Jennifer Schober
Zentrum für Astronomie Heidelberg

"X-Ray Emission from Young Galaxies"
- Signatures of Cosmic Rays and Magnetic Fields

Collaborators:

Ralf Klessen (Heidelberg, Germany)
Dominik Schleicher (Göttingen, Germany)

"Chandra Workshop", July 2014

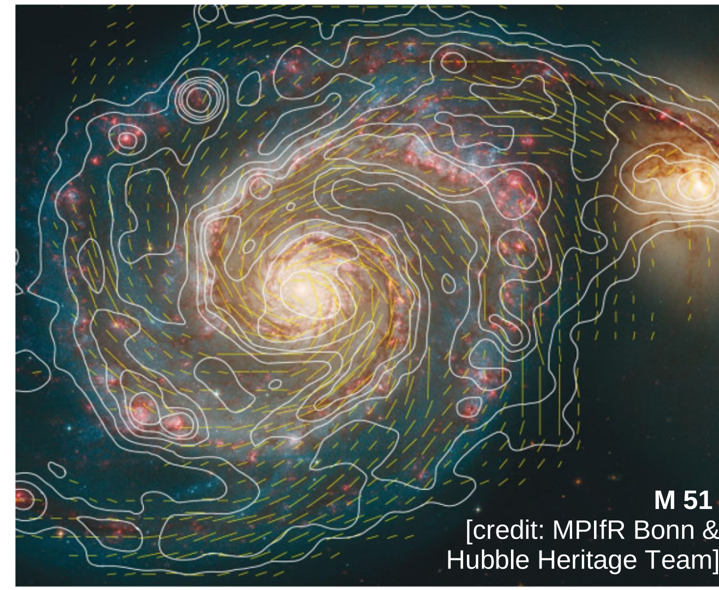

1. Introduction

Magnetic Fields in Galaxies

- (spiral) galaxies today:
  ordered + unordered field component with

  $$B \approx 10^{-5}\ \mathrm{G}$$

  (e.g. review by Beck 2011)



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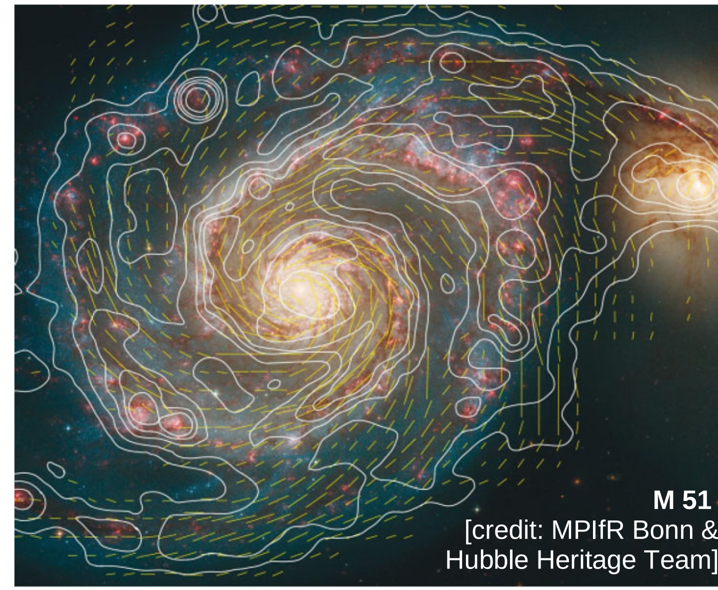
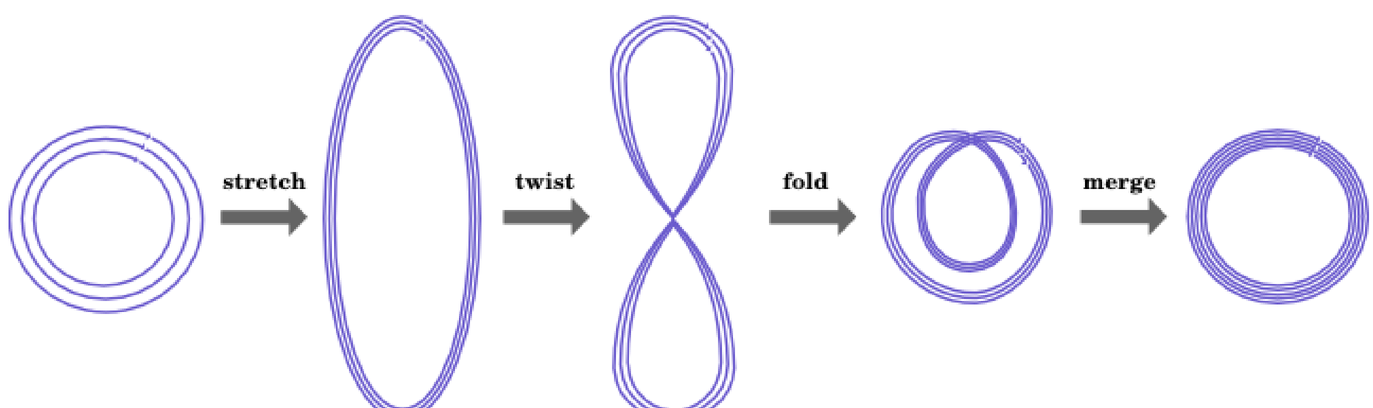


- young galaxies:
  rapid amplification of field by the turbulent dynamo (Schober et al. 2013)



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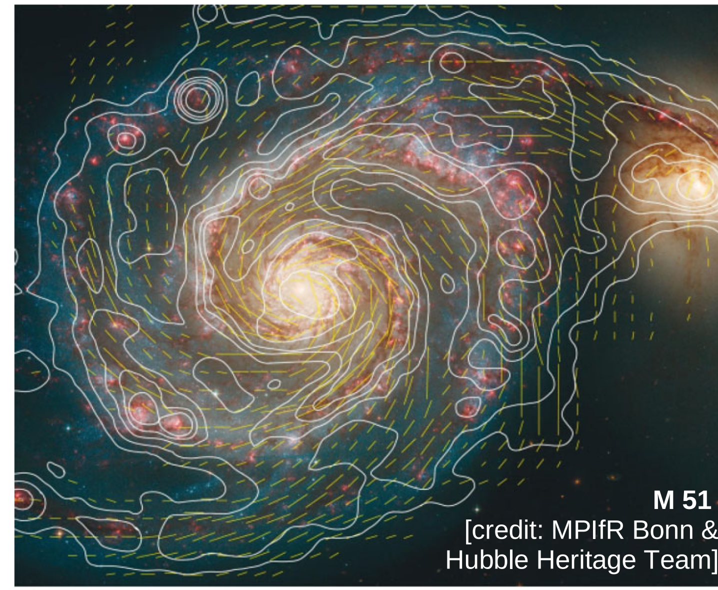
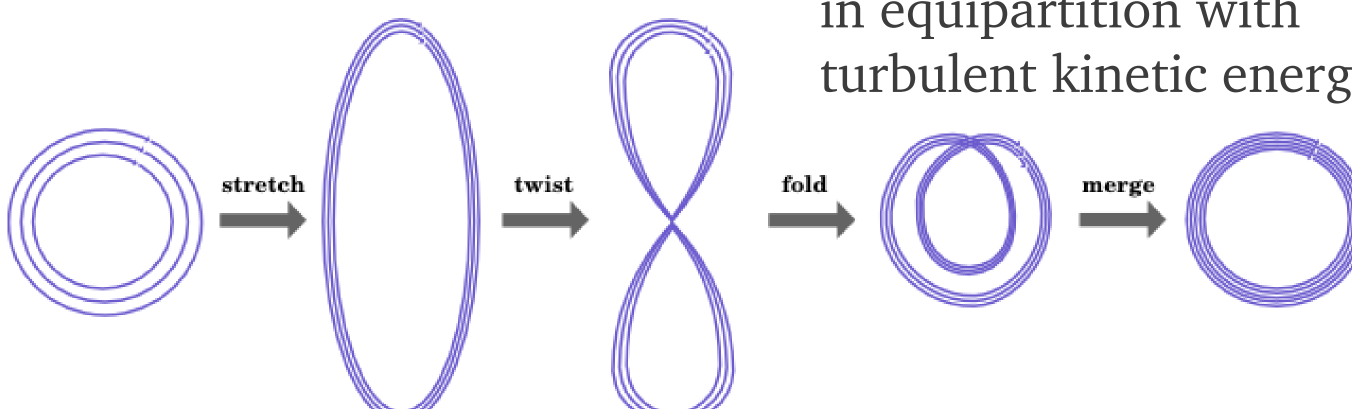


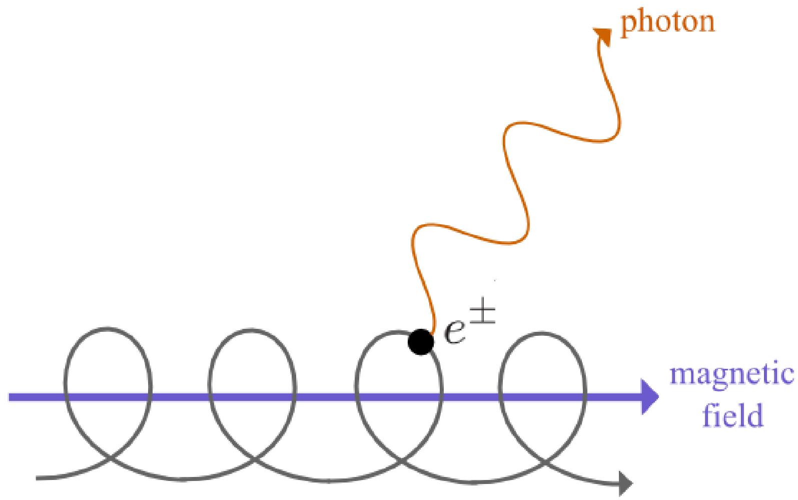
- <u>young galaxies:</u>
  rapid amplification of field by the turbulent dynamo (Schober et al. 2013)

→ magnetic energy is “always” in equipartition with turbulent kinetic energy



Observations of Local Galaxies

- synchrotron emission:



emitted power:

$$P_{\rm synch} \propto E^2 B^2$$

timescale:

$$\tau_{\rm synch} = \frac{E}{P_{\rm synch}} \propto E^{-1} B^{-2}$$

radio flux $\rightarrow$ energy density of cosmic rays $u_{\rm CR}(B)$

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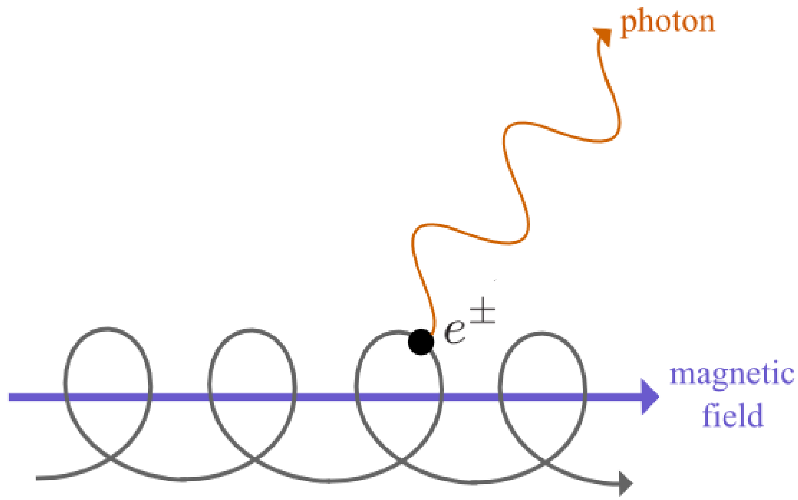

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radio flux → energy density of cosmic rays $u_{\rm CR}(B)$

- equipartition assumption:

CR energy density = magnetic energy density

$$u_{\rm CR}(B) = B^2/(8\pi)$$

→ estimate for magnetic field strength B
(see, e.g. Beck & Krause 2005)

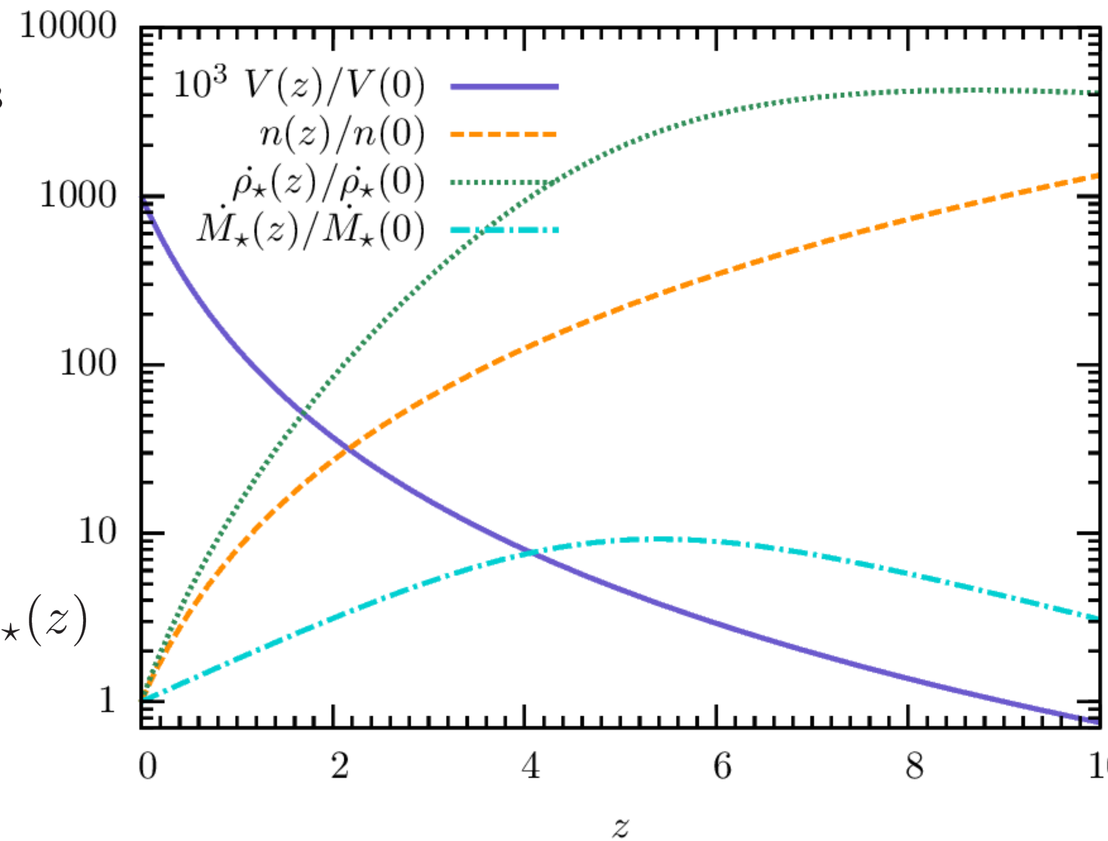
2. Energy Losses of Cosmic Ray Electrons

Galaxy Model

- volume: $V(z) \propto (1+z)^{-3}$
- density: $n(z) \propto (1+z)^3$
- star formation rate: $\dot{M}_\star(z) = V(z)\ \dot{\rho}_\star(z)$
- star formation rate density:

$$\dot{\rho}_\star(z) \propto \frac{\kappa_2\ \exp[\kappa_1(z - z_\mathrm{m})]}{\kappa_2 - \kappa_1 + \kappa_1\ \exp[\kappa_2\ (z - z_\mathrm{m})]}(1+z)^3$$

(Hernquist & Springel 2002)



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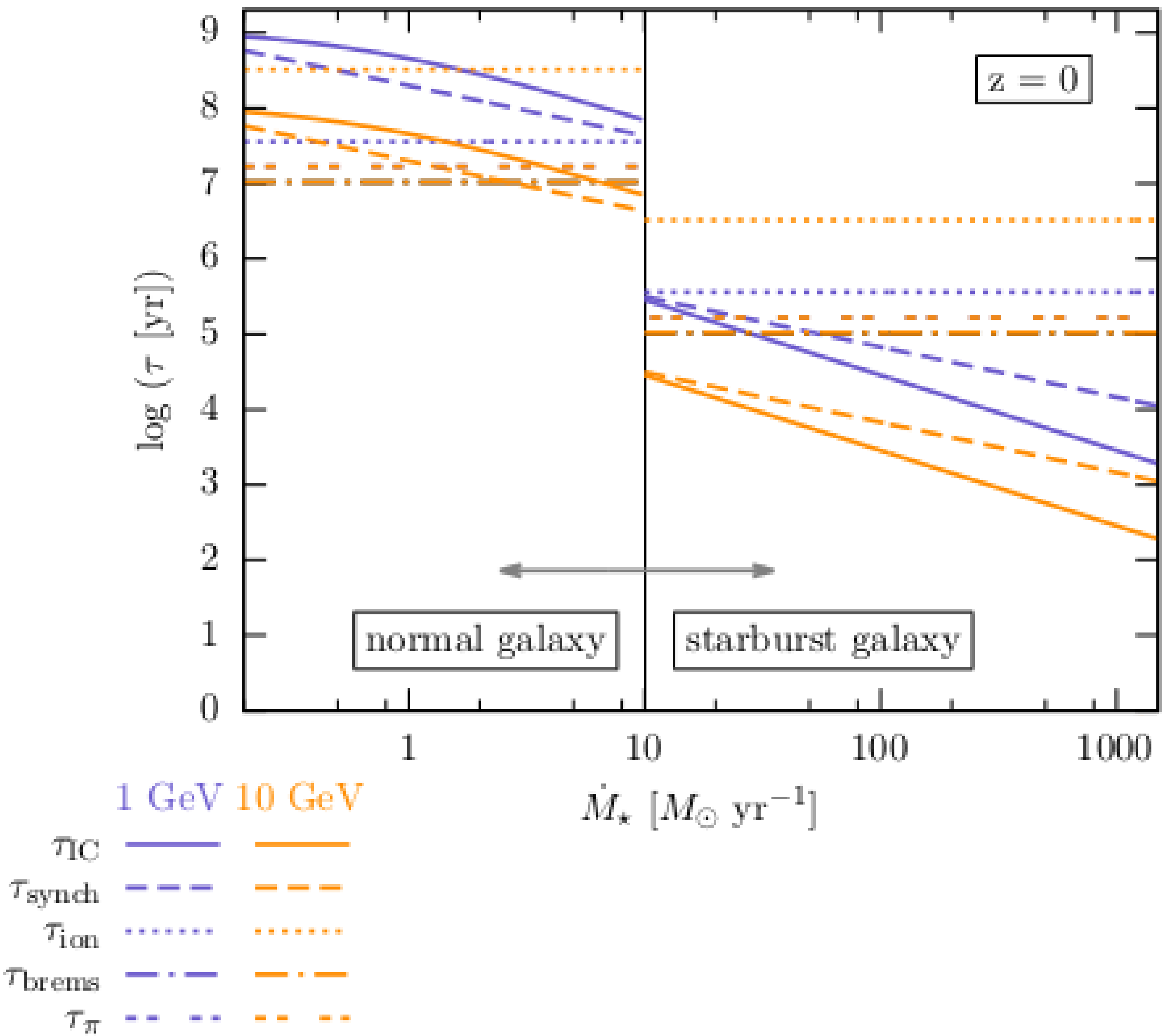
Energy Losses of CR Electrons



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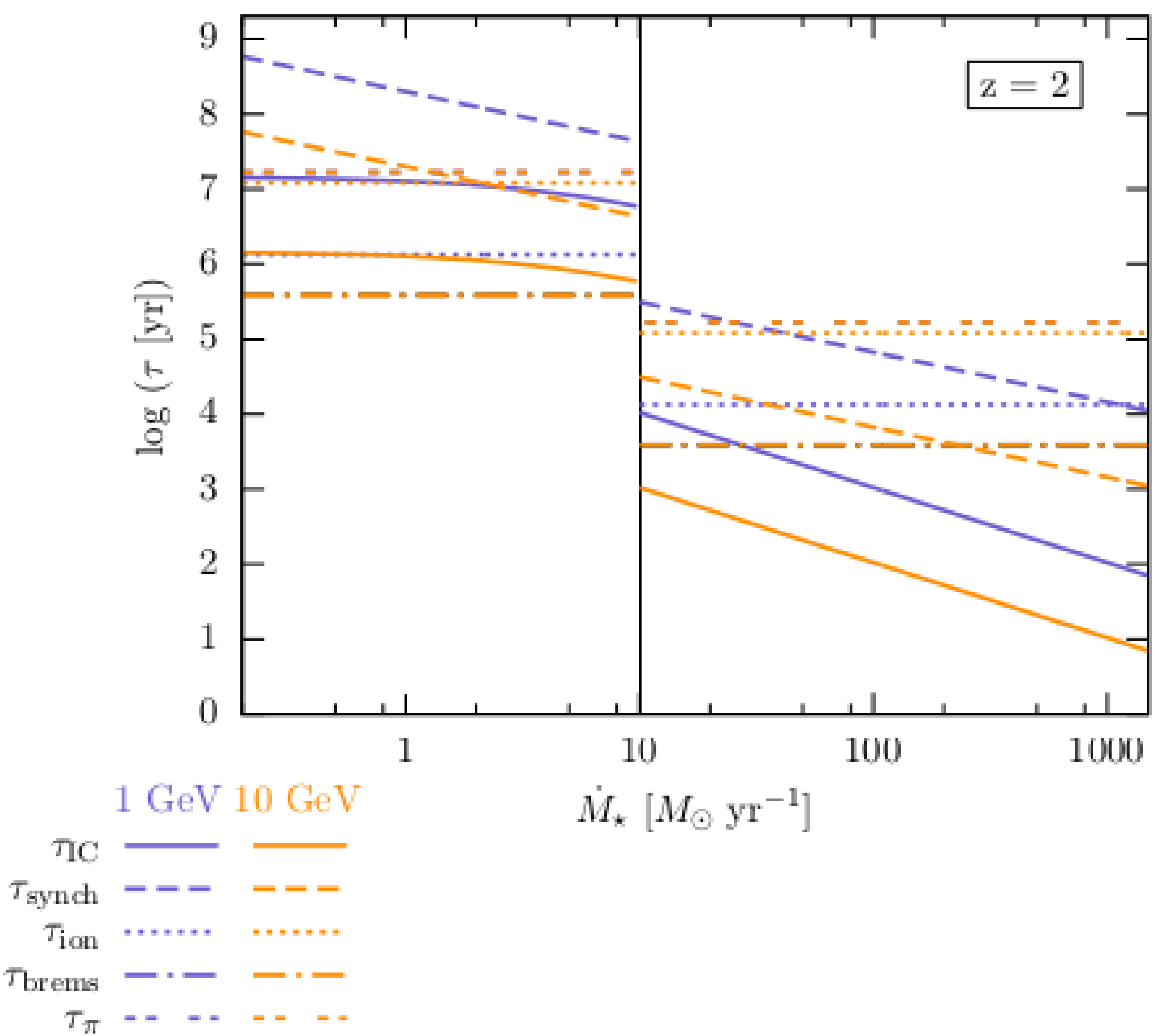
"X-Rays from Young Galaxies"

Energy Losses of CR Electrons



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“X-Rays from Young Galaxies”

1. Introduction

2. **Energy Losses of Cosmic Ray Electrons**

3. X-Ray Emission from Inverse Compton Scattering

4. Summary

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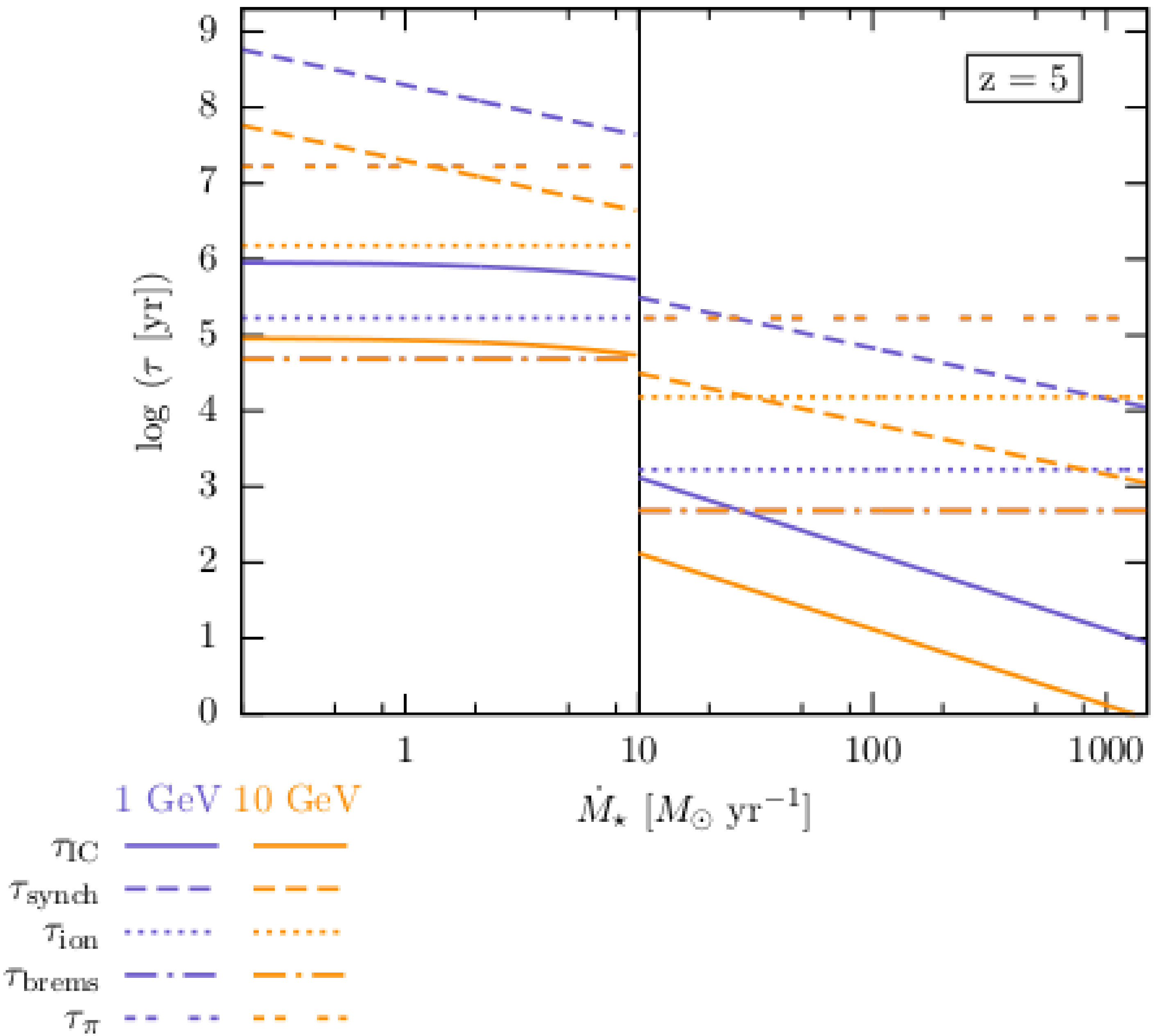
Energy Losses of CR Electrons



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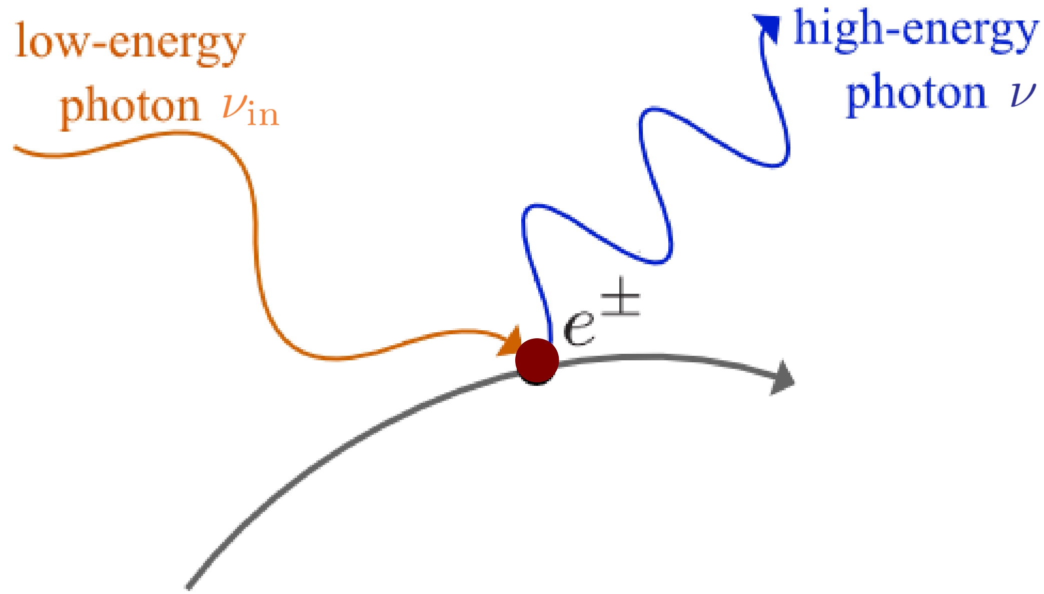
3. X-Ray Emission from Inverse Compton Scattering

Inverse Compton Scattering

- scattering process:



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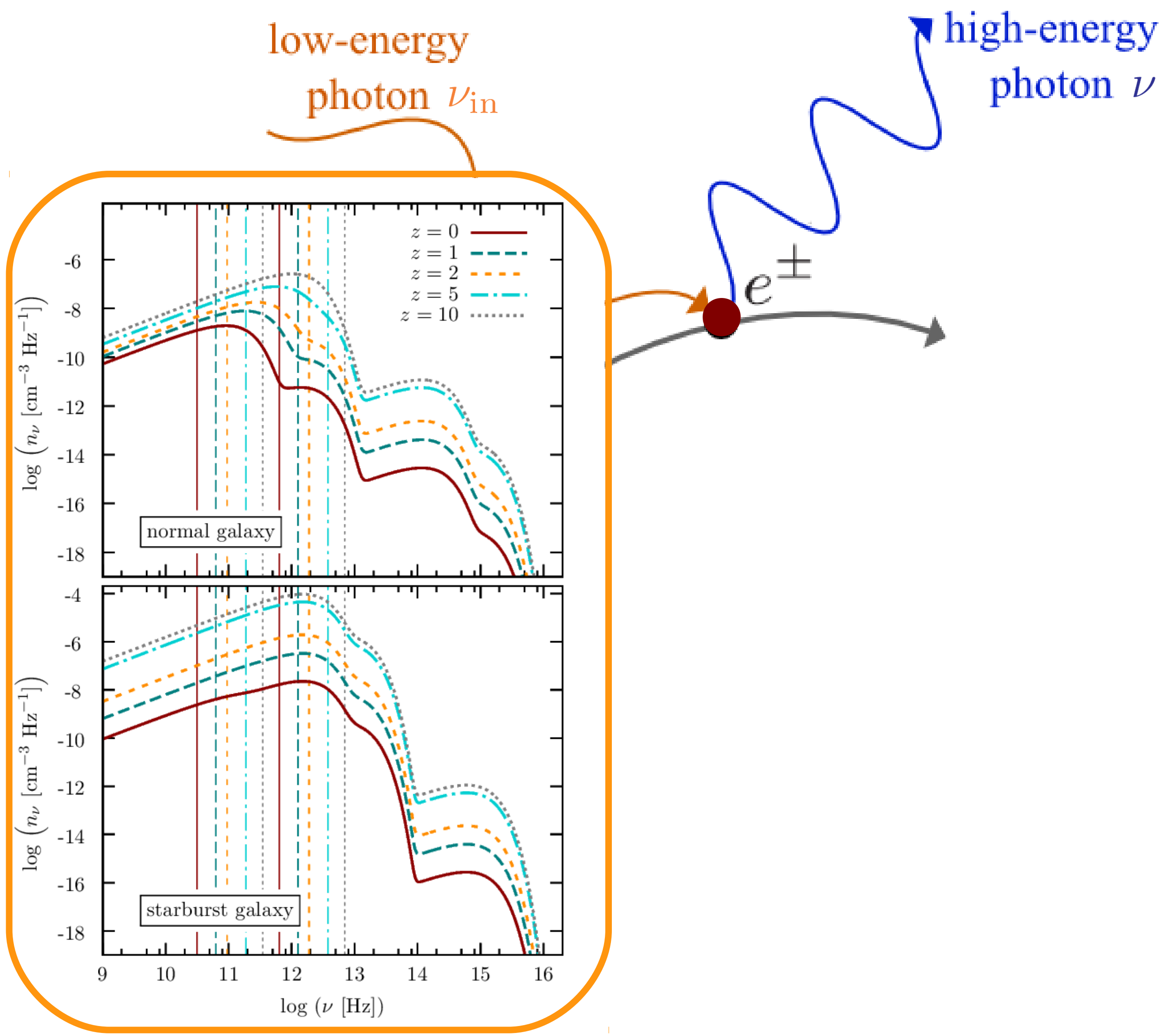
Inverse Compton Scattering

- scattering process:



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Inverse Compton Scattering

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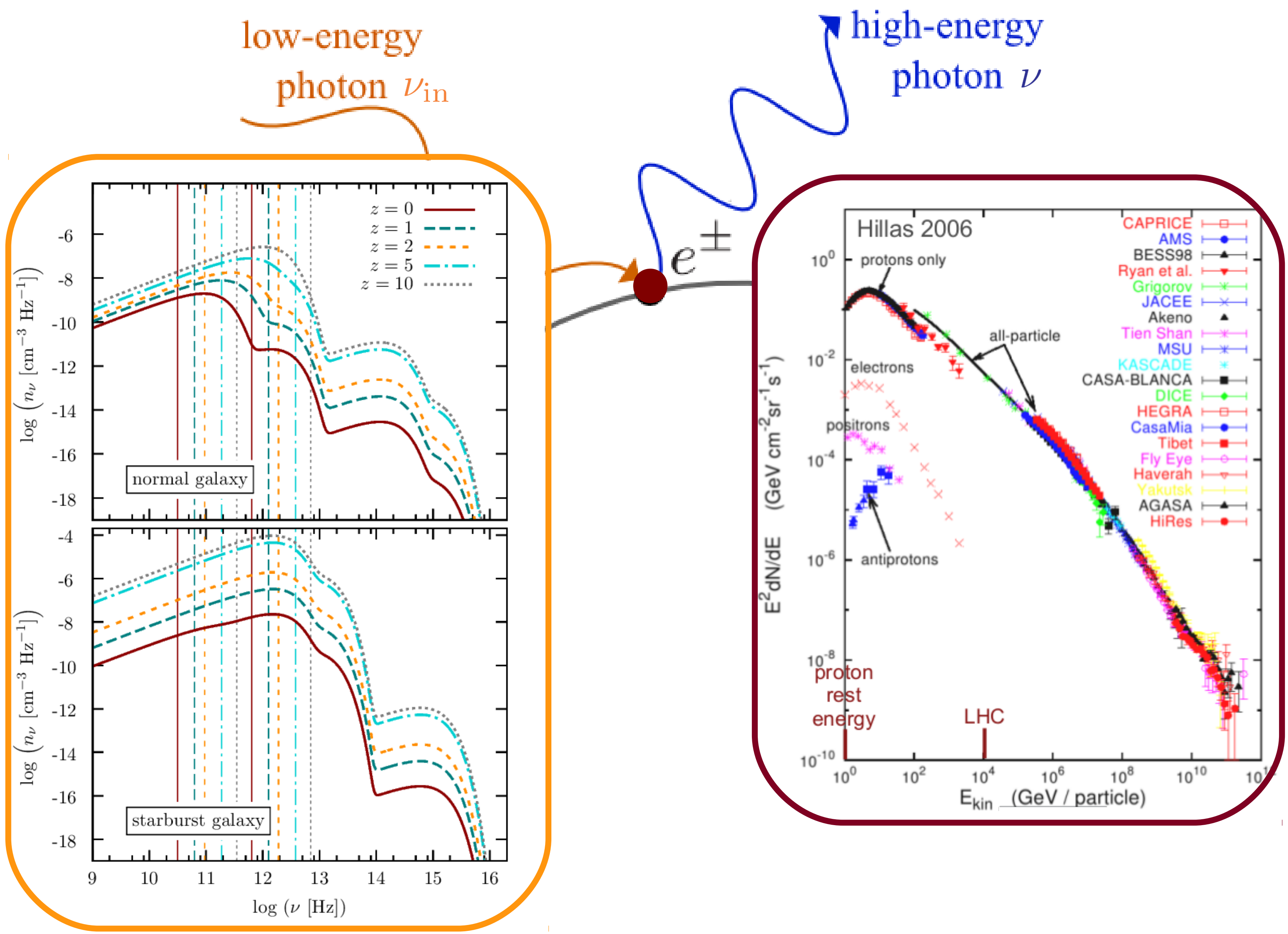

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Inverse Compton Scattering

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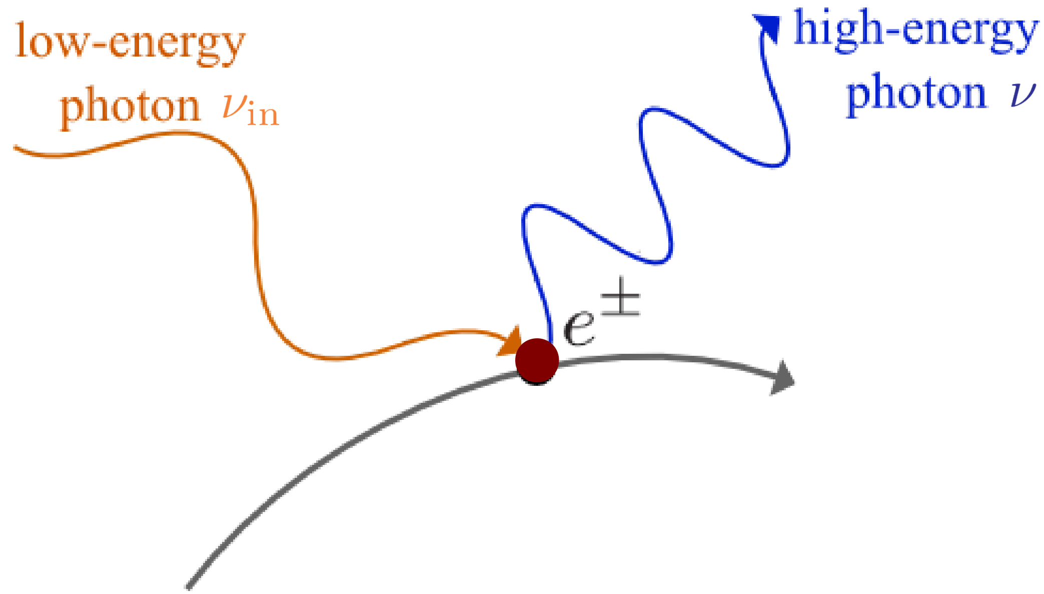

- spectral power distribution of inverse Compton emission (Blumenthal & Gould 1970):

$$Q_{\rm IC}(\nu) = \int_0^\infty \int_{\gamma_{\rm min}}^\infty N_{\rm e}(\gamma) Q_{\rm IC,e}(n_{\rm ISRF}, \gamma, \nu_{\rm in})\ {\rm d}\gamma {\rm d}\nu_{\rm in}$$

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Inverse Compton Luminosity

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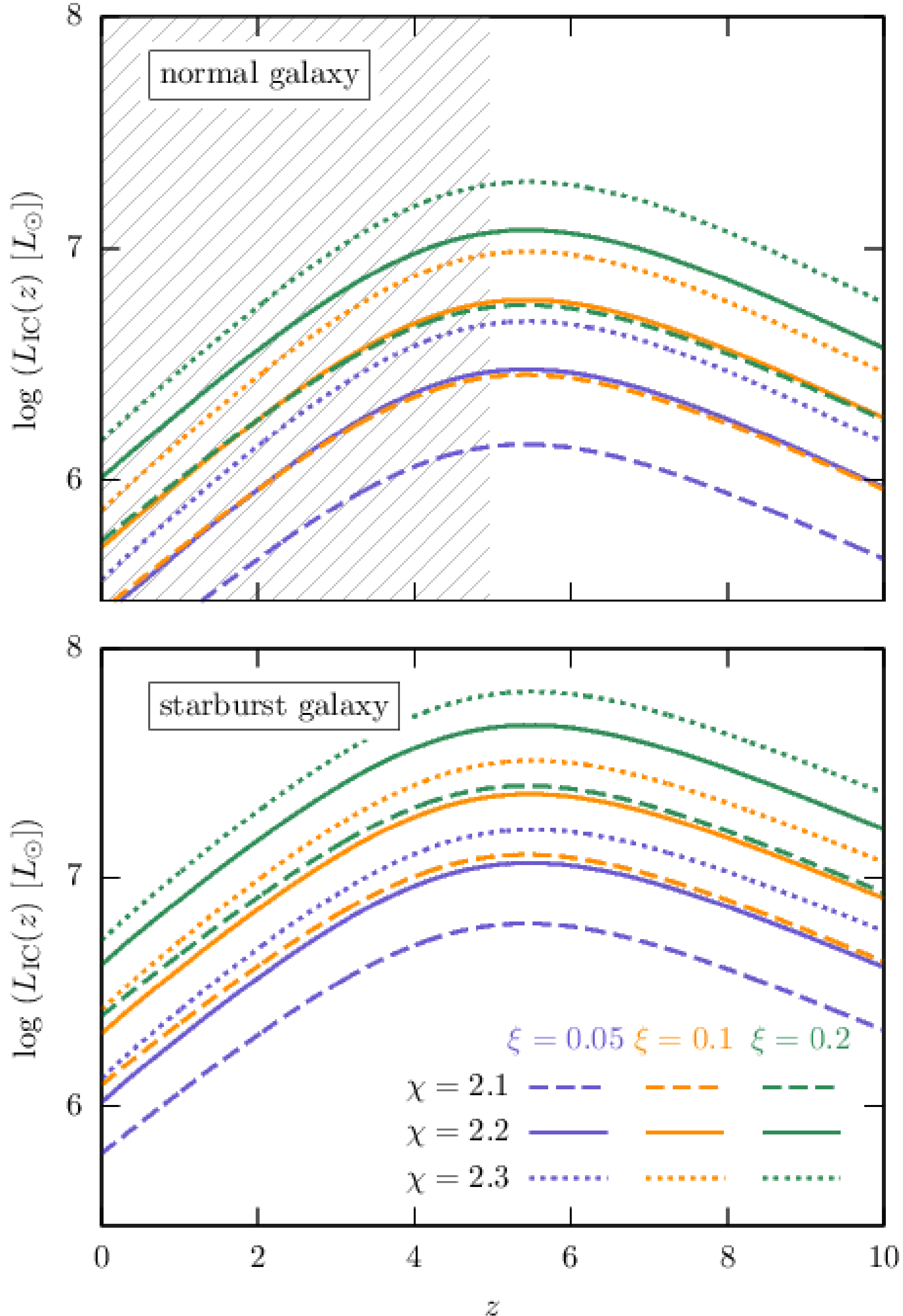
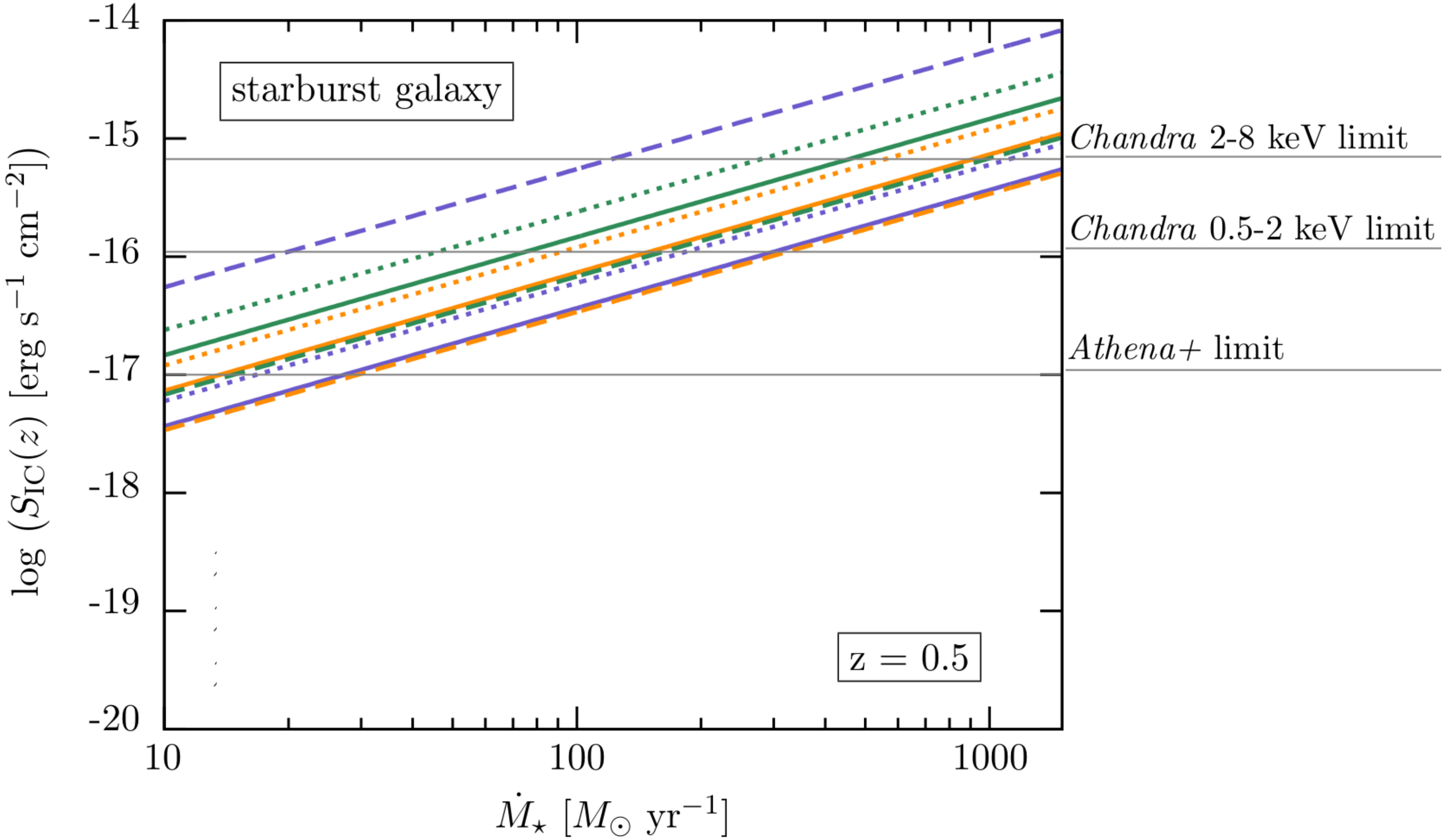


cosmic ray spectrum:

$$N_{\rm e}(\gamma) \propto \xi \gamma^{\chi}$$

Inverse Compton Flux

- flux as a function of star formation rate:



cosmic ray spectrum:

$$N_e(\gamma) \propto \xi \gamma^\chi$$

	$\xi = 0.05$	$\xi = 0.1$	$\xi = 0.2$
$\chi = 2.1$	dashed	dashed	dashed
$\chi = 2.2$	solid	solid	solid
$\chi = 2.3$	dotted	dotted	dotted

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Inverse Compton Flux

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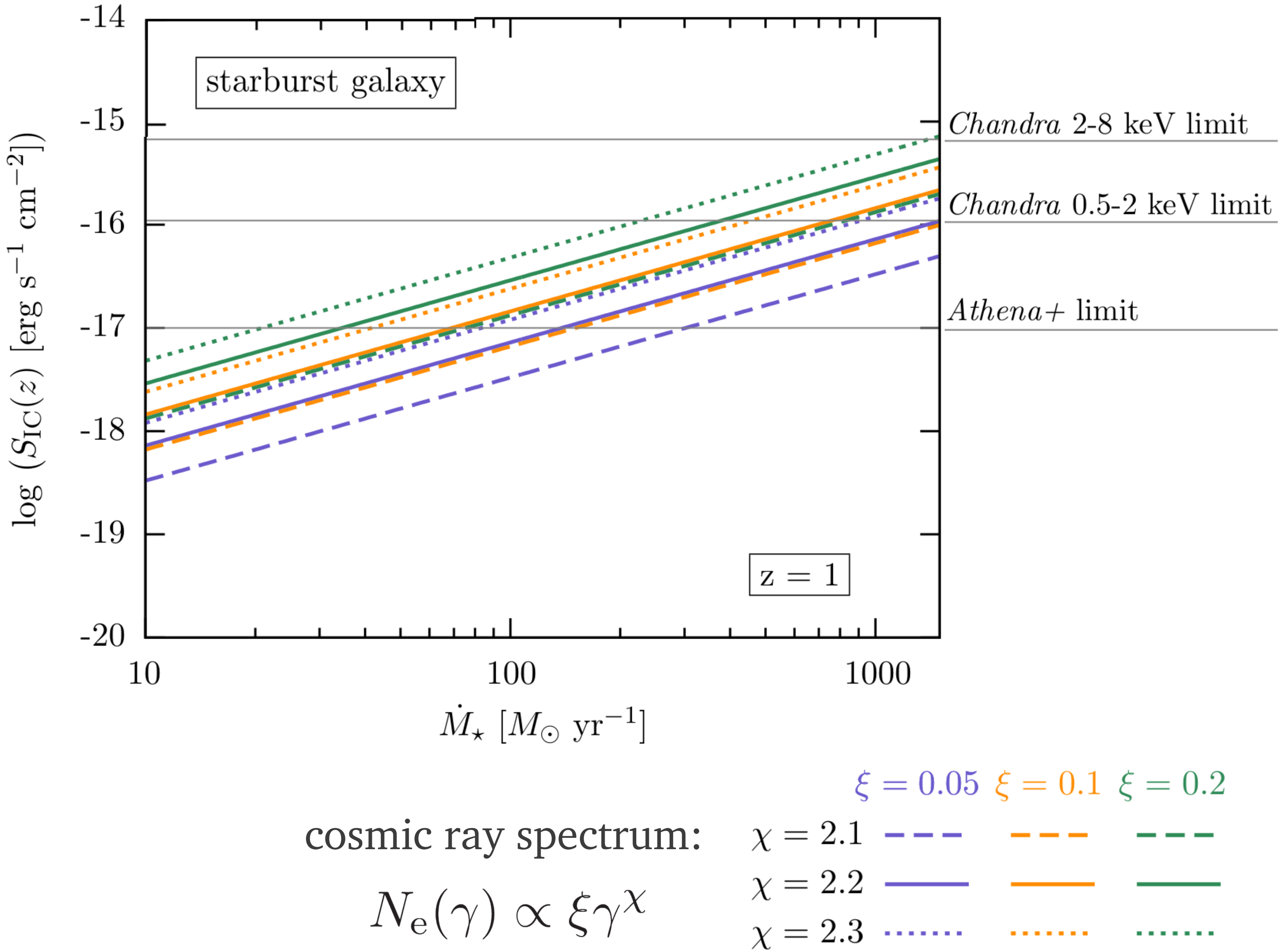

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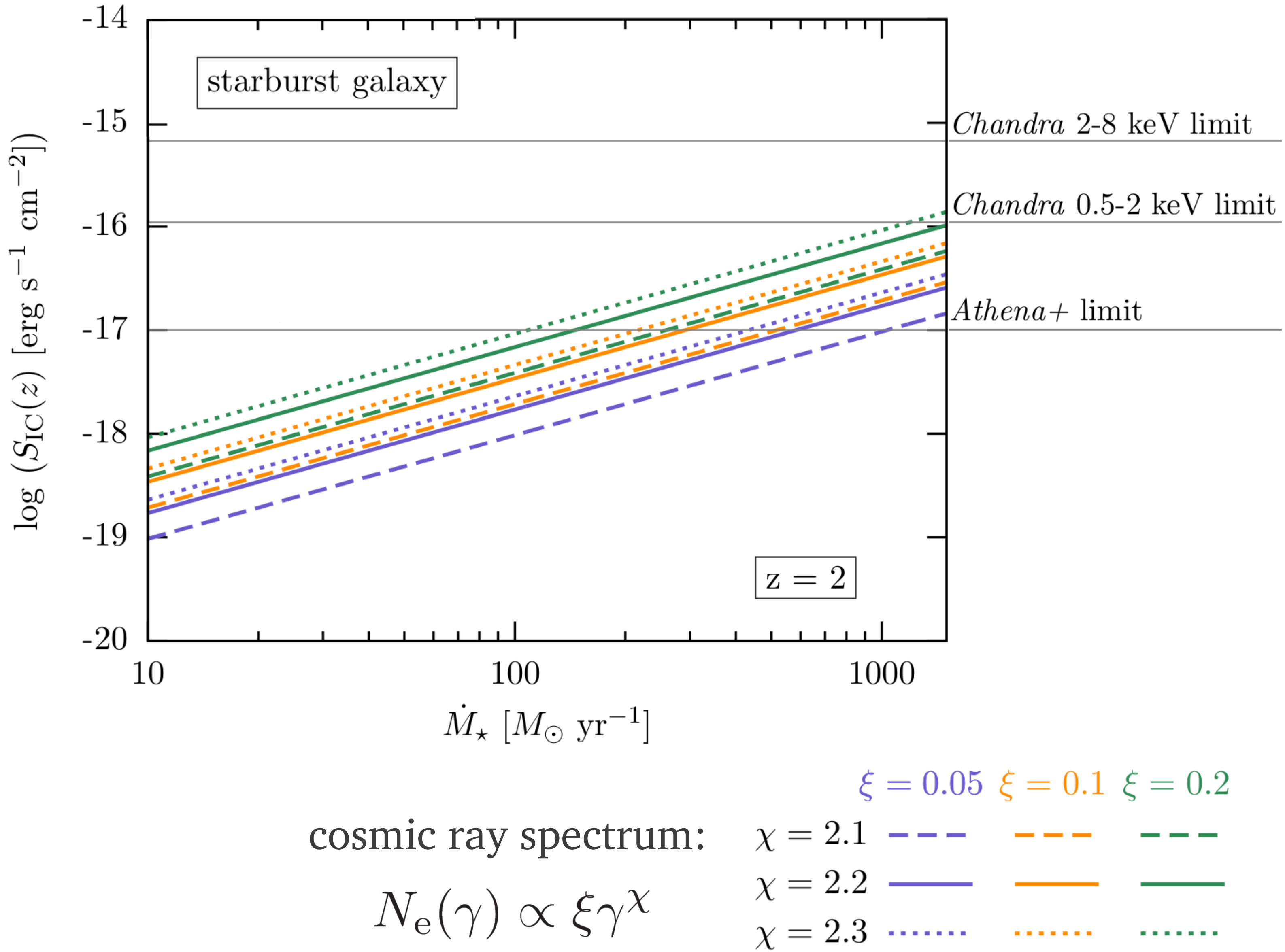

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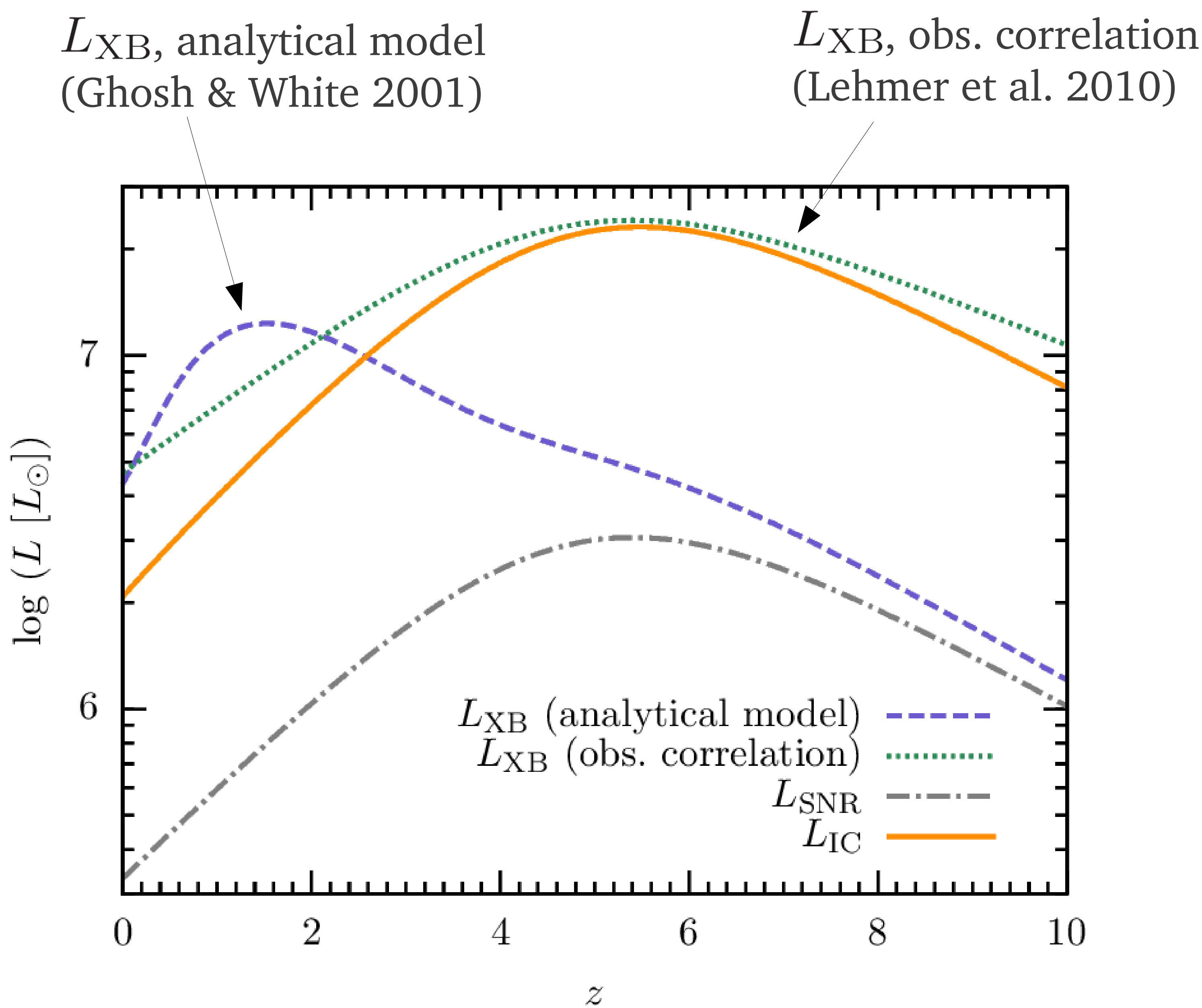
Additional X-Ray Sources



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4. Summary

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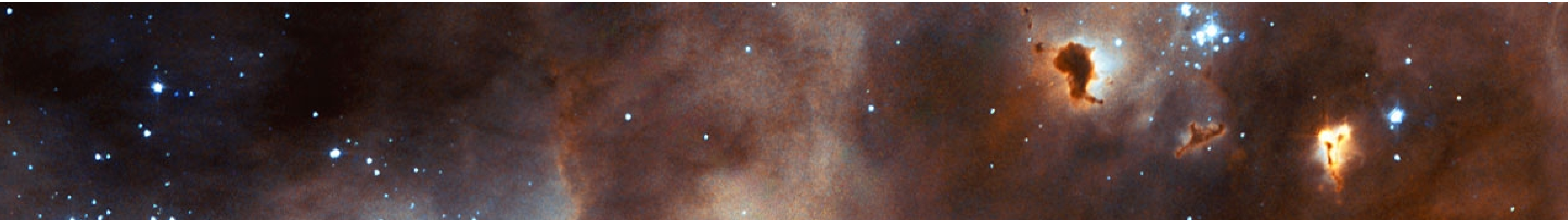
Summary

- motivation: magnetic fields are already important in young galaxies
- inverse Compton scattering most important energy loss of cosmic ray $e^{\pm}$ for
  - Milky Way-type galaxies at $z \gtrsim 5$
  - starburst galaxies
- *Chandra* observations of pure inverse Compton scattering in starbursts possible up to $z \lesssim 2$
- additional X-ray sources need to be considered carefully



Thanks for your attention!

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