Aspects of X-ray data analysis for accreting compact objects: theory and results

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PhD lecture series, 2025, fall semester

Lecture 2

Radiative processes

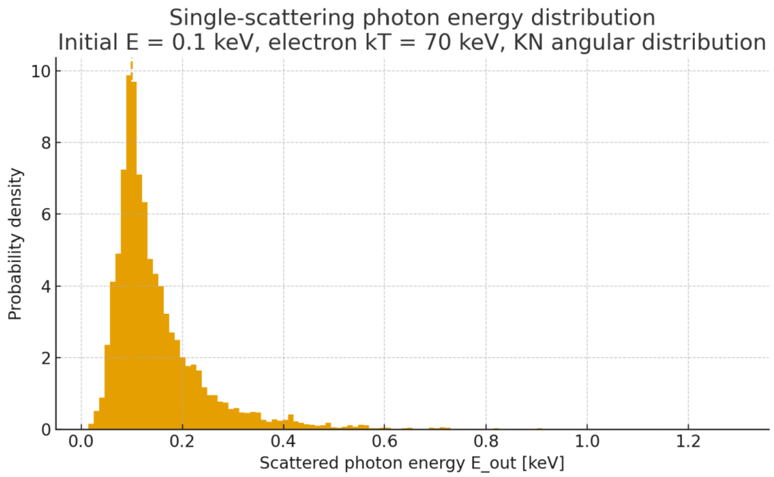
Inverse Compton spectra

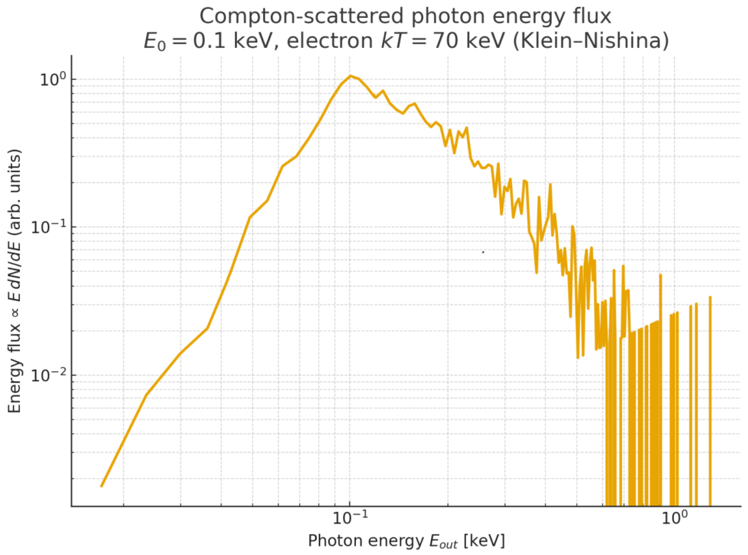
Inverse Compton emission

- Statistical approach (not only in physics):
  - We work on distributions, not single cases (particles)
  - Distributions evolve as a result of interactions

Realistic case: inverse Compton emission

- Spectra: principles and solutions
  - Single scattering





Chat GPT

Realistic case: inverse Compton emission

Single scattering: average energy shift and dispersion

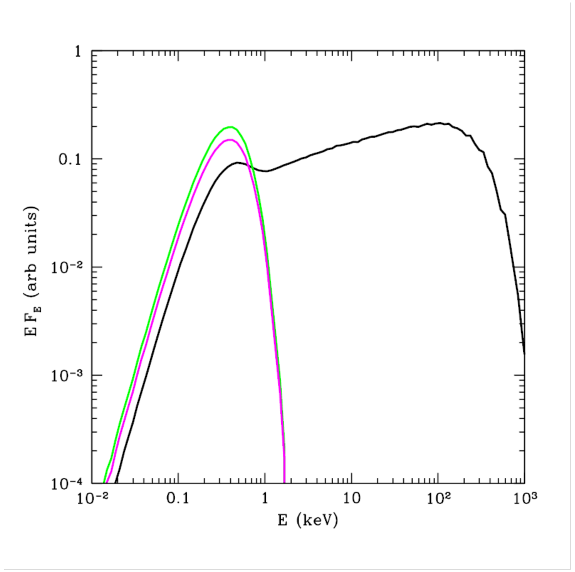
$$\frac{\langle \Delta E \rangle}{E} \approx 4\theta - \frac{E}{m_e c^2}$$

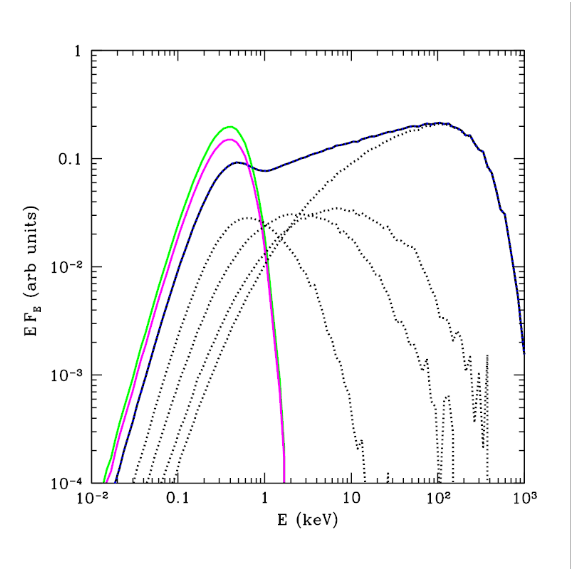
$$\frac{\langle (\Delta E)^2 \rangle}{E^2} \approx 2\theta$$

$$\theta \ll 1, E \ll m_e c^2$$

$$\theta = \frac{kT}{m_e c^2}$$

Multiple scattering





What are the parameters?

$$y = \frac{4kT_e}{m_e c^2} max(\tau, \tau^2)$$ – measures the strength of Comptonization

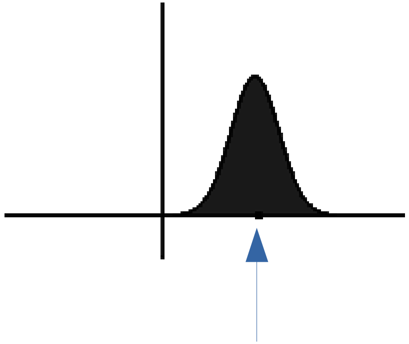
- Plasma temperature
- Optical thickness (depth) $\tau = N_e \sigma_{es} = n_e l \sigma_{es}$
- Geometry

$$\Gamma \approx \frac{9}{4} y^{-2/9} \qquad N_E \sim E^{-\Gamma}$$

Realistic case: inverse Compton emission

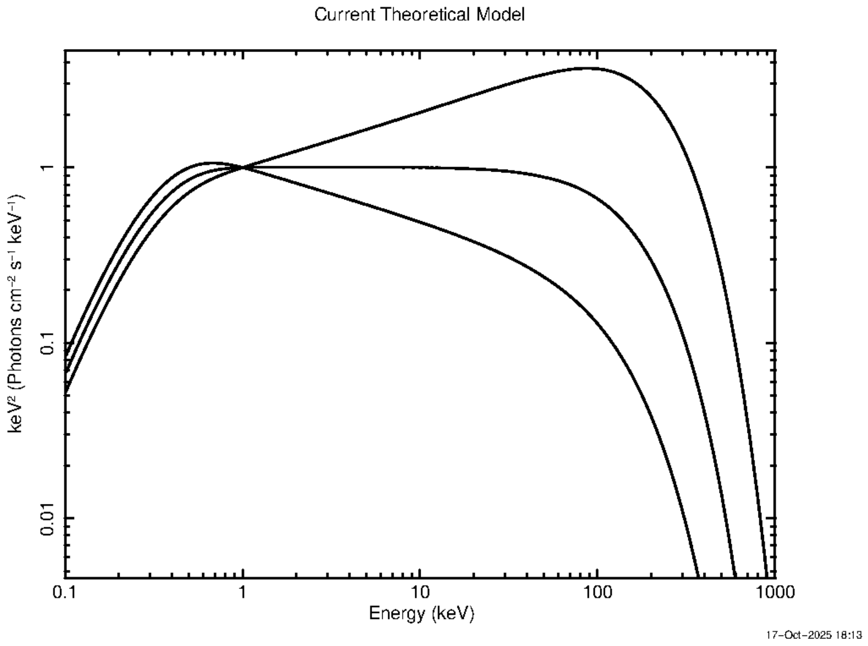
- Numerical codes for spectra
  - Kompaneets equation approach

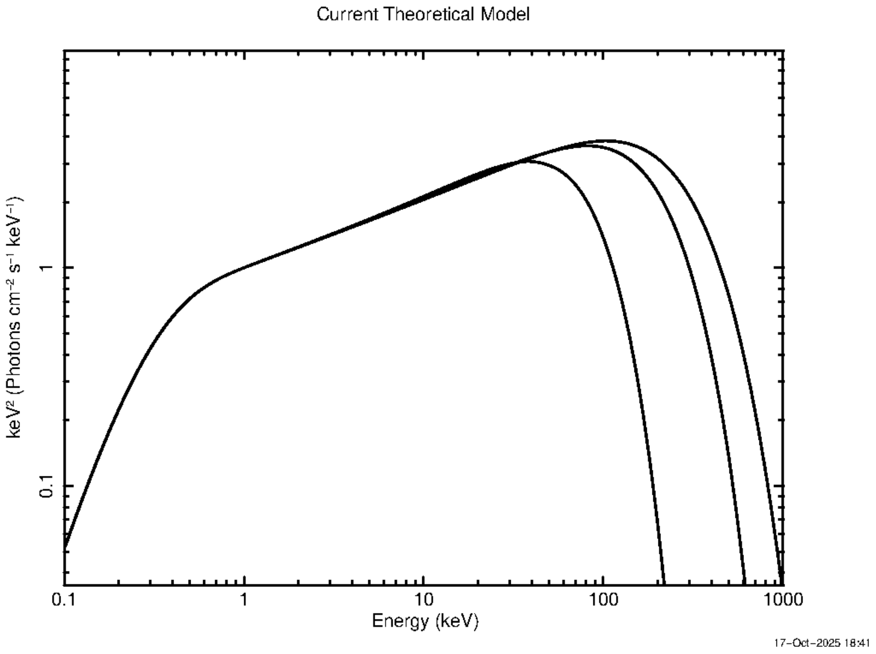
$$\frac{\partial}{\partial t} p(x,t) = -\frac{\partial}{\partial x}\left[\mu(x,t)p(x,t)\right] + \frac{\partial^2}{\partial x^2}\left[D(x,t)p(x,t)\right]$$



Numerical codes available, **nThComp** in XSPEC

Spectra from thComp code



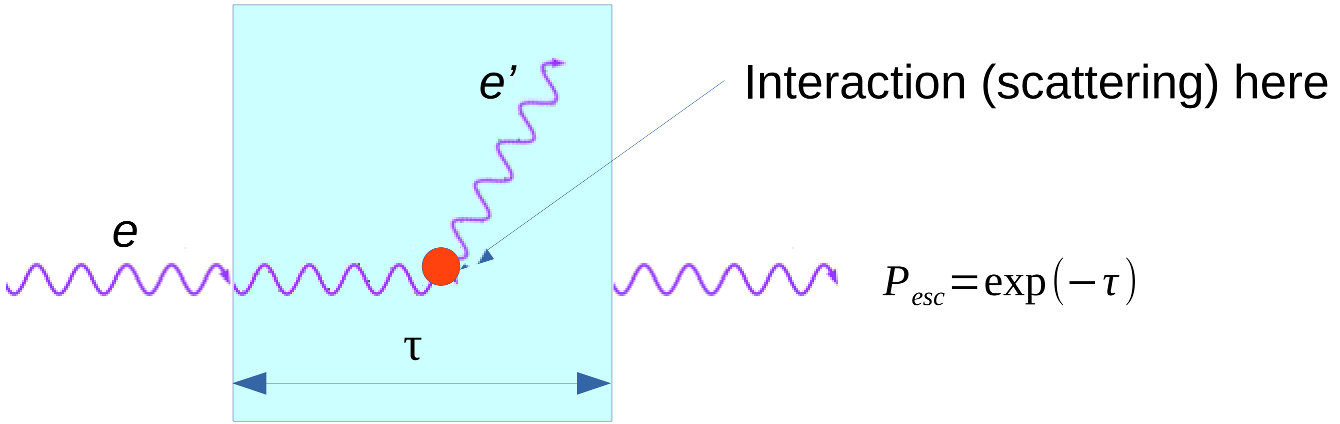


kT (keV)	Gamma	y	theta	Delta	tau
100	1,7	3,53	0,20	19,04	1,68
100	2	1,70	0,20	9,68	1,06
100	2,3	0,91	0,20	5,63	0,69

kT (keV)	Gamma	y	theta	Delta	tau
50	1,8	2,73	0,10	28,90	2,19
100	1,8	2,73	0,20	14,95	1,43
150	1,8	2,73	0,29	10,30	1,10

Realistic case: inverse Compton emission

- Numerical codes for spectra
  - Monte Carlo method



Monte Carlo method

How to simulate the distance travelled?

$$P(\tau)=\exp(-\tau)$$

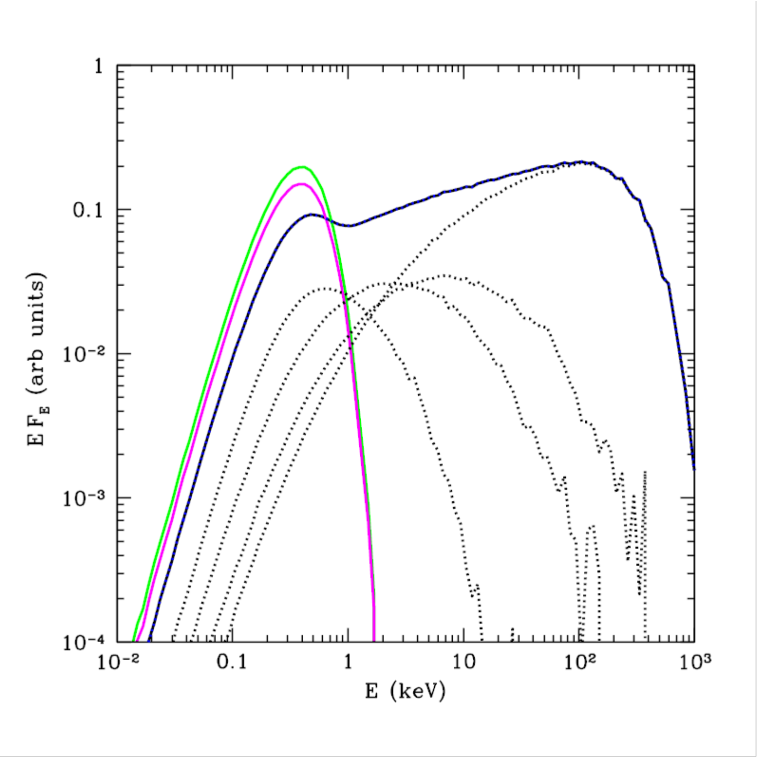
$$C(\tau)=1-\exp(-\tau)$$ cumulative distribution

$$\tau=-\ln(RND)$$ inversion of the cumulative distribution *

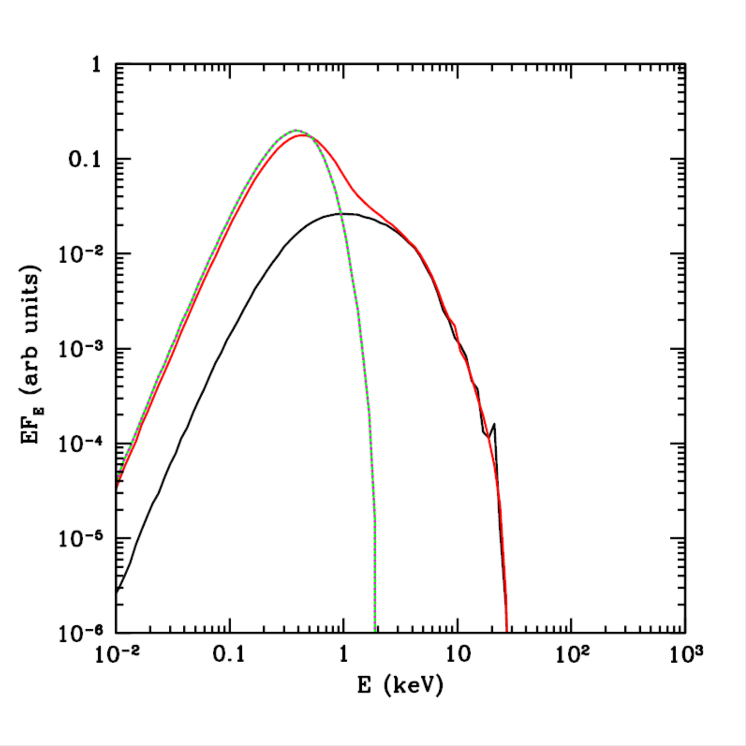
If τ > distance to the edge ==> escape

* one of the general methods

Monte Carlo simulations of spectra



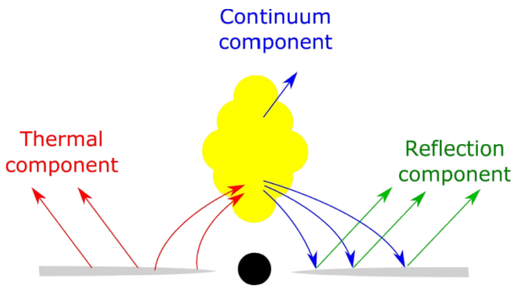
$kT_e = 100\,keV, \tau = 0.7$



$kT_e = 2\,keV, \tau = 10$

Reflected/reprocessed component

- Geometry and physics behind it
- Computational methods: Monte Carlo



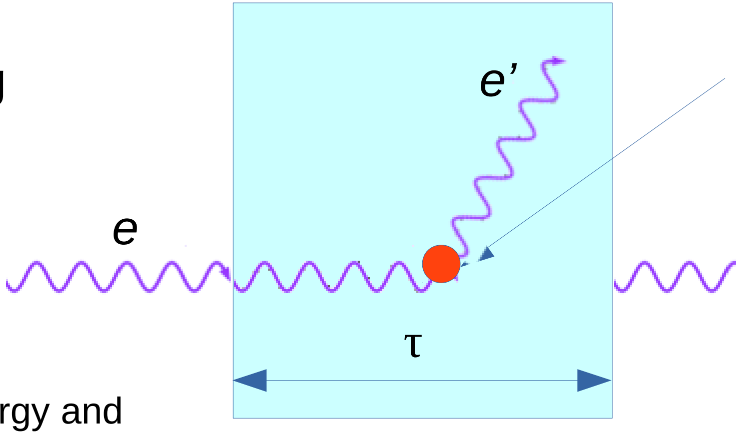
Interaction:

absorption

- photon dissapears
- fluorescence
  (above K edge)
  (Auger effect)

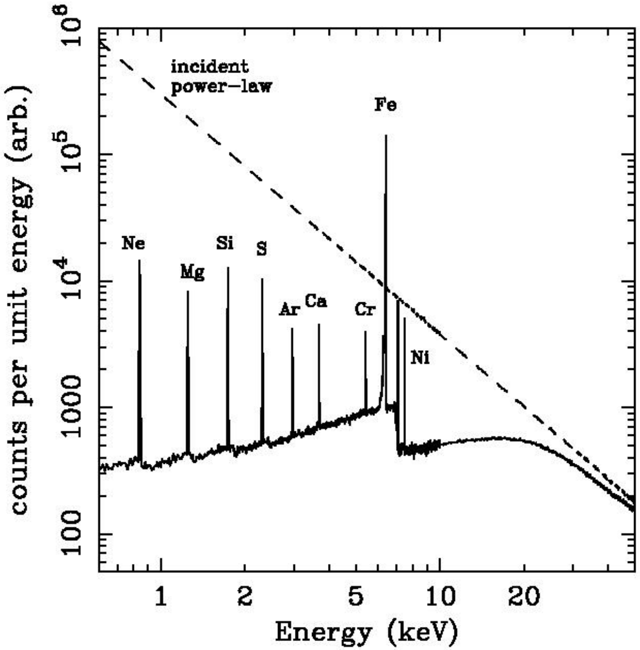
scattering

- change of energy and direction of photon

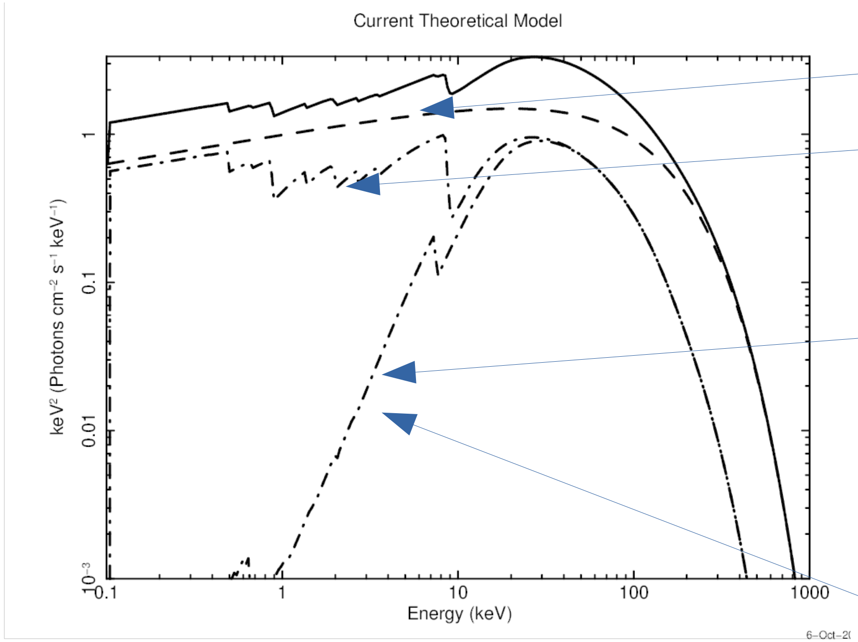


$$P_{esc} = \exp(-\tau)$$

Reflected/reprocessed component



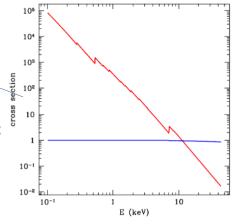
Reynolds C. S., 1996, Ph.D thesis, Univ. of Cambridge



Primary emission

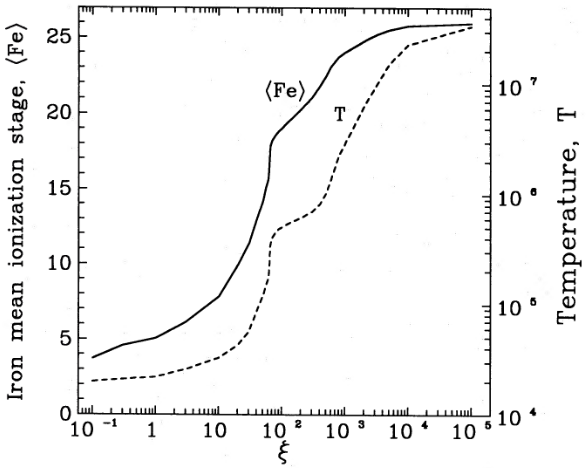
Ionized reflection

Neutral reflection

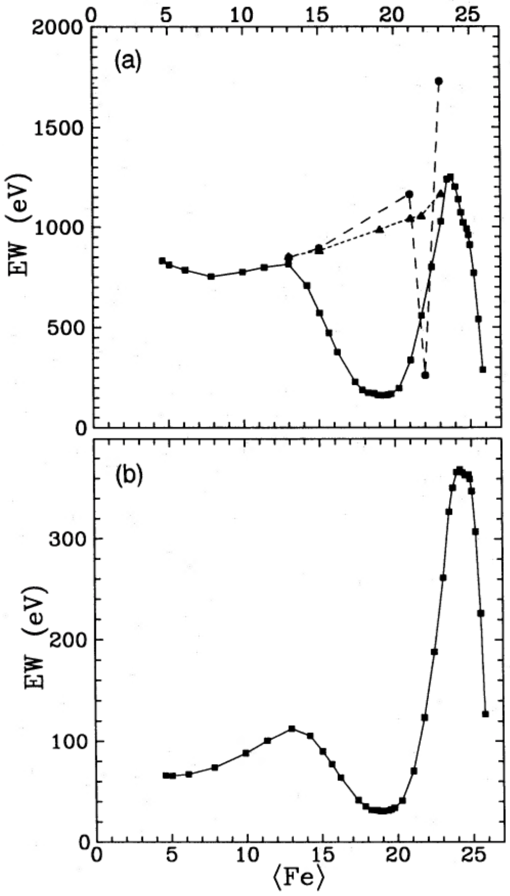


pexrav/pexriv model of Magdziarz & Zdziarski (1995, MNRAS, 273, 837)

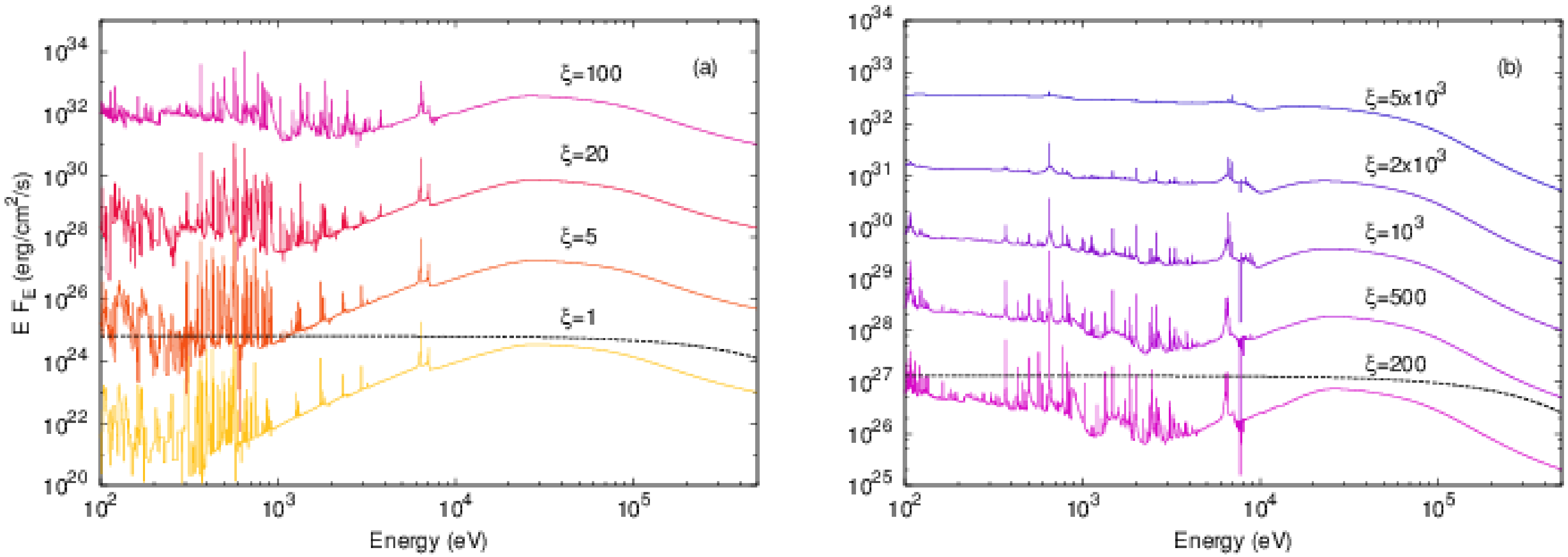
Reprocessing by ionized medium



Życki & Czerny, 1994, MNRAS, 266, 653

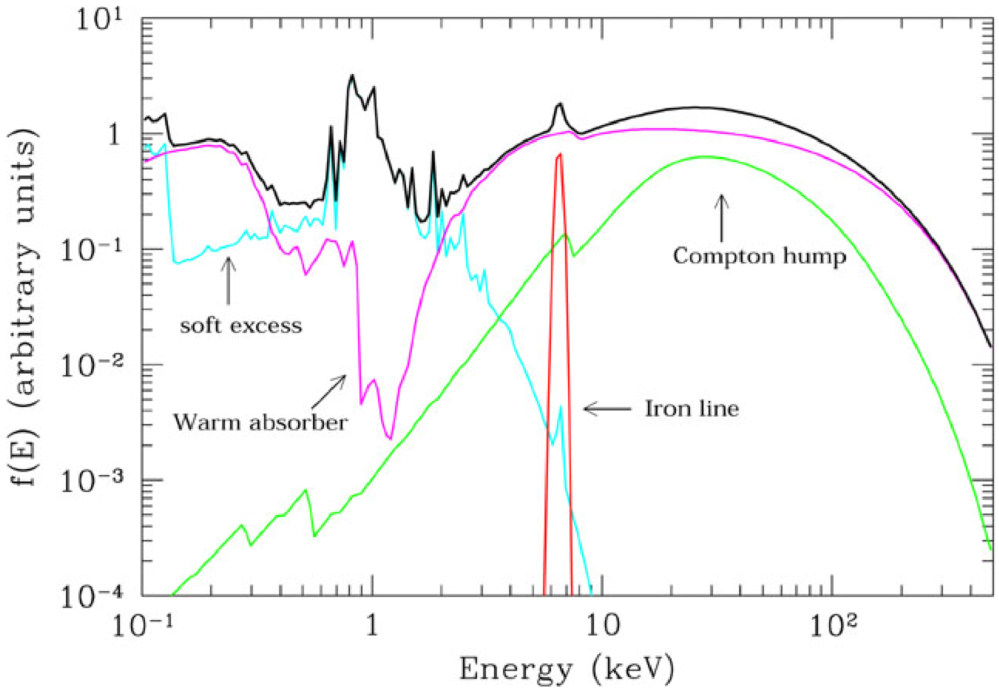


Reprocessing by ionized medium



xillver model of Garcia & Kallman, 2010, ApJ, 718, 695

Warm absorbers



G. Risaliti and M. Elvis, "A panchromatic view of AGN", in Supermassive Black Holes in the Distant Universe