EFFECT OF GALACTIC OUTFLOWS IN COSMOLOGICAL HYDRODYNAMICAL SIMULATIONS

MILENA VALENTINI

SUPERVISORS:
G. MURANTE, S. BORGANI, A. BRESSAN

COLLABORATORS:
A. LAPI, G.L. GRANATO, P. MONACO

ma per seguir virtute e canoscenza
SISSA

OSSERVATORIO ASTRONOMICO DI TRIESTE
INAF ISTITUTO NAZIONALE DI ASTROFISICA

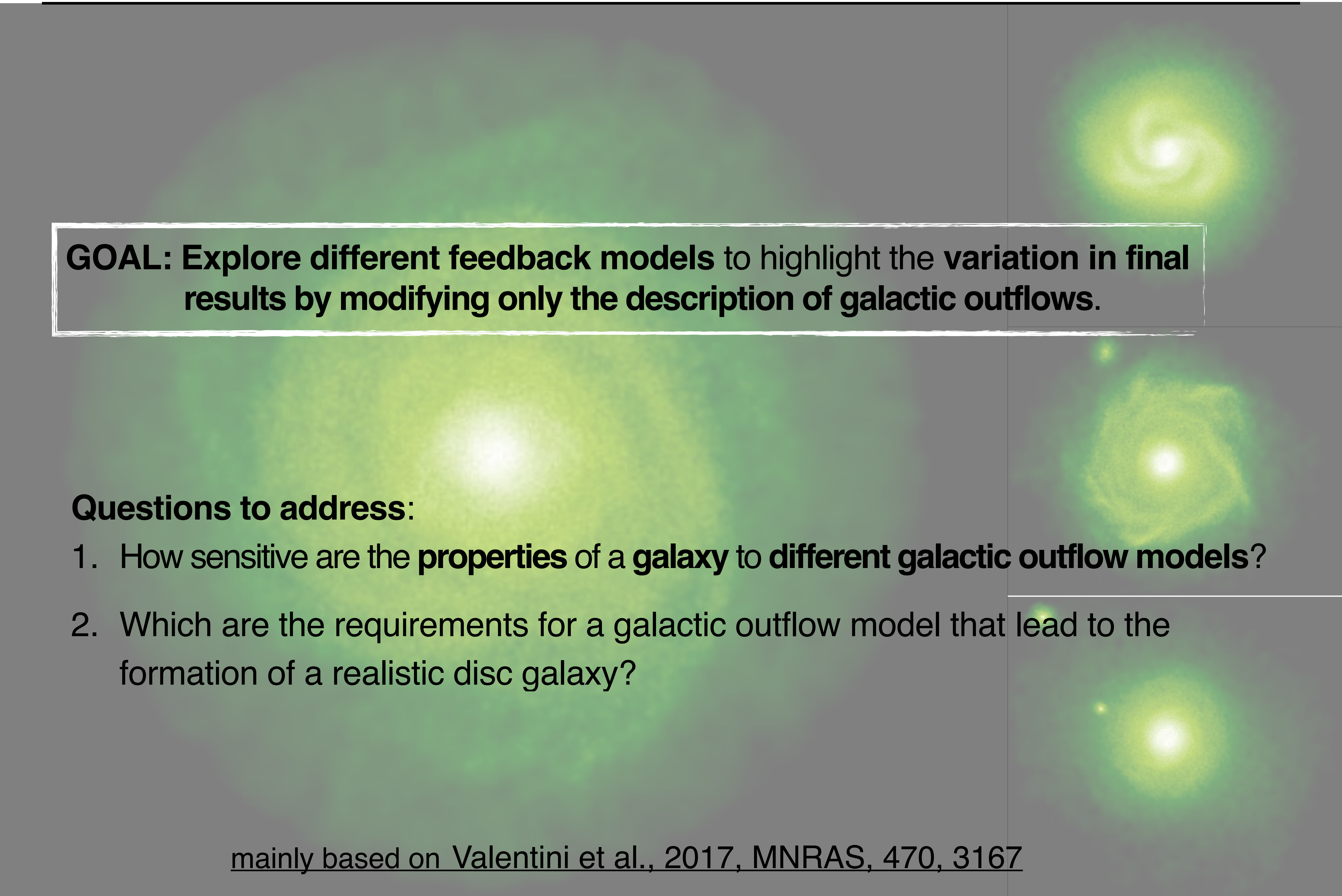
TRIESTE - SEPTEMBER 25TH, 2017

GALACTIC OUTFLOWS

- Intergalactic medium (IGM): reservoir of baryons for galaxy formation.
- Inflowing gas from IGM → accretion of metal poor gas → star formation
- Stars form, evolve and die: SN explosions → galactic outflows → interaction galaxy/surrounding medium

Continuous interplay between galaxy and circumgalactic medium

- Outflows are important because:
  - shape galaxy morphology, determine size and properties (Crain+ 2015, Hayward+ 2017, Vogelsberger+ 2014, Schaye+ 2015 …)
  - expel low-angular momentum gas at high z (Brook+ 2012, Übler+ 2014, Teklu+ 2015, Genel+ 2015 …)
  - counterbalance inflow and regulate accretion (Stinson+ 2013, Aumer+ 2013, Barai+ 2015 …)
  - heat up and ionize ambient gas (Bond+ 2001, Ménard+ 2009, …)
  - drive outward chemical enriched gas from galaxies (Aguirre+ 2001, Gauthier+ 2012, …)
- Outflows: observed in galaxies in local Universe and out to z ~ 6 (Veilleux+ 2005, Wilman+ 2005, Weiner+ 2009, …)
- Crucial component in simulations



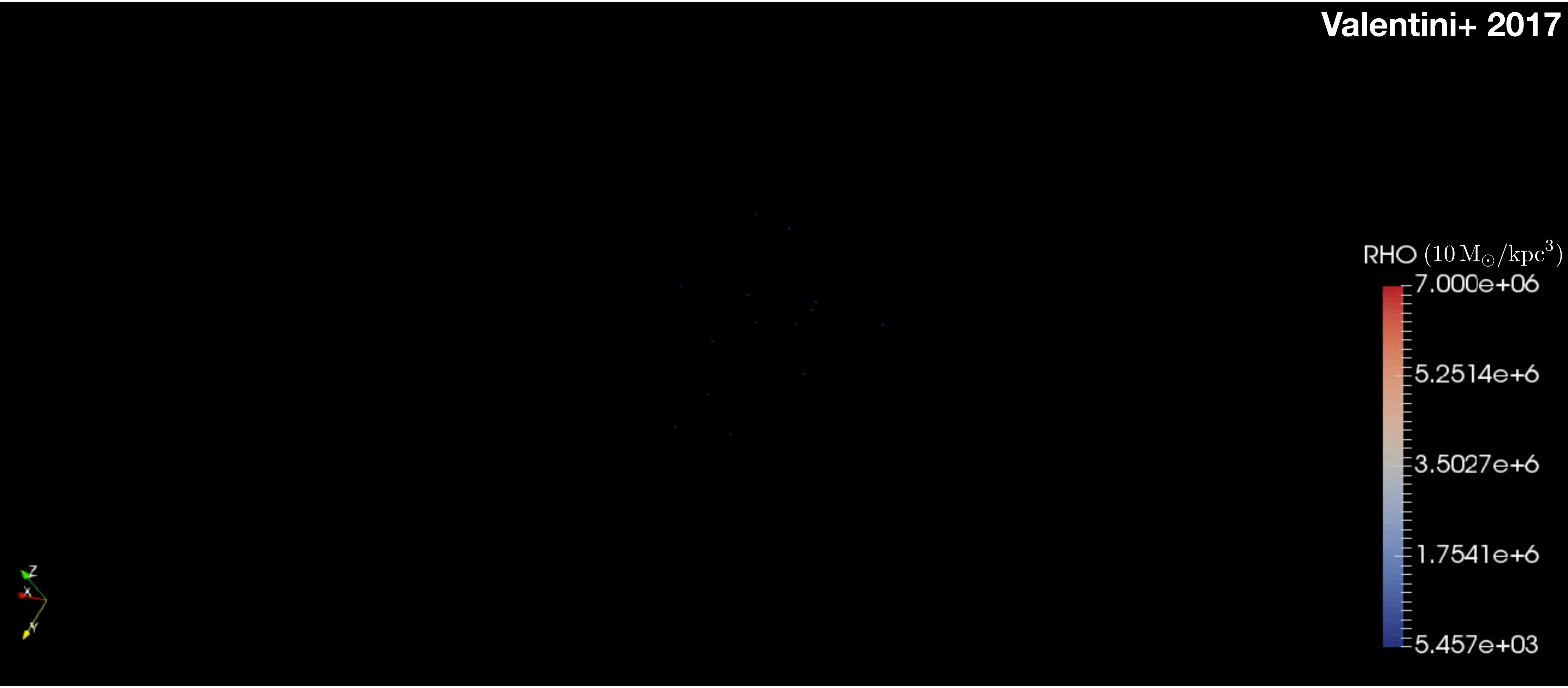
GOAL: Explore different feedback models to highlight the **variation in final results by modifying only the description of galactic outflows**.

Questions to address:

1. How sensitive are the **properties** of a **galaxy** to **different galactic outflow models**?
2. Which are the requirements for a galactic outflow model that lead to the formation of a realistic disc galaxy?

mainly based on Valentini et al., 2017, MNRAS, 470, 3167

COSMOLOGICAL SIMULATIONS

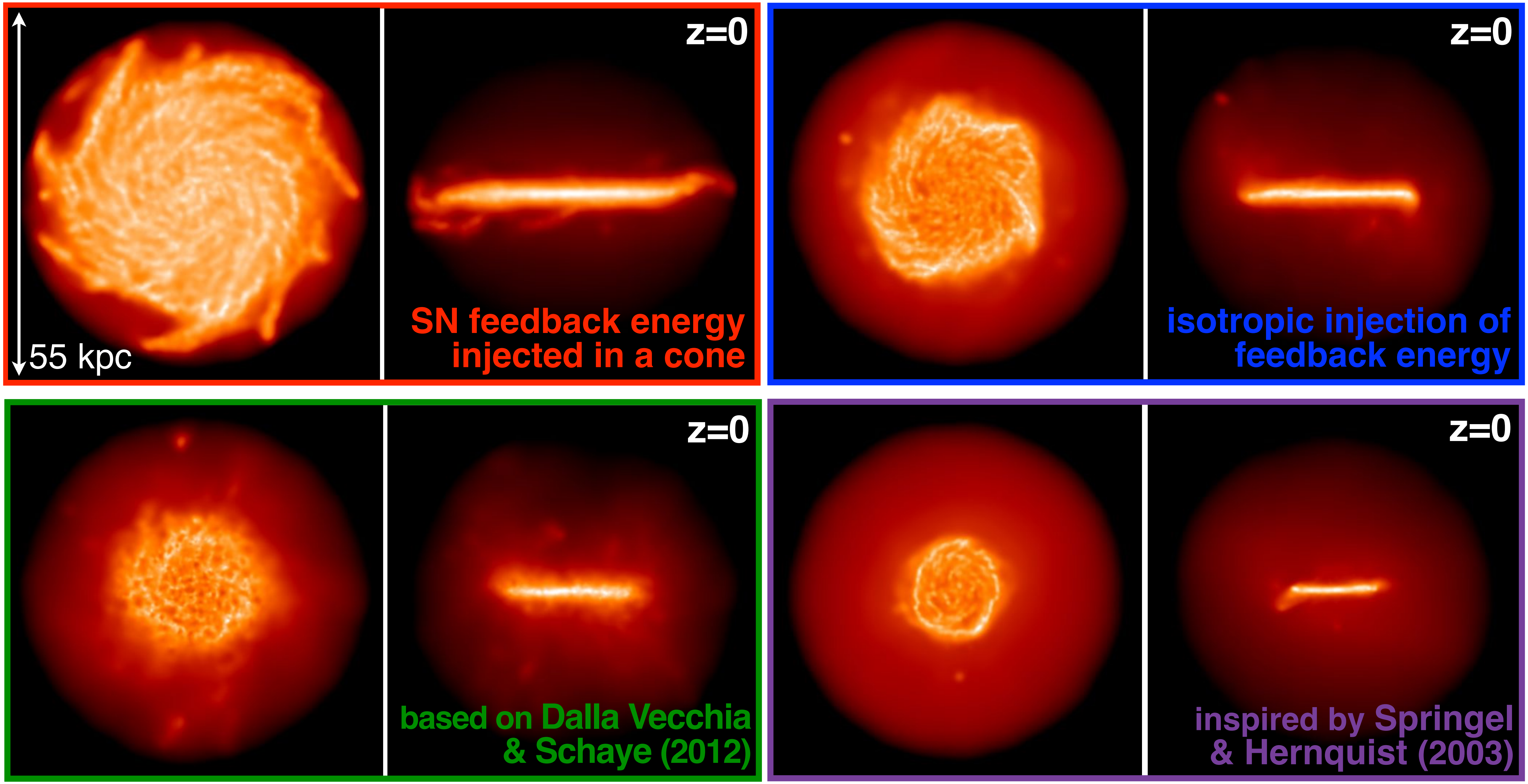


- GADGET-3 (TreePM+SPH, update of GADGET-2, Springel, 2005) with a sub-resolution model for star formation and feedback (Murante+ 2010, 2015; Valentini+ 2017)

- Initial conditions (*AqC*, Springel, 2008):
  halo of $\mathrm{M_{vir}} \simeq 2 \cdot 10^{12}\ \mathrm{M}_\odot h^{-1}$
- Cosmology: $\Omega_{\mathrm{bar}} = 0.04,\ \Omega_m = 0.25,$
  $\Omega_\Lambda = 0.75,\ \mathrm{H}_0 = 73\,\mathrm{km\ s^{-1}Mpc^{-1}}$

- Box size $= 100\,\mathrm{Mpc\ h^{-1}}$
- Resolution AqC5:
  - mass of DM particles $1.6 \cdot 10^6 h^{-1}\mathrm{M}_\odot$
  - initial mass of gas particles $3.0 \cdot 10^5 h^{-1}\mathrm{M}_\odot$
  - softening length $325\,h^{-1}\mathrm{pc}$

GALACTIC OUTFLOW MODELLING



Valentini+ 2017

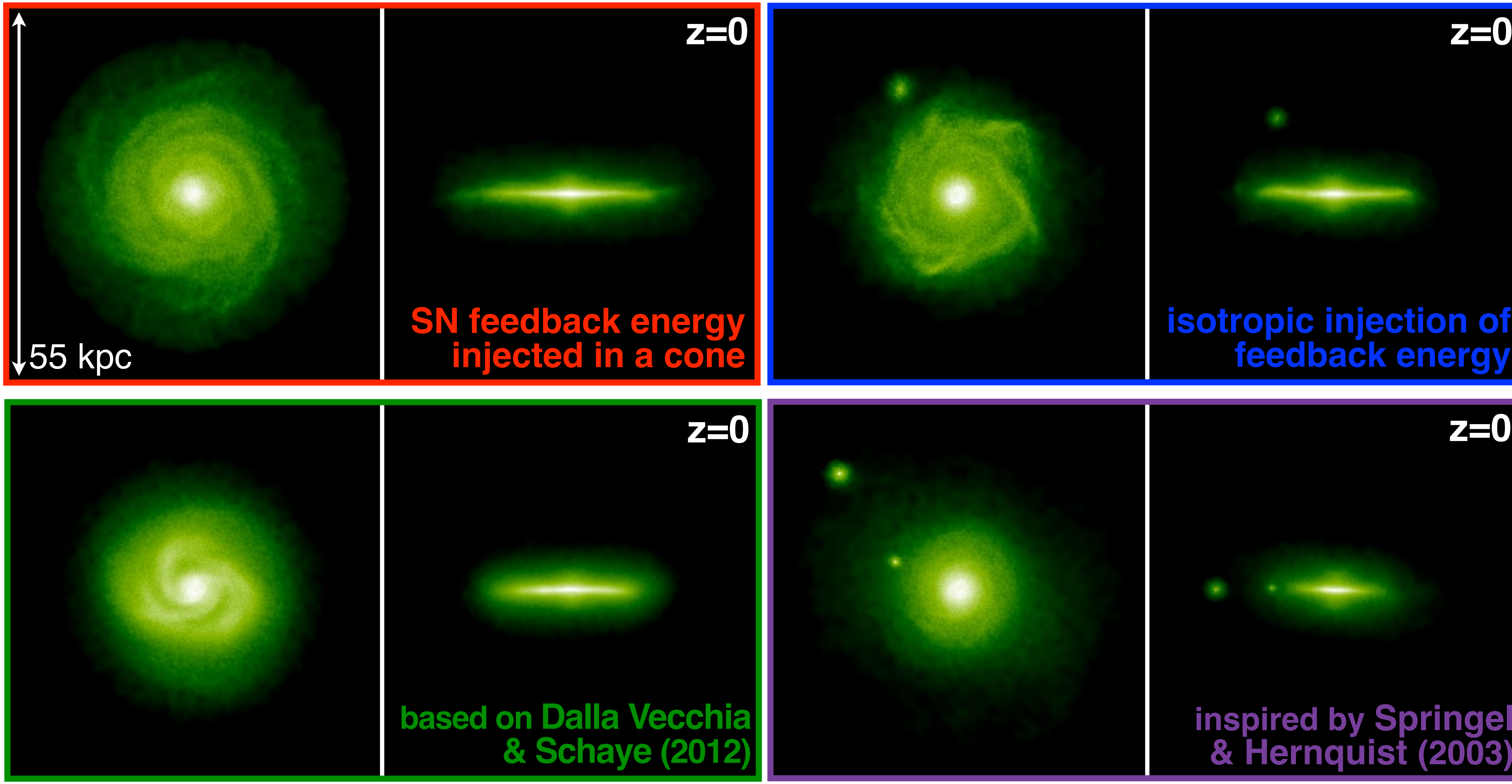
$M_{gas} = 2.91 \cdot 10^{10}\, M_\odot$ within $R_{gal} = 24.01\,\mathrm{kpc}$

$M_{gas} = 2.07 \cdot 10^{10}\, M_\odot$ within $R_{gal} = 23.90\,\mathrm{kpc}$

$M_{gas} = 3.33 \cdot 10^{10} M_\odot$ within $R_{gal} = 24.76$ kpc

$M_{gas} = 8.82 \cdot 10^{9}\, M_\odot$ within $R_{gal} = 23.58\,\mathrm{kpc}$

GALACTIC OUTFLOW MODELLING



Valentini+ 2017

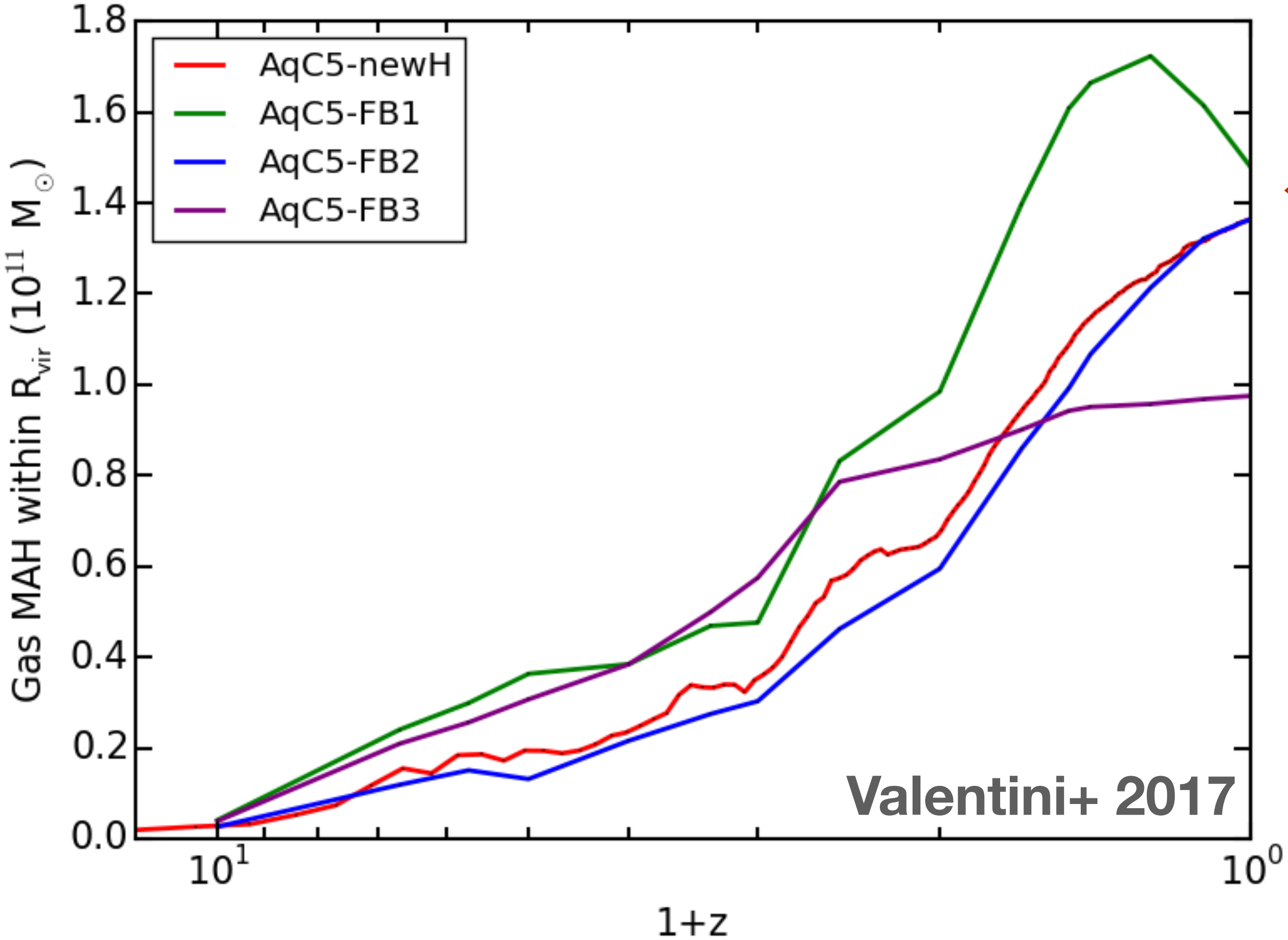
$M_* = 4.74 \cdot 10^{10}\, M_\odot$ within $R_{gal} = 24.01\,\mathrm{kpc}$

$M_* = 3.29 \cdot 10^{10}\, M_\odot$ within $R_{gal} = 23.90\,\mathrm{kpc}$

$M_* = 9.34 \cdot 10^{10} M_\odot$ within $R_{gal} = 24.76\,\mathrm{kpc}$

$M_* = 2.94 \cdot 10^{10}\, M_\odot$ within $R_{gal} = 23.58\,\mathrm{kpc}$

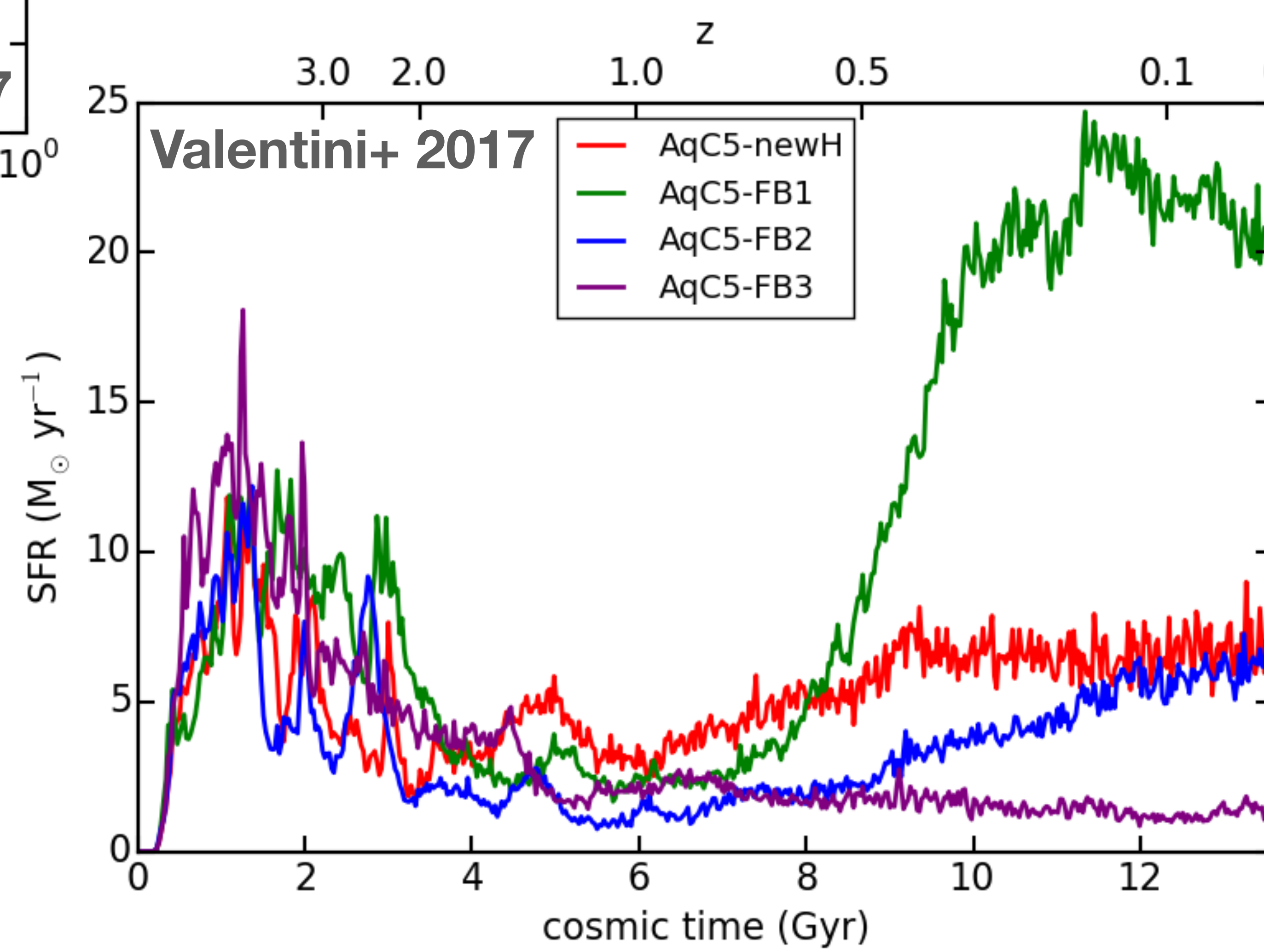
EFFECT OF GALACTIC OUTFLOWS



Gas mass accretion history

Effect of different outflow models on the regulation of gas accretion: key differences in galaxy stellar mass at low z

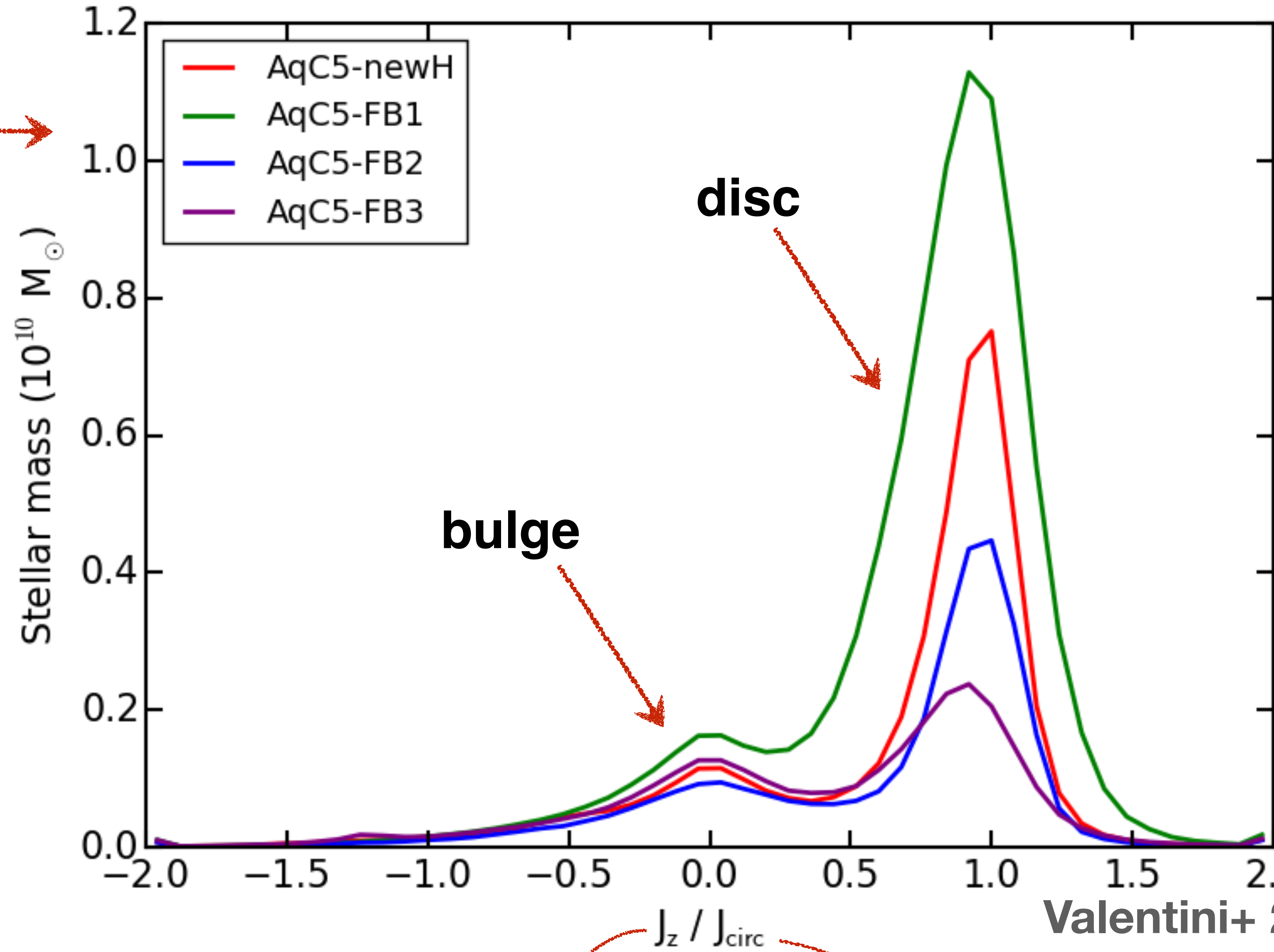
Star formation history



Galactic outflow models determine the galaxy star formation rate

EFFECT OF GALACTIC OUTFLOWS

Stellar mass as a function of the circularity of stellar orbits



Valentini+ 2017

B/T ratios: 0.30, 0.19, 0.35, and 0.54.

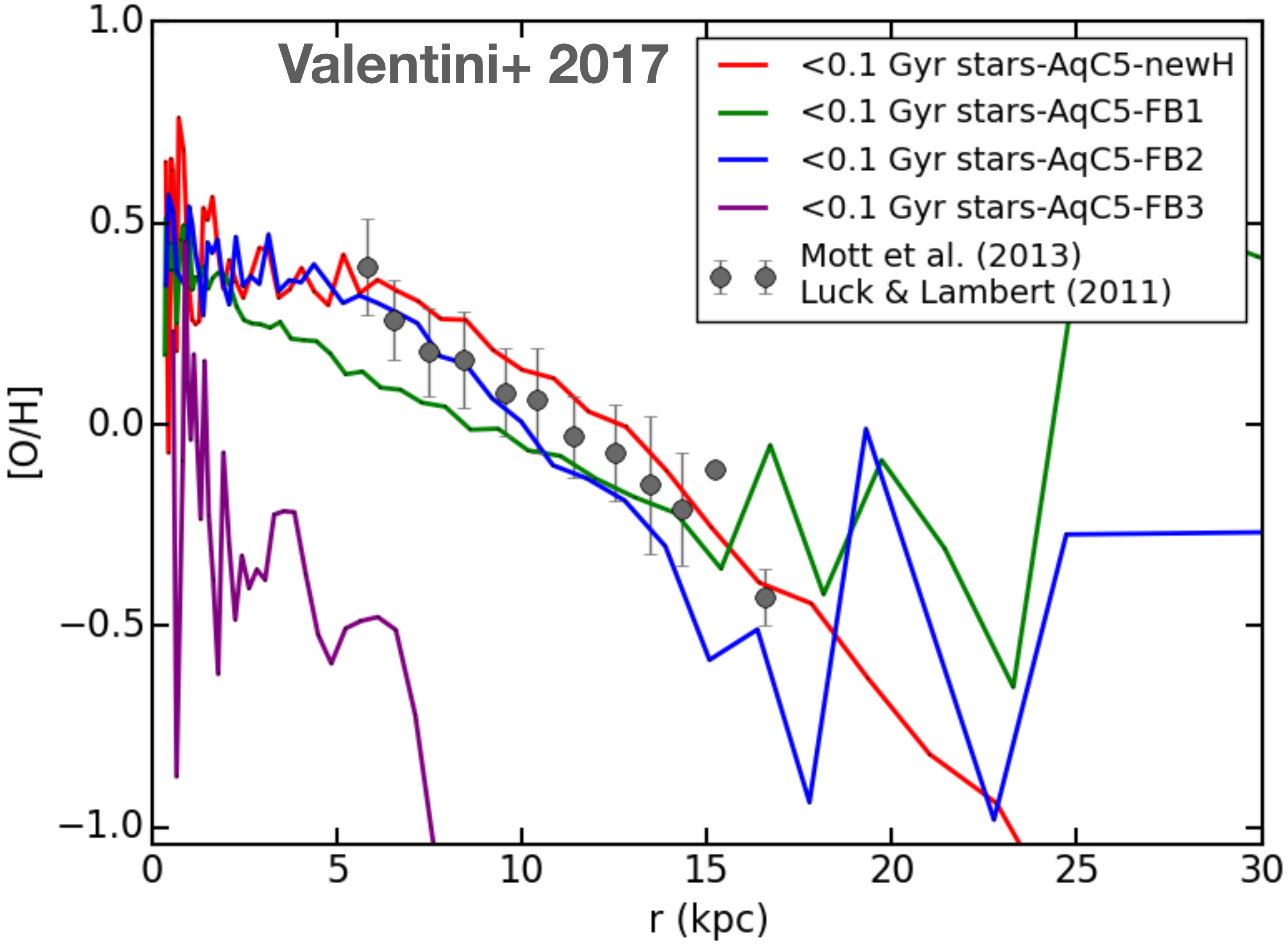
specific angular momentum in the direction perpendicular to the disc

specific angular momentum of a reference circular orbit

$$J_{circ} = r \cdot v_c(r) = r(GM(<r)/r)^{1/2}$$

Prominence of the disc component: sensitive dependence on the adopted outflow model

METALS

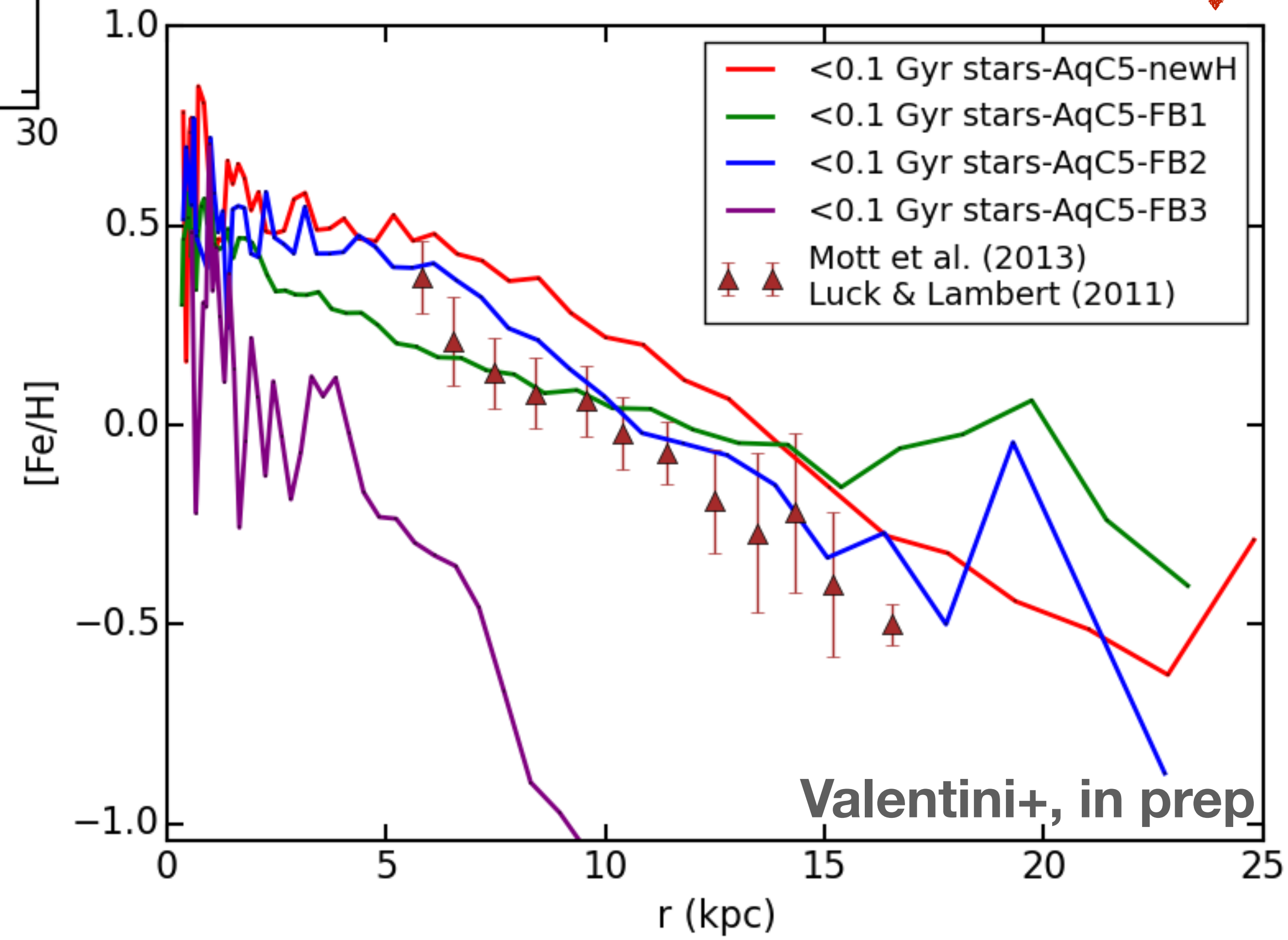


Oxygen abundance in young stars

Logarithm of the ratio of the abundance by mass of Oxygen over Hydrogen, compared to that of the Sun

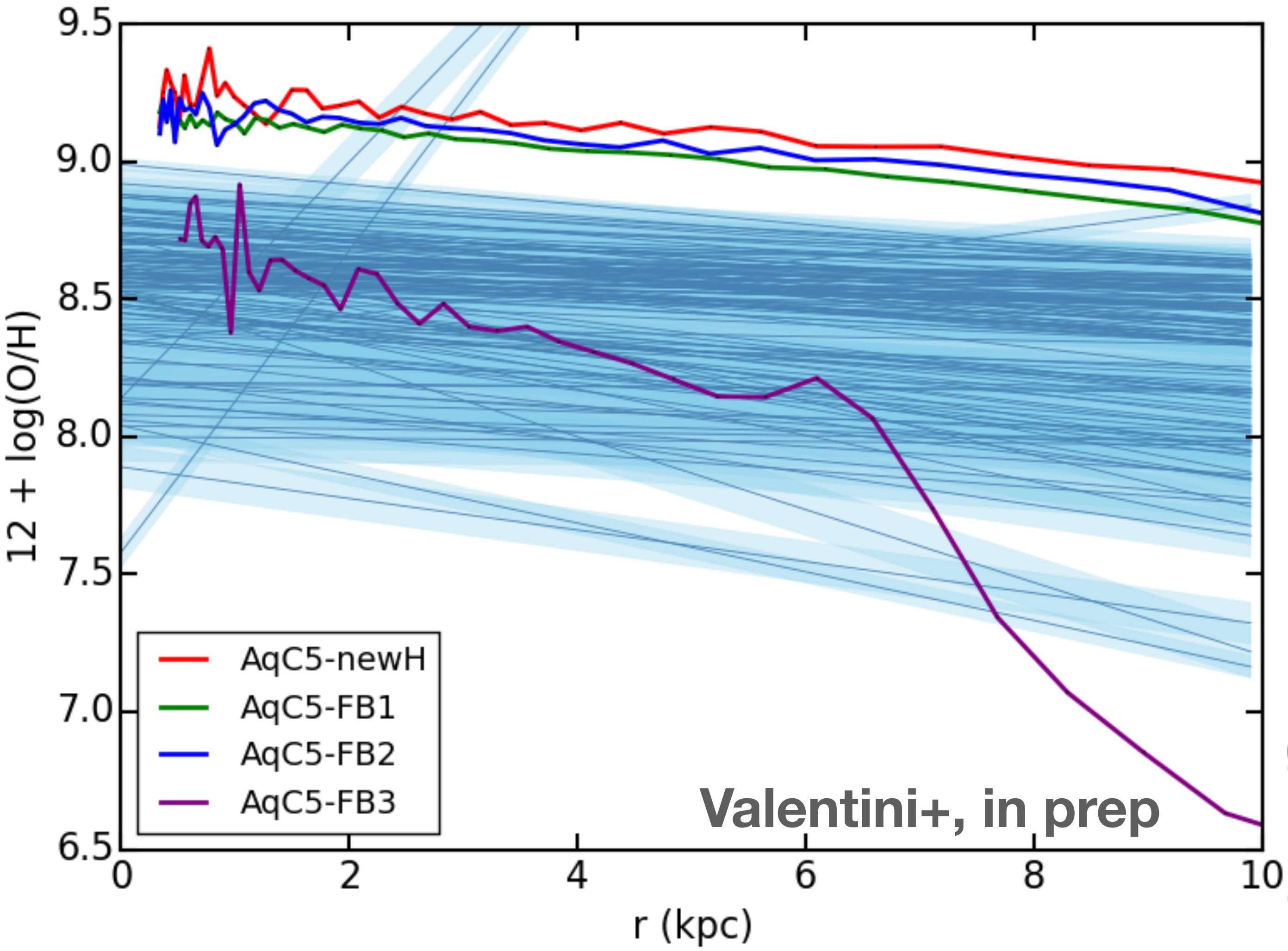
$$[O/H] = \log_{10}(O/H) - \log_{10}(O/H)_\odot$$

Iron abundance in young stars

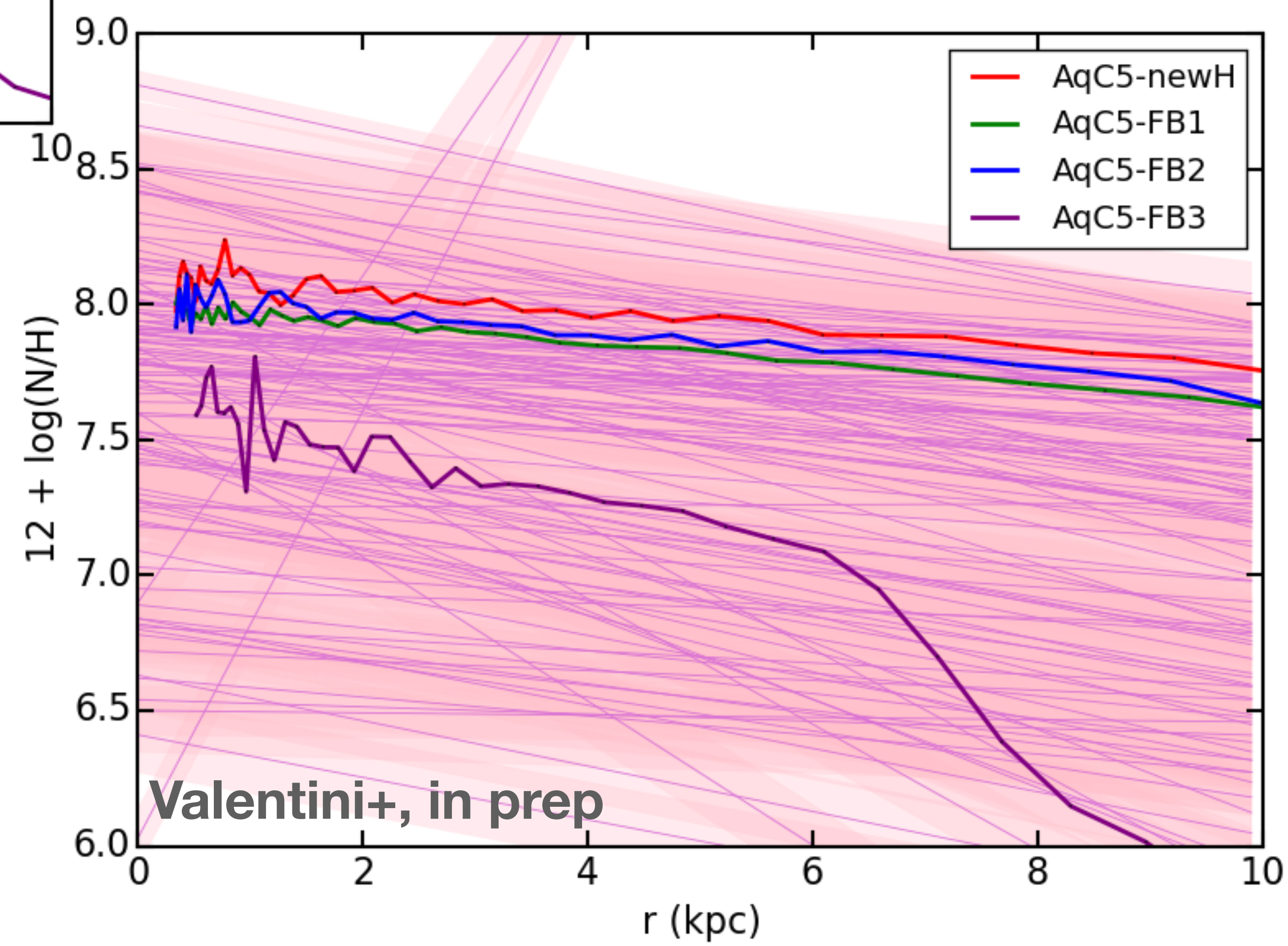


- Negative radial abundance gradients recovered, as suggested by observations of stars in MW
- Effectiveness of galactic outflow models to properly describe the chemical enrichment of the galaxy at different positions

METALS



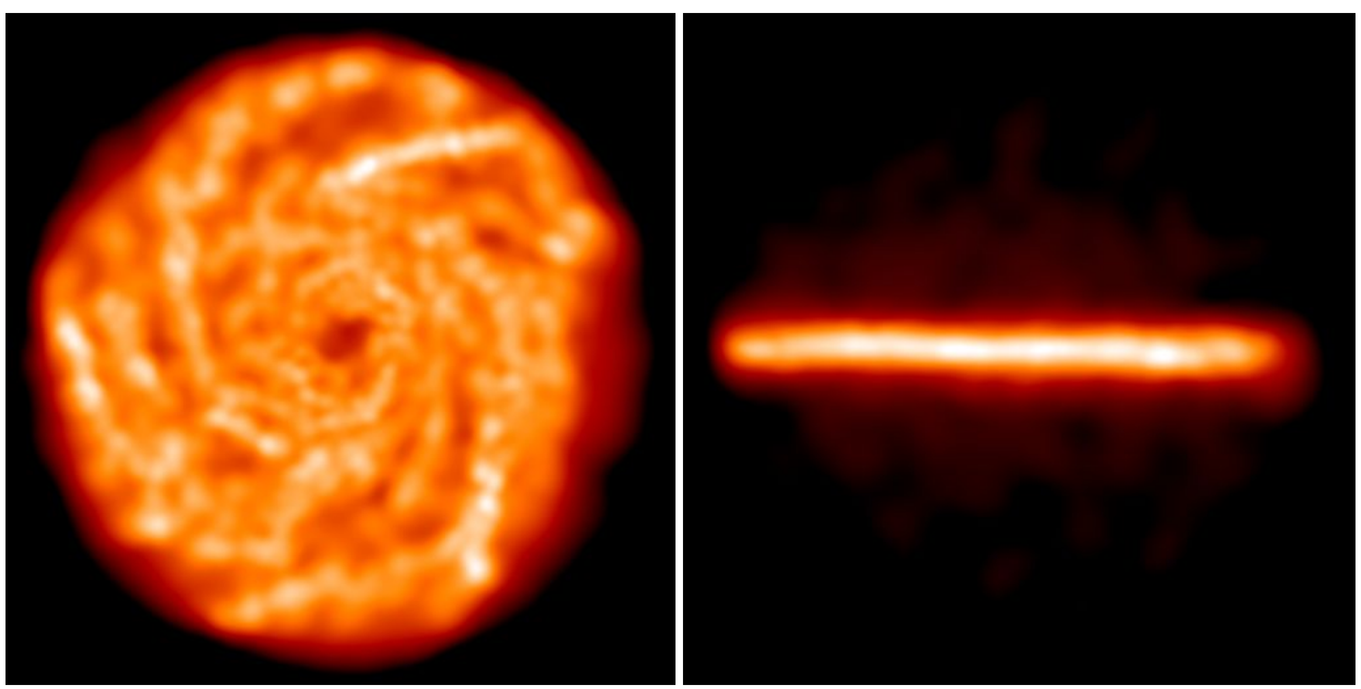
Oxygen and Nitrogen abundance in gas → comparison with observations from a sample of 130 nearby late-type galaxies (Pilyugin+ 2014)



- Small overproduction of metals in gas wrt observations: expelled gas (that then falls back) is too enriched when driven outward by galactic outflows
- AGN feedback helps to expel pristine gas at higher z

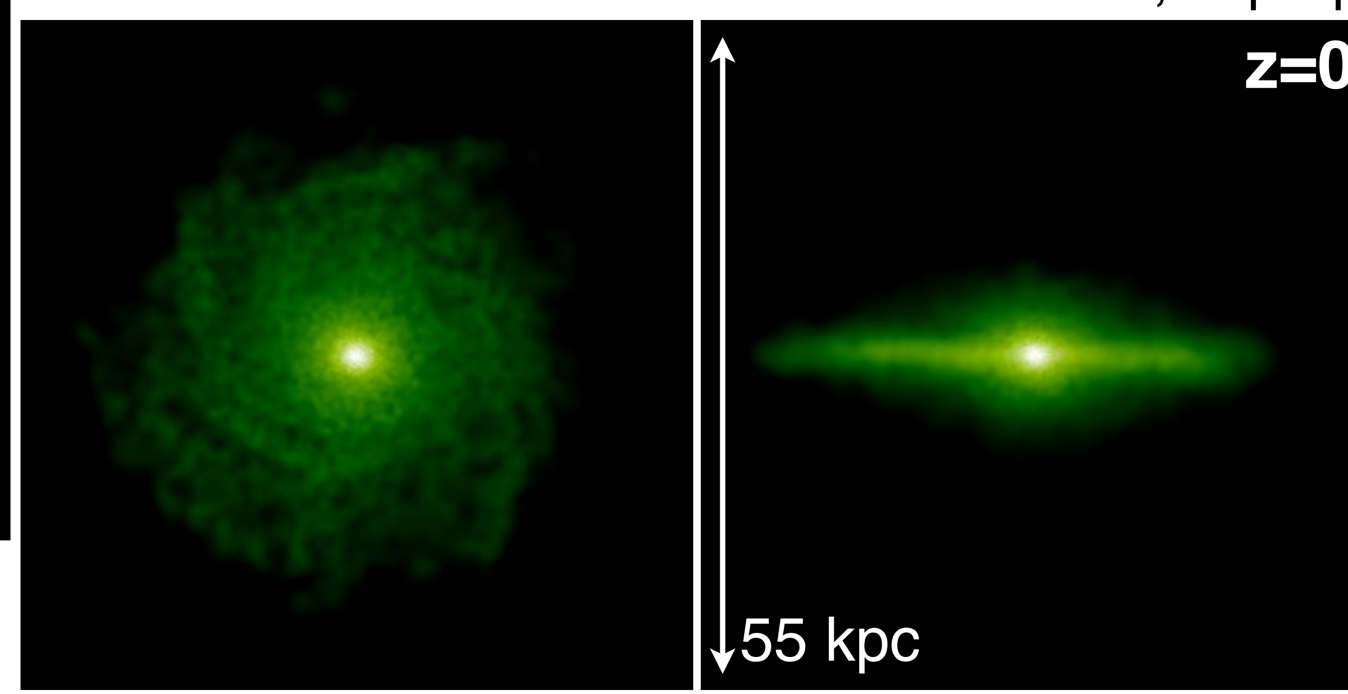
INCLUDING AGN FEEDBACK

- BH grows with an accretion rate: $\dot{\mathrm{M}}_{\mathrm{BH}} = \min\left(\dot{\mathrm{M}}_{\mathrm{B,\,hot}} + \dot{\mathrm{M}}_{\mathrm{B,\,cold}}, \dot{\mathrm{M}}_{\mathrm{Edd}}\right)$
- Bondi accretion rate (modified): $\dot{\mathrm{M}}_{\mathrm{B}} = \alpha \frac{4\pi\, G^2\, \langle\rho\rangle \mathrm{M}_{\mathrm{BH}}^2}{(\langle c_s\rangle^2 + \langle v\,\rangle^2)^{3/2}}$ $(\alpha_{\mathrm{hot}} = 10, \alpha_{\mathrm{cold}} = 100)$
- BH growth → radiated luminosity: $L_r = \varepsilon_r\, \dot{\mathrm{M}}_{\mathrm{BH}}\, c^2$
- A fraction ε_f of L_r is thermally and isotropically coupled to the surrounding gas as feedback energy: $\dot{\mathrm{E}}_{\mathrm{fb}} = \varepsilon_f\, L_r = \varepsilon_f \varepsilon_r \dot{\mathrm{M}}_{\mathrm{BH}}\, c^2$
- Coupling to different ISM phases according to the covering factor of the cold phase

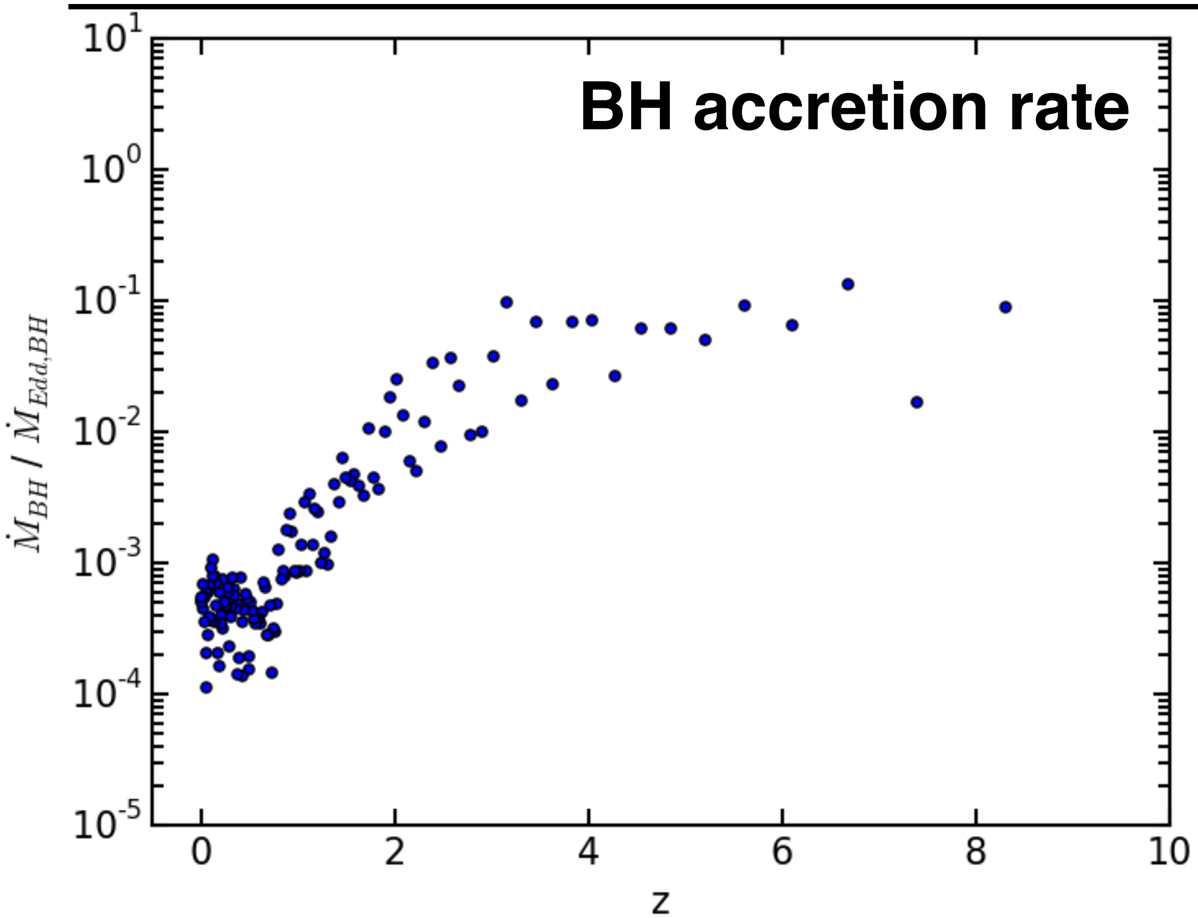


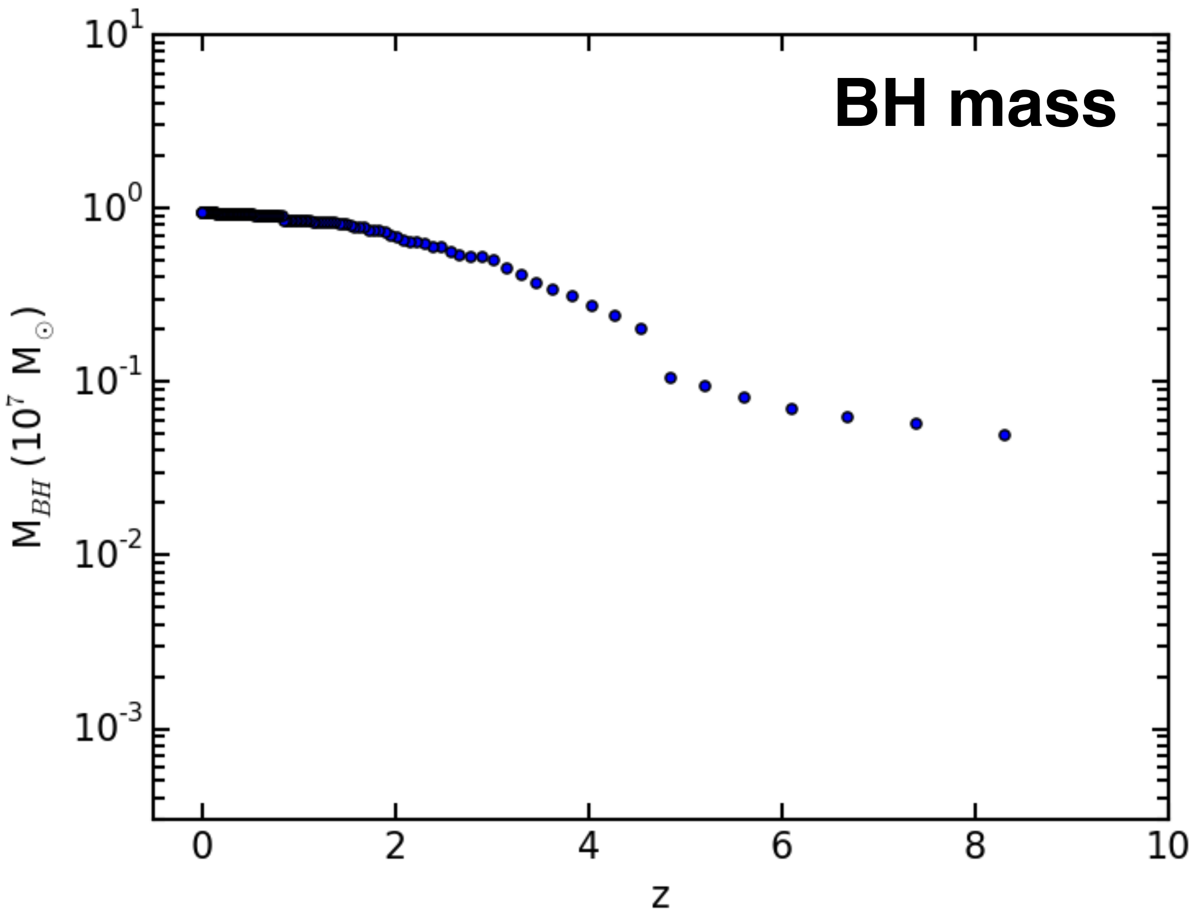
In collaboration with A. Lapi and G.L. Granato

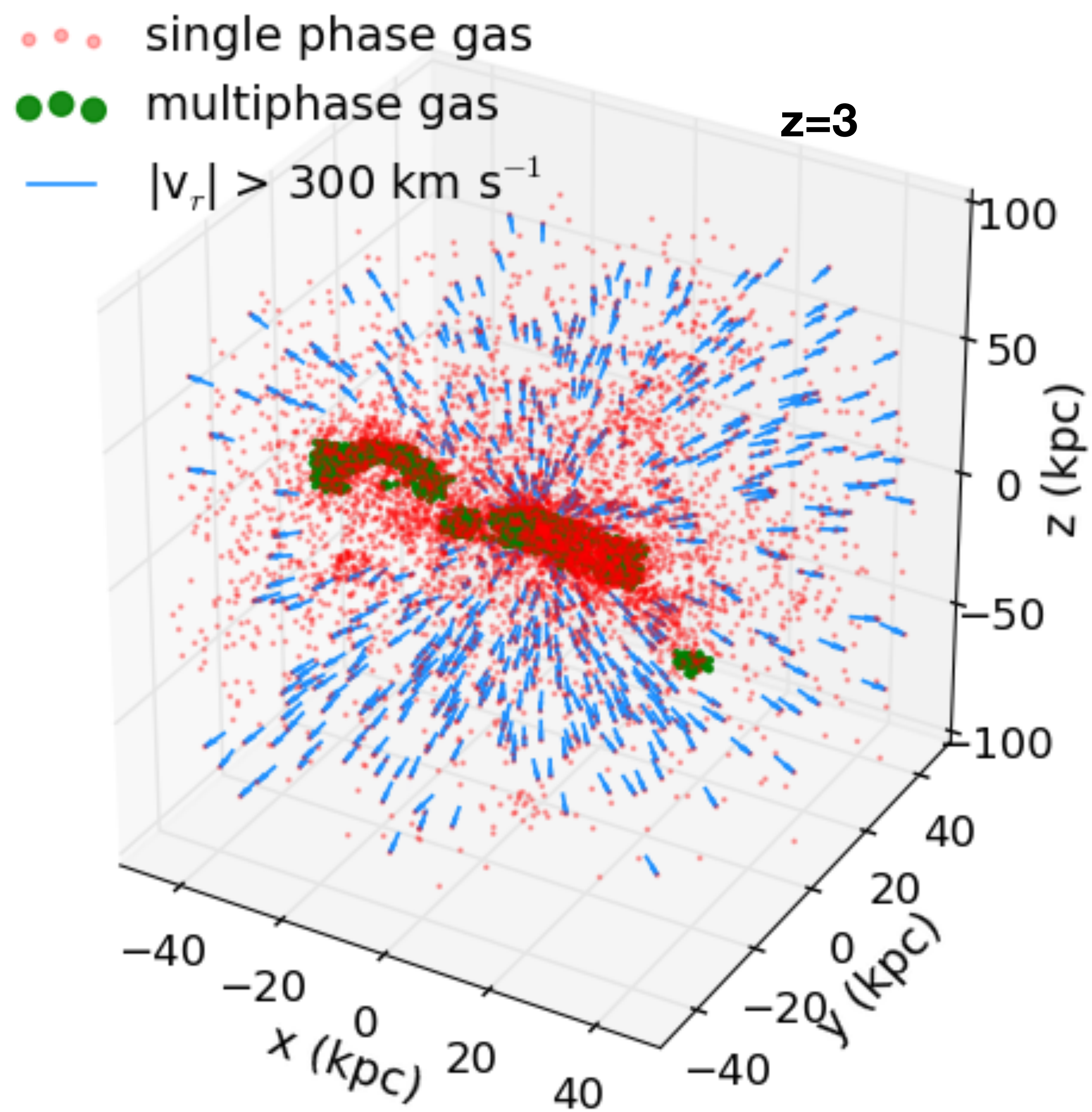
Valentini+, in prep



AGN: ACCRETION AND OUTFLOWS







Valentini+, in prep

In collaboration with A. Lapi and G.L. Granato

CONCLUSIONS

- Sub-grid prescriptions for outflows: **main shaping factor of the stellar component at low redshift**
- Essential requirements for a successful galactic outflow model: **correct timing of gas fall-back after its ejection from the forming halo** and **ability to promote or quench the cosmological gas infall**
- **Comparison** between **predicted stellar metallicity** profiles (for different ion abundances) **with observations: crucial** test **to validate the history of chemical enrichment predicted by simulations** and **to probe or reject** different **models of feedback**
- **Trends suggested by observations recovered** for distributions of different abundance ratios
- **AGN** feedback: additional mechanism to stellar feedback to **promote outflows**, and crucial component to recover kinematic and chemical properties of galaxies