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Star Formation History from Radio Observations: A New Look at an Important Cosmological Parameter

R. B. Partridge

Haverford College, 370 Lancaster Avenue, Haverford, PA 19041, USA

Abstract. The radio wavelength luminosity of starburst galaxies correlates well with their star formation rates (Condon, 1992). Using this connection and three deep radio surveys, Haarsma and I constructed the global star formation history. Our results (see Haarsma et al., Ap. J., 2000 for details) show a steep increase from $z = 0$ to $z = 1$, matching calculations of the global SFR based on optical observations, when those observations have been corrected for the obscuration caused by dust. We note that our method requires no corrections for dust obscuration. We do, however, need to correct our results for radio emission from AGN. We do so using the extensive optical identifications available in these three fields.

1. Using Radio Surveys

We used three deep radio surveys for this work. Two were made at 8.5 GHz, of the HDF and SSA13 (Richards et al., 1998 and Windhorst et al., 1995, respectively). The third field was observed by Fomalont et al.(1991) at 5 GHz. The advantages of using radio data to determine the star formation history of the Universe are: no correction for dust extinction is needed (unlike the case in the optical); deep radio surveys are available; there is good positional accuracy, making the optical identification secure (unlike the case in the FIR) and the radio results provide an interesting check on optical measures of the SFR. The disadvantages are that our work depends on the tight correlation between FIR and radio flux, well documented but poorly understood, and that the radio fluxes may be contaminated by AGN emission. We correct for the latter by defining three samples, allowing us to isolate sources we believe to be free of AGN activity (see below).

Optical identifications are secure for these sources. Fifty–eight percent have spectroscopic redshifts, and a further 13% photometric redshifts based on I- or HK$'$-magnitudes. The remaining 29% of the sources have appropriately assigned redshifts (see Haarsma et al., 2000 for details).

We account for contamination of the radio fluxes by AGN by defining three samples:

• an "upper limit" sample (all 77 sources): all sources (including identifications with elliptical, emission line, and a few Seyfert galaxies, but not verified QSOs which were removed from sample). This sample shows the maximum star formation rate that the data would allow, assuming all radio flux from all detected sources is due to star formation.

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• a "lower limit" sample (23 sources): only those sources which are both identified with spiral/irr/mergers and have spectroscopic redshifts. These are the sources which definitely belong in the population of interest—starforming systems with no AGN.

• a "middle value" sample (37 sources): only those sources for which two criteria are met:

- redshifts are spectroscopic or based on I- or HK′-band mag. (none randomly assigned)

- galaxy type is spiral/irr/merger, or faint/red. In addition, about 80% of the "unknown" identifications are assumed to be spiral/irr/merger or faint/red and are included here.

This sample is our best estimate of the true redshift distribution of star-forming radio galaxies.

2. Two routes to determining the star formation history

Route 1: model the evolving radio luminosity function (RLF), then use it to calculate the SFR history. We begin by parameterizing the RLF following Condon (1989). We adopt a parametric form for the evolution of the RLF, including both luminosity and number evolution (Condon, 1984). We then use radio luminosities, the redshift distribution and the overall radio background brightness to constrain the parameters of the evolving RLF. While those parameters are not strongly constrained, the best fit we find is for strong luminosity evolution and weak number evolution. The luminosity relates directly to SFR (Condon, 1992).

Route 2: calculate the SFR directly. We begin by summing the radio luminosity in each redshift bin. We need to correct these sums for the luminosity from radio sources too weak to enter our catalogs. We do this using the evolving RLF; clearly the correction is larger at higher redshifts. The bold crosses are the result. The curve is a relation found using Route 1; while not totally independent, the two Routes use the data in quite different ways so their agreement is heartening. Note that the upper limits on the SFR, based on the upper sample defined above, include all radio sources (and hence possible AGN contamination) but increase the SFR by only a factor of ~ 1.6. That suggests both that AGN contamination is not a large problem in our work, and that the fraction of radio luminosity generated by AGNs does not increase sharply with redshift.

3. Comparison to optical measurements of the SFR

First, our radio results are in qualitative agreement with the optical results (e.g., Madau et al., 1998; Rowan-Robinson et al., 1997; Steidel et al., 1999) when those are corrected for dust extinction. Our results (like other work) provide no support for the idea that the SFR remains essentially constant in the interval $z = 0 - 1$ (Cowie et al., 1999; Mobasher et al., 1997). While there is acceptable qualitative agreement with the optical results, our SFRs appear to be roughly a factor of 2 higher than the optical values. That leads us to ask whether the correction for dust extinction made in the optical work has been underestimated (see Hopkins et al., 2000 and Cesarsky and Franceschini here).

So far, we have too few secure redshifts above 2 to constrain the SFR in the range $z = 2 - 5$. Our results do suggest that the SFR remains high at $z > 2$. If that is the case, it follows that much of the high–redshift star formation is hidden in the optical (but is visible in the radio window).

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