Flatiron Institute
Center for Computational
Astrophysics (CCA)

Linking galaxy structural and star formation properties to black hole activity with IllustrisTNG

Melanie Habouzit (Flatiron PostDoc Fellow, CCA)

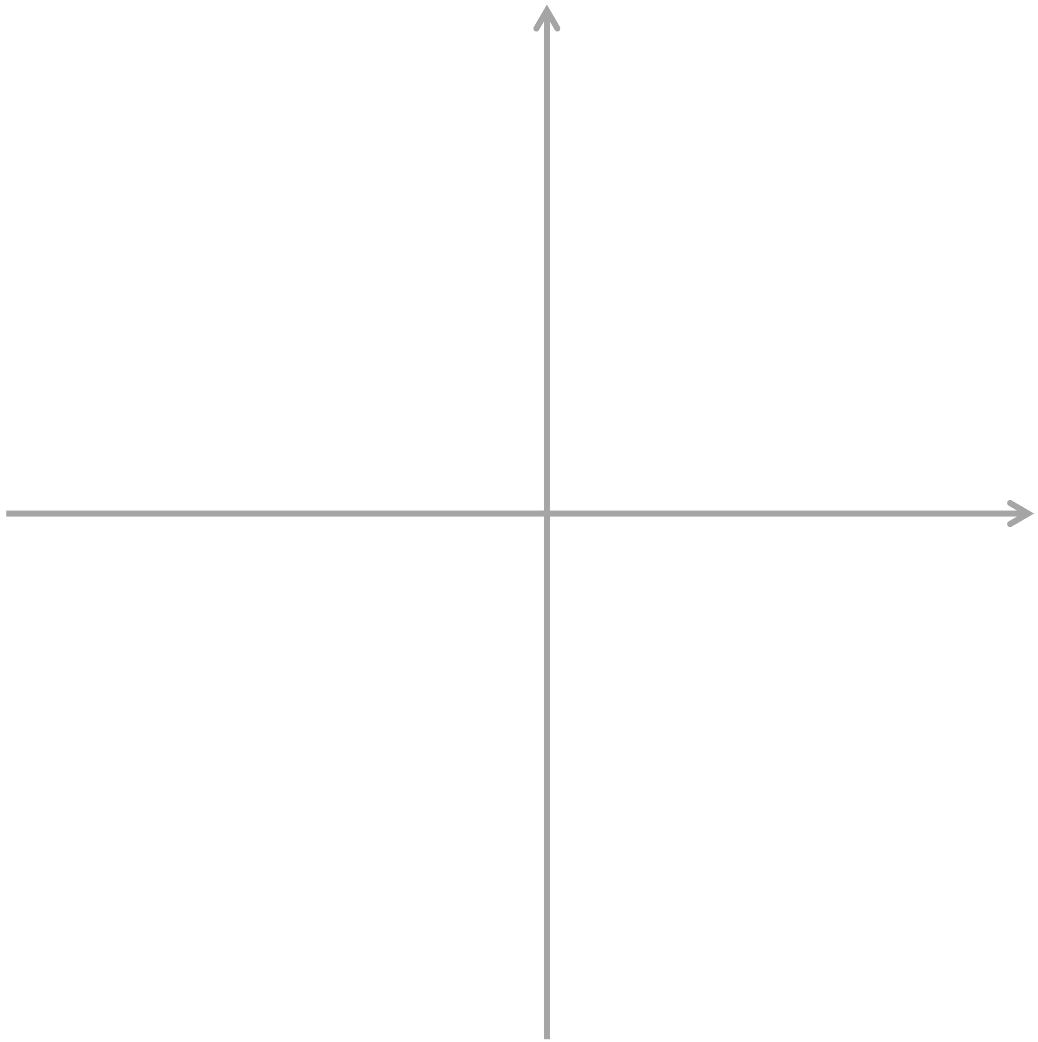
Rachel Somerville, Shy Genel, Dale Kocevski, Avishai Dekel, Michaela Hirschmann,
Ena Choi, and the IllustrisTNG team.

Durham, 2018, Are AGN special?

Keys goals of galaxy evolution today is to understand how massive passively evolving galaxies observed at low-redshift obtained their present-day properties.

- How and when did the quiescent galaxies form ?
- How did they grow their central SMBHs ?
- What are the physical processes responsible for quenching their star-formation activity ?

Galaxies with redshift $1 \leqslant z \leqslant 3$



Melanie Habouzit (CCA)

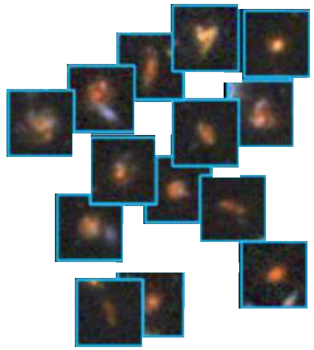
Galaxies with redshift $1 \leqslant z \leqslant 3$

$\log_{10}$ sSFR (Gyr^{-1})

Extended star-forming galaxies (eSF)

Disk-like morphologies, irregular, clumpy.

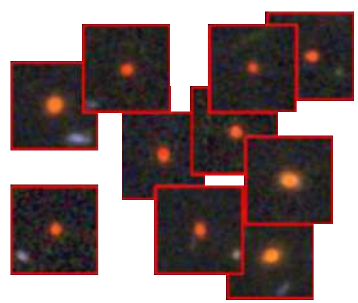
Elmegreen & Elmegreen 2005, Elmegreen 2007, Kriek et al. 2009, Guo et al. 2012



Barro+13

$\log_{10} \Sigma$ ($M_\odot$/pkpc)

with $\Sigma = 0.5\ M_*/\pi r^2$



Compact quiescent galaxies (cQ)

Compact elliptical, suppressed SFR, small sizes.

Szomoru et al. 2011, Bell et al. 2012, Williams et al. 2010, Wuyts et al. 2011

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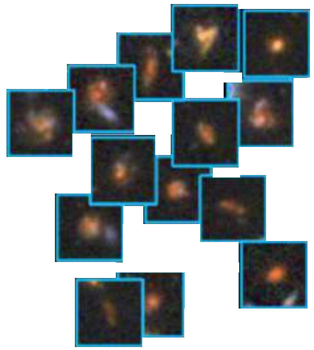

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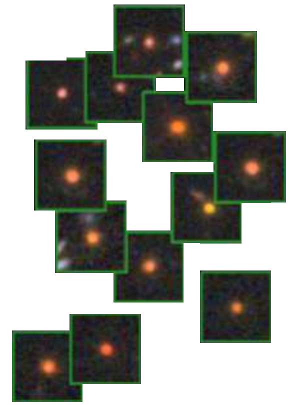

Large stellar mass, spheroid-like structures, more compact, heavily obscured SF.

Wuyts et al. 2011, Petel et al. 2012, Stefanon et al. 2013, Williams et al. 2013, Barro et al. 2013

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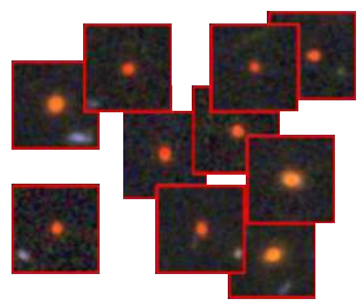

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Wet mergers, disk instability

Dekel+09,+13,Barnes+91, Hopkins+06, Porter+14, Zolotov+15, Wellons+15

$\log_{10} \Sigma$ ($M_\odot$/pkpc)

with $\Sigma = 0.5\, M_*/\pi r^2$

?

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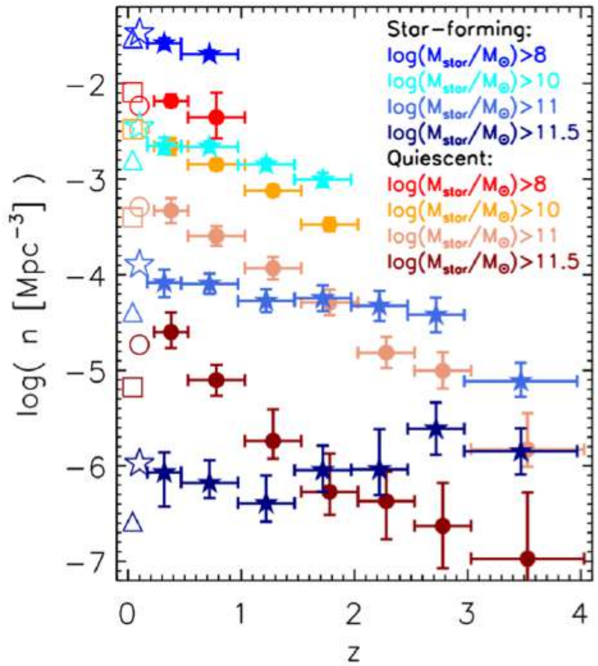
Muzzin+14

Number density, mass, size, SFR, qualify compact SF galaxies as the likely progenitors of the compact quiescent galaxies.

Fontana+09, Ilbert+10, Brammer+11, Muzzin+13, Barro+13



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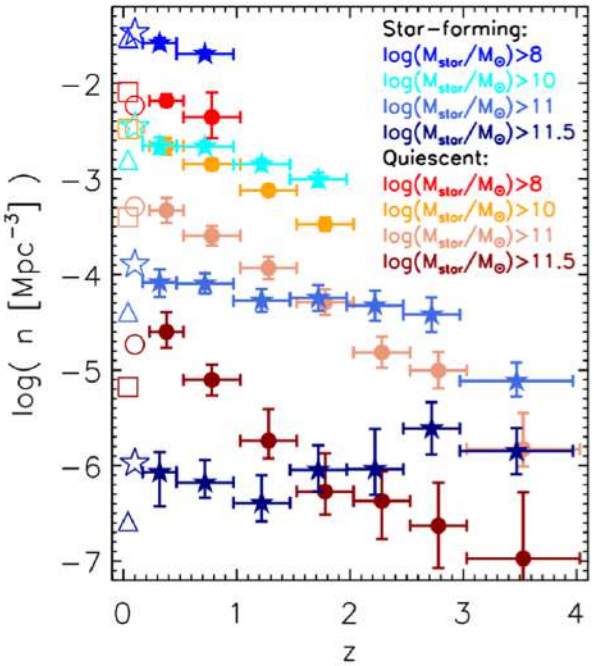

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Observational evidence for a high fraction of AGN among compact star-forming galaxies

Clumpy and compact galaxies at z~0.11 harbor a high AGN fraction in SDSS
Trump+13

Compact star-forming galaxies in GOODS-S at z~2 more likely to host bright AGN
Barro+14

40% of compact star-forming galaxies in $1.4 \leqslant z \leqslant 3$ in the candels fields host an AGN
Kocevski+17

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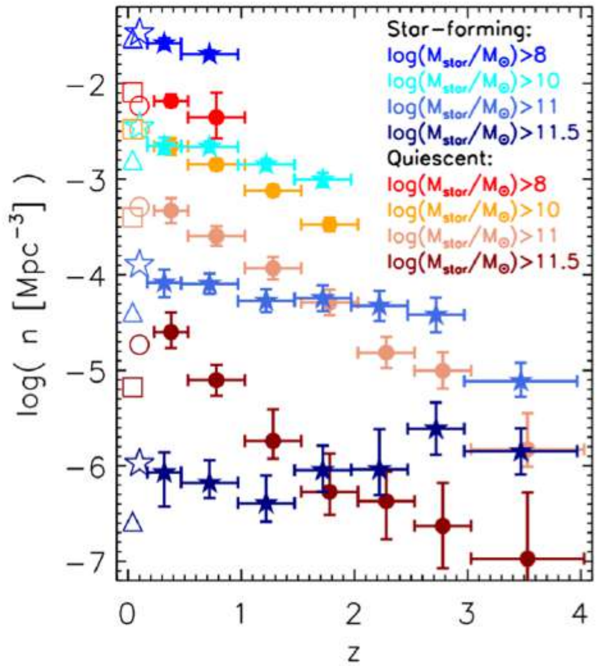

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GOALS:

- Connections between compact SF and compact quiescent galaxies ?
- Dependence of AGN fraction on a galaxy's location of the sSFR-compactness diagram ?
- Role of AGN feedback in quenching galaxies ?

Cosmological hydro simulations IllutrisTNG100 and IllustrisTNG300

Redshfit z=127-0

$m_{DM} = 7.5\text{x}10^6\,M_\odot$, $m_{DM} = 60\text{x}10^6\,M_\odot$

$m_{gas} = 11\text{x}10^6\,M_\odot$, $m_{gas} = 1.4\text{x}10^6\,M_\odot$

Radiative cooling and photoheating by UV background.

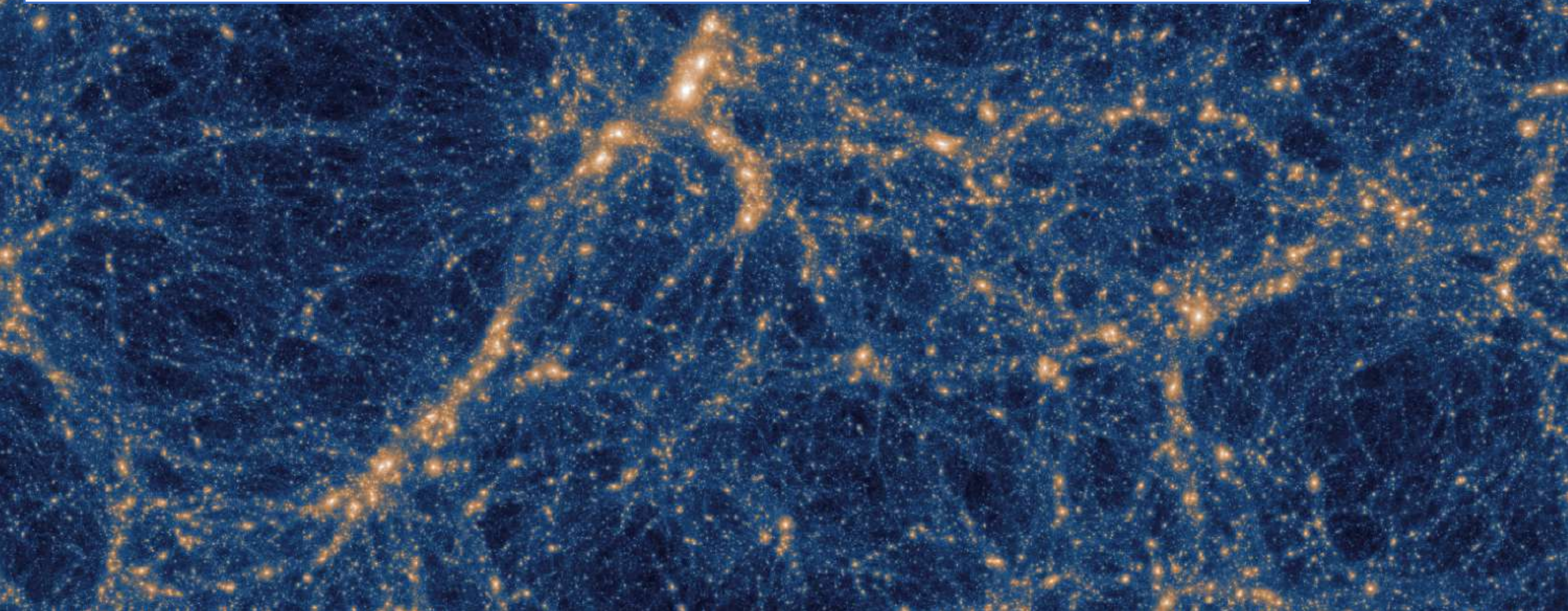
Star formation and SN feedback, metal enrichment.

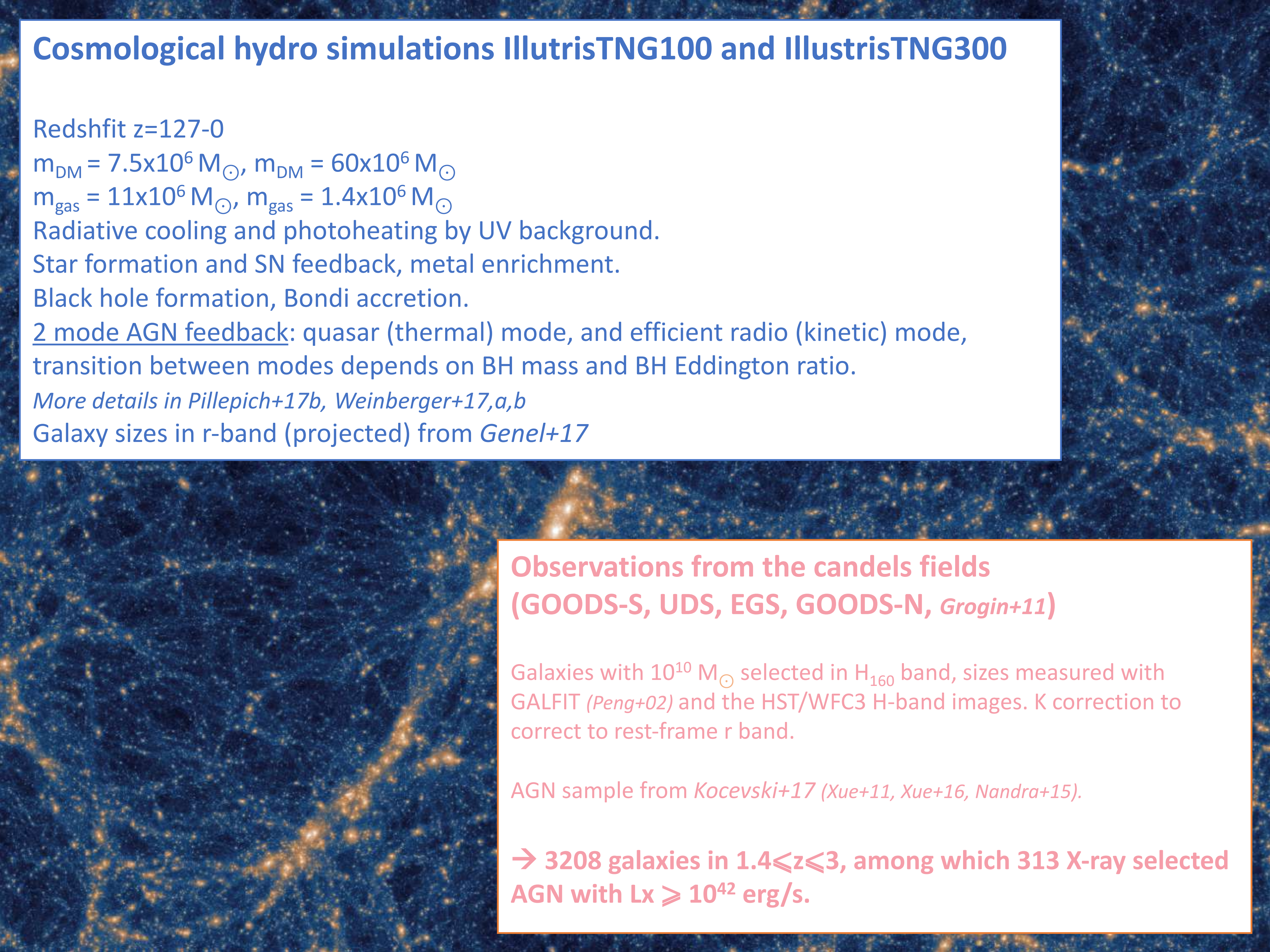
Black hole formation, Bondi accretion.

2 mode AGN feedback: quasar (thermal) mode, and efficient radio (kinetic) mode, transition between modes depends on BH mass and BH Eddington ratio.

More details in Pillepich+17b, Weinberger+17,a,b

Galaxy sizes in r-band (projected) from *Genel+17*





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Observations from the candels fields (GOODS-S, UDS, EGS, GOODS-N, *Grogin+11*)

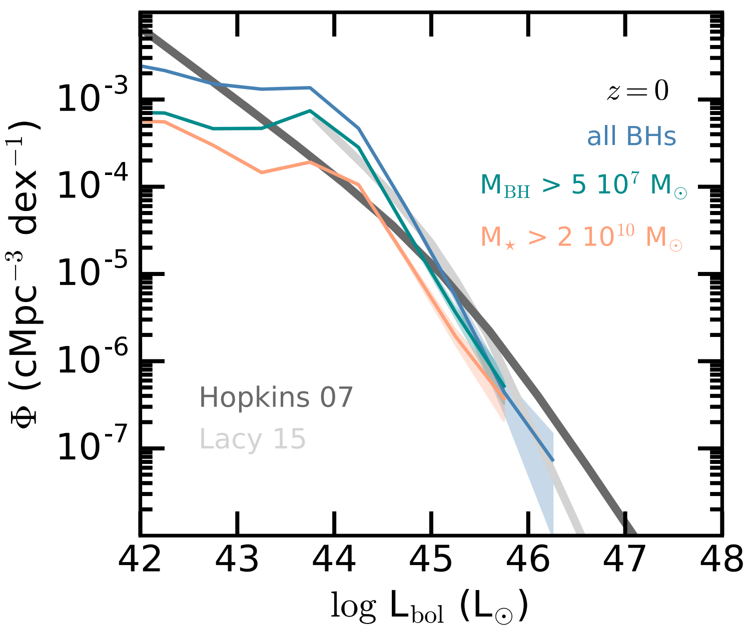
Galaxies with $10^{10}\, M_\odot$ selected in H_{160} band, sizes measured with GALFIT *(Peng+02)* and the HST/WFC3 H-band images. K correction to correct to rest-frame r band.

AGN sample from *Kocevski+17 (Xue+11, Xue+16, Nandra+15).*

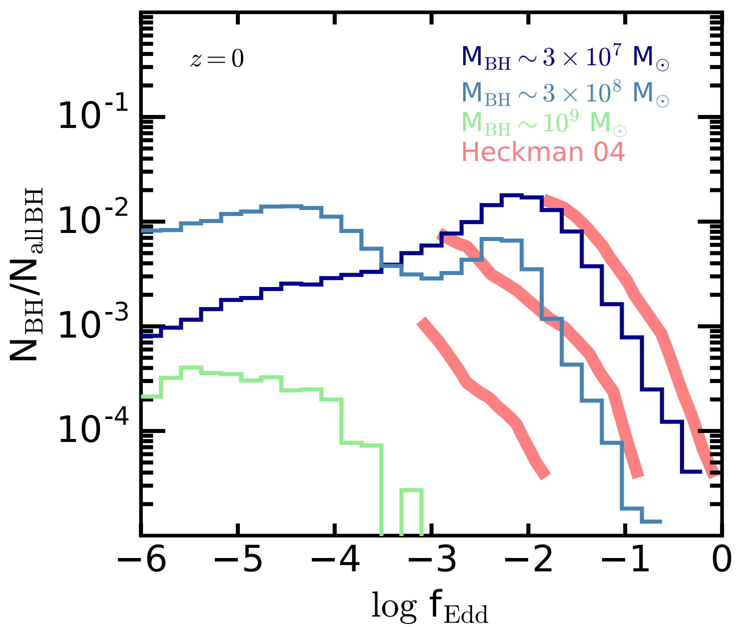
→ 3208 galaxies in $1.4 \leqslant z \leqslant 3$, among which 313 X-ray selected AGN with $Lx \geqslant 10^{42}$ erg/s.

Population of black holes in IllustrisTNG

BH bolometric luminosity function



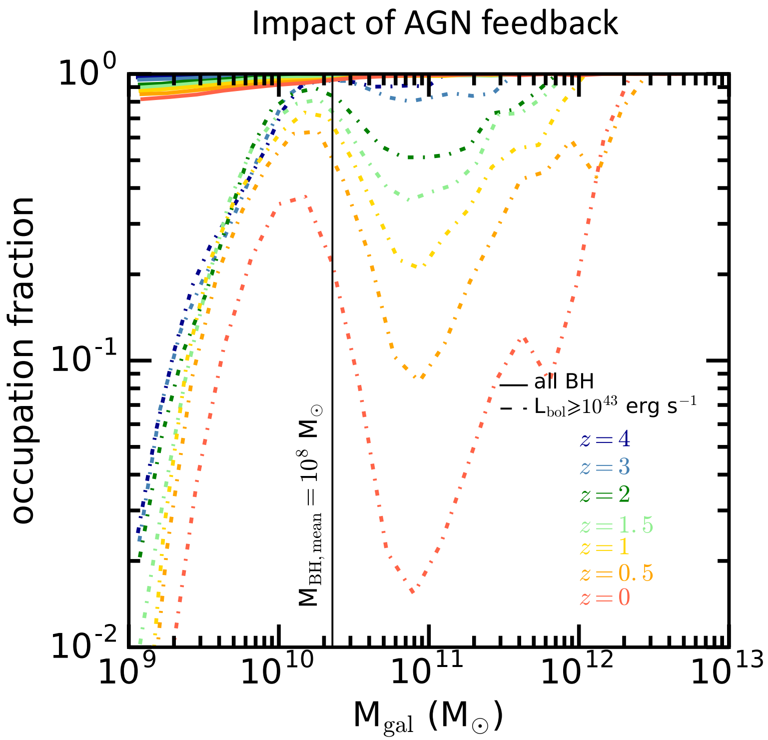
Eddington ratio distribution

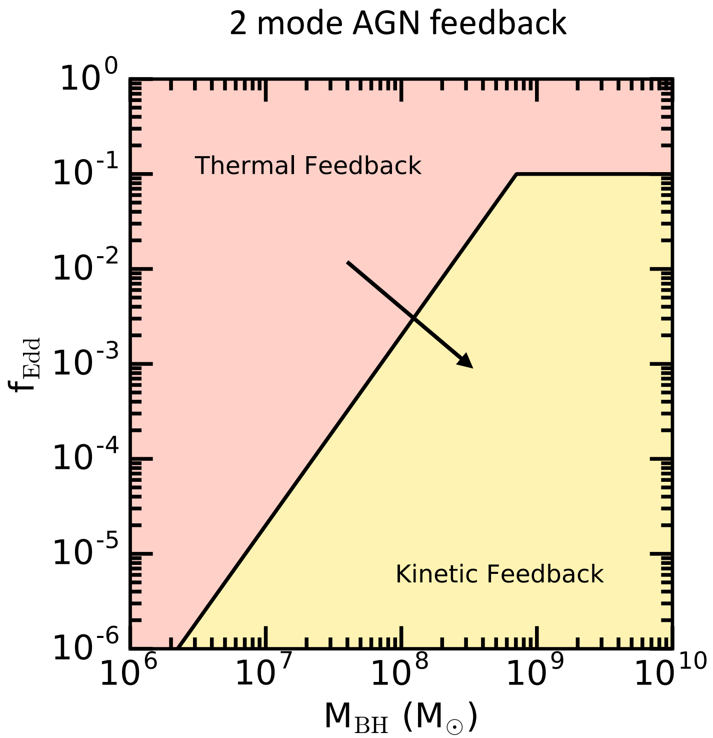


→ Overall good agreement with observational constraints, but faint AGN are overproduced, and bright AGN underproduced.

→ Massive BHs have lower Edd ratio than observed ones, due to effective kinetic feedback.

Population of black holes in IllustrisTNG



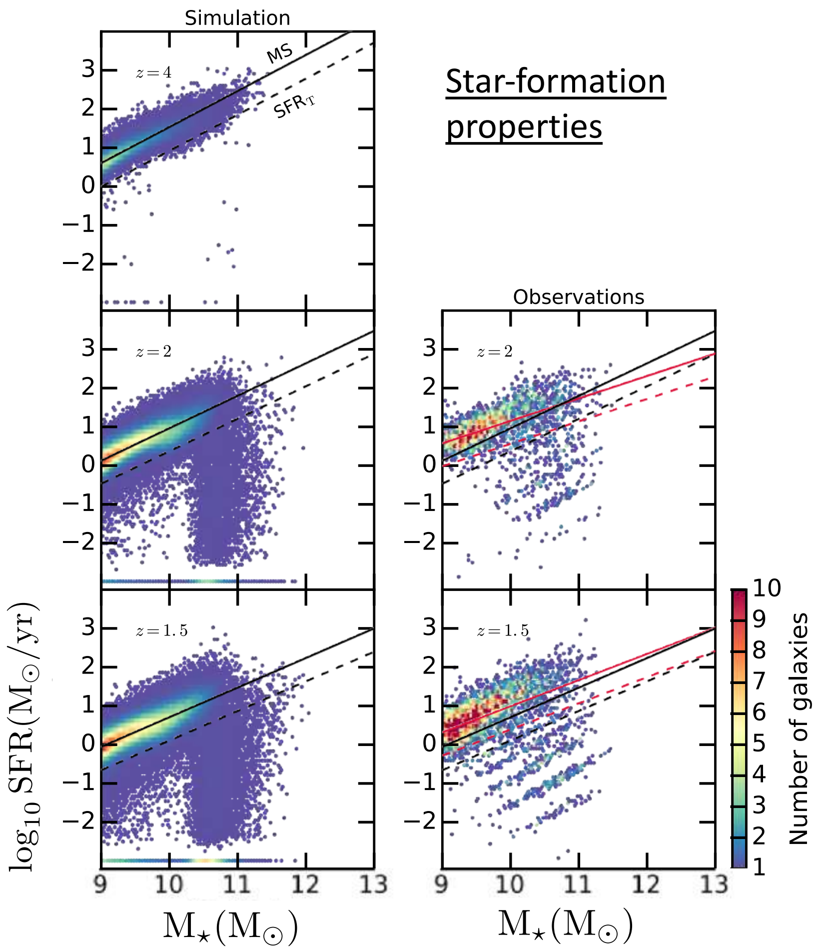


→ Massive BHs of ~$10^8\ M_\odot$ transition from the thermal mode to the very efficient kinetic mode.

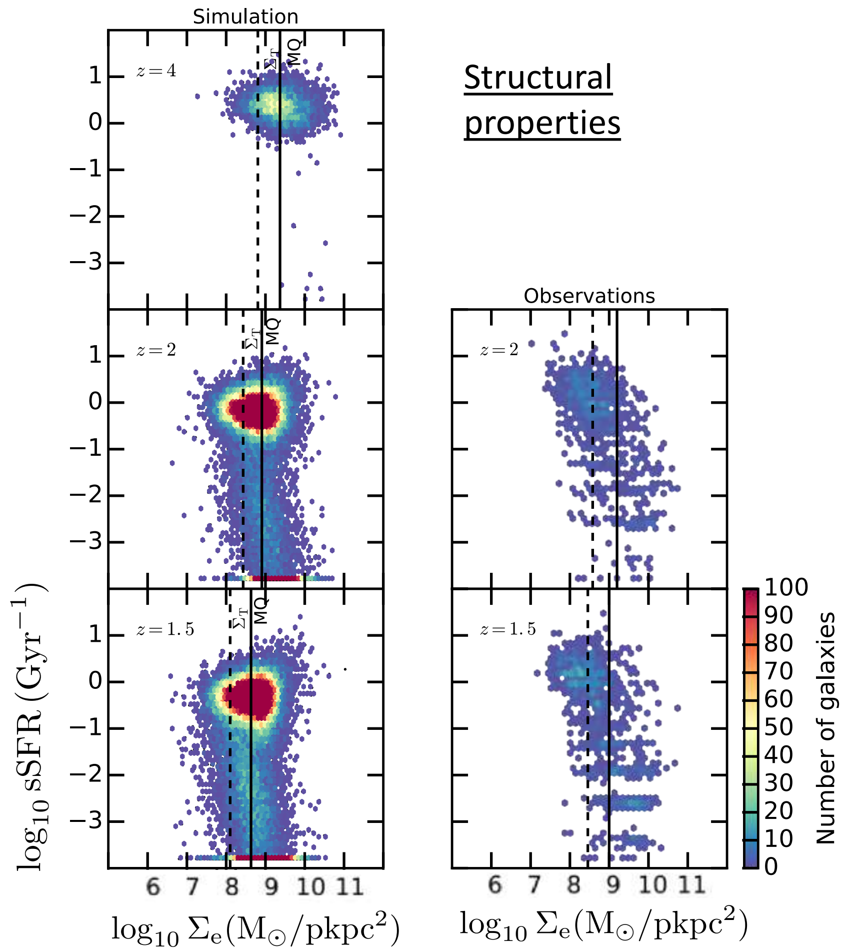
→ Thermal AGN feedback mode: continuous injection of thermal energy into BH surroundings.

→ Kinetic AGN feedback mode: pulsed and directed injected of momentum.

Time evolution of the populations of simulated and observed galaxies



Star-formation properties



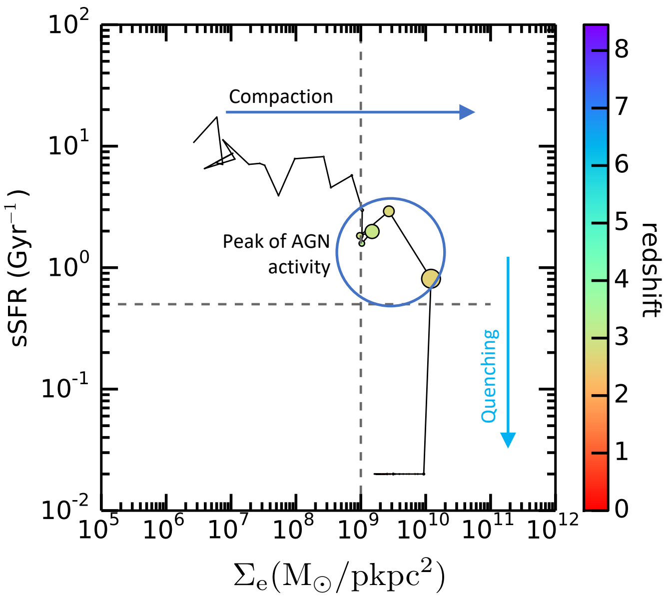
Structural properties

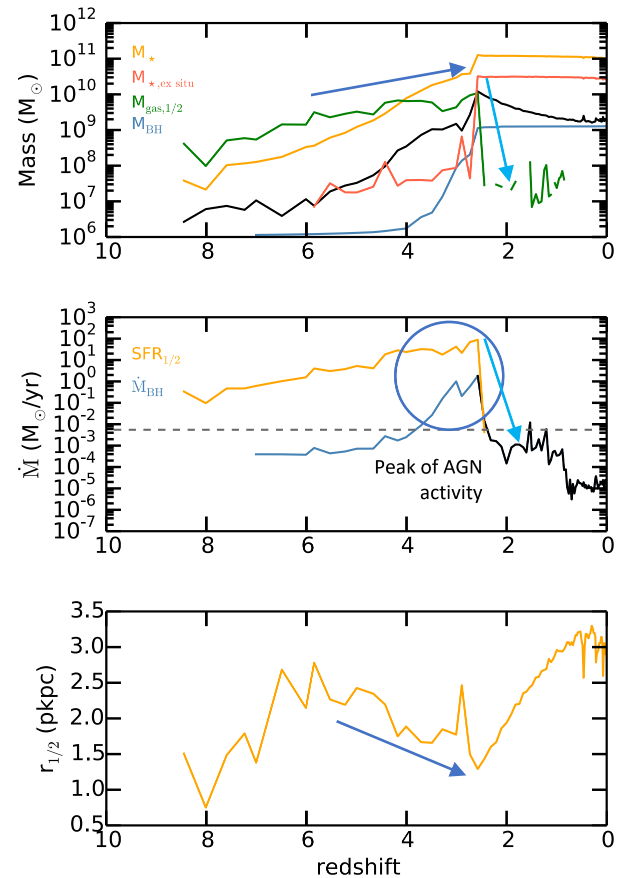
- → Good agreement of the main sequence of simulated and observed galaxies.
- → Good agreement of the sSFR-compactness diagram.
- → Identify galaxy types (eSF, cSF, eQ, cQ) with sample- and redshift-dependent thresholds based on SFR (25% of the main sequence), and Σ_e (25% of the main relation for quiescent galaxies).

The full story for an individual TNG galaxy

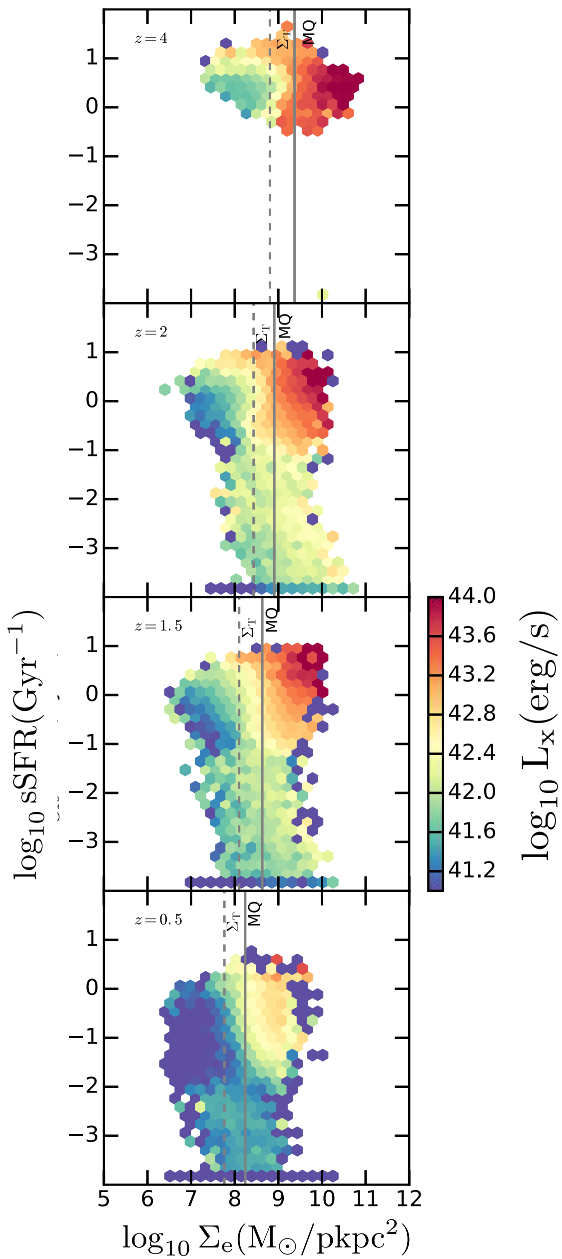
→ We identify massive quiescent galaxies at z=0, and trace them back in time.

1. *<u>Compaction</u>* while the galaxy is still star-forming.
2. Peak of SFR and AGN activity, corresponds to a minimum of the galaxy size.
3. Massive BH enters the efficient kinetic mode of AGN feedback.
4. *<u>Quenching</u>*: SFR and BH activity are surppressed.





Dependence of AGN fraction on a galaxy's location of the sSFR-Σ_e diagram



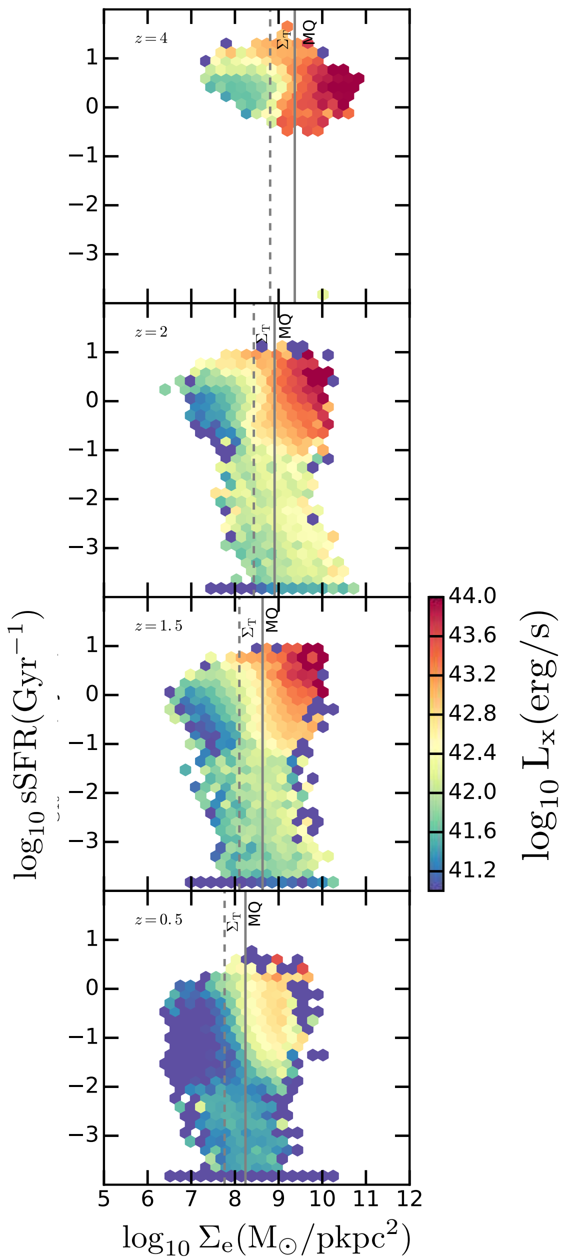
Dependence of AGN luminosity

Galaxies with $M_* = 10^{9.5}\ M_\odot$
Hexabins color coded by BH hard (2-10 keV) X-ray luminosity.

→ Compact star-forming galaxies host BHs with higher X-ray luminosity.

→ Compact quiescent galaxies host very faint AGN, or quiescent BHs.

Dependence of AGN fraction on a galaxy's location of the sSFR-Σ_e diagram

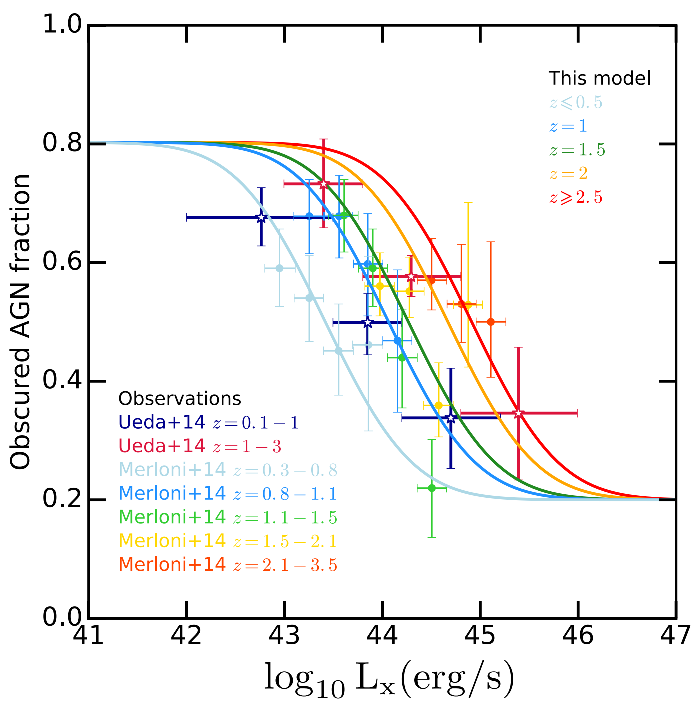


Moving to AGN fraction: Correction for Obscured AGN

→ We follow *Ueda et al. 2014, Merloni et al. 2014*

→ Build a redshift-dependent model with anti-correlation between the obscured AGN fraction and BH X-ray luminosity.

→ Most likely also depends on galaxy structural properties.
See Chang+17, galaxy with obscured AGN are more compact.



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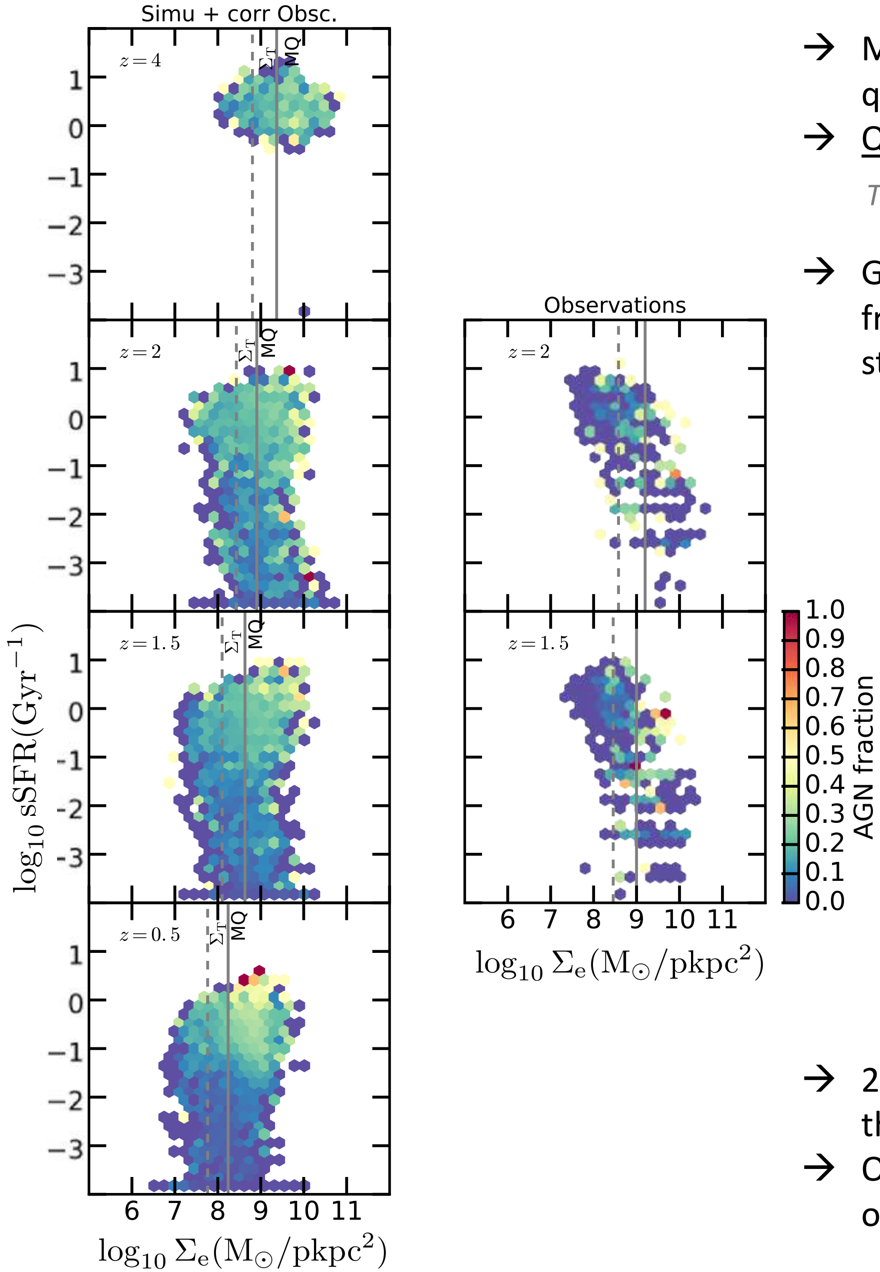
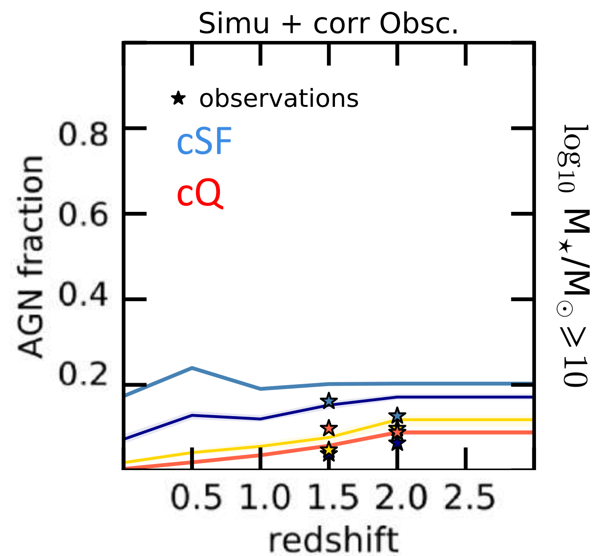


→ More compact SF galaxies host AGN than the compact quiescent galaxies, and they are brighter.

→ <u>Qualitatively</u> in good agreement with observations.

Trump+13, Barro+14, Kocevski+17

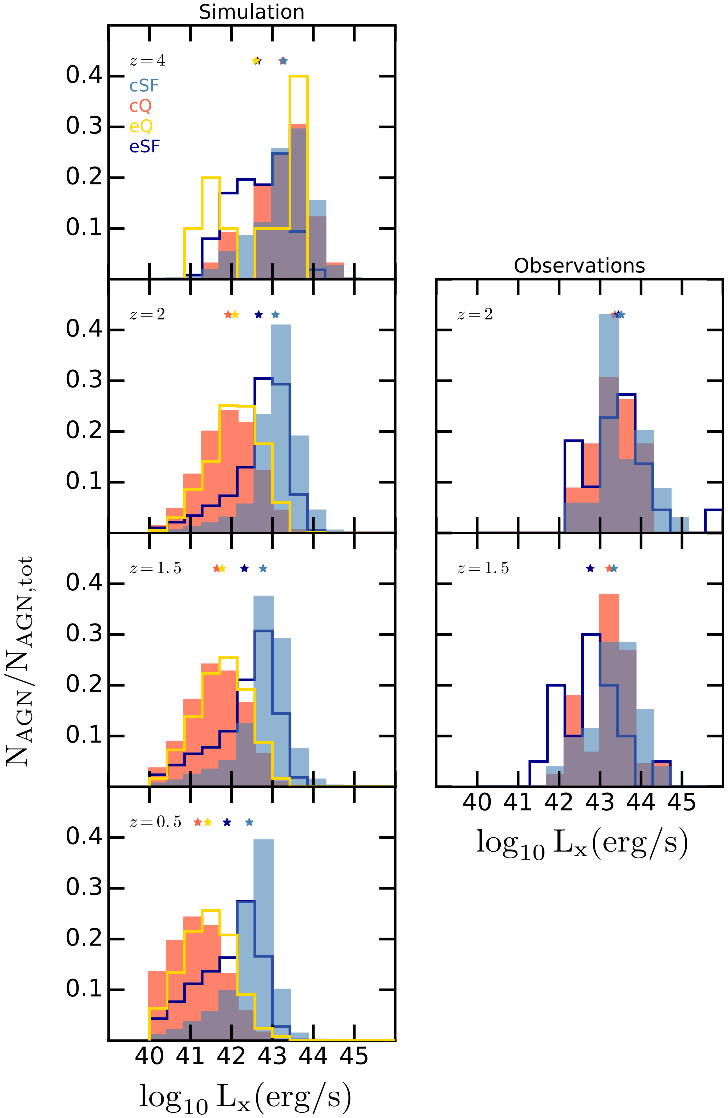
→ Good <u>quantitative</u> agreement in the amplitude of the AGN fractions in the simulation and the candels observations, but strongly depends on the correction for obscured AGN.



→ 20% of the **cSF** host a X-ray AGN in the simulation, 13-16% in the observations.

→ Only 6-9% of the simulated **cQ** do so, 9-10% in the observations.

The BH luminosity distribution: large discrepancy between observations and TNG.



→ AGN luminosity distributions of simulated cQ galaxies peak at one order of magnitude lower luminosities than cSF.

→ However, luminosity distributions are similar in the candels observations.

Linking galaxy structural and star formation properties to BH activity with IllustrisTNG

Habouzit et al., to be submitted

- **Properties of simulated and observed (candels) galaxies** in good agreement for the SFR-M_*, sizes-M_*, and sSFR-Σ_e relations.
- **Population of simulated BHs** consistent with observational constraints, but the faint-end of the LF may be overproduced, and the bright-end underproduced due to the very efficient radio (kinetic) AGN feedback.
- Carried out a **self-consistent comparison**, using sample- and redshift-dependent selection thresholds to identify galaxy types in both observations and simulations.
- Qualitative agreement with observations: compact star-forming galaxies host *more and brighter* AGN than compact quiescent galaxies.
- Quantitative agreement on the AGN fractions when we apply our luminosity- and redshift-dependent model for the fraction of obscured AGN.
- Implication for the **role of AGN feedback** in quenching galaxies.