Radiation and *Kinetic* processes in the corona of accreting black holes

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[1]CESR
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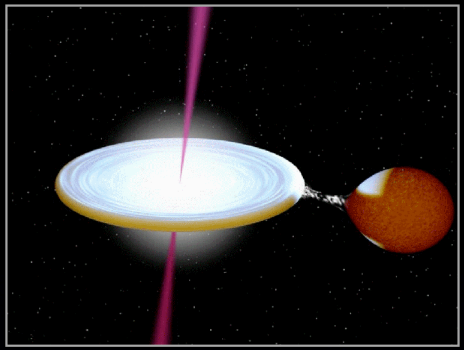
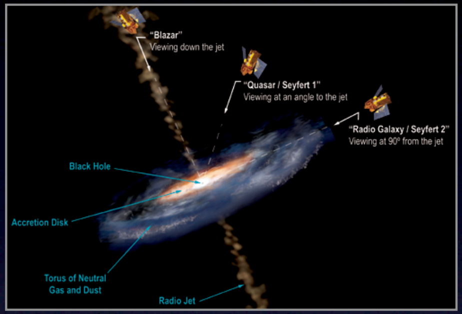
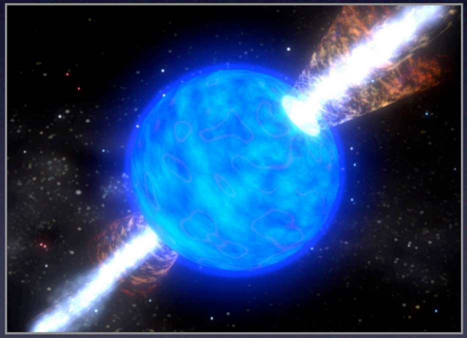
Introduction







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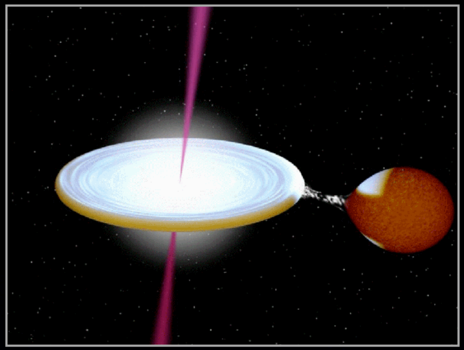
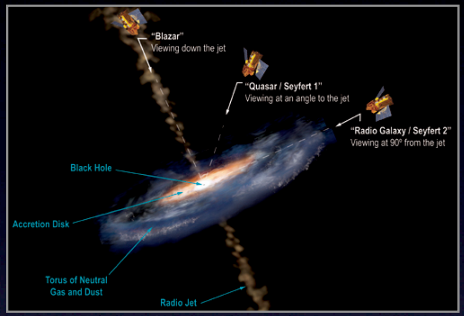
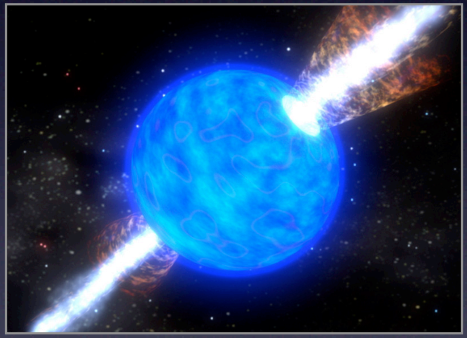
  - ✓ *Scaling laws*
  - ✓ *General microphysics*







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- ✓ Accepting systems
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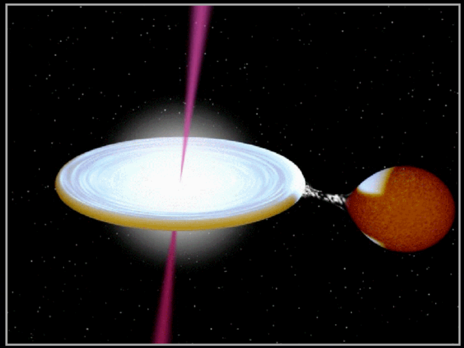
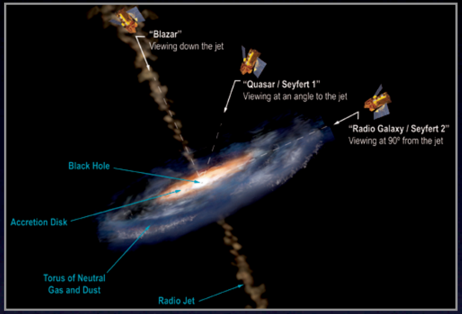
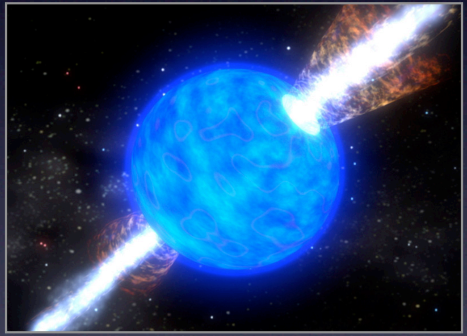
- ✓ Key issues:
  - ✓ *Radiation*
  - ✓ *Acceleration*
  - ✓ *Thermalization*
  - ✓ *Geometry/transport*







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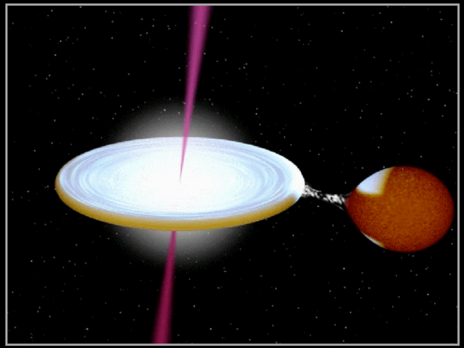
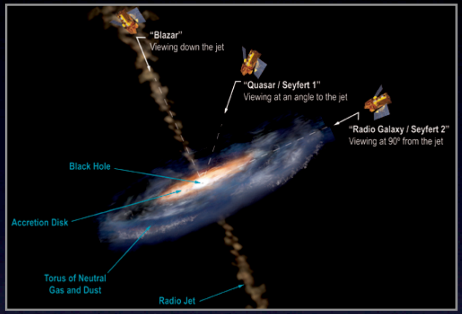
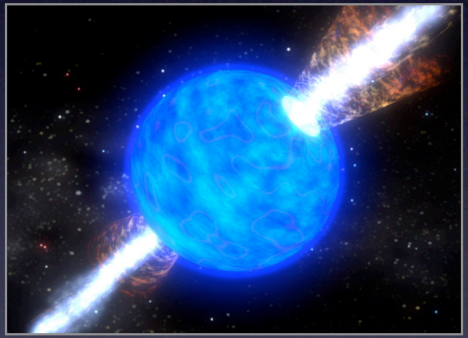
- ✓ Outline
  - ✓ Coronae of X-Ray Binaries
    - ✓ *Thermal and non thermal emission*
  - ✓ Modelling the coronal emission
    - ✓ *New code developed*
  - ✓ Constraints acceleration processes
    - ✓ *Comparison with Cyg-X1 observations*







I. A few things on X-ray binaries and their "*corona*"...

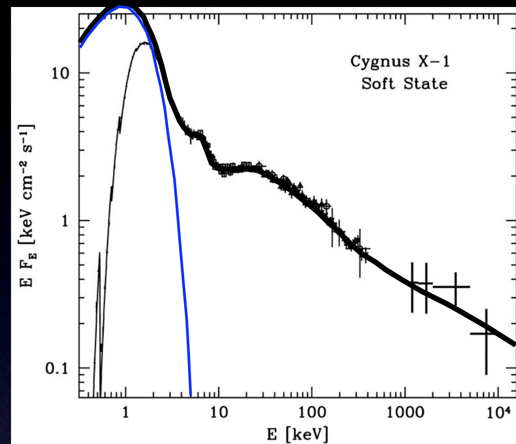
Observational constraints

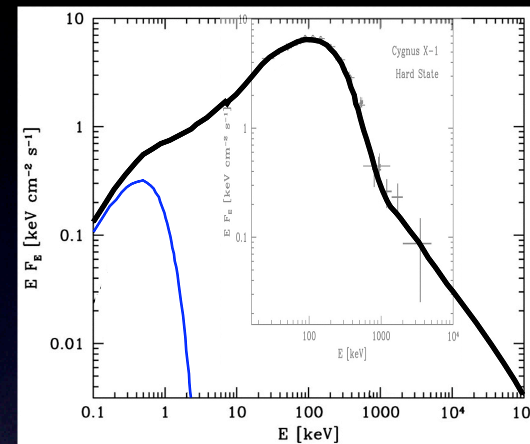
High-Soft state

Low-hard state

Observational constraints

High-Soft state





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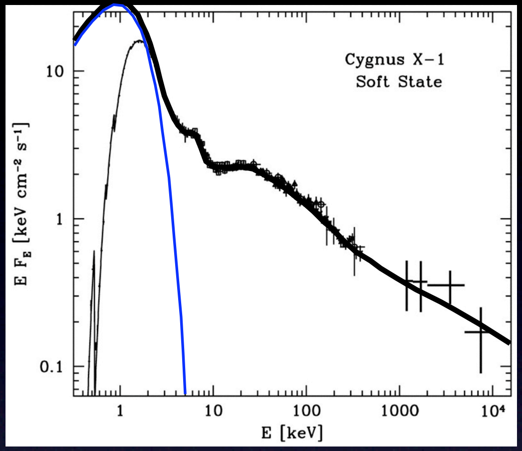

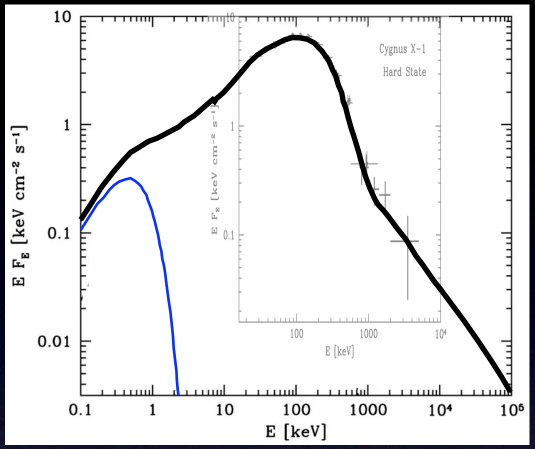

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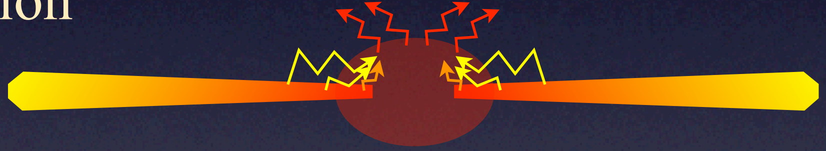

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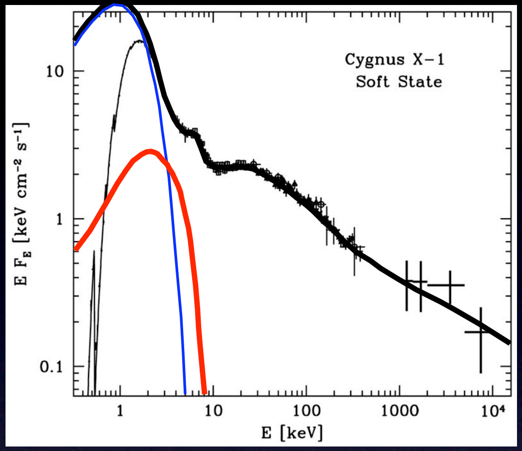

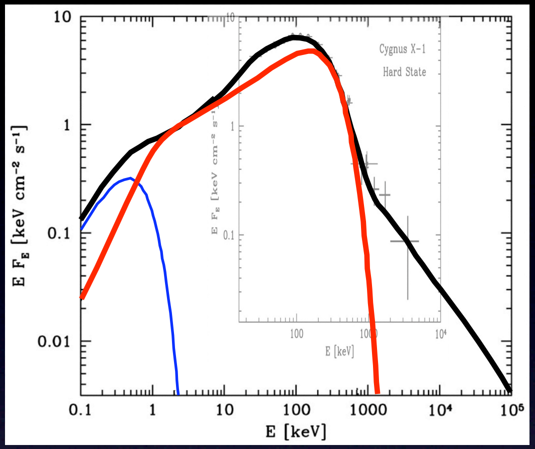

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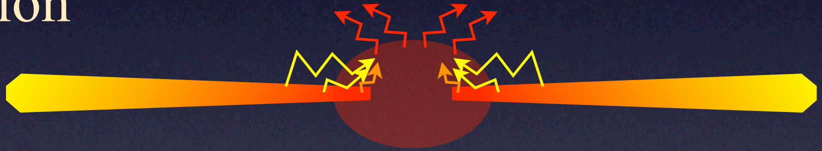

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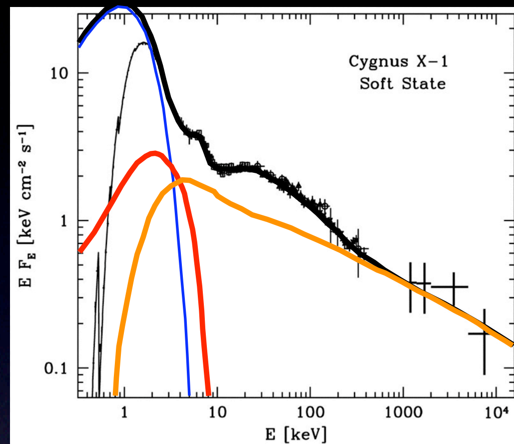

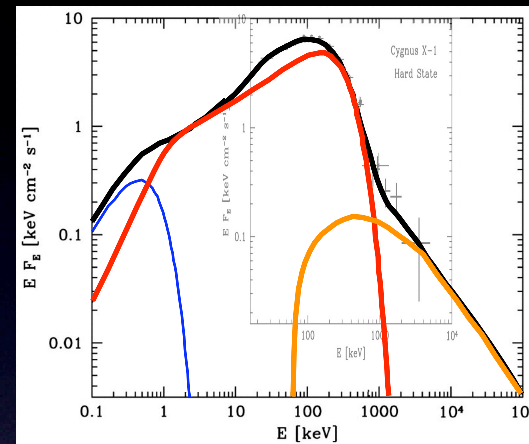

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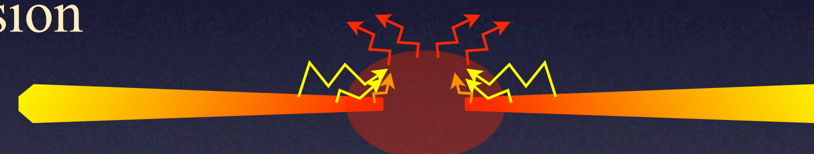

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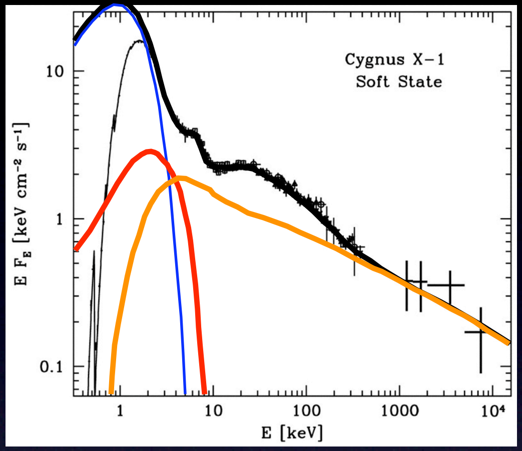

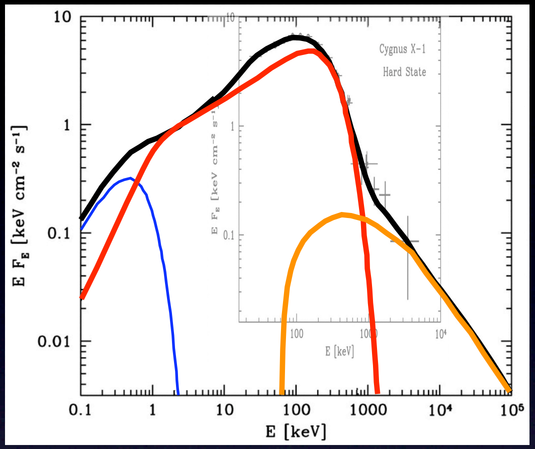

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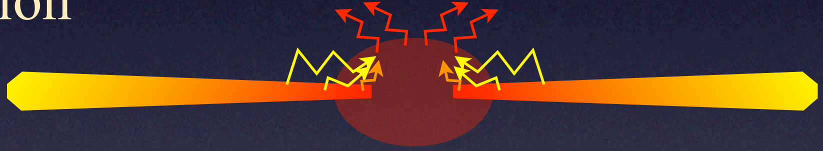

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  - ✓ Optical depth $\tau \approx$ 0.1-1
  - ✓ Size: $R \approx 10s\ R_S$ (but small covering factor)
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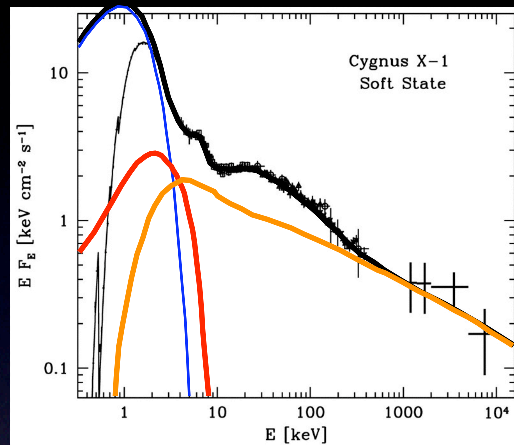

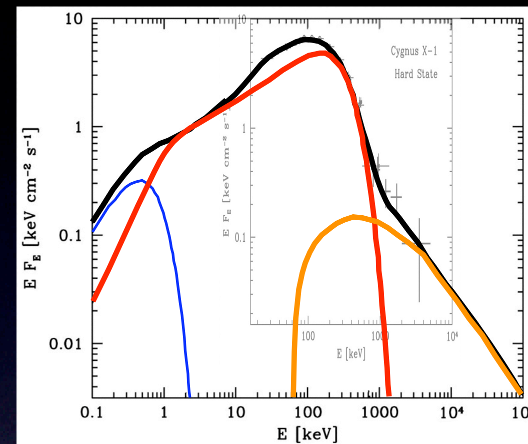

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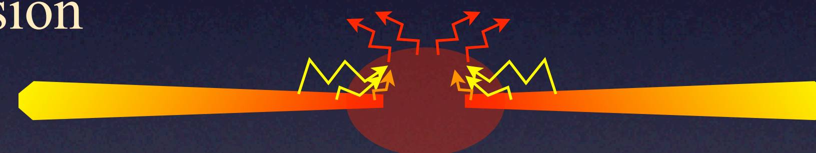

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  - ✓ Accretion power fraction: $f \lesssim 1$
- ✓ Open issues:
  - ✓ Geometry (base of the jet, spherical, slab, homogeneous, patchy...)
  - ✓ Link with accretion disc, ejection
  - ✓ Heating/acceleration (viscosity, reconnection, shocks, turbulence...)

One-zone kinetic modelling

(Belmont et al. 2008)

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  - ✓ One-zone code: global prescription for geometry

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- ✓ Highly non-linear, coupled integro-differential equations
  - ✓ Fokker-Planck terms: $\partial_t N_e(\gamma) = \partial_\gamma \left(A N_e\right) + \frac{1}{2}\partial^2_{\gamma^2}\left(D N_e\right)$
  - ✓ Integrals over distributions: $\partial_t N_e(\gamma) = \iint N_e(\gamma_0) N_\omega(\omega_0) c\sigma(\gamma_0,\omega_0;\omega) d\gamma_0 d\omega_0 - N_e(\gamma) \int N_\omega(\omega_0) c\sigma_0(\gamma,\omega_0) d\omega_0$

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- Numerically robust and general code
  - All particle energies (sub- to ultra relativistic regime)
  - All photon frequencies (radio to TeV)

Microphysics

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  - ✓ Compton scattering (KN cross section)
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- Particle-particle interactions
  - e-e and e-p Coulomb exchange
- Prescriptions for heating/acceleration…
  - Thermal *(e.g. ADAFs)*
    - Collisions with hot protons
  - Non-thermal *(reconnection, shocks...)*
    - Power-law injection
  - Stochastic *(turbulence)*
    - 2nd order Fermi diffusion

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  - ✓ Magnetic field (l_B)
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Coupled kinetic equations

- Outputs
  - Photon spectrum
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- ✓ Mono-energetic injection of high energy particles (γ=10, l_e=3, l_B=30)
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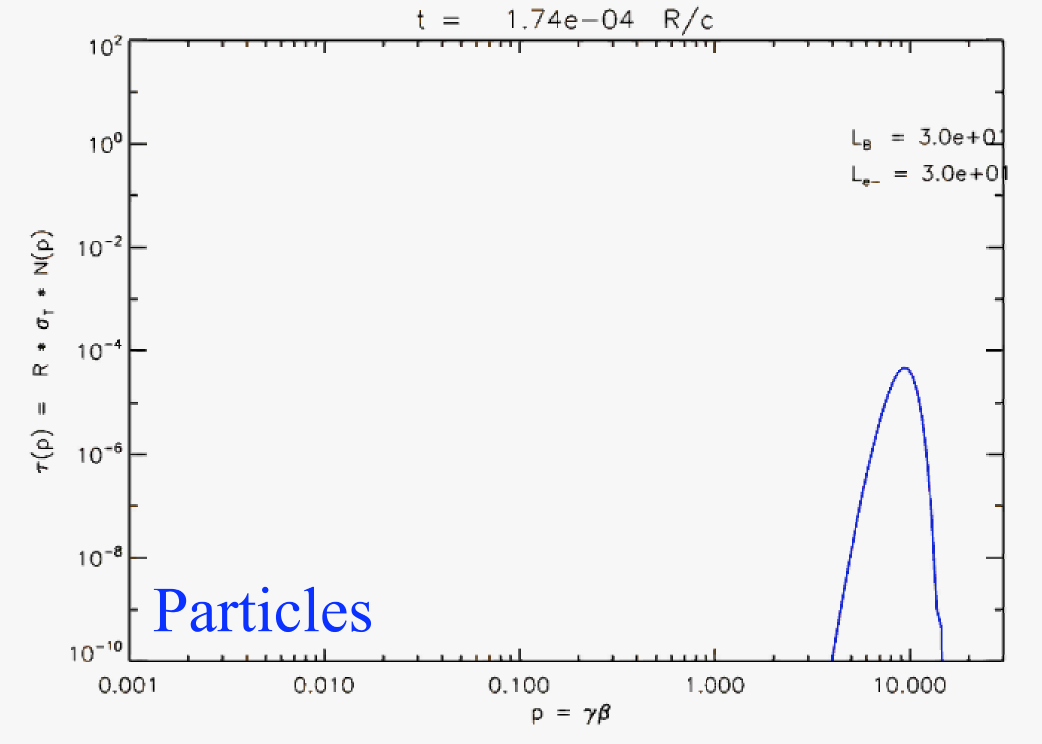

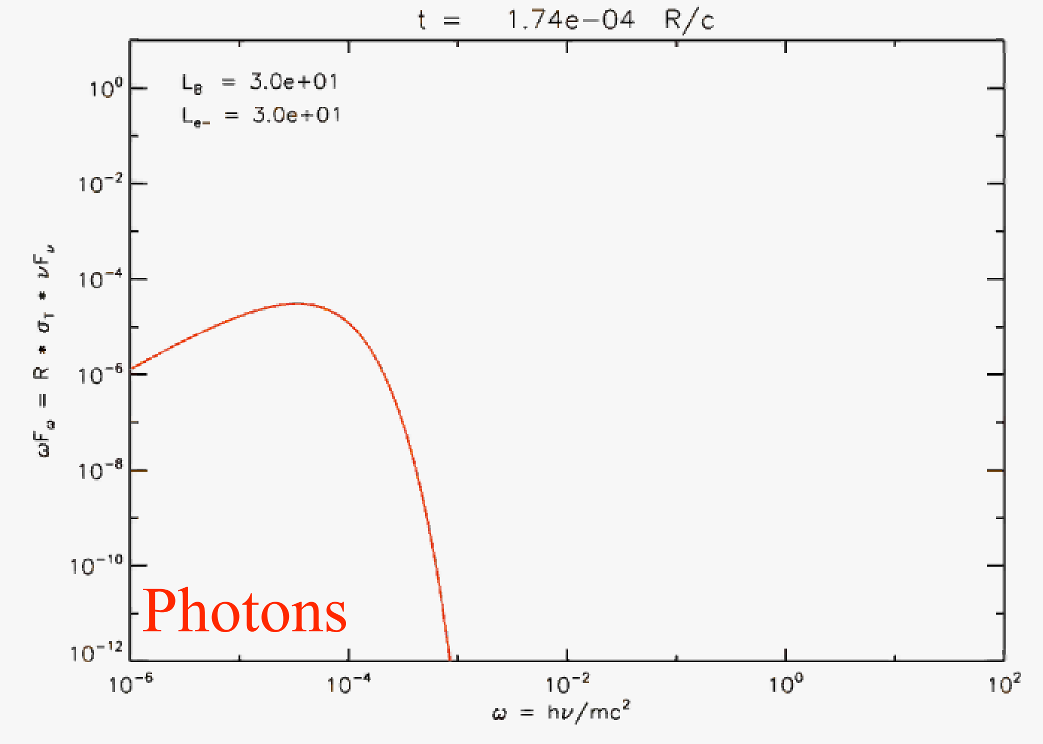

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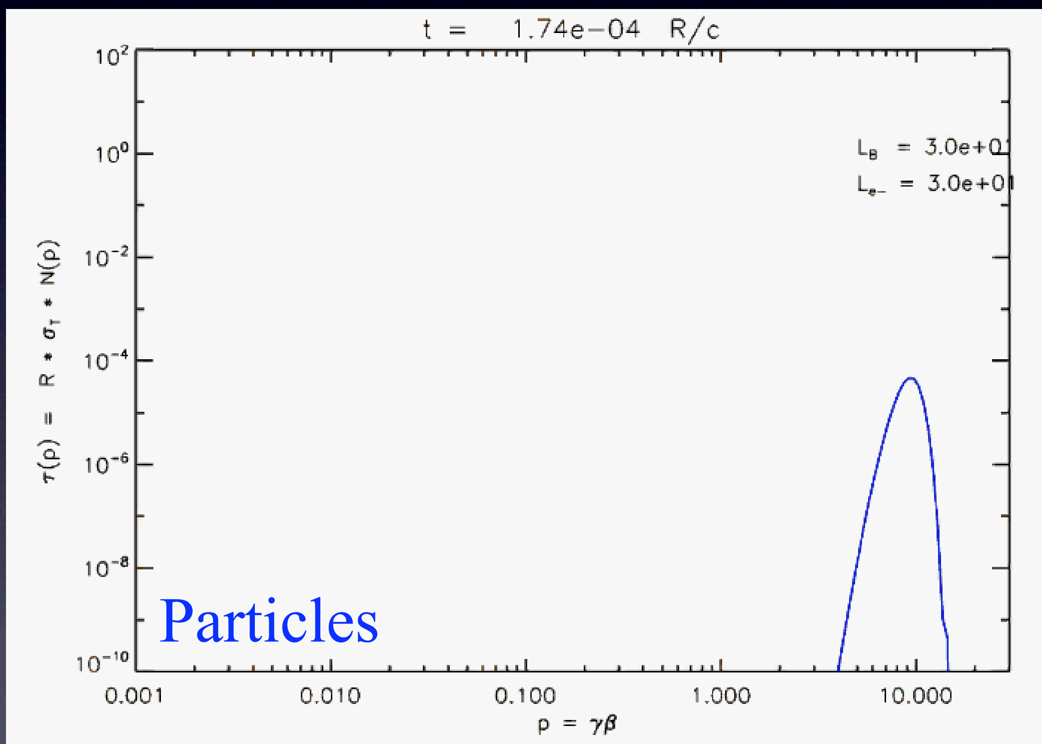

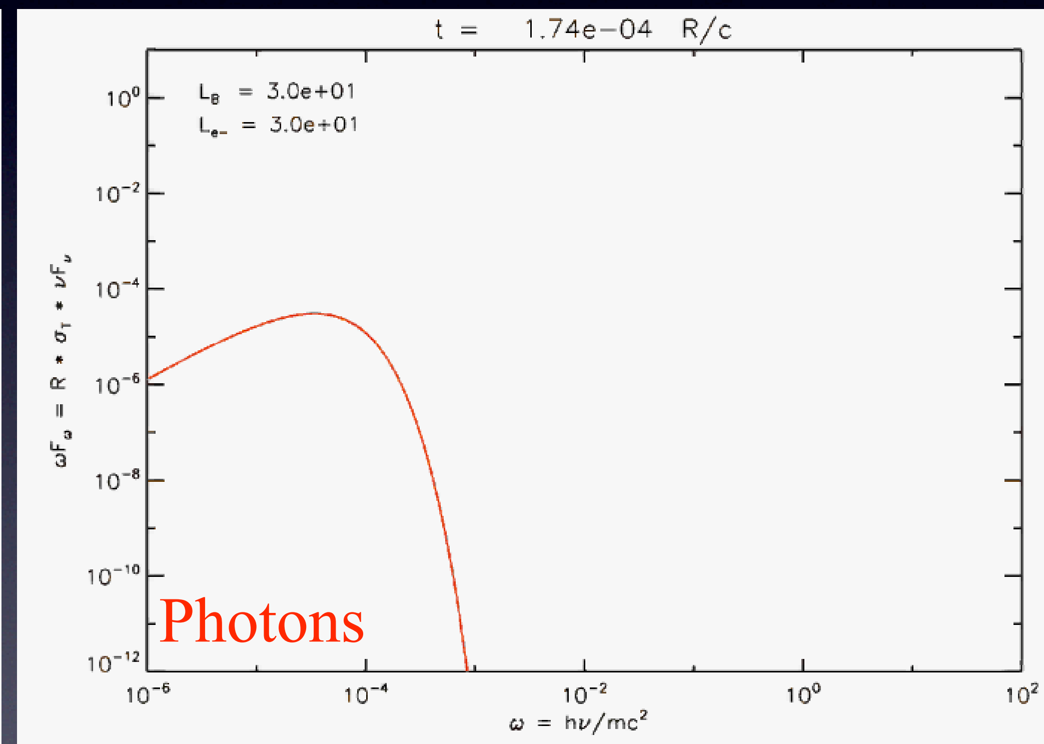

- Particle thermalization by exchange of synchrotron photons *(Ghisellini et al. 1998)*
- Quenching by Compton scattering

II. Heating and Acceleration in the corona of X-ray binaries

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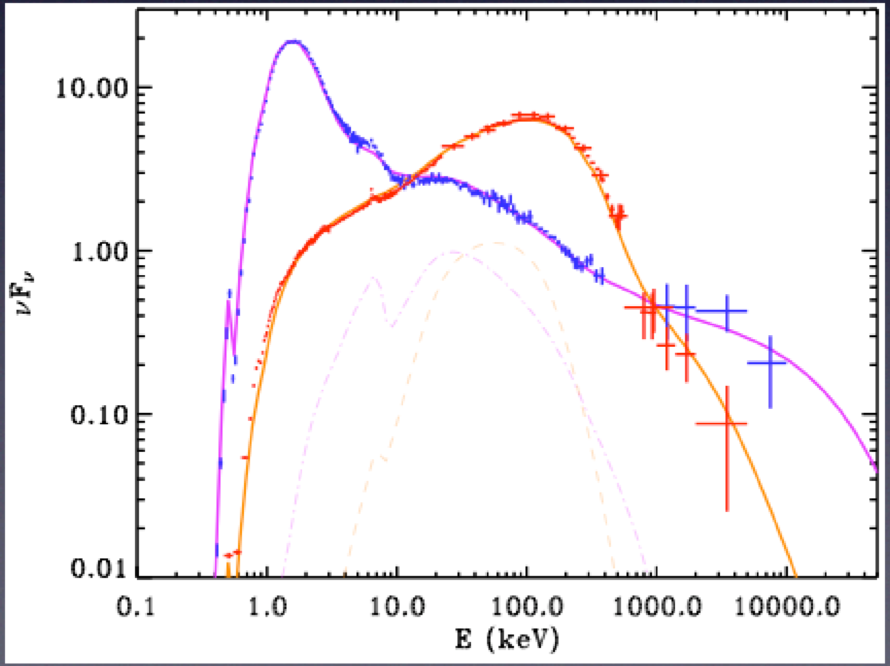

- Thermal heating ?
- Non thermal heating ?
- Stochastic acceleration ?

Thermal heating

- ✓ Two-temperature discs (ADAFs, RIAFs, ADIOS...)
- ✓ Coulomb collisions with hot protons
- ✓ One additional parameter: T_p (or l_{th})

Pure SSC model

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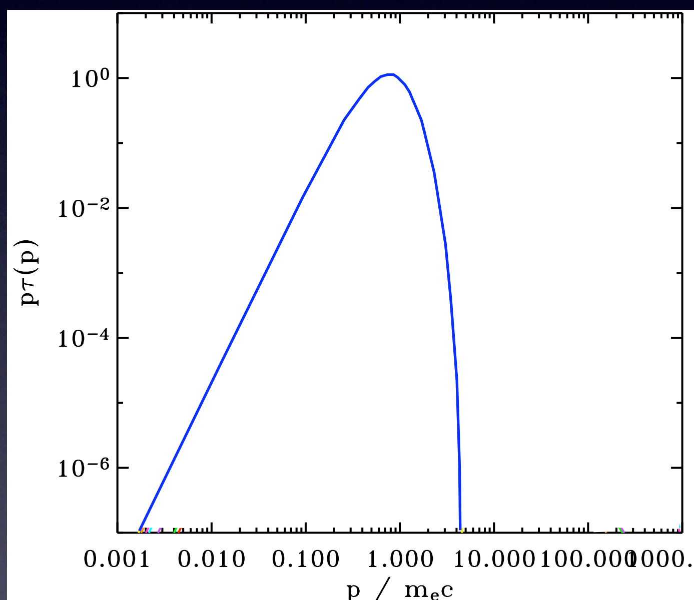

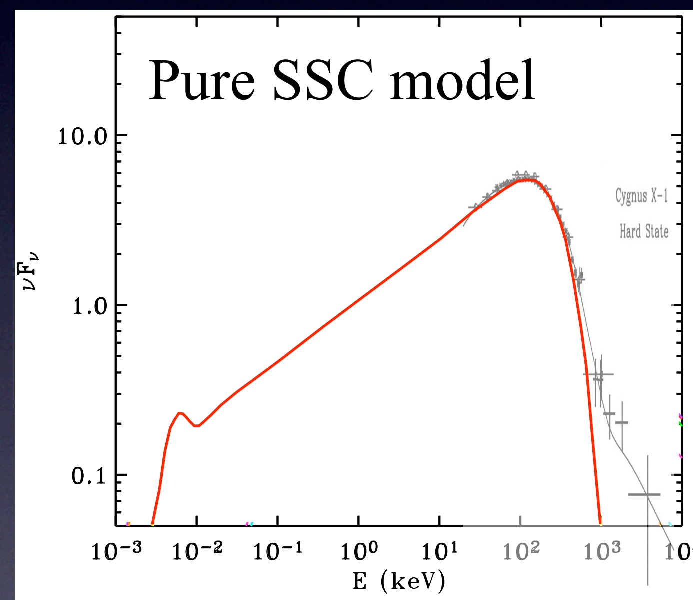

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$l_{nth} = 0$
$l_{th} = 4.75$
$l_B = 200$
$\tau = 1.45$

$k_B T_e = 83$ keV
$k_B T_p = 1.3$ MeV

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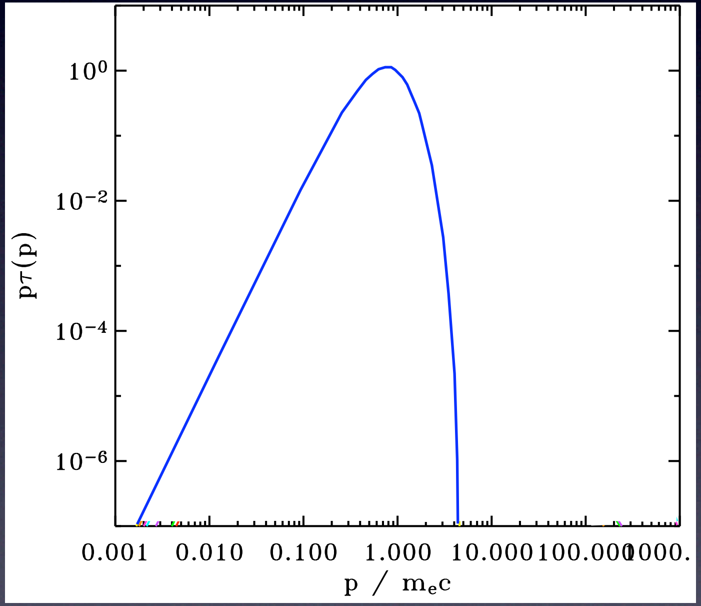

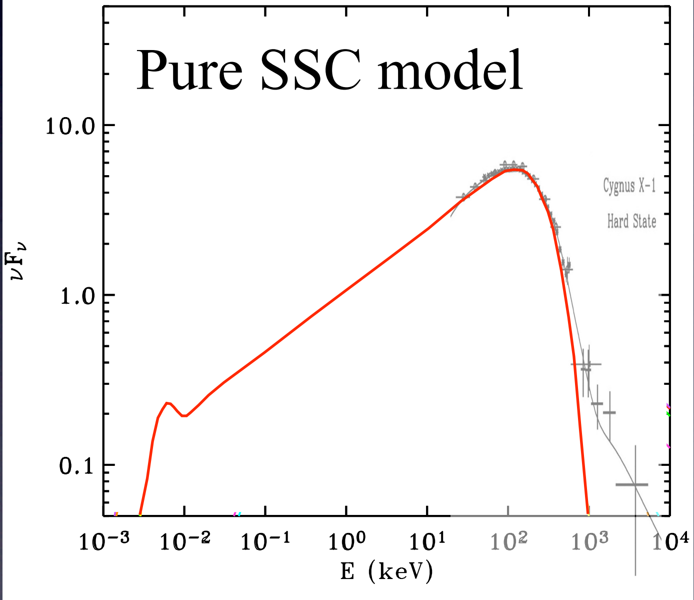

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- Thermal emission characteristic of the low-hard state
  - ➡ $T_p < 1$ MeV or $R < 3R_G$: questions the 2T models
- Missing non-thermal emission

Non thermal acceleration

- Reconnection, shocks...
- Power-law injection of high energy particles
- 4 additional parameters: γ_{min}, γ_{max}, Γ, l_{nth}

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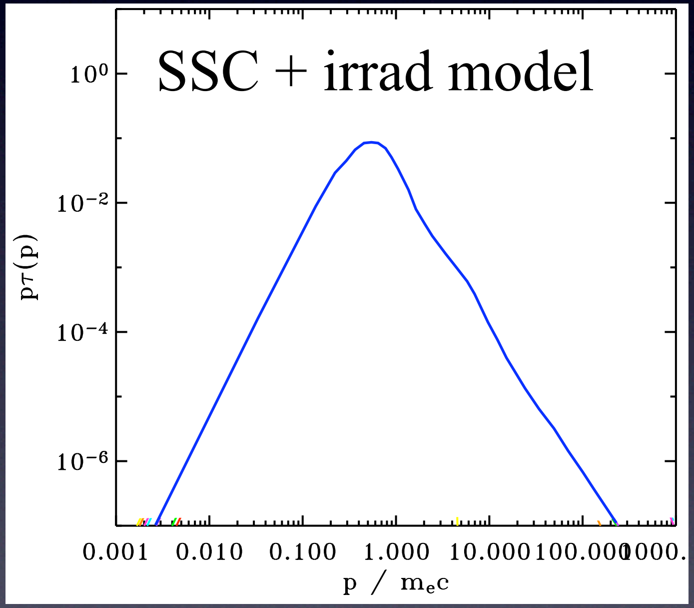

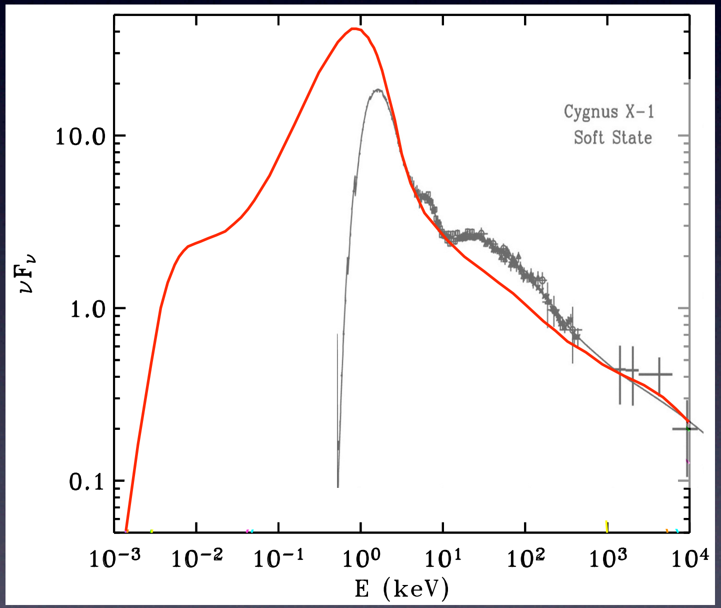

l_s = 16.7
l_{nth} = 5.50
l_{th} = 0
l_B = 17.6
τ = 0.12
Γ = 2.64
γ_{min}=1
γ_{max}=10^3

$k_B T_e$ = 48 keV

Non thermal acceleration

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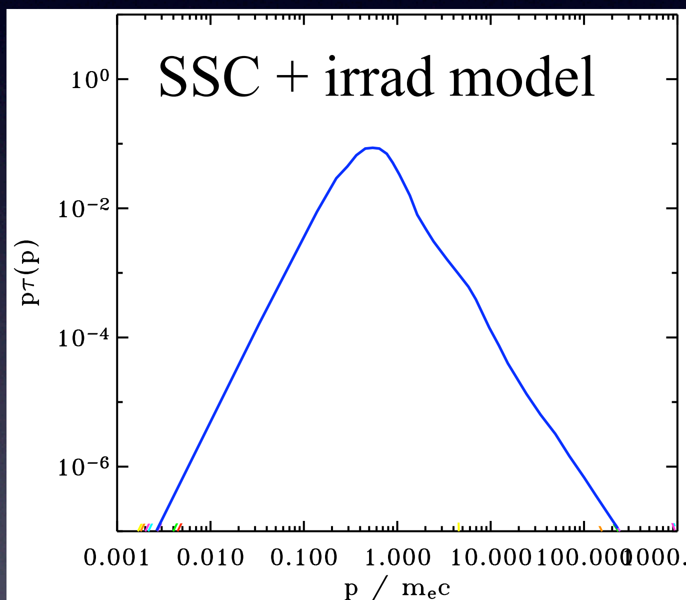
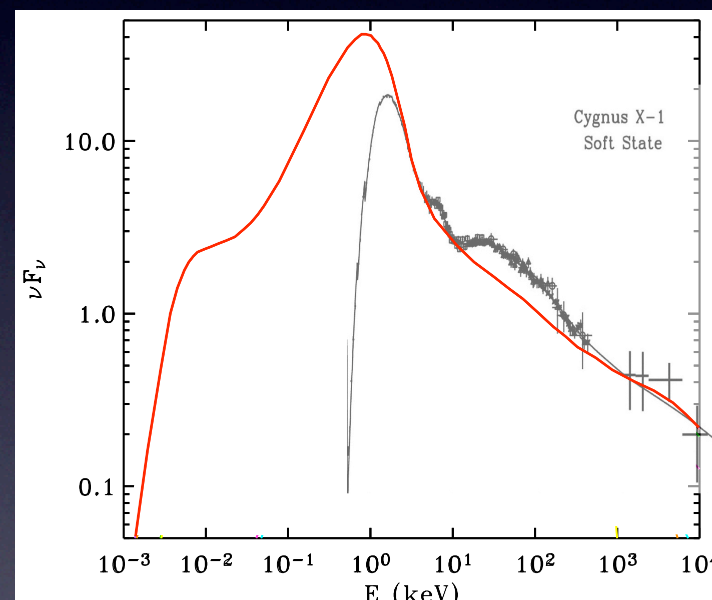
- 4 additional parameters: γ_{min}, γ_{max}, Γ, l_{nth}





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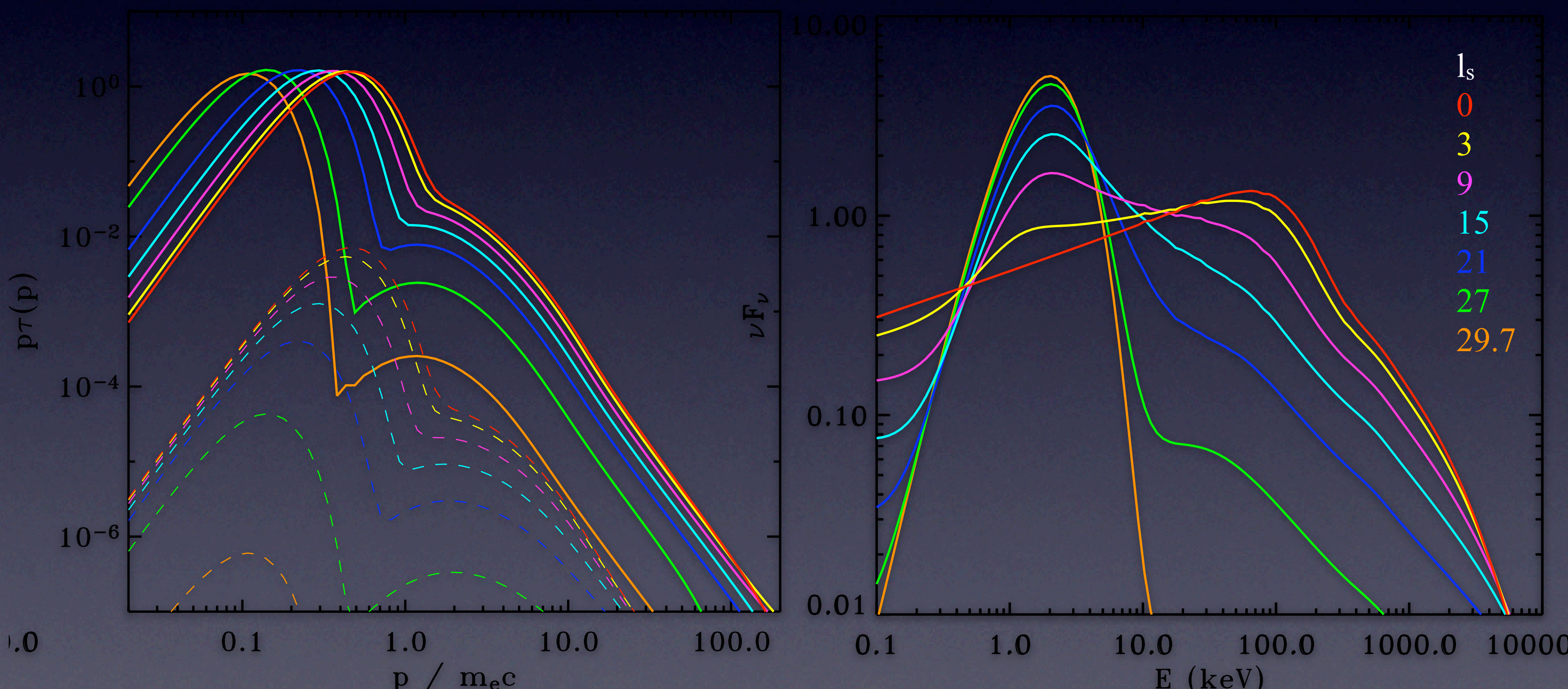
- Non thermal emission characteristic of the high-soft state
  - Constraints on the injection slope Γ
  - No need for additional thermal heating

Non thermal acceleration 2

(Malzac & Belmont 2008)

- Varying illumination
  - Motivated by expected changes in the geometry
  - External illumination limits the electron temperature
  - Competition illumination/synchrotron emission for seed photons



$l_s + l_{nth} = 30$
$l_{th} = 0$
$l_B = 10$
$\tau = 2$
$\Gamma = 3$
$\gamma_{min} = 1$
$\gamma_{max} = 10^3$

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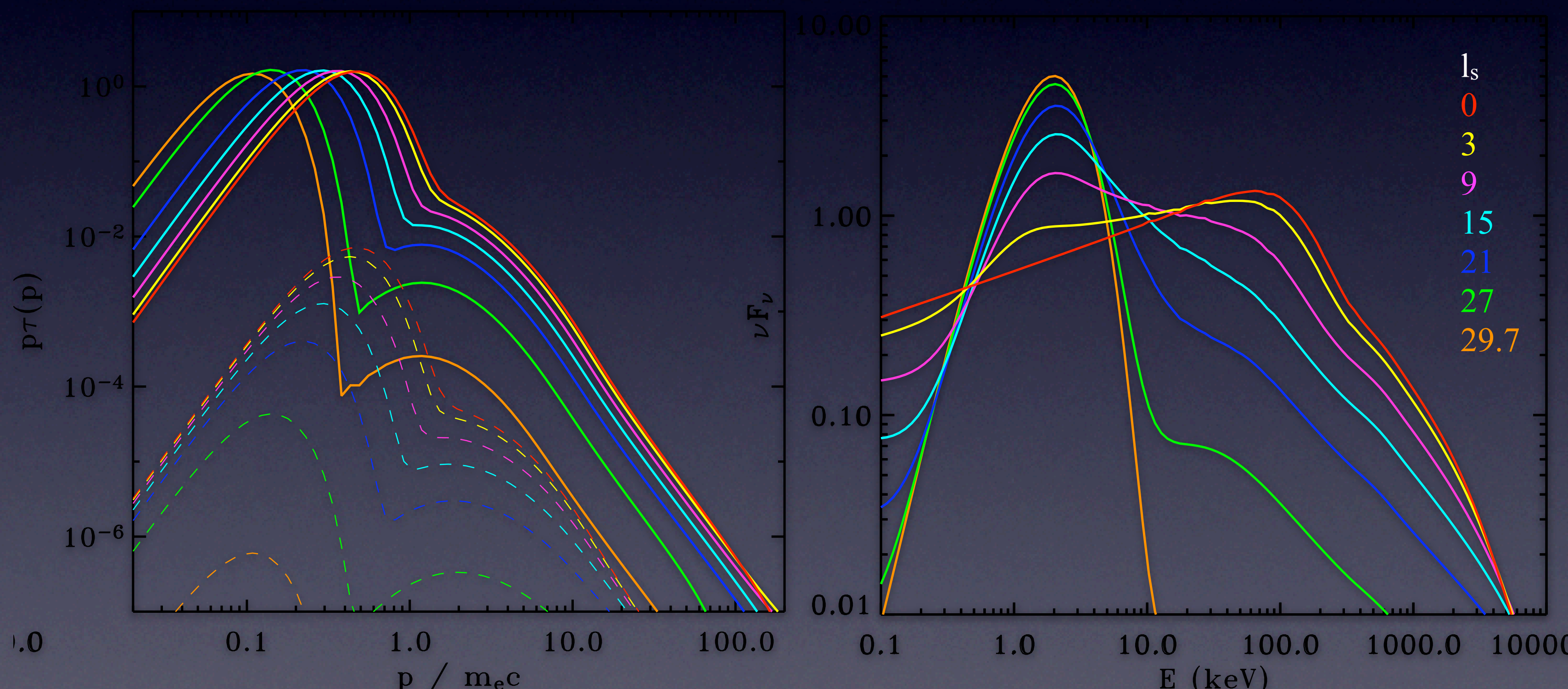
  - Competition illumination/synchrotron emission for seed photons



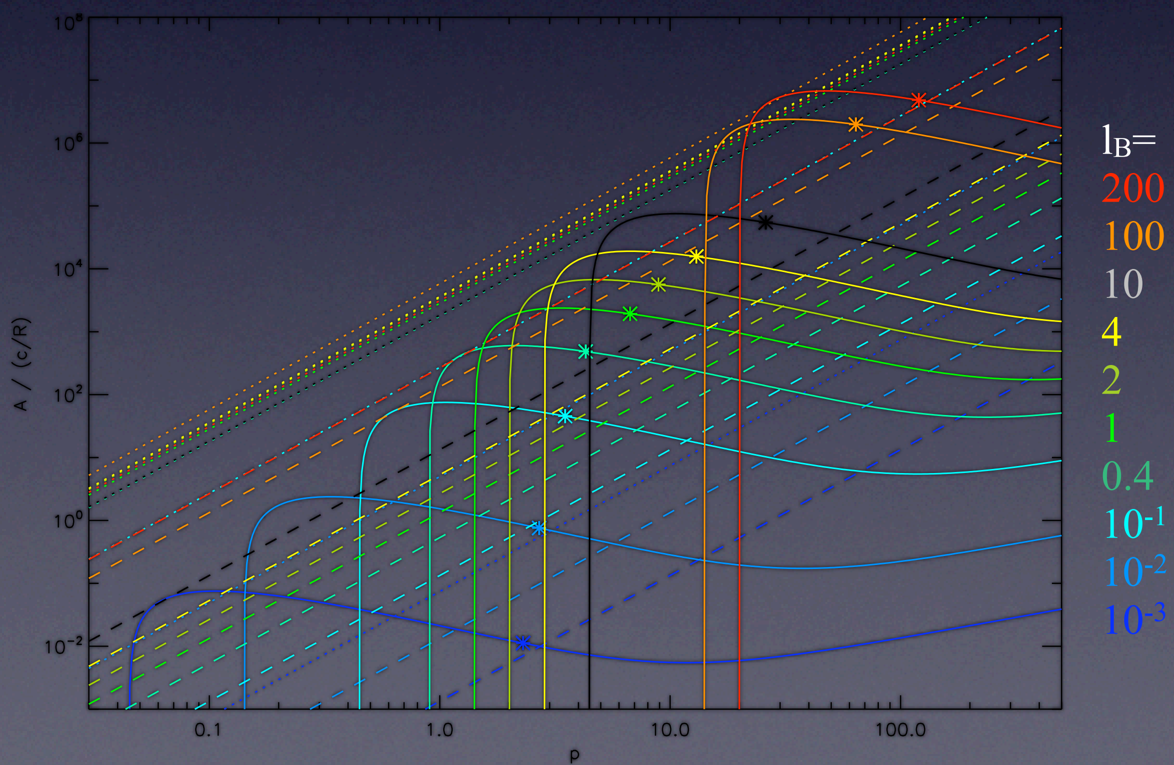
$l_s + l_{nth} = 30$
$l_{th} = 0$
$l_B = 10$
$\tau = 2$
$\Gamma = 3$
$\gamma_{min} = 1$
$\gamma_{max} = 10^3$

- Both soft and hard states obtained !
- No need for thermal heating in the thermal low-hard state

Stochastic acceleration

(Belmont et al. 2009)

- Resonant acceleration with plasma waves in a turbulent medium *(Dermer et al. 1996, Li et al. 1997)*
  - Sonic waves: dissipated at large scale
  - Alfvén waves: dissipated at small scale
- The smaller the dissipation scale, the lower energy the accelerated particles: acceleration threshold



Stochastic acceleration

(work in progress...)

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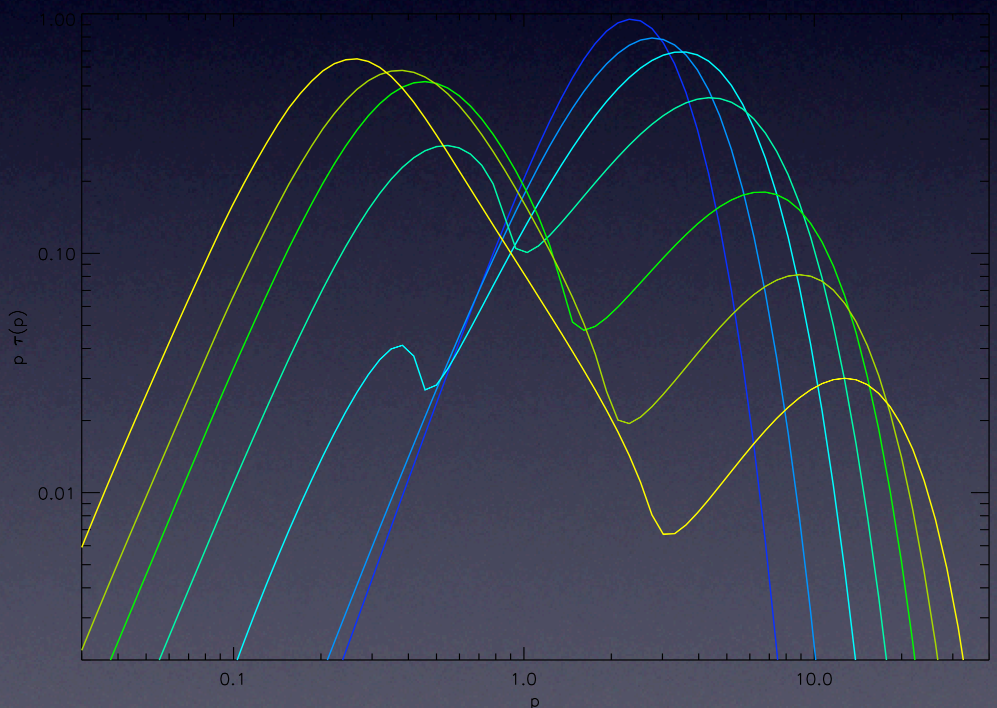
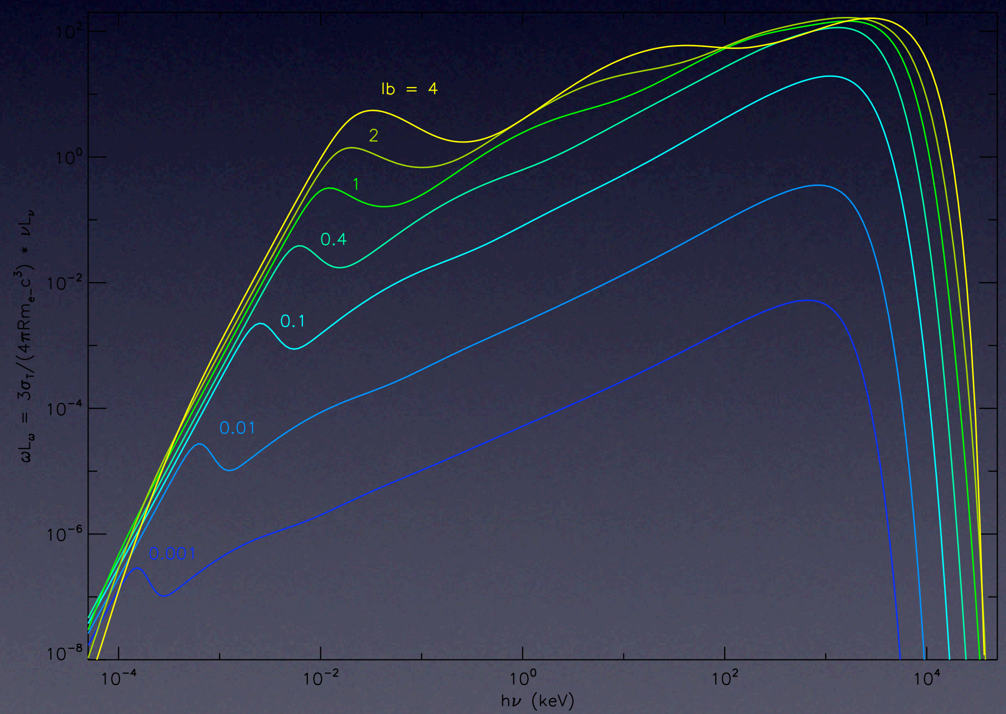
- ✓ Varying the magnetic field in pure SSC models





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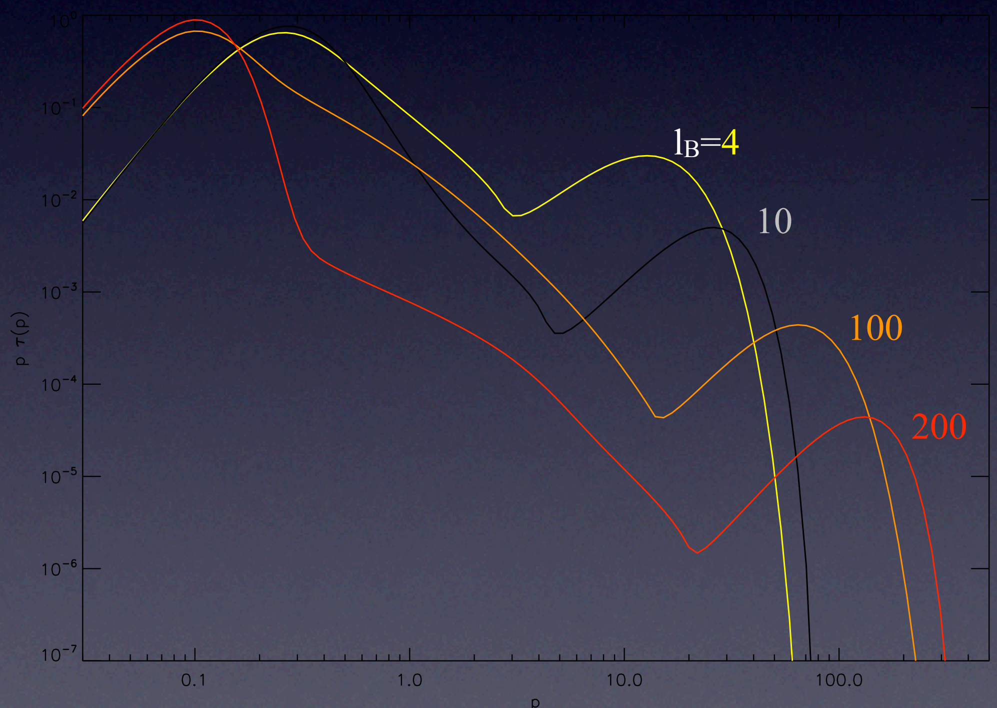

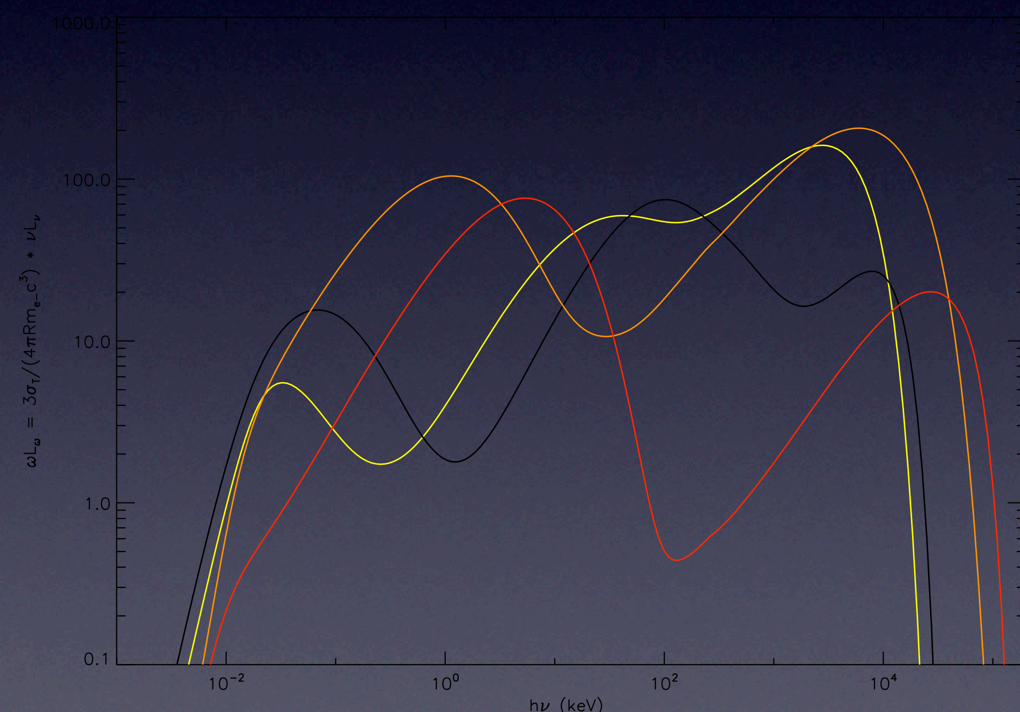

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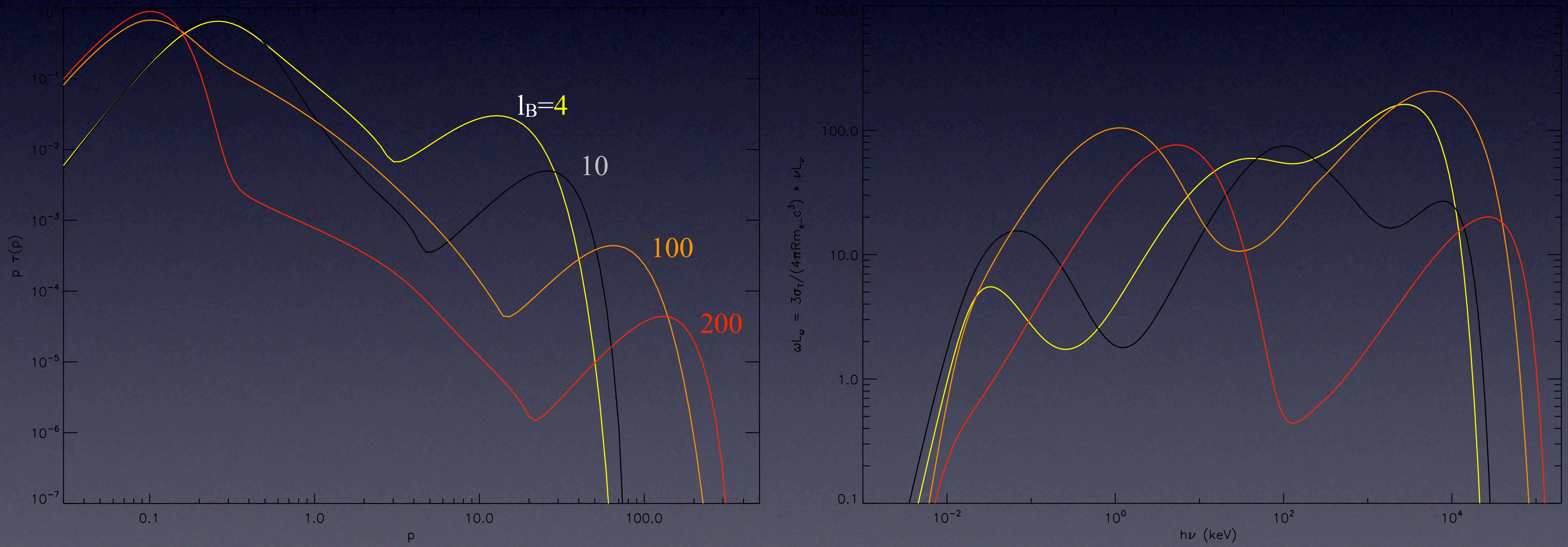

- ✓ At low B: thermal state
- ✓ At high B: non-thermal state

Summary

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  - ✓ One-zone code
  - ✓ New features:
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- Dynamical and geometrical aspects to be modelled