Modeling the thermal reverberation in AGN

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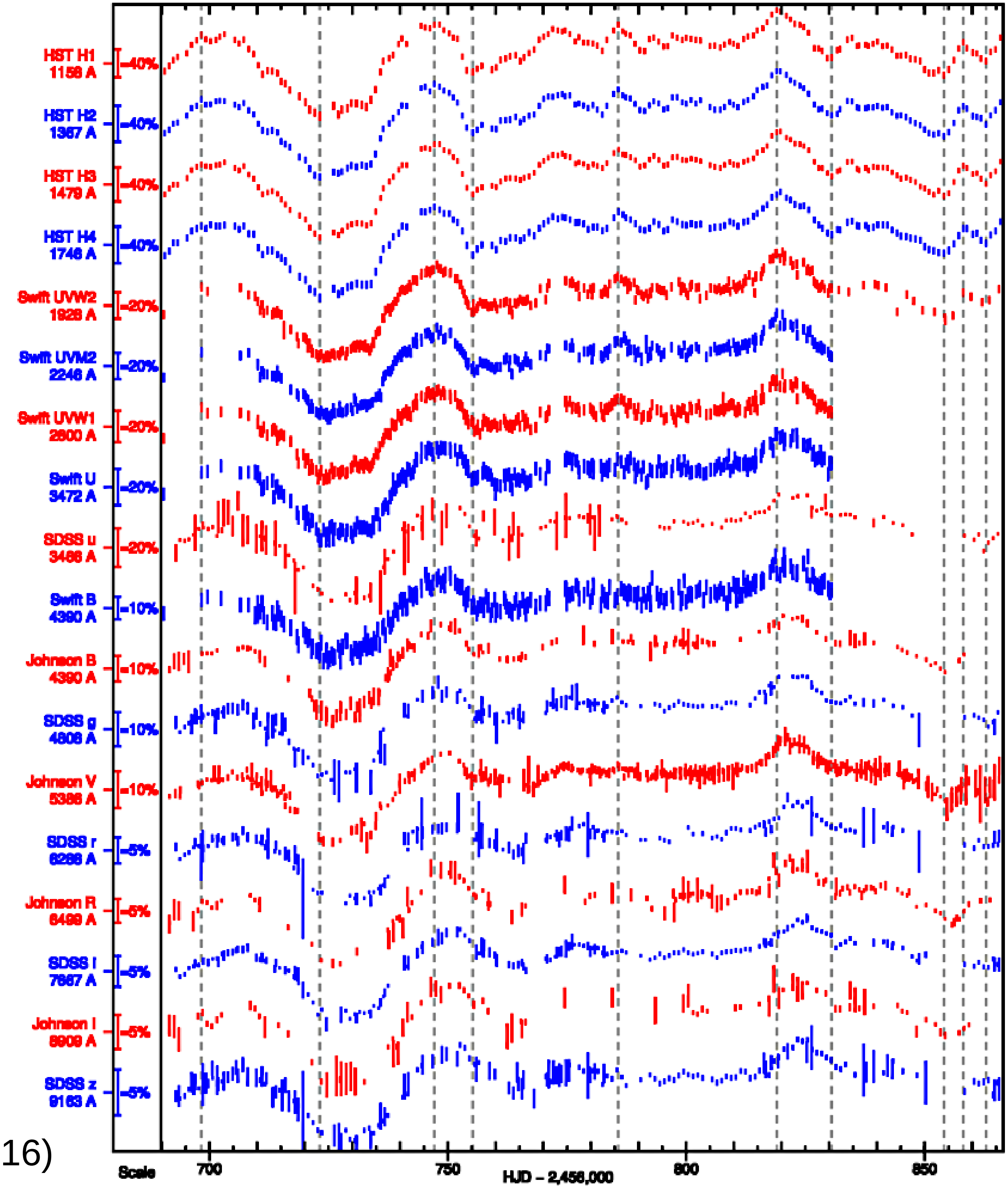
Observations – NGC 5548

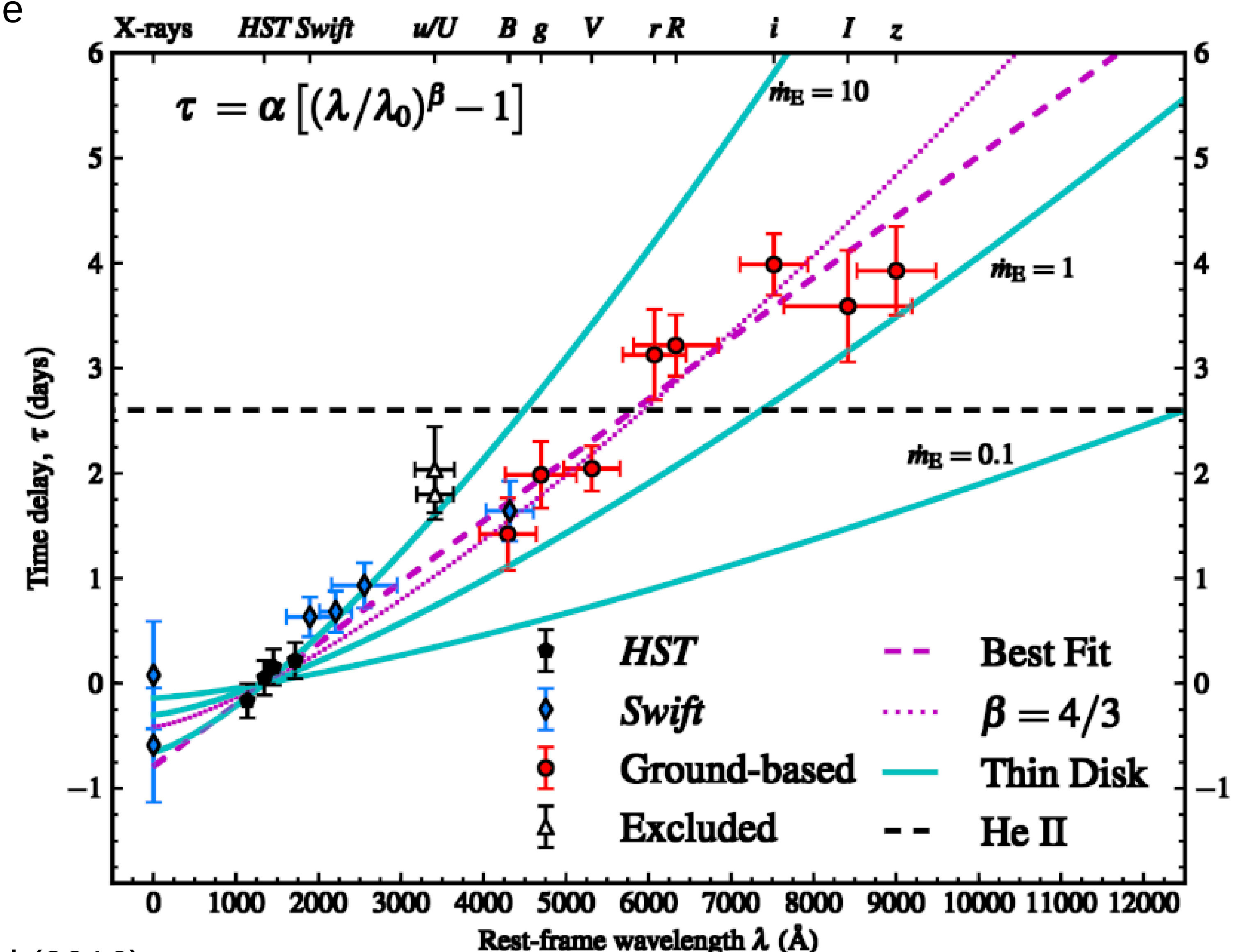
- Observations: UV/optical delays with respect to X-rays that increase with wavelength
- This may be due to reprocessing of X-rays in the accretion disc:
  - part of the X-rays is reflected off the disc
  - part is absorbed in the disc where it is thermalized and causes temperature increase
  - thus the disc UV/optical emission will increase
  - X-rays variations must be followed by the variations in the reprocessed UV/optical emission with lags increasing with wavelength



Fausnaugh et al (2016)

UV/optical time lags in NGC 5548

- Observed UV/optical time lags vs. wavelength λ
- The shape agrees well with the predictions of a Shakura-Sunyaev α-disc.
- The amplitude is too large.
- The disc appears larger.



Fausnaugh et al (2016)

Model assumptions for NGC 5548

black hole: $M = 5 \times 10^7 M_\odot,\ a = 0, 1$

primary isotropic power-law emission with energy cut-offs:

$h,\ L_\mathrm{X}(2-10\mathrm{keV}) = 0.0034\, L_\mathrm{Edd},\ \Gamma = 1.5$

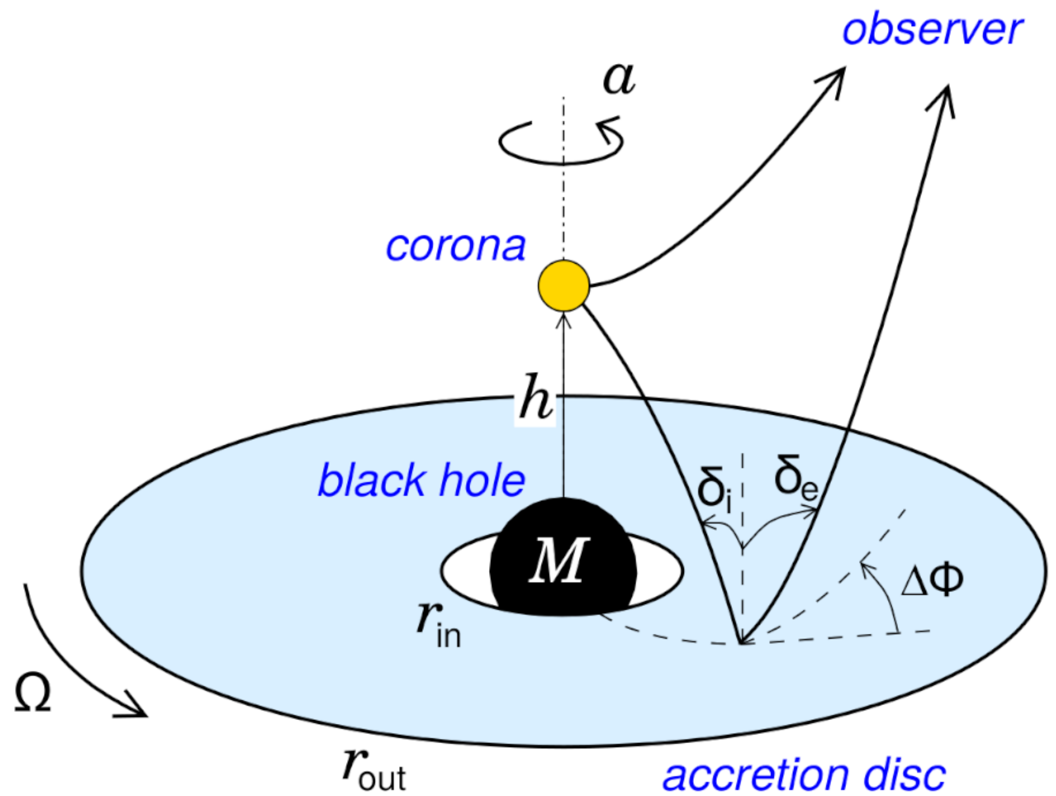
$E_0 = 0.1\,\mathrm{keV},\ E_\mathrm{c} = 300\,\mathrm{keV}$

Novikov-Thorne accretion disc:

$\dot{M},\ r_\mathrm{in} = \mathrm{ISCO},\ r_\mathrm{out} = 10000\, r_\mathrm{g},\ f_\mathrm{c} = 2.4$

Other parameters:

$\mathrm{incl} = 40^\circ,\ D = 75\,\mathrm{Mpc}$



$$F_\mathrm{abs}(r,\varphi) = F_\mathrm{inc}(r,\varphi) - F_\mathrm{refl}(r,\varphi)$$

$$T_\mathrm{new}(r,\varphi) = \left[\frac{F_\mathrm{abs}(r,\varphi) + F_\mathrm{NT}(r)}{\sigma}\right]^{1/4}$$

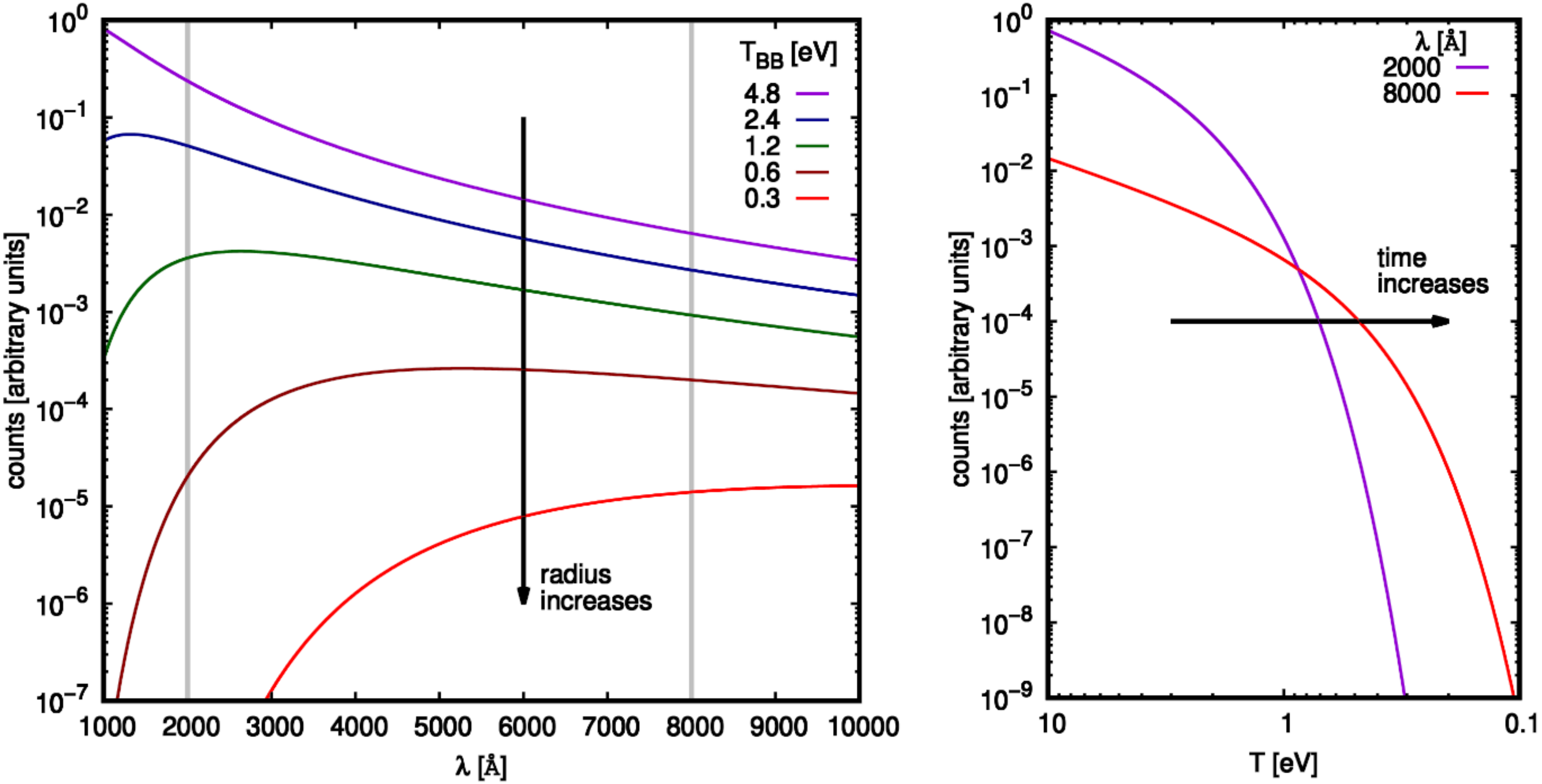
$$\Psi(\Delta\lambda,\tau_\mathrm{obs}) = \frac{F_\mathrm{rev}(\Delta\lambda,\tau_\mathrm{obs}) - F_\mathrm{NT}(\Delta\lambda)}{F_\mathrm{X0}\,\Delta t}$$

F_refl – given by XILLVERD (Garcia et al. 2016)

KYNXILREV model

– all relativistic effects included

Black body properties

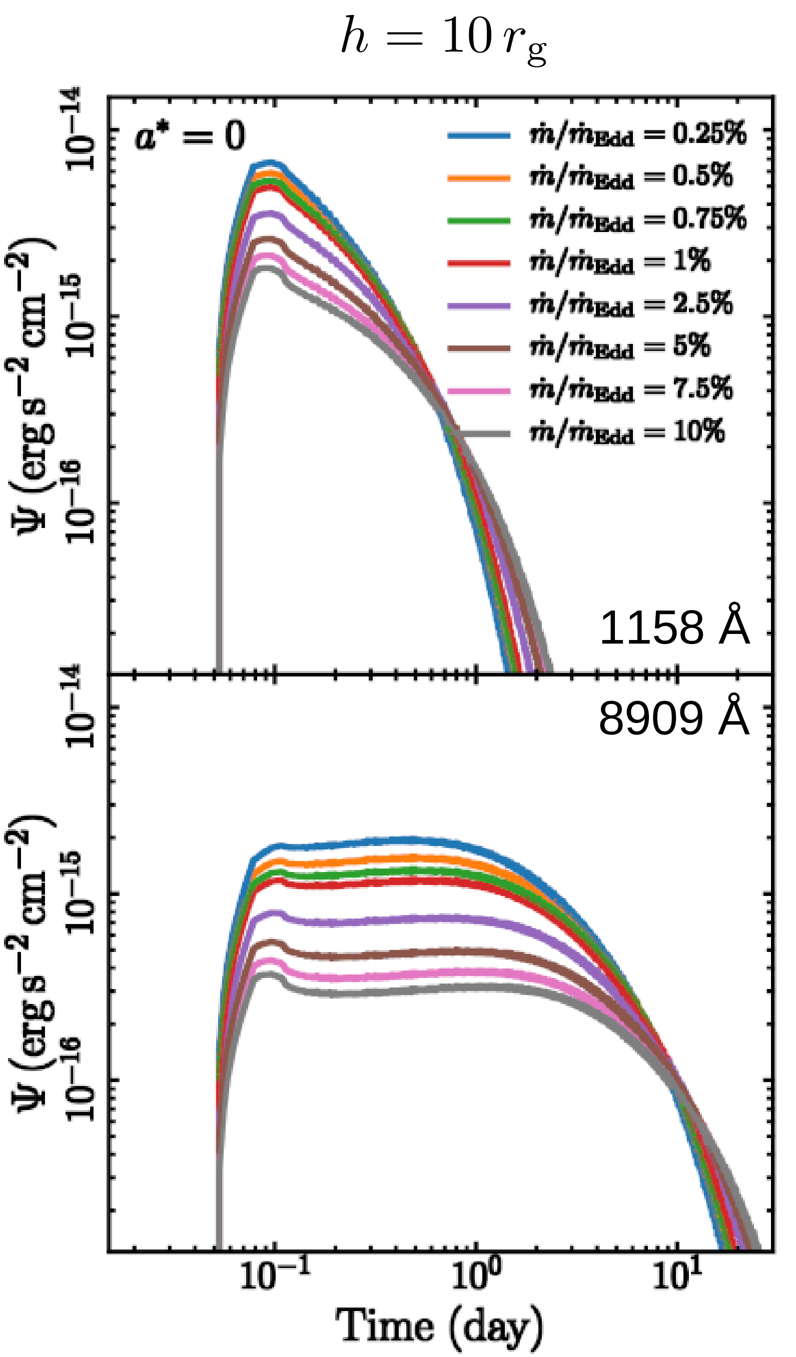


- flux decreases with decreasing temperature much faster for small λ
- the temperature decreases with radius (~$r^{-3/4}$) and with time

Response dependence on accretion rate

The response:

- start rising at the same time for all λ
  - ➔ close to the BH the temperature is high enough for the BB to be emitted at all studied λ
- is shorter for smaller λ
  - ➔ BB with smaller temperature at larger radius does not contribute to smaller λ
- is higher for lower accretion rate
  - ➔ disc temperature is lower thus $\boldsymbol{F}_{\mathbf{NT}}$ is smaller, the same $\boldsymbol{F}_{\mathbf{abs}}$ will cause larger change in BB
- is shorter for lower accretion rate
  - ➔ disc temperature is lower thus response diminishes earlier

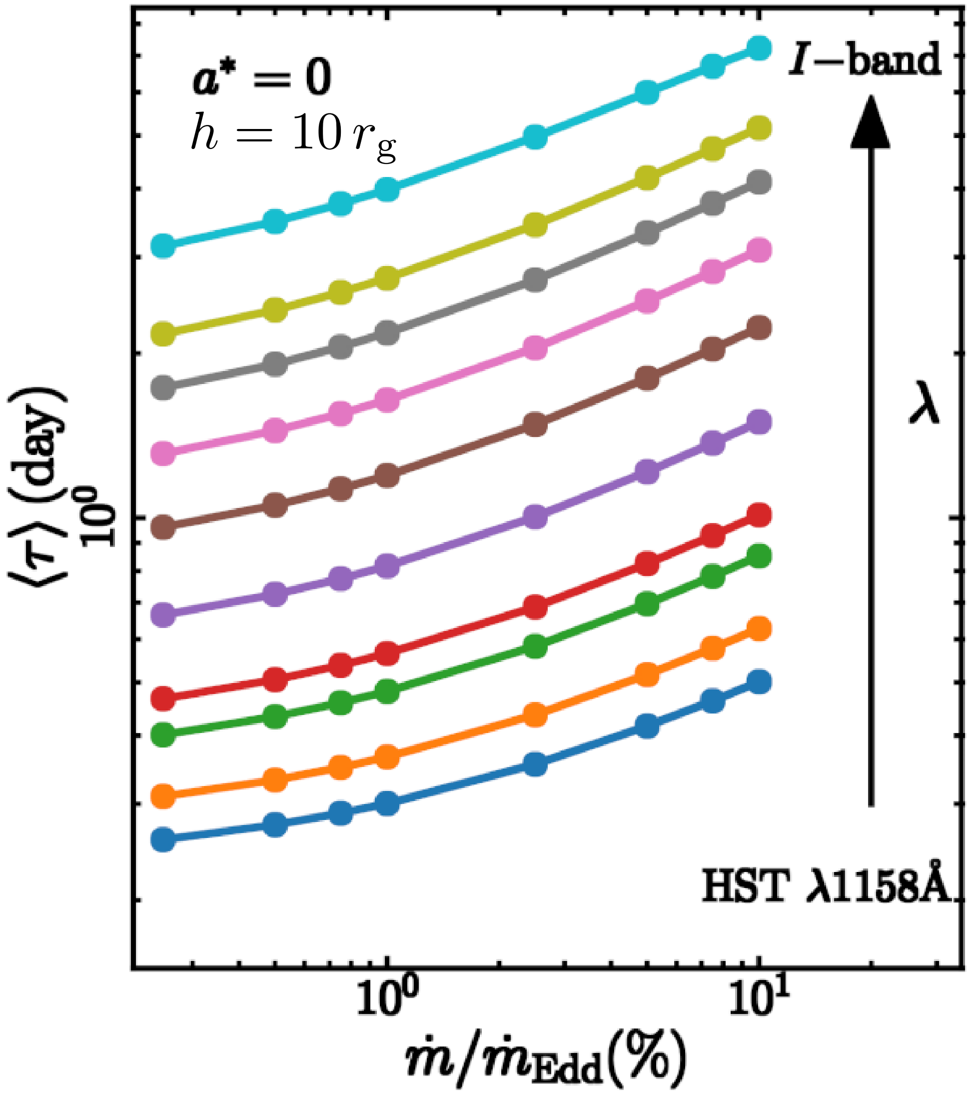


Delay dependence on accretion rate

$$\langle \tau \rangle = \frac{\int_0^\infty t\,\Psi(\lambda, t)\,\mathrm{d}t}{\int_0^\infty \Psi(\lambda, t)\,\mathrm{d}t}$$

As a consequence **the delay:**

- is shorter for smaller λ
  - → since response is shorter
- increases with accretion rate
  - → since response is longer

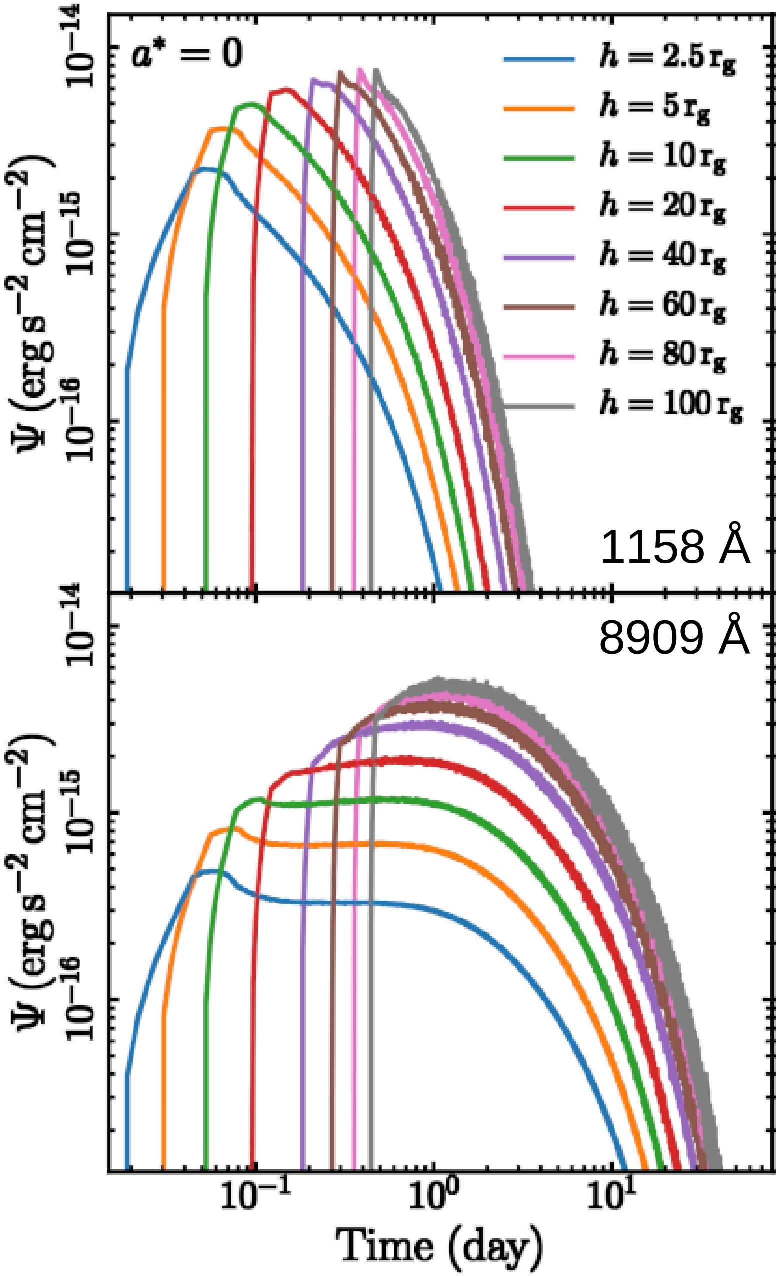


Response dependence on height

The response:

- starts earlier and is shorter for smaller height
  - ➔ light travel time is shorter
- is higher for larger heights
  - ➔ incident flux is proportional to the cosine of the incident angle – by increasing the height cosine increases leading to a larger incident flux and thus larger $\boldsymbol{F_{abs}}$

$$\dot{m} = 0.01\,\dot{m}_{\rm Edd}$$

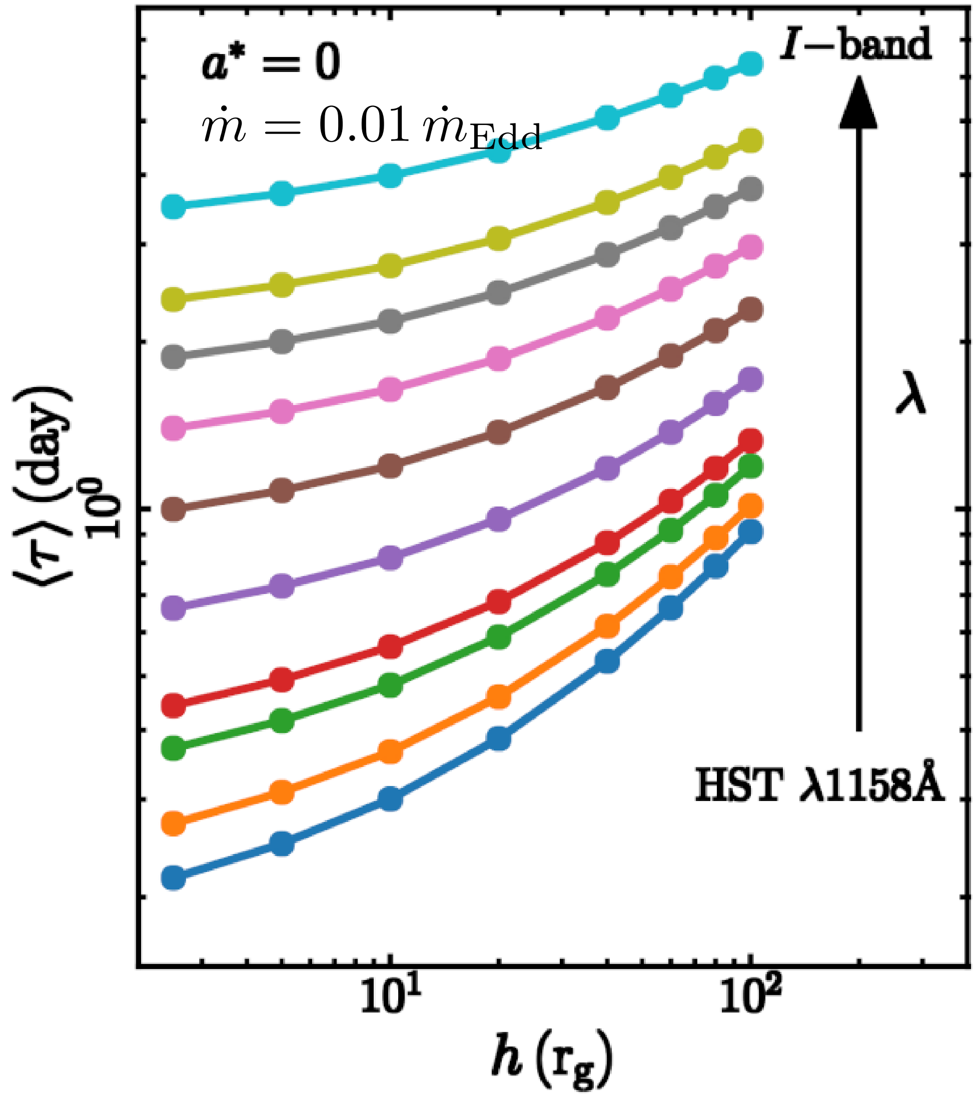


Delay dependence on height

$$\langle \tau \rangle = \frac{\int_0^\infty t\, \Psi(\lambda, t)\ \mathrm{d}t}{\int_0^\infty \Psi(\lambda, t)\ \mathrm{d}t}$$

As a consequence **the delay:**

- is higher for higher height
  - since the response starts later and lasts longer

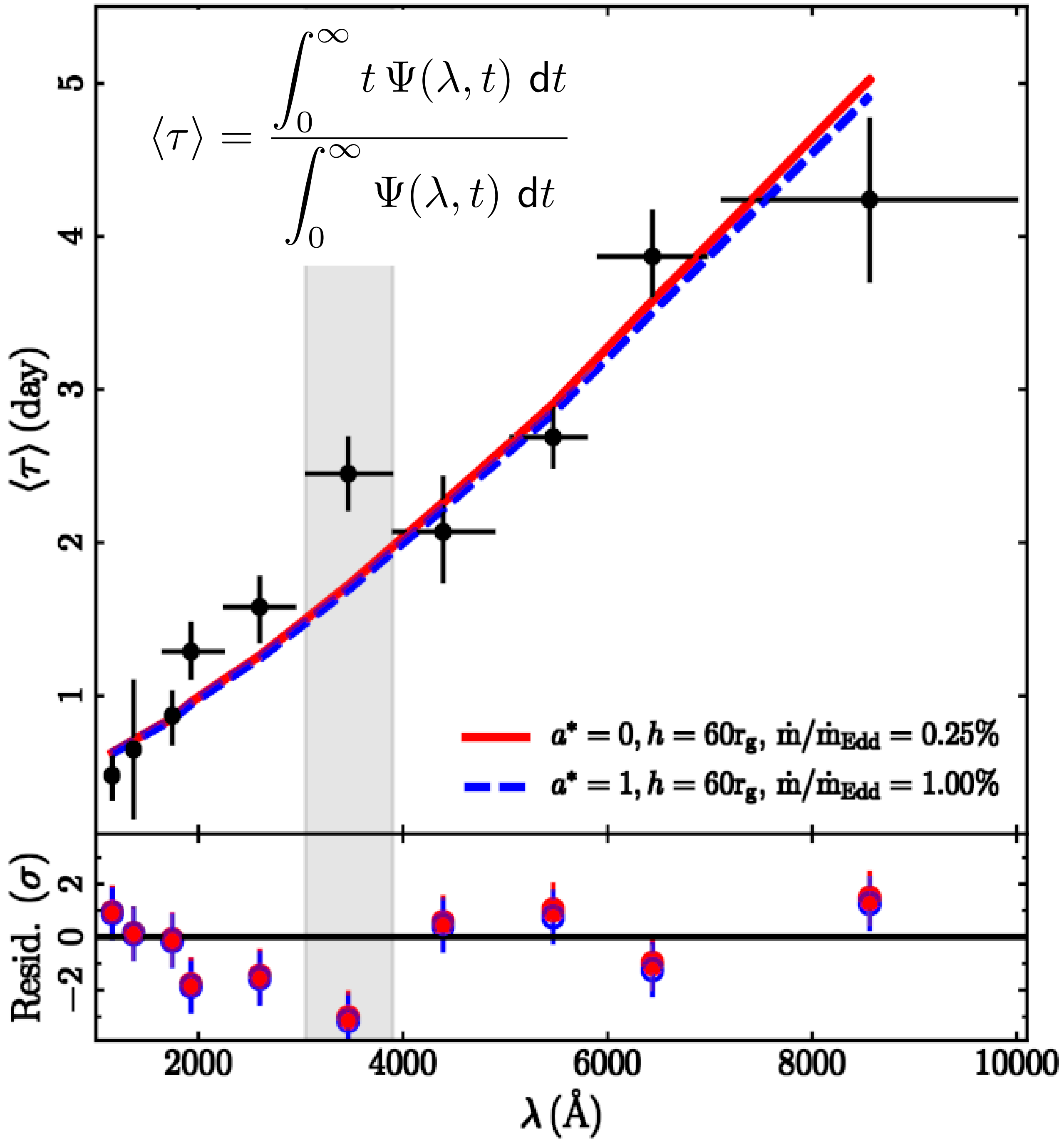


Fitted delay

- 0.65-day delay between X-rays and HST λ1367 added
- fit in the grid of different accretion rates and heights
- U-band point excluded from fitting due to an additional delay probably caused by the Balmer jump in BLR (Korista & Goad 2001)

$$\chi^2/\mathrm{dof} = 10.8/7 \text{ for } a = 0$$

$$\chi^2/\mathrm{dof} = 10.7/7 \text{ for } a = 1$$



Summary

- The disc response in all UV/optical bands increases when the source height increases and the accretion rate decreases.
  - → *Therefore, we do not expect a strong thermal reverberation signal in objects with high accretion rate and strong X-ray reflection signatures like, for example, the X-ray bright narrow-line Seyfert-1 galaxies.*

- The delays between X-rays and optical/UV bands increase with increasing source height and increasing accretion rate.

- We have successfully fitted the delays with NT disc for NGC 5548 with reasonable accretion rates, $\dot{m} = 0.01\,\dot{m}_{\rm Edd}$, and height, *h* ~ 60 r_g which is consistent with X-ray reflection fitting by Brenneman et al (2012) where height, *h* ~ 100 r_g.

- We have used our reverberation code **KYNXILREV** model.

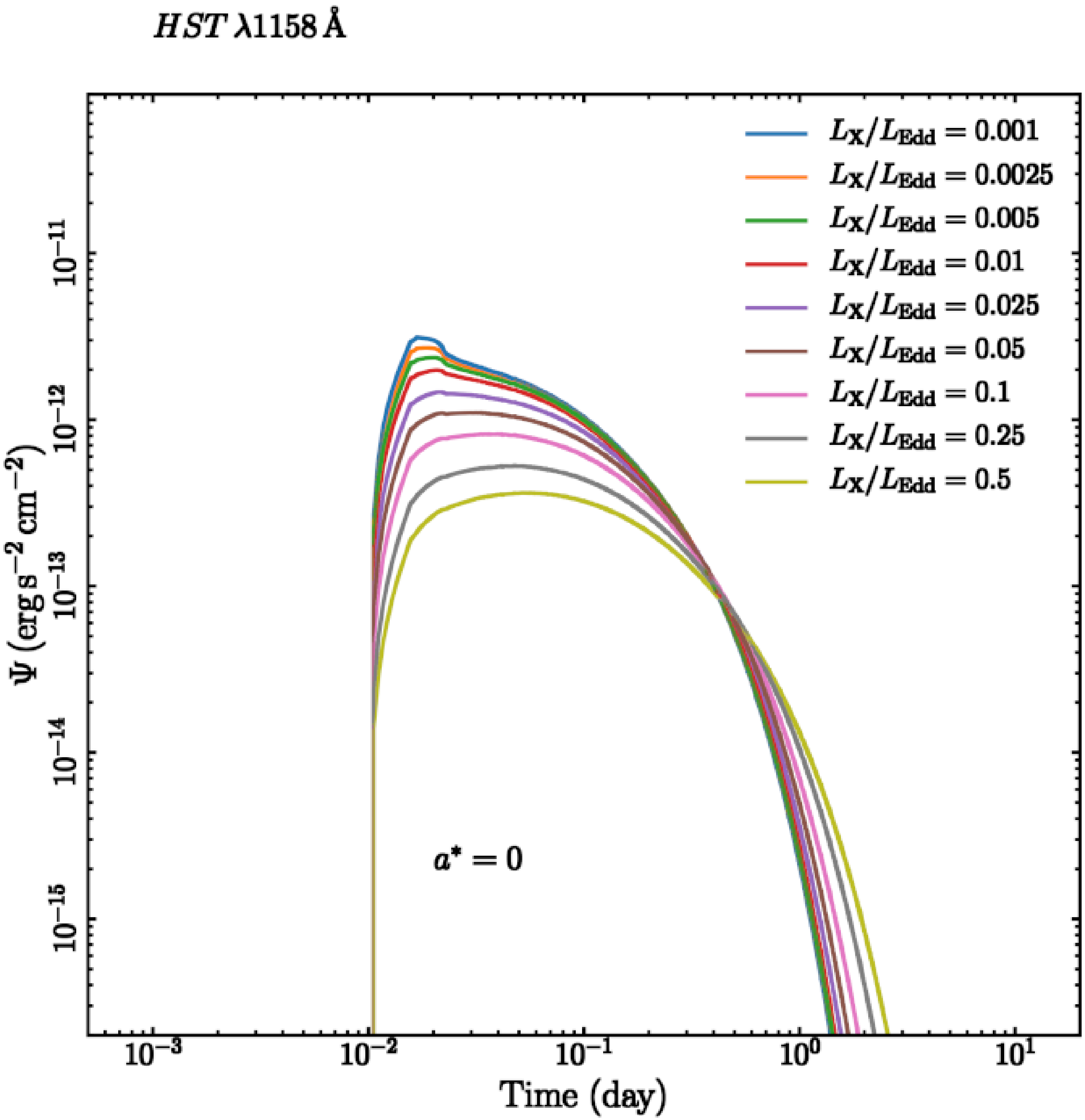
- More details in: **Kammoun, Papadakis & Dovčiak (2019)**.

- Future plans:
  - → study the effect of other parameters: M, L_X, Γ, E_0, E_c, inclination, non-razor thin discs
  - → fit other AGN with observed UV/optical lags (NGC4593, NGC4151, Mrk 509)
  - → study the connection of UV/optical light curves with X-ray ones

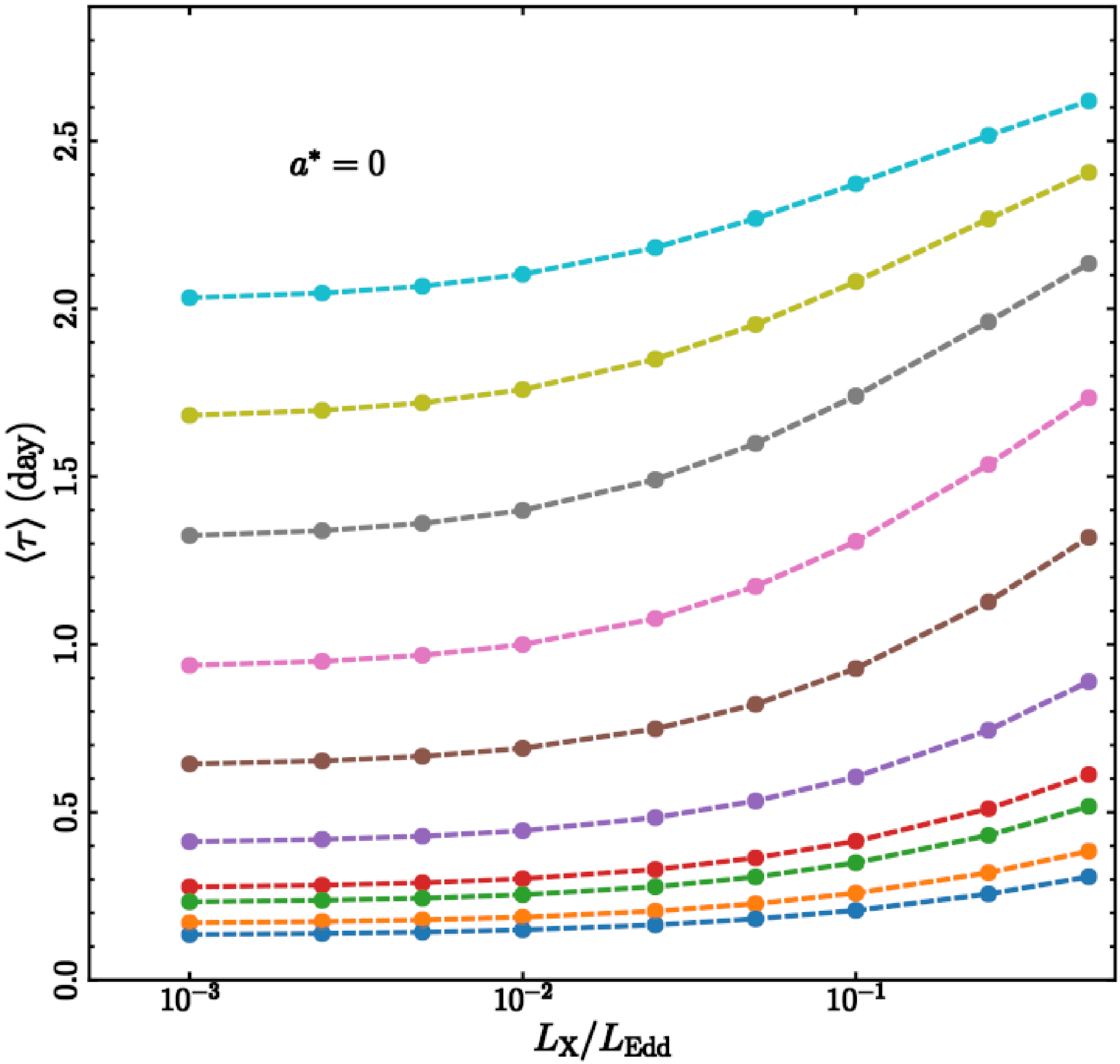
Additional material

Response dependence on L_X

- Thermal reverberation is highly non-linear
- Response function depends on L_X



Delay dependence on L_X



Delay dependence on L_X