Report on Dr. Arti Goyal application for habilitation degree

Dr. Arti Goyal application for habilitation degree is based on her work on temporal variations of blazars/BL Lac's. Study of time series in astronomy is one of core topics of my work while variability of AGN's for me was of secondary importance as I have co-authored only two papers on the subject. I feel thoroughly familiar with Dr. Goyal methodology and thus I feel competent to review her application. As it is customary, Dr. Goyal application is based on one hand on a series of 4 publications related by topics on aspects of blazar variability (H1-H4) and on the other hand on her total science output.

Among over dozen of Polish habilitation and professor degrees applications I have reviewed, this one stands out as based on a series of papers with applicant being consistently first author and, remarkably on its own, of which two are single author papers. All are published in 2 of 5 leading international astronomical journals. It undermines a common belief that in modern times it is impossible to achieve anything out of a large team. This said, Dr. Goyal output demonstrates that she is also able to meaningfully contribute to effort of a large collaborations exceeding 100 scientists.

One sure thing about stochastic variability of radio-load AGN's in general and blazars in particular is that its source, over at least 6 timescale decades is largely unknown. Energy spectrum of blazars shows two maxima at highest (Gamma/TeV) energies and at intermediate energies. Because of polarization one proposed explanation involves relativisticly accelerated particles moving in magnetic field of jets at lower energies yielding synchrotron radiation and also yielding high energy photons by inverse Compton effect. Unfortunately it is already known that such a simple single source explanation breaks instantly at the evidence of different shapes of temporal power density spectra at different elektromagnetic bands.

To improve understanding blazar variability source better data and methods of analysis are needed and here fit contribution of Dr. Goyal and her collaborators, aiming to assemble best available sets of observations of bright blazars and to analyze them with state-of-art proven statistical methods. These in particular involve PSD distribution fitting by (PSRESP, Uttley et al. 2002, Max-Moerbeck et al. 2014) method by first simulation of a power law stochastic process and DFT processing in the same fashion as real data to compare real and simulated PSD suffering from the same sampling distorsions in papers H1,H3,H4. This method is widely accepted, and as illustrated by simulations in Appendix of H1, on occasions may reproduce steep red-noise-type power spectra better than LSP and FT of the ACF.

The complementary method in H2 is CARMA(p,q) simulations (Kelly et al, 2014) replacing power law. Otherwise it resembles PSRESP by relying on MC simulations. This reduces to fitting PS with a squared absolute value of a complex polynomial rational function of frequency of order (p,q). In particular, for (1,0), i.e. CAR(1), it reduces to $\beta=2$ power law (red noise) breaking to $\beta=0$ (white noise) at low frequencies. As shown in H2 Appendix D both PSRESP and CARMA yield similar PSD estimates, except possibly at highest frequencies, from Kepler light curve. On one hand although methods employed in H1-H4 are state-of-art, they are not new and neither analyzed observations were untouched before: they mostly come from public archives and literature, including Dr. Goyal own optical observations from India. Her real achievement is to assemble widest available data sets on the whole range of electromagnetic spectrum, as opposed to past fragmentary analyses, to re-reduce them often laboriously, and to analyze them in a near uniform way. In these way for energies from TeV down to radio waves and time scales from hundred years down to minutes she obtained information on power spectra inclinations in a homogeneous fashion. For example, already several campaigns were carried for OJ287, including archival by Hudec et al, and Kepler data are public, yet it was Dr. Goyal who have first assembled them together to get the optical PSD spectrum covering near 6 orders of frequencies in optical and compared with those from gamma and radio observations.

Because of different power law inclinations in the same object, depending on energy, these results in general underscore already emerging view that no 'one-fits-all' source of variability exists in reality. In particular for OJ287 (H2) PSD Fermi-LAT saturates at 1/150 d^-1 and overall has different shape from optical and radio one. While these conclusions are based on purely statistical properties (different power laws) clearly they project into a range of physical scenarios at work. In the same object OJ287 this is underscored by optical power law steepening at 1 d^-1, pointing to some variability damping/smoothing at highest frequencies. Similar impressions stem from analysis of optical only observations of variability of a broader

sample of 14 bright blazars (H4), yielding a range of power law inclinations closer to 1 or 2 in different objects. For a particular blazar PKS 0735+178 often exhibiting low polarization and erratic PA, analysis in H1 of optical variability revealed spells of inactivity/indetectable variability lasting up to 80% of observation time. If polarization/inactivity correlation holds for other blazars it may consist better indicator of weak-and-entangled/strong-and-ordered magnetic fields than jet broadening.

PSRESP has own problems, rarely discussed: even step interpolation of irregularly sampled light curves introduces spurious re-weighting and smoothing of stochastic variability and affects correlation of observations at high frequencies. The fact that the same affects simulated data does not make high frequency end more reliable. DFT and PS obtained from interpolated data no longer are uncorrelated between frequencies and any derived probabilities should rely on covariance matrices and not variances alone. Another neglected technical fact is that because of normalization by variance PS have β distribution and not χ^2 as widely claimed. To my knowledge nobody have investigated how these effects distort PSRESP analysis, and if less than window function effects in pure DFT approach.

I do not understand a comment in H1: "We have not subtracted the constant noise floor level[...], as some of the data points are below this level". Are noise level estimates faulty?

To summarize, H1-H4 provide both good data and reliable analysis, are well connected to basic problematic in the AGN field and reveal good grasp of the involved science. Processing of such amount of different data and complex Monte Carlo analysis reveal hard and well organized work. Despite large set of data at disposal, Dr. Goyal exercises commendable critical restraint in discussing QPO and not jumping a fashionable band-wagon to claim yet another detection on flimsy evidence. She is an accomplished observer, starting from CCD photometry in India up to ESO VLT nights, and as demonstrated in H3, familiar with reductions of space and radio observations.

Most of applicants other output is listed in point 2. of "Description of achievements..." form. For many papers self-citations are 0 or 1, and in the remaining usually are 10% or less of all citations. Taking into account name confusion, Dr. Goyal output can be investigated in the ADS astro-publication data base with collection limited to [astronomy] and keywords [author:"Goyal, Arti" year:2000-2022]. The ADS search yields 99 results with 2,075 total citations and 75.59 total normalized citations. The corresponding H-Index is 24. Without paying undue significance to such statistics, it must be observed that such numbers are also encountered in mediocre to median applications for **professor** title, hence they are well **over** ones encountered in median **habilitation** application. (Web of Science is useless.)

Dr. Goyal demonstrated ability to contribute both in large international collaborations (e.g. LOFAR, HESS) and smaller on national level in India and Poland. Because of research jobs her teaching experience is limited to (co-)guiding og PhD and MSc students, yet similar problem affects other researchers in Poland on research jobs, e.g. in NCAC.

Some scientists exhibits spells of ingenuity interspersed with intervals of little progress. Science accomplishments of Dr. Goyal are an opposite example: she reveals steady progress based on amount of hard meticulous work and produces, yielding reliable output on topics of significance. Her work H1-H4 is good science both as concerned of observations, reduction, statistical analysis and astrophysical conclusions. She has demonstrated ability of independent planning and executing science projects. Her application may be considered over-due given that her overall output and international impact (citations/collaboration) substantially exceeds what is expected for habilitation degree in Poland. Just I fully support Dr. Goyal application for habilitation degree and ask our commission to proceed to completion of the procedure.

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