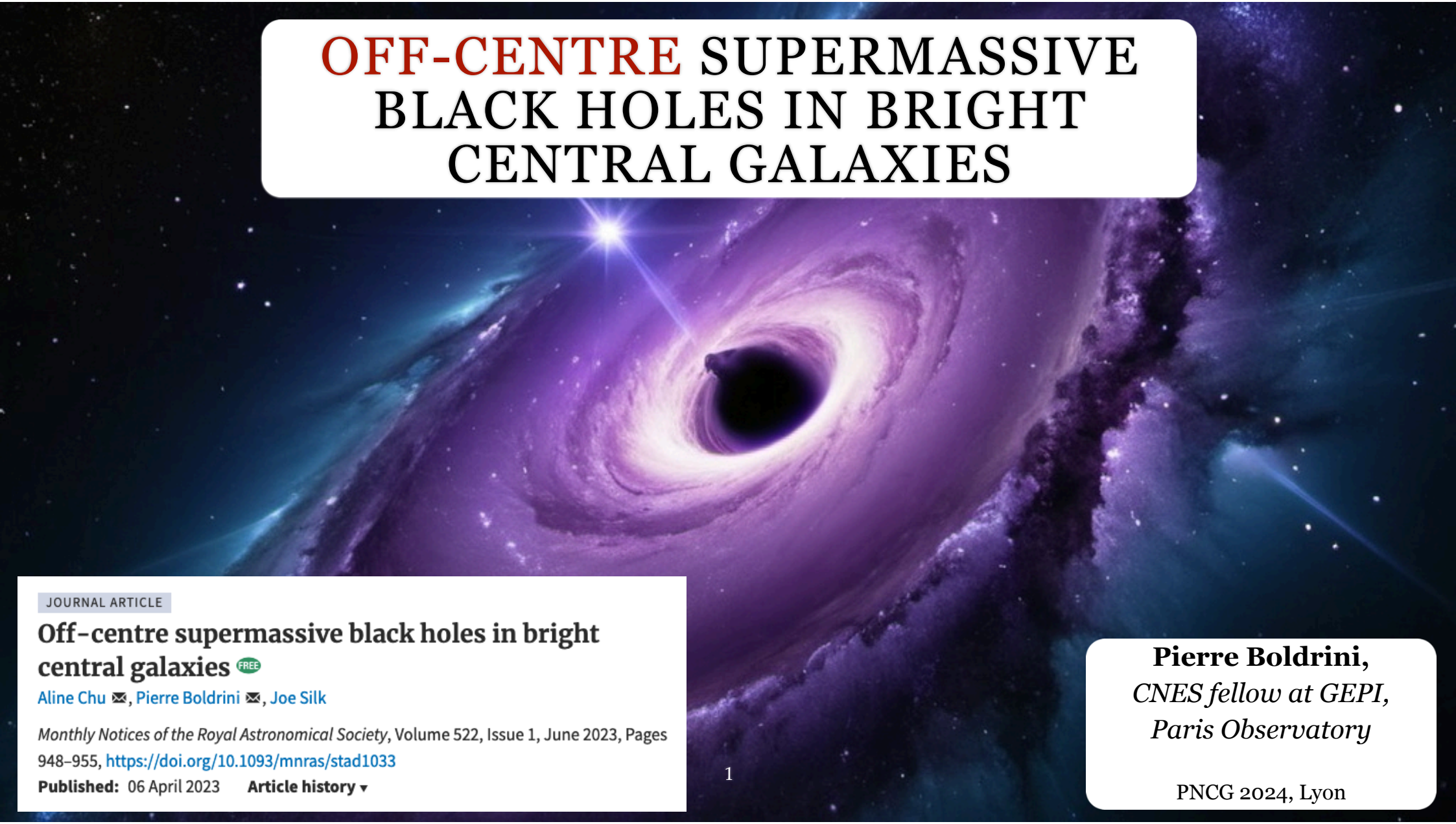
OFF-CENTRE SUPERMASSIVE BLACK HOLES IN BRIGHT CENTRAL GALAXIES



JOURNAL ARTICLE

Off-centre supermassive black holes in bright central galaxies FREE

Aline Chu ✉, Pierre Boldrini ✉, Joe Silk

Monthly Notices of the Royal Astronomical Society, Volume 522, Issue 1, June 2023, Pages 948–955, https://doi.org/10.1093/mnras/stad1033

Published: 06 April 2023 **Article history** ▾

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PNCG 2024, Lyon

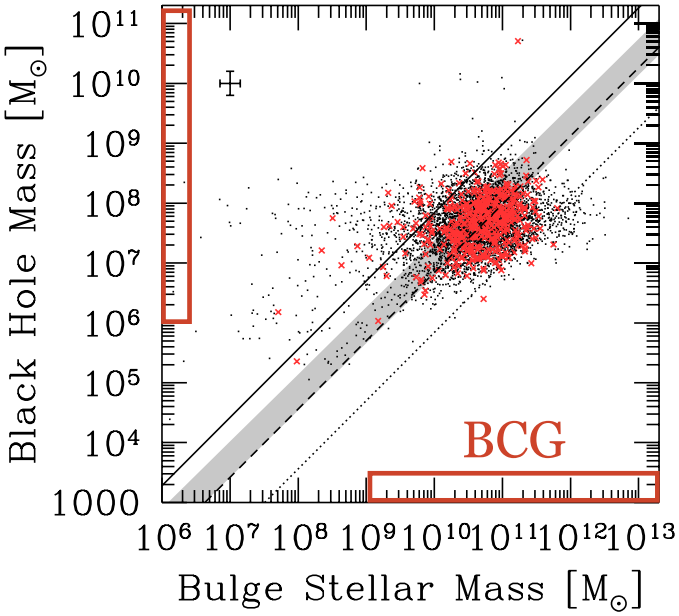
BRIGHTEST CLUSTER GALAXIES (BCGS)

- **Most massive** galaxies observed in the Universe
- **Central** galaxies of galaxy clusters (rich systems of 100 - 1000 galaxies)
- They have **undergone many mergers** (~20 mergers per BCG in TNG-300)
- **Stellar mass:** 10^9 - 10^{13} $M_\odot$

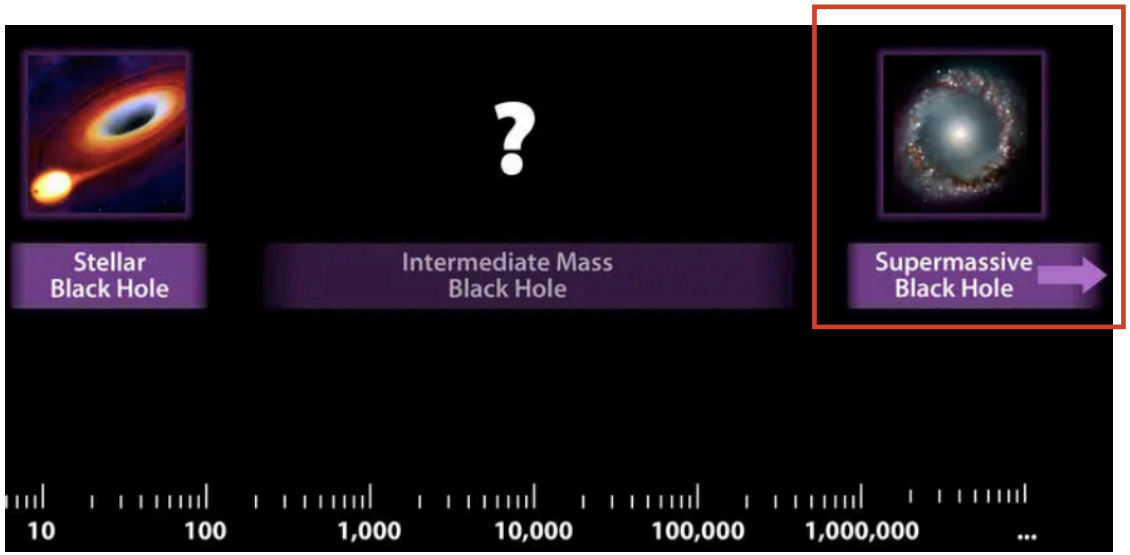
Crédits : ESA/Hubble, NASA, Rivera-Thorsen et al.

BCGs are the final product of hierarchical merging

BLACK HOLES



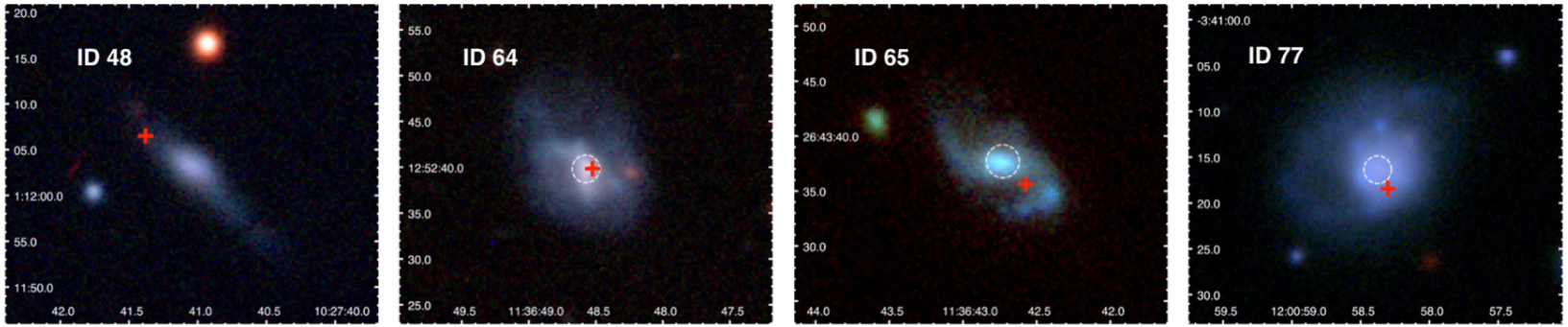
Marleau et al. +13



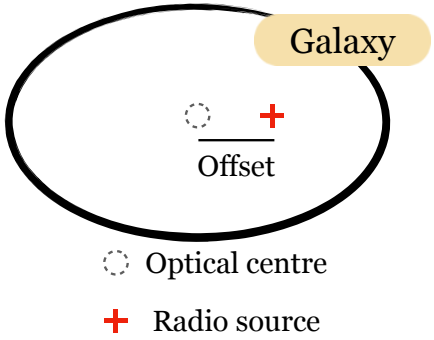
Black holes grow at the same time as their host galaxies

OFF-CENTERED BLACK HOLES

AGN observations in dwarf galaxies

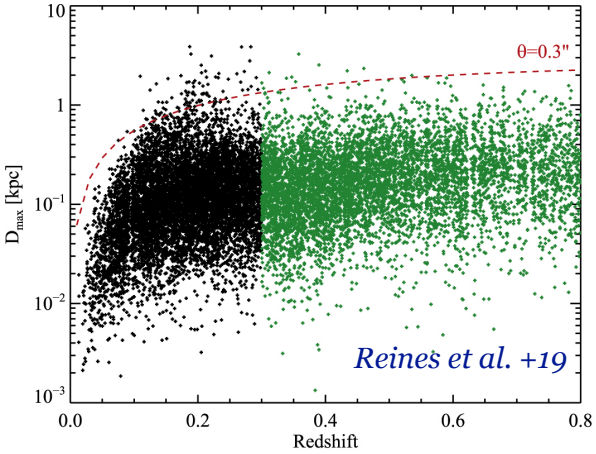


Shen et al. +19



Scenarios:

- Presence of a binary system *Sundararajan et al. +10*
- Recoil of merging BHs *Merritt et al. +05; Volonteri et al +05; Loeb +07; Komossa +12*
- Interactions/mergers with other galaxies *Bellovary et al. +18,+19,+21; Pfister et al.+19*
- Infall of DM subhalos *Boldrini et al. +20*



BHs are not necessarily located exactly at the bottom of the galaxy potential

MOTIVATIONS-CHALLENGES

In large volume cosmological simulations

- **Dynamical friction:** complex problem at sub-kpc scale

  e.g. Reines et al. +20; Pesce et al +21

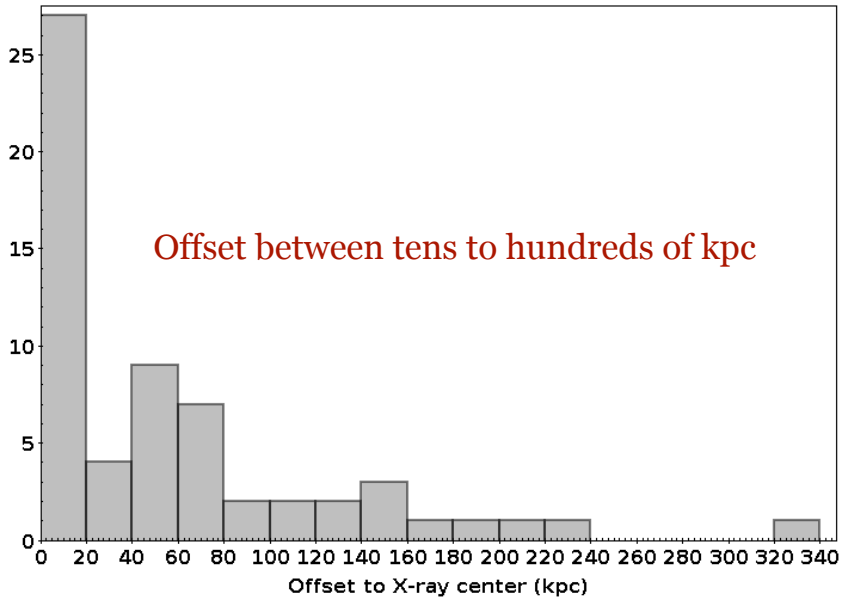
- **Repositioning methods:** periodically or continuously 'teleporting' black holes towards the center of the galaxy potential

  e.g. Davé et al. +19; Bassini et al. +20, Bahé et al. +22

In observations

- Offsets between the BCG and the cluster X-ray centers in dynamically disturbed clusters

Chu et al. +21



Need of a new approach to study BH dynamics at sub-kpc scale

MOTIVATIONS-CHALLENGES

What is the impact of mergers in BCGs on their central supermassive black hole?

Crédits : Illustris TNG

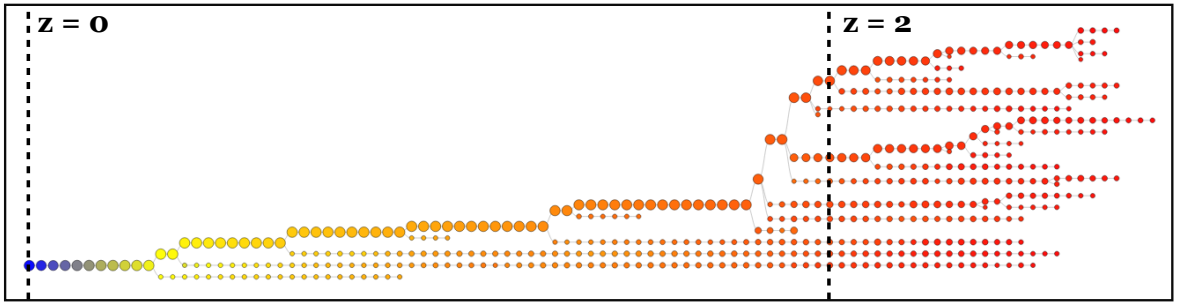
A main driver for such BH displacements in BCGs?

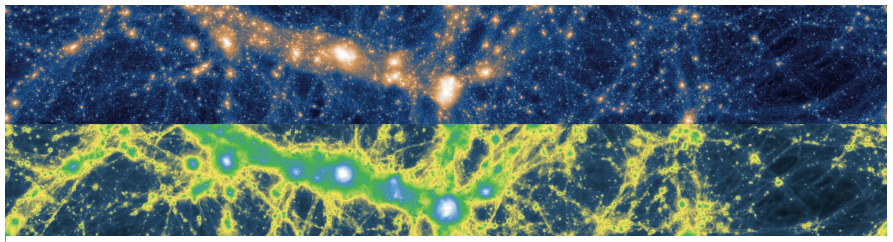
METHODOLOGY

Cosmological simulation *Illustris TNG-300*

1 Retrieve the merger history of the 370 BCG since z = 2

Barnes et al. +18





Crédits : Illustris-TNG

Merger and BCG histories by *Illustris TNG-300*, satellite and BH dynamics by *galpy*

METHODOLOGY

Cosmological simulation *Illustris TNG-300*

Orbital integration methods via

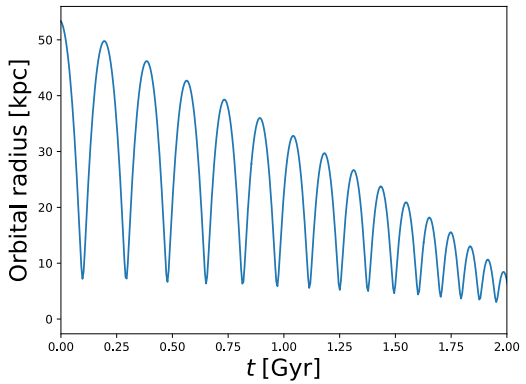
Bovy +15

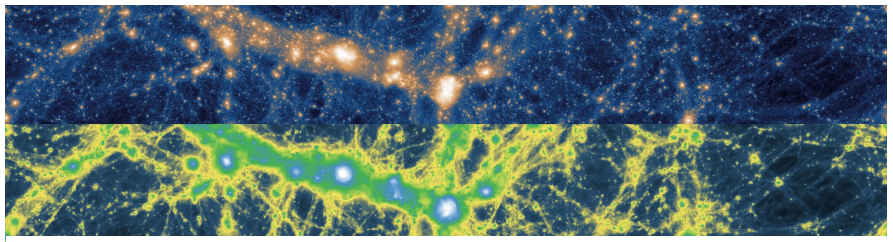
1 Retrieve the merger history of the 370 BCG since z = 2

Barnes et al. +18

2 Compute the orbit of the satellites in the BCG potential

BCG potential = Hernquist profile + Plummer profile
+ (DM) (stars)
Chandrasekhar dynamical friction





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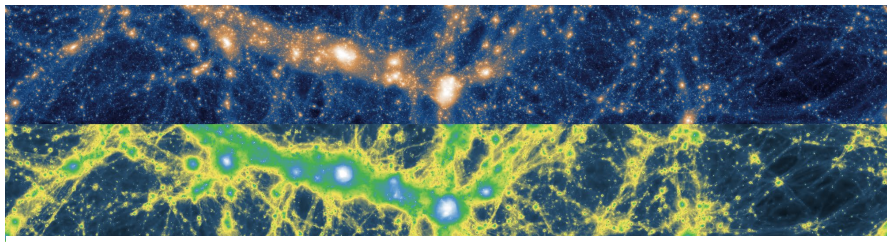
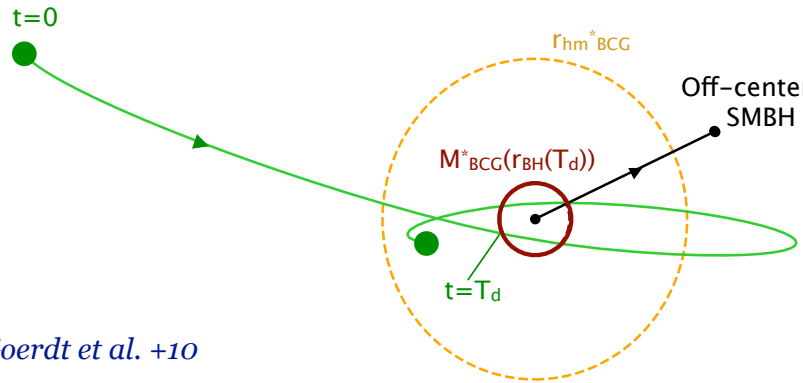
3. Identify all satellites which can potentially affect central SMBHs



Crédits : Illustris-TNG

- Radial merger $d \leq r_{\mathrm{hm}}^{\mathrm{sat}}$
- Massive enough satellites $M_{\mathrm{tot}}^{\mathrm{sat}} \geq M_{\mathrm{int}}^{\mathrm{BCG}}(d)$

Read et al +06; Goerdt et al. +10



*Chu, **Boldrini** and Silk +23*

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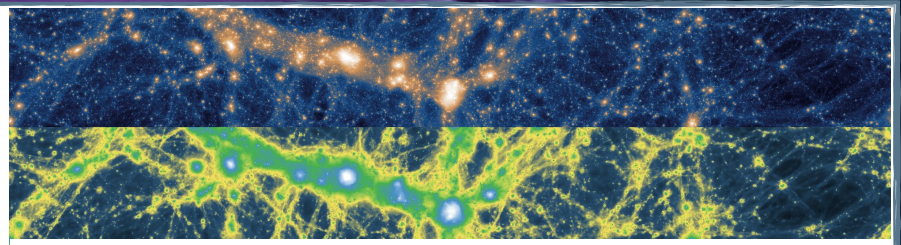

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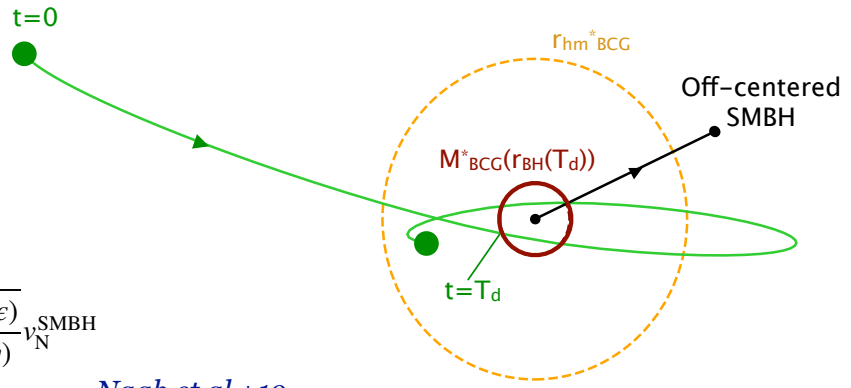

*Chu, **Boldrini** and Silk +23*

Satellite-BH velocity ratio

$$v_{\rm kick}^{\rm first} = \sqrt{\frac{(1+\eta\epsilon^2)}{(1+\eta)}}\, v_{\rm c}^{\rm SMBH}$$

Satellite-BCG mass ratio

$$v_{\rm kick}^{\rm sub} = \sqrt{\frac{(1+\eta\epsilon)}{(1+\eta)}}\, v_{\rm N}^{\rm SMBH}$$

Naab et al +19

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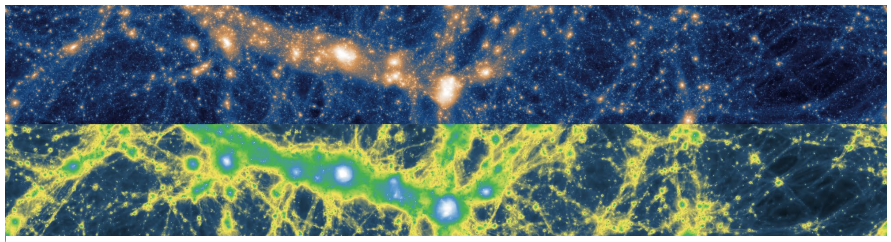

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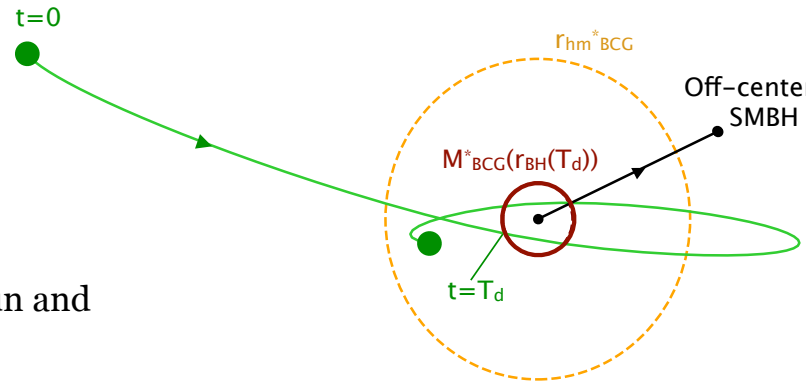


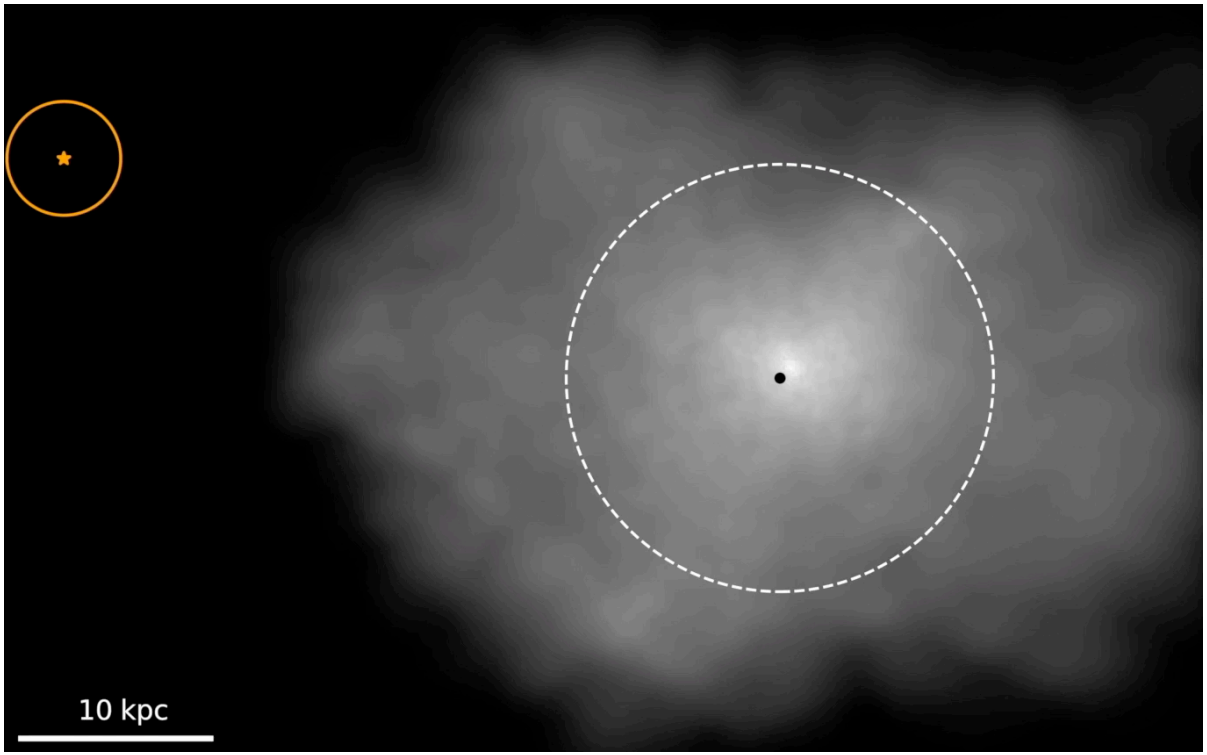
*Chu, **Boldrini** and Silk +23*

- **Advantages:** accurate orbital resolution (~pc), no repositioning, 20 CPU hrs run and applied in post-treatment of simulations

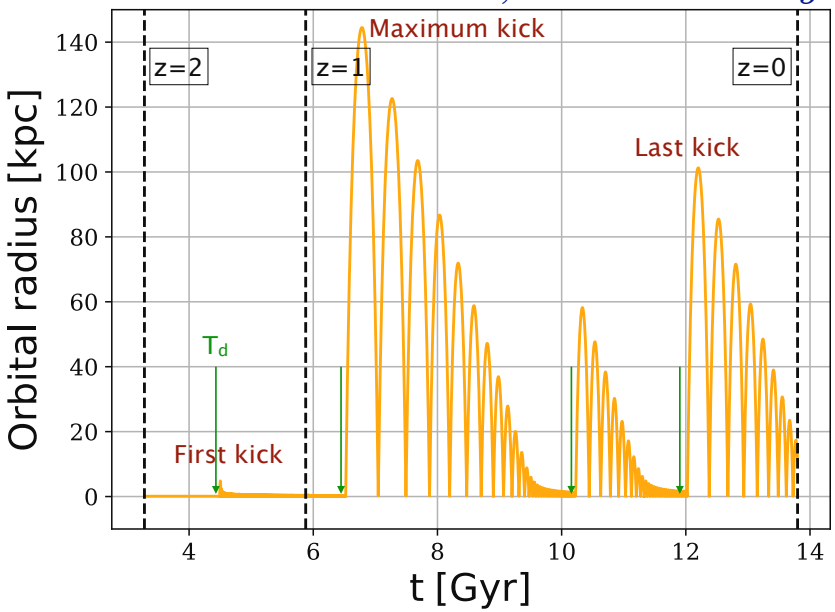
Merger and BCG histories by *Illustris TNG-300*, satellite and BH dynamics by *galpy*

RESULTS

Example of a BH kick



*Chu, **Boldrini** and Silk +23*



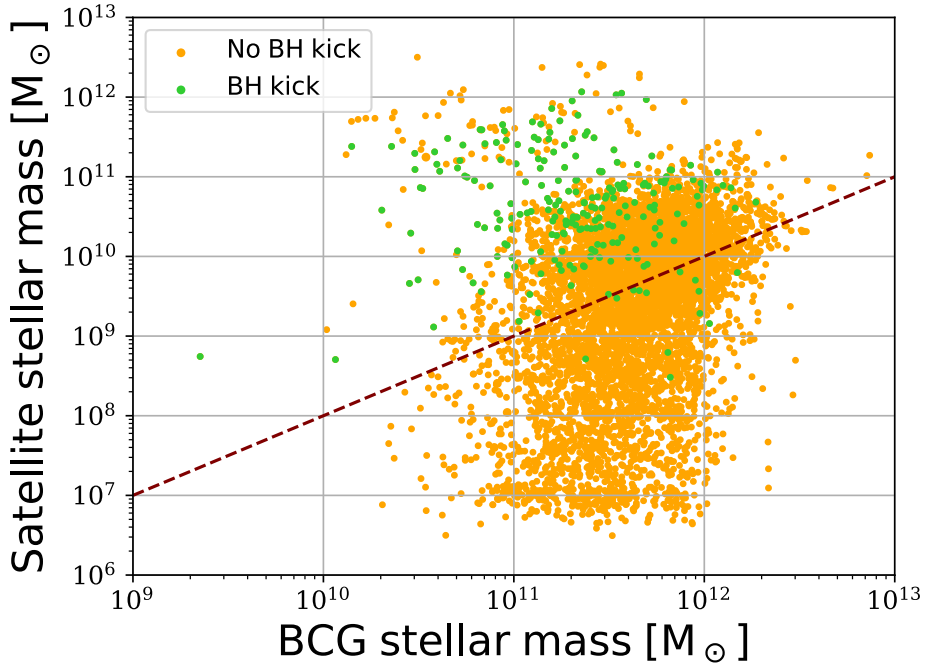
17 mergers since $z = 2$ but only 4 mergers have satisfied our criteria, off-centered by 10 kpc at z=0

RESULTS

- Efficient mechanism to off-center SMBHs?

  - 3% (229/6628) mergers have affected the central SMBH
  - 46% (70/370) SMBHs kicked away from the center at least once since z = 2

*Chu, **Boldrini** and Silk +23*



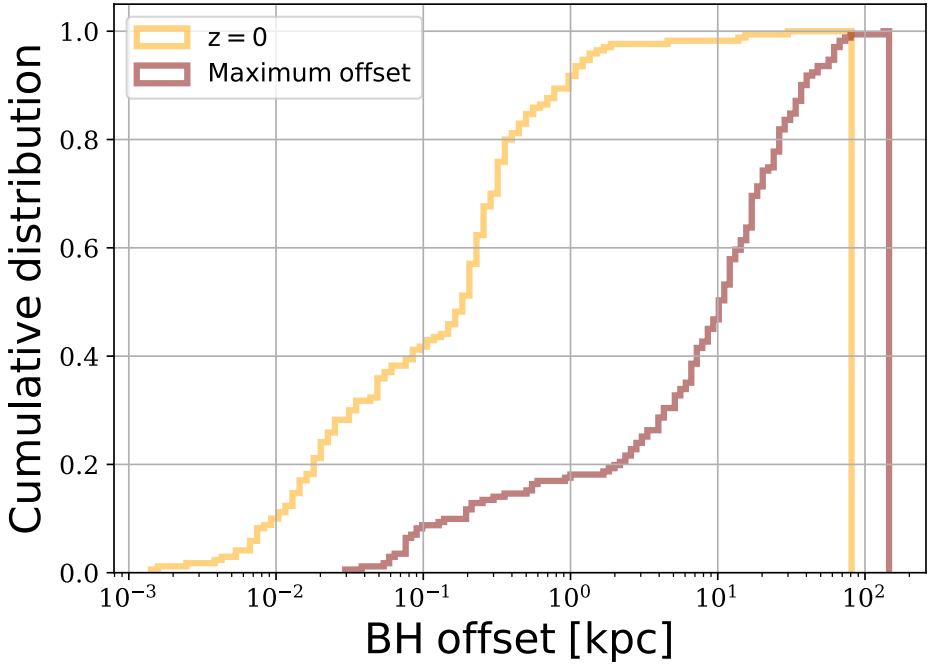
BHs are mainly kicked by satellites which have stellar masses $M_*^{sat} > M_*^{BCG}/100$

RESULTS

- Where are located SMBHs at z=0?

  - 60% of SMBHs off-centered at r > 100 pc at z = 0
  - **Offset range:** 2 pc - 200 kpc

*Chu, **Boldrini** and Silk +23*



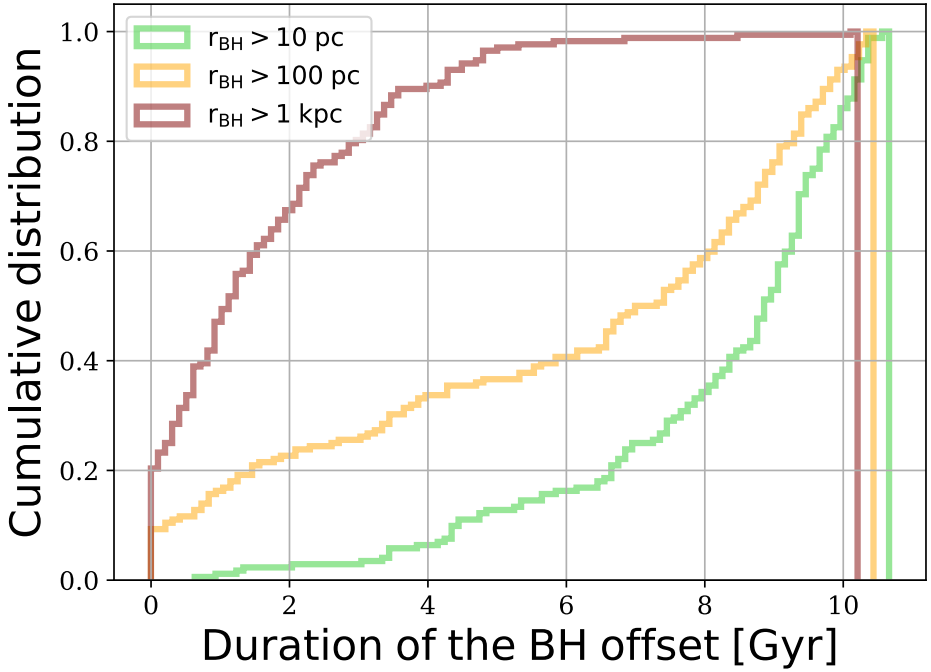
SMBH offsets are common in BCGs

RESULTS

- How much time BHs are off-centered?

  - 60% of SMBHs spent more than 6 Gyr at r > 100 pc

*Chu, **Boldrini** and Silk +23*

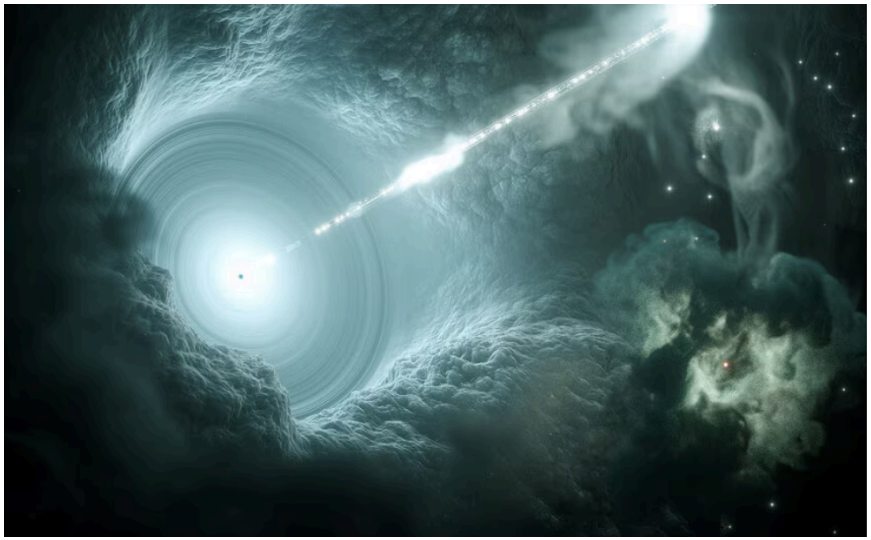


SMBHs in BCGs spend more than half of their lifetimes off-centered

RESULTS - IMPLICATIONS

SMBH is kicked out from the central region of BCG

- Lower counts of BH-BH mergers
  Barausse et al. +20; Bahé et al. +21
- **Accretion less efficient:** gas clumps mostly condensed in the centre
  Smith et al. +18
  - Black hole growth halted
    Bahé et al. +22
  - Black hole feedback inefficient
    Heckman et al. +14; Boldrini et al. +20



Credits: DESY

The displacement of BH has significant consequences on its growth and feedback

PUBLIC DATA & CODE

About me | Astro news | Publications | Collaborators | Talks | Public data and codes | Contact

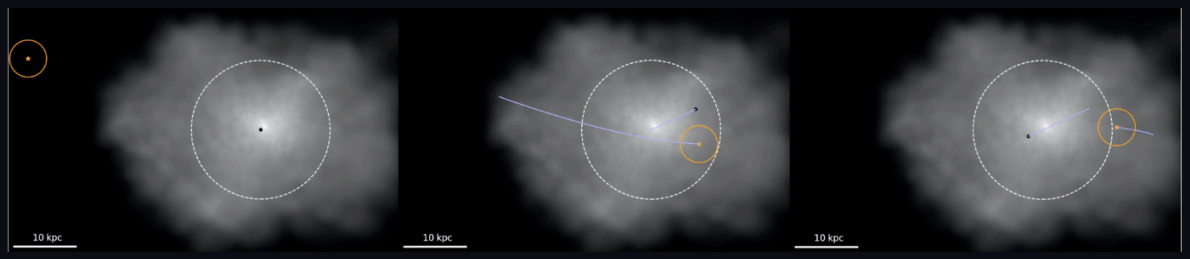
"Off-centre black holes in galaxy clusters" - Aline Chu, P. Boldrini, and J. Silk (2023).

- 370 galaxy cluster merger history extracted from Illustris-TNG 300 (2 Mo of hdf5 files)
  [BCG, FirstProg, NextProg][DM mass, DM r_{hm}, Id, Stellar mass, Stellar r_{hm}, posx, posy, posz, redshift, velx, vely, velz]

Pierre Boldrini
Blackholan · he/him

python 3.8.2 | License MIT

pyCelebi (CEntraL massivE Black hole orbital Integration)



Data and codes are public on GitHub and on my website https://www.iap.fr/useriap/boldrini/

17

FUTUR WORKS

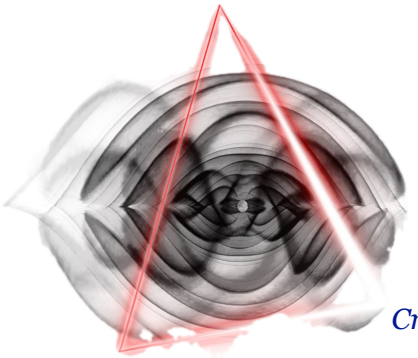
- **Advantage:** Applying to other cosmological simulations.
- **Improvement:** Modelling a complex potential that accounts for satellites and mergers (new function available in ***galpy)***
- **Extension:** Applying this to the population of wandering black holes and providing predictions for LISA
- **Other application:** Similar approach to add globular clusters in post-processing of simulations (CNES project with P. Di Matteo)

Moving object potential

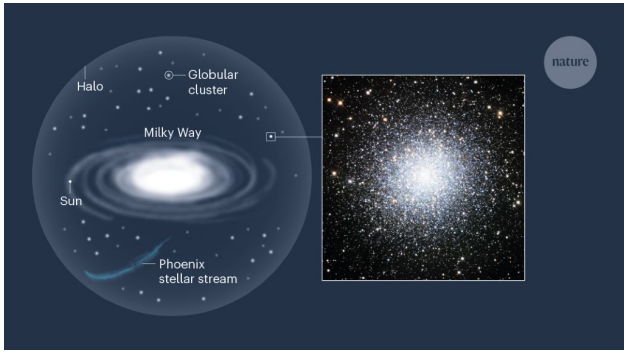
class galpy.potential.**MovingObjectPotential**(*orbit*, *pot=None*, *amp=1.0*, *ro=None*, *vo=None*) [source]

Class that implements the potential coming from a moving object by combining any galpy potential with an integrated galpy orbit.

Credits : galpy



Credits : LISA



Credits : Nature


THANK YOU!