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Probing the wind and funnel formed in super-Eddington accretion using X-ray reverberation

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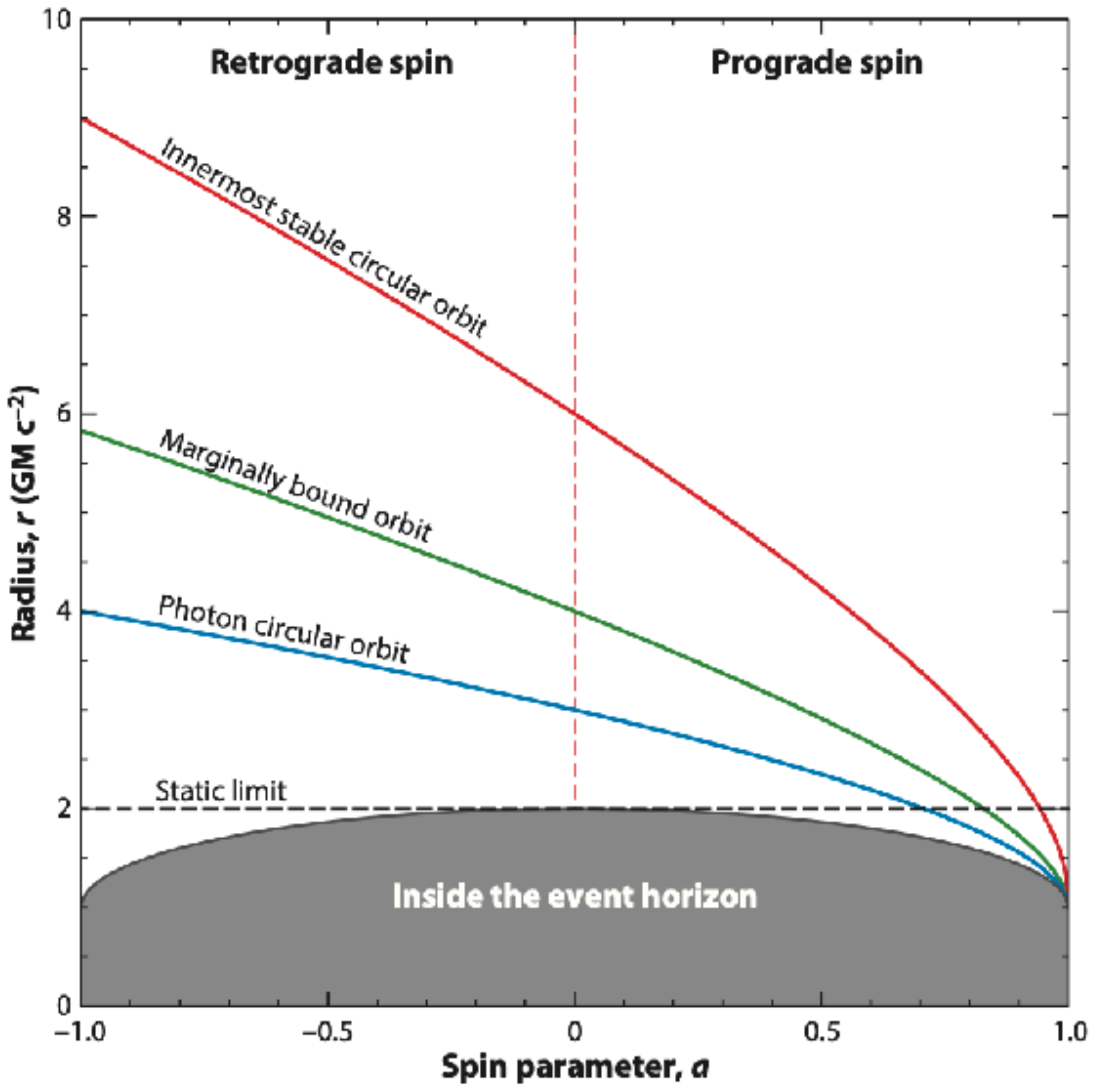
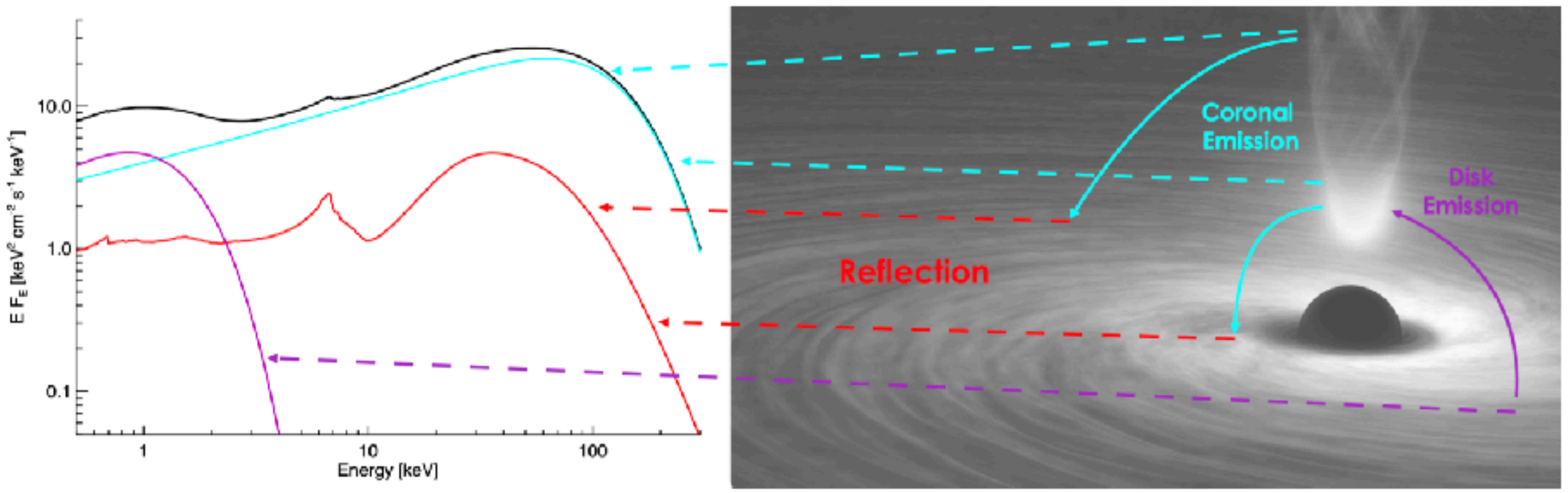
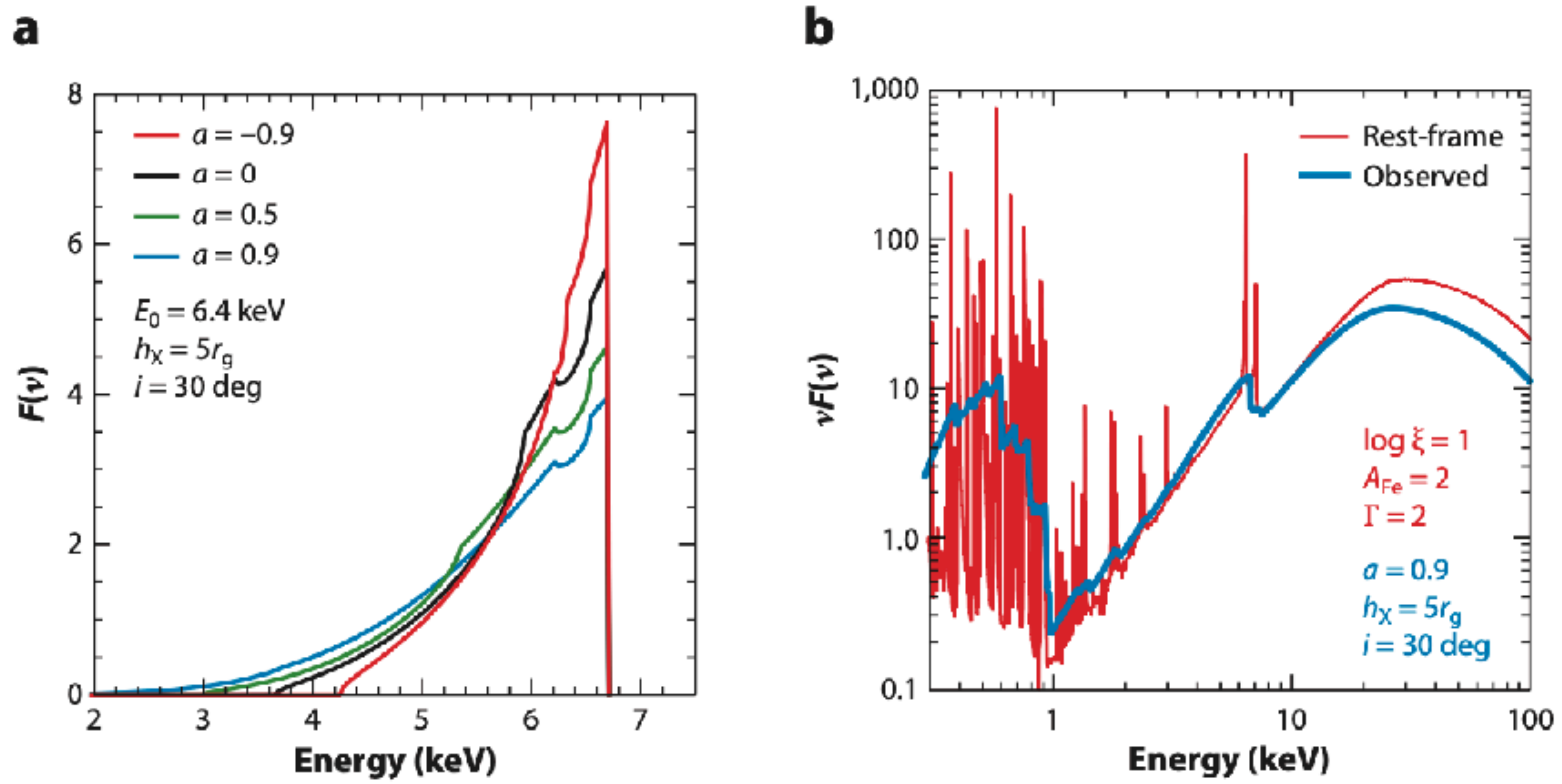
Reverberation

Measurement of Spin





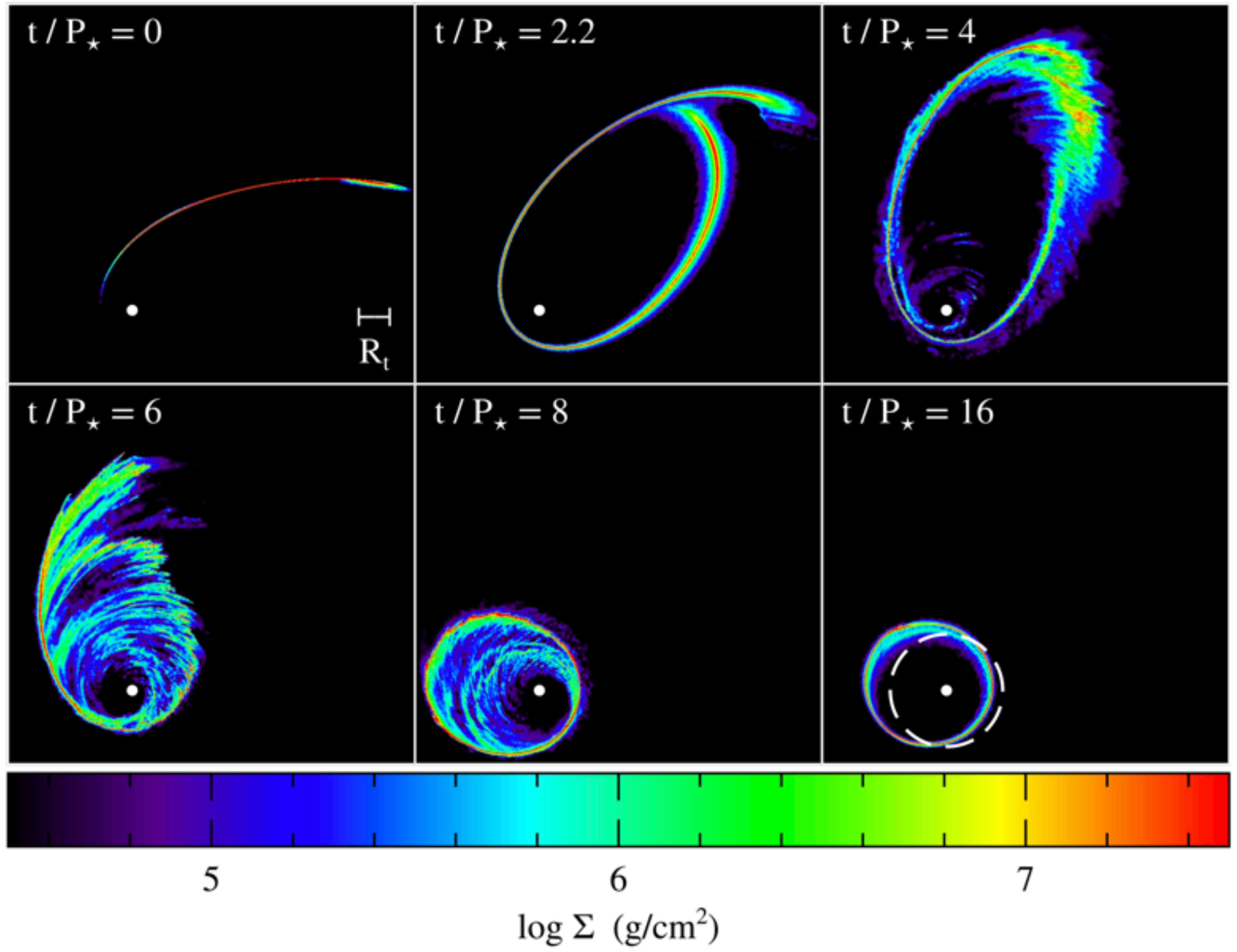
Kalemci et al. 2022



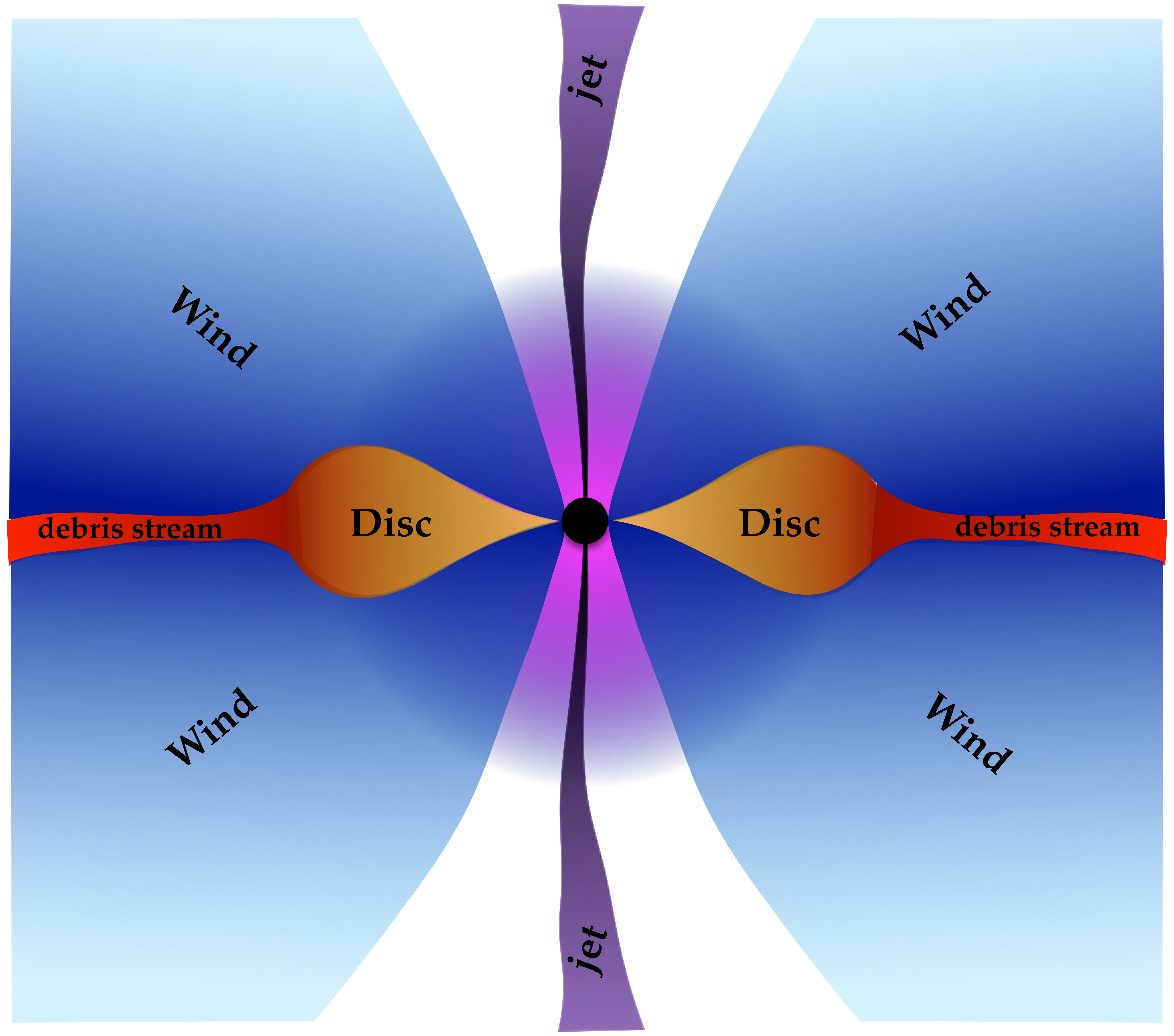
Reynolds 2021

Super-Eddington Accretion

Different geometry and outflow



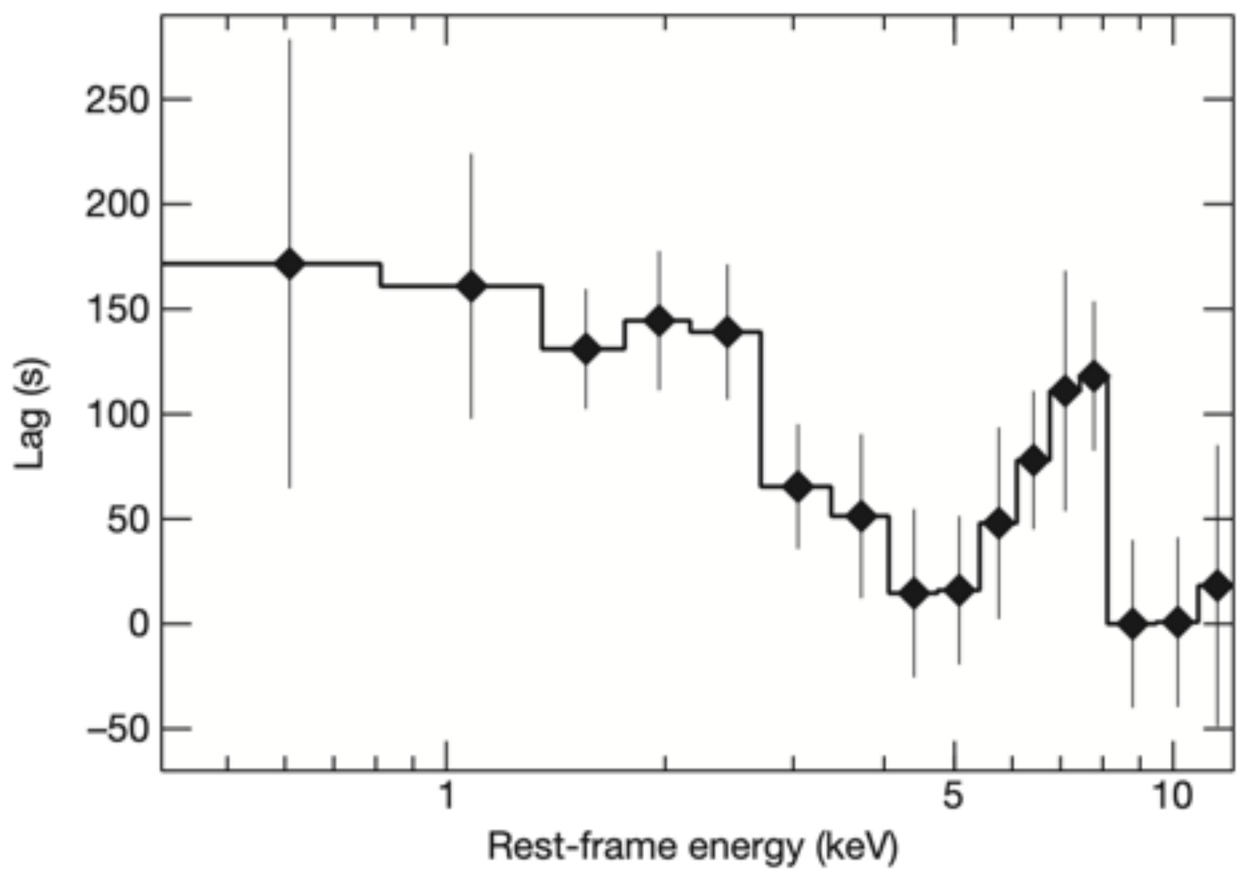
Bonnerot et al. 2016

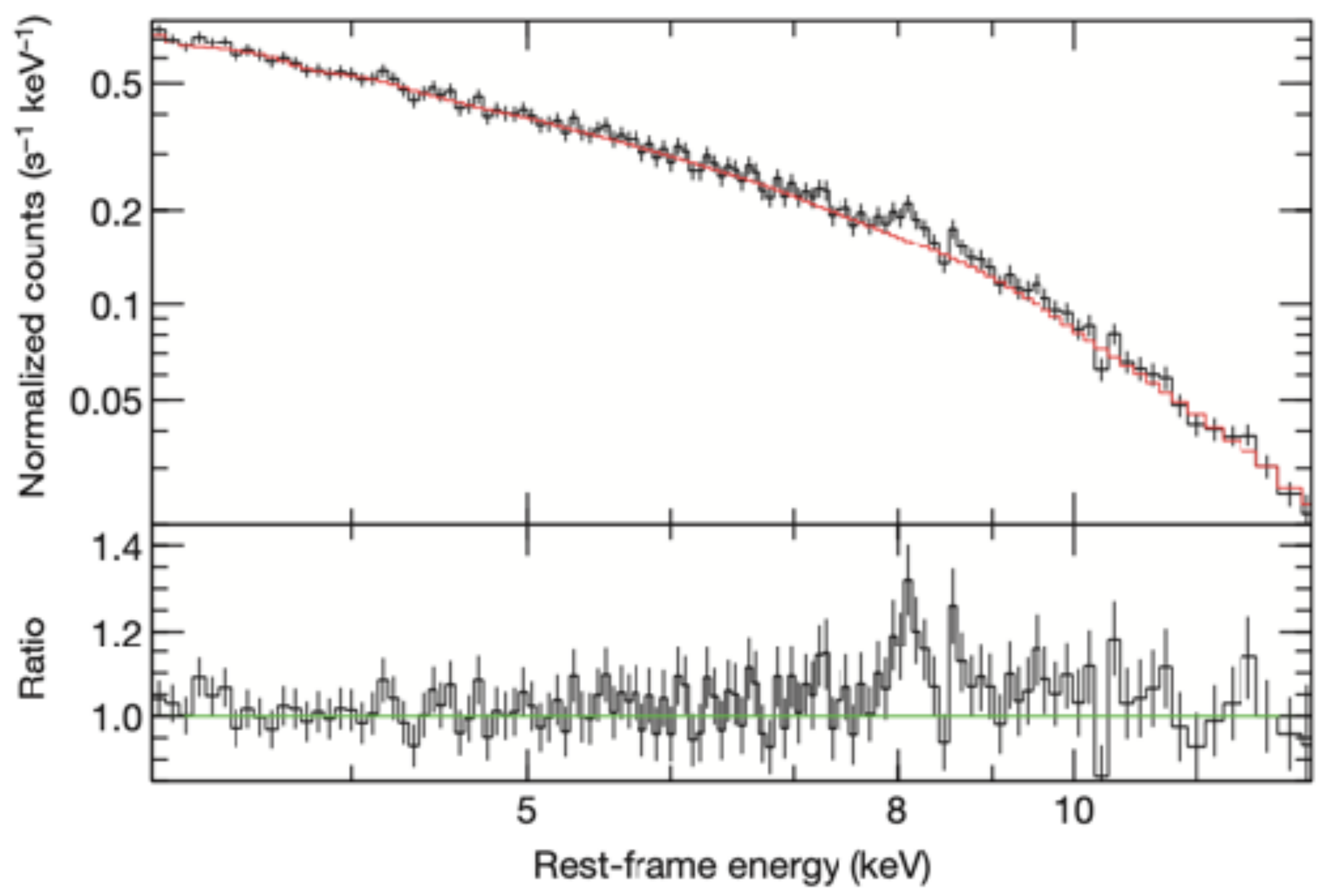


Dai et al. 2021

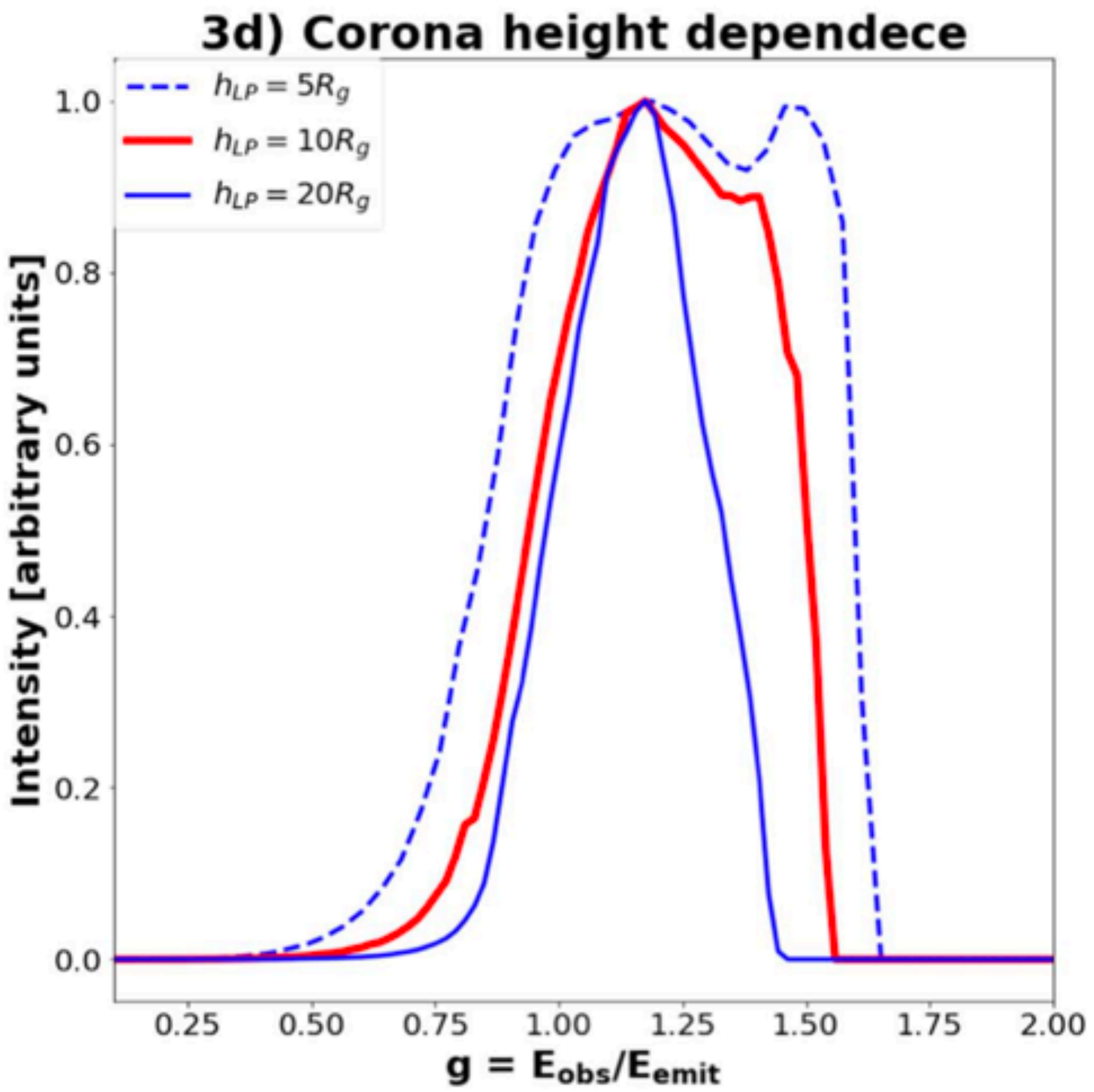
Super-Eddington Accretion

X-ray reverberation





Kara et al. 2016



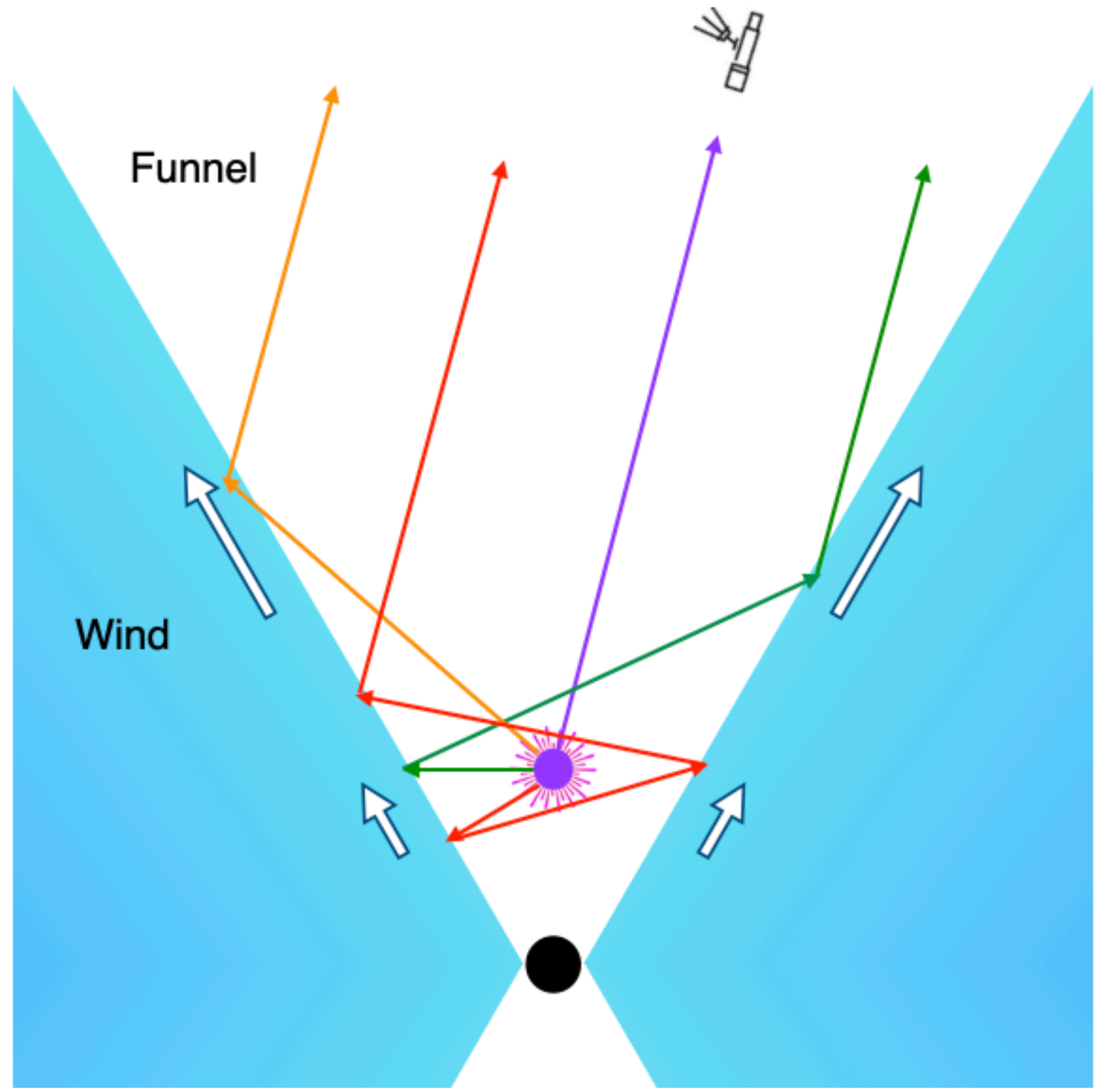
Thomsen et al. 2019

Set-up

Corona-wind-funnel system

Assumption:

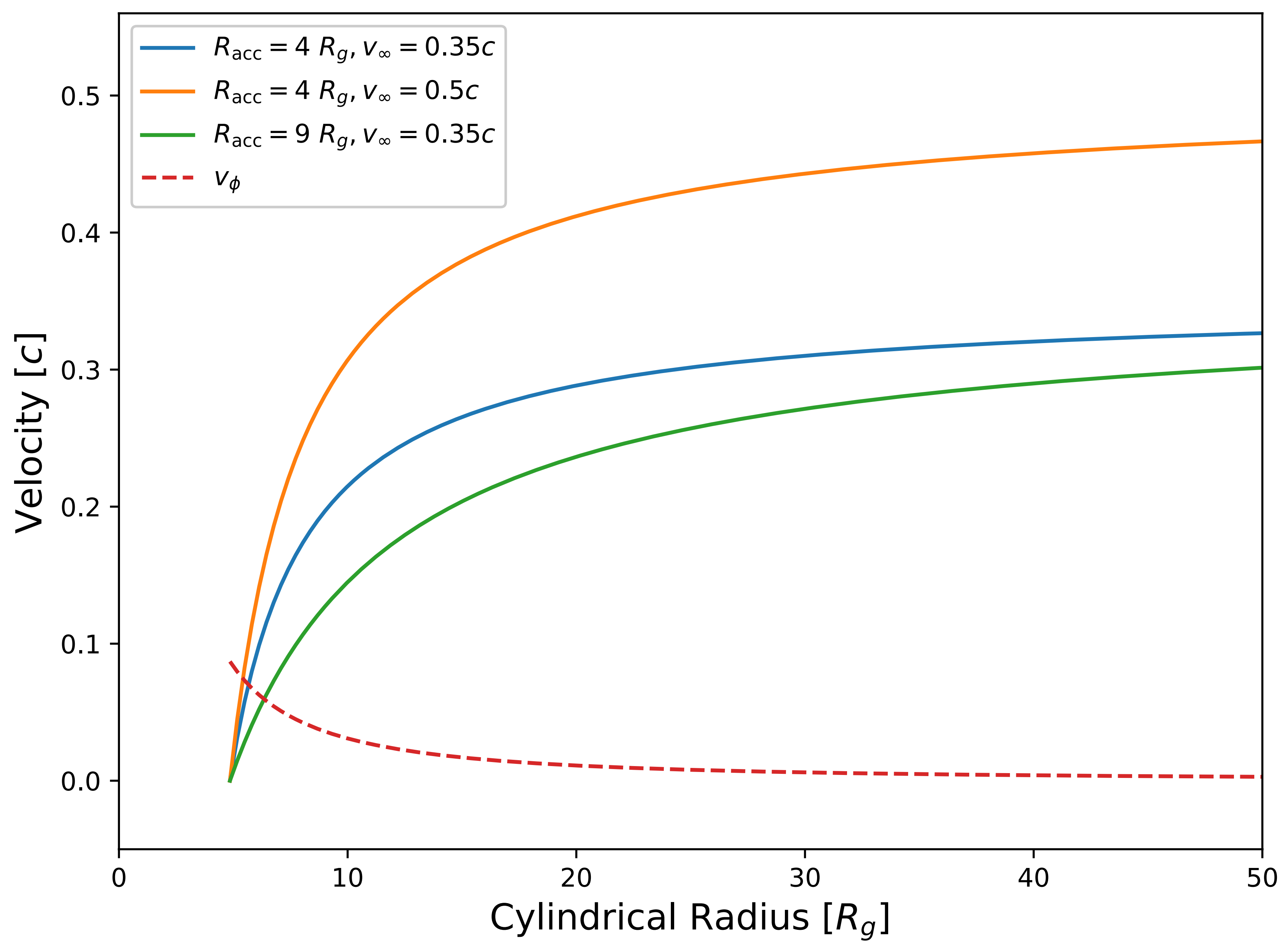
(1) Cone geometry
(2) Radial wind (ignore rotation for now)
(3) Lamp post corona



Parameters:

(1) Corona Height
(2) Funnel open angle
(3) Wind velocity (terminal velocity & 1 parameter for acceleration)

$$v = v_0 + (v_\infty - v_0)\left[\frac{(l/R_{\rm acc})^\alpha}{(l/R_{\rm acc})^\alpha + 1}\right]$$



Method

GR ray-tracing

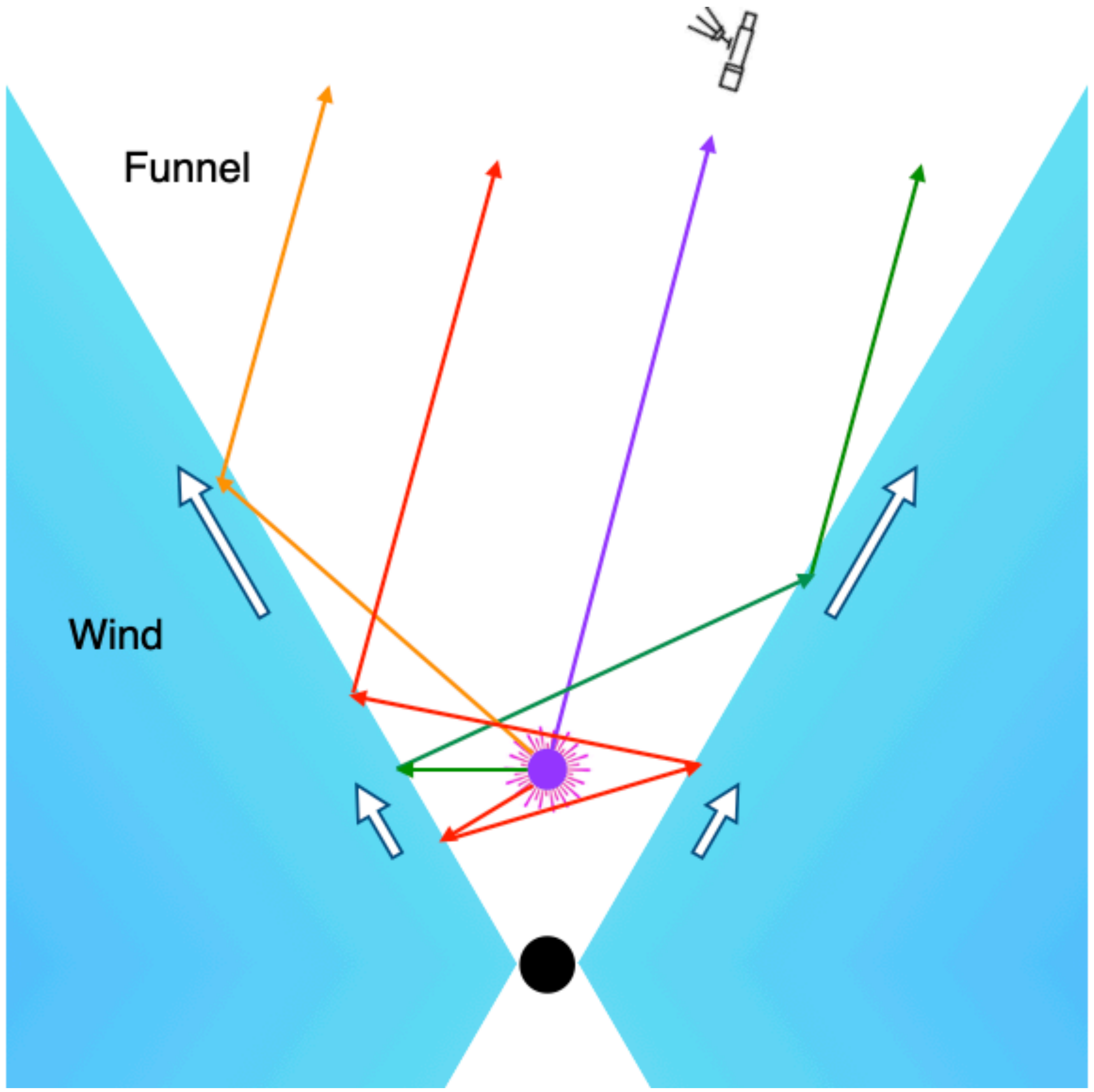
$$p_t = -E \quad \dot{t} = E + \frac{2r(r^2+a^2)E - 2aL}{\Sigma\Delta}$$

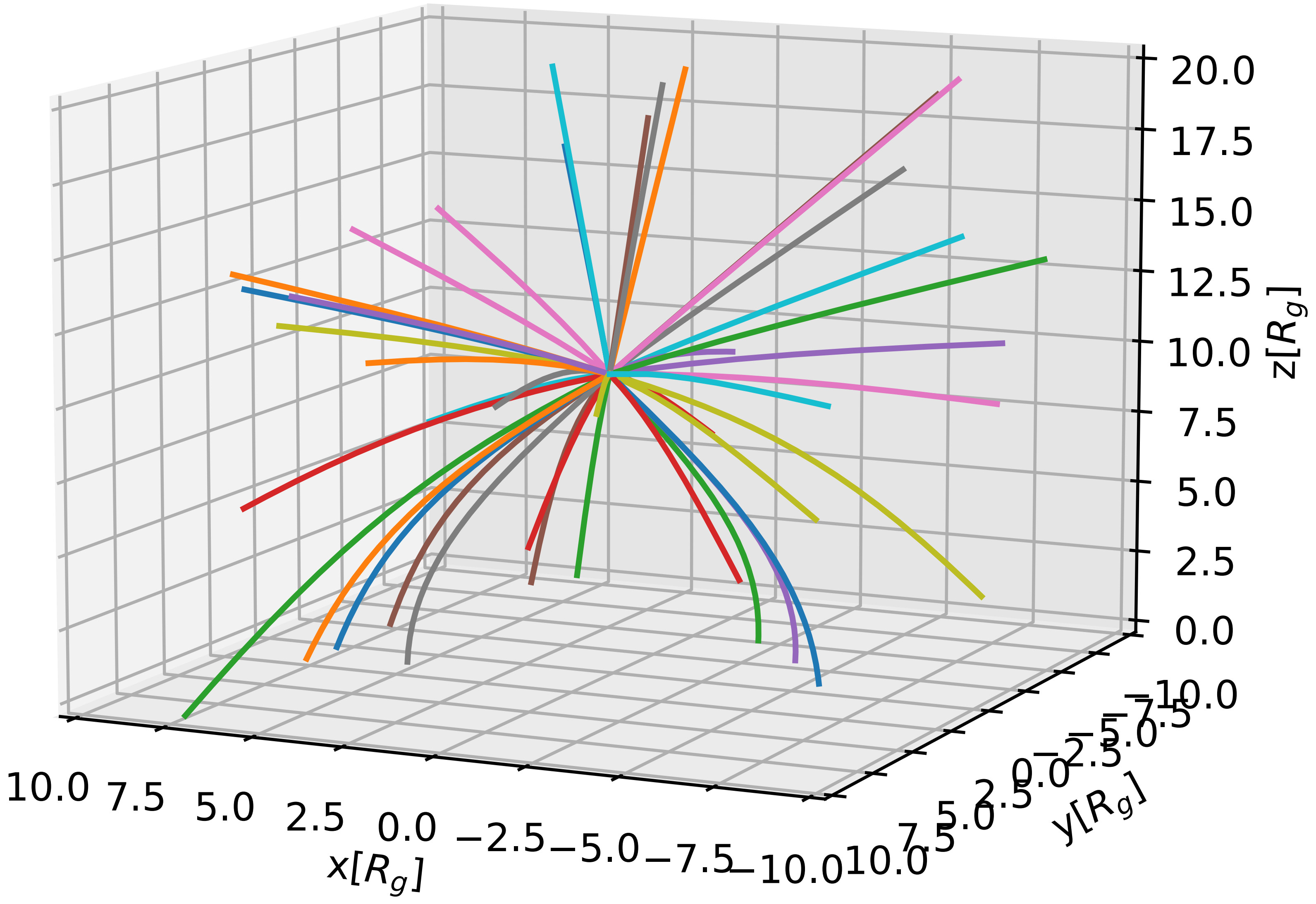
$$p_r = \frac{\Sigma}{\Delta}\dot{r}$$

$$\dot{p}_r = \frac{(r-1)((r^2+a^2)H - \kappa) + rH\Delta + 2r(r^2+a^2)E^2 - 2aEL}{\Sigma\Delta} - \frac{2p_r^2(r-1)}{\Sigma}$$

$$p_\theta = \Sigma\dot{\theta} \quad \dot{p}_\theta = \frac{\sin\theta\cos\theta}{\Sigma}\left(\frac{L^2}{\sin^4\theta} - a^2(E^2+H)\right)$$

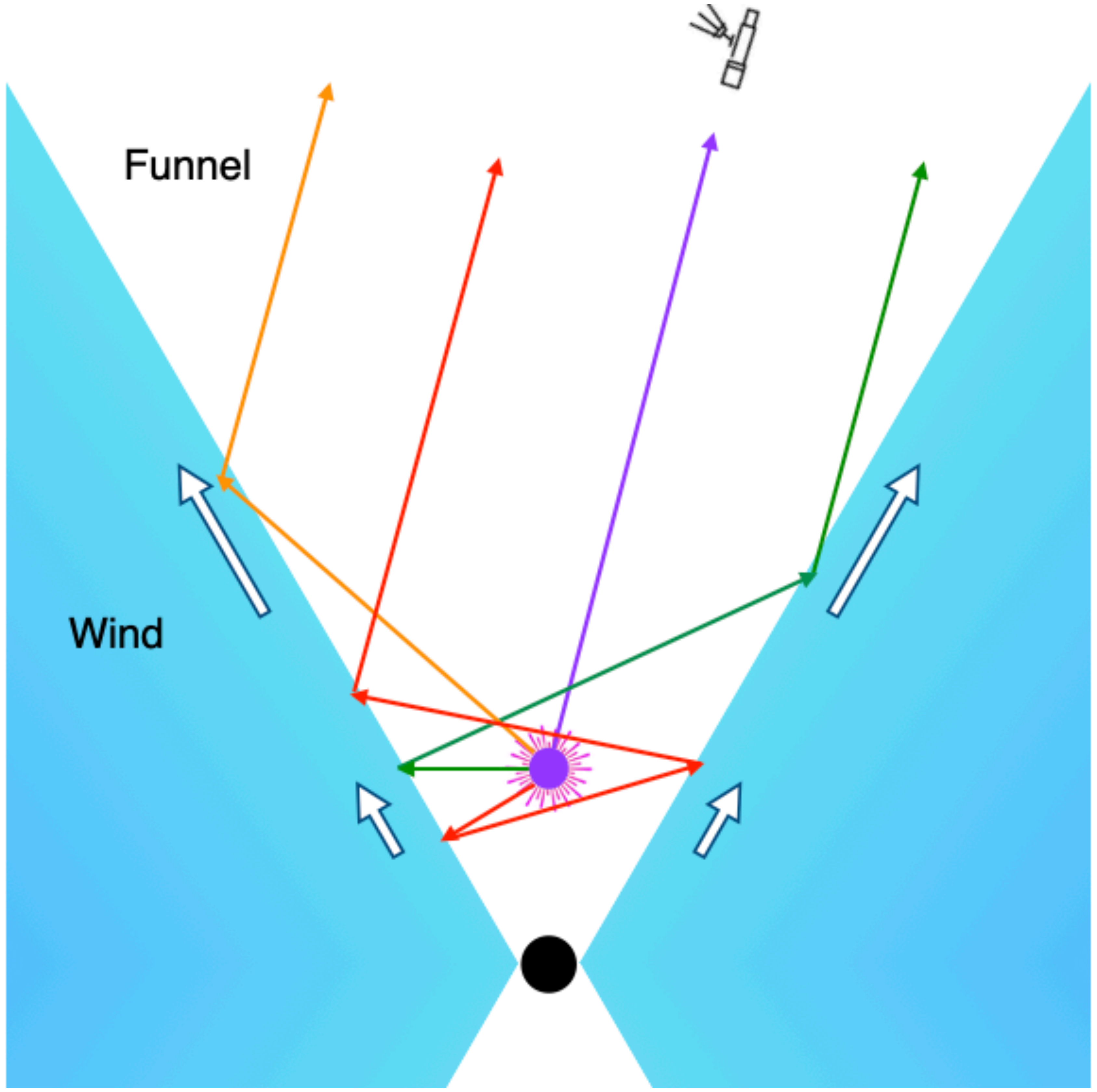
$$p_\phi = L \quad \dot{\phi} = \frac{2arE + (\Sigma - 2r)L/\sin^2\theta}{}$$





Method

Monte-Carlo simulation



1. Generate photons with energy following a power-law distribution, emitted isotropically in the frame of corona

2. Forward ray-tracing from corona to funnel (or escape)

3. After the photon crosses the funnel, use Monte-Carlo method to decide if an interaction happens within the step or not.

4. If an interaction happens, determine whether an elastic scattering or fluorescence process (generating a Fe Kα line) happens

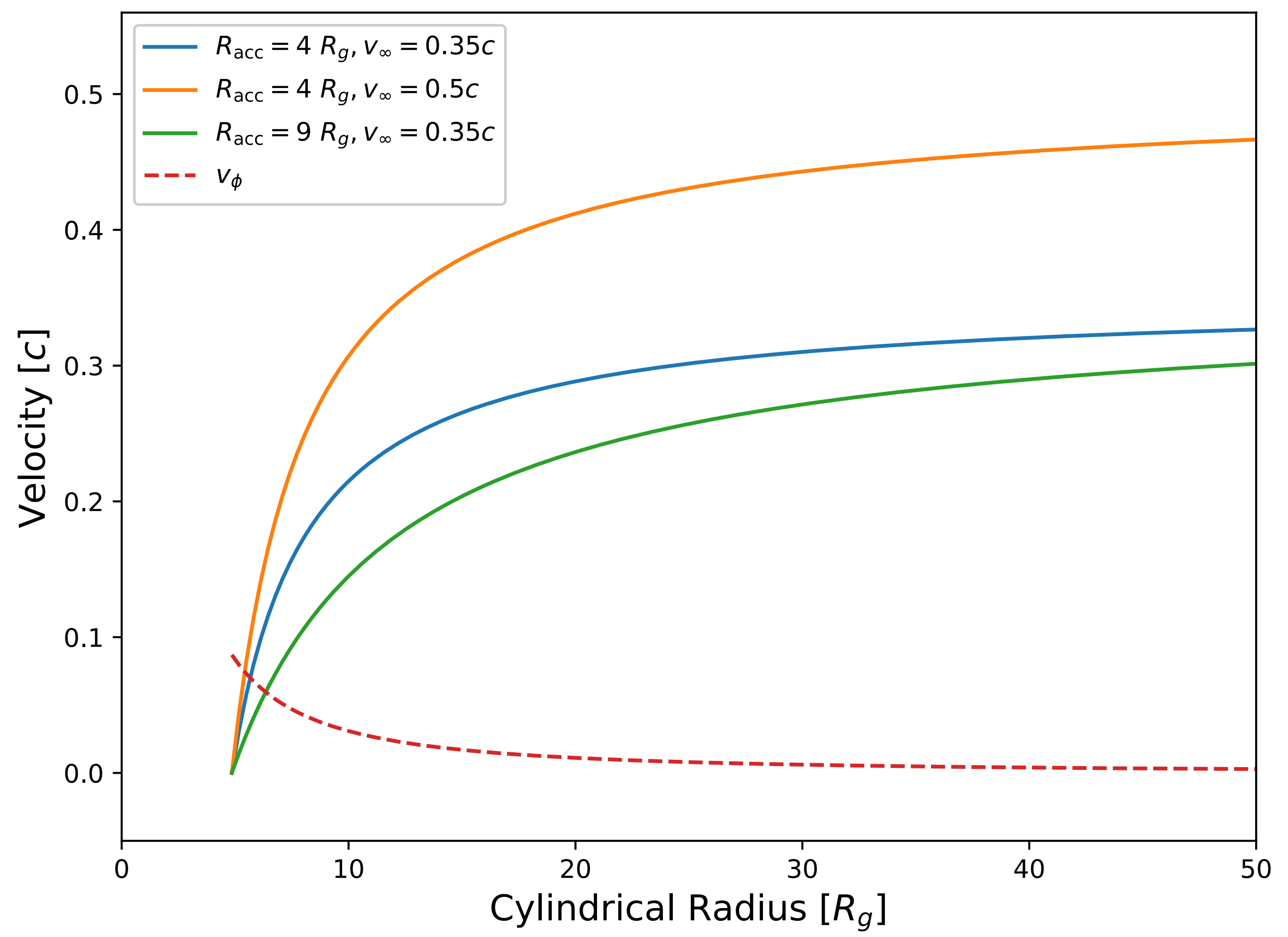
5. The reflected photon is emitted isotropically in the frame of the funnel gas element

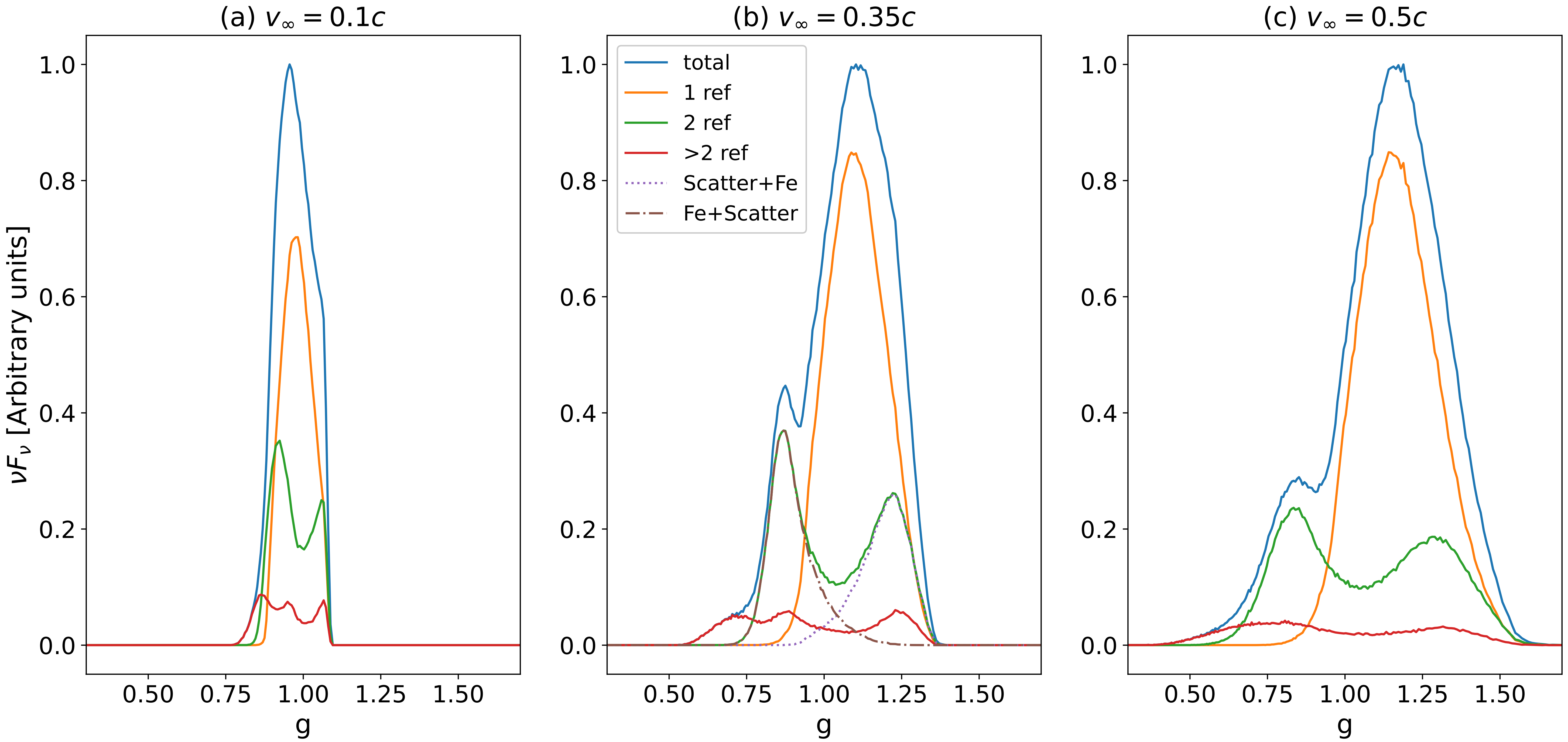
6. Go back to step 2, and trace 2nd and more reflections.

7. Eventually, we collect the photons escaped

Result

Dependence on terminal velocity



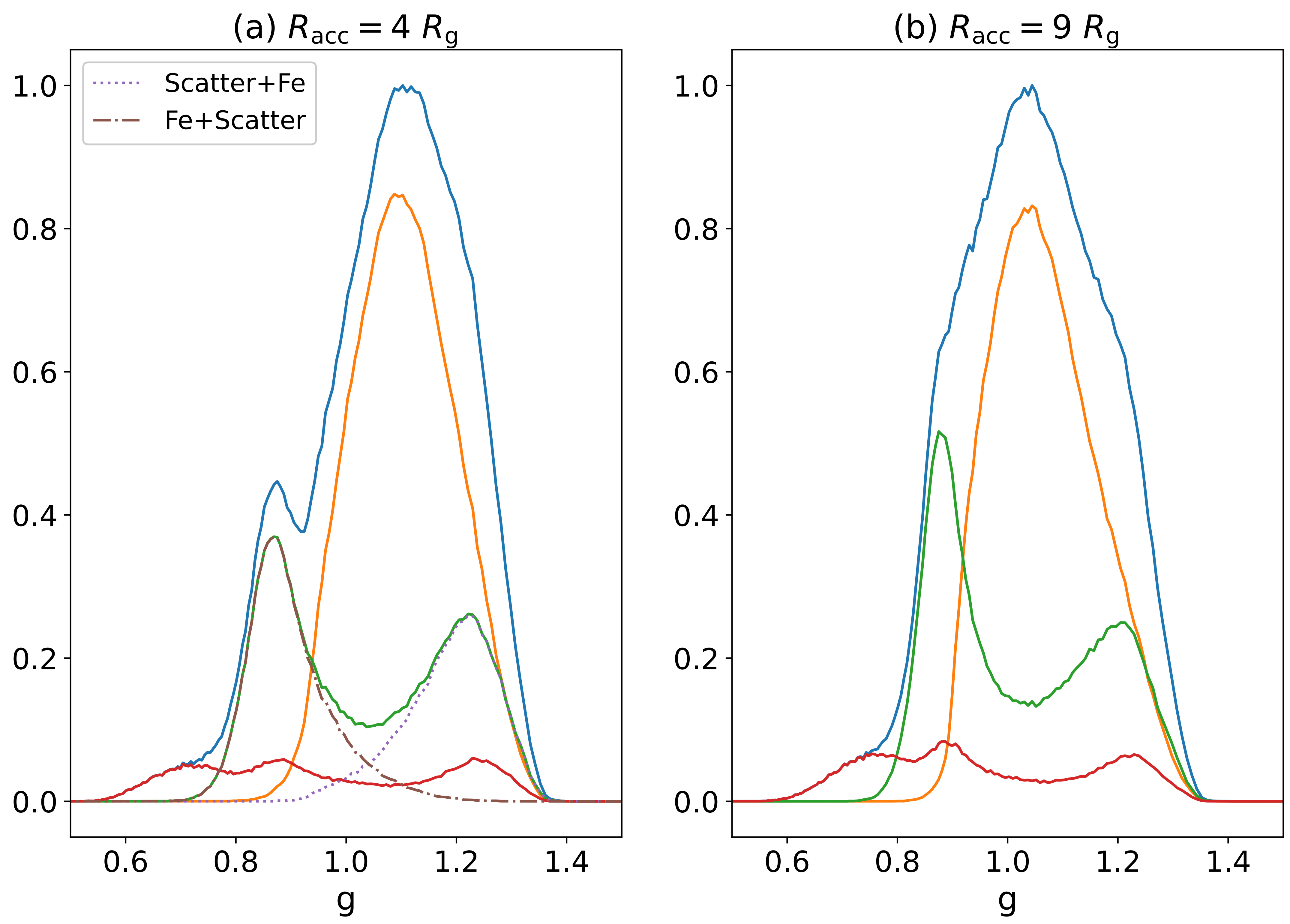


As the terminal velocity increases, the following will also increase:

1. Blueshift of the primary peak
   ——Doppler blueshift
2. Line width of the primary peak
   ——Large velocity span, larger energy shift span
3. Separation between the primary and secondary peak
   ——the winds are moving away from each other
4. The ratio flux (1 ref)/(2 ref)
   ——beaming effect

Result

Dependence on acceleration radius



$$v = v_0 + (v_\infty - v_0)\left[\frac{(l/R_{acc})^\alpha}{(l/R_{acc})^\alpha + 1}\right]$$

As the R_acc increase, the following will decrease:

1. Blueshift of the primary peak

   ——slower acceleration

2. Separation between the primary and secondary peak

   ——the winds are moving away from each other

3. The ratio flux (1 ref)/(2 ref)

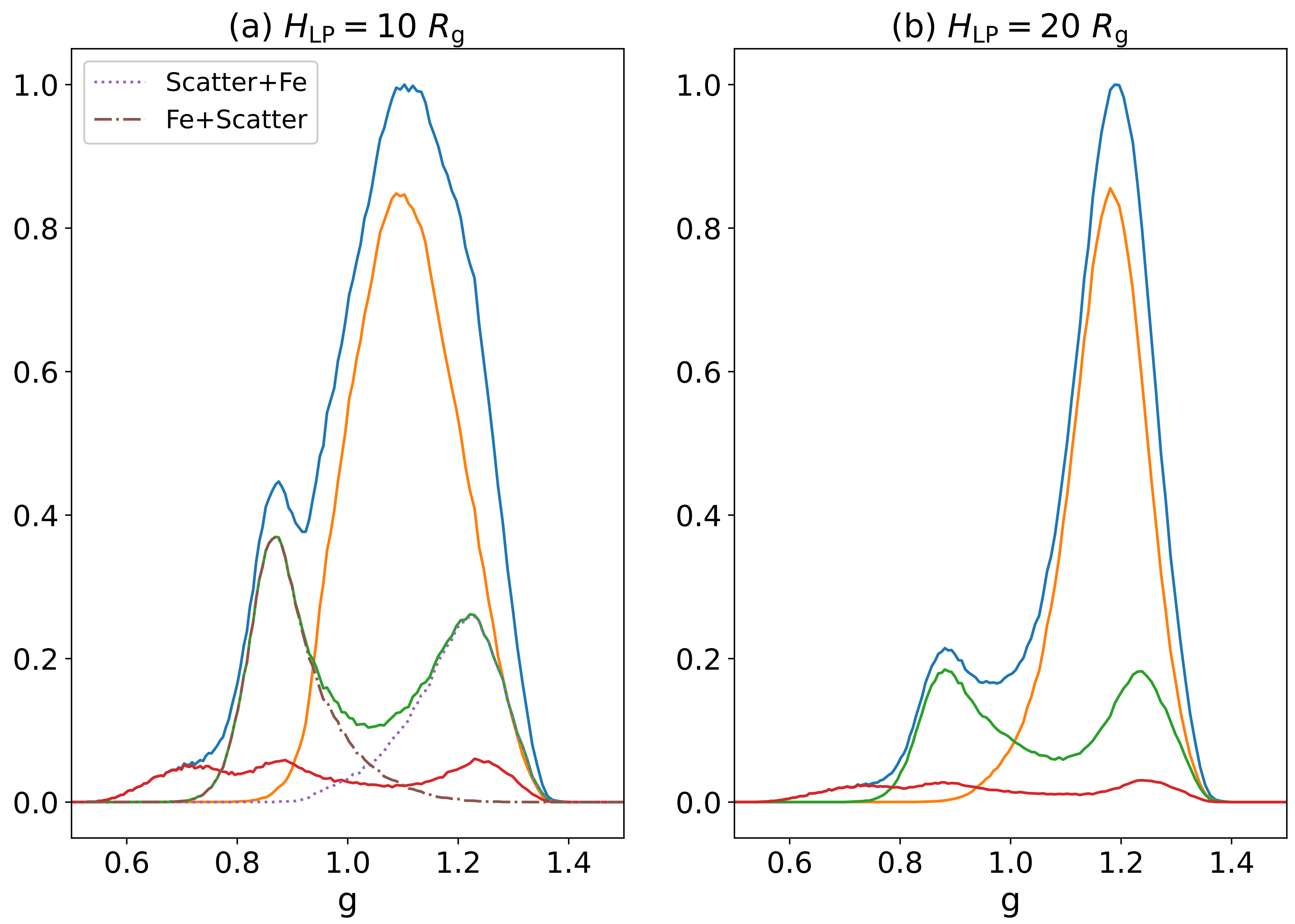
   ——beaming effect

No apparent change on the line width of the primary peak

——decided by the terminal velocity

Result

Dependence on corona height



As the terminal velocity increase, the following will also increase:

1. Blueshift of the primary peak

    ——Doppler blueshift

2. Separation between the primary and secondary peak

    ——the winds are moving away from each other

3. The ratio flux (1 ref)/(2 ref)

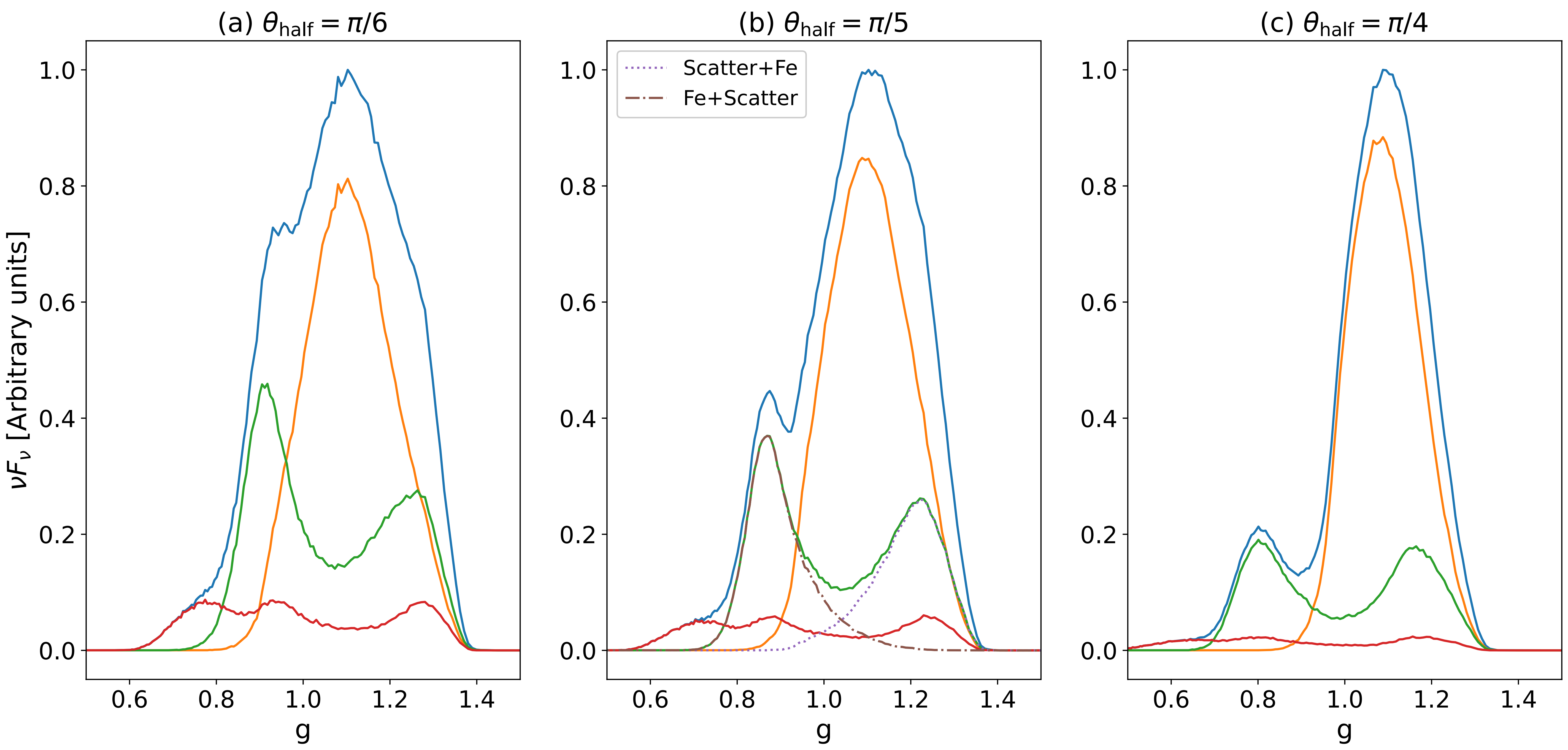
    ——beaming effect

But the line width decreases

——less illumination on the lower part which has a strong redshift

Result

Dependence on open angle



As the open angle increase, the following will also increase:

1. Separation between the primary and secondary peak

   ——the winds are moving away from each other

2. The ratio flux (1 ref)/(2 ref)

   ——more likely to escape after 1 reflection

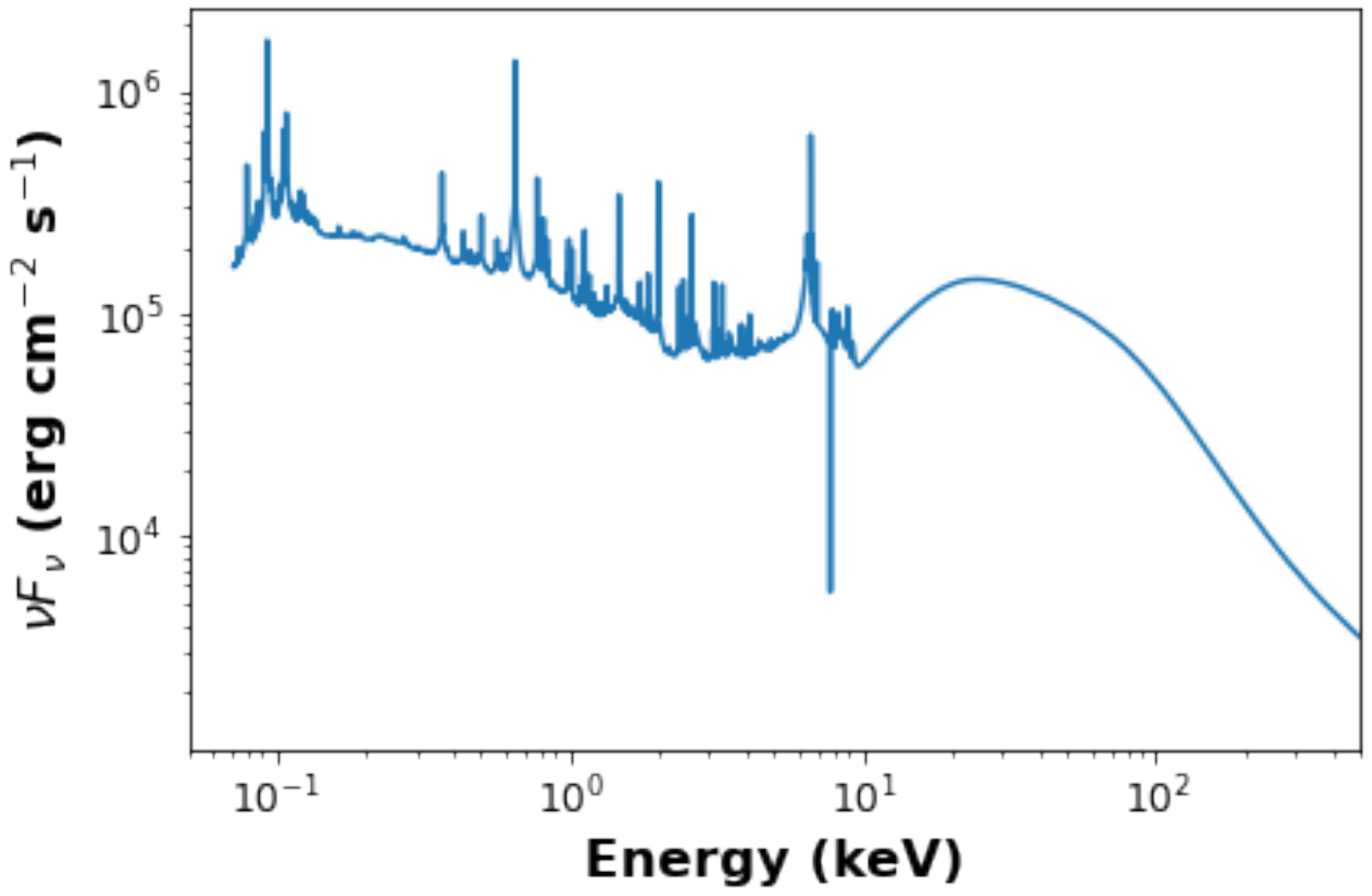
Summary and discussion

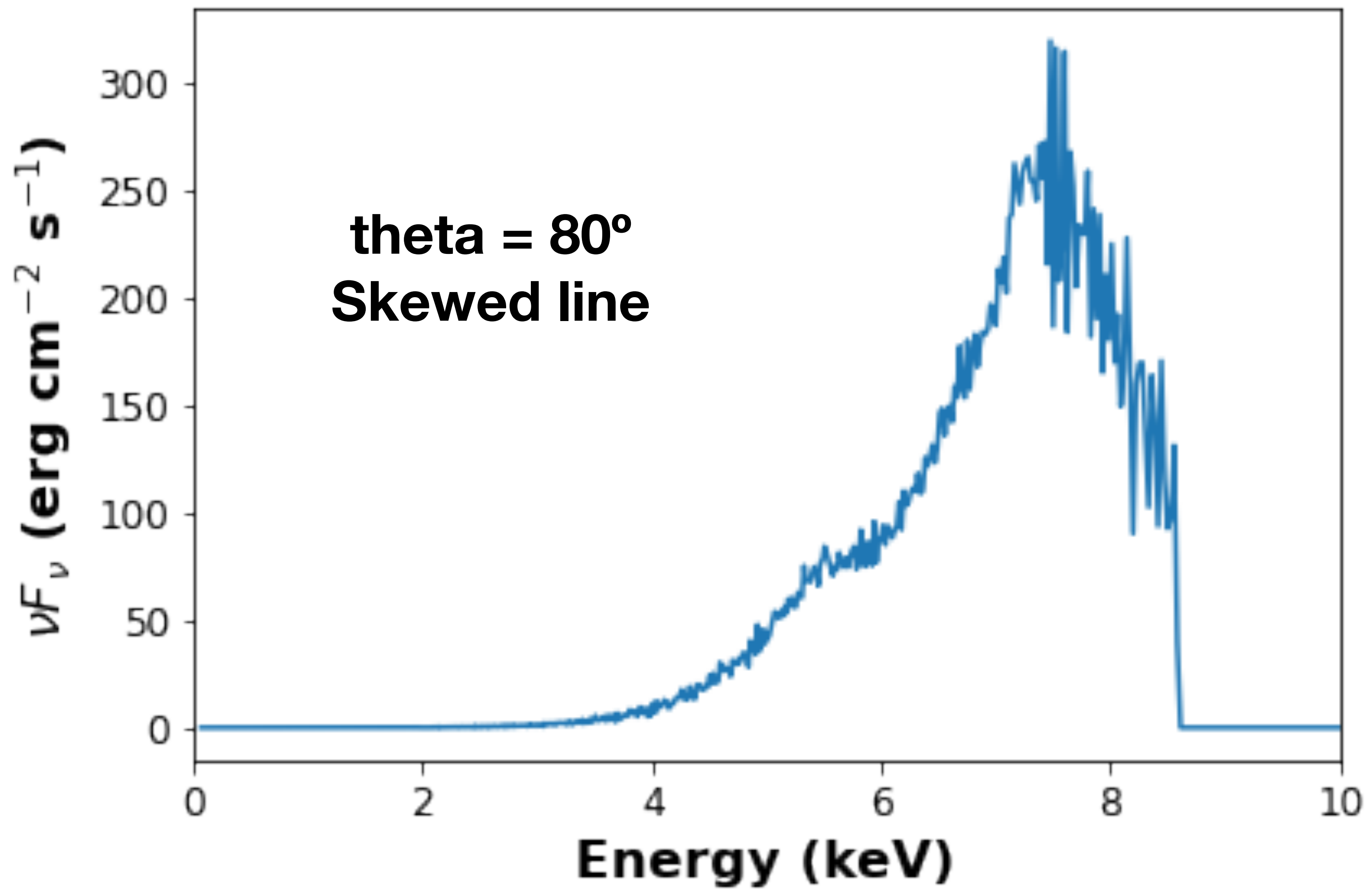
- We use GR ray-tracing and Monte-Carlo method to generate a series of Fe Kα spectra from a super-Eddington system
- The spectral behavior is generally consistent with previous work
- Double-peak spectra can also appear in super-Eddington system
- Application
    - (1) probing the corona, wind and geometry
    - (2) time evolution

Thank you!

Future plan

Apply it to X-ray reflection spectra





Convolve
Single emission angle
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