The UV/X-ray Relation in NGC 4151

Durham University

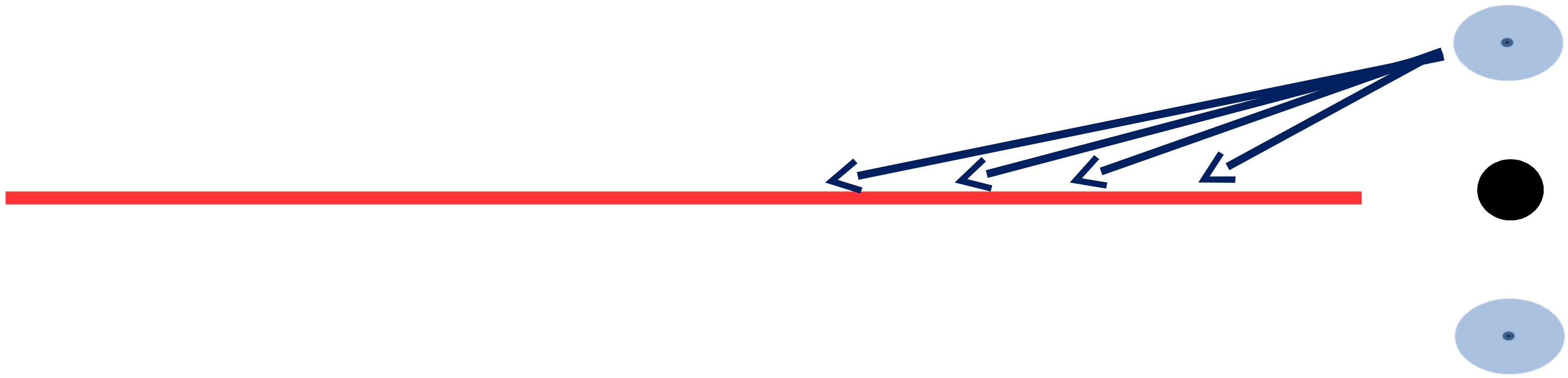
Ra'ad Mahmoud
& Chris Done
Many thanks to Rick Edelson,
Swayamtrumpta Panda, Bozena Czerny, Emma Gardner

Durham Centre for Extragalactic Astronomy

Mapping the Central Regions of AGN, Guilin, 2019

The Optical-UV/X-ray Relation in AGN

- Canonical models of inner accretion zone have hard Compton corona(e) near BH, UV/optical disc within ~100 Rg (Shakura & Sunyaev, Galeev+1979).
- Implies strong correlation between optical/UV+X-rays…

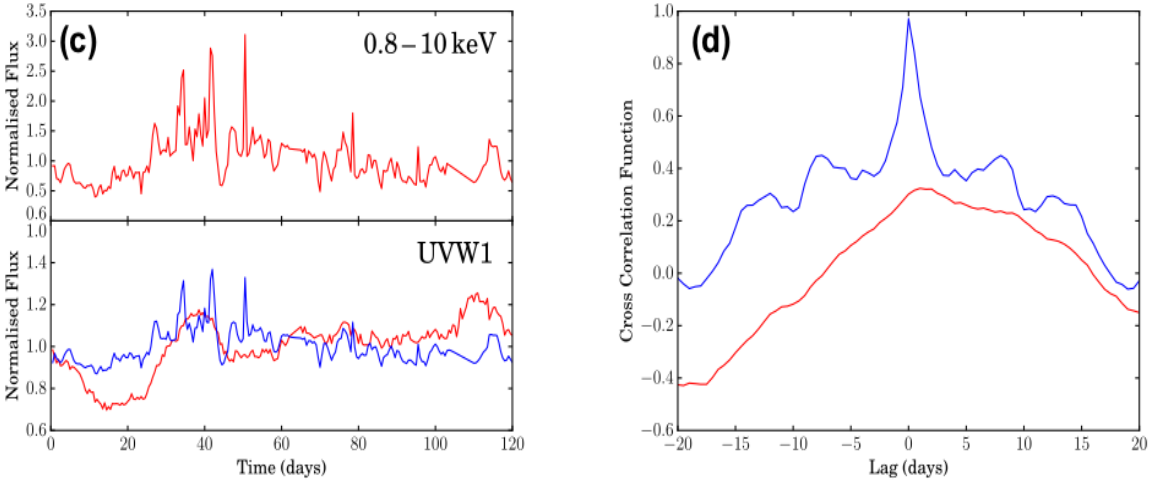


The Optical-UV/X-ray Relation in AGN

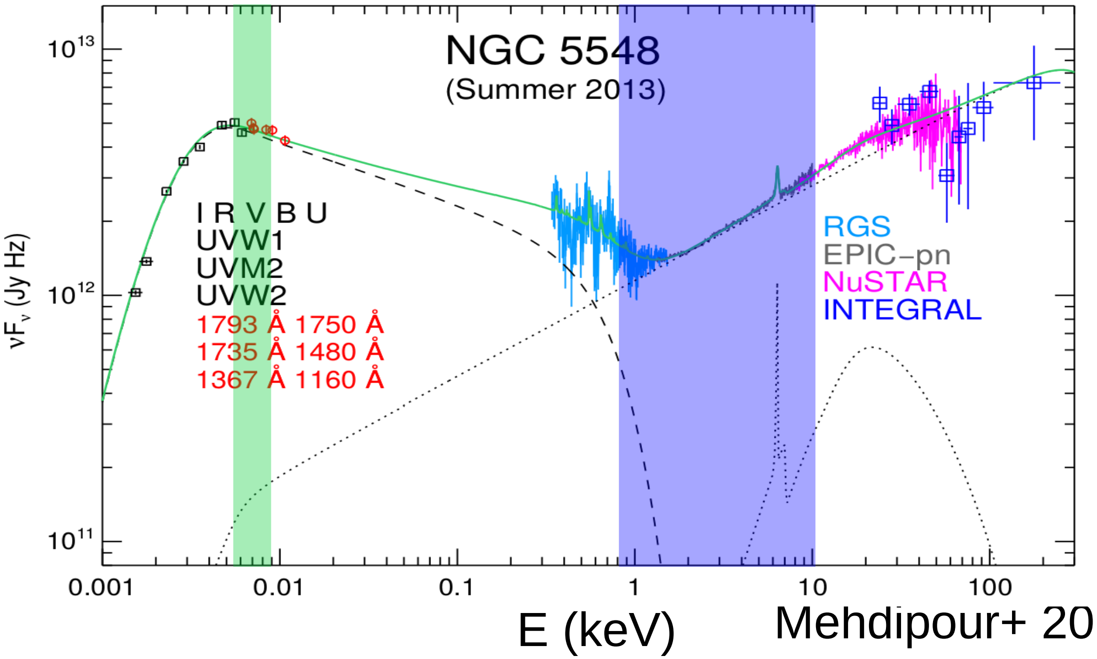
- Canonical models of inner accretion zone have hard Compton corona(e) near BH, UV/optical disc within ~100 Rg (Shakura & Sunyaev, Galeev+1979).
- Implies strong correlation between optical/UV+X-rays…
- But recent broad-band monitoring campaigns have revealed curious lack of correlation in optical-UV vs. X-rays in many AGN.

Previously: NGC 5548

- Edelson+ 2015 HST+Swift campaign on NGC 5548 is good example.
- Optical-UV/X-ray poorly correlated, unlike models.
- But heavily absorbed in XRT band.
- And max energy from Swift-XRT only 10 keV.
- Maybe "high energy" band was not only tracking the hard corona?



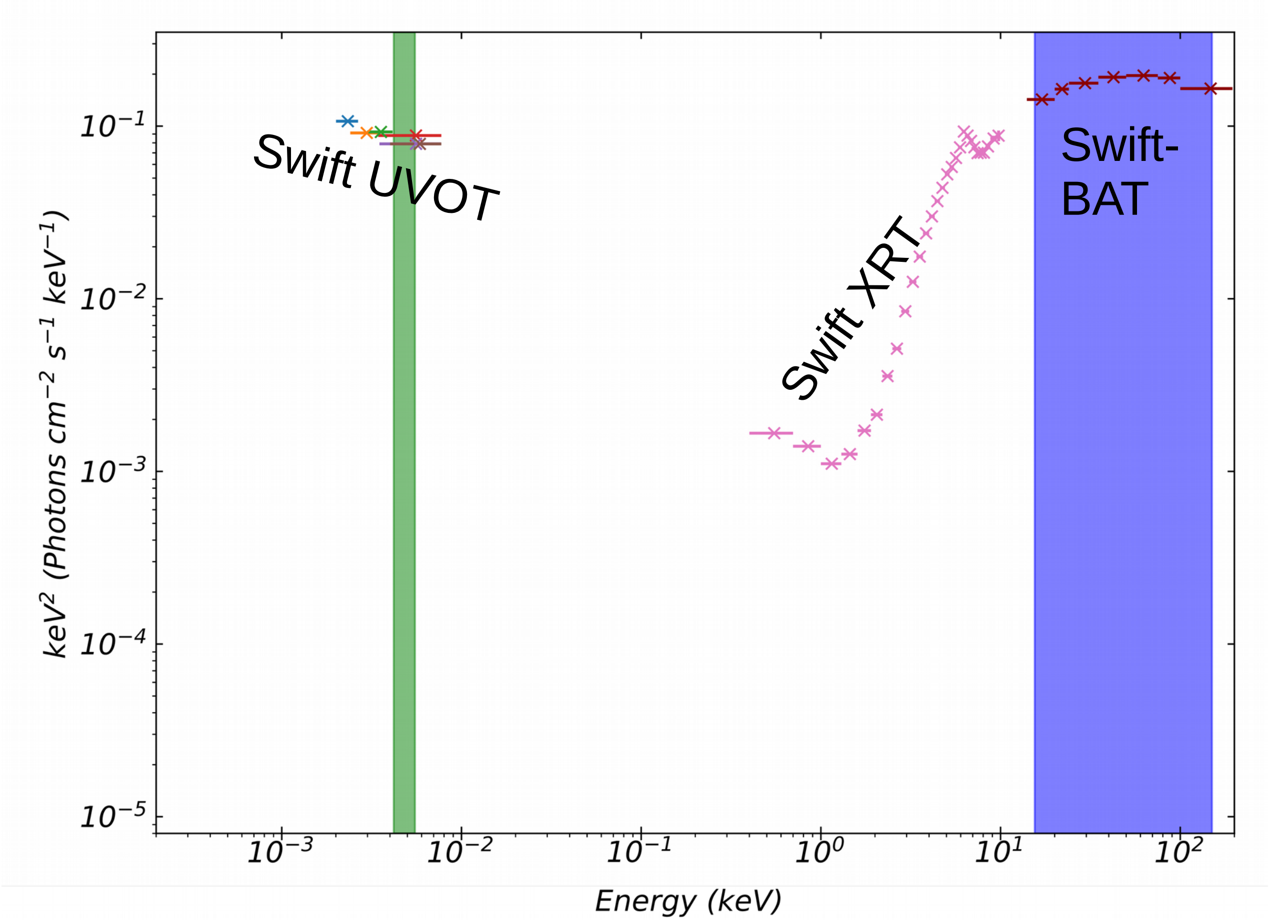
Gardner + Done 2017



Mehdipour+ 2015

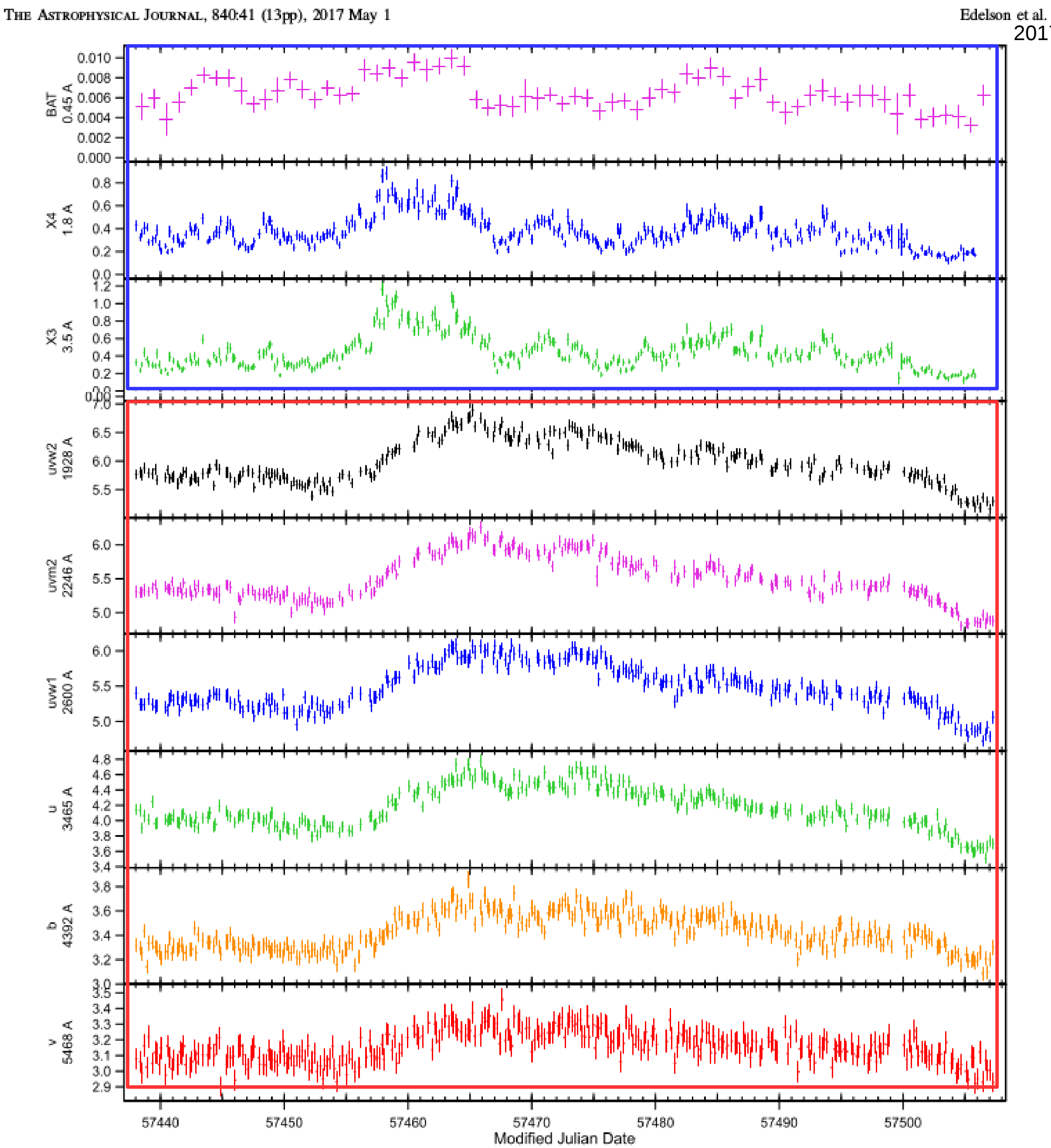
Now: NGC 4151

- One of the brightest Type 1 AGN in the sky. Bright enough to get reasonable S/N in Swift-BAT; up to ~lightcurves up to 50 keV!
- This can only be tracking coronal luminosity.
- Minimal absorption in bands of interest.

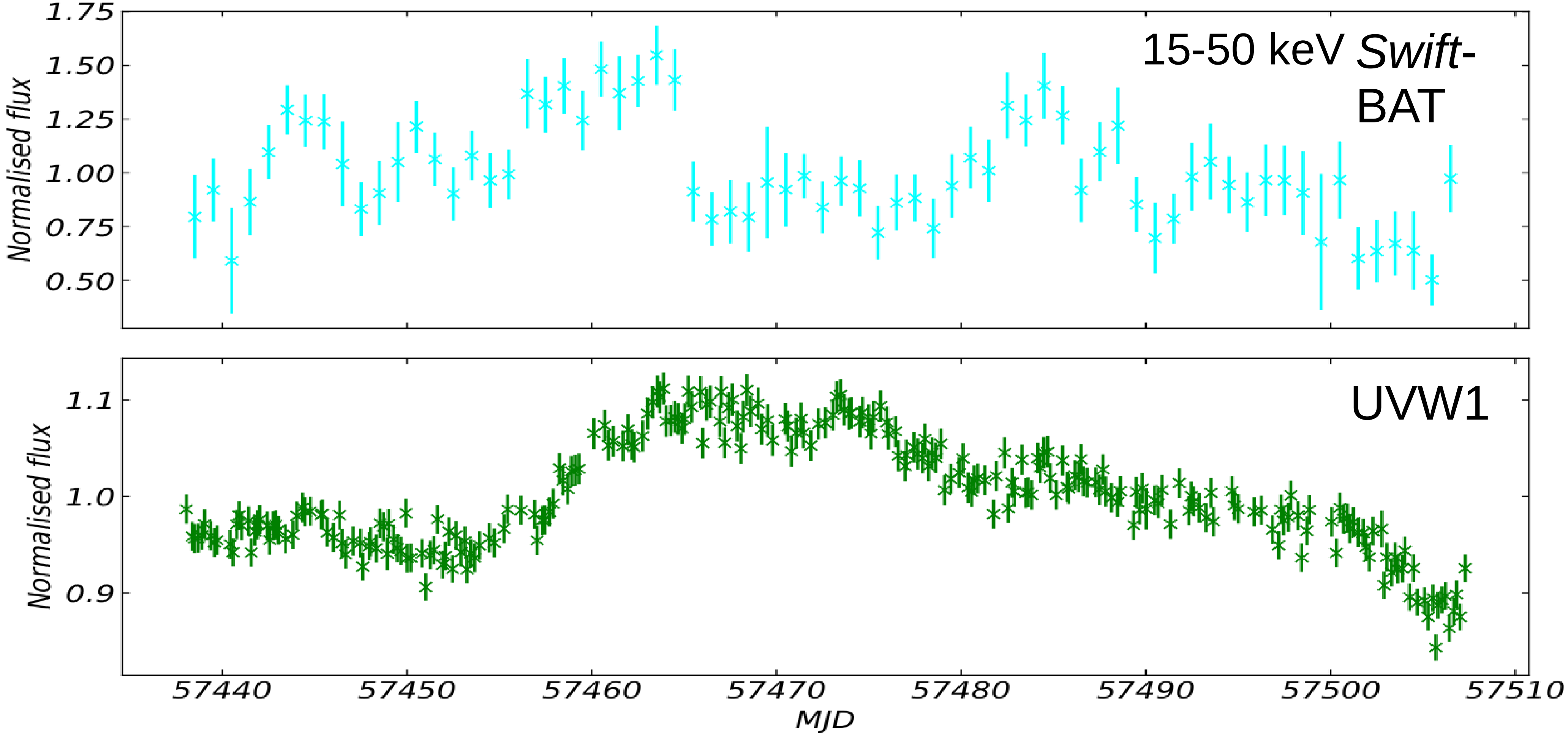


Now: NGC 4151

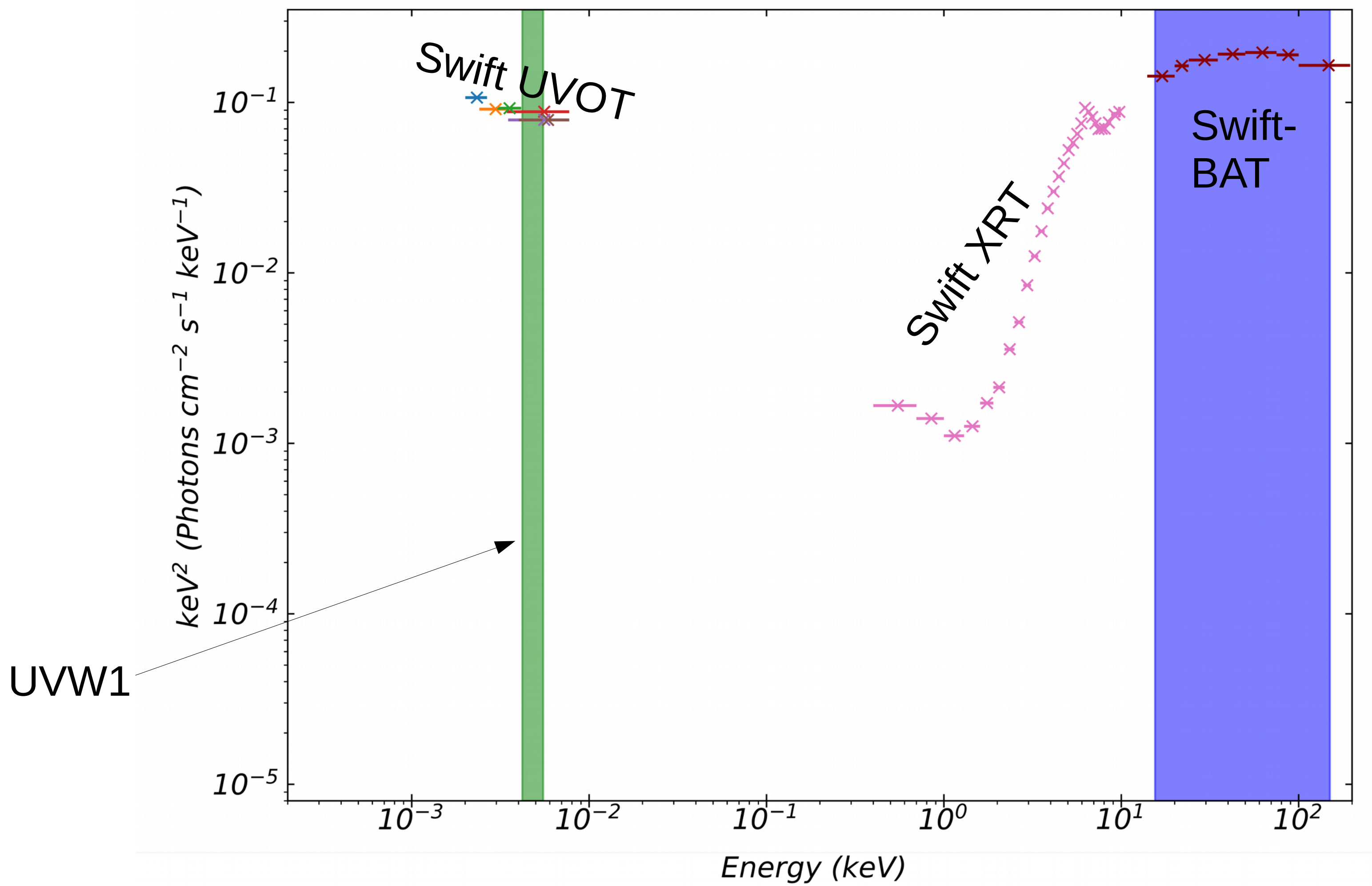
- One of the brightest Type 1 AGN in the sky. Bright enough to get reasonable S/N in Swift-BAT; up to ~lightcurves up to 50 keV!
- Edelson+2017 ~69 day campaign is unprecedented window into nature of continuum UV/X-ray variations.

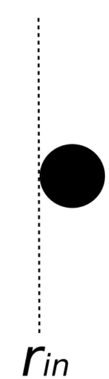


- X-rays all well correlated.
- UV/optical all well correlated.
- So let's focus on BAT (tracks bolometric), and UVW1 (compromise between host galaxy & absorption).



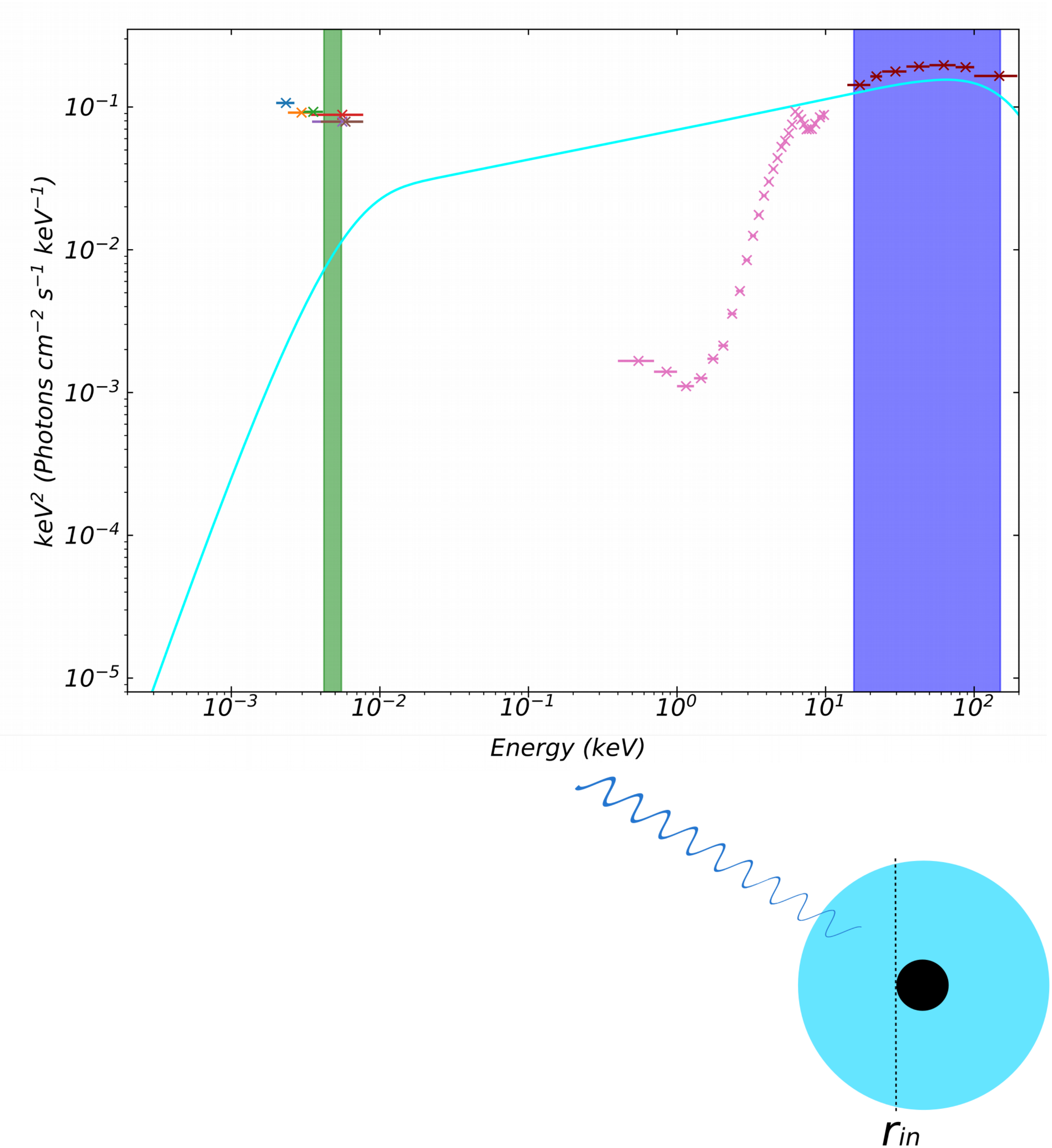
Building the intrinsic SED





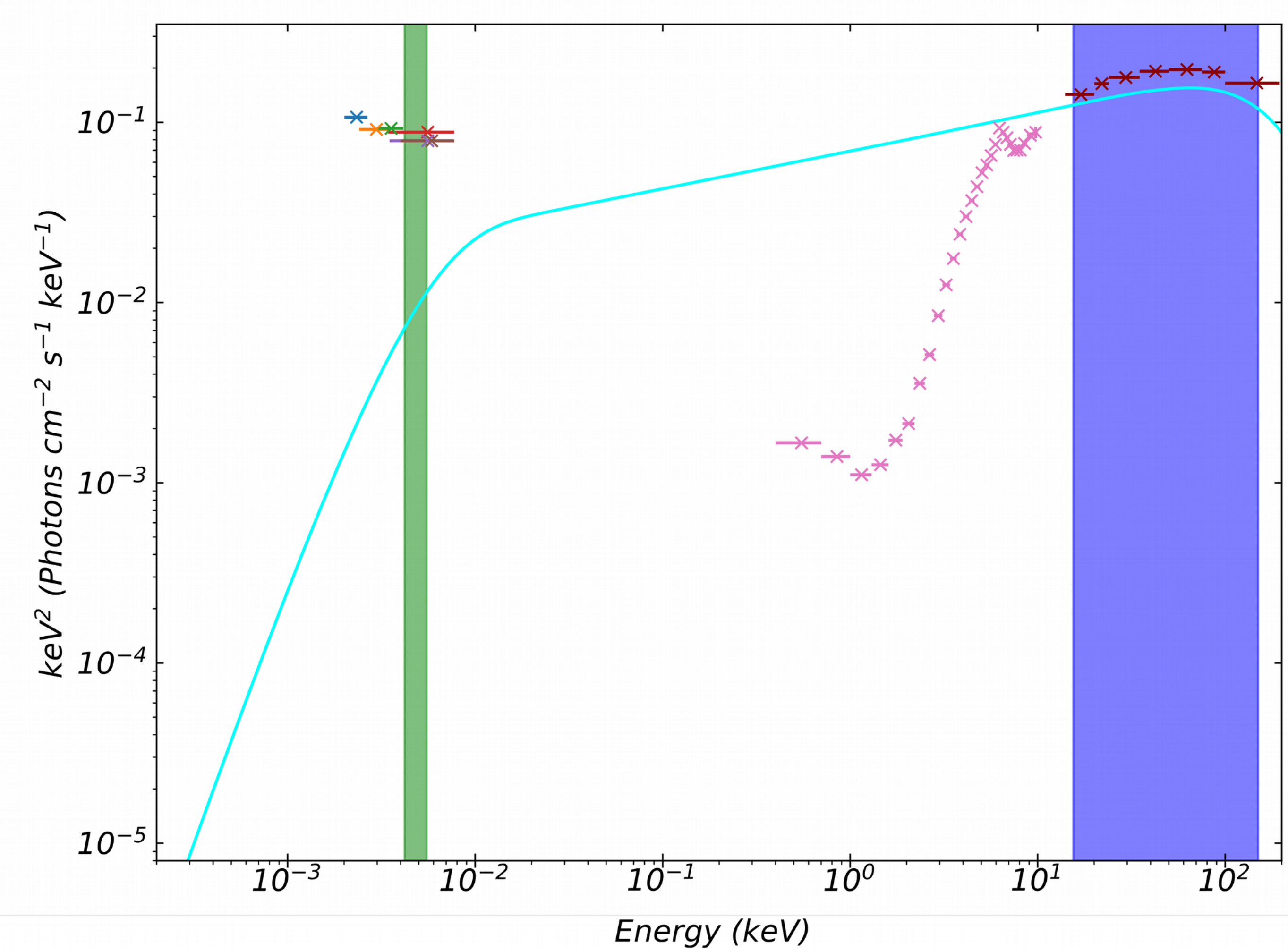
Building the intrinsic SED

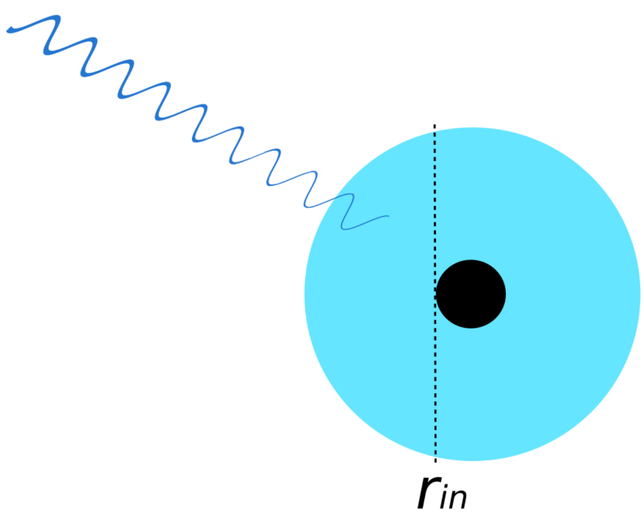
- We need a hard coronal component which matches the turnover in BAT.
- Best fit component has Γ_{hard}=1.8, $kT_{electron}$ >=100



Building the intrinsic SED

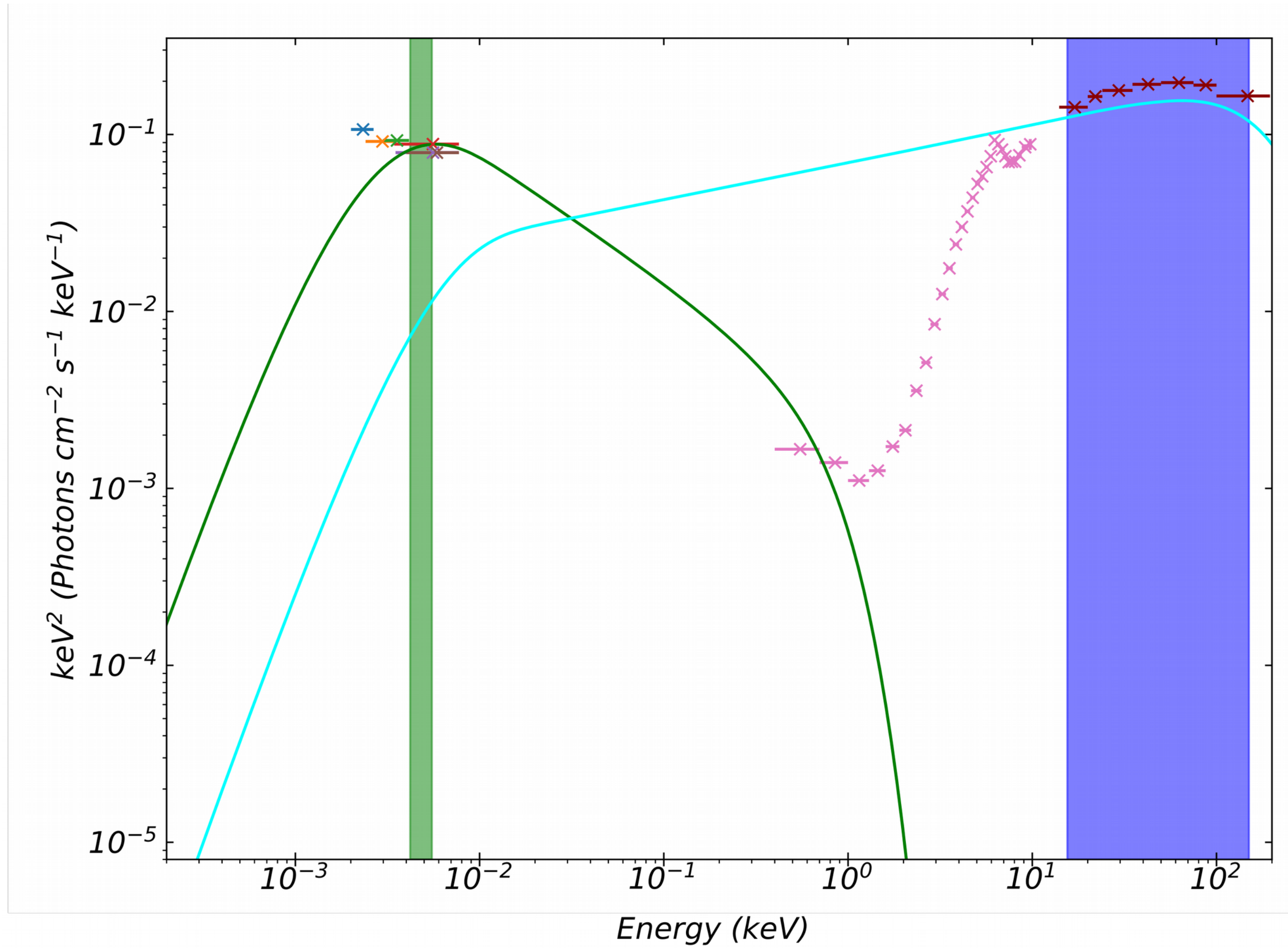
- Next: UV-optical is too red for a disc...
- Requires something broader: warm Compton on thin disc (Petrucci+ 2018).

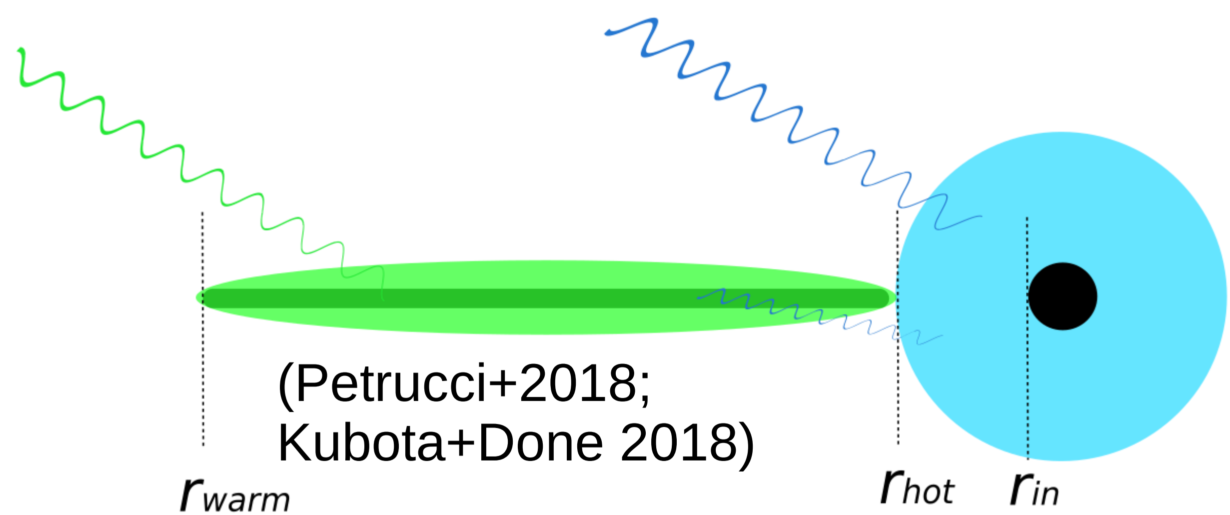




Building the intrinsic SED

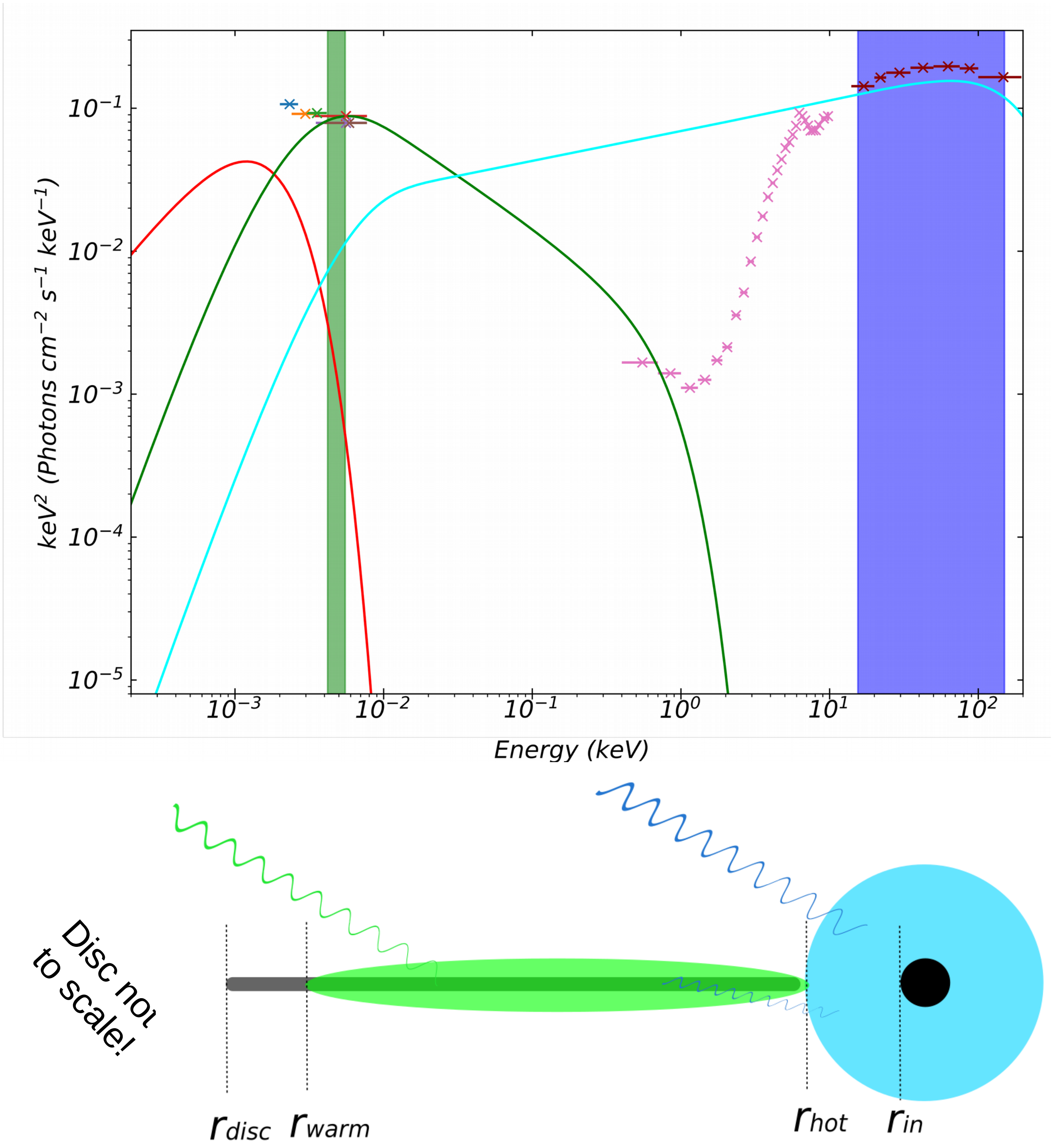
- Next: UV-optical is too red for a disc...
- Warm Compton layer above the disc from 390 to 90 R_g (fit)
- Geometry hardwires Γ_{warm} = 2.7.





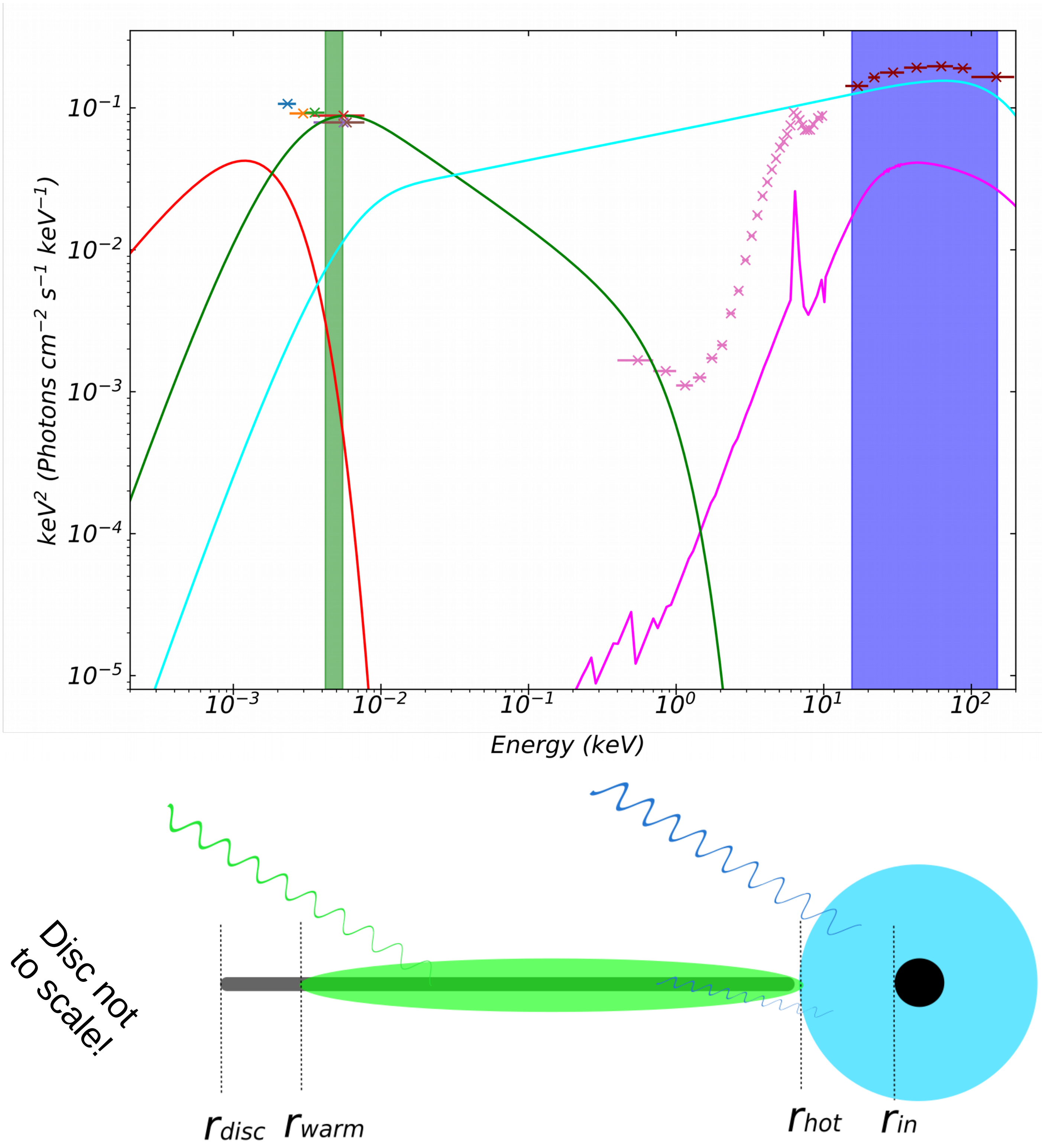
Building the intrinsic SED

- Next: outer disc to feed seed photons to corona, to feed material to the inner zone.
- Thermal disc from 10^5 - 390 R_g



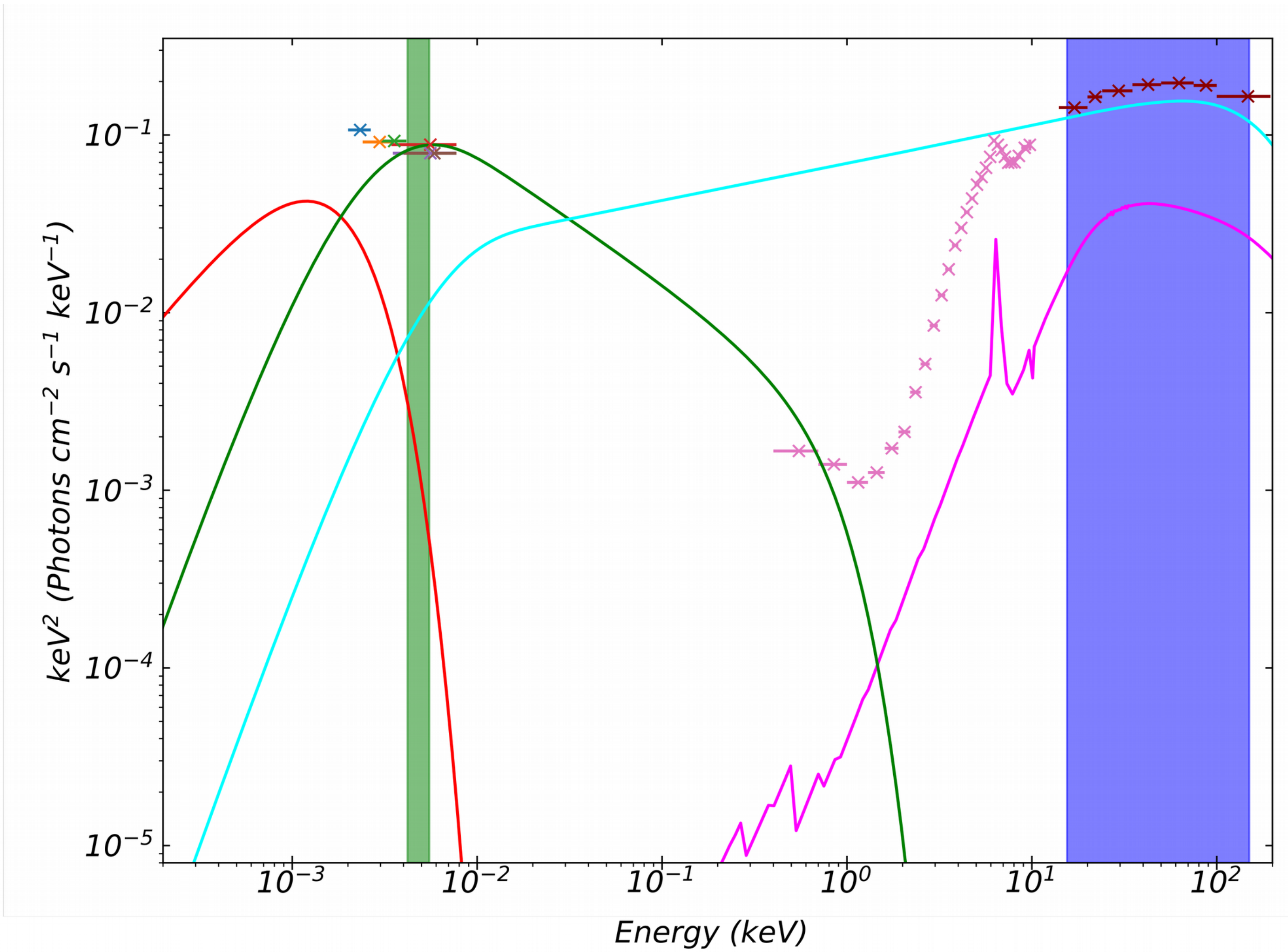
Building the intrinsic SED

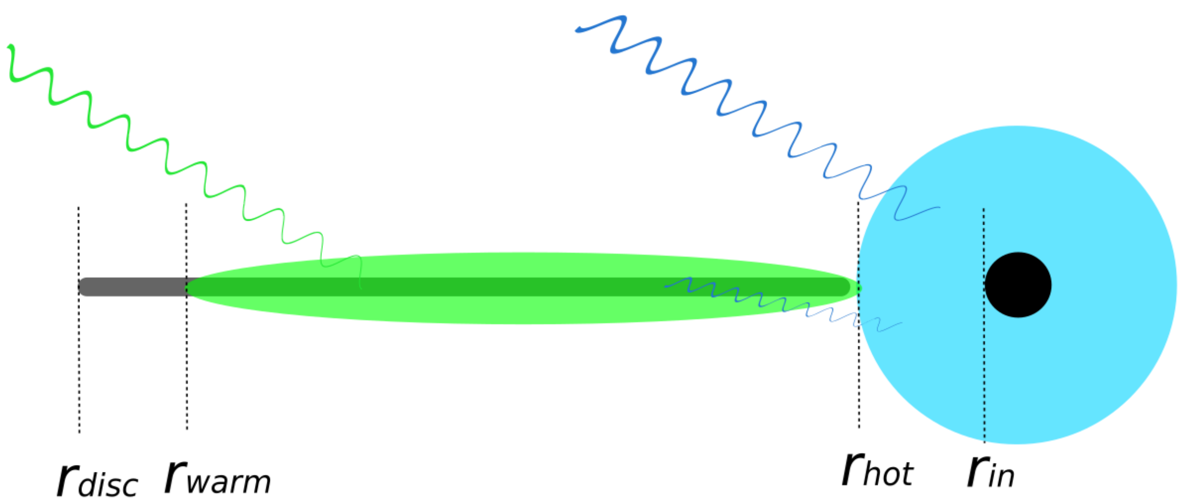
- Some reflection from outer material for the FeK-alpha line (pexmon).



Building the intrinsic SED

- These data are also absorbed by:
  - Intergalactic dust (phabs).
  - Two obscurers (pcfabs) within the AGN, with covering fractions 1 and 0.5 respectively (Beuchert+ 2017).





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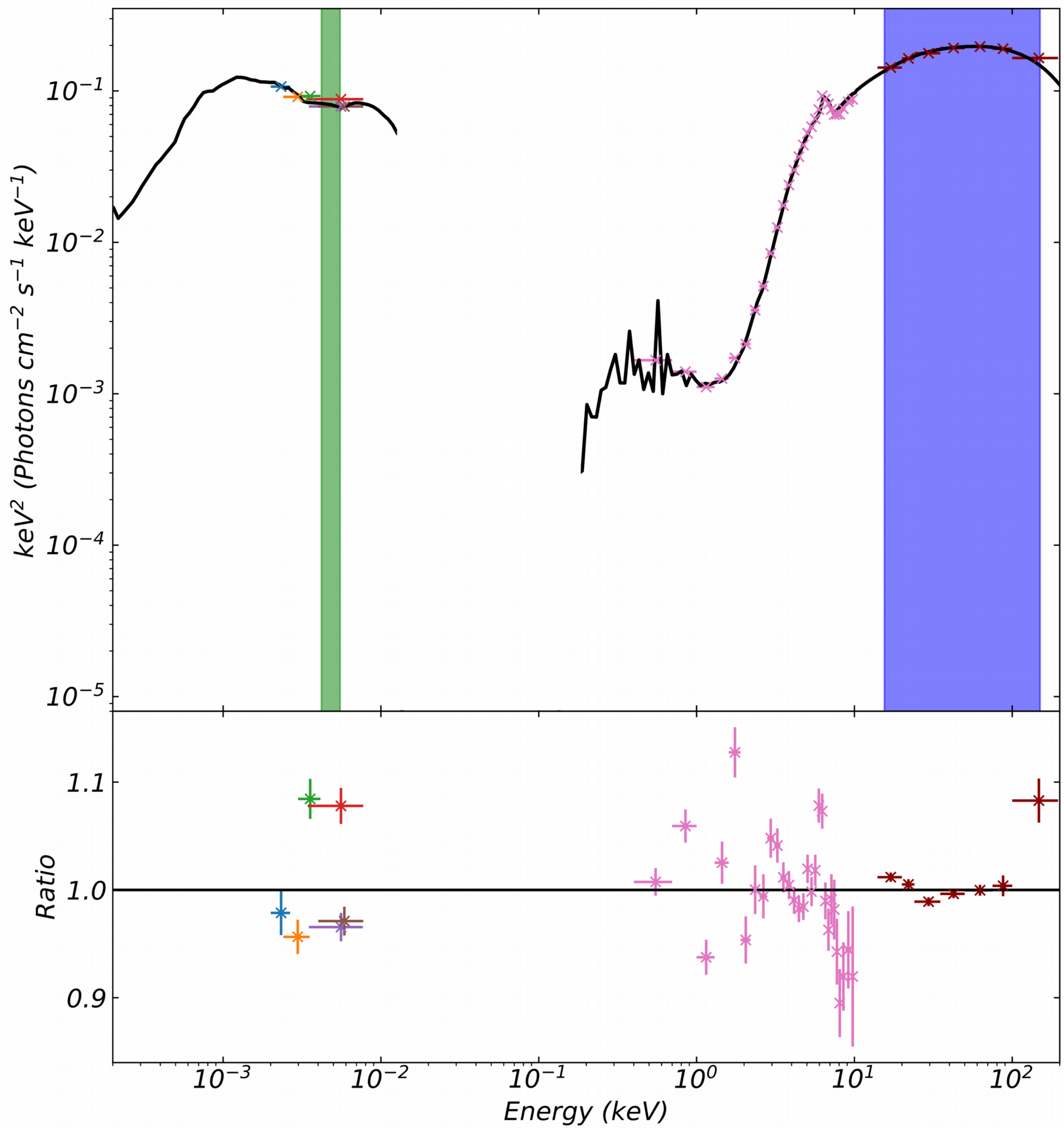
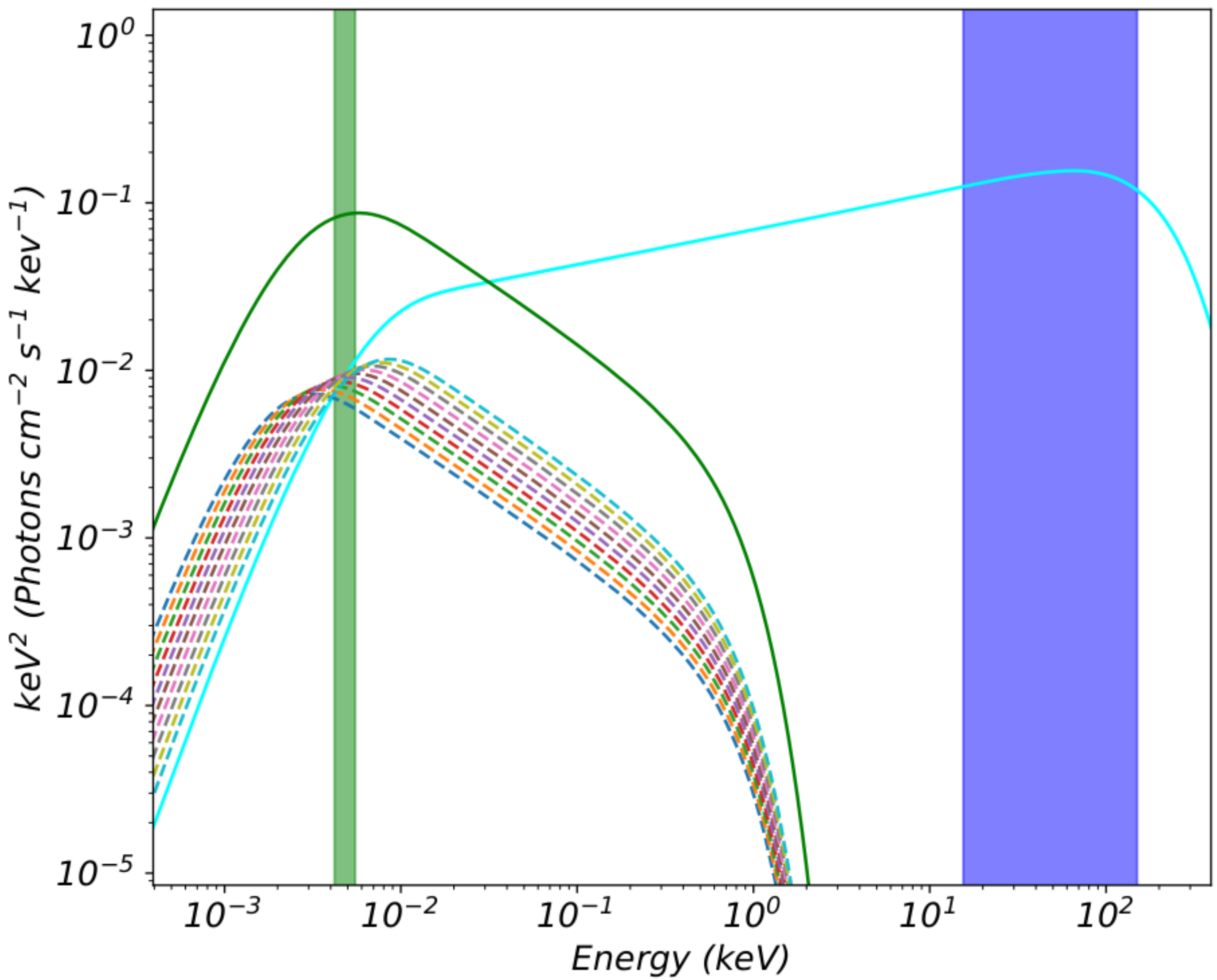
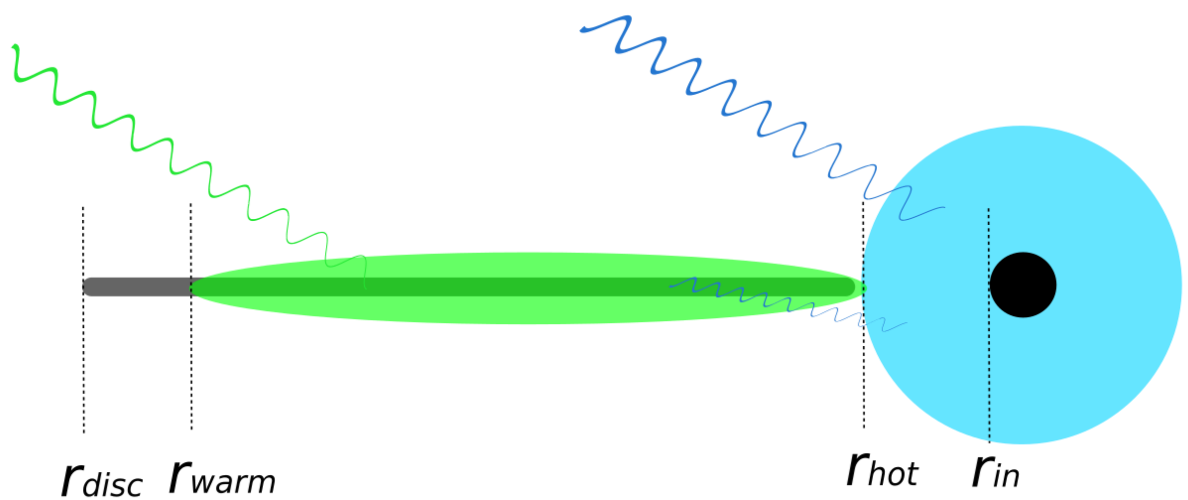


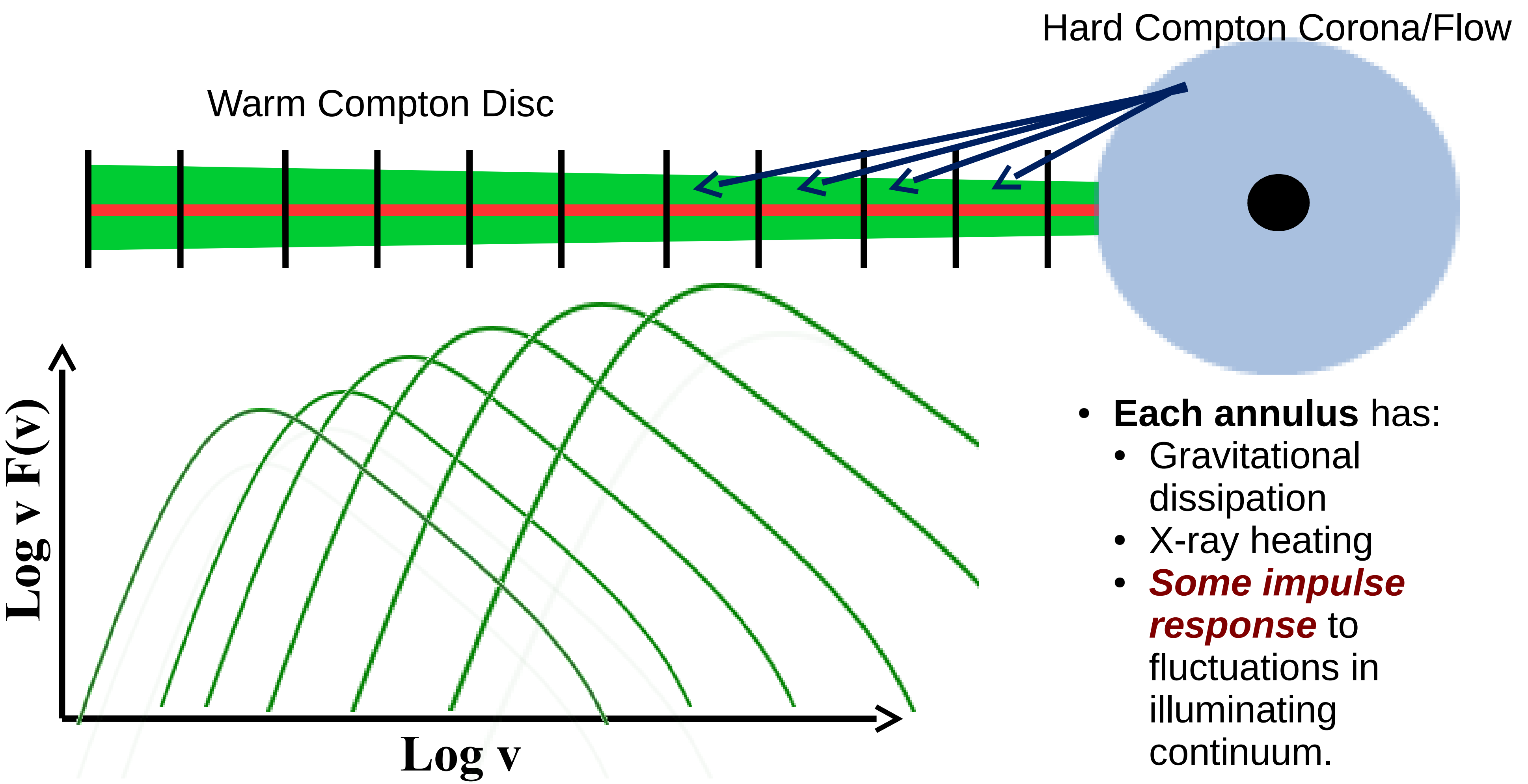
Building the intrinsic SED

- Most important components for BAT/UVW1 are the hard Compton corona and warm Compton disc.





Simple Disc-Geometry Reprocessing



- **Each annulus** has:
  - Gravitational dissipation
  - X-ray heating
  - ***Some impulse response*** to fluctuations in illuminating continuum.

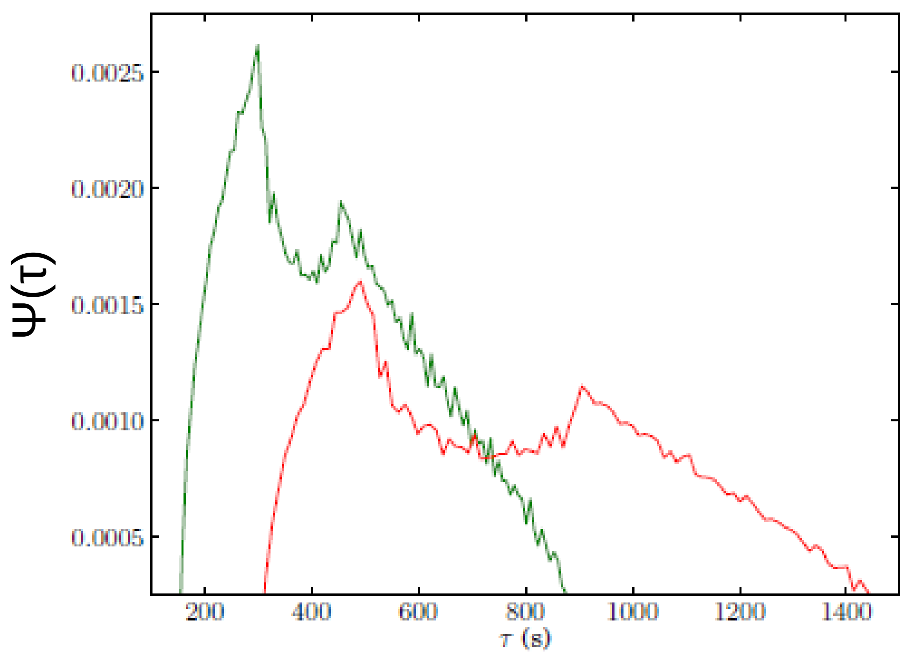
$$T_{seed}(r,\ t) = \quad T_{grav}(r)\left(\frac{F_{rep}(r,\ t) + F_{grav}(r)}{F_{grav}(r)}\right)^{1/4}$$

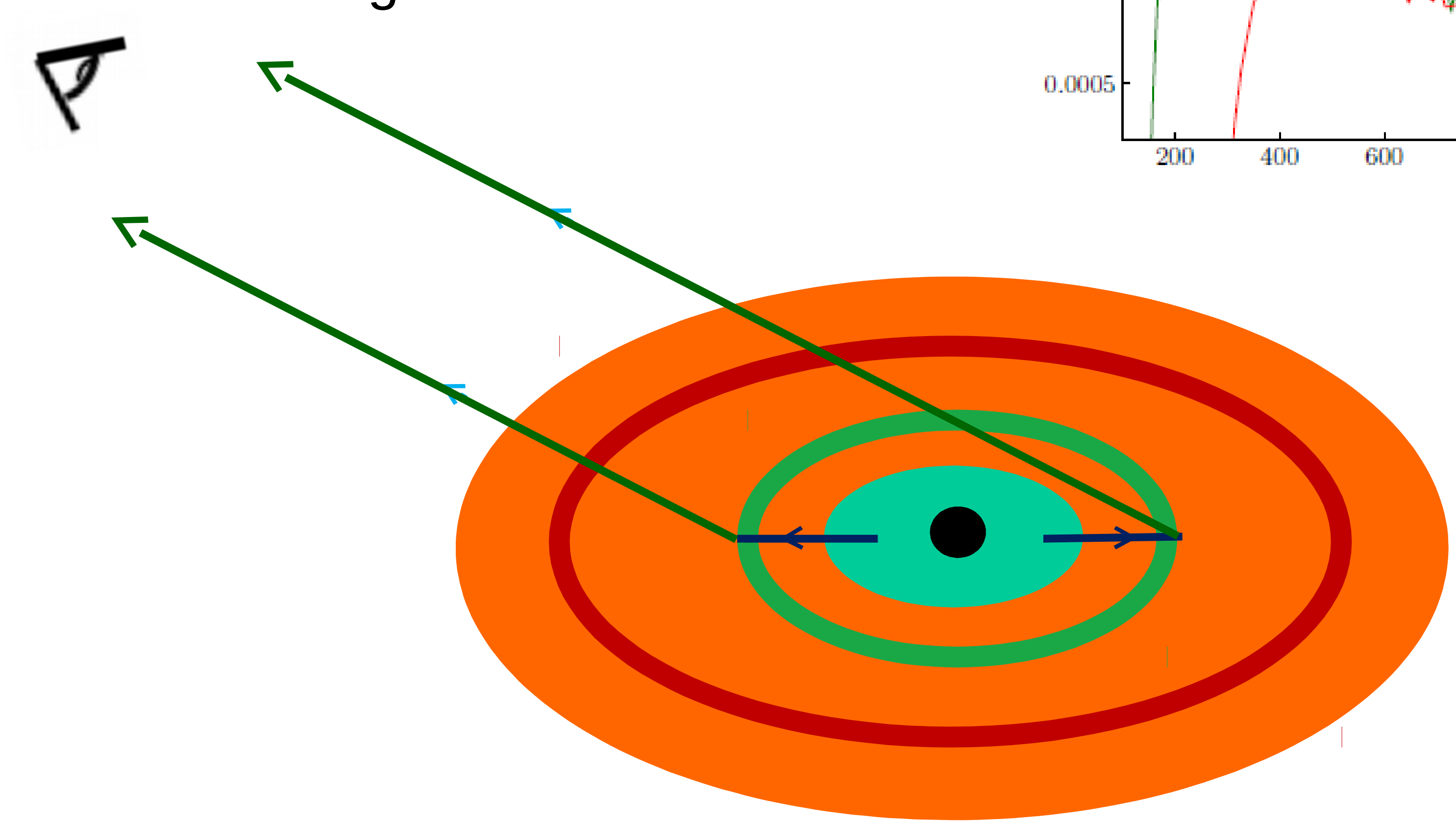
Simple Disc-Geometry Reprocessing

- Transfer function/***impulse response function***,Ψ(τ)

- Convolve with the driving (coronal) signal to delay and smooth for each annulus.

- Smooths on lag timescale.





We'll just use the simple disc response function of Welsh & Horne (1991), as in Gardner & Done (2017).

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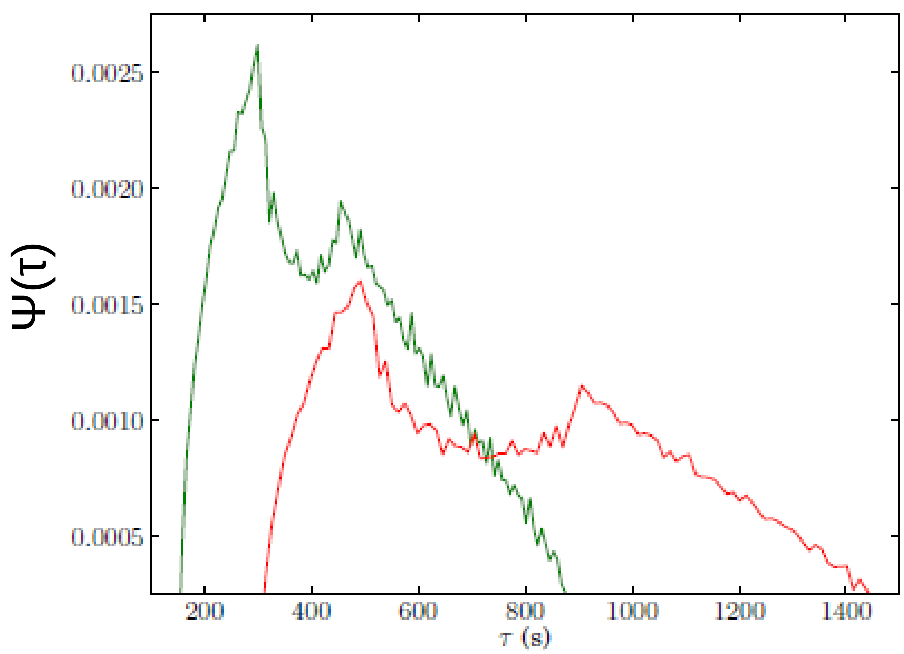

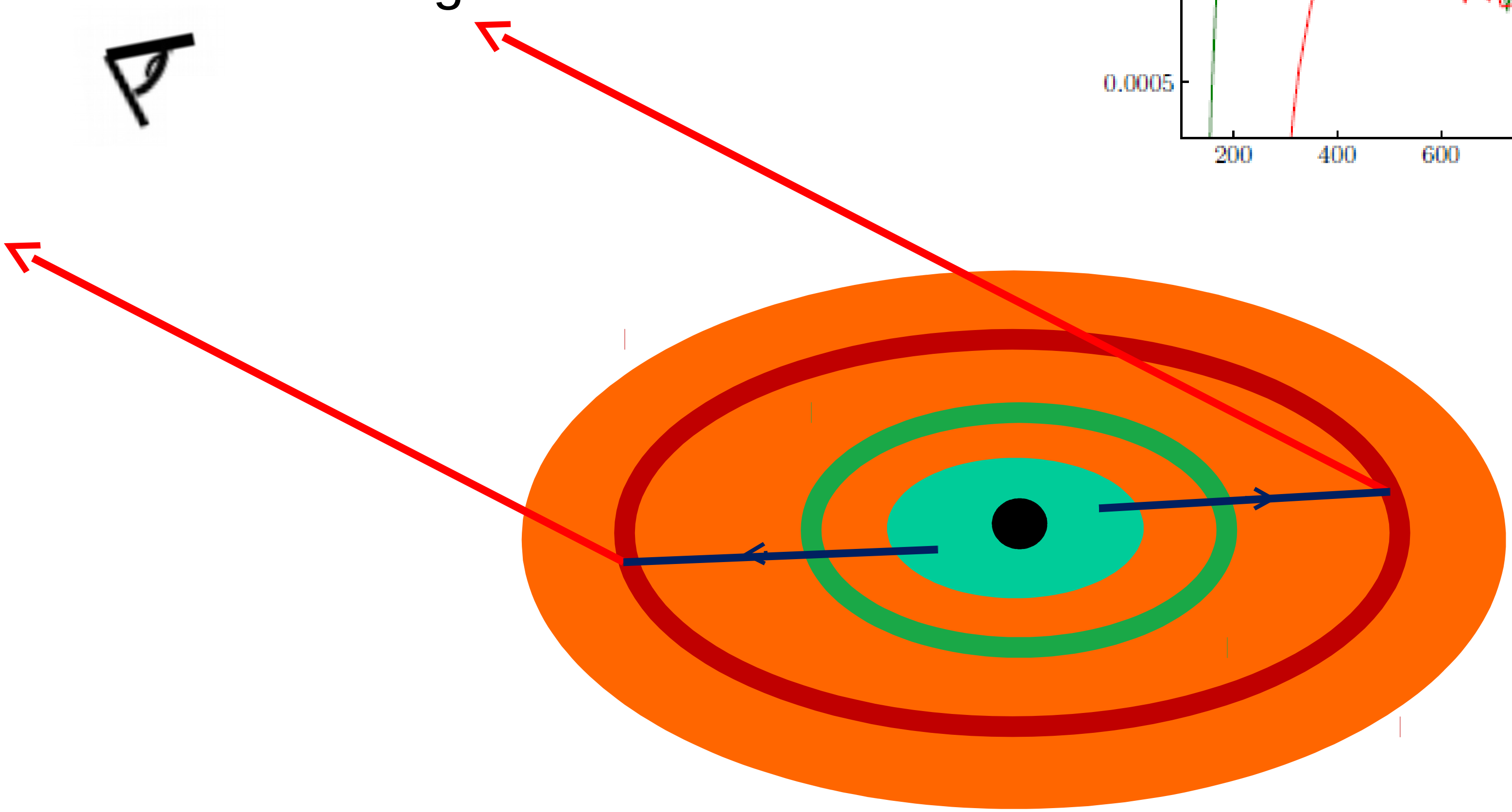

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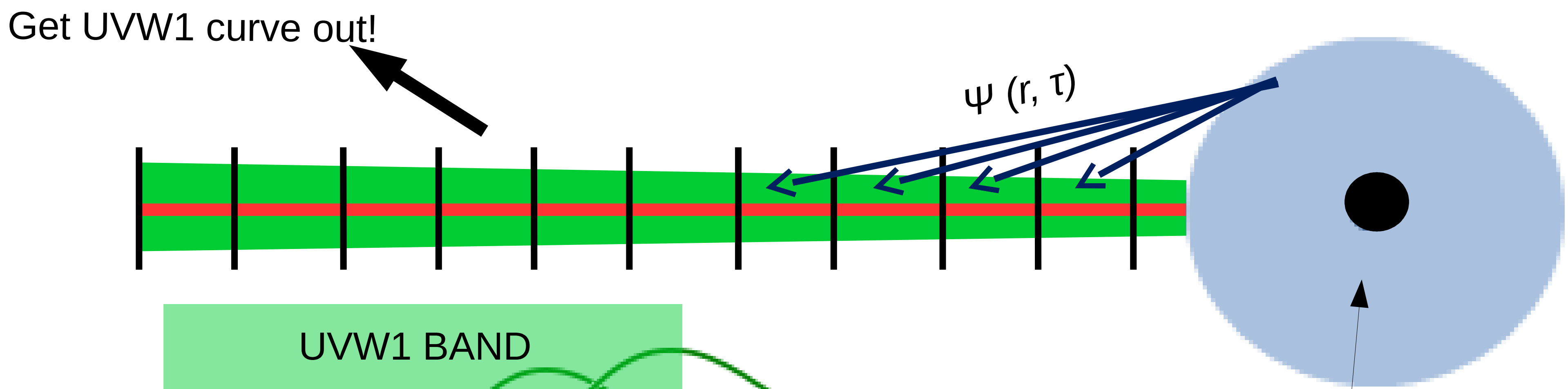
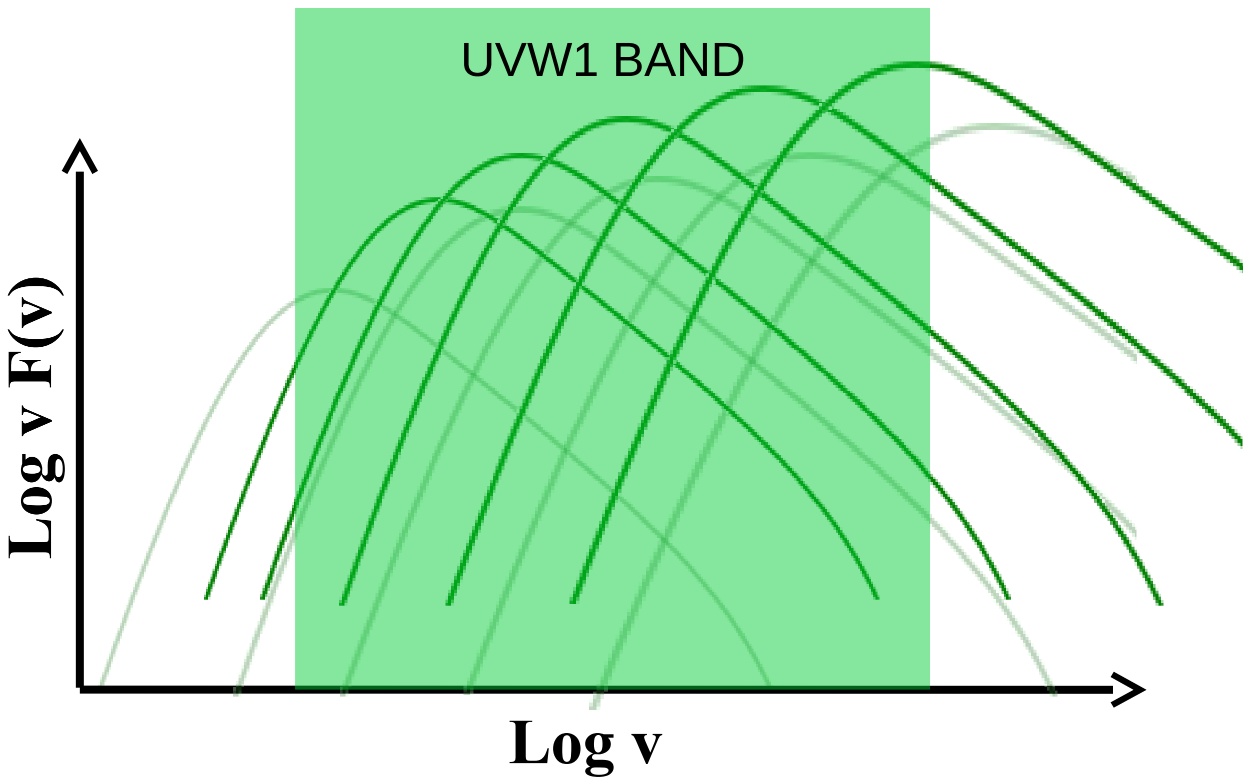
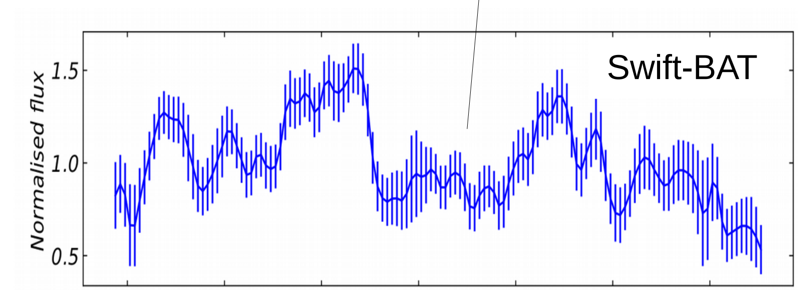




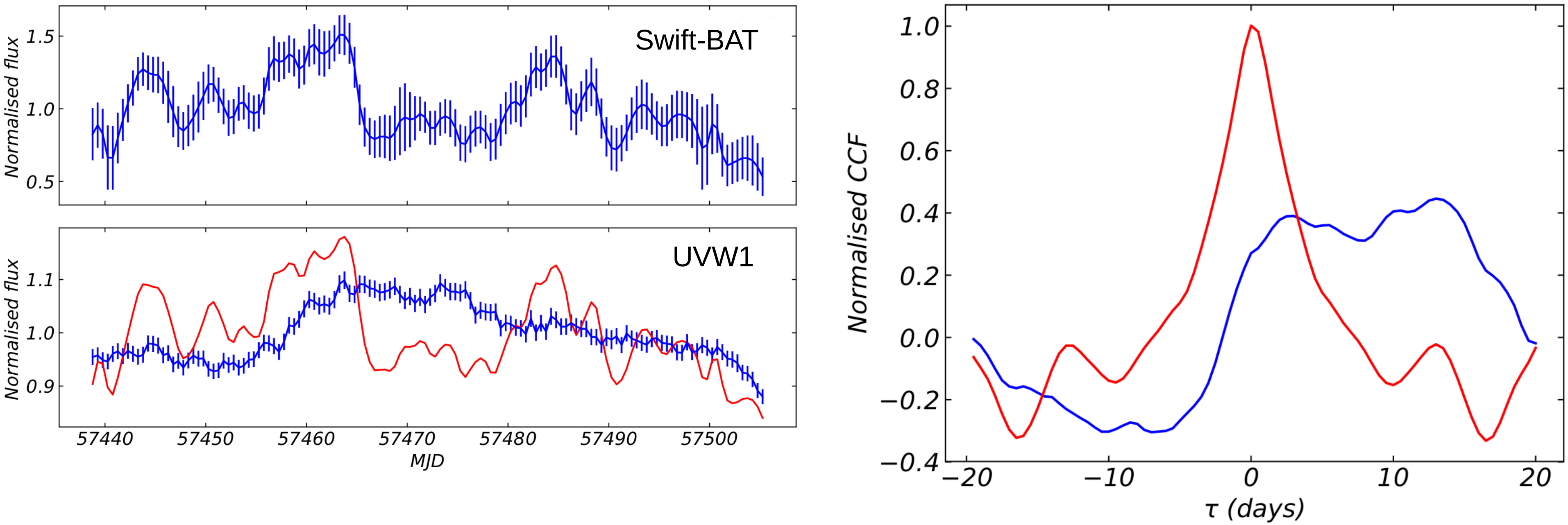


- Hard coronal fluctuations go **like Swift-BAT.**
- Drives changes in norm & T_{seed} of each annulus in SED-fit warm Compton.

$$T_{seed}(r,\, t) = \quad T_{grav}(r)\left(\frac{F_{rep}(r,\, t) + F_{grav}(r)}{F_{grav}(r)}\right)^{1/4}$$

Simple Disc-Geometry Reprocessing

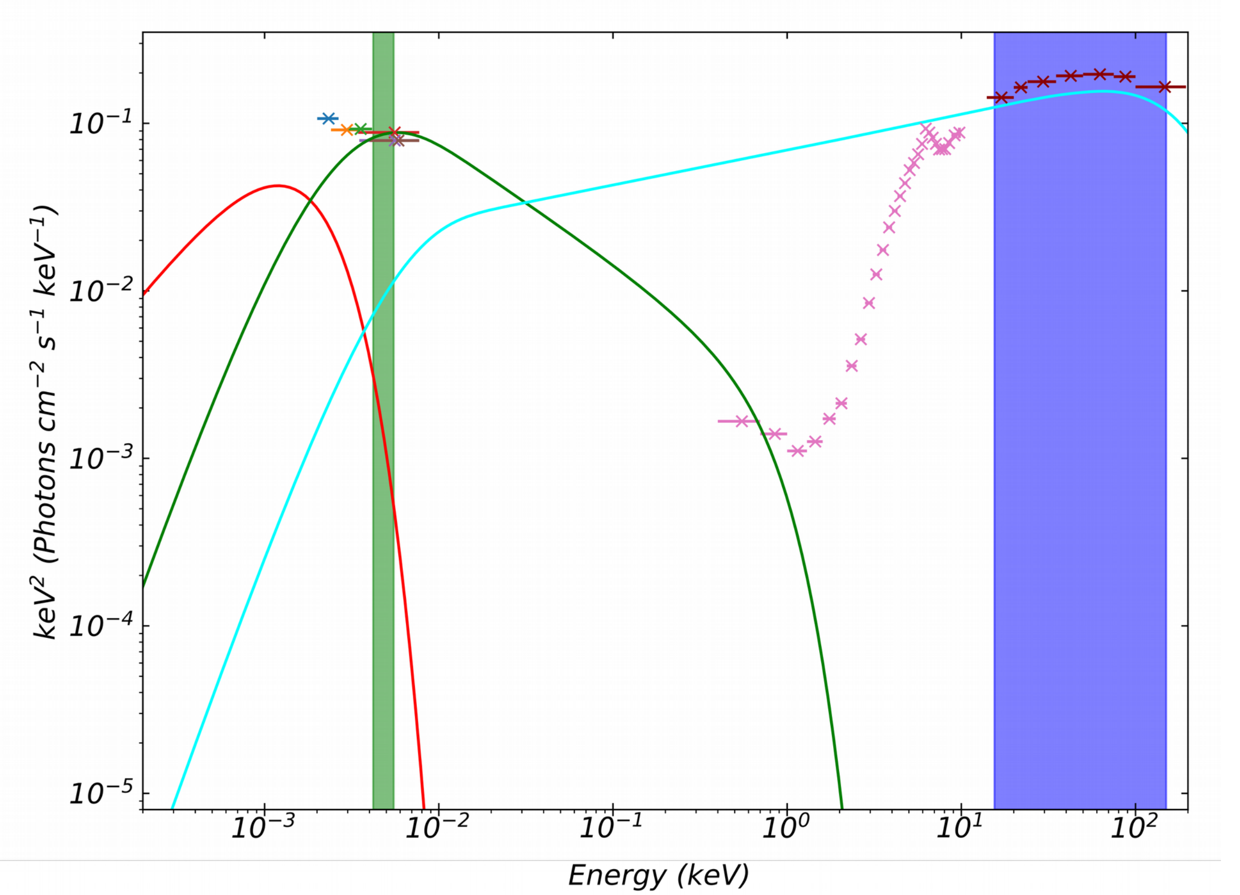
- Blue is data, red is model



- UVW1 lightcurve and BAT/UVW1 cross-correlation are not having a good time!
- Model predicts ***much*** higher cross-correlation than observed.
- Our data doesn’t agree with a UV response on small size scales. We’ve seen this before. (Gardner + Done 2017; Buisson+ 2018)

Recovering the IRF

- Seems like canonical geometry doesn't work.
- What ***could*** work to make the UVW1 from X-ray fluctuations?
- Parameterise the UVW1 curve in terms of:
  - A constant component (*fc*)
  - A slow-varying component (*fs*)
  - A direct, fast component (*1-fc-fs*).

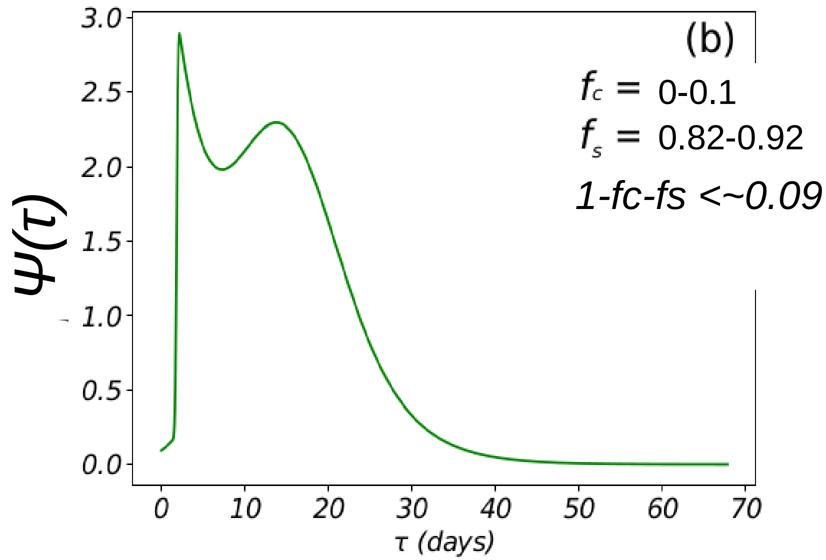


$$\frac{F_{UVW1}(t)}{< F_{UVW1}(t) >} = f_c + f_s\ \Psi(t) \circledast \frac{F_{BAT}(t)}{< F_{BAT}(t) >} + (1 - f_c - f_s)\frac{F_{BAT}(t)}{< F_{BAT}(t) >}$$

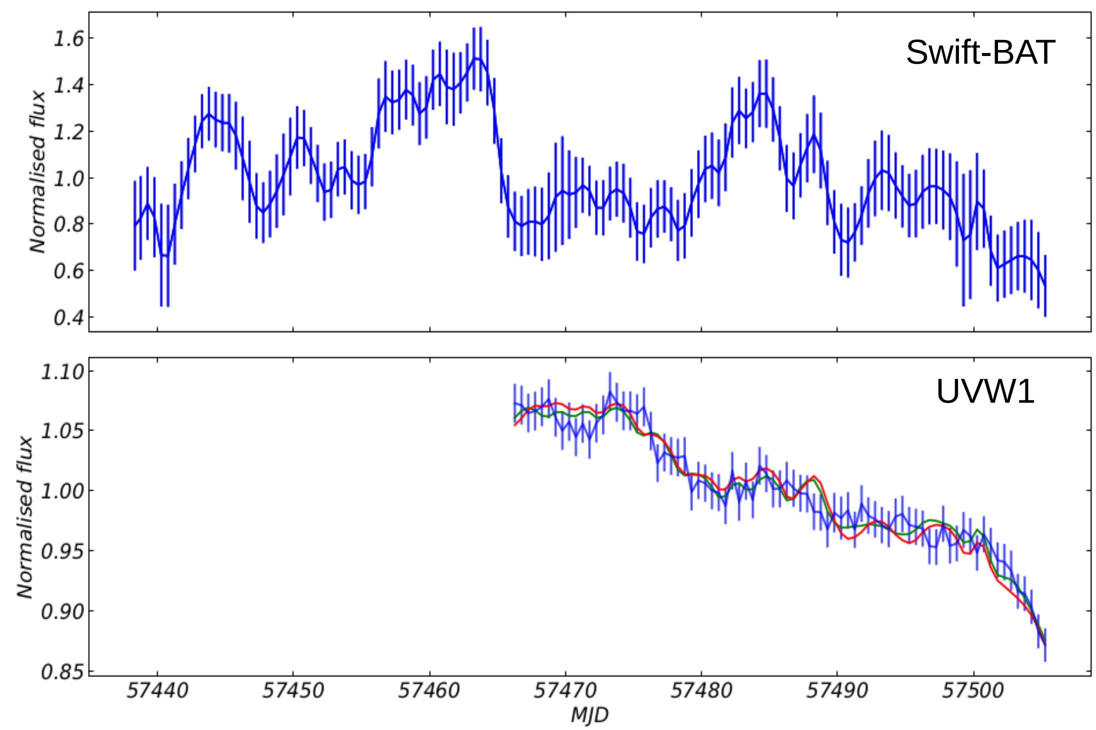
Free *Ψ(t)!!*

Recovering the IRF

$$\frac{F_{UVW1}(t)}{< F_{UVW1}(t) >} = f_c + f_s\ \Psi(t) \circledast \frac{F_{BAT}(t)}{< F_{BAT}(t) >} + (1 - f_c - f_s)\frac{F_{BAT}(t)}{< F_{BAT}(t) >}$$

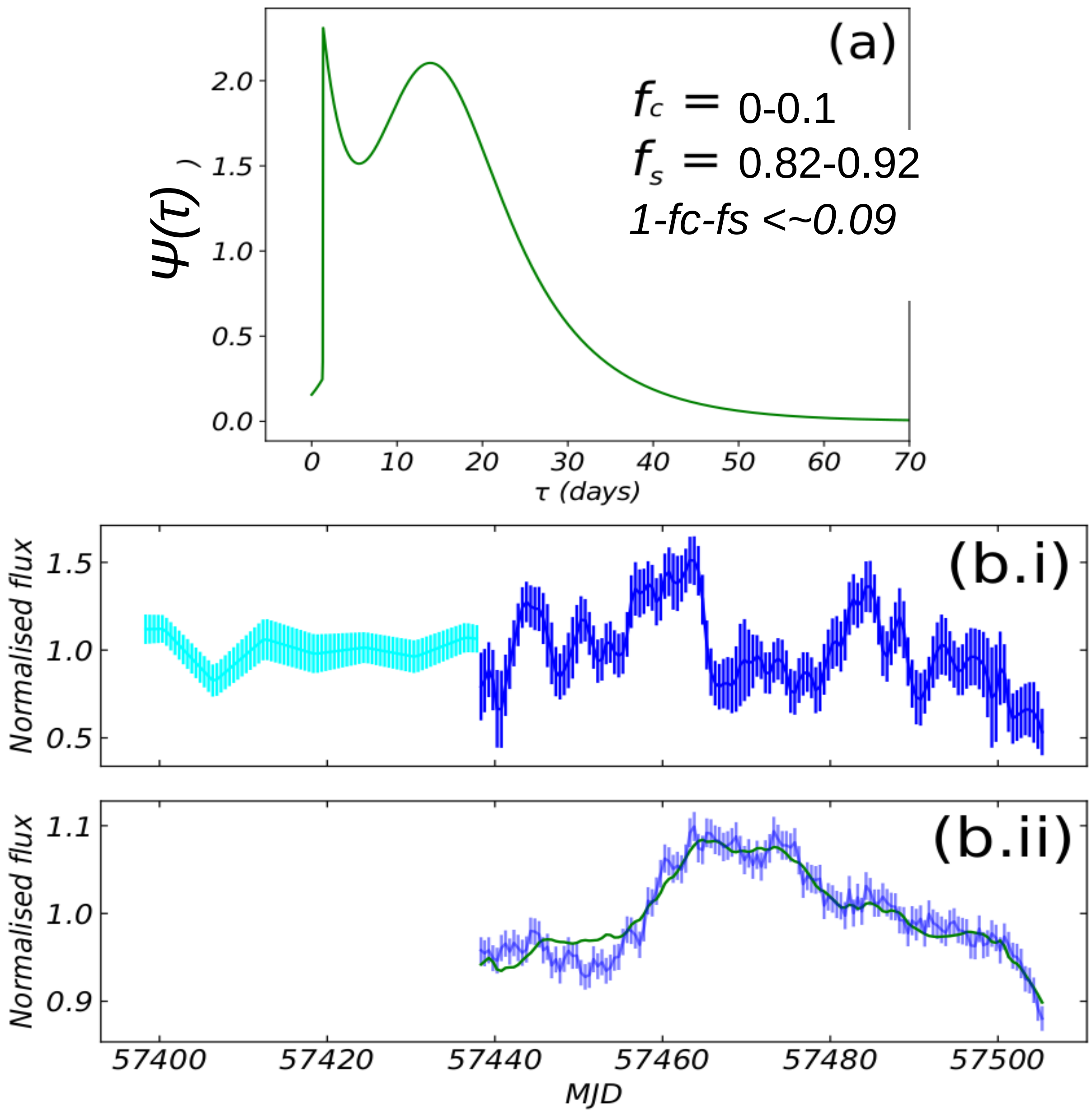


- Then we can fit to the light curve by varying *f*c, *f*s and *Ψ(τ)*.
- Broad *Ψ(t)* means we need to truncate first ~30 days.
- Good fit but lost too much information!



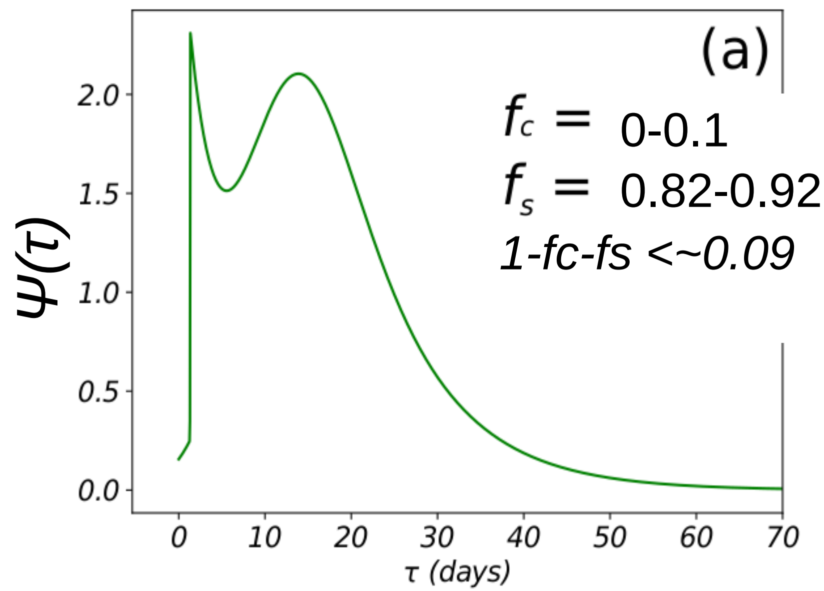
Recovering the IRF

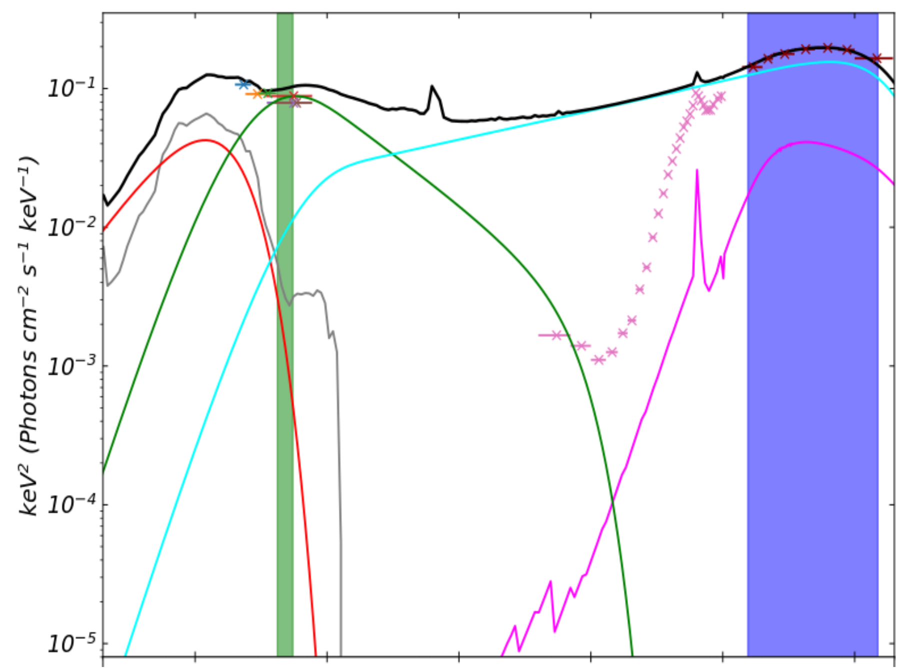
- Extend the X-ray light curve back in time using Swift-BAT all-sky monitoring. Rebin on 6 days and interpolate on 0.5.
- Can now fit UVW1 for the full 69 day pointed campaign.



Recovering the IRF

- Fit requires <~9% from fast continuum (1-fc-fs <~ 0.09)
  - SED fit had 9.5% dilution from hard in UVW1.
- Seems little room for response on scale less than 1 light-day (~ 400 R_g).
- Even ***passive*** disc at 250 Rg gives >4% contribution to UVW1.
- Consistent with Zoghbi+ 2019 who find a $3.3^{+1.8}_{-0.7}$ light-day FeKα response, but none for <light-day-timescale.





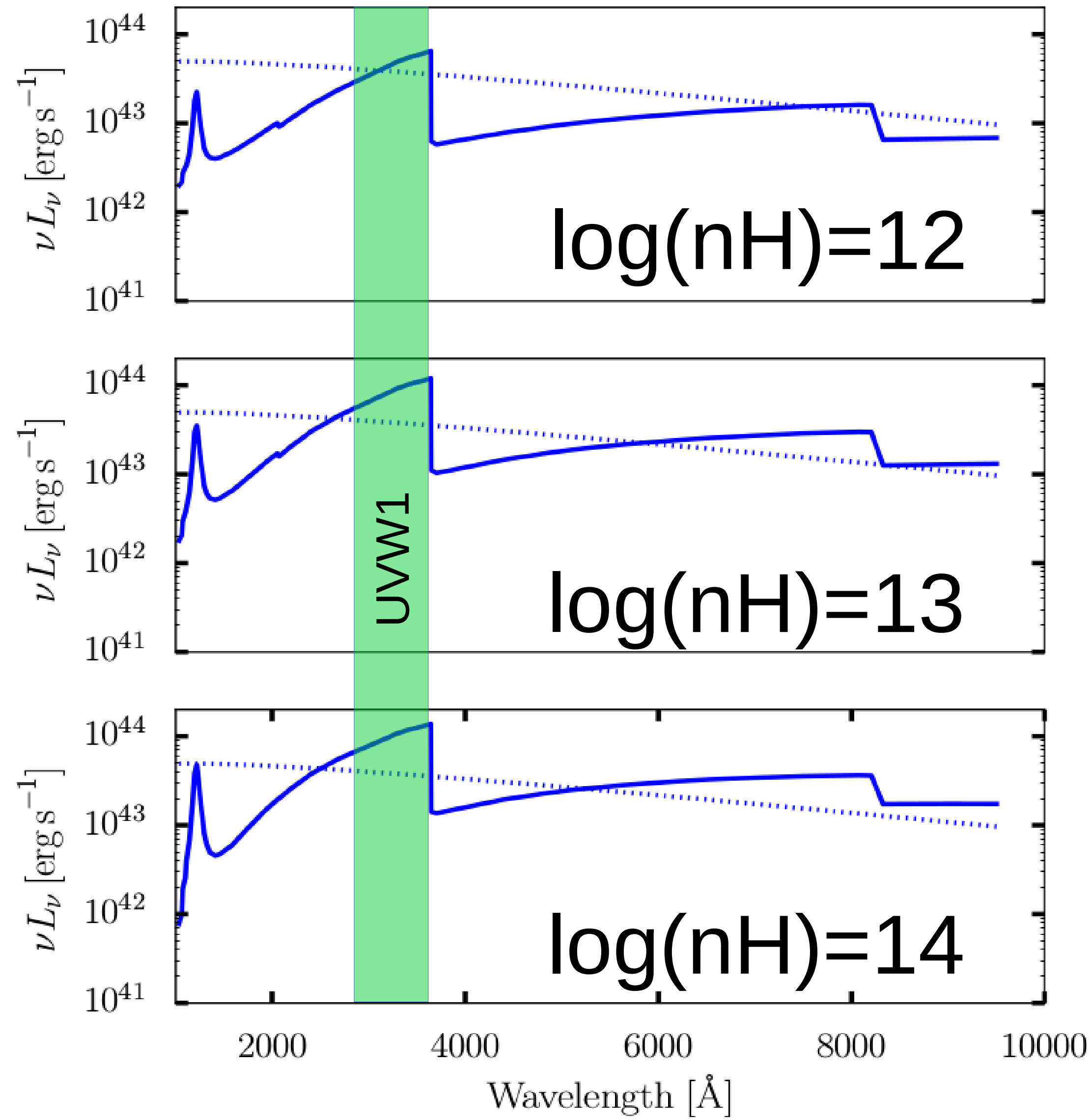
UV: Diffuse Continuum from the BLR?

- Can get up to ~50% of the UVW1 diffuse continuum from the BLR for log(nH)>~14.
- Density not too high! Or emission thermalizes to optical.
- And could we get even more diffuse continuum in UVW1?...

Quantifying the Diffuse Continuum Contribution of BLR Clouds to AGN Continuum Inter-band Delays (2018)

Lawther, D.,[1] Goad, M.R.,[2] Korista, K.T.,[3] Ulrich, O.,[3] Vestergaard, M.[1,4]

Dashed: incident. Solid: diffuse BLR



UV: Diffuse Continuum from the BLR?

- UV/blue optical contrubution from X-ray reprocessing in inner BLR (free-free/free-bound interactions).
- Cutting edge CLOUDY model for winds at inner of BLR is very promising candidate for the UV continuum in NGC 4151!

Dehghanian et al. 2019B, cf Gerard Kriss' talk

A WIND-BASED UNIFICATION MODEL FOR NGC5548 5

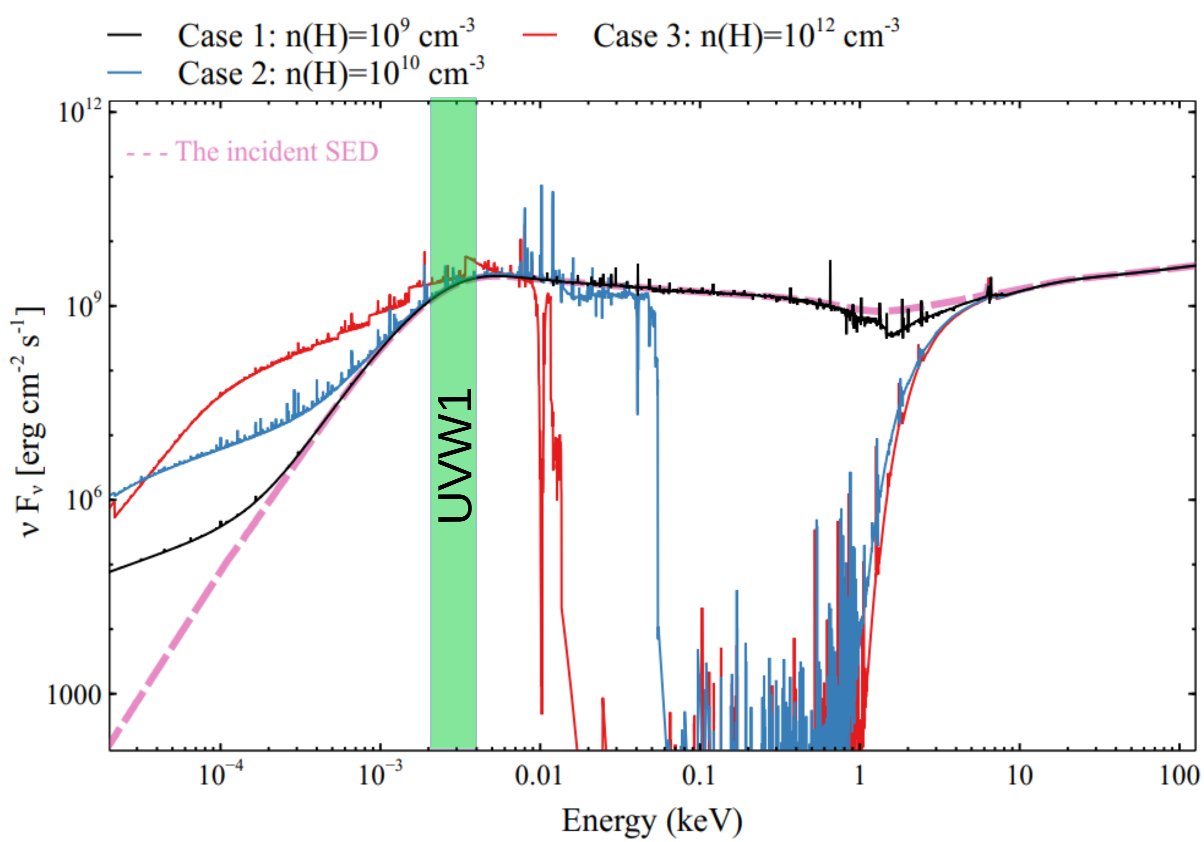
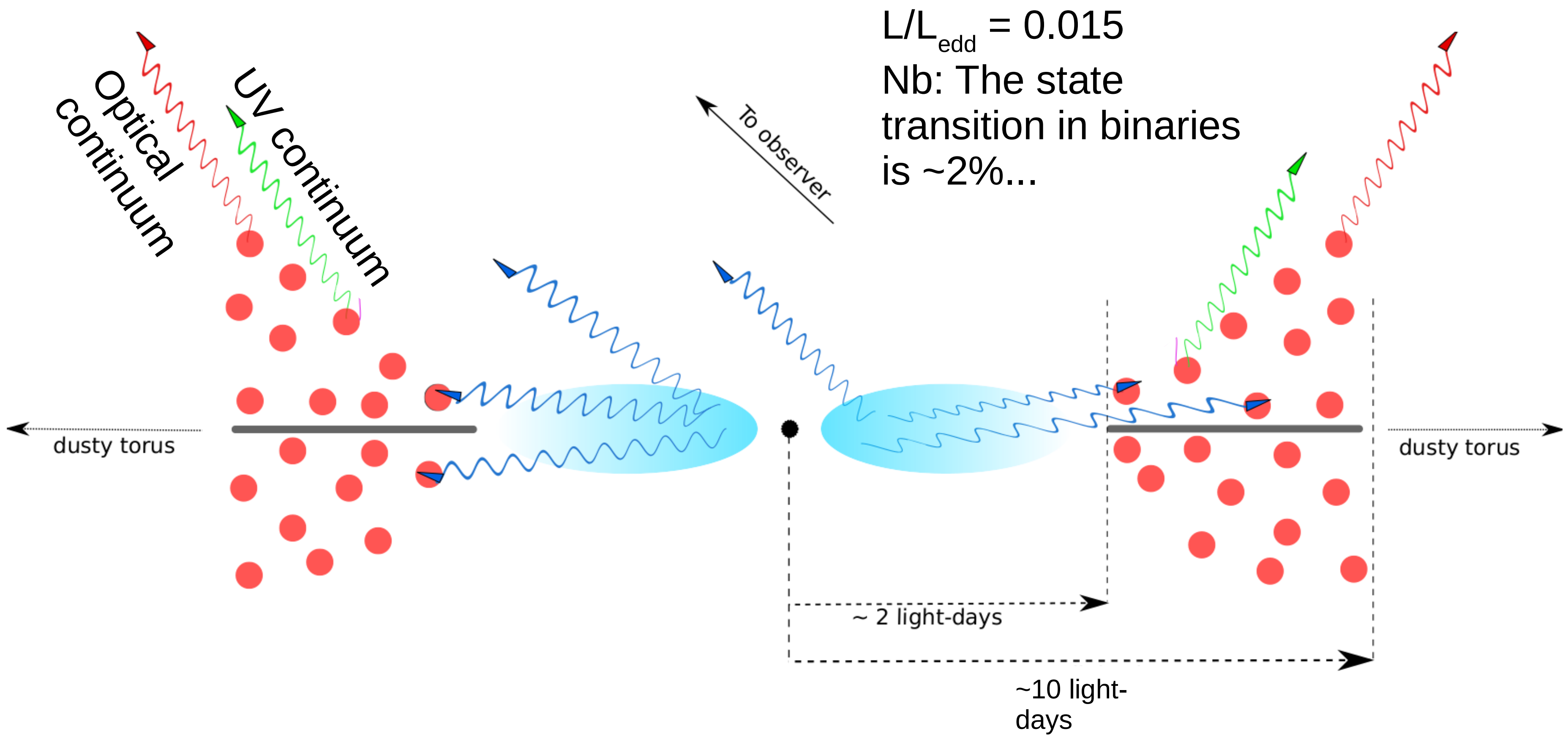


Figure 3. The SED transmitted through equatorial obscurer and incident upon the BLR is shown for three different values of the hydrogen density. The unextinguished SED is also shown. The SED is dramatically dependent on the hydrogen density of the obscurer. High hydrogen densities produce strong emission in UV/optical regions.

New Picture

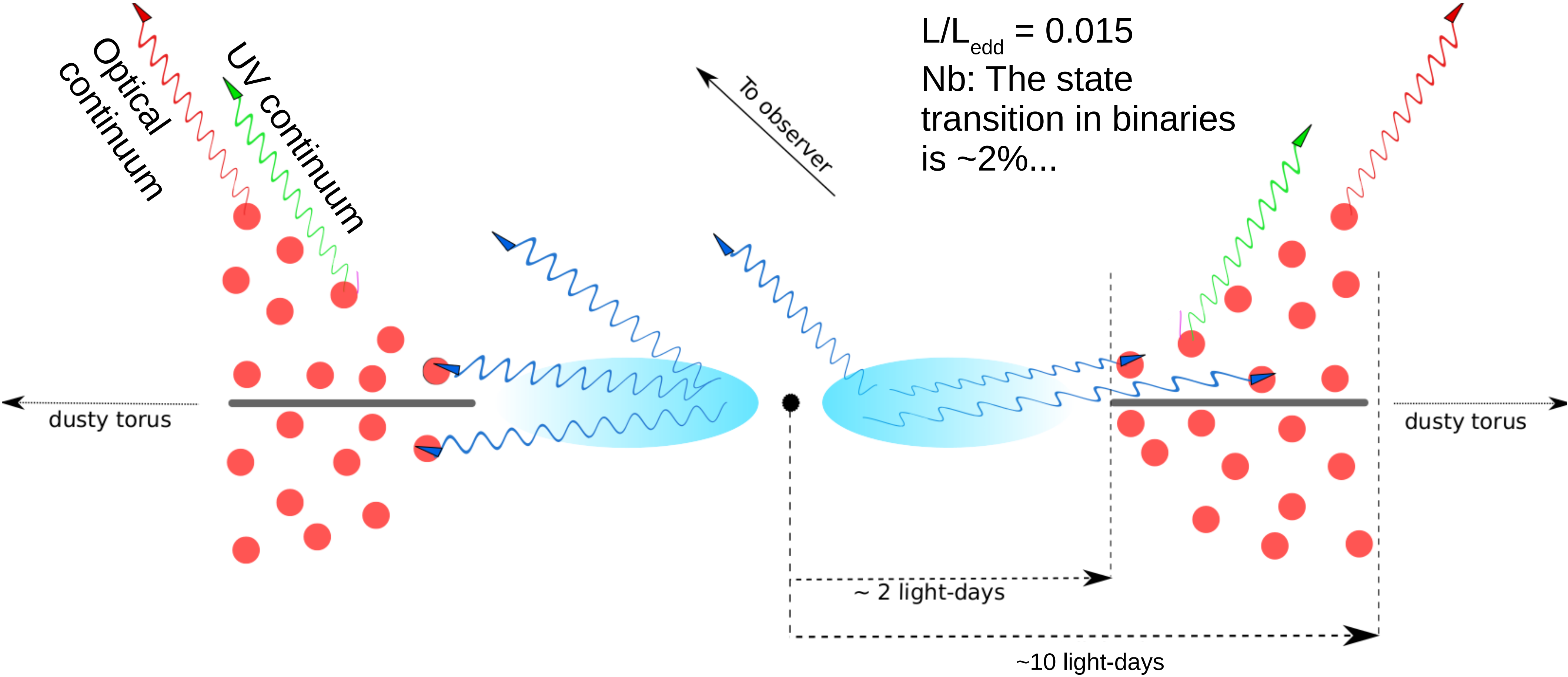


- Hot corona seed photons from cyclo-synchrotron.
- UV/optical continuum produced with radial stratification by BLR clumps.

Summary & Conclusions

- In 2016 in NGC 4151, observed X-rays were well correlated across all bands. So were optical/UV.
- X-ray vs. UV lightcurves completely inconsistent with standard corona/warm Compton/disc models.
- Much more consistent with most optical/UV being produced on BLR size scales. Probably free-free/free-bound diffuse (Lawther+2018; Dehghanian+2019b).
- Very little room left in fast variability for optically thick reprocessing on <2 light days.

New Picture



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