magnetic field in the jet of quasar 3C454.3

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A.B. Pushkarev

Granada 14 June 2013

Jet launching and role of magnetic field

Blandford & Znajek (1977)

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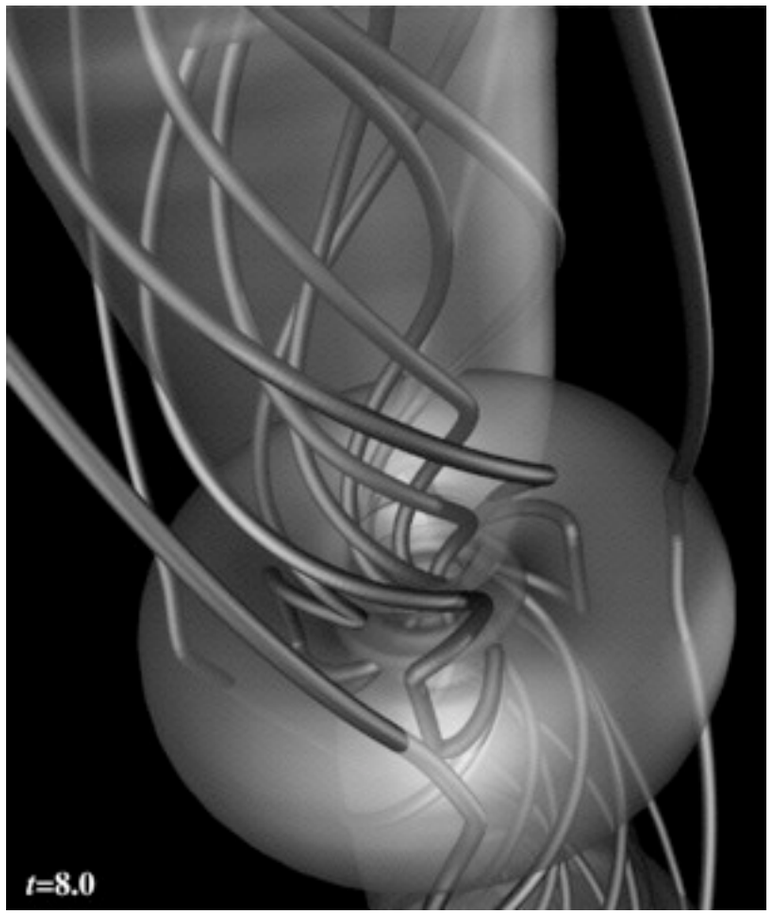
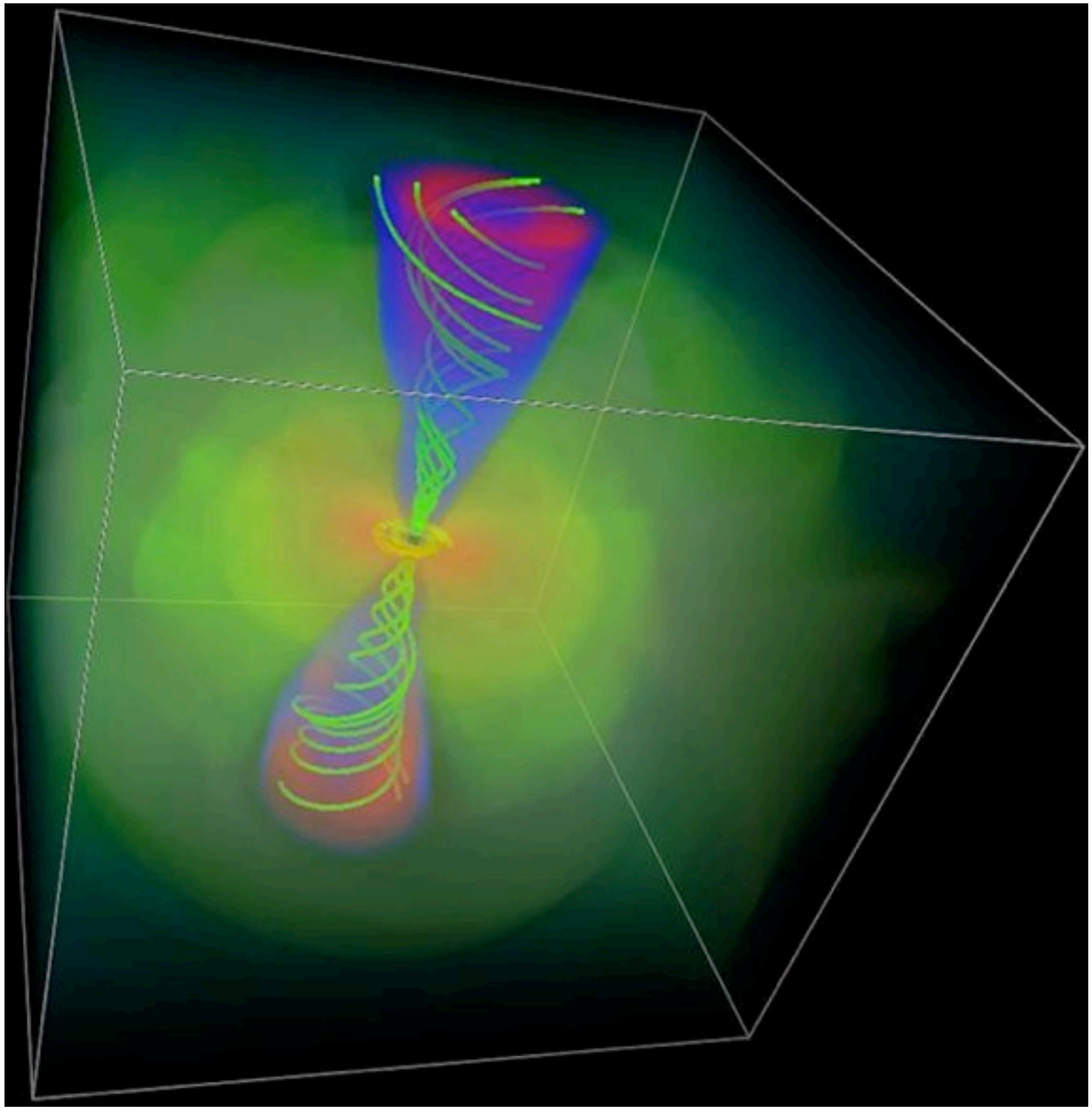
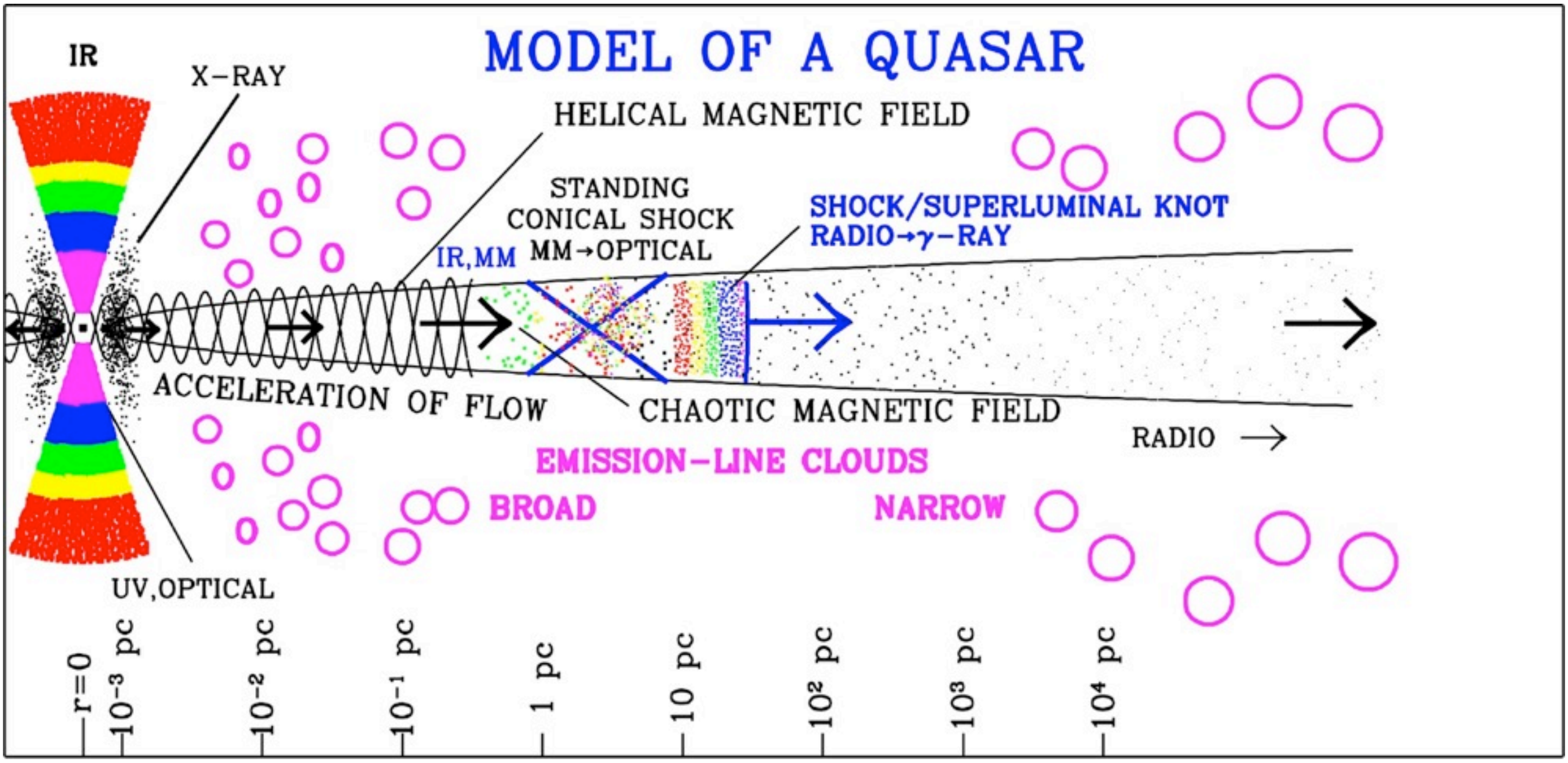


Meier & Uchida 2002
Uchida et al. 2004



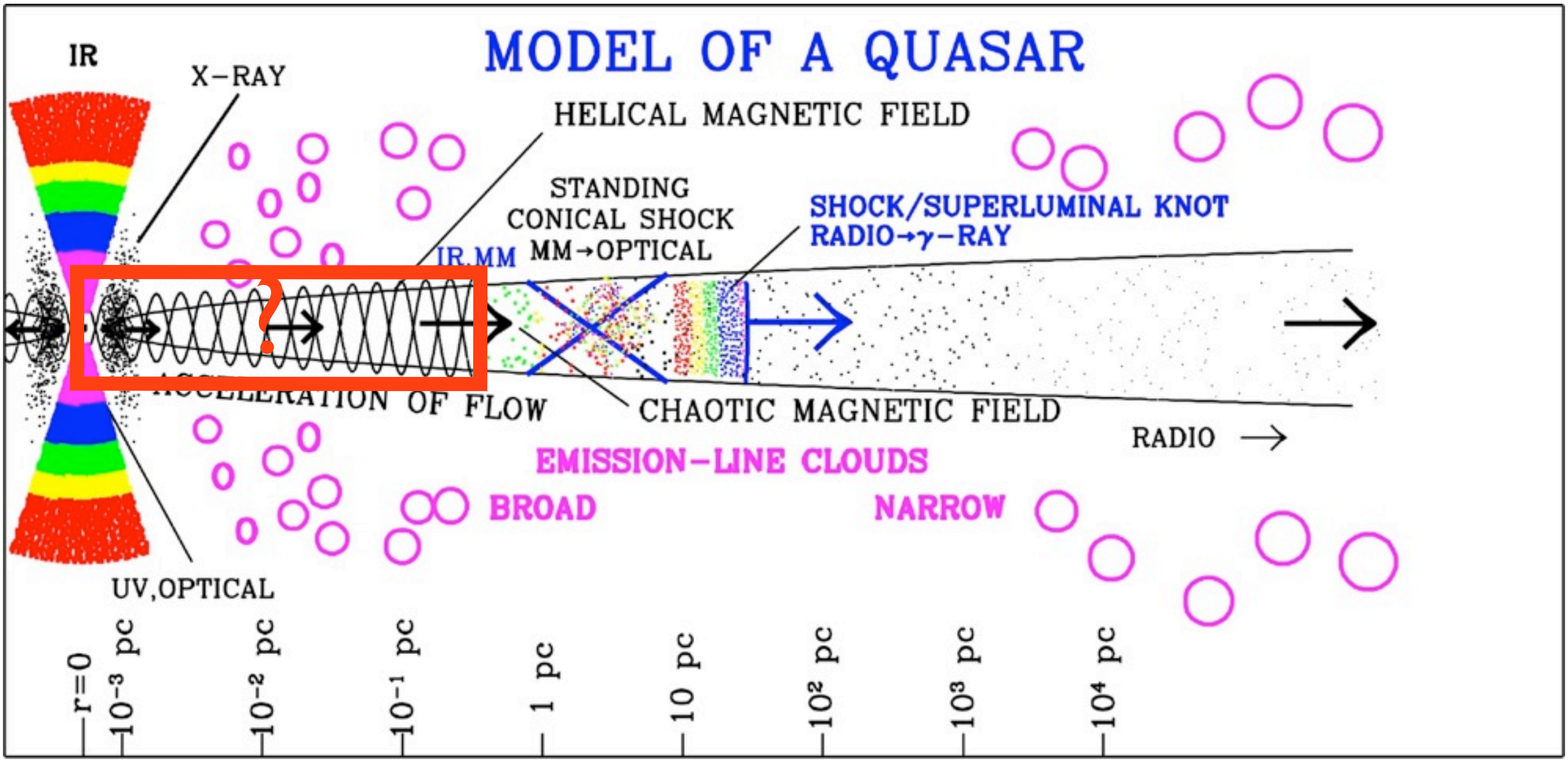
McKinney et al. 2009

to what extent?



courtesy of Alan Marscher/BU Blazar group

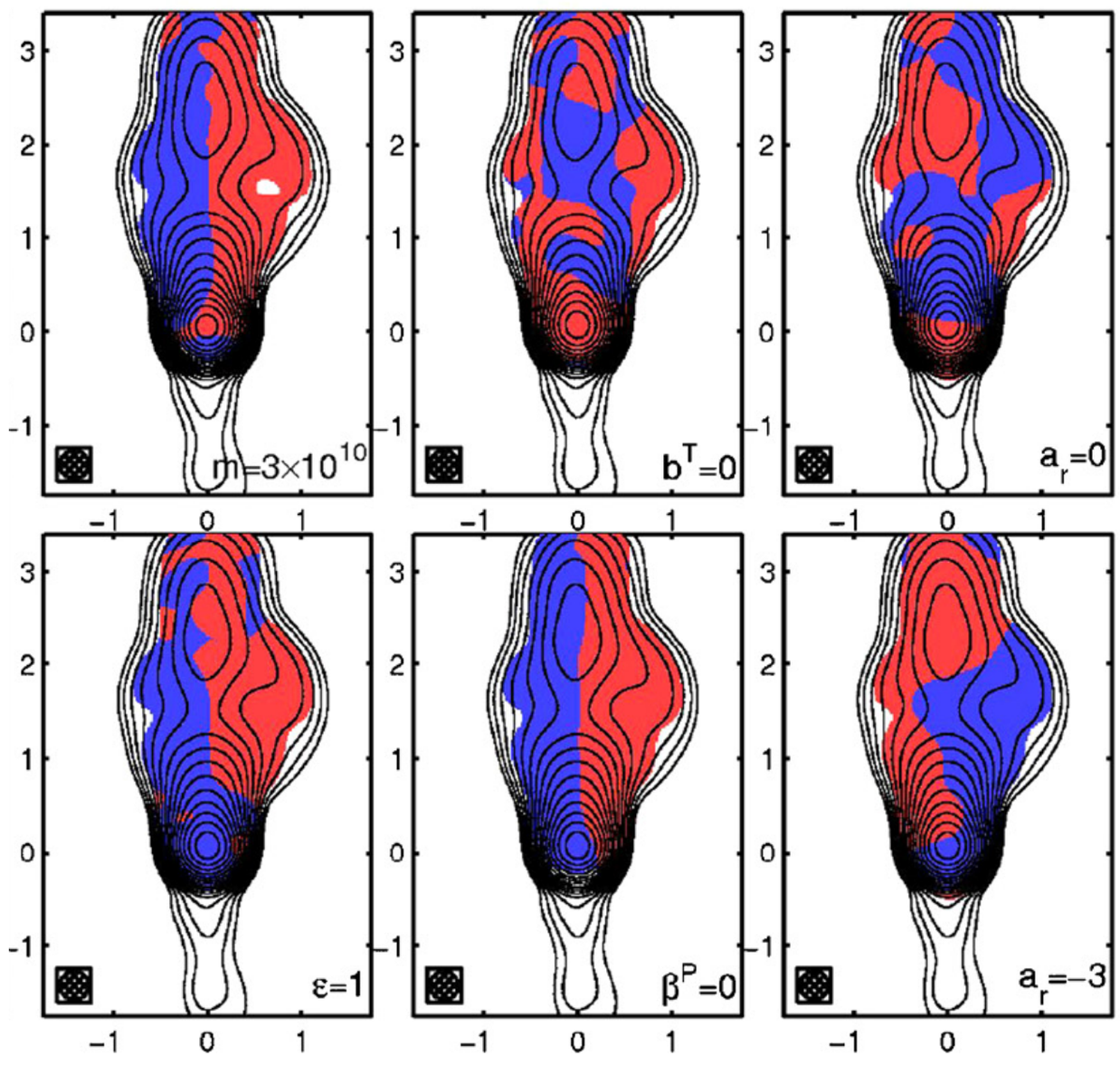
to what extent?

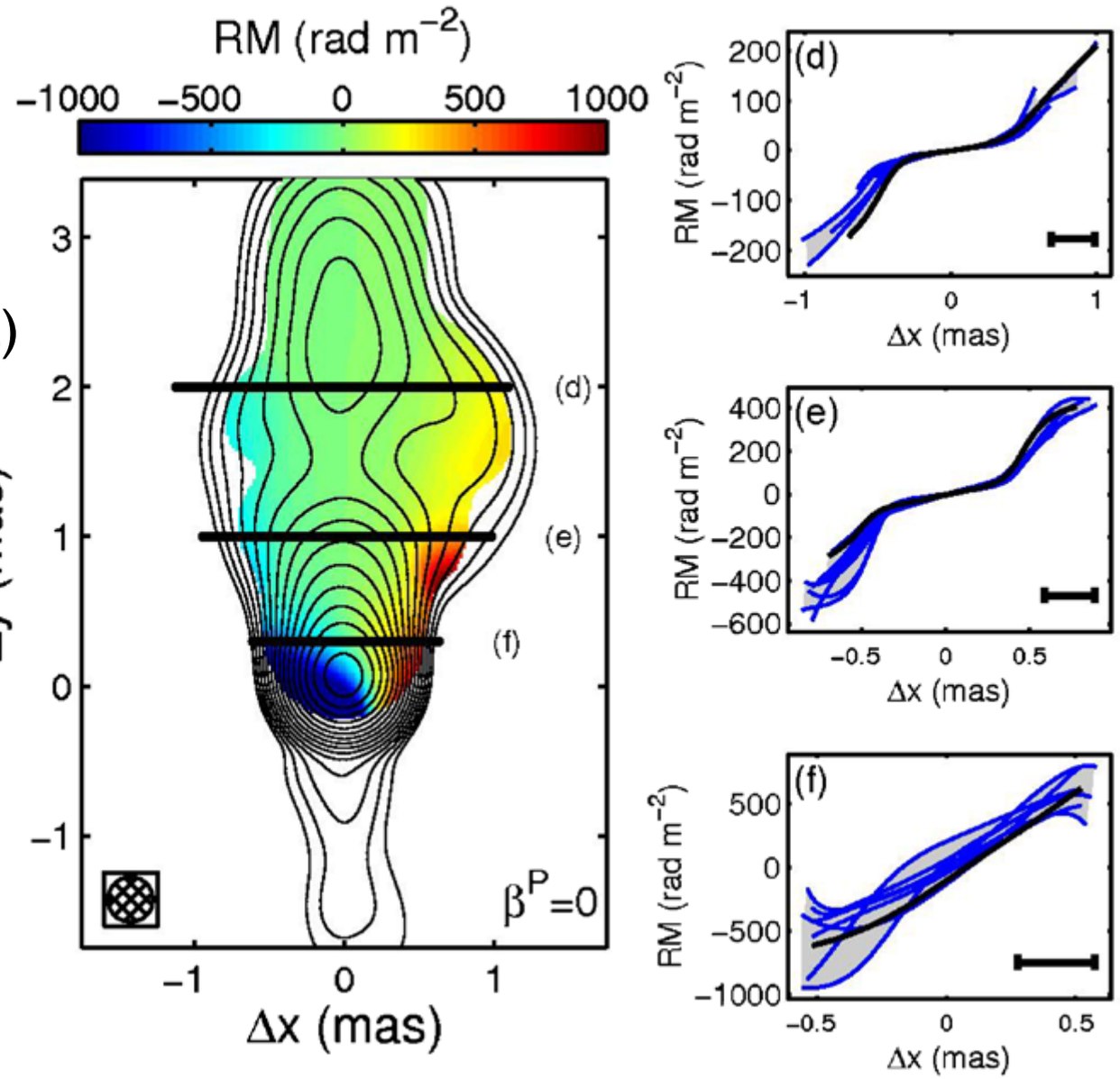


courtesy of Alan Marscher/BU Blazar group

reports of such detections:

Gabuzda et al., Taylor et al.,
review paper by Pudritz, Hardcastle & Gabuzda (2012)

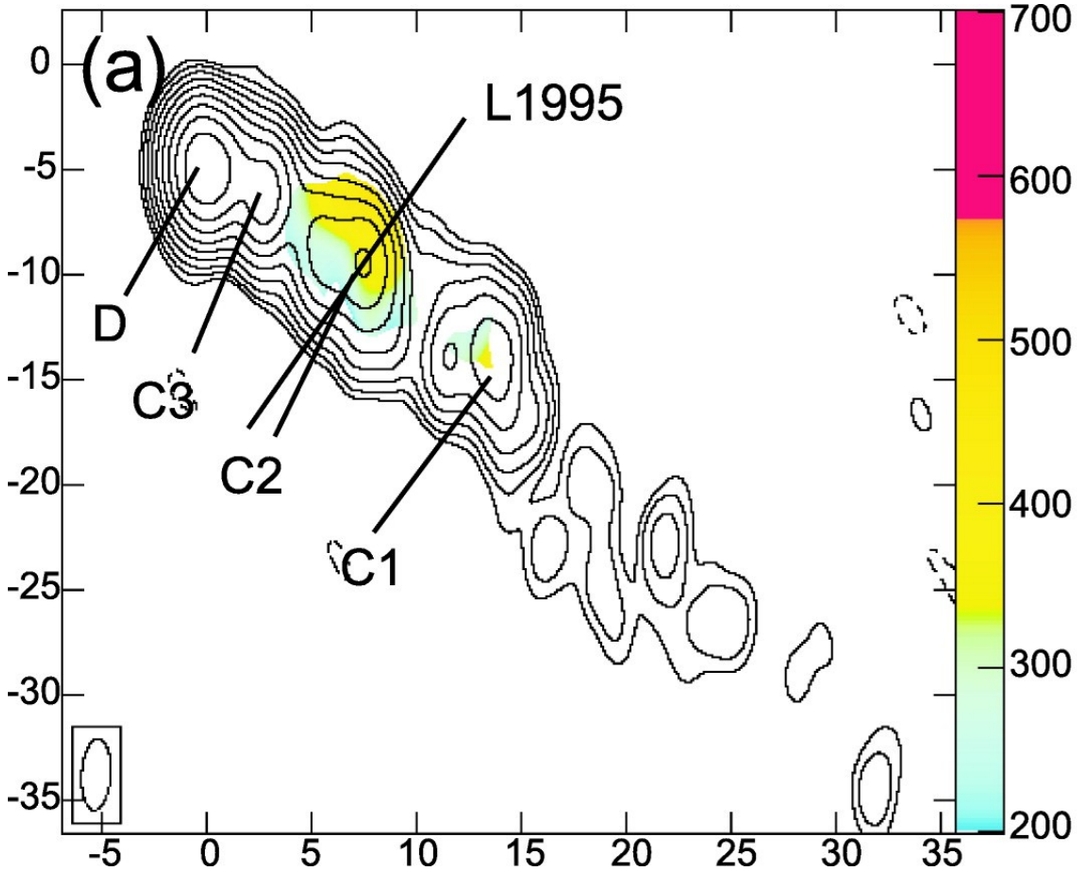


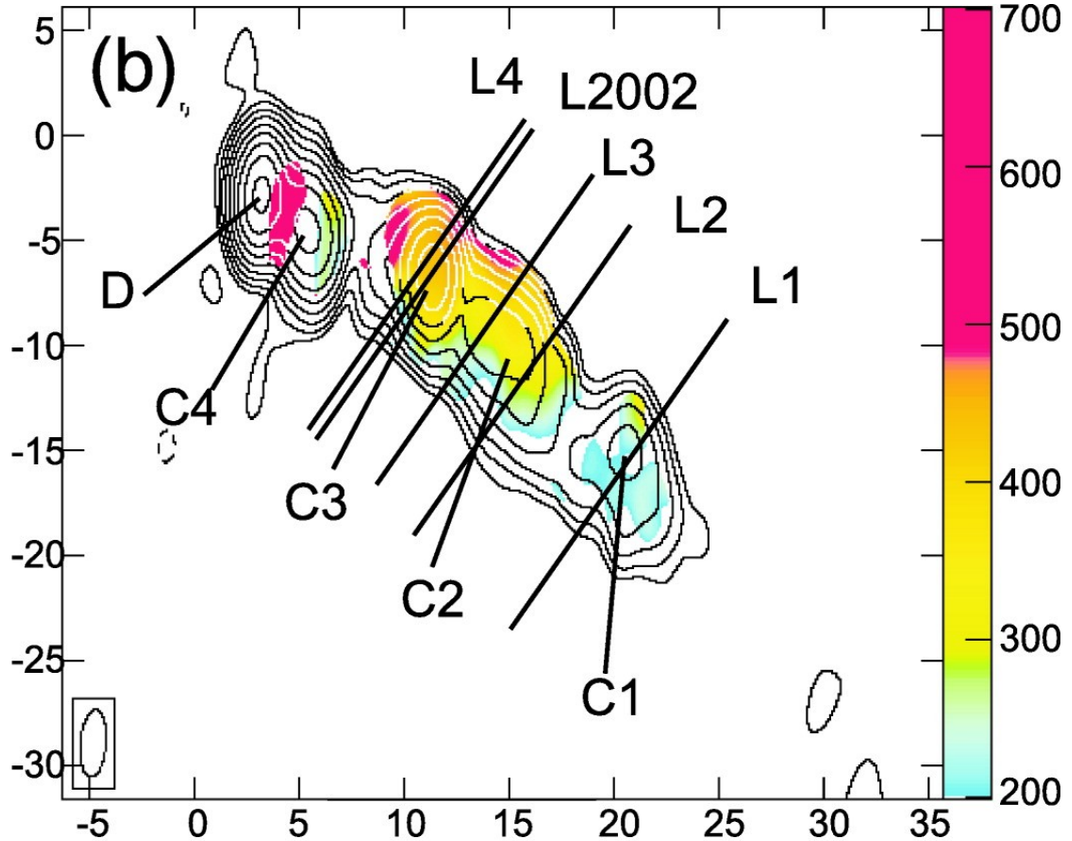


Broderick & McKinney 2010
see also Porth et al. 2011

$$\Delta\chi = RM\lambda^2$$

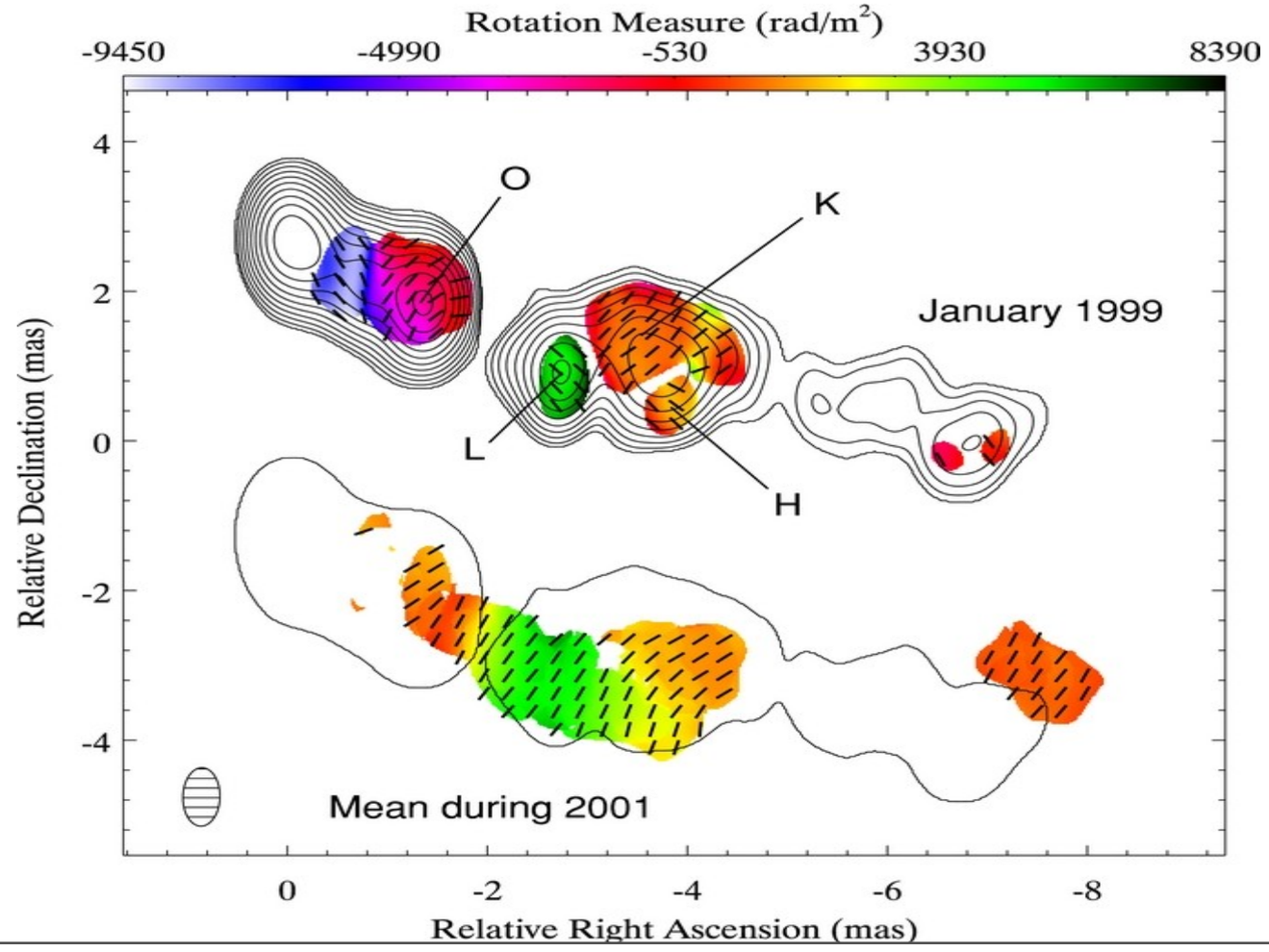
$$RM \propto \int nB_{||}dl$$





3C 273

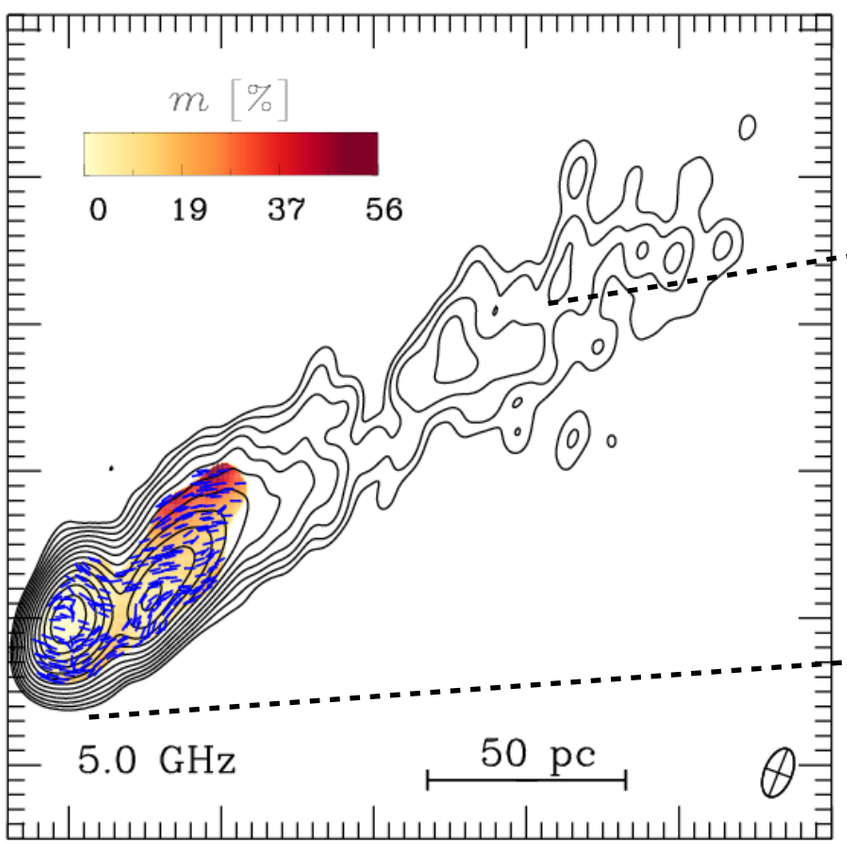
Asada 2002, 2008

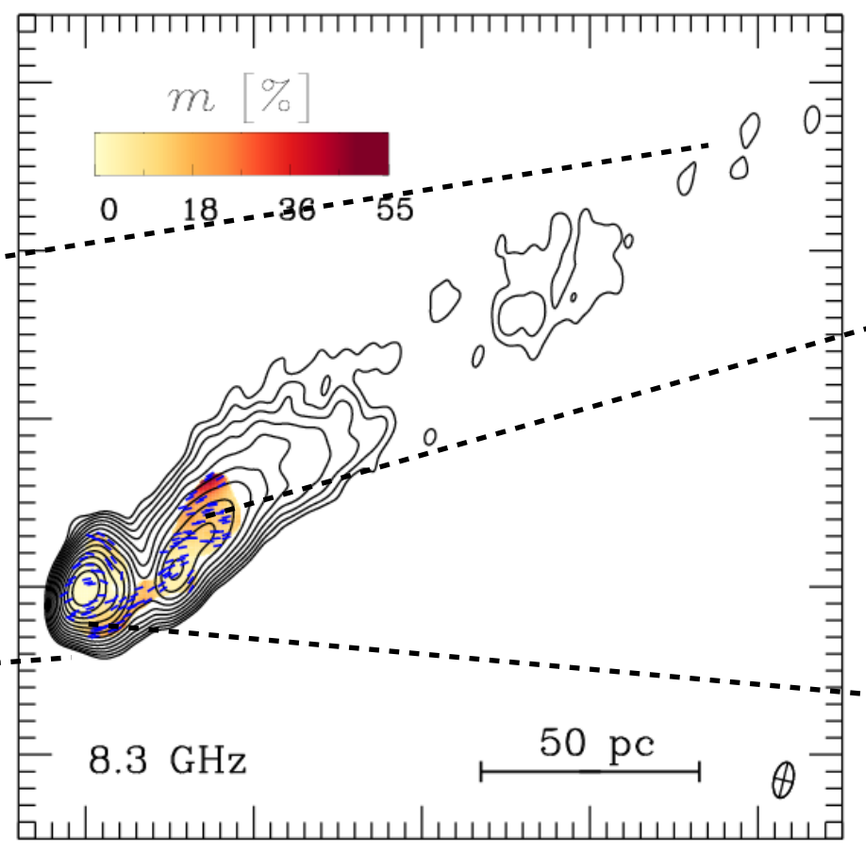


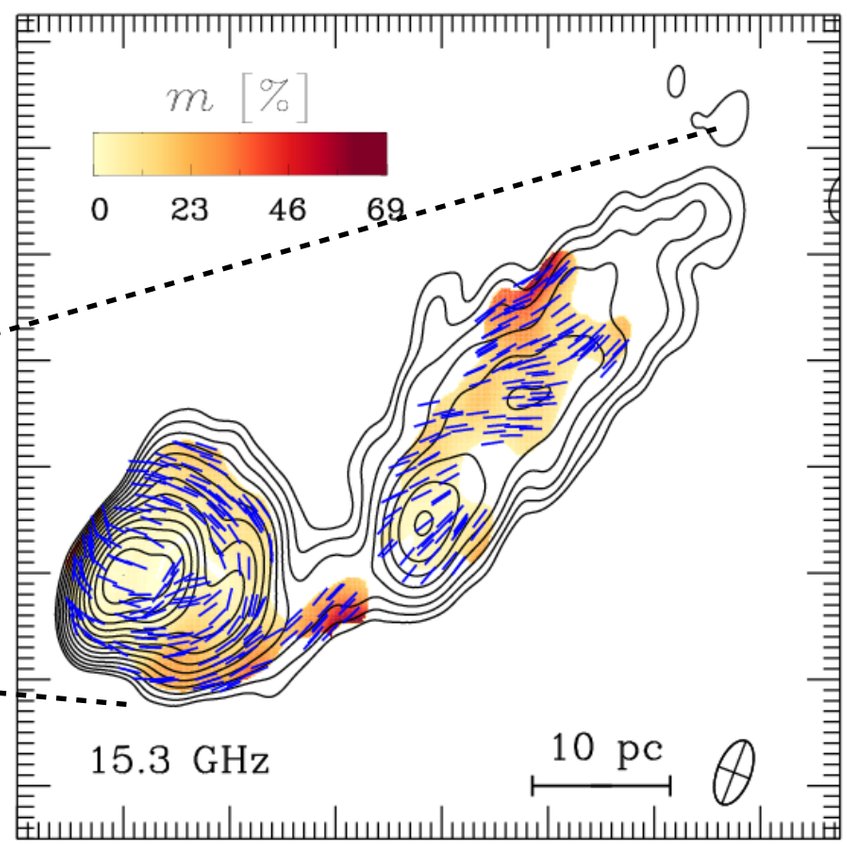
3C 120

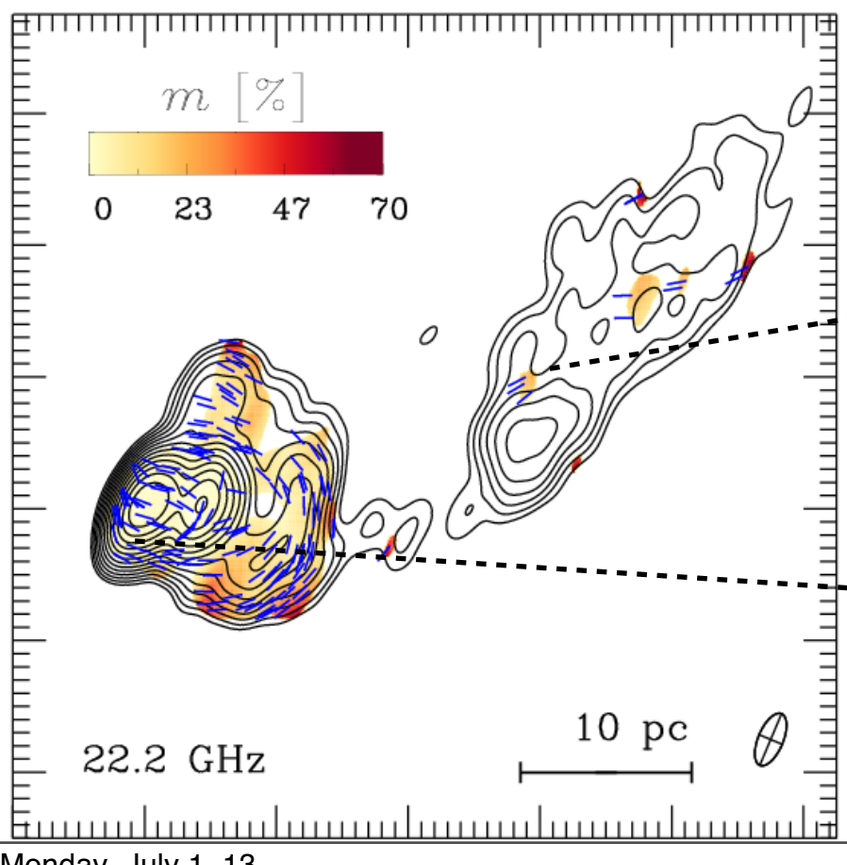
Gomez et al. 2010

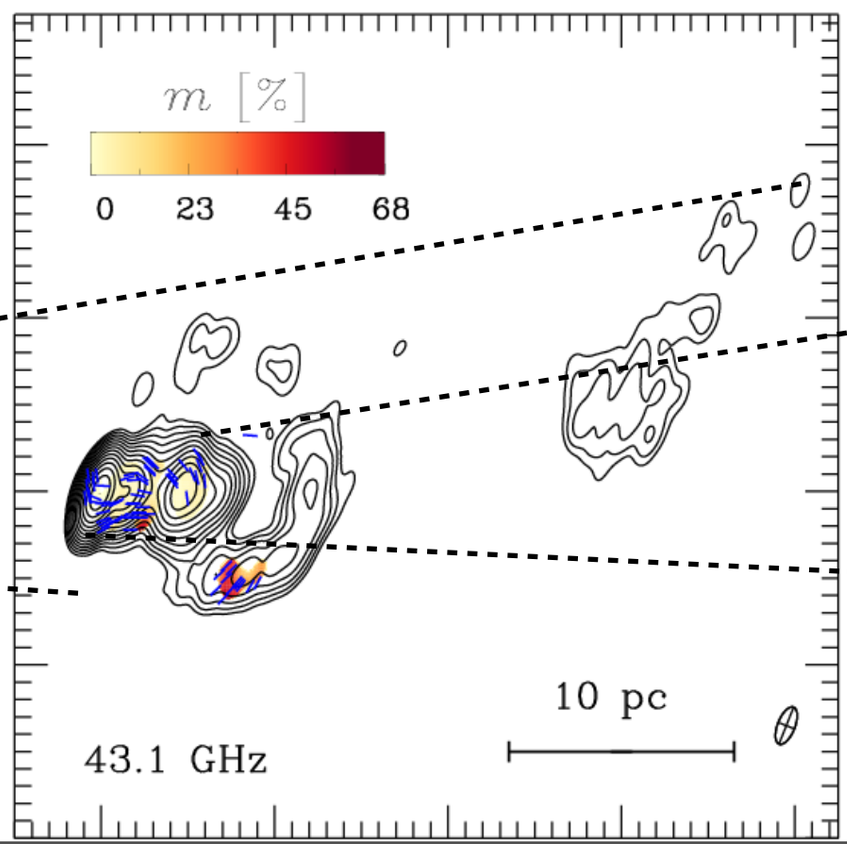
19 May 2005

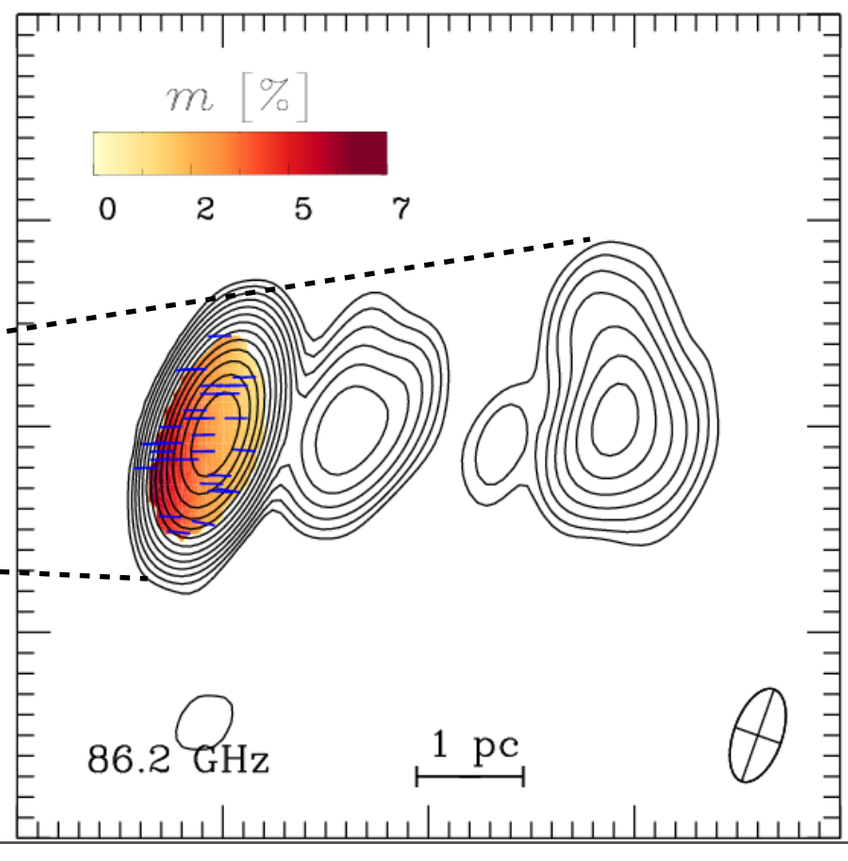

m [%]
0 19 37 56
5.0 GHz
50 pc

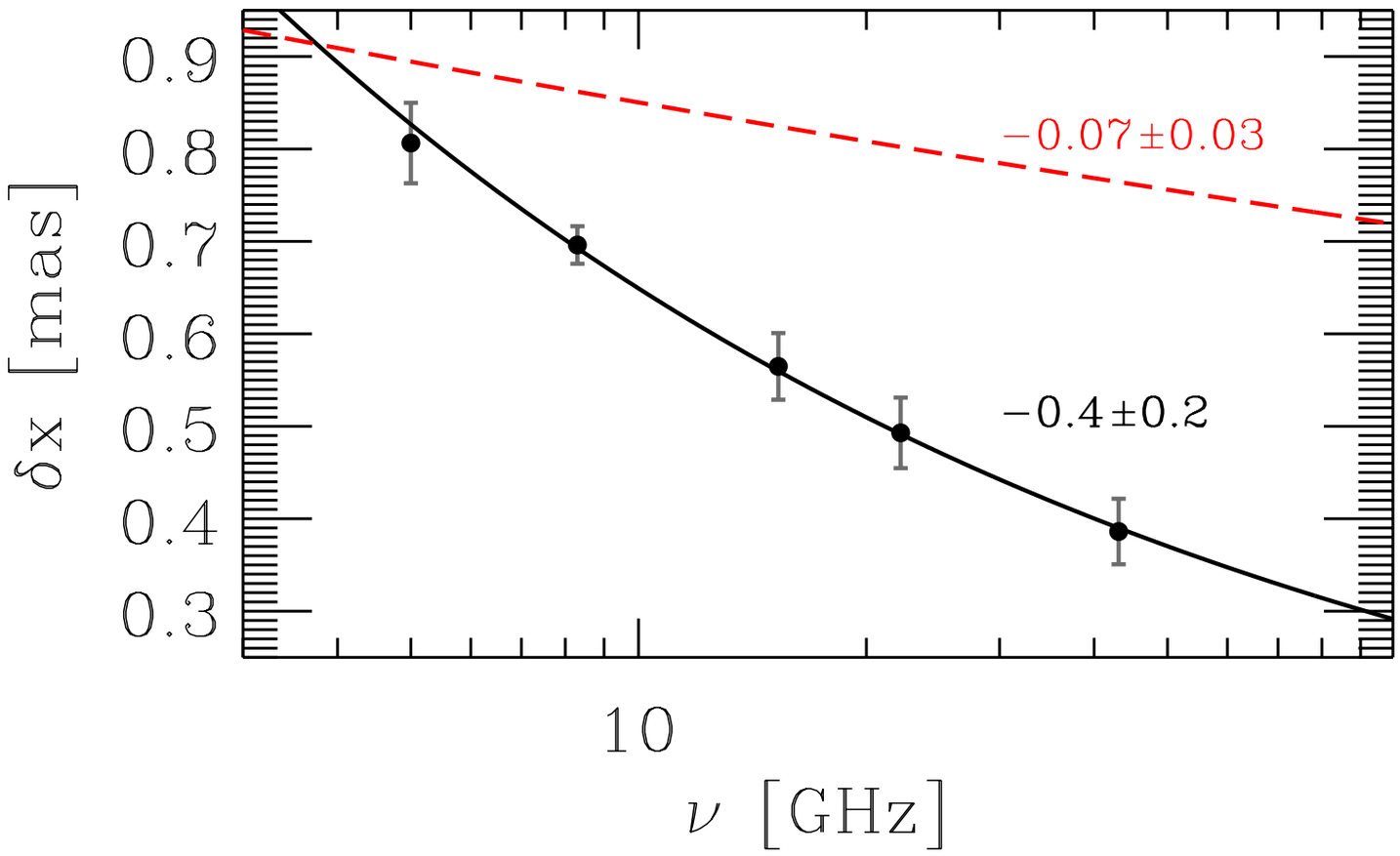

m [%]
0 18 36 55
8.3 GHz
50 pc

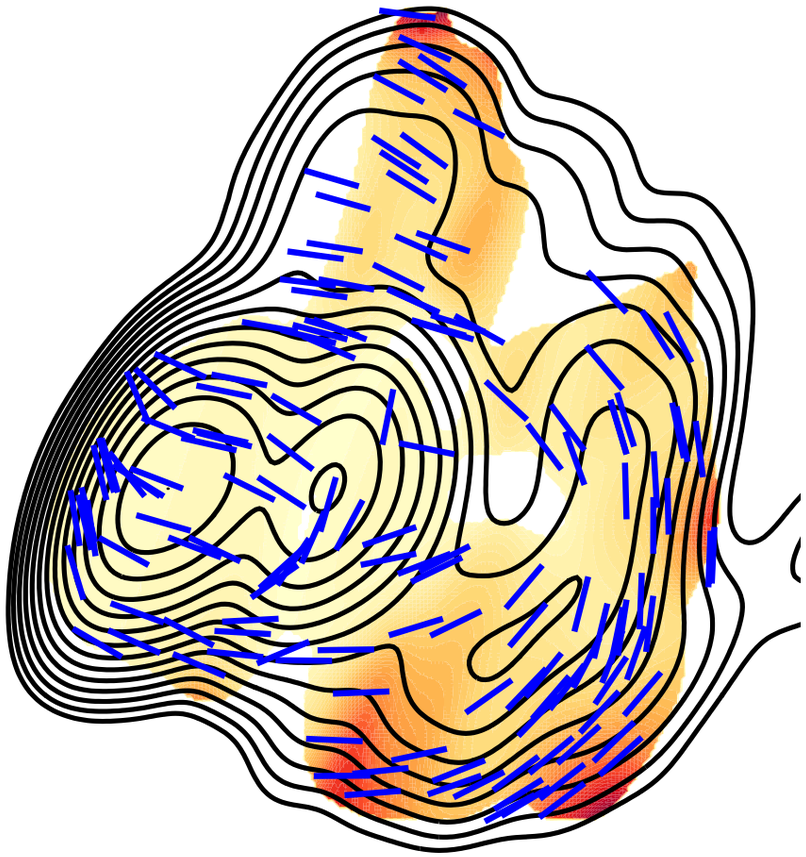

m [%]
0 23 46 69
15.3 GHz
10 pc

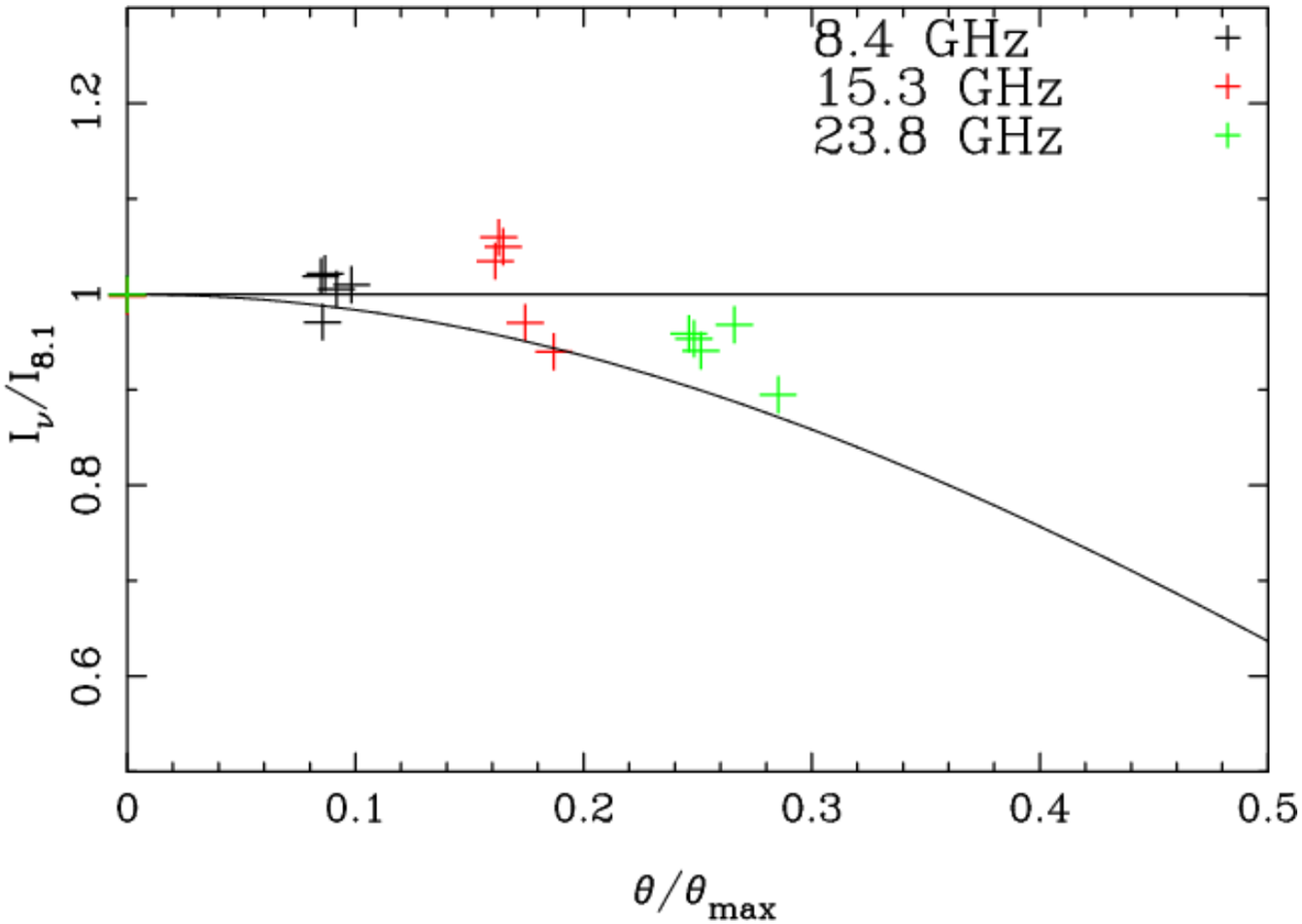

m [%]
0 23 47 70
22.2 GHz
10 pc

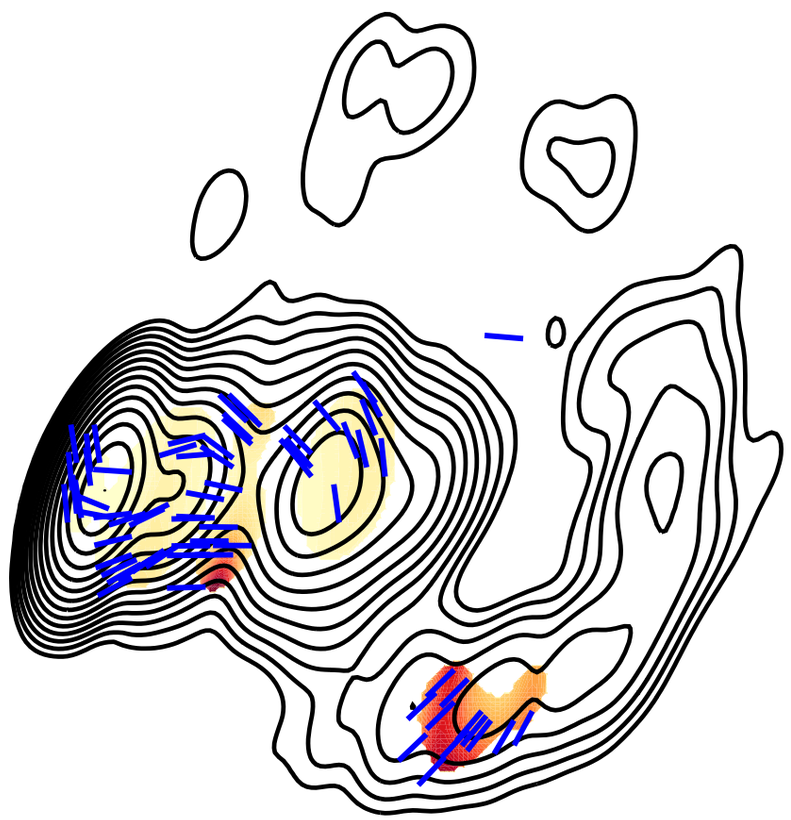

m [%]
0 23 45 68
43.1 GHz
10 pc

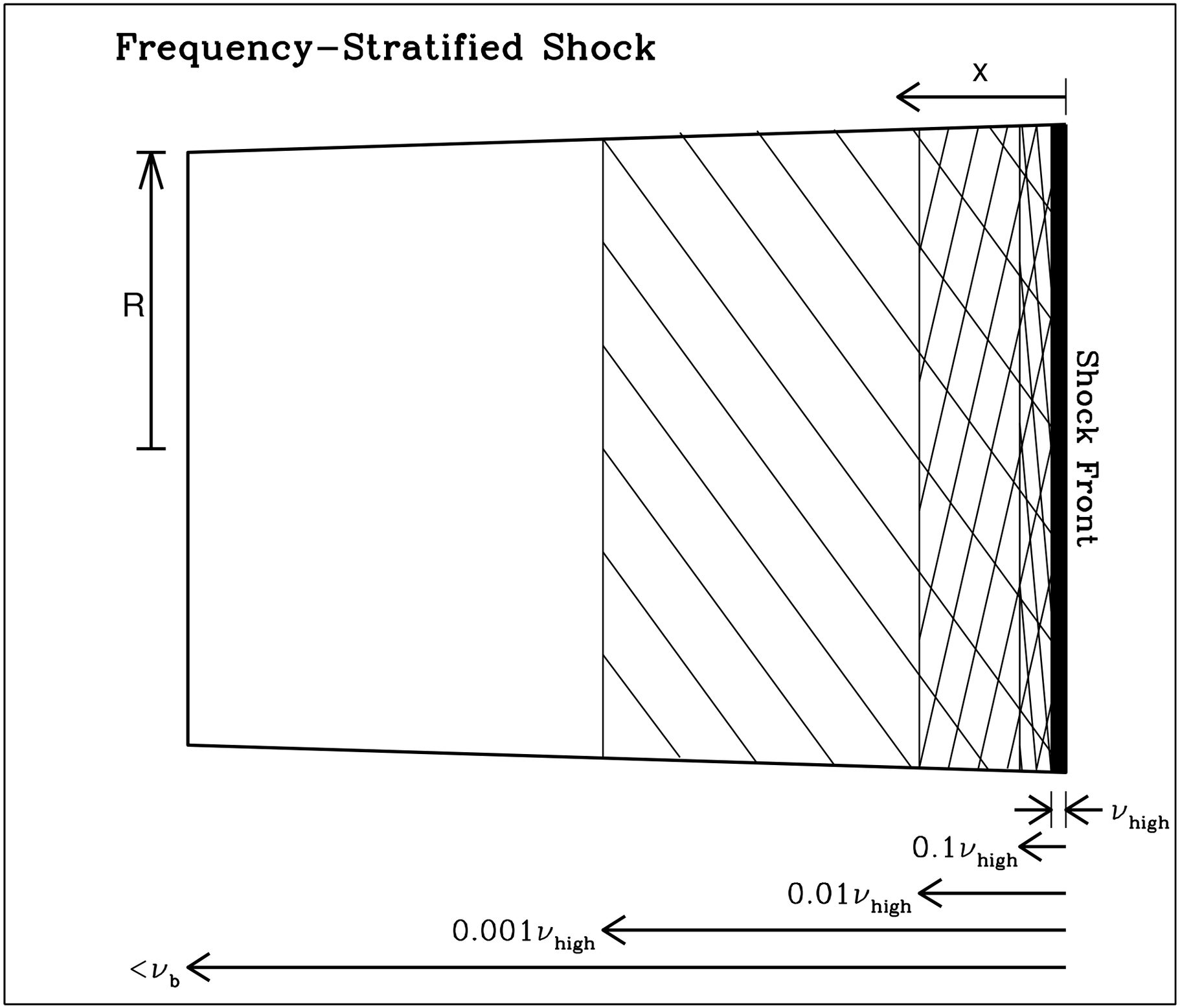

m [%]
0 2 5 7
86.2 GHz
1 pc


0.9
0.8
0.7
0.6
0.5
0.4
0.3
δx [mas]
−0.07±0.03
−0.4±0.2
10
ν [GHz]

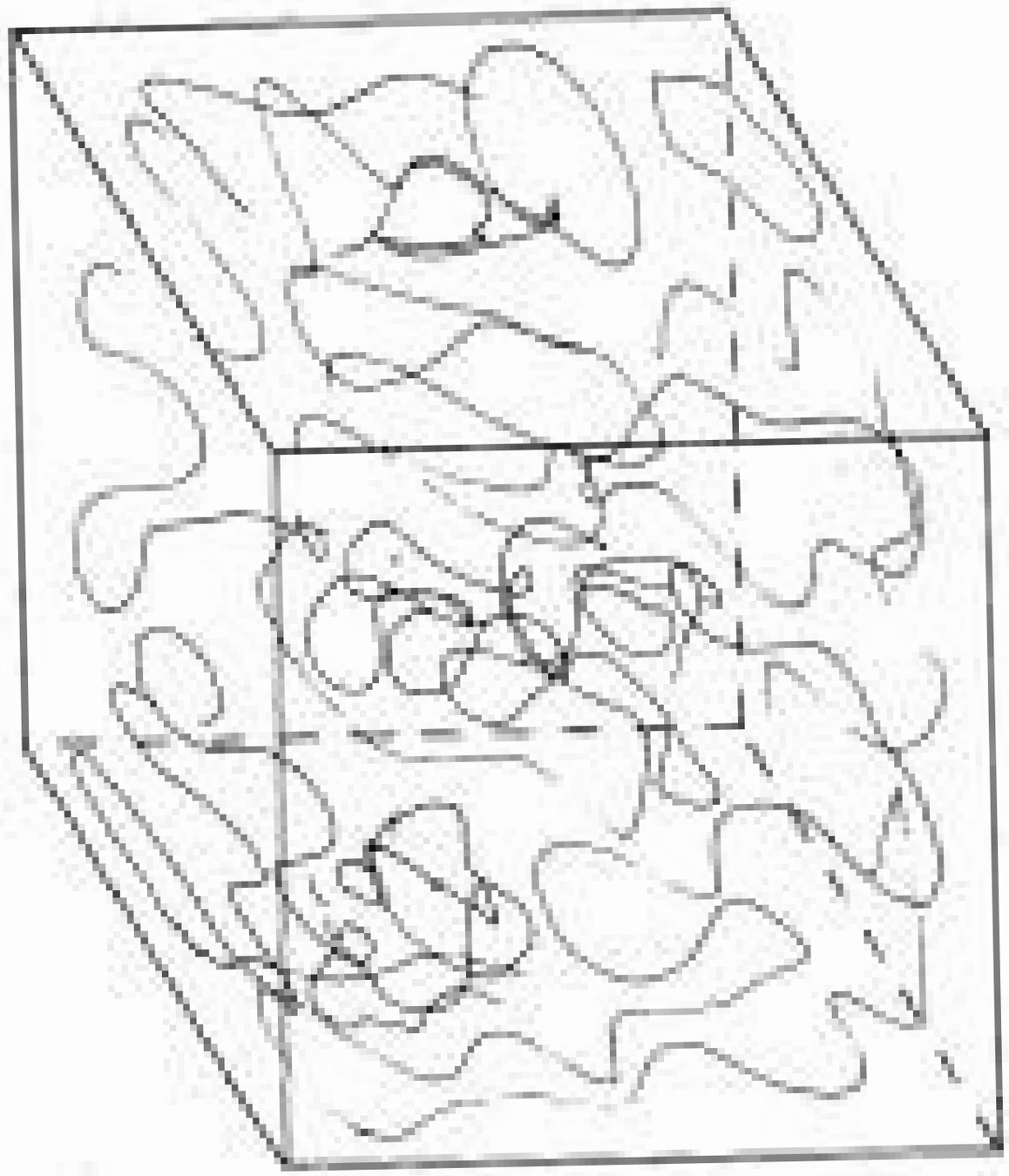


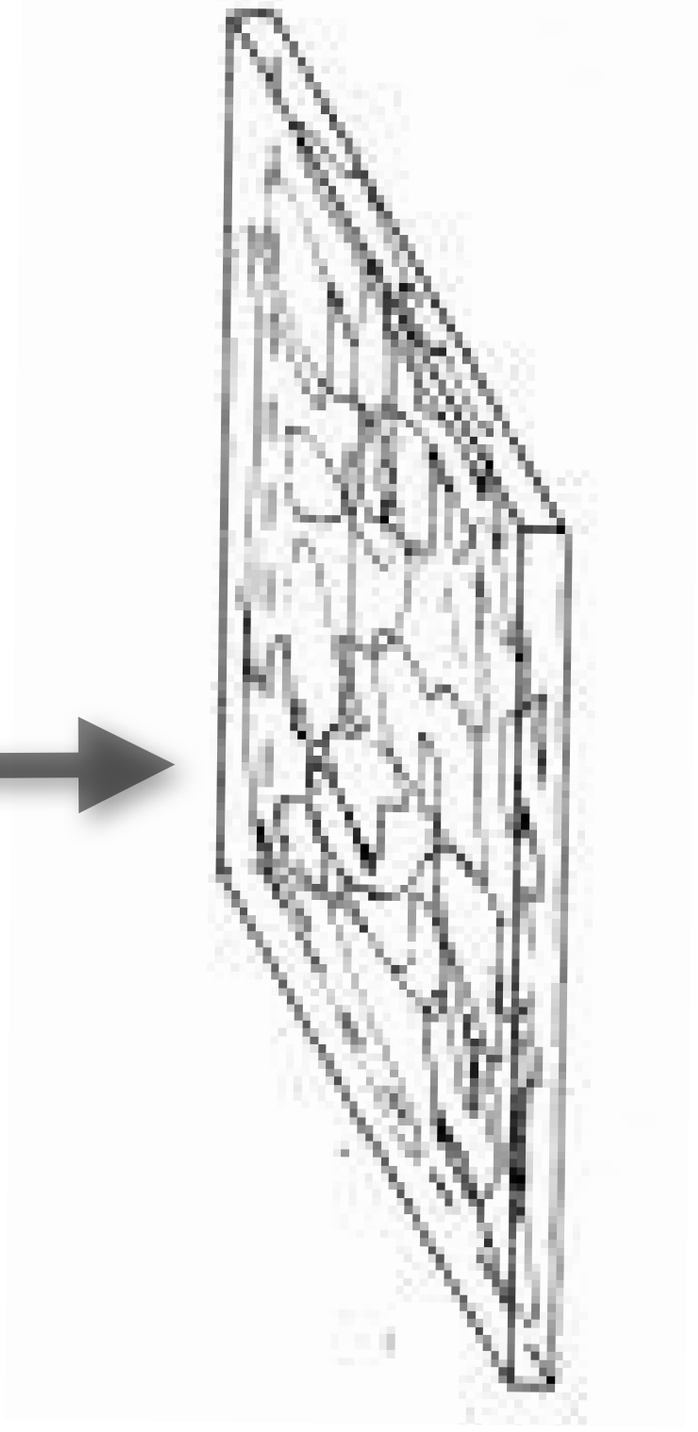

8.4 GHz
15.3 GHz
23.8 GHz
1.2
1
0.8
0.6
$I_\nu/I_{8.1}$
0
0.1
0.2
0.3
0.4
0.5
θ/θ_{max}

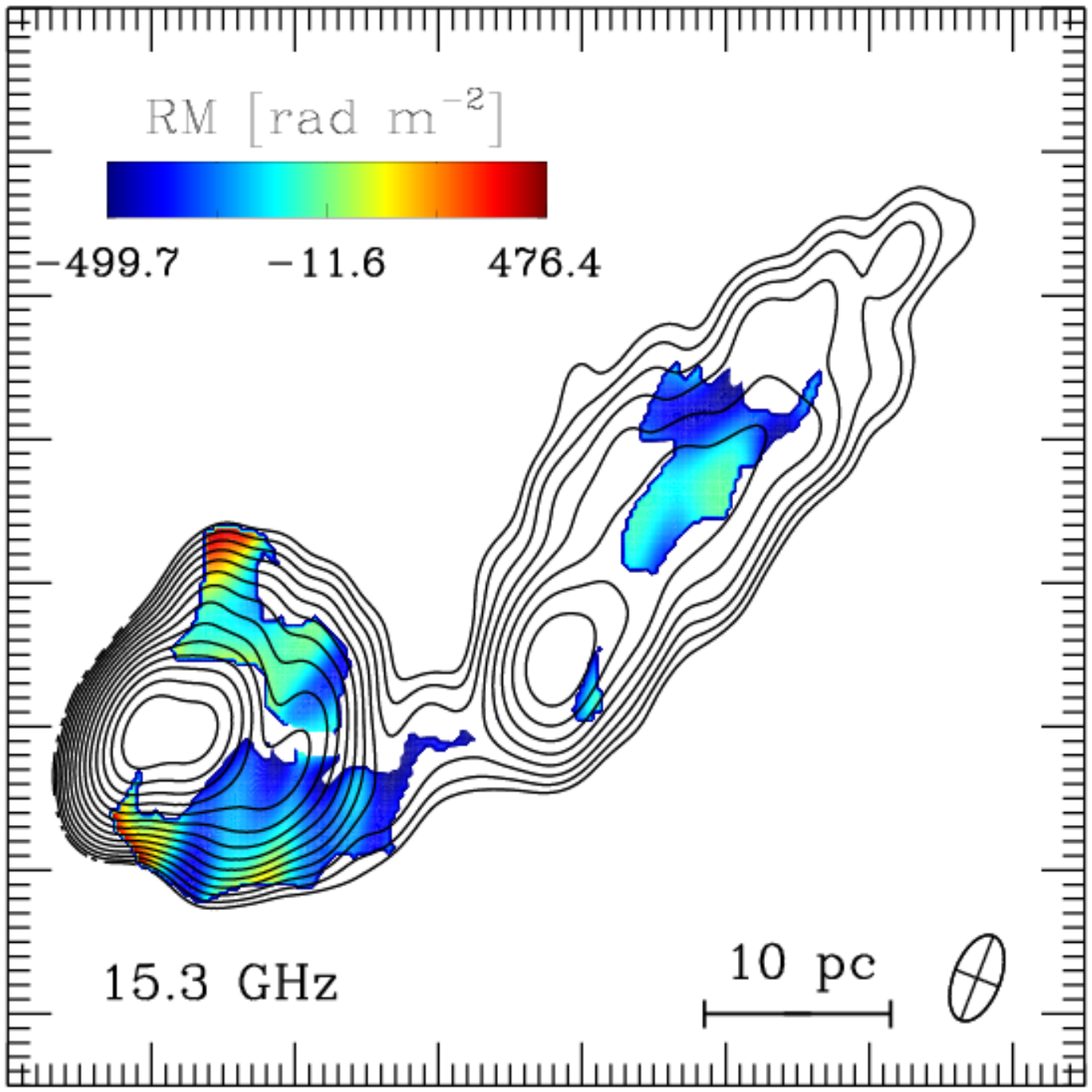




Marscher 2009





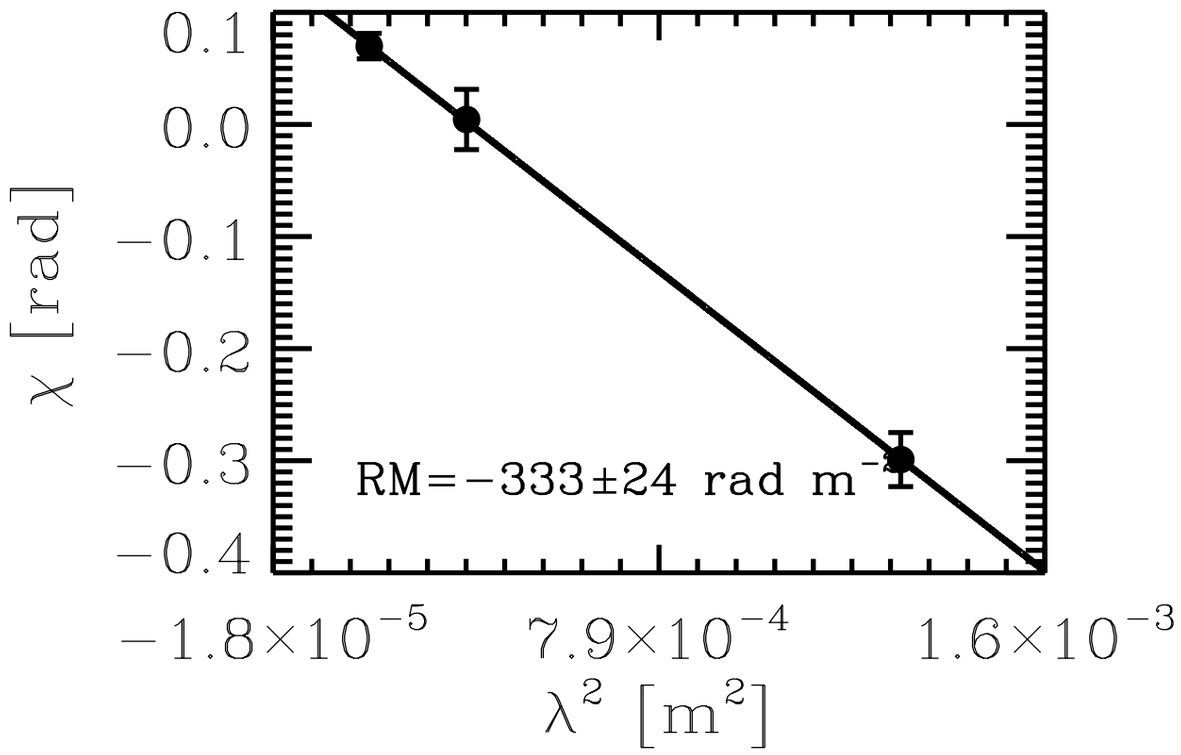


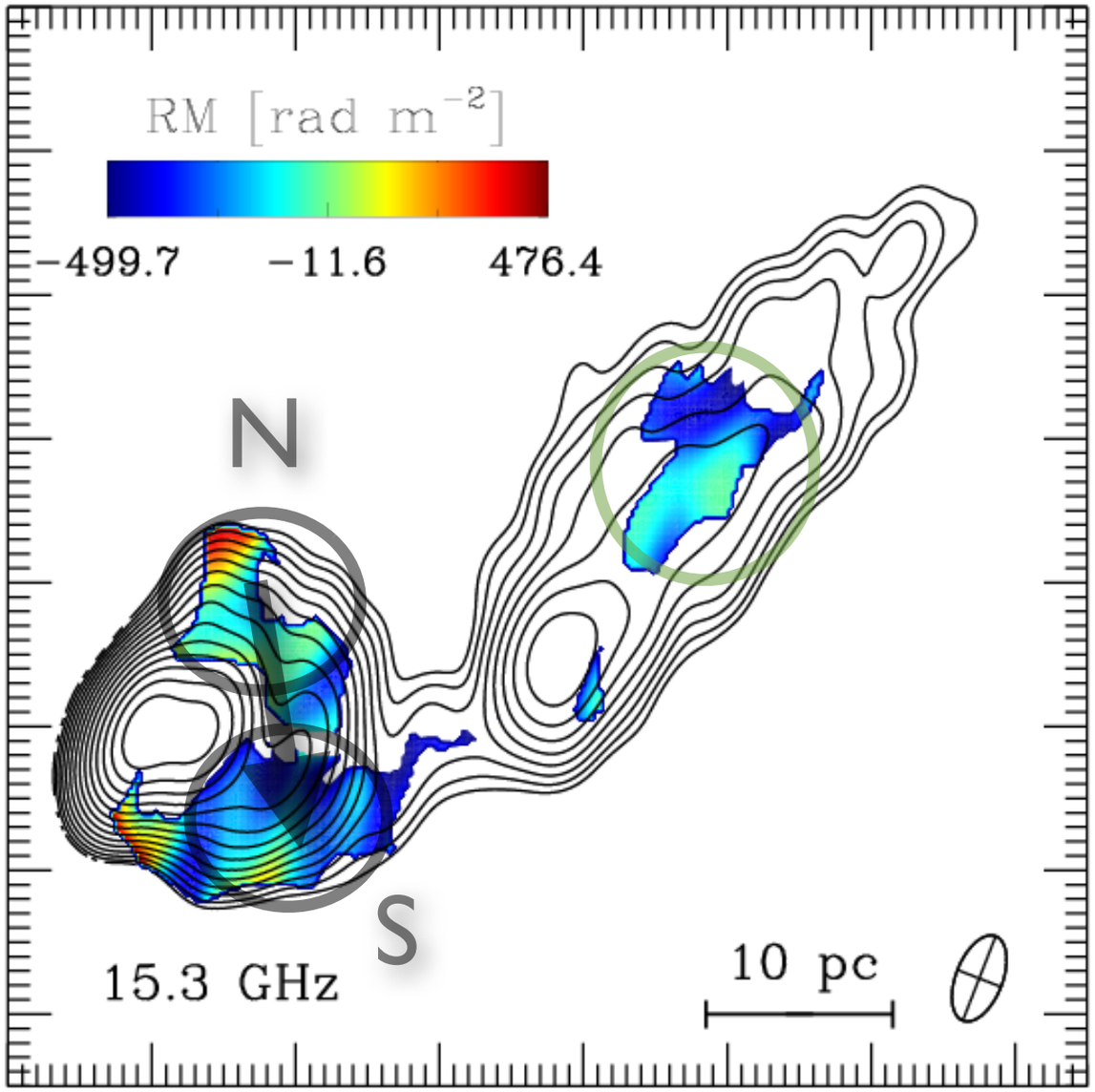
PACERMAN algorithm

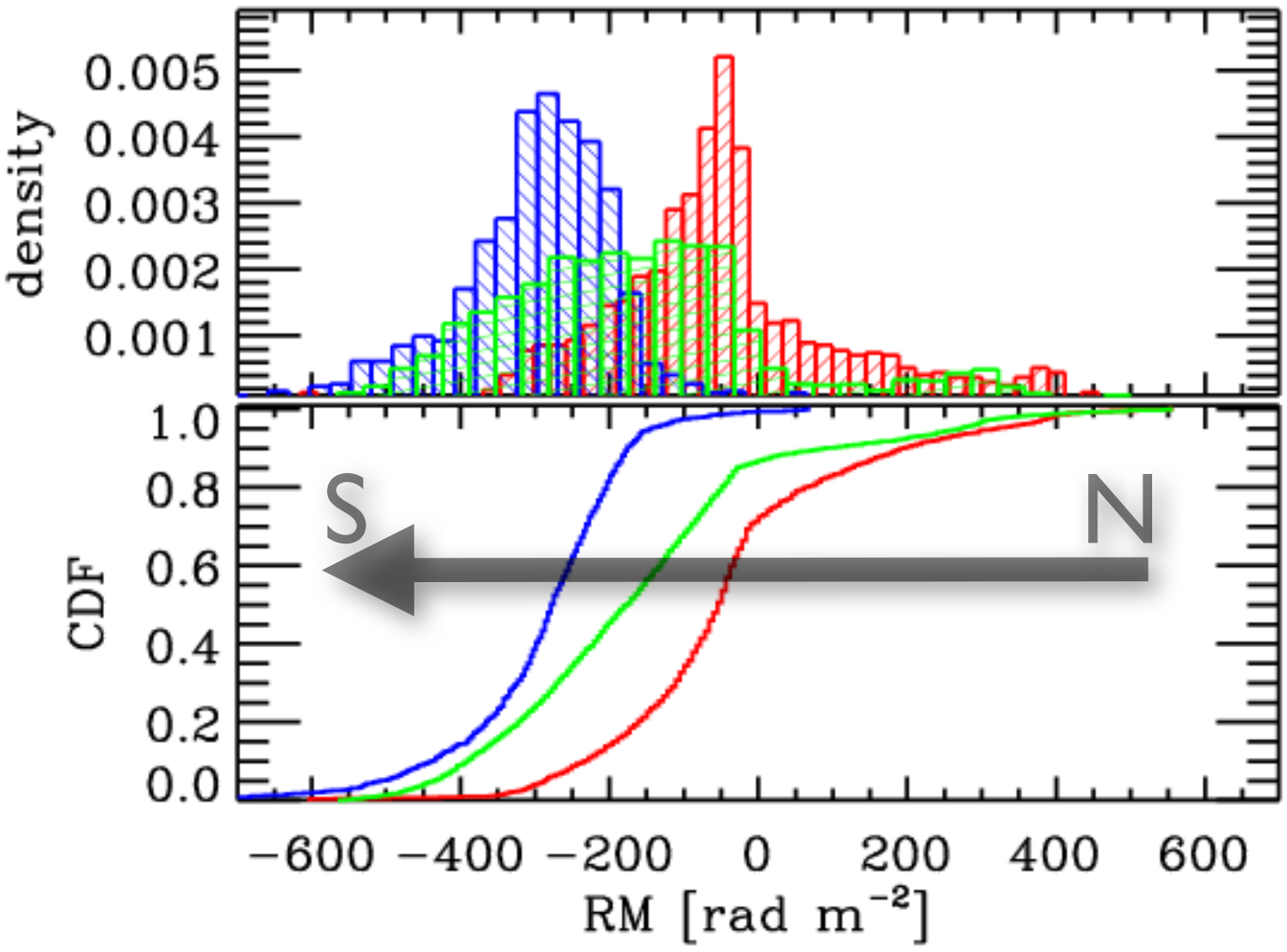
C. Vogt, K. Dolag, T. A. Ensslin, 2005

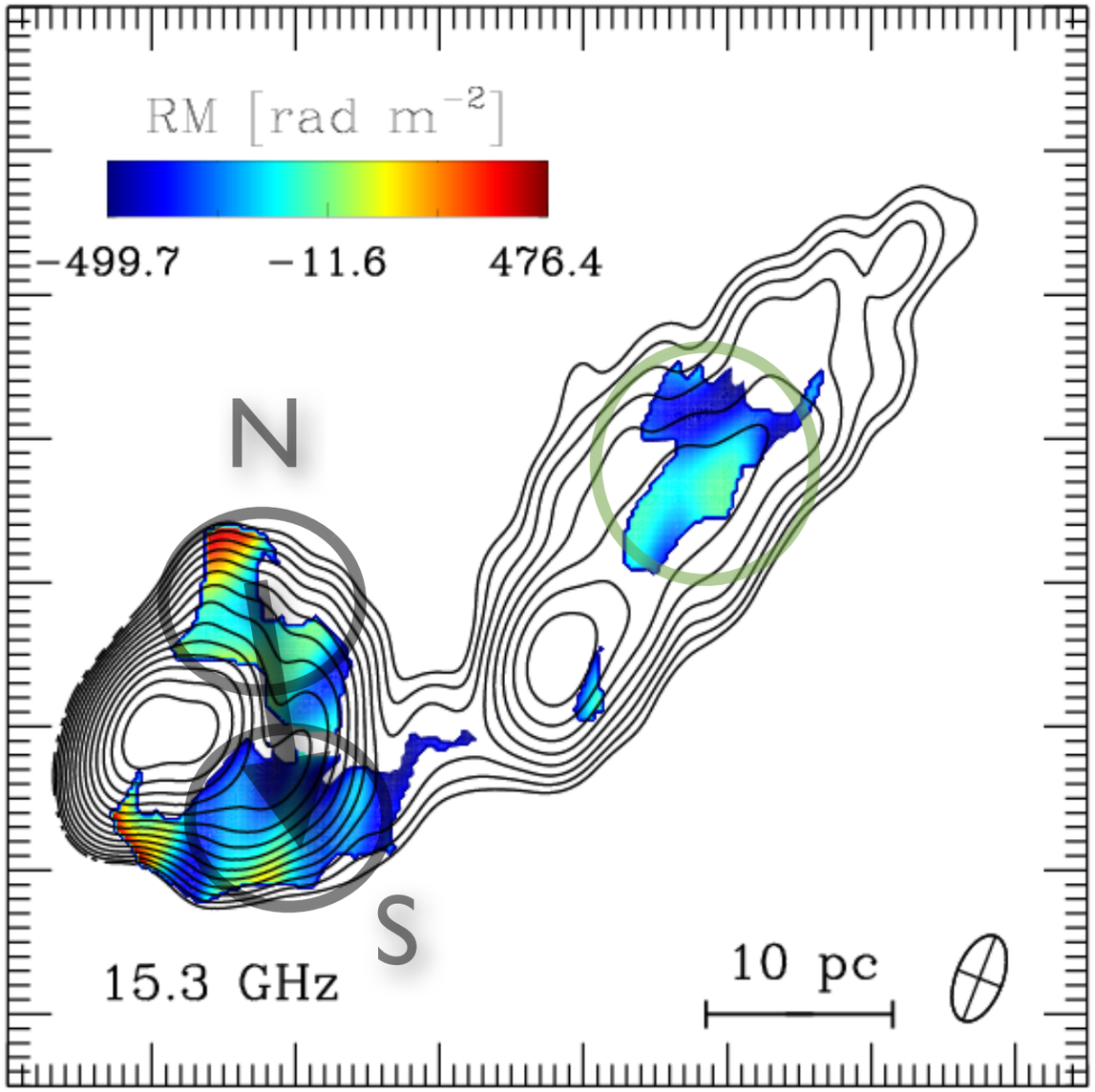
$$\Delta\chi = RM\lambda^2$$

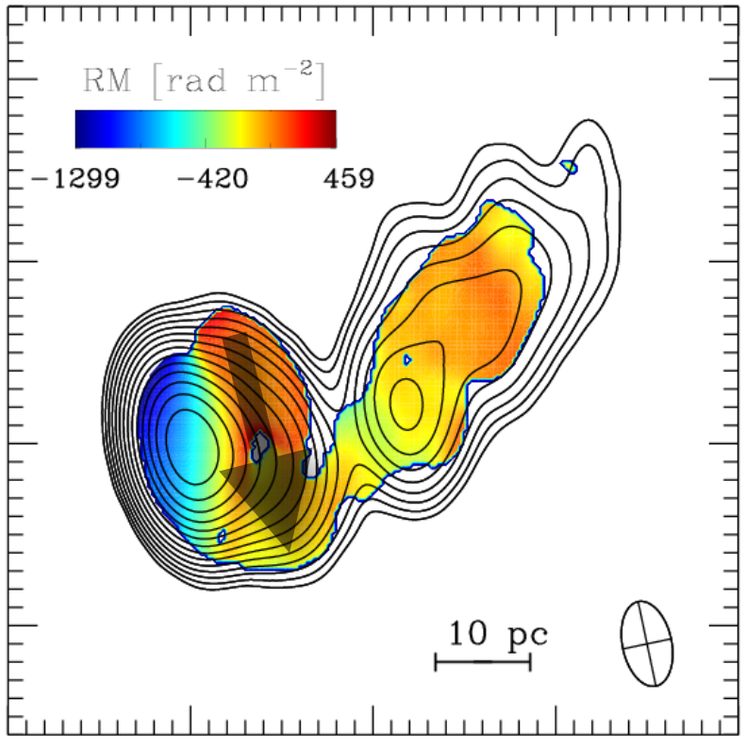
$$RM \propto \int nB_{||}dl$$

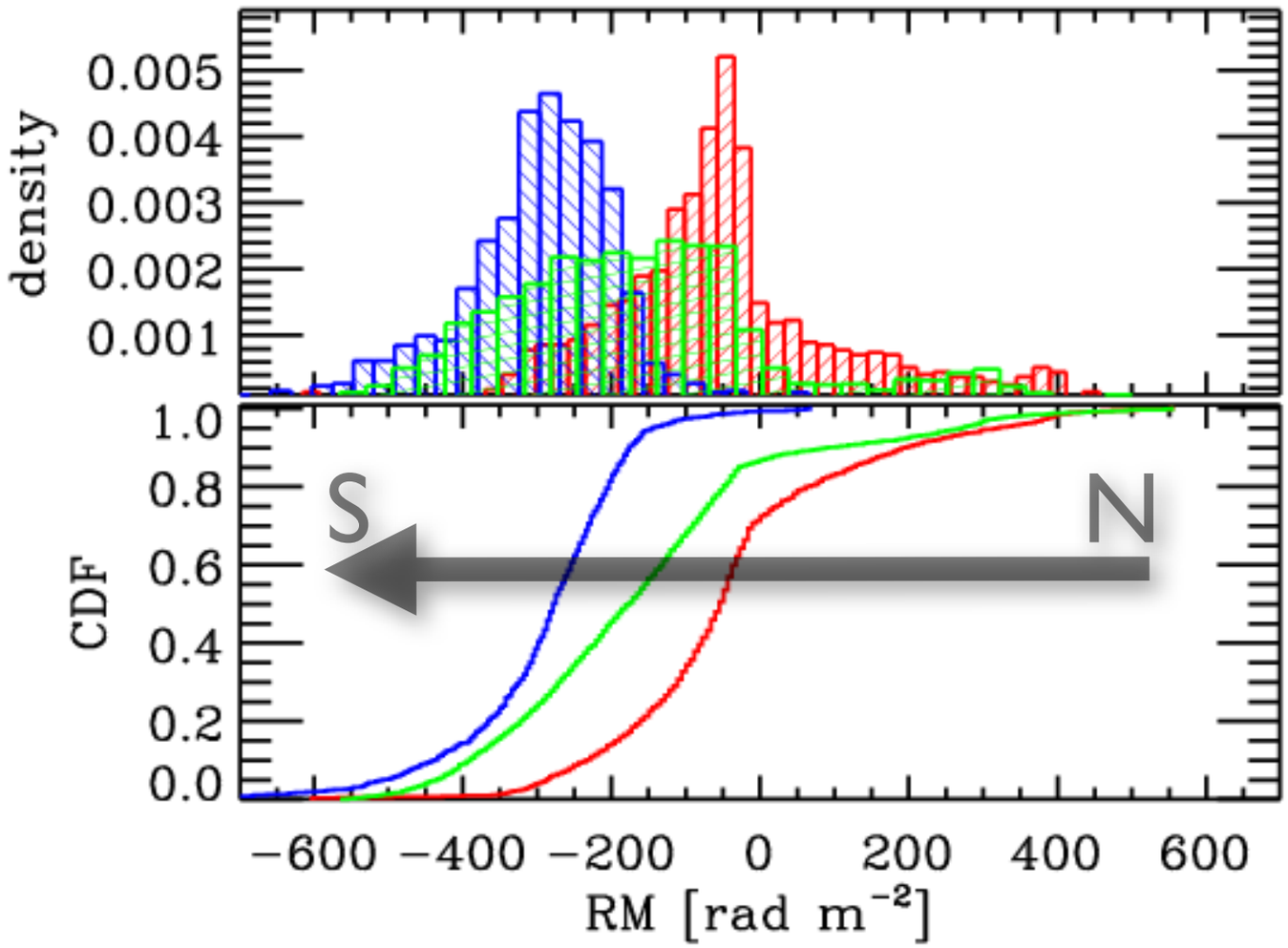


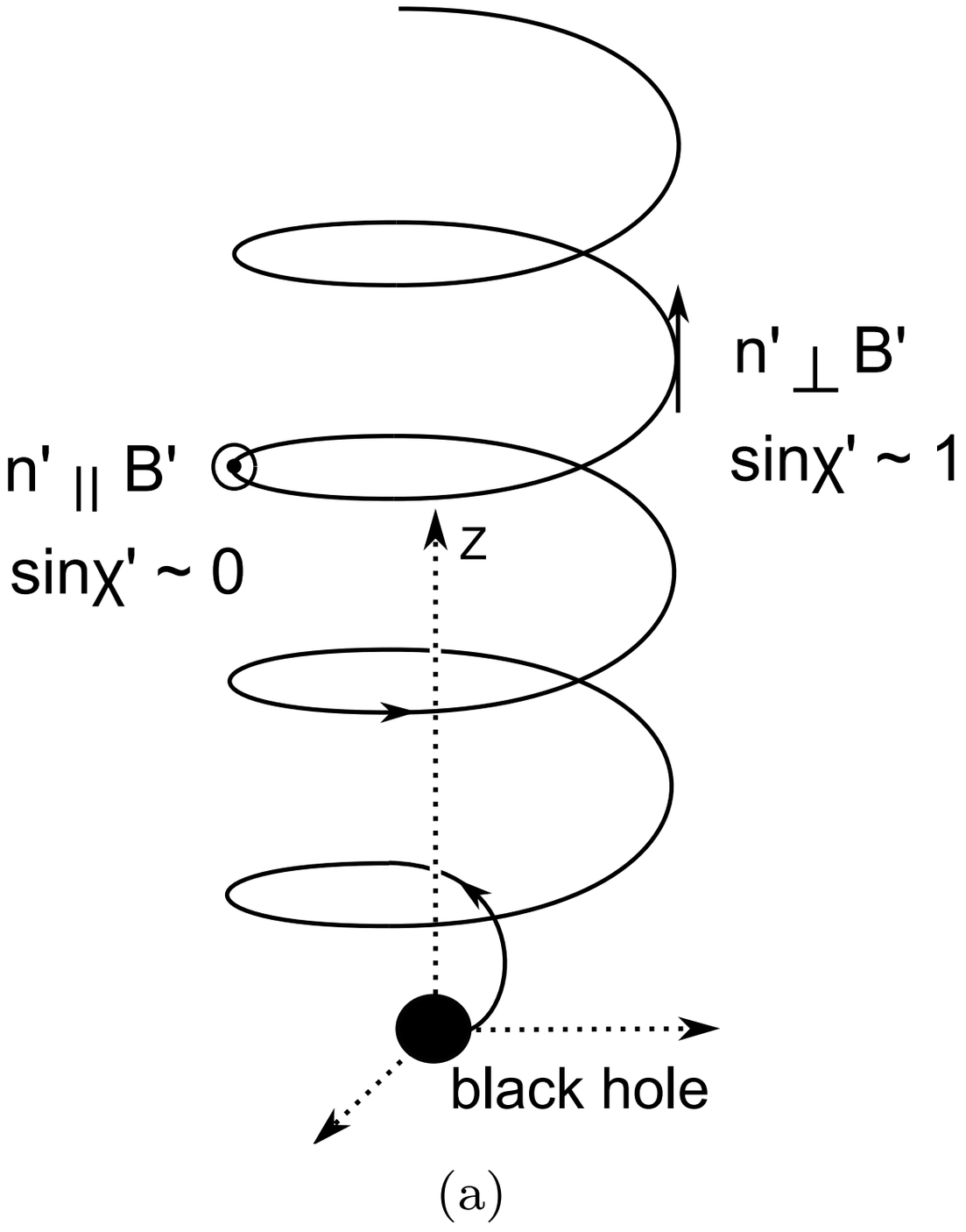

RM [rad m^{-2}]
−499.7
−11.6
476.4
N
S
15.3 GHz
10 pc


0.005
0.004
0.003
0.002
0.001
density
1.0
0.8
0.6
0.4
0.2
0.0
CDF
S
N
−600
−400
−200
0
200
400
600
RM [rad m^{-2}]


RM [rad m^{-2}]
−499.7
−11.6
476.4
N
S
15.3 GHz
10 pc

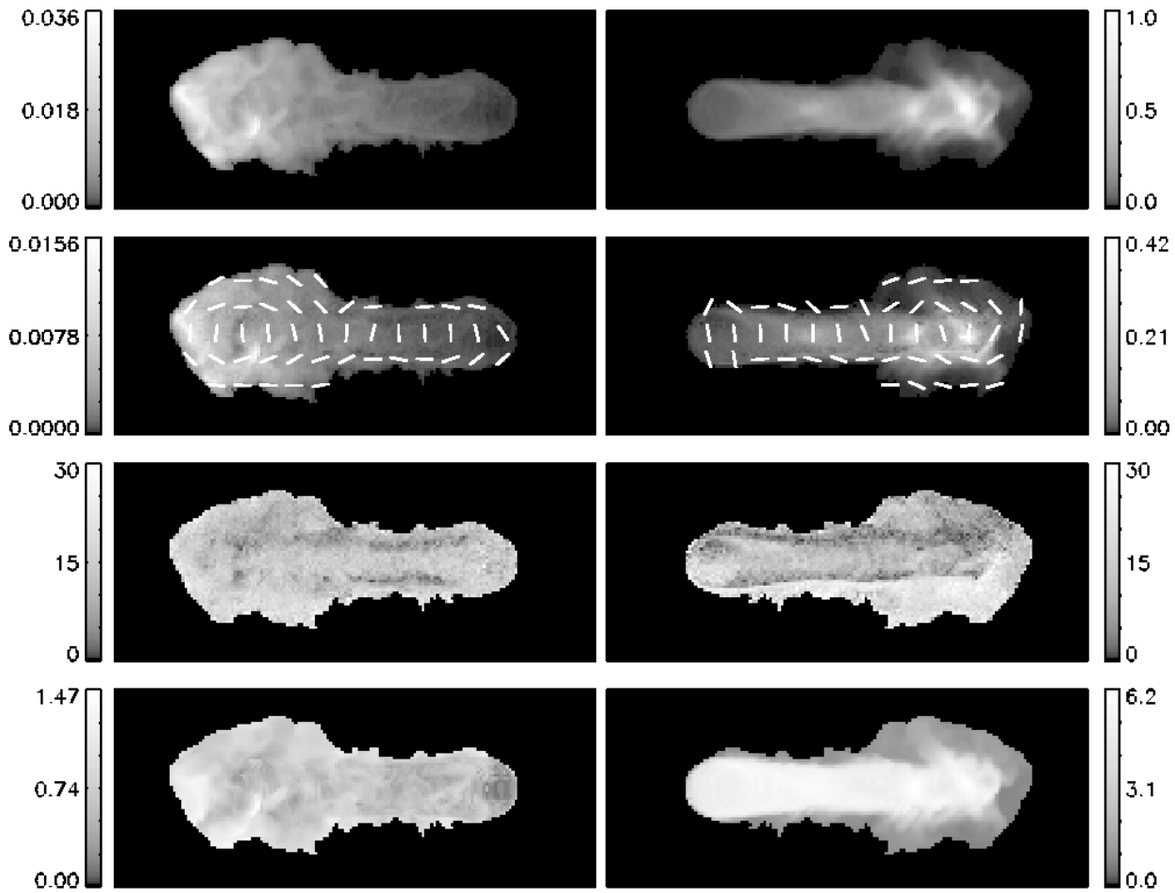

RM [rad m^{-2}]
−1299
−420
459
10 pc

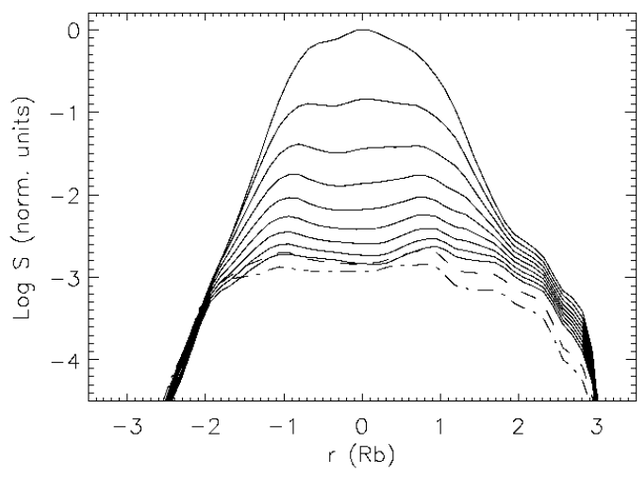

density
0.005
0.004
0.003
0.002
0.001
CDF
1.0
0.8
0.6
0.4
0.2
0.0
S
N
−600
−400
−200
0
200
400
600
RM [rad m^{-2}]

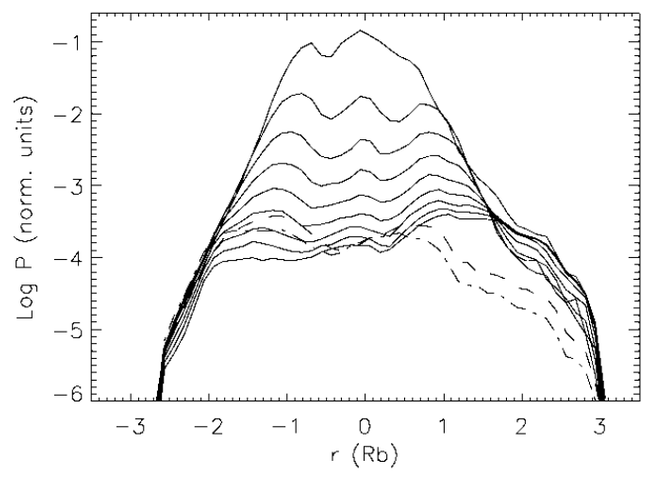


(a)

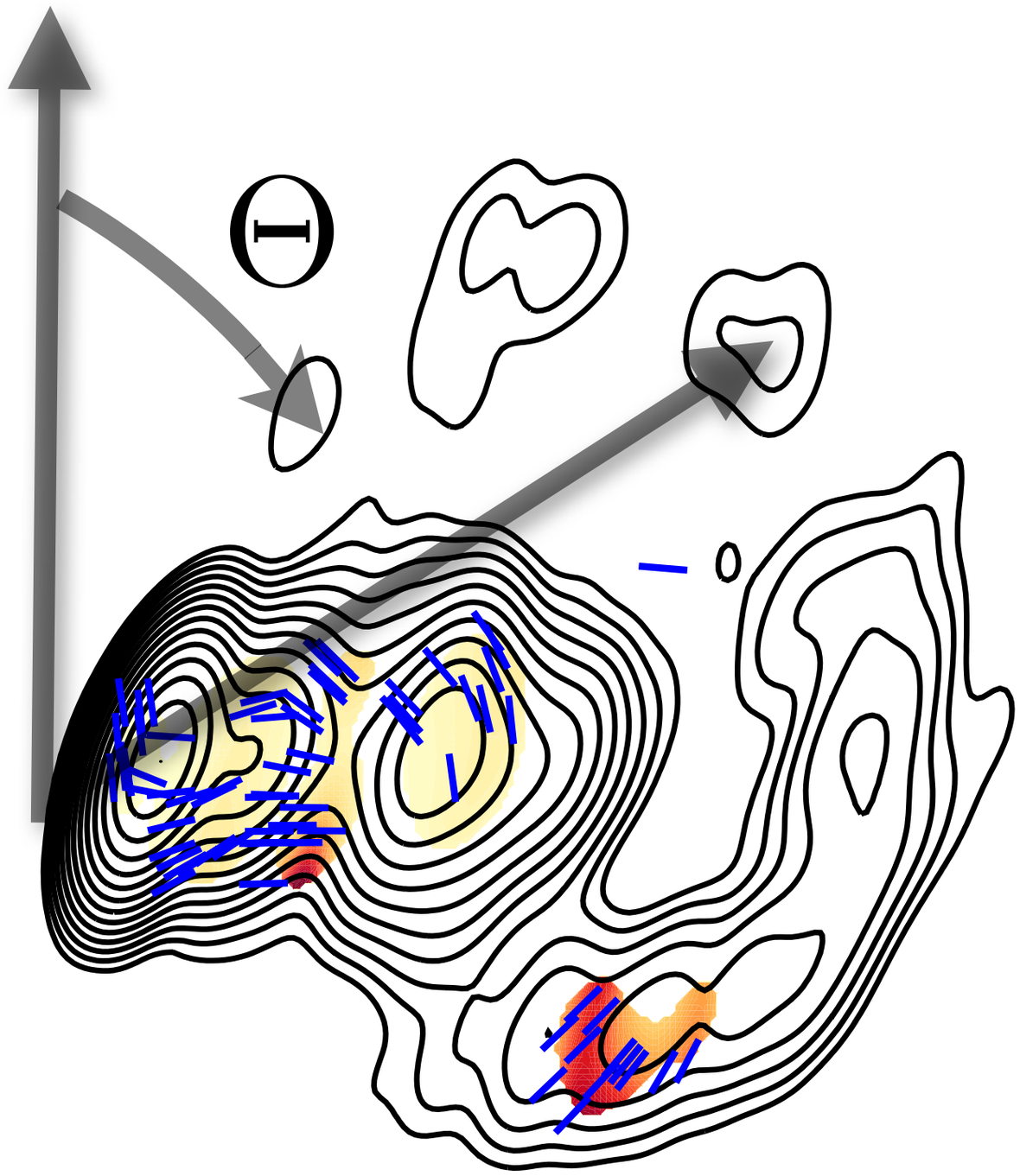
Clausen-Brown et al. 2011

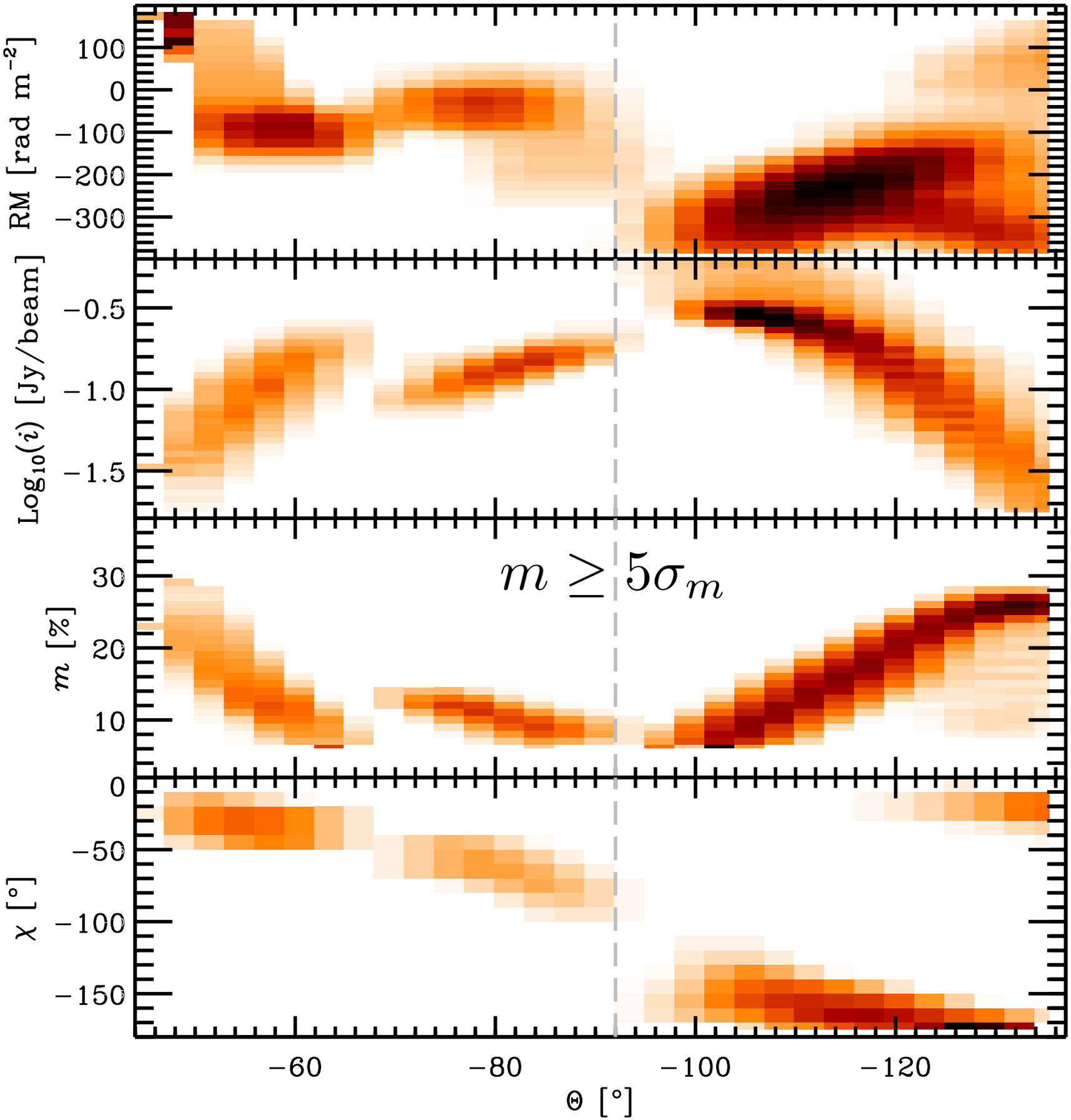






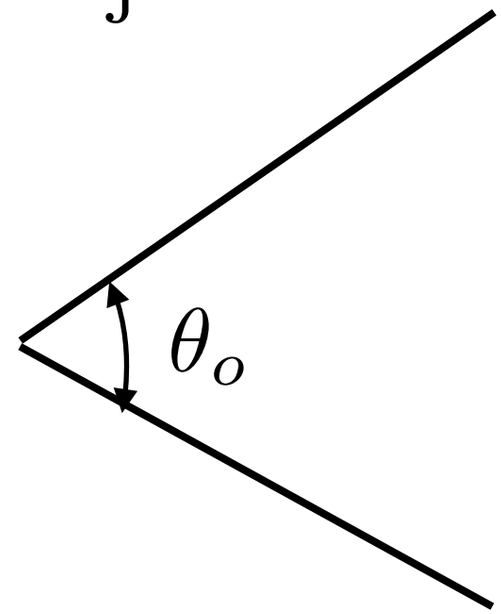
Aloy et al. 2000

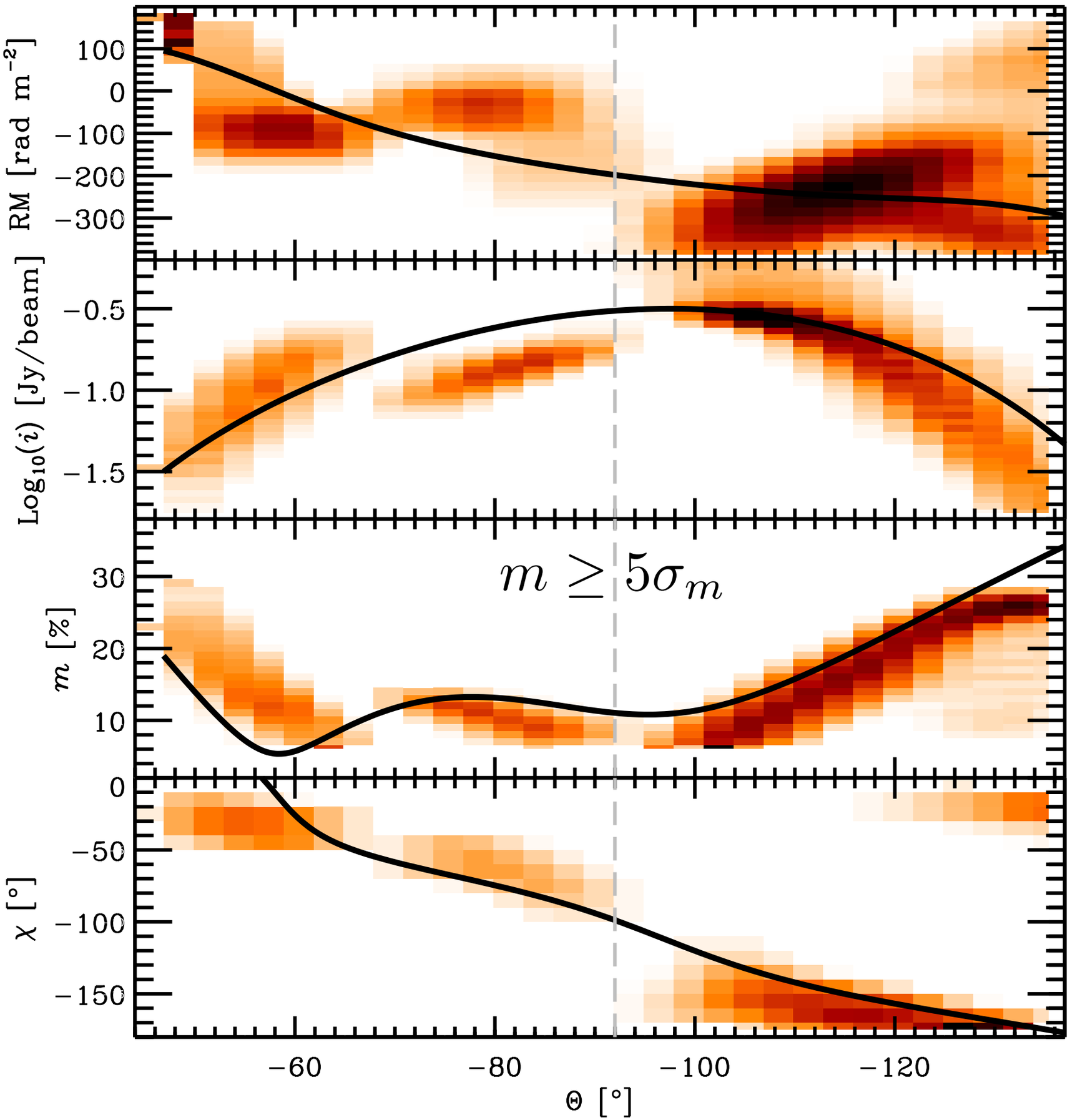

Θ

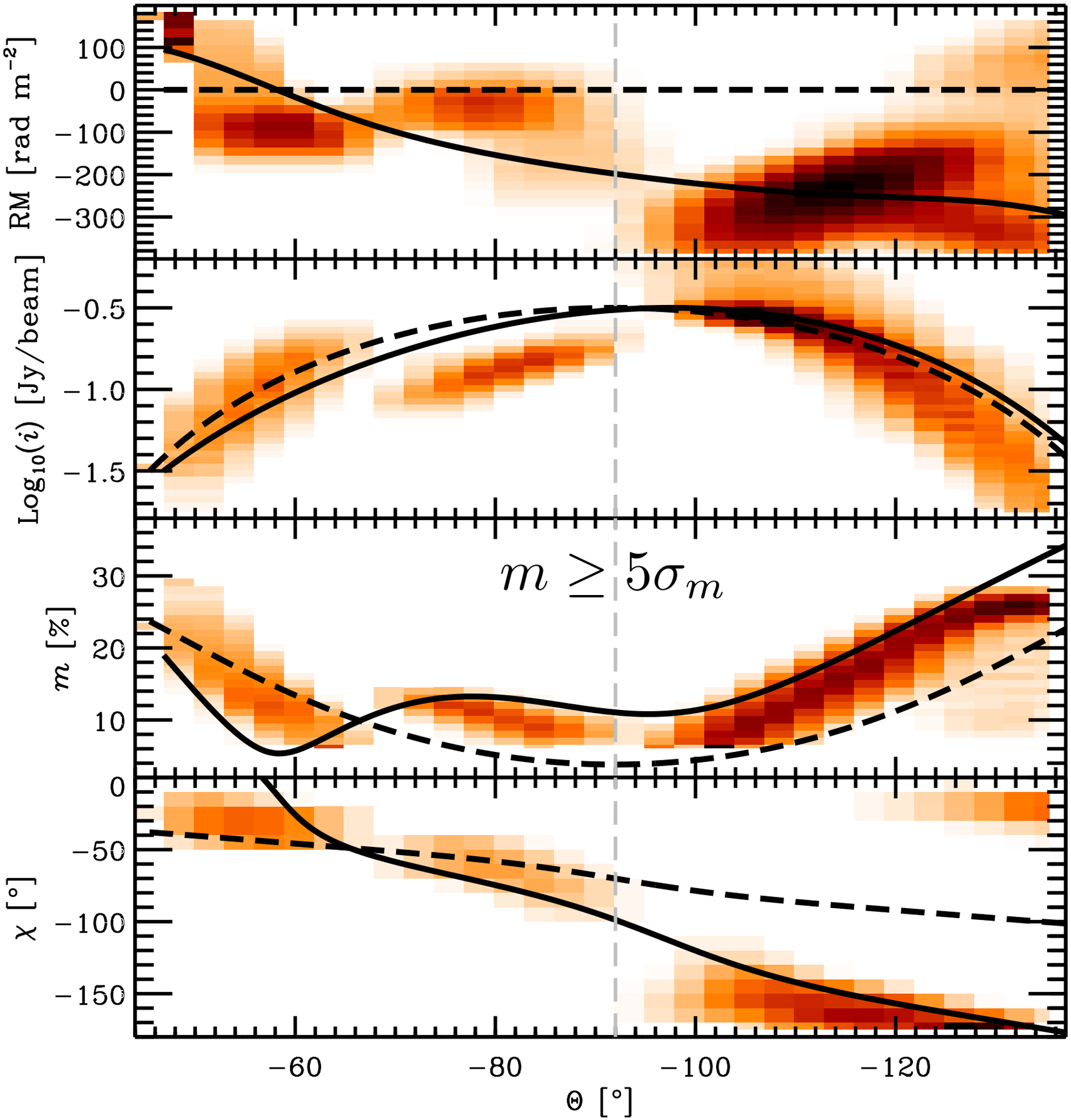

RM [rad m^{-2}]
100
0
−100
−200
−300
Log$_{10}(i)$ [Jy/beam]
−0.5
−1.0
−1.5
$m \geq 5\sigma_m$
m [%]
30
20
10
0
χ [°]
−50
−100
−150
−60
−80
−100
−120
Θ [°]

Clausen-Brown et al. 2011

$$\theta_{\rm j} = 0.1/\Gamma$$

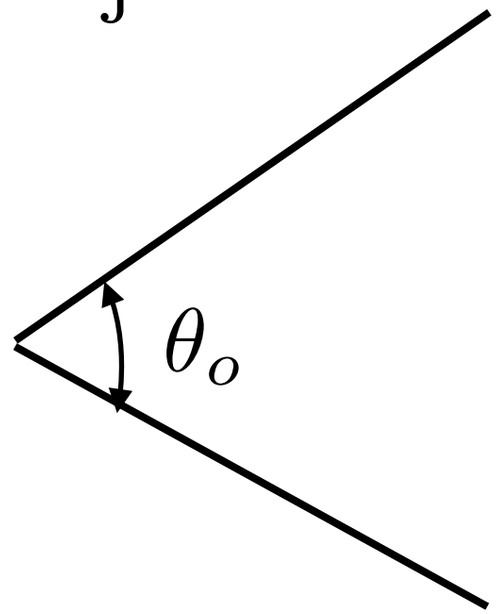






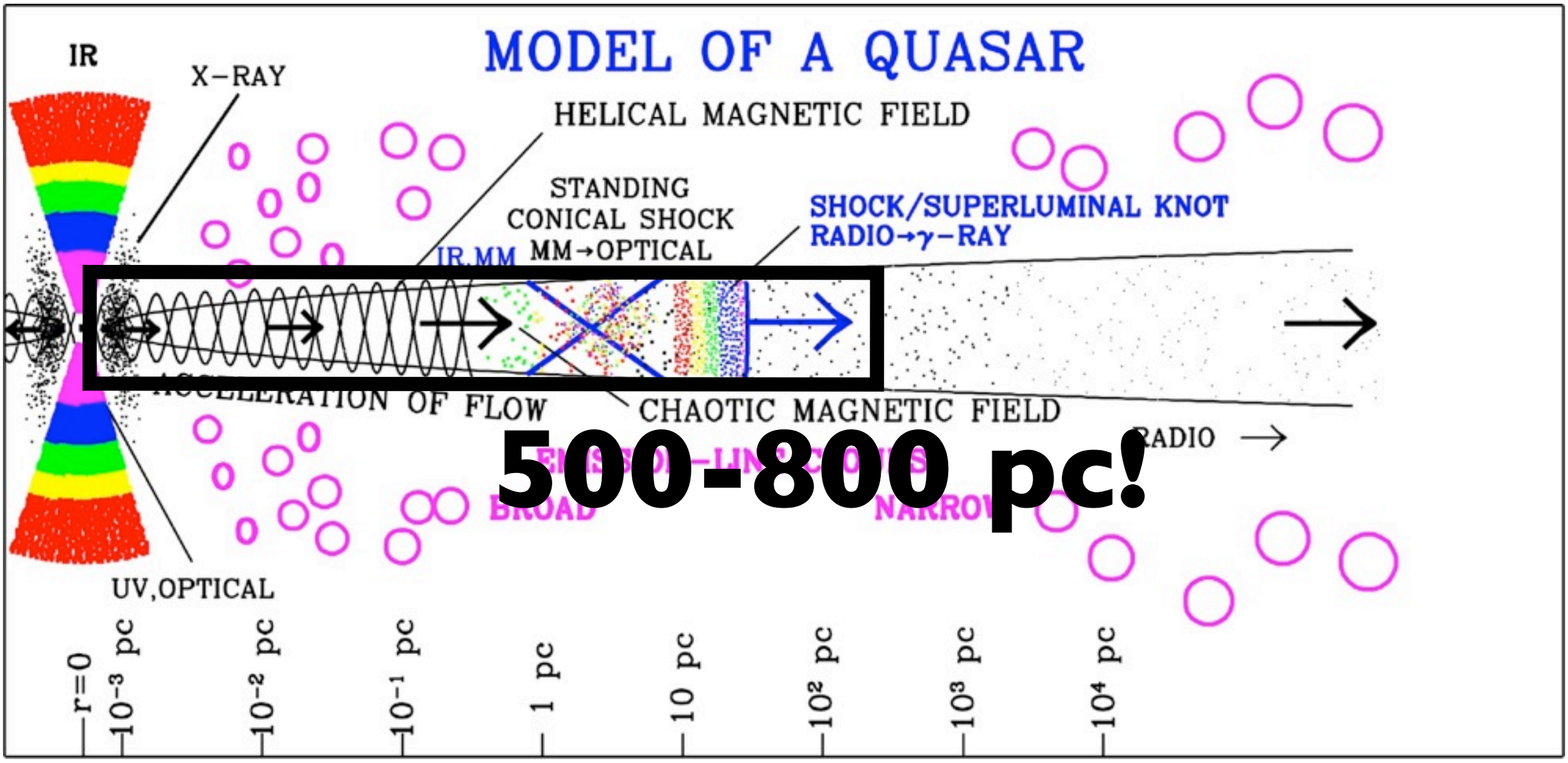
Clausen-Brown et al. 2011

$$\theta_j = 0.1/\Gamma$$



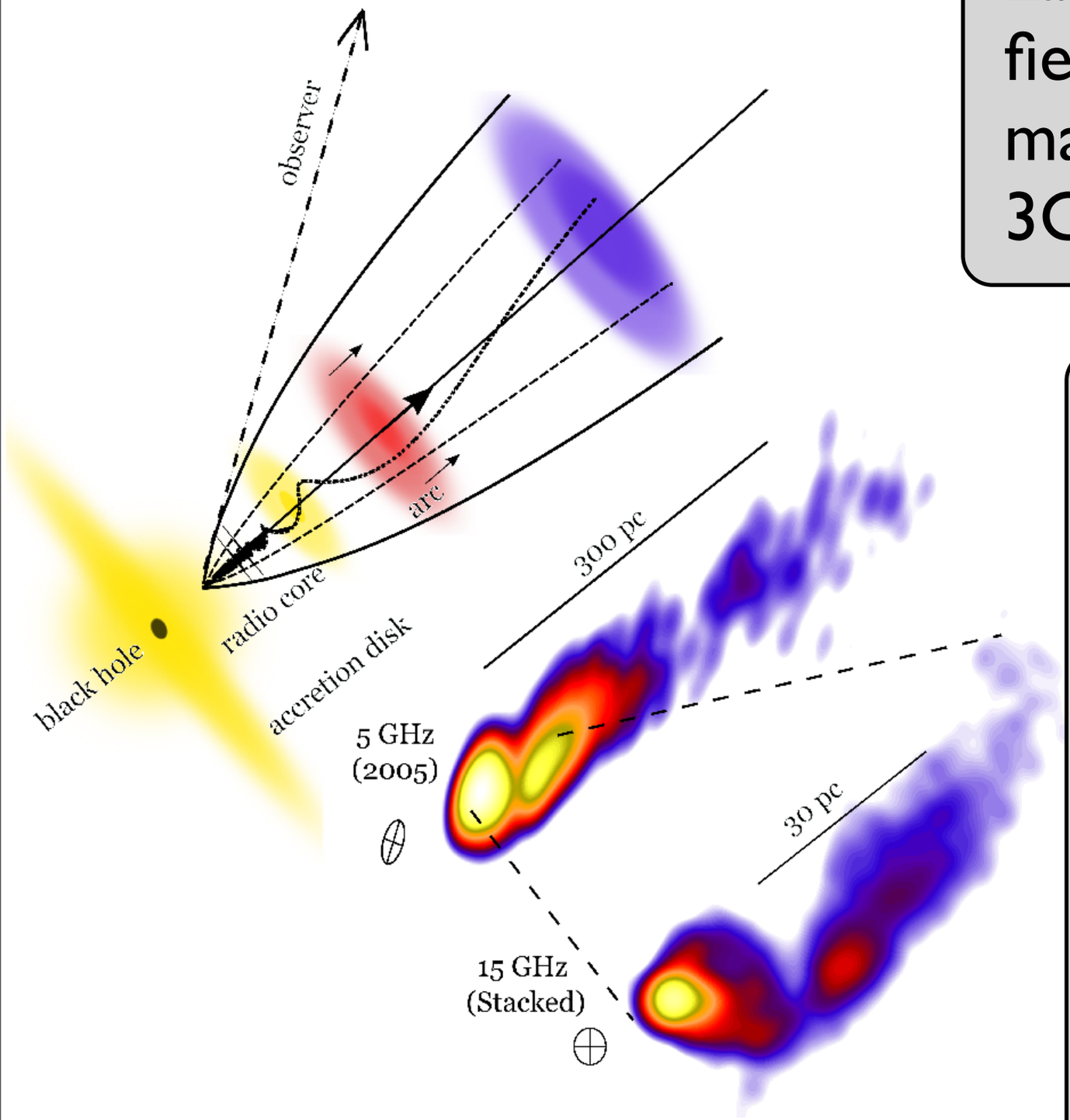
random field

to what extent?



500-800 pc!

courtesy of Alan Marscher/BU Blazar group



Large-scale ordered magnetic field far from the central engine may not be limited to the 3C454.3.

Out of 191 sources in the MOJAVE sample, only 9 show transverse sizes larger than at least two times the synthesized beam in polarized flux, which is needed for detecting asymmetries.

4 out of those actually demonstrate significant transverse gradient in RM.

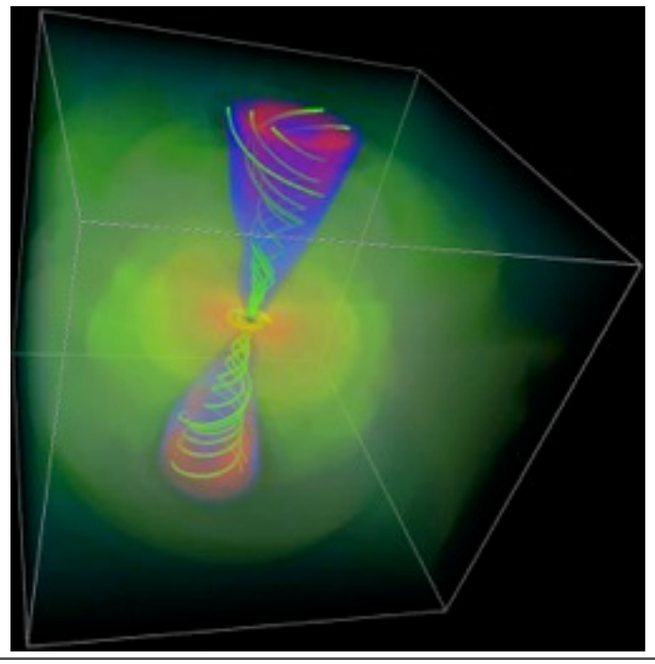
Hovatta et al. 2012

$*\approx 400\ \mathrm{rad\ m^{-2}}$ transverse gradient + sign reversal.

* clear detection of a change in the sign of the observed Faraday rotation across the jet can easily be explained by the presence of a helical field, but not by electron-density gradients.

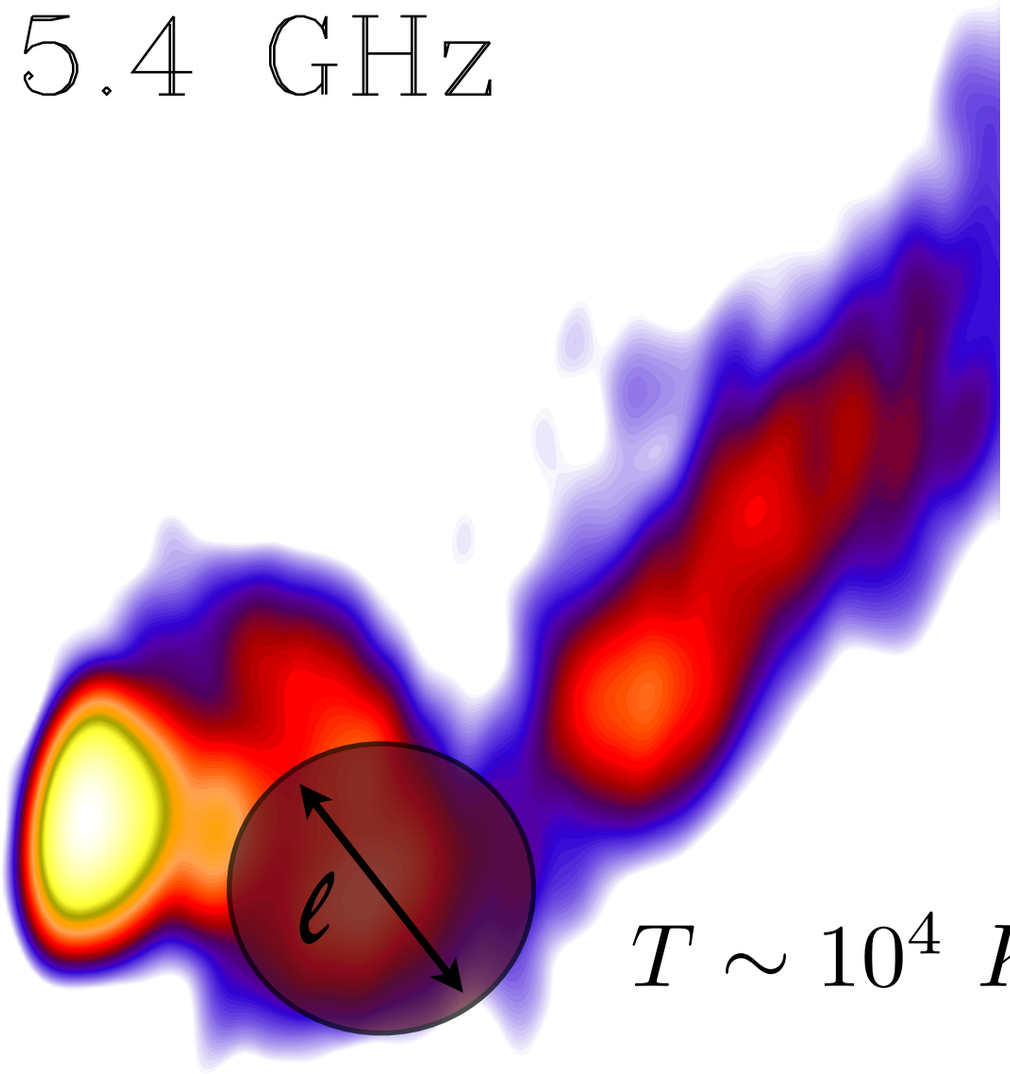
* an ordered helical magnetic field component at a distance of $\approx 500 - 800\ pc\ (10^7 r_g)$ from the launching point!!

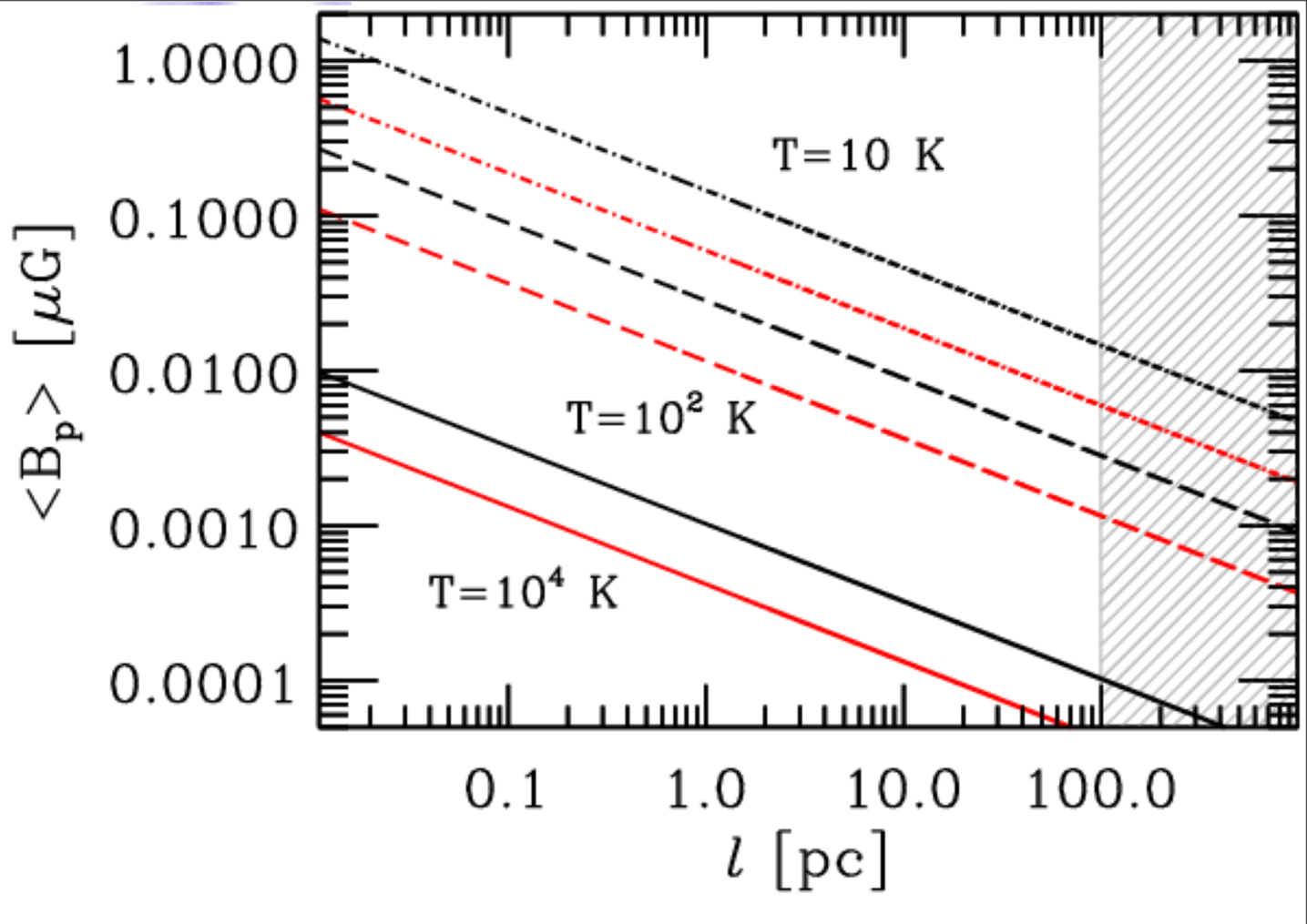
* already hinted from 3D simulations up to $10^3\ r_g$



McKinney & Blandford 2009

15.4 GHz





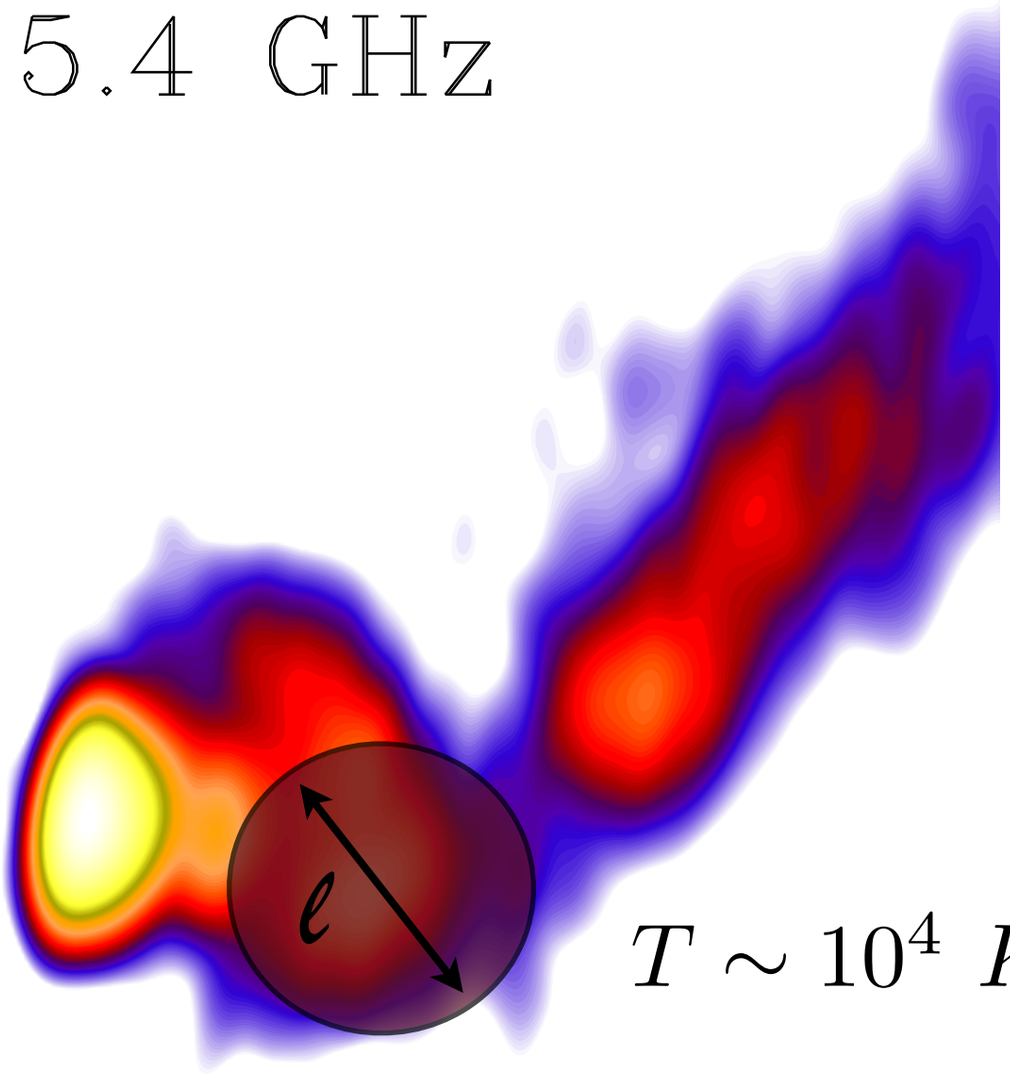
$T \sim 10^4\ K$

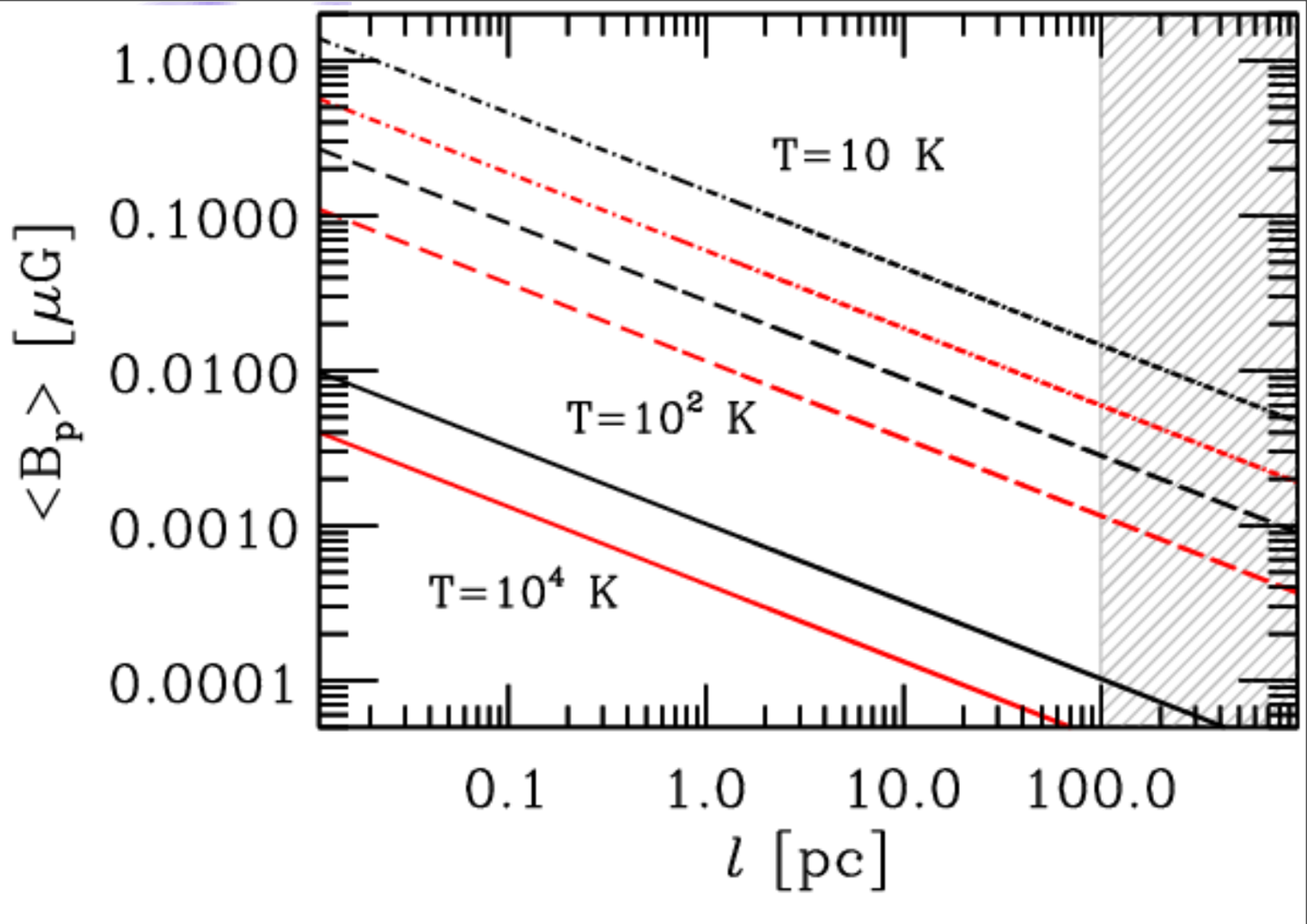
$$\tau_{\rm ff} = 9.8 \times 10^{-3} l\ n_{\rm th}^2\ T^{-1.5} \nu^{-2} [17.7 + \ln (T^{1.5} \nu^{-1})]$$

$$\tau_{\rm ff} \geq 0.7 \longrightarrow n \simeq 5 \times 10^3\ cm^{-3}$$

$$RM \sim 10^2\ rad\ m^{-2} \longrightarrow B \sim 10^{-9}\ G$$

15.4 GHz





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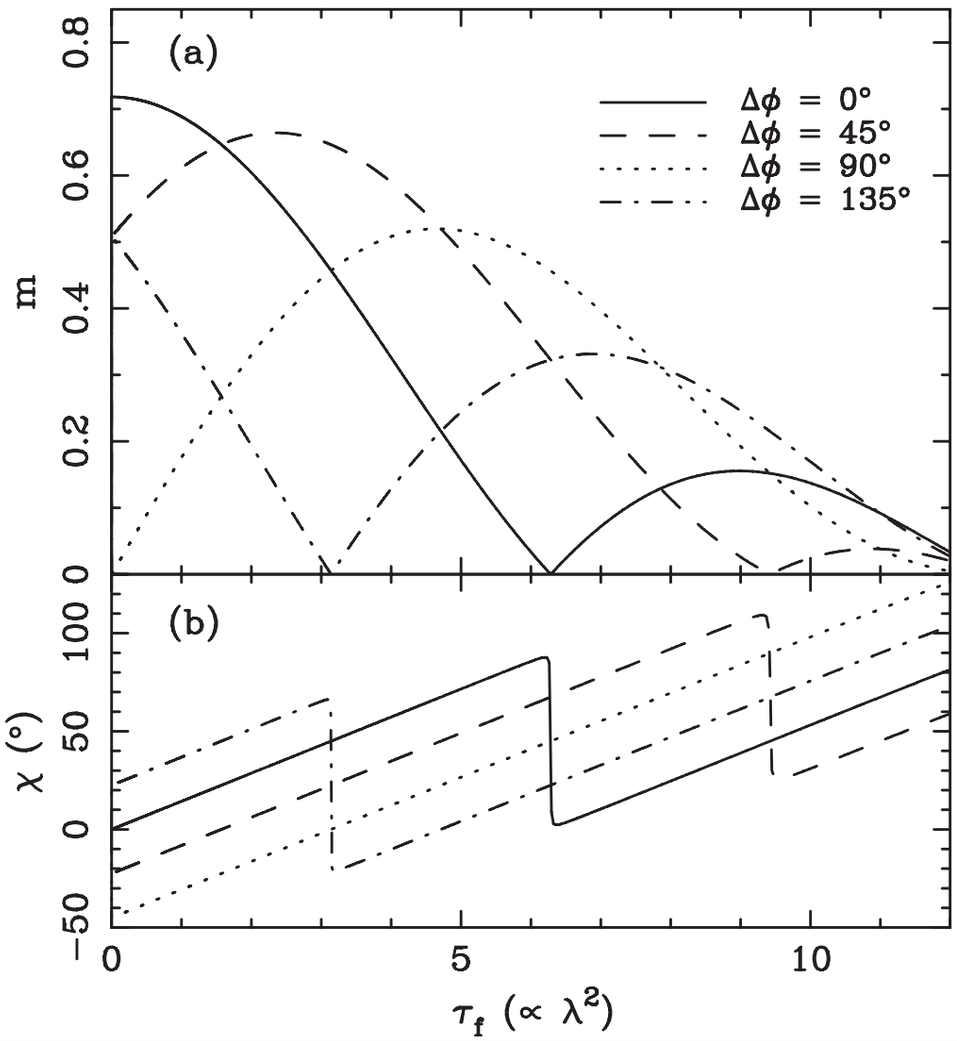
$\tau_{\rm ff} \geq 0.7$ → $n \simeq 5 \times 10^3\ cm^{-3}$

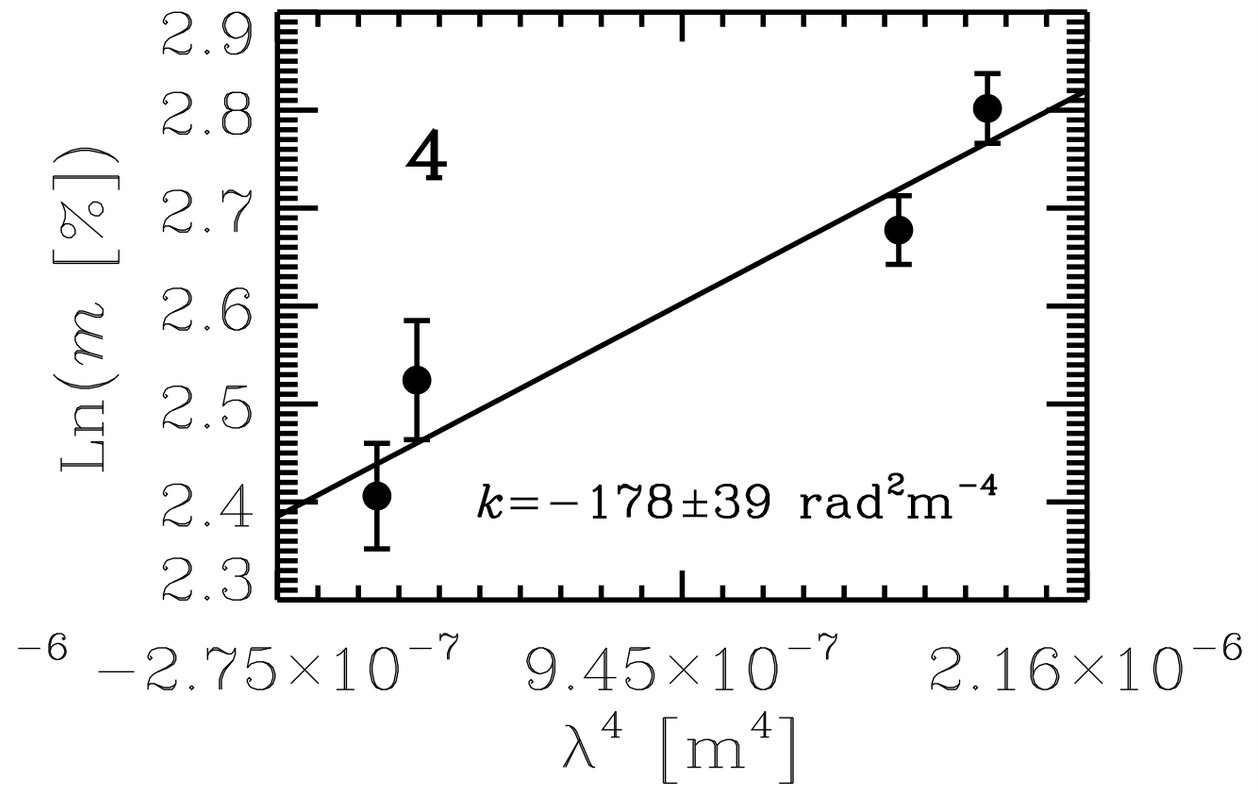
$RM \sim 10^2\ rad\ m^{-2}$ → $B \sim 10^{-9}\ G$

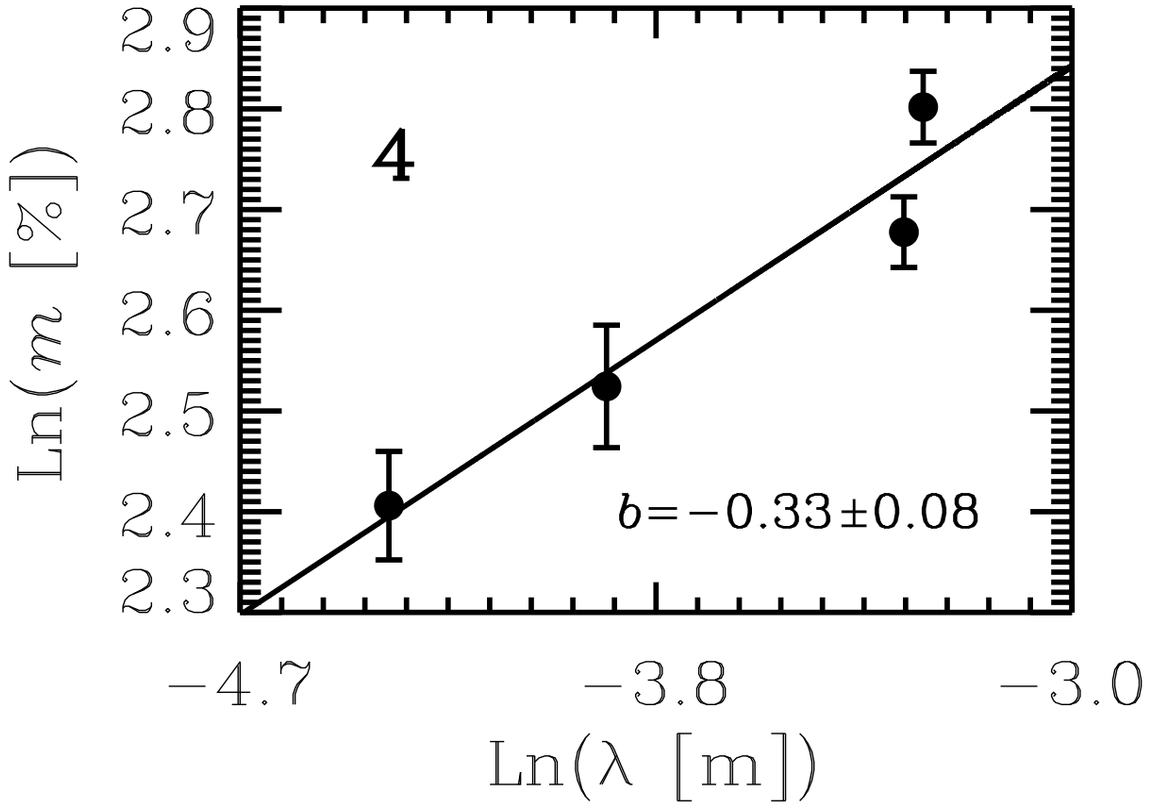
$$m(\lambda) = m_0 \exp(-k\lambda^4)$$

Burn de-polarization (Burn 1966)

Homan 2012, ApJL inverse-depolarization







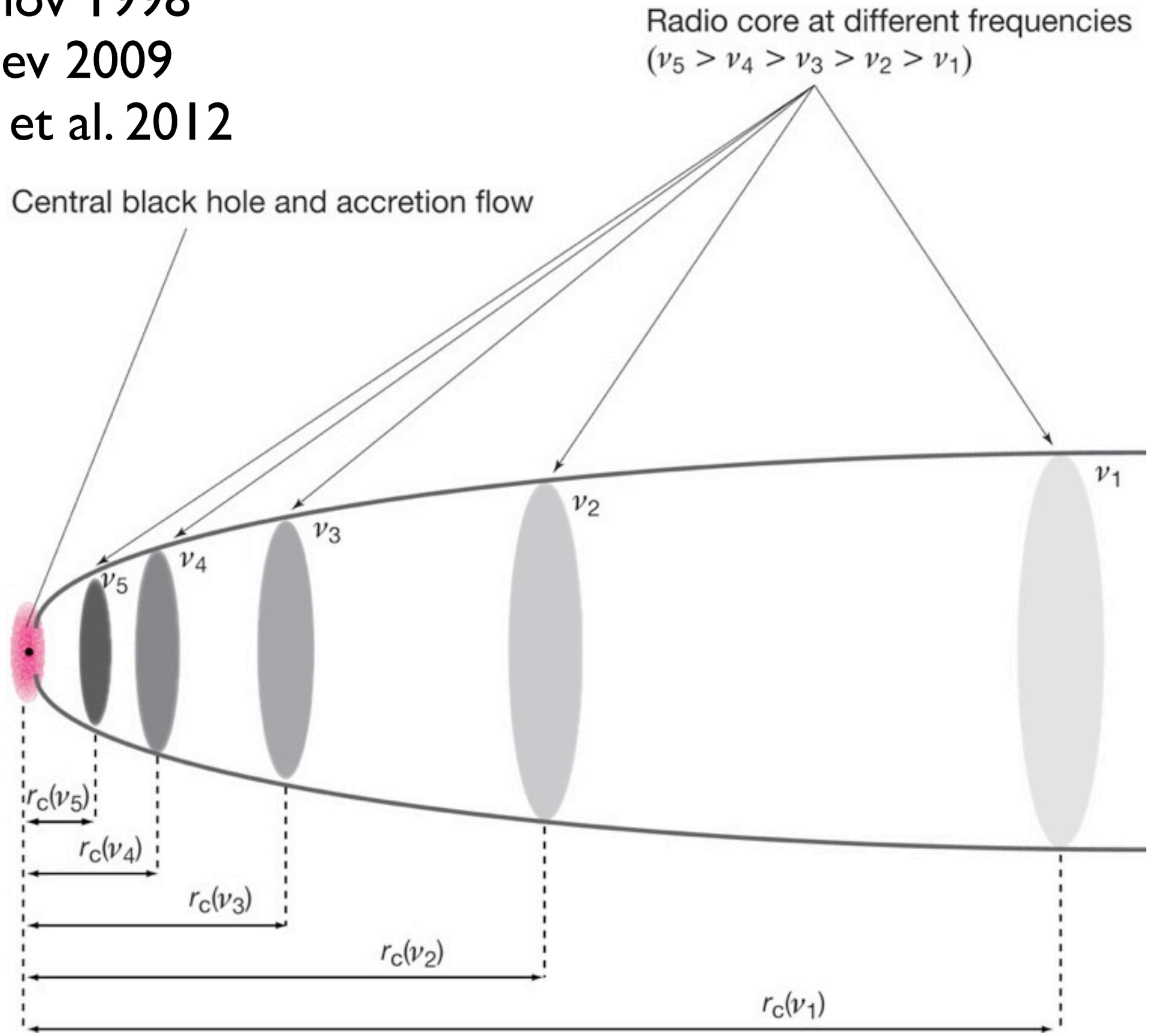
Summary

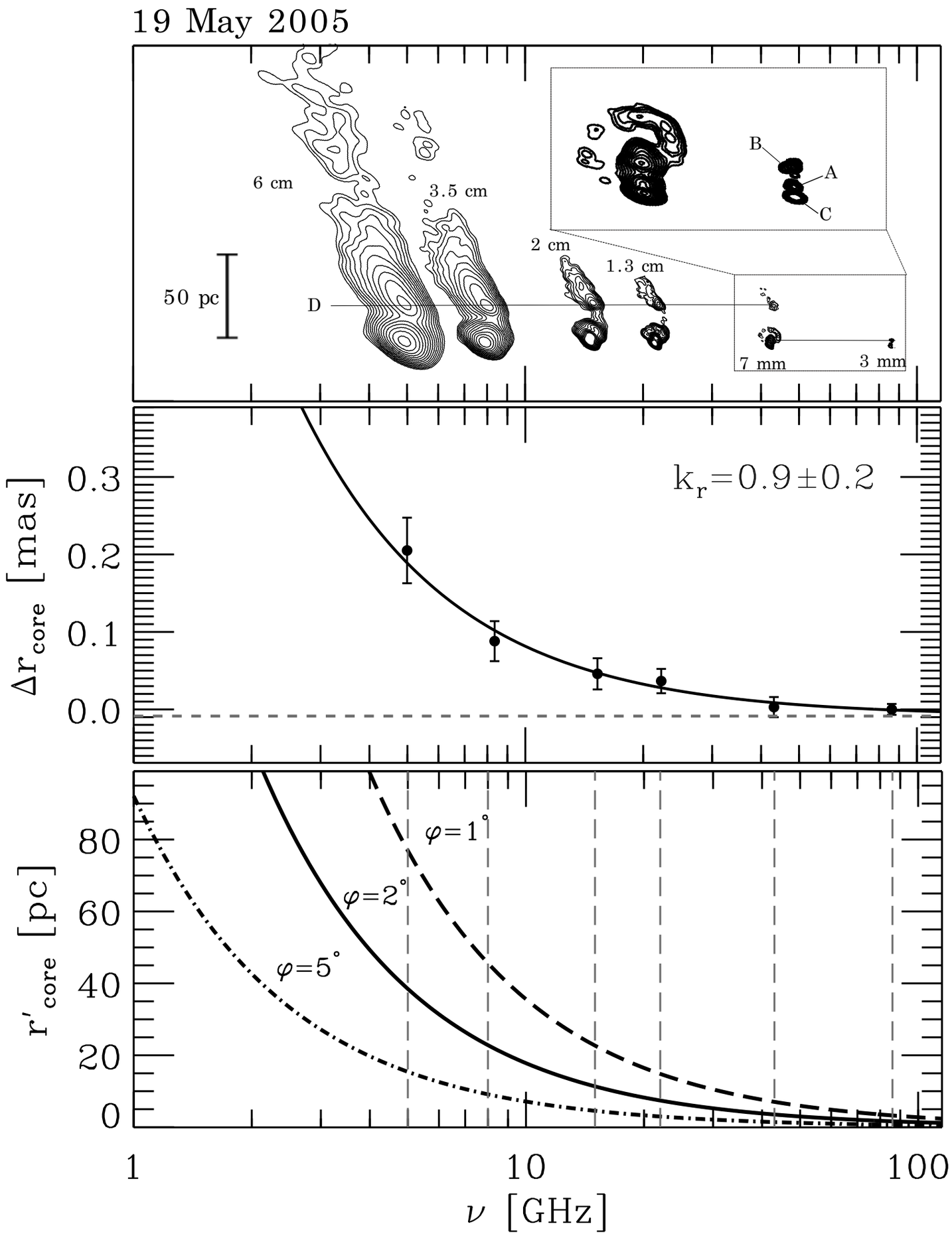
* Multi-frequency polarimetric radio imaging of the outflow shows significant transverse asymmetries in intensity, spectral index, linear polarization and Faraday rotation measure, as is expected in the presence of a large-scale helical magnetic field.

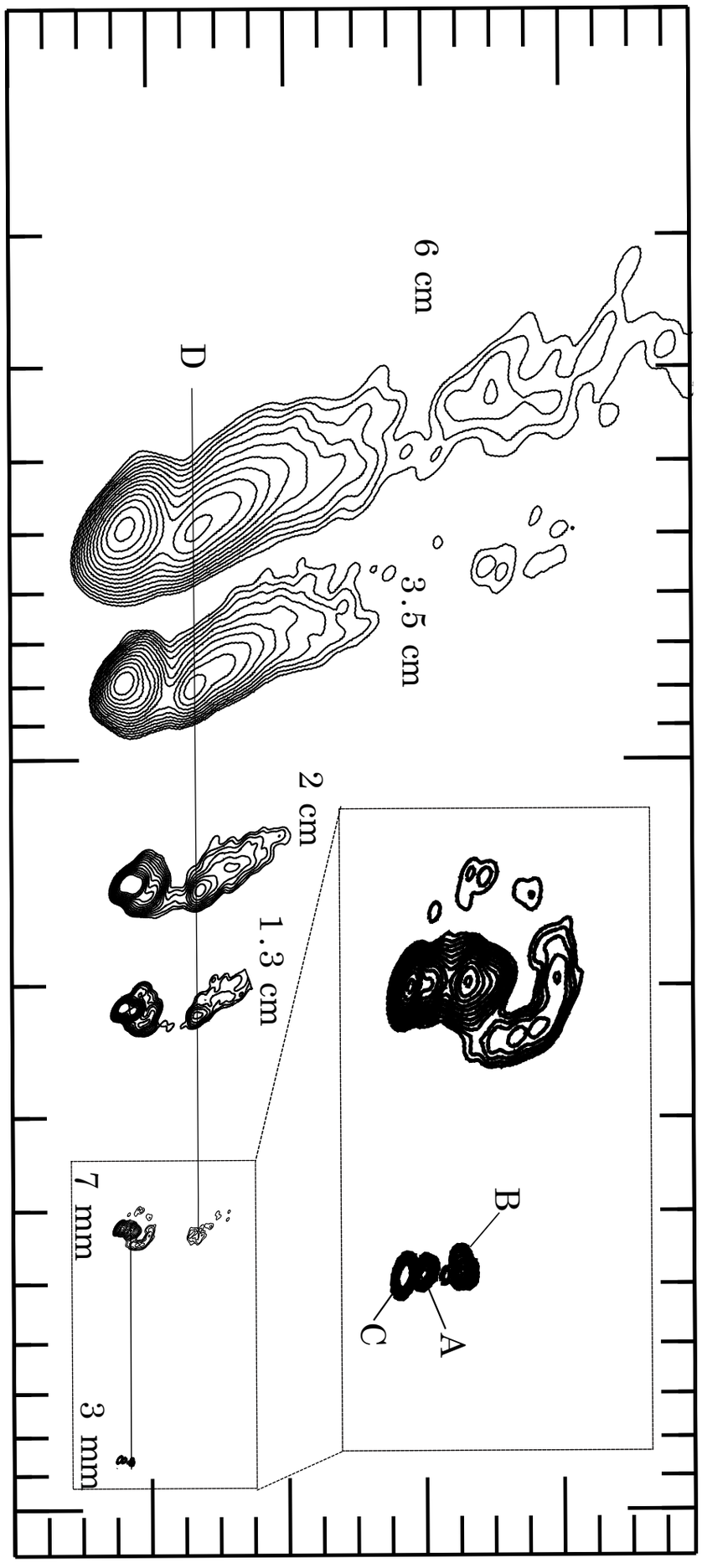
* 3C 454.3 shows the first compelling evidence that the radio emission from the jet of a quasar exhibits signatures of a large-scale, ordered helical magnetic field component at a distance of hundreds of parsecs from the launching point.

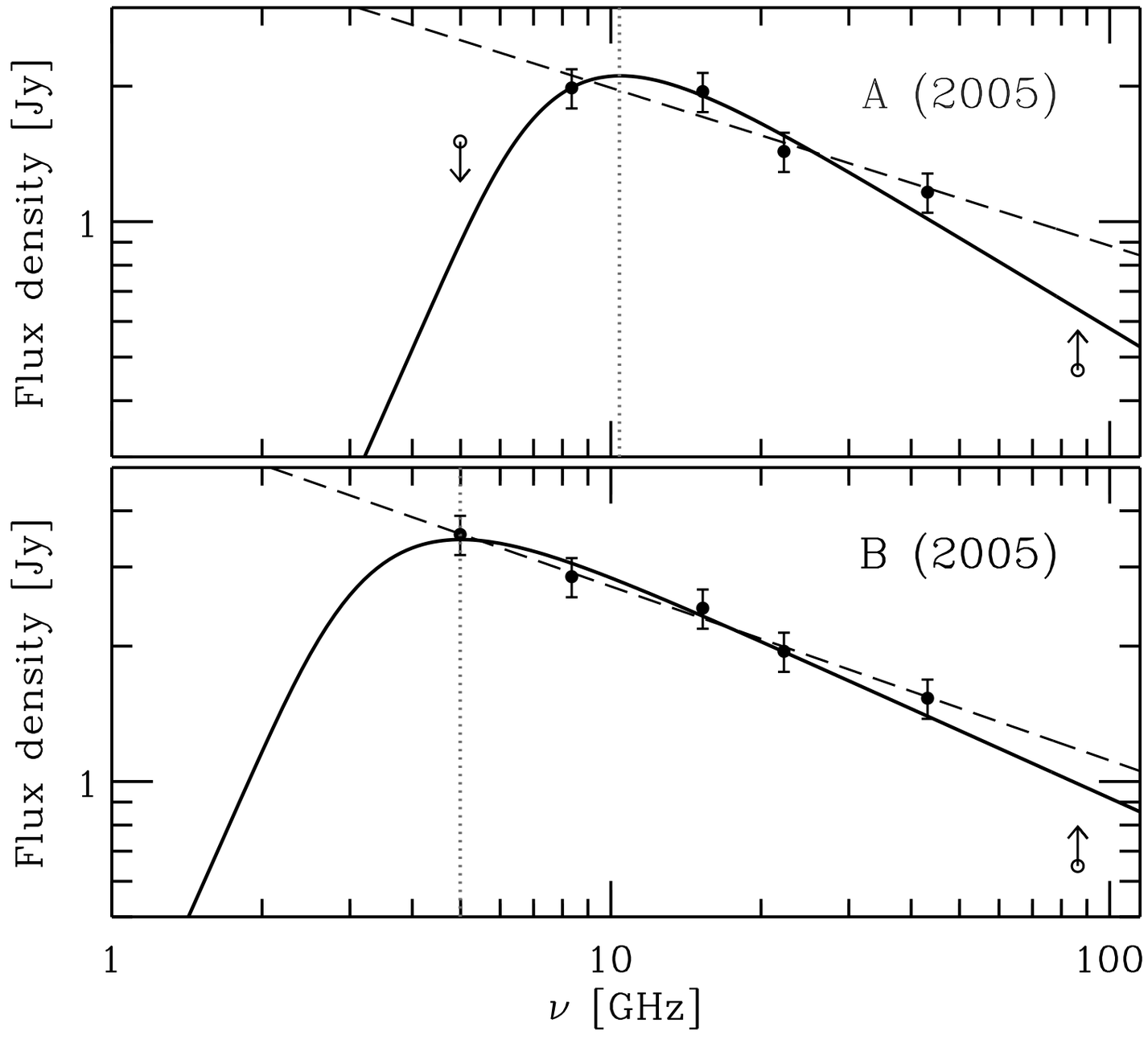
* Our results provide observational support for magnetic jet launching models and demonstrate the stability of the ordered field component over a large distance down the jet.

Lobanov 1998
Kovalev 2009
Hada et al. 2012

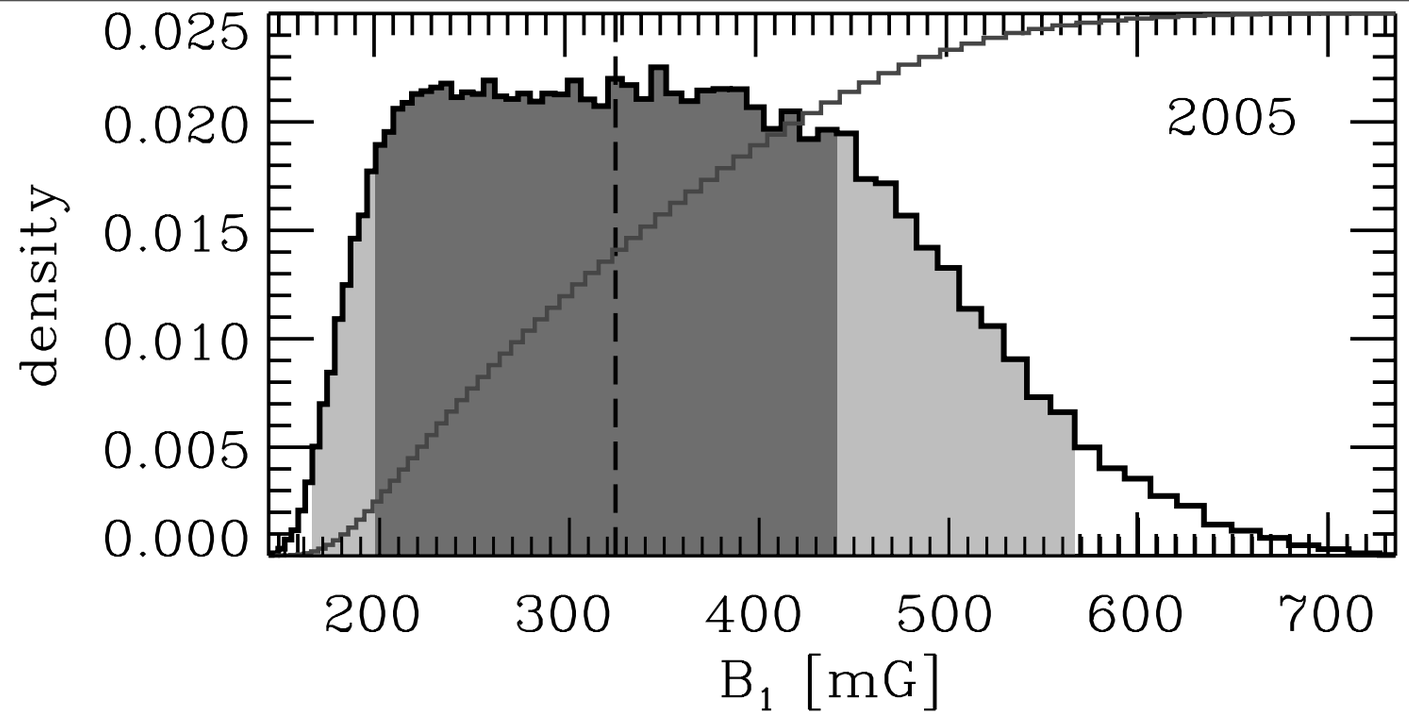



19 May 2005
6 cm
3.5 cm
2 cm
1.3 cm
7 mm
3 mm
B
A
C
D
50 pc
k_r=0.9±0.2
Δr_{core} [mas]
0.3
0.2
0.1
0.0
r'_{core} [pc]
80
60
40
20
0
φ=1°
φ=2°
φ=5°
1
10
100
ν [GHz]


6 cm
3.5 cm
2 cm
1.3 cm
7 mm
3 mm
D
A
B
C

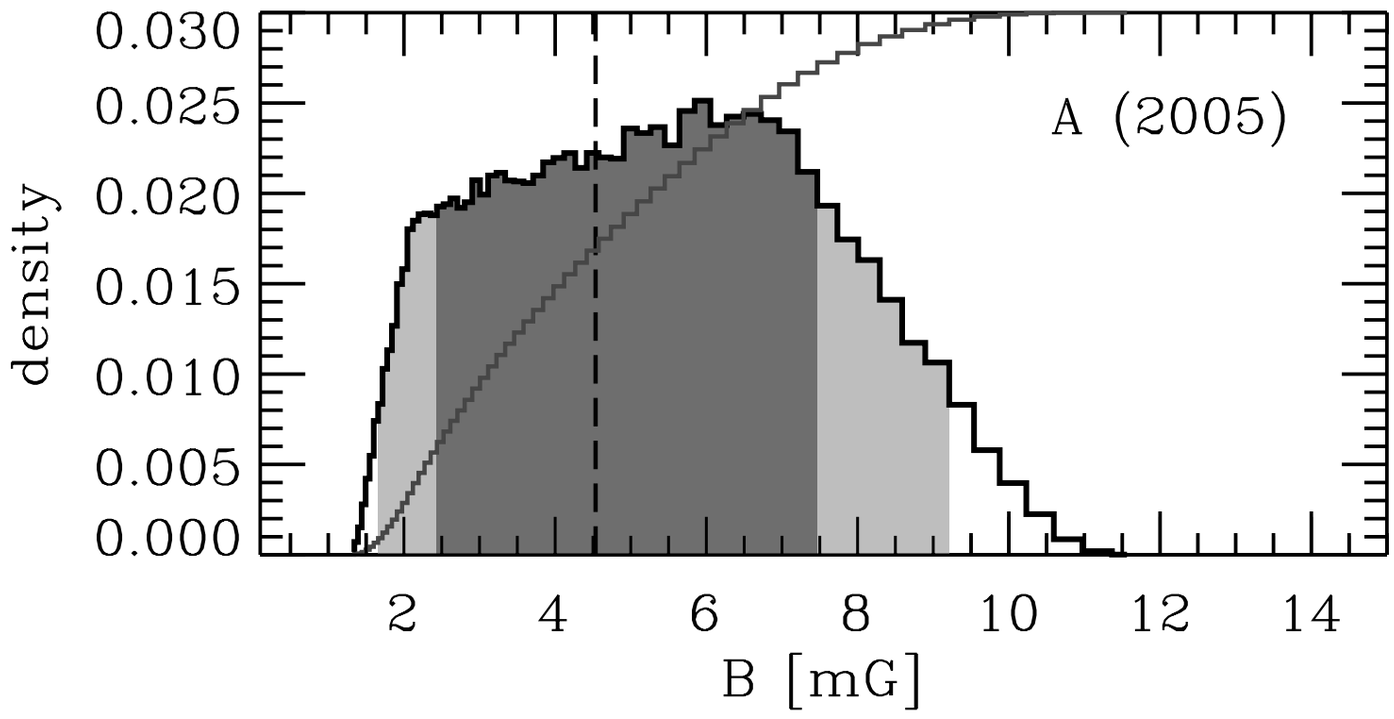

A (2005)
B (2005)
Flux density [Jy]
Flux density [Jy]
1
1
1
10
100
ν [GHz]

Opacity core-shift



$$B_1 = \frac{2\pi\nu_0 m_e c}{e}\left(\frac{\Omega_{r\nu}^{k_r}}{\nu_0 \sin^{k_r}\theta}\right)^{\frac{5-2\alpha}{7-2\alpha}}\left(\frac{(-2\alpha)C_\alpha \pi r_1 K \phi}{\gamma_{\min}^{2\alpha+1} r_0 \sin\theta}\left(\frac{\delta}{1+z}\right)^{\frac{3}{2}-\alpha}\right)^{\frac{2}{2\alpha-7}}$$

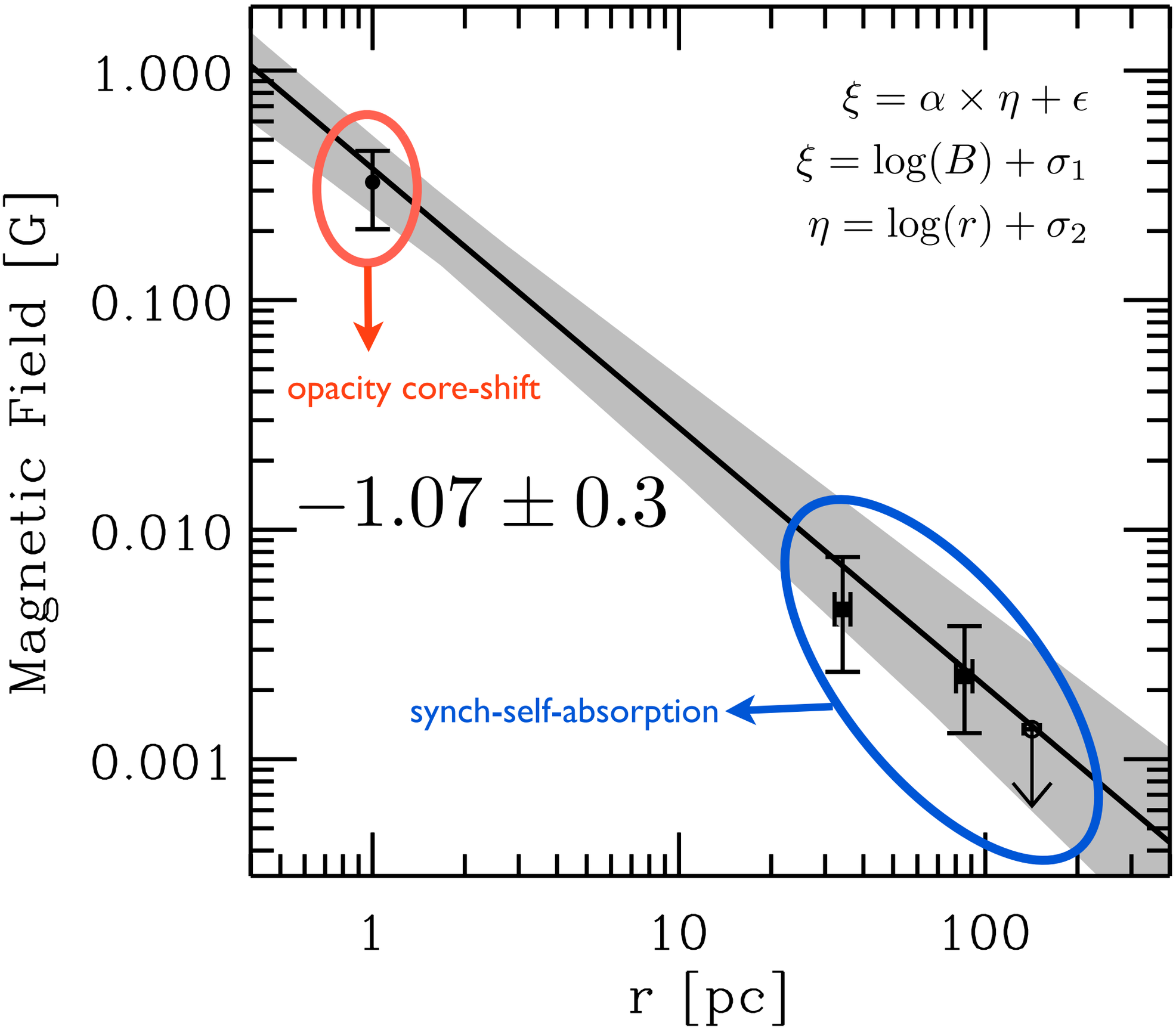
O'Sullivan+ 2009



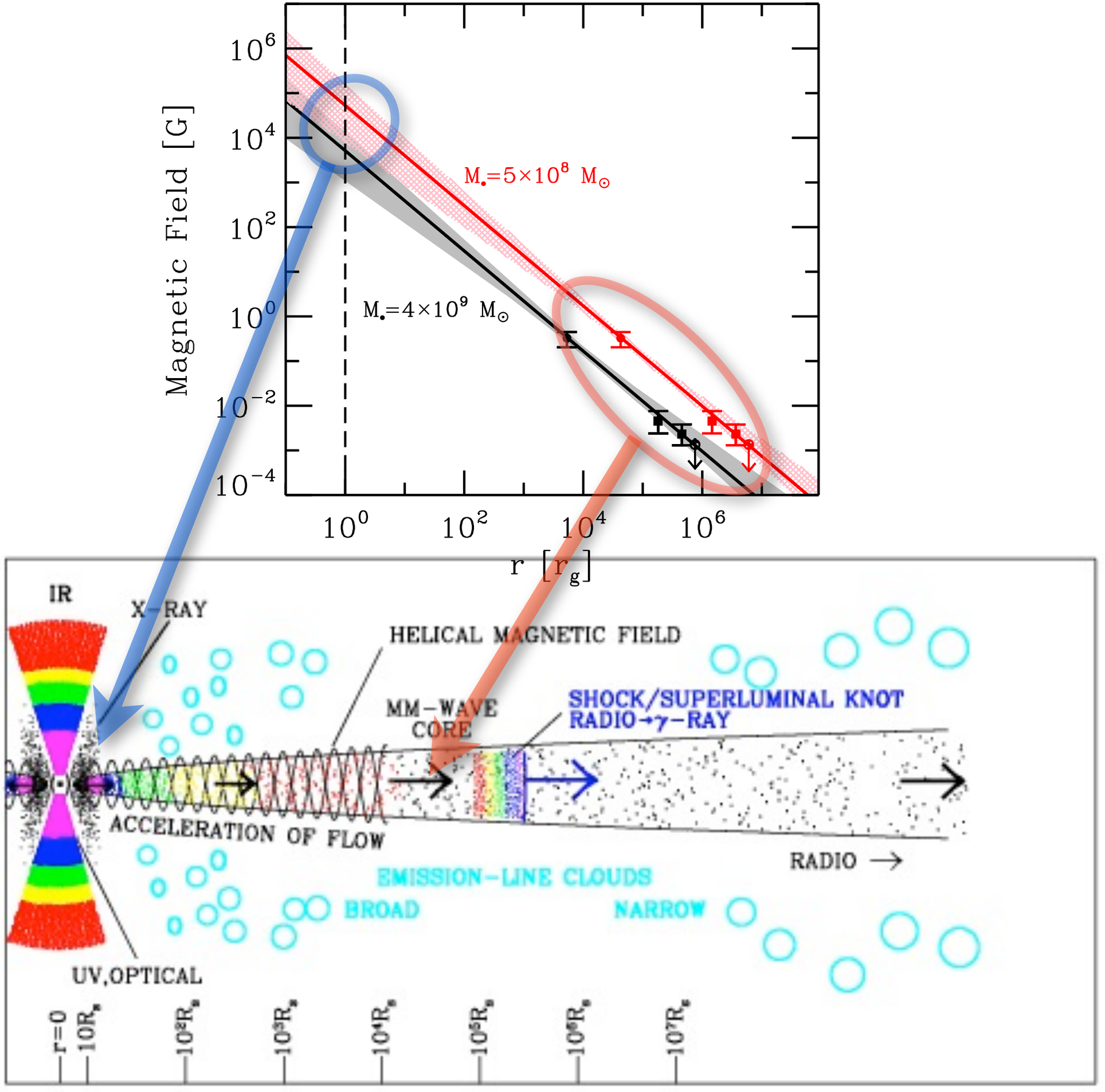
Hirotani 2005

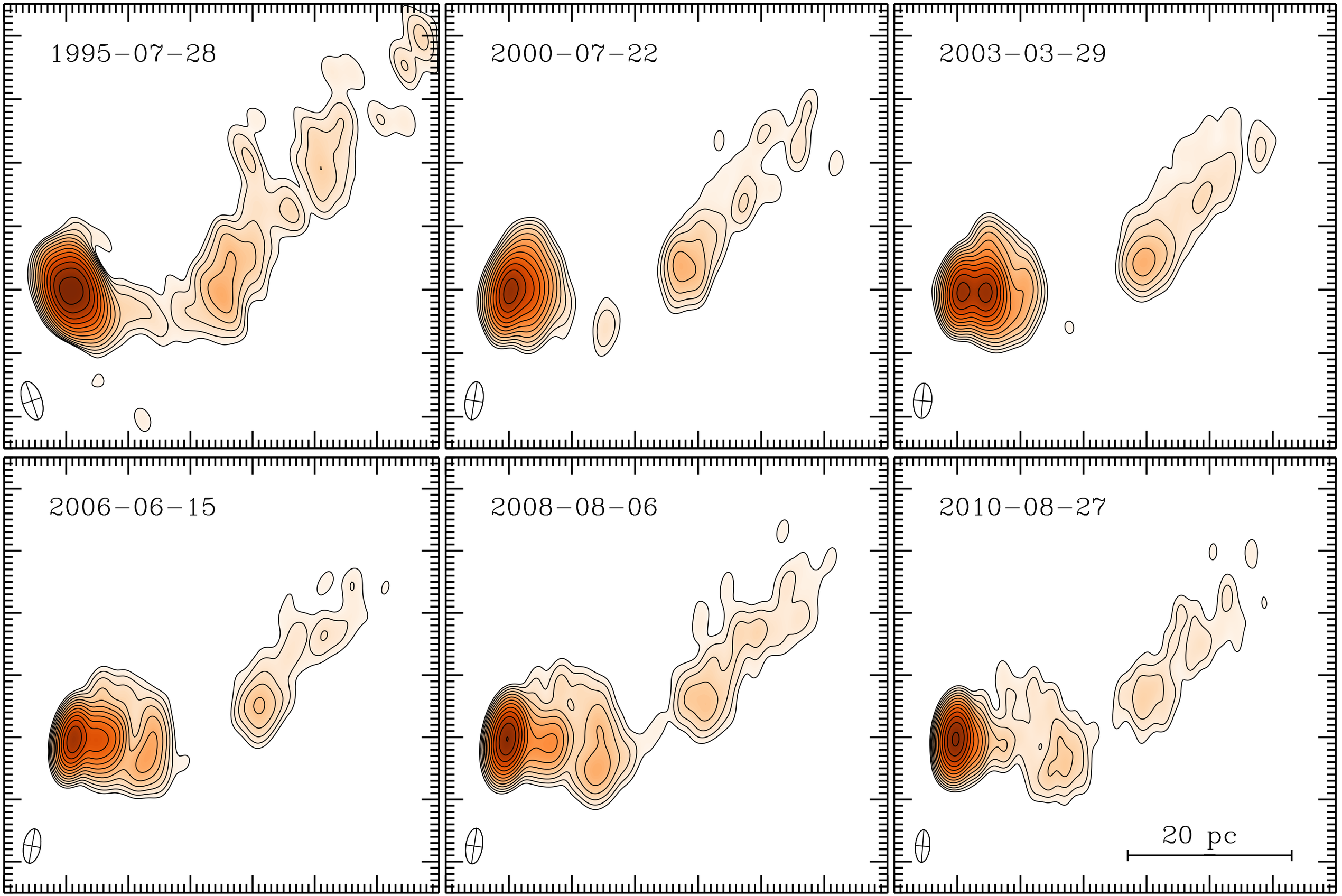
Synchrotron self-absorption

$$B = 10^{-5} b(\alpha)\left(\frac{\nu_m}{\mathrm{GHz}}\right)^5\left(\frac{\theta_d}{\mathrm{mas}}\right)^4\left(\frac{S_m}{\mathrm{Jy}}\right)^{-2}\frac{\delta}{1+z};$$



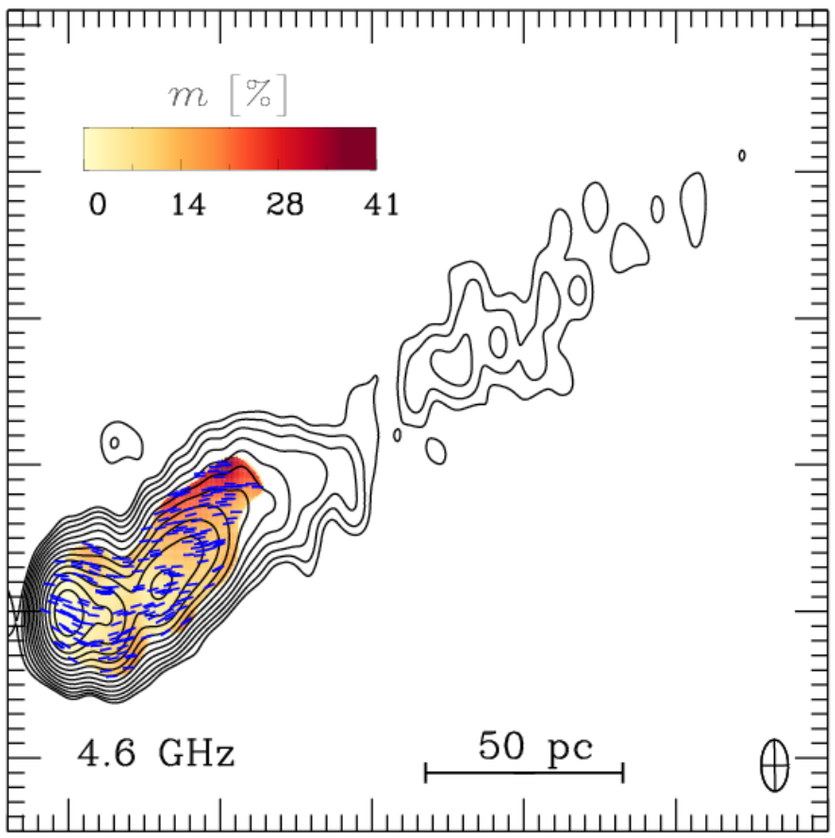
Bayesian linear regression Kelly 2007

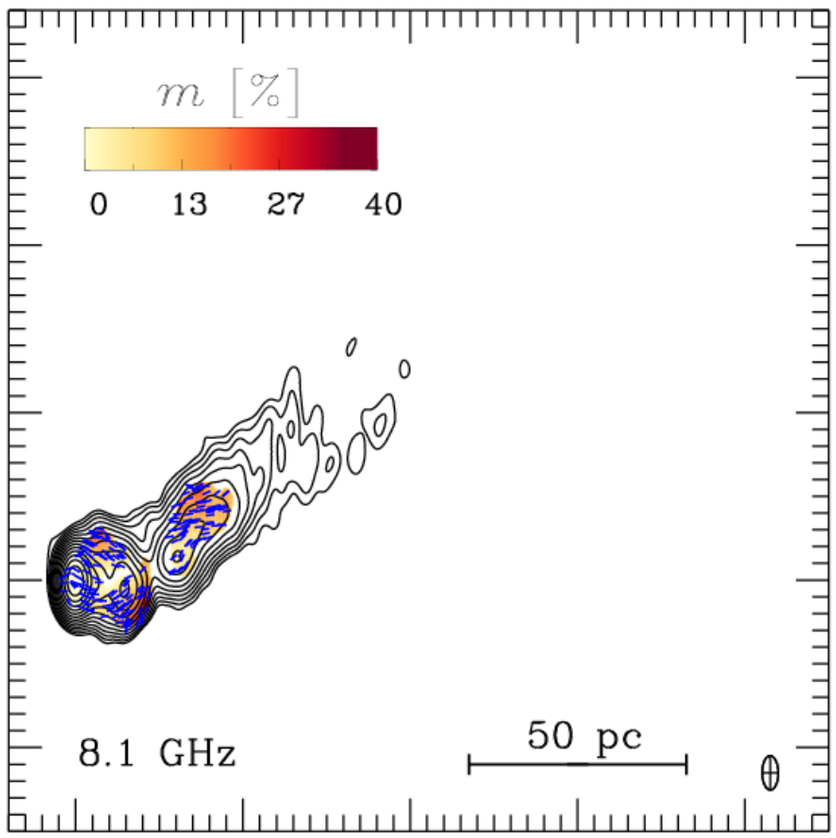

Magnetic Field [G]
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
$M_\bullet=5\times10^8\ M_\odot$
$M_\bullet=4\times10^9\ M_\odot$
10^0
10^2
10^4
10^6
r [r_g]
IR
X-RAY
HELICAL MAGNETIC FIELD
MM-WAVE CORE
SHOCK/SUPERLUMINAL KNOT
RADIO→γ-RAY
ACCELERATION OF FLOW
RADIO →
EMISSION-LINE CLOUDS
BROAD
NARROW
UV,OPTICAL
r=0
10R*
10²R*
10³R*
10⁴R*
10⁵R*
10⁶R*
10⁷R*

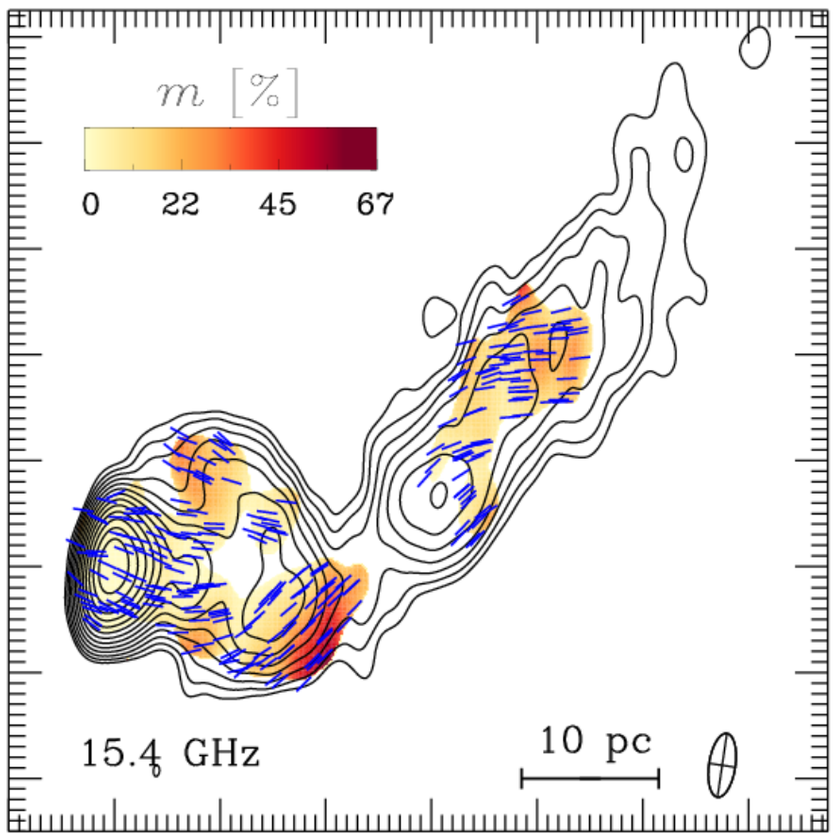


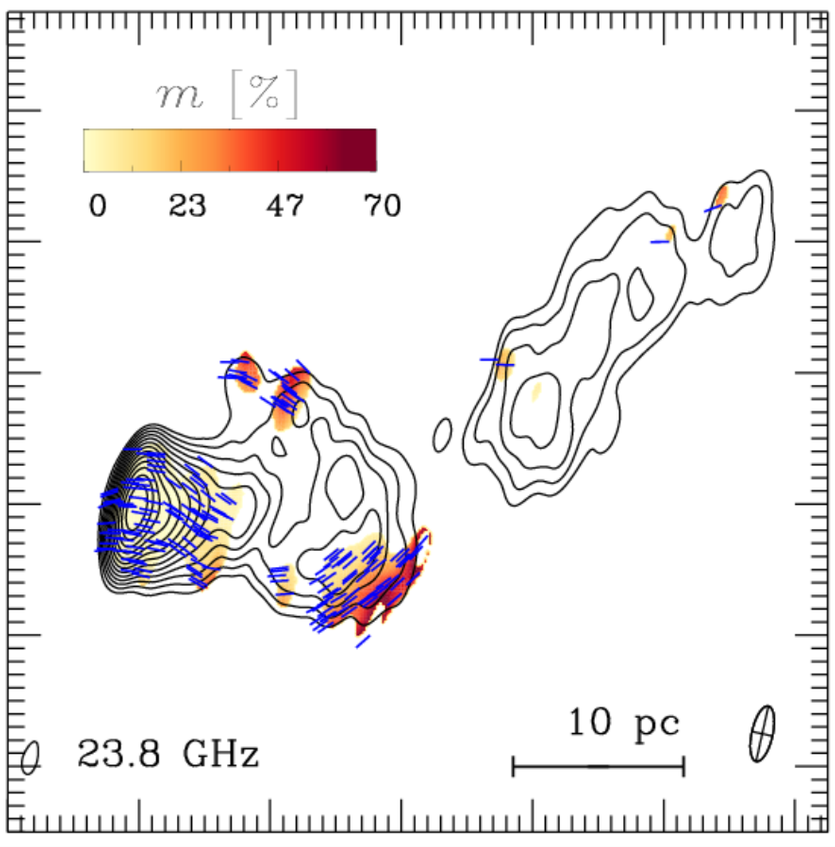
MOJAVE survey / Matt Lister et al.

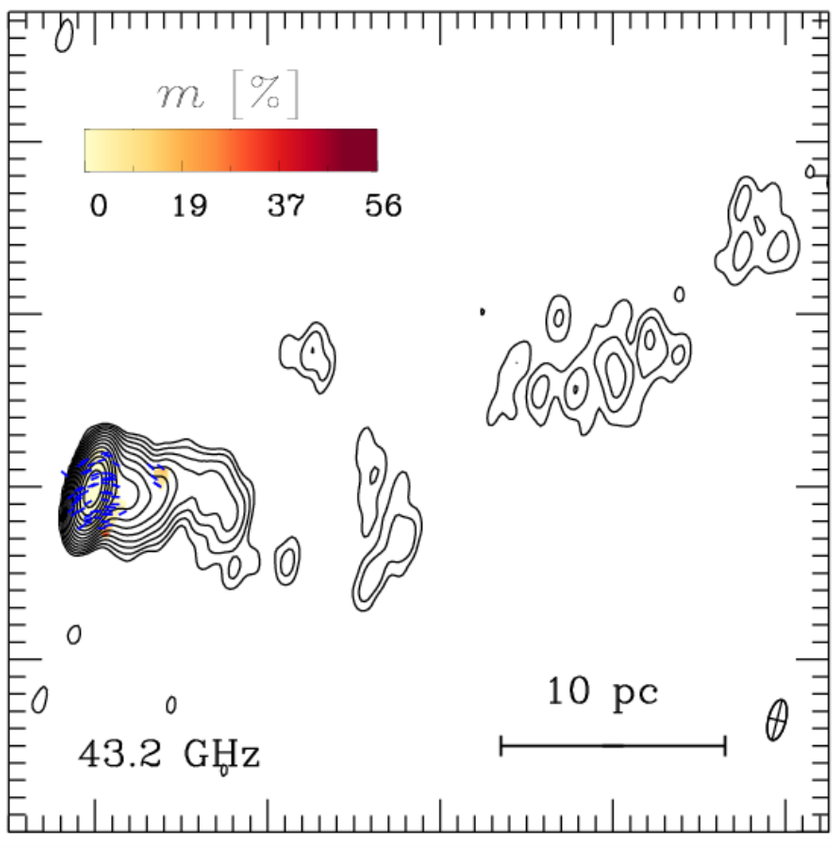
22 September 2009



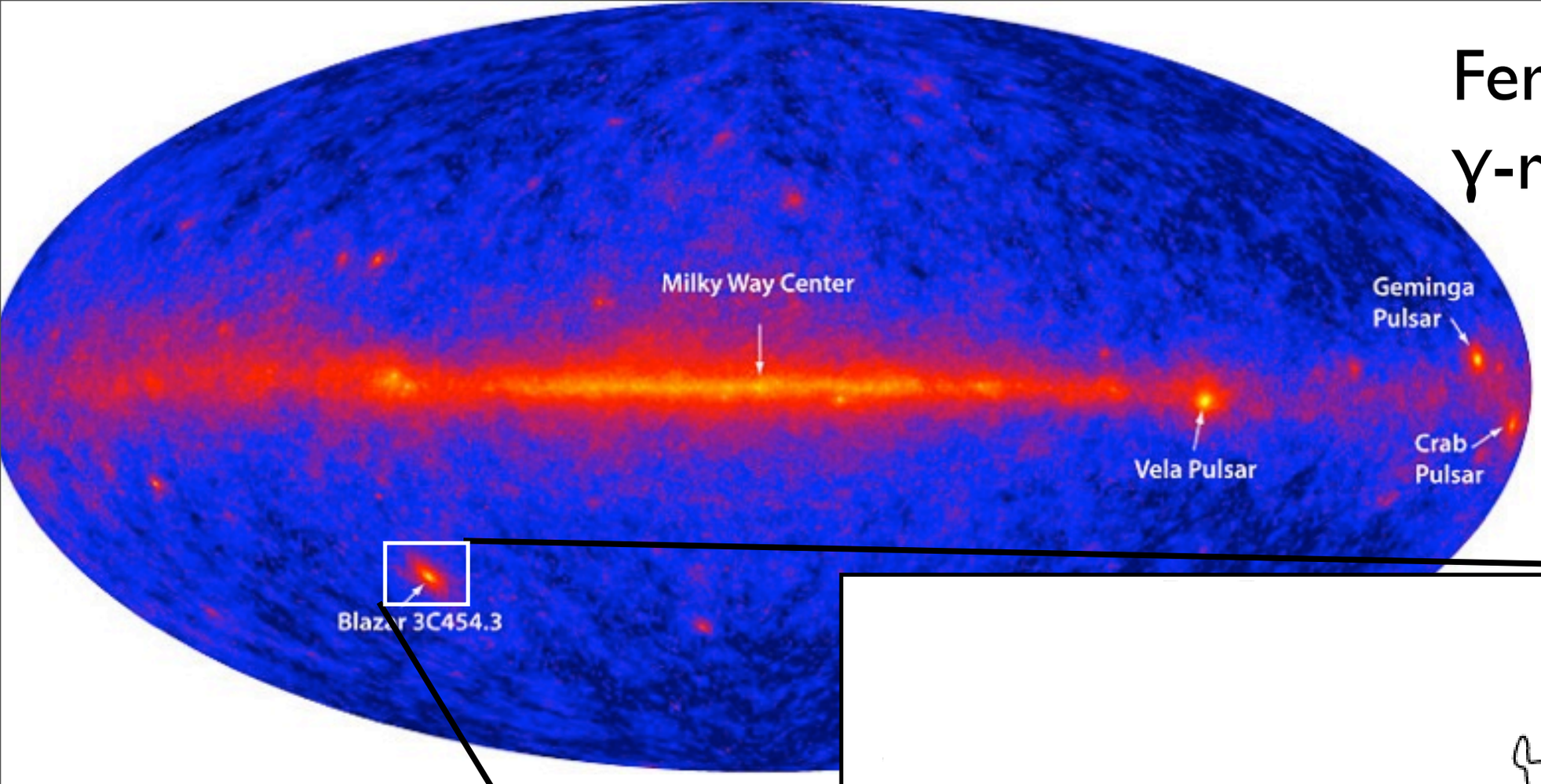


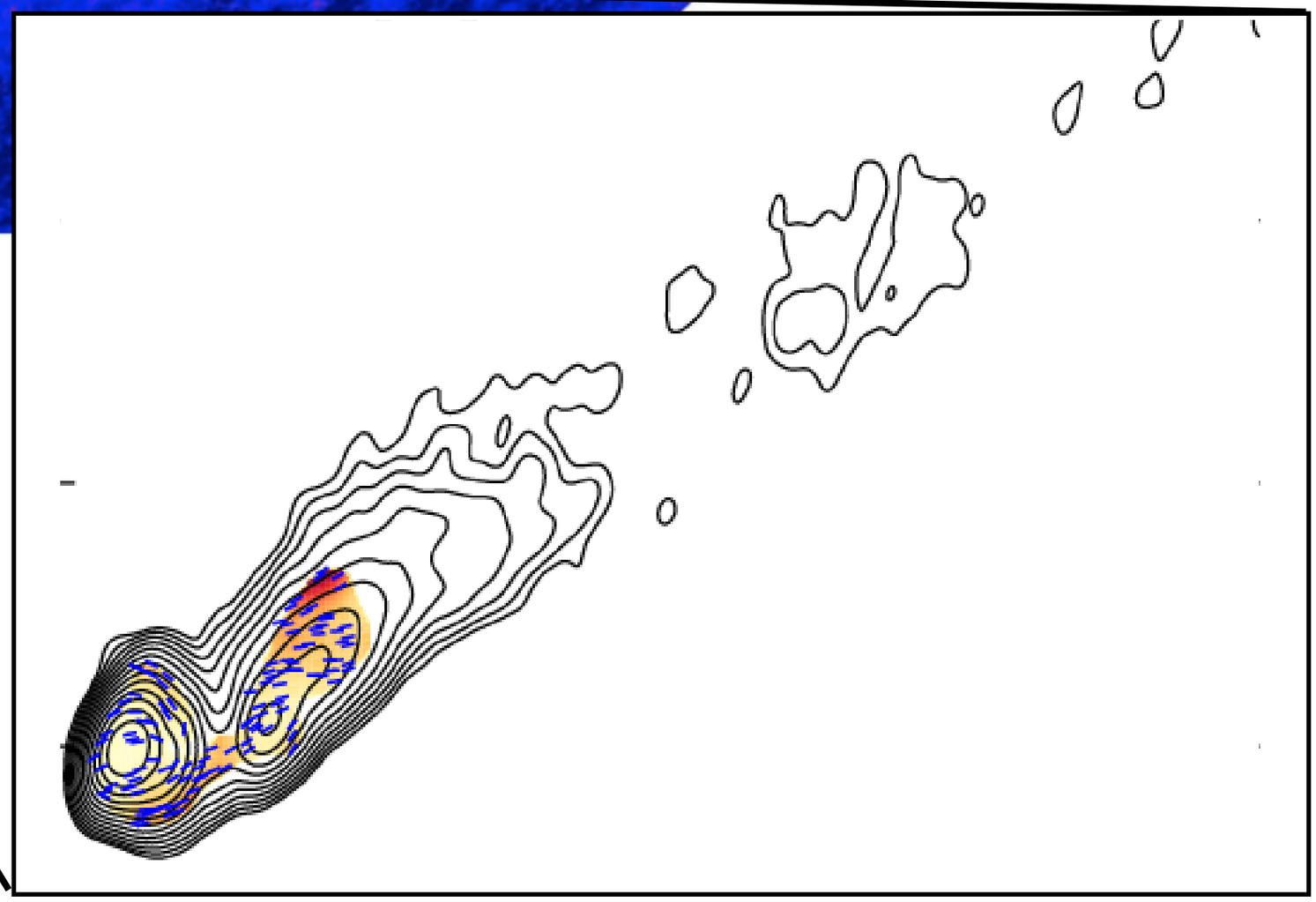




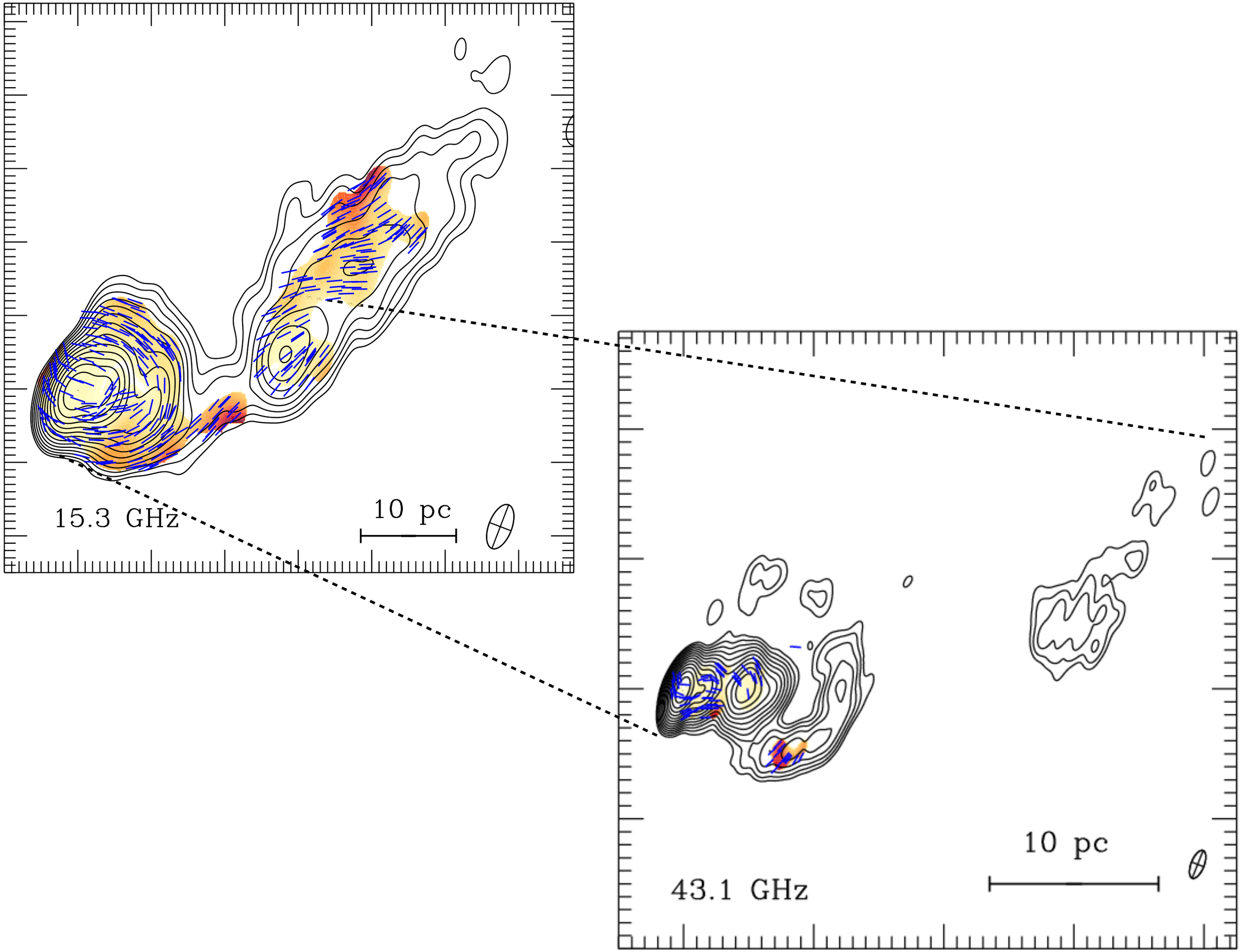


Fermi map of the γ-ray sky





3C454.3, quasar, z=0.859


15.3 GHz
10 pc
43.1 GHz
10 pc