On Line Driven AGN Winds in the Presence of Raidative Heating

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Athena++ Workshop @ UNLV

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Collaborators: Daniel Proga, Sergei Dyda, Tim Waters, & Tim Kallman

Motivation

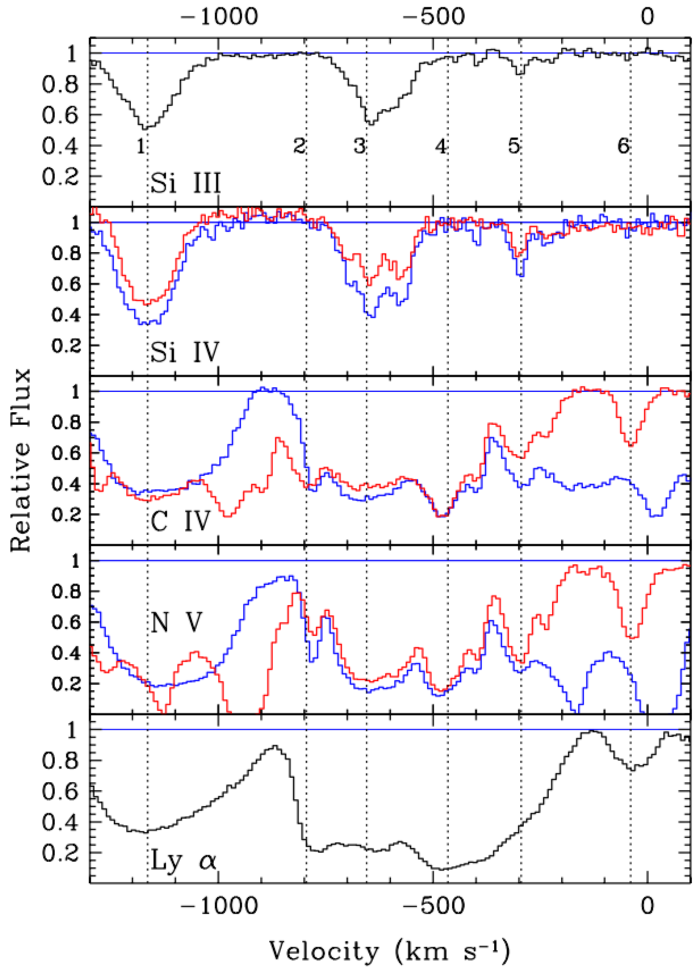
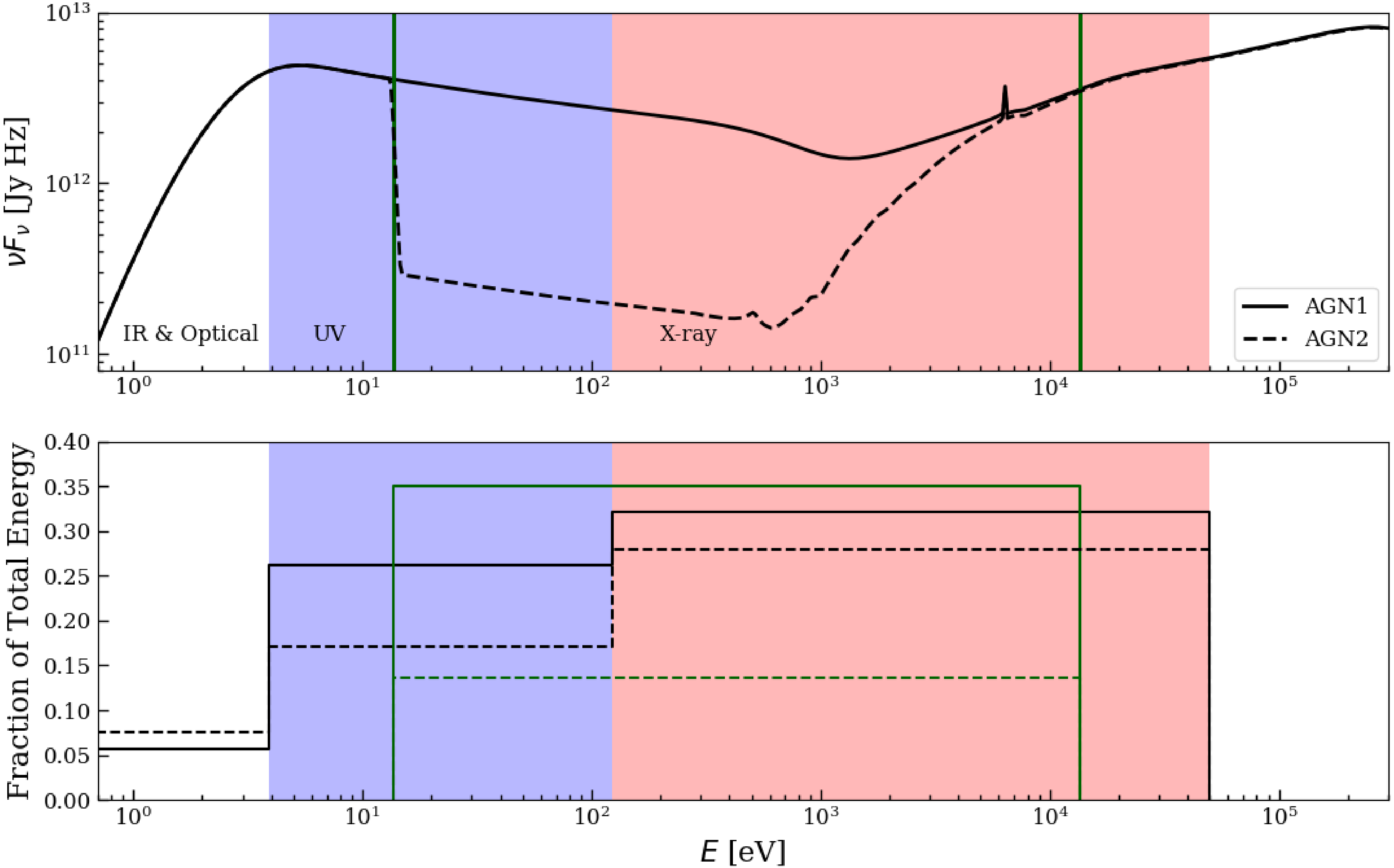


Fig. 1. Intrinsic absorption features in the 2013 COS spectrum of NGC 5548. Normalized relative fluxes are plotted as a function of velocity relative to the systemic redshift of $z = 0.017175$, *top to bottom*: Si III λ1206, Si IV $\lambda\lambda$1394, 1403, C IV $\lambda\lambda$1548, 1550, N V $\lambda\lambda$1238, 1242, and Ly α, as a function of rest-frame velocity. For the doublets the red and blue components are shown in red and blue, respectively. Dotted vertical lines indicate the velocities of the absorption components numbered as in Crenshaw et al. (2003).

Arav et al. 2015

Spectral Energy Distribution

Mehdipour et al. 2015



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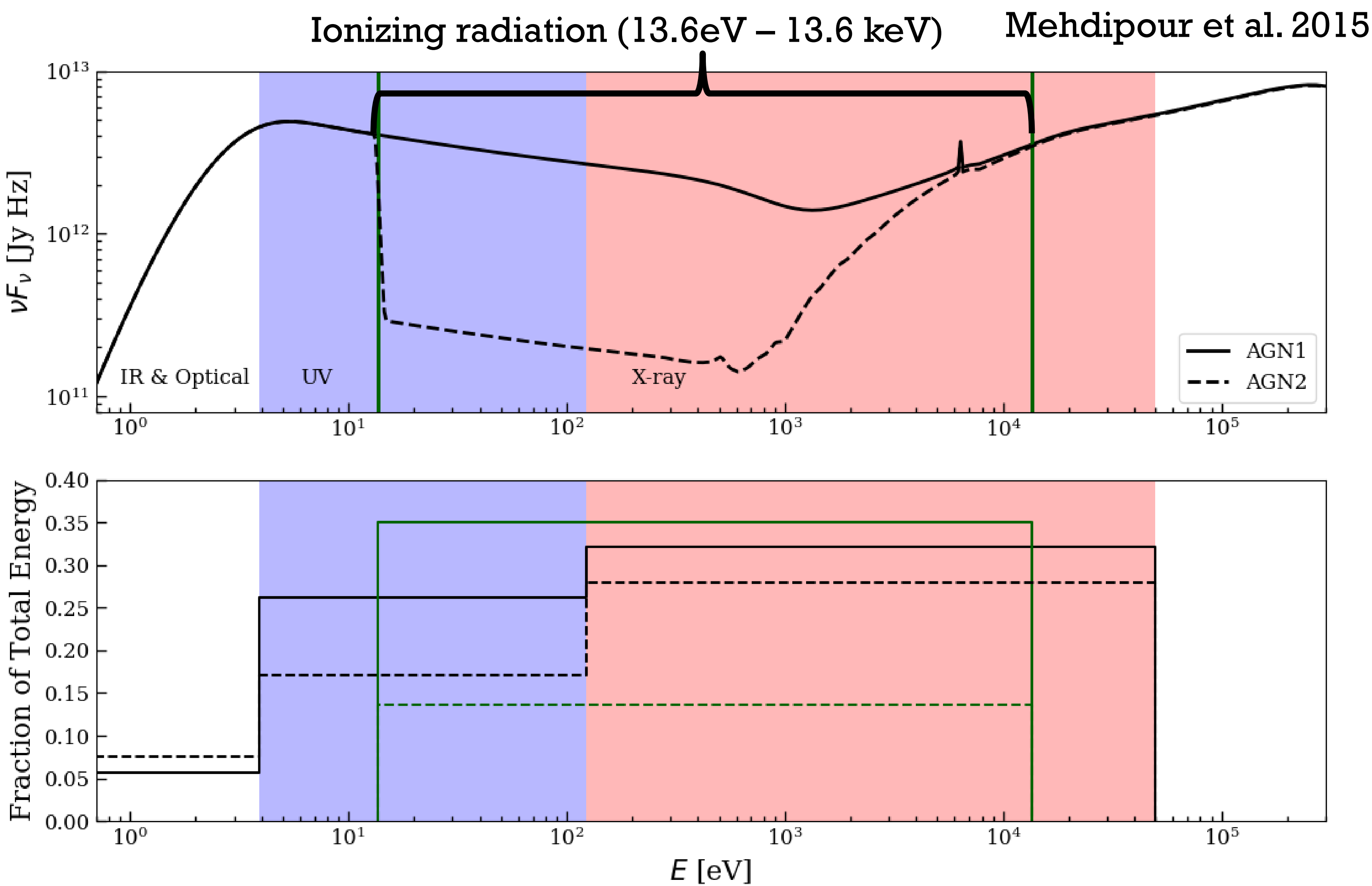

Introduction

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0,$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v} + \mathbf{P}) = -\rho \nabla \Phi + \rho \mathbf{F}^{\mathrm{rad}},$$

$$\frac{\partial E}{\partial t} + \nabla \cdot ((E + P)\mathbf{v}) = -\rho \mathbf{v} \cdot \nabla \Phi - \rho \mathcal{L} + \rho \mathbf{v} \cdot \mathbf{F}^{\mathrm{rad}}$$

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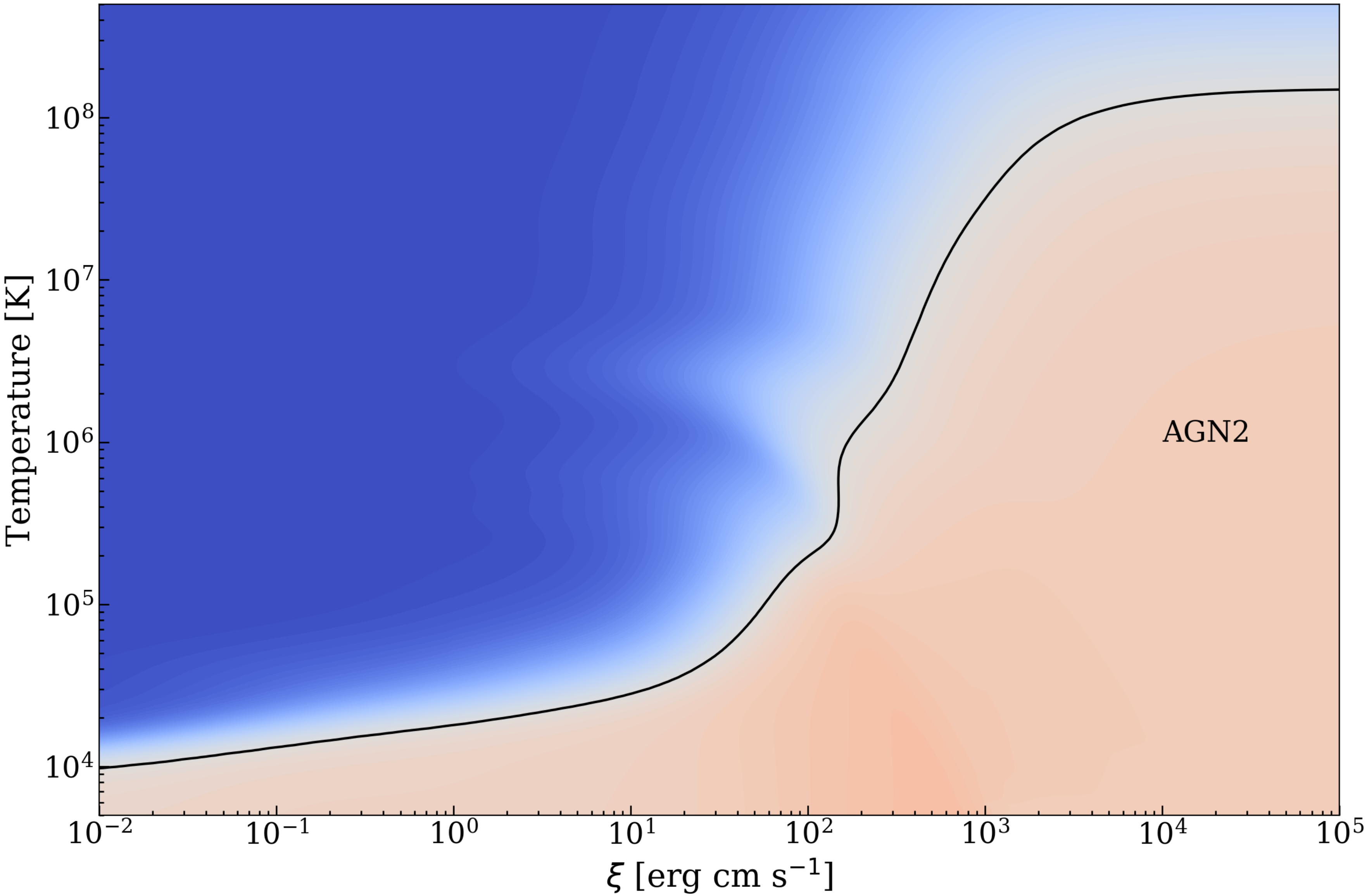
The radiative heating and cooling rates due to the incident SEDdetermined by the photoionization code *XSTAR* (Bautista & Kallman 2001), dependent on the ionization parameter, ξ, and gas temperature.

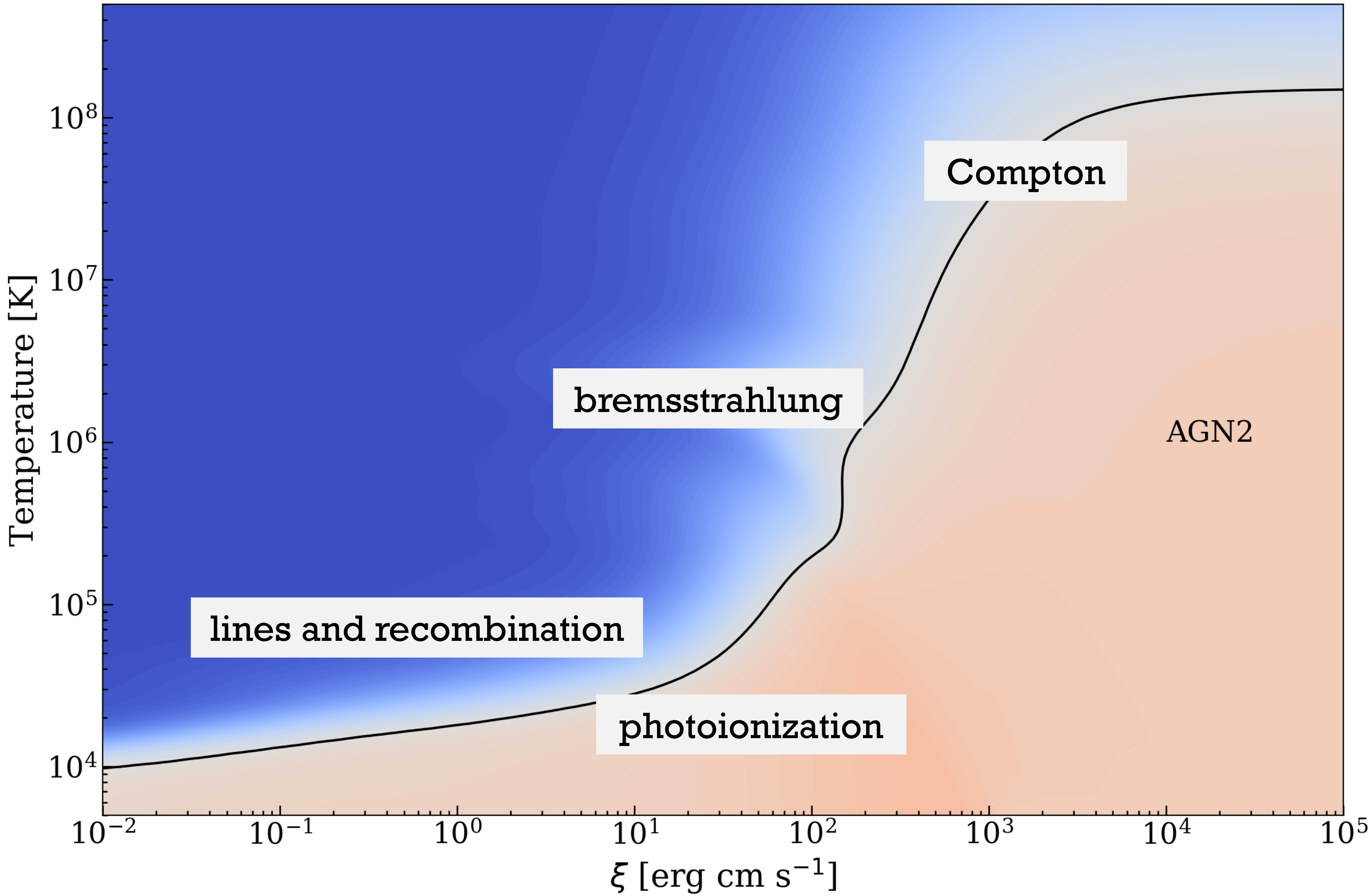
$$\xi = \frac{L_x}{n r^2}$$

XSTAR is a command- driven computer program for calculating the physical conditions and emission spectra of photoionized gases (Bautista & Kallman 2001).

Heating and Cooling



Heating and Cooling



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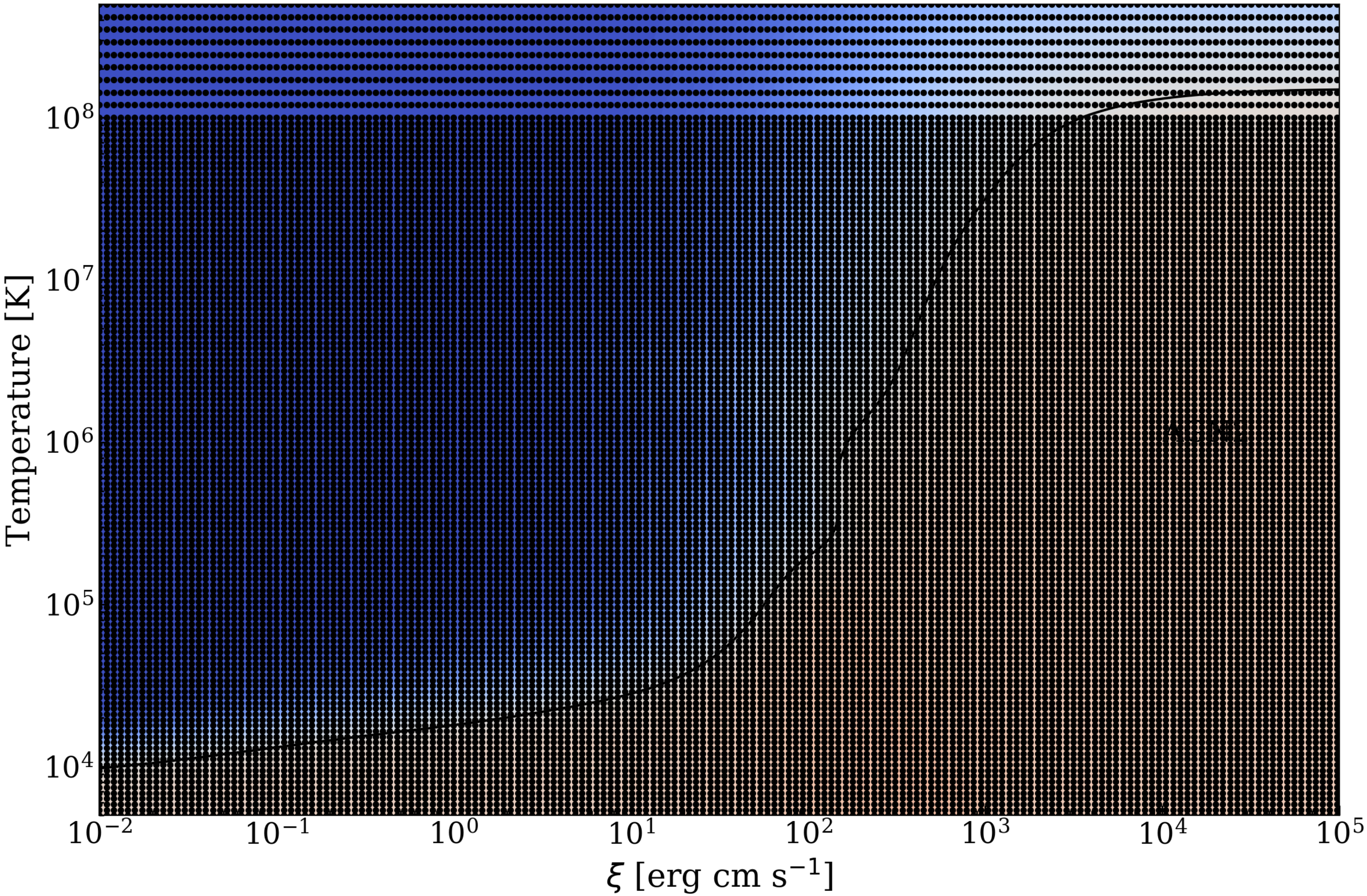

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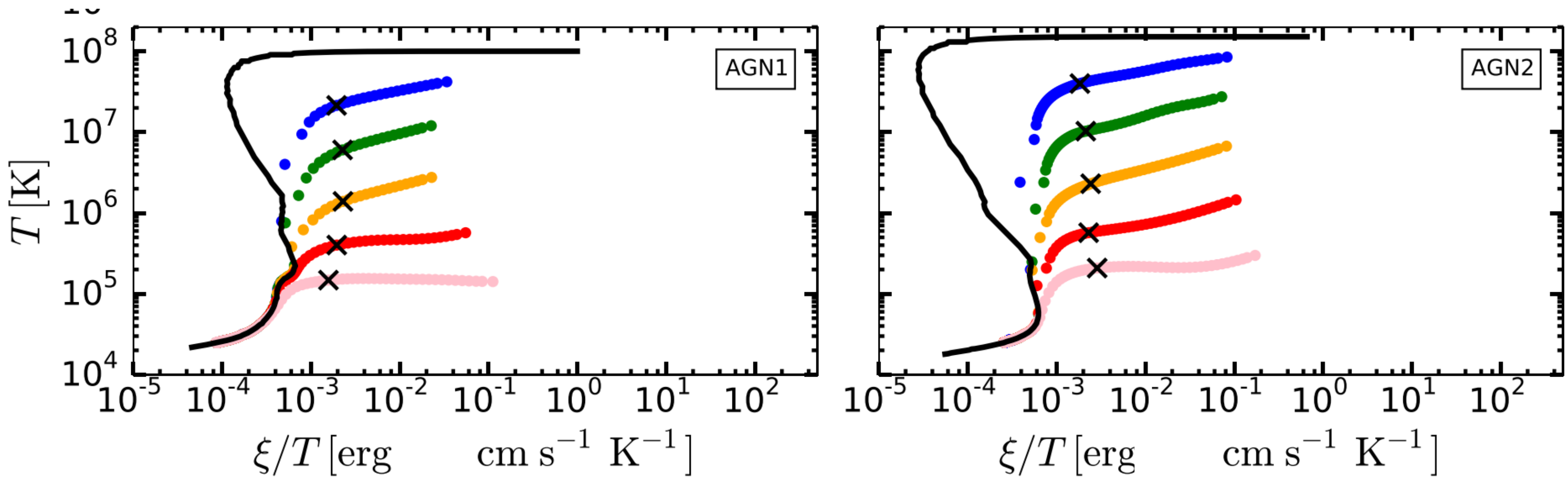
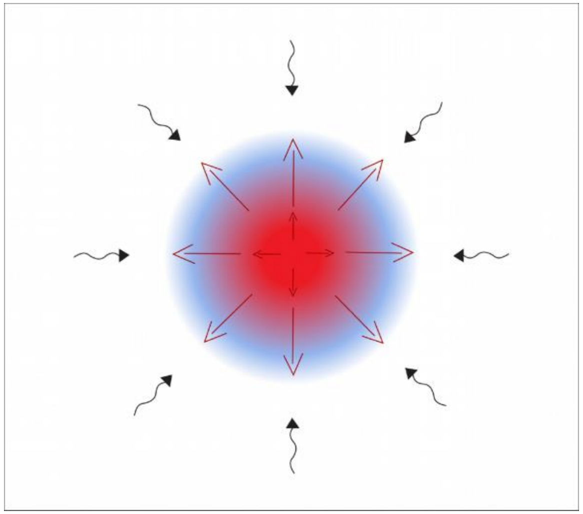
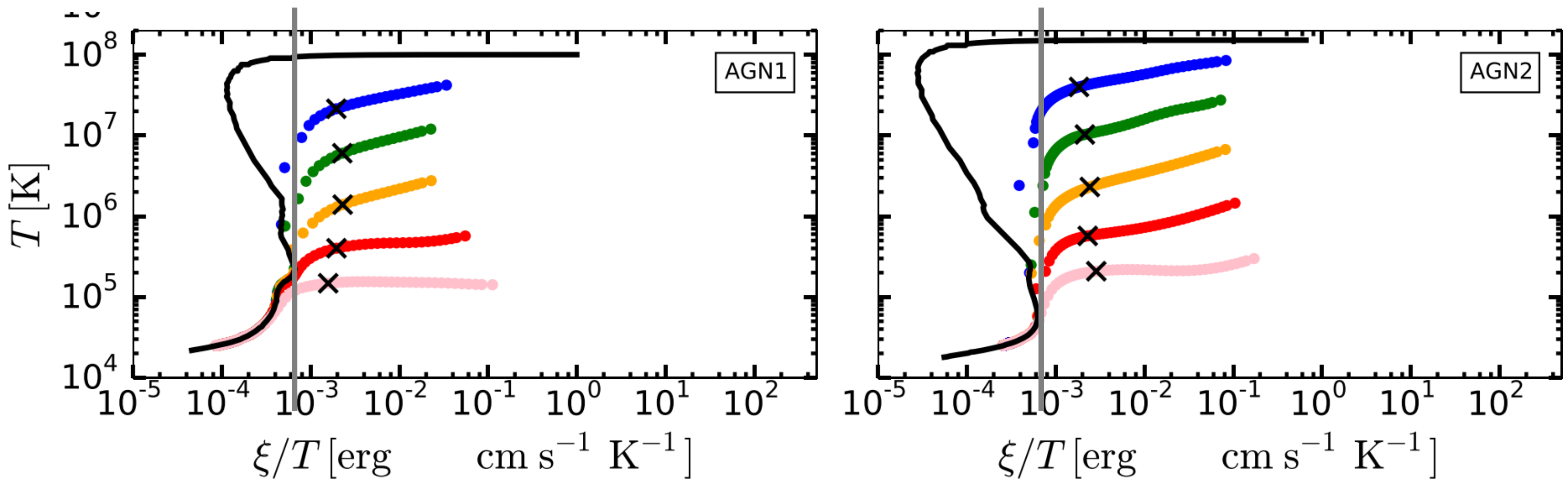


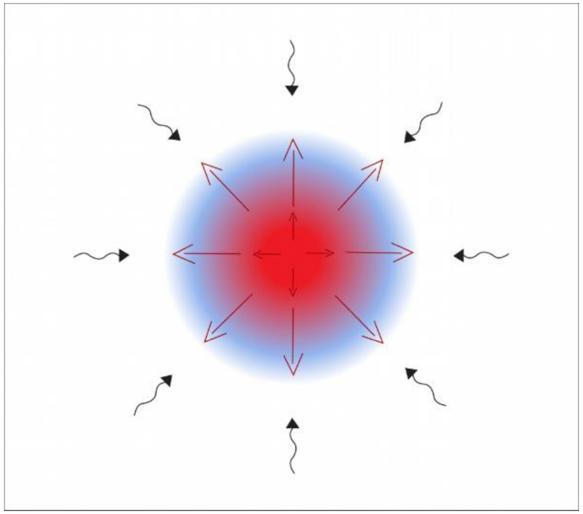


Assuming spherically symmetric distribution for the gas irradiated by a uniform radiation field.

Dyda et al. 2017

Heating and Cooling





Assuming spherically symmetric distribution for the gas irradiated by a uniform radiation field.

Dyda et al. 2017

Radiation Force

$$
\begin{aligned}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0, \\
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\frac{\partial E}{\partial t} + \nabla \cdot ((E + P)\mathbf{v}) &= -\rho \mathbf{v} \cdot \nabla \Phi - \rho \mathcal{L} + \rho \mathbf{v} \cdot \mathbf{F}^{\mathrm{rad}}
\end{aligned}
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$$\mathbf{F}^{\mathrm{rad}} = \left([1 + M(t, \xi)] \hat{\mathbf{n}} \frac{\sigma_e I d\Omega}{c} \right)$$

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The force multiplier due to line absorption.

$$\mathbf{F}^{\mathrm{rad}} = \left([1 + M(t, \xi)] \hat{\mathbf{n}} \frac{\sigma_e I d\Omega}{c} \right)$$

electron scattering

CAK

Castor, Abbott, & Klein (1975; CAK hereafter) give us an expression for the radiation force due to lines,

$$f_{\rm rad,L} = \frac{\kappa_L F_\nu \Delta\nu}{c} \min(1, 1/\tau_L)$$

$$\kappa_L = \frac{\pi e^2}{m_e c} g f \frac{N_L/g_L - N_U/g_U}{\rho \Delta\nu_D}$$

$$\tau_L = \rho \kappa_L \frac{v_{\rm th}}{|dv/dl|}$$

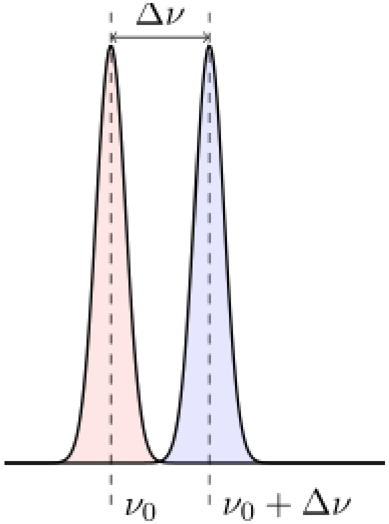
We now introduce scaling factor using the Sobolev approximation

$$t = \frac{\sigma_e \rho v_{\rm th}}{|dv/dr|}$$

Sobolev Approximation

To simplify our calculations, we introduce the Sobolev approximation, one of the most effective means if modeling spectra of astrophysical objects (V.P.Grinin, 2001). The approximation is as follows: for an astrophysical object with large velocity gradients, the interaction between the matter and radiation can characterized by it's local properties.

$$s_l = \frac{v_{\rm th}}{|dv/dl|}$$



CAK

Modified CAK

$$f_{\rm rad,L} = \frac{\kappa_L F_\nu \Delta\nu}{c} \min(1, 1/\tau_L)$$

$$\kappa_L = \frac{\pi e^2}{m_e c} g f \frac{N_L/g_L - N_U/g_U}{\rho \Delta\nu_D}$$

$$\tau_L = \rho \kappa_L \frac{d \ln \xi}{dr}$$

So maybe we can use the ionization parameter length scale instead?

$$t = \sigma_e \rho \frac{d \ln \xi}{dr}$$

CAK

Now let's write an expression for the total force due to lines

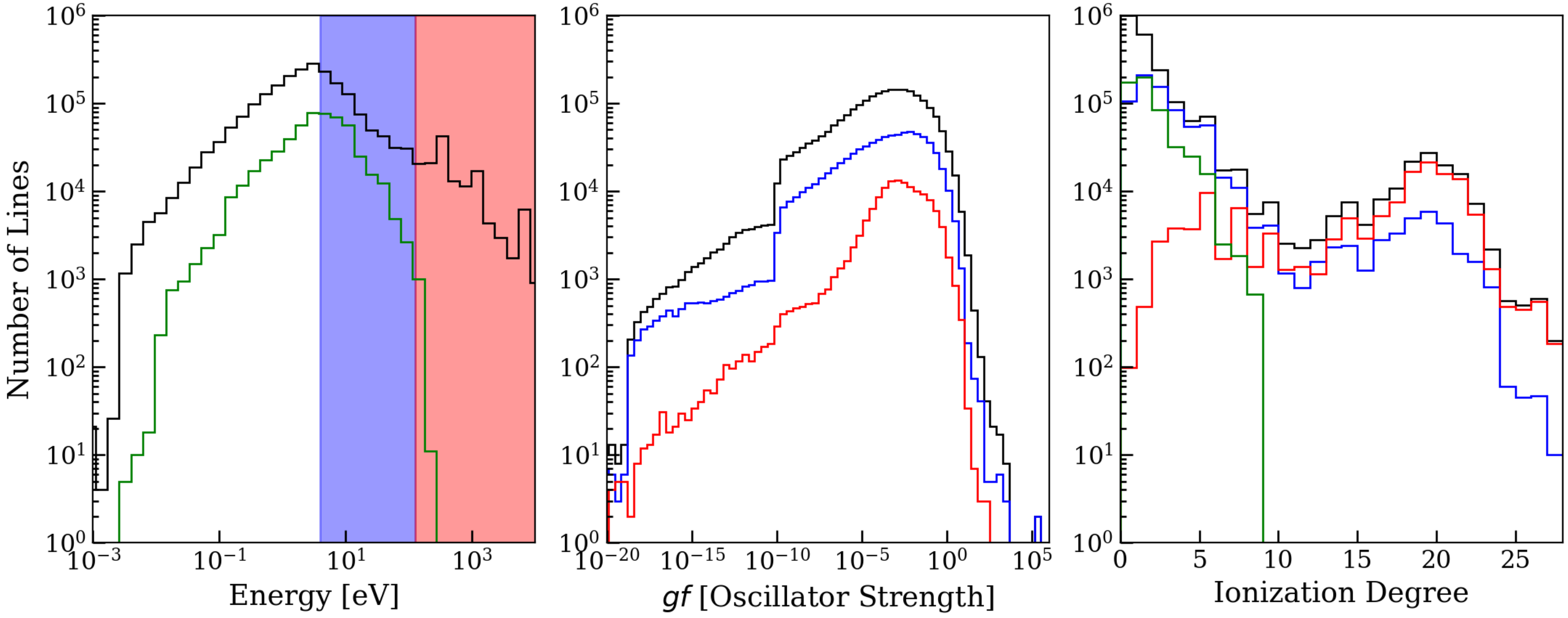
$$f_{\rm rad} = \frac{\sigma_e}{c} F M(t)$$

Where M(t) is our force multiplier (Abbot 1982),

$$M(t) = \sum_{\rm lines} \frac{F_c \Delta\nu_D}{F} \frac{1}{t} \left(1 - e^{-\eta t}\right)$$

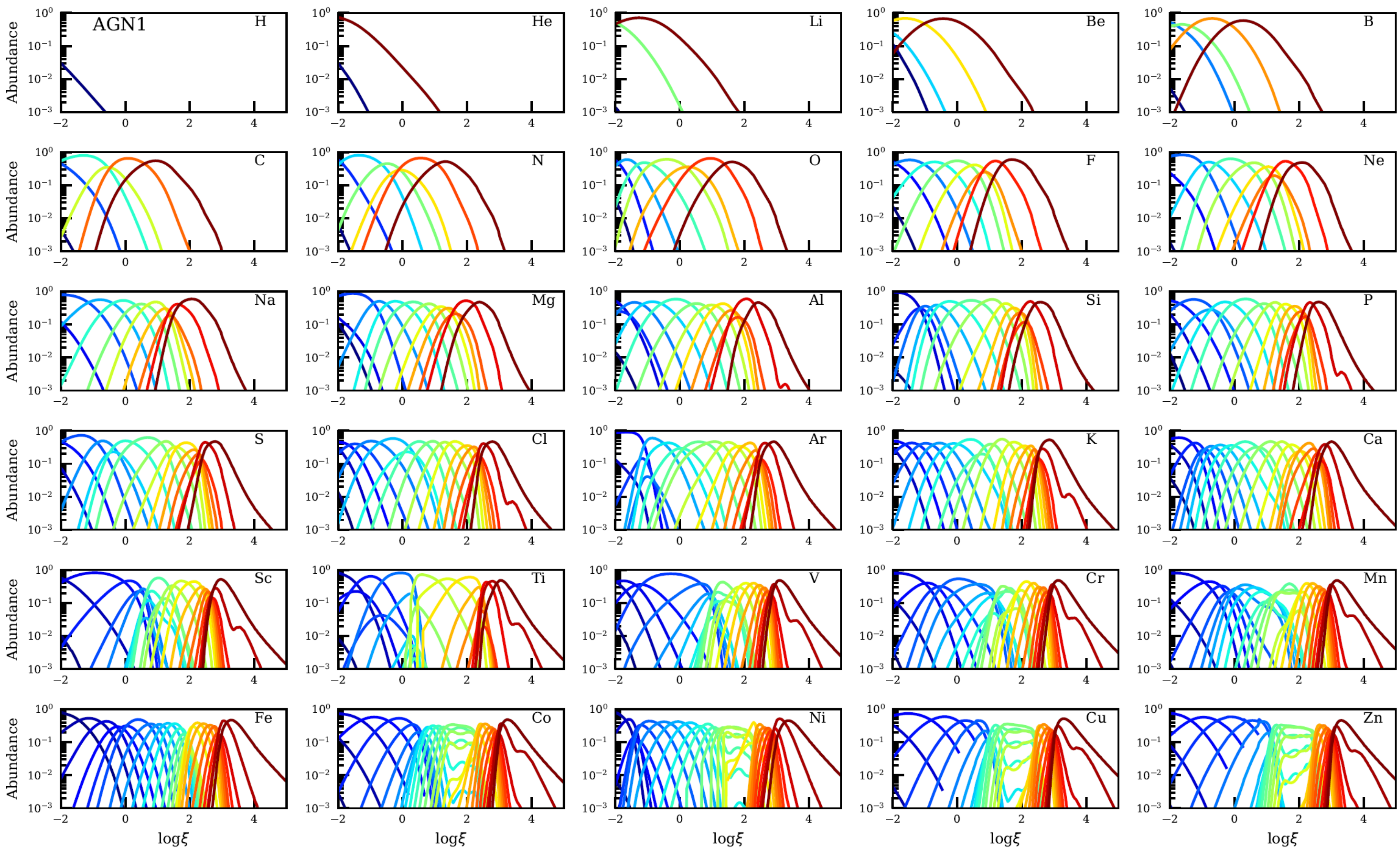
$$\eta = \frac{1}{\beta} = \frac{\pi e^2}{m_e c} g f \frac{N_L/g_L - N_U/g_U}{\sigma_e \rho \Delta\nu_D}$$

Line List

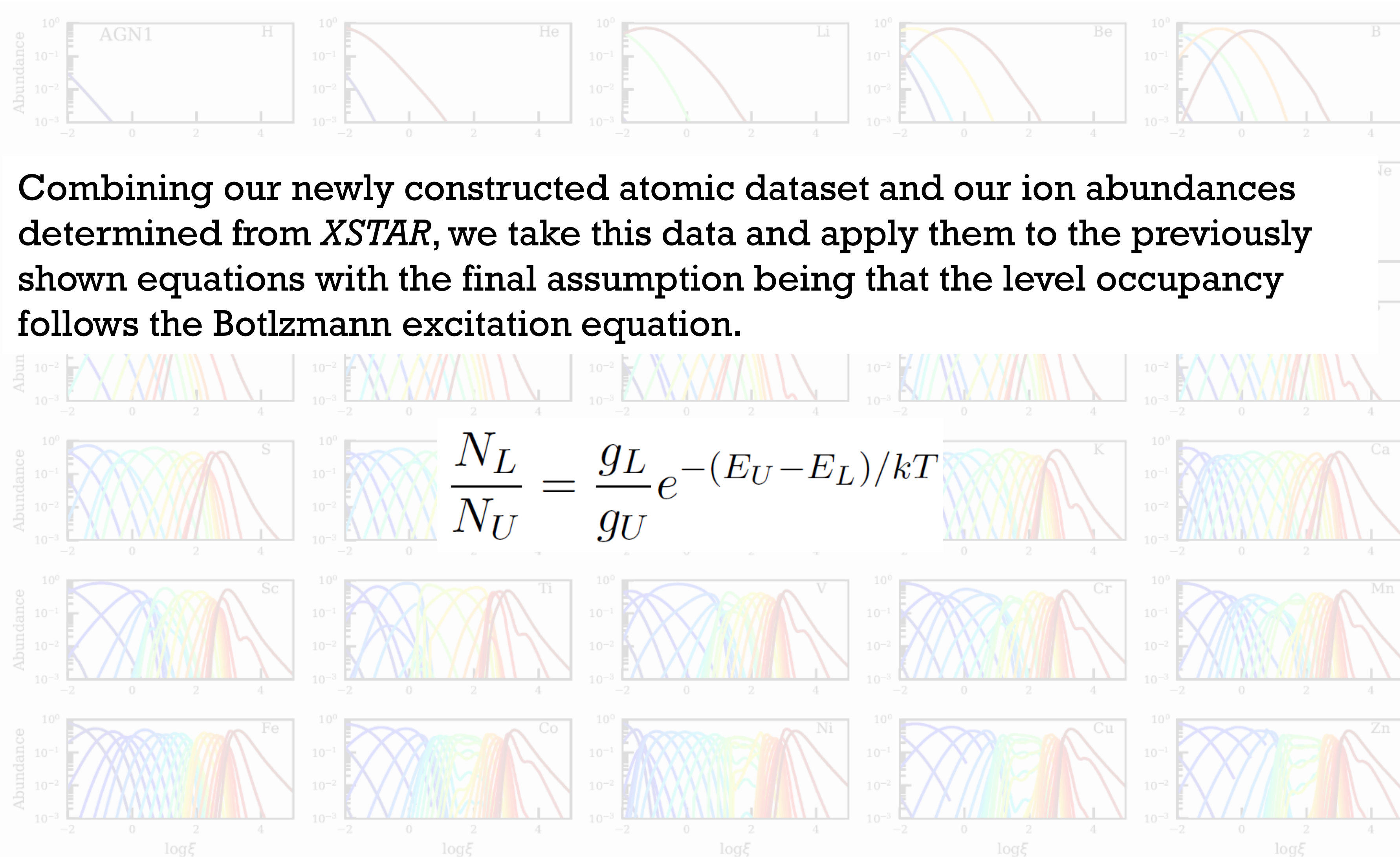


Number of Lines
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^{-3}
10^{-1}
10^1
10^3
Energy [eV]
10^{-20}
10^{-15}
10^{-10}
10^{-5}
10^0
10^5
gf [Oscillator Strength]
0
5
10
15
20
25
Ionization Degree

Ionic Abundances



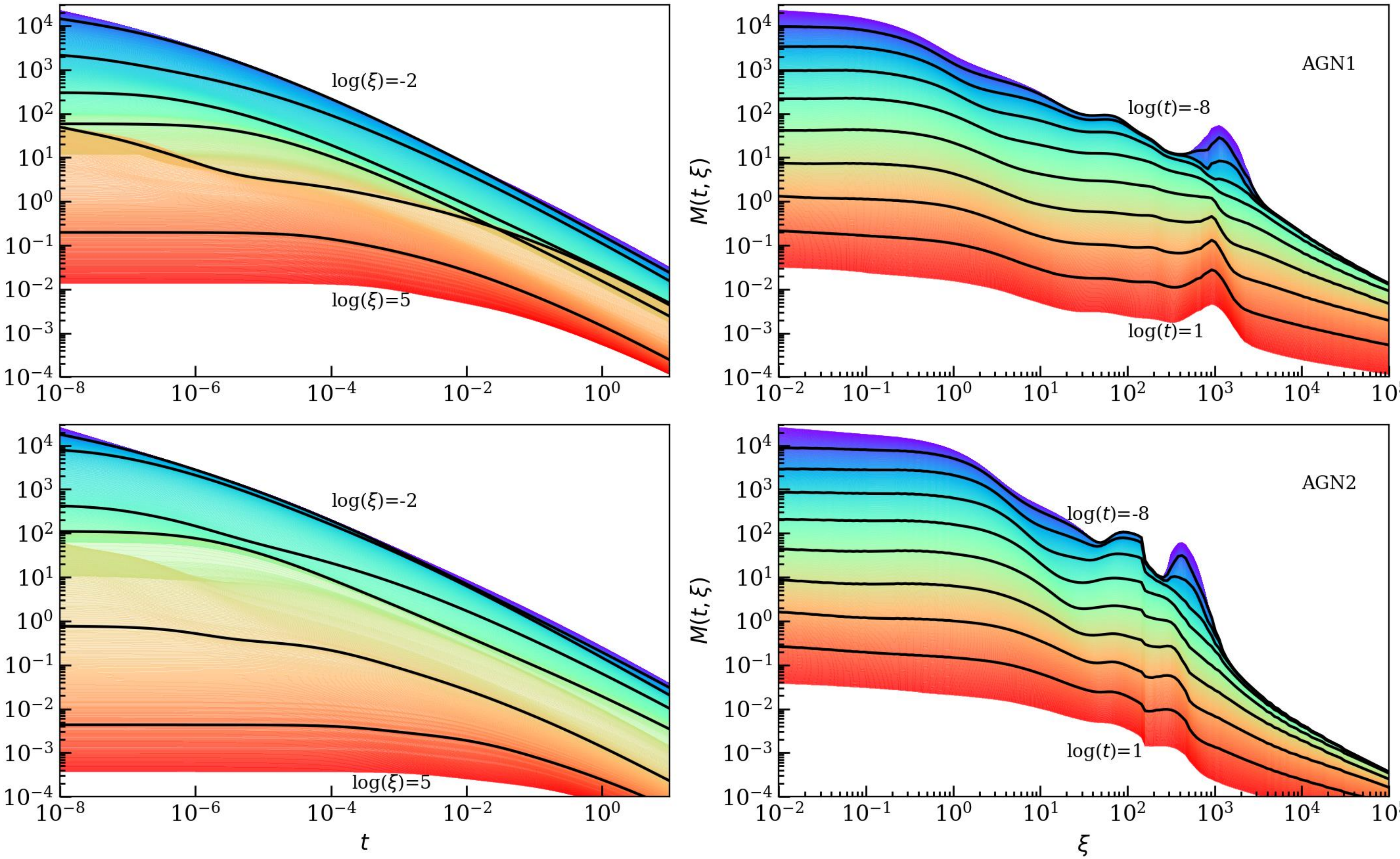
Level Populations



Combining our newly constructed atomic dataset and our ion abundances determined from *XSTAR*, we take this data and apply them to the previously shown equations with the final assumption being that the level occupancy follows the Botlzmann excitation equation.

$$\frac{N_L}{N_U} = \frac{g_L}{g_U} e^{-(E_U - E_L)/kT}$$

Force Multiplier Results



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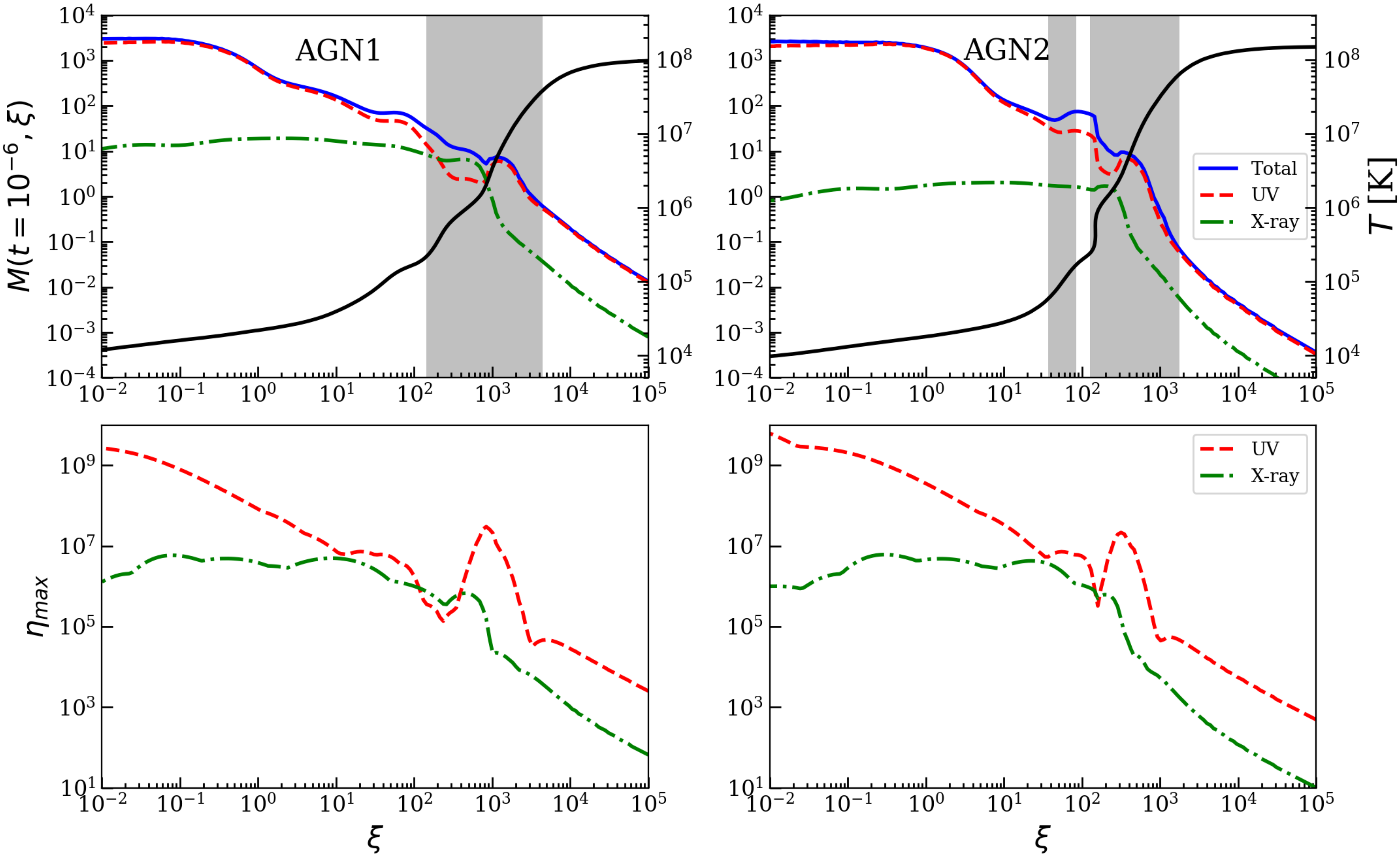

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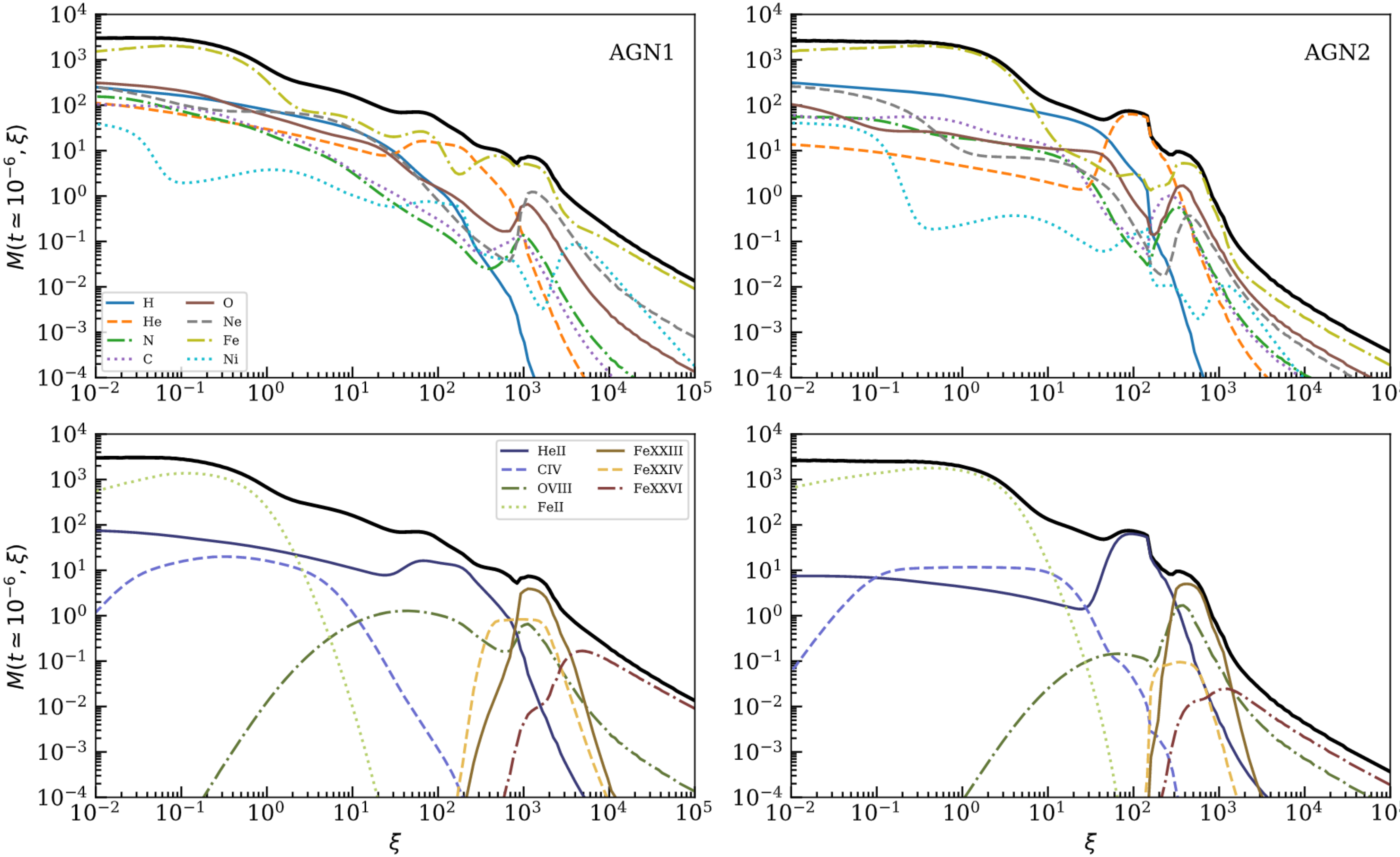
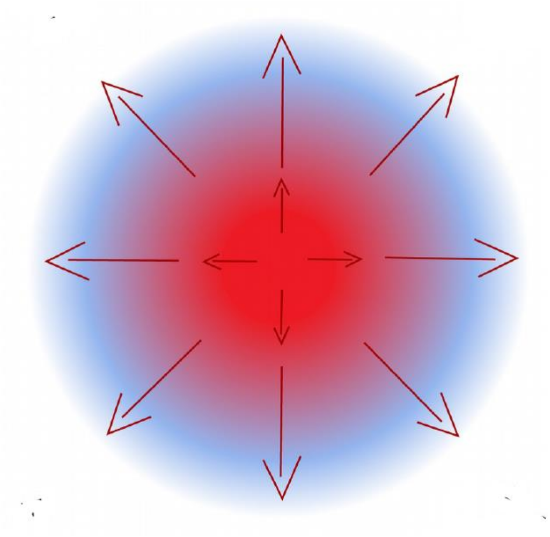


Hydro Setup

Much like for the thermally driven winds, we choose a spherically symmetric setup, but instead of a uniform radiation field, we instead assume the radiation is provided by a central point source.



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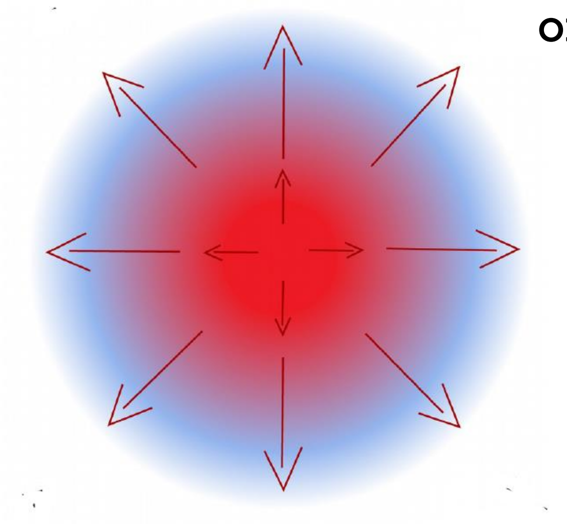
Much like for the thermally driven winds, we choose a spherically symmetric setup, but instead of a uniform radiation field, we instead assume the radiation is provided by a central point source. We need to specify three quantities at the inner boundary.



First, we specify the ionization parameter at the inner radius of our domain

$$\xi = \frac{4\pi F}{n}$$

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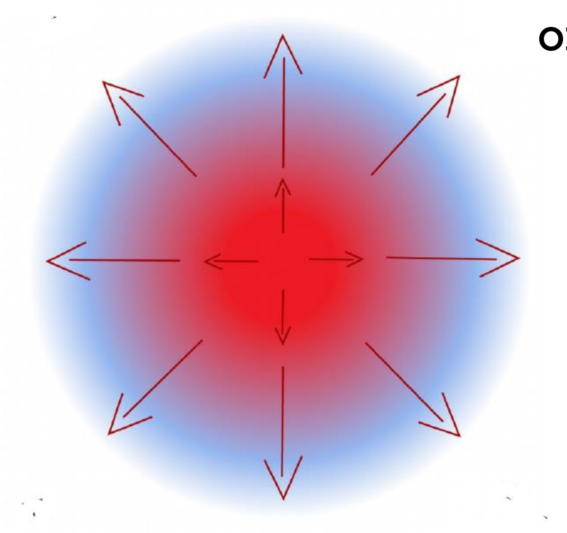

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$$F = \Gamma \frac{G M c \mu m_p}{\sigma_T r_*^2}$$

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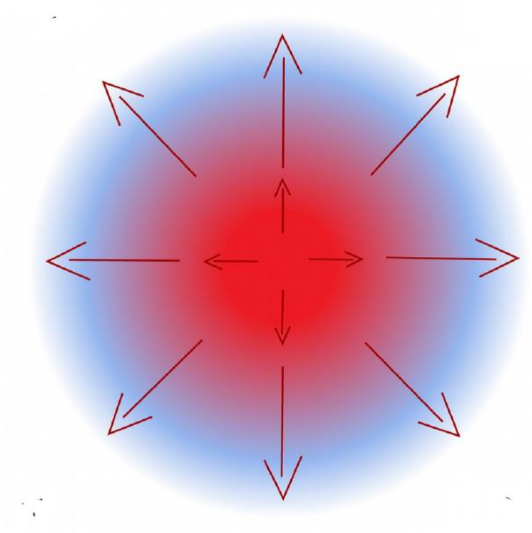

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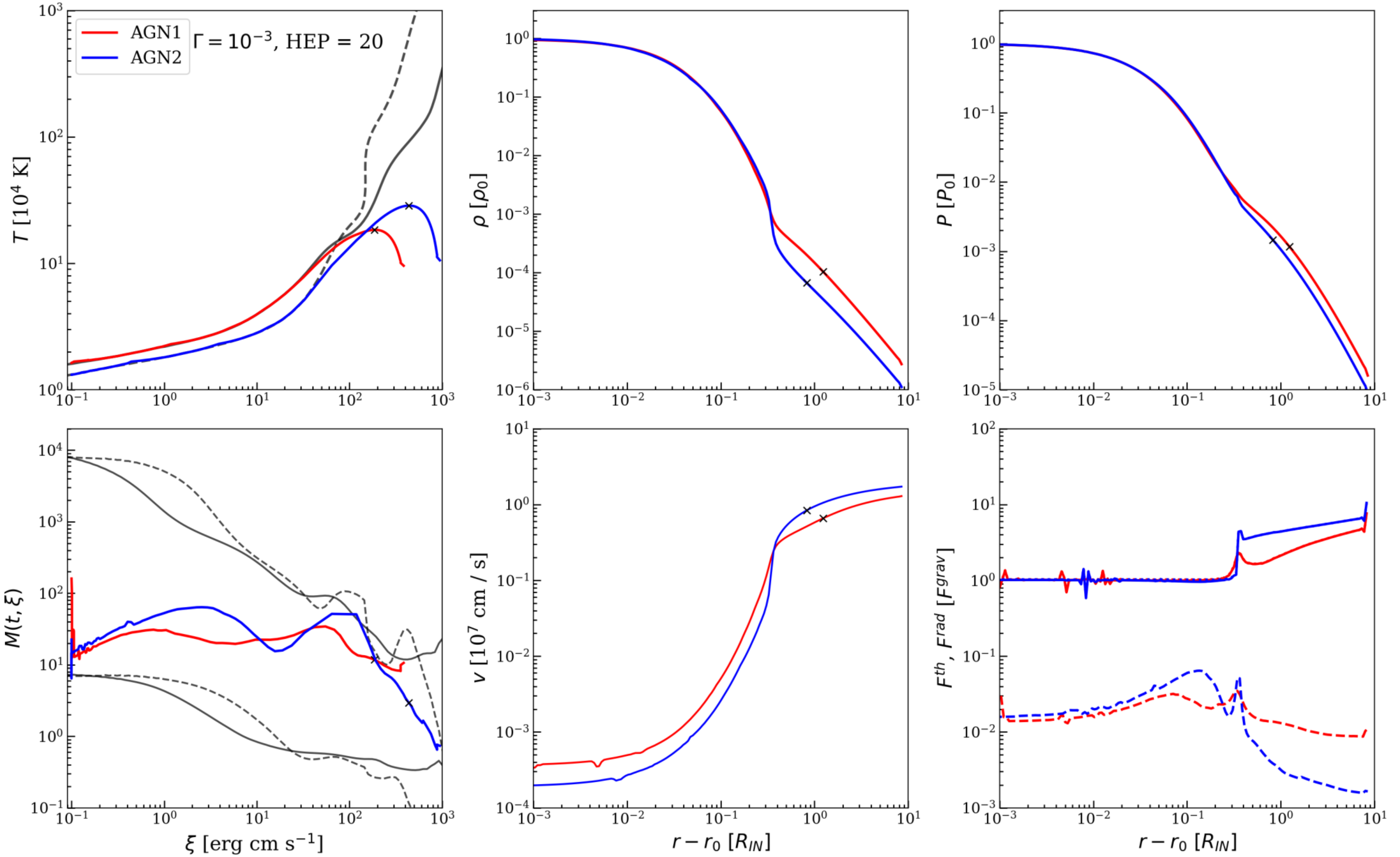
We define HEP as the ratio of the gravitational and thermal energy. For HEP $<$ 10, we should find a thermally driven wind.

$$\mathrm{HEP} = \frac{\mathrm{GM}}{\mathrm{c_s^2 r_*}} = \frac{\mathrm{e_{grav}}}{\mathrm{e_{th}}}$$

Prelimanary Results



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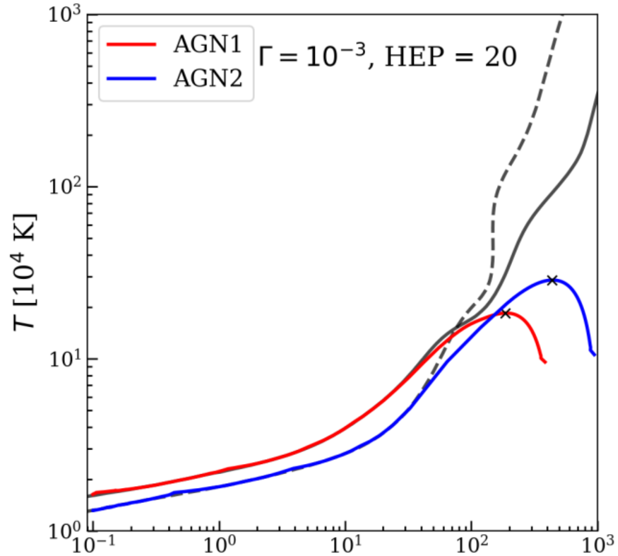

- We find that although the force multiplier can be large, even for highly ionized gas, we see that through the coupling of the our parameters (photoionization parameter, Flux, and HEP) we cannot produce a radiative driven wind, the force of gravity will always be much larger than the radiation.

- Thermal driving will dominate the line driving, even when the gas is nearly isothermal.