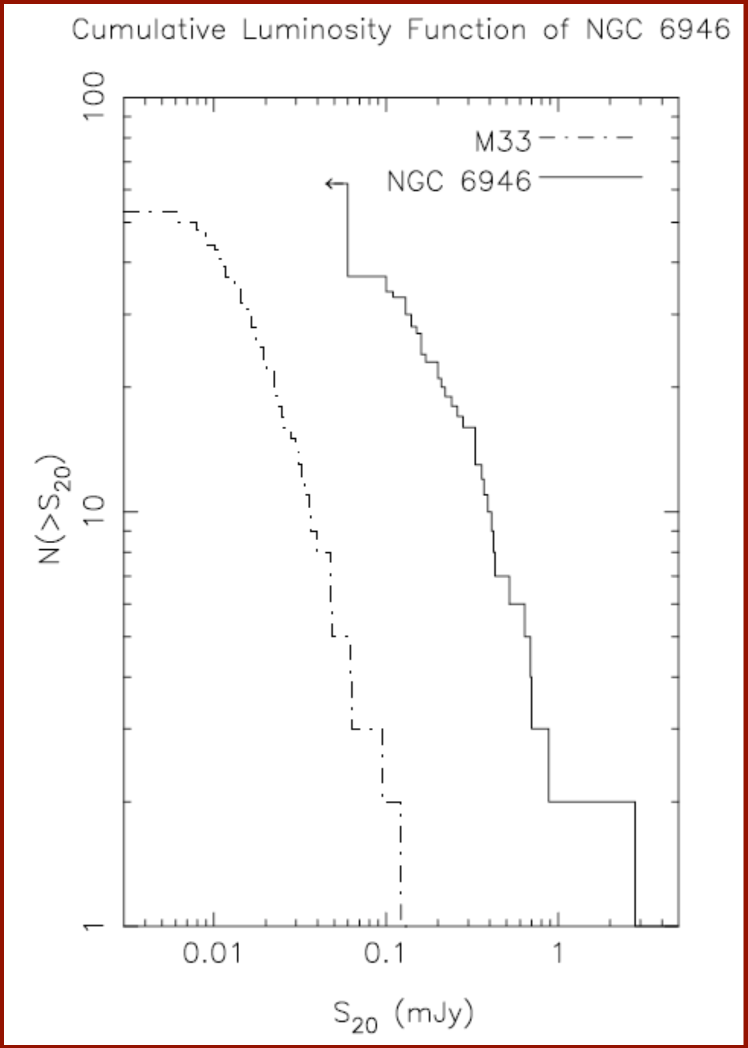
A Universal Luminosity Function for Radio Supernova Remnants

Laura Chomiuk
University of Wisconsin--Madison

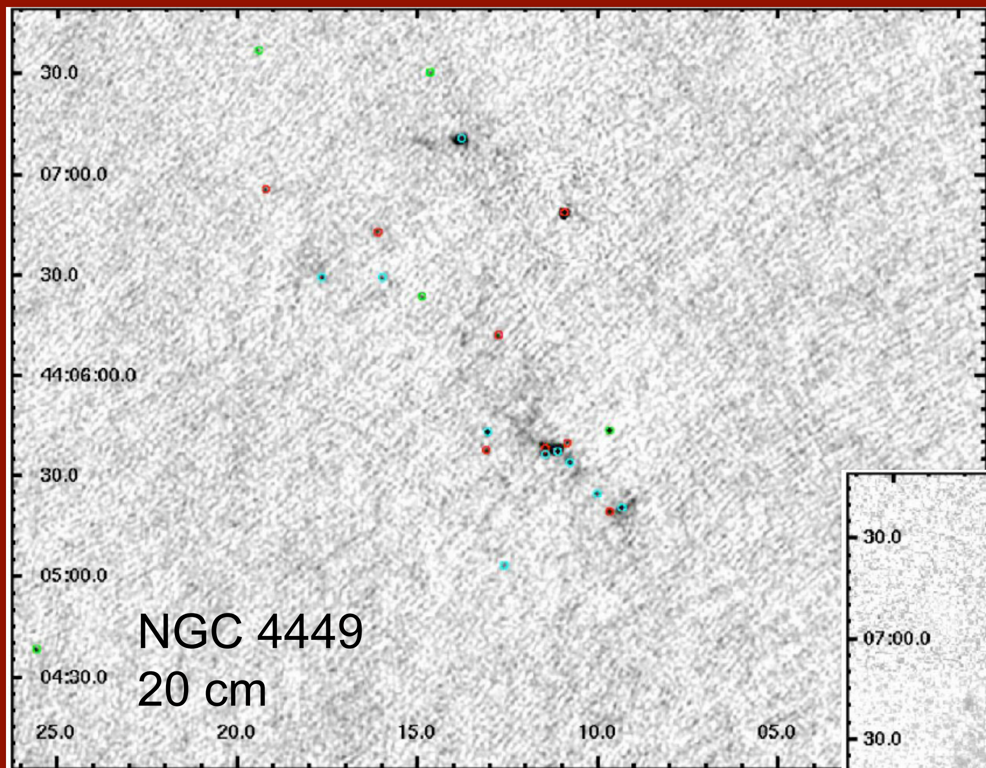
Are SNRs fundamentally the same across galaxies?

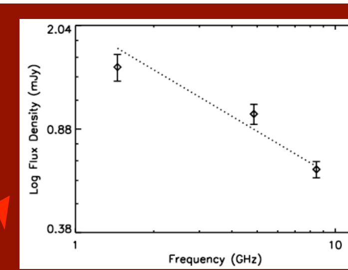


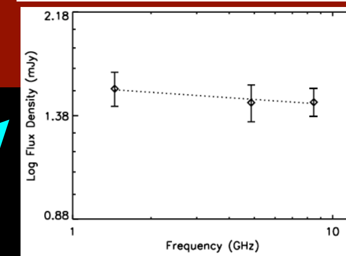
Lacey & Duric (2001)

The brightest SNR in M33 is ~10 times less luminous than the brightest SNR in NGC 6946.

Radio SNRs in Other Galaxies



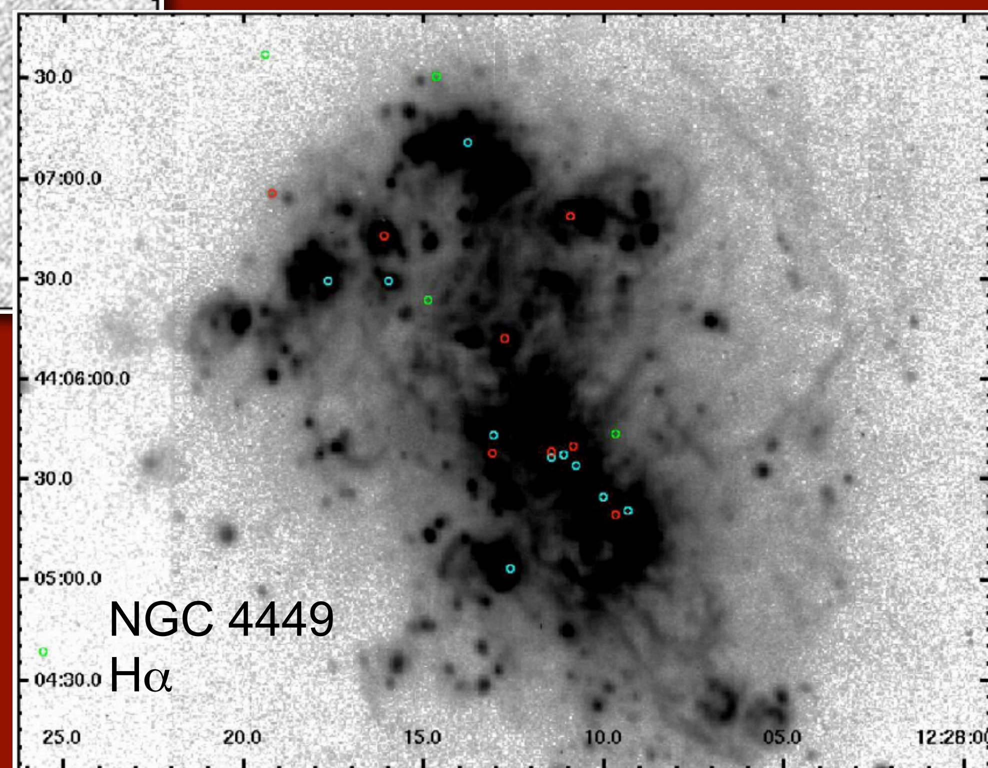




SNR

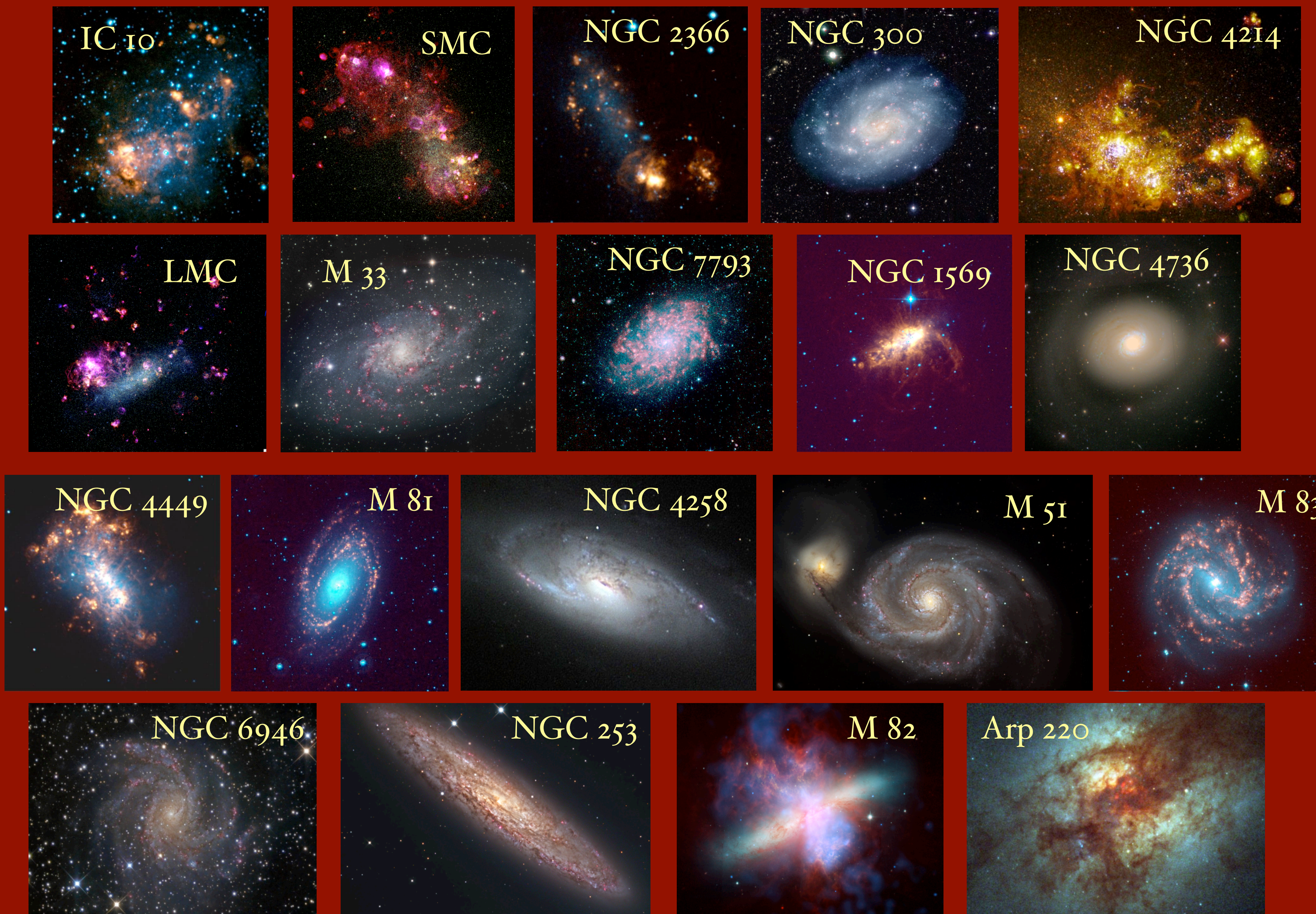
H II region

Background source

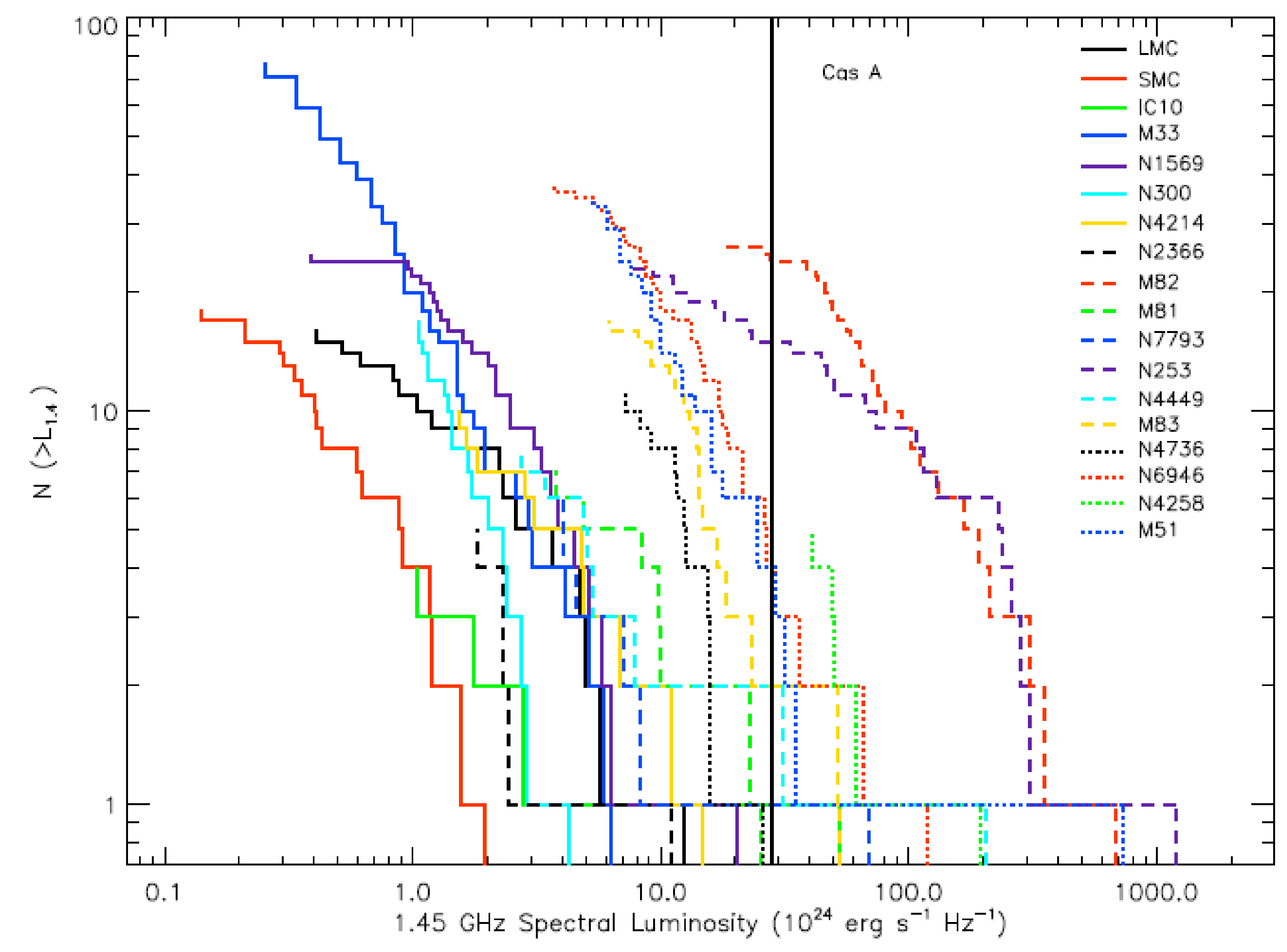


8 SNRs found in NGC 4449 by Chomiuk & Wilcots (2009).

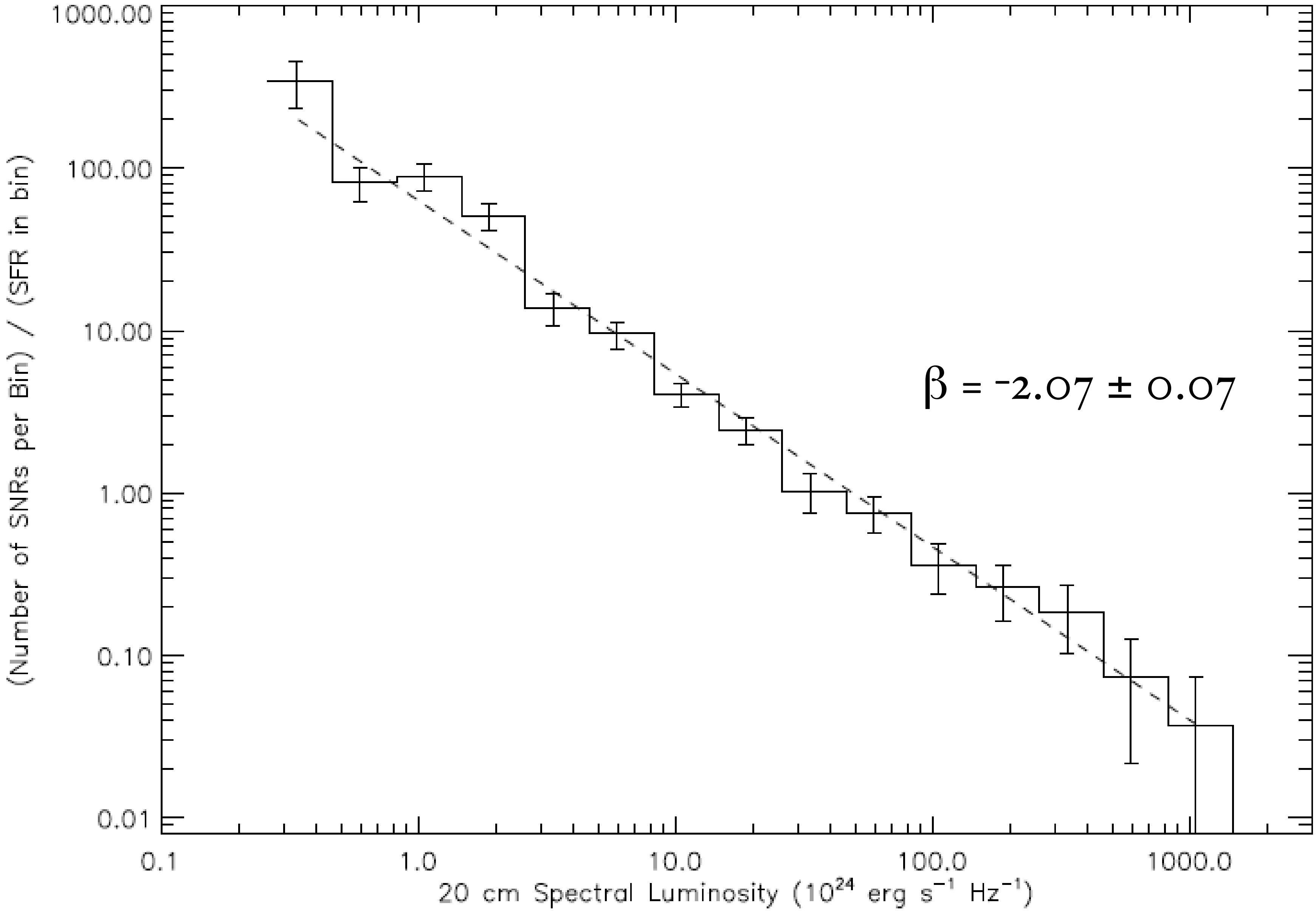
SNRs in 19 Nearby Galaxies



Cumulative Luminosity Functions

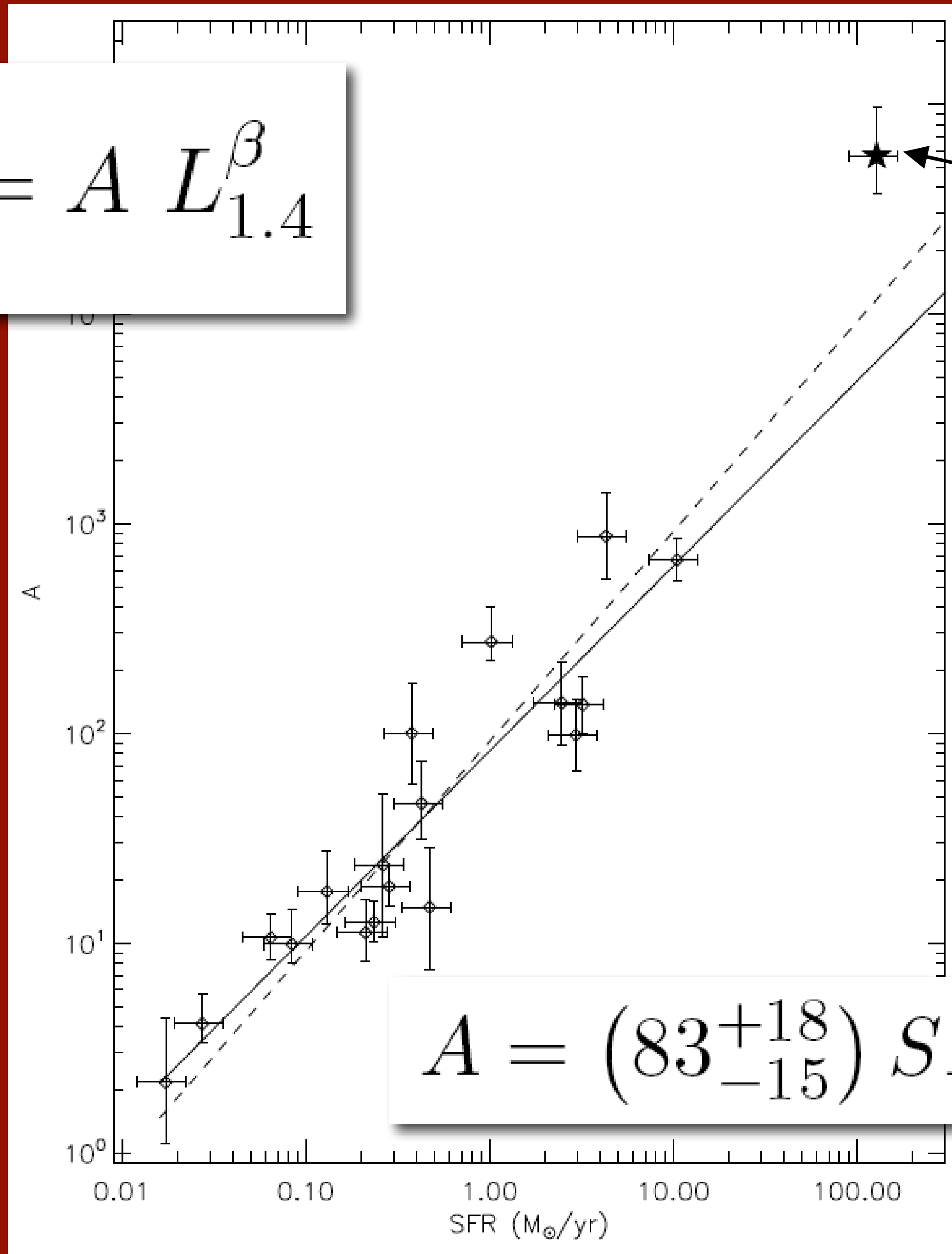


Composite SNR Luminosity Function



$$\frac{dN}{dL_{1.4}} = A\ L_{1.4}^{\beta}$$

LF scaling factor (assuming β= -2.13) →



Arp 220: outlier?

Approximately linear relation:

$$A = (83^{+18}_{-15})\ SFR^{0.88\pm0.08}$$

Therefore, the SNR LF can be described as:

$$\frac{dN}{dL_{1.4}} = 83\ \mathrm{SFR}^{0.88}\ L_{1.4}^{-2.07}$$

We can rewrite dN/dL as:

$$\frac{dN}{dL_{1.4}} = \frac{dN}{dt}\ \left(\frac{dL_{1.4}}{dt}\right)^{-1}$$

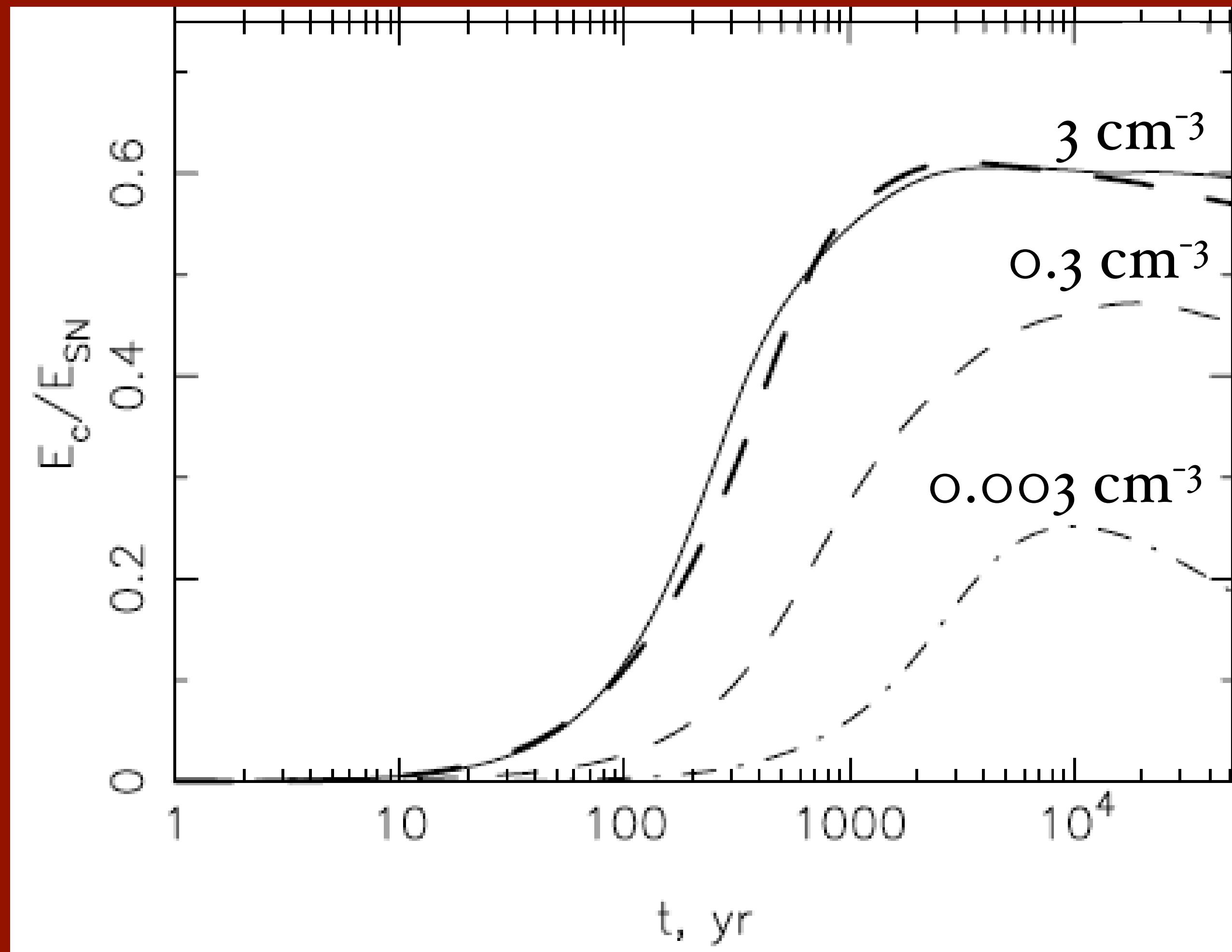
dN/dt is the production rate of SNRs, ∝ SFR.

dL/dt describes the luminosity evolution of SNRs.

Some Approximations

- Radio SNRs are in the adiabatic phase.
- In the adiabatic phase, the CR energy does not depend on time or ISM density.

$E_{CR}/E_{SN} \approx$ constant.



From Berezhko & Volk (2004)

Therefore, it is the magnetic field that determines dL/dt.

Standard prescription for magnetic field amplification:

$$B^2/(8\pi) = 0.01\ \rho_0\ v_s^2$$

Making these simplifications, we find an expression for the time evolution of synchrotron luminosity:

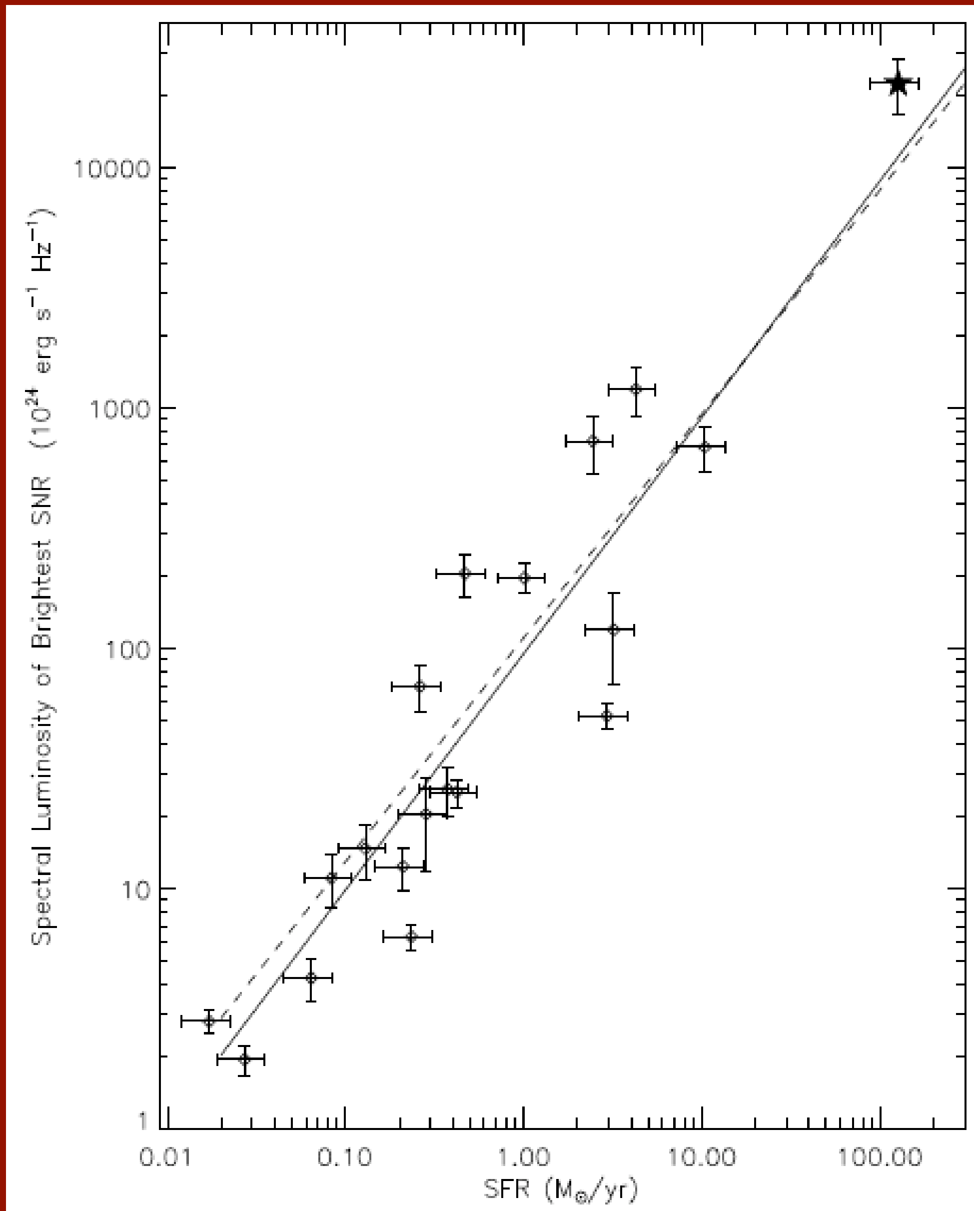
$$L_\nu \propto E_{SN}^{1.3}\ \rho_0^{0.45}\ t^{-0.9}$$

And for the luminosity function:

$$\frac{dN}{dL_{1.4}} \propto SFR\, E_{SN}^{1.4}\ \rho_0^{0.5}\ L_{1.4}^{-2.1}$$

β= -2.1
A very good fit to the data!

The L_{max}--SFR relation

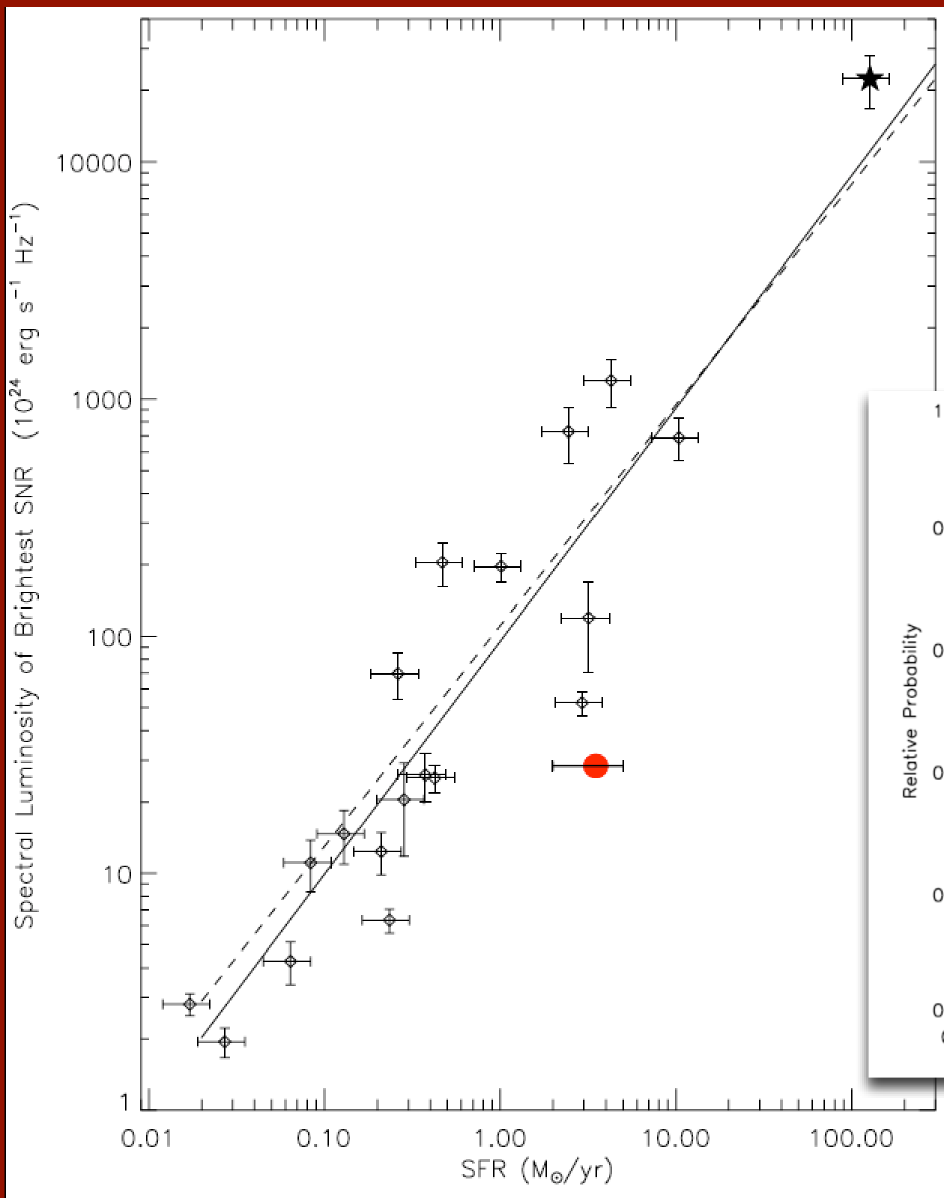


Just a statistical sampling effect?

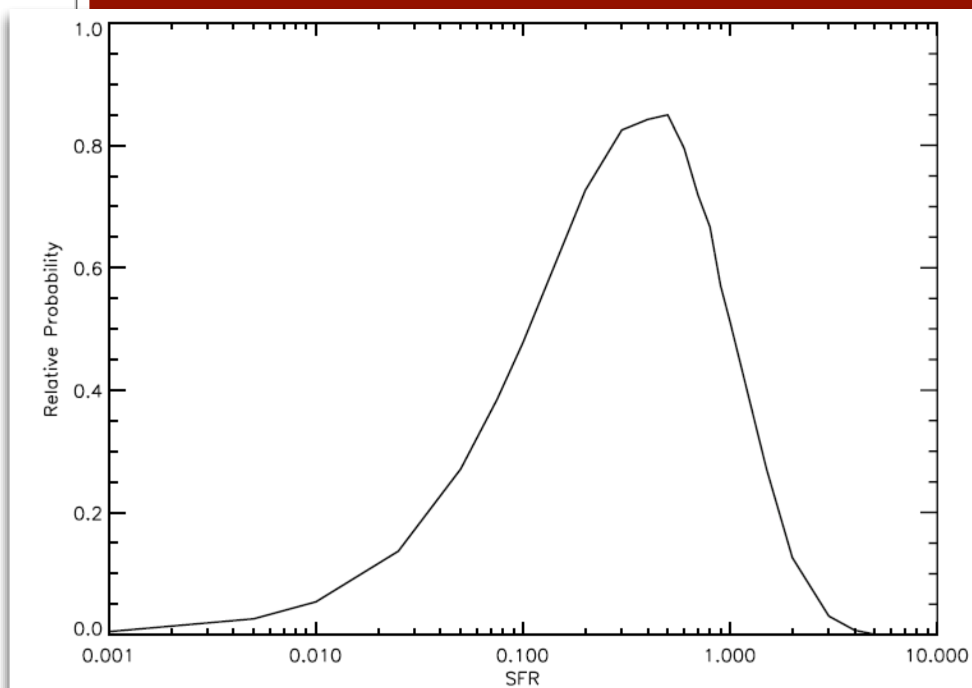
Best fit to data

Prediction for statistical sampling from Monte Carlo simulations

Cas A on the L_{max}--SFR relation



Only a 3% probability that a galaxy with $L_{max} \approx L_{Cas\ A}$ has a SFR > 2 $M_\odot$/year



Conclusions

• The SNR LF is remarkably similar across galaxies. It is consistent with a power law of constant index and scaling ∝ SFR.

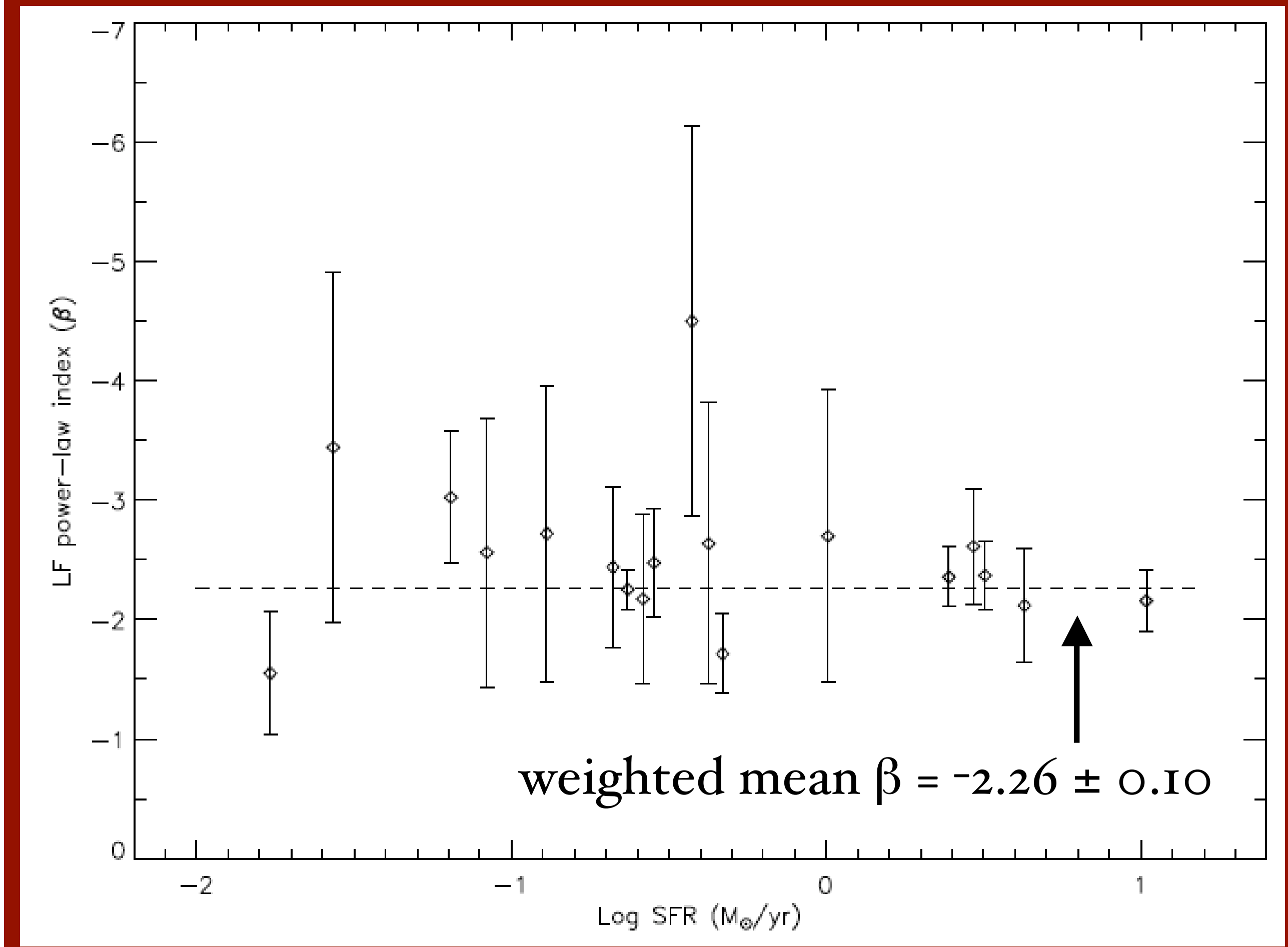
• The SNR LF is well fit with models of diffusive shock acceleration + magnetic field amplification, given a few simplifying assumptions.

• Galaxies with higher SFRs host more luminous SNRs; this can be completely explained by statistical sampling effects.

• The luminosity of Cas A implies that current estimates of the Milky Way SFR may be too high.

Model the SNR LFs as power laws

$$n(L_{1.4}) = \frac{dN}{dL_{1.4}} = A\ L_{1.4}^{\beta}$$



The four "best" galaxies (N_{SNR}>20) all have similar best-fit β:

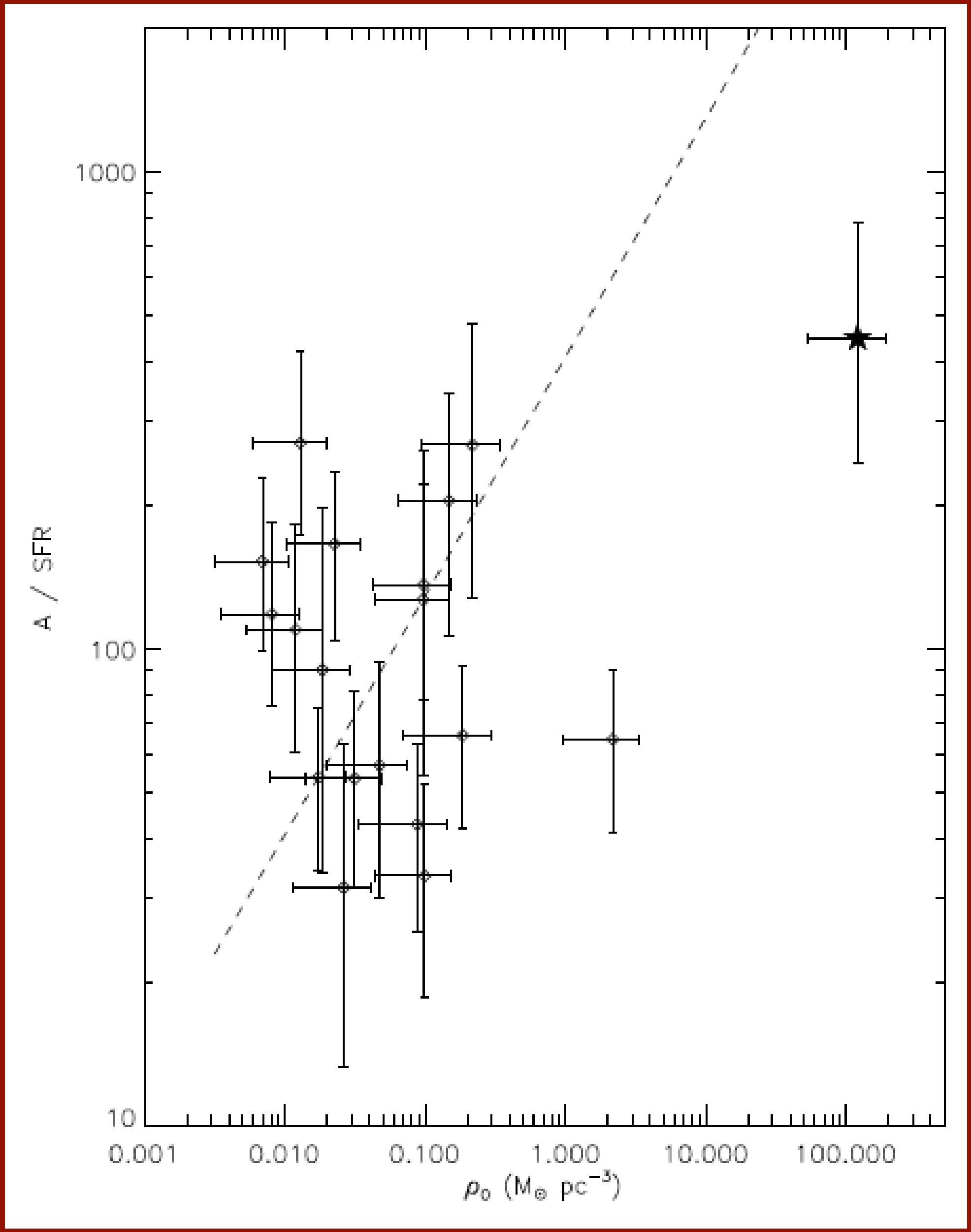
M 33	-2.25 ± 0.17
M 51	-2.36 ± 0.25
NGC 6946	-2.37 ± 0.29
M82	-2.16 ± 0.26

Is there a dependence on ISM density?

$$\frac{dN}{dL_{1.4}} \propto SFR\, E_{SN}^{1.4}\ \rho_0^{0.5}\ L_{1.4}^{-2.1}$$

$$E_{SN} \approx \text{constant}$$

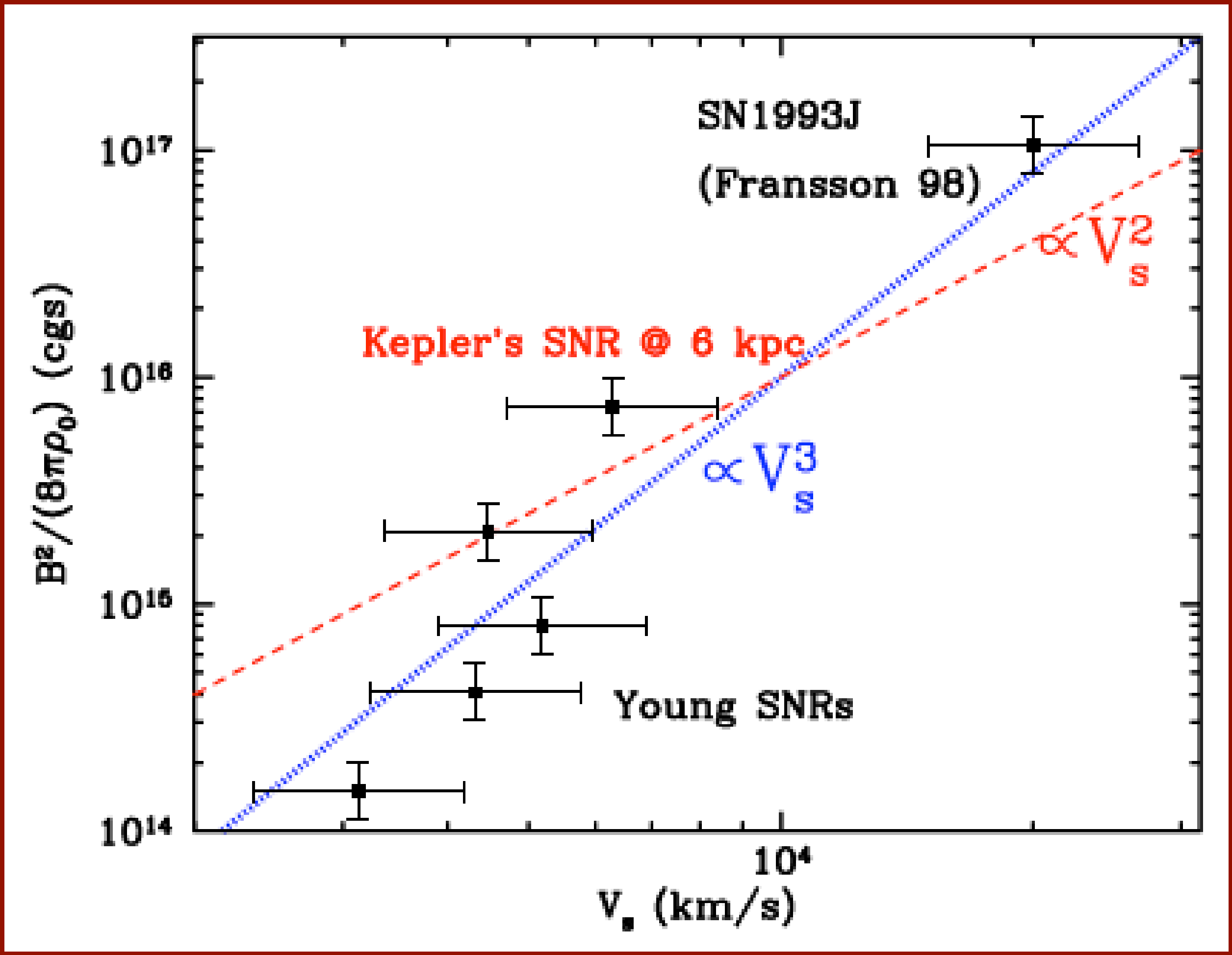
$$A \propto SFR\ \rho_0^{0.5}$$



Line marks theoretical prediction:

$A/SFR \propto \rho_o^{0.5}$

There are claims that $B^2 \propto \rho_o v_s^3$ instead of $\propto \rho_o v_s^2$.



From Vink (2004).

This would predict $dL/dN \propto L^{-1.74}$.

Decidedly *not* in agreement with the SNR LF data.