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Centimeter-band Variability in GPS Sources

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Abstract. Monitoring results are presented for the Stanghellini 1 Jy GHz-peaked-spectrum source sample, illustrating that several members exhibit variability in total flux and/or linear polarization over timescales of order a decade. The variability occurs while the spectrum, based on the integrated fluxes, remains steep and characteristic of a transparent source. Total flux variability is unexpected in view of recent VLBI observations indicating no or hidden cores in several members. However, both the variability, and the detection of circular polarization in one class member, argue for the presence of opacity in some portion of the radio jet.

1. Introduction

To investigate the total flux density and polarization properties of GHz-peaked sources, we commenced systematic observations of the 1 Jy Stanghellini (Stanghellini et al. 1998a) sample with the University of Michigan Radio Astronomy Observatory (UMRAO) 26-meter telescope in November 1999. The class of objects is of particular interest because they are believed to be young sources, primarily based on their small sizes, or, alternatively, sources confined by dense gas in their ambient medium (O'Dea 1998). Expected class properties from prior VLA and VLBI observations (e.g. O'Dea 1998) are low level variability and low ($< 1\%$) fractional linear polarization. Recent VLBA observations at 15 GHz suggest no or hidden cores (Stanghellini et al. 2001).

The selection criteria for the sample are:
1) declination $\delta > -25°$, galactic latitude $|b| > 10°$;
2) S> 1 Jy at 5 GHz:
3) Turnover frequency in the range $0.4 \leq \nu_{to} \leq 6$ GHz; and spectral index $\alpha > 0.5$ in the high frequency (presumably optically thin) part of the spectrum ($S_\nu \propto \nu^{-\alpha}$).
By optical class the objects are a mix of quasars and galaxies. By radio morphology 1/3 of the sample are known or suspected compact symmetric objects (cso), a group identified as exhibiting low variability (Fassnacht & Taylor 2001).

Thirty-two of the 33 sample members are within the declination limits of the Michigan 26-meter paraboloid. These objects have been observed at least tri-monthly at 4.8, 8.0, and 14.5 GHz for total flux density and linear polarization since November 1999. Eighteen of the sources have been observed for a decade or more with sufficient sampling to identify variability, if present; limited data with ad hoc sampling are available for 9 additional objects; and only 6 sources had not been observed by us prior to November 1999. Twelve objects are currently members of the 2cm VLBA survey MOJAVE (Kellermann et al. 1998), providing important complementary information on pattern speeds and structural changes. Preliminary results for some sample members indicate relatively slow component speeds (Lister private communication; see also http://www.cv.nrao.edu/2cmsurvey/).

In Figure 1 we compare fractional linear polarization for the GPS sample and for the Pearson-Readhead (hereafter PR) sample (Pearson & Readhead 1988), a flux and position limited sample; the latter is taken for comparison because it is believed to be representative of extragalactic objects, and insensitive to most selection effects. We have systematically been observing it since 1984 (Aller, Aller, & Hughes 2002). Only galaxies and QSOs are included for the PR sample since there are no BL Lacs with GPS spectra. Comparison of the distributions confirms that that on average the 4.8 GHz polarization is low in GPS sources relative to the general population of extragalactic objects; a KS test gives a low probability of 0.000034 that these distributions are drawn from the same parent population.

In contrast to the abnormally low fractional polarizations at 4.8 GHz however, several sources show fractional polarization at 14.5 GHz at levels comparable to those in AGNs; in several these are clearly time-variable with time scales of order several years to a decade. As an example, we show in Figure 2, the total flux density and linear polarization light curves for the galaxy, 1358+624, a source classed as a cso by radio morphology. While there is little to no flux variability as expected for objects of this type, a long-term outburst in linear polarization occurred at both 8 and 14.5 GHz during the mid to late 1980s. We find similar behavior, low amplitude variability in total flux and variability in linear polarization at 14.5 and tentatively at 8.0 GHz in the suspected cso, 1117+146.

Plausible mechanisms discussed in the literature to explain low fractional linear polarizations are (Stanghellini et al. 1998b) Faraday depolarization in the radio-emitting region, or a tangled magnetic field along the line of sight. A third possibility, beam depolarization, has recently been rejected (Stanghellini et al. 2001). We believe that a tangled magnetic field would not readily account for the frequency-dependent differences in linear polarization we find in our data.

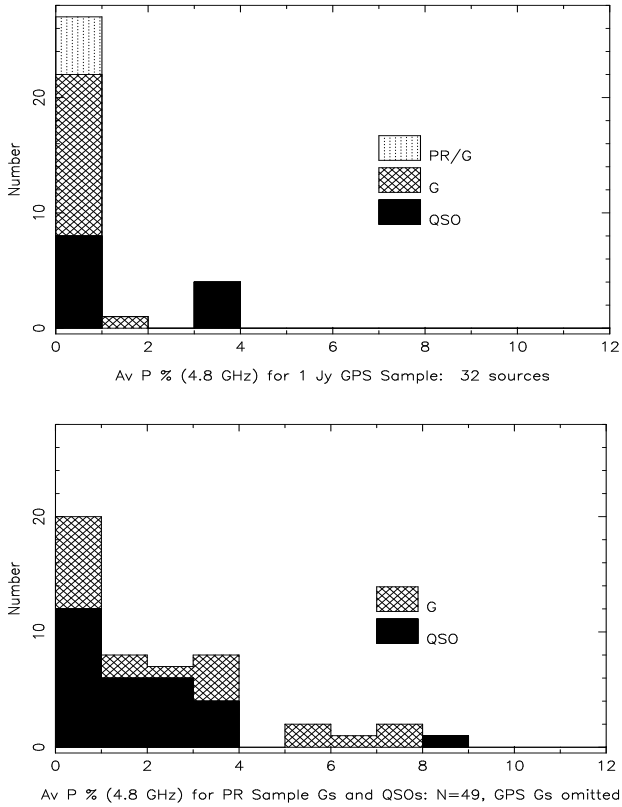

Fig. 1. Average polarization from time-averages of the daily measurements of the Q and U Stokes parameters. Top panel: GPS sources; bottom panel: Pearson-Readhead sources. P has been corrected for bias due to random noise (Wardle & Kronberg 1974). The five sources common to both samples are omitted from the distribution in the bottom panel.

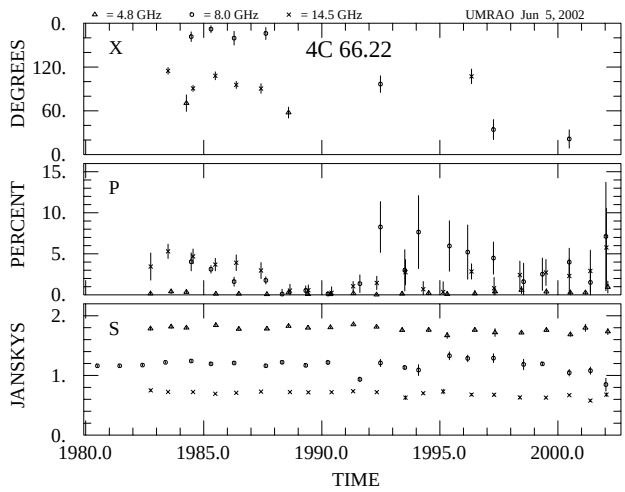

Fig. 2. Light curves for 4C 66.22 (1358+624) based on yearly averages of the UMRAO data. From bottom to top: total flux density, fractional linear polarization, and position angle of the electric vector of the polarized emission (EVPA). The data at 4.8 GHz are denoted by triangles, at 8 GHz by circles,and at 14.5 GHz by crosses. This convention is adopted in subsequent figures.

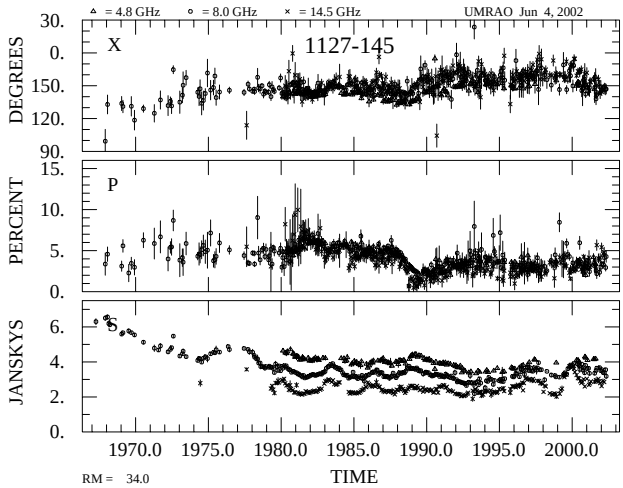

Fig. 3. Monthly averages of the data for 1127-145. The polarization has been corrected for Faraday rotation assuming the low value of 34 rad/m^2 given in Rusk 1988. The EVPAs in the top panel do not show a λ^2 separation, the signature of Faraday rotation.

In Figure 3 we show light curves for the QSO 1127-145, a source which has exhibited variability in both total flux and linear polarization. A goal of our program has been to determine whether the GPS spectrum is maintained over decades, or whether for some sources this spectral character is a short-term phase. In the case of 1127-145, the source maintained its GPS spectral shape for nearly 20 years, but in 1999 a large outburst commenced at 14.5 GHz, and the spectrum flattened. Thus, based on its current spectrum, it would not have been classed as a GPS source.

To investigate the nature of the variability in this source, we show in Figure 4 a structure function based on the data shown in Figure 3. Structure functions are useful tools providing two pieces of information. The slope of the linear portion gives information on the noise process responsible for the variability. It is typically found to be $\sim$1 in AGNs (Hughes, Aller, & Aller 1992) a result indicative of shot noise. The turnover gives a measure of the characteristic time scale and is typically of order 2 years, with some spread from source to source. In the structure function for this source we find a slope of 0.57 ± 0.18, which does not match *any* well-studied, ideal noise processes, and a relatively long, frequency-dependent characteristic variability time scale ranging from 4.1 years at 4.8 GHz to over a decade at 8 and 14.5 GHz. The behavior of this structure function illustrates that the nature of the variability is both unusual and complex in this source.

In Figure 5 we show light curves for a second variable source, 2134+004, which has been well-studied with VLBI (e.g. Pauliny-Toth et al. 1989). Rotation measure mapping (Taylor 2000) has identified significant Faraday rotation in this source which is highly position-dependent. Our EVPAs have been corrected for Faraday rotation adopting Taylor's value for component A, one of two nearly-

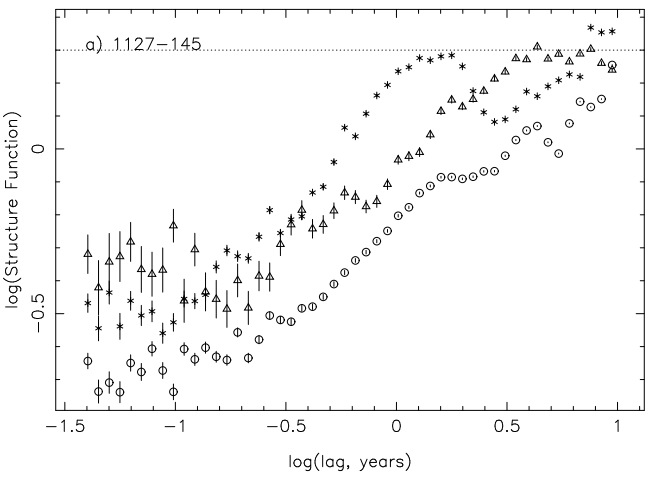

Fig. 4. First-order structure function for 1127-145 based on monthly averages of the data. The dotted line near the top marks $2\sigma^2_{signal}$.

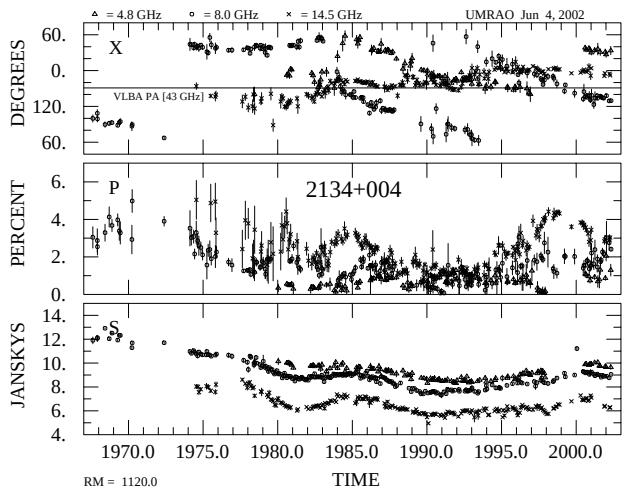

Fig. 5. Monthly averages of the data for 2134+004. The polarization had been corrected for Faraday rotation assuming a time-independent rotation measure of 1120 rad/m^2. An ambiguity of 180° in our EVPA determinations produces the apparent discontinuities in the EVPA light curve. The line in the top panel marks the orientation of the VLBI structural axis determined from data at 43 GHz (Lister & Smith 2000).

identical unresolved components. This correction brings the EVPAs at the 3 frequencies into agreement at Taylor's VLBA epoch (1998.58), but at other epochs a wavelength-dependent separation remains which most likely is due to a combination of time-variable opacity and time-variable Faraday rotation. We are, unfortunately, unable to unravel these effects with our single dish measurements.

In Figure 6 we show the light curves for OI 363, a QSO for which our sampling is irregular. While the observations cannot be used to identify the details of the variability, they clearly reveal that the source is variable in both total flux density and fractional linear polarization, and the data are consistent with a variability time scale of order a

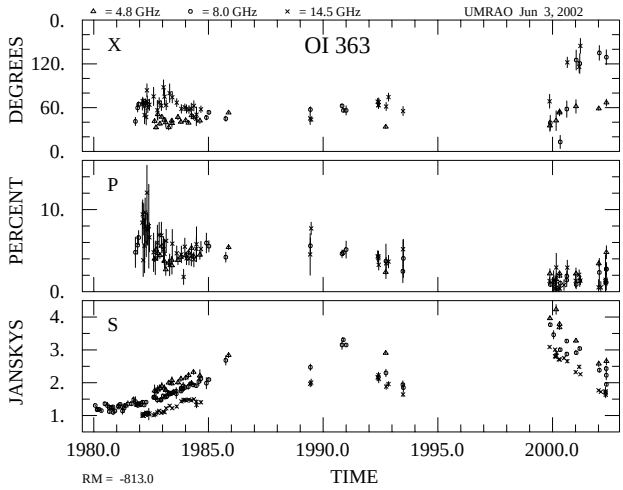

Fig. 6. Daily averages of the data for OI 363 (0738+313). The polarization has been corrected for Faraday rotation assuming the rotation measure given in Stanghellini et al. 1998a. Note that the fractional linear polarization exceeded 10% at 14.5 GHz in the early 1990s but is now only a few percent.

decade. Note that the GPS spectral shape in maintained during the observing window of two decades.

In Figure 7 we show data for a poorly sampled source which has only been observed with regularity since the start of the program. However, even with this limited sampling, the ordered changes in total flux density since late 1999 are consistent with the presence of low level variability. While the linear polarization is only of order a few percent, this is a source in which we have recently detected relatively high levels of circular polarization ($-0.71 \pm 0.07\%$) in our single dish measurements at 4.8 GHz; CP with a comparable magnitude and sign has also been detected in this source by Homan et al. 2001 ($-0.46 \pm 0.06\%$) using VLBA observations obtained in December 1996, a time period in which we, unfortunately, have no data. The most plausible mechanism for the production of the circular polarization is linear-to-circular conversion in a partially-opaque emitting region.

2. Conclusions

Our main conclusions are:

1) Several sample members exhibit variability in total flux with amplitudes comparable to those in AGNs. Of the 18 good-to-well observed sources, 10 show total flux density variations at some level. The characteristic time scales of these variations are typically long compared to other UMRAO program sources.

2) In general the characteristic GPS spectrum is maintained over decades, including times when flux variability is present.

3) The time-averaged fractional linear polarizations at 4.8 GHz are low compared to results based on the Pearson-Readhead sample at 4.8 GHz, confirming that this is a GPS class property.

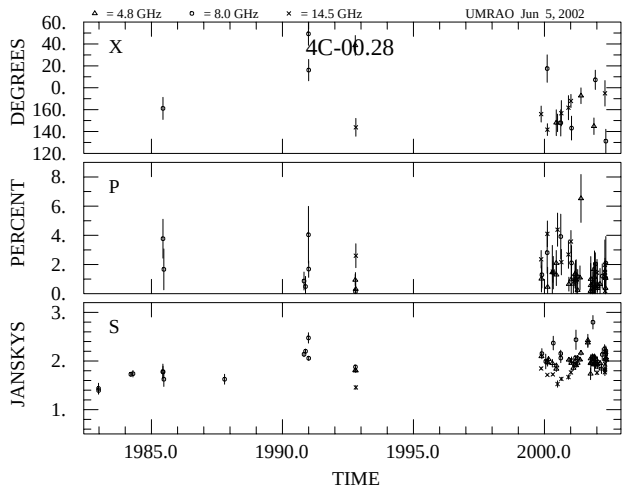

Fig. 7. Daily averages for the core-jet source, quasar 4C-00.28(0743-006)

4) At 14.5 GHz, several sources exhibit higher fractional polarization than at 4.8 GHz which in some sources is time-variable, reaching values as high as 10%; 2 confirmed or suspected cso sources exhibit extremely low level variability in total flux while exhibiting well-defined variations in fractional polarization at 14.5 GHz, as illustrated in Figure 2.
5) The frequency-dependence in the EVPA in some sources is consistent with significant Faraday rotation, which may be time-variable.

While the spectral shape is characteristic of a transparent source, both the variability we find and the detection of circular polarization in one class member are most easily explained by the presence of significant opacity in some portion of the jet flow. This hypothesis can best be tested by spectral mapping of selected group members. Hopefully, longer-term observations will answer the questions of whether variability is a property of most, if not all, sample members which are not csos, and, more importantly, of whether the sample is, in fact, a collection of physically-different objects joined together on the basis of their (in some cases) evolving radio spectra.

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