Accretion wake of recoiled black holes

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Galaxy (black hole) mergers

BHs at the centre of many galaxies

Galaxy mergers

↓

BH mergers

↓

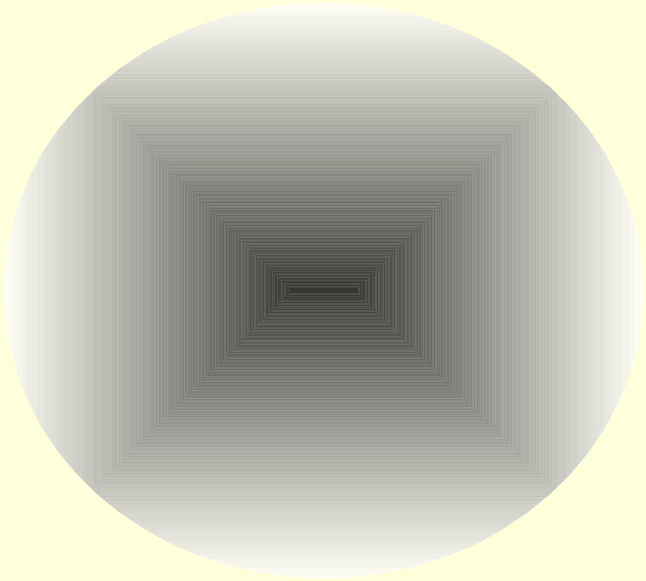
Emission of gravitational waves

↓

formation of a new central BH

Black hole & dark matter

Initially : $\rho_{initial} \sim r^{-\gamma}$

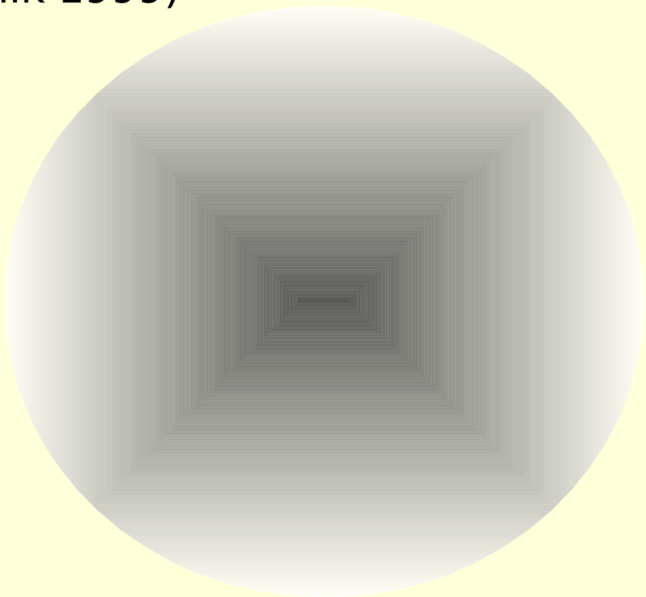


Adiabatic accretion:

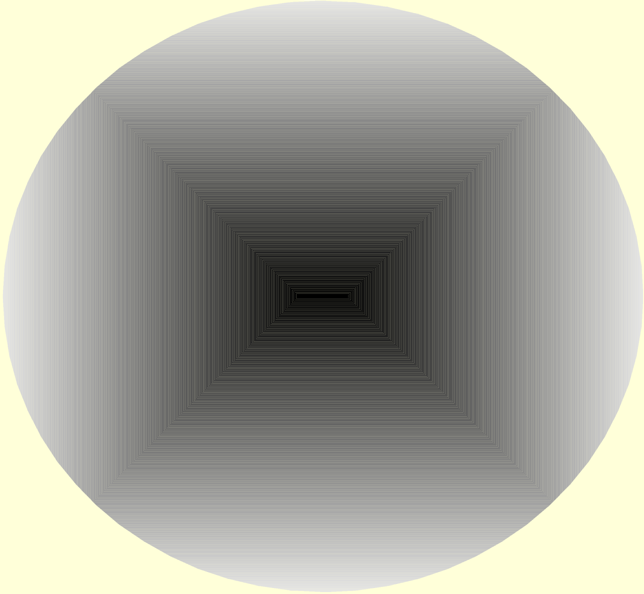
$$f_{final}(E_{final},L_{final}) = f_{initial}(E_{initial},L_{initial})$$

Black hole & dark matter

(Bahcall & Wolf 1977, Young 1980, Gondolo & Silk 1999)



Without BH : $\rho_{initial} \sim r^{-\gamma}$



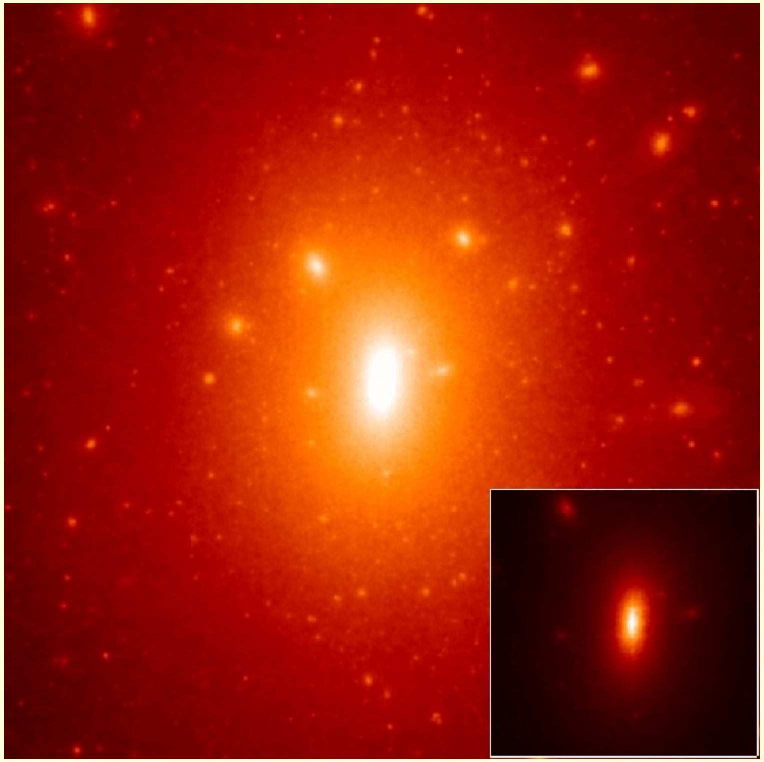
With BH : $\rho_{final} \sim r^{-(9-2\gamma)/(4-\gamma)}$

Absolute luminosity (L) of BH in γ-rays

$$\chi + \chi \longrightarrow \gamma$$

$$L = \text{luminosity factor} \times \int \rho^2 \, dV \qquad \gamma/s$$

$$\text{luminosity factor} = [N_\gamma \langle \sigma v \rangle / m_\chi^2] \qquad c^4/cm^3/s/Gev^2$$



10,000,000 particles
Stoehr et al 2003

Galaxy (black hole) mergers

BHs at the centre of many galaxies

Galaxy mergers

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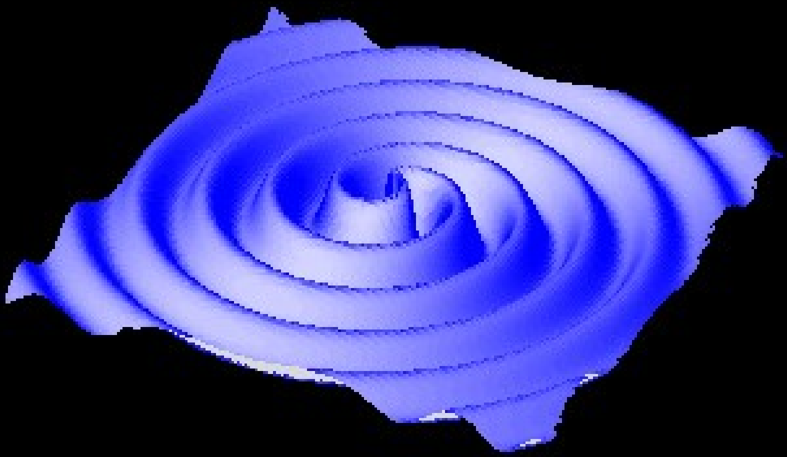
BH mergers

⇩

Emission of gravitational waves



⇩

If isotropic

⇩

formation of a new central BH

Galaxy (black hole) mergers

BHs at the centre of many galaxies

Galaxy mergers

BH mergers

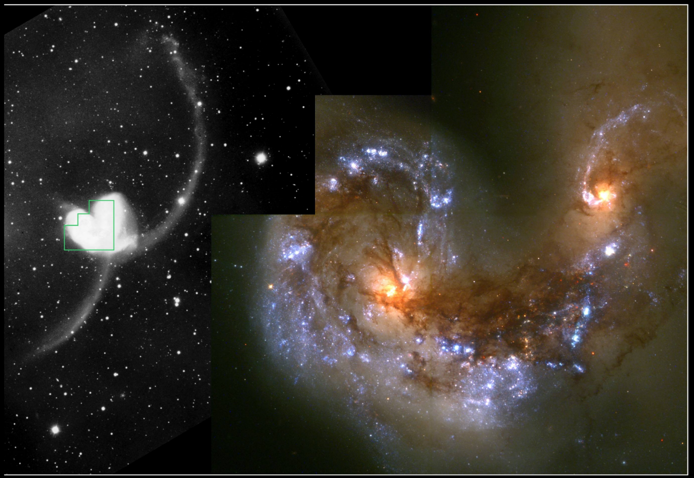
Emission of gravitational waves

If isotropic

formation of a new central BH

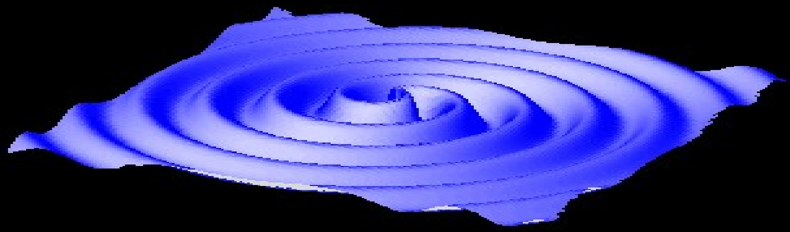
If anisotropic

Ejection of the BH From the galaxy

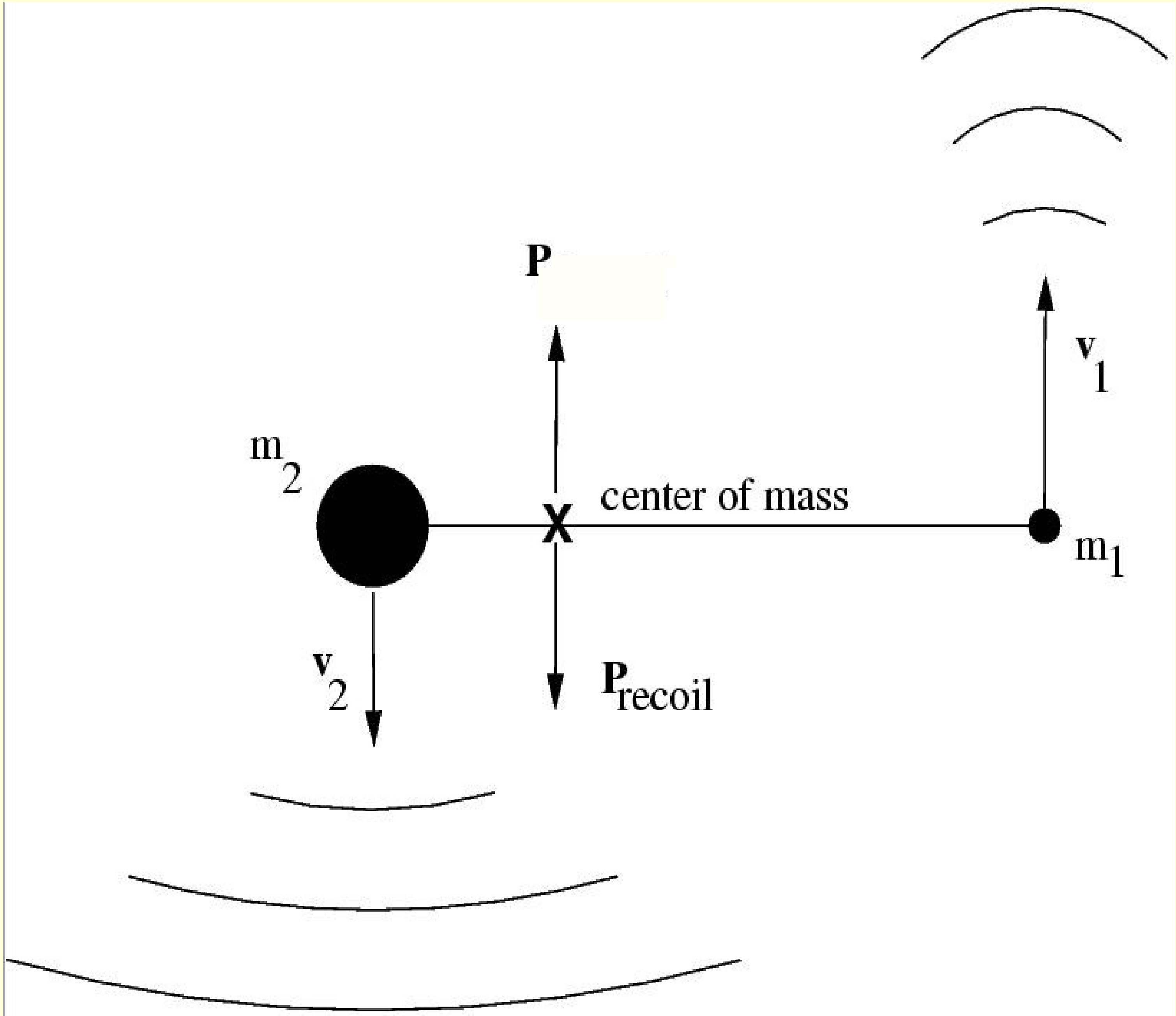


Colliding Galaxies NGC 4038 and NGC 4039
Hubble Space Telescope • Wide Field Planetary Camera 2

RC97-34a • ST ScI OPO • October 21, 1997 • B. Whitmore (ST ScI) and NASA

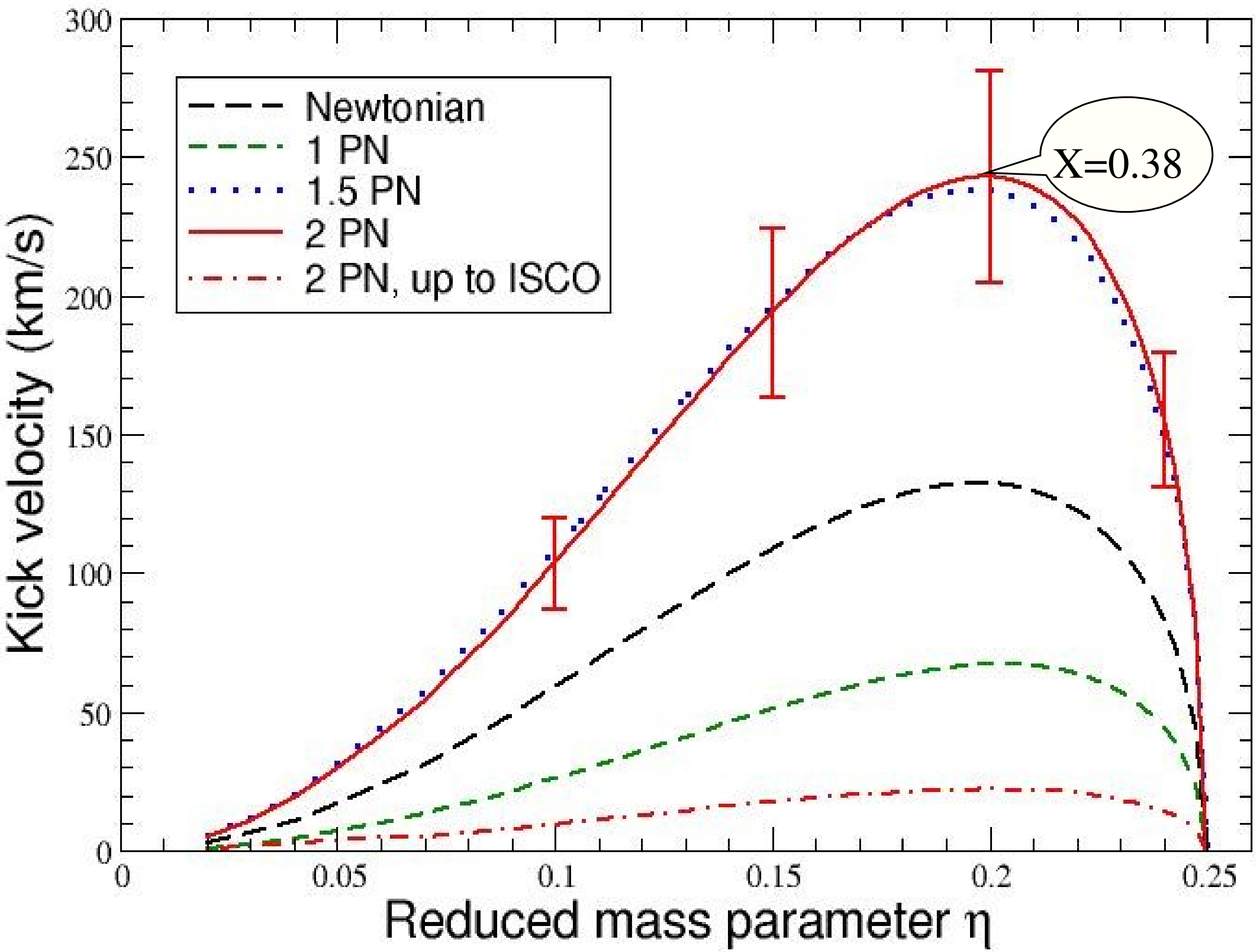


Ejection of a black hole during galaxies mergers



Ejection of a black hole during galaxies mergers

Spin=zero



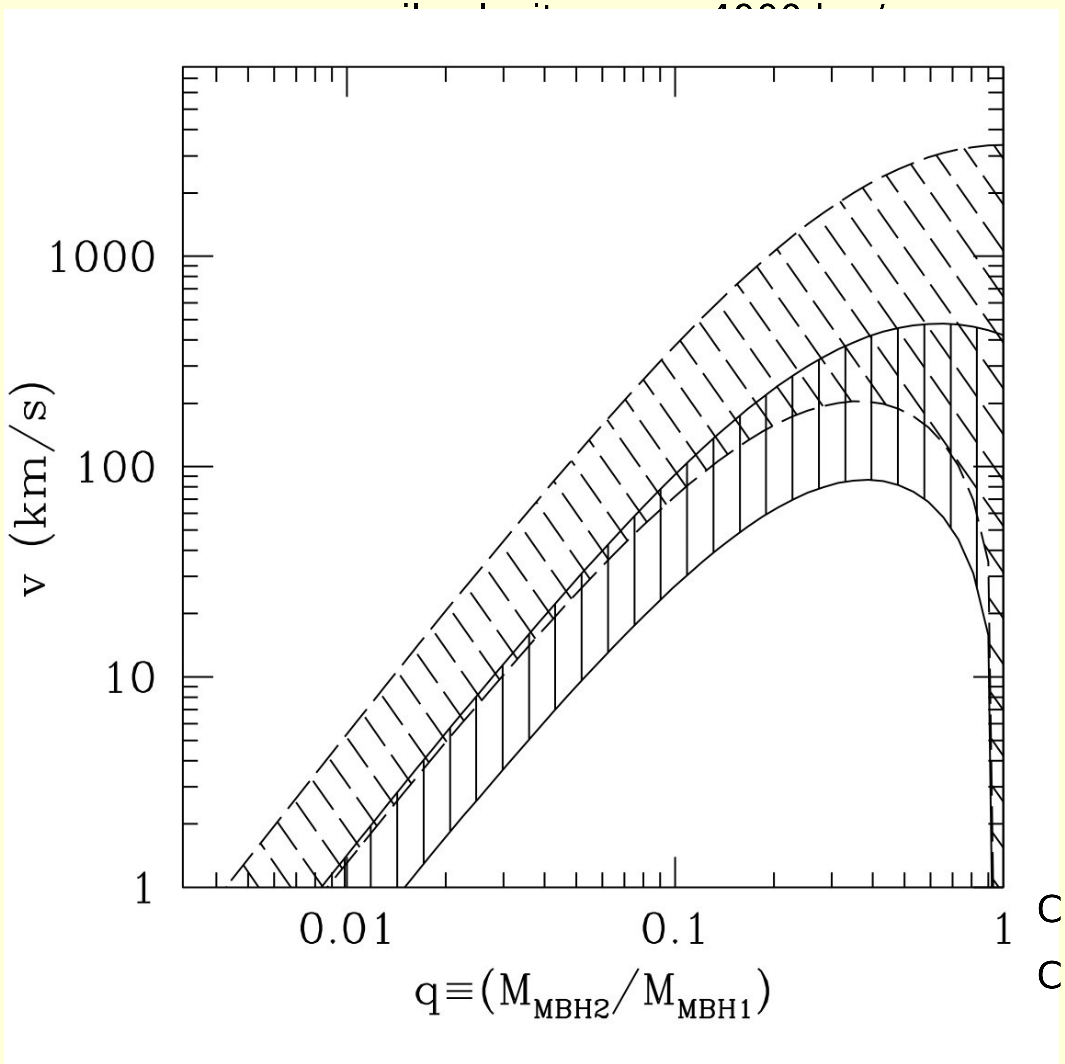
$h=\frac{m_1 m_2}{(m_1+m_2)^2}$

¿ $\frac{X}{(1+X)^2}$

Ejection of a black hole during galaxies mergers

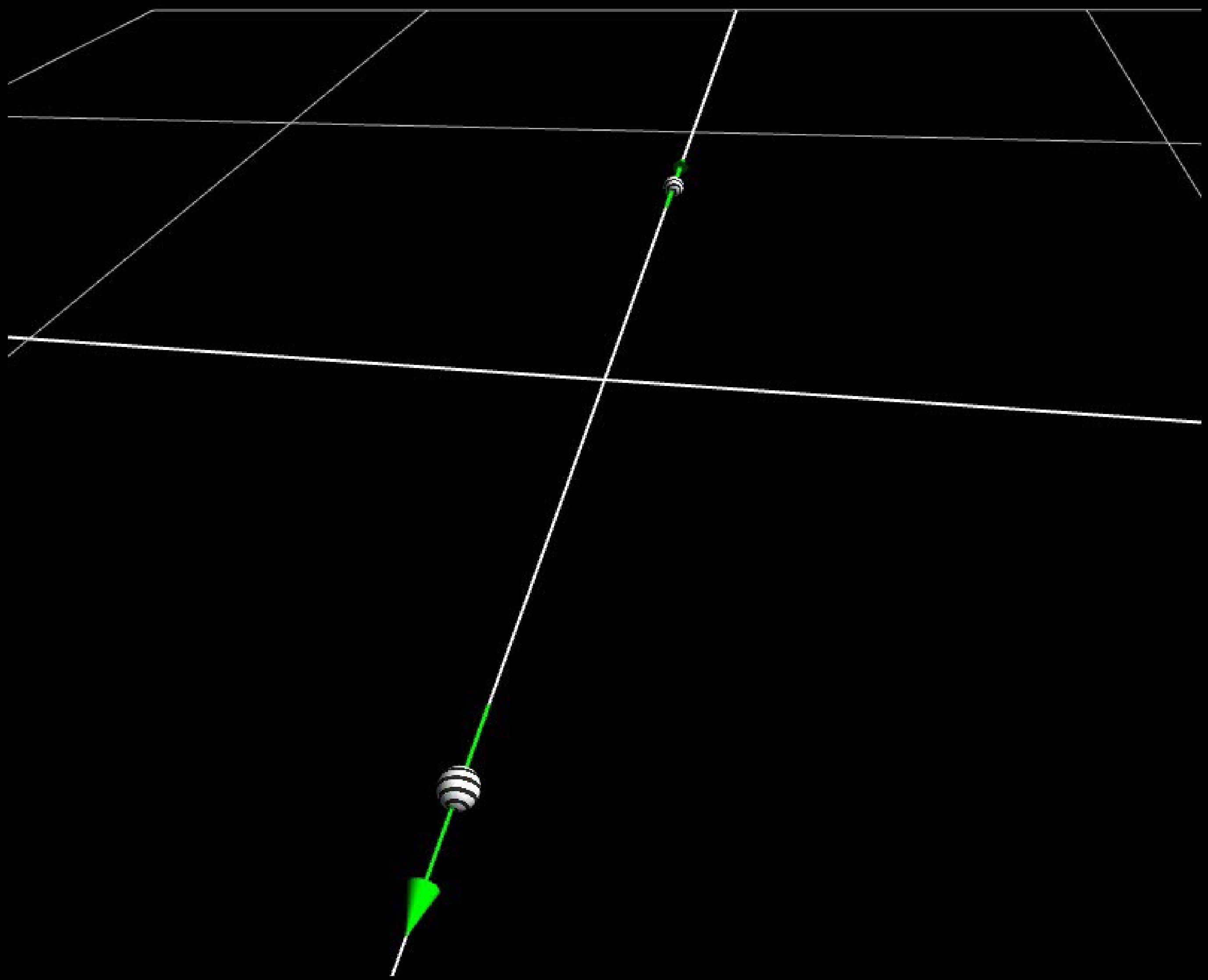
spin ≠ 0

⟶

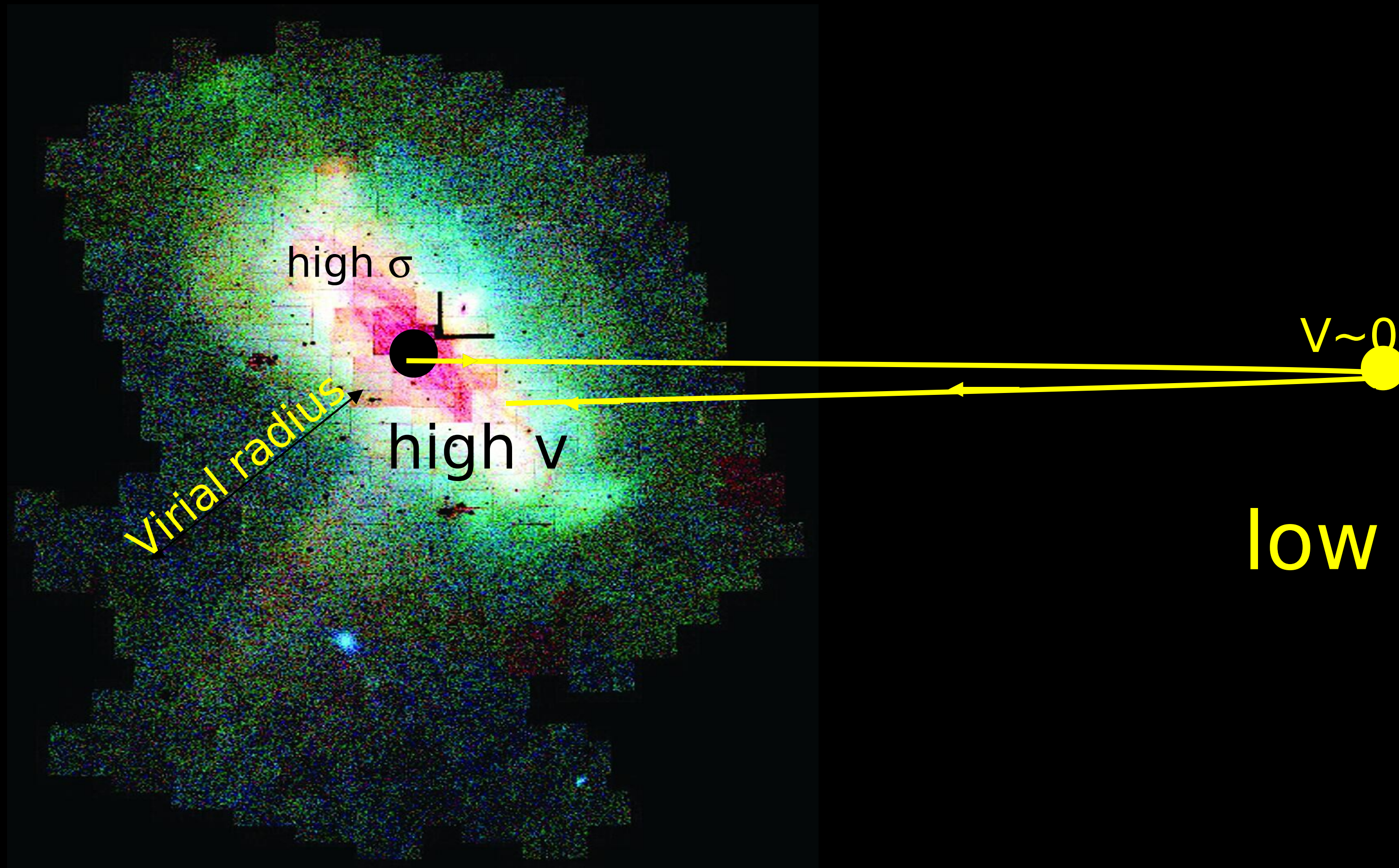


Campanelli et al 2007

Courtesy: volonteri 2007



Orbit of an ejected BH

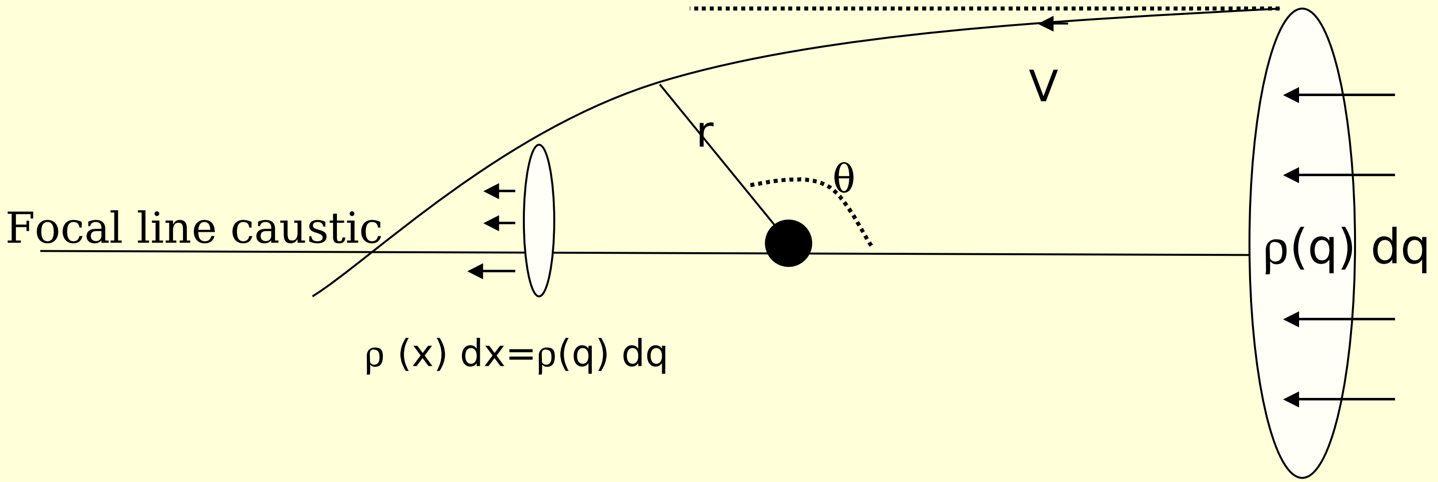


Density profile of the accretion wake

Cold medium >Bondi-Hoyle accretion (1944)

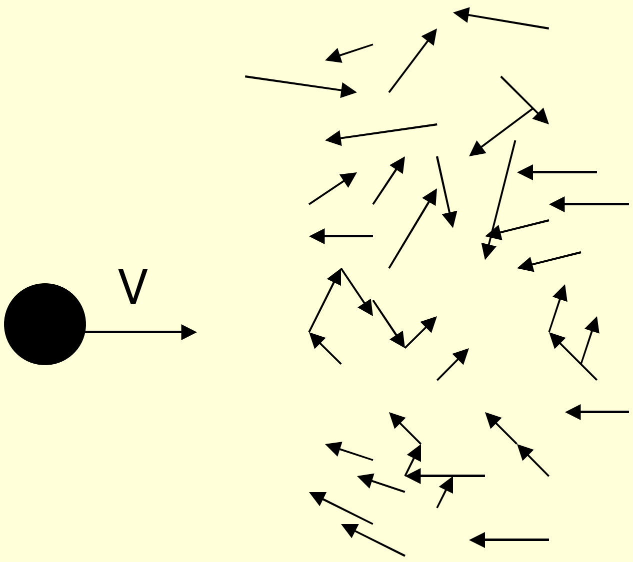
Chandrasekhar, dynamical friction (1943)

Two-body problem +mass conservation



Density profile of the accretion wake

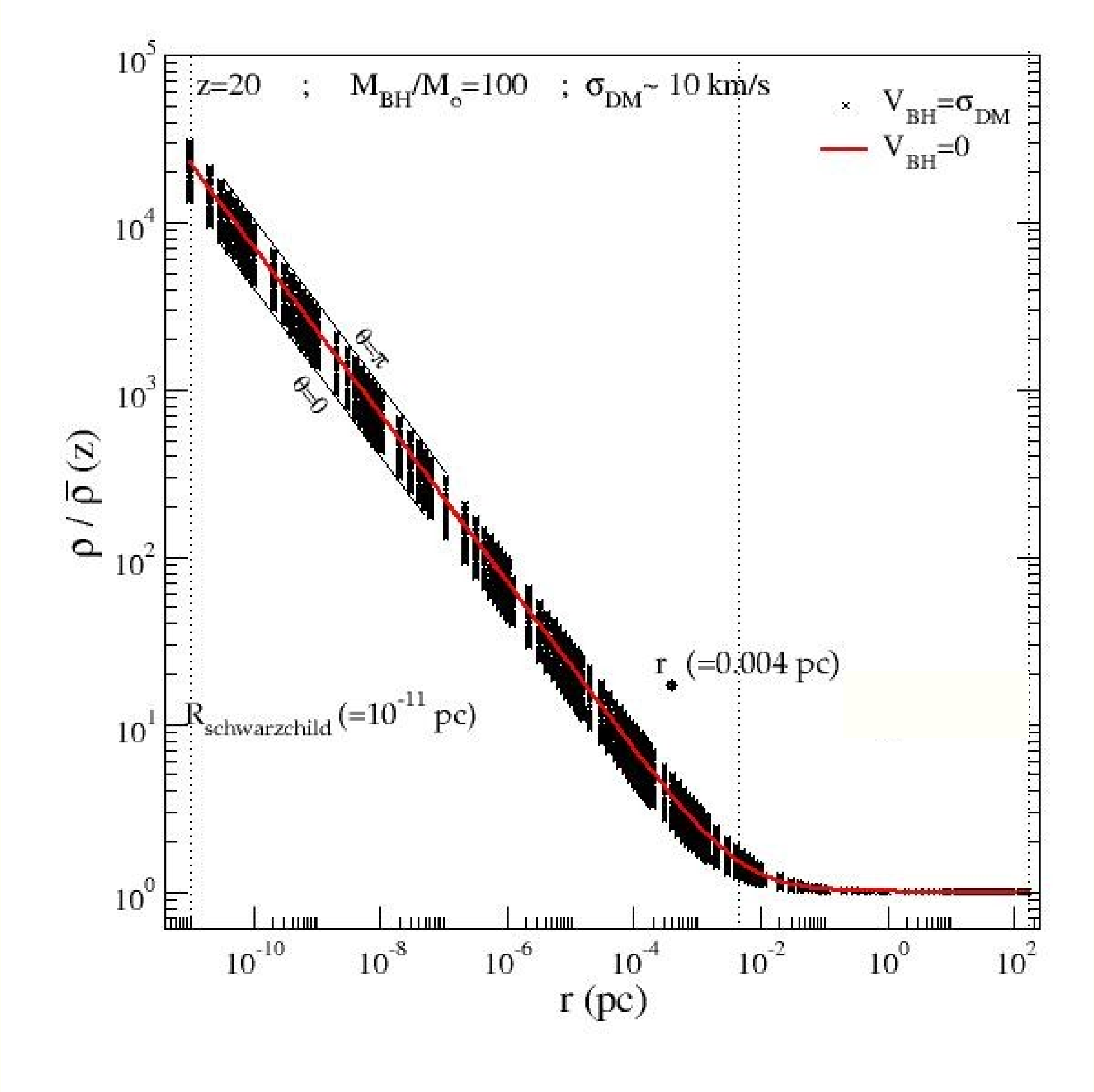
hot medium (e.g. Maxwellian velocity distribution) > Danby & Camm (1957)

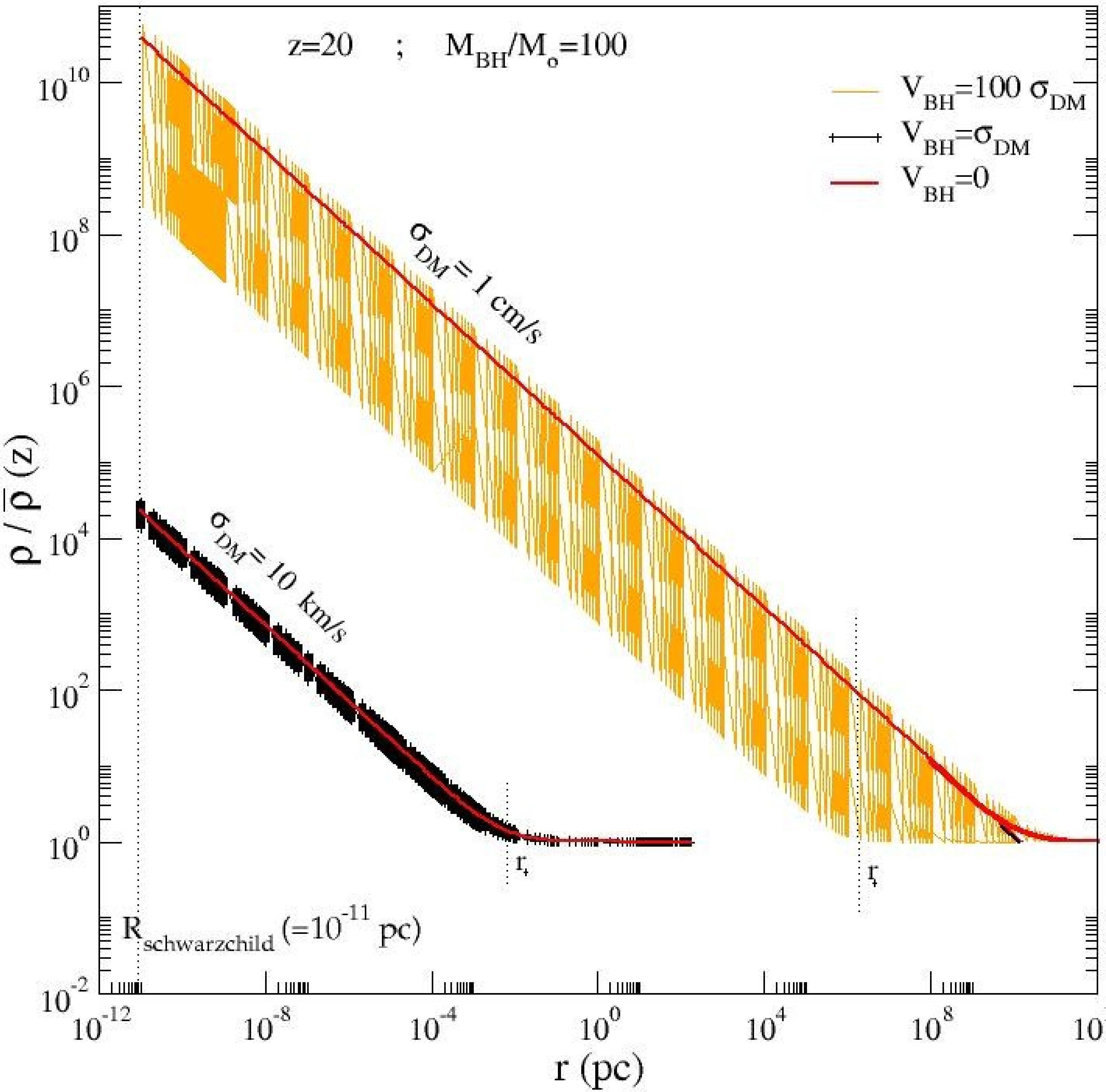


Jean’s theorem → numerical solution for density

Analytic solution for stationary BHs : $\rho(r) \sim 1/\sqrt{r}$

Wake density : radius of influence

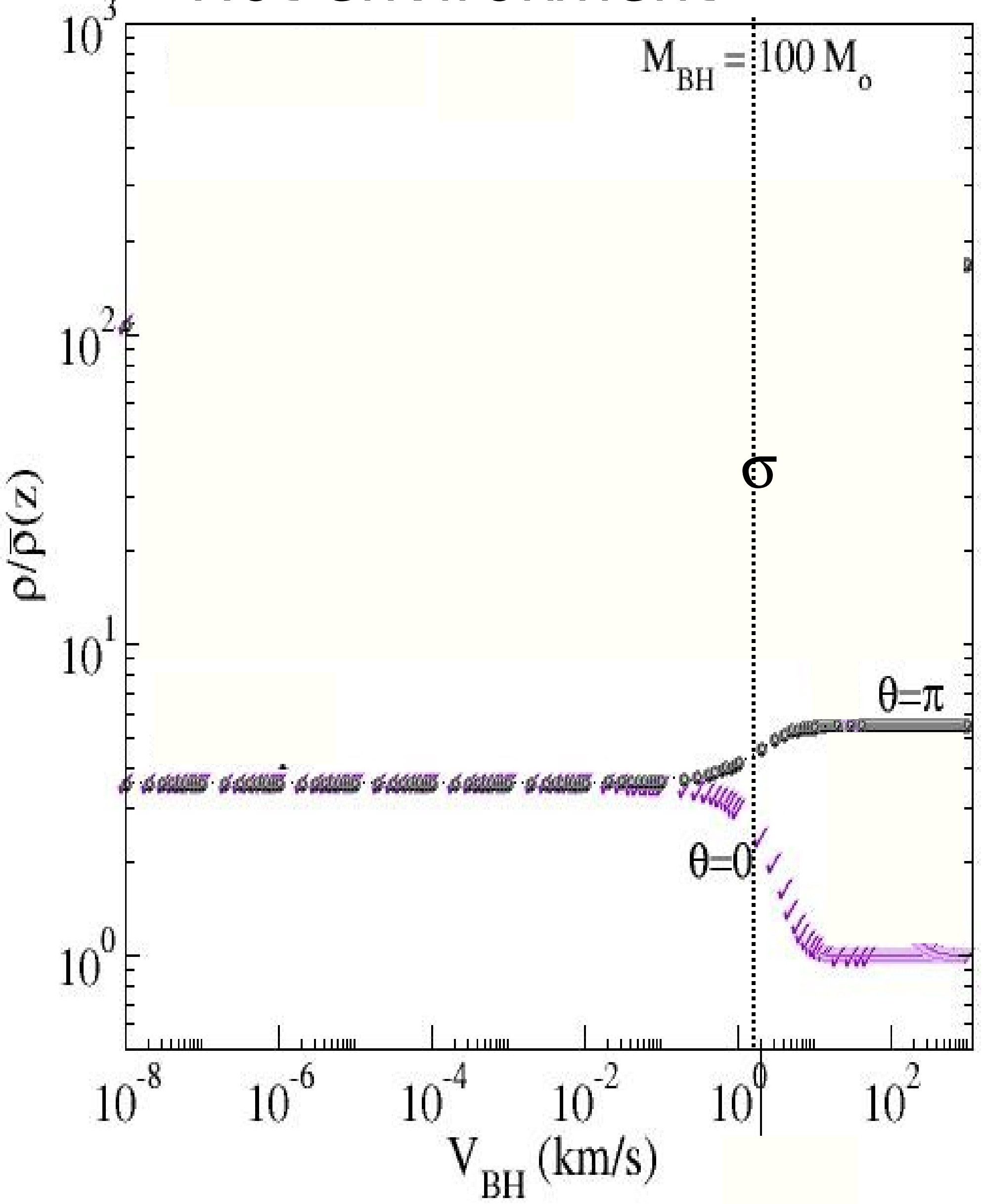




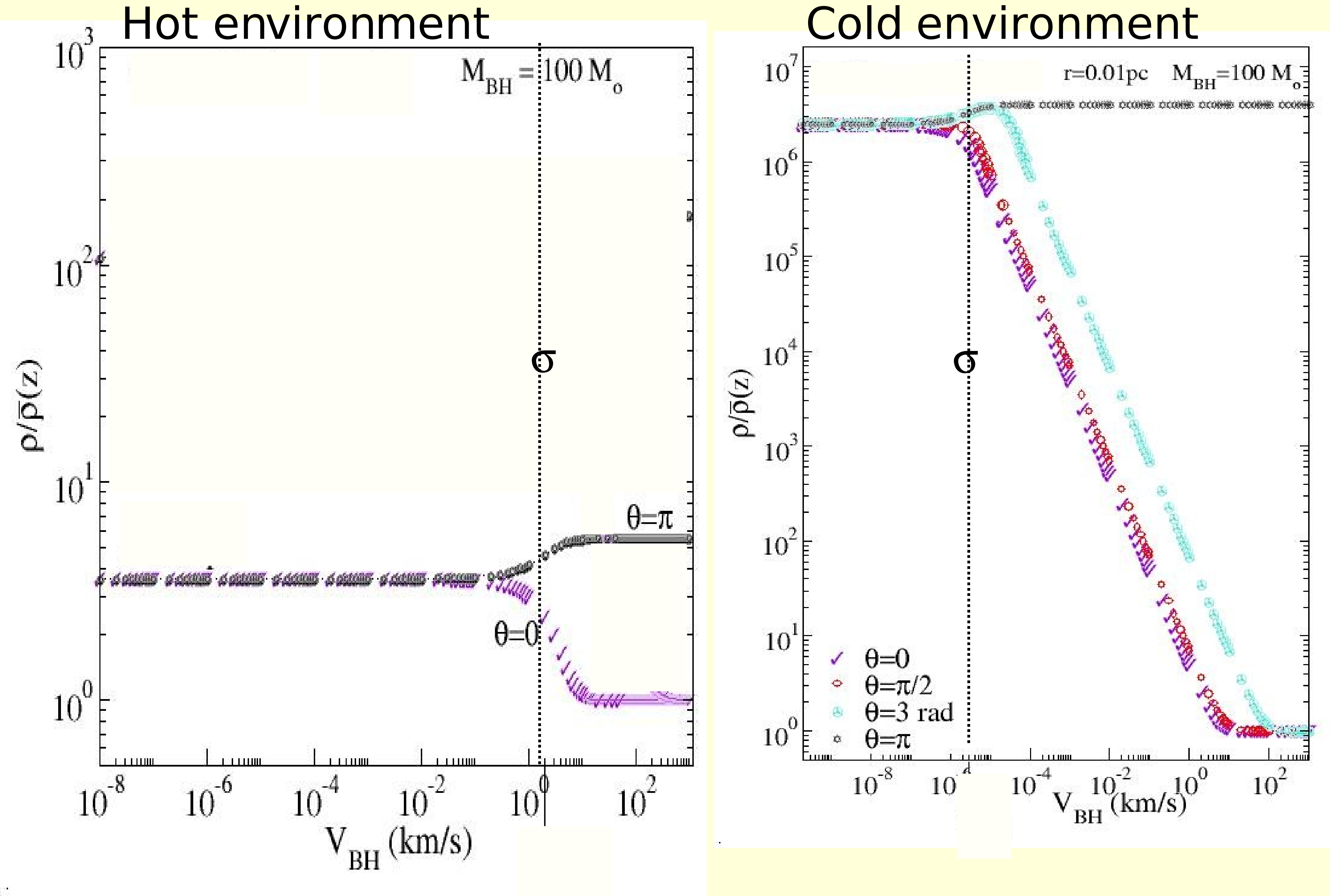
z=20 ; M_BH/M_o=100
V_BH=100 σ_DM
V_BH=σ_DM
V_BH=0
σ_DM= 1 cm/s
σ_DM= 10 km/s
r_t
r_t
R_schwarzchild (=10^-11 pc)
ρ / ρ̄ (z)
r (pc)
10^10
10^8
10^6
10^4
10^2
10^0
10^-2
10^-12
10^-8
10^-4
10^0
10^4
10^8

Wake density : hot versus cold medium

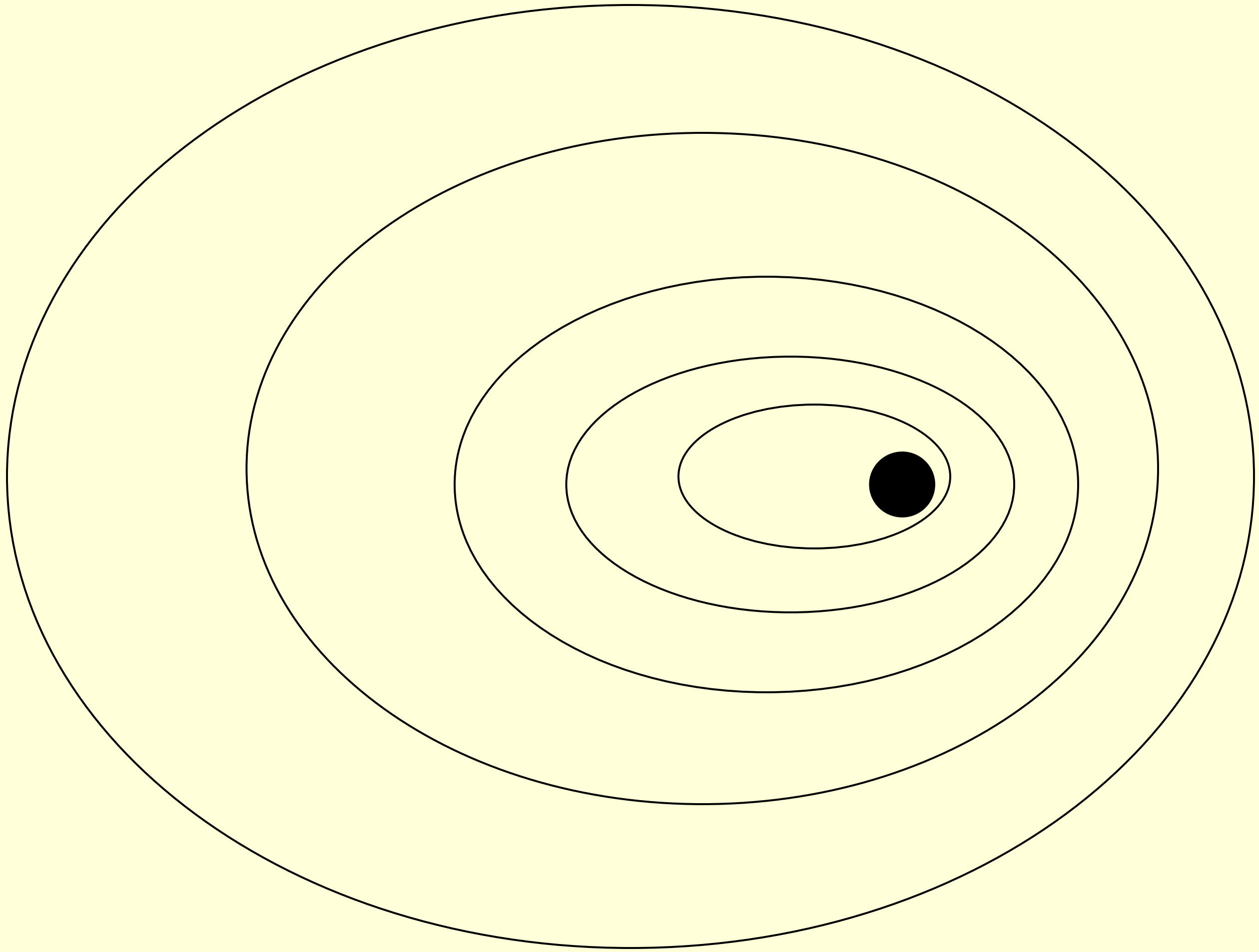
Hot environment



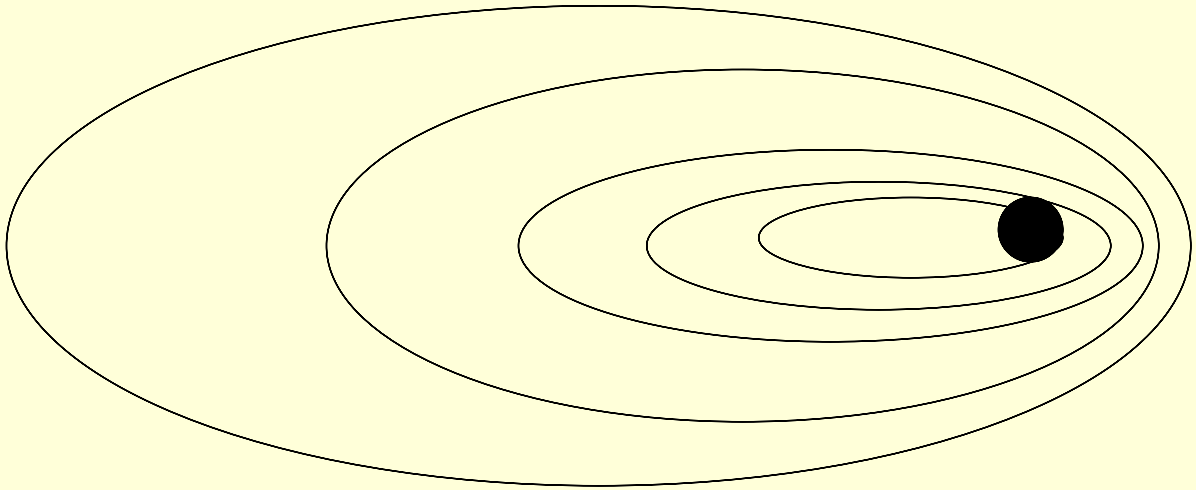
Wake density : hot versus cold medium



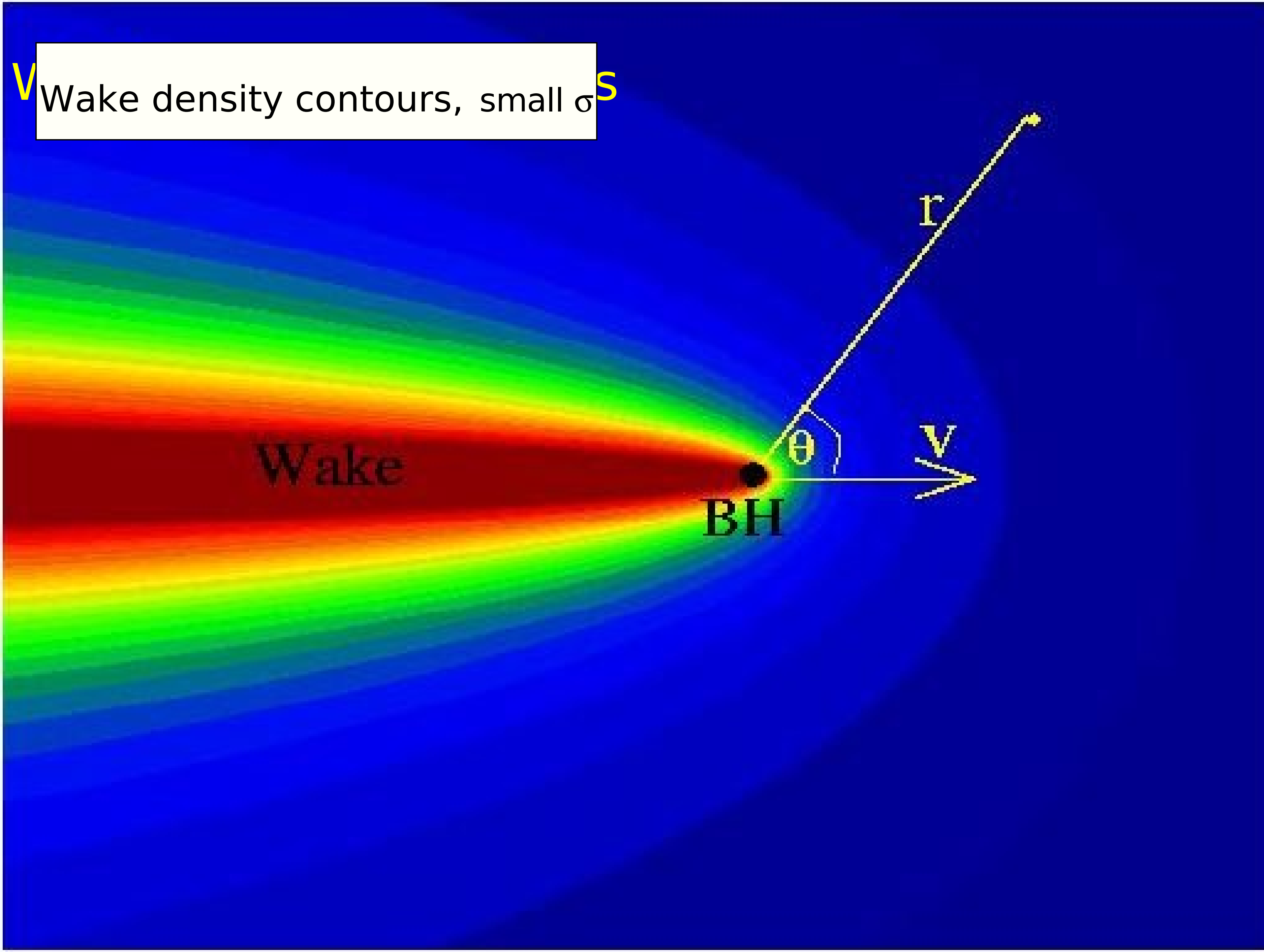
Constant density contours : large σ



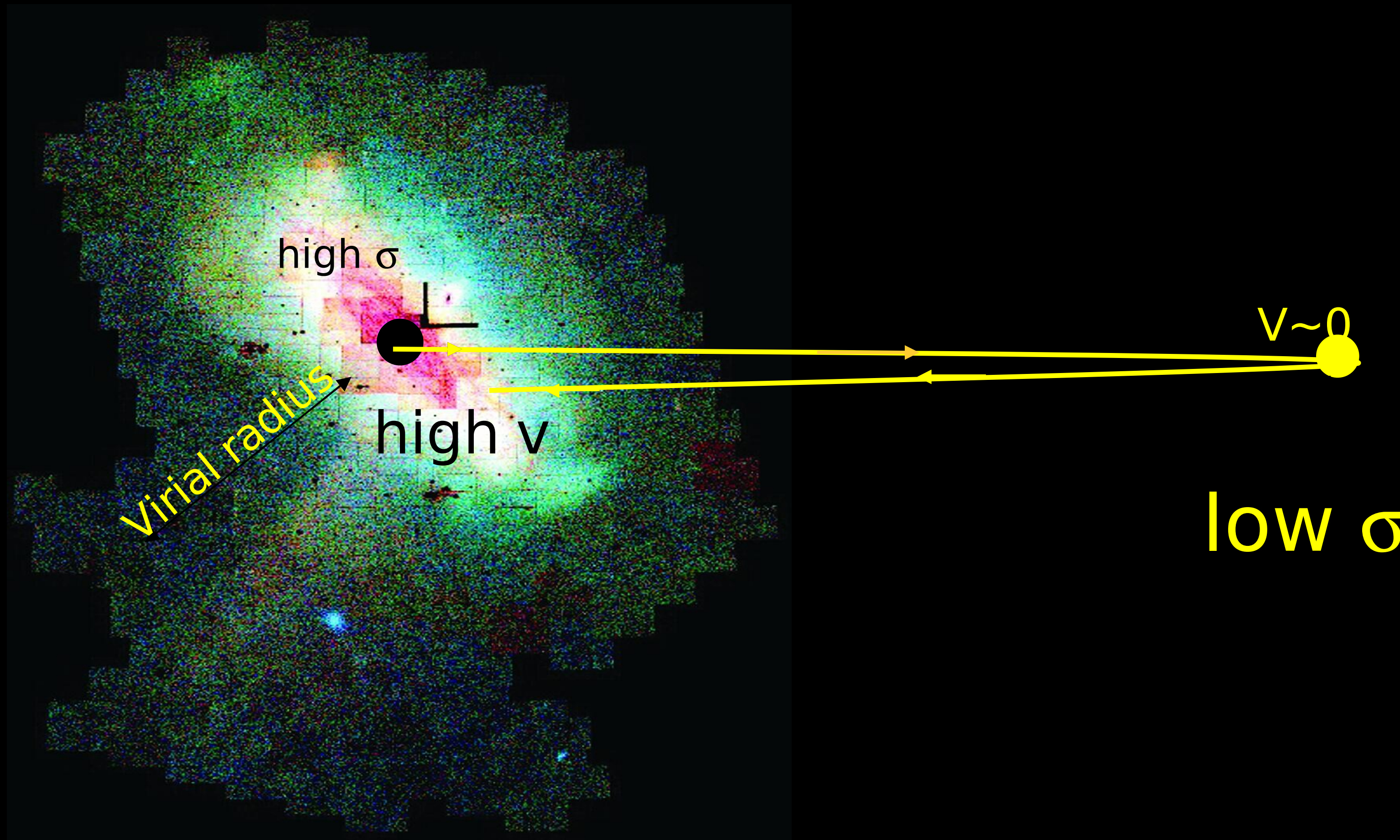
Constant density contours : reducing



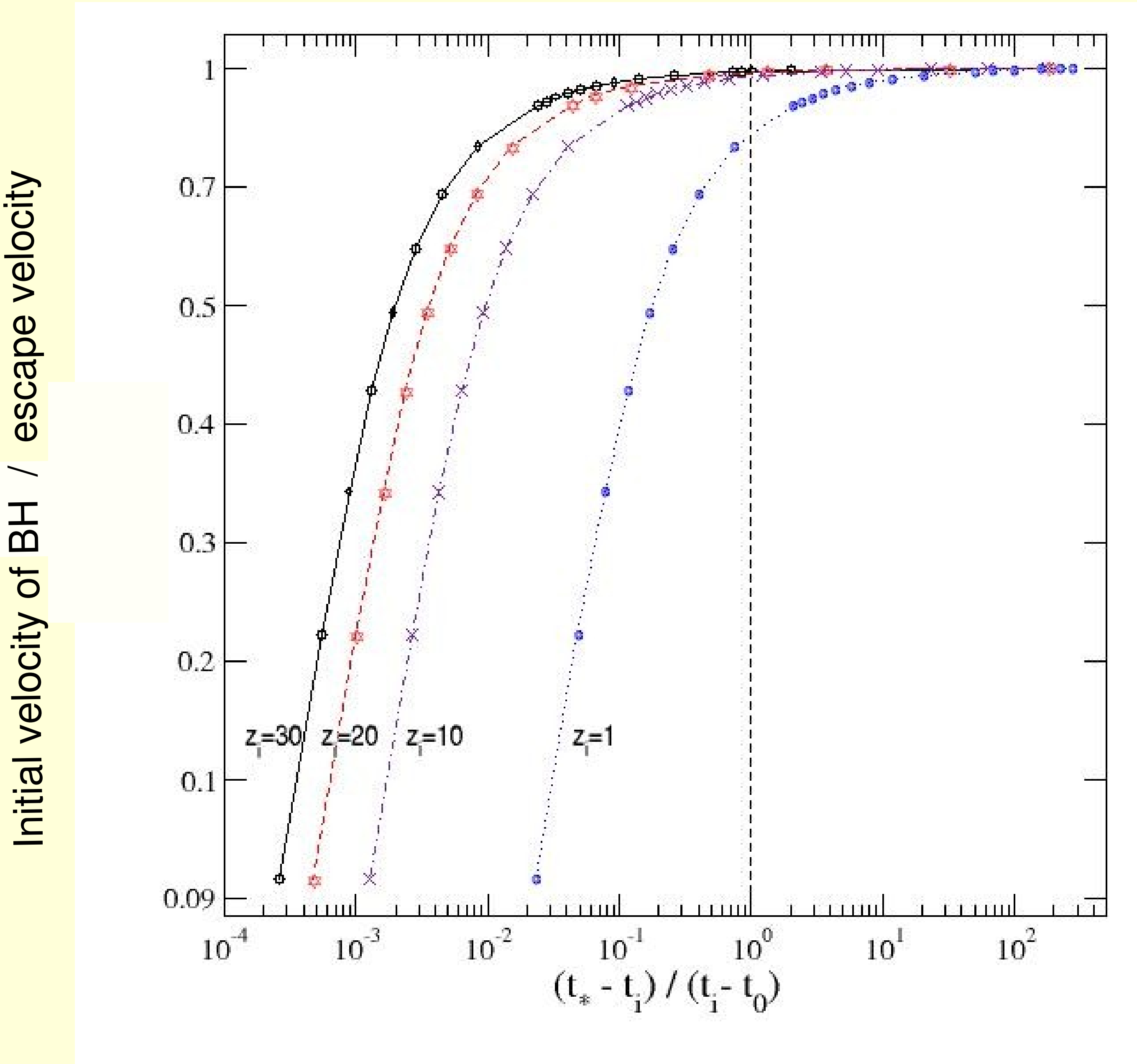
Wake density contours, small σ



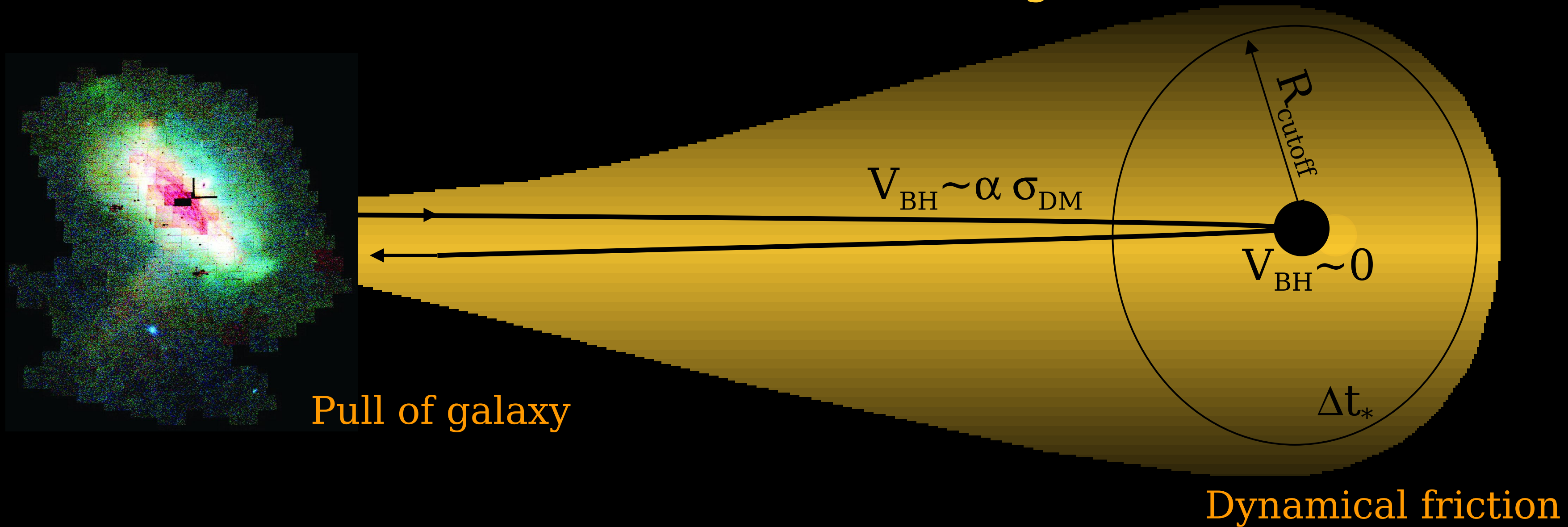
Highest density at the apapsis passage



Time to reach the apapsis



BH Luminosity

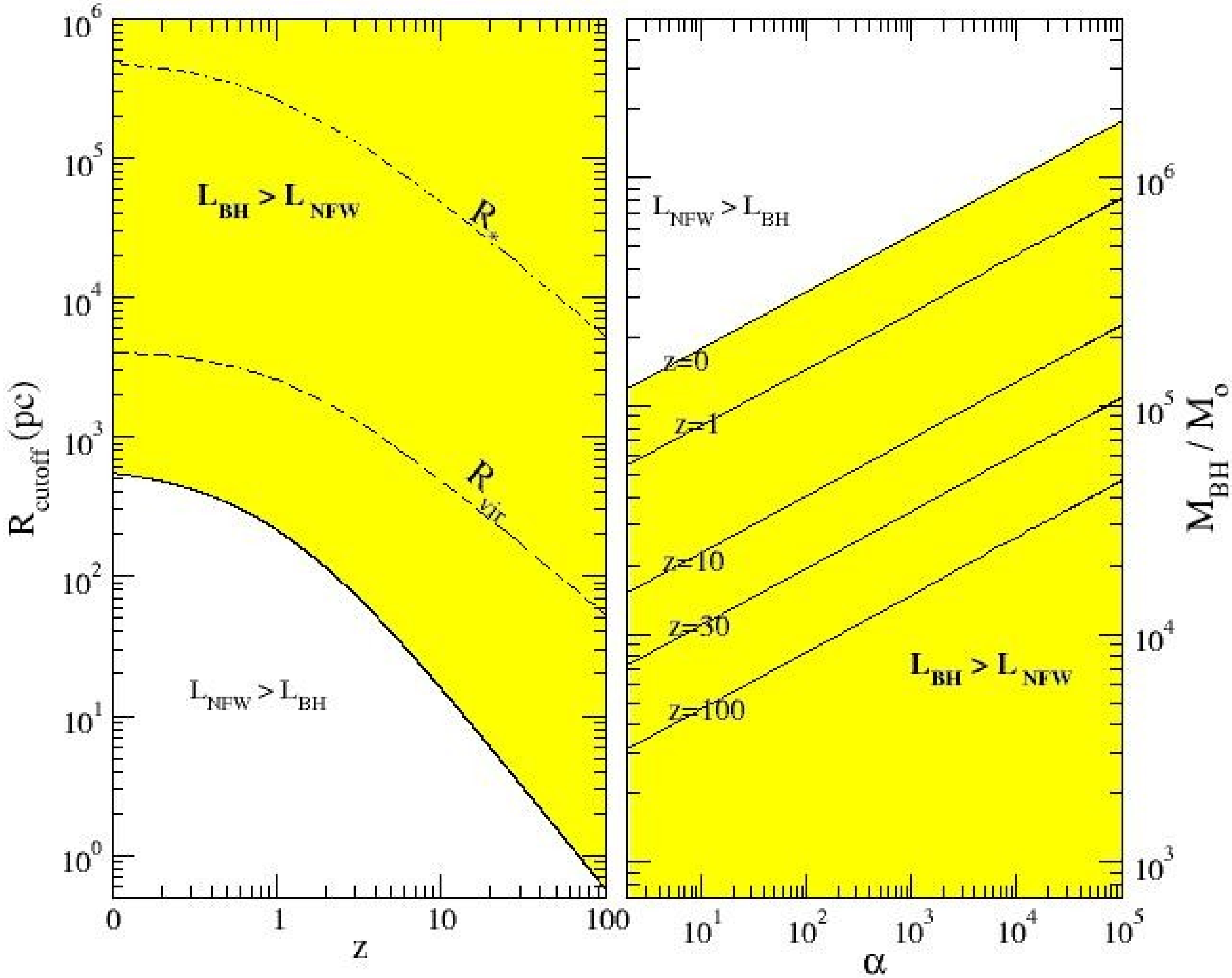


$$\rho/\bar{\rho} \sim \sqrt{(r_* / r)}$$

$$L_{BH} \sim \int^{Rcutoff} \rho^2 \;\; r^2 \, dr$$

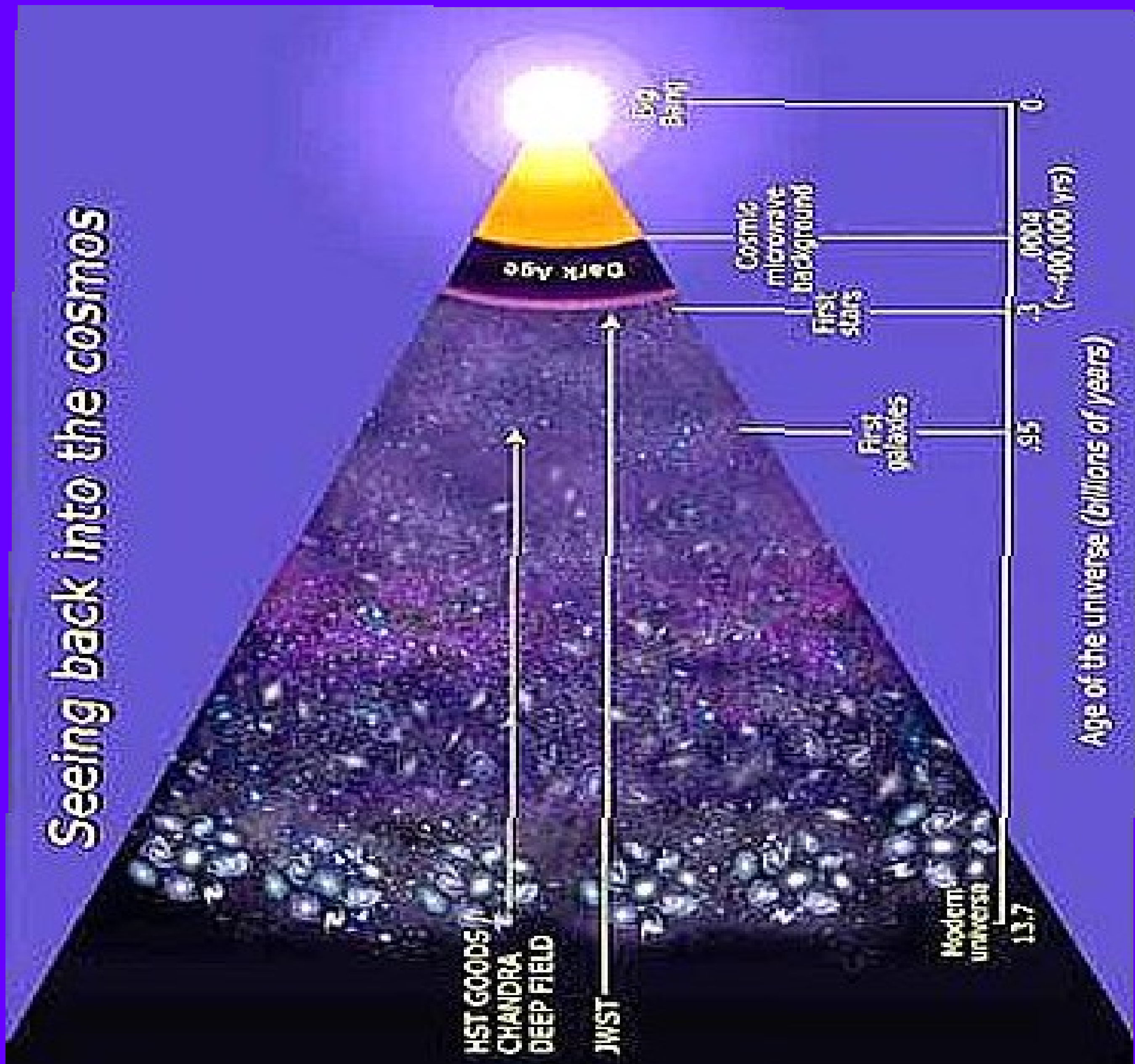
Absolute luminosity of a recoiled BH in γ-rays

$$L(M,z) = [N_\gamma <\sigma v>/m_\chi^2] \int \rho^2 \, dV \qquad \gamma/s$$



$$L_{BH} = 10^{25} (1+z)^4 (M/M_o) R^2_{cutoff} \qquad \gamma/s$$

Diffused γ-ray background



Diffused γ-ray background

$$\Phi = H_0 \int\int \Delta t(M,z) \quad L(M,z) \quad N(M,z) \quad dM \quad dr(z)$$

Time the BH spends at apapsis

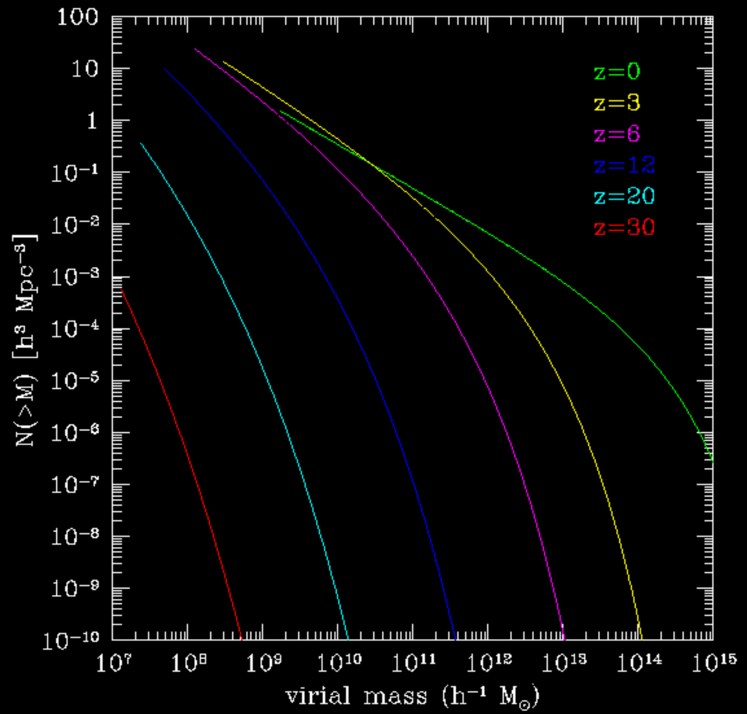
Press-Schechte
mass function

$$10^{25} (1+z)^4 (M/Mo) \quad R^2_{cutofff} \qquad \gamma/s$$

BH Mass function

Press & Schechter (1974)
Density peaks in initially random gaussian field collapse to form ‘‘galaxies’’

Number density of galaxies of mass M at redsift z
N(M,z)



Diffused γ-ray background

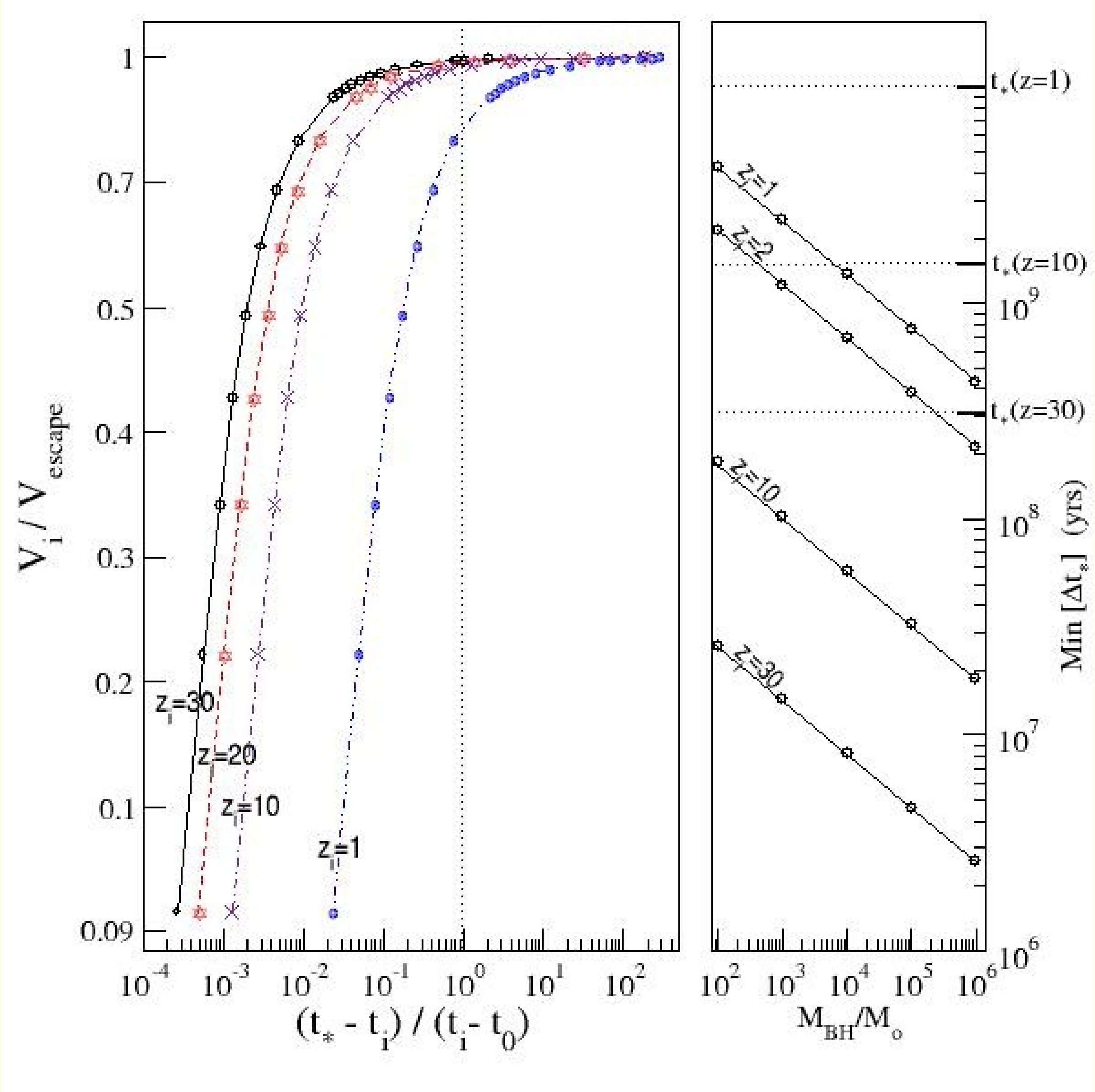
$$\Phi = H_0 \int\int \Delta t(M,z) \quad L(M,z) \quad N(M,z) \quad dM \quad dr(z)$$

Press-Schechte
mass function

Time the BH spends at apapsis

$10^{25}\ (1+z)^4\ (M/Mo)\ \ R^2_{cutofff}\ \ \ \gamma/s$

Time spent at apapsis



Diffused γ-ray background

$$\Phi = H_0 \int\int \Delta t(M,z) \quad L(M,z) \quad N(M,z) \quad dM \quad dr(z)$$

Time the BH spends at apapsis

$10^{25}\ (1+z)^4\ (M/Mo)\ \ R^2_{cutofff}\quad \gamma/s$

Press-Schechte
mass function

$\Phi_{haloes} \sim 10^{-6}\quad \gamma cm^{-2} s^{-1} sr^{-1}$

$\Phi_{BH} \sim 10^{-14}\quad \gamma cm^{-2} s^{-1} sr^{-1}$

Note: Optical depth, secondary interactions
Not taken into account

Future Prospects:

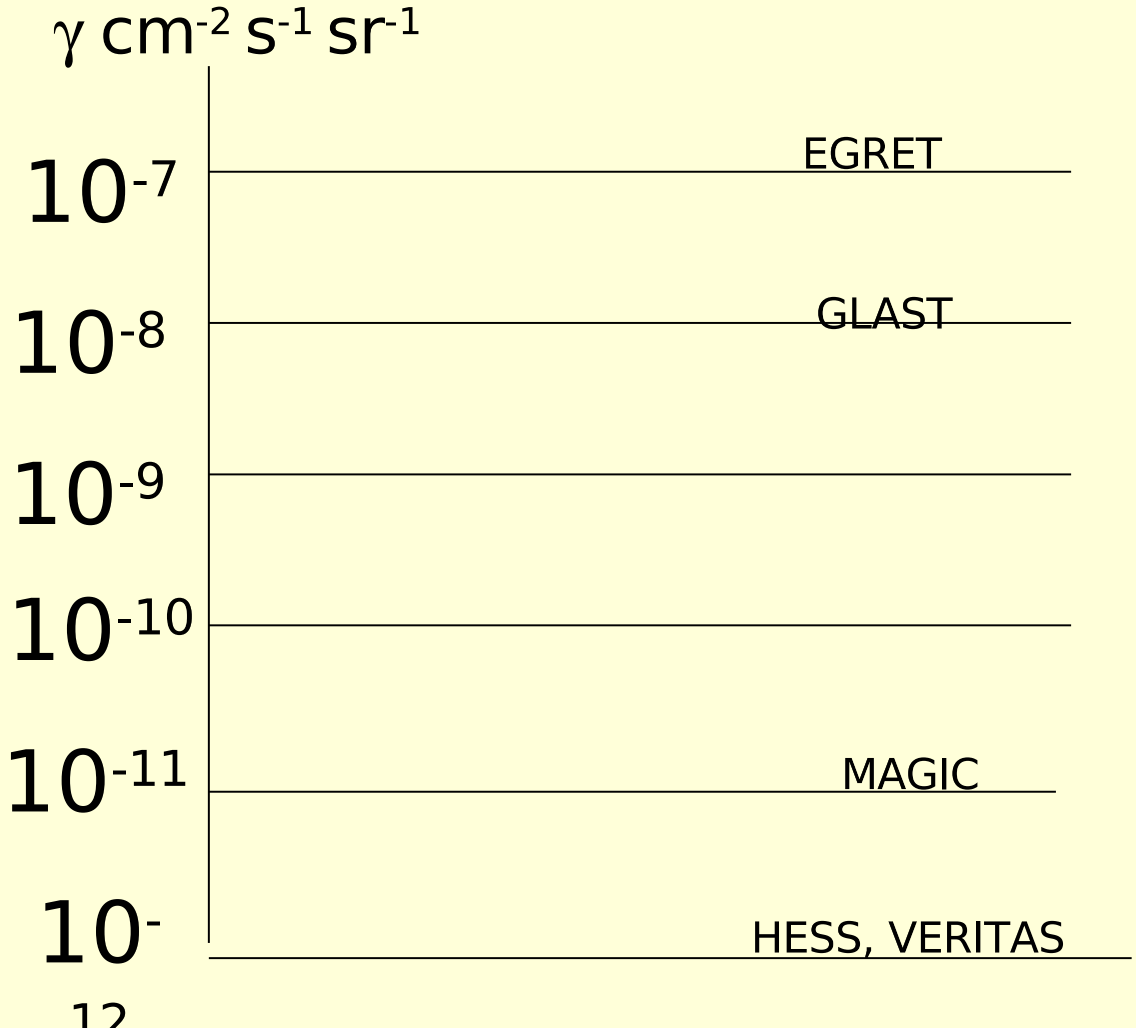
(4) Test against N-body simulations

- Validity of dynamical friction
- Population of recoiled BHs
- Homogeneity of the BH
- Radius of influence of BH

(2) Confronting the gamma-ray observations

Future Prospects: Confronting the observations

$\Phi > 10^{-8}\ \gamma\ cm^{-2}\ s^{-1}\ sr^{-1}$



Time spent at apsis

$\Phi = H_0 \int\int \Delta t(M,z)\ L(M,z)\ N(M,z)\ dM\ \ dr(z)$