Deep Surveys with ALMA

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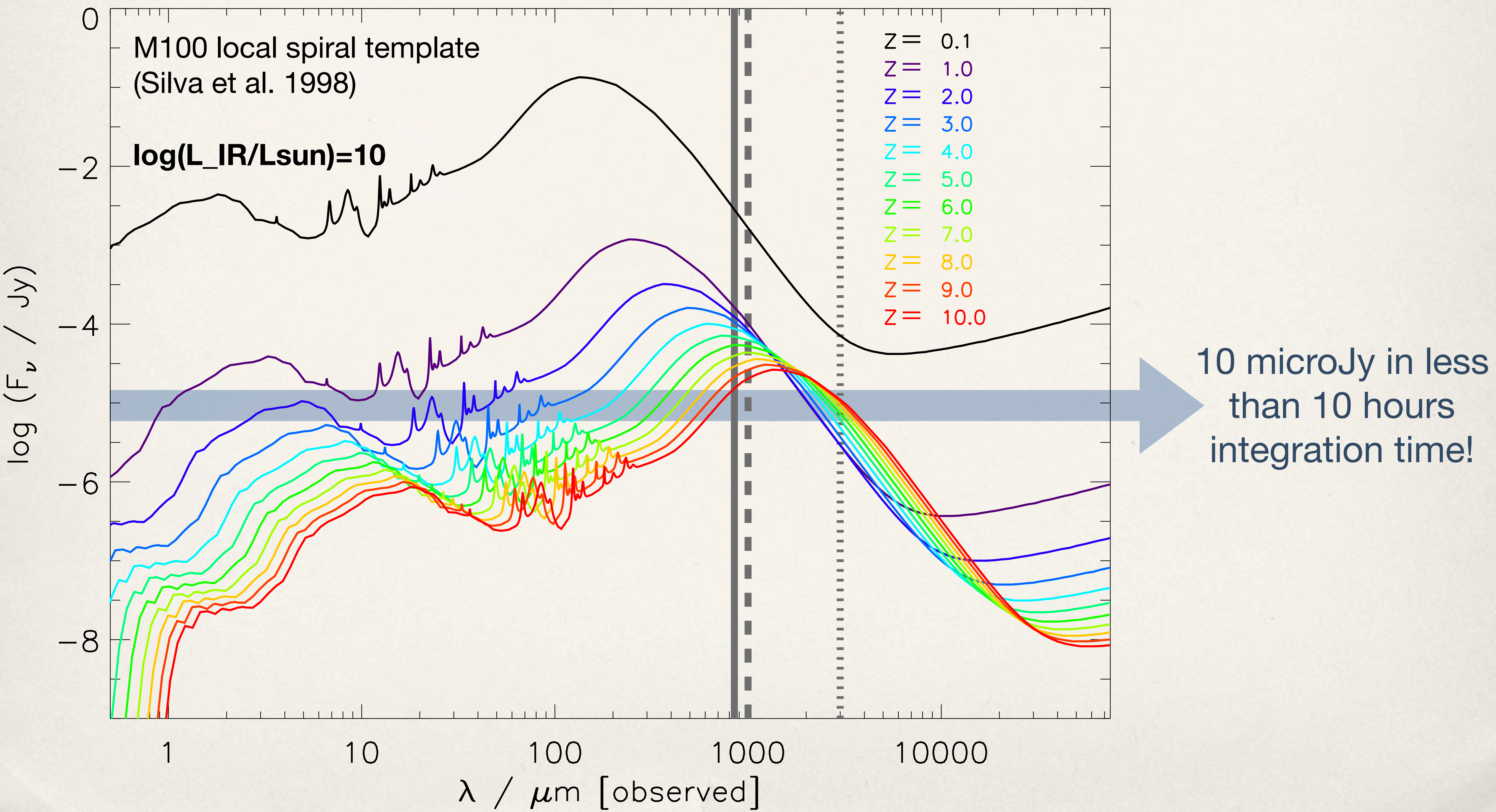
image credit: ESO

ALMA: The future is now

- **ALMA will detect ‘normal’ galaxies out to high redshift**




Hubble Ultra Deep Field
HST ▪ ACS
NASA, ESA, S. Beckwith (STScI) and The HUDF Team
STScI-PRC04-07a

The Data

- Photometric catalogue of Coe et al. (2006):
  - total of 18 700 sources;
  - **ACS *BVi'z'* + NIC3 *JH***;
  - redshifts (mostly photometric)

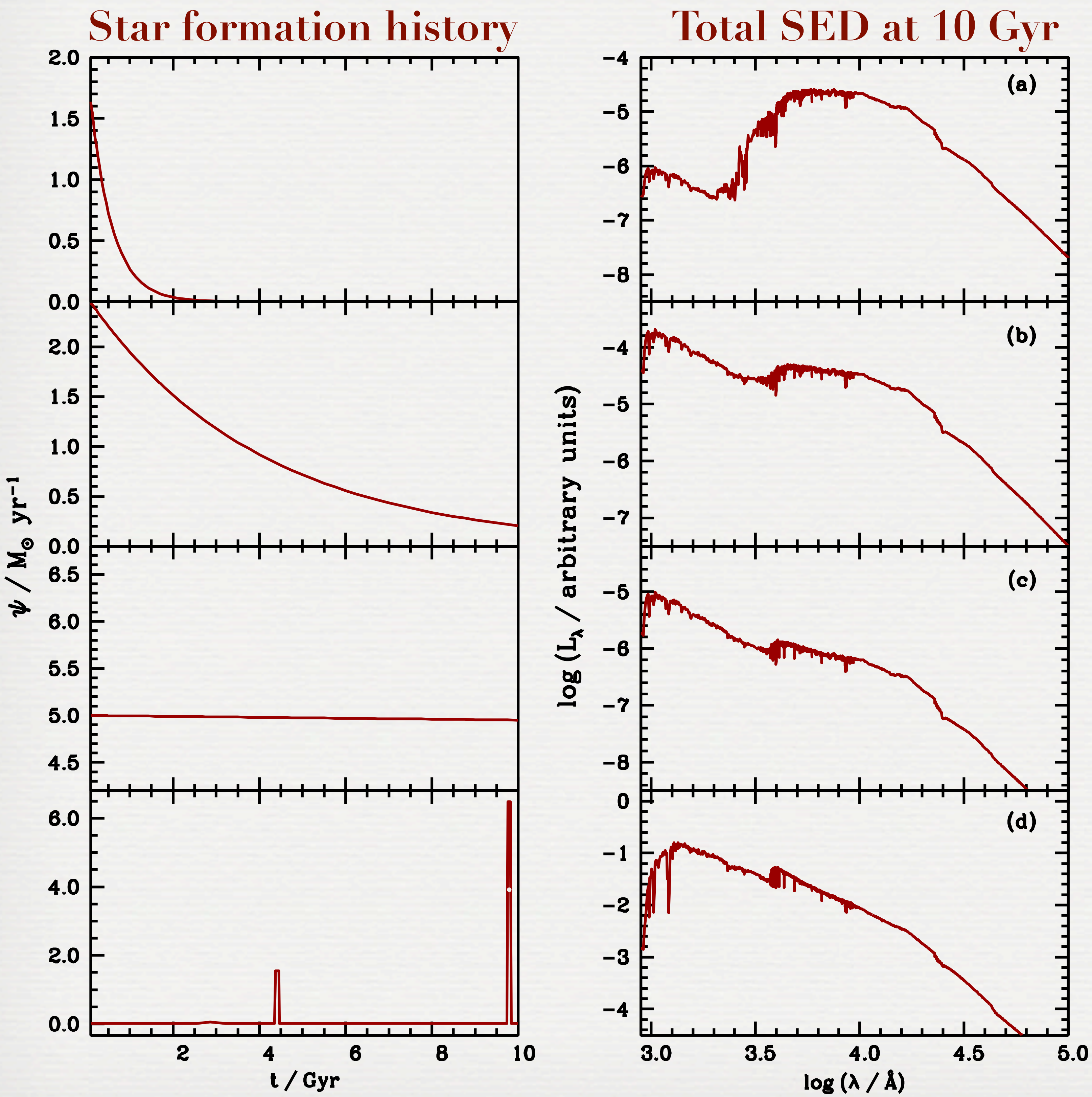
- ~ **3000 galaxies** detected in at least 4 bands and above limiting magnitude in all bands

Modelling the SEDs

da Cunha, Charlot & Elbaz (2008) MNRAS

Code publicly available at: www.iap.fr/magphys

Emission from stellar populations

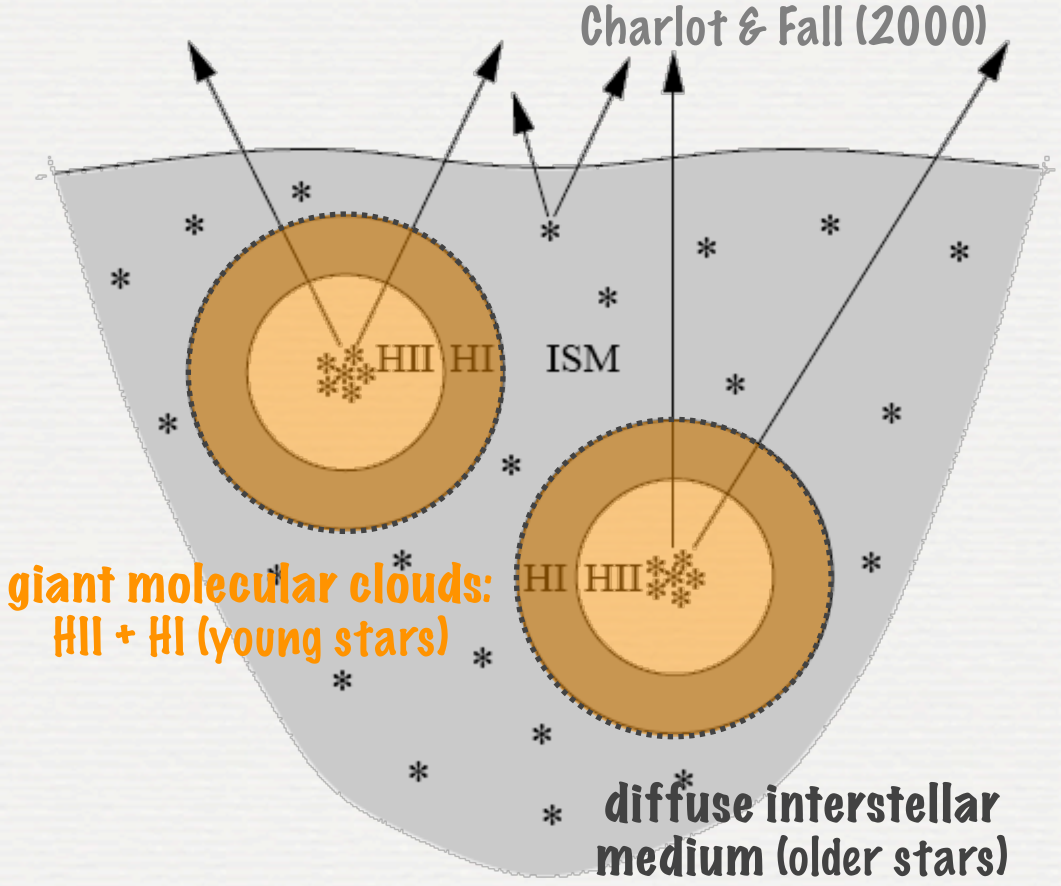


- Latest version of **Bruzual & Charlot spectral synthesis models:** CB07; improved treatment of TP-AGB stars
- Chabrier IMF
- Main adjustable parameters:
  - age
  - star formation history: **exponentially declining + stochastic bursts**
  - metallicity

The effect of dust

- Stars are born in dense molecular clouds (***birth clouds***), which have a lifetime t_{BC}.

- Attenuation affecting stars older than t_{BC} in the ***diffuse ISM*** is only a fraction of that affecting young stars in the birth clouds.



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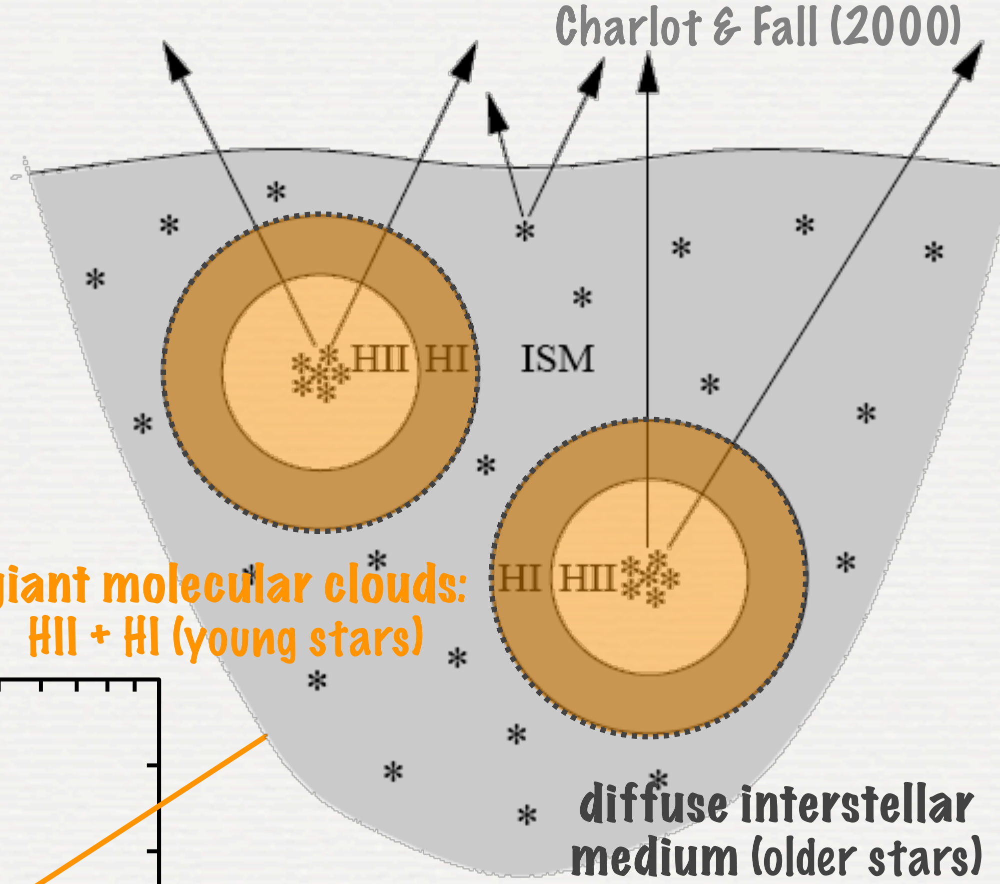
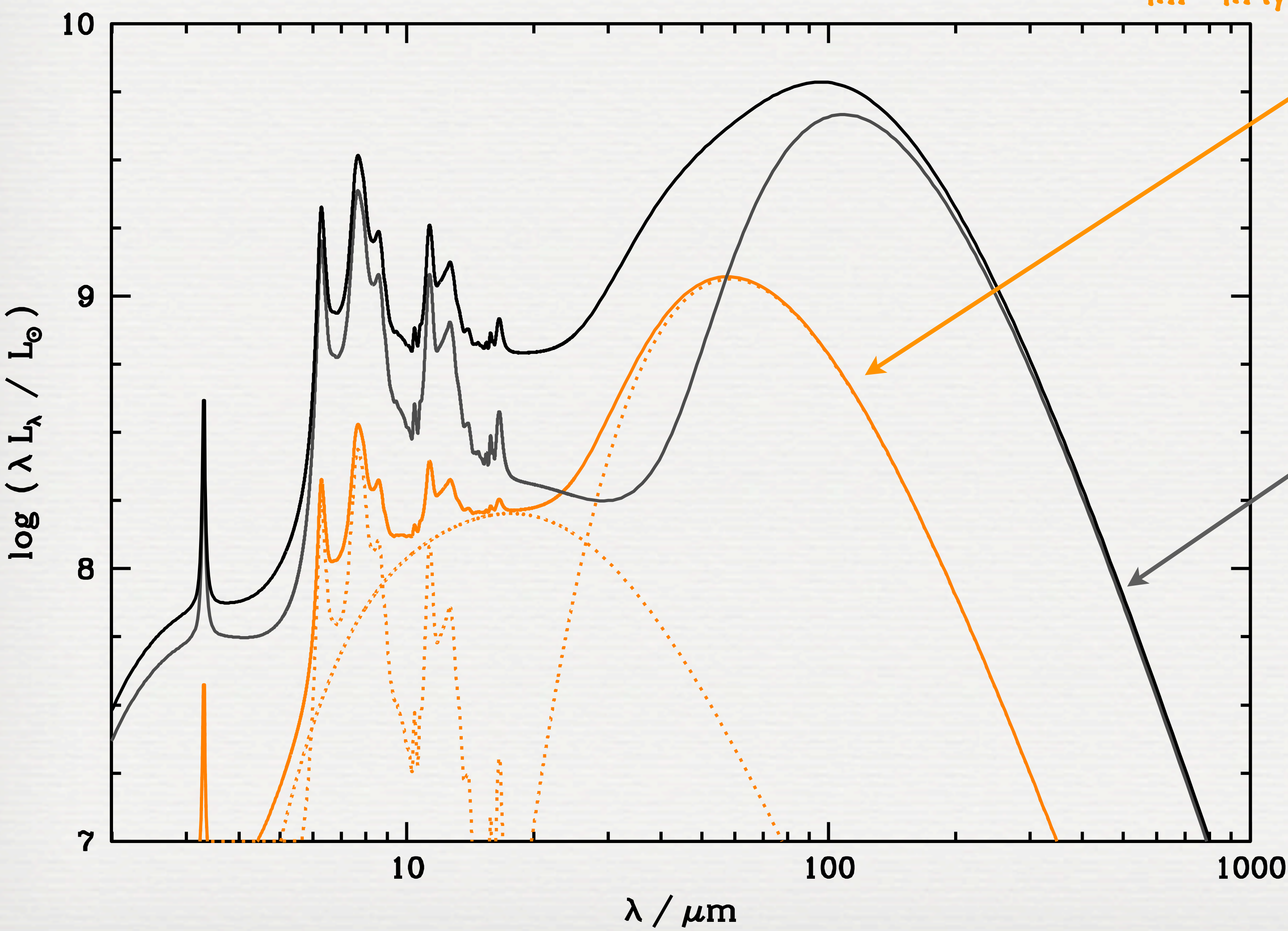


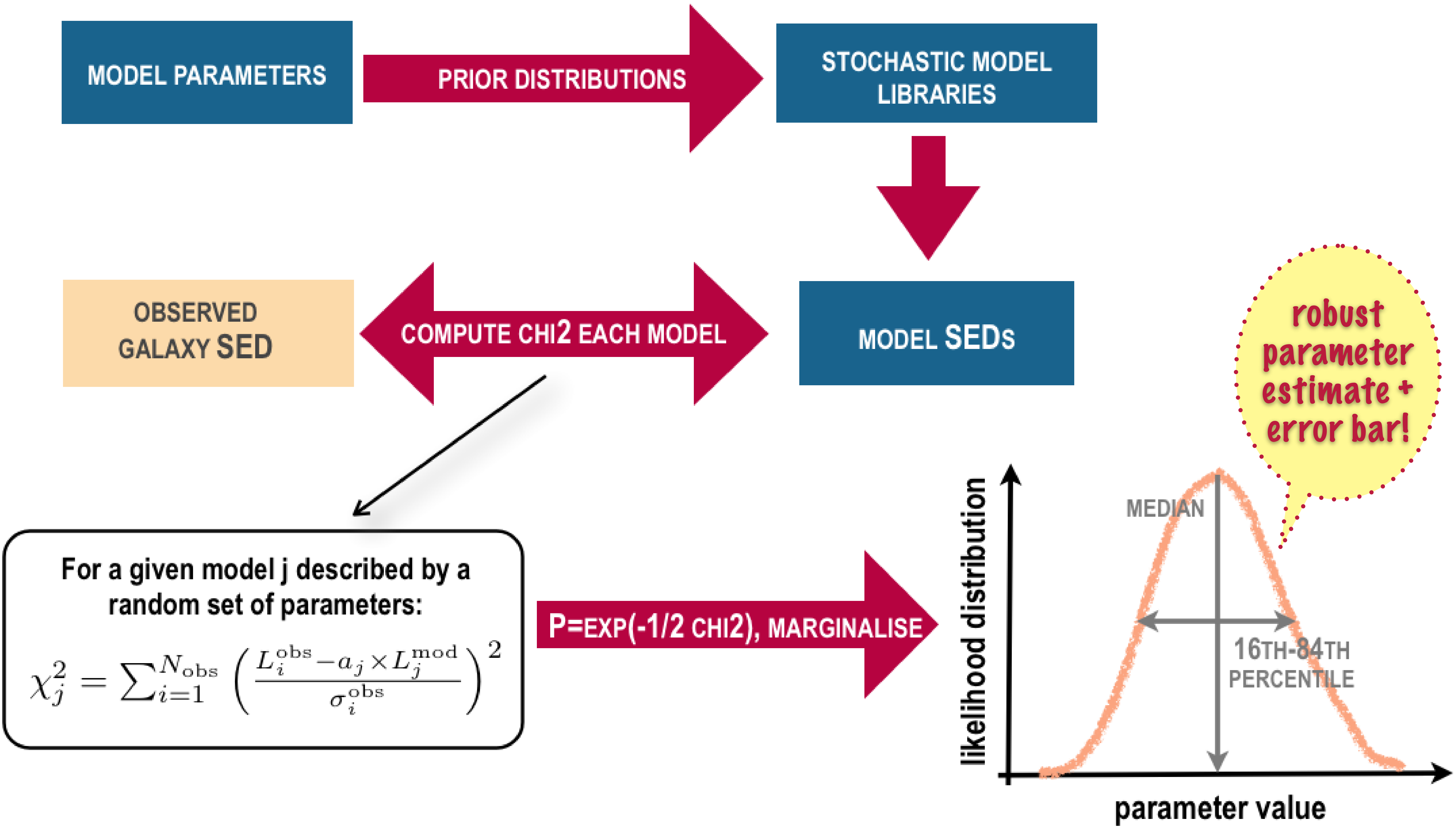


- ***Energy balance***

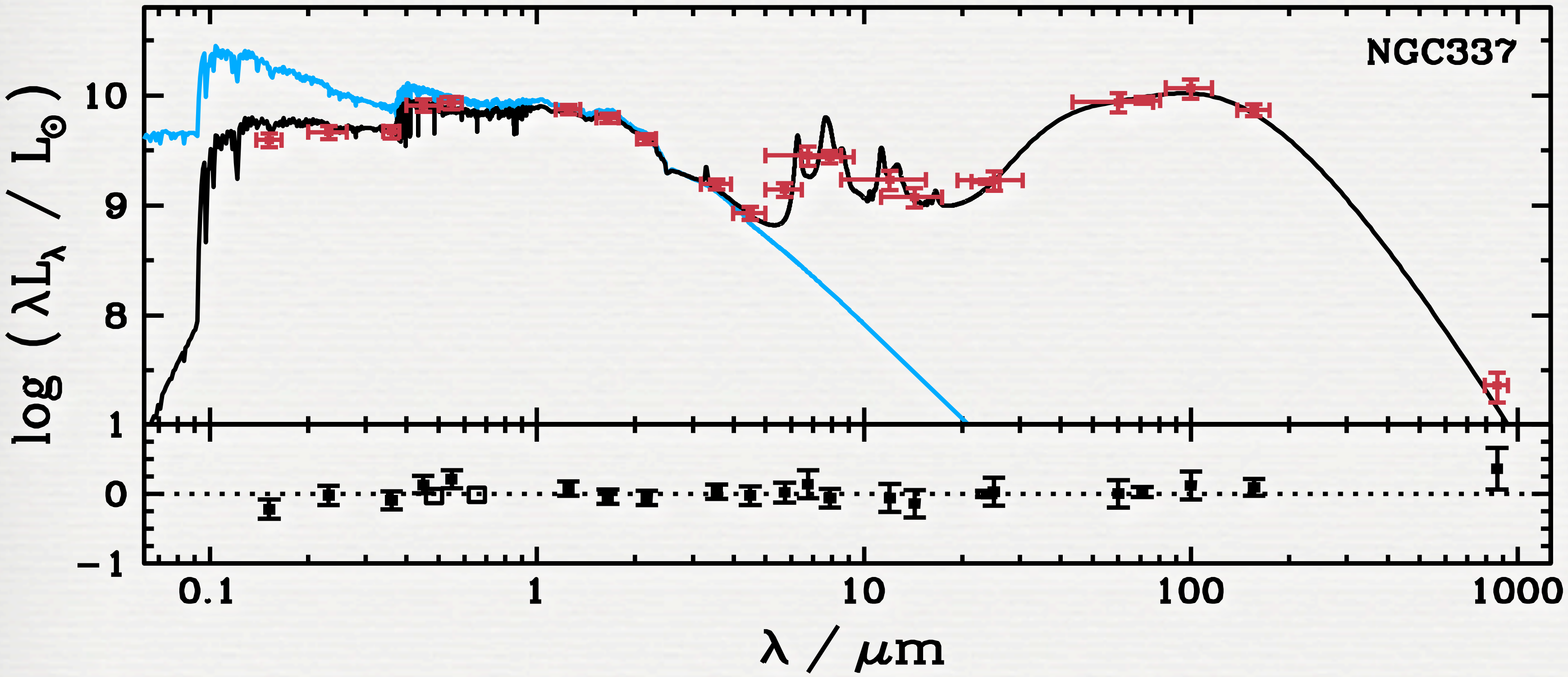
- ***Dust components:***
  - PAHs,
  - Hot mid-IR continuum,
  - Warm dust in thermal equilibrium (30 - 60 K),
  - Cold dust in thermal equilibrium (15 - 25 K)

Statistical constraints on physical parameters

See also e.g.:
Kauffman et al. (2003)
Gallazzi et al. (2005)
Salim et al. (2007)

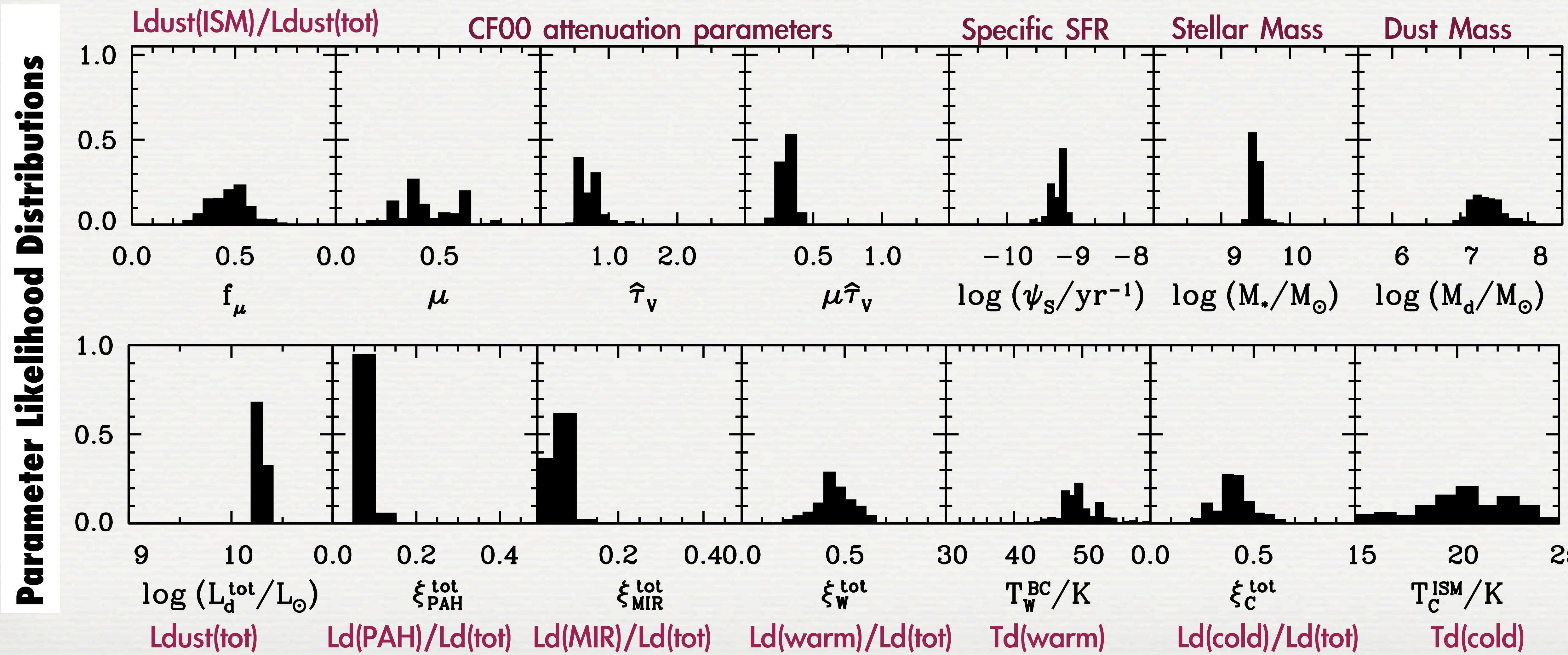


Example: SINGS local spiral



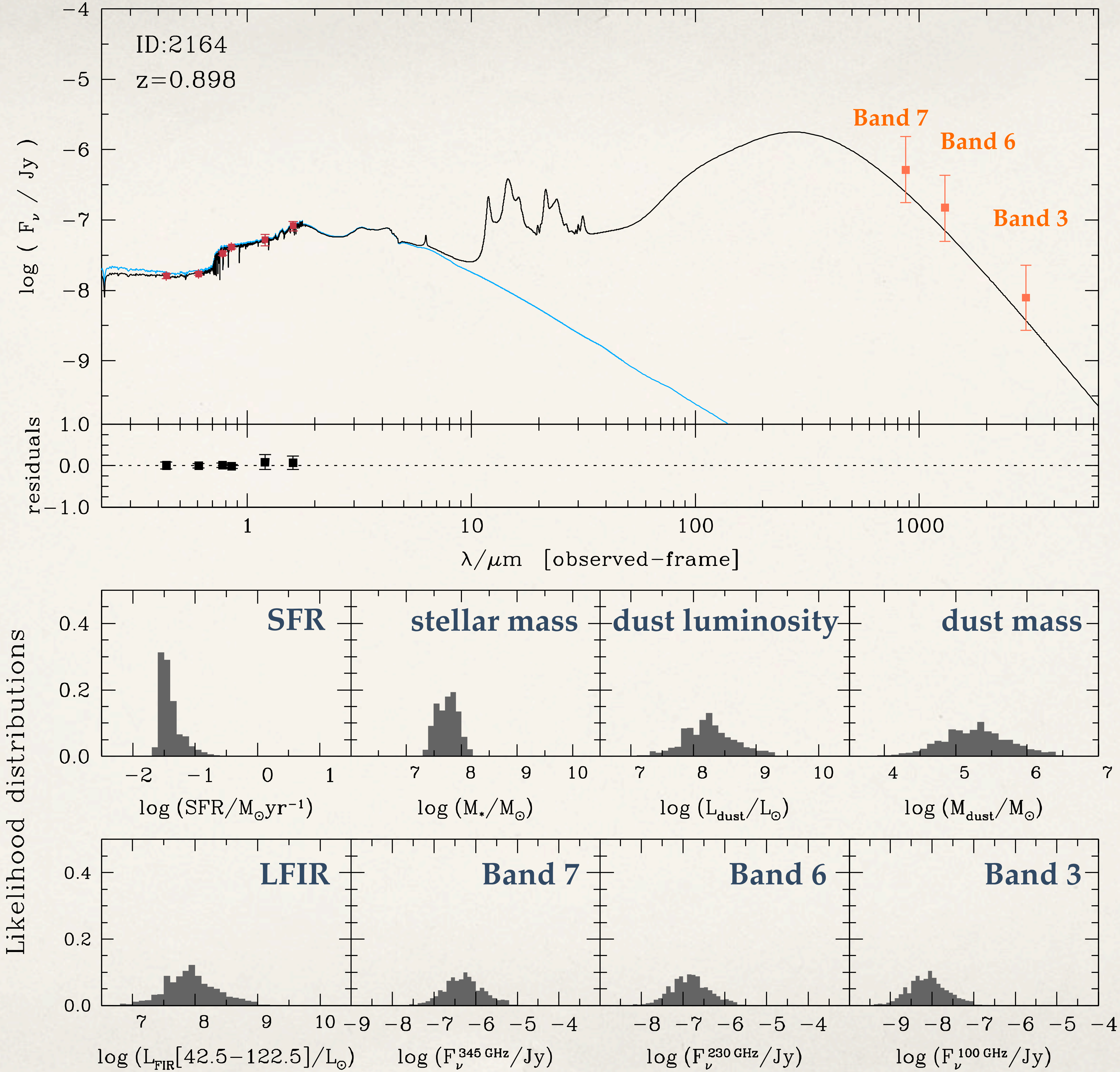
da Cunha, Charlot & Elbaz (2008)

SINGS Team



Fitting the SEDs of UDF galaxies

- Fit UV/optical photometry using library of 50,000 models - wide range of possible star formation histories and dust attenuation parameters
- For each combination SFH+dust attenuation --> likelihood distribution for dust luminosity (via **energy balance**)
- Dust luminosity + priors on dust masses/temperatures --> **likelihood distribution for L_FIR and continuum fluxes in ALMA bands.**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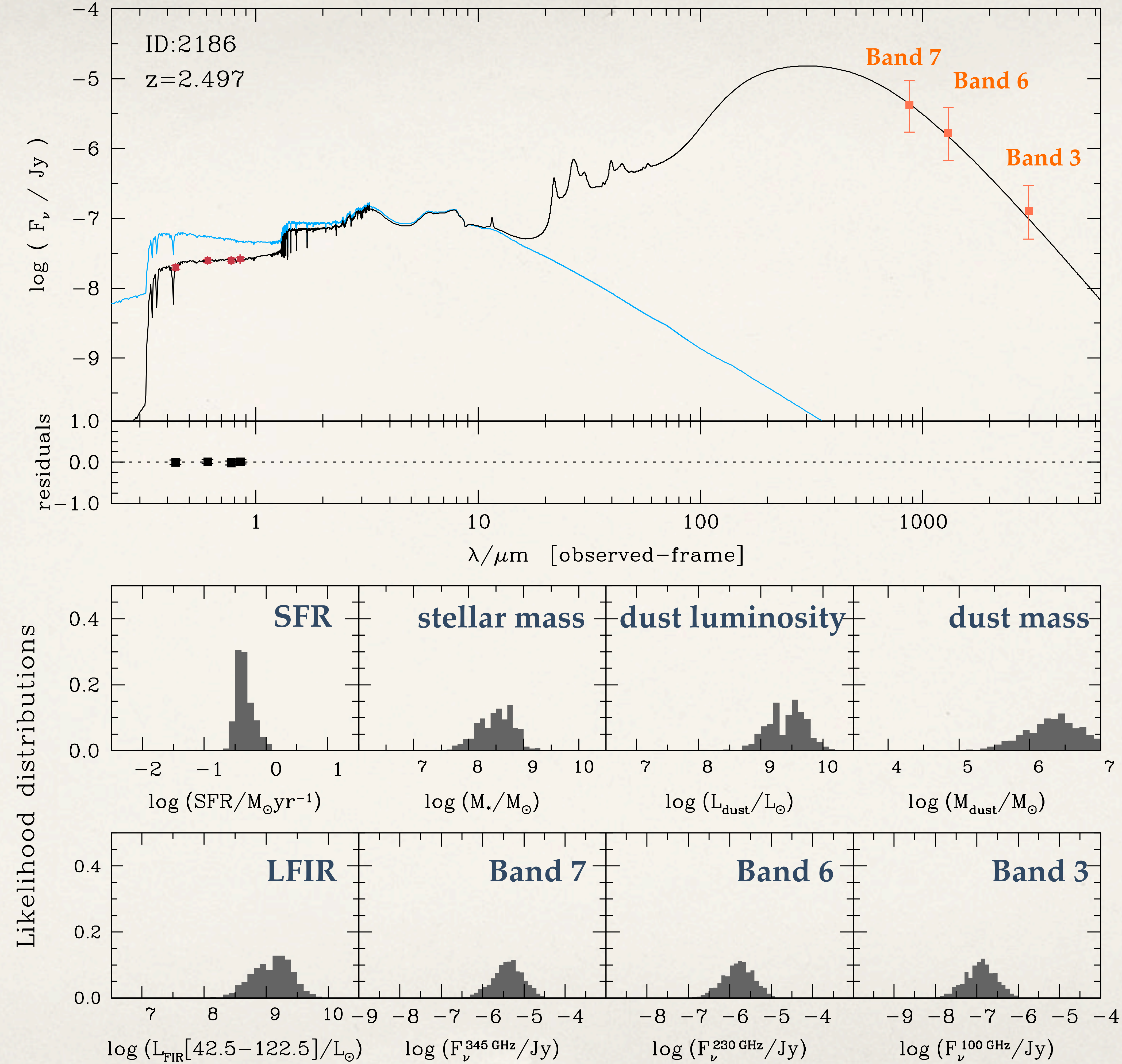
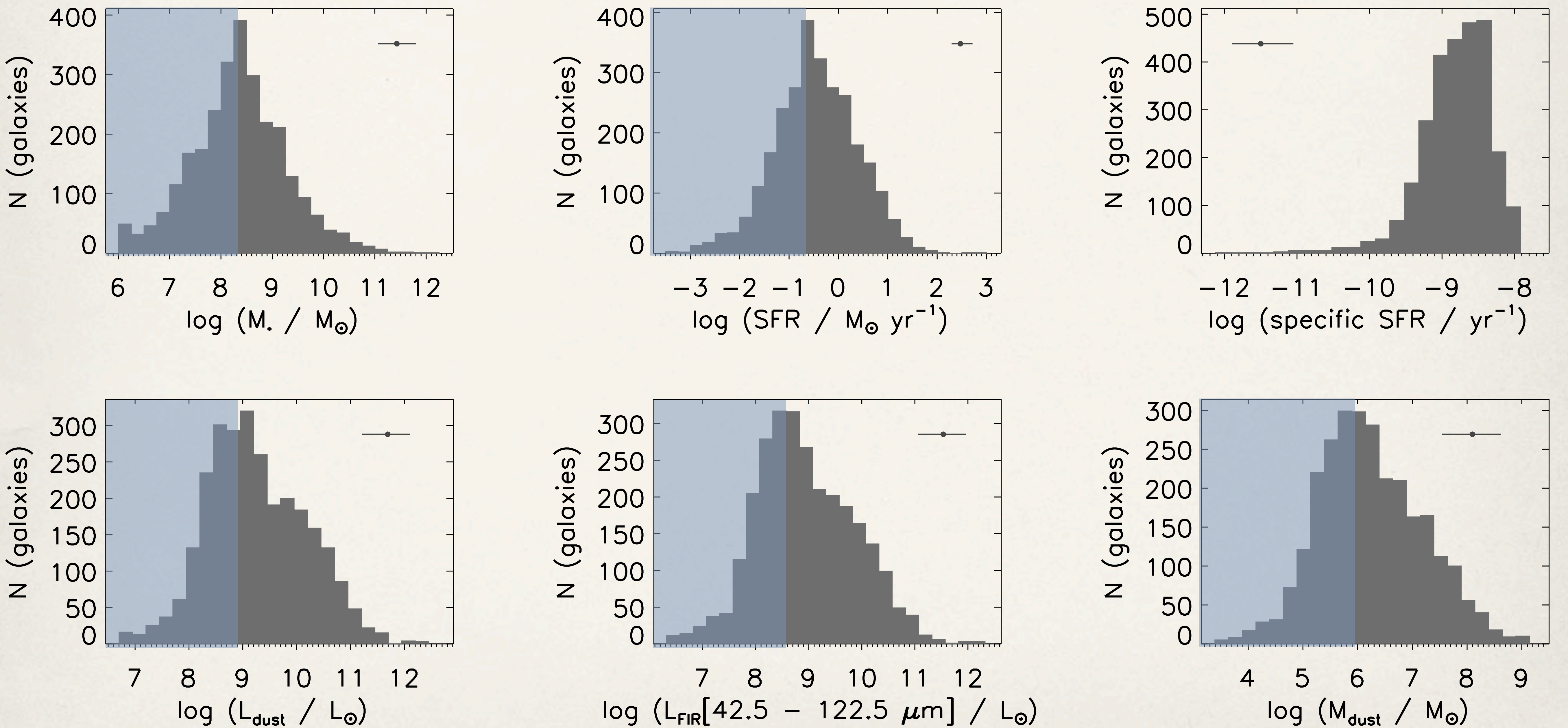
z=0.898
Band 7
Band 6
Band 3
log (F_ν / Jy)
residuals
λ/μm [observed−frame]
Likelihood distributions
SFR
stellar mass
dust luminosity
dust mass
log (SFR/M_⊙yr⁻¹)
log (M_*/M_⊙)
log (L_dust/L_⊙)
log (M_dust/M_⊙)
LFIR
Band 7
Band 6
Band 3
log (L_FIR[42.5−122.5]/L_⊙)
log (F_ν^345 GHz/Jy)
log (F_ν^230 GHz/Jy)
log (F_ν^100 GHz/Jy)

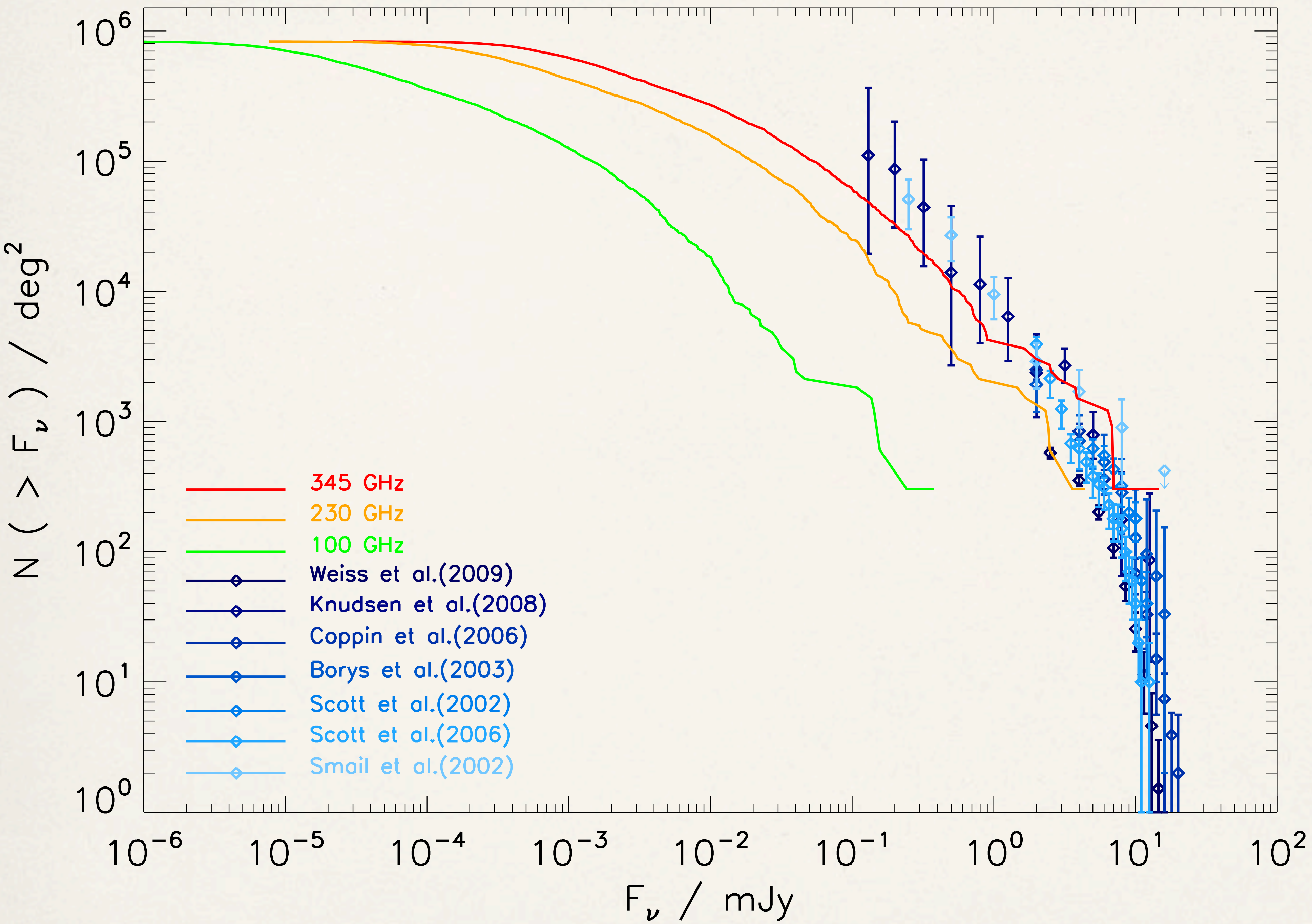


ID:2186
z=2.497
Band 7
Band 6
Band 3
log (F$_\nu$ / Jy)
residuals
λ/μm [observed−frame]
Likelihood distributions
SFR
stellar mass
dust luminosity
dust mass
log (SFR/M$_\odot$yr^{-1})
log (M$_*$/M$_\odot$)
log (L$_{dust}$/L$_\odot$)
log (M$_{dust}$/M$_\odot$)
LFIR
Band 7
Band 6
Band 3
log (L$_{FIR}$[42.5−122.5]/L$_\odot$)
log (F$_\nu^{345 GHz}$/Jy)
log (F$_\nu^{230 GHz}$/Jy)
log (F$_\nu^{100 GHz}$/Jy)

Physical parameters

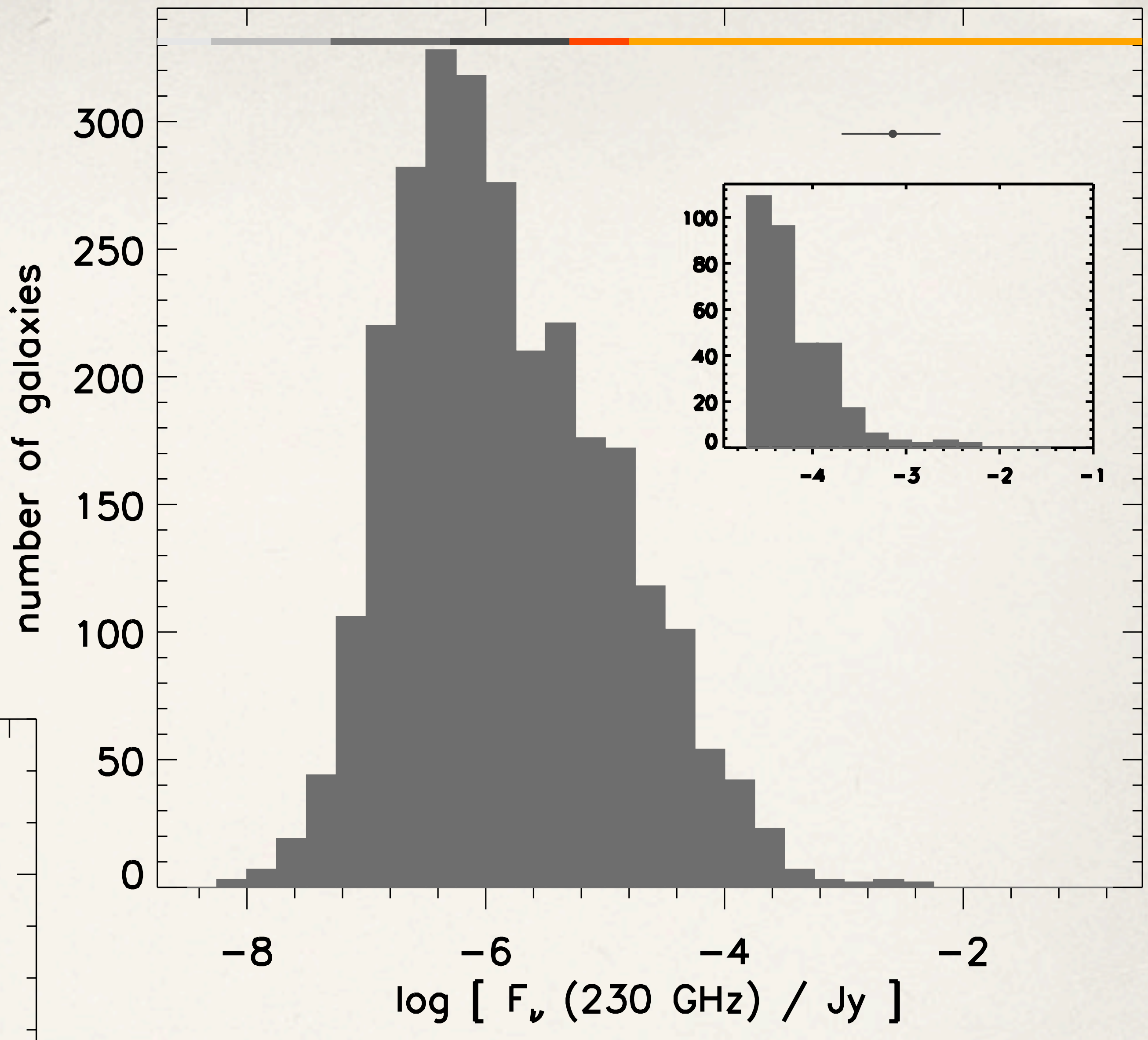


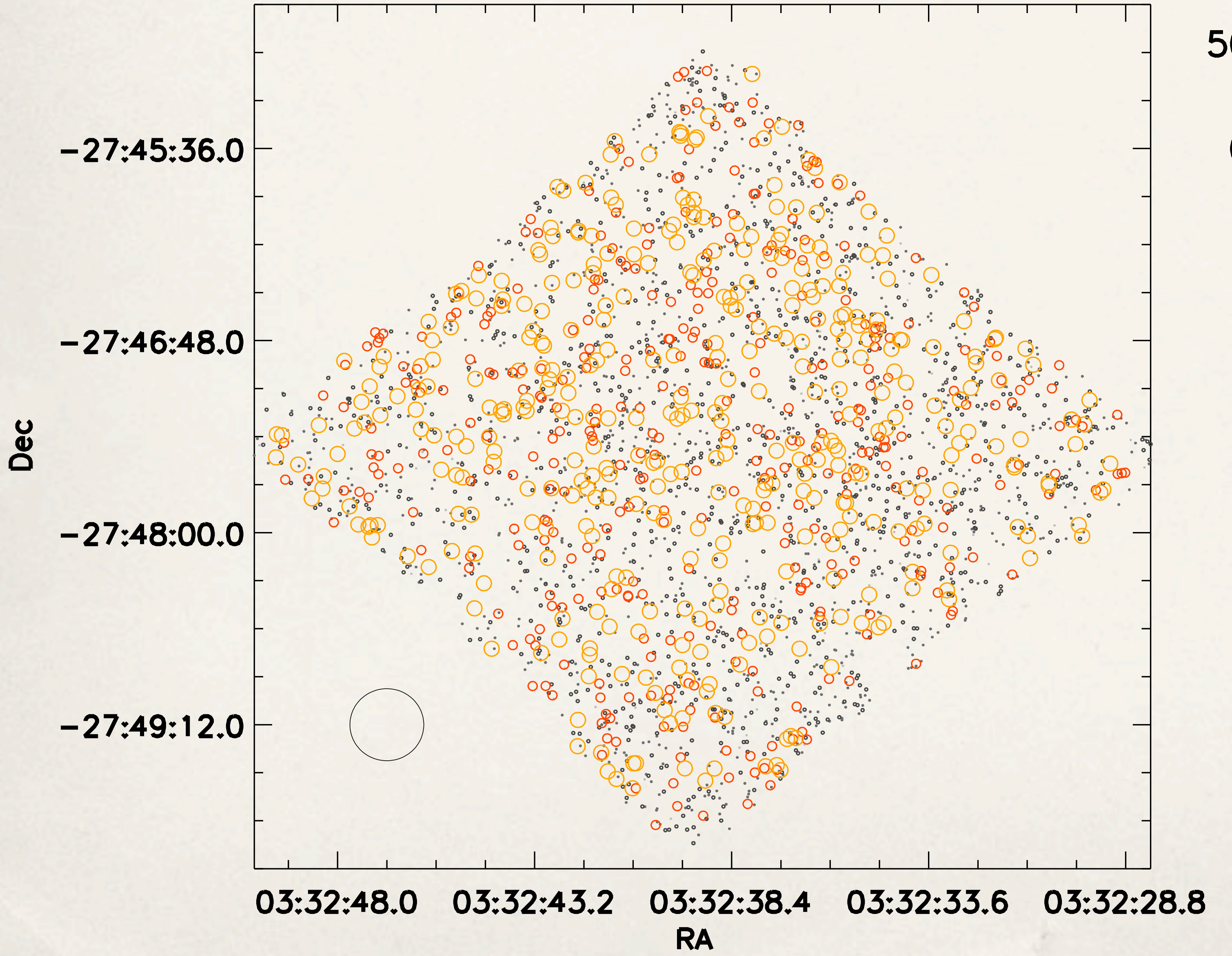
Continuum number counts



EBL @ 345 GHz = 43.5 Jy/sq. deg.
(consistent with Greve et al. 2010)

Continuum fluxes in Band 6





rms=0.01 mJy

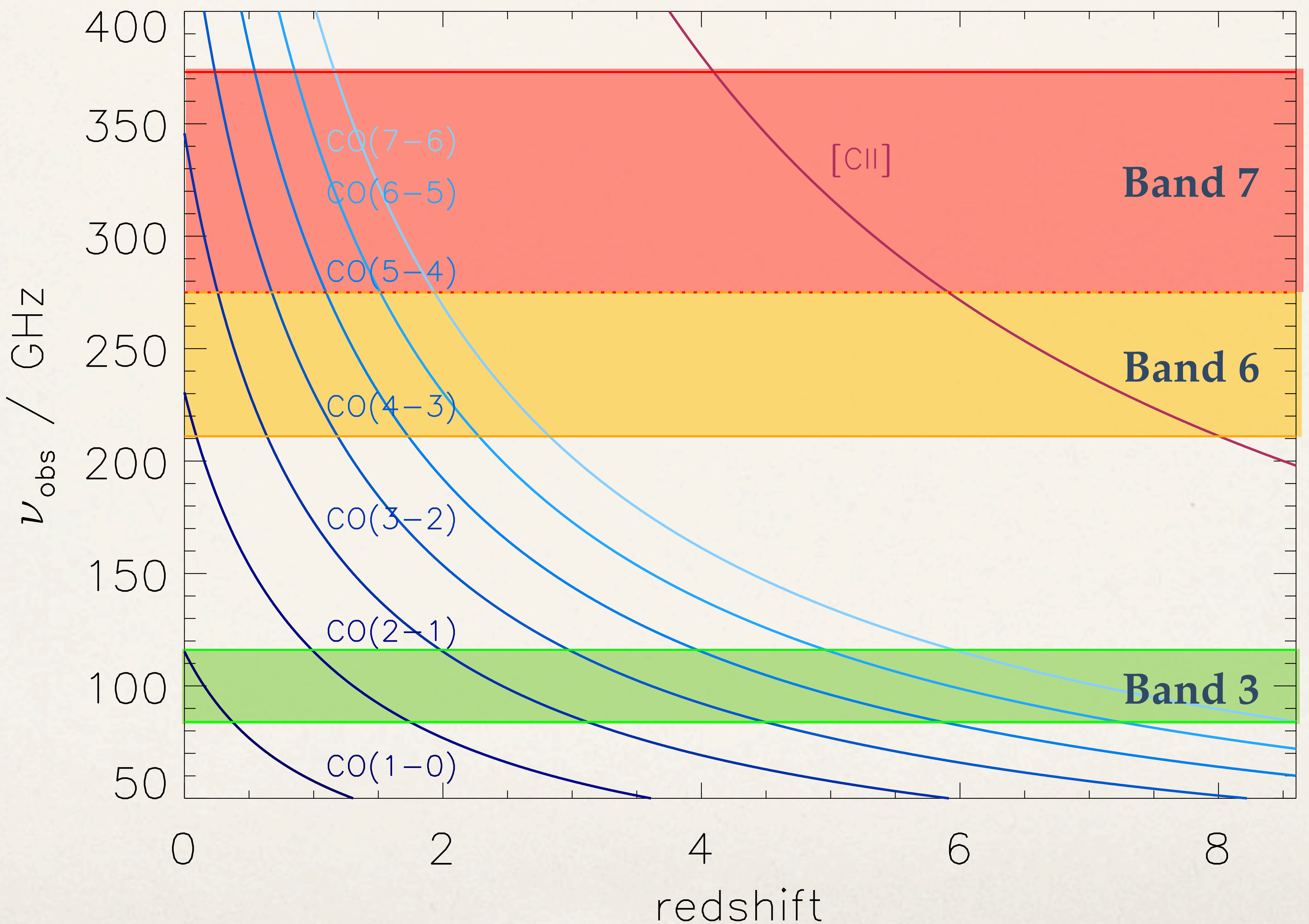
orange circles:

fluxes above 3sigma (**~400 detections**)

red circles:

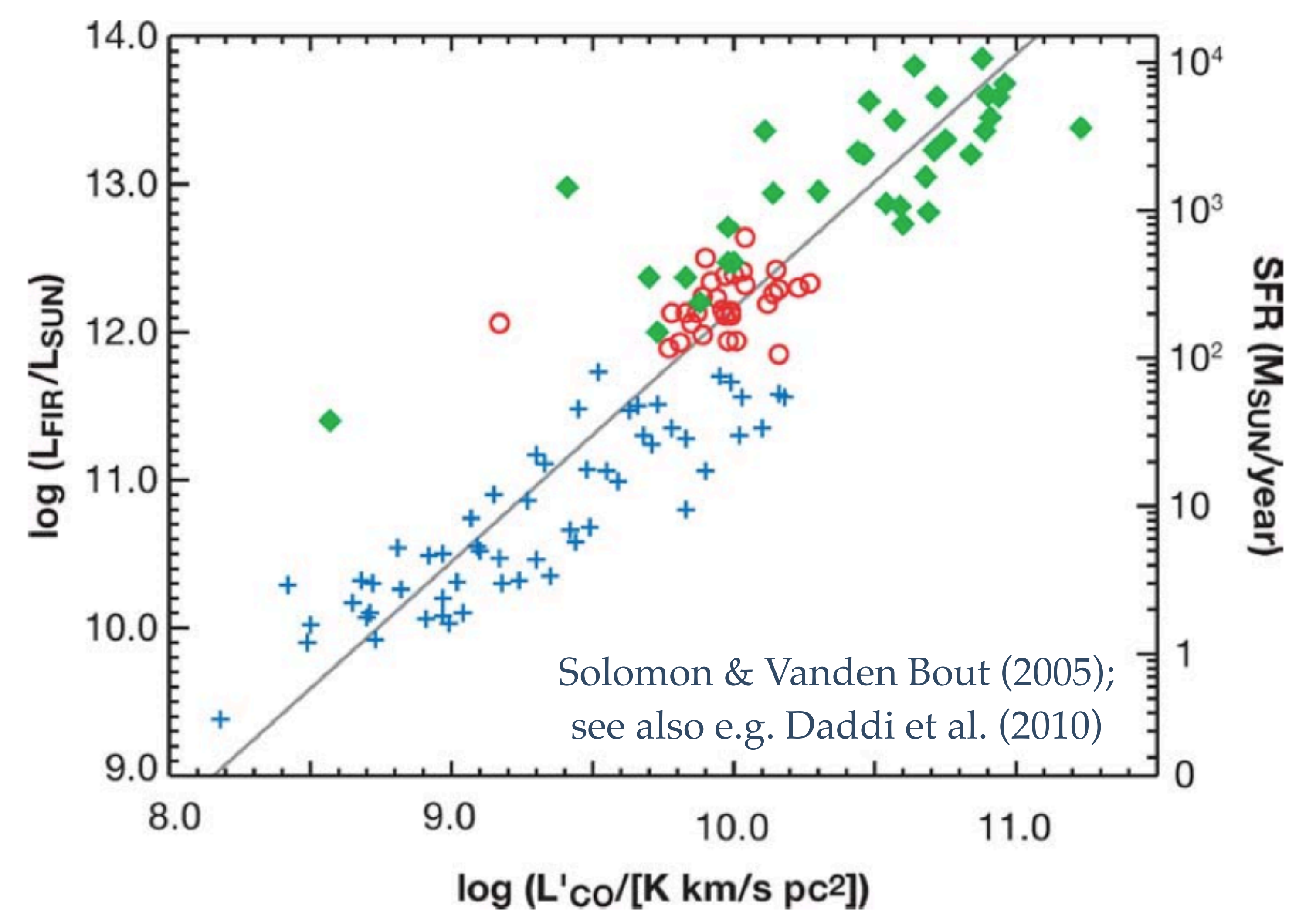
fluxes above sigma

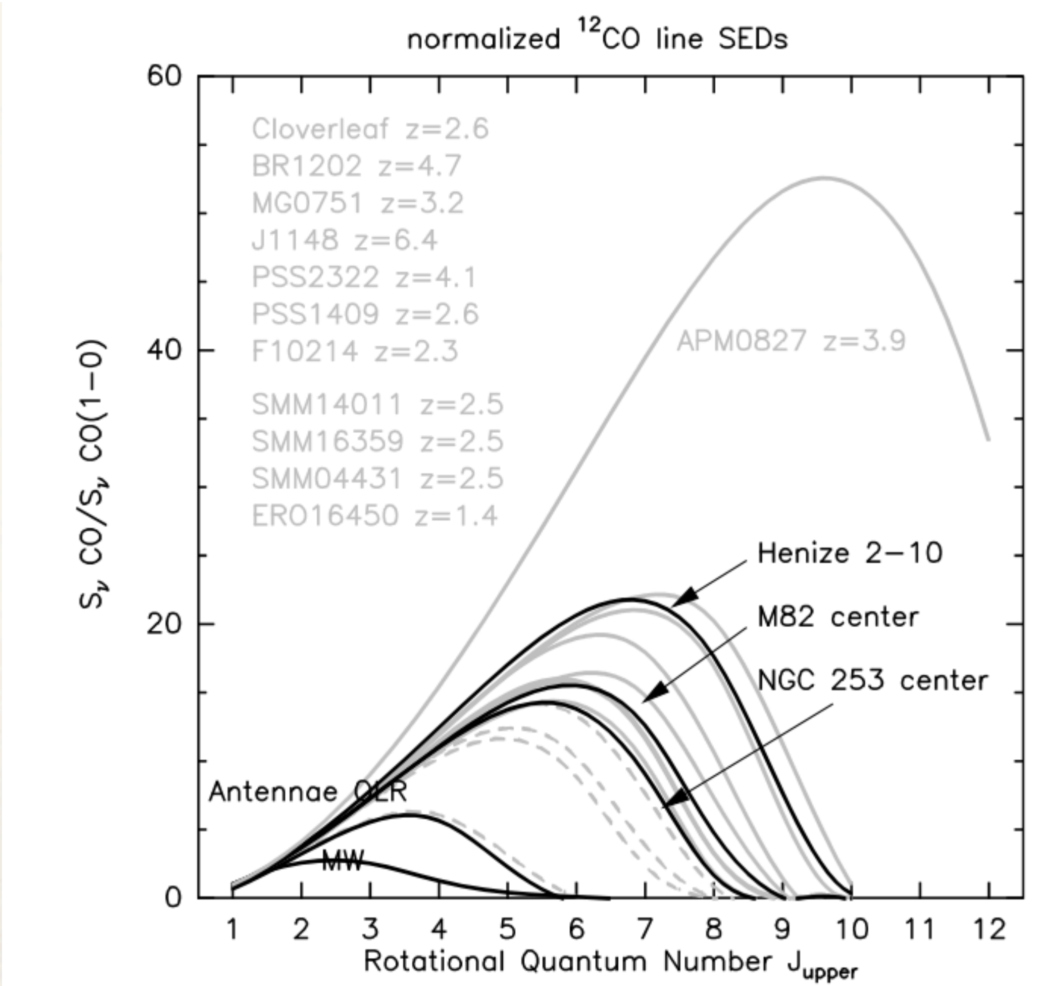
Lines - diagnostics of SF & ISM



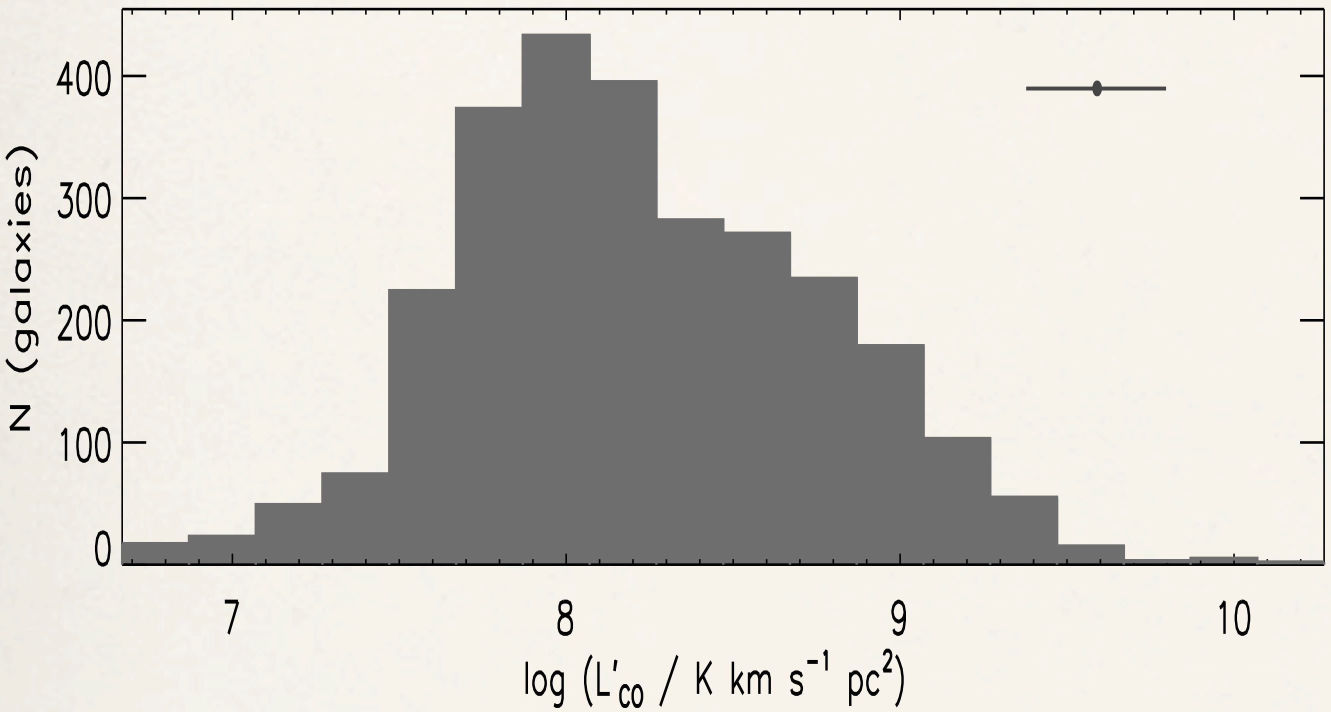
CO lines

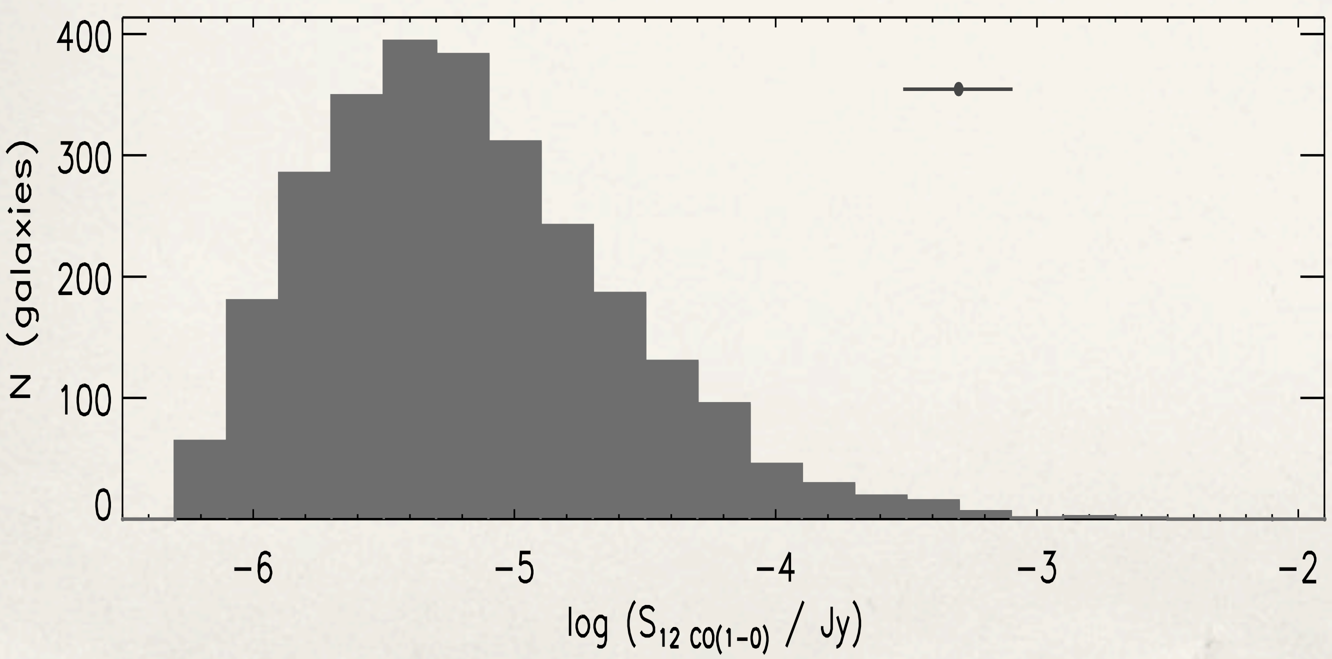
- Likelihood distribution of L_FIR from SEDs
- Calibration between L_FIR and L_CO(1-0) -> Likelihood distribution for L_CO(1-0)
- Assume CO line width: CO(1-0) predicted flux
- Higher *J* transitions: CO SEDs from A. Weiss et al.





CO flux predictions





Band 3 [84 – 116 GHz] $5\sigma = 0.13$ mJy		
Line	Milky Way	M 82 center
CO(1–0)	30	30
CO(2–1)	25	63
CO(3–2)	2	32
CO(4–3)	0	51
CO(5–4)	0	0
CO(6–5)	0	0
CO(7–6)	0	0

Band 6 [211 – 275 GHz] $5\sigma = 0.38$ mJy		
Line	Milky Way	M 82 center
CO(1–0)	not observable	not observable
CO(2–1)	3	4
CO(3–2)	25	84
CO(4–3)	12	108
CO(5–4)	3	87
CO(6–5)	0	41
CO(7–6)	0	15

Summary & Conclusions

- ALMA will allow us to routinely detect Milky Way-type galaxies at high redshifts
- SED modelling of optically-detected galaxies in the Hubble UDF using physically-motivated models + statistical approach allow us to predict the sub-mm fluxes of these galaxies
- A large (500 hours) deep field of the UDF with ALMA will yield at least several hundreds of continuum detections and tens to hundreds of CO line detections
- Statistical studies of star formation & ISM of the `normal' galaxy population at high redshifts