

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

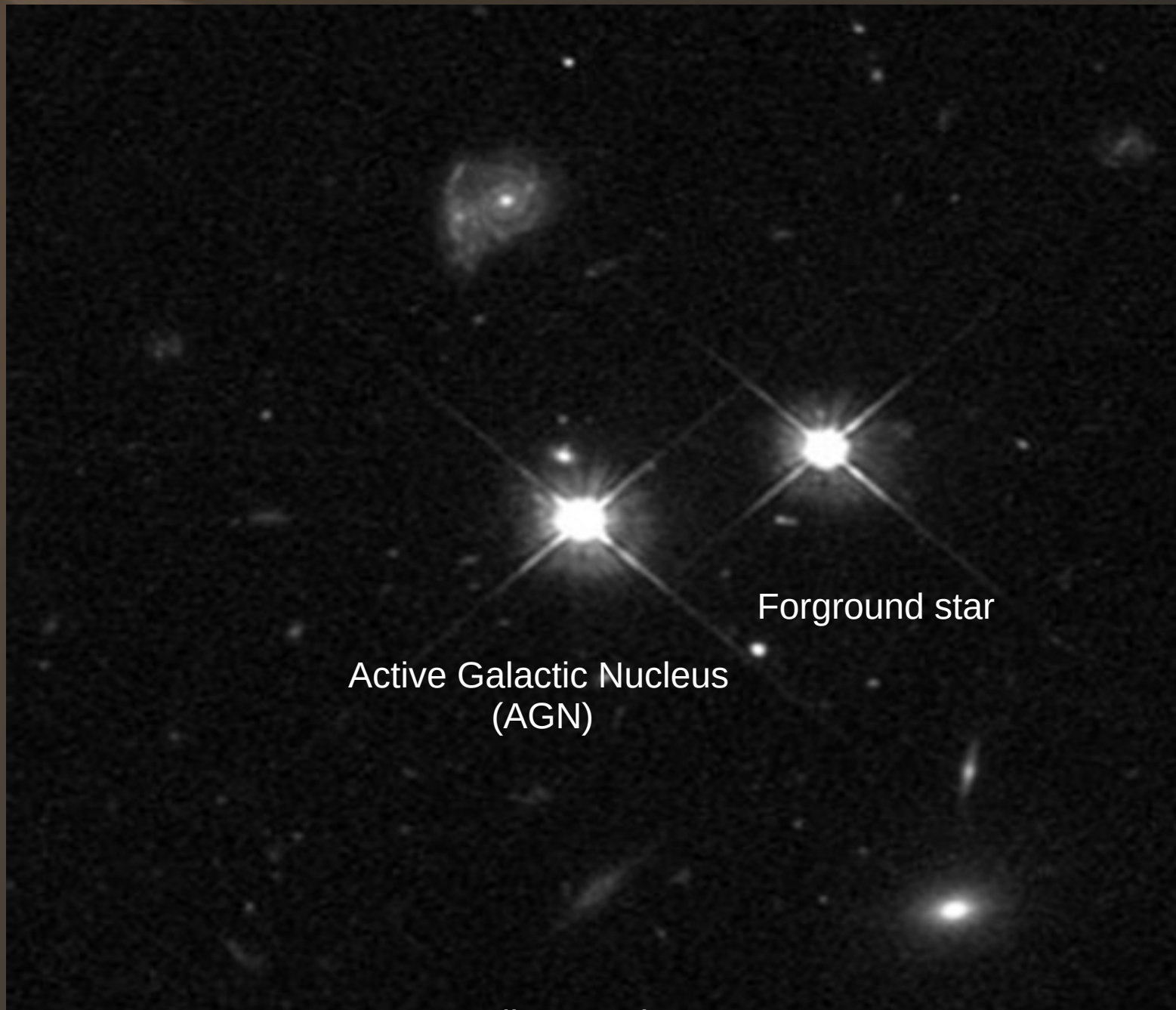
- **Introduction: AGNs, Unification, AGN basics, disk, Corona**
- **Physical Processes in high energy domain**
- **Interplay between the X-ray corona and the accretion disk**
- **Testing the real nature of the accretion disk**

Images of two stars ?



Credit : HST image

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Energy budget

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

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- 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

highly variable

Eddington limit
=> large mass

small
source size

Accretion onto SMBH

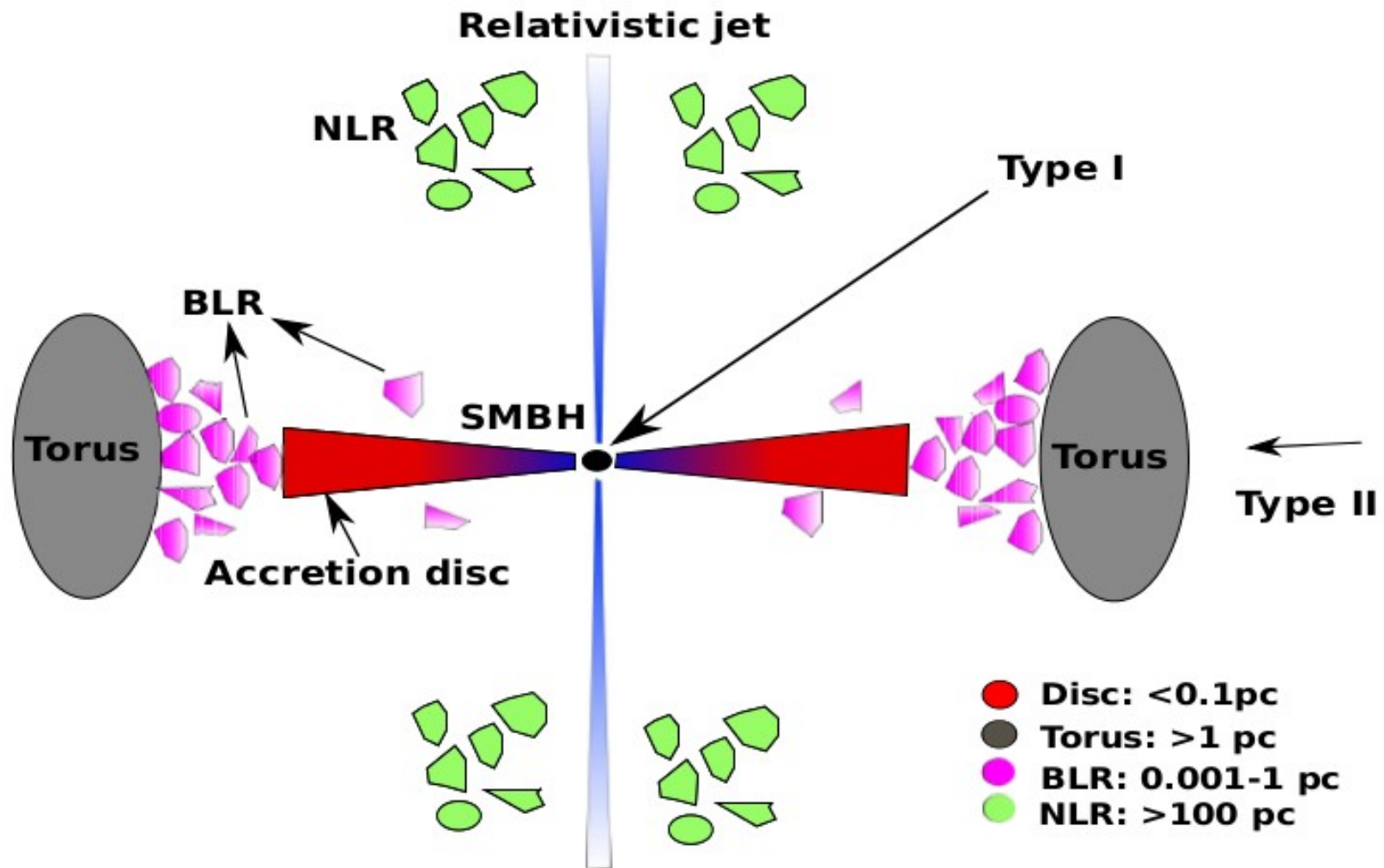


- Central SMBH
($M_{BH} \sim 10^5 - 10^{10} M_{\odot}$)
- Powered by accretion
($L = \eta \dot{M} c^2$)
- Size scale : Schwarzschild radius
($R_S = \frac{2GM_{BH}}{c^2}$)
- Luminosity : Eddington luminosity :

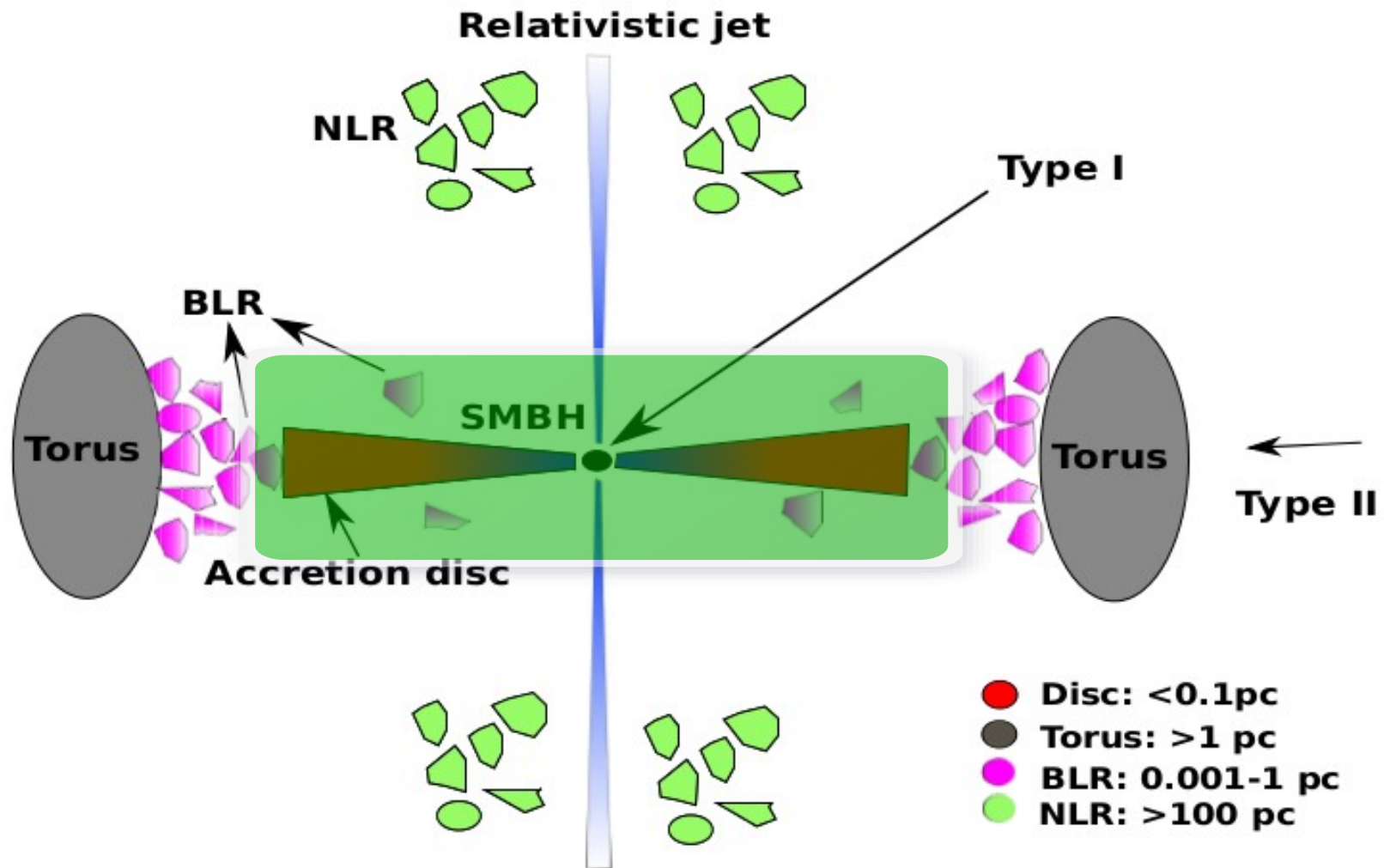
$$F_{rad} = F_{gravity}$$

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

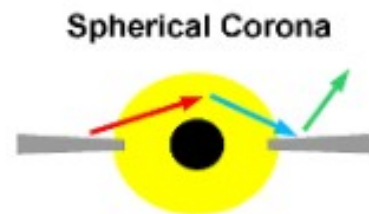
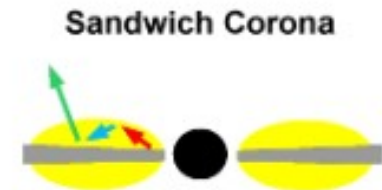
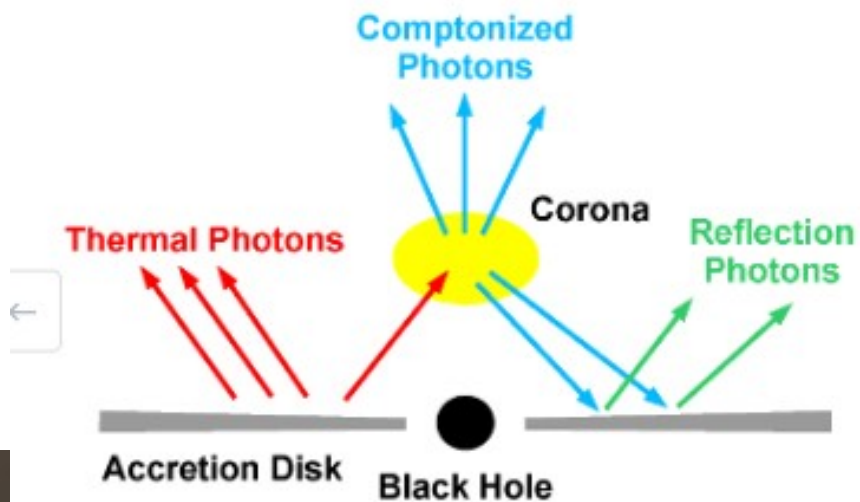
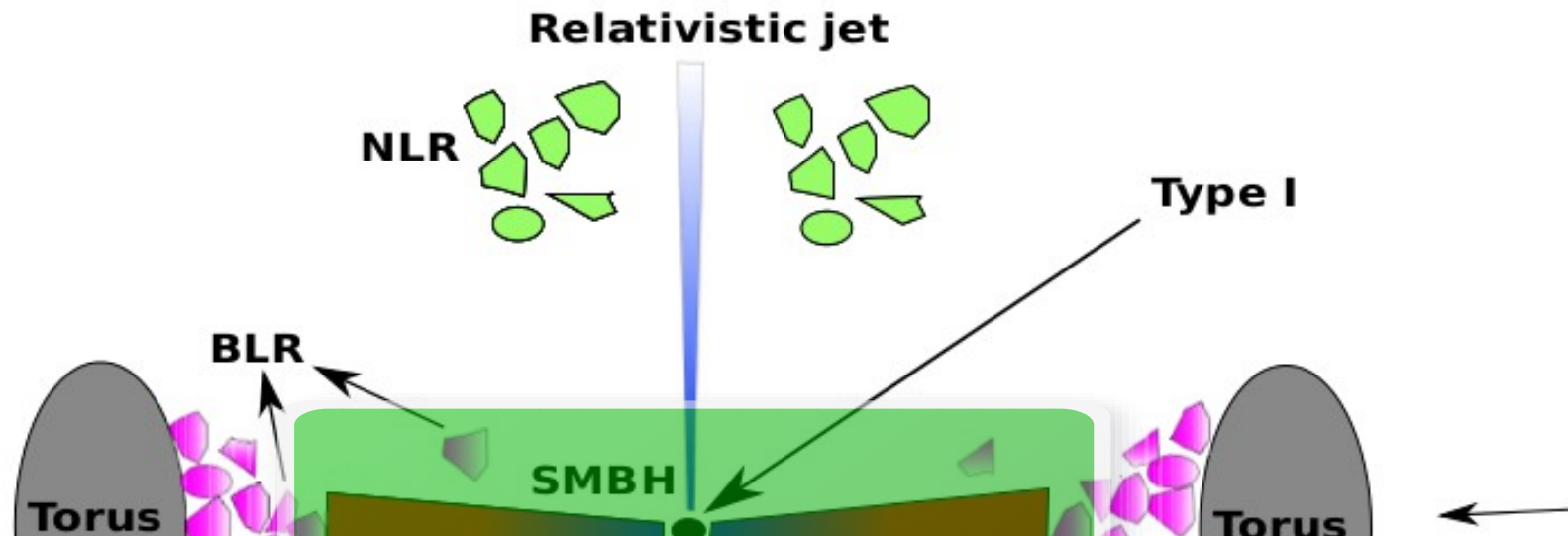
Unification Model



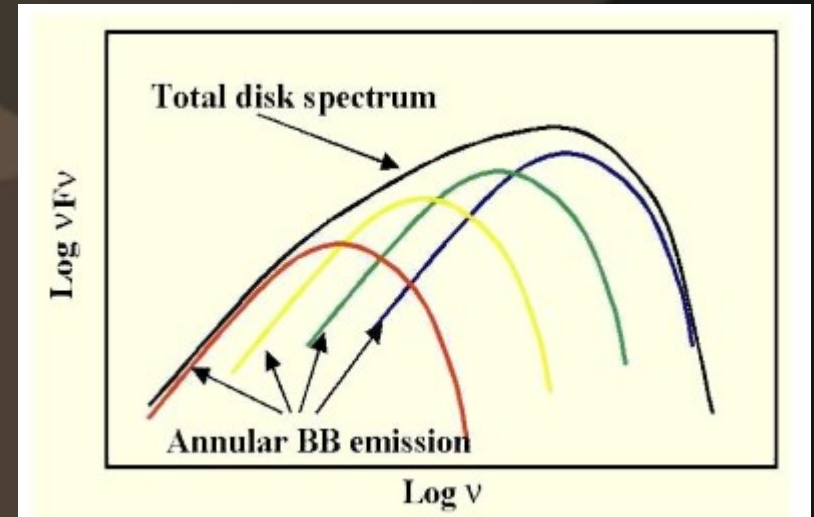
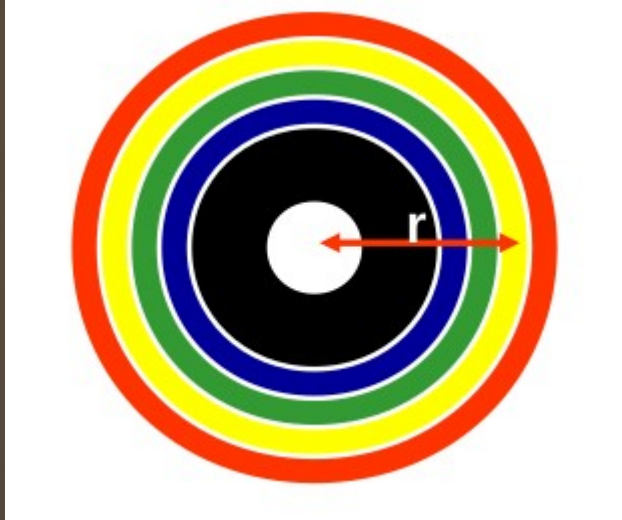
Unification Model



Unification Model



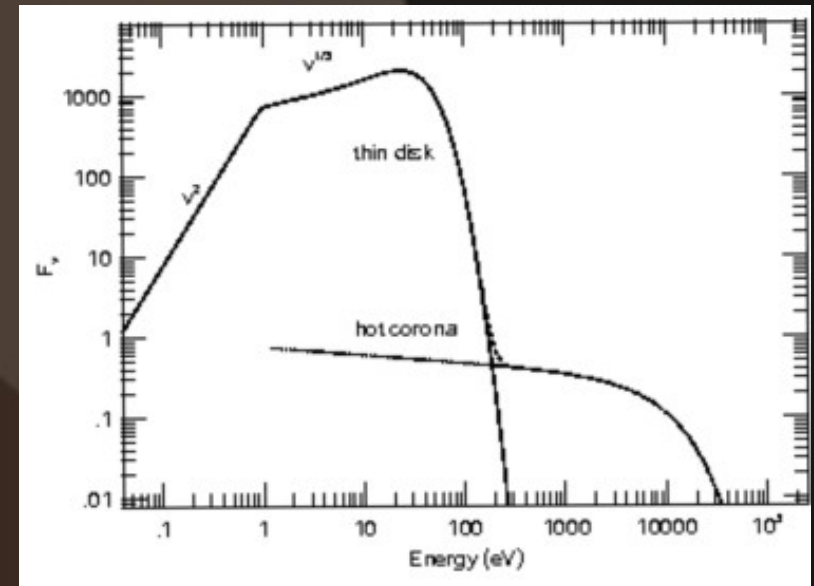
Thermal Emission: Standard Accretion Disk



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

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

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



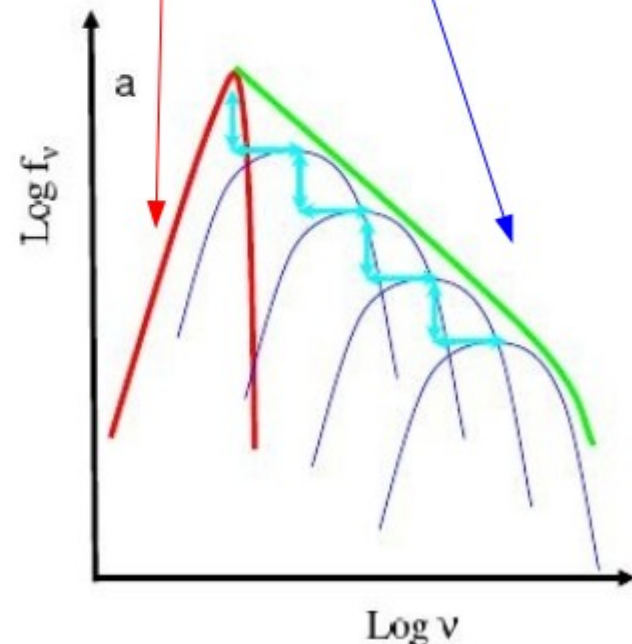
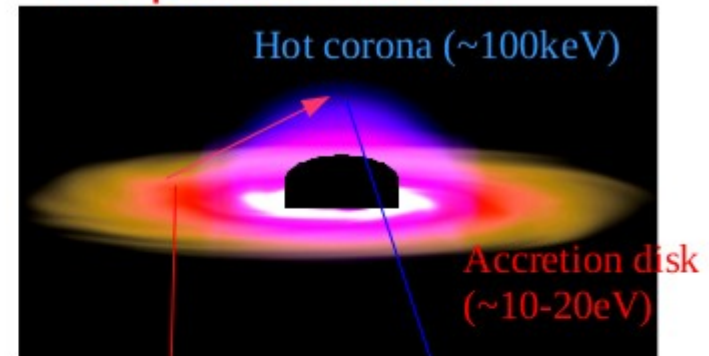
Non-Thermal Emission : X-ray Corona

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

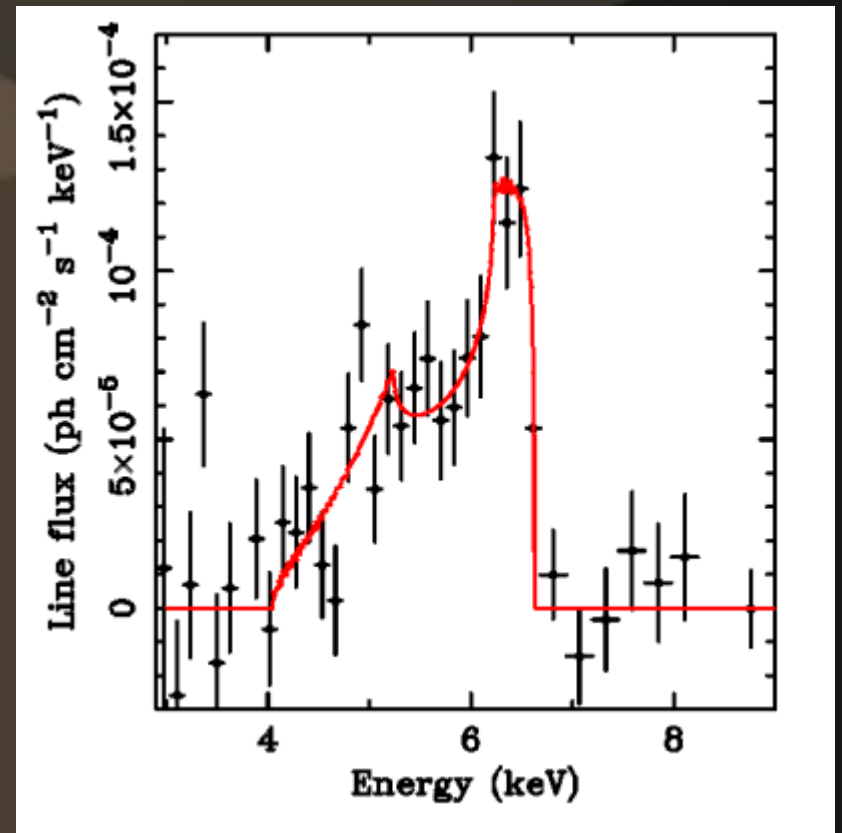
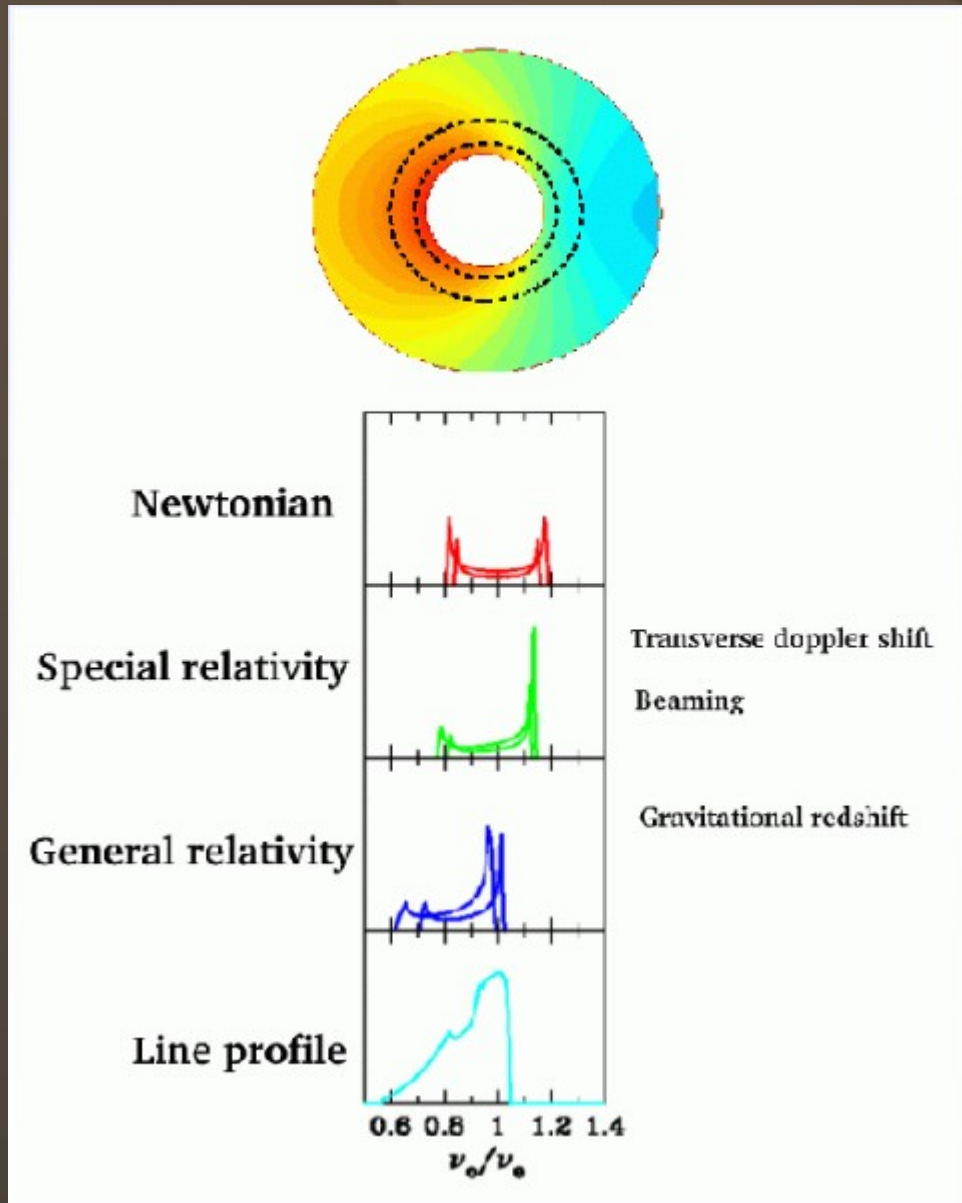
$$E_{cut} \sim kT_e$$

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

Two phase model

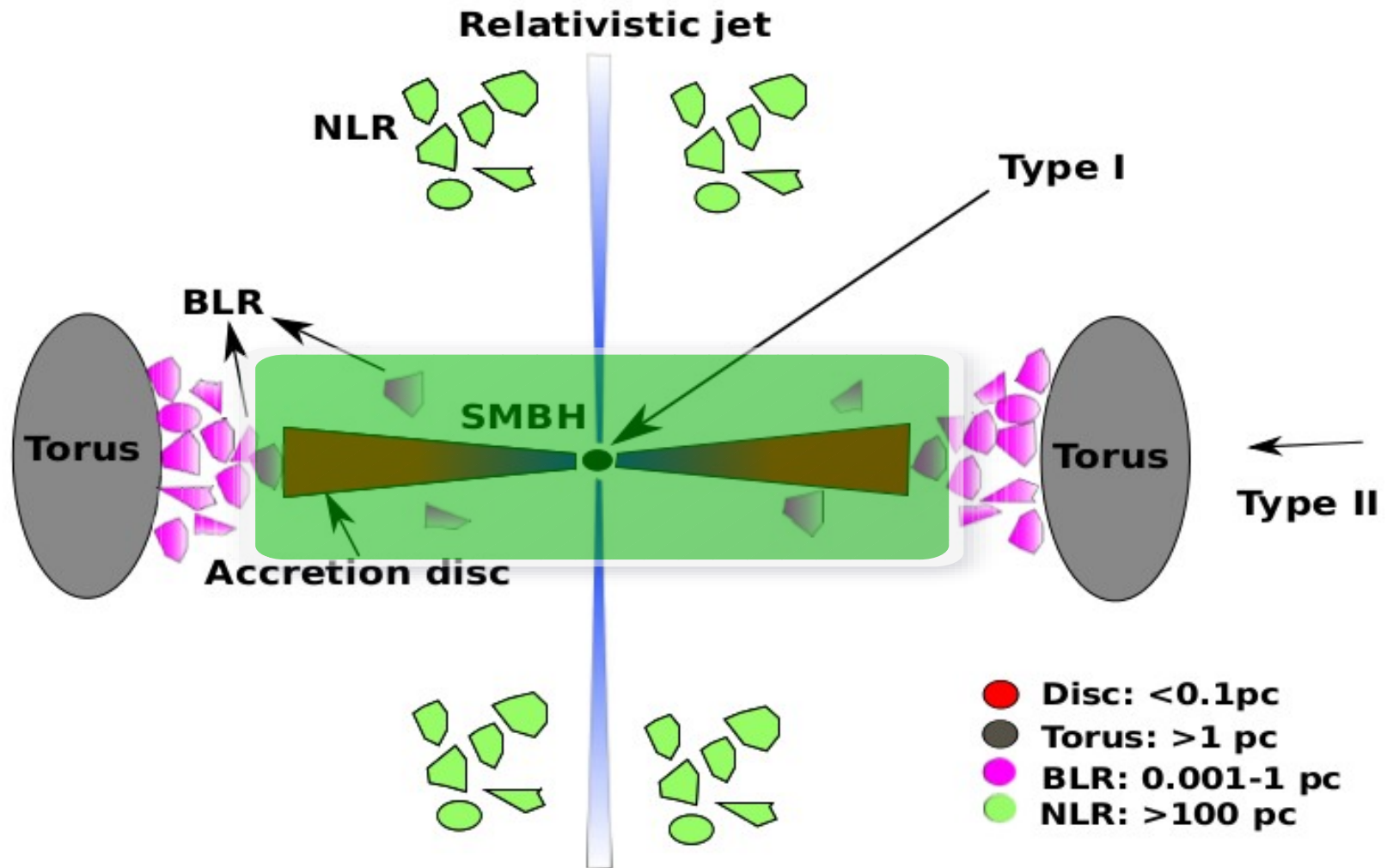


Broad Fe-K line in AGN

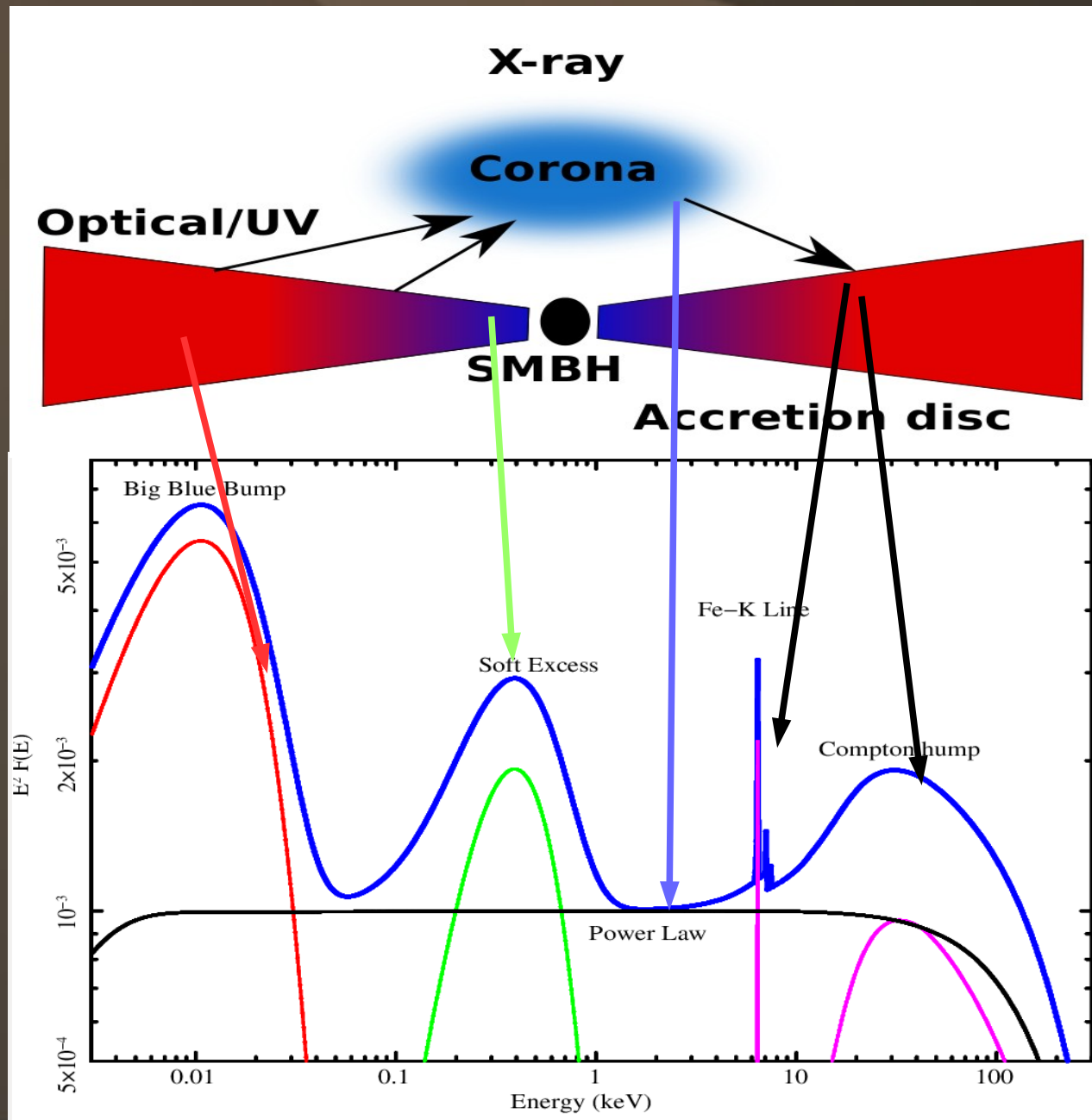


Iron Line in MCG-6-30-15
(Tanaka et al 1995)

Unification Model



Central engine and spectrum of a bare Seyfert 1 AGN



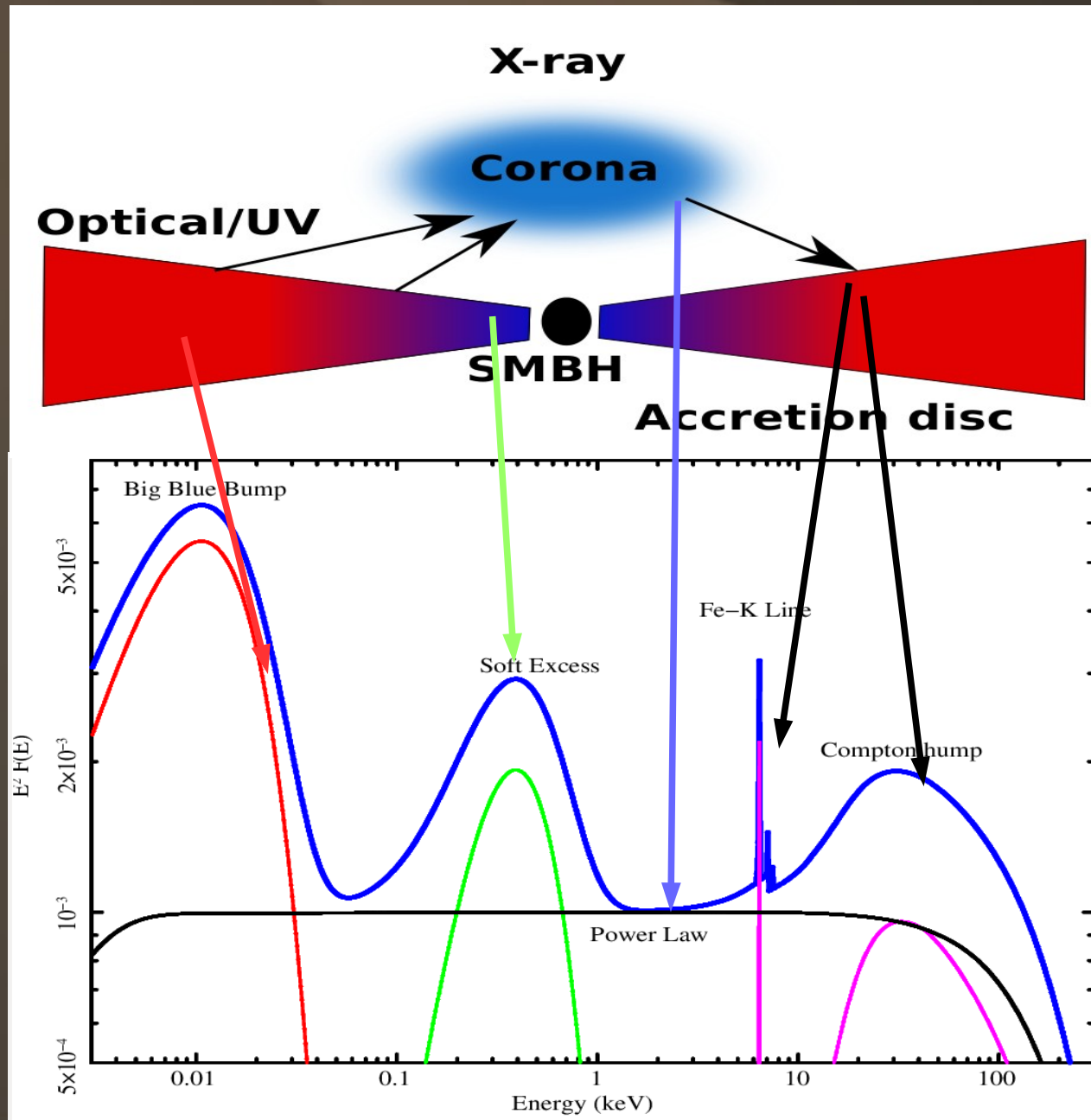
1. Compton reflection hump due to the Compton back Scattering from the electrons of optically thick matter i.e. disk

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.

Central engine and spectrum of a bare Seyfert 1 AGN



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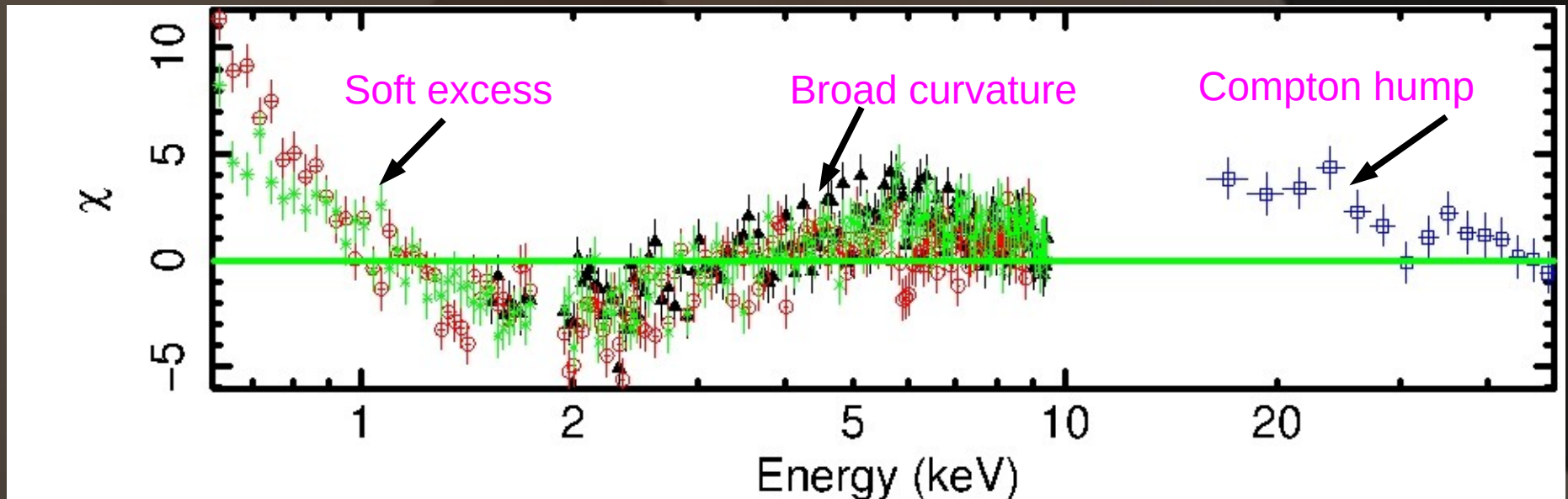
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Can be studied these using NuStar, XMM, AstroSat, Swift, XPOsat

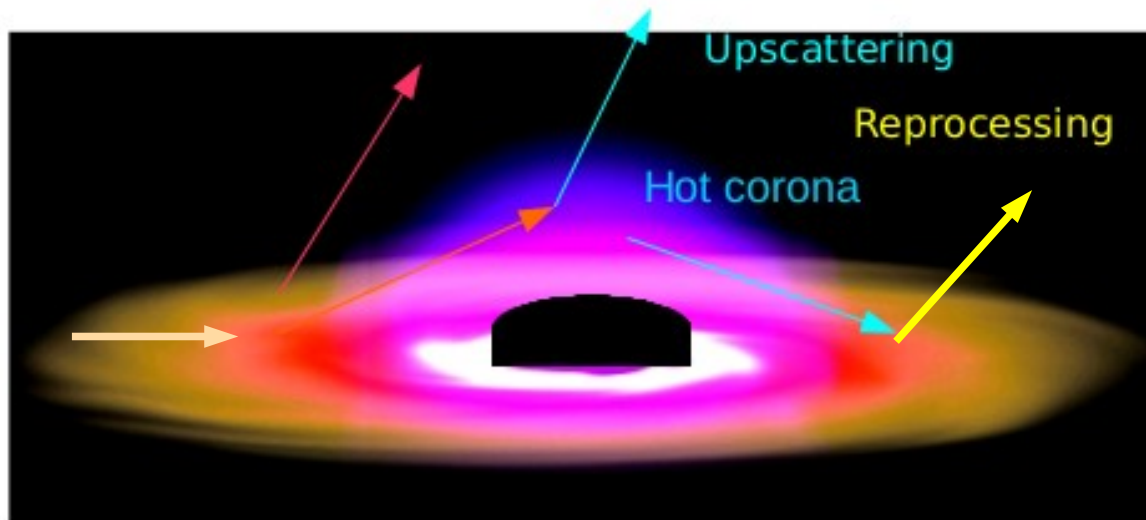
1H 0419-577

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 :



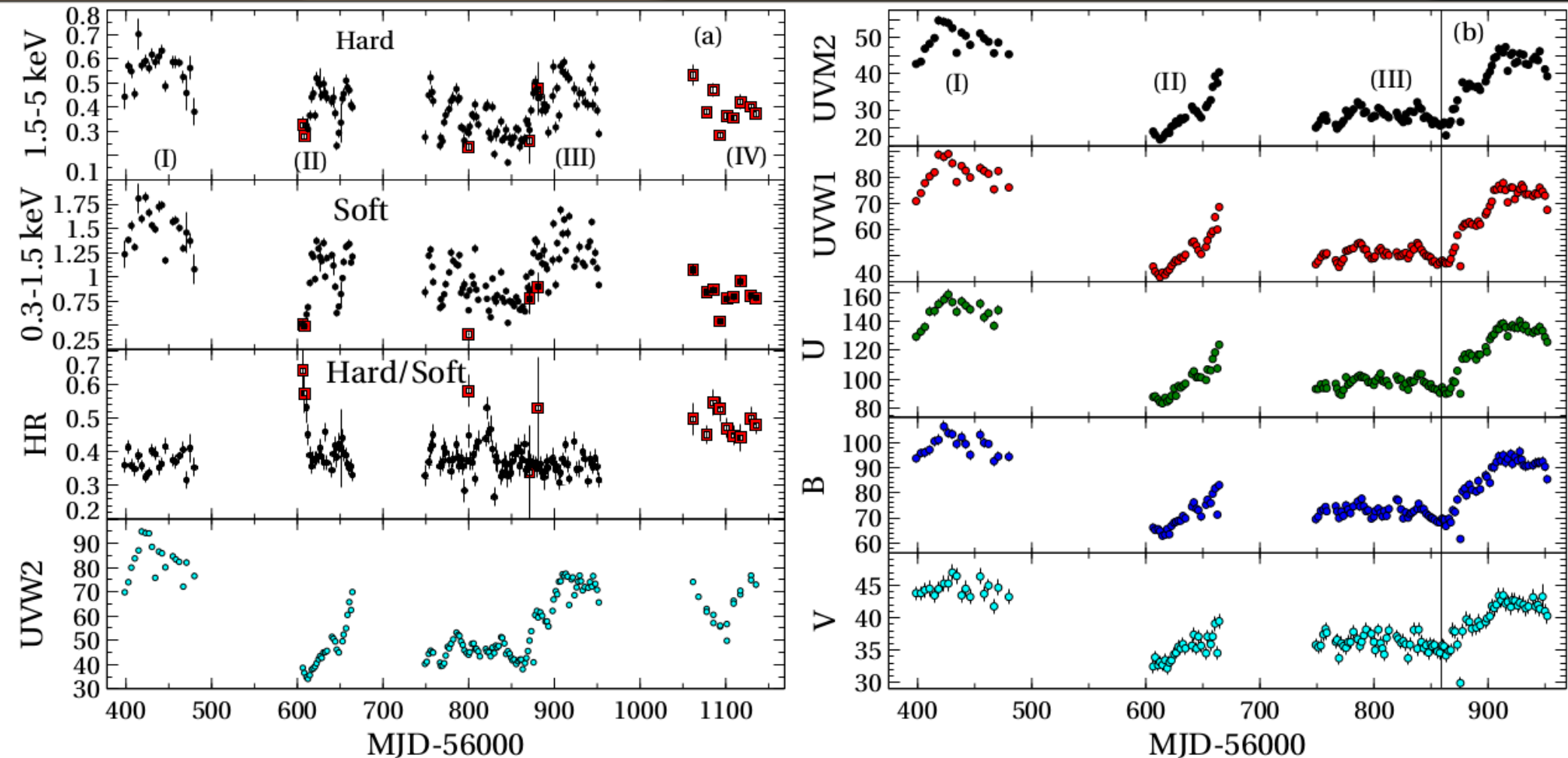
UV/Optical and X-ray connection



- Reprocessing of X-rays into optical/UV
 - Compton upscattering of optical/UV photons into X-rays
 - Propagation of accretion rate fluctuations
- Optical/UV should lag behind X-rays with light crossing time
Time lag Vs wavelength => Probe accretion disks
- Optical/UV should lead X-rays
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***Fairall 9:** Swift historical XRT/UVOT lightcurve*

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

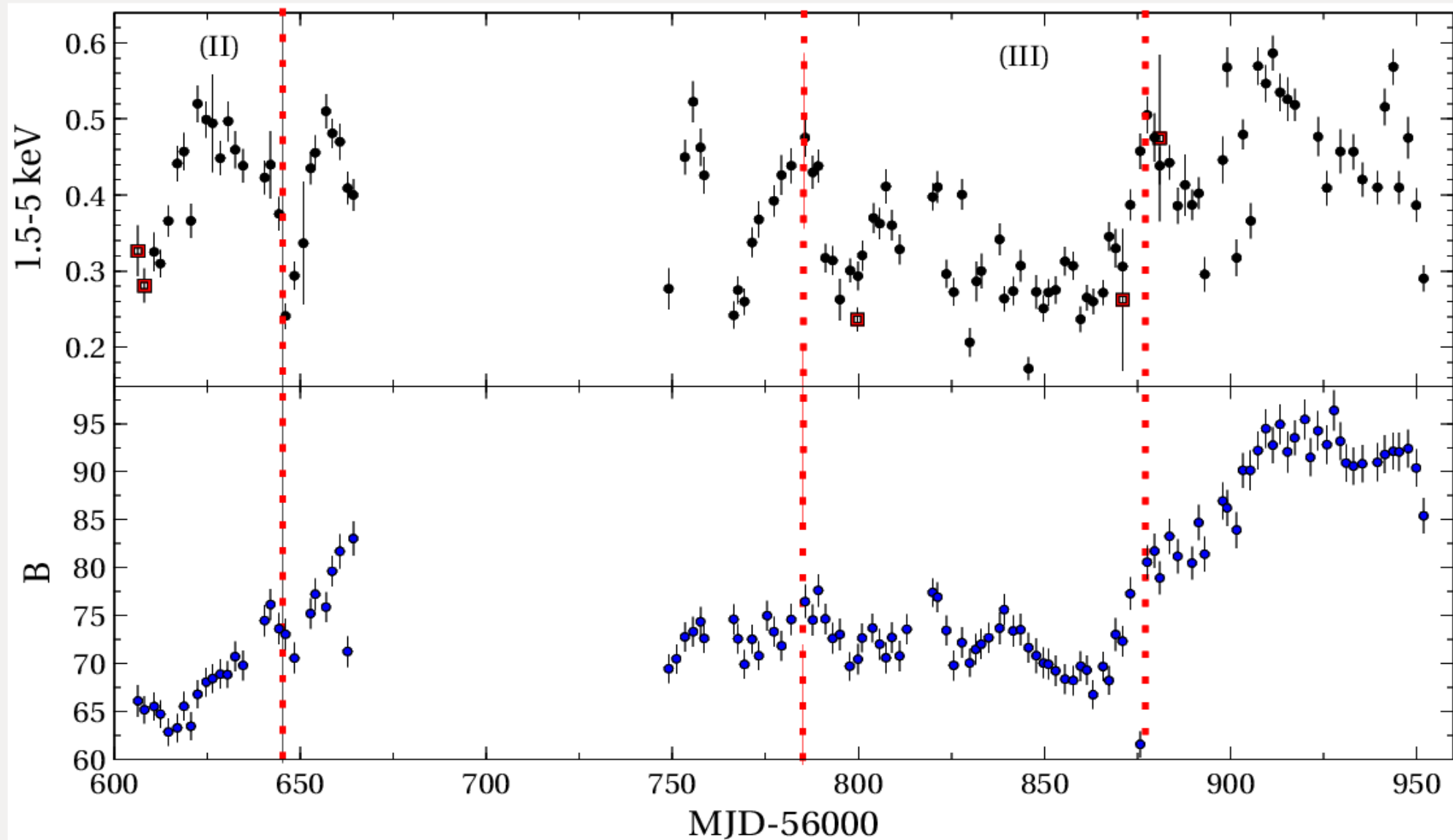


165 pointings; Coverage: 1.7-550 nm (X-ray to UV/optical)

All lightcurves show similar features.

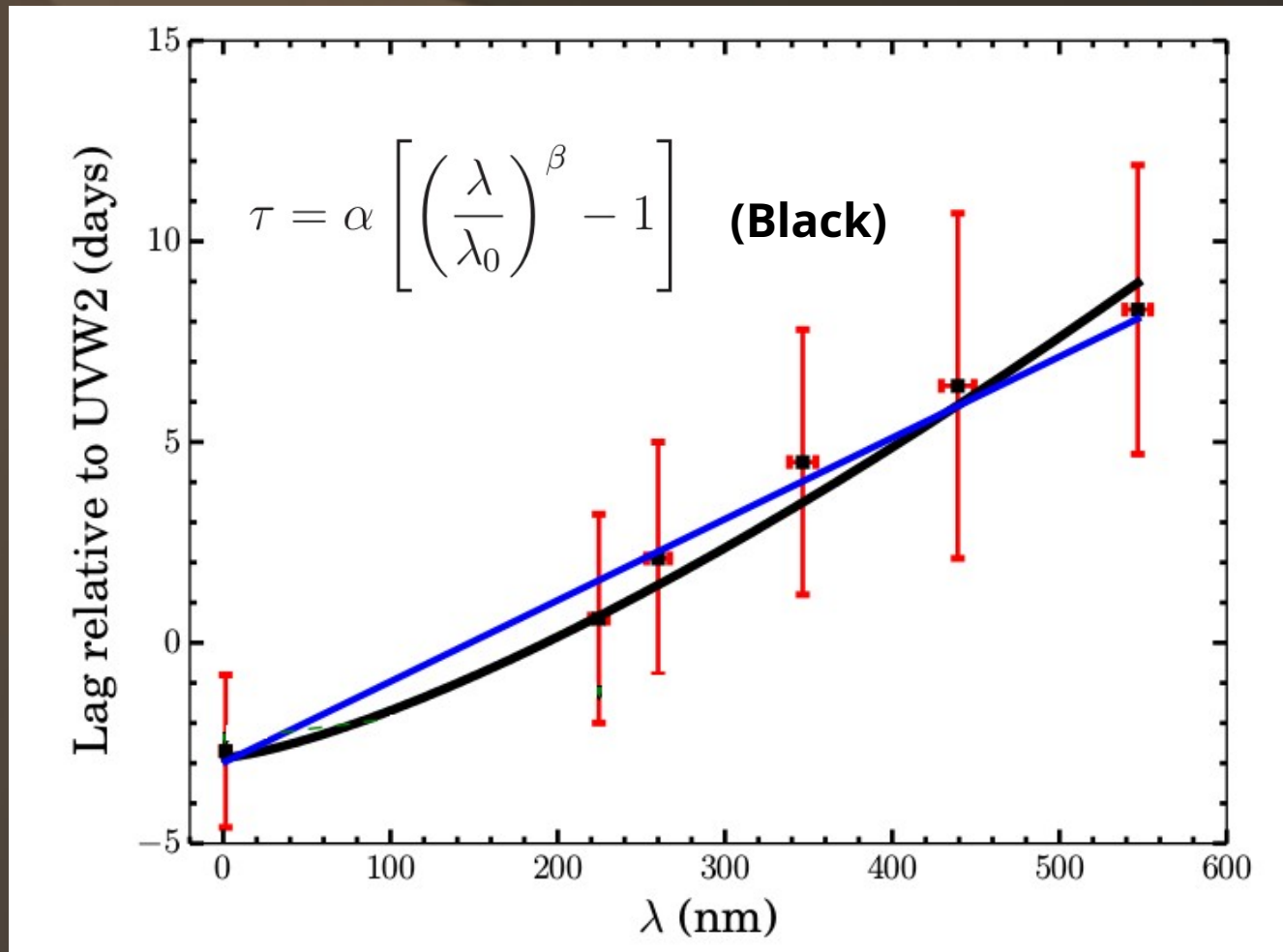
Main Pal et al. 2017

Fairall 9: Hard band and B band



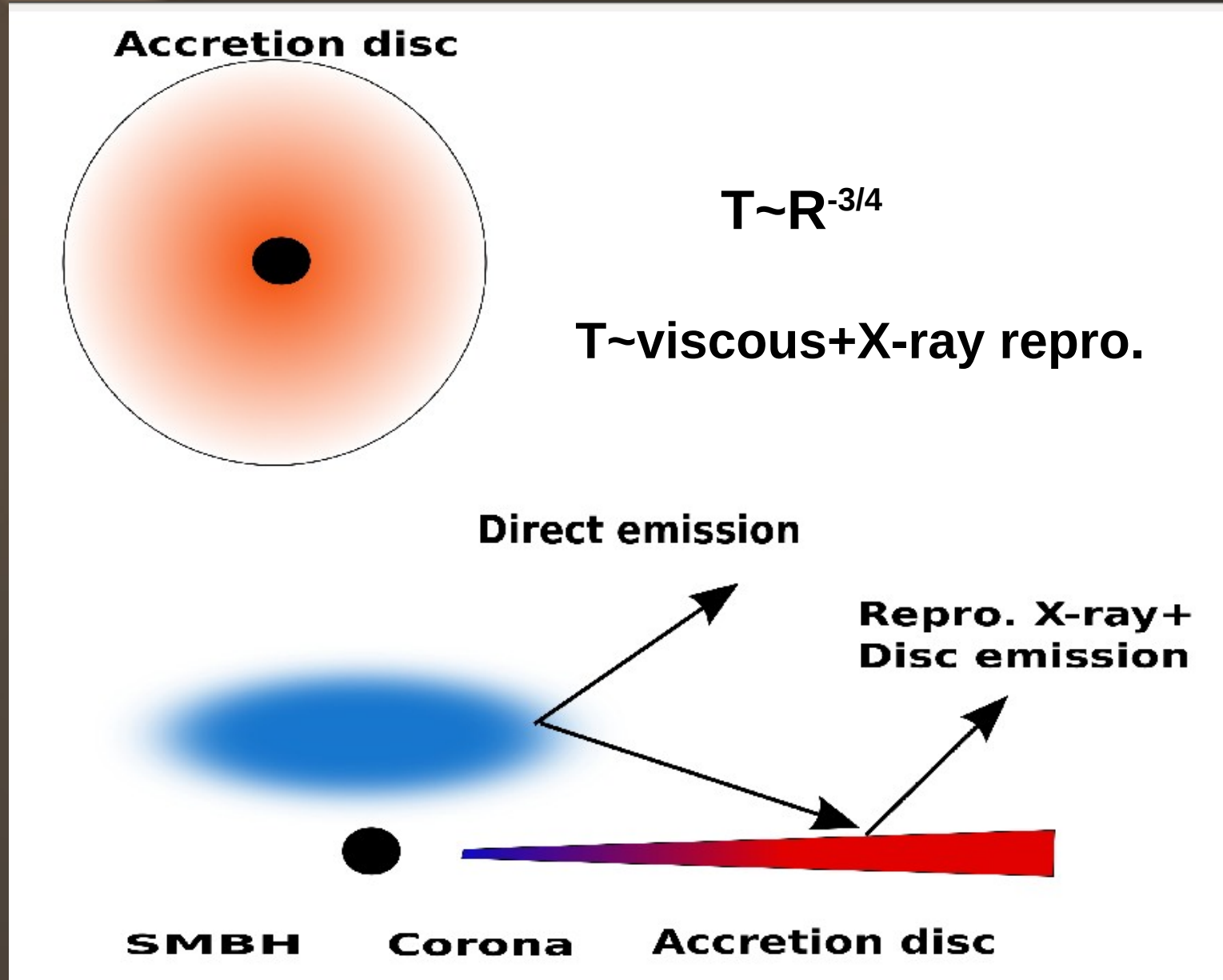
Fairall 9: Lag spectrum - powerlaw model or linear model ?

Main Pal et al. 2017



Model	Expression	Best-fit parameters	χ^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 \sim light travel time \sim 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 λ_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

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

Fairall 9: Lag profile of standard disc

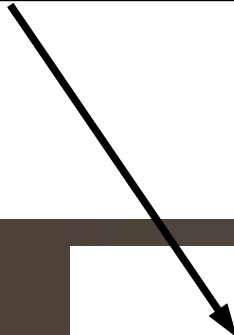
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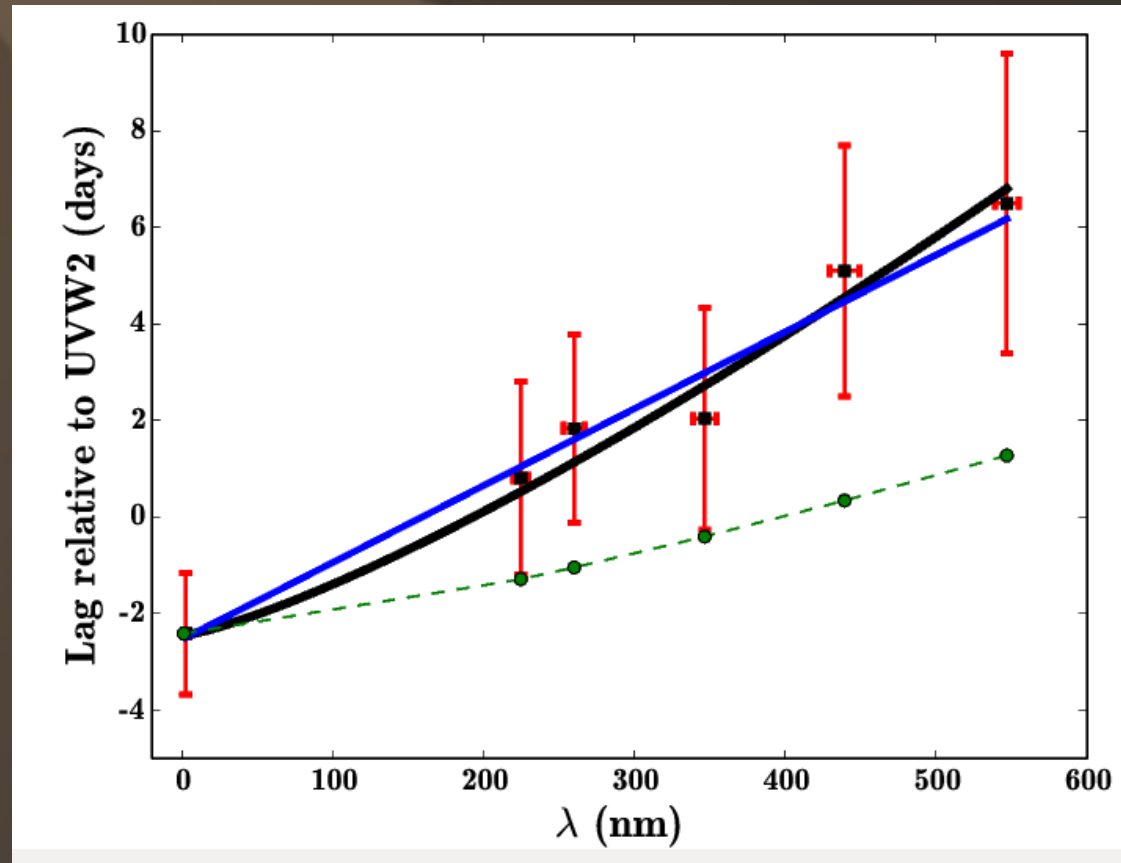
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- Functional form of the lag


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

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