Ray-tracing reflection spectra of black-hole binaries

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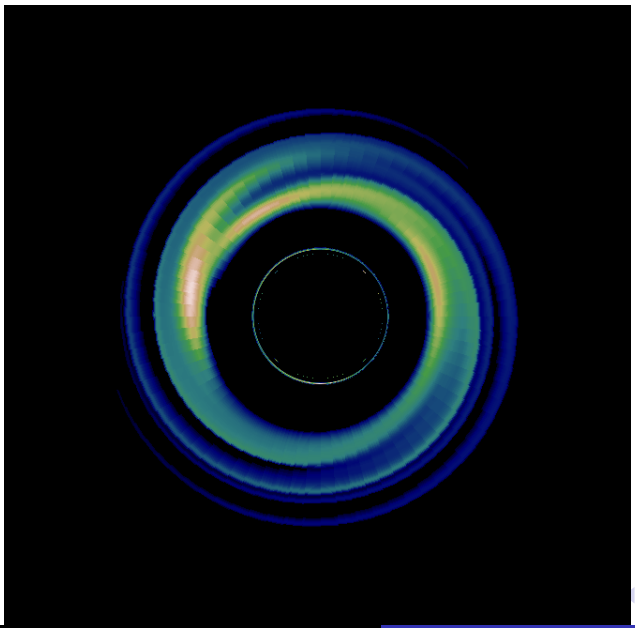

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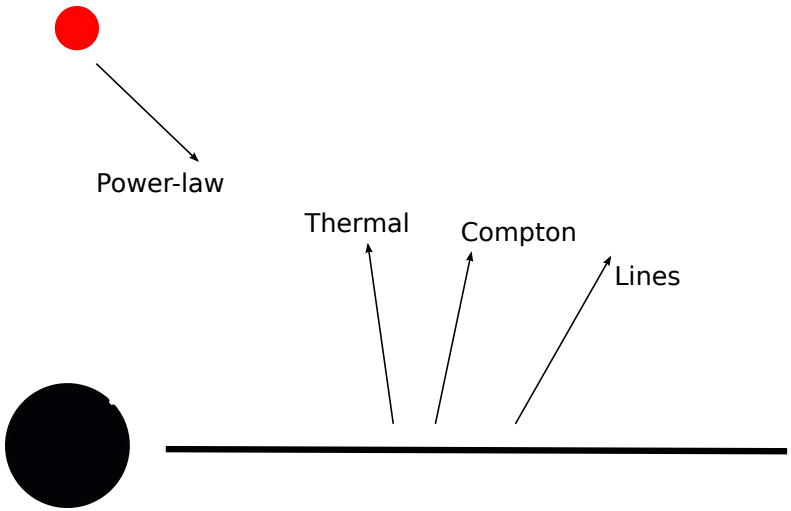
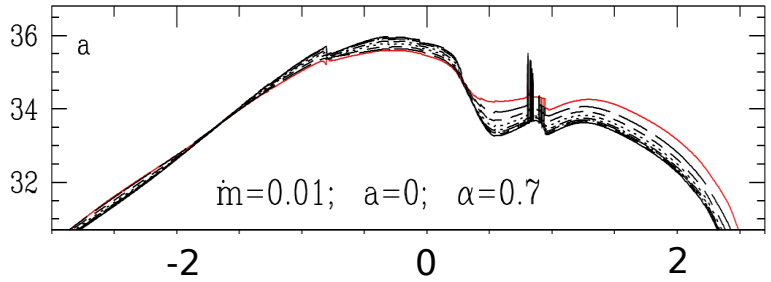




Rozanska+11

Relection spectrum

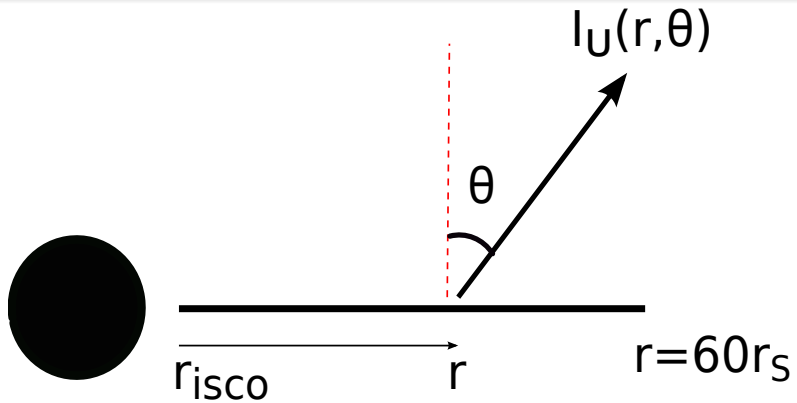
- X-ray source (lamp)
- Reprocessed in the disk
- Emitted spectrum = thermal + Compton + lines

Agata's code

- Hydro equilibrium: slim disk (Sądowski+11)
- Radiative transfer: PL, BB, Compton, iron lines
- Radiative equilibrium

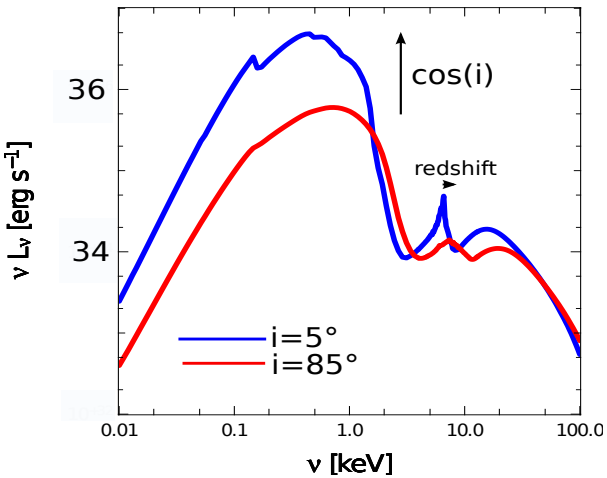
End product

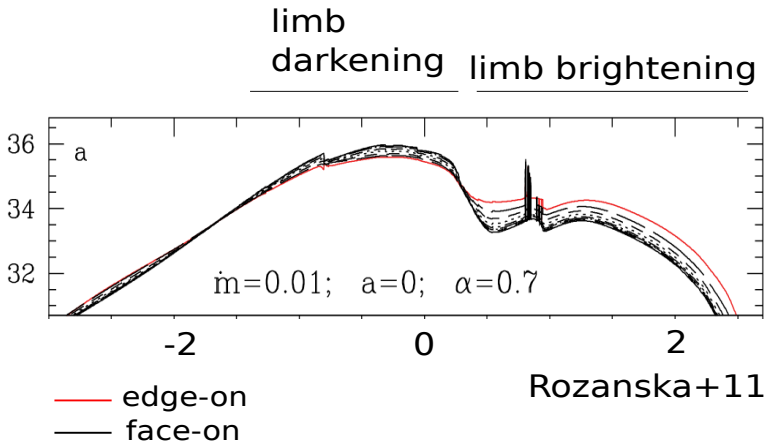
- $I_\nu(r,\theta) \rightarrow$ raytracing $\rightarrow$ observable spectrum



Agata's code: parameters

- BH: $M = 10\,M_\odot$, $\dot{m} = 0.01\,\dot{m}_{\rm Edd}$, $a = 0$ or 0.98
- Lamp: $\alpha = 0.7$ ($I_\nu^{\rm lamp} \propto \nu^{-\alpha}$), $z_{\rm lamp} = 5\,r_S$
- Ionization parameter: $\log \xi \approx 6$





Comparing spectra

- Raytraced spectrum; Agata's "local" spectrum
- GR broadening of the line

GR effects

Redshift effect

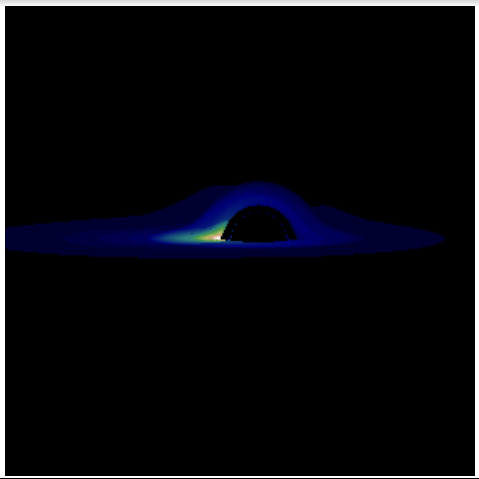
- $\nu^{\rm obs} = g\,\nu^{\rm em}$ (g redshift factor)
- $I_\nu^{\rm obs} = g^3\, I_\nu^{\rm em}$ [... movie ...]

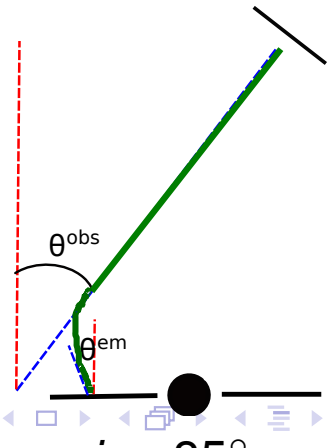
Beaming

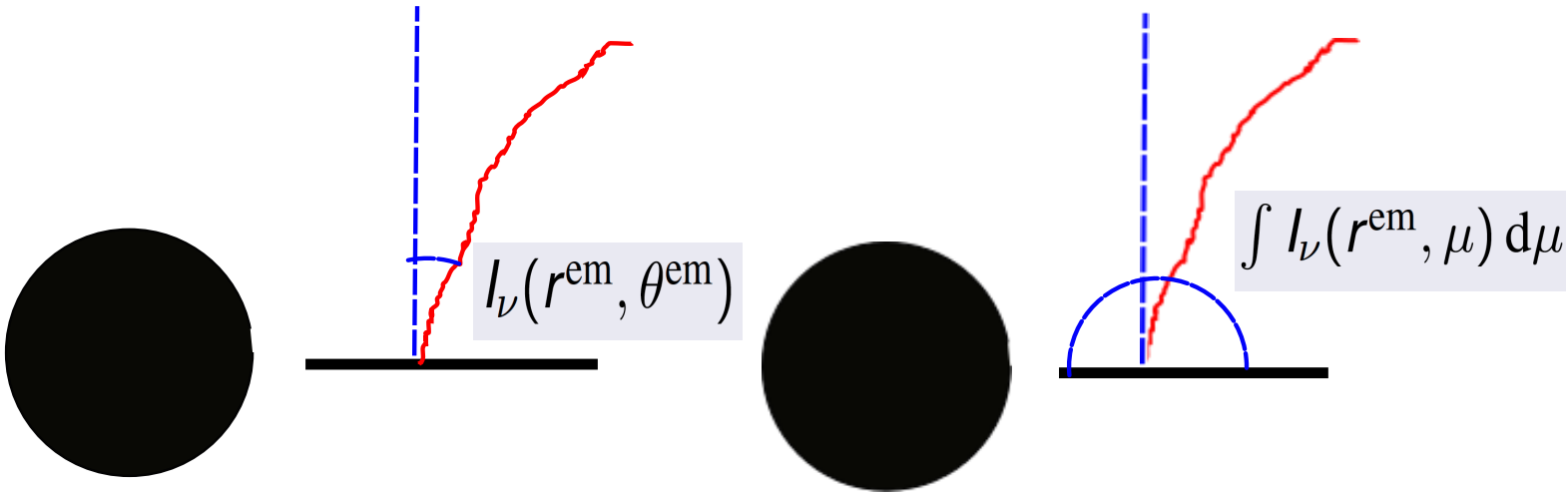
- High inclination $\rightarrow$ flux peaked at a small location

Lensing effect

- Emitted angle different from inclination angle







My question

- Is it important to compute **directional** intensities?
- Does BH **spin** impact the spectrum?

Why is it important?

- People use angle-averaged spectra to constrain spin
- See Garcia et al. 2014
- Same study with independent codes

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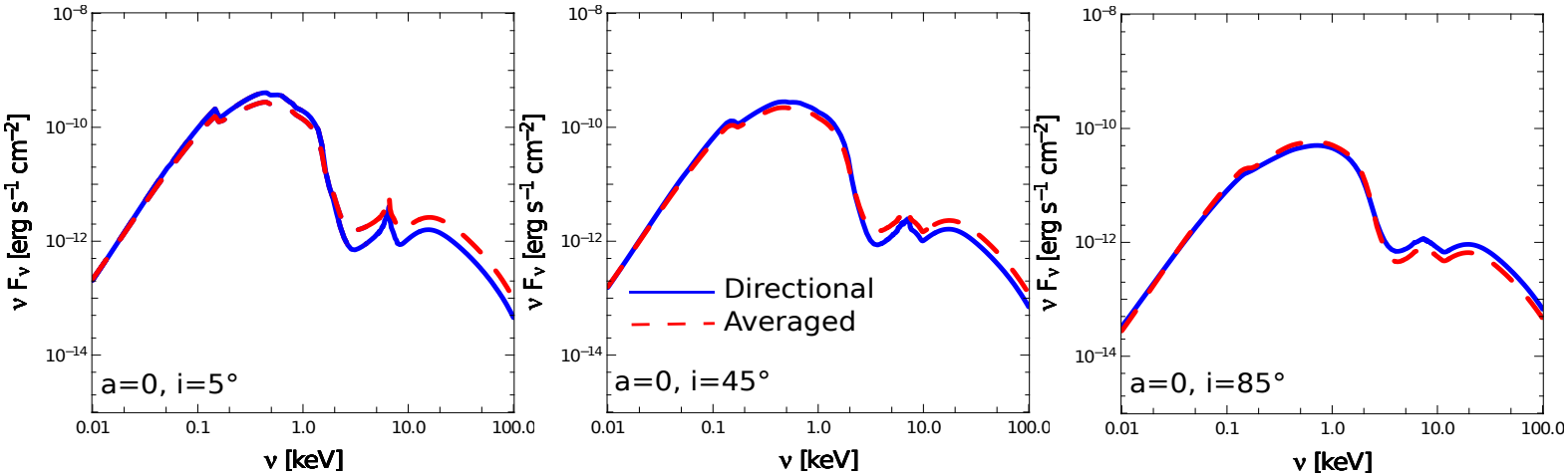
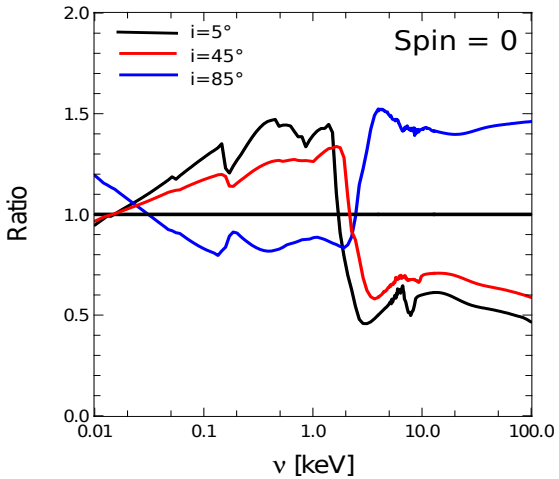


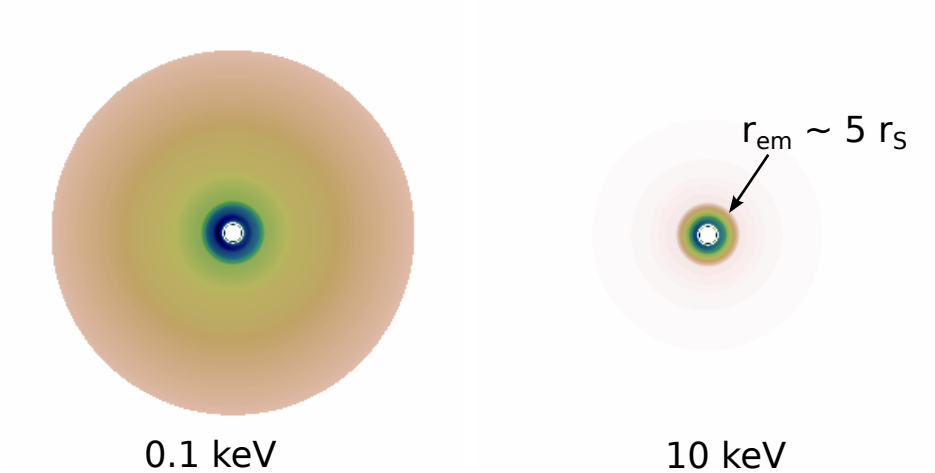
Spectra for spin 0

- Question:
  understand spectra in the region $[1 - 10]$ keV
- Why is the directional spectrum below at low i and above at high i?



Spectra for spin 0

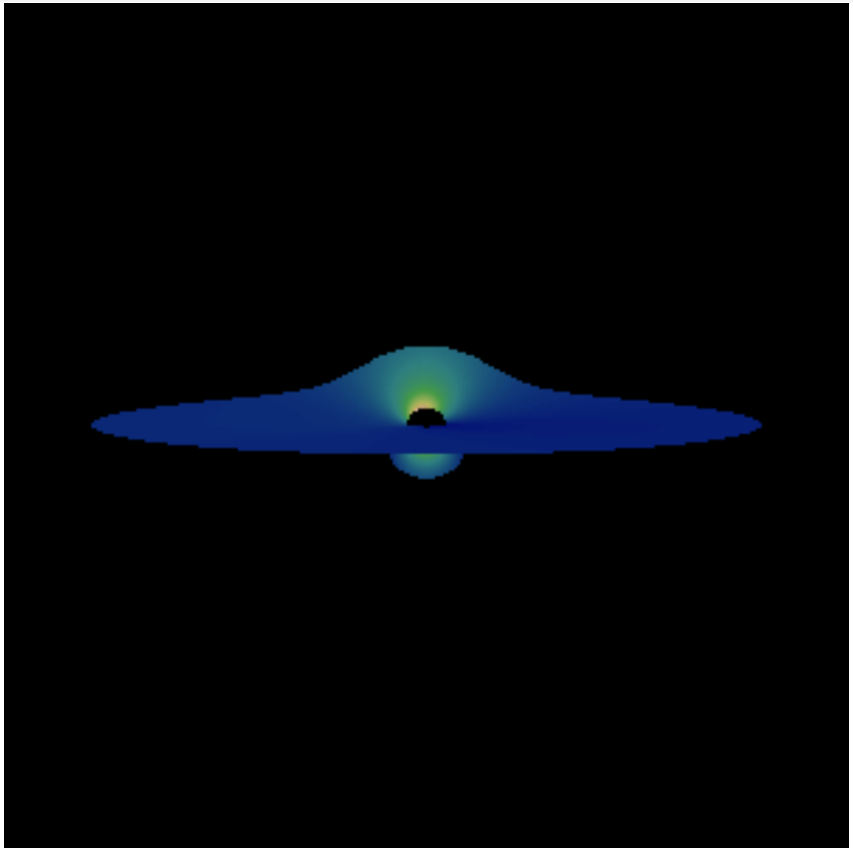
- Important effect, up to 50% difference!



Where does flux comes from?

- Answer:
  from the **center** for $[1 - 10]$ keV

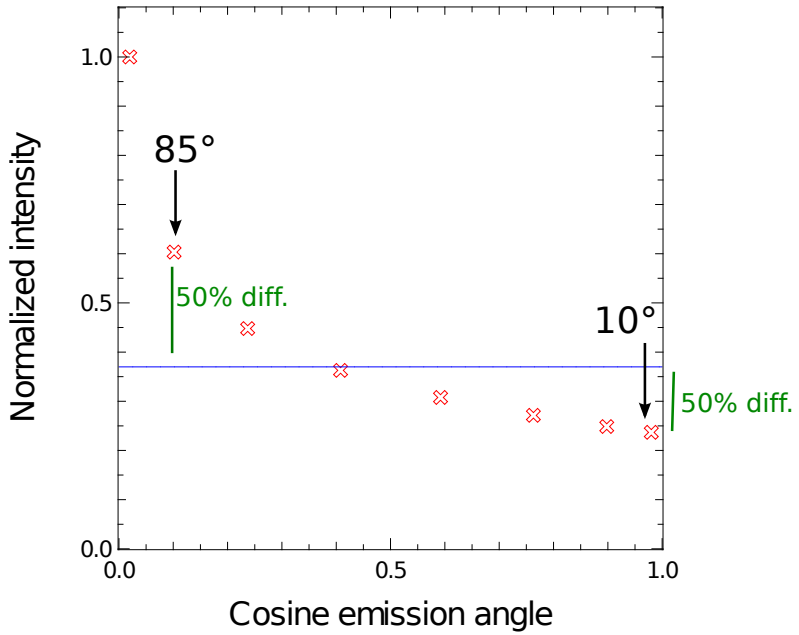
$i = 5°$



$i = 85°$

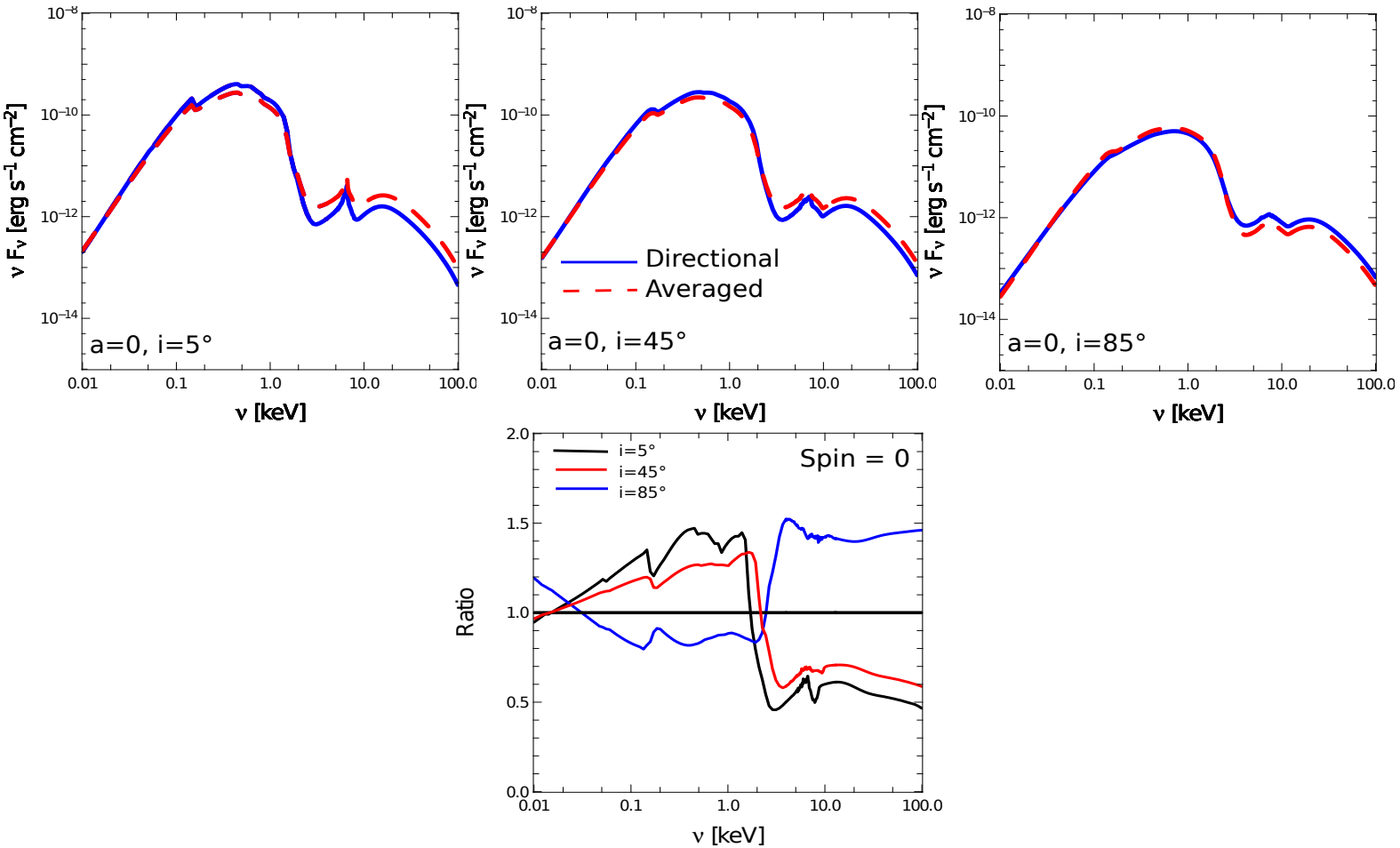
How varies the emission angle?

- Answer:
  5°: rather constant; 85°: more spread
- *But*: beaming $\rightarrow$ angle always rather **constant**: $\theta^{\mathrm{em}} \approx i$

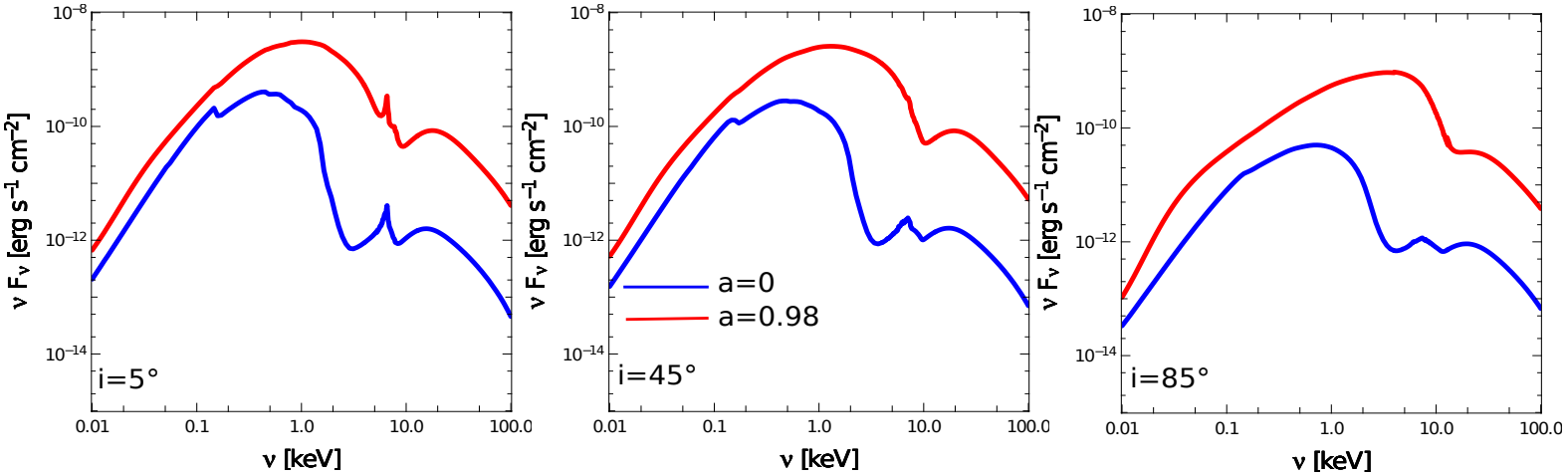


Intensity variation

- $I_\nu(\mu)$ at $r \approx 5\, r_S$ and $\nu = 10$ keV
- 5°: directional is 50% below averaged
- 85°: directional is 50% above averaged

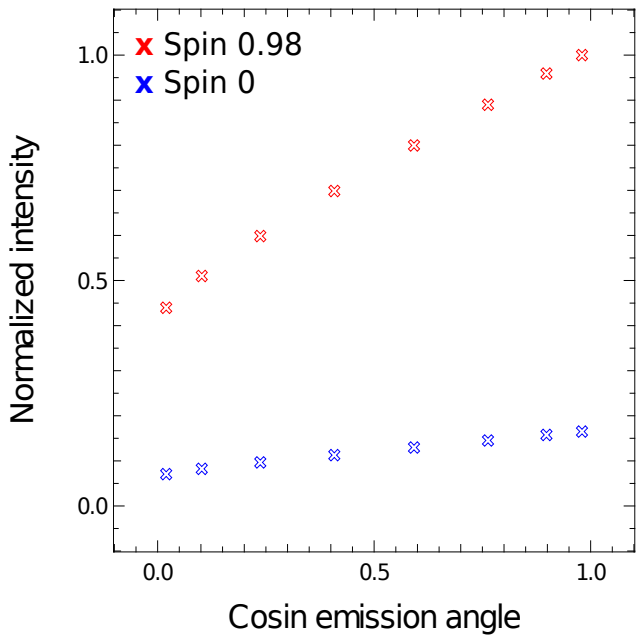


Spectra for spin 0: explanation



Spectra for both spins

- Factor of ≈ 10 more flux at high spin
- Because disk goes closer to BH and is hotter at every r
- $T(r = 3\,r_S, a = 0) \approx 6 \times 10^5$ K;
  $T(r = 3\,r_S, a = 0.98) \approx 4 \times 10^6$ K
- Higher spin/inclination : broader redshift range; continuum varies more near iron line at spin 0.98; $\rightarrow$ iron line less visible at higher spin



Spectra for both spins

- $I_\nu(\mu)$ at $r \approx 5\, r_S$ and $\nu = 1$ keV
- Factor of ≈ 10 in intensity $\rightarrow$ factor of ≈ 10 in spectrum

Conclusion

- BH parameters constrained from angle-averaged spectra
- $\approx 50\%$ difference due to averaging whatever the spin
- Take spin into account properly for continuum + line

Conclusion

- BH parameters constrained from angle-averaged spectra
- $\approx$ 50% difference due to averaging whatever the spin
- Take spin into account properly for continuum + line

- Thanks for your attention!