Modelling hydrodynamics and thermal SNII feedback

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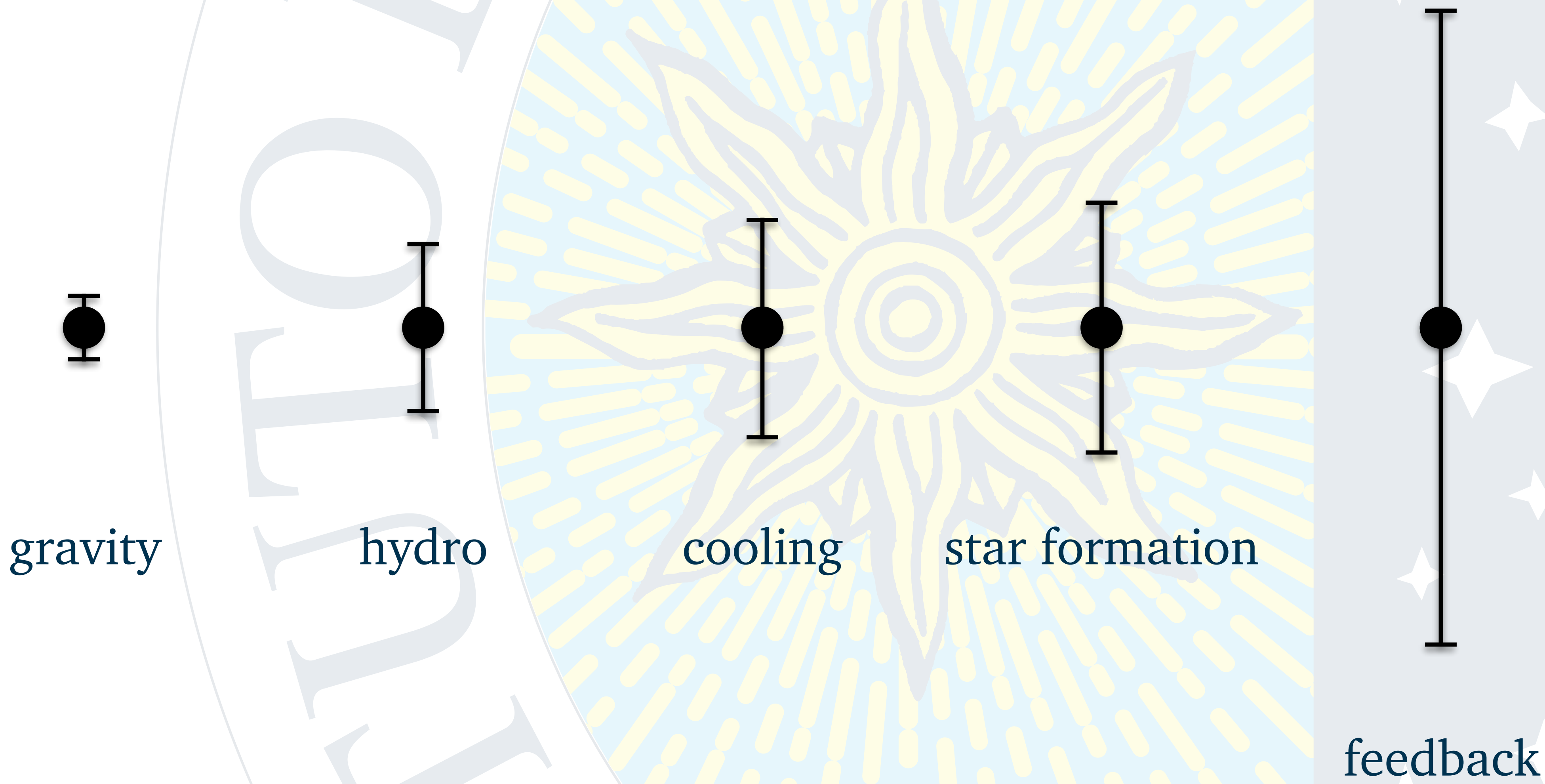
Uncertainties in the modelling

The situation few years ago



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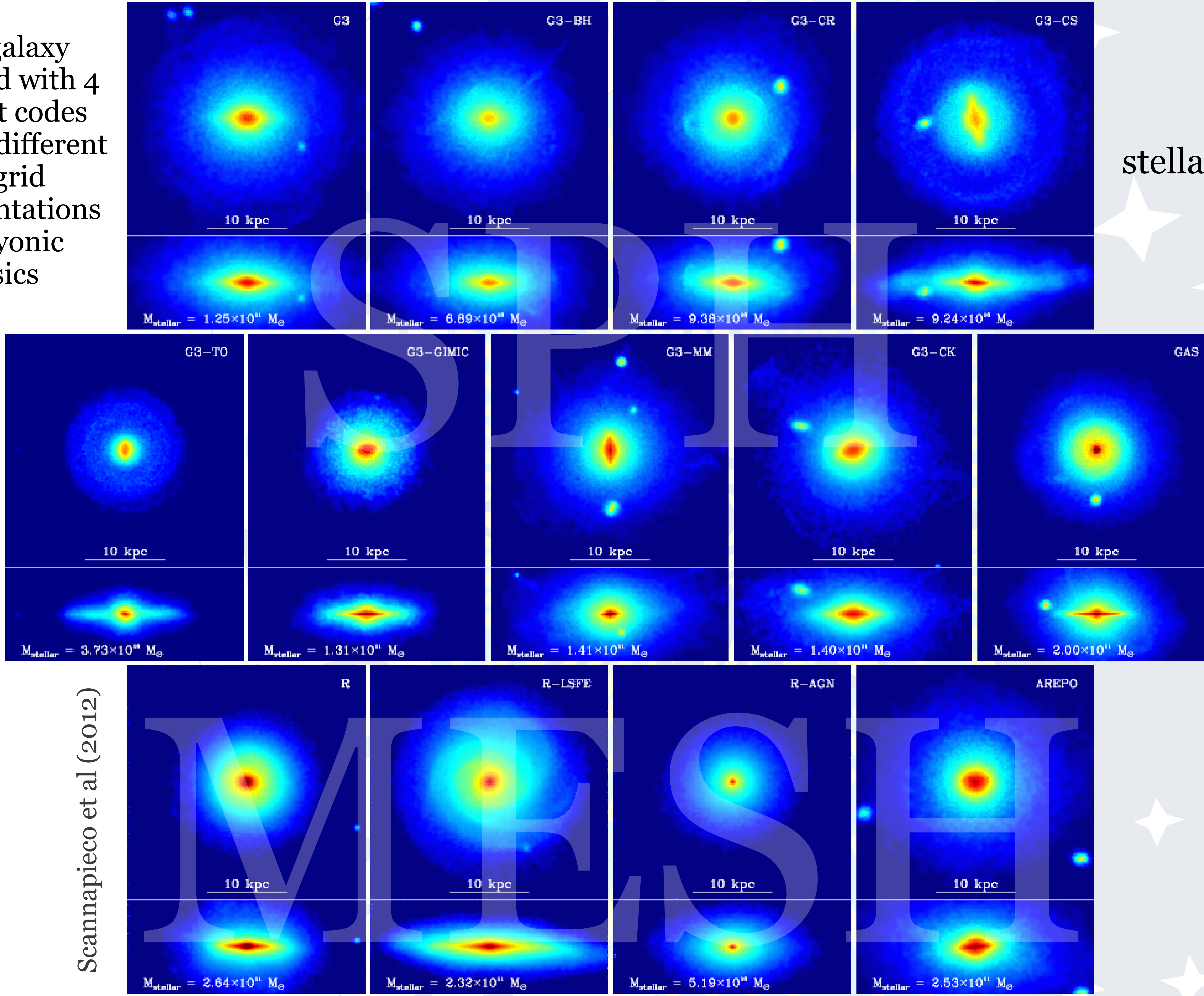
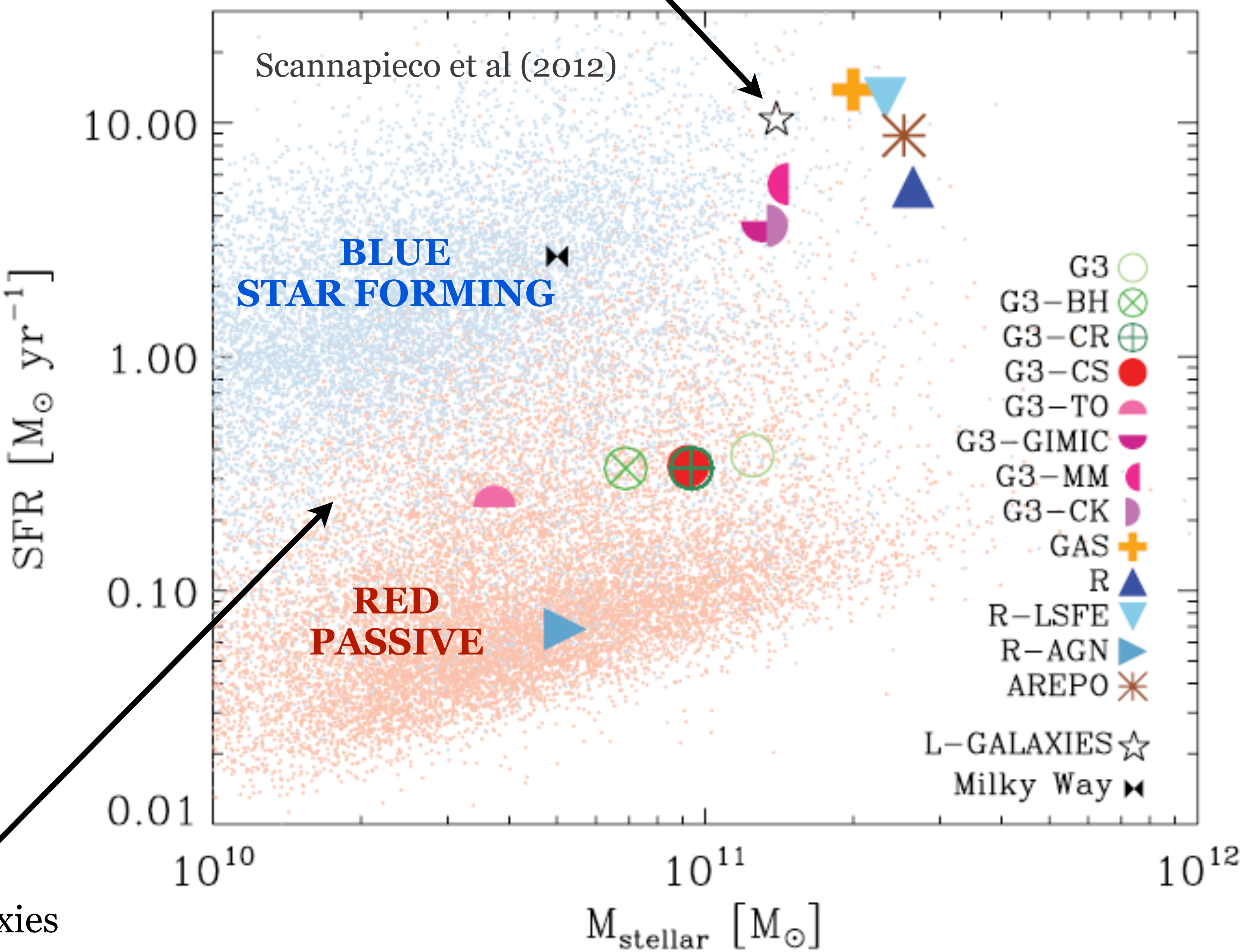
same galaxy simulated with 4 different codes and with different sub-grid implementations of baryonic physics



stellar density

Scannapieco et al (2012)

galaxy expected from semi-analytic modelling of the growth of the halo



SDSS galaxies

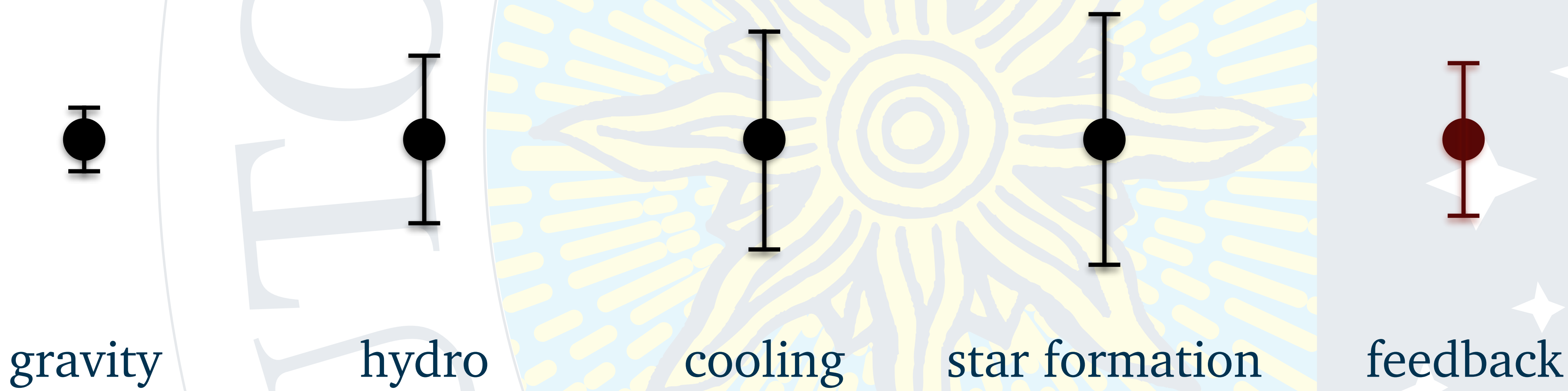
models may be too sensitive to changes of numerical parameters

models may be too sensitive to resolution

“In galaxy formation, strong feedback is the driving mechanism”

Uncertainties in the modelling

The situation now



EAGLE - Anarchy

Generalised SPH formulation
(Hopkins, 2013)

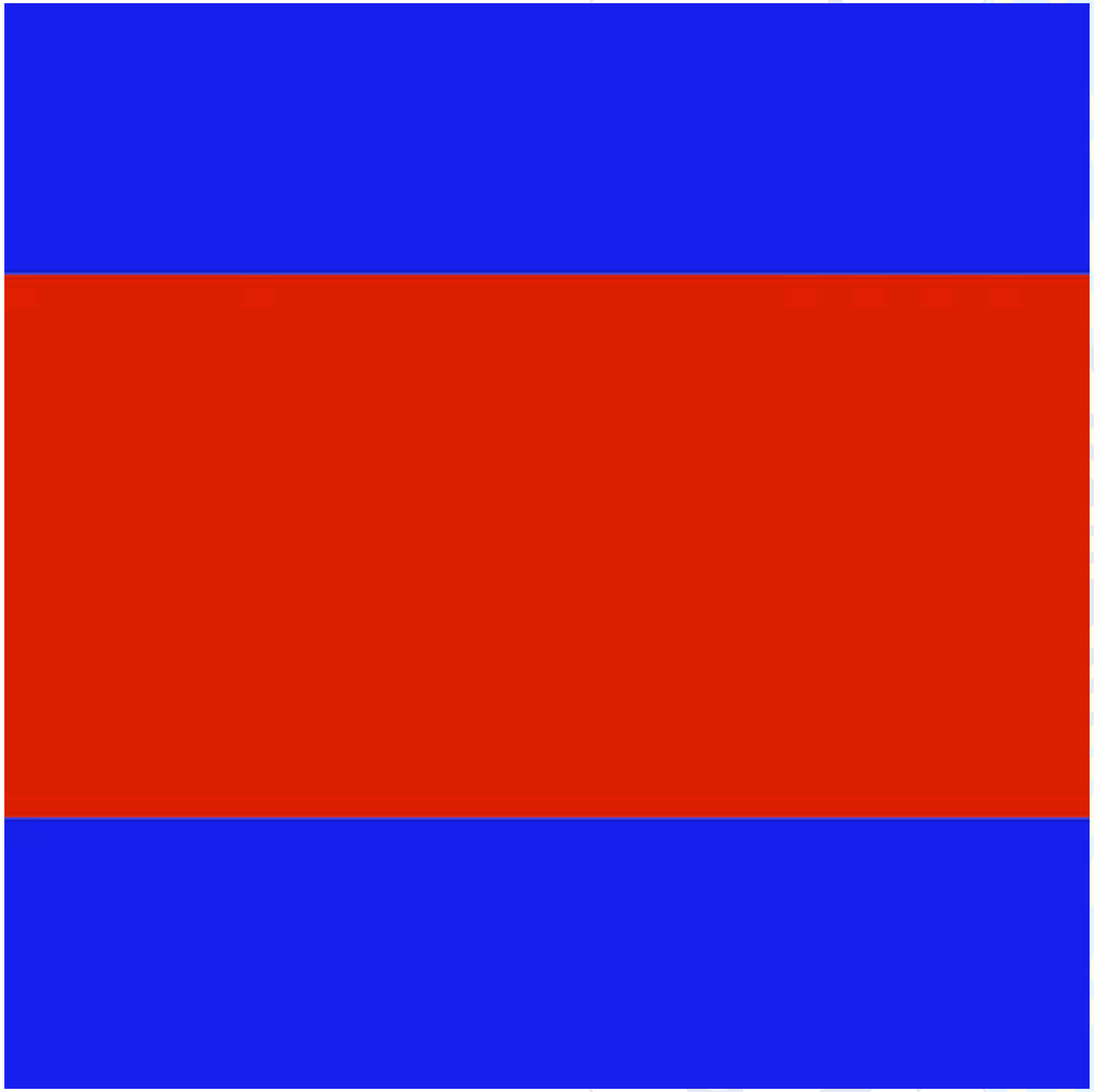
Time variable artificial viscosity
(Cullen & Dehnen, 2011)

Entropy diffusion
(Price, 2008)

New class of SPH kernels
(Dehnen & Aly, 2012)

Time step limiter
(Durier & Dalla Vecchia, 2012)

Anarchy - entropy mixing

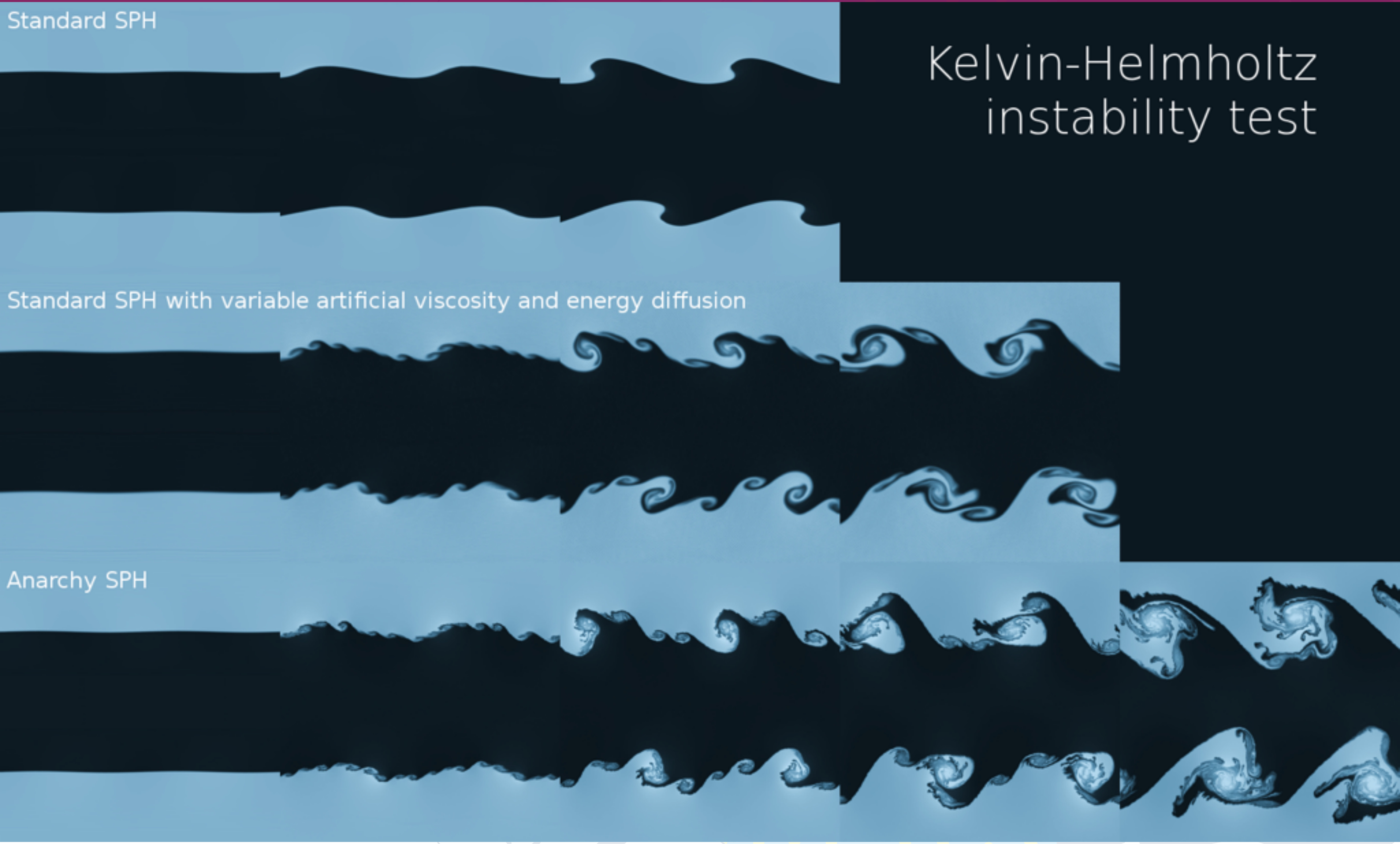


(Price, 2008)

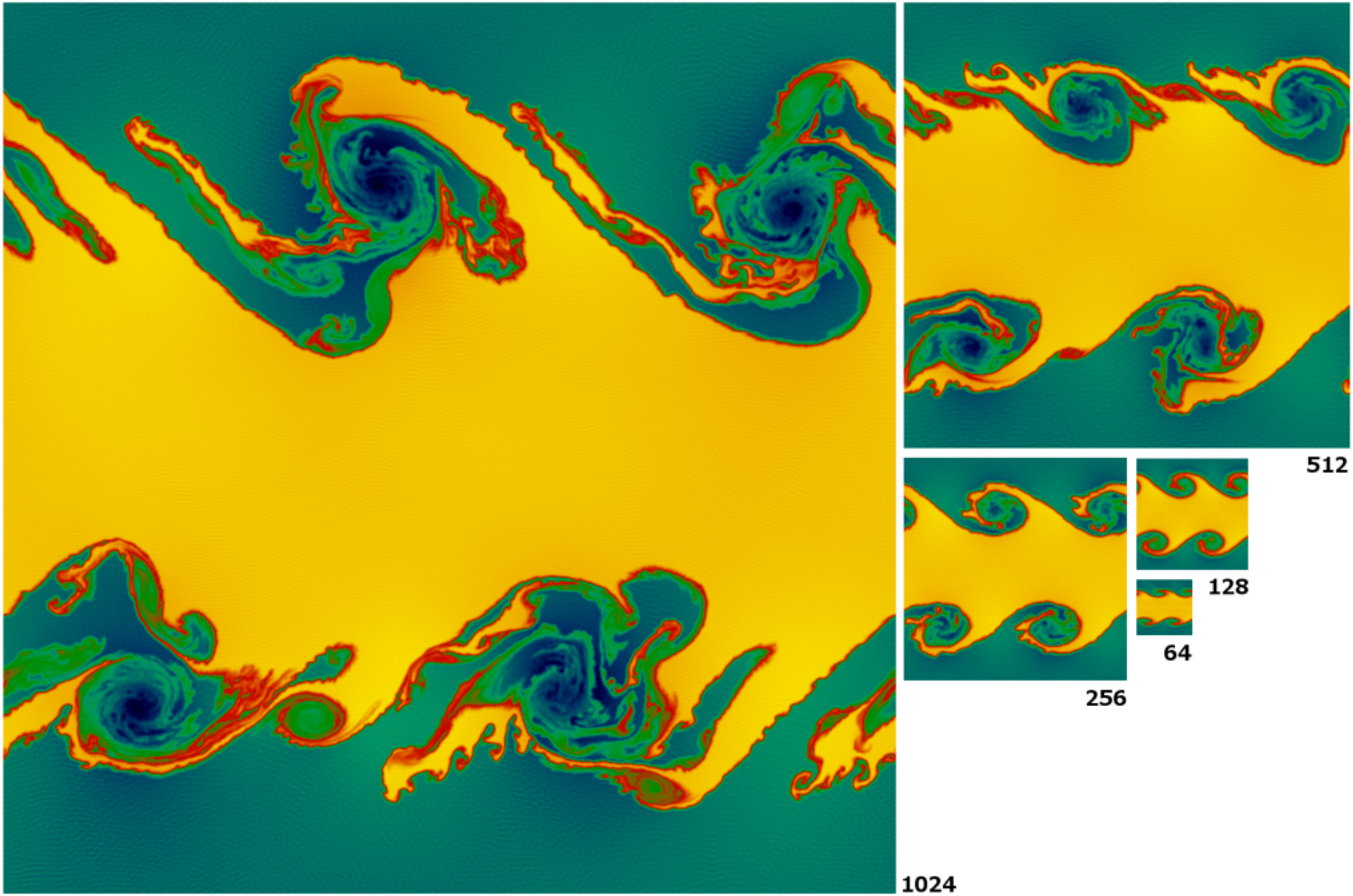
$$S_i = \frac{h_i \nabla^2 u_i}{\sqrt{u_i}} \propto \frac{c_{s,i}}{h_i} \times \beta$$

It has not implemented to solve contact discontinuities, but to mix gas phases

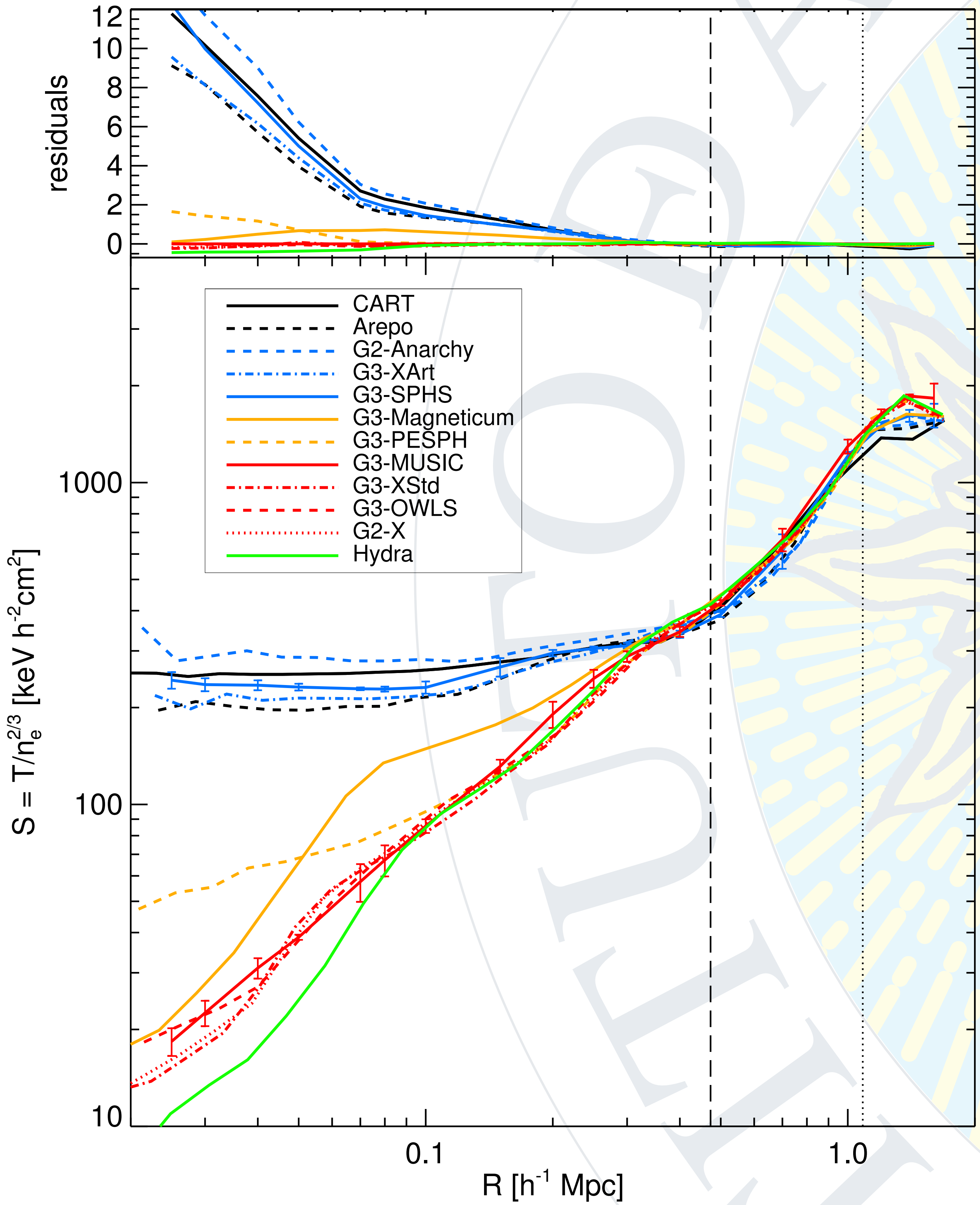
Anarchy - entropy mixing



Anarchy - entropy mixing



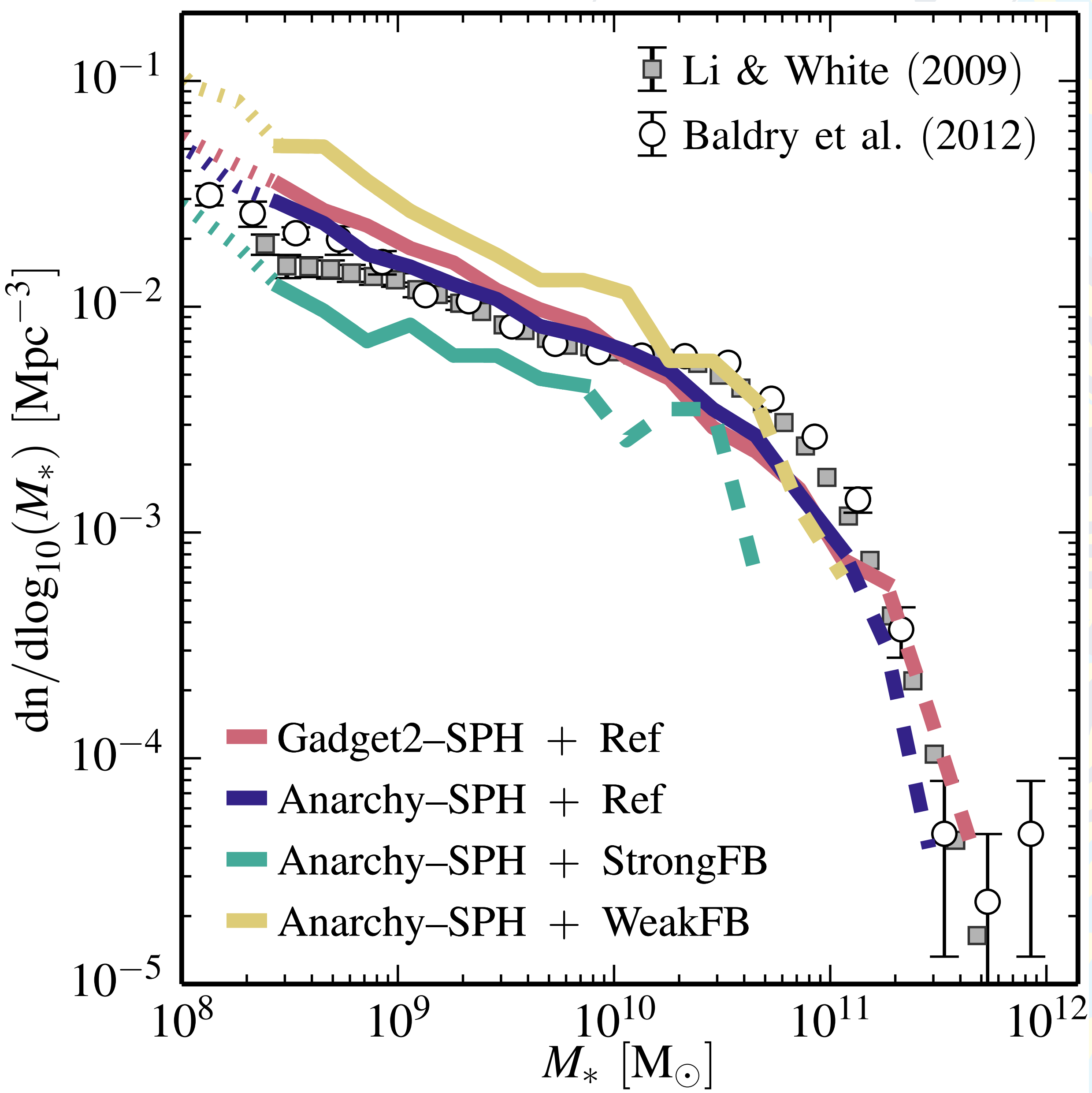
nIFTy galaxy cluster comparison



In non-radiative simulations, Anarchy gives results comparable to grid codes

Sembolini et al. 2015
Cui et al. 2016

The importance of the hydro scheme



There is an excess of massive galaxies hinting to inefficient AGN feedback

Schaller et al. 2015

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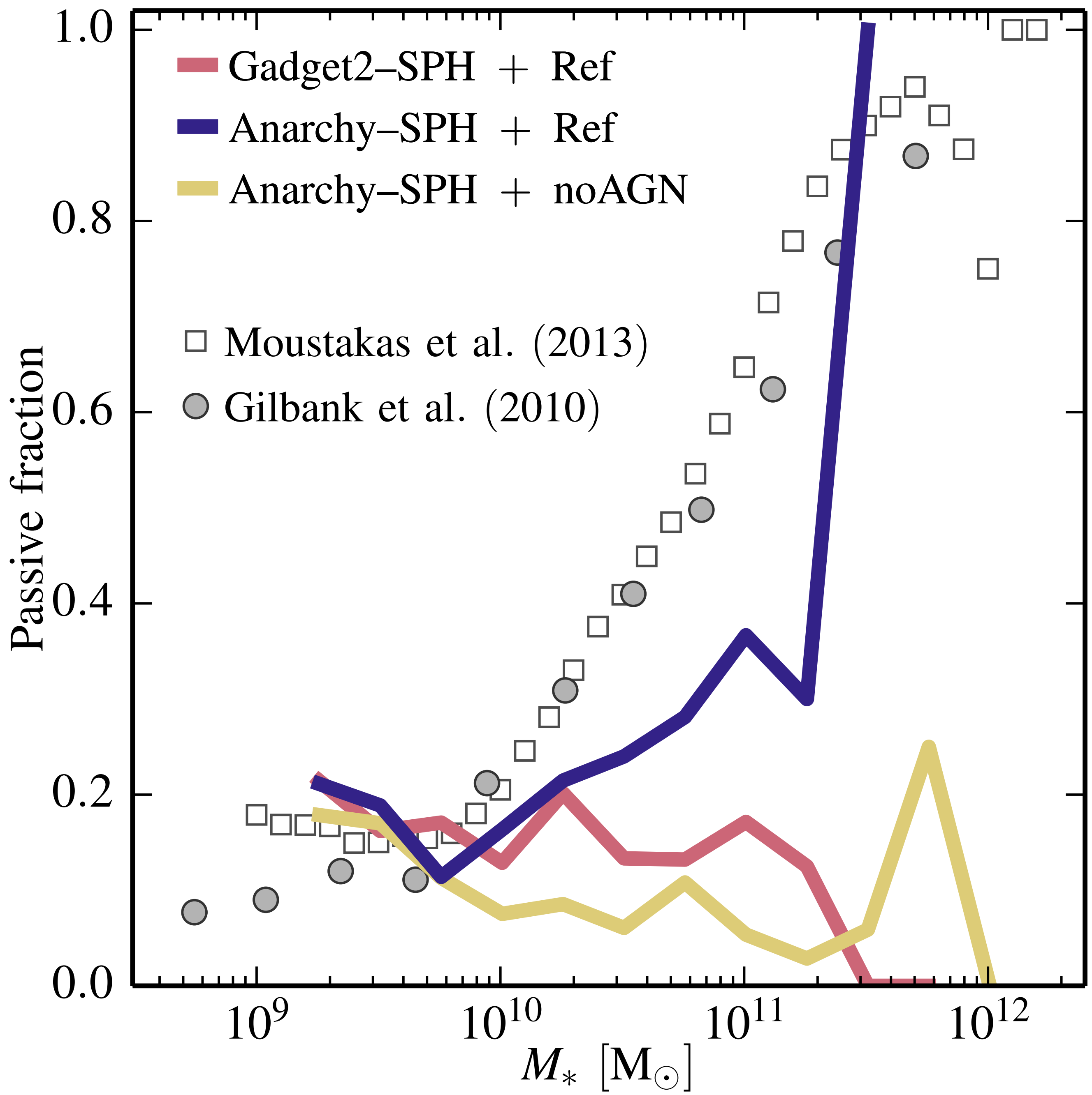
The importance of the hydro scheme



The shortage of passive galaxies in the GADGET simulation at the high-mass end of the galaxy population and the higher SSFR for high-mass objects both indicate that the star formation quenching processes are inefficient in the largest haloes

Schaller et al. 2015

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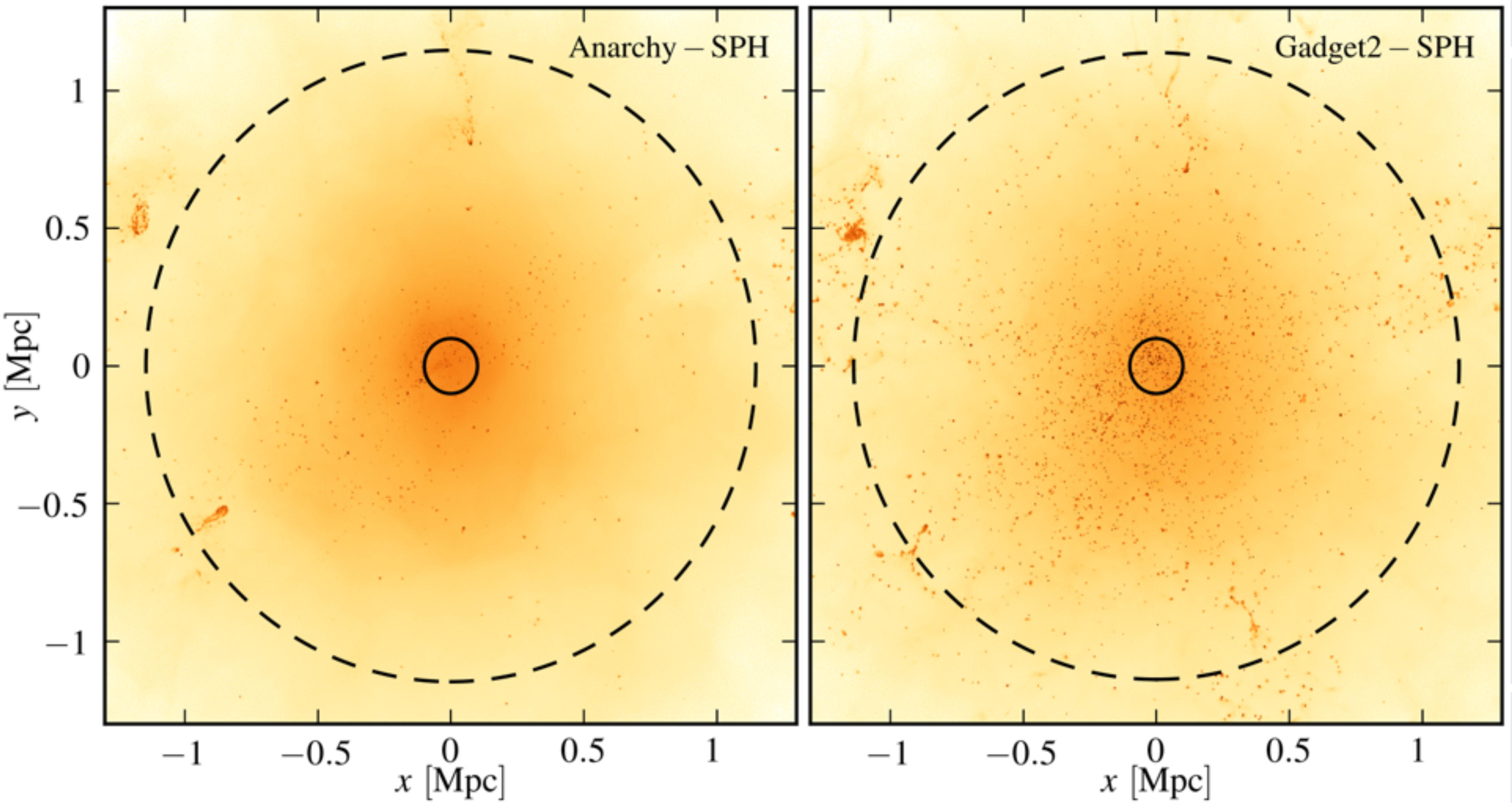
The importance of the hydro scheme



Schaller et al. 2015

Summary

Even in low resolution simulations, there may still be regimes in which the hydrodynamic scheme may give rise to large differences between models

Tuning the AGN feedback may solve the problem

Thermal feedback

Designed to limit numerical radiative losses and drive galactic winds (Dalla Vecchia & Schaye 2012)

Used in several simulation projects:

FiBY (e.g. Paardekooper et al. 2015),
EAGLE (Schaye et al. 2015, Crain et al. 2015),
AURORA (Pawlik et al. 2016)

Coupled with the time-step limiter (Durier & Dalla Vecchia 2012)

Thermal feedback

SN II energy per unit mass for a SSP

$$\epsilon_{\rm SNII} = 8.73 \times 10^{15} \ {\rm erg \ g^{-1}} \left(\frac{n_{\rm SNII}}{1.736 \times 10^{-2} \ {\rm M_\odot^{-1}}} \right) E_{51}$$

Heating a given gas mass with the above energy

$$\Delta T = 4.23 \times 10^{7} \ {\rm K} \left(\frac{n_{\rm SNII}}{1.736 \times 10^{-2} \ {\rm M_\odot^{-1}}} \right) \left(\frac{\mu}{0.6} \right) E_{51} \frac{m_*}{m_{\rm g,heat}}$$

Number of heated neighbours

$$\langle N_{\rm heat} \rangle = 1.34 \, f_{\rm th} E_{51} \left(\frac{n_{\rm SNII}}{1.736 \times 10^{-2} \ {\rm M_\odot^{-1}}} \right) \left(\frac{\mu}{0.6} \right) \left(\frac{\Delta T}{10^{7.5} \ {\rm K}} \right)^{-1}$$

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Thermal feedback

Preventing over-cooling

$$\left(t_\mathrm{s} = \frac{h}{c_\mathrm{s}}\right) \ll \left(t_\mathrm{c} = \frac{u}{\Lambda}\right)$$

Heating a given gas mass with the above energy

$$\frac{t_\mathrm{c}}{t_\mathrm{s}} \simeq 98 \left(\frac{n_\mathrm{H}}{1\ \mathrm{cm}^{-3}}\right)^{-2/3} \left(\frac{T}{10^{7.5}\ \mathrm{K}}\right) \left(\frac{\langle m \rangle}{7 \times 10^4\ \mathrm{M}_\odot}\right)^{-1/3}$$

Maximum density for which feedback is efficient

$$n_{\mathrm{H},t_\mathrm{c}=f_\mathrm{t} t_\mathrm{s}} \simeq 31\ \mathrm{cm}^{-3} \left(\frac{T}{10^{7.5}\ \mathrm{K}}\right)^{3/2} \left(\frac{f_t}{10}\right)^{-3/2} \left(\frac{\langle m \rangle}{7 \times 10^4\ \mathrm{M}_\odot}\right)^{-1/2}$$

see also Creasey et al. 2011

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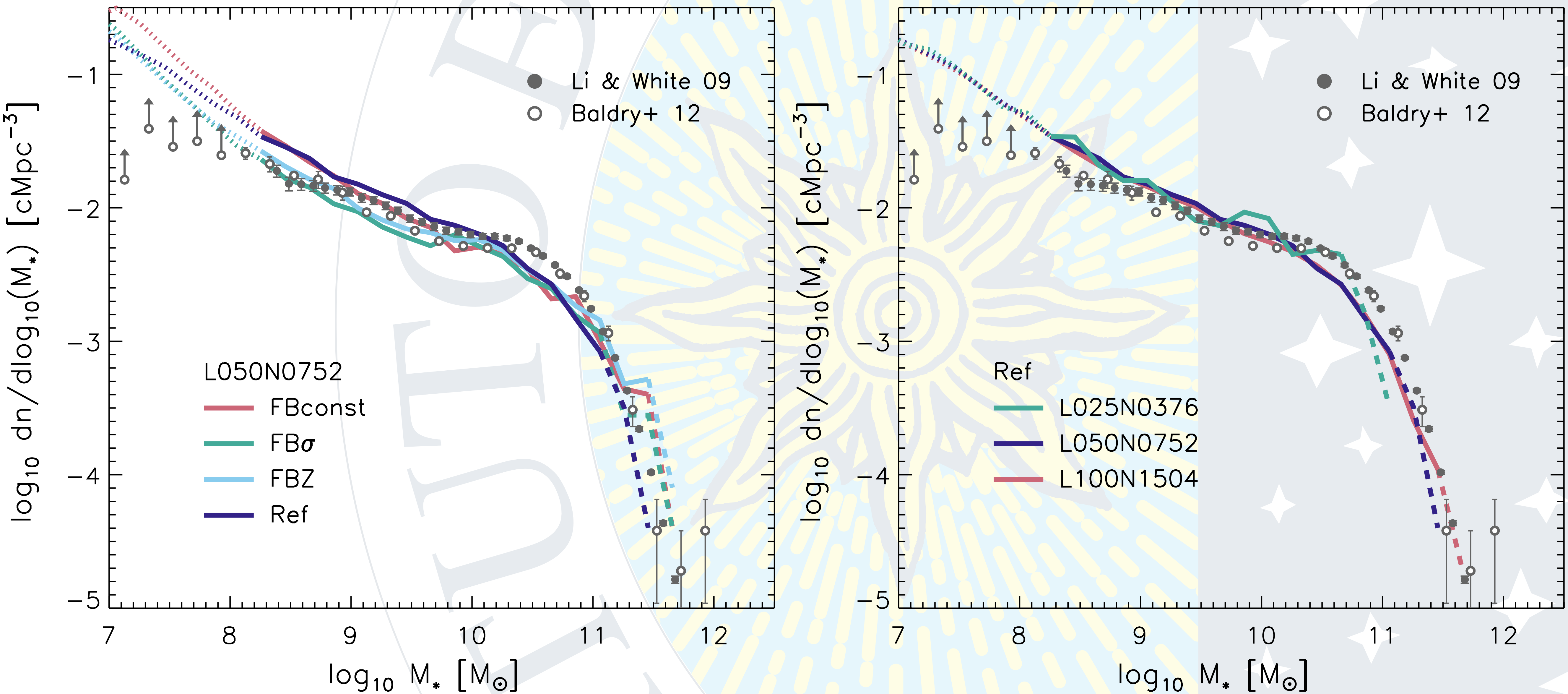
Feedback inefficiency

At low mass resolution, a large fraction of stars form in dens gas where SN feedback is highly inefficient

Solution: artificially increase feedback efficiency at these densities (calibration, Crain et al. 2015)

Stellar mass function



Crain+ 2015

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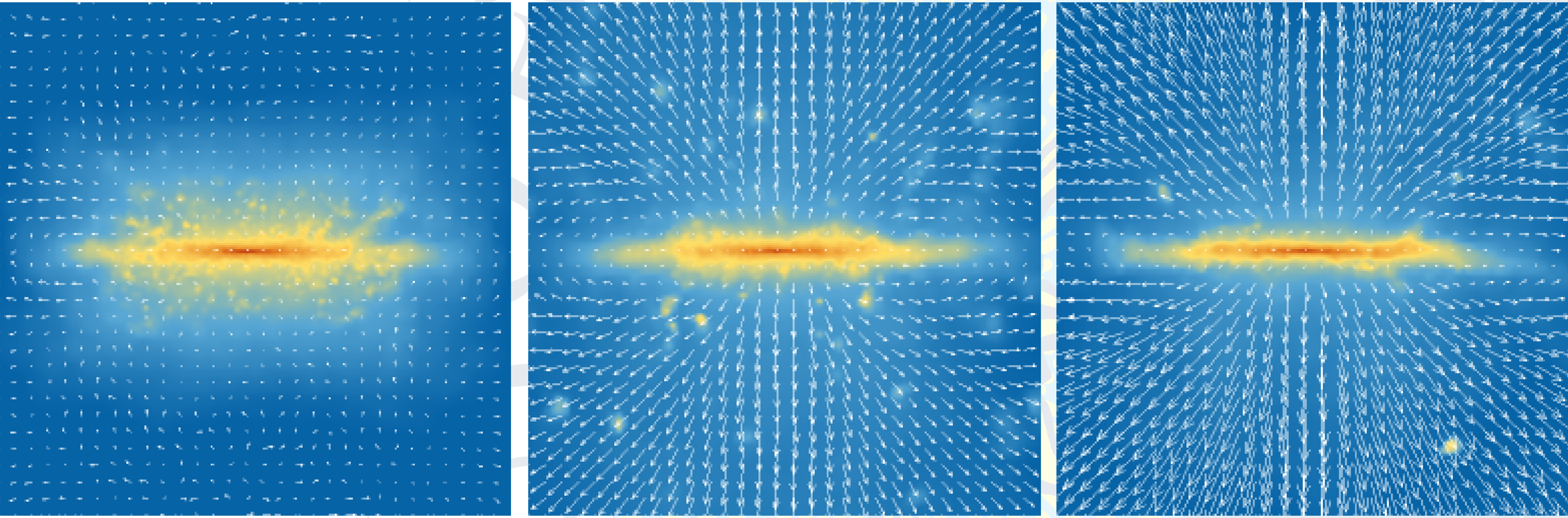
Is it gas recycling?

(Dalla Vecchia & Schaye 2012)



$T = 10^{6.5}$ K $\quad T = 10^{7.5}$ K $\quad T = 10^{8.5}$ K

Summary

Thermal feedback is a valid option
provided that numerical effects are carefully treated

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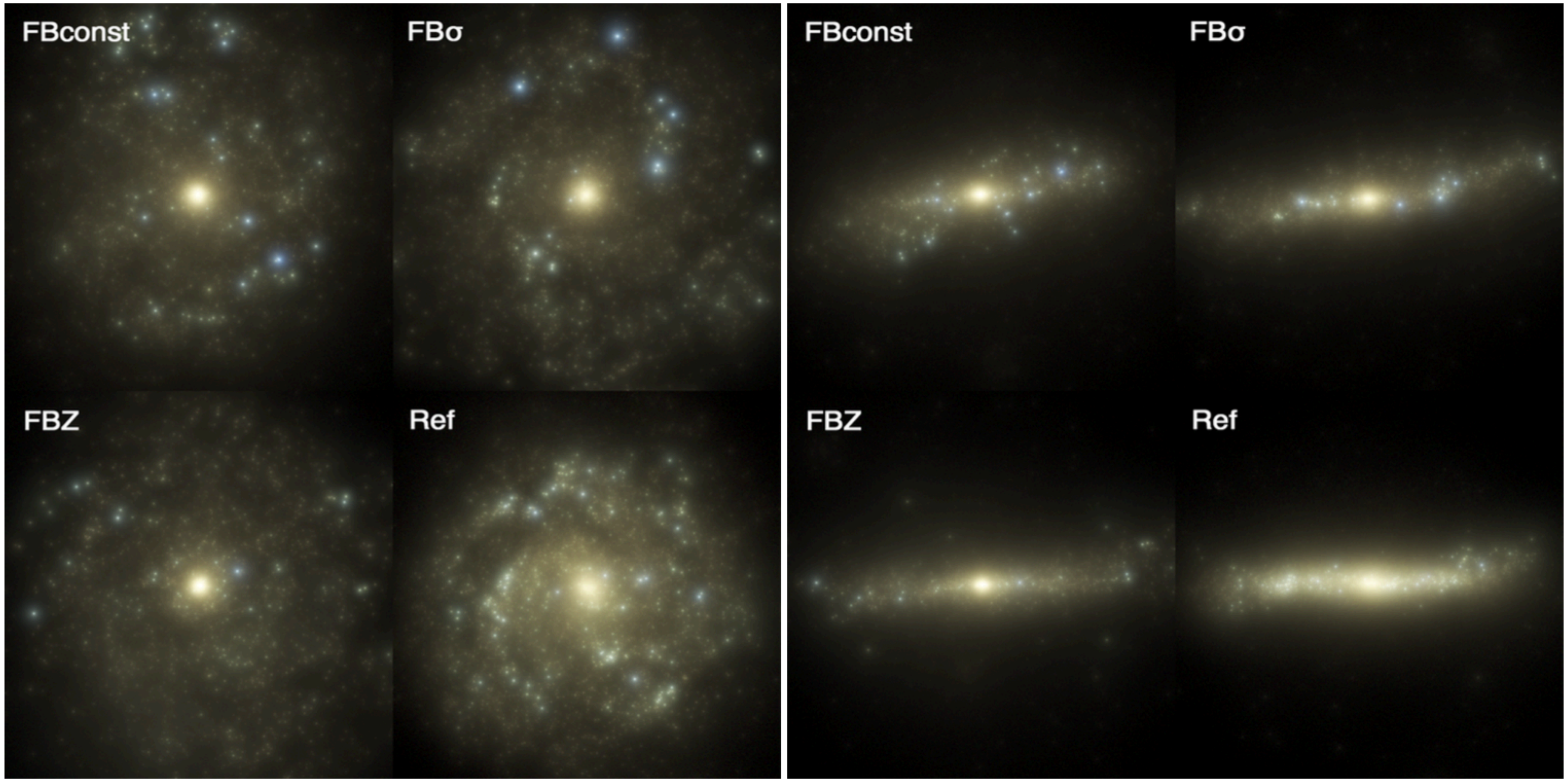
Galaxies sizes



Crain+ 2015

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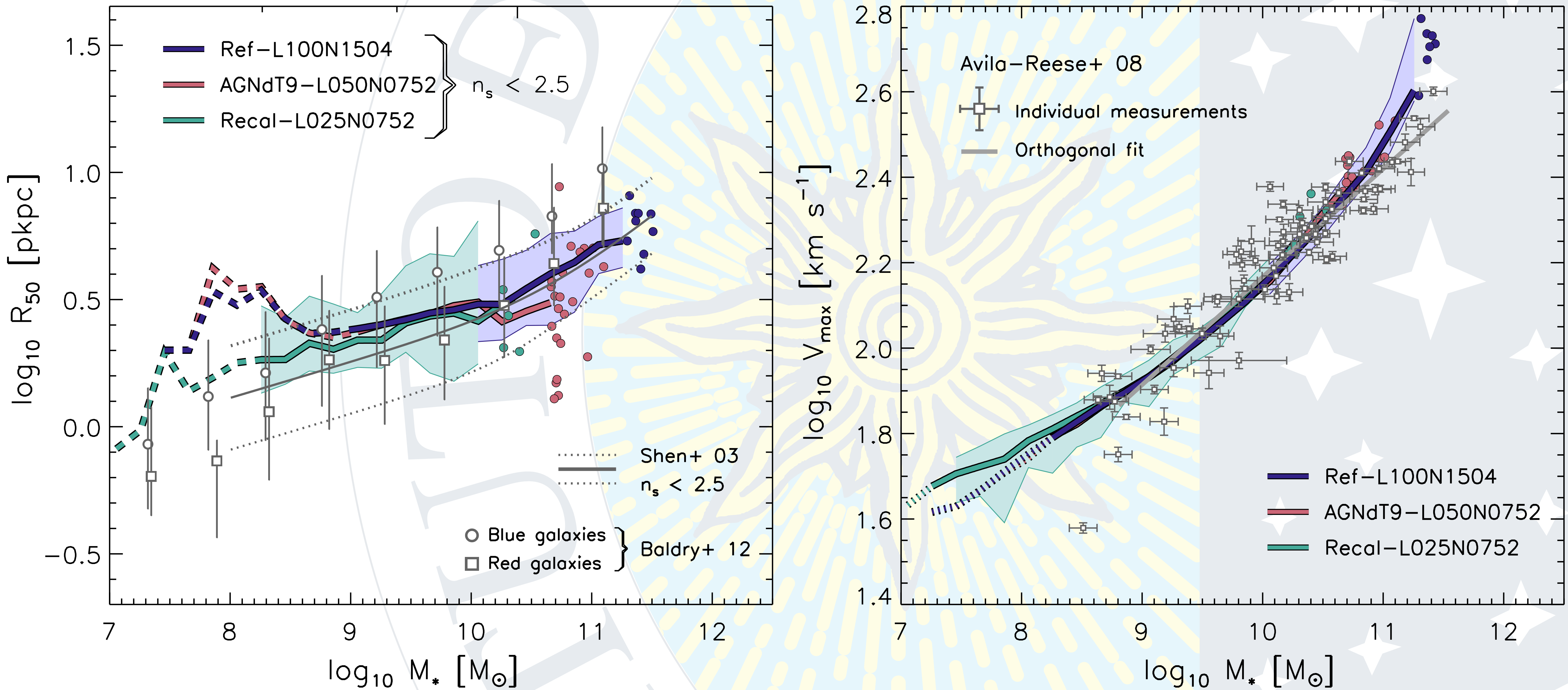
Galaxy sizes



Schaye+ 2015

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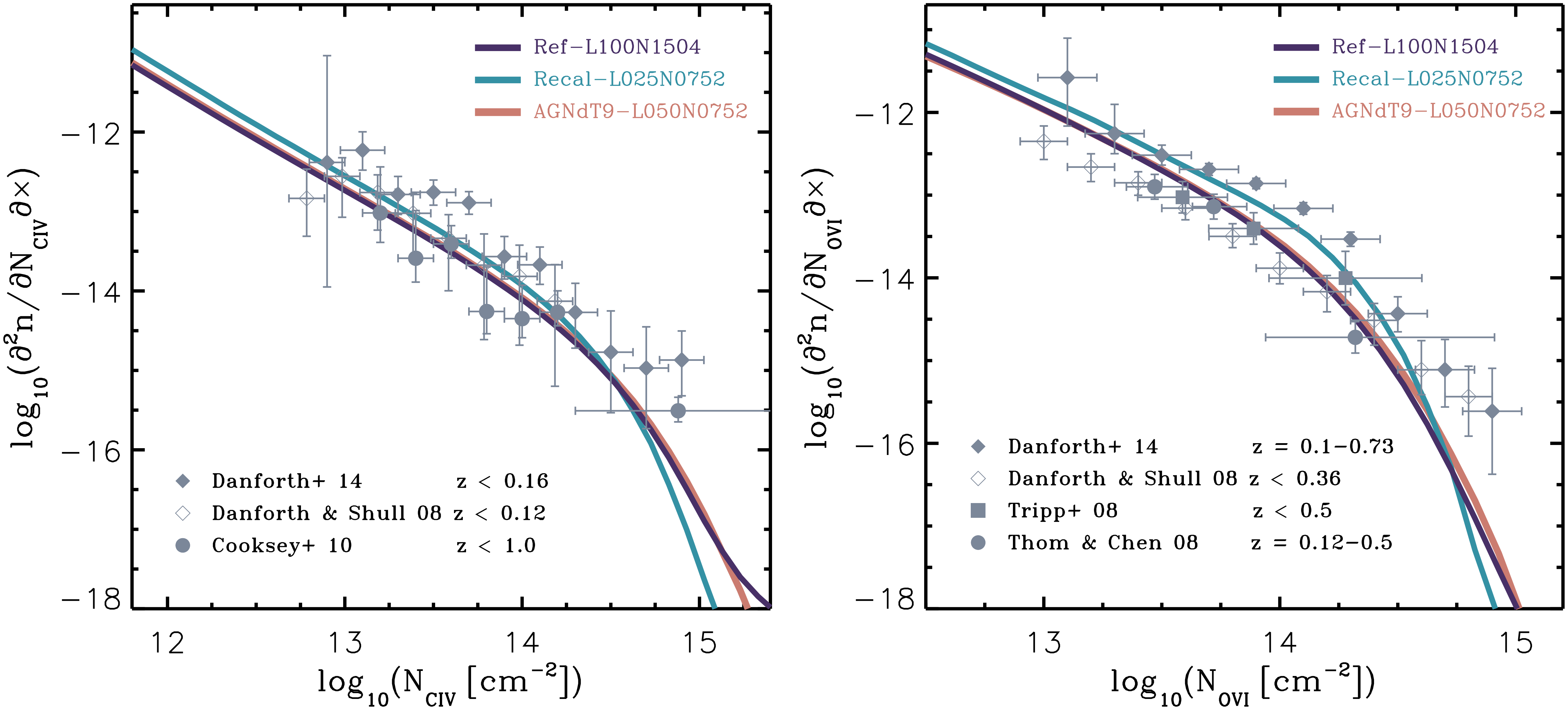
Properties of the IGM



Schaye+ 2015

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