Star formation across
space and time

ESTEC, Noordwijk, 13/11/2014

UNVEILING OBSCURED STAR FORMATION AND DUST ATTENUATION UP TO Z=4

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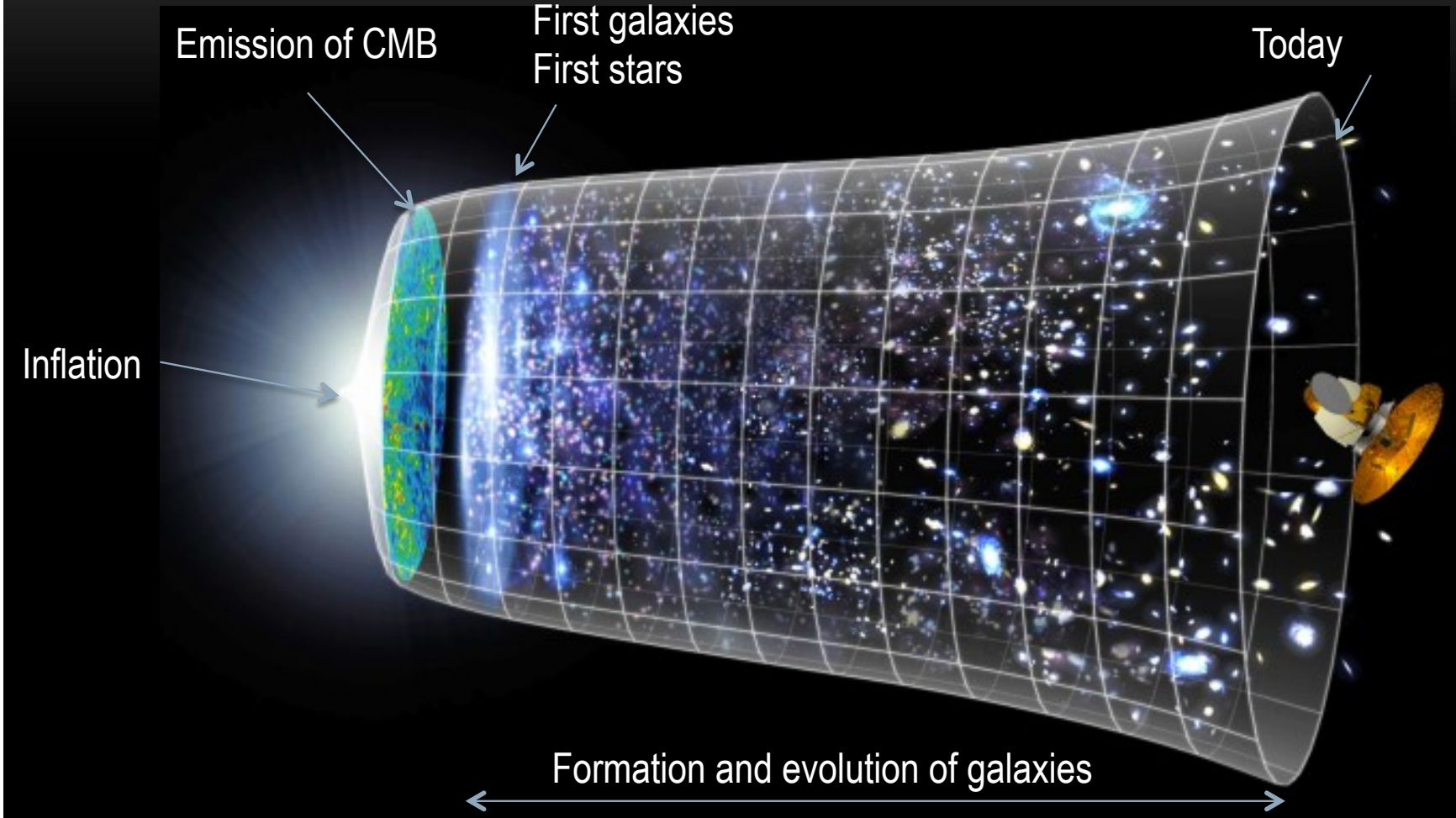
ESO Garching

in replacement of Véronique Buat (LAM, Marseille)

with Sébastien Henis, Emannuel Bernhard, Denis Burgarella, and many others

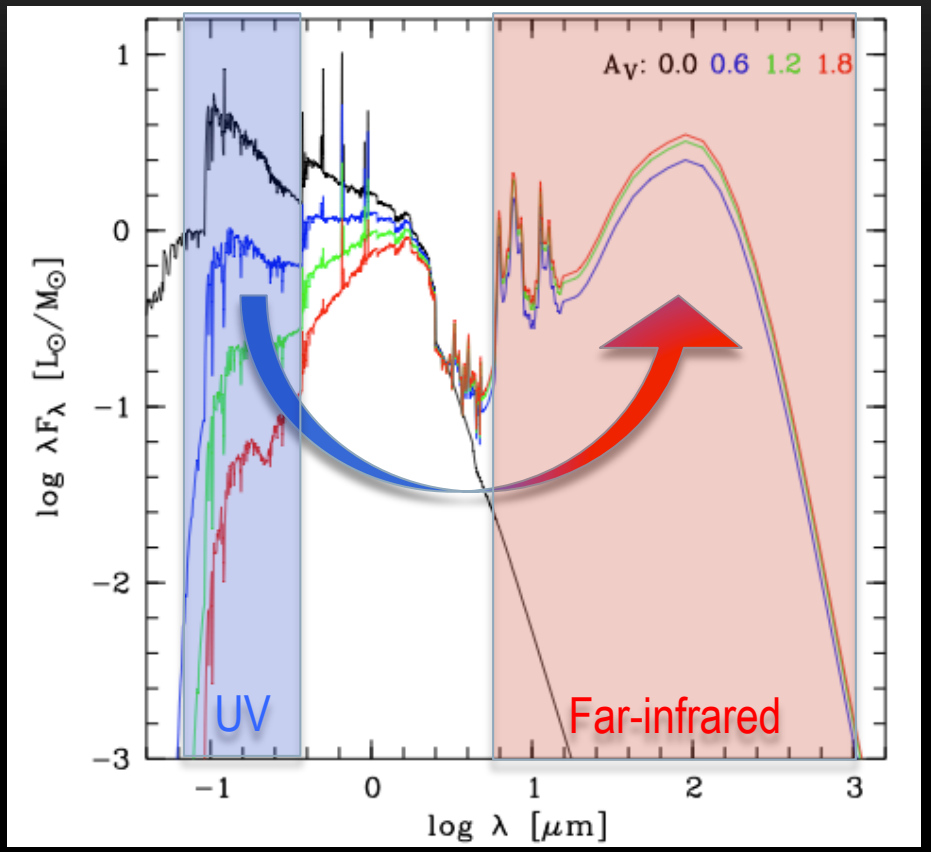
STAR FORMATION ACROSS COSMIC TIMES



NASA/WMAP
science team

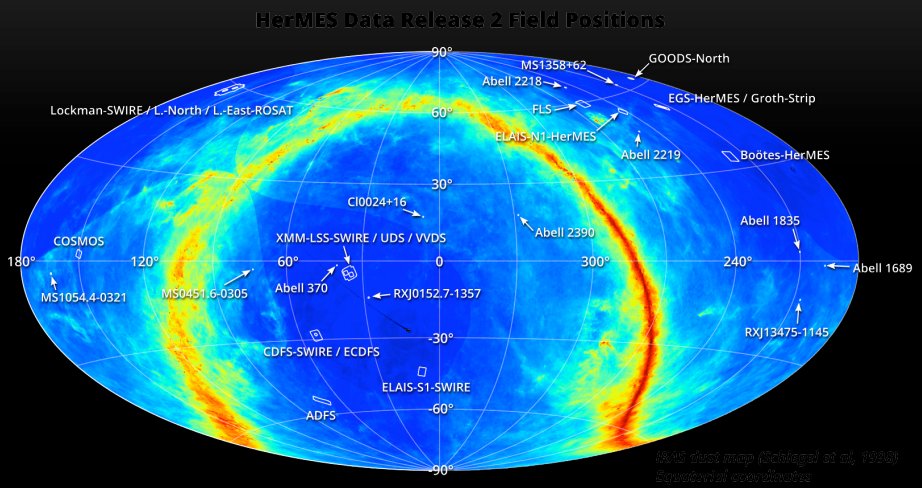
ESTIMATION OF STAR FORMATION RATE IN DISTANT GALAXIES

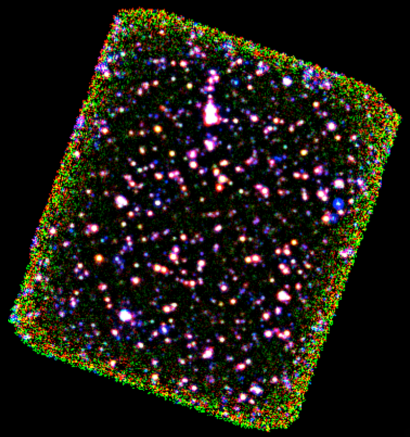
- UV emissions of galaxies dominated by massive, hot, short-lived stars
  => tracer of recent star formation.
- PROBLEM: UV strongly absorbed by dust around regions of star formation.
- Re-emission of UV by dust in the far-IR = good tracer of reprocessed UV.

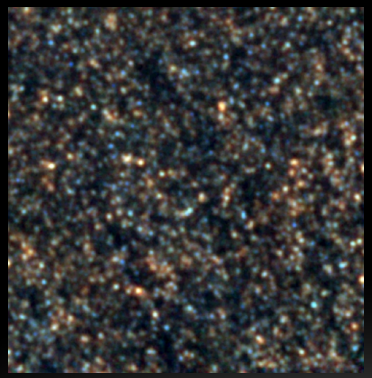


Spectral energy distribution of a galaxy (Noll+09)

HERSCHEL DEEP SURVEYS







- HerMES (P.I.: S. Oliver)
- PEP (P.I.: D. Lutz)
- GOODS-Herschel (P.I.:D. Elbaz)

OUTLINE

- Obscured and unobscured star formation history
  Burgarella et al. 2013, A&A 554 70

- Connection between UV and IR galaxy populations
  Heinis et al. 2013, 2014, MNRAS 429 1113 and 437 1268
  Bernhard et al. 2014, MNRAS 442 509

- The nature of high-redshift massive galaxies
  Heinis et al. 2014, MNRAS 437 1268
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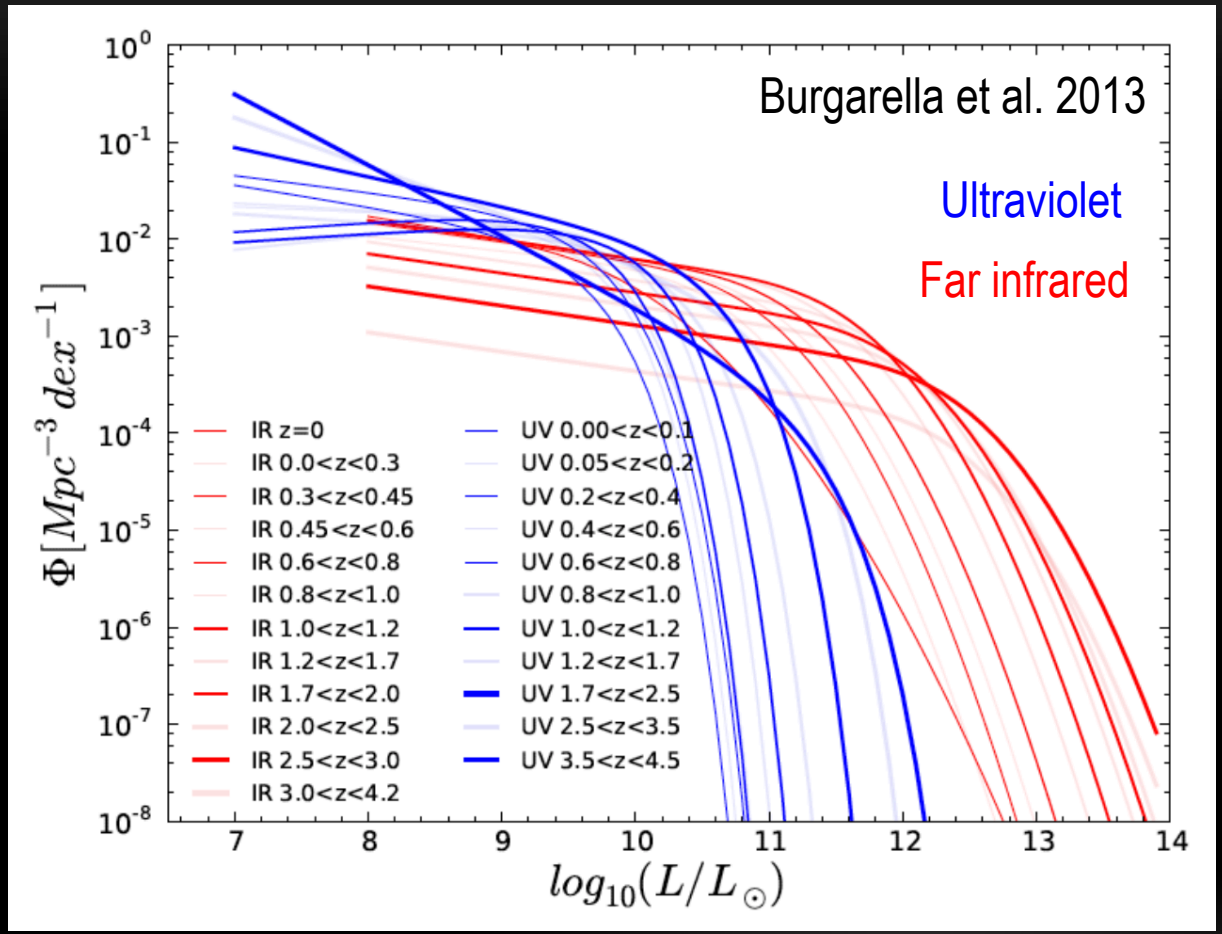
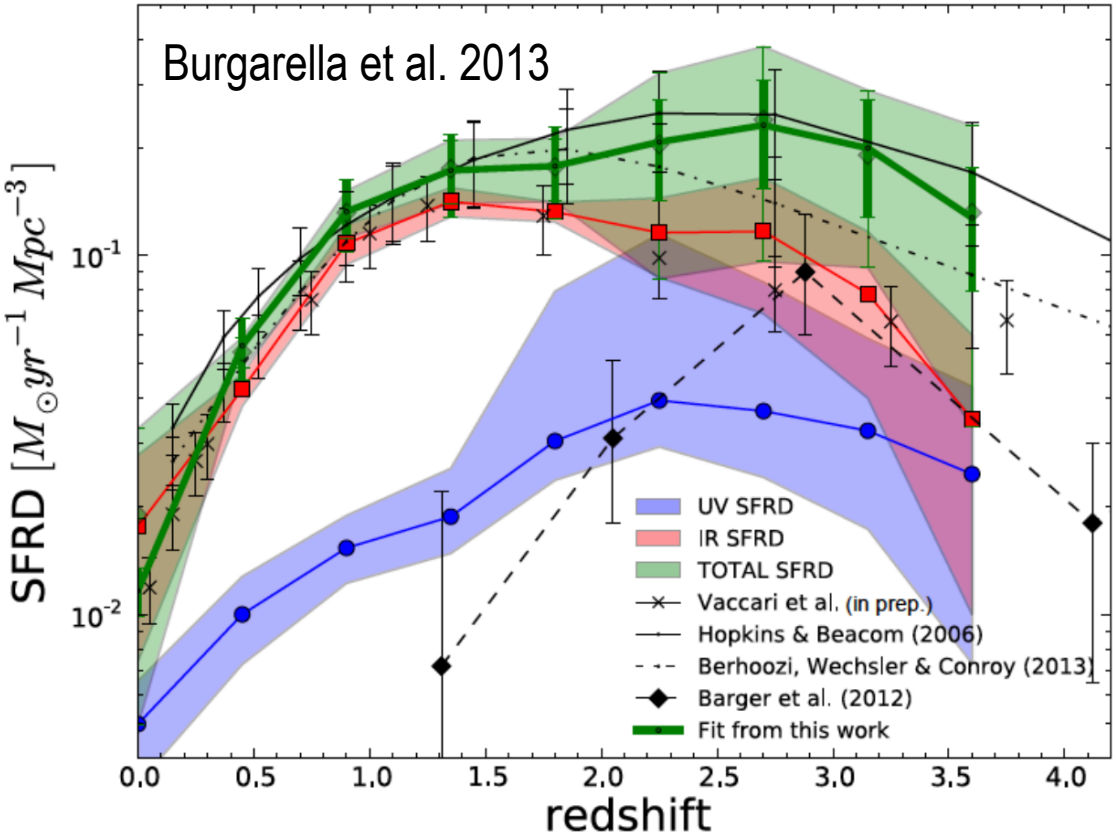
EVOLUTION OF FAR-INFRARED AND UV LUMINOSITY FUNCTIONS ACROSS COSMIC TIMES



Far-UV (150 nm) luminosity functions from Cucciati et al. (2012)

IR bolometric (8-1000 microns) luminosity functions from Gruppioni et al. (2013, PEP +HerMES)

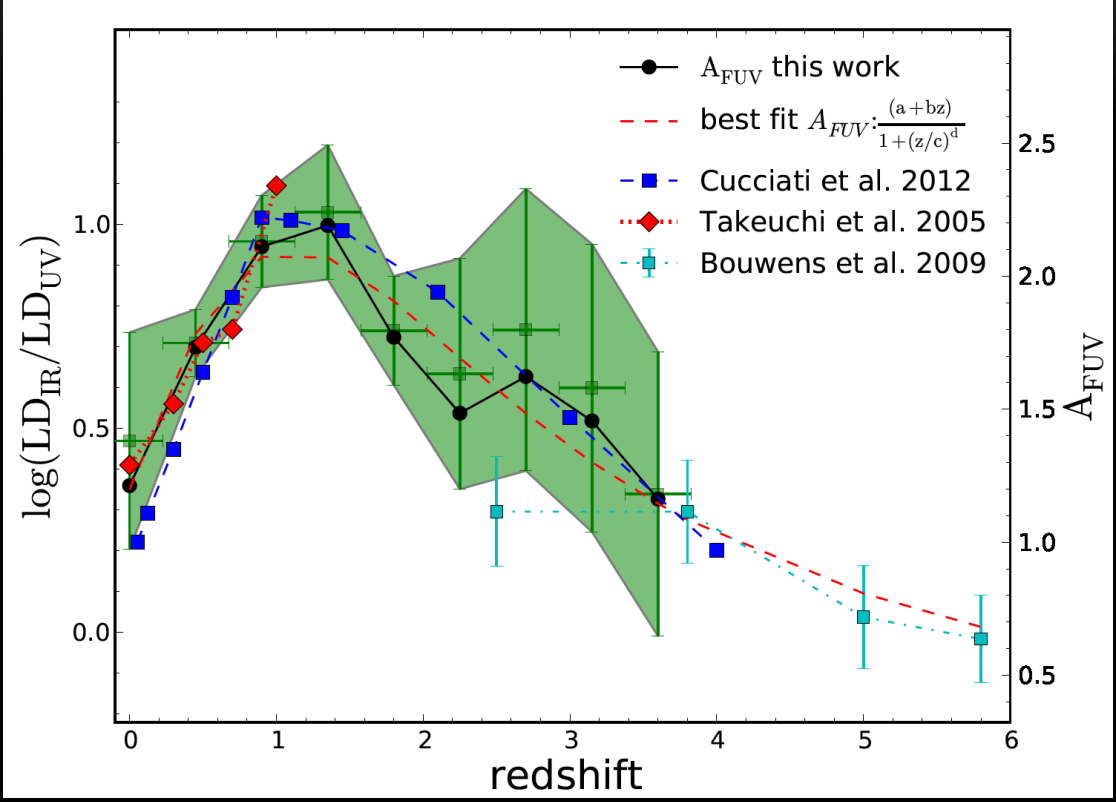
OBSCURED AND UNOBSCURED STAR FORMATION DENSITY ACROSS COSMIC TIMES



$\rho_{SFR,total} = \rho_{SFR,UV} + \rho_{SFR,IR}$

- z<3.5: obscured SFRD always dominates unobscured.
- Plateau or slight decrease at z>1
- Extrapolation of Herschel LF agrees with CIB fluctuations (Planck XXX)

EVOLUTION OF THE AVERAGE ATTENUATION



Evolution of the average attenuation of galaxies versus redshift (Burgarella et al. 2013)

- Average attenuation = ratio between all FIR and all UV in a volume of Universe
- Maximum at z~1, similar values at z=0 and z=4,
  Why?

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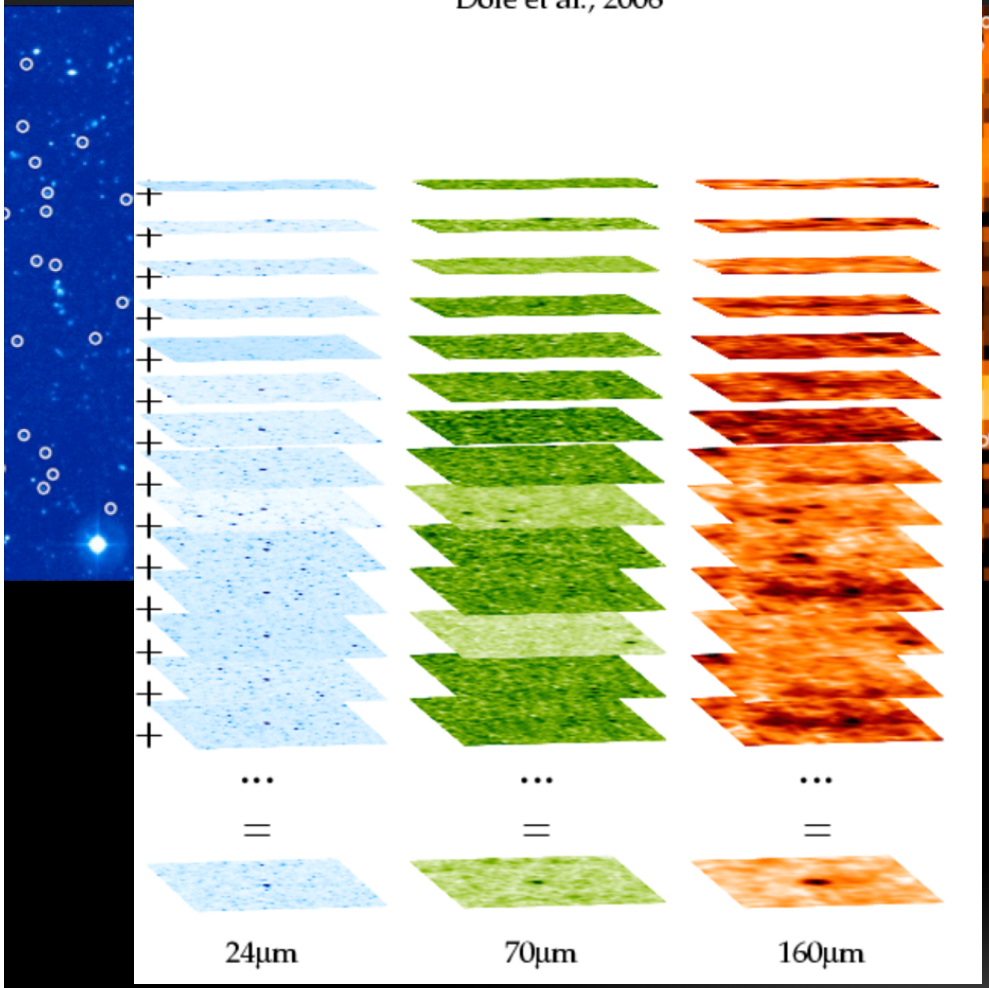
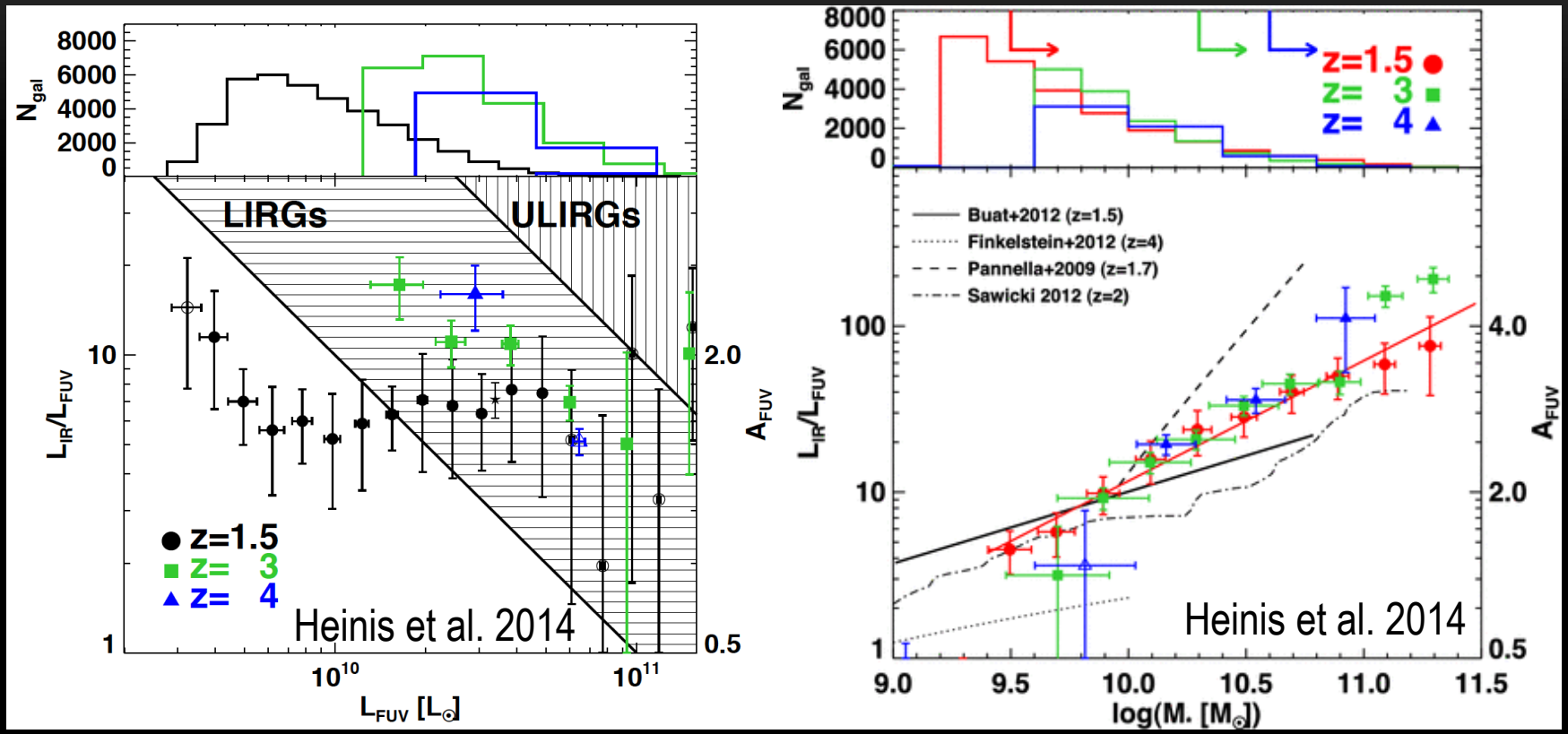
NECESSITY OF A STACKING ANALYSIS



- Small fraction of high-redshift UV sources detected in IR (<1%)
- Stacking analysis necessary for mean LIR of UV/ optically-selected galaxies

MEAN ATTENUATION AS A FUNCTION OF GALAXY PROPERTIES

LIR / LUV

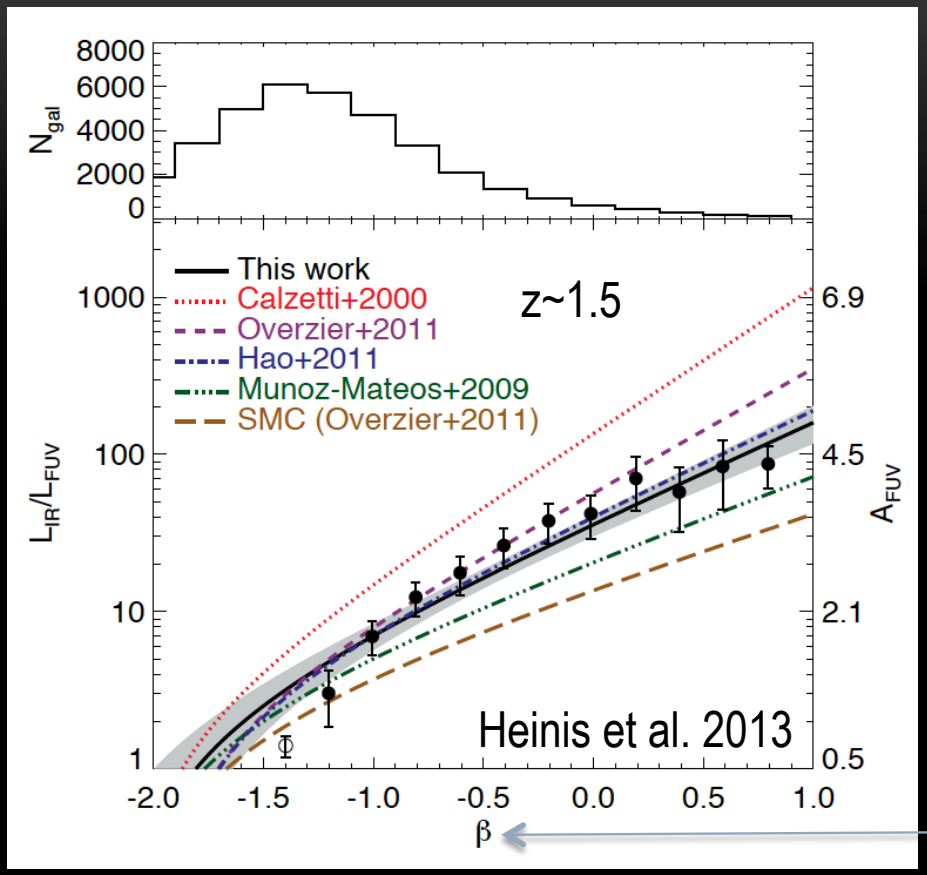


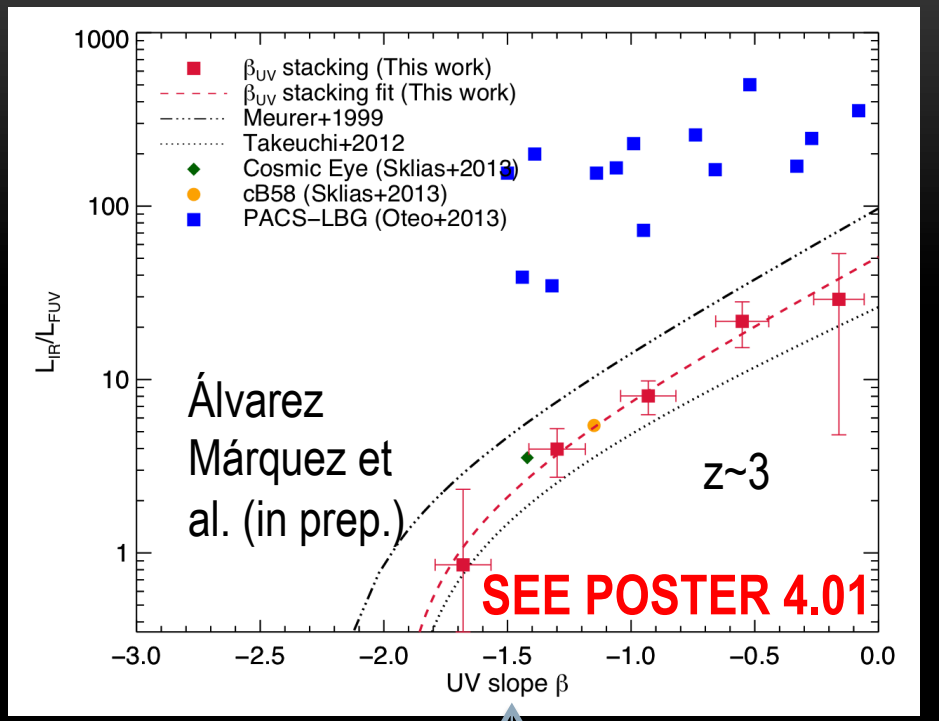
No correlation with UV luminosity… but strongly depend on stellar mass

How can we explain this?

MEAN ATTENUATION VERSUS UV SLOPE

LIR / LUV





Slope of the UV continuum

- Average attenuation versus UV continuum slope relatively similar to local relations
- LBGs with Herschel detections are strong outliers

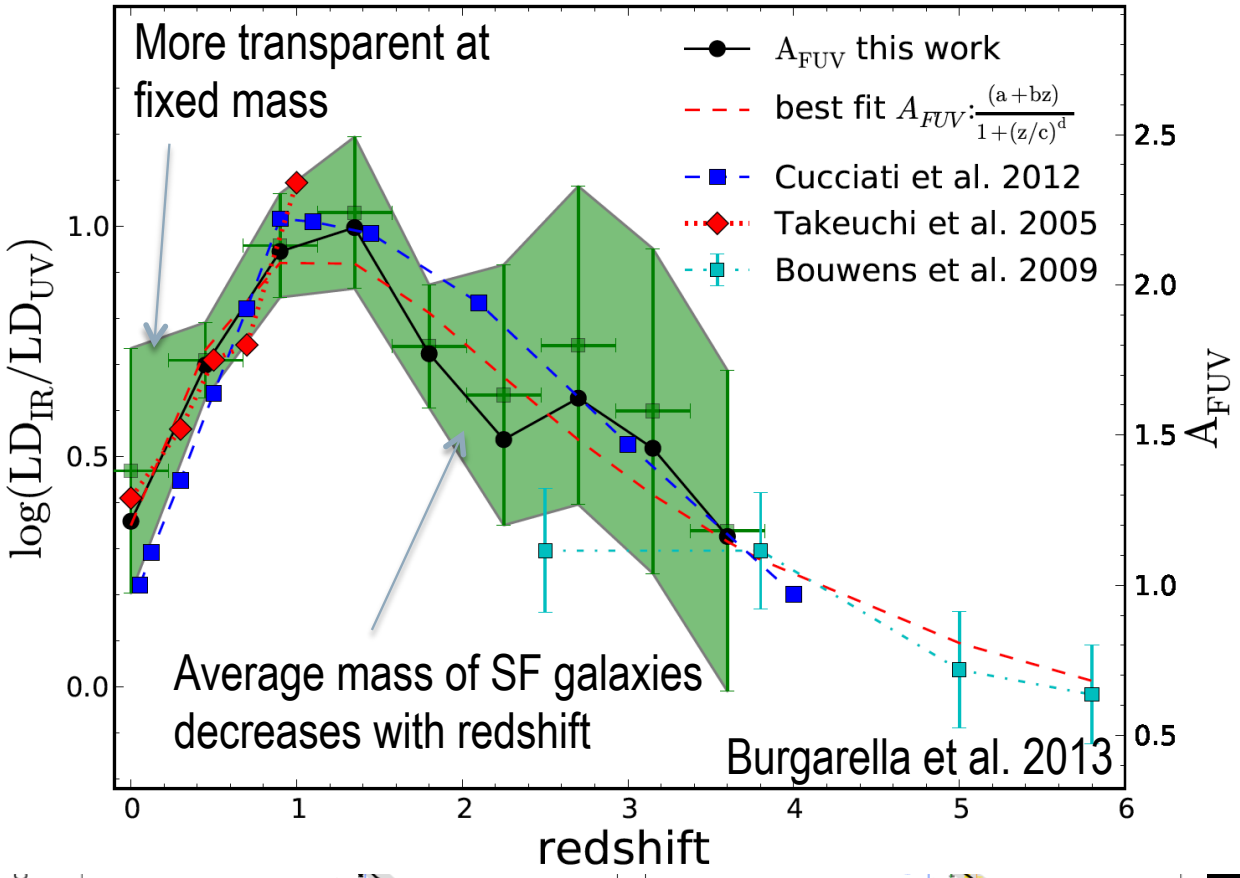
AN EMPIRICAL MODEL TO UNDERSTAND THE CONNECTIONS BETWEEN UV AND IR MODELS

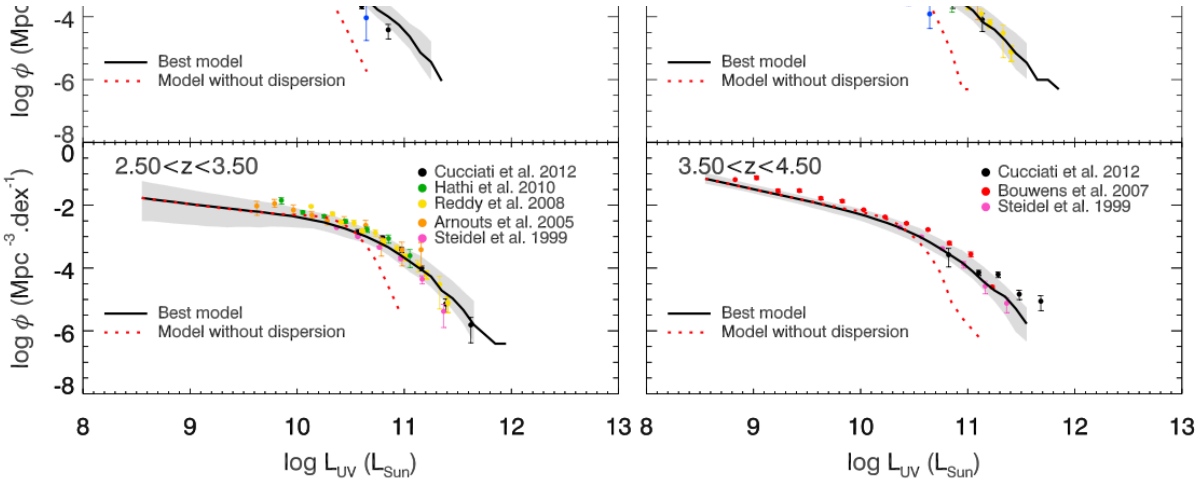
- Extension of Béthermin et al. 2012 IR galaxy model:
  - based on observed evolution of main-sequence and stellar mass function
  - population of starbursts (~3% in number, ~15% of star formation density)
  - reproduce a large set of IR observables (counts, LF, CIB fluctuations)

- Assume observed attenuation vs stellar mass of Heinis et al. (2014) and distribute SFR between an obscured an unobscured component.

Bernhard et al. (2014)

THE EVOLUTION OF THE UV LUMINOSITY FUNCTION



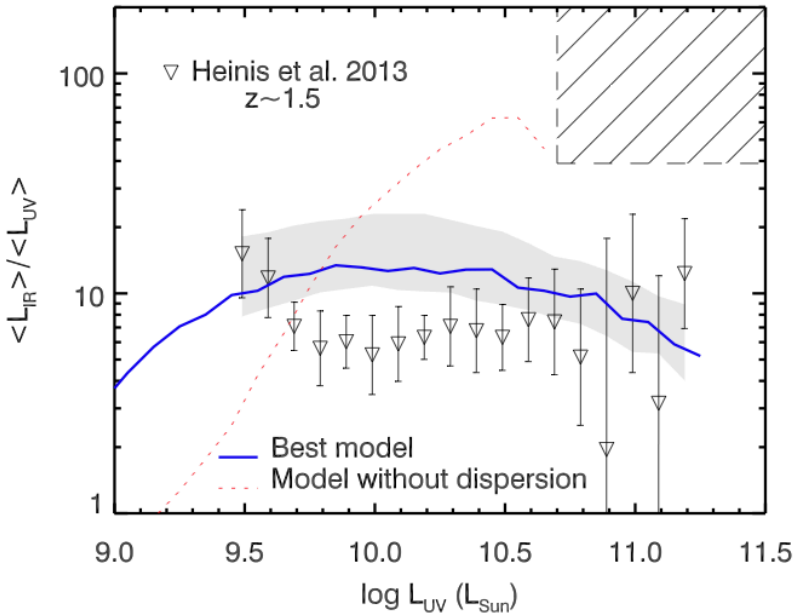


- Need a scatter of ~0.4 dex on attenuation-mass relation to reproduce UV data.
- IR almost insensitive to hypotheses on attenuation.
- Data well reproduced at z>1; Need lower attenuation at fixed mass at z<1

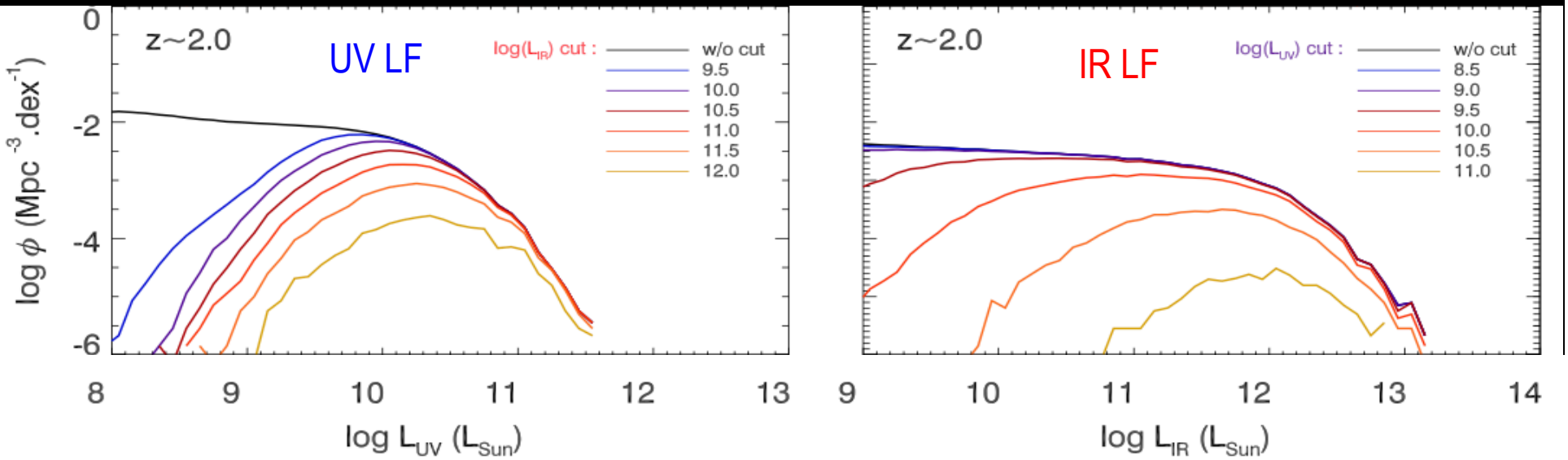
UV luminosity function (non corrected for dust attenuation) from z=0 to z=4 (Bernhard et al. 2014)

SOME INTERESTING RESULTS OF THIS WORK

- Reproduce naturally the flat attenuation vs LUV if strong scatter
- Bright and faint IR galaxies have similar LUV. UV-selected galaxies have very diverse LIR.



Attenuation as a function of the UV luminosity at z~1.5 (Bernhard et al. 2014)



Contribution of IR-selected galaxies to the UV luminosity function (left) and the inverse (right) (Bernhard et al. 2014)

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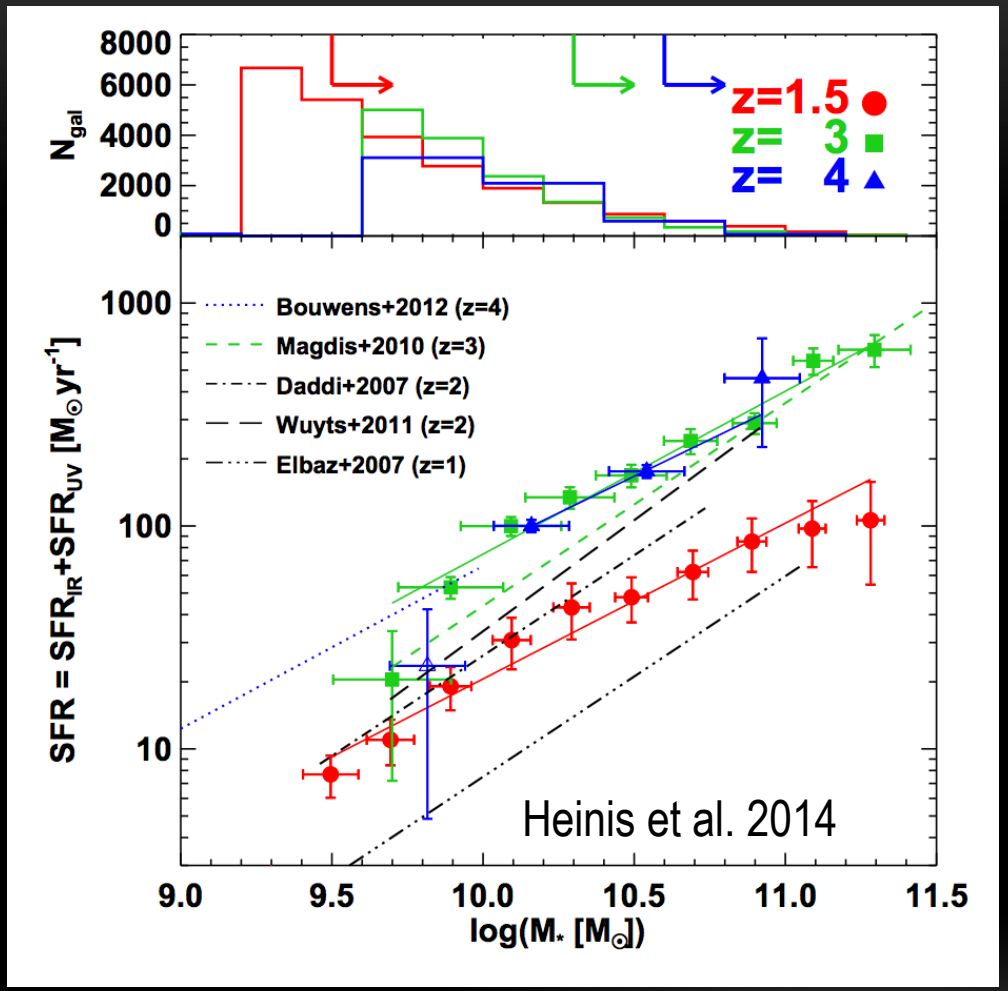
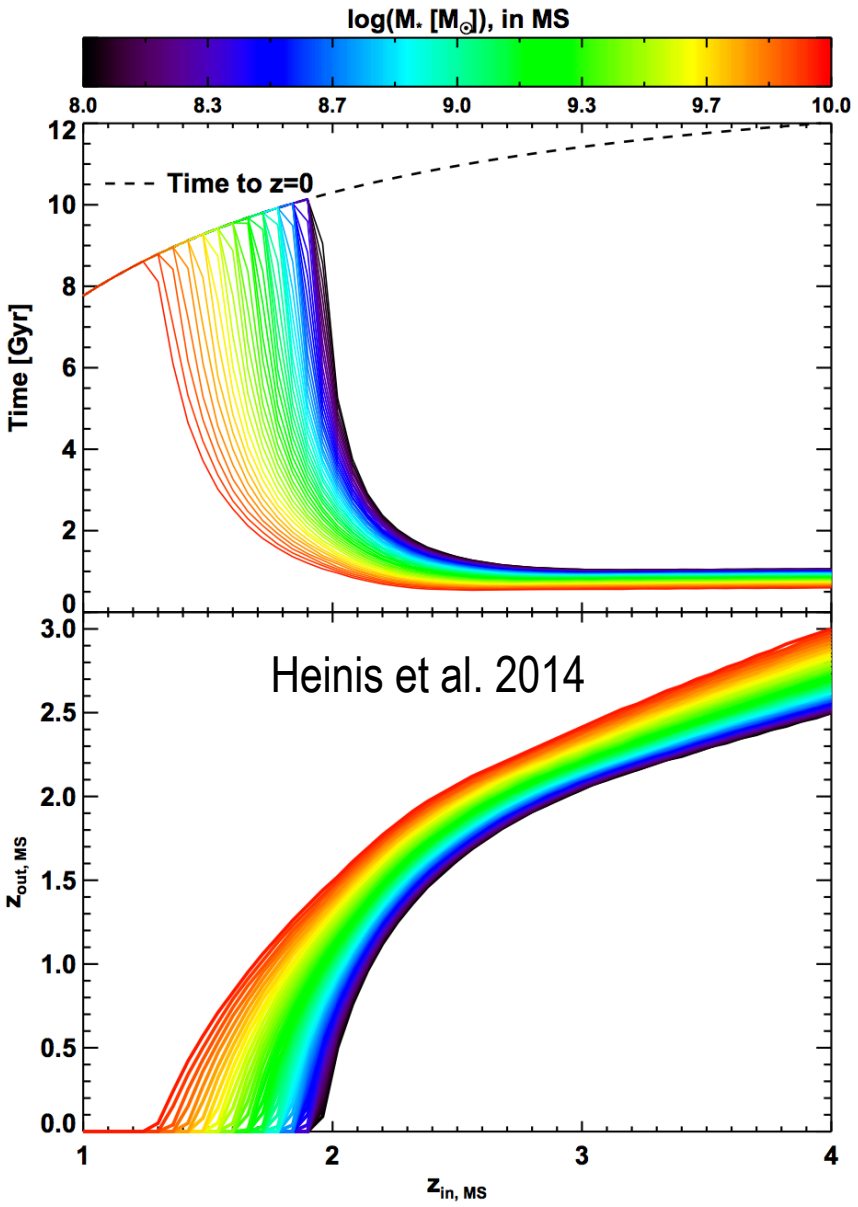
MAIN-SEQUENCE OF STAR-FORMING GALAXIES



- ULIRG star-formation rate in >10^{10} Msun galaxies at z=3-4
- Still a relation between average SFR and Mstar at z>2 when using IR.
- How can we explain such high star-formation rates?

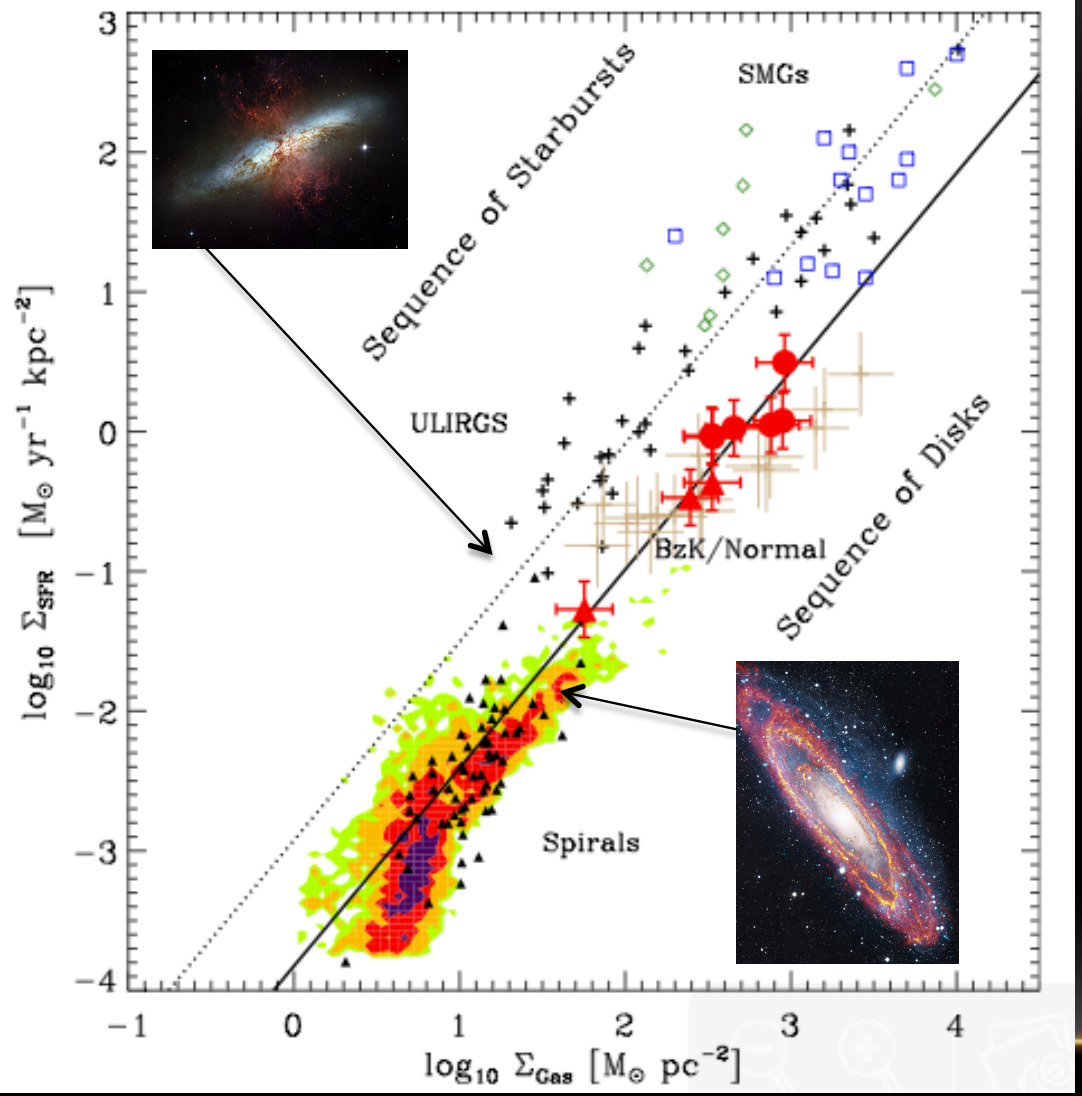
See also Corentin Schreiber's talk

HOW LONG CAN GALAXY STAY ON THE MAIN SEQUENCE?



- Majority of Mstar=10^{11} Msun galaxies quenched at low and highz (e.g., Ilbert et al. 2013)
- Galaxies entering on the MS at z=4 should reach this ‘quenching mass’ around z=2.5
- High-z main-sequence should be star-forming only during ~500 Myr.

MOLECULAR GAS IN NORMAL STAR-FORMING GALAXIES AND STARBURSTS

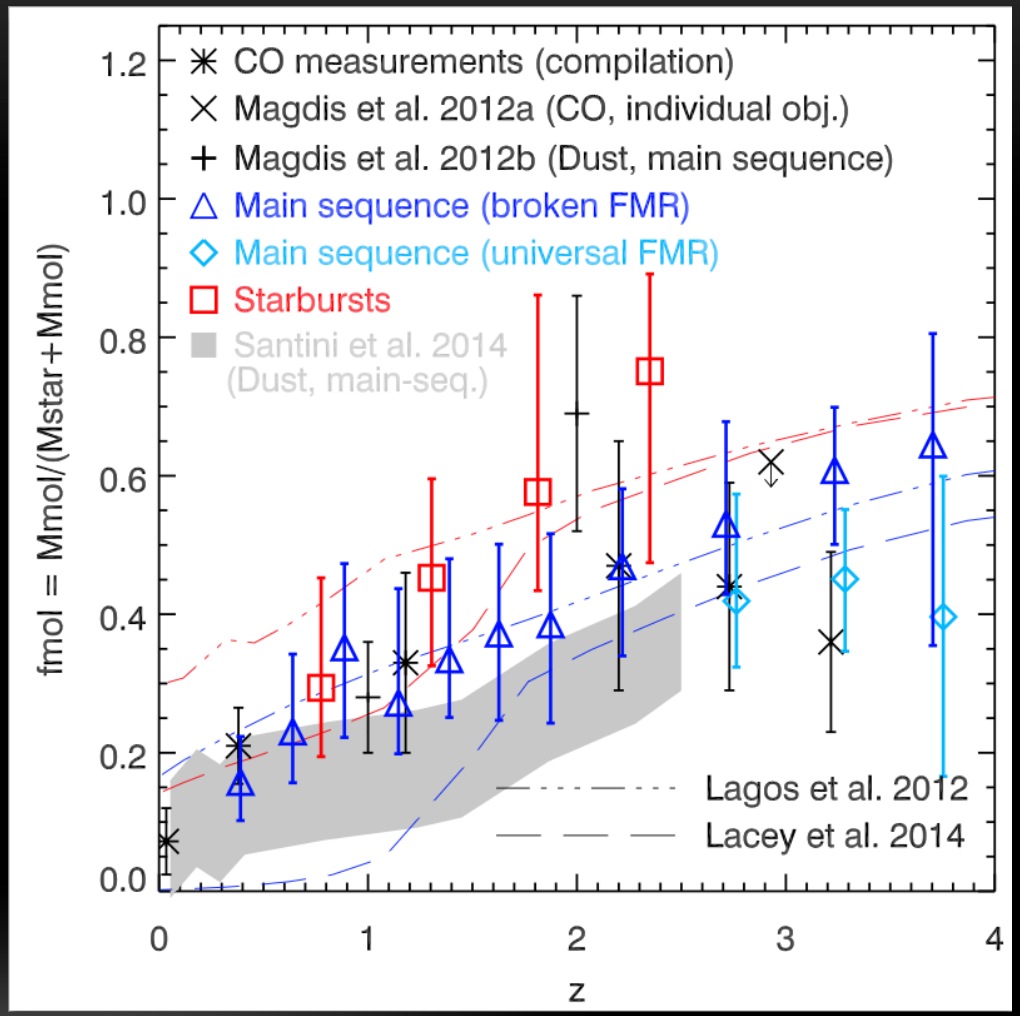


- Local Universe: most of the star formation in disk galaxies; higher SFR (higher IR luminosity) in mergers-induced starburst.
- Two sequences of star-formation for normal and starburst galaxies: star formation efficiency higher in mergers.
- High SFR at high z: more gas or merger-induced?

Relation between the surface density of gas and of star fornation for normal star-forming and starbursts galaxies (Daddi+10, see also Genzel+10)

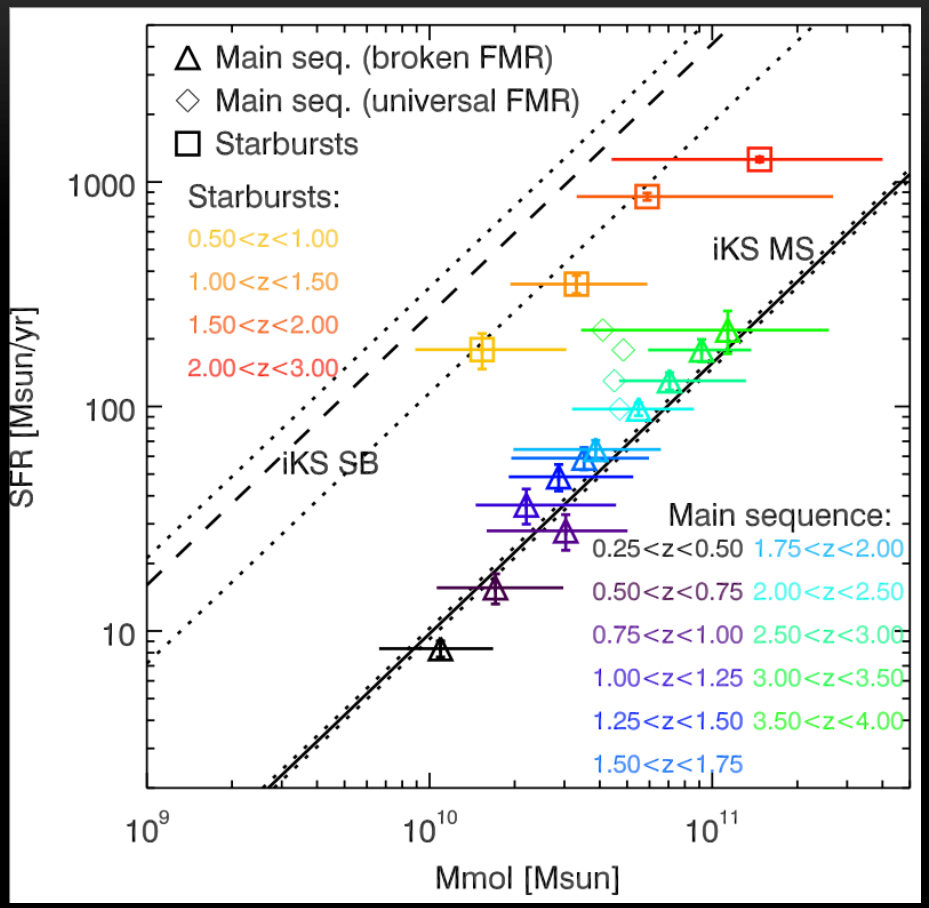
EVOLUTION OF THE GAS FRACTION WITH REDSHIFT

- Sample of star-forming galaxies with Mstar>3x10^{10} Msun
- Average dust content from stacking analysis of Spitzer, Herschel, LABOCA, and AzTEC data.
- Converted into gas mass using locally calibrated G/D vs Z.
- Quick rise up to z=2, slower at higher z.



Evolution of the average gas fraction with redshift (Béthermin et al. 2014)

CONSEQUENCES ON THE NATURE OF THE STAR-FORMATION PROCESSES AT HIGH REDSHIFT



Average properties of our objects in the integrated Schmidt-Kennicutt diagram (Béthermin et al. 2014)

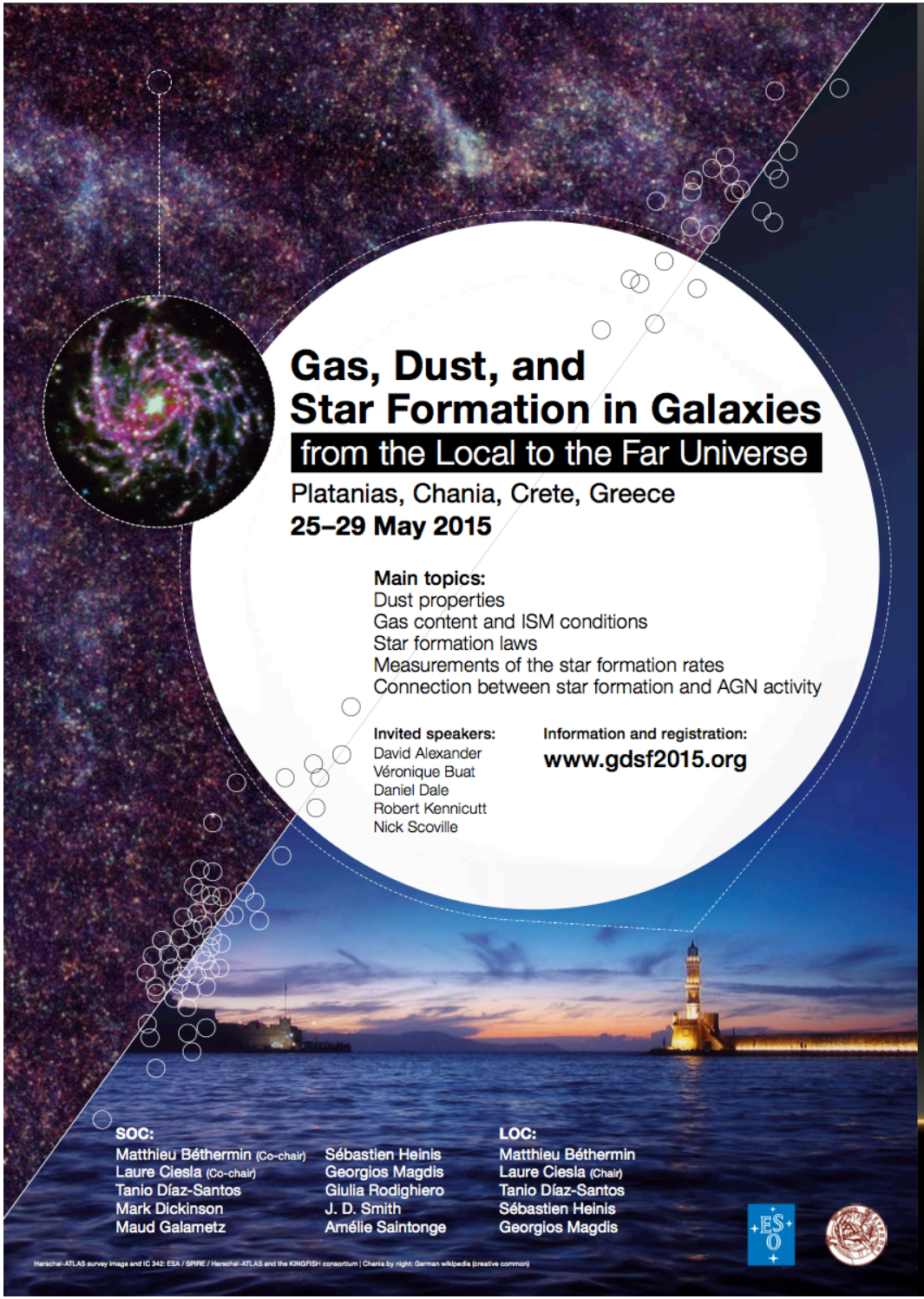
- Check the position of our average measurements in the integrated Schmidt-Kennicutt diagram (Sargent+13 compilation used here).
- Average star formation in main-sequence galaxies follows the trend of normal galaxies (local spiral, BzK, see Daddi+10b)
- Quick rise of the sSFR driven by the larger gas reservoirs.

CONCLUSION

- Obscured star formation history probed up to z=4.
  IR still dominates UV.
  Crossing at z=5?, 6?

- Attenuation strongly correlates with mass, but not UV flux
  Can be understood with statistical models
  Complex selection biases for UV or IR-selected samples

- Existence of SFR-Mstar relation at z=4
  Massive galaxies on average in the same locus as local spiral in SK diagram
  Suggest that SF at z=4 is dominated by gas rich objects, not major mergers driven starbursts



Gas, Dust, and Star Formation in Galaxies from the Local to the Far Universe

25-29 May 2015

Chania, Crete, Grece

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Deadline for abstract: 26 Jan 2015