Radio—Far infrared correlation in "blue cloud" galaxies up to z~1.2.

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24th June 2015, EWASS

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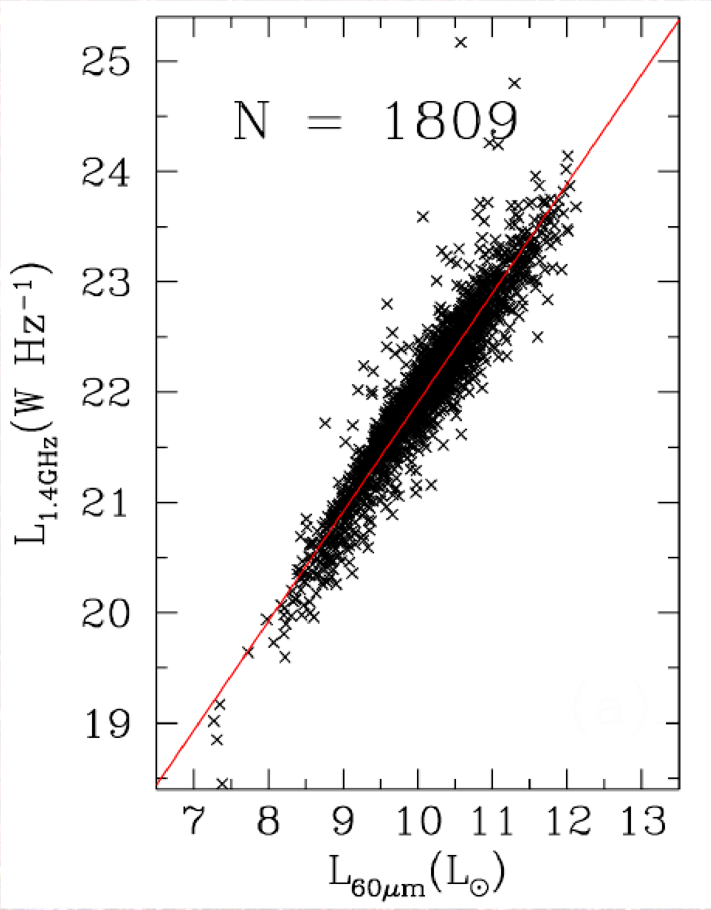
Outline:

Radio—FIR correlation.

Selection of “star-forming” galaxies.

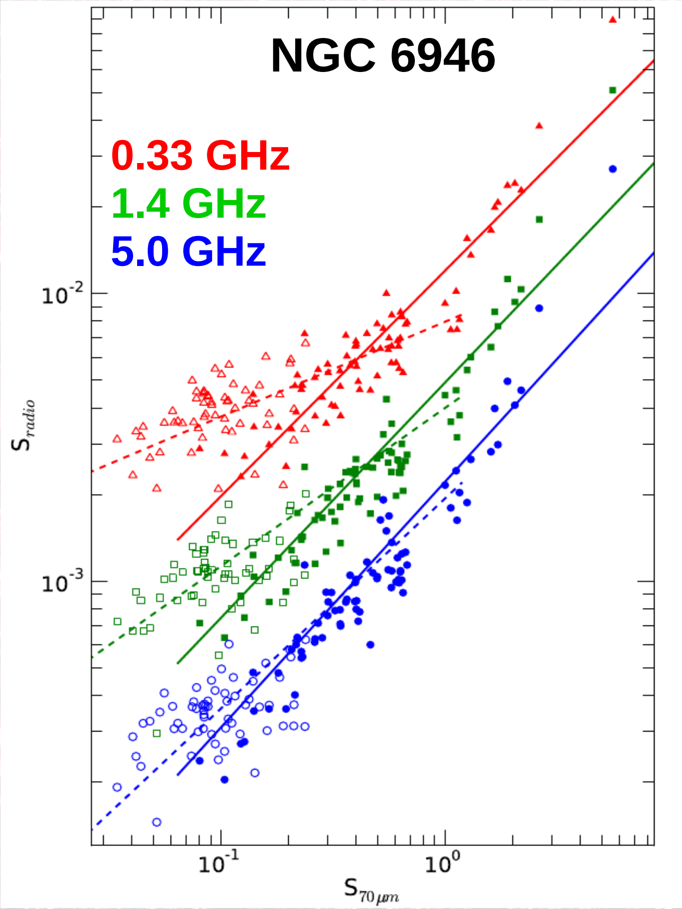
Radio—FIR correlation of μJy galaxy population.

Radio—FIR correlation:



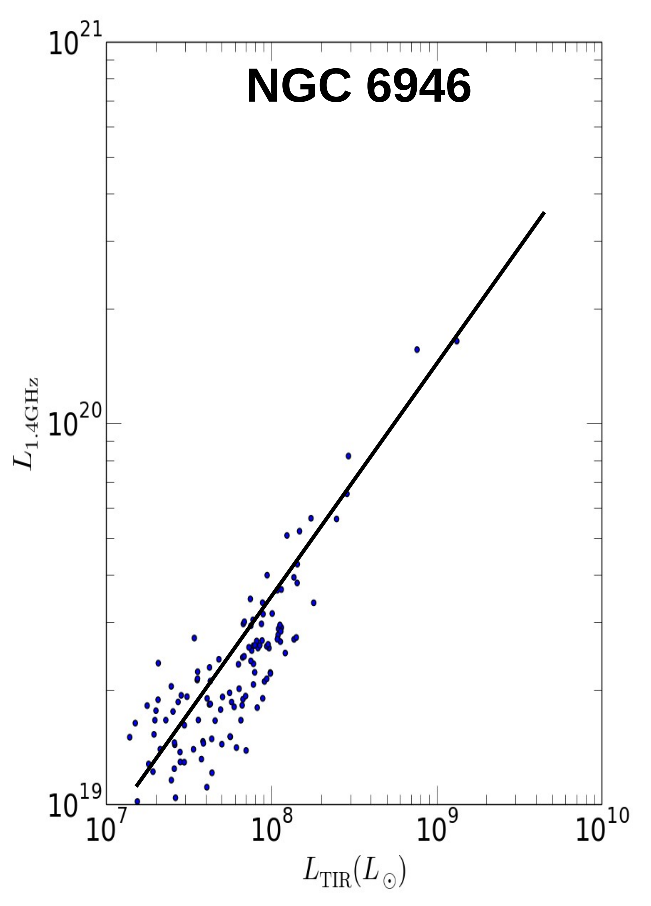
Yun et al. (2001)

At global scales.



Basu et al. (2012);
Basu & Roy (2014)

At ~100s pc



Tabatabaei et al. (2013)

At ~100s pc

Radio vs. Total IR

Connected by star—formation activity:

Star formation —> Heats dust —> IR emission

—> Supernova —> CRE + B —> Radio emission

Tightness requires:

$$B \propto \rho_{gas}^{\kappa} \quad \equiv \quad B \propto \Sigma_{SFR}^{a}$$

Schleicher & Beck (2013)

A direct consequence of turbulent amplification of magnetic field.

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A direct consequence of turbulent amplification of magnetic field.

MHD simulations: Gent et al. (2013a,b); de Avillez et al. (2005); Cho & Vishniac (2000)

Observations: Tabatabaei et al. (2013); Basu & Roy (2014); Rodrigues et al. (2015); van Eck et al. (2015)

Parameters:

$$q = \log_{10}\left(\frac{L_{\mathrm{IR}}}{L_{\mathrm{radio}}}\right)$$

'q' parameter

$$L_{\mathrm{radio}} = a\; L_{\mathrm{IR}}^{b}$$

Slope 'b'

Studies based on 'q' and slope:

$$q \sim \frac{\rho_{\mathrm{dust}} Q(\lambda, a) B_{\lambda}(T_{\mathrm{dust}})}{n_{\mathrm{CRe}} B^{1+\alpha_{\mathrm{nt}}}}$$

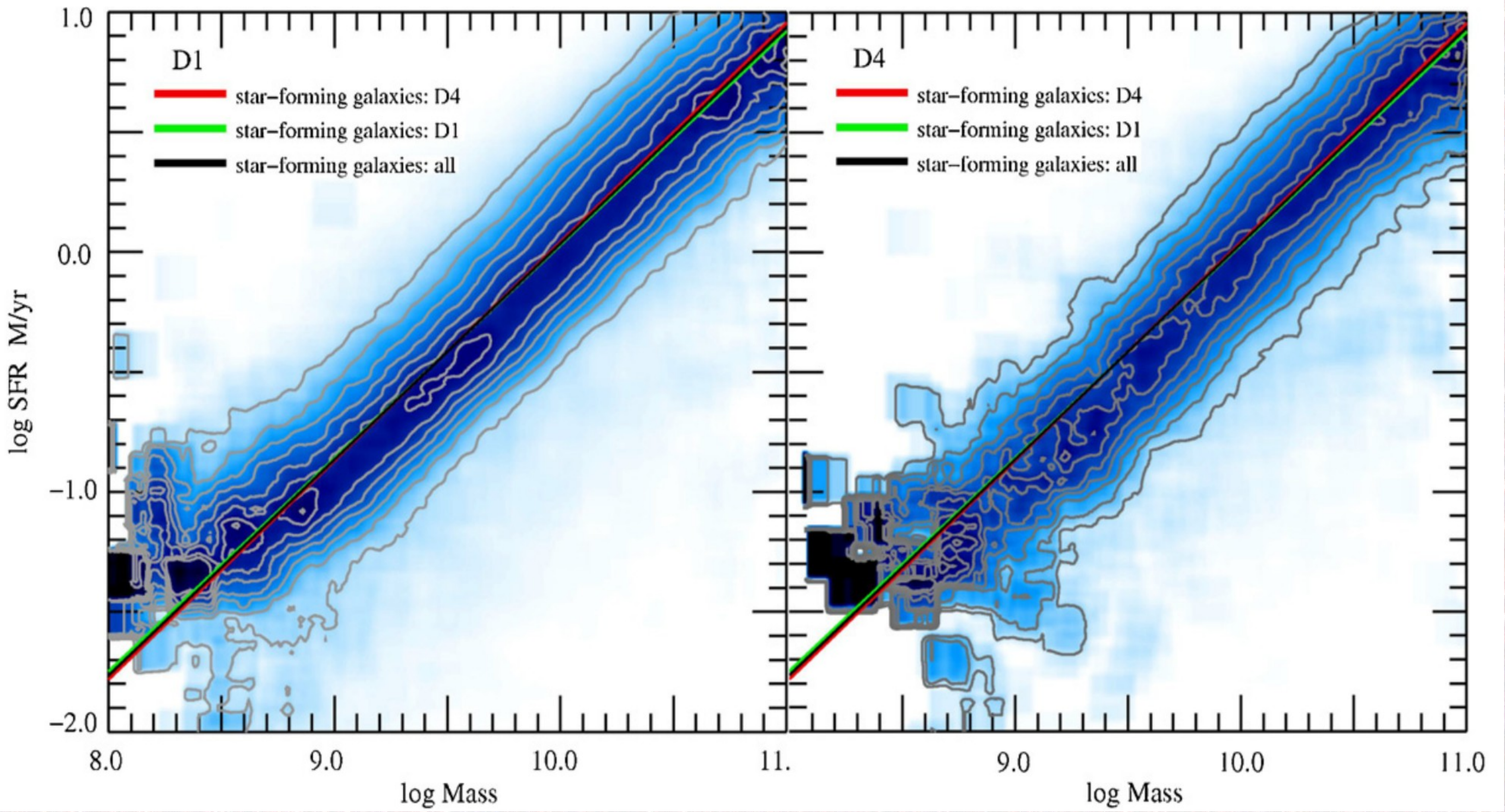
Requires “Controlled” sample selection.

Based on: Star-formation activity, stellar mass, etc.

$$b = \begin{cases} \dfrac{\kappa(3+\alpha)}{n}, & \text{optically thick dust} \\ \dfrac{\kappa(3+\alpha)}{n+1}, & \text{optically thin dust} \end{cases}$$

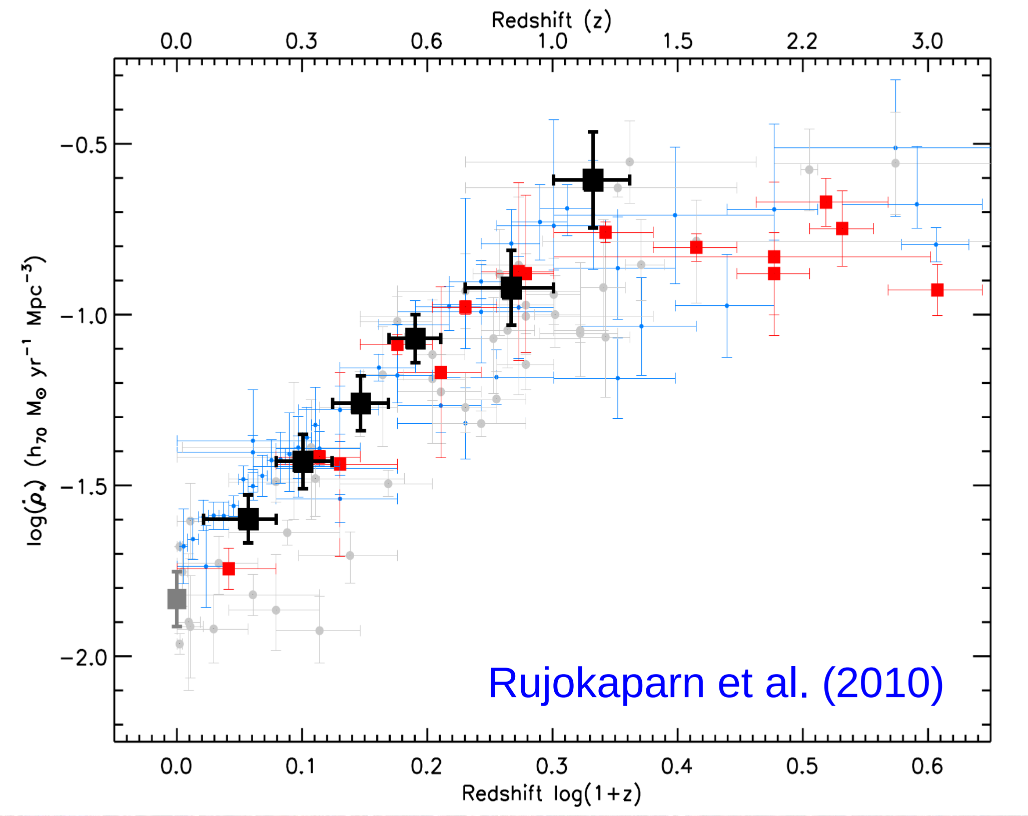
Depends on the coupling between the ISM parameters.

The Main sequence:

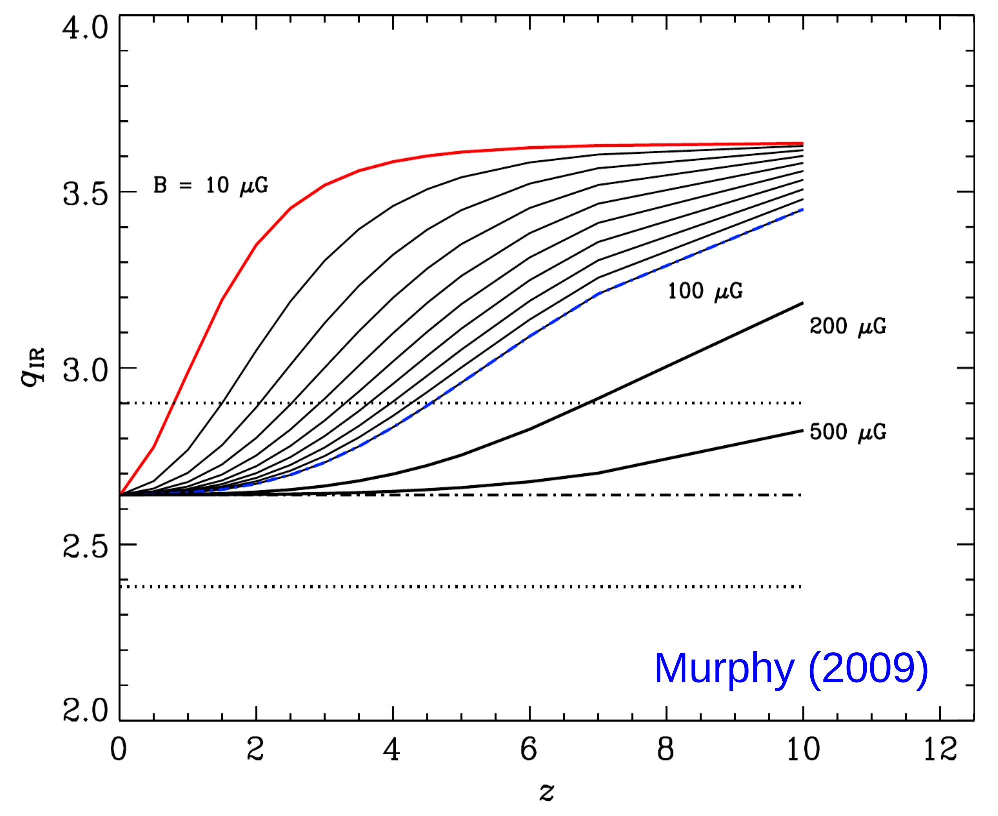


Peng et al. (2010)

Radio—FIR correlation at high-z:



Rujokaparn et al. (2010)



Murphy (2009)

"Peak of the action: star-formation"

$$z_c + 1 = \left(\frac{\Sigma_{\rm SFR}}{4.5 \times 10^{-3}\ M_\odot {\rm kpc}^{-2} {\rm yr}^{-1}} \right)^{1/(6-\epsilon/2)}$$

Schleicher & Beck (2013)

$B \sim 3.3\ (1 + z)^2\ \mu G$

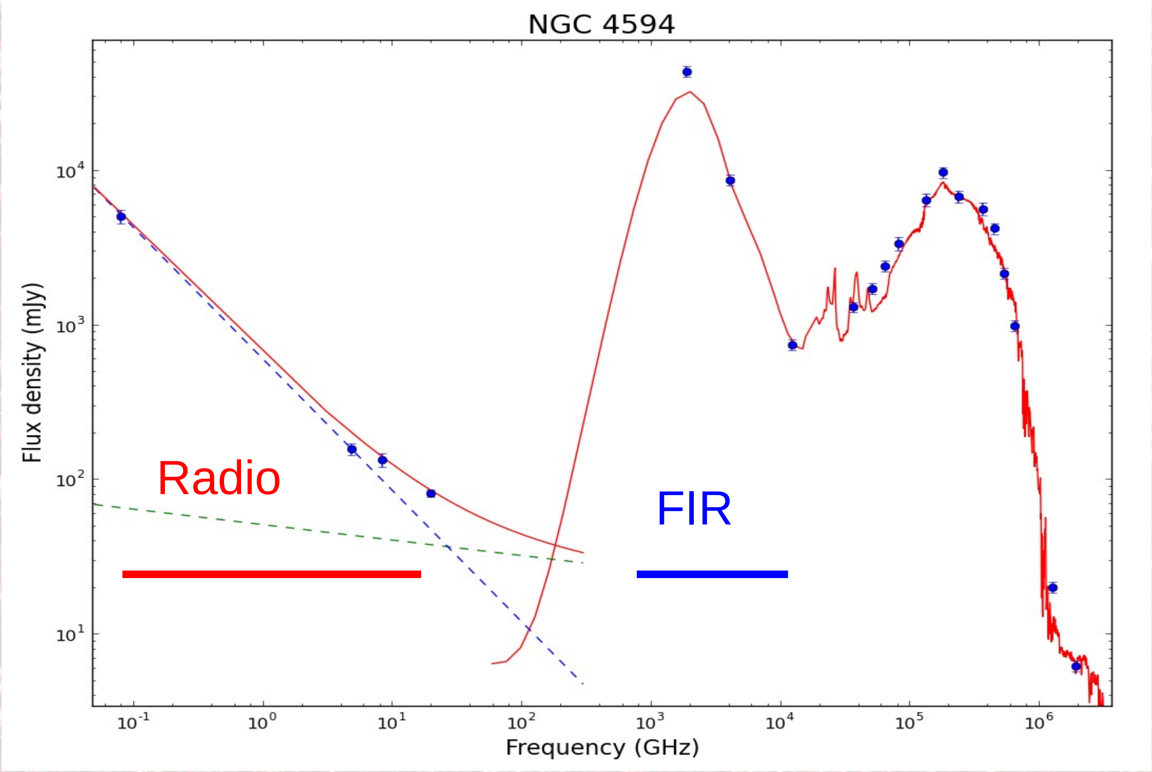
Radio—FIR correlation at high-z:

Robust spectroscopic survey of galaxies for $z > 0.5$ (identification)

Deep radio survey at low radio frequencies (nonthermal emission)

Deep Far-infrared survey (avoid PAH emission at high z)

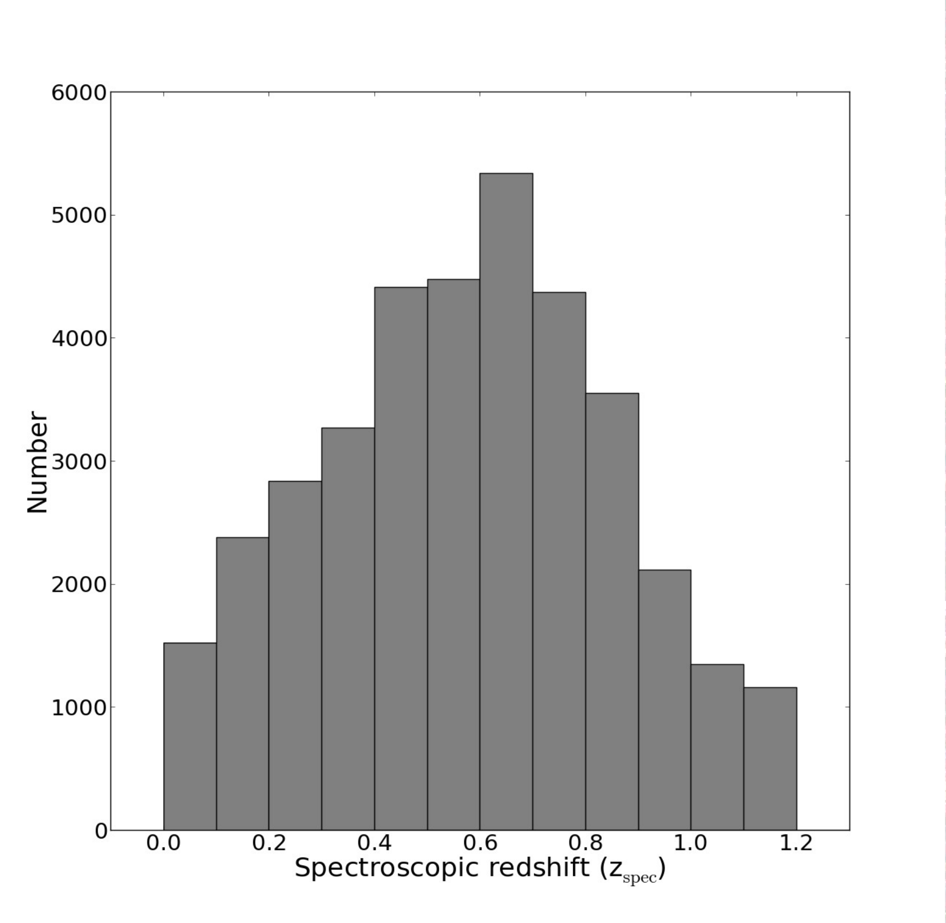
Synchrotron
+
Bremsstrahlung

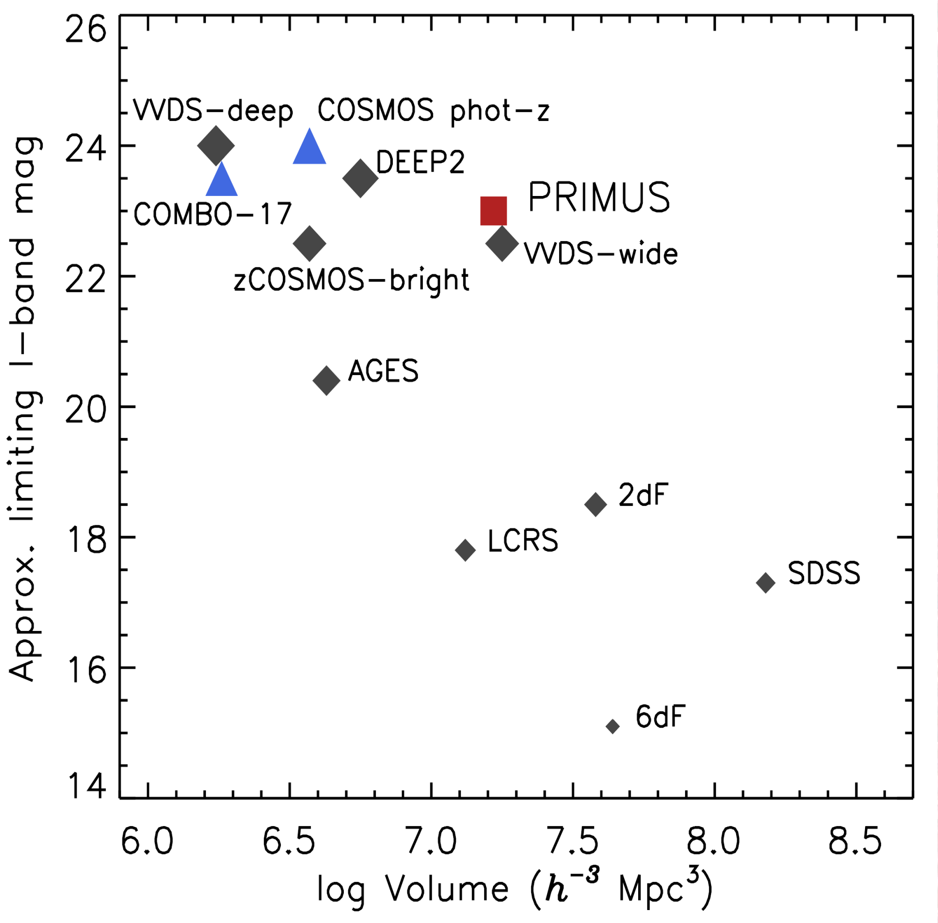


Sample of Normal Galaxies:

PRIMUS: PRIsm MUlti-object Survey

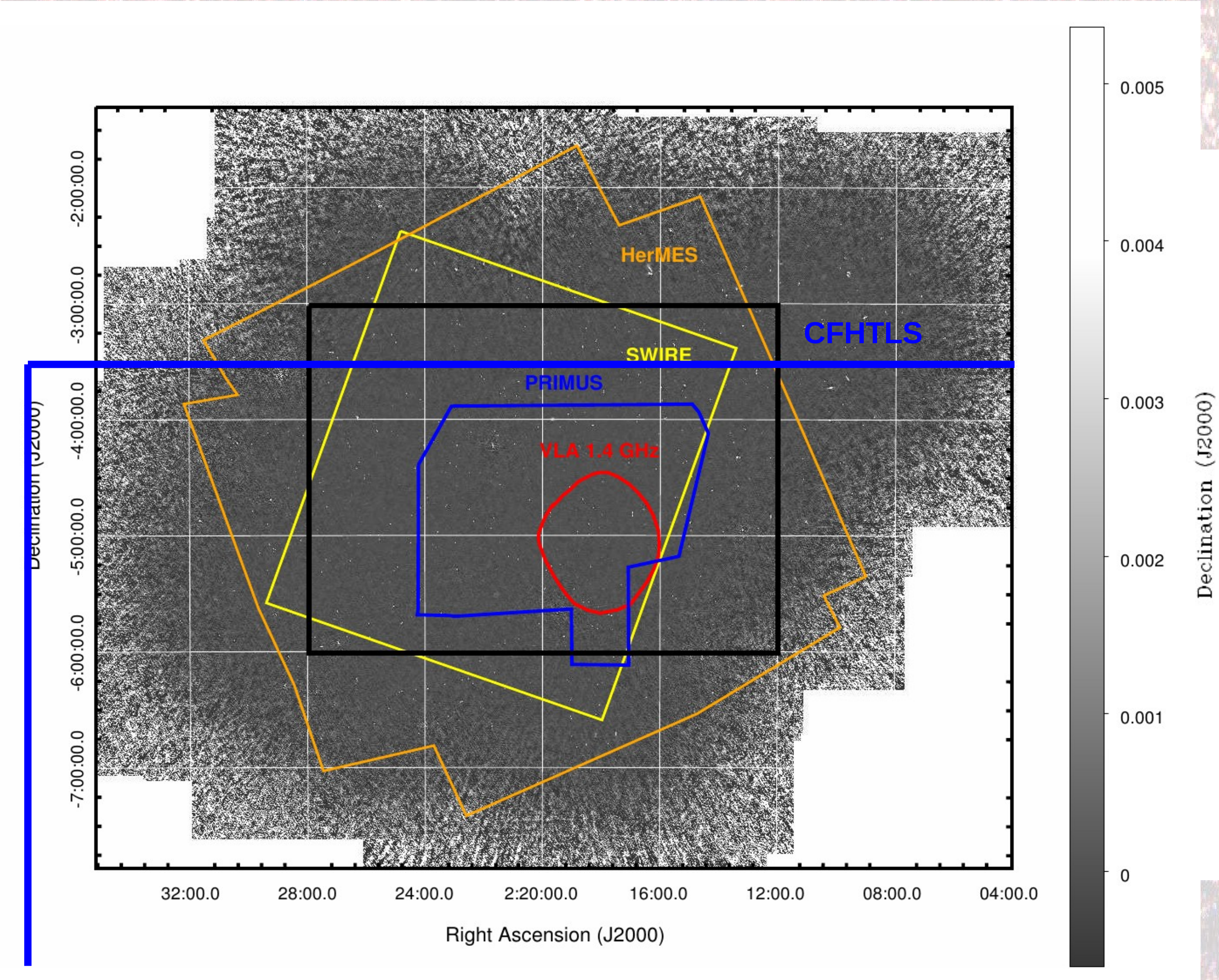
Coil et al., 2011, ApJ, 741, 8

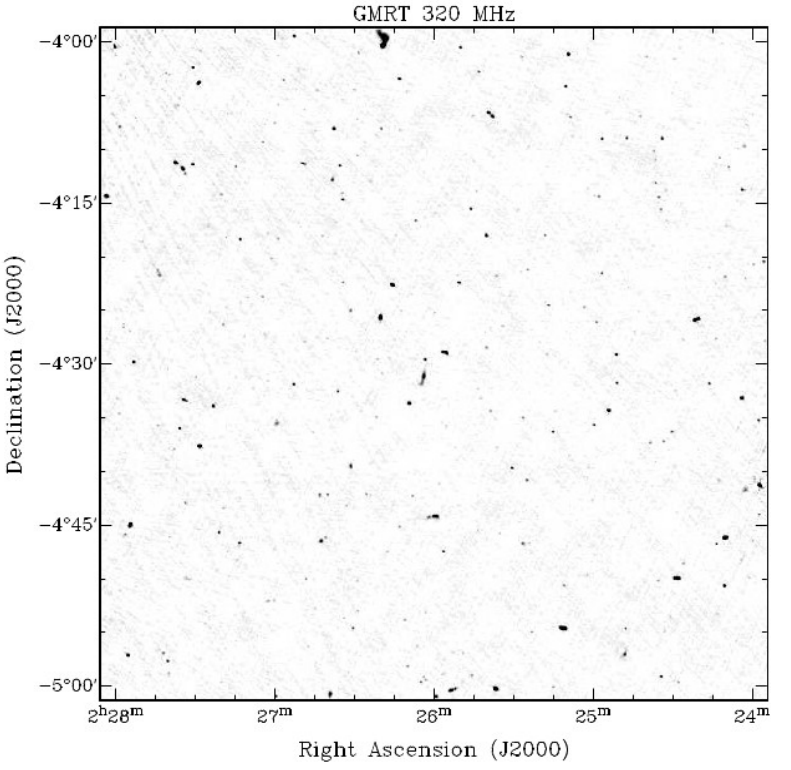




43000 robust galaxy spectra in the XMM-LSS field (2.88 sq. deg.)

GMRT 325 MHz: XMM-LSS field





Wadadekar, Sirothia, Basu, et al. (2015) *in prep.*

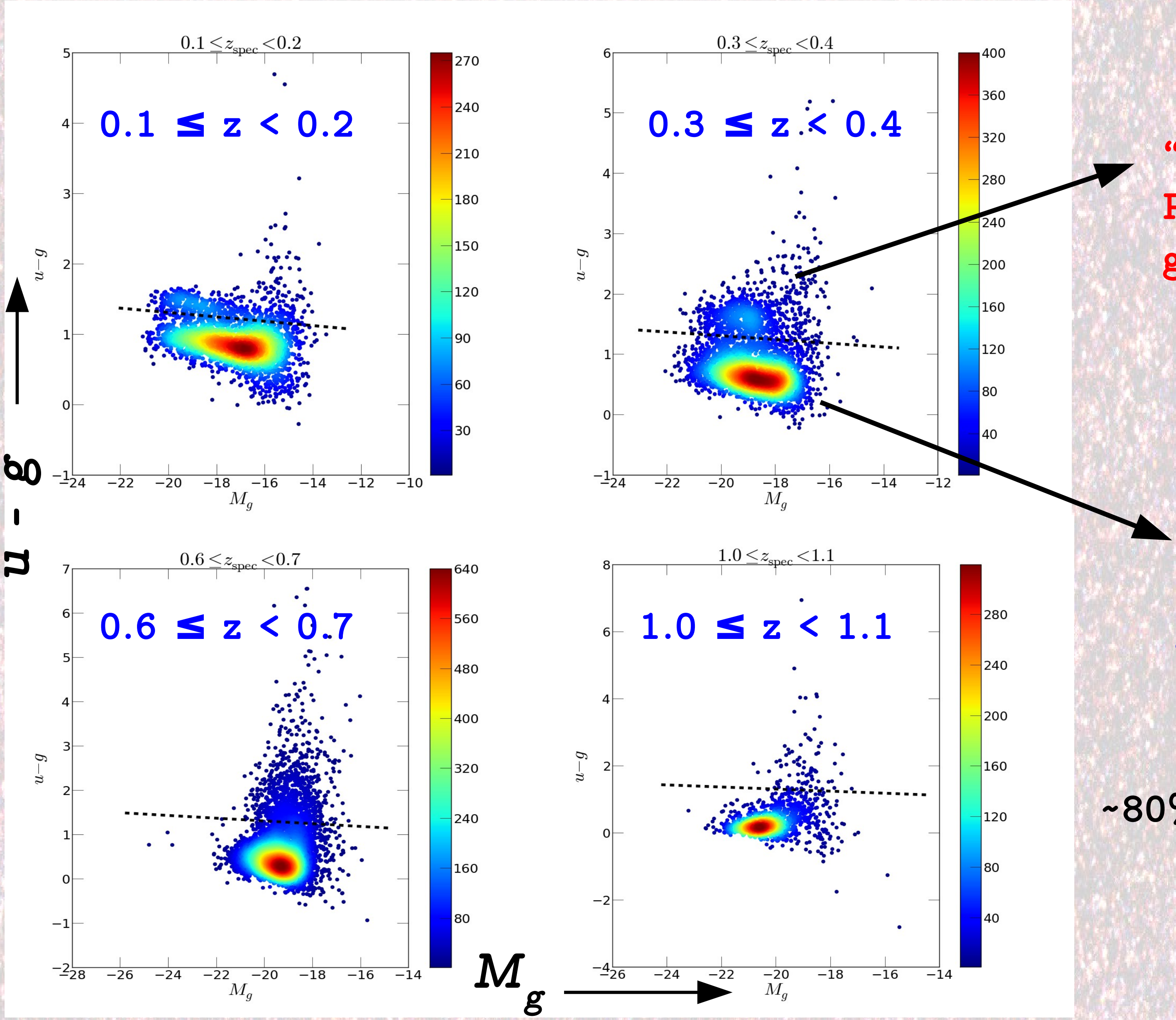
Area: ~ 12 sq. deg.

RMS noise ~ 150 μJy/beam

6σ completeness of 98% (3929 sources; 6649 above 3σ)

Resolution: 9.4 x 7.4 arcsec^2

“Blue cloud” and “red sequence”:



“Red”:
Passive star forming galaxies.

“Blue”:
Active star forming galaxies.

~80% galaxies are “blue”

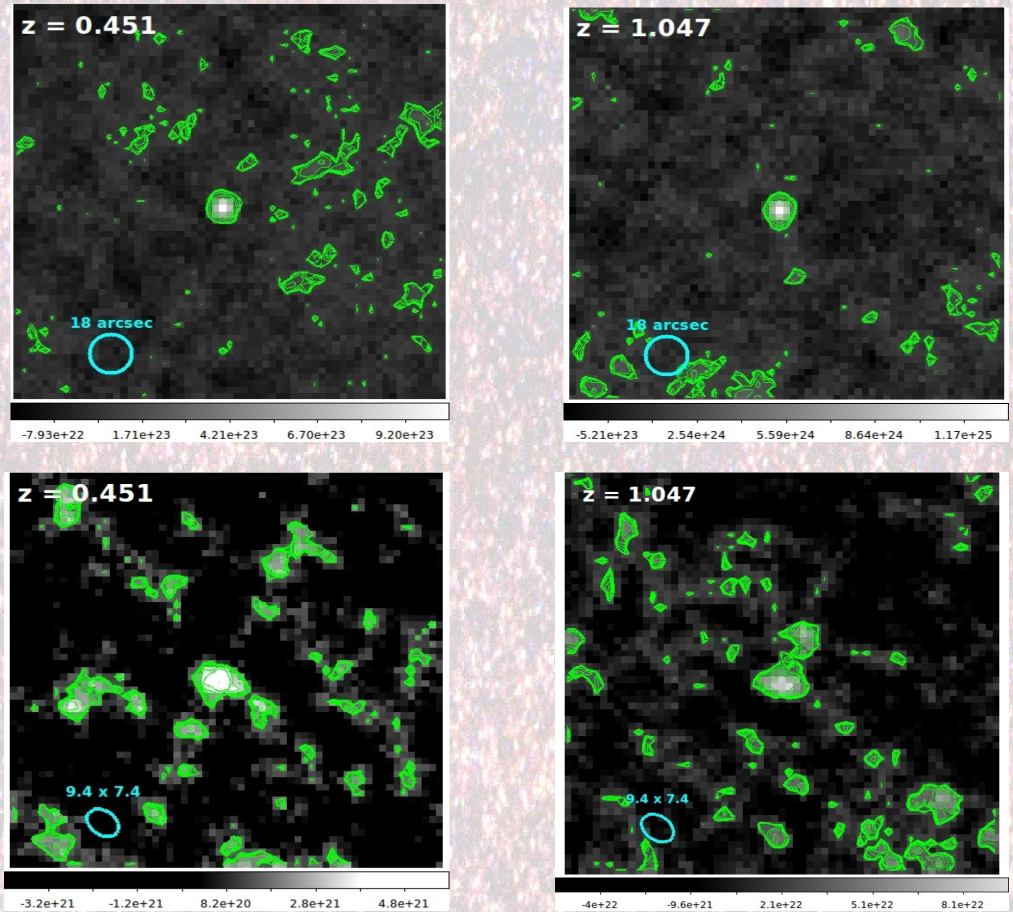
$$(u-g)_{\rm cut} = -0.031M_g - 0.065z + 0.695.$$

Skibba et al. (2014)

Mean stacking: Luminosity space

HerMES 250 µm

GMRT 325 MHz



~5—10 µJy rms at 325 MHz.

Galaxies are detected down to **~20 µJy at 325 MHz** with > 4σ significance.

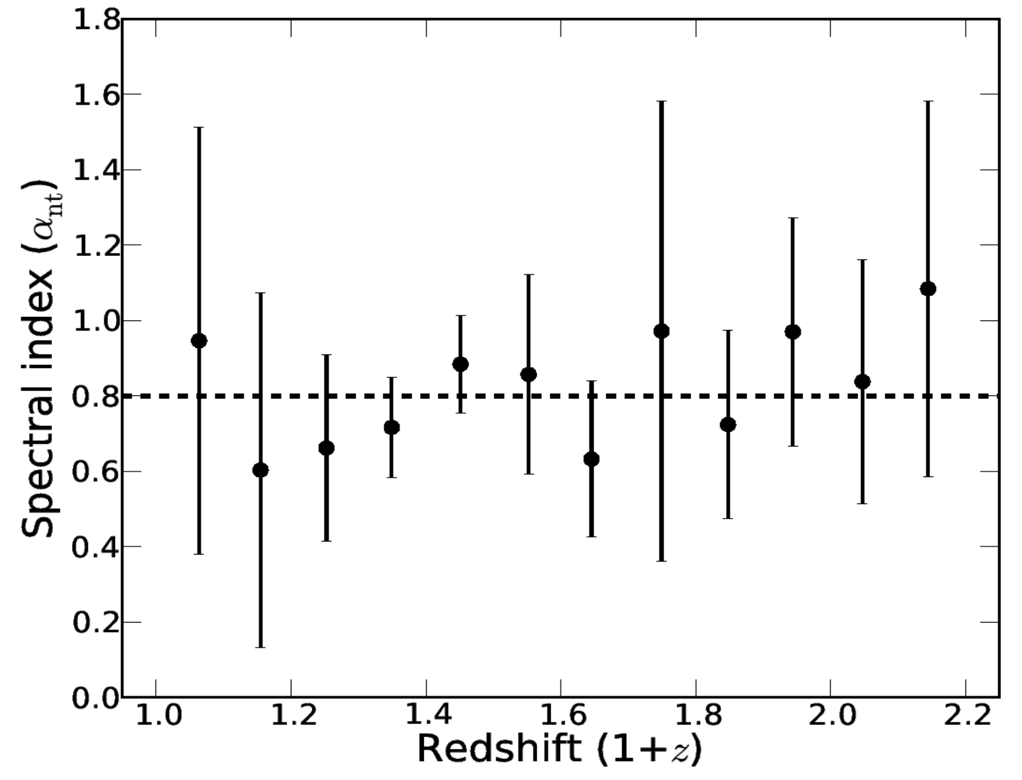
$L_{1.4GHz} \sim 10^{20}$—10^{23} W/Hz

SED fitting: k-correction

>95% of the emission at 325 MHz for nearby galaxies is nonthermal in origin.

Basu et al. (2012a)

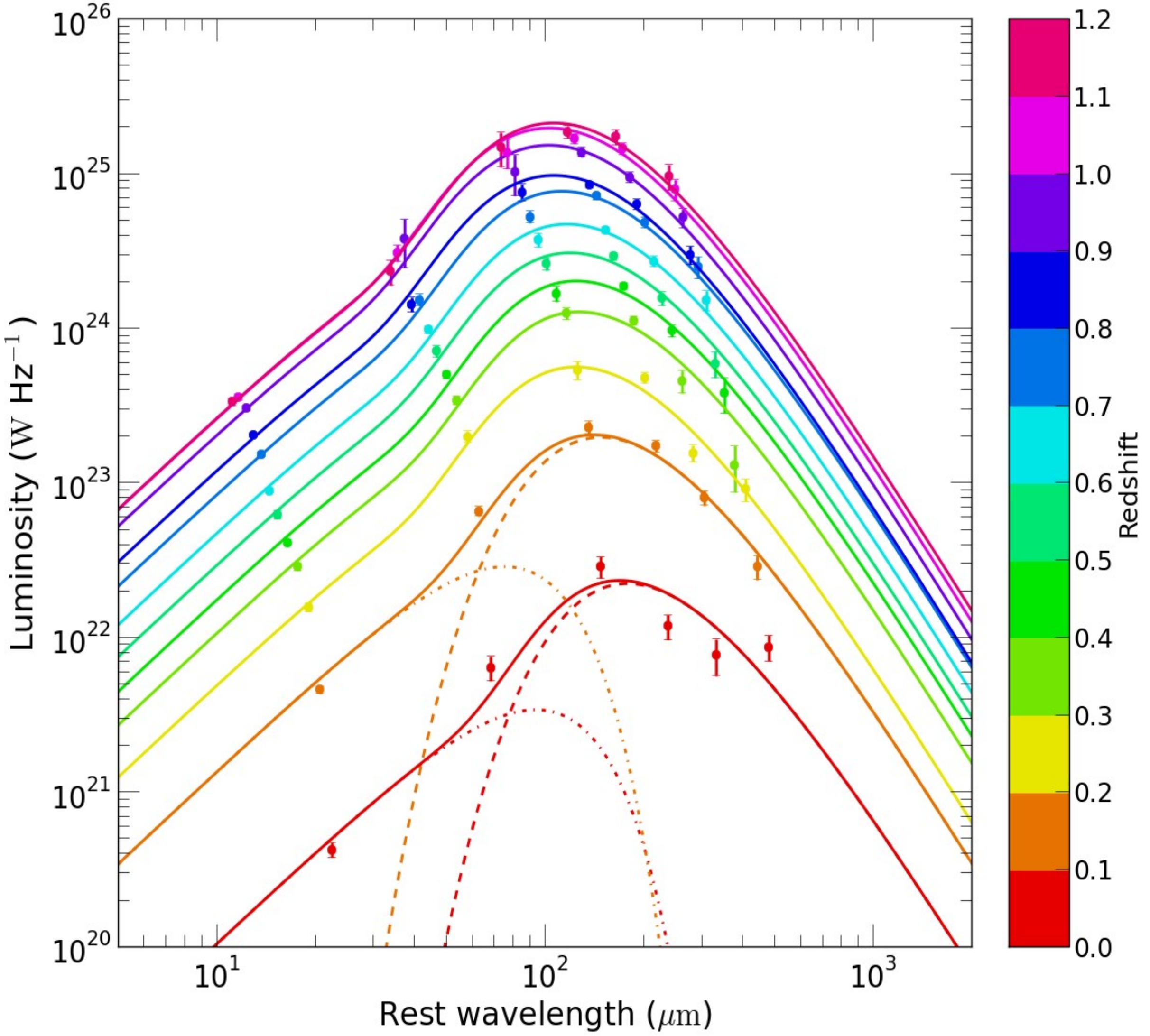
k-corrected the 325 MHz luminosity to 1.4 GHz rest frequency using α = 0.8.



Stacked SED fits:

$$S(\lambda) = A_{\mathrm{PL}} \left(\frac{\lambda}{\lambda_{\mathrm{c}}}\right)^{\alpha} e^{-(\lambda/\lambda_{\mathrm{c}})^2} + A_{\mathrm{GB}} \frac{(1 - e^{-\tau_\lambda})\lambda^{-3}}{(e^{hc/\lambda kT} - 1)}$$

Casey (2012)



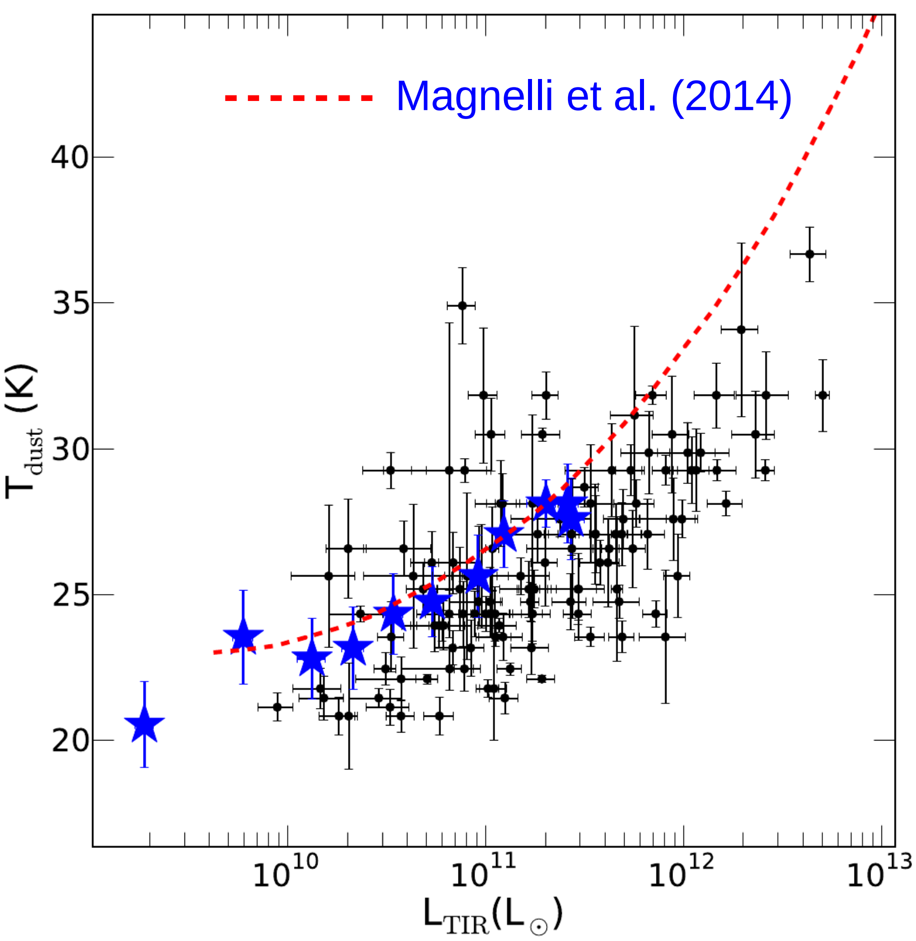
$T_{\mathrm{dust}} = b/\lambda_{\mathrm{peak}}$

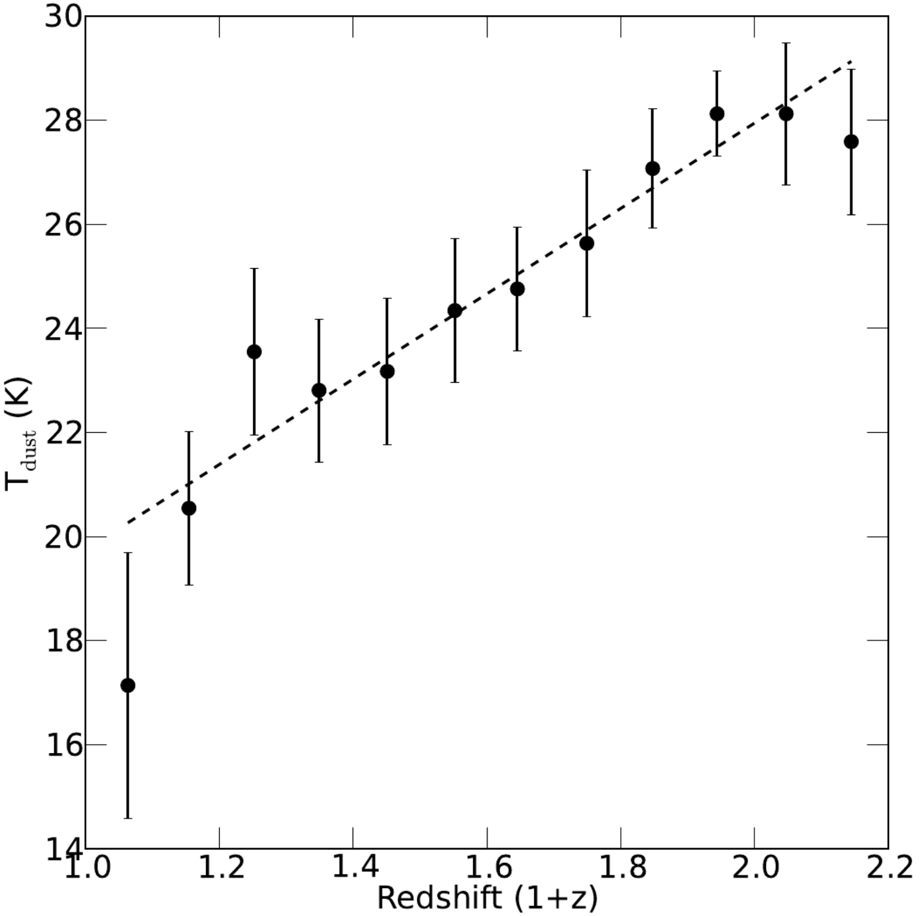
T_{dust} ~ 18—30 K

$\beta = 1.5$ (~1.2—2.5)

Sadavoy et al. (2013);
Smith et al. (2013).

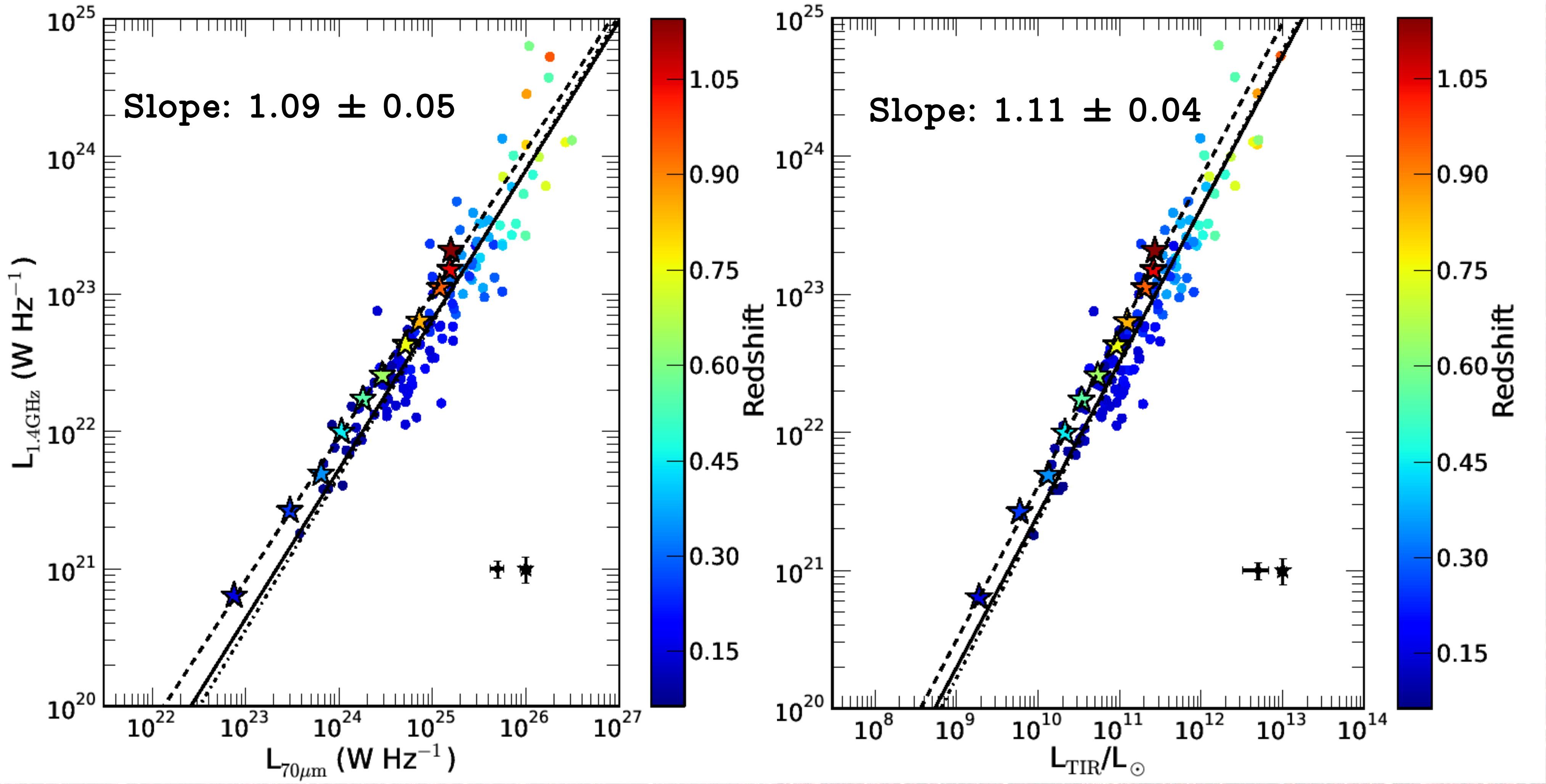
Variation of dust temperature:





$$T_{dust} = (8.2 \pm 0.9)\ (1+z) + (11.5 \pm 1.5)$$

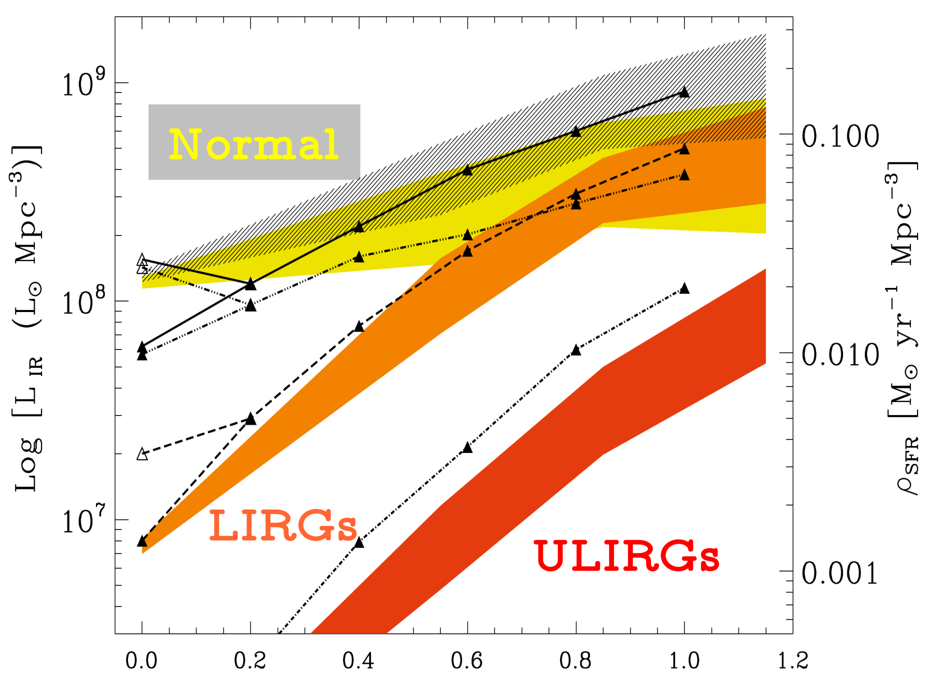
Radio—FIR correlation:



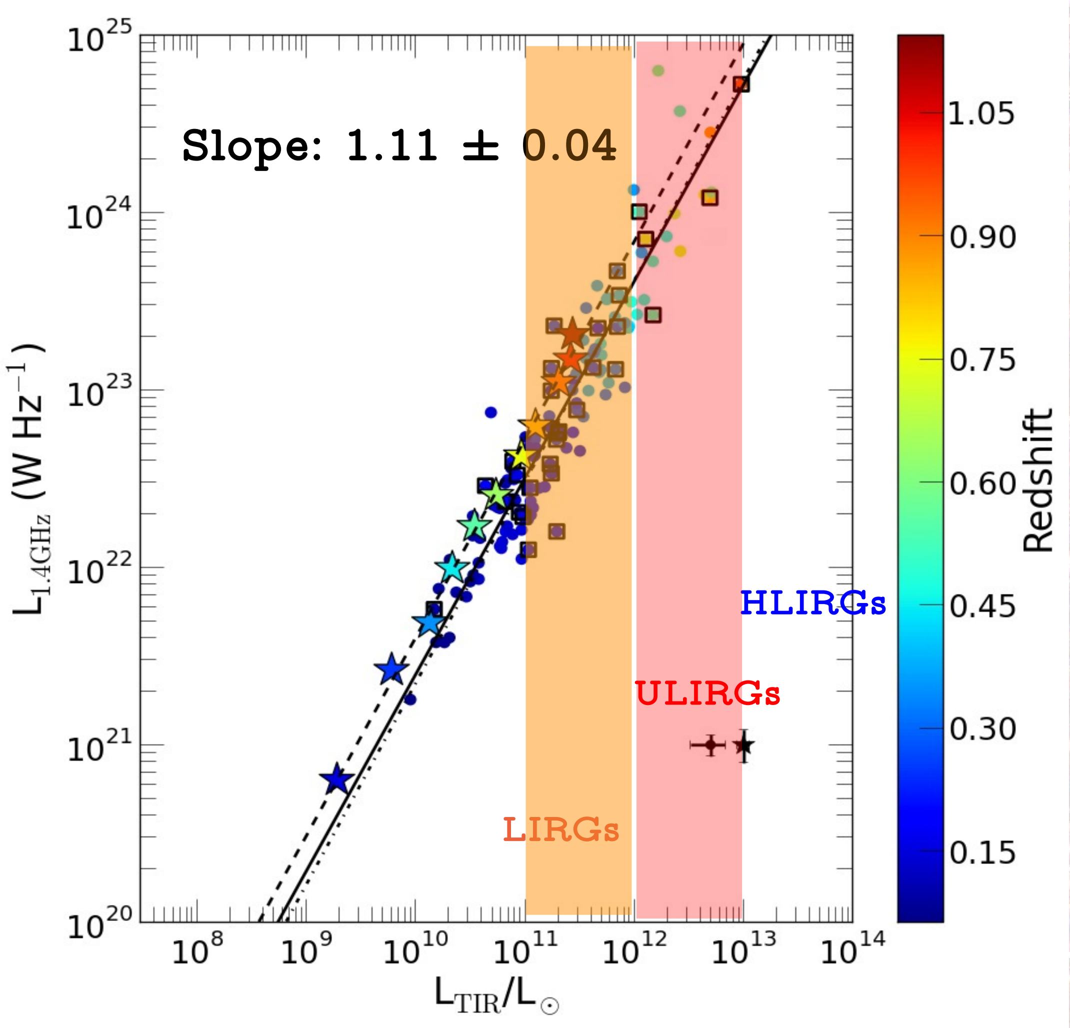
Monochromatic

Bolometric (8—1000 μm)

Radio—FIR correlation:

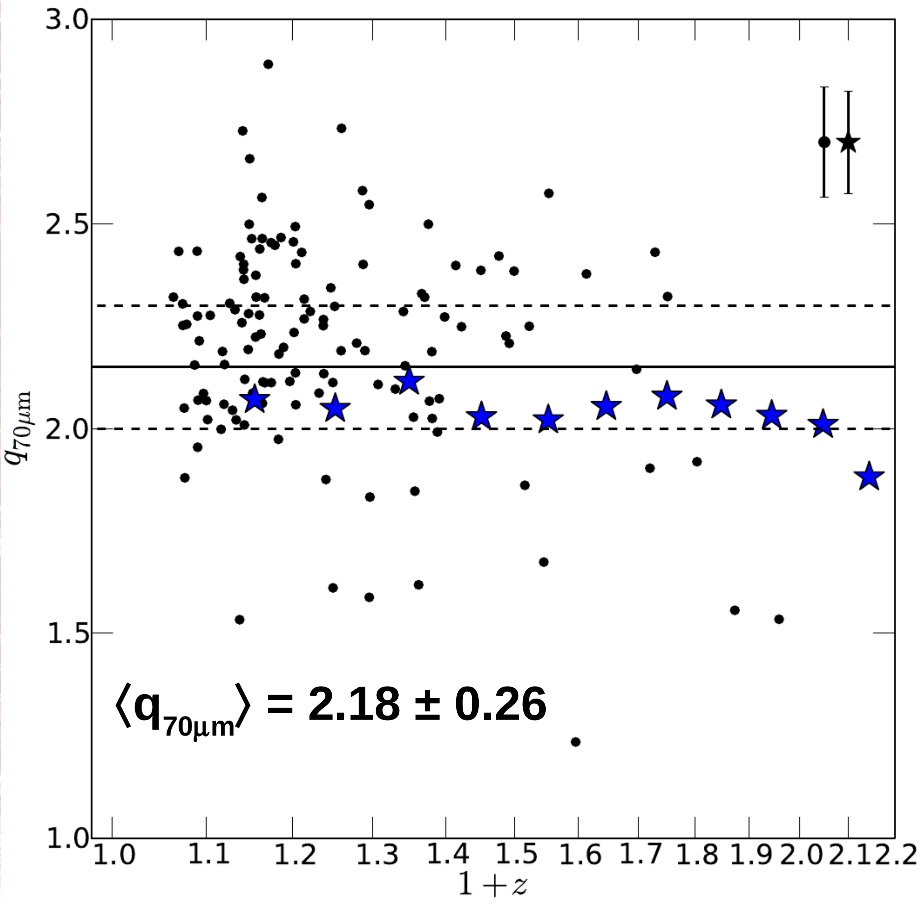


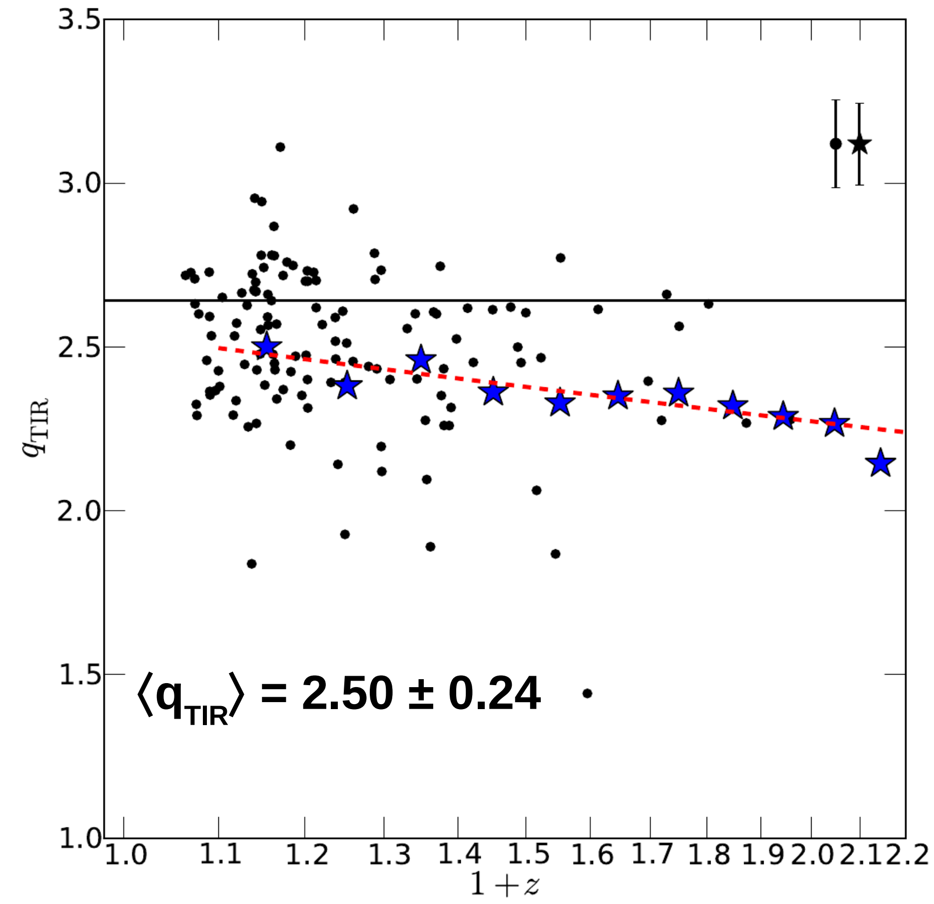
Magnelli et al. (2009)



Bolometric (8—1000 μm)

Variation of 'q':





$q_{70\mu m} = \log_{10}(L_{70\mu m}/L_{1.4GHz})$

$q_{TIR} = \log_{10}[L_{TIR}/(3.75x10^{12}L_{1.4GHz})]$

$q_{TIR} = (2.53 \pm 0.04)(1 + z)^{-0.16 \pm 0.03}$

also by Ivison et al. (2010); Bourne et al. (2011); Magnelli et al. (2012, 2014)

Is ‘q’ an indicator of evolution of the correlation?

$$q \sim \frac{\rho_{\rm dust} Q(\lambda, a) B_\lambda(T_{\rm dust})}{n_{\rm CRe} B^{1+\alpha_{\rm nt}}}$$

$\rho_{dust} \equiv \rho_{dust}(z)$: Star-formation

$T_{dust} \equiv T_{dust}(z)$: Galaxy population

$B \equiv B(z)$: Turbulent amplification

$n_{CRe} \equiv n_{CRe}(z)$: Starburst/SN timelag + Energy losses

$\alpha_{nt} \equiv \alpha_{nt}(z)$: Energy losses

$Q(\lambda,a) \sim (\lambda/\lambda_0)^\beta \equiv f(z)$: SED evolution

Highly degenerate!!!

Requires “Controlled” sample selection.

Is ‘q’ an indicator of evolution of the correlation?

$$L_{1.4\mathrm{GHz}} = aL_{\mathrm{IR}}^{b}$$

$$q = -\left(\frac{1}{b}\right)\log_{10} a + \left(\frac{1-b}{b}\right)\log_{10} L_{1.4\mathrm{GHz}}$$

‘*q*’ is constant only if b=1

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$$\Delta q_{\mathrm{TIR}} = \left(\frac{1-b}{b}\right)\log_{10}\left(\frac{L_{1.4\mathrm{GHz}}\,|_{z=1}}{L_{1.4\mathrm{GHz}}\,|_{z=0}}\right)$$

Δq = -0.27 for b=1.1

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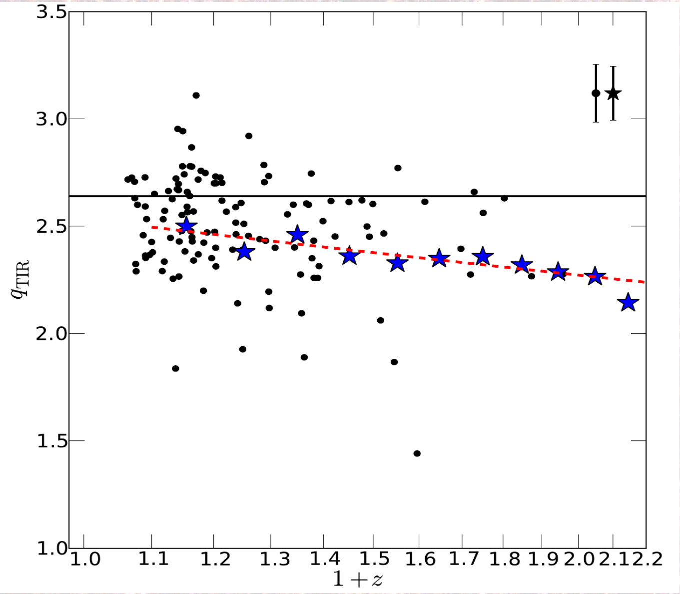

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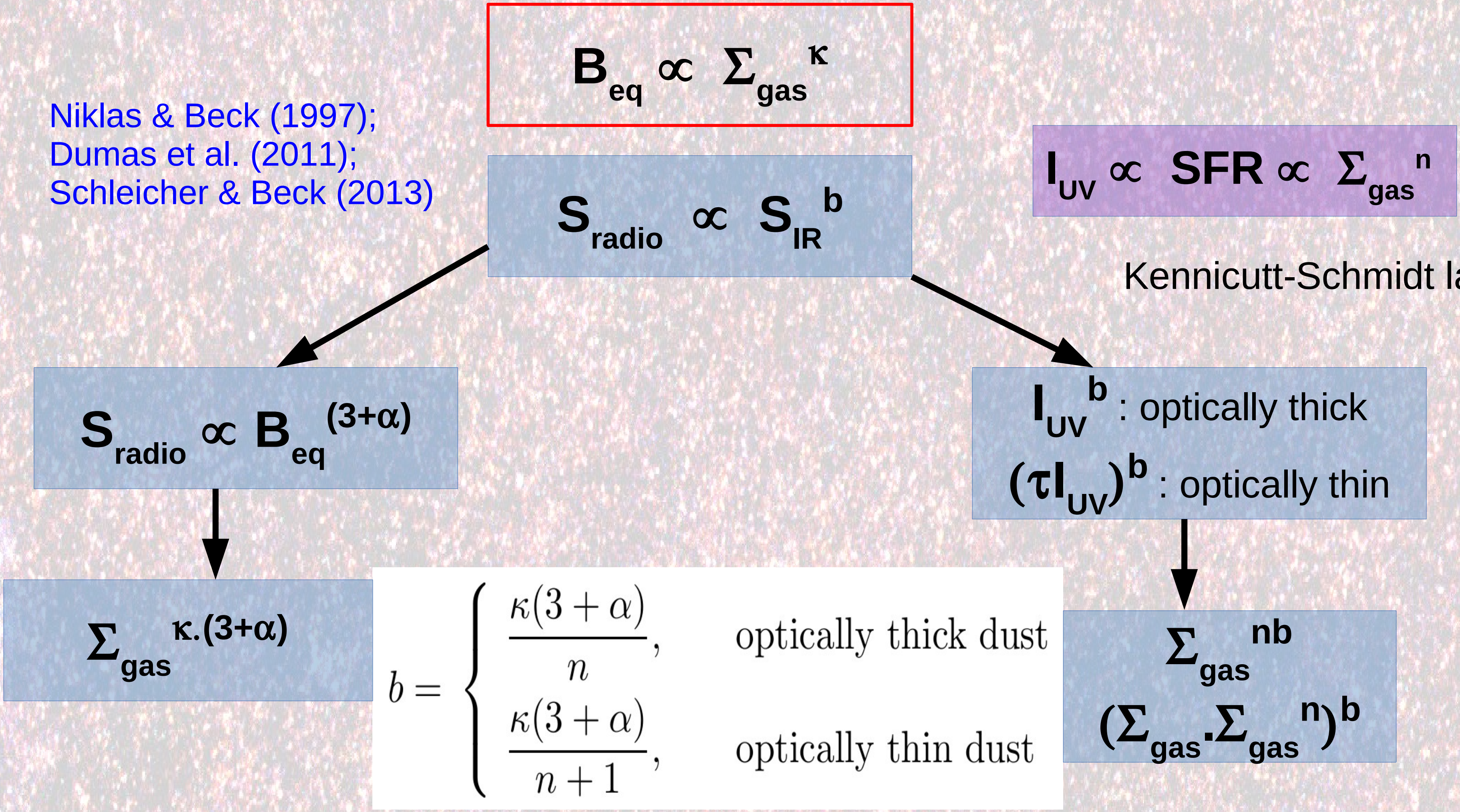
$\Delta q = -0.27$ for $b=1.1$

(Also reported by Bell 2003; Niklas & Beck, 1997; Price & Duric, 1992)

$q_{\mathrm{TIR}} = (2.53 \pm 0.04)(1 + z)^{-0.16 \pm 0.03}$

$\Delta q = -0.26$

Connection to ISM parameters:



Niklas & Beck (1997);
Dumas et al. (2011);
Schleicher & Beck (2013)

$B_{eq} \propto \Sigma_{gas}^{\kappa}$

$S_{radio} \propto S_{IR}^{b}$

$I_{UV} \propto \text{SFR} \propto \Sigma_{gas}^{n}$

Kennicutt-Schmidt law

$S_{radio} \propto B_{eq}^{(3+\alpha)}$

I_{UV}^{b} : optically thick

$(\tau I_{UV})^{b}$: optically thin

$\Sigma_{gas}^{\kappa.(3+\alpha)}$

$$b = \begin{cases} \dfrac{\kappa(3+\alpha)}{n}, & \text{optically thick dust} \\ \dfrac{\kappa(3+\alpha)}{n+1}, & \text{optically thin dust} \end{cases}$$

Σ_{gas}^{nb}

$(\Sigma_{gas}.\Sigma_{gas}^{n})^{b}$

'b', NOT 'q', connects the various ISM parameters in understanding the radio—FIR correlation

Summary:

We probed the statistical properties of "normal star-forming" galaxies up to z=1.2 (about 10—100 times fainter).

The slope of the radio—FIR correlation is found to be significantly non-linear and is steeper than unity.

The correlation is found to hold with similar parameters (slope and 'q') for normal star-forming galaxies and (U)LIRGs.

The 'q' parameter should be used cautiously to study the evolution of the radio—FIR correlation.

We do not find any evolution of the radio—FIR correlation with redshift !!!

Basu, Wadadekar, Beelen, Singh, Archana, Sirothia, Ishwara-Chandra, 2015, ApJ, 803, 51
[arXiv:1502.00330]