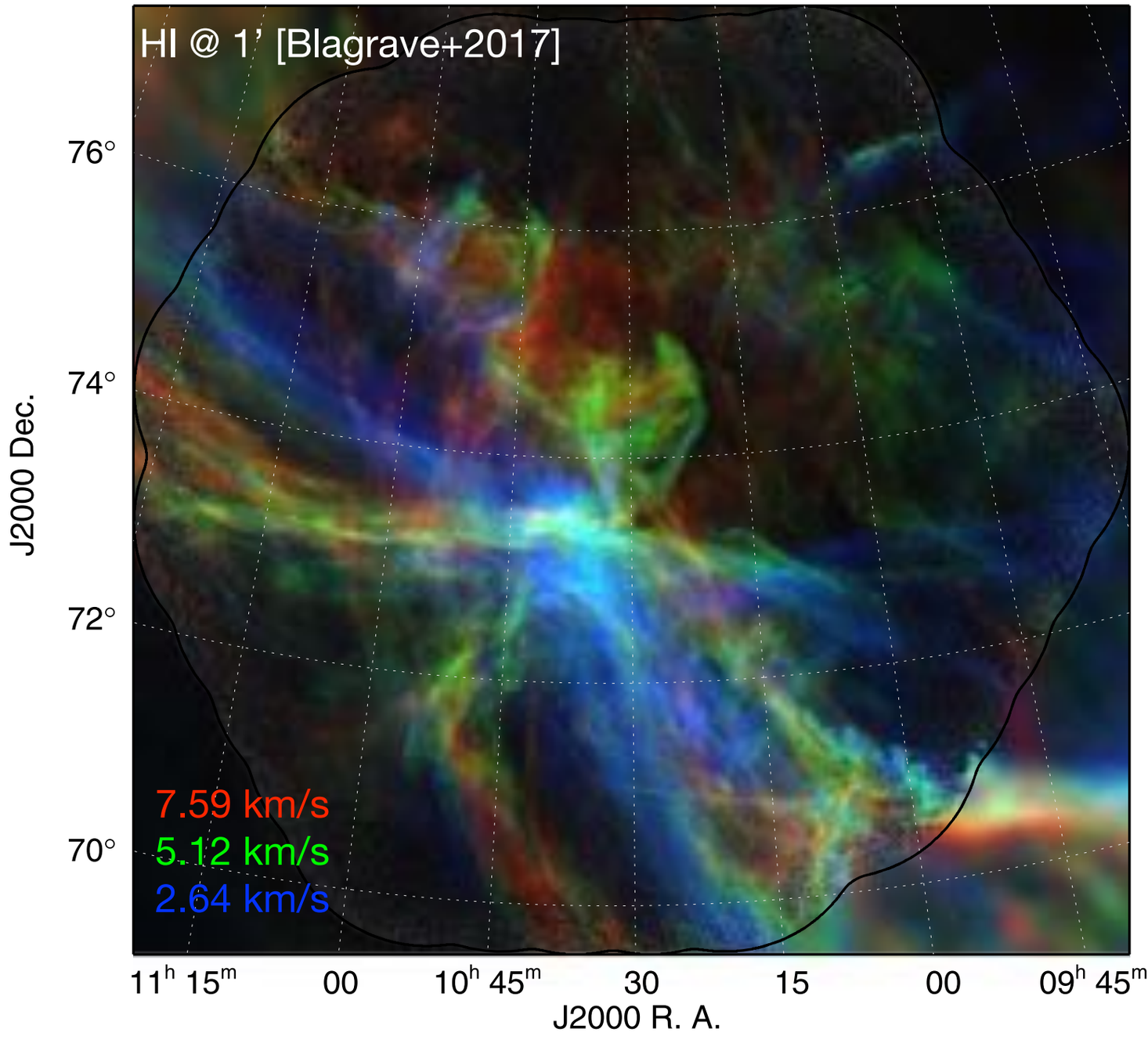




SKA will provide fully-sample imaging of HI emission at high angular & velocity resolution;
~ 2×10^5 absorption measurements against radio sources [McClure-Griffiths+2015]

Interstellar turbulence

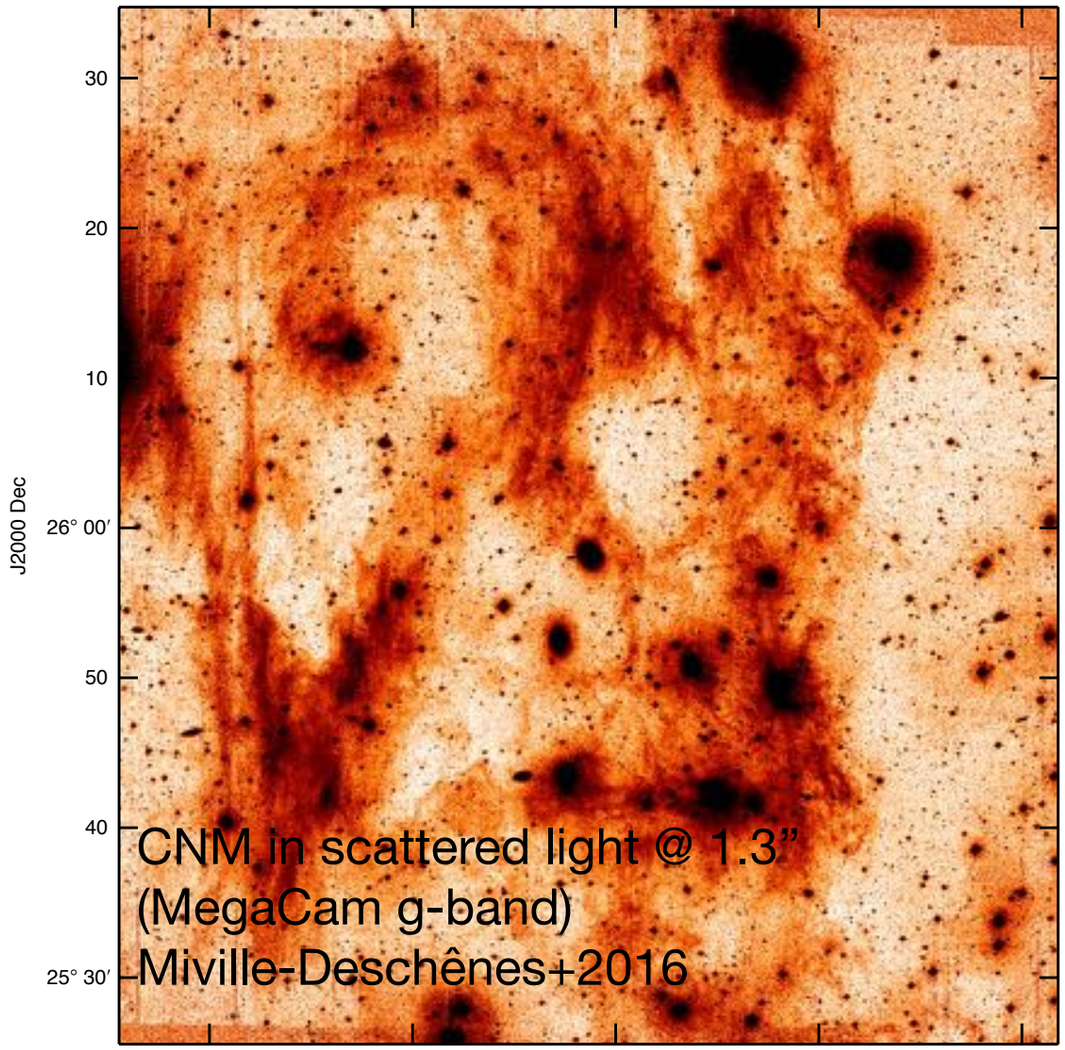
What are the properties of turbulence in each ISM phase?
And how does turbulent energy dissipate?

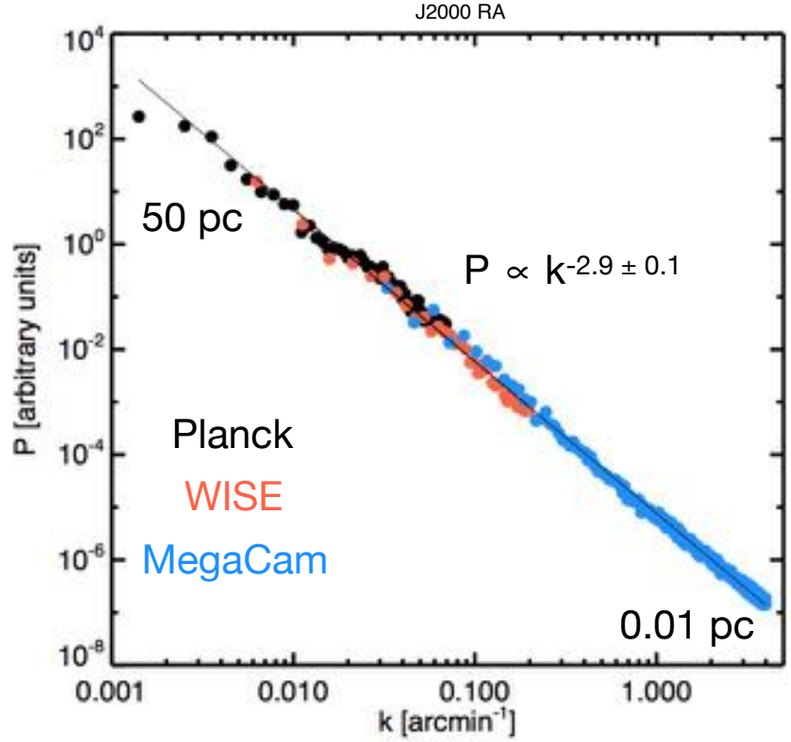
Turbulence determines the distribution of
matter in the ISM ➡ regulates star formation

ISM is turbulent:
— energy injected at large scales (100s pc — kpc)
by massive stellar feedback, Galactic shear
— energy cascades down to smaller scales (10^{-5} pc)
until it dissipates

Spatial scales & power-law index give information
on the nature of turbulence [e.g. Kolmogorov+1941,
Goldreich & Sridhar 1995, Kritsuk+2007]
➡ compressible, super-sonic, sonic, magnetic!…

Need to probe turbulence in different phases
(inc. in polarisation) and across a large range
of spatial scales (~kpc to AU)





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- SKA HI data (high angular resolution, CNM/WNM separation)
  Probe smaller physical scales (scales of 10s AUs)
- SKA RRL, OH spectral data
  Probe different gas phases

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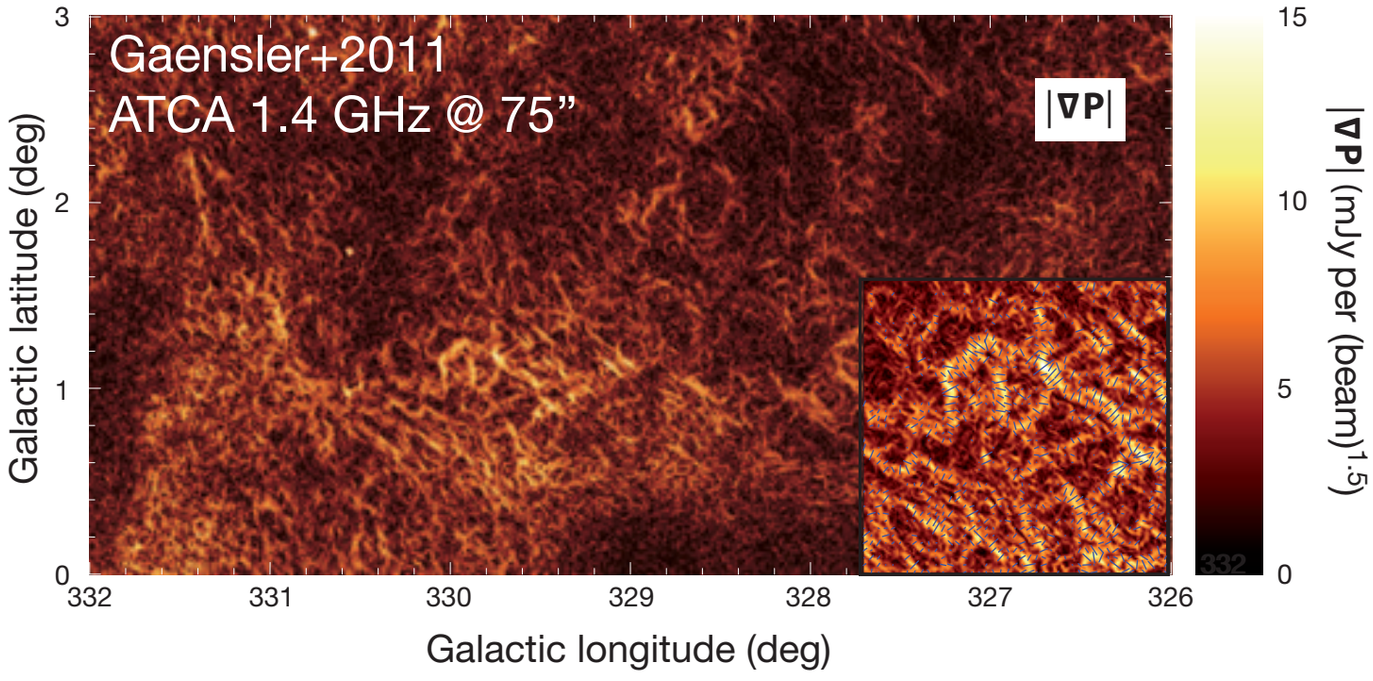
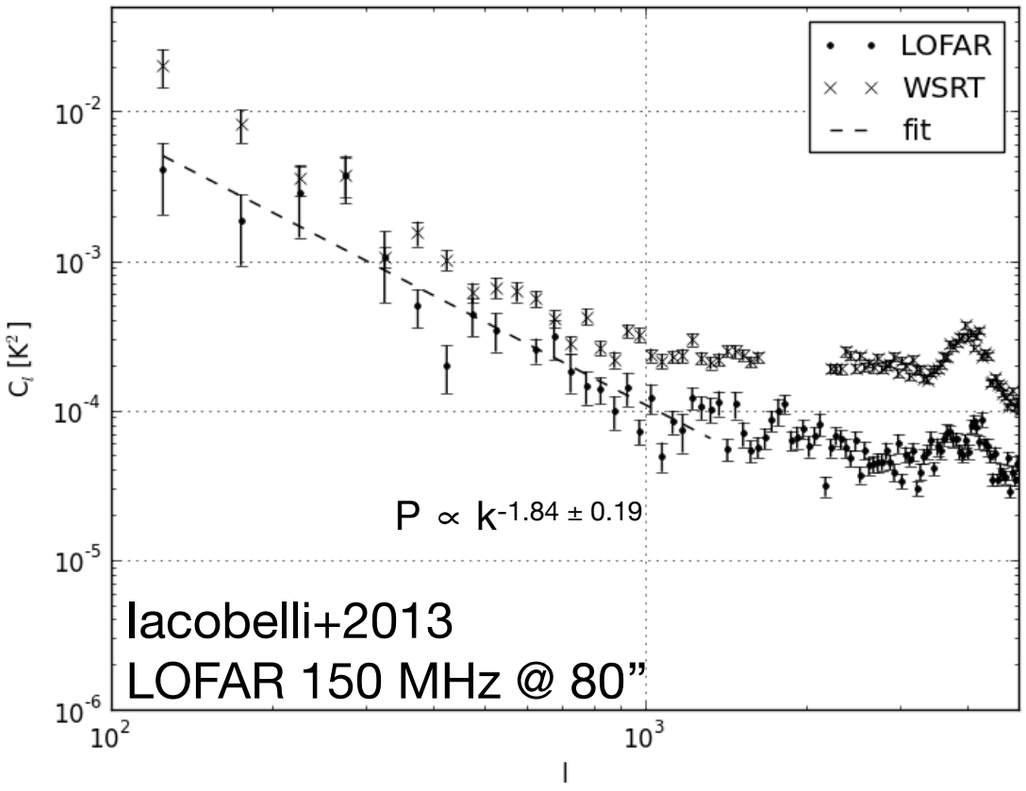
- SKA HI data (high angular resolution, CNM/WNM separation)
  Probe smaller physical scales (scales of 10s AUs)
- SKA RRL, OH spectral data
  Probe different gas phases
- SKA synchrotron and polarisation data
  Probe magnetised turbulence



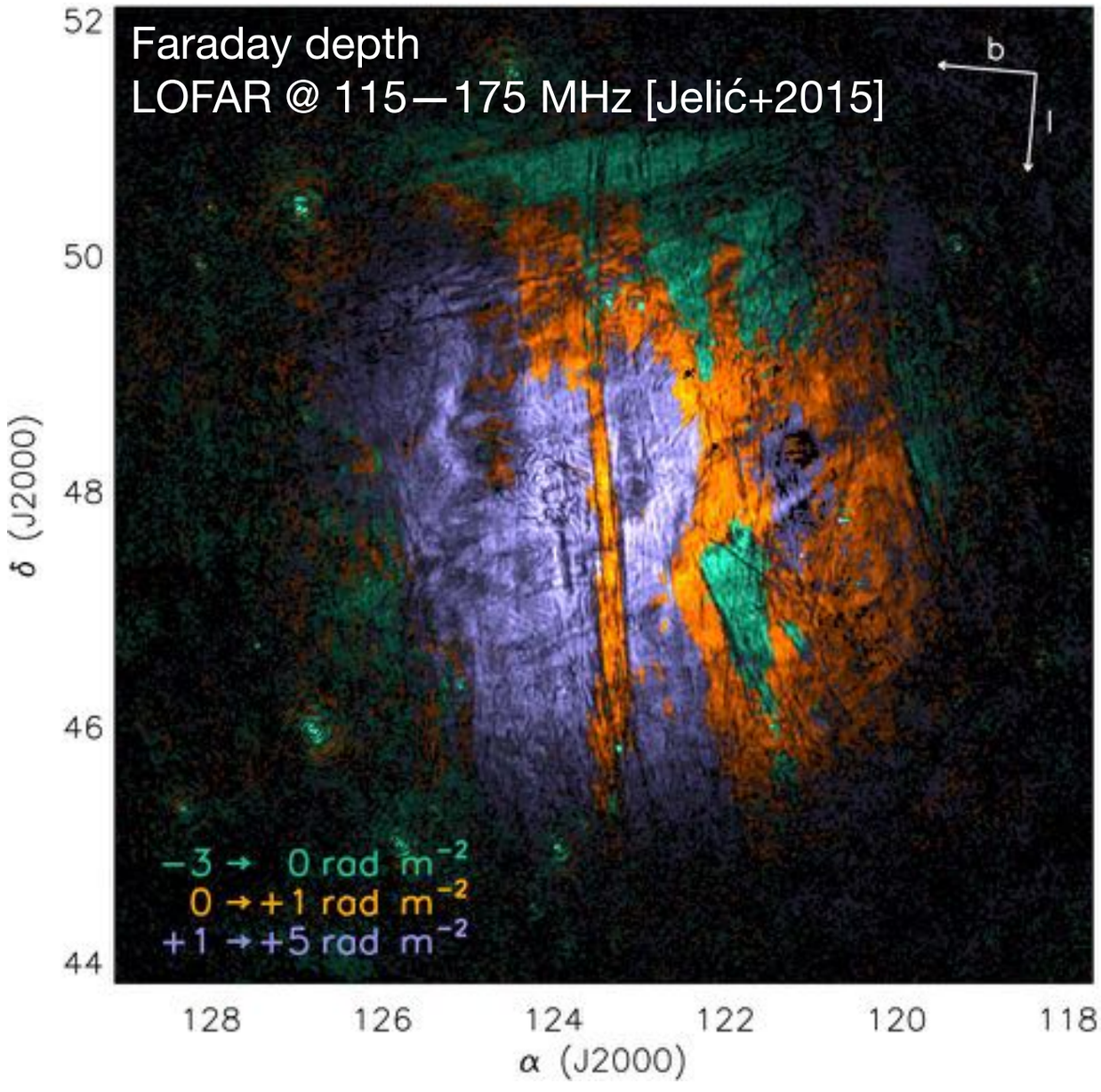


Magnetic fields: diffuse interstellar medium

How does the magnetic field control the formation and evolution of interstellar structures?

Faraday tomography
(synchrotron emission + Faraday rotation):
magnetic field in cosmic-ray and ionised media in 3D

➡ New structures in the ISM!



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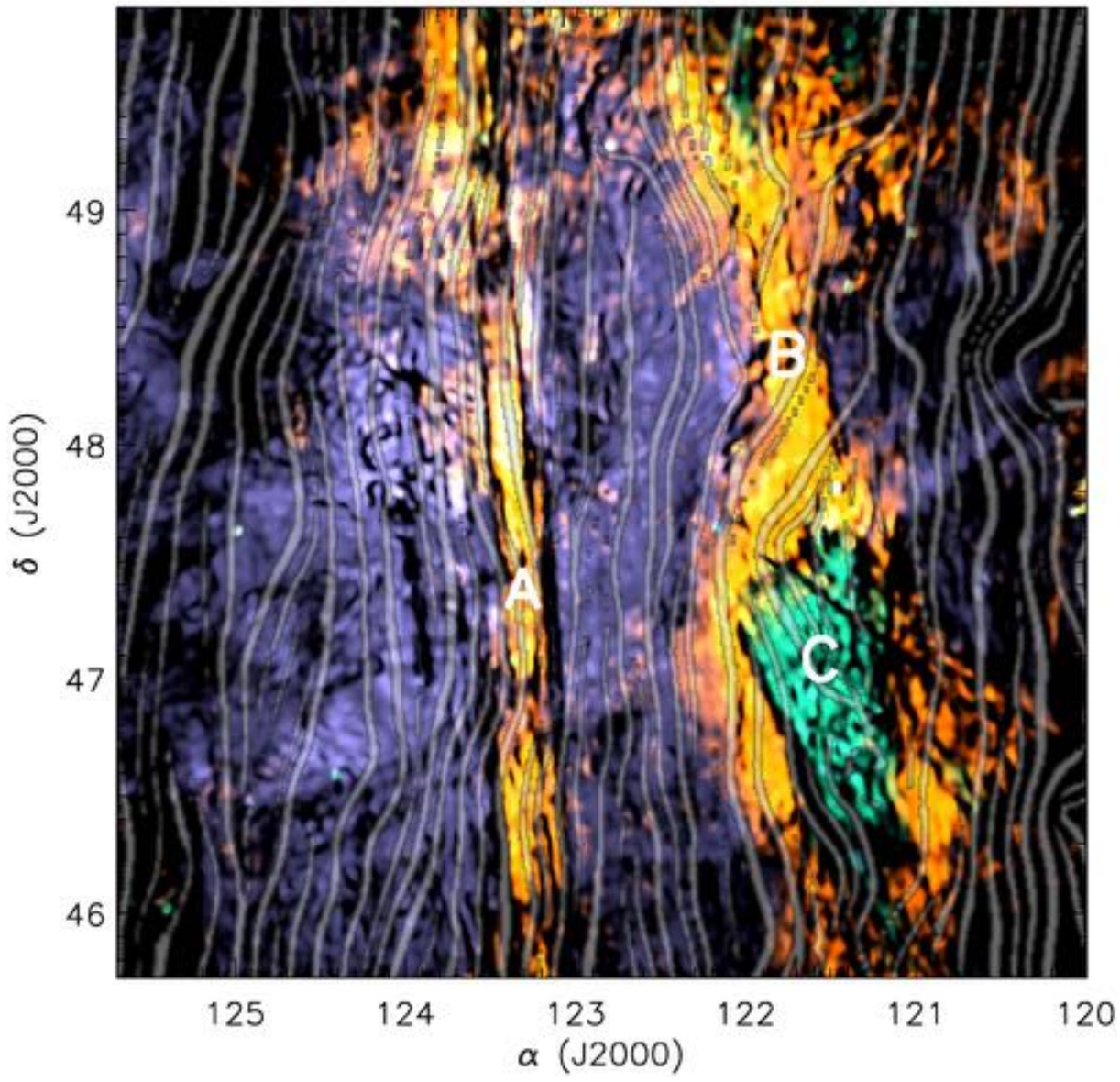
➡ New structures in the ISM!

➡ Unexpected correlation!
Tracers of the field in ionised and neutral media

SKA will be a true Faraday tomography machine
owing to large frequency coverage
➡ deeper in Faraday (physical) depth



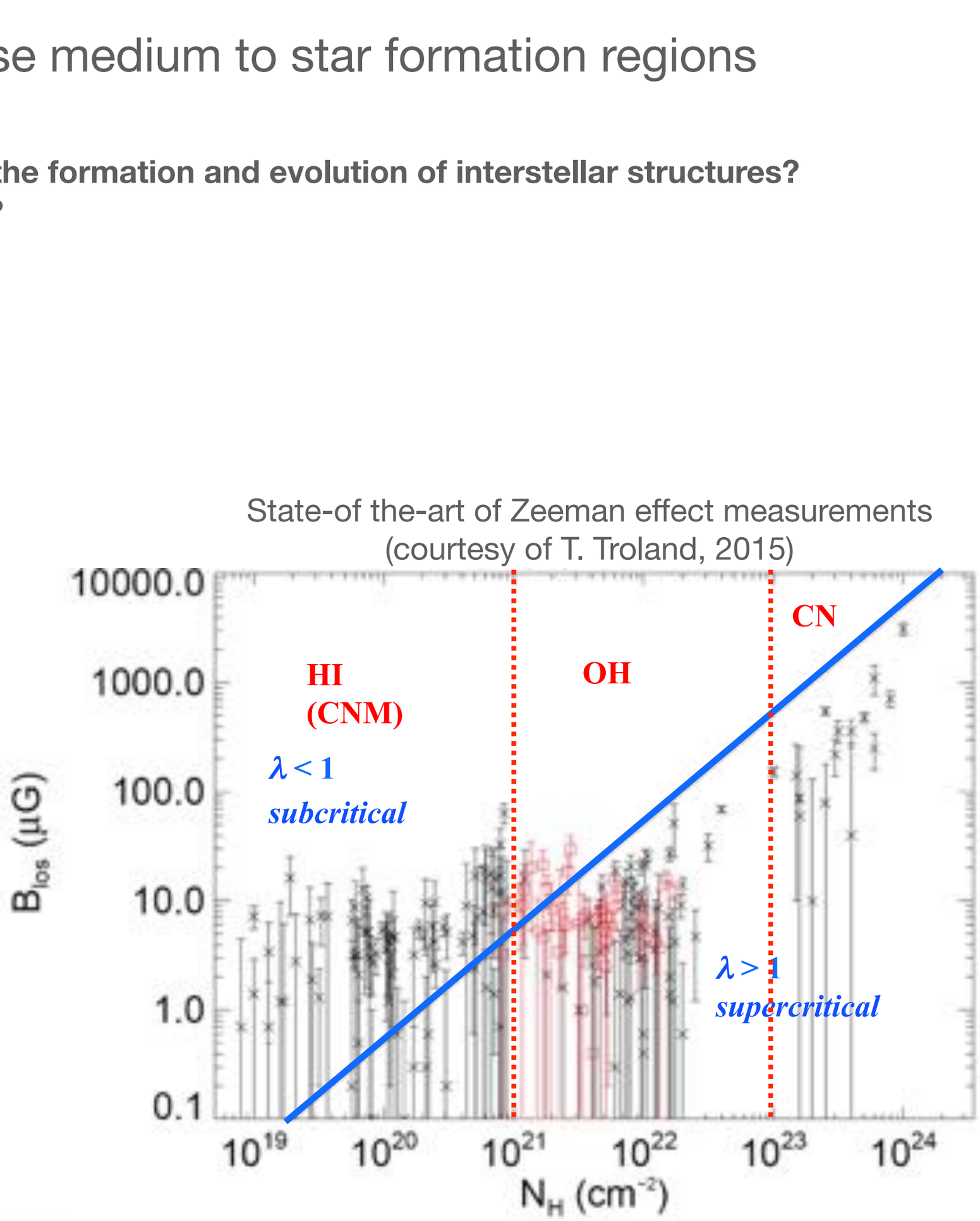
Faraday depth & Planck magnetic field lines
[Zaroubi+2015]

Magnetic fields: from diffuse medium to star formation regions

How does the magnetic field control the formation and evolution of interstellar structures?
And ultimately the formation of stars?

Need to measure the strength of
magnetic field in star formation regions
➡ Zeeman effect

State-of the-art of Zeeman effect measurements
(courtesy of T. Troland, 2015)



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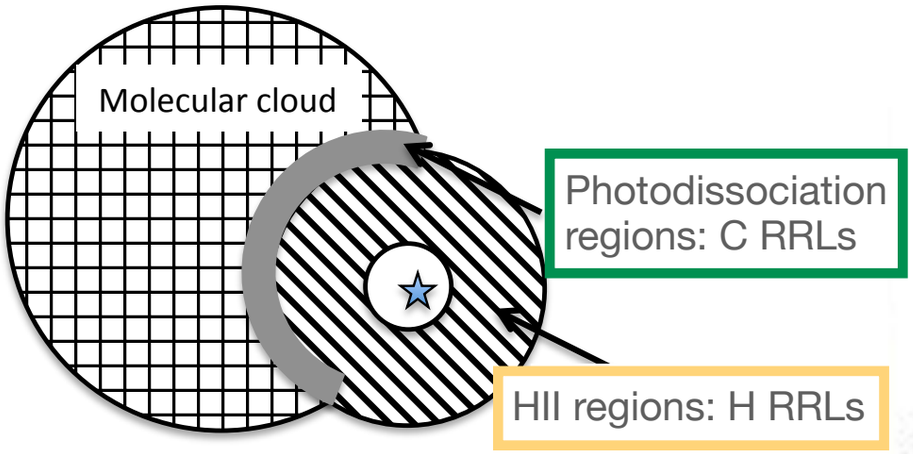
SKA will measure the Zeeman effect of

- HI, OH, CH
- H (never detected before*) and C RRLs



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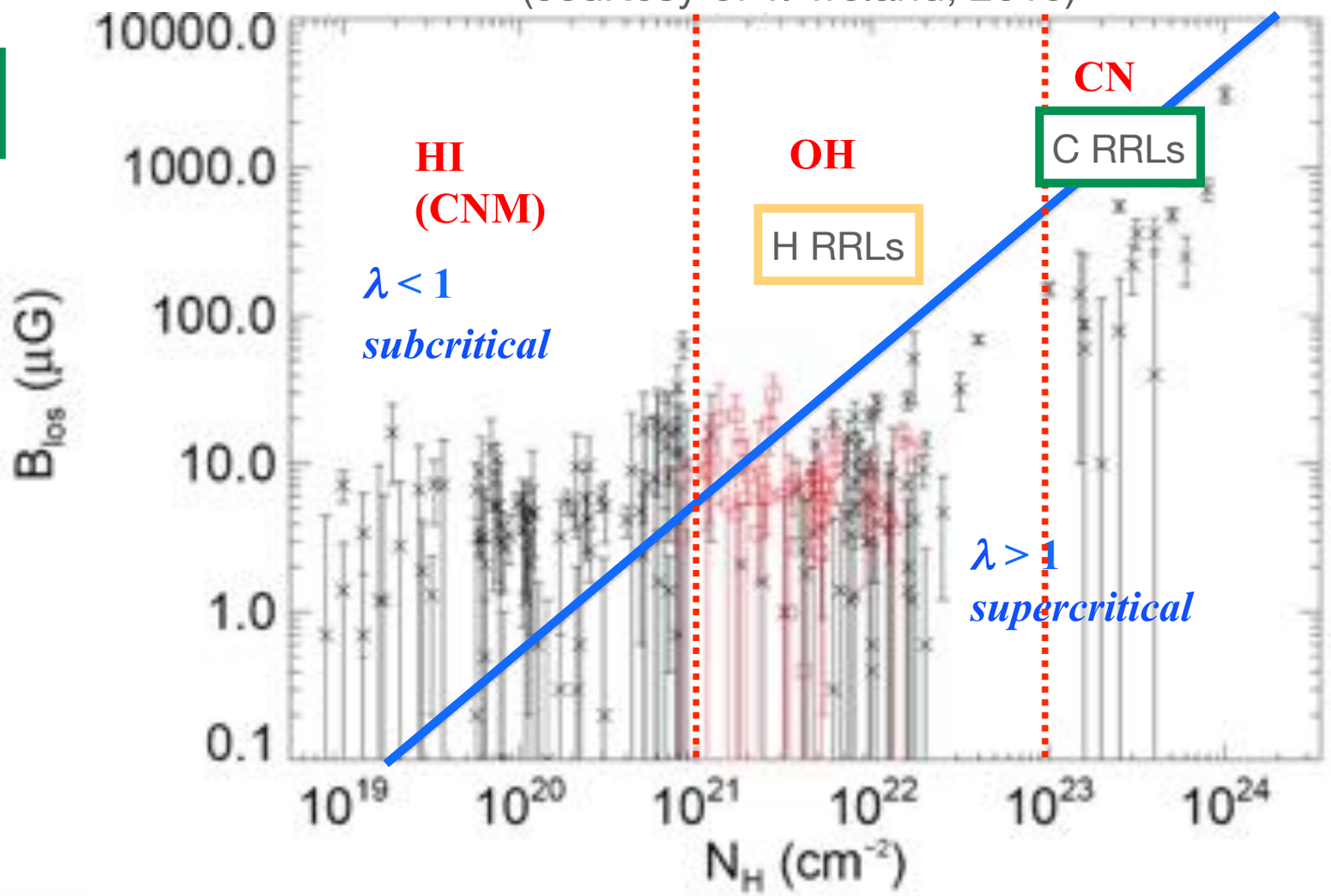


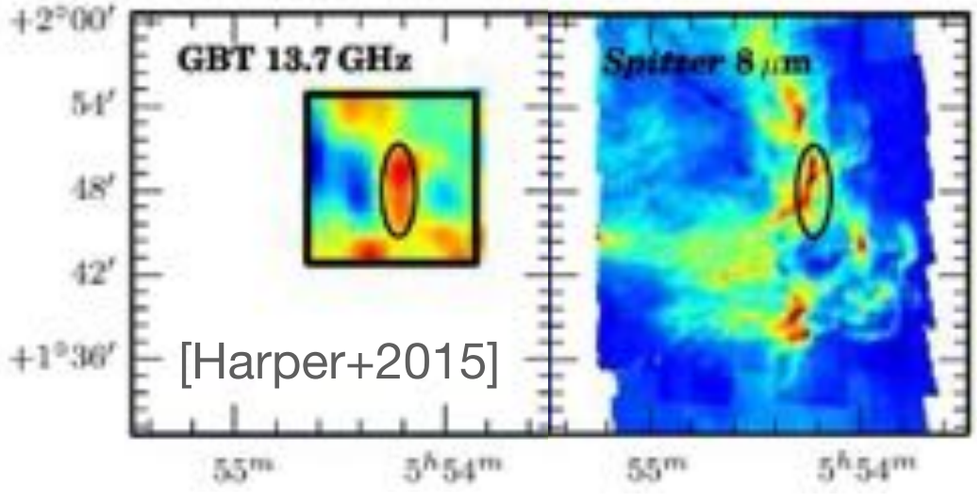
*Except for H RRL maser emission [Thum & Morris 1999]

Dust evolution in the interstellar medium

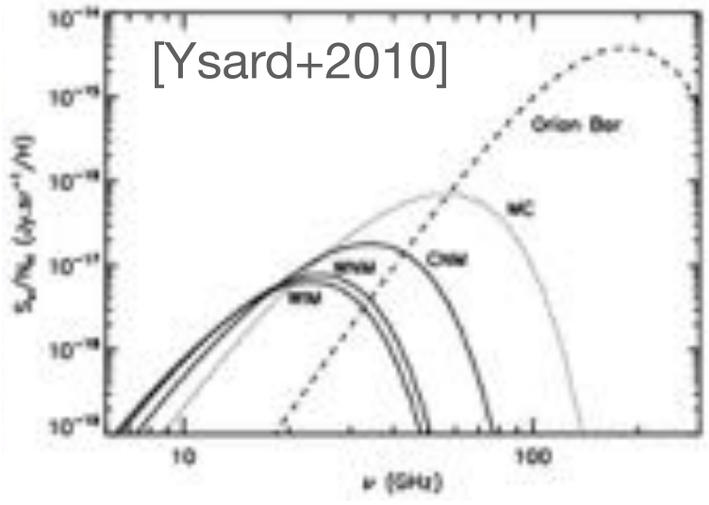
What are the properties of dust grains in the different phases of the ISM and how do they evolve?
What is the nature of the “anomalous microwave emission”?

AME: microwave emission correlated with infra-red dust emission; most likely PAHs — still debated!

What are the real carriers of AME?



[Harper+2015]



[Ysard+2010]

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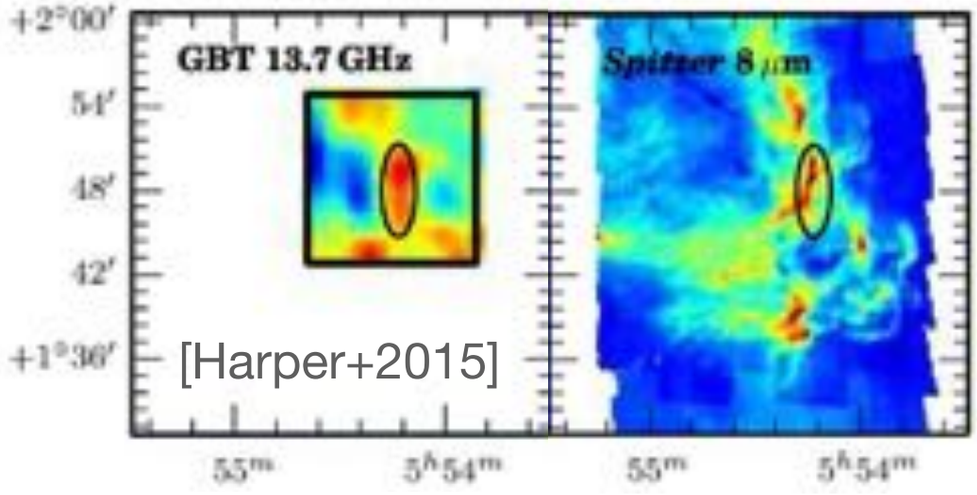

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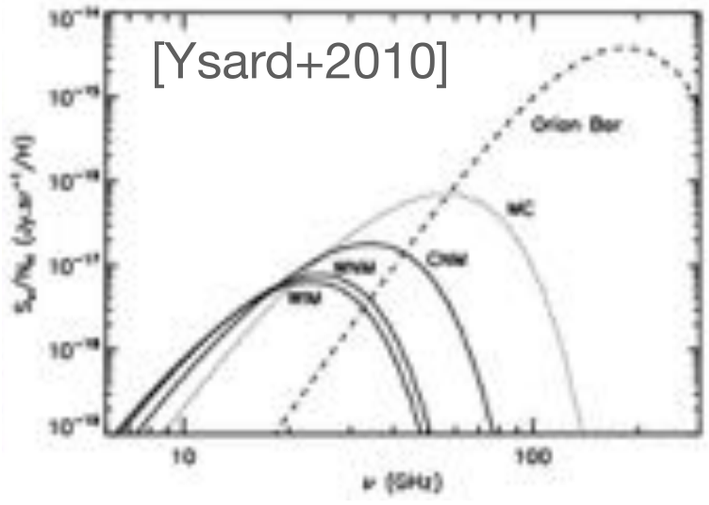


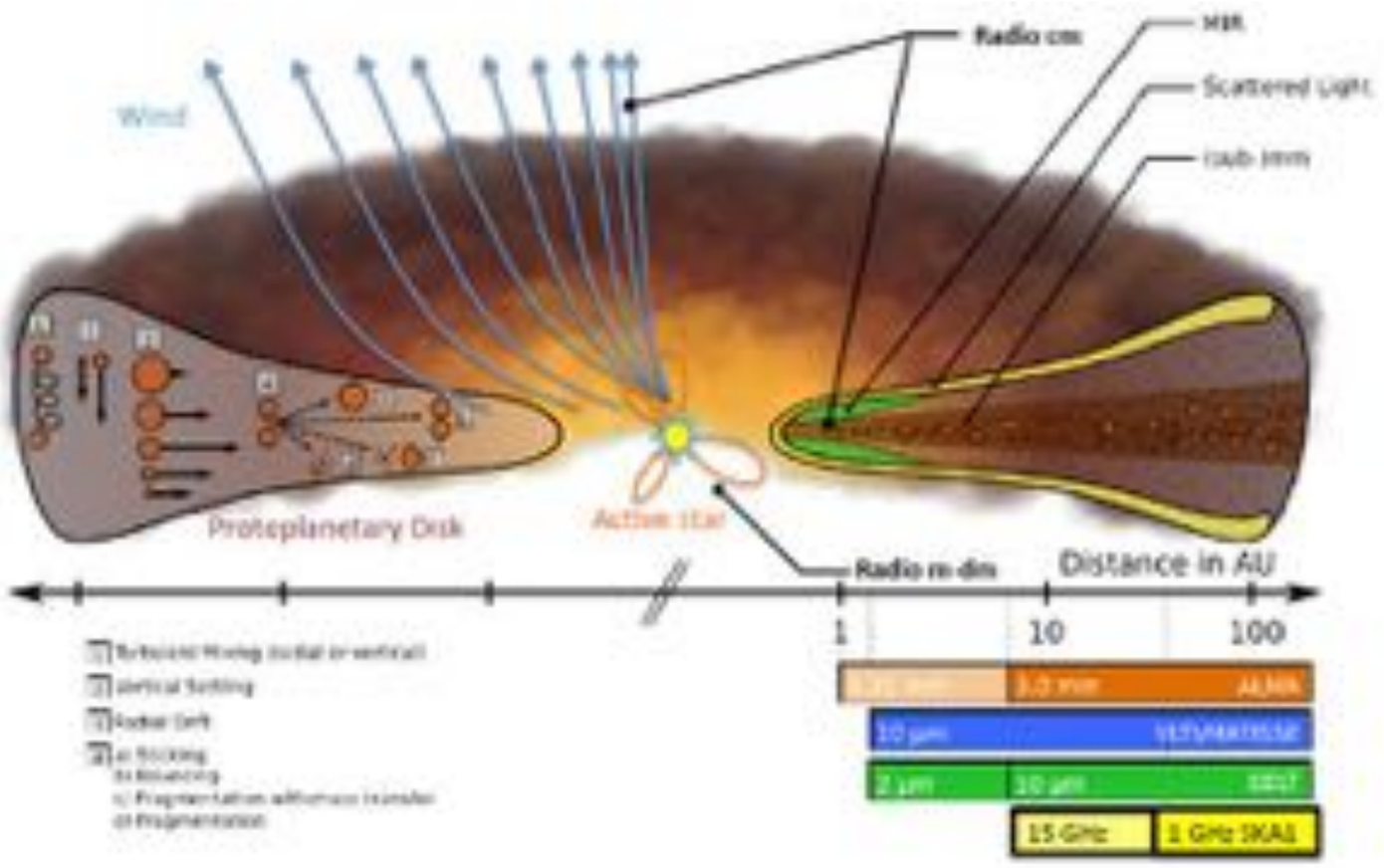
[Ysard+2010]

SKA will provide the high angular resolution to observe dense clouds - key to advance in these studies

Confirmation of AME mechanism would make this emission a new probe of ISM physics

Dust evolution in the interstellar medium — protoplanetary disks

How do dust grains grow to pebble size in disks?



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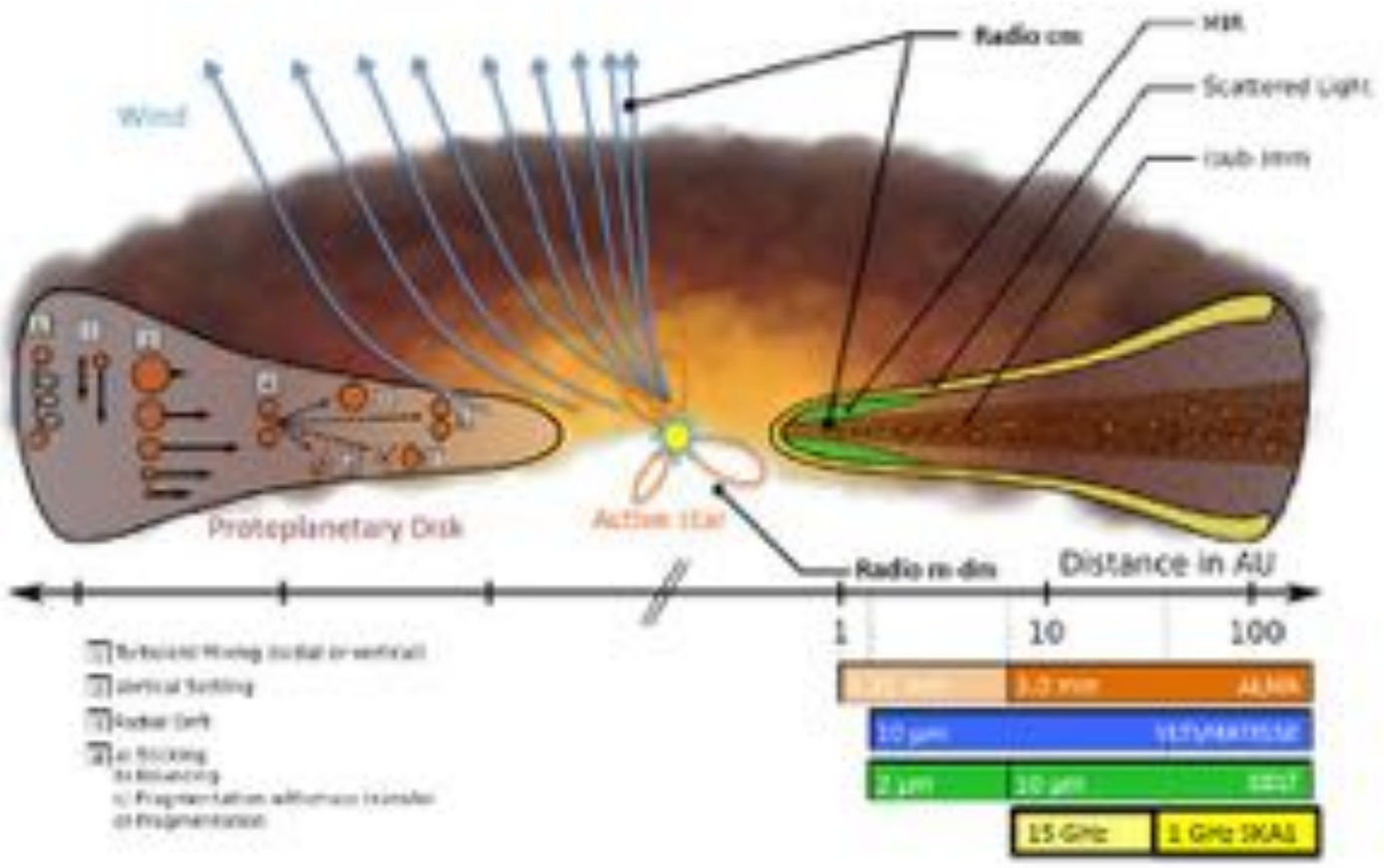

- SKA will for the first time resolve disks in the microwave domain + detect wind emission
  Trace grain growth down to a few AU scales

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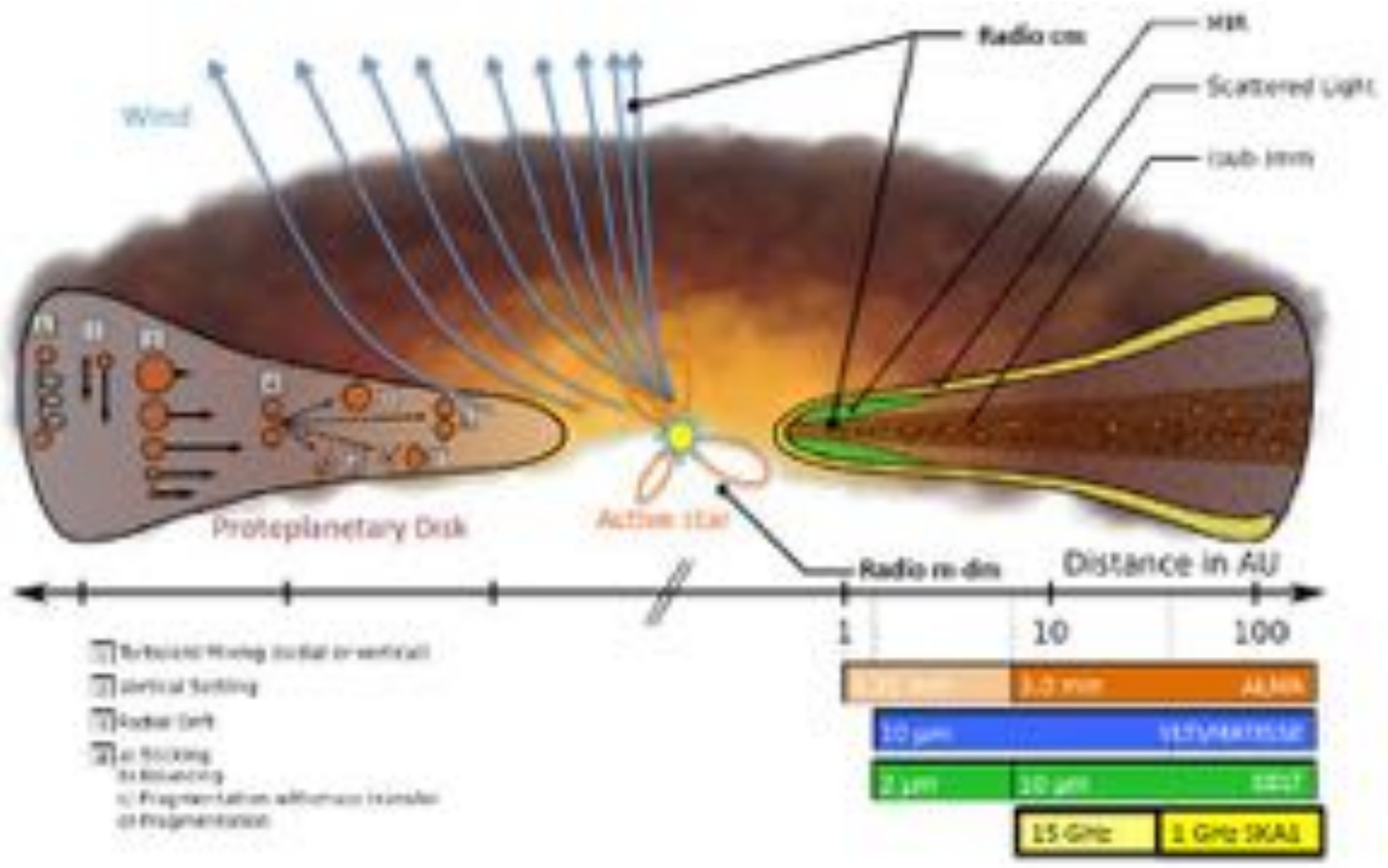

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- SKA will tell us more about AME in protoplanetary disks!
  PAHs? Nano-diamonds? [Greaves+2018, Hoang+2018]

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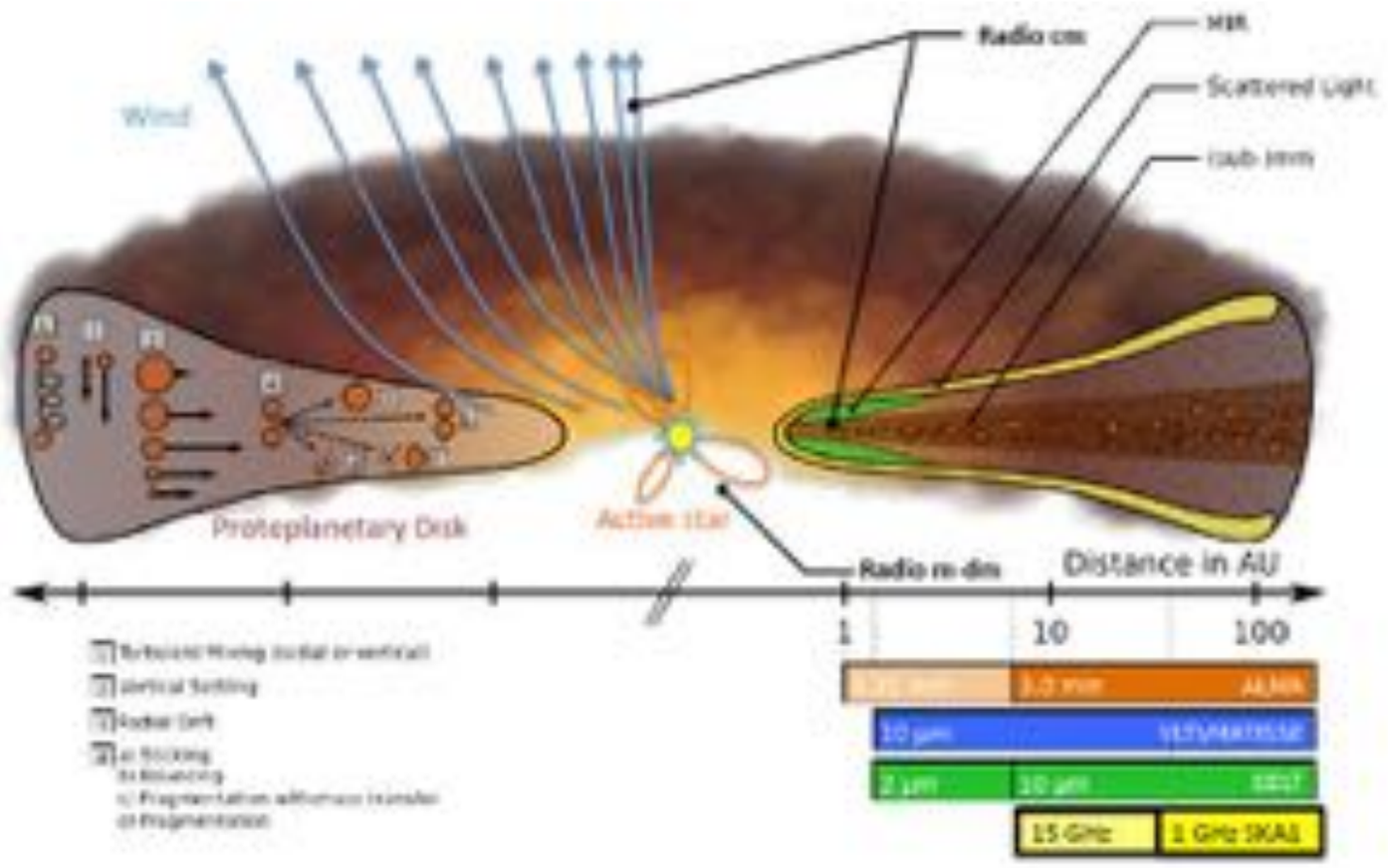

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HOT TOPIC

- SKA will detect numerous complex organic molecules (e.g. HC_nN) in low-mass protostars
  SKA2 (higher sensitivity and higher frequency coverage) to hope to detect glycine!

Conclusion

- **SKA will revolutionise our understanding of the Galactic ISM**
- **The French ISM community has unique expertise (White Book) and will be able to carry out new science with the SKA**

Thank you!