

# *Active Galactic Nuclei and High Energy Astrophysics*

***Workshop on the introduction of Astronomy and Astrophysics***

***@ IIT Tirupati***

***January 25, 2026***

*Main Pal  
Sri Venkateswara College, University of Delhi,  
New Delhi*

# *Outline*

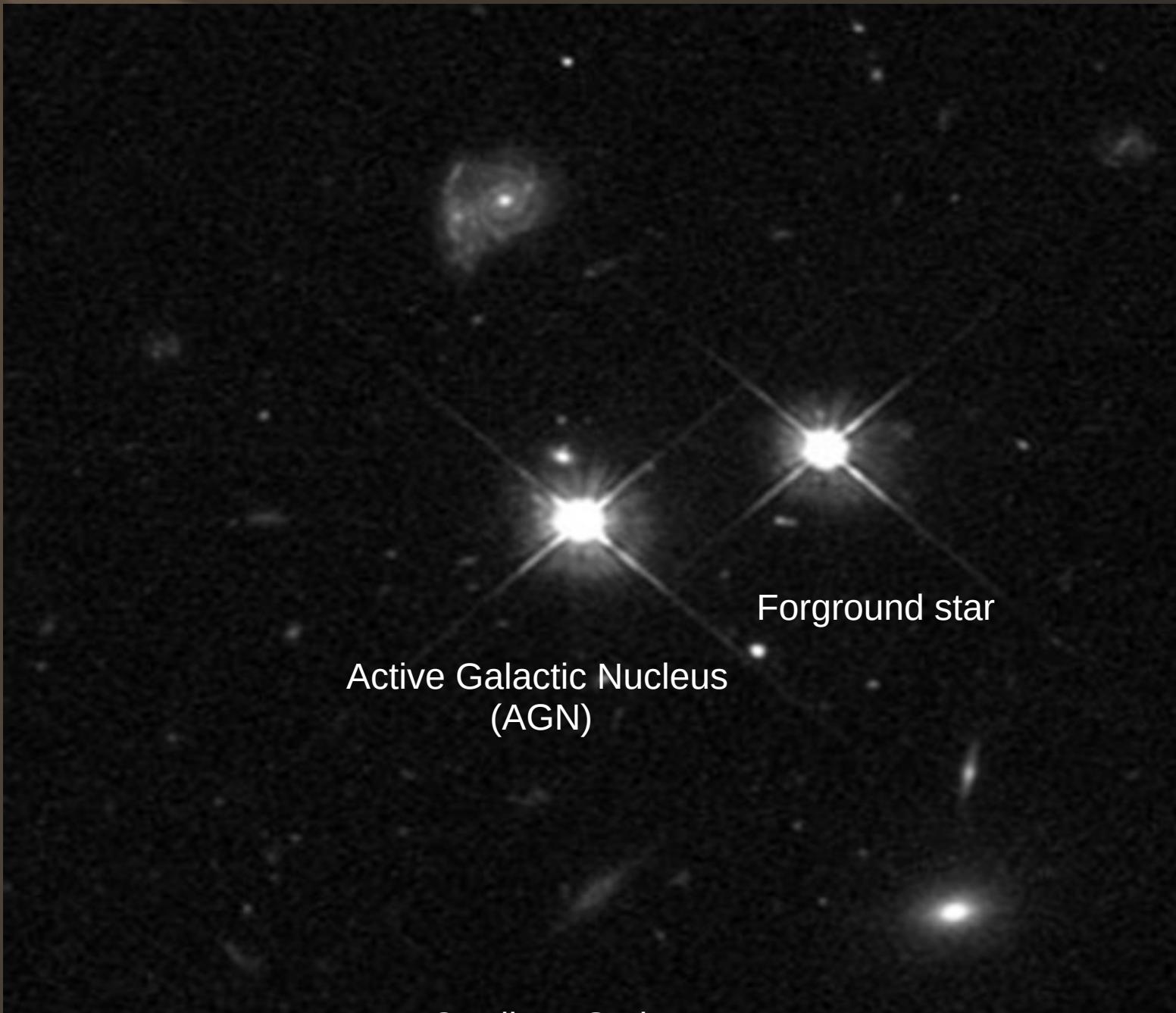
- **Introduction: AGNs, Unification, AGN basics, disk, Corona**
- **Physical Processes in high energy domain**
- **Interplay between the X-ray corona and the accretion disk**
- **Testing the real nature of the accretion disk**

*Images of two stars ?*



Credit : HST image

# *Images of two stars ?*



# *Energy budget*

- No nuclear fusion (like in sun) process is efficient to produce such energy due to lack of fuel.

# *Energy budget*

- No nuclear fusion (like in sun) process is efficient to produce such energy due to lack of fuel.
- Accretion process is likely to produce such large energy

# AGN : Basic Physical Picture

high luminosities



Eddington limit  
=> large mass

highly variable



small  
source size

**Accretion onto SMBH**



- Central SMBH

( $M_{BH} \sim 10^5 - 10^{10} M_{\odot}$ )

- Powered by accretion

$$(L = \eta \dot{M} c^2)$$

- Size scale : Schwarzschild radius

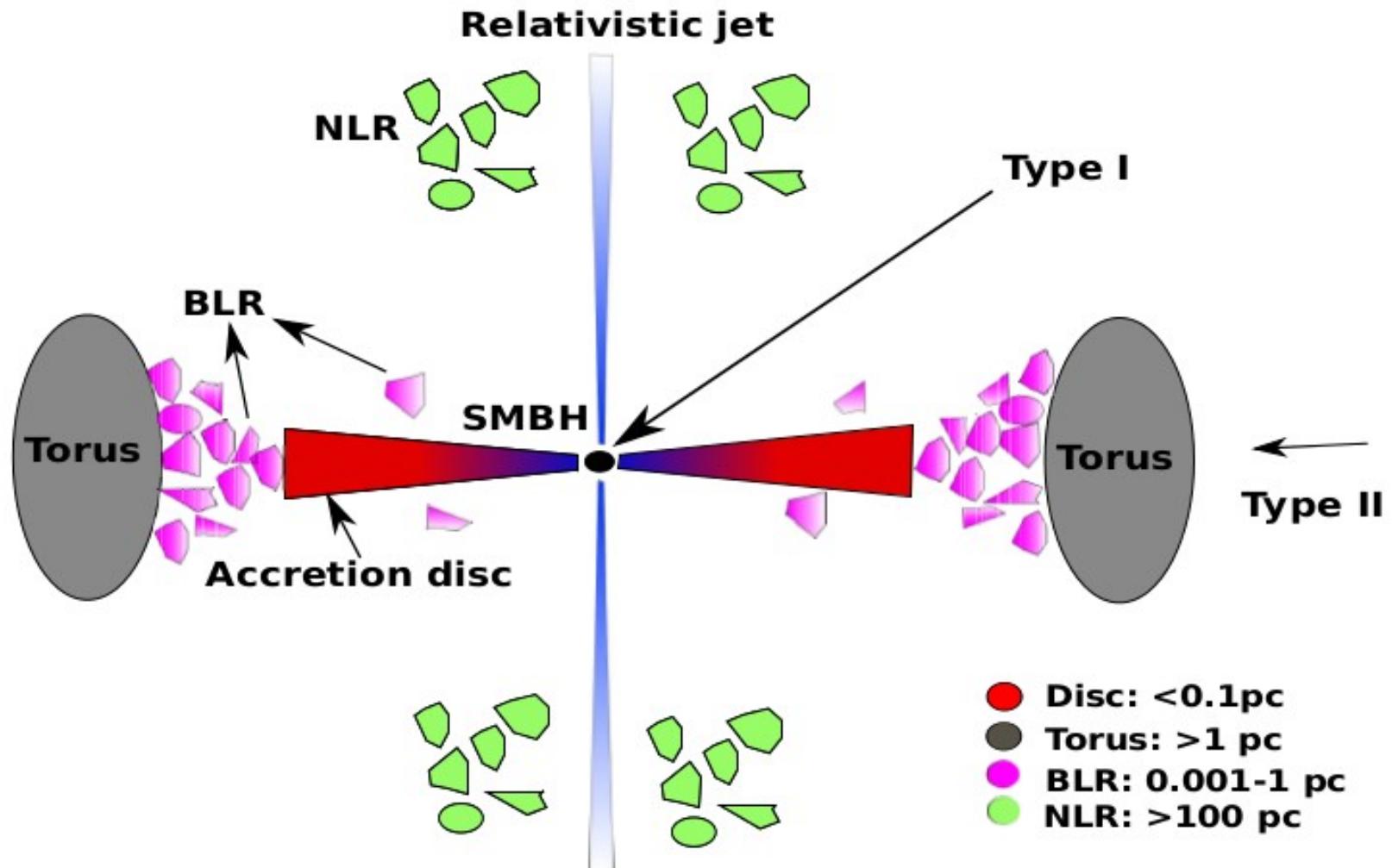
$$(R_S = \frac{2GM_{BH}}{c^2})$$

- Luminosity : Eddington luminosity :

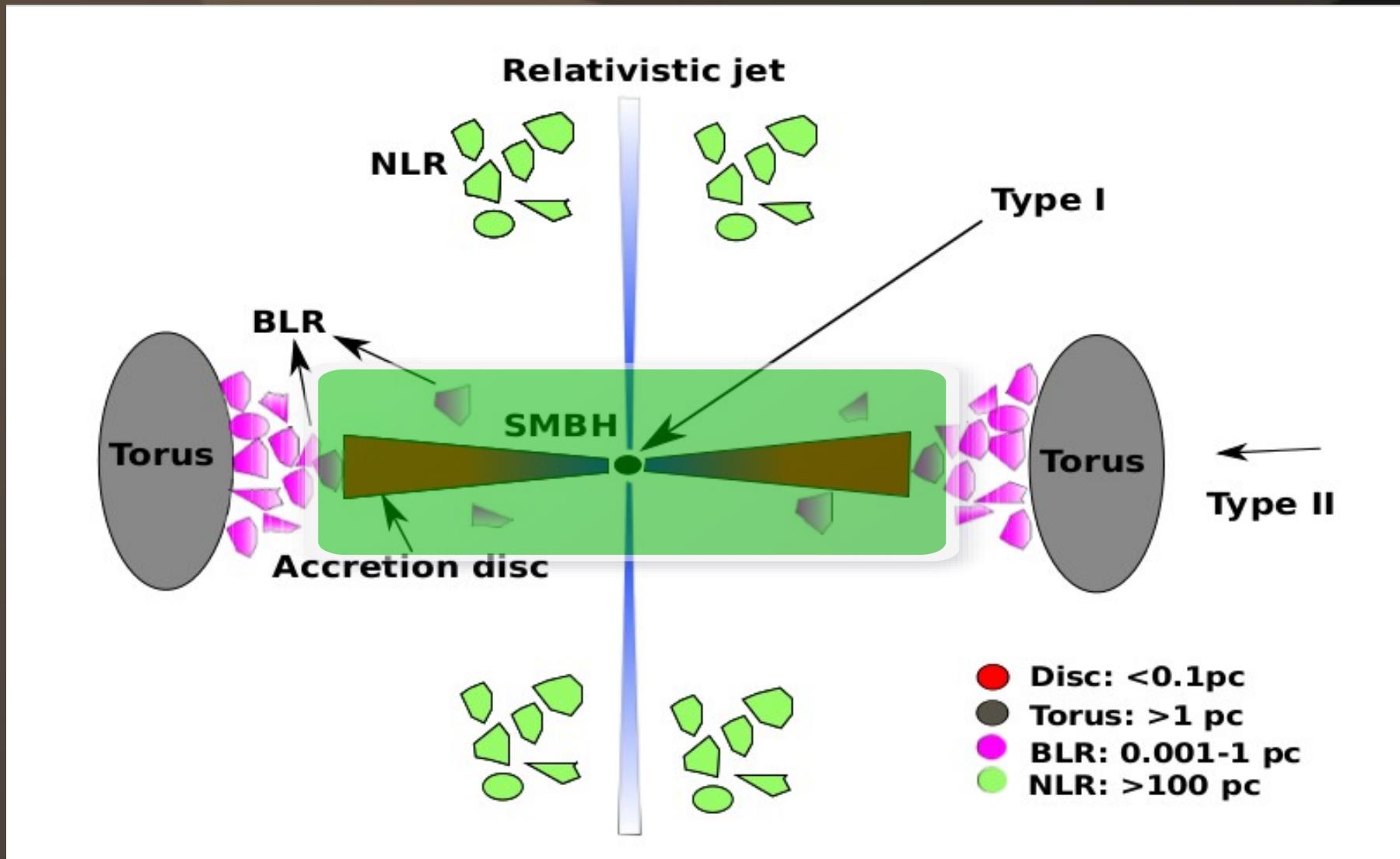
$$F_{rad} = F_{gravity}$$

$$\Rightarrow L = 1.38 \times 10^{38} \left( \frac{M_{BH}}{M_{\odot}} \right) \text{erg s}^{-1}$$

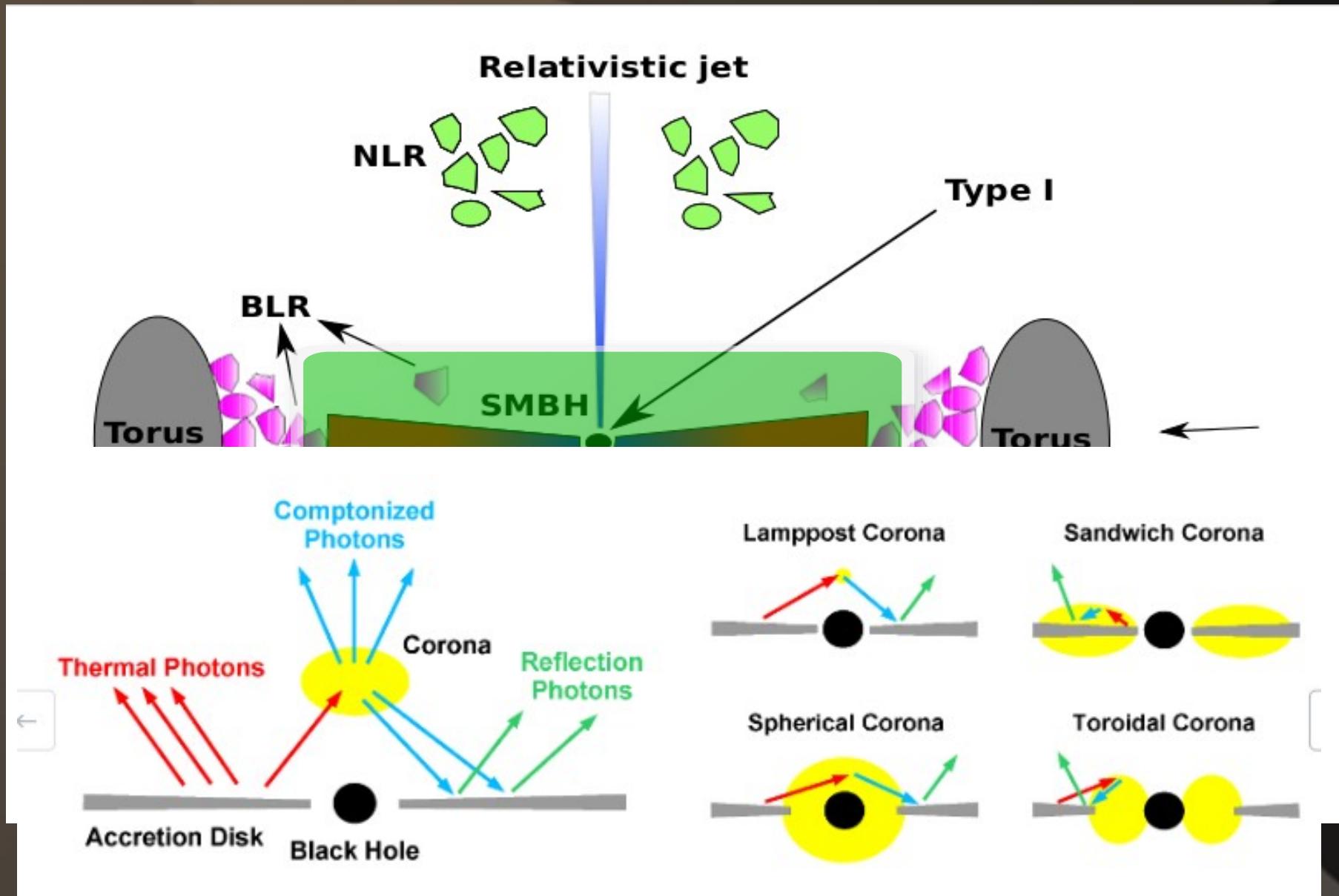
# *Unification Model*



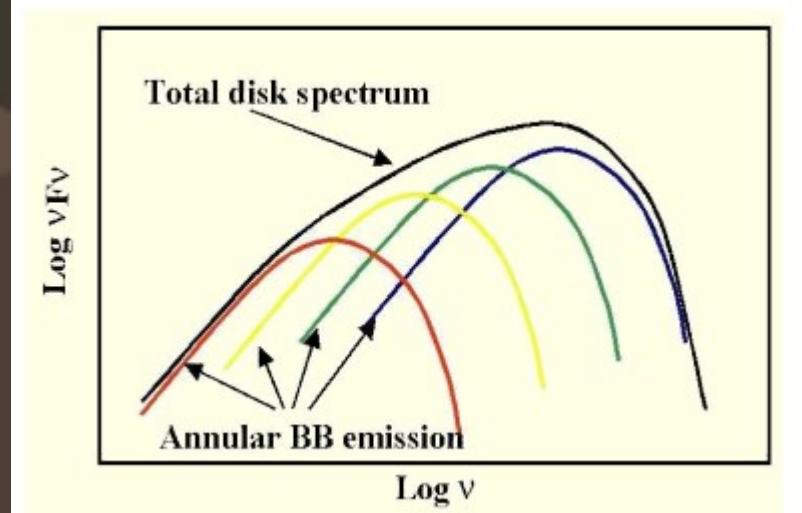
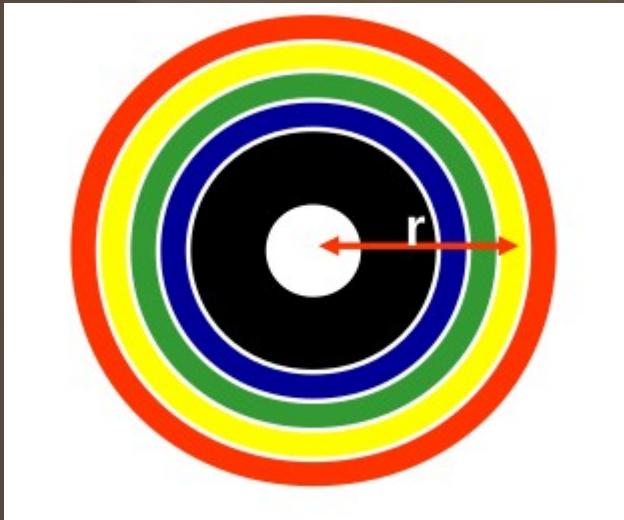
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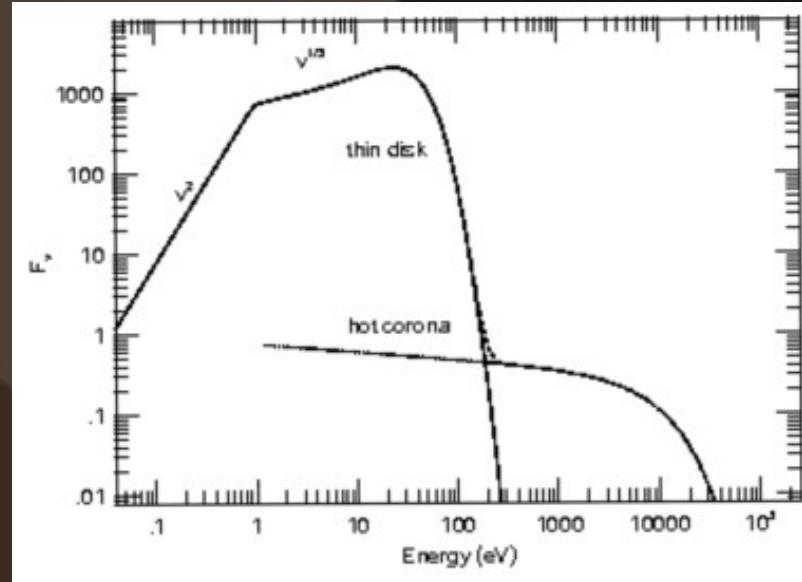
# *Thermal Emission: Standard Accretion Disk*



$$T(R) = \left[ \frac{3GM_{\text{BH}}\dot{M}}{8\pi\sigma R^3} \left( 1 - \sqrt{\frac{R_{\text{in}}}{R}} \right) \right]^{1/4}$$

$$T(r) \approx 6.3 \times 10^5 (\dot{M}/\dot{M}_E)^{1/4} M_8^{-1/4} \left(\frac{r}{R_S}\right)^{-3/4}$$

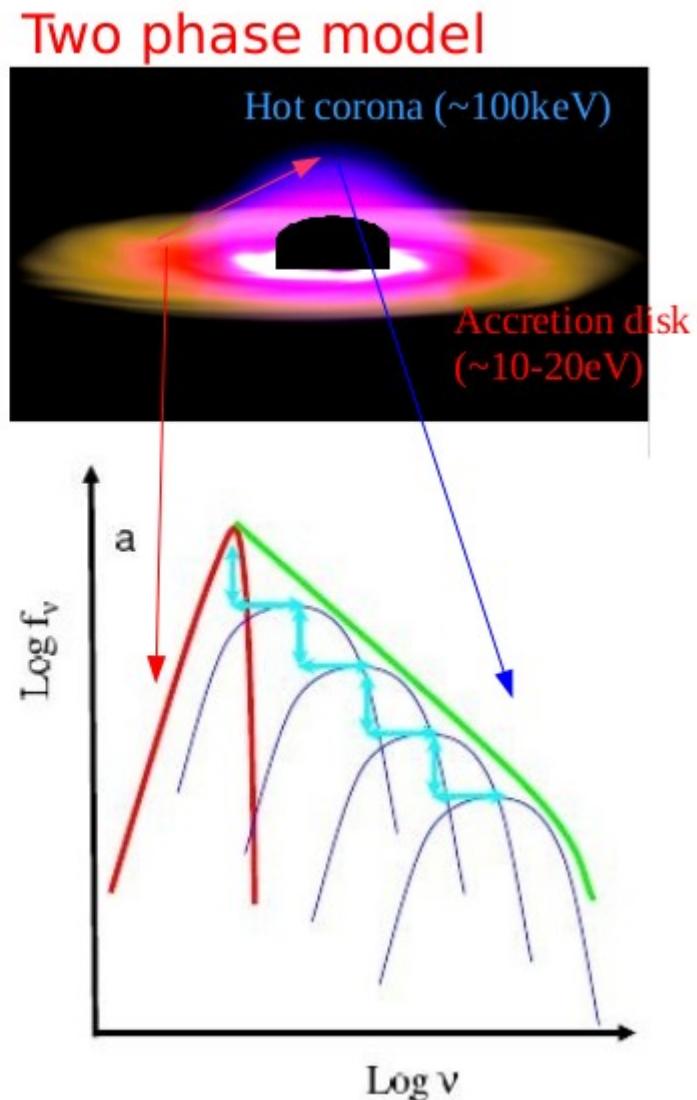
$$T \propto r^{-3/4}$$



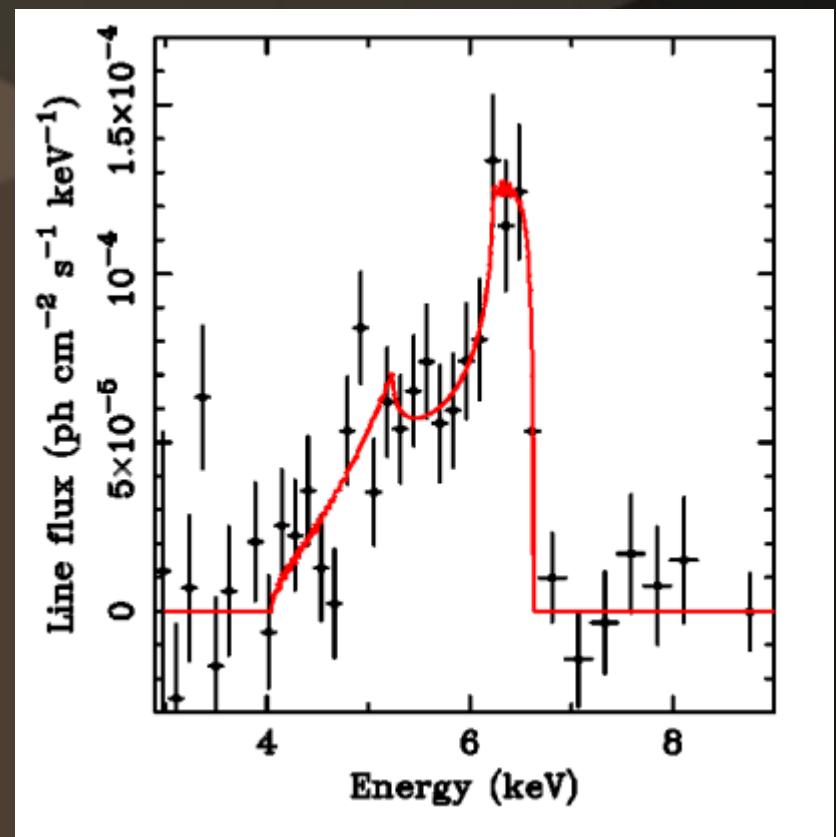
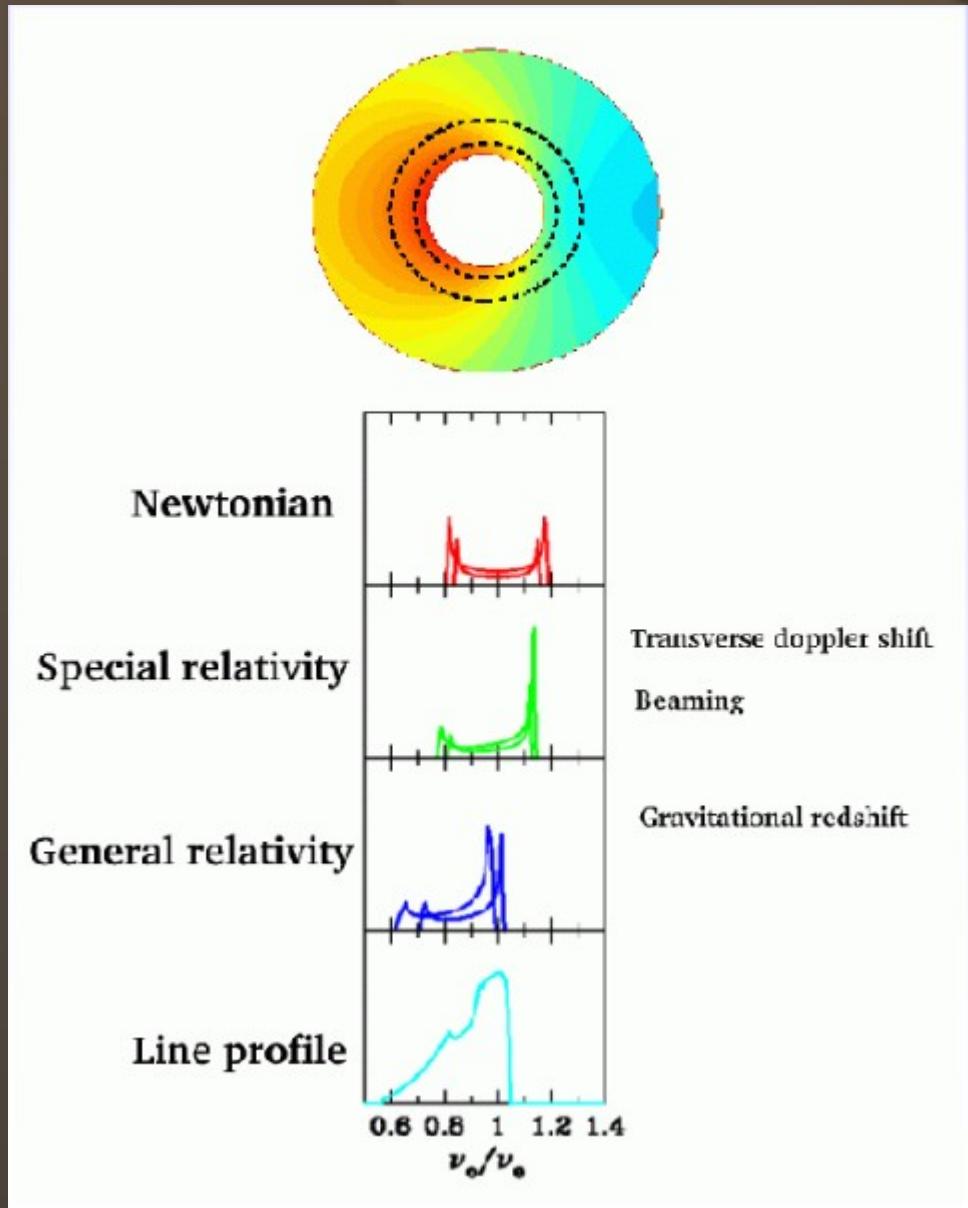
# *Non-Thermal Emission : X-ray Corona*

- Compton up-scattering of soft photons from a cool accretion disk ( $< 50\text{eV}$ ) in an optically thin hot corona ( $100\text{keV}, \tau < 1$  )
- A fraction  $\tau$  of seed photons get upscattered to energies by a factor  $1 + \frac{4kT_e}{m_e c^2}$
- Repeated upscattering => powerlaw with a cutoff  
$$E_{cut} \sim kT_e$$

Haardt & Maraschi (1991, 1993), Done (2010)

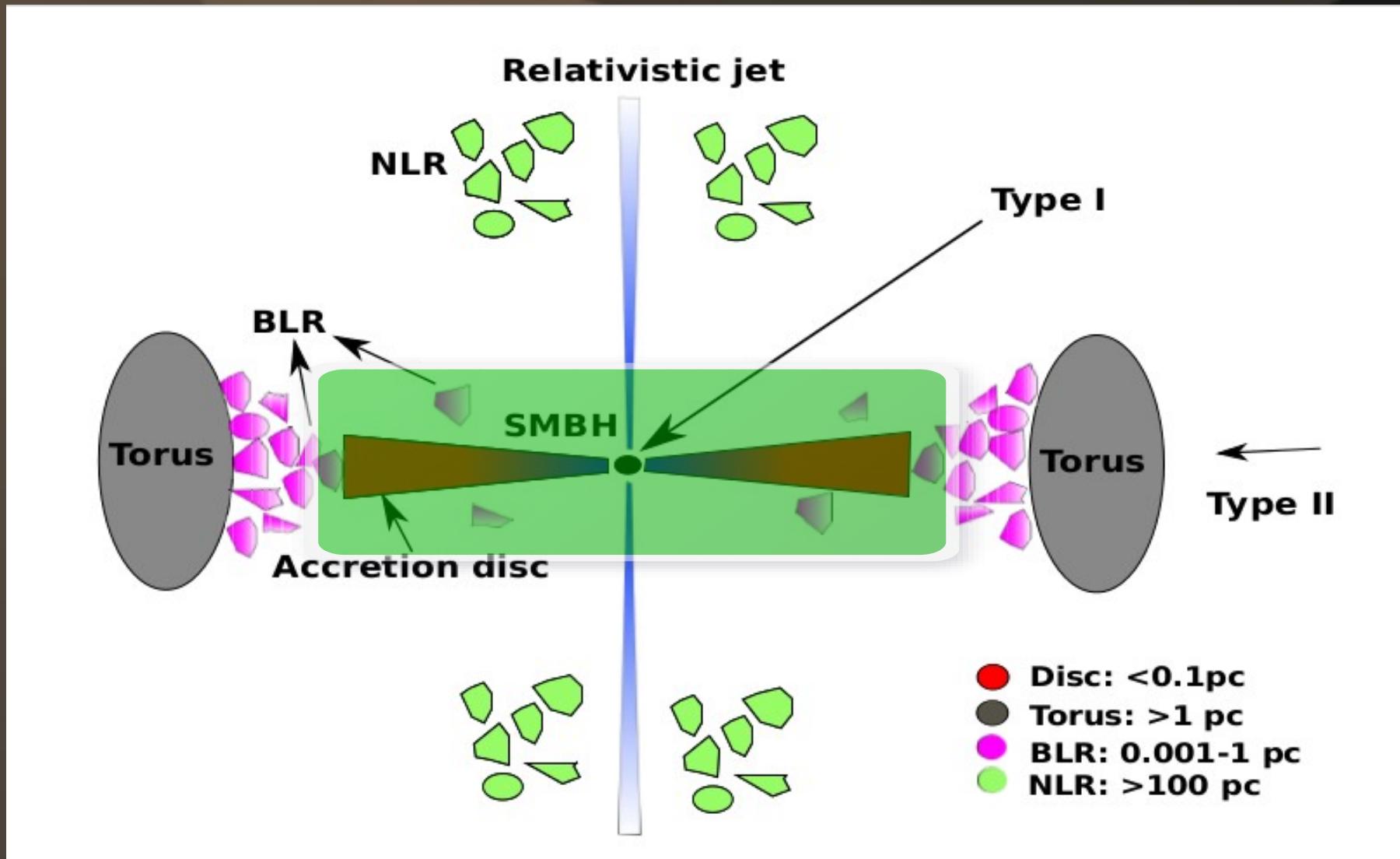


# *Broad Fe-K line in AGN*

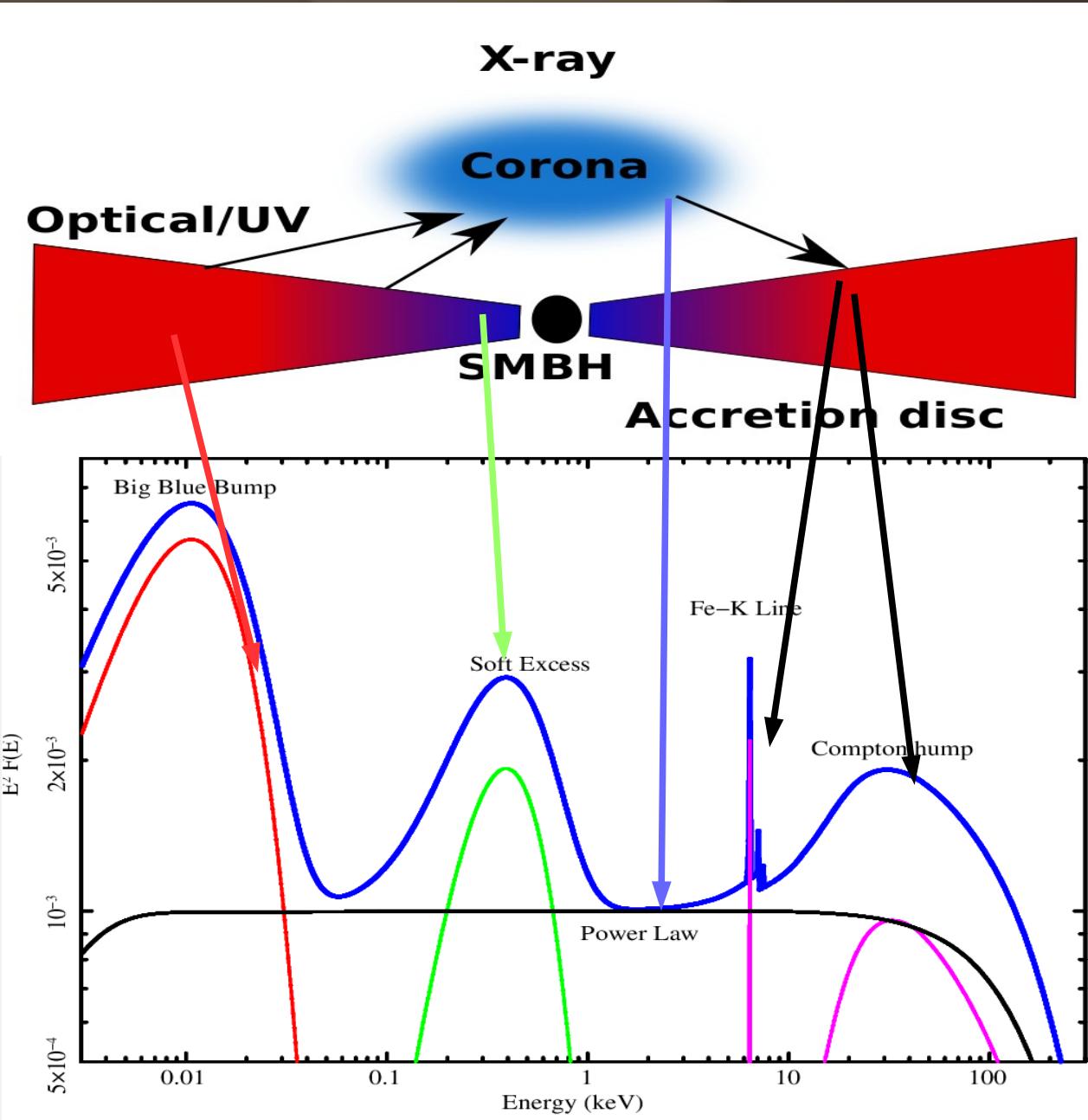


Iron Line in MCG-6-30-15  
(Tanaka et al 1995)

# *Unification Model*

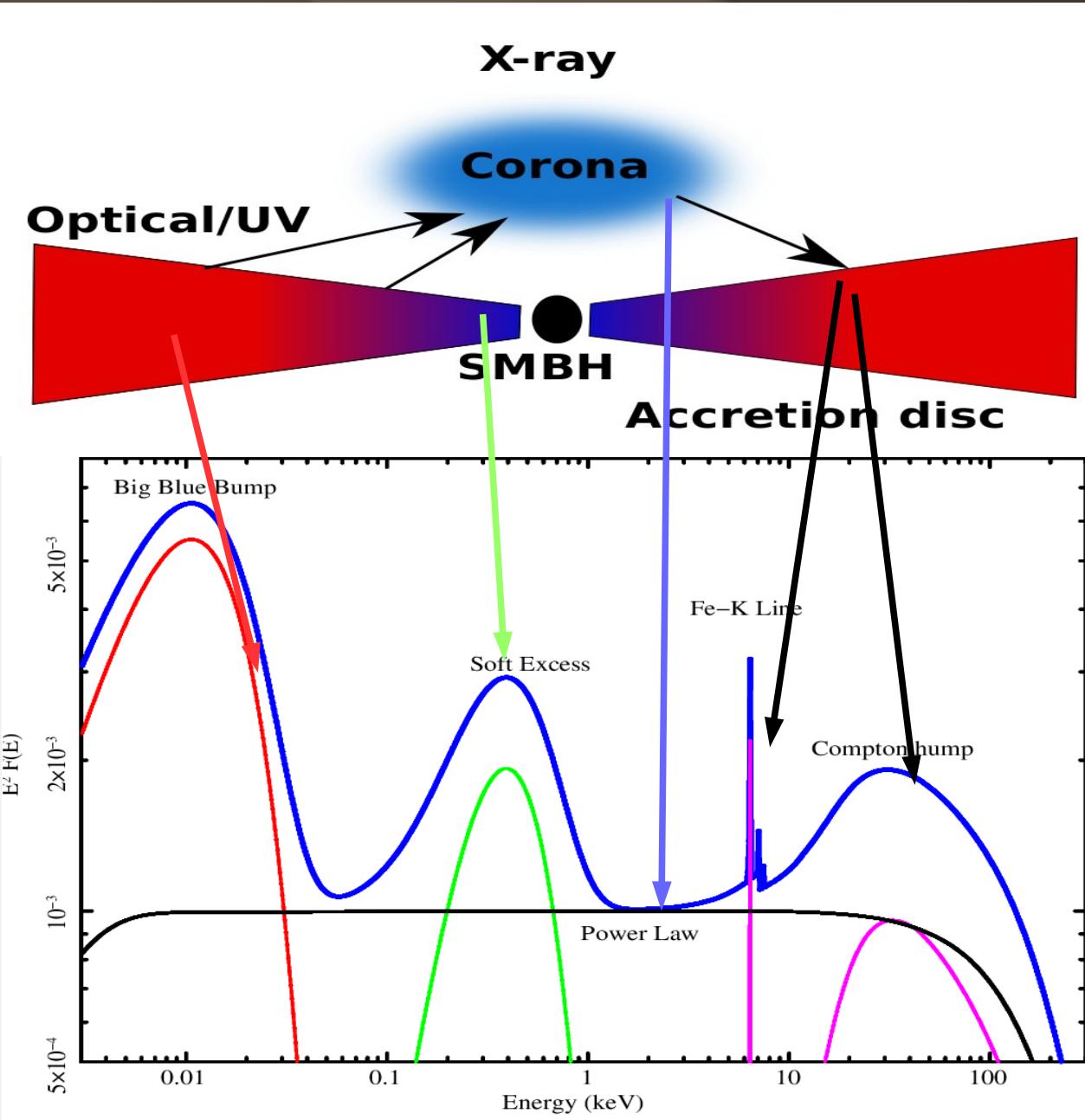


# *Central engine and spectrum of a bare Seyfert 1 AGN*



1. Compton reflection hump due to the Compton back Scattering from the electrons of optically thick matter i.e. disk
2. Fe-K line due to the fluorescence phenomena
3. The soft X-ray excess is not well understood, however, this can be described by blurred reflection or cool Comptonization processes.
4. The big blue bump is thought from accretion disk. However, associated variability in UV/optical emission and the structure of disk is not known clearly.

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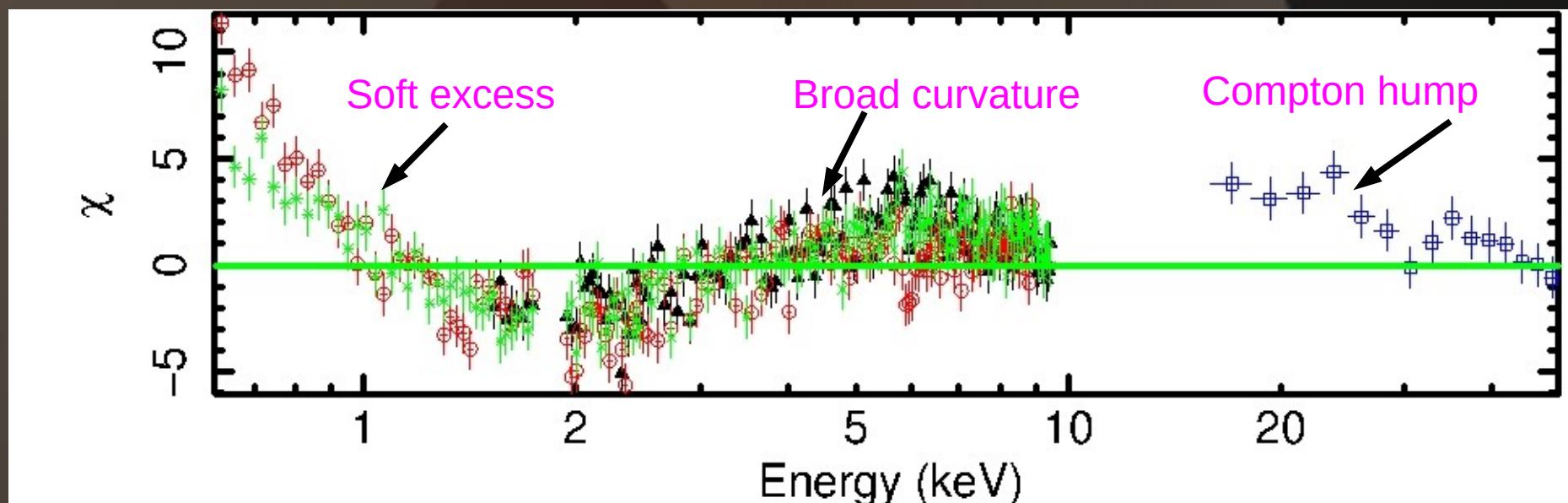


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  3. The soft X-ray excess is not well understood, however, this can be described by blurred reflection or cool Comptonization processes.
  4. The big blue bump is thought from accretion disk. However, associated variability in UV/optical emission and the structure of disk is not known clearly.
- Can be studied these using NuStar, XMM, AstroSat, Swift, XPoSat

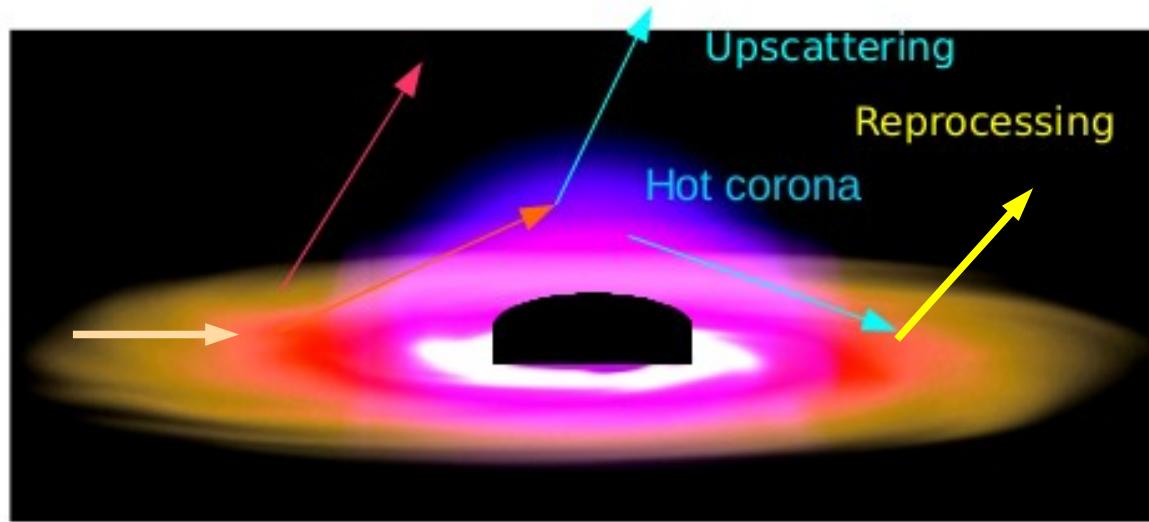
# 1H 0419-577

Main Pal & GCD 2013

- This is **Seyfert type 1** AGN located at **z=0.104**.
- It is X-ray luminous source  $L_X \sim 10^{45}$  ergs/s.
- This is also UV bright source
- Its complex spectrum consists of all primary components :



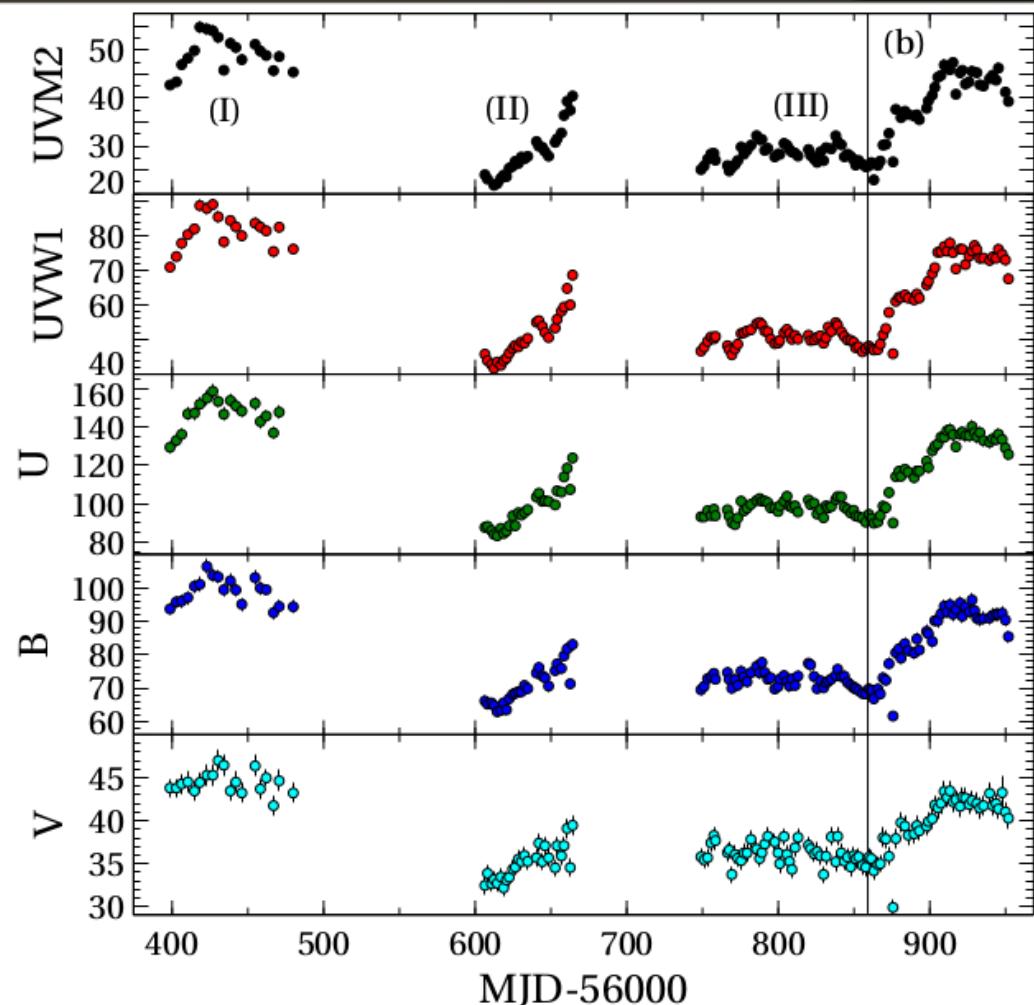
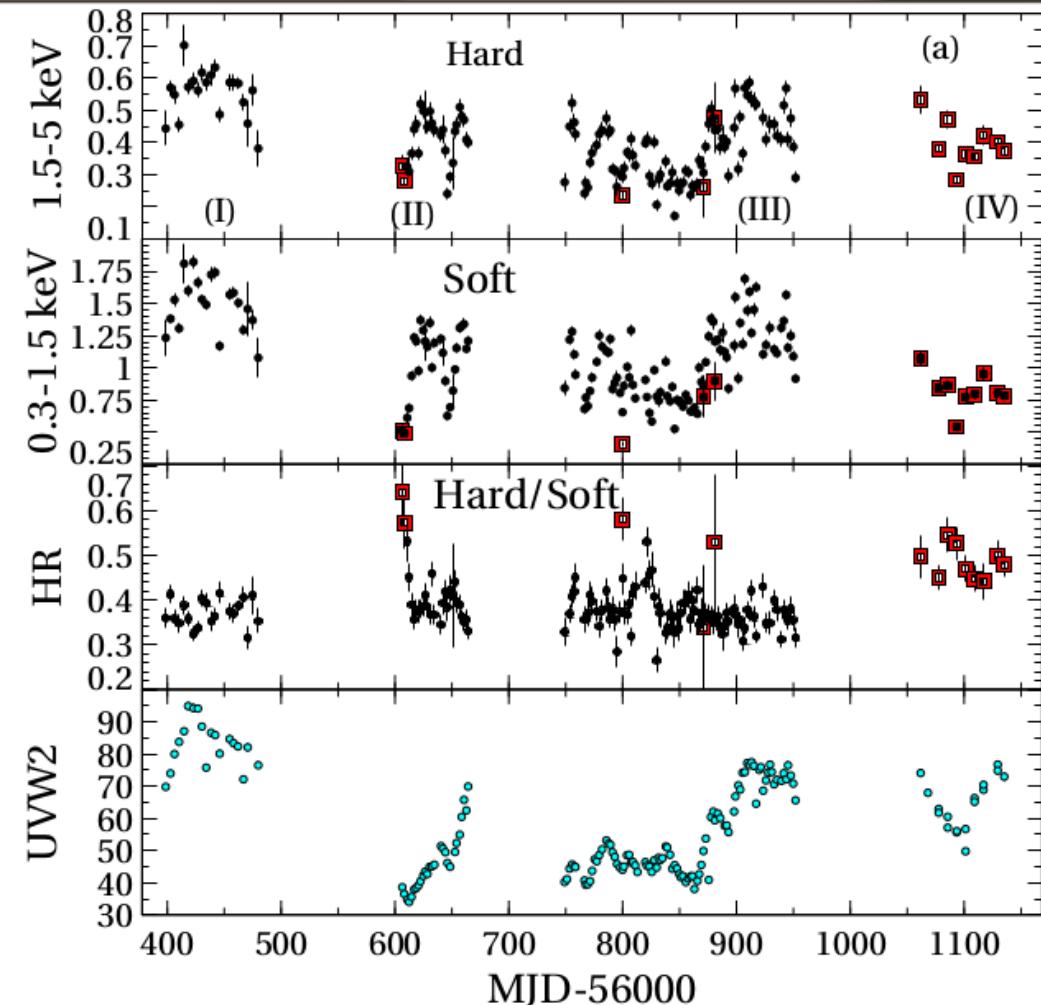
# *UV/Optical and X-ray connection*



- Reprocessing of X-rays into optical/UV
  - Optical/UV should lag behind X-rays with light crossing time  
Time lag Vs wavelength => Probe accretion disks
- Compton upscattering of optical/UV photons into X-rays
  - Optical/UV should lead X-rays
- Propagation of accretion rate fluctuations
  - Optical/UV should lead X-rays

# Fairall 9: Swift historical XRT/UVOT lightcurve

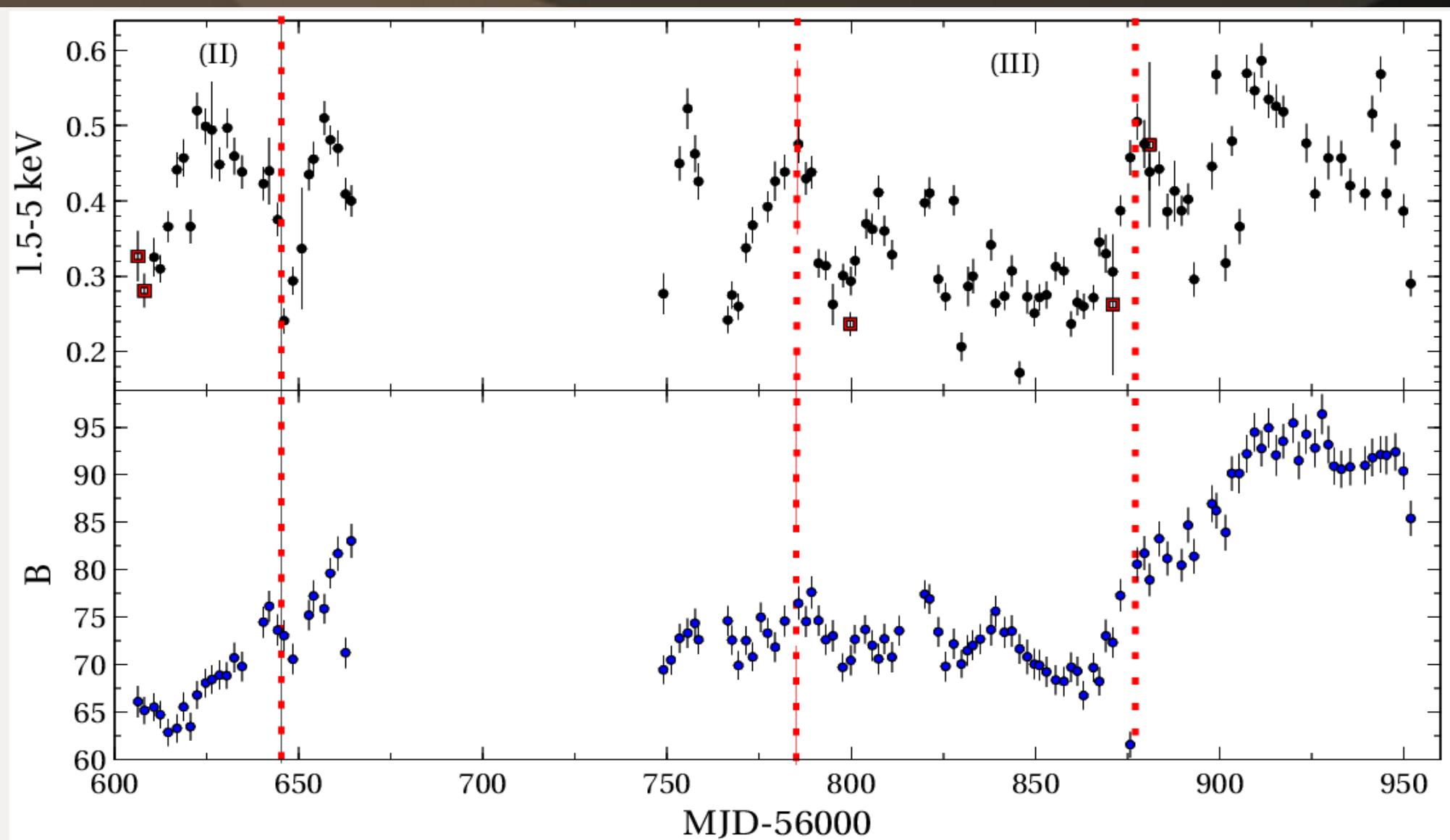
Intervals-1st: 4 days, 2 & 3rd: once in 2 days, 4th: weekly



165 pointings; Coverage: 1.7-550 nm (X-ray to UV/optical)

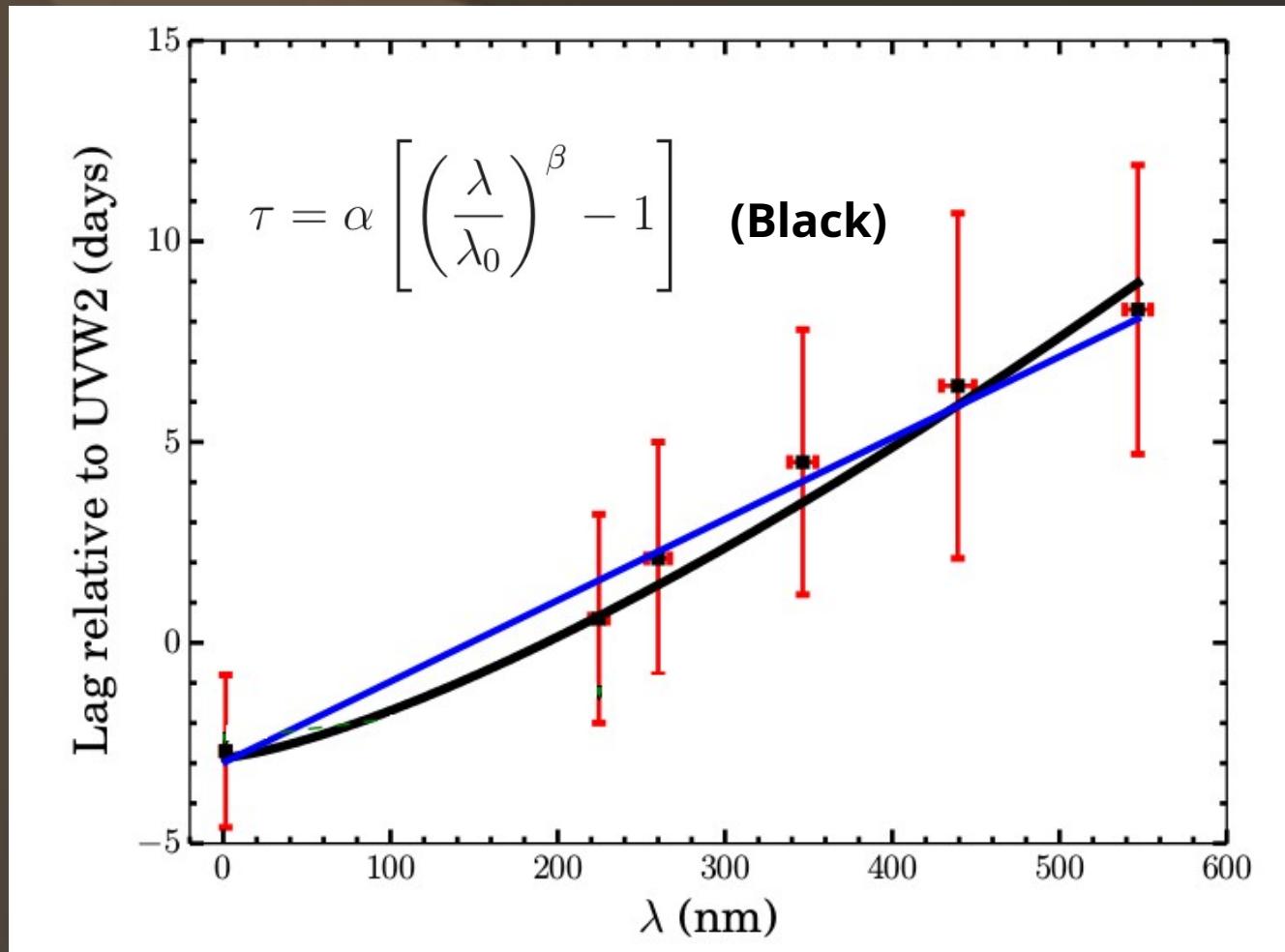
All lightcurves show similar features.

# *Fairall 9: Hard band and B band*



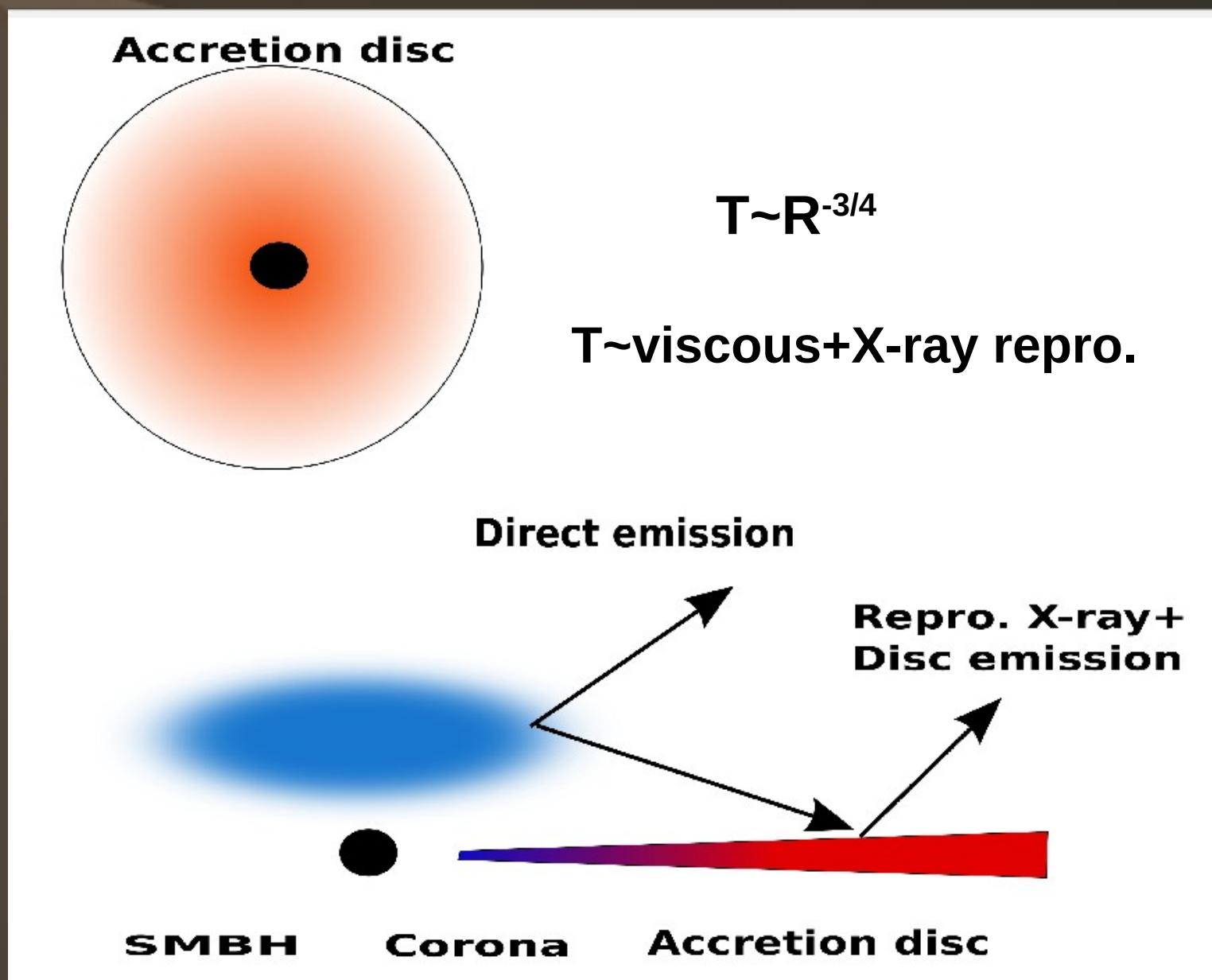
# Fairall 9: Lag spectrum - powerlaw model or linear model ?

Main Pal et al. 2017



Model	Expression	Best-fit parameters	$\chi^2_{red}/dof$
Linear	$A + B \times \lambda$	$A = -2.53 \pm 0.31, B = 0.016 \pm 0.001$	0.1/4
Std. disc	$\alpha[(\lambda/\lambda_0)^\beta - 1]$	$\alpha = 2.45 \pm 0.34, \beta = 1.28 \pm 0.13$	0.1/4

## *Fairall 9: X-ray reprocessing model*



Timescale ~light travel time ~hours to days  
Optical/UV emission lag the X-rays (Krolik et. al 1991)

## Fairall 9: Lag profile of standard disc

- Gravitational heating + X-ray illumination on the disc ( $H \ll R$ ,  $R_{\text{in}} \ll R$ ), temperature

$$T(R) = \left( \frac{3GM\dot{M}}{8\pi\sigma R^3} + \frac{(1-A)L_X H}{4\pi\sigma R^3} \right)^{1/4}$$

- Lag with respect to  $\lambda_0$

$$\tau - \tau_0 = \left( \frac{1}{c} \right) \left( \frac{\lambda_0}{k} \right)^{4/3} \left( \frac{3GM\dot{M}}{8\pi\sigma} + \frac{(1-A)L_X H}{4\pi\sigma} \right)^{1/3} \left[ \left( \frac{\lambda}{\lambda_0} \right)^{4/3} - 1 \right].$$

- Functional form of the lag

$$\tau = \alpha \left[ \left( \frac{\lambda}{\lambda_0} \right)^\beta - 1 \right]$$

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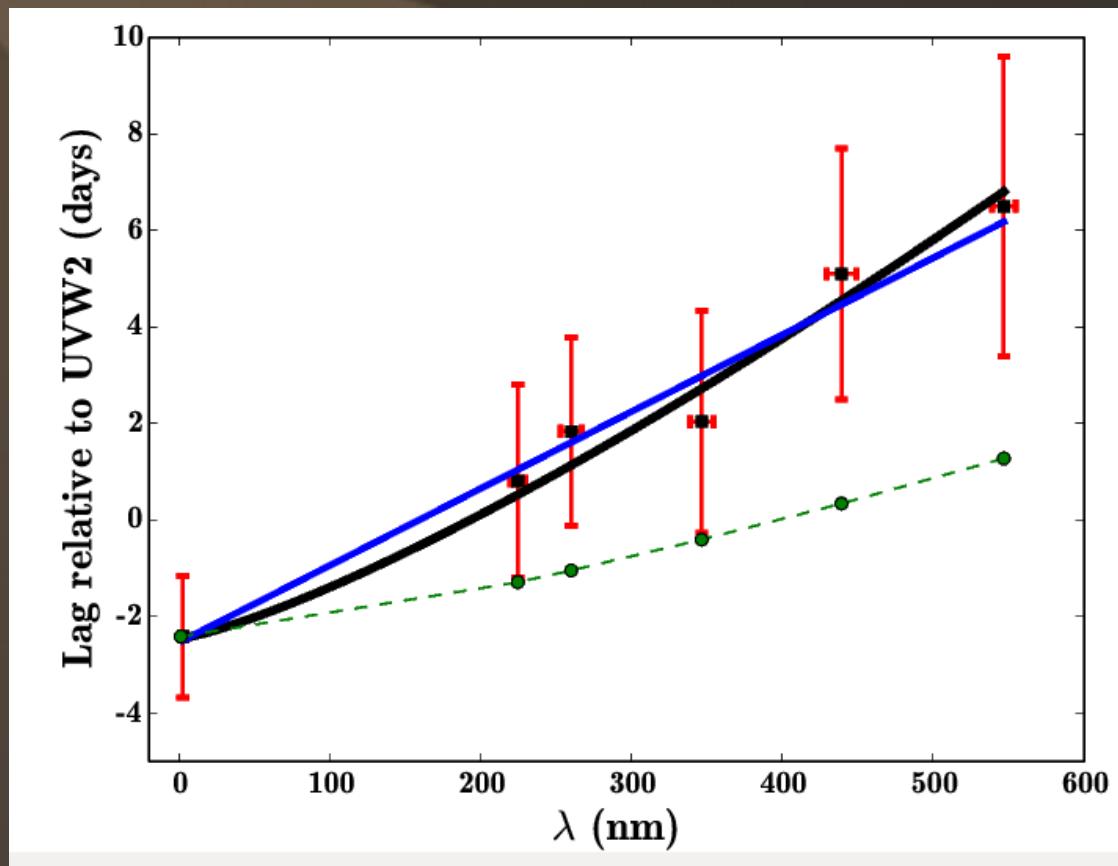
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- Functional form of the lag

$$\tau = \alpha \left[ \left( \frac{\lambda}{\lambda_0} \right)^\beta - 1 \right]$$

# *Fairall 9: Lag spectrum - disk model or linear model ?*



Std. Disk model  
: dashed line

Functional form  
of disk lag : Black

Linear model  
Model 2 : Blue

Real disk seems larger than expected from standard disk as found in another AGN NGC 5548.

## *Summary and conclusion*

- Corona geometry is complex
- Disk seems larger than predicted
- Soft excess is very complicated to understand

**Thank you**