Spherical Accretion of self-gravitating dark matter onto a black hole with back-reaction

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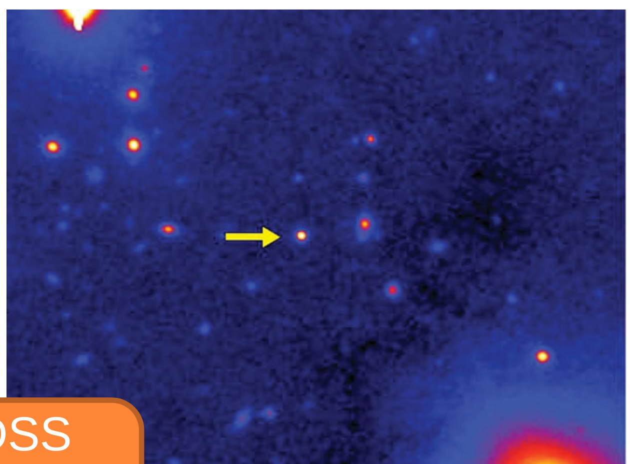
The problem with Supermassive Black Holes

- If accretion of baryonic matter can under the best circumstances produce BH the size of ~ 10^9 solar masses in 1.6 Gyr, why do we see them at redshift values of z = 6.4 or ~ 0.85 Gyr?
- Anti-hierarchical appearance of these SMBH.
- Quasars observed today much closer to us don't get much bigger. So it's fair to assume that they haven't grown much since.



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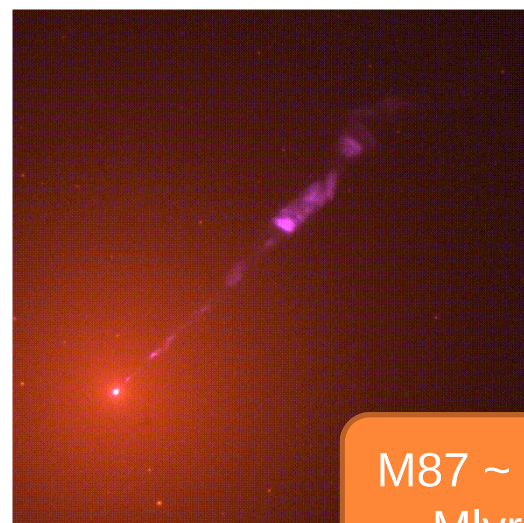


M87 ~ 55 Mlyr

Symbiotic scenario to the rescue

- The fix to this problem was proposed by symbiotic scenario where large degenerate clouds of sterile neutrino dark matter were accreted by stellar mass seed BH

MC Richter, GB Tupper, RD Viollier JCAP 0612:015 (2006) (astro-ph/0611552)

- The timeframe problem and early maturation of the larger quasars can be explained with this classical picture as accretion time is reduced to

Reworking the problem with GR

- Classical picture showed such a favourable explanation for the observed accretion timescale and hierarchy problem

- Accretion of sterile neutrino ball of mass $M = 3 \times 10^9$ solar masses shown to occur in ~ 840 Myr

- However, classical theory breaks down for such large masses!

→ attempt the full-blown GR treatment

THE ACCRETION PROCESS GOES A LITTLE SOMETHING LIKE THIS…

- The classical Bondi accretion picture has a large accreting BH surrounded by a thin shell of negligible mass → also called accretion of the "test fluid"

- This won't work, since for our picture we require a small seed BH at the center of a vast cloud of dark matter, which is subsequently accreted

  → Schwarzschild metric isn't the complete picture

- The effect that the massive surrounding material has on the spacetime and hence the flow and accretion rate is called the **backreaction due to the selfgravity of the DM.**

- Since this backreaction has not been studied extensively, its effect on the physical aspects of the fluid flow are not well known.

For that to work, we need Einstein's recipe

- Start with a the most general spherically symmetric line element

$$ds^2 = e^{\nu} dt^2 - e^{\lambda} dr^2 - r^2 \left(d\theta^2 + \sin^2\theta d\phi^2 \right) ,$$

where $v = v(r, t)$ and $\lambda = \lambda(r, t)$ then start adding the particular constraints to our system.

In fact, choose

$$e^{\lambda} = \frac{1}{1 - \frac{2GM}{r}},$$

where $M = M(r, t)$.

choosing our observer at infinity

$$T_{\mu}^{\ \nu} = (\rho + P)\, U_{\mu} U^{\nu} - \delta_{\mu}^{\ \nu} P.$$

$$U^0 = \frac{e^{-\nu/2}}{\sqrt{1 - v^2}}\ ,\ U^r = -\frac{v e^{-\lambda/2}}{\sqrt{1 - v^2}}.$$

equations

$$\dot{\rho} = \dot{P} = 0$$

$$\dot{v} = 0$$

mix in a little bit of perfect fluid

require a stationary flow model

MORE DETAIL…

- Leads to the generalised accretion equations

$$\frac{dM}{dr} = 4\pi r^2 \left(\frac{\rho + v^2 P}{1 - v^2}\right),$$

$$\frac{dM}{dt} = 4\pi r^2 (\rho + P) \frac{v}{1 - v^2}\sqrt{1 - \frac{2GM}{r}}\, e^{\nu/2};$$

$$\frac{1}{2}\frac{d\nu}{dr} = \frac{G}{r^2}\left[\frac{M + 4\pi r^3 \left(\frac{P + v^2\rho}{1 - v^2}\right)}{1 - \frac{2GM}{r}}\right],$$

$$\frac{vv'}{1 - v^2} + \frac{P'}{\rho + P} + \frac{G}{r^2}\left(\frac{M + 4\pi r^3 P}{1 - \frac{2GM}{r}}\right) = 0.$$

Analogue of gravitational potential

has similarities to Bondi models

generalised TOV equation

- Can be solved numerically once an equation of state is chosen

EQUATION OF STATE "MENU"

- Polytropic equations of state:

$$P = w\rho$$

Speed of sound in the fluid c_S^2

where w = 1 (stiff matter) or w = 1/3 (radiation).

- Relativistic Fermi Gas:

$$P = k\left\{x\left(1+x^2\right)^{1/2}\left(2x^2/3-1\right)+\ln\left[x+\left(1+x^2\right)^{1/2}\right]\right\},$$

$$\rho = \frac{k}{c^2}\left\{x\left(1+x^2\right)^{1/2}\left(2x^2+1\right)-\ln\left[x+\left(1+x^2\right)^{1/2}\right]\right\}$$

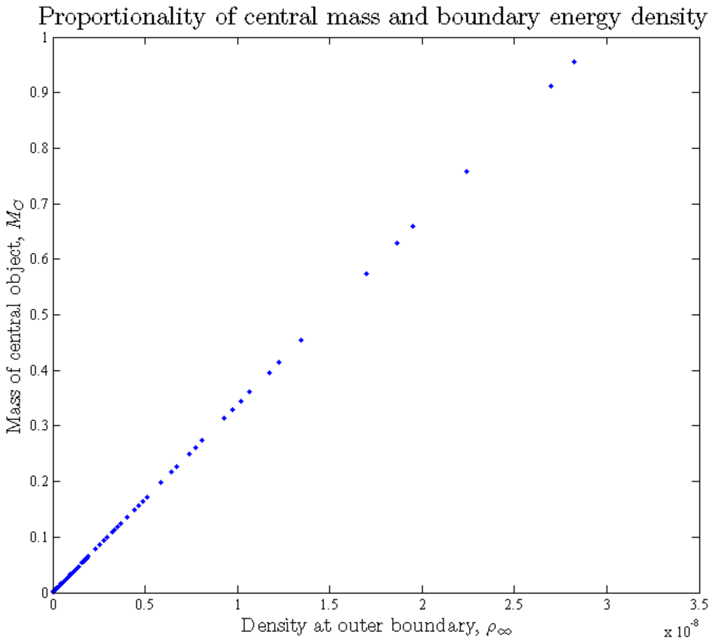
Non-dimensional Fermi Momentum

CHARACTERISTICS OF THE ACCRETION

- The stiff matter case agrees well with analytical solutions
  → shows no transonicity ($c_S^2 = c$), hence no shock in the flow.

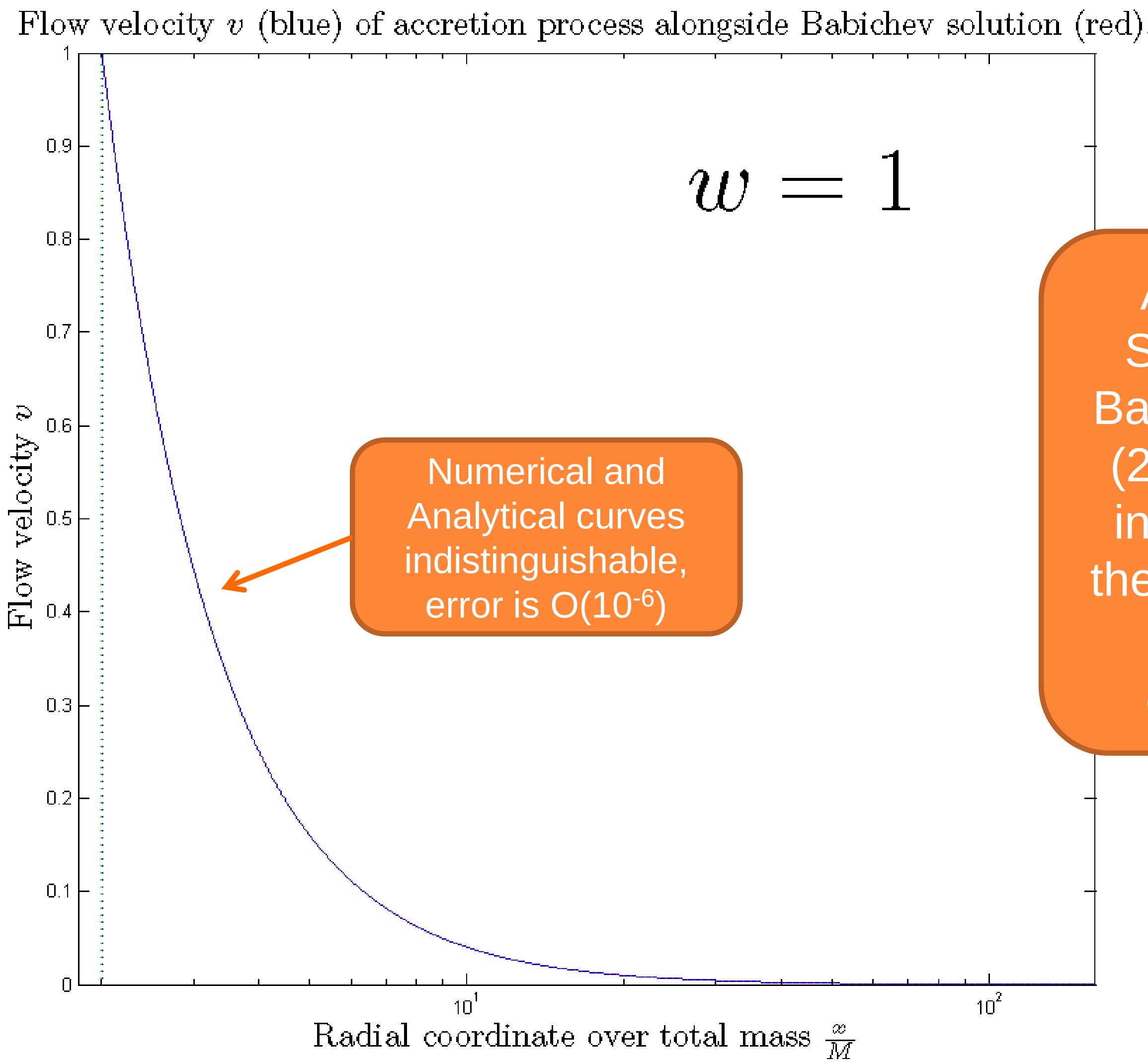
- For the polytrope *w* = 1/3, we see shock in the flow around the critical point that is consistent with transonic flow analysis (such as F.C. Michel and S.L. Shapiro and S.A. Teukolsky)

- Mass of central object determined by IC density at the outer boundary



SOLVING THIS NUMERICALLY

- Stiff matter EoS

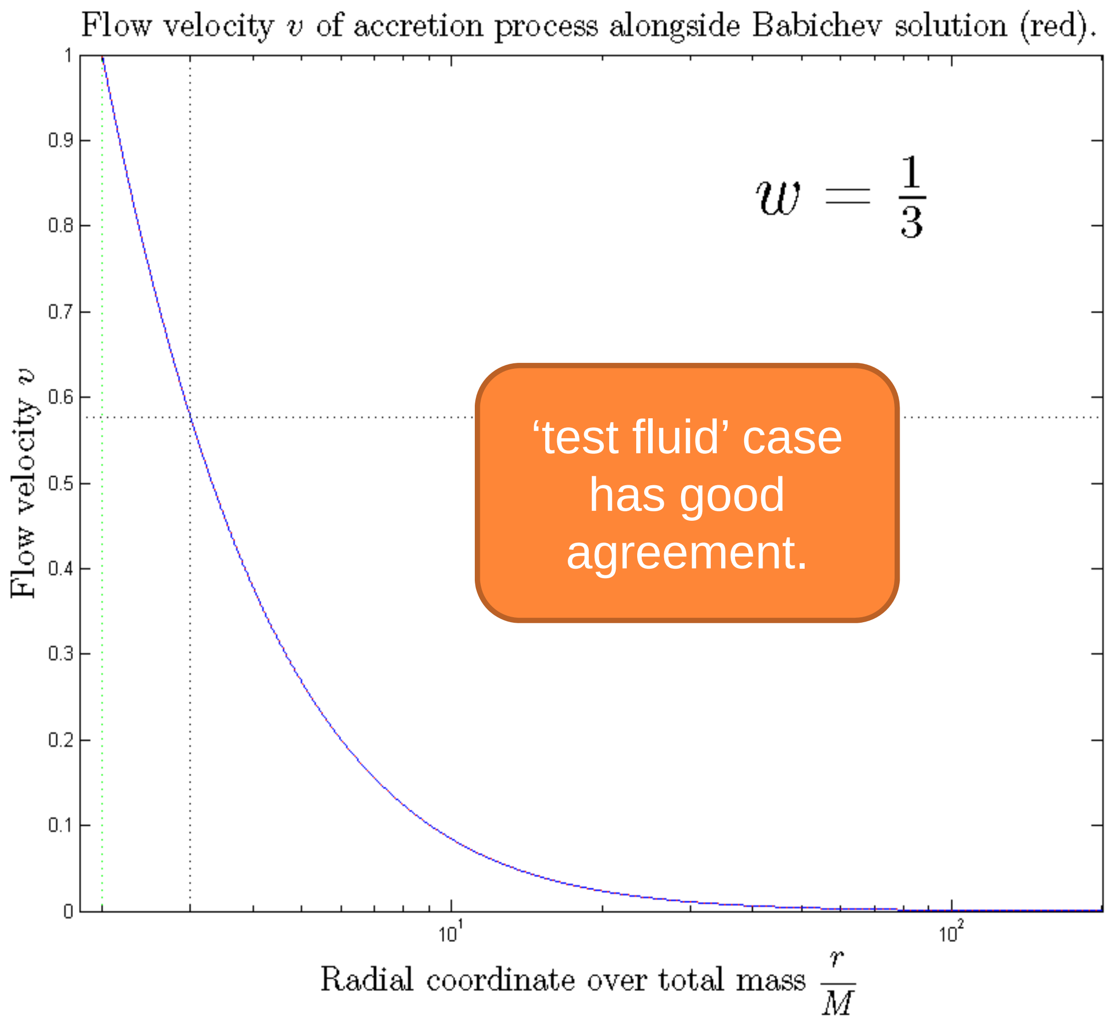


Numerical and Analytical curves indistinguishable, error is $O(10^{-6})$

Analytical Solution by Babichev et al (2004) takes into account the Bondi type test fluid accretion

SOLVING THIS NUMERICALLY

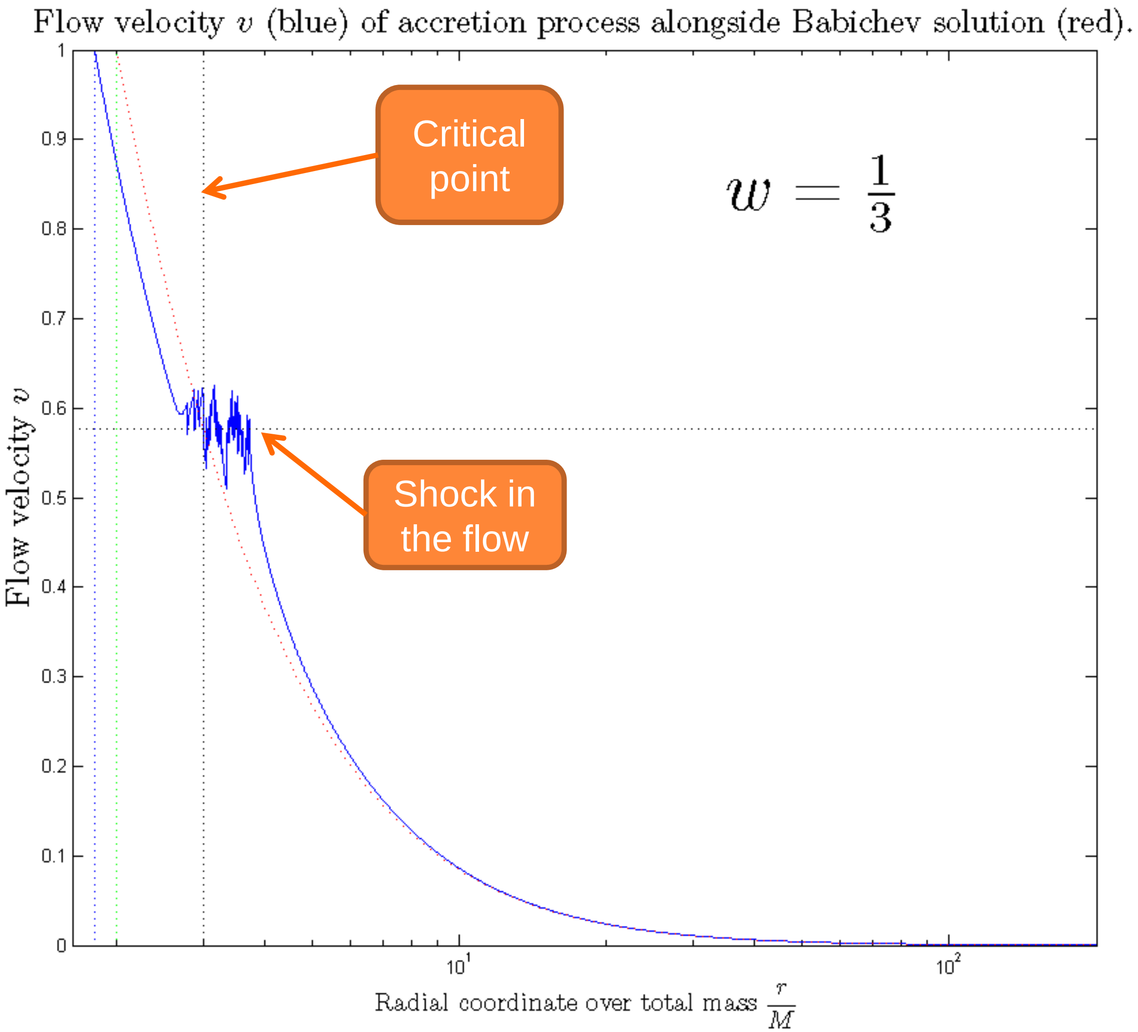
- Radiation EoS



Solving this numerically

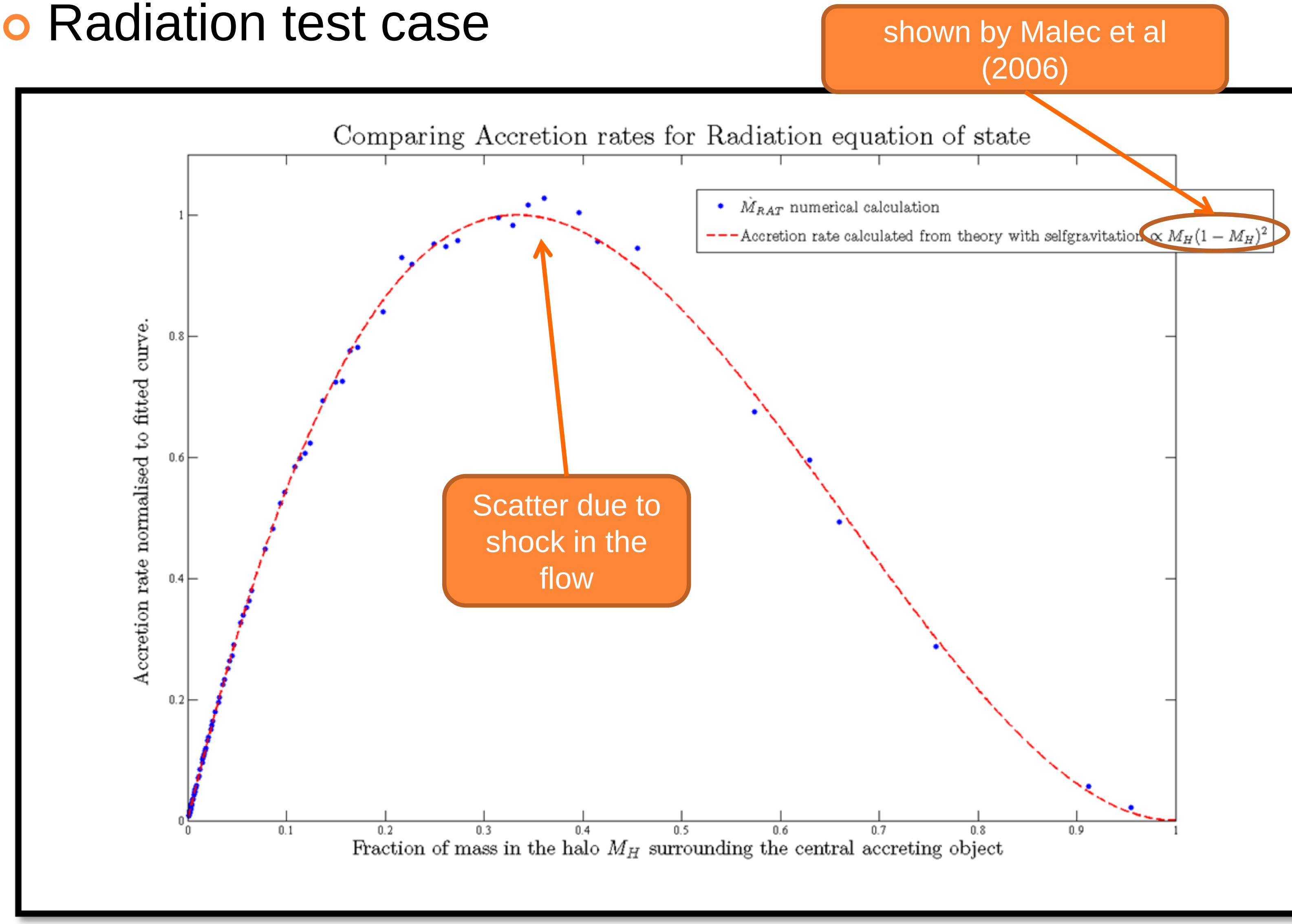
- Radiation EoS

When we move away from small halo case.



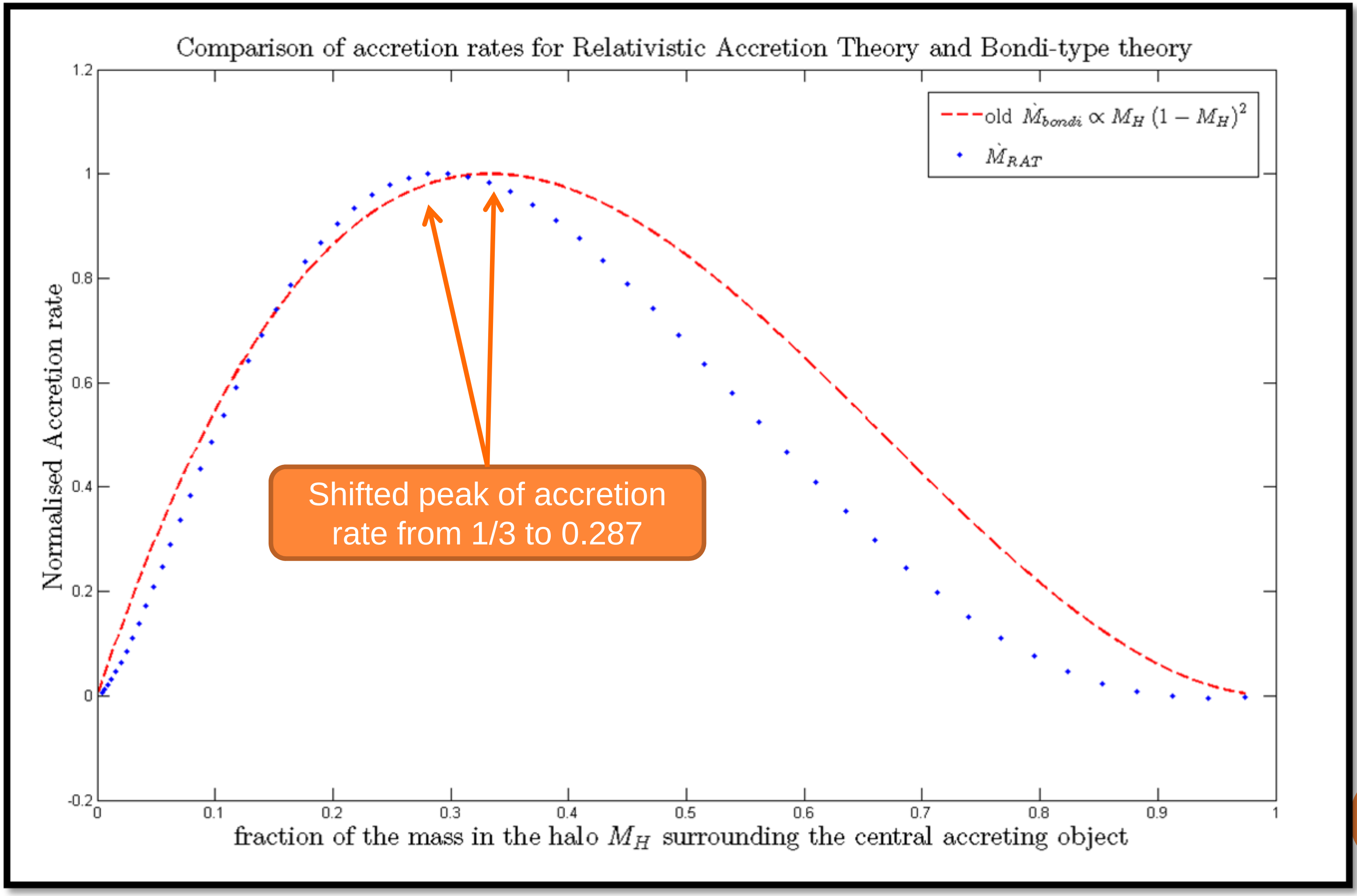
SOLVING THIS NUMERICALLY

- Radiation test case



Solving this numerically

- Relativistic Fermi Gas



IN CONCLUSION

- The model agrees with analytical solutions of Bondi-type accretion in the “test-fluid” limiting case as set out by Babichev et al (2004), while giving a feasible picture for accretion with back-reaction.
- Model with the polytropic EoS also agrees with other selfgravitating models of accretion such as Malec et al (2006).
- Easily accommodates the case of relativistic Fermi gas accretion to accurately describe sterile neutrino dark matter accretion including the effect of selfgravitation.

  → warrants further calculations

Thank You!