Galaxy evolution workshop (2018)
Ehime University

Dust properties from cosmological simulation

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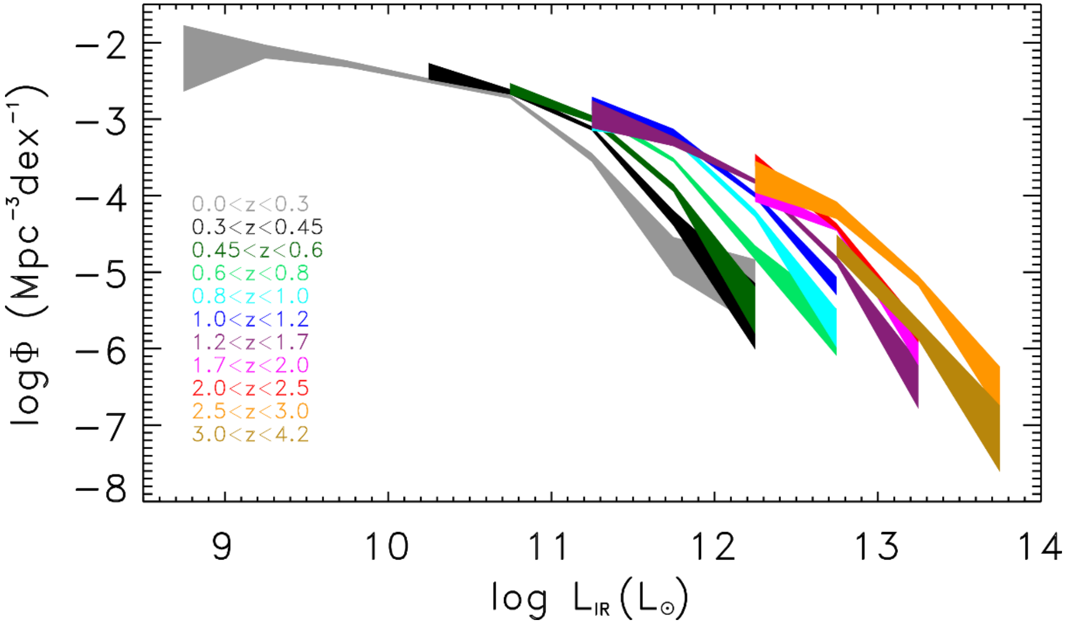
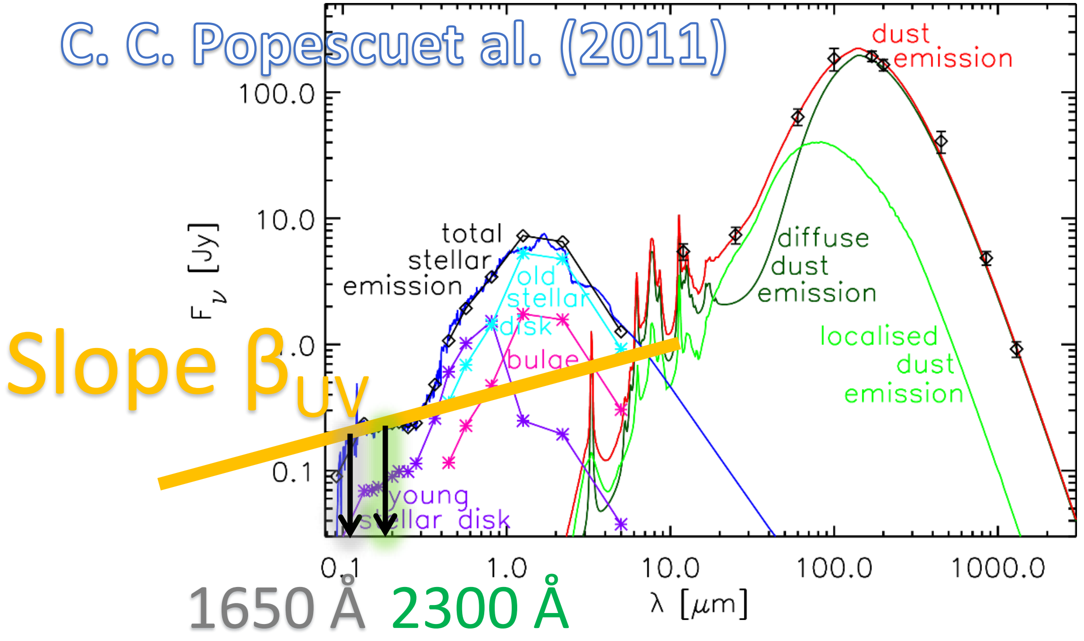
Aoyama et al. in preparation.

Introduction

- Dust absorbs UV-optical light and reprocess it into the IR.
- IR luminosity function, T_{dust} and IRX-β_{UV} indicate the dust abundance, distribution and the interstellar radiation field.
- They are observationally obtained with many ground observatory (e.g. JCMT) and satellites (e.g. *Herschel*, *Spitzer*, *IRAS*) at various redshift (0<z<4).
- Recently, STUDIES (JCMT/PI: Wei-Hao Wang) revealed the property of optically-faint, IR-luminous and high-z objects.



C. Gruppioni et al.(2013)[1302.5209]



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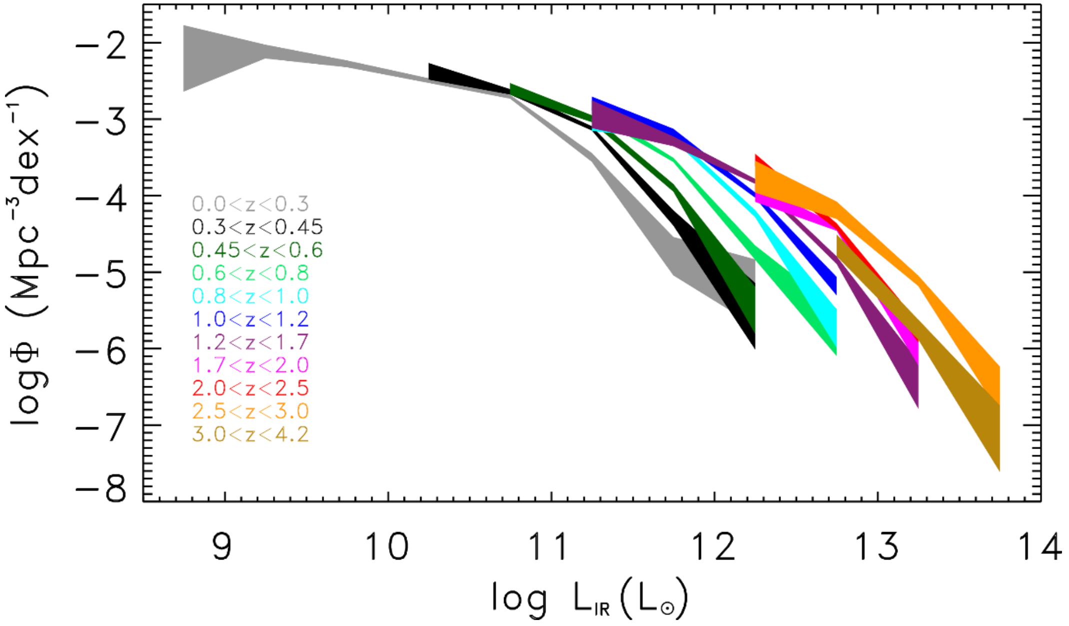
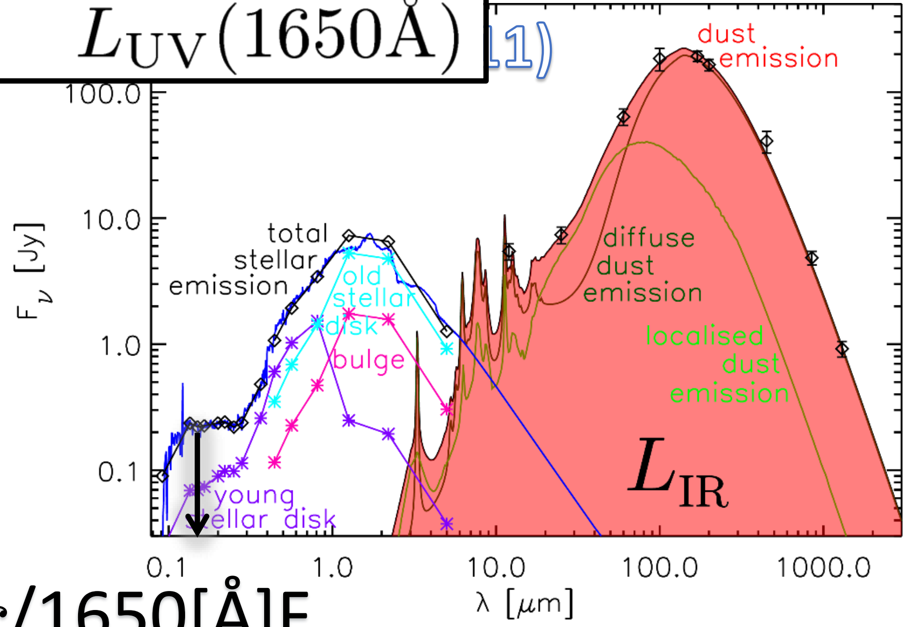


(2013)[1302.5209]

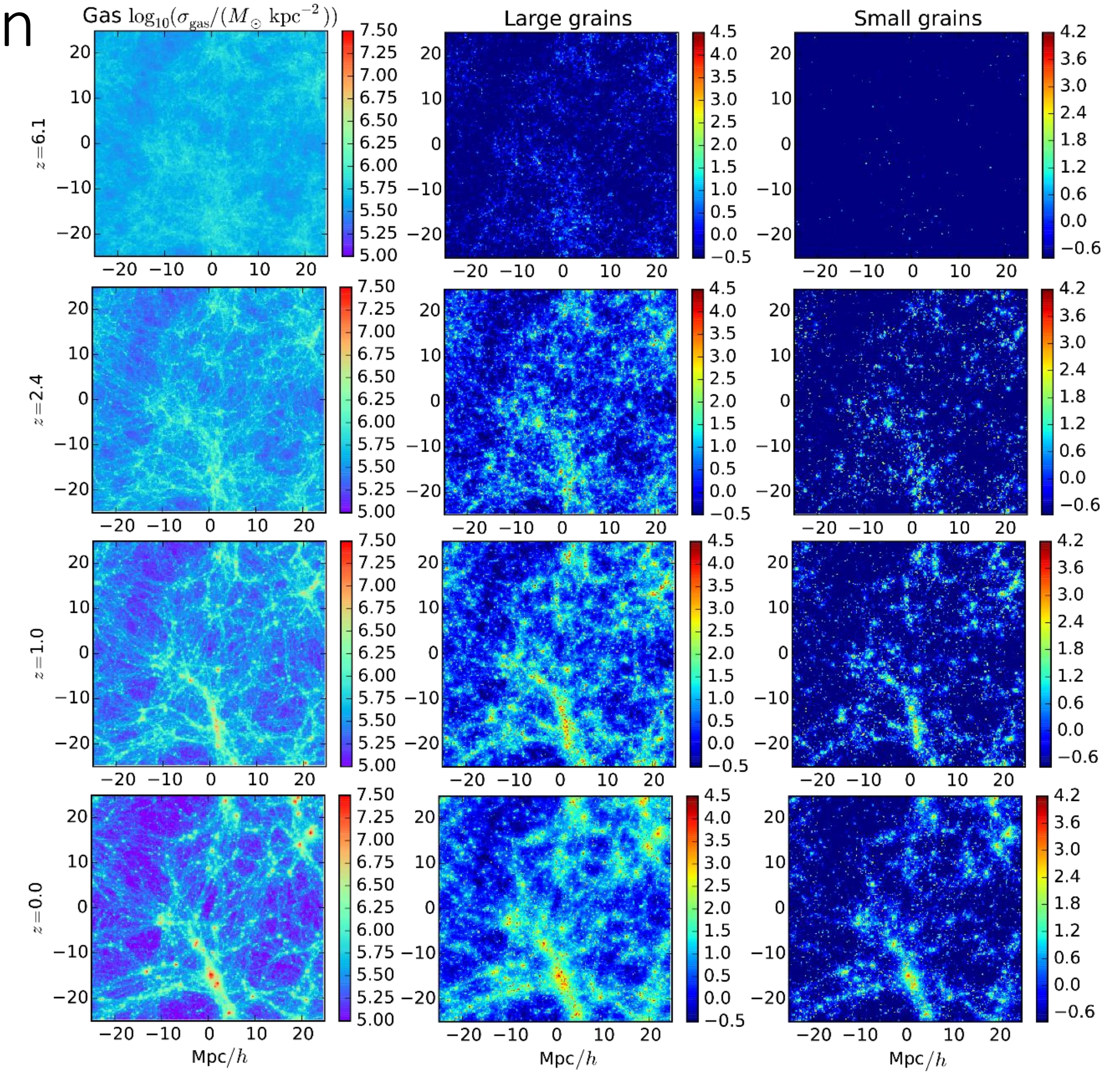
$$\mathrm{IRX} = \frac{L_{\mathrm{IR}}}{L_{\mathrm{UV}}(1650\mathrm{\AA})}$$



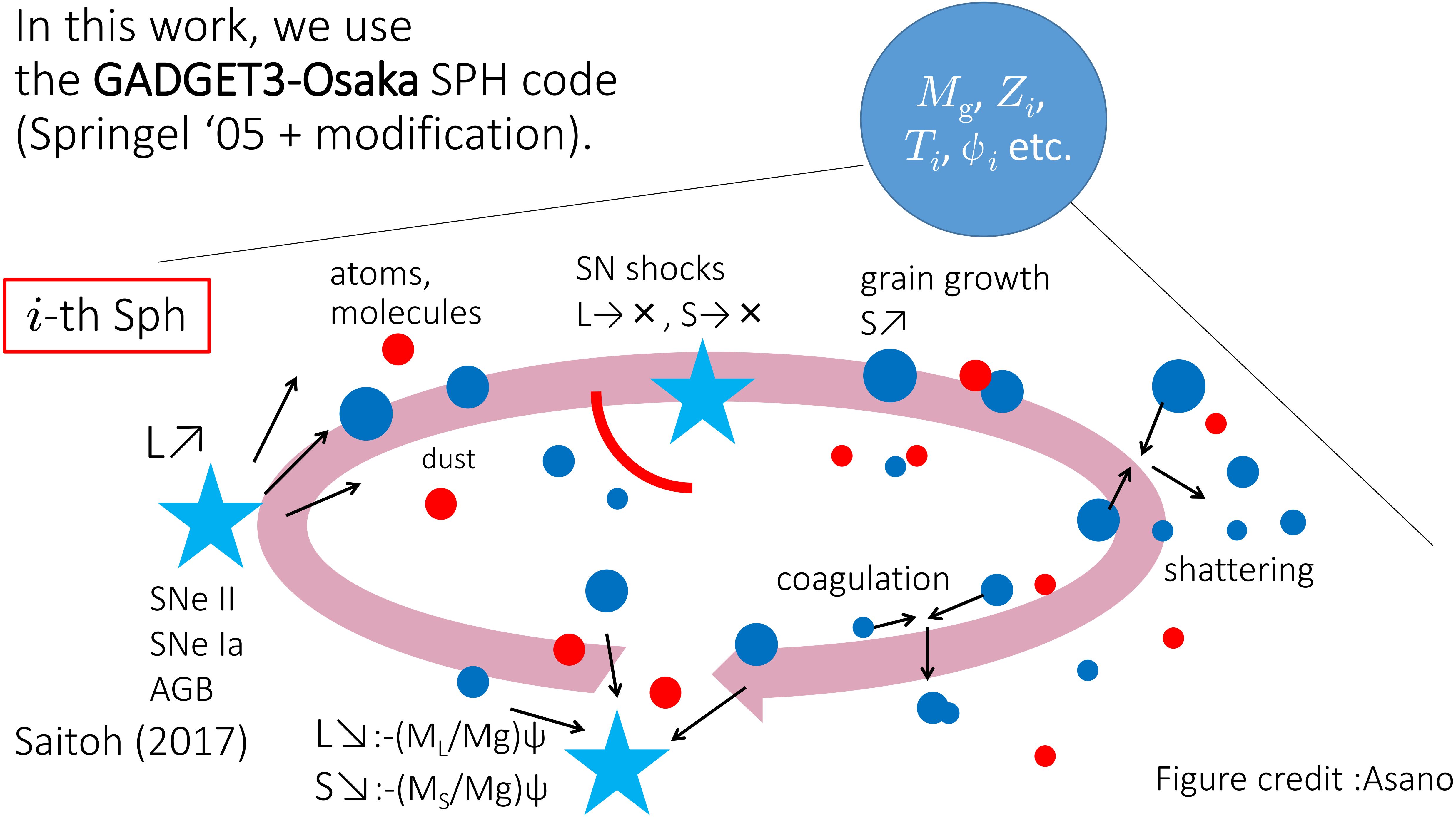
$L_{UV}(1650)=c/1650[\text{Å}]F_\nu$

Simulation (Aoyama et al. 2018 MNRAS accepted) [1802.04027]

- Cosmological hydro-dynamical simulation with dust evolution is performed by GADGET3-Osaka.
- Boxsize: 50 Mpc/h
- Resolution: 3 ckpc (2×512^3)
- Dust size distribution is represented as Hirashita (2015).
- Not only dust production and growth (accretion)
  but also dust-dust interaction (coagulation and shattering).



In this work, we use the **GADGET3-Osaka** SPH code (Springel '05 + modification).

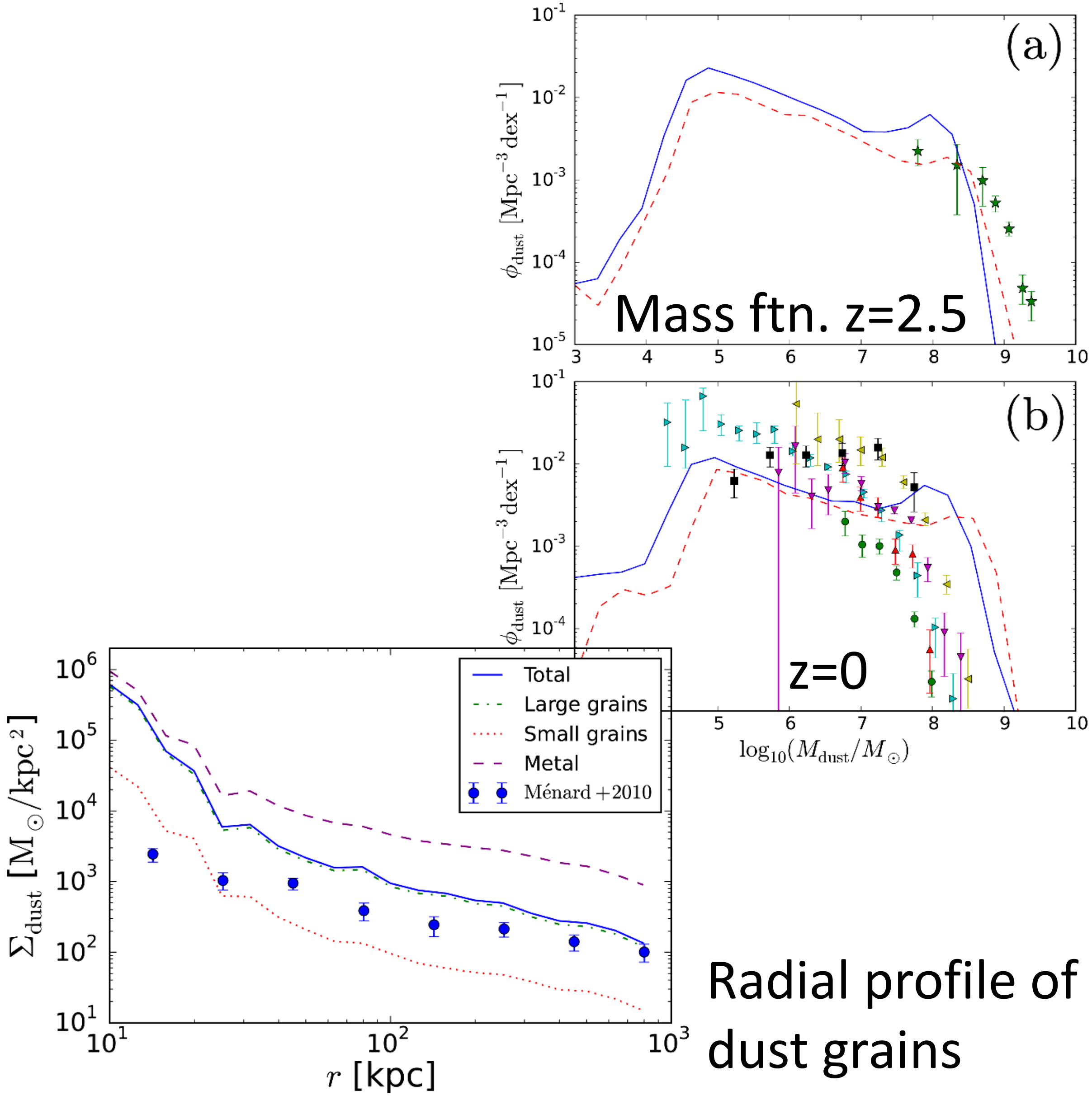


Saitoh (2017)

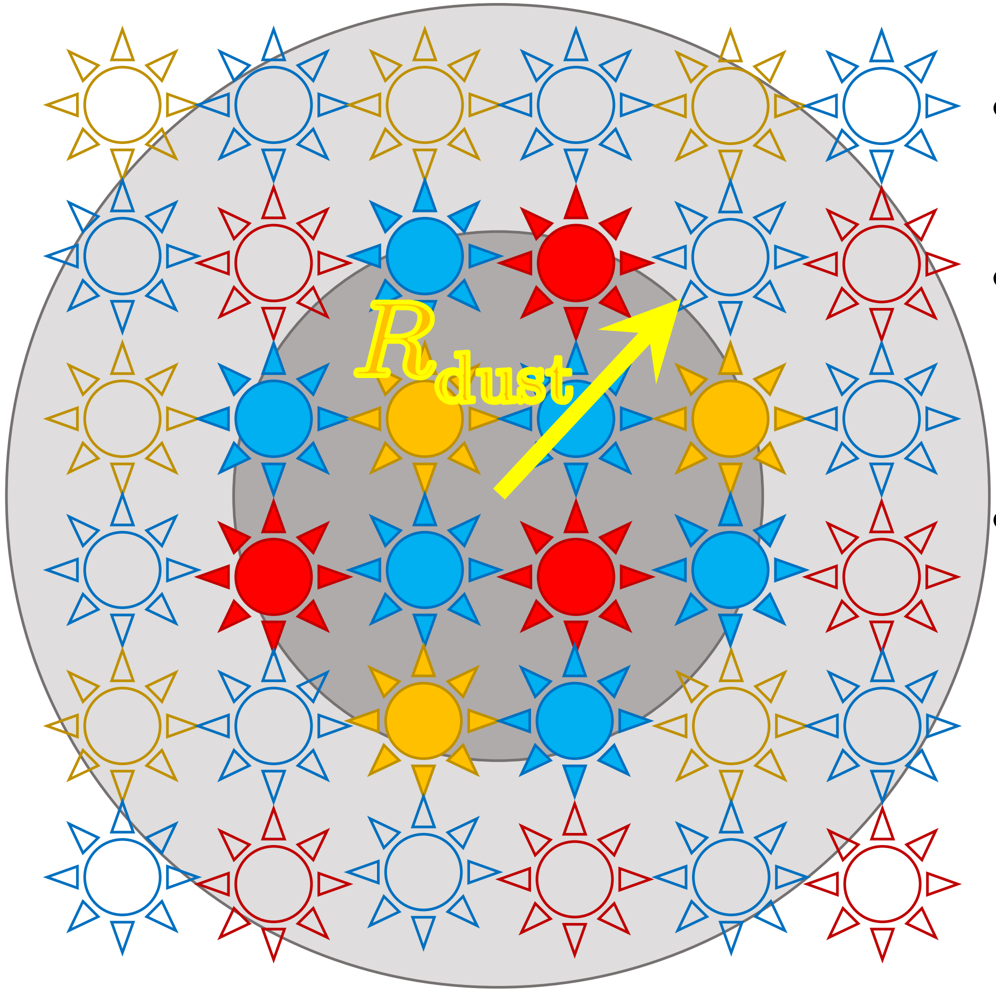
Figure credit :Asano

Mass Fcn and dust radial profile

- Hydro-dynamical simulation with dust evolution is performed by GADGET3-Osaka.
- Dust size distribution is represented as Hirashita (2015) and not only dust production and growth (accretion) but also dust-dust interaction (coagulation and shattering).
- We successfully reproduce the dust mass function and radial profile of dust etc.



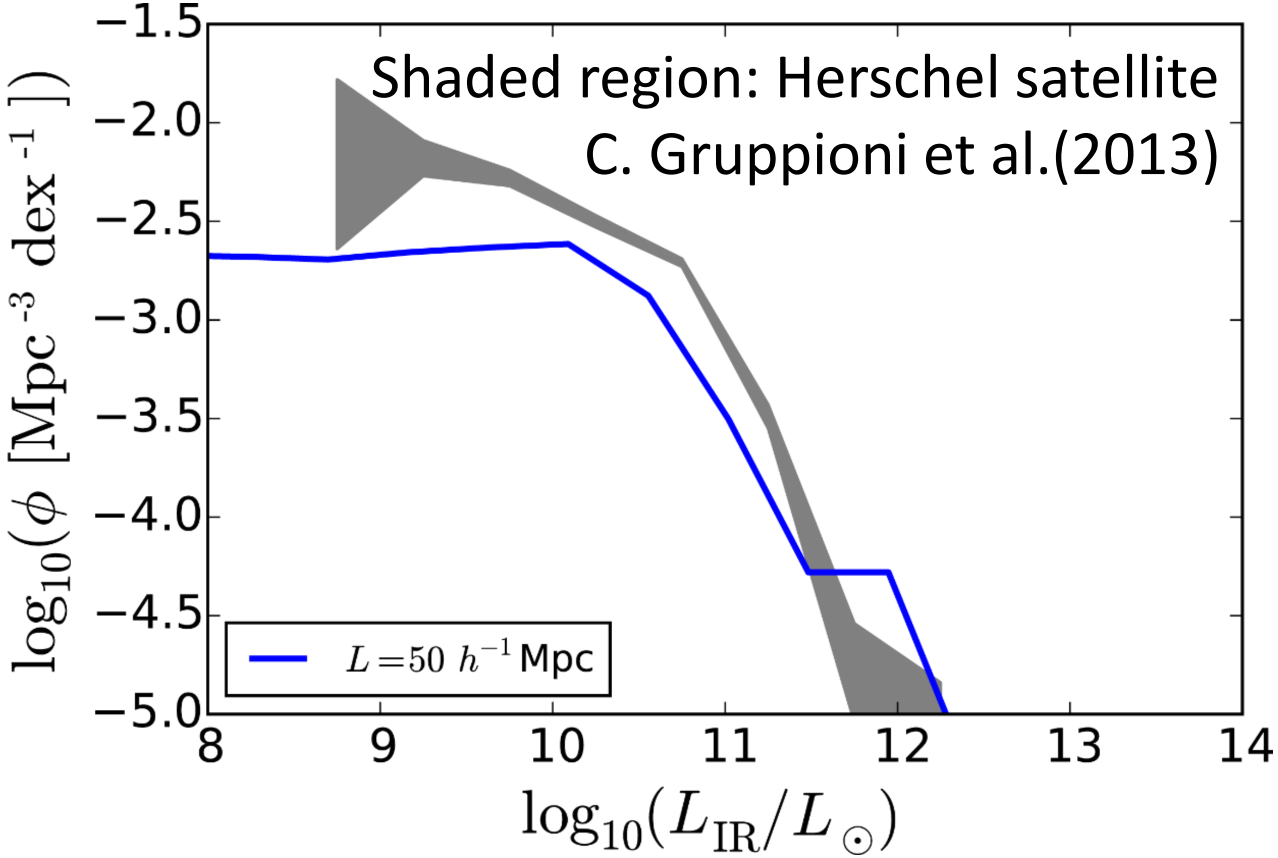
Modeling of dust absorption and emission



- We estimate the radius of IR emitting region $R_{\rm dust}$ by performing the exponential fitting of radial profile of dust mass density.
- We take into account stars and dust grains at $0 < R < R_{\rm dust}$.
- The intrinsic SEDs of stars are estimated by their age and metallicity based on Bruzual & Charlot (2003).
- The extinction is estimated based on the mixed geometry.

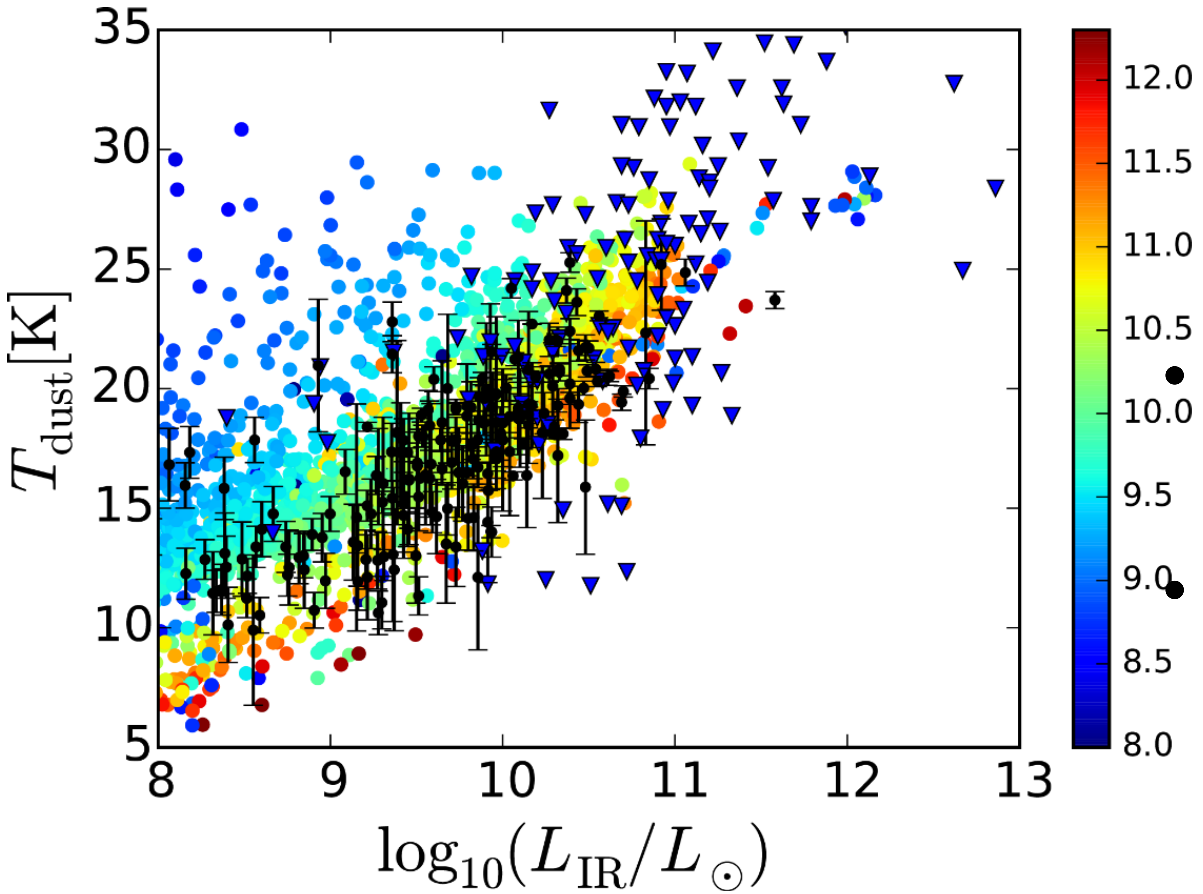
$$f_{\rm esc}(\lambda) = \frac{1 - \exp\left(-\tau(\lambda)\right)}{\tau(\lambda)}$$

Luminosity function at z=0



- We compare the LF with observation result with *Herschel*.
- Overall statistics is consistent with observation.
- From the LF, we cannot say anything about individual galaxies,
  so this statement is irrelevant.

T_{dust}-L_{IR} at z=0



●:M. S. Clemens et al. (2013)

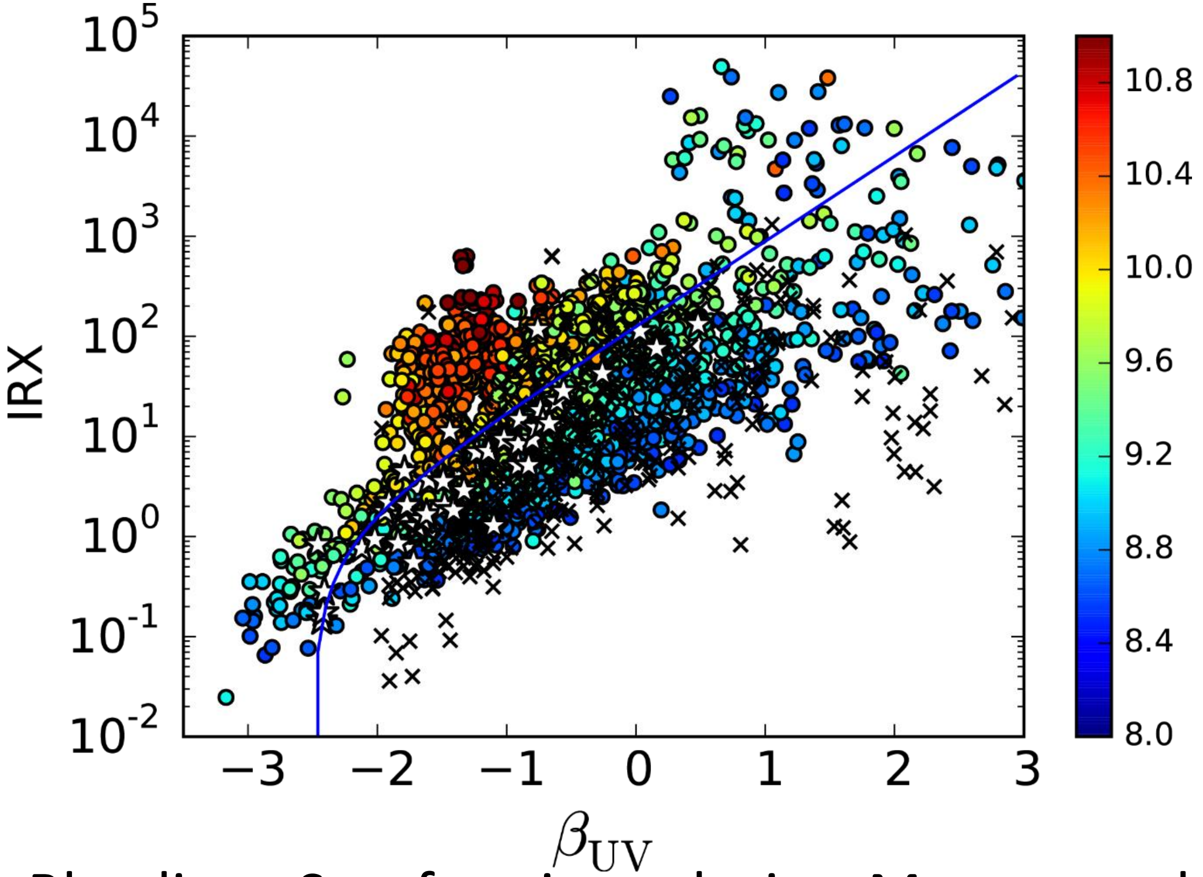
▼:A. Amblard et al.(2010)

- Dust temperature is estimated by

$$T_{dust} = 7.866 \left(\frac{L_{IR}/L_{\odot}}{M_{dust}/M_{\odot}} \right)^{\frac{1}{6}} \text{K}$$

- Reproduced T_{dust}—L_{IR} relation
- It indicates that our dust model describes the IR luminosity and the dust optical depth (or dust surface density) consistently.

IRX-β_{UV} relation at z=0

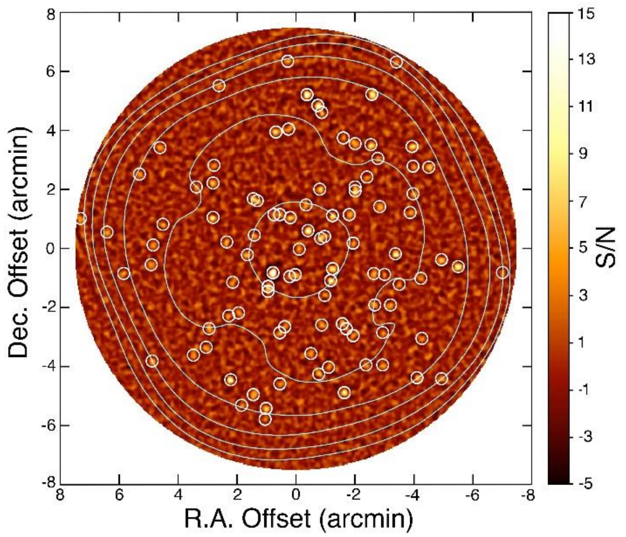


Blue line : Star forming galaxies: Meurer et al. (1999)

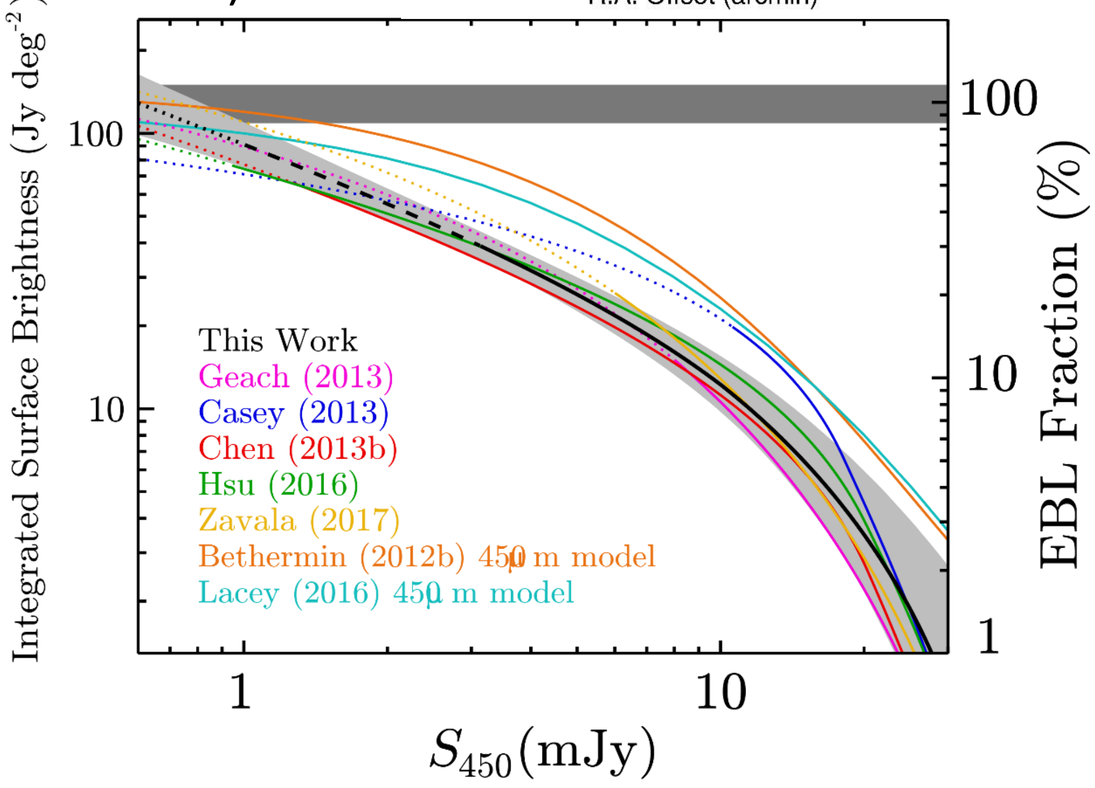
- Observational points are shown as stars(☆: Meurer et al. 1999) and cross(✕ : C.M. Casey et al. 2014).
- We predict observational sequence and the scatter.
- Affected by the assumed geometry of dust distribution. -> screen geometry could disperse these points.

STUDIES (SCUBA2)

W-H. Wang et al. (2017), C-H. Lim in prep.

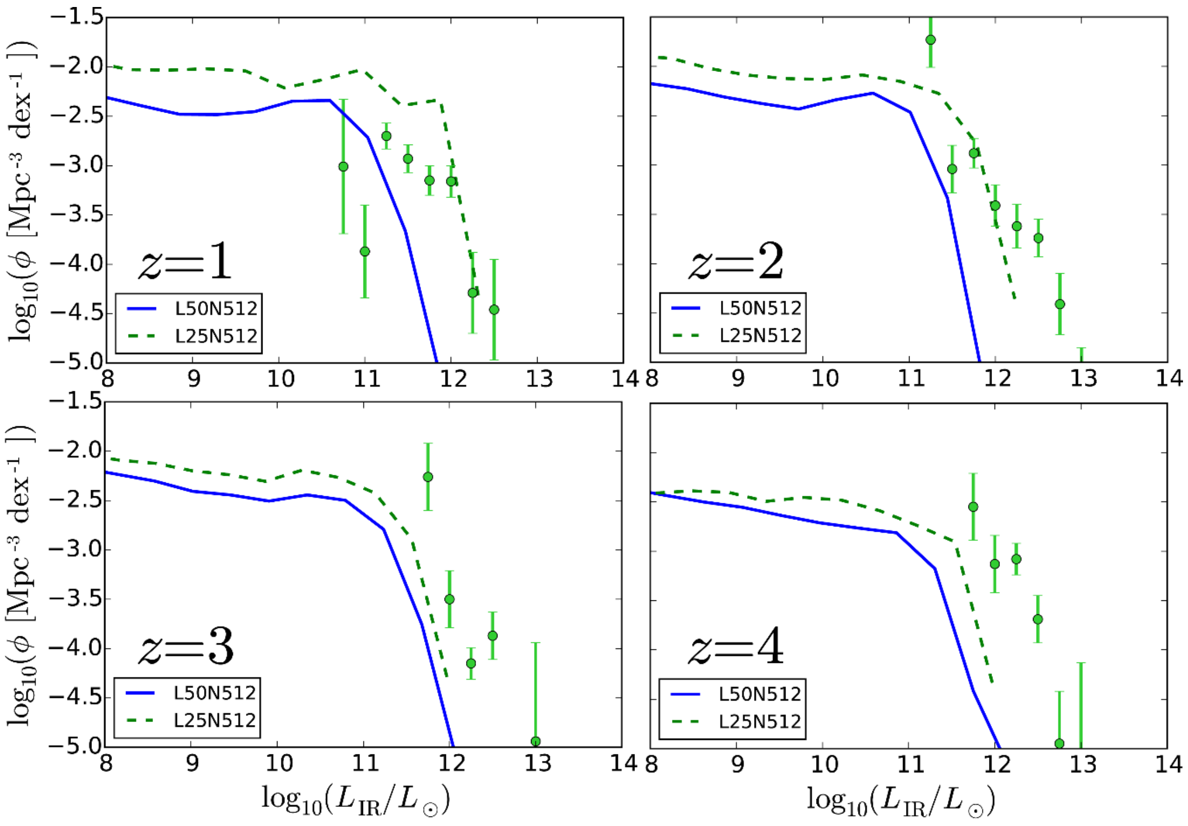


- λ=450, 850 μm
- Survey area: COSMOS-CANDELS region (151 $arcmin^2$)
- Noise level 0.91 mJy
- **Merit of JCMT**
  Taking advantage of the large aperture, fainter objects which *Herschel* cannot detect can be observed.
- The integrated surface brightness down to 1mJy can account for up to 83^{+15}_{-16} % of COBE background.



W-H. Wang et al. (2017)

Luminosity function @high-z universe

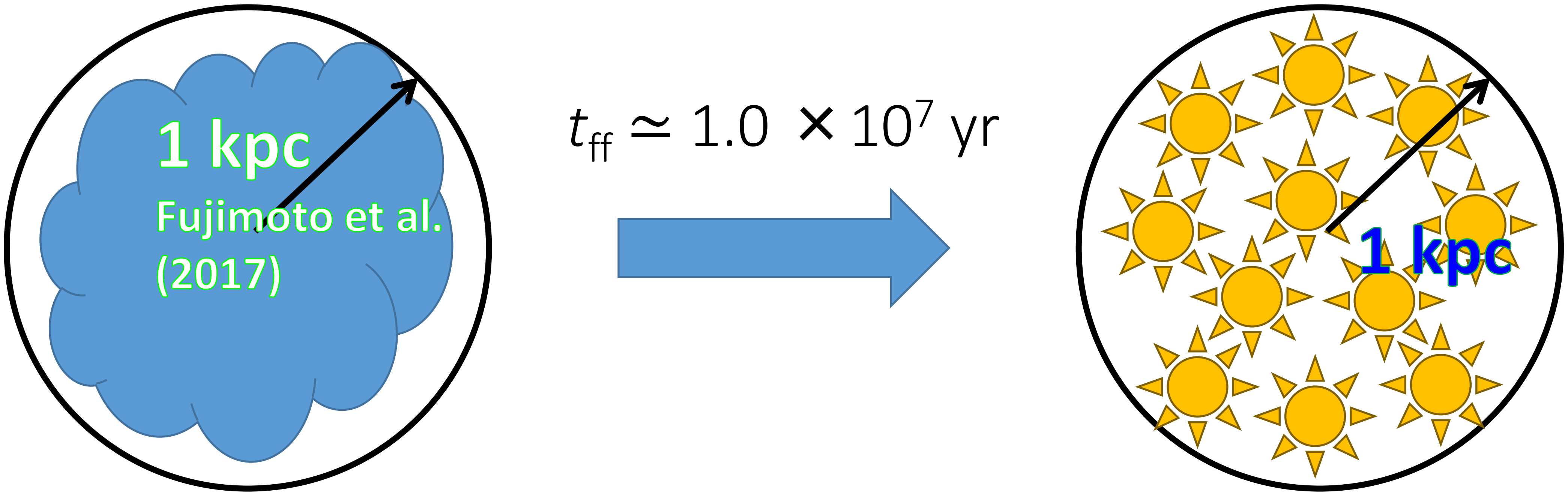


Solid L50N512 (Default)

Dashed L25N512

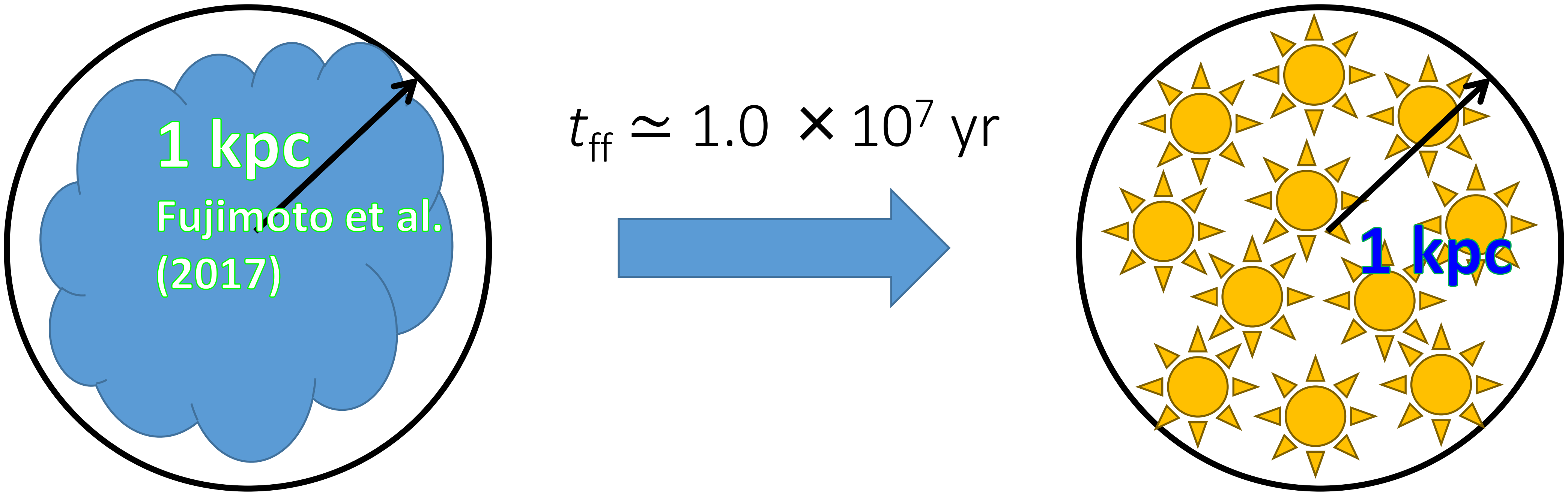
- Our snapshots are consistent with observation only at z≲1.
- When we performed a simulation whose spatial resolution is 2 times better, we can explain LF still up to z≃2.
- It means that we cannot reproduce compact star burst at high-z.
- Neglecting AGN heating does not make this difference.
  (e.g. Y-Y. Chang et al. 2017,
  C. Gruppioni et al. 2013)

"Maximum" stellar mass in this simulation



- When we consider a situation that all gas particles bounded in IR emitting region are converted into star particles within dynamical time scale.
- Because of the resolution (≃0.3 comoving kpc), only 37 particles can be packed within IR emitting region (≃1kpc: S. Fujimoto 2017) at z=3. Thus created star mass becomes $7.0 \times 10^8 M_\odot$ (the age $\simeq 1.0 \times 10^7$ yr).
- According to SED table (Bruzual & Charlot 2003), the luminosity becomes $2.5 \times 10^{11} L_\odot$.

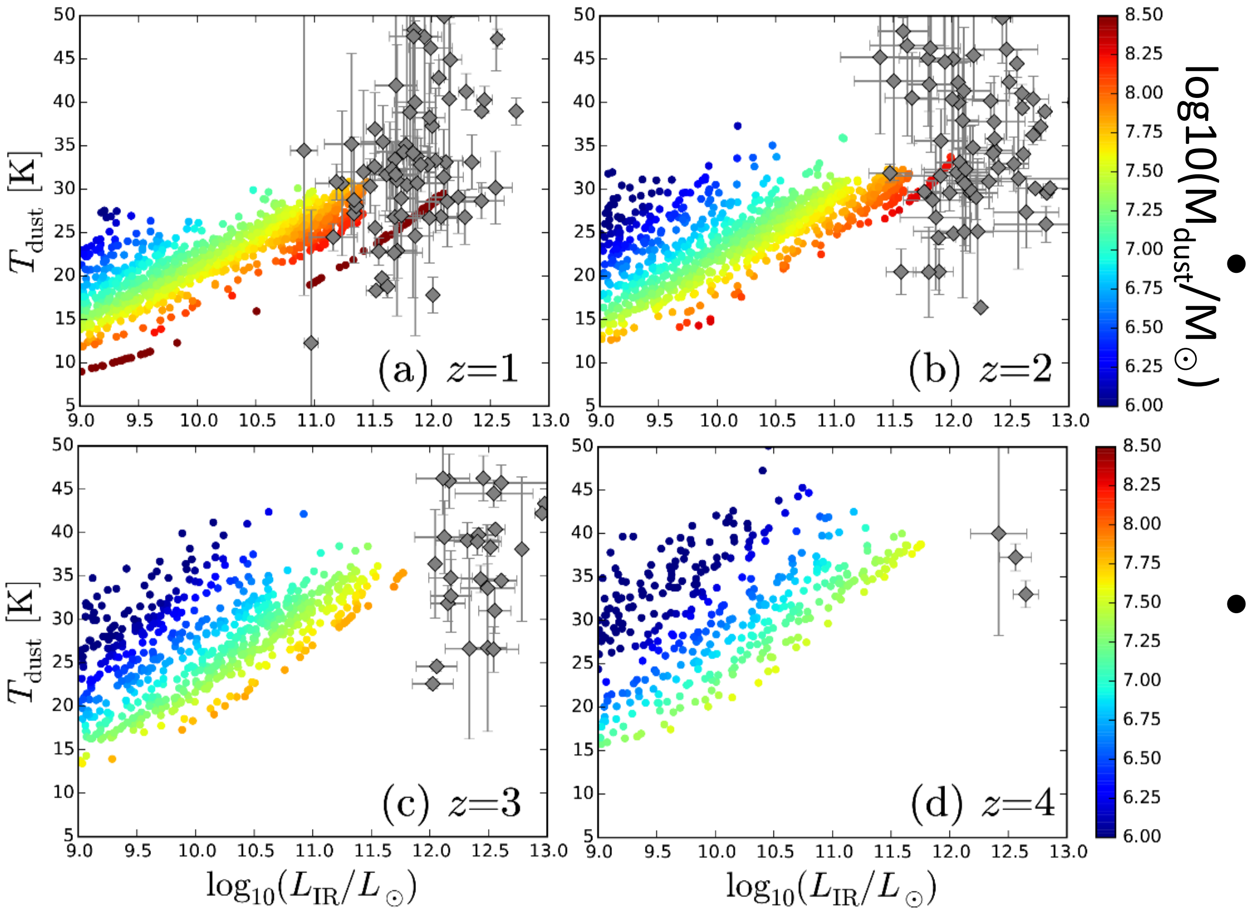
“Maximum” stellar mass in this simulation



- Particle-based simulations with the finite resolution (0.3 ckpc) have the luminosity limit ($2.5 \times 10^{11} L_\odot$).

Cf. a theoretical limit (Eddington limit) $10^{13}\ L_\odot \mathrm{kpc}^{-2}$ (R. M. Crocker et al 2018)

T_{dust}-L_{IR}@high-z universe

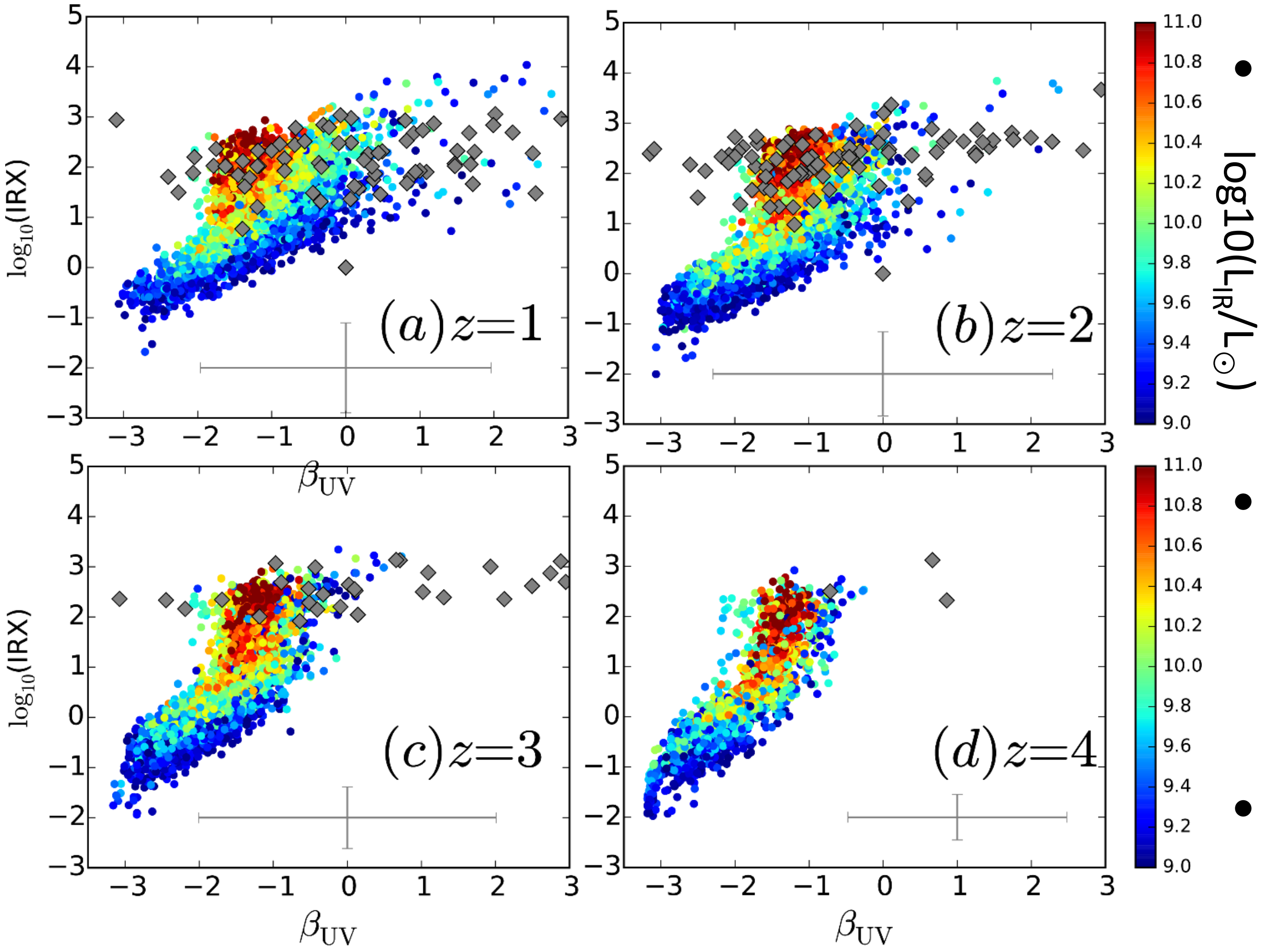


- Our prediction is located at luminous end around the center of the observational data points.
- In dusty galaxies, dust temperature becomes low because of increase of dust to stellar mass ratio.
- Because of lacking of star bursts, we cannot produce luminous enough galaxies at high-z.

IRX-β_{UV}@high-z universe

$$\mathrm{IRX} = \frac{L_{\mathrm{IR}}}{L_{\mathrm{UV}}(1650\text{Å})}$$

β_{UV}: Slope of SED at UV



- IRX-β_{UV} relation are explained by simulation results up to z≃3. Dust abundance and extinction are successfully treated even at high redshift (z ≲ 3).

- The observation uncertainty of β_{UV} becomes large because the targets are optically faint.

- At z≃4, some galaxies whose SEDs are very red cannot be explained.

Summary

- We analyze our simulation results (Aoyama et al. 2018) and obtained IR luminosity function, dust temperature and IRX-β_{UV} relation.

- At z=0, our simulation can explain IR luminosity function, dust temperature and IRX-β_{UV} relation.

- At high redshifts, they are not explained by our simulation because of a lacking of star bursts due to basically resolution limit.
- However our treatment of dust extinction and IR emission works well when we compare the observation data (STUDIES).