Growth of BH seeds via gaseous dynamical friction: perspectives for GW detections

GWVerse 2020

14/01/2020

Lumen Boco

Observation of quasars at z>6

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Super Eddington accretion: $\lambda \sim 3 - 4$

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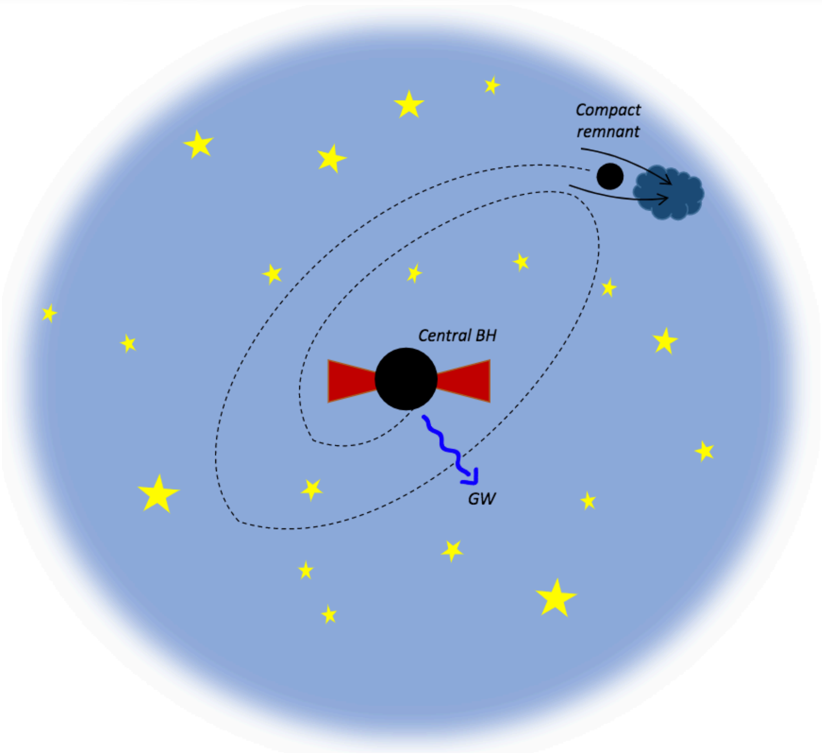
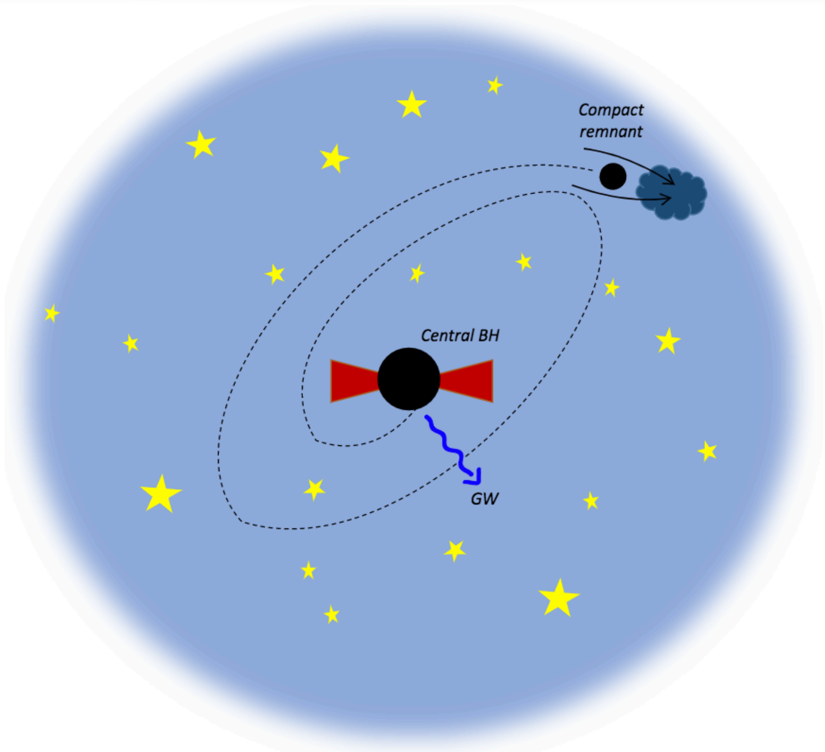
Heavy black hole seeds:
$M \sim 10^3 - 10^5 M_\odot$

Dynamical friction between stellar compact remnants and gas



Dynamical friction process

Dynamical friction between stellar compact remnants and gas

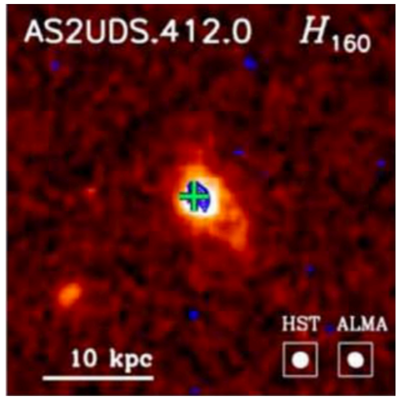


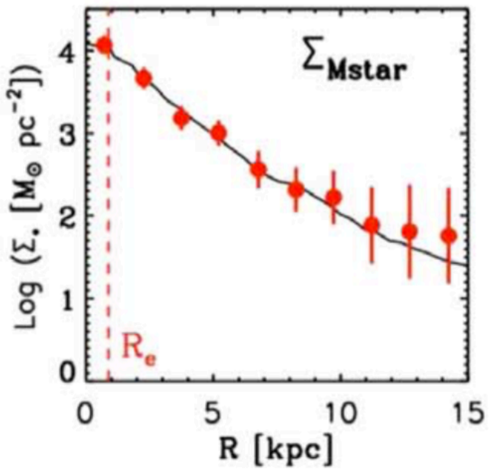
ALMA observation of a large population of highly star-forming dusty-obscured ETG progenitors

High level of star formation $\psi \sim 10^2 - 10^3 M_\odot/\mathrm{yr}$

High gas density $M_{\mathrm{gas}} \sim 10^{10} - 10^{12} M_\odot$

$R_{\mathrm{e}} \sim 1\mathrm{kpc}$





Lang et al. 2019, ApJ, 879, 54

Dynamical friction timescale

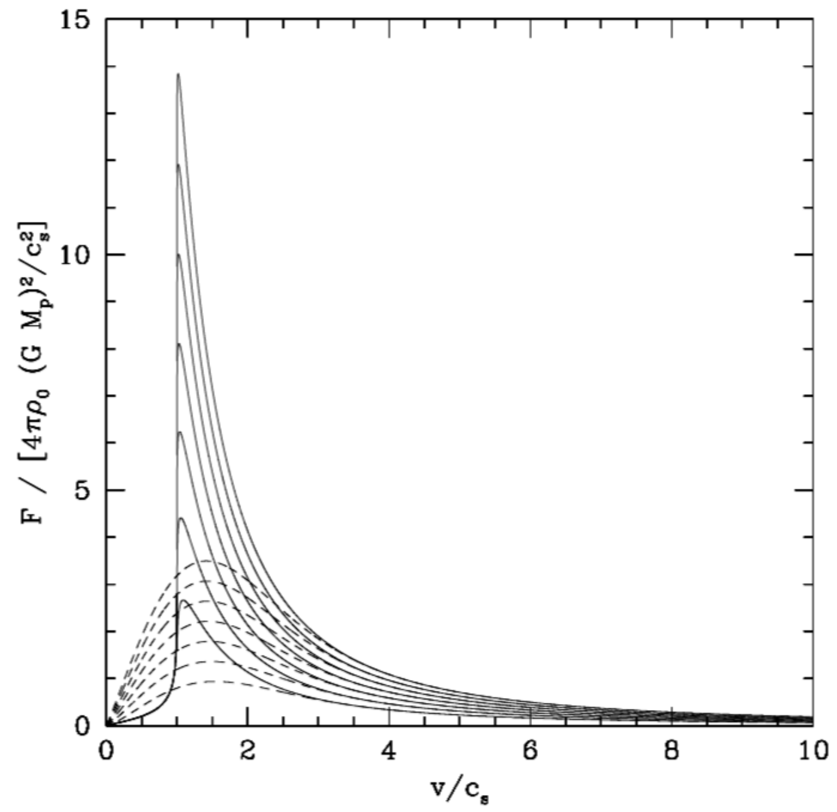
$$F_{\mathrm{DF}} = \frac{4\pi G^2 m_\bullet^2 \rho}{v^2} f(\mathscr{M})$$

Ostriker 1999, ApJ, 513:252-258

Sanchez-Salcedo et al. 2001, MNRAS, 322, 67

Escala et al. 2004, ApJ, 607, 765

Tagawa et al. 2016, MNRAS, 462, 3812



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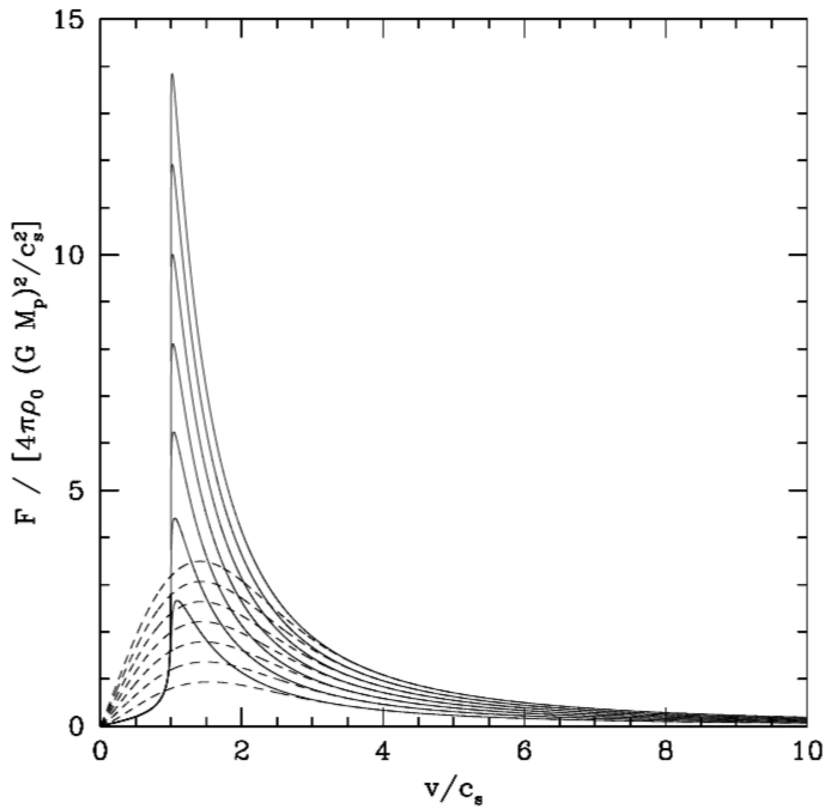

$$\tau_{\rm DF} \sim N(n,\alpha)\left(\frac{m_\bullet}{100M_\odot}\right)^{-1}\left(\frac{M_{\rm gas}}{10^{11}M_\odot}\right)^{1/2}\left(\frac{R_{\rm e}}{1{\rm kpc}}\right)^{(\alpha-3)/2}\left(\frac{r_{\rm c}(e)}{10{\rm pc}}\right)^{3-\alpha/2}\left(\frac{j}{j_{\rm c}(e)}\right)^{1.5}$$

$$N \sim 3\times 10^8 {\rm yr}$$

Merging rates

$$R_{\rm merge}(m_\bullet,\tau) = \int {\rm dr}\frac{\rm dp}{\rm dr}\int {\rm dv}_\theta\frac{\rm dp}{{\rm dv}_\theta}\int {\rm dv_r}\frac{\rm dp}{\rm dv_r}{\rm R_{birth}}({\rm m}_\bullet,\tau-\tau_{\rm DF}({\rm m}_\bullet,{\rm e},{\rm j}))$$

Boco et al. 2019, ApJ, 881, 157

Merging rates

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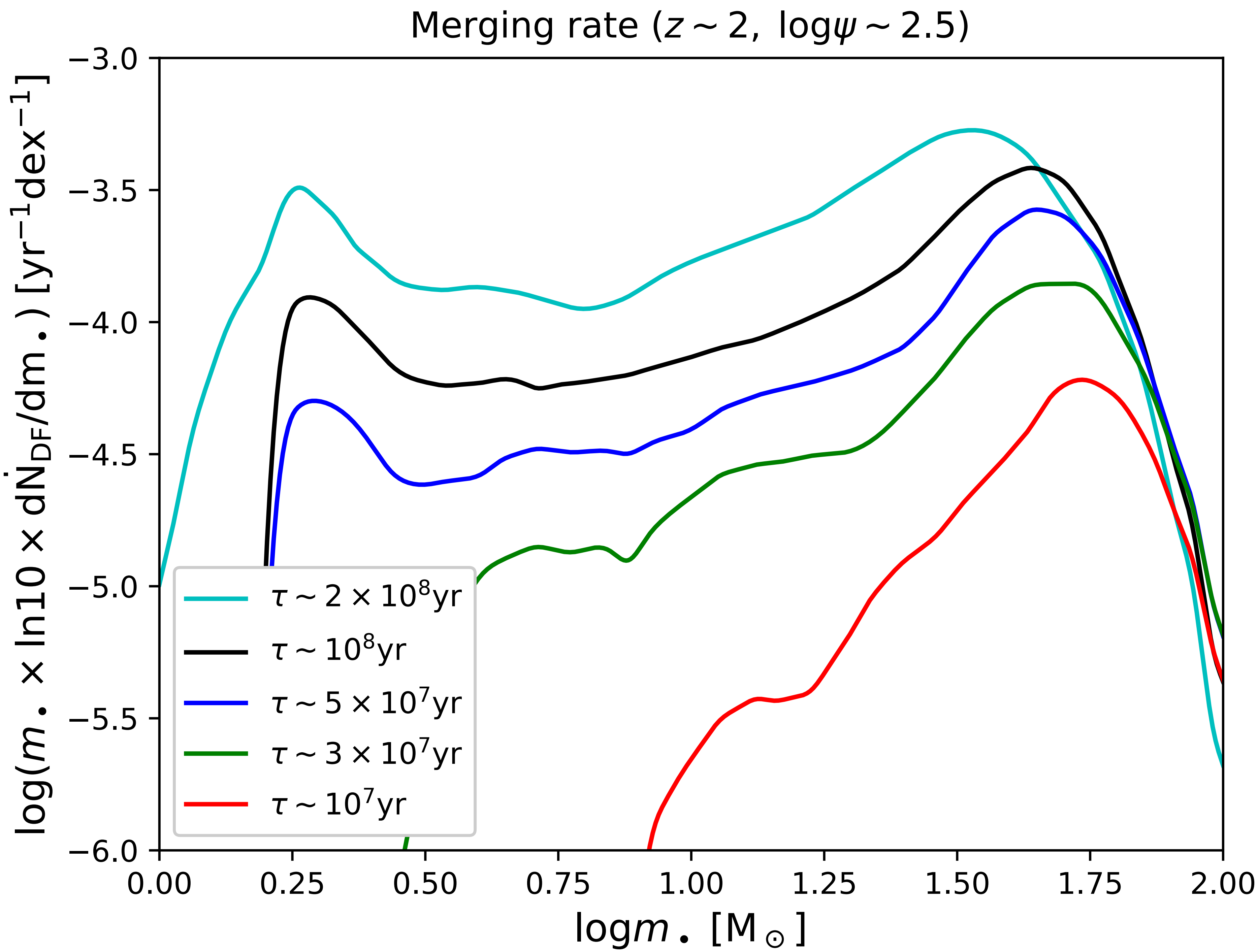

Central mass growth

Merging driven growth

$$\dot{M}_{\bullet,\mathrm{DF}}(\tau) = \int \mathrm{dm_\bullet m_\bullet R_{merge}(m_\bullet}, \tau)$$

Gas accretion

$$\dot{M}_{\bullet,\mathrm{gas}}(\tau) = 2.2 \times 10^{-9} \frac{\lambda}{\eta} \frac{M_\bullet(\tau)}{\mathrm{yr}}$$

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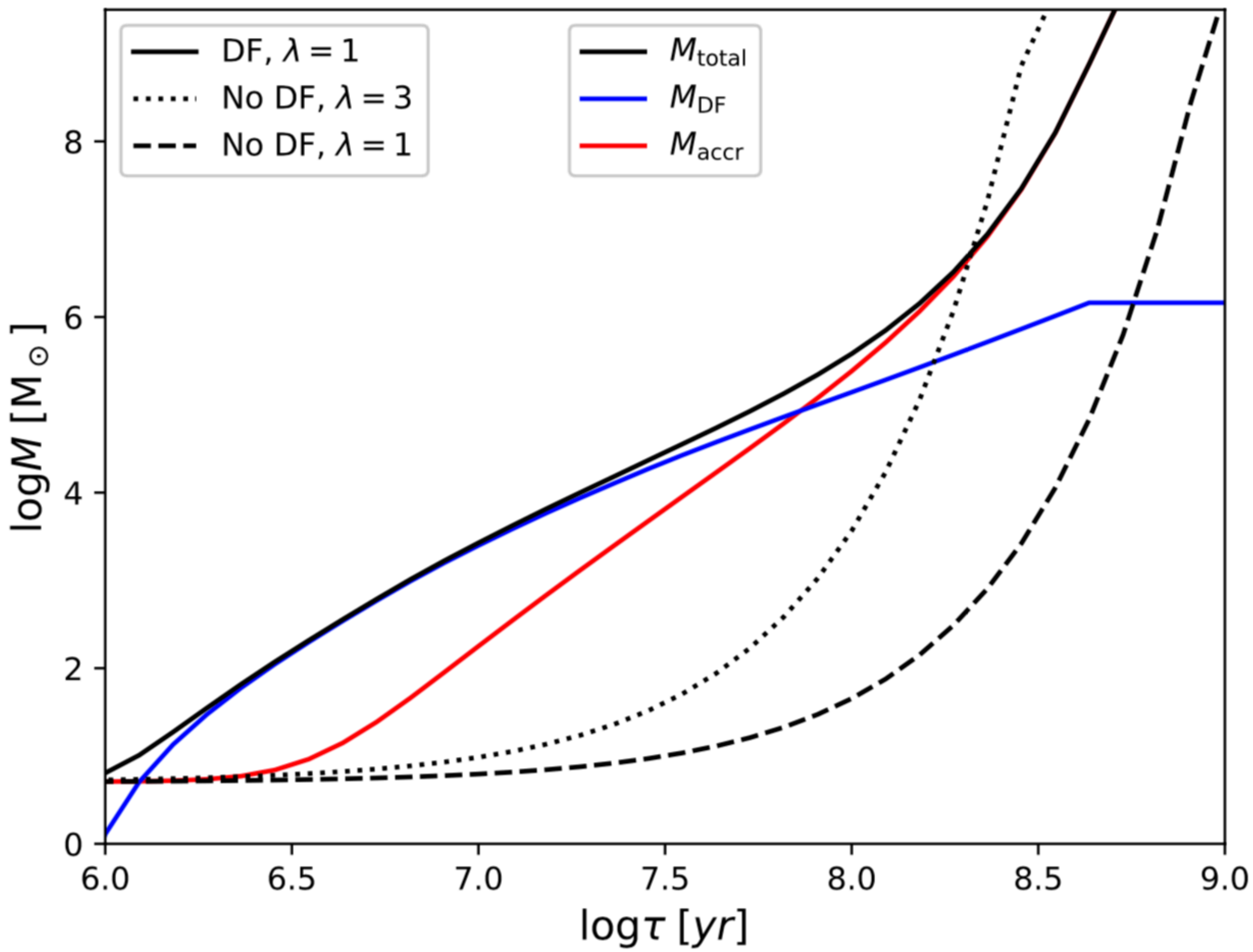

Gravitational waves emission

$$\frac{d\dot{N}}{dVd\mathscr{M}}(z,\mathscr{M}) = \int d\psi \frac{dN}{dVd\psi} \int_{t_z-\tau_\psi}^{t_z} dt_f \frac{dp}{dt_f} \frac{d\dot{N}_{DF}}{d\mathscr{M}}(\mathscr{M}, t_z - t_f | \psi, z)$$

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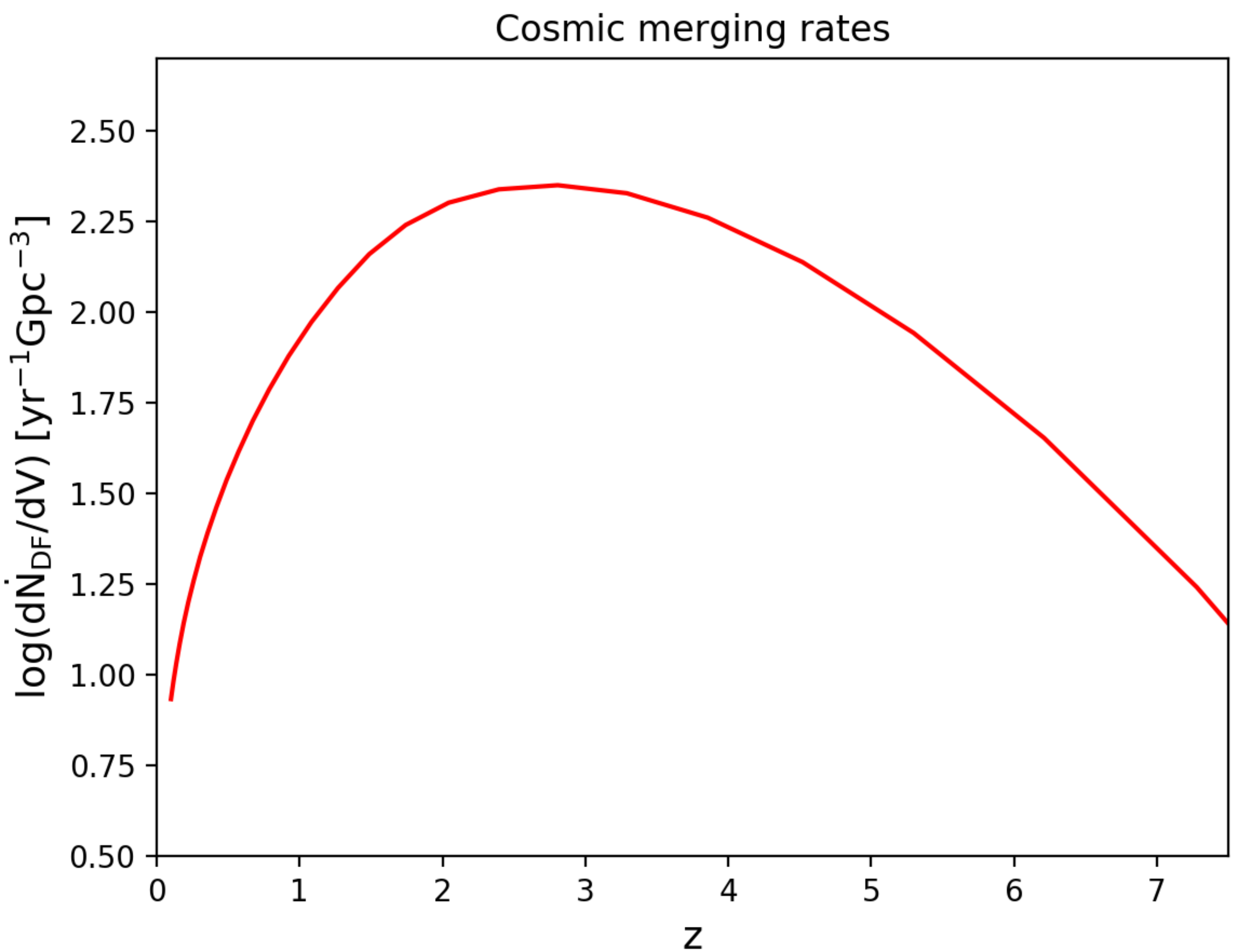
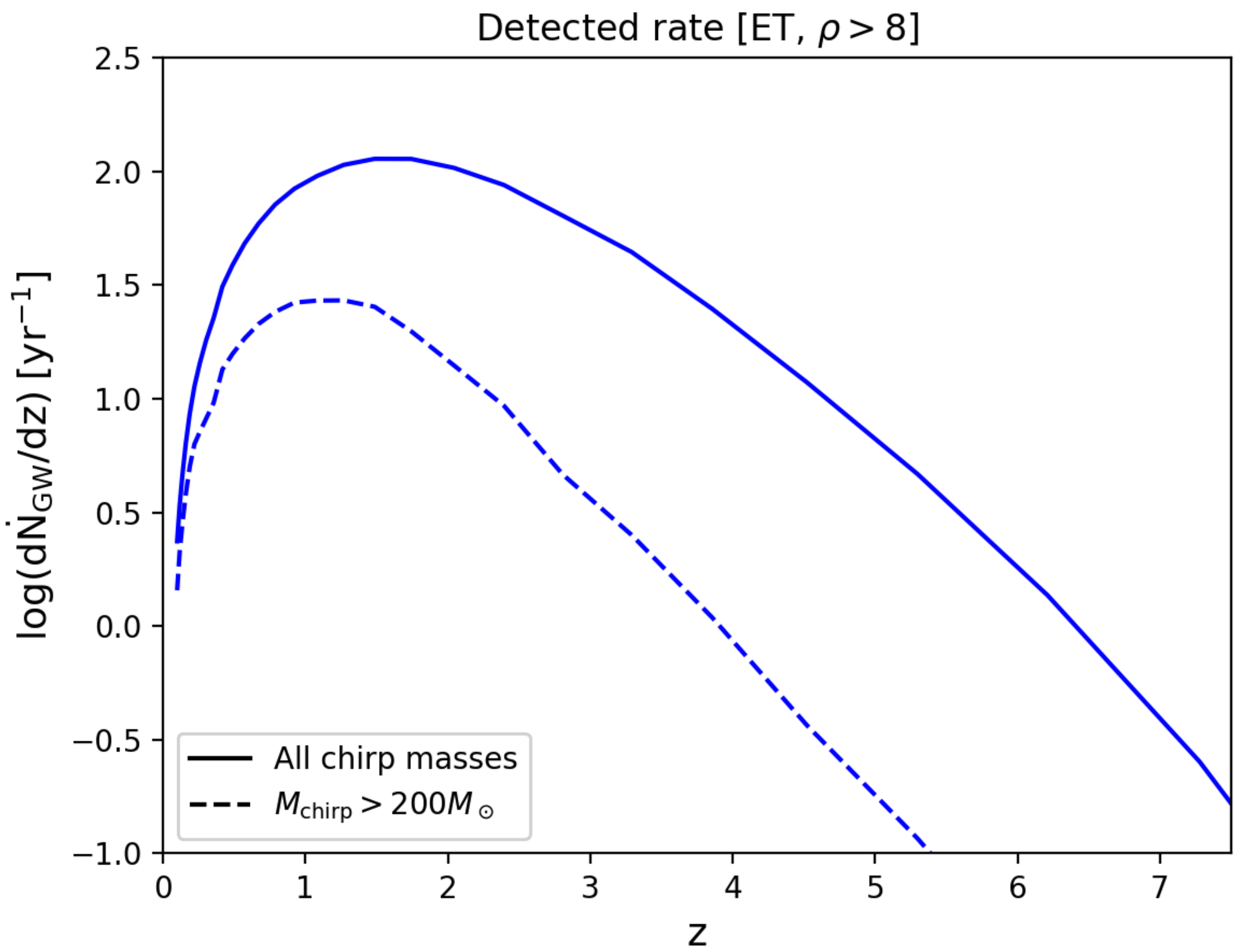
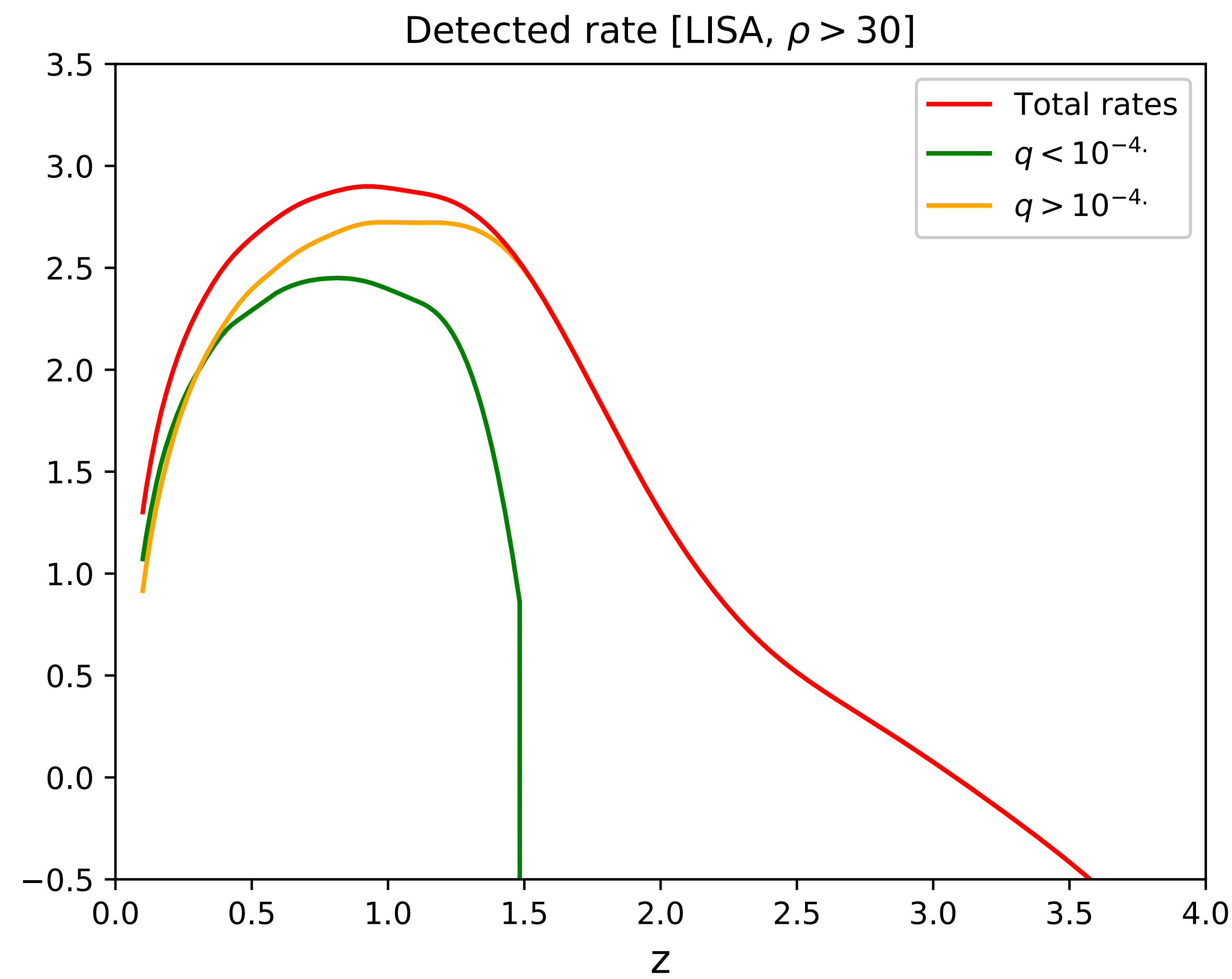


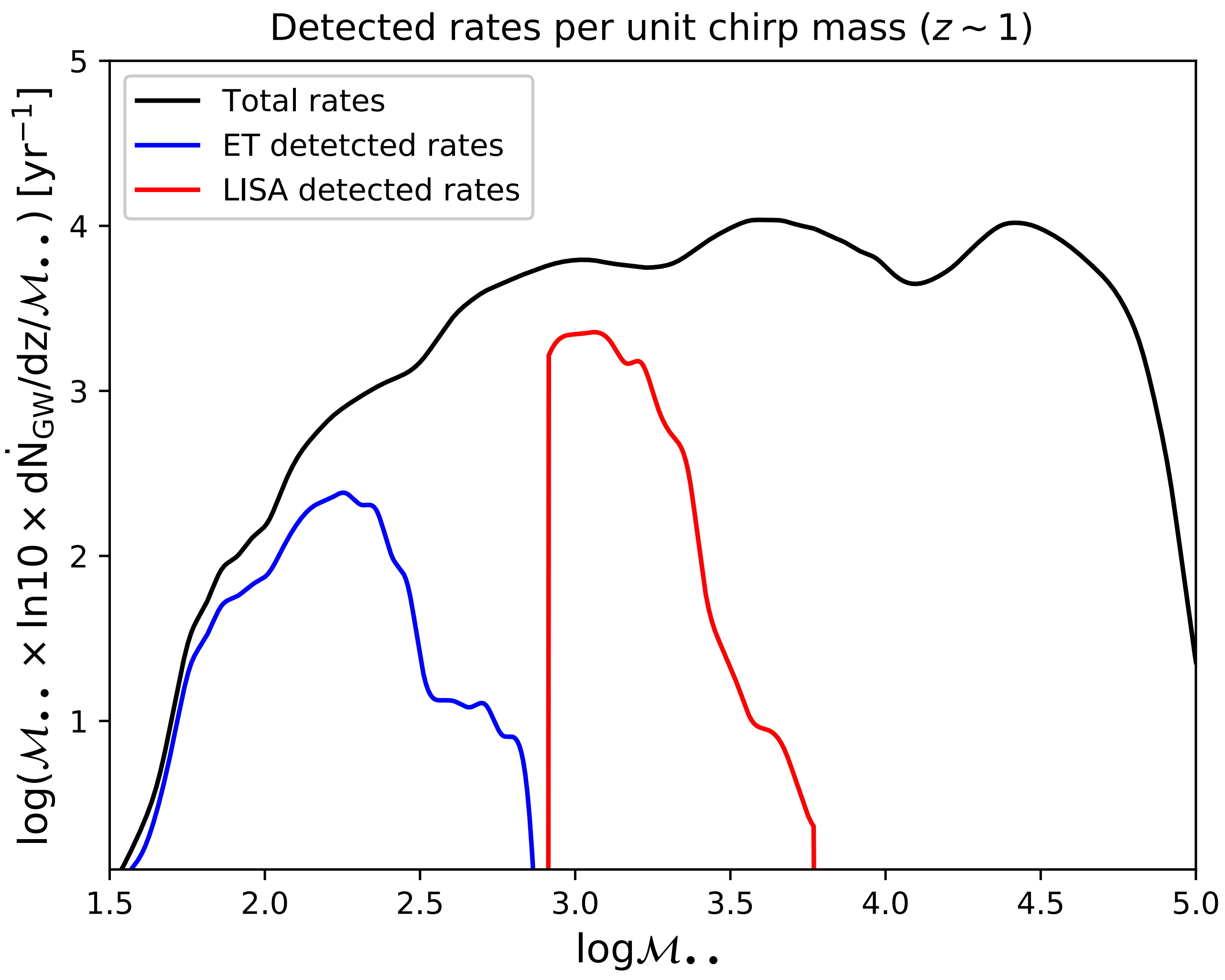
Einstein Telescope



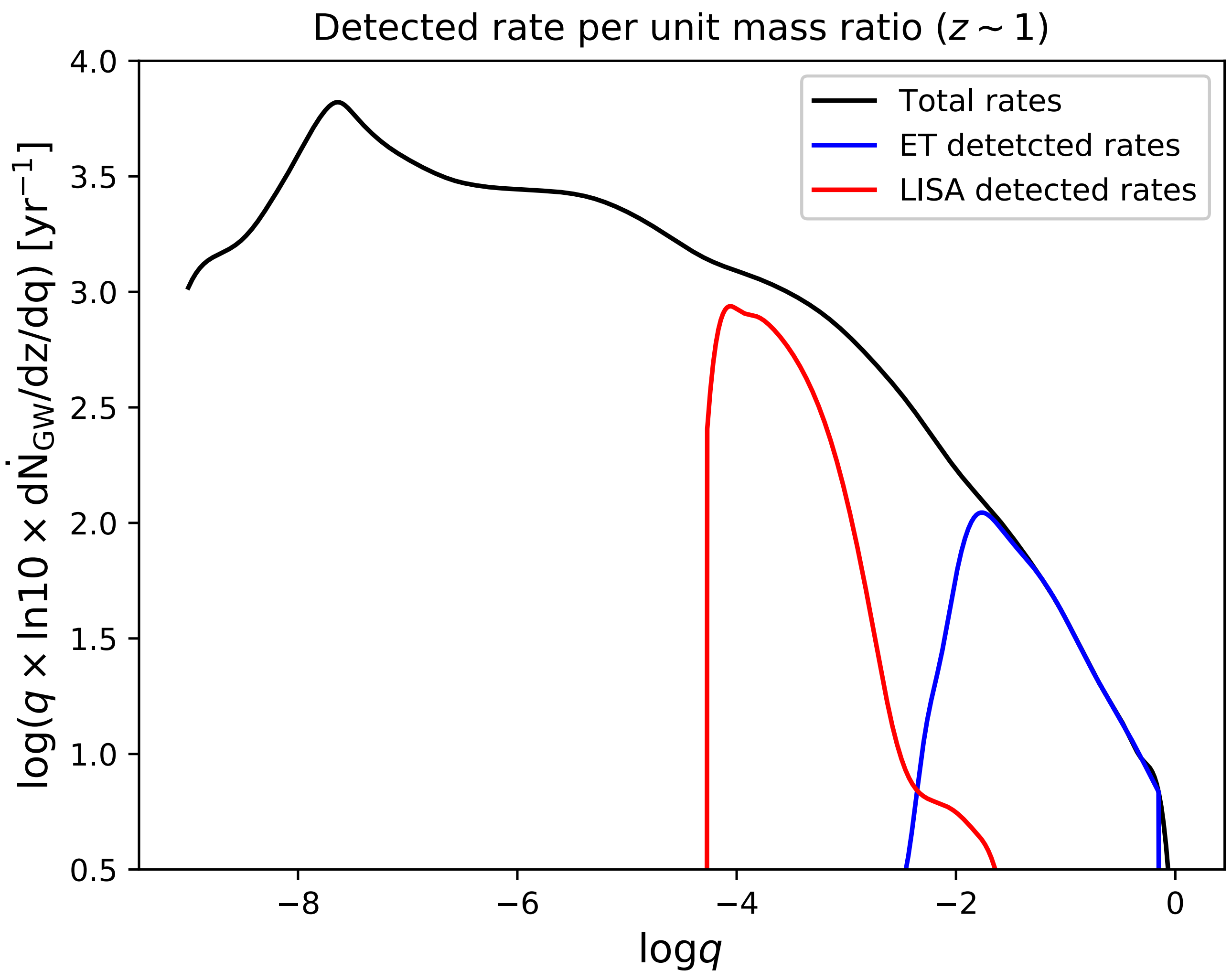
LISA



Detected rates per unit chirp mass

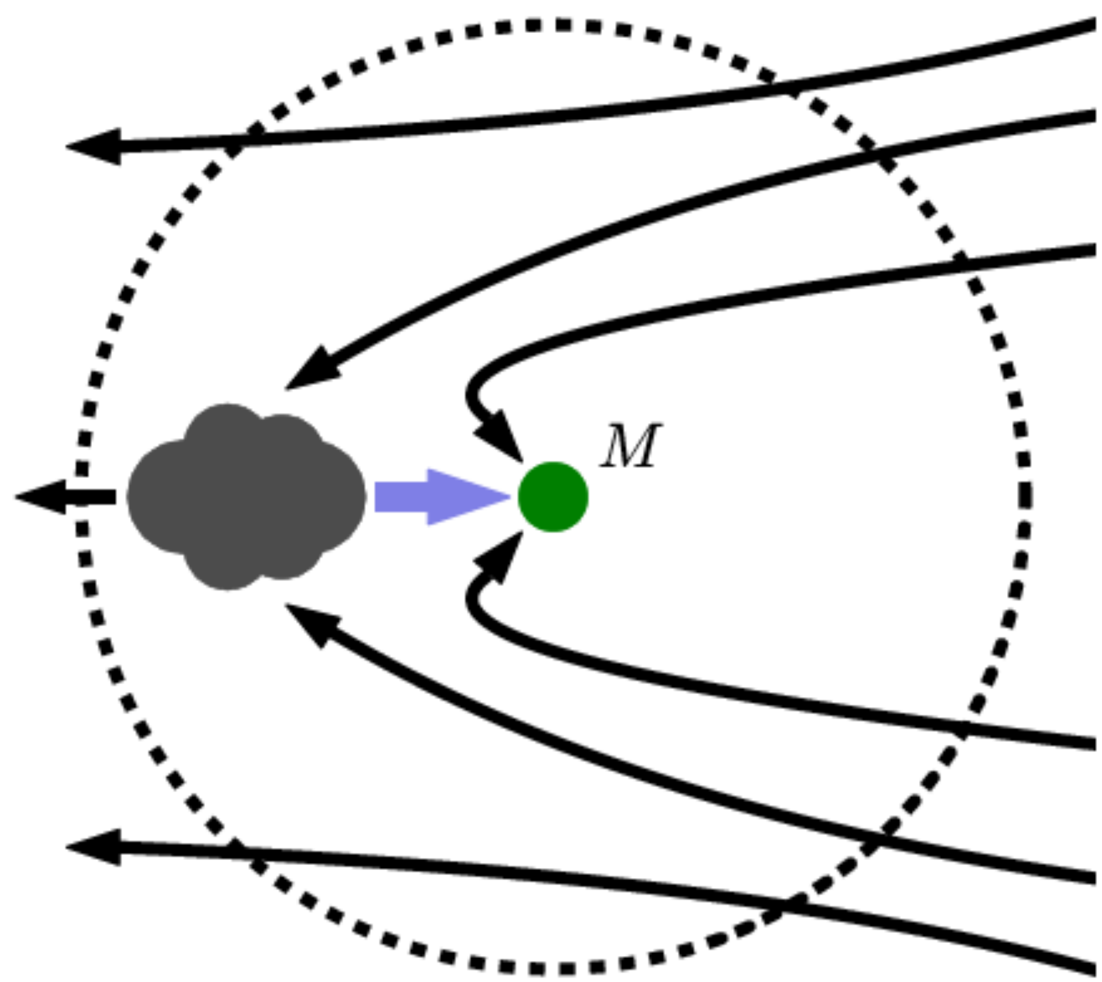


Detected rates per unit mass ratio



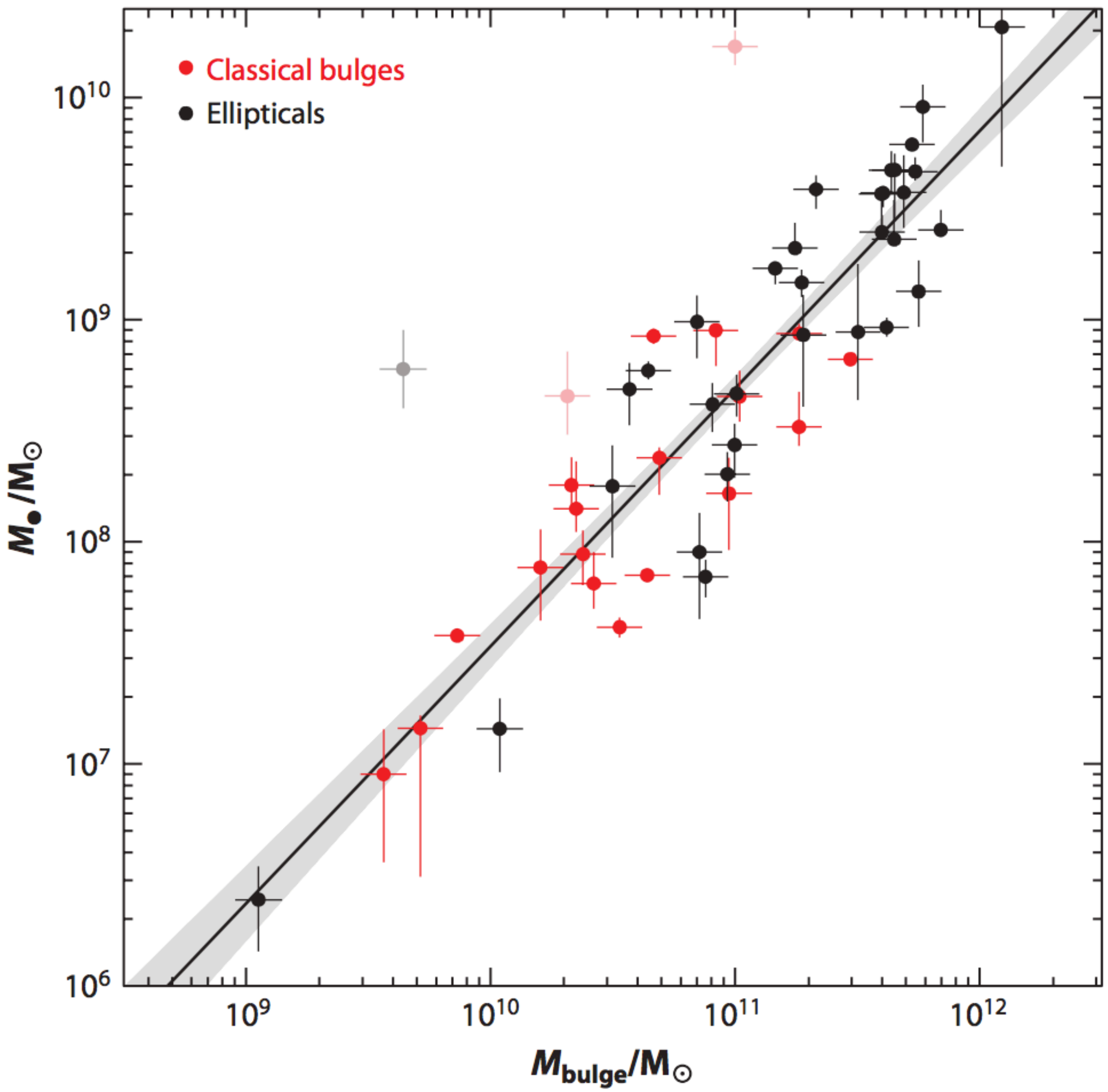
Thank you for the attention!

Dynamical friction process



Lee & Stahler 2014, A&A, 561, A84

BH and bulge mass relation



Kormendy & Ho 2013, ARA&A, 51, 511

Timescales

$$\frac{\mathrm{de}}{\mathrm{dt}} = -v\frac{|F_{\mathrm{DF}}|}{m_\bullet} \longrightarrow \langle\frac{\mathrm{de}}{\mathrm{dt}}\rangle = -\frac{\int_{r_-}^{r_+}\mathrm{dr}(\mathrm{v}/\mathrm{v_r})\,|\mathrm{F_{DF}}|/\mathrm{m}_\bullet}{\int_{r_-}^{r_+}\mathrm{dr}/\mathrm{v_r}}$$

$$\frac{\mathrm{dj}}{\mathrm{dt}} = -\frac{r v_\theta}{v}\frac{|F_{\mathrm{DF}}|}{m_\bullet} \longrightarrow \langle\frac{\mathrm{dj}}{\mathrm{dt}}\rangle = -j\frac{\int_{r_-}^{r_+}\mathrm{dr}(1/\mathrm{v_r v})\,|\mathrm{F_{DF}}|/\mathrm{m}_\bullet}{\int_{r_-}^{r_+}\mathrm{dr}/\mathrm{v_r}}$$

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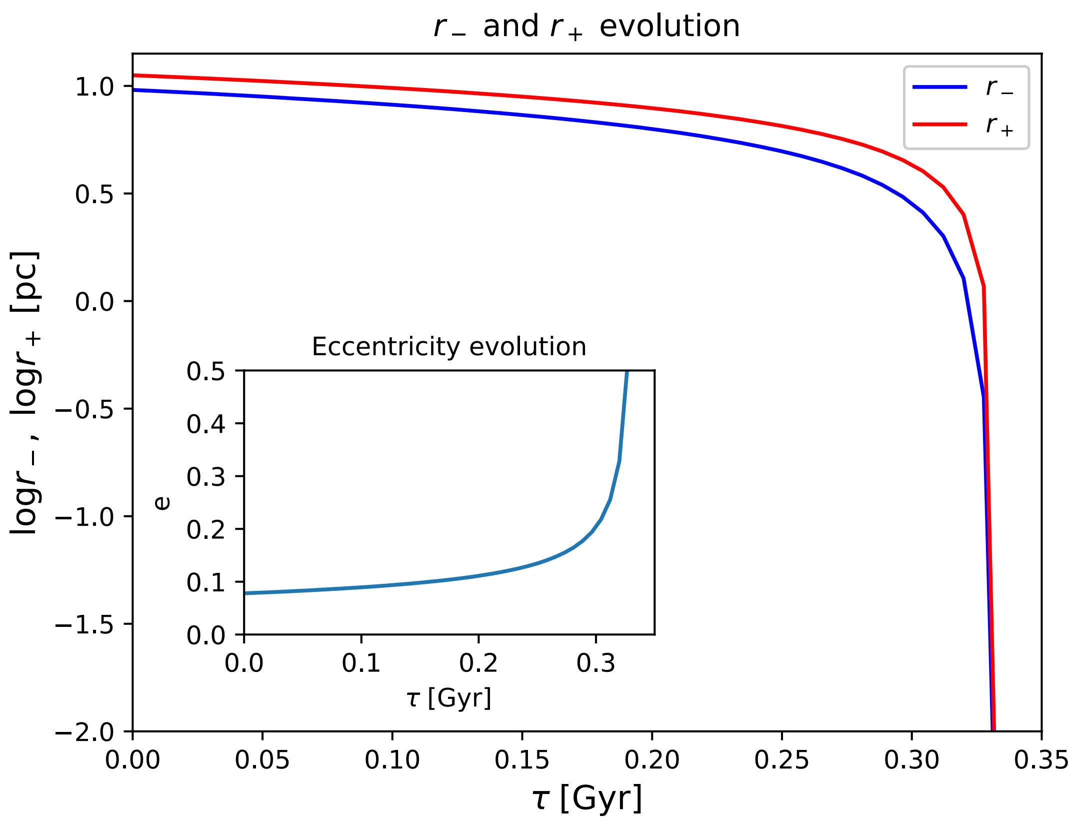
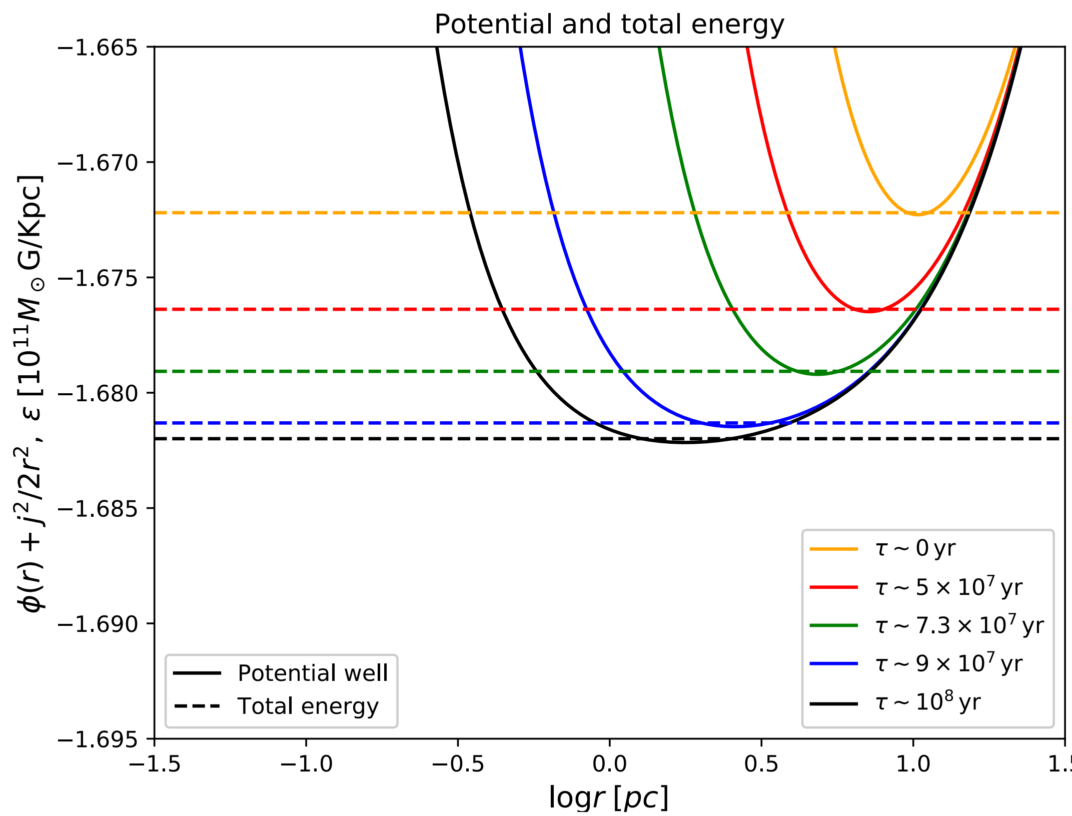


r_- and r_+ evolution
r_-
r_+
Eccentricity evolution
e
τ [Gyr]
$\log r_-$, $\log r_+$ [pc]
τ [Gyr]



Potential and total energy
$\tau \sim 0$ yr
$\tau \sim 5 \times 10^7$ yr
$\tau \sim 7.3 \times 10^7$ yr
$\tau \sim 9 \times 10^7$ yr
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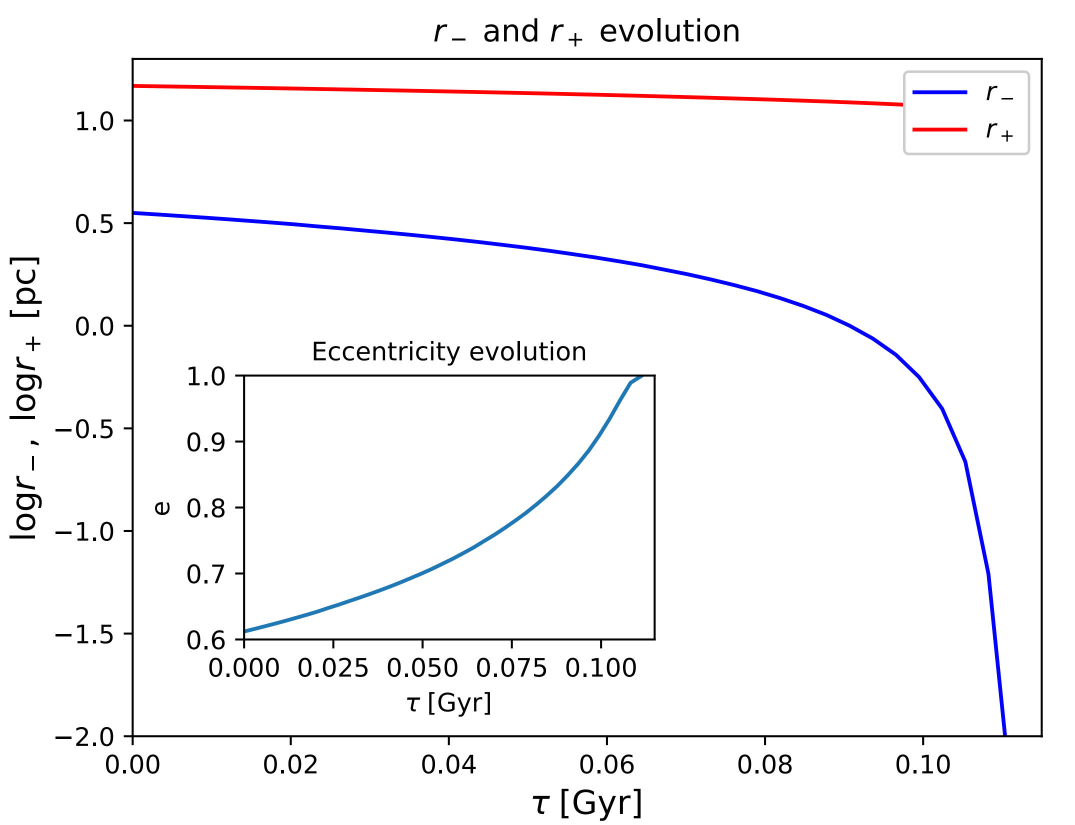
Potential well
Total energy
$\phi(r) + j^2/2r^2$, ε [$10^{11} M_\odot$ G/Kpc]
$\log r$ [pc]



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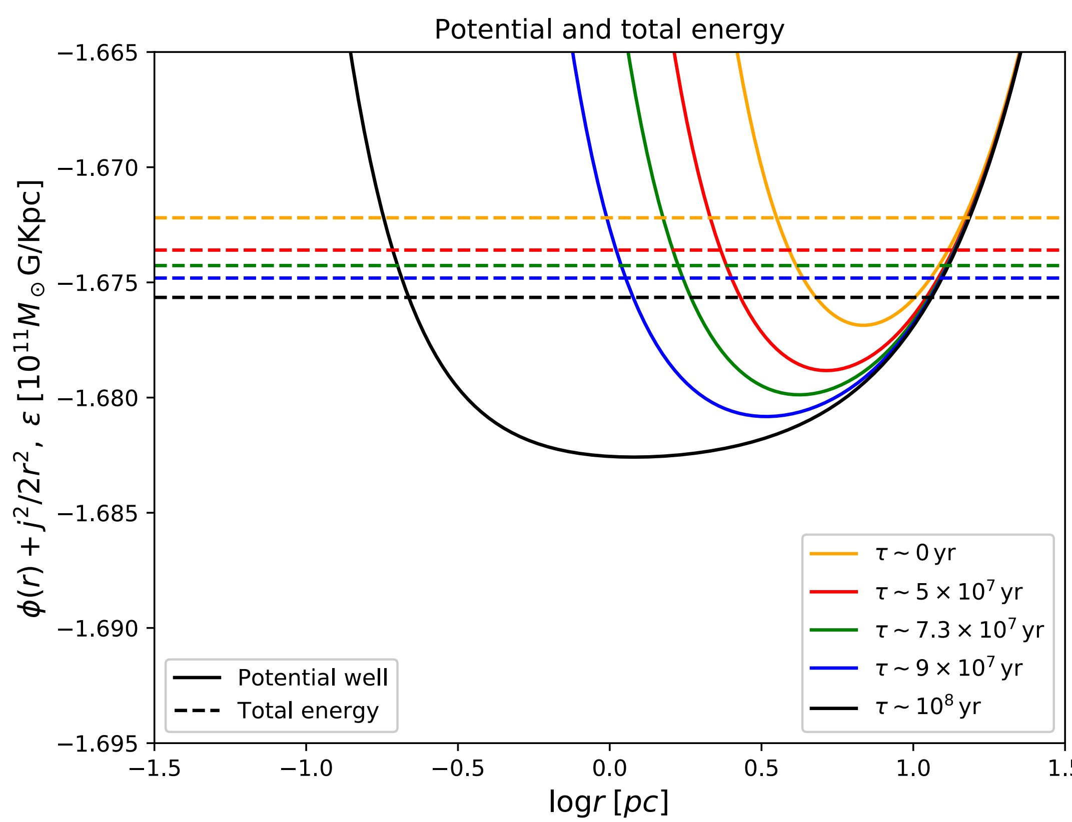

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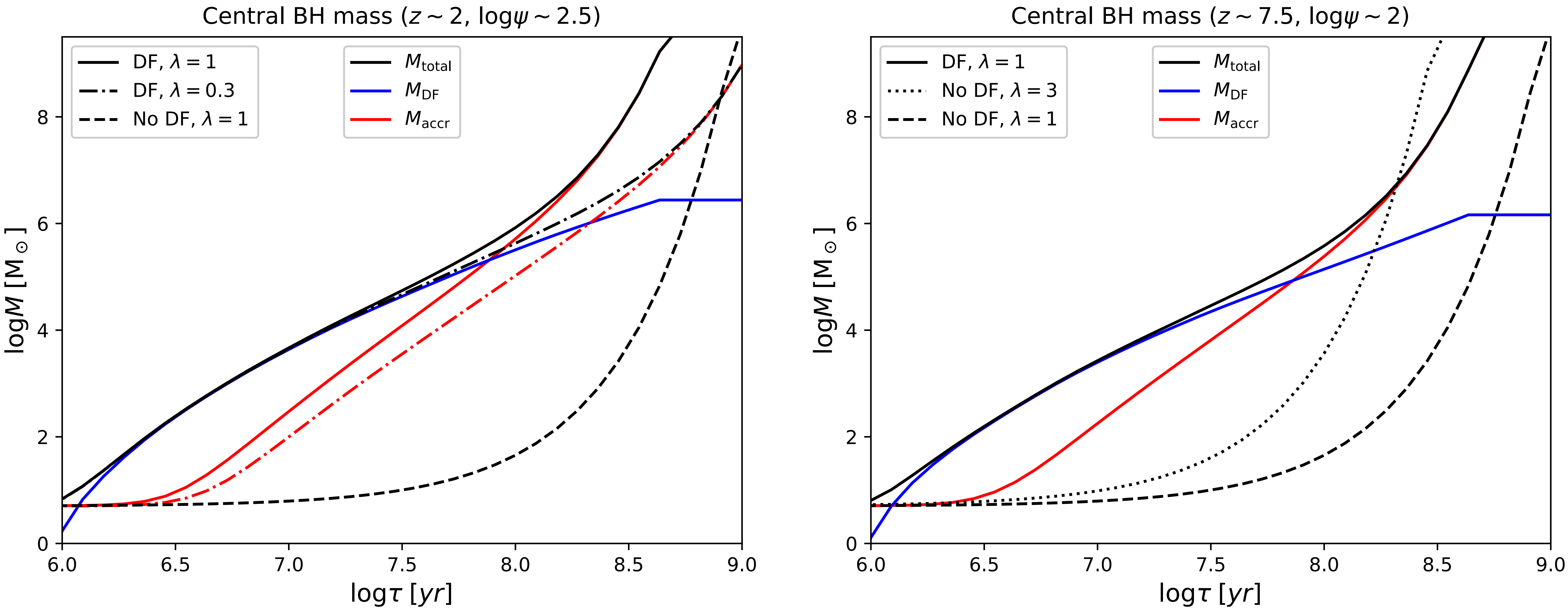

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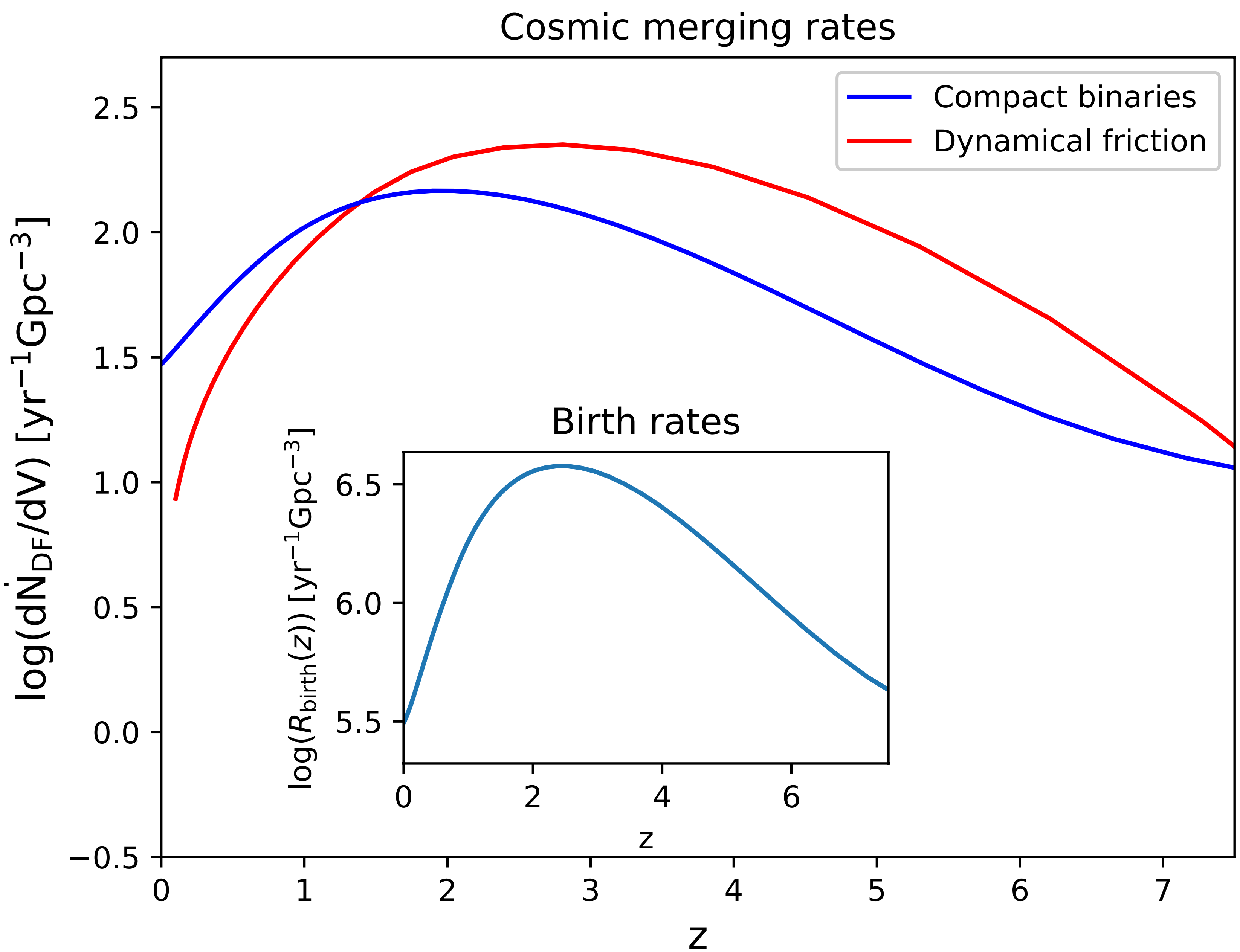

Gravitational waves detection