Radio-to-$\gamma-$ray, broad-band variability of the classical BL Lac PKS 0735+178

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Abstract

The power spectral densities (PSDs) of the blazar light curves, $P(\nu_k) = A\nu_k^{-\beta}$, where A is the normalization and β is the slope, indicate that the variability is generated by the underlying *stochastic* processes (i.e., $\beta \simeq 1-3$, characteristic of flicker/red noise). Study of power-law slopes, normalization or characteristic timescales (if any), in the PSD is important for constraining the physics of emission and energy dissipation processes in the blazar jets. We present the results of PSD analysis of the BL Lac object PKS 0735+178 light curves at GeV (*Fermi*-LAT), optical (R-band) and radio (GHz band from UMRAO and OVRO programmes), covering few decades to sub-hours timescales. The novelty of this study is that at optical frequency, by combining long-term and densely sampled R-band intra-night light curves, we constructed the PSD for time periods ranging from 23 years down to sub-hours timescales. Our main results are : (1) nature of processes generating flux variability at optical/radio frequencies is different from those at GeV frequencies ($\beta \sim 2$ and 1, respectively); (2) the main driver behind the optical variability is same on years, months, days, and hours timescales ($\beta \sim 2$).

Introduction and analysis

The radio-to-optical emission of blazars is known to be predominantly the synchrotron radiation of relativistic electrons in a jet while the high energy ($\gamma-$ray) emission is most widely believed to be due to the inverse-Compton emission of the same or distinct electron population. Besides the quiescent, slowly varying emission, blazars exhibit flares and outbursts on timescales less than a day (known as intra-night variability; INV, or microvariability), pronounced especially at higher energies (i.e., X-rays or $\gamma-$rays; Aleksić et al. 2011 and the references theirin). The origin of such dramatic flux changes, and in particular their relation to smaller-amplitude but short-timescale variability observed at lower frequencies (including microvariability), is still being widely debated. There are several competing models which have been proposed to explain the rapid total flux and polarized flux variability of blazar sources. These models, favoured due to increase in fractional polarization and concomitant swing of the polarization angle, advocates various plasma instabilities and development of compact shocks in relativistic jets (e.g., Marscher 2014; Goyal et al. 2012), or the magnetic reconnection events (Giannios 2013). PSDs are generated following Uttley et al. (2002).

Radio-to-γ-ray lightcurve

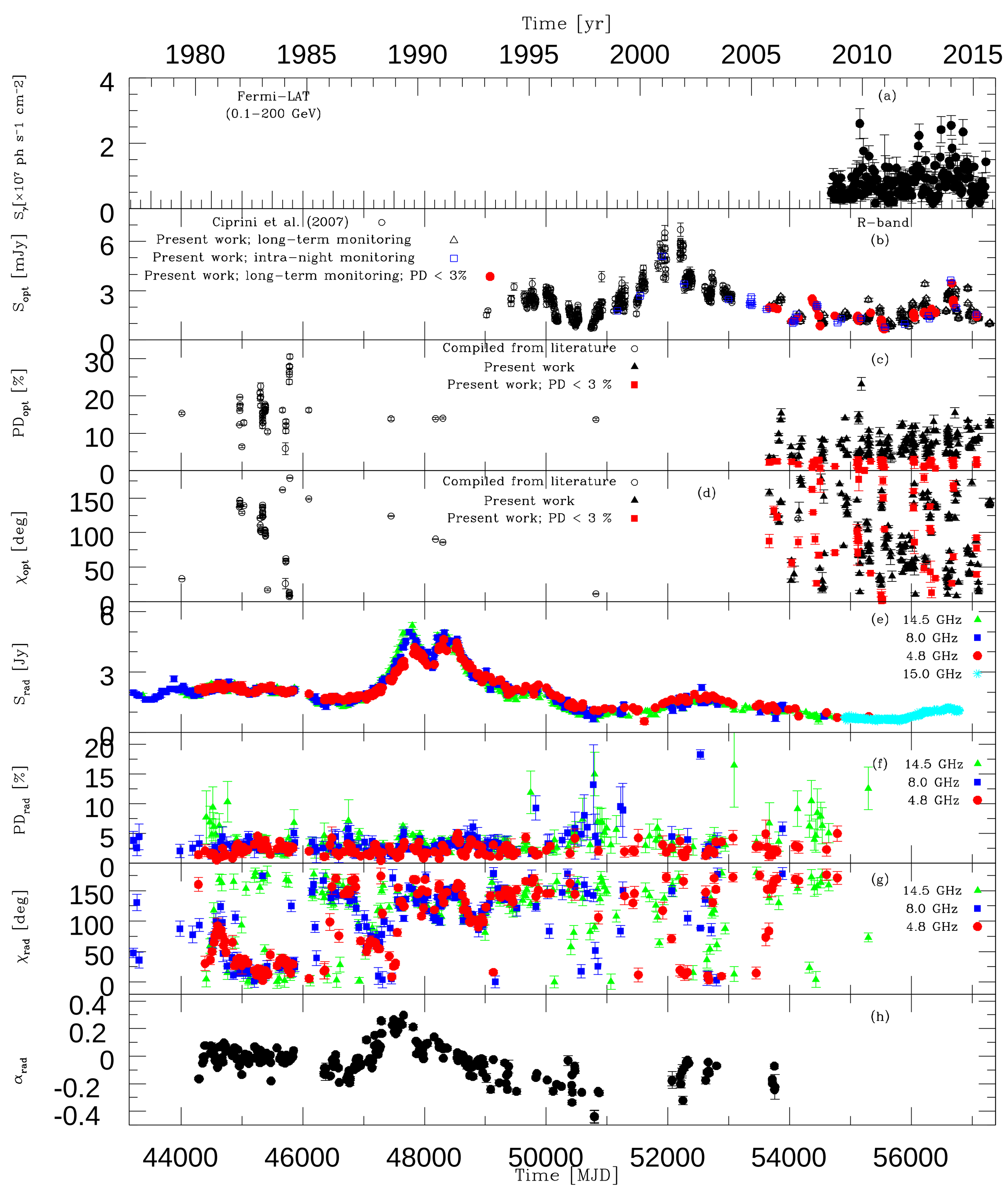

Figure 1: Long-term variability (LTV) lightcurve. Fig. 1a, 1b, 1c and 1d shows the Fermi-LAT, R-band photometric flux, PD_{opt} and χ_{opt} light curves, respectively. Fig. 1d, 1e and 1f shows the GHz frequencies radio flux, PD_{rad} and χ_{rad}, respectively. The bottom panel, Fig. 1h shows the run of radio spectral index (defined as $S_\nu \propto \nu^\alpha$) calculated by a linear regression analysis of the flux values at the three frequencies (note that measurements at these frequencies were treated as simultaneous if occurred within 14 days, i.e., $q = 0.04$ yr).

PSDs

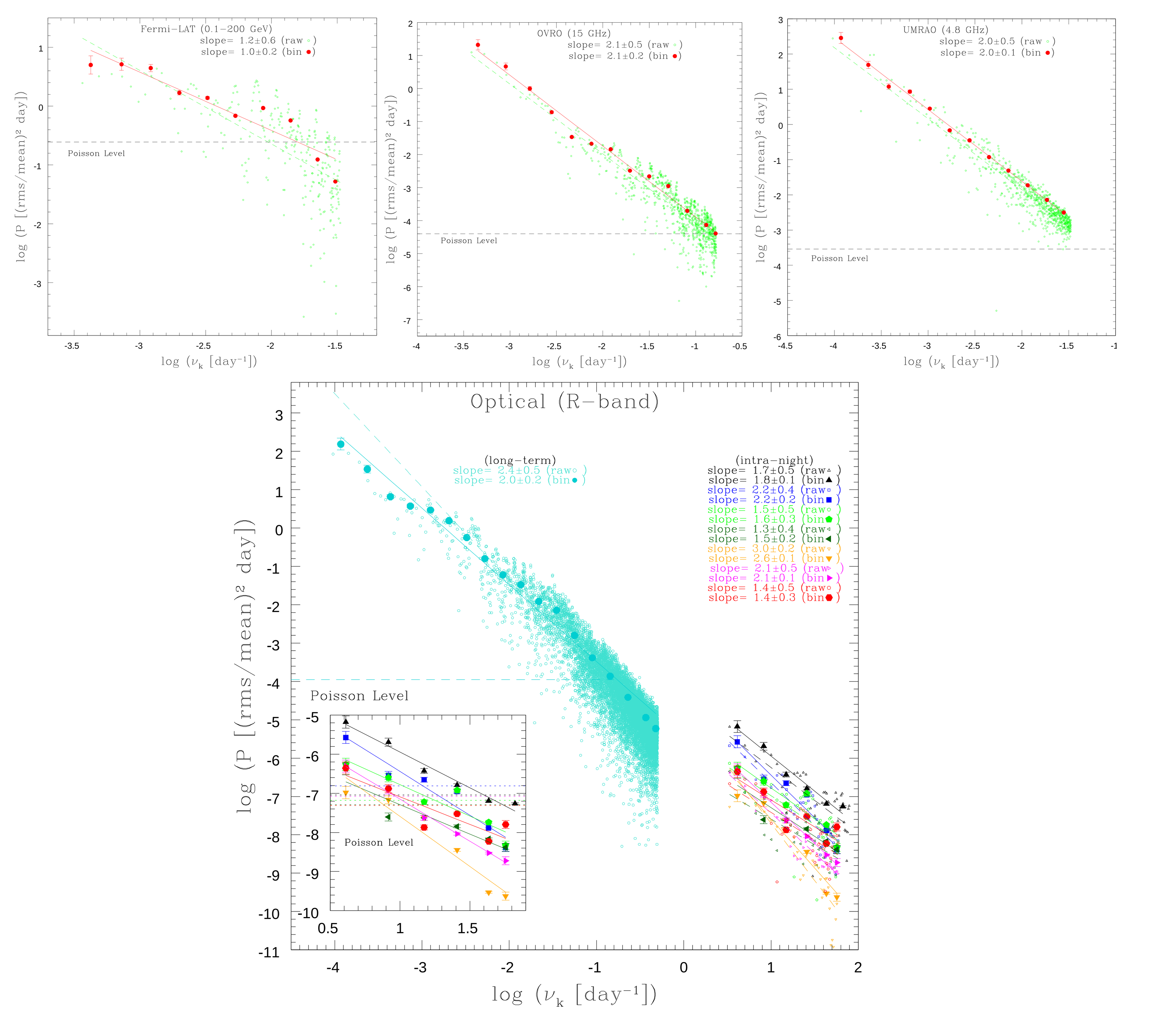

Figure 2: PSDs of light curves shown in Fig. 1 at $\gamma-$rays (Fermi-LAT), optical (R-band) and radio (OVRO, UMRAO) frequencies. Empty and filled symbols shows the raw and binned periodogram estimates, respectively, while the dashed horizontal line shows the Poission noise level due to measurement uncertainty achieved in our observations. Note that R-band PSD includes PSDs drawn using intra-night light curves when confirmed INV was seen (not shown here, see Table 1, Goyal et al. 2016, in prep.). Turquoise shows long-term flux measurements (Fig. 1b) while red (10-12-04), magenta (23-12-04), orange (05-01-05), dark green (09-01-05), green (15-12-07), blue (07-01-13) and black (23-12-13) INV PSDs (epoch of monitoring is given in the parentheses: dd-mm-yy). Inset plot shows the zoomed in 'binned' INV PSDs to enable better visibility.

Conclusions

1. The newly obtained long-term Fermi-LAT and optical data show a factor 2 intensity change on timescales of months while the OVRO data shows a steady increase in intensity by the same amount, over timescales of 3 years (see, Fig. 1). The long-term photo-polarimetric data shows large variations in the optical PA (traced during 2005-2015) on timescales of weeks/months and years, which seem correlated neither with optical PD nor with the optical flux changes (Fig. 1). In addition to this, the optical PD frequently goes below 3%. The photo-polarimetric data shows absence of "grand design" (e.g., helical) magnetic field structure in the jet (in contrast to Gabuzda et al. 2006), as the χ_{opt} and PD_{opt} changes observed on timescales of weeks-to-years are erratic and uncorrelated with flux changes. The jet seems fully turbulent, with 'un-coupled' perturbations in the bulk velocity, particle density, and magnetic field, driving all together the uncorrelated flux-PA-PD variability.
2. The PSD slopes from our analysis of long-term *Fermi*-LAT (0.1-200 GeV), optical (R-band) and radio light curves (4.8,8.0,14.5 and 15 GHz from UMRAO and OVRO) on timescales ranging from years to $\sim$weeks indicates that the statistical character of gamma-ray flux changes ($\beta \sim$1; flickering/pink noise) is different than that of GHz band radio and optical flux changes ($\beta \sim$2; strict red noise). This behaviour could be explained by hypothesizing that $\gamma - ray$ variability is shaped by a linear superposition of two stochastic processes : (1) same process driving optical (and radio) variability with relaxation time $\geq$ decades, such as growth and decay of the shocks leading to instabilities/turbulence, or, MHD related instabilities, (2) another process characterized by much shorter relaxation timescale ($\sim$days), relevant only for gamma-rays such as driven by release of magnetic field stresses in the reconnection regions (Sironi et al. 2015), or the innermost most radii of the accretion disk/X-ray corona system (Sobolewska et al. 2014). Normalization is also different for $\gamma-$rays as compared to radio/optical frequencies, indicating more variability power in $\gamma-$ray fluctuations on similar timescales (Fig. 2). Our results indicate that radio-to-$\gamma-$ray emission cannot be explained by simple one zone synchrotron self-Compton (SSC) model for this blazar.
3. The optical PSDs on intra-night timescales (for the nights during which INV has been detected) shows range of PSD slopes ($\beta \sim 1-3$). In all the cases the normalization is either consistent with a simple extrapolation of the pure-red-noise-type optical PSD from lower frequencies (Fig. 2), indicating that the main driver behind the optical variability of the jet is same on years, months, days, and hours timescales, given by same PSD normalization for our long-term and intra-night data ($\sim$ 23 years down to sub-hour timescales). This argues against the scenario where different drivers behind the long-term and intra-night flux changes are considered, such as internal shocks due to the jet bulk velocity fluctuation (long-term flux changes) versus small-scale magnetic reconnection events taking place at the jet base (intra-night flux changes). However, we note that relaxation timescales corresponding to magnetic field stresses in the reconnection regions, could be driven by large-scale modulations in the jet.

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