Lyman-alpha emission from high-redshift disk galaxies

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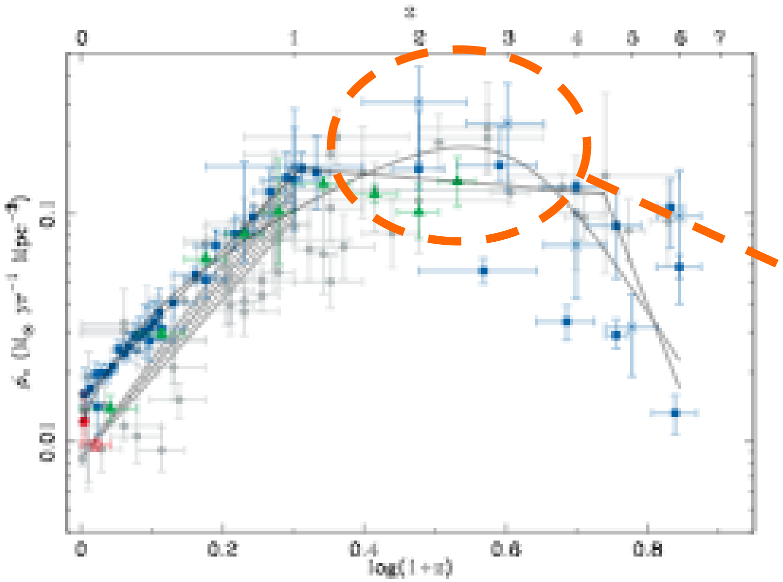
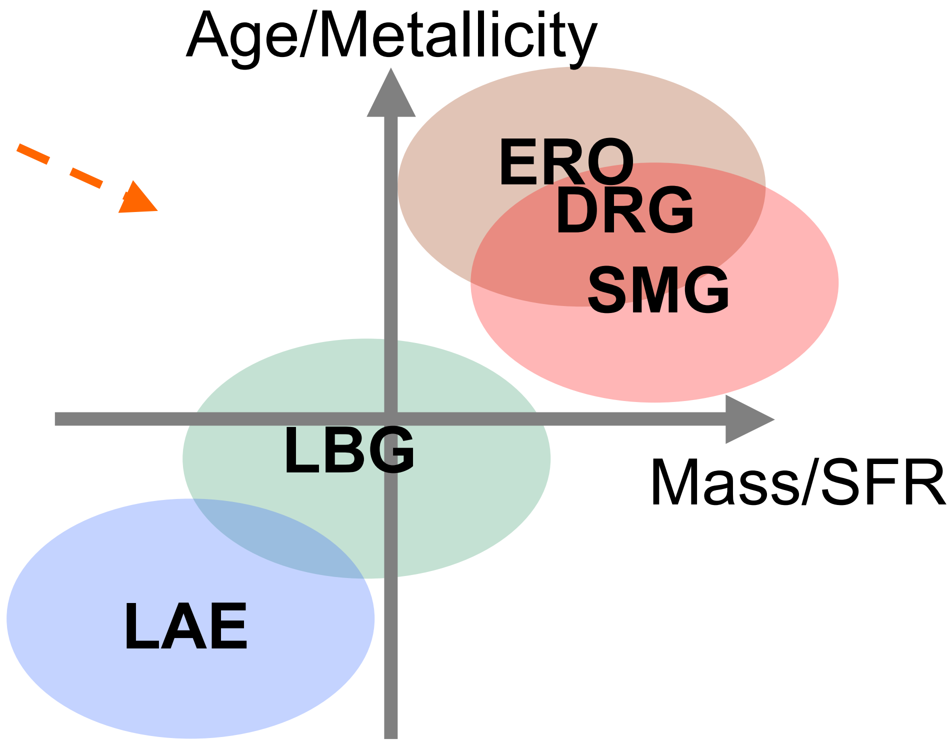
DEX Meeting 2014@Durham

High-z galaxy zoo



Hopkins+06

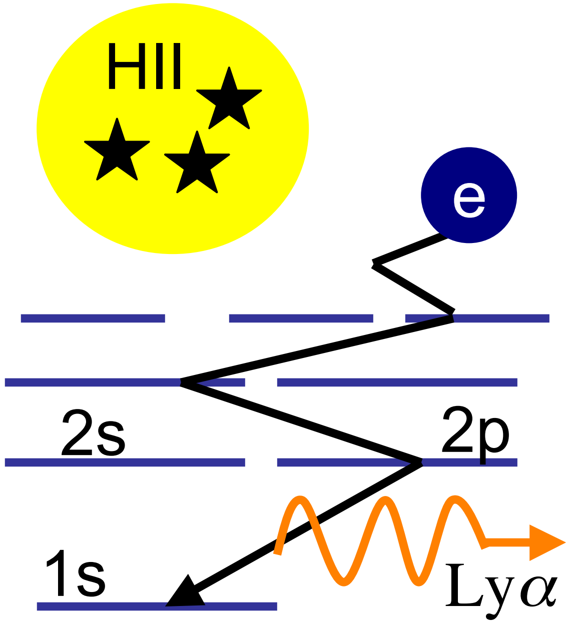
Galaxy zoo at z>1-2



LAE: Lyman-alpha emitter
LBG: Lyman break galaxy
SMG: Sub-millimeter galaxy
DRG: Distant red galaxy
ERO: Extreme red object

How did they form?
How were they relating with each other?

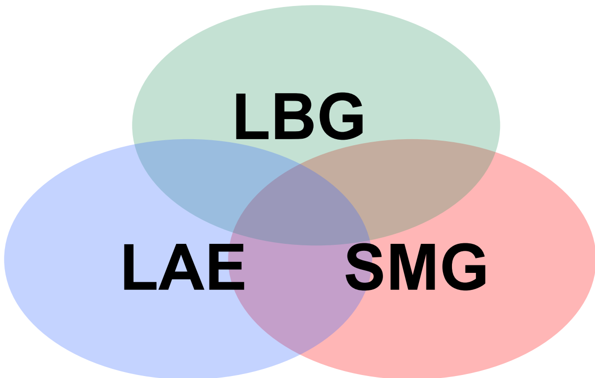
Lyman-alpha emission from galaxies



Recombination process in HII region

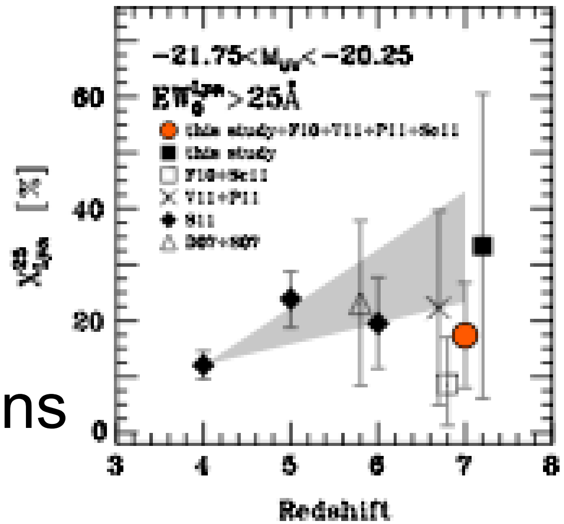
Lya lines are important
Because they are relating with
star formation, dust, velocity field of HI gas

$$L_{\mathrm{Ly}\alpha} = 1.1 \times 10^{43}\,\mathrm{erg/s}\left(\frac{\mathrm{SFR}}{1\ \mathrm{M_{sun}}/\mathrm{yr}}\right)$$



Overlap of the different populations

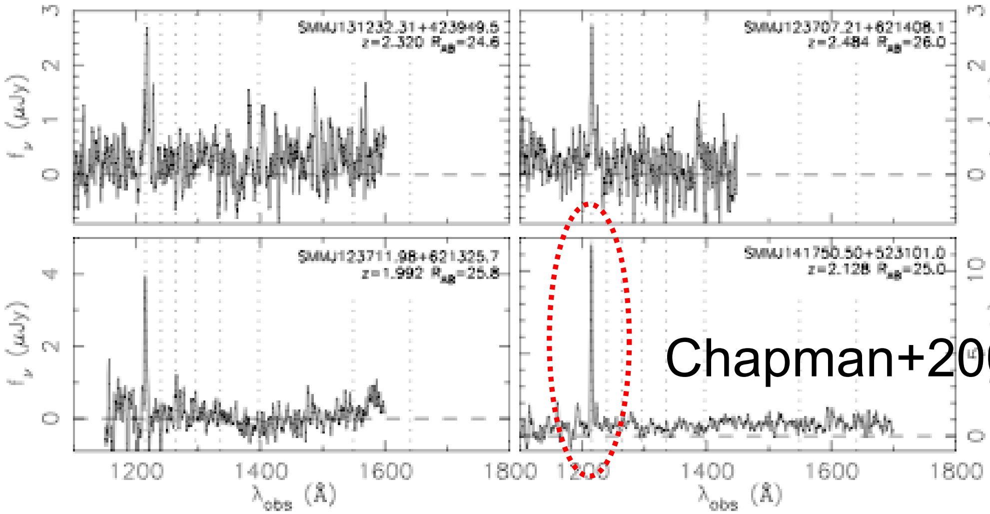
LAEs in LBGs



Ono+2012

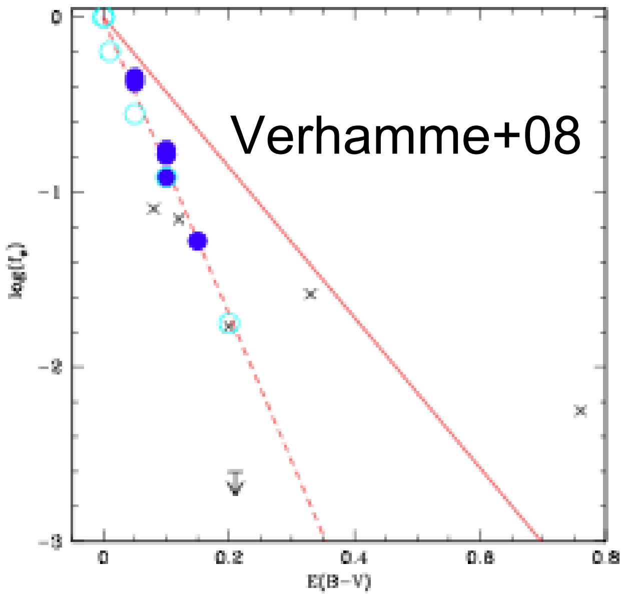
Lyman-alpha emission from massive dusty galaxies

About half of SMGs show Lyman-alpha lines despite they have much dust



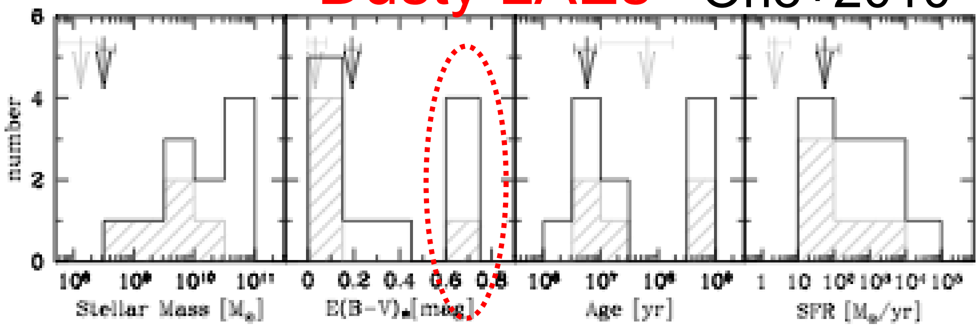
Chapman+2005

Escape fraction is very small to dusty galaxy in spherical model



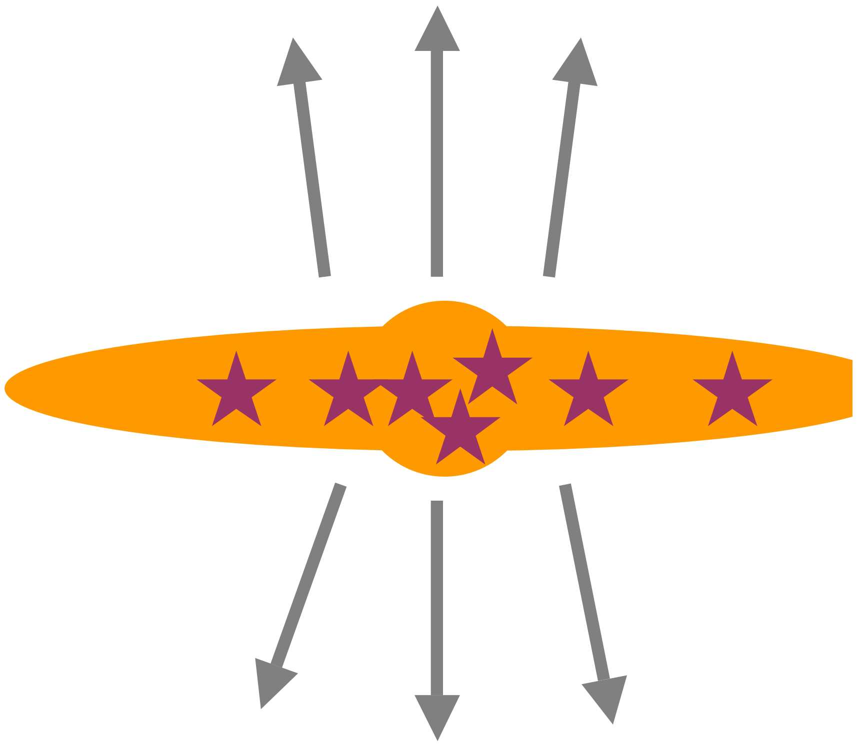
Verhamme+08

Dusty LAEs Ono+2010

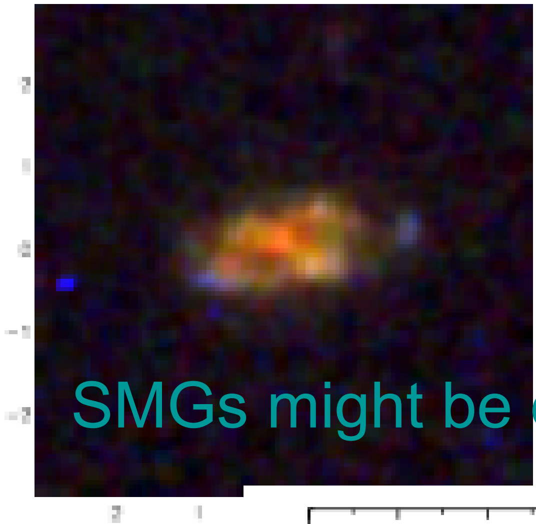


How could Lya photons escape from dusty galaxies?

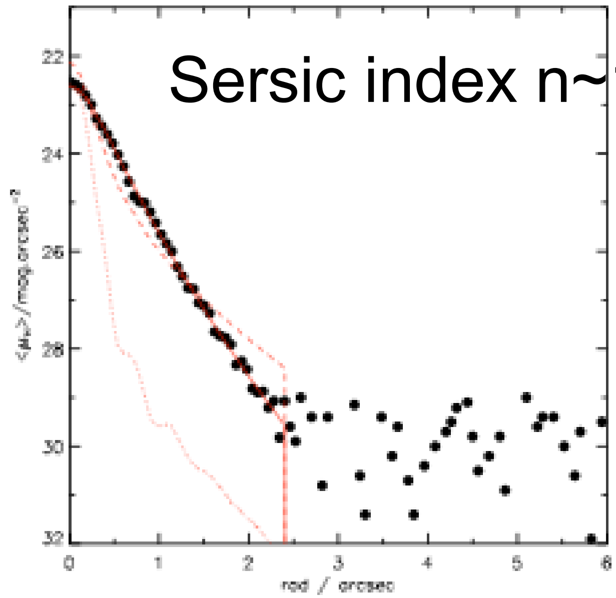
Escape from disk?



Escape due to low column density
or gas outflow?



SMGs might be disk galaxies



Sersic index n~1.5

Targett et al. 2011, 2013

Purpose

- We investigate escape of Lyman-alpha and other continuum photons from high-redshift disk galaxies by using hydrodyanmics simulations and radiative transfer calculations

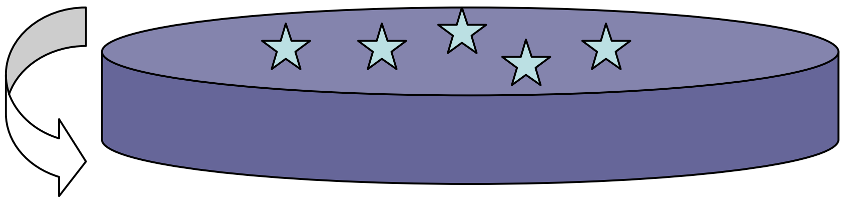
Hydrodynamics simulations

SPH simulations of isolated disk galaxies by Gadget-3 (Springel et al. 2005)

$N_{gas} = 4 * 10^5$, $N_{DM} = 6 * 10^6$

Redshift = 3.5

$M_h = 10^{10}, 10^{11}, 10^{12}, 10^{13}\ M_{sun}$



Dark Matter: Hernquist profile (Henquist 1990)

$$\rho_{DM} = \frac{M_{vir}}{2\pi} \frac{a}{r(r+a)^3}$$

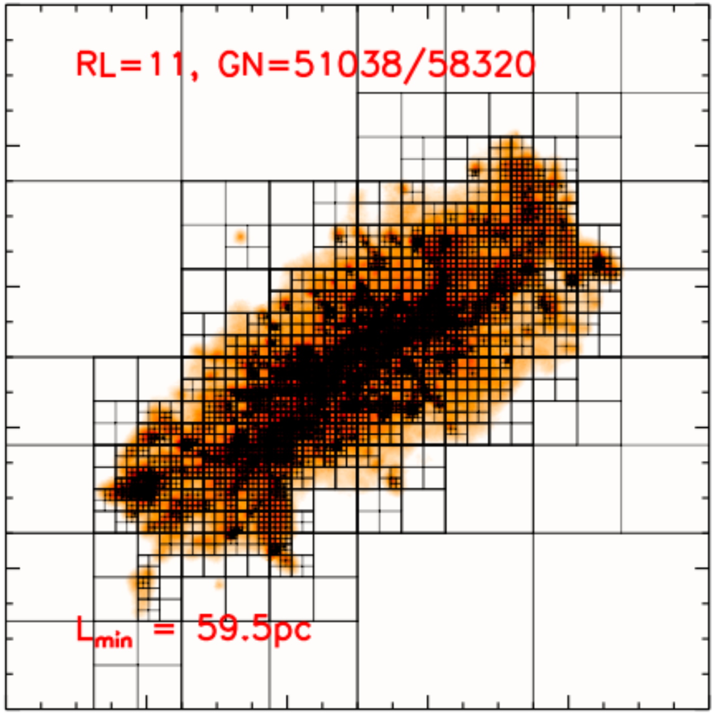
Buldge: Hernquist profile

Gas disk: Exponential profile (Springel et al. 2005)

$$\Sigma_{gas} = \frac{M_{gas}}{2\pi h^2} \exp\left(-\frac{r}{h}\right)$$

3D Radiative Transfer code: ART^2

*All-wavelength Radiative Transfer
with Adaptive Refinement Tree (ART^2)
(Li et al. 2008, Yajima et al. 2012)

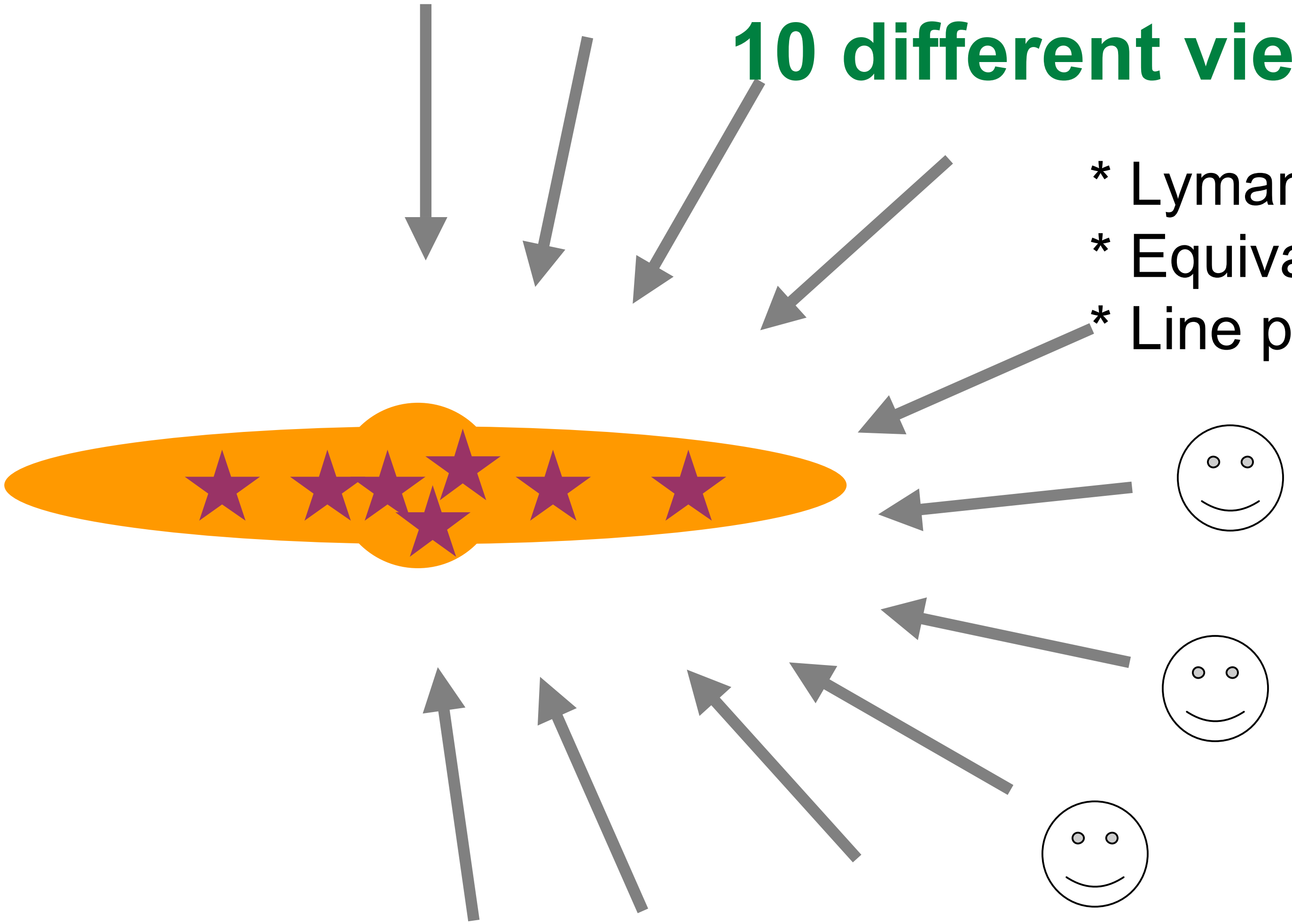


- Monte Carlo technique
- Adaptive refinement grid structure
- Lyman-alpha line
- Continuum photons from X-ray to radio
- Ionization of hydrogen
- Dust temperature and absorption/emission
- Two-phase cloud model in a cell
- Parallelized

Viewing angle scatter

We set cameras to
10 different viewing angles

* Lyman-alpha luminosity
* Equivalent width
* Line profile



Dust model

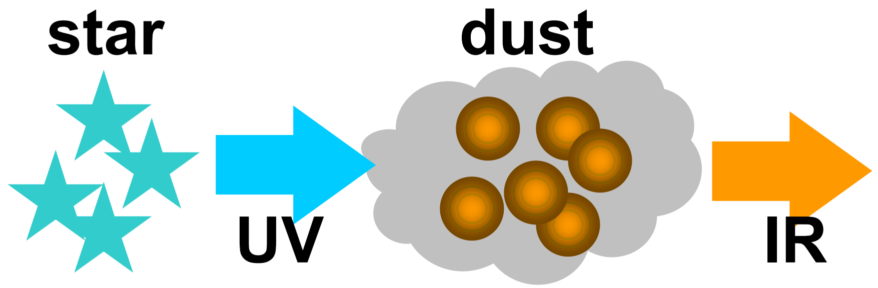
* Dust-to-gas mass ratio

$$M_{\mathrm{dust}} = 0.008 \times \frac{Z}{Z_{\mathrm{sun}}} \times M_{\mathrm{gas}}$$

(Draine+07)

* Size distribution

Supernova model
(Todini&Ferrara01)



* Optical depth

$$d\tau = Q_\nu \pi \cdot ds \cdot \int r_{\mathrm{d}}^2 \cdot n_{\mathrm{d}}\left(r_{\mathrm{d}}\right) dr_{\mathrm{d}}$$

* Temperature

Radiative equilibrium

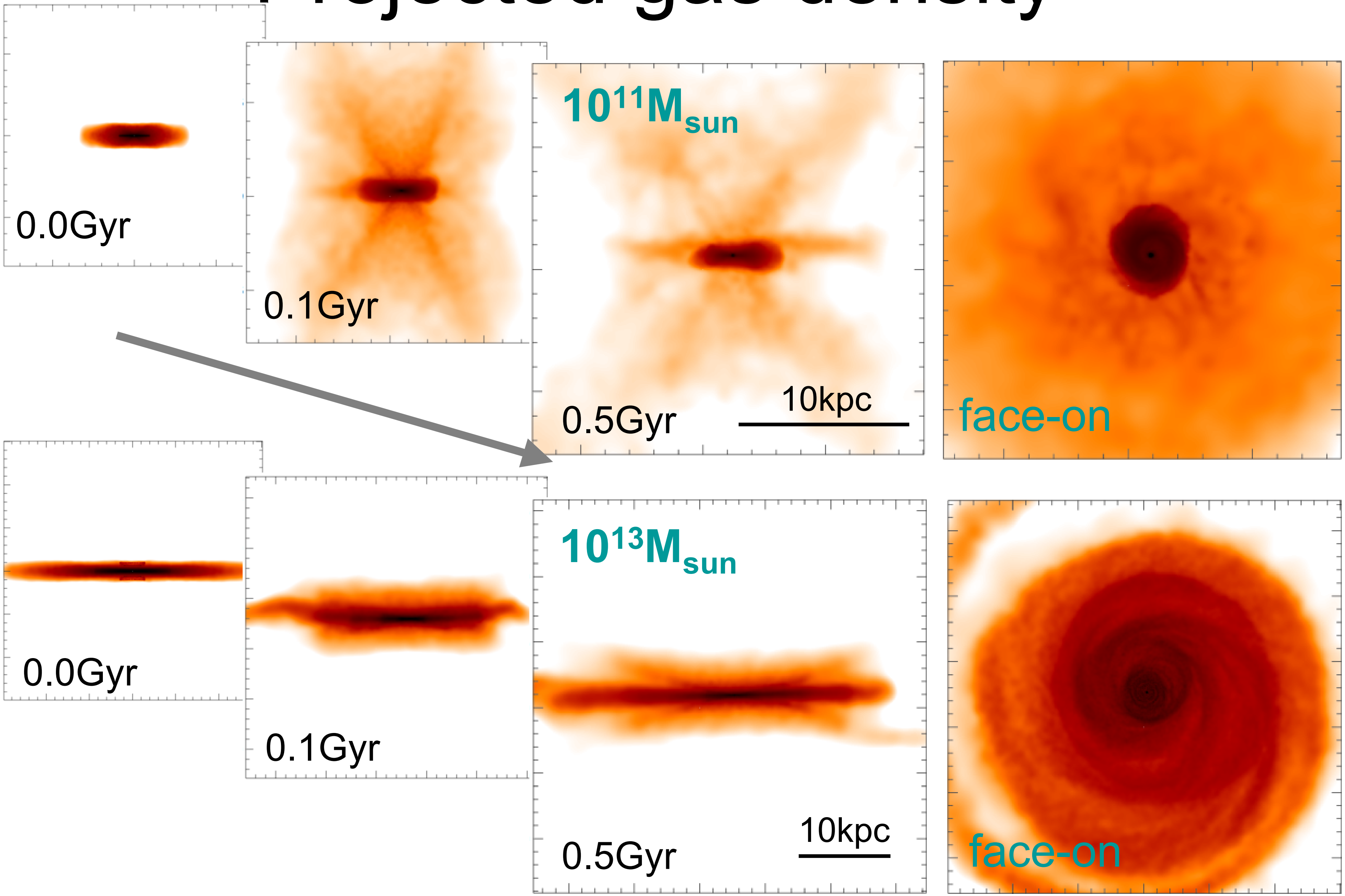
Absorption of continuum flux ＝ Thermal emission

$$\int F_\nu \pi r_{\mathrm{d}}^2 Q_\nu \mathrm{d}\nu = \int 4\pi^2 r_{\mathrm{d}}^2 Q_\nu B_\nu\left(\mathrm{T_d}\right) \mathrm{d}\nu$$

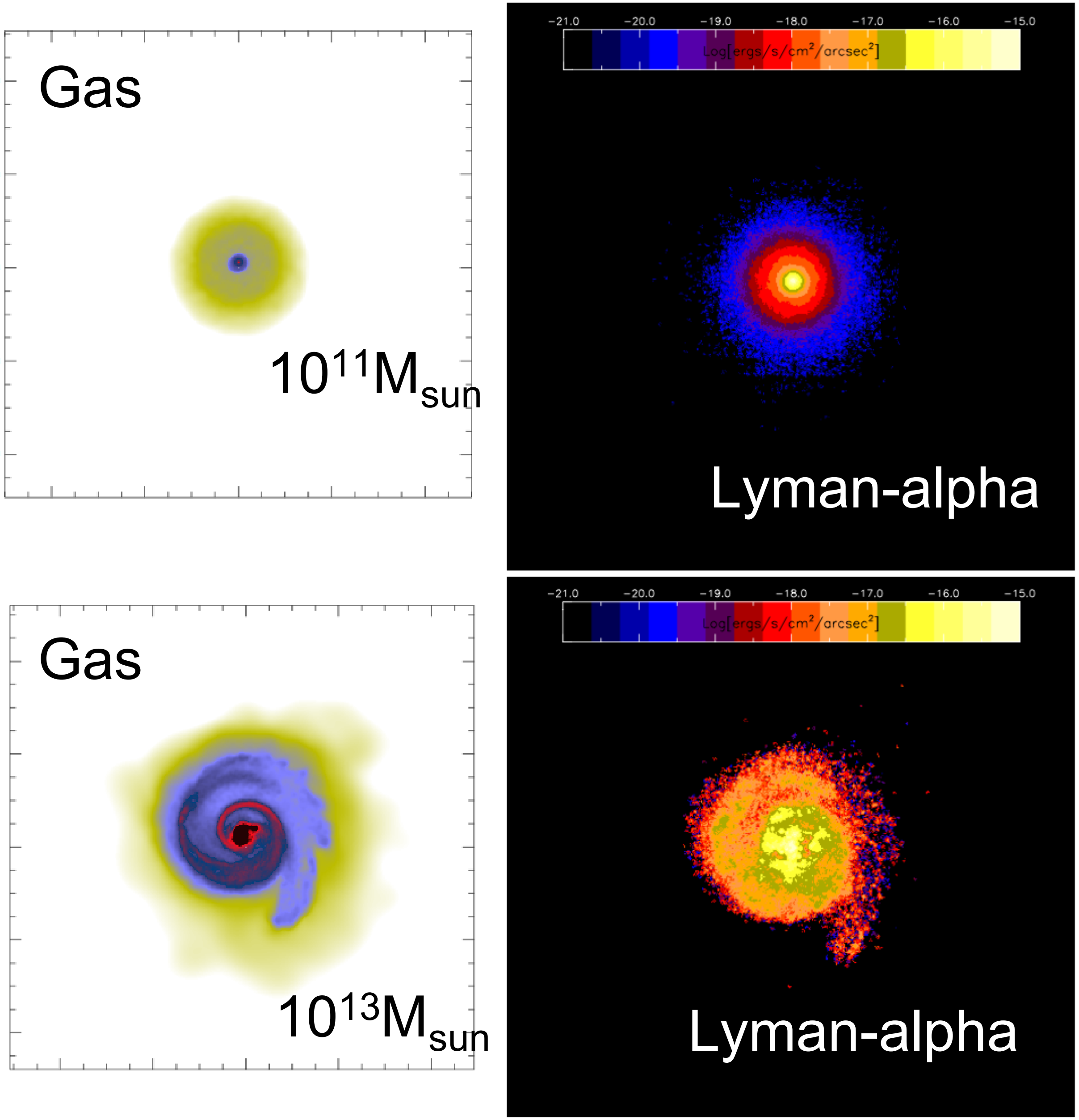
Results

- Gas distribution, physical properties
- Lyman-alpha properties, Effects of viewing angle
- Sub-millimeter flux

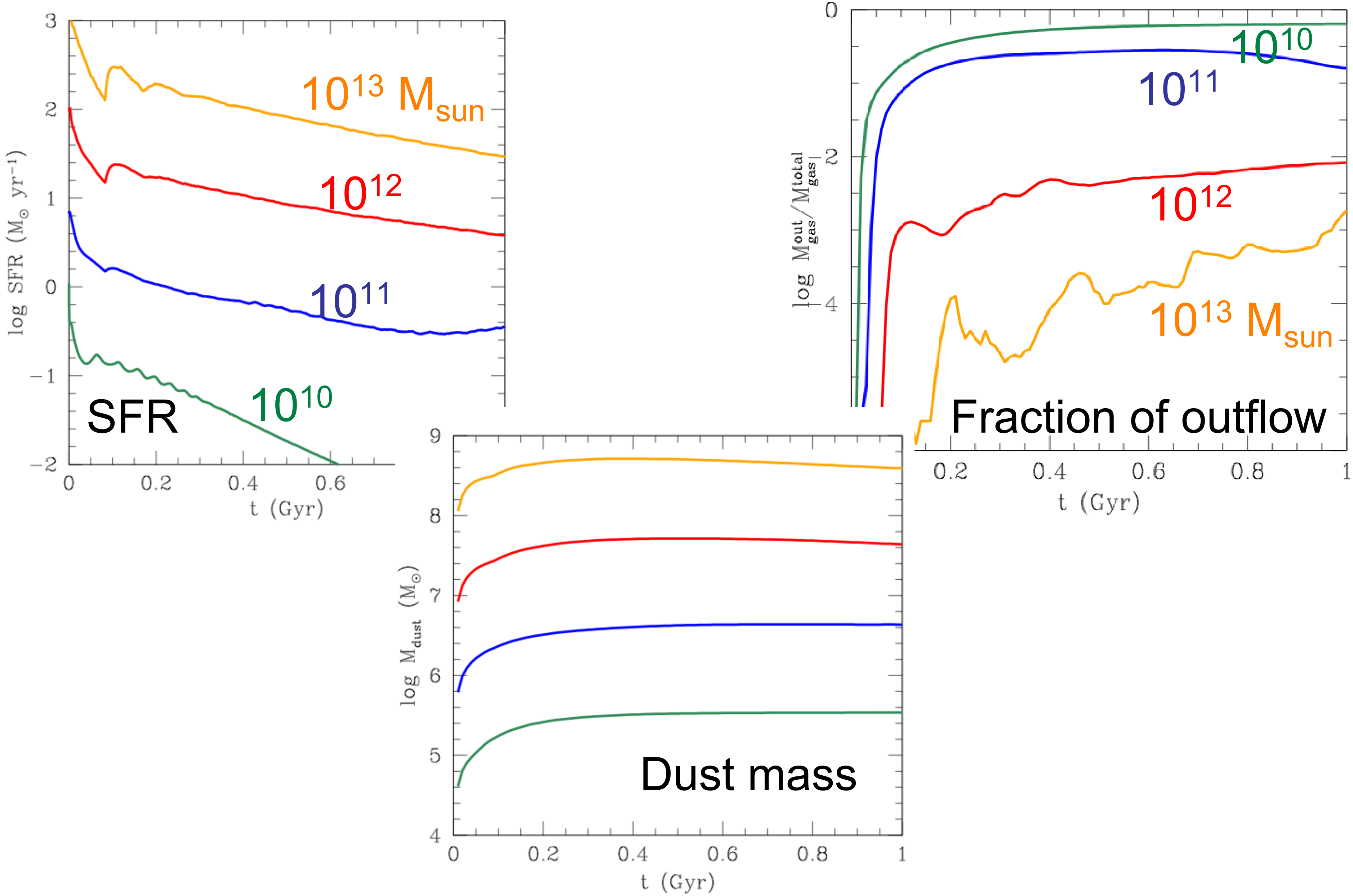
Projected gas density



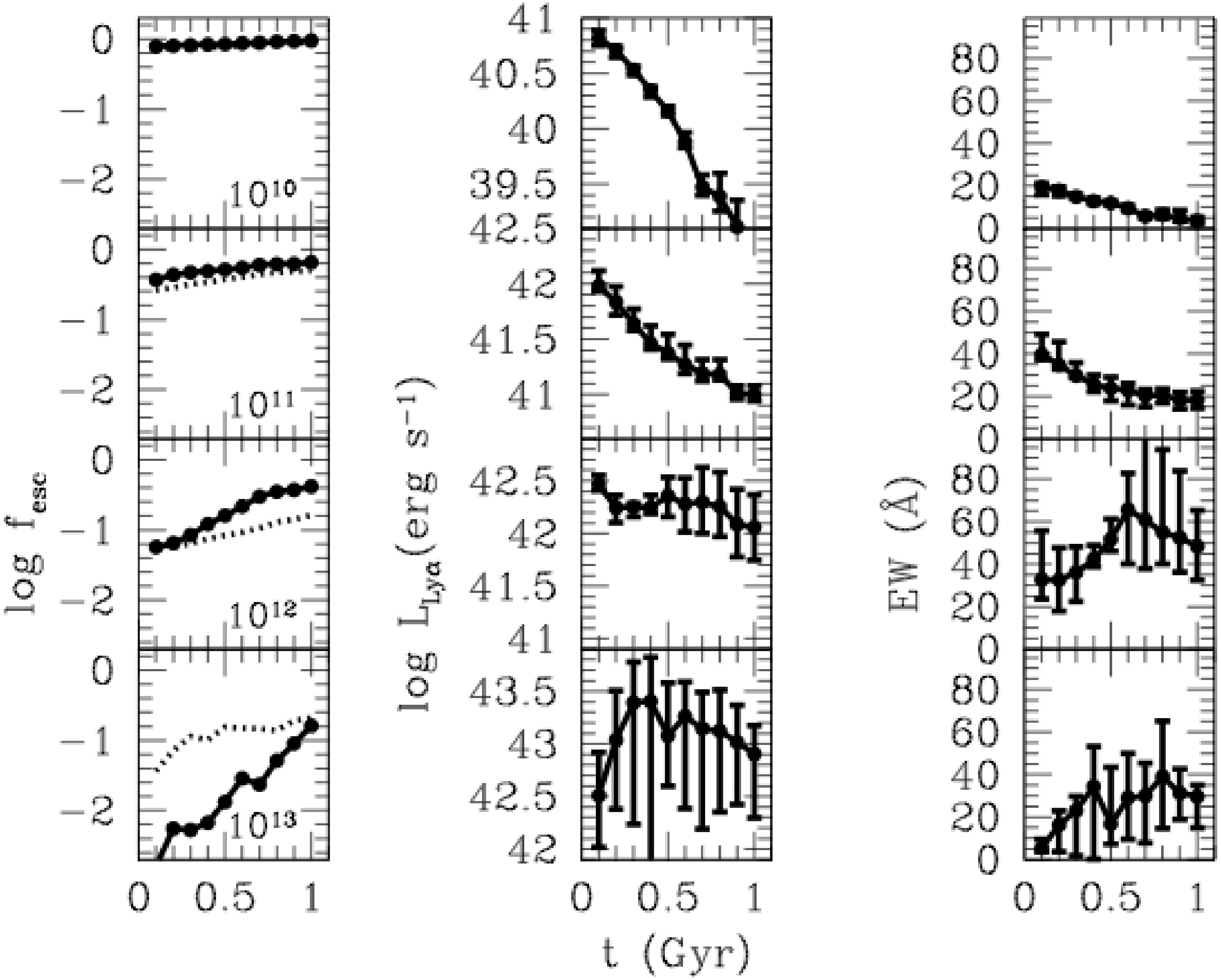
Surface brightness



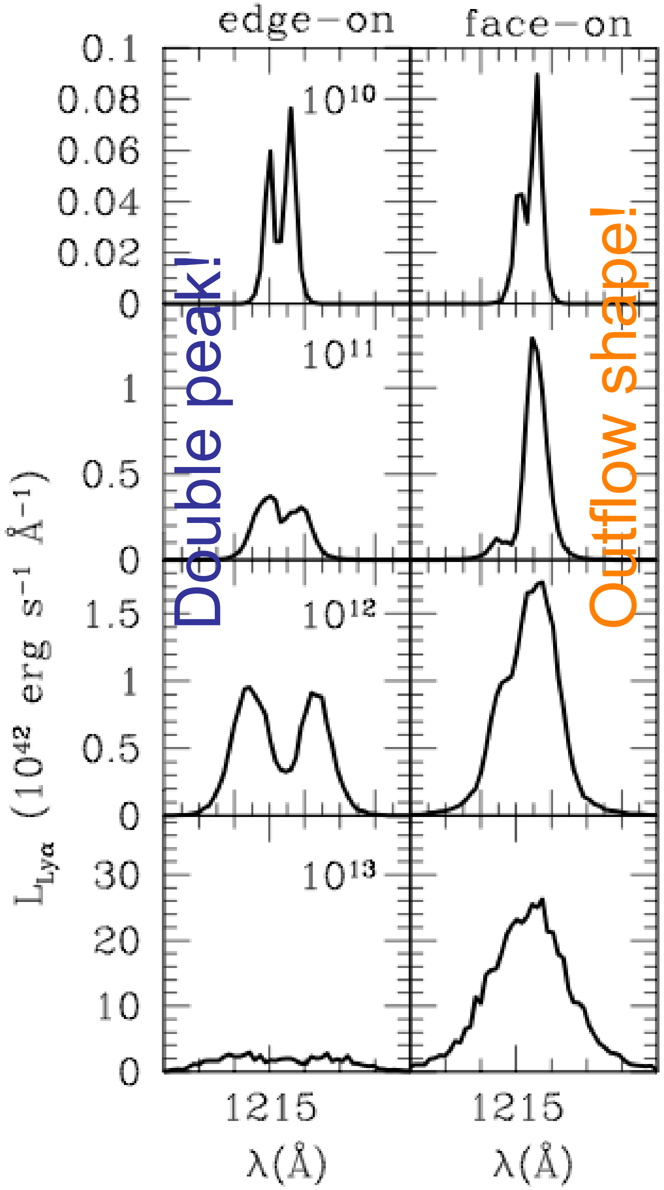
SFR and dust mass

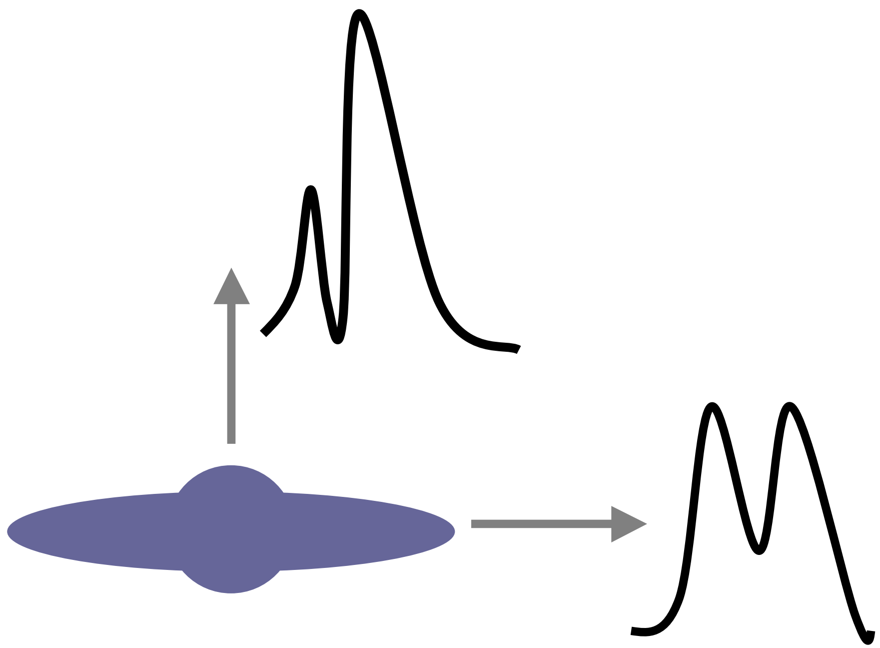


Lyman-alpha properties

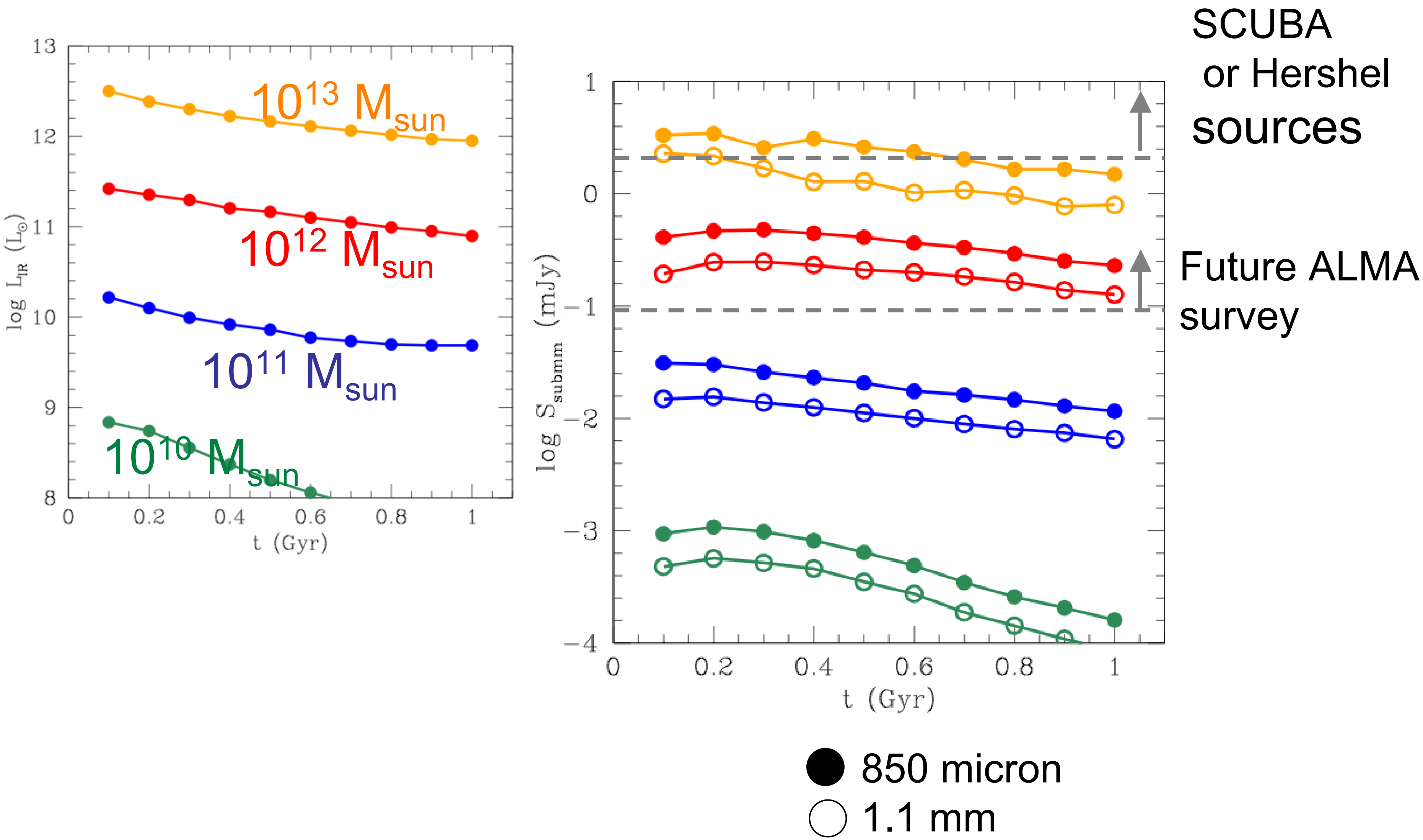


Line profile





Sub-millimeter flux



Summary

*Lyman-alpha photons can escape from massive dusty galaxies along face-on viewing angle if galaxies have gas disks

*Lyman-alpha properties significantly change with viewing angles. Line profile shows out-flow shape to face-on, while it is double-peak to edge-on viewing angle.

*Most of gas in low-mass galaxies are quickly blown out, and hence star formation rate and Lyman-alpha flux are suppressed

Future plan:
We are planning to study formation of first disk galaxies by cosmological simulations and their radiation properties

End