Merge – Strip – Explode?

A Tale about Galaxy Simulations

Anna Ivleva

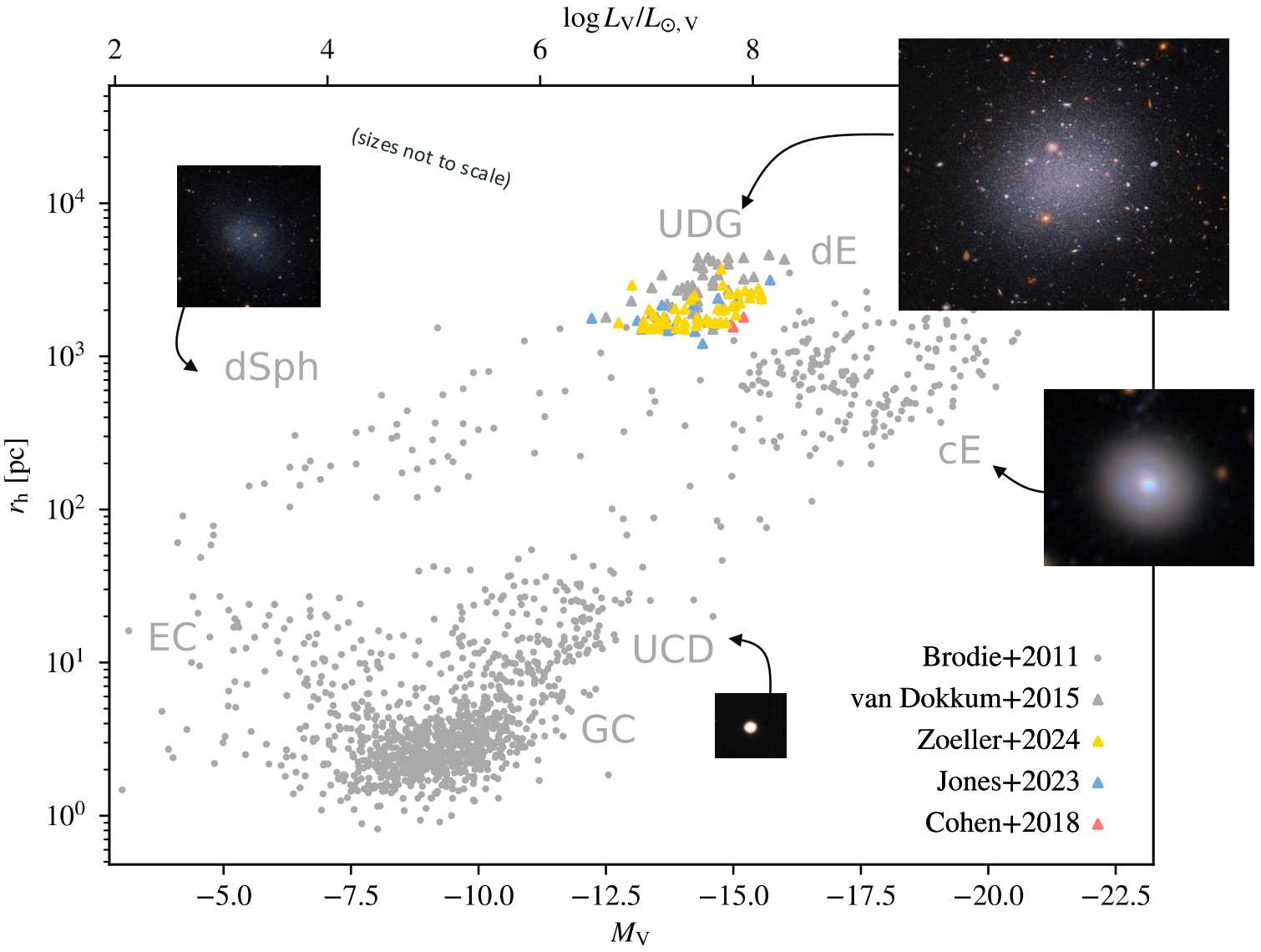
30.07.2024 - OpenGADGET3 User Meeting

Merge – Strip – Explode?

Merge and Strip: dwarf galaxies inside clusters can be formed by galaxy mergers

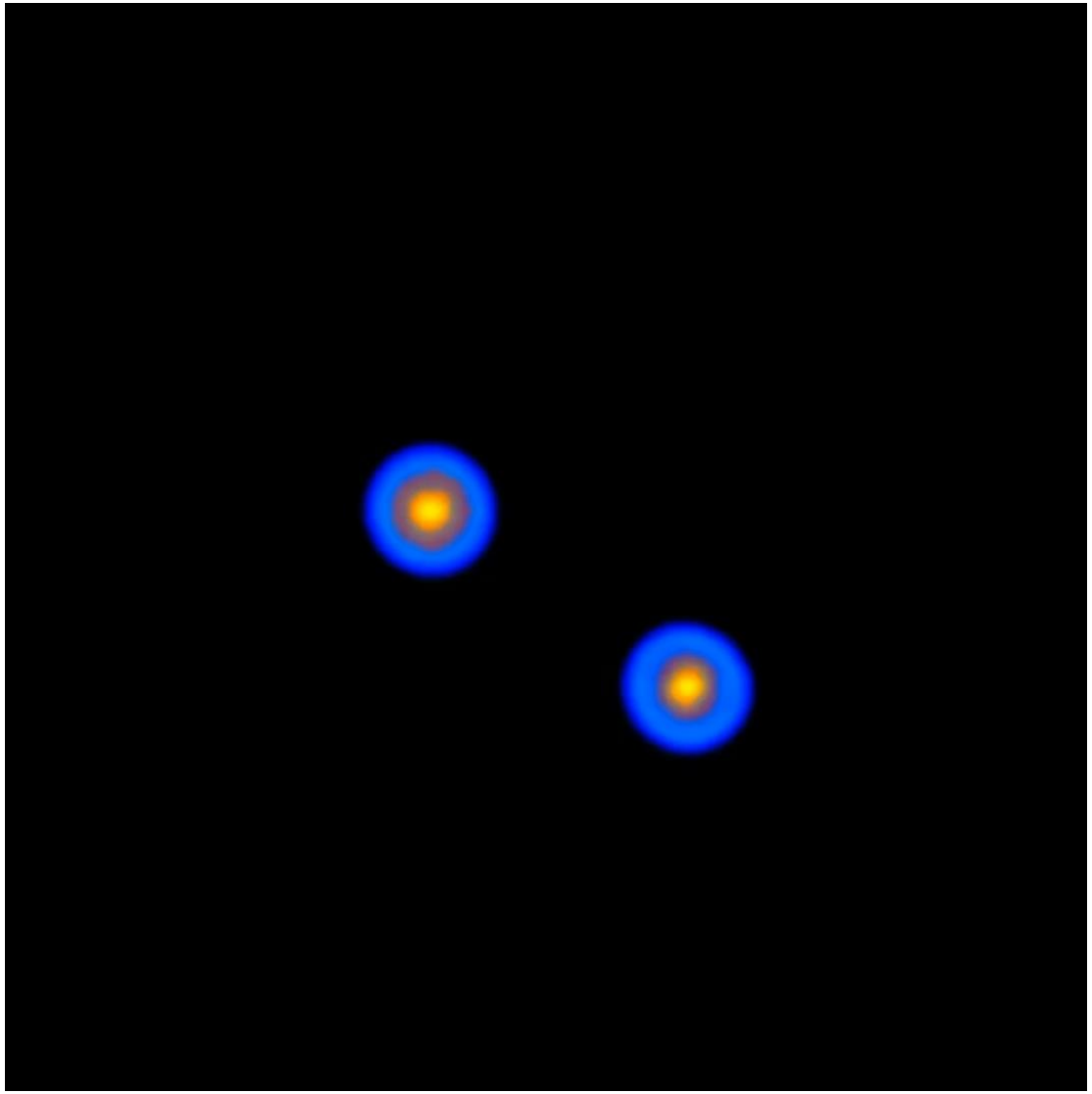
Merge and (hopefully) don't explode: using Stefan's Quintet as a benchmark for galaxy group evolution

Dwarf Galaxies: Out of Sight, But Not Out Of Mind



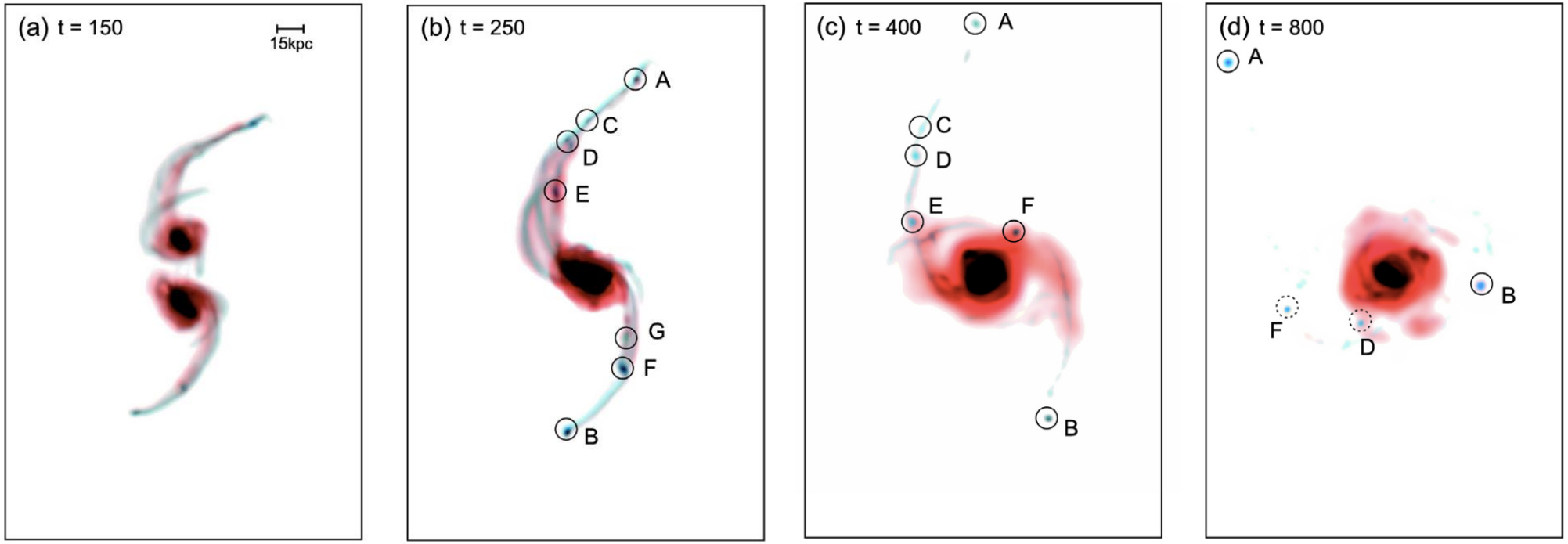
Is a tidal origin possible?

TDGs in Isolated Merger Simulations



Bournaud & Duc, 2006

Tidal dwarf galaxies in isolated merger simulations



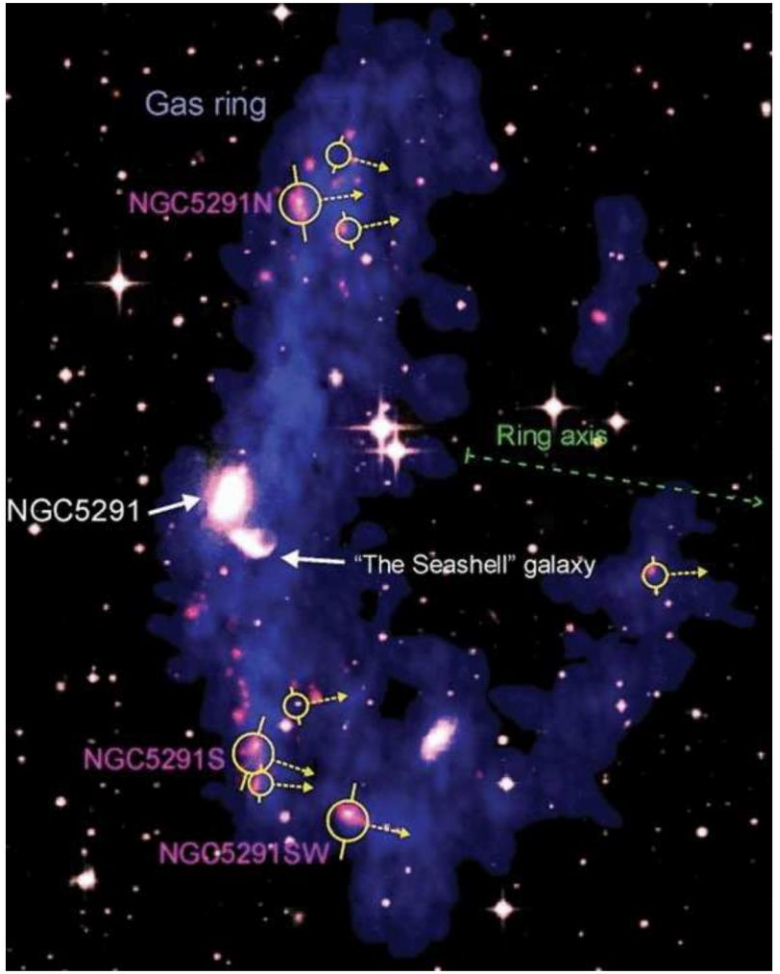
Bournaud & Duc, 2006

Tidal dwarf formation:

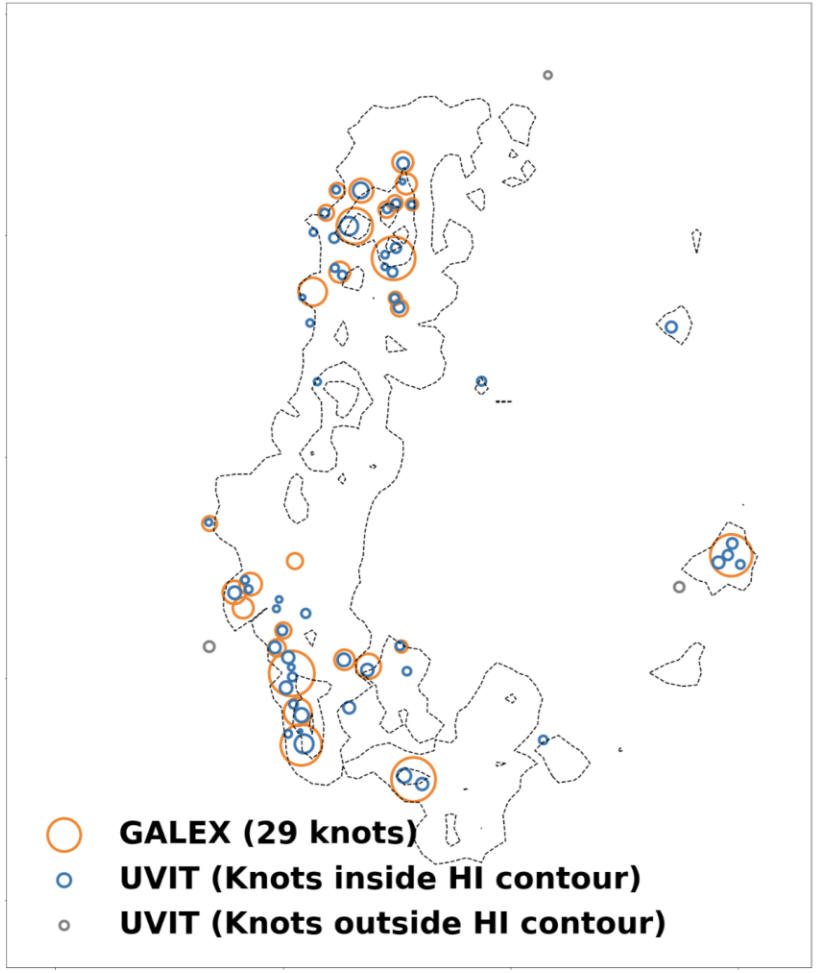
- in galaxy potential outskirts → dark matter-poor
- out of pre-enriched gas → metal-rich?

TDGs in Observations: NGC5291 + Seashell

optical ©ESO



UV (GALEX) **+ HI** (VLA) **+ opt.** Bournaud et al., 2004



Rakhi et al., 2023

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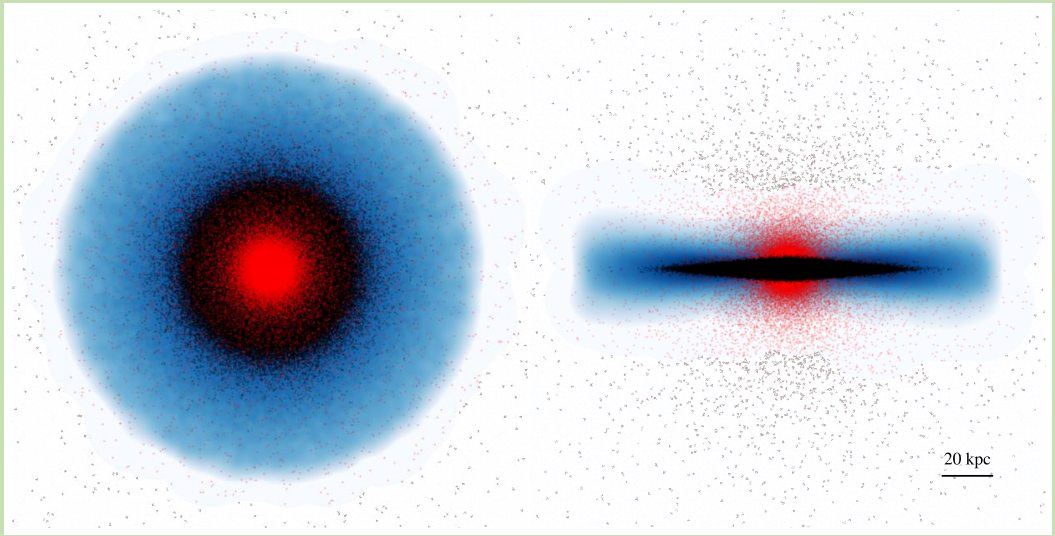
Constructing Initial Conditions: the building blocks

Late Type Galaxies (Springel et al., 2005)



Cold gas, stellar disk, stellar bulge (& dark matter halo)

Exponential Profile

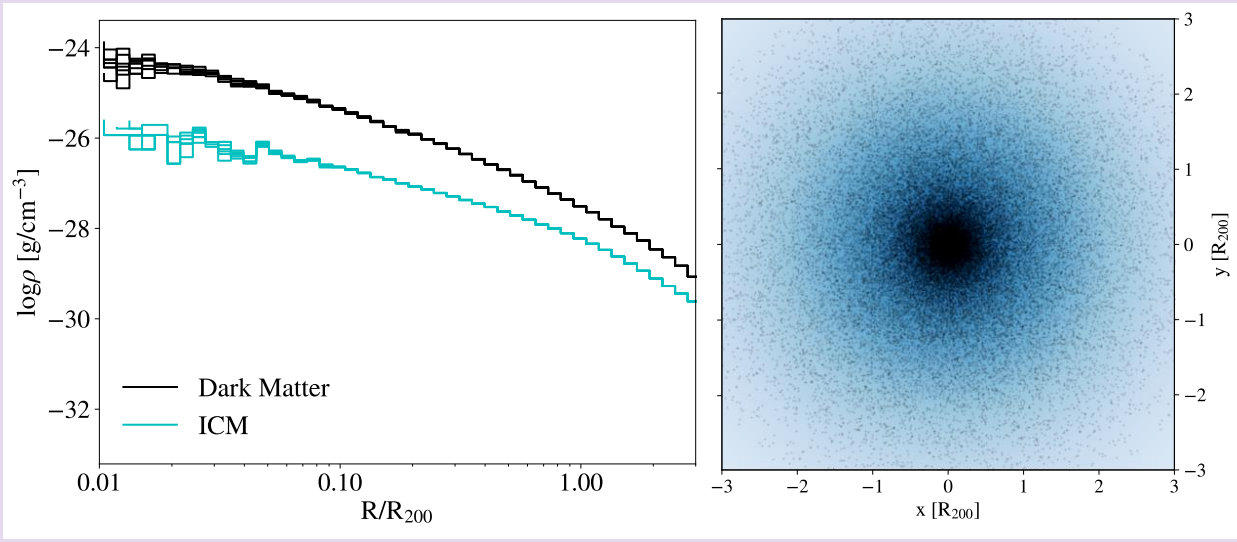
$$\Sigma(r) \propto \exp\left(-\frac{r}{l_i}\right)$$

Hernquist Profile

$$\rho(r) \propto \frac{1}{r(r+a)^3}$$

$f_{\rm gas} = 0.5$ (gas rich), $l_{\rm gas} = 2\, l_{*\rm disk}$ (extended HI disk)

Galaxy Clusters (Donnert, 2014)



Dark matter halo & Hot intracluster gas

(Hernquist profile)

Beta-Profile

$$\rho_{\rm ICM} = \rho_0 \left(1 + \frac{r^2}{r_c^2}\right)^{-3\beta/2}$$

$f_{\rm baryon} = 0.14$, $\beta = 2/3$ (Masopietro & Burkert, 2008)

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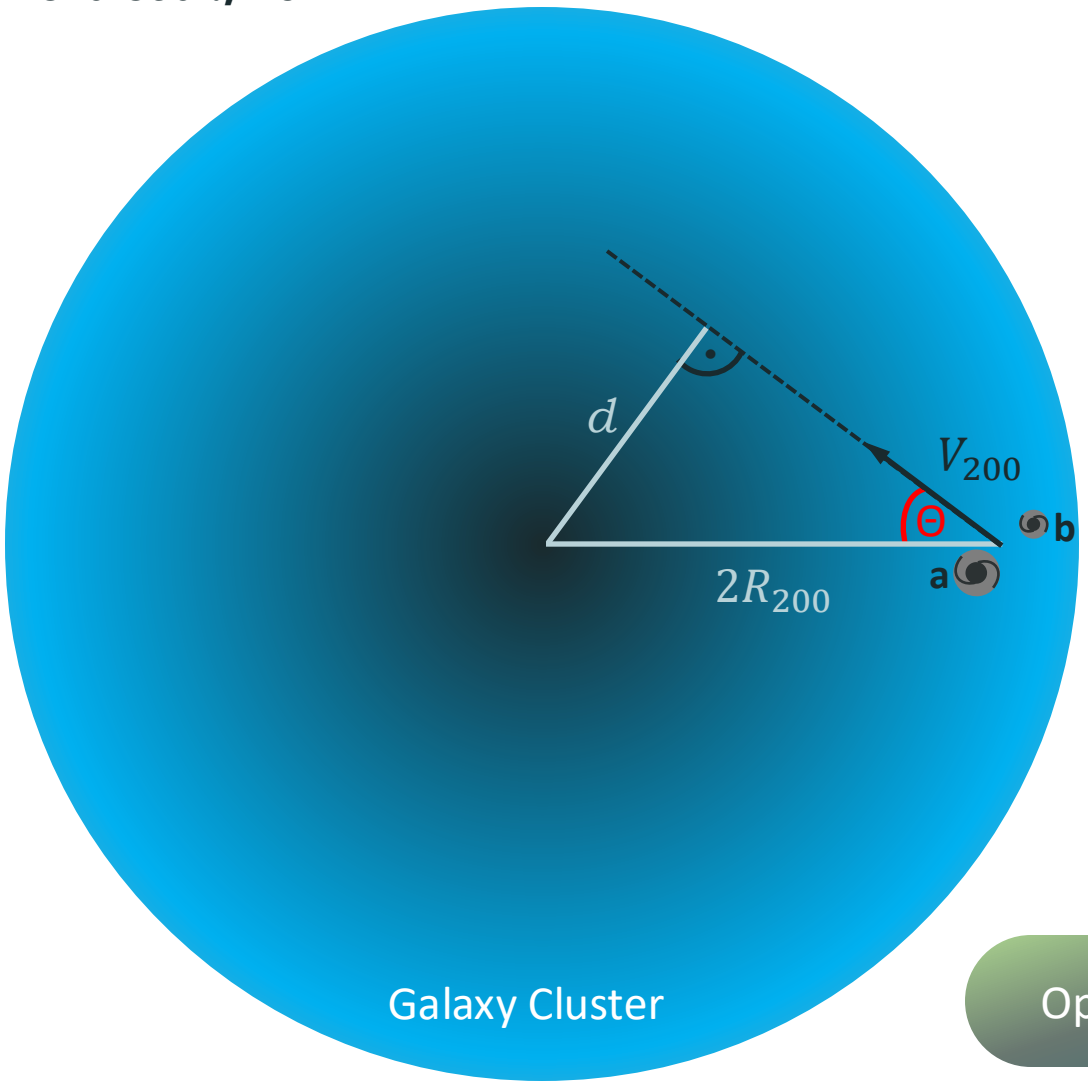
Constructing Initial Conditions: the dynamical setup

Ivleva et al., 2024



Variation of infall angle only
difference between setups

Config.	Impact angle Θ	Impact parameter d [Mpc]
C0	0°	0
C25	25°	0.8
C45	45°	1.3

Object	M_{200} [10^{11} $M_\odot$]	R_{200} [kpc]
Galaxy a	9.5	203
Galaxy b	4.8	161
Cluster	1000.0	957

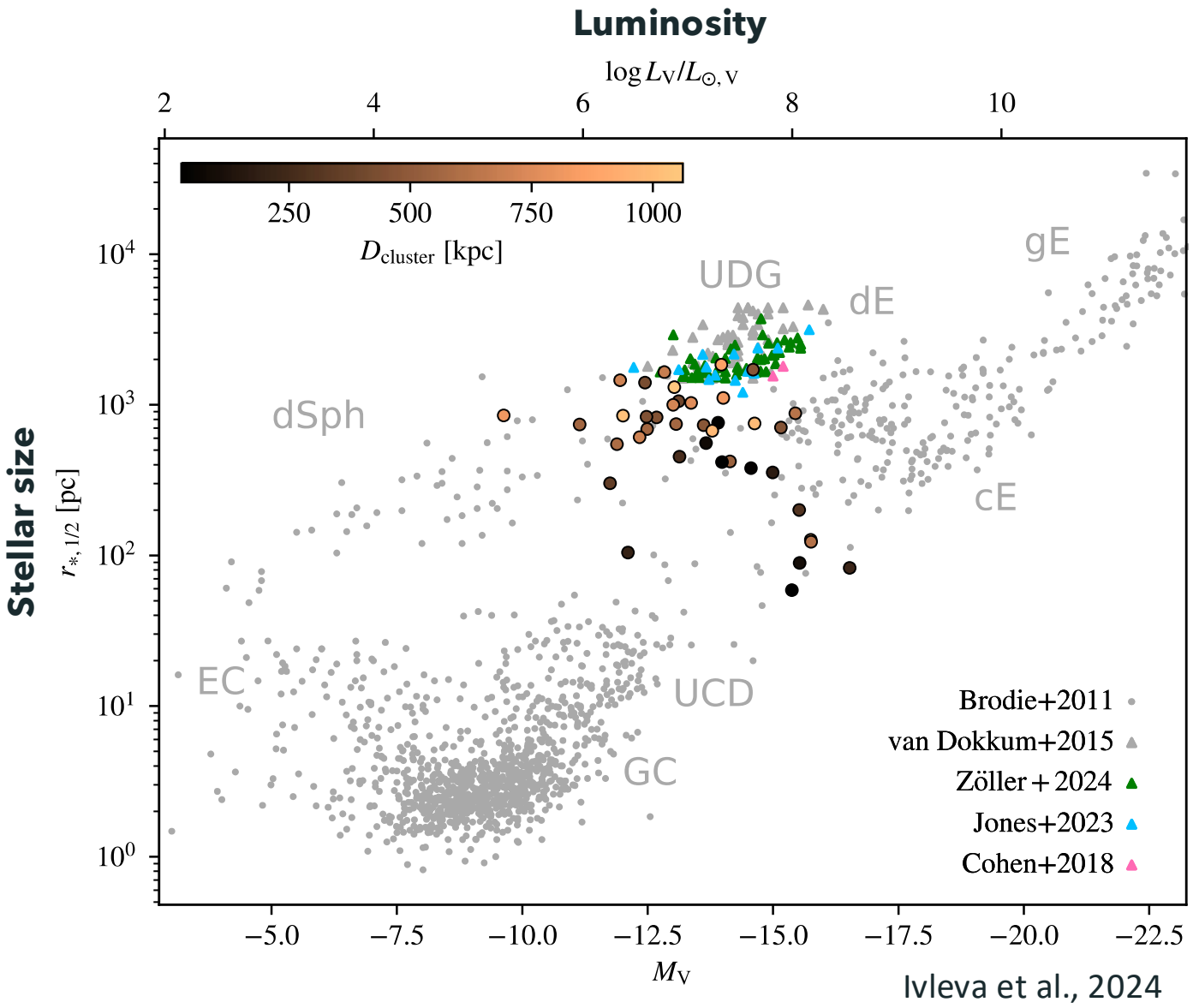
$$m_{\rm dm} = 3.2 \times 10^6 \ M_\odot \qquad m_{\rm bar} = 6.5 \times 10^5 \ M_\odot$$

OpenGadget3

For all baryonic particles, including ICM!


Ivleva et al., 2024
t=1420 Myr
ram pressure

The Zoo of TDGs



Ivleva et al., 2024

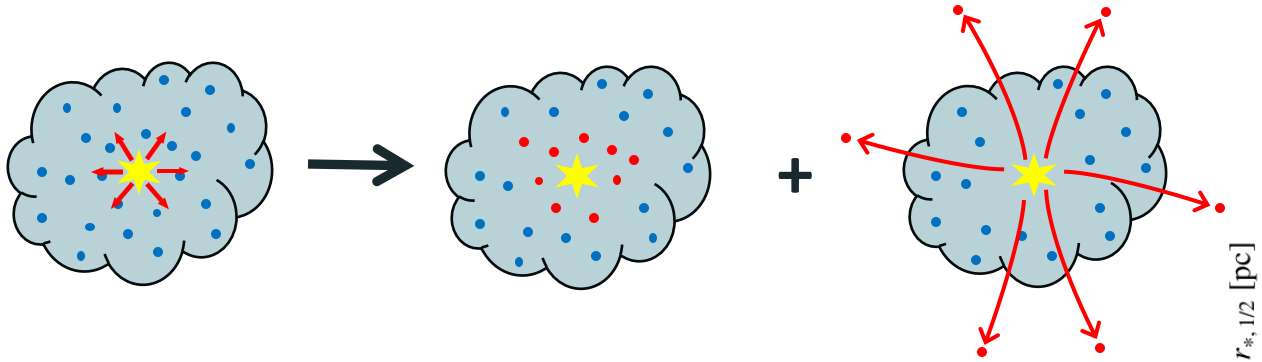
- Simulated tidal dwarfs cover wide range of observed low-mass galaxies
- **Dwarf size** correlates with **cluster distance!**

Feedback Shaping Dwarf Galaxies

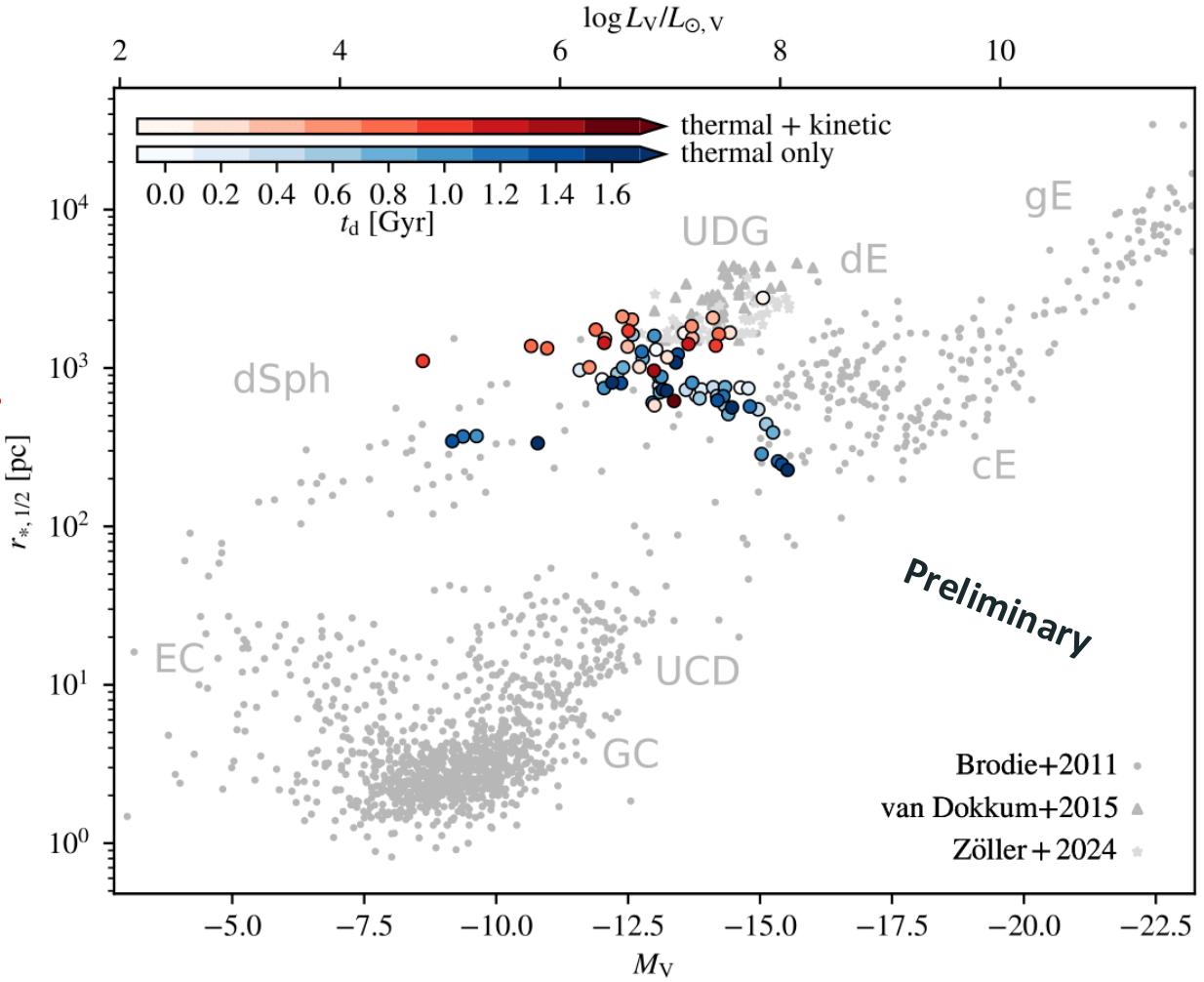
Springel & Hernquist (2003)

thermal feedback (= heating)

kinetic feedback (= stellar winds)



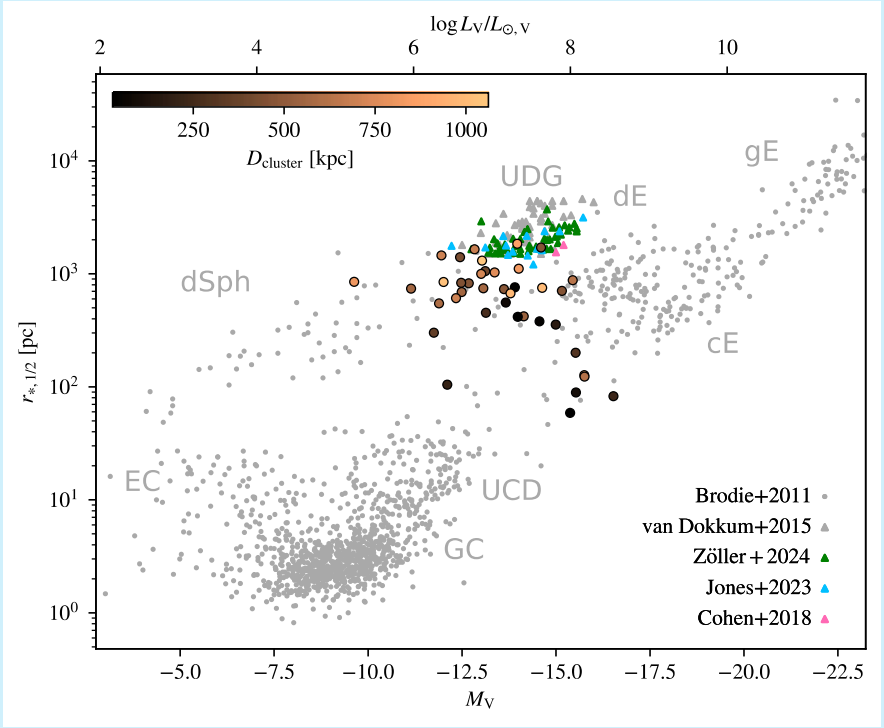
Strong feedback is promoting the formation of diffuse dwarfs!

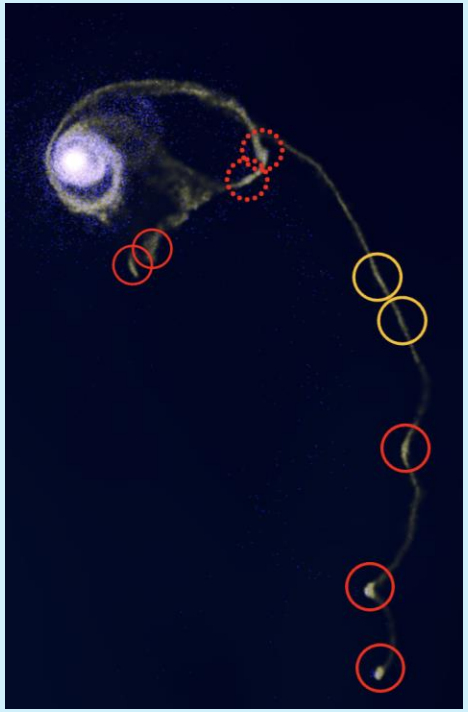


Ivleva et al. (a) in prep

Tidal dwarf galaxies inside galaxy clusters: short summary

- **Stripping of tidal dwarf galaxies** can produce a large variety of different dwarf types **lacking dark matter** inside galaxy clusters.
- **Strong stellar feedback** is particularly promoting the formation **(ultra-) diffuse galaxies**.






Next: MHD!

The well observed Stefan's Quintet

What is driving this massive shock? Let's simulate!

Image credit: CFHT + Chandra

optical + X-Ray

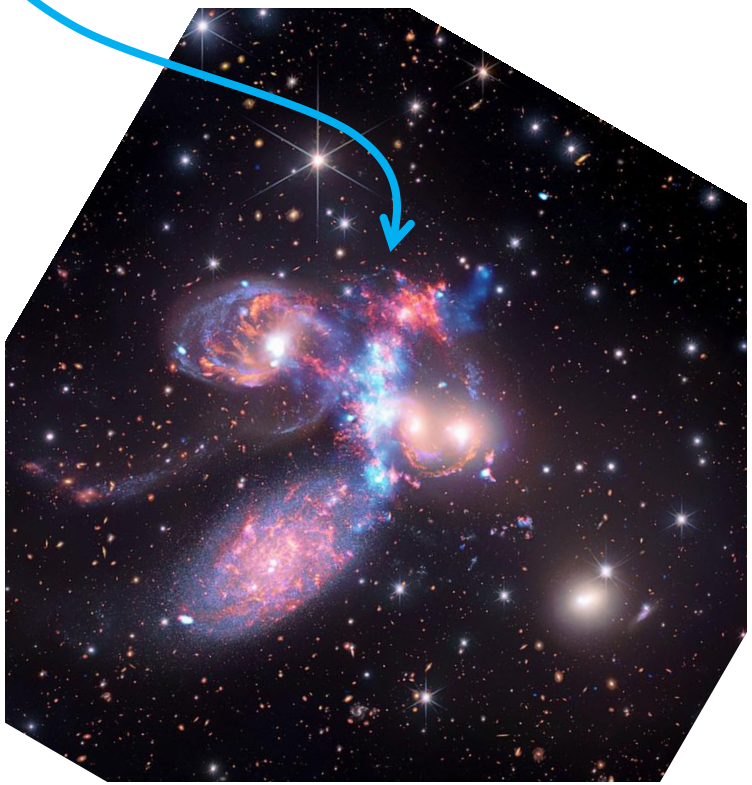
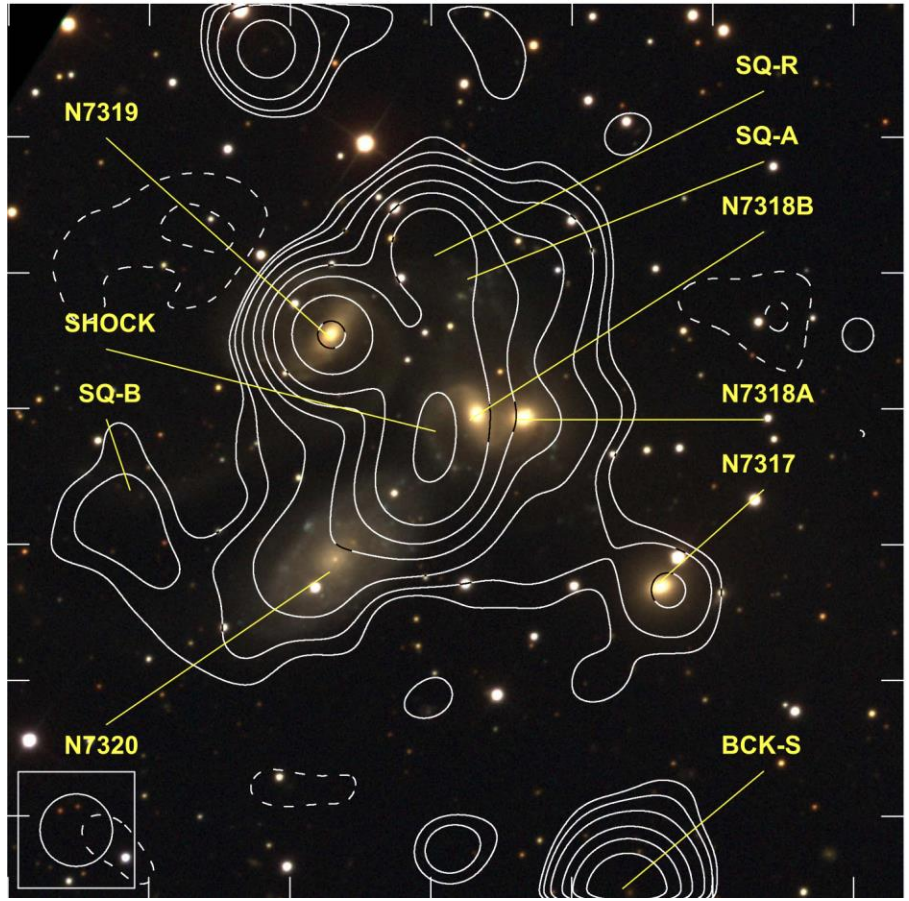


Image credit: JWST + Chandra

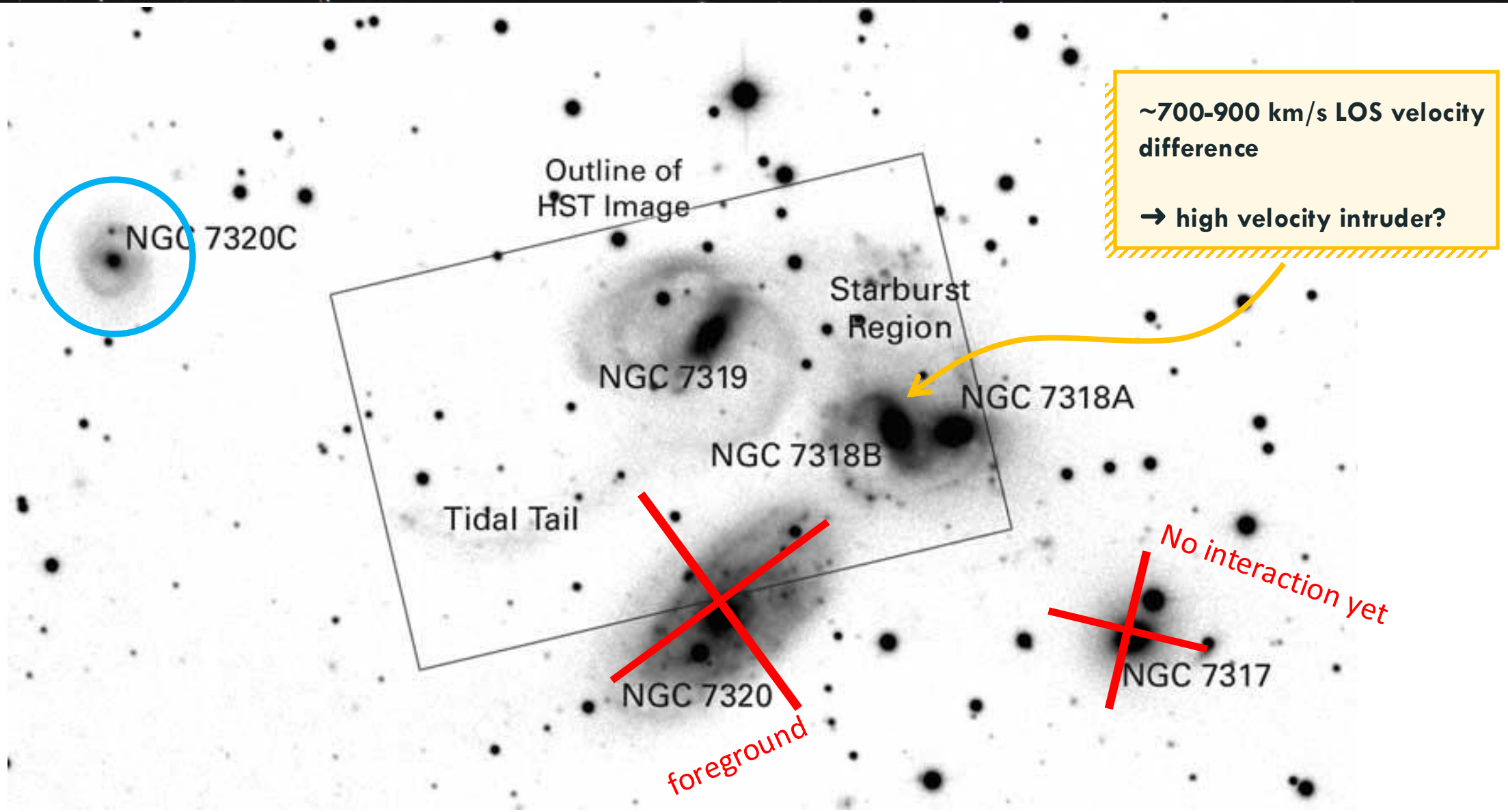
infrared + X-Ray



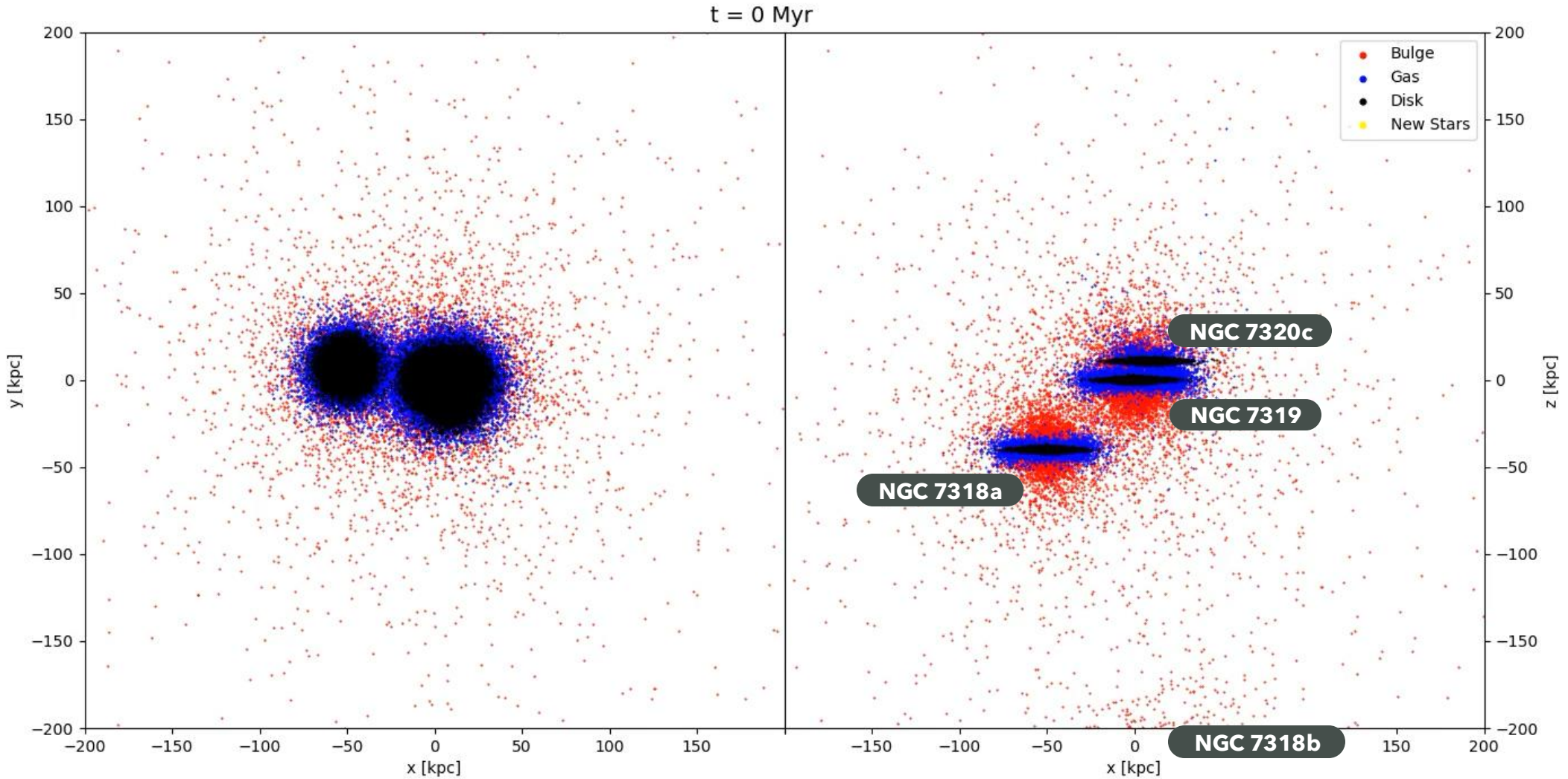
Wroczyński et al., 2020

Radio

Stefan's ~~Quintet~~ Quartet (dynamically speaking)



IC Model by *Hwang et al. (2012)* & *Geng et al. (2012)*



+ hot ambient IGM with constant density (not included in reproduction)

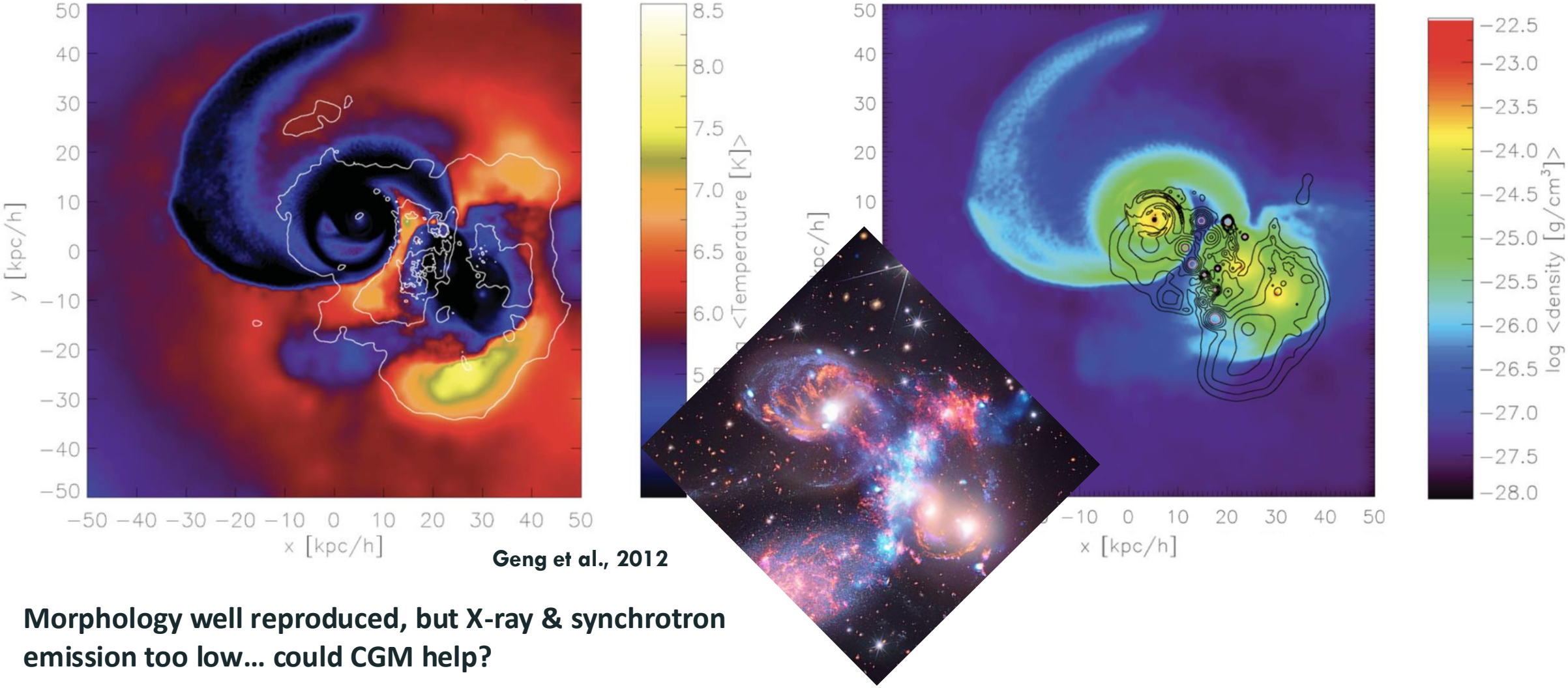
movie by Anna Ivleva

IC Model by *Hwang et al. (2012)* & *Geng et al. (2012)*

synthetic maps

X-ray

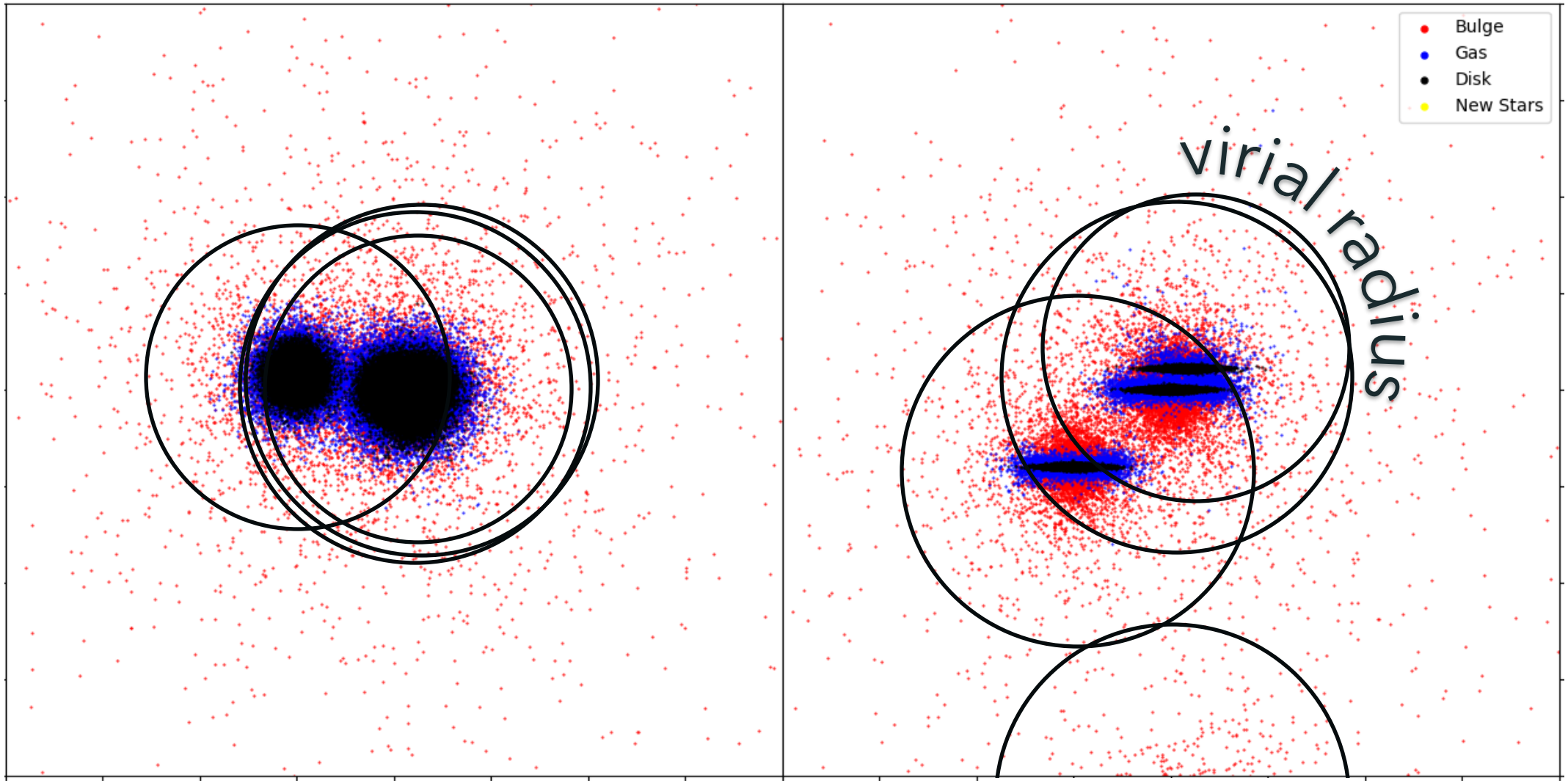
Radio



Geng et al., 2012

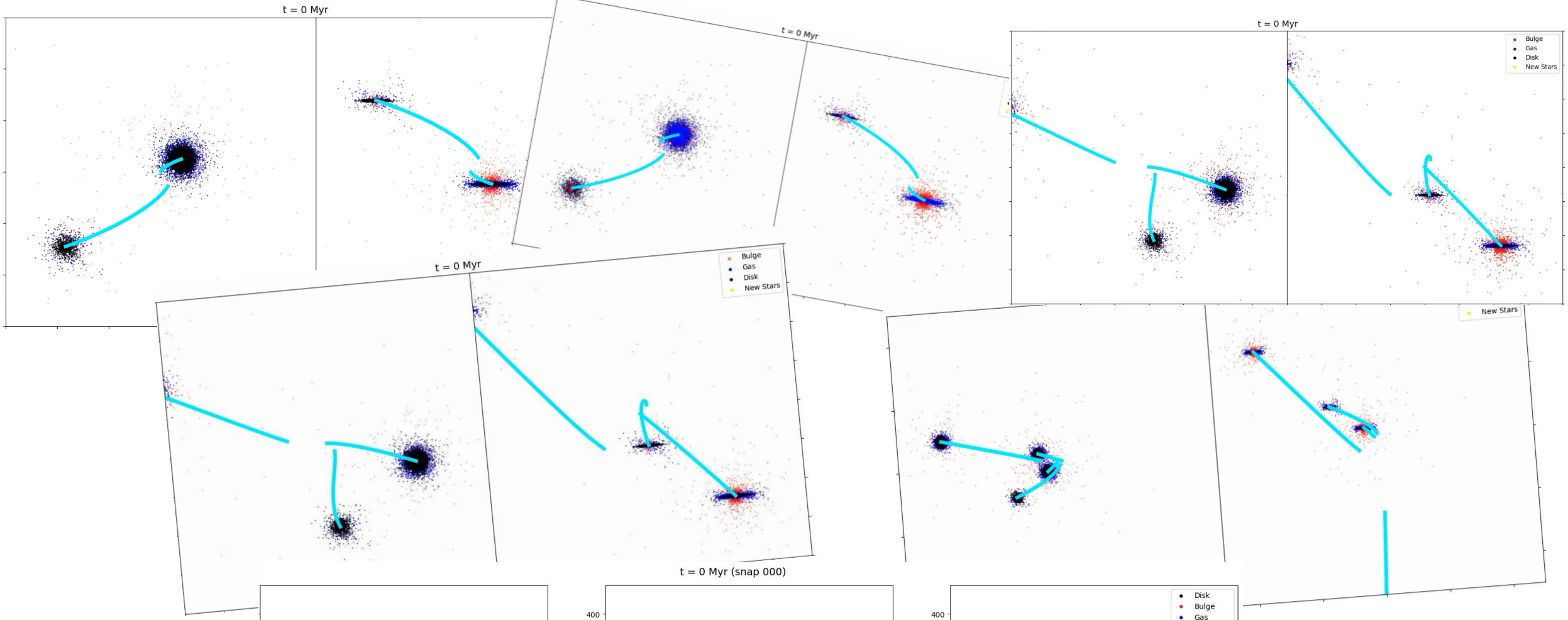
Morphology well reproduced, but X-ray & synchrotron emission too low… could CGM help?

IC Model by *Hwang et al. (2012)* & *Geng et al. (2012)*

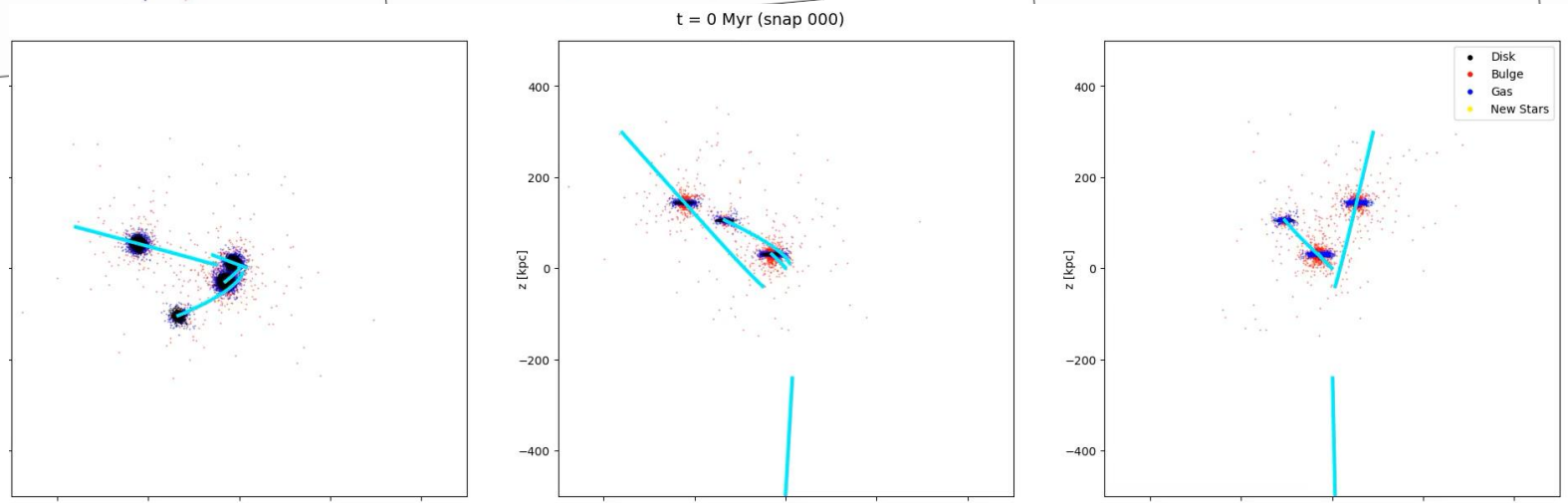


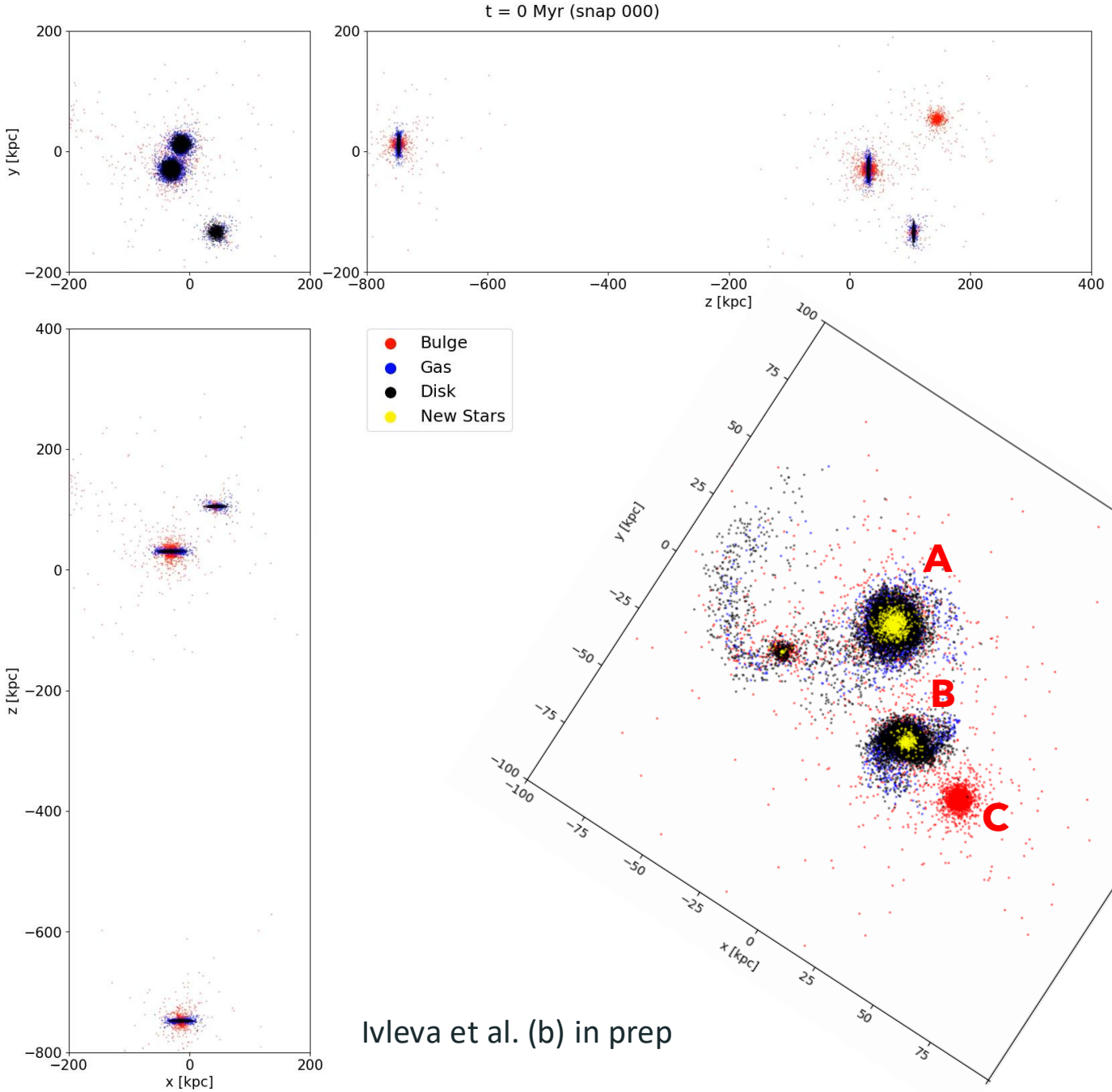
Current IC is very late stage of merger ➜ Implementation of CGM not possible. We need to go backwards…

simulation + movies by Anna Ivleva

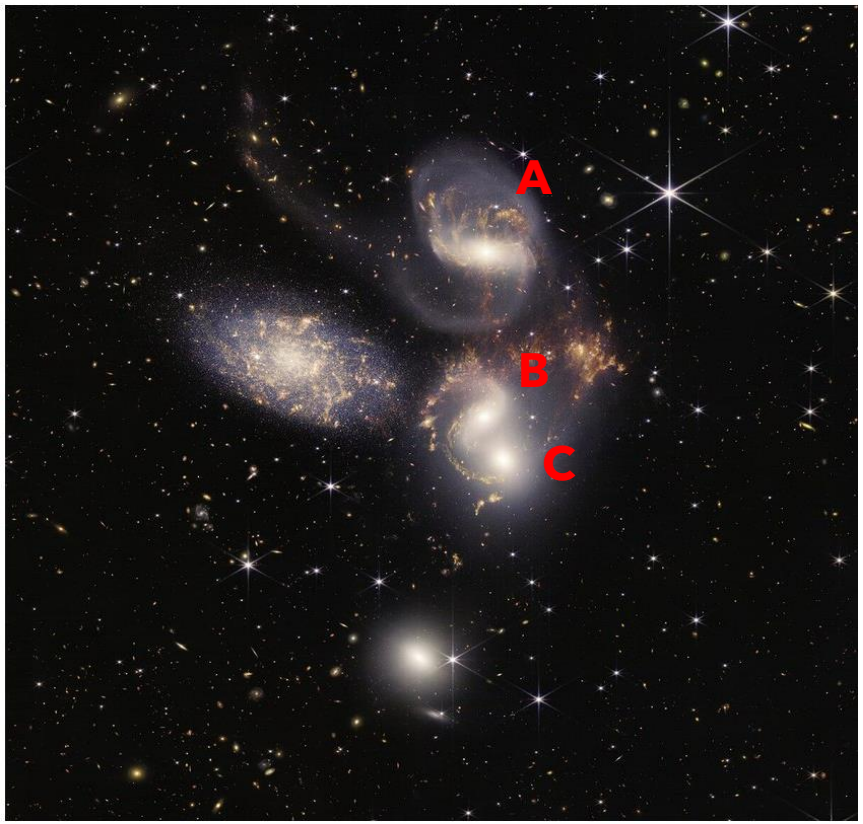


To show a few…





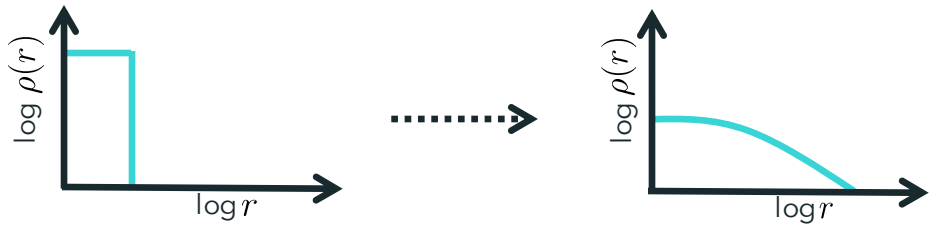
Preliminary "best fit" dynamical model

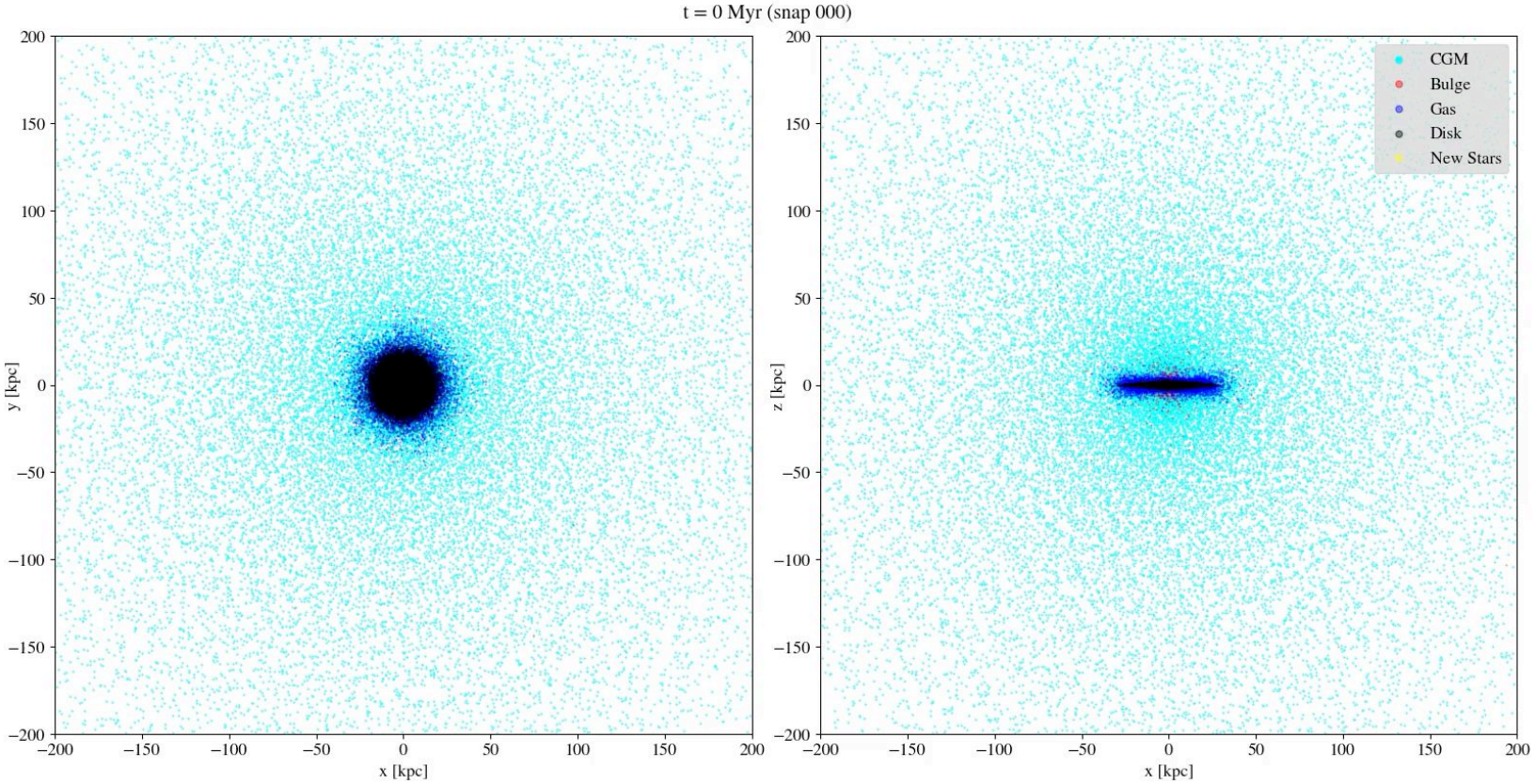


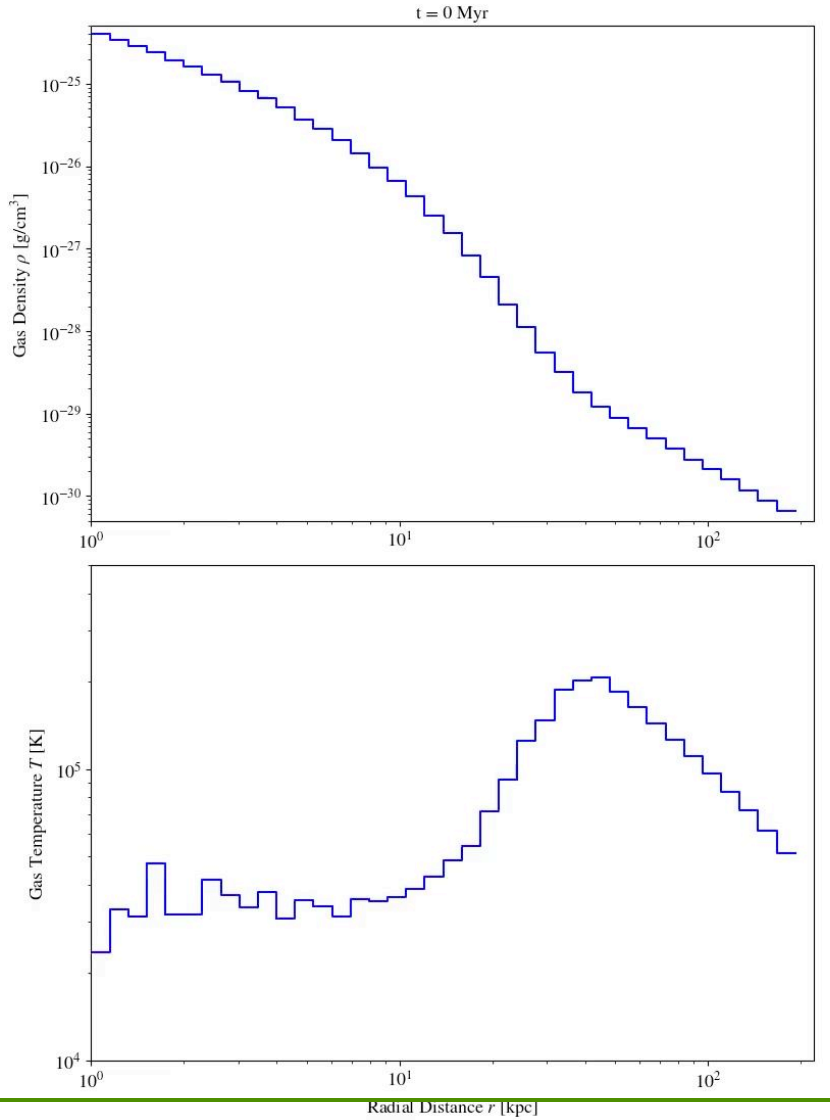
Ivleva et al. (b) in prep

Sanity Check: sampled β-profile for CGM is stable

Resampling =

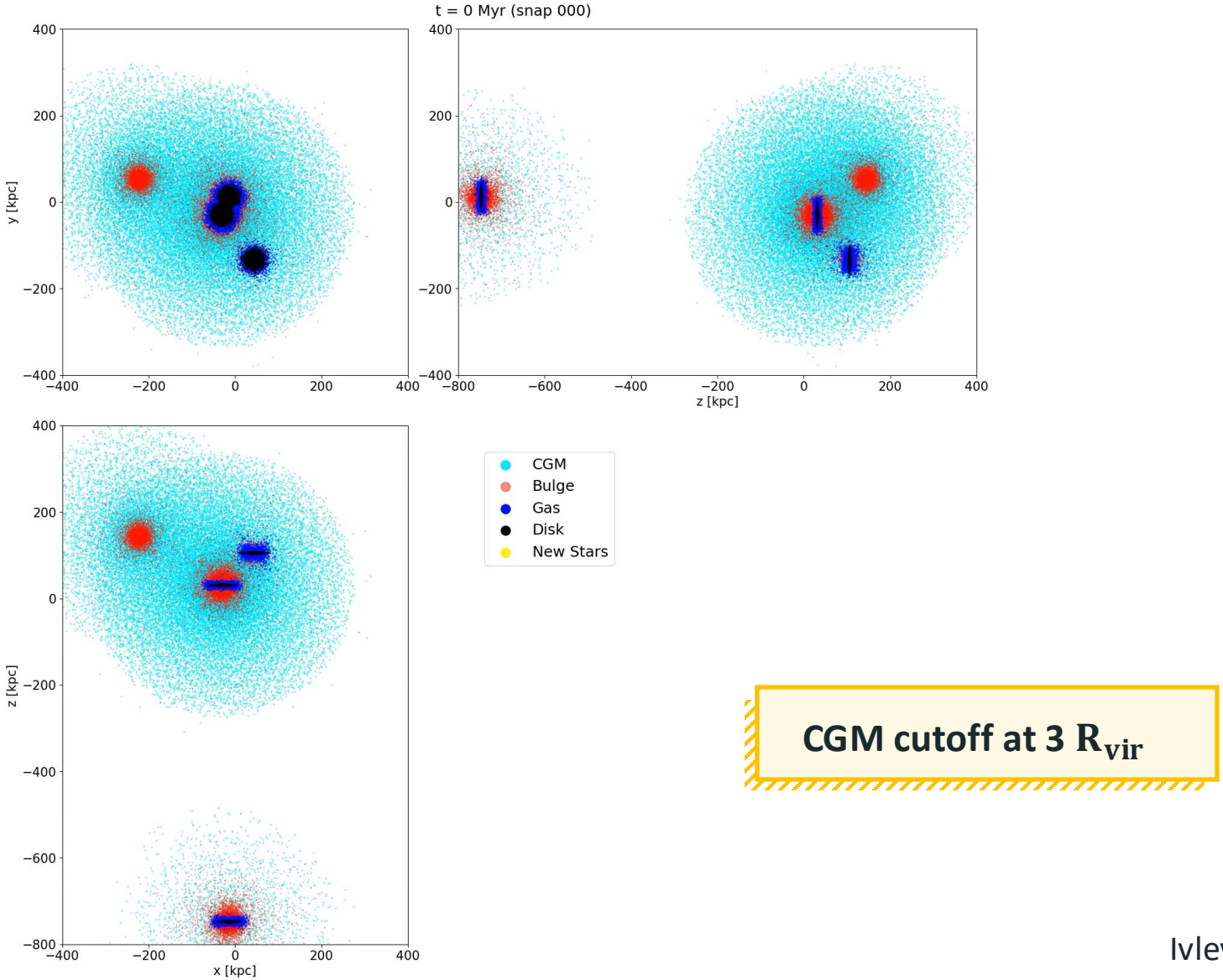






Ivleva et al. (b) in prep

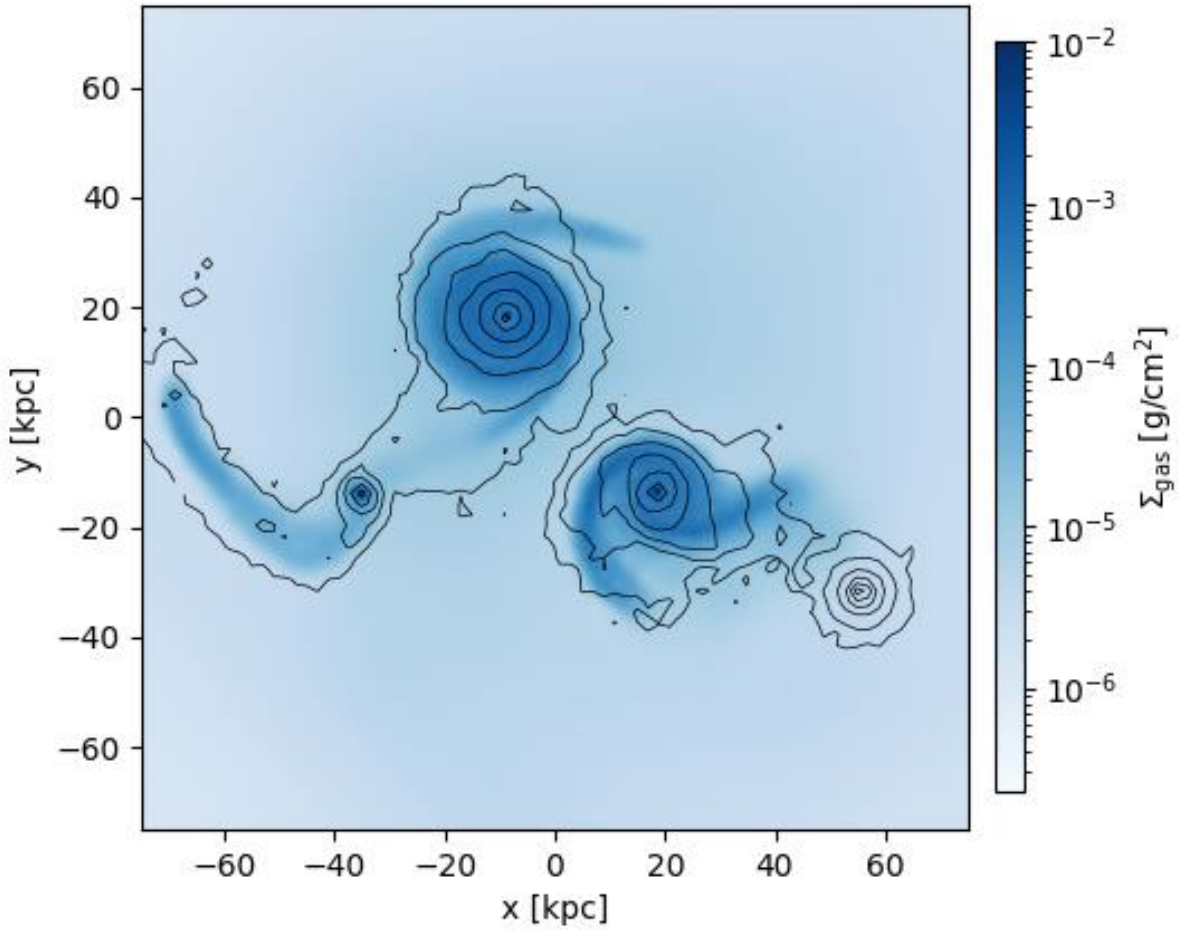
Stefan's Quintet with CGM

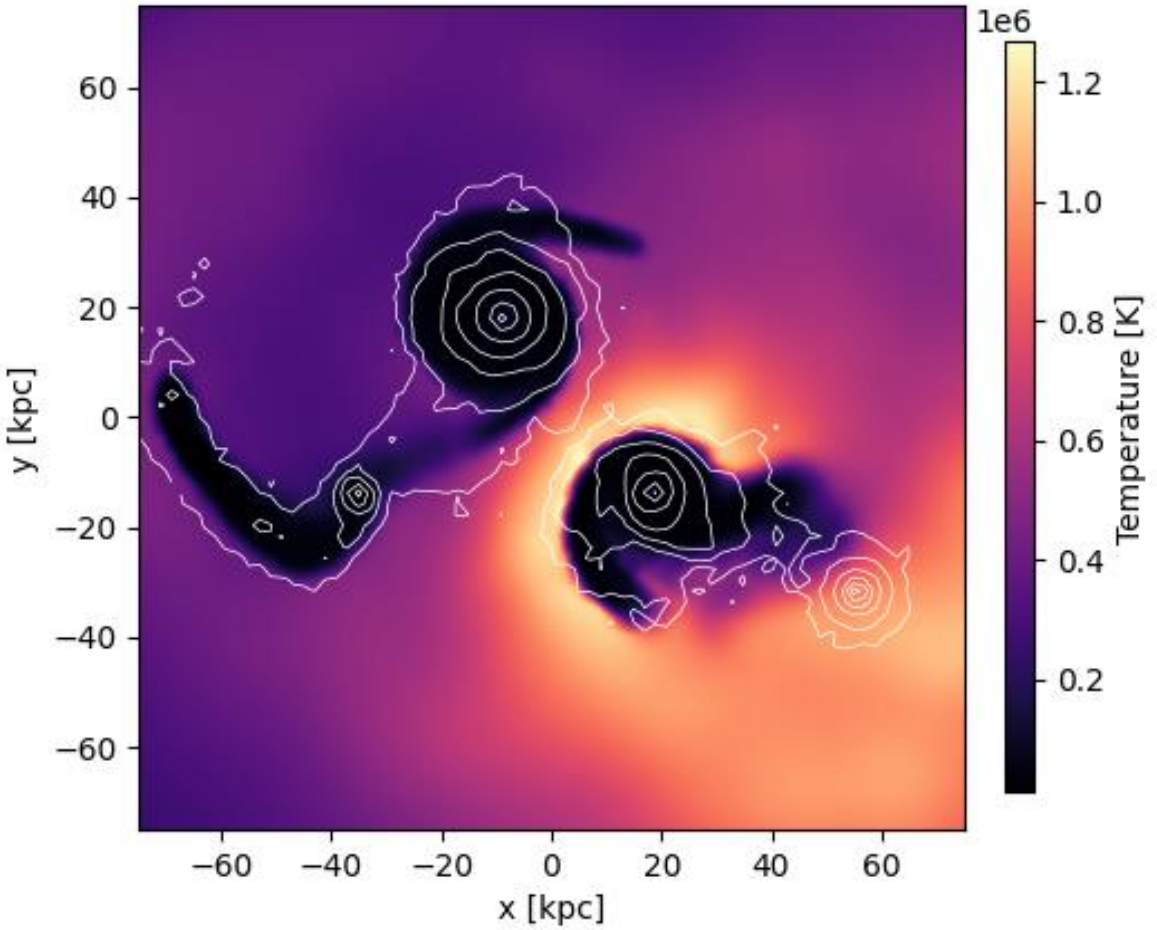


CGM cutoff at 3 R_{vir}

Ivleva et al. (b) in prep.

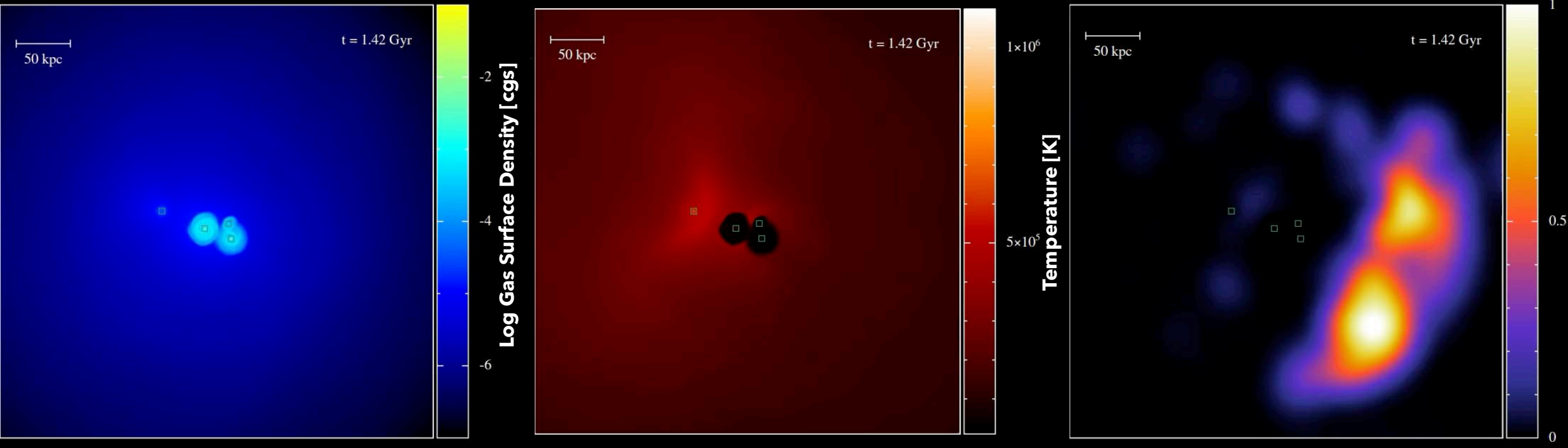
Evolution in maps





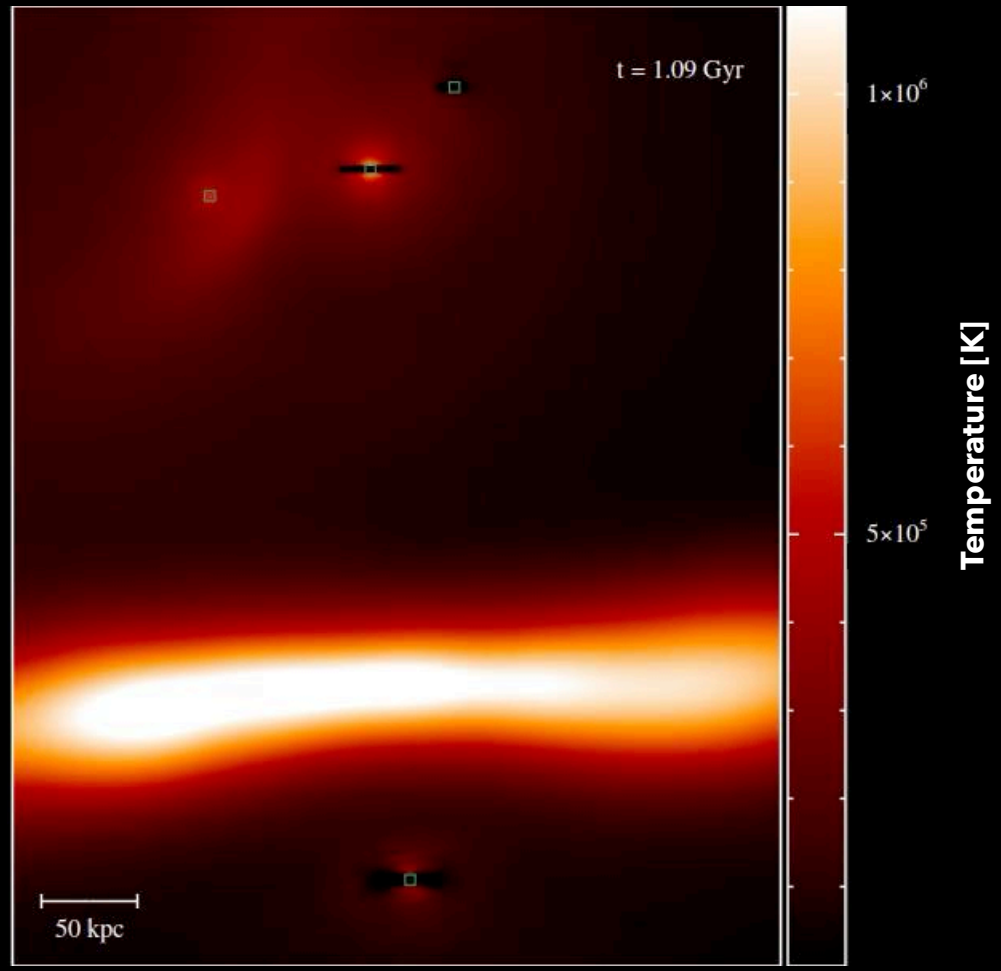
Ivleva et al. (b) in prep.

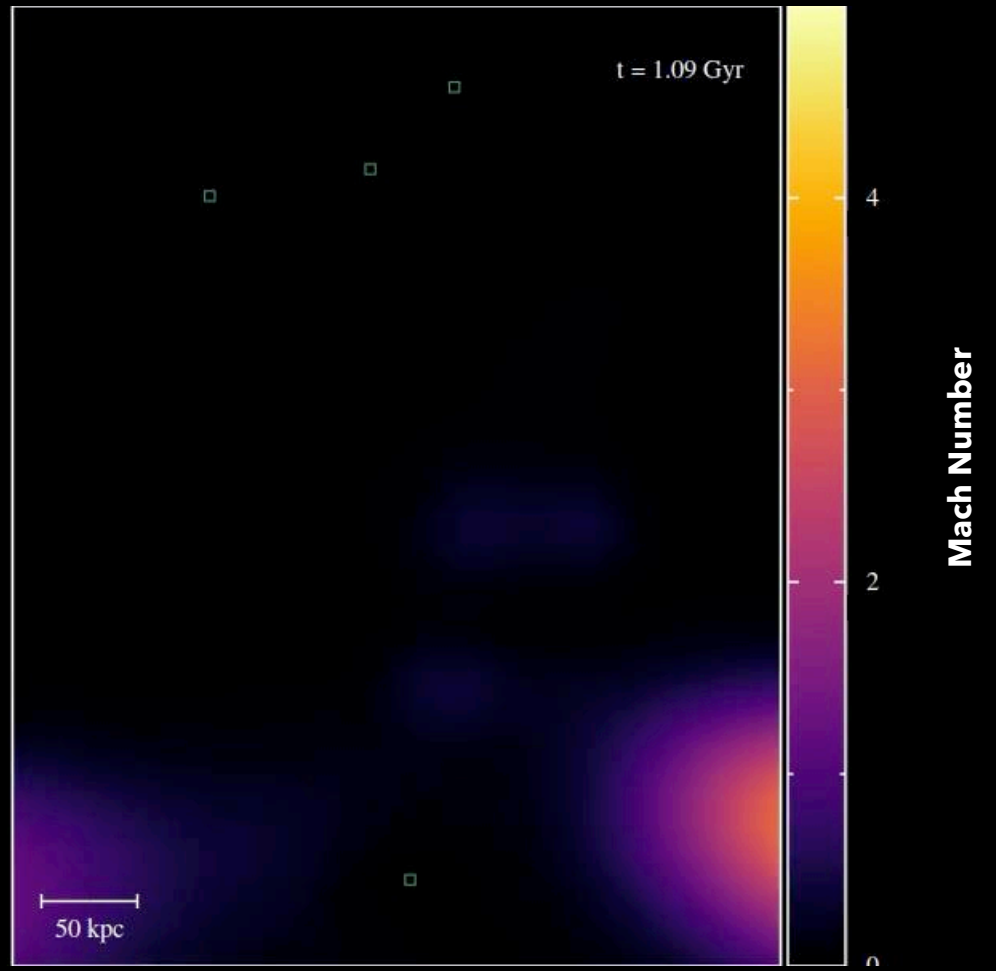
Evolution in maps



Ivleva et al. (b) in prep.

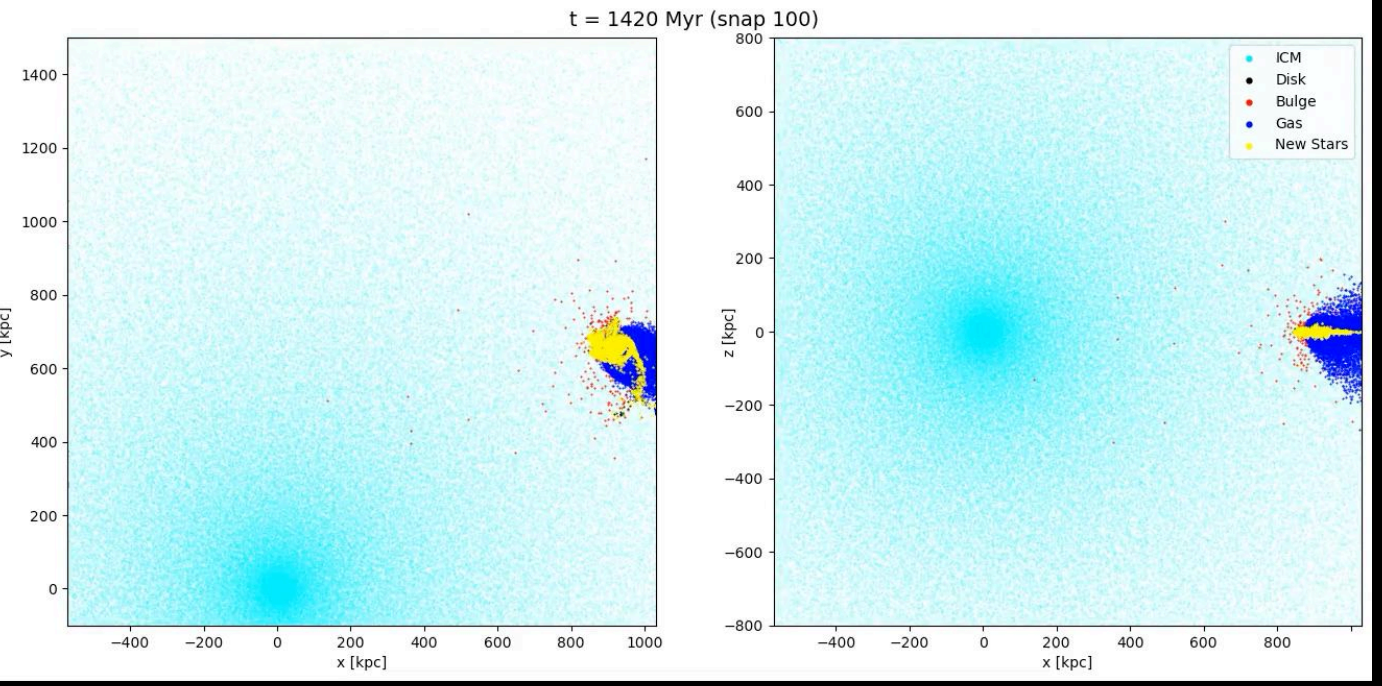
Evolution in maps

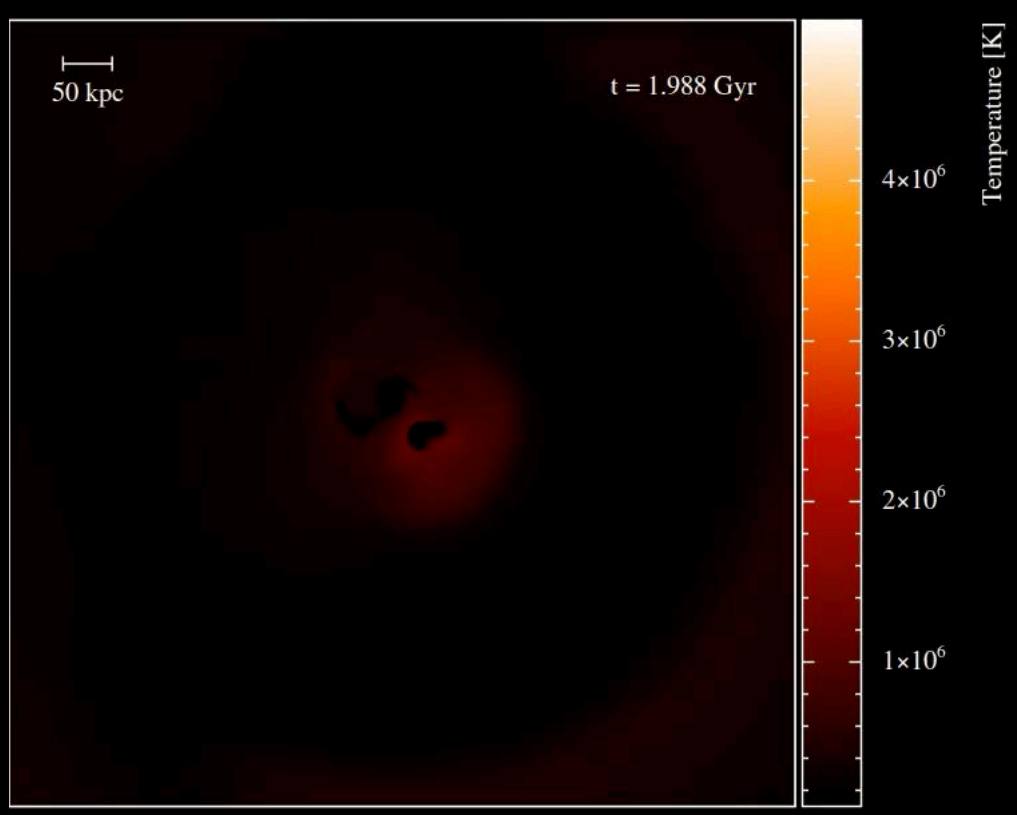




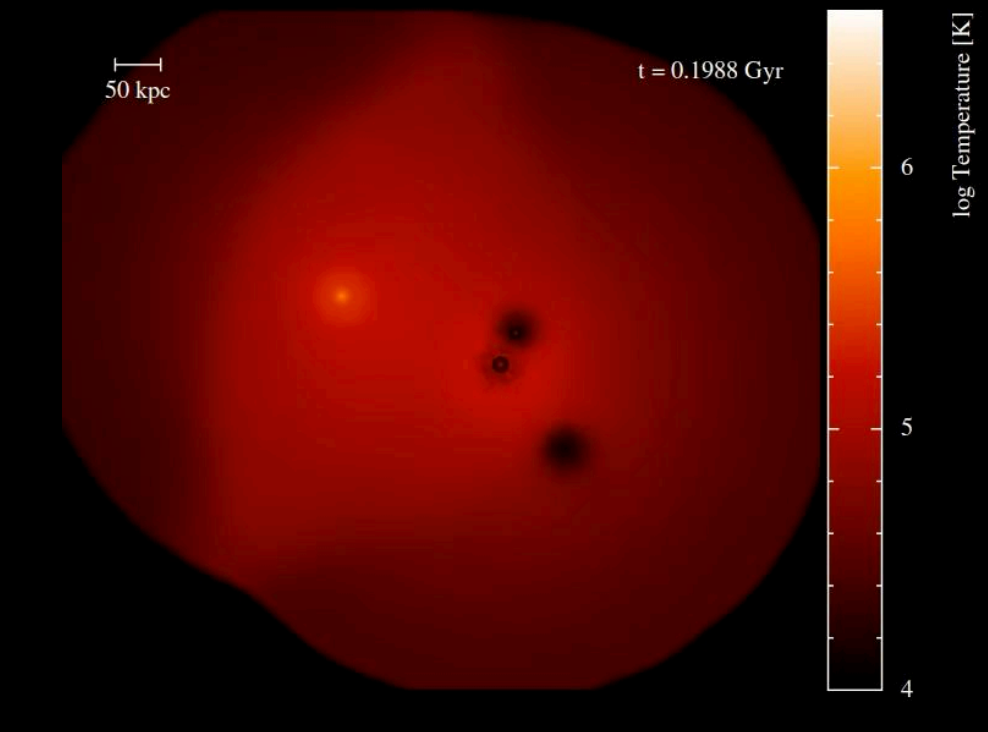
Edge-on projection

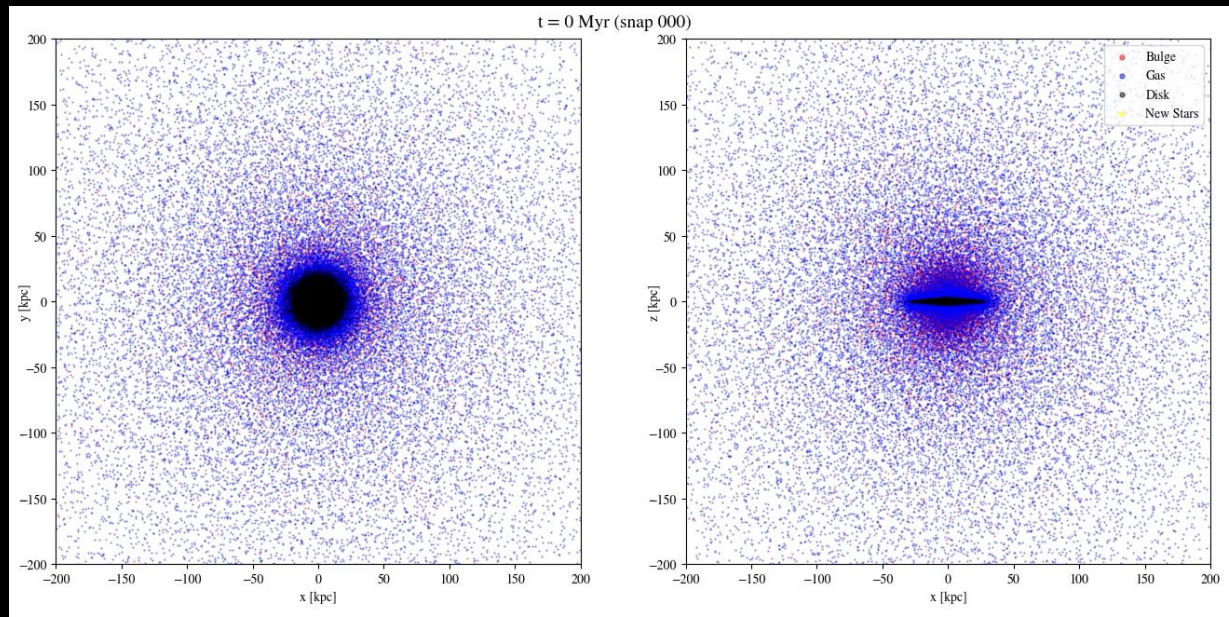
Ivleva et al. (b) in prep.


t = 1420 Myr (snap 100)
ICM
Disk
Bulge
Gas
New Stars
x [kpc]
y [kpc]
z [kpc]


50 kpc
t = 1.988 Gyr
Temperature [K]
4×10^6
3×10^6
2×10^6
1×10^6

Bloopers


50 kpc
t = 0.1988 Gyr
log Temperature [K]
6
5
4


t = 0 Myr (snap 000)
Bulge
Gas
Disk
New Stars
x [kpc]
y [kpc]
z [kpc]

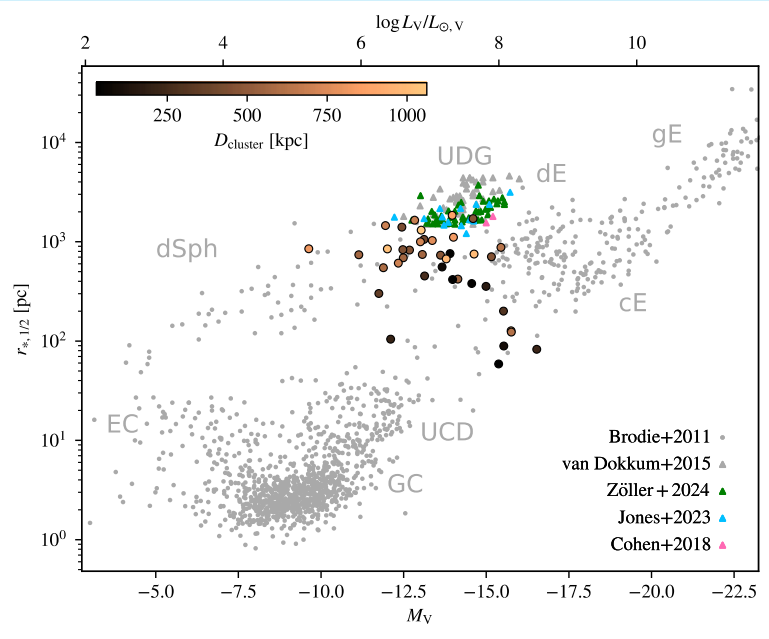
Summary & Open Questions

Tidal dwarf galaxies inside galaxy clusters:

- channel for variety of DM-deficient dwarf galaxies
- Properties **correlate with age/cluster distance**
- **strong stellar feedback** prefers diffuse dwarfs

ToDos:

- Impact of **code physics**: MHD, true viscosity, AGNs, …
- Correlation with **cluster mass?**



MHD in group evolution (Stefan's Quintet):

- Missing piece in gas dynamics:
- CGM **main culprit?**
- different **CGM properties** → different **shock properties?**
- Impact of **halo mass?**
- **Cosmic rays?**