BLACK HOLE FEEDBACK AND THE M-σ RELATION IN NON-ISOTHERMAL GALAXIES

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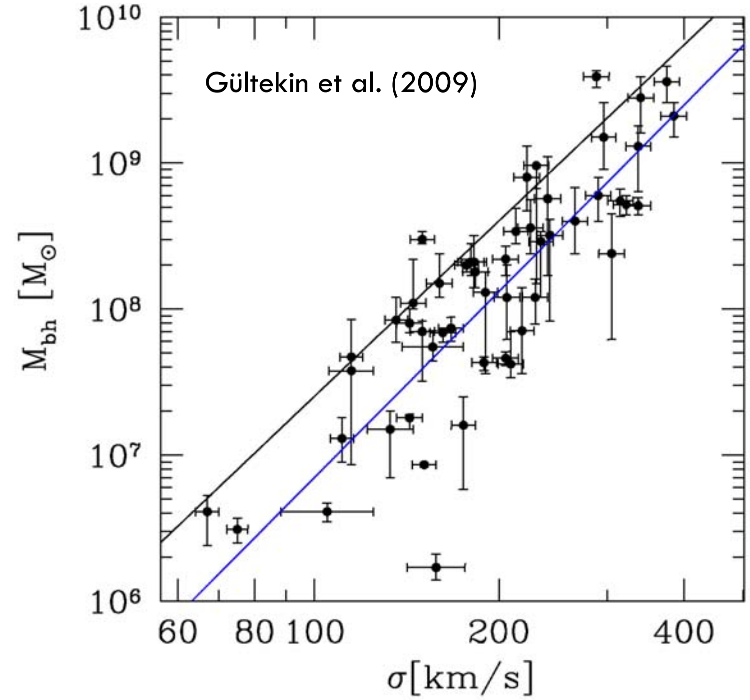
R. C. McQuillin & D. E. McLaughlin (2011)

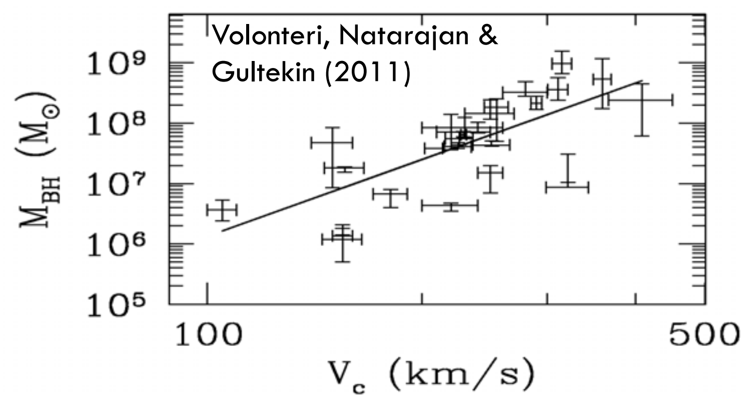
The M_{BH}-σ relation

- Tight correlation between SMBH mass and host galaxy velocity dispersion.
- Result of momentum driven feedback
- Singular isothermal sphere:

$$M_{crit} = \frac{f_0 \kappa}{\pi G^2} \sigma_0^4 = 4.5 \times 10^8 \sigma_{200}^4 M_{sun}$$

(King 2005, 2010)





The M_{BH}-I ???? ??

- Open issues:
  - Switch to energy driven,
  - Additional momentum input from bulge star formation (Murray et al. 2005; Power et al. 2010),
  - Escape speed (Silk & Nusser 2011)
  - Real haloes are not isothermal
    - What is I $_X$????O?
    - ?? ??????????????? ????σ??? $_{??}$ σ?-?? $_?$O
- Here:
  - First revisit SIS,
  - Look at non-isothermal haloes,
  - Natural characteristic dispersion is $\sigma_0 = V_{c,pk}/\sqrt{2}$
  - Show that (McQuillin & McLaughlin 2011)

$$M_{crit} \equiv \frac{f_0 \kappa}{\pi G^2} \frac{V_{c,pk}^4}{4}$$

for *ANY* halo, for purely momentum-driven feedback.

Equation of motion

- In general we have

$$\frac{d}{dt}\left[M_g(r)\ v\right] = \frac{L_{Edd}}{c} - \frac{GM_g(r)}{r^2}\left[M_{BH} + M_{DM}(r)\right]$$

with $L_{Edd} = \dfrac{4\pi G M_{BH} c}{\kappa}$, (as in King & Pounds 2003)

- Then let $M_g(r) = f_0 h(r) M_{DM}(r)$

$$\frac{d}{dr}\left[M_{DM}^2(r)h^2(r)v^2\right] = \frac{2h(r)M_{DM}(r)L_{Edd}}{f_0 c} - \frac{2M_{DM}^2(r)h^2(r)}{r^2}\left[M_{BH} + M_{DM}(r)\right]$$

so solving for $v^2(r)$

Singular isothermal sphere:

T e x r SMA G

- Solution: $$v^2 = 2\sigma_0^2\left[\frac{M_{BH}}{M_{crit}} - 1\right] - \frac{2GM_{BH}}{r} + \frac{C}{r^2}$$

where $M_{crit} = \frac{f_0\kappa}{\pi G^2}\sigma_0^4$, as defined by King (2005, 2010)

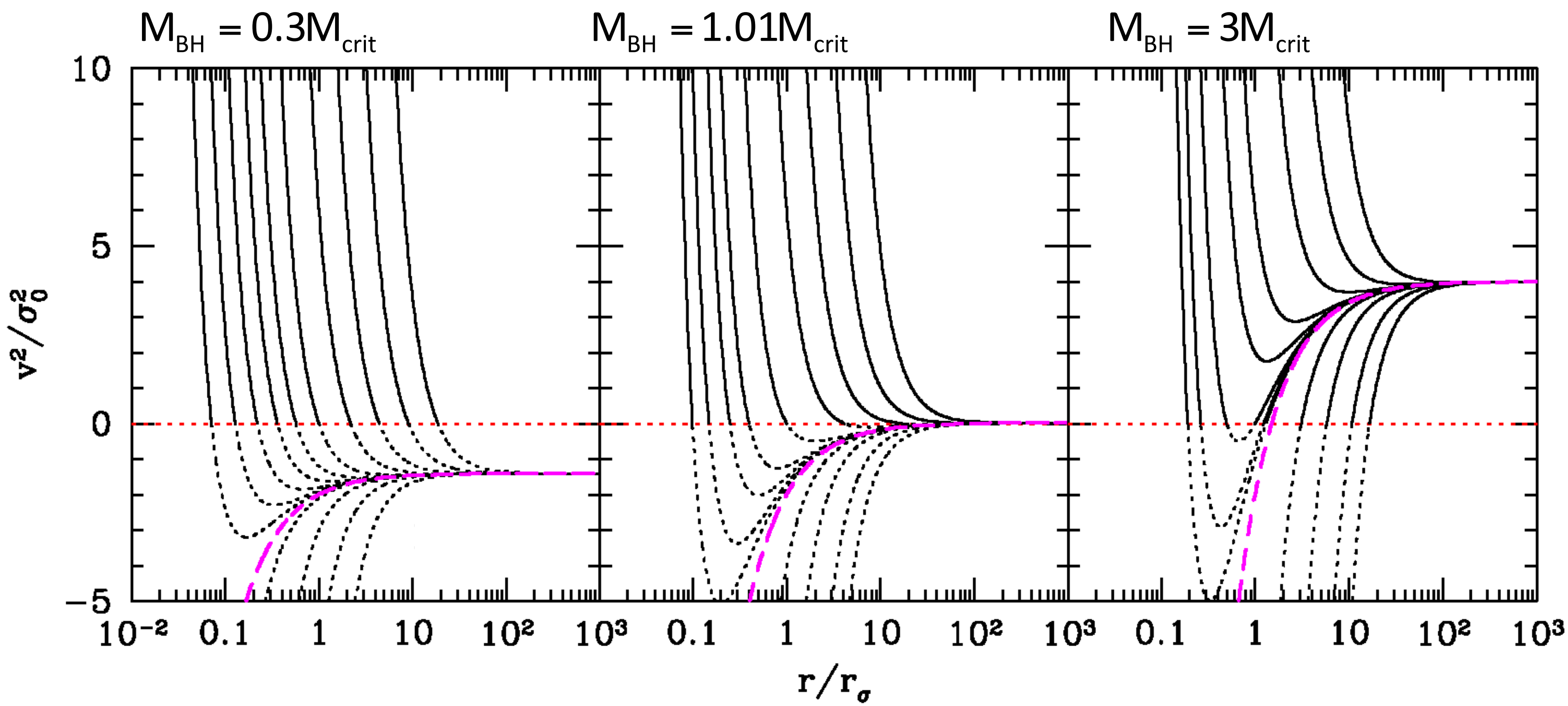
- Only physical if $v^2 > 0$
- At large radius this requires

$$M_{BH}/M_{crit} > 1$$

- In detail, though necessary, this is not sufficient for escape

Singular isothermal sphere:

$\rho_{DM} = \sigma_0^2 / (2\pi G r^2)$



$r_\sigma \approx 50 \text{ pc } \sigma_{200}$

$$M_{crit} \equiv \frac{f_0 \kappa}{\pi G^2} \frac{\sigma_0^4}{4} = 4.5 \times 10^8 \sigma_{200}^4 M_{sun}$$

Non-isothermal haloes

McQuillin & McLaughlin (2011)

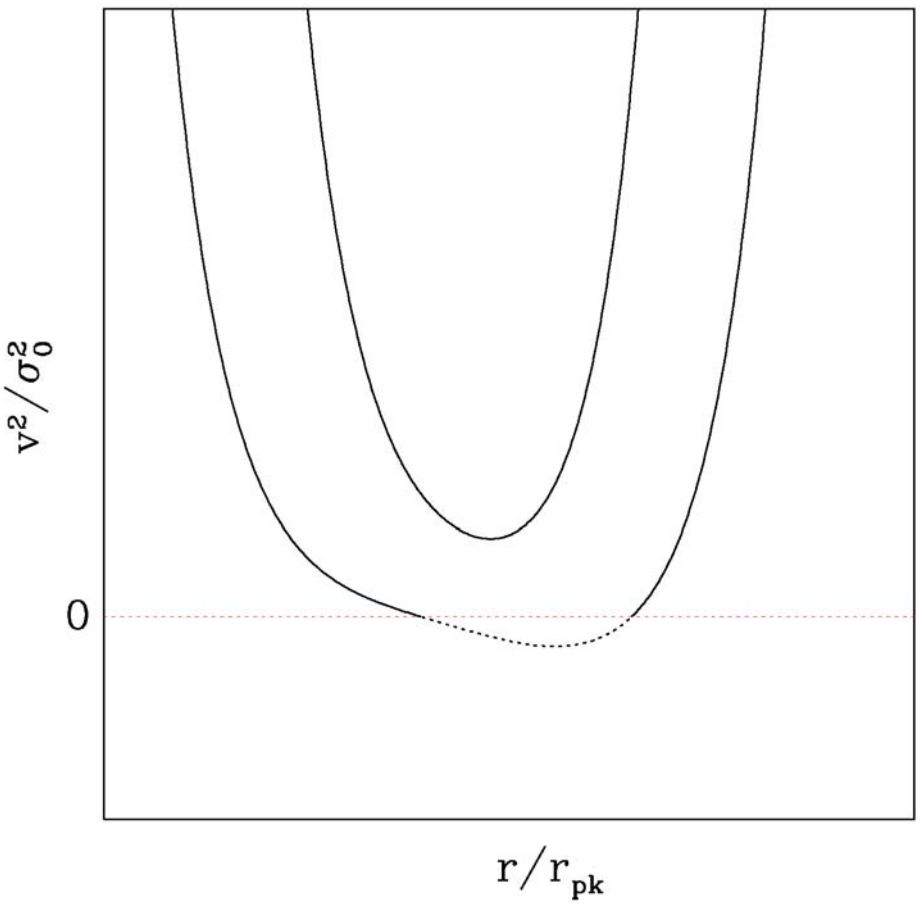
- Small radius: $\rho(r) \propto r^{-\alpha}, \ \alpha \approx 1$
- Large radius: $\rho(r) \propto r^{-\beta}, \ \beta \geq 3$

e.g. Hernquist $(\alpha,\beta) = (1, 4)$, Dehnen & McLaughlin $(7/9, 31/9)$.

- V_c^2 increases outwards, peaks, then decreases outwards, so $\sigma_0 = V_{c,pk} / \sqrt{2}$
- Implies shell decelerating at small radius and accelerating at large radius.
- Must be a minimum in $v^2(r)$ at some point between.

Non-isothermal haloes

McQuillin & McLaughlin (2011)



- Can have purely momentum-driven escape if minimum $v^2 > 0$.

Non-isothermal haloes

McQuillin & McLaughlin (2011)

- Can have momentum-driven escape if minimum $v^2 > 0$.
- Recall eq'n of motion

$$\frac{d}{dr}\left[M_{DM}^2(r)h^2(r)v^2\right] = \frac{2h(r)M_{DM}(r)L_{Edd}}{f_0 c} - \frac{2M_{DM}^2(r)h^2(r)}{r^2}\left[M_{SMBH} + M_{DM}(r)\right]$$

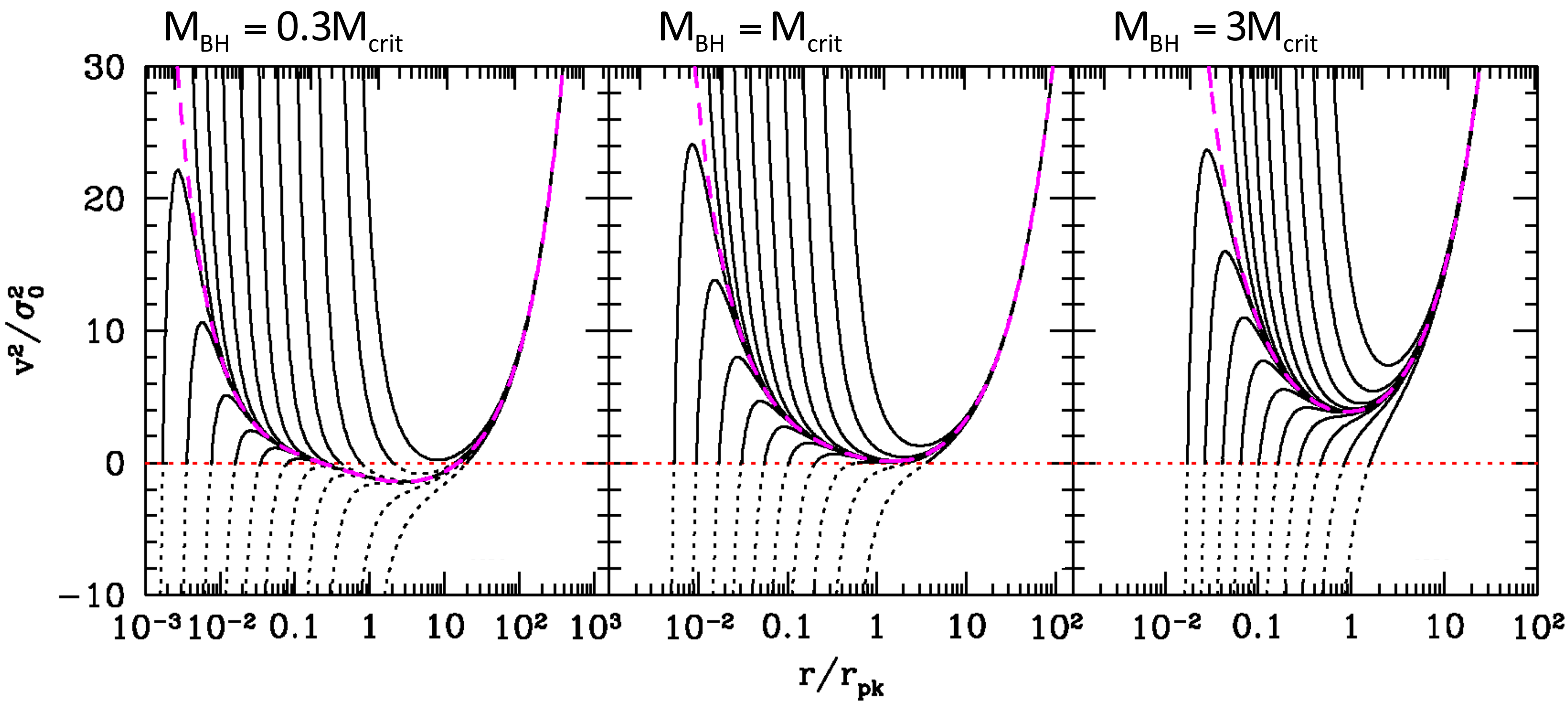
- We show analytically that minimum $v^2(r) > 0$ requires

$$M_{BH} \geq M_{crit} \equiv \frac{f_0 \kappa}{\pi G^2} \frac{V_{c,pk}^4}{4}$$

in *ANY* realistic non-isothermal halo

Navarro, Frenk & White (1996, 1997):

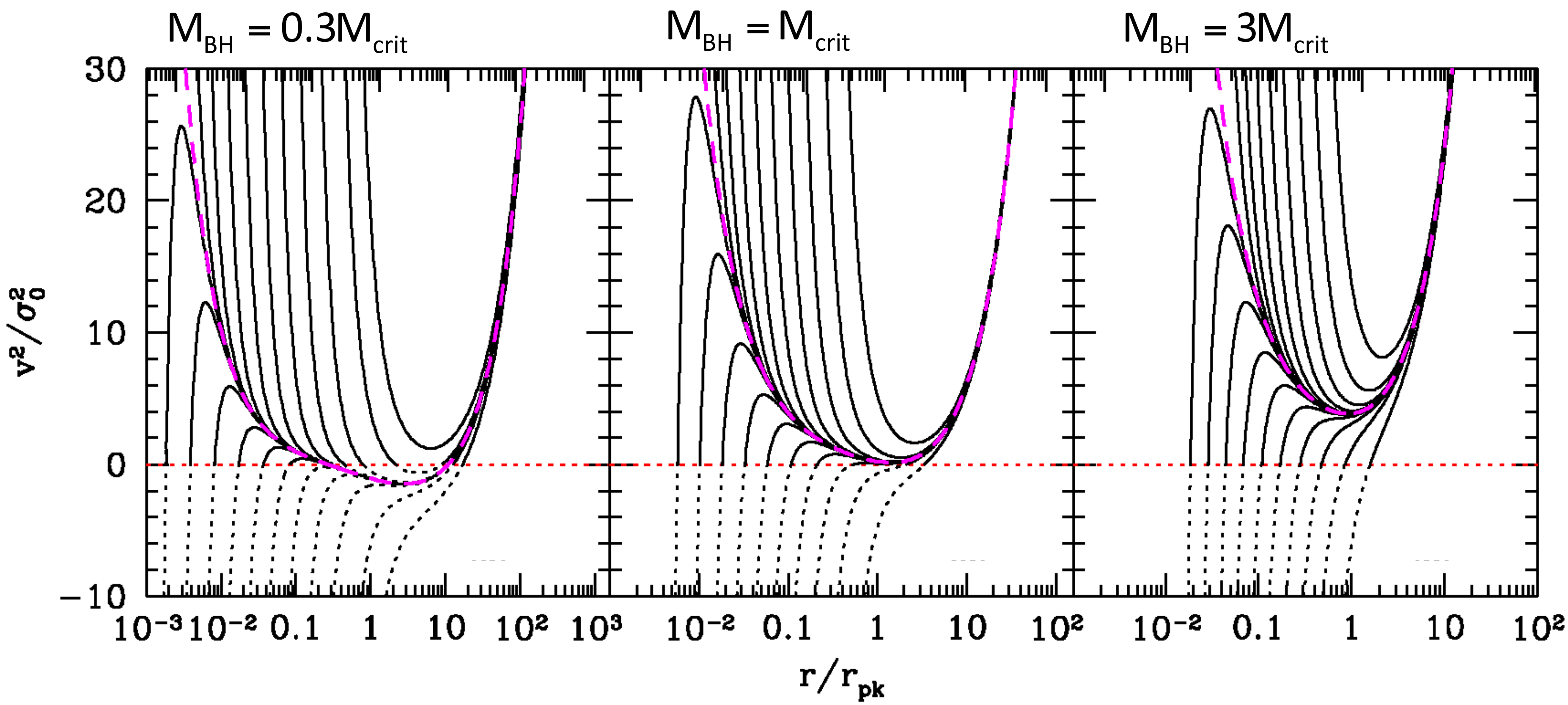
$$\rho_{DM}(r) \propto r^{-1}(r_0 + r)^{-2}$$



$$r_{pk} \approx 55\left(\frac{V_{c,pk}}{220\ \mathrm{km\ s^{-1}}}\right)\ \mathrm{kpc}$$

$$M_{crit} \equiv \frac{f_0 \kappa}{\pi G^2}\frac{V_{c,pk}^4}{4} \approx 1.7\times10^8 M_{sun}\left(\frac{V_{c,pk}}{220\ \mathrm{km\ s^{-1}}}\right)^4$$

Hernquist (1990): $\rho_{DM}(r) \propto r^{-1}(r_0 + r)^{-3}$



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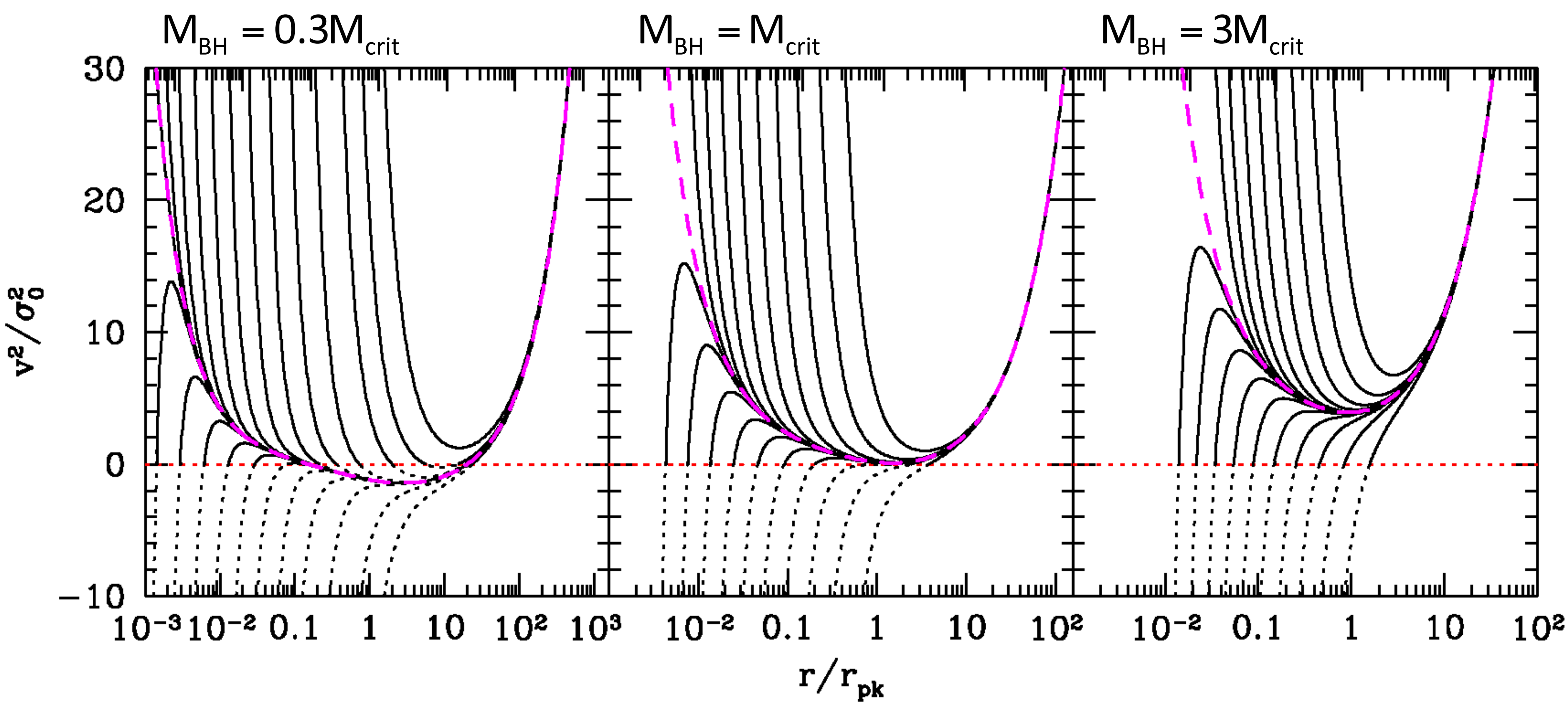
Dehnen & McLaughlin (2005):

$$\rho_{DM}(r) \propto r^{-7/9}\left(r_0^{\;4/9} + r^{4/9}\right)^{-6}$$



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Conclusions

- Found critical mass for any realistic halo:

$$M_{crit} \equiv \frac{f_0 \kappa}{\pi G^2} \frac{V_{c,pk}^4}{4}$$

where $\sigma_0 = V_{c,pk} / \sqrt{2}$ recovers the SIS condition (King 2005)

- SIS: $M_{BH} \geq M_{crit}$ is necessary but not sufficient for escape.
- Non-isothermal haloes: $M_{BH} \geq M_{crit}$ is sufficient for escape of shell,
- $M_{BH} < M_{crit}$ still and upper limit