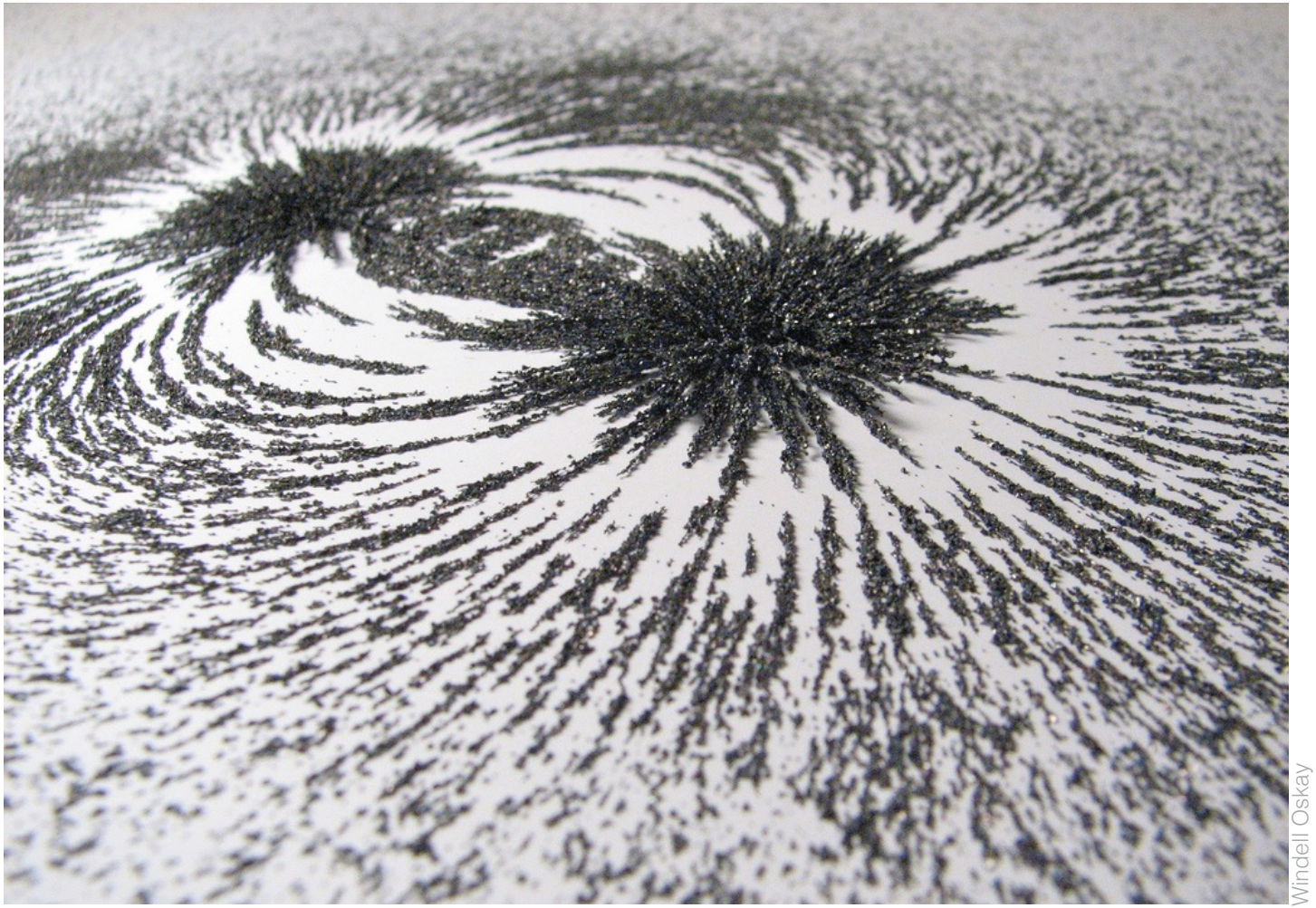
The magnetized dusty interstellar medium

François Boulanger
Ecole Normale Supérieure, Paris



Windell Oskay

A tracer is needed to image magnetic field lines → Dust grains

Magnetic fields create anisotropic patterns → ISM structure formation

Magnetic fields are the hidden (*dark*) agent of baryon physics across the universe

➡ PICO will contribute to two main questions related to Cosmic Origins:

★ The origin of cosmic magnetic fields
(Talk by L. Pogosian)

★ Their role in the formation of galaxies and stars
(+ Talks by S. Clark and L. Fissel)

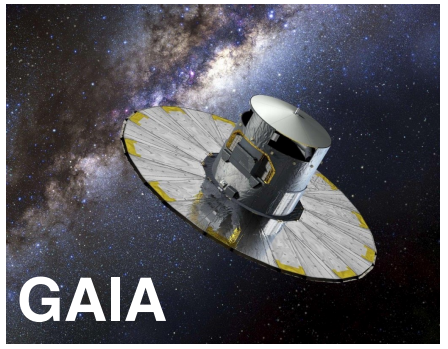
A timely research field

Cosmic magnetism is a highlighted research field of several large (present and future) observatories

★SKA and its precursors: Synchrotron, Faraday rotation and Zeeman spectroscopy

★ALMA and NOEMA(IRAM) interferometers: Dust polarization and Zeeman spectroscopy

★Stellar polarization surveys + GAIA : Tomography of Galactic dust polarization

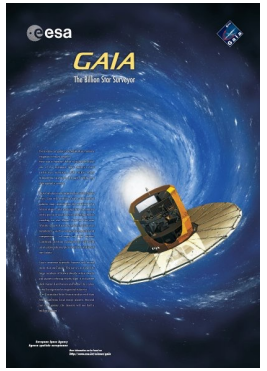


A unique perspective from PICO

★SKA will be unique to probe magnetic fields in distant galaxies, clusters and the cosmic web.

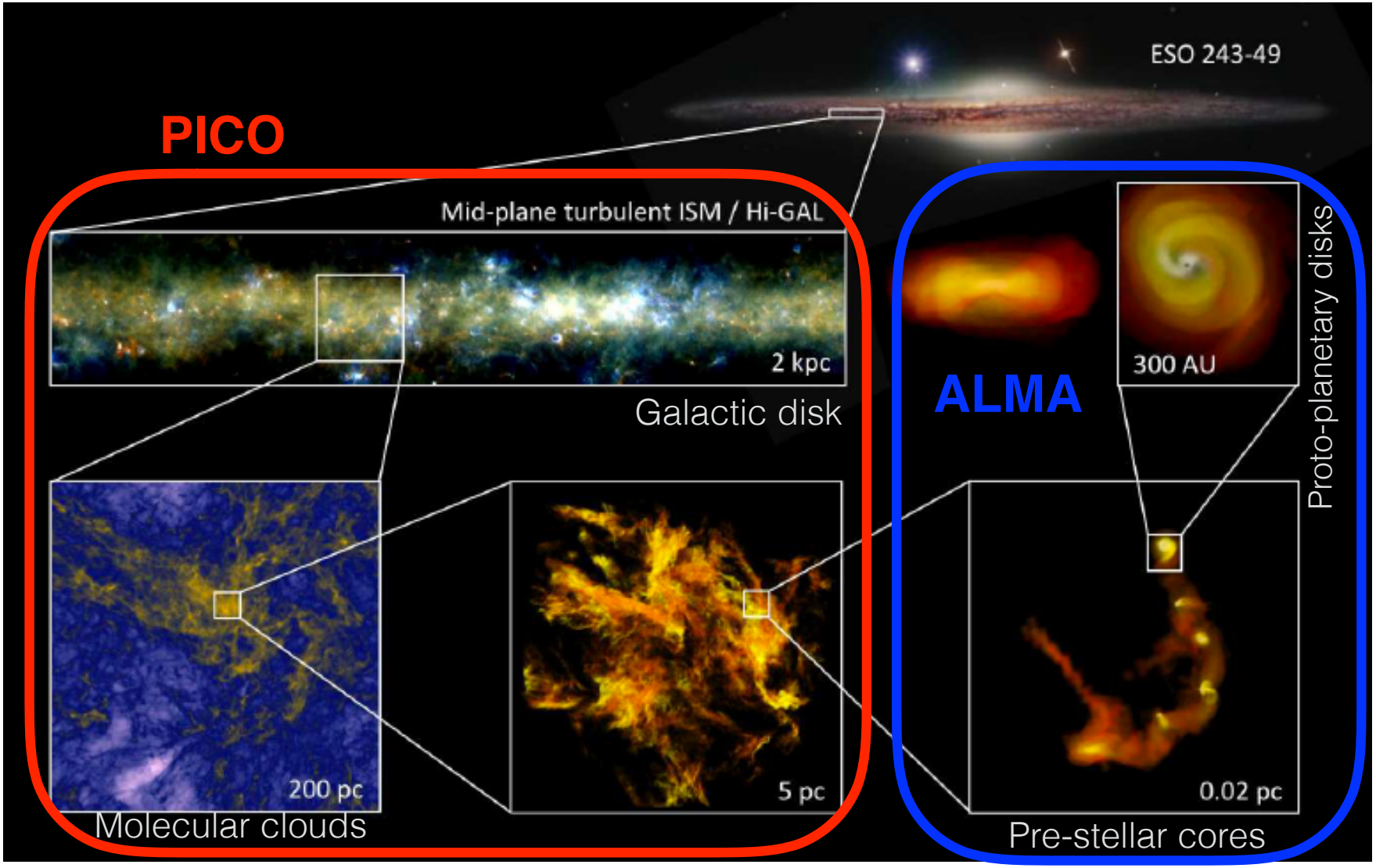
★ALMA provides the angular resolution to study magnetic fields from pre-stellar cores to proto-stars and their proto-planetary disks

★GAIA astrometry combined with surveys of stellar polarimetry will allow us to build a 3D model of the Milky Way magnetic field on Galactic scales



➡ PICO will have a unique capability to characterize statistically interstellar turbulence: the interplay between matter and magnetic fields in cosmic space

PICO and ALMA will provide complementary perspectives



Interstellar turbulence

★The origin of Galactic magnetic fields

- Interstellar magnetic fields are induced by interstellar gas flows, and random (turbulent) flows are at the heart of both small-scale and large-scale dynamos

★Structure formation on scales relevant to star formation

- Turbulence creates a range of density structures in interstellar matter and locally the initial conditions for star formation

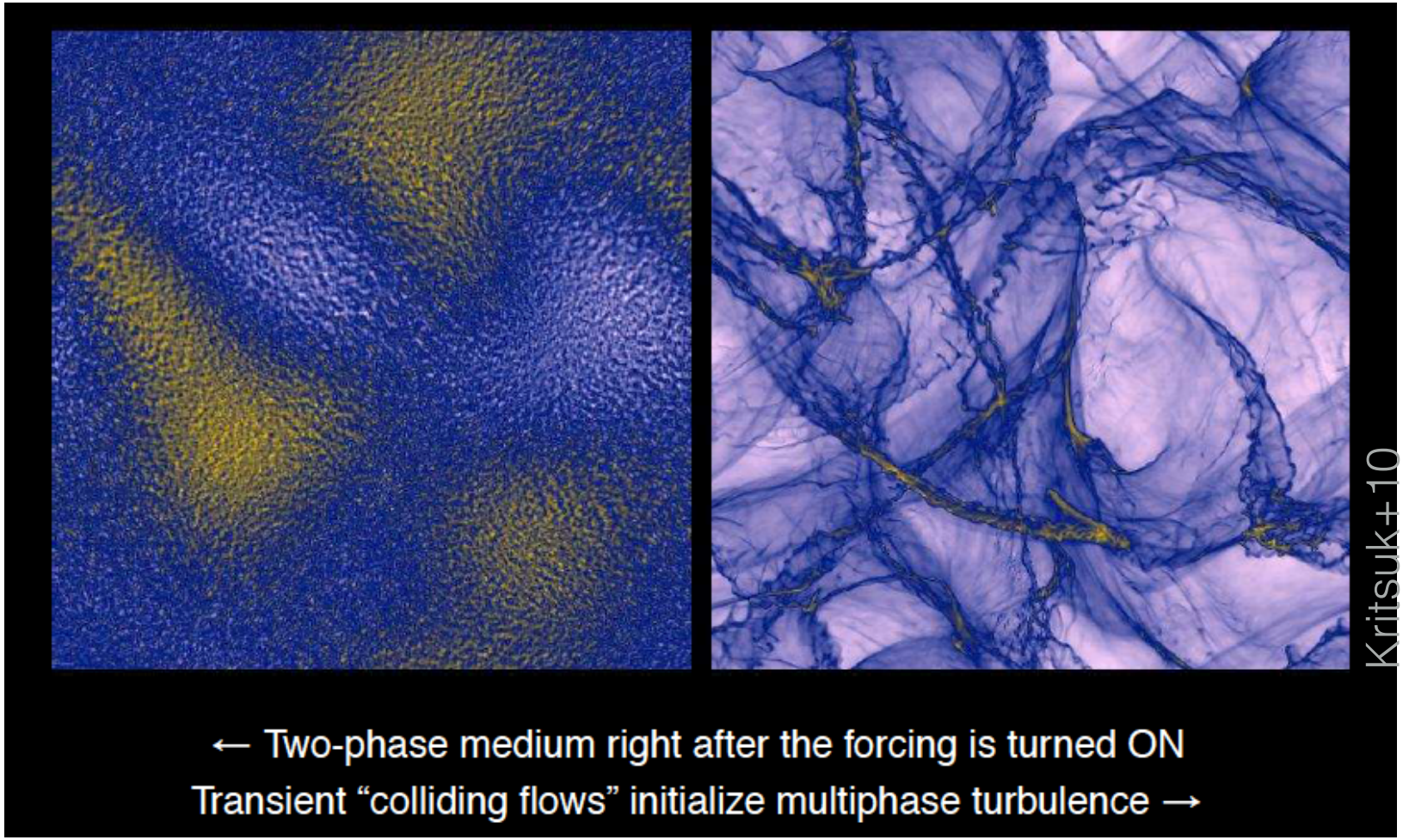
★Physics of feedback: the energetics of star and galaxy formation

- Turbulence drives the mass, momentum and energy exchange among ISM phases
- Energy in bulk motions cascades into turbulent and magnetic energy

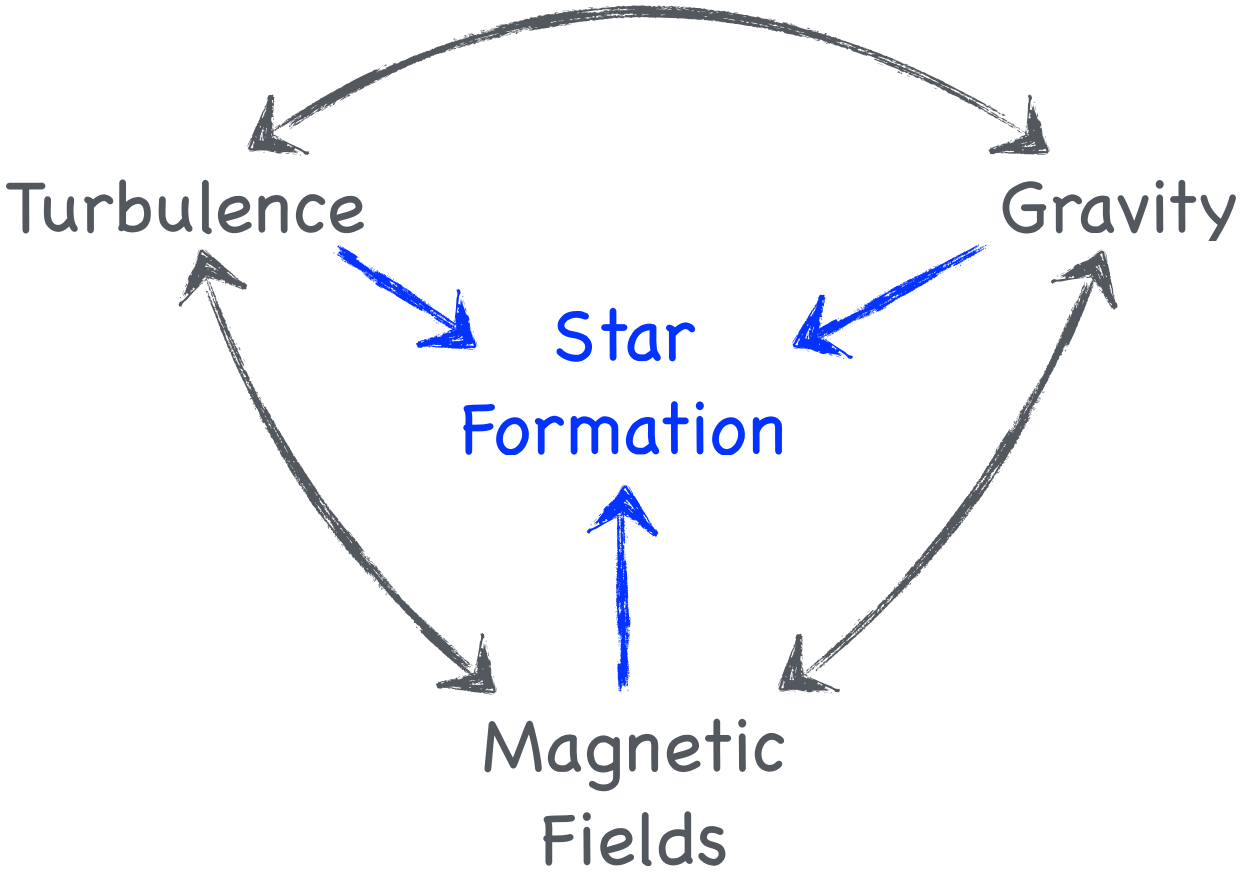
★The structure of the B-field is also key to model cosmic-ray diffusion and acceleration (talk by Alex Lazarian)

Numerical simulations resemble observations in terms of structures and scaling laws, but because of their limited numerical resolution, they cannot reach the very large Reynolds numbers of interstellar and intergalactic gas flows.

Projected gas density



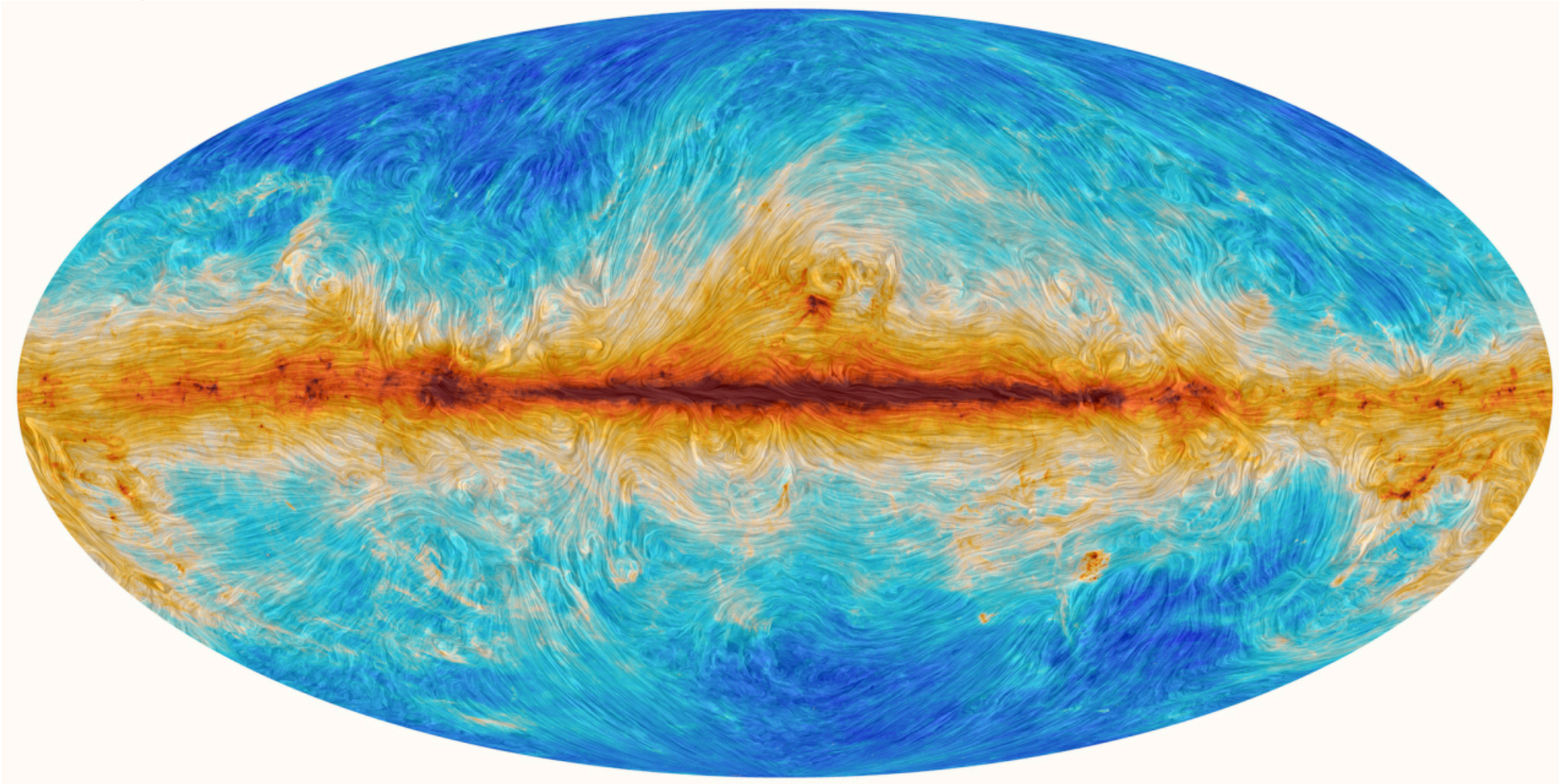
➡ Statistical studies required to bridge theory, simulations and observations



The gas physics that **initiates star formation and control its efficiency (feedback)** is encoded in the statistics of relevant scalar and vector fields: gas density and temperature, gas velocity and magnetic-fields

➡ PICO will provide data on magnetic fields we can uniquely get from a space mission

Dust polarization 353 GHz

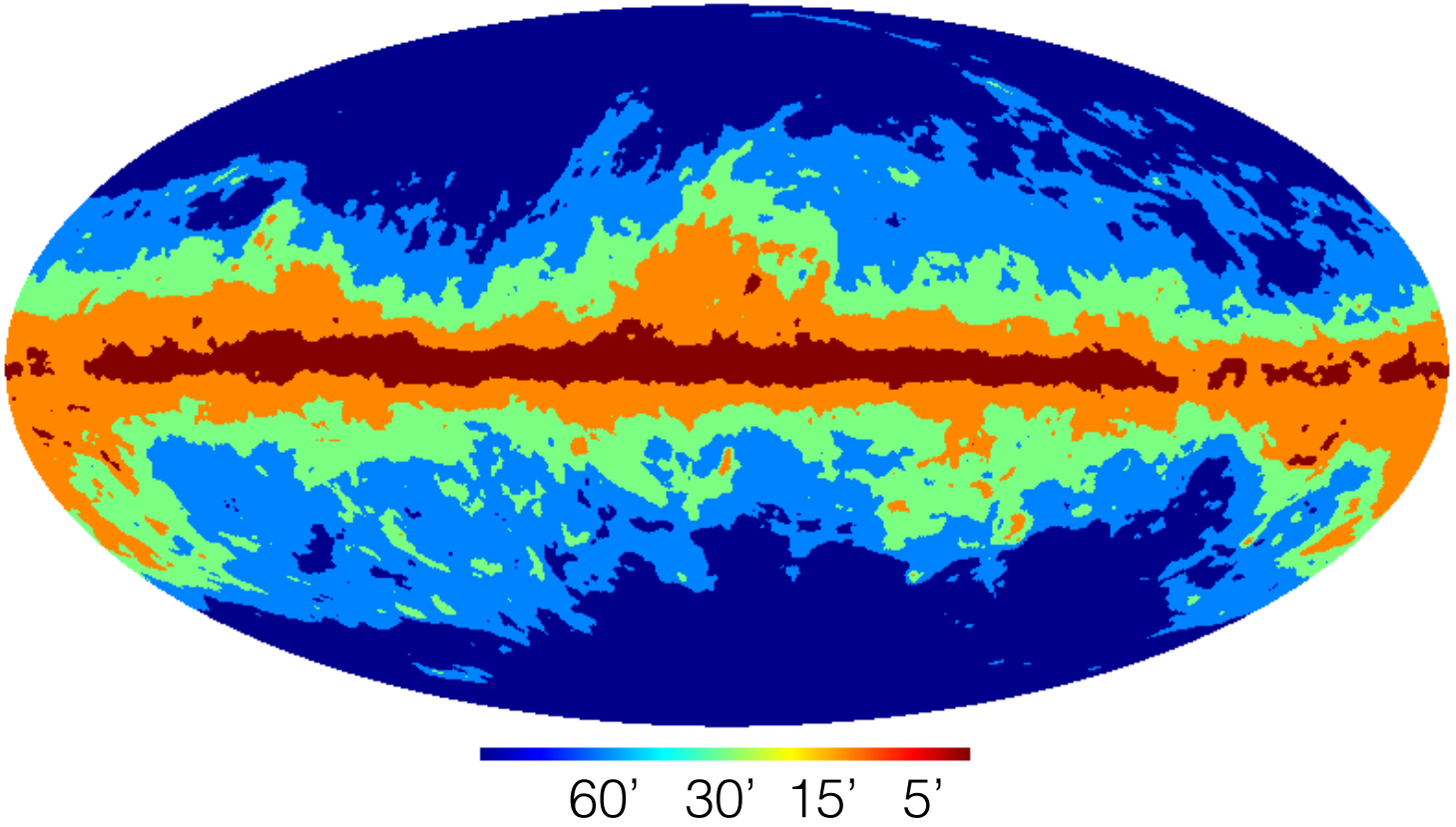


Planck Collaboration - Overview paper 2015

Overcoming Planck limits

Angular scale where EE dust power = Planck noise

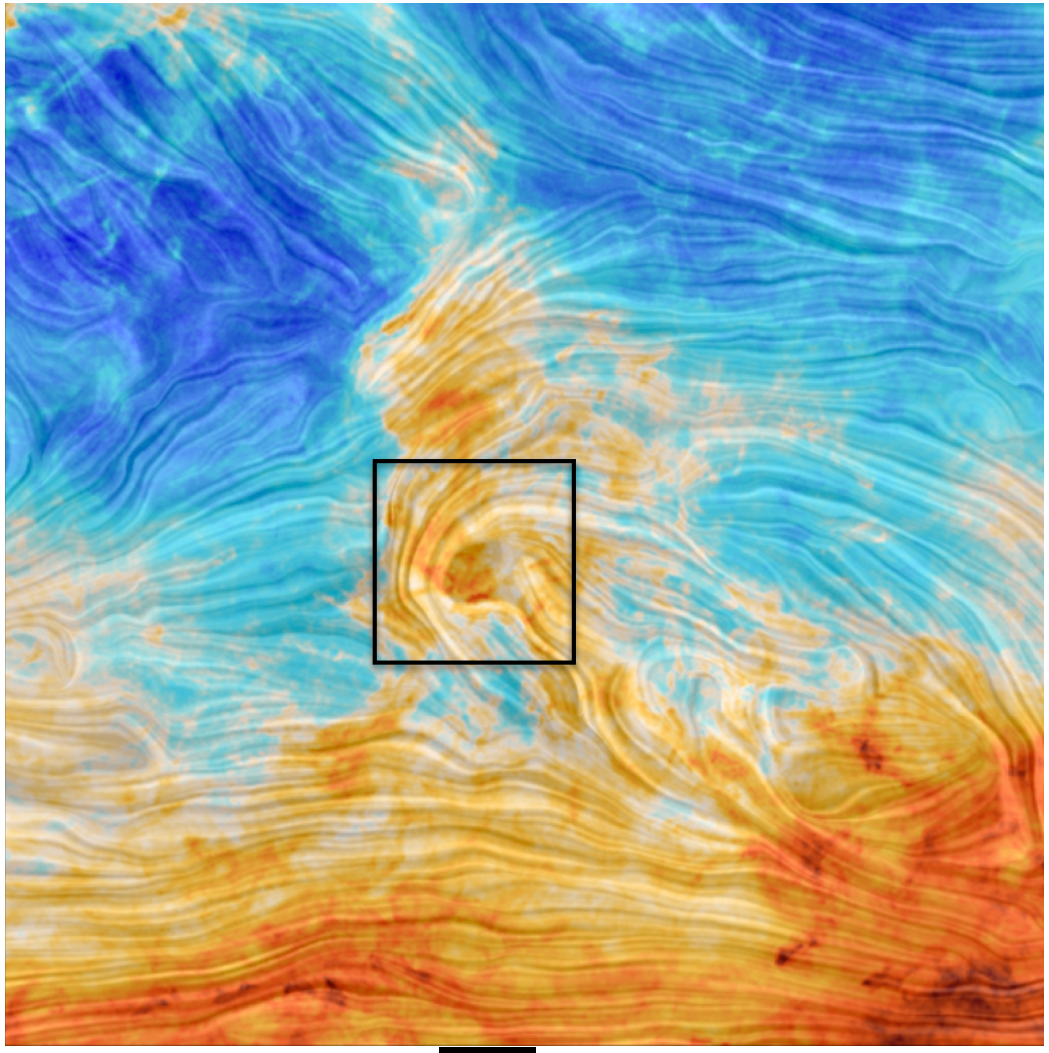
Based on power spectra in Planck intermediate XXX 2015

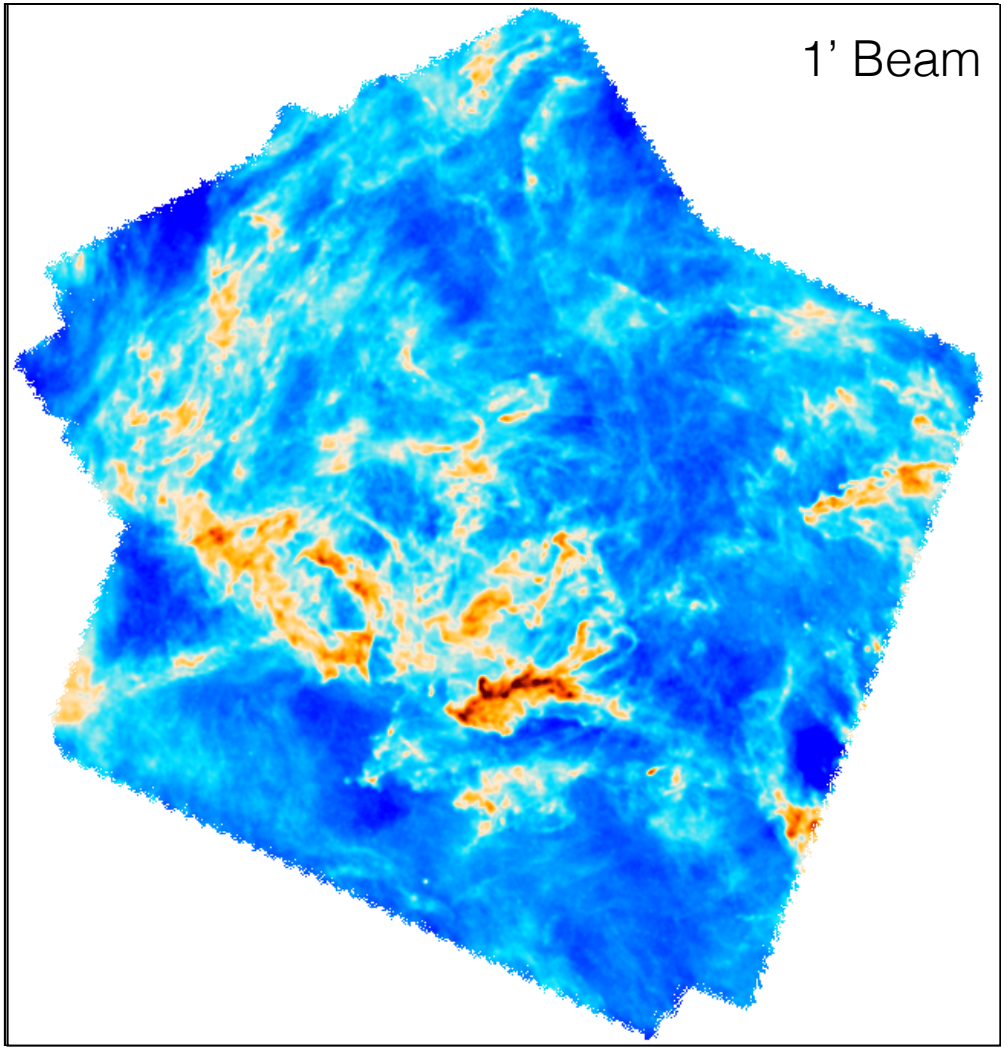


➡PICO high frequency data will provide the sensitivity to increase the range of measured angular scales by a factor 20, i.e. the number of measured modes will multiplied by a factor 400 from 2 10^6 to 8 10^8

Planck

Herschel





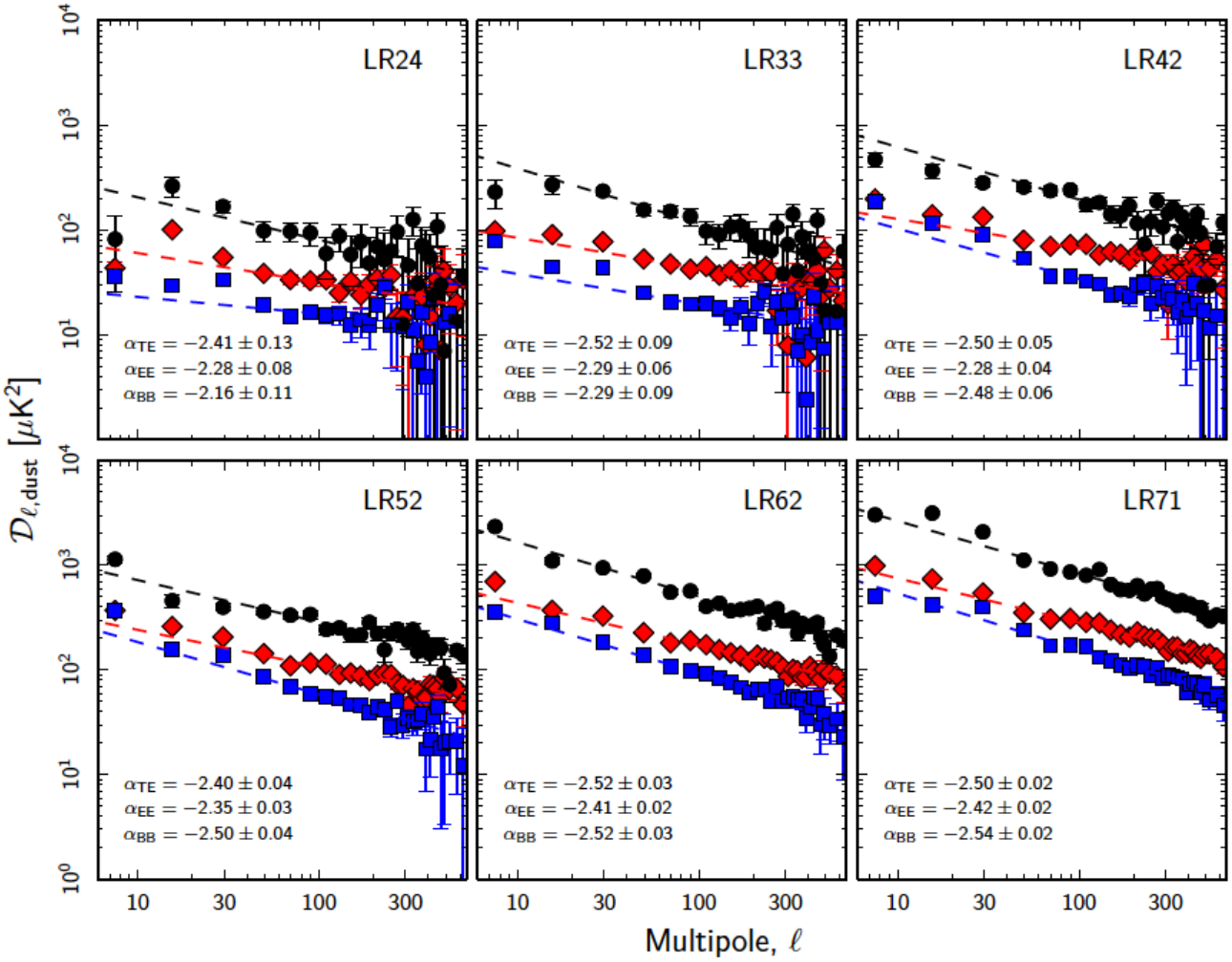
30°

➡ PICO will map the magnetic field in similar details to those visible in the Herschel map, greatly enhancing the Planck view at the interplay between gas - its density structure and dynamics - and magnetic fields

Planck Dust angular power spectra

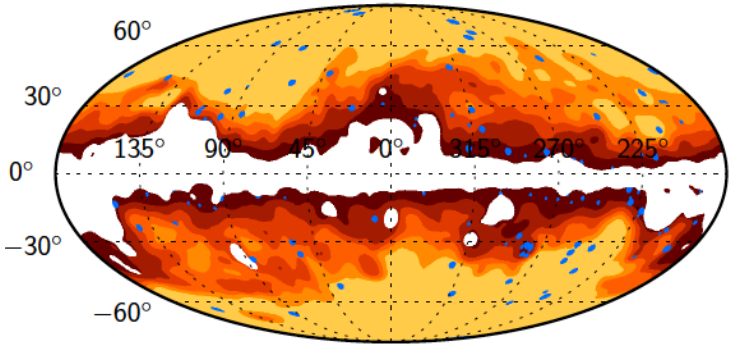
TE, EE & BB

Planck intermediate results LIV arXiv: 1801.04945

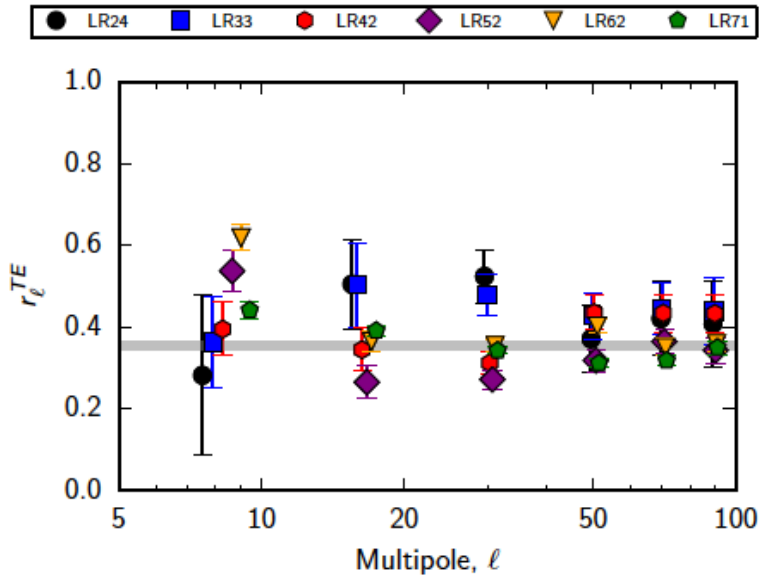


PICO will extend power spectra analysis to $\ell_{max} = 10^4$ for all sky regions. Will we see a break to a steeper Kolmogorov spectrum at higher ℓ?

Sky regions



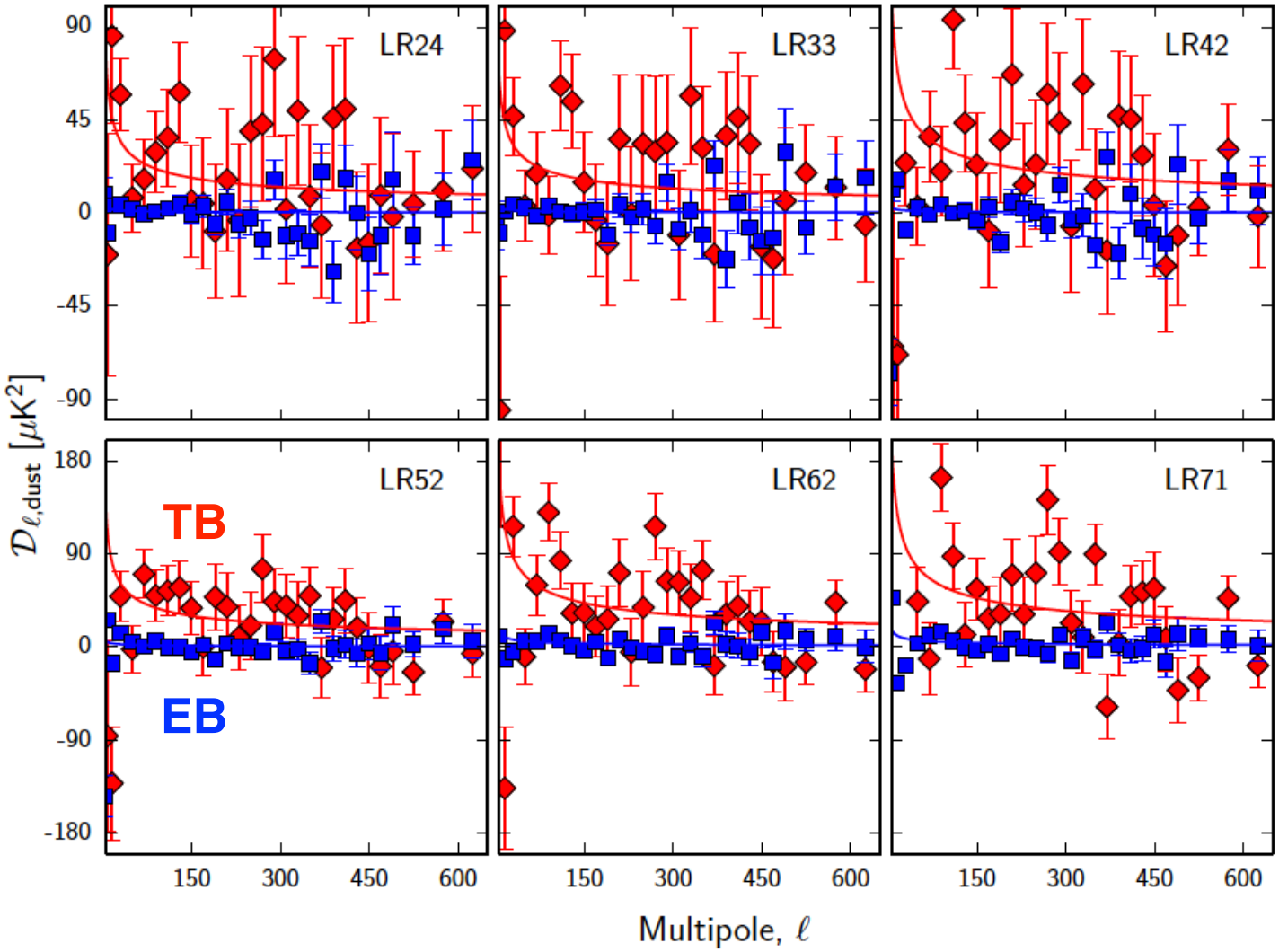
TE correlation ratio



The TE correlation relates to the anisotropy of MHD turbulence. Is it scale dependent?

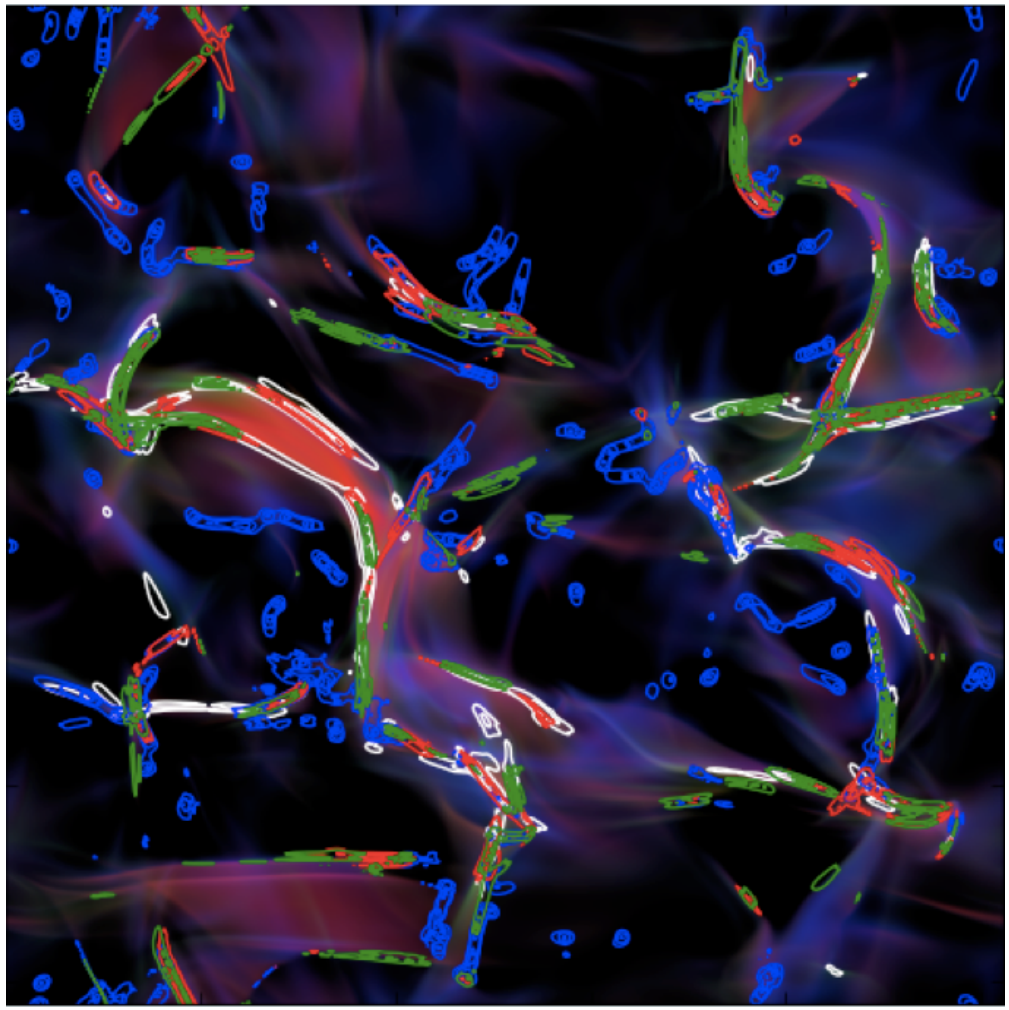
TB Correlation of dust polarization

Planck intermediate results LIV arXiv: 1801.04945



Dust polarization is not mirror symmetric. This result has not yet received an interpretation. PICO will provide the sensitivity to image structures accounting for the TB dust signal.

Turbulent energy dissipation



Momferratos+ 2014
Falgarone+2015

Numerical simulations suggest that turbulent energy dissipation occurs in coherent non-Gaussian structures

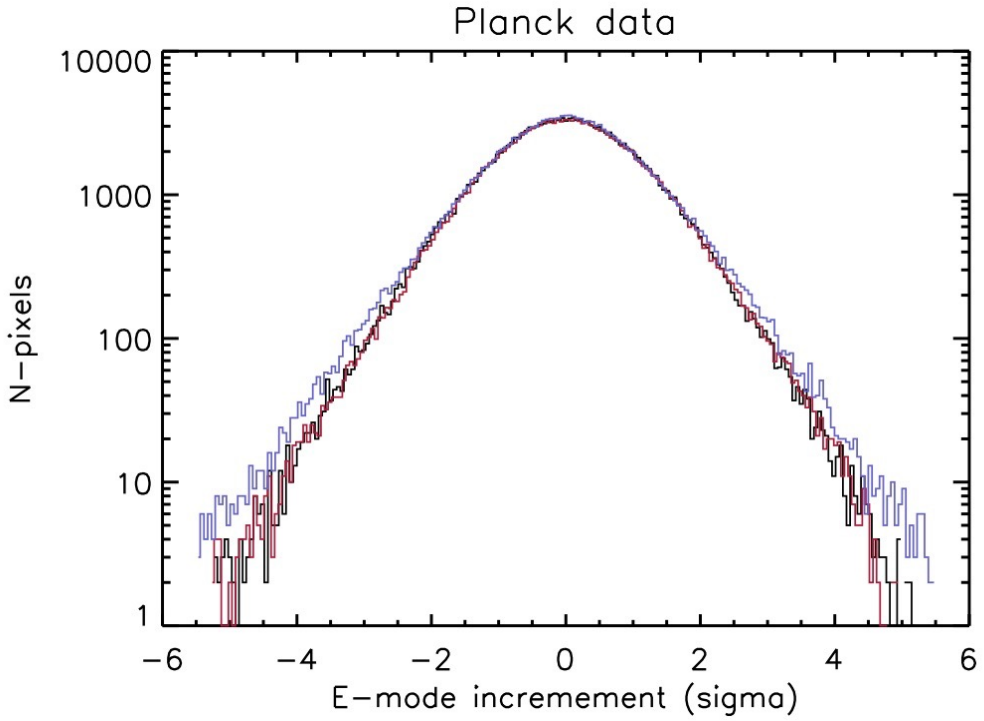
- Ohmic dissipation in red
- Viscous dissipation in green
- Ambipolar diffusion in blue

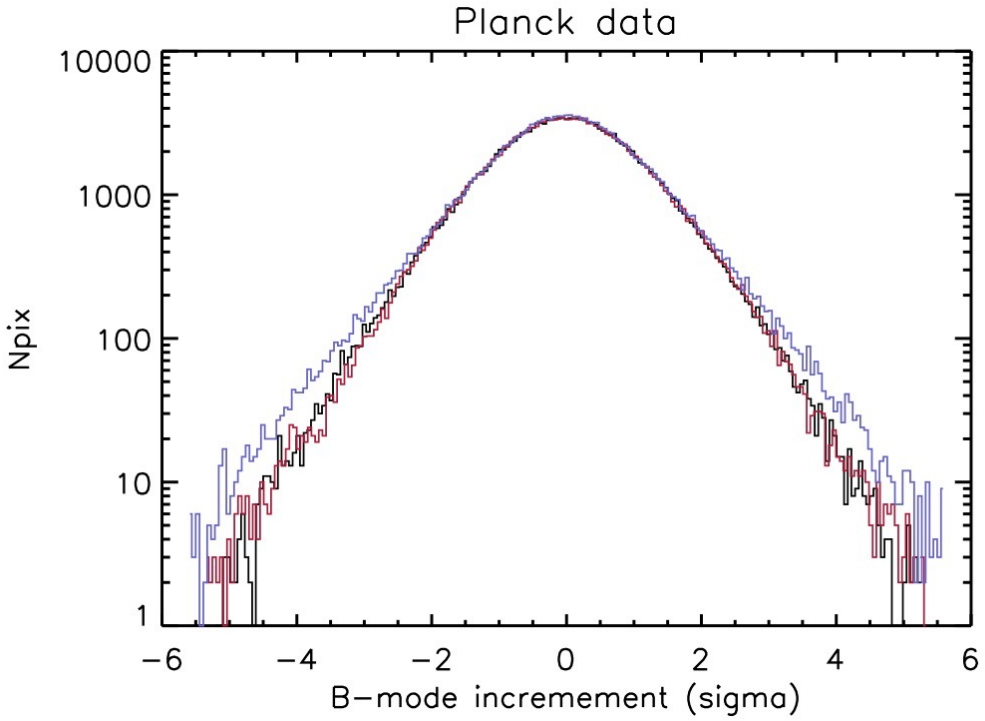
Dissipative structures are correlated to observable quantities

- Velocity increments in white
- Stokes Q and U increments in green and red
- Increments of polarization angles in blue

E & B Increments

E/B decomposition of Q/I and U/I maps





Probability distribution function of increments on scales of 0.5, 1 and 2 degrees, over the Diffuse ISM (f_{sky} = 30%) at intermediate Galactic latitudes

PICO will characterize non-Gaussianity of magnetic fields structure over a two orders of magnitude larger range of scales characterizing turbulence dissipation

Summary

★Magnetism is a fascinating facet of our Cosmic Origins to be unveiled

★PICO will provide unprecedented statistics (up to 10^9 modes) to study interstellar turbulence and characterize the interplay between matter and magnetic fields in space

- Access to the inertial range of the turbulent energy cascade
- Characterization of non-Gaussianity of turbulence

★It can uniquely address three key astrophysics questions involving magnetic fields

- The origin of Galactic magnetic fields
- Structure formation towards star formation
- Physics of feedback: the energetics of star and galaxy formation

➡More perspectives from upcoming talks