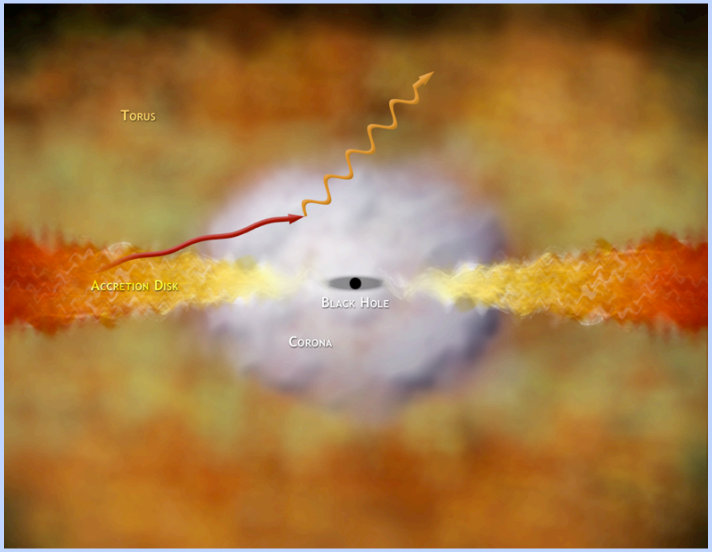
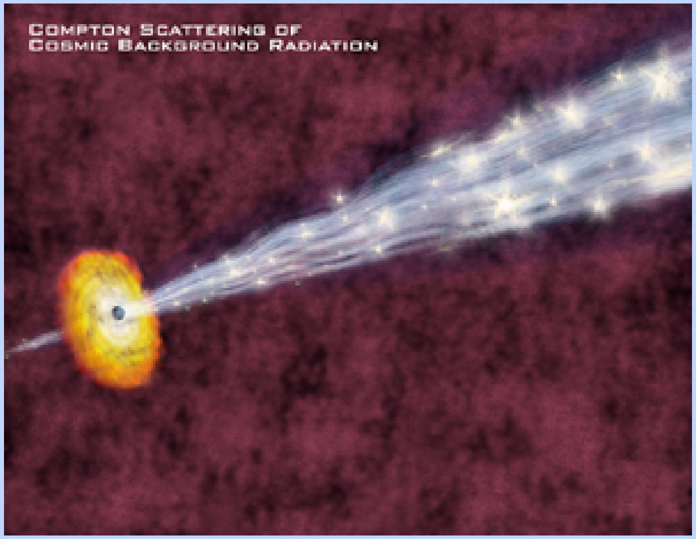
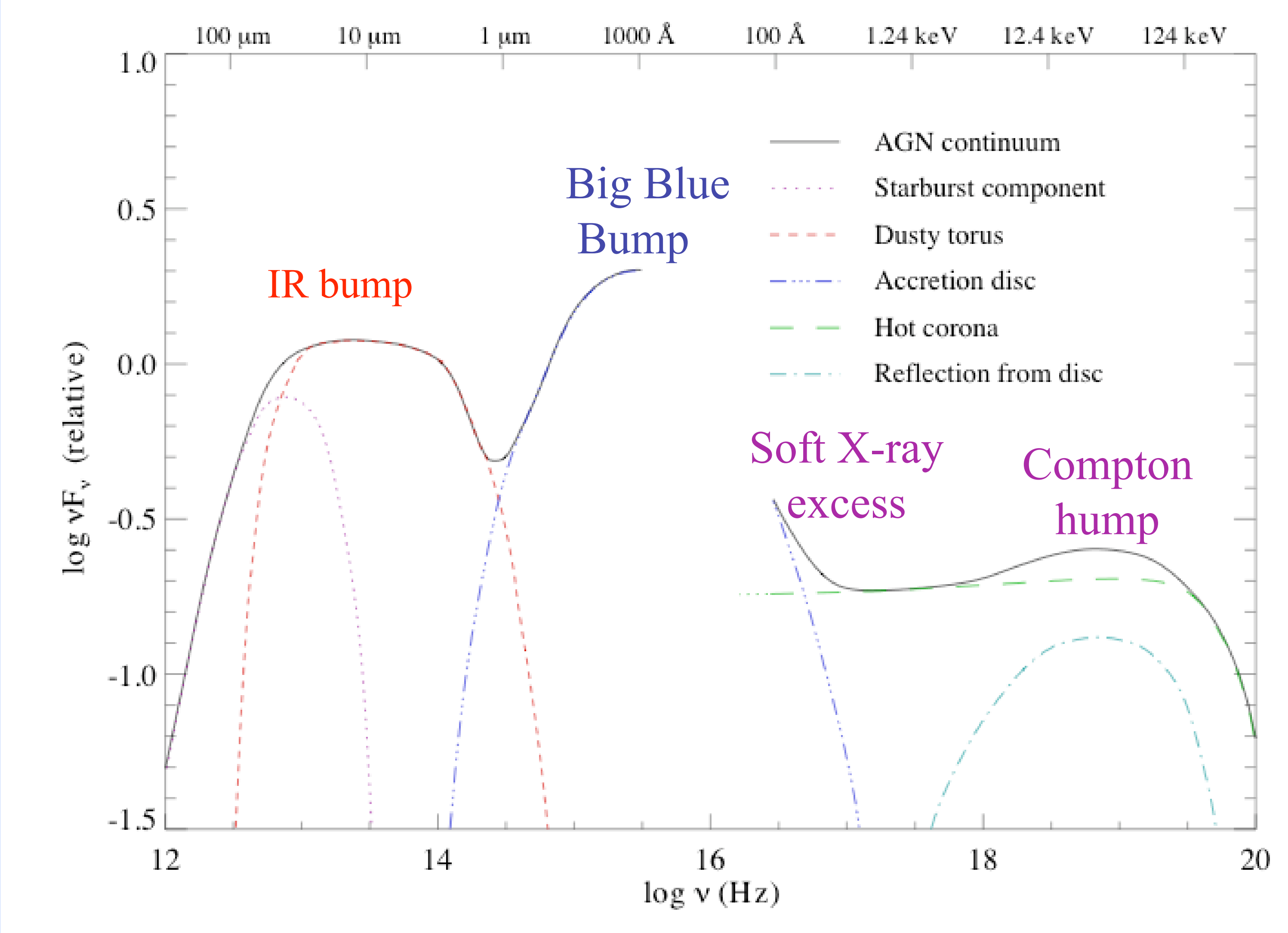
AGN Continuum Emission

- Characterization of Continuum
- Schematic Spectral Energy Distribution (SED)
- Observed SEDs for Different Types of AGN
- The BBB and Accretion Disks
- The X-ray Spectrum and Coronae
- The IR bump and the "Torus"





Schematic Continuum SED for Seyferts



(http://www.roe.ac.uk/~jcm/thesis/node5.html)

- RQ quasars have similar SEDs

Characterization of Continuum SEDs

- Typically characterized by power-laws over a limited range in frequency (or wavelength):

$F_\nu \propto \nu^{-\alpha_\nu}$ (larger $\alpha_\nu \rightarrow$ "steeper" continuum)

For $F_\lambda \propto \lambda^{-\alpha_\lambda} \rightarrow \alpha_\lambda = 2 - \alpha_\nu$

X-ray folks tend to use photon flux (photons s^{-1} cm^{-2} keV^{-1})

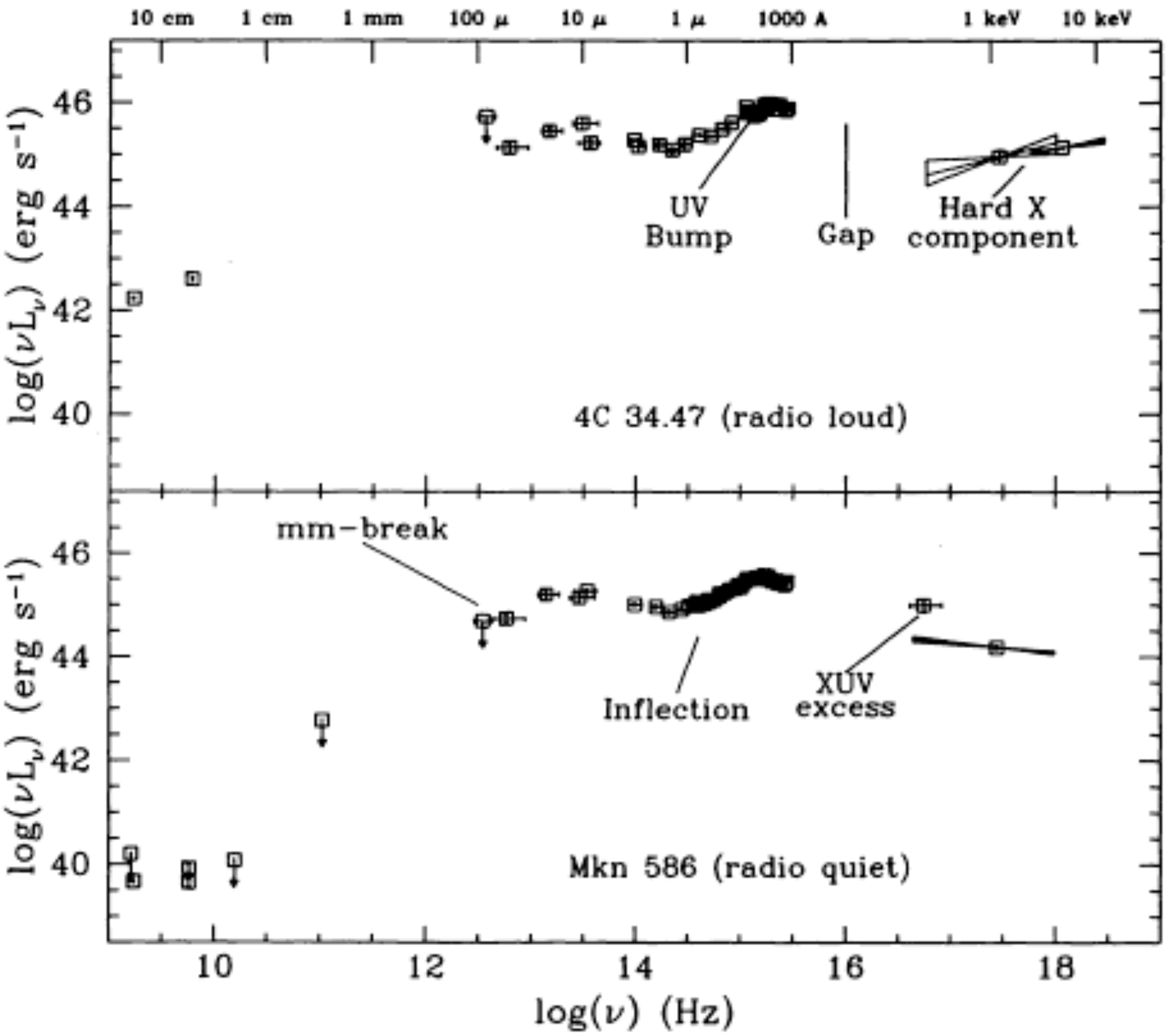
$F_{ph} \propto E^{-\Gamma} \rightarrow \Gamma = \alpha_\nu + 1$

- SED often plotted as νF_ν - represents energy output at each ν

If $\alpha_\nu < 1 \rightarrow \nu F_\nu \propto \nu^{1-\alpha_\nu} \propto \nu^{pos.\#}$ (positive slope in νF_ν plot)

If $\alpha_\nu > 1 \rightarrow \nu F_\nu \propto \nu^{1-\alpha_\nu} \propto \nu^{neg.\#}$ (negative slope in νF_ν plot)

Observed Quasar SEDs (Elvis 1994)



- Radio-quiet (RQ) quasars - similar to Seyfert 1s
- Radio-loud (RL) quasars ~100x brighter in radio than RQ

Continuum SEDs for Seyferts/Quasars

1) Optical/UV: $\alpha_\nu \approx$ 0.5 to 1.0

Note: low luminosity AGN contaminated by starlight in optical

2) Soft X-rays (E < 1 - 2 keV): $\Gamma > 2$ (steep, "soft X-ray excess")

- however, often absorbed by MW and host galaxy hydrogen, torus

3) Hard X-rays (E > 1 - 2 keV): $\Gamma \approx 1.7$ (flat out to ~10 keV)

- Compton reflection (down-scattering) from disk: hump at E>10 keV

4) EUV: Galaxy is optically thick to H-ionizing radiation - interpolate

Optical (2500 Å) to X-ray (2 keV): $\alpha_{ox} \approx 1.5$

5) IR continuum: often fit with a combination of blackbodies (hot dust)

- dust sublimates at $T \approx 2000$ K, which leads to a minimum at ~1µm

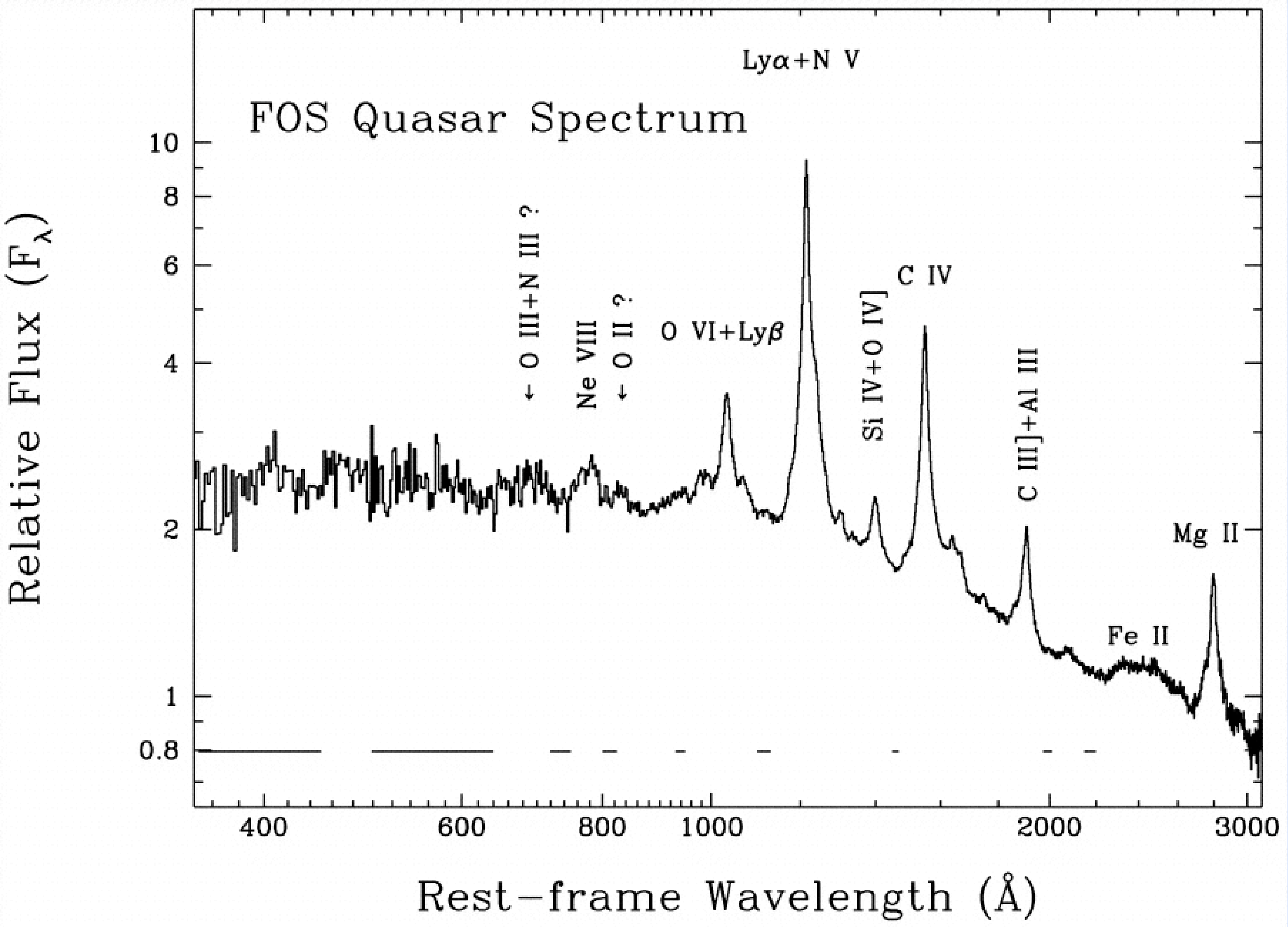
6) Sub-mm break: sharp drop to radio, $\alpha > 2.5$

- probably synchrotron self absorption

7) Radio: very weak in Seyferts and RQ quasars

- VLBI detects weak, aligned radio blobs instead of relativistic jets

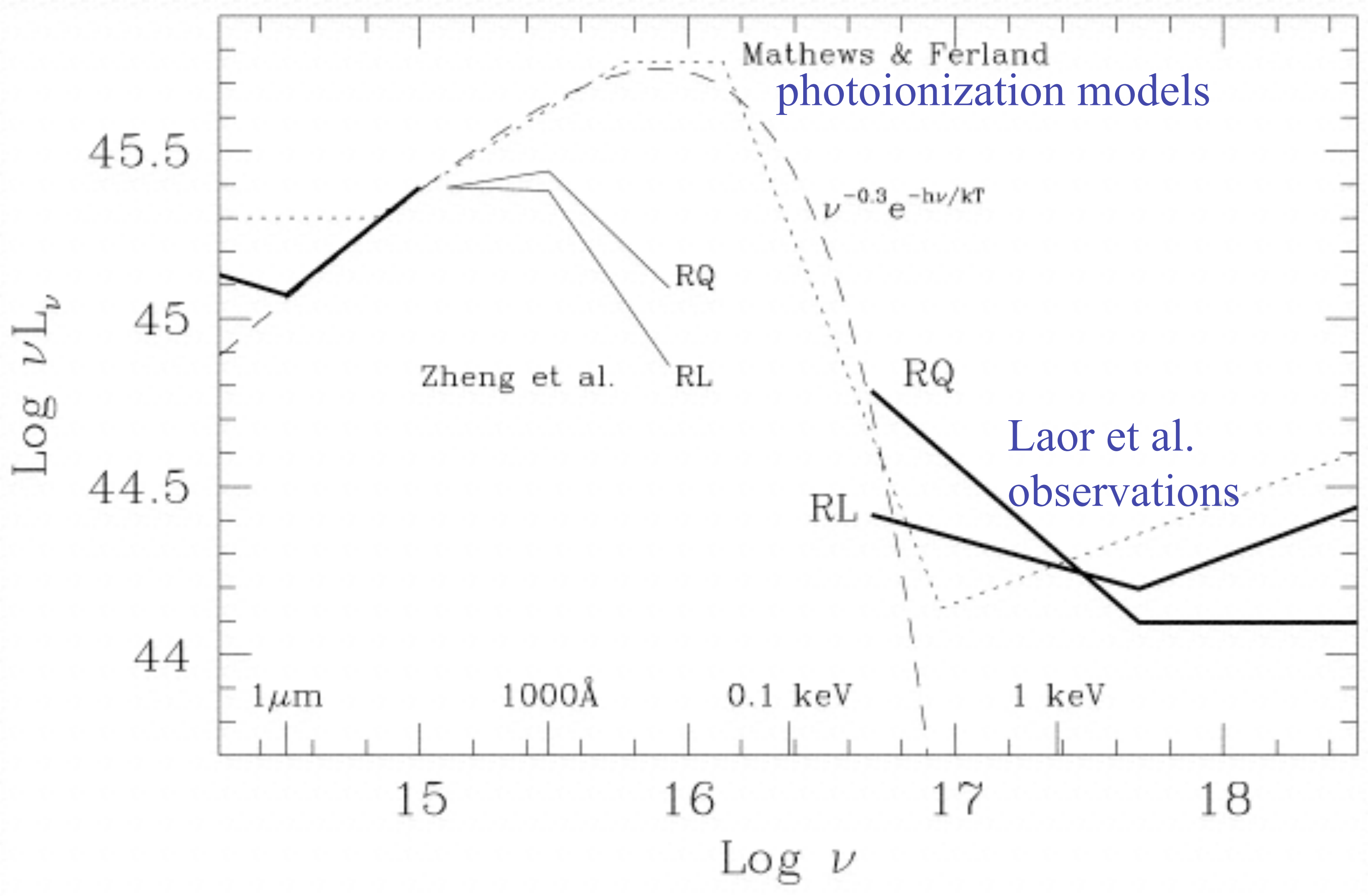
The BBB and Accretion Disks



(Zheng, et al. ApJ, 475, 569)

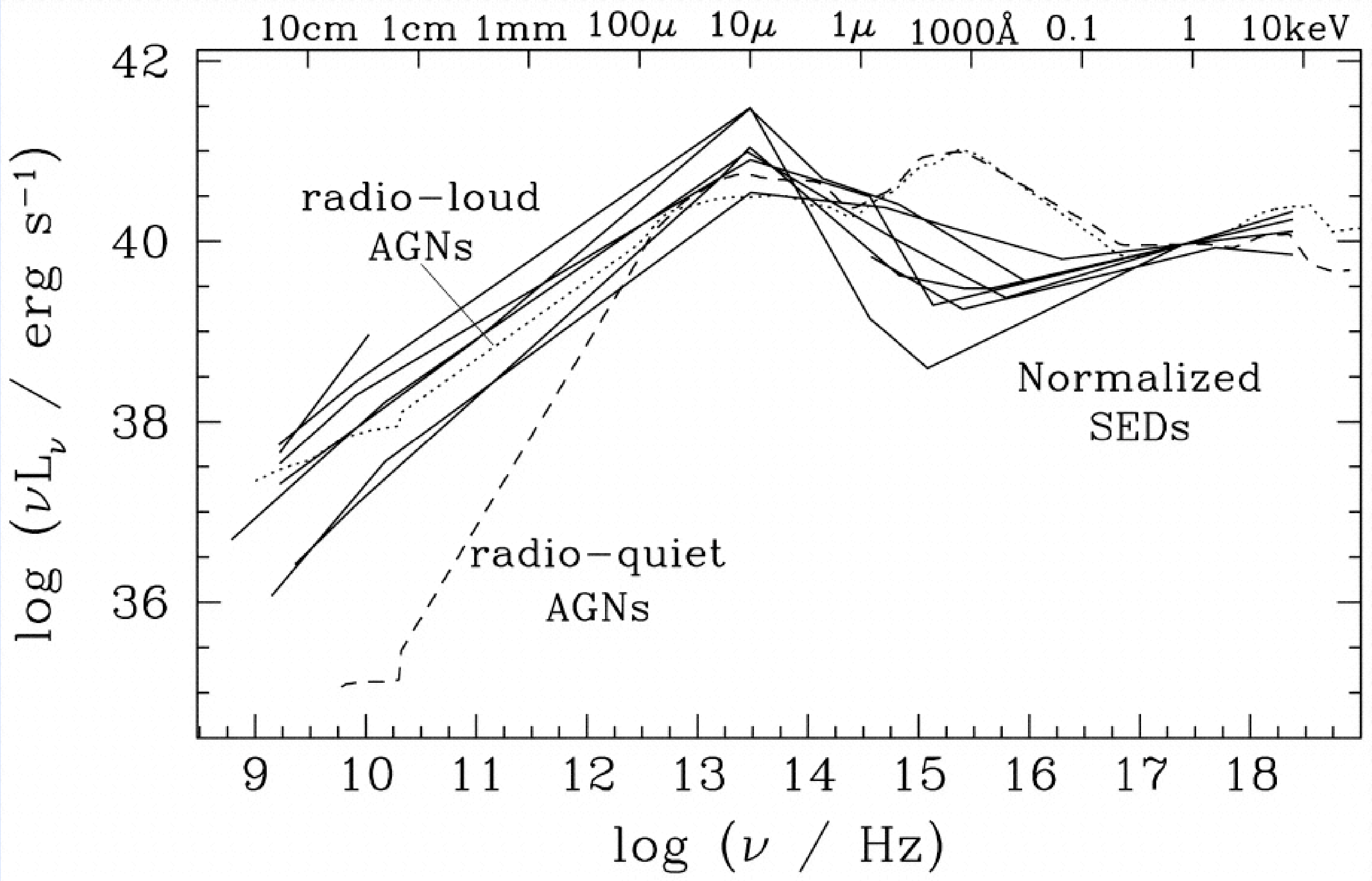
- Composite spectrum from quasars at different z's
- Turns over in EUV more quickly than previous photoionization models predicted (Mathews & Ferland 1987).

Big Blue Bump - not so big? (Laor 1997)



- Model predictions based on strong high-ionization lines (e.g., He II)
- X-ray and UV observations combined

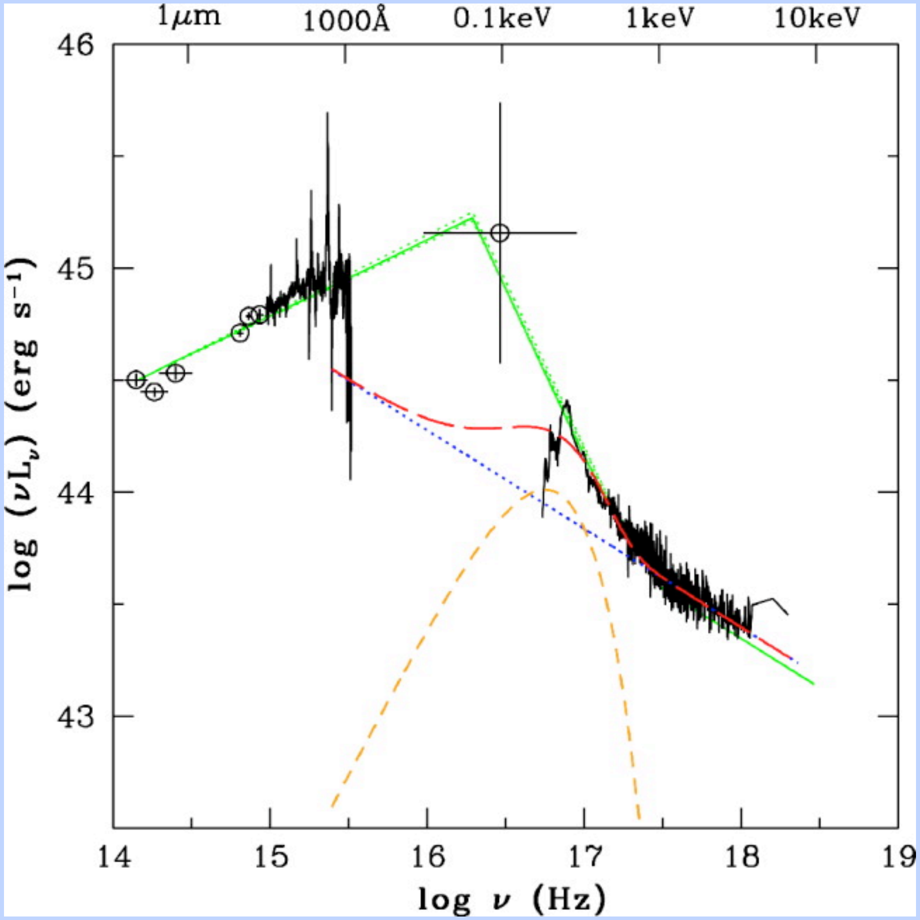
SEDs of LINERs (solid lines)



(Ho, 1999, ApJ, 516, 672)

- LINERs have weak or nonexistent BBBs and low L/L_E
- Consistent with idea that their disks are ADAFs

SEDs of NLS1s



(Turner, et al. 2002, ApJ, 568, 120)

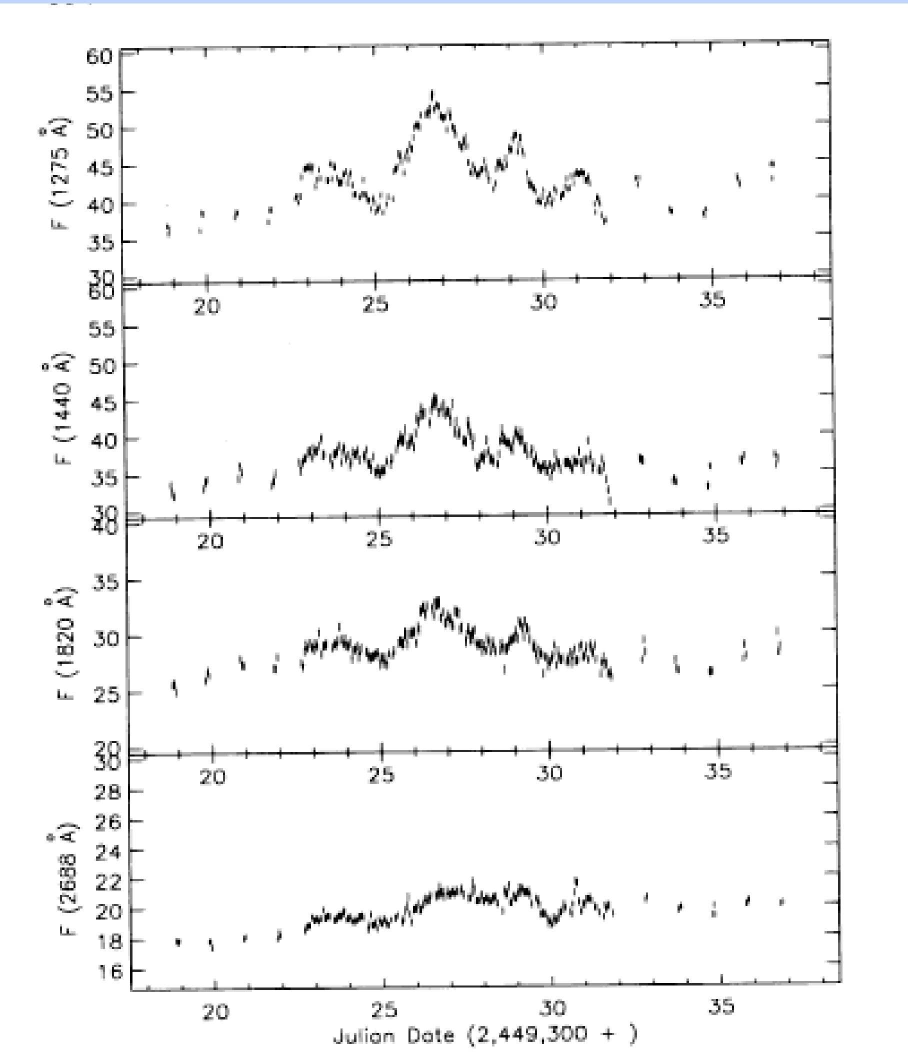
- NLS1s may have strong BBBs (more observations needed)
- Peak emission may be shifted to higher energies? - strong, soft X-ray excess
- Consistent with low mass and high L/L_E

The BBB and Accretion Disk Models

(Koratkar & Blaes 1999, PASP, 111, 1)

- Problems with building a physical model of an accretion disk:
  1) How do you get rid of angular momentum? MHD wind?
  2) How do you physically model the viscous stress? Still using Shakura & Sunyaev (1973) prescription.
  3) What is the vertical structure of the disk (important for radiative transfer)?
- Problems with matching models and observations:
  1) Blackbody disk predicts $F_\nu \propto \nu^{1/3}$ in optical/UV (Peterson, p. 44)
     - But observed is $F_\nu \propto \nu^{-0.5}$ (can match if accretion disk is cooler, but then the soft X-rays are way underpredicted)
  2) Stellar atmospheres more appropriate than black bodies, but:
     - Predicted Lyman limit absorption not observed.
     - Predicted polarization (up to 10%) from scattering electrons not observed.

Constraints from Continuum Variability



(Crenshaw et al. 1996, ApJ, 470, 322)

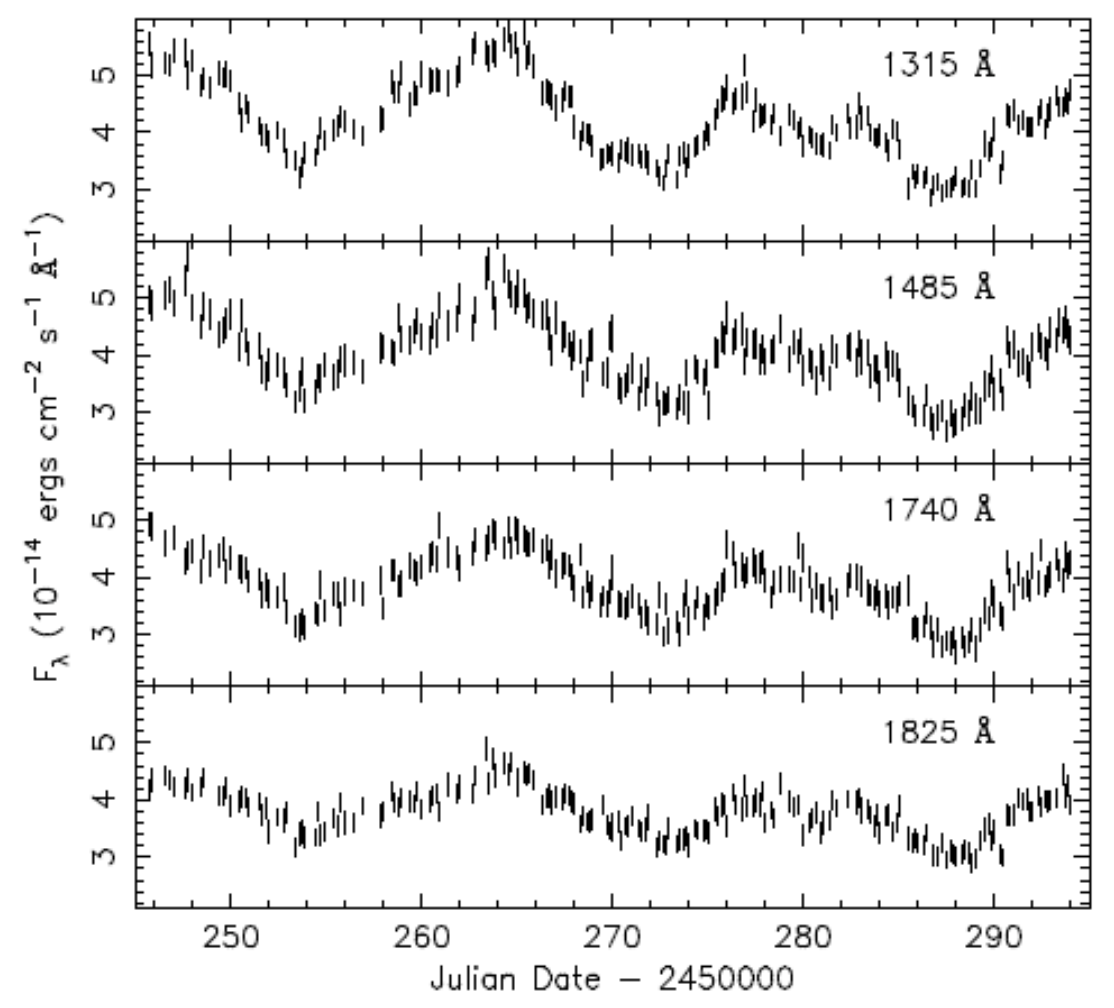
IUE Monitoring of NGC 4151
(and other campaigns):

- UV continuum gets “bluer” as it gets brighter
- smallest time scale ~ 2 days
- both consistent with thin accretion disk predictions
- no lag detected between bands:
  1) disturbance faster than sound speed

  or

  2) UV is reprocessed radiation from X-ray corona (irradiated disk)

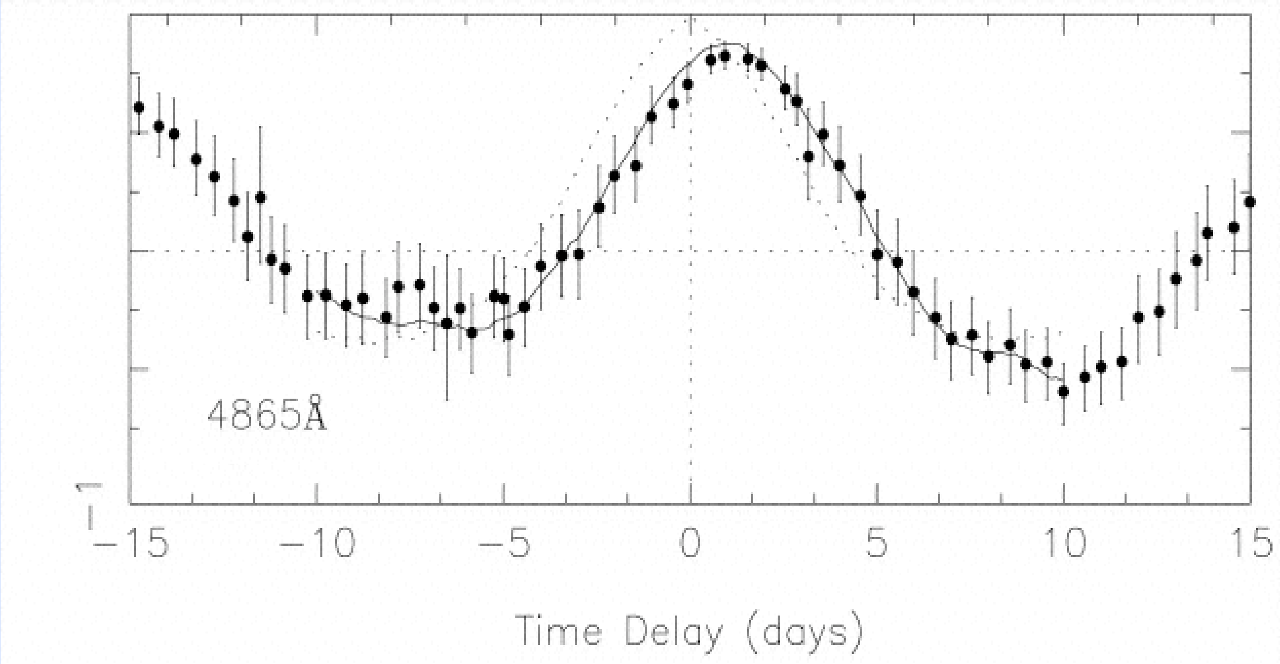
UV Continuum Variability of NGC 7469



(Wanders, et al., ApJS, 113, 69)

- most intensive IUE monitoring campaign

NGC 7469: Cross-Correlation of Optical (4865Å) with UV (1315Å)

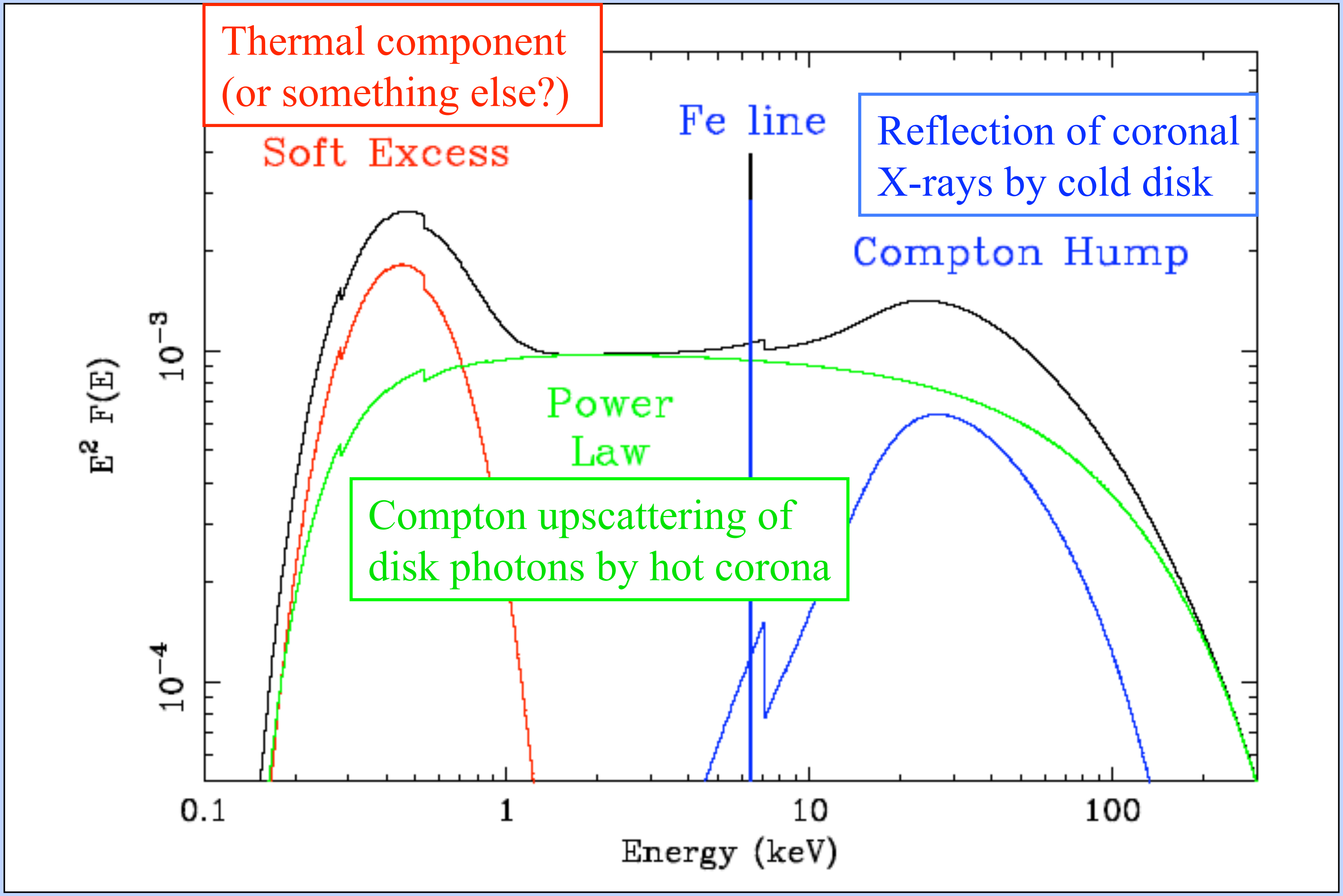


Dotted - ACF
Solid - CCF
Points - DCF
(similar to CCF)

(Colliers, et al. 1998, ApJ, 500, 162)

- Optical continuum lags the UV by ~1.2 days
- From various bins: Lag $\propto \lambda^{4/3}$
- If the lag is interpreted as a radius - results are consistent with an *irradiated* disk (disturbance travels close to speed of light, not the sound speed)

Components of X-ray Emission



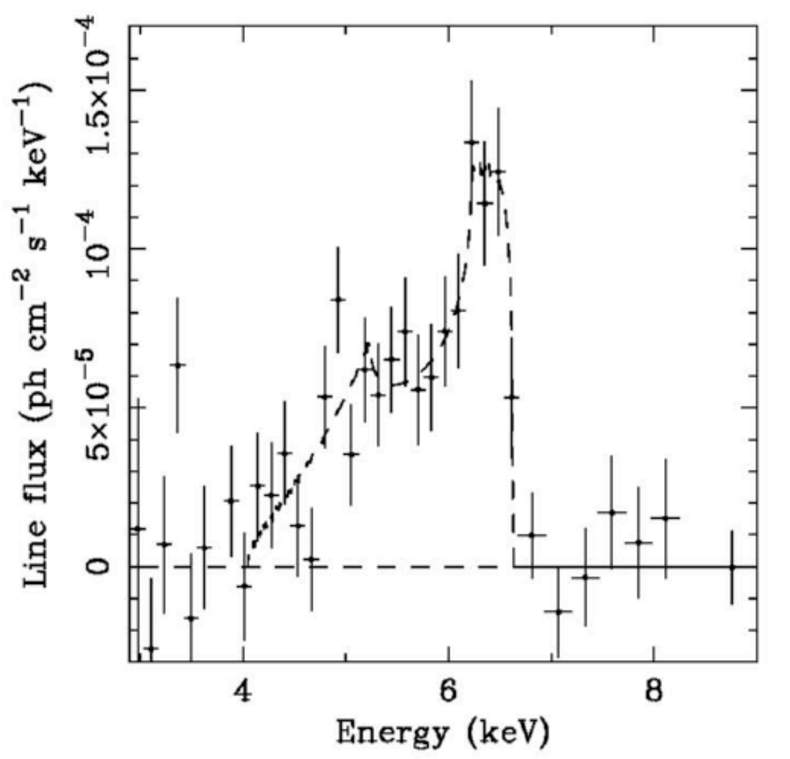
Thermal component (or something else?)

Reflection of coronal X-rays by cold disk

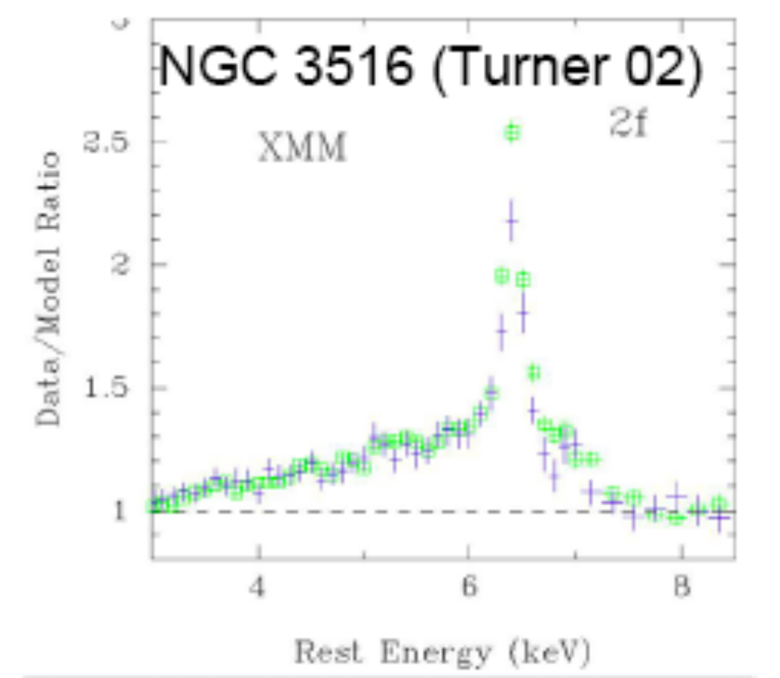
Compton upscattering of disk photons by hot corona

(Fabian, 2006, AN, 327, 943)

Fe Kα Emission Line

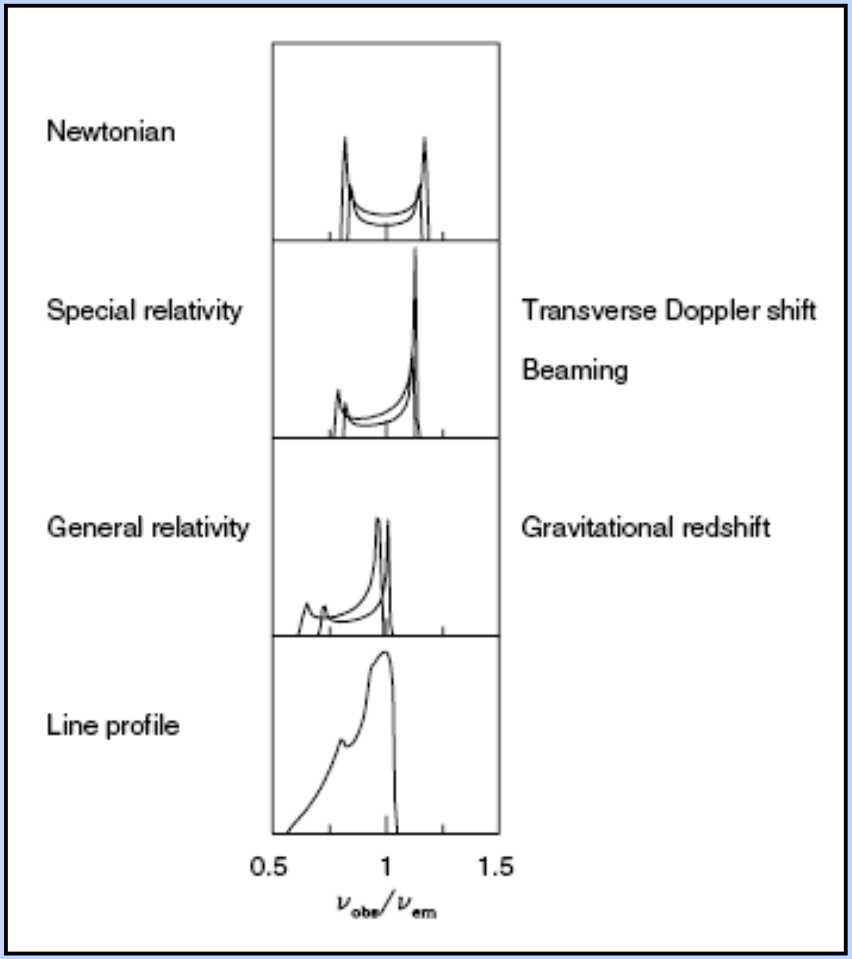


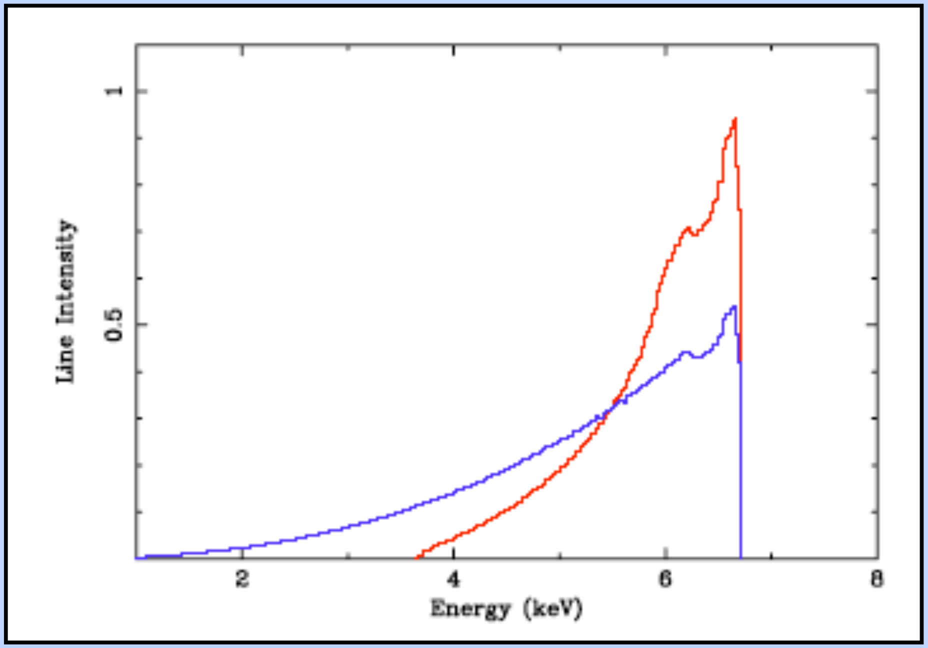
MCG -6-30-15 (Tanaka et al. 1995)



- ASCA detected a number of broad Fe Kα emission lines in Seyfert 1s
- Gravitationally redshifted wing - direct evidence for accretion disk origin
- From ionization of K-shell electron and subsequent recombination
- Recent Chandra and XMM observations find most Fe-Kα lines show strong “narrow” components - could be from BLR, inner NLR, or torus

Broad Fe Kα - Accretion Disk Models





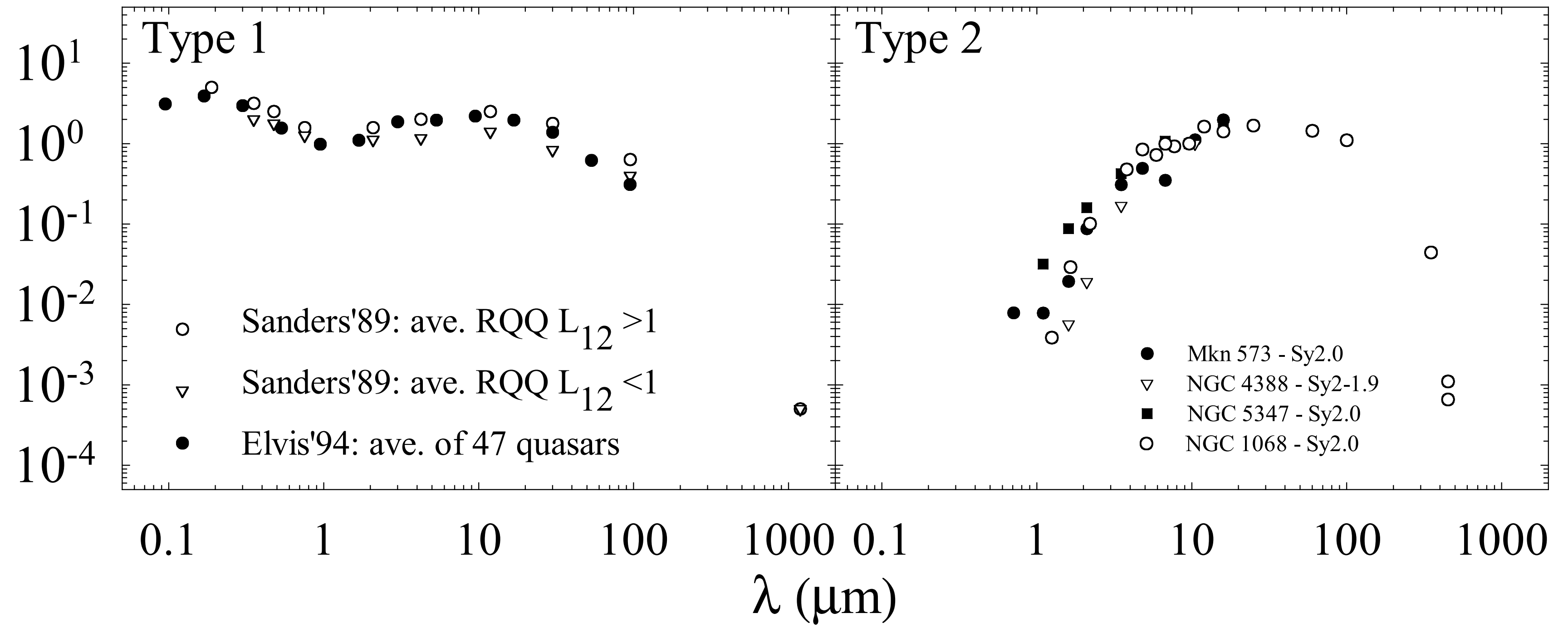
(Fabian, 2006, AN, 327, 943)

--- Schwarzschild BH, inner radius = 6 r_g

--- Kerr BH, inner radius = 1.24 r_g

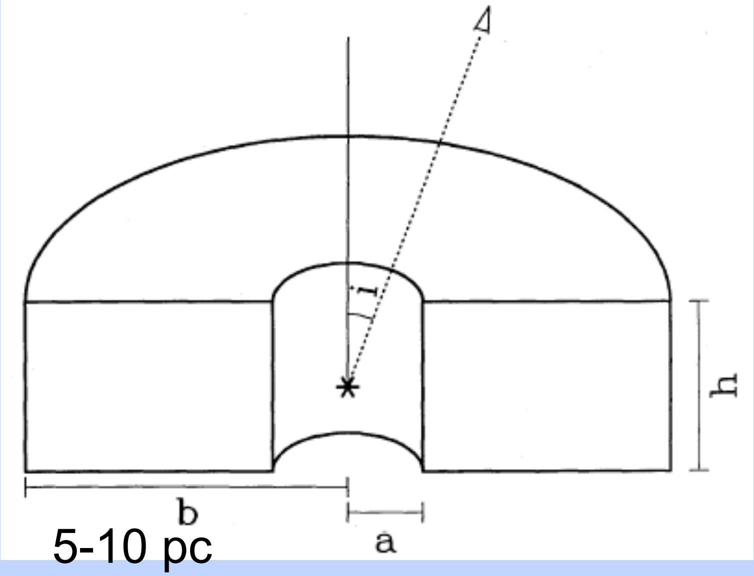
Ultimate goal: fit profile to get the black hole spin (a) and accretion disk inclination

IR Bump and the “Torus”



- Seyfert 1s show strong optical/UV from accretion disk
- Both Seyfert 1s and 2s show mid-IR bump peaking at ~150 K
  → torus emission

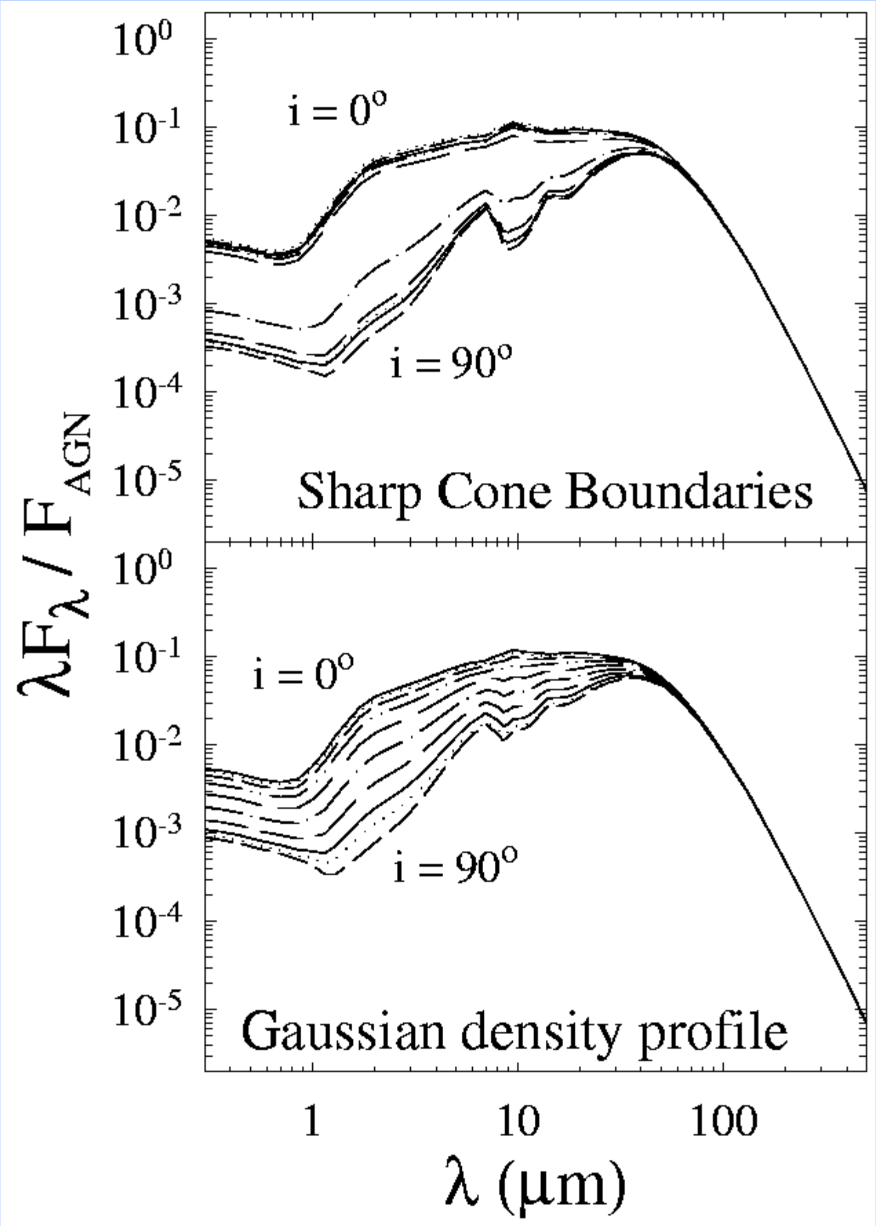
Smooth Tori

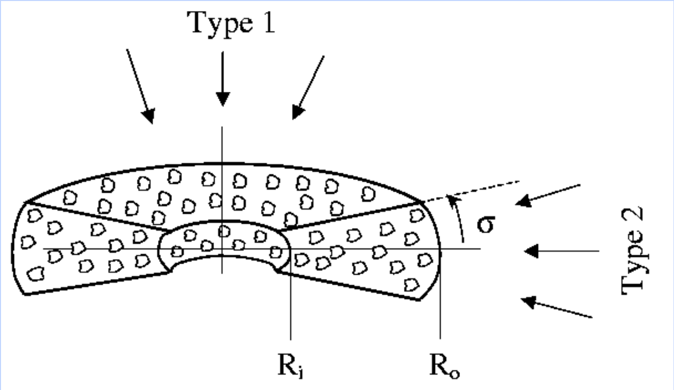


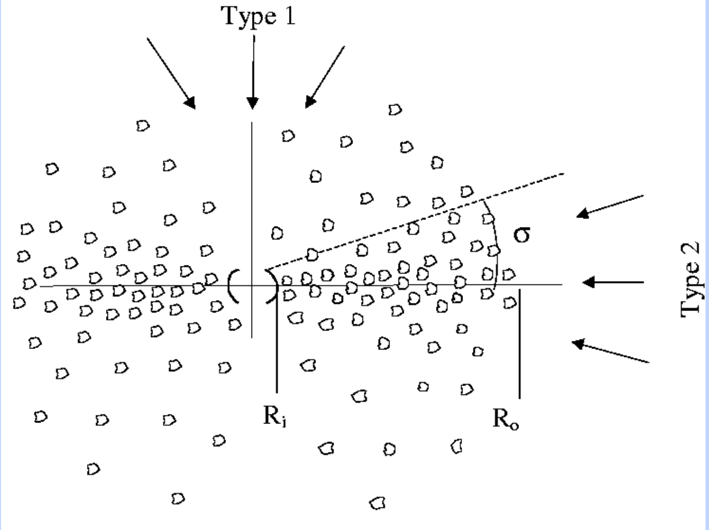
Given the observed hydrogen column densities for Seyfert 2s (10^{22} - 10^{25} cm^{-2}) Pier & Krolik (1992) and subsequent models of a uniform torus predict:

1) Seyfert 1 tori should be much hotter than Seyfert 2s, since you are looking down the “throat” of the torus - but Seyfert 1 and 2 SEDs are pretty similar
2) Seyfert 2s should show deep silicate 10 µm absorption from dust - but the absorption is very modest
3) Seyfert 1s should show 10 µm emission - but little or none observed
4) Dust columns from optical/IR and gas columns from X-rays should be same - but dust column appears to be much smaller than gas column

Solution - Clumpy Tori?

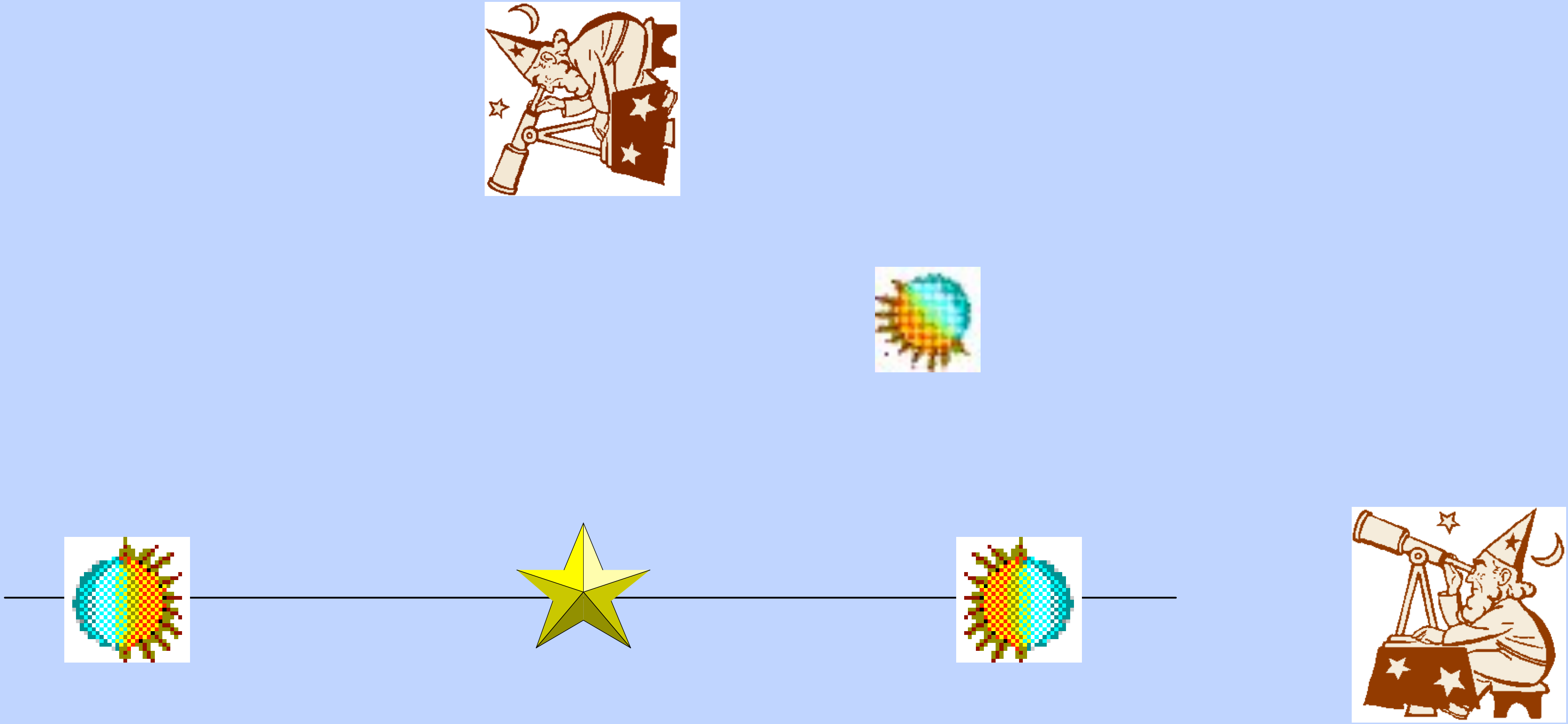






(Nenkova, Ivesic, & Elitzur, 2002, ApJ, 570, L9)

Clump Emission - Anisotropy



- X-ray column is huge, since clumps cover the central source in the line of sight
- Silicate 10 μm absorption is filled in by view of irradiated faces of clumps
- Dust column appears much smaller for the same reason
- IR SEDs are more uniform, since you can see unobstructed emission at any angle