Cusp-core problem

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Nature of dark matter

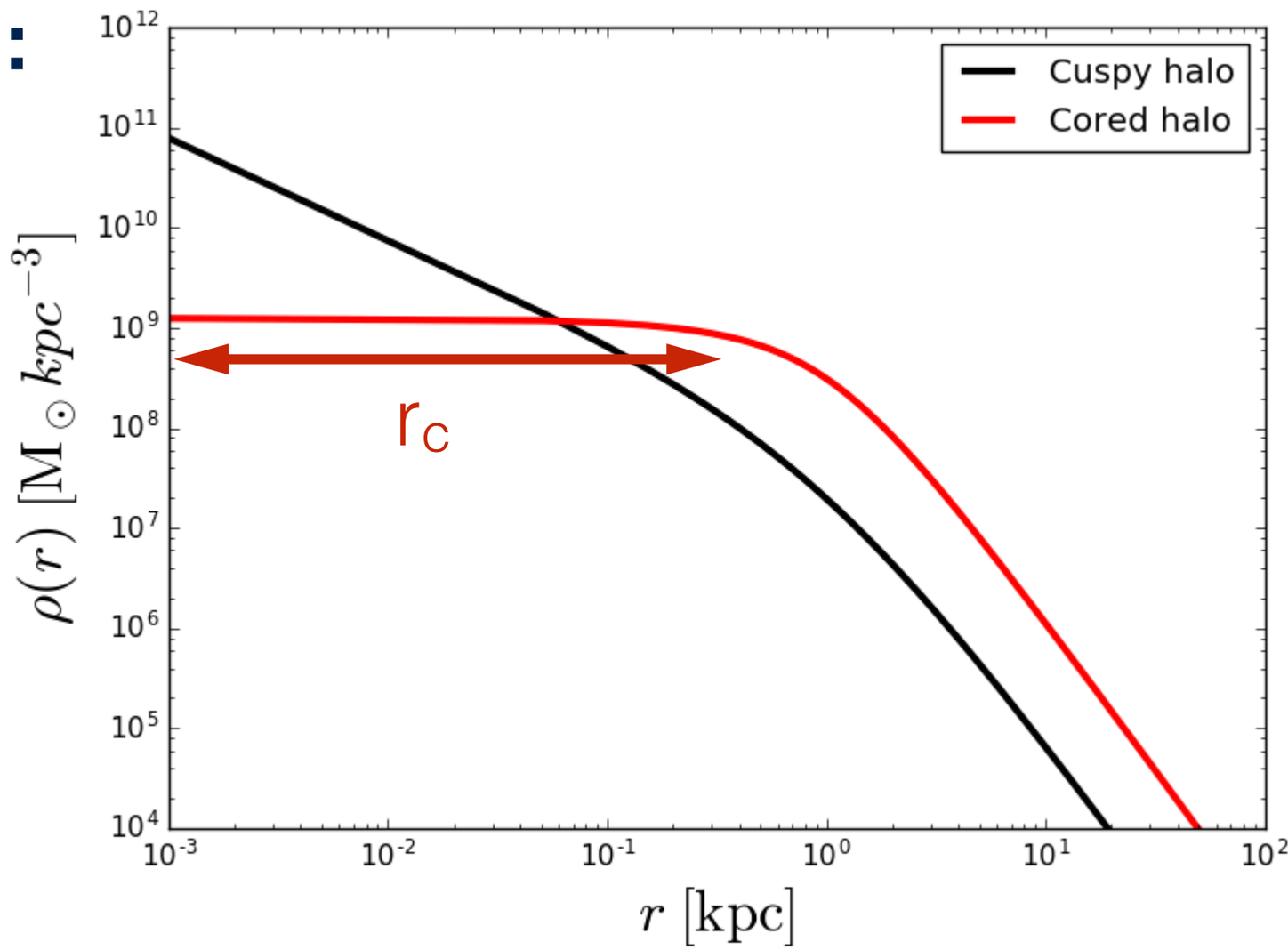
- **Cold Dark Matter**
- **Warm Dark Matter**
- **Fuzzy Dark Matter**
  (Hu et al. 2000, Hui et al. 2016)
- **Self-Interacting Dark Matter**
  (Spergel & Steinhardt 2000)

Cusp-core problem

Astrophysical constraints:

- **Large-scale constraints**
  e.g. CMB

- **Small-scale constraints**
  e.g. Number of satellite galaxies, Dark matter density profile



Cusp or core?

Cusp-core problem

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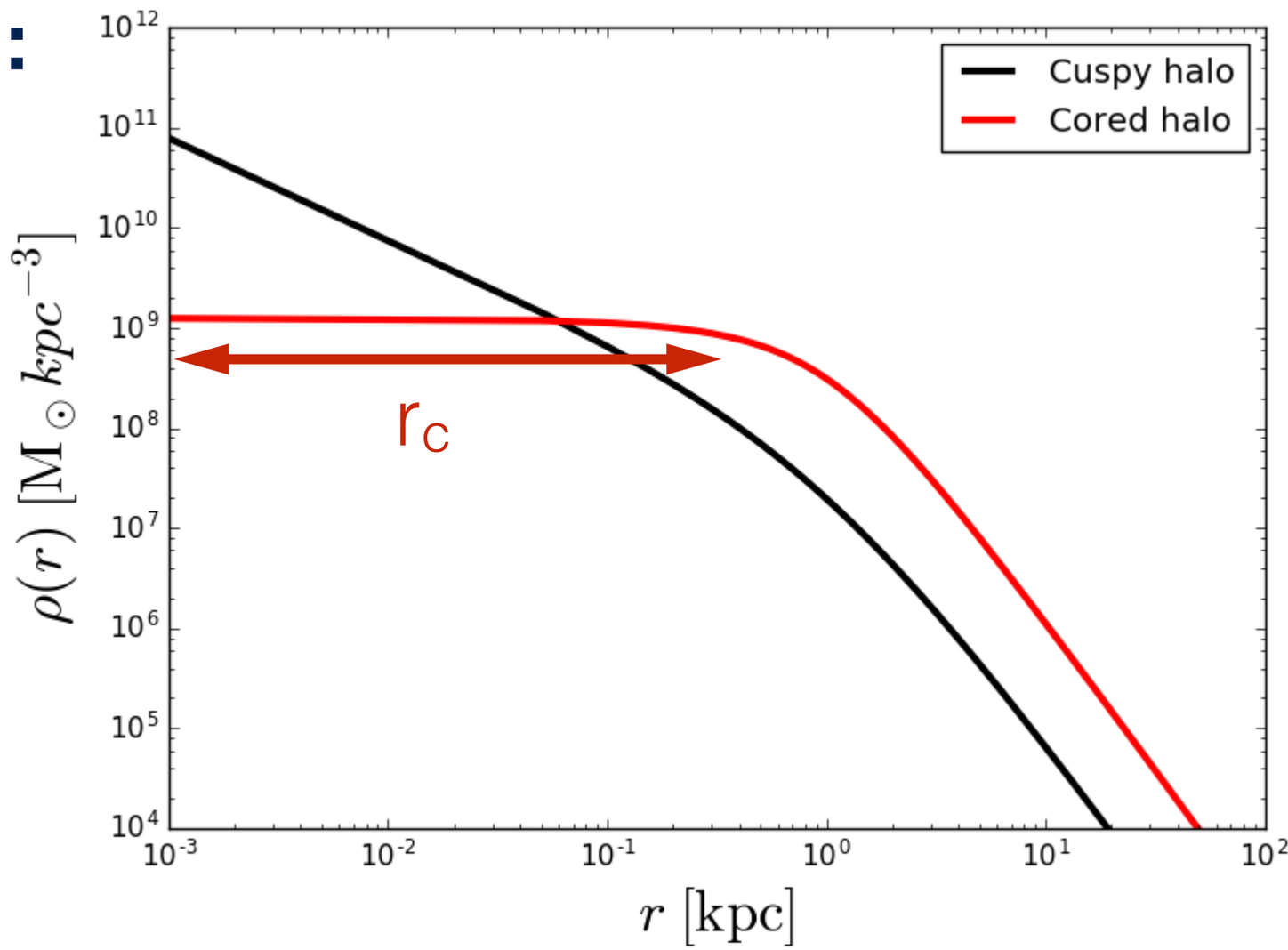

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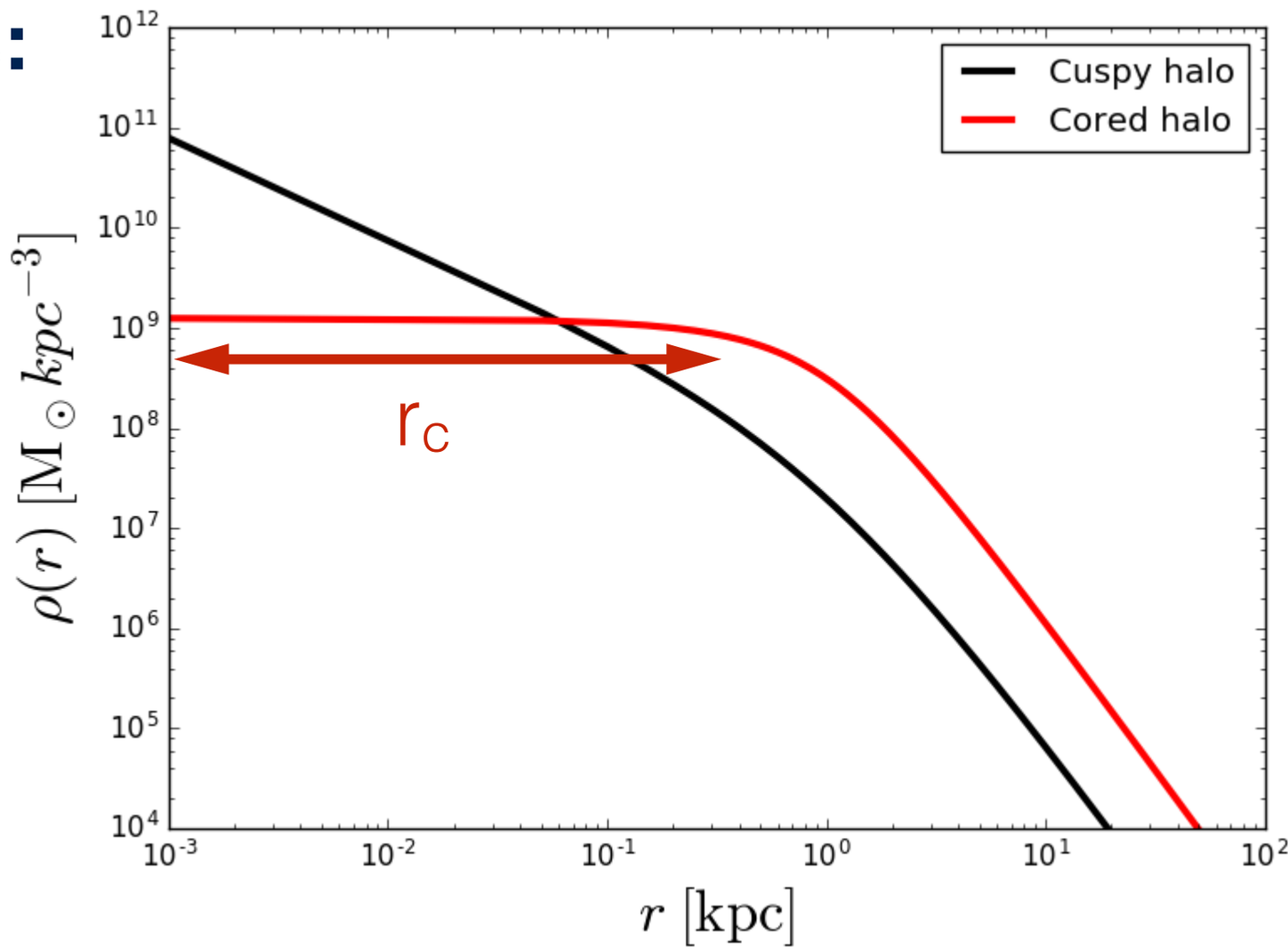


Cusp or core?

Nature of dark matter: cusp or core

- **Cold Dark Matter** — **Cusp**
- **Warm Dark Matter** (Colin et al. 2000; Bode et al. 2001) — **Core**
- **Fuzzy Dark Matter** (Hu et al. 2000; Hui et al. 2017) — **Core**
- **Self-Interacting Dark Matter** (Vogelsberger et al. 2012) — **Core**

Projets de thèse

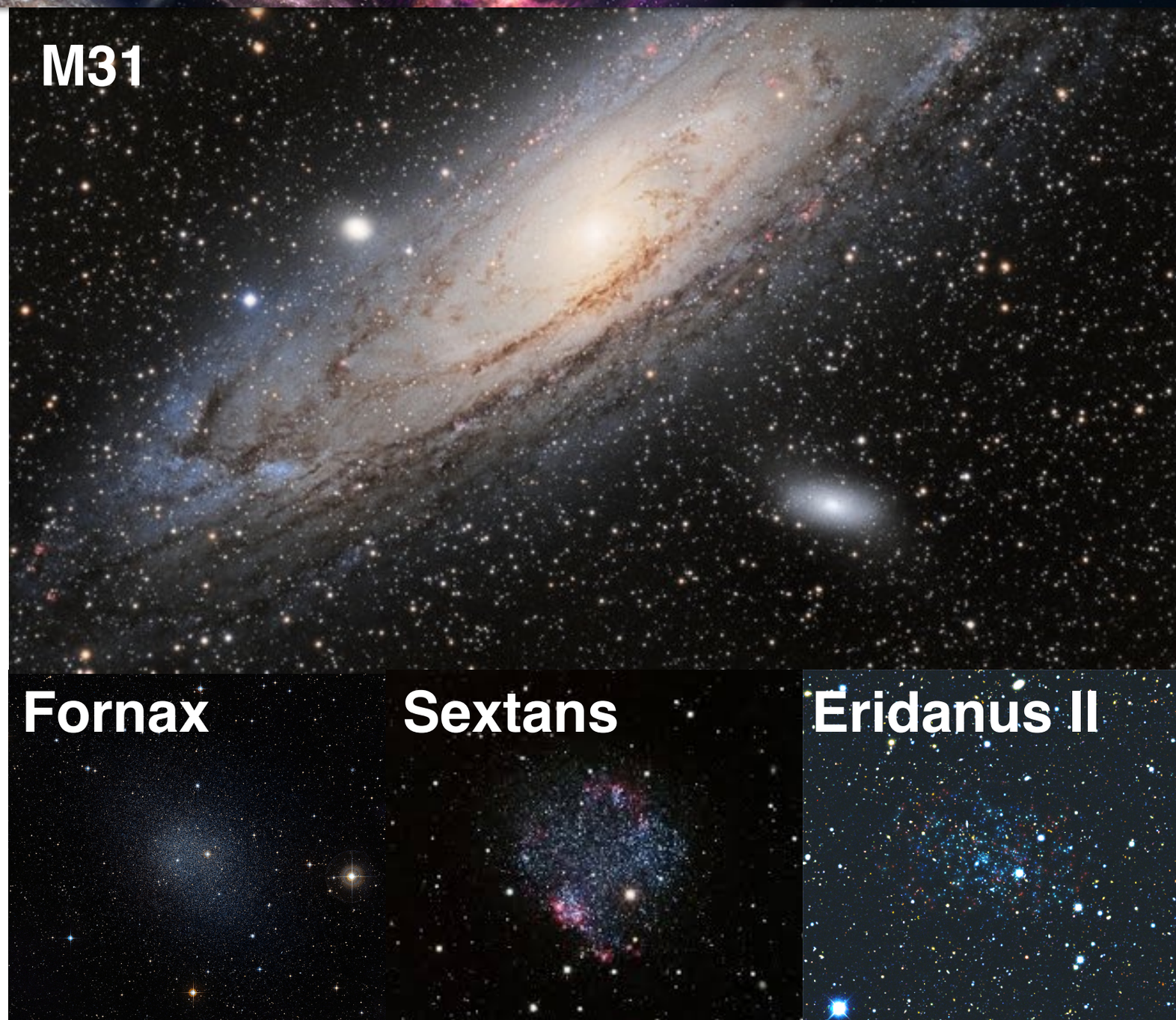
5 projets:

1 achevé,
2 en cours,
2 nouveaux

Projets de thèse

5 projets:

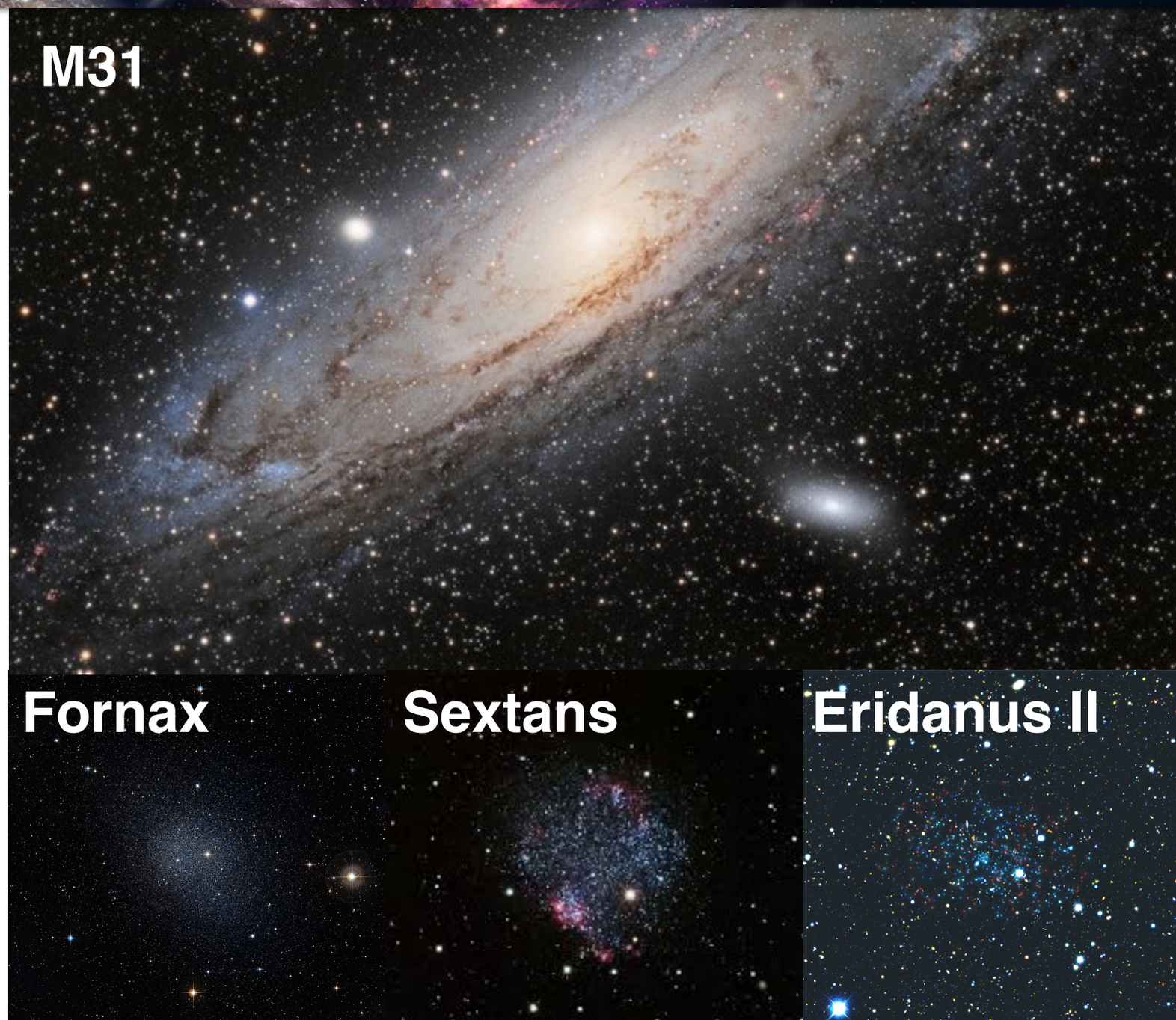
1 CPU N-body,
3 GPU N-body
1 HST data analysis



Projets de thèse

5 projets:

2 IAP,
1 IAP-LERMA,
1 IAP-ITC Tokyo,
1 IAP-LERMA-ROE



Projets de thèse

5 projets:

- P1. Fornax: cusp or core?
- P2. Primordial black holes
- P3. Remnant galaxy in M31
- P4. Subhalos of GCs
- P5. Star cluster relics

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- **P1. Fornax: cusp or core?**
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- P3. Remnant galaxy in M31
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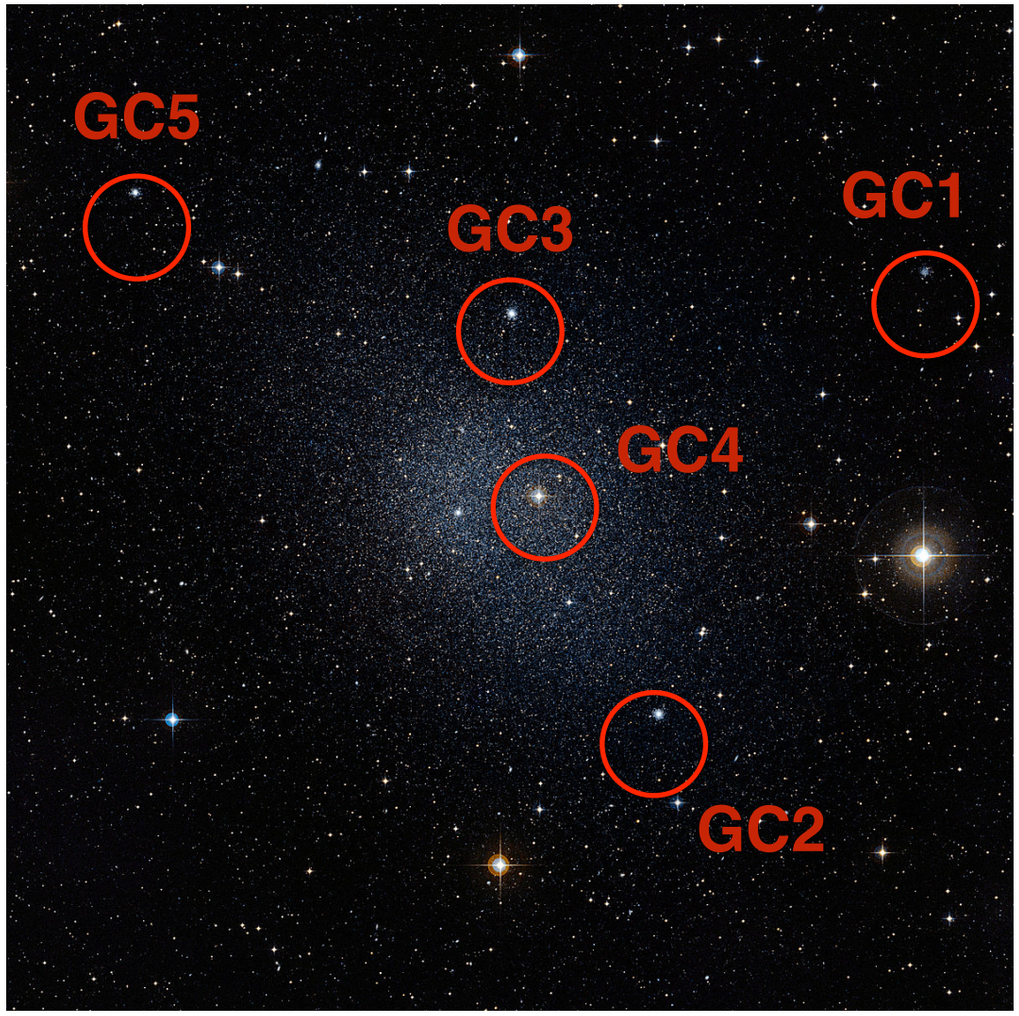
P1. Fornax: cusp or core?

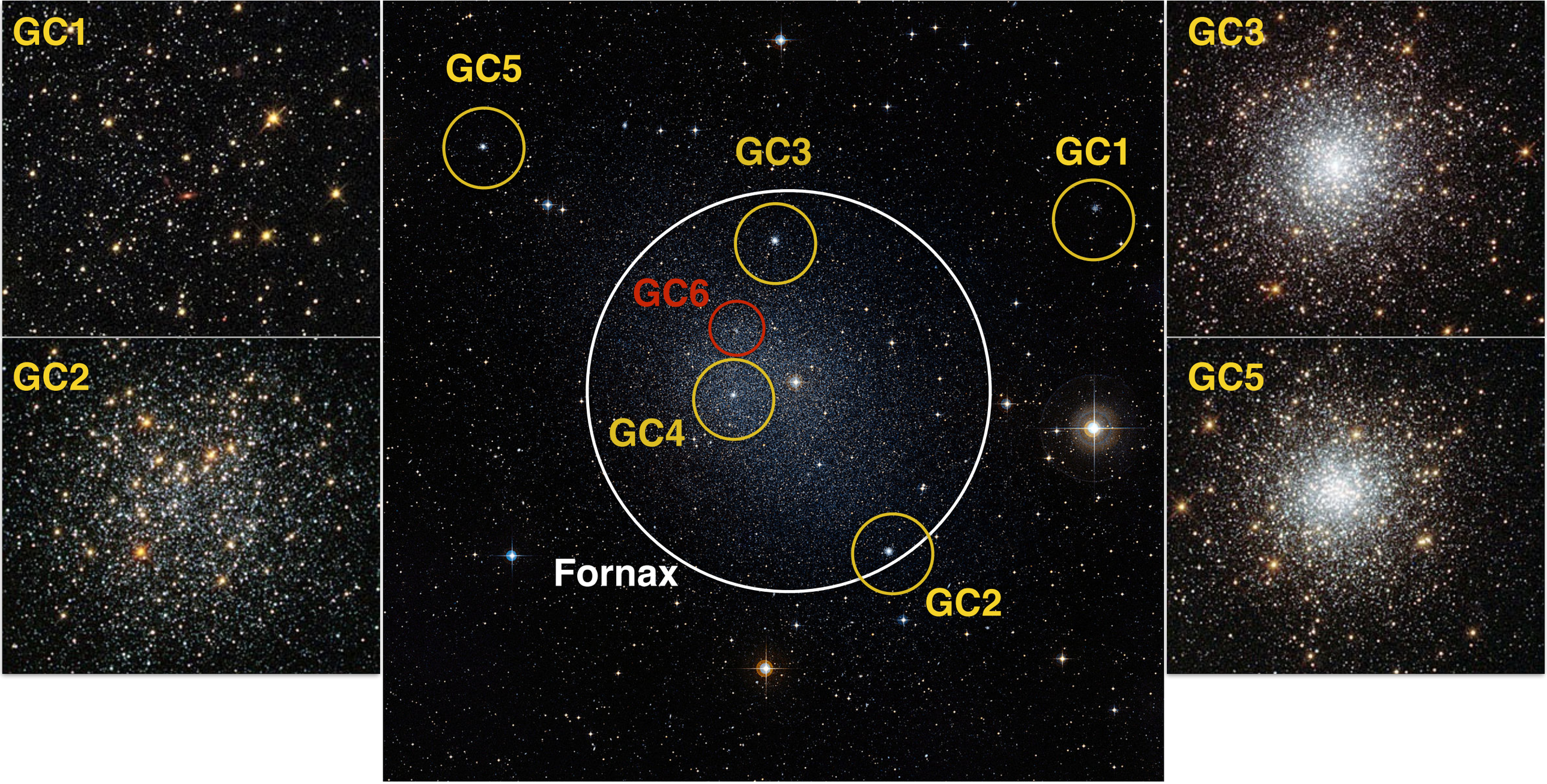


Credit: ESO/Digitized Sky Survey 2

Object	M^a [$10^5\ M_\odot$]	r_c^b [pc]	$r_t^{d,e}$ [pc]	D_p^b [kpc]	D_{MW}^a [kpc]
Fornax	382 ± 12	668 ± 34^c	-	-	147 ± 4
GC1	0.42 ± 0.10	10.03 ± 0.29	59.06 ± 1.70	1.6	147.2 ± 4.1
GC2	1.54 ± 0.28	5.81 ± 0.19	108.19 ± 3.54	1.05	143.2 ± 3.3
GC3	4.98 ± 0.84	1.60 ± 0.07	108.17 ± 4.73	0.43	141.9 ± 3.9
GC4	0.76 ± 0.15	1.75 ± 0.18	115.62 ± 11.89	0.24	140.6 ± 3.2
GC5	1.86 ± 0.24	1.38 ± 0.11	25.69 ± 2.05	1.43	144.5 ± 3.3

Globular cluster data:
positions, masses

Cusp or core?

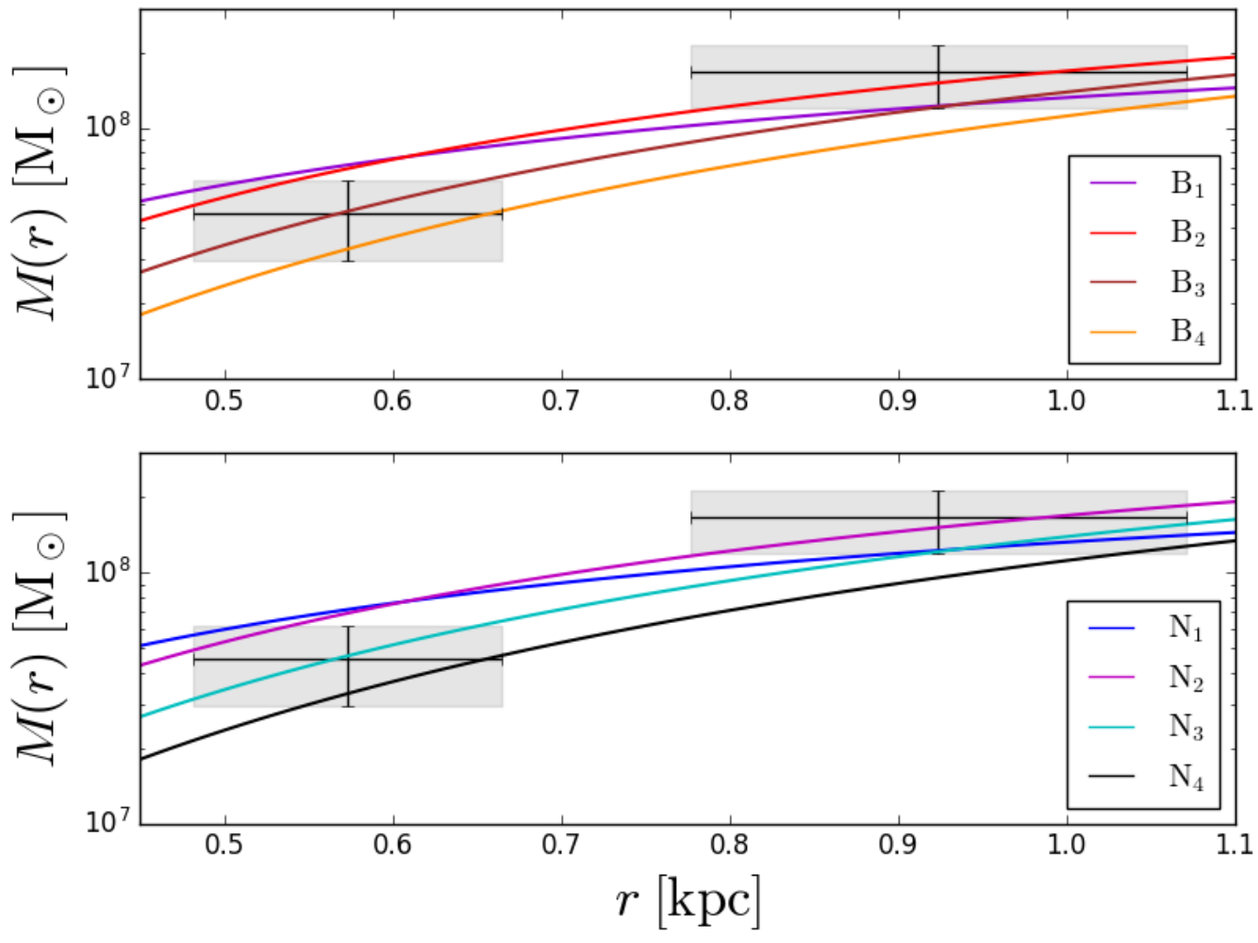

GC1
GC2
GC5
GC3
GC1
GC6
GC4
Fornax
GC2
GC3
GC5

P1. Fornax: cusp or core?

Live simulations:

Halo + stars ~ 6×10^6
5 GCs ~ 10^3-10^4
MW static potential

Model	Density profile	r_s [kpc]	M_h [$M_\odot$]	r_t [kpc]	m_p [$M_\odot$]
B_1	Burkert	0.25	0.318×10^9	2.81	89
B_2	Burkert	0.5	0.88×10^9	3.95	230
B_3	Burkert	0.75	1.1×10^9	4.52	285
B_4	Burkert	1	1.28×10^9	4.98	329
N_1	NFW	0.5	0.6×10^9	3.87	160
N_2	NFW	1.0	1.2×10^9	4.87	310
N_3	NFW	1.5	1.6×10^9	5.25	410
N_4	NFW	2	2.0×10^9	5.77	510



Walker & Penarrubia (2011)

P1. Fornax globular clusters

75 N-body simulations with Gadget2:

- Ri = [1, 1.5, 2.0, 2.5, 3.0] kpc **x 5 initial radii**

- Mi = [2.5, 5.0, 7.5, 10] $M_\odot$ **x 4 masses**

- e = [0, 0.9] **x 2 eccentric parameters**

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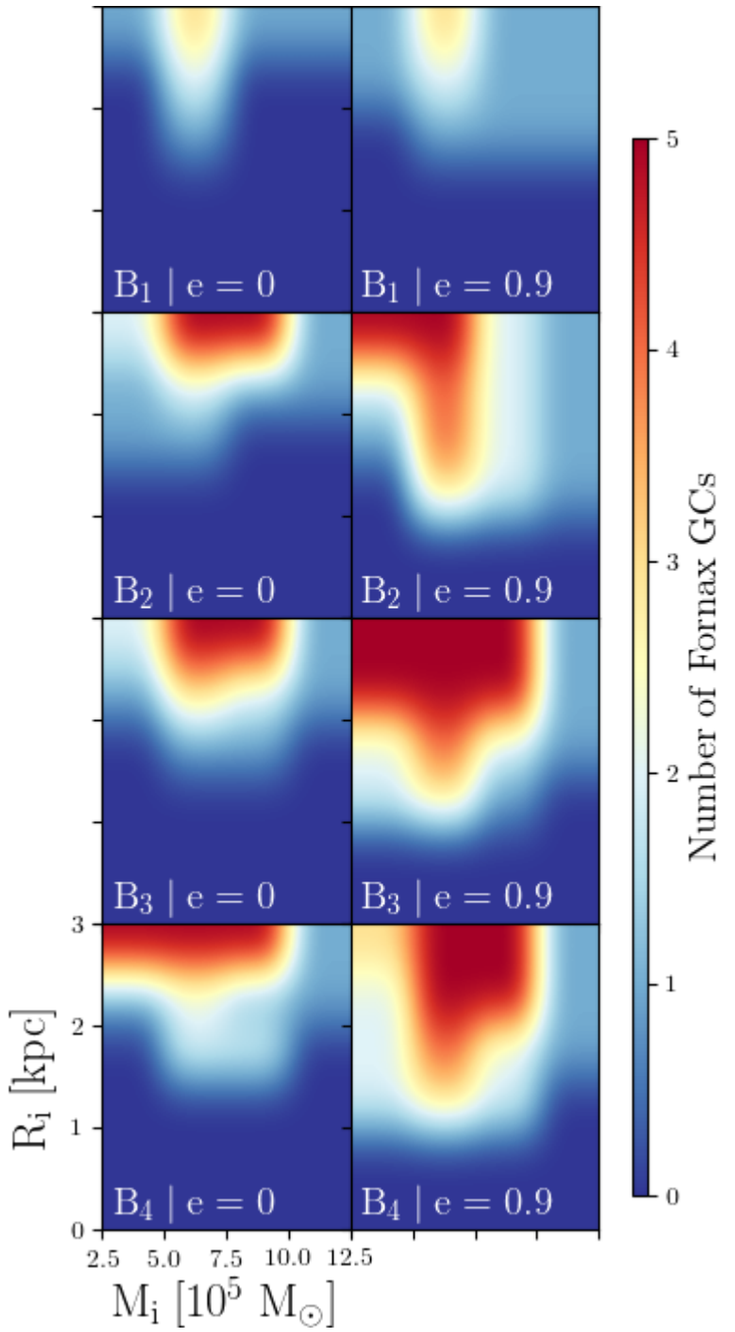
x 8 models/ 5 GCs

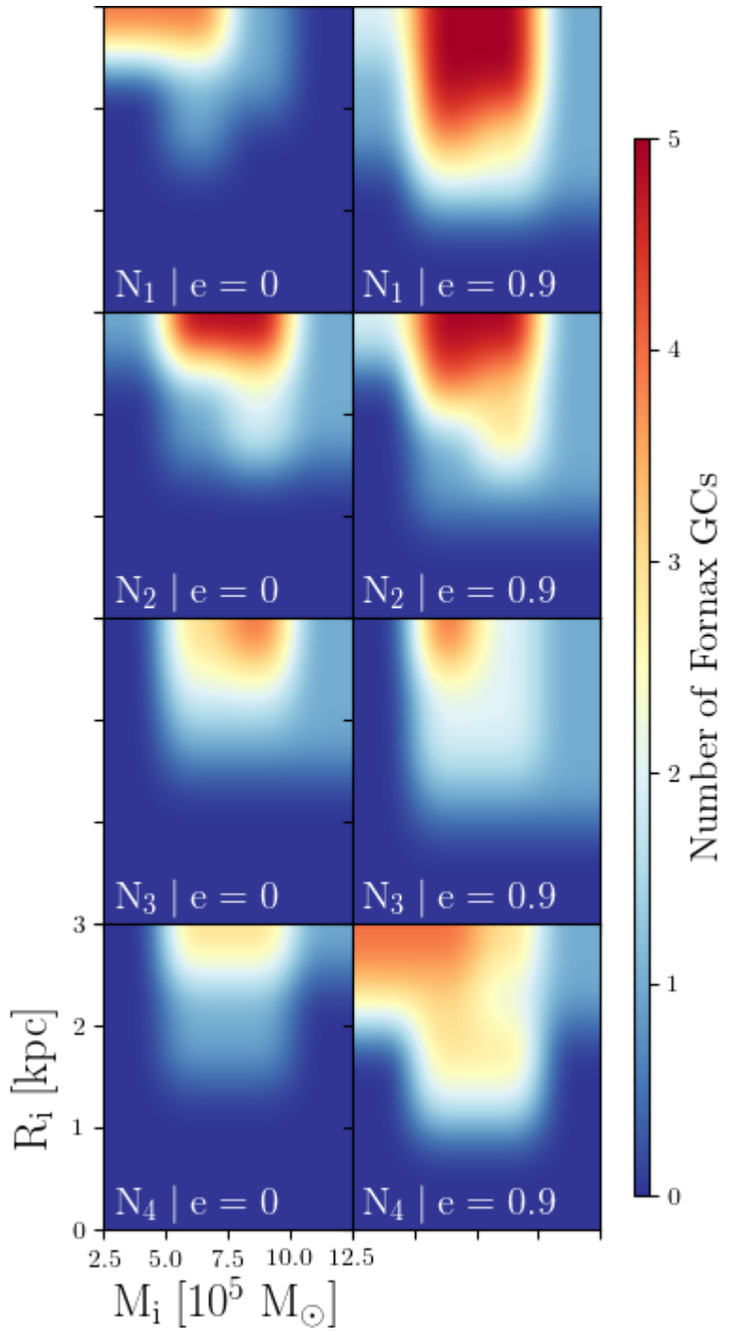
Over 11 Gyr

P1. Fornax: cusp or core?

Cored halo



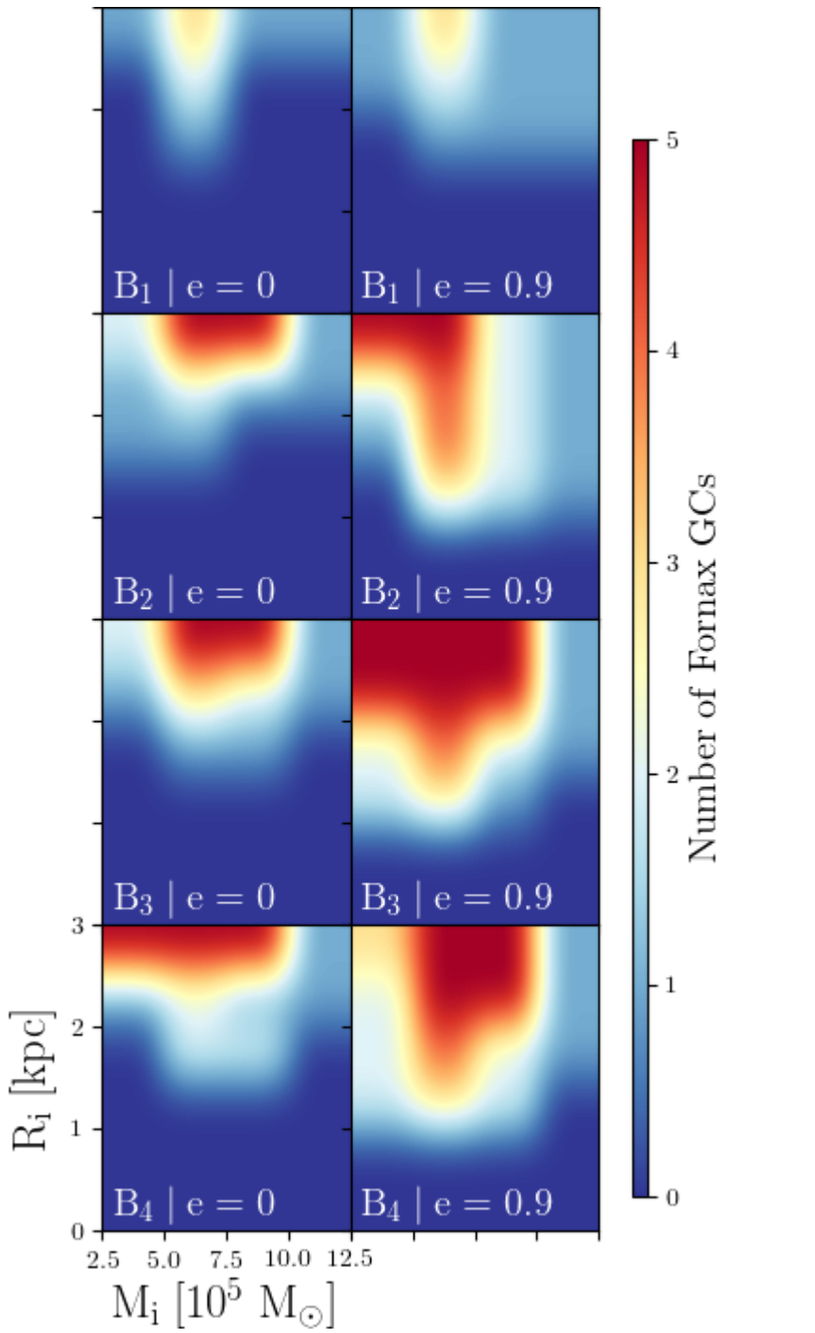
Cuspy halo



P1. Fornax: cusp or core?

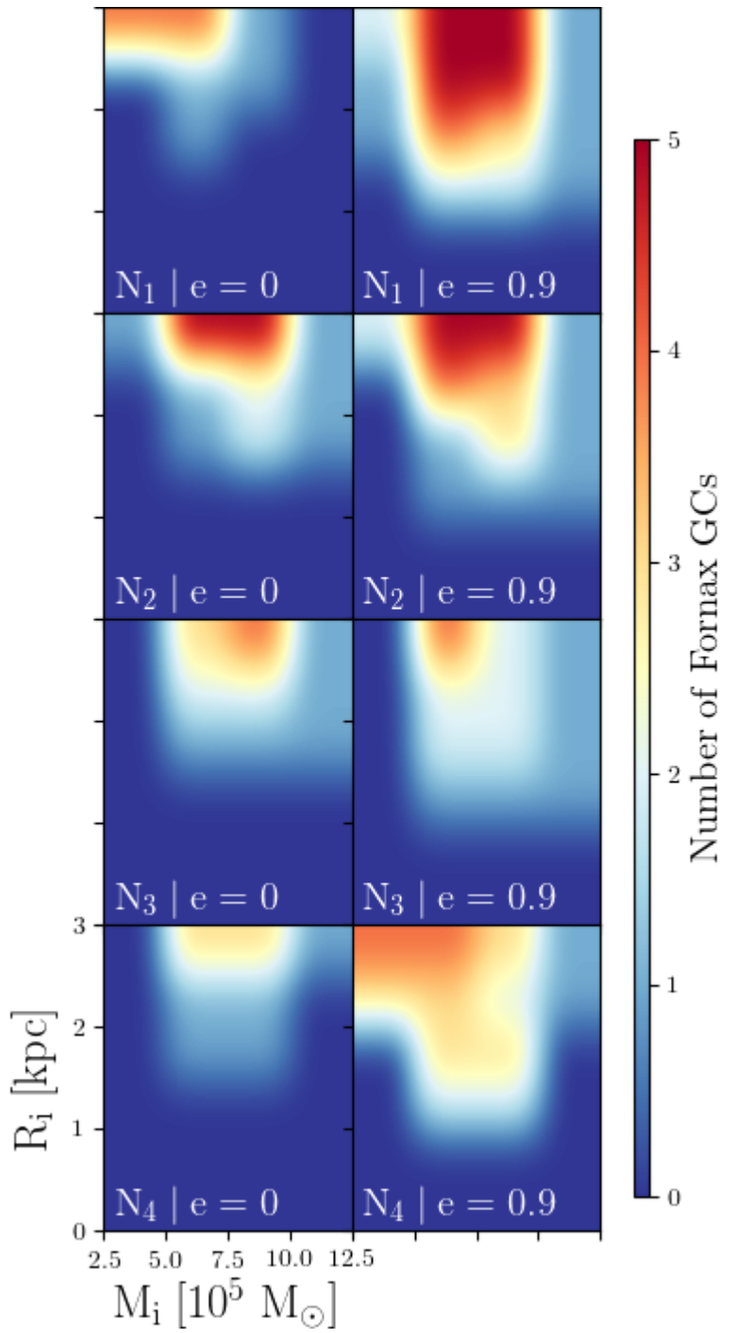
Cored halo

$r_c \gtrsim 0.5$



Cuspy halo

NFW profile not ruled out



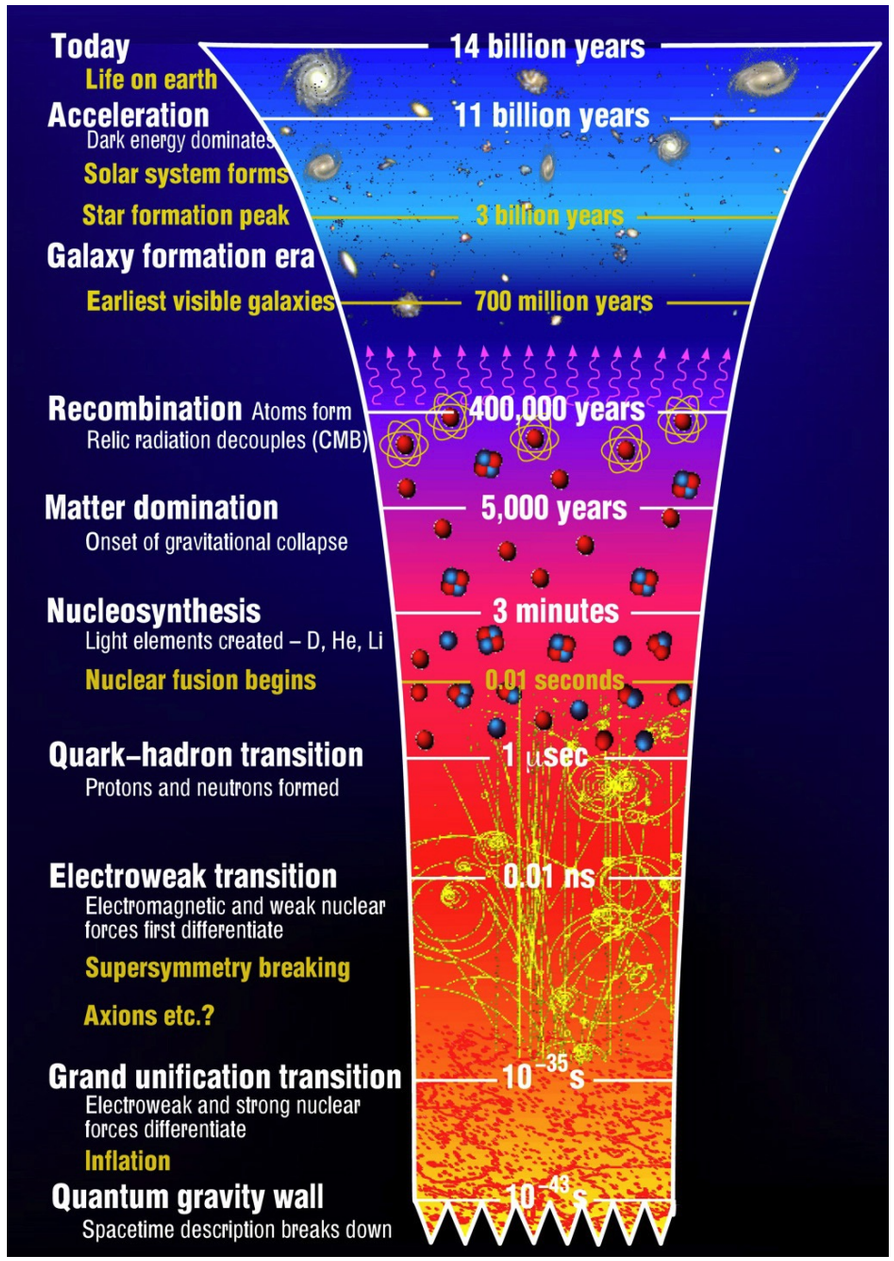
P2. Primordial black holes

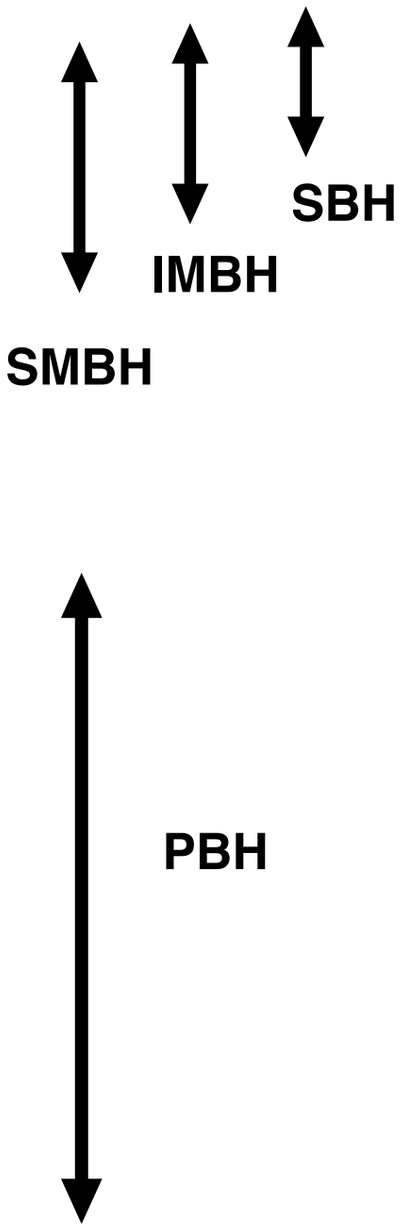
- Stellar black hole (SBH)
  10^{1}-10^{2} $M_{\odot}$

- Intermediate-mass black hole (IMBH)
  10^{3}-10^{5} $M_{\odot}$

- Supermassive black hole (SMBH)
  10^{6}-10^{9} $M_{\odot}$

- Primordial black hole (PBH)
  5×10^{-16} $M_{\odot}$, 2×10^{-14} $M_{\odot}$ & 25-100 $M_{\odot}$





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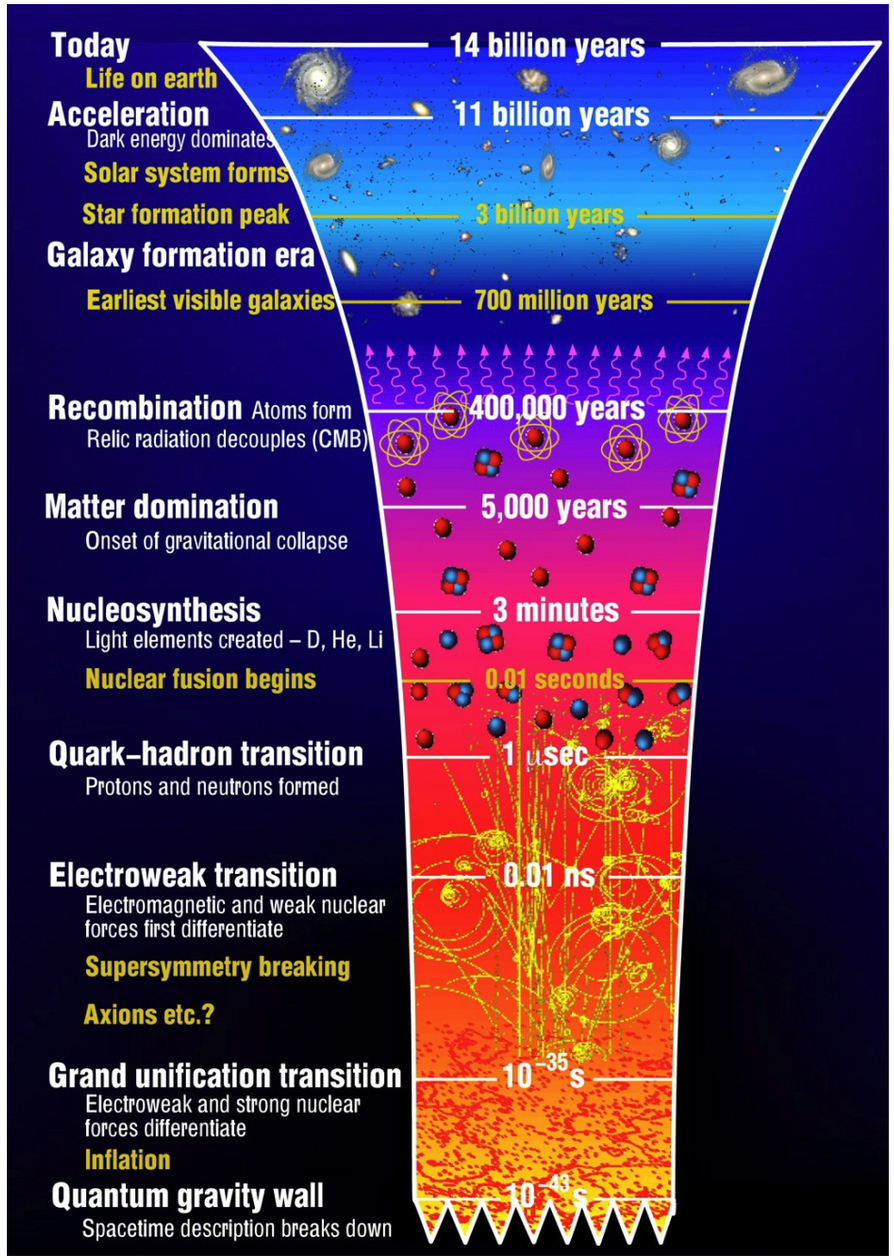
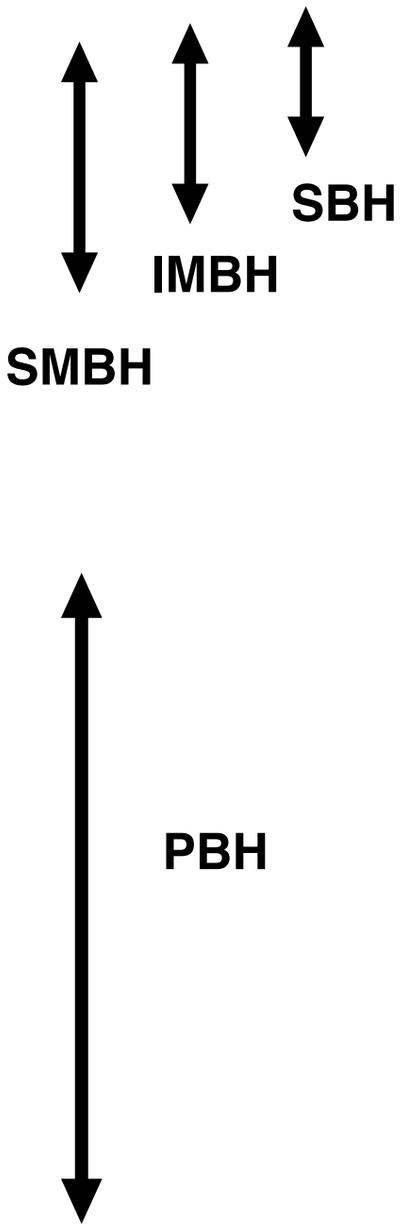


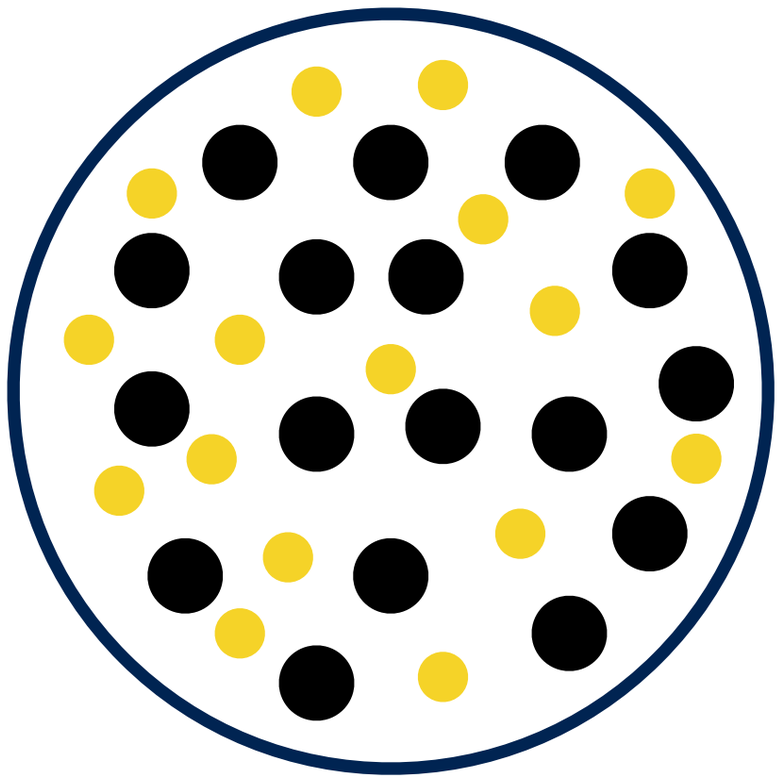


P2. Primordial black holes

DM being composed of PBHs

LIGO detection ~ 10-50 $M_\odot$

Mass window ~ 25-100 $M_\odot$



$f = M_{PBH}/M_{DM}$

P2. Primordial black holes

Simulations with GOTHIC:

- f = [1, 0.1,0.01,0]

- m_{PBH}= [25, 50, 75, 100] $M_\odot$ & m_{DM} = 1 $M_\odot$

- M_H= [10^7, 10^8, 10^9] $M_\odot$

- r_s^{PBH}= [1, 0.5] r_s^{DM}

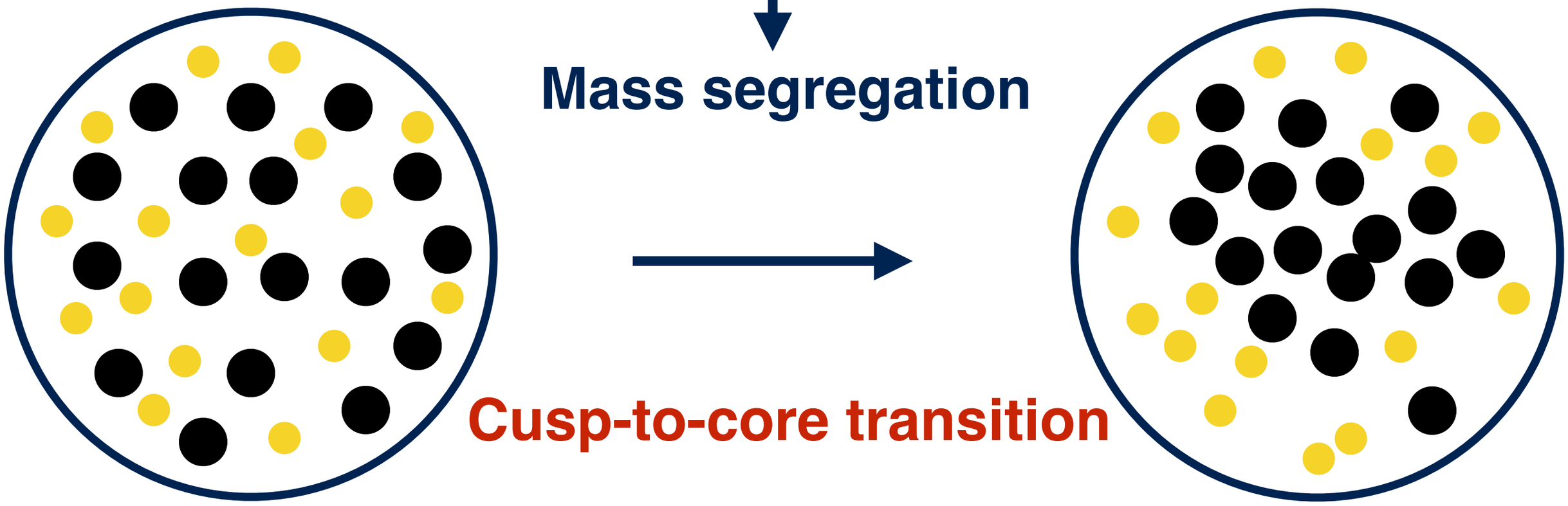
P2. Primordial black holes

Scattering DM by PBHs

$f = M_{PBH}/M_{DM}$

Two-body relaxation

Mass segregation



Cusp-to-core transition

P2. Primordial black holes

Relaxation times

	$f = 1$	$f = 0.1$	$f = 0.01$	$f = 0$
$T_R(r = r_s)$ [Gyr]	14.32	85.55	344.58	1432.33
$T_R(r = 100\ \mathrm{pc})$ [Gyr]	2.0	12	48.36	201
$T_R(r = 30\ \mathrm{pc})$ [Gyr]	0.24	1.46	5.88	24.42

Table 1. Relaxation times for dark matter ($m_d = 1\ M_\odot$) and primordial black holes ($m_p = 100\ M_\odot$) for fractions $f = 1,0.1,0.01$ and 0 based on the two different formulas

$$T_R \simeq \frac{v^3}{8\pi(n_d m_d^2 + n_p m_p^2)G^2 \ln\left(\frac{b_{max}}{b_{min}}\right)}$$

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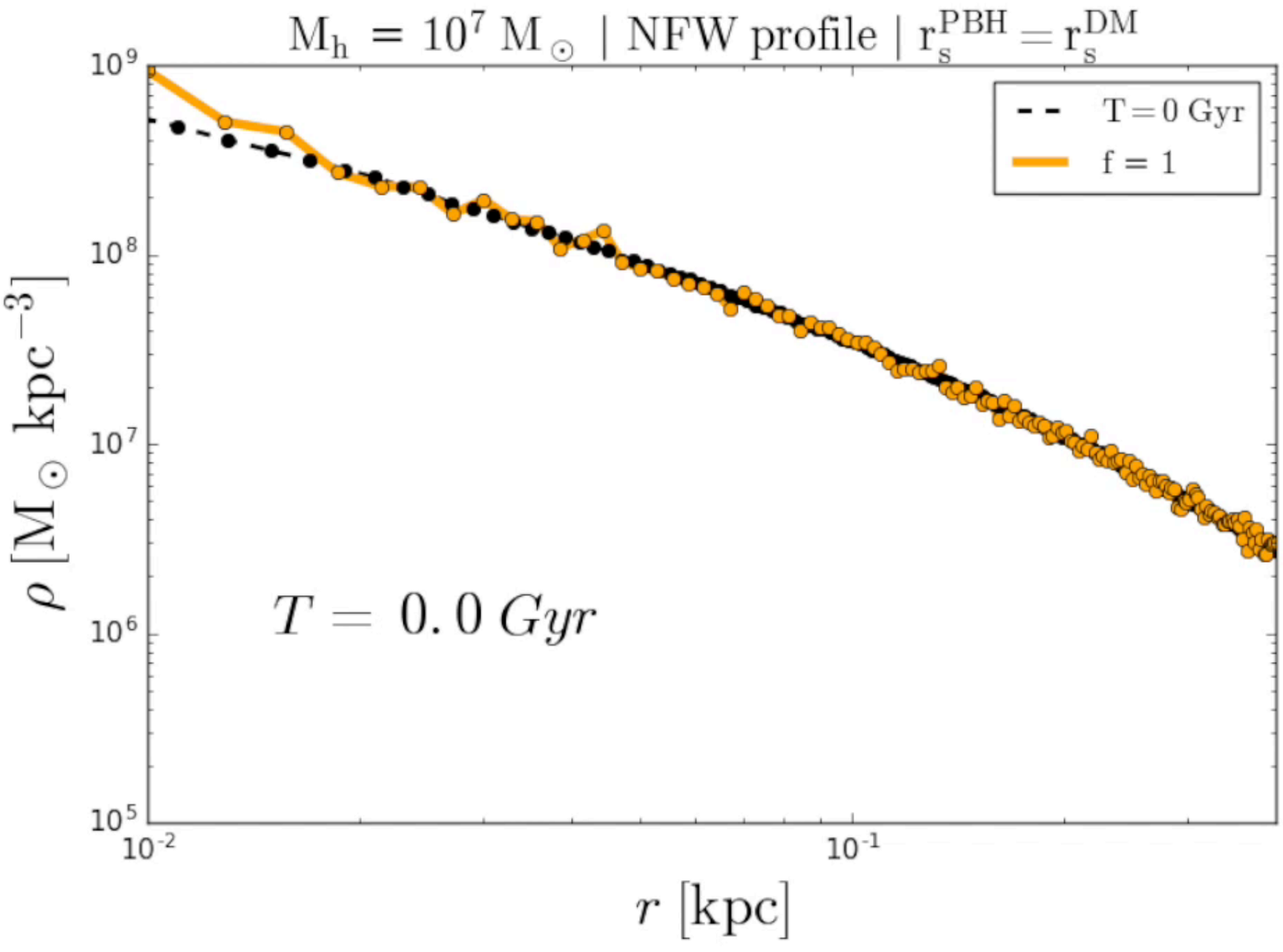
P2. Primordial black holes



m_{PBH}= 100 $M_\odot$

$f=M_{PBH}/M_{DM}$

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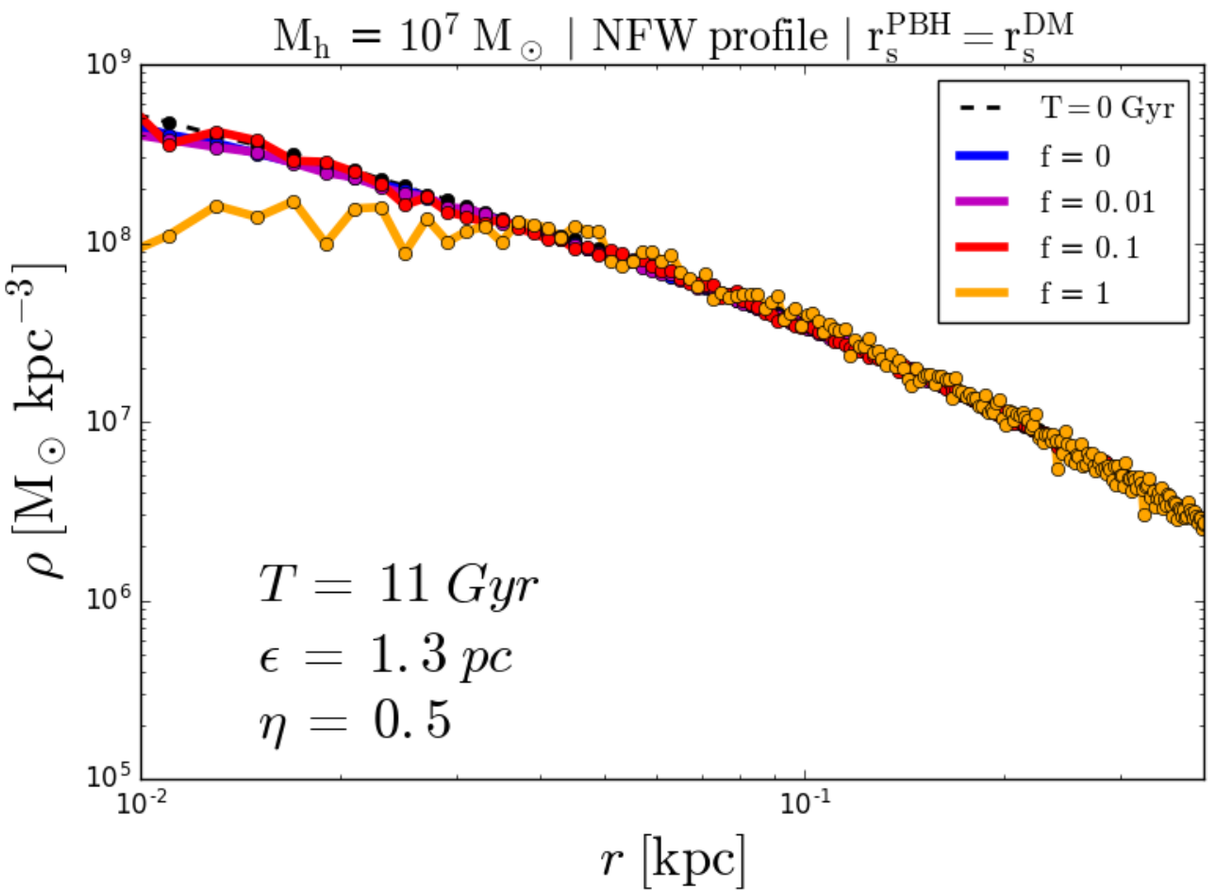

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Formations scientifiques

Cours doctoraux (60h):

- Amas de Galaxies et grandes structures de l'Univers, Collège de France (**10h**) ✅
- Préparation au forum de recrutement PhD Talent Career Fair 2018, IFD (**4h**) ✅
- Climats extrêmes et analogues actuels : des derniers millénaires à l'optimum holocène, Collège de France (**7h**) ❌
- Neutrino Astrophysics, IAP (**13h**) ❌
- Cours d'éthiques (**8h**) ❌

Winter school (30h):

- KMI School: Dark Matter, Nagoya, Japon (**24h**) ✅

Presentation:

- ICAP meeting juin 2018 ✅

Publications

Publication (1ère année)

- « ***Fornax globular cluster distributions: implications for the cusp-core problem*** », Boldrini, Mohayaee & Silk (**MNRAS, submitted 2018, submitted revised version 2019**)

Projets de publications (2ème année)

- « ***Primordial black hole as dark matter: cusp-to-core transition*** », Boldrini, Miki, Wagner, Mohayaee & Silk

- « ***Where is the satellite galaxy, which merged with M31 to form the GSS?*** », Boldrini, Valls-Gabaud, Mohayaee & Silk

Projets de publications (3ème année)

- « ***Star cluster relics: implications for the cusp-core problem***», Boldrini, Mohayaee & Silk

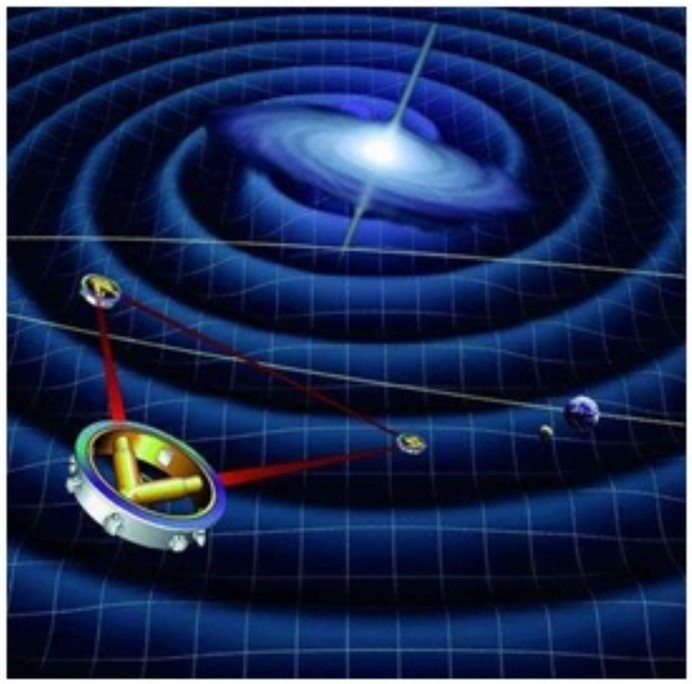
- « ***Dynamics of MW globular clusters with subhalos***», Boldrini, Valls-Gabaud, Peñarrubia, Mohayaee & Silk

Collaboration

Full member of the LISA consortium & LISA FRANCE (since 2019)

LISA Work Packages

- Analysis of IMBHs and IMRIs



Questions?