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The Magnetic field in M31

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Mainz, 10.7.2012

Rainer Beck, Elly Berkhuijsen, George Heald, Andrew Fletcher

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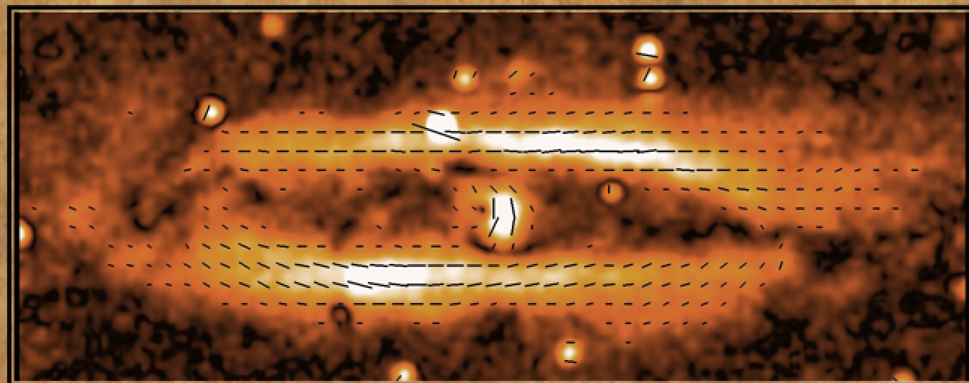
WANTED

BRIGHT OR DEPOLARIZED



THE MAGNETIC FIELD OF M31

AT 350,000,000 HZ

"Howdy, stranger!"

short introduction

distance:
~2.5 mio.lyr / 780 kpc
(690 kpc)

position angle of the major axis:
37°

inclination:
~77° (center ~45°?)

diameter:
~200 000 lyr / 50 kpc
(2x Milky Way)

avg. magnetic field:
~6 μG

infrared: ESA/Herschel/PACS/SPIRE/J. Fritz, U. Gent;
X-ray: ESA/XMM-Newton/EPIC/W. Pietsch, MPE; optical: R. Gendler

M31 at 6 cm (Effelsberg)

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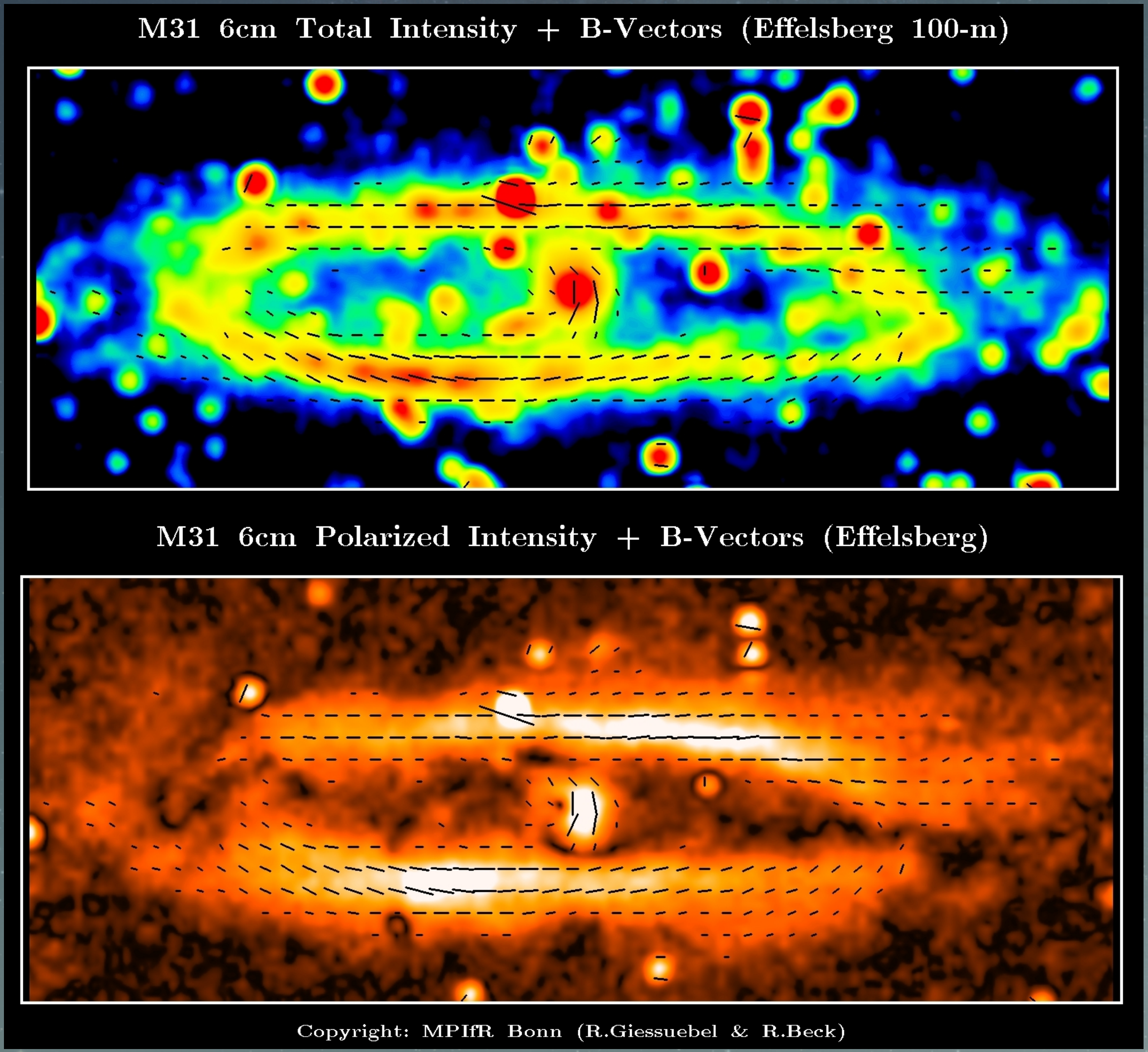

Effelsberg 6 cm/4850 MHz
HPBW: 156"
rms (I, PI): 290, 55 μJy/beam
Field: 140'x80'

polarized "ring"
m=0 mode dominant
R. Beck (1982)

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The magnetic field of M31

Dynamo at work

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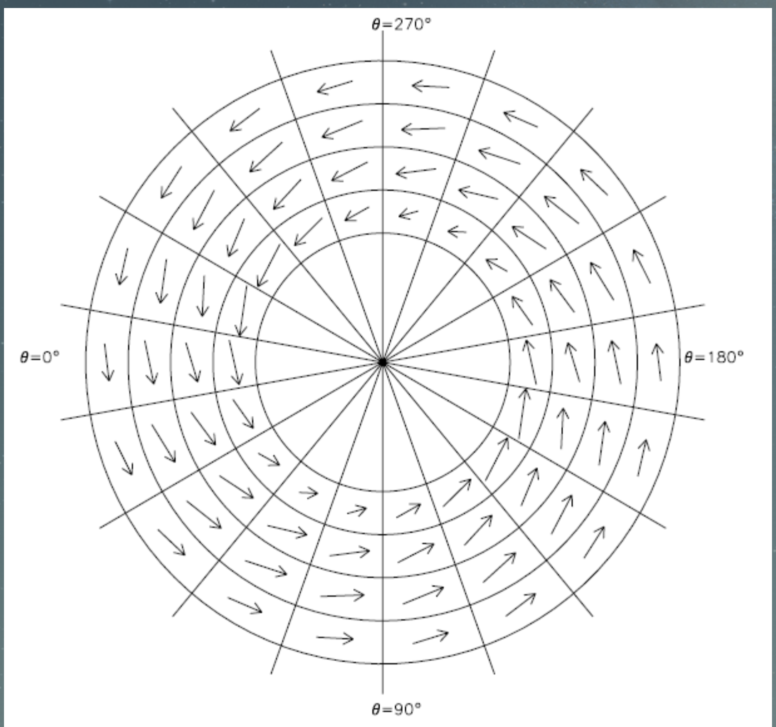
non-zero pitch angles
axis-symmetric spiral field

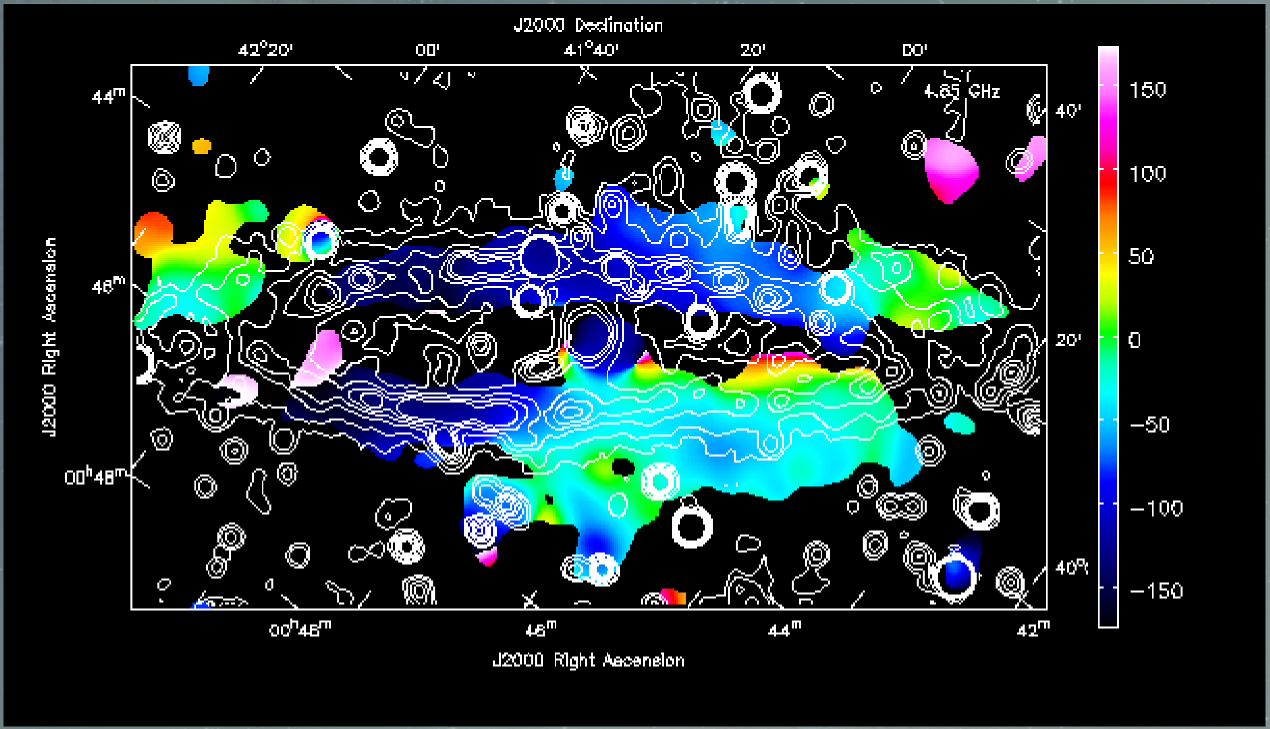
hint for a dynamo (m=0 mode)

RM map: regular field

⟶ dynamo



Fletcher et al. (2004)



new RM map (11cm,6cm), contours: 6cm Effelsberg
(11cm from David Mulcahy)

M31 at 92 cm
Westerbork Observation

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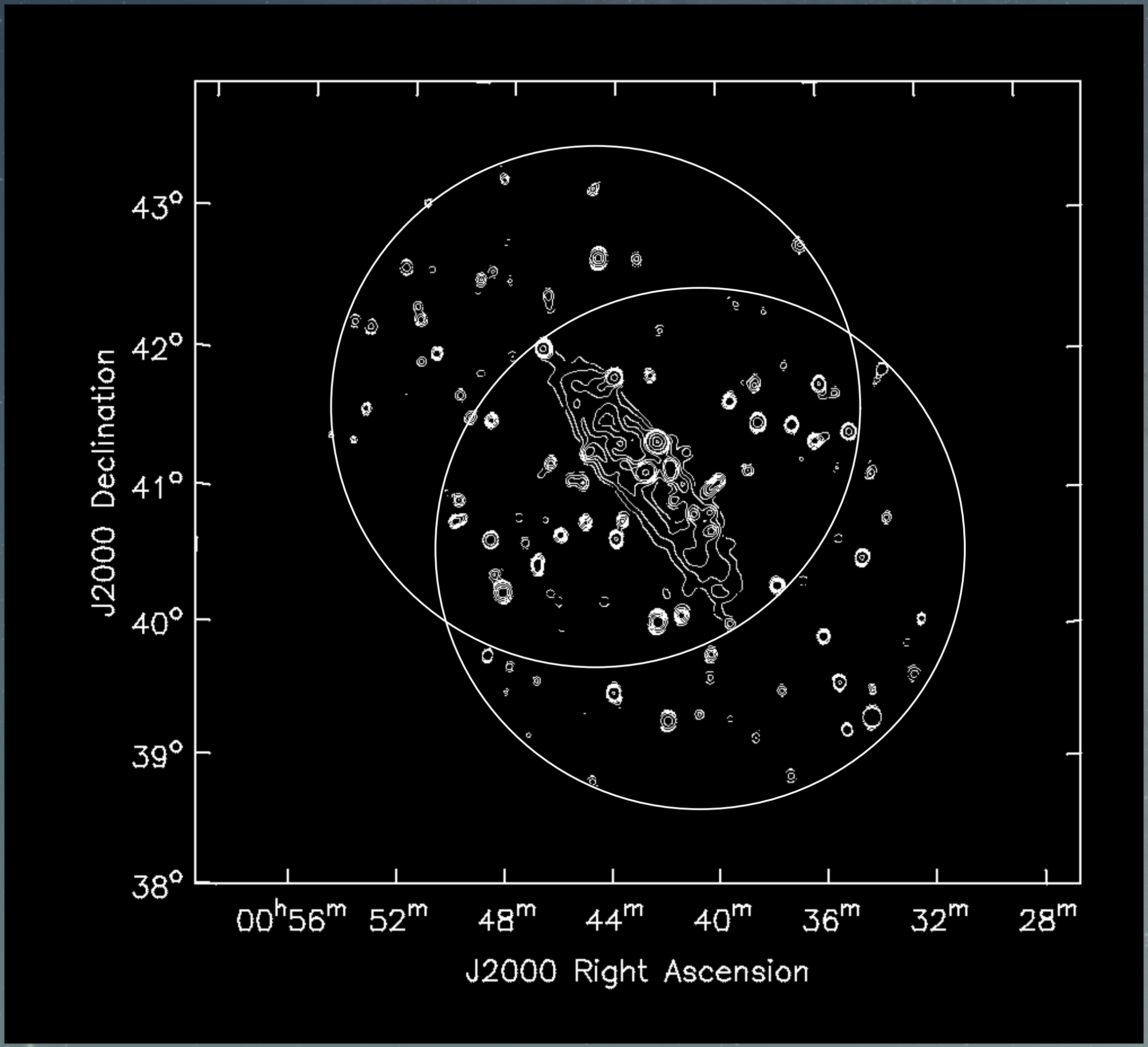

Summary:

Observation date:
December 2008

mosaic of 2 fields
24h on each field
over 4 days

8 x 128 channels
310-390 MHz
ChanWid (kHz): 78.125
TimeInt (s): 60

M31 at 92 cm

Total Power

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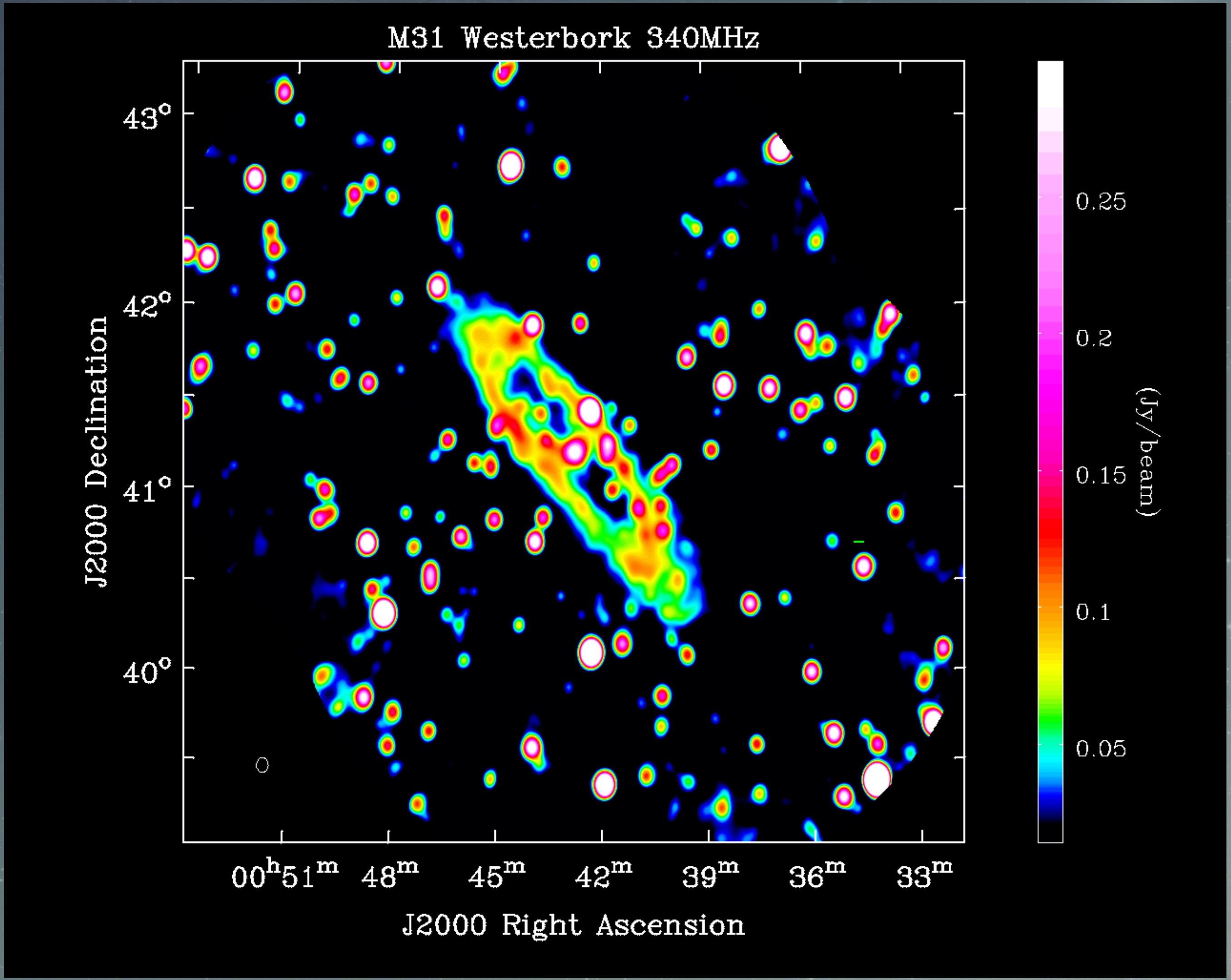

HPBW: 300”, rms: 0.014 Jy/beam

RM Source Catalog

RM map of the sources

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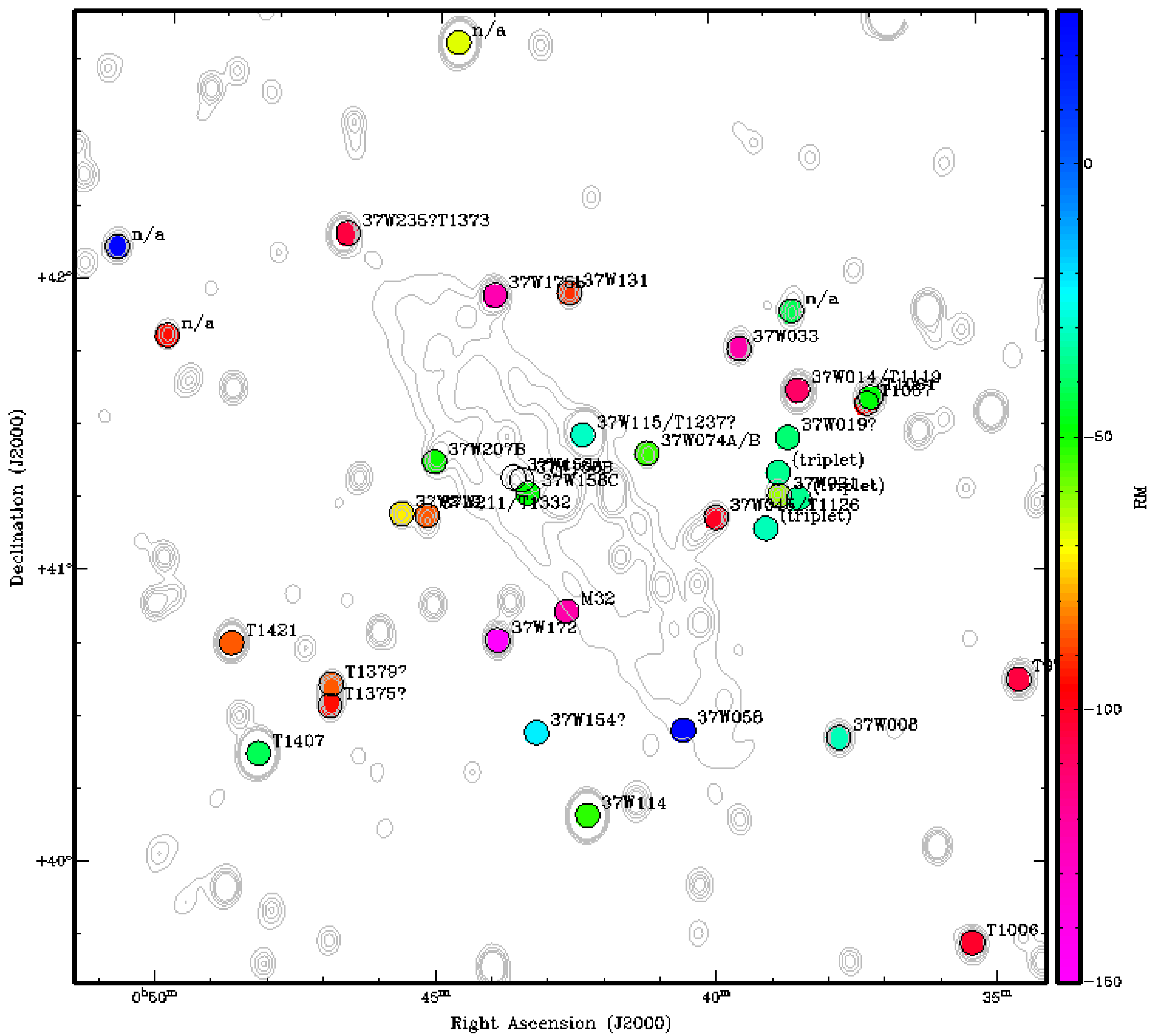

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RM Source Catalog

“foreground map” (handle with care)

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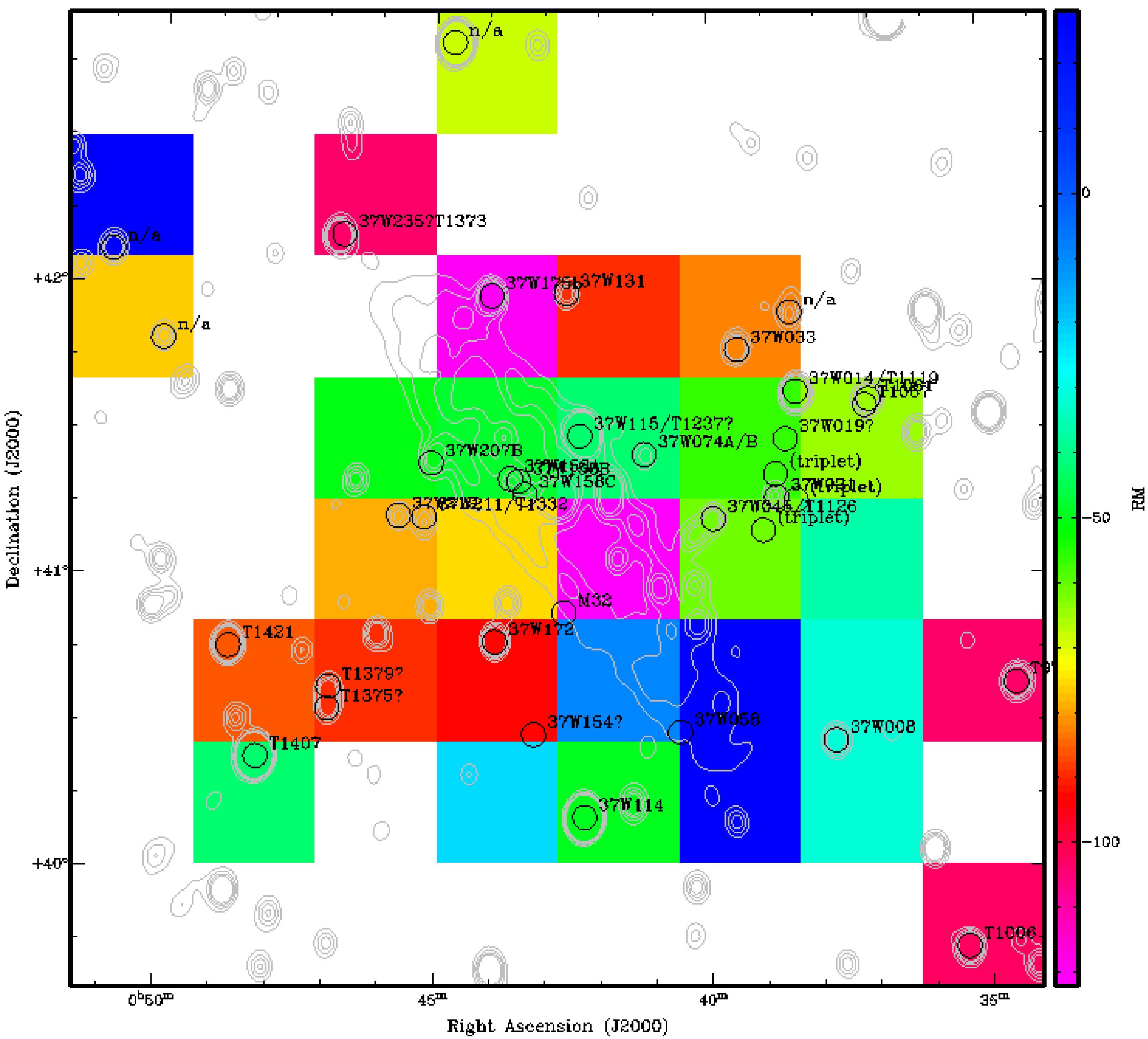

RM Source Catalog

comparison of RM with literature values

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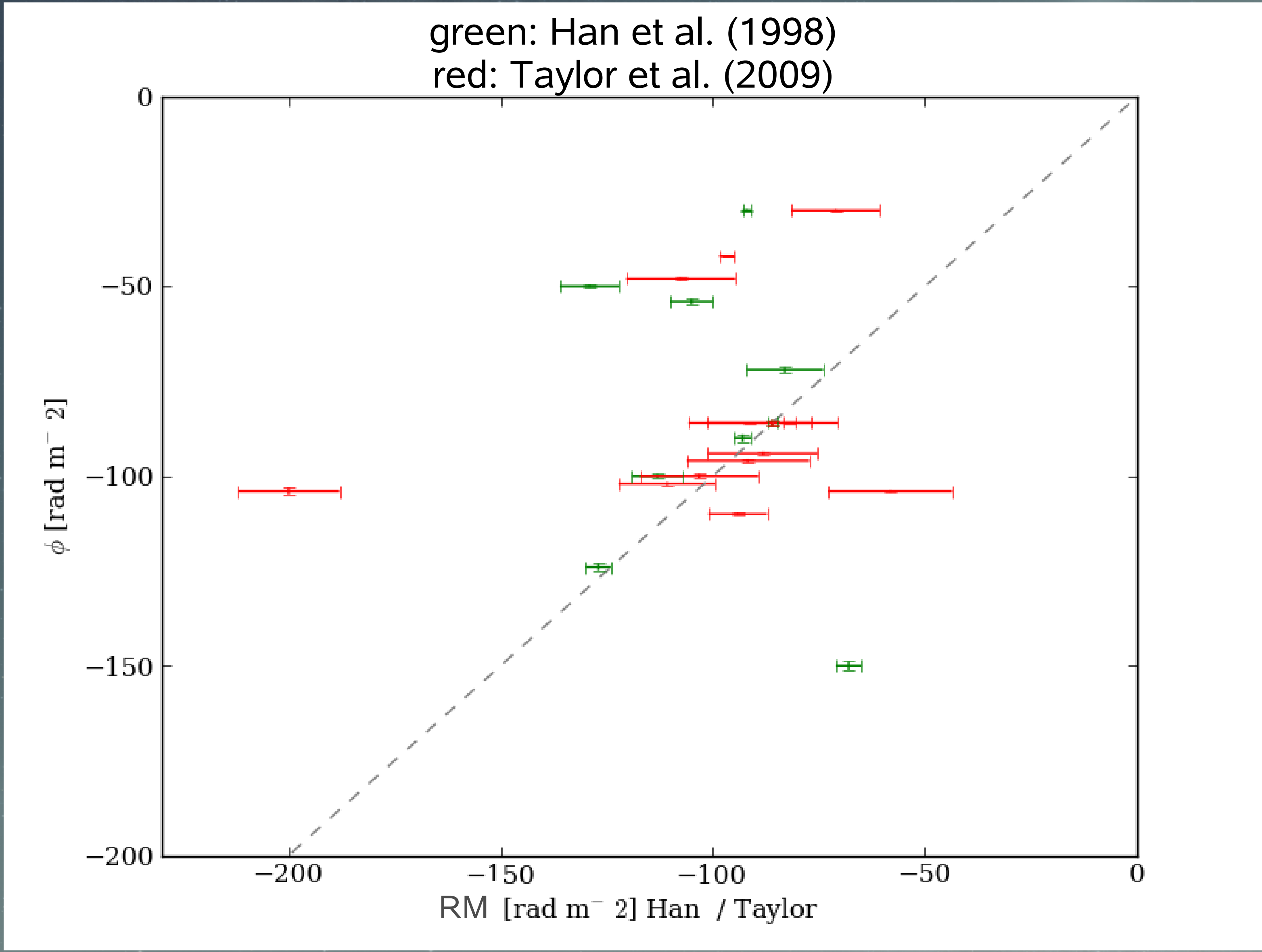

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comparison of RM with literature values

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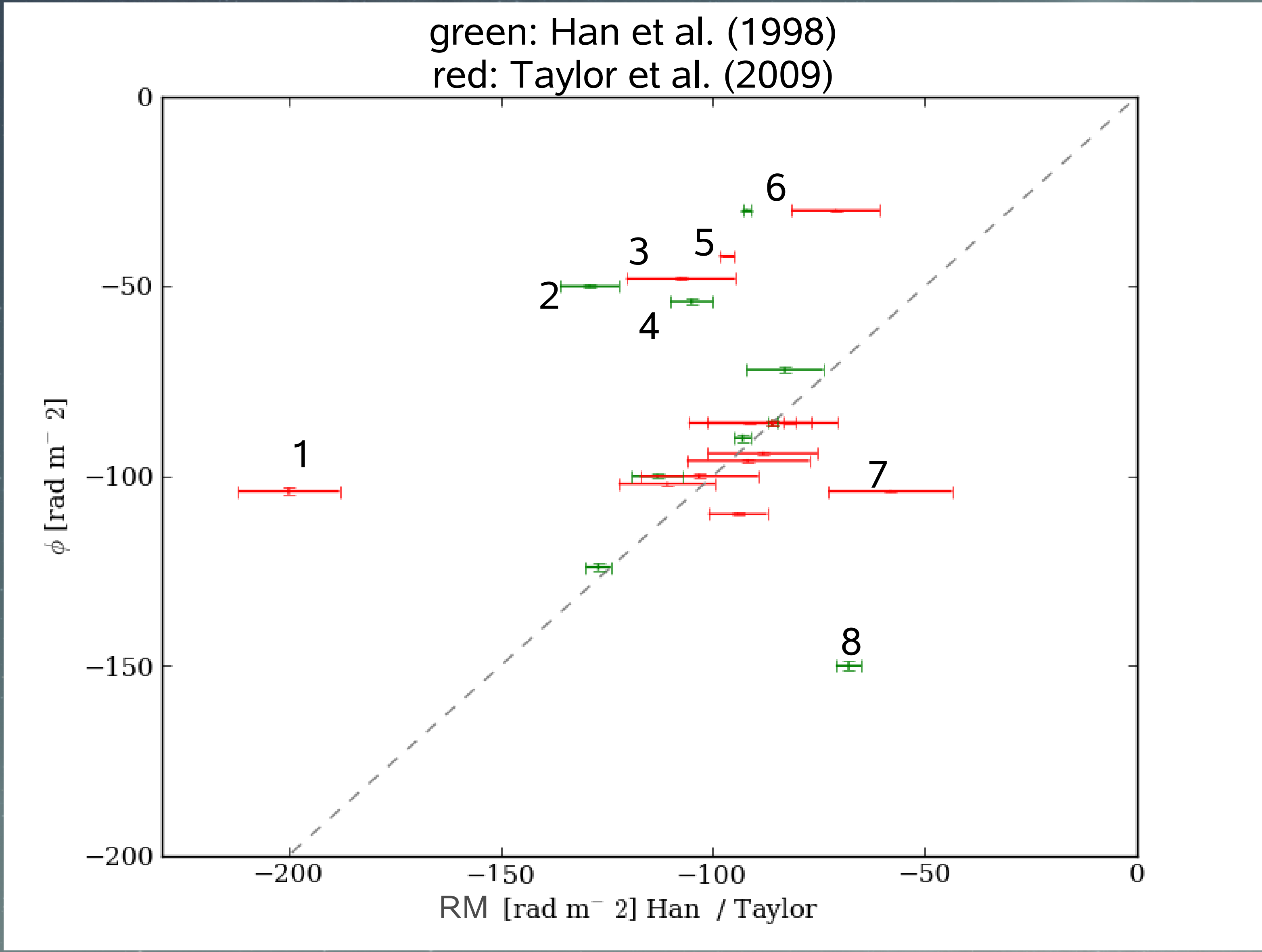

RM Source Catalog

where are the bad guys?

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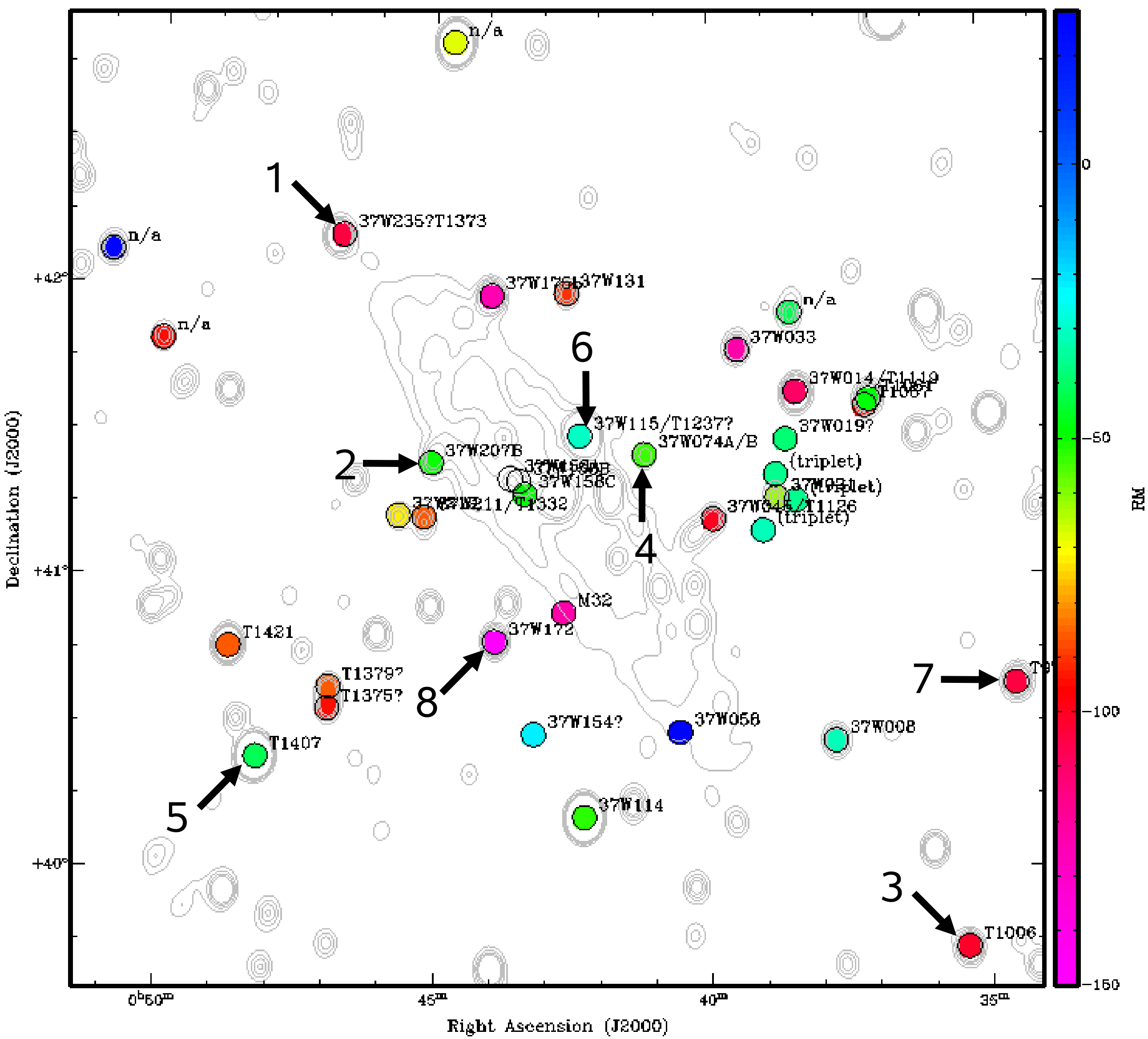

RM Source Catalog

depolarization of the sources

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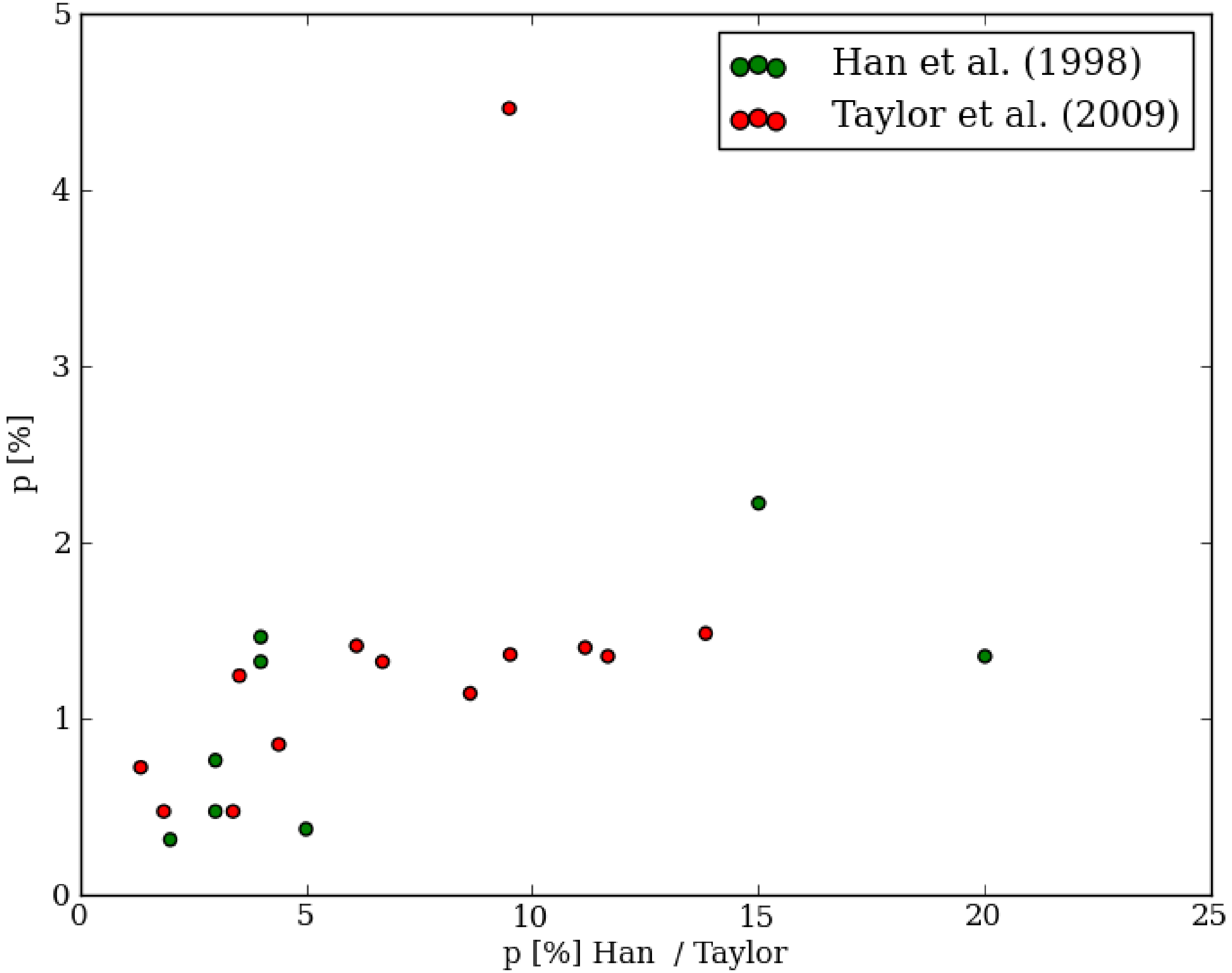
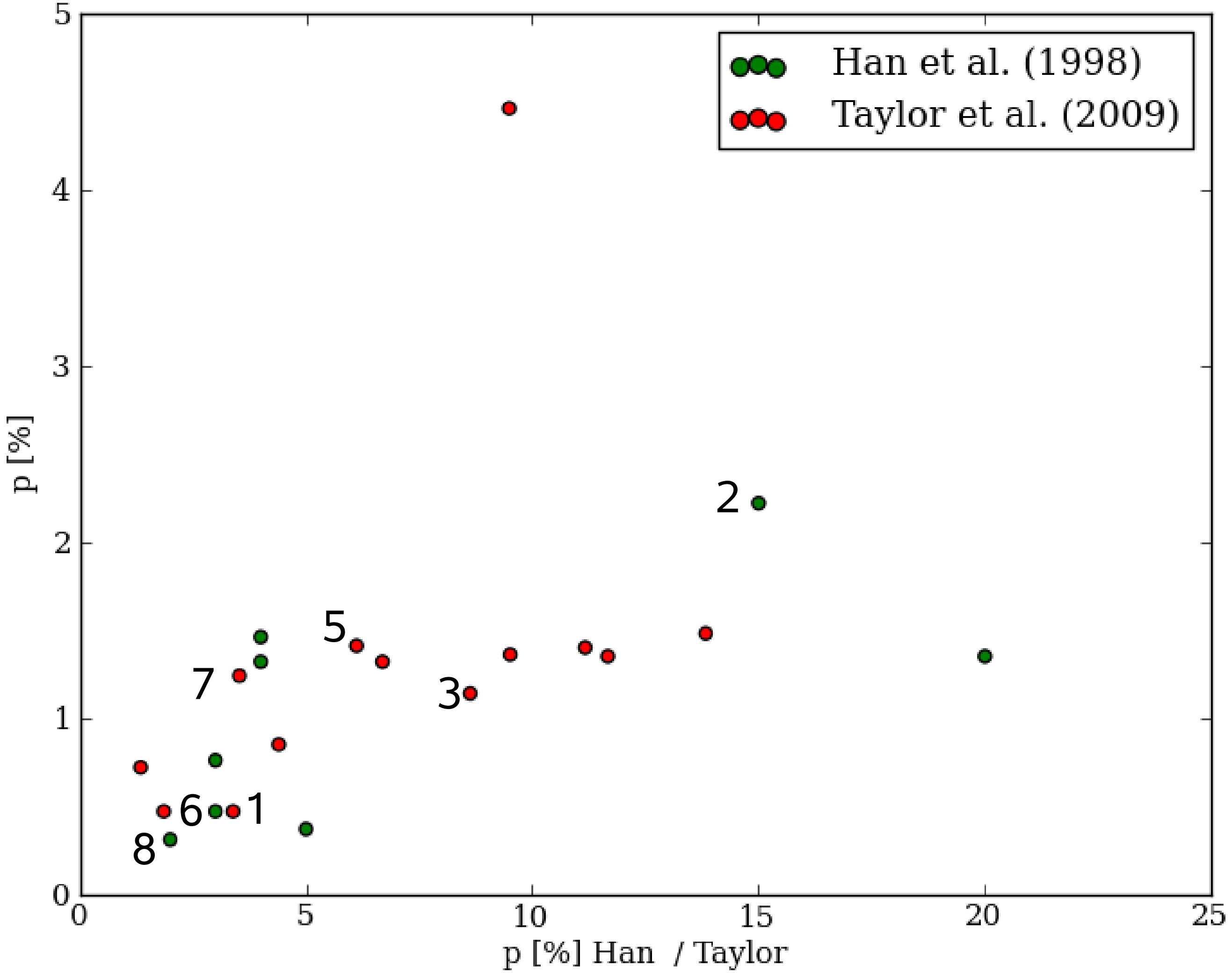
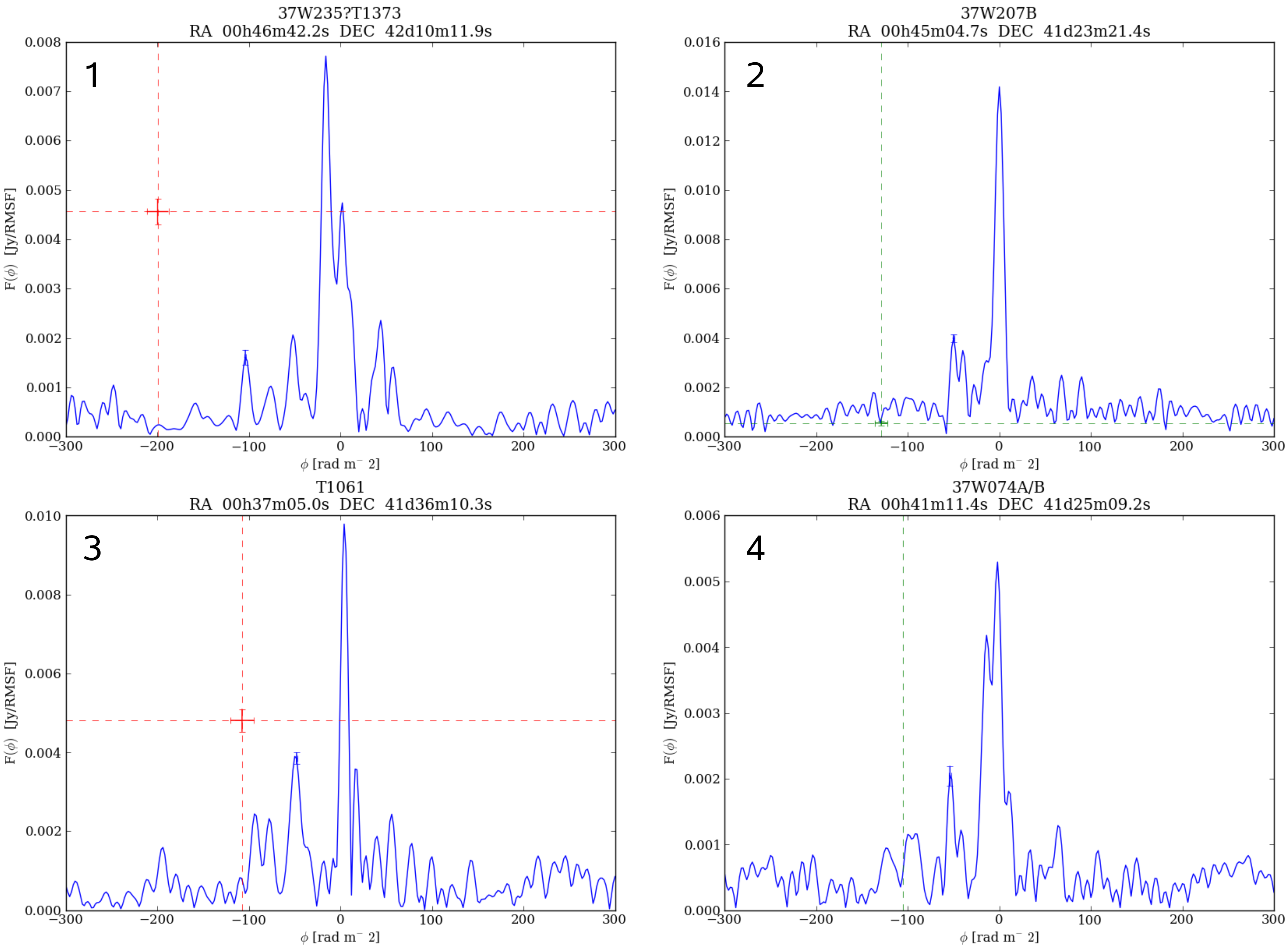
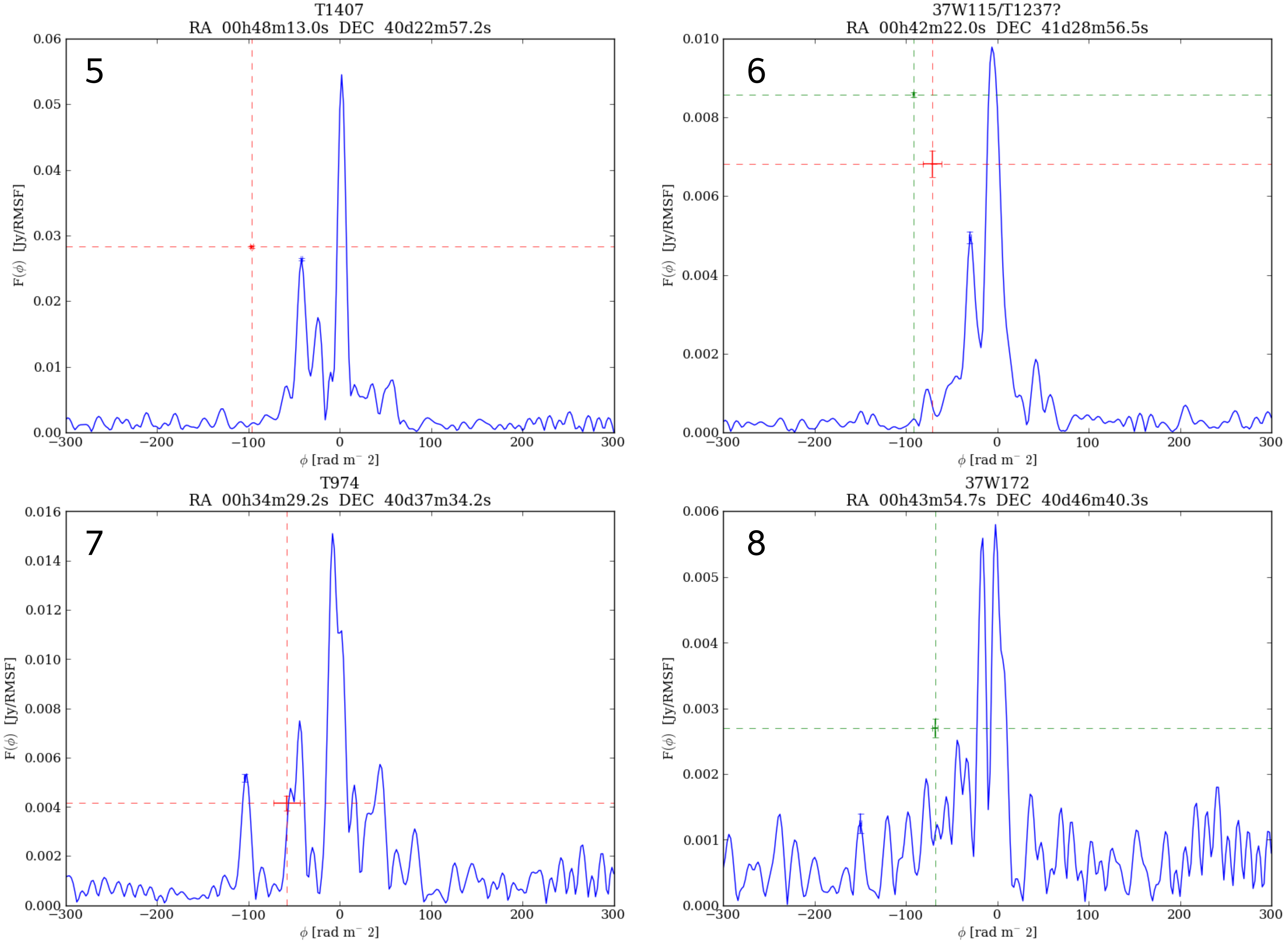


RM Source Catalog

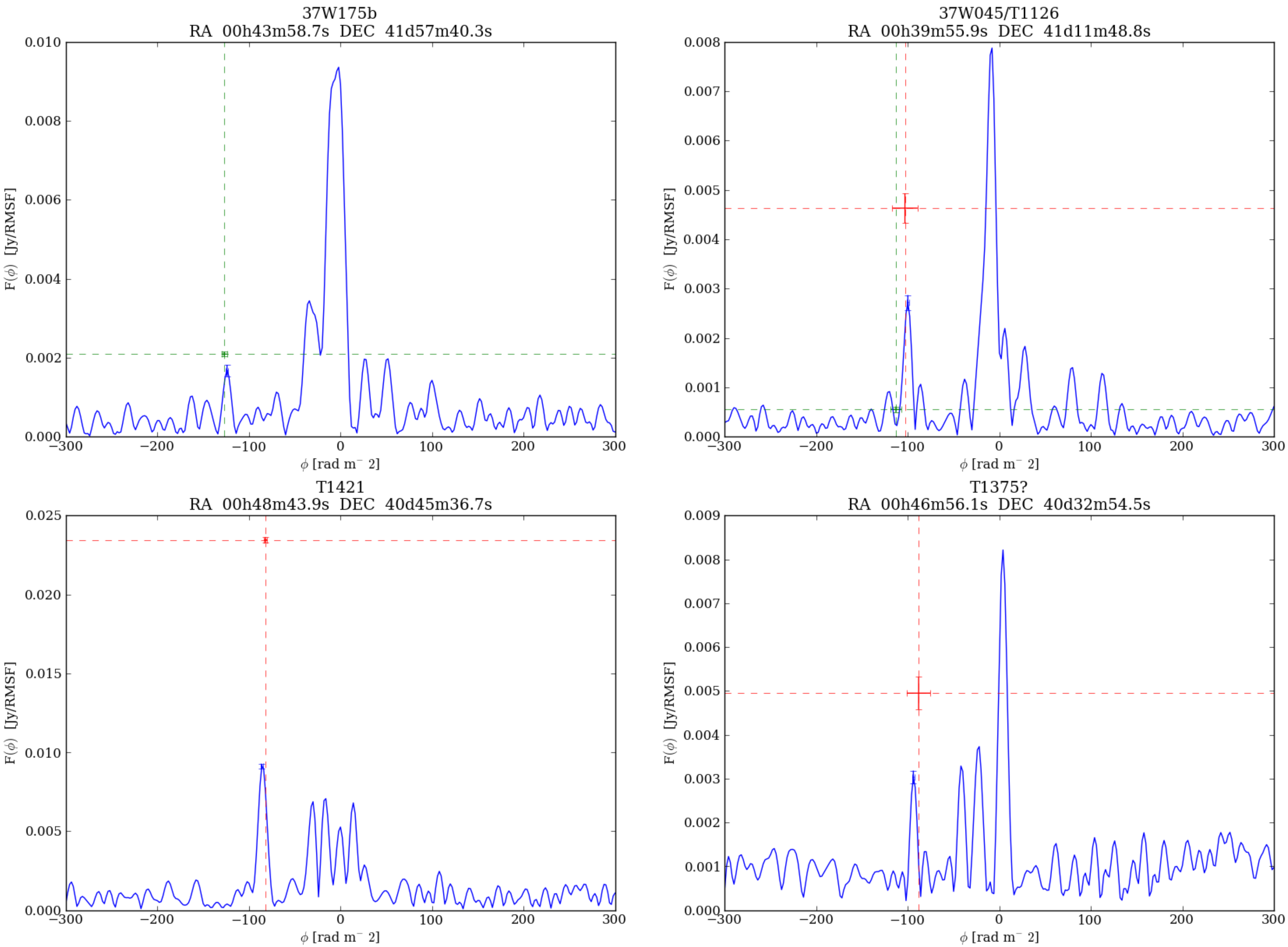




Faraday spectra of deviating sources



Faraday spectra of deviating sources



Faraday spectra of “normal” sources

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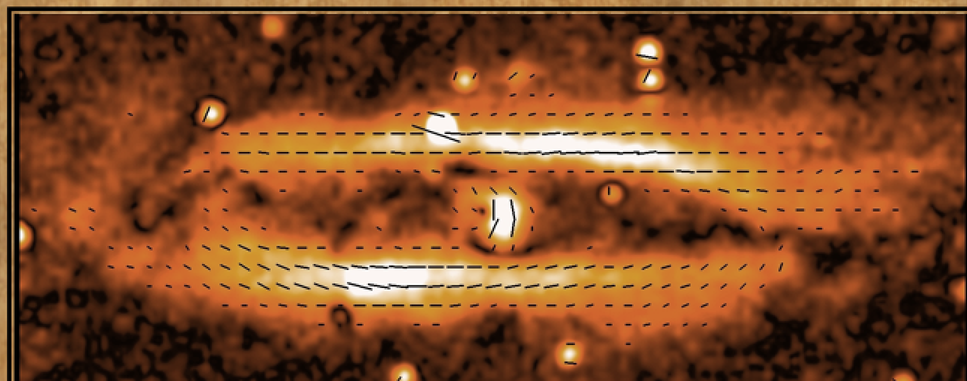

THE MAGNETIC FIELD OF M31

AT 350,000,000 HZ

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Where is it?

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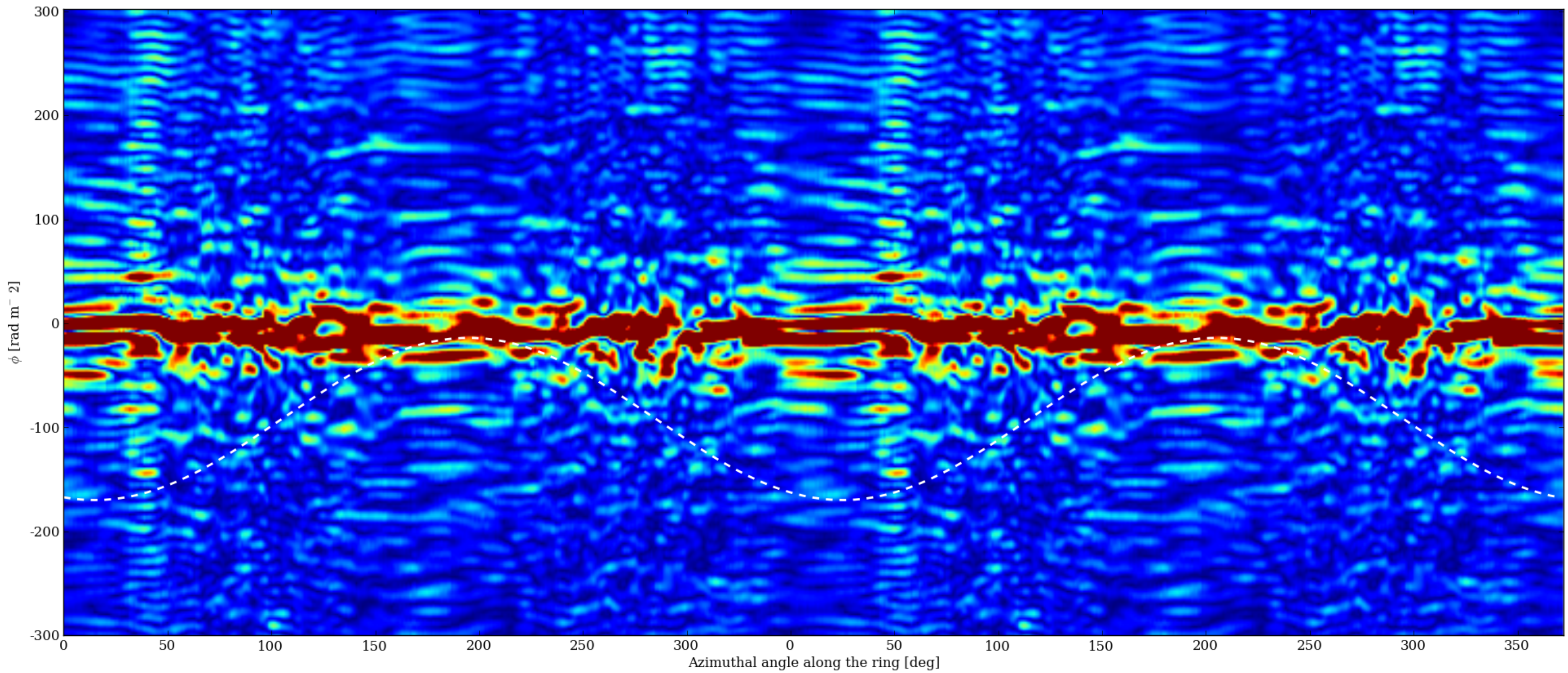

slice along the “ring”

Where is it?

an upper limit

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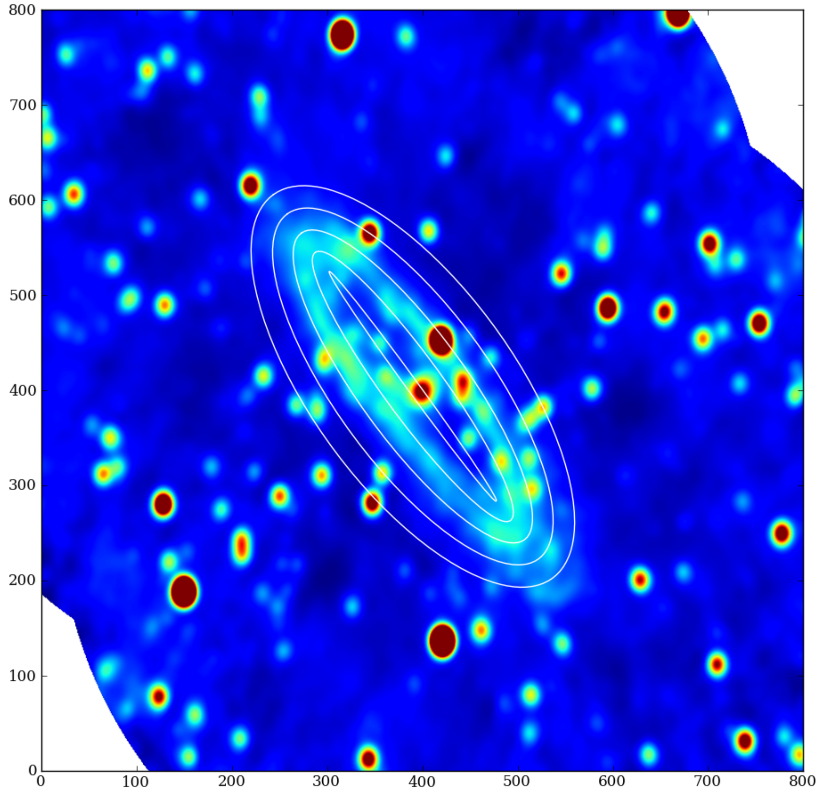
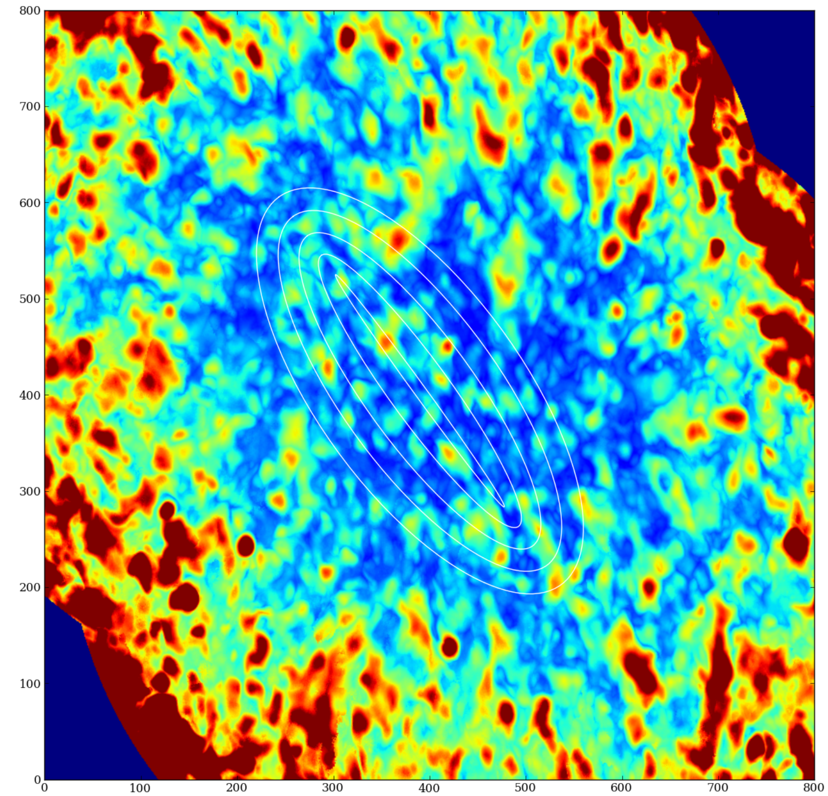
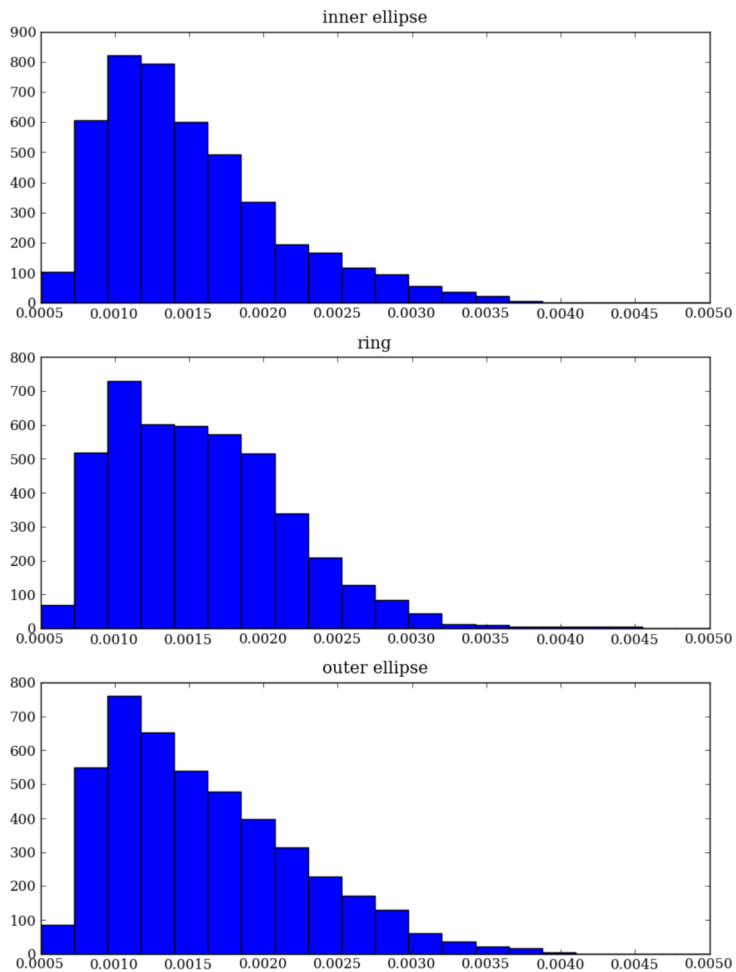




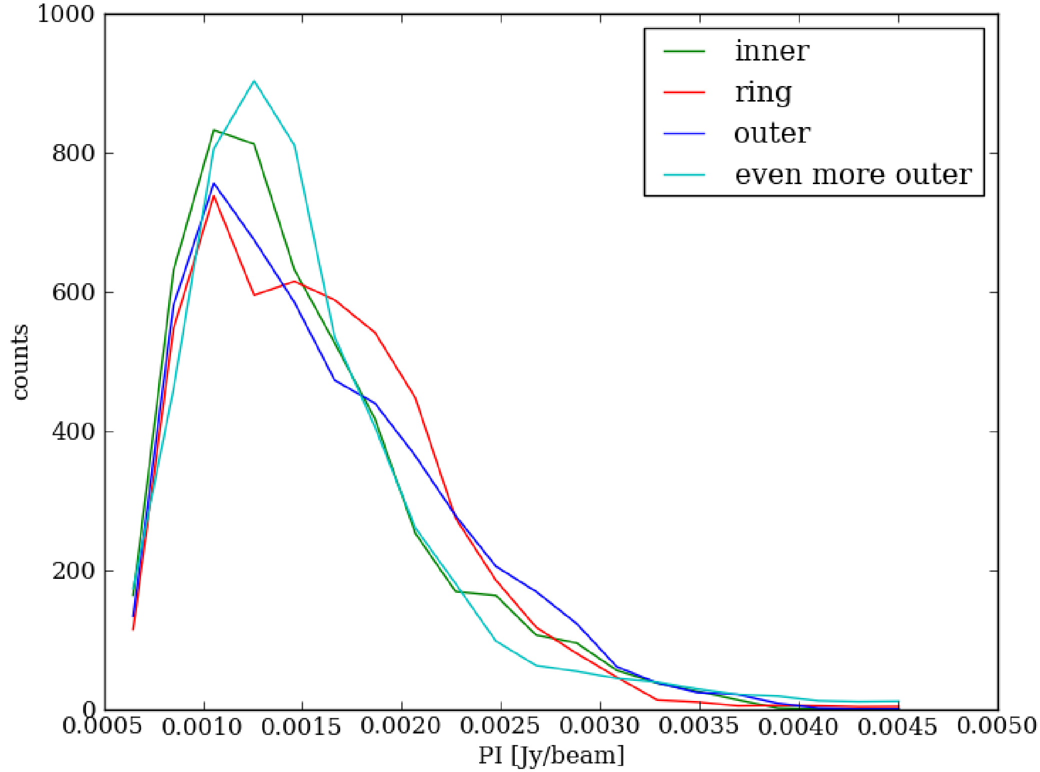
position of the ellipses

"PI peak map"

There it is!
an upper limit



Histograms of the ellipses



PI_{max}= 1.5 mJy/beam

p_{max} = 1.7%

$DP_{min}(90/6)=(PI_{90}/PI_{6})(\nu_{6}/\nu_{90})^{\alpha}=0.03$

Depolarization

Faraday dispersion

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Burn (1966); Sokoloff et al. (1998)

$$DP_{int} = \frac{1 - \exp(-S)}{S}$$

$$DP_{ext} = \exp(-S)$$

$$S = 2\sigma_{RM}^2 \lambda^4$$

$$\sigma_{RM}^2 = (0.81 n_e B_{turb} d)^2 \frac{fL}{d}$$

electron density	$n_e = 0.06$ cm^{-3}
turbulent magnetic field	$B_{turb} = 5$ µG
synchrotron scale height	$h_{syn} = 200$ pc
turbulent scale	$d = 50$ pc
filling factor	$f = 0.2$

$\rightarrow$ $L = 2{*}h_{syn}/\cos(\mathrm{incl}) = 1.9$ kpc

Fletcher et al (2004)

Depolarization

Faraday dispersion

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electron density	$n_e = 0.06\ cm^{-3}$
turbulent magnetic field	$B_{turb} = 5\ \mu G$
path length	L = 1.9 kpc
turbulent scale	d = 50 pc
filling factor	f = 0.2

Fletcher et al (2004)

@ 350 MHz:

DP = 0.0008
p = 0.05 %

measured:

$DP_{min}(90/6)=0.03$

p_{max} = 1.7%

Depolarization

Faraday dispersion

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@ 350 MHz:

$$DP_{int} = \frac{1-\exp(-S)}{S}$$

$$DP_{ext} = \exp(-S)$$

Tribble (1991)

$$S = 2\sigma_{RM}^2\lambda^4 \longrightarrow S = 2\sigma_{RM}\lambda^2$$

$$\sigma_{RM}^2 = (0.81 n_e B_{turb} d)^2 \frac{fL}{d}$$

electron density	$n_e = 0.06$ cm^{-3}
turbulent magnetic field	$B_{turb} = 5$ µG
path length	L = 1.9 kpc
turbulent scale	d = 50 pc
filling factor	f = 0.2

Fletcher et al (2004)

Depolarization
Faraday dispersion

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@ 350 MHz:

$$DP_{int} = \frac{1 - \exp(-S)}{S}$$

$$DP_{ext} = \exp(-S)$$

$$DP = \frac{1}{2\sigma_{RM}\lambda^2}$$

Tribble (1991)

$$S = 2\sigma_{RM}^2\lambda^4$$

$$S = 2\sigma_{RM}\lambda^2$$

$$\sigma_{RM}^2 = (0.81 n_e B_{turb} d)^2 \frac{fL}{d}$$

electron density	$n_e = 0.06$ cm^{-3}
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Fletcher et al (2004)

Depolarization

Faraday dispersion

@ 350 MHz:

$$DP_{int} = \frac{1 - \exp(-S)}{S}$$

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Tribble (1991)

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Depolarization
Faraday dispersion

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@ 350 MHz:

$$DP_{int} = \frac{1-\exp(-S)}{S}$$

$$DP_{ext} = \exp(-S)$$

$$DP = \frac{1}{2\sigma_{RM}\lambda^2}$$

Tribble (1991)

$$S = 2\sigma_{RM}^2\lambda^4$$

$$S = 2\sigma_{RM}\lambda^2$$

$$\sigma_{RM}^2 = (0.81 n_e B_{turb} d)^2 \frac{fL}{d}$$

electron density	$n_e = 0.06\ \mathrm{cm}^{-3}$
turbulent magnetic field	$B_{turb} = 5\ \mu\mathrm{G}$
path length	L = 1.9 kpc
turbulent scale	d = 50 pc
filling factor	f = 0.2

Fletcher et al (2004)

DP = 0.02
p = 1.4 %

measured:
$DP_{min}(90/6)=0.03$
p_{max} = 1.7%

Summary

implications for LOFAR

Summary

implications for LOFAR

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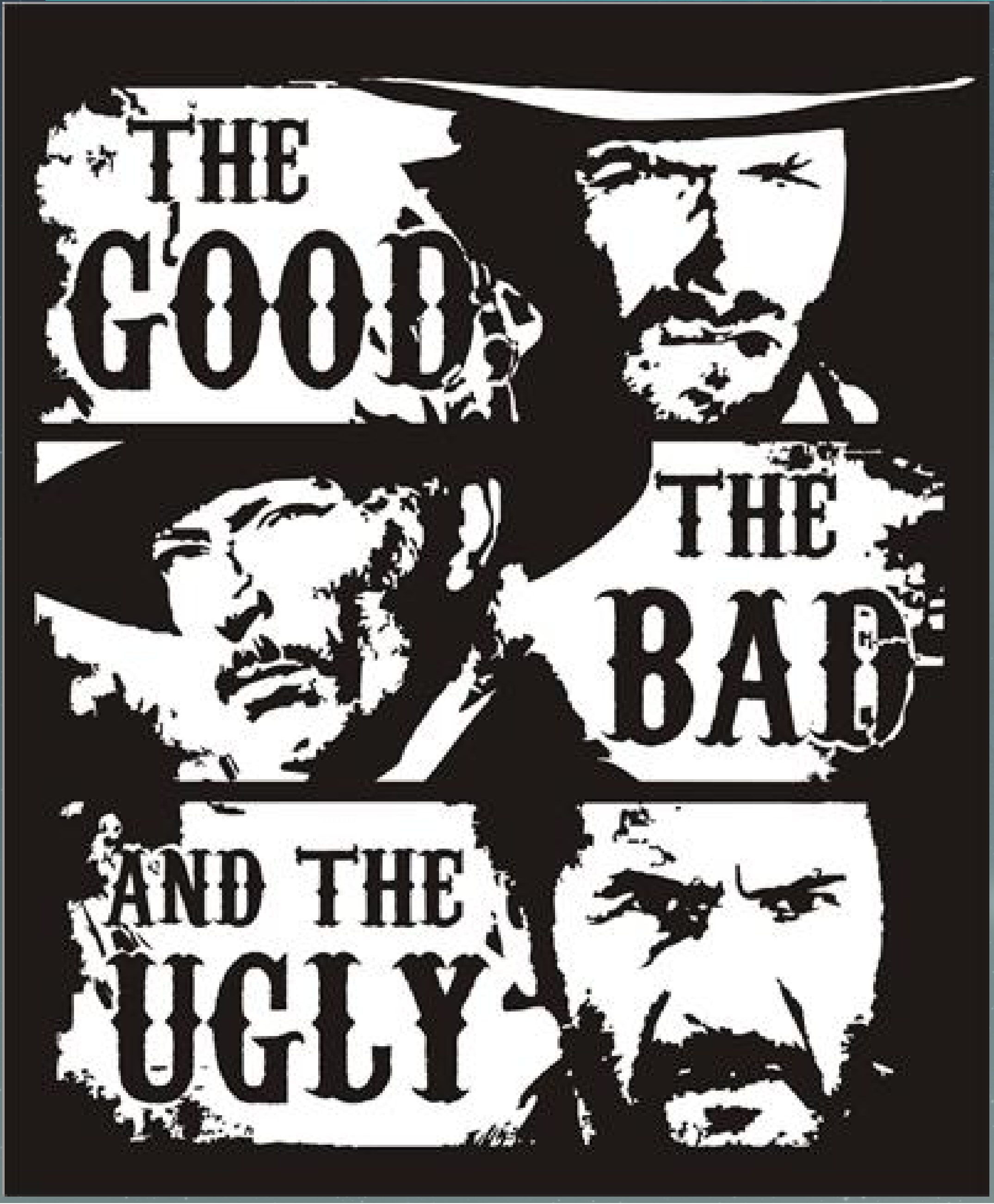

Summary

implications for LOFAR

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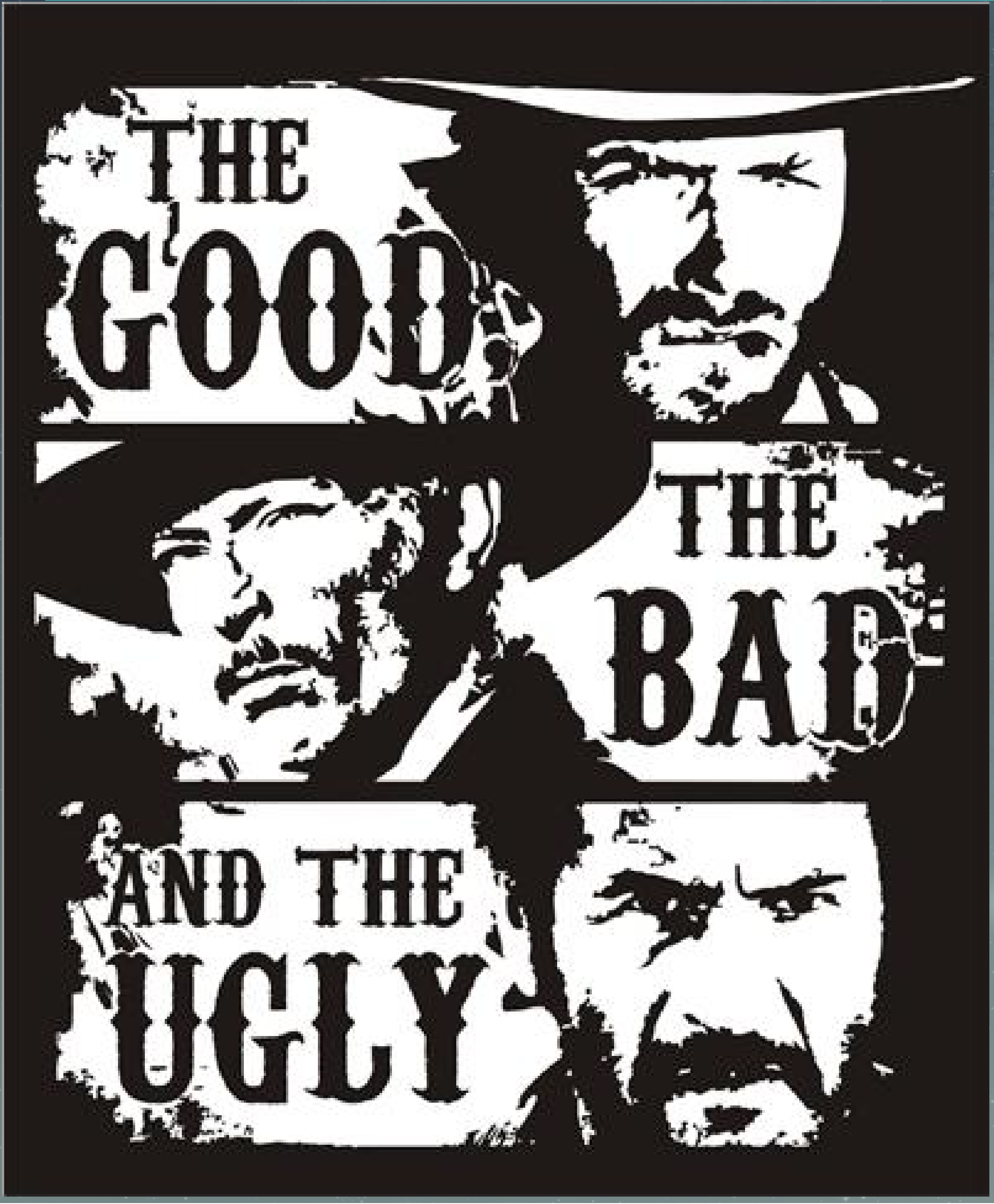

- quite a number of polarized sources
- many have same RM as at GHz
- higher resolution may help
- M31 is highly inclined

Summary
implications for LOFAR

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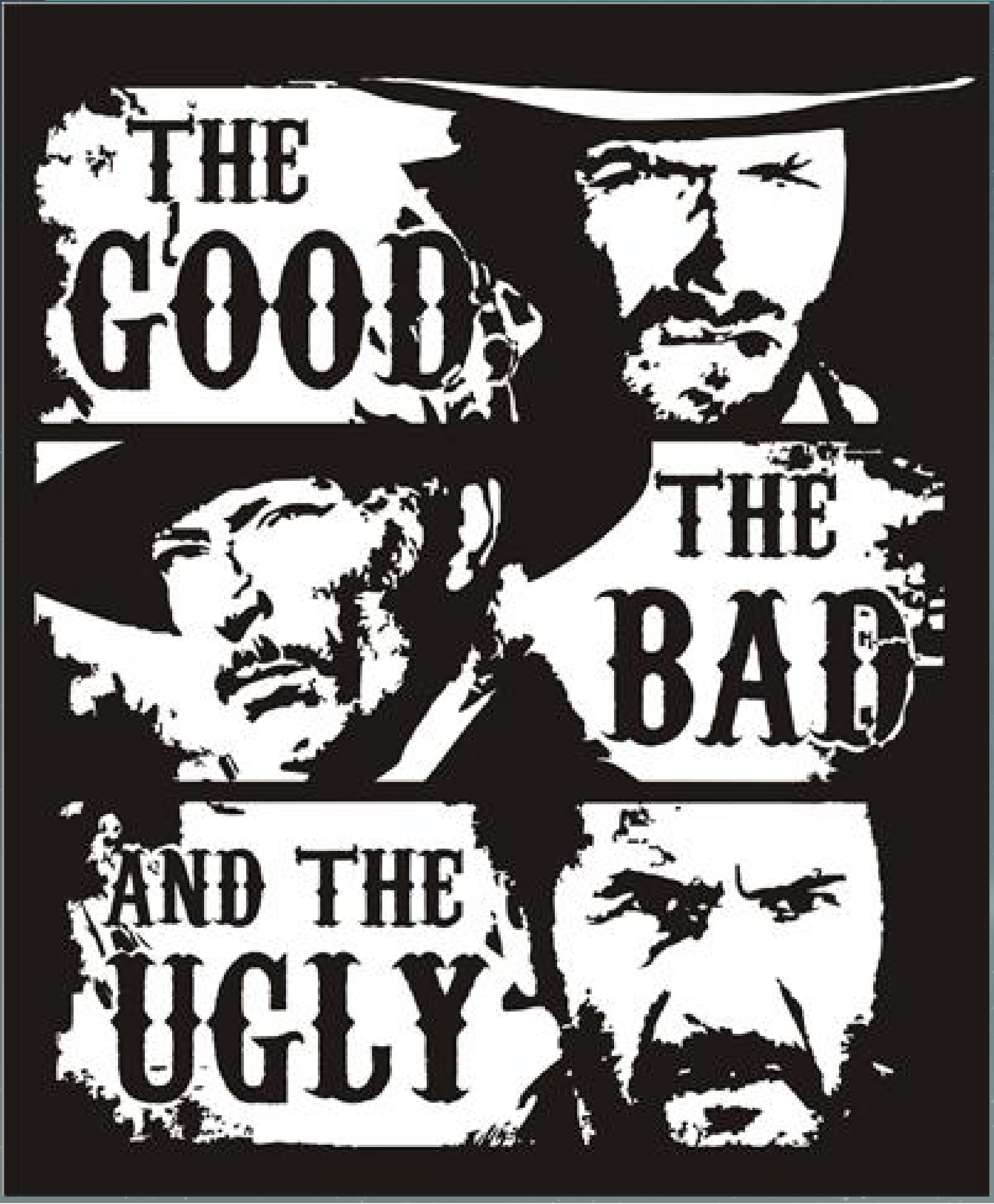

- quite a number of polarized sources
- many have same RM as at GHz
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- high depolarization
- M31 not seen in RM cube
- lot of sources have different RM
- less sources than expected (needed)

Summary
implications for LOFAR

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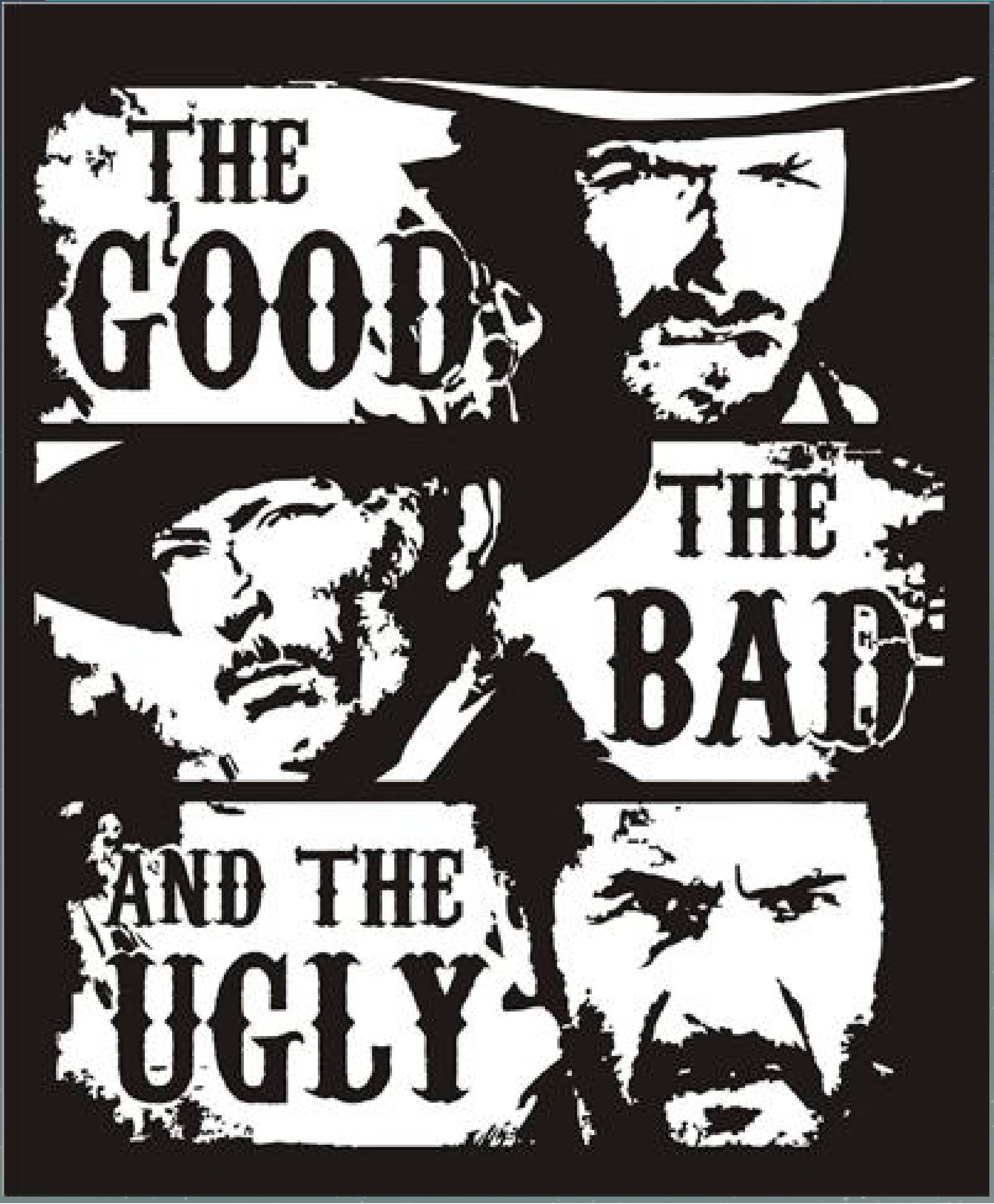

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- higher resolution may help
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- high depolarization
- M31 not seen in RM cube
- lot of sources have different RM
- less sources than expected (needed)

- LOFAR: factor 4 in wavelength higher (things get worse with λ^2)
- RM-grid: need to know and understand source structure

Summary
implications for LOFAR