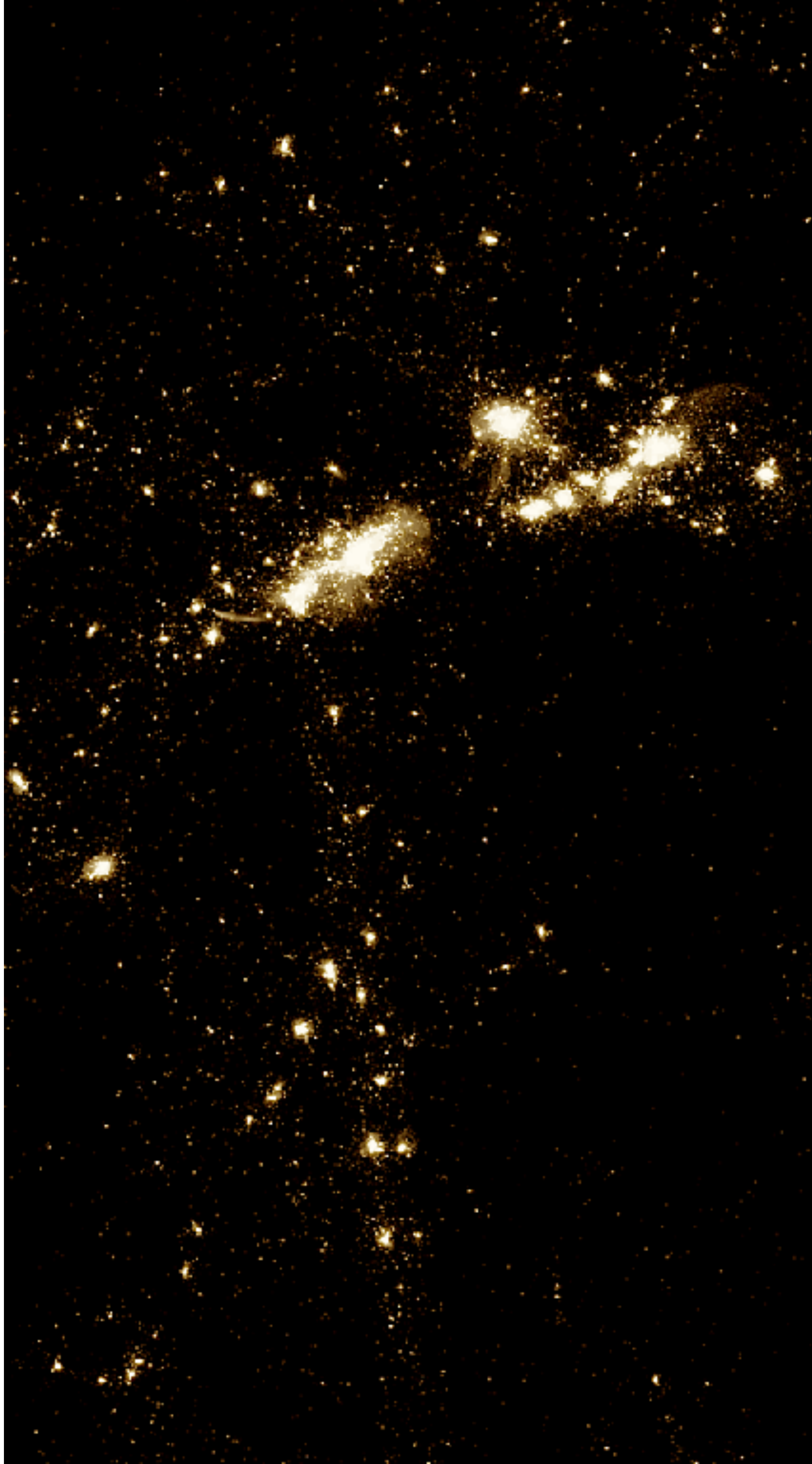
TIDAL DWARF GALAXIES
IN COSMOLOGICAL SIMULATIONS

S Y L V I A
P L O E C K I N G E R
L e i d e n   O b s e r v a t o r y

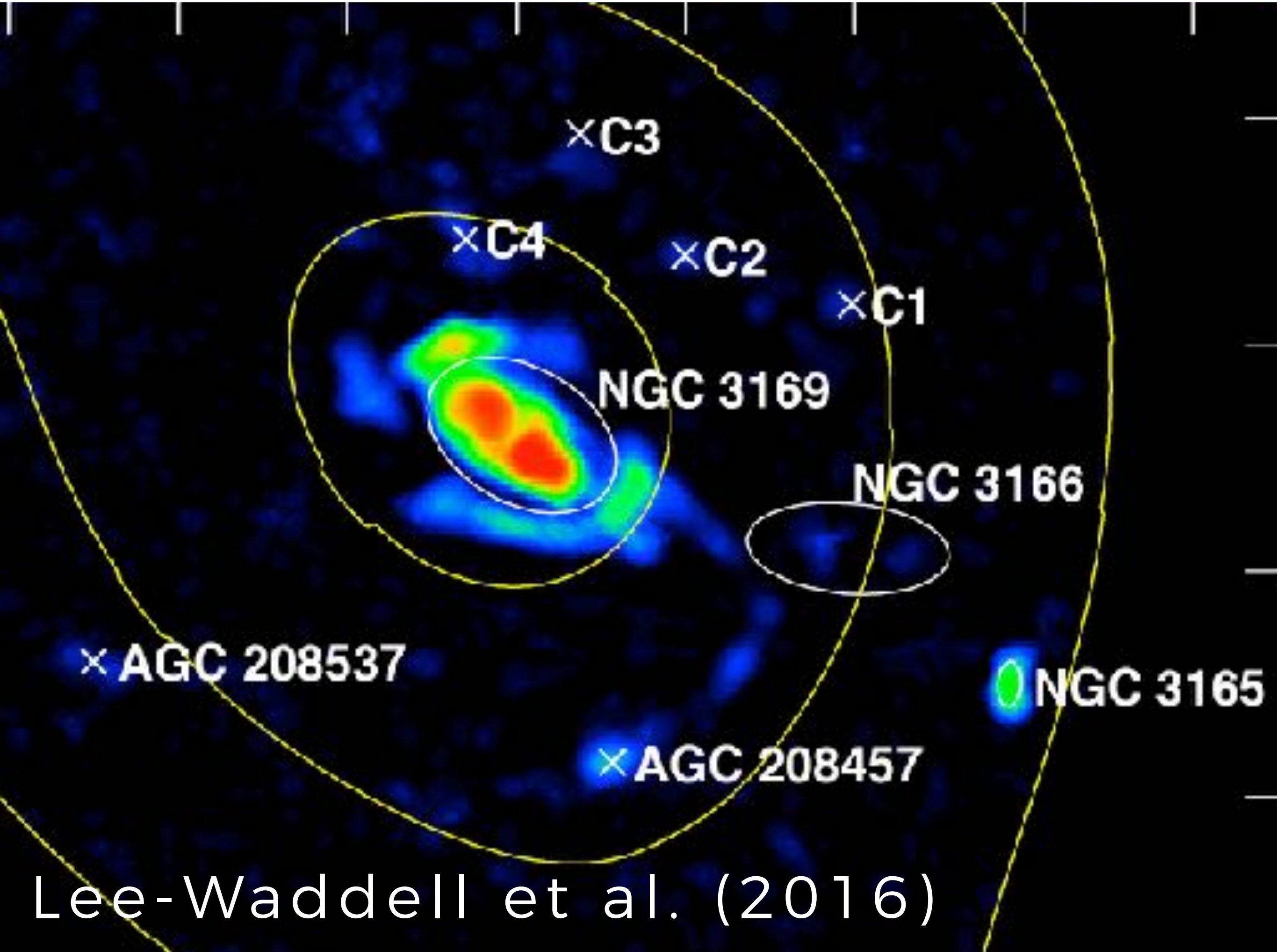
WITH K. SHARMA, J. SCHAYE

AND THE EAGLE TEAM

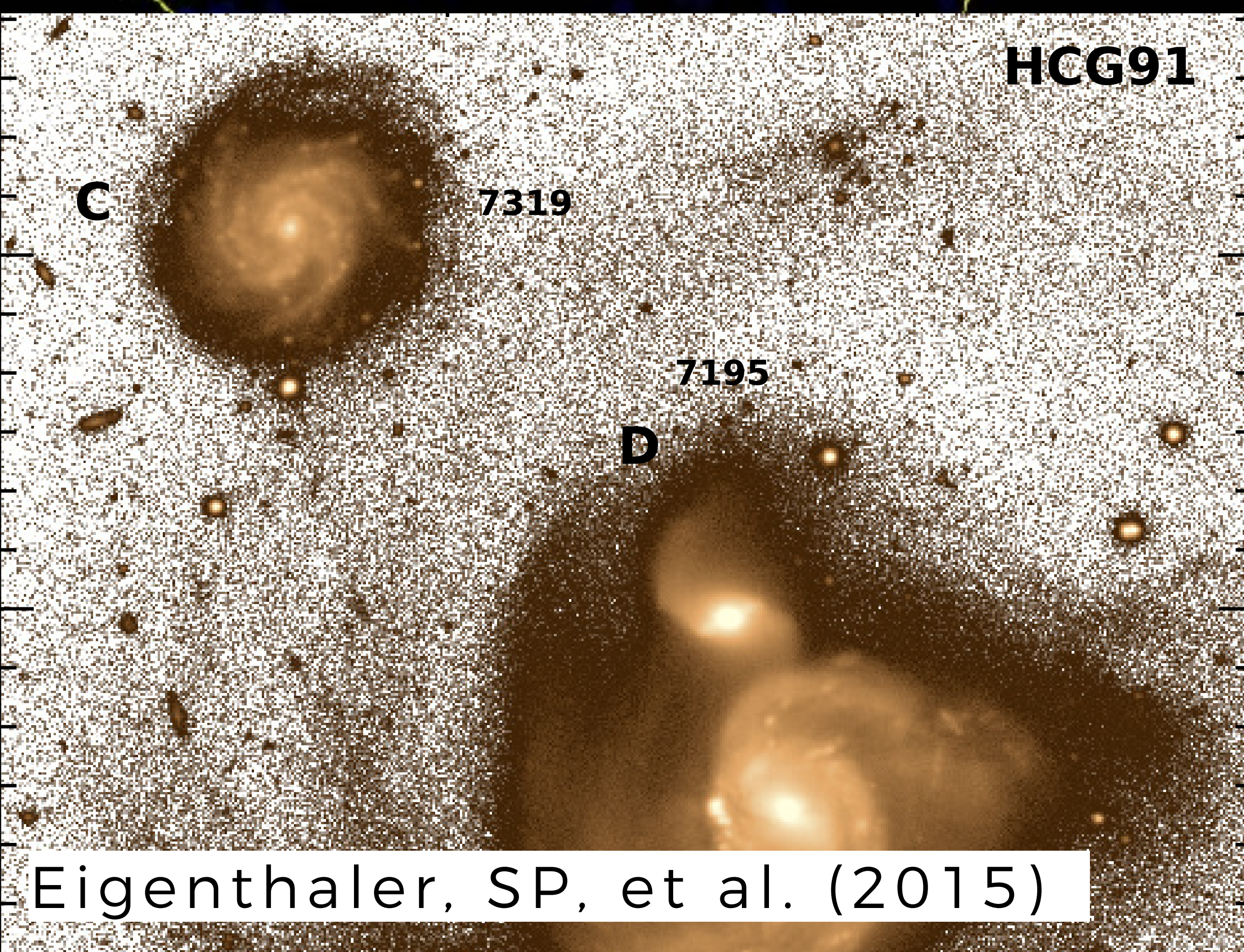


TIDAL DWARF GALAXIES

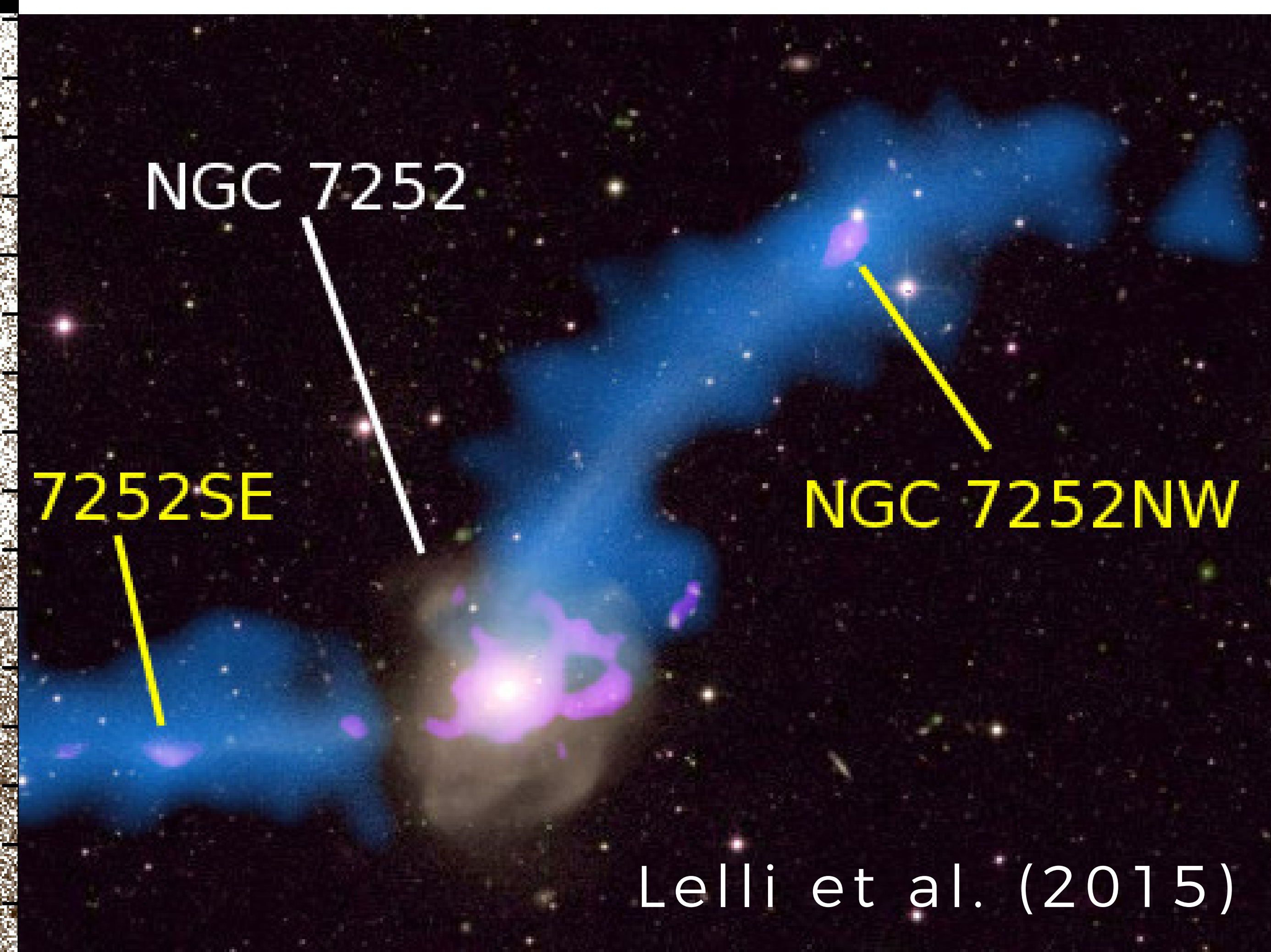
Observations



Lee-Waddell et al. (2016)



Eigenthaler, SP, et al. (2015)



Lelli et al. (2015)

OVERVIEW OF PROPERTIES OF TDG IN A LCDM UNIVERSE

mass, size	star formation	dark matter	metallicity
as dwarf galaxies	active, young stars	none bound to TDG	increased for stellar mass

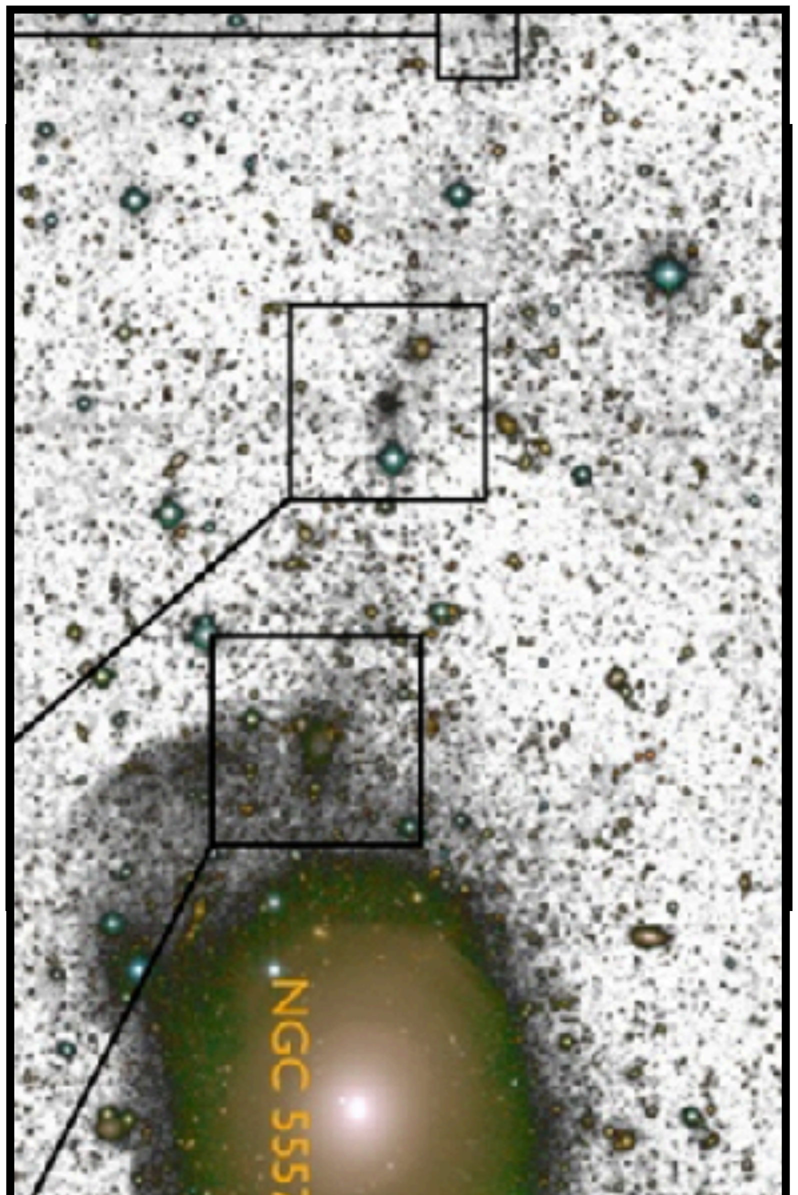
How many old TDGs do we expect in LCDM?

SURVIVAL TIMESCALE

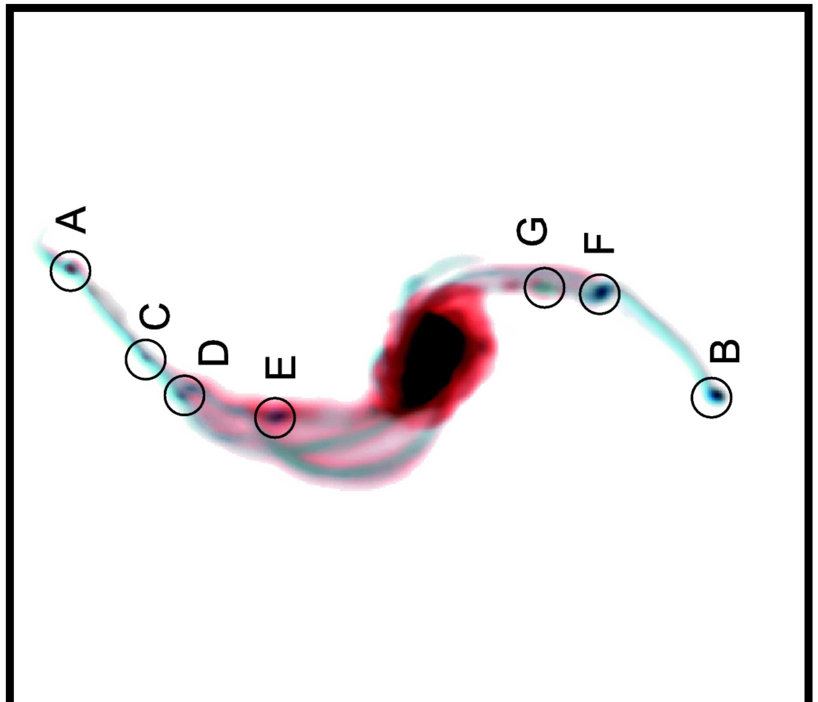
FORMATION RATE

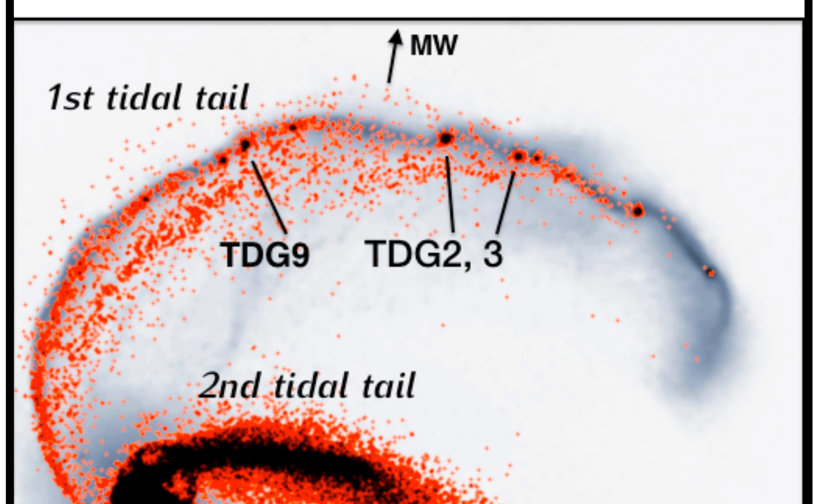
SURVIVAL TIMESCALE

O B S E R V A T I O N S

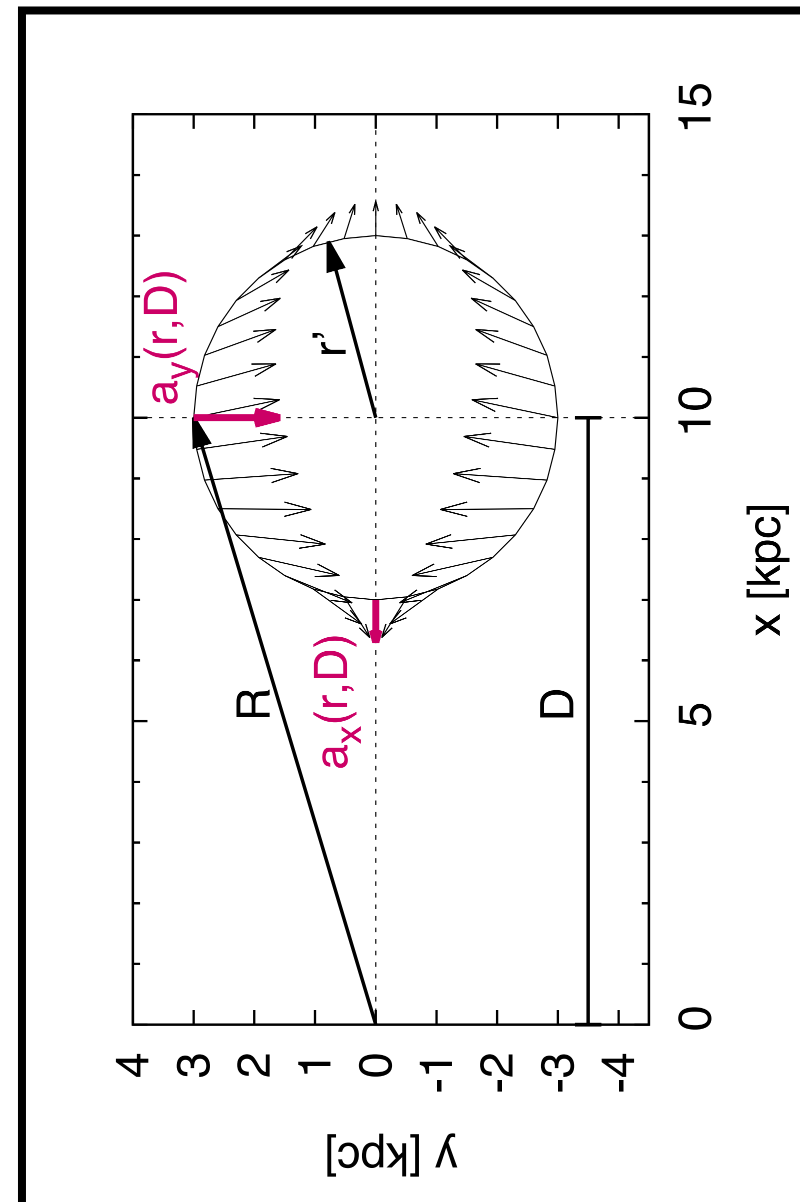


S I M U L A T I O N S





A N A L Y T I C A L



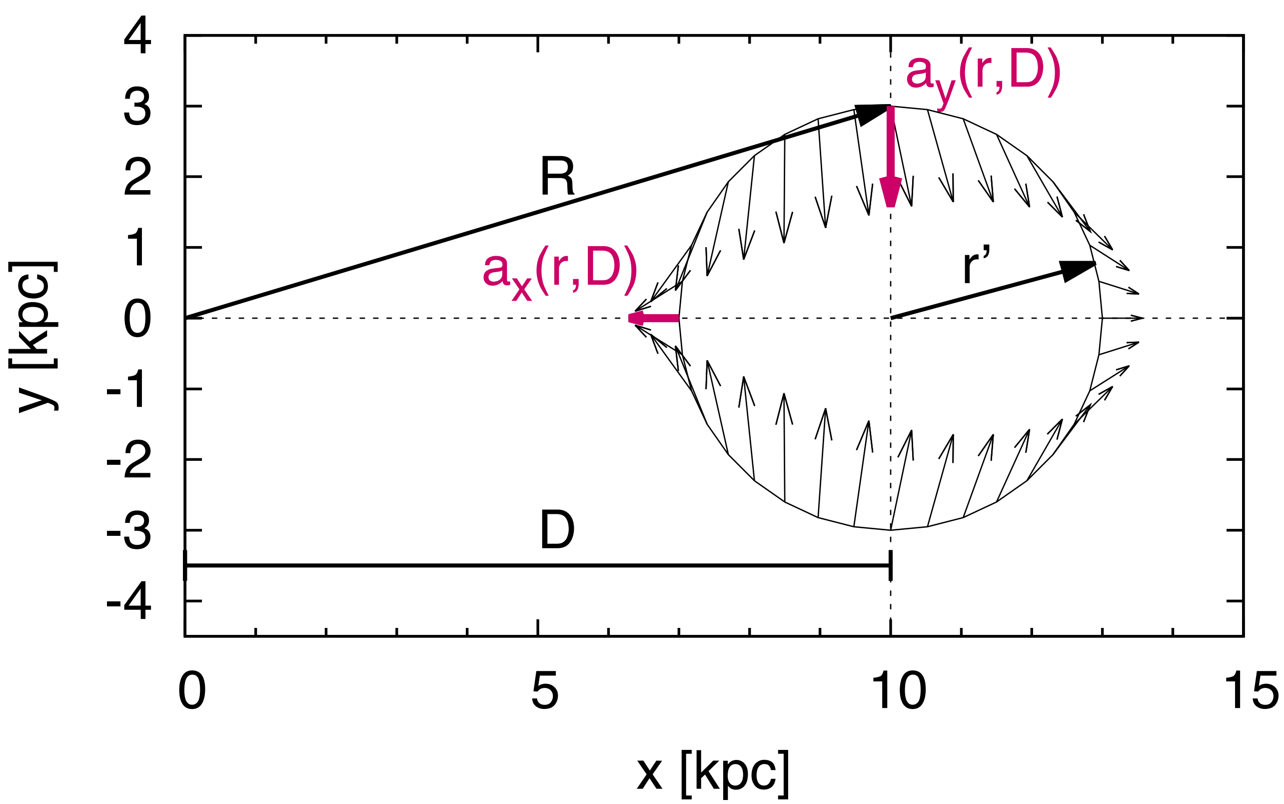
Duc et al. (2014)

Bournaud & Duc (2006)

Yang et al. (2014)

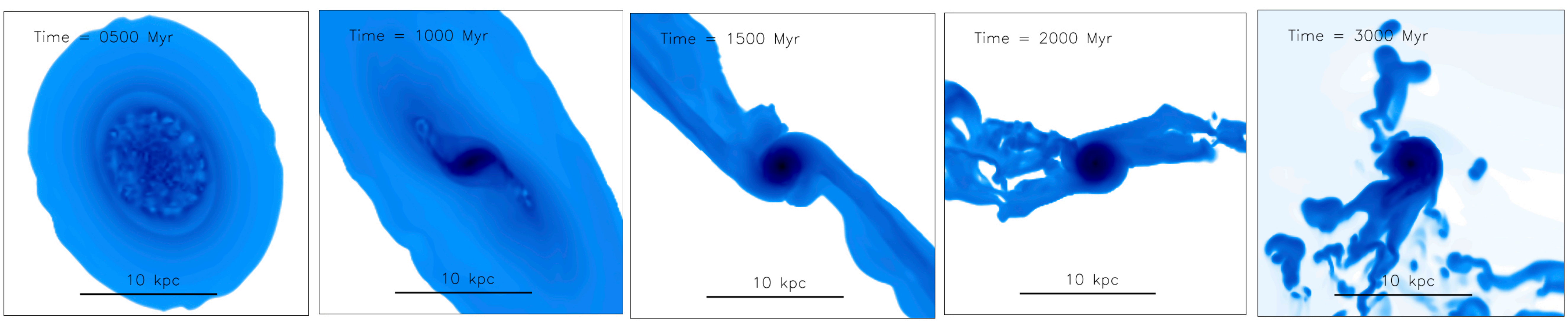
Ploeckinger (2015)

SURVIVAL TIMESCALE: CAN THE TIDAL FIELD STABILISE THE YOUNG GAS-RICH TDG?



GAUSS' LAW OF GRAVITY

$$\oint_{\partial V} \vec{g} \cdot \mathrm{d}\vec{A} = -4\pi G M_{\mathrm{enc}}$$



Ploeckinger et al. (2015), Ploeckinger (2015)

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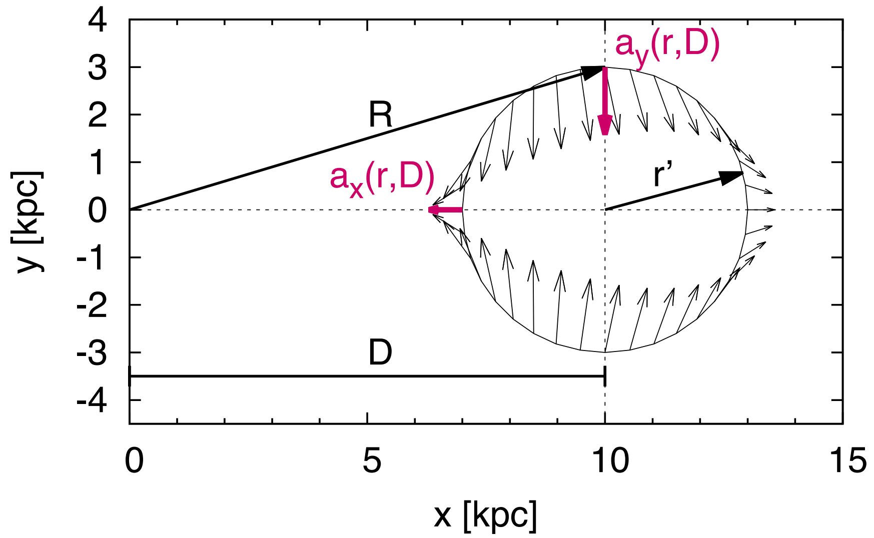
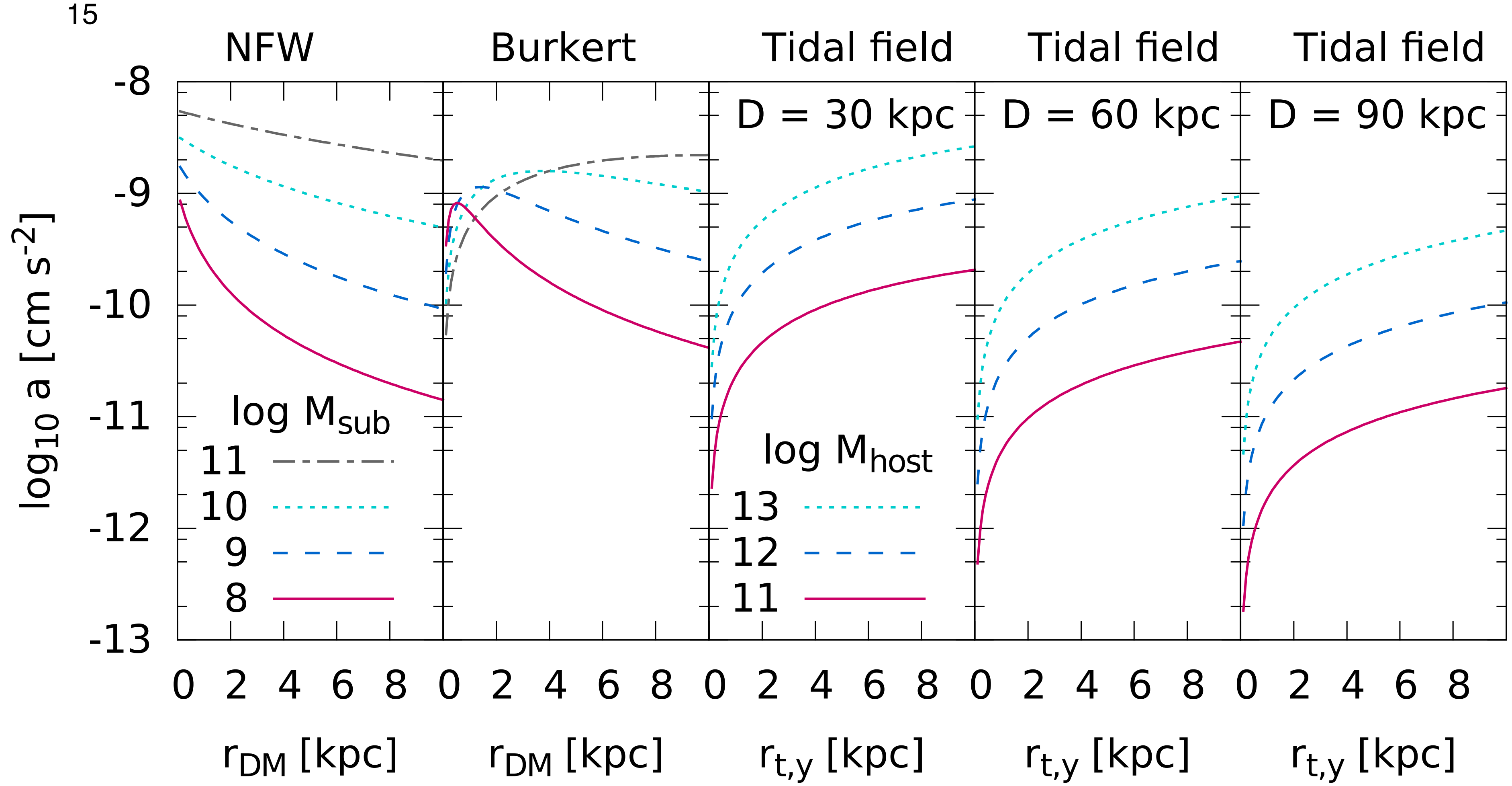
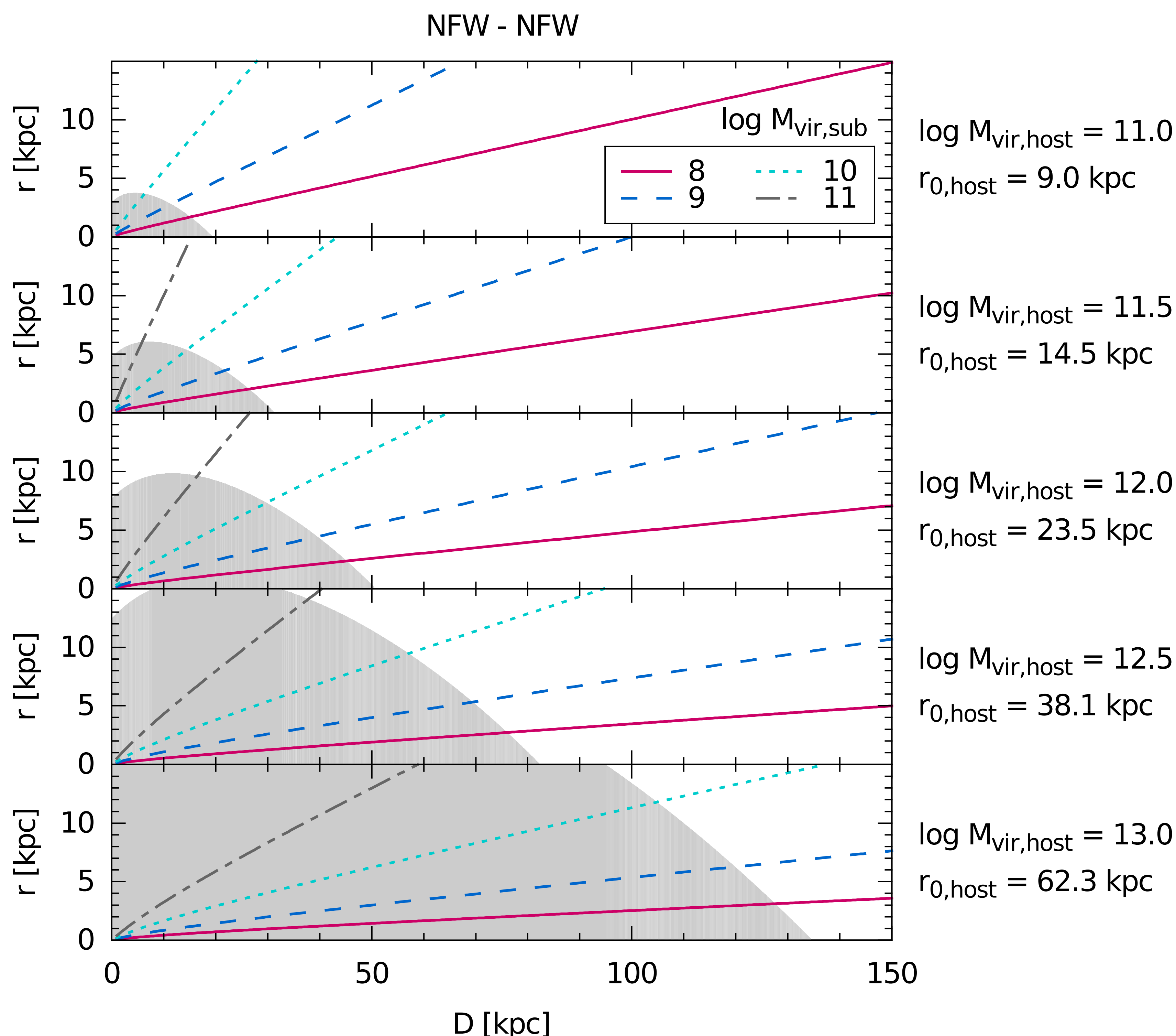




Ploeckinger (2015)

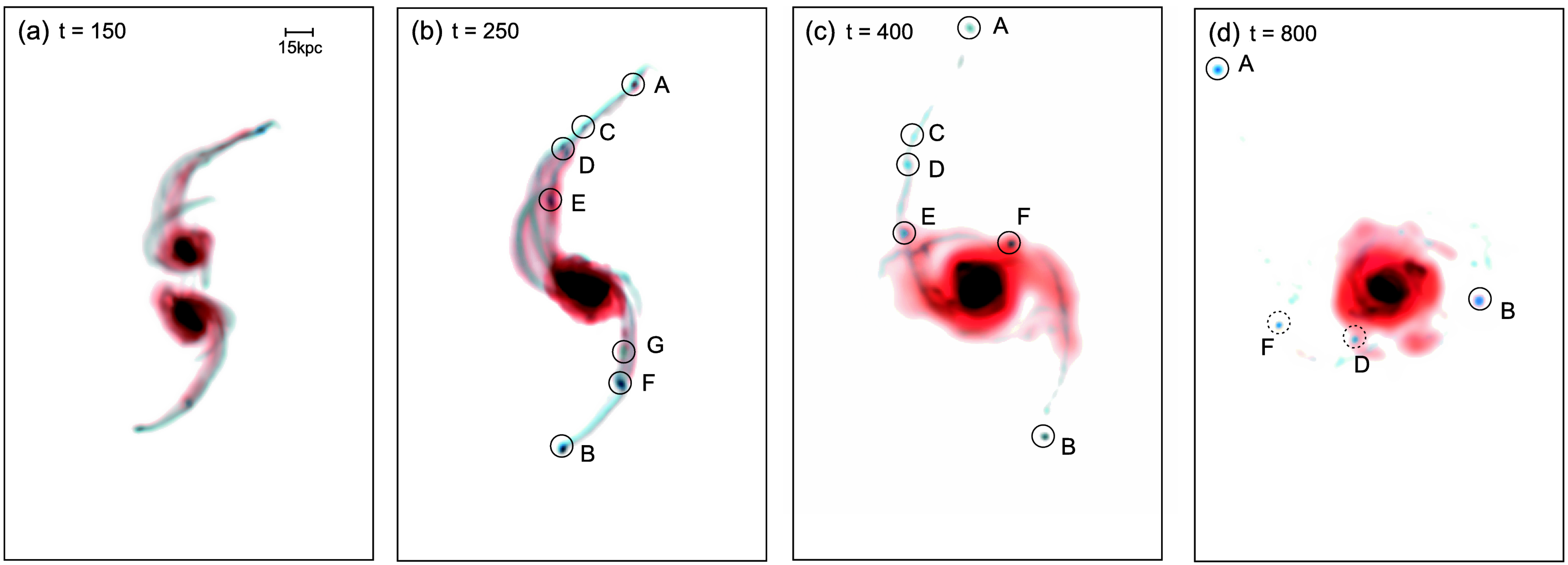
SURVIVAL TIMESCALE: CAN THE TIDAL FIELD STABILISE THE YOUNG GAS-RICH TDG?



Ploeckinger (2015)

FORMATION OF TDGS

Parameter	Simulated range	Range most favorable to long-lived TDG formation
Relative velocity	50 to 320 km s^{-1}	50 to 250 km s^{-1}
Impact parameter	15 to 200 kpc	30 to 200 kpc
Orbit inclination	0 to 60 degrees	0 to 40 degrees
Orbit orientation	Prograde/Retrograde	Prograde only
Mass ratio	10:1 to 1:10	4:1 to 1:8



Bournaud & Duc (2006)

(see also e.g. Fouquet et al. 2012, Yang et al. 2014)

next step: cosmological (LCDM) context

THE EAGLE SIMULATIONS (PI: J. SCHAYE)

Evolution and Assembly of GaLaxies and their Environments

6.8 bn

PARTICLES

in the largest simulation box

4.3 m

CPU HOURS

1.5 months on 4000 CPU

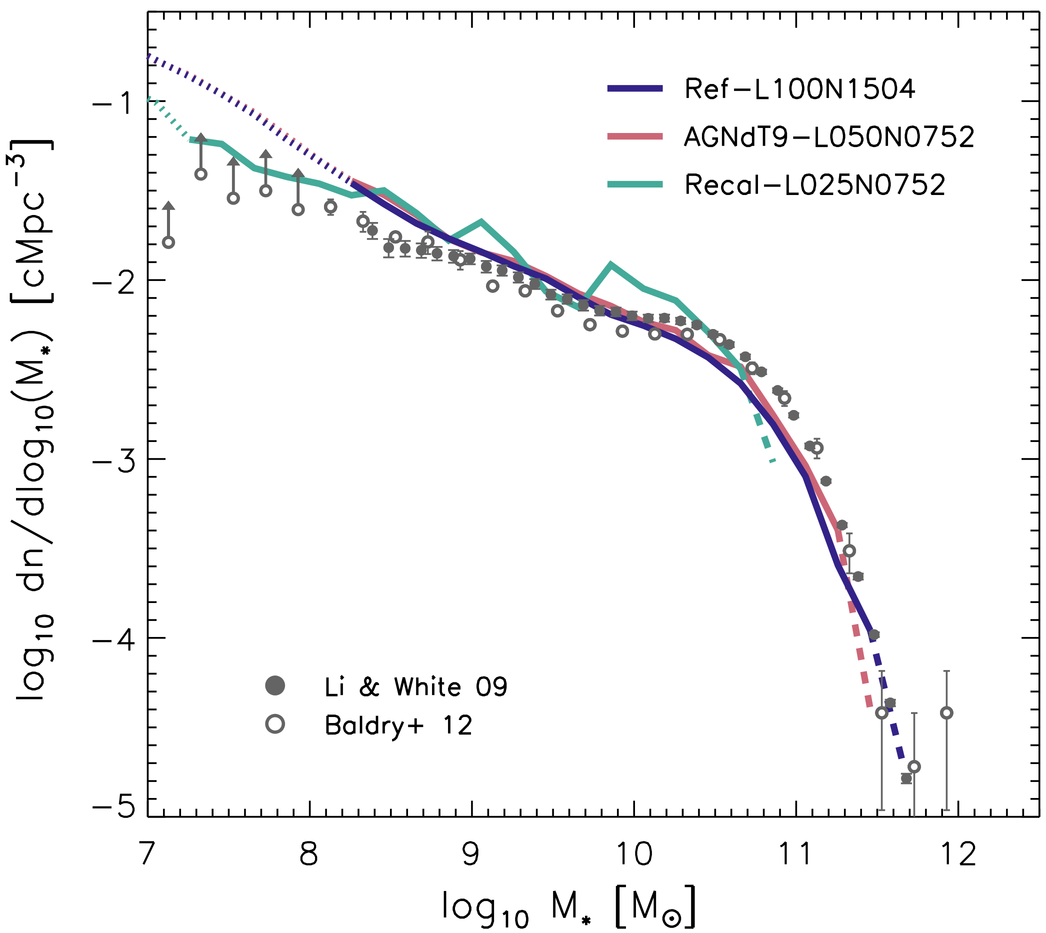
122 TB

data

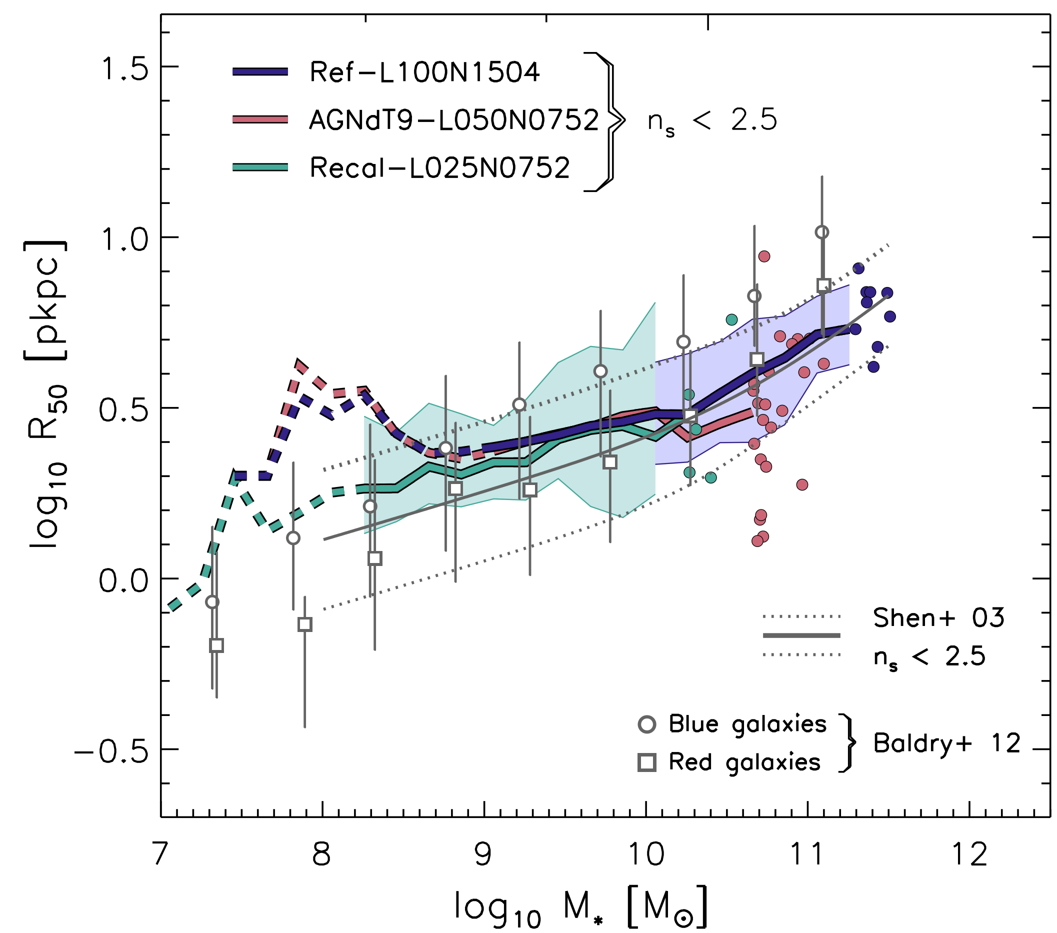
per simulation run

CALIBRATED GALAXY PROPERTIES IN EAGLE

> 10000 simulated galaxies: statistical comparison with observations



GALAXY STELLAR MASS FUNCTION

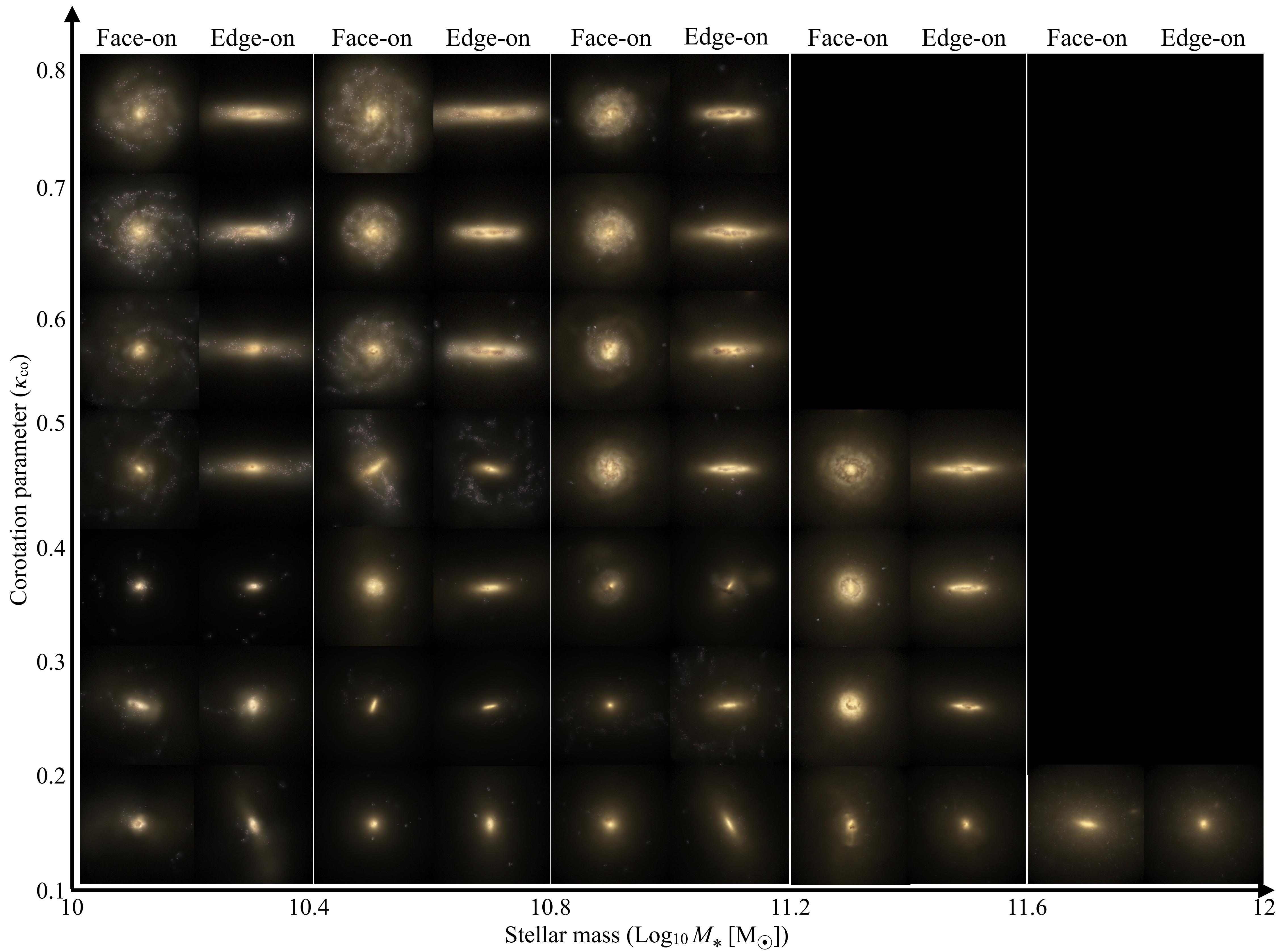


GALAXY SIZES

Schaye et al. (2015)

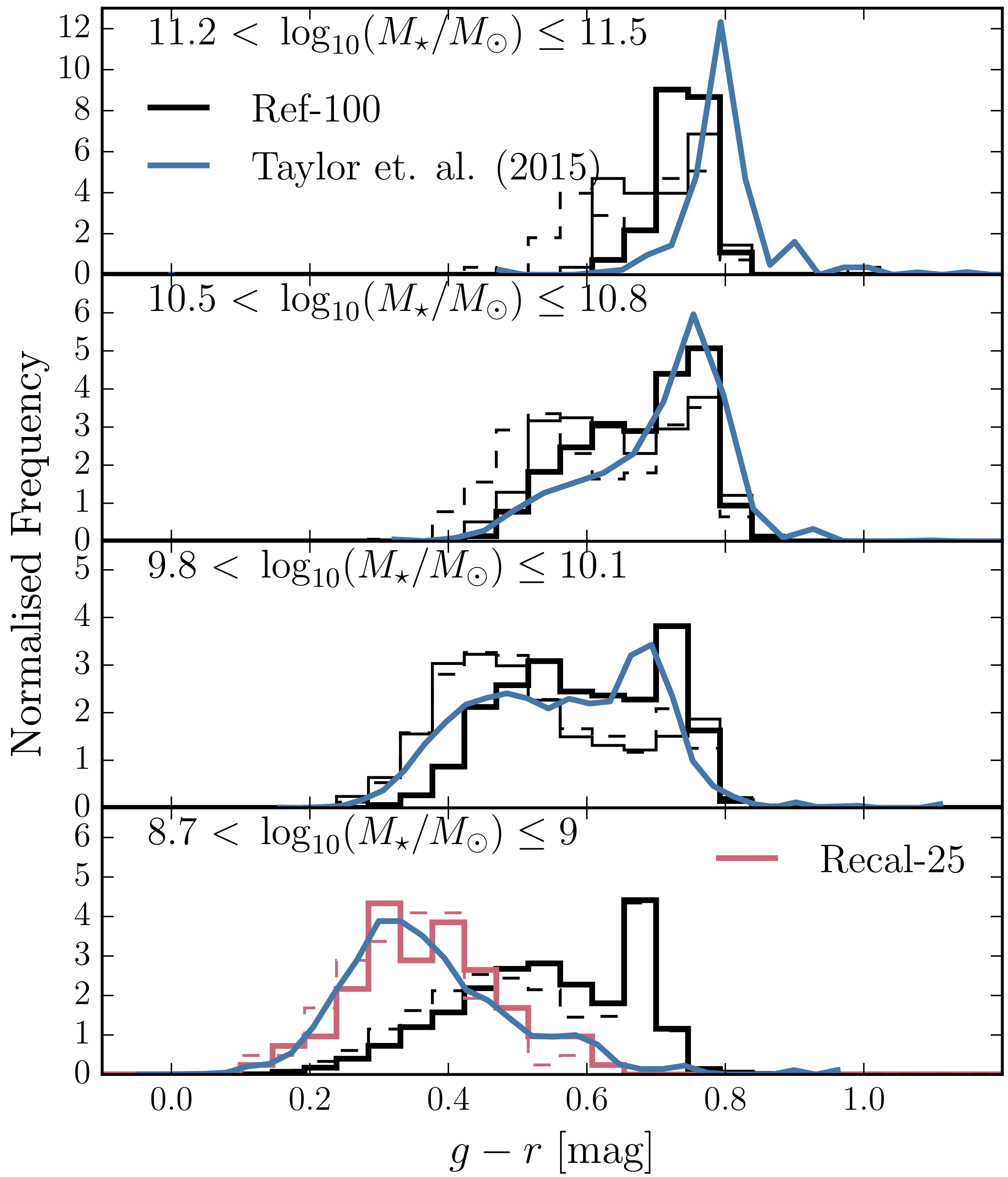
no calibration on TDGs!

GALAXY POPULATION IN EAGLE - morphology



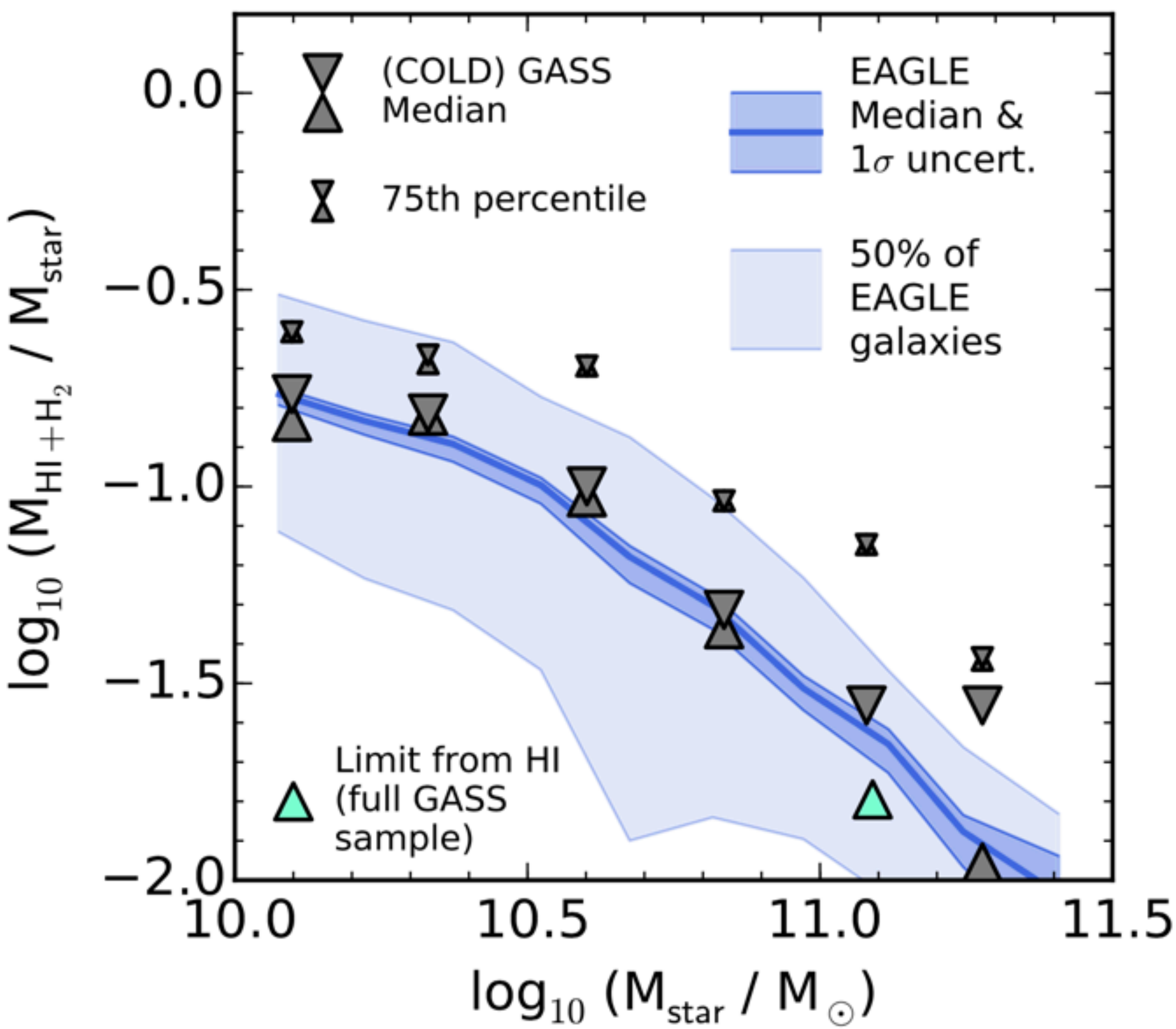
Correa et al. (arXiv:1704.06283)

GALAXY POPULATION IN EAGLE



Trayford et al. (arXiv:1705.02331)

GAS DISKS IN EAGLE



Bahé et al. (2016)

EAGLE HIGH-RES BOXES

Name	L (cMpc)	N	m_g ($M_\odot$)	m_{dm} ($M_\odot$)	ϵ_{com} (comoving kpc)	ϵ_{prop} (pkpc)
L025N0376	25	376^3	1.81×10^6	9.70×10^6	2.66	0.70
L025N0752	25	752^3	2.26×10^5	1.21×10^6	1.33	0.35
L050N0752	50	752^3	1.81×10^6	9.70×10^6	2.66	0.70
L100N1504	100	1504^3	1.81×10^6	9.70×10^6	2.66	0.70

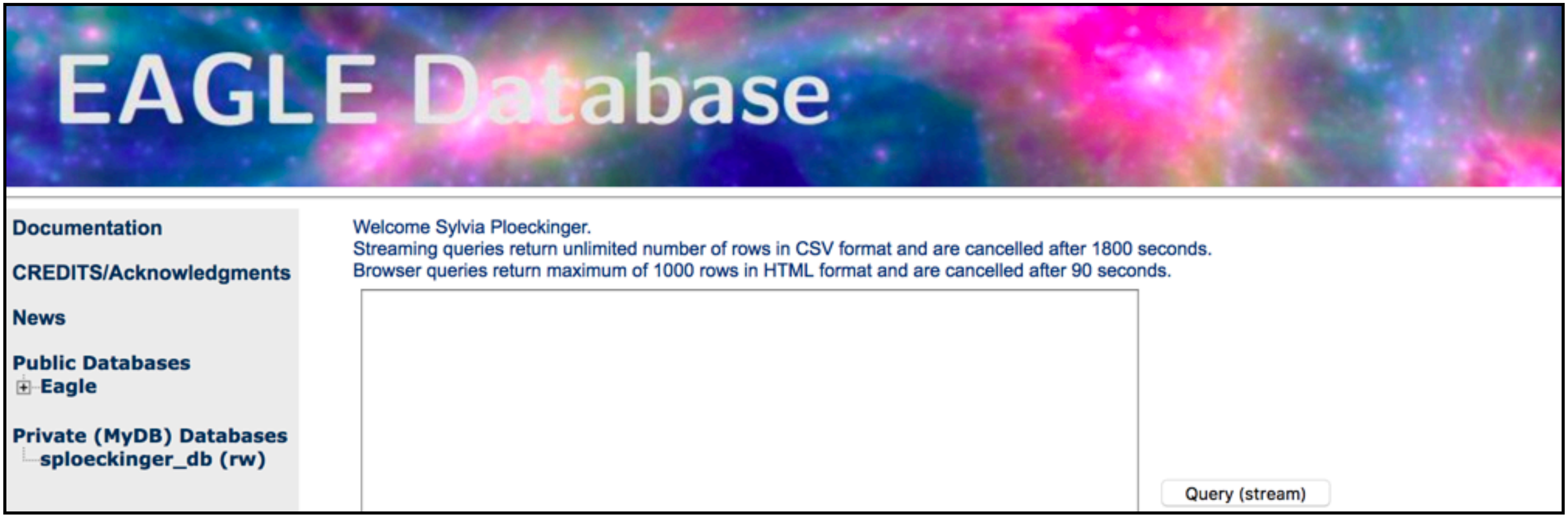
Ref-L025N0752

Recal-L025N0752

Schaye et al. (arXiv:1705.02331)

The public EAGLE database

McAlpine et al. (2016)

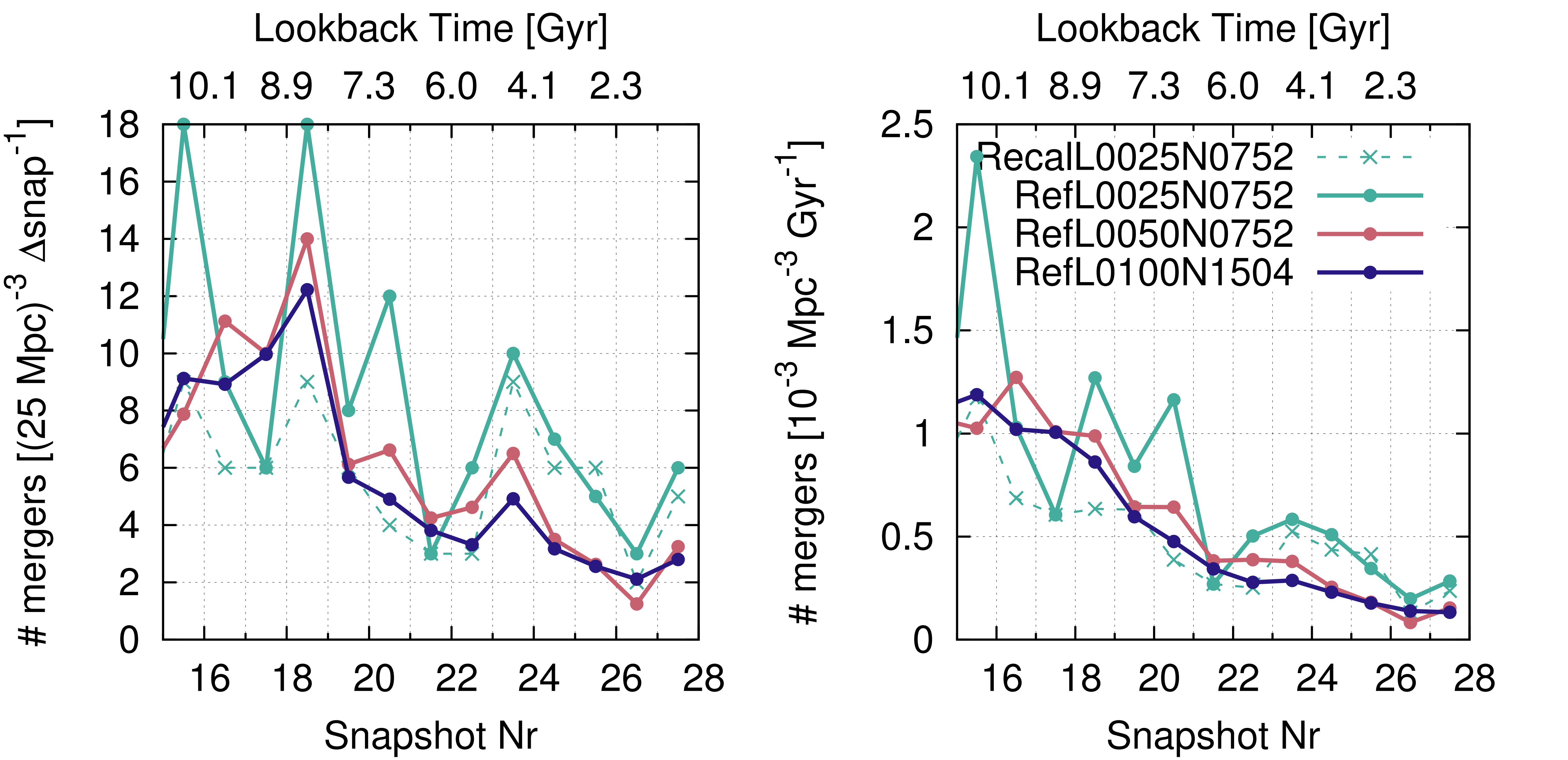


SUBFIND algorithm run on all particle types!

Merger trees (Qu et al. 2017)

http://icc.dur.ac.uk/Eagle/database.php

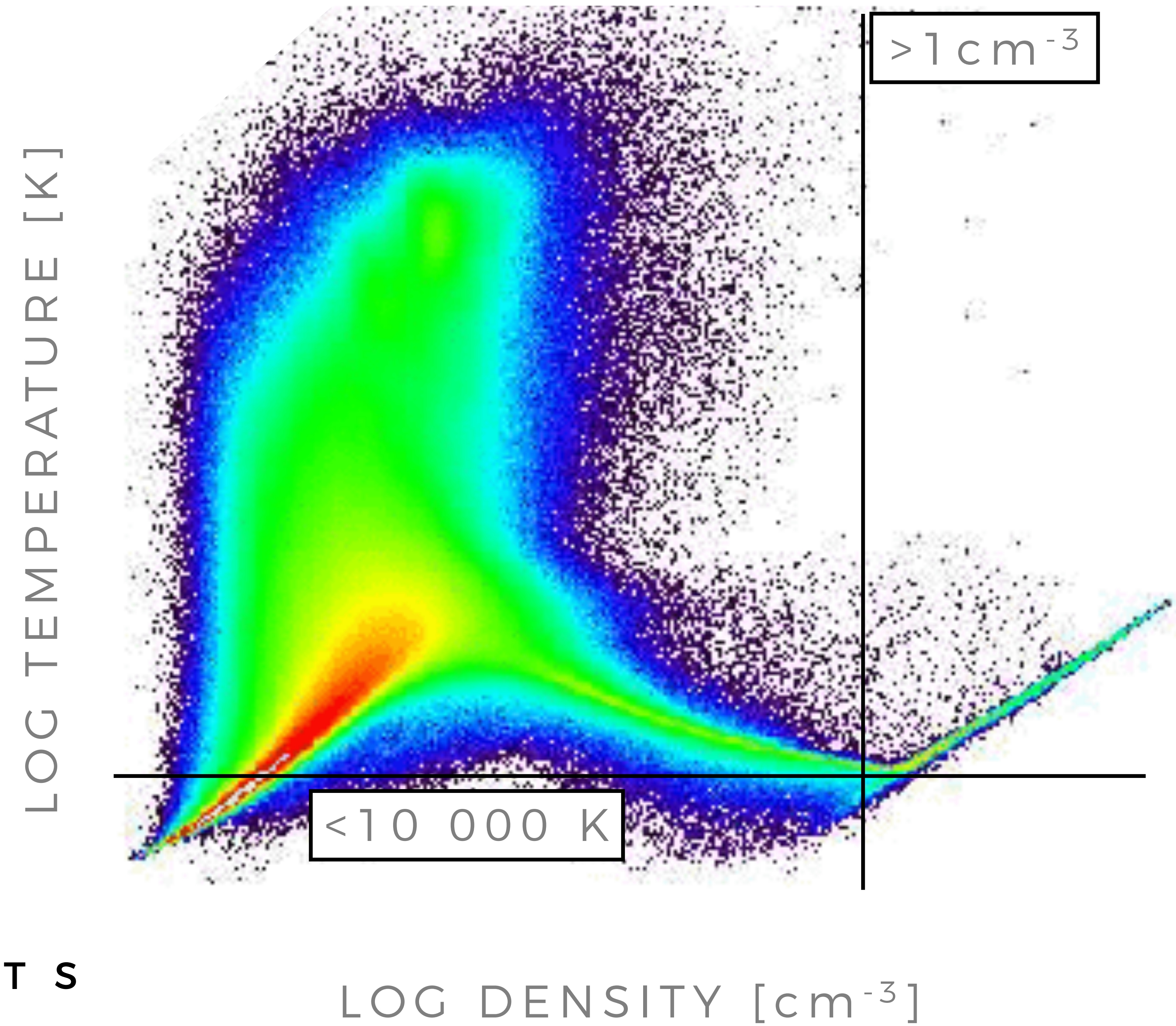
How many TDGs are expected in the high-res boxes?



Ploeckinger et al. (in prep.)

ADDITIONAL CHALLENGES

- ARTIFICIAL PRESSURE FLOOR
- STOCHASTIC STAR FORMATION
- LOW OUTPUT FREQUENCY FOR SNAPSHOTS

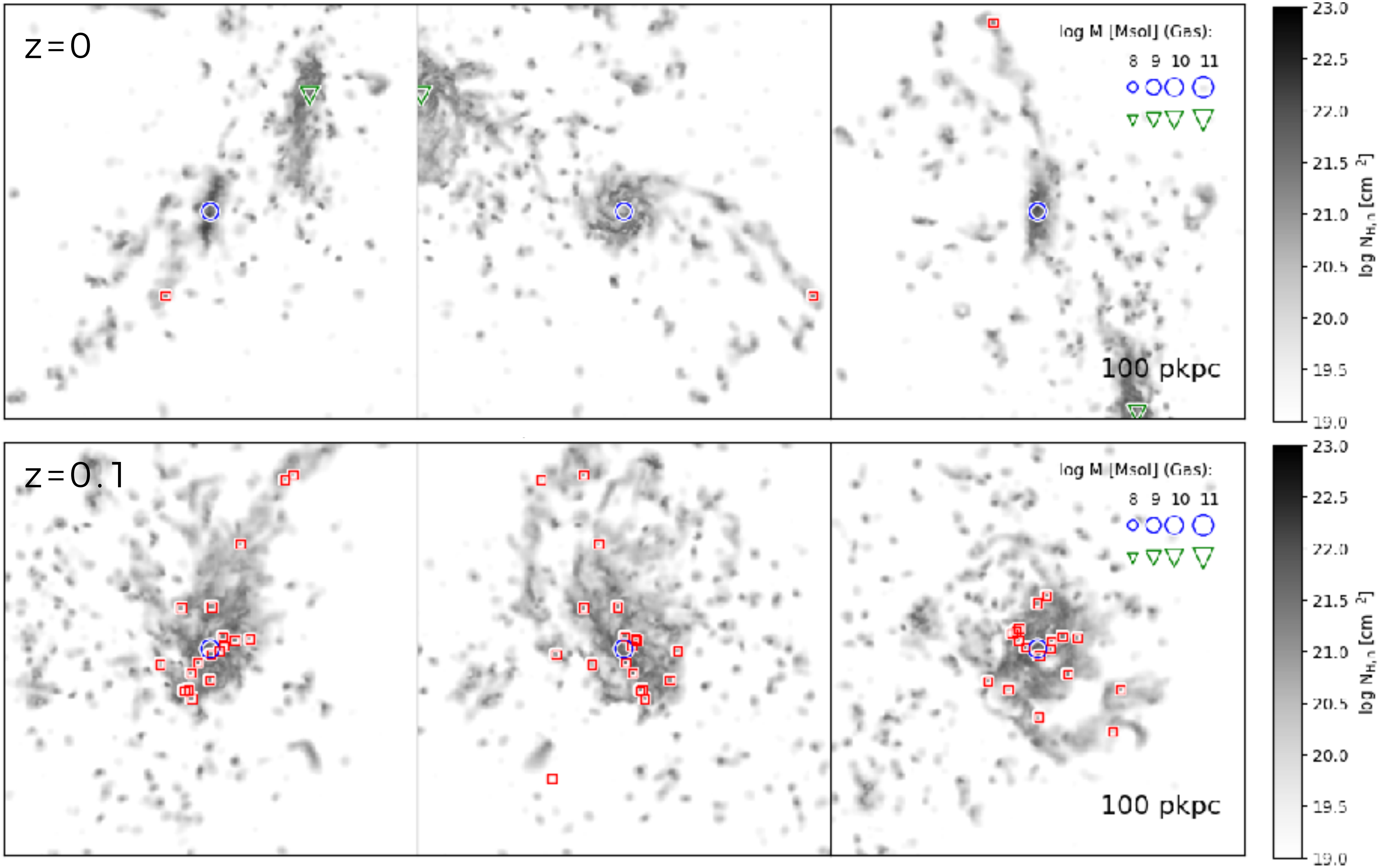


Step 1:
Use the public EAGLE database to find dark matter free substructures outside the host galaxy disks

	$\geq$	$\leq$
$M_{\mathrm{TDGC,gas}}$	$10^7 \mathrm{M}_\odot$	-
$M_{\mathrm{TDGC},\star}$	$2.26 \times 10^5 \mathrm{M}_\odot$	-
$M_{\mathrm{TDGC,DM}}$	0	0
$M_{\mathrm{TDGC,BH}}$	0	0
$d_{\mathrm{TDGC-host}}$	$2 \times R_{\mathrm{h,gas}}$	$\min(20 \times R_{\mathrm{h,gas}},\ 200\ \mathrm{pkpc})$
$\bar{d}_{\mathrm{TDGC-host,tb}}$	-	$\min(2 \times R_{\mathrm{h,gas}},\ 70\ \mathrm{pkpc})$
$M_{\mathrm{host,gas}}$	$10^9 \mathrm{M}_\odot$	-

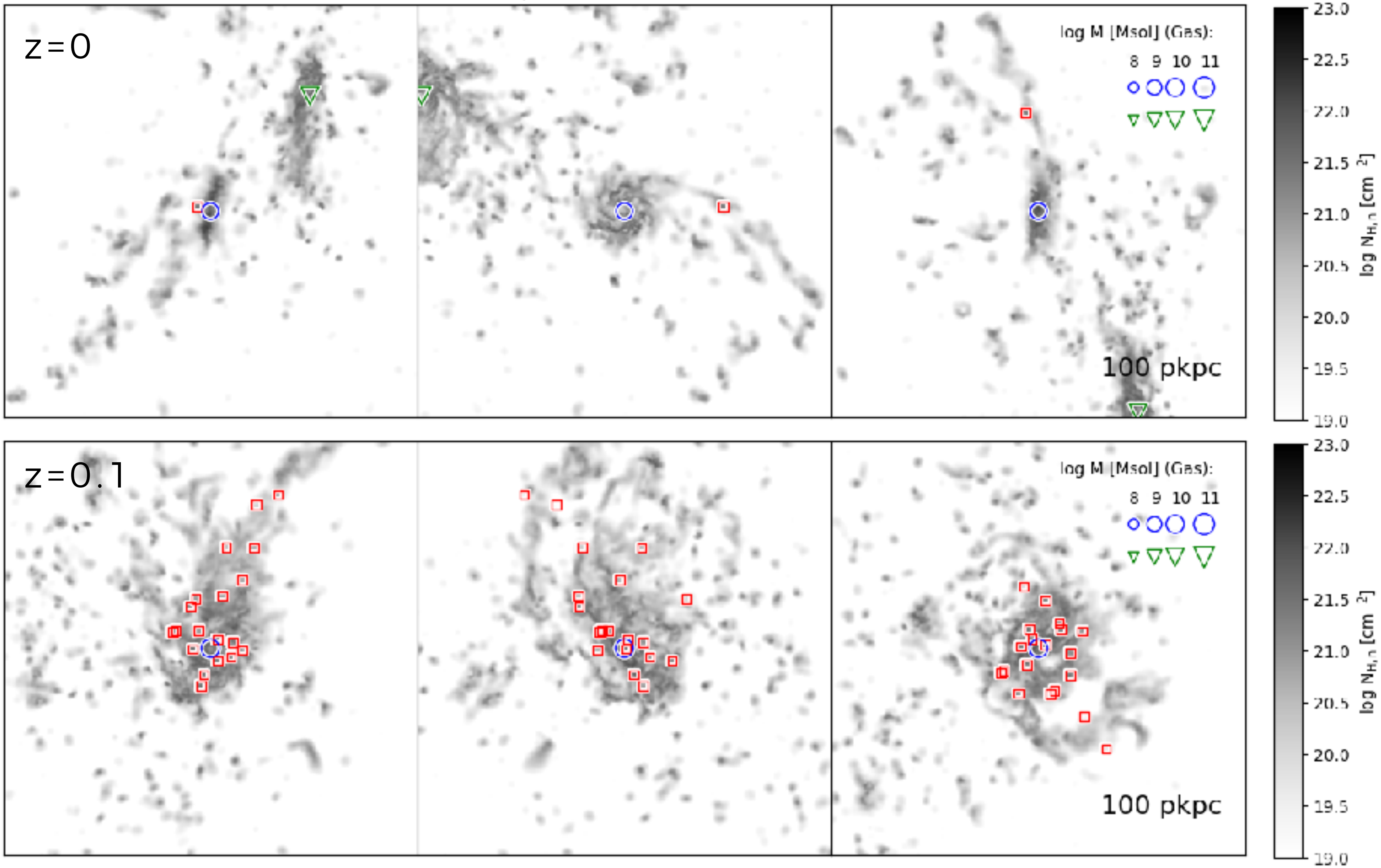
Step 2:
Trace the most bound particles of the identified TDGC back to the previous snapshot

Results



Ploeckinger et al. (in prep.)

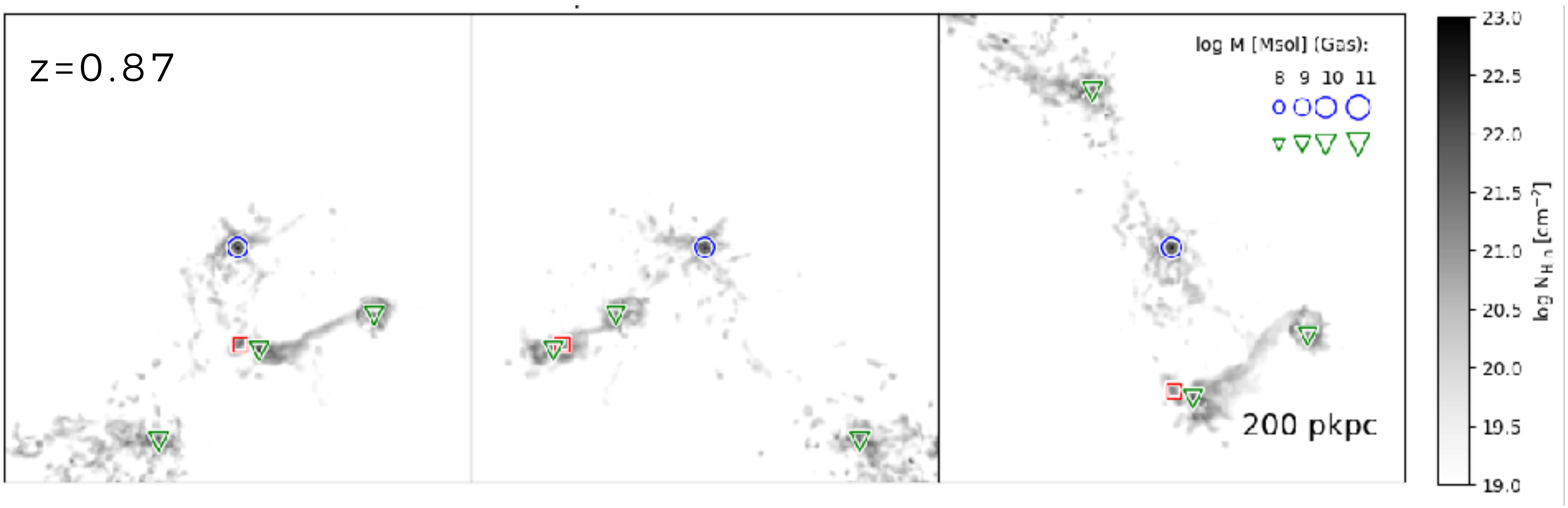
Another TDGC in the same galaxy pair



Ploeckinger et al. (in prep.)

Previously unaccounted for TDGCs:

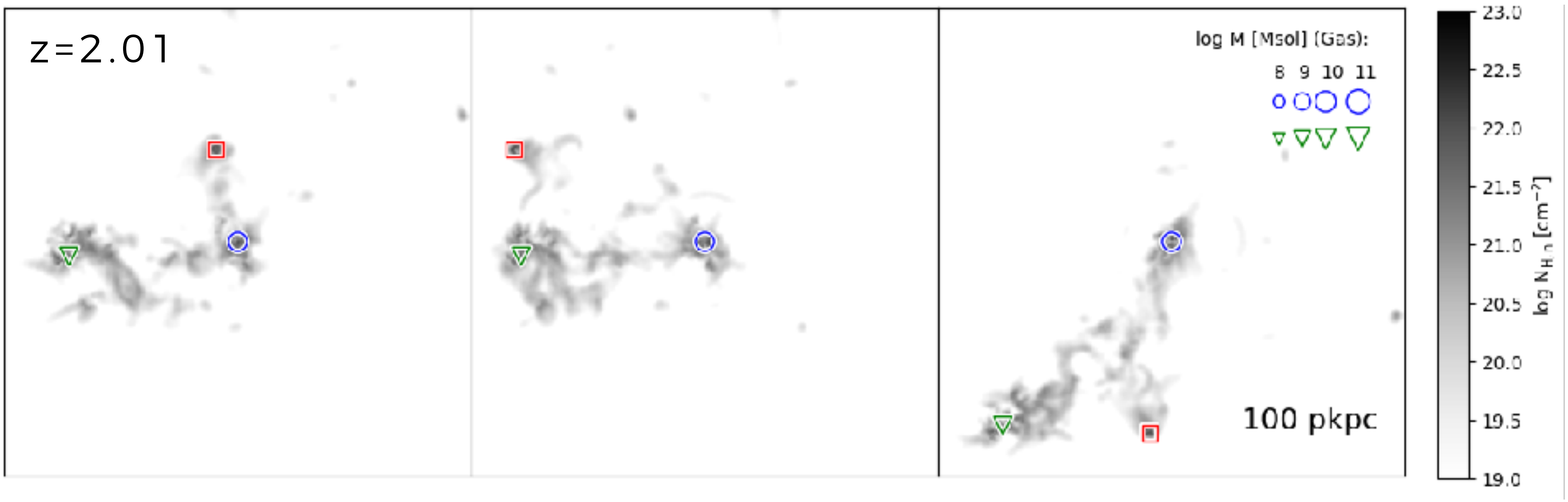
Complicated interaction geometries with multiple galaxies involved



Ploeckinger et al. (in prep.)

Previously unaccounted for TDGCs:

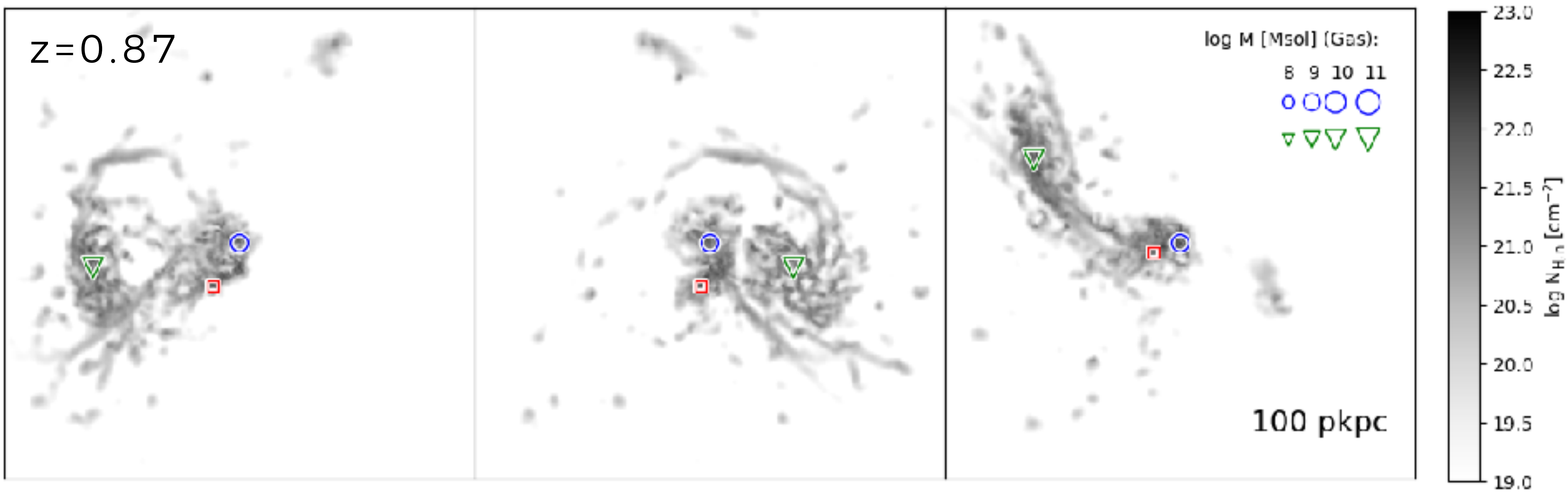
Formation of TDGCs (or GCs?) at high redshift



Ploeckinger et al. (in prep.)

Previously unaccounted for TDGCs:

Formation of TDGCs in low mass ratio interactions



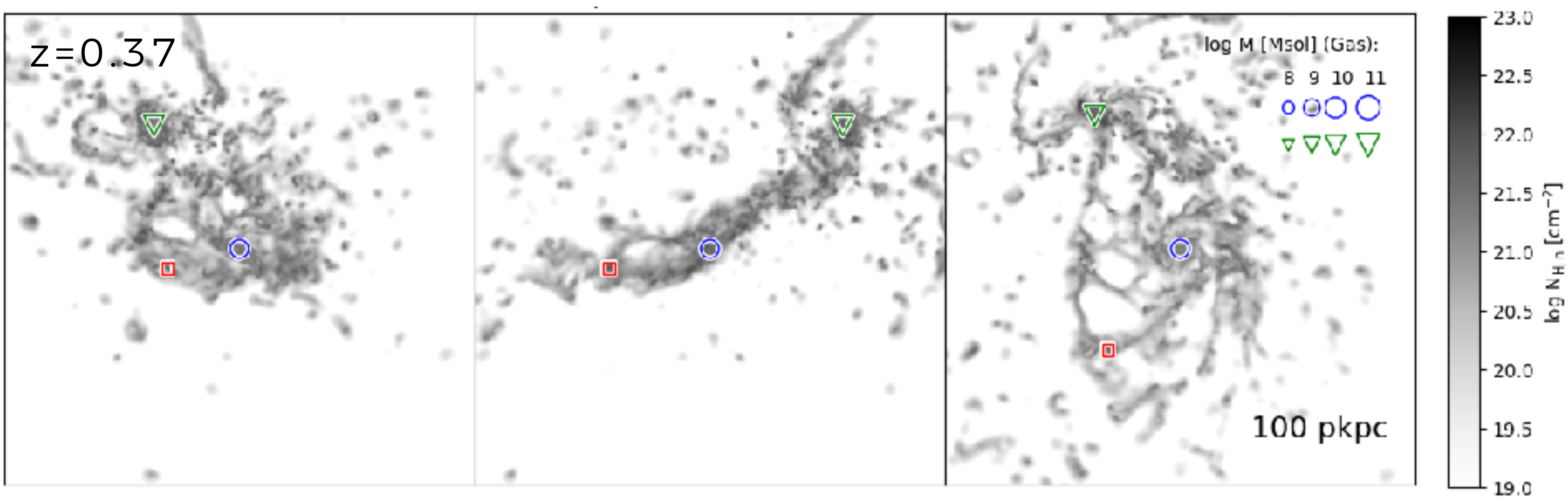
Baryonic mass ratio: 1:13, Gas mass ratio : 1:6

TDG particles are at larger distances to the host galaxy at the next snapshot

Ploeckinger et al. (in prep.)

Previously unaccounted for TDGCs:

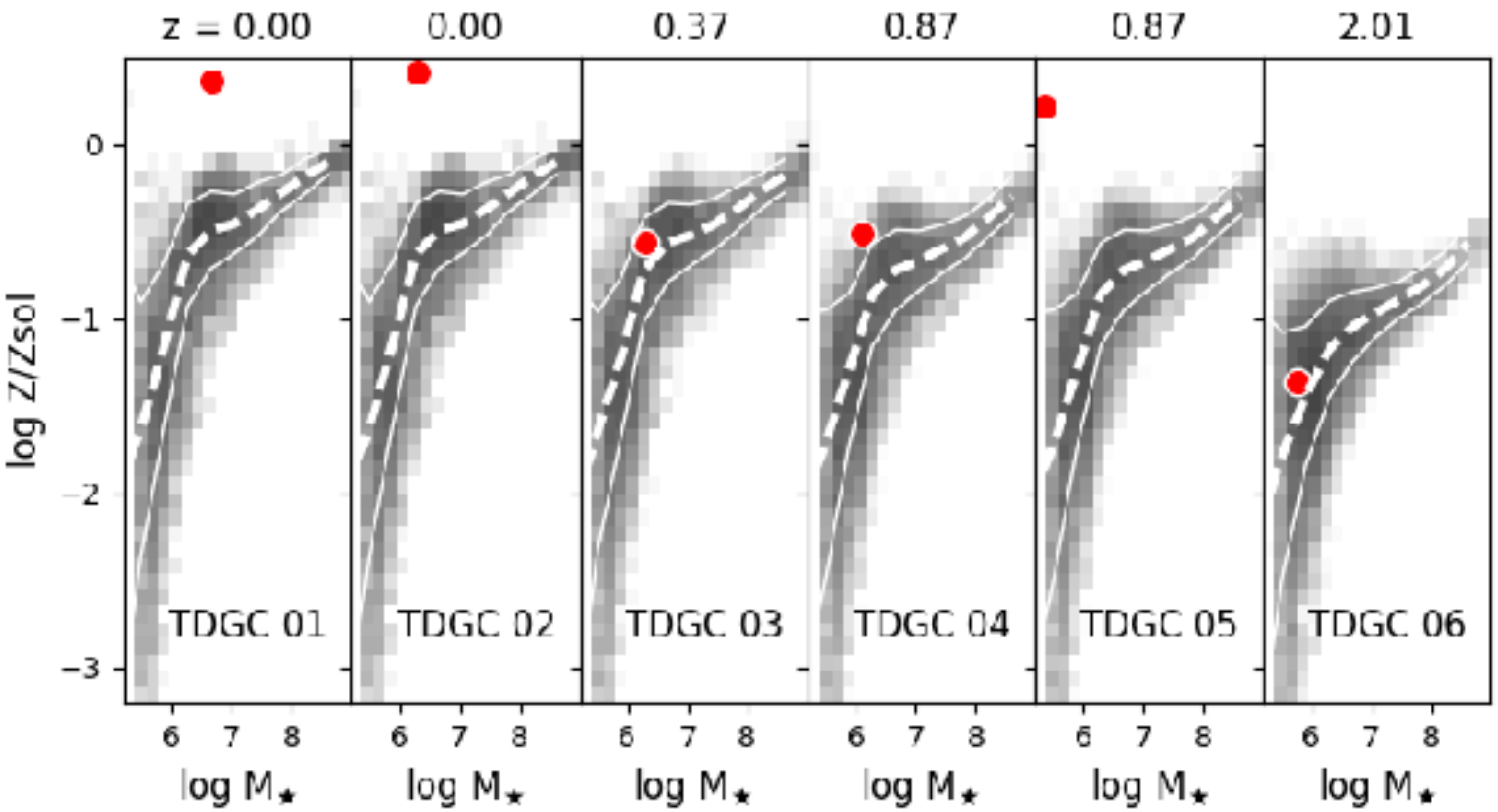
TDG formation in high-speed encounters



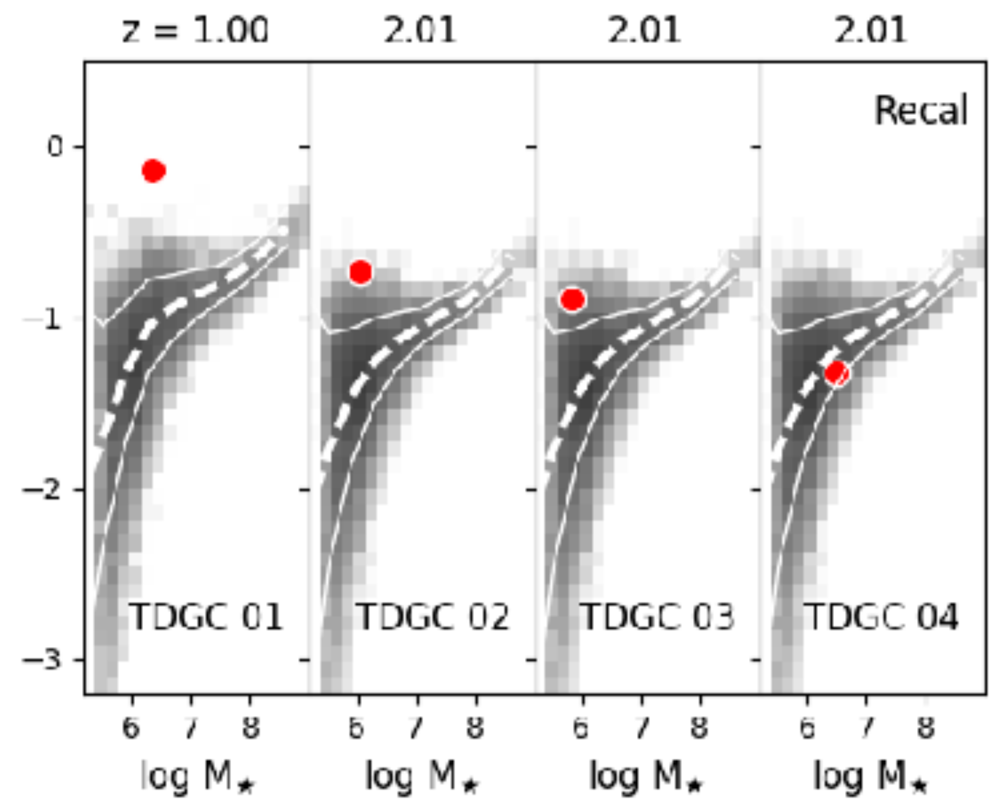
relative velocity: 430 km/s; do not fully merge until redshift 0

Ploeckinger et al. (in prep.)

Mass-metallicity relation



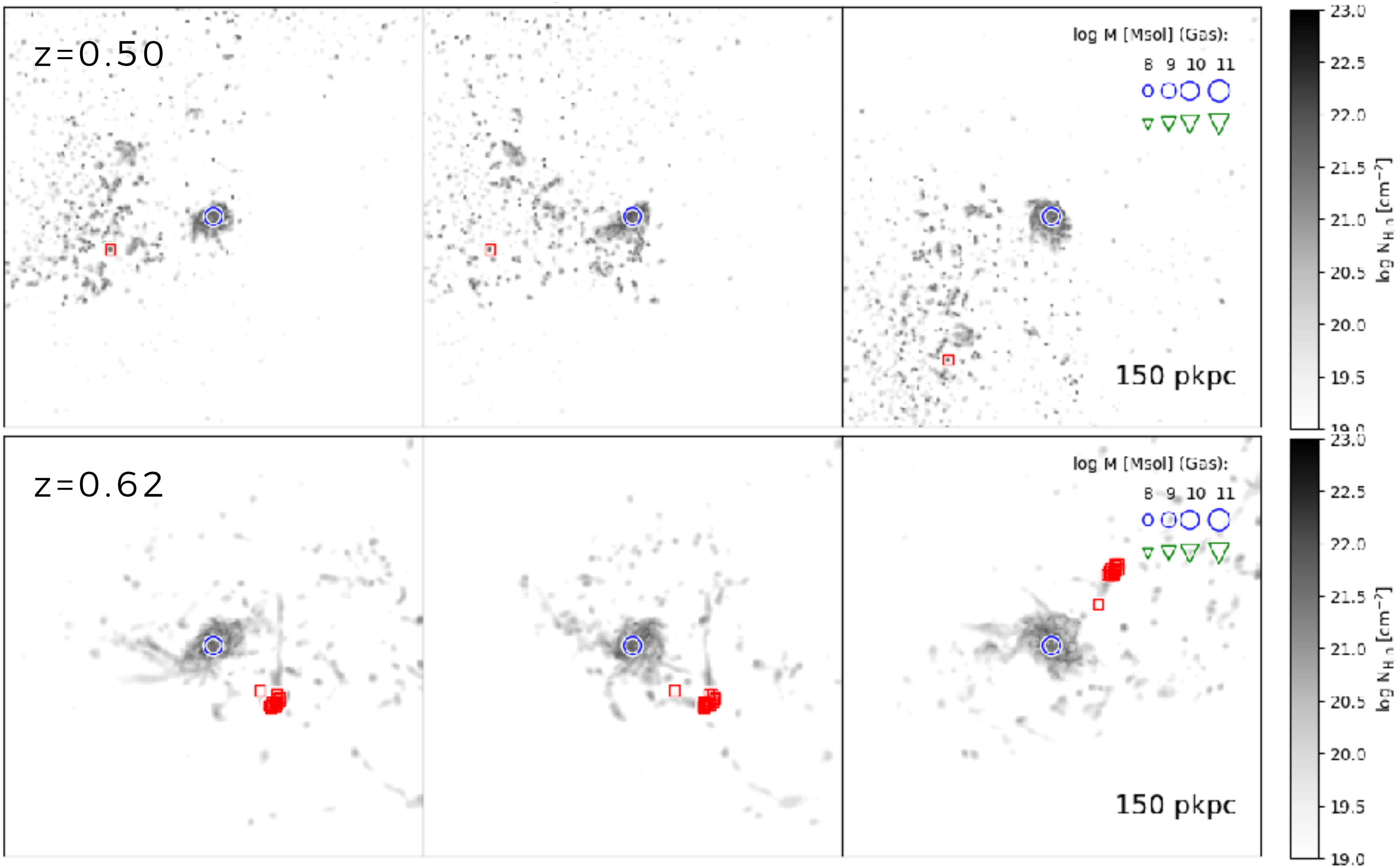
Ref-L025N0752



Recal-L025N0752

Ploeckinger et al. (in prep.)

Another interesting object:



Ploeckinger et al. (in prep.)

What do we need to constrain the formation rate of TDGs from cosmo simulations better?

- higher resolution for better sampling of star formation
- no / lower EOS to trace the collapse further
- reversed merger trees to study the anti-hierarchical structure formation (GCs, TDGs, ram pressure stripped DGs)
- better sub halo identification during major mergers