Probing Turbulence in Ionized Interstellar, Circumgalactic, and Intergalactic Media Using an ALPACA to Detect Bursts in the Direction of M31 and the Virgo Cluster

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Fast radio bursts and other radio transients provide the means for probing magnetoionic media along their entire propagation paths. Combined with optical measurements of Balmer lines, radio bursts yield dispersion measures (DM), Faraday rotation measures (RM), and emission measures (EM), which provide information about electron densities and magnetic fields, and scattering measures (SM), which quantify microstructure in the electron density. Density microstructure in the Milky Way has scales as small as ~ 1000 km and is associated with turbulence and also with processes that produce filaments and sheets. Observations of extragalactic bursts show the same phenomena (multipath broadening of pulses and frequency structure from scintillation) as seen from Galactic scattering of pulsars. Presumably the underlying processes are the same, allowing the conditions in the intergalactic medium (IGM) as well as inside the host galaxies of FRBs, in circumgalactic media, and in intervening galaxies to be inferred using the same methodologies as we use for pulsars.

The ALPACA instrument on the GBT is ideal for exploiting radio pulses and bursts as probes of the magnetoionic media in and near local galaxies, in particular M31 and galaxies in the Virgo cluster. The large sizes of these objects are beneficial for capturing bursts from background sources but a burst detection program requires a proportionally large field of view and exposure time in order to detect enough bursts.

A GBT/ALPACA program on these targets is sensitive to two source classes: (1) radio pulsars that emit giant pulses, like those seen from the Crab pulsar that are easily detectable at the distance of M31 and include pulse amplitudes on the power-law tail of the amplitude distribution to be seen from pulsars in Virgo; and (2) FRB sources in the background of M31 and Virgo. Pulse or burst detection would use standard methods of dedispersion and matched filtering on data in all Stokes parameters. ALPACA provides sufficient time and frequency resolution for identifying scintillation-induced frequency structure as well as pulse-broadening from scattering.

Based on analyses of FRBs (so far), we find that scintillation is produced by scattering in the Milky Way while pulse broadening is from scattering in the host galaxies of FRB sources. This may be the same situation for the media in M31 and Virgo but it is also possible that scintillation (vs. pulse broadening) will be seen along some lines of sight through M31 and Virgo. While the IGM along sight lines to distant FRB sources makes significant contributions to dispersion measures, scattering in the IGM appears to be negligible. We expect that this conclusion, along with the proximity of M31 and to some extent the Virgo cluster, will allow the scattering inventory of ALPACA detections to be assessed. The same situation appears to hold for Faraday rotation, with rotation measures being dominated by the Milky Way and host or intervening galaxies.

The net result of a GBT/ALPACA program will be (a) mapping of dispersion and scattering vs location in M31 and inferring the strength of turbulence across the galaxy; (b) mapping of the Faraday RM across M31 and estimation of the mean magnetic field by using M31's contributions to both DM and RM; (c) constraints on the contributions to DM, RM, and SM from the circumgalactic medium of M31; and (d) similar analyses and conclusions for galaxies in Virgo.

Observations: pulse and burst detection across M31 can be done with a commensal program to map HI that is discussed by D. J. Pisano and collaborators. A survey in the direction of the Virgo cluster could also be done as a commensal program but might require a dedicated survey.

ALPACA Searches for FRBs/Magnetars in Nearby Galaxies

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Evidence in favor of a magnetar origin for fast radio bursts (FRBs) has gained significant credence recently, thanks to a detection of FRB-like pulses from a known Galactic magnetar, SGR 1935+2154, as well as an FRB in the spiral arm of the nearby galaxy M81. An important prediction of the FRB--magnetar connection is that FRBs should be detectable, in nearby galaxies with high star formation rates. As discussed by Bochanek et al. (2020), an excellent candidate for such searches is the prototypical starburst galaxy M82. We are currently monitoring this galaxy using the 20 m radio telescope at the Green Bank observatory in West Virginia. We take advantage of a high-speed data connection between Green Bank and West Virginia University, as well as a deep-learning based pipeline to automatically classify likely FRB candidates.

So far, from 28 days of M82 observations, no bright FRBs were detected. We have amassed a sample of >200 FRB-like signals with signal-to-noise ratios below 10, with some of these appearing to repeat at consistent dispersion measures. From a Poissonian analysis, we conclude that not enough pulses are currently present to claim a statistically significant FRB detection.

Our current experiment is clearly sensitivity limited and the wide field of view of ALPACA coupled with the GBT's superior sensitivity. For a power-law luminosity function of magnetars in M82 with an exponent of -1.5, typical of pulsars, we would achieve our current level of depth within 30 minutes! In addition, the multi-beaming capability of ALPACA would greatly facilitate any detection of fainter candidates which are currently ambiguous with the single pixel of the 20 m. A deep observation of M82 would place definitive constraints on magnetars in this galaxy and undoubtedly lead to follow-up studies of individual objects. We envisage scaling the experiment up to a larger campaign to target other nearby galaxies for a more comprehensive census on the timescale of a single PhD student.