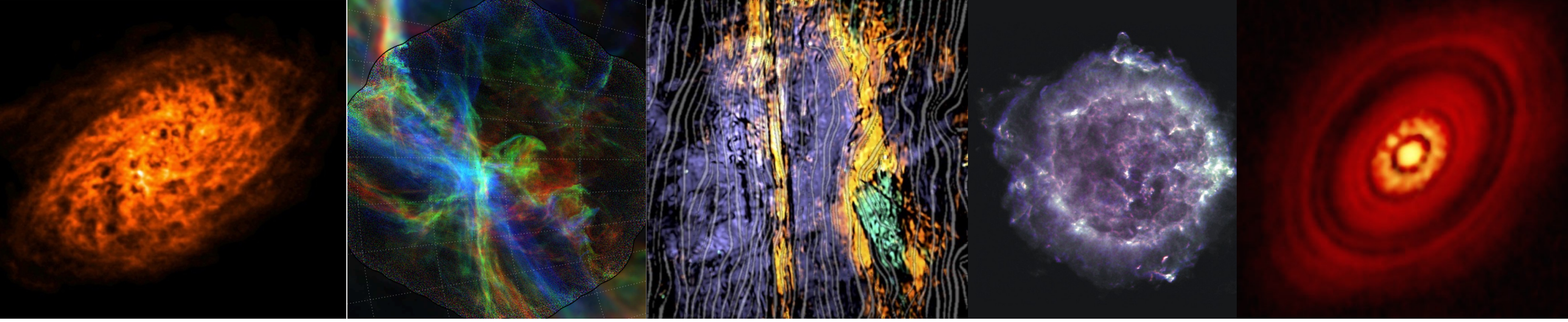

The SKA : a unique instrument to study the interstellar medium

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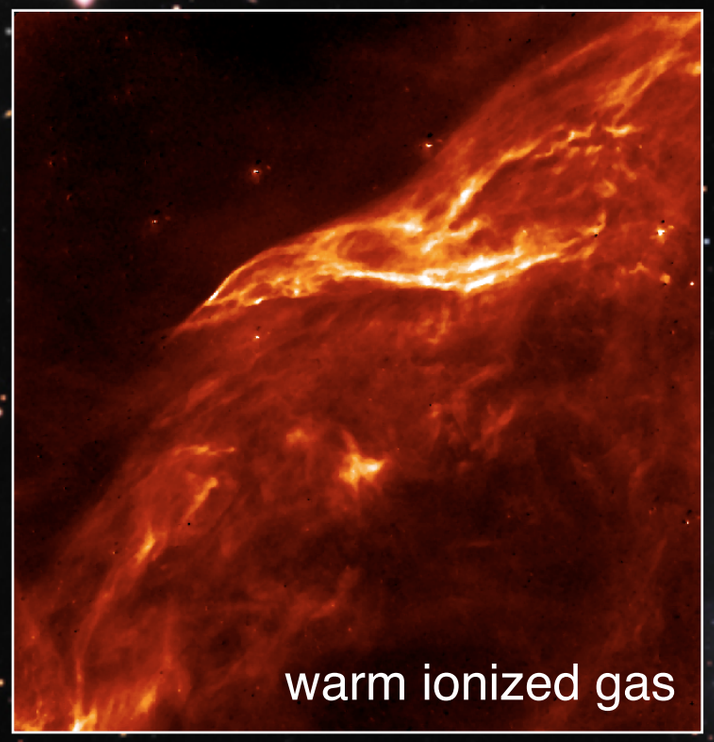
Institut d'Astrophysique Spatiale, Orsay

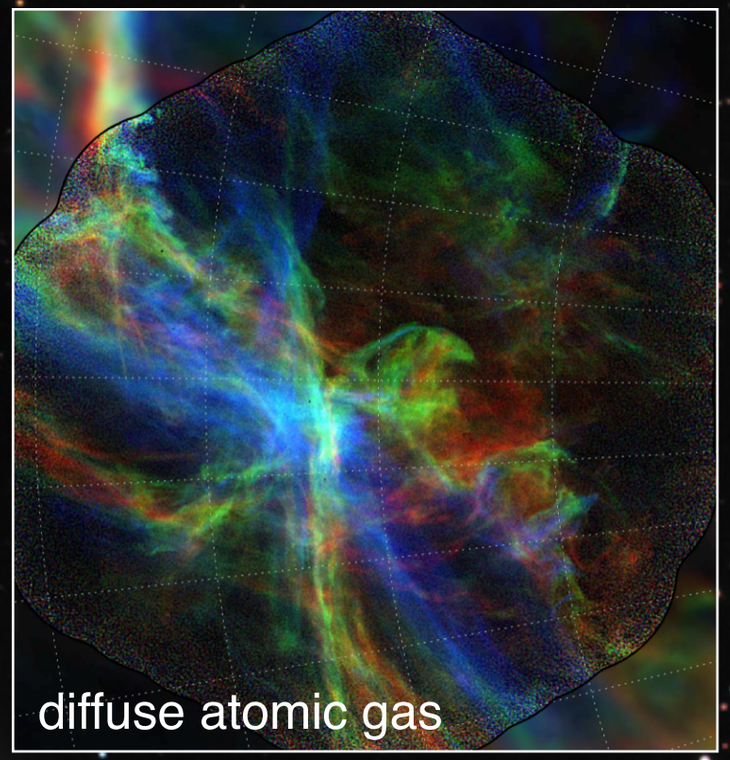
in collaboration with
Katia Ferrière, **Marta Alves** and **Ludovic Montier**
Institut de Recherche en Astrophysique et Planétologie, Toulouse

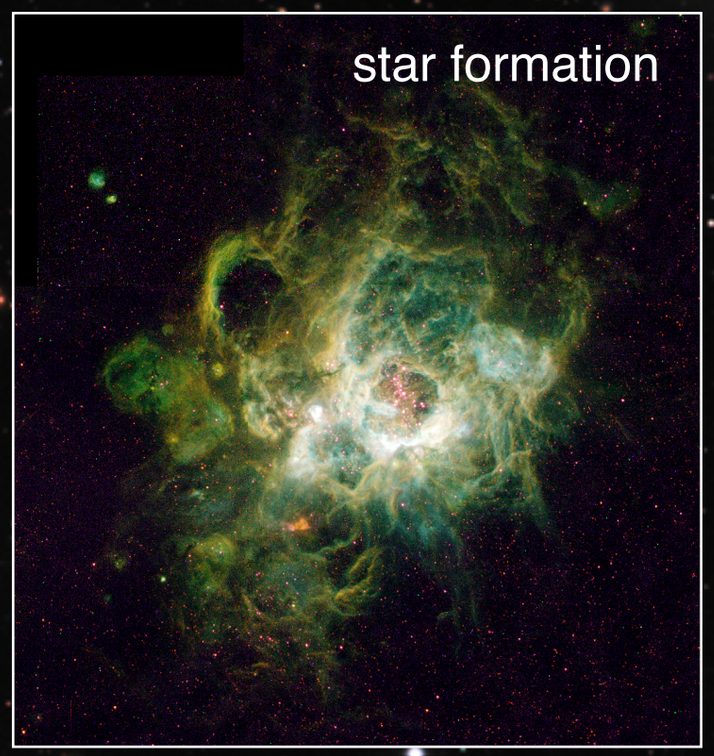
and
the french ISM SKA community (40 scientists from 12 institutes)

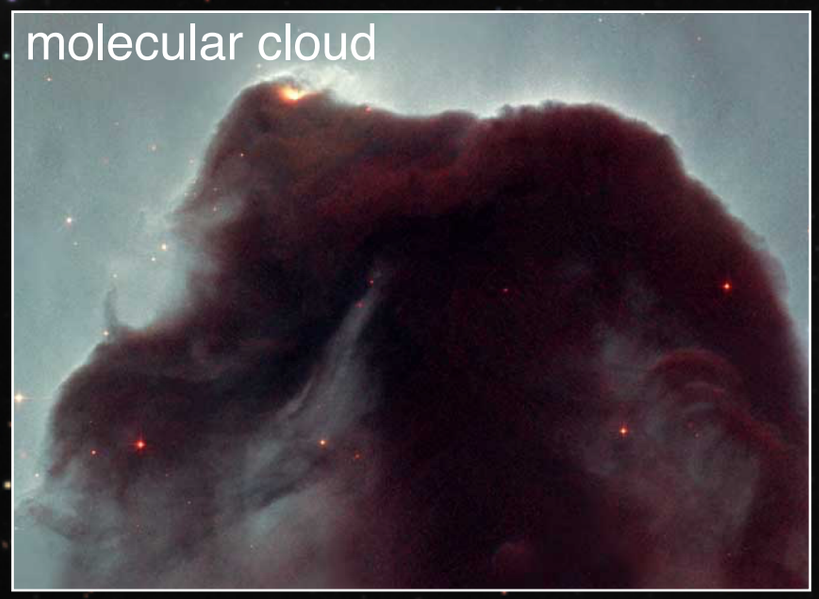
pcmi

the interstellar medium in galaxies

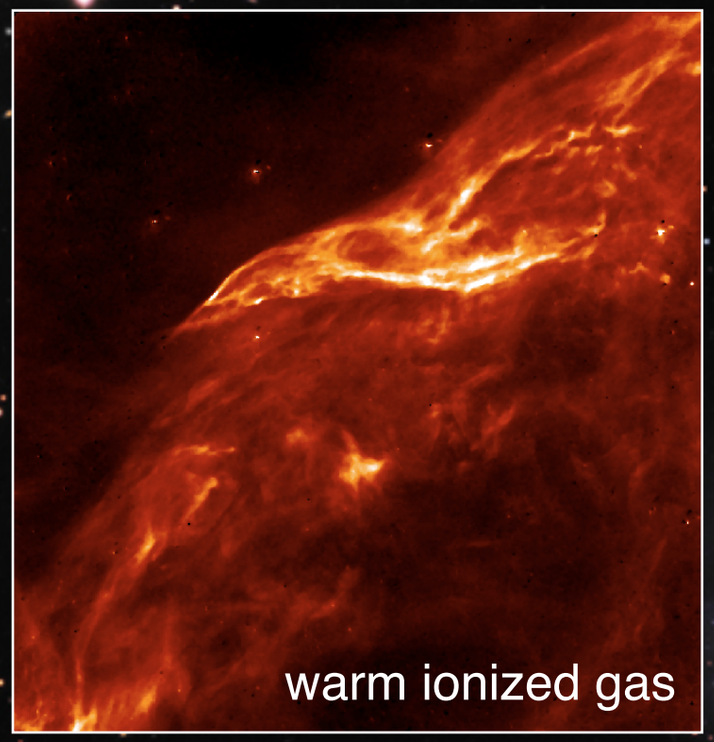


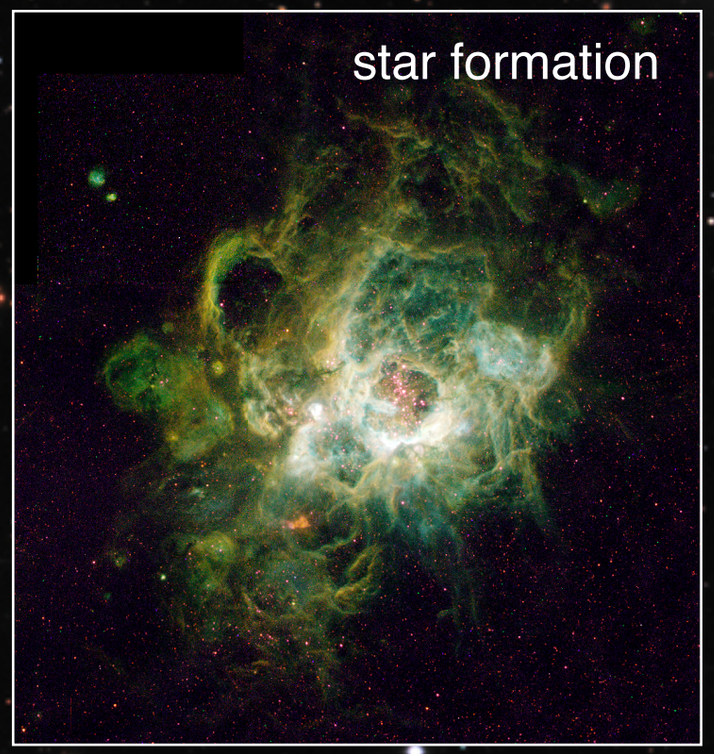






the interstellar medium in galaxies

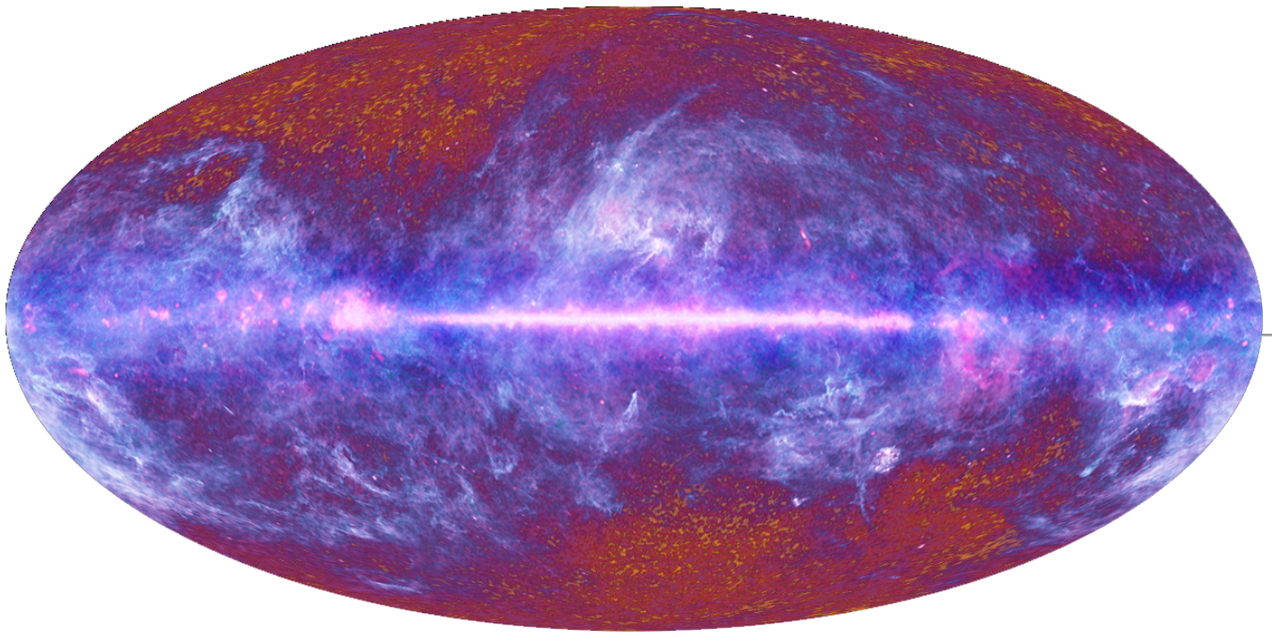


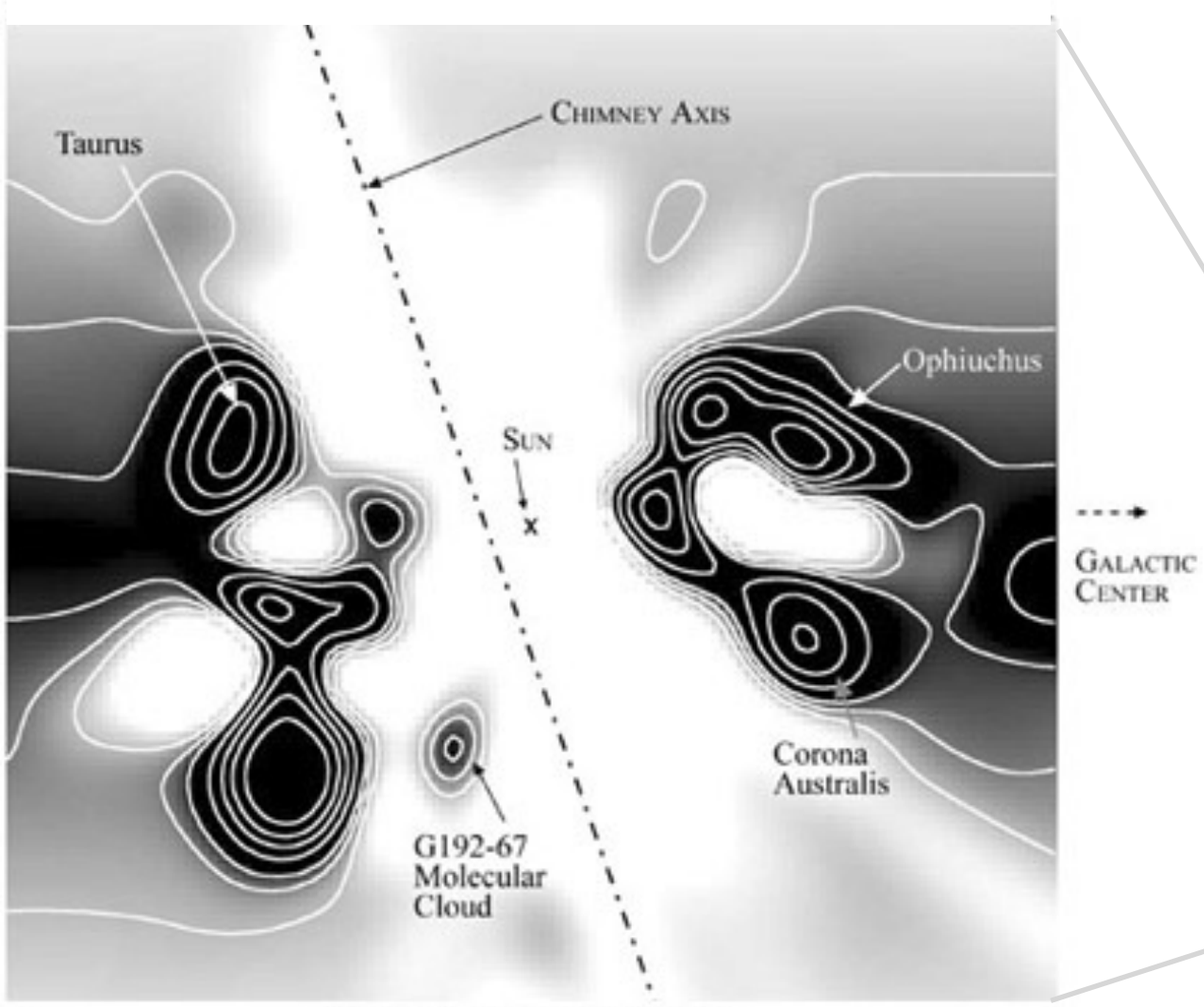


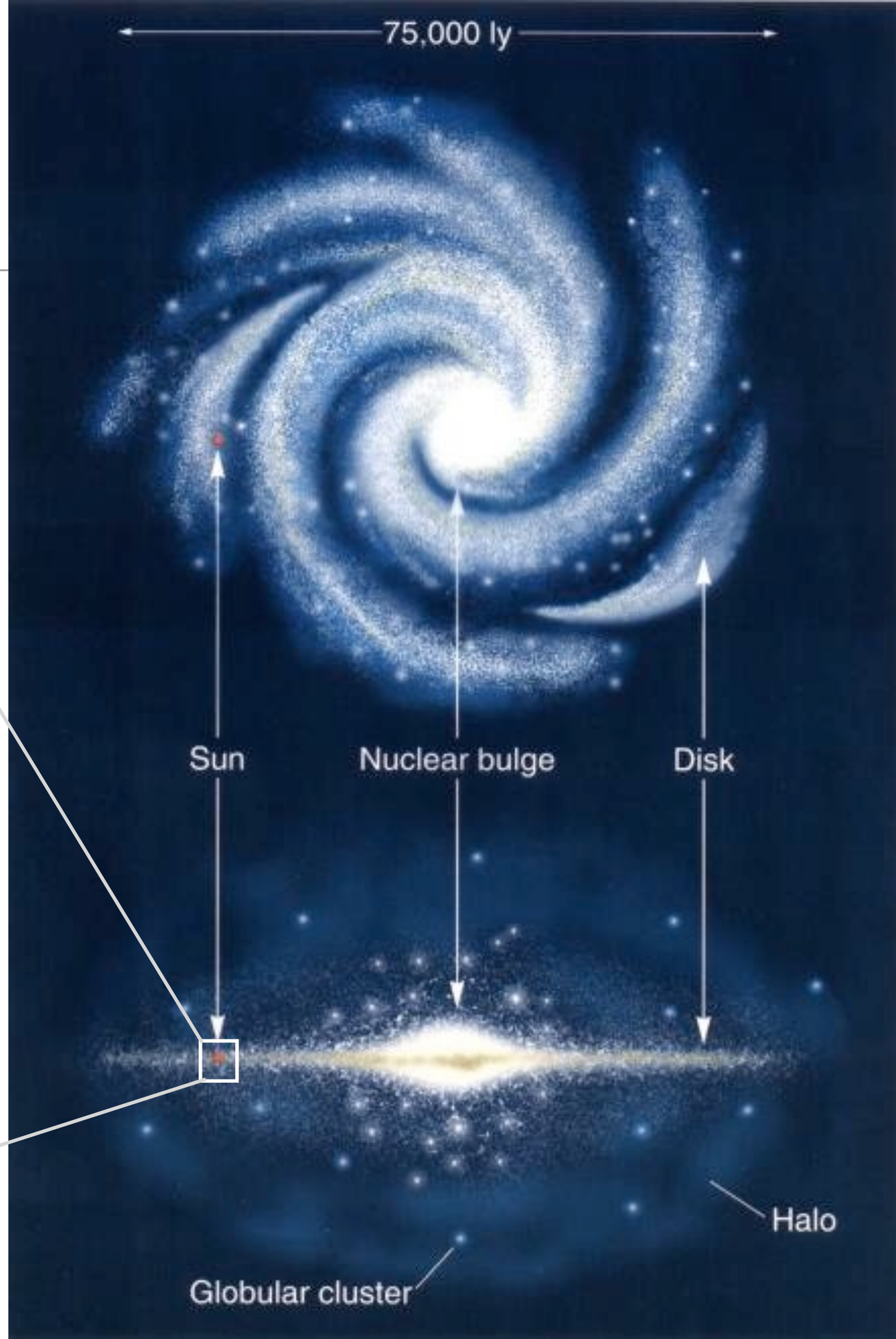
- Scientific goal
  - Cycle of star formation in galaxies
  - Growth of solids in space
  - Evolution of molecular complexity

- Processes
  - Hydrodynamics
  - Magnetic field
  - Gravity
  - Heating and cooling
  - Stellar feedback
  - Chemistry
  - Cosmic rays
  - Dust

- Tools
  - Multi-wavelength observations
  - Numerical simulations
  - Models
  - Laboratory experiments
  - Data science







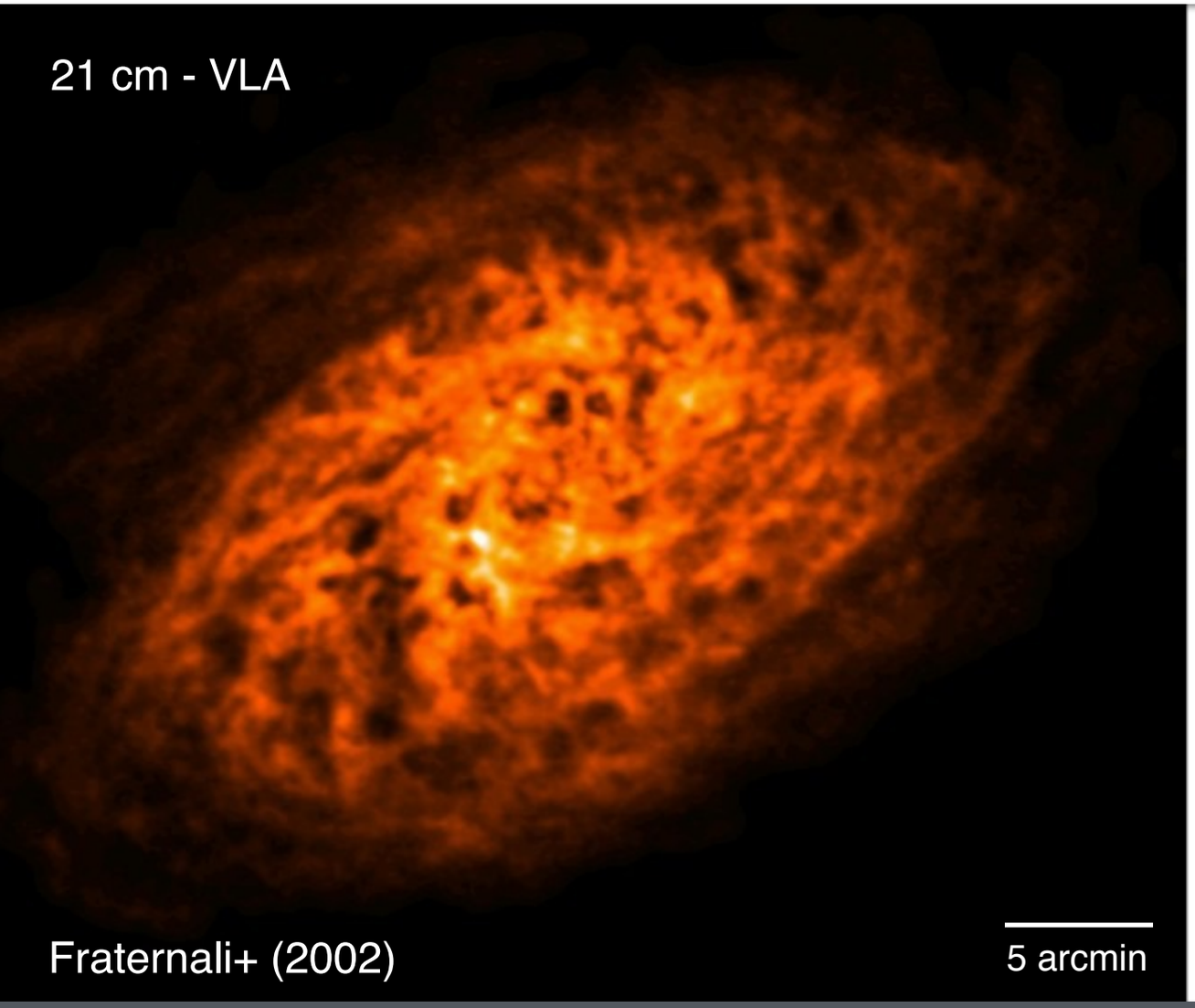
The Milky Way is our laboratory

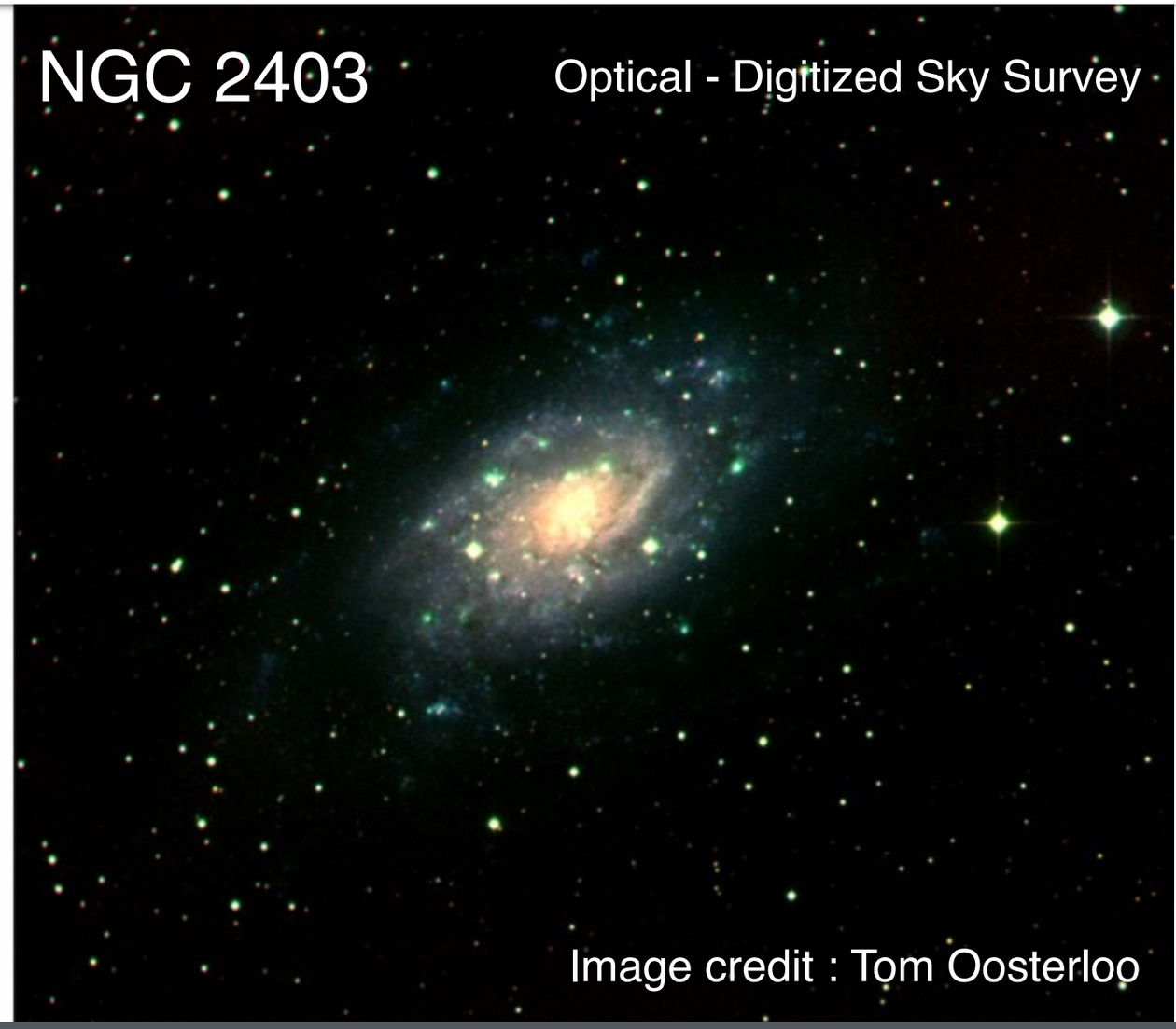
Why is SKA unique for ISM studies ?

Why is SKA unique for ISM studies ?

- **Frequency coverage** : a wealth of diagnostics
  - 21cm, OH, RRLs (H, He, C), free-free, synchrotron, dust continuum, anomalous microwave emission, molecular lines (COMs)
  - Innovative magnetic field diagnostics: Zeeman, Faraday tomography
  - Hyperspectral data over large areas
- **Angular resolution**
  - Small-scale structures : disks, filaments, shocks, dissipation
  - Astrophysics of galaxies like for the Milky Way
  - Distance determination (parallax) and proper motion in dense regions
- **Mapping speed** : multi-scale physics, connection with the environments
- **Sensitivity** : Galactic halo, external galaxies, small-scale features, HI absorption, pulsars, faint line emission…

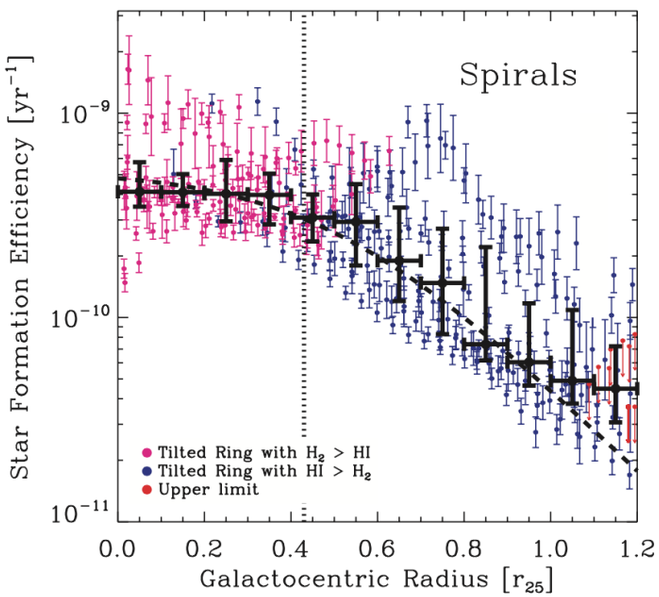
HI in galaxies

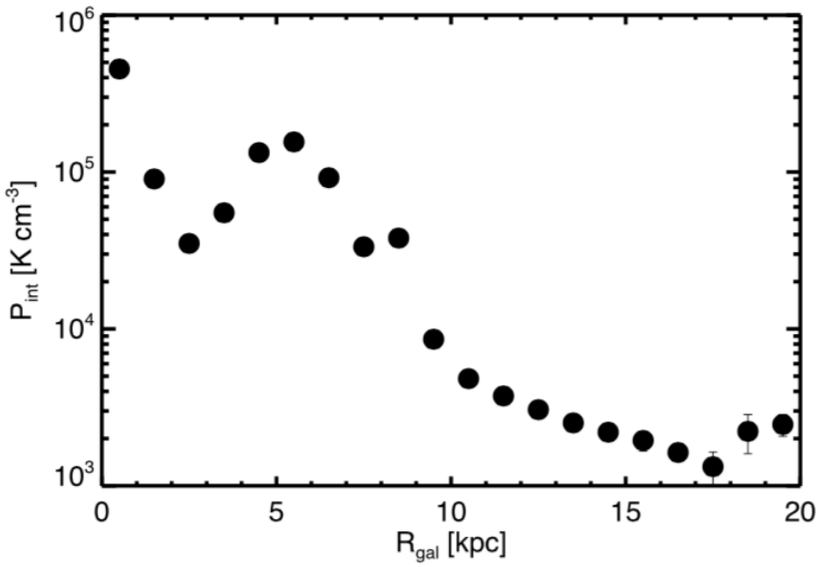




Star formation efficiency vs Gal. radius in spiral galaxies

Leroy+ 2008

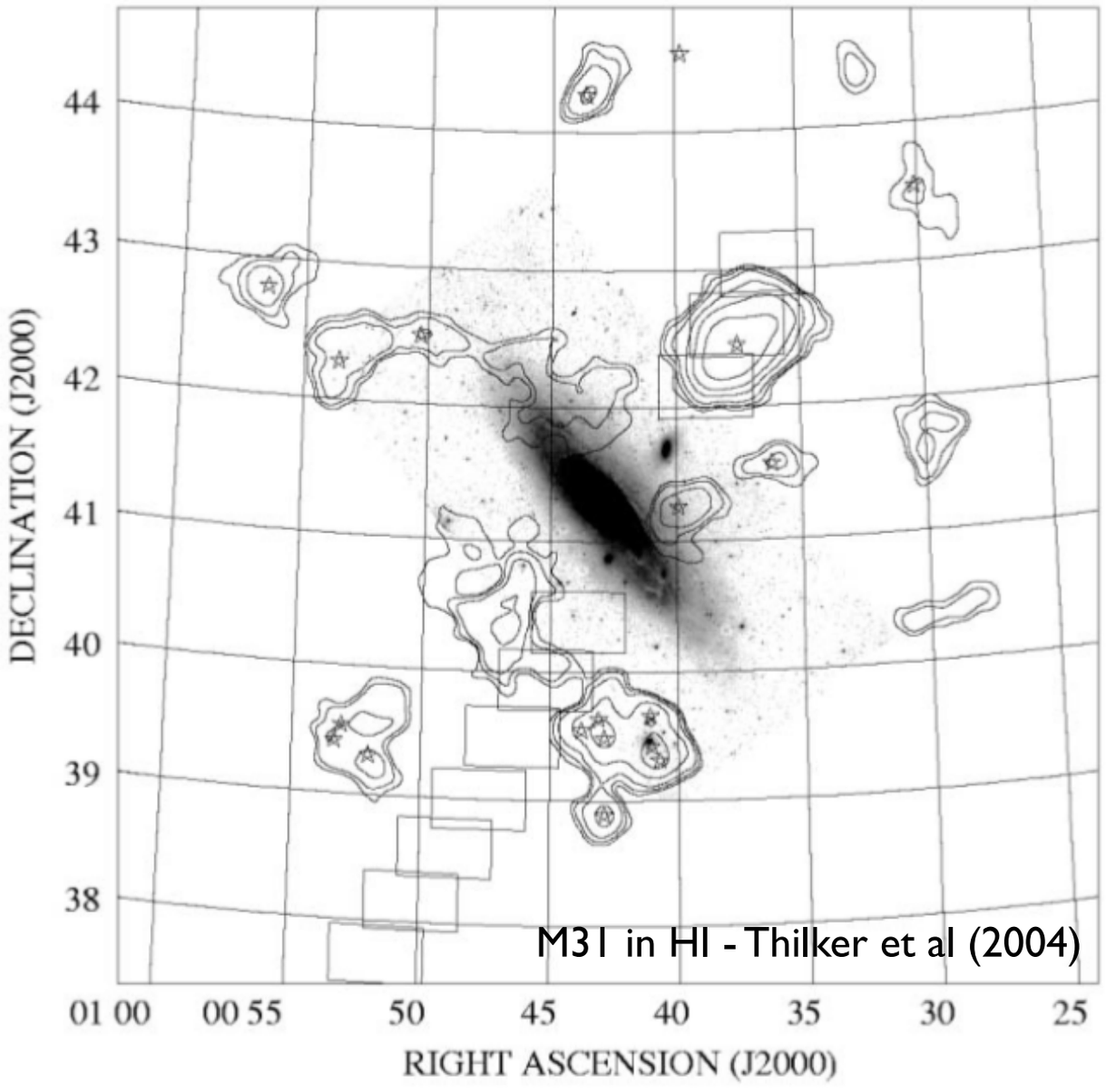




Gas pressure vs Gal. radius in Milky Way

M.-D.+2017

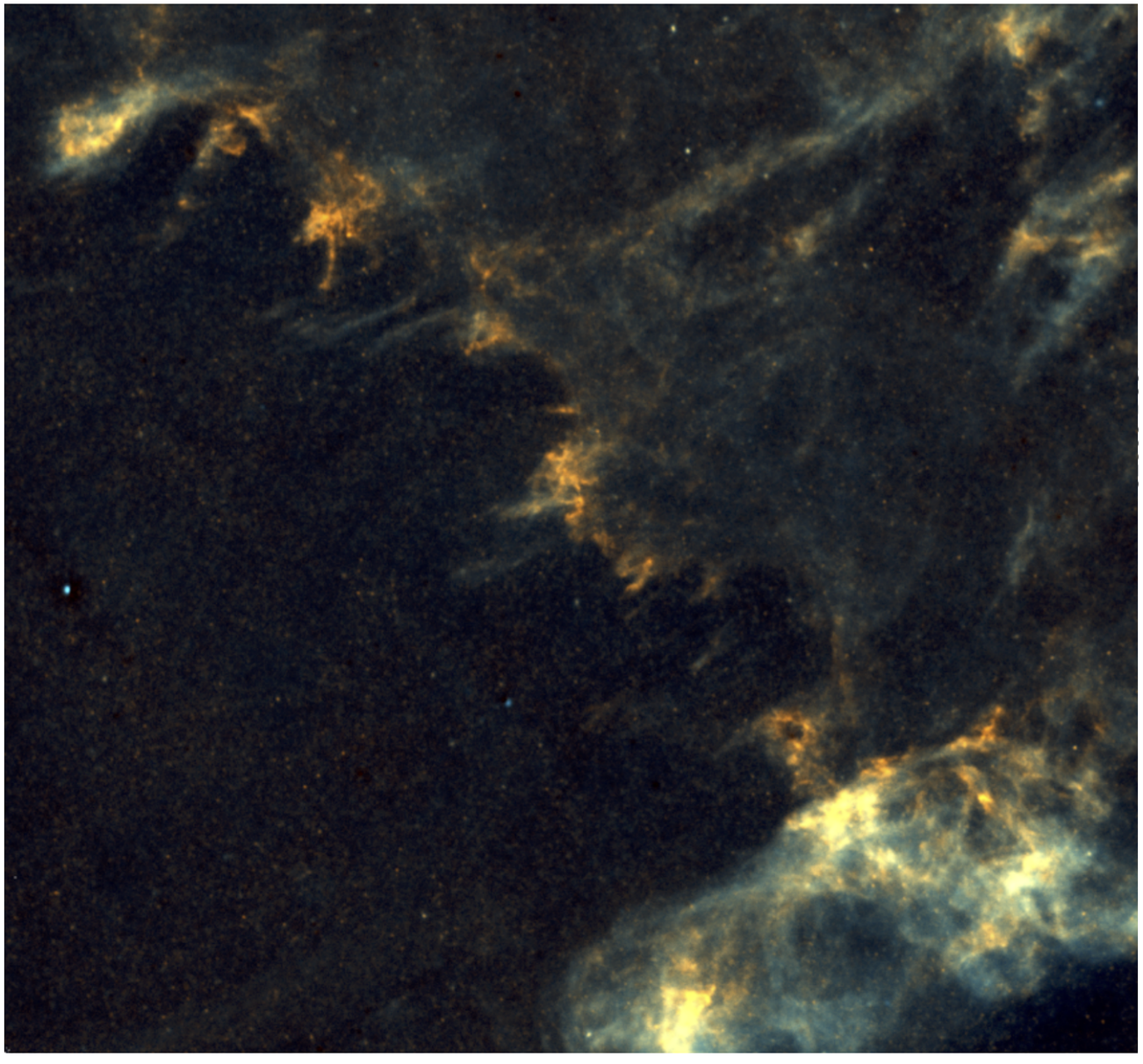
Disk-halo circulation and Galactic accretion



M31 in HI - Thilker et al (2004)

- Origin of neutral gas in the halo ?
  - gas stripped from satellite galaxies
  - thermal instability of the coronal gas
  - Galactic fountain
  - Residu of Galaxy formation
- What is the infall rate ?
  - Need the infall of ~1 solar mass/year for several Giga year to sustain star formation
- What is the metallicity of the infalling material ?
- In which phase is the gas ?
- **SKA will reveal the faint HI gas falling on nearby galaxies**

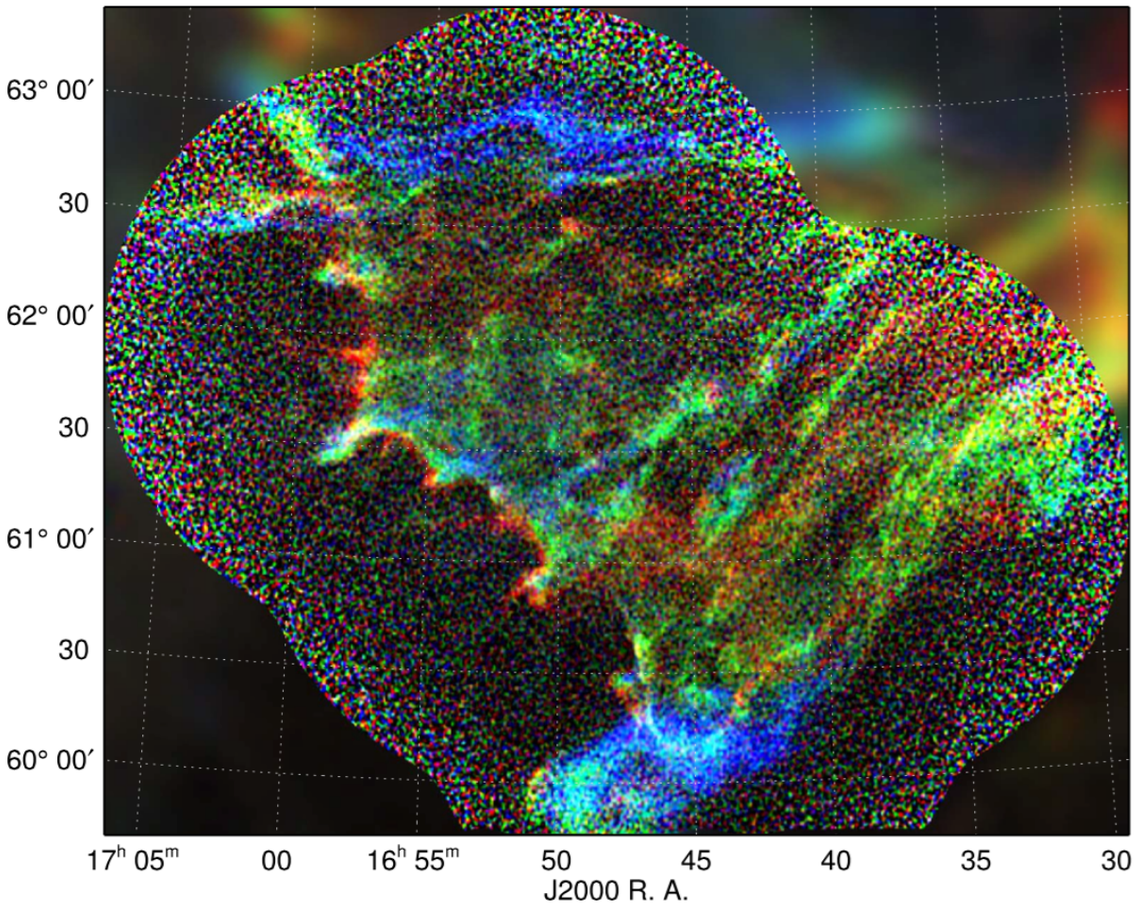
Disk-halo circulation and Galactic accretion



Herschel (250 micron) + WISE (12 micron) : 15 arcsec res.

Miville-Deschênes et al. (2017)

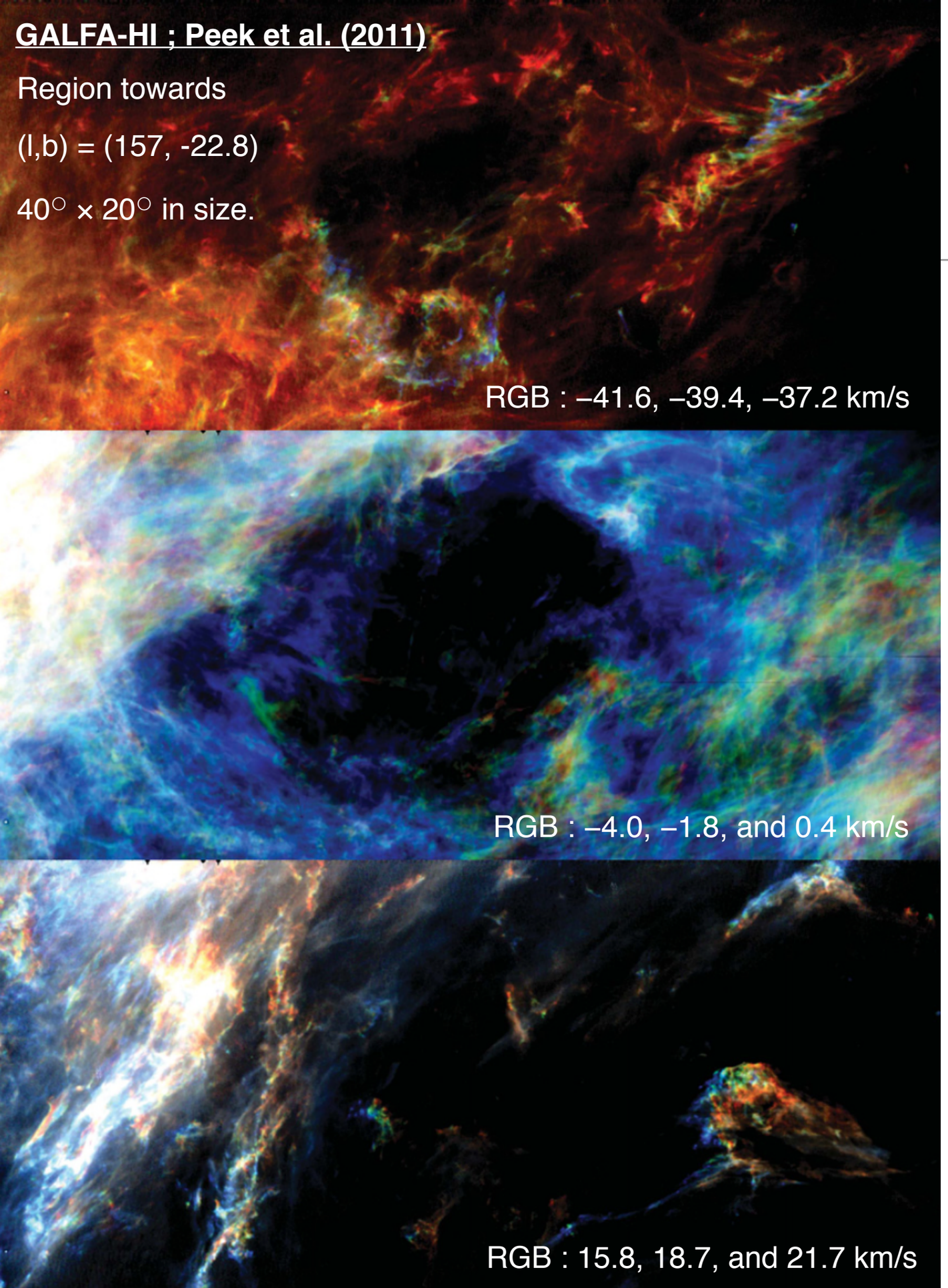
Draco Nebula



DRAO + GBT (21 cm) : 1 arcmin res.

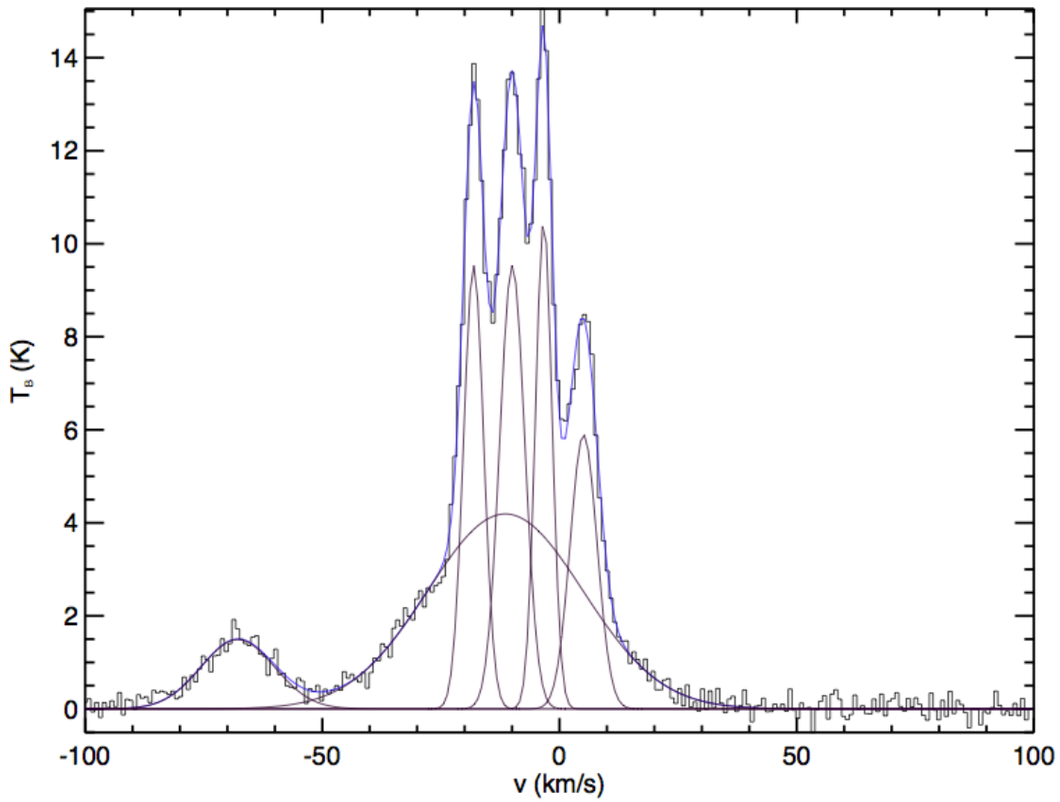
RGB : -19.6 km/s, -22.1 km/s, -24.6 km/s

Blagrave et al. (2017)



phase transition in the diffuse ISM

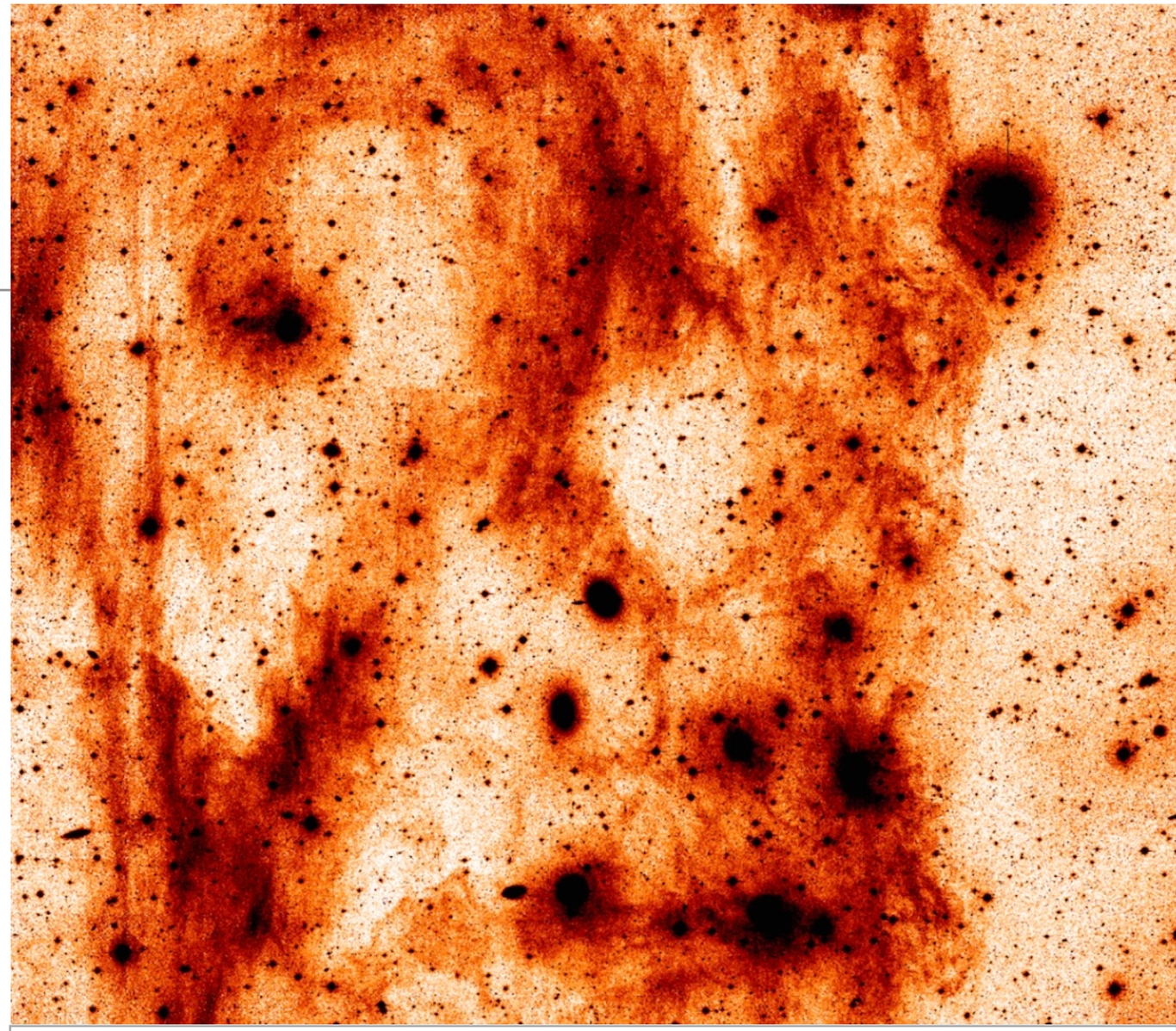
How cold-dense structures form from the warm and diffuse phase ?



SKA will provide hyperspectral 21cm and RRLs data combined with absorption measurements allowing the mapping of the structure formation process

Interstellar turbulence

- **Importance of turbulence**
  - sets how matter is organized
  - sets the efficiency of star formation
  - sets the mass distribution of stars
- **Interstellar turbulence is complex**
  - compressible
  - multi-phase
  - supersonic or sonic
  - magnetic
- **The questions are**
  - What are the properties of interstellar turbulence in each phase ?
  - How does turbulent energy dissipate ?
- **What SKA will bring**
  - Multi-scale and multi-phase (ionized and neutral cold/warm) description of turbulence
  - Study of the dissipation process (density and velocity fluctuations at 10s AU scales)



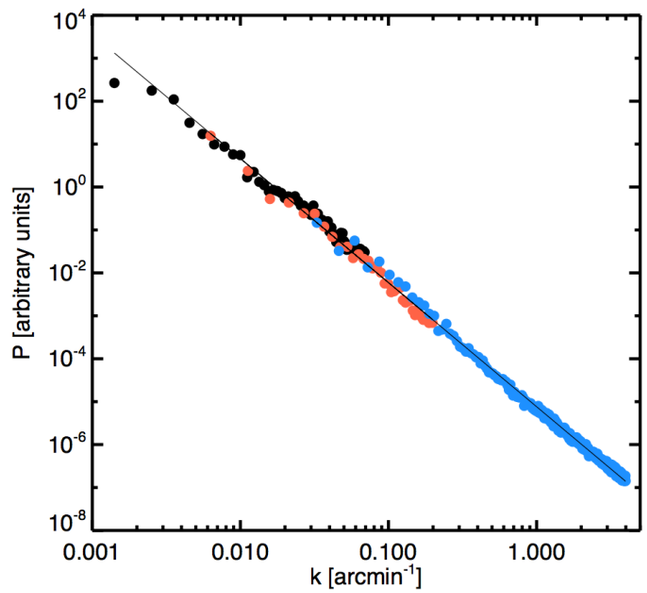
- CFHT Megacam g band

- resolution : 1.3”

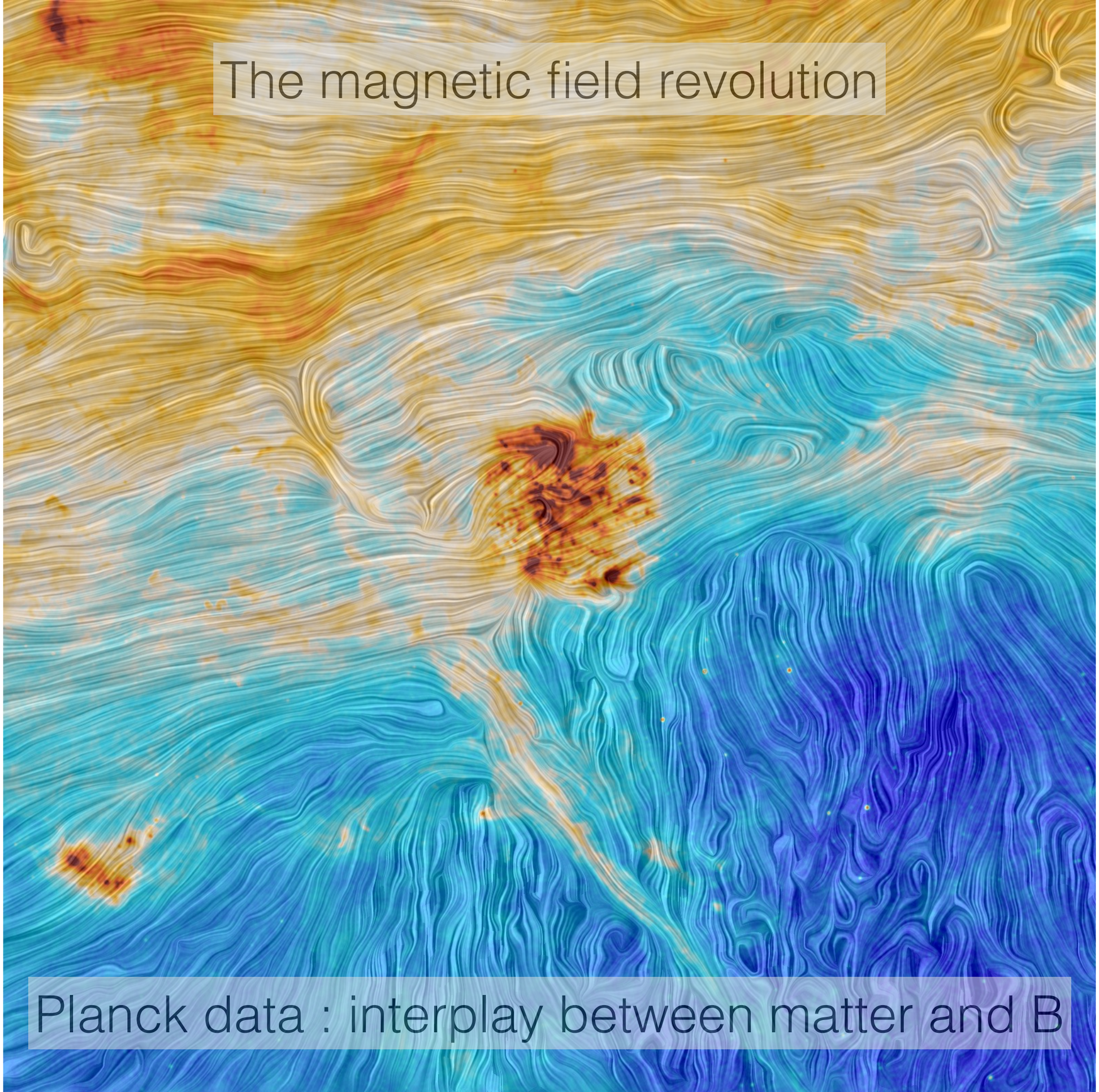
- fov : 1 square deg.

- P(k) ~ k^-2.9

- Miville-Deschenes+ 2016



The magnetic field revolution

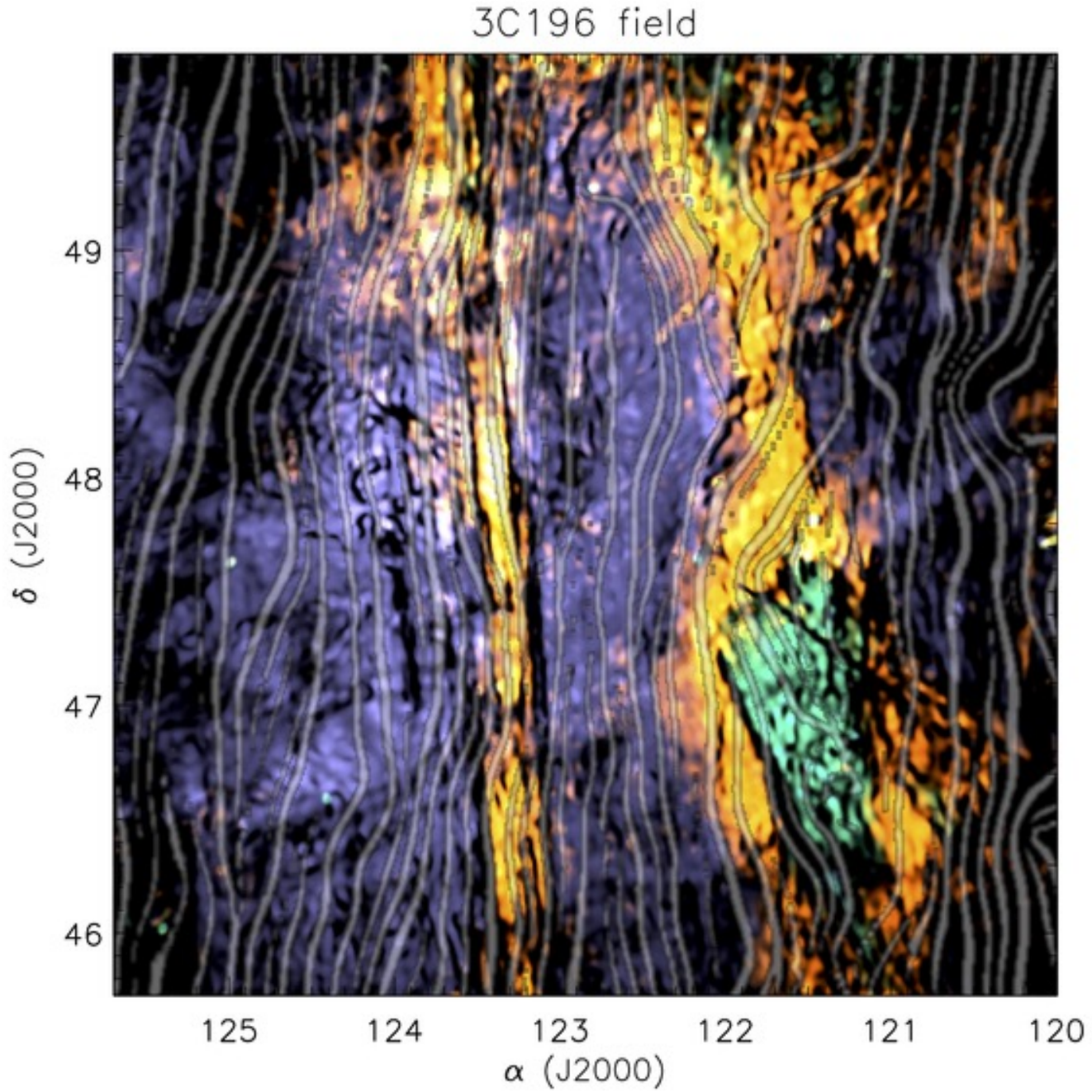


Planck data : interplay between matter and B

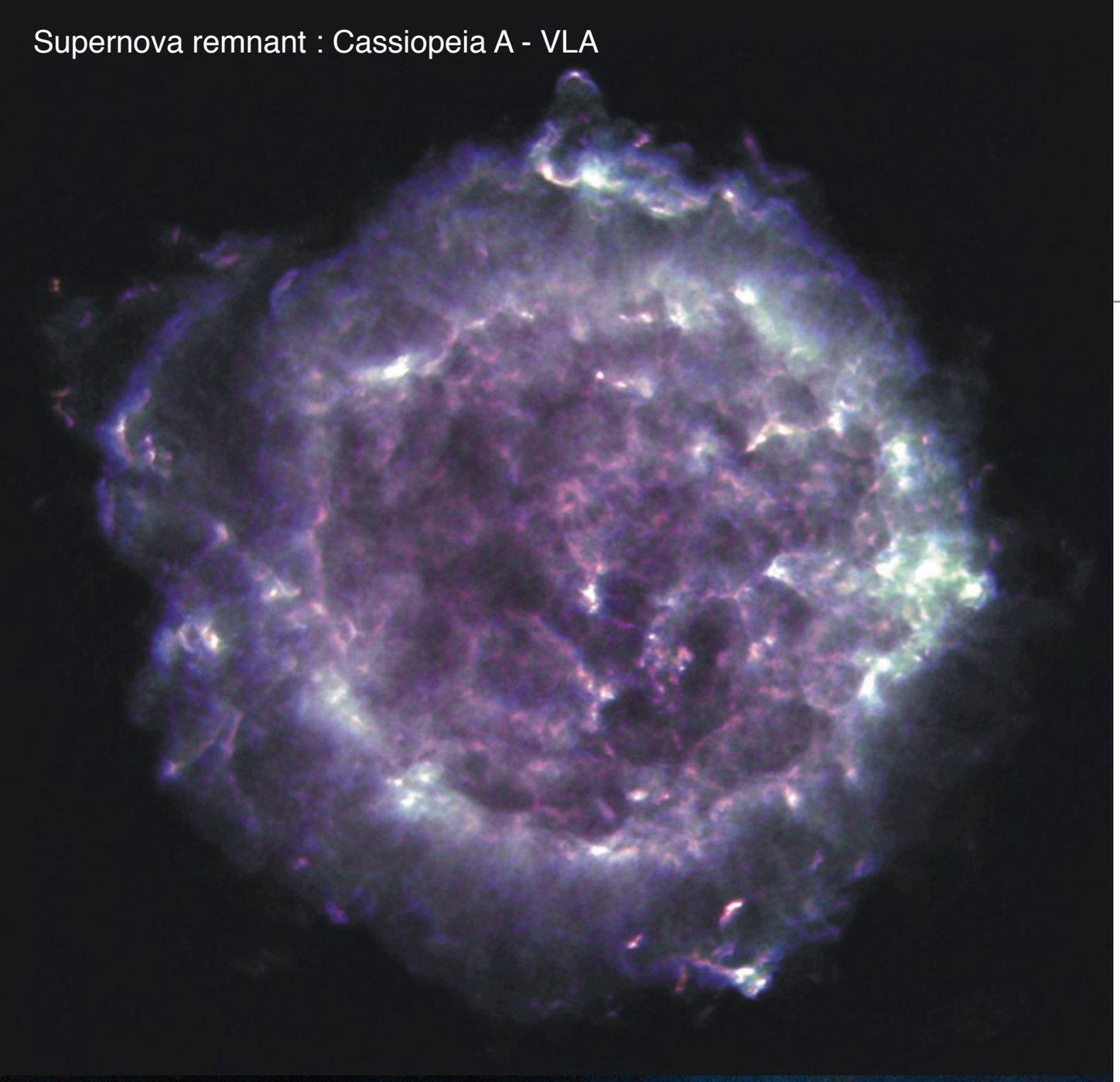
Structure and evolution of the magnetic field through ISM phases

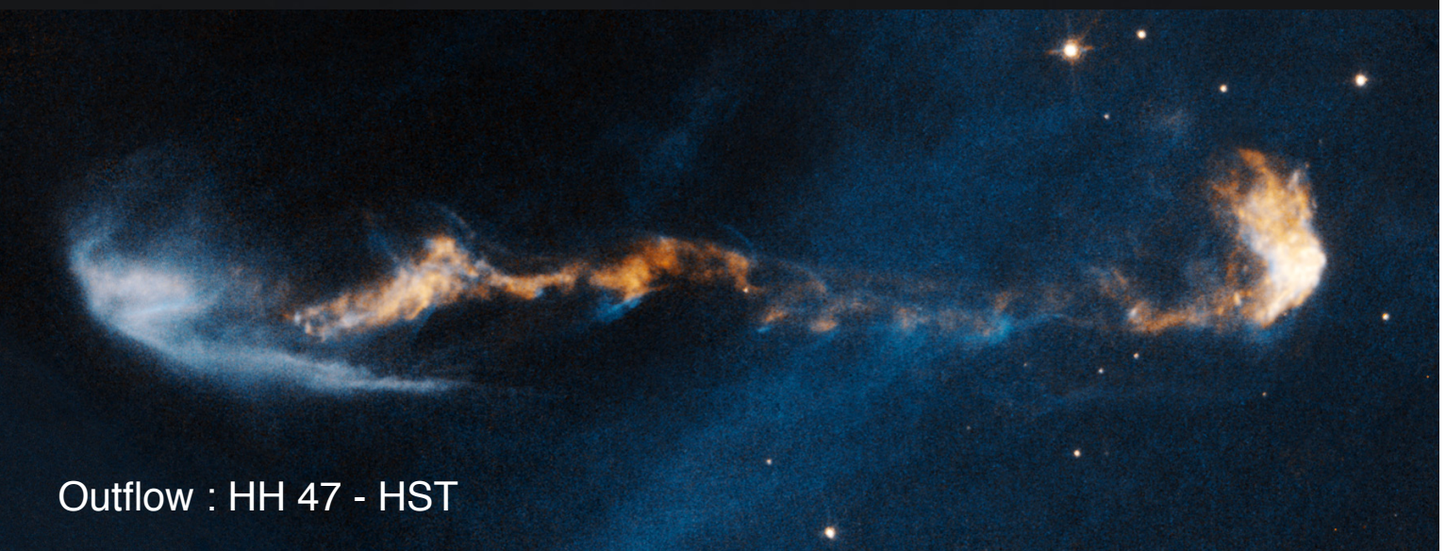
- **Surprising result on the structure of the Galactic magnetic field**
  - Spatial correlation of magnetic field structures seen in Faraday depth (ionized gas) and dust polarization (neutral gas) in a diffuse region at high Galactic latitude

- **The unique contribution of SKA**
  - Survey of large areas with a large frequency coverage will allow us to map the 3D structure of the magnetic field using Faraday tomography.
  - SKA will enable direct measures of the magnetic field strength using the Zeeman effect of H and C Radio Recombination Lines
  - Dispersion measures and Faraday rotation measures on pulsars will also allow for the 3D mapping of the interstellar magnetic field



Jelic et al. (2015), Zaroubi et al. (2015)



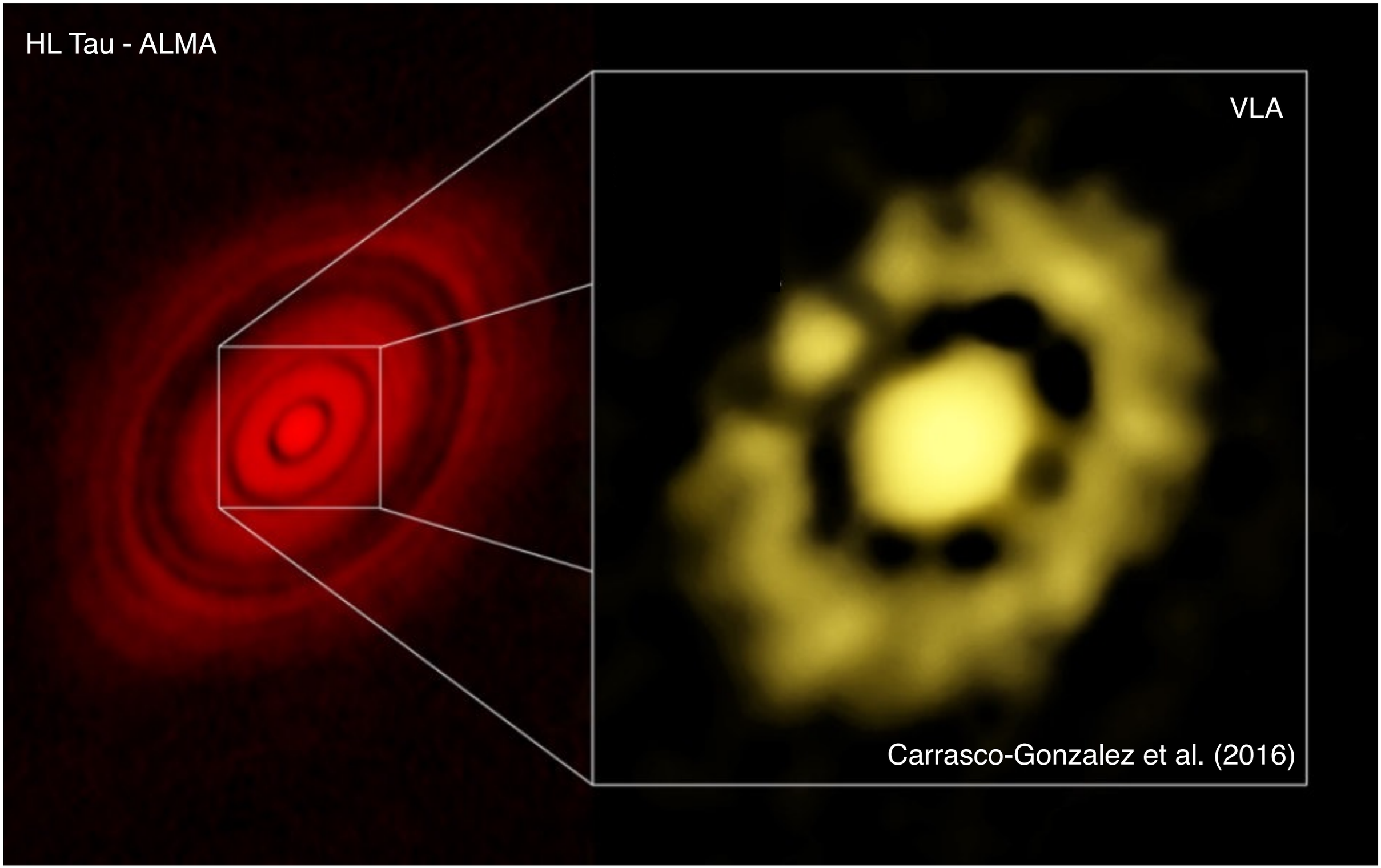


Stellar feedback : supernovae, winds and outflows

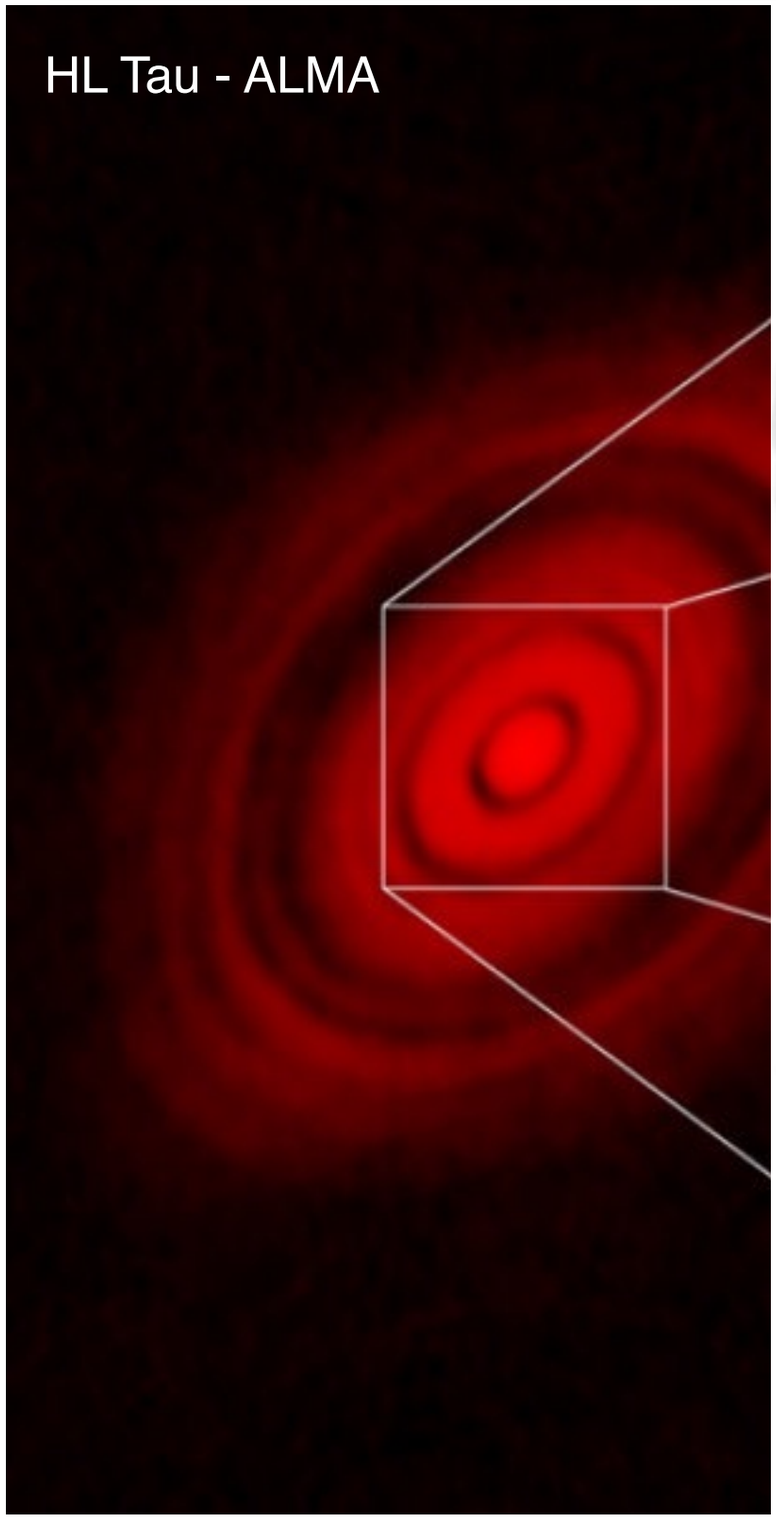
- **SKA will allow us to**
  - constrain shock structures
  - study magnetic field amplification
  - study cosmic ray composition, acceleration and propagation mechanisms
  - measure energy and momentum injected in the ISM (RRL)
  - discover a large number of new SNRs, crucial to identify gamma-ray sources

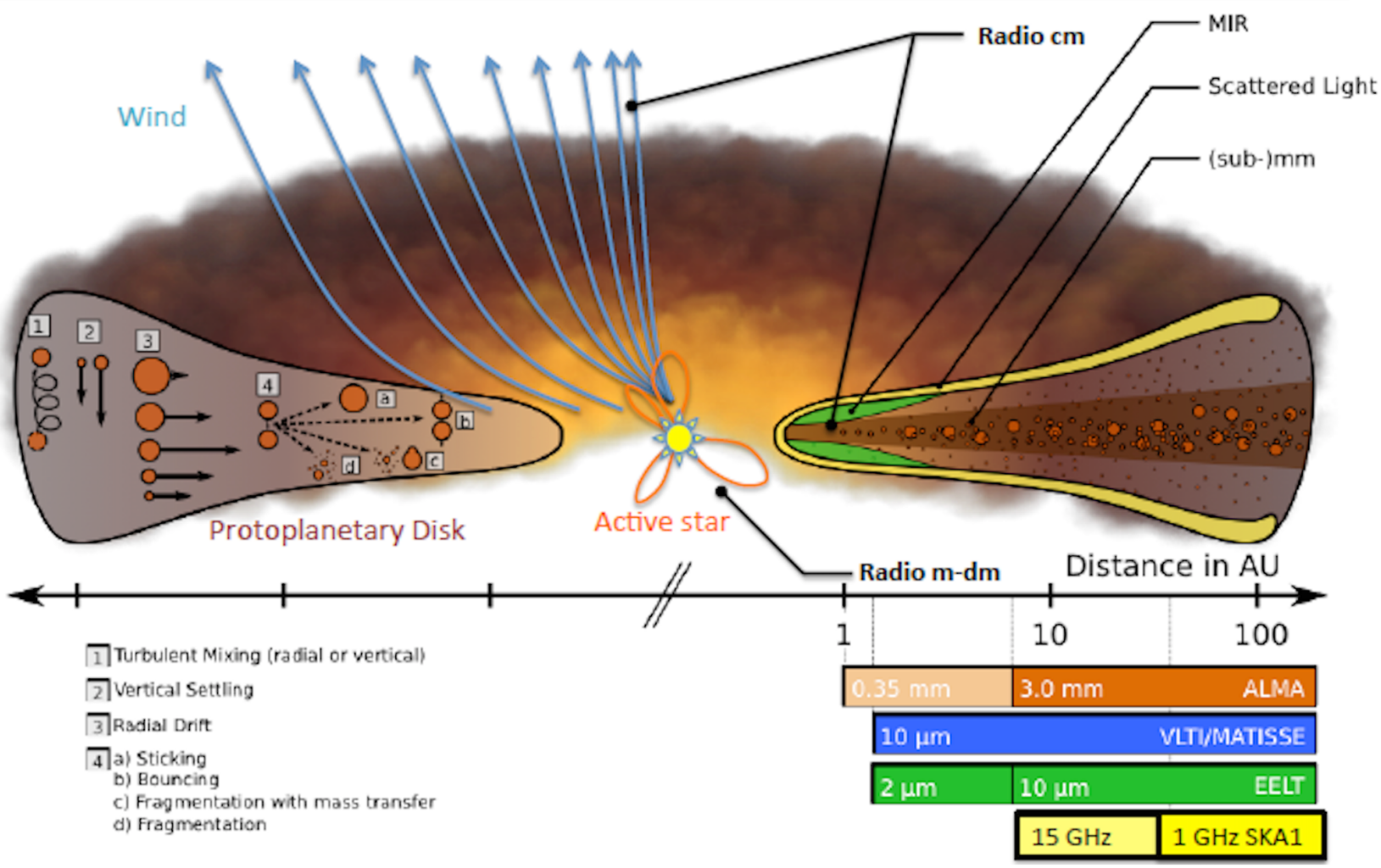
- **Results will bring essential new constraints for our understanding of the global ISM cycle**

Dust in protoplanetary disk



Dust in protoplanetary disk





What SKA will bring

- Quantification of dust growth effects
- Radial variation of dust size
- Separation from wind free-free emission
- Potential detection of Complex Organic Molecules in low-mass protostars (hot corinos)

Conclusion

- **A large range of diagnostics at high resolution and high sensitivity**
  - 21cm, OH, RRLs (H, He, C), free-free, synchrotron, dust emission, molecular lines (COMs)
  - Innovative magnetic field diagnostics: Zeeman, Faraday tomography
  - Hyperspectral data over large areas
  - Distance and proper motion determination
- **A large range of ISM scientific topics**
  - Cosmic magnetism
  - Turbulent cascade
  - Phase transitions and structure formation
  - Galactic halo and infall
  - Stellar feedback : supernovae, outflows
  - Star formation : disks, dust growth and molecular complexity
- **Strong ISM community in France**
  - Large range of expertise covering data analysis, models, numerical simulations and laboratory experiments
  - Interested by many SKA topics (11 chapters in the french white book)
  - Potentially the most active ISM community in SKA

A strong interest by the french ISM community

1) The nearby interstellar medium
2) Interstellar turbulence
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 and RRLs
8) Jets, outflows and young stellar objects
9) Supernova remnants
10) Pulsar census and probe of the interstellar medium
11) Distance determination

Contributions by 40 scientists from 12 institutes :

- SAp, IPAG, IRAP, LUMP, IAS, Strasbourg, LPC2E, LERMA, LAB, GEPI, IRAM, OCA

Editors

- Katia Ferrière (IRAP)
- Marta Alvès (IRAP)
- Ludovic Montier (IRAP)
- M-A Miville-Deschênes (IAS)