Studying Galactic interstellar turbulence through fluctuations in synchrotron emission with LOFAR

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On behalf of the MKSP

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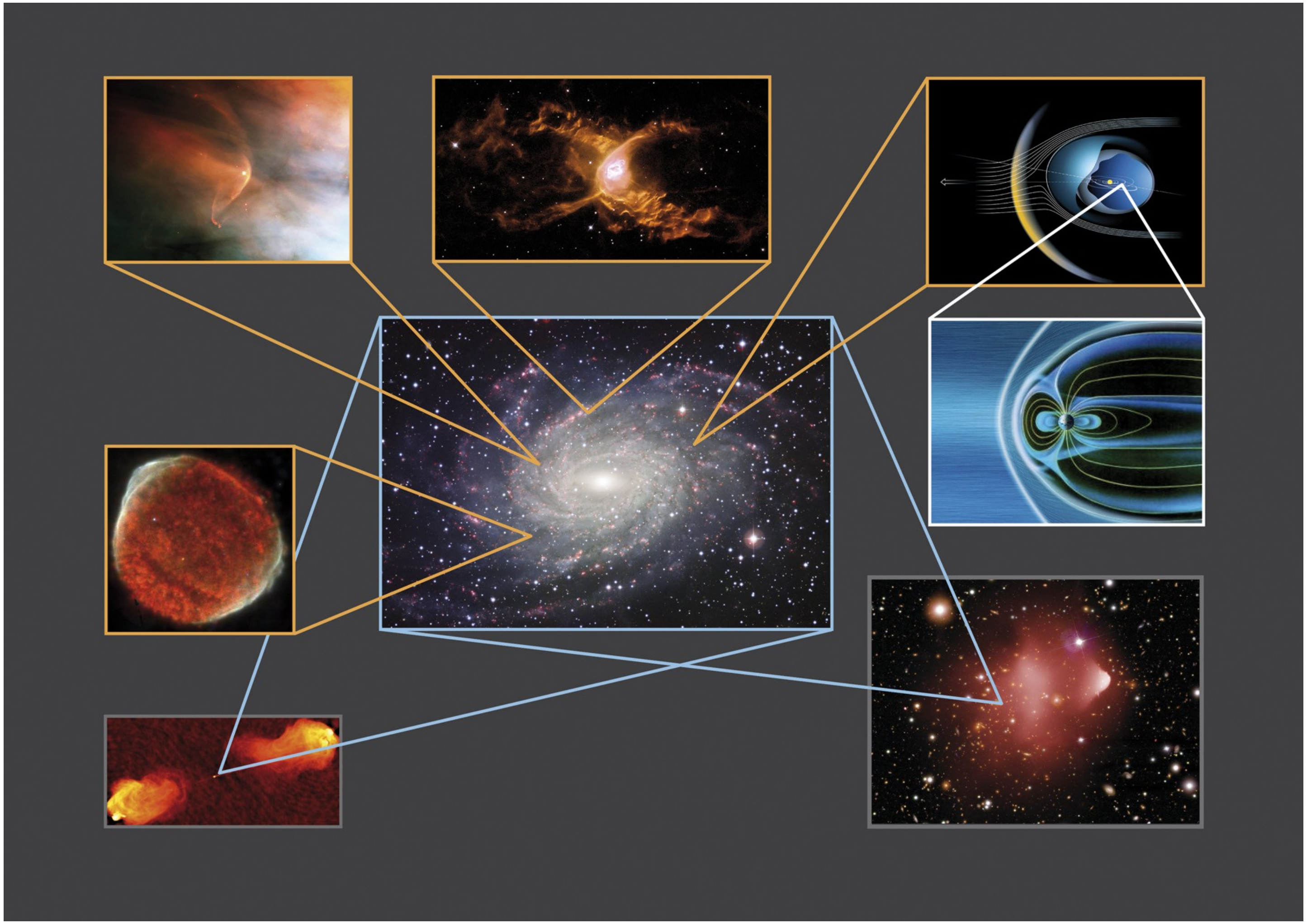
Looking at the interplay between ...



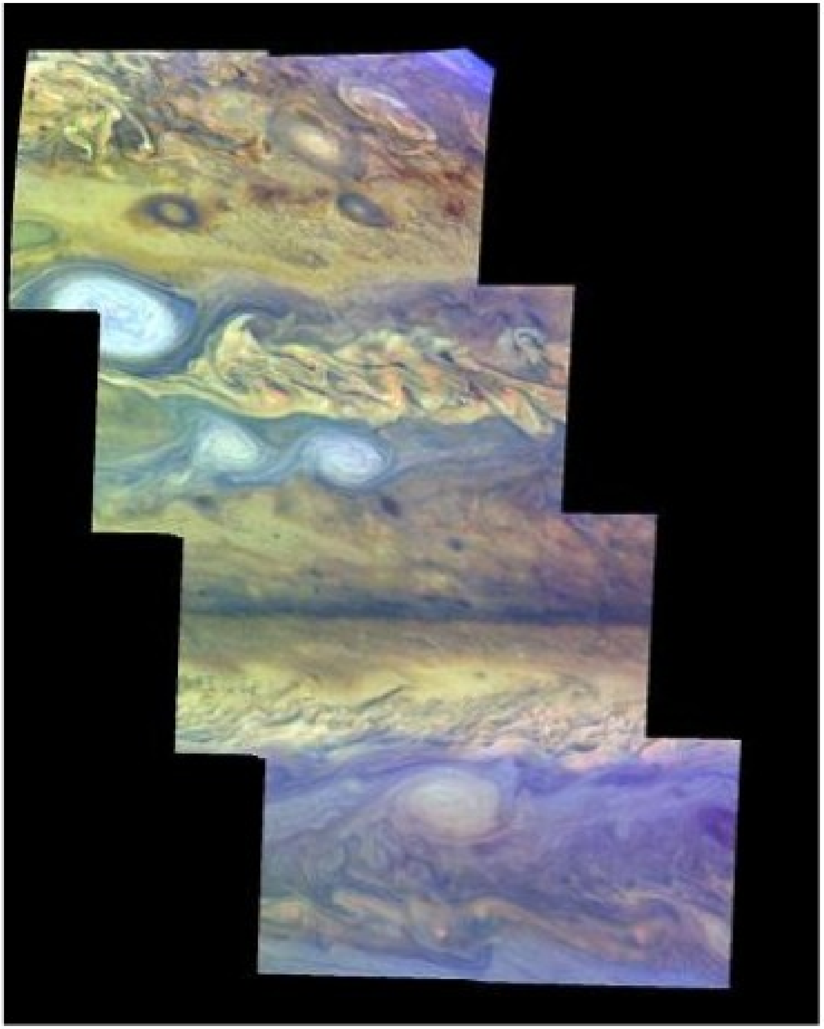
Credit: ESA

(MHD) interstellar turbulence

Turbulence ... what does it stand for?

A complicated state of motion, strongly irregular and chaotic, both in space and time.

The gross features of a turbulent flow are reproducible but details are not predictable.



- **Turbulence involves a hierarchy of scales**
- **A large number of interacting degrees of freedom involved**
- **Energy is spread over all scales**
- **Self-similarity is observed**

We have to **use a statistical approach** to turbulence.

The impact of the interstellar (MHD) turbulence ...

Due to the interplay of GMFs with turbulence in the diffuse ISM

→ it is responsible for the distribution and dissipation of energy

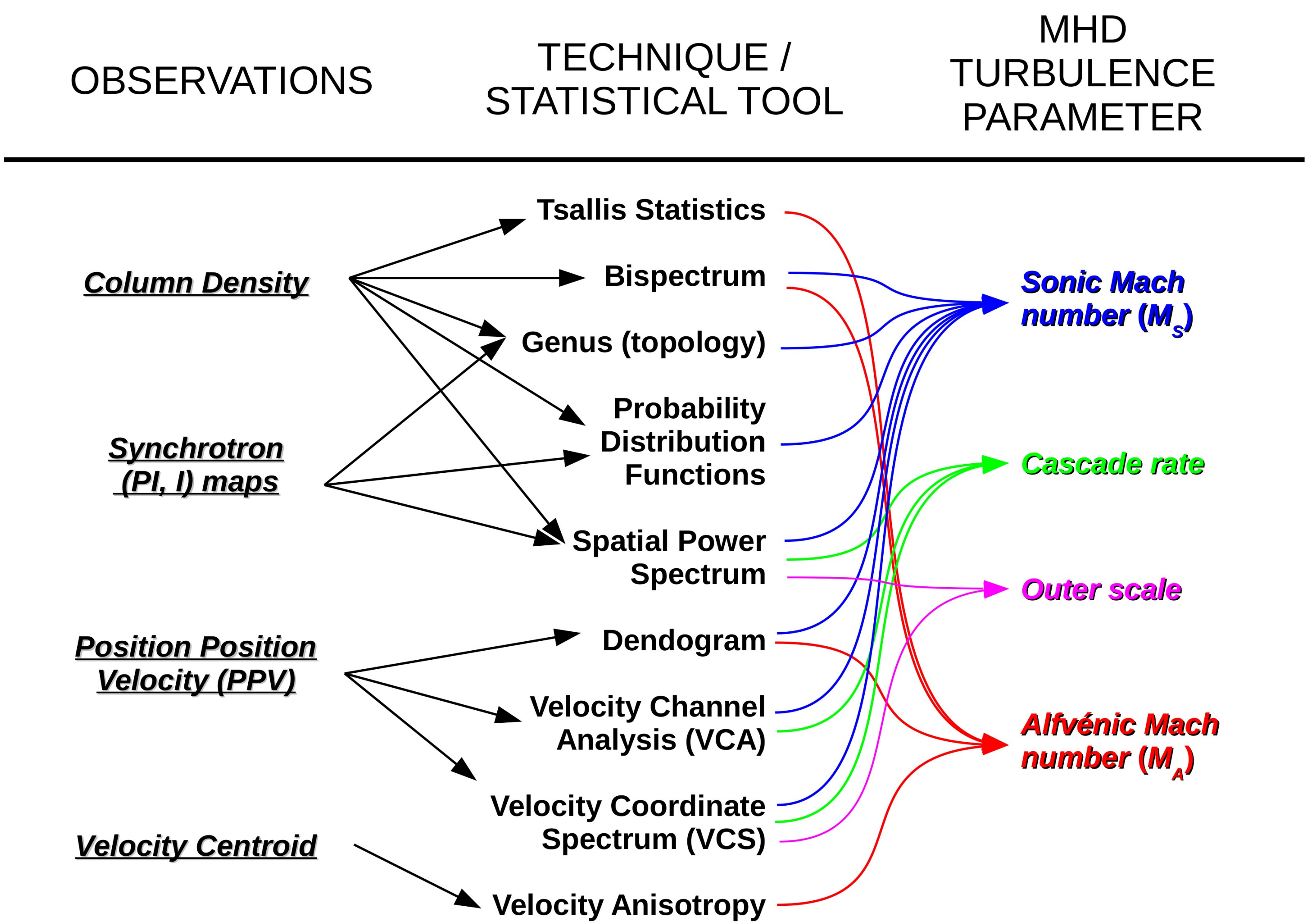
→ it favours mixing and coupling between gas phases and GMF

→ it affects star formation (Krumholz & McKee 2005)

→ it determines cosmic ray propagation (Spangler 2001)

→ interplay with the Galactic dynamo ...

MHD turbulence in the ISM: how to study it ?



Method & Results

(MHD) Turbulence of the diffuse Galactic foreground

Galactic radio synchrotron continuum contain imprints of MHD turbulence in the ISM (see e.g. Eilek 1989; Waelkens et al. 2009; Junklewitz et al. 2011; Lazarian & Pogosyan 2012).

Foreground turbulent fluctuations in synchrotron emission: <u>how to measure them?</u>

Low-frequency radio observations

Below ν~1 GHz, relativistic electrons assumed to be uniformly distributed over the scales of magnetic field inhomogeneities (Regis 2011).

⇒

The fluctuations of synchrotron radiation emitted over a large volume and detected in total intensity radio maps directly reflect the spectrum of magnetic fluctuations.

(MHD) Turbulence of the diffuse Galactic foreground

Foreground turbulent fluctuations in synchrotron emission:
<u>why are relevant?</u>

Insights about interstellar turbulence.

$B_{ordered}/B_{random}$ relevant for understanding evolution of magnetic fields in galaxies (Arshakian et al. 2009).

The characterisation of the diffuse synchrotron foreground at arcminute angular scales is fundamental for cosmological studies (e.g. EOR).

The Galactic foreground as a screen constituting a limiting factor for precise cosmology measurements.

Interstellar MHD turbulence towards the Fan region

12 hours observation performed on 2012 January 07-08th using the LOFAR high band antennas (HBAs) arranged into 57 stations

Data reduction strategy:

-removal of the two sources Cas A and Cyg A,

-(single direction) calibration of the target field visibilities,

-identification and removal of bad data per station (15 stations neglected, bandwidth between 145-174 MHz)

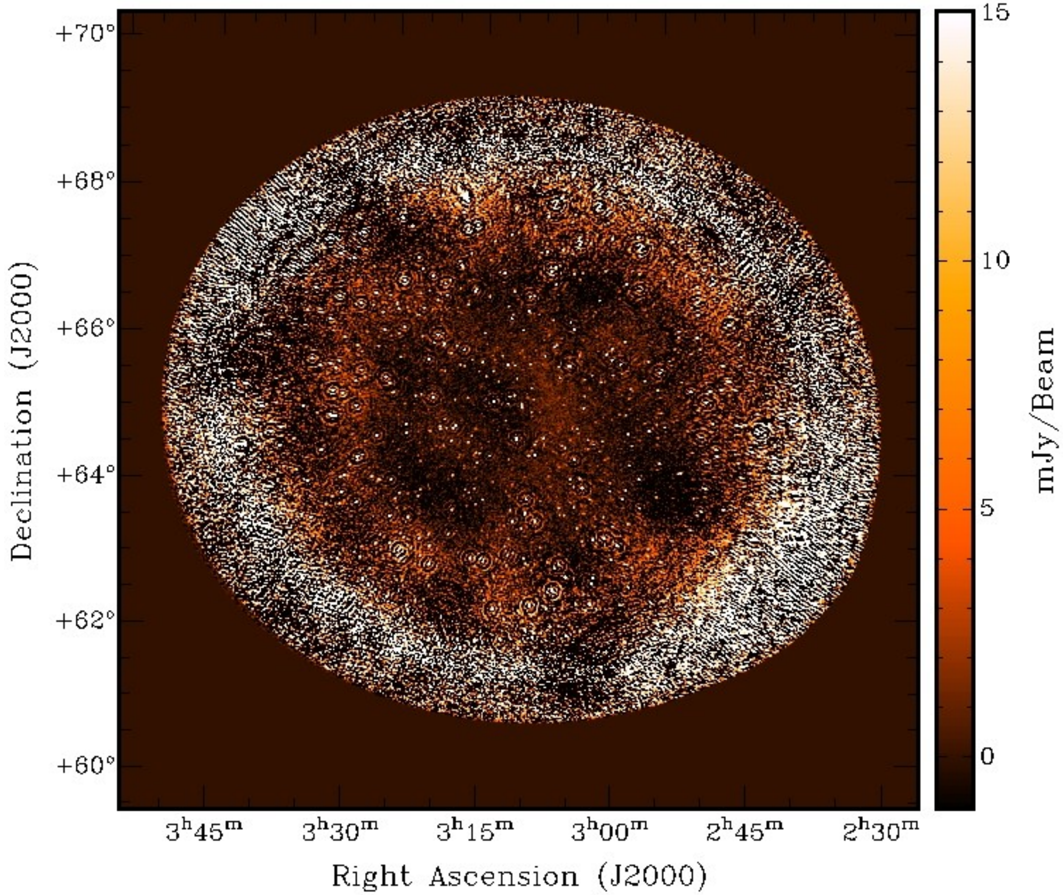
-self-calibration to correct for direction-dependent effects,

-imaging.

Interstellar MHD turbulence towards the Fan region

Multi-scale fluctuations of continuum emission at 160 MHz
(1' resolution and noise @ 0.4 mJy/beam): a LOFAR prime

Iacobelli et al. 2013



Interstellar MHD turbulence towards the Fan region

From a residual map we calculate the angular power spectrum over a region of 3°×3° degrees centred on the field centre

The power spectrum shows a power law behaviour at low l, while at high l is flat.

Large-scale foreground (Galactic) emission toward the Fan region

The rms confusion noise due to the point source contamination

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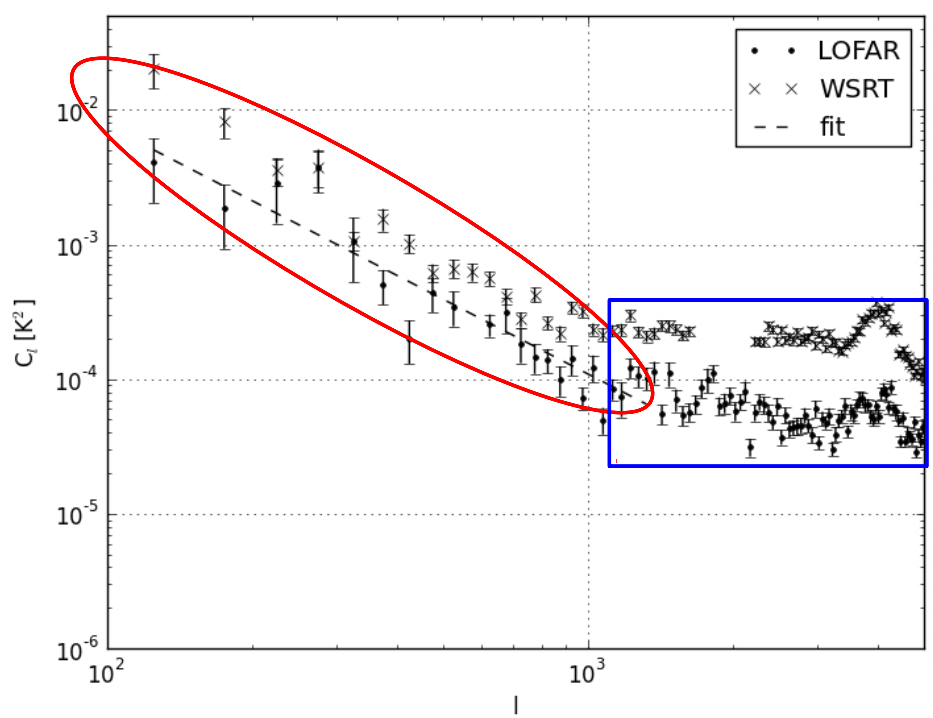


Power law ($C_l \propto l^{\alpha}$) fit gives a slope $\alpha = -1.84 \pm 0.19$ for $l \in [100,1300]$

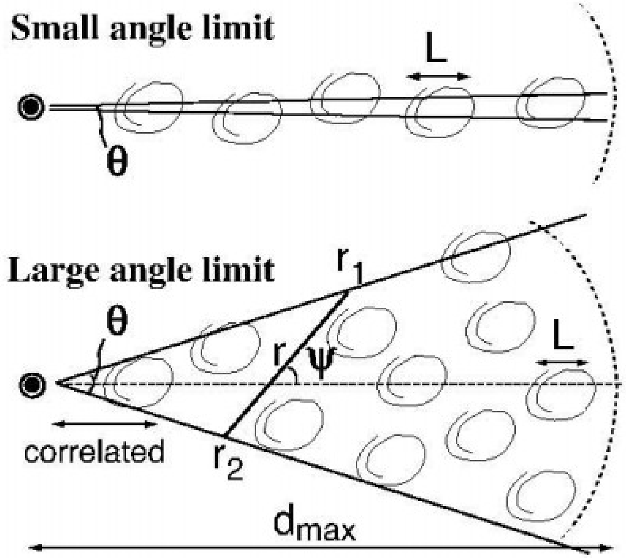
Consistent with the estimate from WSRT data (Bernardi et al. 2009).

Theoretical arguments ...

The outer scale of fluctuations L_{out}:

Cho & Lazarian (2002) model of the synchrotron emissivity

$$I_{cr} \sim \pi \frac{L_{max}}{L_{out}} \qquad L_{max} = \frac{H_{sync}}{\sin(b)}$$



Cho & Lazarian 2002

The ratio of magnetic field strengths:

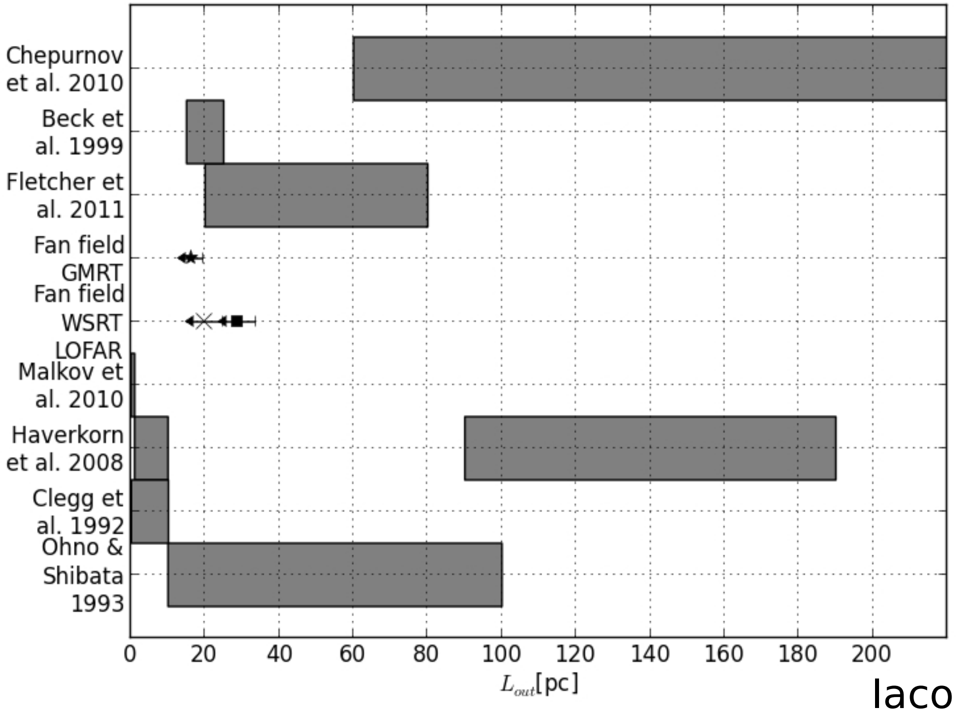
effects of MHD turbulence in subsonic and transonic regimes on the total intensity of an extended radio source as described by Eilek (1989a,b) under the assumptions: L_{out} is much smaller than L_{max}, the fluctuations obey a Gaussian statistics and the cosmic ray spectral index of ~3.

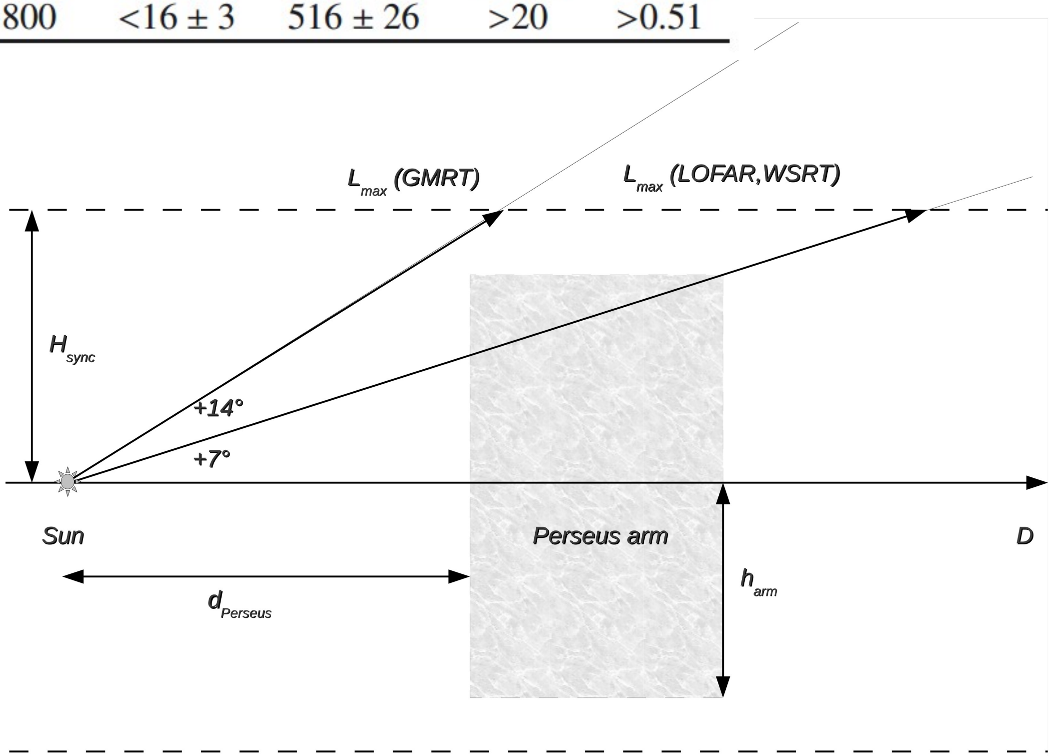
$$\frac{B_o}{B_r} = (A^{1/2} - 1)^{1/2} \quad \text{where} \quad A = \frac{\langle I \rangle}{\sigma_I}\left(\frac{L_{out}}{L_{max}}\right)^{1/2}$$

Results and comparison with GMRT data

Hints for spatial variations?

Telescope	(l, b) coordinates	L_{max} [kpc]	ℓ_{cr}	L_{out} [pc]	$\langle I \rangle$ [K]	σ_I [K]	B_0/B_r
LOFAR	137.00°, 7.00°	8.2 ± 1.6	>1300	<20 ± 6	587 ± 30	>25	>0.28
WSRT	137.00°, 7.00°	8.2 ± 1.6	>1000	<29 ± 6	587 ± 30	>30.5	>0.26
GMRT	151.80°, 13.89°	4.1 ± 0.8	>800	<16 ± 3	516 ± 26	>20	>0.51





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Conclusions

Turbulence of the diffuse Galactic foreground

In the framework of the commissioning activities to characterise the LOFAR performance, we present results from a LOFAR observation of a field in the Fan region, between 110 and 174 MHz.
Fluctuations in the diffuse total power emission used to characterise turbulence scale and magnetic field ratio in the diffuse ISM.

- First LOFAR detection and imaging of Galactic diffuse total power fluctuations, at an angular resolution of ~1' and in a wide frequency range around 160 MHz.
- Statistical properties of the foreground synchrotron fluctuations probed up to l~1300 (i.e. ~8 arcmin). The power spectrum of the turbulent fluctuations is approximately a power law with slope -1.84.
- $L_{out} \approx 16-29$ pc, in agreement with previous estimates of L_{out} in spiral arms but the Galactic halo or interarm regions: observed fluctuations partially due to synchrotron emission in the Perseus arm.
- Lower limit for the ratio $(B_{ordered}/B_{random}) \geq 0.3$ is found, consistent with magnetic field ratios at other places in the ISM.

Thank you!

Any Questions?