WHAT ARE IR-DETECTED HIGH-REDSHIFT GALAXIES AND HOW WELL CAN WE MODEL THEM?

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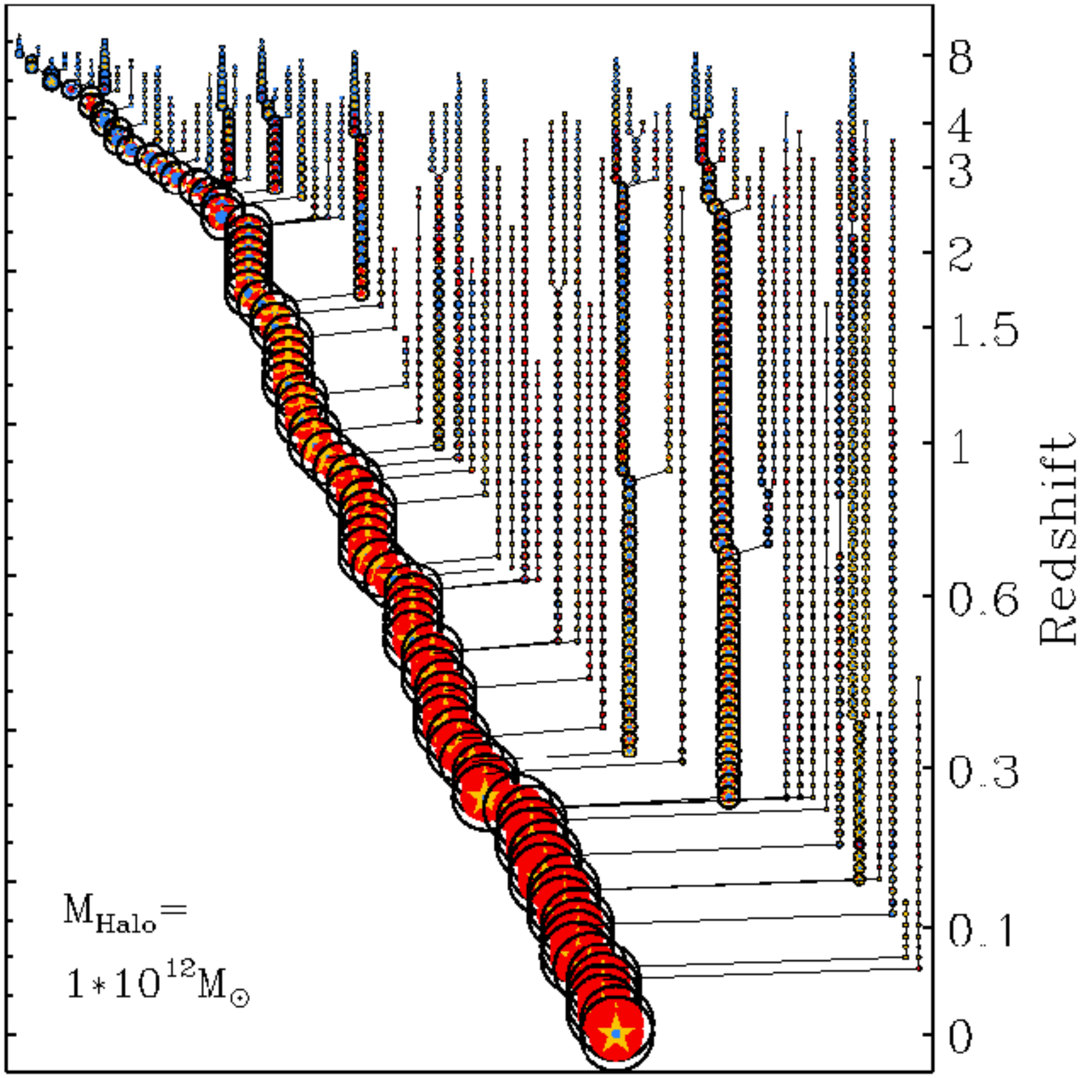
REFERENCES

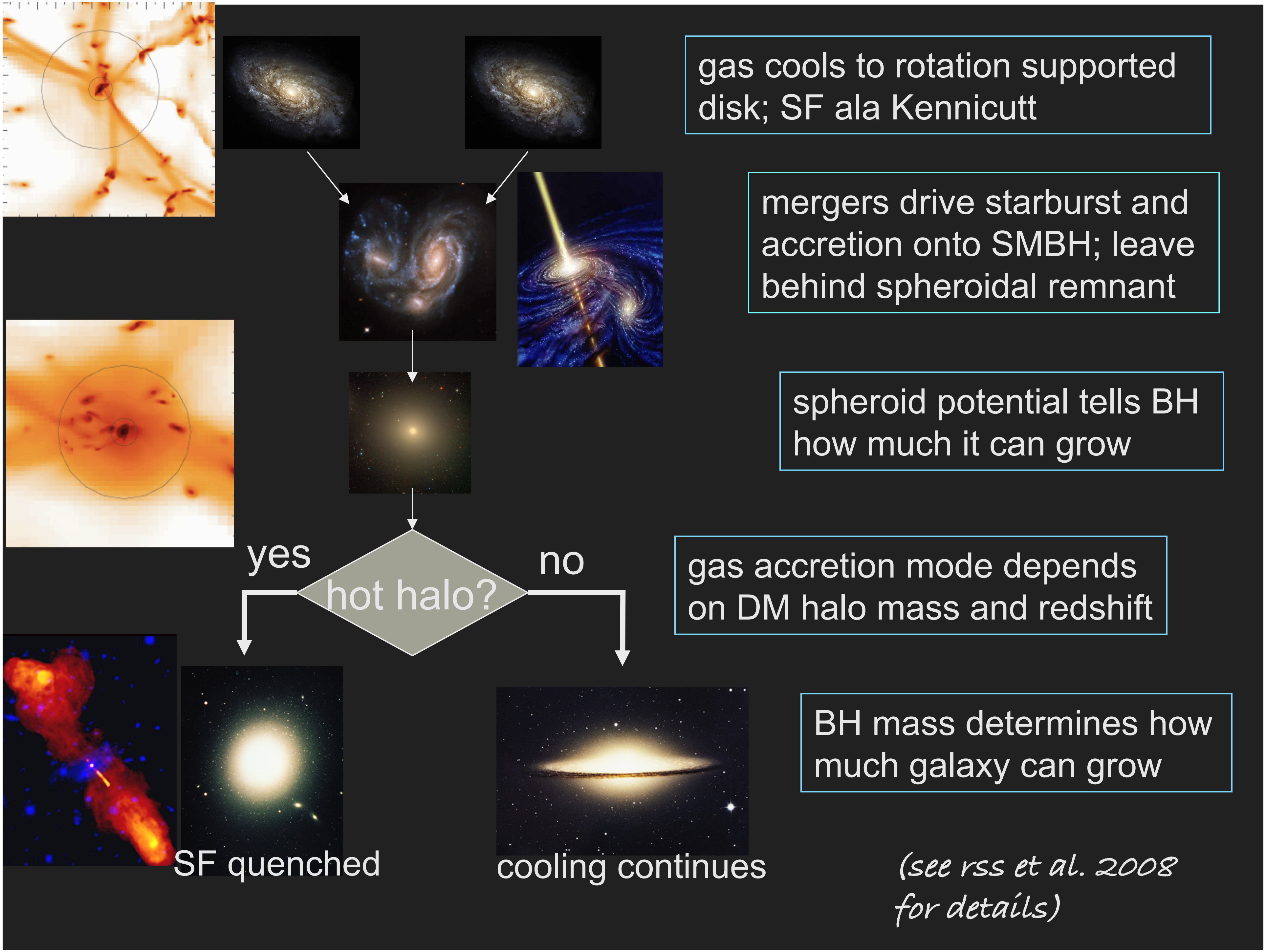
- rss, Gilmore, Primack & Dominguez 2011 (SGPD11; submitted, on astro-ph)
- Niemi, rss, Ferguson et al. 2011 (submitted, on astro-ph soon)
- Fontanot, rss et al. 2009; Fontanot & rss 2011 (published)



Hirschmann et al. 2010

- shock heating & atomic cooling
- photoionization squelching
- merging
- star formation (quiescent & burst)
- SN heating & SN-driven winds
- chemical evolution
- stellar populations & dust

e.g. White & Frenk 1991
Kauffmann et al. 1993
Somerville & Primack 1999
Cole et al. 2000


gas cools to rotation supported disk; SF ala Kennicutt
mergers drive starburst and accretion onto SMBH; leave behind spheroidal remnant
spheroid potential tells BH how much it can grow
gas accretion mode depends on DM halo mass and redshift
BH mass determines how much galaxy can grow
yes
hot halo?
no
SF quenched
cooling continues
(see rss et al. 2008 for details)

CURRENT MODELS MATCH MANY OPTICAL/NIR GALAXY OBSERVATIONS:

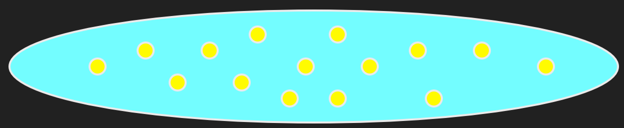
- galaxy stellar mass function (0<z<4)*
- SFR vs. stellar mass rln (0<z<4)*
- gas fraction vs. stellar mass (z=0)
- mass-metallicity relation (z=0)
- global star formation and stellar mass assembly history (0<z<6)
- shorter SF timescales & earlier quenching of massive galaxies (i.e. "downsizing")
- fraction of early vs. late type galaxies as fcn of stellar mass
- positive [α/Fe] vs. mass/sigma correlation for early type galaxies

Bower et al. 2006; Croton et al. 2006; de Lucia & Blaizot 2007
rss et al. 2008; Kimm et al. 2008; Fontanot et al. 2009
Hopkins, rss et al. 2009; Arrigoni et al. 2009

MODELING DUST ABSORPTION AND EMISSION

- hydrodynamic simulations + full (3D) radiative transfer in post-processing (e.g. Jonsson et al. 2005 (*Sunrise*) – Narayanan talk)
- SAM + full radiative transfer applied within simplied geometries (e.g. Silva et al.1998 (GRASIL); Lacey et al. '07; Fontanot et al. '07 – Benson talk)
- SAM + analytic recipes for dust absorption & dust emission templates (e.g. Guiderdoni et al. 1987; Devriendt & Guiderdoni 2000)

DUST ABSORPTION



two-component model:
diffuse 'cirrus'
dense 'birthclouds'

optical depth of 'cirrus' dust proportional
to column density of metals/gas in disk $\tau_c \sim Z_{gas}\, N_{gas}$
stars and dust assumed uniformly mixed in a 'slab'

optical depth of 'birthclouds' proportional to τ_c
stars within birthclouds enshrouded within a 'screen' of dust
stars are freed from birthclouds on timescale $\sim 10^7$ yr

Charlot & Fall 2000; de Lucia & Blaizot 2007;
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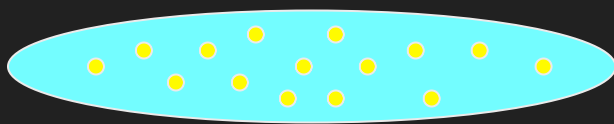
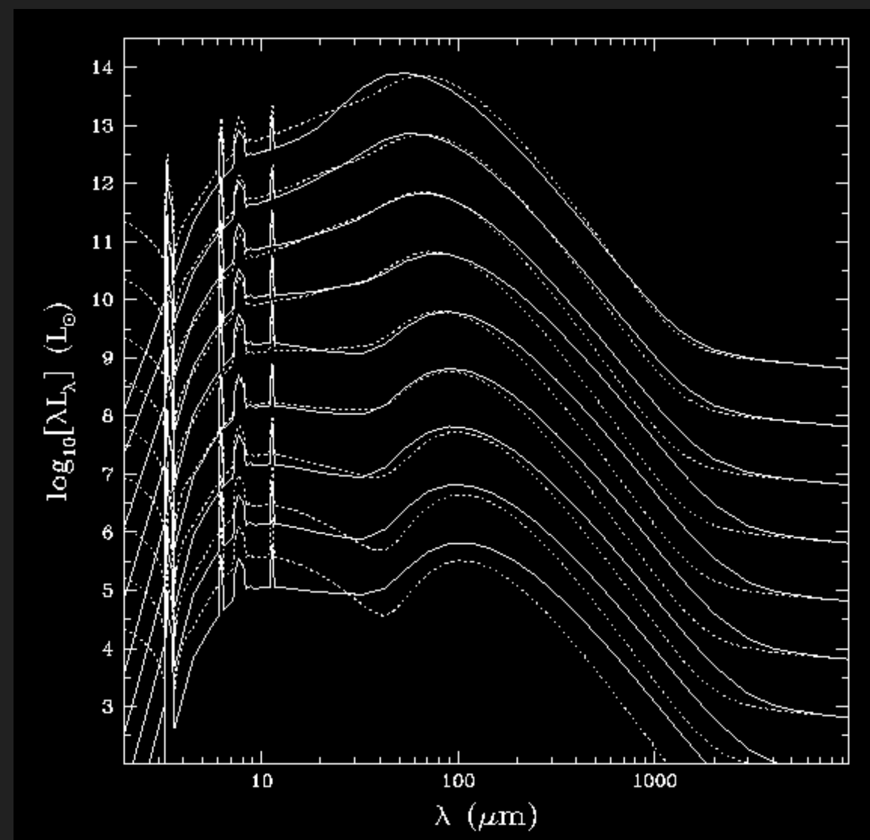
DUST EMISSION



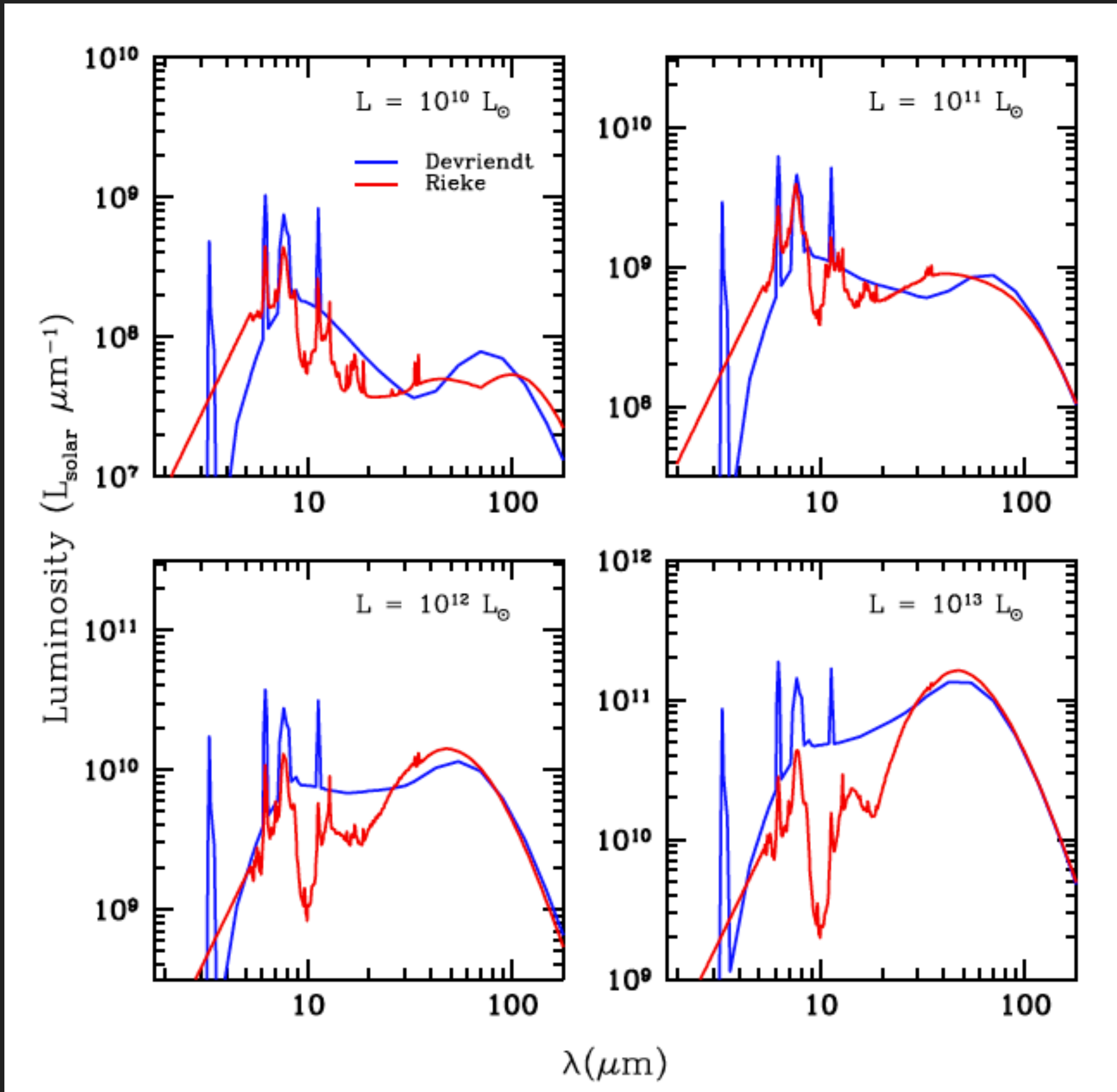
energy emitted = energy absorbed

empirical template emission spectra: L_{dust} determines shape of emission spectrum (ratio of warm/cold dust)



e.g. Sanders & Mirabel 1996; Devriendt, Guiderdoni & Sadat 2000; Chary & Elbaz 2001

DUST EMISSION TEMPLATES



Devriendt et al. 1999
Rieke et al. 2009

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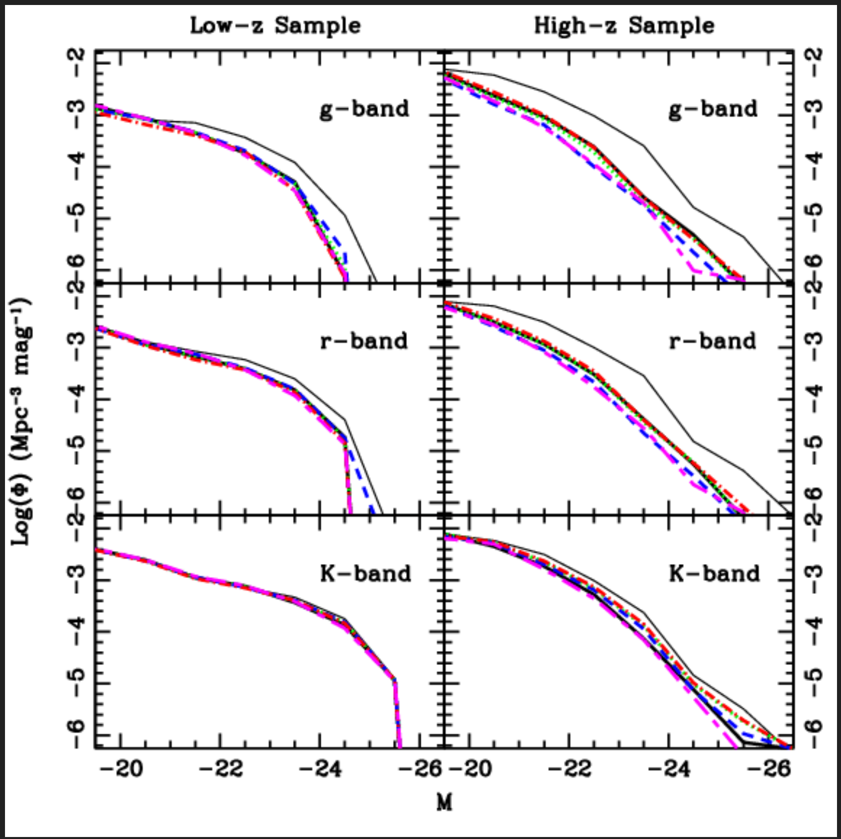
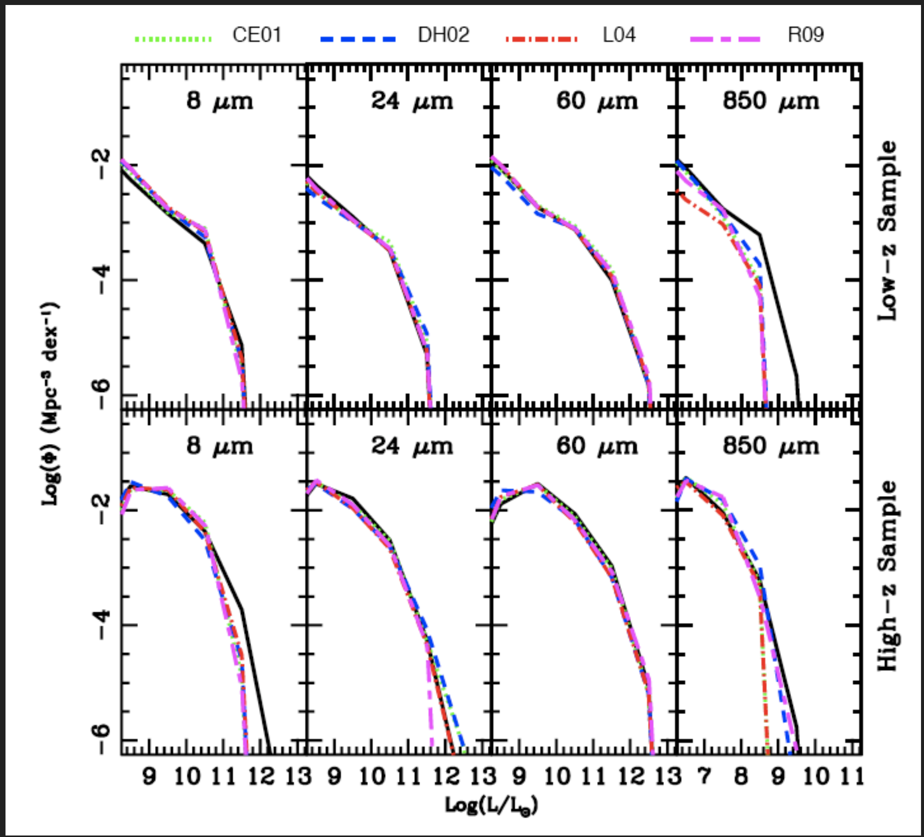
SANITY CHECK

for most statistical quantities (such as LF and counts), the semi-analytic dust recipe gives similar results to full RT with GRASIL (assuming simplified geometries)

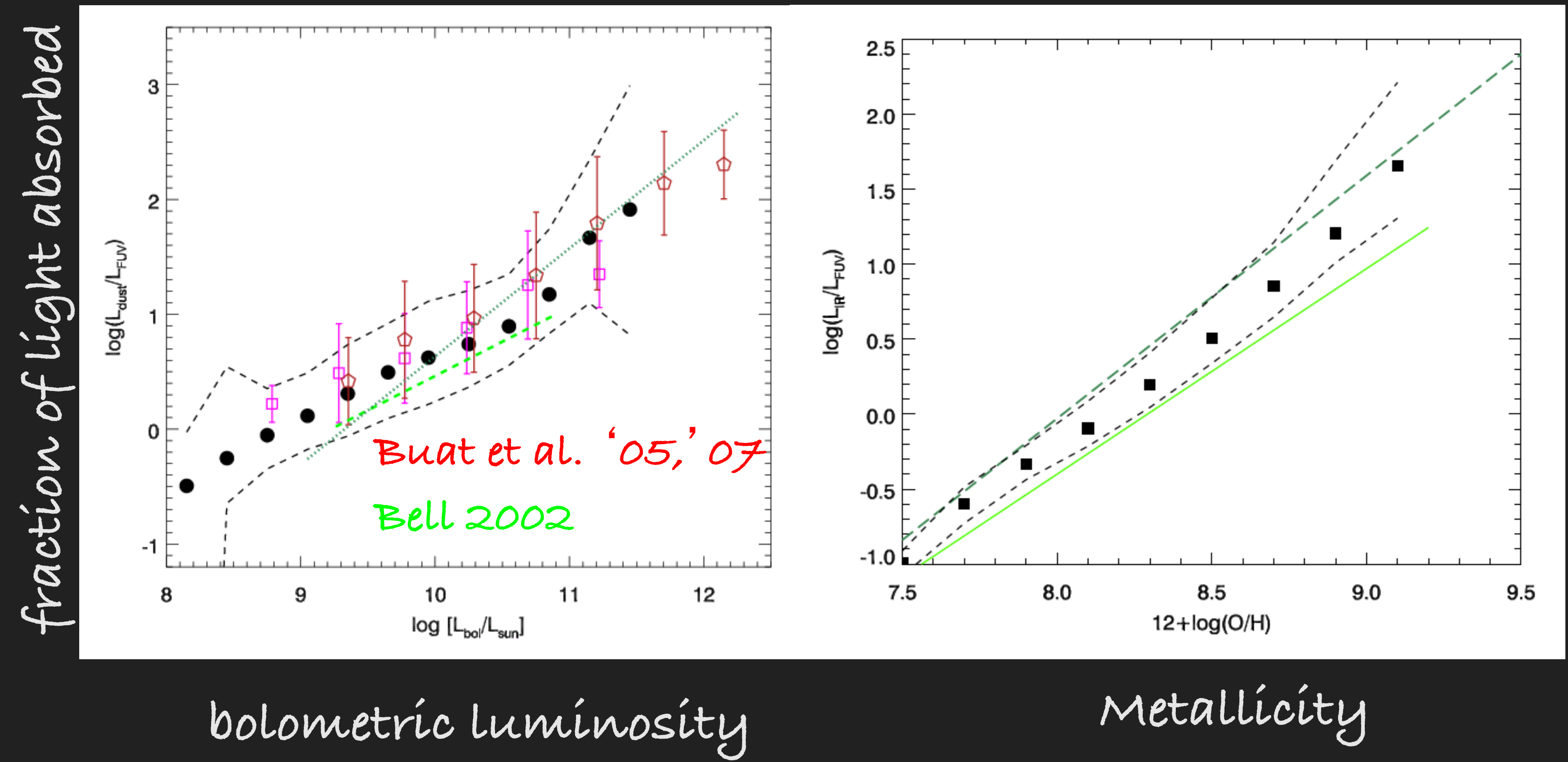




Fontanot, rss, Silva, Monaco, Skibba 2009

Fontanot & rss 2011

DUST ABSORPTION AT Z=0



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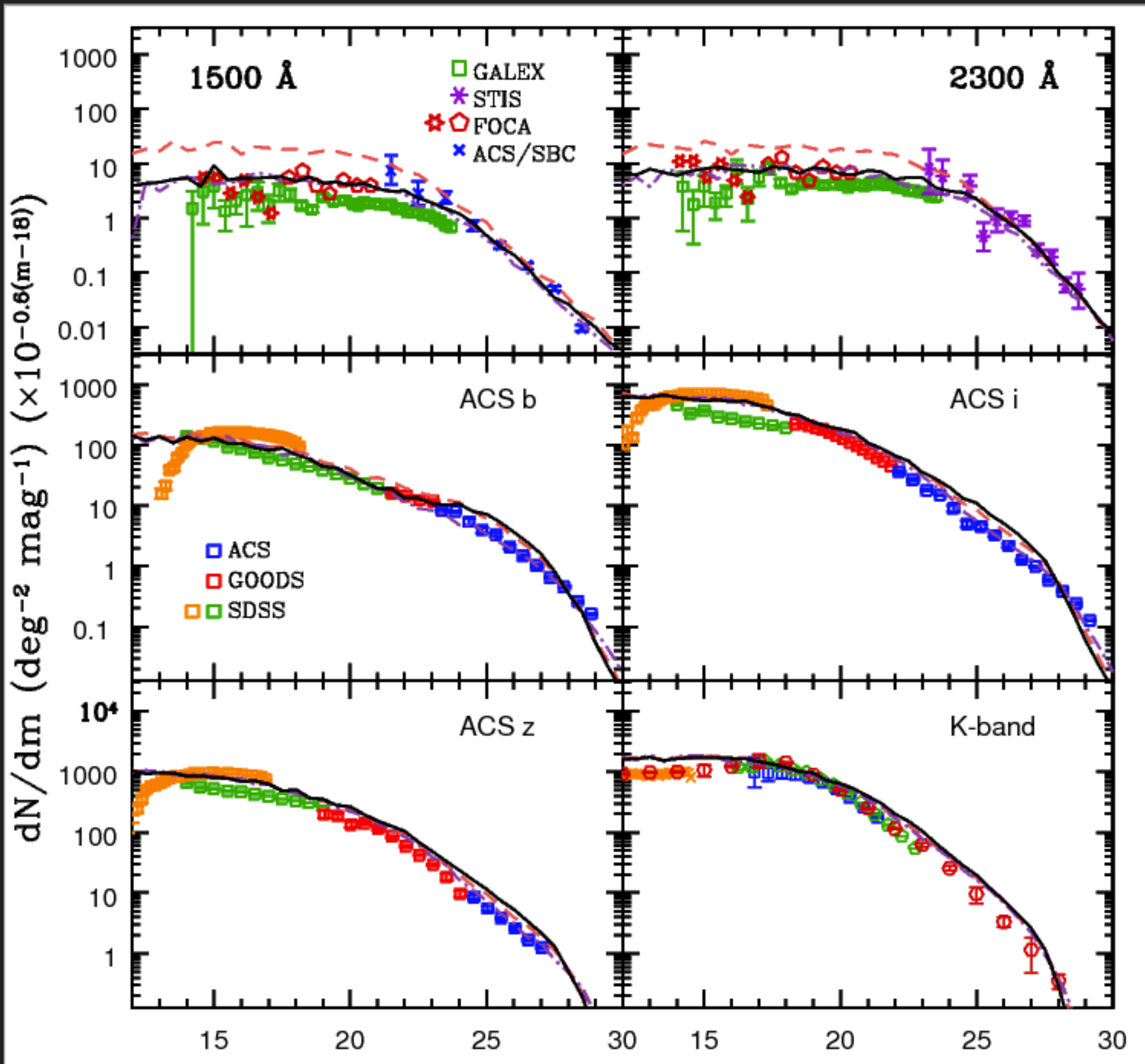
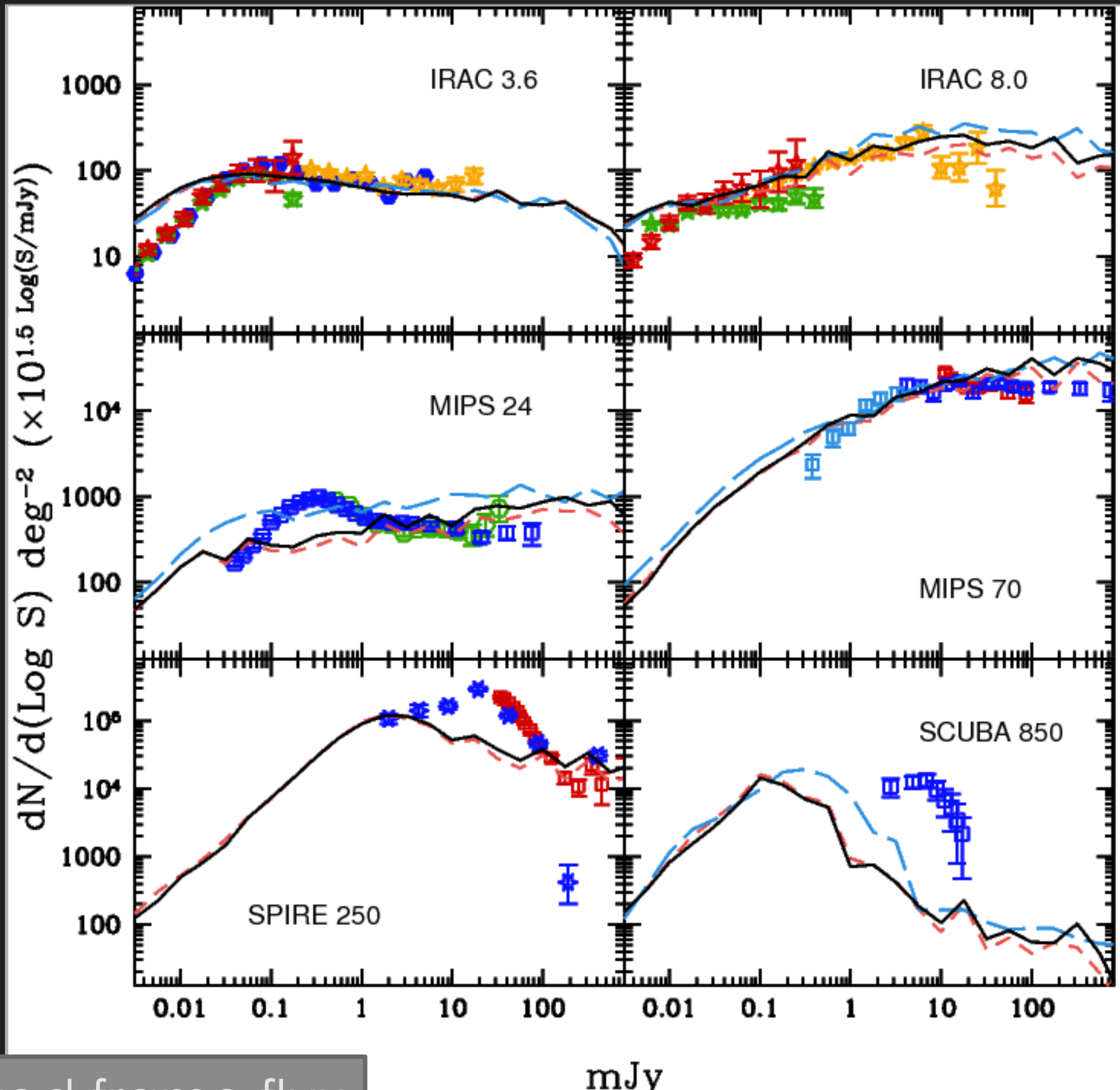

1500 Å
2300 Å
GALEX
STIS
FOCA
ACS/SBC
ACS b
ACS i
ACS
GOODS
SDSS
ACS z
K-band
dN/dm (deg⁻² mag⁻¹) (×10^{-0.6(m-18)})
observed frame magnitude

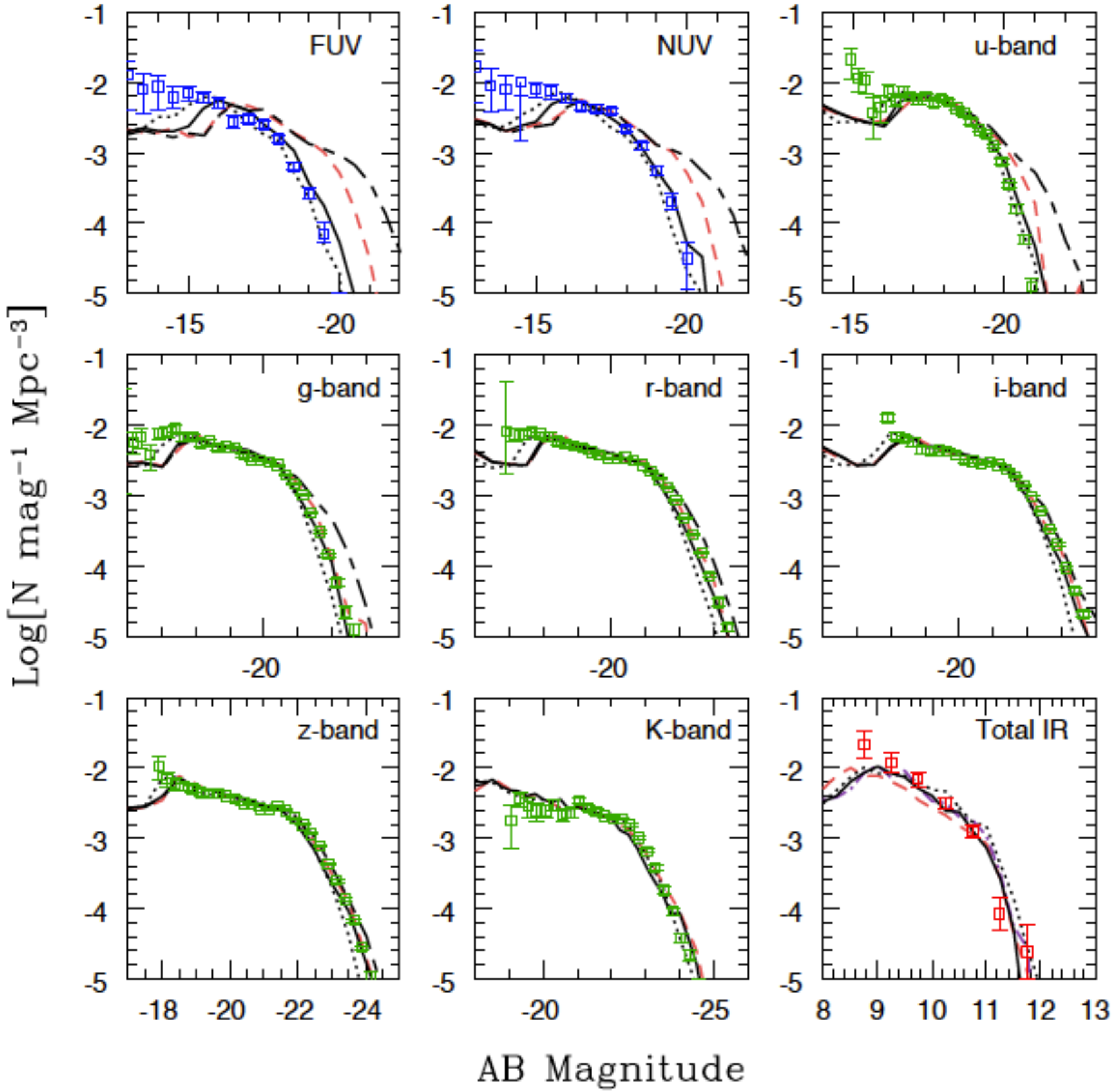
SGPD11



black = Rieke et al. 2009
blue= Devriendt et al. 1999 dust emission templates

observed frame flux

SGPD11



z=0
rest frame

solid black=
fiducial model

need 'composite'
attenuation law
to fit optical
& UV

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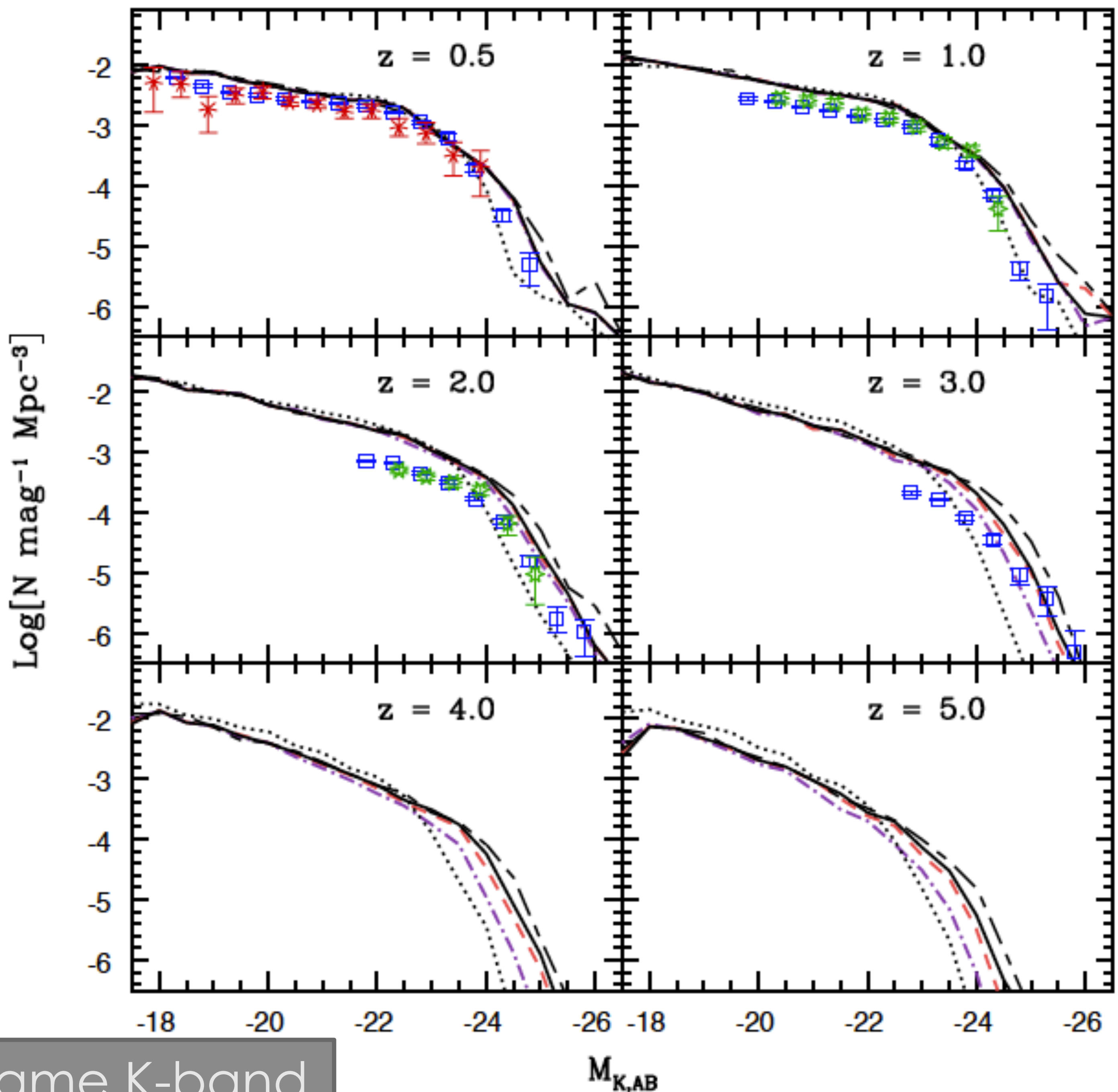
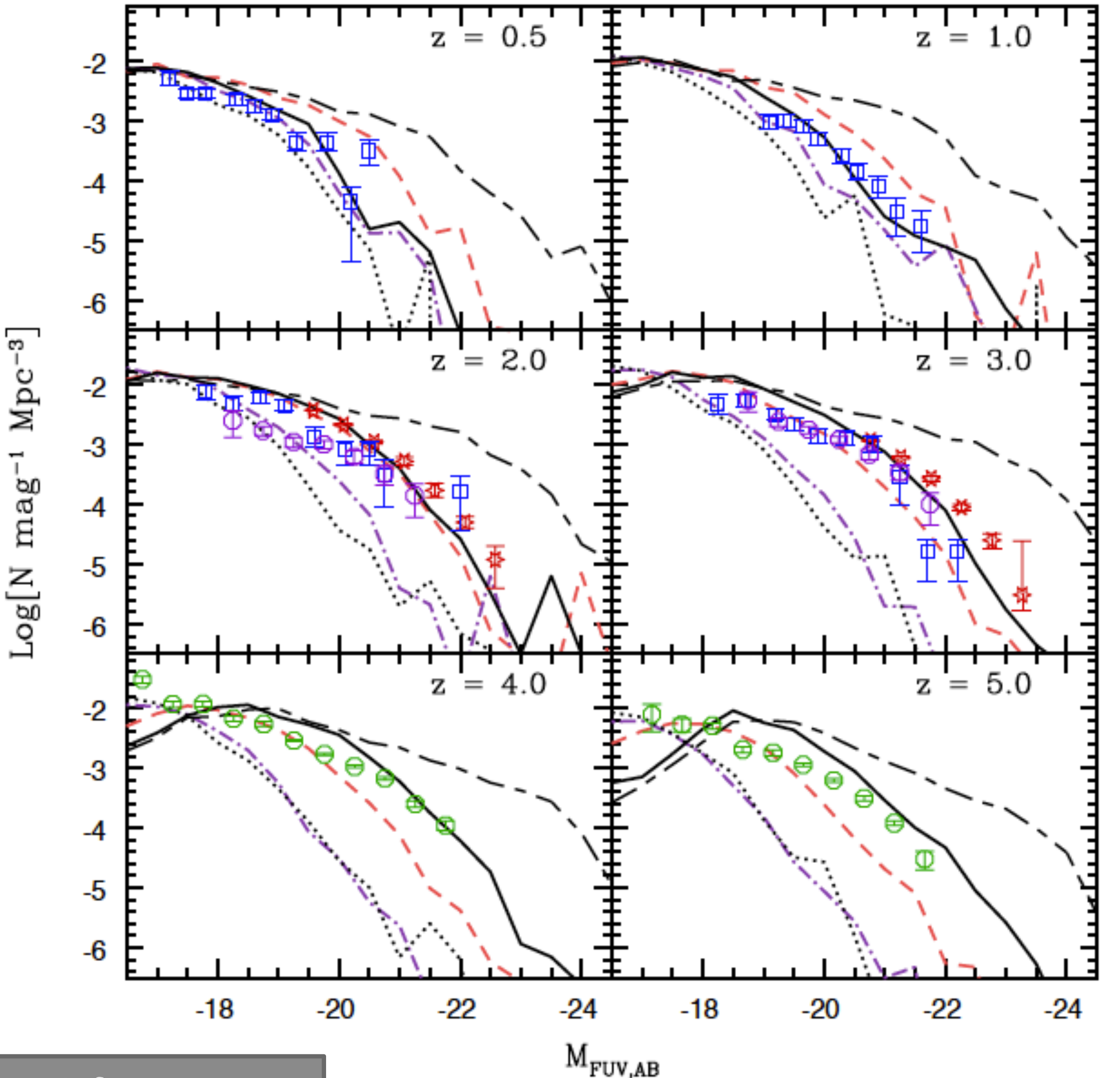


rest frame K-band

SGPD11



dot-dash: no dust

black=fiducial (evolving dust)

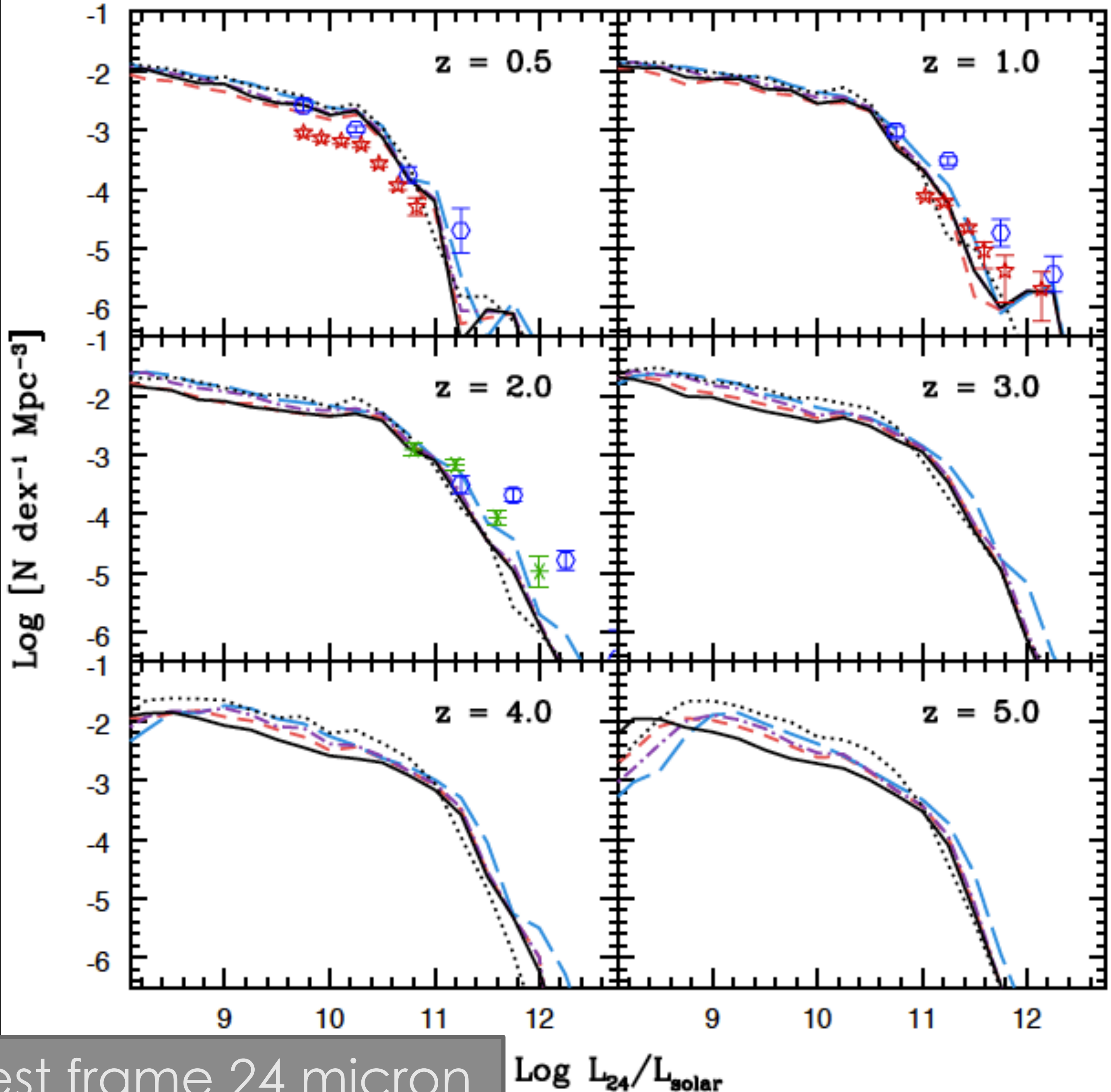
purple=fixed dust

red=Calzetti+ fixed dust

galaxies must be less extinguished at high-z

rest frame UV

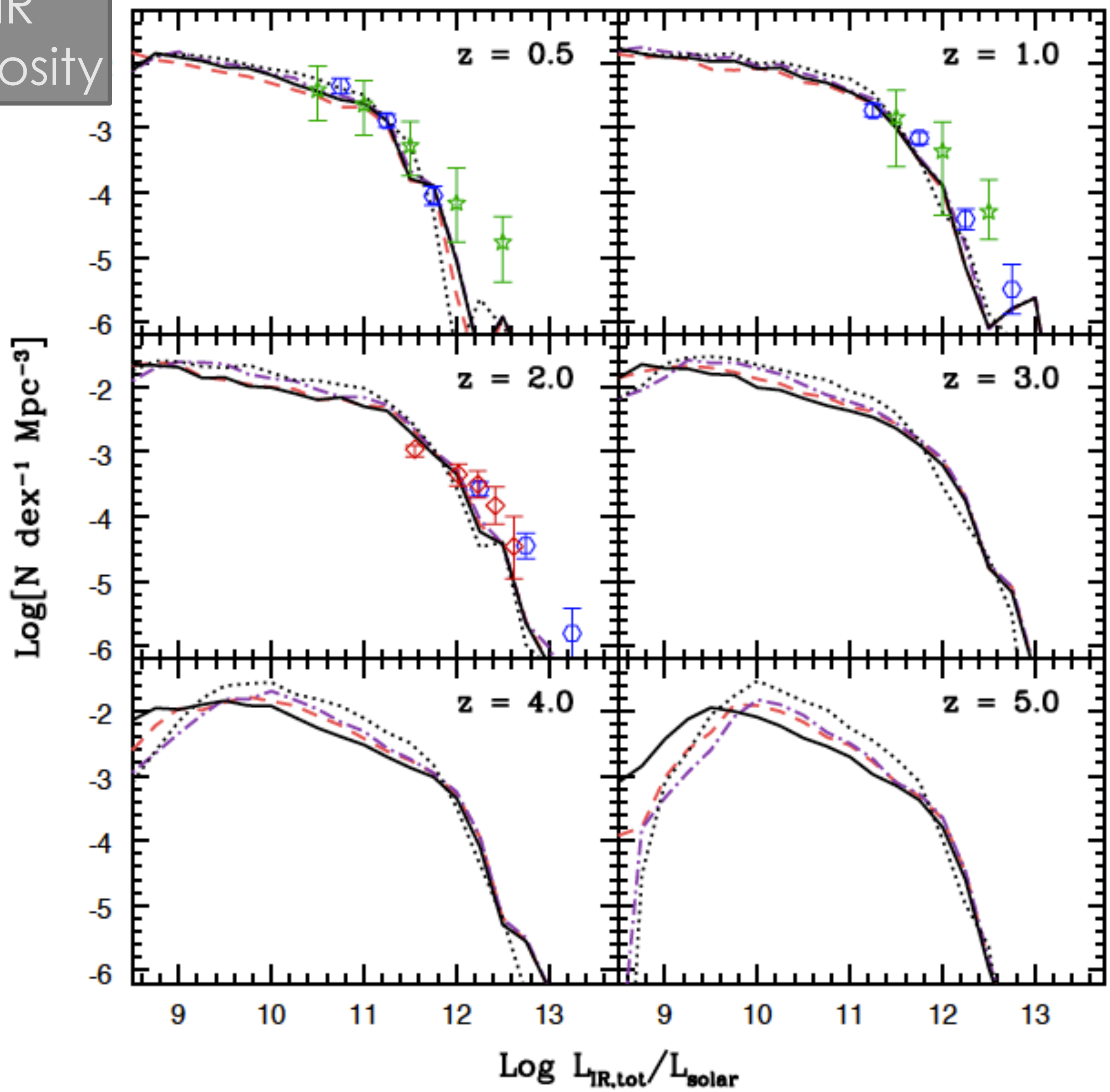
SGPD11



rest frame 24 micron

black=fiducial
blue=DGS99
dust emission
templates

total IR luminosity



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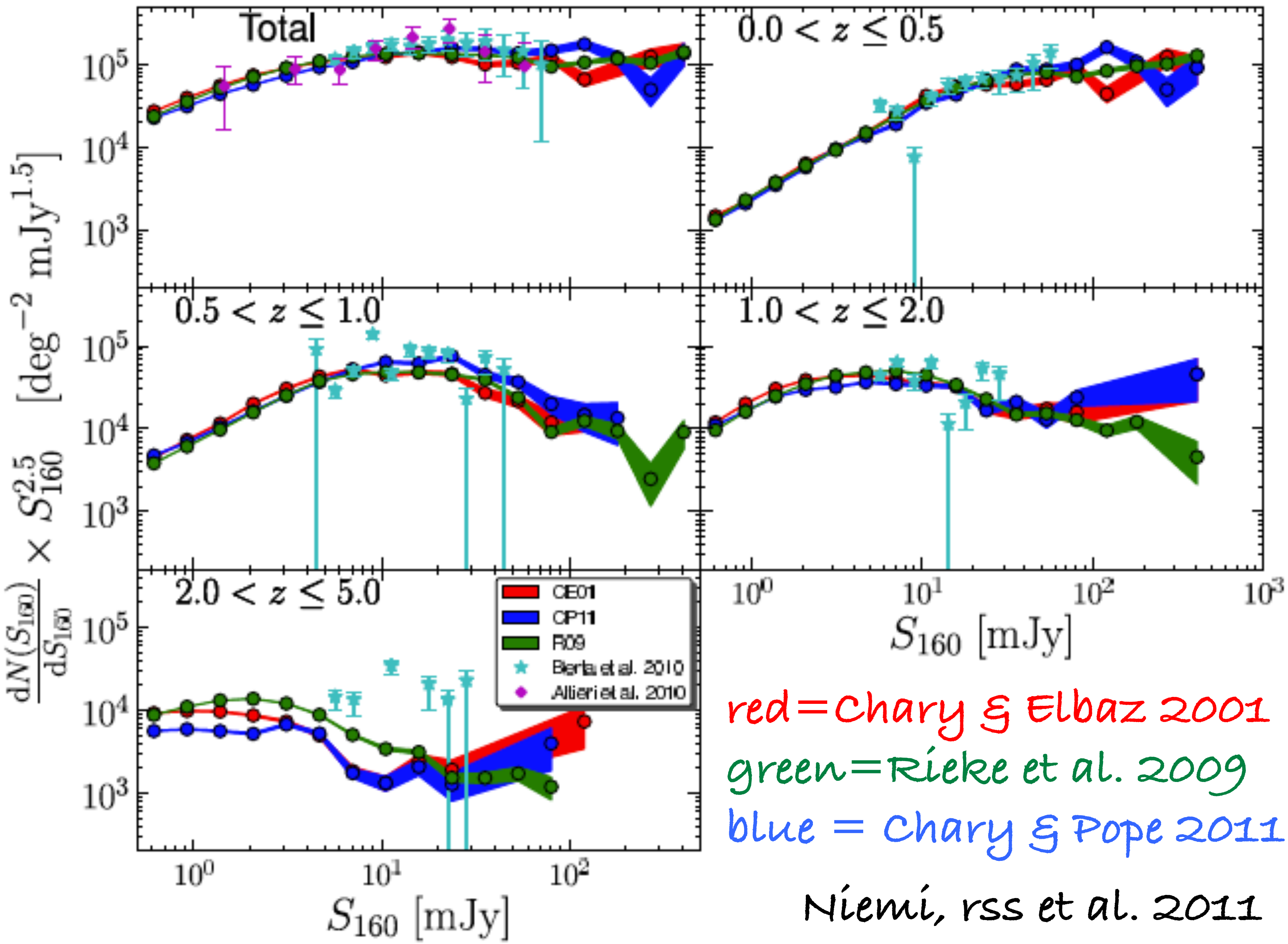
Herschel predictions: PACS



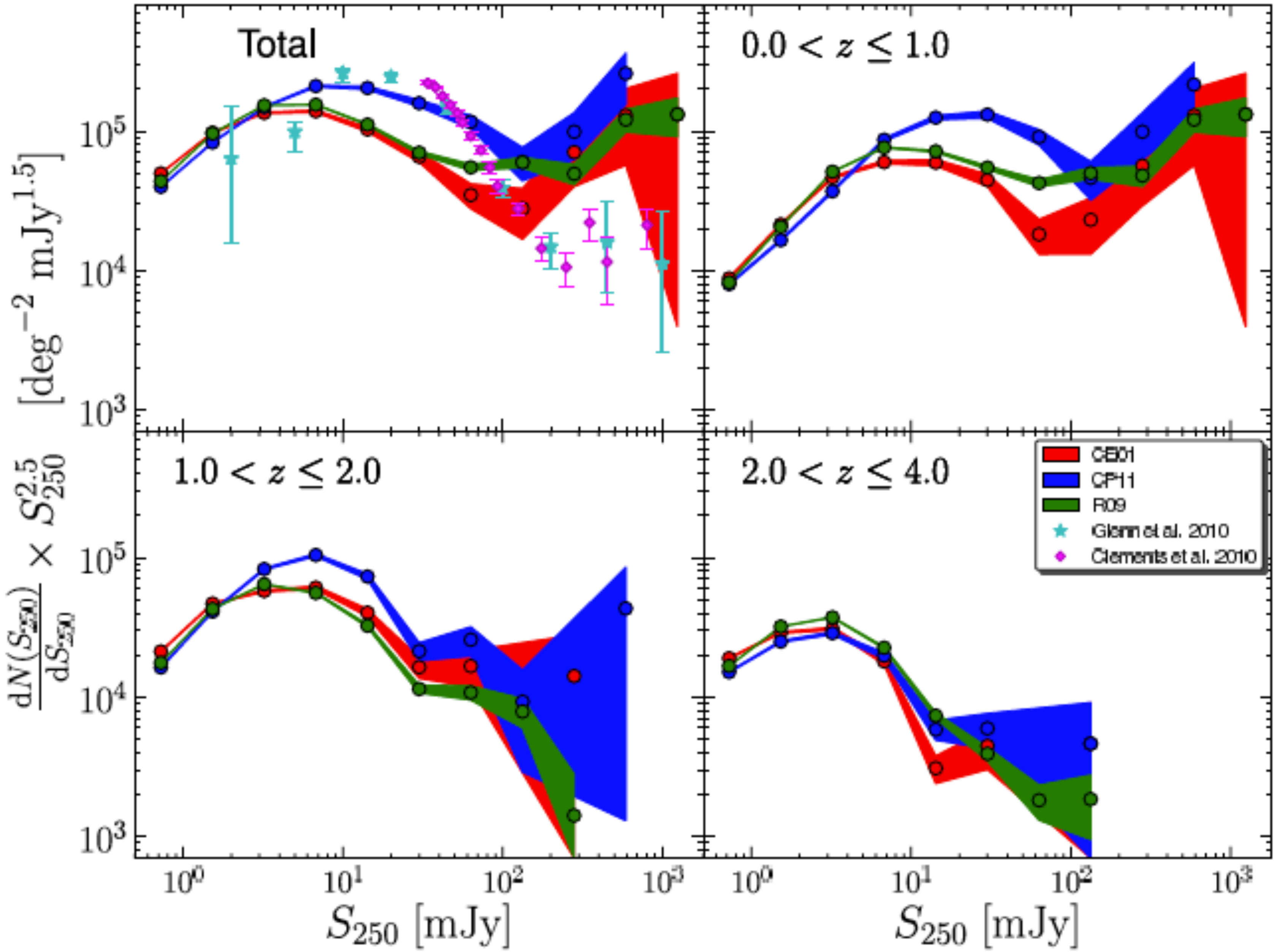
red=Chary & Elbaz 2001

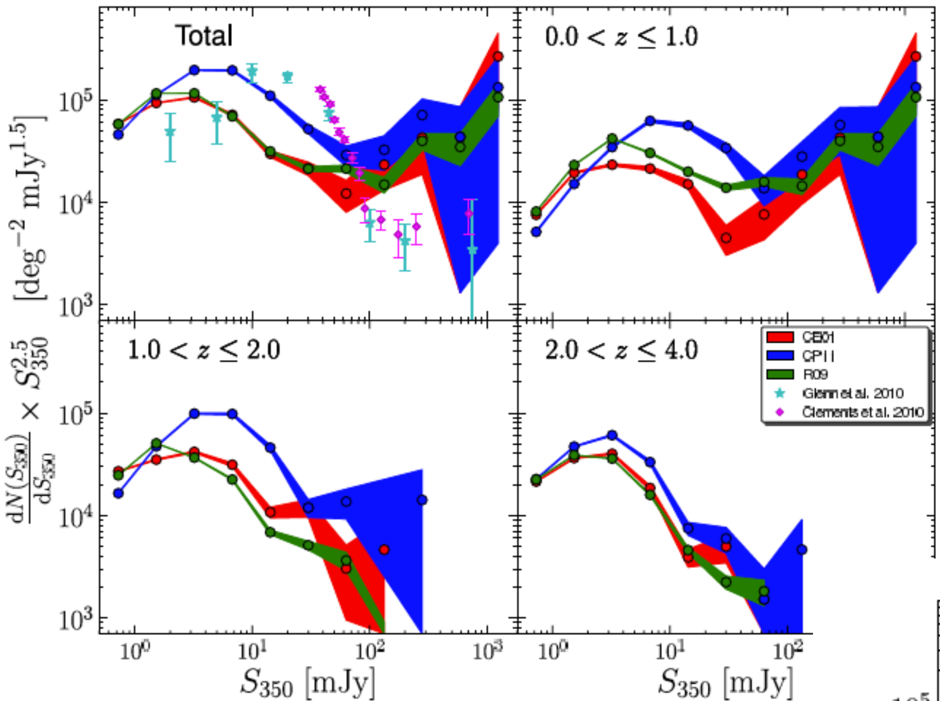
green=Rieke et al. 2009

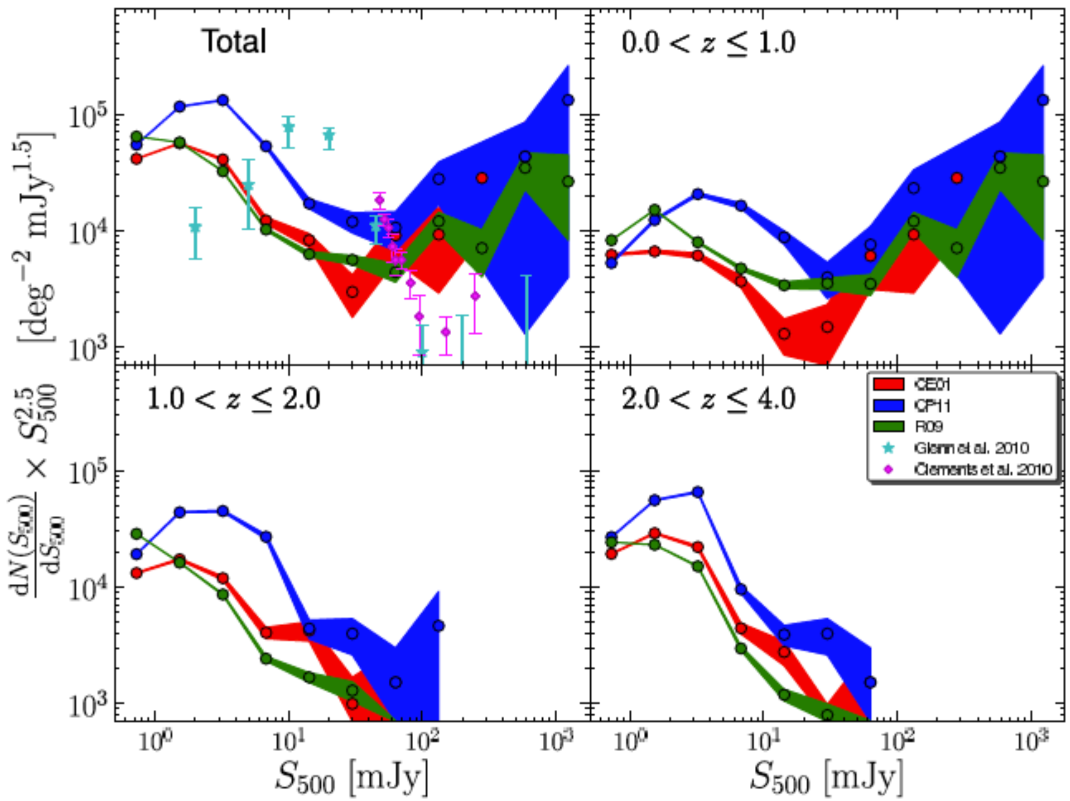
blue = Chary & Pope 2011

Niemi, rss et al. 2011

Herschel predictions: SPIRE





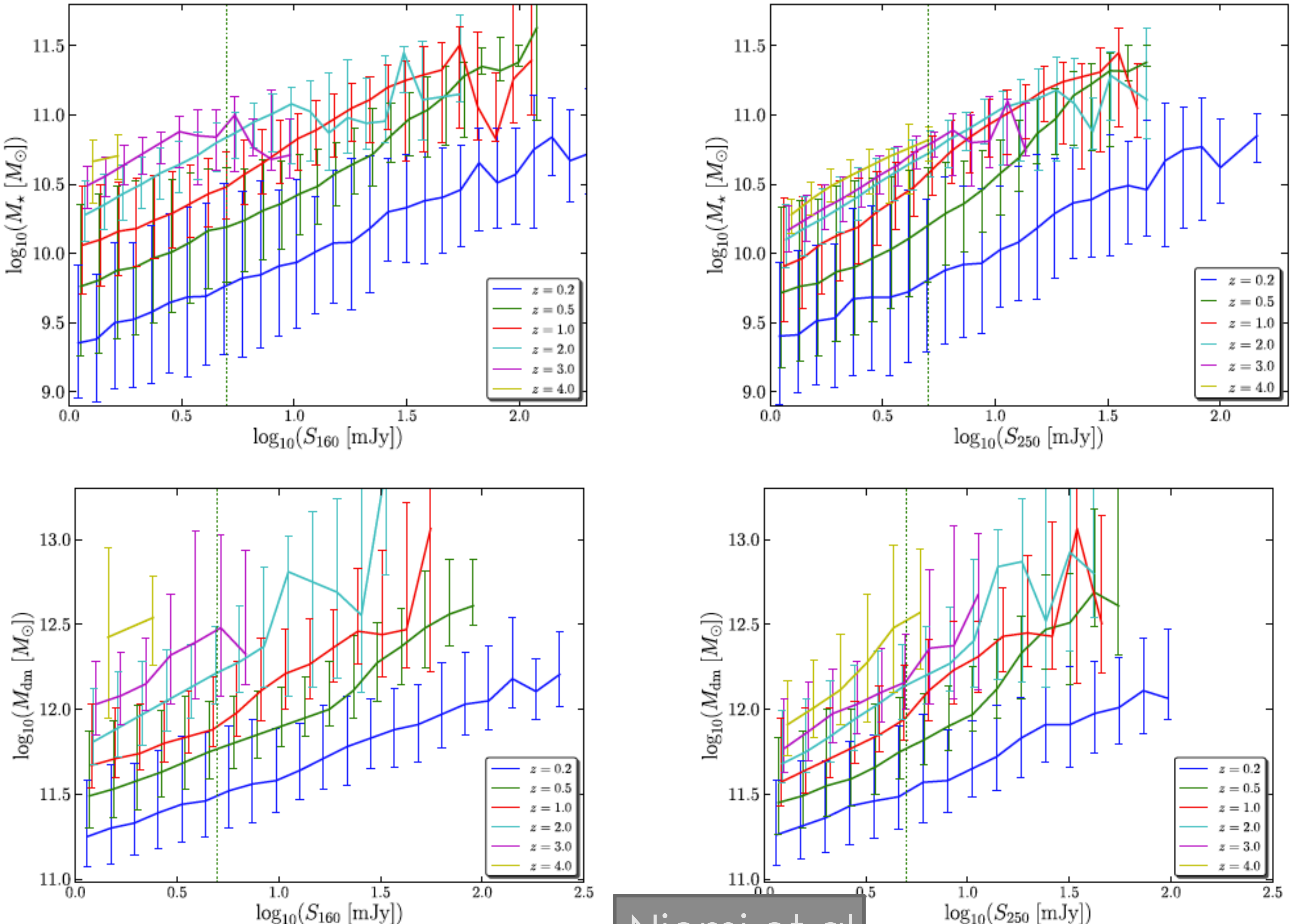


Niemi, rss et al. 2011

Physical properties of Herschel-selected galaxies

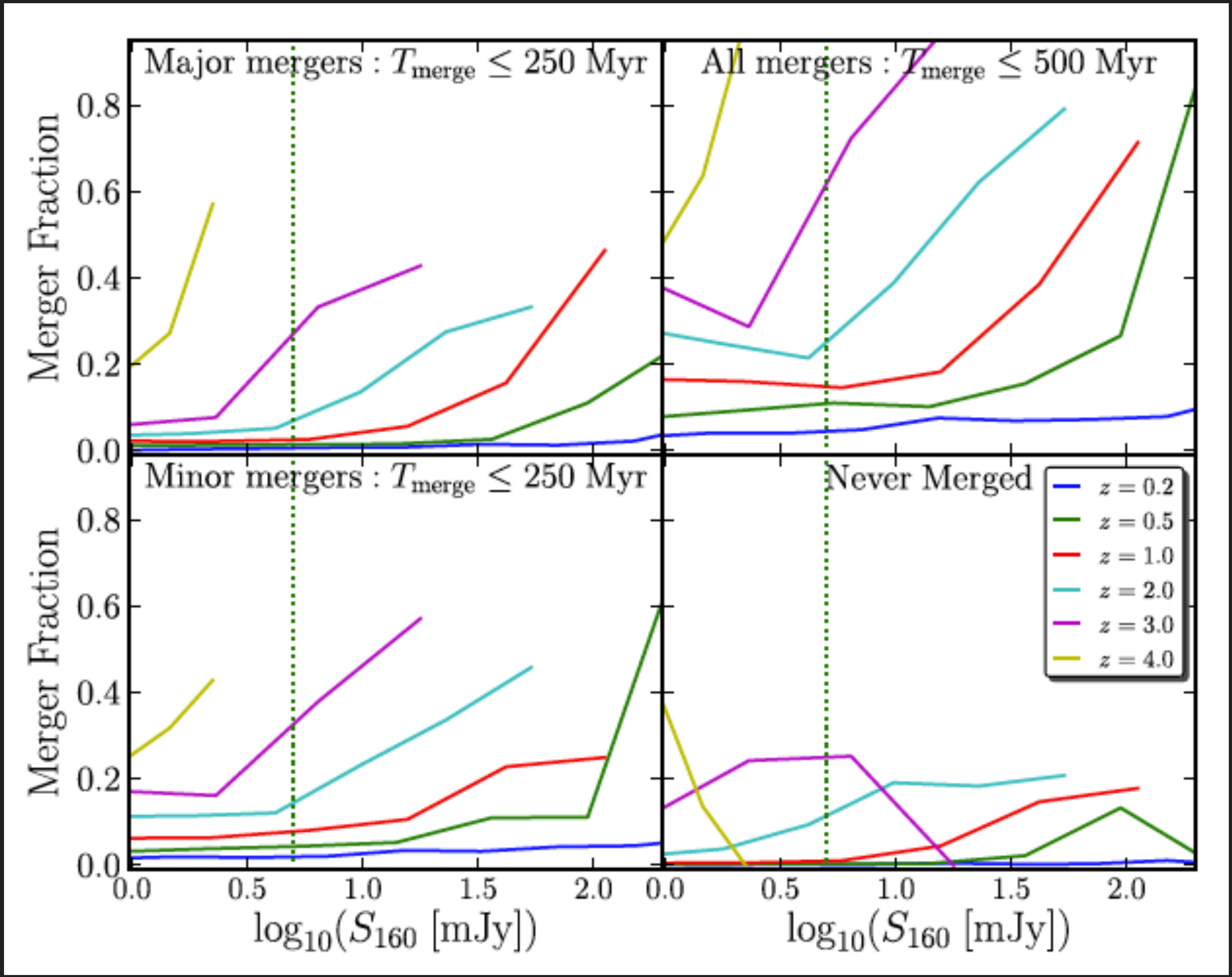
- PACS(160) and SPIRE (250) flux, z=0.2-4, vs.
  - stellar mass
  - DM halo mass
  - SFR
  - total IR luminosity
- size-mass relation

Niemi, rss, Ferguson, et al. submitted



$\log_{10}(M_\star\ [M_\odot])$
$\log_{10}(S_{160}\ [\mathrm{mJy}])$
$\log_{10}(S_{250}\ [\mathrm{mJy}])$
$\log_{10}(M_{\mathrm{dm}}\ [M_\odot])$
$z = 0.2$
$z = 0.5$
$z = 1.0$
$z = 2.0$
$z = 3.0$
$z = 4.0$

Niemi et al.



Niemi, rss et al. 2011

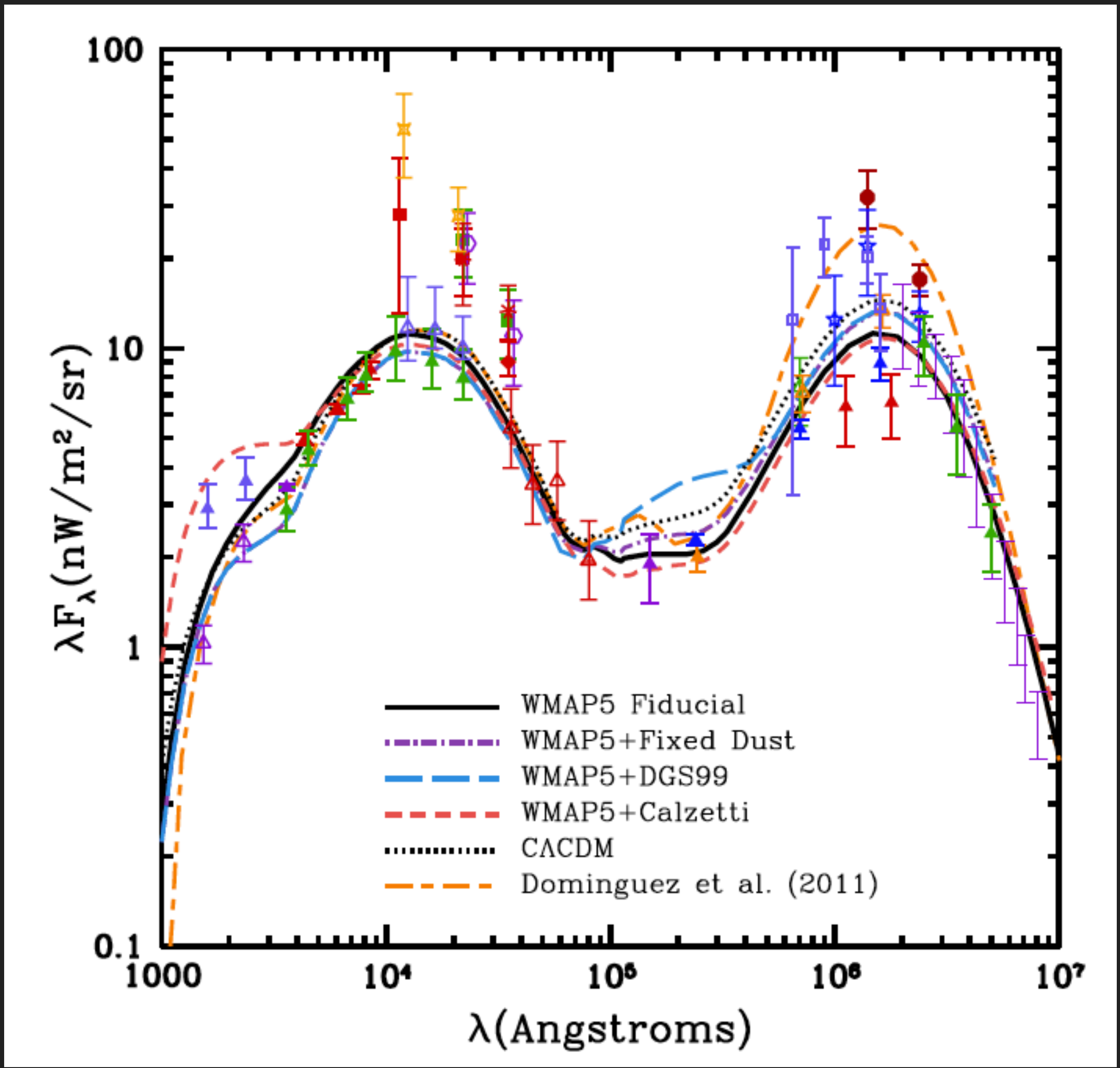
SUMMARY

- cosmological models of galaxy formation do reasonably well at matching observed galaxy LFs from FUV through NIR (i.e. stellar emission) over broad redshift range $(0<z<6)$
- model agreement breaks down in the mid-to-FIR in the critical regime $z\sim2$
- things get worse at higher L and longer wavelength

OPEN QUESTIONS

- non-universal IMF (e.g. top heavy in bursts or at high redshift)?
- evolving dust temperature (IR templates), scatter or additional parameters in dust emission templates?
- physics of cooling/SF/SN & AGN feedback ?
- impact of flux boosting/ blending/lensing on observed counts at long wavelength?
- contamination by obscured AGN?

EXTRAGALACTIC BACKGROUND LIGHT



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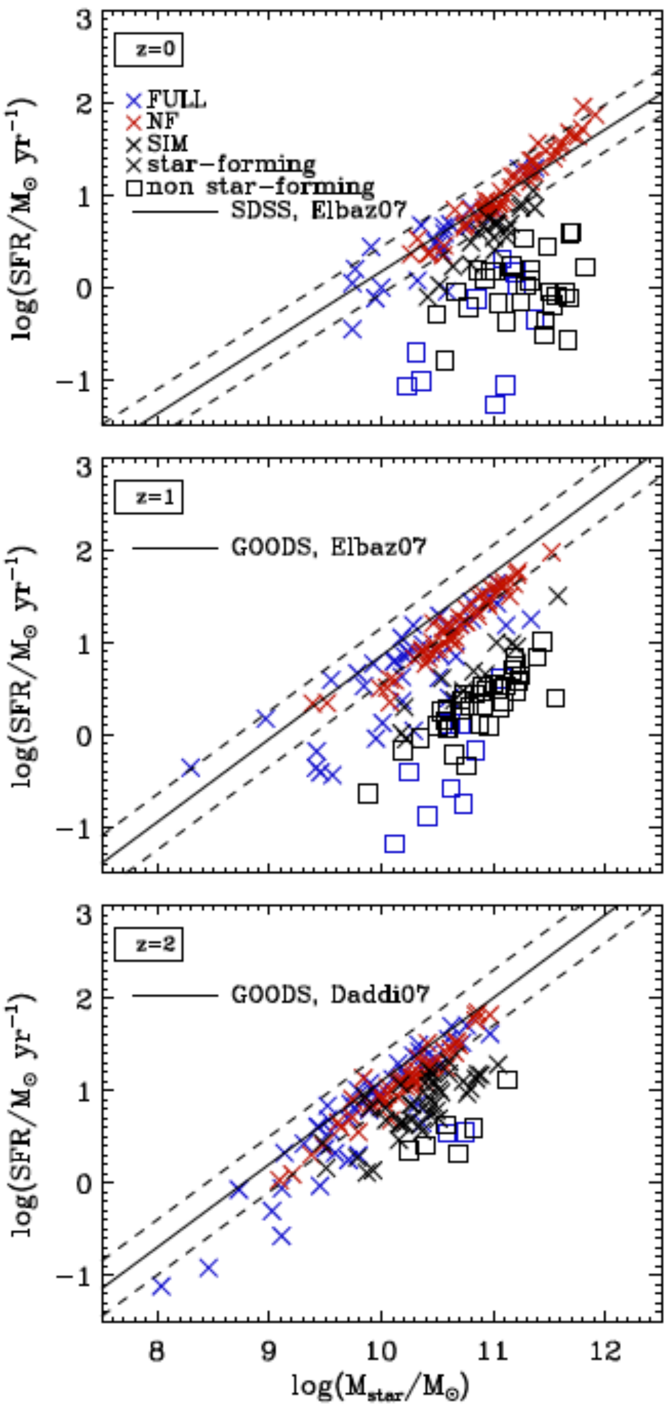
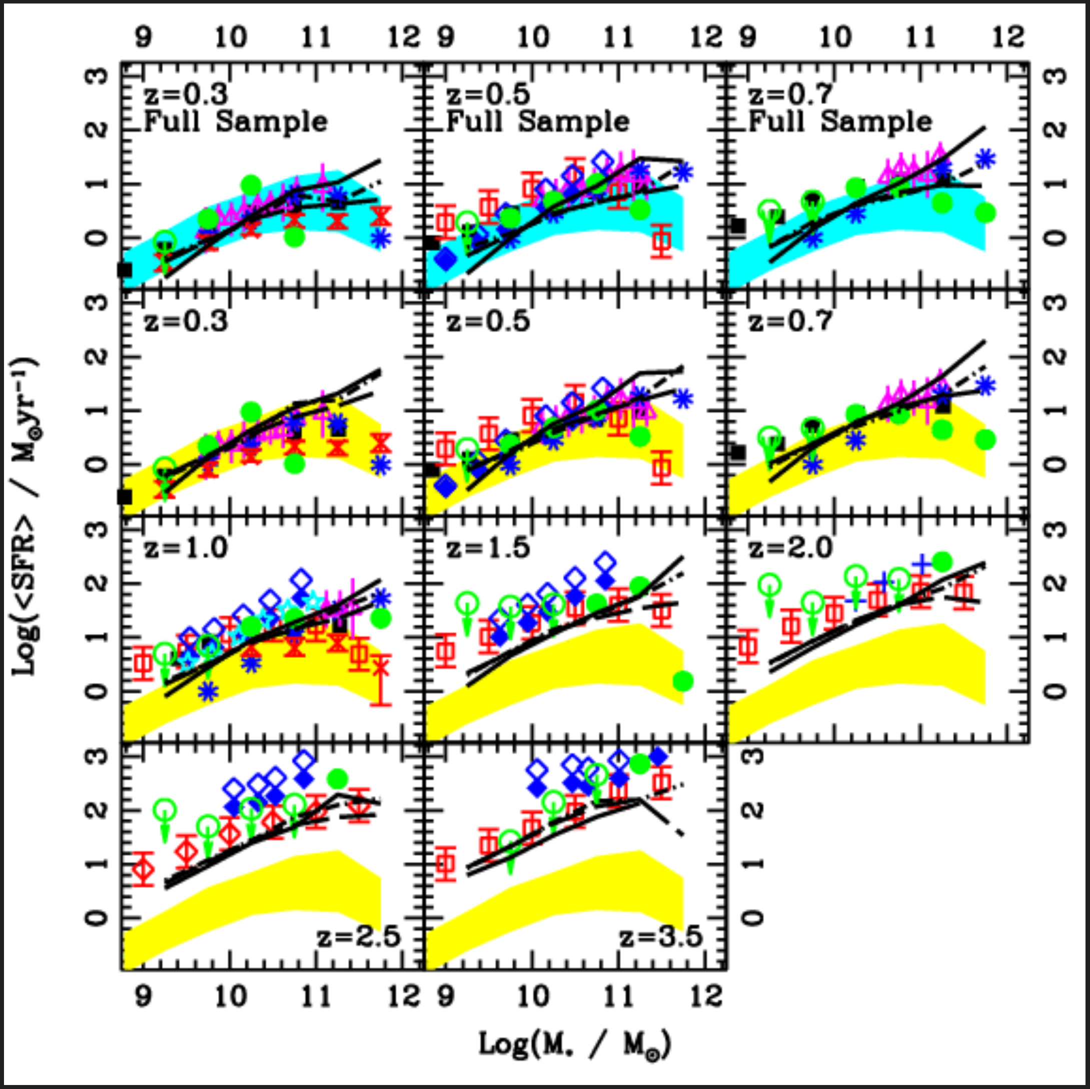
implications for TeV gamma rays: see Gilmore, rss et al. 2011



z=0
FULL
NF
SIM
star−forming
non star−forming
SDSS, Elbaz07
z=1
GOODS, Elbaz07
z=2
GOODS, Daddi07
log(SFR/M⊙ yr−1)
log(Mstar/M⊙)

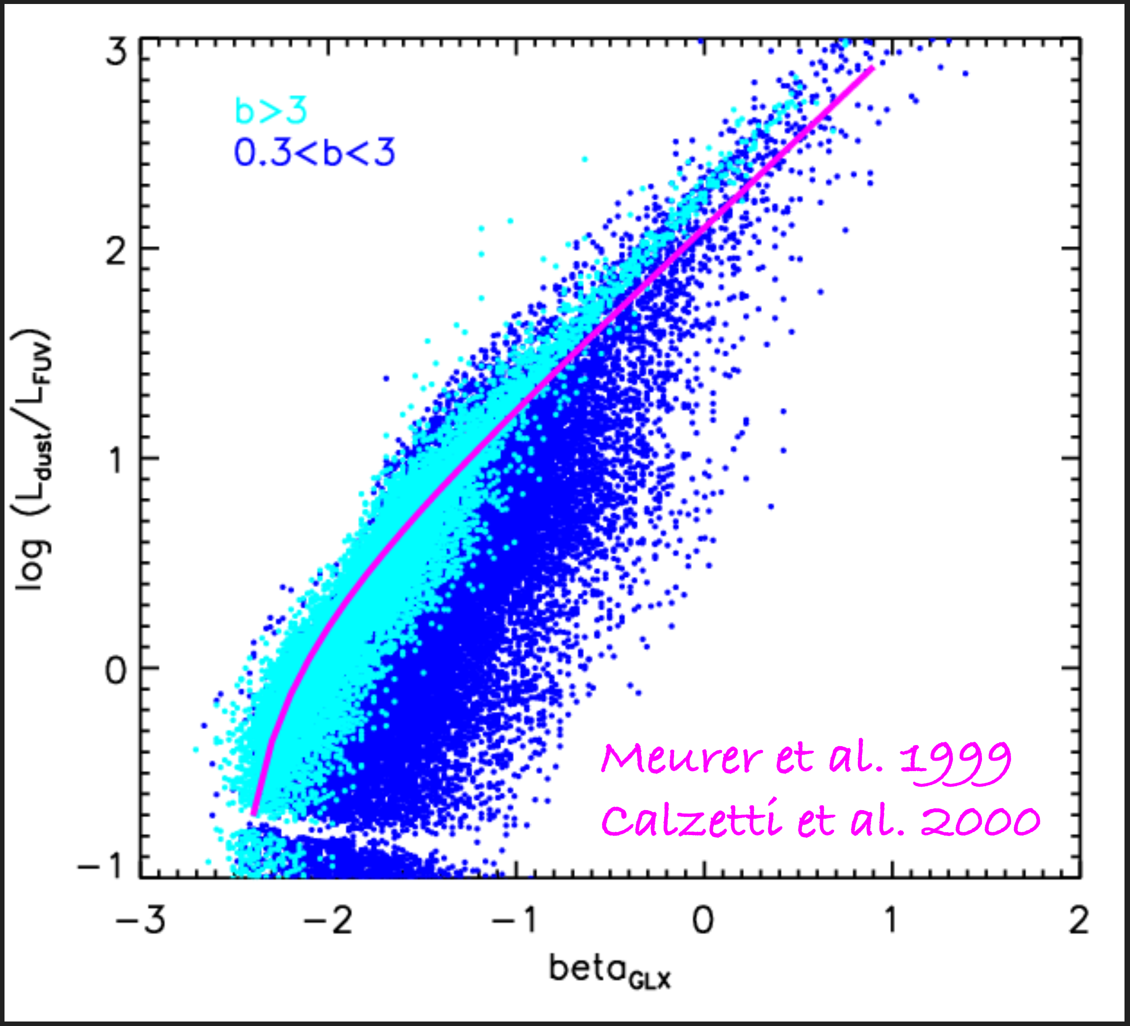
EVOLUTION OF THE SF SEQUENCE



data:
red square: Drory et al. 2008
blue: Bell et al. 2007
cyan: Martin et al. 2007
green: Grazian et al. 2006
magenta: Noeske et al. 2007
red x: Chen et al. 2008
blue diamond: Dunne et al. 2008

- SFR from different indicators/surveys differ by up to x10
- models do pretty well for massive galaxies at low z; low-mass galaxies are too low at all z; all (maybe) too low at high z

Fontanot et al. 2009



UV slope (GALEX color)

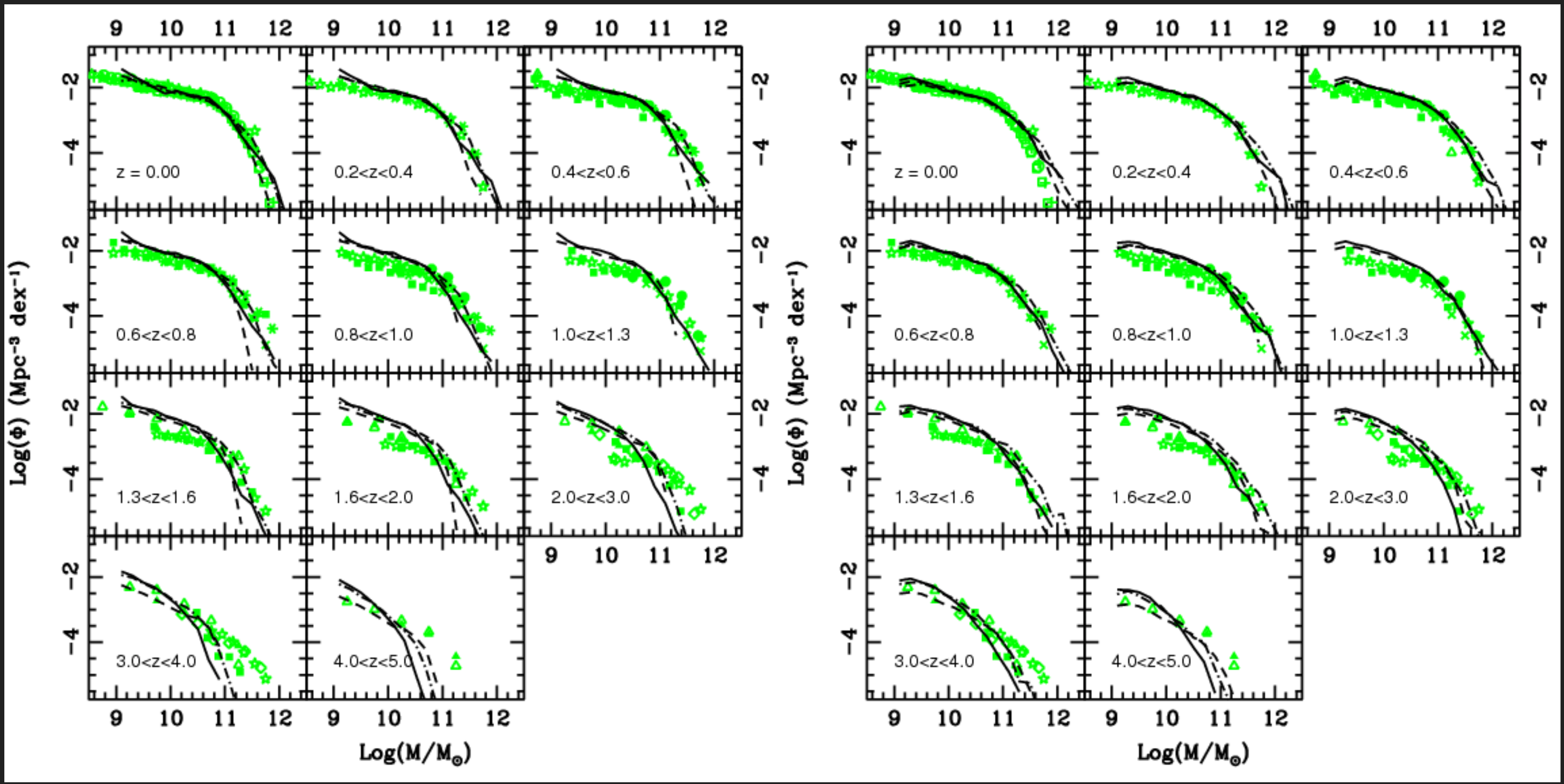
STELLAR MASS FUNCTION EVOLUTION

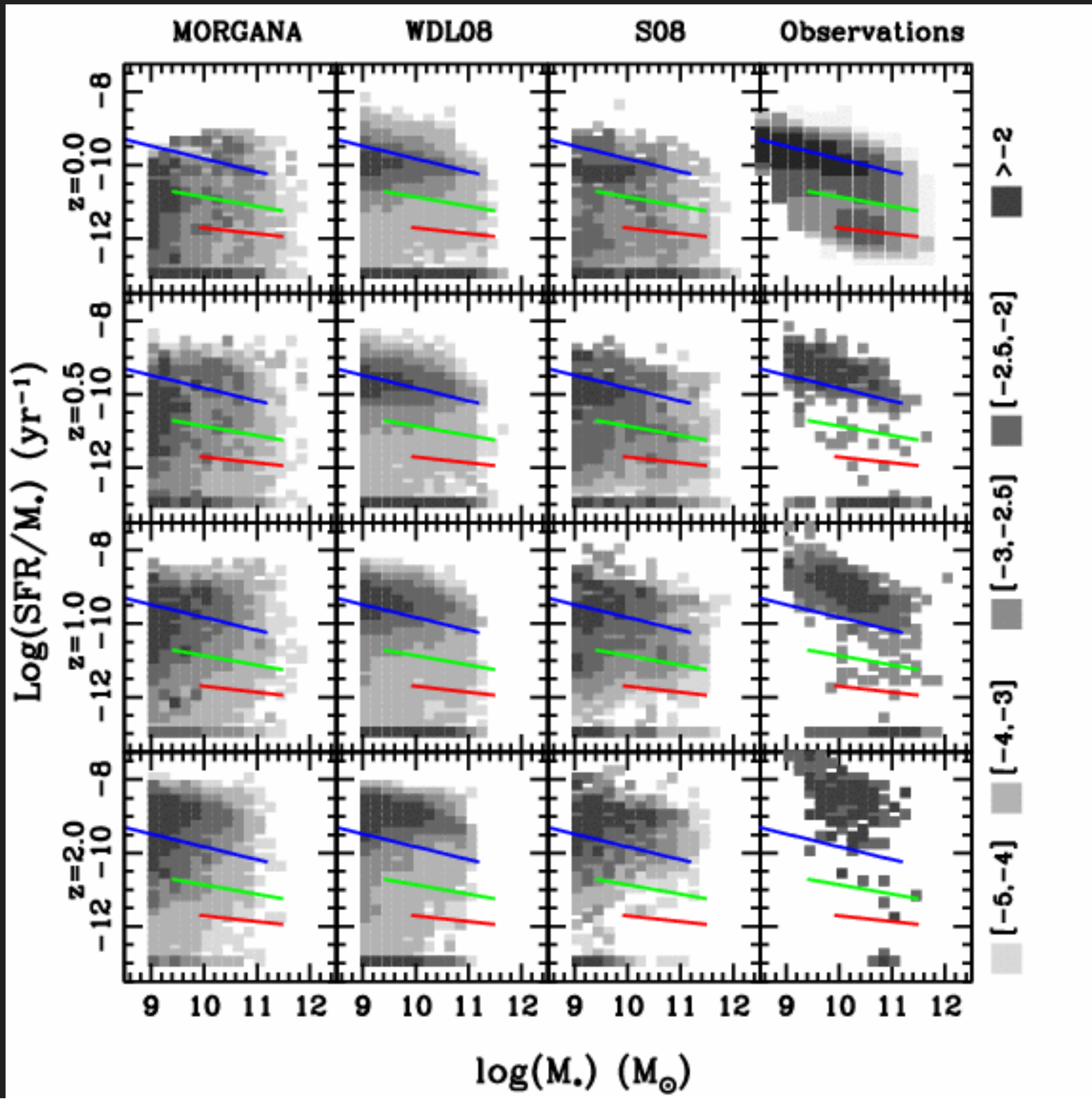
Fontanot, de Lucia, Monaco, rss, Santini 2009

solid: MORGANA
dash: Munich Mill.
dot-dash: rss08

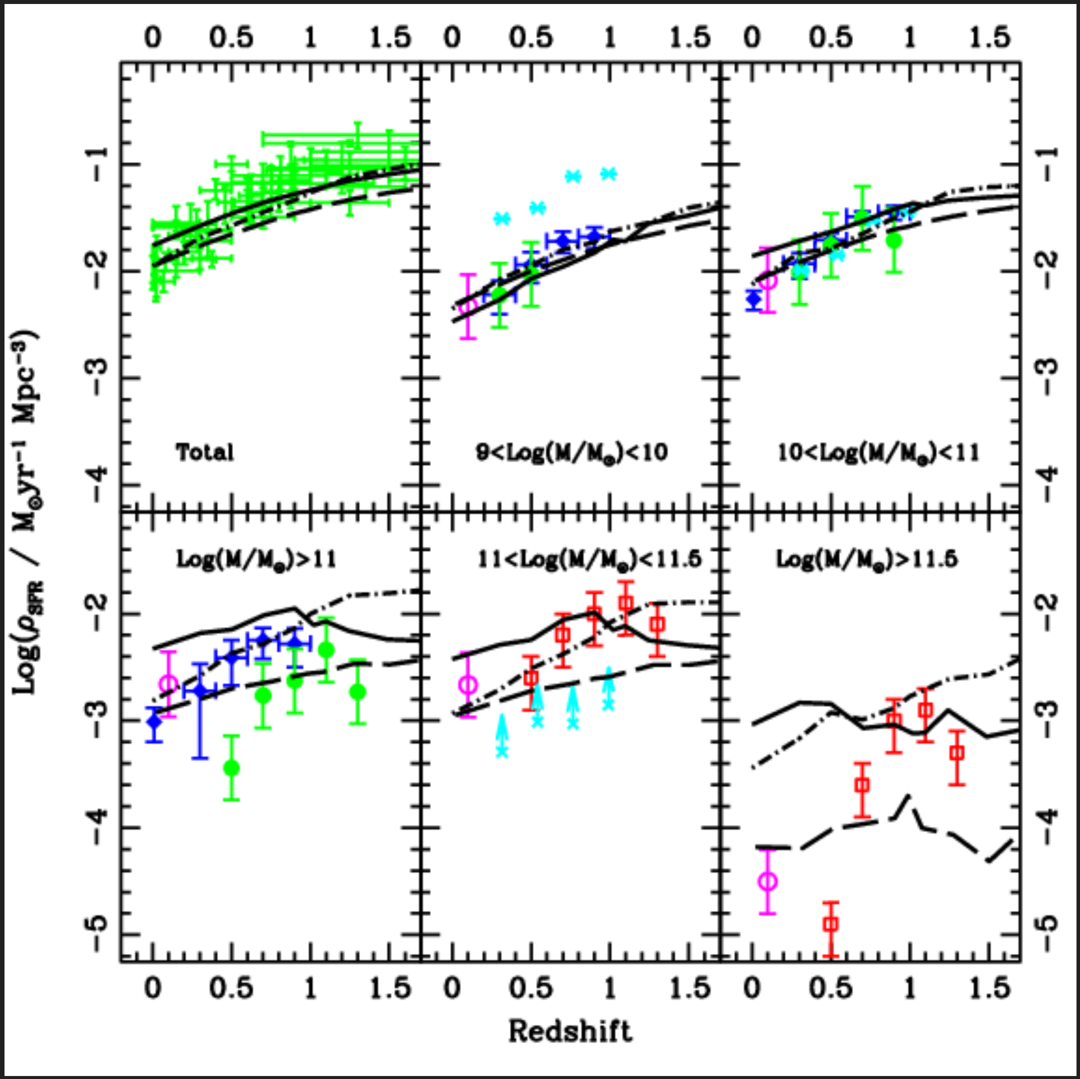
“raw” model predictions

with convolved errors




MORGANA
WDL08
S08
Observations
z=0.0
z=0.5
z=1.0
z=2.0
Log(SFR/M*) (yr⁻¹)
log(M*) (M☉)
>-2
[-2.5,-2]
[-3,-2.5]
[-4,-3]
[-5,-4]

STAR FORMATION RATE DENSITY AS FUNCTION OF GALAXY MASS

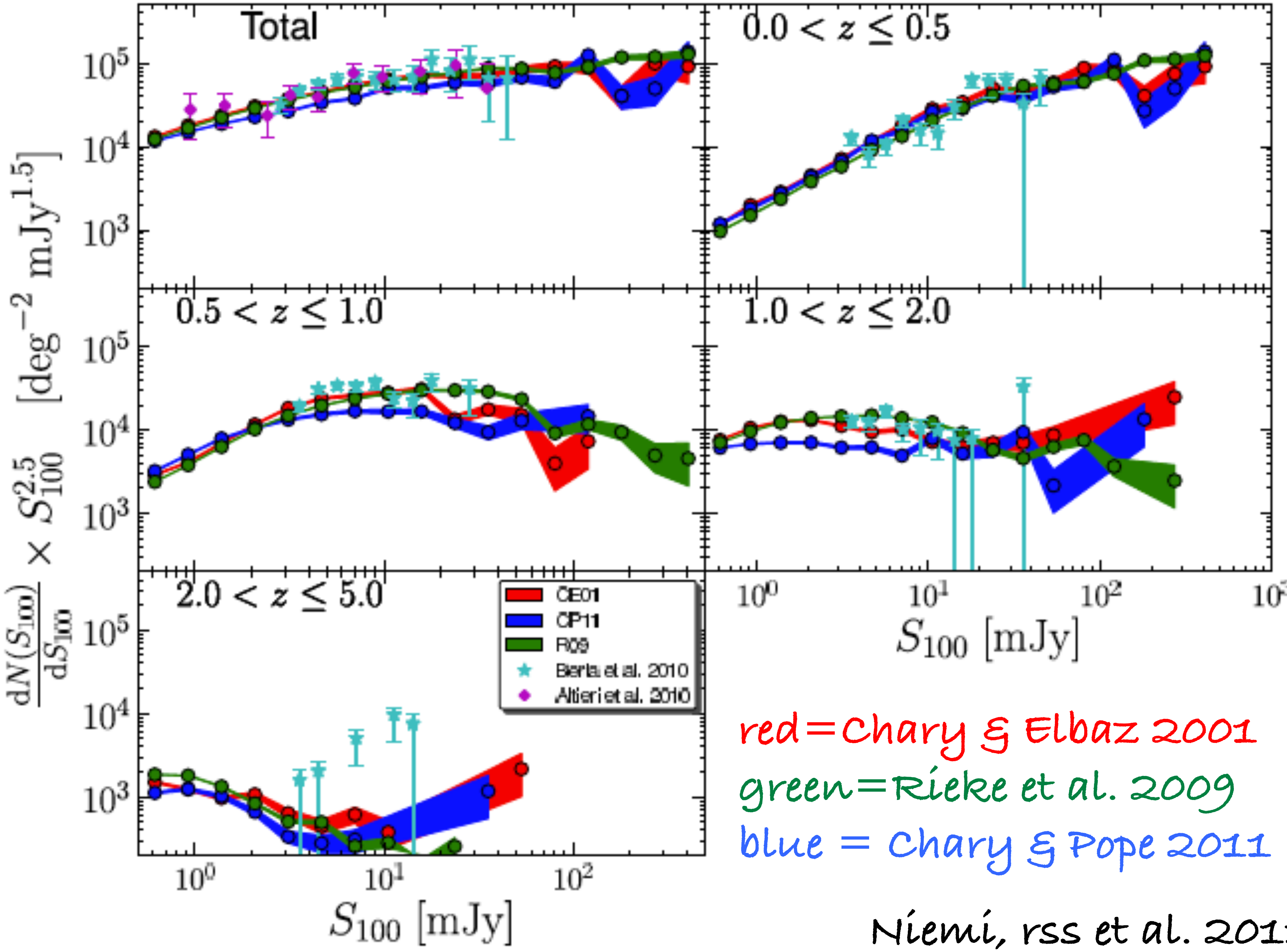


- agrees for low mass galaxies by accident
- high-mass galaxies over-quenched in Munich, underquenched in MORGANA?

solid: MORGANA
dash: Munich Mill.
dot-dash: rss08

green: GOODS; blue: Zheng et al. (COMBO-17)
red: Conselice et al.; cyan: Mobasher et al. 2008

Fontanot et al. 2009



red=Chary & Elbaz 2001

green=Rieke et al. 2009

blue = Chary & Pope 2011

Niemi, rss et al. 2011