Formation of astrophysical blackholes

NCTS 2017 Taiwan

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CONTENTS

Origin of SMBHs in the Early Universe

- Direct gravitational collapse

  Hirano, Hosokawa, NY, Kuiper, 2017, Science

  Chon, Hosokawa, NY, 2018, MNRAS

Massive Population III Binaries

- LIGO gravitational wave sources

  Hirano, NY, Sakurai, Fujii, arxiv:1711.07315

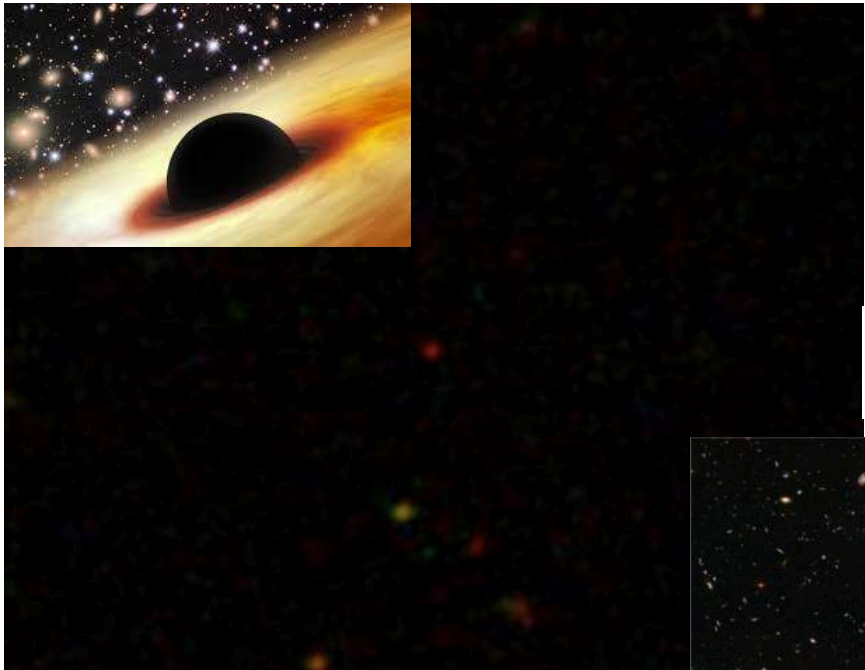
Intermediate Mass Blackholes

- Runaway collisions in dense star clusters

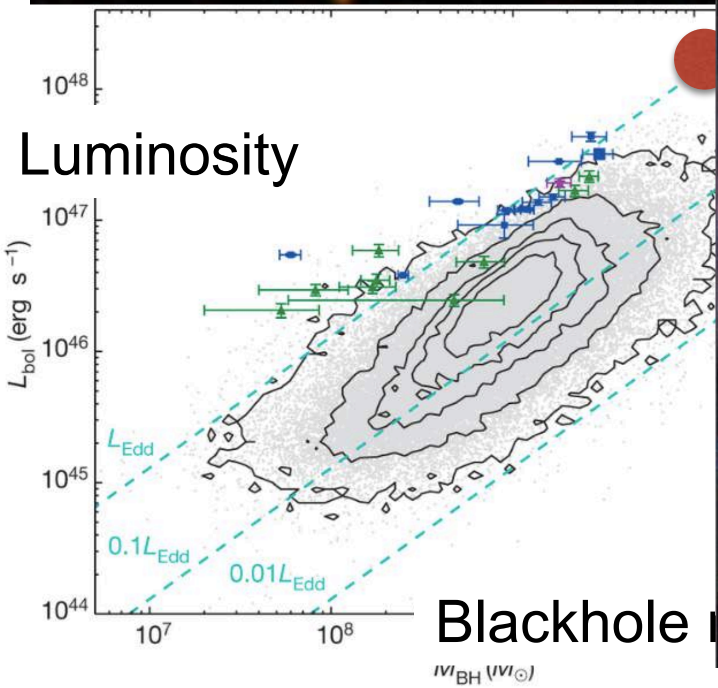
  Sakurai, NY, Hirano, Fujii, MNRAS

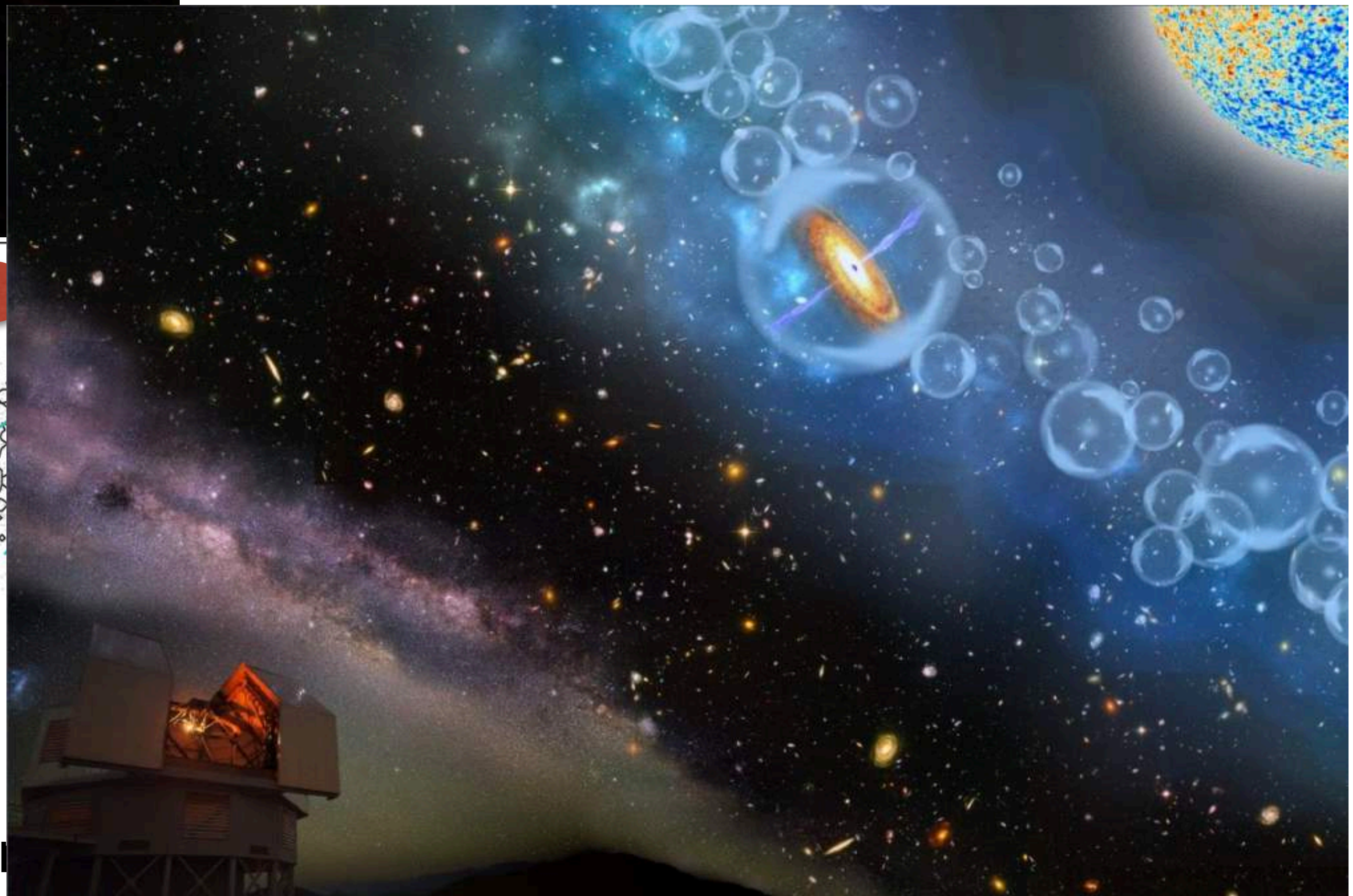
  Kawana, Tanikawa, NY, arXiv:

A young, monstrous blackhole



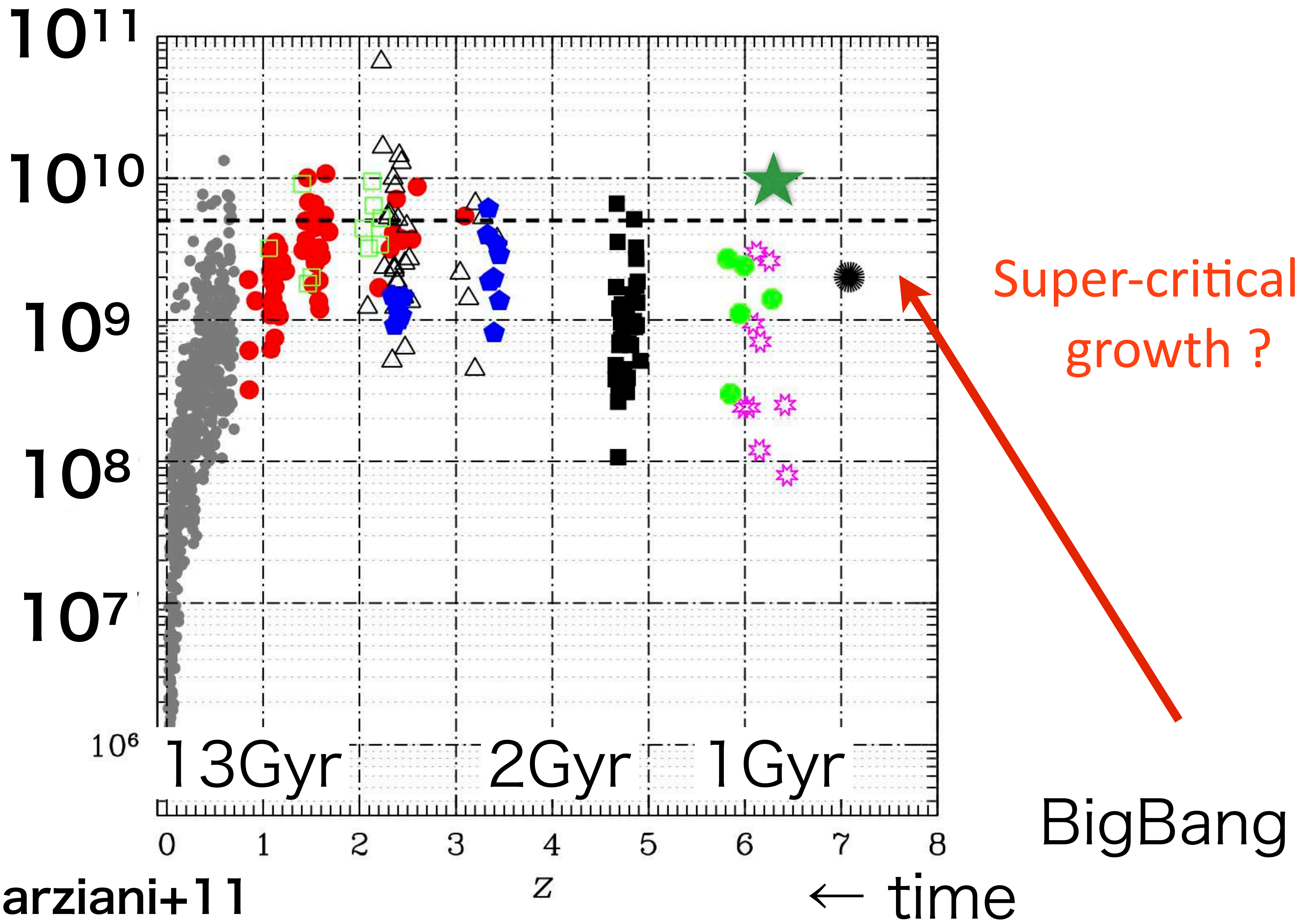
Wu et al. Nature 2015
SDSS J0100+2802
12 billion solar-masses
0.9 Gyrs after the big bang





Observed wavelength (Å)

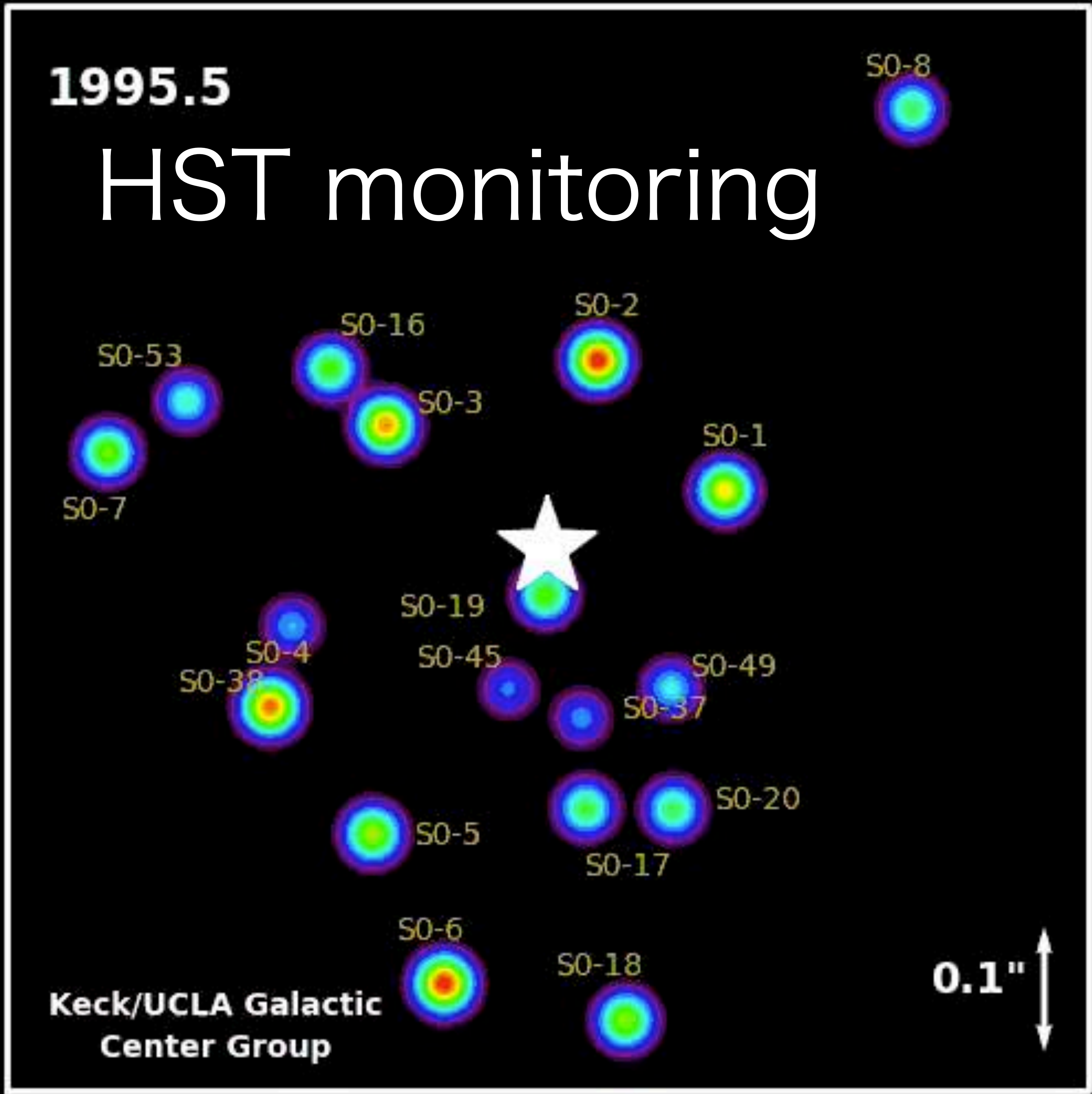
Blackhole mass

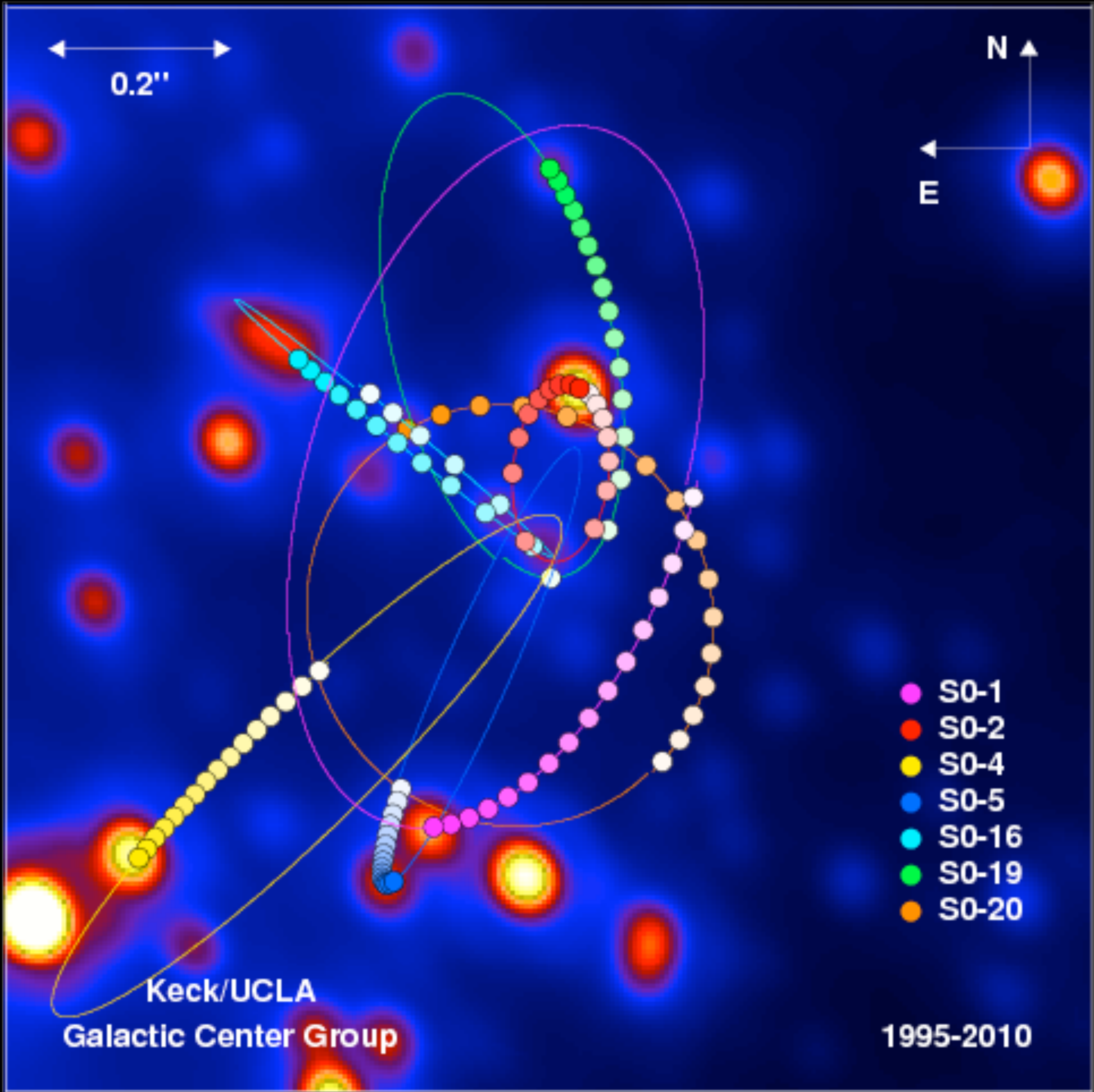


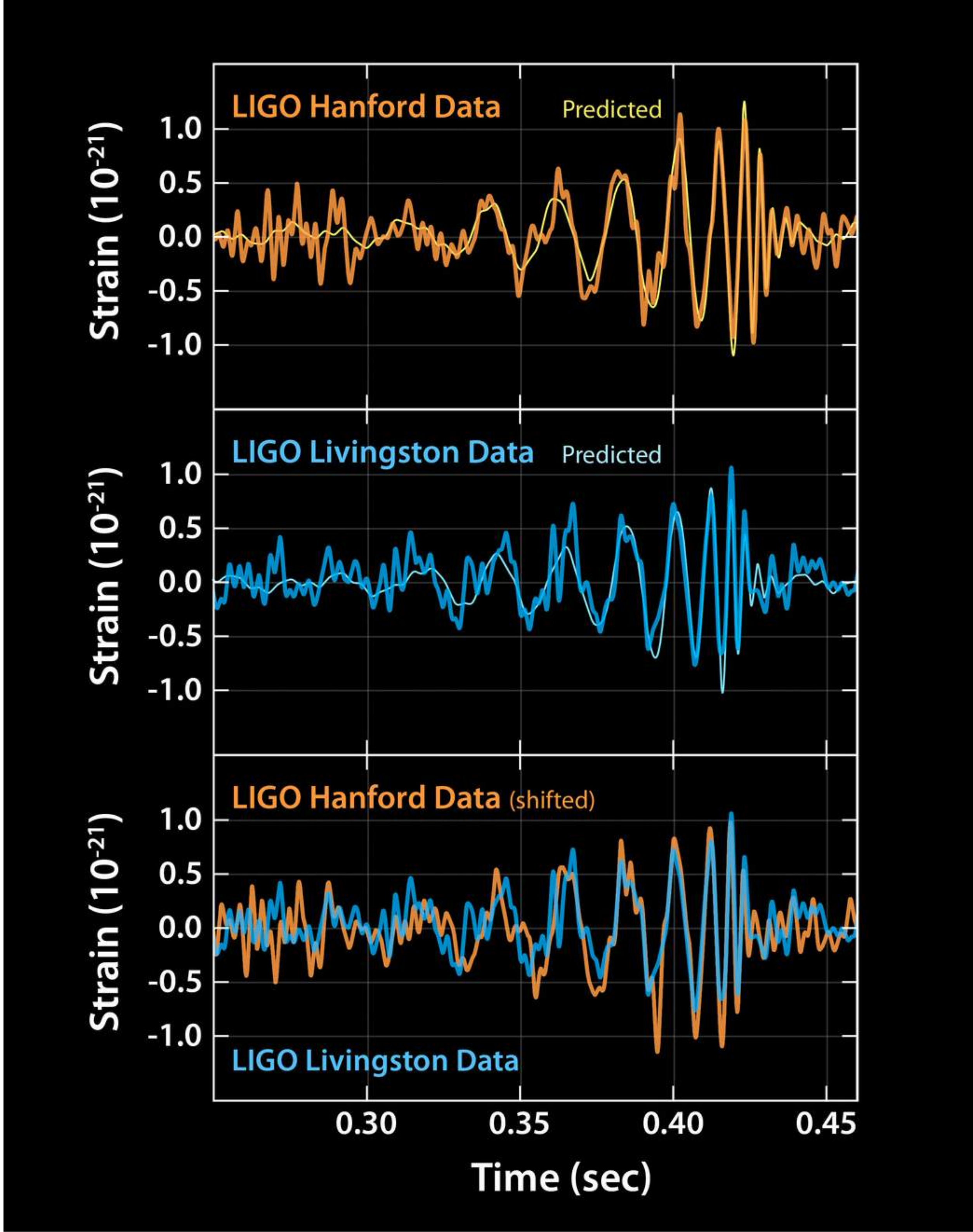
Marziani+11

BH in Milky Way!

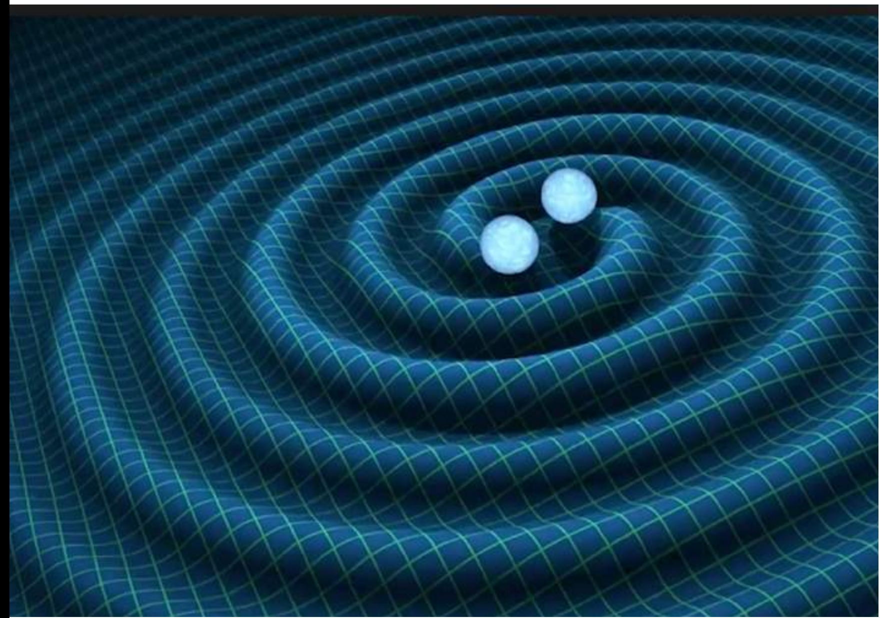
HST monitoring




0.2''
N
E
S0-1
S0-2
S0-4
S0-5
S0-16
S0-19
S0-20
Keck/UCLA
Galactic Center Group
1995-2010



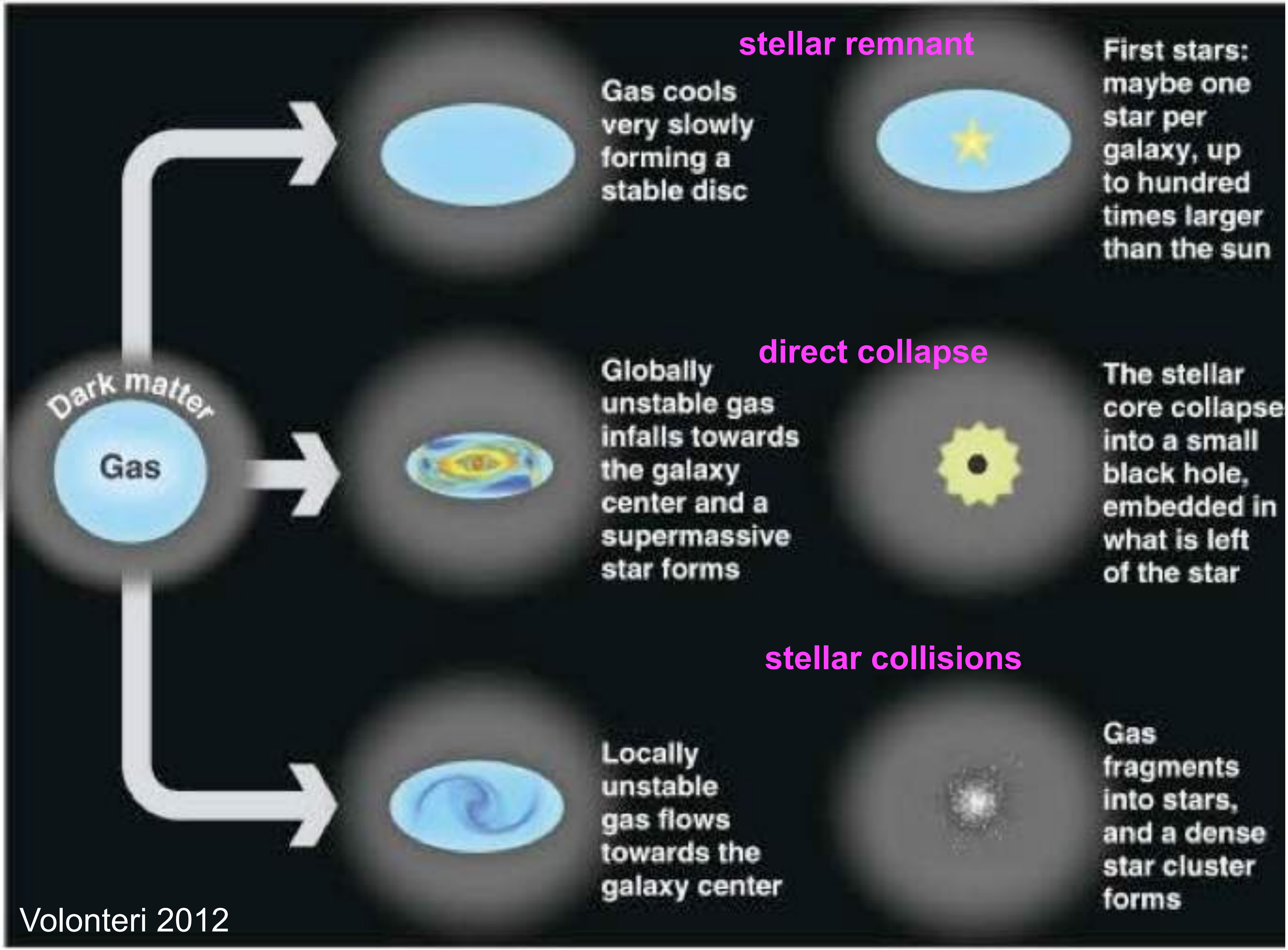
GW detection



Merging of twin massive blackholes.

How did blackholes with $> 30\ M_{sun}$ formed ?

The origin of super-massive blackholes


stellar remnant
direct collapse
stellar collisions
Dark matter
Gas
Gas cools very slowly forming a stable disc
First stars: maybe one star per galaxy, up to hundred times larger than the sun
Globally unstable gas infalls towards the galaxy center and a supermassive star forms
The stellar core collapse into a small black hole, embedded in what is left of the star
Locally unstable gas flows towards the galaxy center
Gas fragments into stars, and a dense star cluster forms
Volonteri 2012

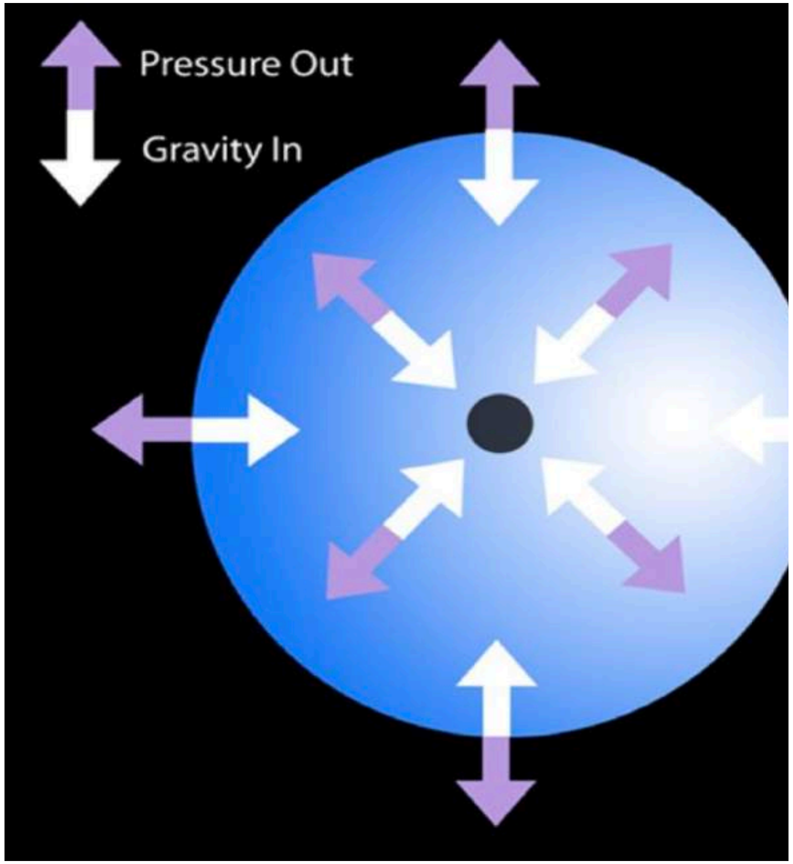
Blackhole growth and the Eddington rate

The Eddington luminosity

$$L_{\mathrm{Edd}} = \frac{4\pi G\, M\, m_{\mathrm{p}} c}{\sigma_{\mathrm{T}}}$$

The radiative efficiency

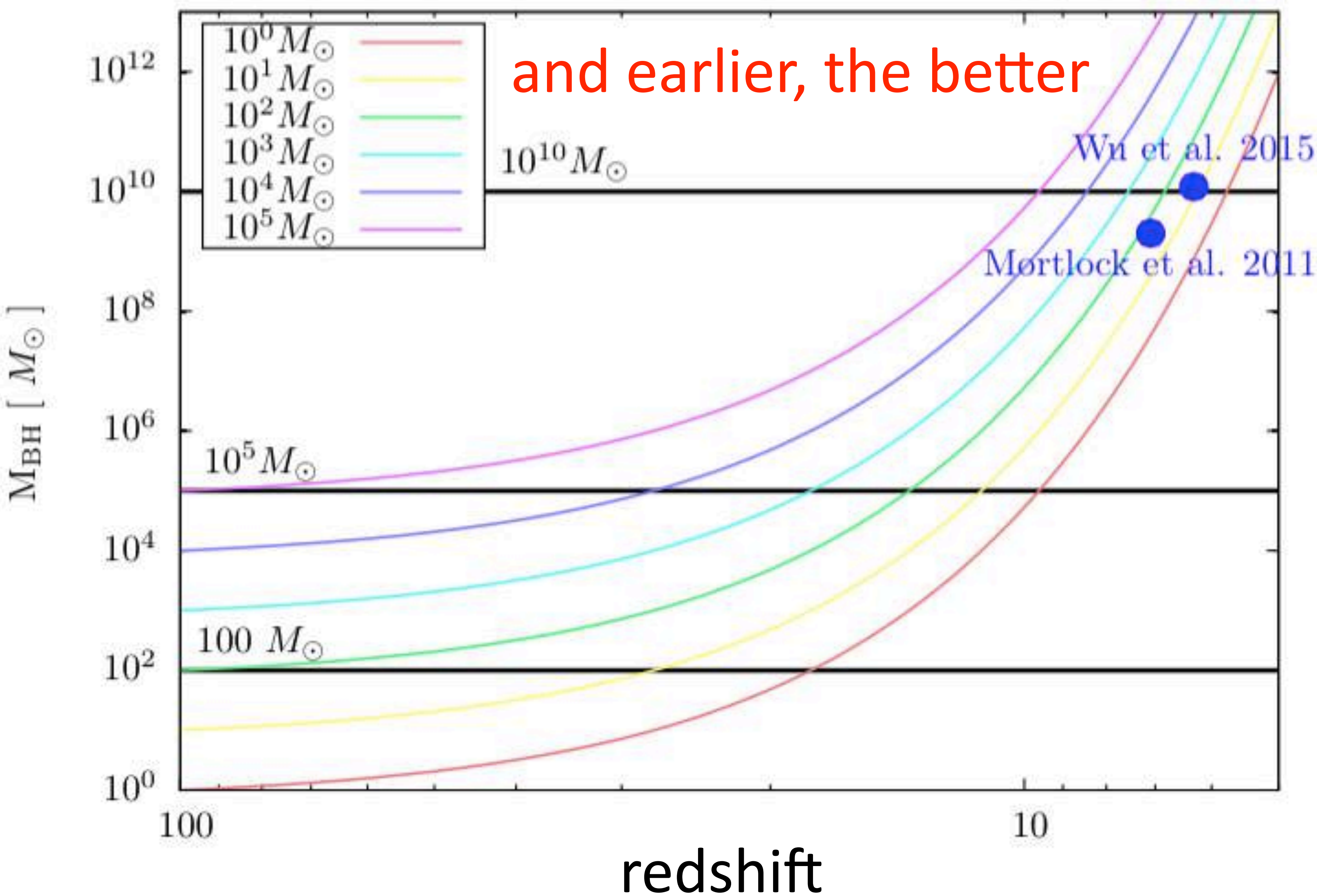
$$L = \varepsilon \dot{M} c^2$$



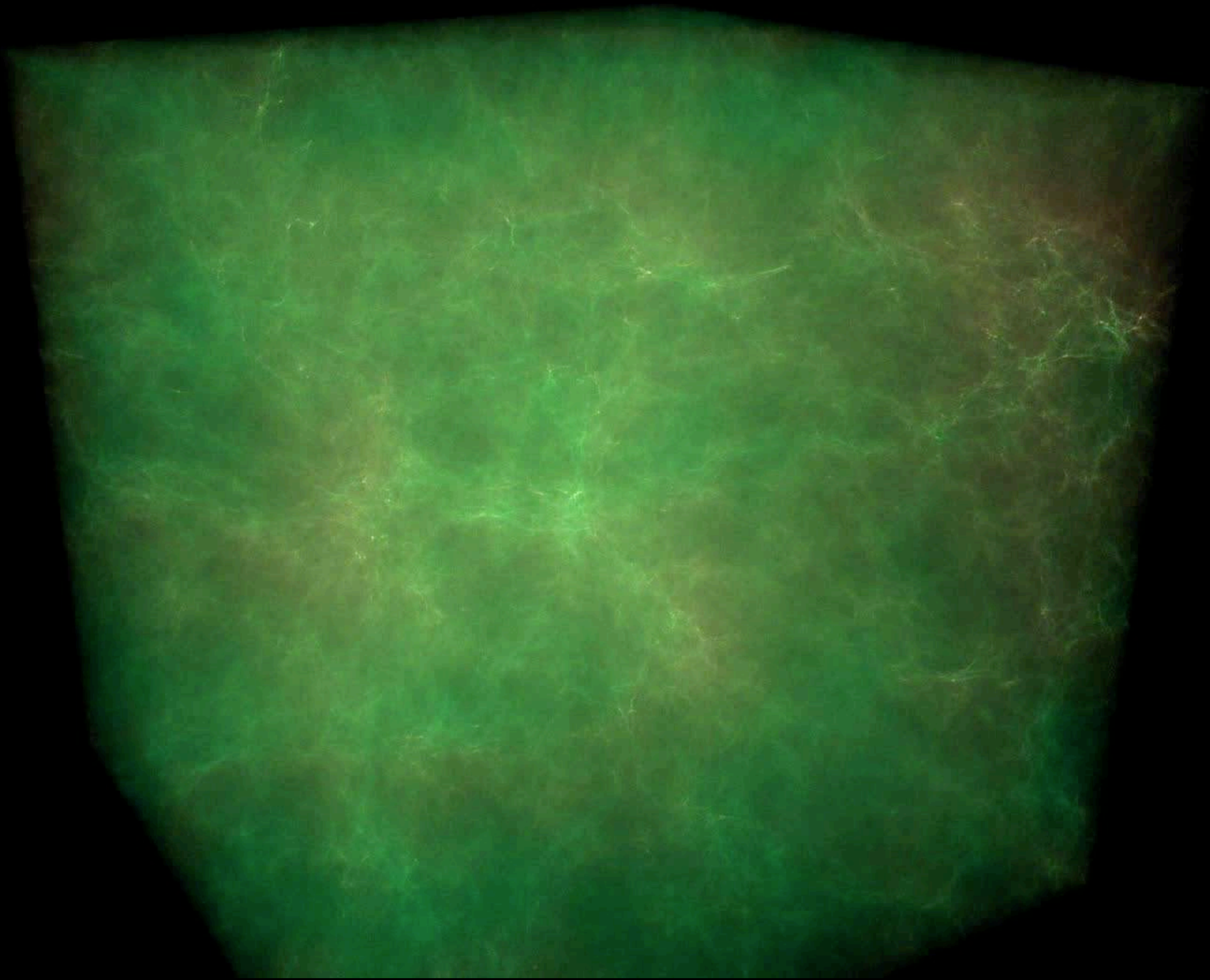
Salpeter time: $M/\dot{M}$ ~ 4 x 10^7 years

for $\varepsilon = 0.1$.

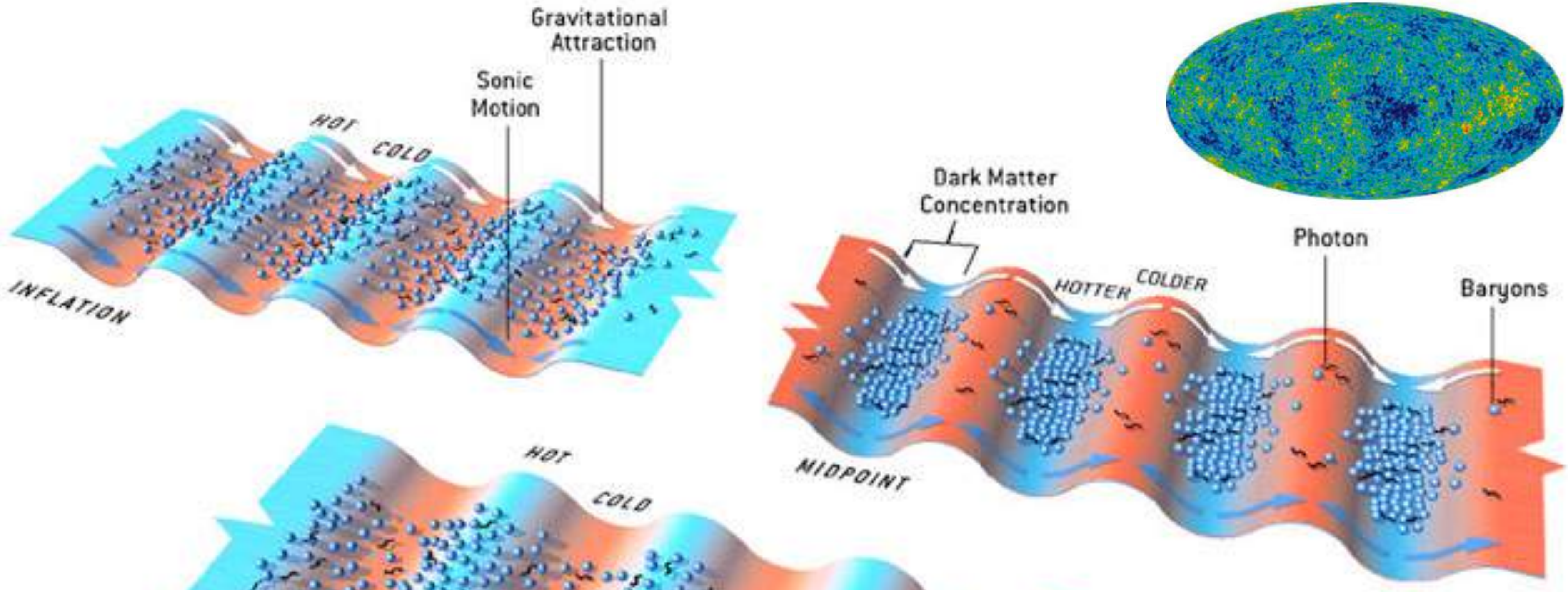
Kick-starting from a massive seed is the key

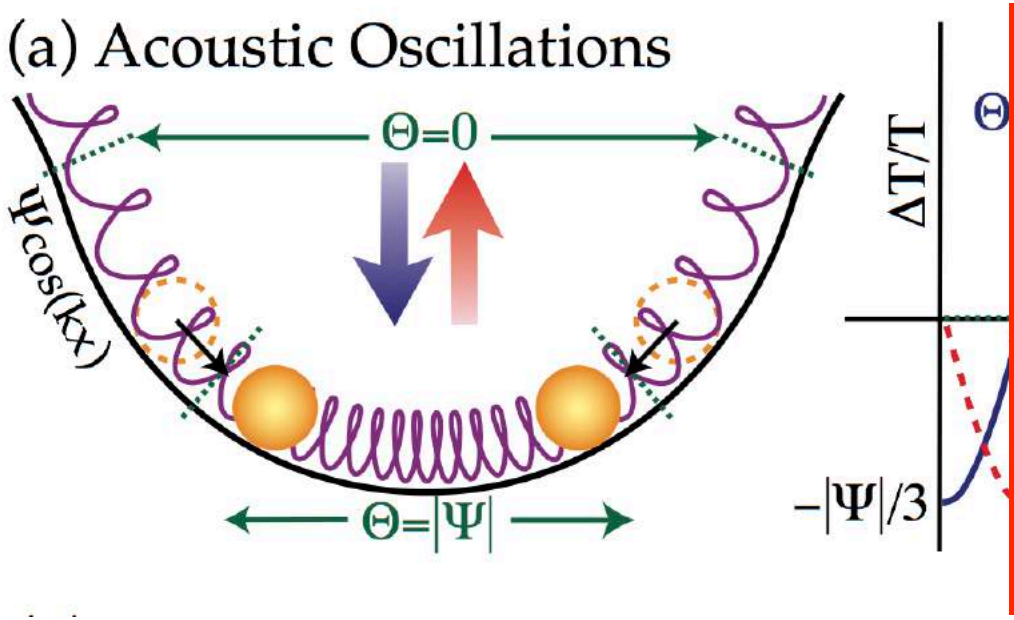


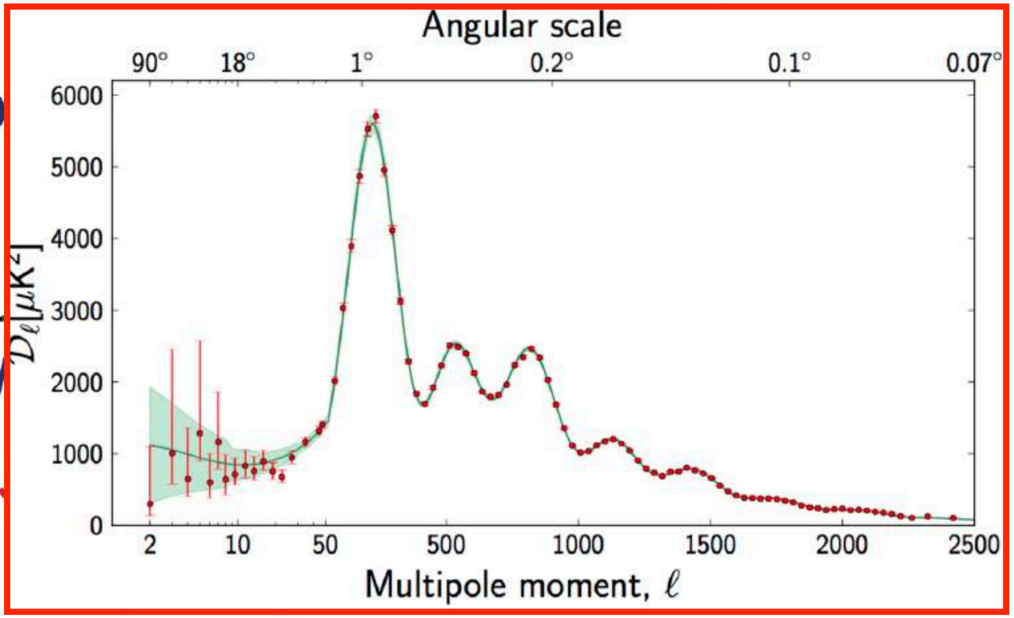
Early universe



Baryon Acoustic Oscillations

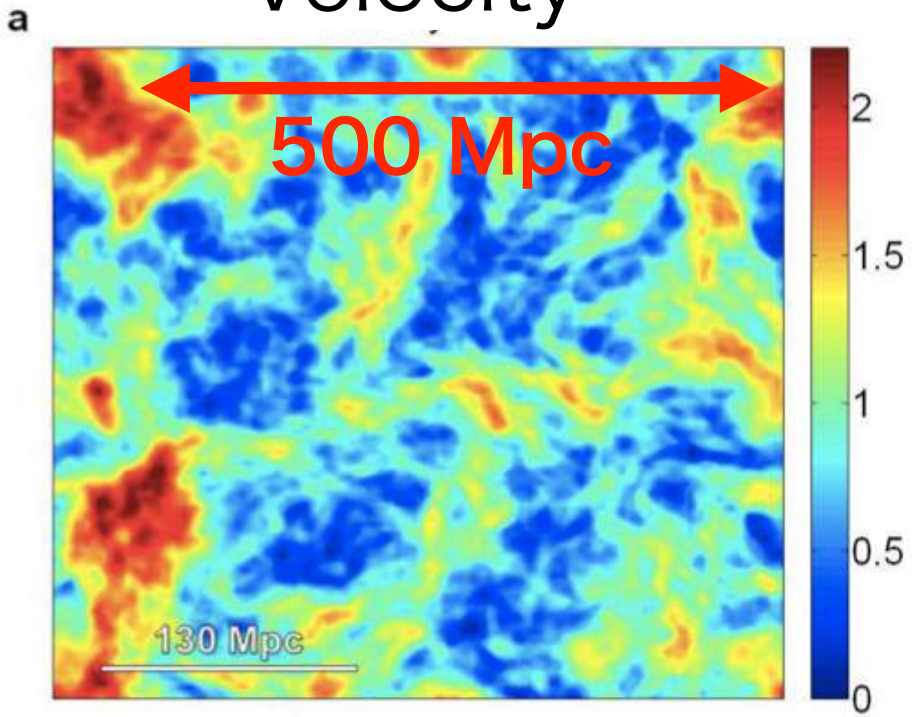




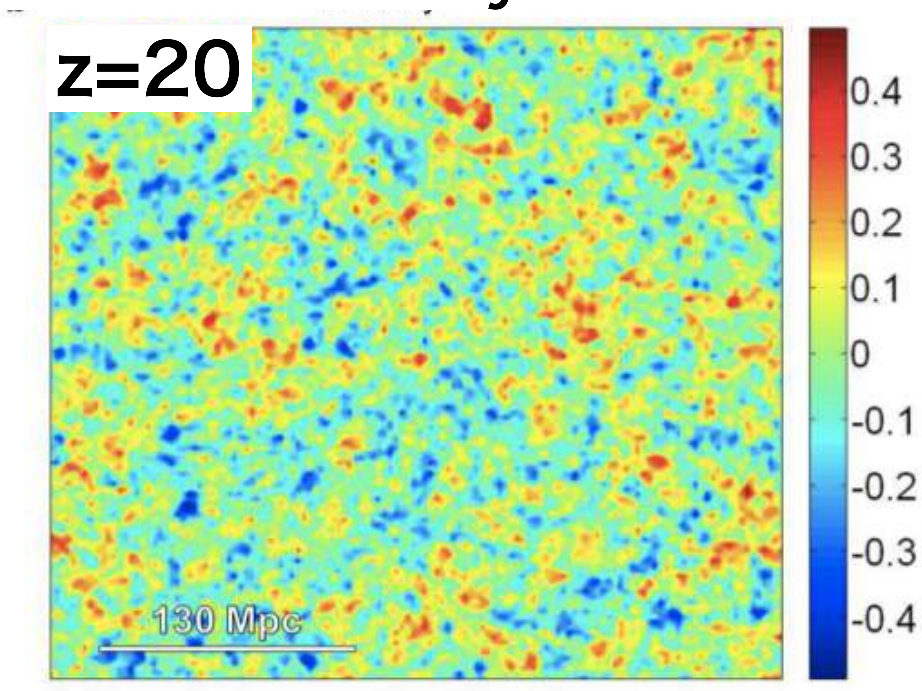


Supersonic gas streams

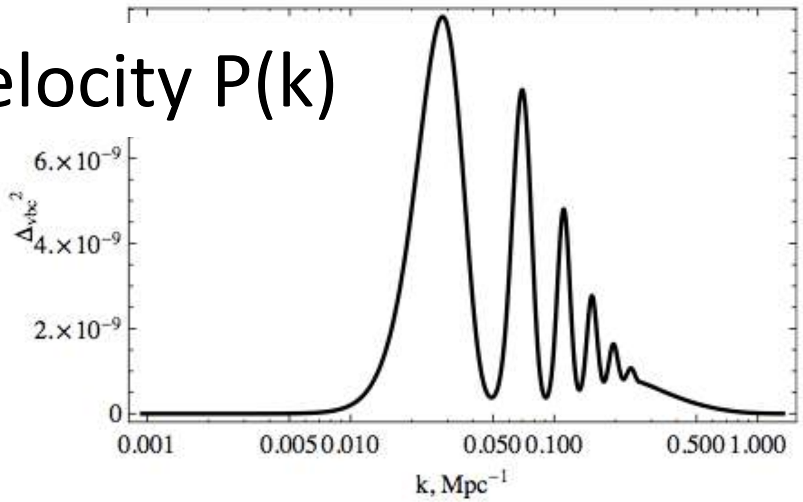
Velocity



Density



velocity P(k)

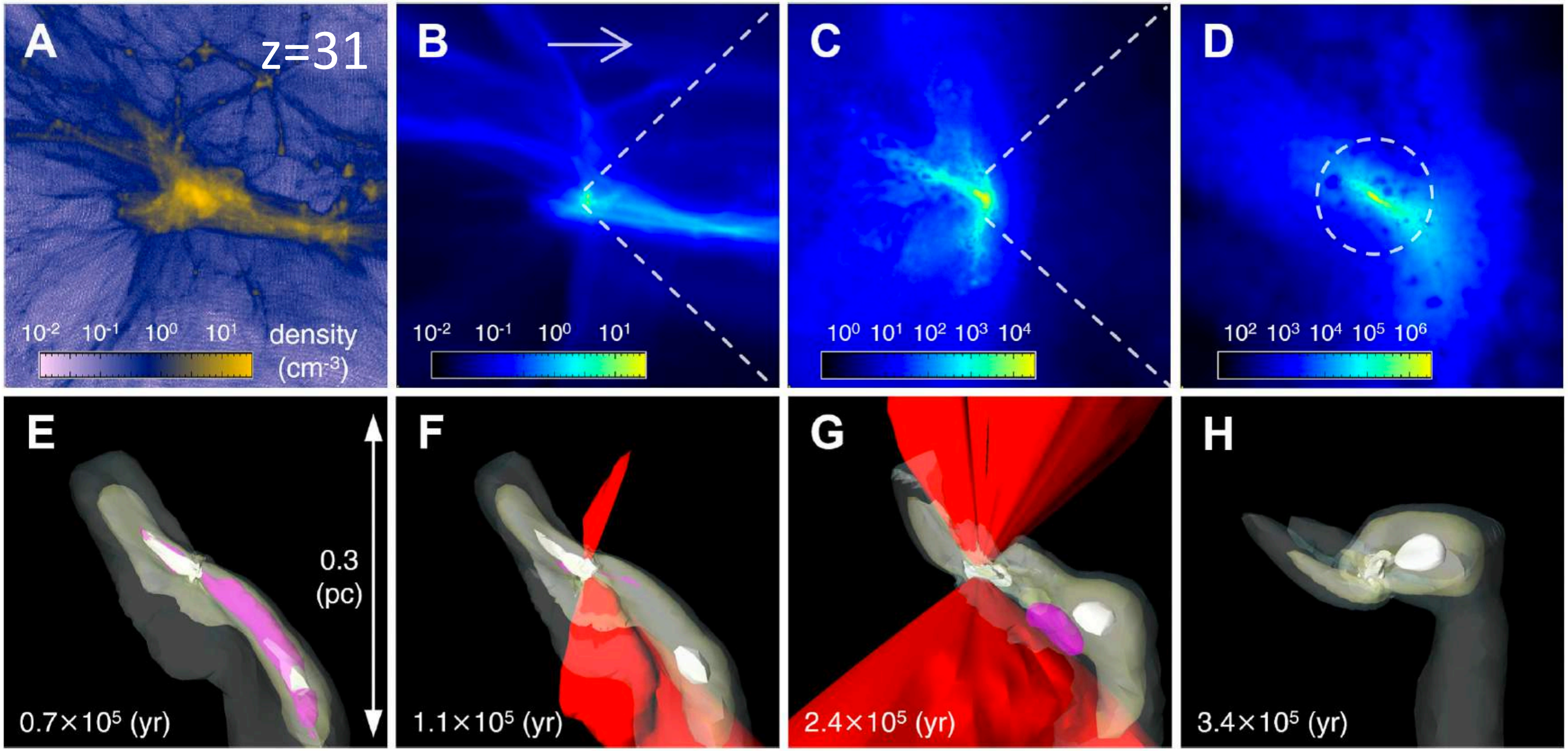


Relative motions between gas and dark matter

Tseliakhovich & Hirata 2011;
Visbal+ 12; Fialkov+ 12

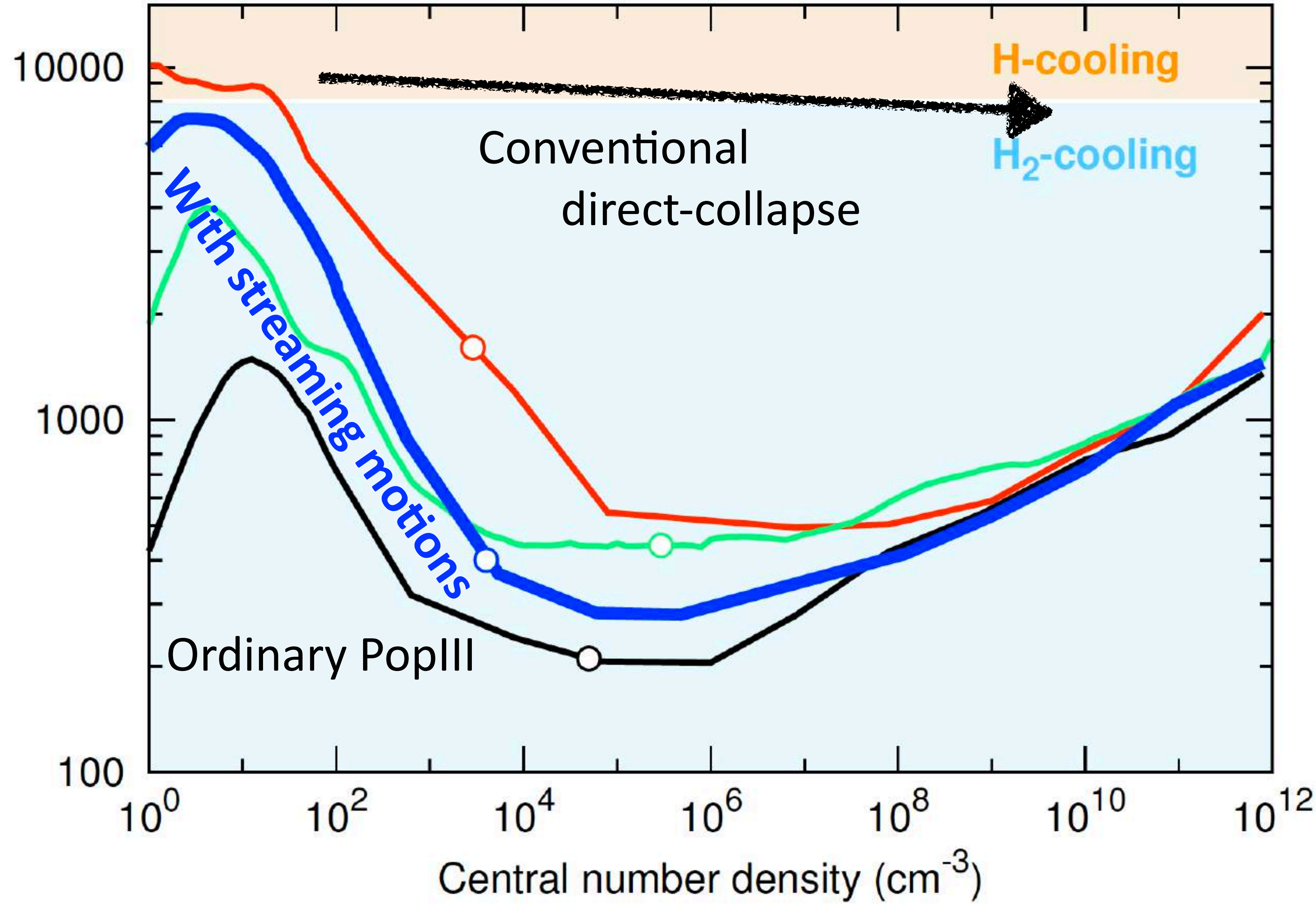
Supersonic gas streams drive BH formation

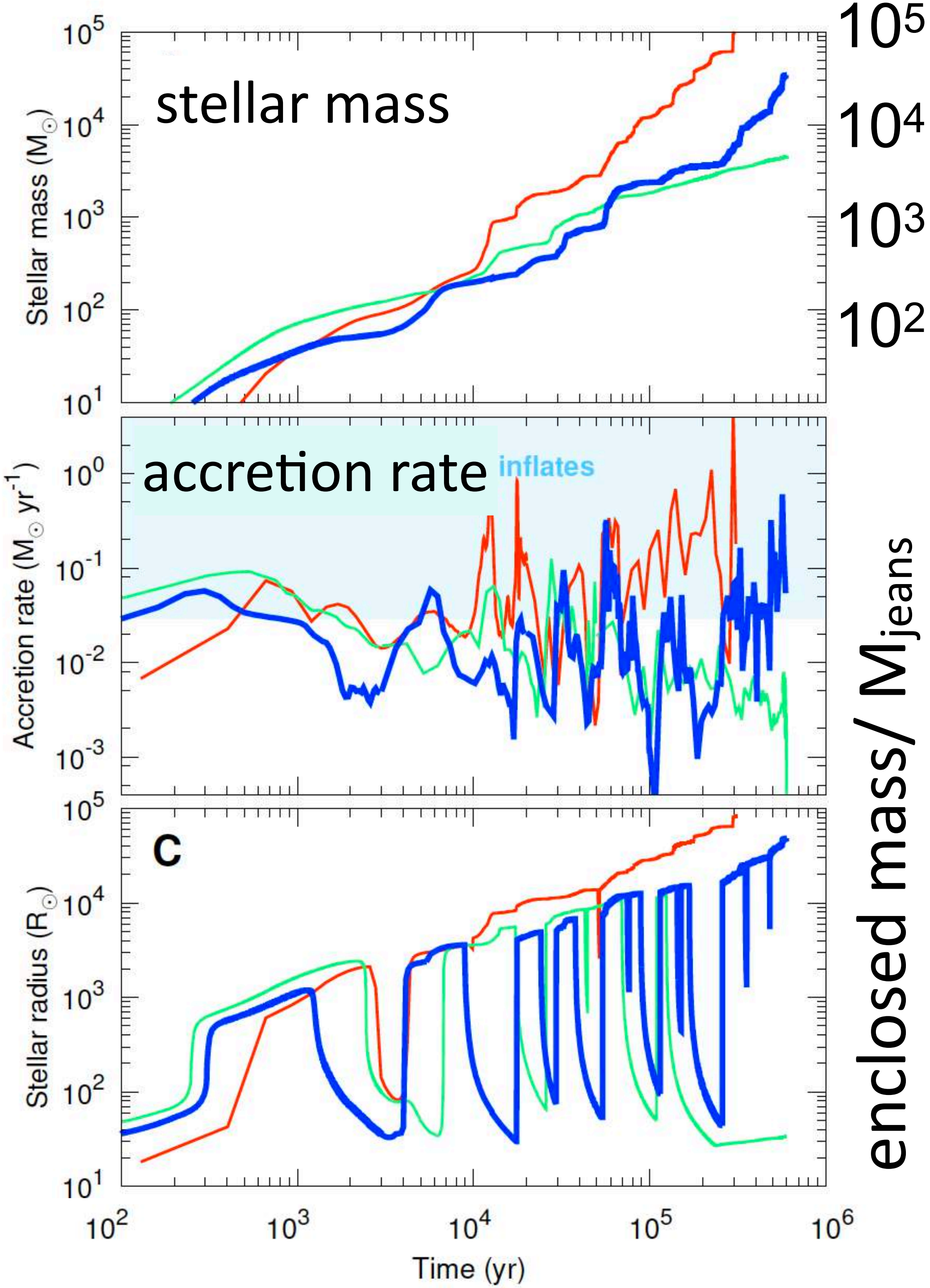
A high-density region with 3-σ streaming velocity (90 km/s @ z=1089)



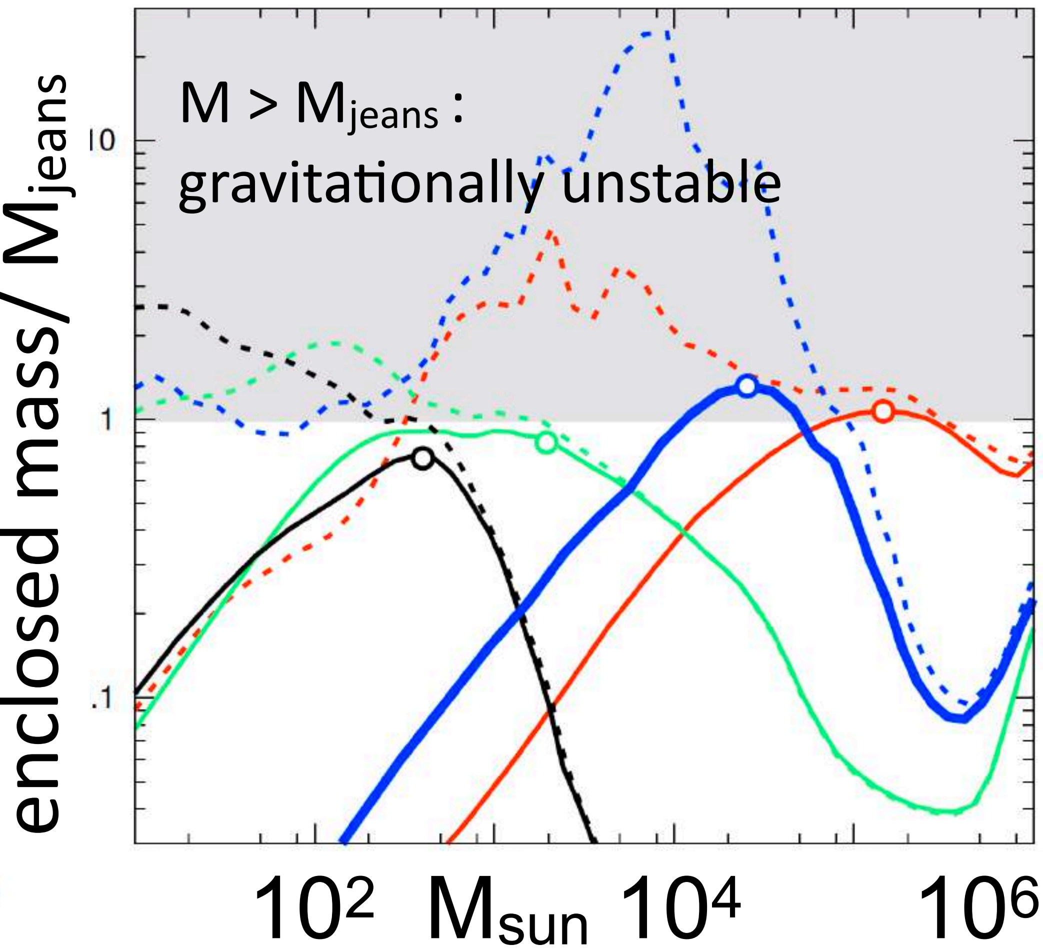
Hirano, Hosokawa, NY, Kuiper, 2017, Science

Gravitational collapse



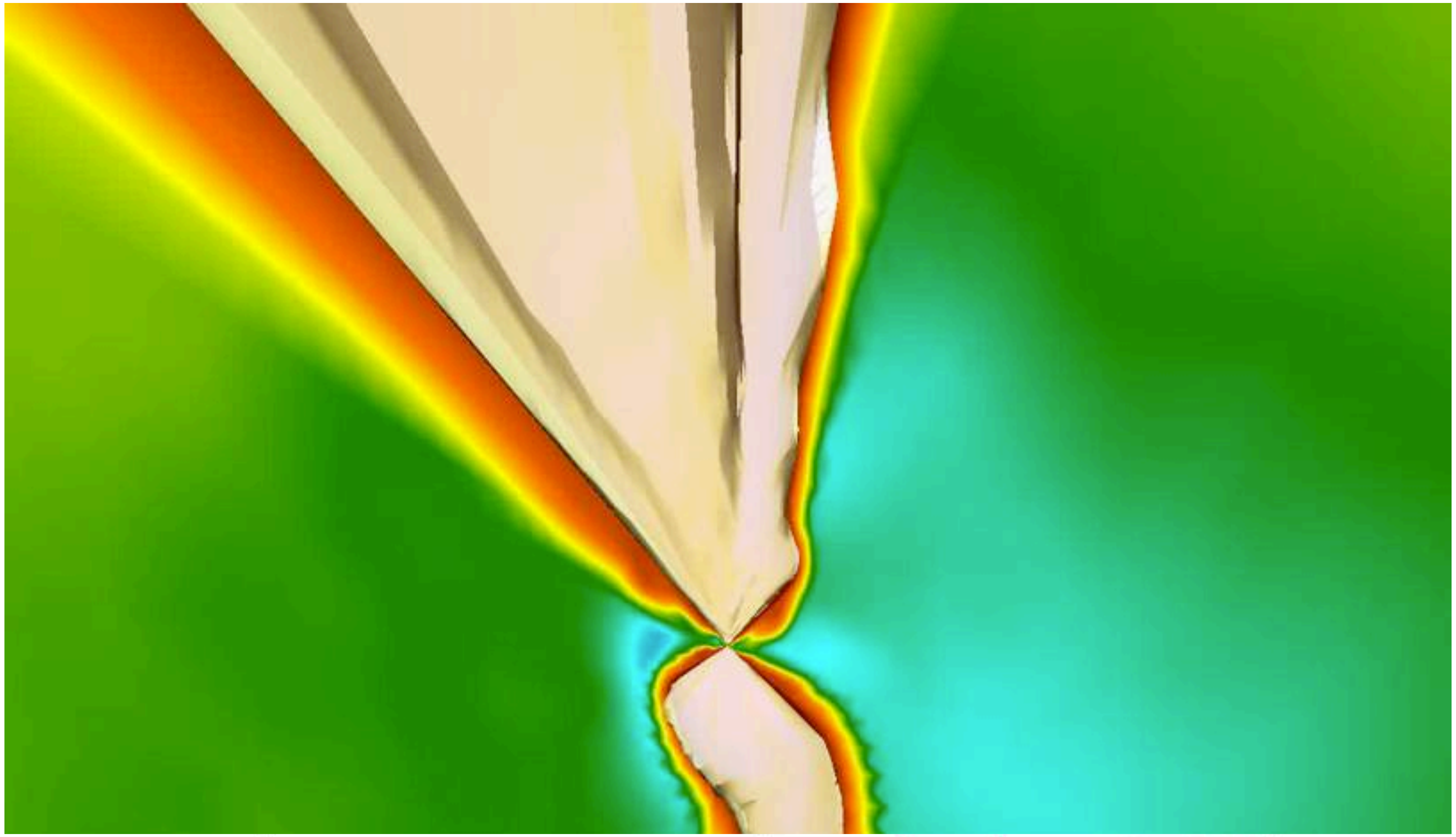


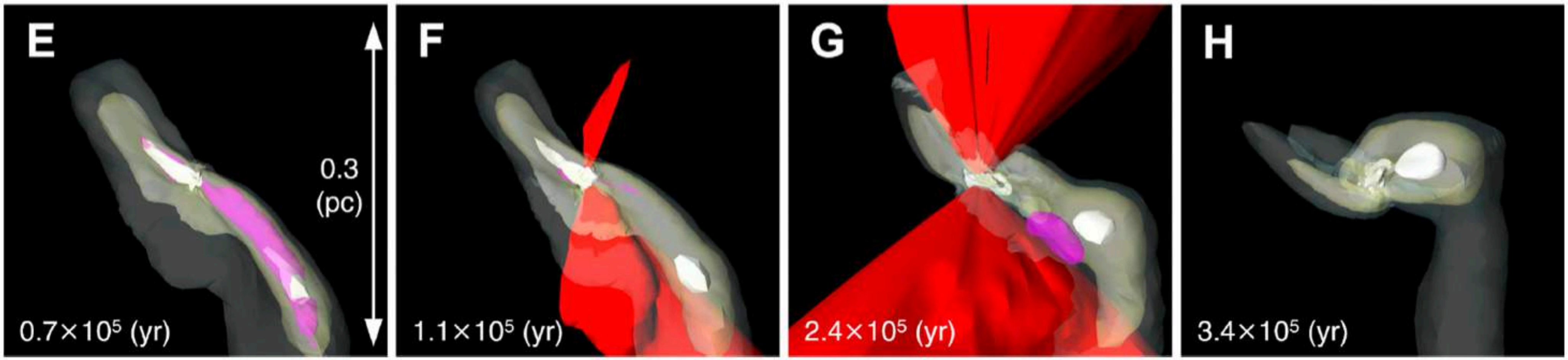
← M_* gets 40000 M_{sun} !
H_2 formation and cooling at high-densities does not delay the cloud collapse



Intermittent UV feedback

Pluto + 3D radiative transfer simulation (EUV, FUV)

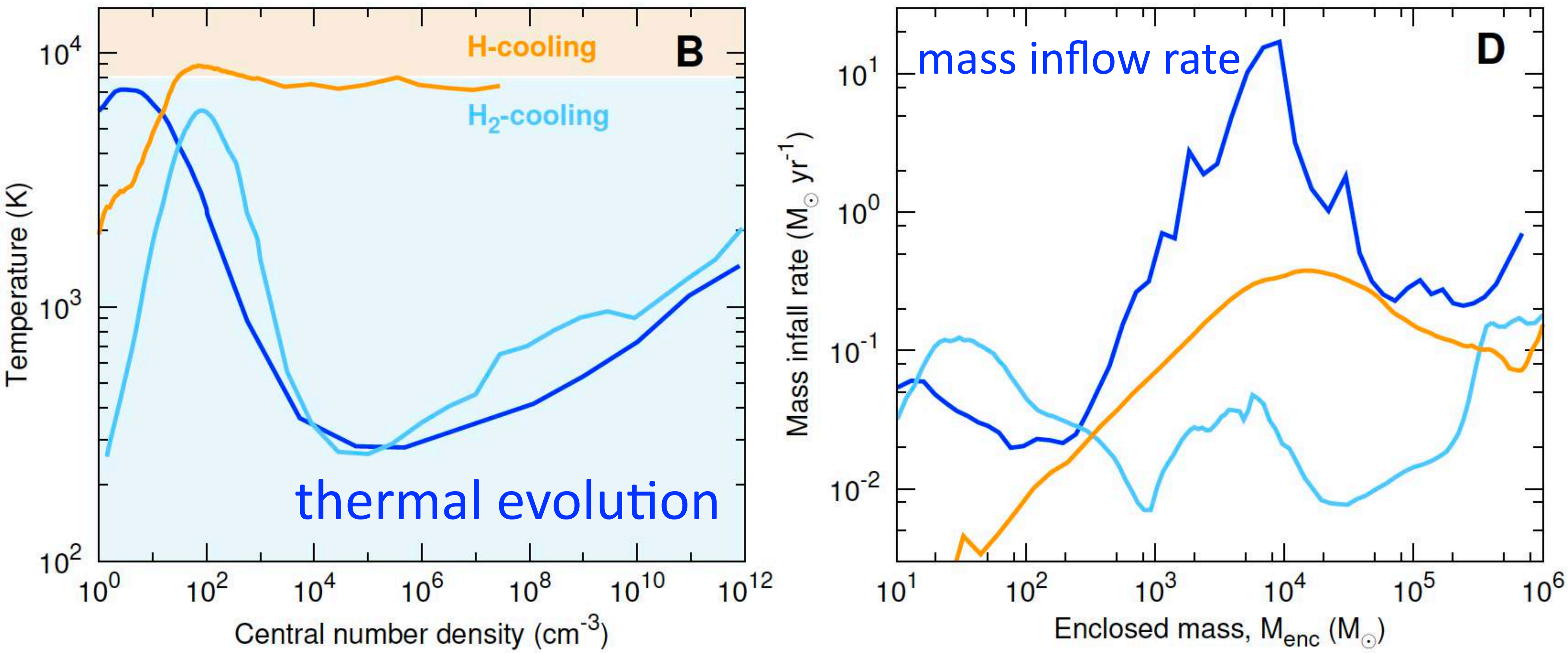




Rapid cloud collapse and $\dot{M}_{acc}$

SV-driven gas collapse:

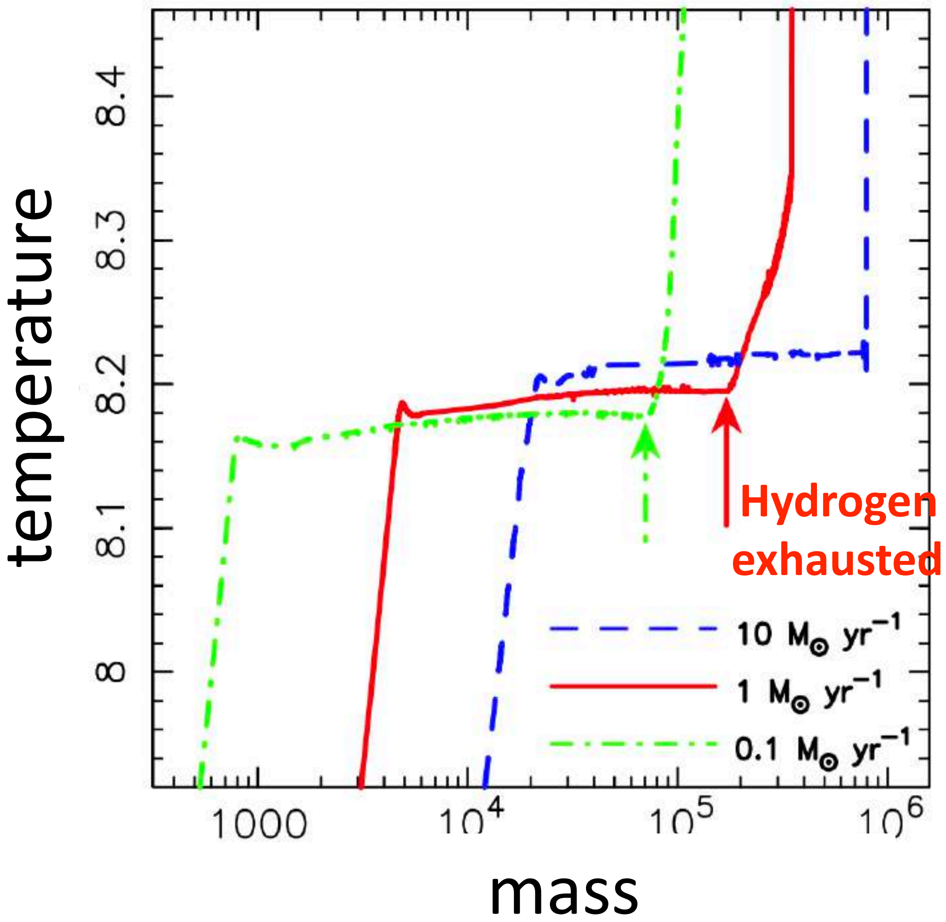
even faster than the typical UV direct collapse case

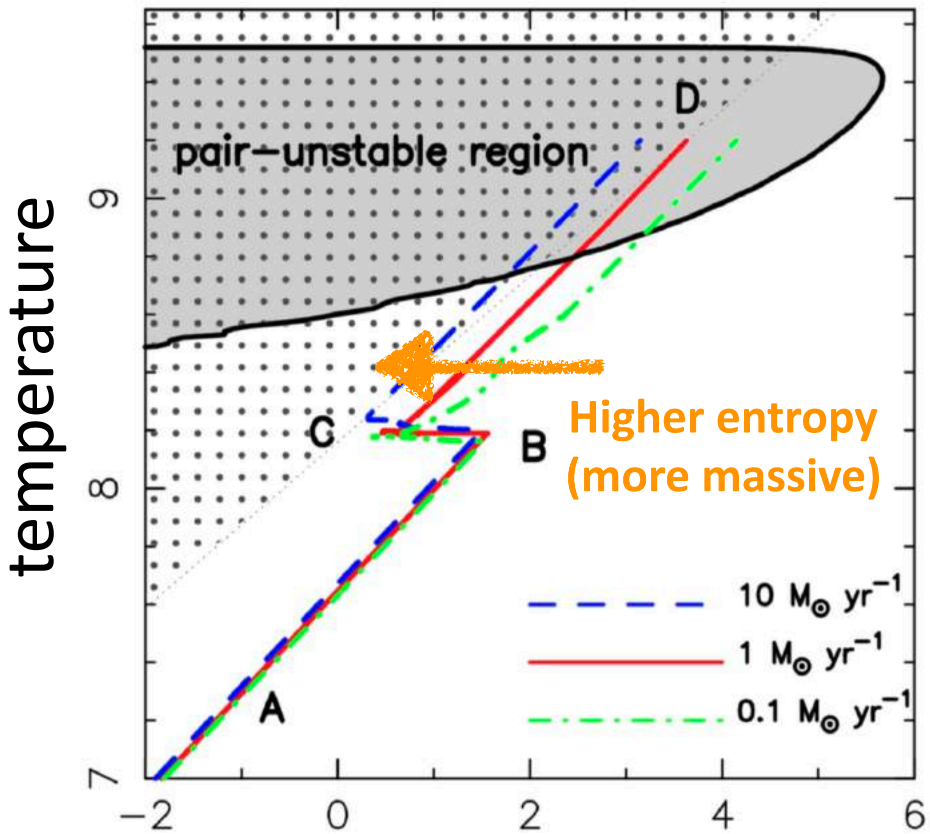


Hirano, Hosokawa, NY, Kuiper, 2017, Science

Core evolution of accreting stars

Umeda, Hosokawa, Omukai, NY 2016, ApJL

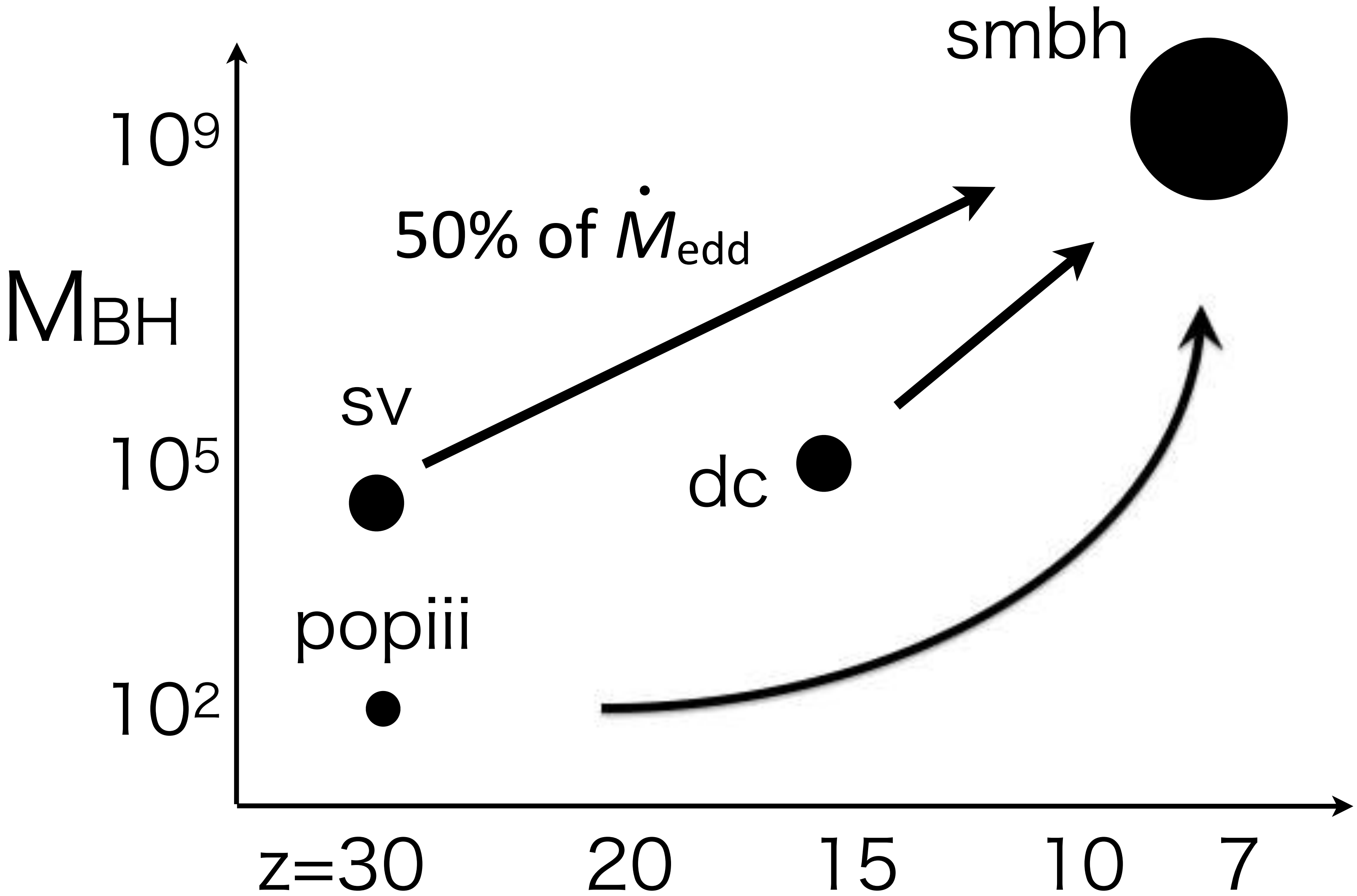




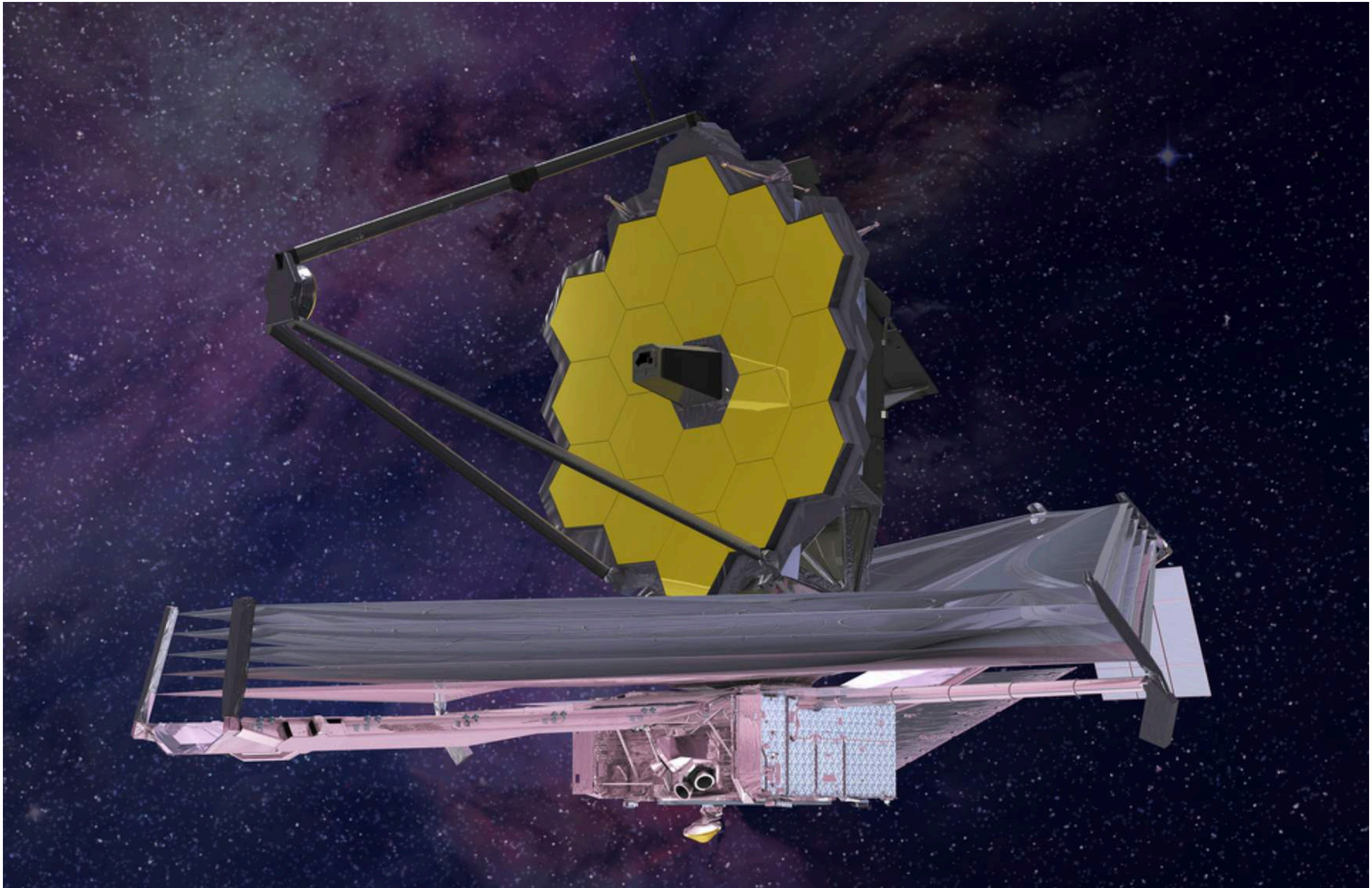
Final Stellar Mass and Composition of the Inner Core

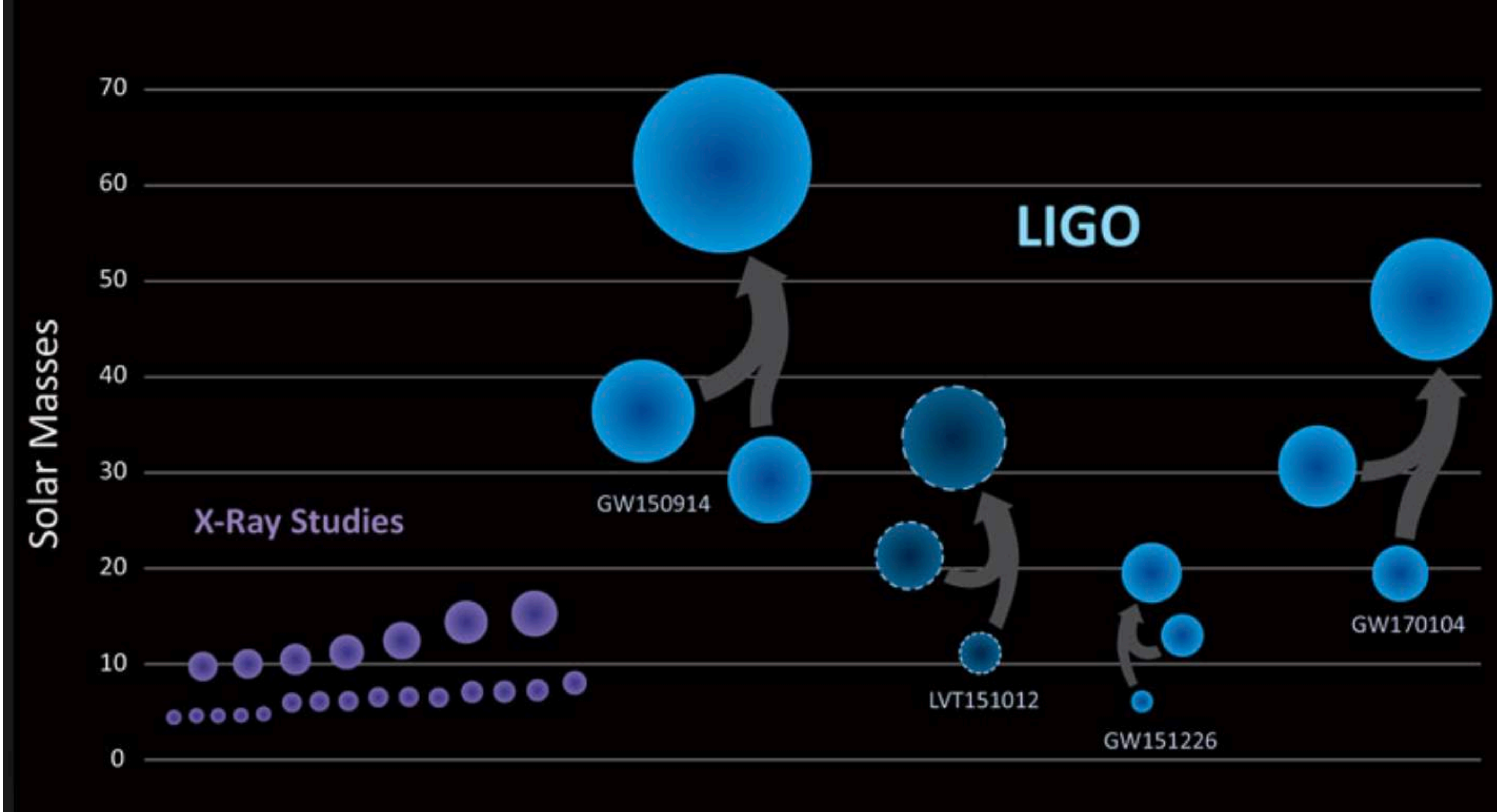
$\dot{M}(M_\odot\ yr^{-1})$	0.1	0.3	1.0	10
$M_f\ (M_\odot)$	1.2×10^5	1.9×10^5	3.5×10^5	8.0×10^5
Y (or X)	0.00	0.99	1.00	(0.51)

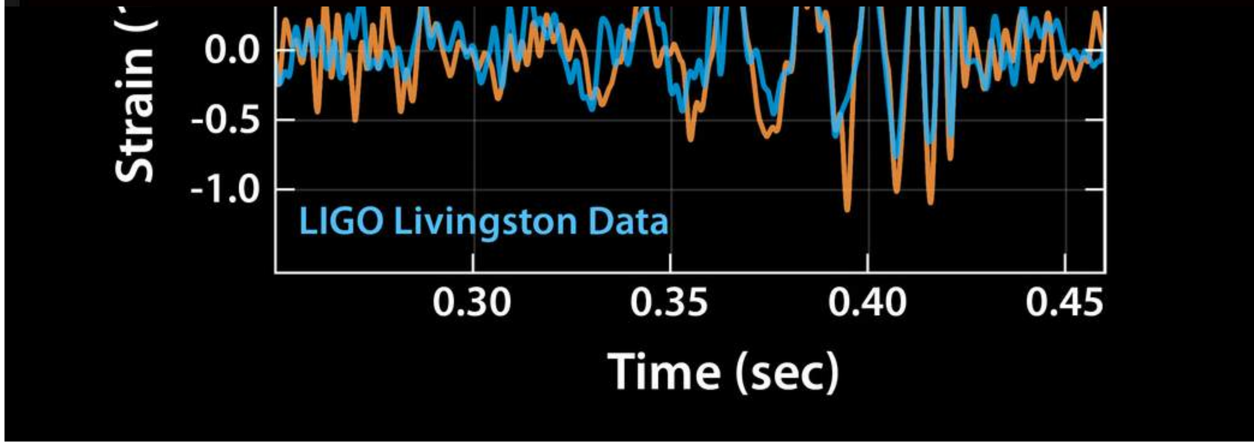
Blackhole growth



James Webb Space Telescope (2019-)

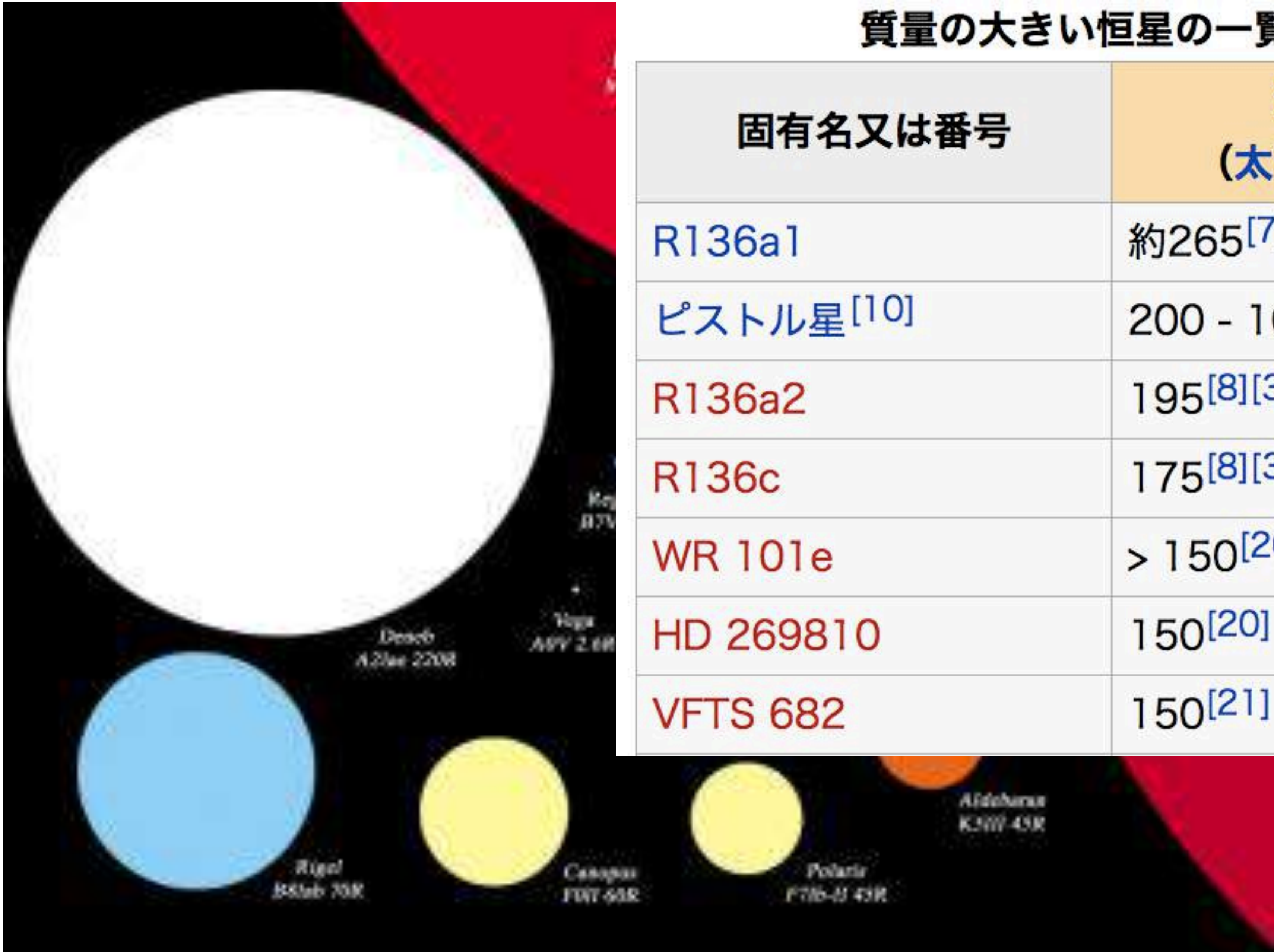






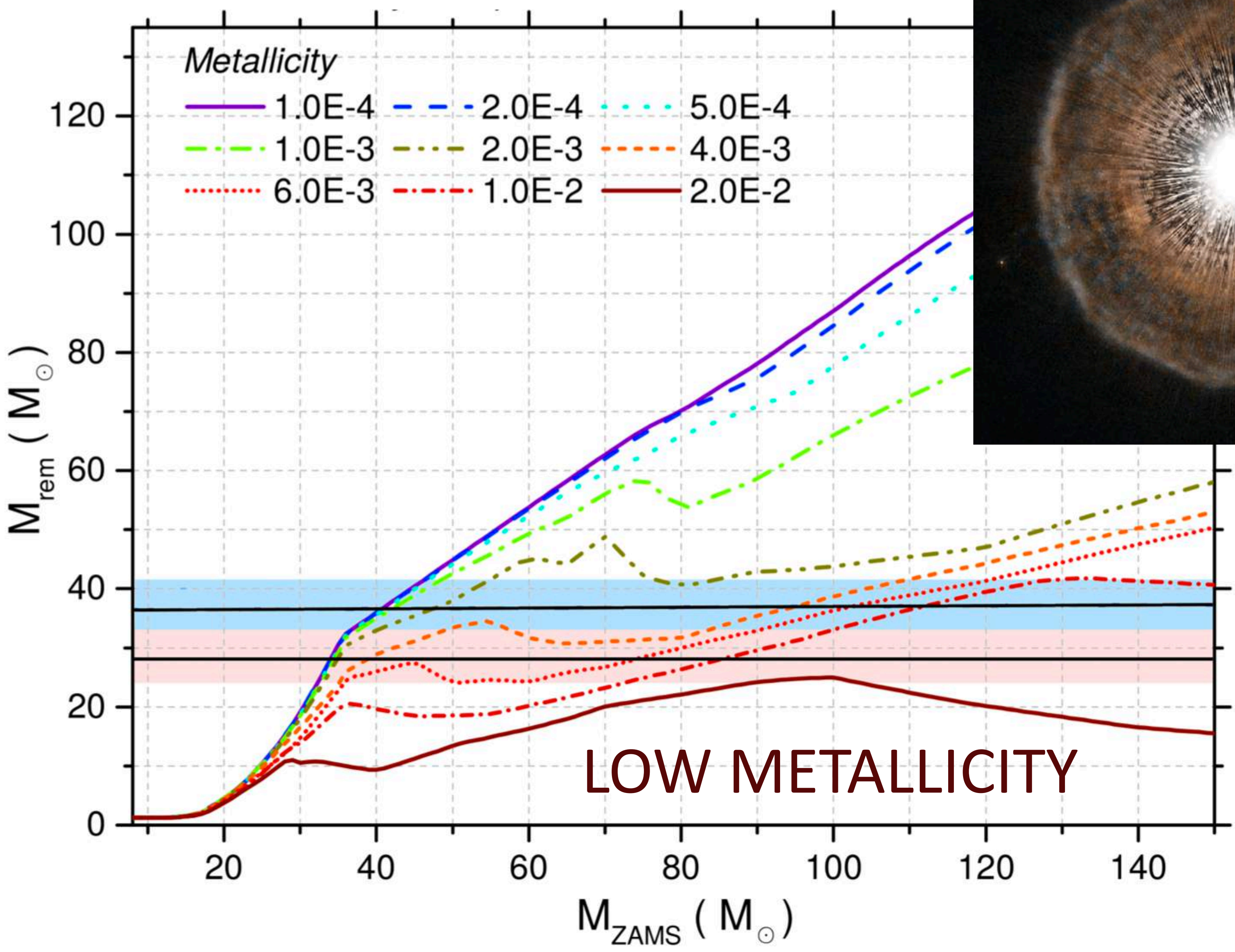
How did blackholes with $> 30\ M_{sun}$ formed ?

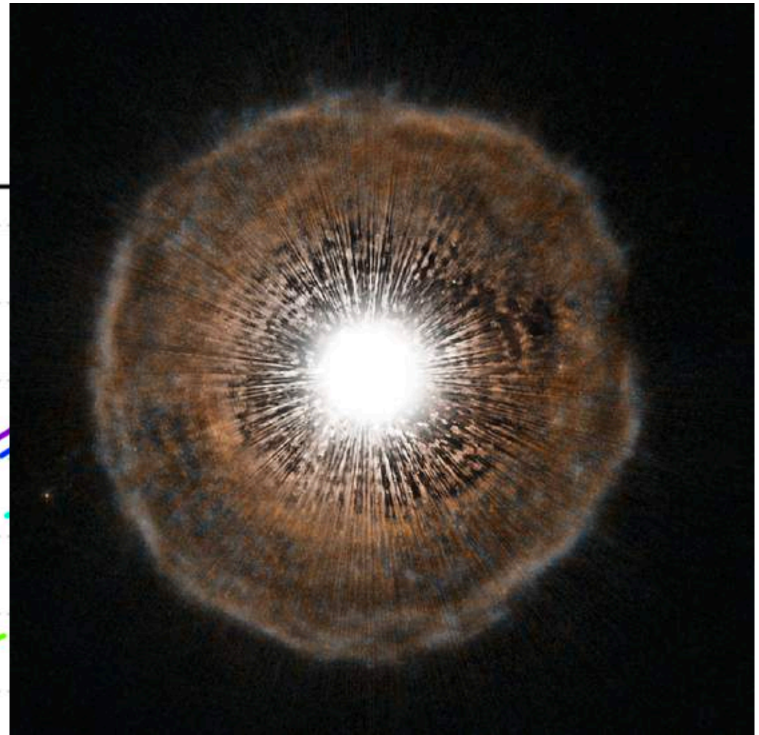
Massive stars are very rare



質量の大きい恒星の一覧

固有名又は番号	質量（太陽 = 1）
R136a1	約265[7][8][3]
ピストル星[10]	200 - 100[12]
R136a2	195[8][3]
R136c	175[8][3]
WR 101e	> 150[20]
HD 269810	150[20]
VFTS 682	150[21]

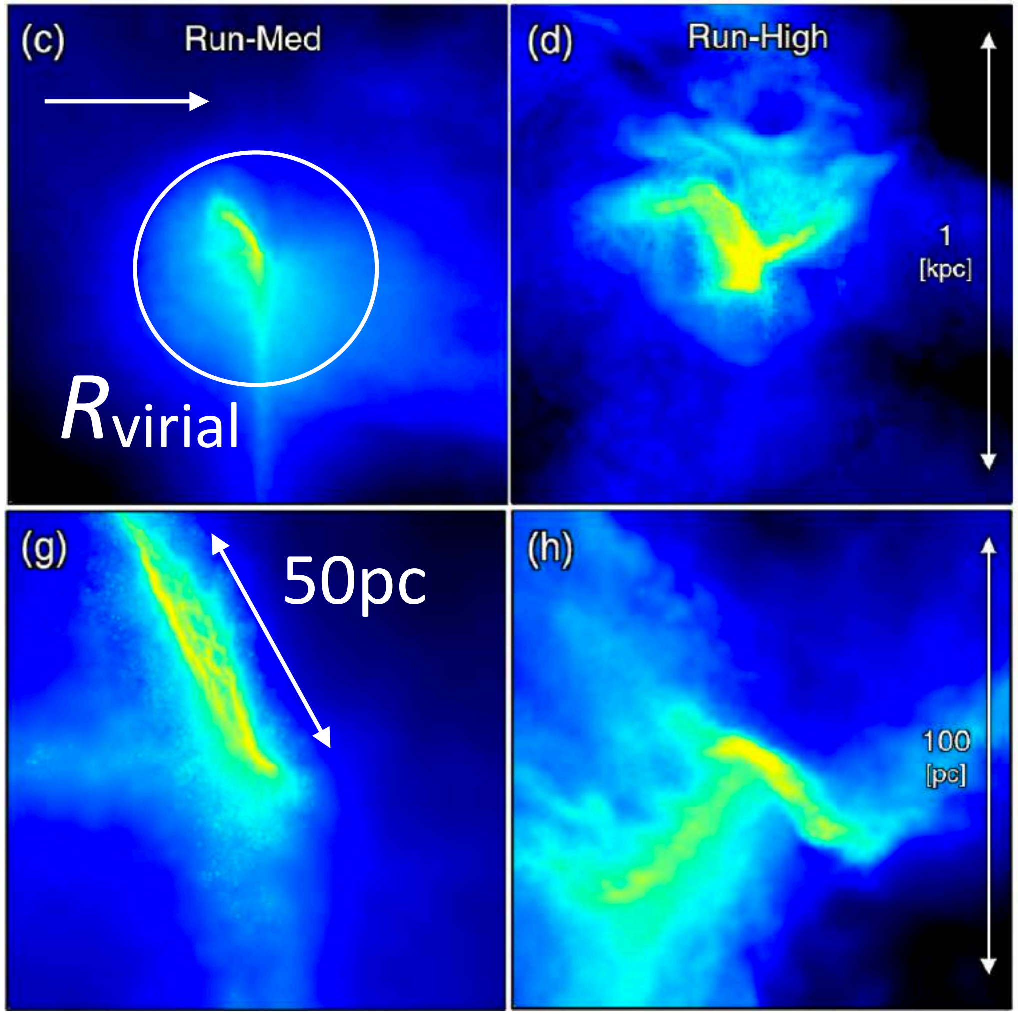


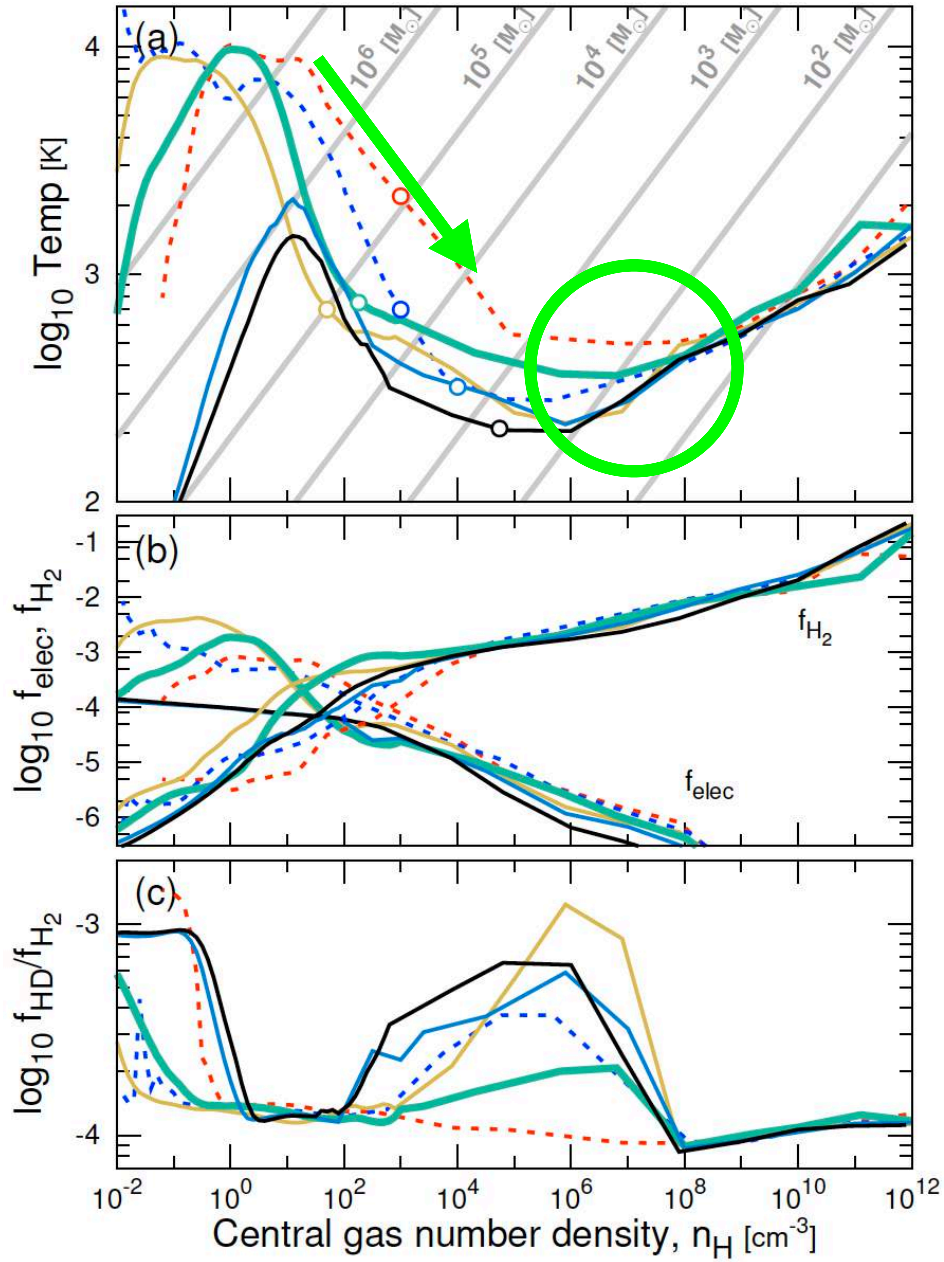


LIGO collaboration arxiv:1602.03846

Giant filament formation

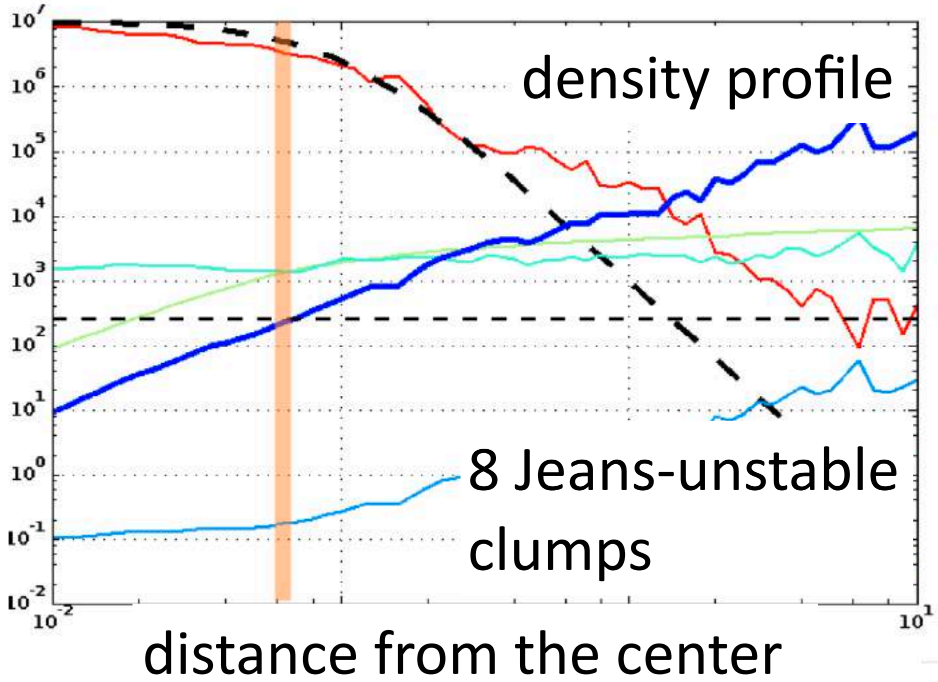
With modest streaming velocity

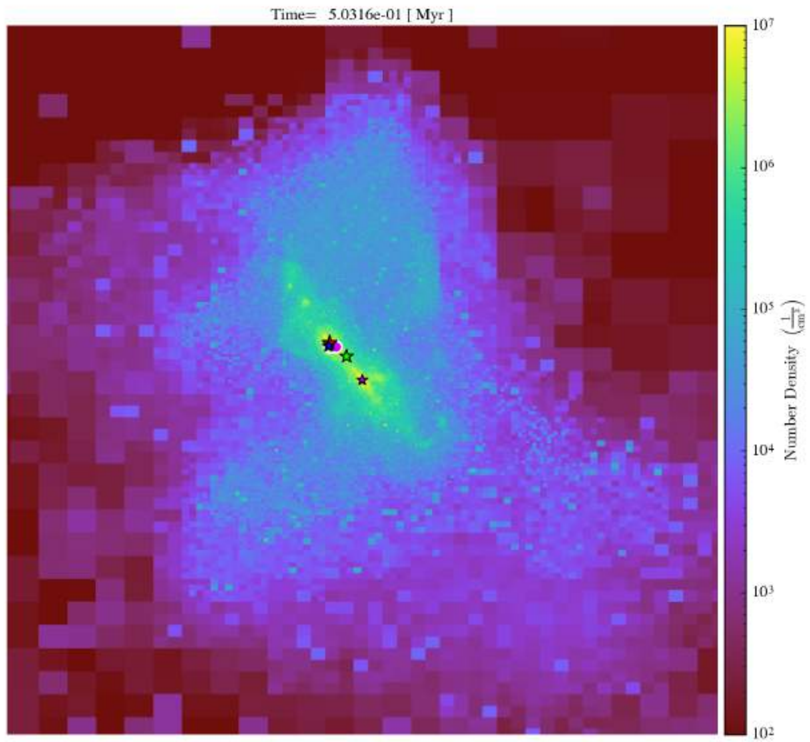


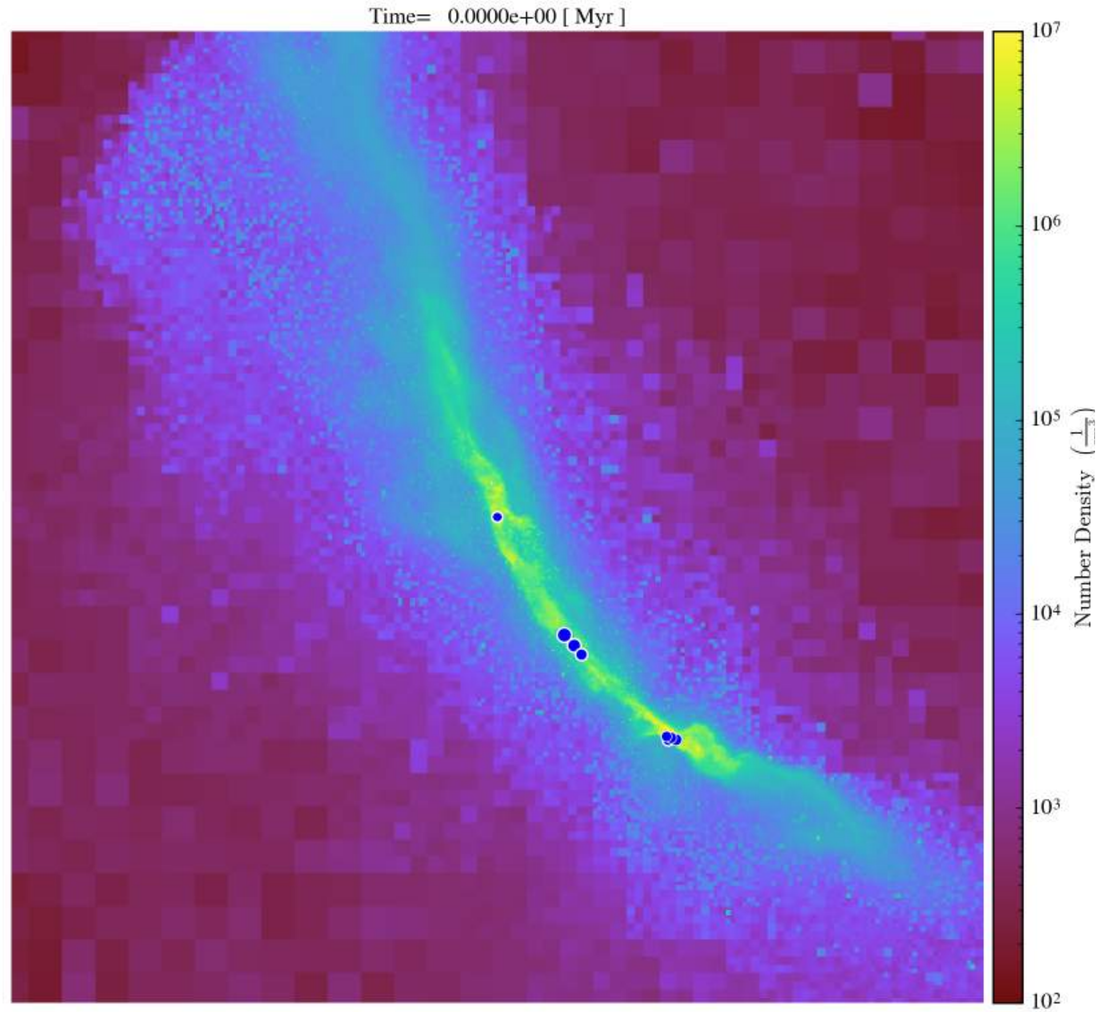


Hirano, NY, Sakurai, Fujii, arxiv:1711.07315

Filament fragmentation



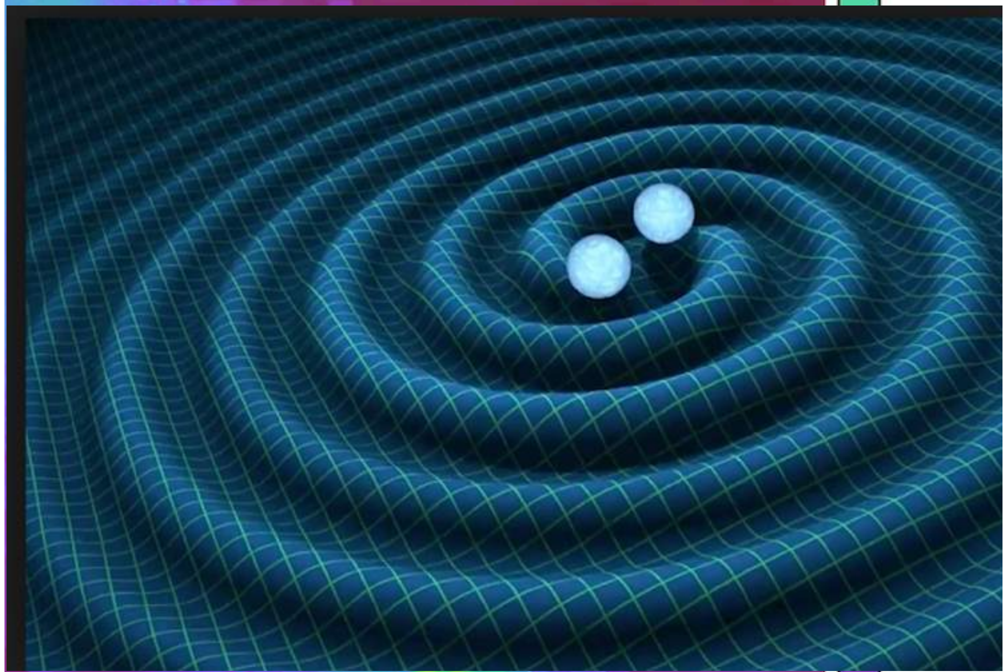




Star cluster and massive binaries

Binary 1

- $(M_1, M_2) = (85, 138)\ M_{sun}$
- a=6.83e-5 pc = 14.1 au
- e=0.967 (very large!)

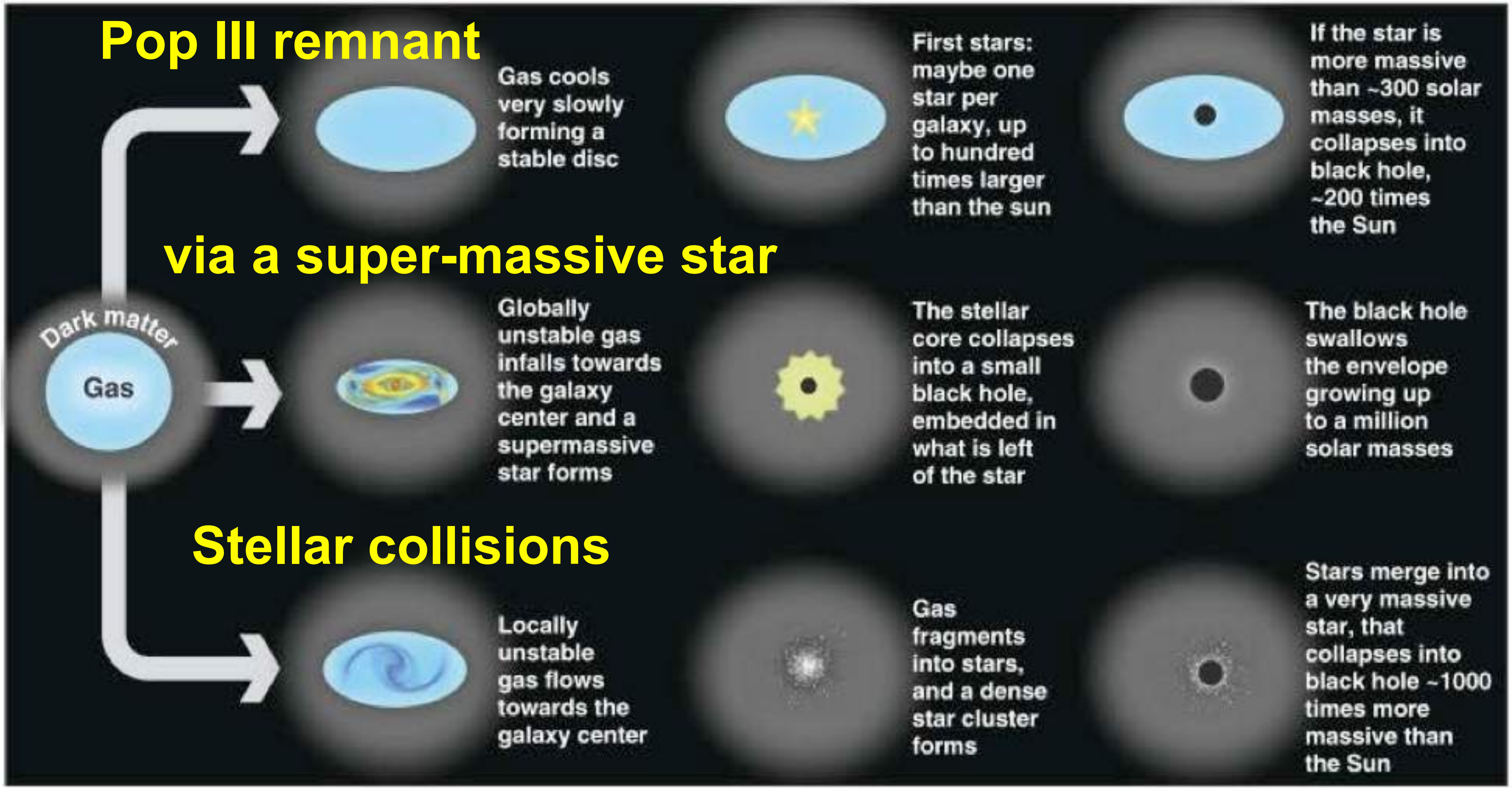


Binary 2:

- $(M_1, M_2) = (63, 71)\ M_{sun}$
- a=0.101 pc (= 2.08e4 au)
- e=0.973

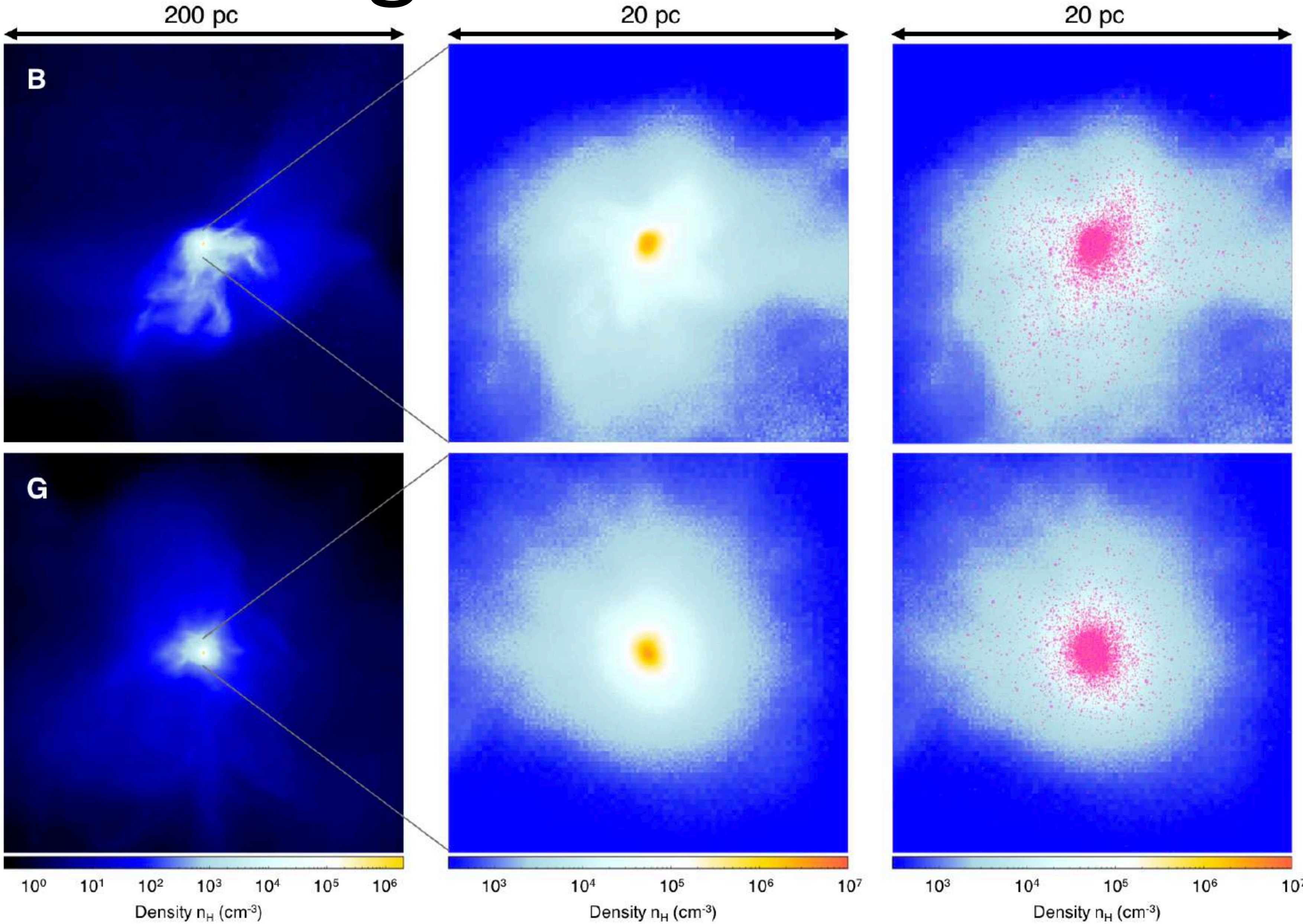
Simulation by
N-body code
BRIDGE

Blackhole seeds: Rees diagram



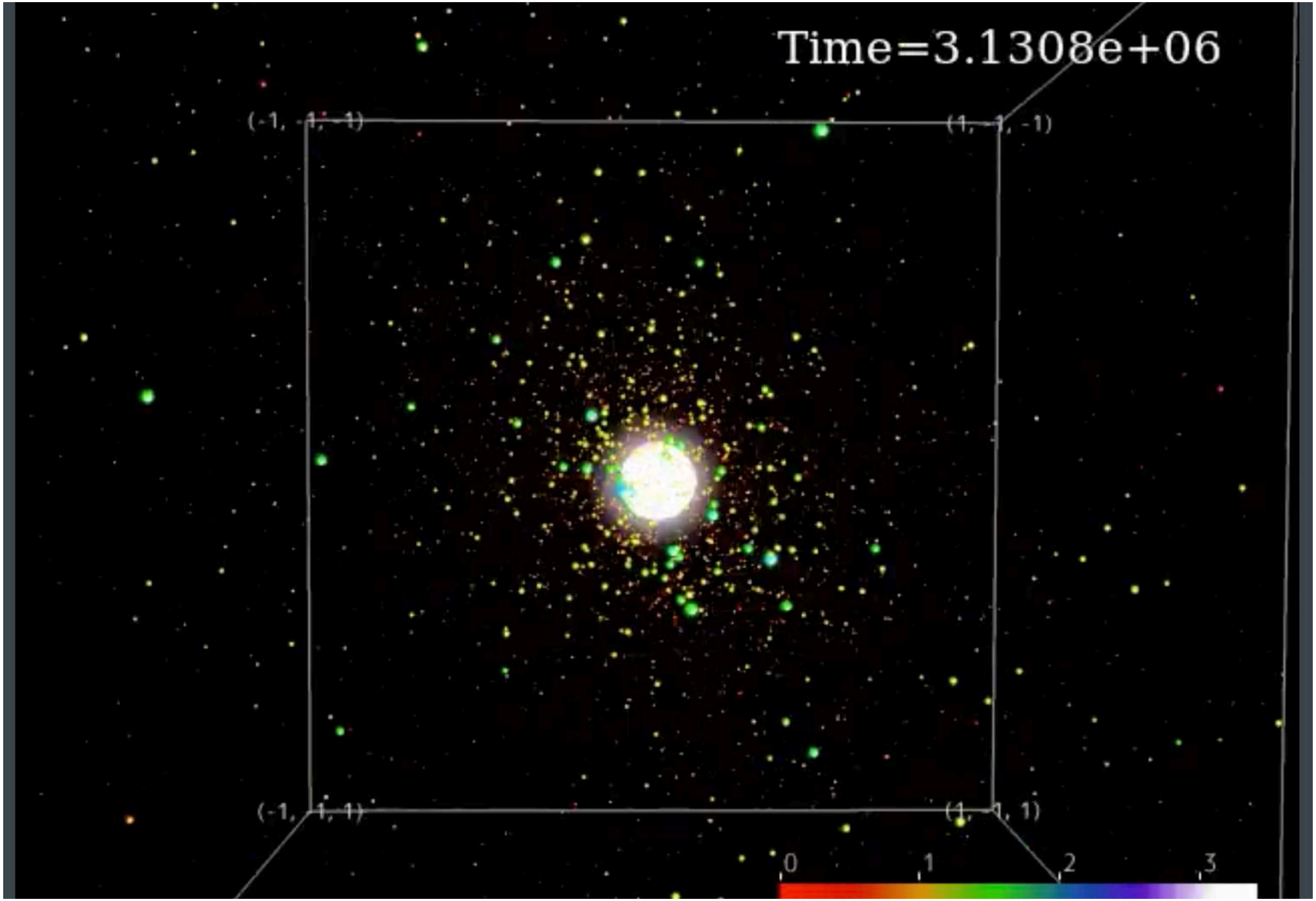
Volonteri 2012, Science

Cosmological initial conditions

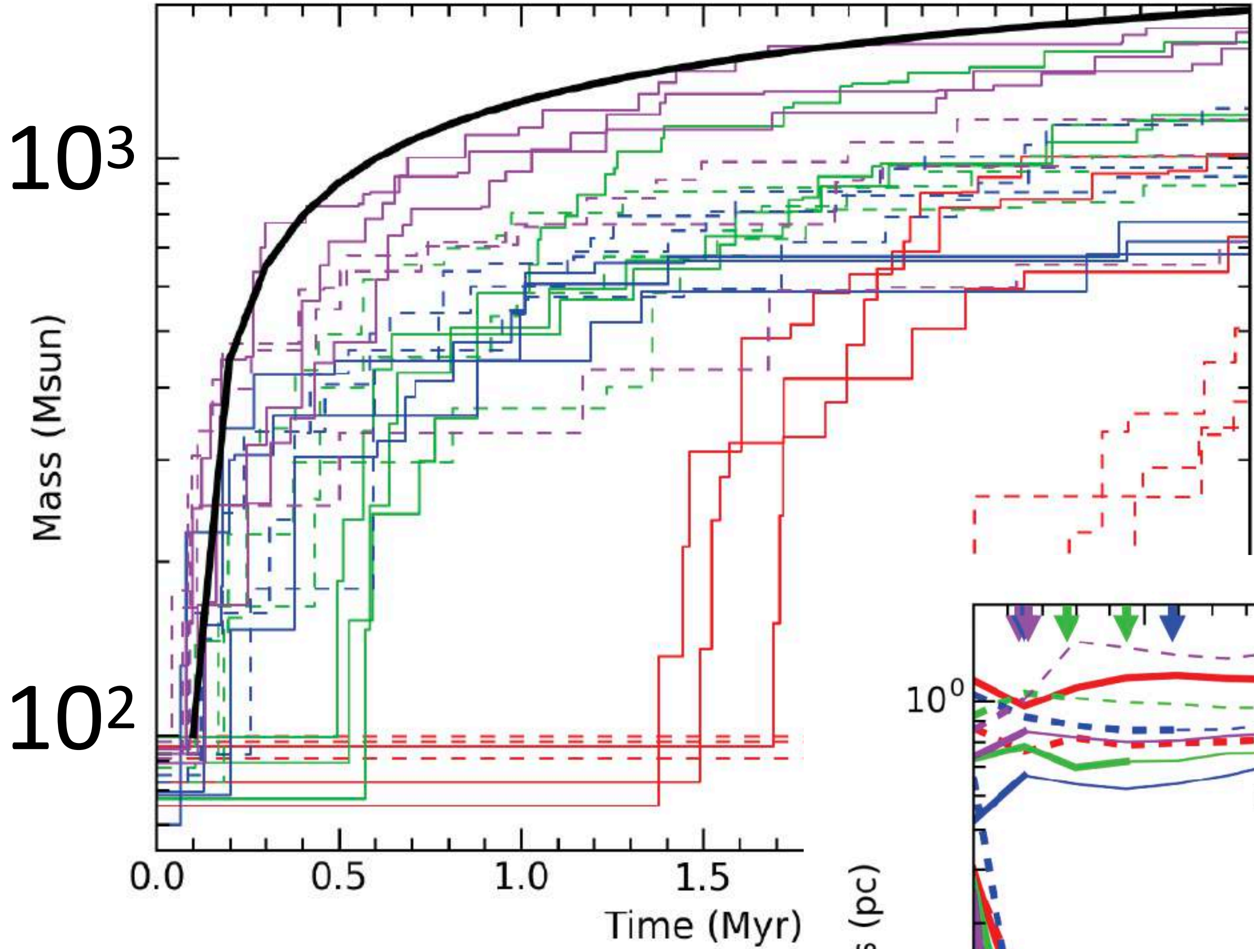


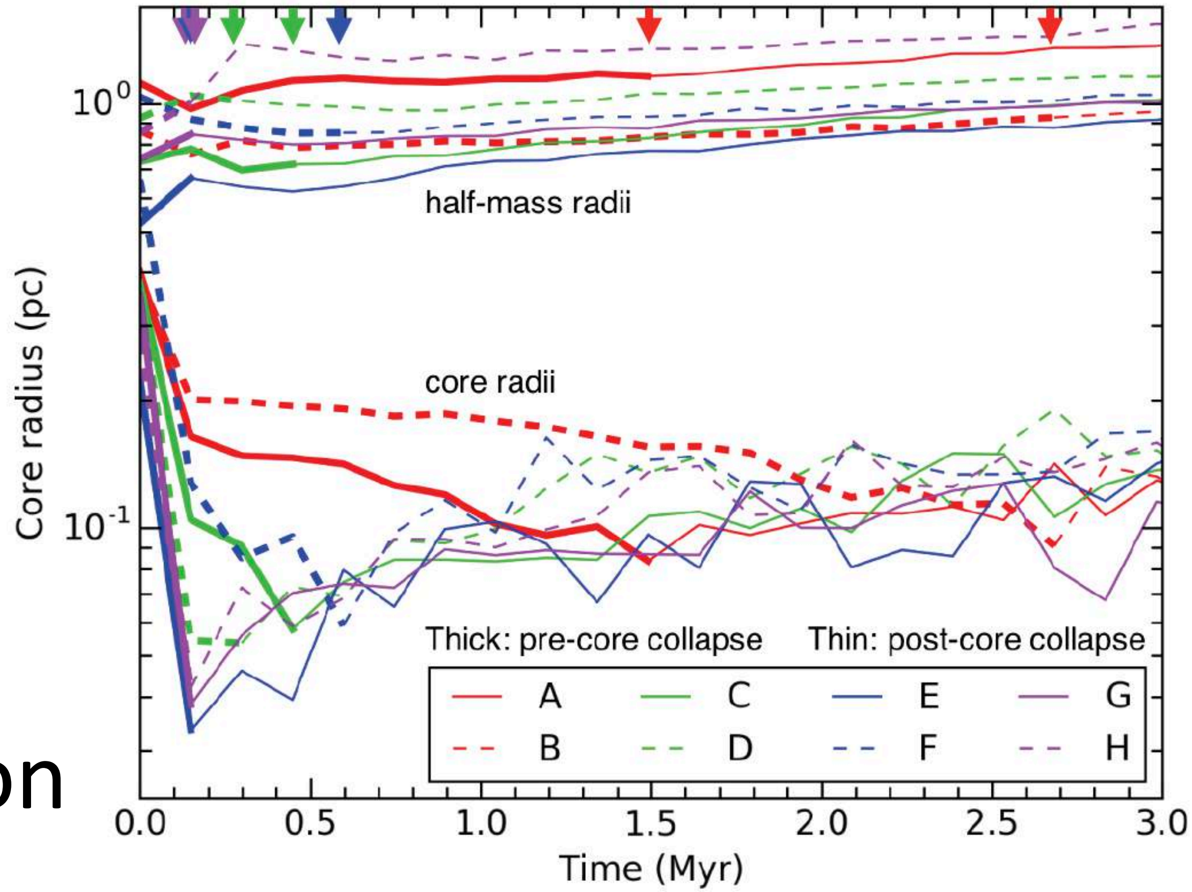
$M_{halo} > 10^7\ M_{sun}$, $M_{cluster} \sim 10^5\ M_{sun}$, $z > 10$

Mass segregation and runaway collisions

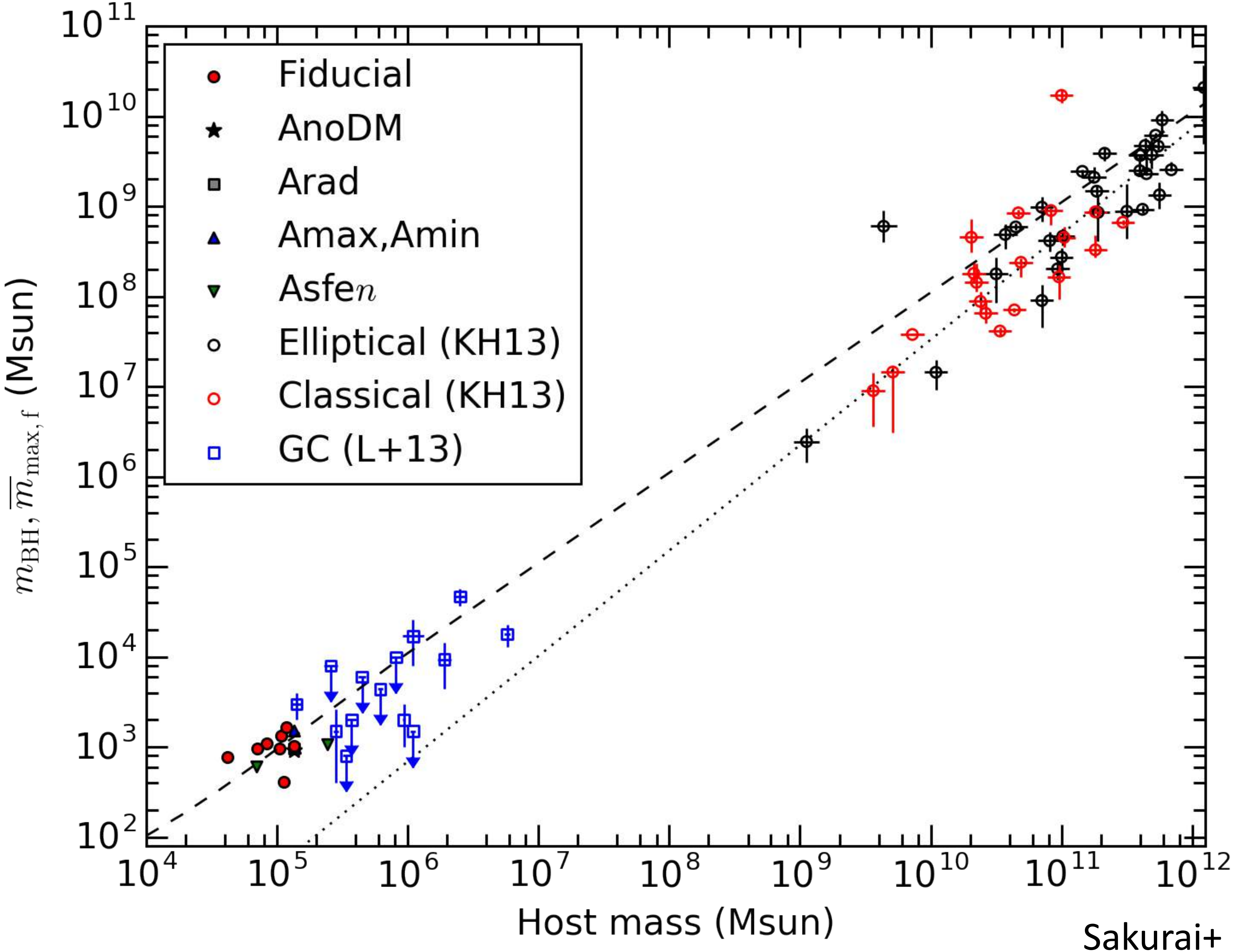


mass growth



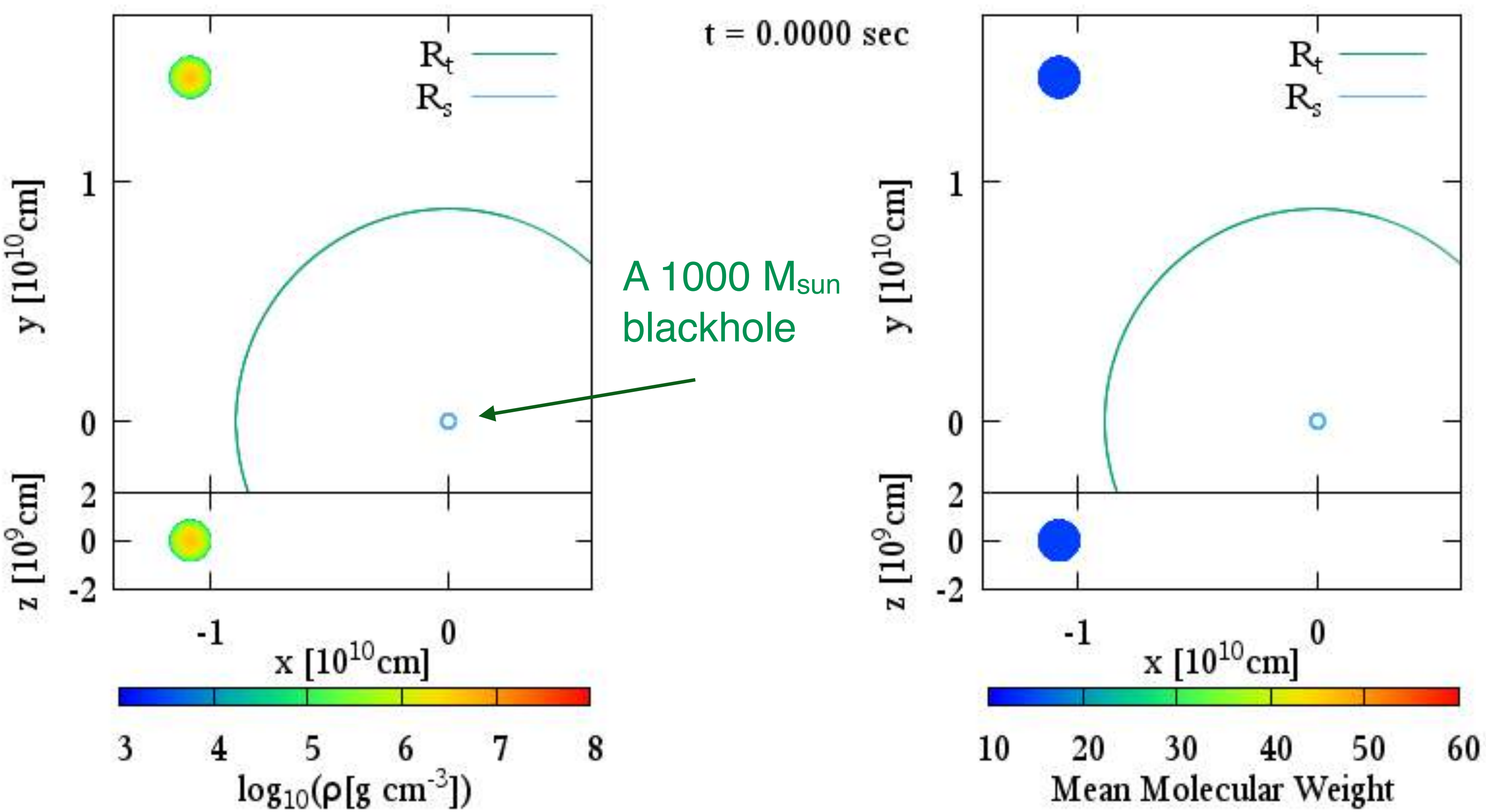


core evolution



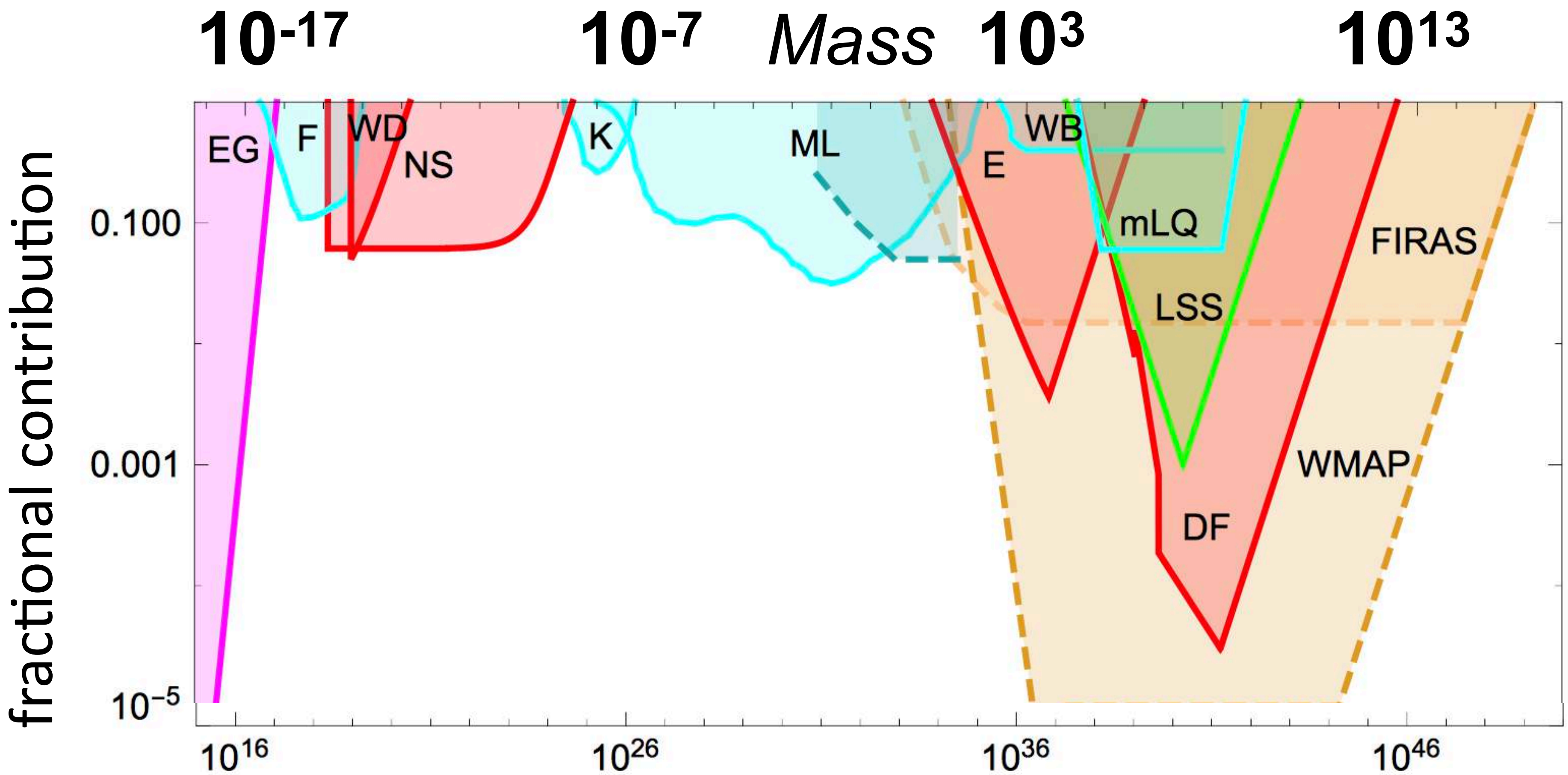
Sakurai+ 2017

How do we find an intermediate mass black hole ?
Tidal disruption of a white dwarf



Simulation by K. Kawana: Relativistic fluid + nuclear reaction

Primordial Black Holes as Dark Matter ?



B. Carr et al. 2016

Summary

Origin of SMBHs at $z > 7$

A variety of pathways

Direct observations by JWST ?

Massive Population III binaries

LIGO GW sources ?

Intermediate Mass Blackholes

Observational signature of WD TDE?