Individual External Collaborator Project Proposal

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WG(s) involved in the project: AGN, CWG

Scientific Project description:

The Cosmic Microwave Background (CMB) exhibits a pronounced dipole anisotropy which is interpreted within the standard ΛCDM cosmological model, in the Friedman-Lemaître-Robertson-Walker (FLRW) framework, as due to our local motion with respect to the 'cosmic rest frame' (CRF) in which the CMB is truly isotropic. The matter on which the CMB last scattered should also be isotropically distributed in the CRF, i.e. the 'matter rest frame' (MRF) in which the large scale structure is isotropic, should coincide with the CRF. This can be tested using a flux-limited catalogue of cosmologically distant sources to check if the dipole due to special relativistic aberration and Doppler shift effects is indeed as expected due to our motion as deduced from the CMB dipole (Ellis & Baldwin 1984). Interesting deviations have emerged between the two rest frames in previous studies in the radio and infrared, culminating in a 4.9σ disagreement found by Secrest *et al*. (2021) using the CatWISE catalogue of 1.36 million quasars derived from WISE data. This suggests a possible intrinsic anisotropy in the Universe, which violates the 'Cosmological principle' upon which FLRW is based. While the statistical significance of the CatWISE result is, by far, the highest to date, this result, if true, can so profoundly alter the current cosmological paradigm that confirmation using a systematically independent catalogue is critical. The eRASS point source catalogue, provides an excellent opportunity to do this fundamental test using the sample of high-redshift AGNs.

We propose to use the eRASS1 point source catalogue to constrain our relative motion wrt the MRF as traced by X-ray sources. In the 0.2-2.3 keV band, eRASS1 is expected to detect >200,000 AGN in the Western Galactic hemisphere at the lower (ecliptic equatorial) flux sensitivity of $f_X \geqslant 5 \times 10^{-14}$ erg s^{-1} cm^{2} (Predehl *et al*. 2021) which ensures homogeneous extragalactic survey depth. The catalogue's median redshift of $<z>$ ~1 (Kolodzig *et al*. 2013) suppresses any contribution from local structure sufficiently; we will quantify the expected residual 'clustering dipole' using the provided redshifts. Spectral indices are expected to be provided for most detected AGN and can otherwise be determined from the X-ray count rates in sub-bands.

Galactic X-ray absorption effects will affect the measured fluxes, however this can be simply corrected for. Galactic absorption is expected to bias the number of detected

AGN towards regions with high N_H so these regions will be excluded, along with sources at low Galactic latitude, $|b| \leq 20°$, to mitigate X-ray binary (XRB) contamination. XRBs at higher Galactic latitudes will be removed through cross-matching with regions of high star formation rate and OB associations. Although the hard (2-8 keV) X-ray band is nearly free of any absorption effects, the expected number of AGN detected in this band alone is not enough to perform the proposed test – nevertheless the local kinematics of the Universe can be explored using such AGN.

The statistical significance achieved in such dipole studies depends on the number of selected sources and their properties such as the flux density distribution and spectral parameters. Sky survey systematics that can influence the accuracy of cosmological studies include the survey footprint, anisotropic survey depth at a given flux limit, absorption or reddening due to Galactic gas and dust, variable unresolved sky background, source confusion, and contaminating local or Galactic sources. These effects are generally accounted for by appropriate data cleaning, as well as simulations that capture the effects of these systematics.

No such analysis in X-rays has previously been done and there are several aspects that make it very promising. First, the expected number of detected AGN will eventually be larger than in radio catalogues like NVSS. Second, since AGN spectra have a steeper high energy cutoff than radio sources, for a given dipole there are stronger variations of the source numbers/solid angle across the sky. A drawback is that only the Western Galactic hemisphere will be available. Even with half the sky however, significant results can be achieved, since our motion is roughly towards the middle of the available hemisphere and the unbiased dipole estimator to be used is insensitive to the mask used. Assuming power-law spectra ($S_\nu \propto \nu^{-\alpha}$) with index $\alpha = 1.7$ and power law flux density distribution ($dN/d\Omega(>S_\nu) \propto S_\nu^{-x}$) with index $x = 1.4$ (Kolodzig *et al.,* 2013), the expected quasar dipole amplitude of 0.0071 due to our motion (Ellis & Baldwin 1984) should be constrained at 2σ, increasing to 4σ with eRASS8. Equivalently, any deviations from the CRF expectation can be established at high significance, depending on the amplitude of the found dipole. While requiring careful matching of source fluxes, other available catalogues can be called up to fill the missing part of the sky. However, since this analysis will benefit from maximum sky coverage, it is of great interest to also include the Eastern Galactic hemisphere which ought to yield a >5σ significance result.

In conclusion, this project will provide the first test of the Cosmological Principle using high redshift X-ray AGN and be competitive with respect to previous studies – even with just half the sky. Although not definitive by itself, it will provide the proof-of-principle for further tests with eRASS4 and eRASS8, hopefully using the full sky.

The external co-Is (S. Sarkar, N. Secrest, R. Mohayaee, M. Rameez) have obtained significant results using both radio & IR catalogues and their expertise and experience will be crucial to the success of this project.

REFERENCES

Ellis & Baldwin (1984), MNRAS **206**, 377.
Kolodzig *et al*. (2013), A&A **558**, A89.

Predehl *et al.* (2021), A&A **647**, A1.
Secrest *et al.* (2021), ApJL **908**, 2, L51.

Required data, supporting datasets and/or tools:

eRASS1 point source catalog including fluxes, spectral indices, and sky positions in both soft and hard band. If the provided fluxes are the absorbed ones, the participants can determine the unabsorbed fluxes and account for detection biases. Availability of redshifts will be helpful, although not essential (as these can be obtained from other sources). The necessary statistical tools for the entire analysis are already available.

List of Potential Collaborators within eROSITA_DE

All interested are welcome. Joint study with those analysing the Eastern Galactic hemisphere will be particularly beneficial.

Expected Outcome

The analysis will result in one (or more) refereed scientific publication(s). The corresponding code will be made public.

Expected duration of the project

Receive data ~1st half of 2022, analysis and results +~3 months, paper submission and available data products +~3 months. Estimated end of project ~end 2022.

With future eRASS releases, significant improvement of the above analysis is anticipated and corresponding EC project proposals will be submitted.

Responsibility of the eROSITA member sponsor of the project:

Konstantinos Migkas, as sponsoring member, will ensure that eROSITA data are accessed and used for the purposes of this project only, and not in a way that would negatively affect the scientific interests of existing collaboration members.