Turun yliopisto
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NORDITA

(EoS) constraints using X-ray spectroscopy of thermonuclear bursts

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Outline

- "*Hard to understand - easy to do*" - method

See Juri's talk on Monday

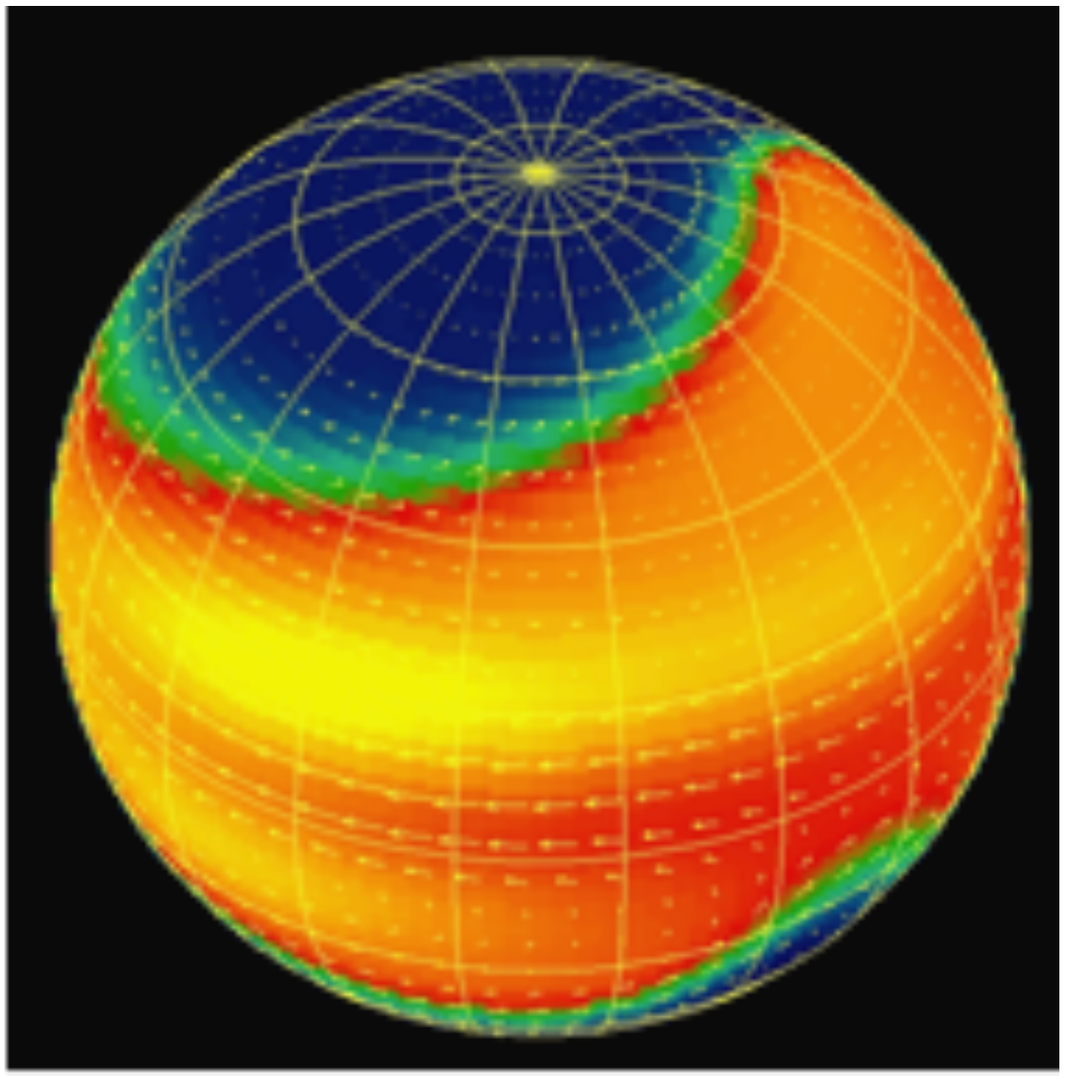
- "*Easy to understand - hard to do*" - method

Thermonuclear X-ray bursts

Photospheric radius expansion

Eddington limit

$$F_{\mathrm{rad}} = F_{\mathrm{g}}$$



A. Spitkovsky

Atmosphere models

$$\frac{\mathrm{d}P_\mathrm{g}}{\mathrm{d}m} = g - g_\mathrm{rad}, \qquad \mathrm{d}m = -\rho\,\mathrm{d}s,$$

Hydrostatic equilibrium

$$\mu\frac{\mathrm{d}I(x,\mu)}{\mathrm{d}\tau(x,\mu)} = I(x,\mu) - S(x,\mu),$$

Radiative transfer

$$\sigma(x,\mu) = \kappa_\mathrm{e}\frac{1}{x}\int_0^\infty x_1\mathrm{d}x_1\int_{-1}^{1}\mathrm{d}\mu_1 R(x_1,\mu_1;x,\mu)\left(1+\frac{C\,I(x_1,\mu_1)}{x_1^3}\right),$$

Electron opacity

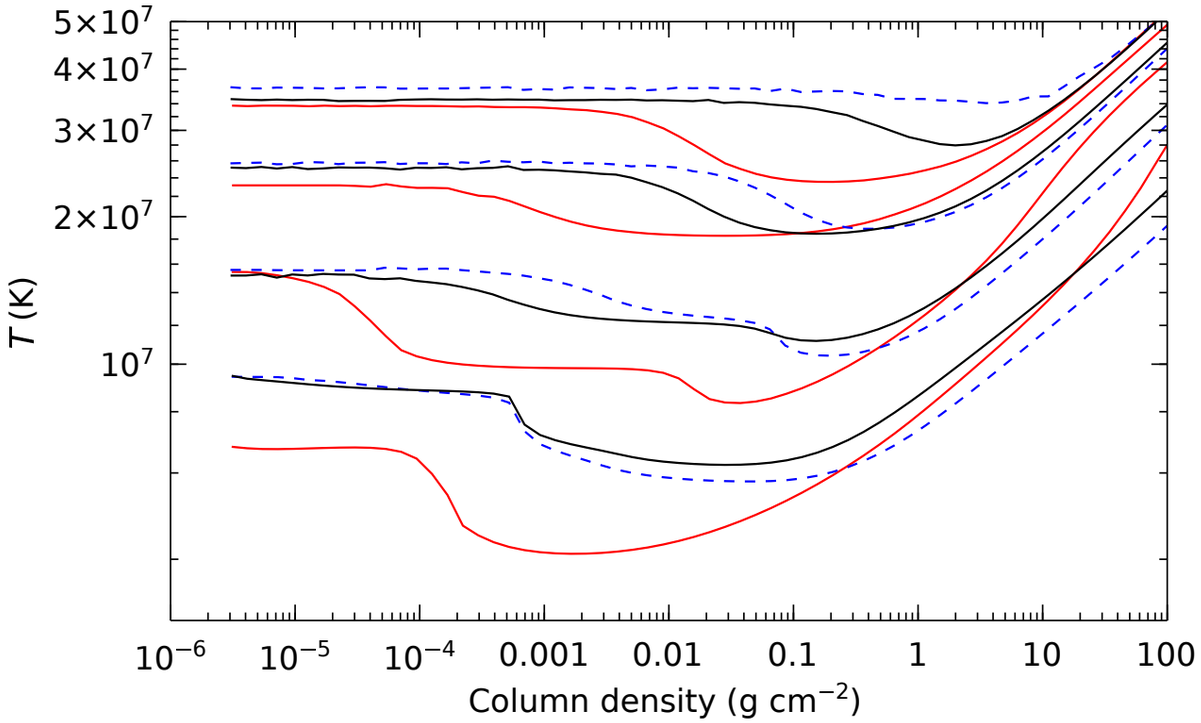
$$\int_0^\infty \mathrm{d}x \int_{-1}^{+1} [\sigma(x,\mu)+k(x)]\,[I(x,\mu)-S(x,\mu)]\;\mathrm{d}\mu = 0,$$

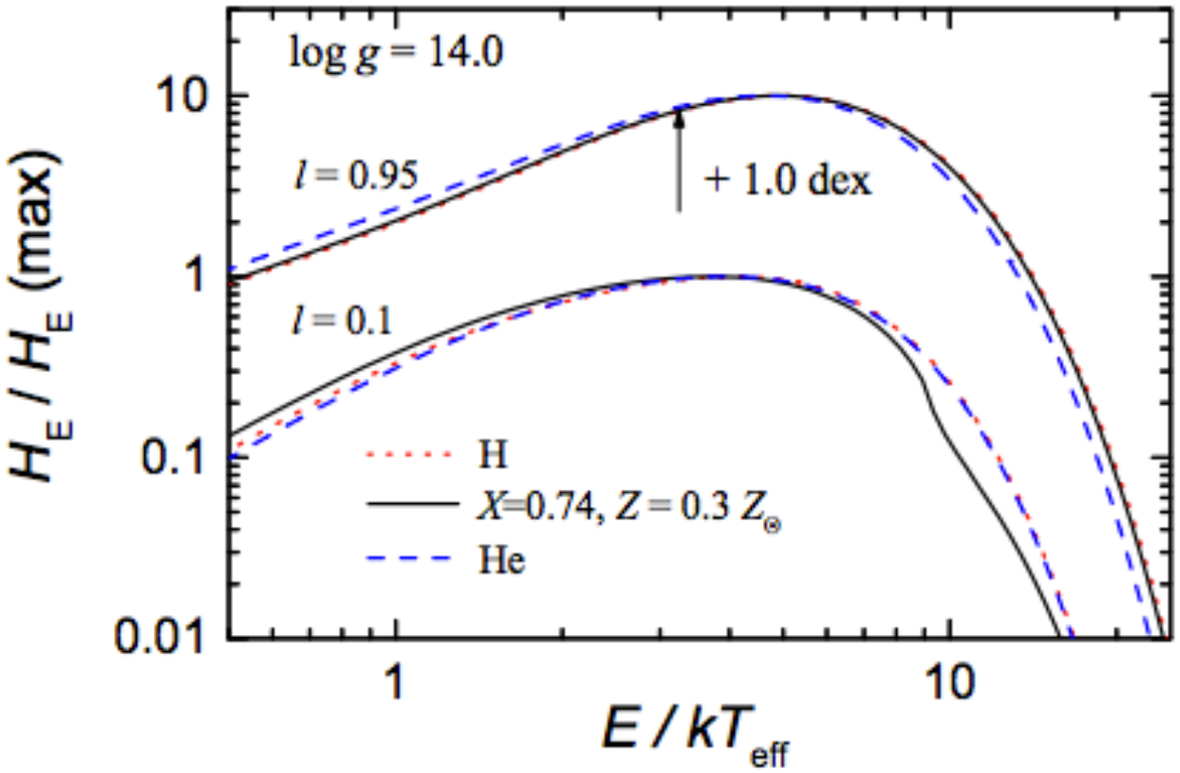
Energy balance

$$P_\mathrm{g} = N_\mathrm{tot}\,kT,$$

Ideal gas law

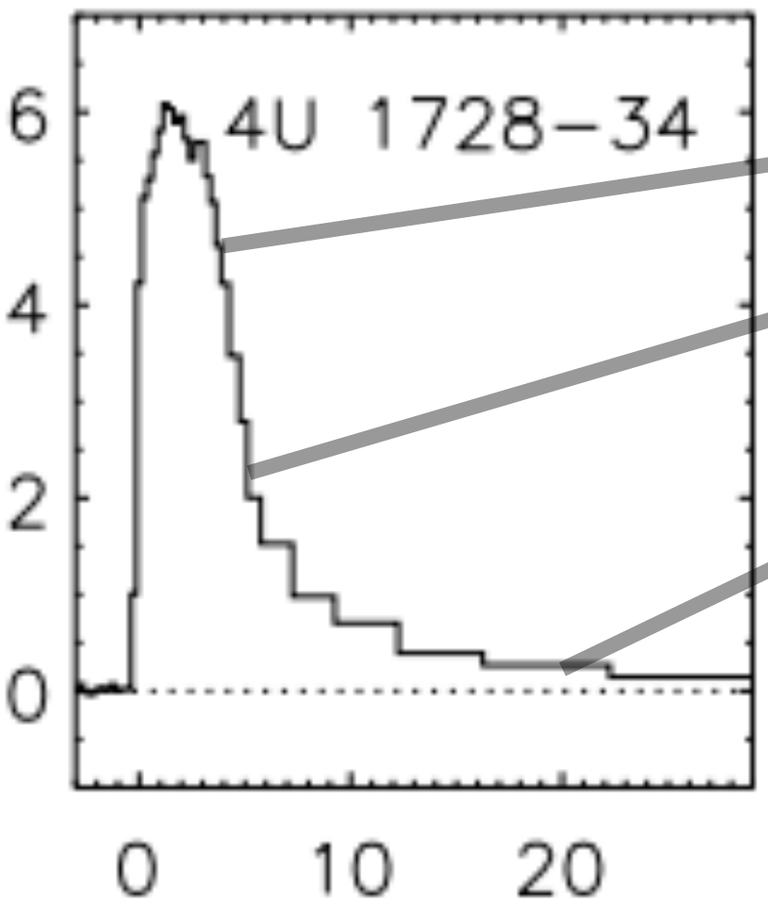
Atmosphere models



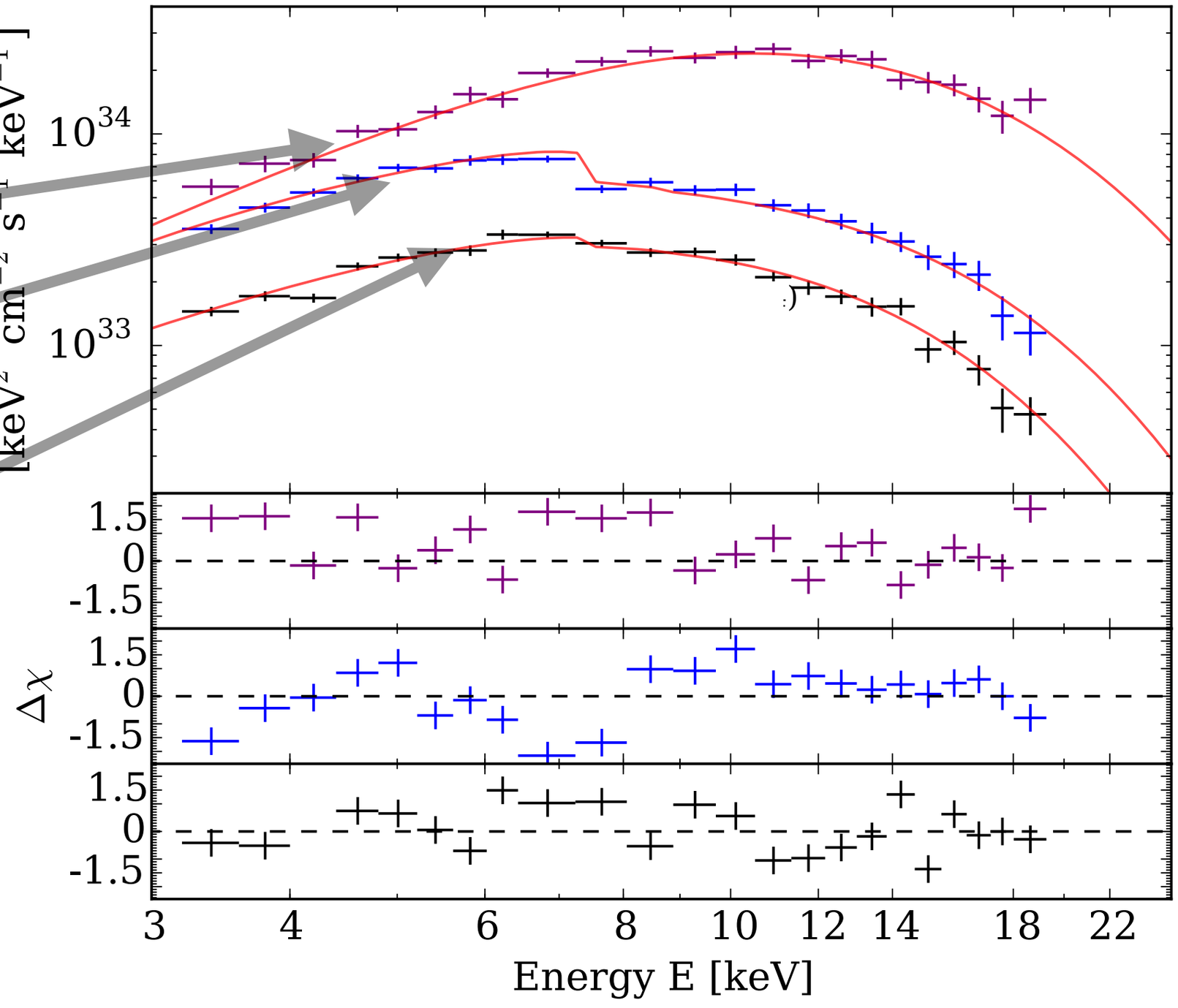


Thermonuclear X-ray bursts

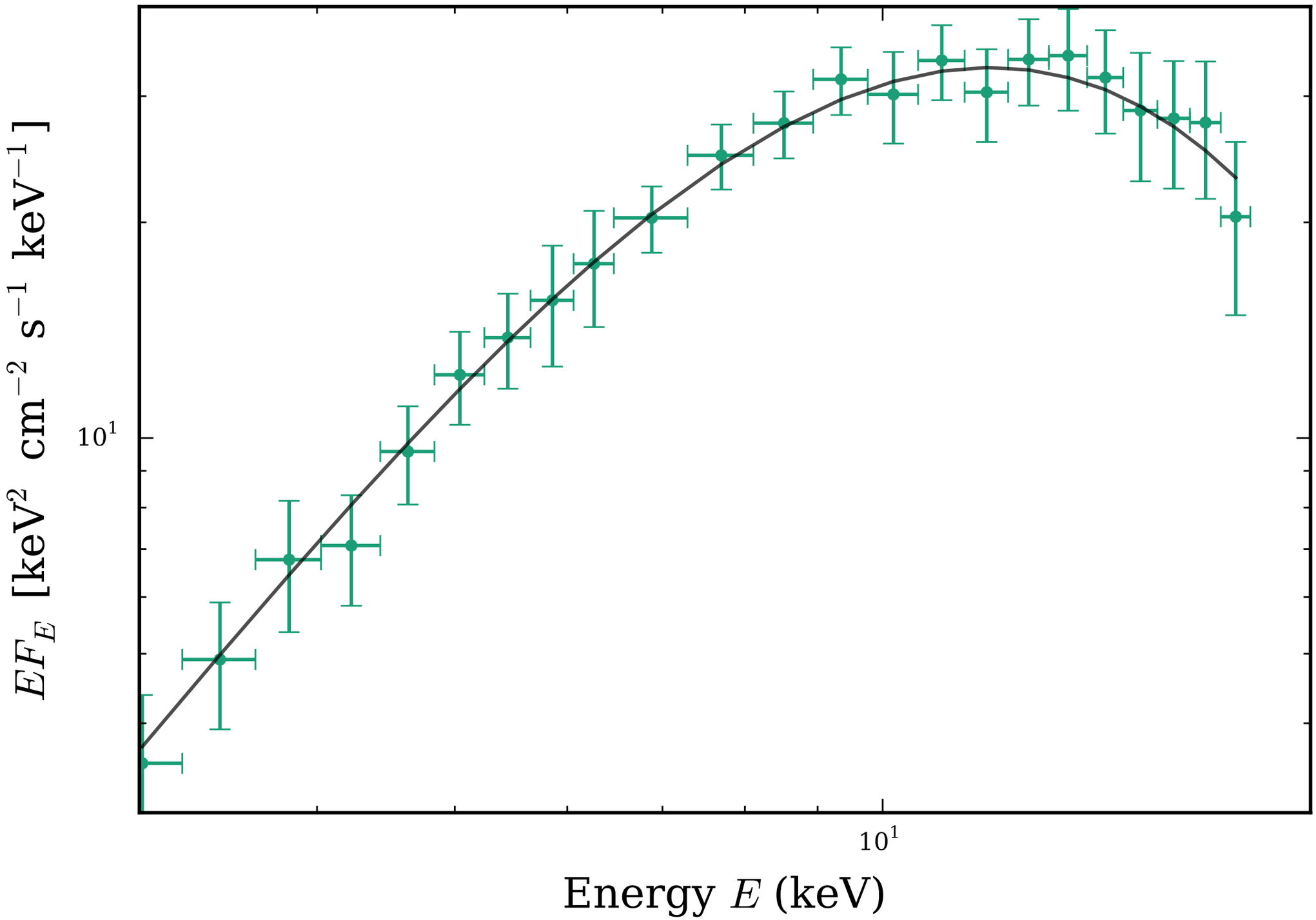
Time-resolved spectroscopy



D. Galloway



Cooling tail evolution



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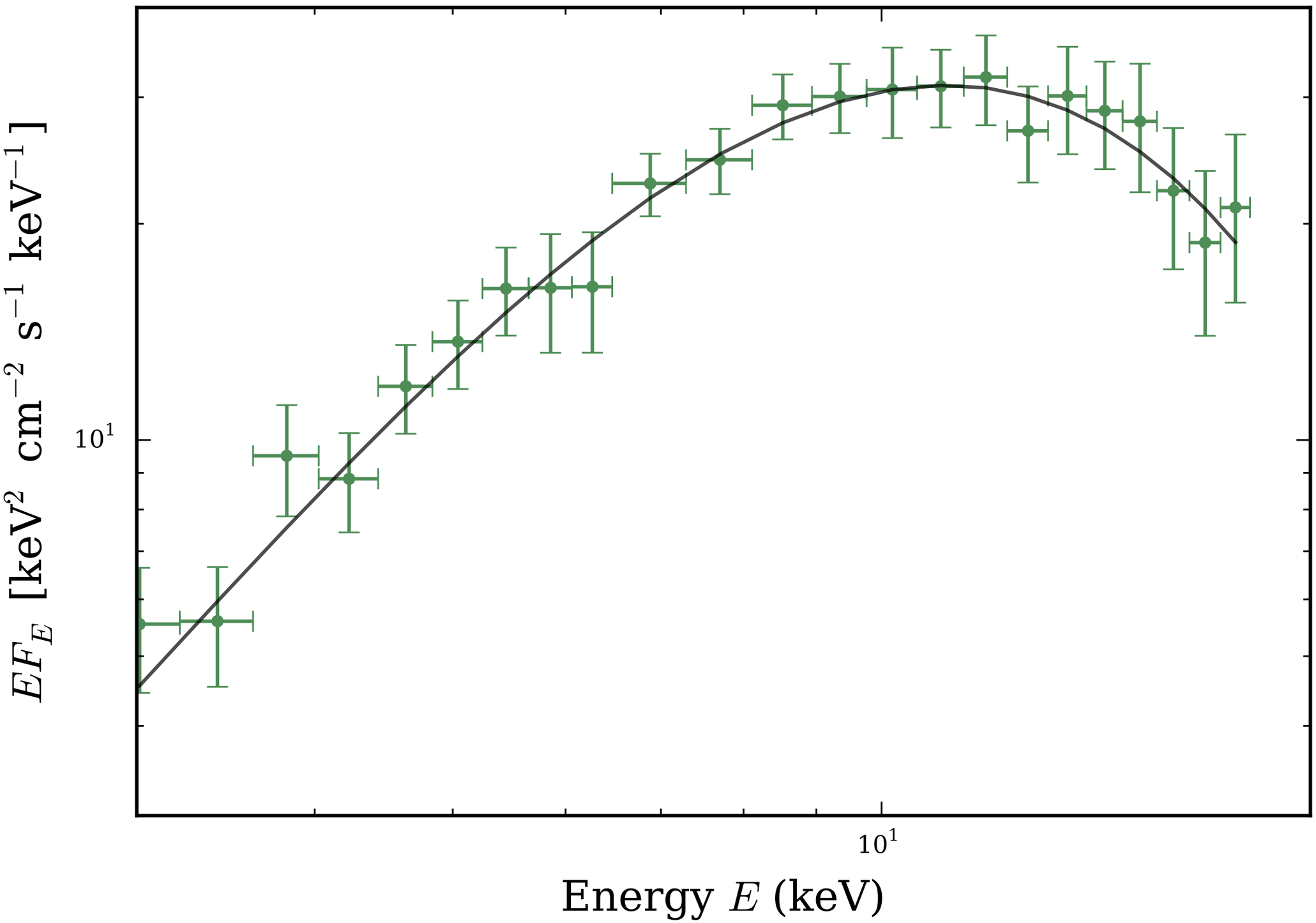

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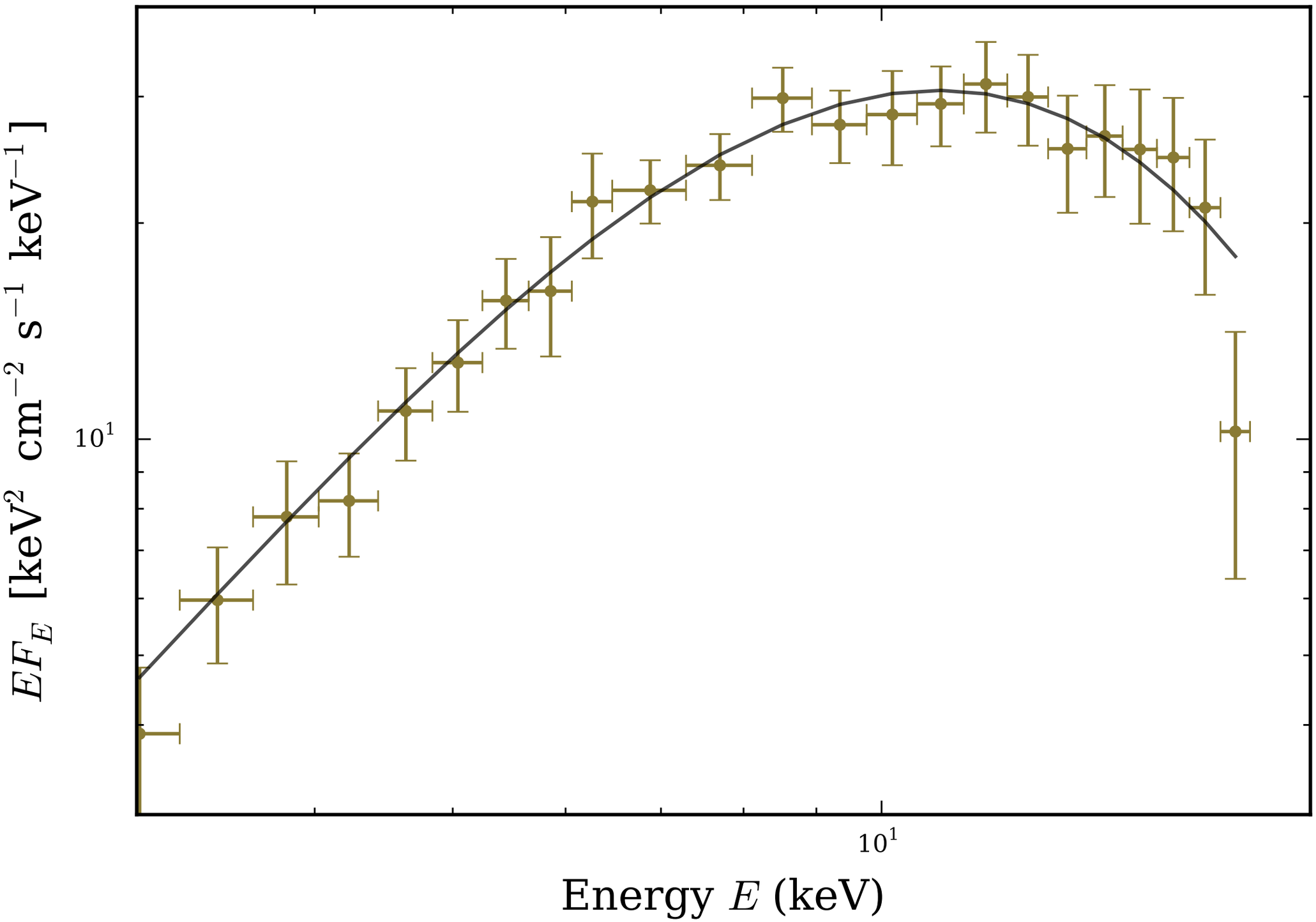

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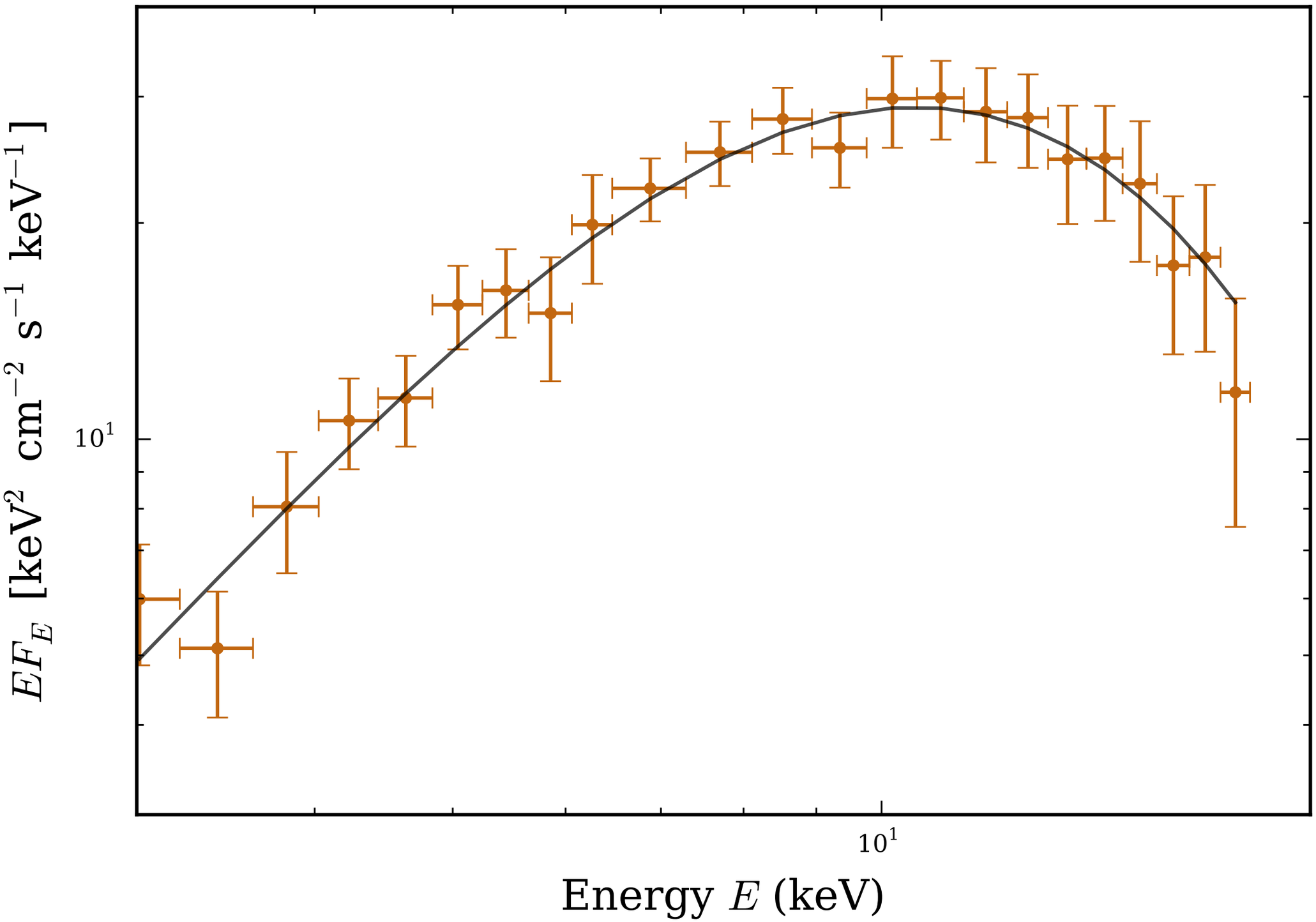

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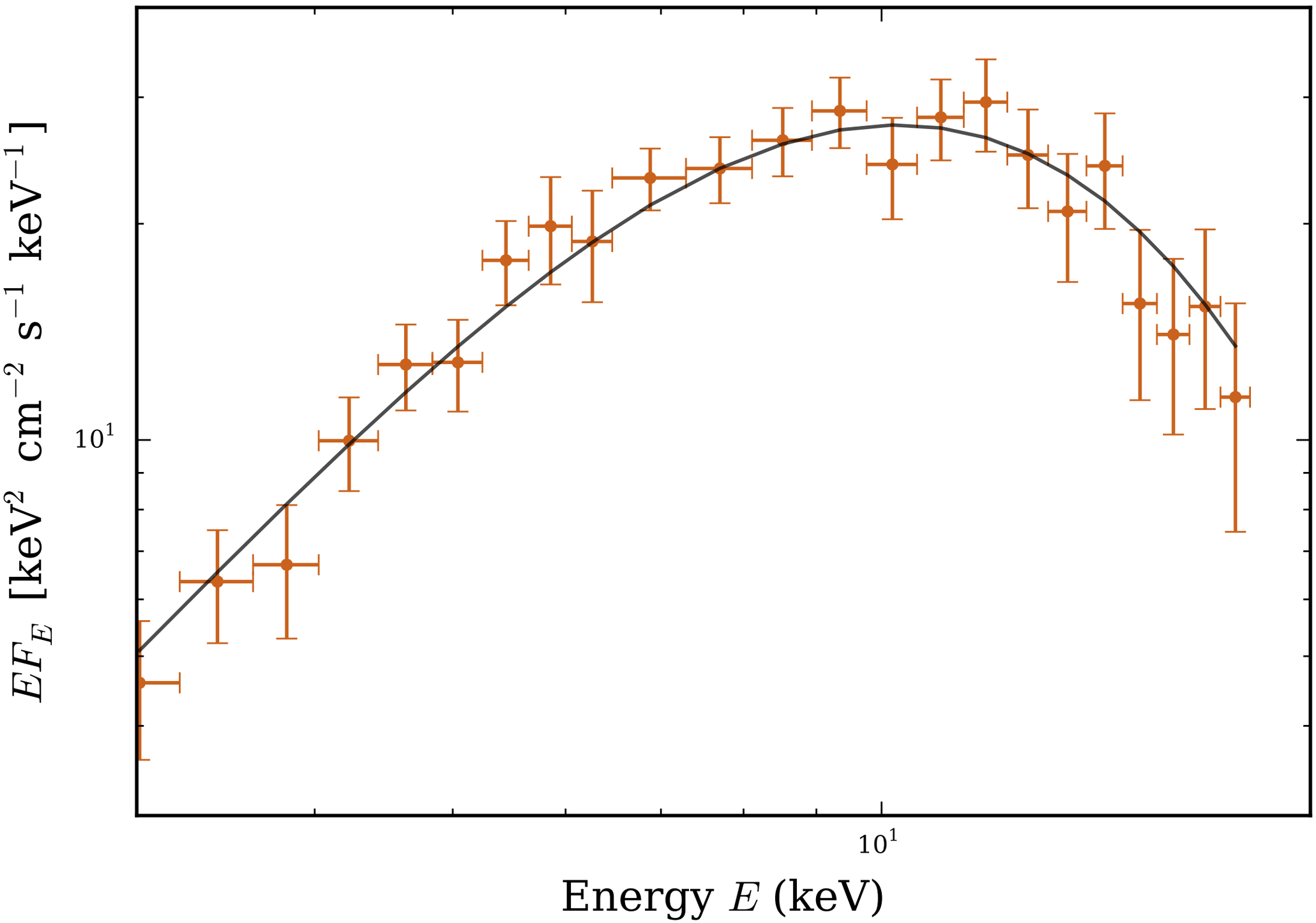

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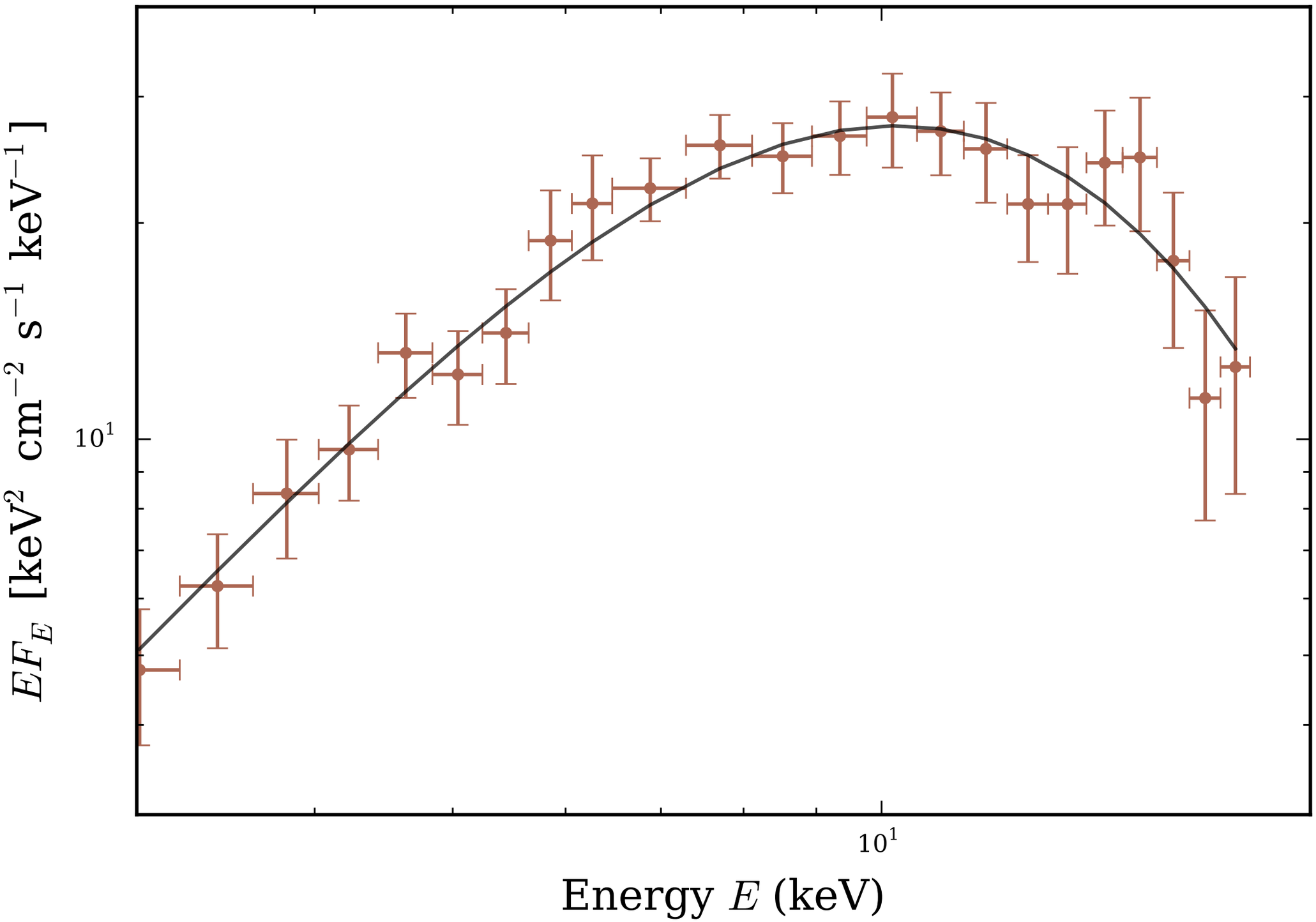

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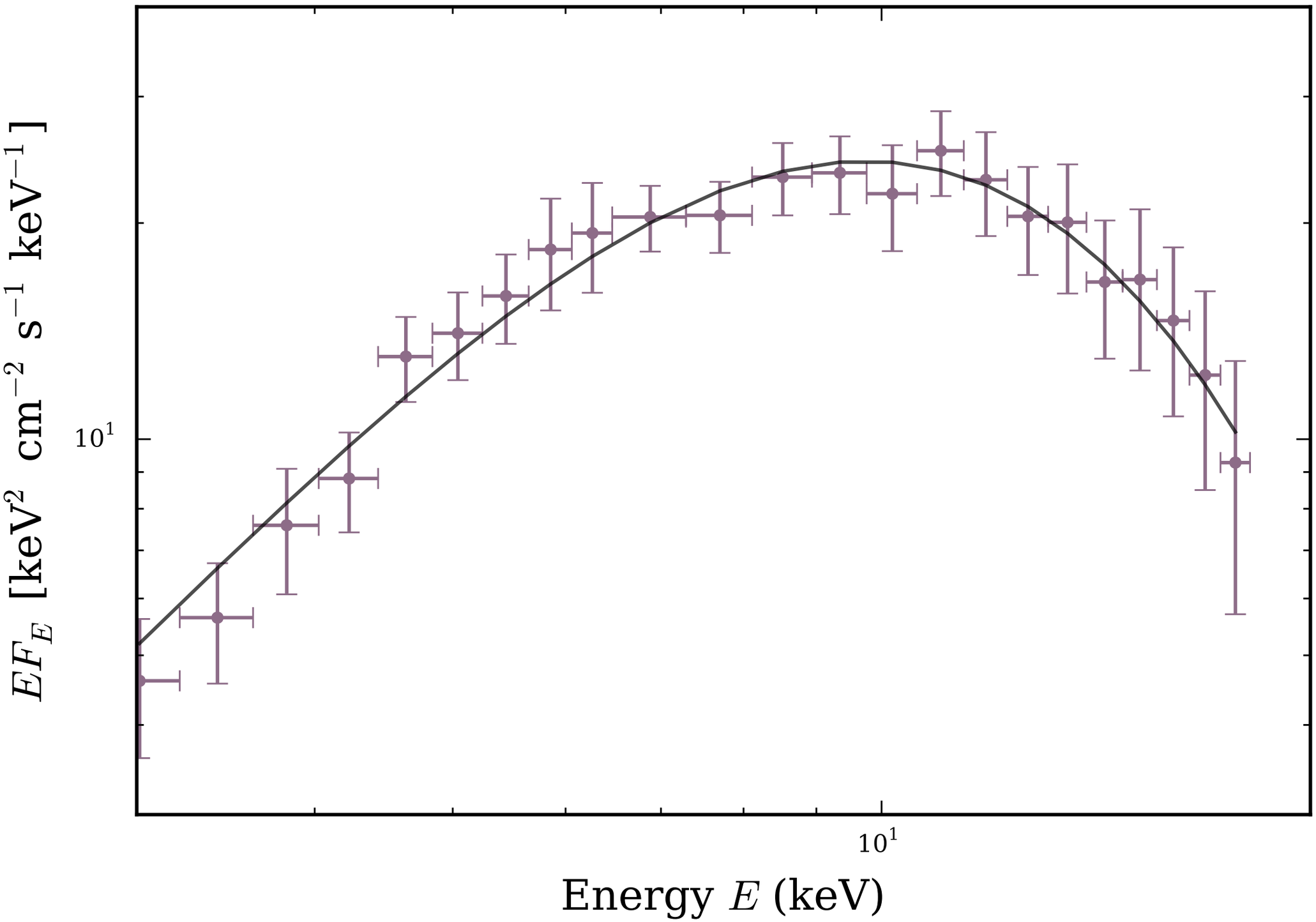

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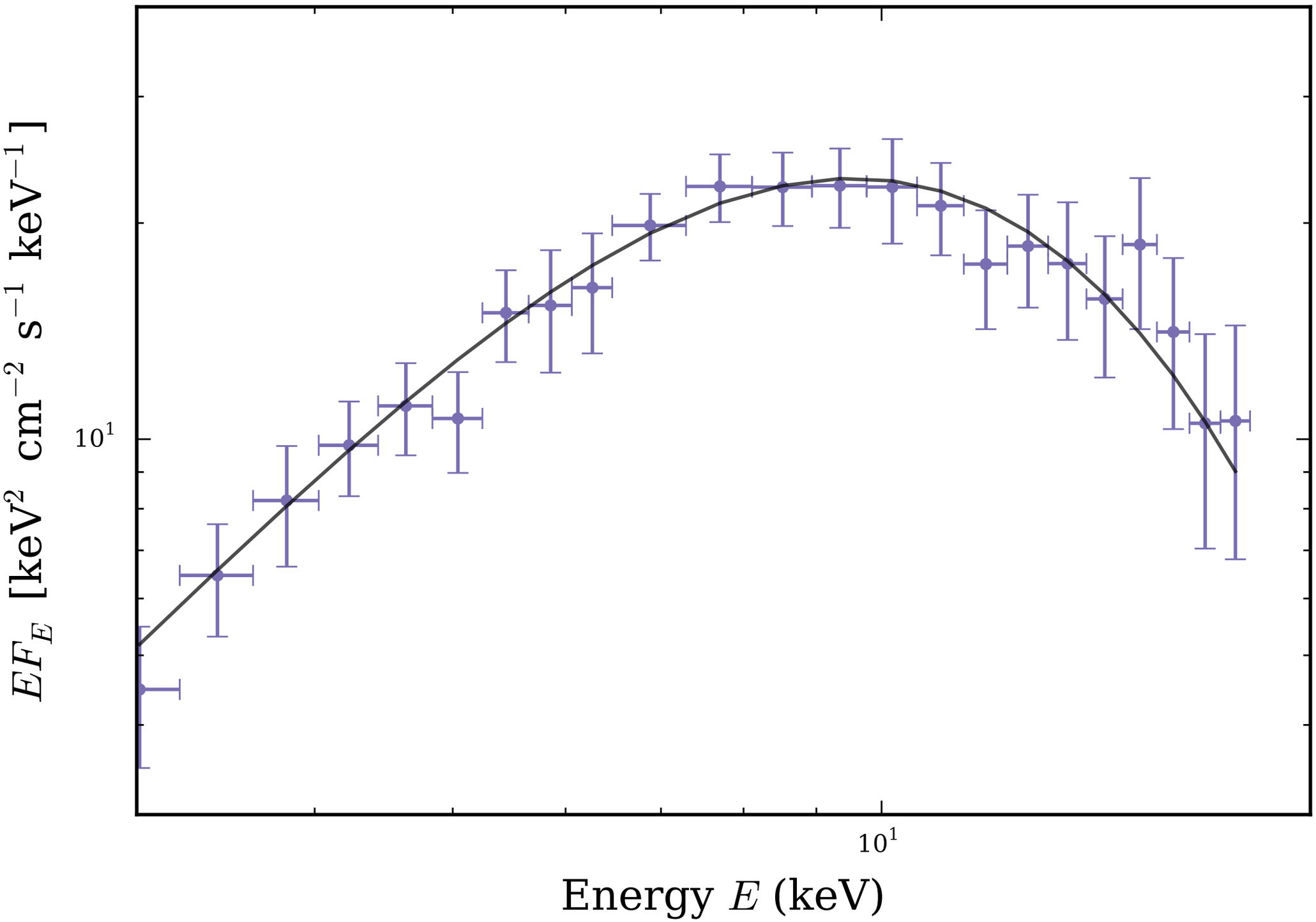

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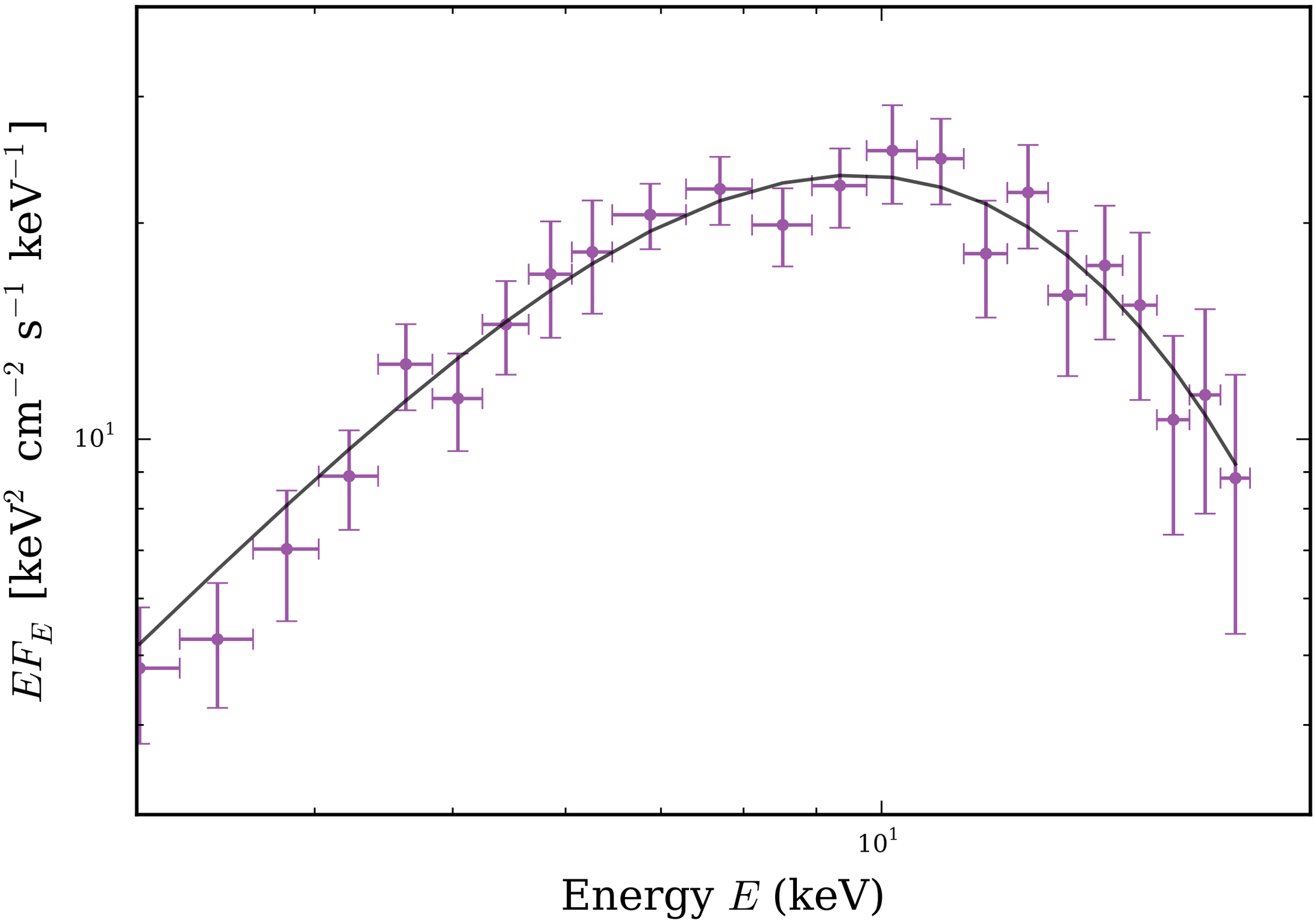

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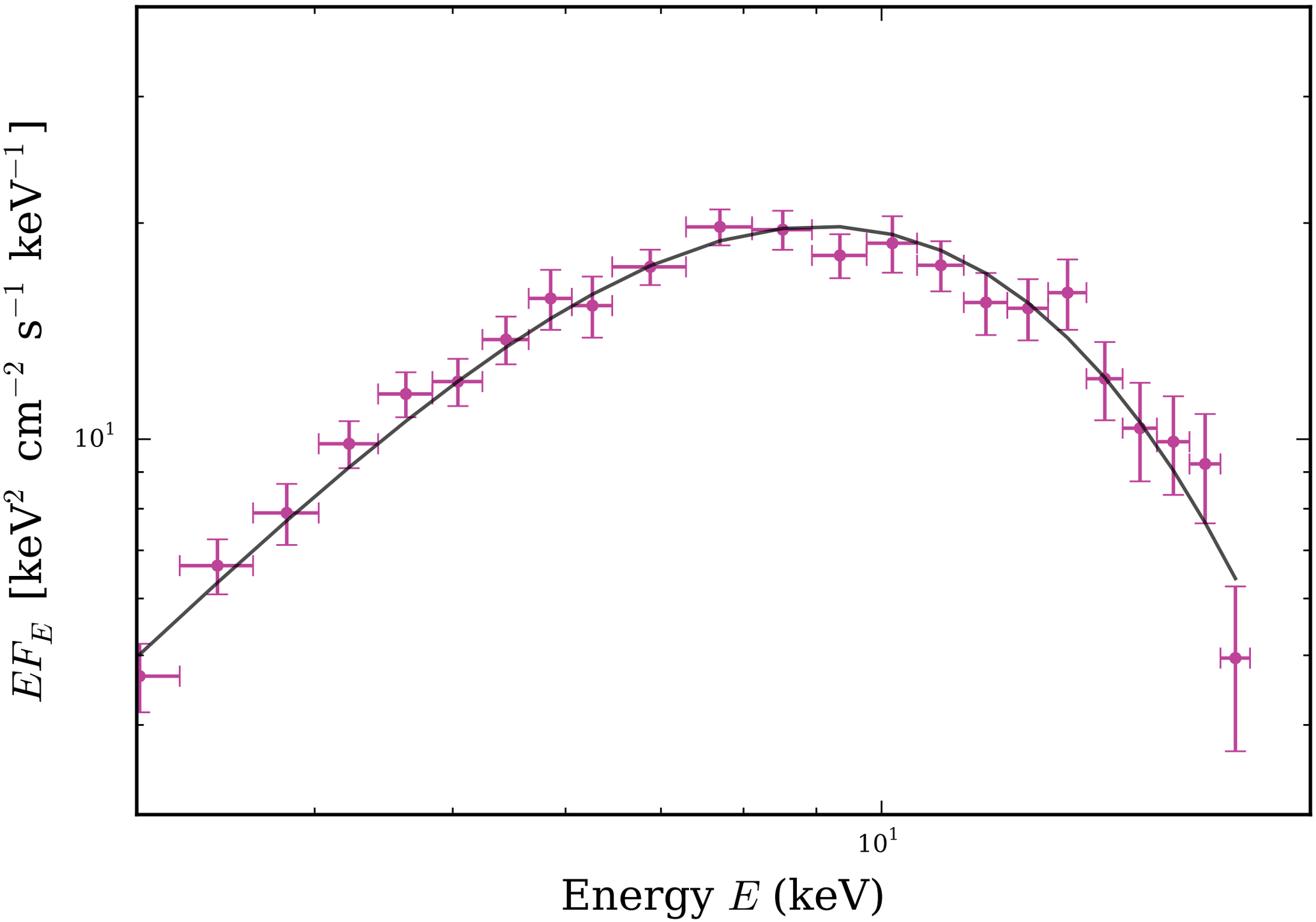

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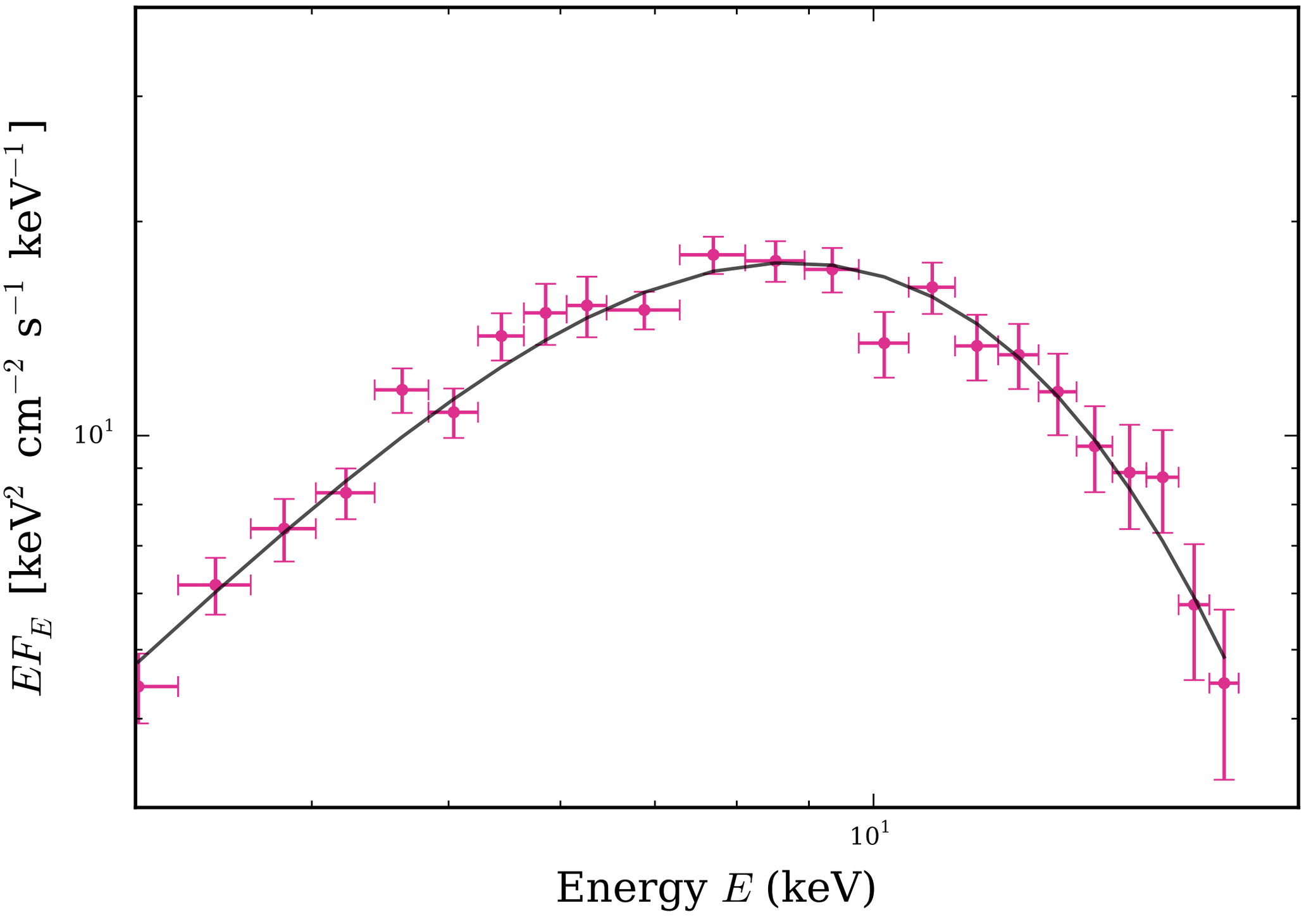

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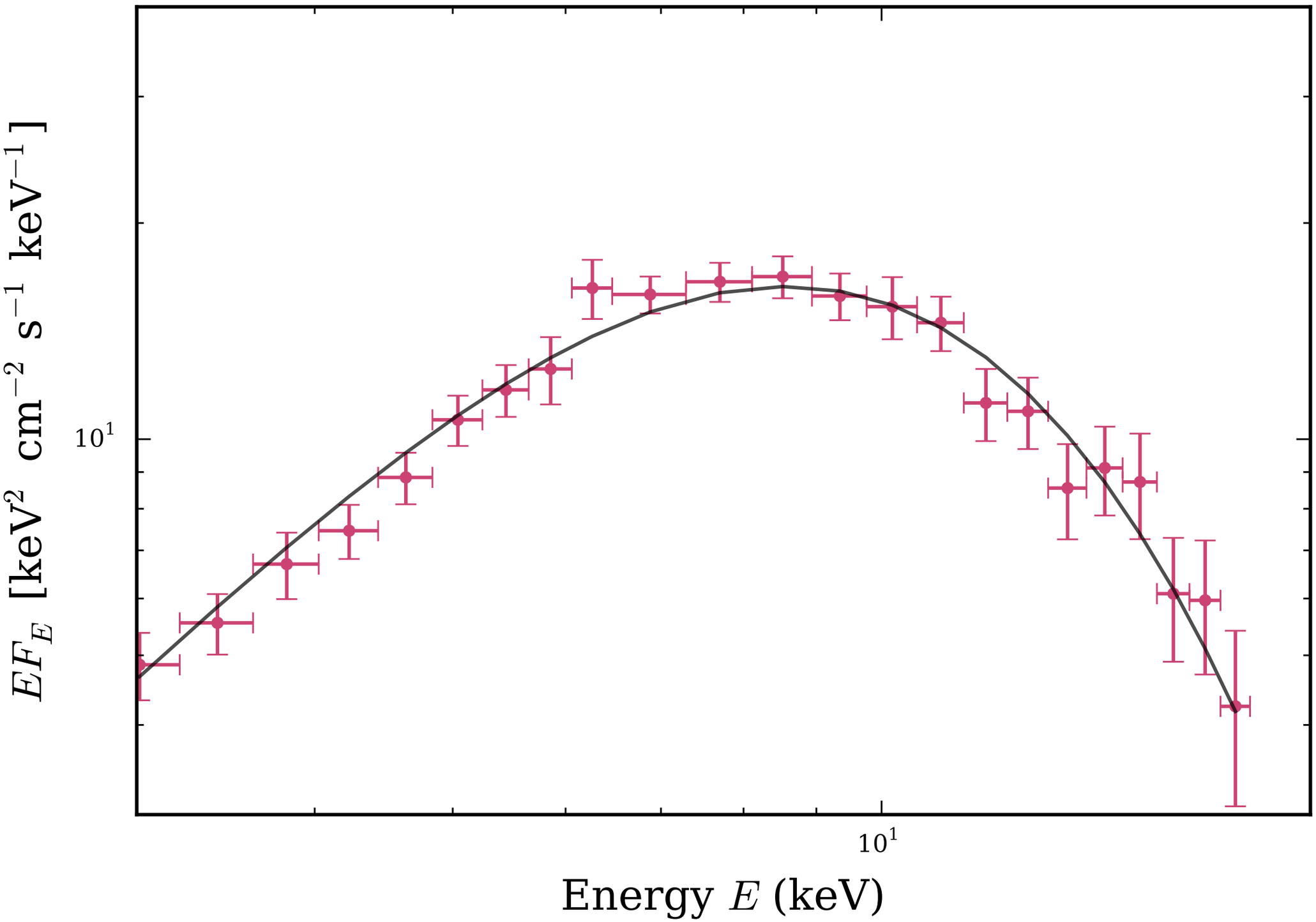

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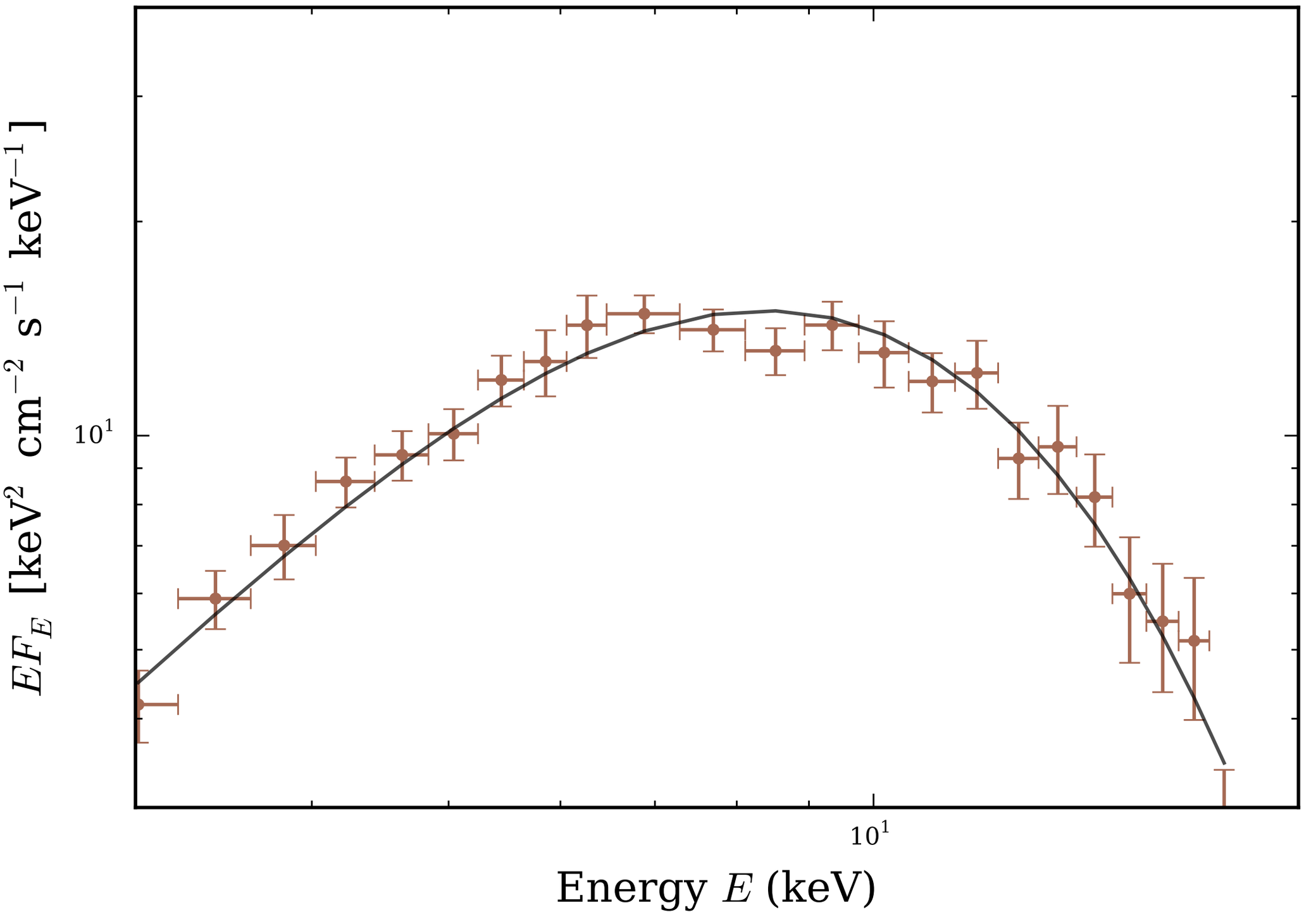

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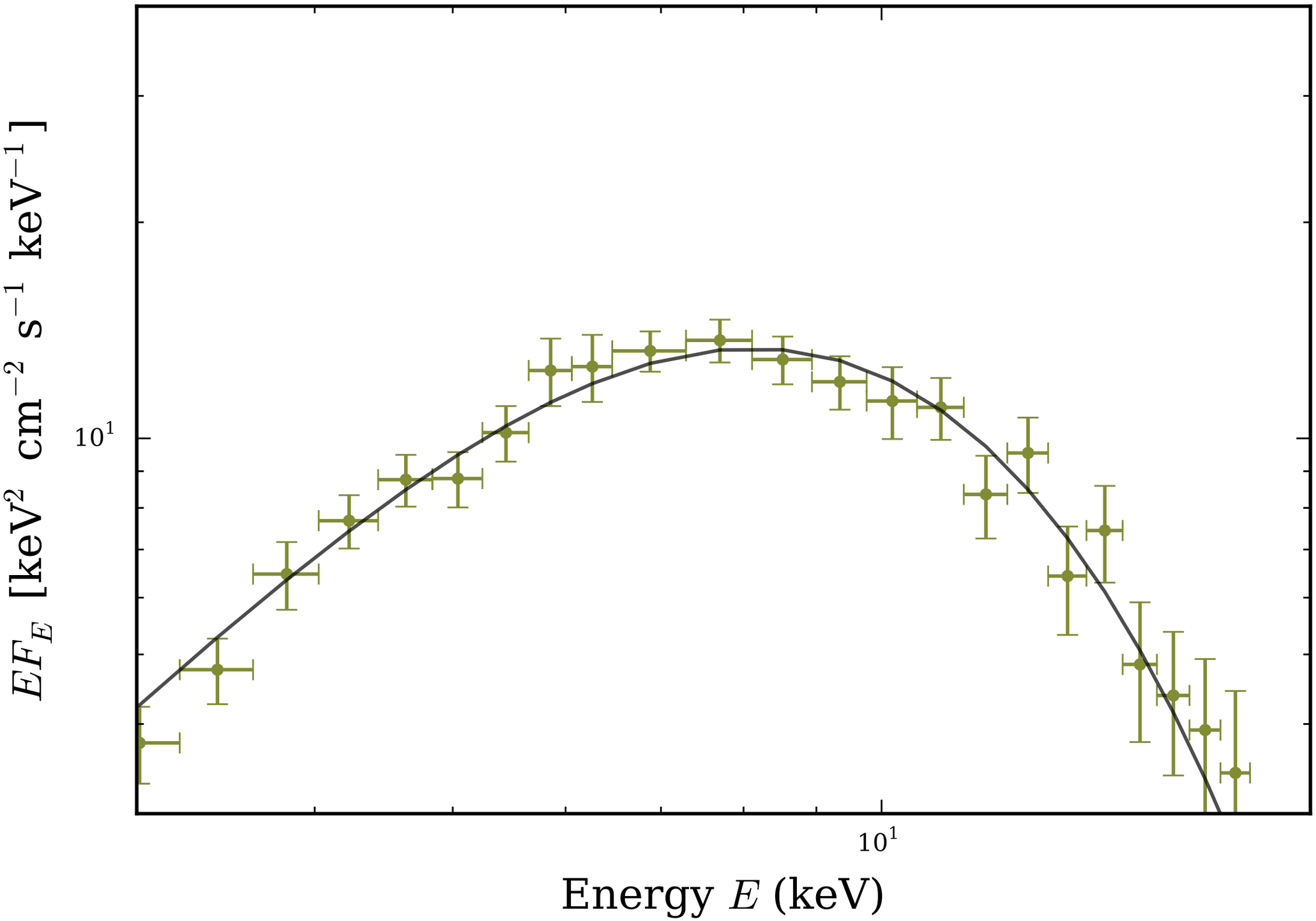

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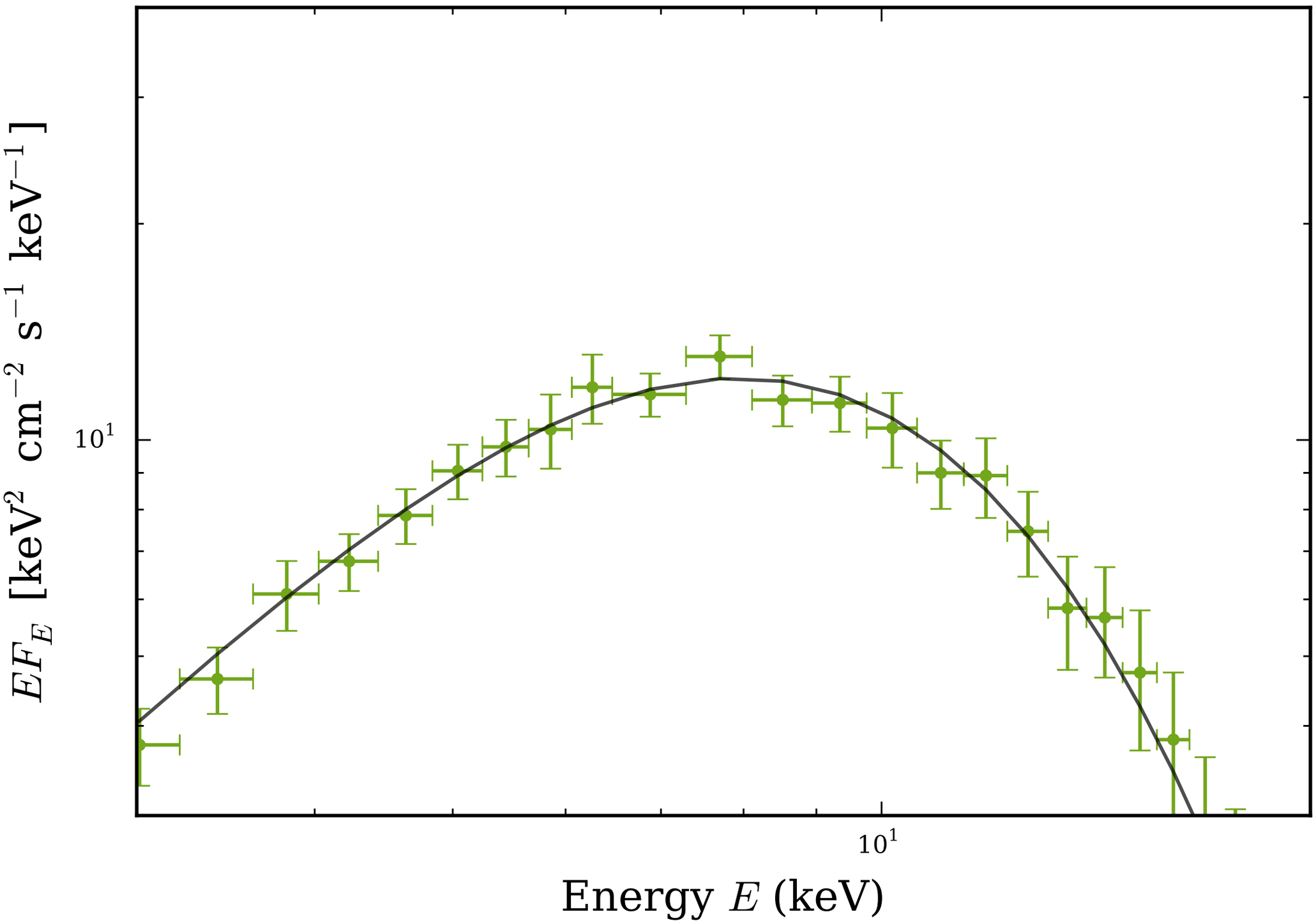
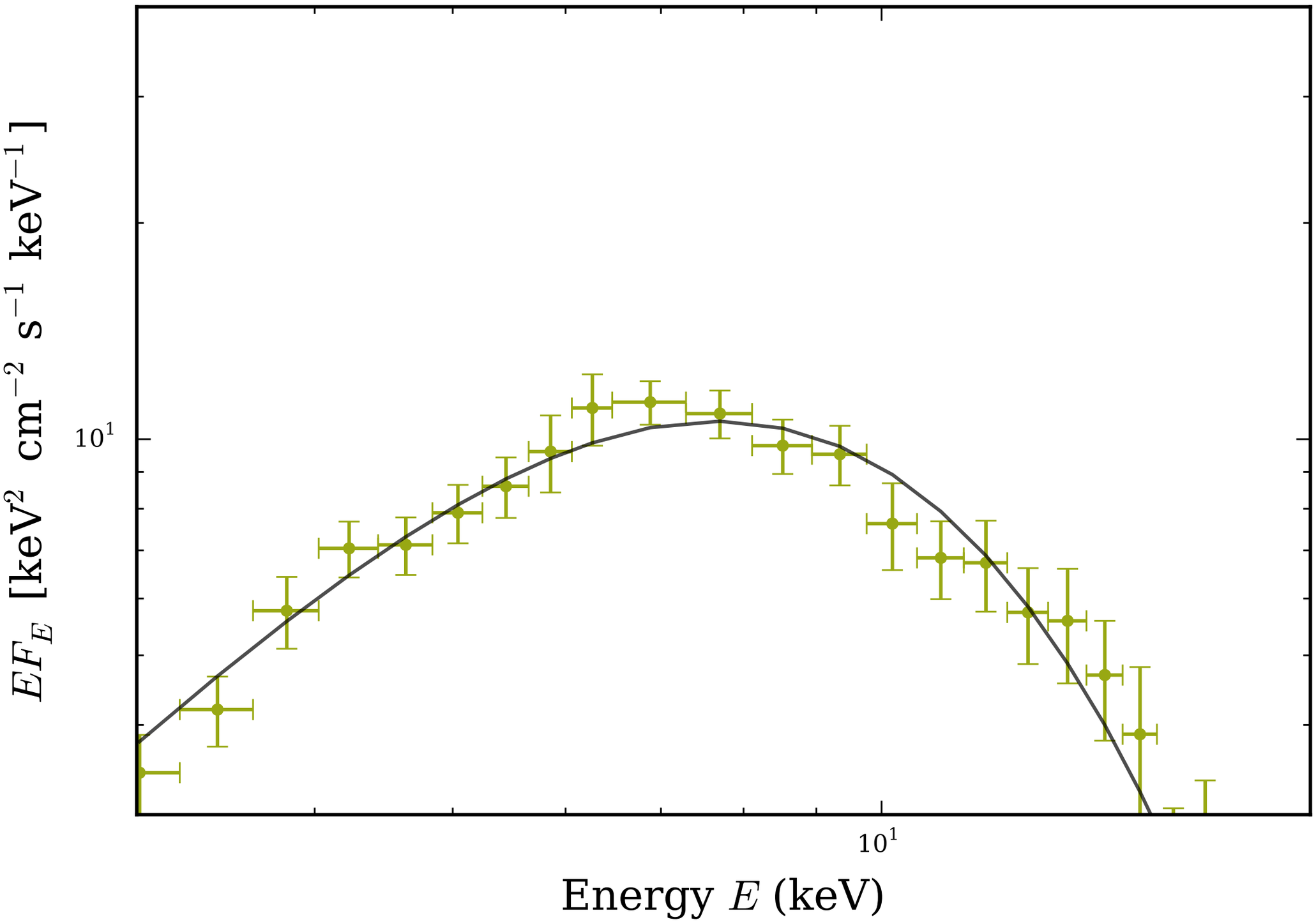


Cooling tail evolution



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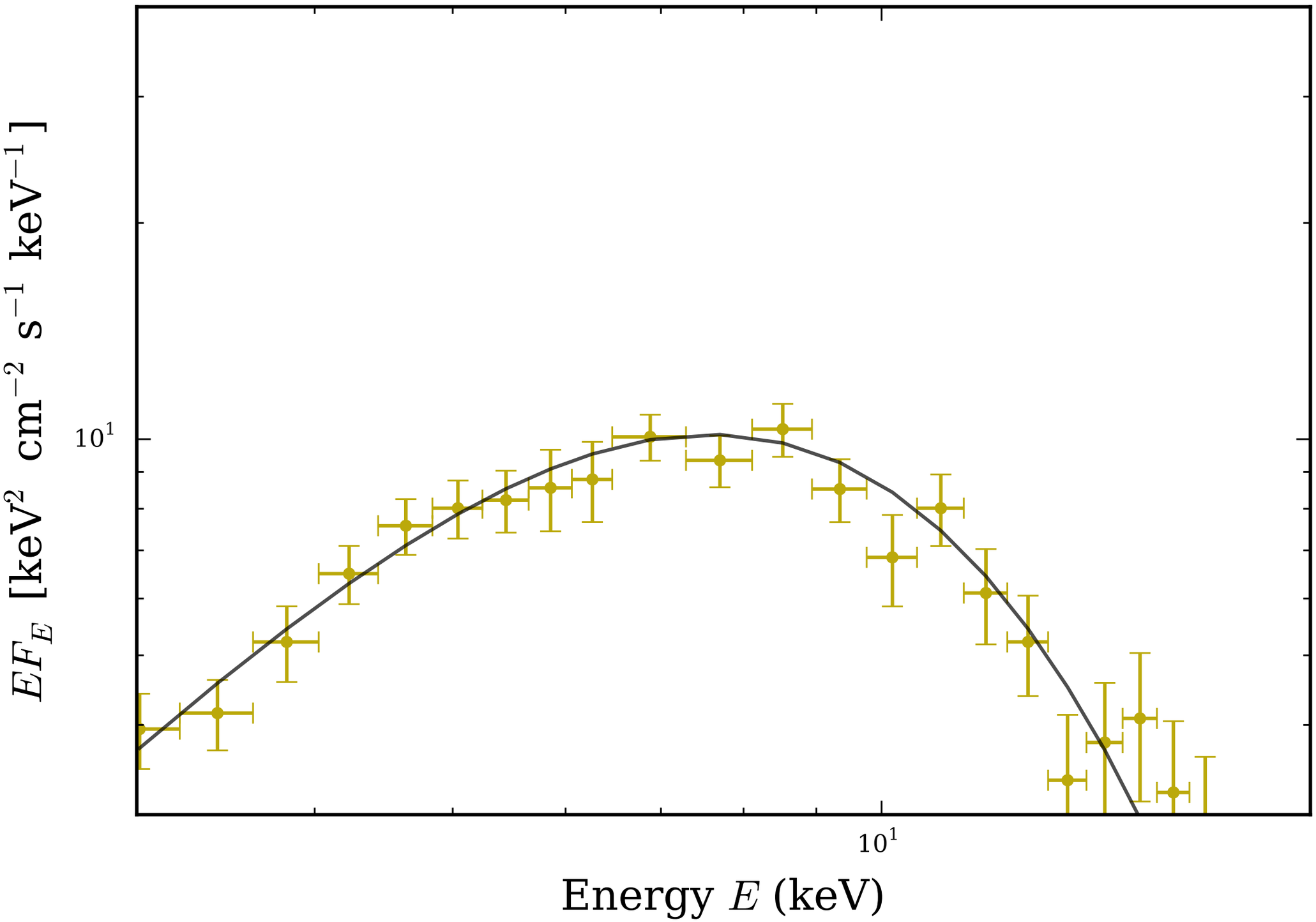

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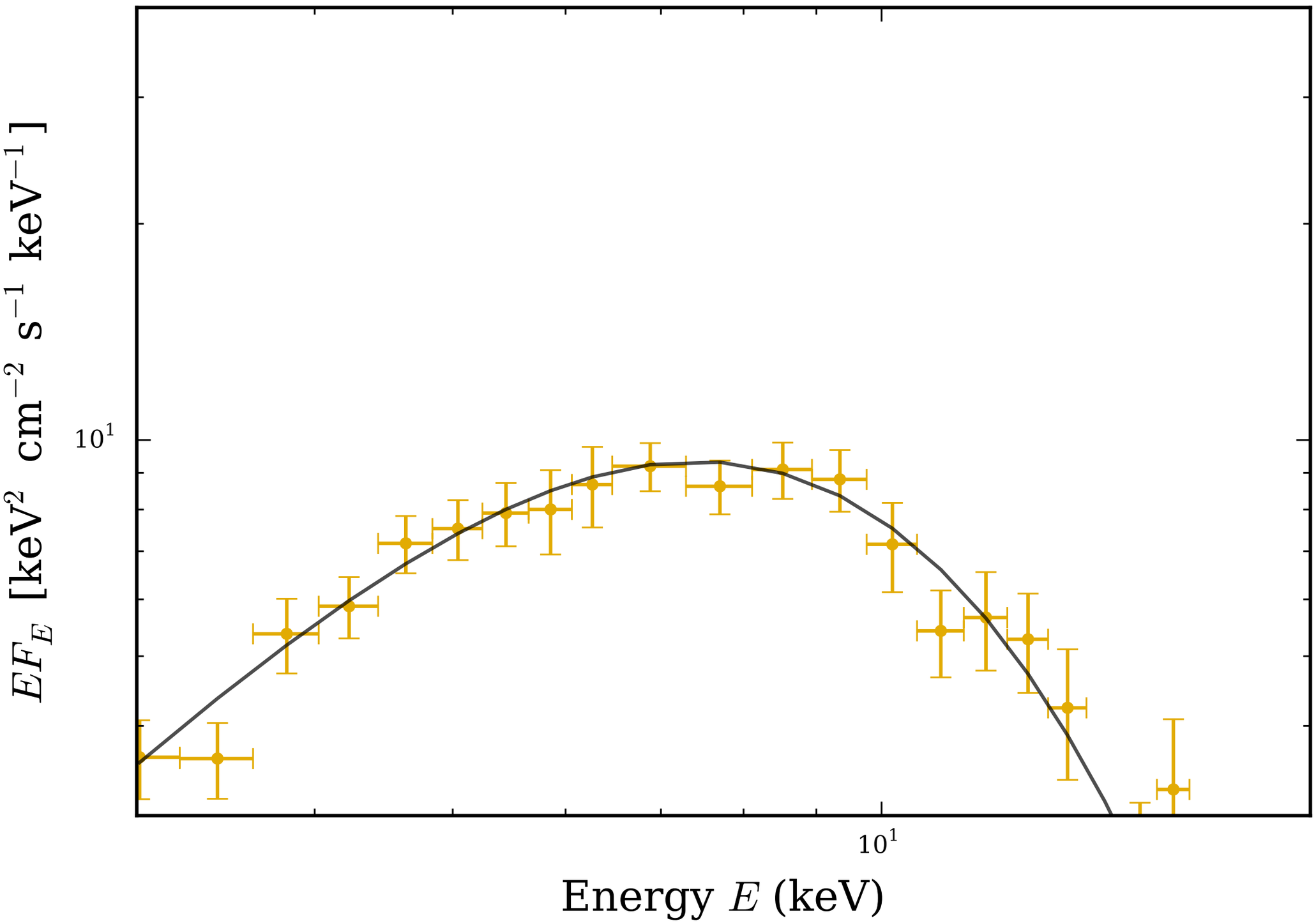

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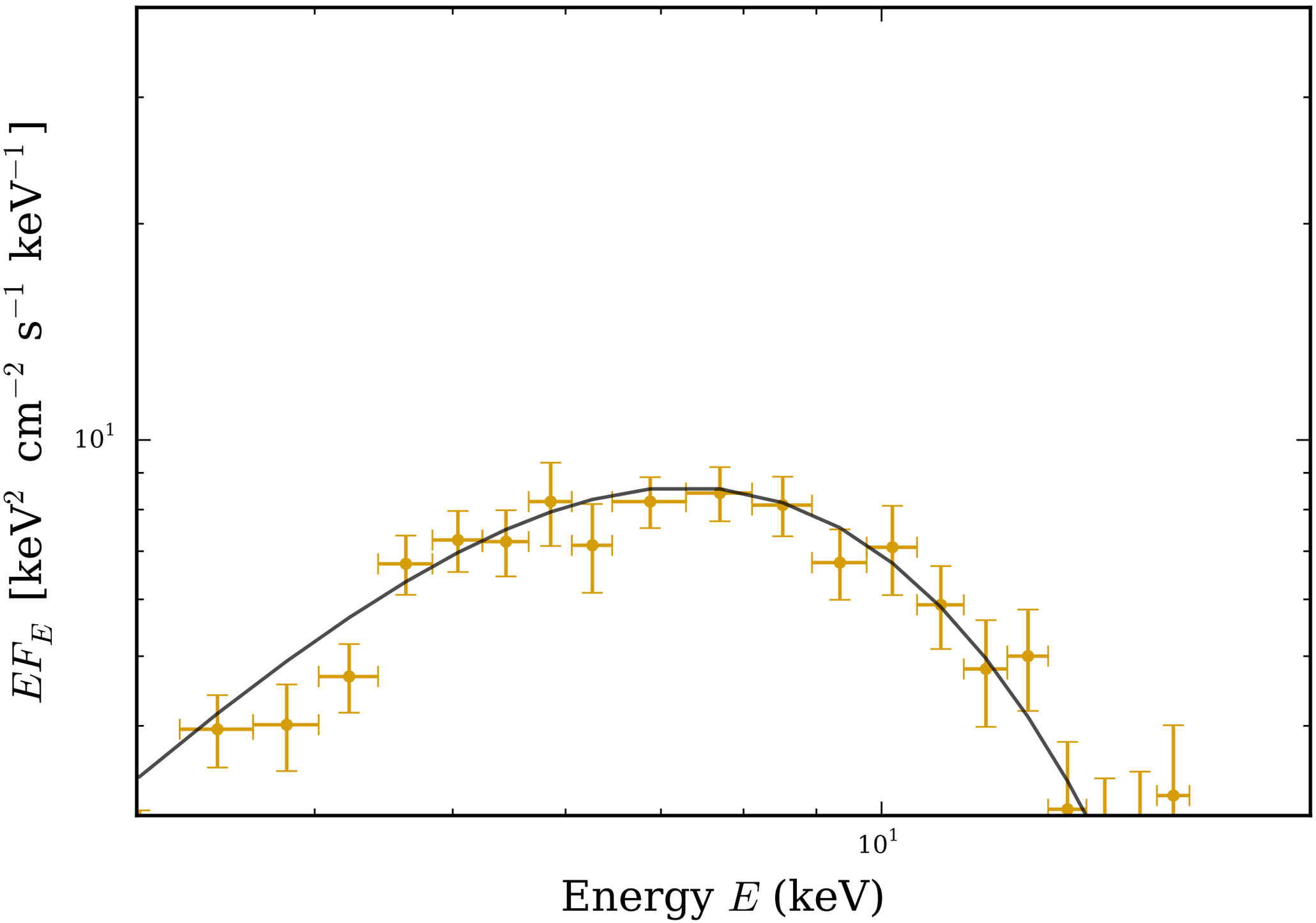

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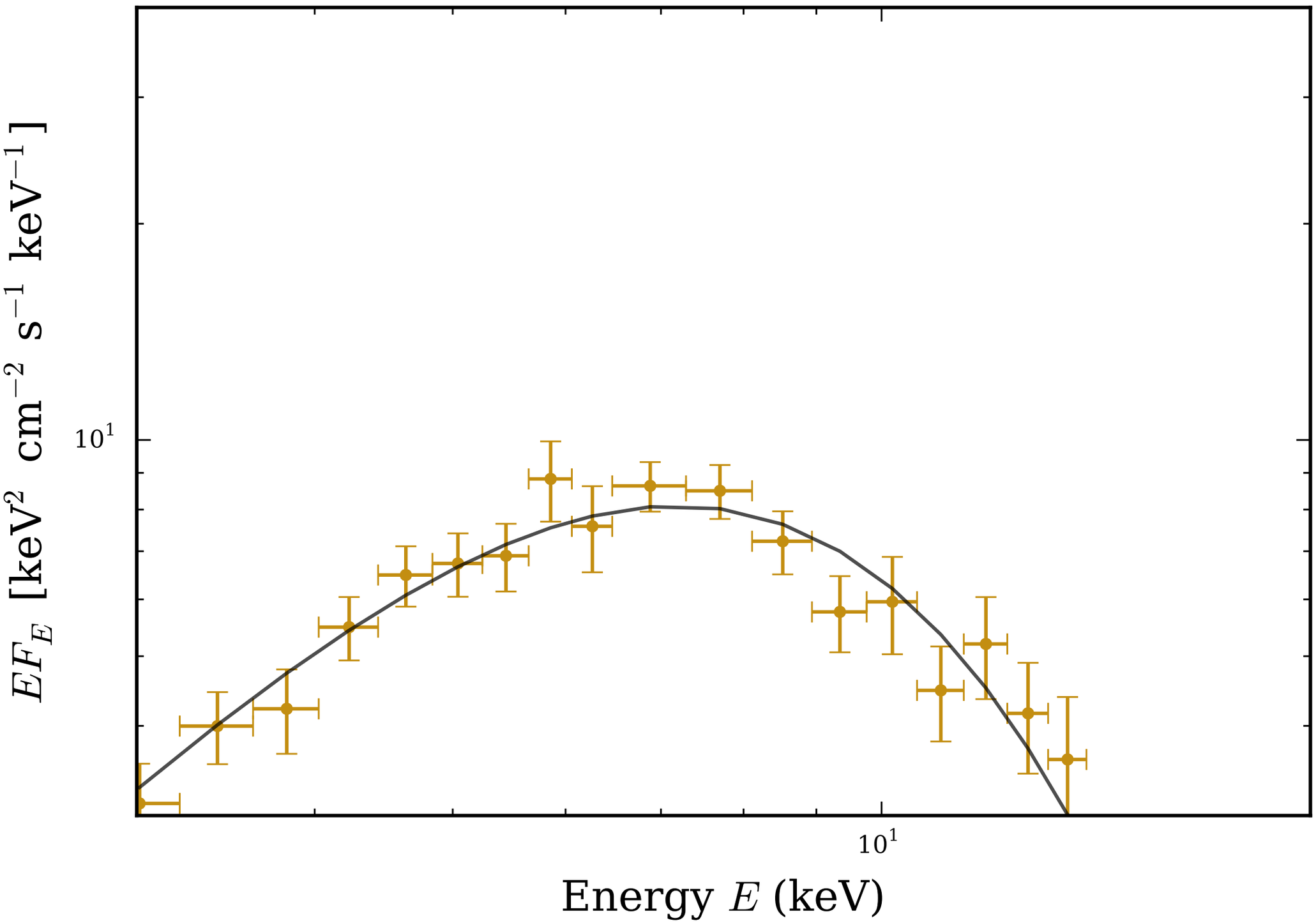


Thermonuclear X-ray bursts

Time-resolved spectroscopy

- Data are well described by atmosphere models
  - Parameters: Mass M
    Radius R
    Distance D
    Composition X

+ each spectrum has a unique temperature T

The problem

$$P(p_j|\mathcal{D})(p_j) \propto \int\int\int\int \ldots \int\int\int\int P(\mathcal{D}|\mathcal{M}) dp_1 \ldots dp_{j-1} dp_{j+1} \ldots dp_N$$

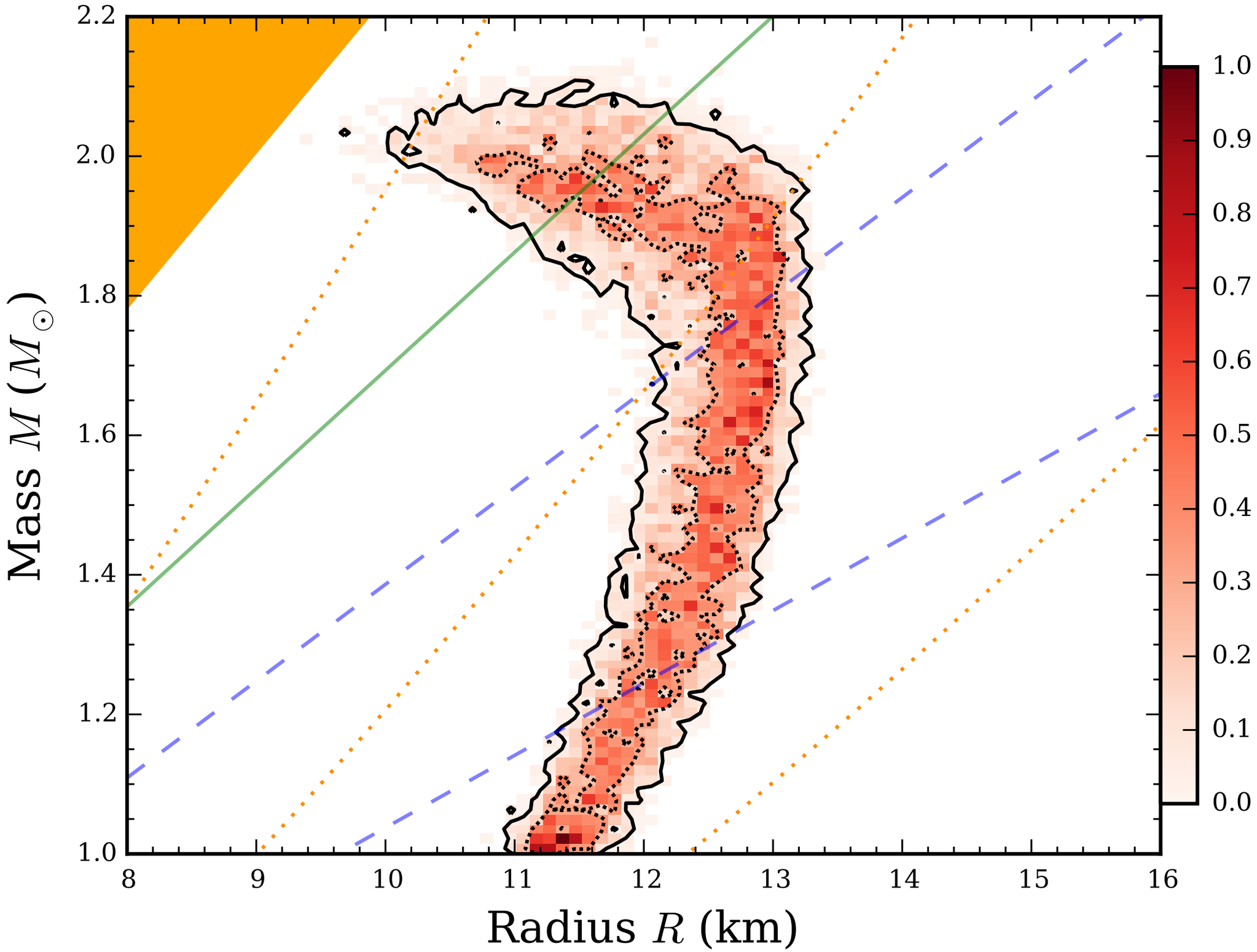
$$N_{\mathrm{b}} \times N_{\mathrm{S}} \times N_{\mathrm{p}} \sim 100 - 300$$

Note: Luckily, in reality, not everything is dependent on everything

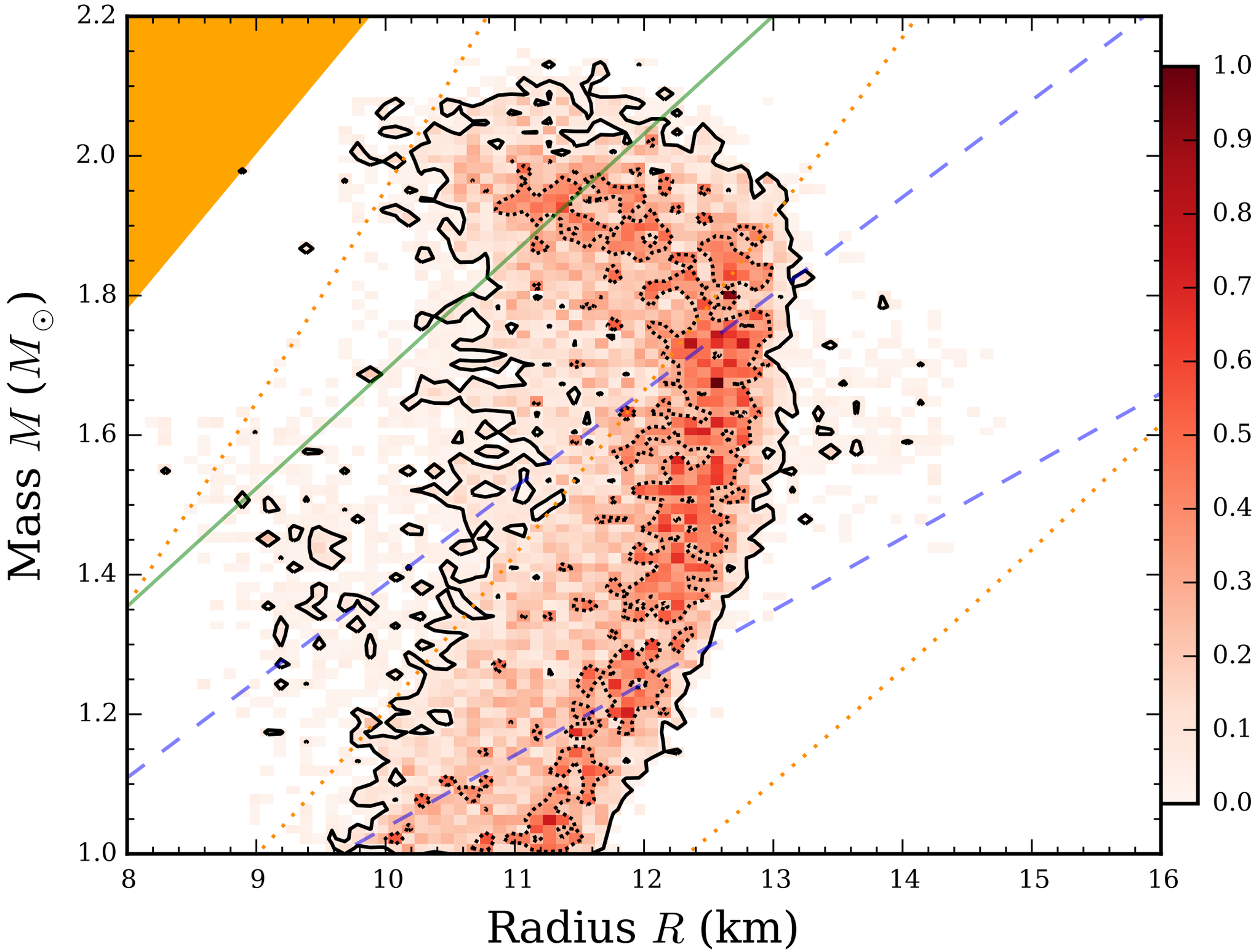
The solution

- Straight out of the oven

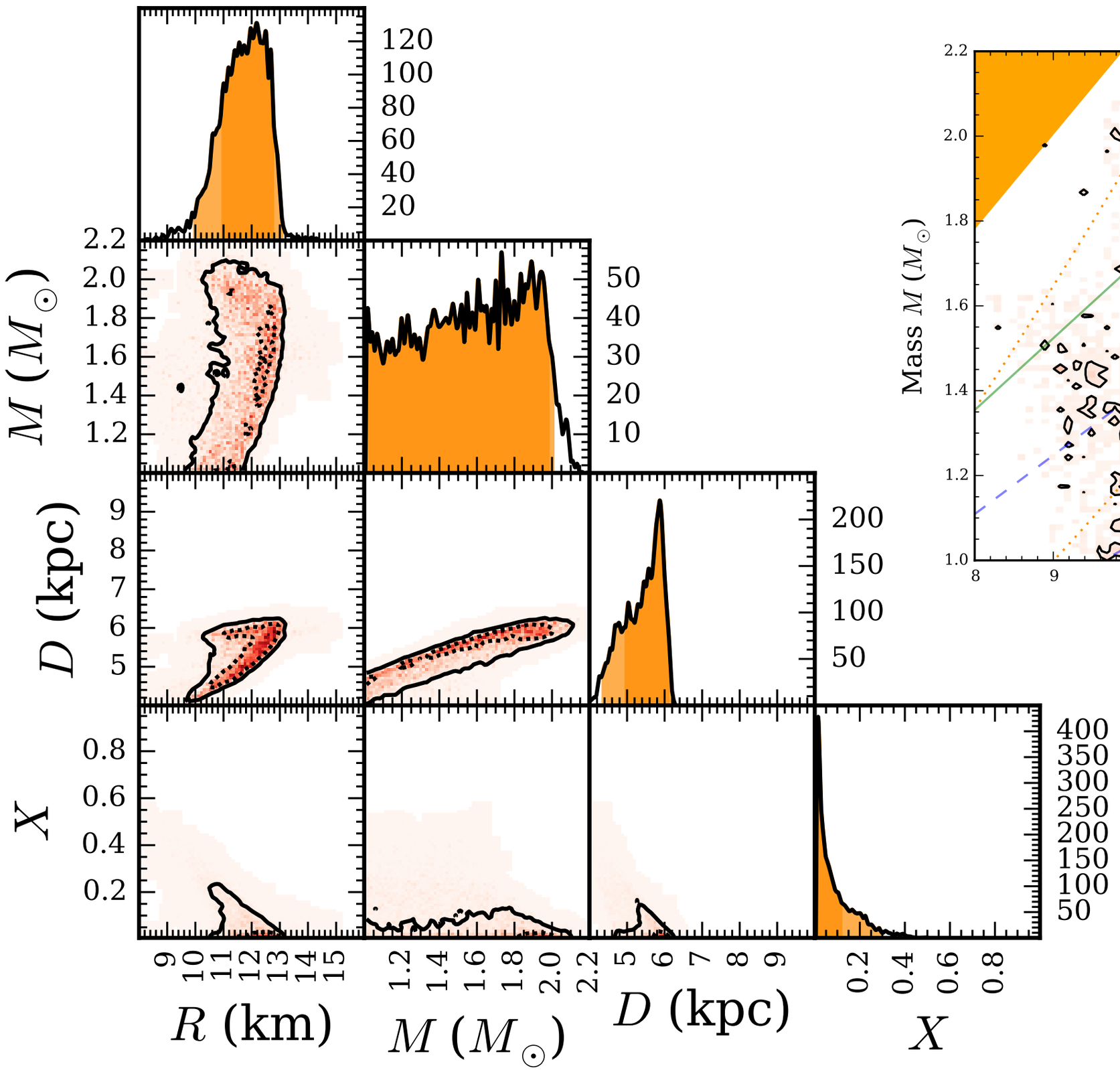
New *M-R* constraints: 4U 1702-429

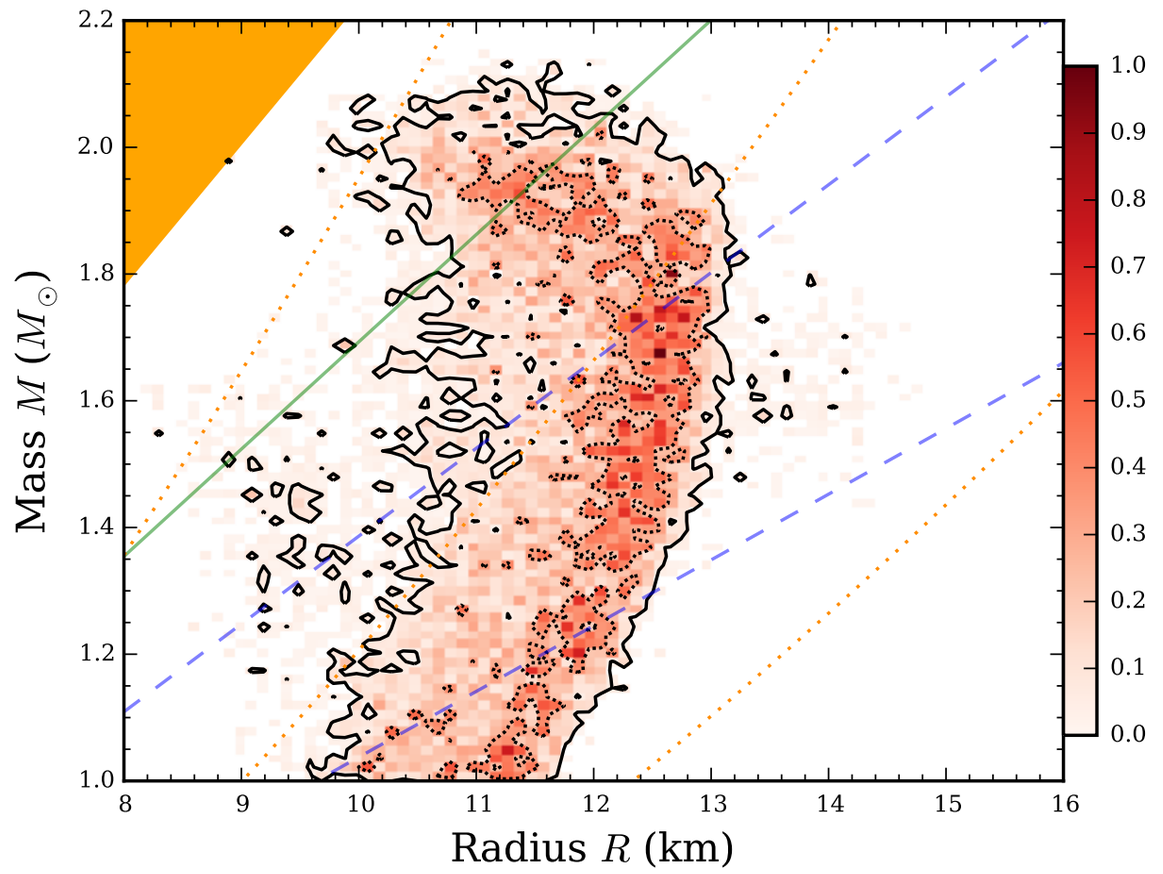


New *M-R* constraints: free X



Full posteriors





Summary

- Thermonuclear X-ray bursts can be a great tool to constrain *M-R*

…If one is cautious!

- Hard state bursts give:

$12 < R < 13$ km for $M = 1.2 - 1.8$ Msun