The Strong Radio Band Circular Polarization Event in 3C 279

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1. Overview

In late 2003 we resumed intensive monitoring of circular polarization at 4.8 and 8.0 GHz after a hiatus of several years and commenced observations at a third, but crucially important frequency, 14.5 GHz, with the University of Michigan 26-meter telescope (Fig 1) located about 15 miles from the campus area. The goal of the program is to use the evolution of the circular polarization spectrum as a diagnostic of the physical conditions and processes in the radio band emitting regions of AGN jets, and specifically to probe the role and properties of the magnetic field embedded within the radio jet. Both the magnitude and sign (polarity) provide important information: in combination with theoretical modeling these data yield constraints on such properties as the low energy cutoff of the radiating particles, the particle composition of the jet (electron-proton or electron-positron plasma), the degree of order of the magnetic field within the radio-emitting region, and the polarity of the magnetic field as a function of time and observing frequency.

Figure 1. The 26−meter UMRAO antenna; located in Dexter, Michigan

1.Origin of CP (Stokes V)

Statistical studies have shown that CP is common in flat spectrum sources; and surveys typically find this emission in 1/4 to 1/2 of the sources studied at a level greater or equal than 3 sigma. The emission is weak $< 1\%$), and most past studies have focused on detection statistics rather than CP variability because of the difficulty in making these measurements. The circularly polarized emission from these AGNs exhibits properties that are consistent with its creation by a stochastic linear-to-circular mode conversion process in a partially opaque region containing a tangled magnetic field (Jones 1988, Beckert & Falcke 2002). VLBP imaging has established that the emission is predominantly generated in or near the compact 'core' regions (τ=1 surface) of the emitting region (Homan 2005; Homan & Lister 2005).

3. The Unusual CP event in 3C 279

Over the past two years, we have been observing 36 sources at all three of our primary observing frequencies to identify AGNs which emit sufficiently strong levels of CP emission to be able to follow the temporal evolution of this emission, including strength and polarity, with the Michigan antenna. A goal is to study the frequency-dependent behavior during 'events' occurring on time scales of several months. The observations require long integration times of several hours because of the weakness of the emission. Calibration relies on measurements of H II regions which we believe do not emit circularly polarized emission; observations of these calibrators are interleaved with observations of our target sources to track the instrumental polarization. Results for an example calibrator are shown in Figure 2.

The best example of a CP event captured to date is plotted in Figure 3 for the QSO 3C 279. As shown, the source emitted strong circularly polarized emission (near 1 percent) at all three frequencies, with a sign change at 4.8 GHz during late 2003- early 2004; this event coincides with a small outburst in total flux and occurred during a time when the fractional linear polarization was decreasing and near 5 percent. The observed sign reversal at 4.8 GHz is inconsistent with the concept that CP is a simple tracer of the net flow of magnetic energy from the central engine to the jet (see Ruszkowski & Begelman 2003) or an indicator of the direction of rotation of the spinning central black hole/accretion disk via the winding up of the initial seed magnetic field (Gabuzda, Murray & Cronin 2004).

Figure 4 shows 3C 345, which did not exhibit CP.

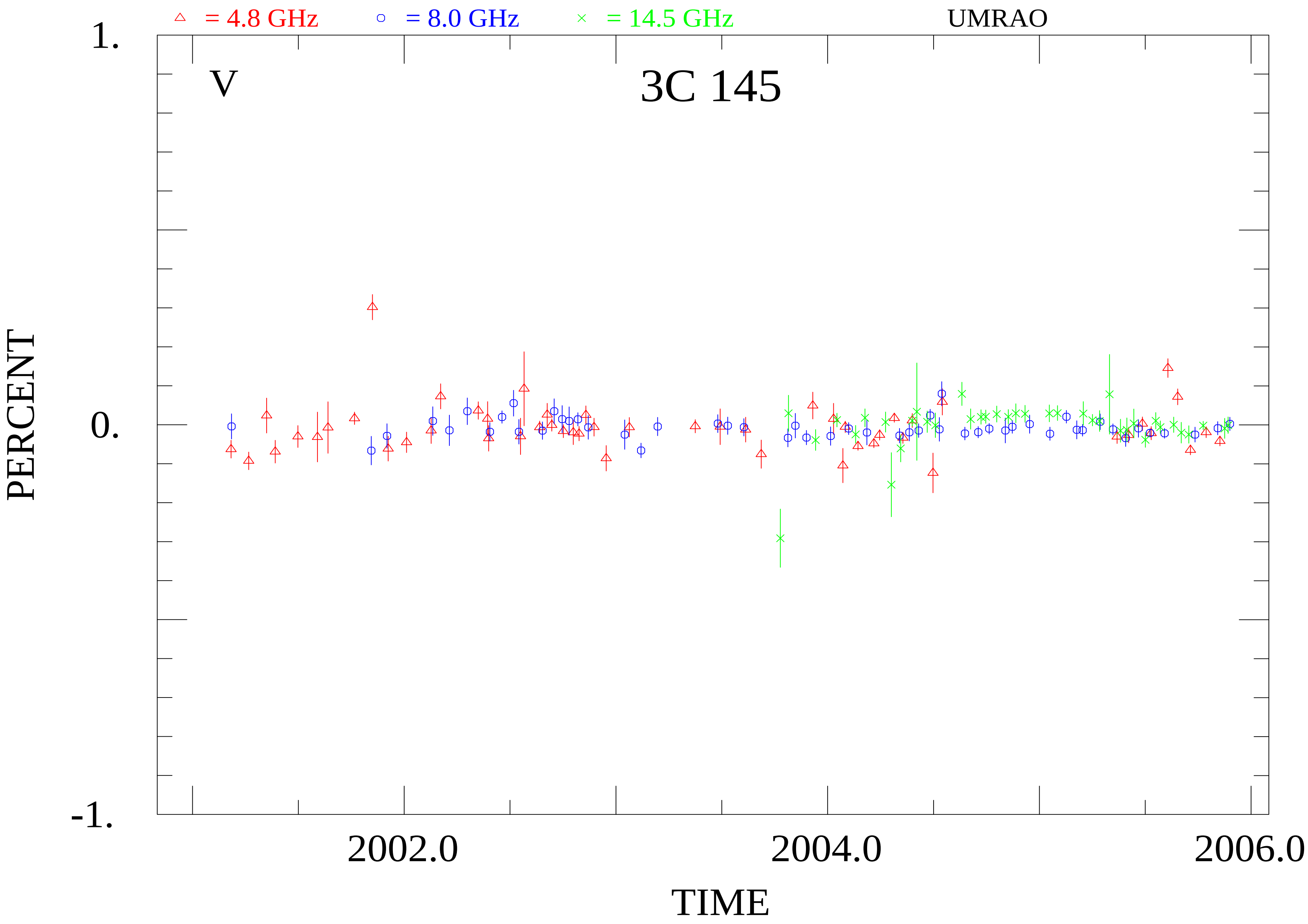

Figure 2. Two−week Averages of Stokes V (circular polarization) for the unpolarized source 3C 145 (M42)

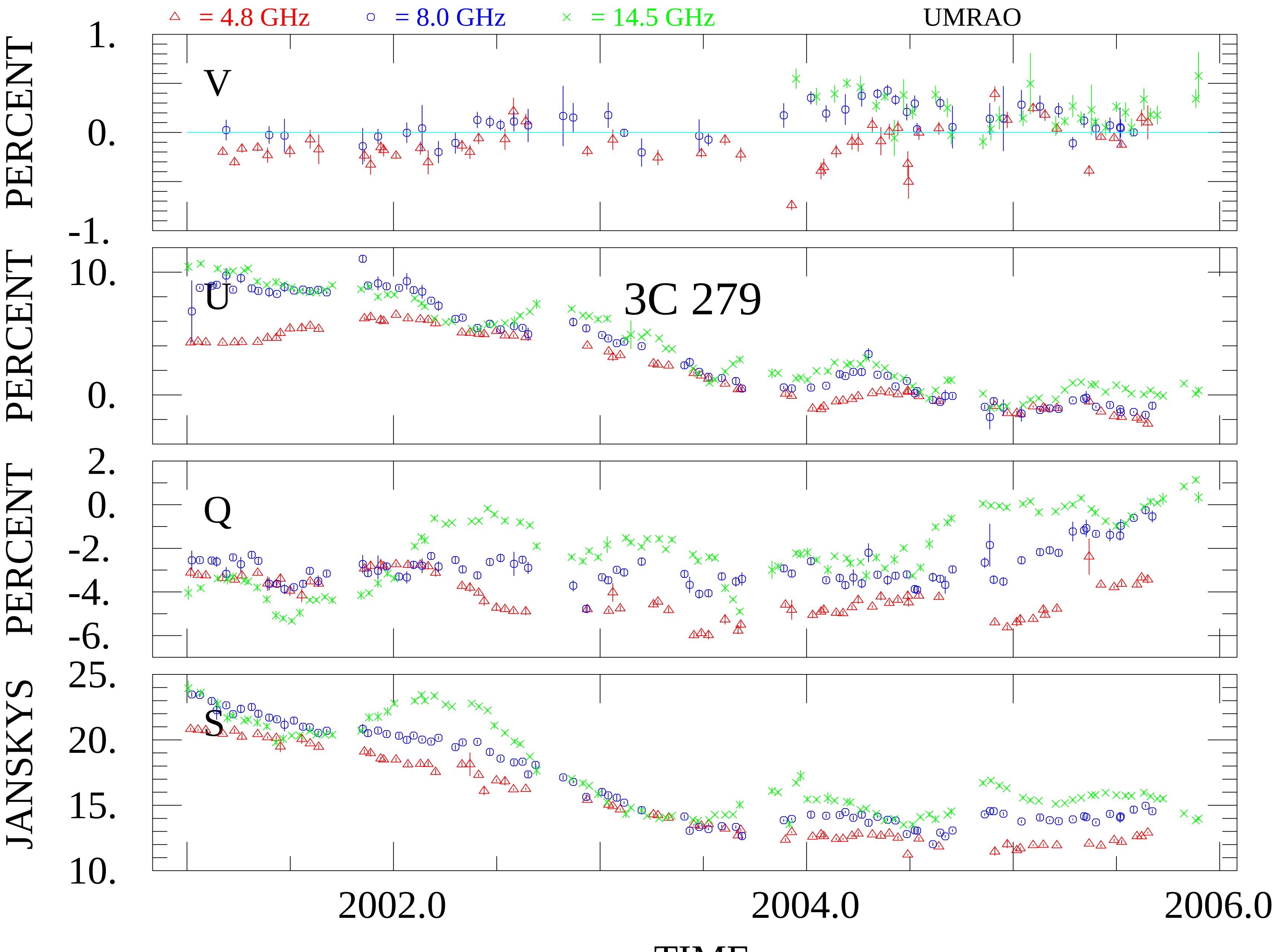

Figure 3 Two−week averages of all four Stokes Parameters for the QSO 3C 279. From Bottom to top: total flux density (S) in Janskys Stokes Q, U, and V in percent. The data at 14.5, 8.0. and 4.8 GHz are denoted by crosses, circles and triangles respectively. The frequency−dependent differences in linear polarization and total flux density imply significantl opacity effects in the region where this emission is produced.

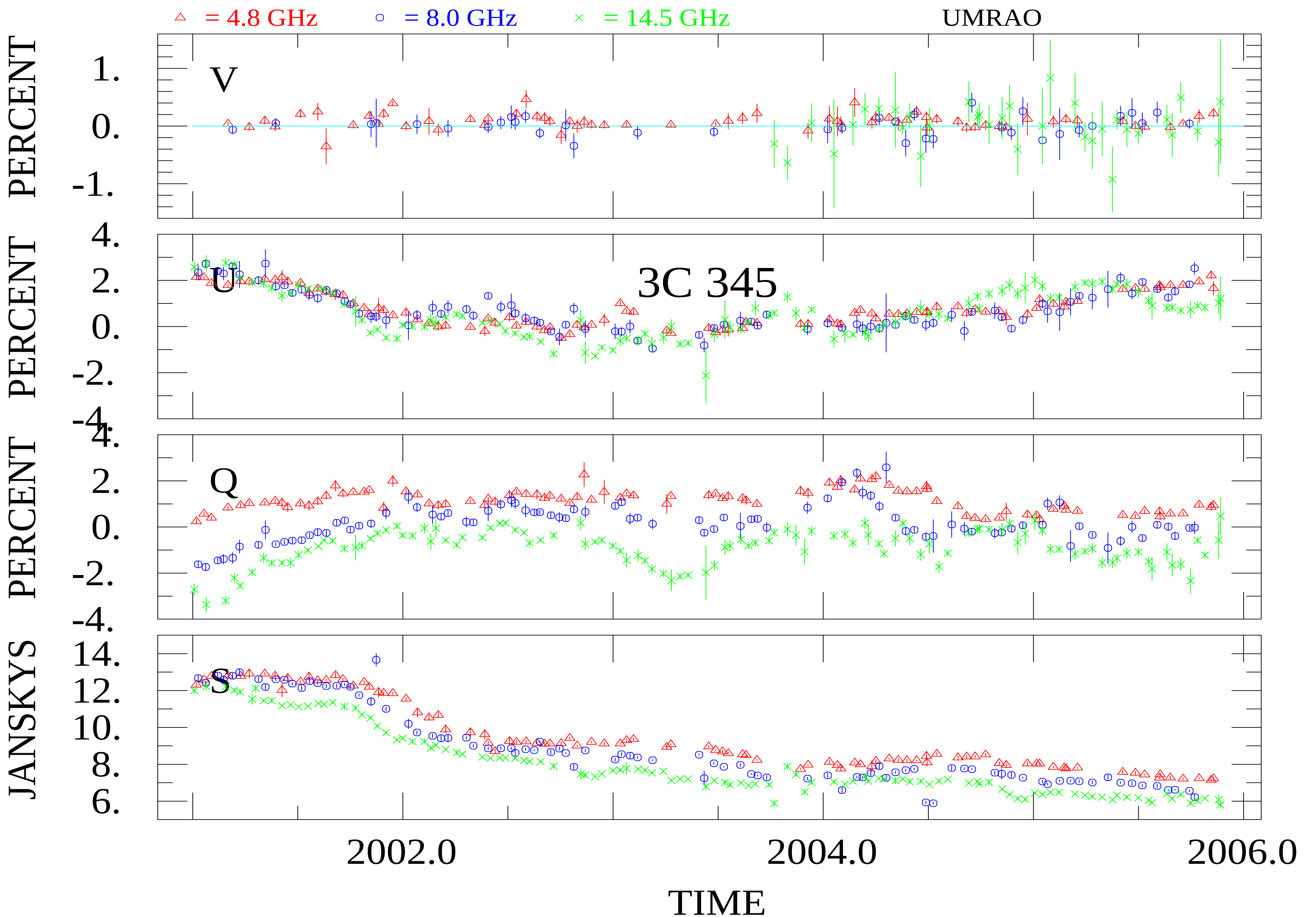

Figure 4. Two−week averages of the data for the program source 3C 345, illustrating the typical behavior of Stokes V in AGN jets. Here the values at the three frequencies track and remain near zero.

4. Interpretation

We have attempted to explain the behavior of the CP spectrum using a simple model which predicts the spectral behavior of the Stokes parameters for flux emerging from a cube of 30x30x30 random cells; we adopt a correlation length of 3 cells, and assume that the emission is due to relativistic electrons. In Figure 4 we show these radiative transfer calculation results. Free parameters in the simulations include the low energy cutoff in the particle energy distribution and the degree of order of the magnetic field. The simulation illustrates that to match the data a moderate level of linear polarization is needed to seed the process. Also, very low particle energy cutoffs are ruled out. Based on this simple grid, the best match to the data requires a γ_{min} of 100 and a relatively well-ordered field with ϵ, the fraction of energy density in an ordered magnetic field, in the range 0.10-0.25. The best fit is obtained for the model denoted with open circles. Note that a sign reversal is predicted by the model, in agreement with the data. While the simulations demonstrate that the observed spectrum can be globally matched by a simple stochastic model, we expect to carry out detailed fits in the near future using more realistic models for the base variables (velocity, density, magnetic field, spectral properties) and to match observed changes in all 4 Stokes parameters with time.

Acknowledgments

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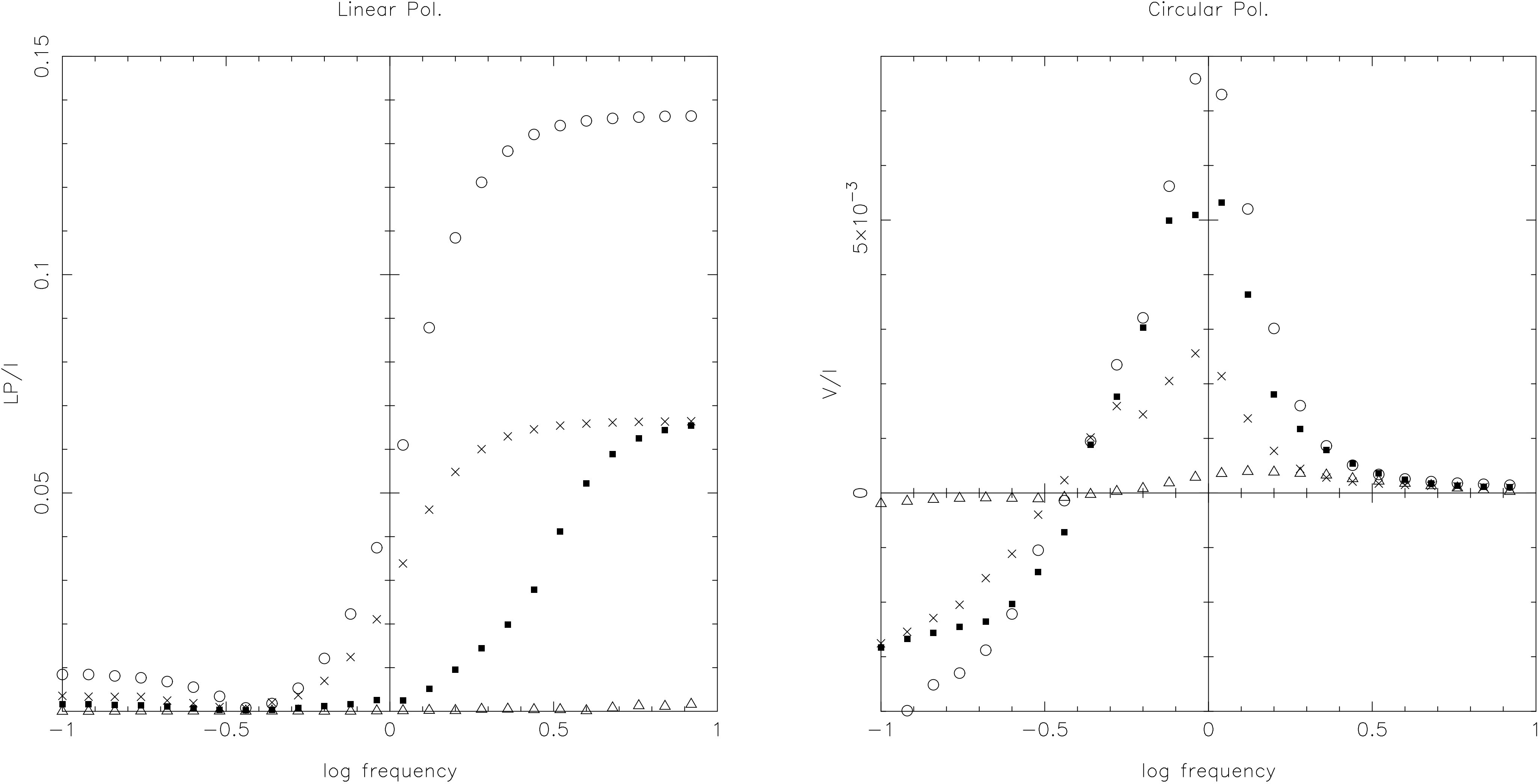

Figure 5. Solutions for the equations of radiative transfer illustrating the spectral behavior of the Stokes parameters for flux emerging from a cube of 30X30X30 random cells. A correlation length of three cells is assumed. Four models are shown:
Crosses: Gamma−min = 100, e = 10% Open Trangles: Gamma−min = 10, e = 10%
Filled squares: Gamma−min = 50, e = 10% Open Circles: Gamma−min = 100, e = 25%
The tau = 1 surface is approximately at the log frequency = 0 line in each panel.

References

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