Magnetic filaments in the nuclear outflow of NGC 253

Volker Heesen[1], Rainer Beck[2], Marita Krause[2], & Ralf-Jürgen Dettmar[3]

[1]University of Hertfordshire
[2]Max-Planck Institute for Radioastronomy
[3]Astronomical Institute of the Ruhr-University Bochum

Outline

- Motivation
- Introduction to NGC 253
- Transport of cosmic-ray electrons
- Magnetic fields in central outflows
- Summary & conclusions

Motivation

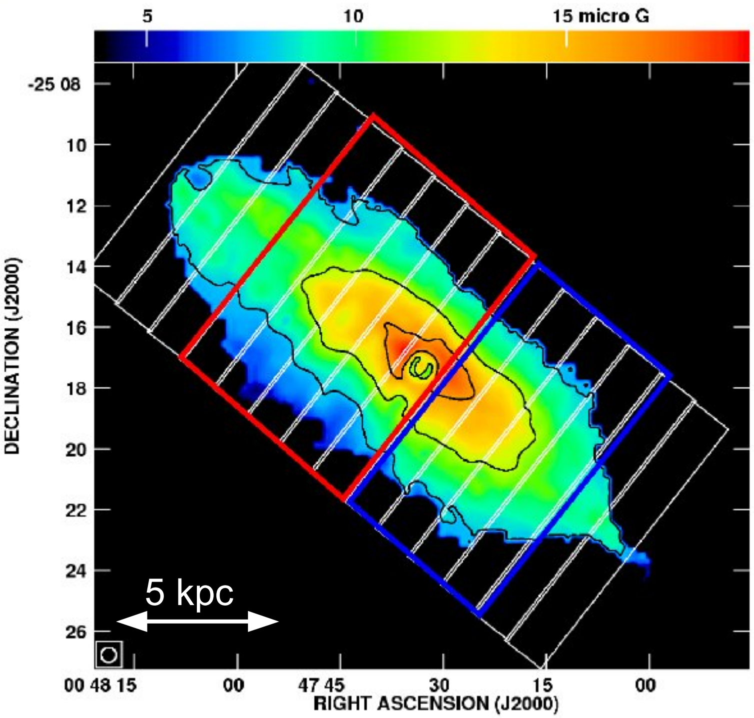
- Magnetic fields trace interaction in the ISM
- Nuclear outflow in radio emission
- Cosmic rays can drive outflows
- Magnetic field structure in galactic winds

R Jay Gabani

Cosmic-ray transport

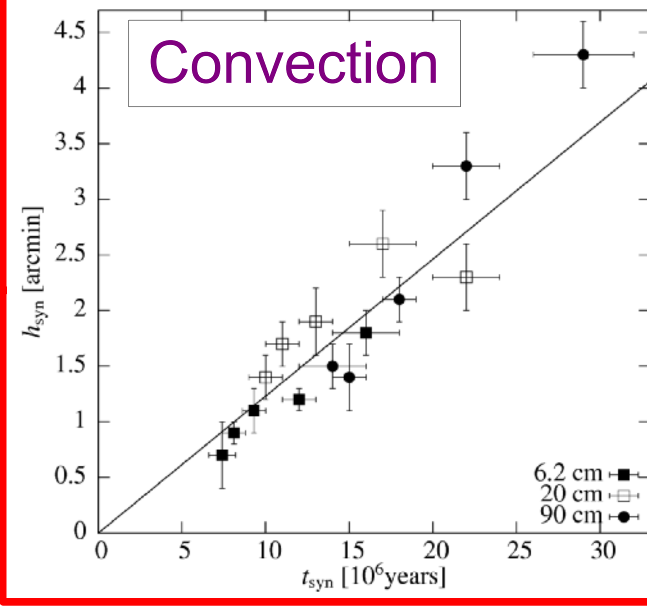
- Electron scaleheight vs. lifetime

Total magnetic field strength

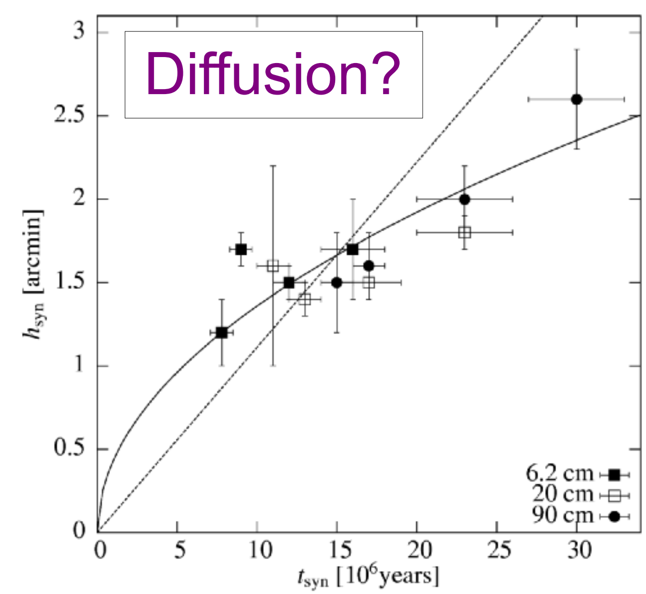


Heesen et al. 2009a

northeastern halo

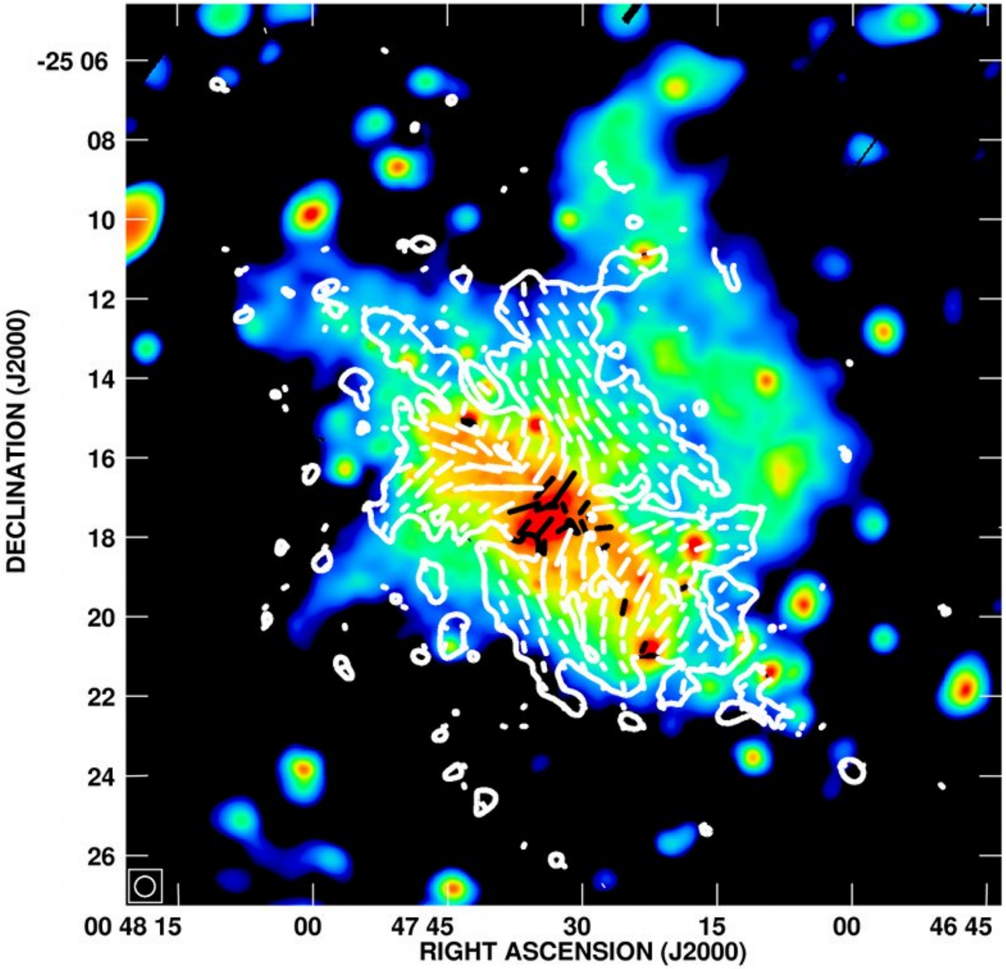


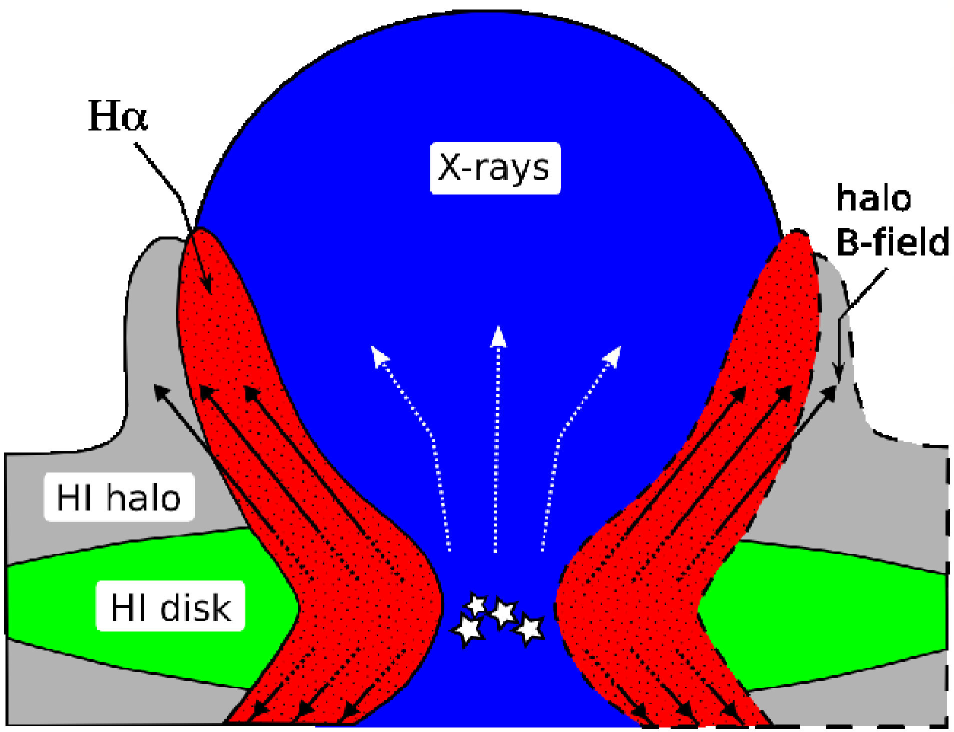
southwestern halo



Even parity halo field

NGC 253:
halo B-field + soft X-ray



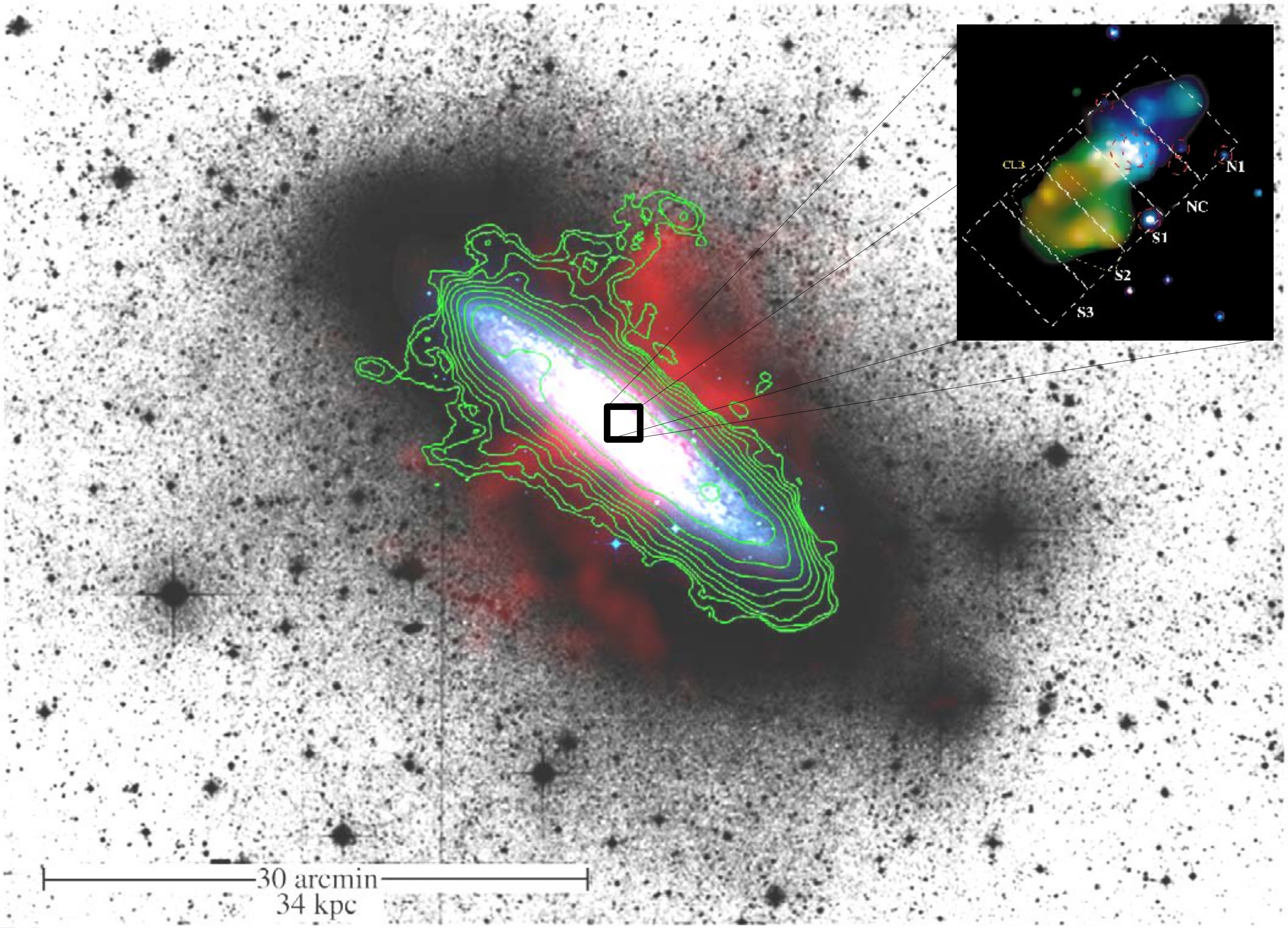


Heesen et al. 2009b

Nuclear starburst

- NGC 253 SN-rate: 0.03 – 0.2 yr^{-1}
- Milky Way SN-rate: (0.02 – 0.08) 10^{-2} yr^{-1}
- SFR = 1.8 – 2.8 M yr^{-1} (300 pc nuclear region)
- SFR = 3.5 – 4.3 M yr^{-1} (entire galaxy)
- No AGN detected (Brunthaler et al. 2009)

The nuclear outflow of NGC 253



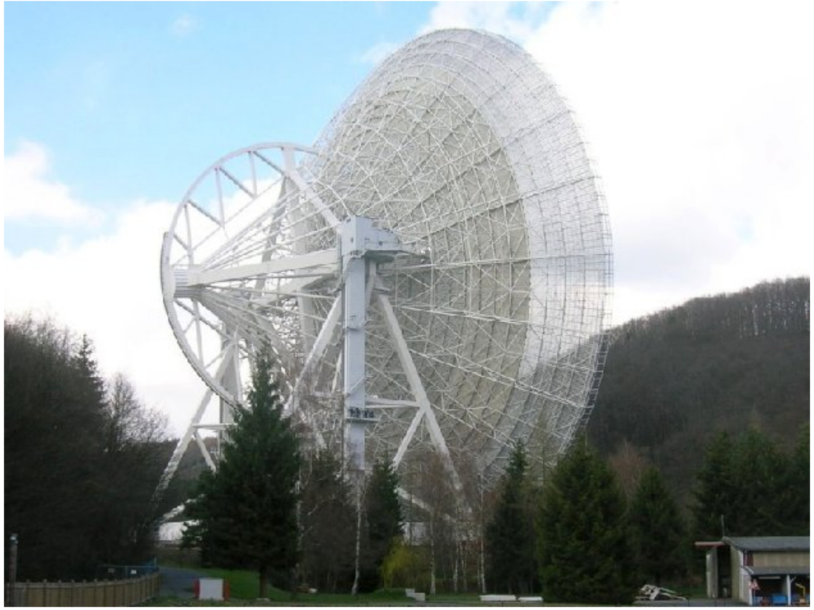
Inset: nuclear outflow in X-rays

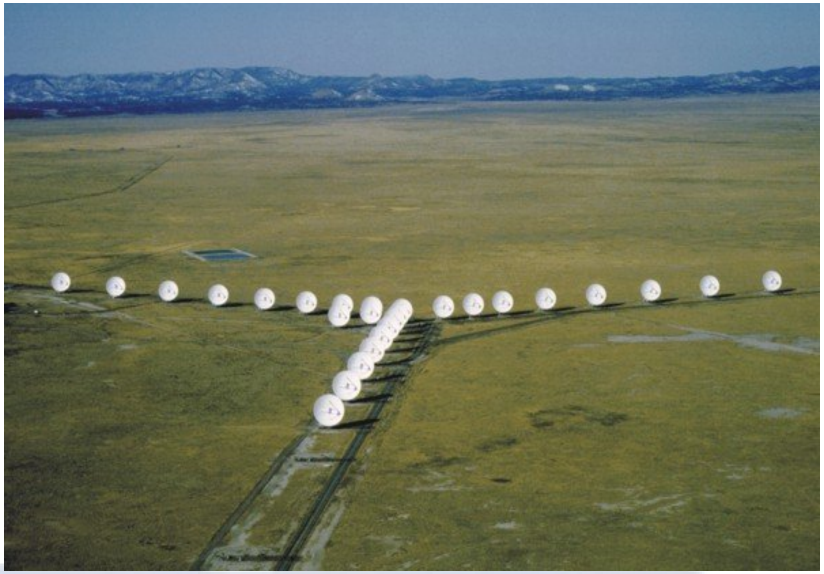
NGC 253
Red: X-rays
Green: HI
Background: Optical

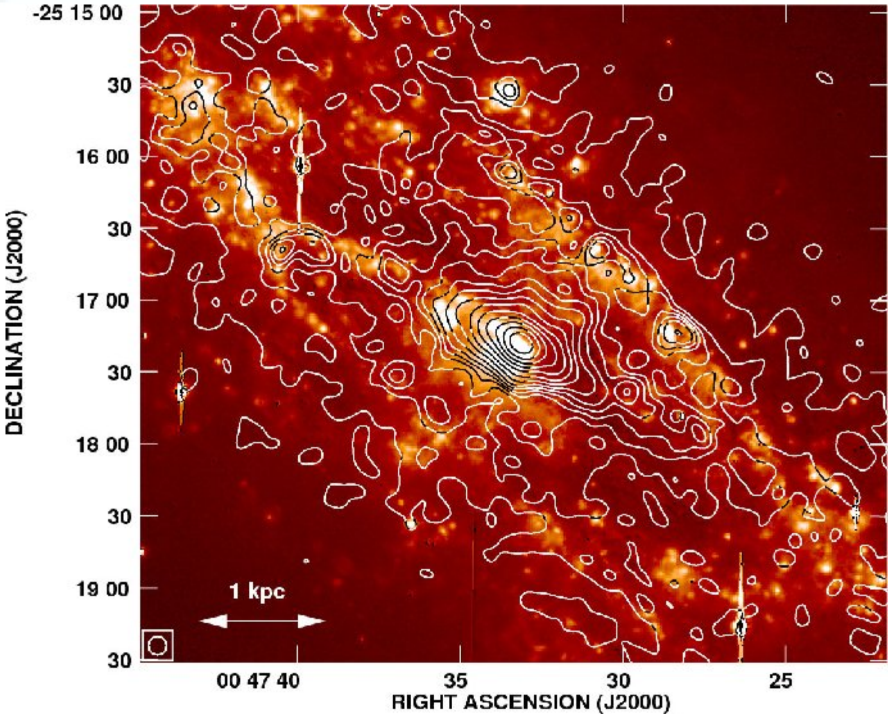
Boomsma (2005) + Strickland (2000)

Radio continuum observations

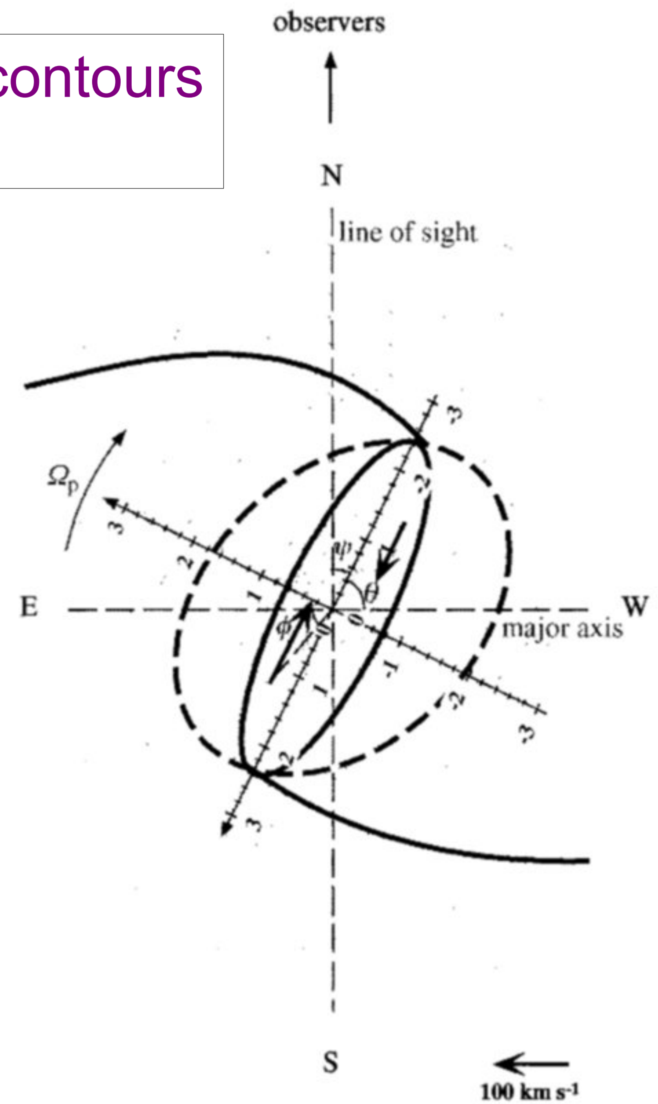
- Combination of VLA and Effelsberg

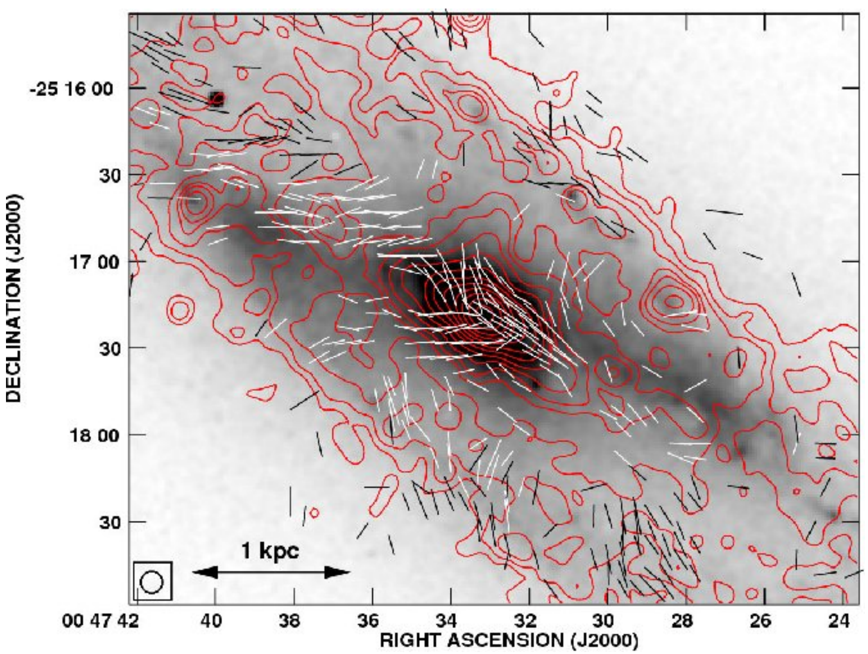






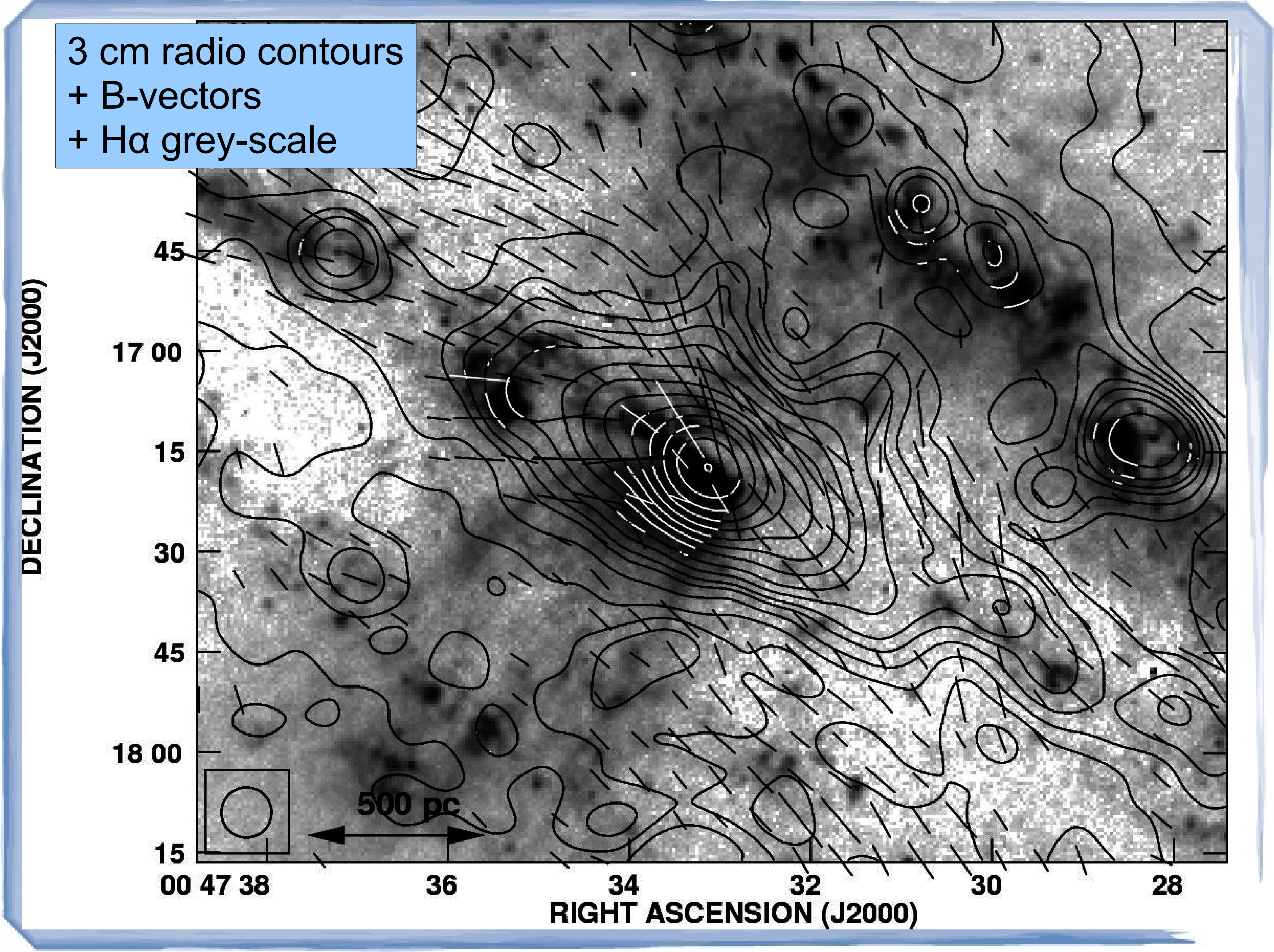
20 cm contours
+ Hα





6 cm contours
+ K-band

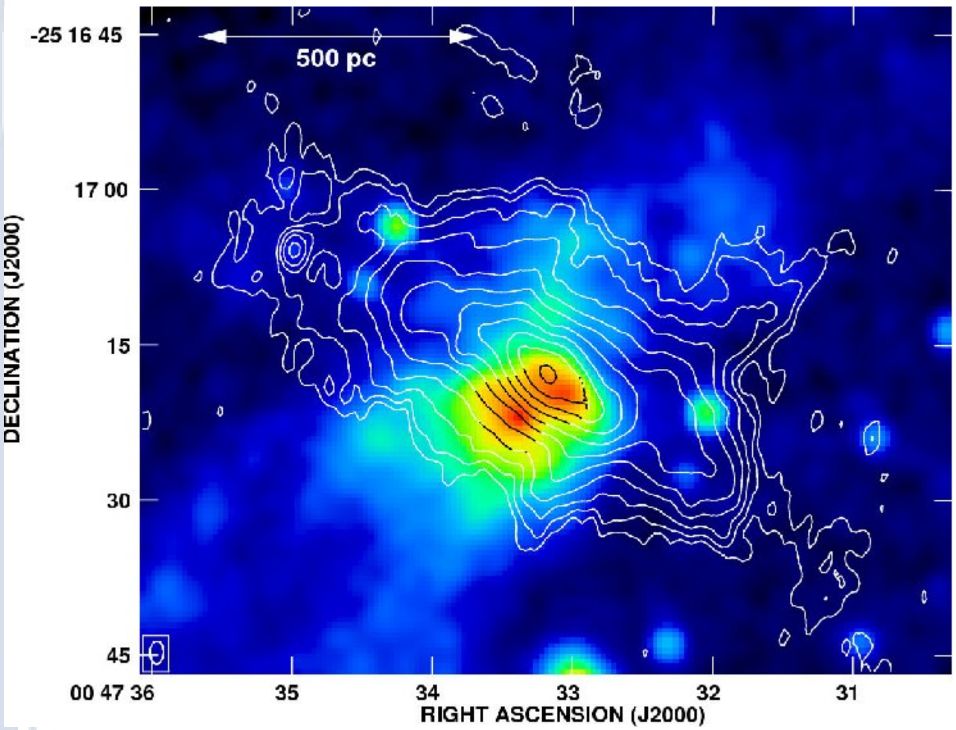
Sorai et al. 2000



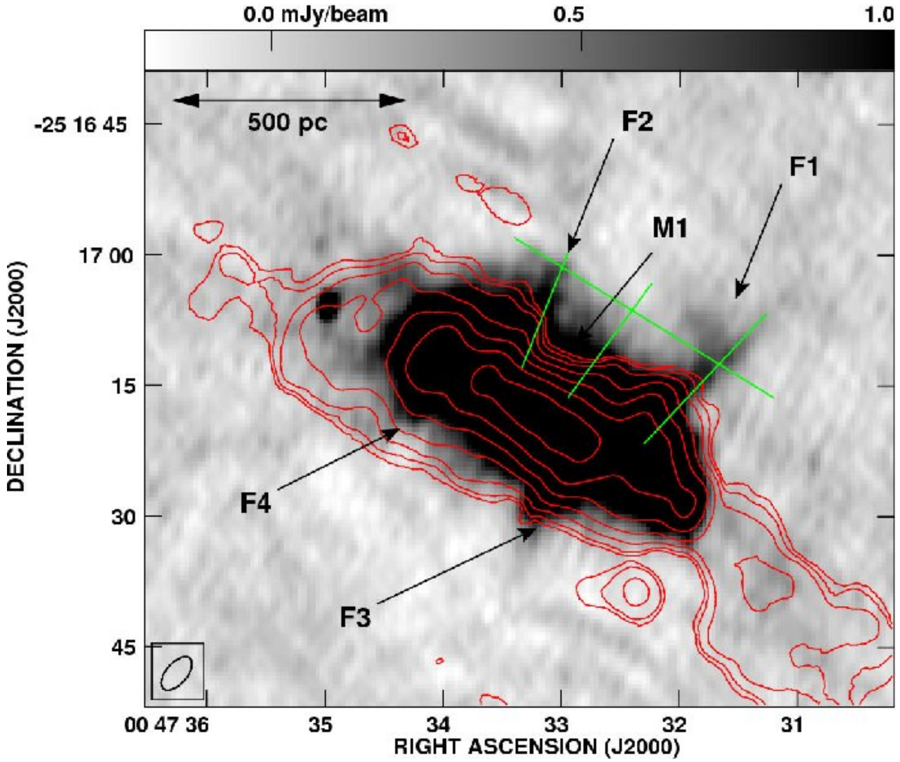
3 cm radio contours
+ B-vectors
+ Hα grey-scale
DECLINATION (J2000)
45
17 00
15
30
45
18 00
15
00 47 38
36
34
32
30
28
RIGHT ASCENSION (J2000)
500 pc

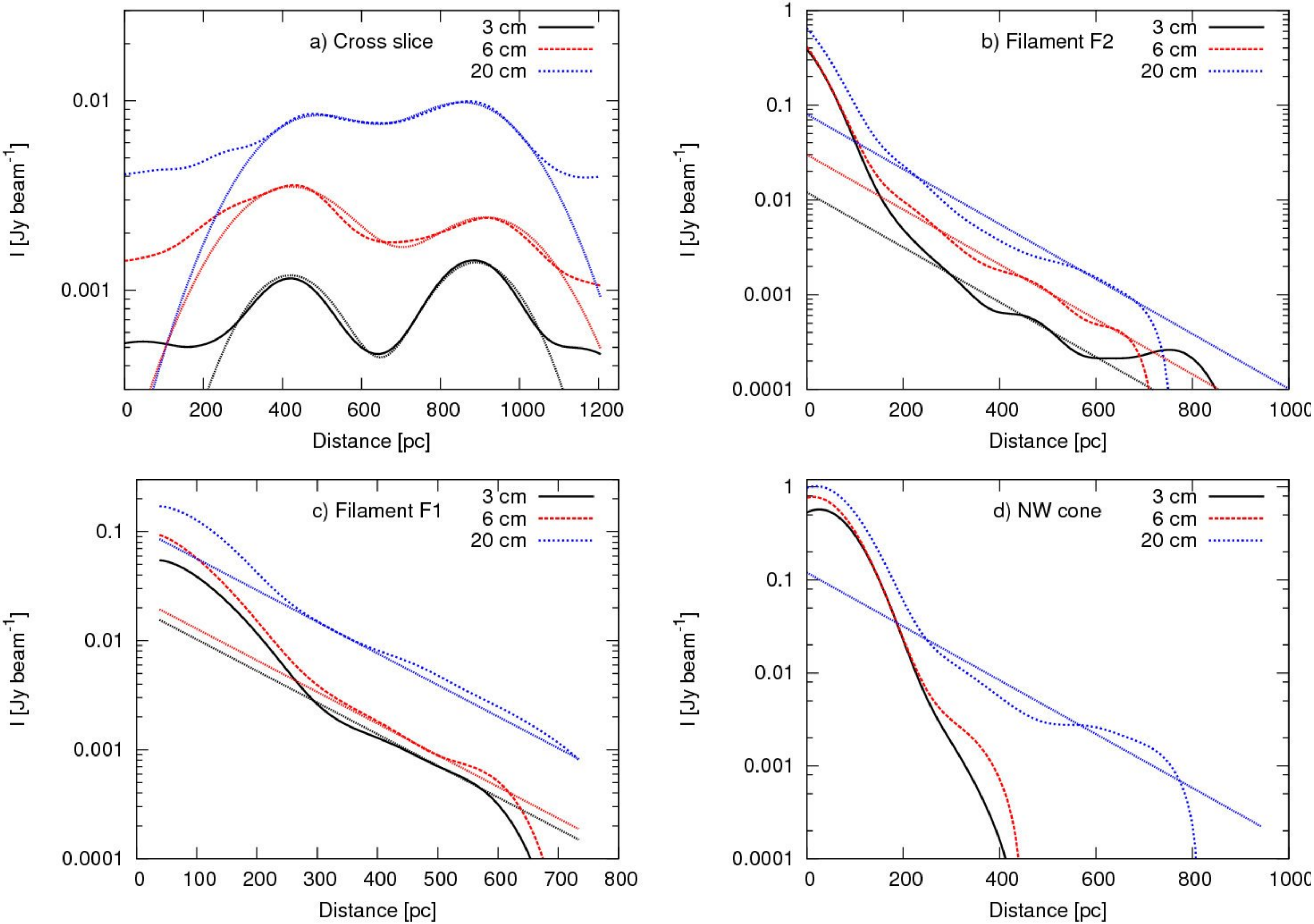
Radio filaments (in projection)

20 cm radio contours
+ Chandra X-ray emission



CO J=2-1 contours
+ 20 cm radio





a) Cross slice
b) Filament F2
c) Filament F1
d) NW cone
3 cm
6 cm
20 cm
I [Jy beam^{-1}]
Distance [pc]

Radio filaments

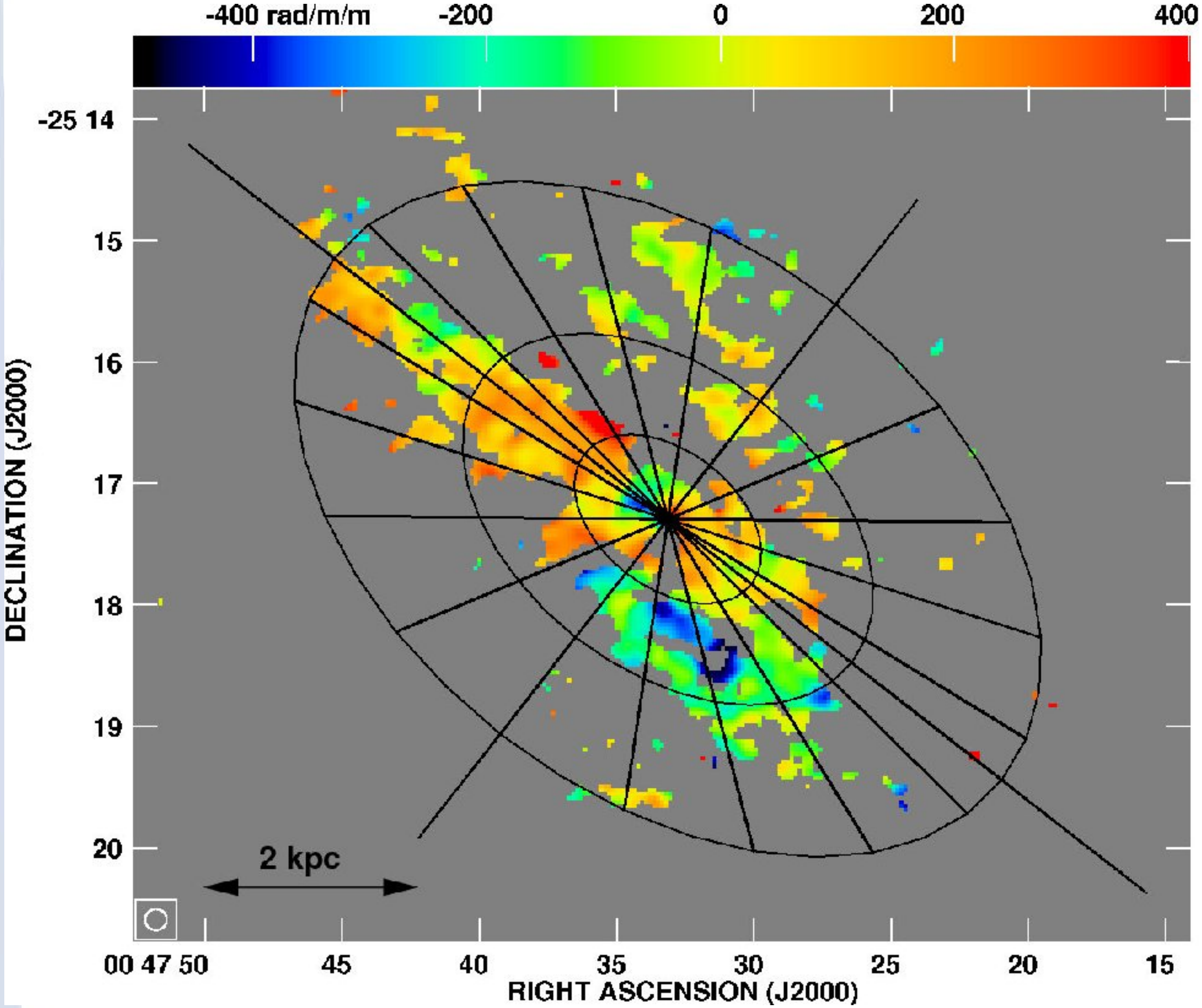
- Scaleheight in radio: 150 pc (20, 6 and 3 cm)
- Spectral index: -1 (non-thermal emission)
- Magnetic field strength: BT=45 muG (total) BO=22muG (ordered) (Equip. K=100)
- Width: <40 pc
- Opening angle: 26 degree (agrees with Chandra)

Cosmic ray transport

- Synchrotron + inverse Compton losses
- Electron lifetime < 1-2 Myr (3-20 cm)
- Constant radio scaleheight: strong adiabatic losses, v >= 300 km s^{-1}
- Filament width: 330 pc (20cm), 350 pc (6cm), 250 pc (3 cm)
- Width ~ kappa * sqrt(lifetime)
- Perpendicular diffusion coefficient: kappa = 1.5×10^{28} cm^2 s^{-1} $E^{0.5+/-0.7}$

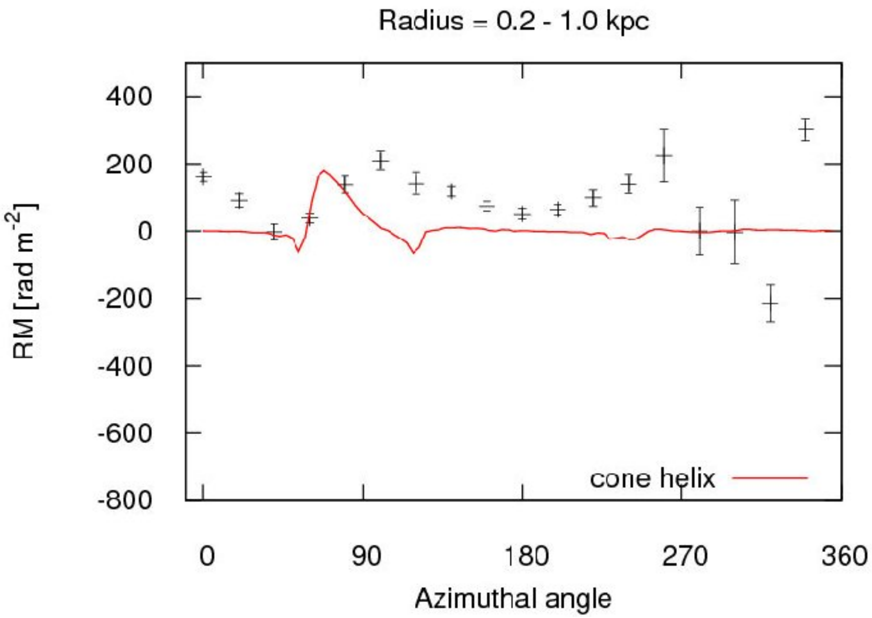
Faraday rotation (= LOS B-field)

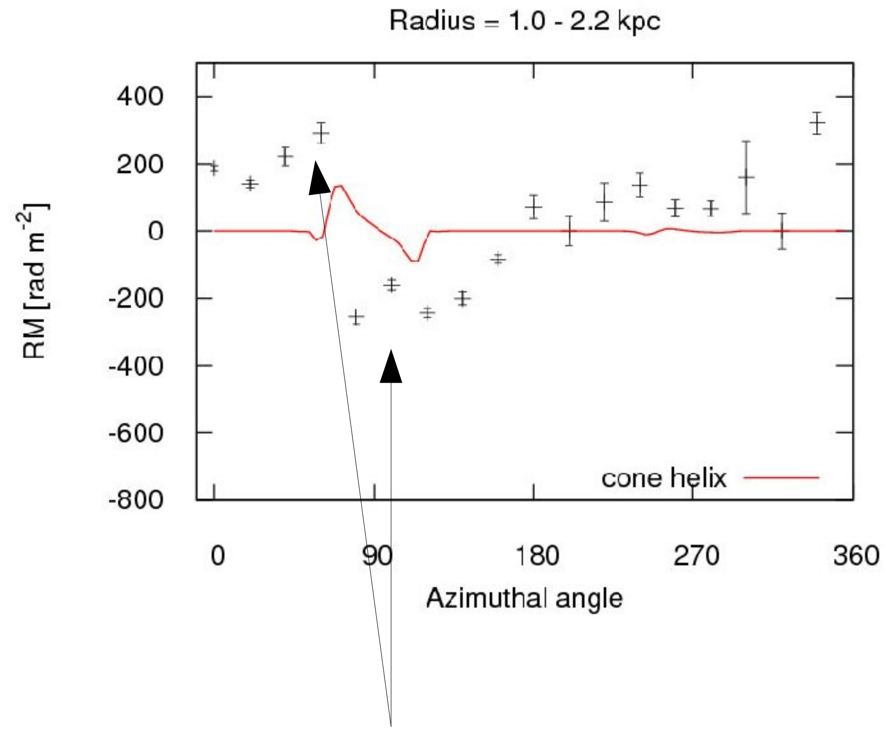
Rotation measure 6/3 cm

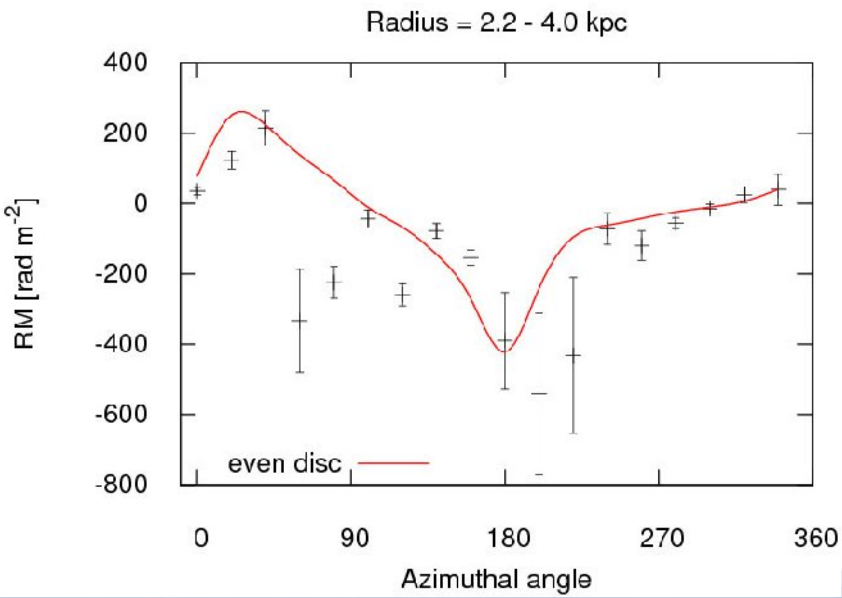


- Line-of-sight B-component
- No ASS field

Azimuthal RM variation







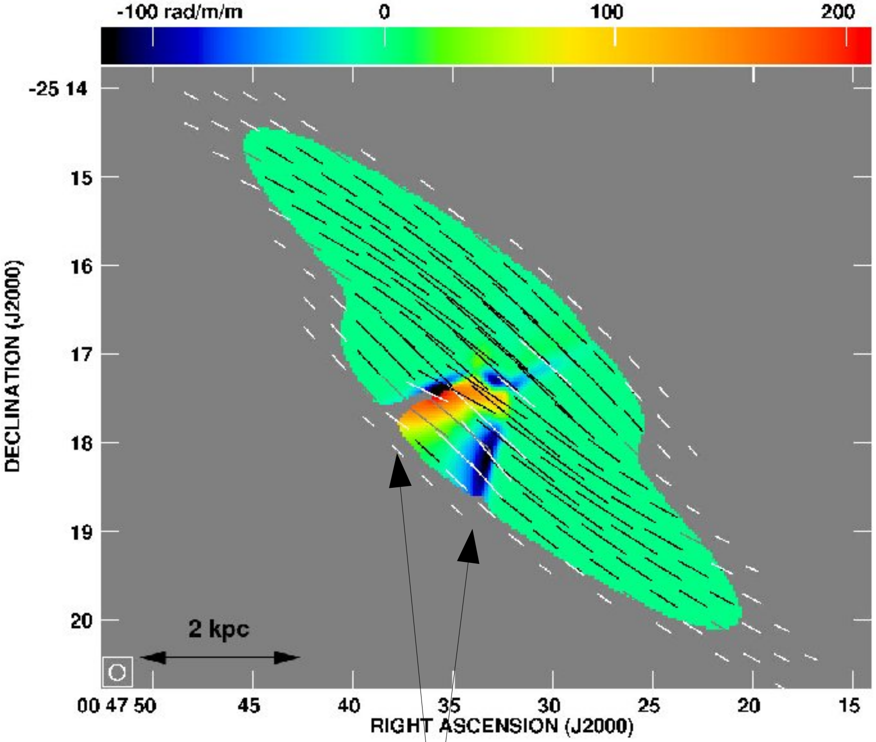
Field reversal

Model assumptions

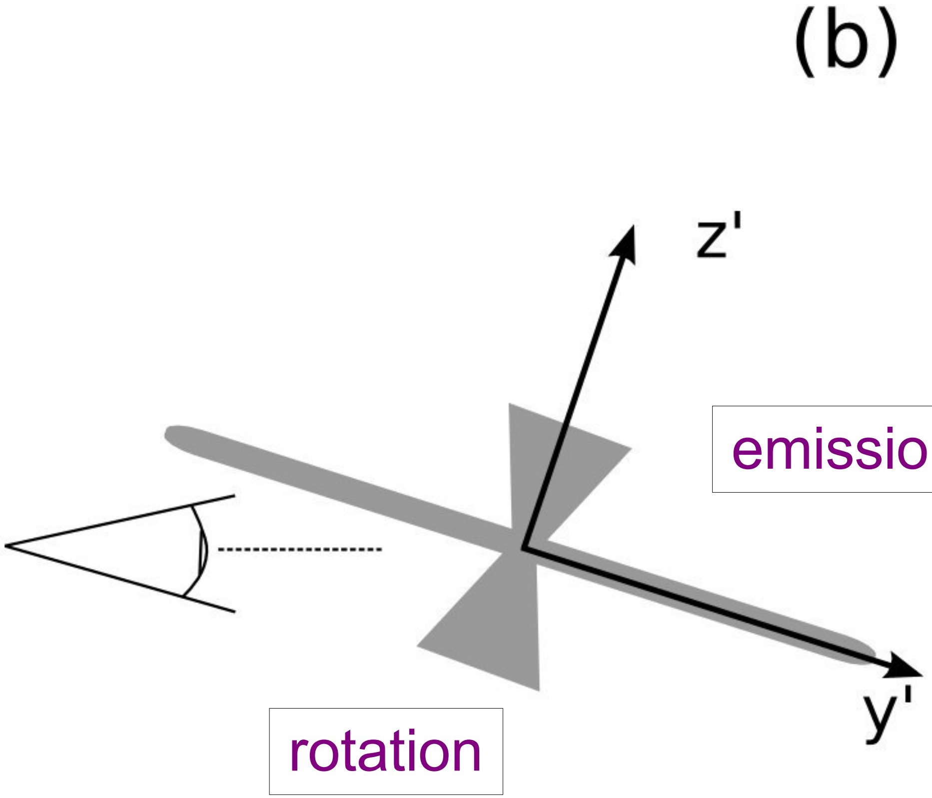
Parameter	Value	Notes
Filament width	40 pc	from λ20 cm
Base length	300 pc	from λ20 cm
Disc field scaleheight h_B^{disc}	1.6 kpc	thin radio disc
Disc field strength B_0^{disc}	4.4 μG	from equipartition
Filament field strength B_0^{fil}	20 μG	from equipartition
Electron density n_e	2 cm^{-3}	from Hα and soft X-ray
Electron scaleheight h_e	1400 pc	from Hα
Cone opening angle 2β	45°	
CRE scaleheight disc	800 pc	thin radio disc
CRE scaleheight filament	200 pc	filaments
Filament field scaleheight h_B^{fil}	600 pc	from equipartition

Model rotation measure

Rotation measure 6/3 cm

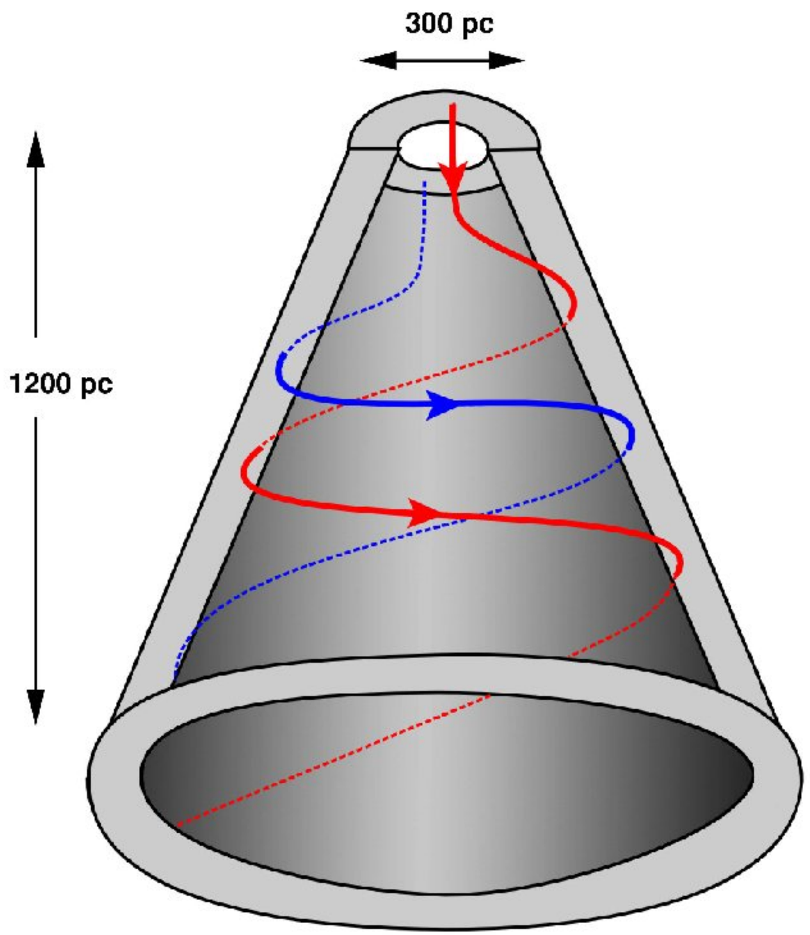


Field reversal



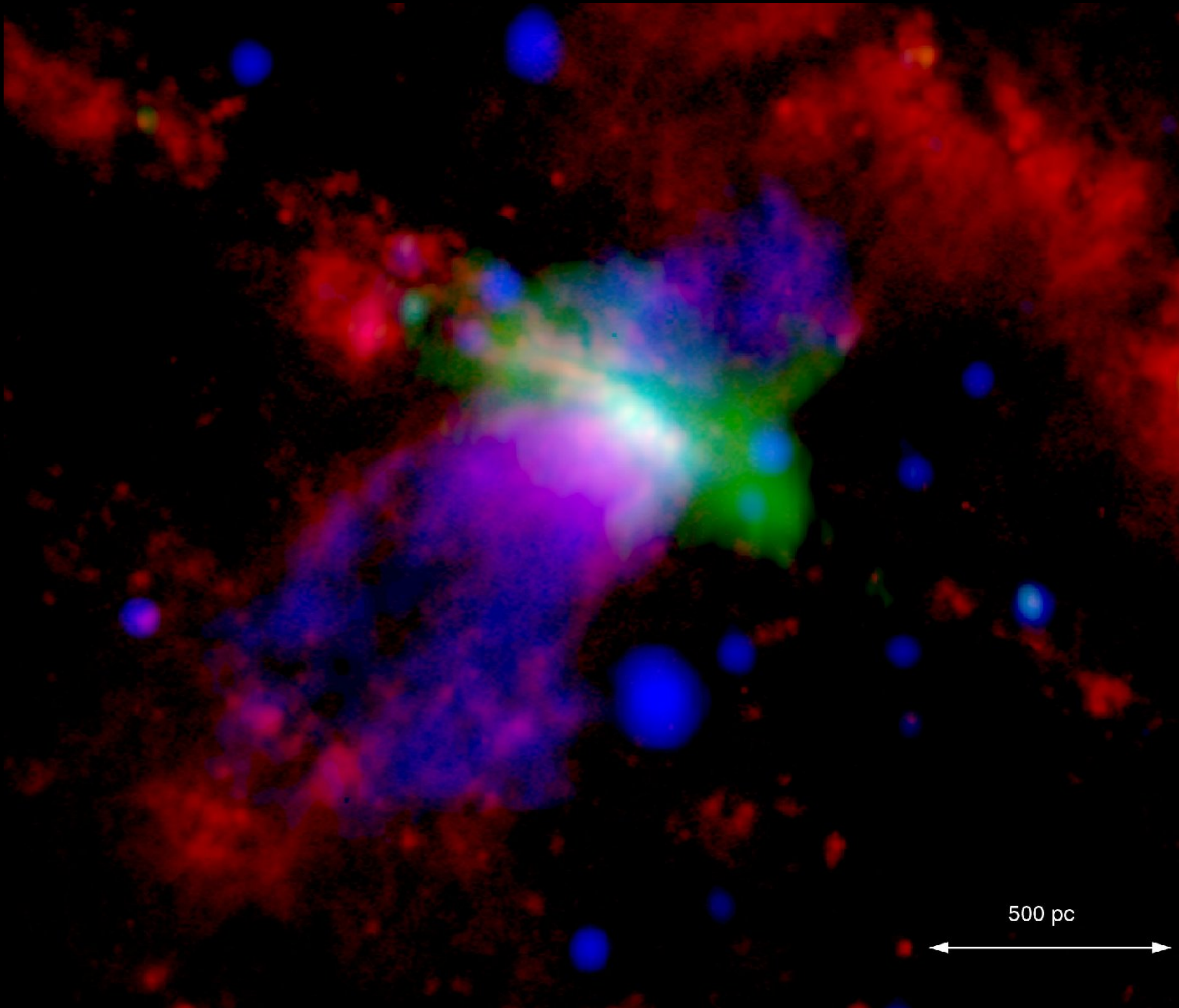
Helical magnetic field

- Radius > 2 kpc: even-parity field in the disc
- Radius < 2 kpc: anisotropic disc field + helical field in nuclear outflow
- "Garden sprinkler" model



Conclusions

- Filament scaleheight 150 pc
- Filament width < 40 pc
- Outflow speed > 300 km/s
- Even parity disc + halo field
- Helical fields in the outflow
- Filaments: 46 / 21 μG (total / ordered)
- Can collimate outflow


500 pc