The multi-phase gas in the semi-analytic model GAEA & Quenching

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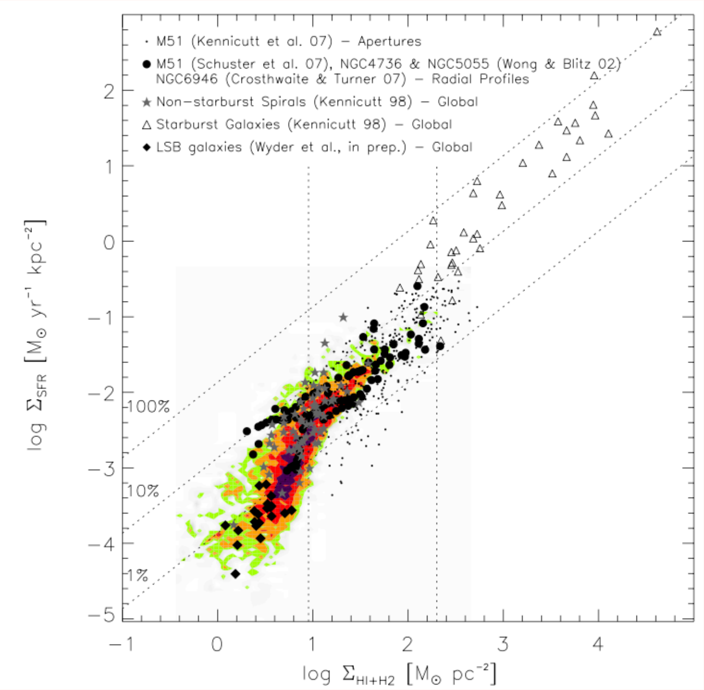
MULTI-PHASE GAS IS NEEDED

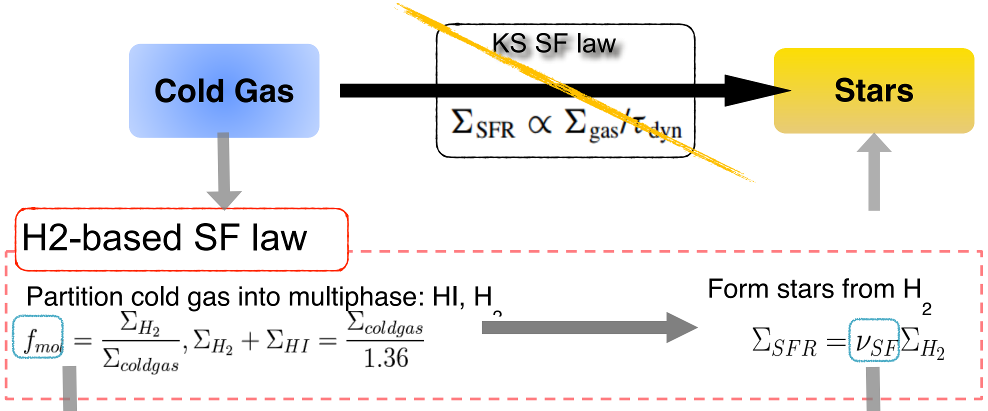
To cope with new facilities

Star formation correlates tightly with molecular hydrogen



SF LAWS — PARTITION COLD GAS

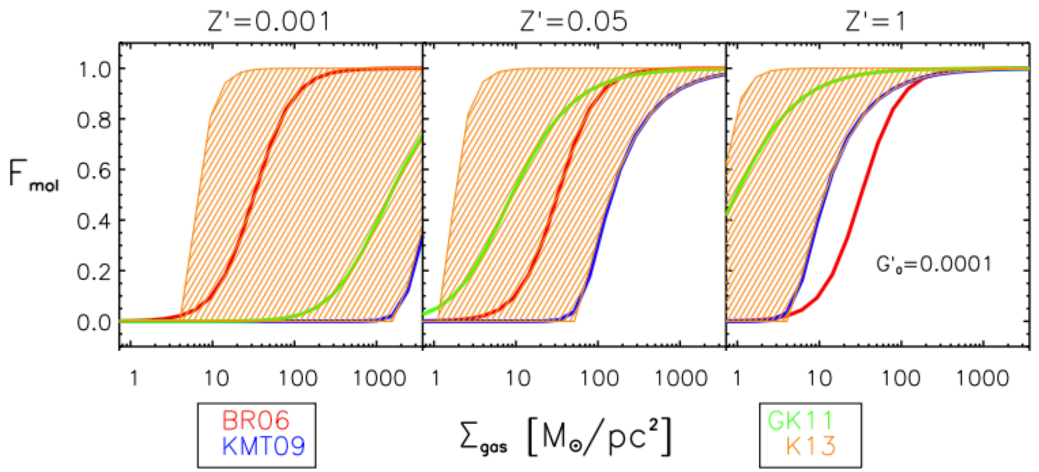
We tested 4 H2-based star formation laws to partition HI and H2



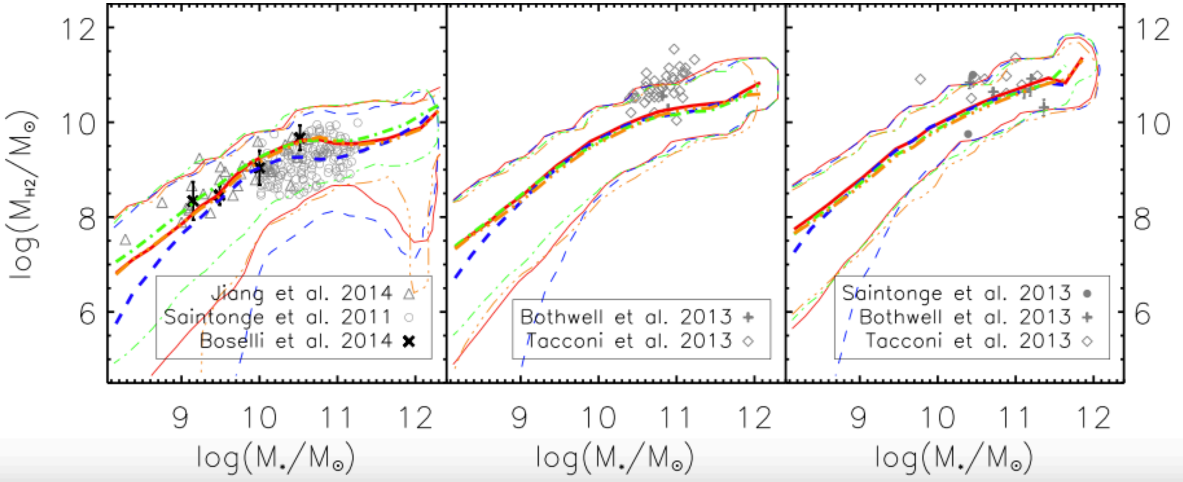
H2-based SF law

- **Fitting functions of nearby galaxies:** Blitz & Rosolowsky 2006 (BR06) .
- **Theories:** Krumholz, Mckee & Tumlinson 2009 (KMT09); Krumholz 2013 (K13)
- **Fitting functions of hydro-simulations:** Gnedin & Kravtsov 2011 (GK11)

Cold Gas = HI + H2 + (He+metals)



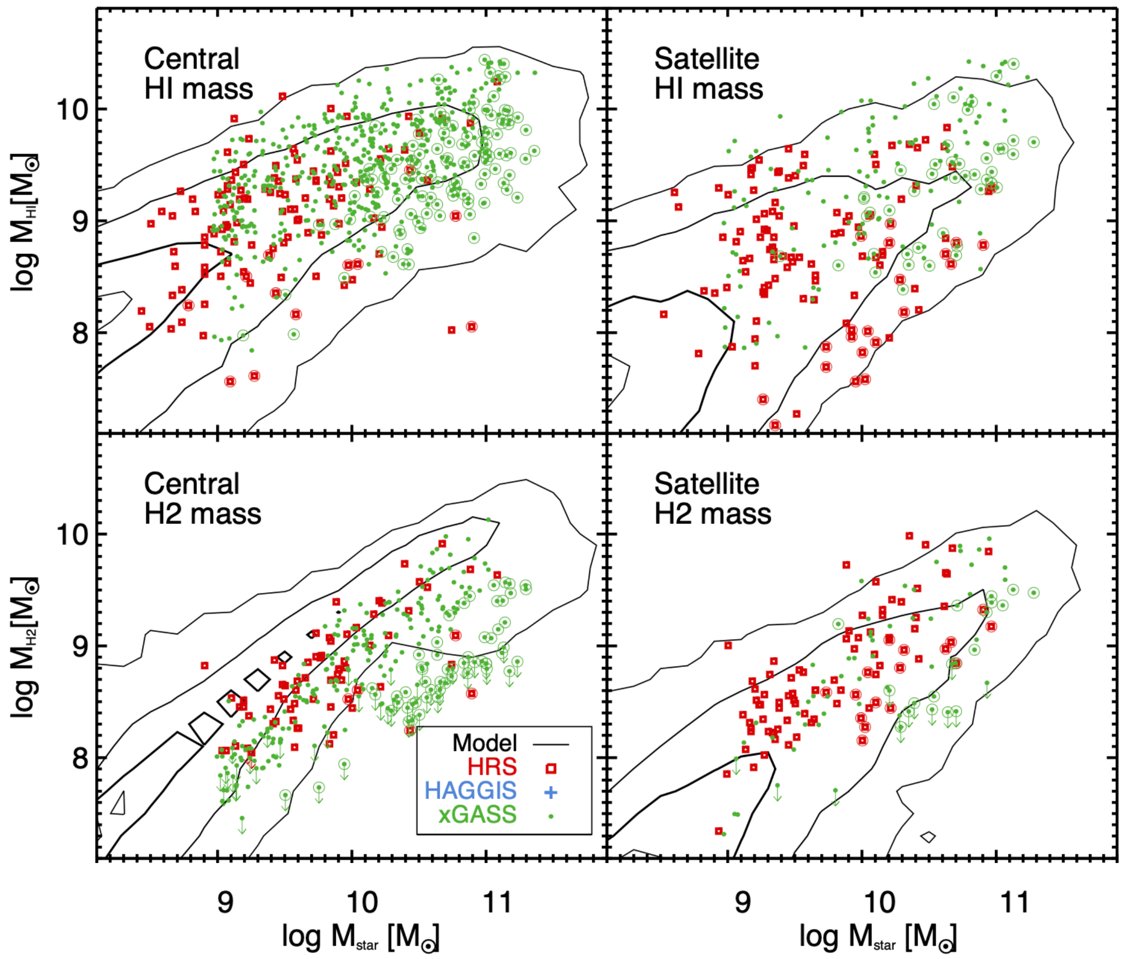
Modifying SF laws has little effect on the median H2 or HI scaling relations — self regulation

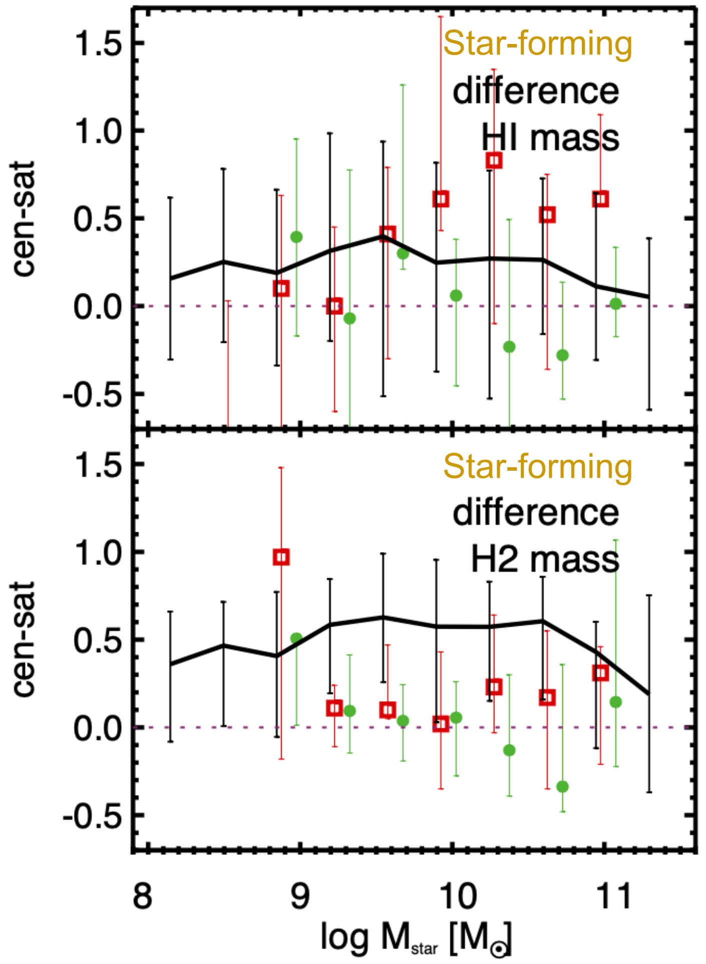


Xie et al. 2017, arXiv: 1611.09372

THE MULTI-PHASE GAS IN GAEA

The Xie 2020 model over-predicts the difference in H2 and SFR between central and satellites.

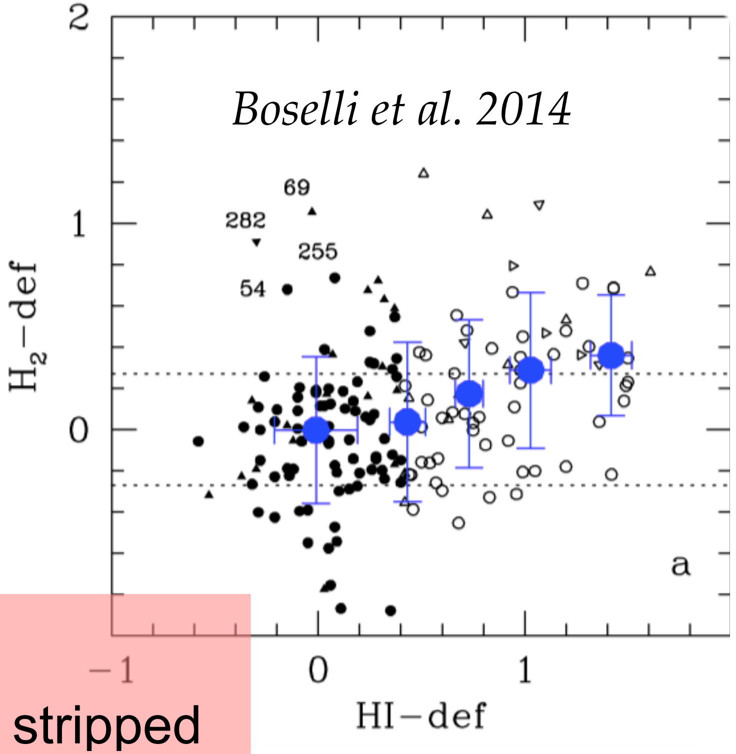


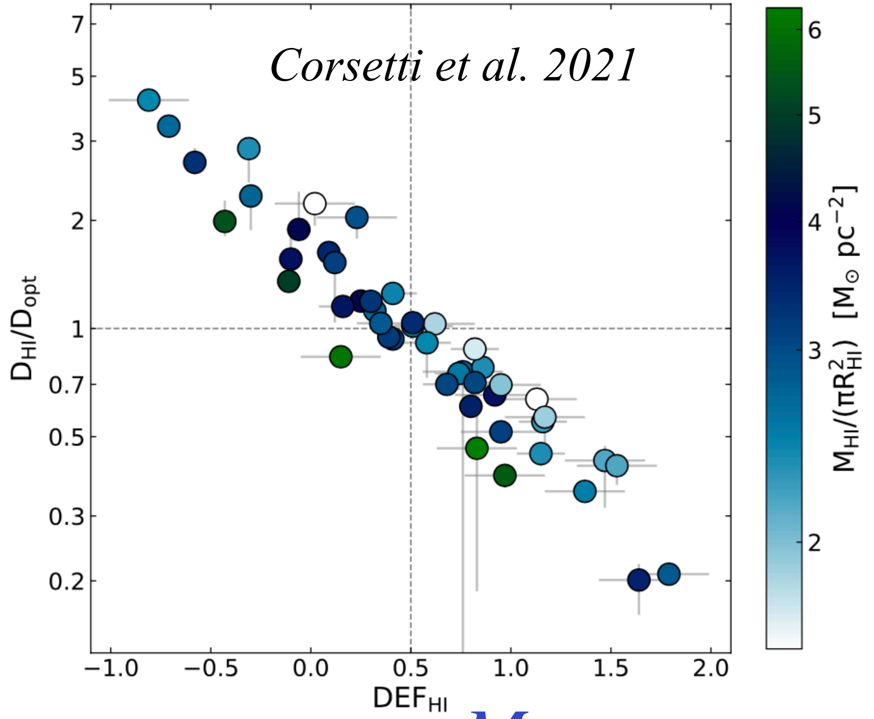


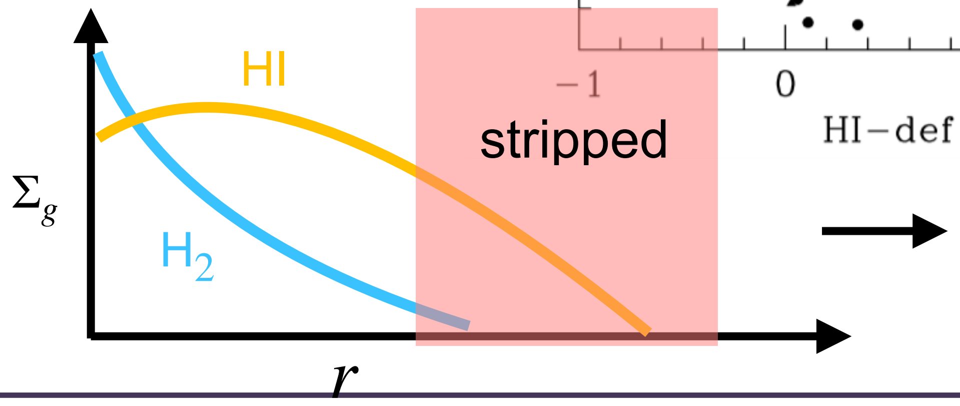
Xie et al. 2018 arXiv: 1808.01628

ENVIRONMENTAL EFFECTS // QUENCHING

From Observations — ram-pressure stripping of cold gas is







$\rightarrow$ $M_{HI}\downarrow$ $M_{H_2}\downarrow$ $R_g\downarrow$ $\frac{M_{H_2}}{M_{HI}}\uparrow$

Xie et al. 2018 arXiv: 1808.01628

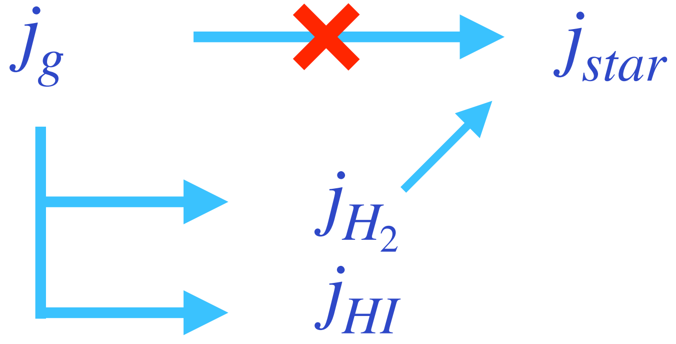
Update environmental effects —

X17 → REALJ → GRADHOT → RPSCOLD

REALJ :

Cooling: $j_{cooling} = 3j_{\rm dm}$ during cold flow; $j_{cooling} = 1.4j_{\rm dm}$ while hot-mode cooling

Star formation: stars form in 20 annuli on the disk, $j_{\rm sf} = j_{\rm SFgas} < j_{gas\ disk}$



specific angular momentum in annulus i $\quad j_{\rm g,i} = \frac{r_{\rm i}}{2r_{\rm g}} j_{\rm g}$

GRADHOT :

tidal stripping + ram-pressure stripping to remove hot gas, stripping time-scale 400 Myr

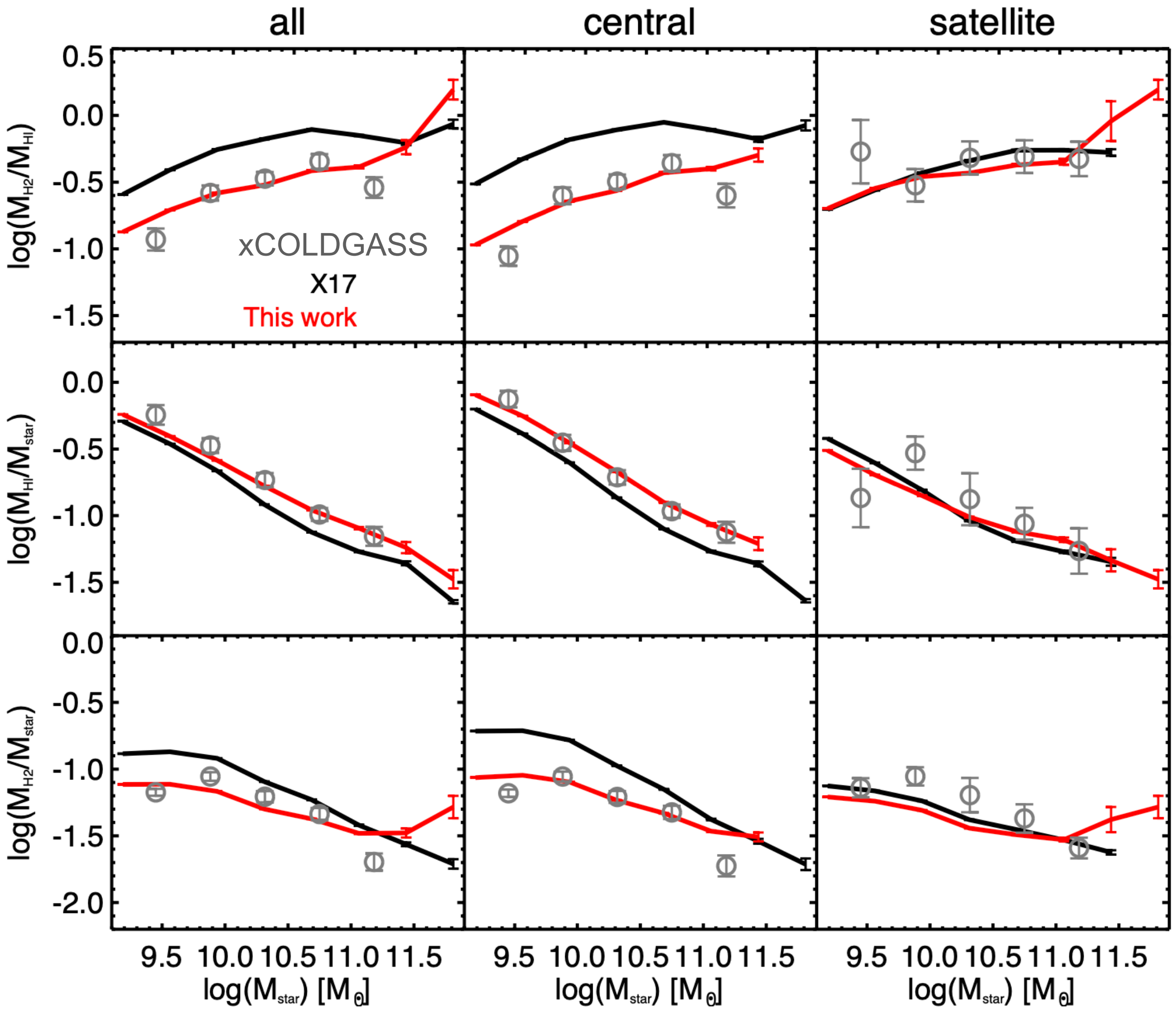
RPSCOLD:

ram-pressure stripping of cold gas in each annulus if $r_{g,i} < r_{\rm hot}$, stripping time-scale 400 Myr

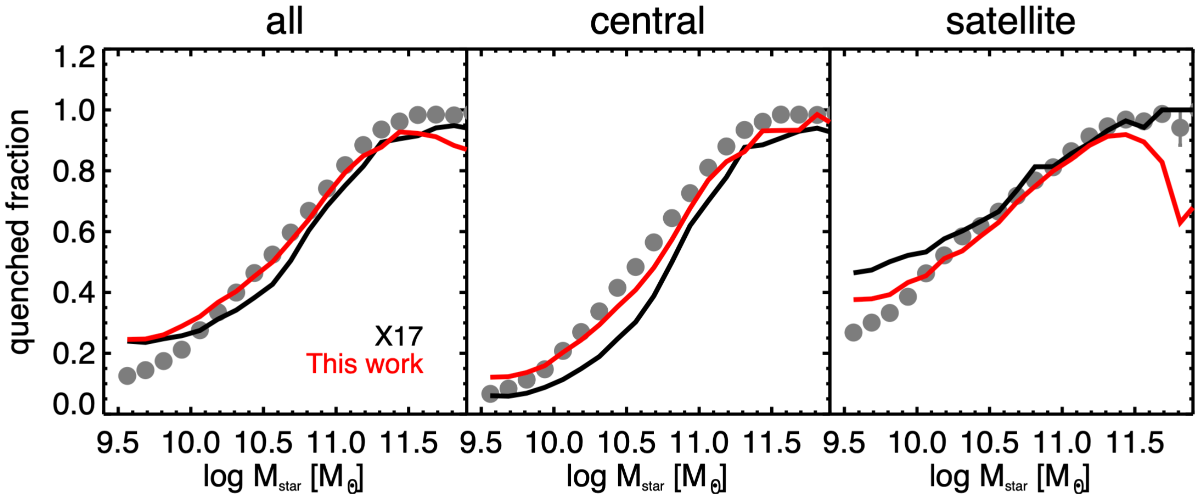
RPS cause a decrease of j_g

Xie et al. 2020 arXiv: 2003.12757

Calibrate model — HI, H2 scaling relations, quenched fraction at z~0



passive: $sSFR < 0.3/t_H$

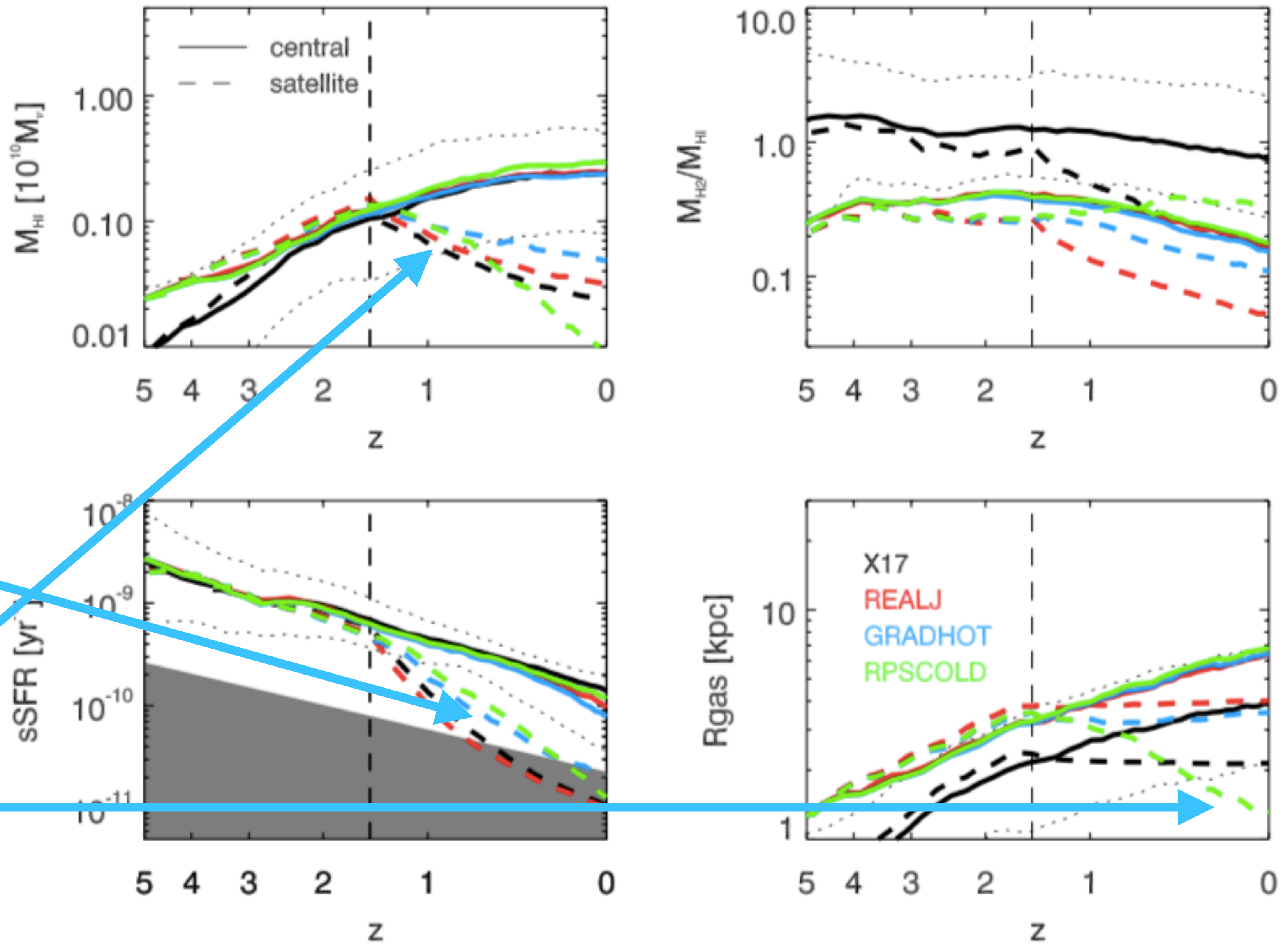


Xie et al. 2020 arXiv: 2003.12757

COMPARE WITH LITERATURE

- X17 = original model
- REALJ = X17 + angular momentum updates
- GRADHOT = REALJ + gradual hot gas stripping
- RPSCOLD = GRADHOT + cold gas stripping

- With gradual stripping of hot gas, the quenching of star formation in satellite galaxies is delayed
- With RPS of cold gas, the HI mass and gas disc sizes decreases rapidly.



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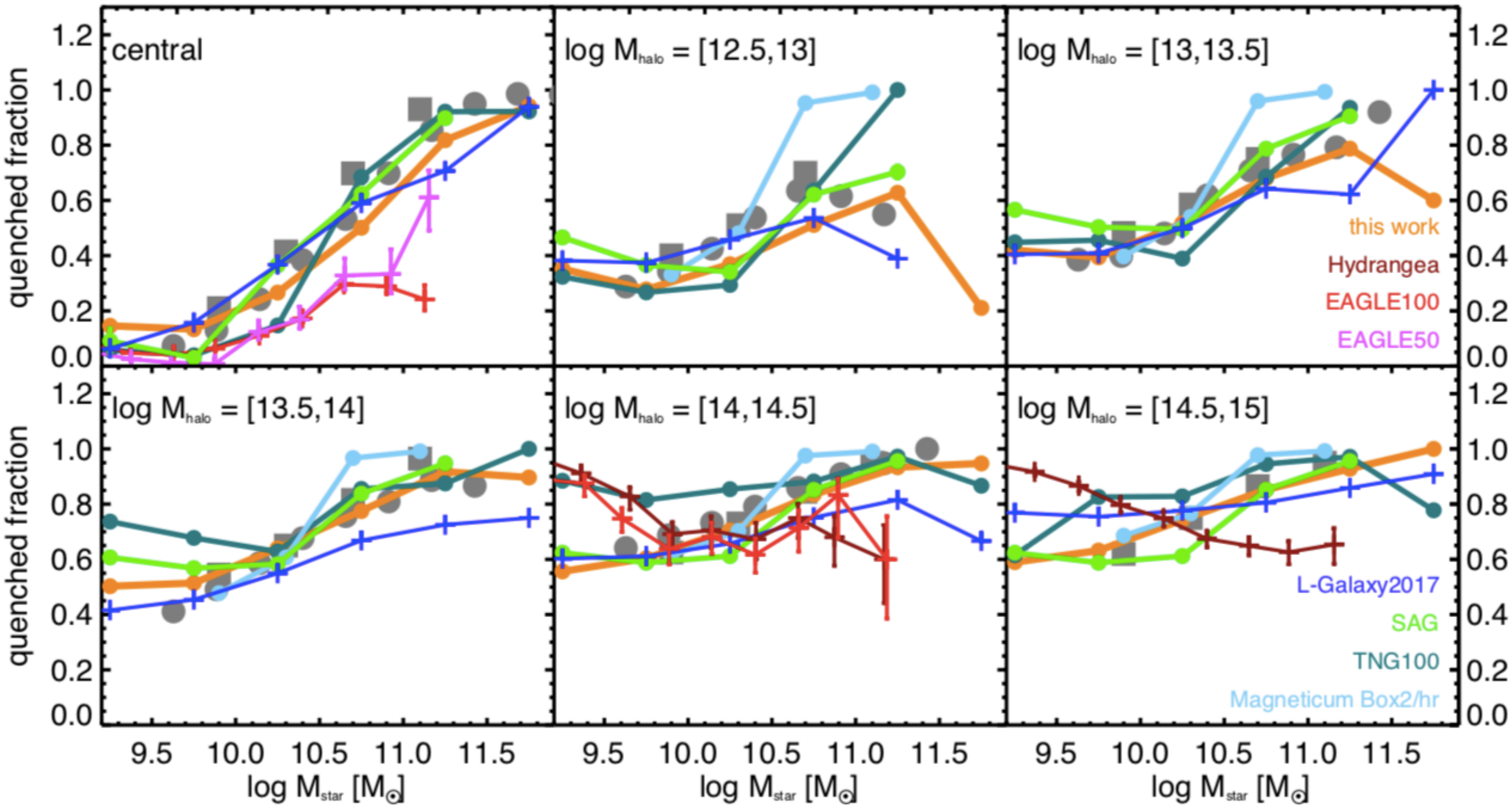

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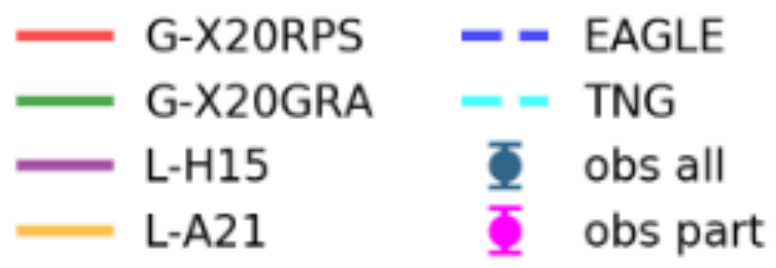
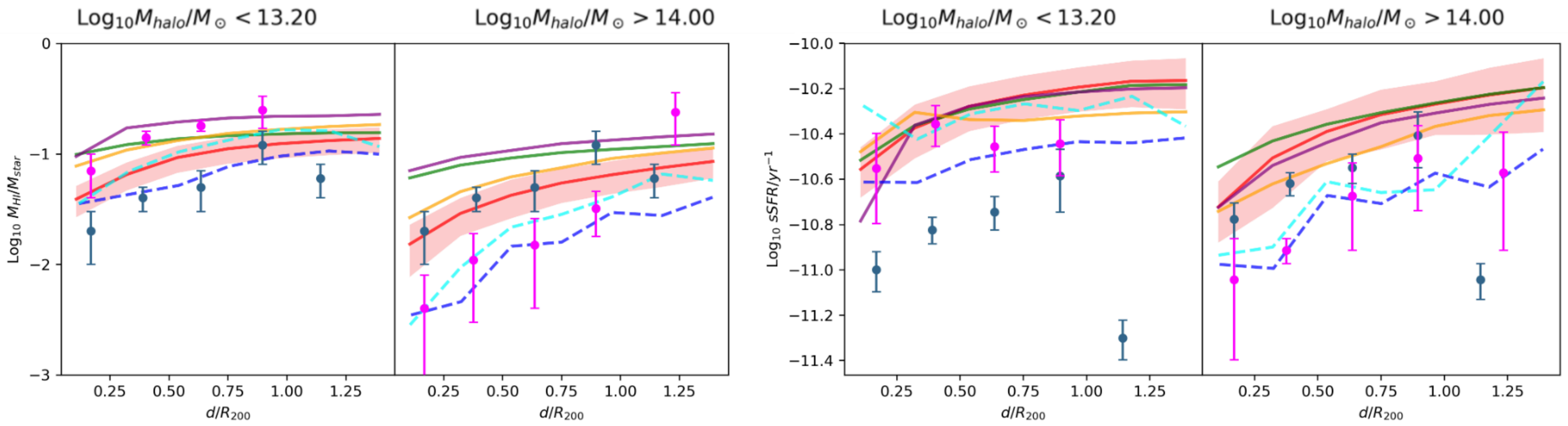
COMPARE WITH LITERATURE

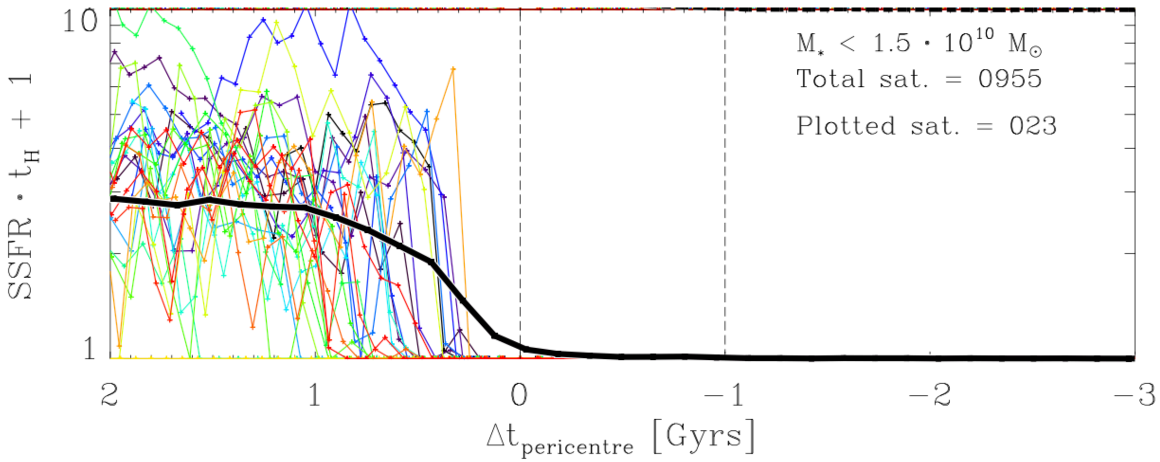


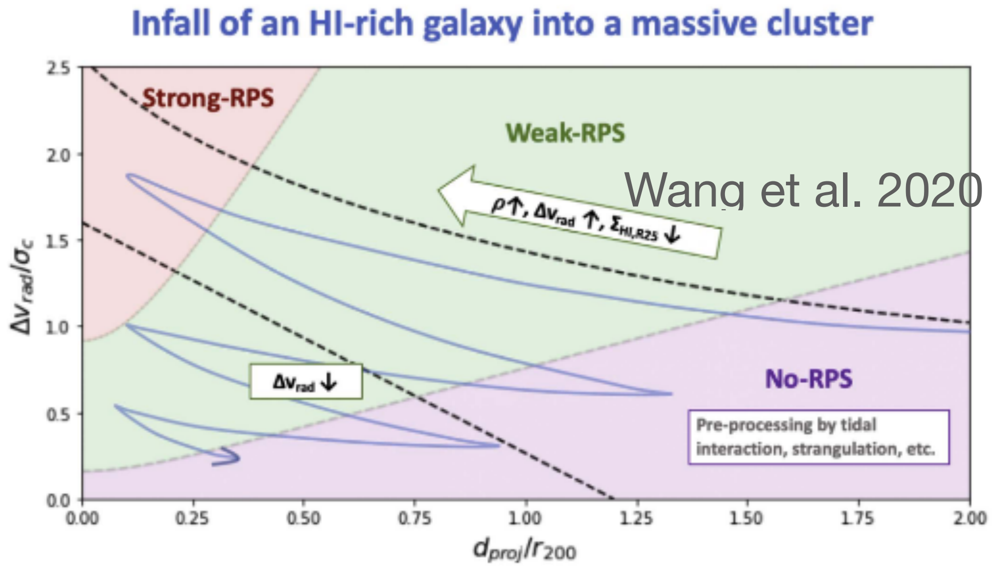
	G-X20GRA	G-X20RPS	L-H15	L-A21
Ram-pressure stripping				
Gas type	Hot gas	Hot gas and cold gas	Hot gas	Hot gas
Limit	satellite galaxies	cold gas stripped only when its radius is larger than hot gas; satellite galaxies	Satellite galaxies within $1R_{200}$; halo mass $M_{200} > 10^{14} M_{\odot}$;	All satellite and central galaxies
Tidal stripping				
Gas type	Hot gas	Hot gas	Hot gas	Hot gas
Limit	All FOF satellites	All FOF satellites	Satellites within $1R_{200}$ of all halos	All FOF satellites



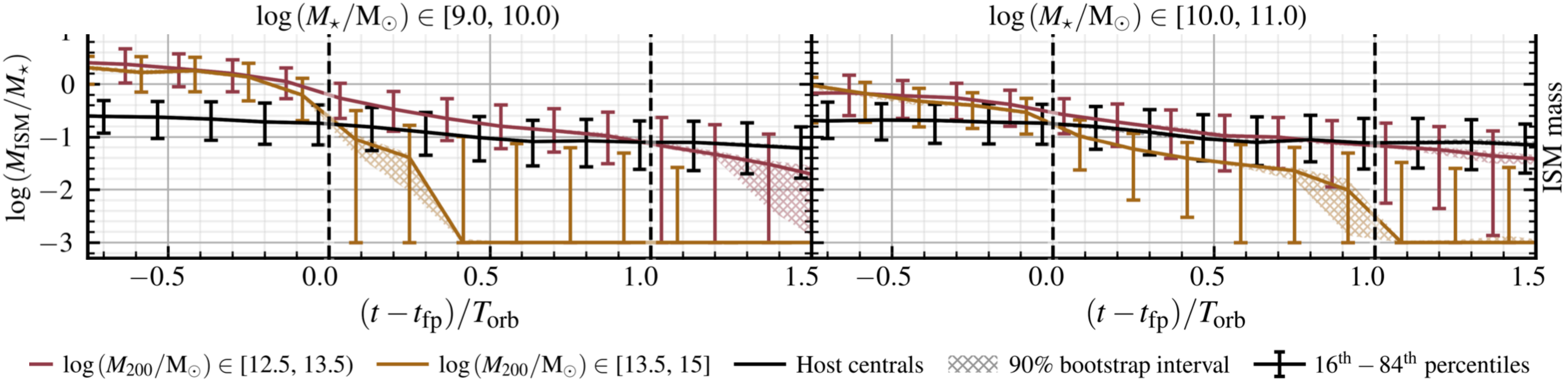
Chen in prep

GAS STRIPPING ALONG INFALLING ORBIT





Wang et al. 2020

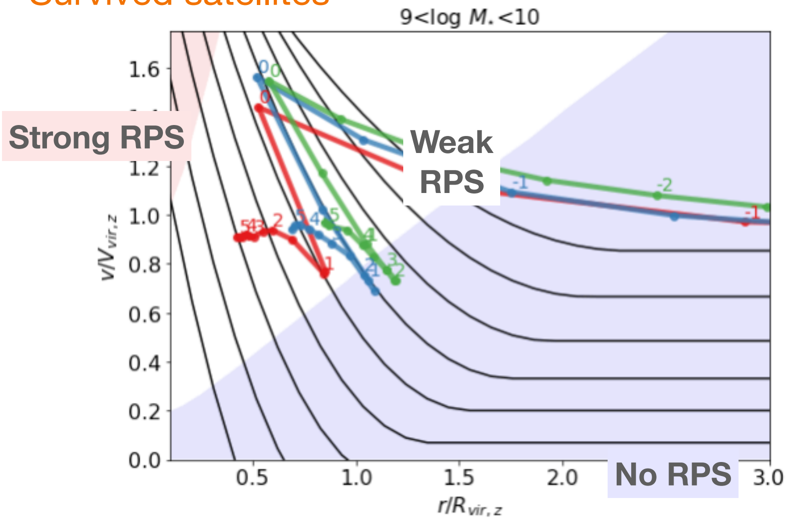


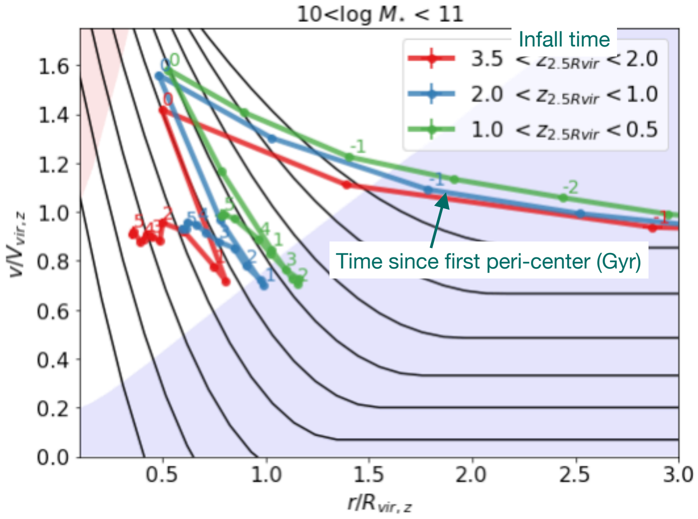
GAS STRIPPING ALONG INFALLING ORBIT

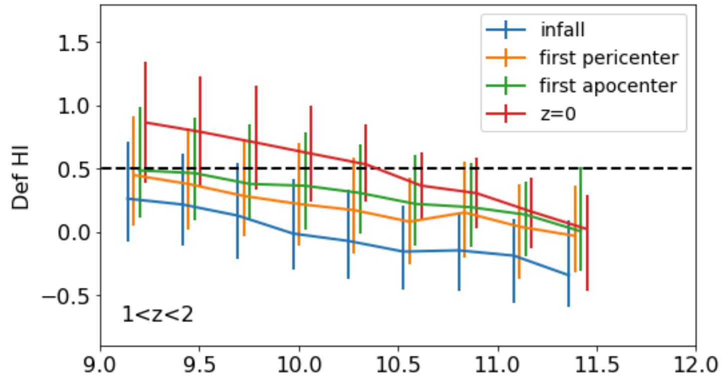
Ram-pressure stripping is too weak to strip off the entire HI reservoir of satellites at the first peri-center

Xie et al in prep.

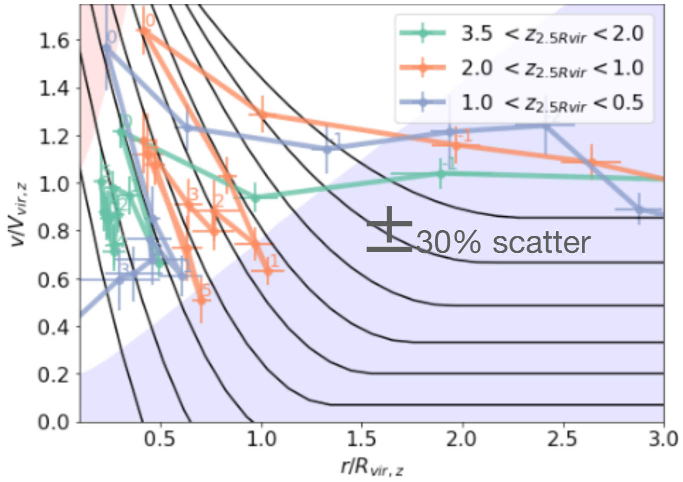
Survived satellites



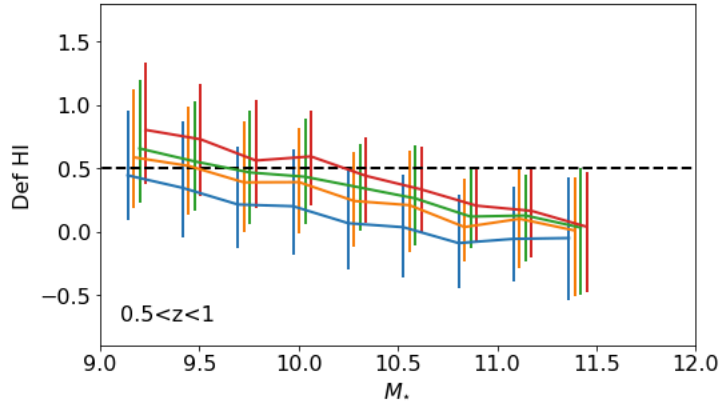




Satellites being merged



- Satellites suffer the strongest ram-pressure stripping at the first pericenter.
- The ram-pressure stripping is weak for most of satellites.
- Satellite are HI-rich at first peri-center and first apocenter.

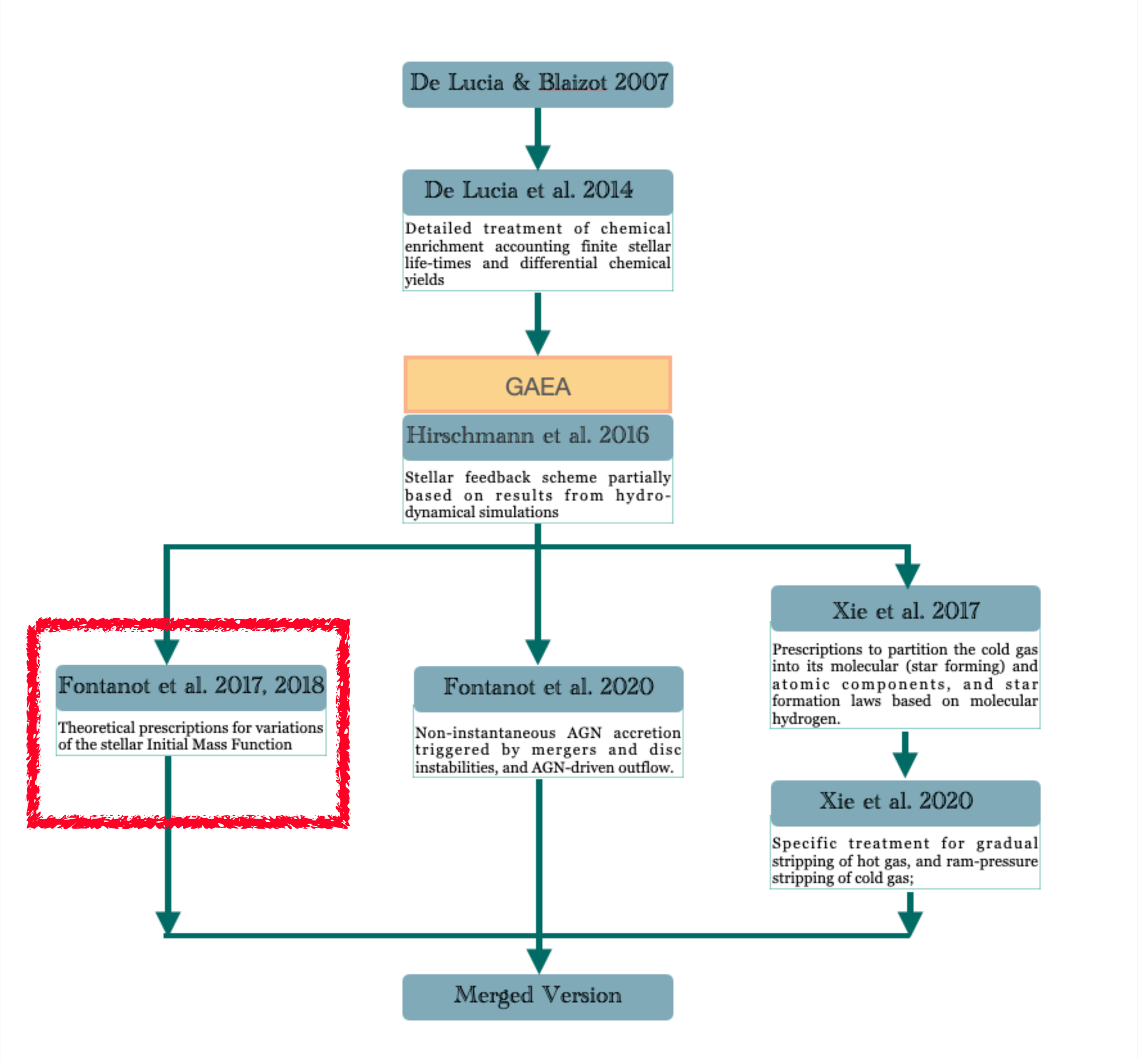


RPS zones: Theoretical deviation for satellites in cluster halos. (from Wang et al. 2020)

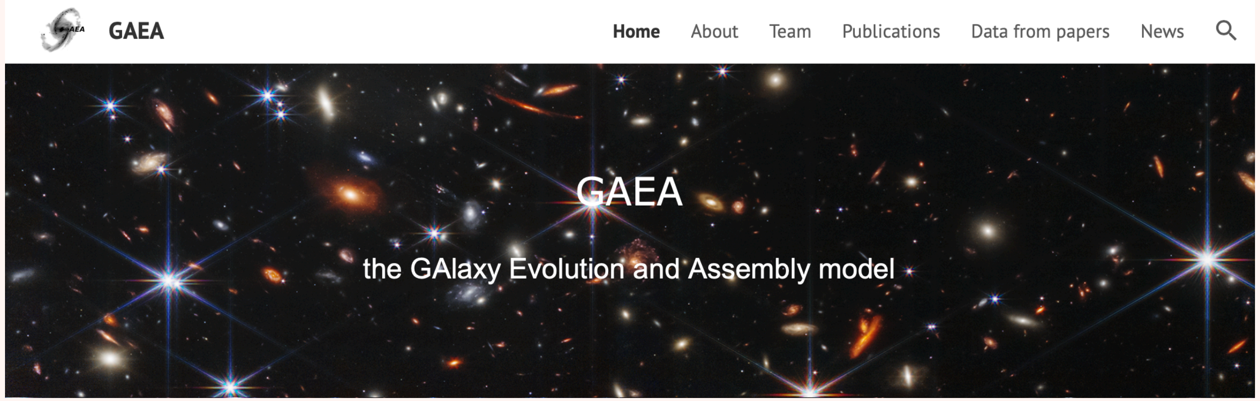
CONCLUSION

- GAEA is implemented with H2-based star formation laws, gradual stripping of hot gas, and ram-pressure stripping of cold gas. The updated version provides good agreement with observed HI, H2 scaling relations, and quenched fractions of central and satellite galaxies, respectively;
- In general, SAM are in better agreement with the observed quenched fraction than hydro-dynamical simulations, however, predict a milder dependence on the halo-centric radius;
- Hydro-simus can reproduce the decreasing trend of HI as a function of decreasing halo-centric radius, as well as the dependence on host halo mass;
- In SAM, galaxies can maintain gas reservoir for a long time after passing the first peri-center.

OUTLINE — GAEA



https://sites.google.com/inaf.it/gaea/



Team members

Gabriella De Lucia

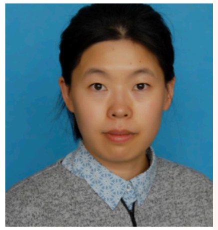
Chemistry, environment, high-z, gas phases.

Fabio Fontanot

IMF, high-z, AGN

Michaela Hirschmann

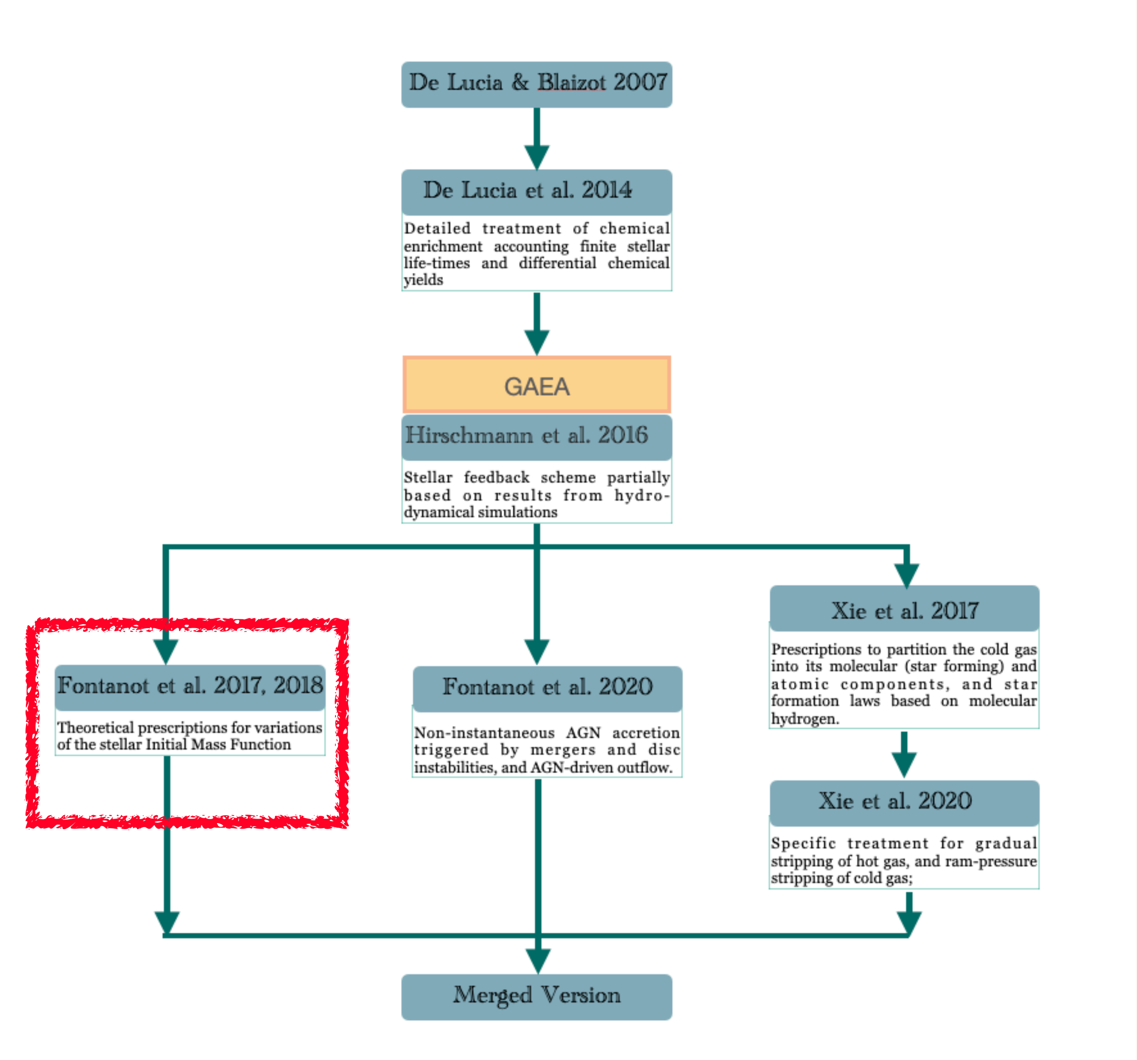
AGN, emission line diagnostics, high-z



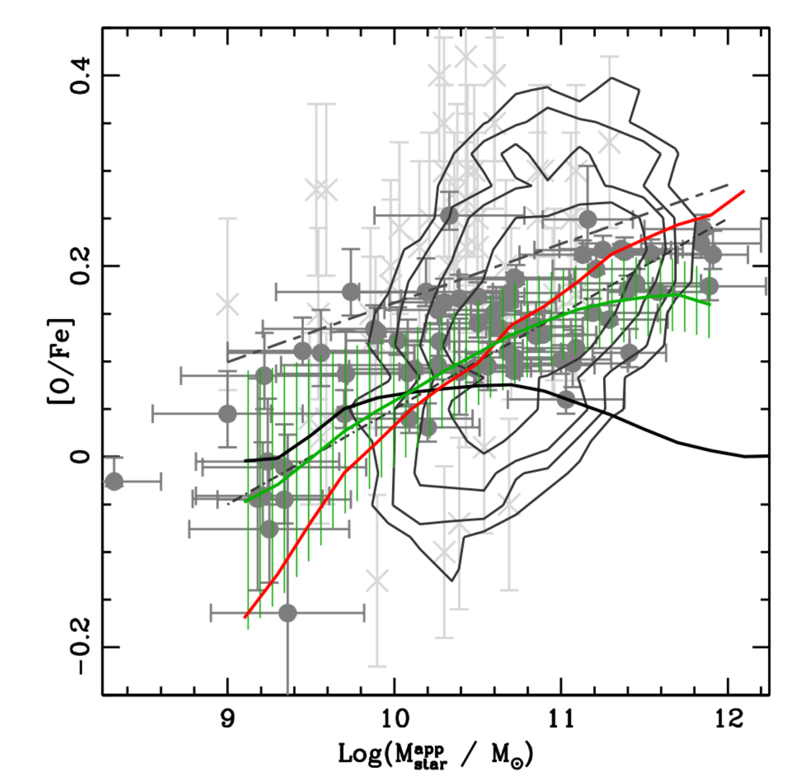
Lizhi Xie

Gas phases, environment

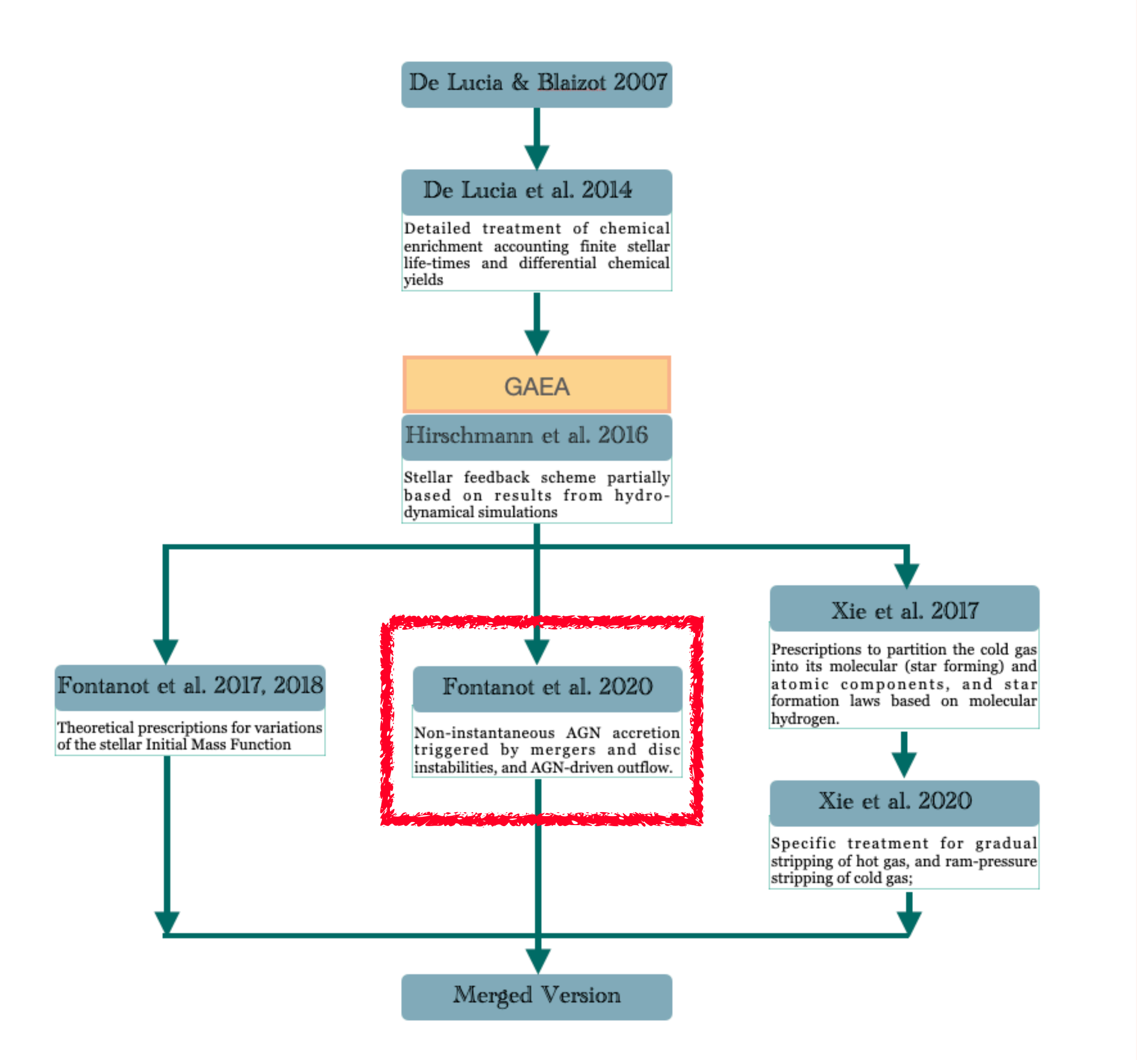
OUTLINE — GAEA



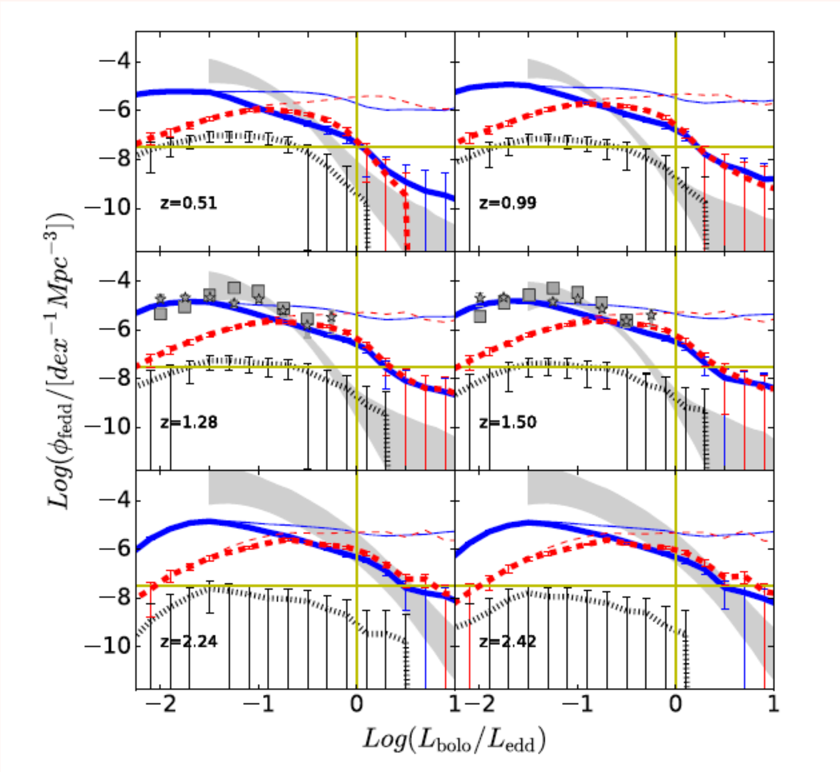
Implement variable IMF



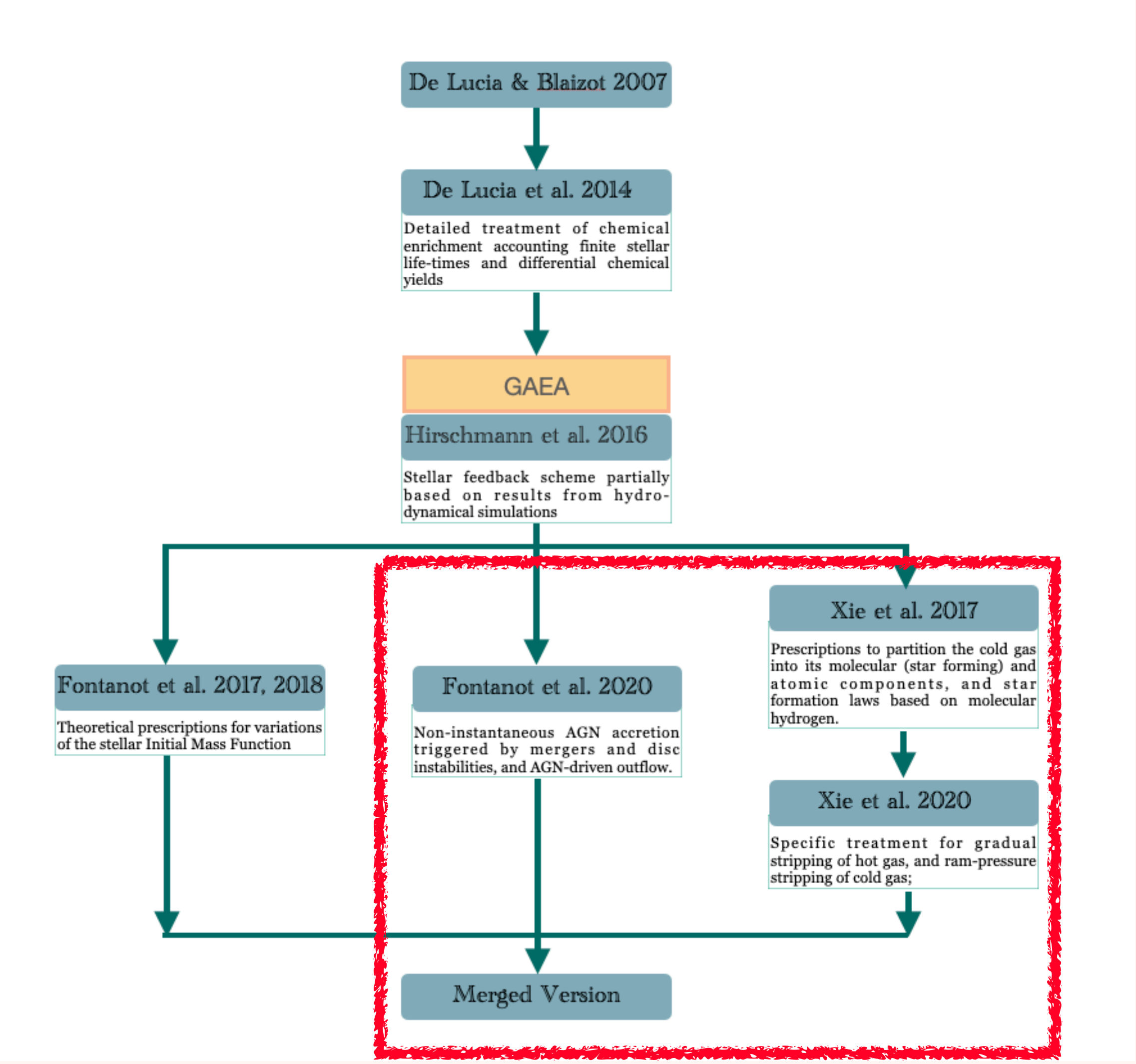
OUTLINE — GAEA



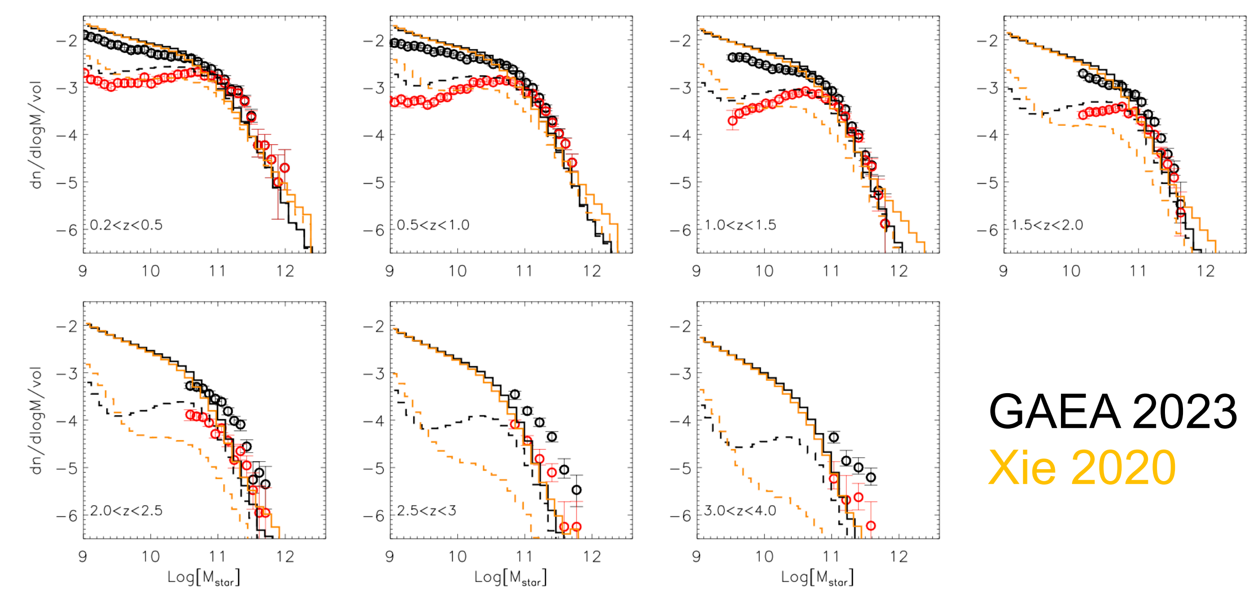
Improve AGN luminosity function



AN UPDATED VERSION OF GAEA

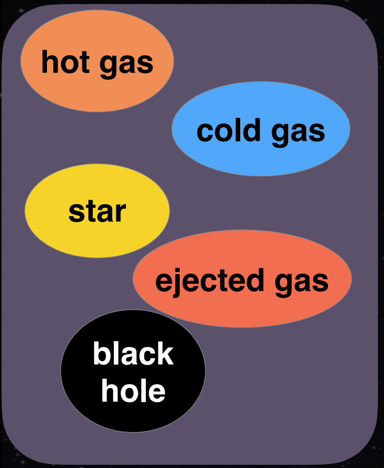


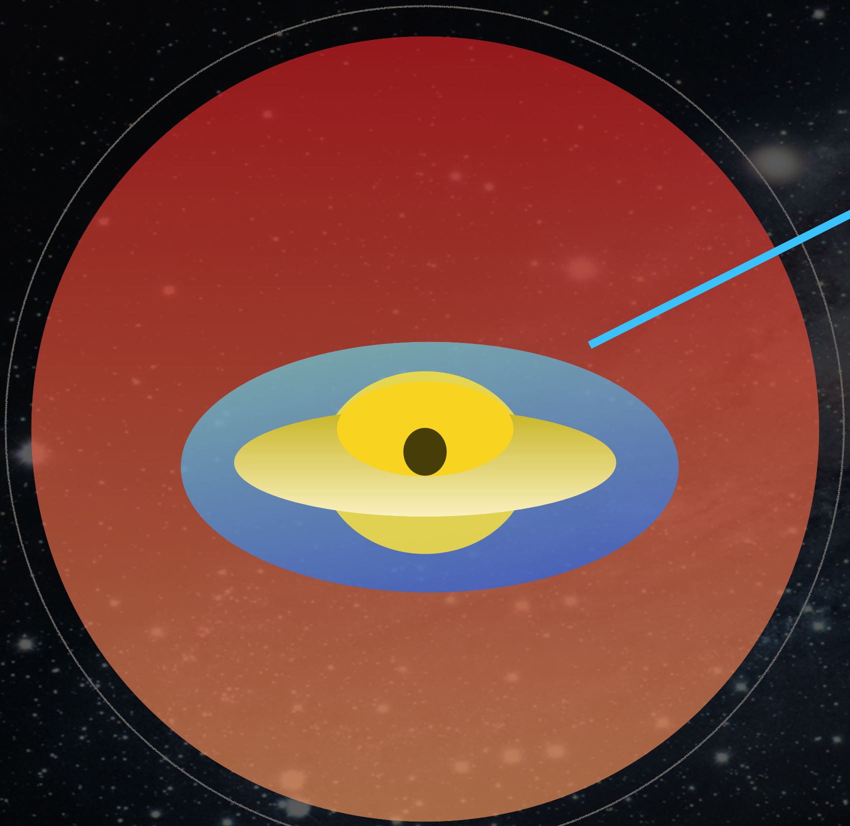
Improve the SMF of quenched galaxies at z > 2

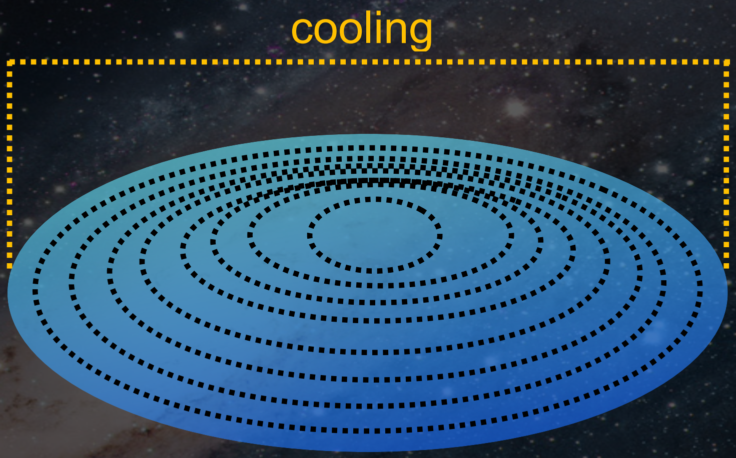


De Lucia in prep.

Gas on the cold gas disk







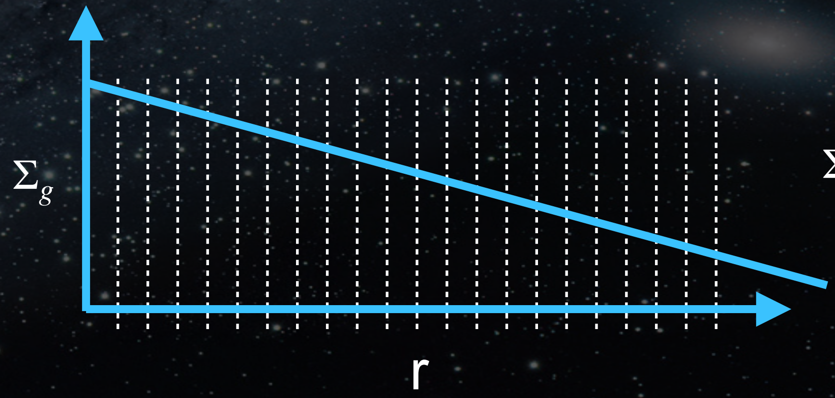
20 annuli, $r_i = [0.2, 10] r_g$

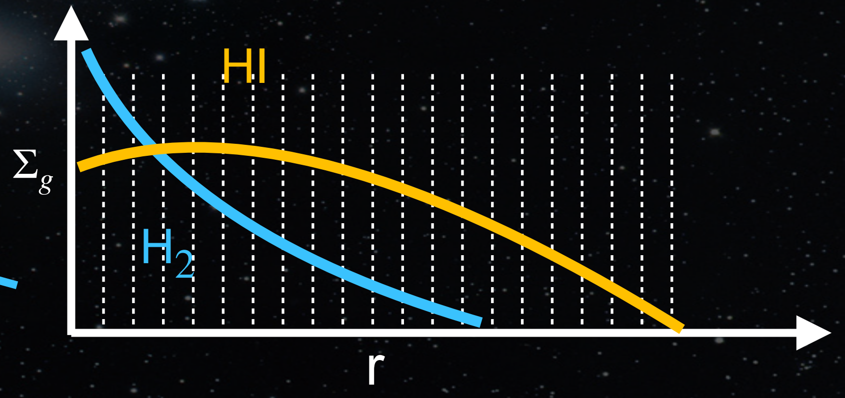
r_g - scale length

$$r_g = \frac{j_g}{2V_{max}}$$

$$\Sigma_{g,i} = \frac{M_g}{2\pi r_g^2} e^{-r_i/r_g}$$

Cold gas density profile
— exponential

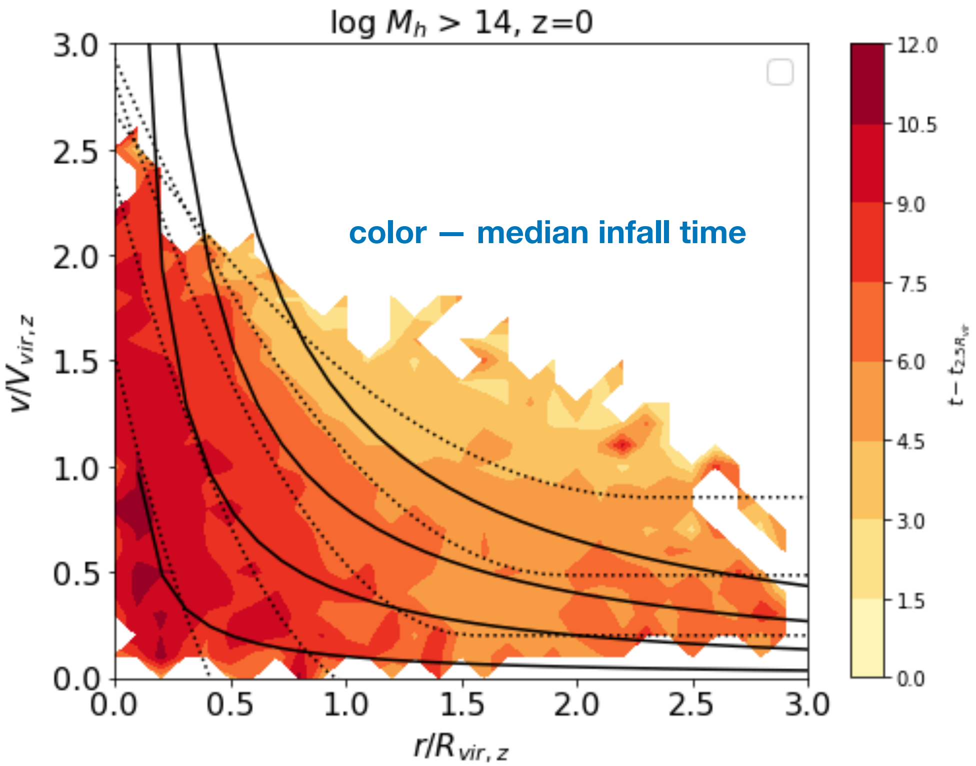


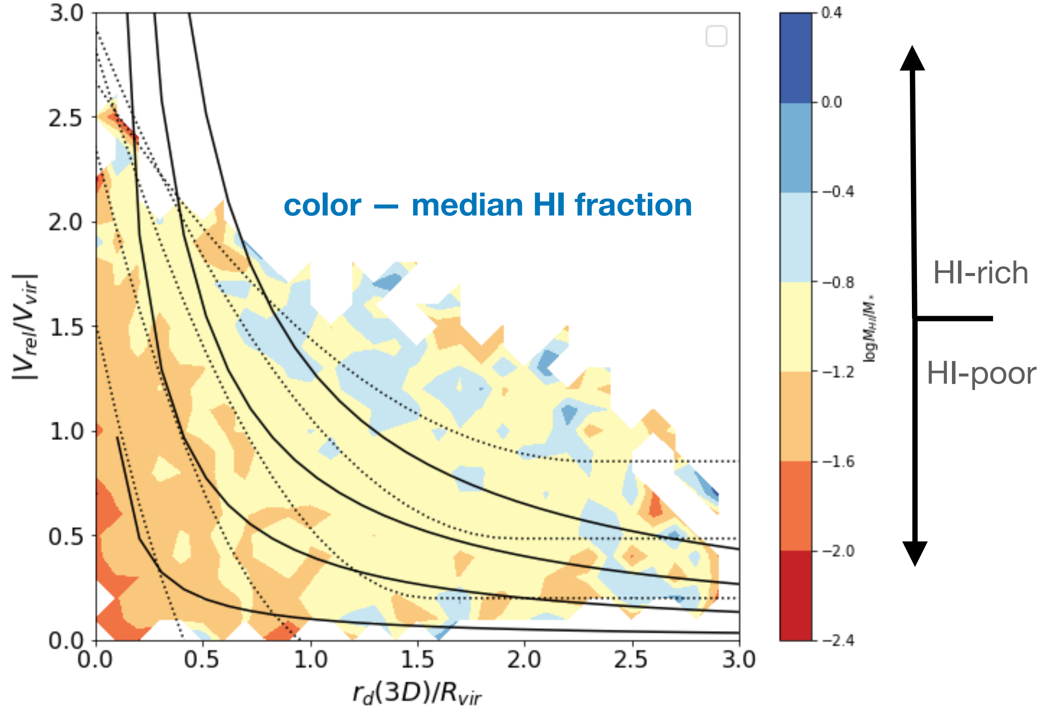


Quench of satellites — Distribution in phase space (3D)

Take HI fraction (/deficiency) as an indicator of infall time?

Xie et al in prep.





Solid curves — caustic profiles

$$\frac{v}{\sigma} \times \frac{r}{R_{vir}} = c$$

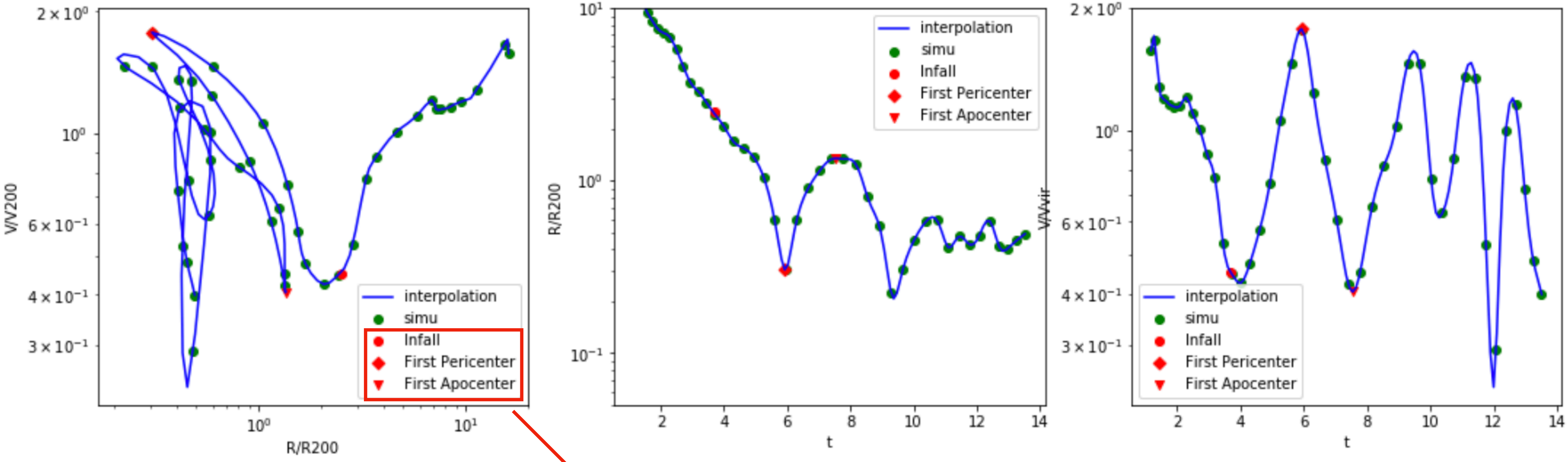
dotted curves — phase space zones in this work:

$$\frac{|\Delta V_{3D}|}{V_{max}} = a\left(\frac{R_{3D}}{R_{vir}}\right)^2 + b\frac{R_{3D}}{R_{vir}} + c \qquad (\ a = -0.018p^3 + 0.28p^2 - 1.74p + 4.27\ )$$

$$(\ b = 0.041p^2 + 0.576p - 5.47\ , \quad c = -0.182p^2 + 1.38p + 0.336)$$

Interpolate orbit — Spline

Infall time — the first time it passes $2.5R_{vir}$



estimated from distances

GAS STRIPPING ALONG INFALLING ORBIT