An empirical study on distances and evolution of supernova remnants: insights from $\Sigma - D$ data distribution

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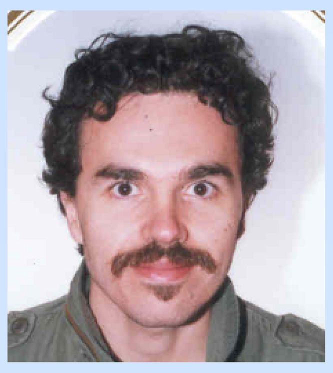

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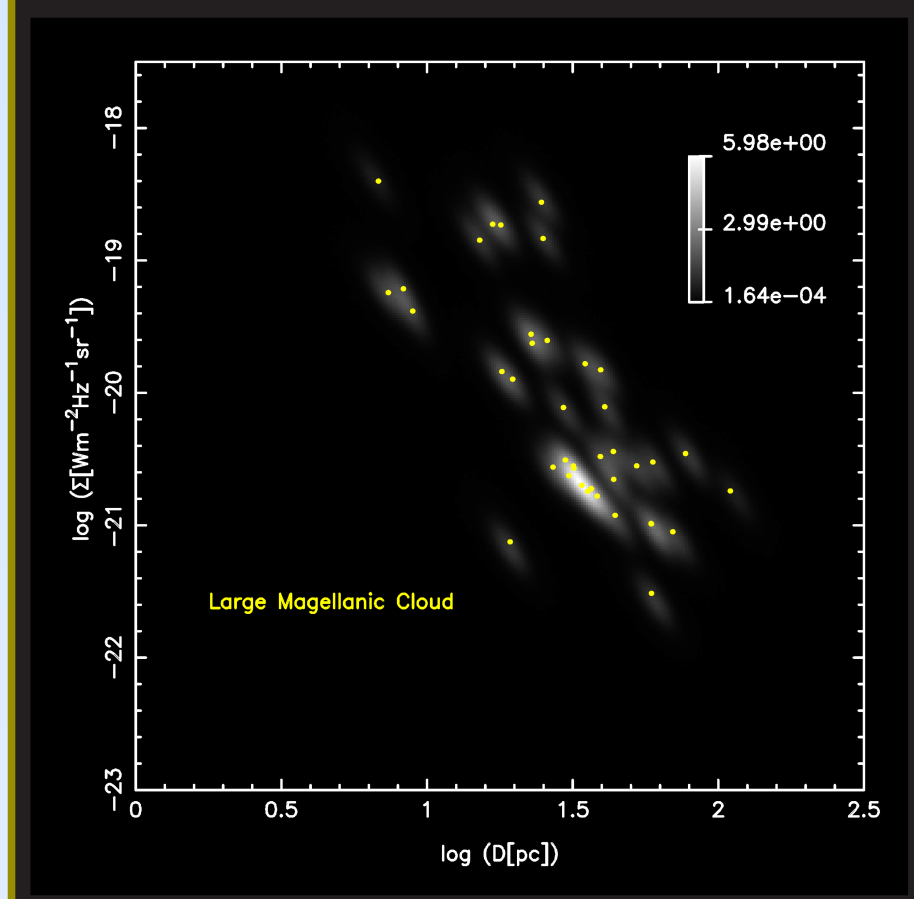
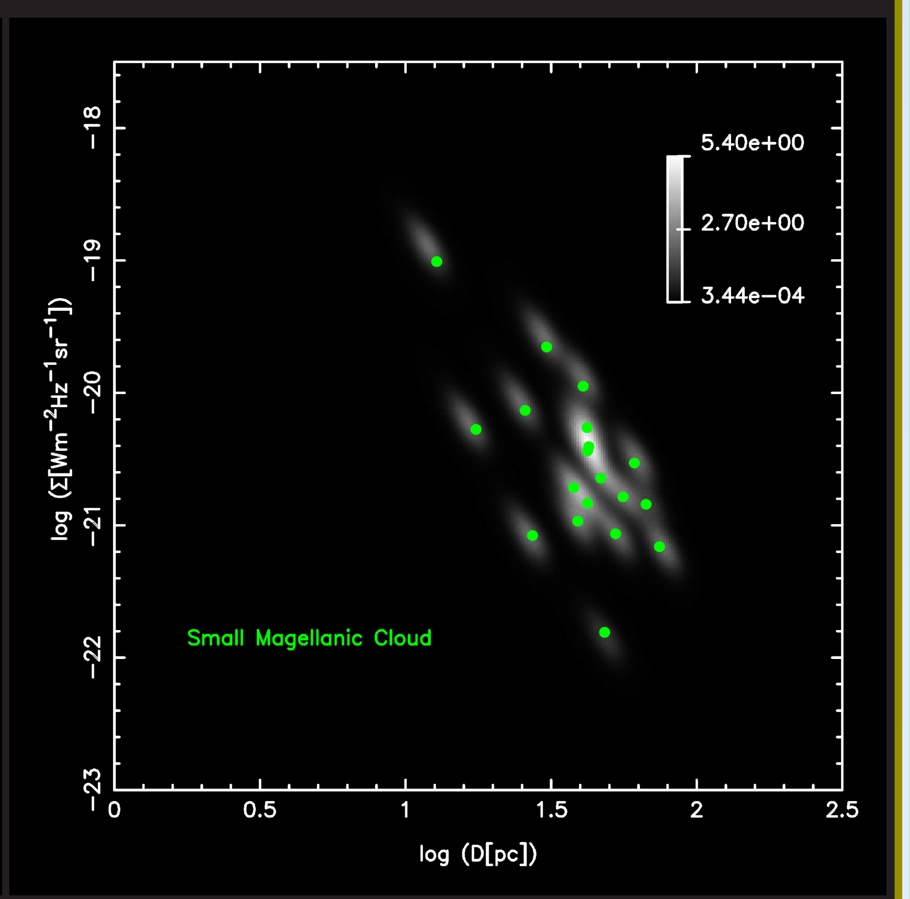
Introduction

For the selected sample of calibrators, with radio surface brightness (Σ) and linear diameter (D) data, we reconstruct the probability density function of the data in the ΣD plane, called ΣD pdf map. We select the samples from Large Magellanic Cloud (LMC), Small Magellanic Cloud (SMC) and Milky Way. The ΣD pdf map is calculated with bootstrap approach by resampling the calibrating sample data (Vukotić et al., 2014). Unlike standard linear fit based calibrations our method gives more robust results. A probability density distribution in D can then be obtained for each particular Σ value. This also gives a probability distribution of the corresponding statistical distance if angular diameter of the remnant with the given Σ value is known. Utilizing the $\Sigma - D$ pdf map we quantify the data grouping in the $\Sigma - D$ plane which can be very useful tool for the studies on $\Sigma - D$ evolution of supernova remnants and calibration of statistical distance scales. As discussed in (Arbutina & Urošević, 2005; Kostić et al., 2016) the Σ is likely to depend on the density of the ambient medium where supernova remnants (SNRs) expand. This results in parallel evolutionary "tracks" in the $Sigma - D$ plane. We therefore select some of the samples according to the density of the ambient medium.

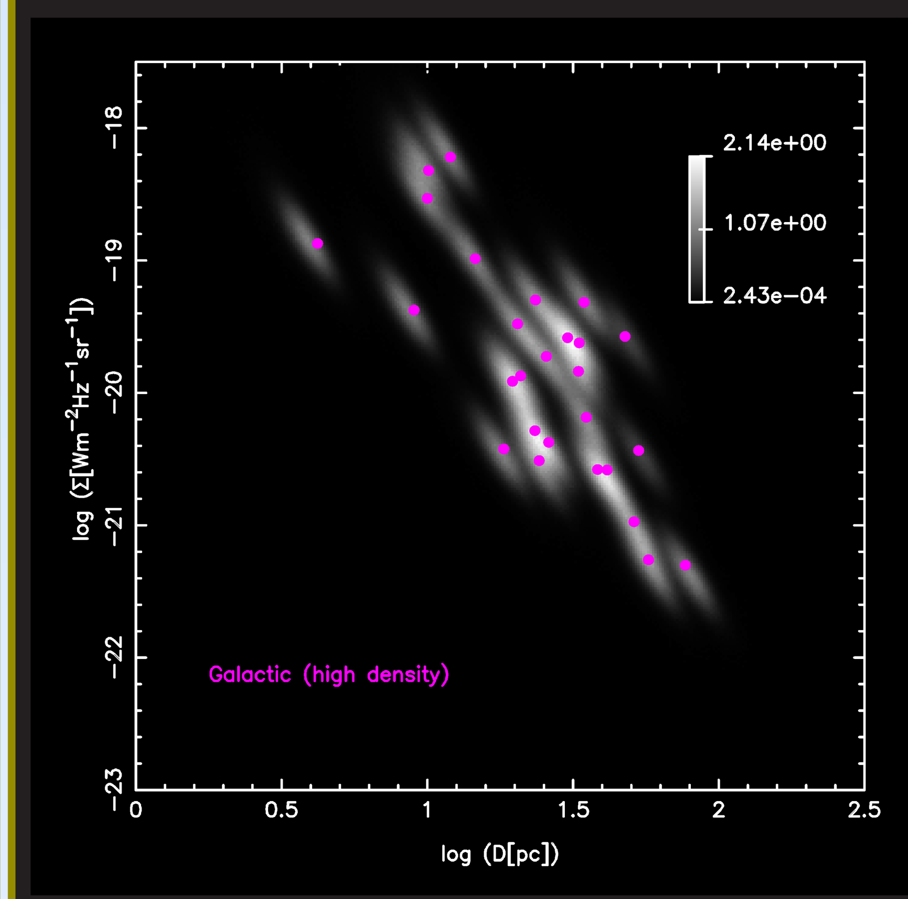
Magellanic Clouds

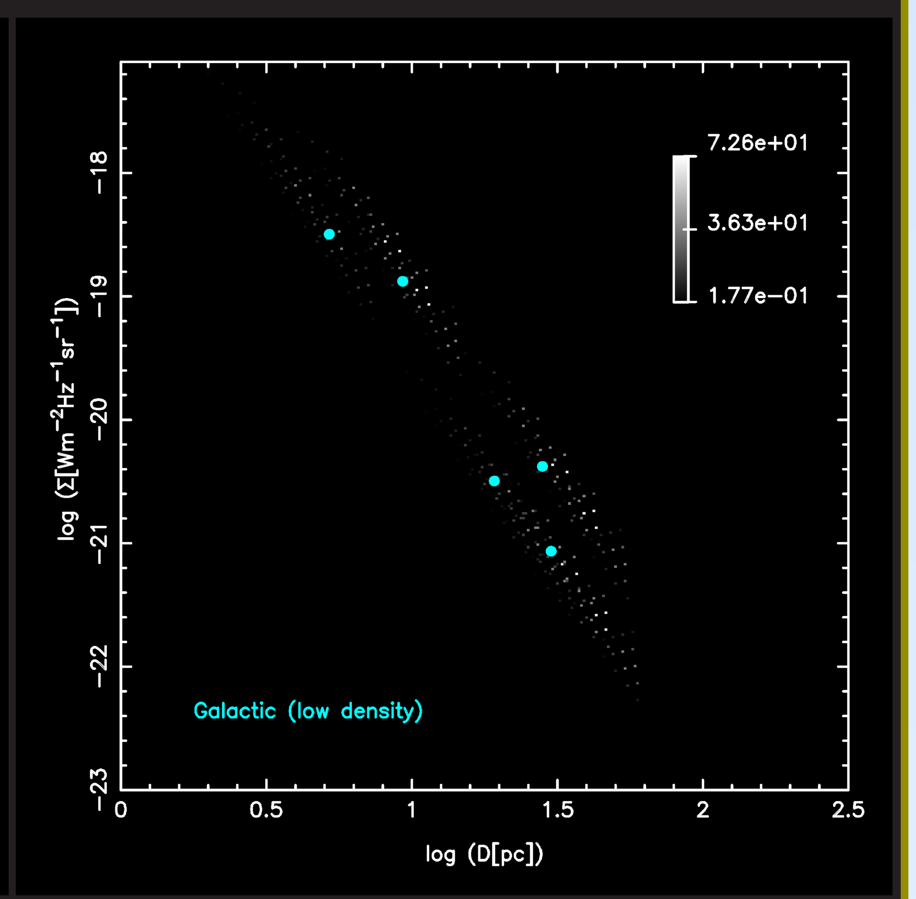




These samples are compared and analysed in Bozzetto et al. (2016). There are 40 objects in Large Magellanic Cloud and 19 objects in Small Magellanic Cloud sample. The data density distribution is also reconstructed for the joint sample in Bozzetto et al. (2016), where the existence of two subsamples is implied. The subsample of larger Σ is argued as objects evolving in a denser environment with a non-zero ambient density gradient while. As seen from the above plots, the LMC data is most concentrated in the region of lower Σ which is indicative of the remnants evolving in a smaller ambient density, while the SMC remnants are more likely to be brighter.

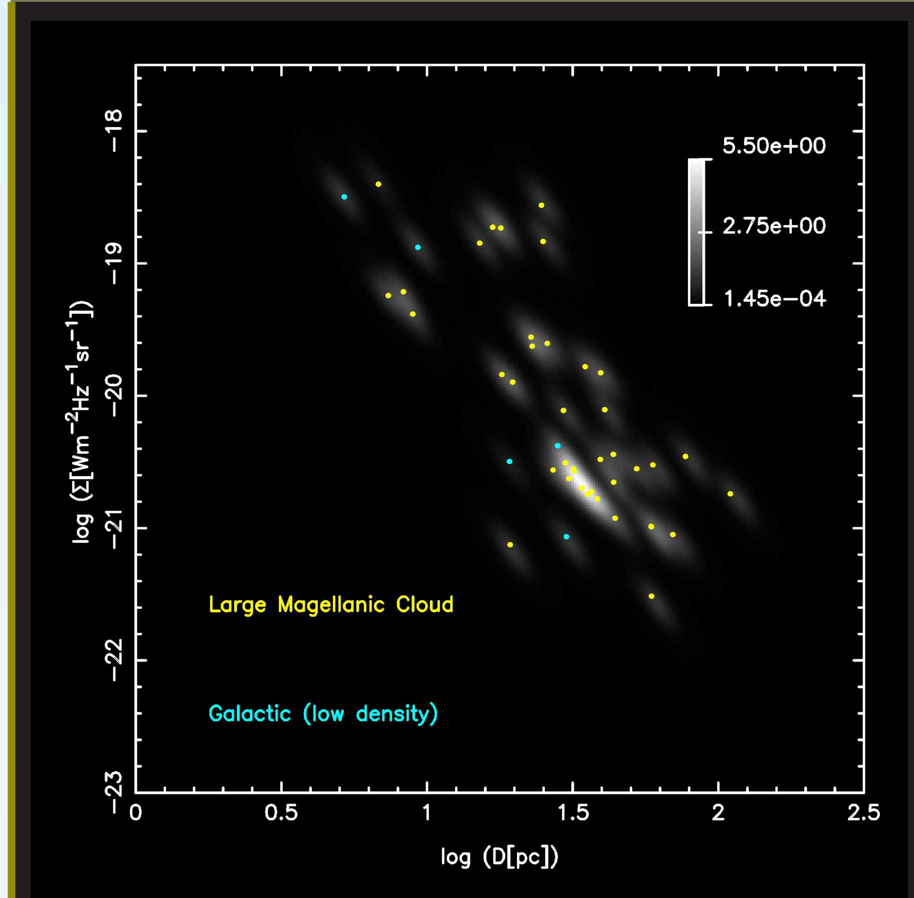
Milky Way

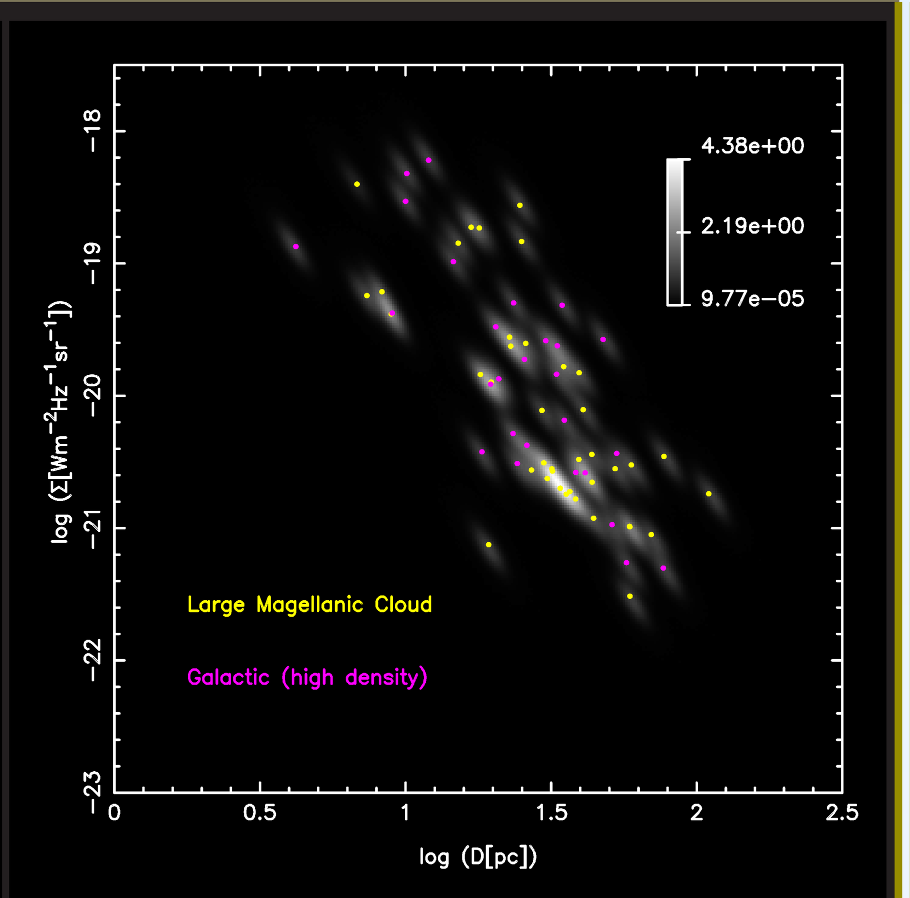




These samples are distinguished in Pavlović et al. (2013) from the sample of 60 Galactic SNRs with reliable distances. The high density sample (28 objects) selection criteria was high ambient density while low density sample is from 5 Balmer-dominated remnants expanding in low density environment. The Balmer-dominated SNRs are clearly at lower Σ values. The remnants associated with the ambient of higher density are scattered across areas of both, higher and lower brightness. If Σ depends on ambient density (as argued in Arbutina & Urošević, 2005; Kostić et al., 2016) then the scatter to lower Σ of the remnants associated with high density ambient might be indicative of ill determined distances.

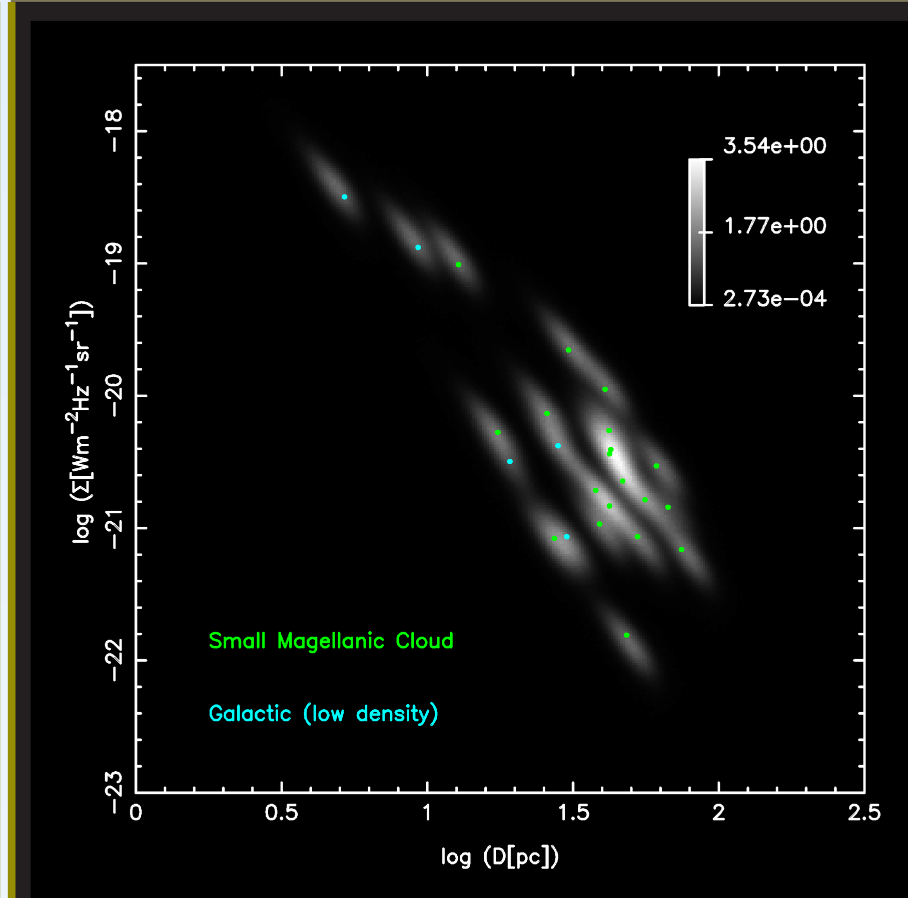
Large Magellanic Cloud mixed samples

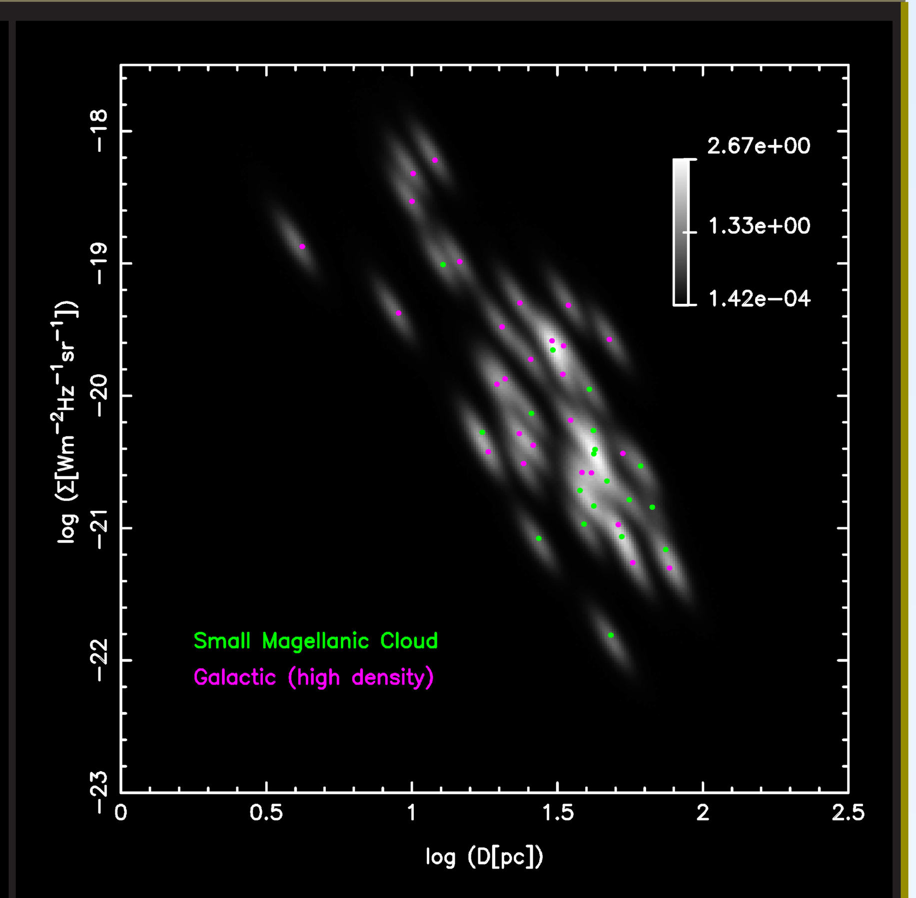




Milky Way sample associatead with low ambient density is likely positioned amongst the low Σ objects from the LMC. Except for the LMC data grouping at the low Σ (at $\log D \sim 1.5$), both, LMC sample and Galactic (high density) sample appear scatter without distinguished evolutionary features.

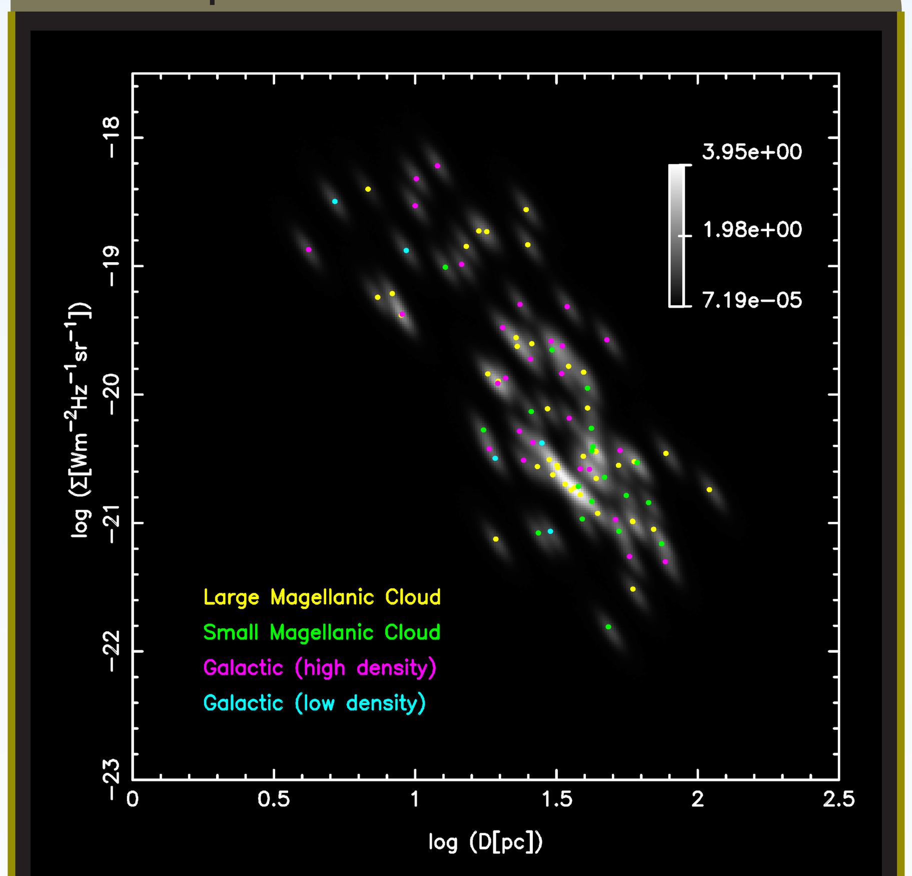
Small Magellanic Cloud mixed samples





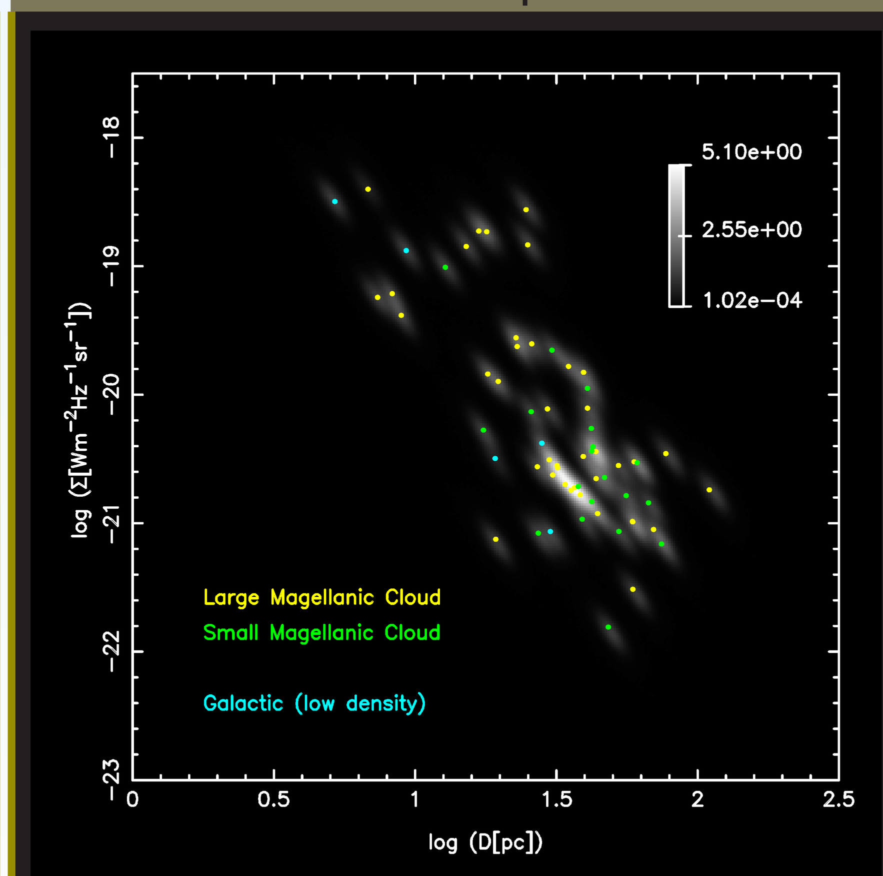
It appears that a low Σ evolutionary track is evident in both cases but because of the small number of data points (Galalctic low density sample) and scatter (Galactic high density sample) strong conclusions should be avoided.

All samples



Even for the reconstructed data distribution for all samples together it appears that the sample is largely incomplete. There are many "empty" areas. Also, the plot does not show any distinctive evolutionary features, in addition to the ones already discussed for other samples.

Selected mixed sample



This sample was selected as the most compact.

The Magellanic Cloud data should not suffer from inaccurate distances, as is usually the case with Galactic samples. The sample of Galactic SNRs for the low density ambient medium is added since these five r remnants do not appear to have substantial distance ambiguities because they appear distributed in a compact manner on the low brightness part of the plot. As with the Magellanic Clouds combined sample from (Bozzetto et al., 2016) two features arise. The brighter remnants evolving in a dense but non-homogeneous ambient (likely associated with molecular clouds) and remnants of somewhat lower brightness evolving in more rarefy, but more homogeneous ambient. In addition, an appearance of evolutionary path for even dimmer remnants can be argued but because of the small number of data points in this part of $\Sigma - D$ plots any conclusions cannot be maid with certainty.

References

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Summary

We reconstructed $\Sigma - D$ data density distribution for several samples of Magellanic Clouds and Galactic SNRs. We distinguished three evolutionary features in single and combined samples:

(i) The largest data grouping is a compact for the low brightness remnants at $\log D \sim 1.5$ and results from the LMC sample.

(ii) Resulting from the SMC data but less apparent than (i) is an evolutionary track of bright remnants possibly expanding in ambient with a non-zero density gradient.

(iii) Contributed from SMC and Galactic samples is a feature of lower brightness than (i), appearing as a single track in a ΣD plane but rather disrupted with the areas of missing data.

Although some evolutionary ΣD features are present the reconstructed data density distributions still appear with "empty" areas and are not reliable for calibration of a distance scale on a full $\Sigma - D$ range. The theoretical conclusions about Σ dependence on ambient density from Arbutina & Urošević (2005); Kostić et al. (2016) are likely to be validated but better sample selection and better surveys are a prime target for future studies on this subjects.