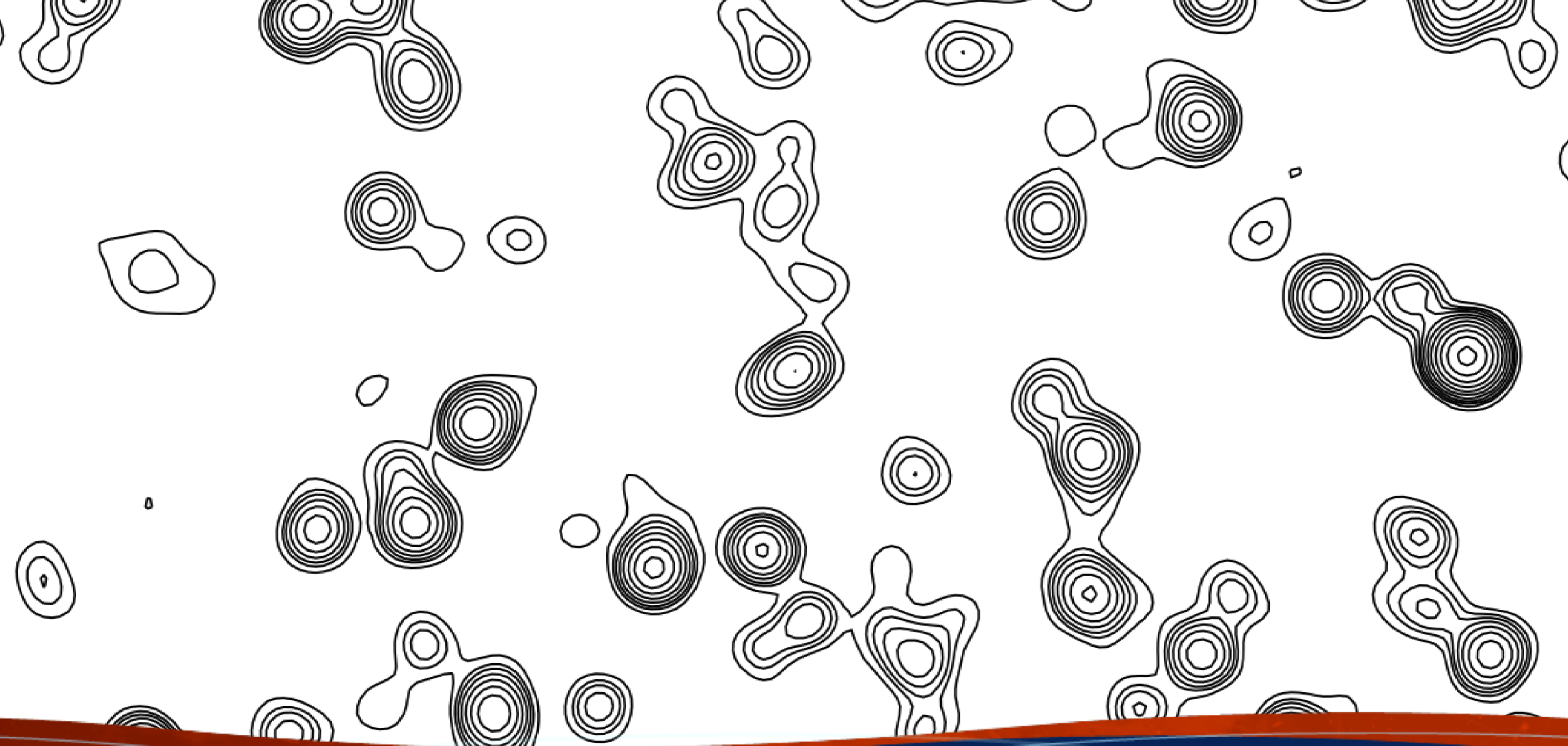

nJy Science II: The Star Formation History of the Universe

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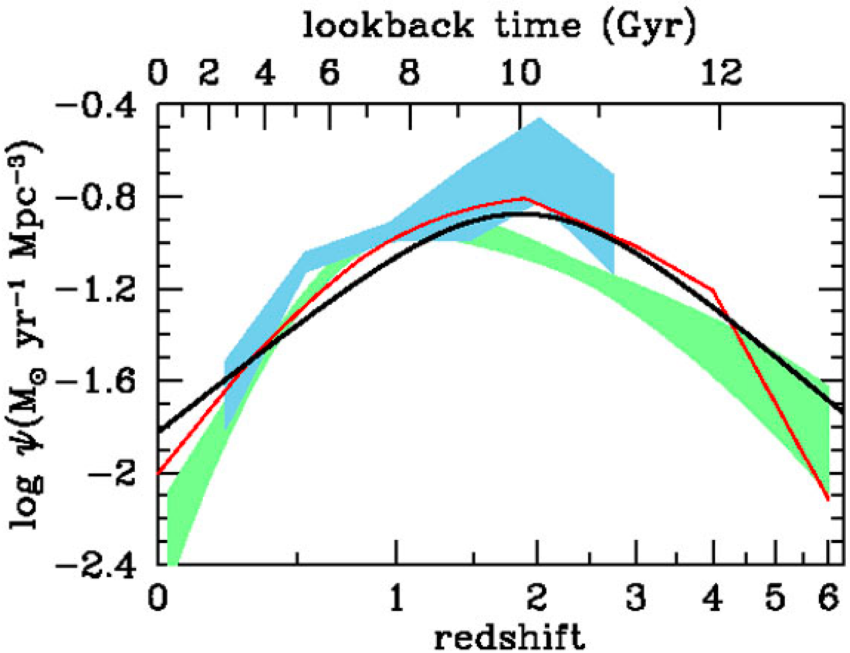
Jim Condon, Bill Cotton (NRAO)

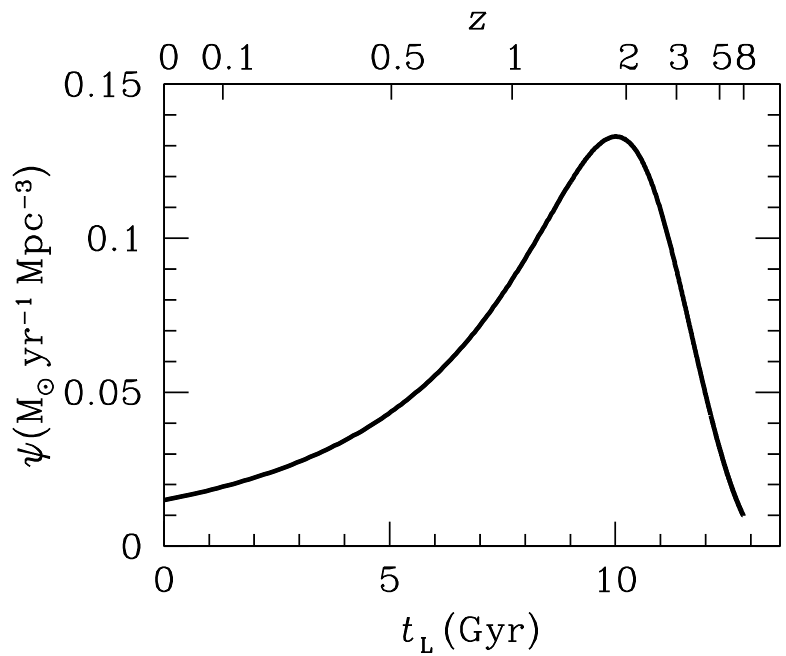
Tom Mauch, Fernando Camilo (SARAO)

Star formation and SMBH growth

- ~91% of all stars (by mass) were formed since z ~ 3.
- Assuming no evolution, 80% of the star formation (by mass) over all redshifts was created by sources with $S \gtrsim 0.25\ \mu$Jy.



Madau & Dickinson (2014)



CM (2018), PASP, 130, 073001

Radio luminosity and star formation

$$\frac{\mathrm{SFR}(M > 0.1M_\odot)}{M_\odot \mathrm{yr}^{-1}} = \kappa \left(\frac{L_{1.4\,\mathrm{GHz}}}{\mathrm{W\,Hz}^{-1}}\right) \quad (\kappa = 10^{-21})$$

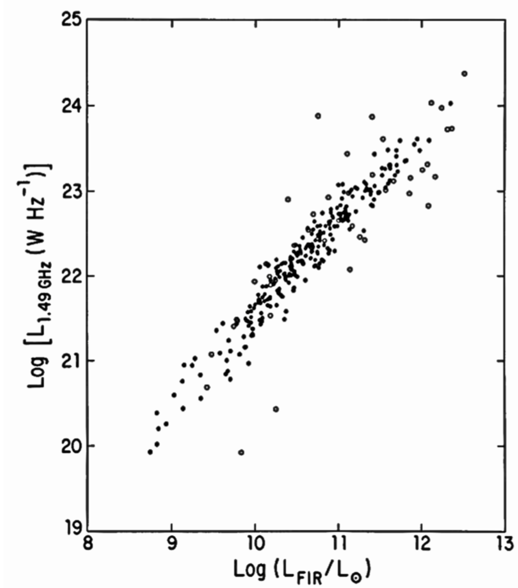
$$\frac{\mathrm{SFR}(M > 0.1M_\odot)}{M_\odot \mathrm{yr}^{-1}} = \begin{cases} 5.52 \times 10^{-22} L_{1.4\,\mathrm{GHz}} & L > L_C, \\ \frac{5.52\times10^{-22}}{0.1+0.9(L/L_C)^{0.3}} L_{1.4\,\mathrm{GHz}} & L \leq L_C \end{cases}$$

$$\frac{\mathrm{SFR}(M > 0.1M_\odot)}{M_\odot \mathrm{yr}^{-1}} \sim 5.64^{81}_{-5.3} \times 10^{-32} \left(\frac{L_{1.4\,\mathrm{GHz}}}{\mathrm{erg\,Hz}^{-1}}\right) \times \left(\frac{U_{\mathrm{rad}}}{\mathrm{erg\,cm}^{-3}}\right)^{-0.316\pm0.102}$$

$$\frac{\mathrm{SFR}(M > 0.1M_\odot)}{M_\odot \mathrm{yr}^{-1}} \approx 1.20 \times 10^{-21} \left(\frac{L_{1.4\,\mathrm{GHz}}}{\mathrm{W\,Hz}^{-1}}\right)$$

Bell (2003), Murphy+ (2011), Condon (1992)

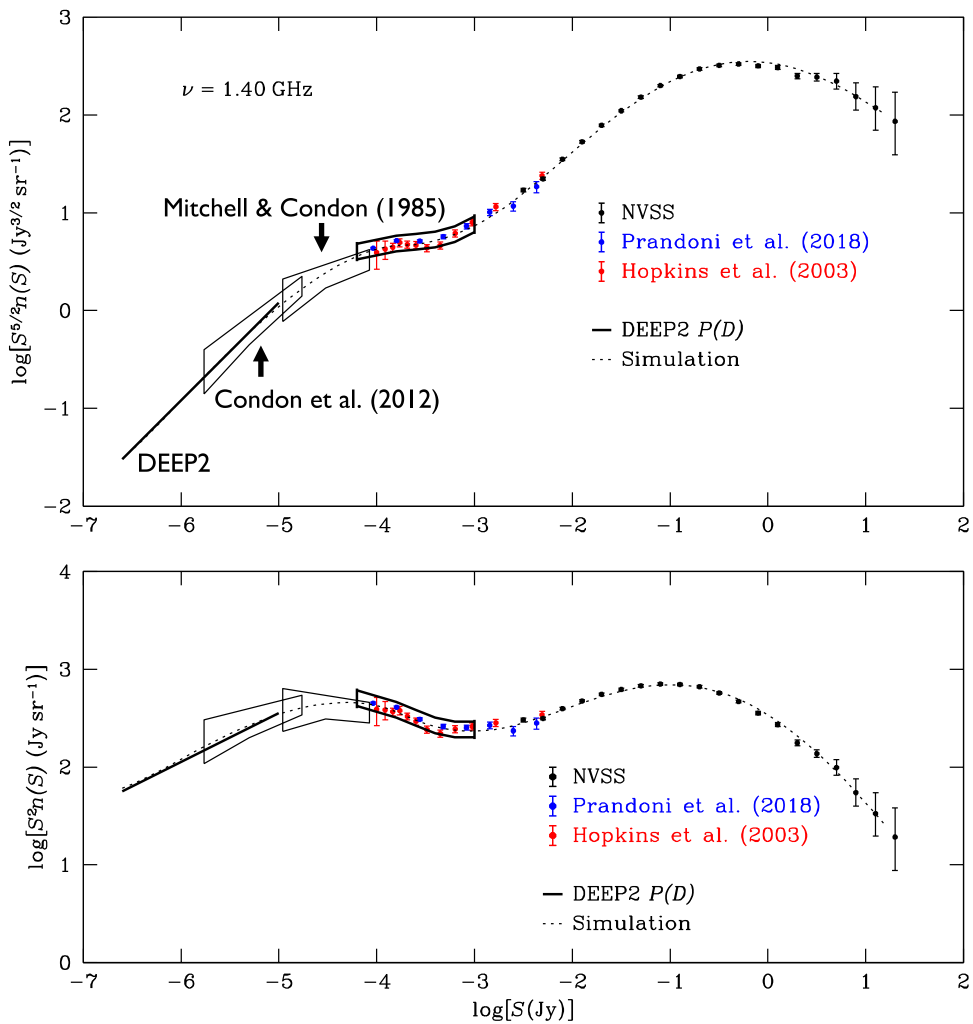
Synchrotron radiation from relativistic electrons accelerated in supernova remnants.



Condon, J. J., Anderson, M. L., & Helou, G. (1991)

Radio source counts

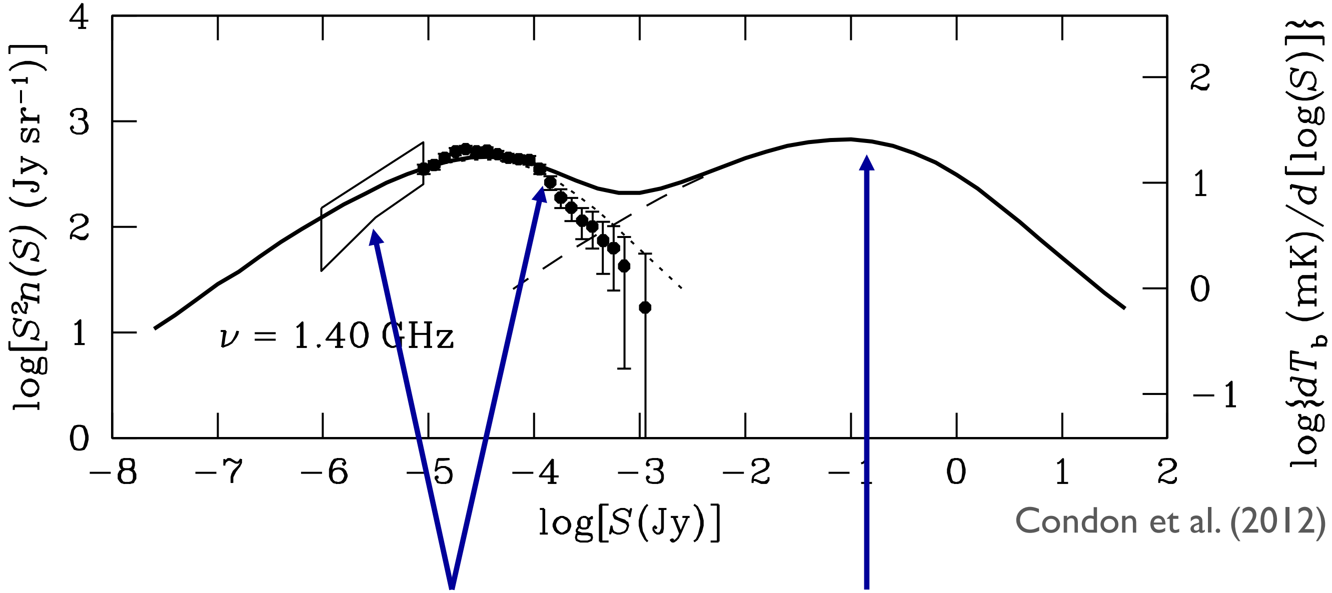
- κ does not alter determination of evolutionary models of the SFRD by comparisons of local radio luminosity functions with radio source counts.



Mauch et al. (2019, in prep)

μJy sources

- SFGs outnumber AGN by an order-of-magnitude.



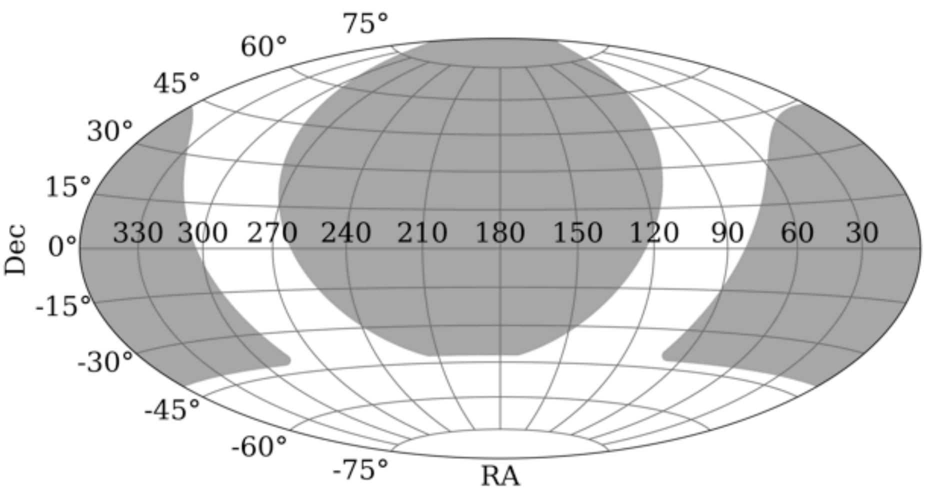
Condon et al. (2012)

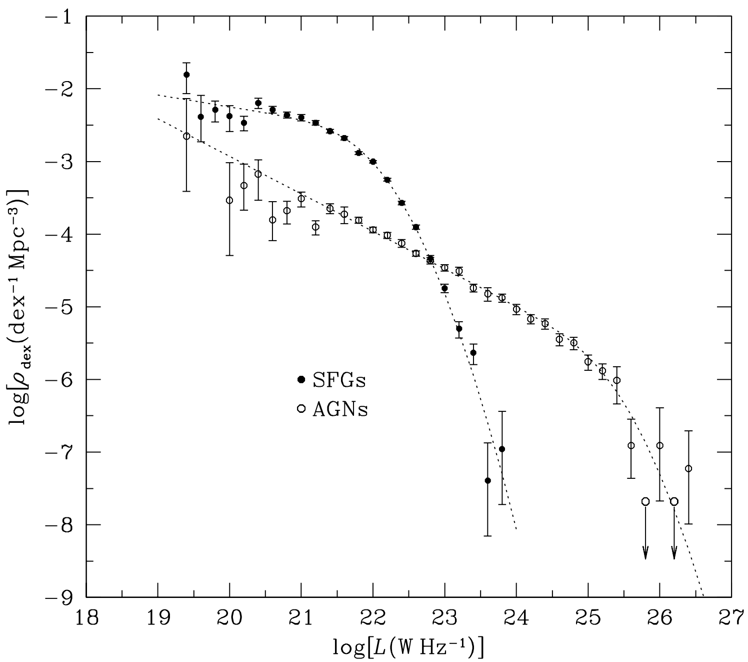
FIR measurements scaled to 1.4 GHz by FIR/radio correlation.

1.4 GHz radio source count.

Measuring the local radio LF

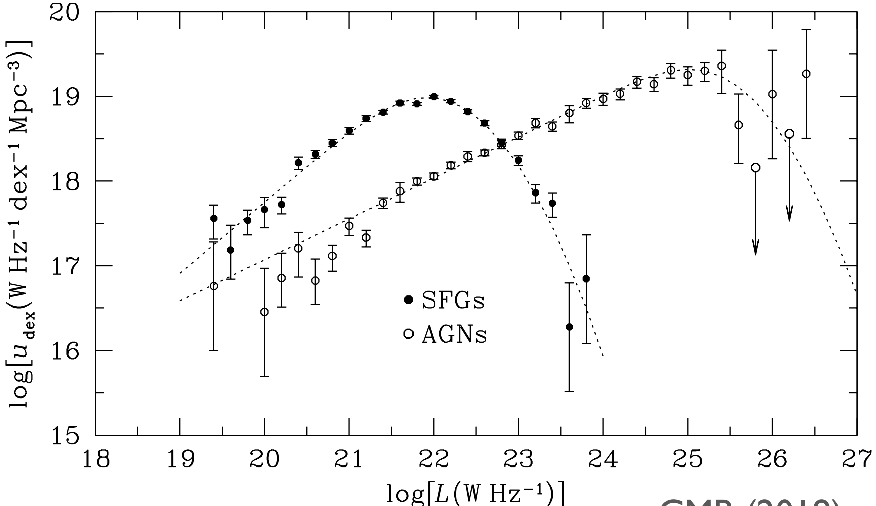
- 9517 NVSS sources cross-identified with 2MASS with spectroscopically measured redshifts.
- Detected >99% of the total power output from local SFGs.





CMB (2019), ApJ, 872, 148C

Local radio LF → Source Counts



CMB (2019)

$$U_{\rm dex}(L_\nu|z) = L\,\rho(L_\nu|z)\frac{dL}{d\log L}$$
$$= L_\nu^2\,\rho(L_\nu|z)\ln(10)$$

$$\eta(S,z) = \rho(L_\nu|z)\,dL_\nu\,dV_C$$

$$S^2\eta(S,z) = L_\nu^2\rho(L_\nu|z)\left[\frac{(1+z)^{\alpha-1}D_{\rm H_0}}{4\pi E(z)}\right]$$

$$S^2\eta(S,z) = U_{\rm dex}(L_\nu|z)\left[\frac{(1+z)^{\alpha-1}D_{\rm H_0}}{4\pi\ln(10)E(z)}\right]$$

$$S^2 n(S) = \frac{D_{\rm H_0}}{4\pi\ln(10)} \times \int_0^\infty U_{\rm dex}(L_\nu|z)\left[\frac{(1+z)^{\alpha-1}}{E(z)}\right]dz$$

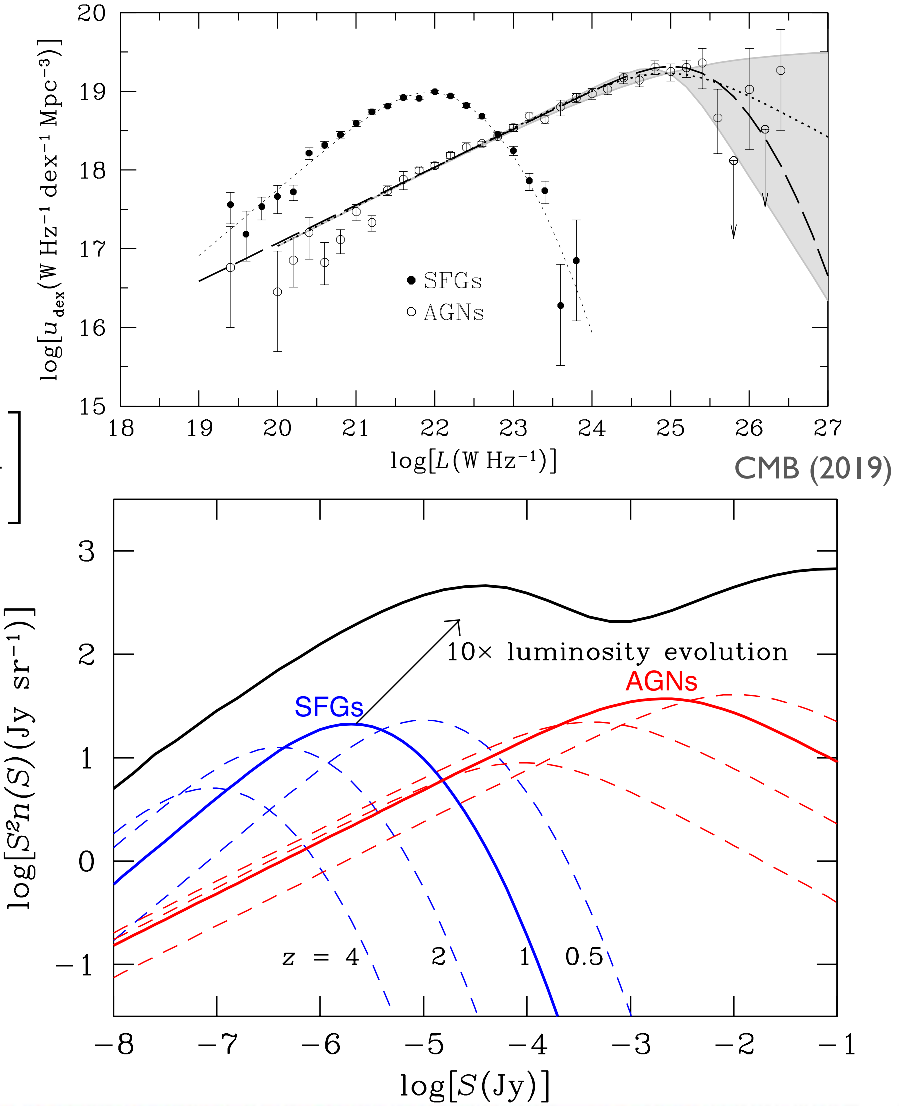
*Calculations from CM (2018), PASP, 130, 073001

Local radio LF → Source Counts

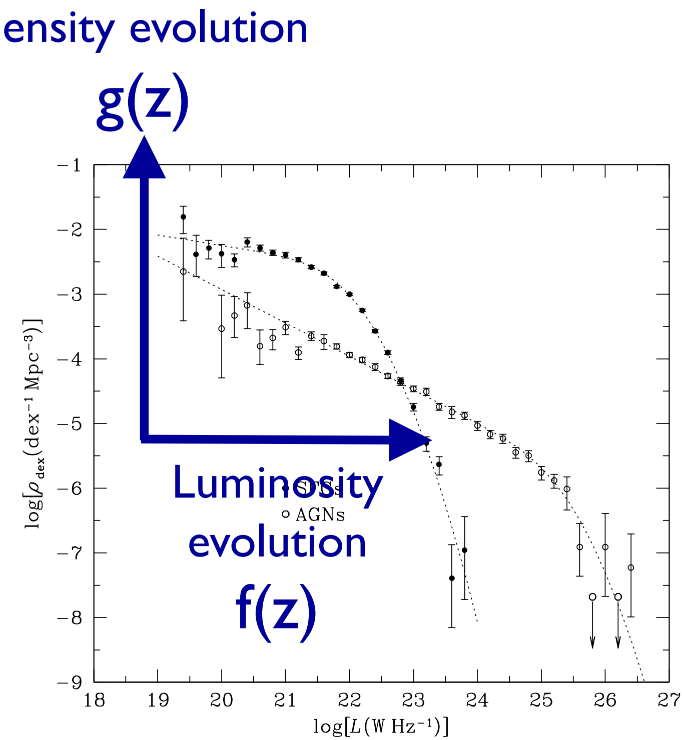
- Counts are exactly the same shape as $U_{\rm dex}$ in narrow-redshift-ranges.

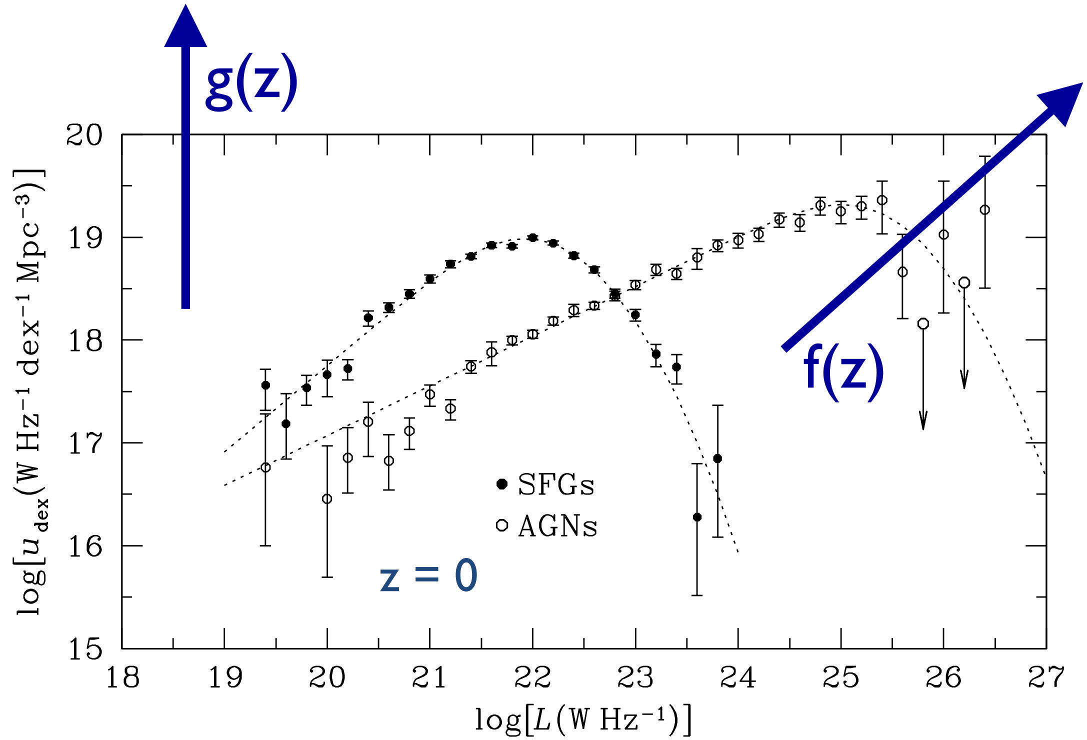
$$S^2\eta(S,z) = U_{\rm dex}(L_\nu|z)\left[\frac{(1+z)^{\alpha-1}D_{\rm H_0}}{4\pi\ln(10)E(z)}\right]$$

- Depends only on distance.



Evolving the local radio LF



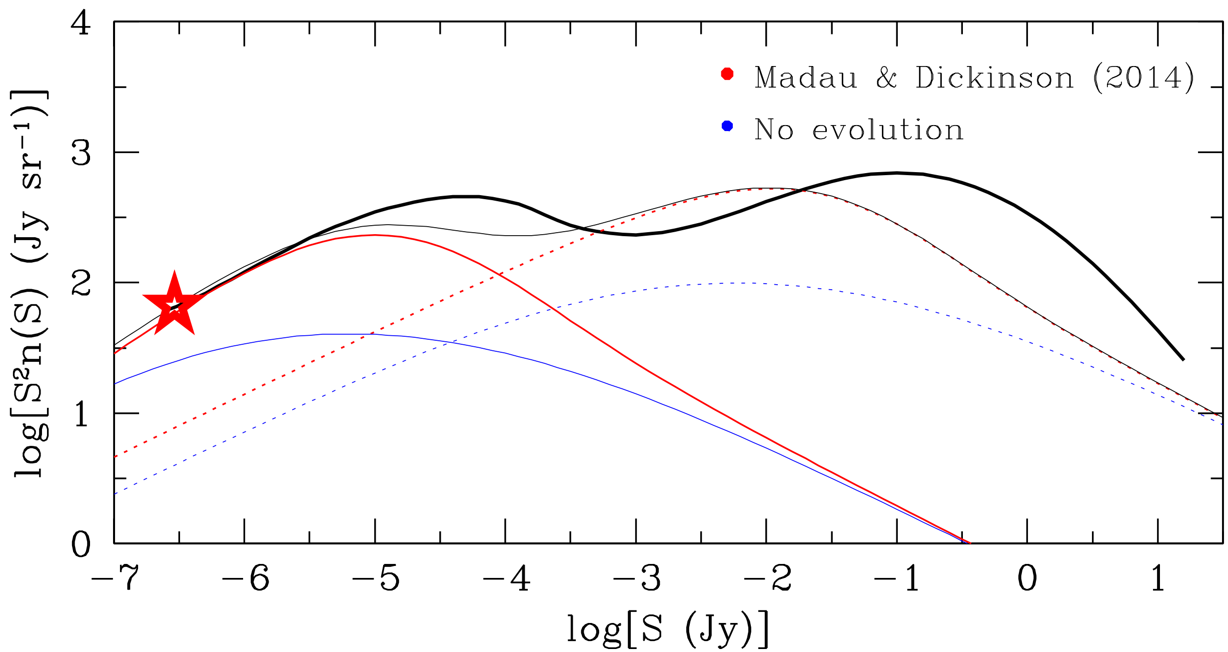


$$\rho_{\rm dex}(L_\nu, z) = g(z)\rho_{\rm dex}(L_\nu/f(z), z=0)$$

Madau and Dickinson SFRD Model

$$\frac{\psi(z)}{\psi(0)} = \frac{(1+z)^{2.7}}{1+[(1+z)/2.9]^{5.6}}$$

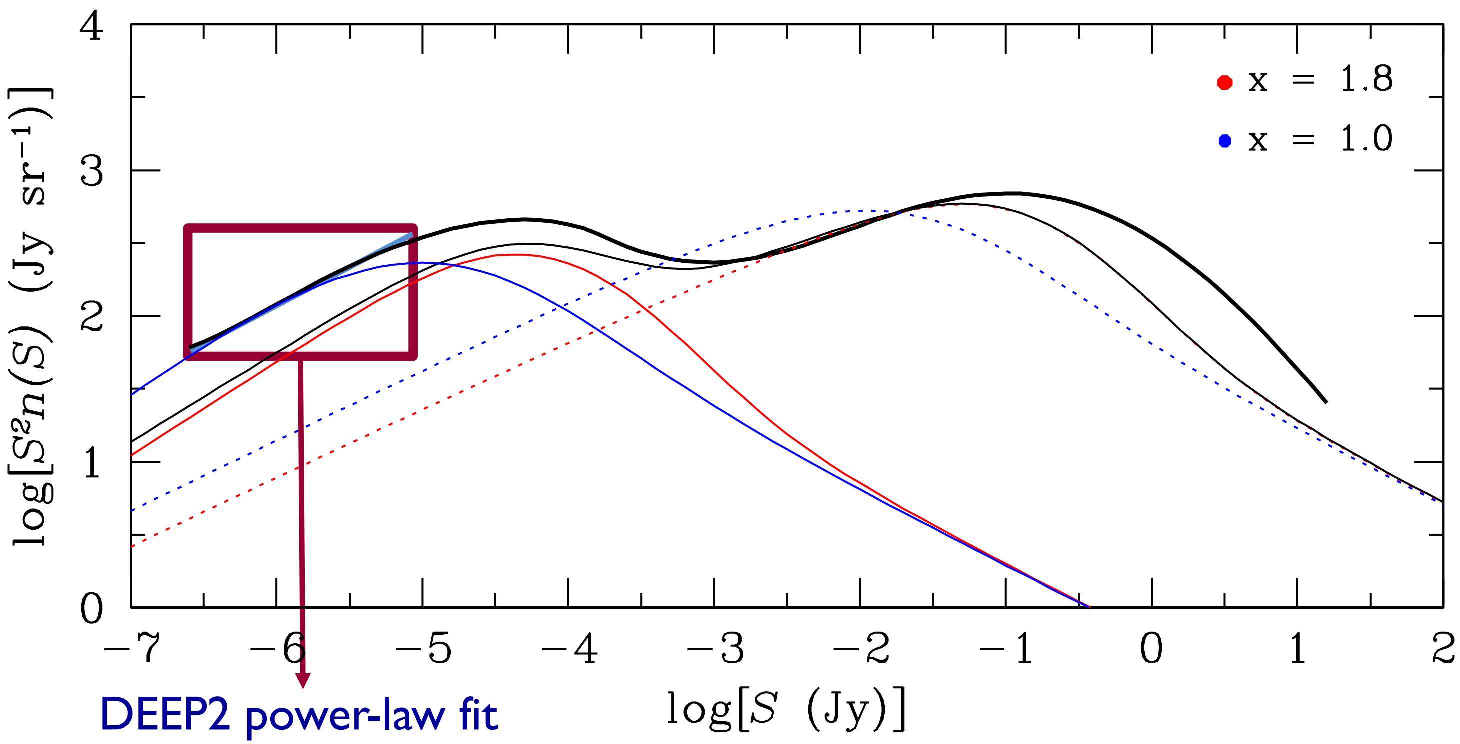
(Assuming pure luminosity evolution)



★ Milky Way at z ~ 4 with 10X luminosity evolution

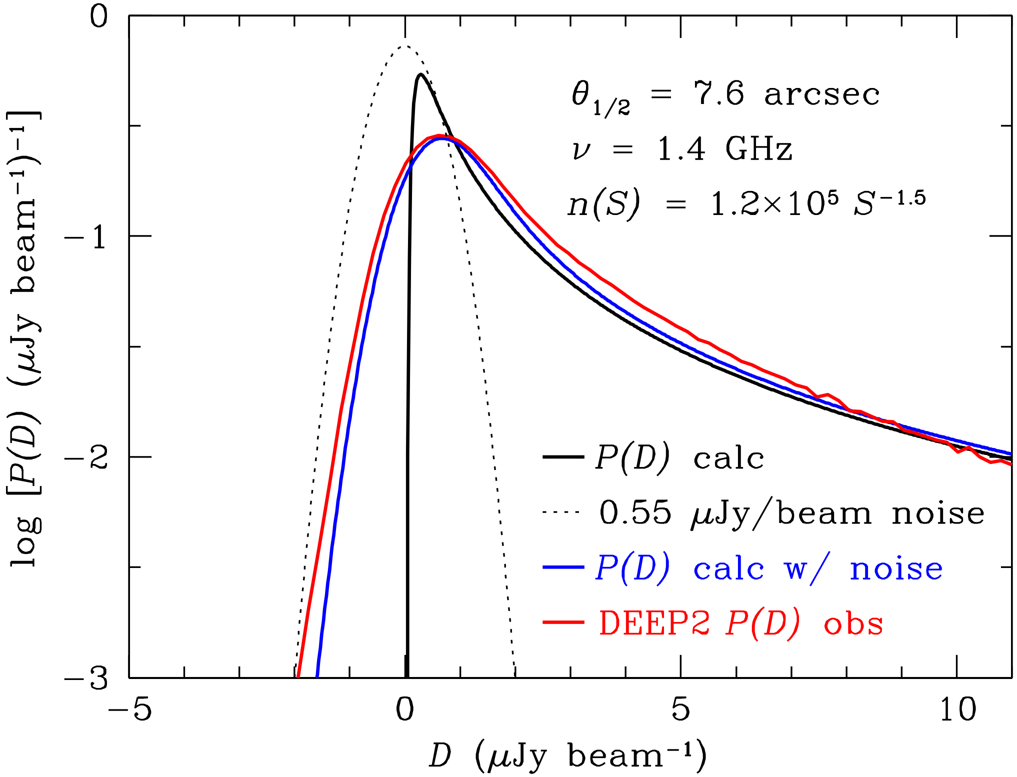
Adding density evolution

$$\frac{\psi(z)}{\psi(0)} = f(z) \times g(z) \longrightarrow f(z) = \left(\frac{\psi(z)}{\psi(0)}\right)^{x},\ g(z) = \left(\frac{\psi(z)}{\psi(0)}\right)^{1-x}$$



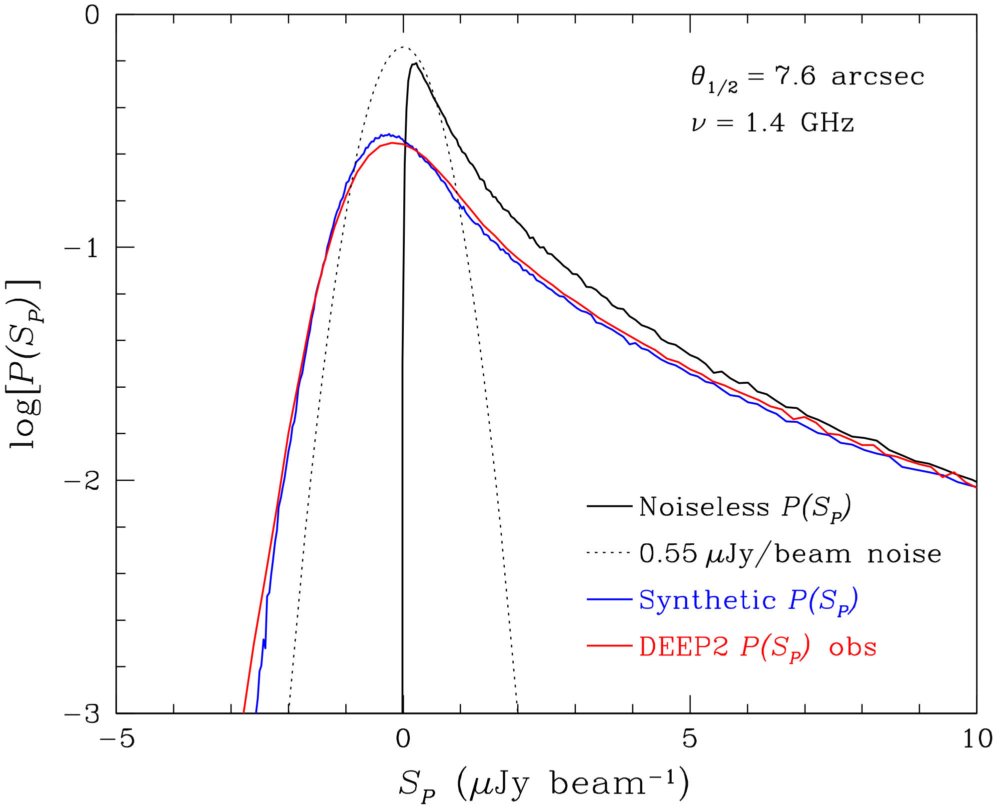
Beyond a power-law

- *n(S)* does not follow a power-law, so cannot analytically derive *P(D)*.
  - Simulate synthetic image from measured *n(S)*.

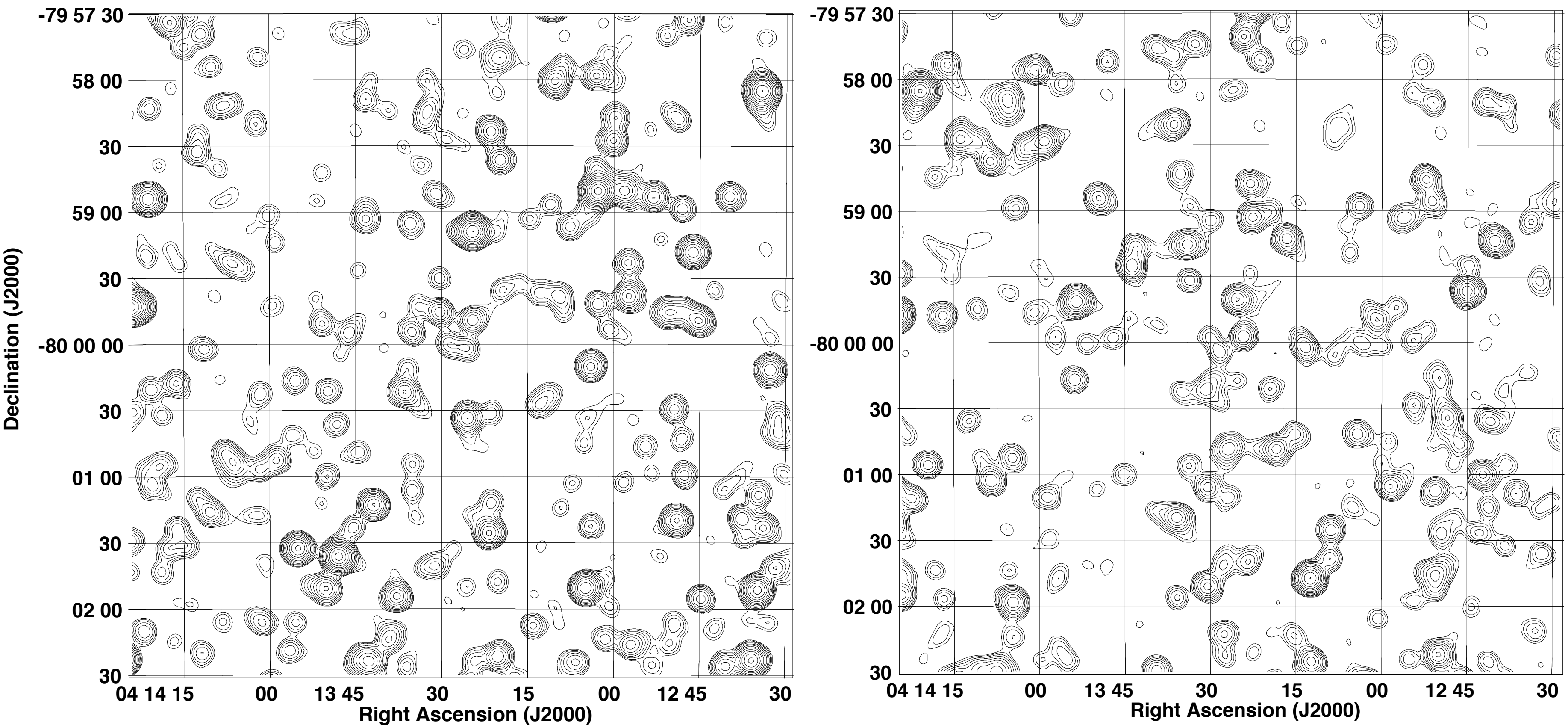


P(D) distribution from simulation

- Simulate P(D) distributions for non power-law source counts.



Synthetic Image



What DEEP2 does for SFHU

→ Differential source counts $n(S)$ down to $\sim 0.25\ \mu$Jy.

→ Sources with $S \gtrsim 0.25\ \mu$Jy (assuming no evolution) account for ~80% of the star formation (by mass) in the universe.

→ Model the cosmic evolution of the SFRD using $n(S)$ and LRLF.