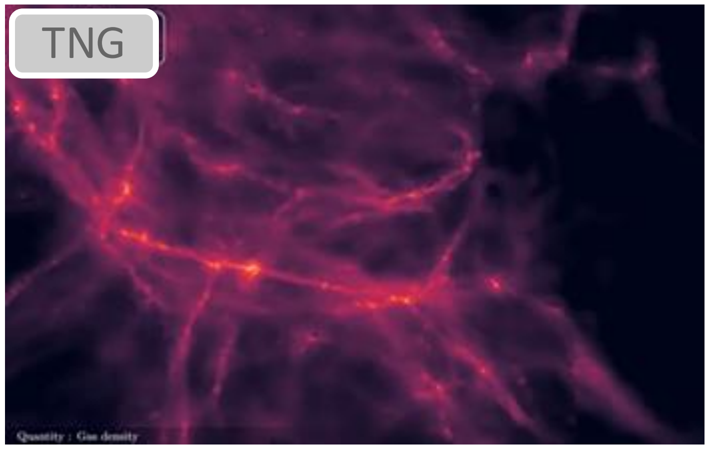
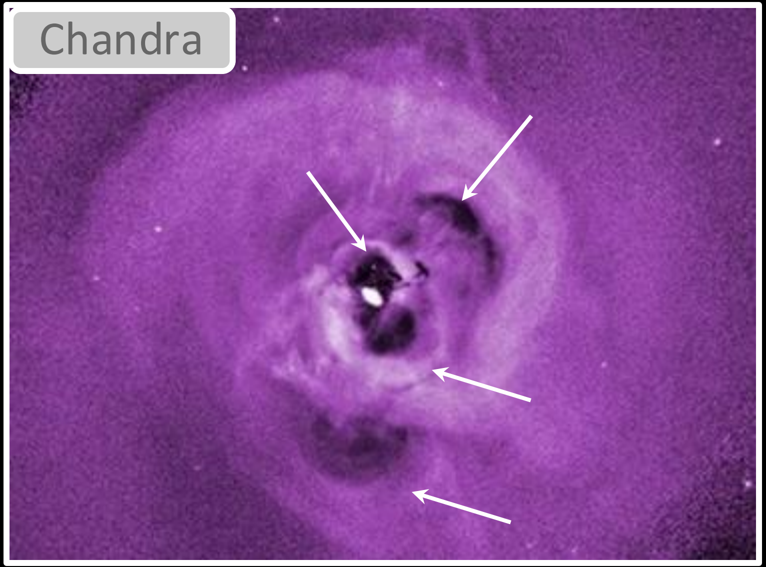
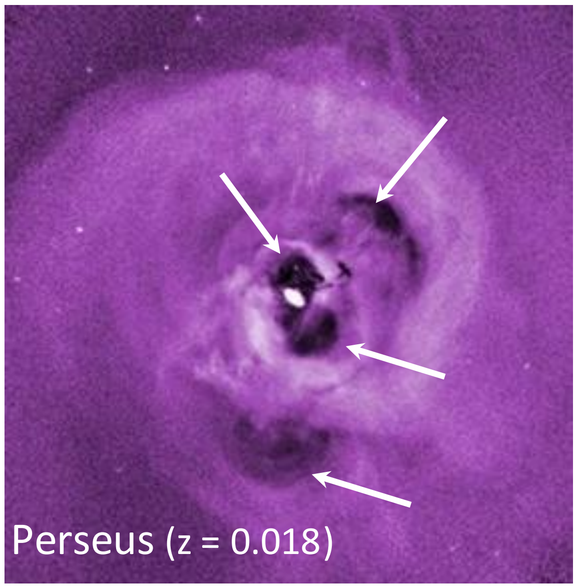
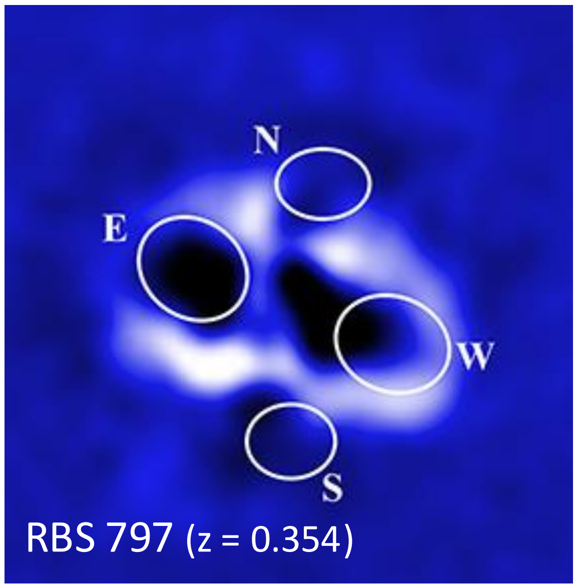
X-ray cavities a synergy between a cosmological simulation and Chandra observations

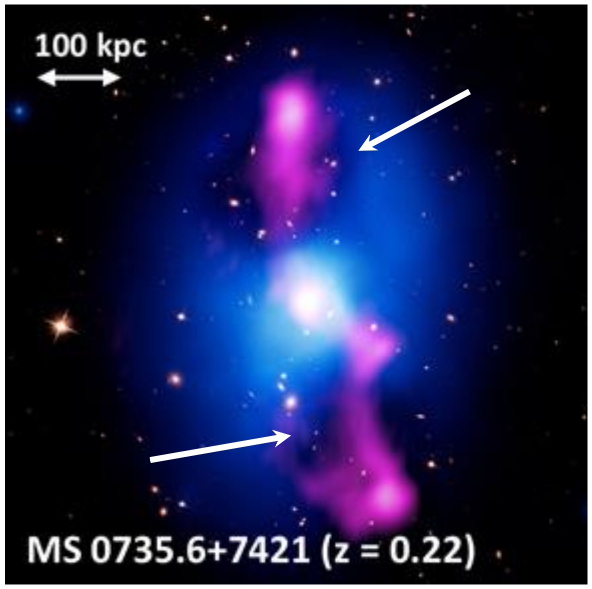


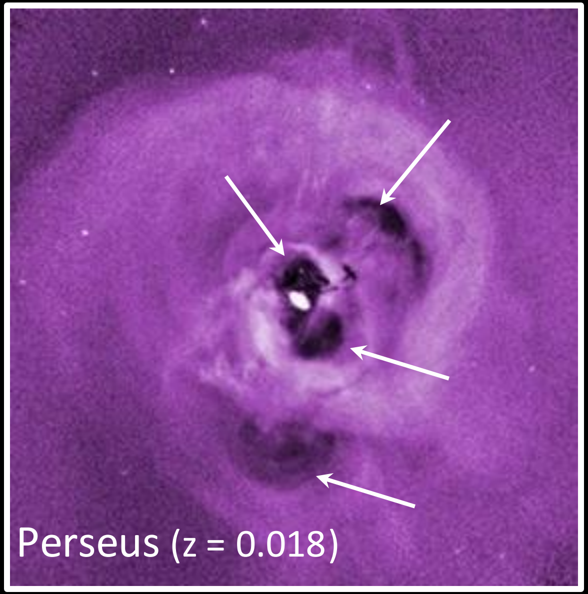


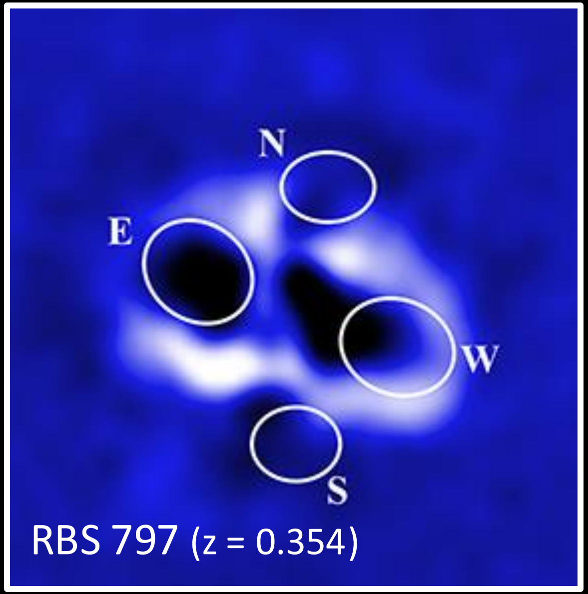
Marine Prunier, PhD candidate
with Julie Hlavacek-Larrondo (UdeM) and Annalisa Pillepich (MPIA)

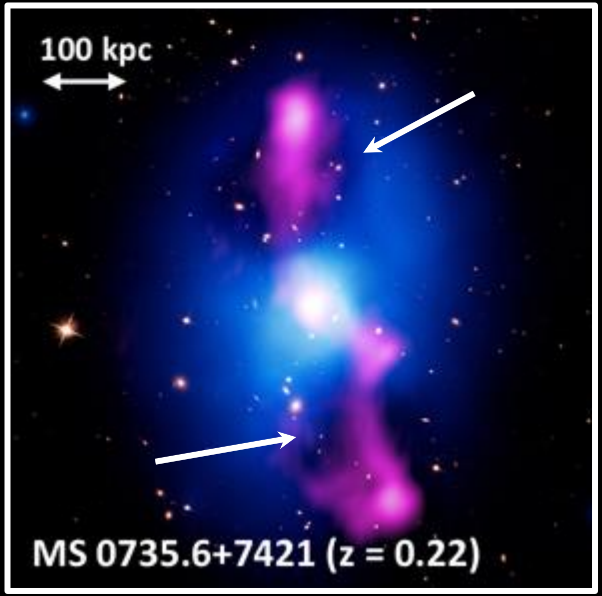

Perseus (z = 0.018)


N
E
W
S
RBS 797 (z = 0.354)

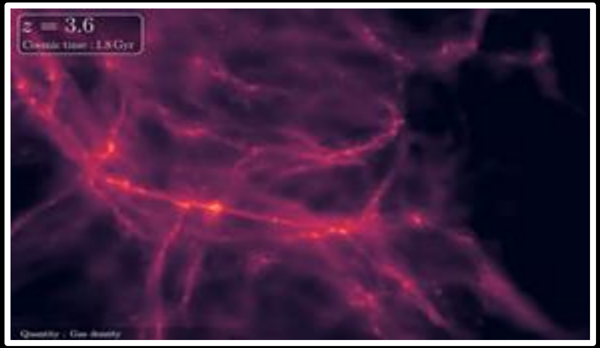

100 kpc
MS 0735.6+7421 (z = 0.22)







Cosmological simulation

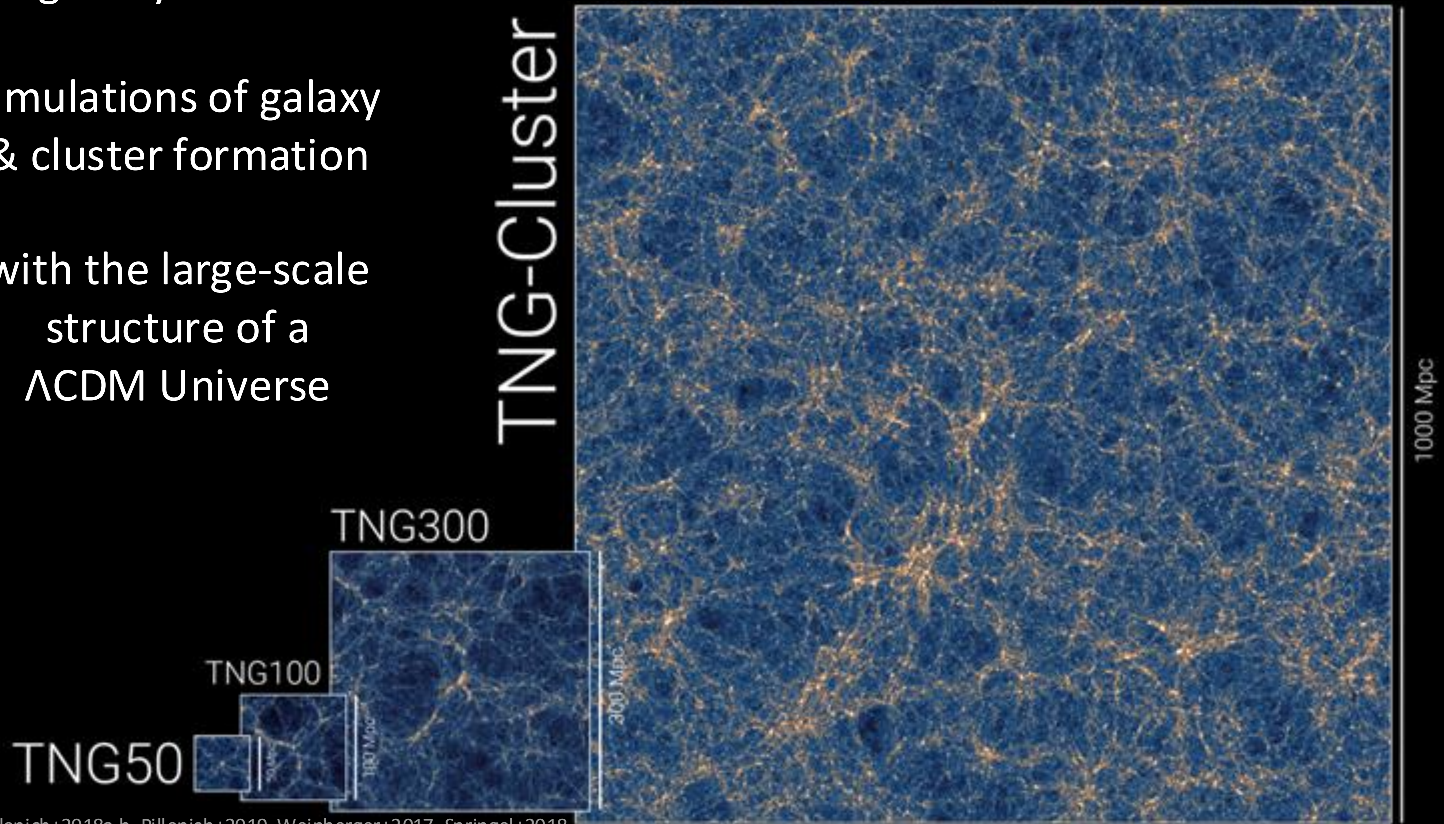


?

gravity + MHD

simulations of galaxy
& cluster formation

with the large-scale
structure of a
ΛCDM Universe



Pillepich+2018a,b, Pillepich+2019, Weinberger+2017, Springel+2018,
Nelson+2018, Nelson+2019a,b, Naiman+2018, Marinacci+2018

Nelson+2024, Truong+2024, Lehle+2024, Lee+2024, Rohr+2024, Ayromlou+2024

-star formation,
evolution,
enrichment

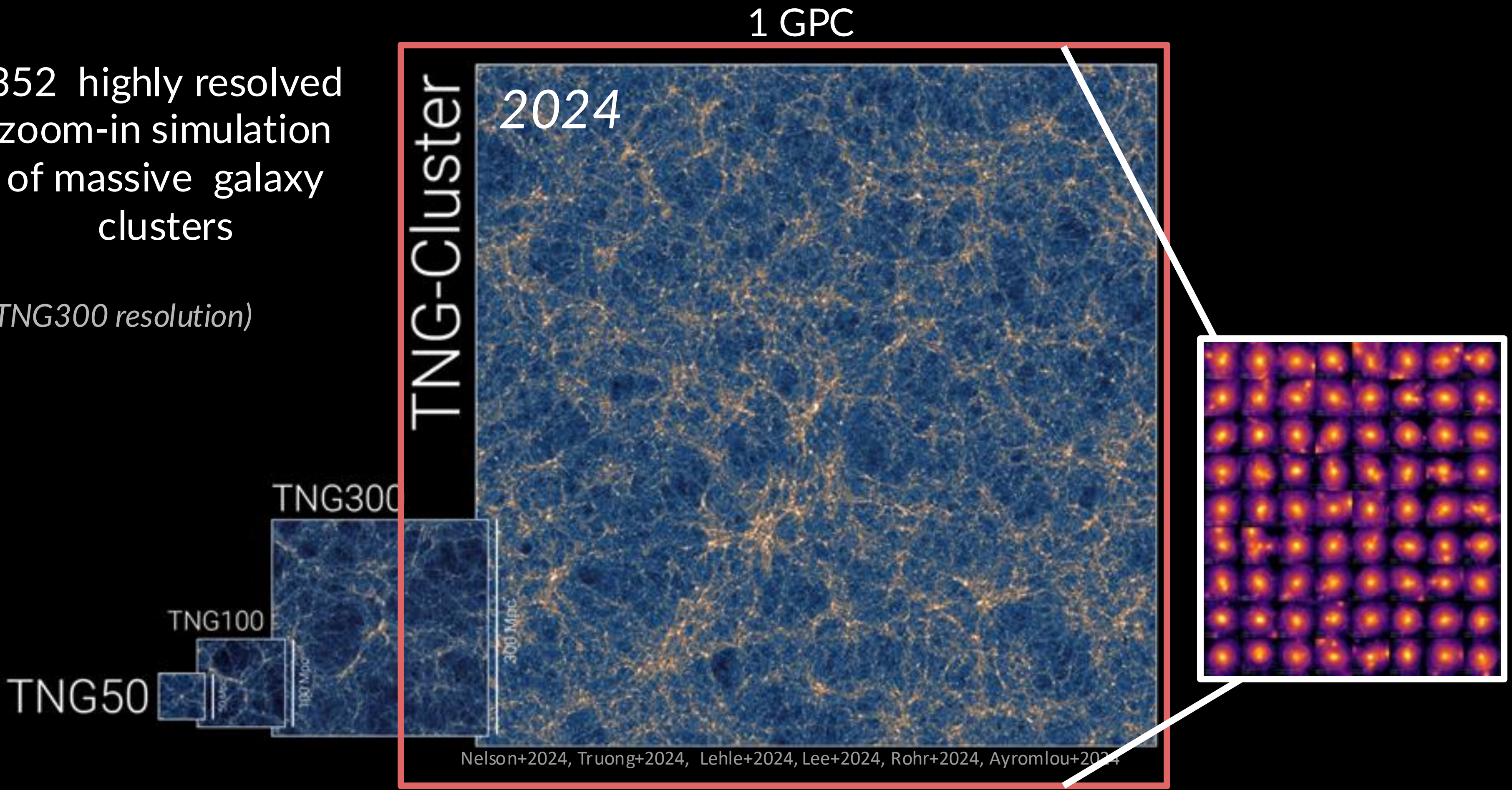
-heating/cooling of
the gas

-stellar feedback

-SMBH growth,
feedback, merger

352 highly resolved zoom-in simulation of massive galaxy clusters

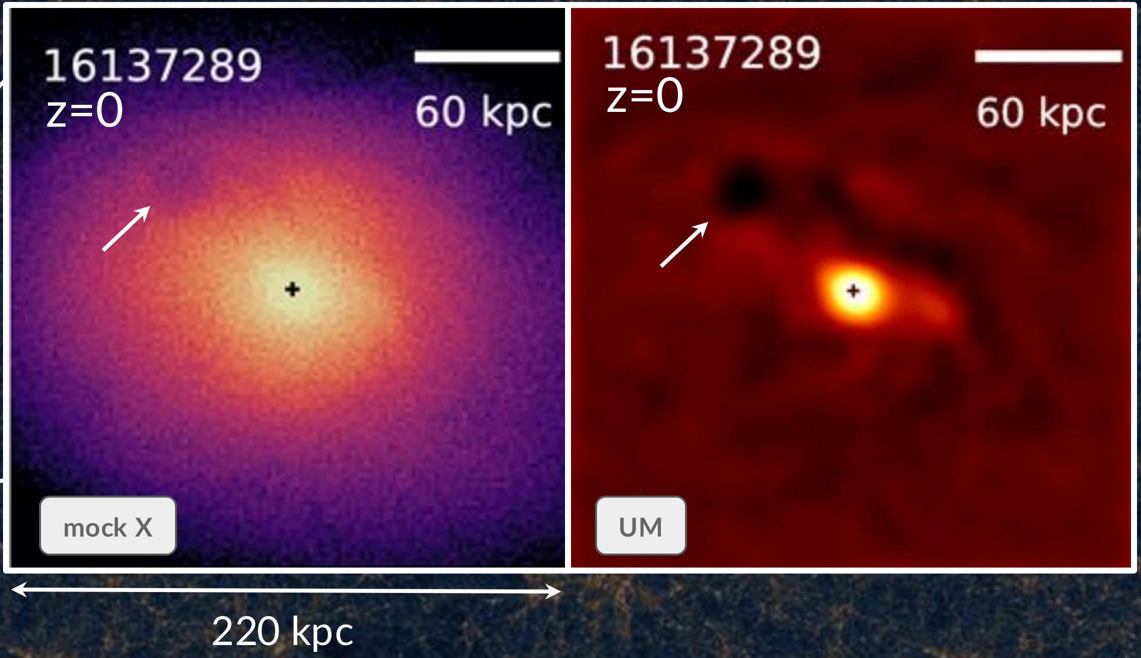
(TNG300 resolution)

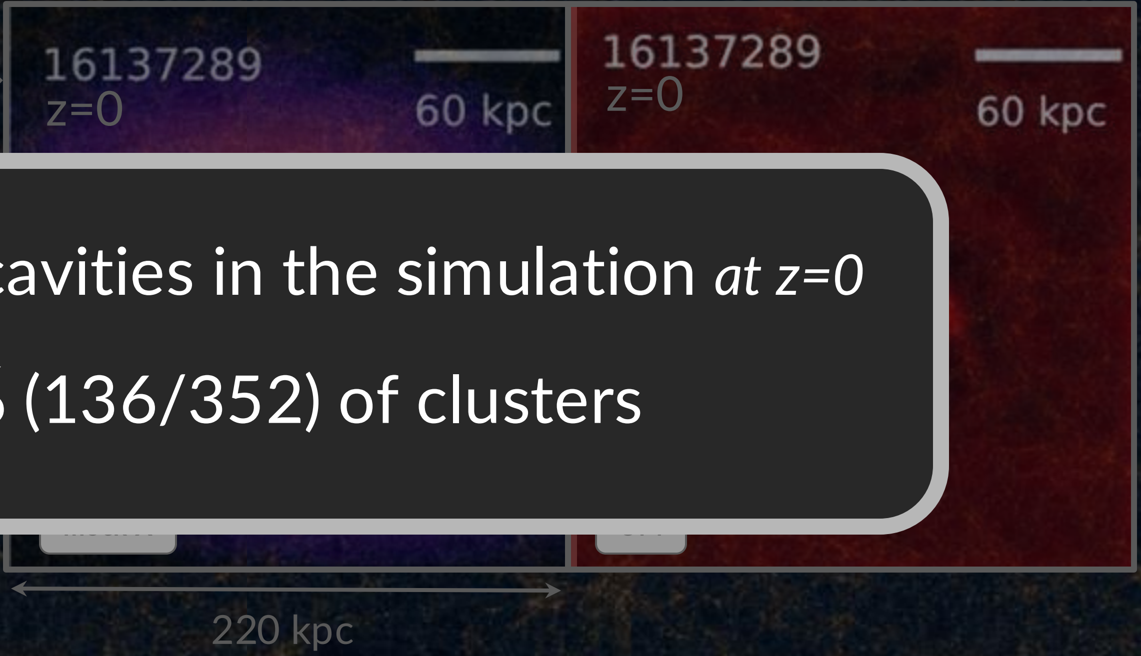


1. Are there X-ray cavities in the clusters simulated with TNG-Cluster?

1. Are there X-ray cavities in the clusters simulated with TNG-Cluster?

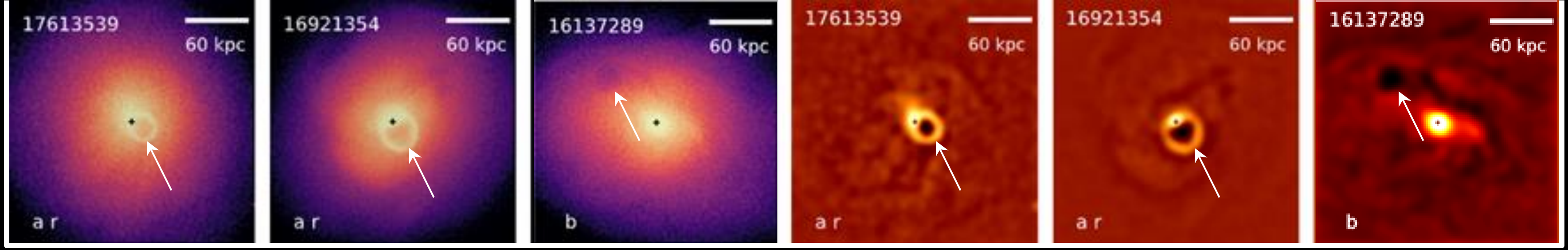
2. Are they realistic compared to the ones observed with Chandra?


16137289
z=0
60 kpc
mock X
16137289
z=0
60 kpc
UM
220 kpc

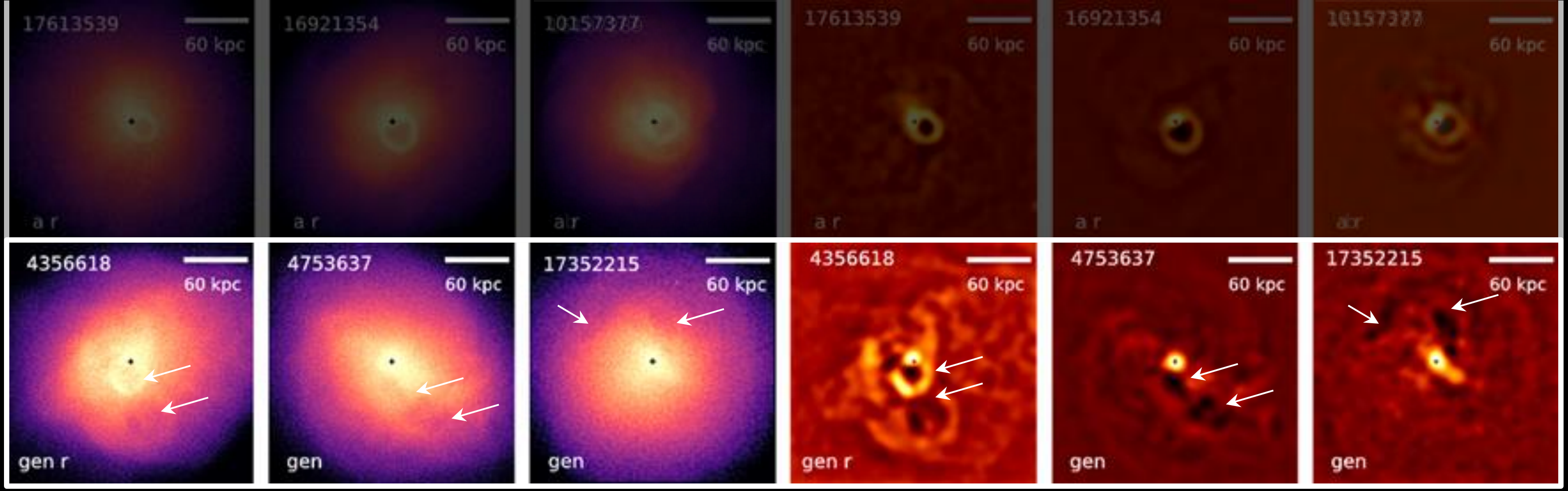


233 X-ray cavities in the simulation *at z=0*

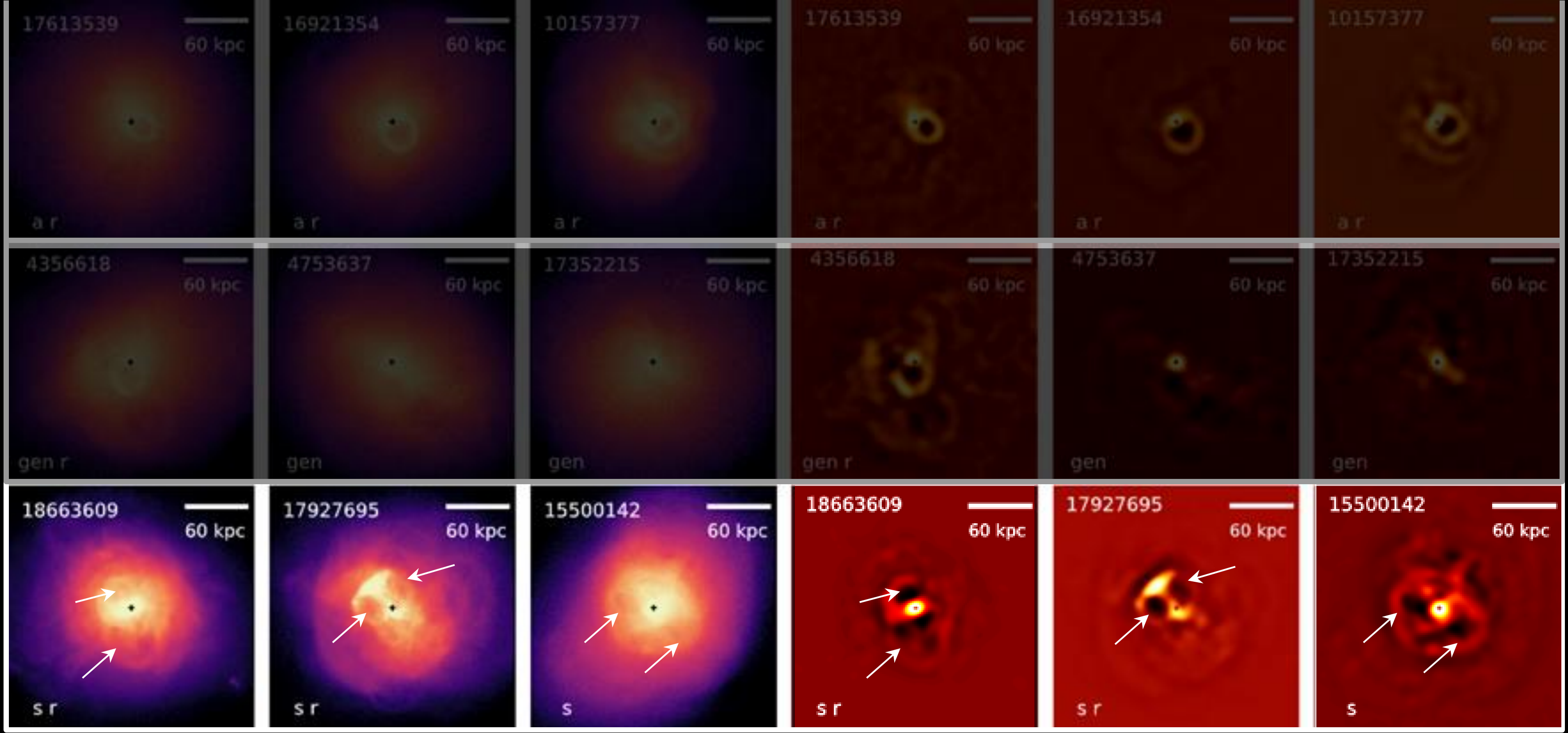
39% (136/352) of clusters



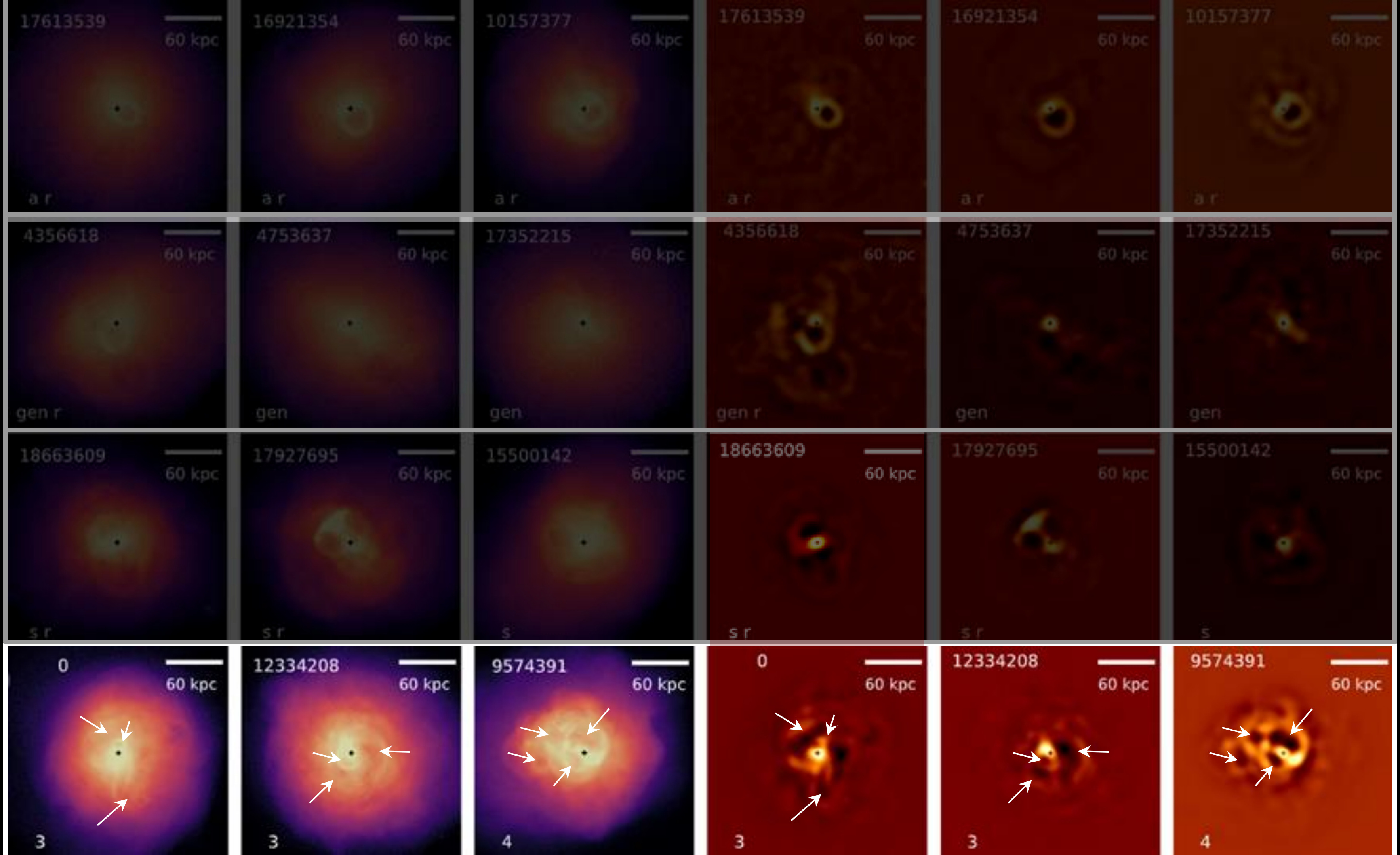
17613539
60 kpc
a r
16921354
60 kpc
a r
16137289
60 kpc
b
17613539
60 kpc
a r
16921354
60 kpc
a r
16137289
60 kpc
b



Different evolutionary stages and generations

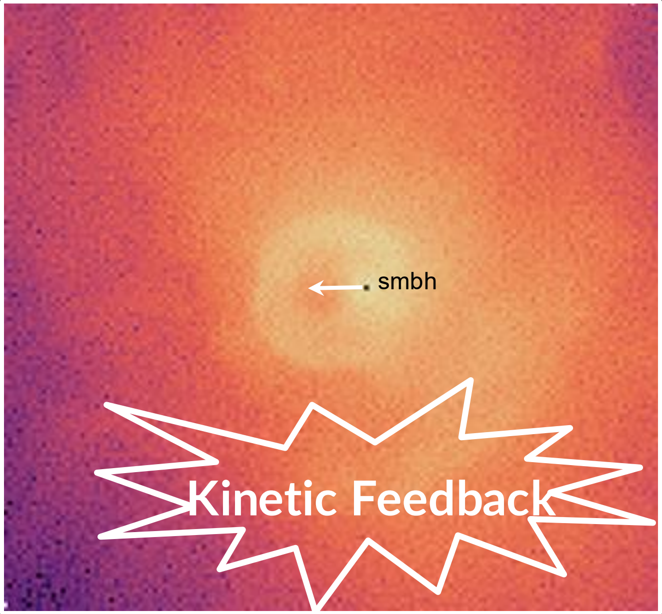


Some symmetric pair of cavities



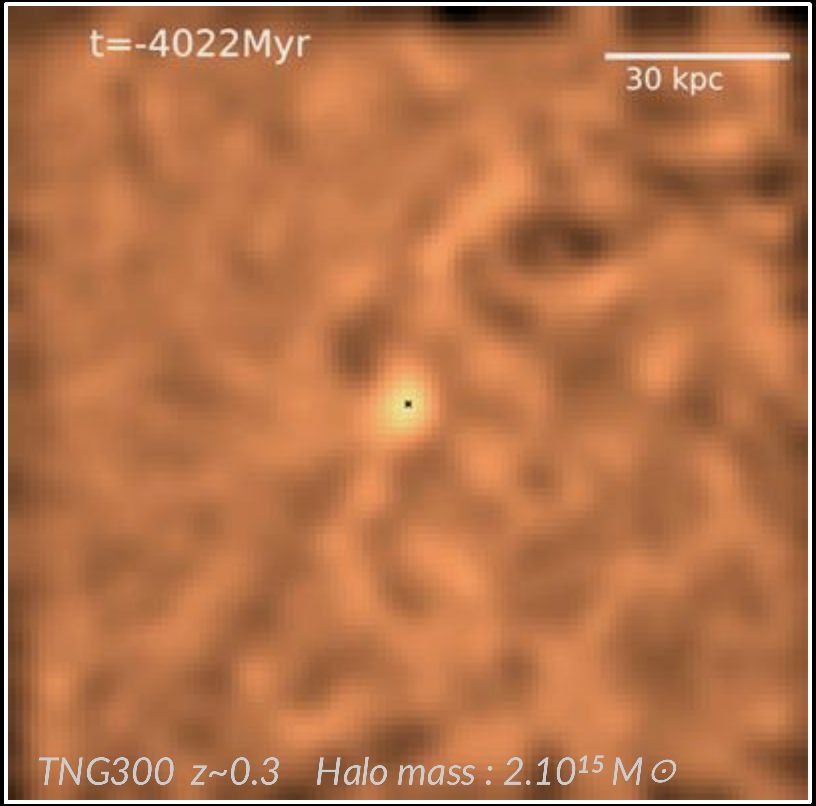
17613539
60 kpc
16921354
60 kpc
10157377
60 kpc
17613539
60 kpc
16921354
60 kpc
10157377
60 kpc
4356618
60 kpc
4753637
60 kpc
17352215
60 kpc
4356618
60 kpc
4753637
60 kpc
17352215
60 kpc
18663609
60 kpc
17927695
60 kpc
15500142
60 kpc
18663609
60 kpc
17927695
60 kpc
15500142
60 kpc
0
60 kpc
3
12334208
60 kpc
3
9574391
60 kpc
4
0
60 kpc
3
12334208
60 kpc
3
9574391
60 kpc
4

no cosmic rays and no collimated jets, but



Weinberger, Springel ,Pillepich 2017 | Pillepich, Springel, Nelson + 2018

X-ray + UM filter



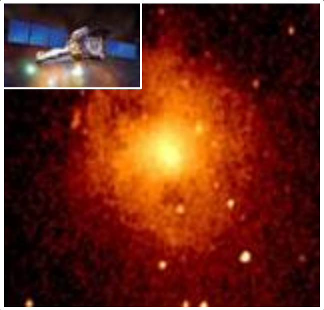
Time resolution : ~10 Myr SMBH: 5.10^{10} M⊙

1. Are there X-ray cavities in the clusters simulated with TNG-Cluster? ✅

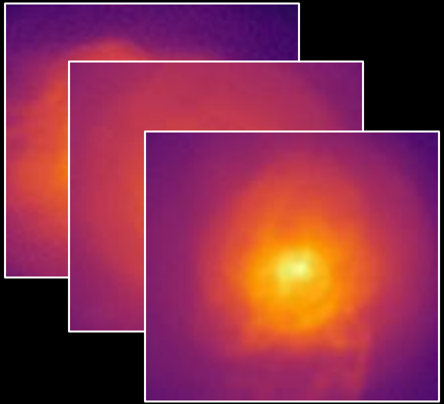
2. **Are they realistic compared to the ones observed with Chandra?**

Observations → Simulation → Mock Observations

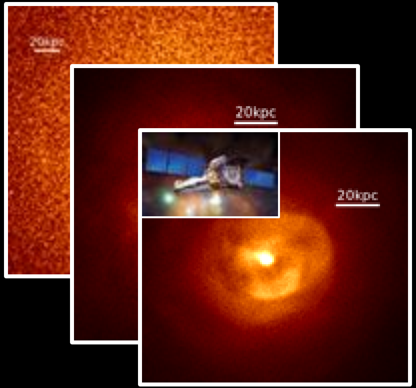
35 real clusters

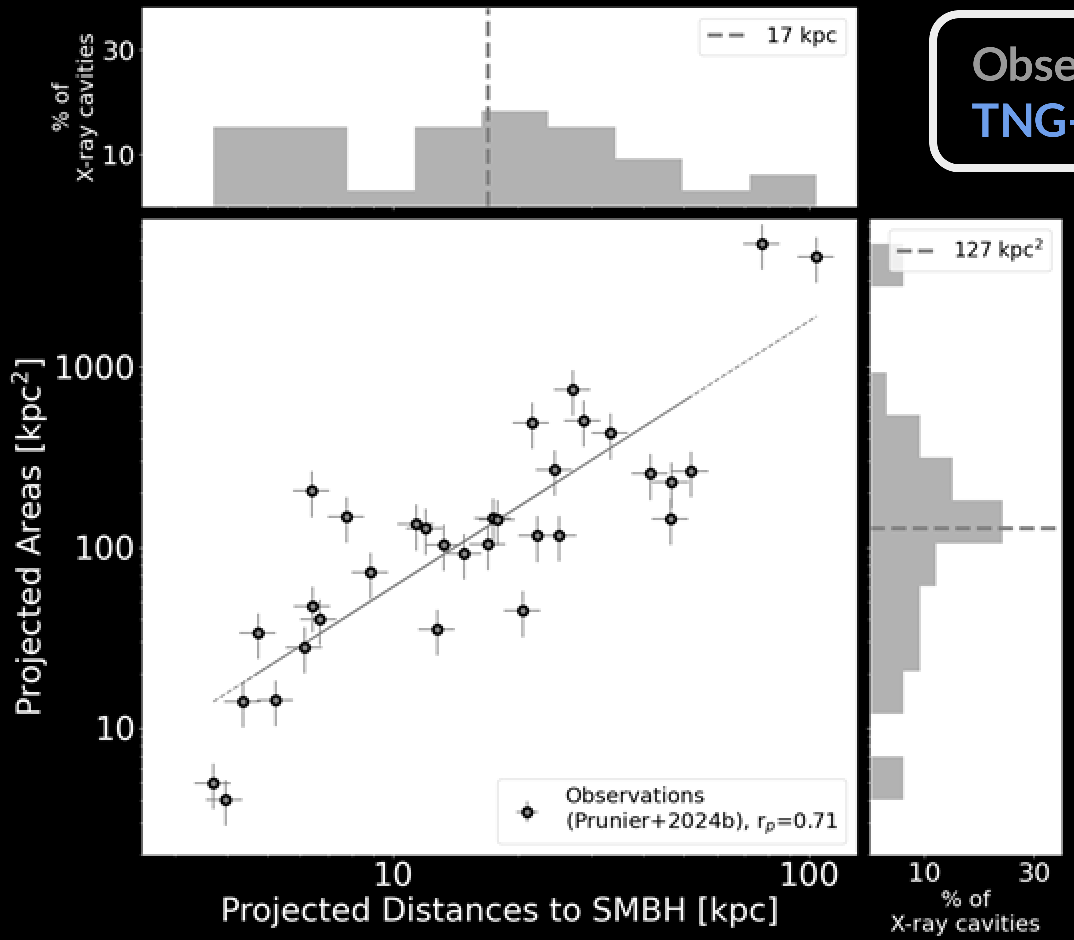


105 TNG-Cluster analogs (L_x & t_{cool})

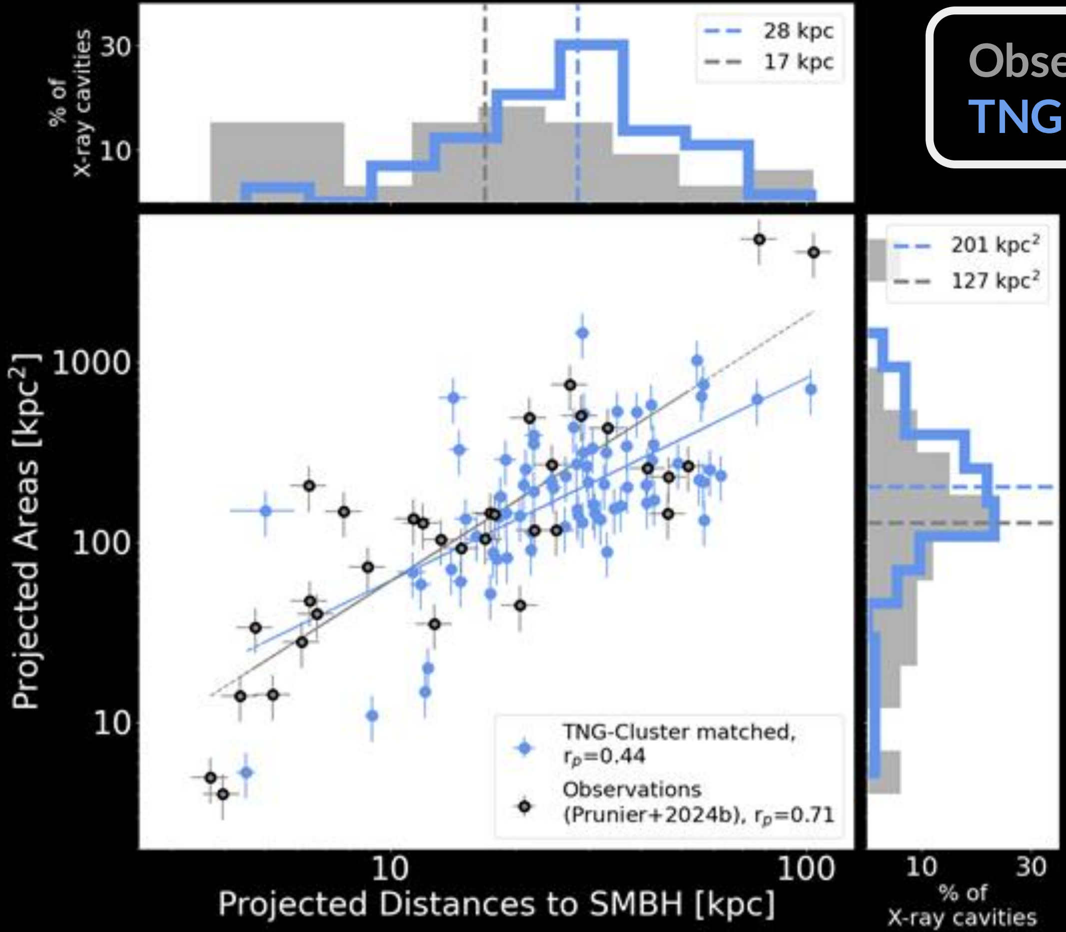


105 mock Chandra images



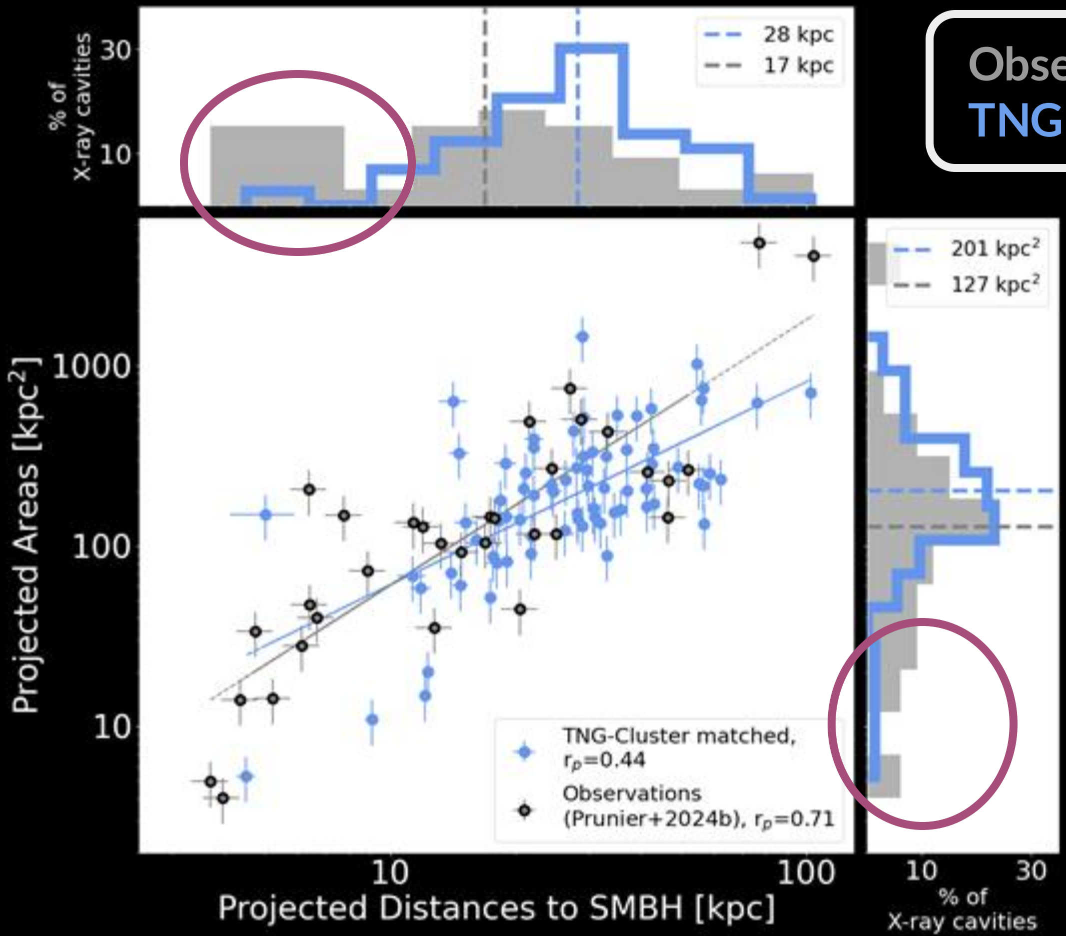


Observations
TNG-Cluster



Observations
TNG-Cluster

- similar detection rate (~ 40%)
- similar trend



Observations
TNG-Cluster

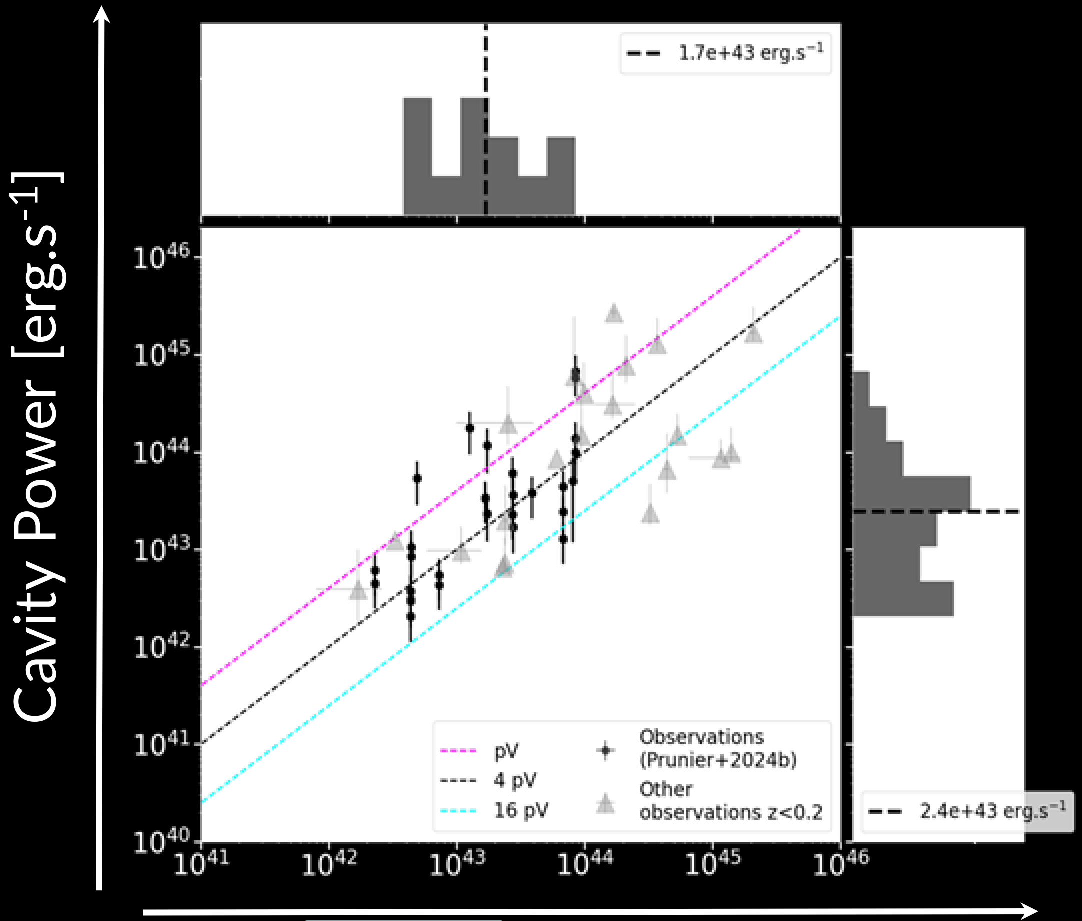
- similar detection rate (~ 40%)
- similar trend

TNG-cavities tend to be **larger and further away from SMBH**

All quantities are measured using observational techniques

Observations
TNG-Cluster

Heating

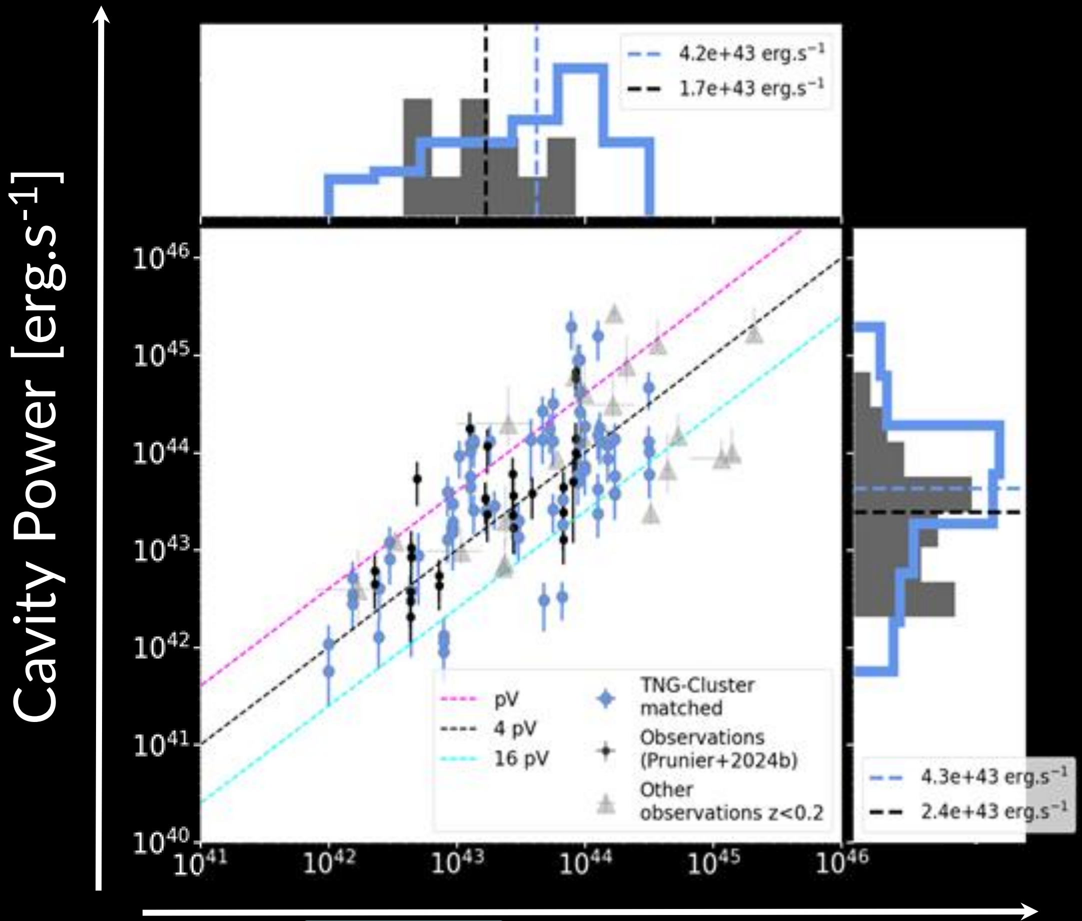


Cooling Luminosity [erg.s^{-1}]

All quantities are measured using observational techniques

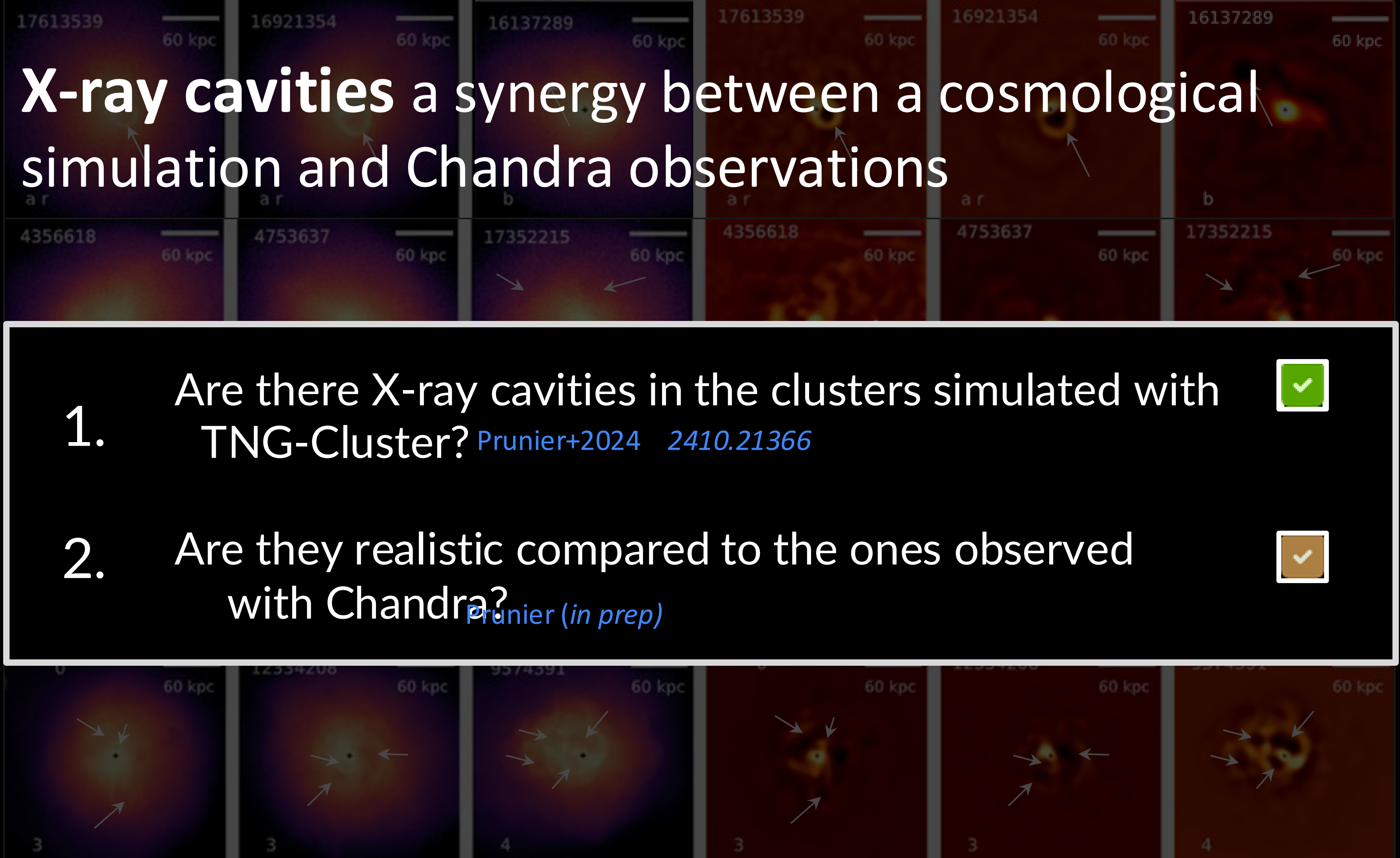
Observations
TNG-Cluster

Heating



Cooling Luminosity [erg.s^{-1}]

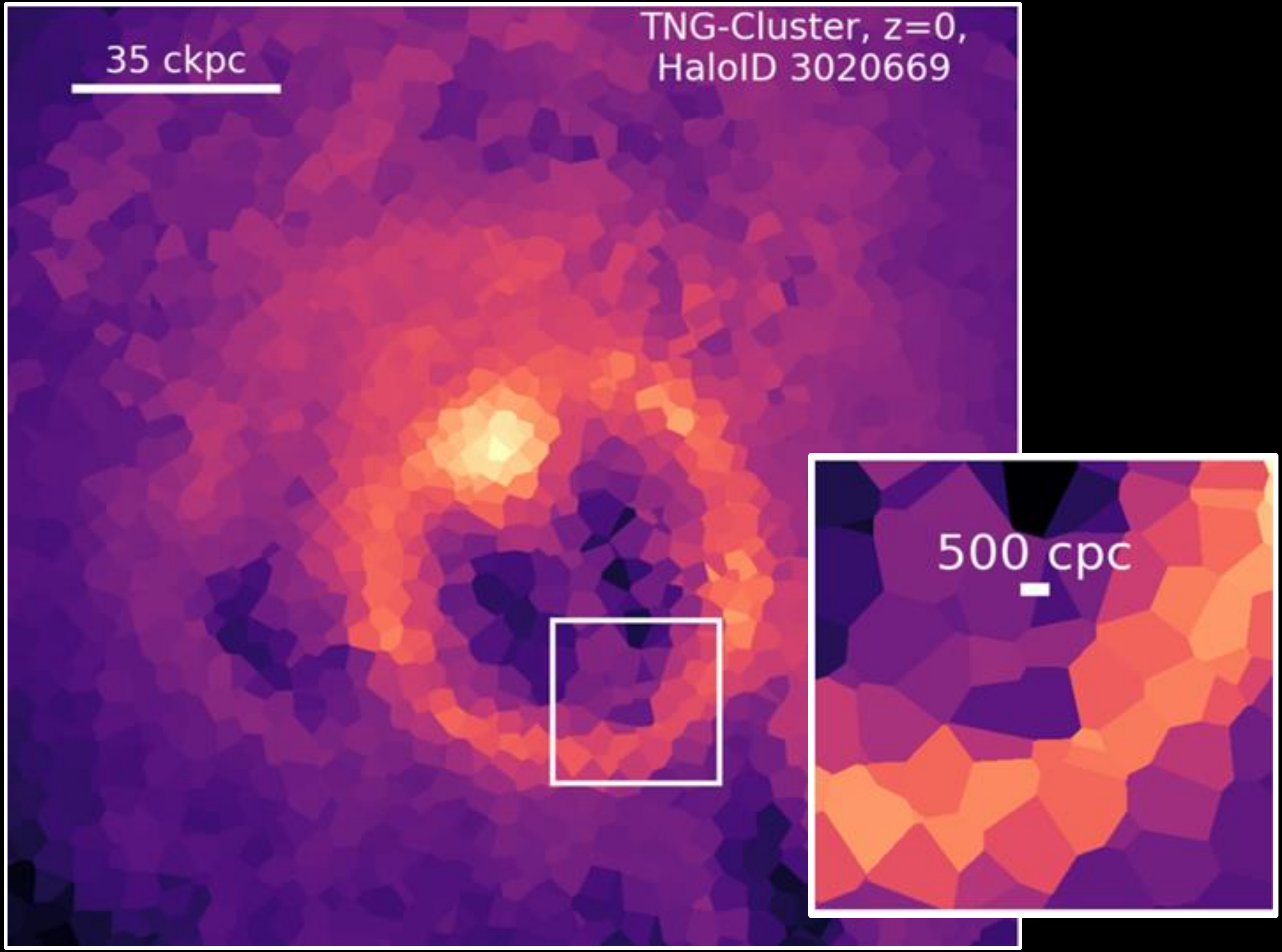
TNG cavities have enough power to offset ICM cooling



X-ray cavities a synergy between a cosmological simulation and Chandra observations

1. Are there X-ray cavities in the clusters simulated with TNG-Cluster? Prunier+2024 *2410.21366*

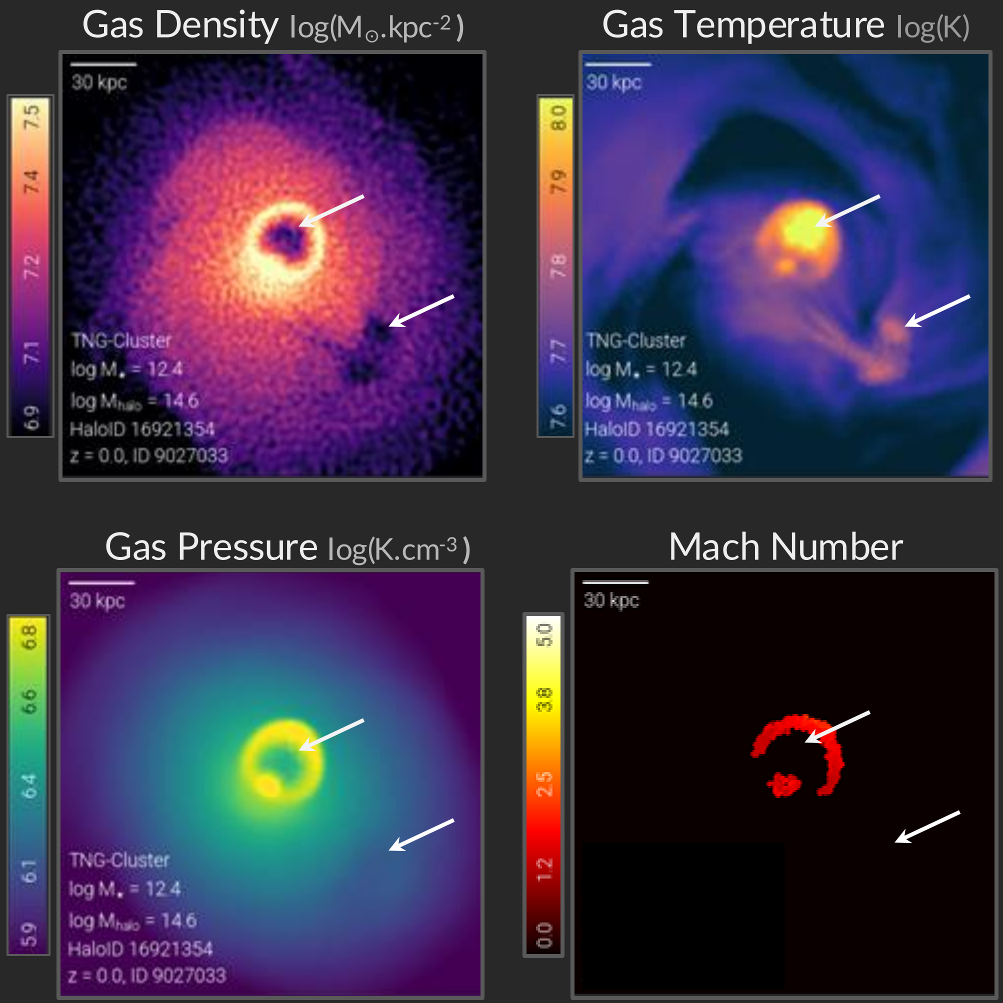
2. Are they realistic compared to the ones observed with Chandra? Prunier (*in prep)*

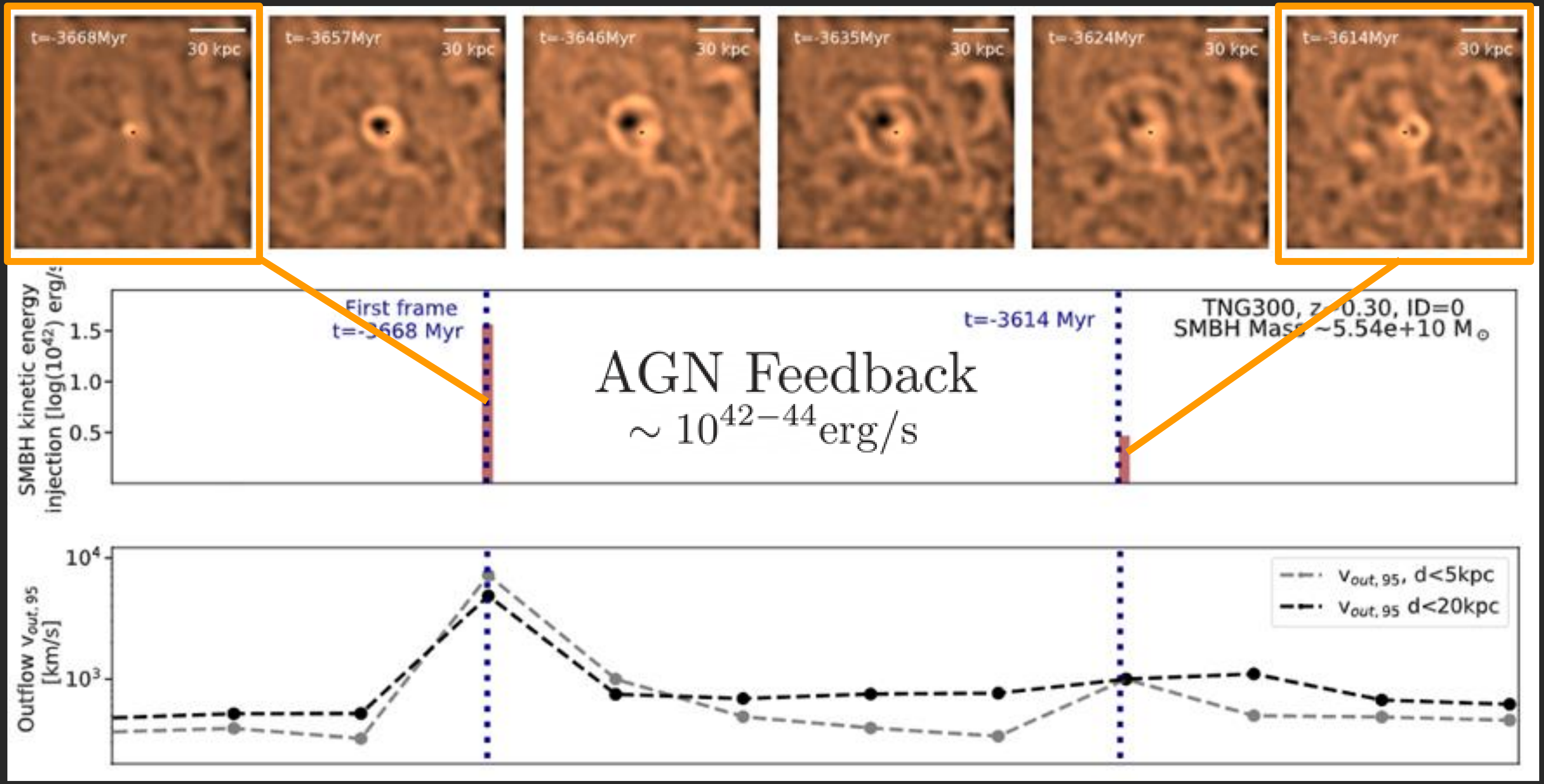

35 ckpc
TNG-Cluster, z=0,
HaloID 3020669
500 cpc

A few properties

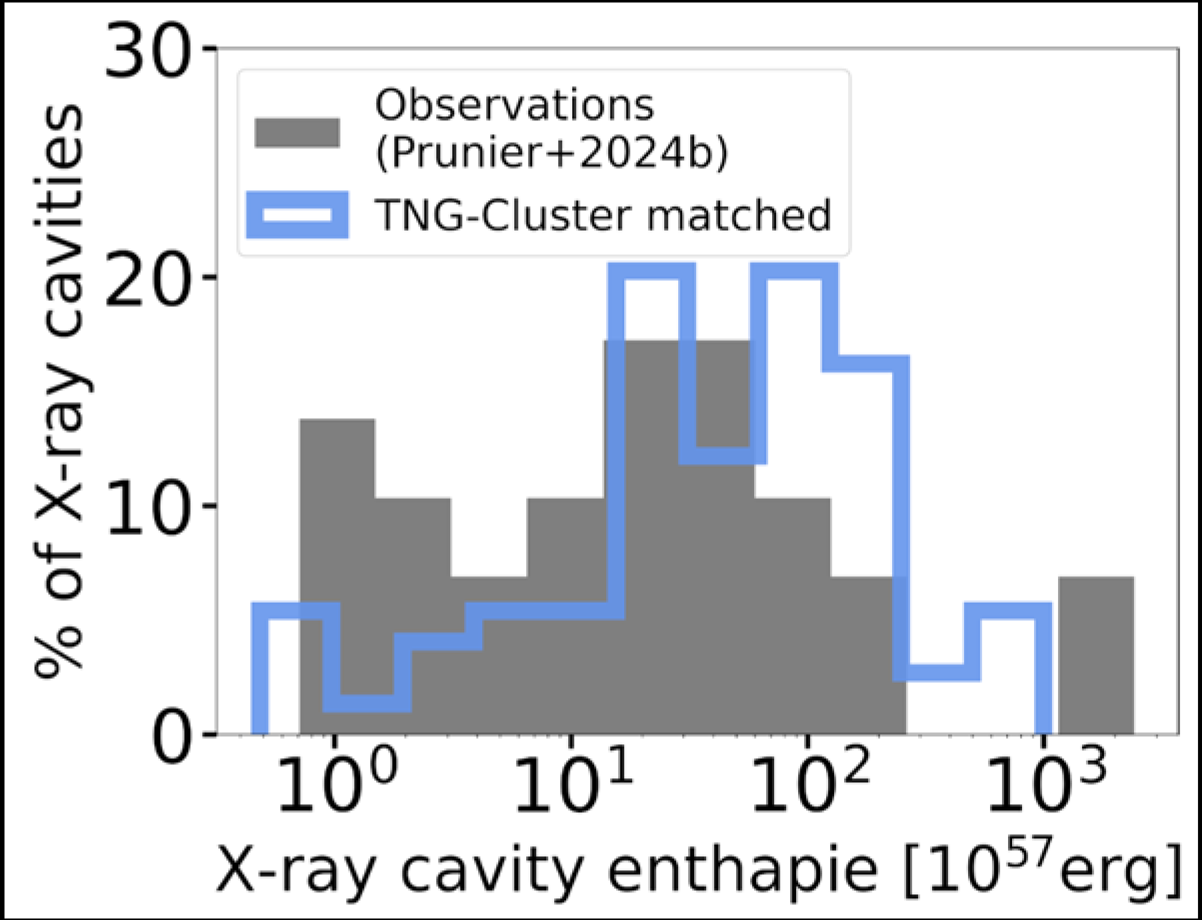
- x-ray brightness depression
- under dense
- filled with hot gas **$10^{8\text{-}8.4}$ K**

~1/4 cavities have:
over pressurised x-ray bright edges with weak shocks (~ 1.2-1.8 mach)

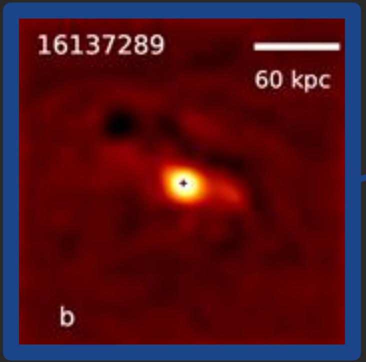


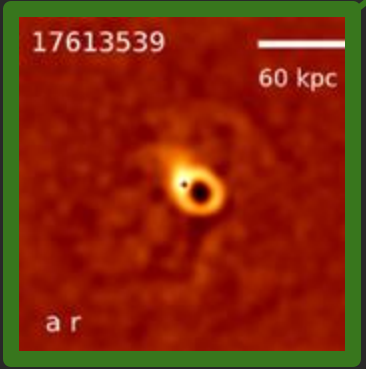


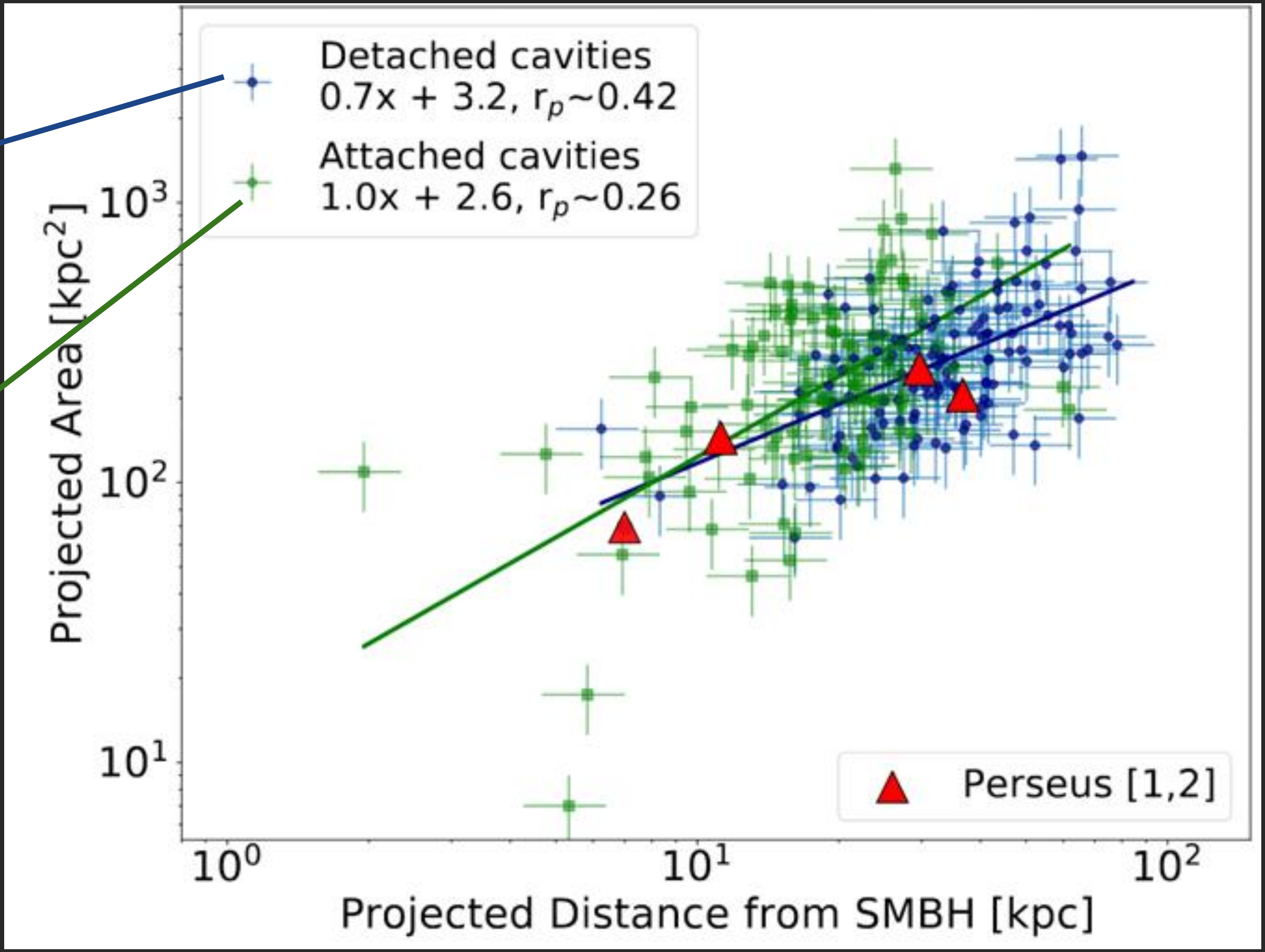
t=-3668Myr
30 kpc
t=-3657Myr
30 kpc
t=-3646Myr
30 kpc
t=-3635Myr
30 kpc
t=-3624Myr
30 kpc
t=-3614Myr
30 kpc
First frame
t=-3668 Myr
t=-3614 Myr
TNG300, z=0.30, ID=0
SMBH Mass ~5.54e+10 $M_\odot$
AGN Feedback
$\sim 10^{42-44}$erg/s
SMBH kinetic energy injection [log(10^{42}) erg/s]
1.5
1.0
0.5
Outflow $v_{out,95}$ [km/s]
10^4
10^3
$v_{out,95}$, d<5kpc
$v_{out,95}$ d<20kpc

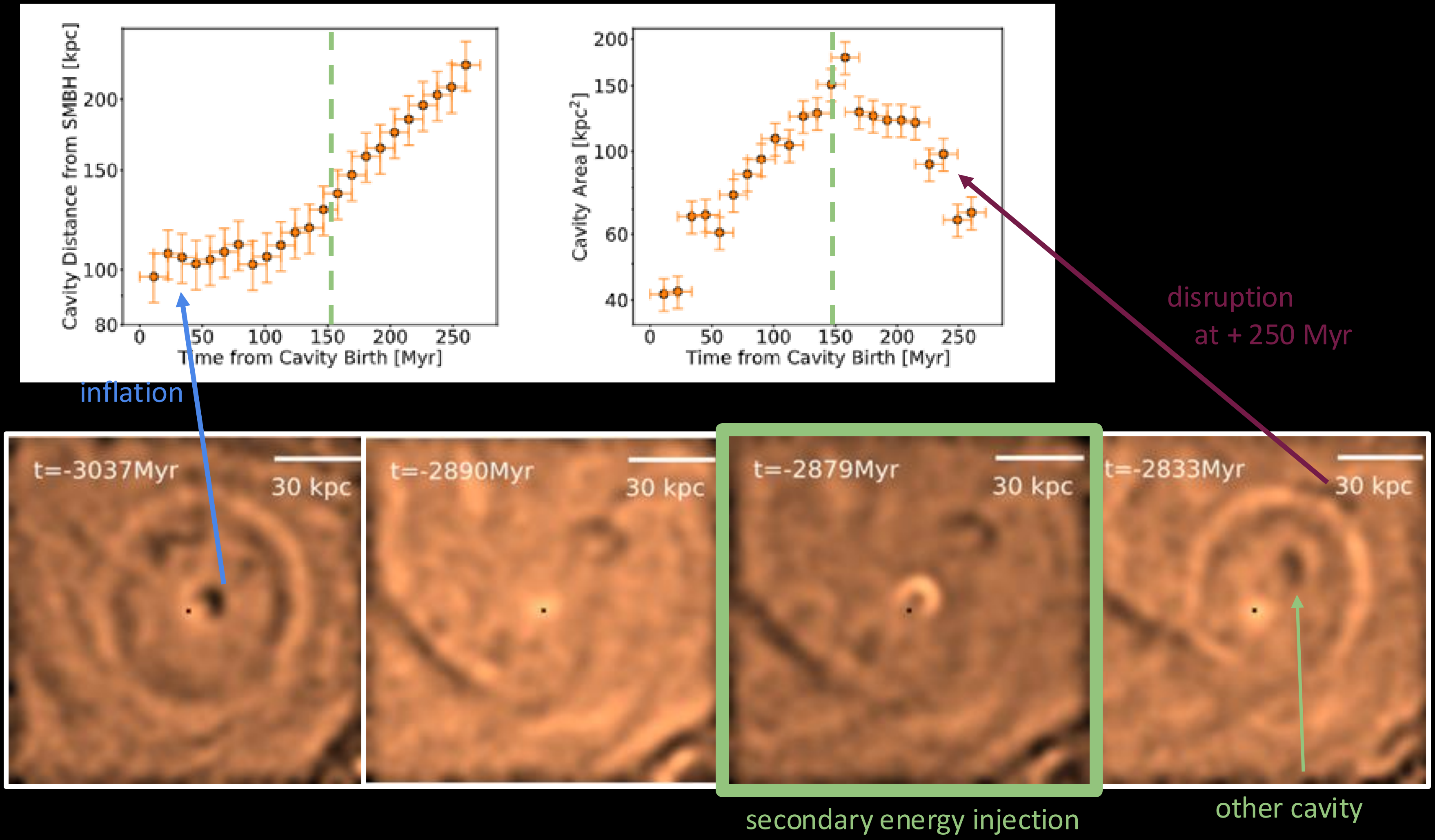


30
20
10
0
% of X-ray cavities
Observations
(Prunier+2024b)
TNG-Cluster matched
10^0
10^1
10^2
10^3
X-ray cavity enthapie [10^{57}erg]


16137289
60 kpc
b


17613539
60 kpc
a r

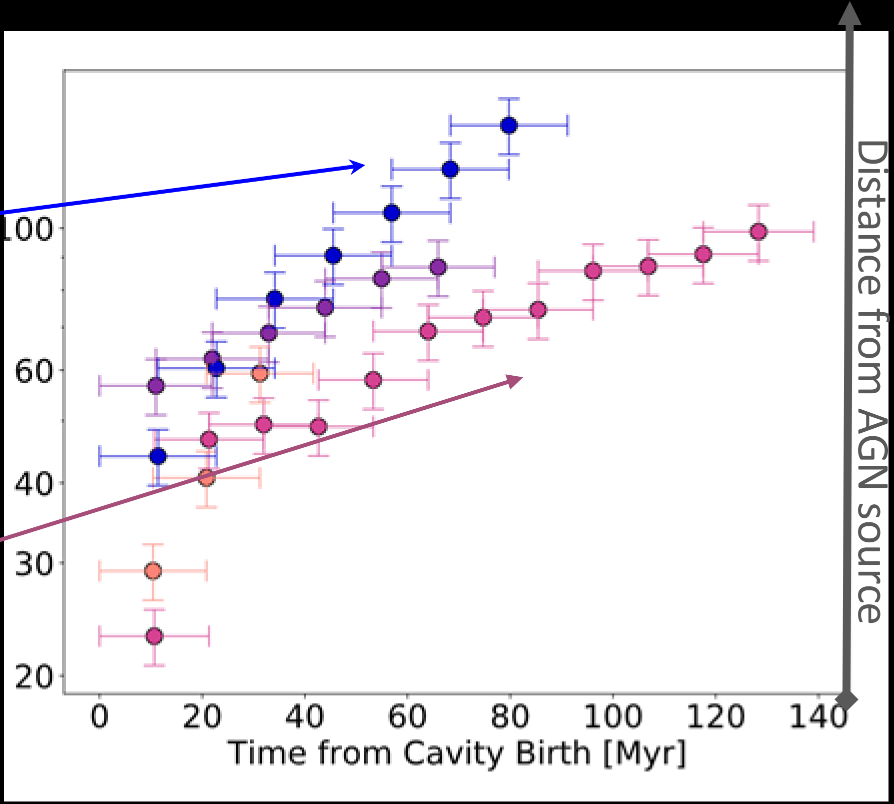

Detached cavities
0.7x + 3.2, r_p~0.42
Attached cavities
1.0x + 2.6, r_p~0.26
Perseus [1,2]
Projected Area [kpc^2]
Projected Distance from SMBH [kpc]
10^0
10^1
10^2
10^1
10^2
10^3



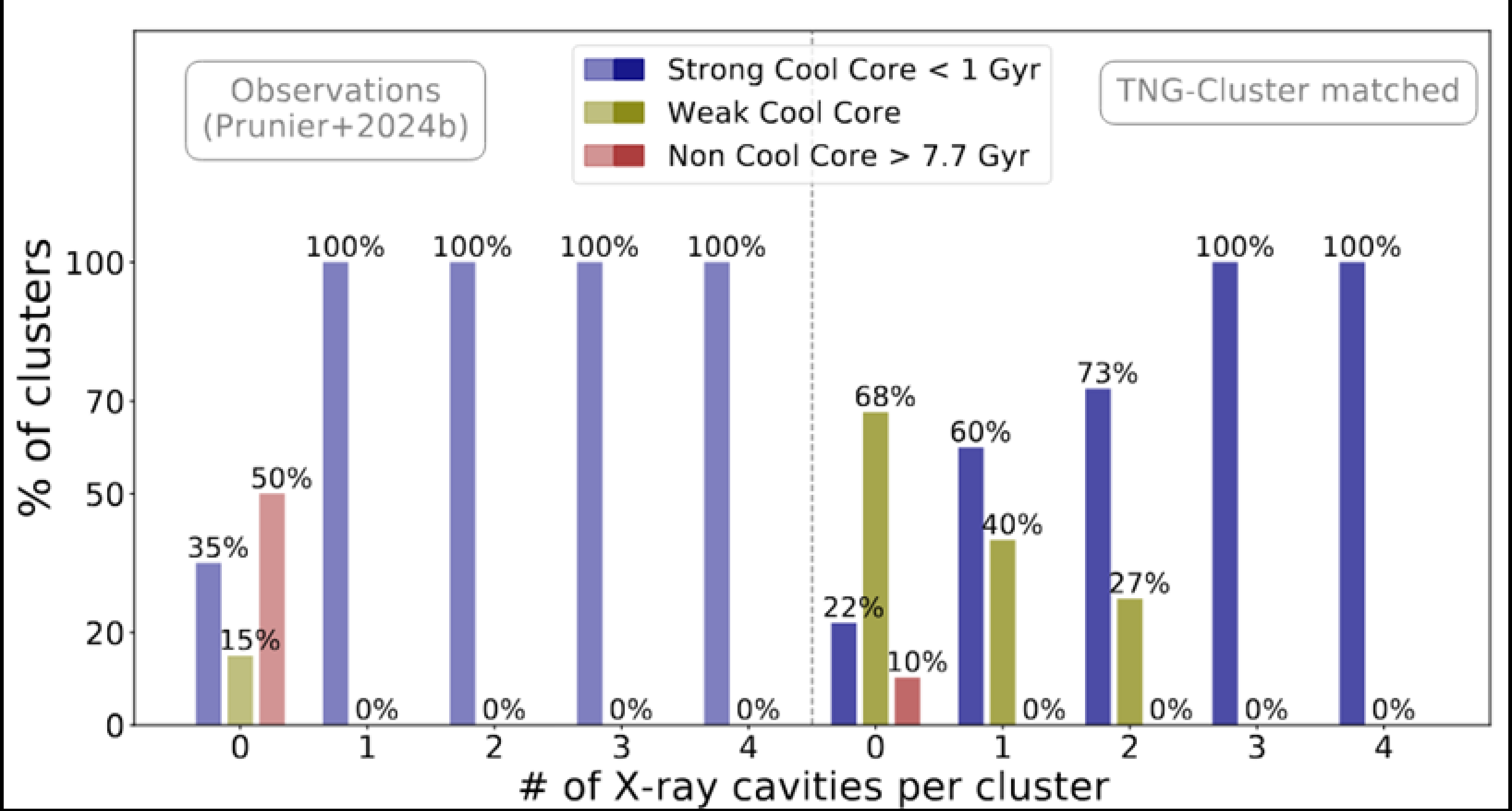
Cavity Distance from SMBH [kpc]
Time from Cavity Birth [Myr]
Cavity Area [kpc^2]
Time from Cavity Birth [Myr]
inflation
disruption
at + 250 Myr
t=-3037Myr
30 kpc
t=-2890Myr
30 kpc
t=-2879Myr
30 kpc
t=-2833Myr
30 kpc
secondary energy injection
other cavity

- **Calm ICM:**
  cavities have time to rise radially
  (life duration ~70 to 150 Myr)

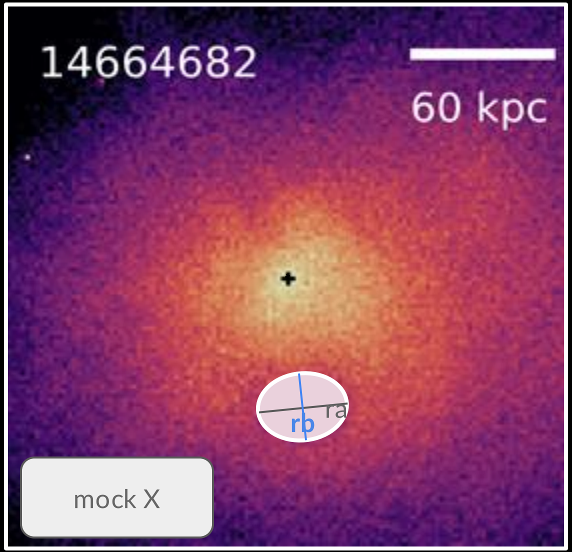
- **Disturbed ICM :** follow sloshing patterns or rise more slowly

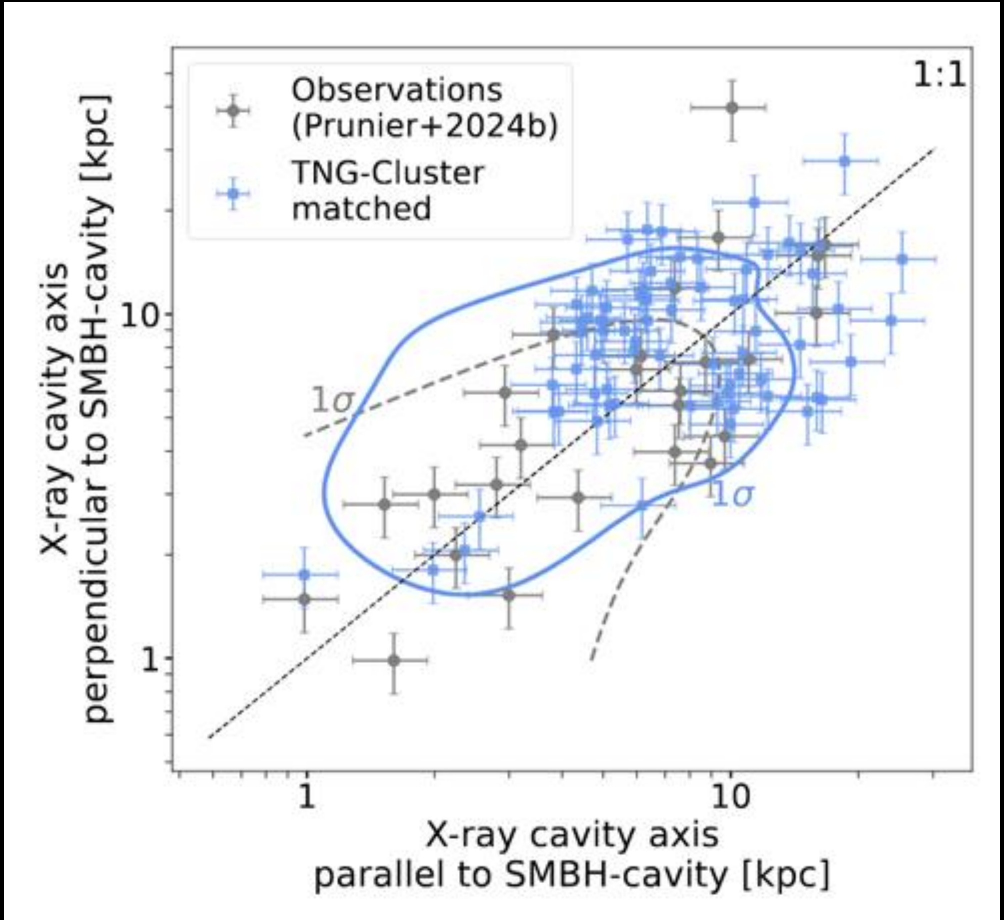


X-ray cavities preferentially in Cool-Cores



Similar morphologies





Sample Selection