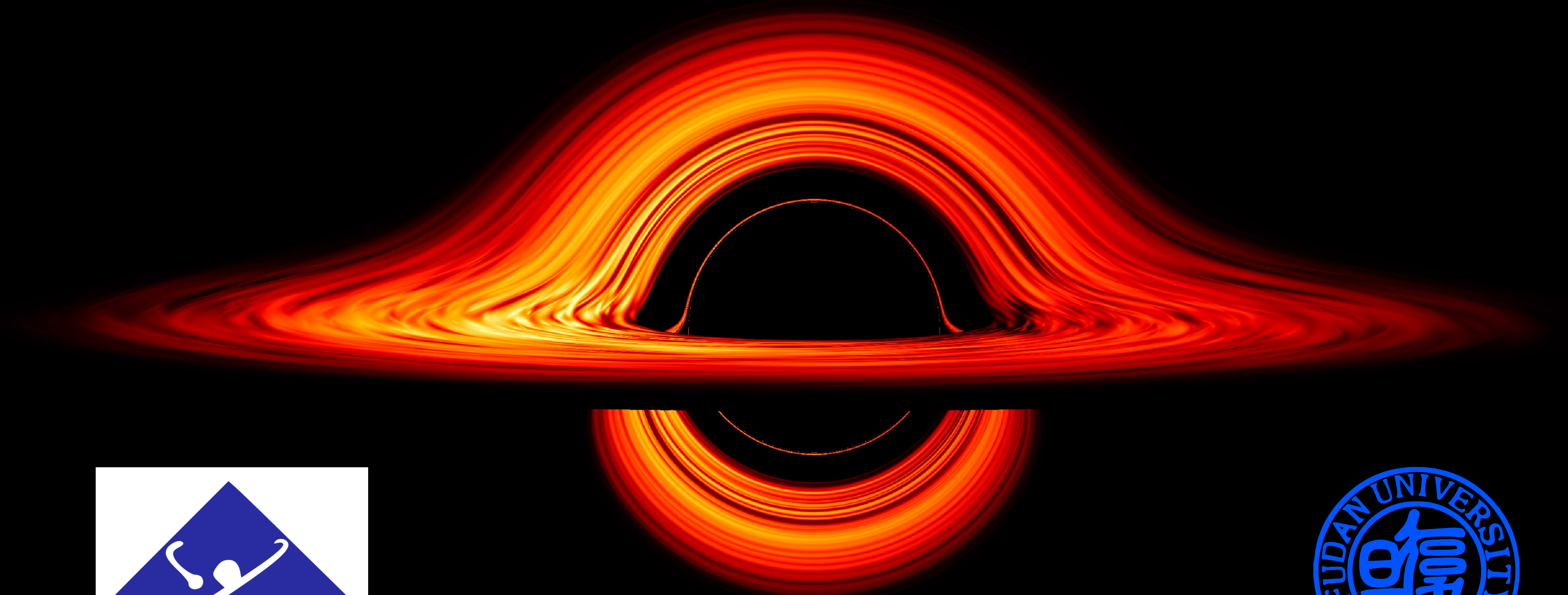
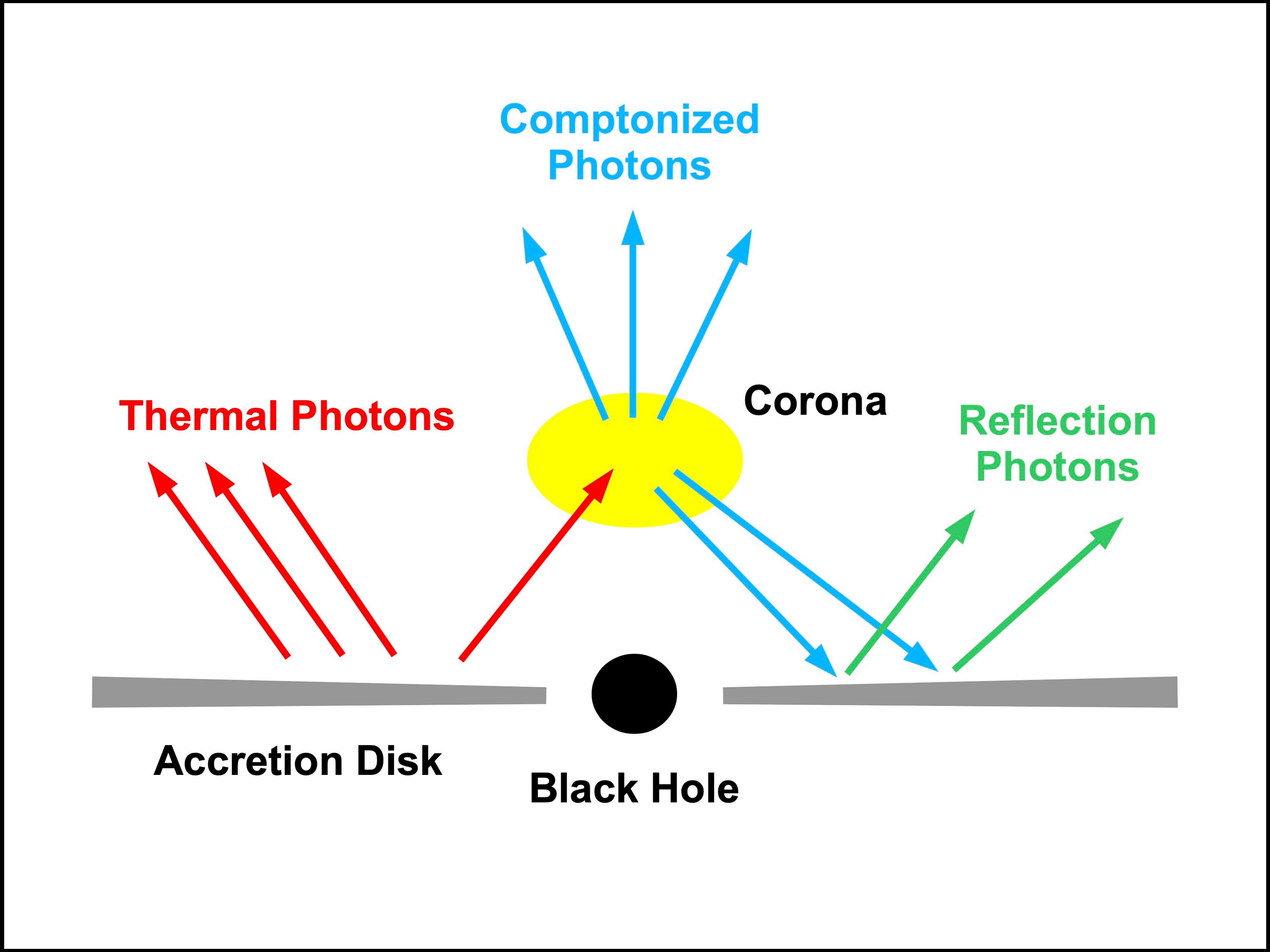
Toward a new generation of reflection models for precision measurements of accreting black holes

Cosimo Bambi
Fudan University

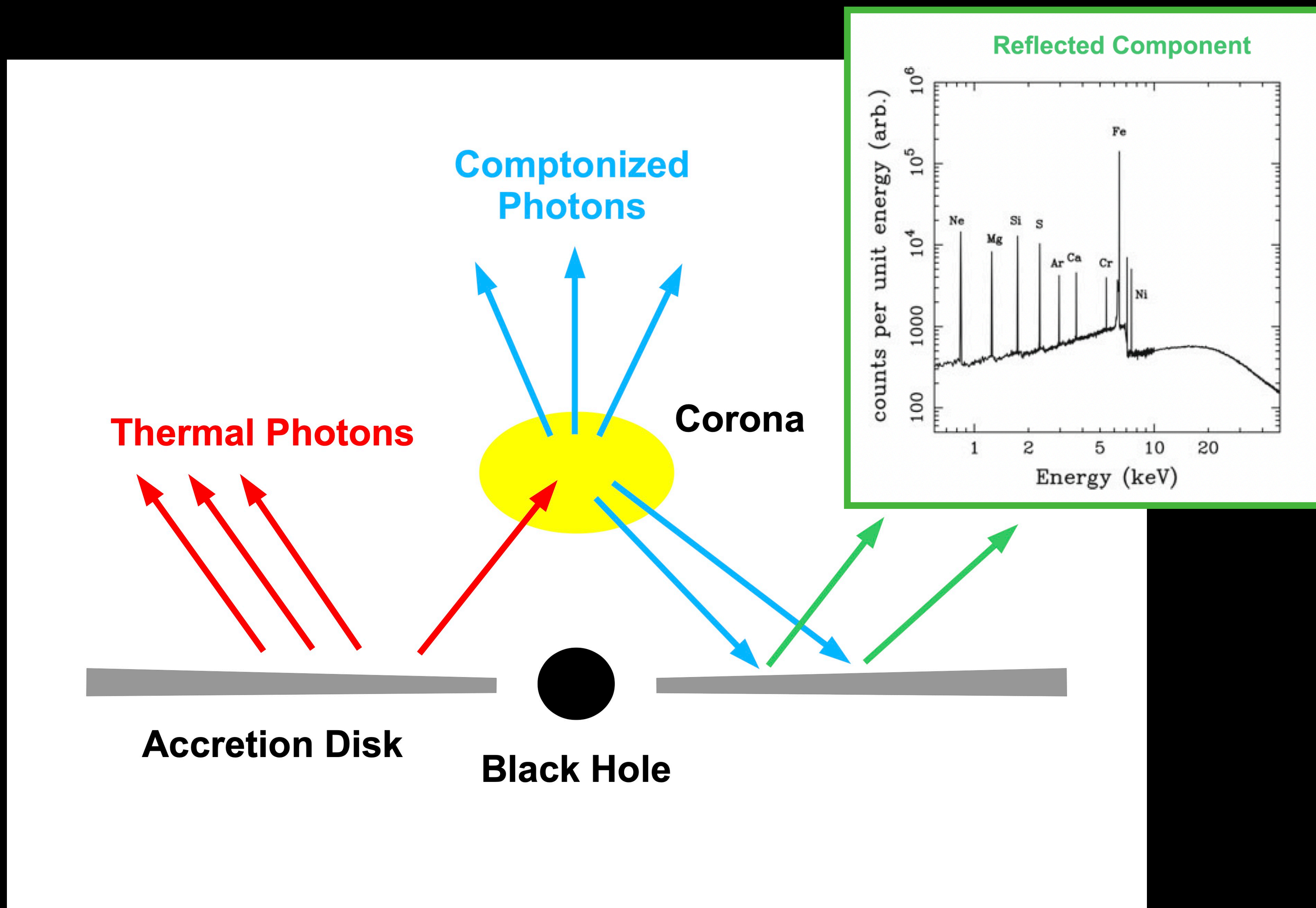


32nd Texas Symposium on Relativistic Astrophysics
Shanghai (11-15 December 2023)

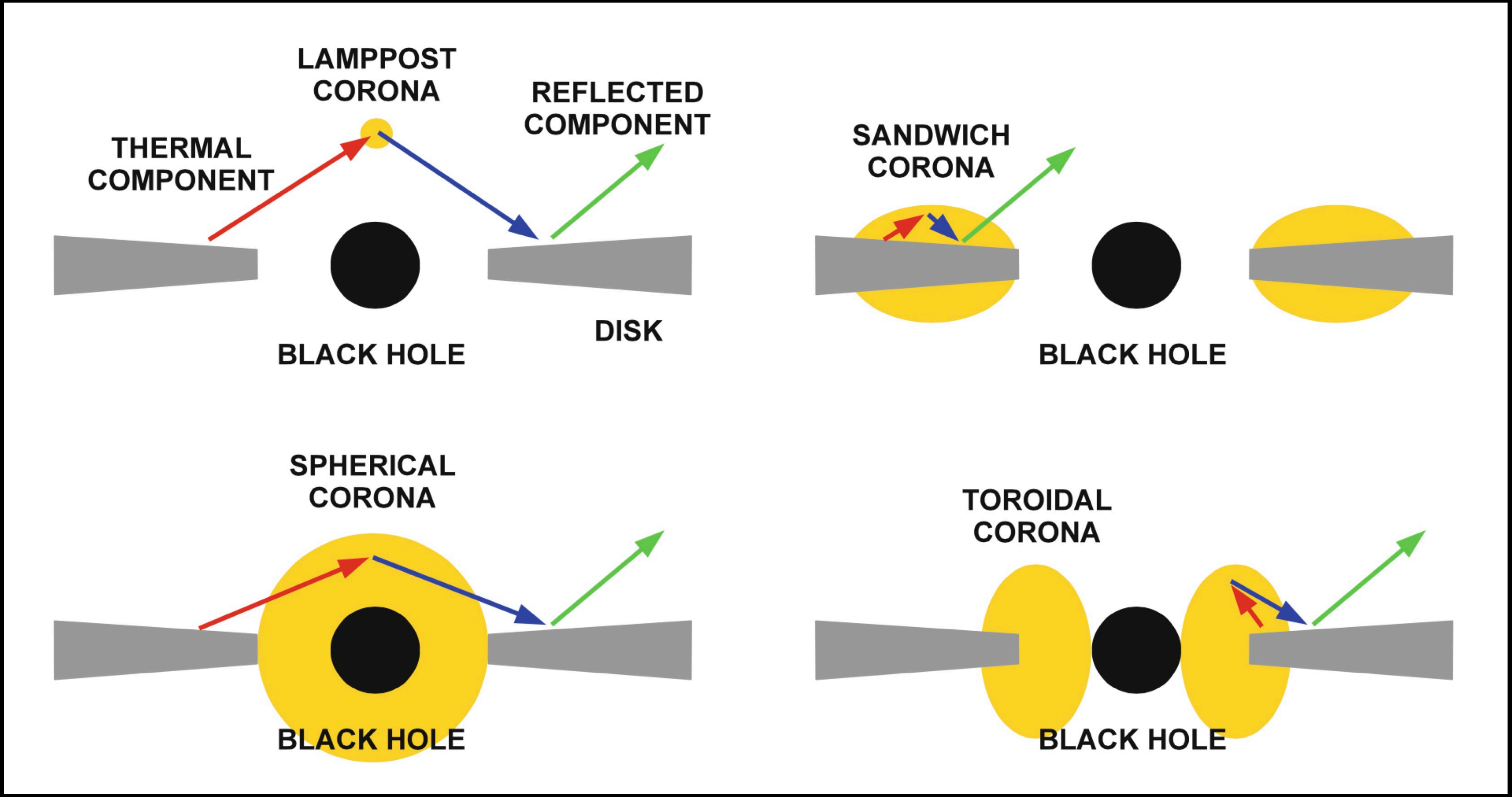
Disk-Corona Model



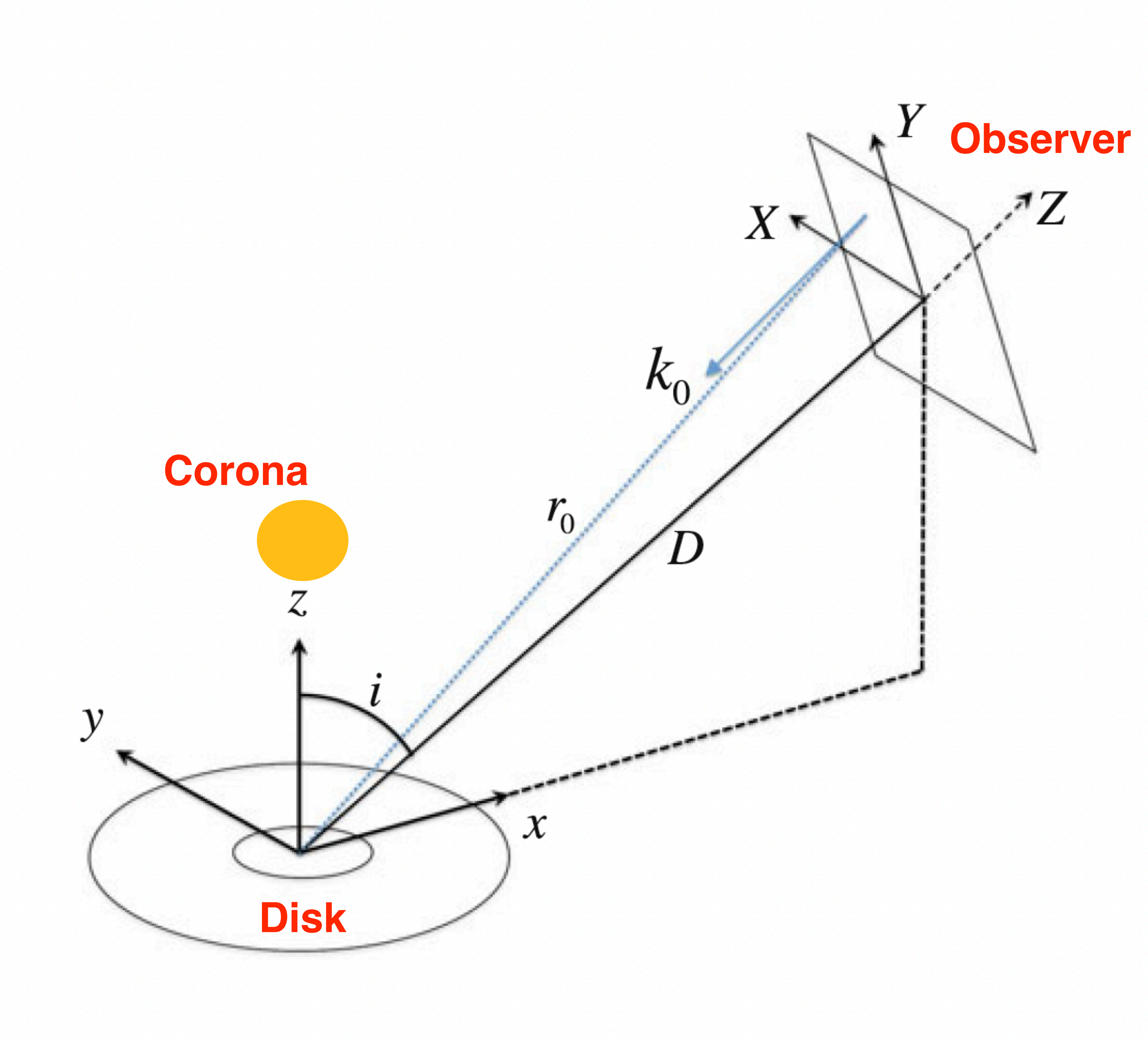
Disk-Corona Model



Coronal Geometries



Disk-Observer System



Redshift Image of the Disk

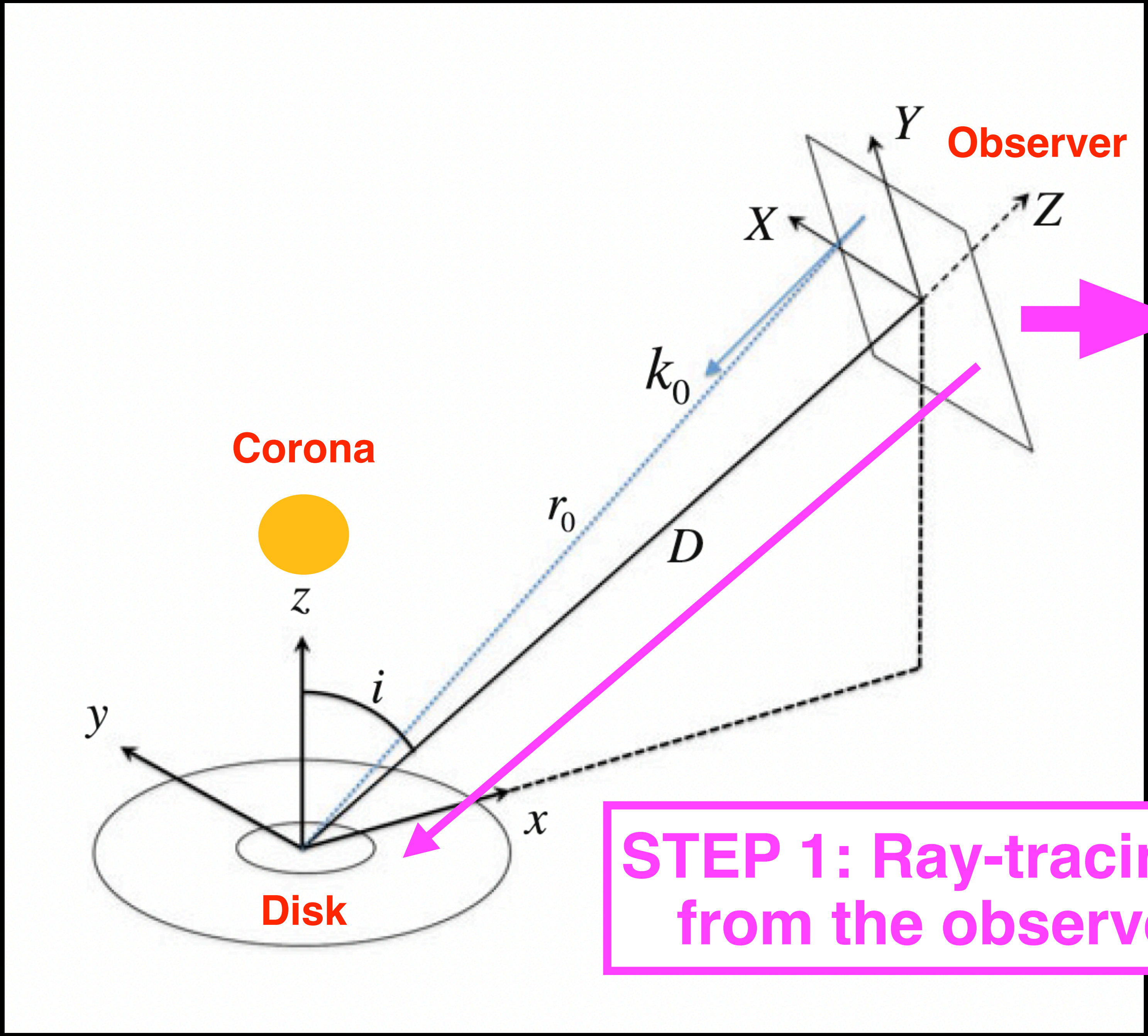
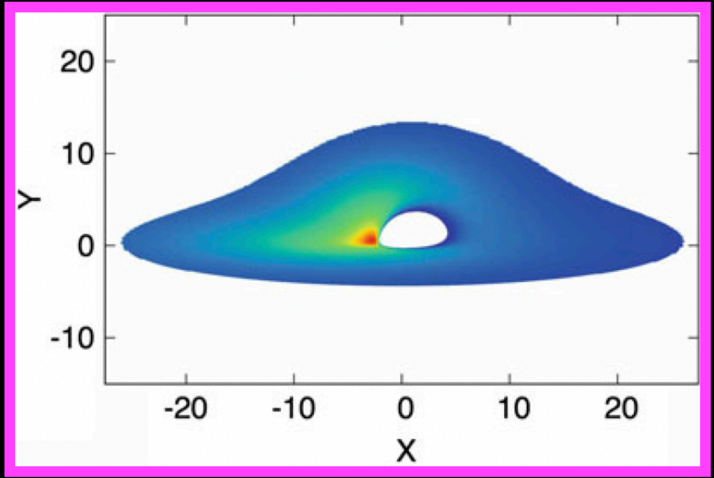


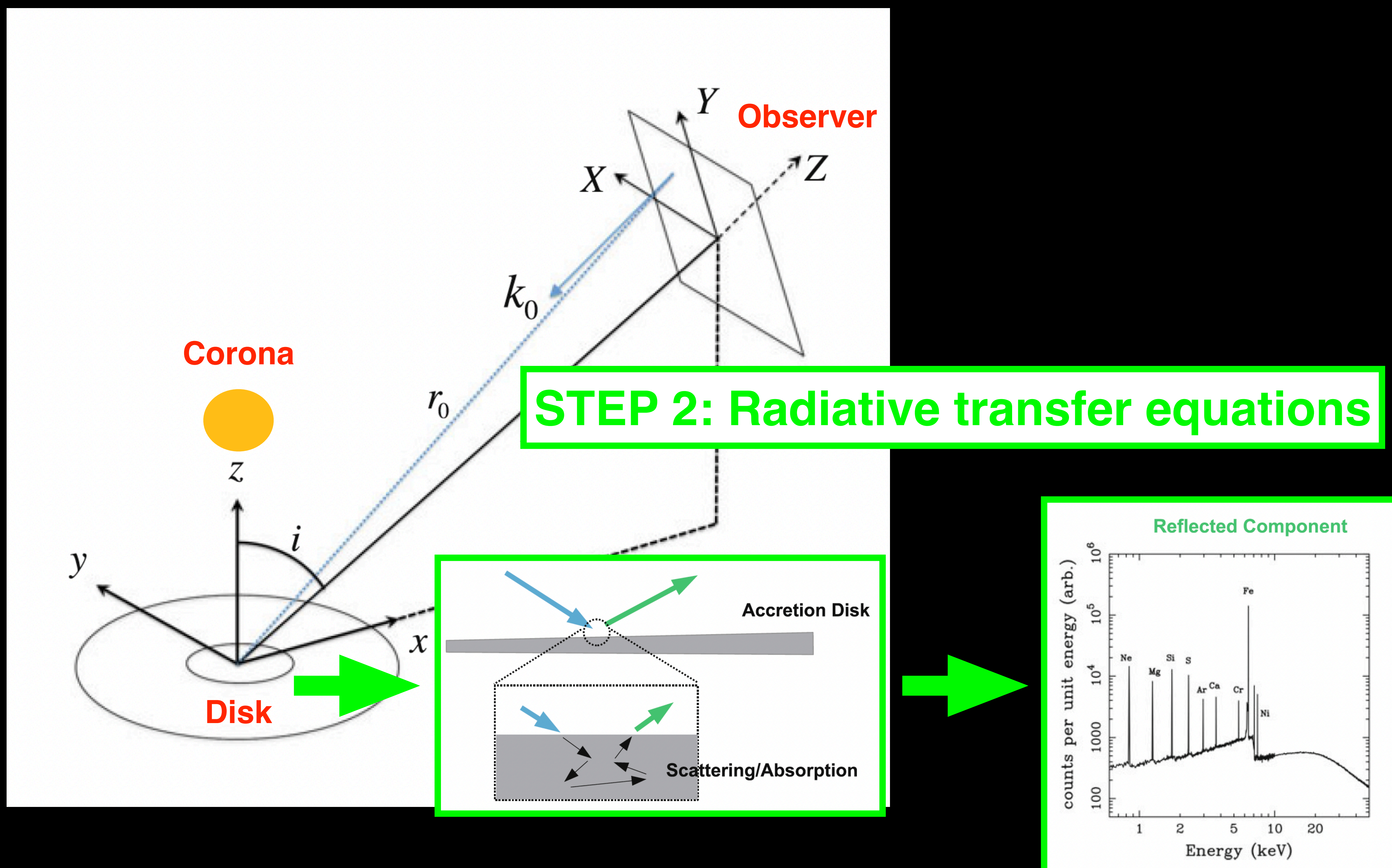
Image of the accretion disk



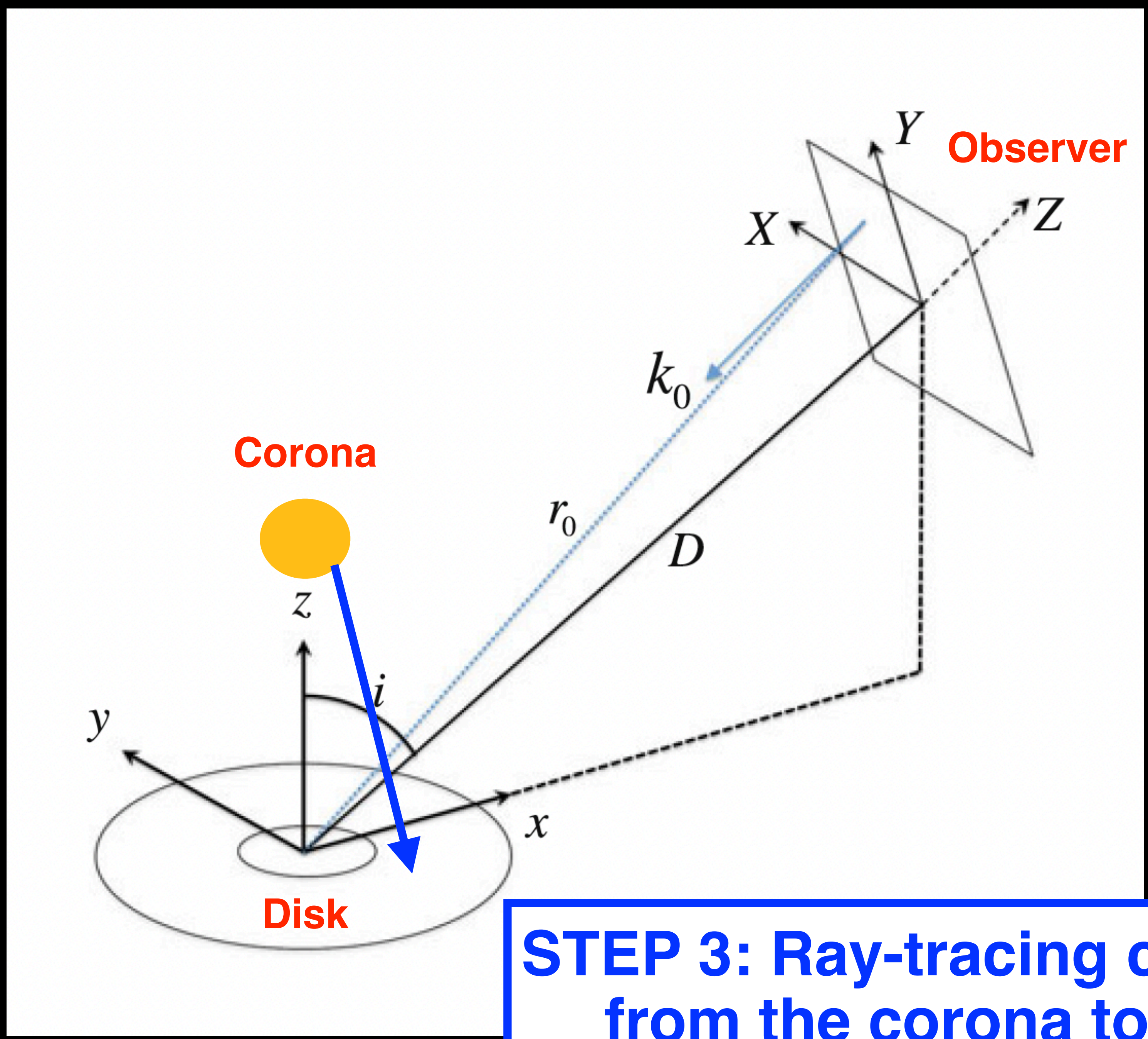
Every point on the image is characterized by its redshift factor *g*

STEP 1: Ray-tracing calculations from the observer to the disk

Local Spectrum



Emissivity Profile of the Disk



STEP 3: Ray-tracing calculations from the corona to the disk

Transfer Function

$$F_{\rm obs}(\nu_{\rm obs}) = \int I_{\rm obs}(\nu_{\rm obs}, X, Y) d\tilde{\Omega} = \int g^3 I_{\rm e}(\nu_{\rm e}, r_{\rm e}, \vartheta_{\rm e}) d\tilde{\Omega} \, ,$$

$$F_{\rm obs}(\nu_{\rm obs}) = \frac{1}{D^2} \int_{r_{\rm ISCO}}^{\infty} \int_0^1 \pi r_{\rm e} \frac{g^2}{\sqrt{g^*(1-g^*)}} f(g^*, r_{\rm e}, i) I_{\rm e}(\nu_{\rm e}, r_{\rm e}, \vartheta_{\rm e}) \, dg^* \, dr_{\rm e} \, .$$

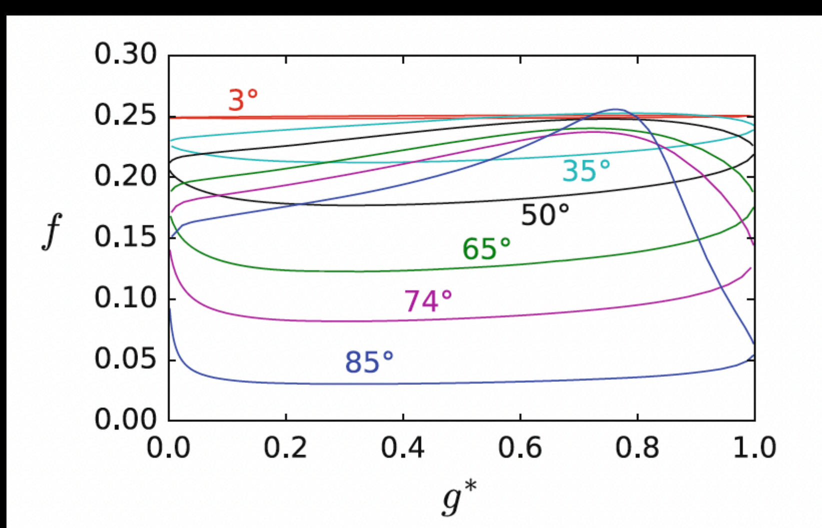
$$g^* = \frac{g - g_{\rm min}}{g_{\rm max} - g_{\rm min}} \, ,$$

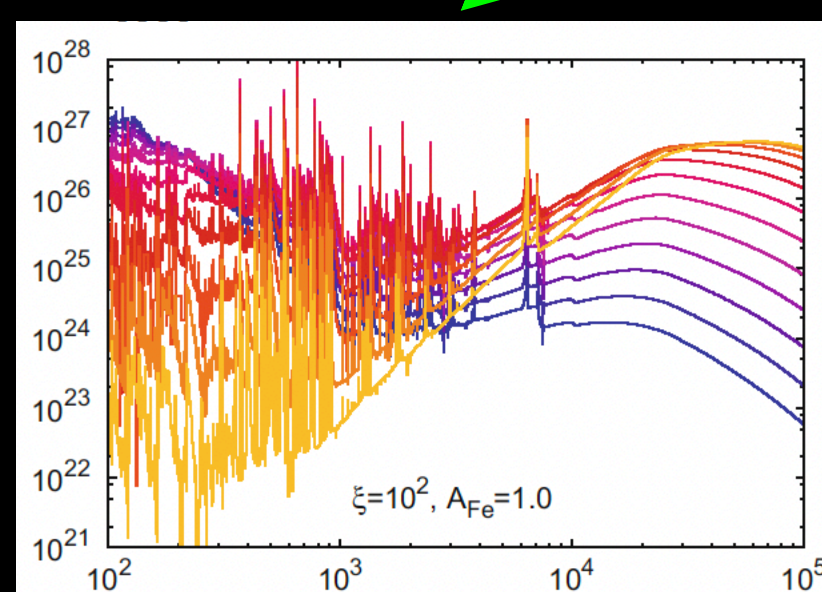
$$f(g^*, r_{\rm e}, i) = \frac{1}{\pi r_{\rm e}} g \sqrt{g^*(1-g^*)} \left| \frac{\partial \left(X, Y\right)}{\partial \left(g^*, r_{\rm e}\right)} \right| \, ,$$

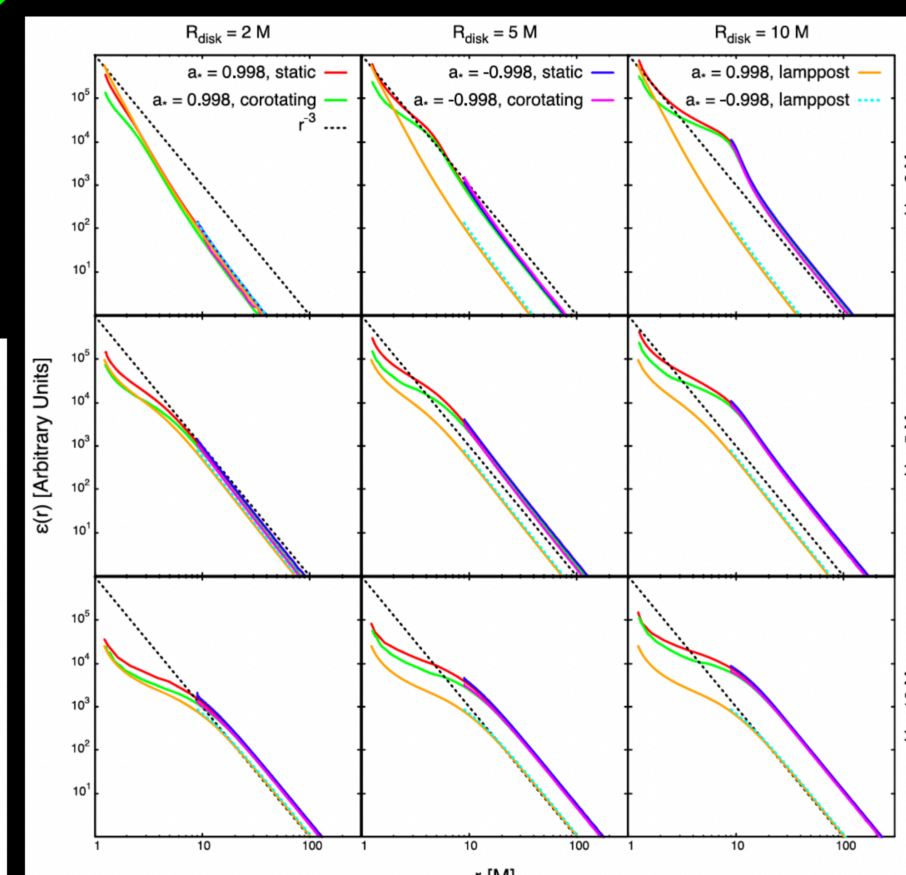
FITS Files

$$F_{\mathrm{obs}}(\nu_{\mathrm{obs}}) = \frac{1}{D^2}\int_{r_{\mathrm{ISCO}}}^{\infty}\int_0^1 \frac{\pi r_{\mathrm{e}}\, g^2}{\sqrt{g^*(1-g^*)}} f_1(g^*, r_{\mathrm{e}}, i) I_{\mathrm{e}}(\nu_{\mathrm{e}}, r_{\mathrm{e}}, \vartheta_{\mathrm{e},1})\, dg^*\, dr_{\mathrm{e}}$$

$$+ \frac{1}{D^2}\int_{r_{\mathrm{ISCO}}}^{\infty}\int_0^1 \frac{\pi r_{\mathrm{e}}\, g^2}{\sqrt{g^*(1-g^*)}} f_2(g^*, r_{\mathrm{e}}, i) I_{\mathrm{e}}(\nu_{\mathrm{e}}, r_{\mathrm{e}}, \vartheta_{\mathrm{e},2})\, dg^*\, dr_{\mathrm{e}}\,,$$







How Can We Improve Current Reflection Models?

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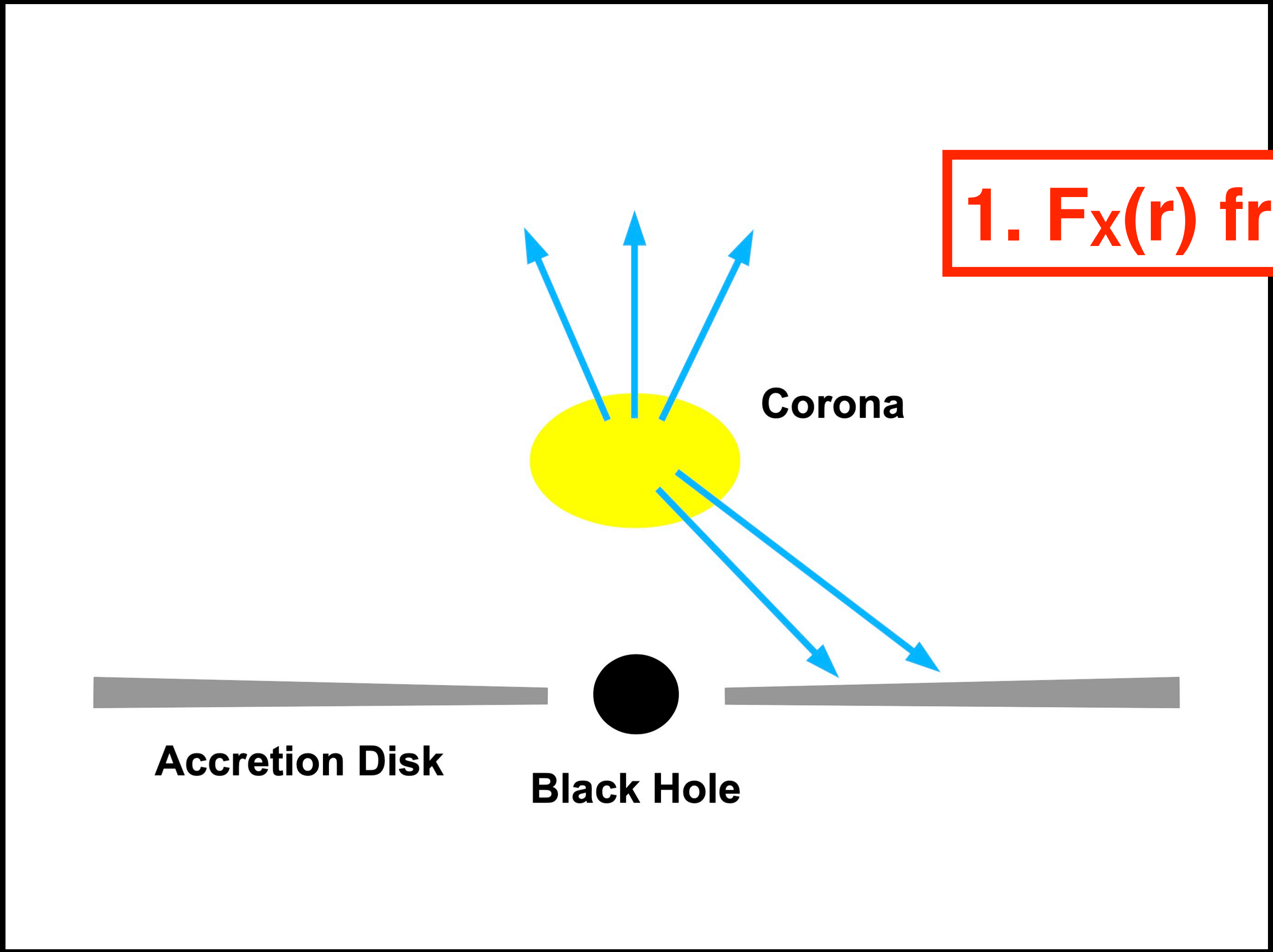
1) Spacetime (Kerr: M, a)
2) Disk (n)
3) Corona (lamppost: h, Γ, T)



1. $F_X(r)$ from the corona

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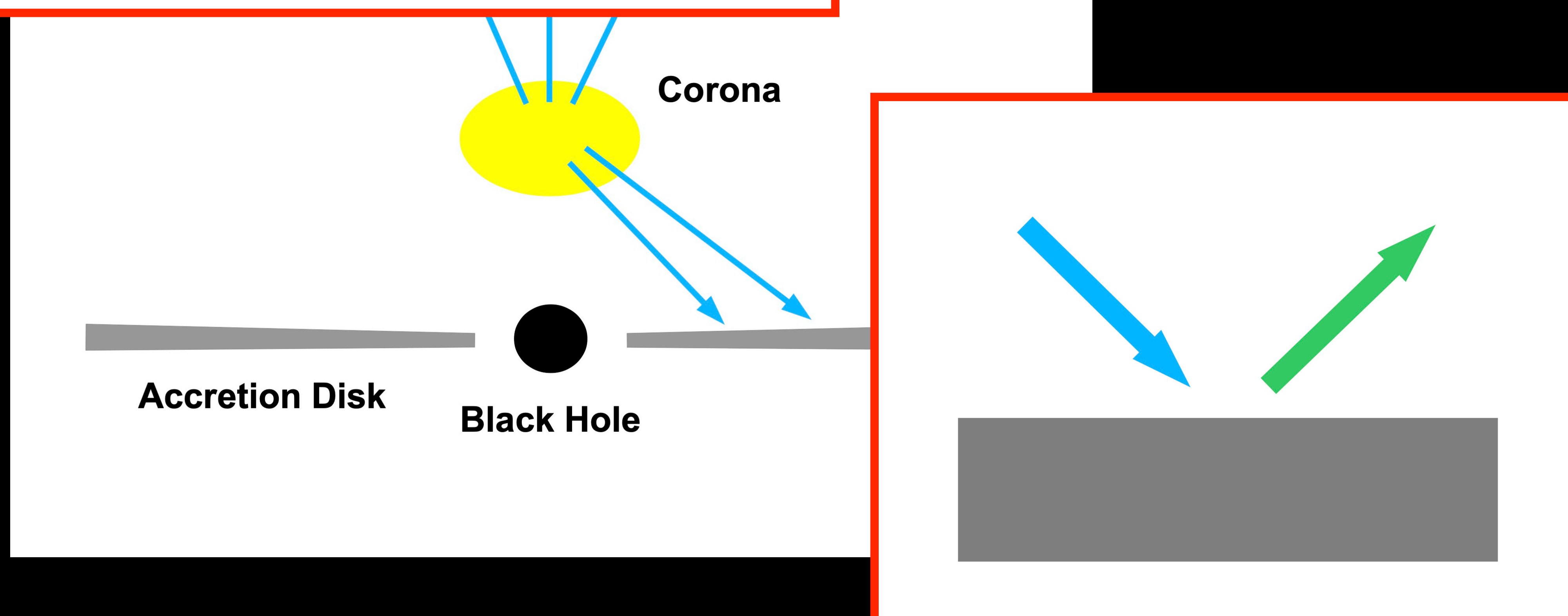
1) Spacetime (Kerr: M, a)
2) Disk (n)
3) Corona (lamppost: h, Γ, T)

2. Reflection spectrum $I_e(r)$
Note: $\xi(r)$, redshifted coronal spectrum



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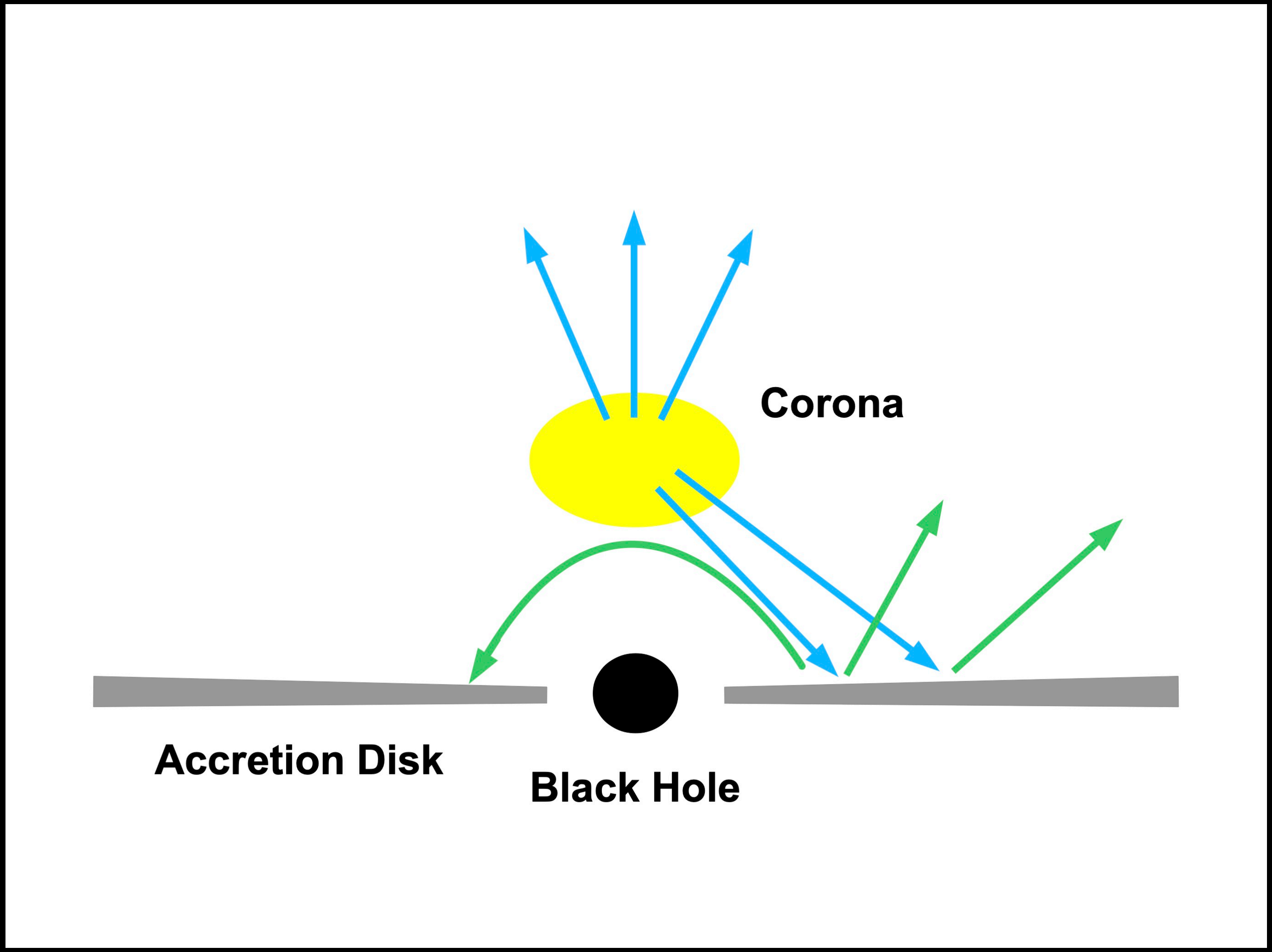
3. Returning radiation at every radius



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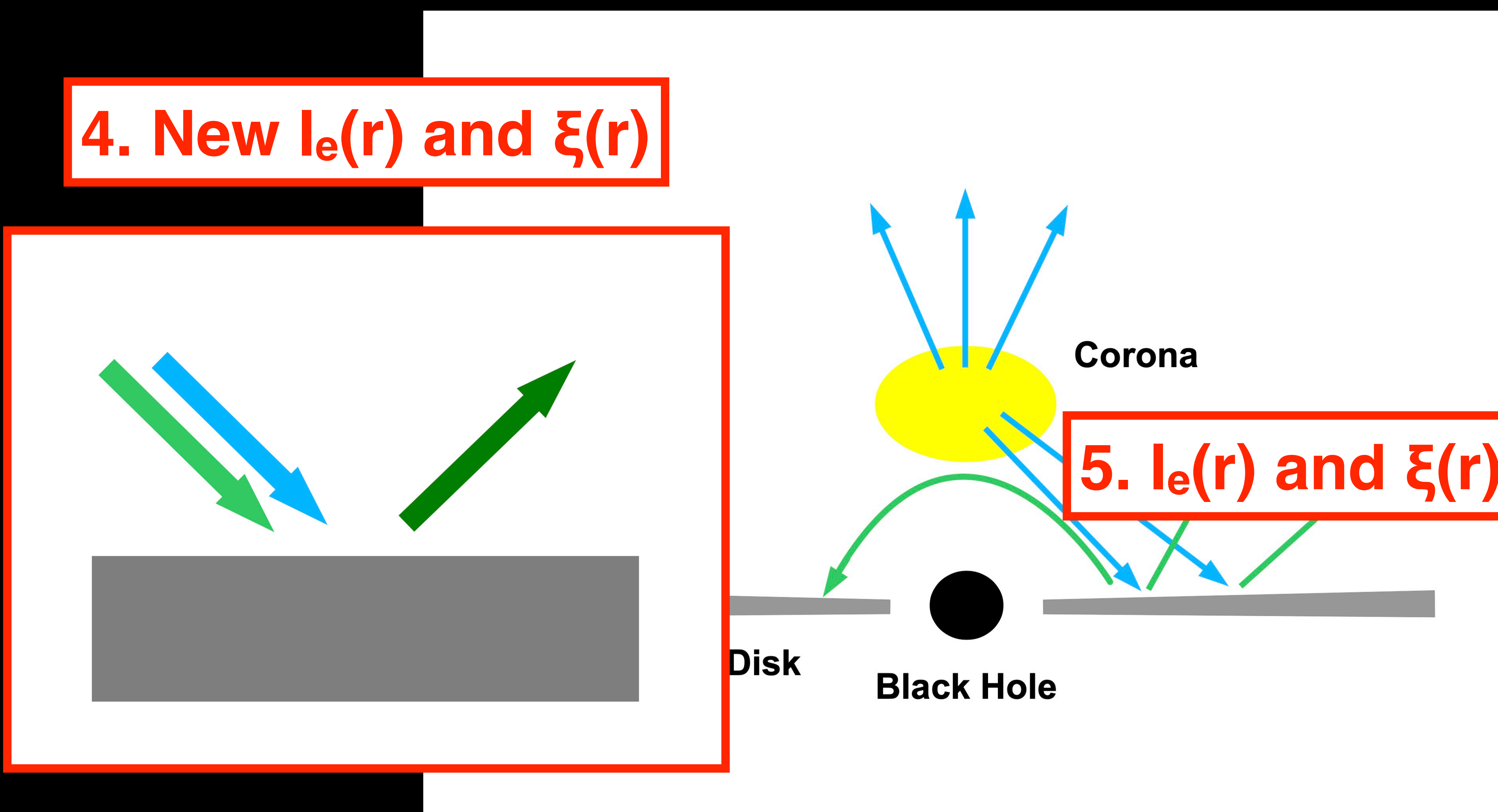
3. Returning radiation at every radius

4. New $I_e(r)$ and $\xi(r)$



5. $I_e(r)$ and $\xi(r)$ at the 4th order

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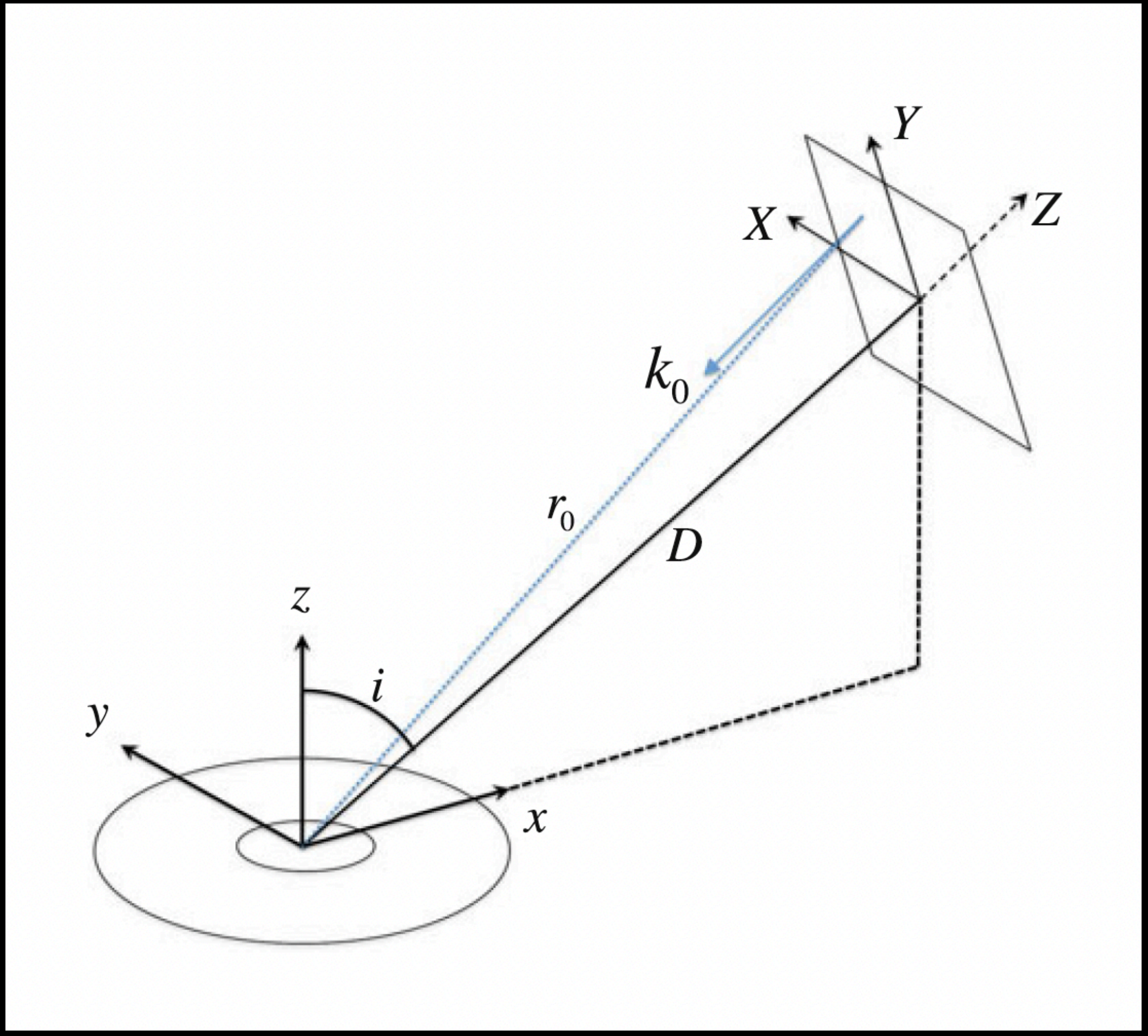
6. Observed reflection spectrum (viewing angle i)



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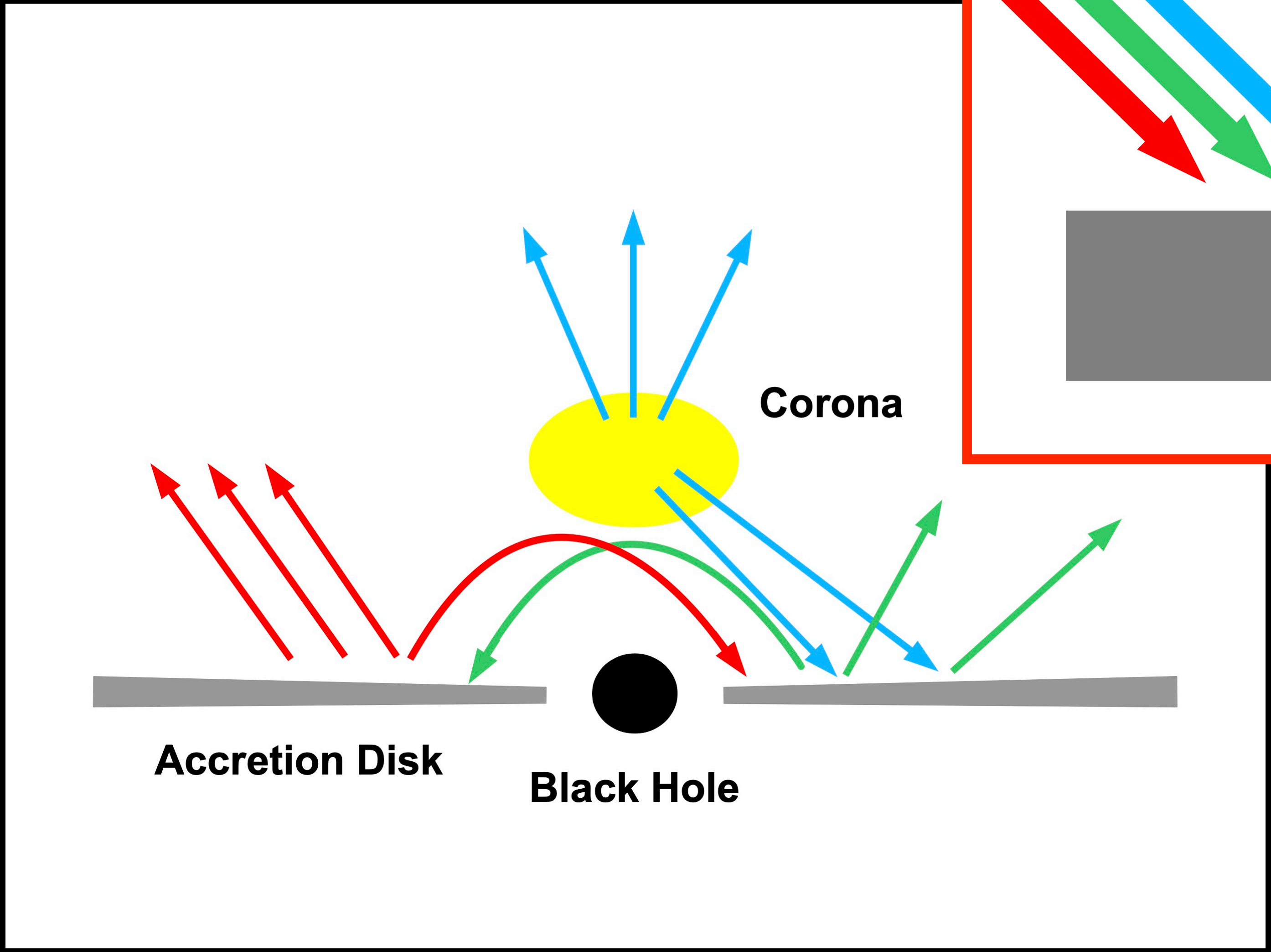
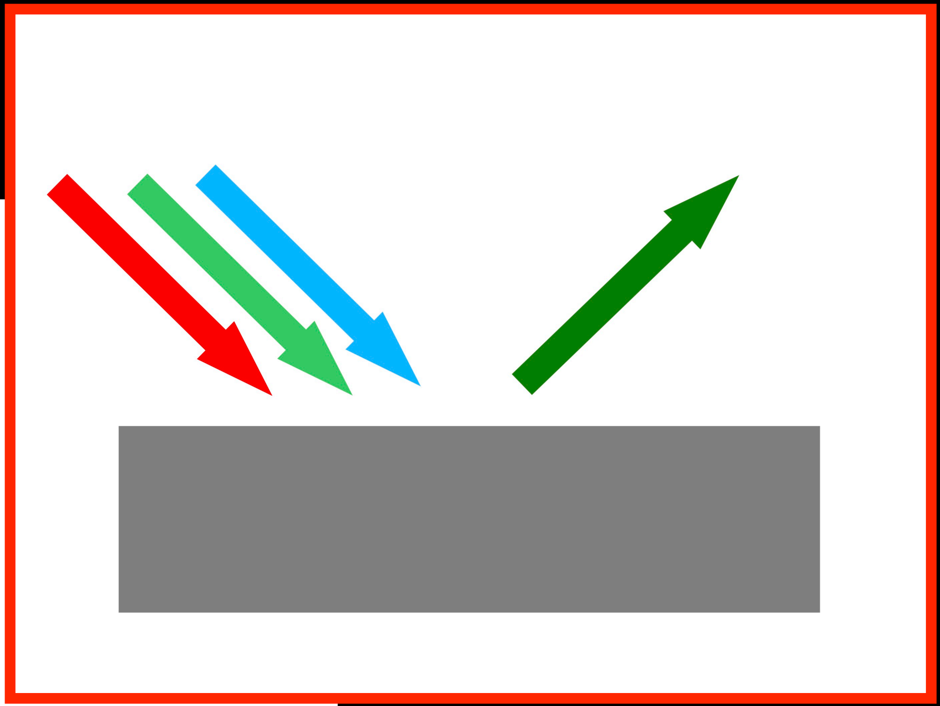
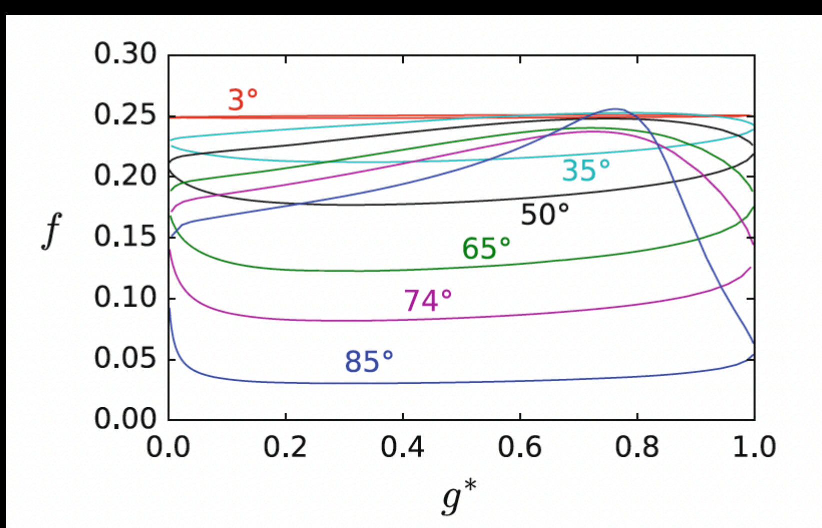
7. Thermal spectrum

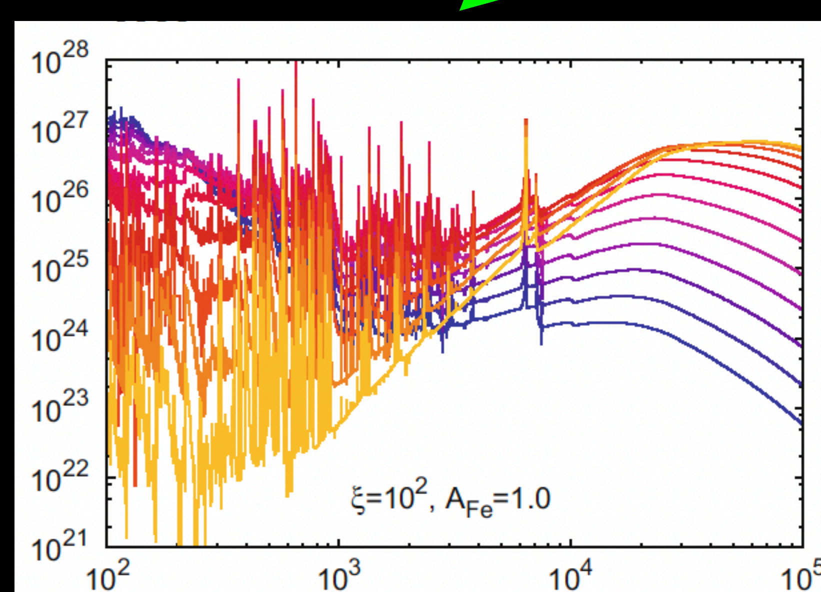


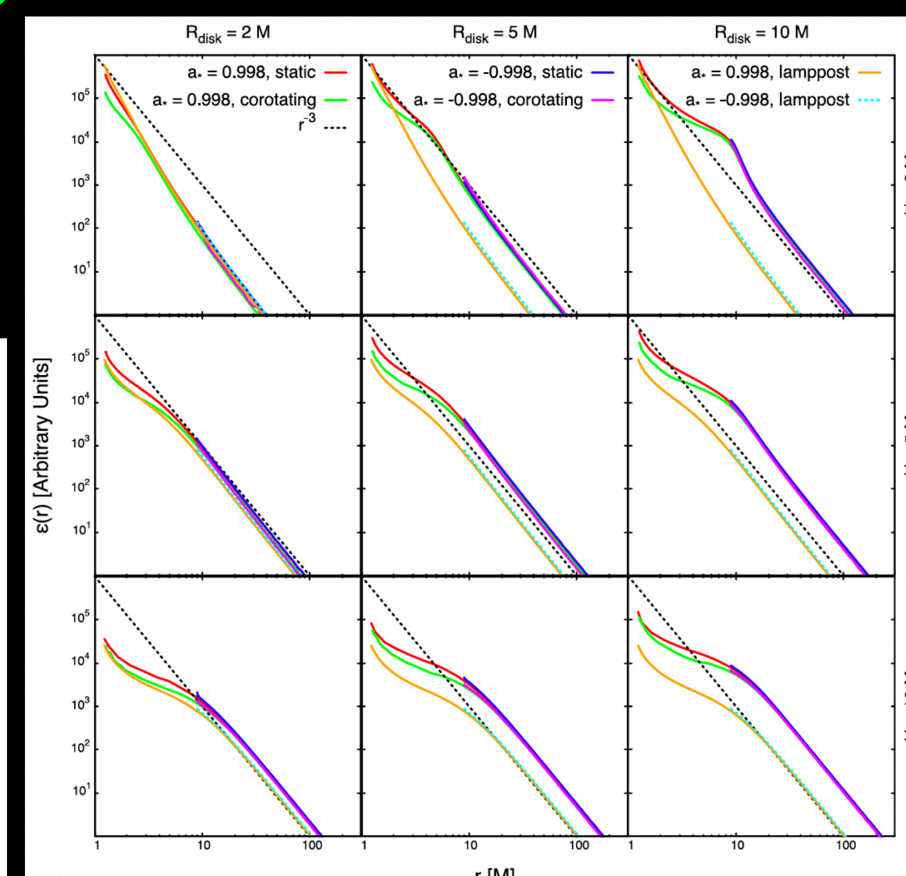


Current Reflection Models for Data Analysis

$$F_{\rm obs}(\nu_{\rm obs}) = \frac{1}{D^2}\int_{r_{\rm ISCO}}^{\infty}\int_0^1 \frac{\pi r_{\rm e}\, g^2}{\sqrt{g^*(1-g^*)}} f_1(g^*, r_{\rm e}, i) I_{\rm e}(\nu_{\rm e}, r_{\rm e}, \vartheta_{\rm e,1})\, dg^*\, dr_{\rm e}$$
$$+\frac{1}{D^2}\int_{r_{\rm ISCO}}^{\infty}\int_0^1 \frac{\pi r_{\rm e}\, g^2}{\sqrt{g^*(1-g^*)}} f_2(g^*, r_{\rm e}, i) I_{\rm e}(\nu_{\rm e}, r_{\rm e}, \vartheta_{\rm e,2})\, dg^*\, dr_{\rm e}\,,$$







Conclusions

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- The analysis of observations from the next generation of X-ray missions (eXTP, Athena, HEX-P, etc.) will necessarily require more sophisticated synthetic spectra than those available today

- New generation of reflection models (neural networks?)

Thank You!