Radio synchrotron halos around pulsars

Pierrick MARTIN, Mickael CORIAT - CNRS/IRAP, Toulouse, France

Abstract

The interpretation of large gamma-ray halos around middle-aged pulsars as electron/positron pairs emitting from inverse-Compton scattering of ambient photon fields naturally leads one to think about the necessary counterpart of such a system: radio synchrotron halos. In this poster, we introduce some first investigations of the detectability of such radio sources in the Milky Way. We developed a halo population model using as pair sources the pulsars listed the ATNF database, and assuming as transport process a simple diffusion-loss propagation in models for the interstellar and radiation fields of the Galaxy. The predicted halo synchrotron emission for each halo candidate is compared to a model for the thermal and non-thermal interstellar diffuse radiation of the Milky Way. From this, we discuss criteria for selecting and ranking the best targets for the detection of radio halos around pulsars, especially in view of the capabilities of the MeerKAT instrument.

Halo population model

We have developed a halo population model by computing halos around known pulsars with ages <1Myr extracted from the ATNF catalog (Manchester et al. 2005), following Tang et al. 2019 for pair transport in two-zone diffusion scheme, using HAWC observations of Geminga to calibrate low-diffusion properties in the vicinity of the halo (Abeysekara et al. 2017), and setting the distribution of pair injection properties at the population level by comparison to the Galactic population of TeV sources. More details can be found in a companion poster (Gamma-ray halos in the HE and VHE Galactic landscape, by P. Martin and S. Abdollahi). The interstellar magnetic field model used is a double exponential distribution with a central peak value of 12muG and characteristic scale radius/height of 6/2kpc. The resulting distribution of radio synchrotron halos is sketched in Fig. 1.

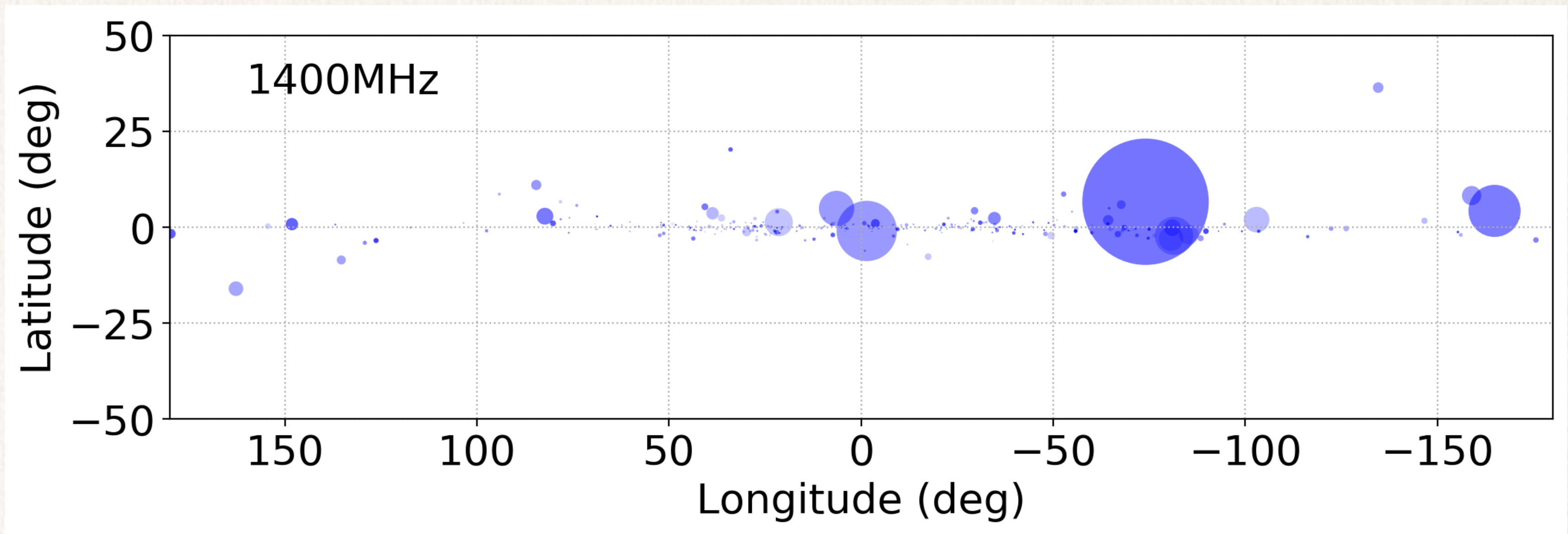

Fig. 1: Chart of potential radio synchrotron halos around known ATNF pulsars with ages <1Myr. The size of each symbol corresponds to the 68% containment radius at 1400MHz and the transparency is proportional to the logarithm of the intensity. Proper motion of pulsars is neglected here.

Halos versus galactic diffuse

We have compared the predicted halo intensity within the 68% containment radius to the average thermal+non-thermal diffuse emission of the Milky Way within the same area, estimating the latter radiation from the Global Sky Model of Zheng et al. 2017. The outcome is illustrated in Fig. 2 for two reference frequencies, 1.4 and 8.0 GHz. Using a softer pair injection index at low energies (2.3 instead of 1.5 below 100 GeV) does bring more halos closer or above the Galactic diffuse level but does not qualitatively change the picture that the vast majority halos are drawn in the diffuse interstellar emission of the Galaxy. In that respect, the situation differs markedly from what is predicted at GeV and especially TeV energies.

Target selection for radio observation

The synchrotron counterpart of simple diffusion-loss halo models, found so far to be satisfactory description of gamma-ray observations of halos, implies 68% containment radii above 0.1-0.2° for the bulk of the radio halo population, as illustrated in Fig. 3. The Galactic diffuse emission is strong over such areas, which may render single-dish observations of >0.2° halos quite challenging. Conversely, interferometric observations of smaller-size halos have the potential to unveil their synchrotron intensity distribution down to small angular scales, while the large scale galactic diffuse emission is filtered out by the interferometric process. MeerKAT is well-suited for that given its degree-scale field of view and high sensitivity to medium scale diffuse emission. In Fig. 4, we illustrate the potential of MeerKAT on one selected halo proposed for observation at the last AO.

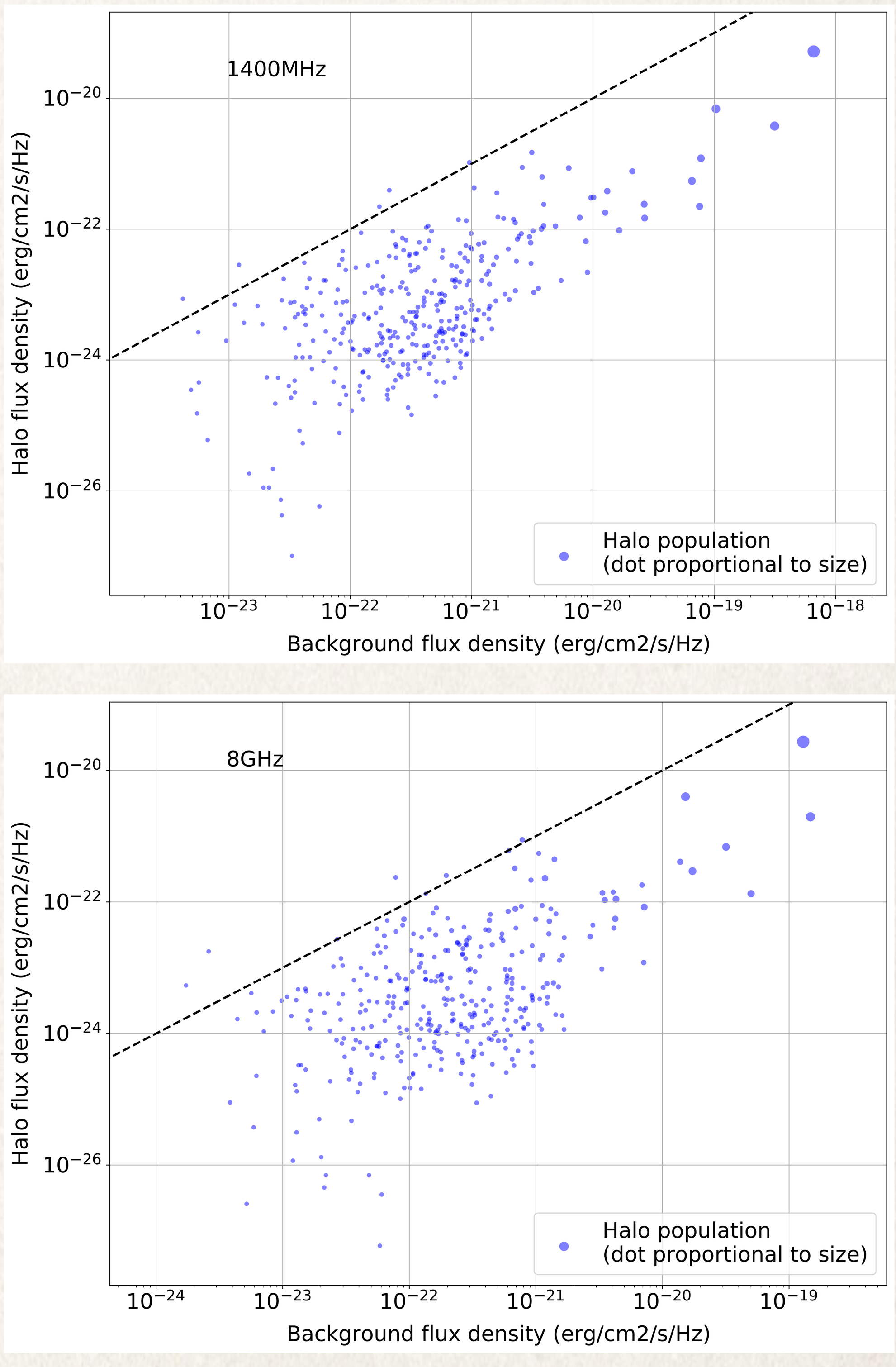

Fig. 2: Comparison of predicted halo emission to the Galactic diffuse emission at two reference frequencies, 1.4 and 8GHz (top and bottom). Average intensities are compared within the 68% containment radius of the halos.

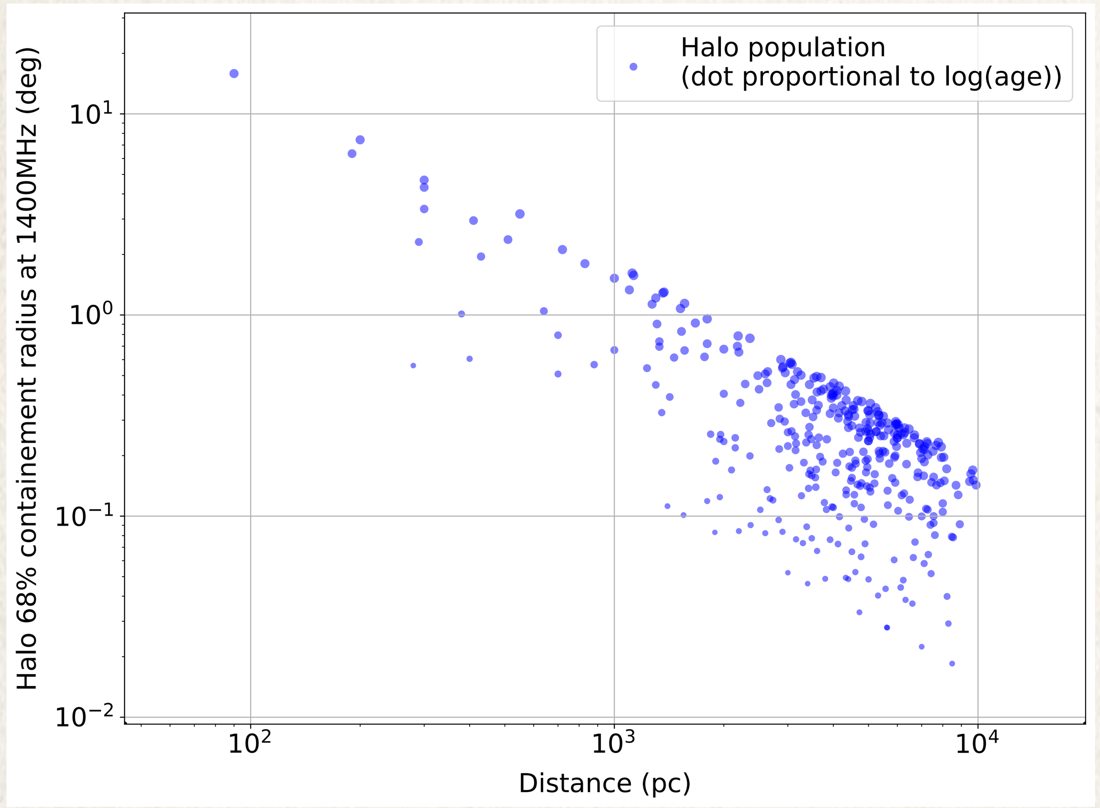

Fig. 3: Radio halos size-distance distribution

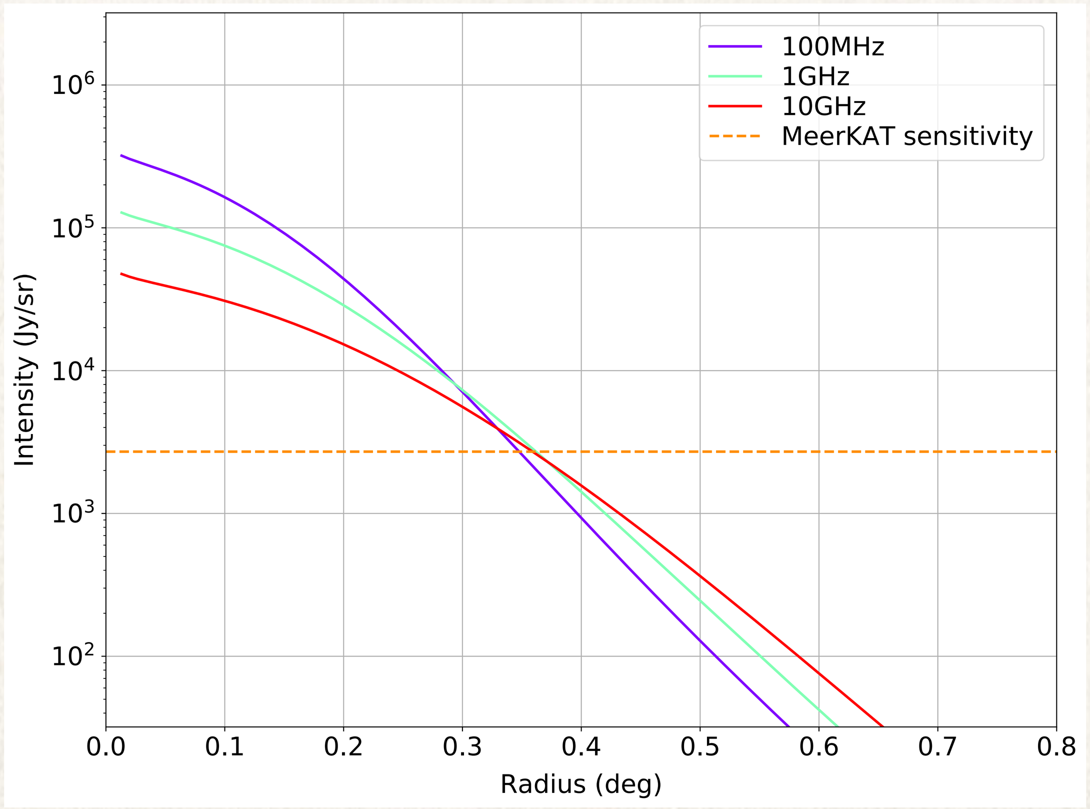

Fig. 4: Radio intensity profile for one selected halo compared to MeerKAT's sensitivity at 1.4GHz for 12h exposure.

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- Astropy (see https://docs.astropy.org and Astropy collaboration 2013 and Astropy collaboration 2018)
- gamma-cat (see https://github.com/gammapy/gamma-cat)
- Naima (see https://naima.readthedocs.io/en/latest/ and Zabalza 2015)