Guido D'Amico

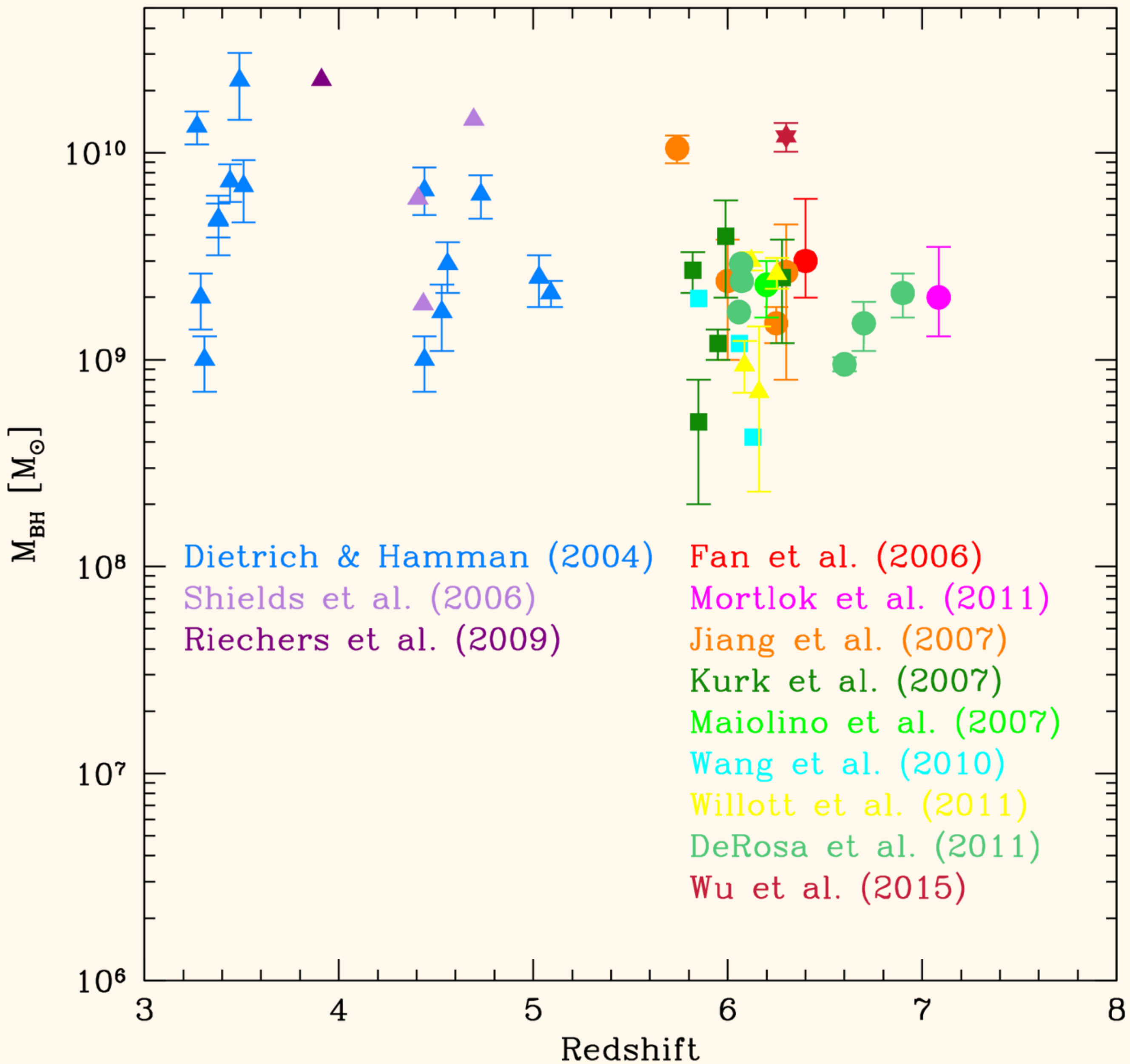
Massive Black Holes from Dissipative Dark Matter

based on GDA, Panci, Silk, Lupi, Bovino
Mon.Not.Roy.Astron.Soc. 473 (2018) no.1, 328
(arXiv: 1707.03419)

Swiss Cosmo Days, 6/2/2018

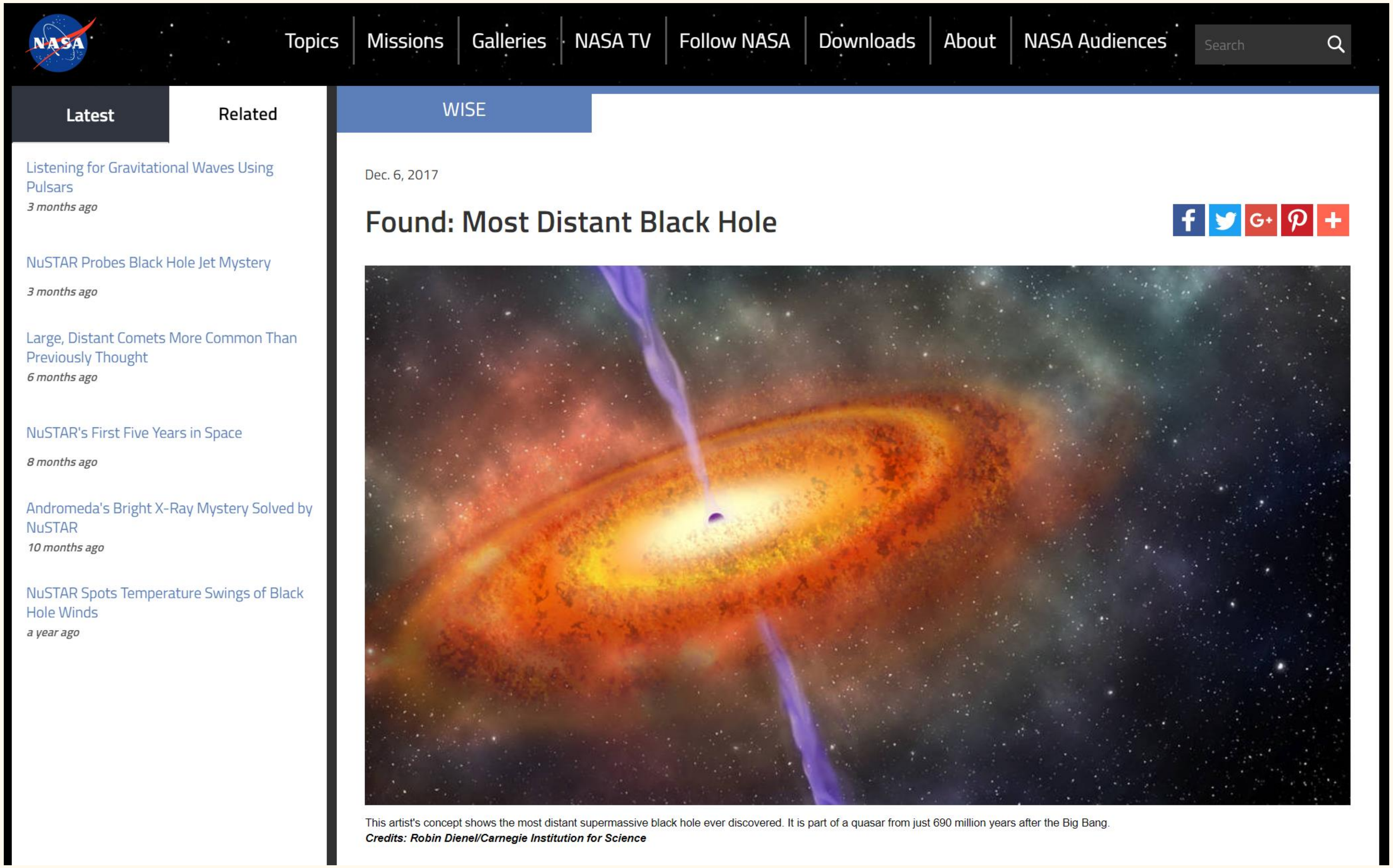
The Problem

- About 40 SMBH have been observed to date, at high-z, with masses > 10^8 M⊙
- Question: how did they form? Why are they so big?



Valiante et al.
PASA 34, 31 (2017)

Still in the news!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Found: Most Distant Black Hole

This artist's concept shows the most distant supermassive black hole ever discovered. It is part of a quasar from just 690 million years after the Big Bang.
Credits: Robin Dienel/Carnegie Institution for Science

$z = 7.54$ $\qquad M = 8 \times 10^8 M_\odot$

Bañados et al., Nature 553, 473

How to make them (so far)

Two main scenarios

Light seeds ($M \lesssim 10^2 M_\odot$)

- PopIII remnants
- Runaway collisions of stars
- Runaway merger of BHs

Heavy seeds ($M \gtrsim 10^2 M_\odot$)

- Direct collapse of a massive gas cloud
- SuperMassive star/Quasistar

Open issues

- Sustained accretion at or above the Eddington limit

- Gas fragmentation
- Angular momentum
- Inflow rates of at least $1 M_\odot / yr$

How to make them?

- Collapse of massive star usually gives a seed of 100 $M_\odot$, doesn't grow fast enough
- Direct collapse black hole scenario: gives a seed ~ 10^4 $M_\odot$ which then has to grow fast enough
- Usually, primordial gas cools down to ~200K via H_2, fragmenting at low densities and producing stars
- We need to suppress H_2: best model to date is through a flux of UV photons, but who gives them?

The main idea

- Production of H_2 is very delicate: a 2-step reaction, catalized by free e^- of which there are few around
- So, instead of destroying it, maybe we won't produce it
- Ordinary baryons in our universe just can't do this… But DM can be a lot of strange things!

$$\mathrm{H} + e^- \rightarrow \mathrm{H}^- + \gamma$$

$$\mathrm{H}^- + \mathrm{H} \rightarrow \mathrm{H}_2 + e^-$$

The ingredients

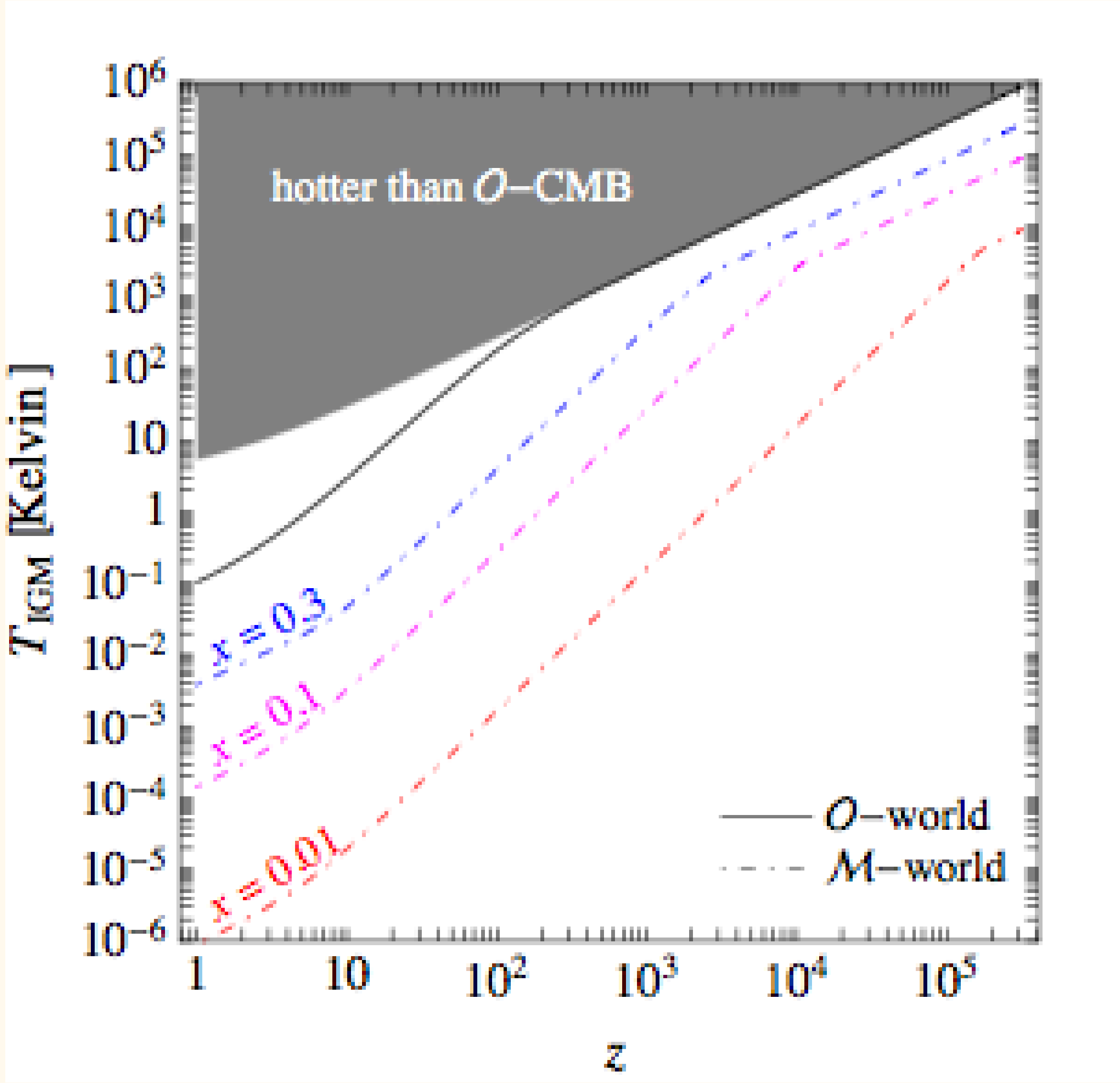
For simplicity, i.e. to avoid messing up with existing bounds and to be able to use standard chemistry, we want:

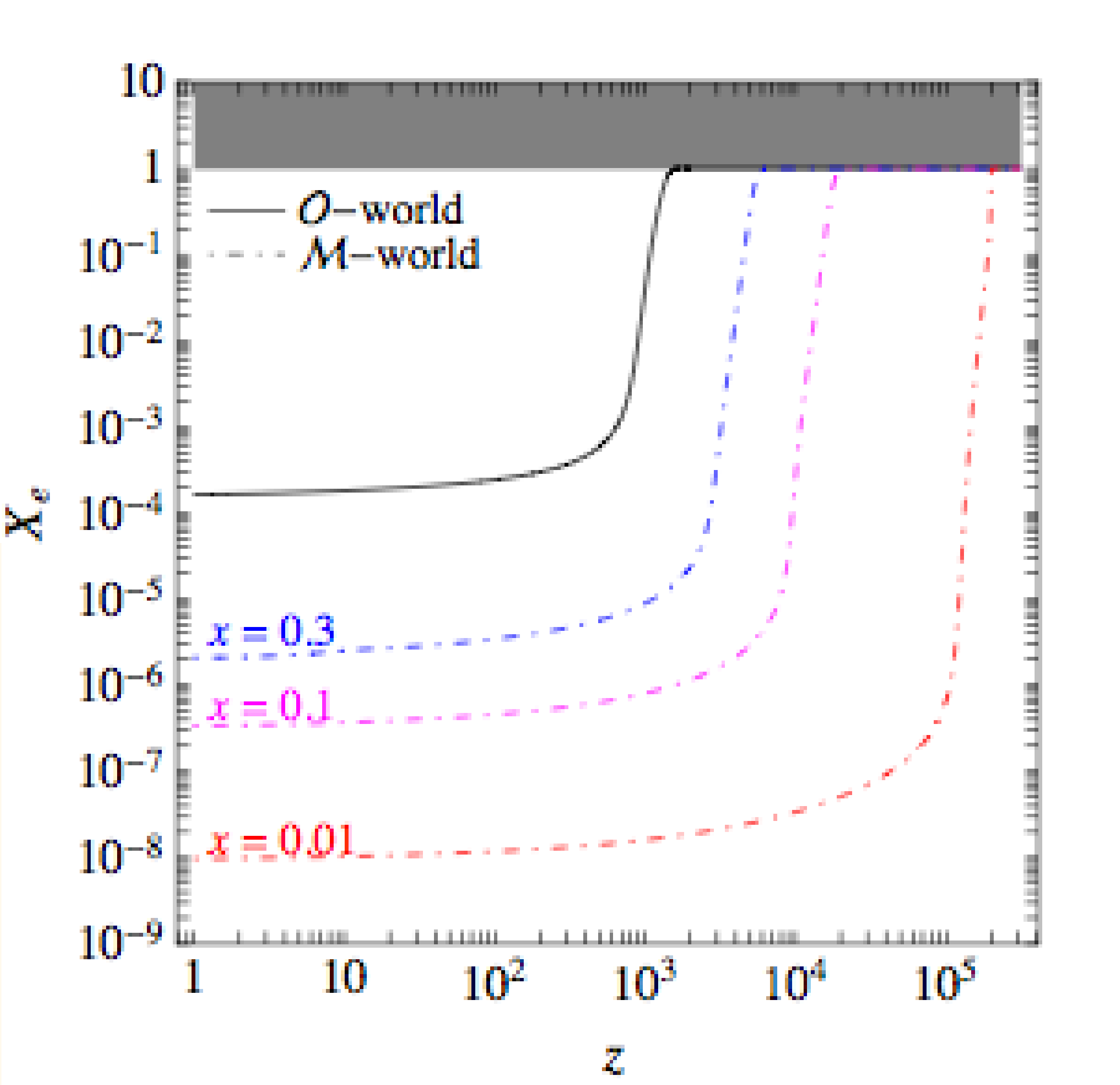
- A *mirror image* of the SM matter.
  We require that recombination happens before, and the photon temperature is then x$\lesssim$0.3
  We assume that mirror baryon abundance is the same as the ordinary one

- A CDM component (for instance, an axion to solve strong-CP) to create potential wells

$x = T'_\gamma / T_\gamma$ $\quad\quad$ $\beta = \Omega'_{\rm b}/\Omega_{\rm b}$ $\quad\quad$ $\Omega_{\rm m} = \Omega_{\rm c} + \Omega'_{\rm b} + \Omega_{\rm b}$

Initial conditions for structures





Dynamics?

- First approximation: dynamics of spherical collapse
- But, before embarking into simulations, let’s try to look for some averaged evolution
- This 0-d evolution is referred to one-zone collapse, and captures quite a bit of what’s going on

The poor men's equations

$$\frac{\dot{T}}{T} + (\gamma - 1)\frac{\dot{\rho}_B}{\rho_B} = \frac{(\gamma - 1)}{k_B T n_B}(\mathcal{H} - \mathcal{C}) \equiv -\frac{1}{t_{\rm cool}}$$

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = \left[\sum_{j,k} k_{jk} x_j(t) x_k(t) - \sum_j k_{ij} x_j(t) x_i(t)\right] n_B(t)$$

$t_{\rm s} > t_{\rm ff}$

$$\frac{\dot{\rho}_B}{\rho_B} = \frac{1}{t_{\rm ff}} = \sqrt{\frac{32 G \rho_{\rm tot}}{3\pi}}$$

OR

$t_{\rm s} < t_{\rm ff}$

$$\rho_B \propto T^{-1}$$

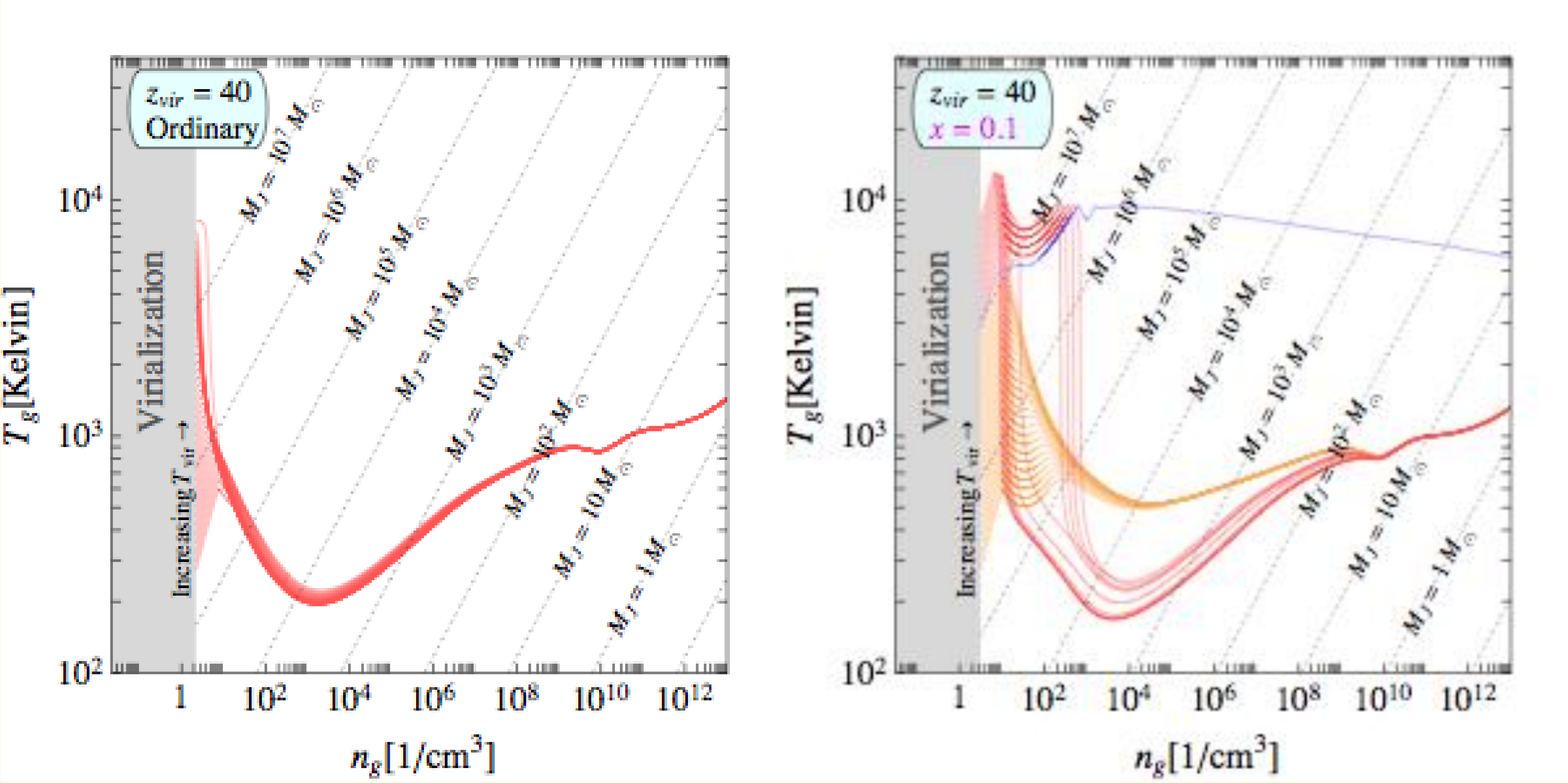
The poor men's I.C.

- A lot of the physics goes also into choosing the right i.c.

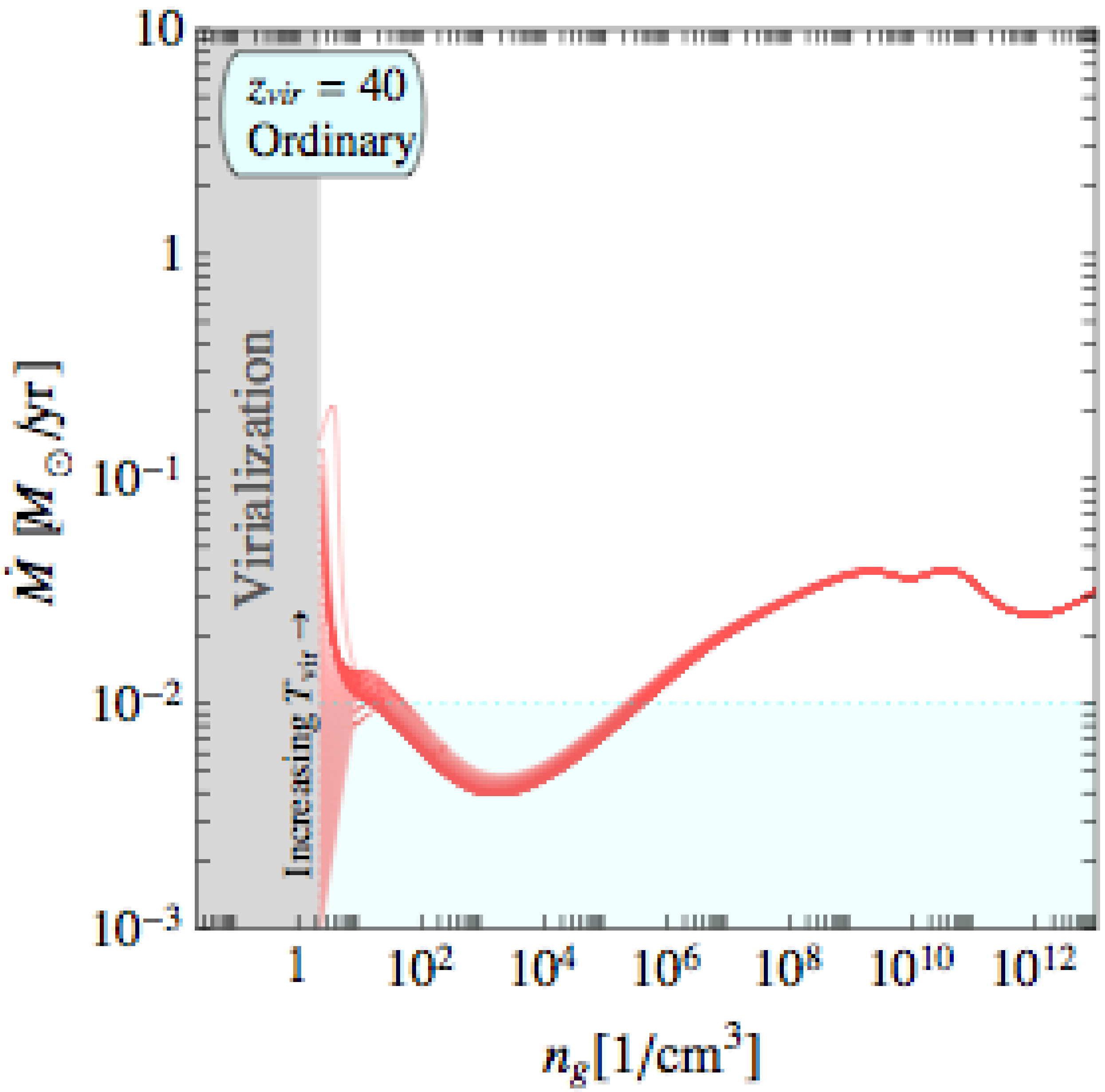
- A naïve possibility:
  Conditions at turnaround of a spherical perturbations
  This doesn't work, as the mirror is *insanely* cold — one would get crazy densities and temperature out of nowhere

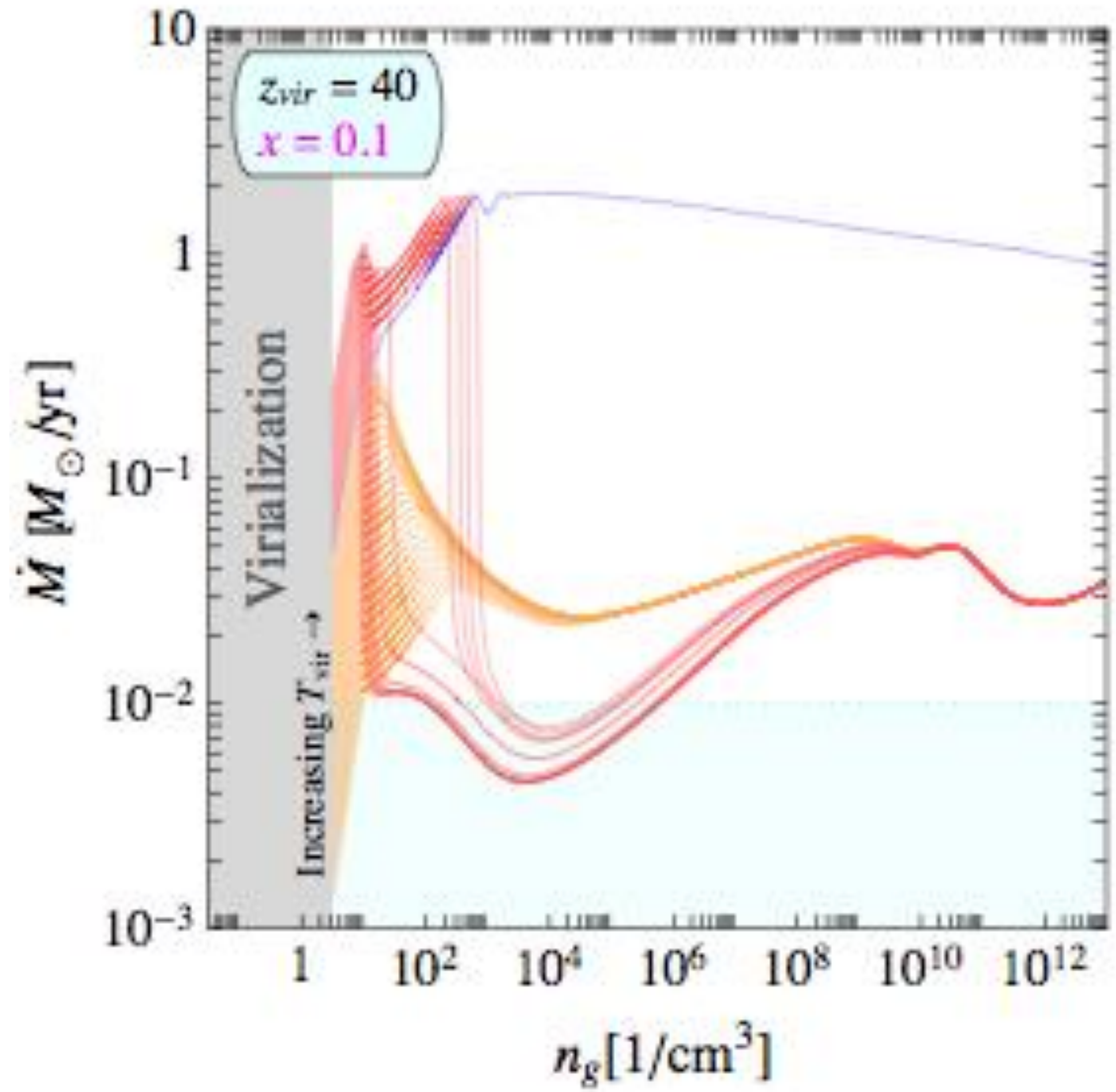
- Take into account virial shock:
  At ~half the turnaround radius, baryons realize they can dissipate, and the final result is a subsonic shock, bringing the density to ~178 times bkg density, and the temperature to $(\gamma-1)\ T_{vir}$

The poor men's solution: phase space

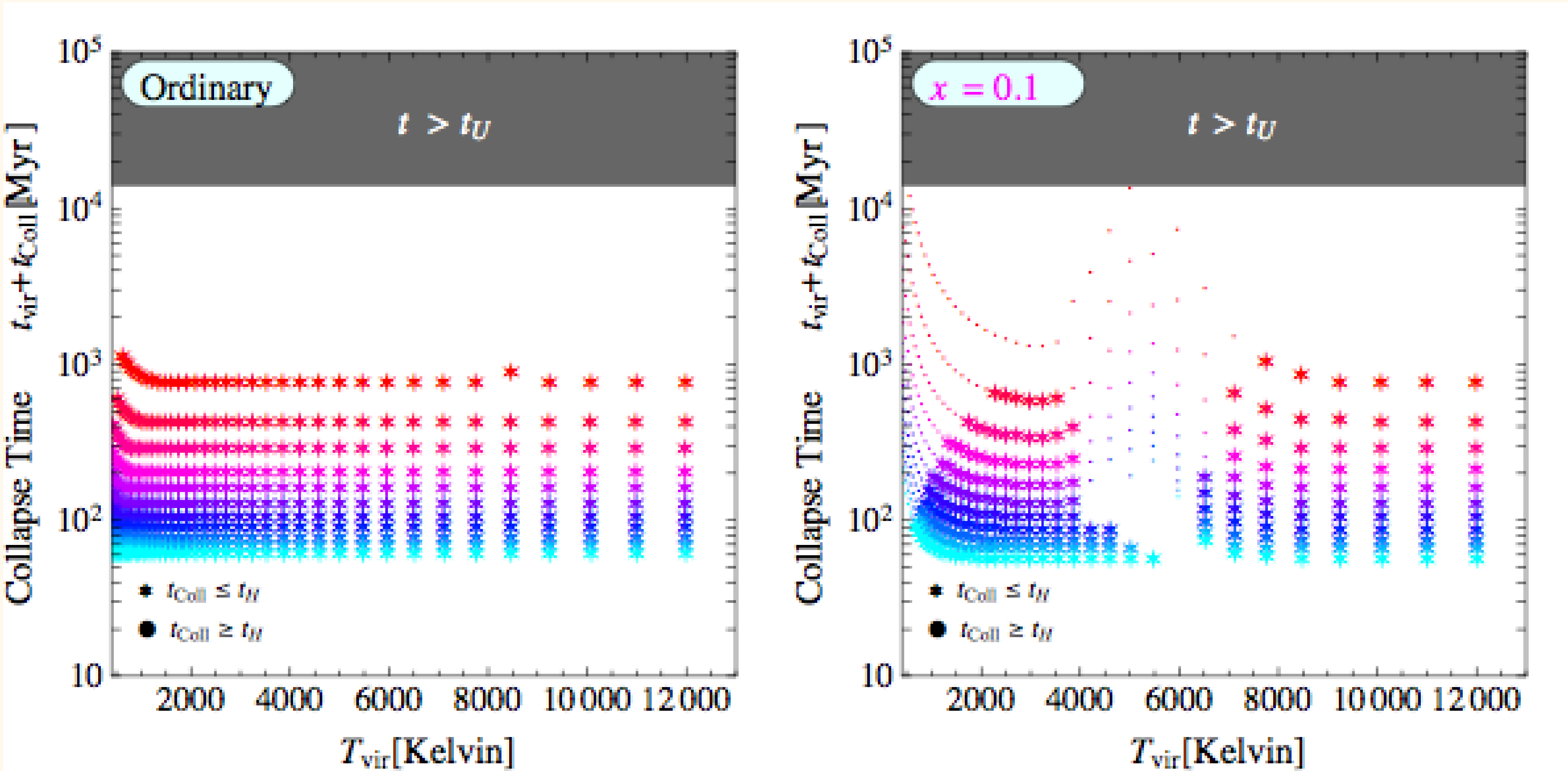


The poor men's solution: accretion





The poor men's solution: time of collapse



Growing the seeds

- In first approximation, we have Salpeter growth

$$M(t) = M_0 e^{(t-t_0)/t_{\rm Sal}} \qquad t_{\rm Sal} = \frac{\epsilon M c^2}{(1-\epsilon)L} \simeq 400\mathrm{Myr}\,\frac{\epsilon}{1-\epsilon}\,\frac{L_{\rm Edd}}{L}$$

- Age of the Universe at z=7 is 771Myr, no time to grow a stellar mass seed
- Need long times at maximum accretion to grow a ~ 10^8 $M_\odot$ seed in ordinary scenario
- However, we have 2 *independent* matter sectors: timescale in the exponential is typically halved!

Redshift vs Time

z = 0	t = 13721 Myr
z = 0.1	t = 12411 Myr
z = 0.5	t = 8628 Myr
z = 1	t = 5903 Myr
z = 3	t = 2171 Myr
z = 7	t = 771 Myr
z = 10	t = 478 Myr
z = 20	t = 180 Myr
z = 30	t = 100 Myr
z = 40	t = 65.65 Myr
z = 50	t = 47.15 Myr
z = 100	t = 16.63 Myr
z = 1100	t = 0.37 Myr

What does this all mean?

- Averaged results are very encouraging
- Phase space behavior and dM/dt are nice symptoms of a runaway direct collapse to black holes
- Accretion is larger than in ordinary sector, so we do expect IMBH seeds to grow into the observed SMBH

Where do we go from here?

- Interesting particle physics models:
  not necessary to have full mirror sector, for instance dark hydrogen with large binding energy

- Definitely the scenario is worth investigating with full cosmological simulations

- Qualitative predictions:
  stellar dynamics
  bullet clusters mass distribution
  microlensing
  GW probes from mergers (LISA)
  (killing of dinosaurs)

Thank you!