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LOFAR

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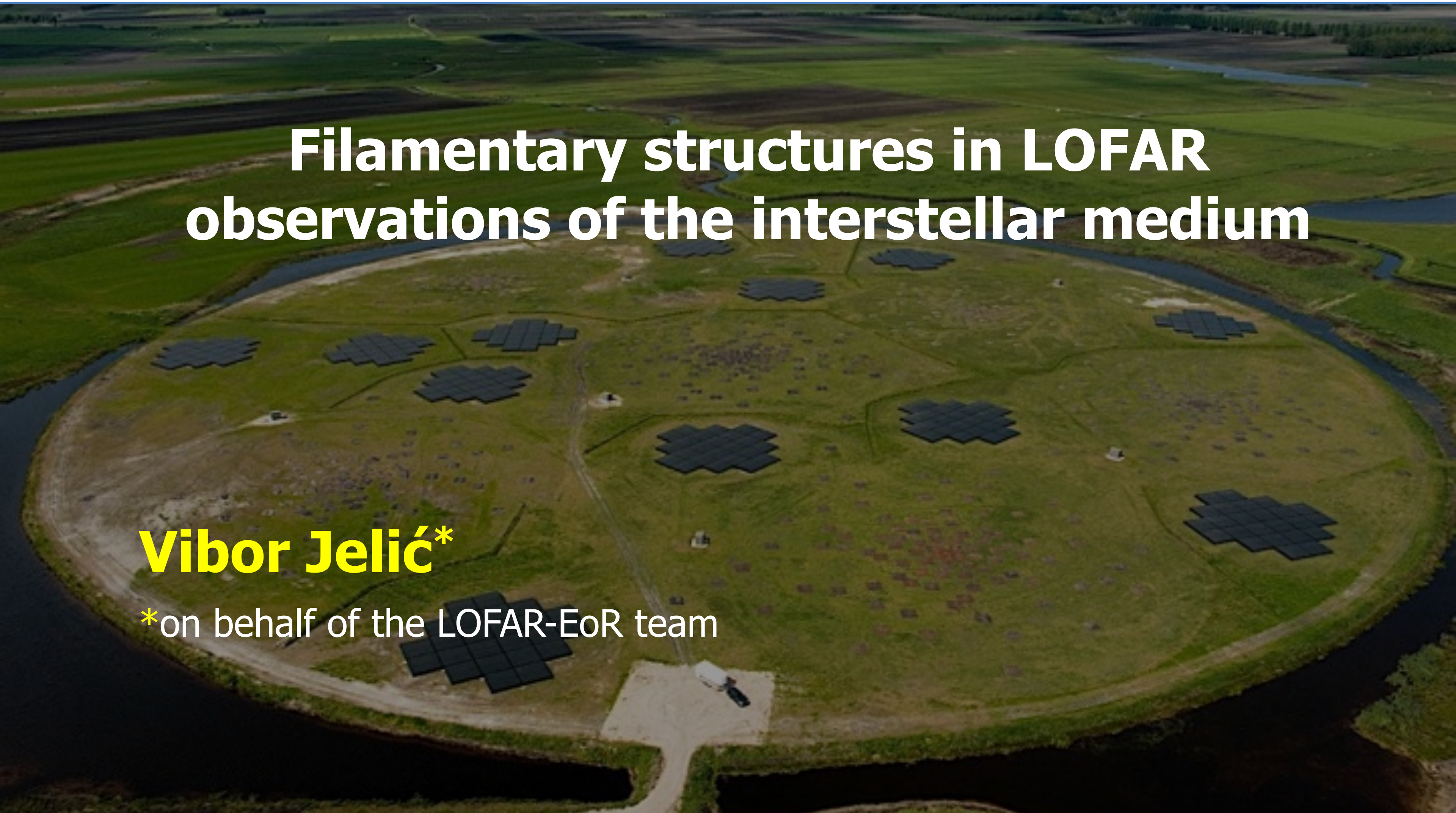


Filamentary structures in LOFAR observations of the interstellar medium

Vibor Jelić*

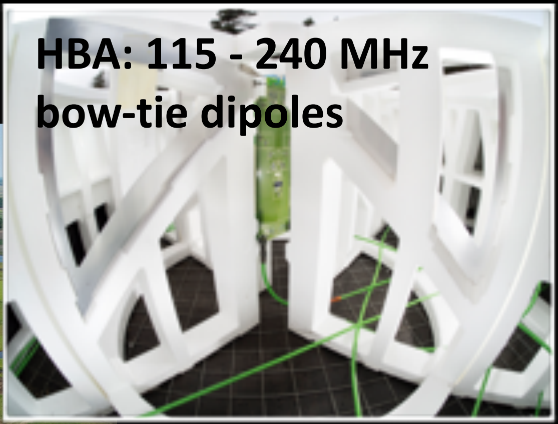
*on behalf of the LOFAR-EoR team

LOFAR: Low Frequency Array

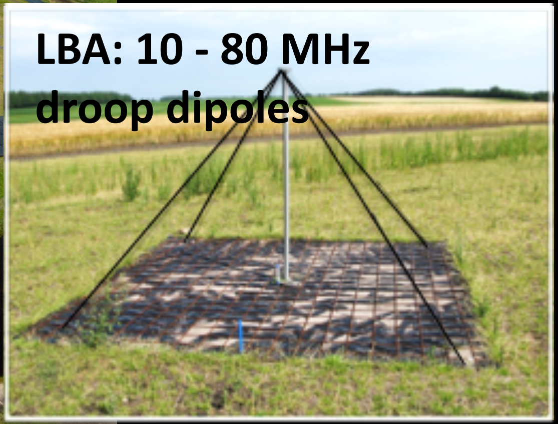
van Haarlem et al., 2013

- **LOFAR-HBA (6-8h) observations**
  - 115 - 175 MHz, 0.2 MHz resolution
  - 5 deg x 5 deg images, 3 arcmin resolution

LOFAR-CORE, near Exloo, the Netherlands



HBA: 115 - 240 MHz
bow-tie dipoles

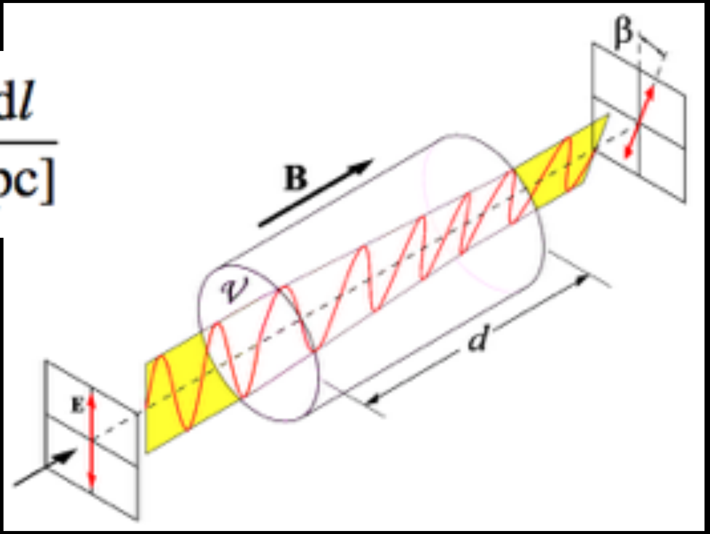


LBA: 10 - 80 MHz
droop dipoles

Rotation Measure synthesis

Brentjens & de Bruyn 2008

$$\frac{\Phi}{[\mathrm{rad\ m^{-2}}]} = 0.81 \int_{source}^{observer} \frac{n_e}{[\mathrm{cm^{-3}}]} \frac{B_{\|}}{[\mu\mathrm{G}]} \frac{\mathrm{d}l}{[\mathrm{pc}]}$$



Faraday rotation ~ $\phi\ \lambda^2$

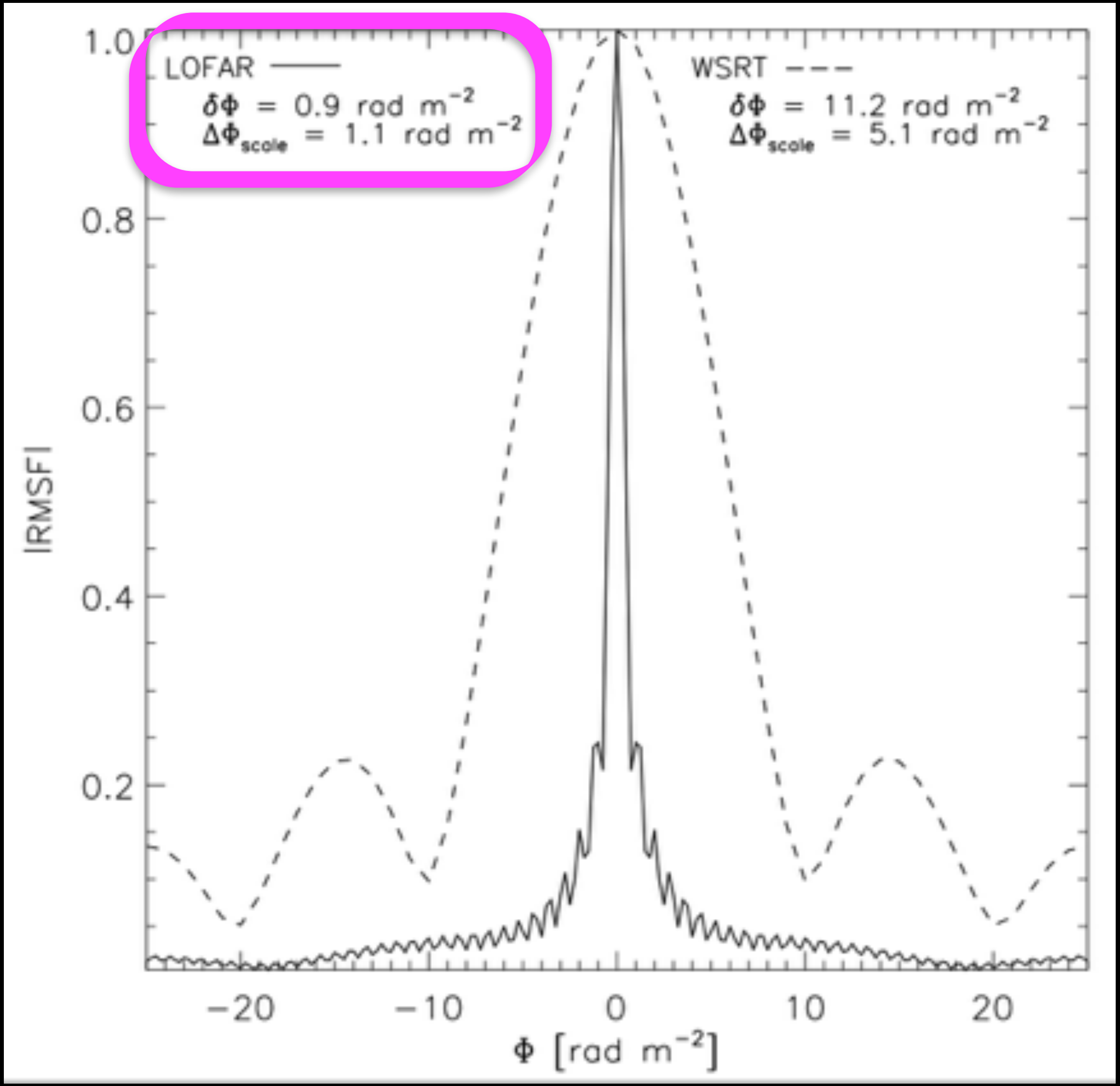
- with radio telescope we observe emission in Stokes I,Q,U,V at different frequencies

$P(\lambda^2) = Q(\lambda^2) + iU(\lambda^2)$

- preform transformation from λ^2 to Faraday depth ϕ (RM synthesis)

$$F(\Phi) = \frac{1}{W(\lambda^2)} \int_{-\infty}^{+\infty} P(\lambda^2) e^{-i2\Phi\lambda^2} \mathrm{d}\lambda^2$$

Rotation Measure Spread Function



resolution ~ spectral bandwidth

$$\delta\Phi \approx 2\sqrt{3}/\Delta\lambda^2$$

LOFAR - 150 MHz (4 m^2)

WSRT - 350 MHz (0.3 m^2)

max scale ~ min frequency

$$\Delta\Phi_{\rm scale} \approx \pi/\lambda^2_{\rm min}$$

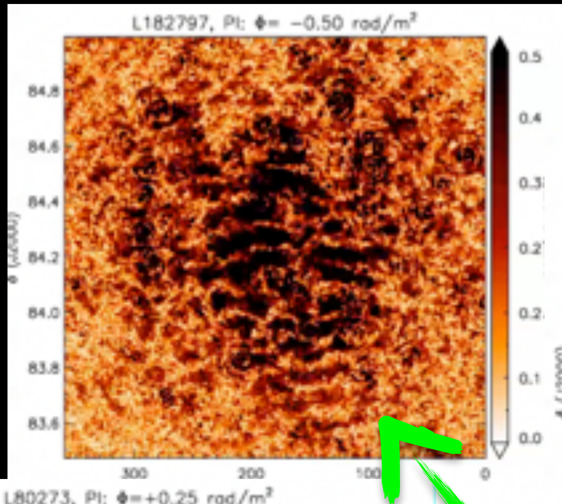
Faraday thin structures

$$\lambda^2\Delta\Phi \ll 1$$

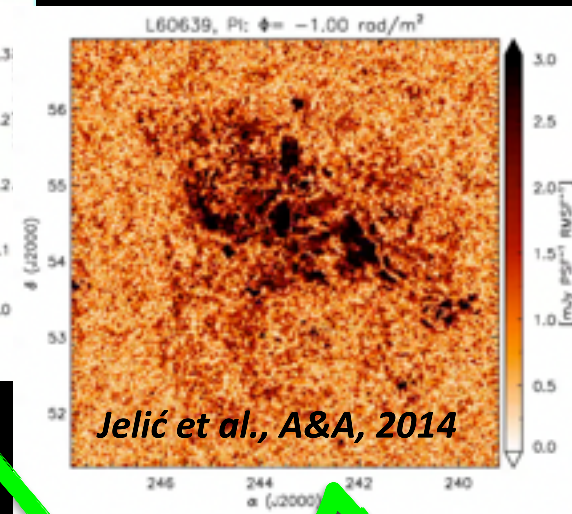
Faraday thick structures

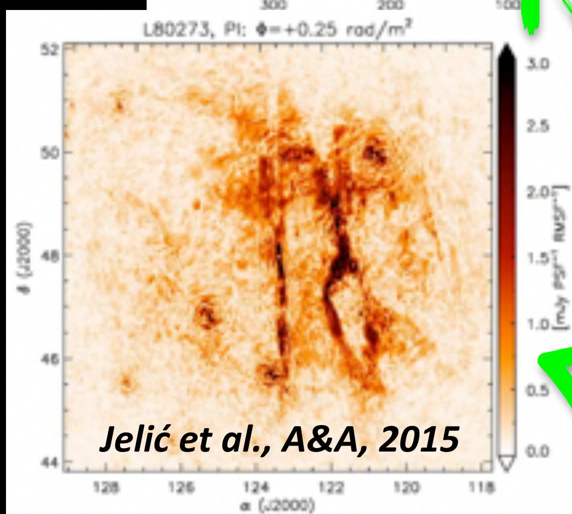
$$\lambda^2\Delta\Phi \gg 1$$

NCP field

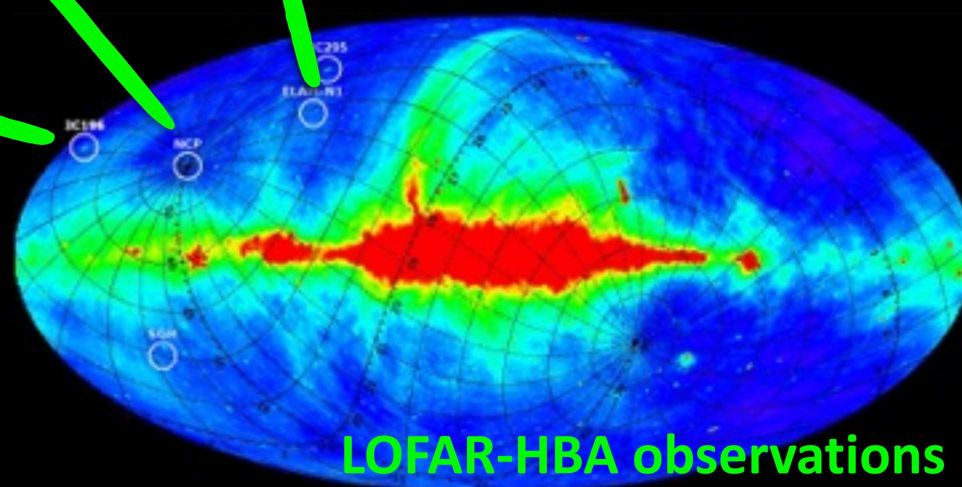


ELAIS-N1 field
from -10 to +13 rad/m^2

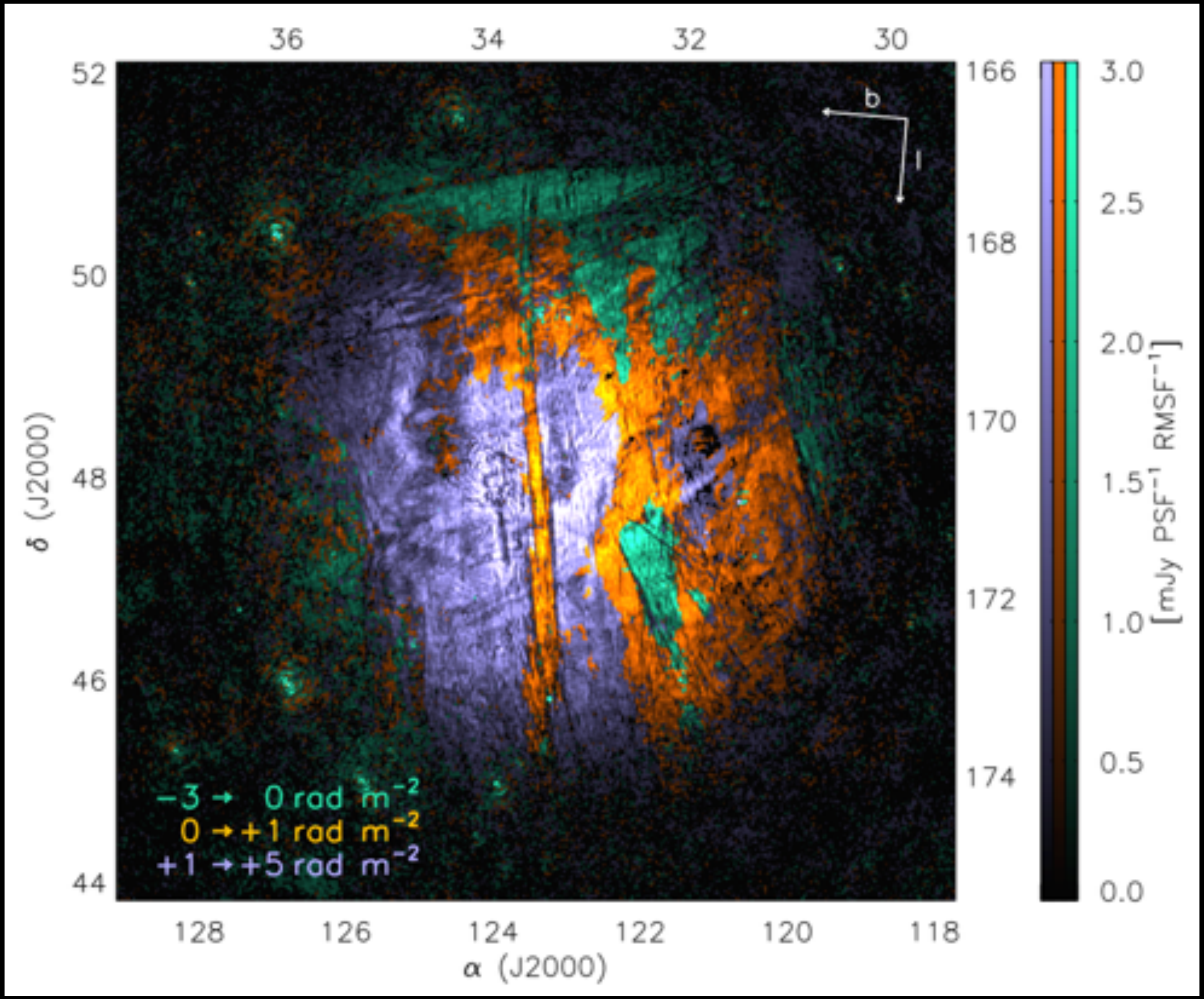




3C196 field
from -3 to +8 rad/m^2



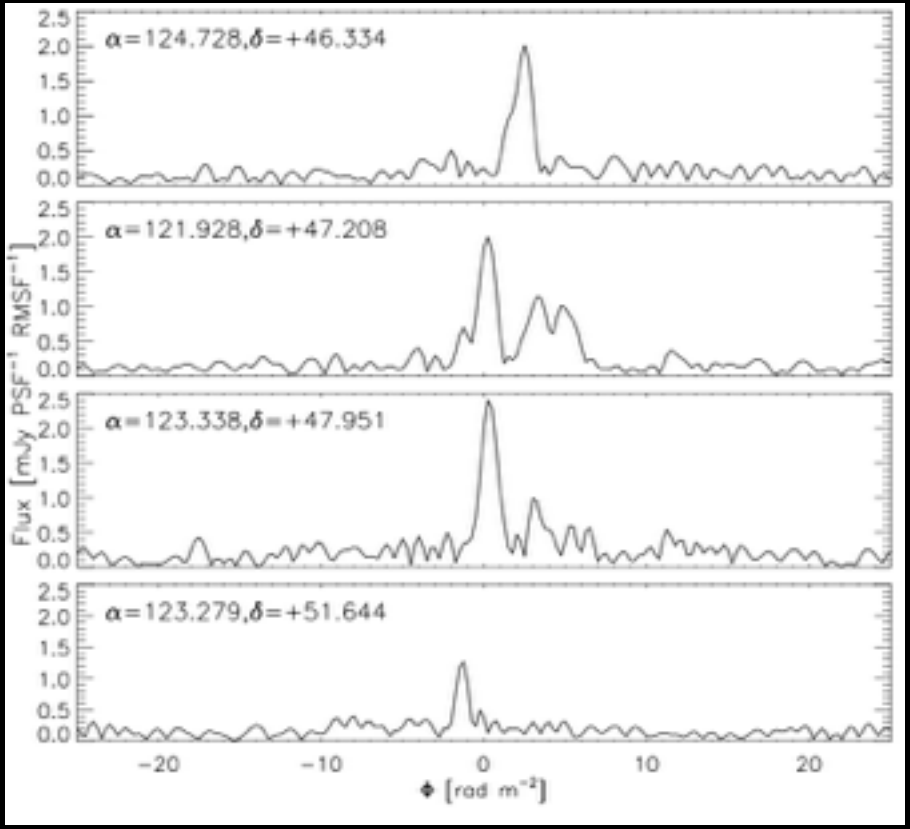
3C196 field



Jelic et al., 2015, A&A

3C196 field: constrains on $B_{||}$

magnetic field reversal(s)



PULSAR 434 ms; +2.7 rad/m^2; 11.3 pc cm^{-3}
(J. Hessels & V. Kondratiev)

$$\frac{\langle B_{\|}\rangle}{[\mu G]} = \frac{\mathrm{RM}\ [\mathrm{rad\ m^{-2}}]}{0.812\ \mathrm{DM}\ [\mathrm{pc\ cm^{-3}}]}$$

$$\langle B_{\|}\rangle = 0.3 \pm 0.1\ \mu G$$

H alpha map (Finkbeiner 2003)

$$\sigma_{\langle B_{\|}\rangle} = \sqrt{\left(\frac{\sigma_{\langle \mathrm{RM}\rangle}}{0.81\,\langle n_e\rangle L}\right)^2 + \left(\frac{\langle \mathrm{RM}\rangle\,\sigma_{\langle n_e\rangle}}{0.81\,\langle n_e\rangle^2 L}\right)^2}$$

$$\sigma_{\langle B_{\|}\rangle} \simeq 0.2\ \mu G$$

3C196 field: constrains on the filament

- the lack of emission in total intensity, an upper limit to the thermal free-free emission, $T_{ff} < 0.2$ K

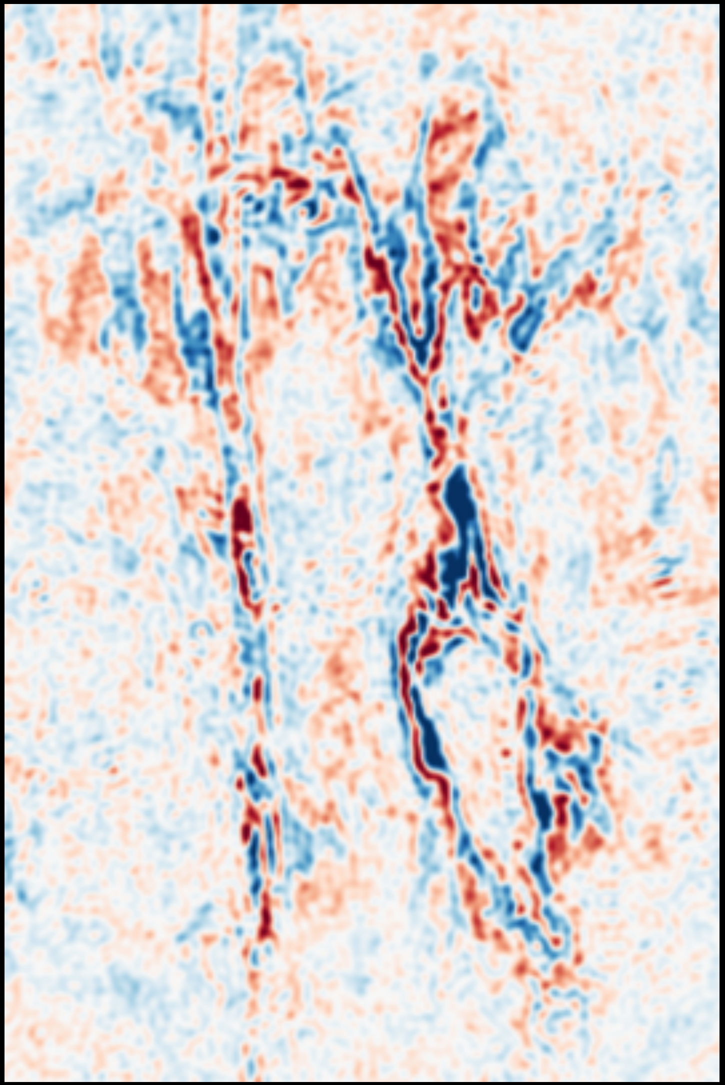
- $T_e = 8000$K and dl=1pc —> **$n_e < 1$ cm^{-3}**

- thickness in Faraday depth of 1 rad m^{-2}

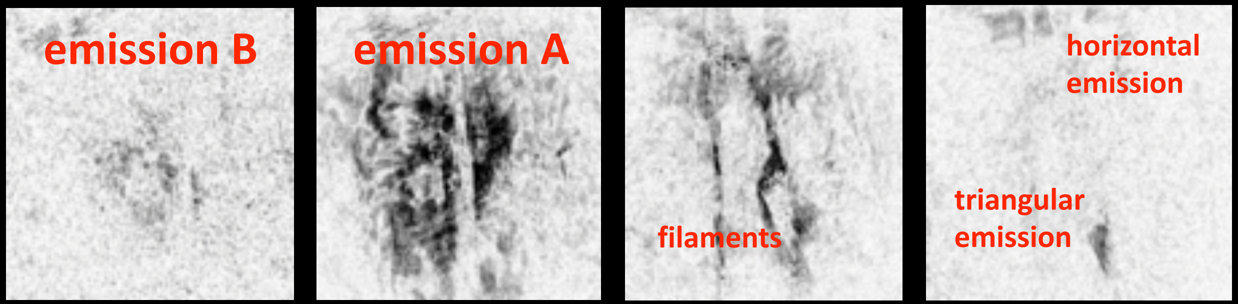
  $B_{||} > 1.2$ microG

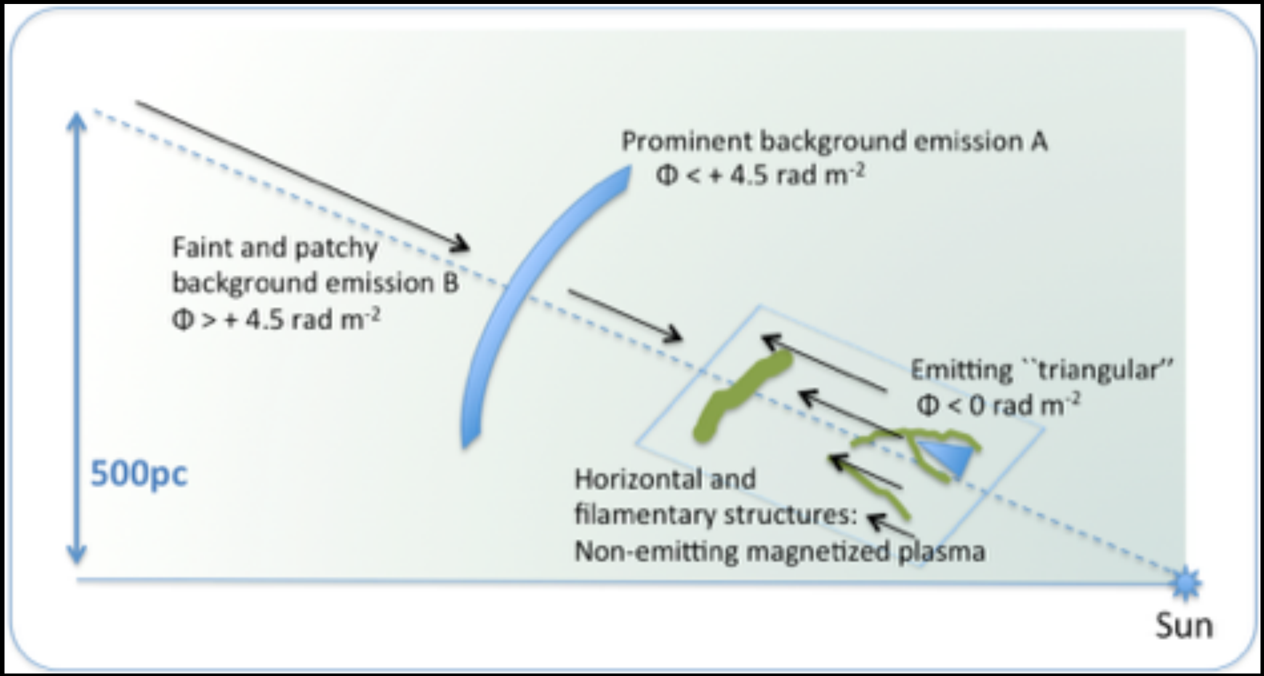
- assuming equipartition between magnetic and thermal energy

  $B_{tot} < 6.5$ microG



3C196 field: a possible model

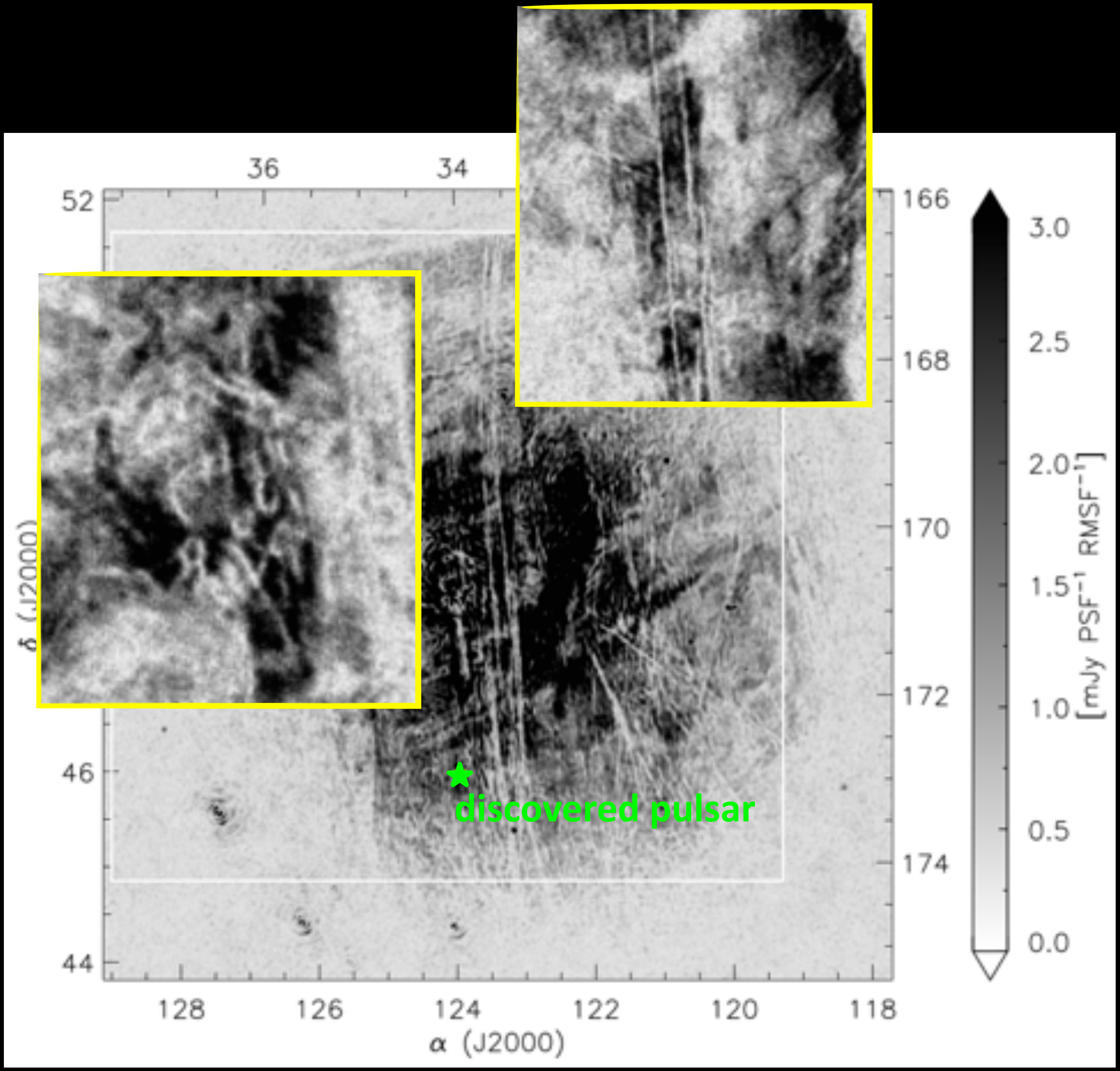




Jelic et al., 2015, A&A

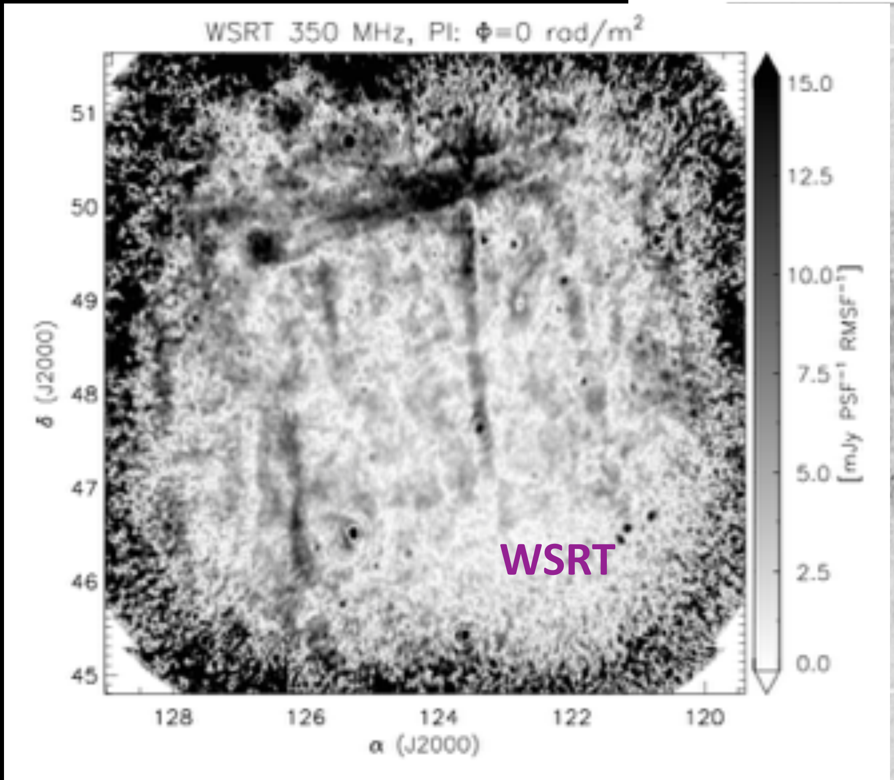
3C196 field

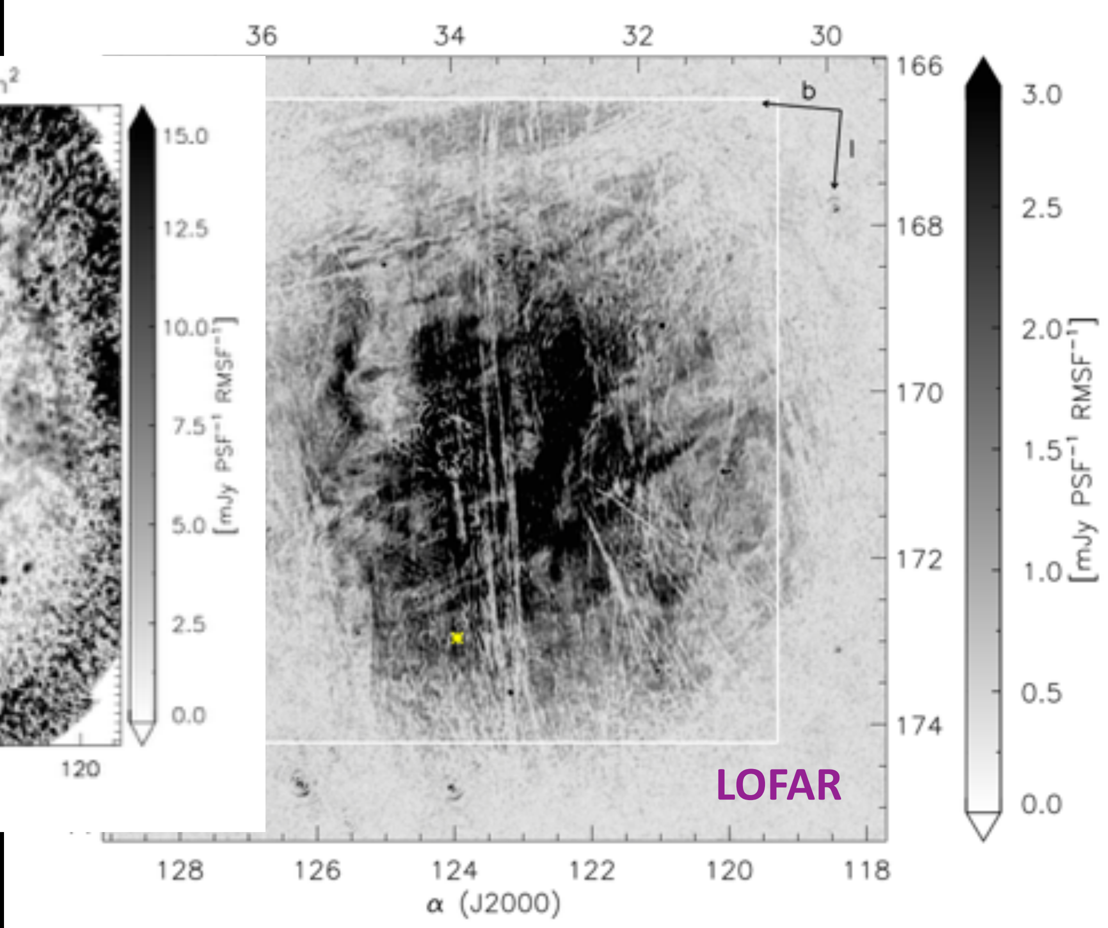
depolarization canals



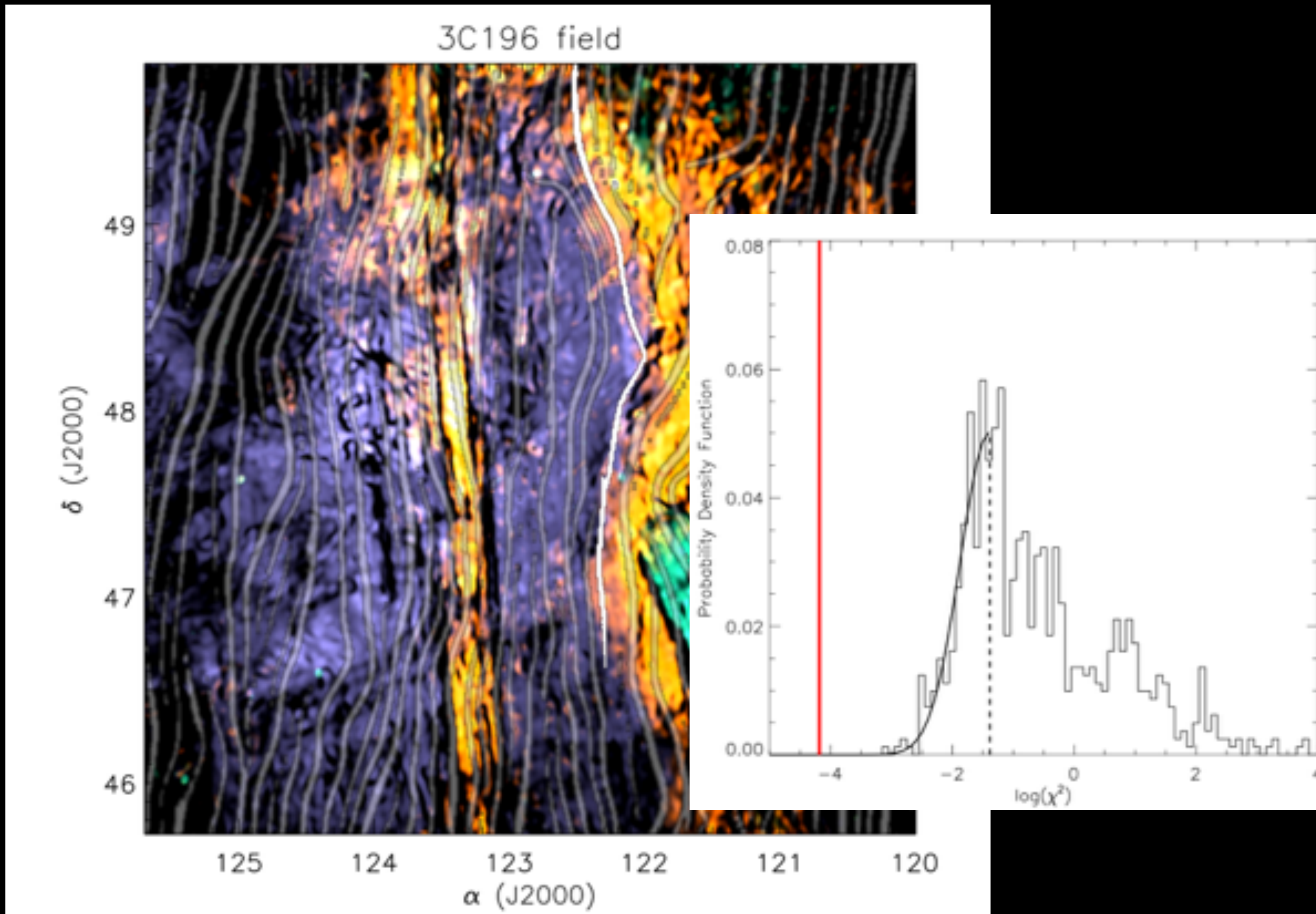
Jelic et al., 2015, A&A

3C196 field: WSRT 350 MHz observations





3C196 field: Planck dust polarization maps



Zaroubi et al., 2015, MNRAS

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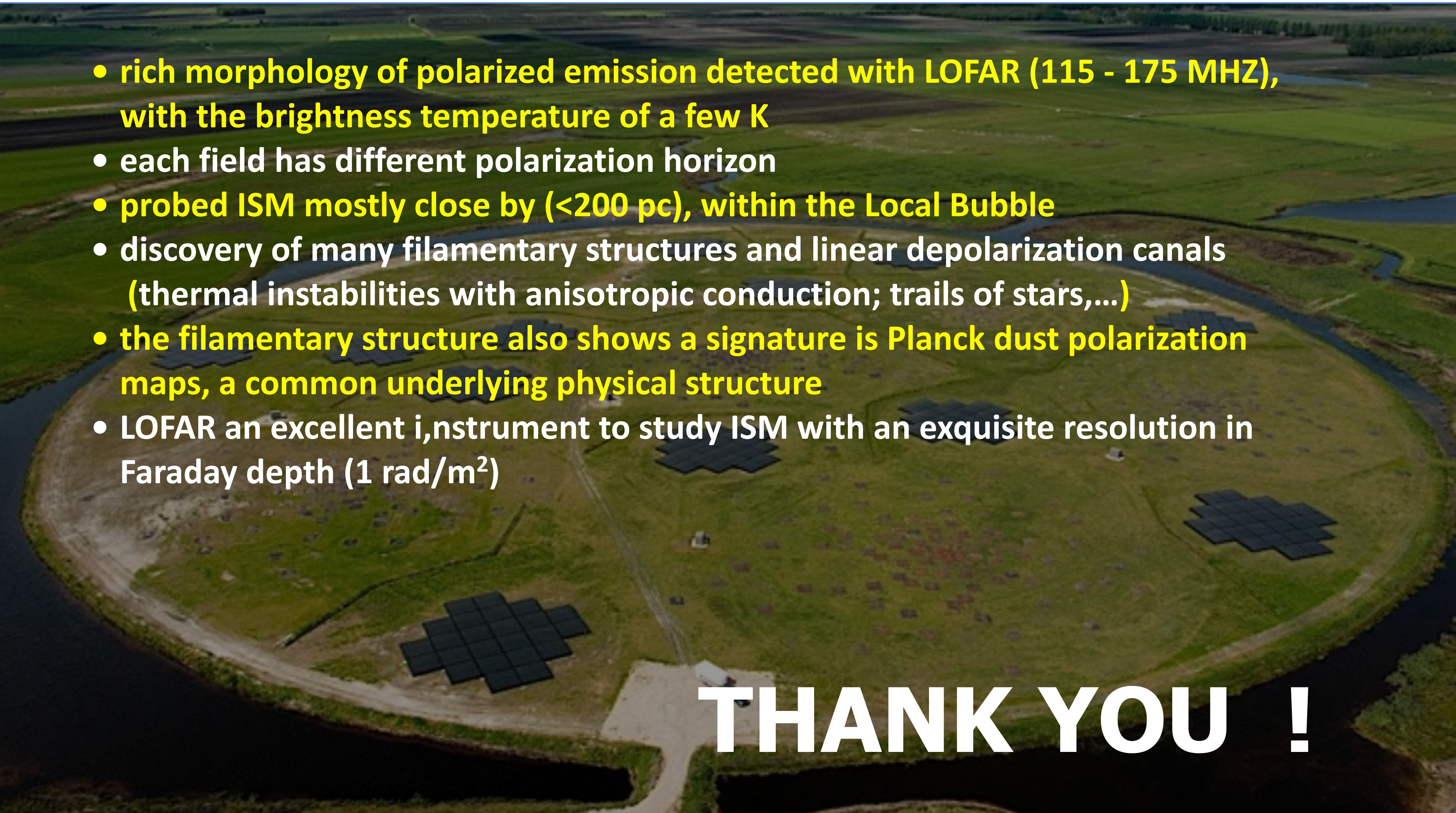

- rich morphology of polarized emission detected with LOFAR (115 - 175 MHZ), with the brightness temperature of a few K
- each field has different polarization horizon
- probed ISM mostly close by (<200 pc), within the Local Bubble
- discovery of many filamentary structures and linear depolarization canals (thermal instabilities with anisotropic conduction; trails of stars,…)
- the filamentary structure also shows a signature is Planck dust polarization maps, a common underlying physical structure
- LOFAR an excellent i,nstrument to study ISM with an exquisite resolution in Faraday depth (1 rad/m^2)

THANK YOU !