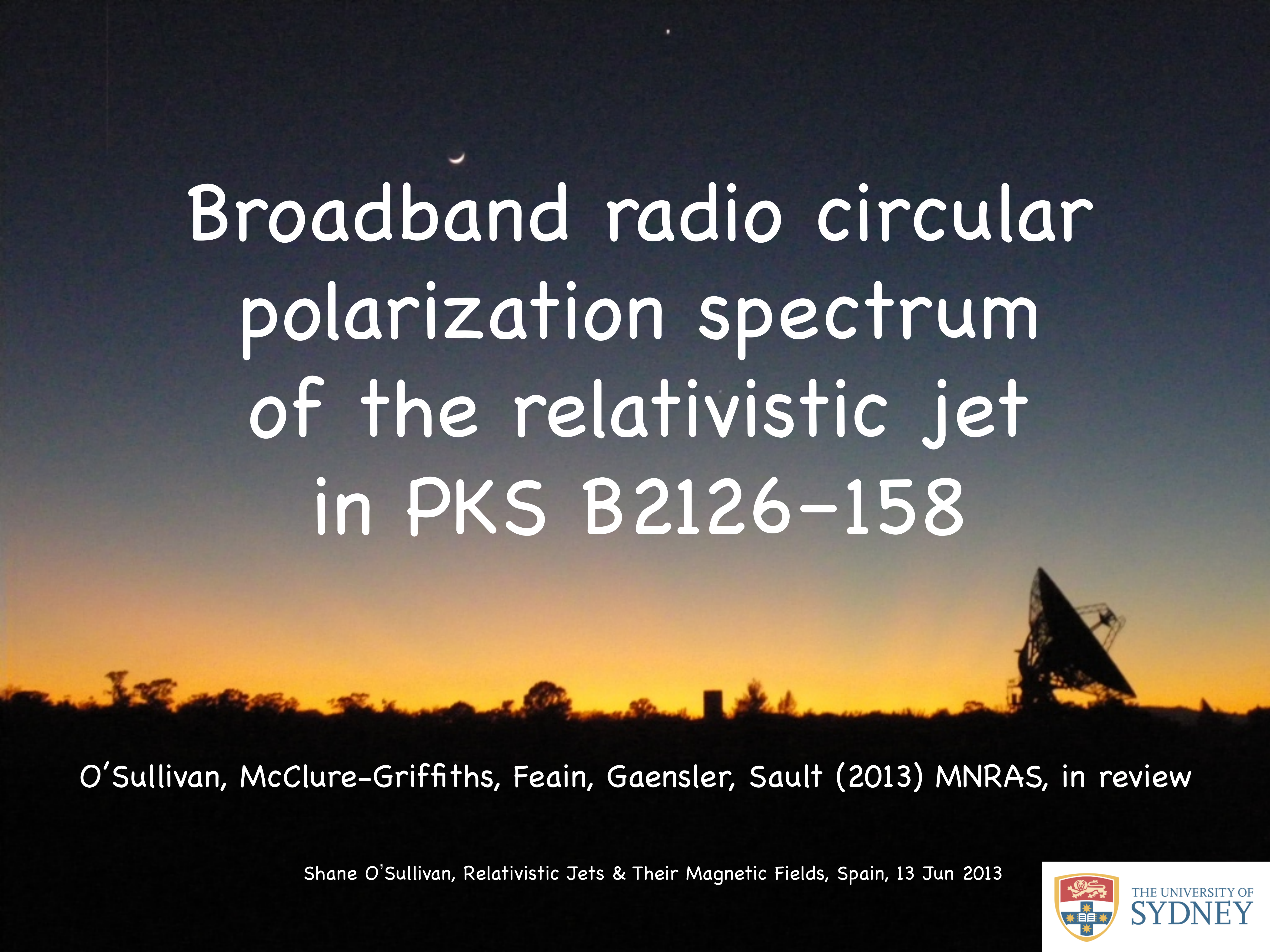

Broadband radio circular polarization spectrum of the relativistic jet in PKS B2126-158

O'Sullivan, McClure-Griffiths, Feain, Gaensler, Sault (2013) MNRAS, in review

Shane O'Sullivan, Relativistic Jets & Their Magnetic Fields, Spain, 13 Jun 2013

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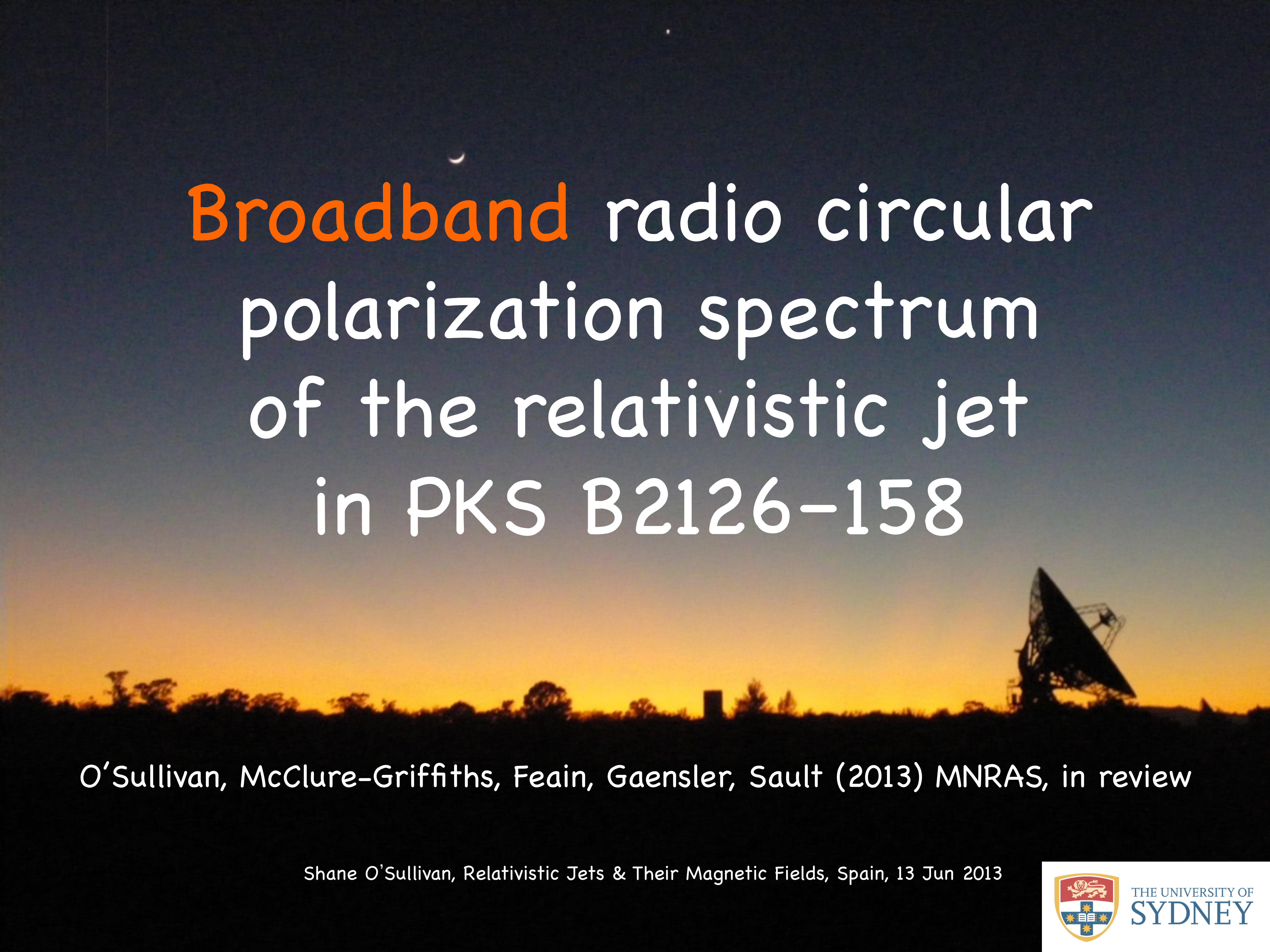

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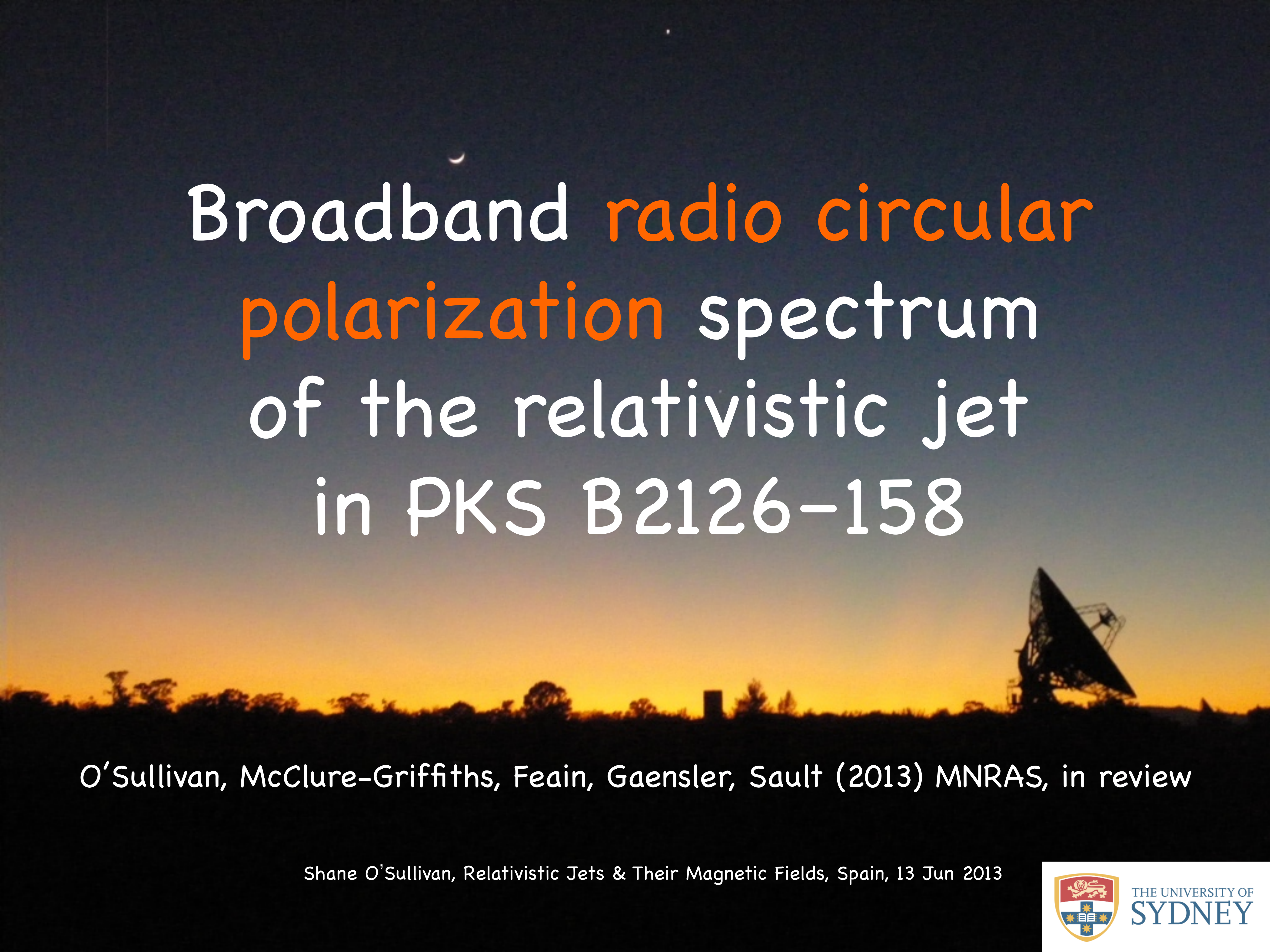

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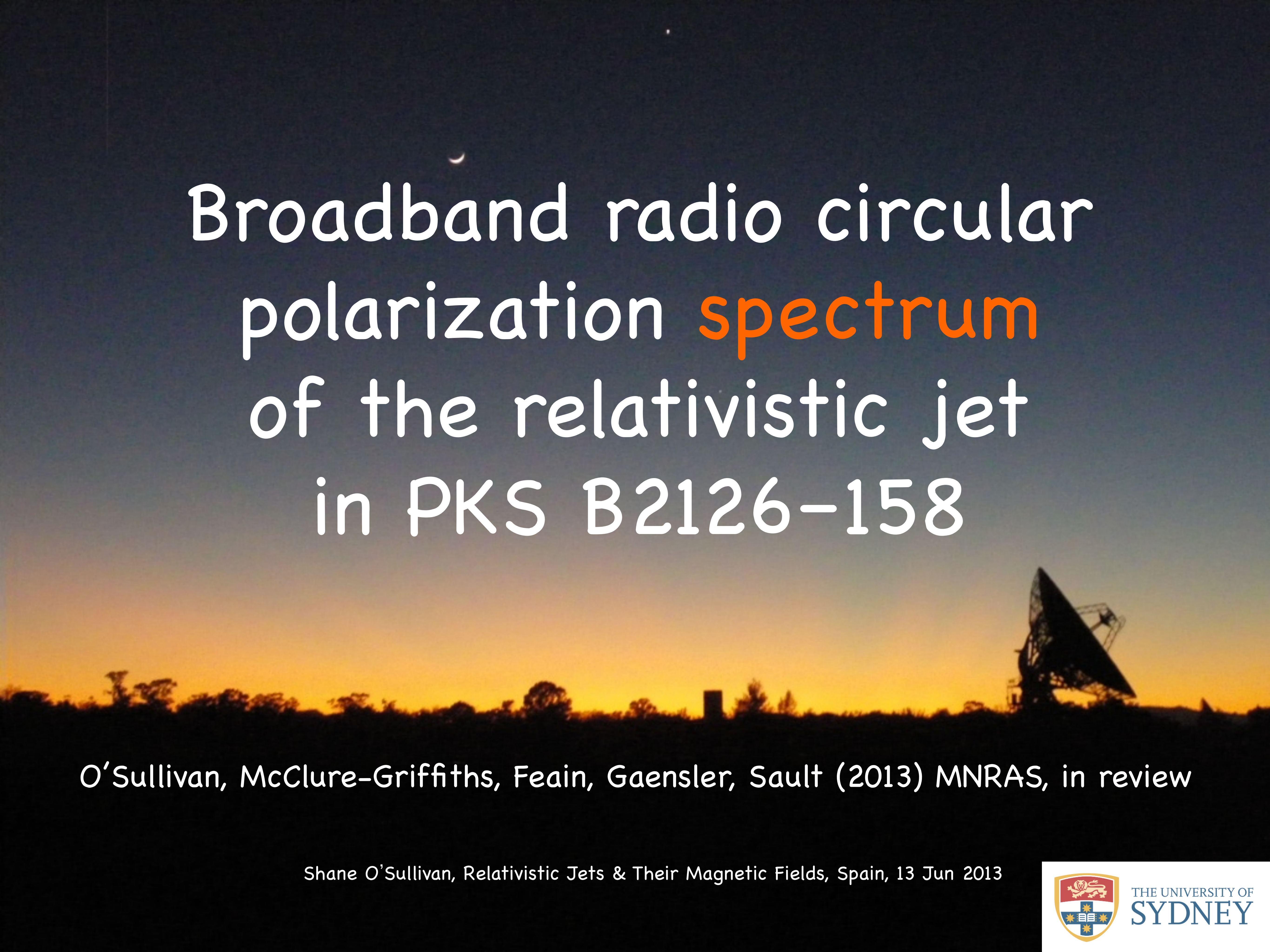

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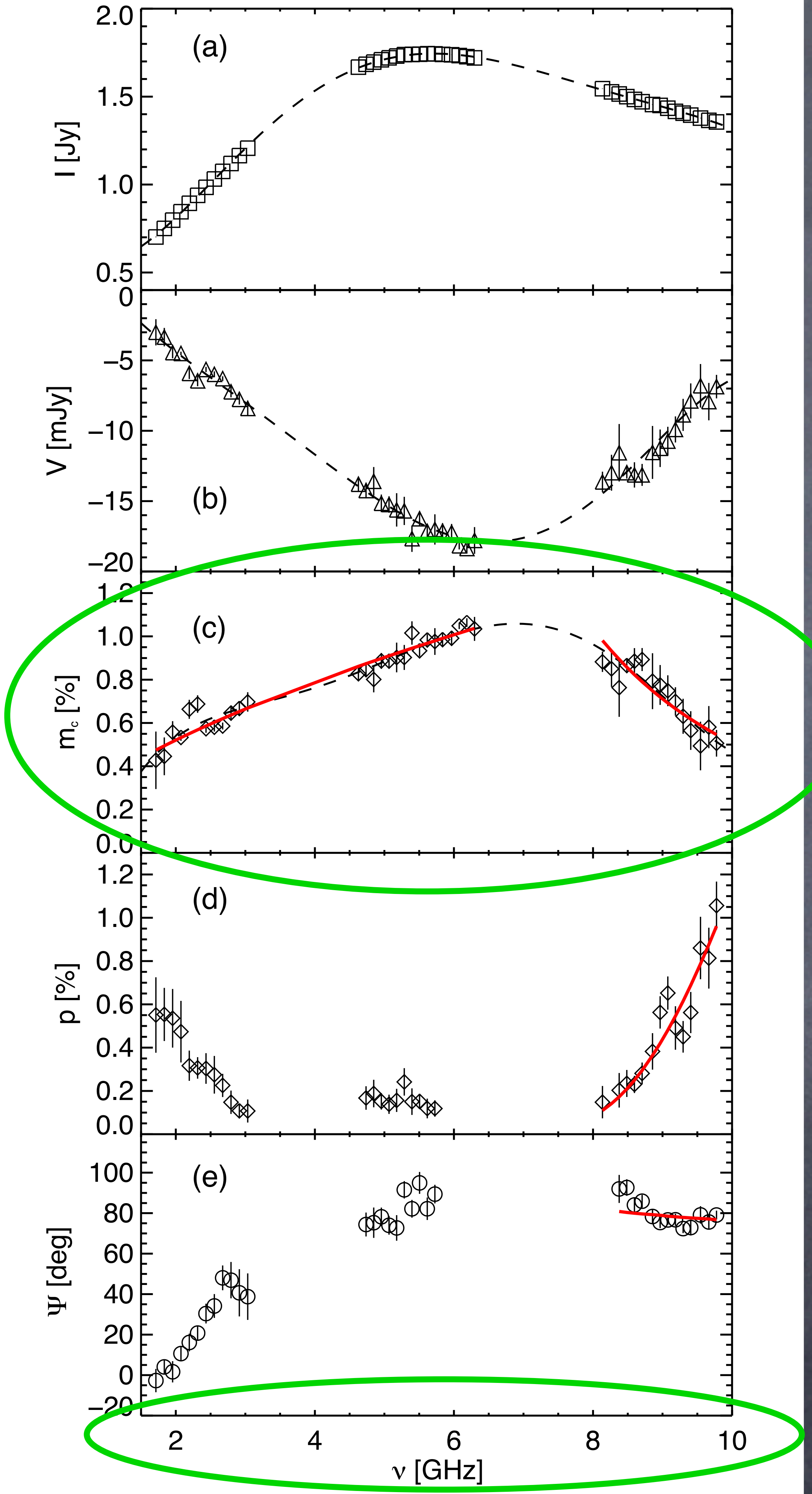

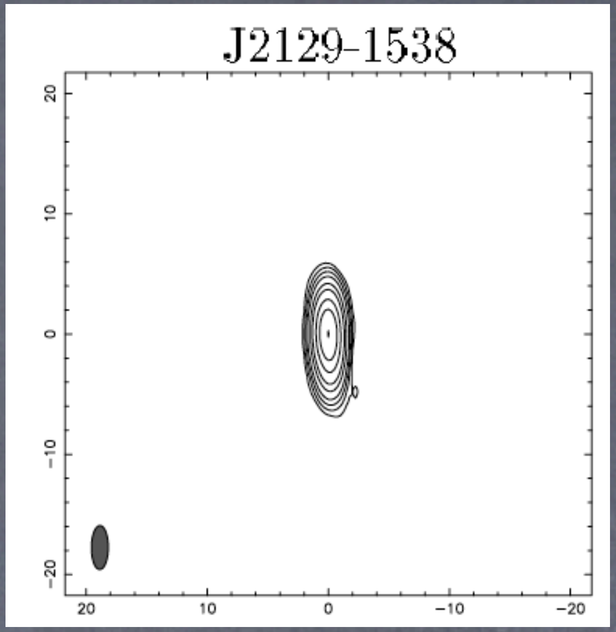

- GPS quasar
- z = 3.268
- M_{BH} ~ 10^{10} M_{sol}
- P_{jet} ~ 10^{48} erg/s
- m_c ~ 1% at 6 GHz

- **Dominant CP generation mechanism: Faraday conversion of LP to CP**
- **Conclusions:**

1. little or no thermal plasma within the jet

2. cannot yet distinguish between magnetic twist and internal Faraday rotation models

3. relativistic particle content unconstrained

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Australia Telescope Compact Array

- 6 x 22 m dishes with 6 km maximum baseline
- Linear feed system ($S_{V/I}$ ~ 0.01%)
- CABB (2 GHz b/w per IF), Wilson et al. (2011)
- 1 to 3 GHz, 4.5 to 6.5 GHz, 8 to 10 GHz (1 to 10 arcsec)

$$I = v_{xx^*} + v_{yy^*}$$

$$Q = v_{xx^*} - v_{yy^*}$$

$$U = v_{xy^*} + v_{yx^*}$$

$$V = v_{xy^*} - v_{yx^*}$$

$$LP = \sqrt{Q^2 + U^2}$$

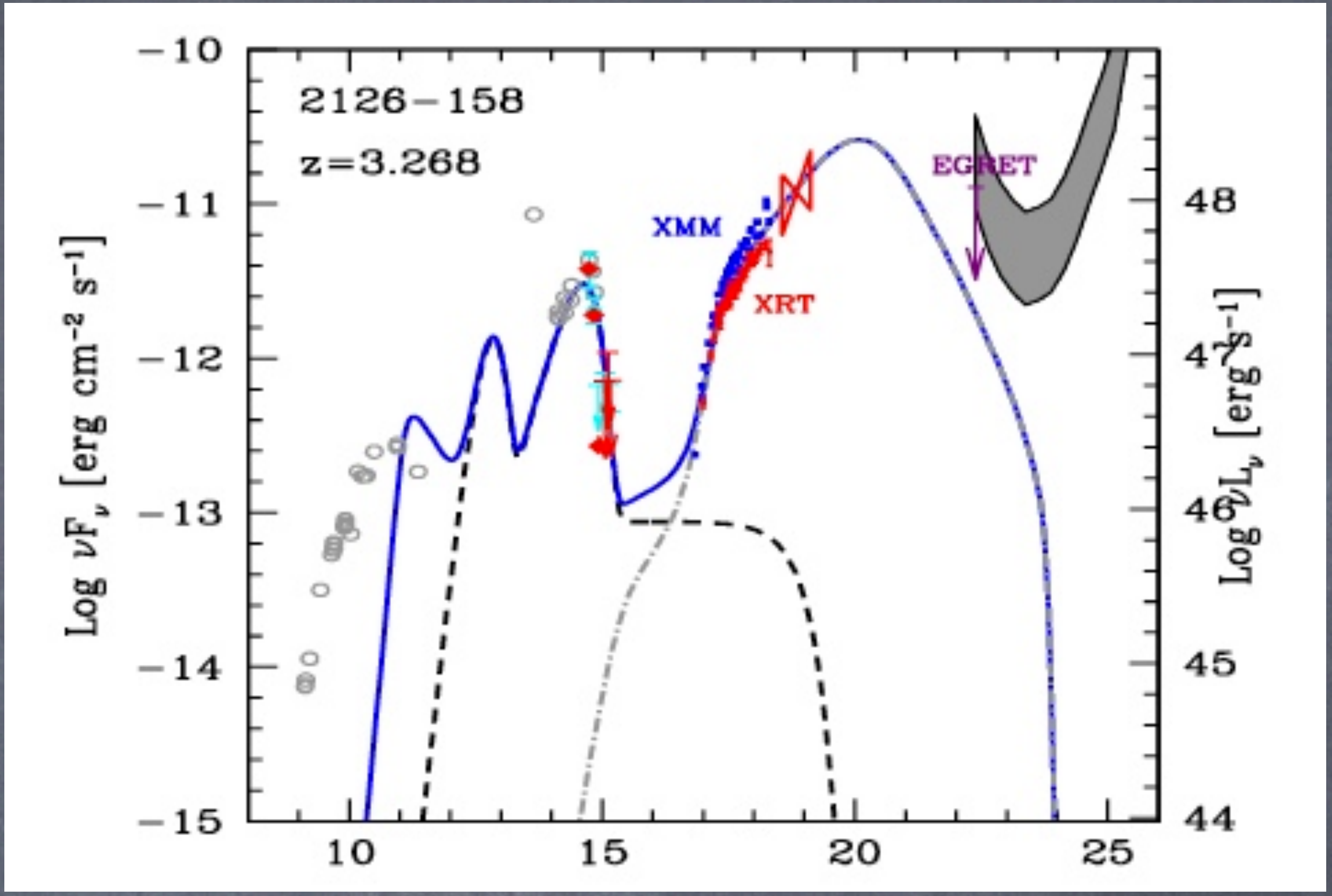
$$\chi = \frac{1}{2} \tan^{-1}(U/Q)$$

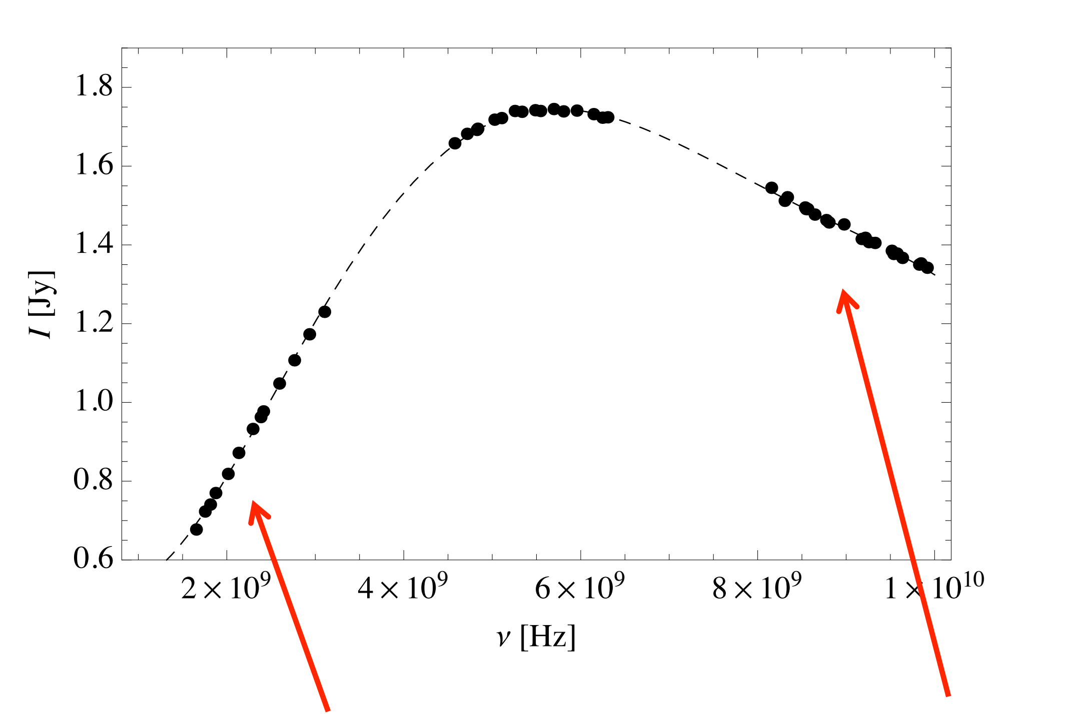
$$CP = V$$

PKS B2126-158

- GPS quasar (Stangellini+98)
- z = 3.268 (Osmer+94)
- $M_{BH} \sim 10^{10}\ M_{sol}$ (Ghisellini+11)

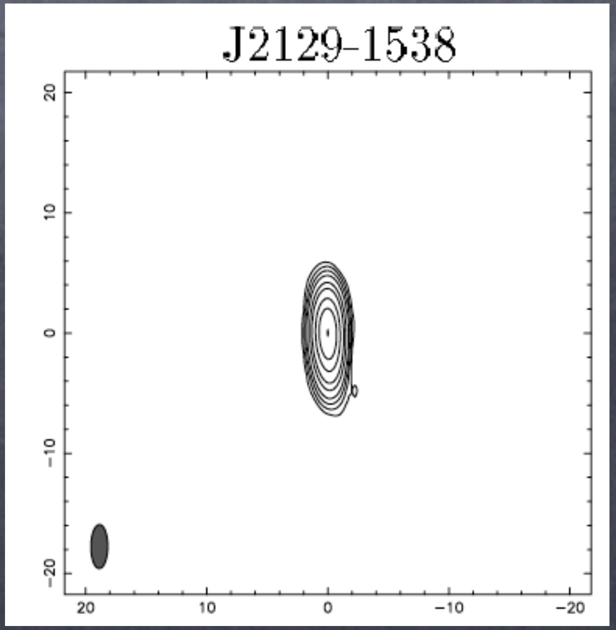
Ghisellini+11





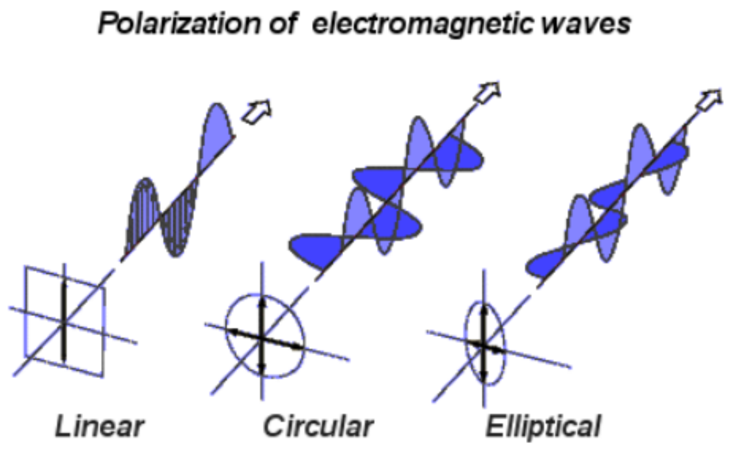
$$S_\nu \sim \nu^{0.9} \qquad S_\nu \sim \nu^{-0.7}$$

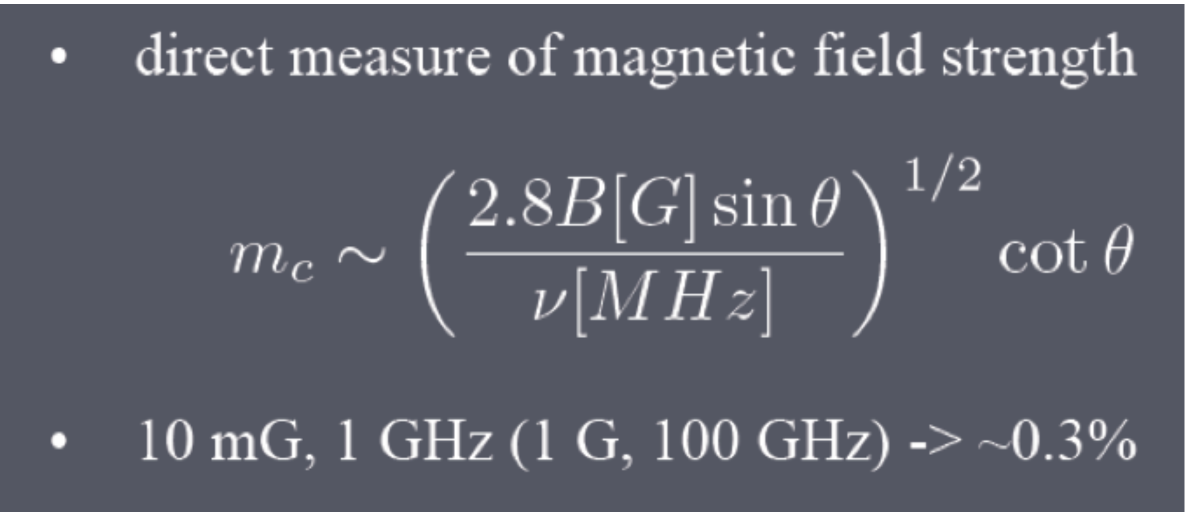
VLBA 5 GHz



Fomalont+95

- Synchrotron from a single electron is elliptically polarized
- CP can be positive/negative (left/right)
- Large CP not expected for an ensemble of electrons with an isotropic distribution of pitch angles



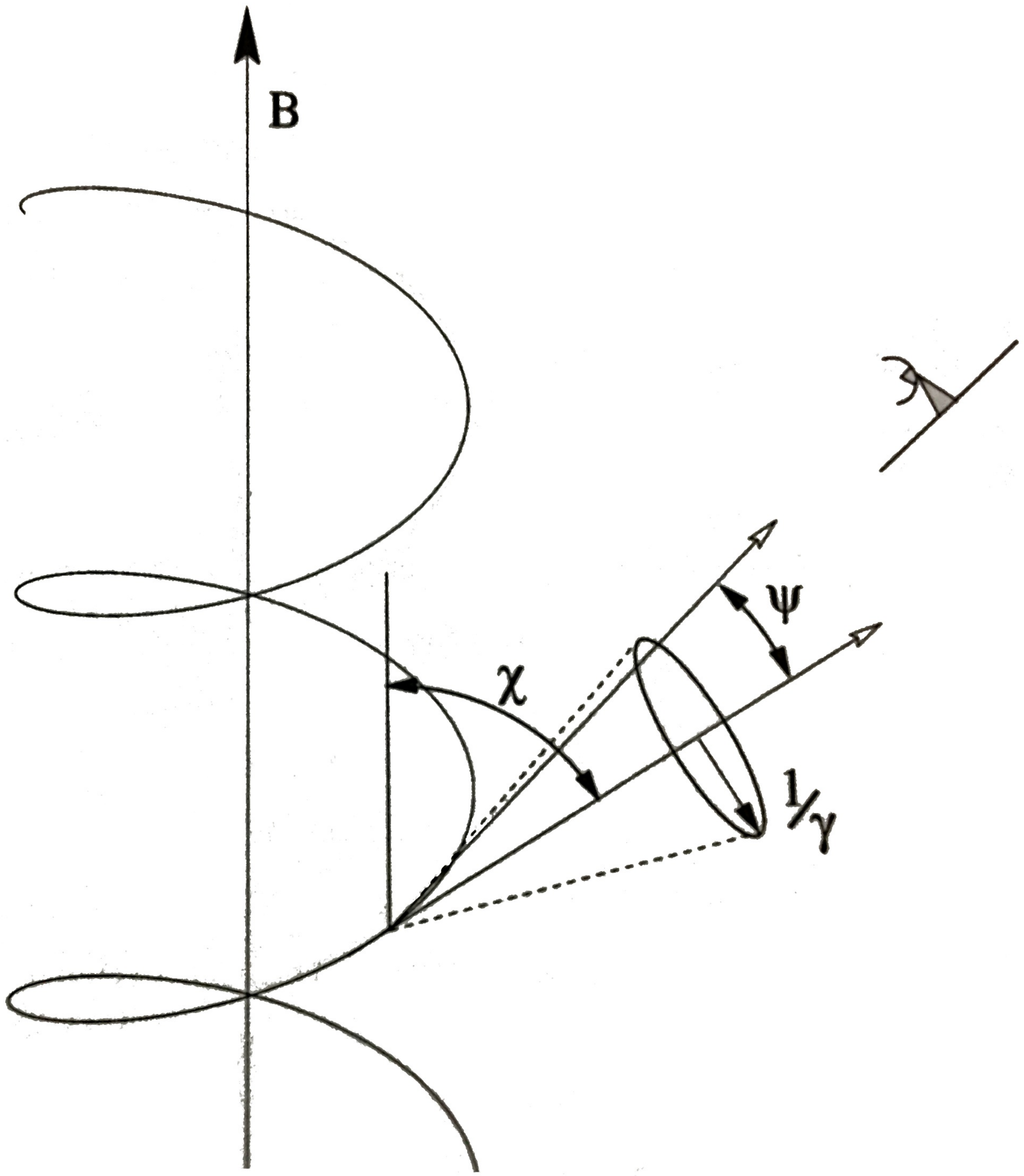


- direct measure of magnetic field strength

$$m_c \sim \left(\frac{2.8B[G]\sin\theta}{\nu[MHz]}\right)^{1/2}\cot\theta$$

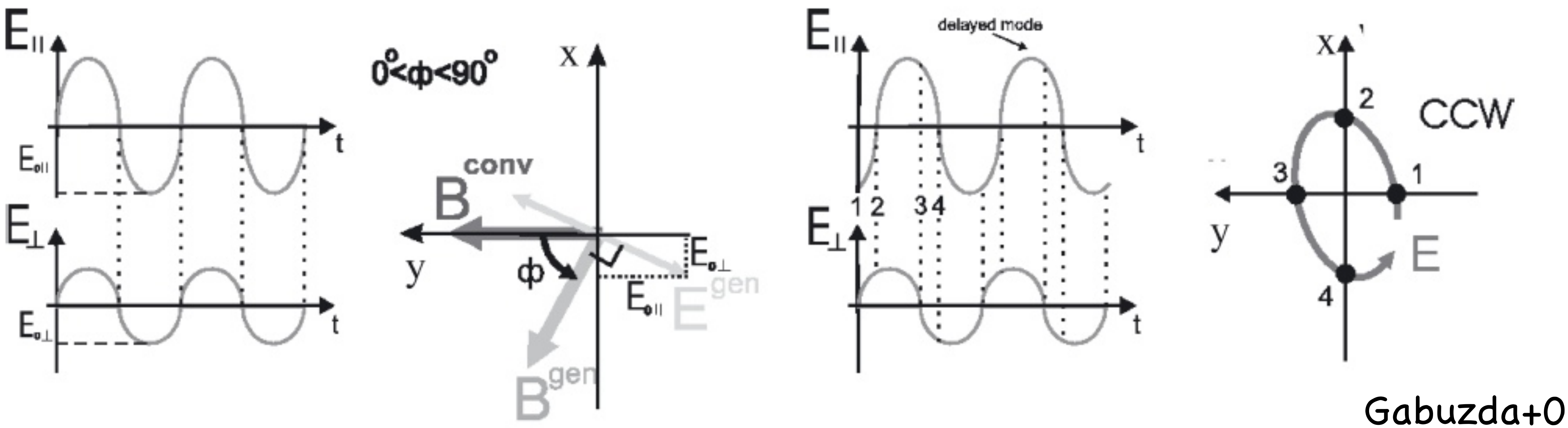
- 10 mG, 1 GHz (1 G, 100 GHz) -> ~0.3%

Legg & Westfold (1968)



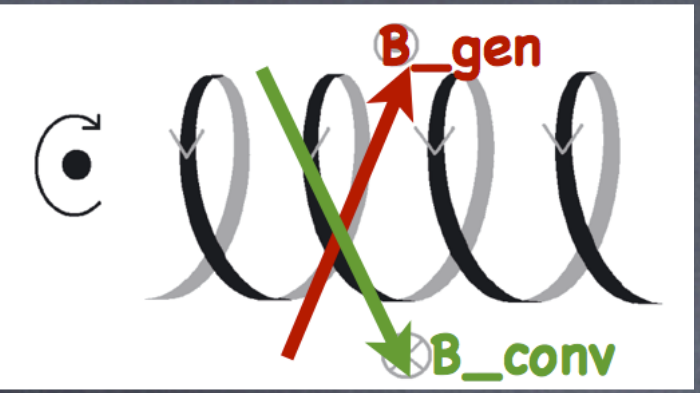
- For completely uniform magnetic field with an ensemble of electrons and random distribution of pitch angles gives LP ~ 75%
- Polarization => strength and degree of order of magnetic field

Conversion of LP to CP

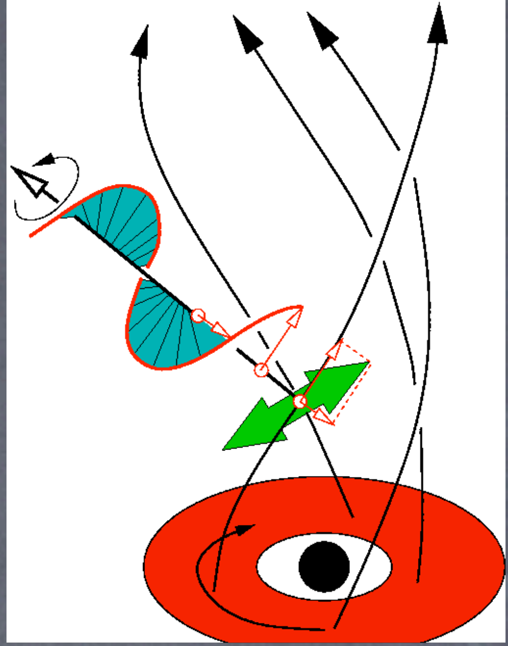


Gabuzda+08

- Propagation effect due to finite width of the jet (B^{conv} induces a delay between $E_{||}$ and E_{perp})
- A change in the orientation of the magnetic field through the jet eg. helical magnetic field
- Conversion due to Faraday rotation: Linear polarization emitted from back of the jet rotated as it propagates through the jet



CP Spectrum



- Determine the CP generation mechanism
- Using correct model allows us to infer:
    - B-field geometry (& strength, flux) (Gabuzda+08, Homan+09)
    - Jet particle composition (e-,p / e-,e+) (Wardle+98)
    - Direction of rotation of accretion disk/black hole spin (Ensslin+03)
    - Polarity of black hole magnetic field (Beckert & Falcke 2002)

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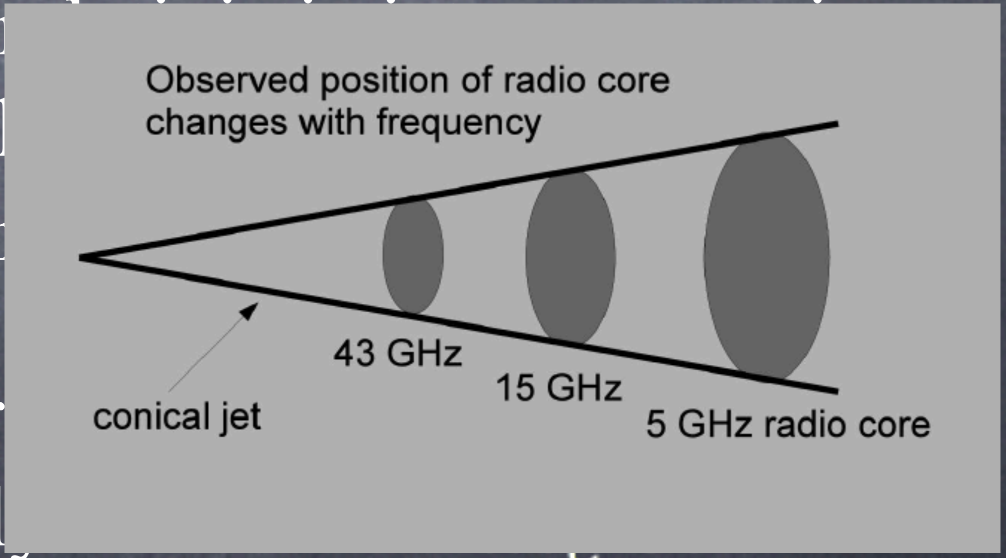
Circular Polarization in AGN

Predicted spectrum: $m_c \equiv |V|/I$

- Intrinsic: $m_c \propto \nu^{-1/2}$
  - Melrose (1972): sign change ~1/2 self-abs turnover freq
- Conversion:
  - Jones (1988): inhomogeneous greatest is region where optical will occur regardless of mecha
  - Kennett & Melrose (1998): for cold plasma: $m_c \propto \nu^{-1}$ purel
  - Wardle & Homan (2003): BK jet: $m_c \propto \nu^{+1}$

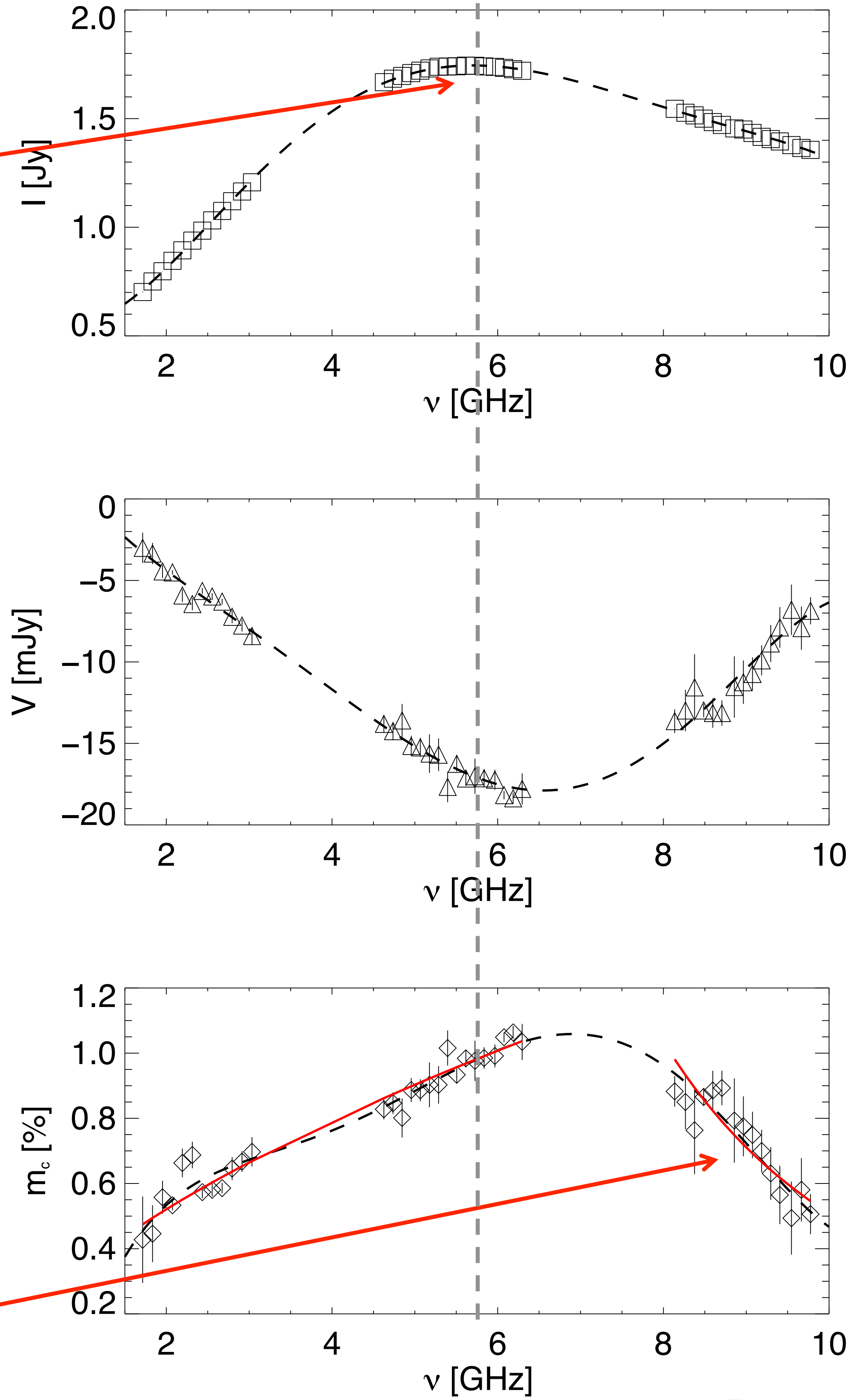


PKS B2126-128

$$\nu_t \sim 5.7 \pm 0.1 \text{ GHz}$$
$$S_{\nu_t} \sim 1.744 \pm 0.001 \text{ GHz}$$

- m_c ~ 1% at 6 GHz
- No sign change in Stokes V
- Turnover in CP spectrum when emission becomes optically thin
- Not dominated by intrinsic CP
- Consistent with Faraday conversion due to uniform B-field in a purely relativistic plasma (no thermal electrons)

$$m_c \propto \nu^{-3.0 \pm 0.4}$$



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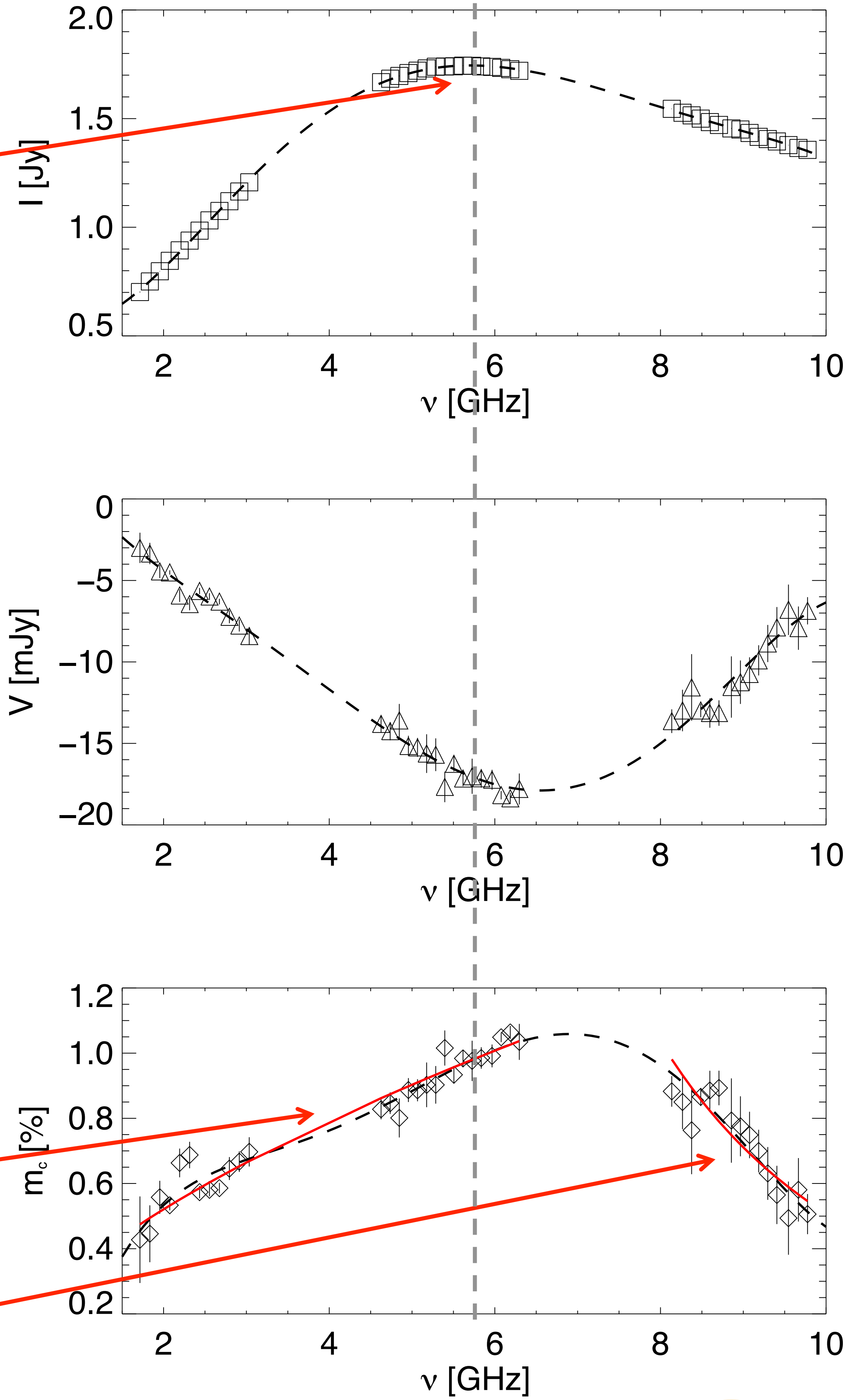
PKS B2126-128

$$\nu_t \sim 5.7 \pm 0.1 \text{ GHz}$$
$$S_{\nu_t} \sim 1.744 \pm 0.001 \text{ GHz}$$

- CP increases with frequency in optically thick regime (inverted CP spectrum)
- Consistent with B&K79 conically self-similar jet
- Unity optical depth surface moves further upstream in the jet at higher frequencies, where the uniform B-field component is stronger

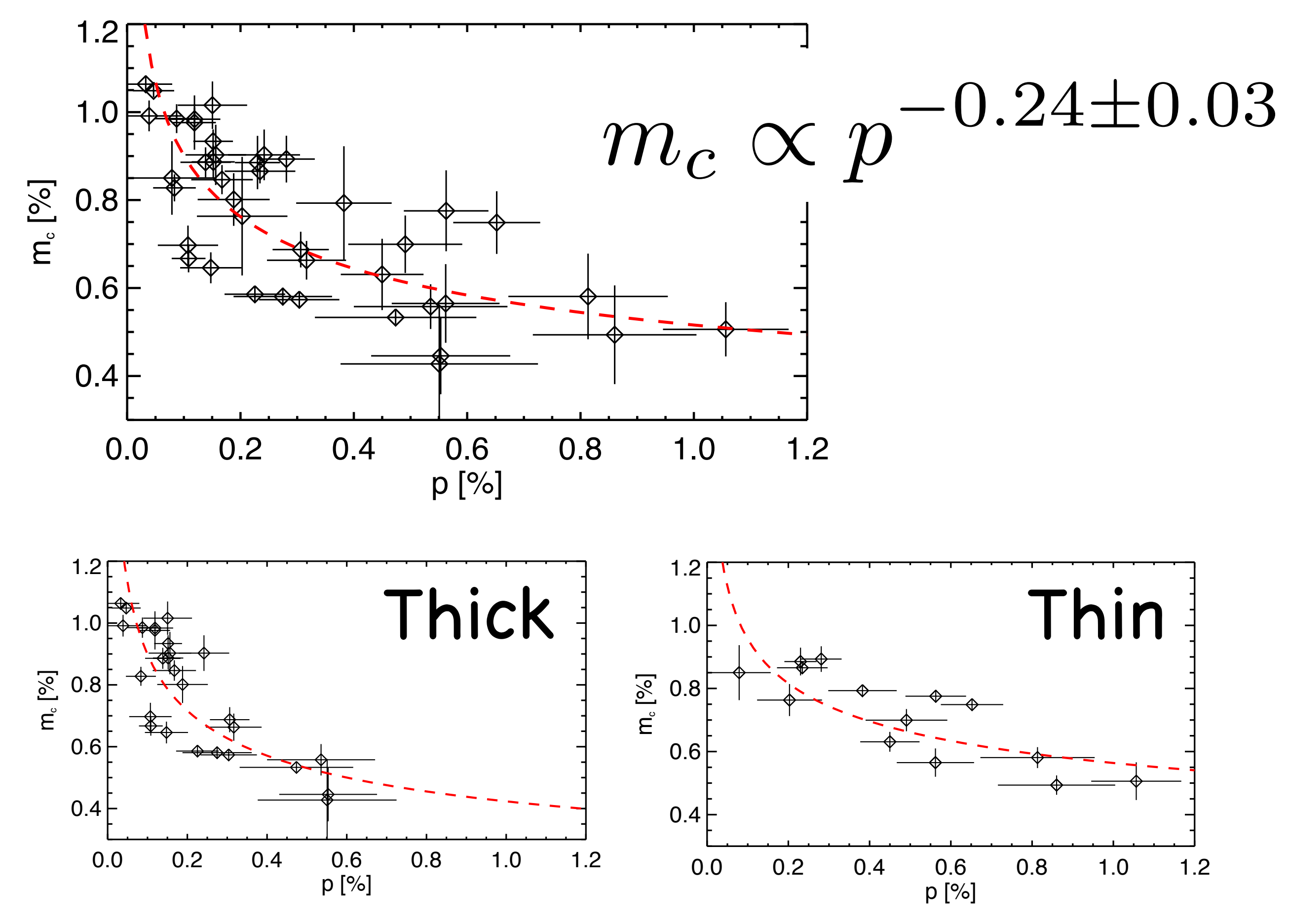
$$m_c \propto \nu^{+0.60\pm0.03}$$

$$m_c \propto \nu^{-3.0\pm0.4}$$

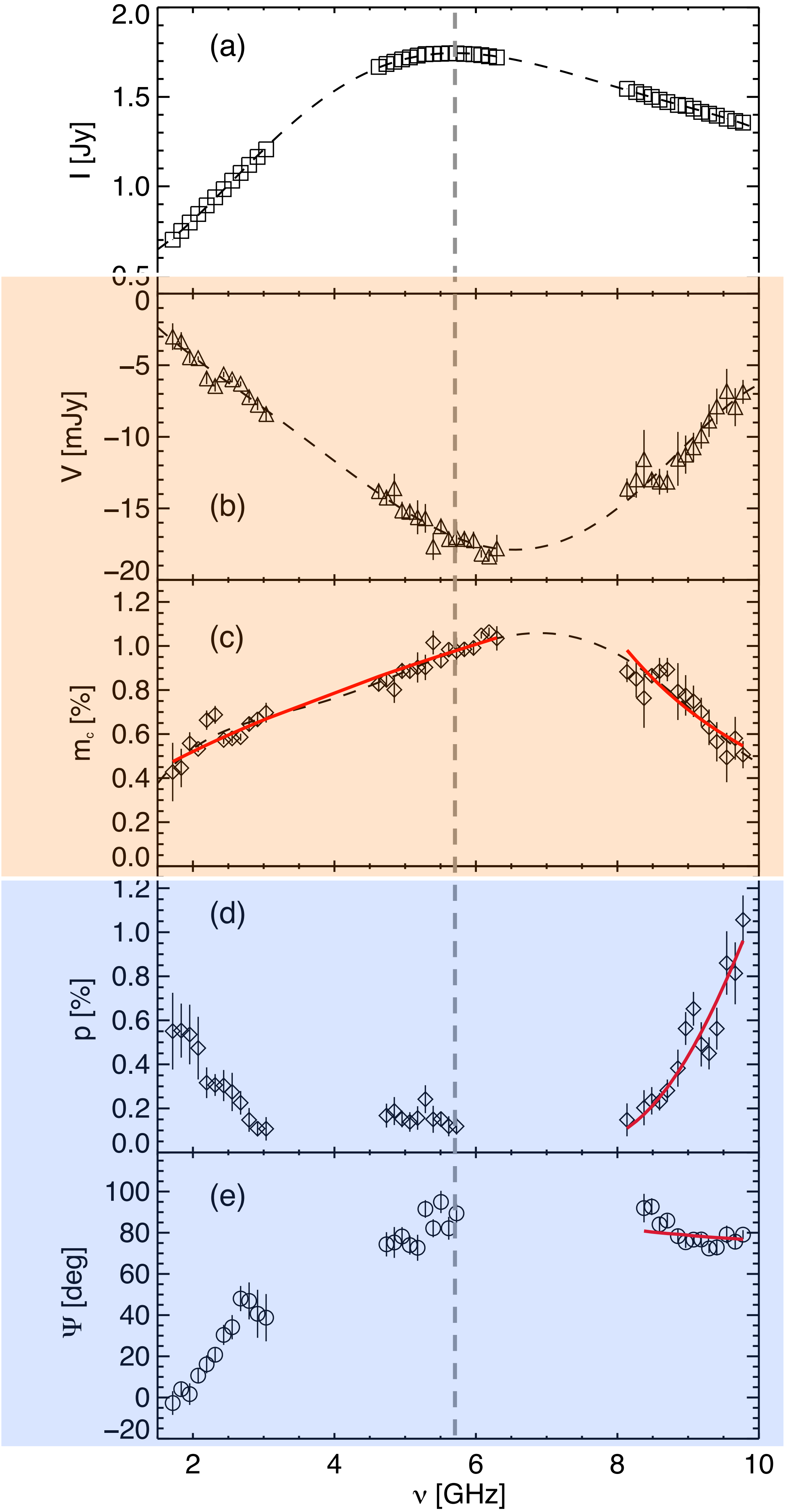


PKS B2126-128

- Linear and circular polarization anti-correlated
- Spearman rank test: -0.8
- Clear signature of Faraday conversion of LP to CP



$$m_c \propto p^{-0.24\pm0.03}$$



Circular Polarization

Linear Polarization

PKS B2126-128

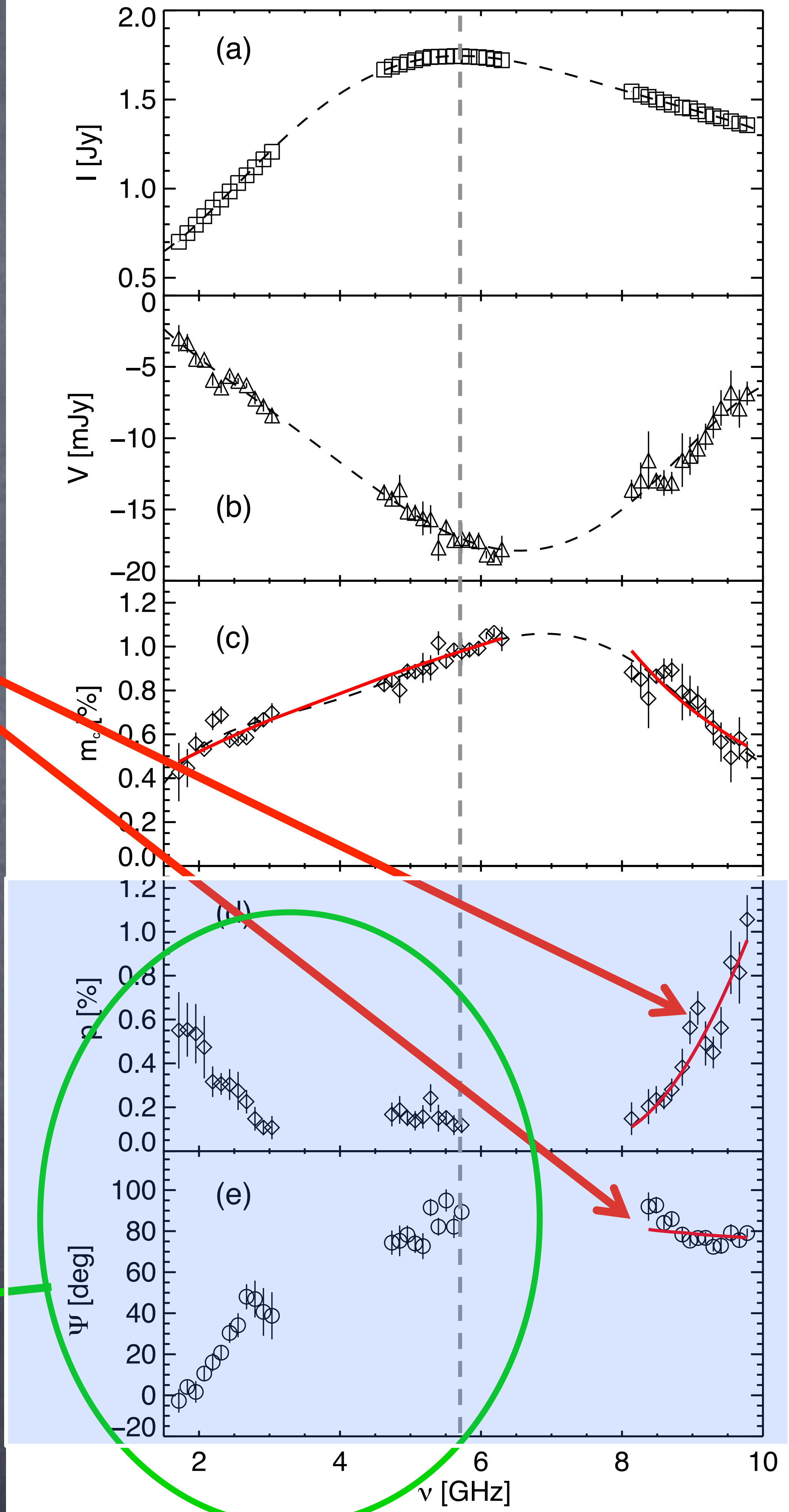
- Faraday rotation and depolarization
- Faraday thick or thin?
- Unconstrained for small range in l^2

$$P = pe^{-2\sigma_{\rm RM}^2\lambda^4} e^{2i(\Psi_0+{\rm RM}\lambda^2)}$$

$${\rm RM} = 190 \pm 21\,{\rm rad\ m}^{-2}$$

$$\sigma_{\rm RM} = 1056 \pm 67 \ {\rm rad\ m}^{-2}$$

$$P = p\,e^{-2\sigma_{\rm RM}^2\lambda^4}{\rm Sinc}\,({\rm RM}\lambda^2)e^{2i\Psi}$$



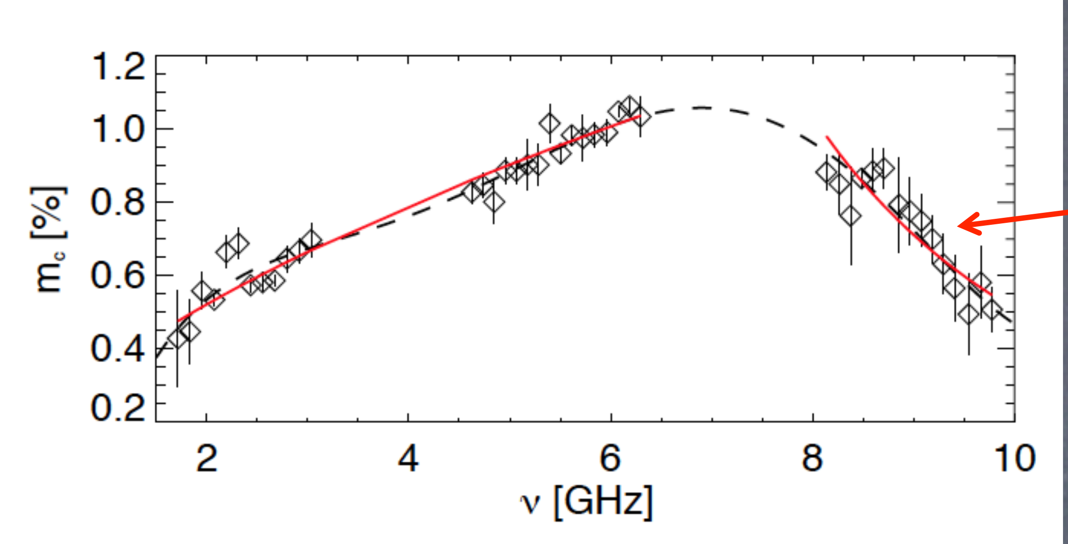
Circular Polarization

Linear Polarization

large increase in p
towards longer
wavelengths

Change in sign of RM?

RRM fit (8 – 10 GHz)



$$V \propto \sin \frac{c^3 \mathrm{RRM}}{\nu^3}$$

$$B = (10^{-9} L^{-1} \mathrm{RRM})^{-1/4}$$

Macquart+01, Kennett & Melrose 98

- Fitting to 8-10 GHz: RRM = 647 +/- 12 rad/m^3
- RRM$_{int}$ = RRM ((1+z)/d)^3 = 50 rad/m^3 for d=10
- Assuming equipartition: B = 15 mG (for L = 1 pc)

$$m_c^{int} \sim \left(\frac{2.8B}{\nu_{obs}(1+z)/\delta} \right)^{1/2}$$

- Intrinsic CP for completely uniform B-field: ~ 0.3% at 8 GHz

SSA analysis

$$\nu_m = 5.7 \pm 0.1\,\mathrm{GHz}$$
$$I_{\nu_m} = 1.744 \pm 0.001\,\mathrm{Jy}$$

$$B = 10^{-5} b(\alpha) S_m^{-2} \nu_m^5 \theta^4 (1+z)^{-1} \delta \;[\mathrm{G}]$$

- Marscher+79,83,87
- Angular size of emission region ~ 0.5 mas (using B = 15 mG)

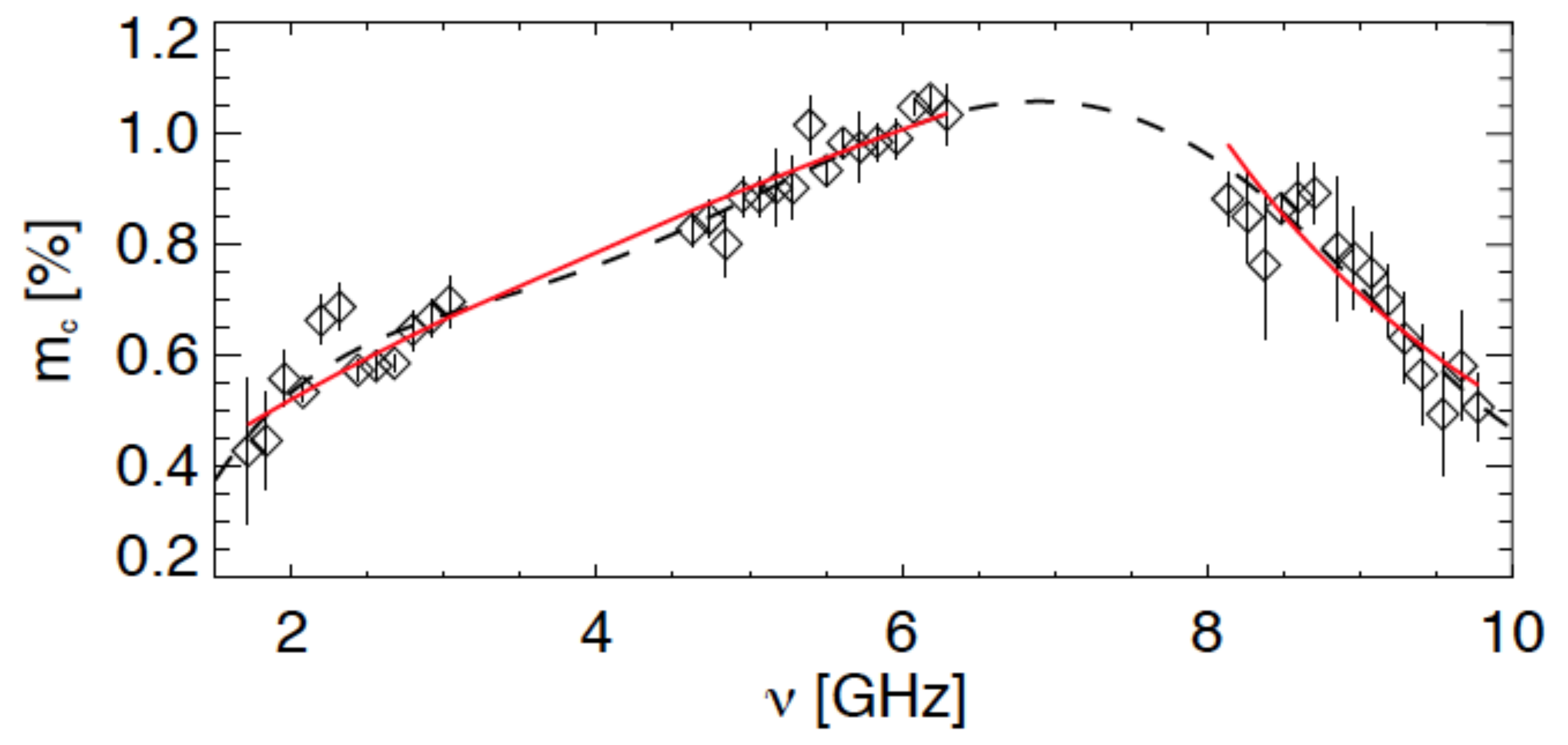
$$U_B = \frac{B^2}{8\pi}\;[\mathrm{erg\ cm^{-3}}]$$

$$U_{re} = 2\ln(\nu_2/\nu_m) D^{-1} \theta^{-9} \nu_m^{-7} S_m^4 (1+z)^7 \delta^{-5}\;[\mathrm{ergs\ cm^{-3}}]$$

- U_{re} >> U_B (particles dominate jet energy density)
- No contraints on g_{min} or jet composition
- VLBI observations + radiative transfer simulations required

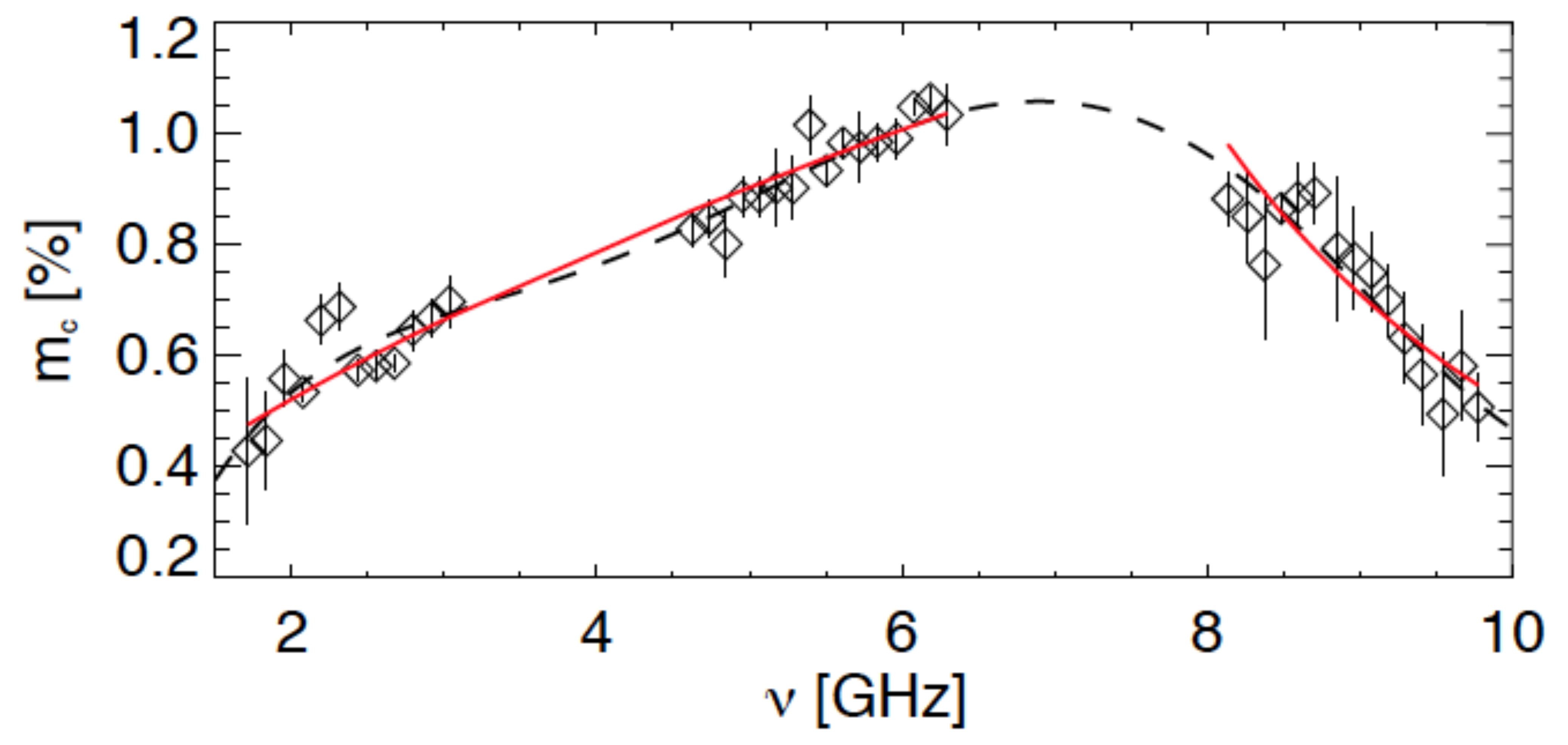
CP generation mechanisms (Homan+09)

1. Stochastic production of CP from tangled B-field: requires intrinsic or conversion or combination. CP should vary in sign and amount across different frequencies
2. Intrinsic CP from a strong (tens of mG) vector-ordered B-field (assuming all emitting particles are e-s, "e-p jet")

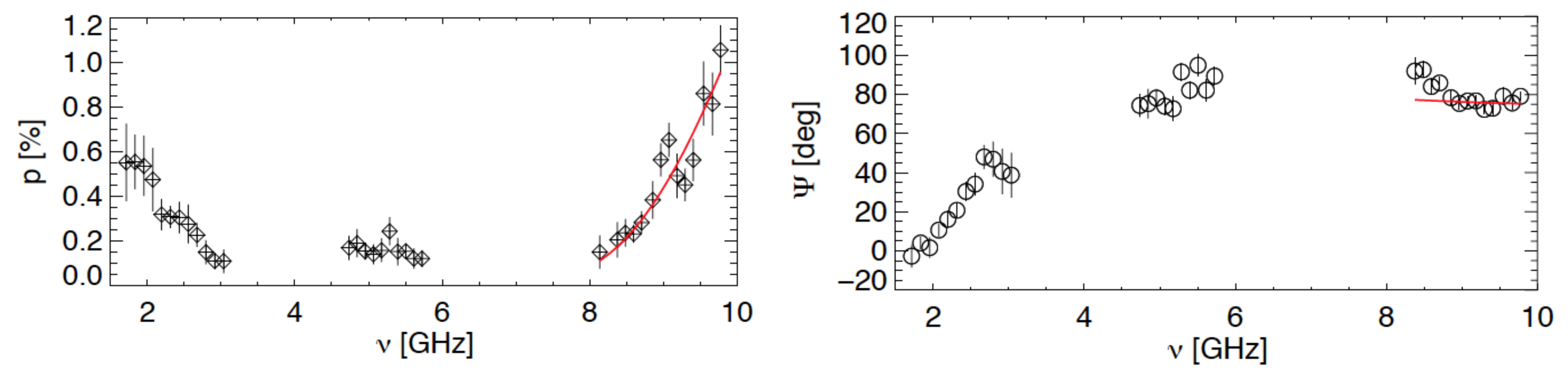


CP generation mechanisms (Homan+09)

1. ~~Stochasti [illegible] tion of CP from tangl [illegible] requires intrinsic or conversion or c [illegible] ary in sign and amount across di [illegible] frequencies~~
2. ~~Intrinsic C [illegible] (tens [illegible] dered B-field (assuming [illegible] particles are [illegible] ist")~~



CP generation mechanisms (Homan+09)



3. Conversion of LP to CP by internal Faraday rotation (thermal or low energy e-). **Small Faraday depth** so that B-field at front of jet converts LP from back of jet into some CP. 2 and 3 will act together to some degree.

4. **High rotation depth** version of 3, where no large scale B-field order is required and net CP can be produced in large amounts with very little net LP

5. Faraday conversion from a helical B-field. **No internal Faraday rotation** required as field orientation at back of jet is already different to that at front of jet

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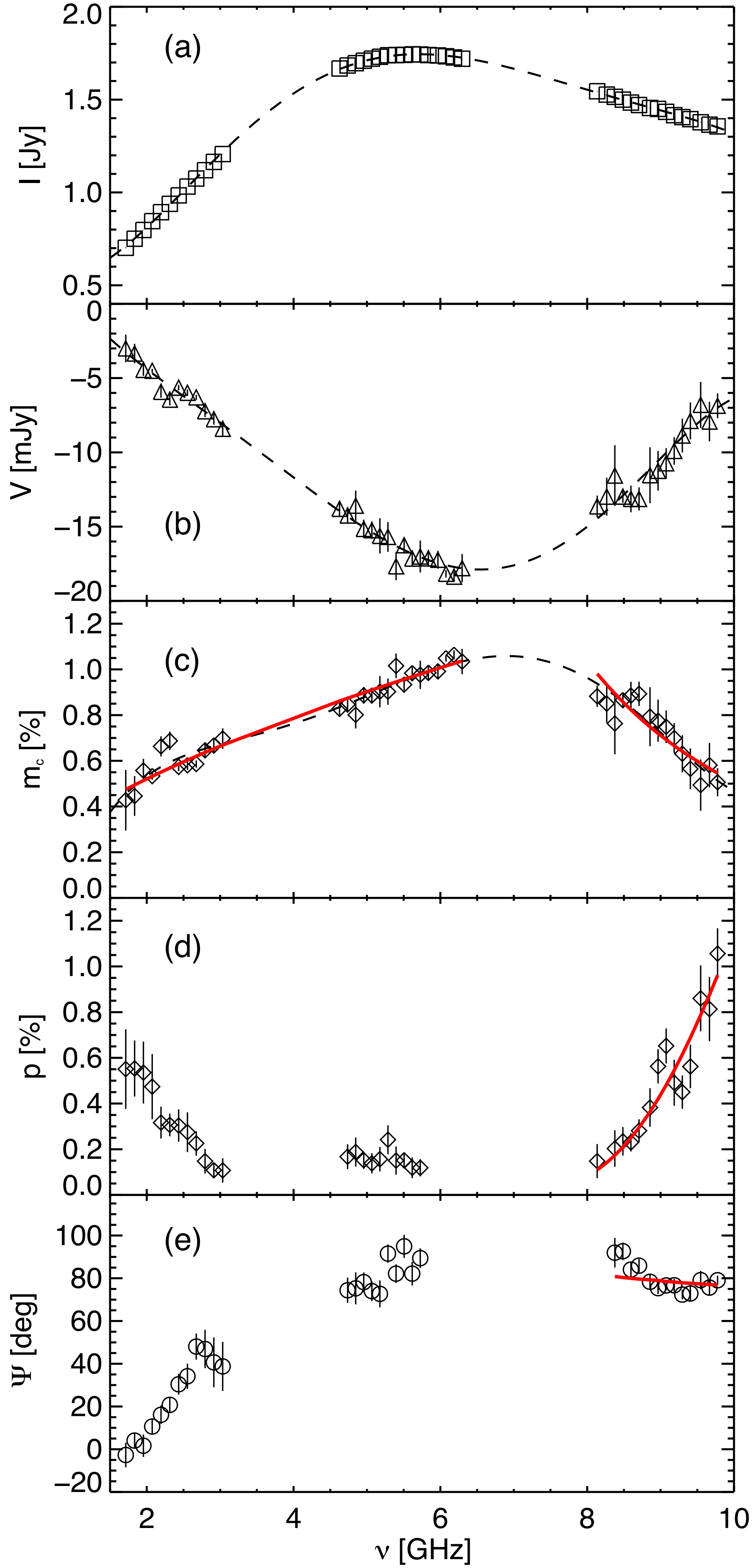

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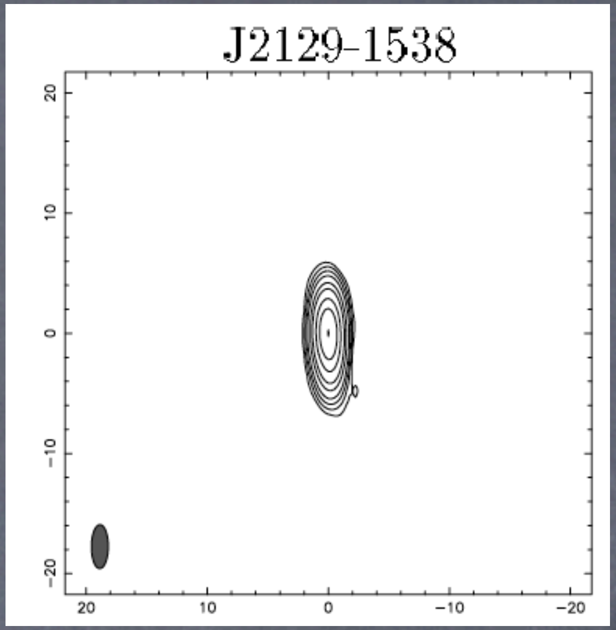


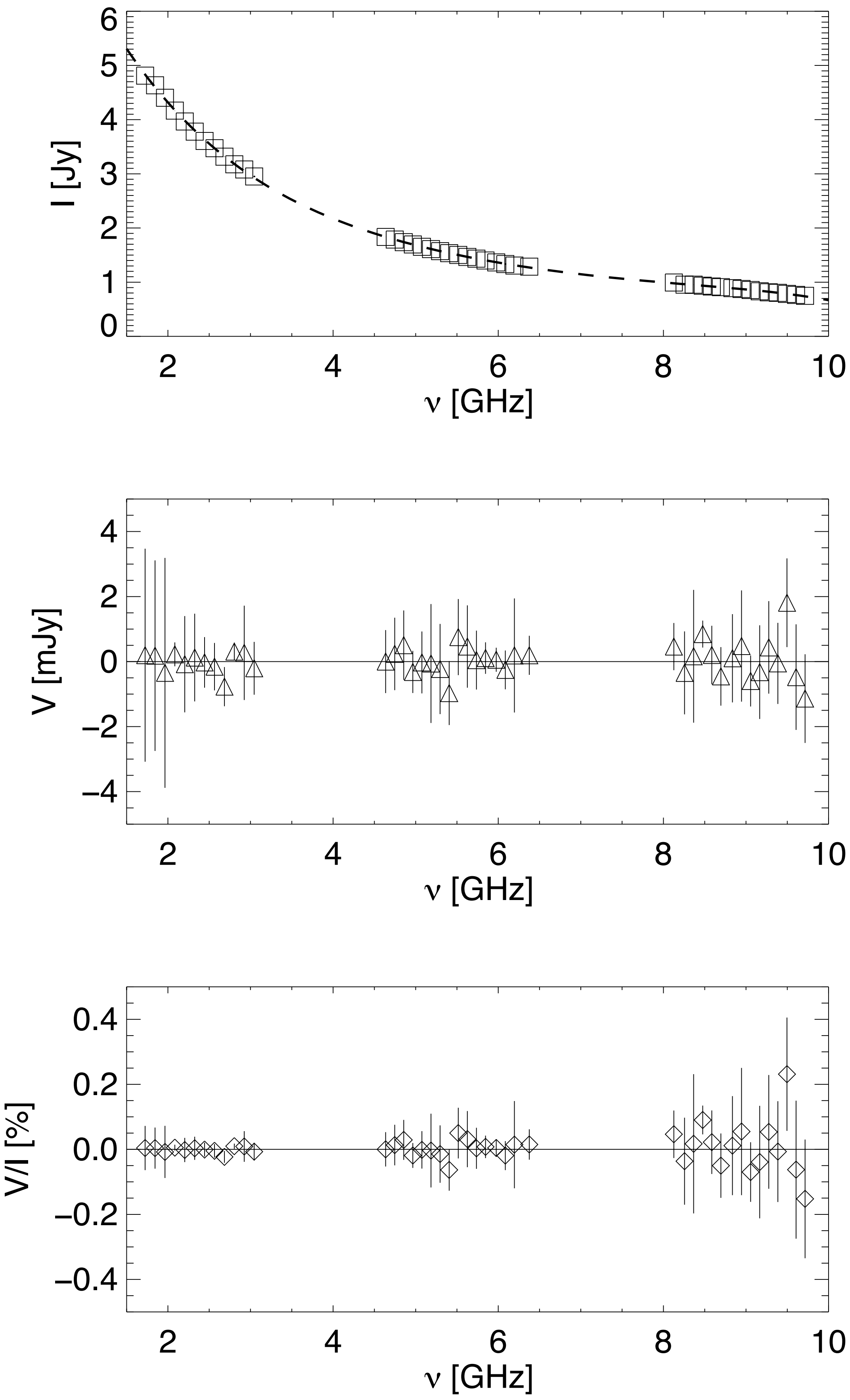
- Dominant CP generation mechanism: Faraday conversion of LP to CP
- Conclusions:

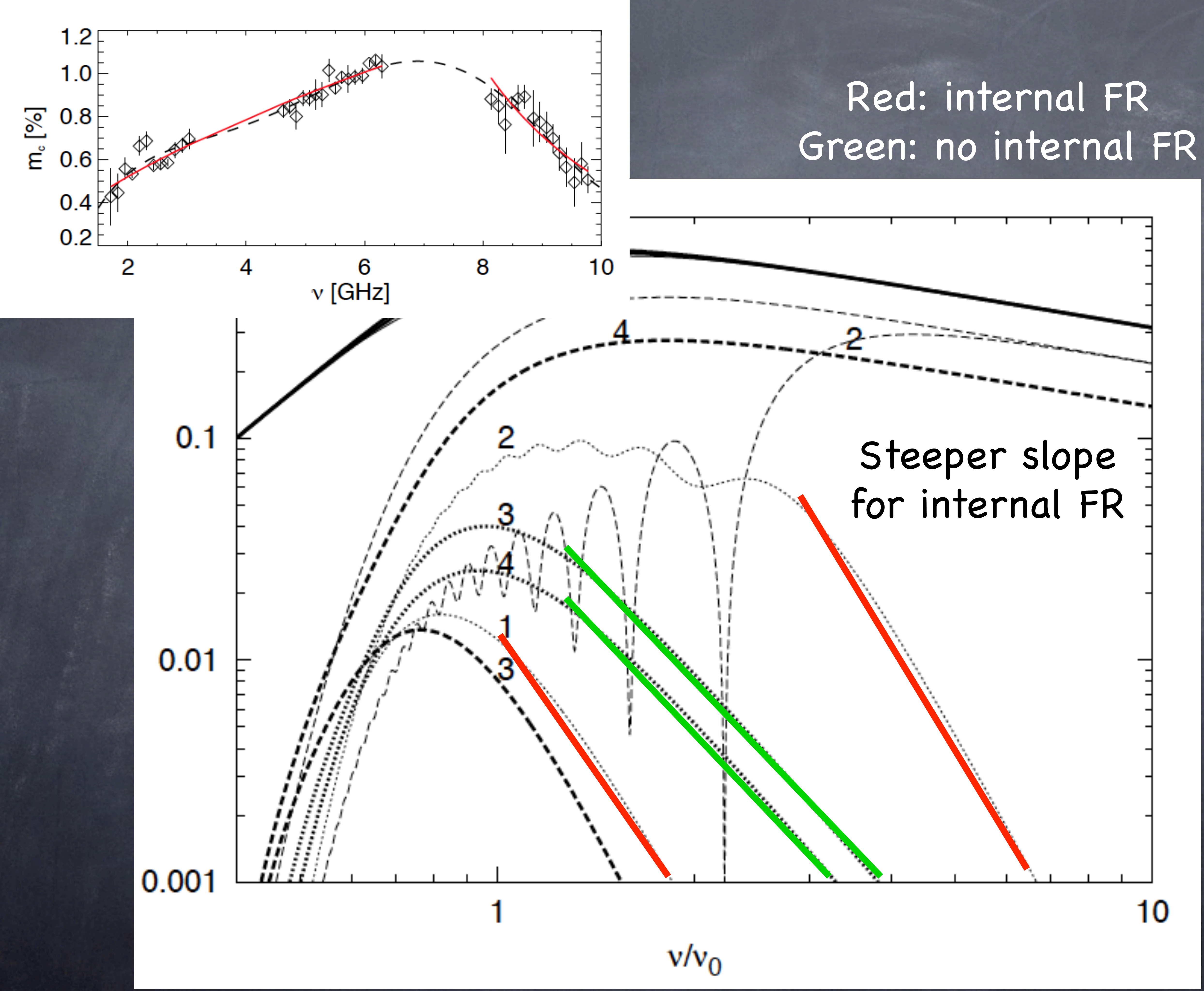
1. little or no thermal plasma within the jet
2. cannot yet distinguish between magnetic twist and internal Faraday rotation models
3. relativistic particle content unconstrained

Thank You

PKS B0252-712

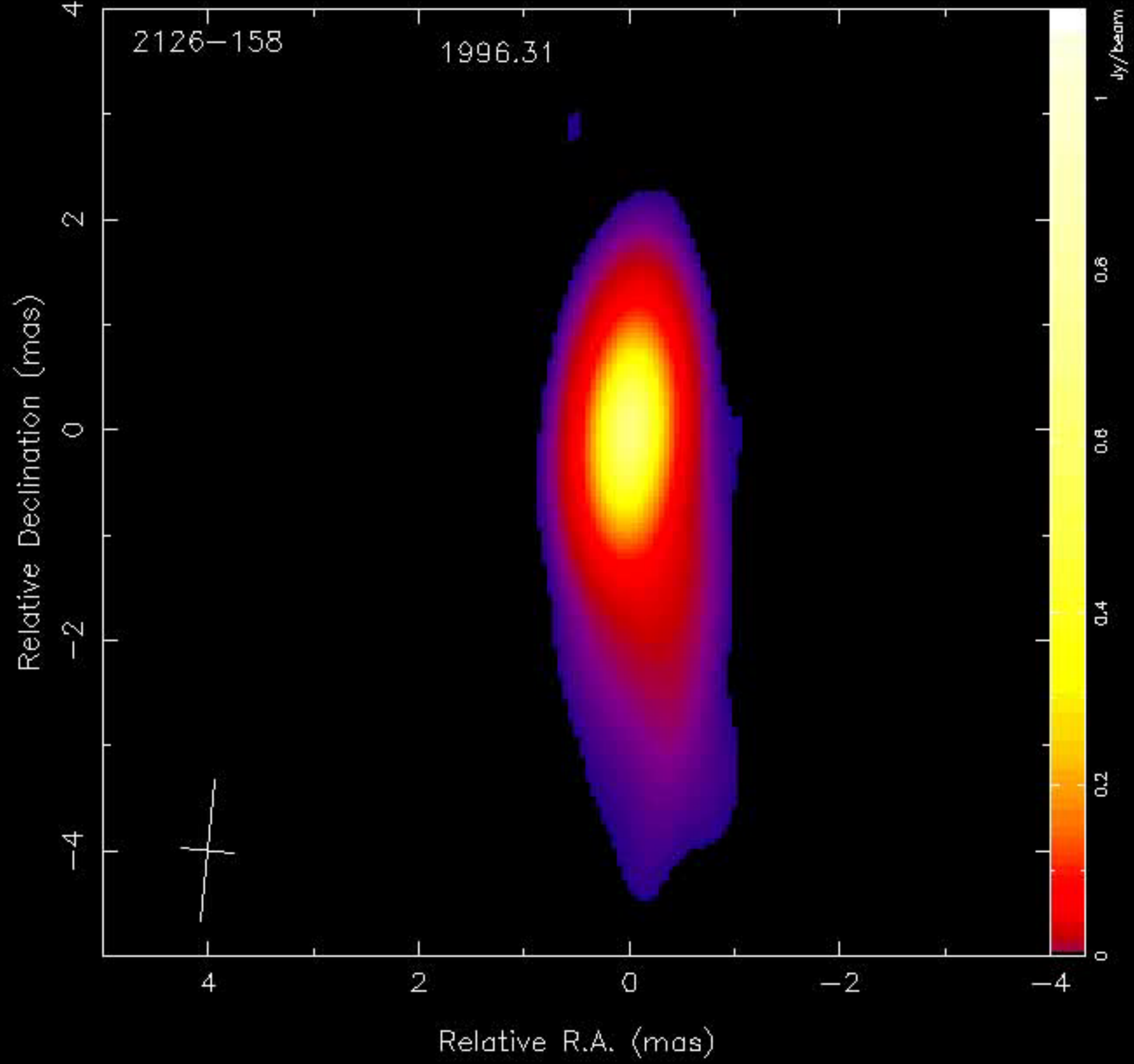
- Source to check calibration against
- CSS radio galaxy





Red: internal FR
Green: no internal FR

Steeper slope
for internal FR


2126−158
1996.31
Relative Declination (mas)
4
2
0
−2
−4
Relative R.A. (mas)
4
2
0
−2
−4
Jy/beam
1
0.8
0.6
0.4
0.2
0