# SKA and Galaxy Formation - Evolution

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*Work based on collabs with*
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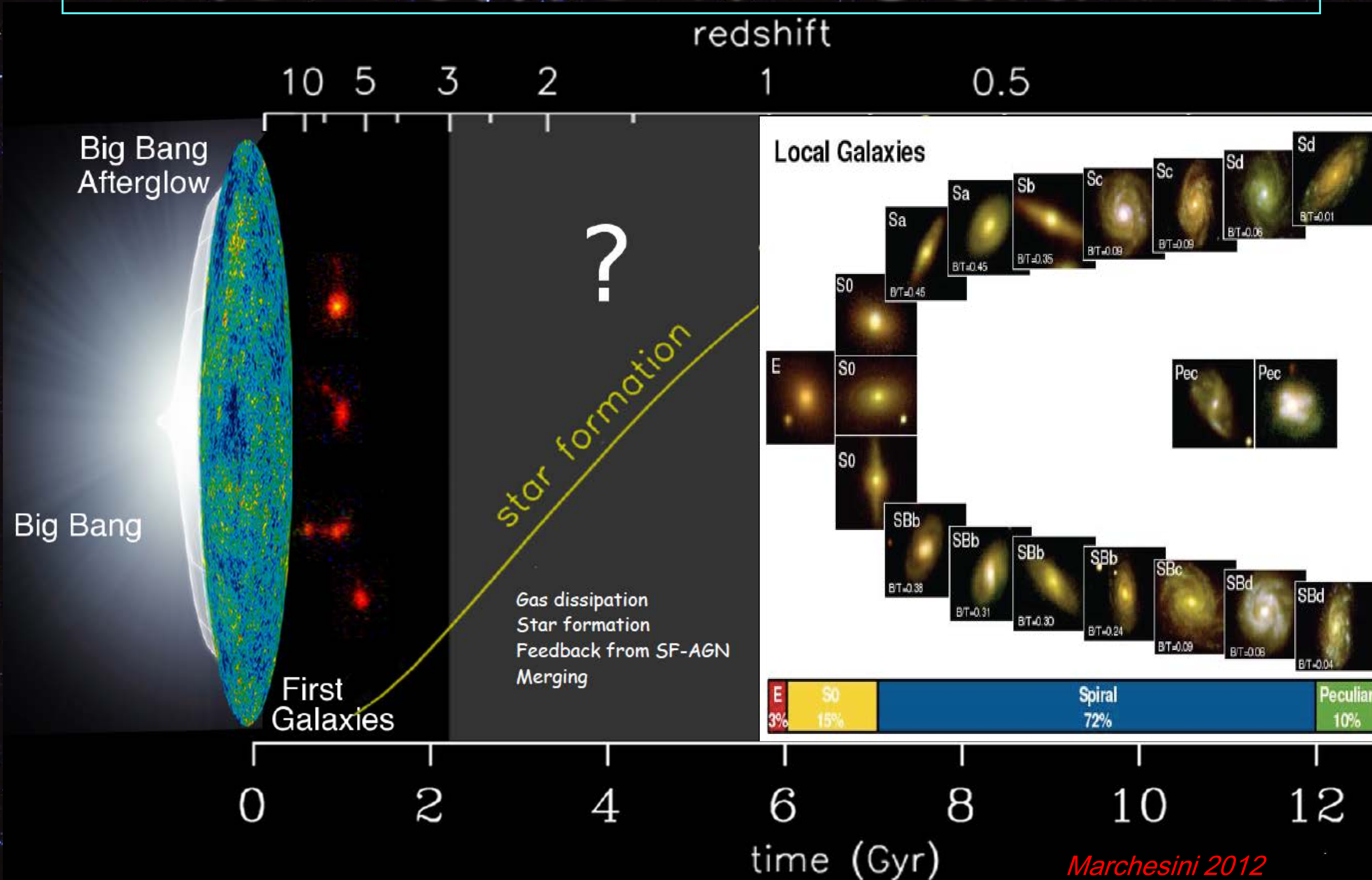
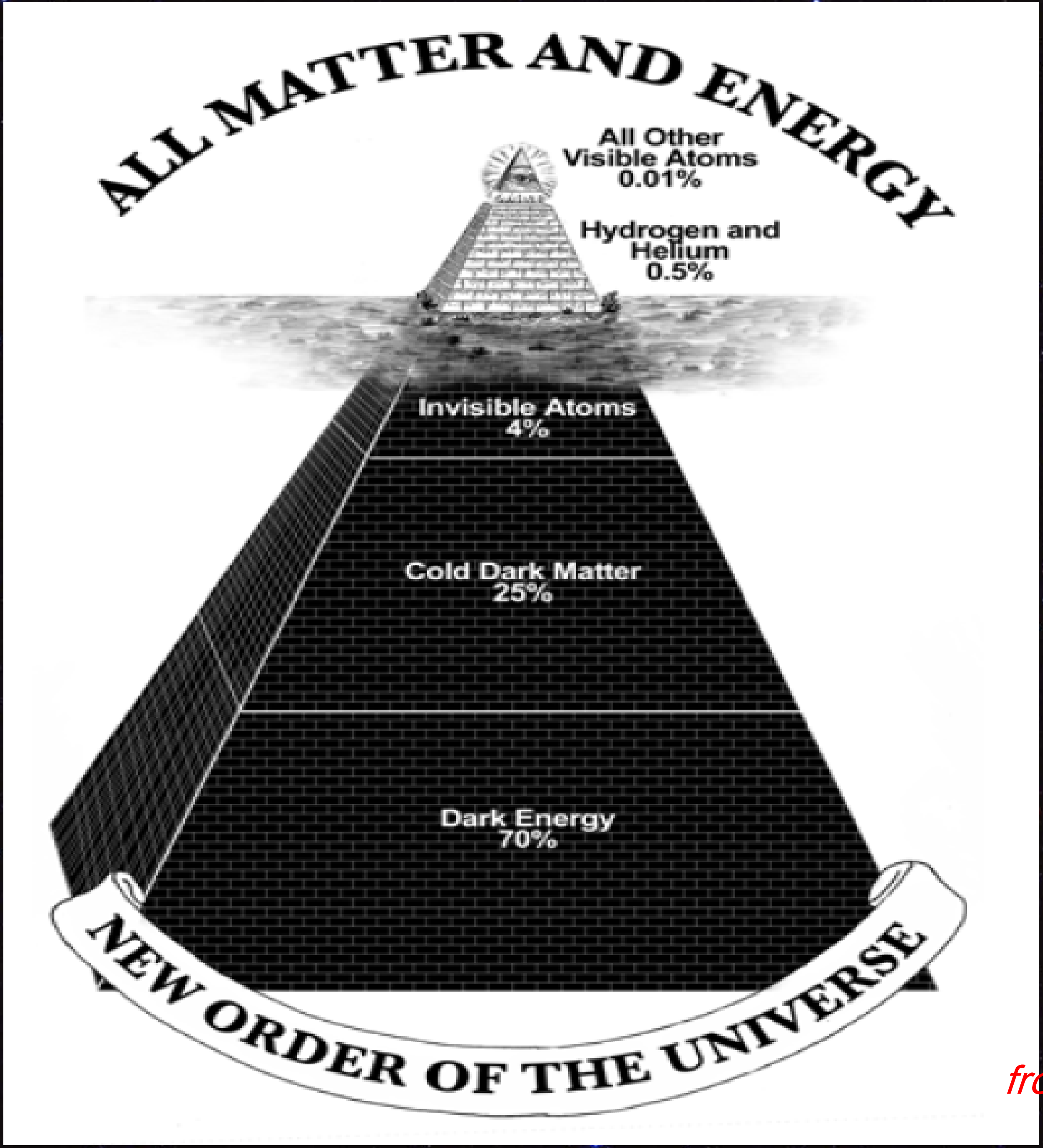
# Overview

- General Intro, baryons in the Universe, main components
- The current scenario for Galaxy Formation and Evolution, the hierarchical clustering scheme, SAM modelling
- Some recent important developments in the field, the Herschel mission looking into the last uncharted e.m. window
- Selected Herschel's results, role of dust extinction
- Source characterization, relation with radio obs.
- Conclusions from present: the more we learn about gal.form., the less we understand it !!
- Future prospects for a new era with SKA
- Relationship with ongoing projects in the SKA era:
  - JWST, ALMA, ELT

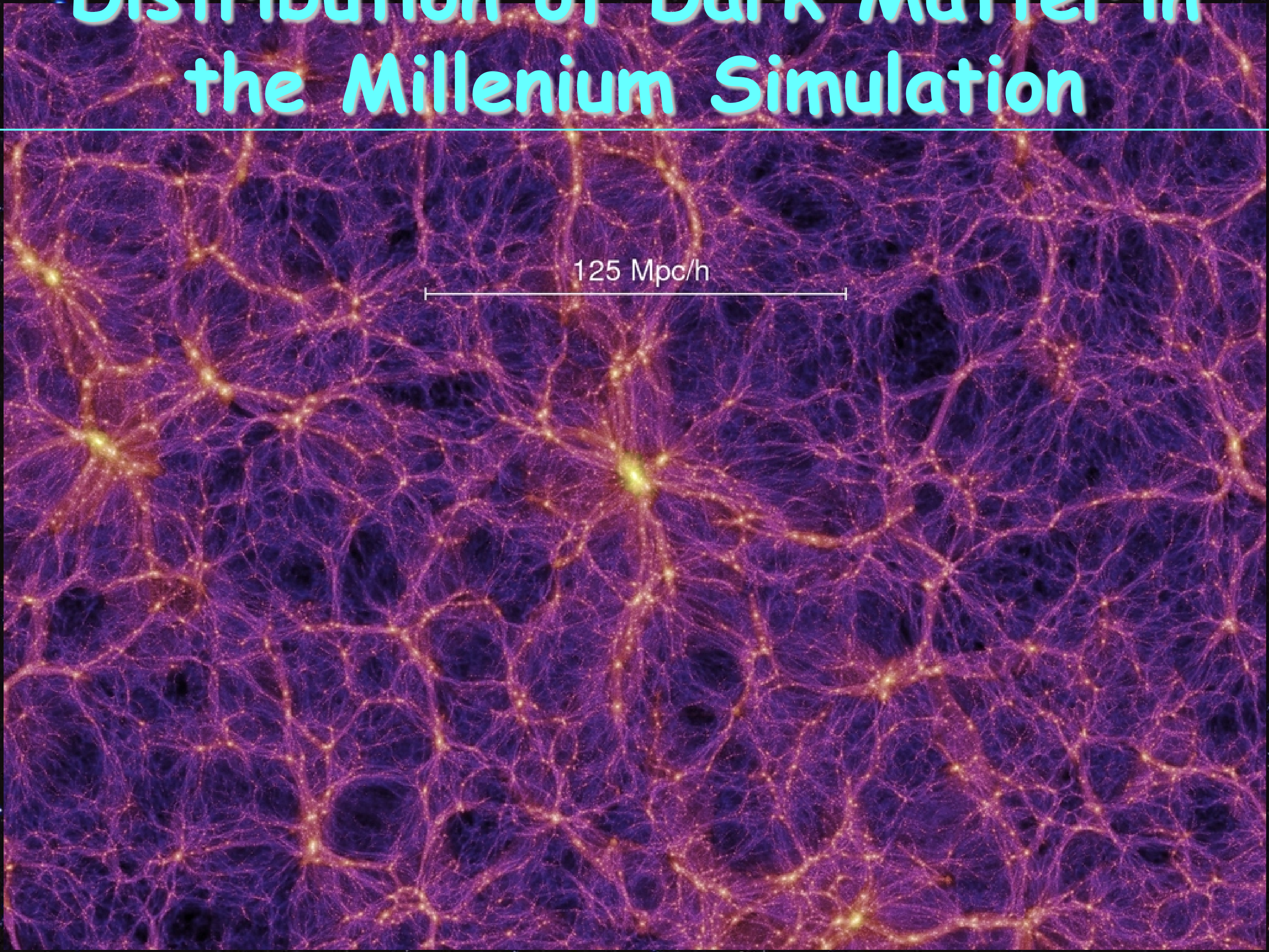
# The Context: Galaxies

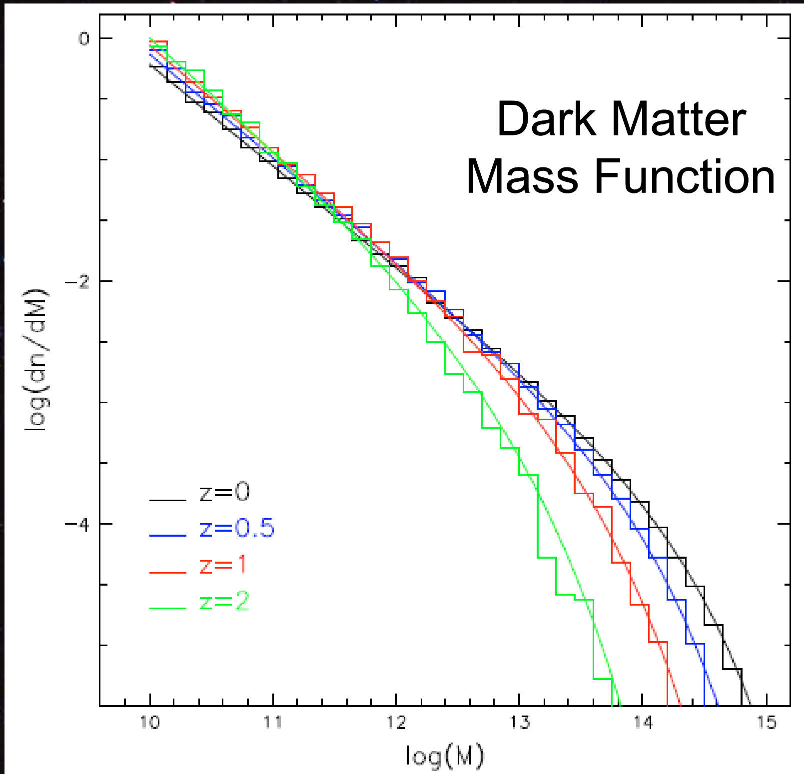




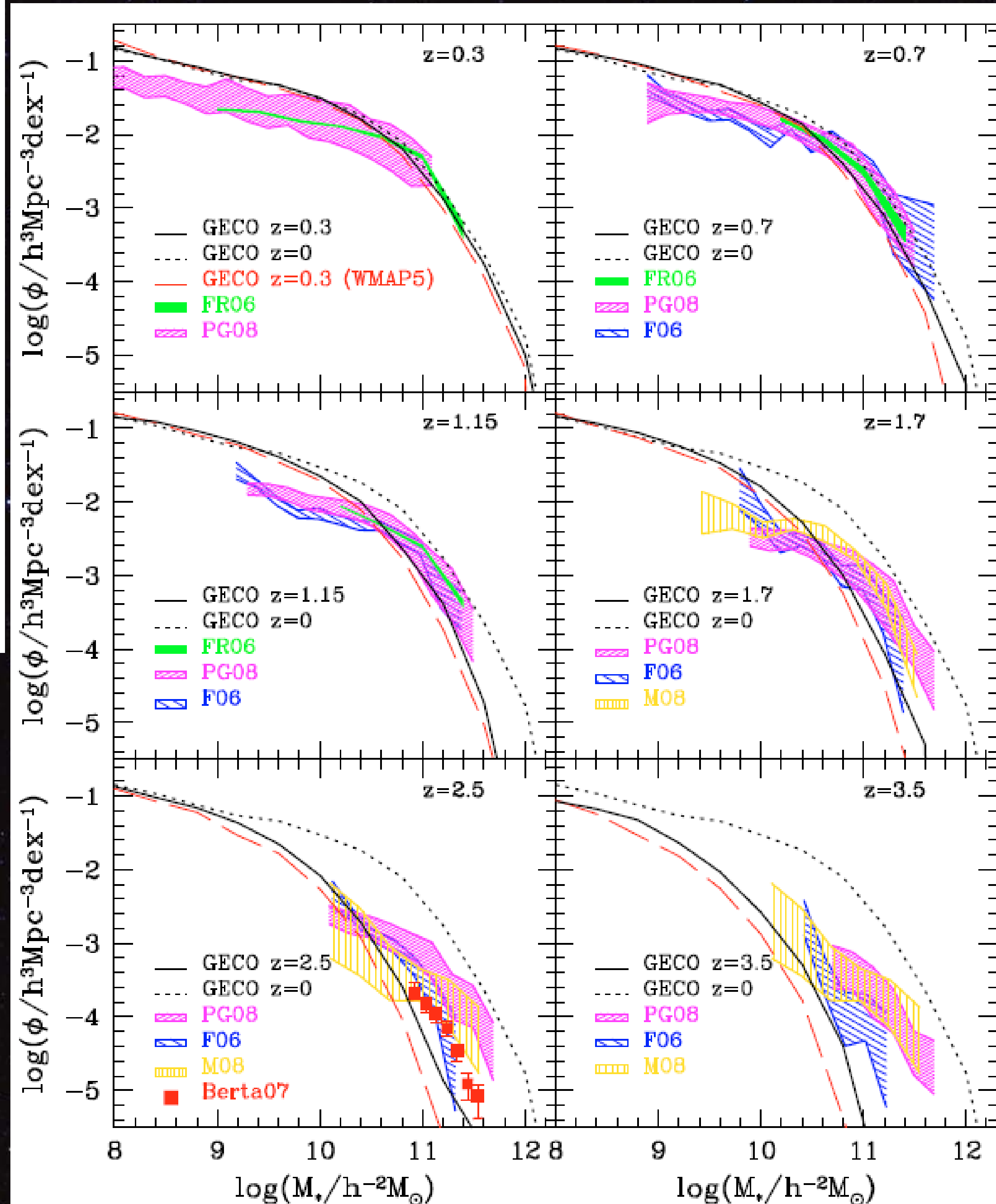

from Joel Primack

# Distribution of Dark Matter in the Millenium Simulation





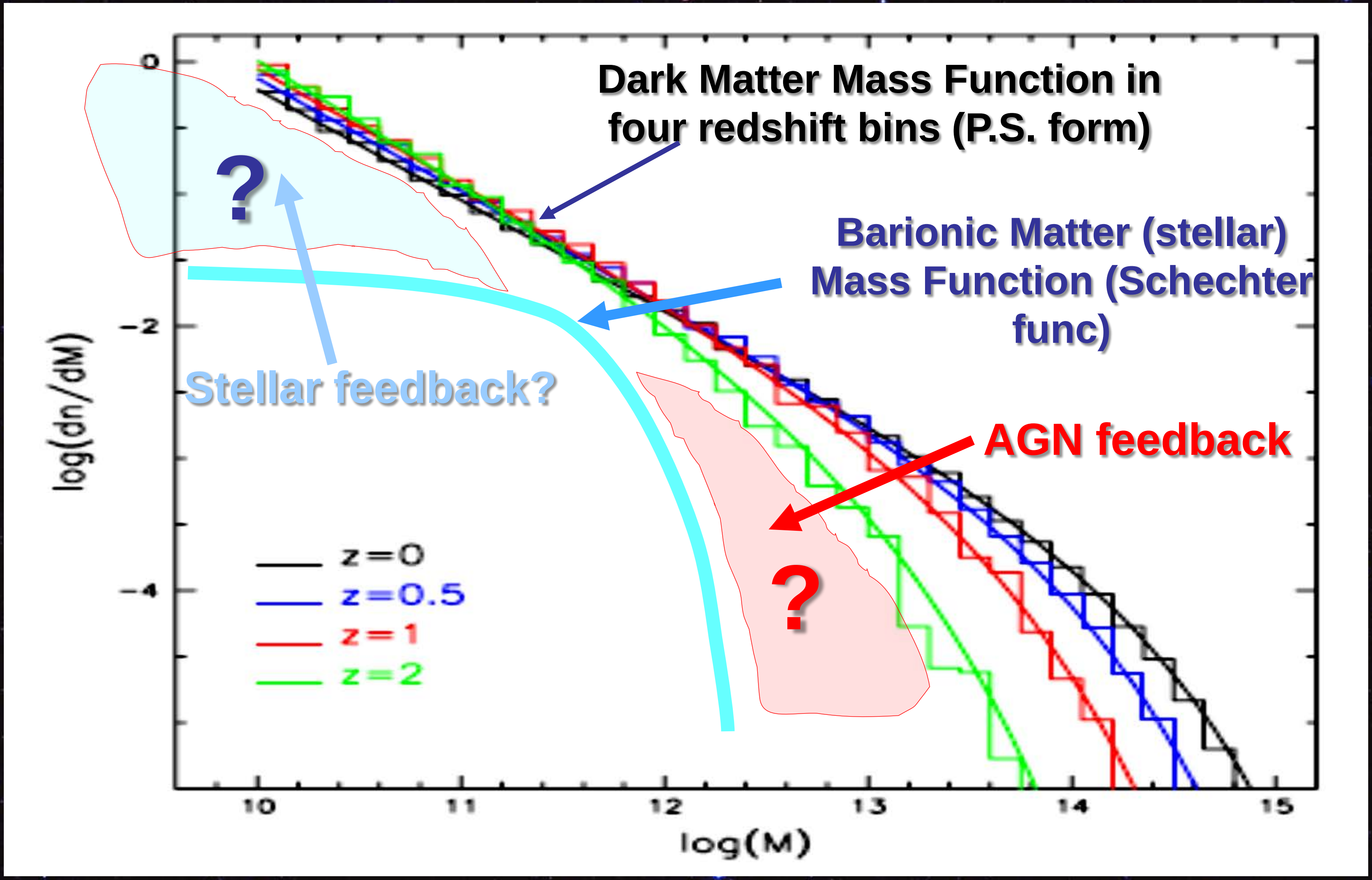

# Galaxy Stellar Mass Functions




- Gas cooling an collapse
- Gas angular momentum
- Star formation
- SN feedback
- AGN feedback
- Cosmological reionization
- Dynamical evolution, collisions
- Satellite and major merging

*Ricciardelli & A.F. 2010*

# A fundamental problem for our understanding of the origin of the cosmic structure (galaxies): how DM maps into the barionic func



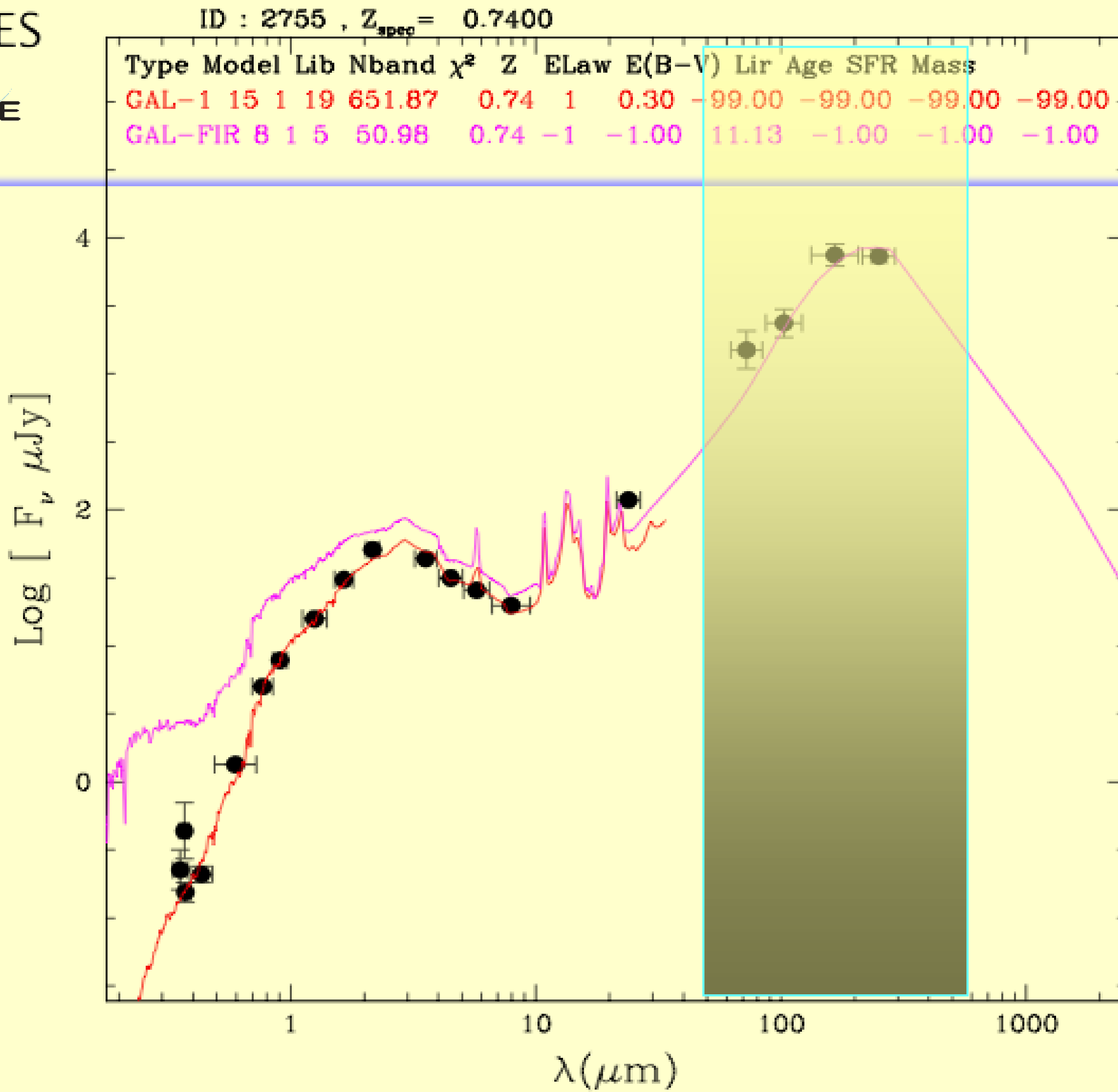
# The Herschel Space Observatory


esa

Astronomy Technology Centre
California Institute of Technology
Cardiff University
CEA, Saclay
Cornell
ESAC
Godard Space Flight Centre

Imperial College, London
Infrared Processing Analysis Centre
Institut d'Astrophysique de Paris
Institut d'Astrophysique Spatiale
Institute Astrophysica Canarias
Jet Propulsion Lab.
Laboratory of Astrophysics of Marseilles

Mullard Space Science Laboratory
OAPd University of Padova
UC Irvine
University of British Columbia
University of Colorado
University of Hertfordshire
University of Sussex

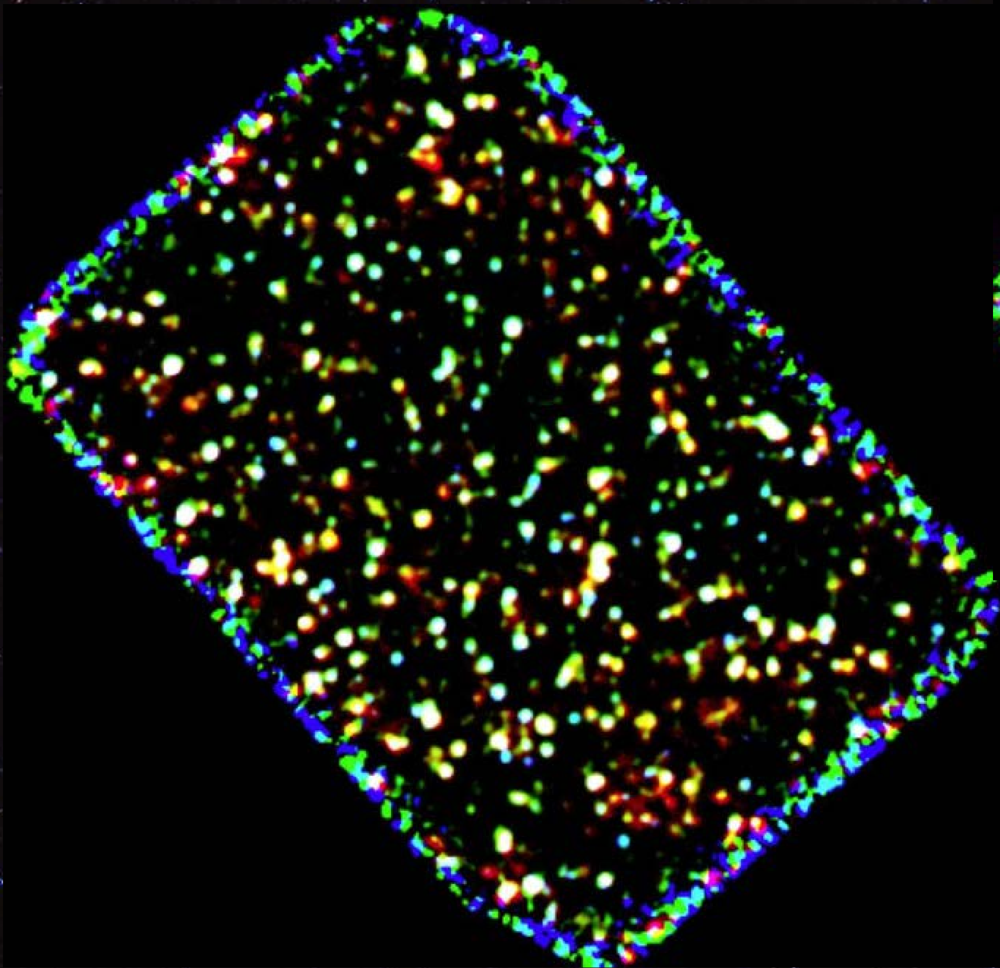

ID : 2755 , Z_spec= 0.7400
Type Model Lib Nband χ² Z ELaw E(B−V) Lir Age SFR Mass
GAL−1 15 1 19 651.87 0.74 1 0.30 −99.00 −99.00 −99.00 −99.00
GAL−FIR 8 1 5 50.98 0.74 −1 −1.00 11.13 −1.00 −1.00 −1.00
Log [ F_ν μJy ]
λ(μm)
4
2
0
1
10
100
1000

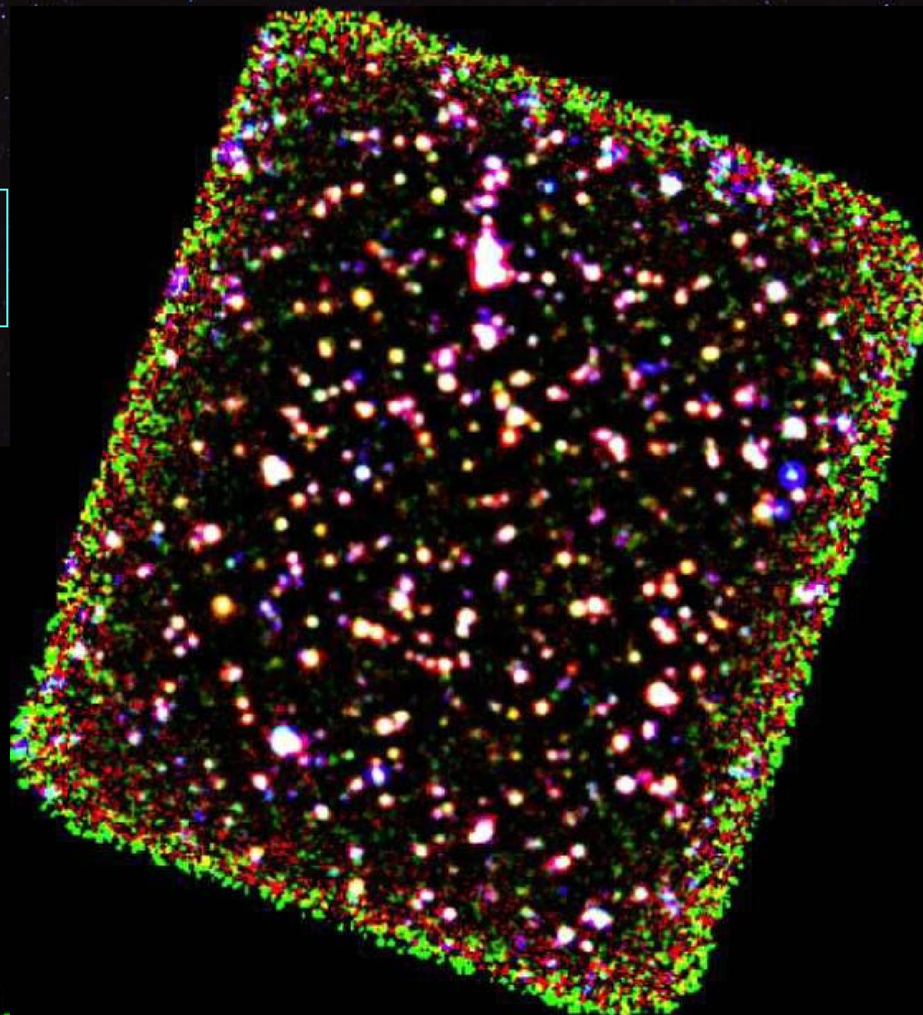
# HerMES : Wedding Cake Survey

**Clusters**

- L1 0.11 □°
- L2 0.36 □°
- L3 1.25 □°
- L4 4 □°
- L5 30 □°
- L6 40 □°
- L7 270 □°

GOODS–North field (10′×15′) at 100 μm (blue), 160 μm (green) and 250 μm (red)



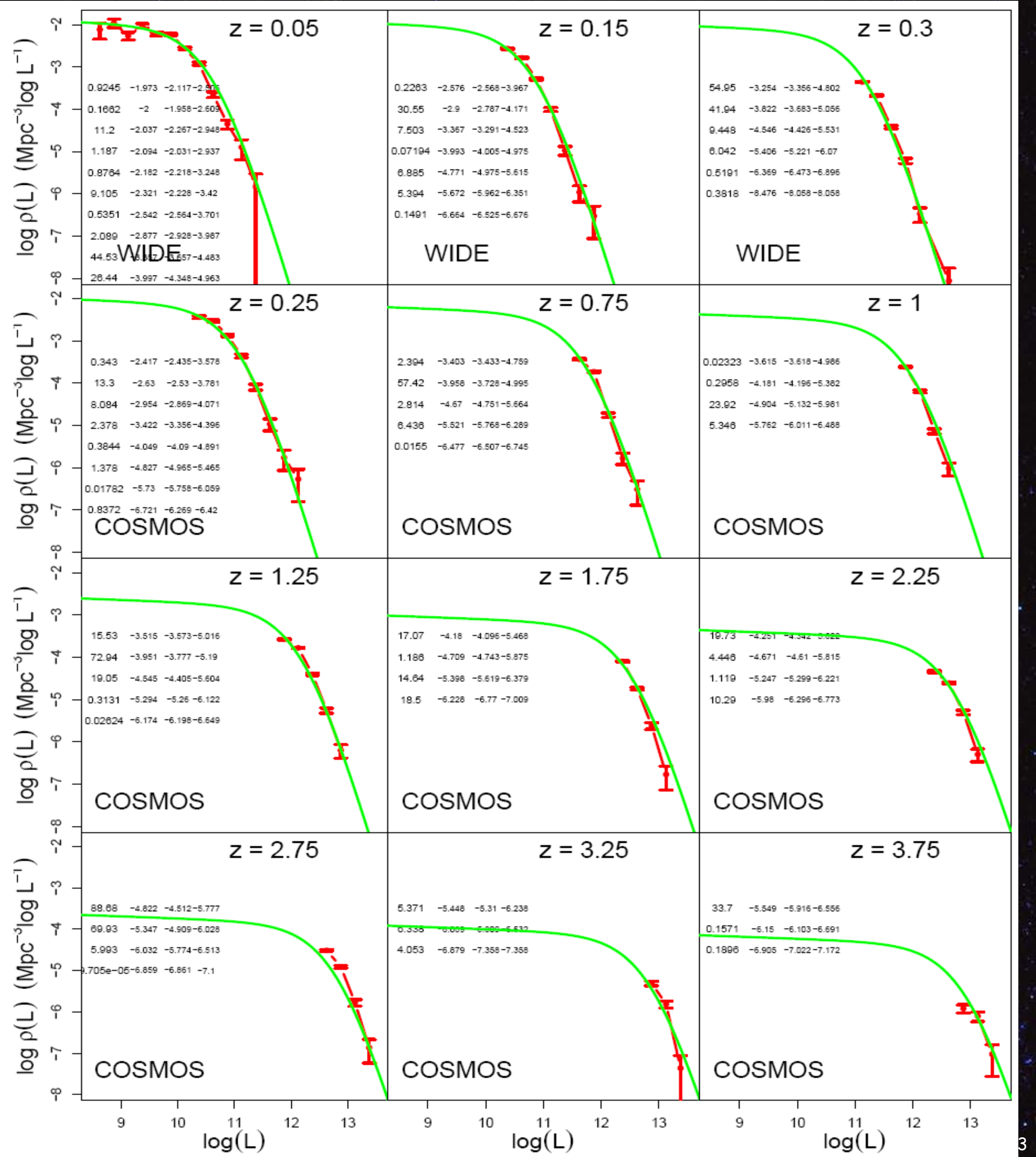


GOODS–South (10′×10′) at 24 μm (blue), 100 μm (green) and 160 μm (red)

*Elbaz et al. 2011*

# Population analyses

## The Evolution of the IR Bolometric Luminosity Function (COSMOS)

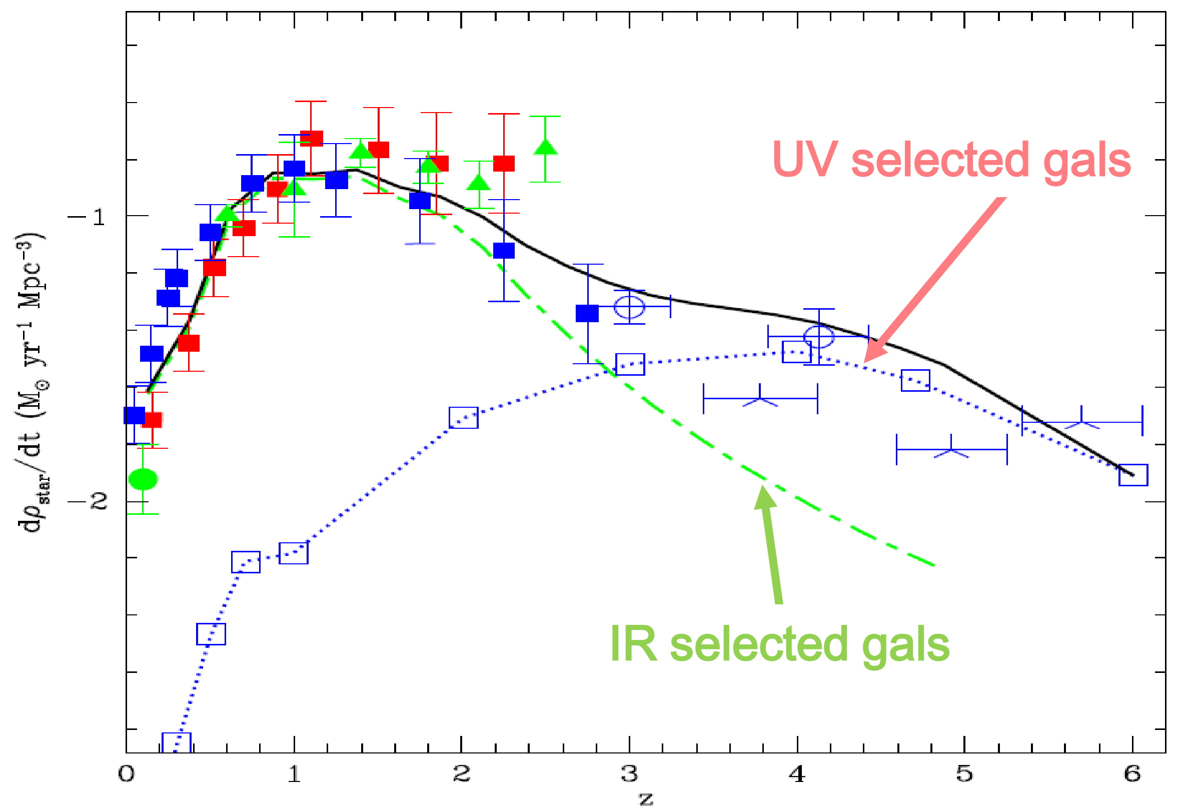



*Vaccari et al. 2012*
*Marchetti et al. 2012*

# Current status: conclusions (1)

1. Very consistent results from independent surveys, strong constraints on the high-z galaxy comoving emissivity
2. Current data indicate: strong *positive* evolution of the bolometric L + very strong *negative* evolution of the comoving density
3. Nothing might be so variant wrt *hierarchical clustering* predictions
4. It appears that the more we learn about galaxy formation/evolution, the less we understand it ...

# Current status: conclusions (2)

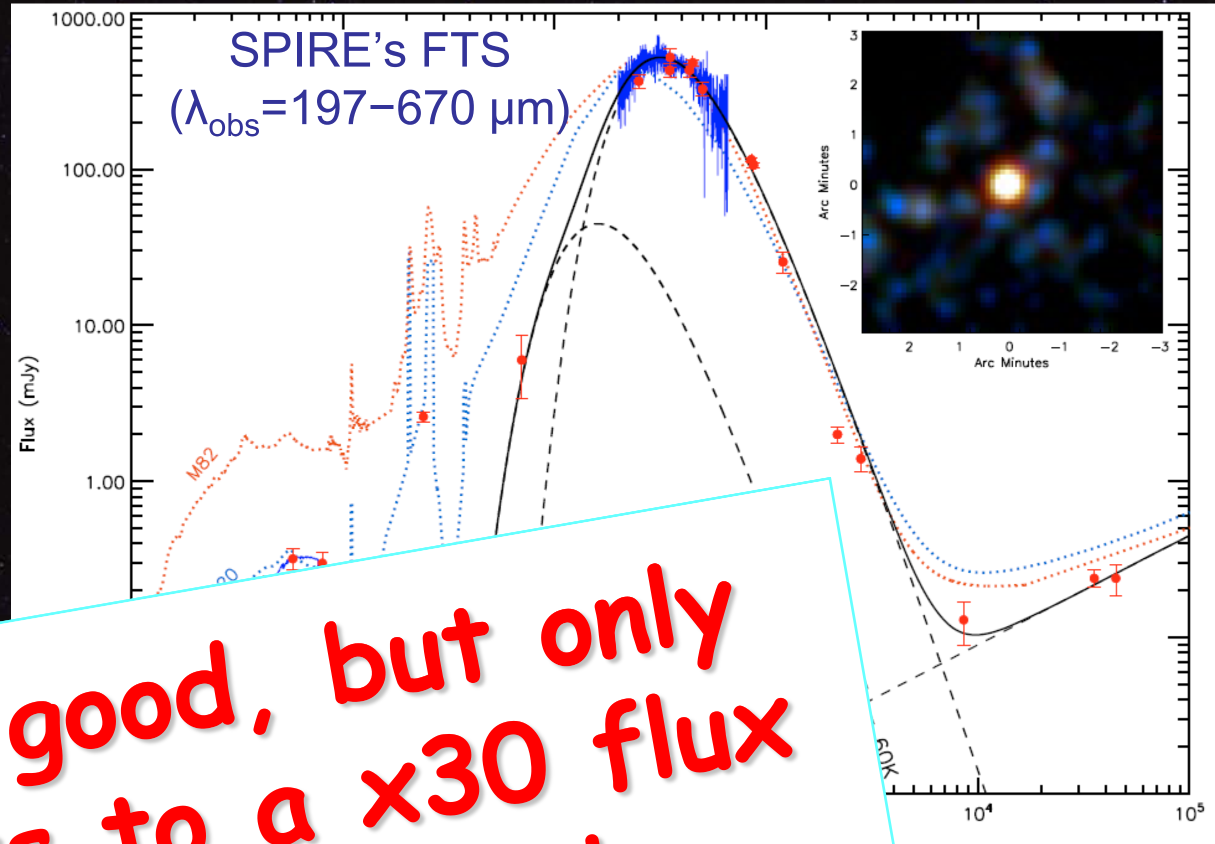


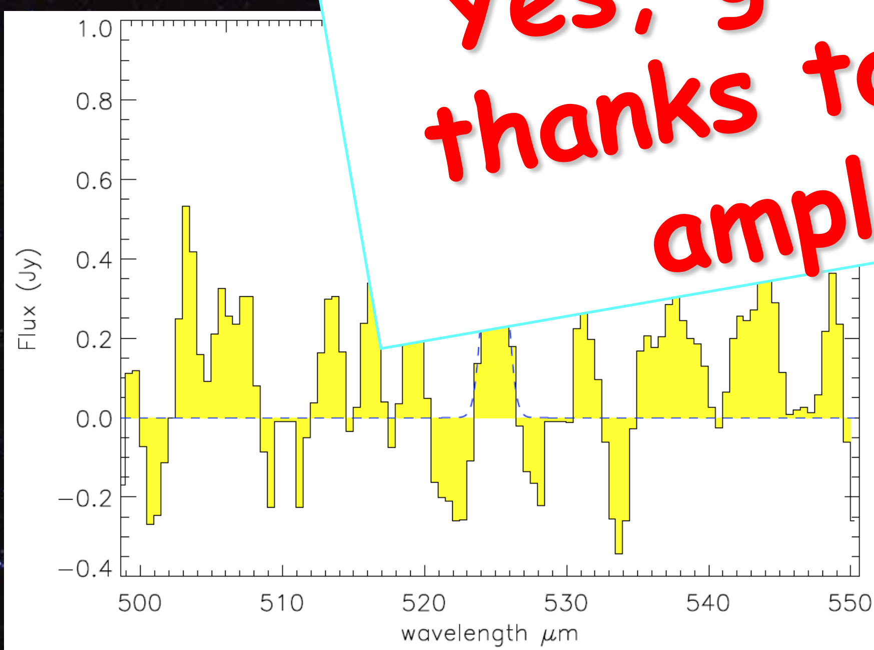

1. The bulk of SF activity at z<3-4 appears to be produced by strongly dust-extinguished galaxies
2. UV bright objects instead dominate on average at z>4

Current role of radio surveys (to moderate depths): ancillary data, e.g. useful for source ID and rough AGN/SB characterization.

However, a role limited by current sensitivity

An example of what can be done currently using lensing amplification of the background IR sources

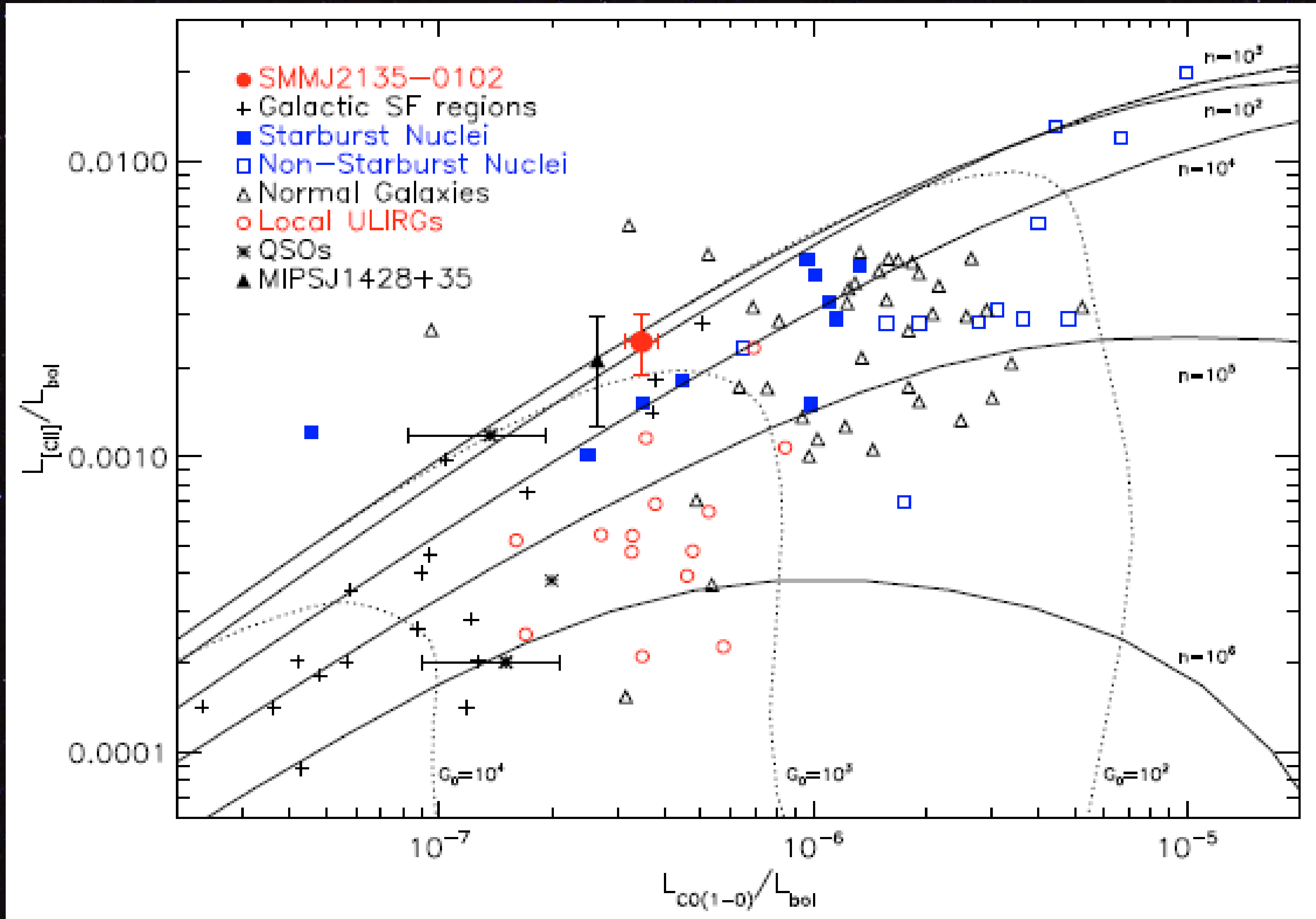



**Yes, good, but only thanks to a x30 flux amplification!**

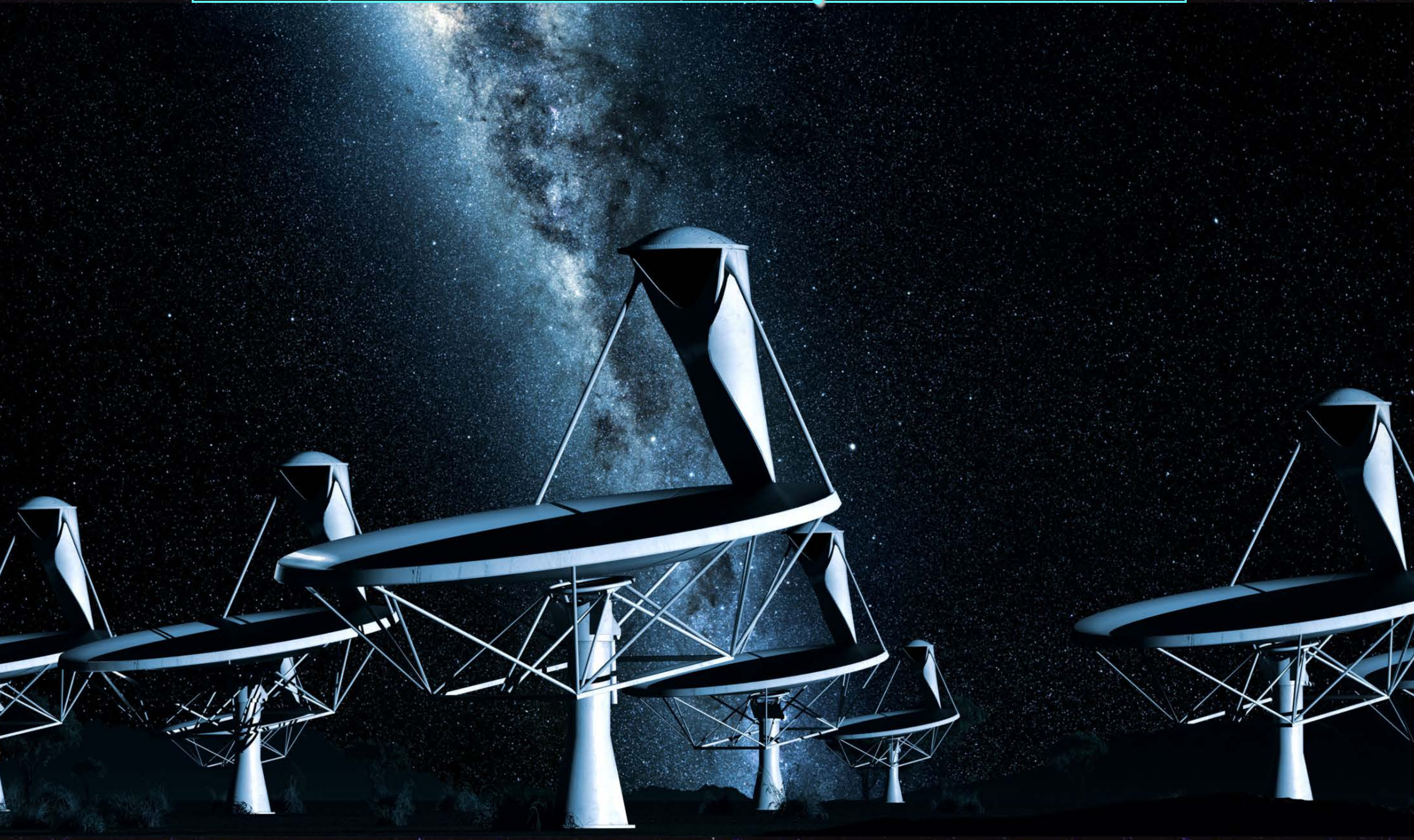
…MMJ2135, with $S_{870\,\mu m}$ = 106 mJy. Its brightness is due to very high amplification (by a factor 32.5 ± 4.5) from a foreground cluster at z=0.325

*Ivison et al. 2010*

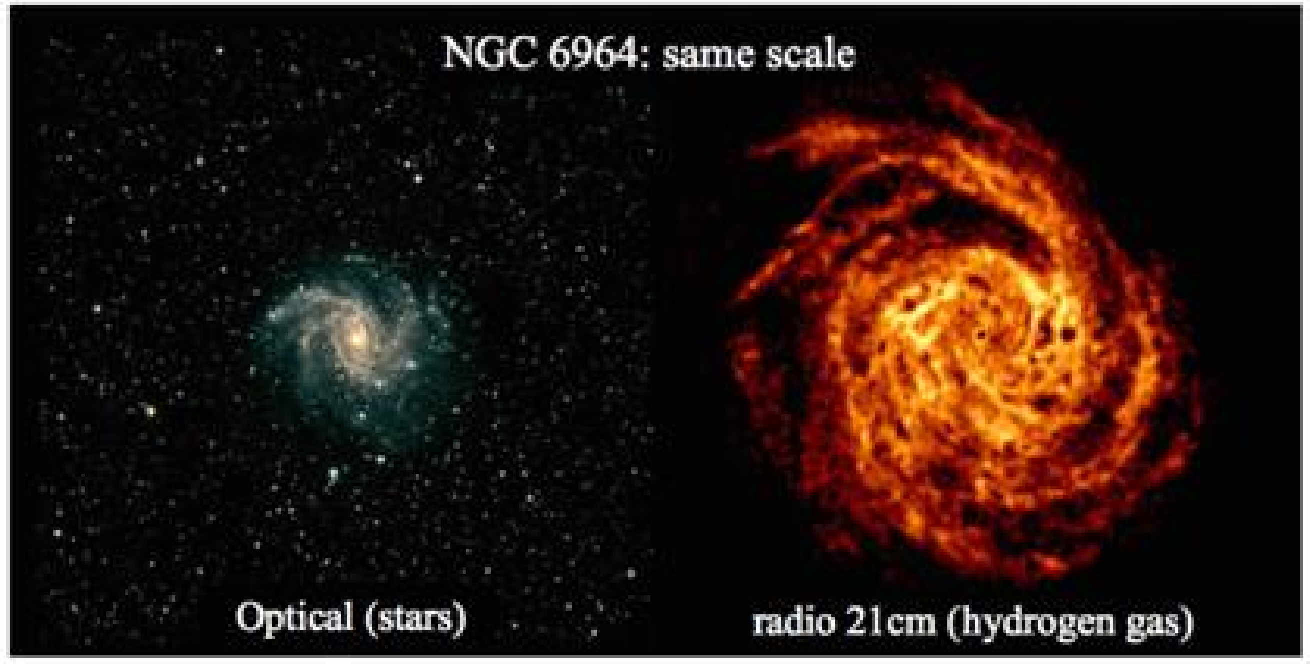



L[CII]/ $L_{bol}$ versus $L_{CO(1-0)}/L_{bol}$ for SMMJ2135 compared to star-forming regions, star-forming galaxies and ULIRGs in the local Universe. Tracks for PDR models of gas density, *n*, and far-UV field strength, *G*0, are taken from Kaufman et al. (1999). The gas in SMMJ2135 experiences a far-UV field similar to that seen in local ULIRGs, but is at much lower densities than the typical material in such systems.

# The SKA Perspective



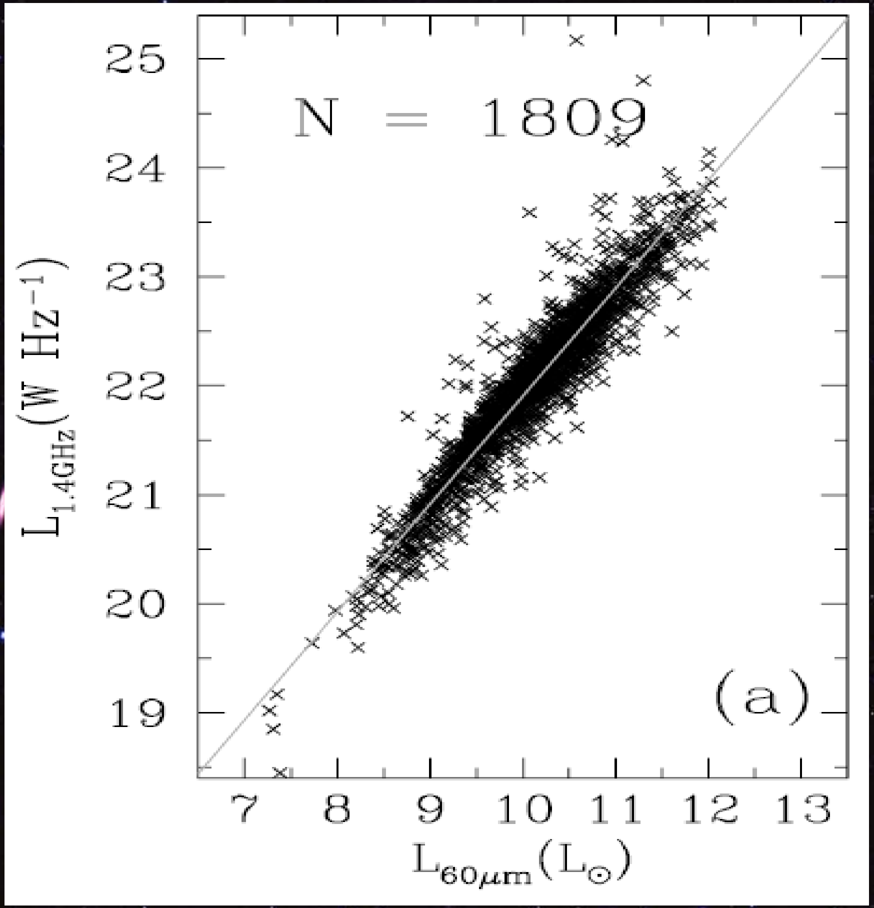
# The key scientific drivers for extragalactic astronomy and cosmology with SKA (1)




Mapping with extraordinary detail the HI neutral gas, that is the component of baryons ready to form stars.
The amount of HI and its kynematics.

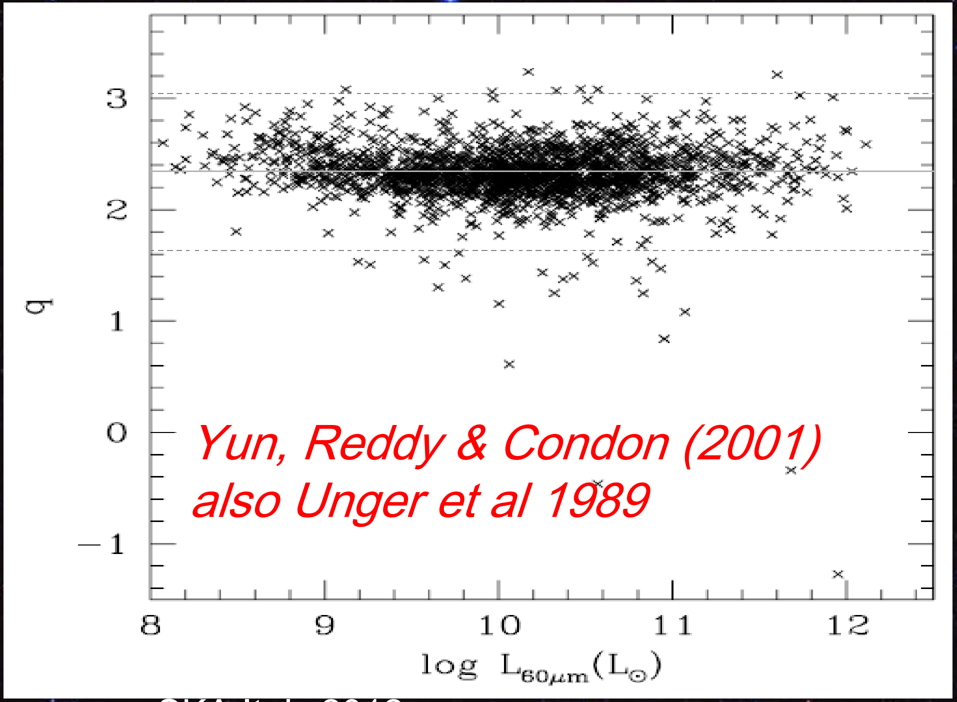
# The key scientific drivers for extragalactic astronomy and cosmology with SKA (2)

## The (magic) radio-FIR correlation



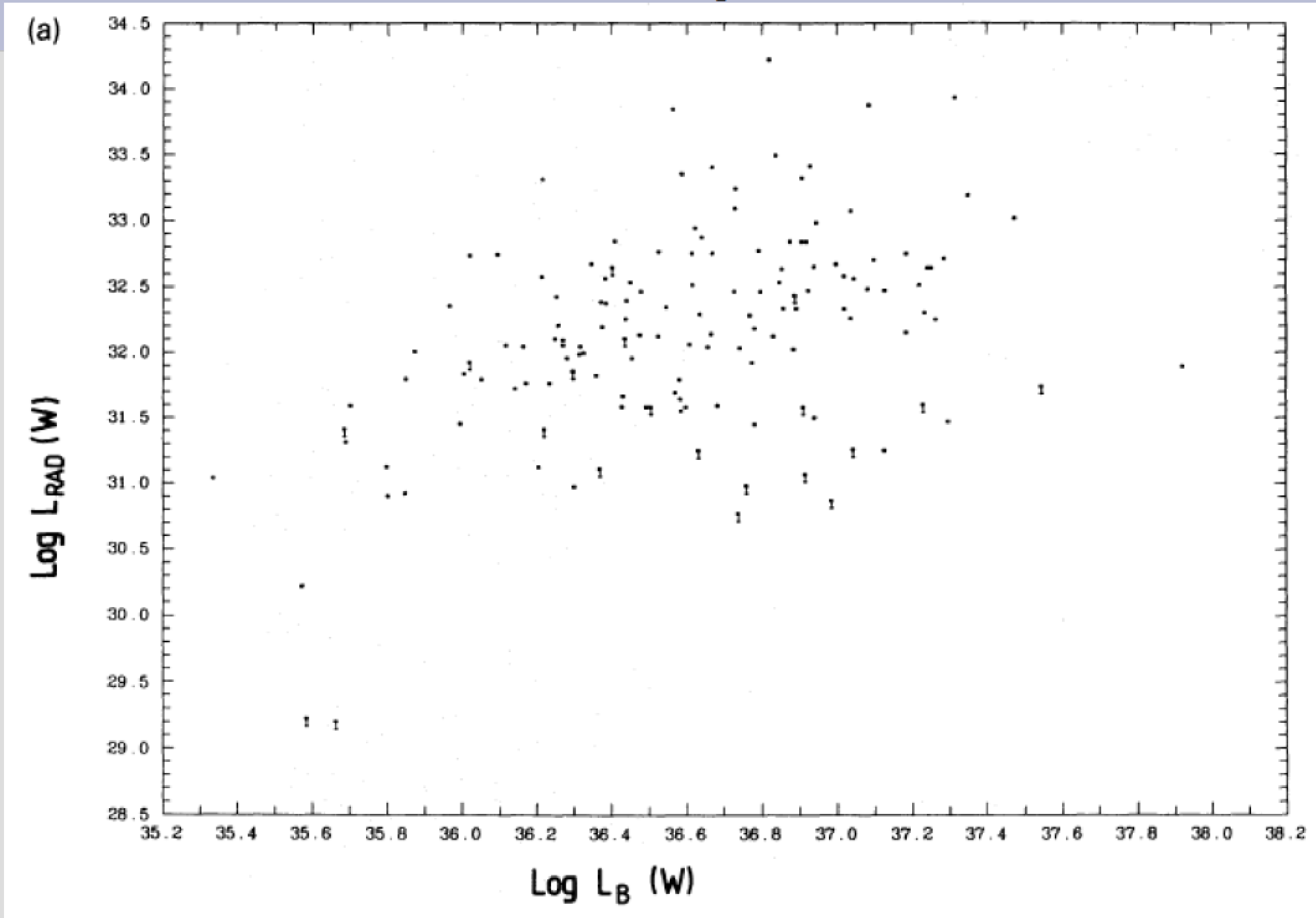

$$q \equiv \log\left(\frac{FIR}{3.75\times10^{12}\ W\ m^{-2}}\right) - \log\left(\frac{S_{1.4\ GHz}}{W\ m^{-2}\ Hz^{-1}}\right)$$

1809 galaxies from IRAS in the NVSS survey region → consistent with a perfectly linear correlation




*Yun, Reddy & Condon (2001)*
*also Unger et al 1989*

# Example: No Tight Correlation between Blue and Radio for Sample Galaxies



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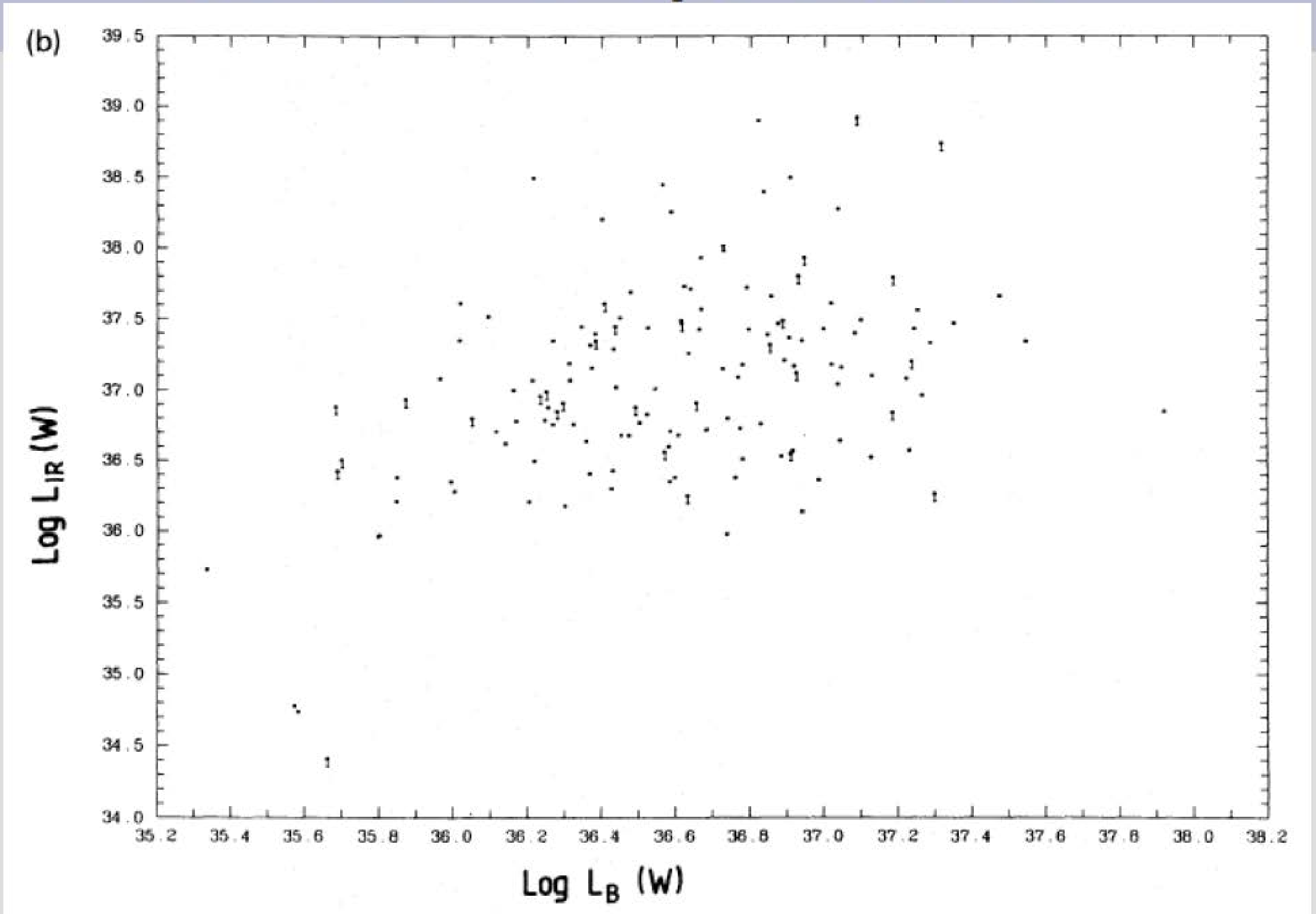
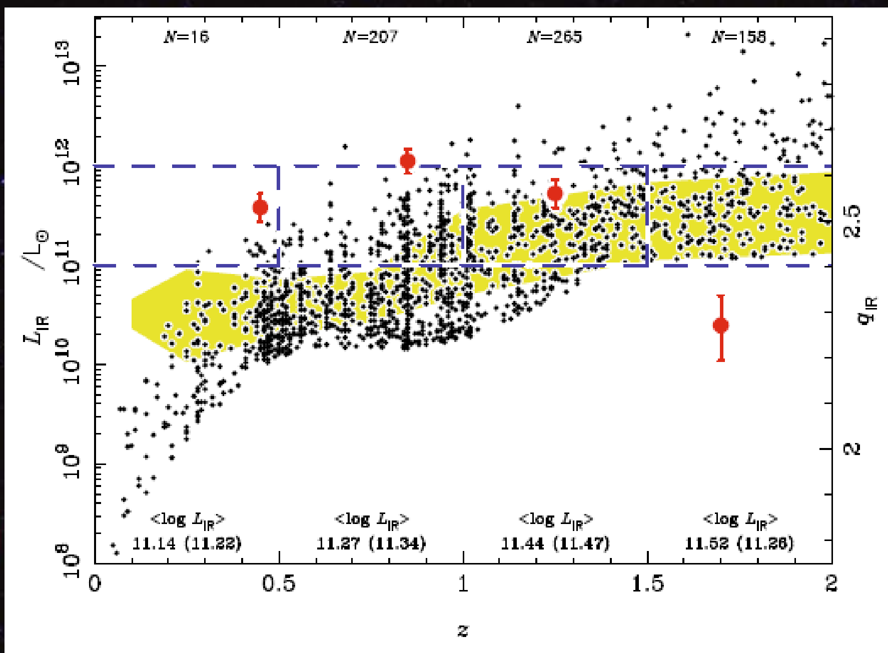
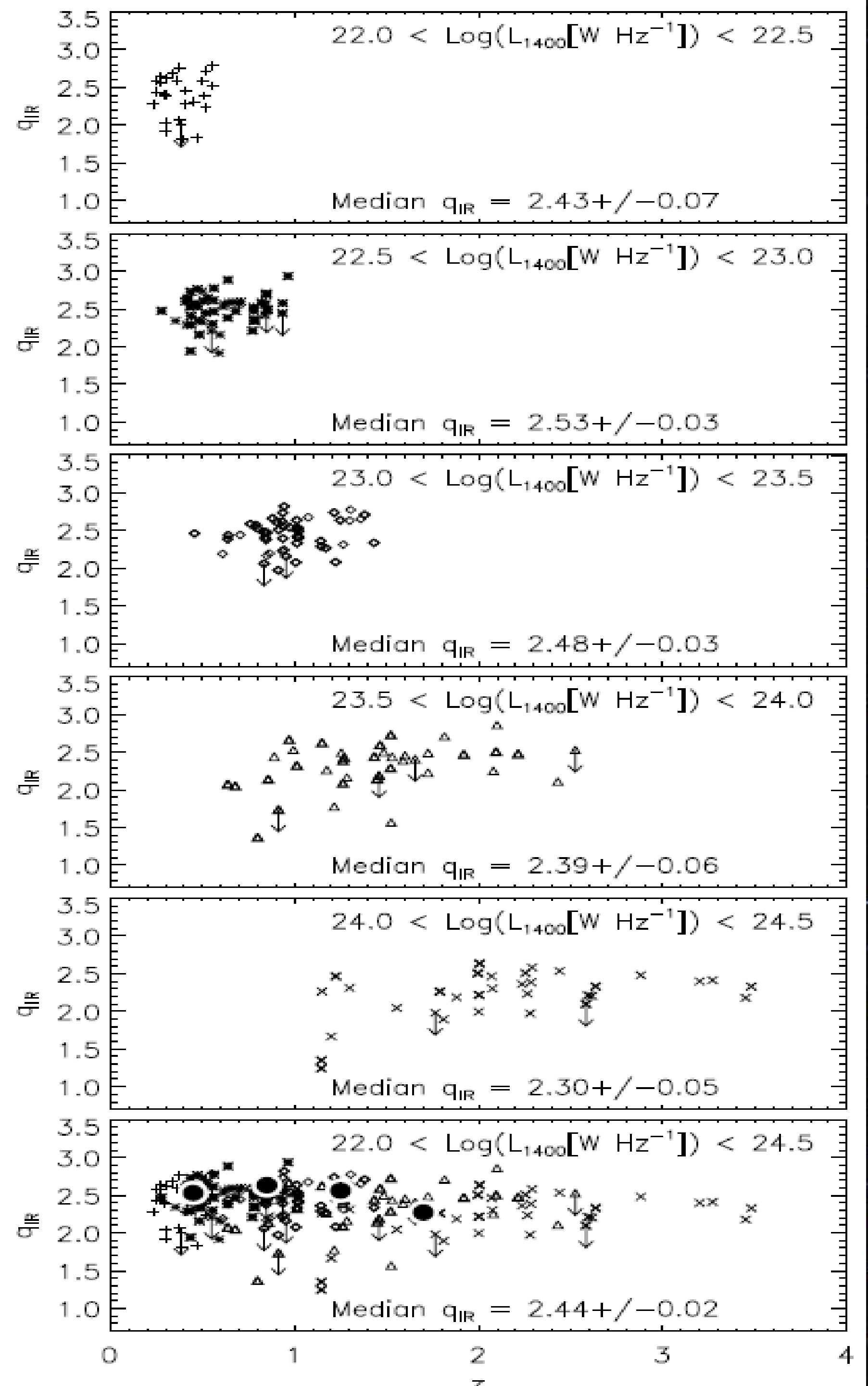


# Insight into the radio-FIR correlation ∀z and ∀L

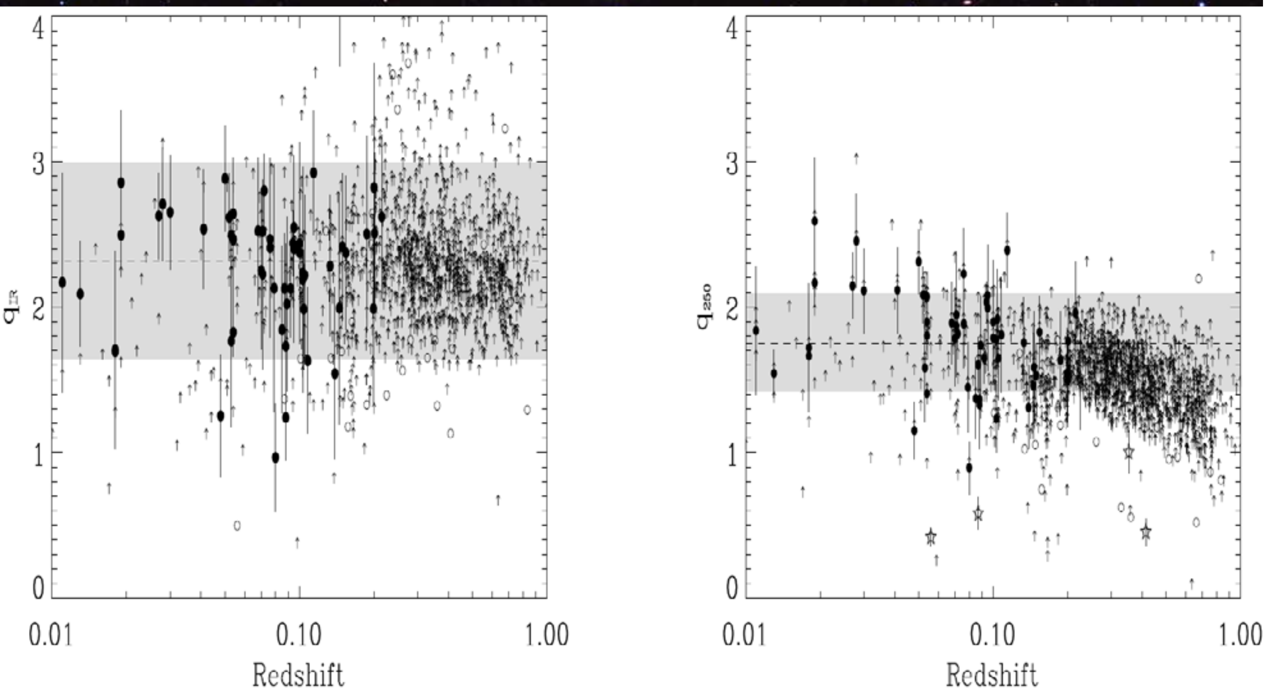


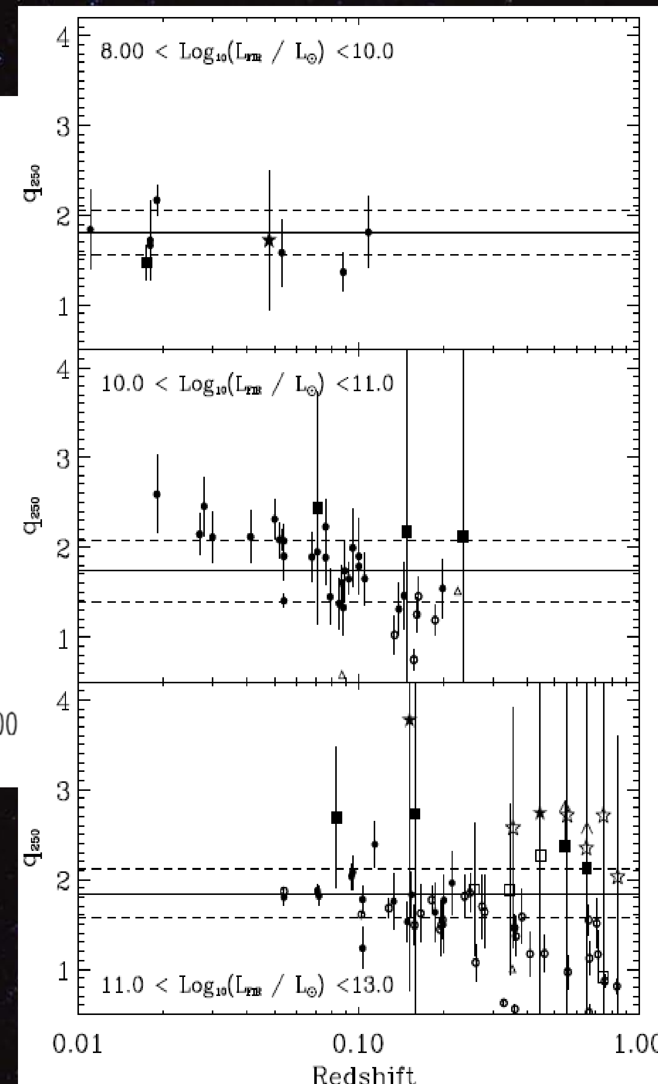

*Ivison et al. 2010*



# The radio-FIR correlation investigated by Herschel (H-ATLAS) and NVSS/FIRST surveys

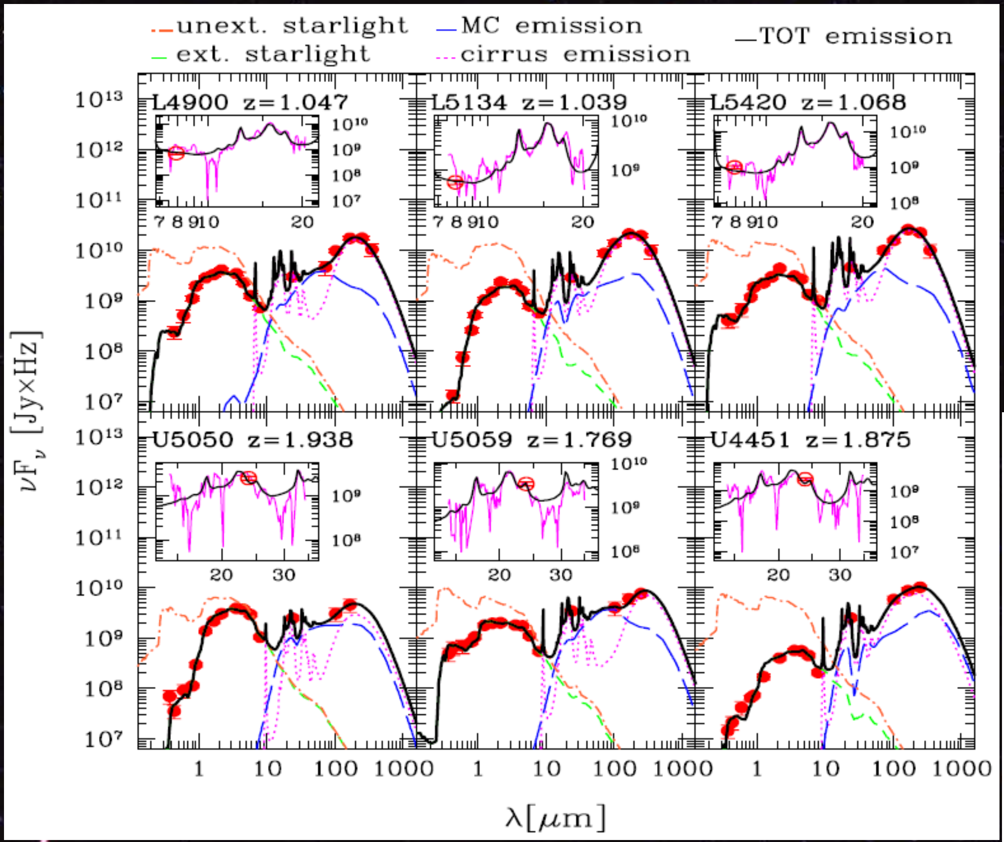
*Jarvis et al. (2010)*



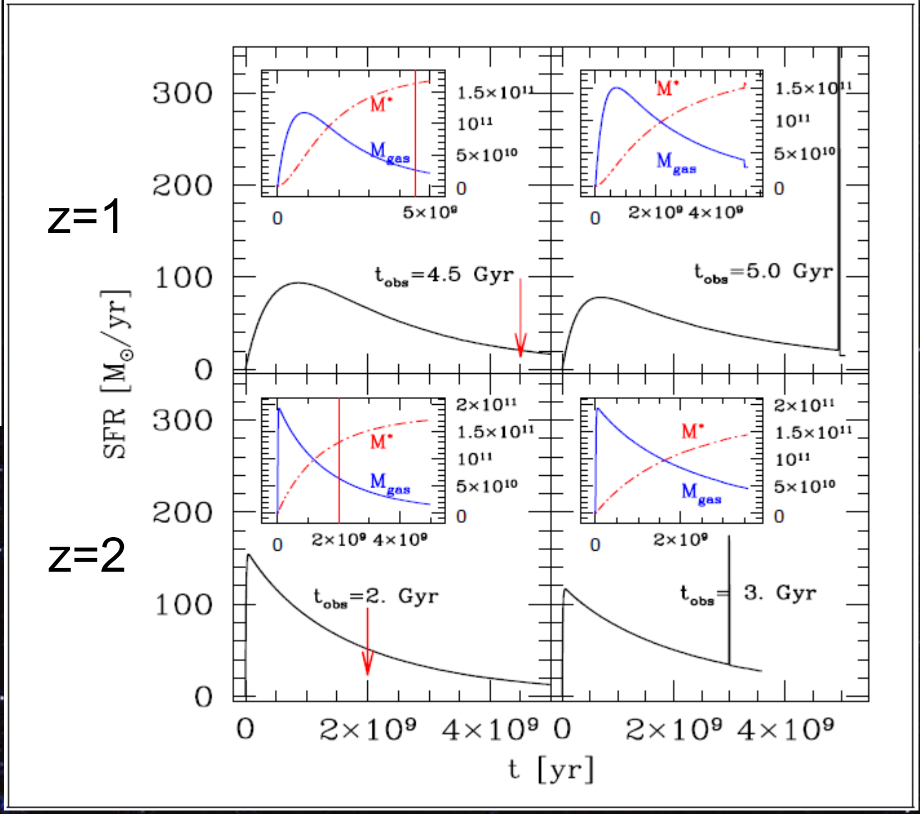




Tentative evidence that the longer wavelength, cooler dust is heated by an evolved stellar population which does not trace the star-formation rate as closely as the shorter wavelength < 250 μm emission or the radio emission.

# Characterization of high-z IR starbursts

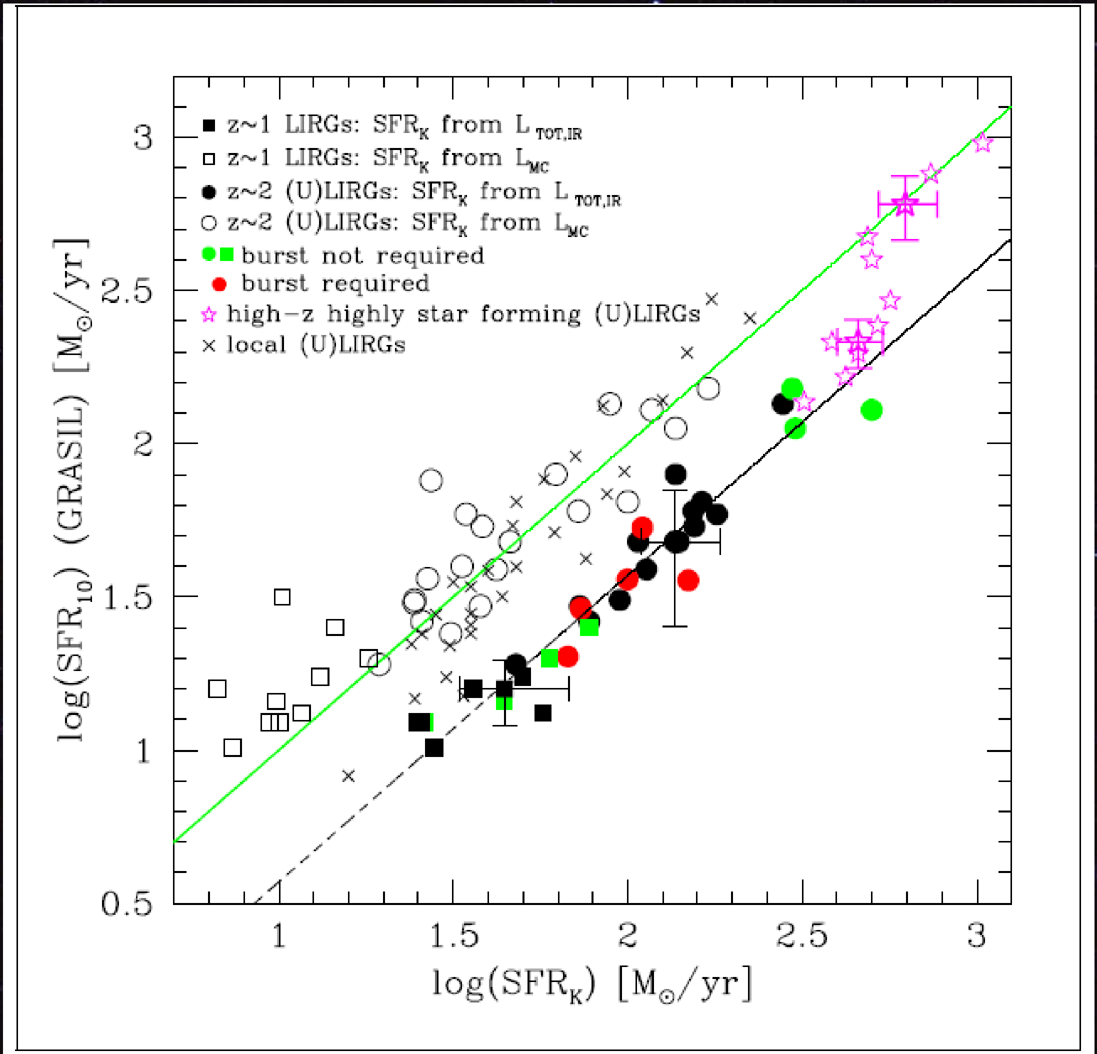



*from Lo Faro et al. 2012*




According to this analysis, the formation redshifts for these sources are z~2 to z~6 and all are detected in a declining phase of SF

# $L_{FIR}$ not likely the best SFR tracer ?




*Lo Faro et al. 2012*

Comparison of a physical estimate of *SFR* (based on the GRASIL code) with that based on the Kennicut (1998) law, $SFR_K$. $SFR_{10}$ is averaged *over 10 Myrs* . Datapoints represent the diffrent *SFR* for LIRGs and ULIRGs at high redshifts. Larger datapoints with errorbars are median values with associated semi-interquartile ranges.

The 2 correlation lines correspond to:

- $L_{FIR}$ dominated by newly formed stars (upper), like in Kennicut's.
- $L_{FIR}$ contributed partly by intermediate and old stellar populations heating the dust (lower).

⇨ Radio flux is likely a much better, more robust tracer of the rate of Star Formation (*SFR*) in distant and forming galaxies (Condon 1992)

# Prospects with SKA for Galaxy Formation Evolution

SKA rms sensitivity in 1 h

| Frequency (GHz) | Bandwidth (MHz) | Rms (μJy) |
|---|---|---|
| 0.2 | 50 | 1.4 |
| 1.4 | 350 | 0.13 |
| 8 | 2000 | 0.06 |
| 20 | 4000 | 0.08 |

**2-6 μJy E-VLA**

- Contiguous imaging field of view: 1 square degrees within half power points at 1.4 GHz, scaling as wavelength squared
- Goal: 200 square degree field of view within half power points at 0.7 GHz, scaling as wavelength squared between 0.5 and 1.0 GHz.

The primary case for SKA: 21cm HI spectroscopic observations → mapping the pristine gas available to be transformed into stars

Enormous sensitivity for continuum measurements → excellent probe of SFR over large areas, the transformation of gas into stars

The mass function of DM halos hosting galaxy formation and evolution (from SKA kynematical surveys, JWST)

Stellar mass function of galaxies from Spitzer, ground-based NIR, JWST

SKA

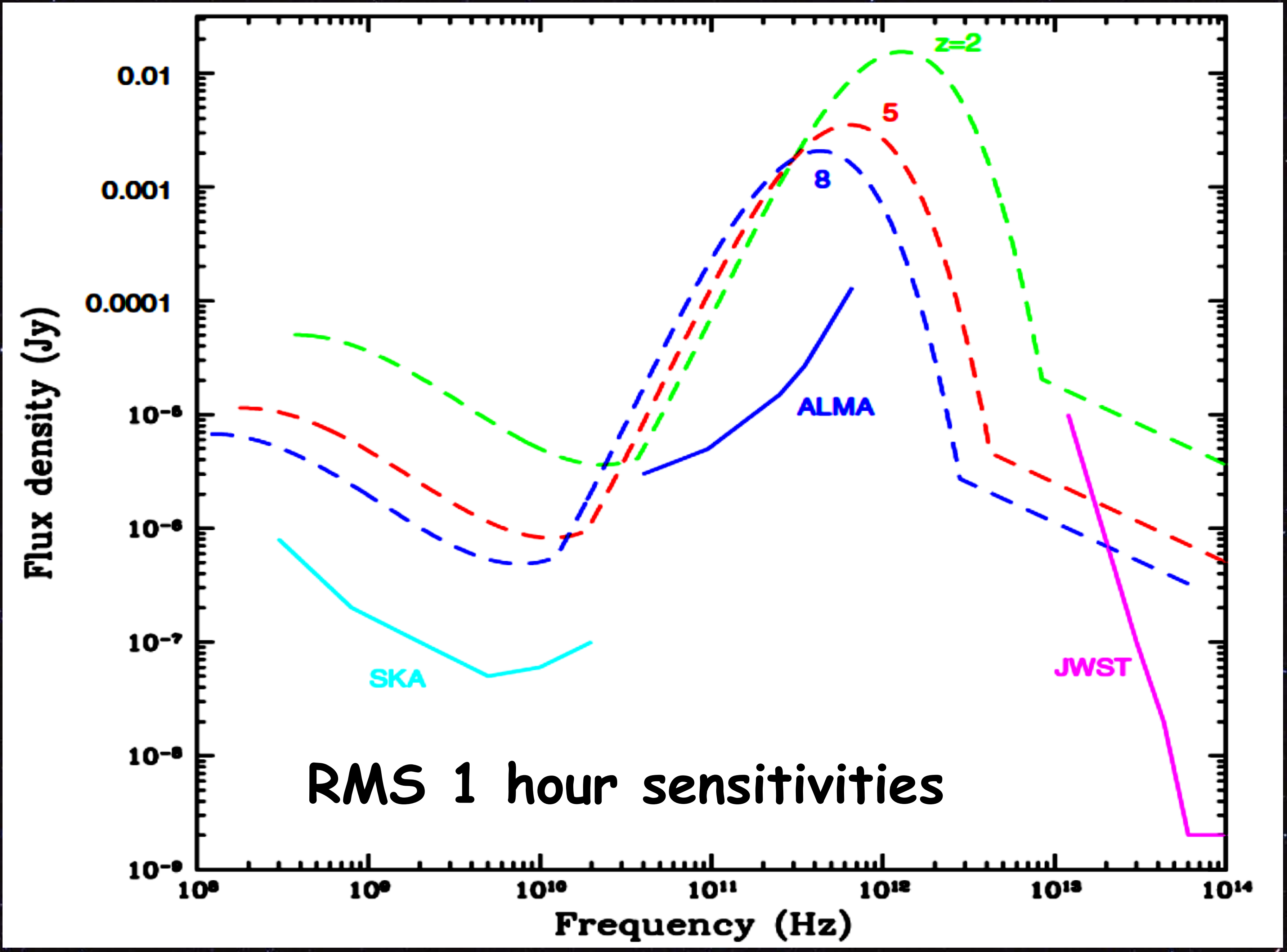
PRISTINE GAS

TE OF STAR FORM.

DM DISTRIBUTION

STELLAR MASS FUNC.

# Galaxy Formation & Evolution


z=2
5
8
0.01
0.001
0.0001
Flux density (Jy)
ALMA
SKA
JWST
RMS 1 hour sensitivities
Frequency (Hz)

# Relationship of SKA and ongoing projects (ALMA, JWST, ELT)

- ALMA, JWST, EELT will mostly be dedicated to in-depth targeted analyses of only small sky fields
- SKA will have the combination of extreme sensitivity and large field-of-view to map wide areas and address the issue of how the cosmic environment affects galaxy evolution
- As for sensitivity to point-source flux: