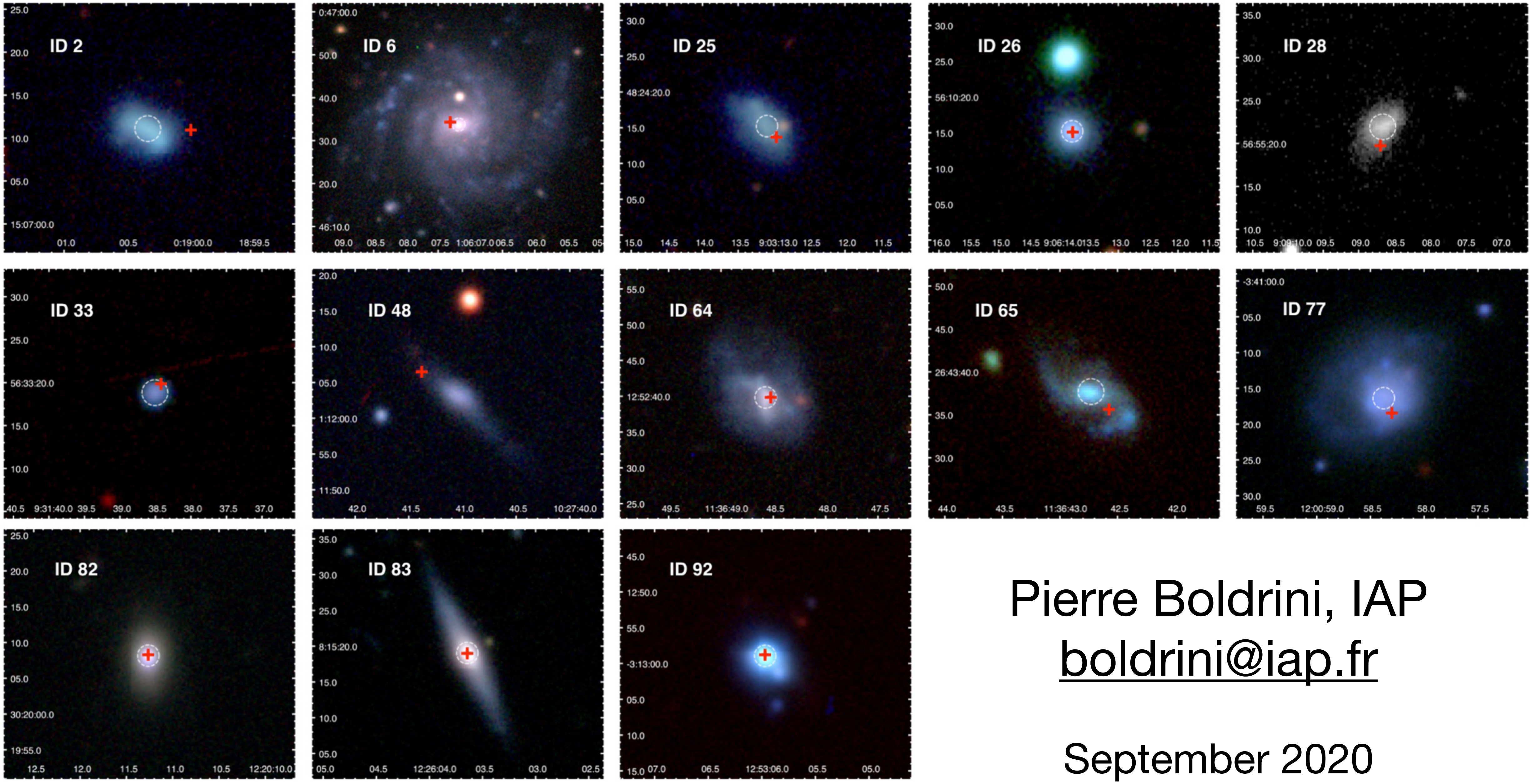
ICAP meeting

Off-centre black holes: a consequence of dark matter heating



(Reines et al. (2019))

Pierre Boldrini, IAP
boldrini@iap.fr

September 2020

In collaboration with Roya Mohayaee & Joe Silk

Institut d'Astrophysique de Paris
Unité mixte de recherche 7095 CNRS - Sorbonne Université

Nature of dark matter

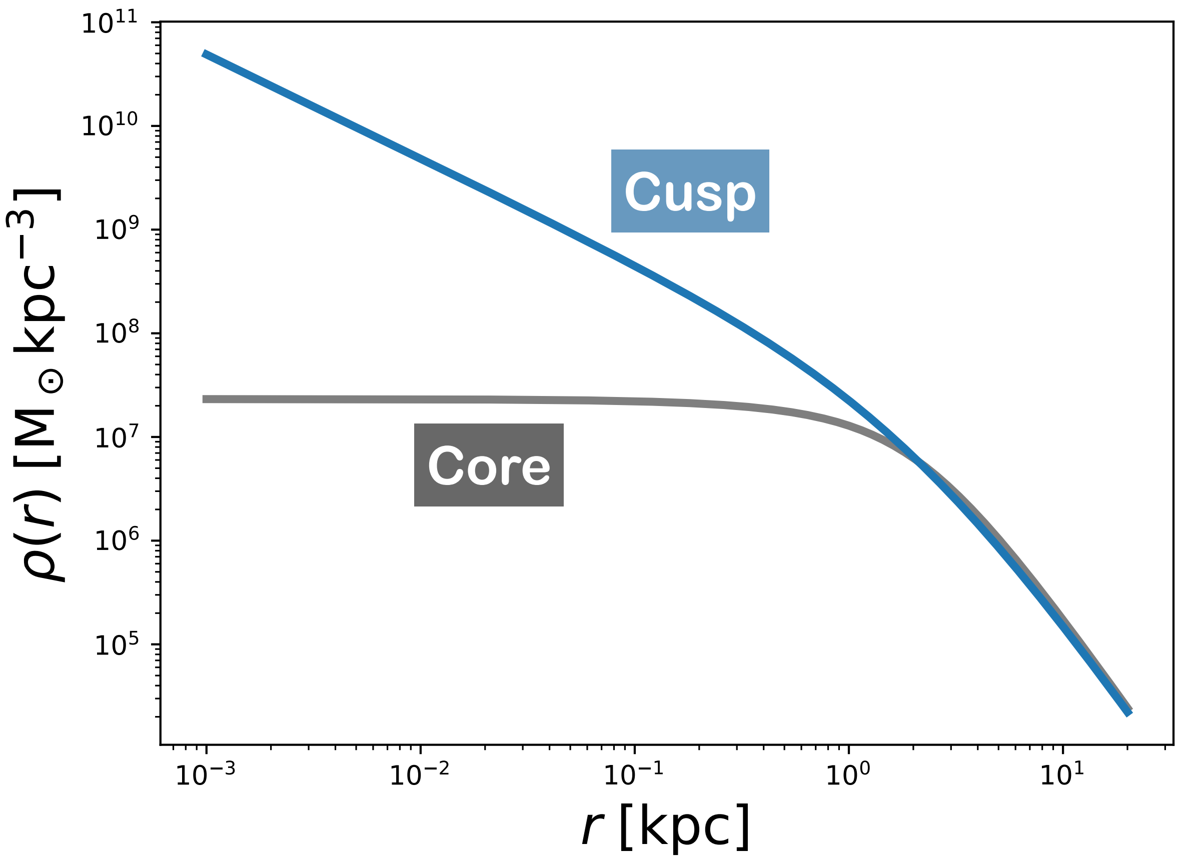
Galaxies are **embedded** in halos of **dark matter**

- Cold dark matter — **Current cosmological model**
- Warm dark matter
- Self-interacting dark matter
- Fuzzy dark matter

Alternative theories

Dark matter distributions in different theories

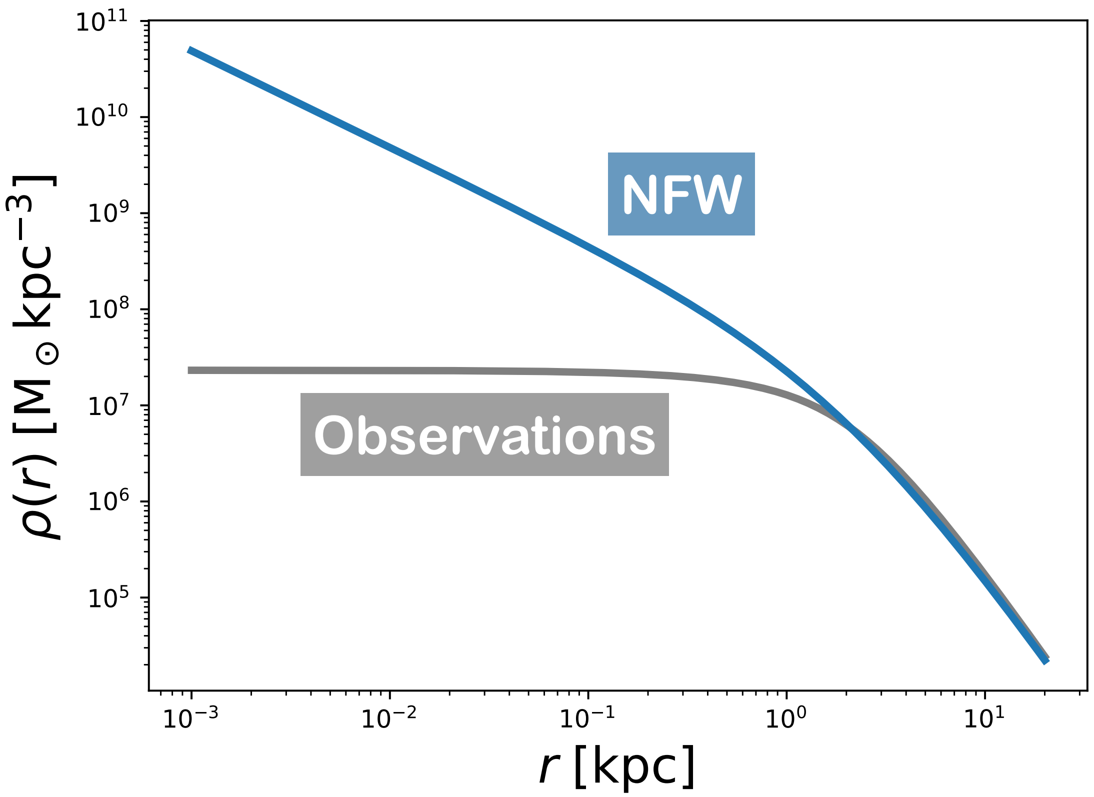
How dark matter is distributed in dwarf galaxies?

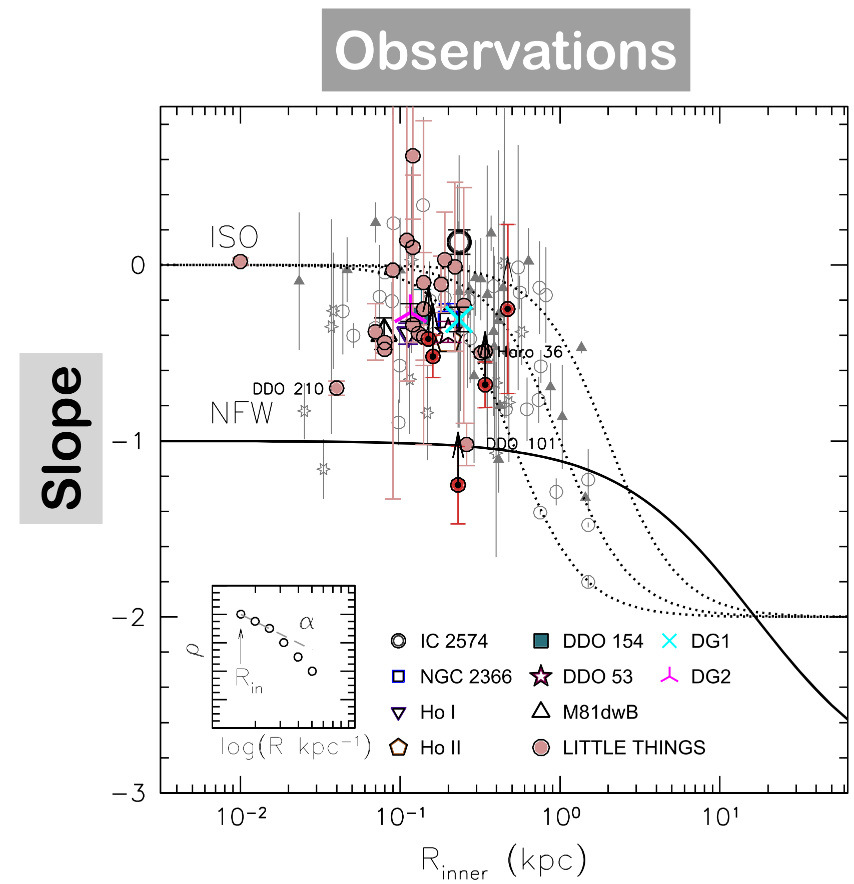


- Cold dark matter **Cusp**
- Warm dark matter **Core**
- Self-interacting dark matter **Cusp** **Core**
- Fuzzy dark matter **Core**

Cusp-core problem

The discrepancy between observations and theory



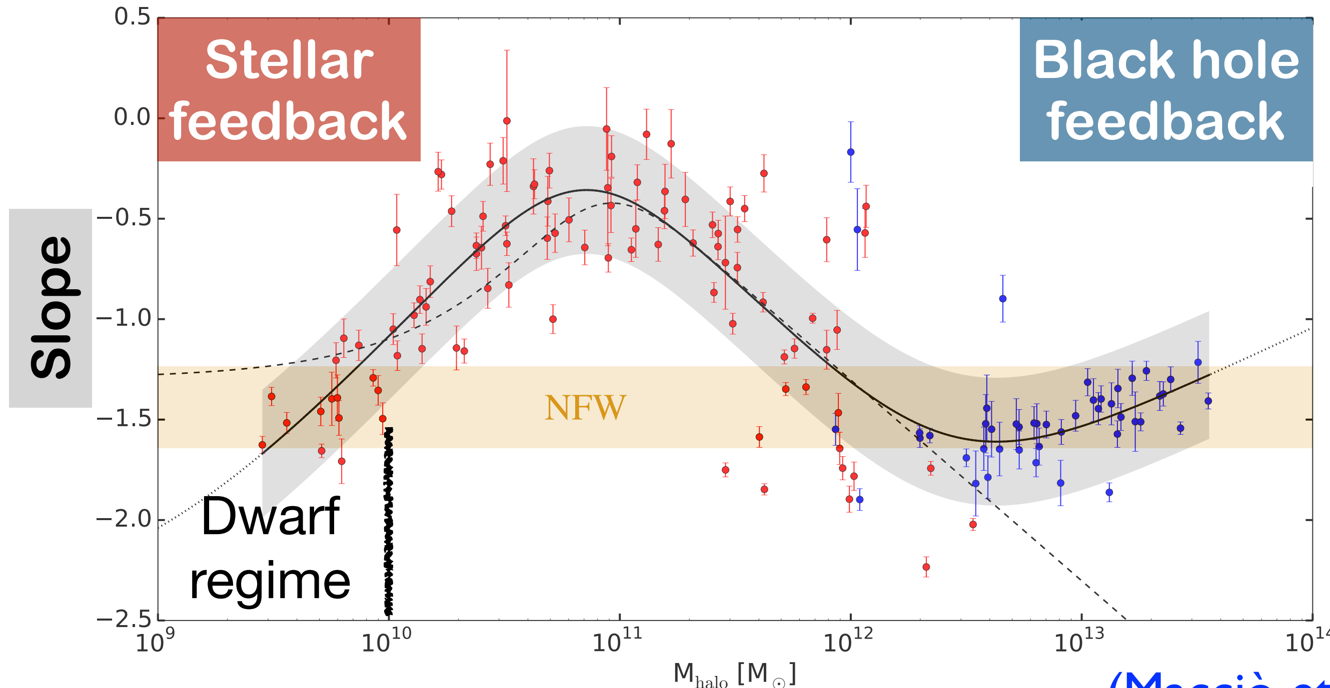


(Oh et al. (2015))

$$\rho(r)_{\mathrm{NFW}} = \rho_0 \left(\frac{r}{r_s}\right)^{-1} \left(1 + \frac{r}{r_s}\right)^{-2}$$

Astrophysical solutions

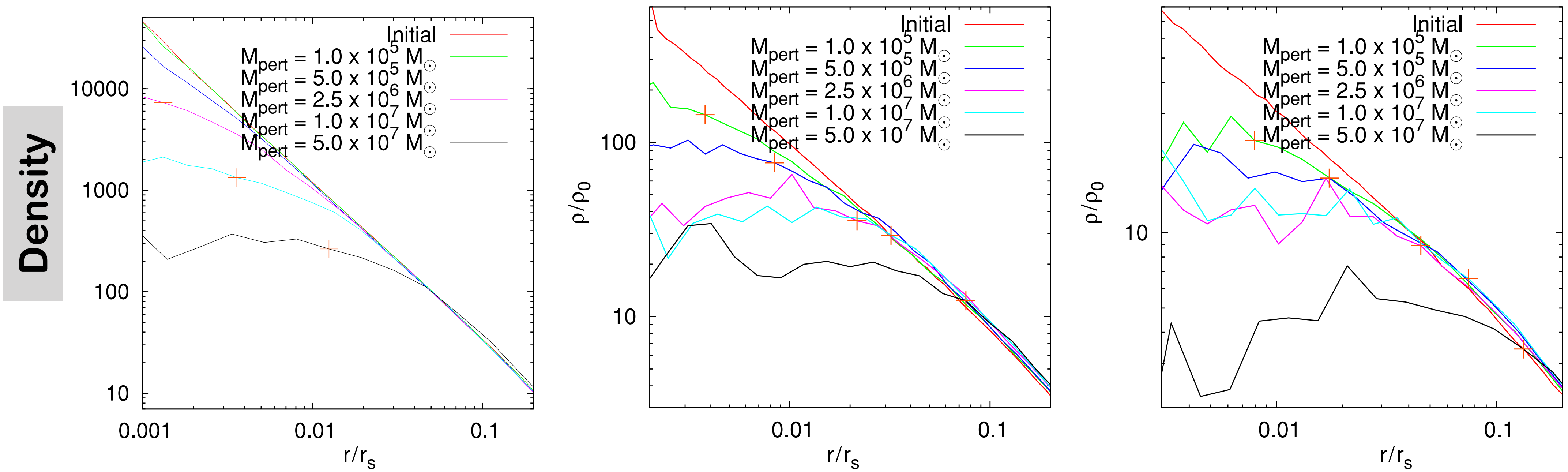
Baryonic feedback



(Macciò et al. (2020))

Sinking massive objects (gas clumps)

(Goerdt et al. (2010))



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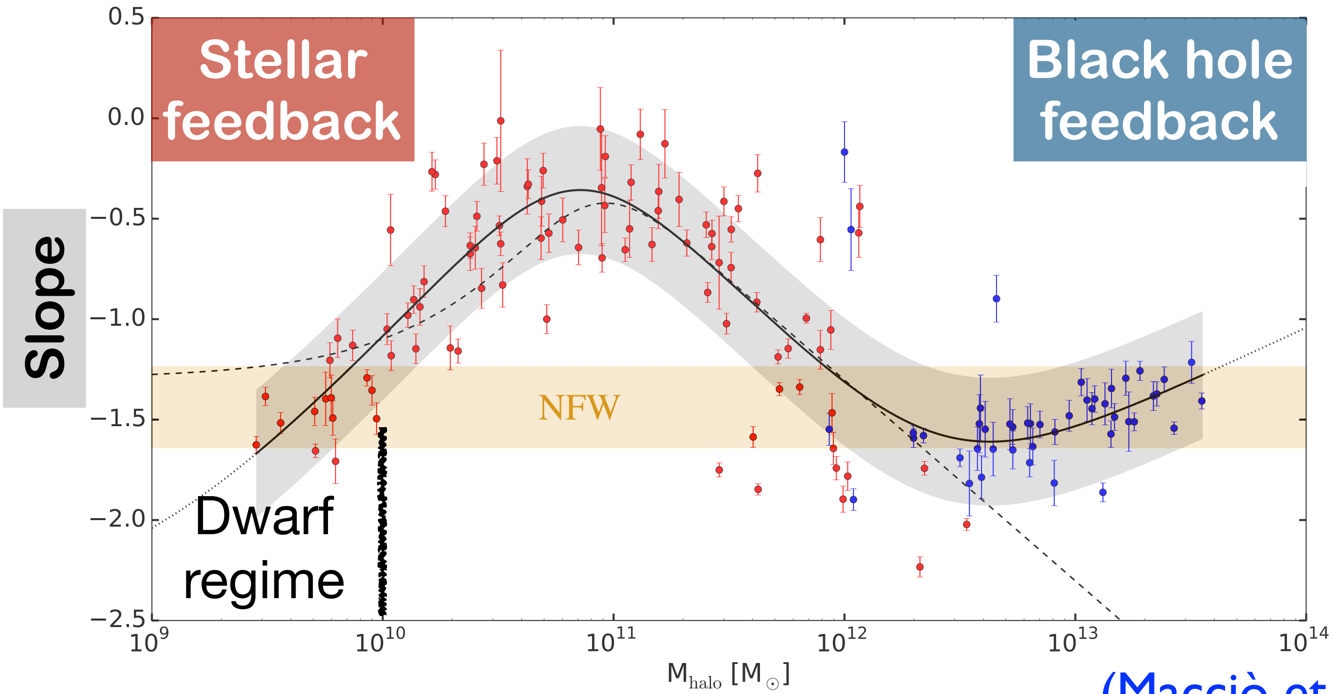

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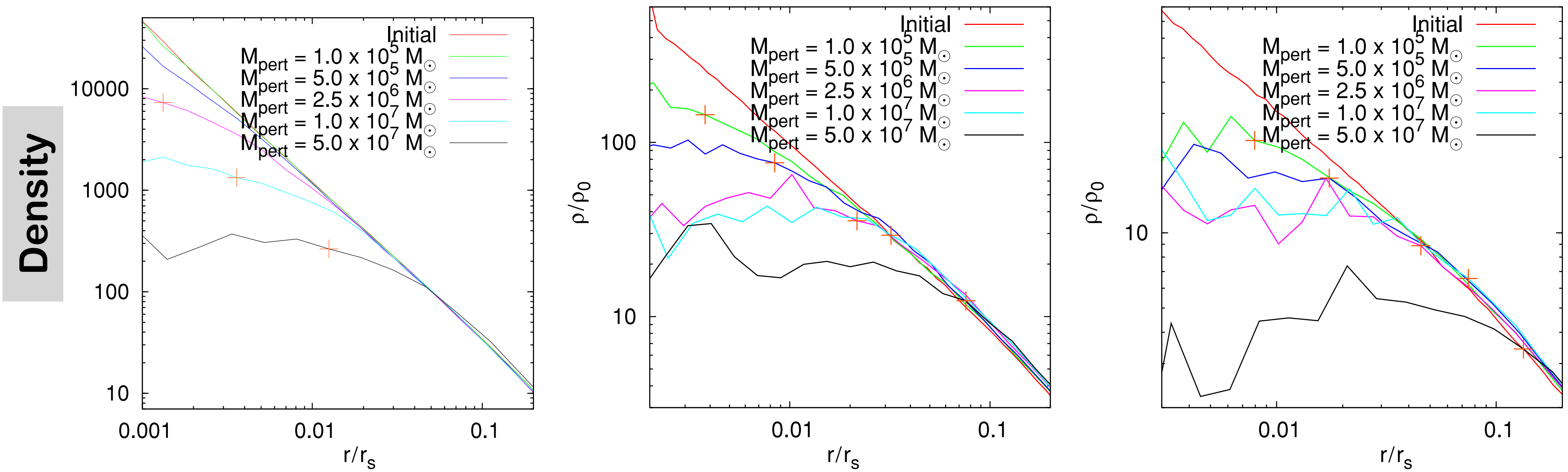
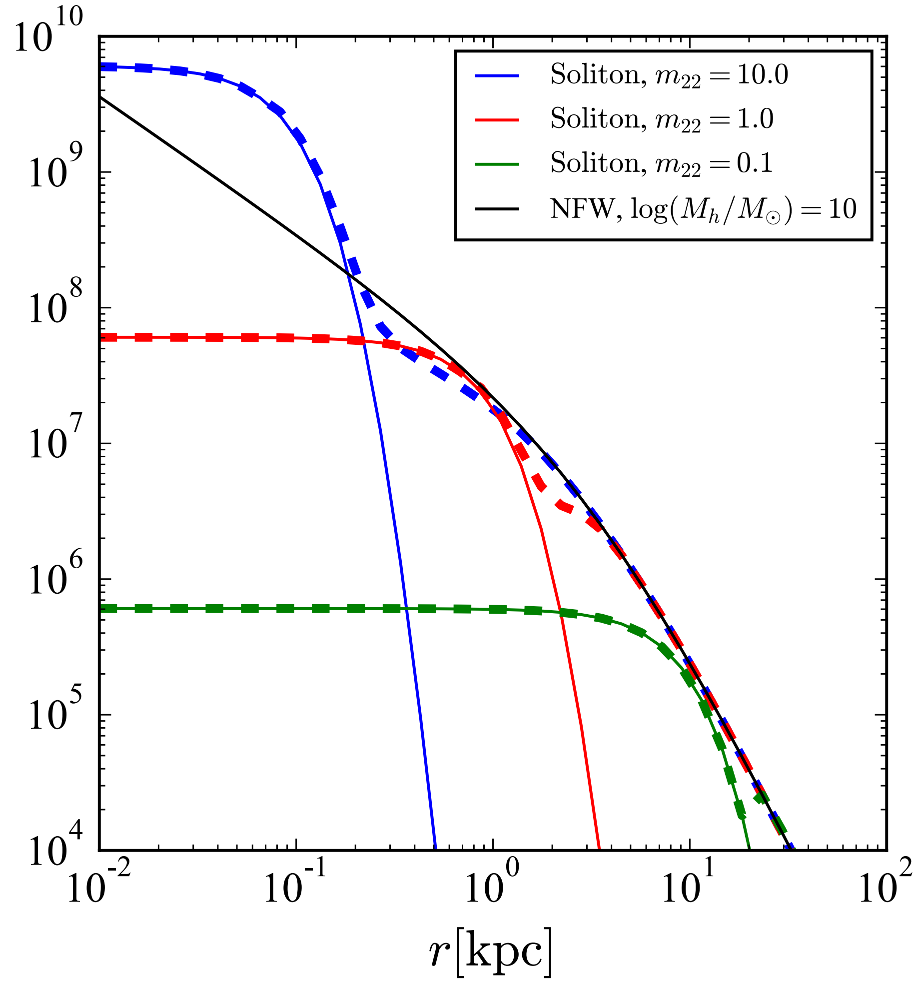


Cosmological solutions

Changing the nature of the dark matter

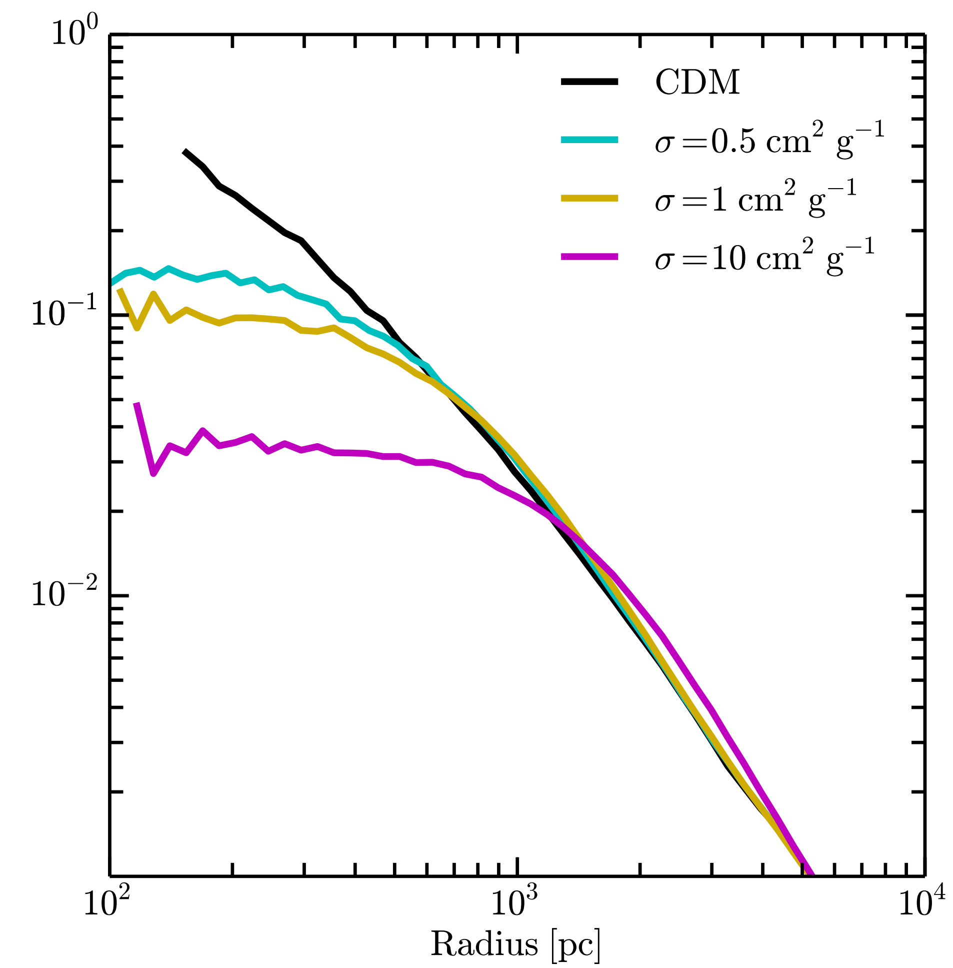
Density

Fuzzy dark matter



(Safarzadeh et al. (2020))

Self-interacting dark matter



(Elbert et al. (2015))

Objectives

Effects of infalling objects on the central black hole

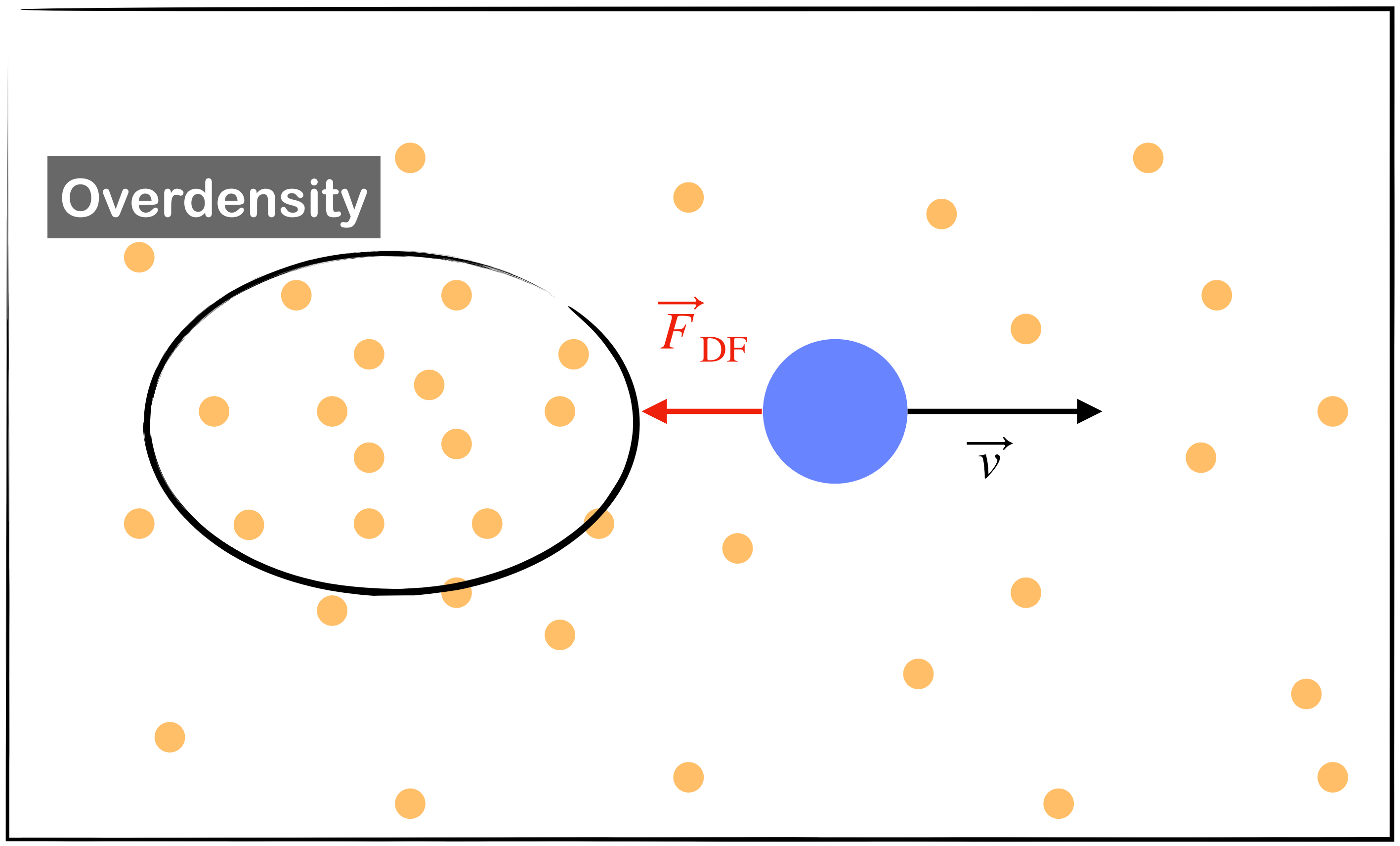
🍎 **Satellite galaxy**

🍎 **Dark matter subhalos**

🍦 Finding new plausible solutions to the cusp-core problem in dwarf galaxies 🍦

Dynamical friction

A drag force induced by the DM background

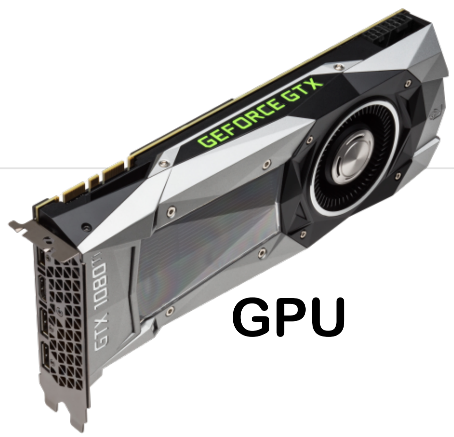


- Slows down the object
- Transfers energy to the background

$$\vec{F}_{DF}(x, v) \propto \rho_{DM}(x)\, M_{perturber}$$ (Chandrasekhar et al. (1943))

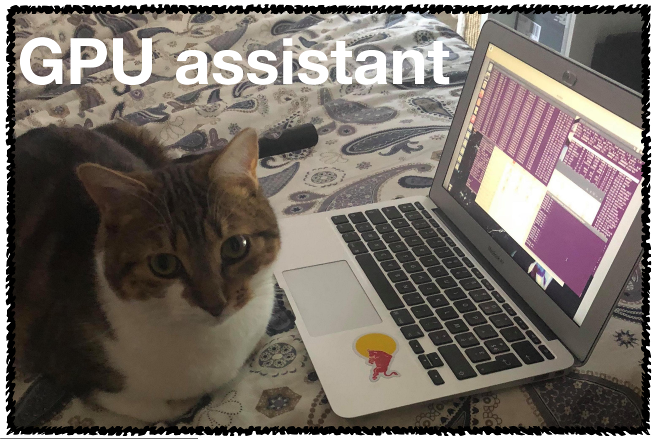
The dynamic depends on the **mass of the perturber** and the **DM background density**

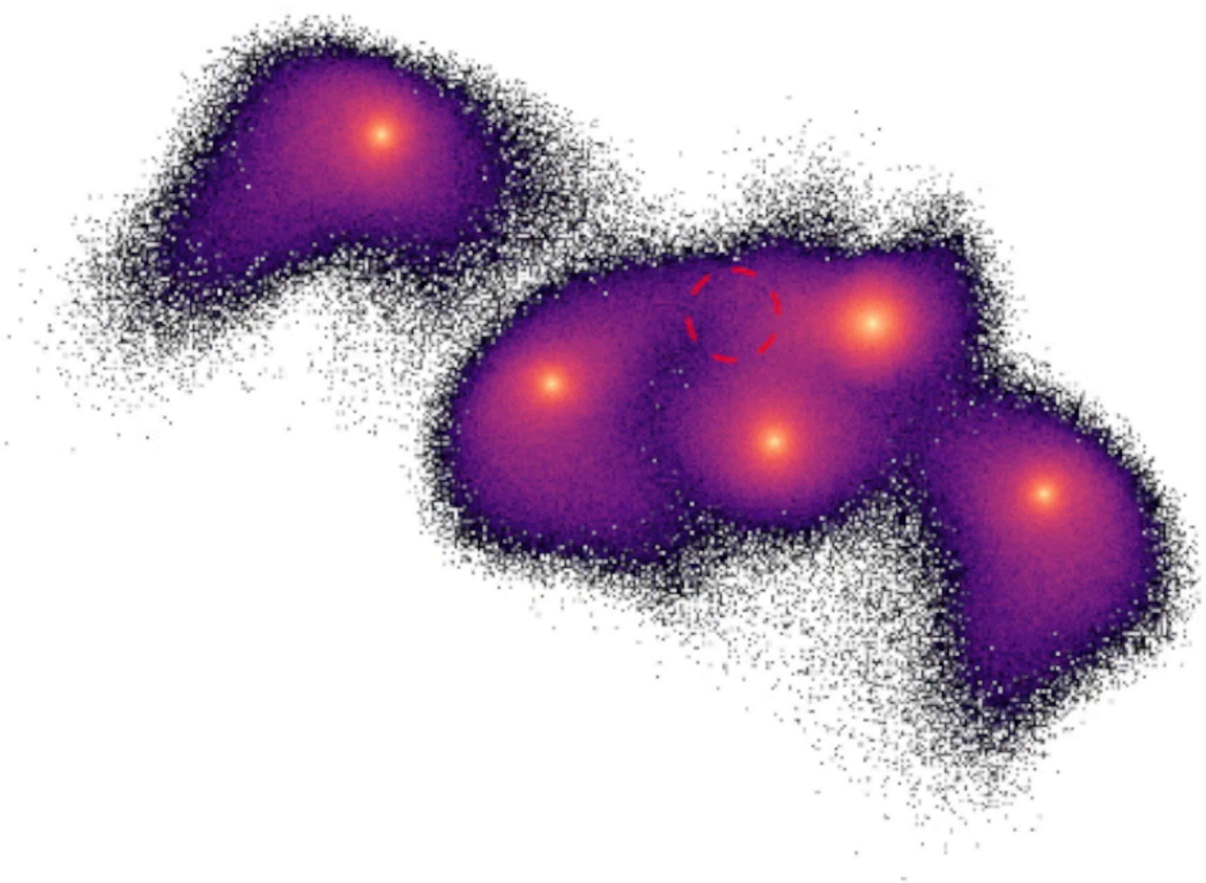
N-body simulations

Collisionless
N-body code
(like Gadget-2)
+


GPU
=
Gravitational
Oct-
Tree code accelerated by
Hierarchical time step
Controlling

(Miki et al. (2017))





Dark matter particles only

Objectives

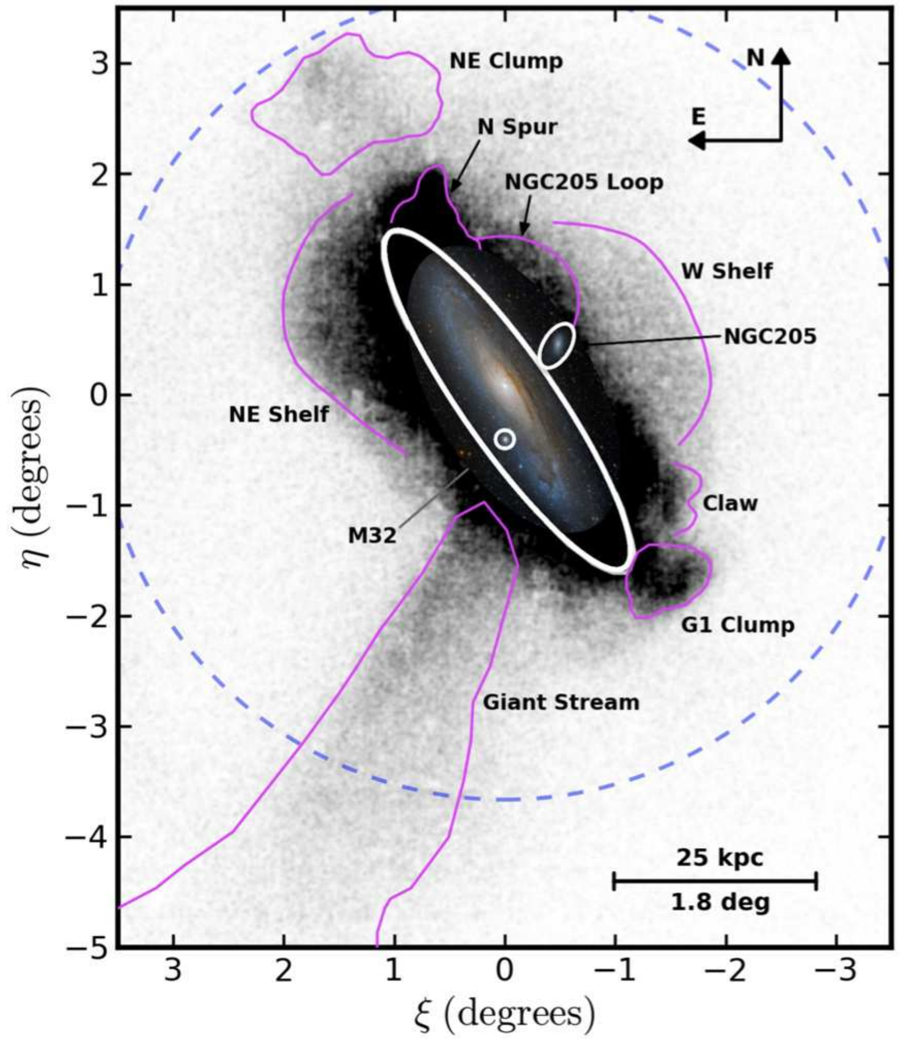
Effects of infalling objects on the central black hole

🍎 **Satellite galaxy**

Satellite galaxy in M31

Observations

Tidal features



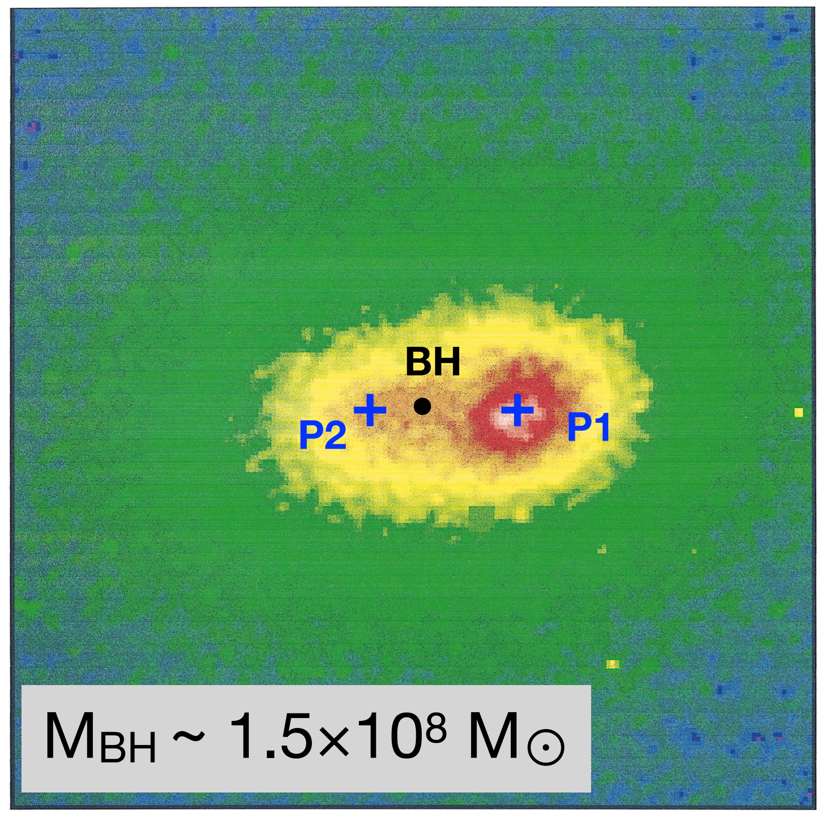
(Ferguson & Mackey (2016))

Phase structures of M31 are results of the **accretion** of a **satellite** galaxy

Satellite galaxy in M31

Observations

Off-centre black hole



(Kormendy & Bender (1999))

The **M31 black hole** is **offset** by **0.26 pc** from P2

Satellite galaxy in M31

Mechanisms for off-centre black holes

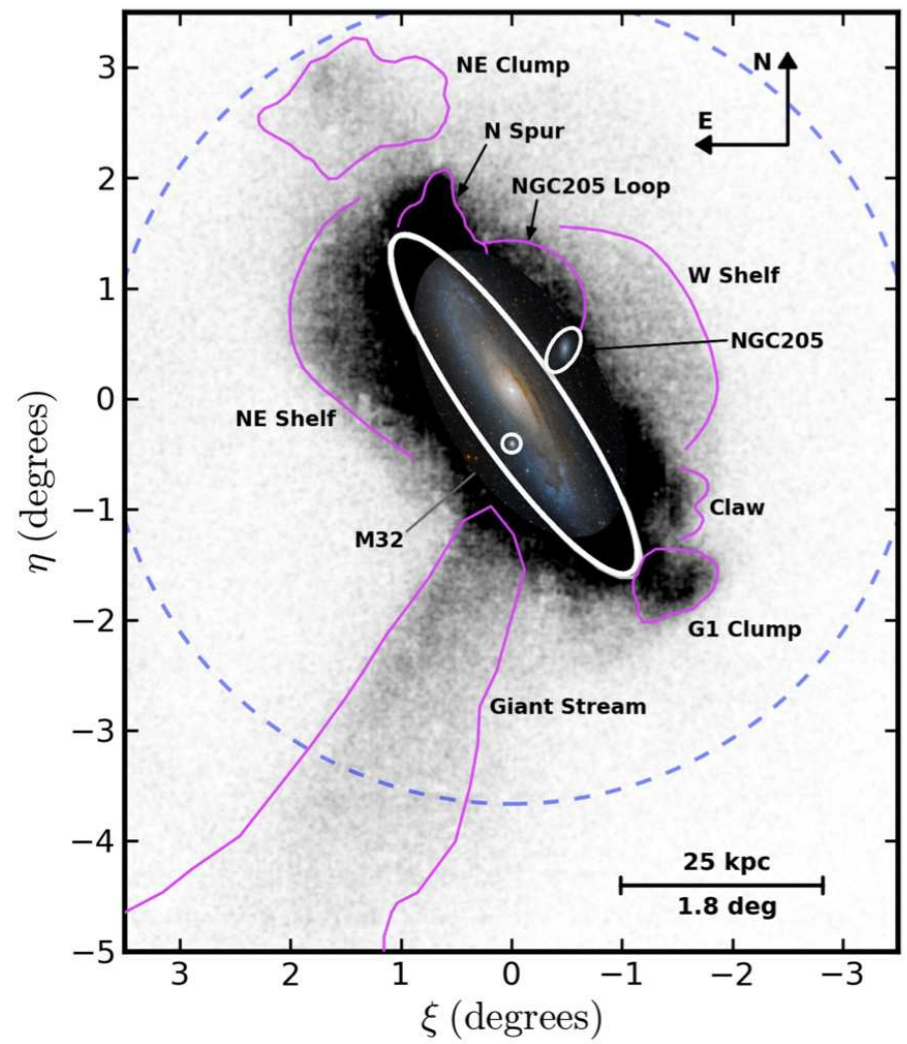
- Binary system before BH merger
- Recoil of merging BHs
- Galaxy mergers

A single minor merger scenario

As the origin of:

- Giant south stream
- Stellar shells

(Ferguson & Mackey (2016))



Satellite galaxy in M31

Andromeda galaxy M31

Component	Profile	a [kpc]	r_{200} [kpc]	Mass [$10^{10} M_\odot$]
M31 halo	NFW	7.63	195	88
M31 bulge	Hernquist	0.61	-	3.24
M31 disk	Exponential	$R_d = 5.4$	-	3.66
	disk	$z_d = 0.6$	-	-
M31 black hole	Point mass	-	-	0.015

(Geehan et al. (2006))

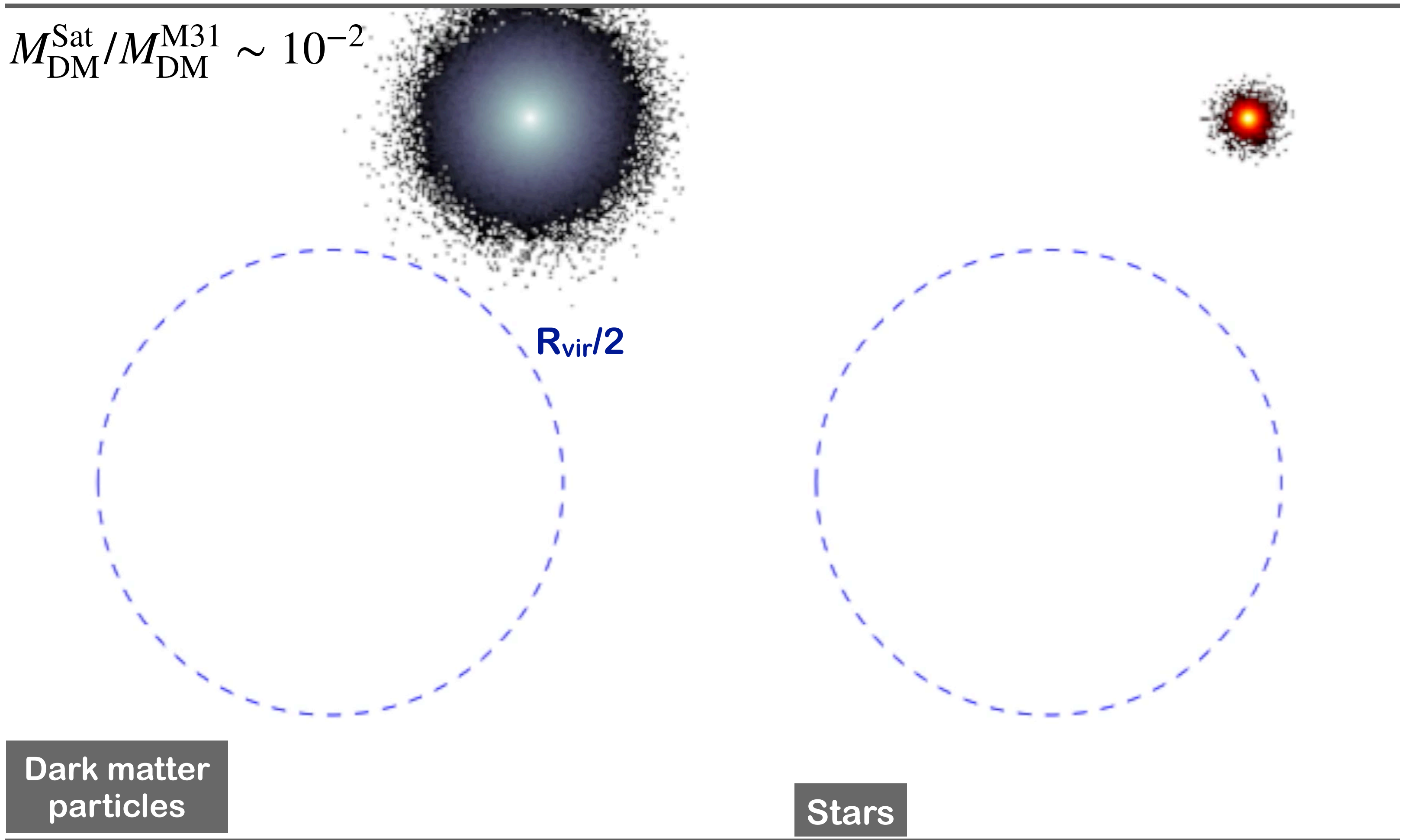
Infalling satellite

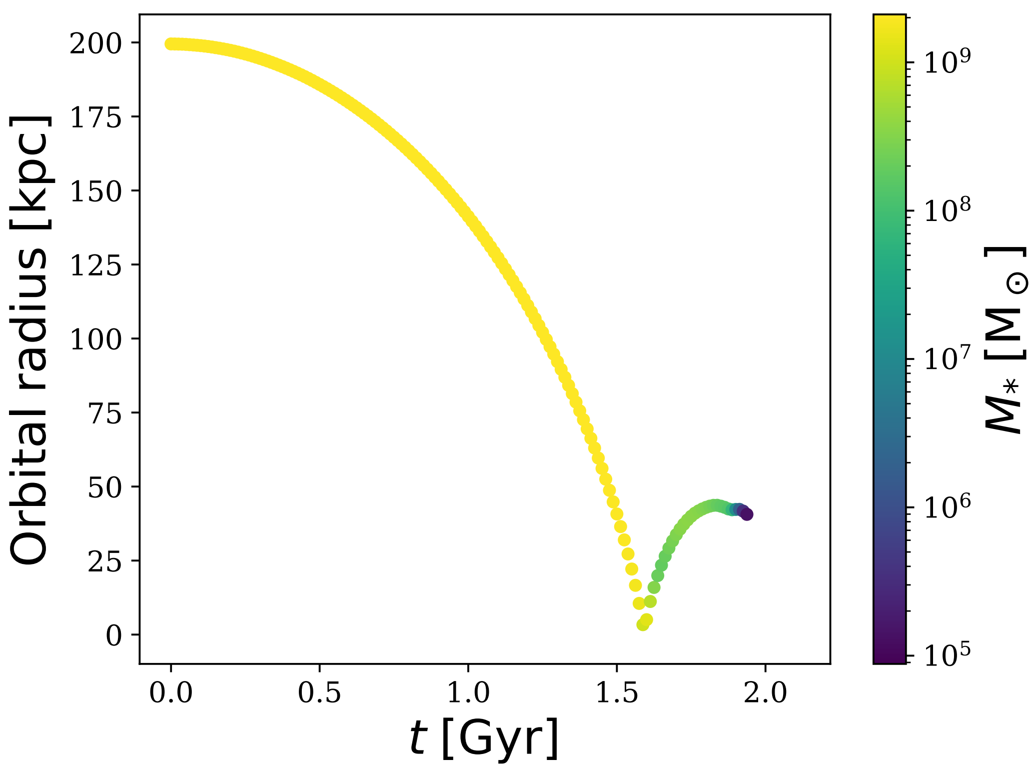
Sadoun, et al. (2014)					
$((M_{DM}/M_*)_{sat} = 20)$	DM halo	Hernquist	12.5	20	4.18
	Stars	Plummer	1.03	-	0.22

The dark matter rich satellite starts at its **first turnaround radius** at **200 kpc** with a **null velocity**

Satellite galaxy in M31

A minor merger scenario with M31 galaxy (Sadoun et al. (2014))



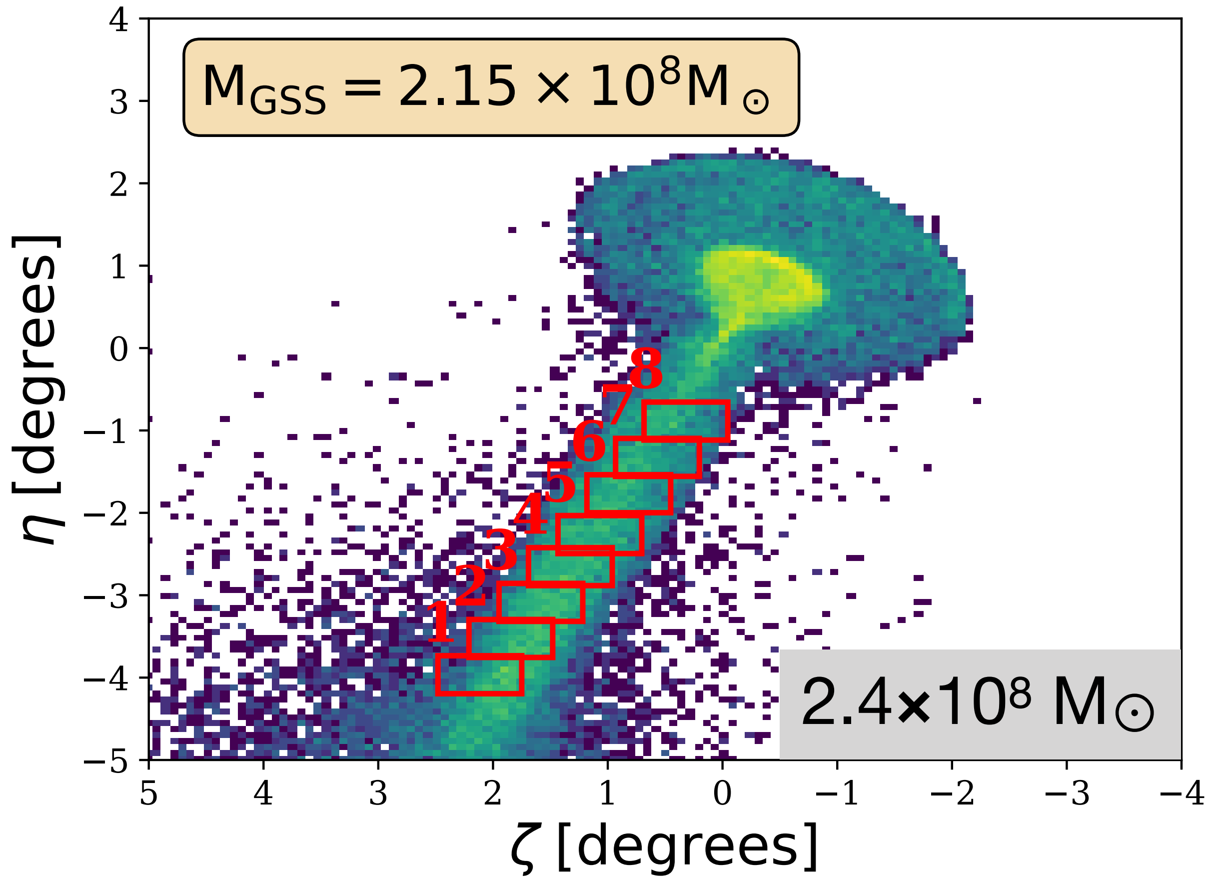


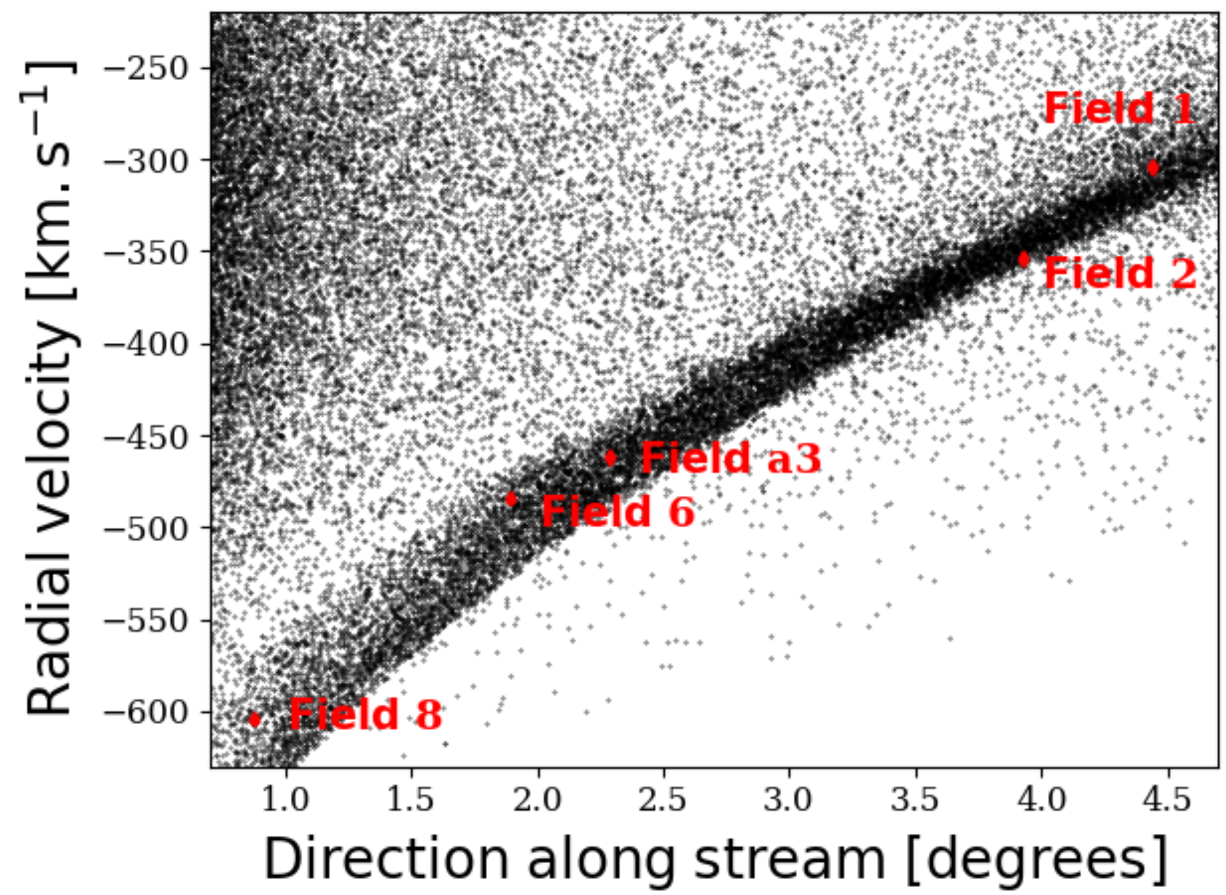
(Boldrini 2020, MNRAS Letters, L137B)

Satellite galaxy in M31

Constraints from observations

At 2.1 Gyr





(Boldrini 2020, MNRAS Letters, L137B)

Satellite galaxy in M31

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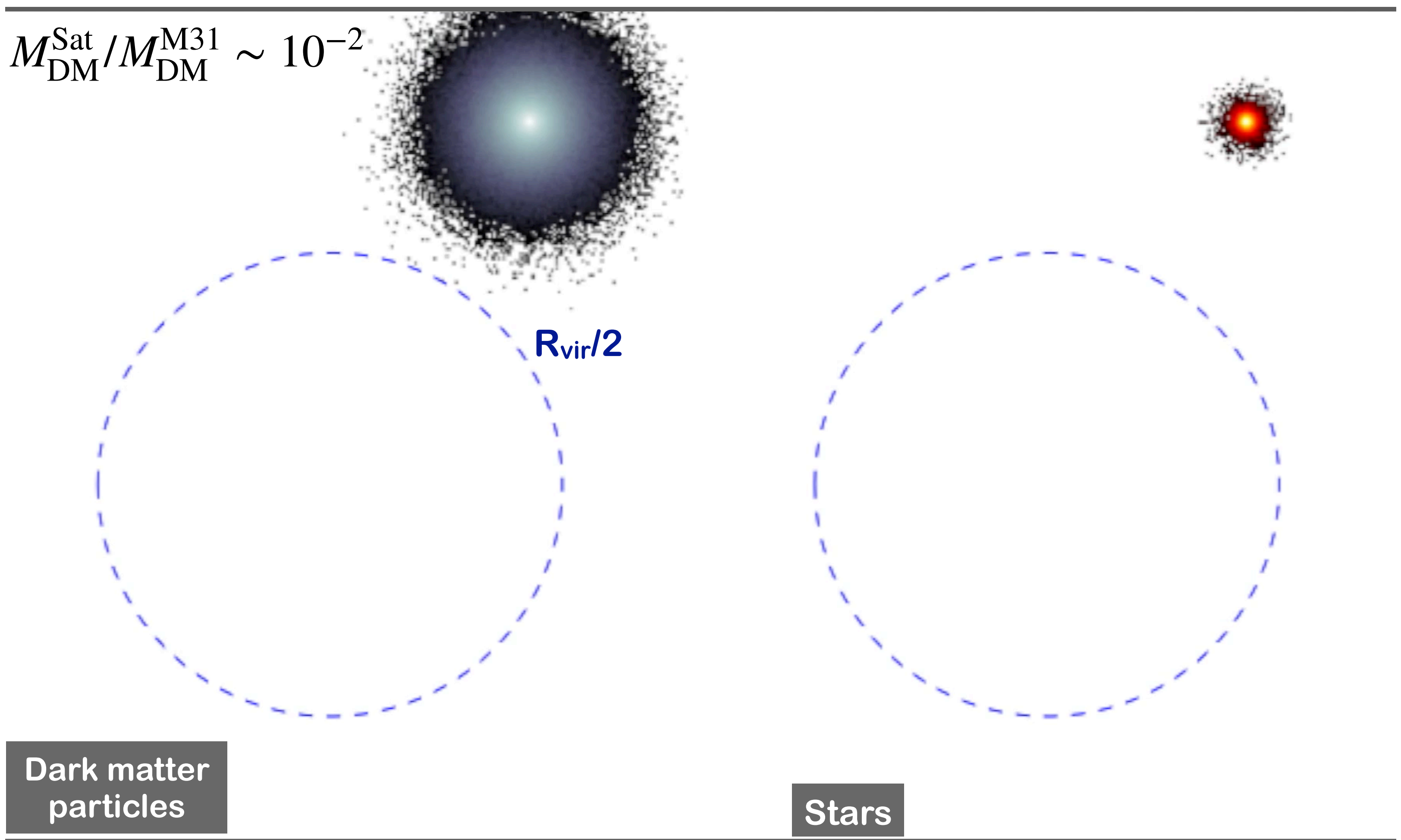
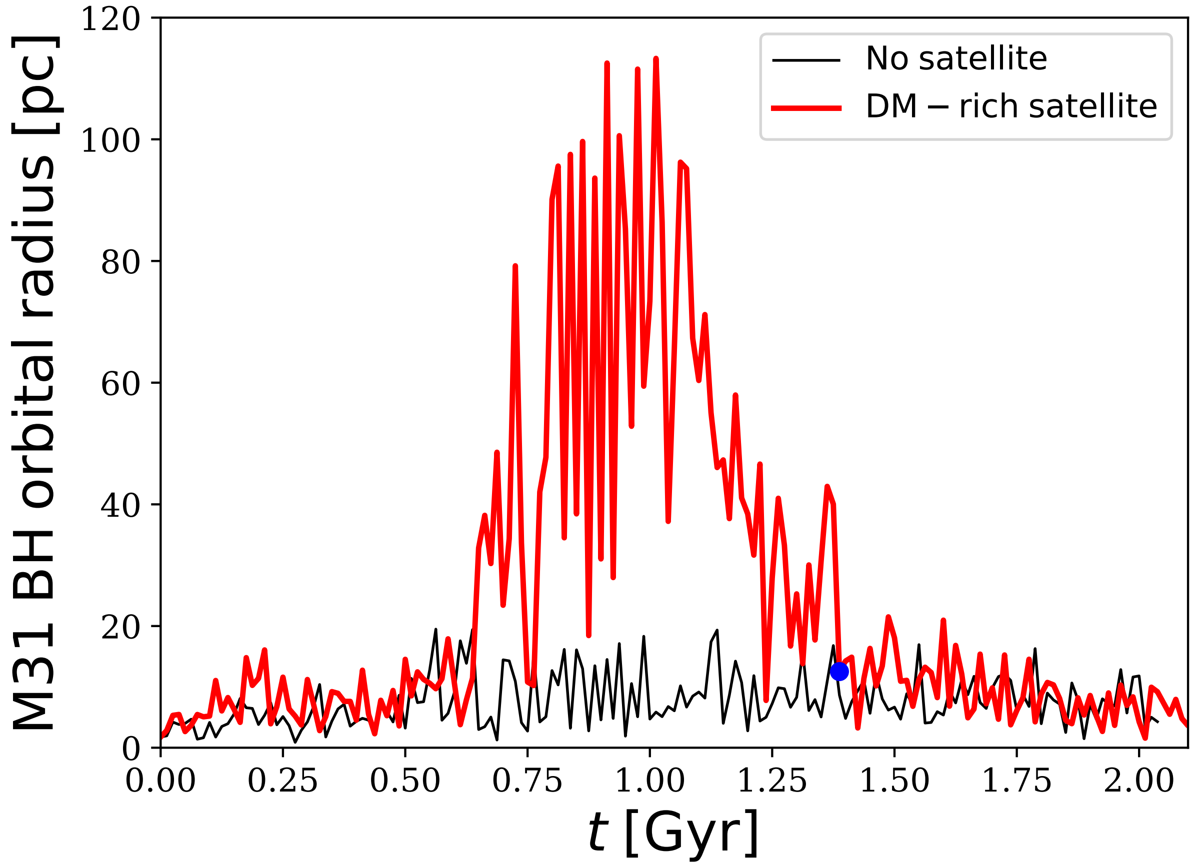


(Boldrini et al. (2020))

What happened to the **M31 central black hole** after this recent merger?

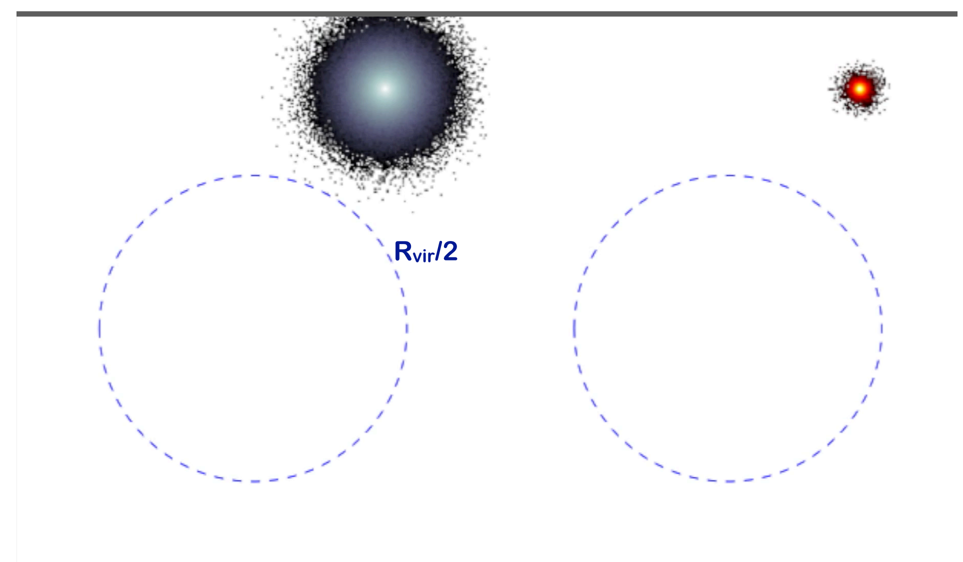
Satellite galaxy in M31

The offset of the M31 black hole



(Boldrini 2020, MNRAS Letters, L137B)

Merger scenario

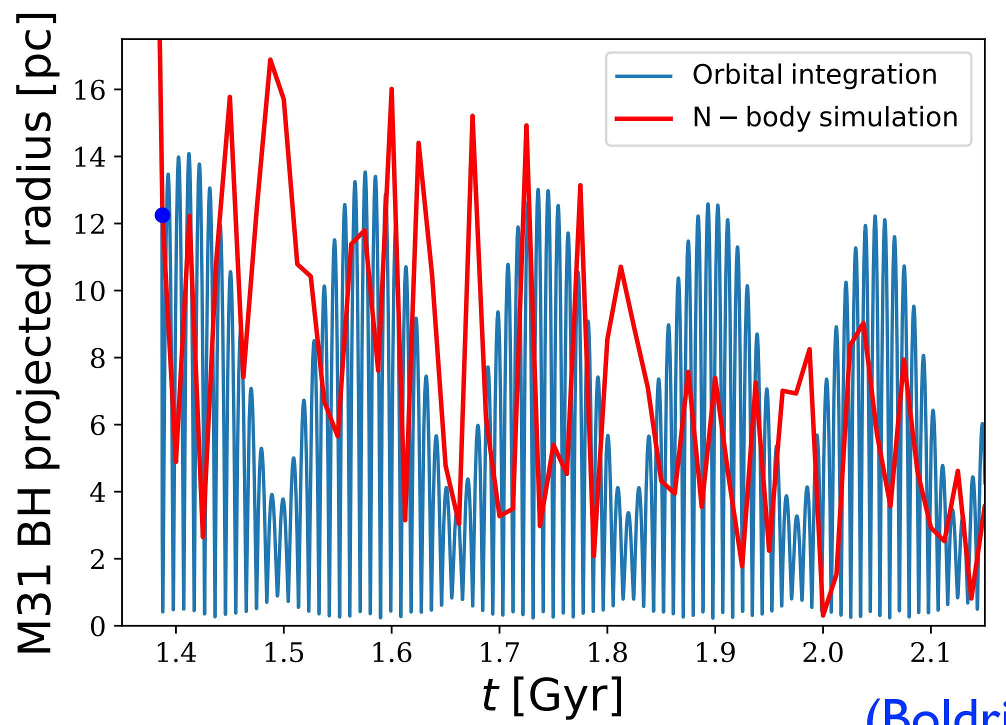


It results in a **kick** of the **black hole** to **hundreds of parsecs** from the galaxy centre

(Boldrini (2020))

Satellite galaxy in M31

Orbit integrations with Galpy (Bovy (2015))



(Boldrini 2020, MNRAS Letters, L137B)

At 2.1 Gyr	Prediction	Observation
Offset by	0.39 pc	0.26 pc

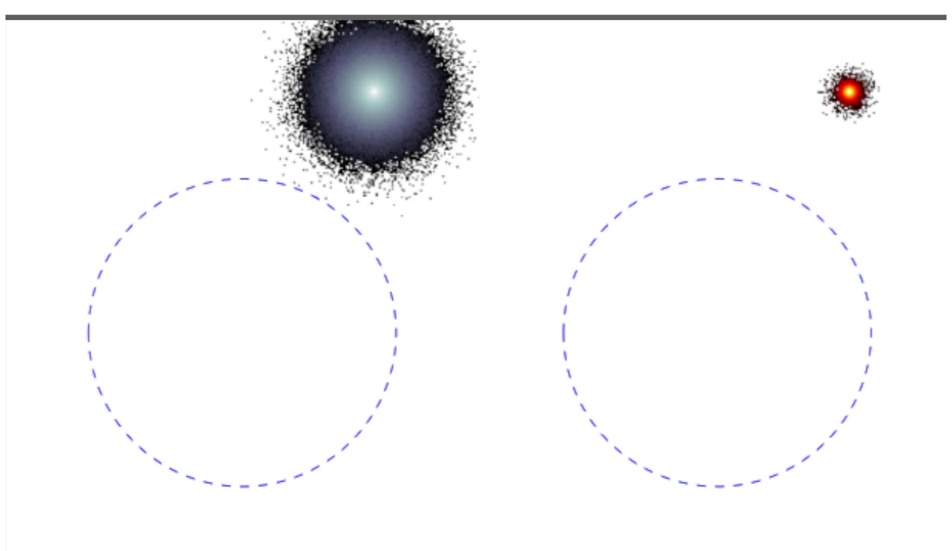
The **infall** of the **accreting satellite** in M31 naturally explains a **black hole offset** by sub-parsecs

Results

Effects of infalling objects on the central black hole

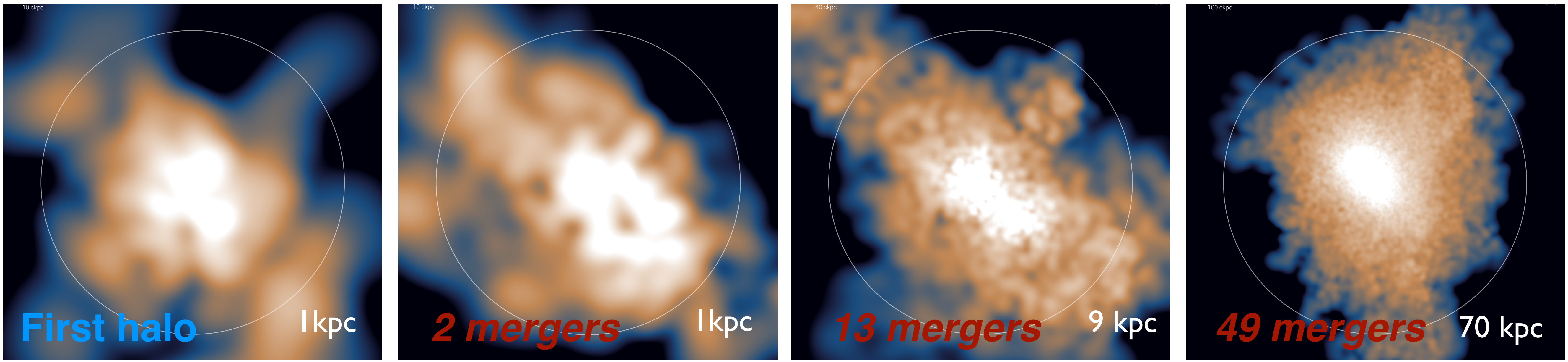
Satellite galaxy

- The infall of M31 satellite can offset the central massive black hole (Boldrini 2020, MNRAS Letters, L137B)



Dark matter subhalos

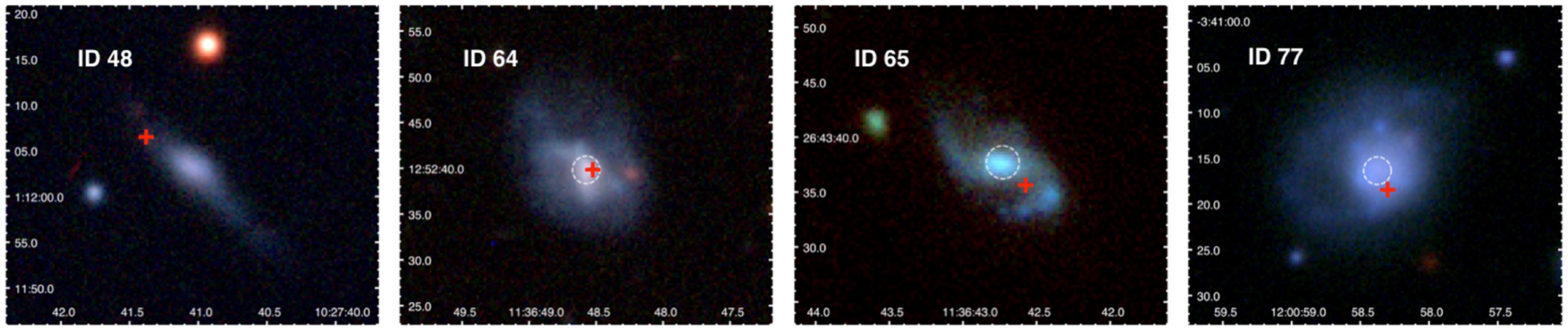
Accretion of dark matter substructures



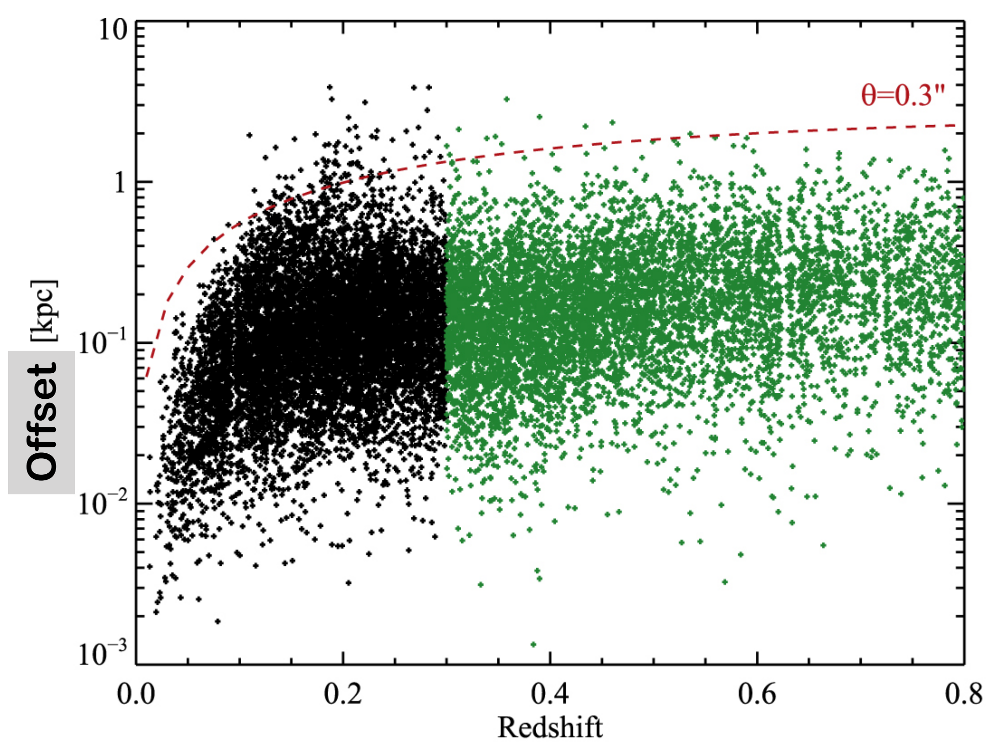
Dark matter halos are **growing** with time by **accretion** of smaller halos, called **subhalos**.

Off-centre black holes in dwarf galaxies

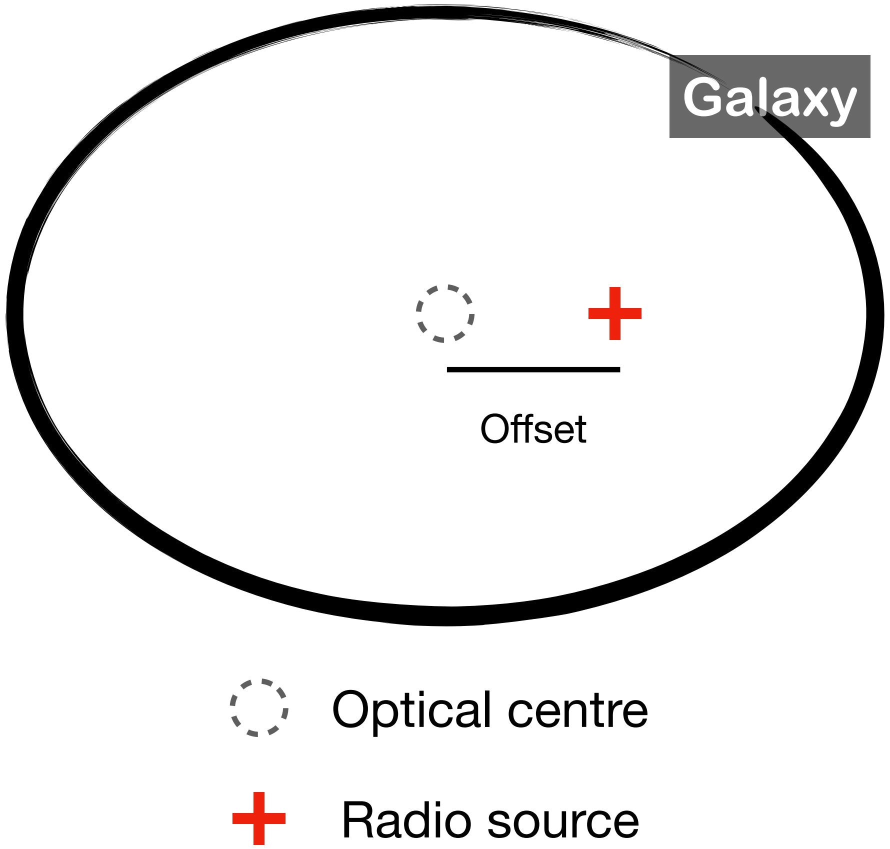
Observations in dwarfs



(Reines et al. (2019))

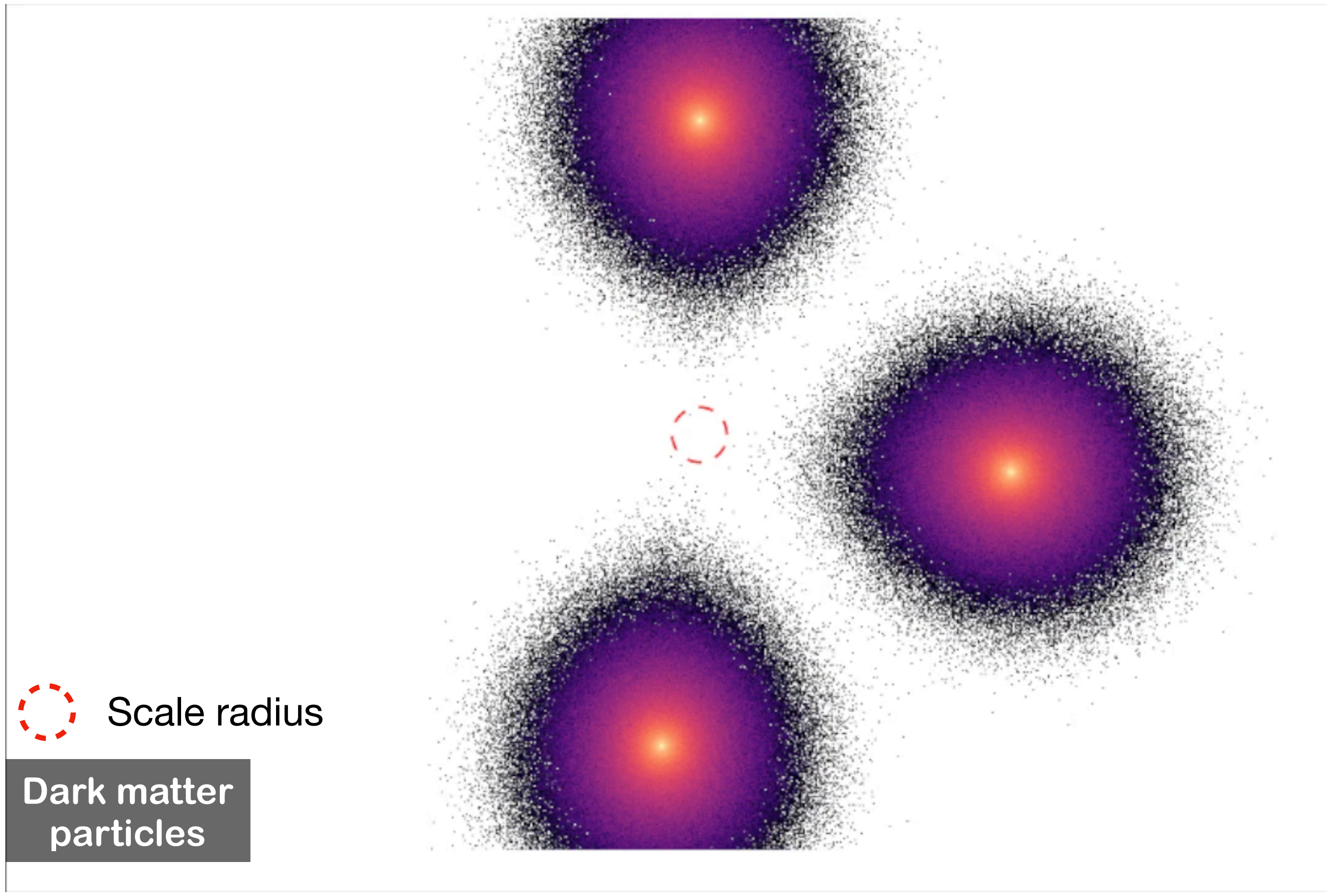


(Shen et al. (2019))



Off-centre black holes in dwarf galaxies

Dark matter subhalos in dwarf galaxies

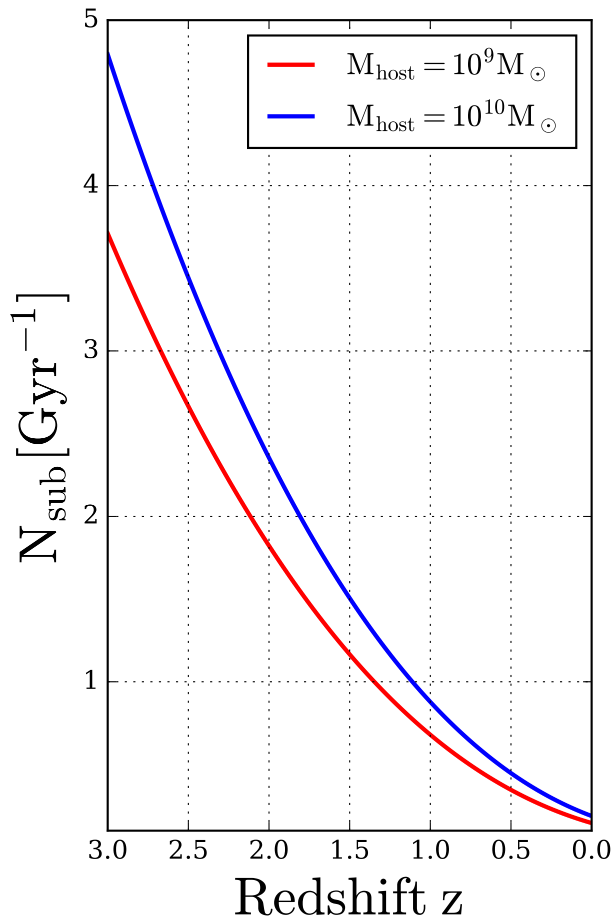


Can dark matter subhalos be also responsible for BH offset?

Off-centre black holes in dwarf galaxies

Subhalo accretions in dwarf galaxies

$10 < M_{host}/M_{sub} < 100$



(Neistein & Dekel (2008))

The **number of subhalo** accretion

in **dwarf galaxies**

can be determined by

the **extended Press-Schecter** formalism

Off-centre black holes in dwarf galaxies

Dwarf galaxies

- NFW form with r_s (z) (Prada et al. (2012)) ~10^{9-10} $M_\odot$
- Plummer profile

Central massive black hole

- Point mass ~10^{5-6} $M_\odot$

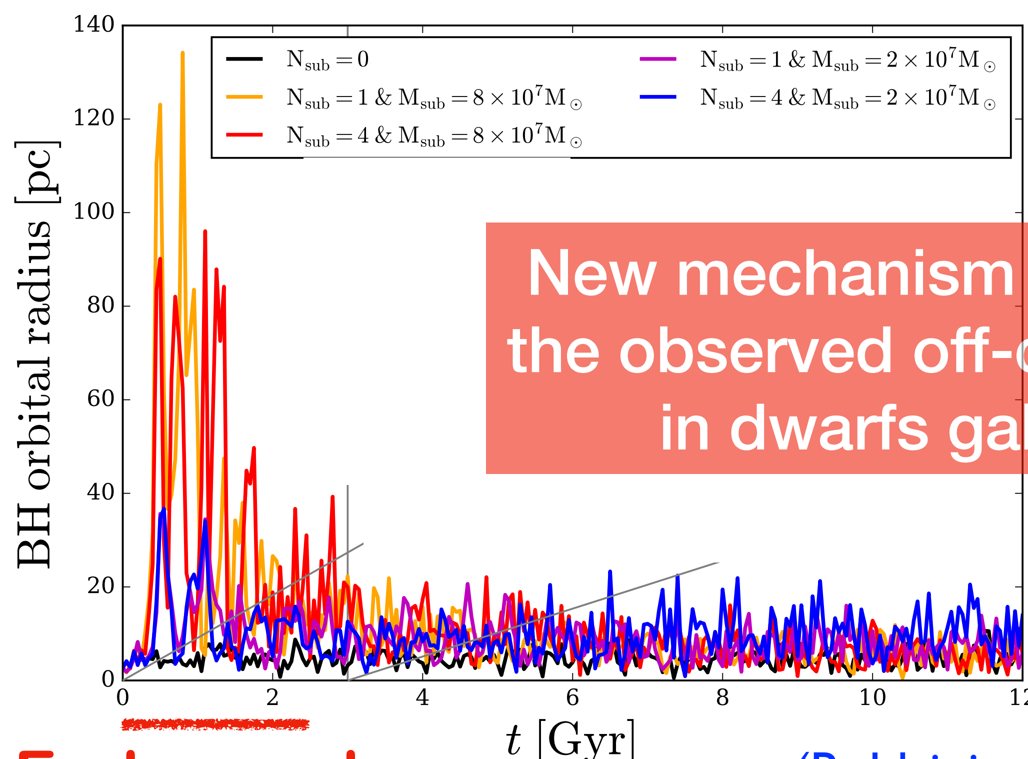
Subhalos ~10^{7-8} $M_\odot$

- NFW form with r_s (z)
- Virial radius as initial orbital radius
- Initial average eccentricity (e=0.86-0.88) (Wetzel (2011))

Off-centre black holes in dwarf galaxies

Heating mechanism

- Sinking toward the central region due to dynamical friction
- Transferring energy via dynamical friction into the dwarf centre



New mechanism to explain the observed off-centre BHs in dwarfs galaxies

Early epochs

(Boldrini et al. , 2020, MNRAS Letters, 495, L12)

This dynamical heating **kicks** any **central MBH** out to **tens of parsecs**, especially at **early epochs** z=1.5 - 3

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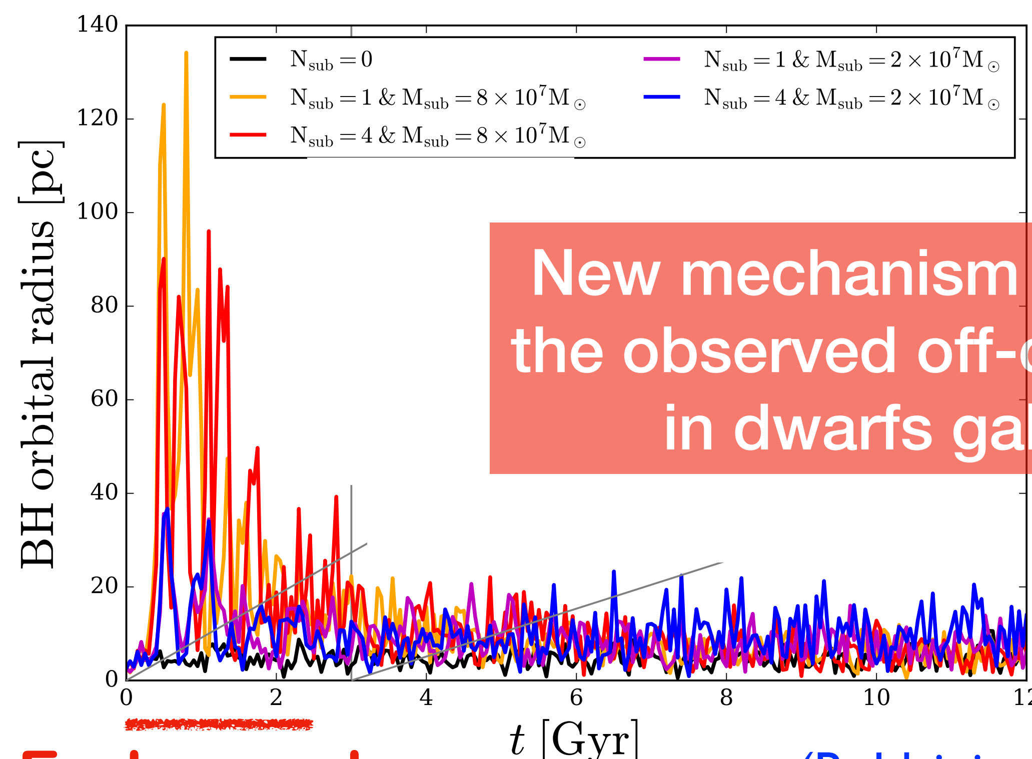
- Sinking of DM subhalos because dynamical friction
- Transferring energy via dynamical friction into the dwarf centre



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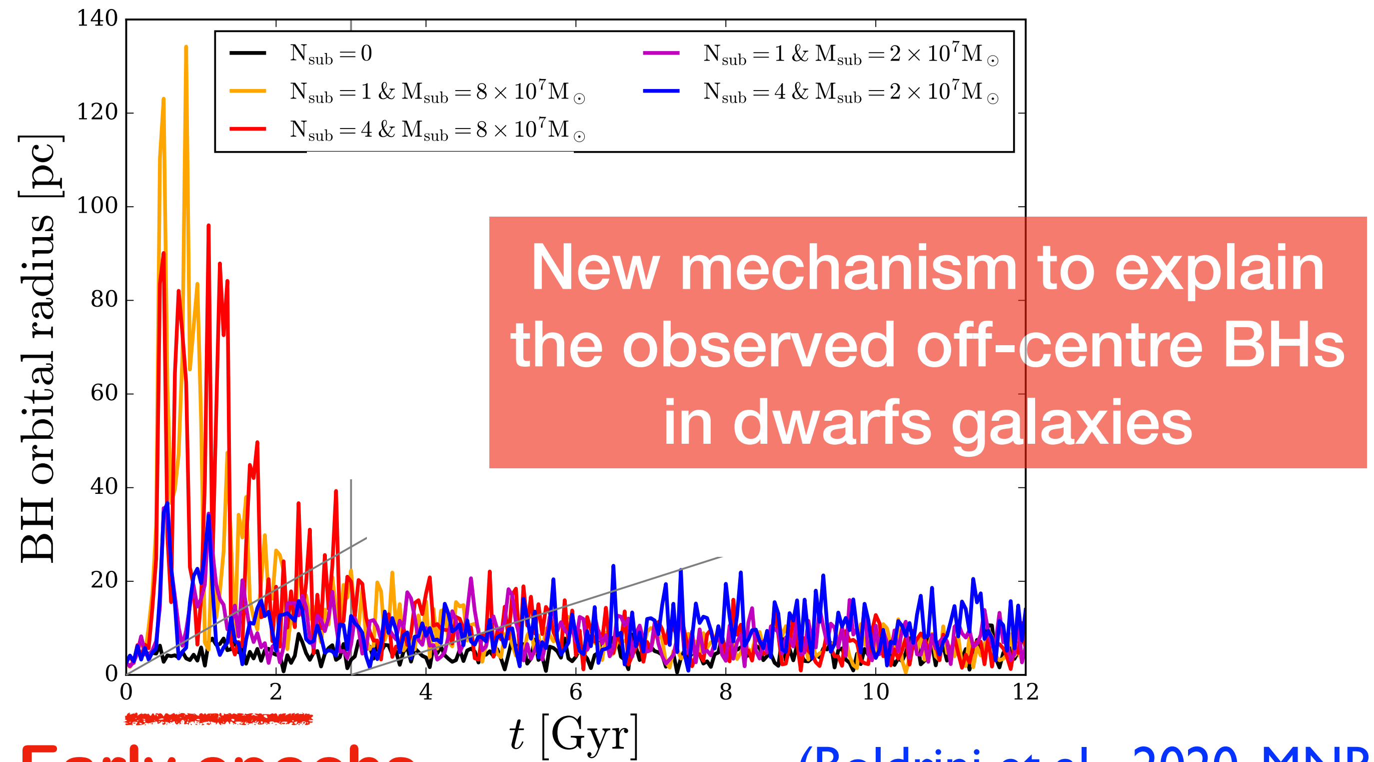

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Off-centre black holes in dwarf galaxies

Cusp-core problem

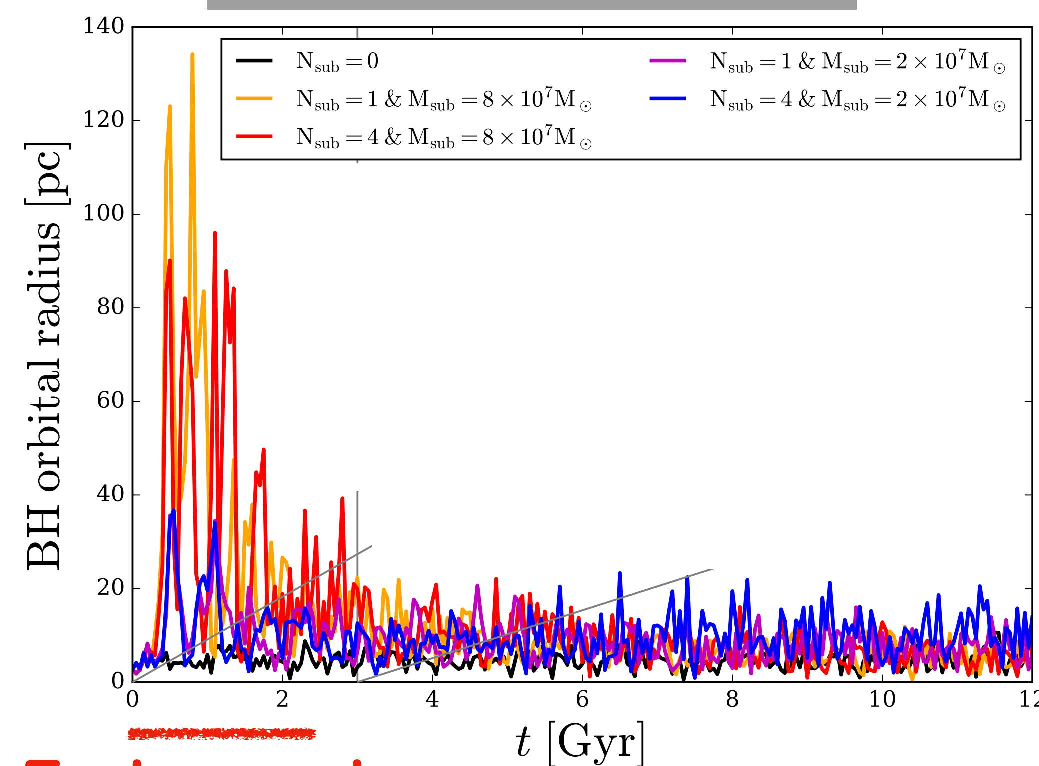
Black hole feedback

- Flattening of the DM density profile
- Peak of BH activity between z~3 and 1.6

BHs **accrete** gas **inefficiently** away from the galaxy centre as **gas clumps** are **centrally located**

(Smith et al. (2018))

Off-centre BH in dwarfs



Early epochs

(Boldrini et al. , 2020, MNRAS Letters, 495, L12)

One consequence of **off-center BHs** during **early epochs** of dwarf galaxies is to **quench any BH feedback**

(Boldrini et al. (2020c))

Results

Effects of infalling objects on the central black hole

Satellite galaxy

- The infall of M31 satellite can offset the central massive black hole
(Boldrini 2020, MNRAS Letters, L137B)

Dark matter subhalos

- The infall of dark matter subhalos leads to off-centre black holes
(Boldrini et al. , 2020, MNRAS Letters, 495, L12)
- One consequence of off-center BHs during early epochs of dwarf galaxies is to quench any BH feedback
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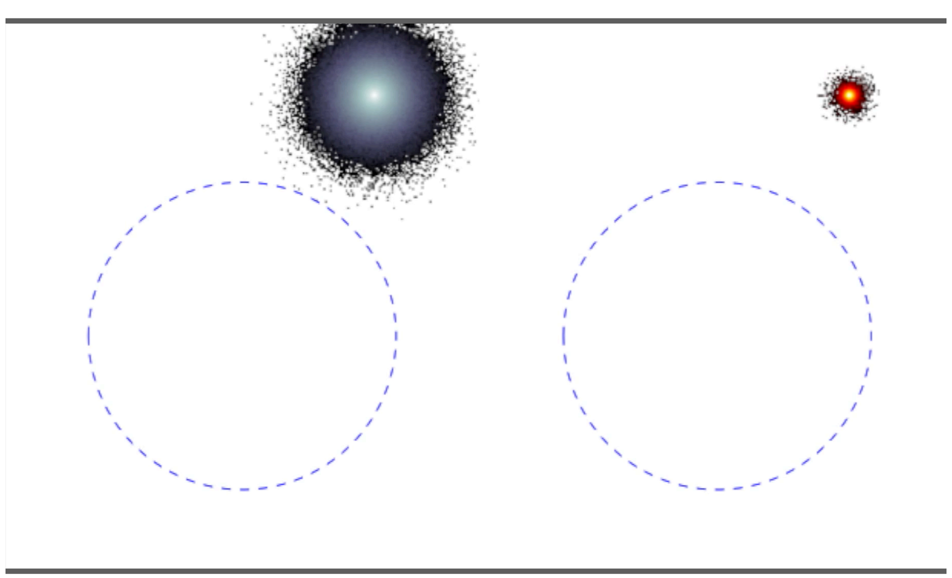

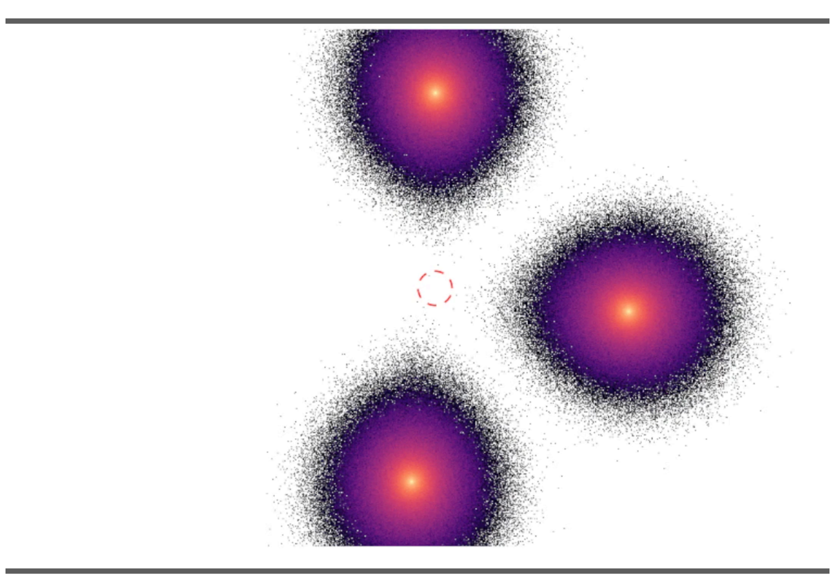

Prospects

Black hole feedback

- 🍿 Add baryonic physics in order to check the quenching of BH feedback
- 🍿 Look at cosmological hydrodynamical simulation (Bartlett et al. 2020)

Alternative dark matter theories such as Self-interacting and Fuzzy DM

- 🍿 Affect the fraction of off-centre BHs (Di Cintio et al. 2017)
- 🍿 Affect the growth and merger history of SMBHs (Cruz et al. 2020)

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Thank you
for your attention