Observational Features of X-ray Irradiated Flows

Sergei Dyda
University of Nevada, Las Vegas

AGN Winds 2017

June 26th 2017

3 Possible Driving Mechanisms

Thermal – What is the thermal pressure?

Radiation – What is the radiation pressure?

Magnetic – What is the magnetic field?

3 Possible Driving Mechanisms

Thermal – What is the thermal pressure?

Radiation – What is the radiation pressure?

Magnetic – What ~~is the magnetic~~ field?

3 Possible Driving Mechanisms

Thermal – What is the thermal pressure?

Radiation – What is the radiation pressure?

Magnetic – ~~What is the magnetic field?~~

Observables (Spectra)

Macrophysics – What is temperature & ionization

T ξ

Microphysics – Atomic abundances, SED

n_x

3 Possible Driving Mechanisms

Thermal – What is the thermal pressure?

Radiation – What is the radiation pressure?

Magnetic – What ~~is the magnetic~~ field?

Observables (Spectra)

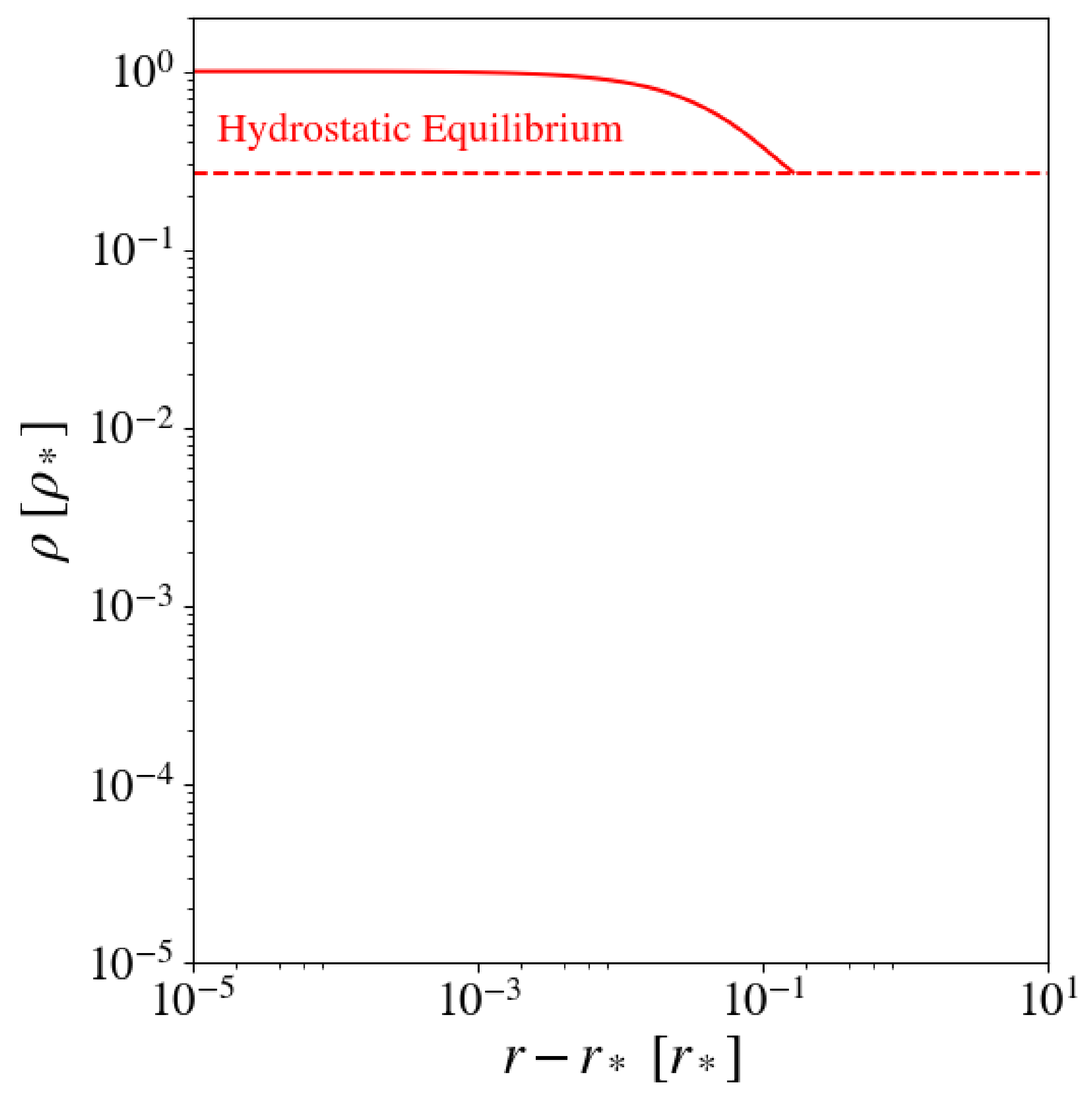
Macrophysics – What is temperature & ionization

T ξ

↕ Self Consistent

Microphysics – Atomic abundances, SED

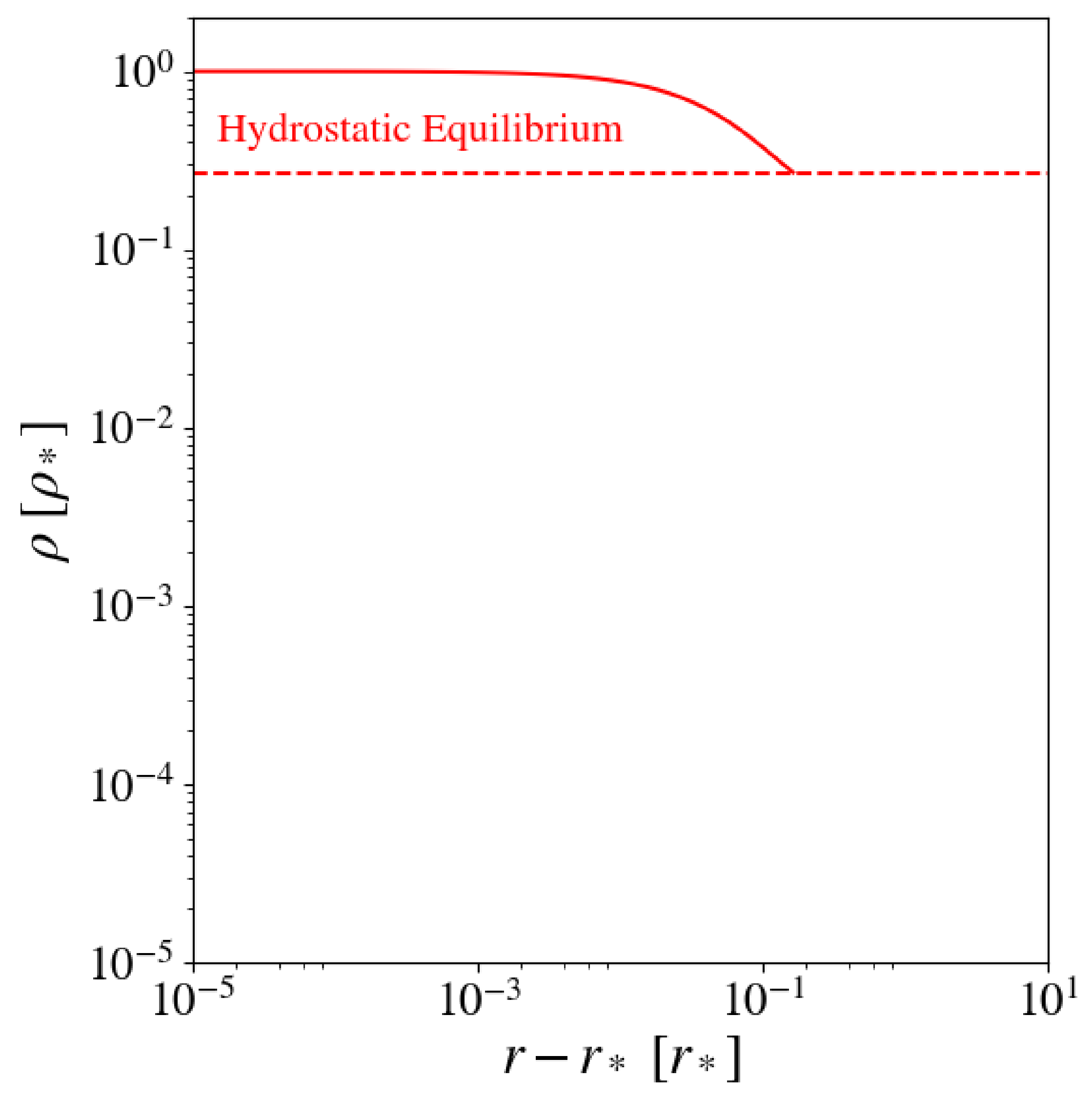
n_x



$$\rho = \rho_* \exp\left\{-\frac{GM}{a^2}\left(\frac{1}{r_*} - \frac{1}{r}\right)\right\}$$

Sound Speed $c_s^2 = \gamma a^2$

Lamers, Cassinelli ‘99



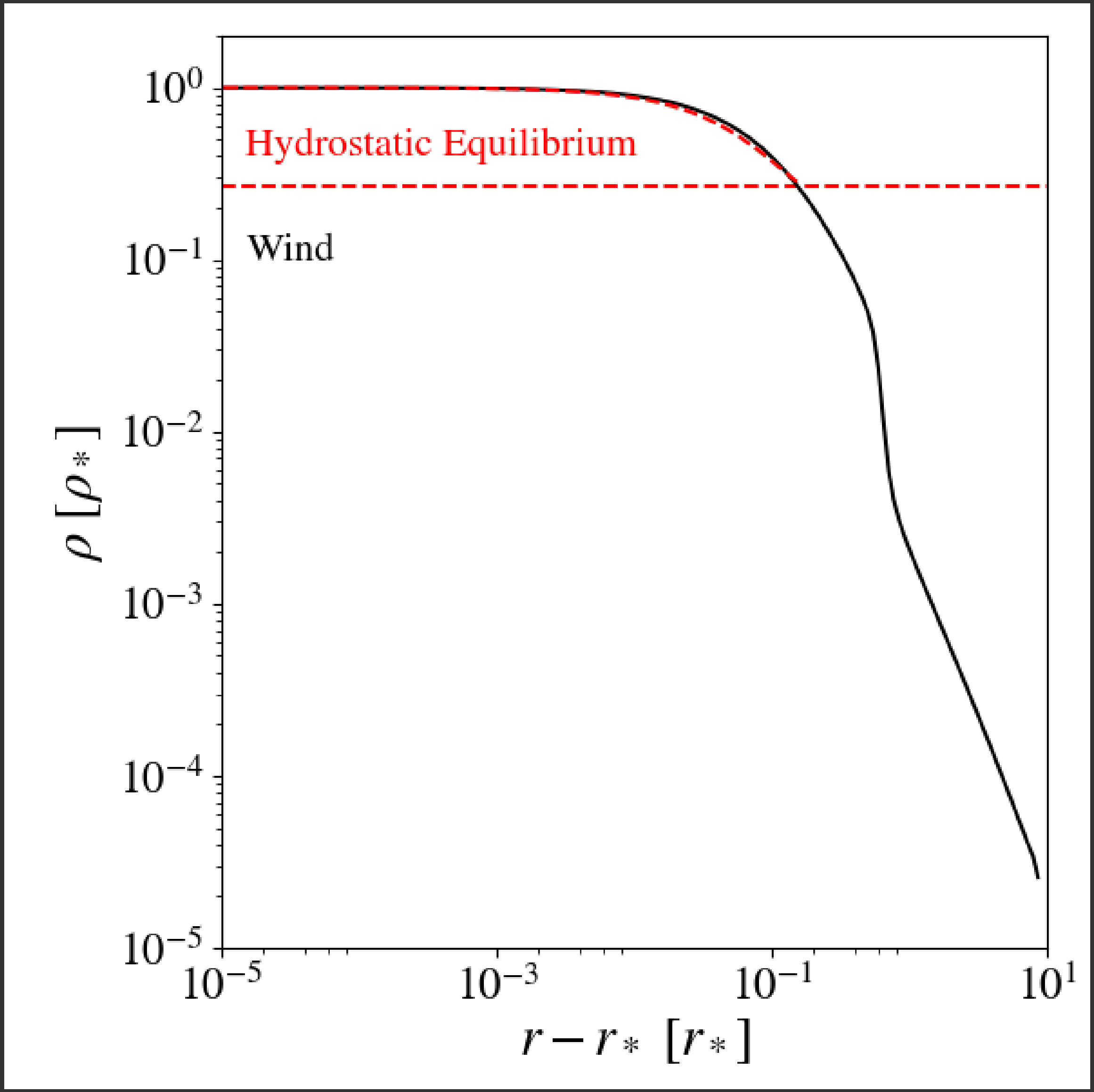
$$\rho = \rho_* \exp\left\{-\frac{GM}{a^2}\left(\frac{1}{r_*}-\frac{1}{r}\right)\right\}$$

Sound Speed $c_s^2 = \gamma a^2$

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

Thermal Wind $\mathrm{HEP} \lesssim 10$

Lamers, Cassinelli ‘99

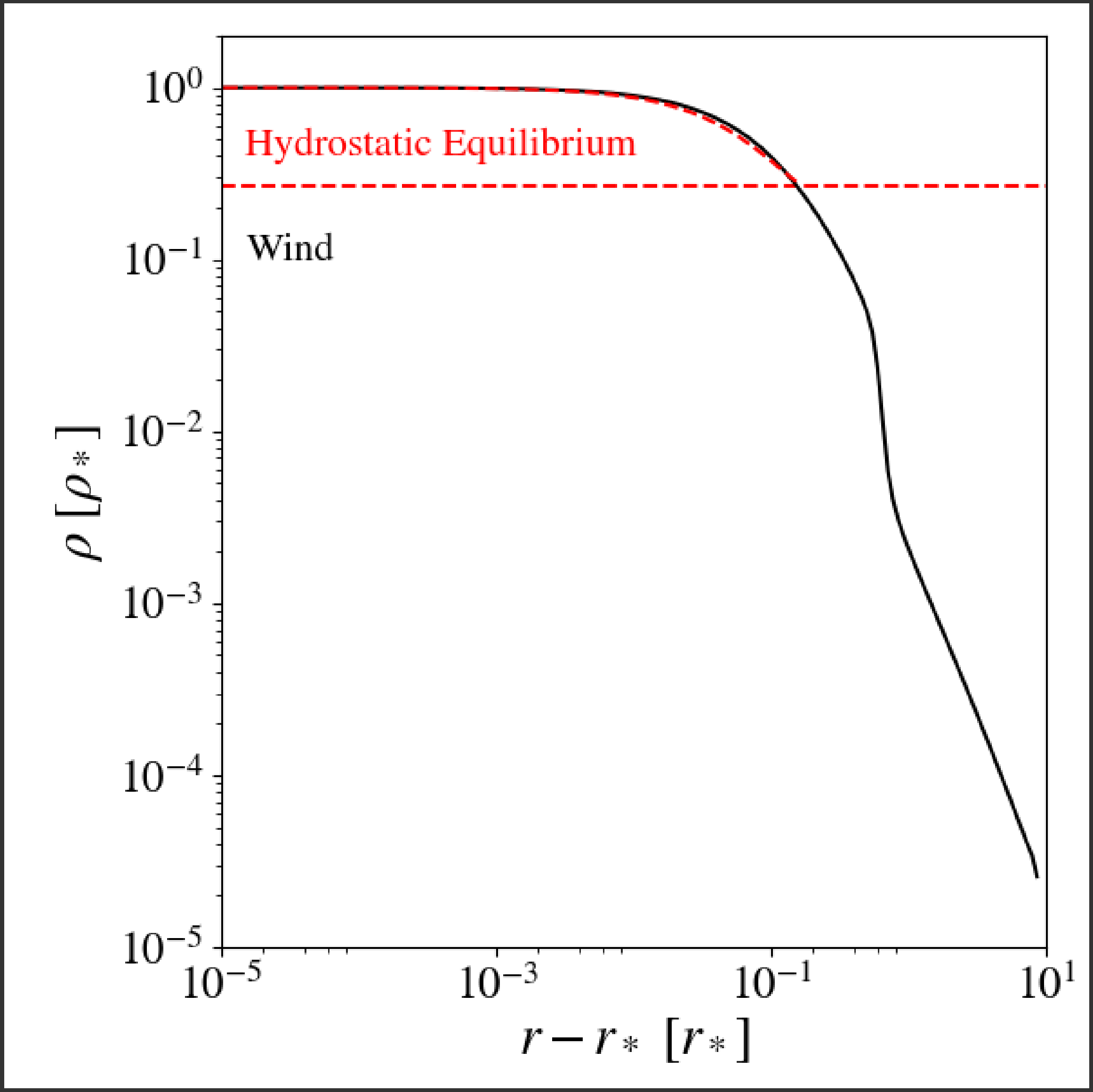


$$\frac{d}{dr}\left(\underbrace{\frac{v_r^2}{2}}_{e_{\rm kin}} + \underbrace{\frac{\gamma}{\gamma-1}\frac{k_bT}{\mu m_p}}_{e_{\rm th}} - \underbrace{\frac{GM}{r}}_{e_{\rm grav}}\right) = -\underbrace{\frac{\mathcal{L}}{v_r}}_{\frac{dQ}{dr}}$$

Energy Conservation

Radiative Cooling $\boxed{\mathcal{L}(\xi, T)}$

Lamers, Cassinelli ‘99



$$\frac{d}{dr}\left(\underbrace{\frac{v_r^2}{2}}_{e_{\rm kin}} + \underbrace{\frac{\gamma}{\gamma-1}\frac{k_bT}{\mu m_p}}_{e_{\rm th}} - \underbrace{\frac{GM}{r}}_{e_{\rm grav}}\right) = -\underbrace{\frac{\mathcal{L}}{v_r}}_{\frac{dQ}{dr}}$$

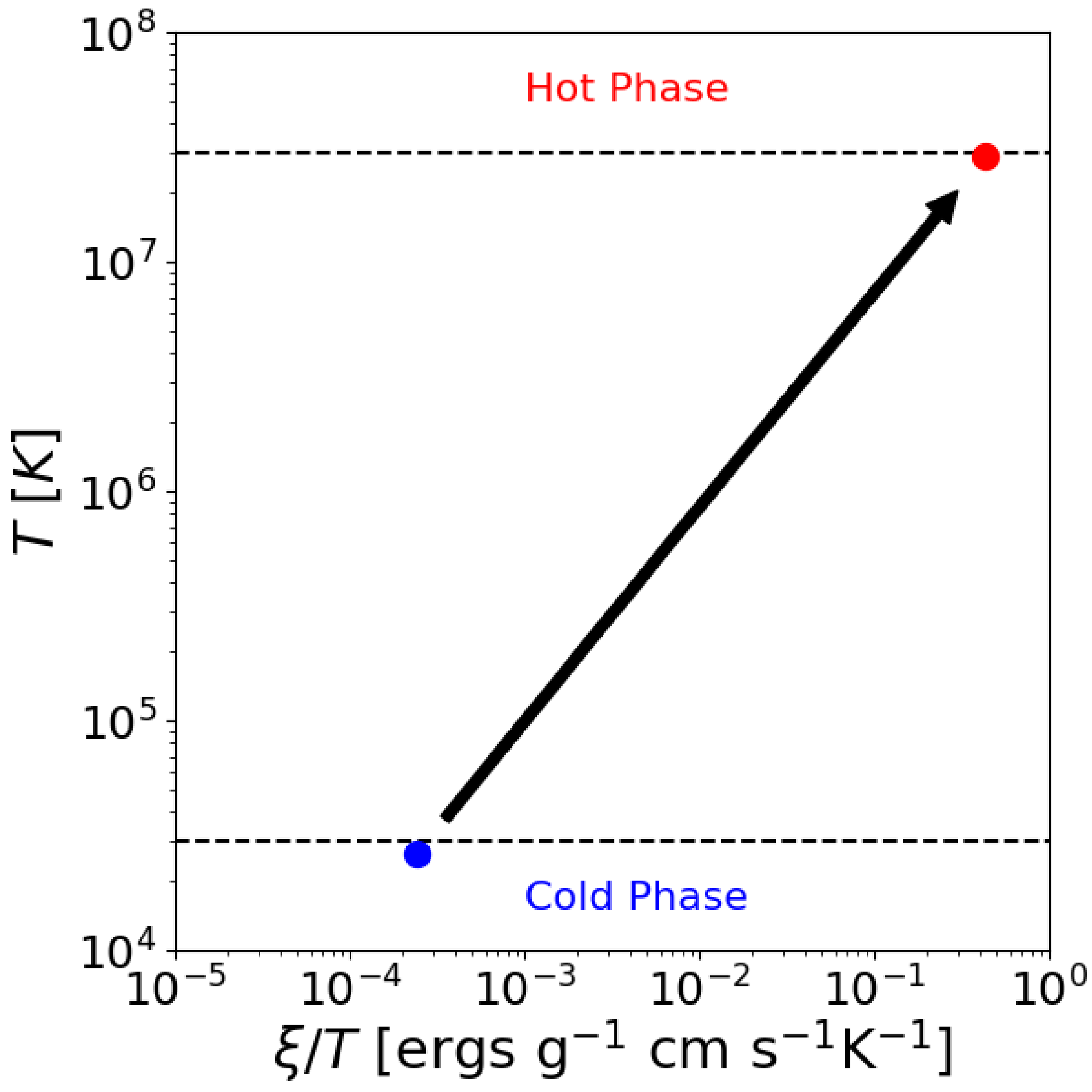
Energy Conservation

Radiative Cooling $\boxed{\mathcal{L}(\xi, T)}$

Ionization

Temperature

Lamers, Cassinelli ‘99

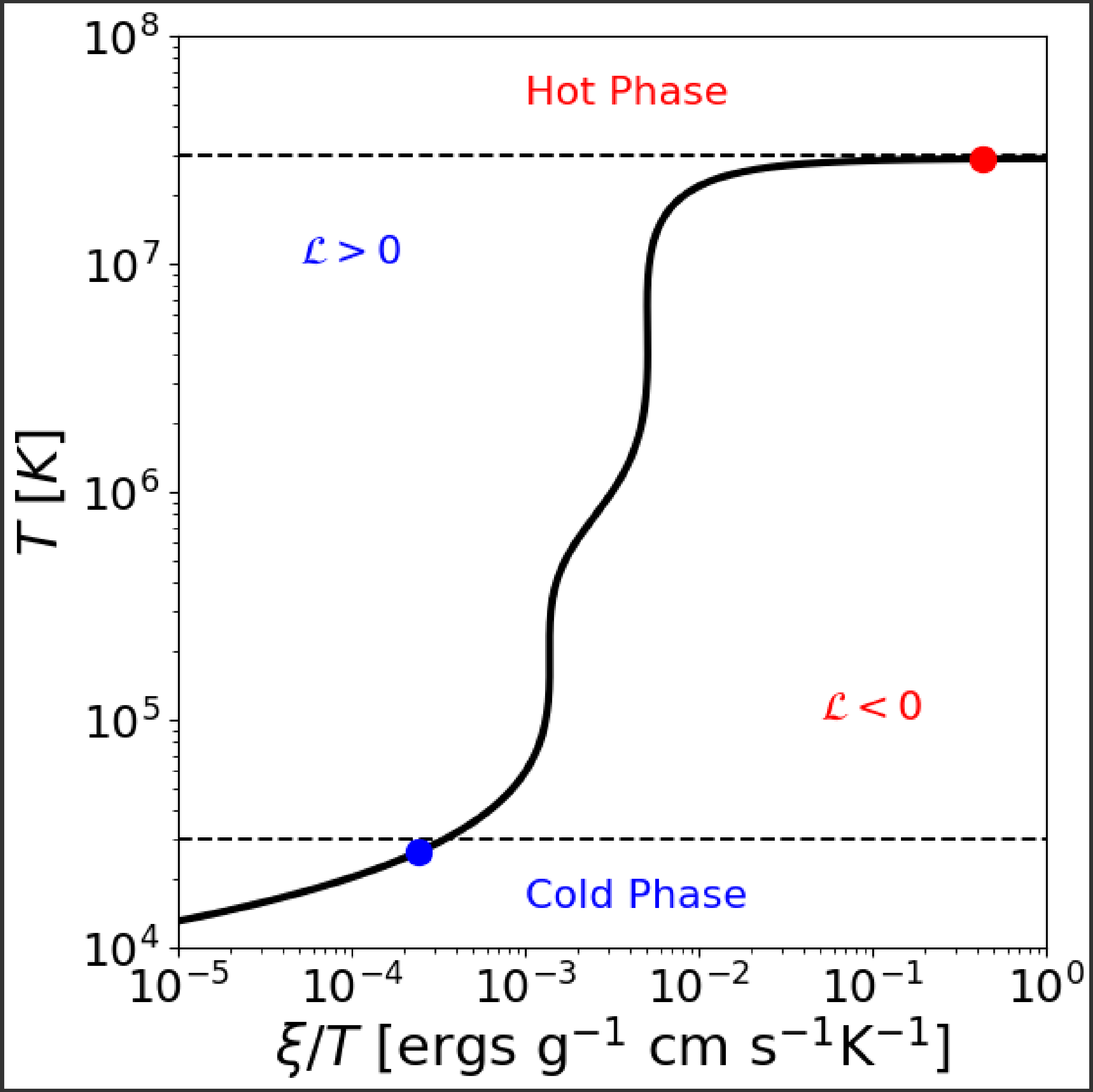


Flow Timescale

$$\tau_f = \frac{r}{v_r}$$

Begelman,McKee,Shields '83

$$\tau_{\mathcal{L}} \ll \tau_f$$



SED dependent

Flow Timescale

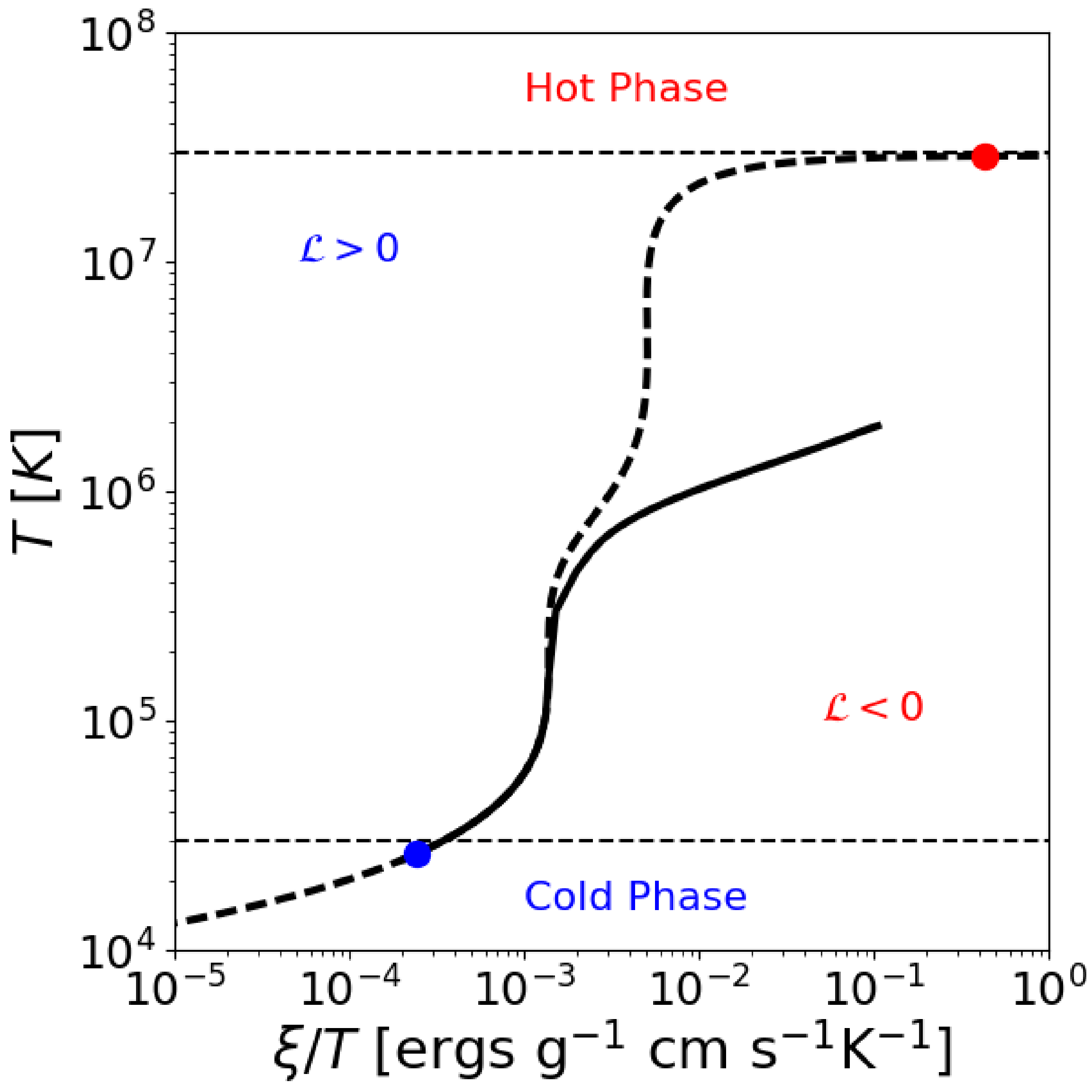
$$\tau_f = \frac{r}{v_r}$$

Heating Timescale

$$\tau_{\mathcal{L}} = \frac{k_b T}{\mu m_p \mathcal{L}}$$

Woods et al. ‘96

$$\tau_a \sim \tau_f \sim \tau_{\mathcal{L}}$$



Flow Timescale

$$\tau_f = \frac{r}{v_r}$$

Adiabatic Timescale

$$\tau_a = \frac{dr}{dv}$$

Dyda et al. ‘17

XSTAR Photoionization Code (Microphysics)

Bautista & Kallman ‘01

Atomic Abundance
(atoms, ions, free e-)
(Lauders et al. ‘09)

Driving SED
(Type 1 or 2 AGN)
(Mehdipour et al. ‘15)

Atomic Processes
(Photoionization/Recombination, Lines, Compton, Bremsstrahlung)

XSTAR Photoionization Code (Microphysics)

Bautista & Kallman '01

Atomic Abundance

(atoms, ions, free e-)

(Lauders et al. '09)

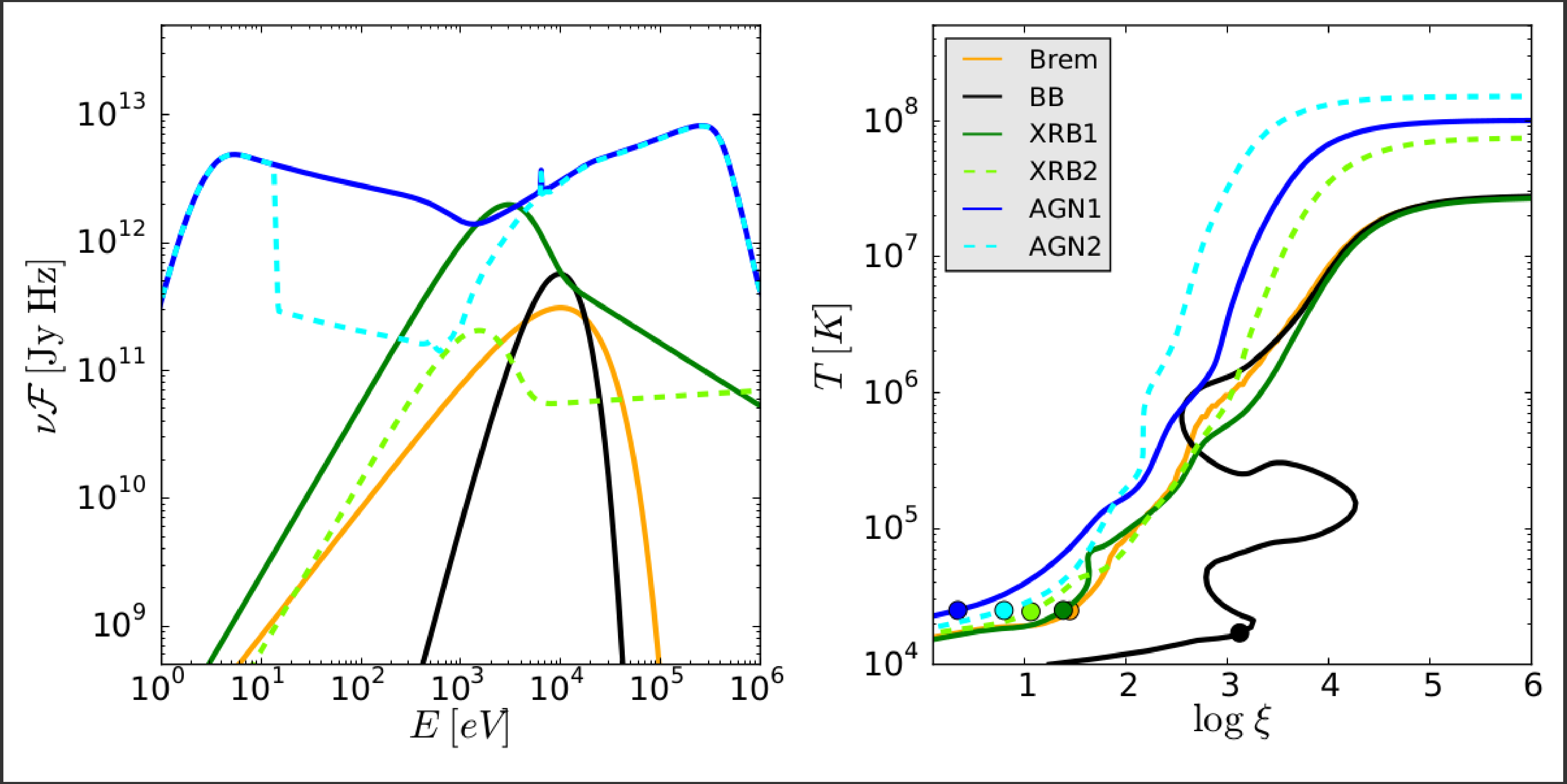
Driving SED

(Type 1 or 2 AGN)

(Mehdipour et al. '15)

Atomic Processes

(Photoionization/Recombination, Lines, Compton, Bremsstrahlung)



XSTAR Photoionization Code (Microphysics)

Dyda et al. ‘17

Atomic Abundance

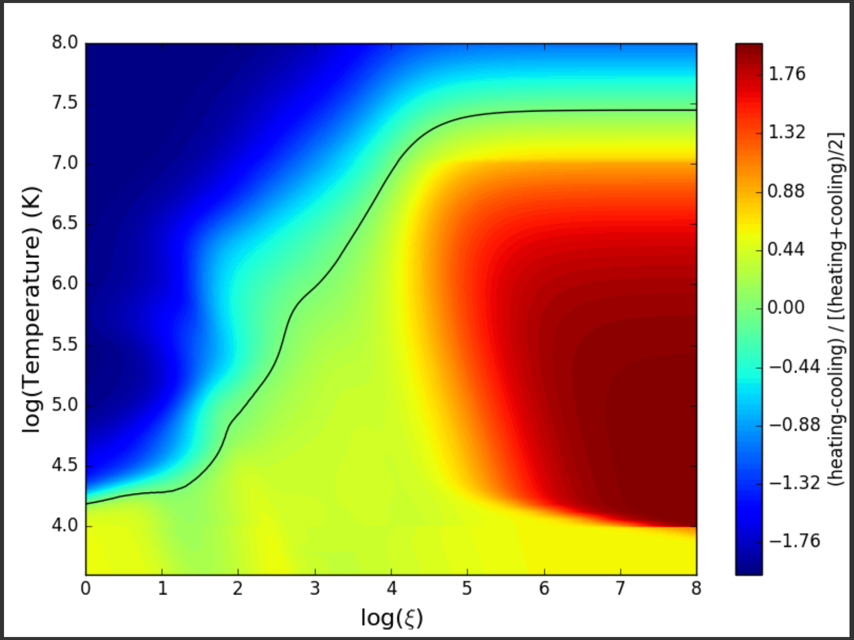
(atoms, ions, free e-)

Driving SED

(Type 1 or 2 AGN)

Atomic Processes

(Photoionization/ Recombination, Lines, Compton, Bremsstrahlung)



XSTAR Photoionization Code (Microphysics)

Dyda et al. ‘17

Atomic Abundance

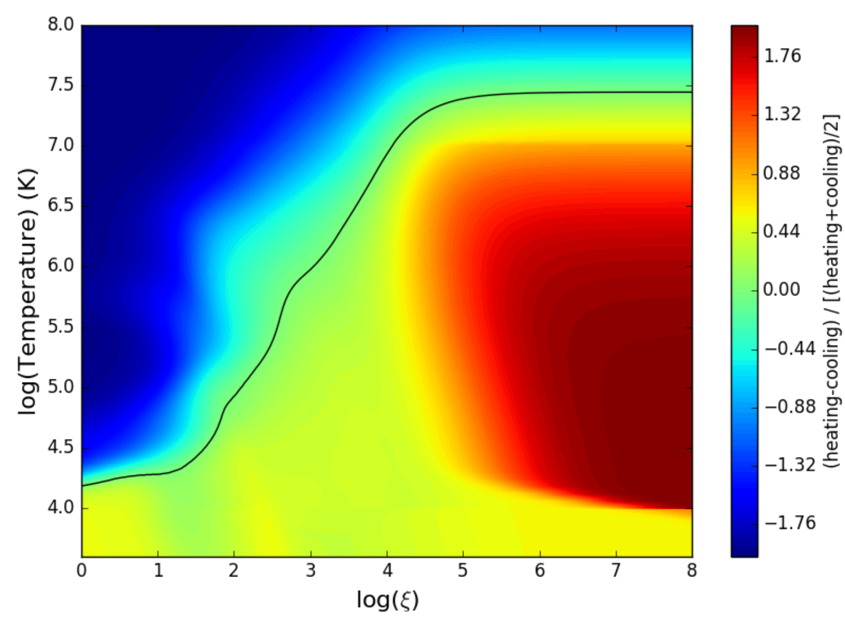
(atoms, ions, free e-)

Driving SED

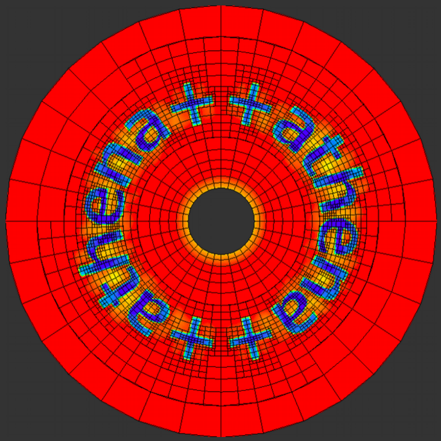
(Type 1 or 2 AGN)

Atomic Processes

(Photoionization/ Recombination, Lines, Compton, Bremsstrahlung)



Athena++ MHD Code (Macrophysics)



Stone, Tomida, White ‘17

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

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

$$\frac{\partial E}{\partial t} + \nabla \cdot ((E + P)\mathbf{v}) = -\rho \mathbf{v} \cdot \nabla \Phi - \rho \mathcal{L}(\xi, T),$$

XSTAR Photoionization Code (Microphysics)

Dyda et al. ‘17

Atomic Abundance

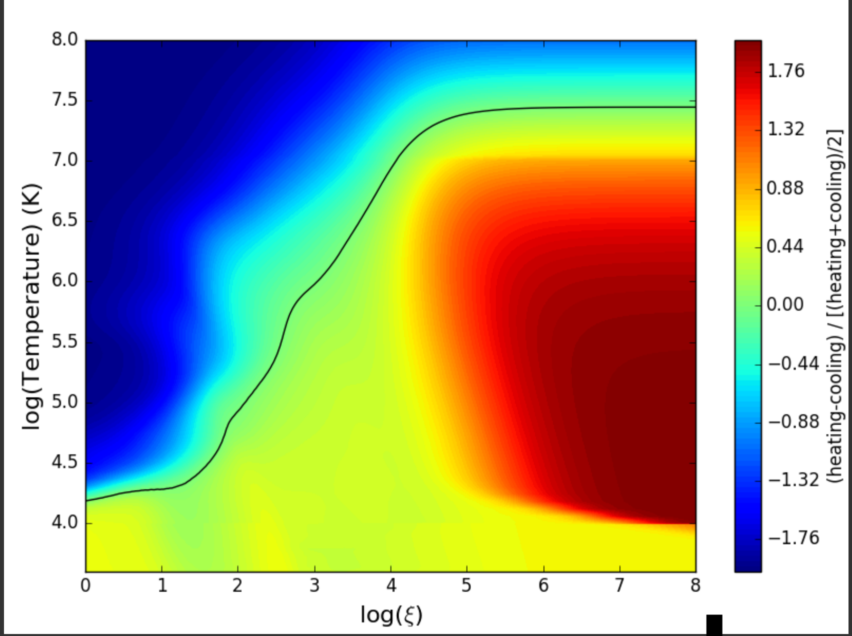
(atoms, ions, free e-)

Driving SED

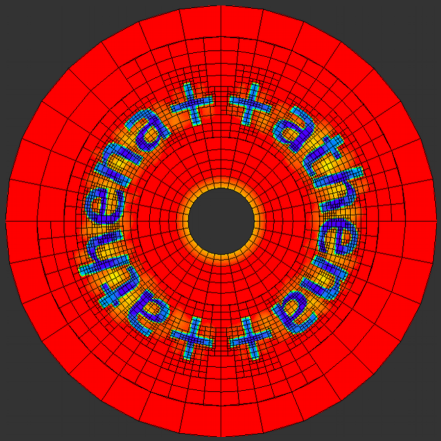
(Type 1 or 2 AGN)

Atomic Processes

(Photoionization/ Recombination, Lines, Compton, Bremsstrahlung)



Athena++ MHD Code (Macrophysics)



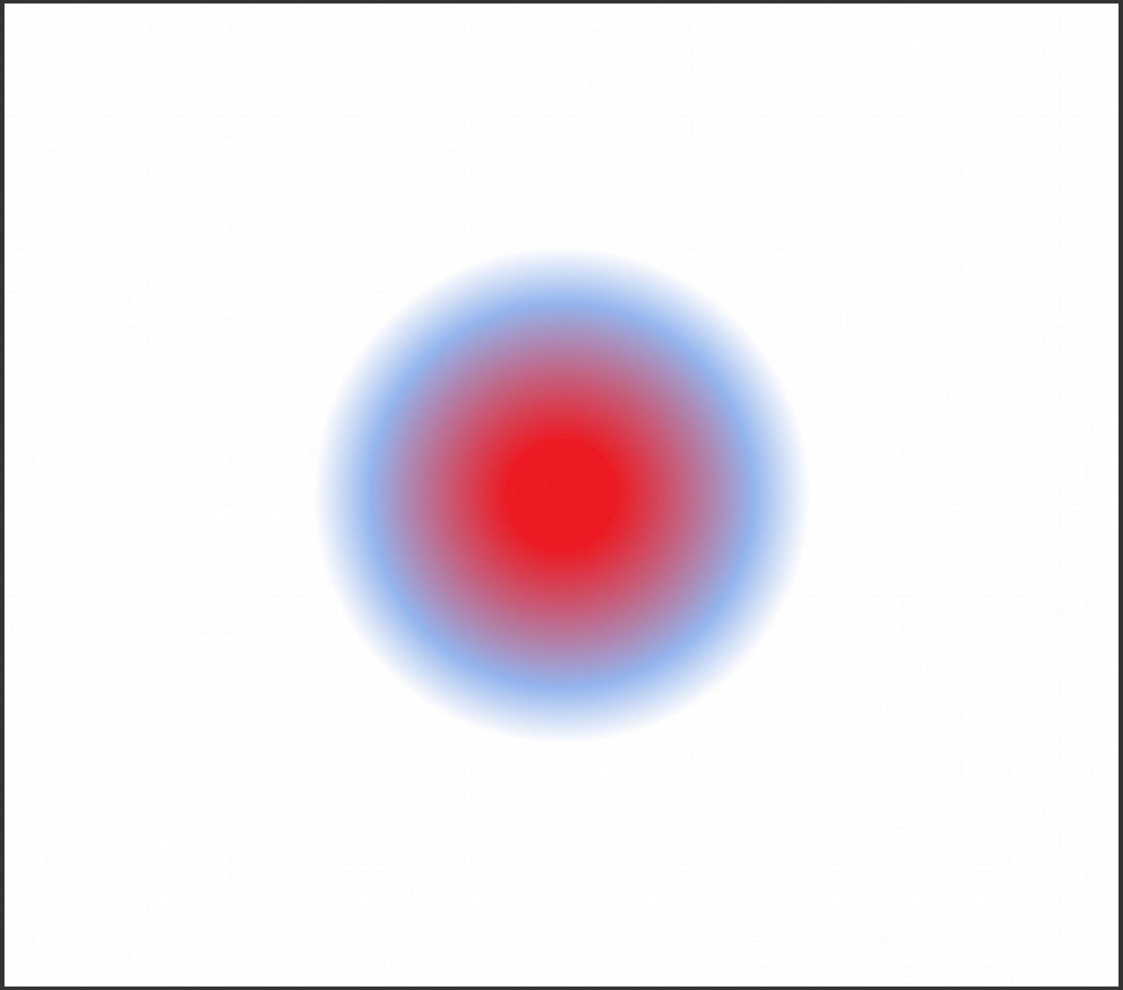
Stone, Tomida, White ‘17

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

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

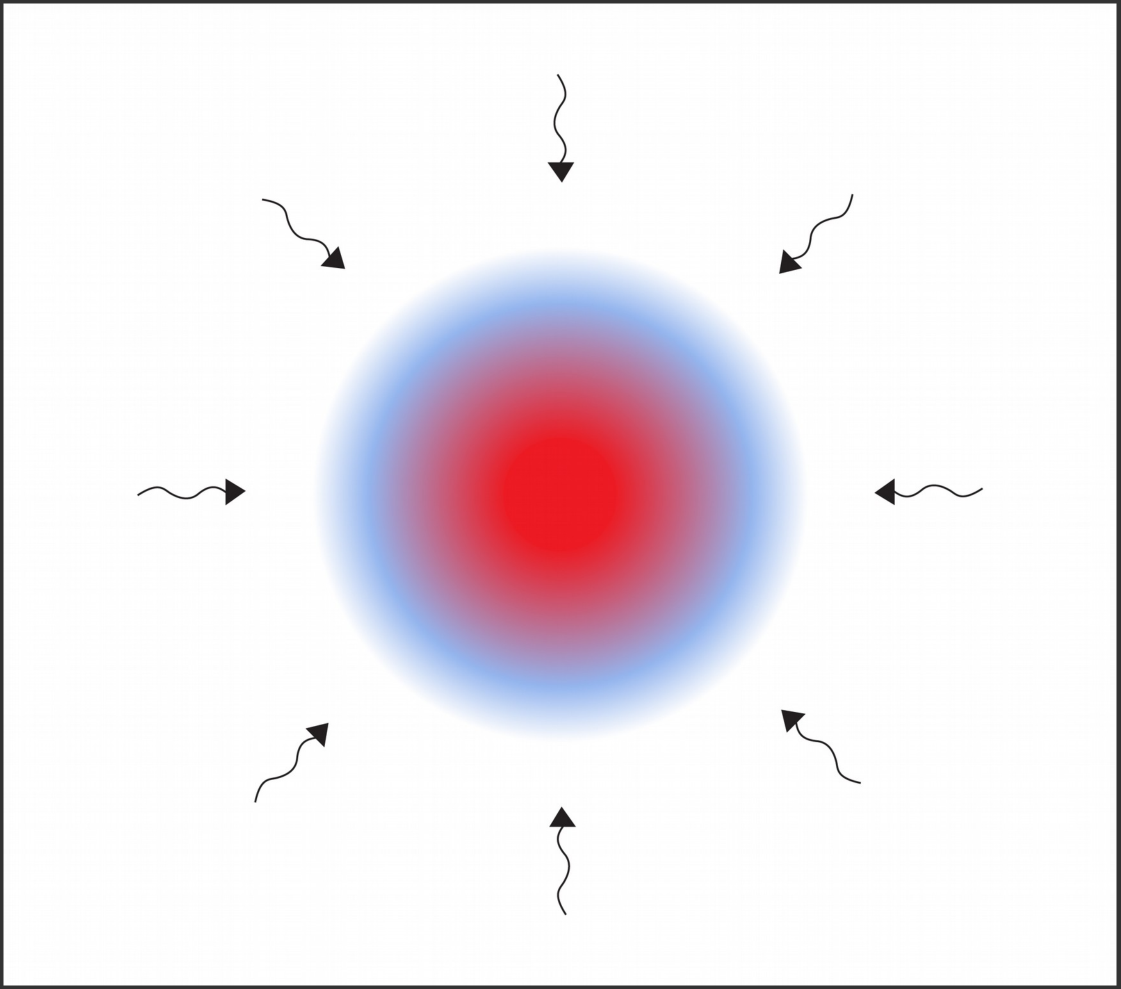
$$\frac{\partial E}{\partial t} + \nabla \cdot ((E + P)\mathbf{v}) = -\rho \mathbf{v} \cdot \nabla \Phi - \rho \mathcal{L}(\xi, T),$$

Physical Setup



Spherically symmetric gas

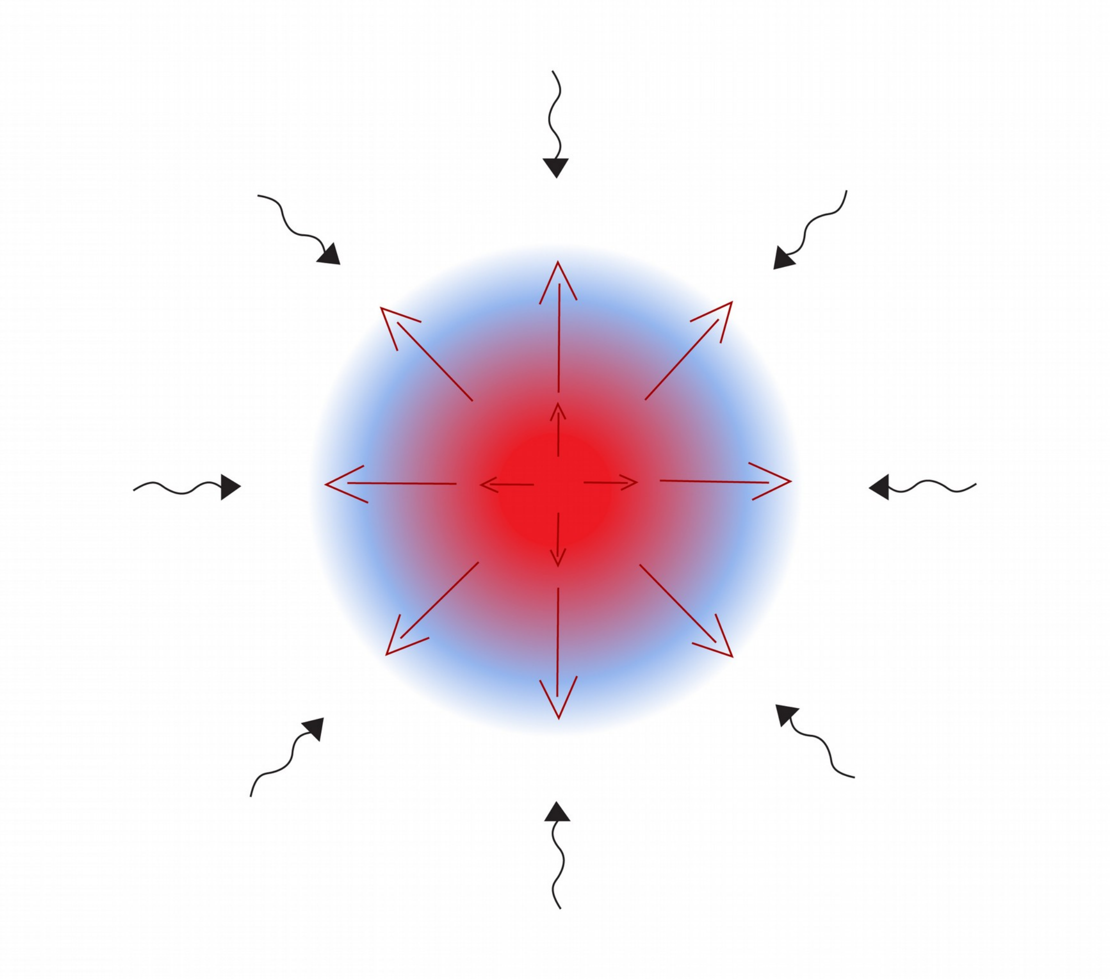
Physical Setup



Spherically symmetric gas

Radiation Field

Physical Setup

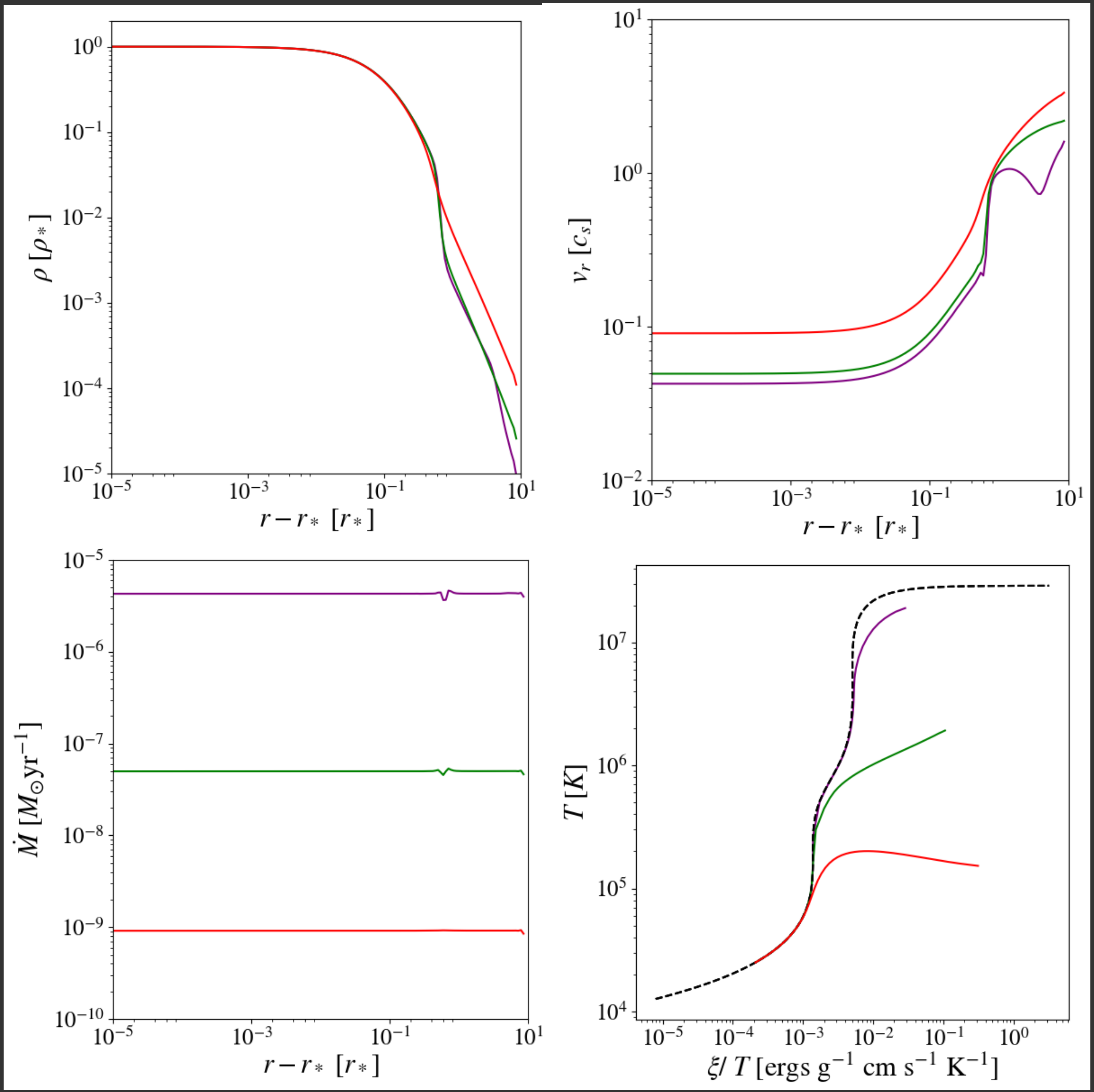


Spherically symmetric gas

Radiation Field

Launch Outflow

Dynamical Variables

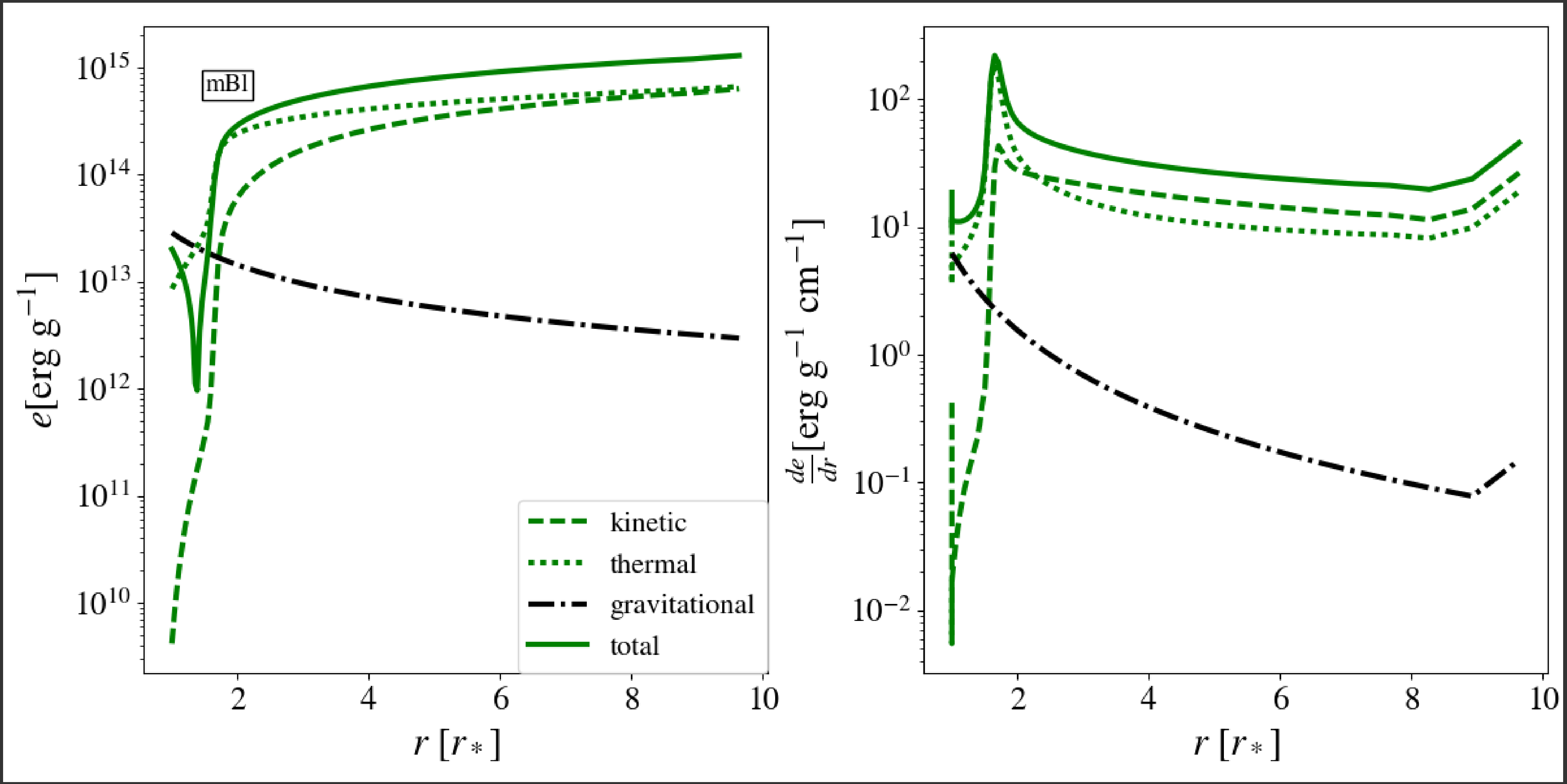


Increasing flux

$\mathcal{F}_X$

Dyda et al. ‘17

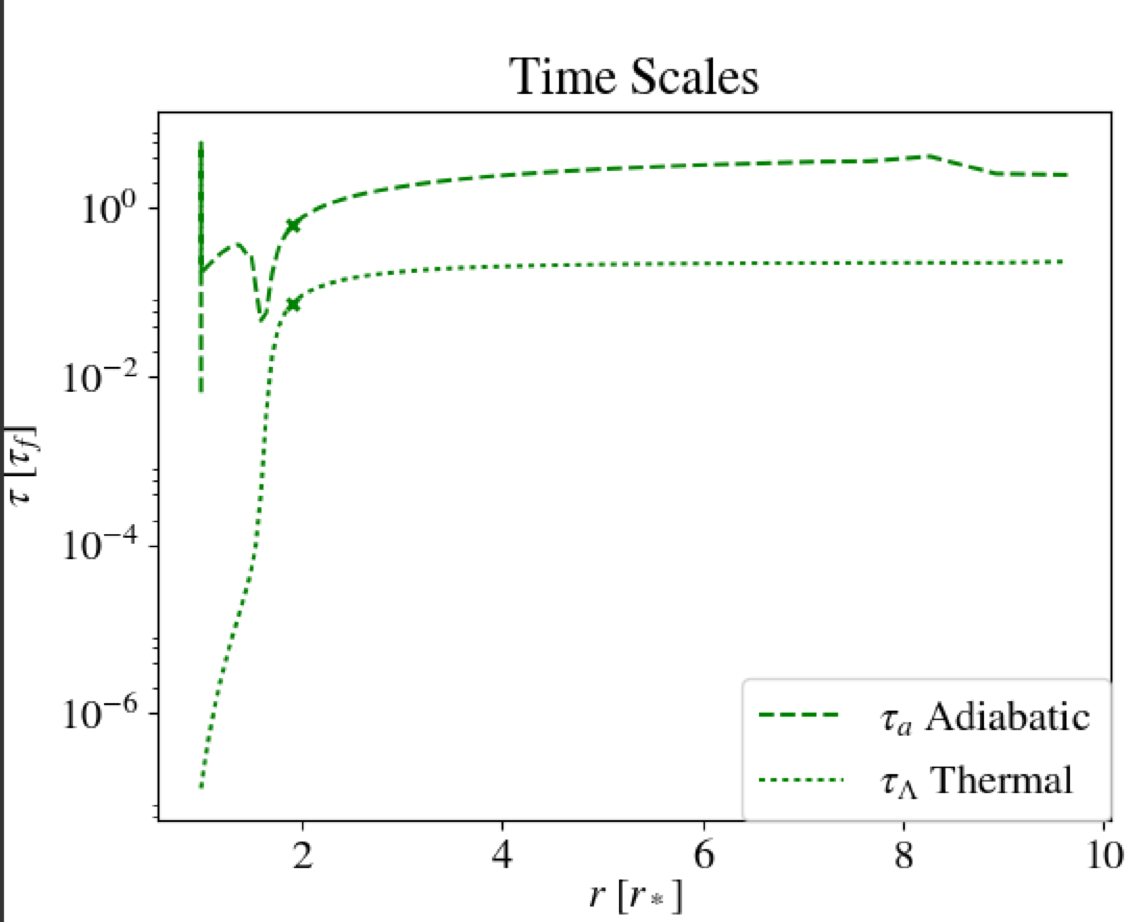
Energy Injection



$$\frac{d}{dr}\left(\underbrace{\frac{v_r^2}{2}}_{e_{\mathrm{kin}}} + \underbrace{\frac{\gamma}{\gamma-1}\frac{k_b T}{\mu m_p}}_{e_{\mathrm{th}}} - \underbrace{\frac{GM}{r}}_{e_{\mathrm{grav}}}\right) = -\underbrace{\frac{\mathcal{L}}{v_r}}_{\frac{dQ}{dr}}$$

Dyda et al. ‘17

Timescales

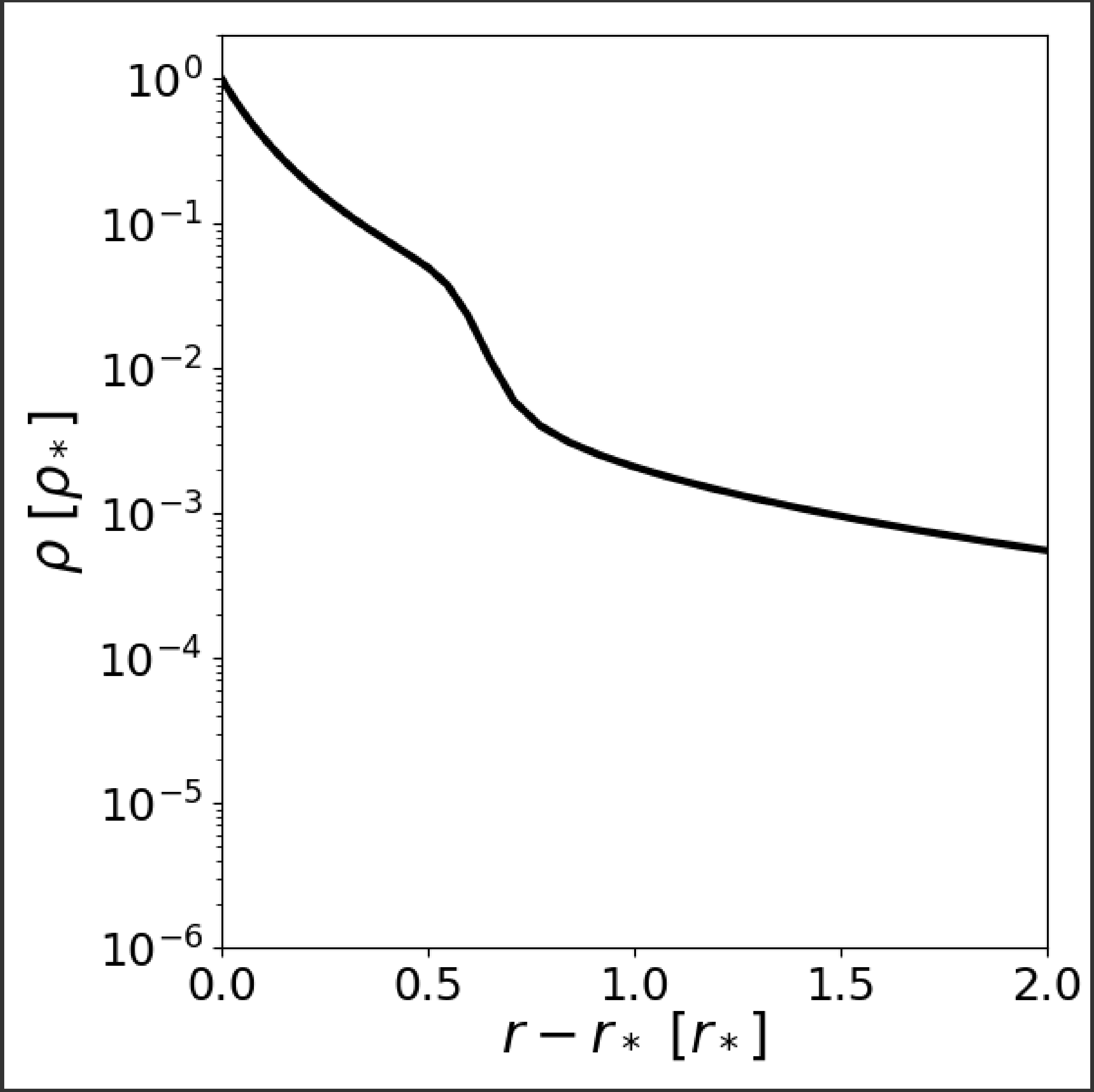


$$\tau_a \sim \tau_f \sim \tau_{\mathcal{L}}$$

No dominant timescale for entire flow

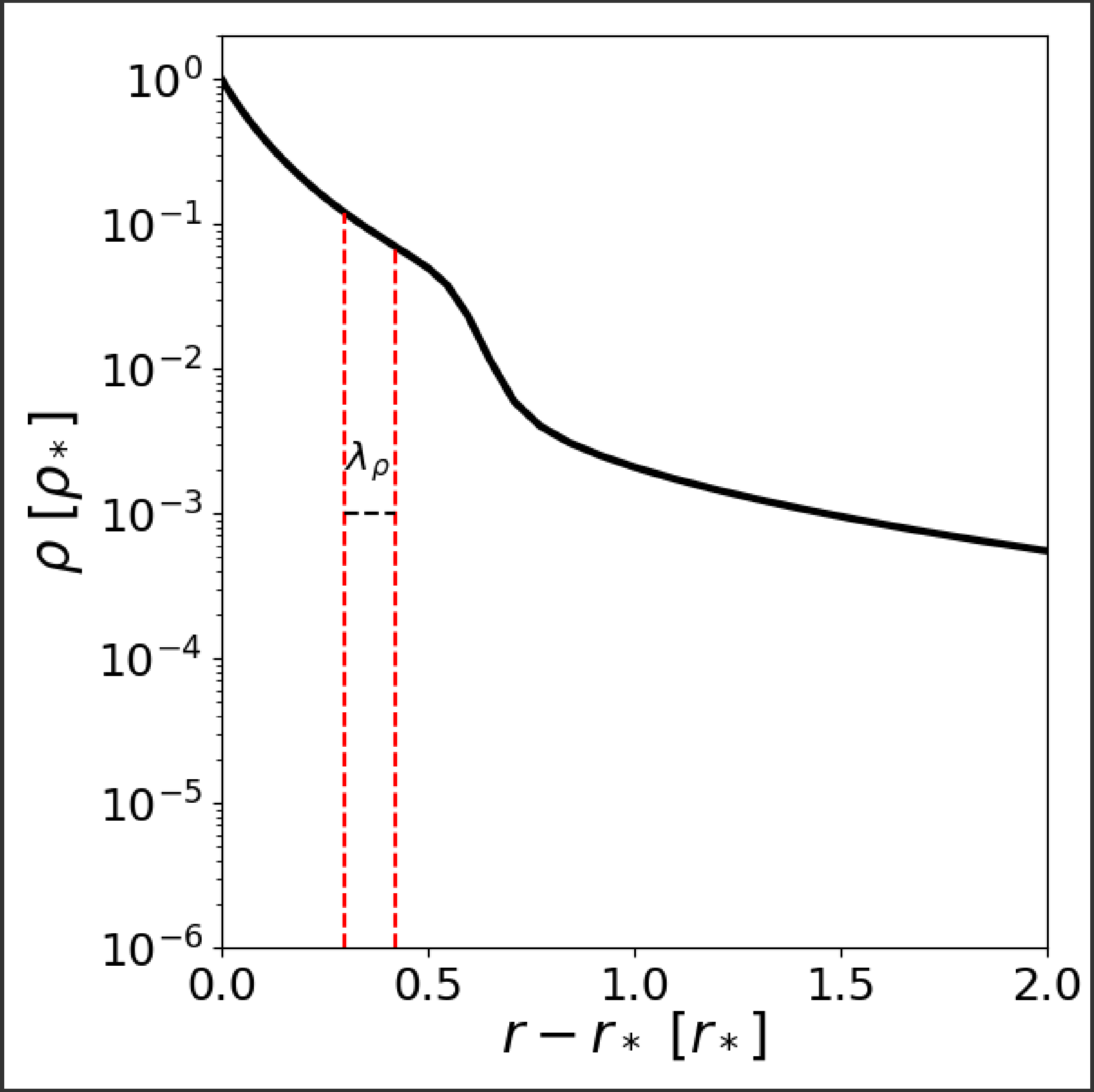
Dyda et al. '17

Absorption Measure Distribution (AMD)



Holczer, Behar, Kaspi, ‘07

Absorption Measure Distribution (AMD)

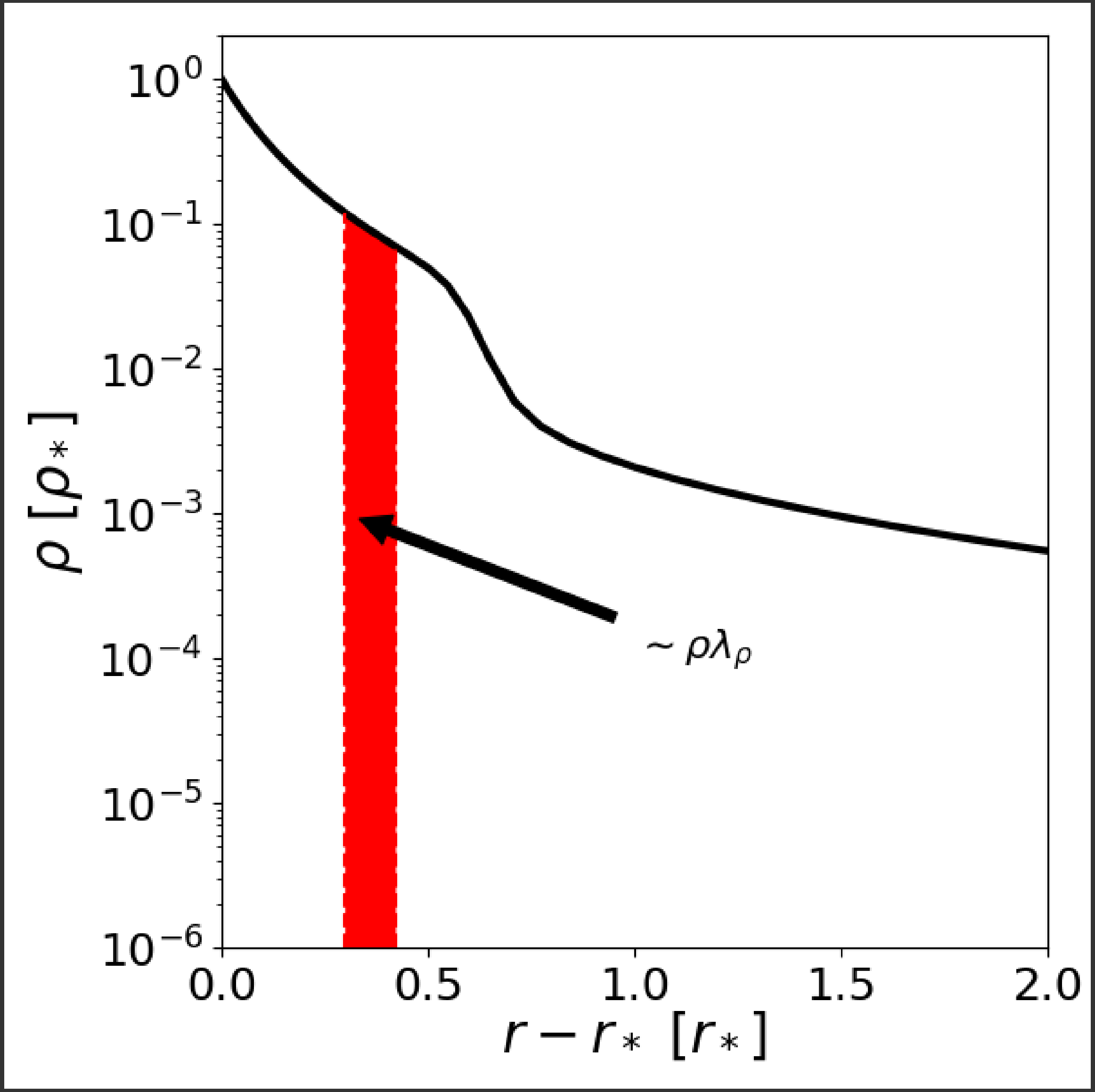


Density Length Scale

$$\lambda_\rho = \left(\frac{1}{\rho}\frac{d\rho}{dr}\right)^{-1}$$

Holczer, Behar, Kaspi, ‘07

Absorption Measure Distribution (AMD)



Density Length Scale

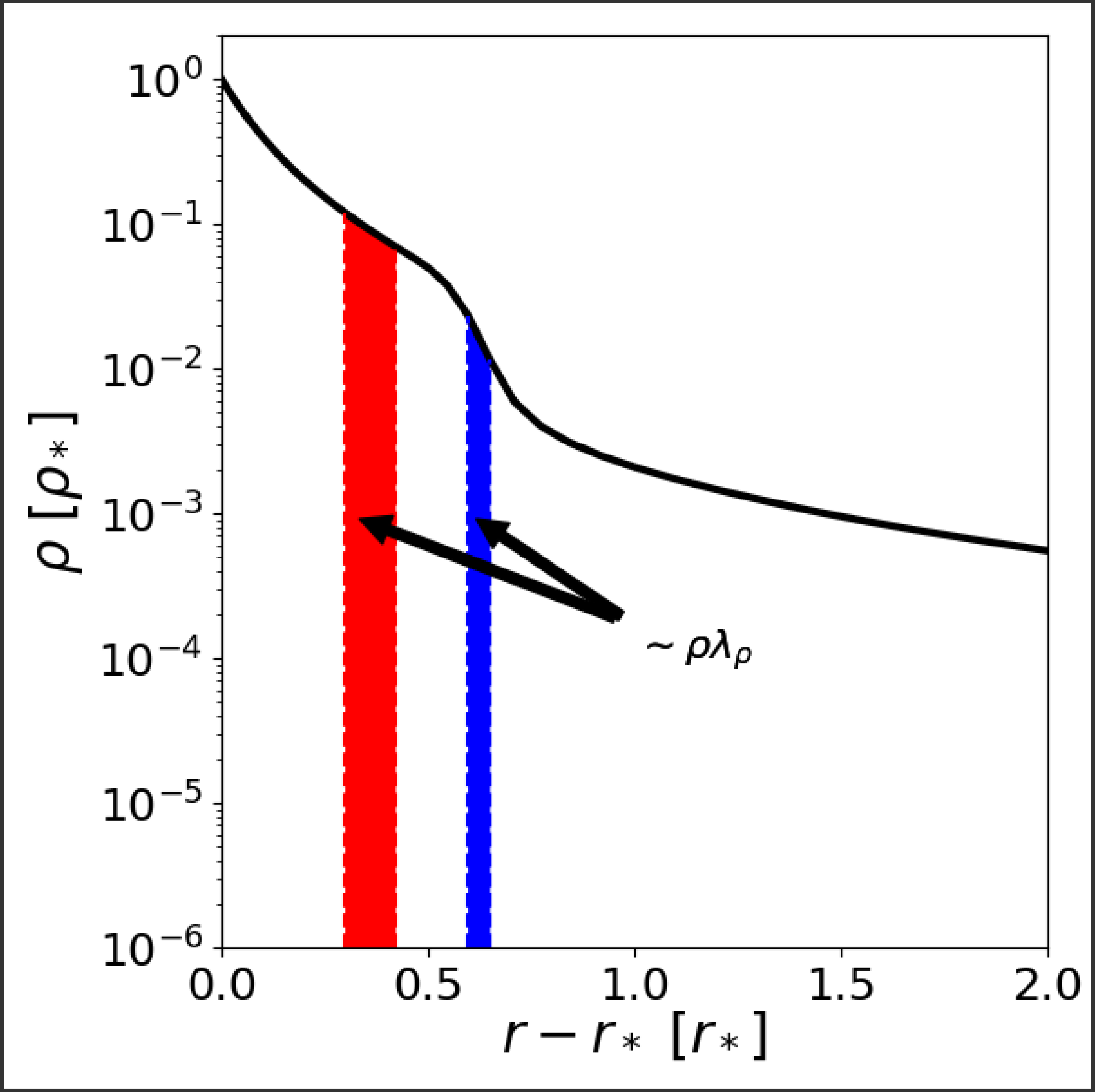
$$\lambda_\rho = \left(\frac{1}{\rho}\frac{d\rho}{dr}\right)^{-1}$$

$$\mathrm{AMD} \sim \rho\lambda_\rho$$

How much gas is at a certain density?

Holczer, Behar, Kaspi, ‘07

Absorption Measure Distribution (AMD)



Density Length Scale

$$\lambda_\rho = \left(\frac{1}{\rho}\frac{d\rho}{dr}\right)^{-1}$$

$$\mathrm{AMD} \sim \rho\lambda_\rho$$

How much gas is at a certain density?

Depends on slope of density profile

Holczer, Behar, Kaspi, ‘07

Absorption Measure Distribution (AMD)

$$AMD = \frac{dN_H}{d(log\xi)} \approx -\rho\lambda_\rho$$

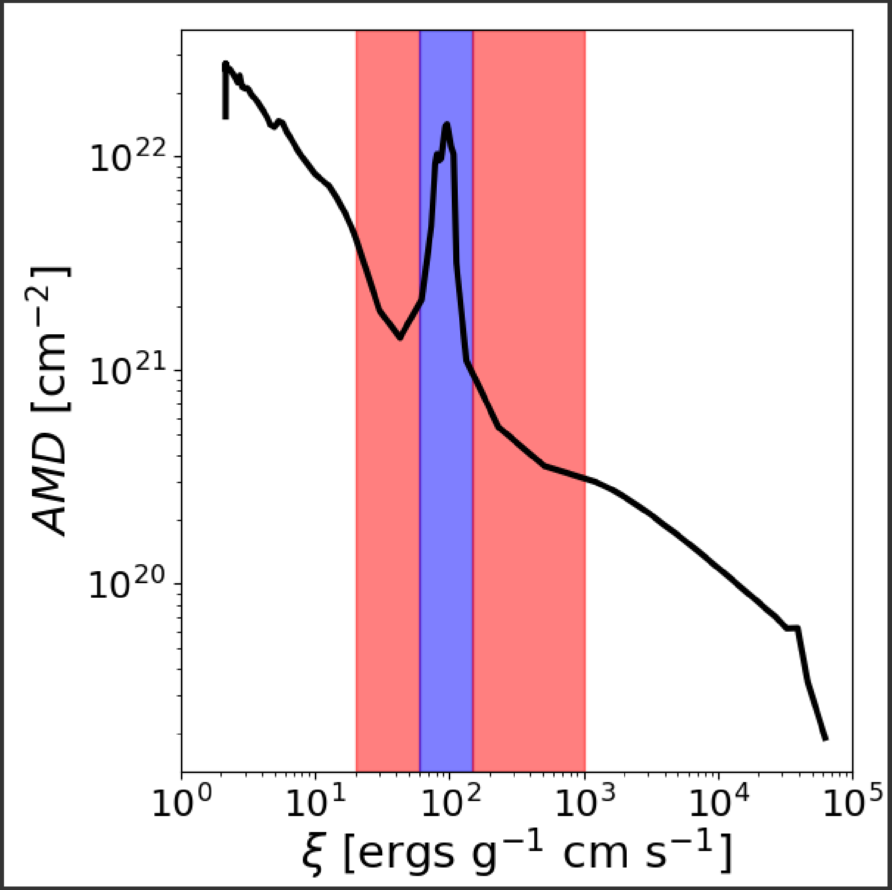
Uniform Radiation Field

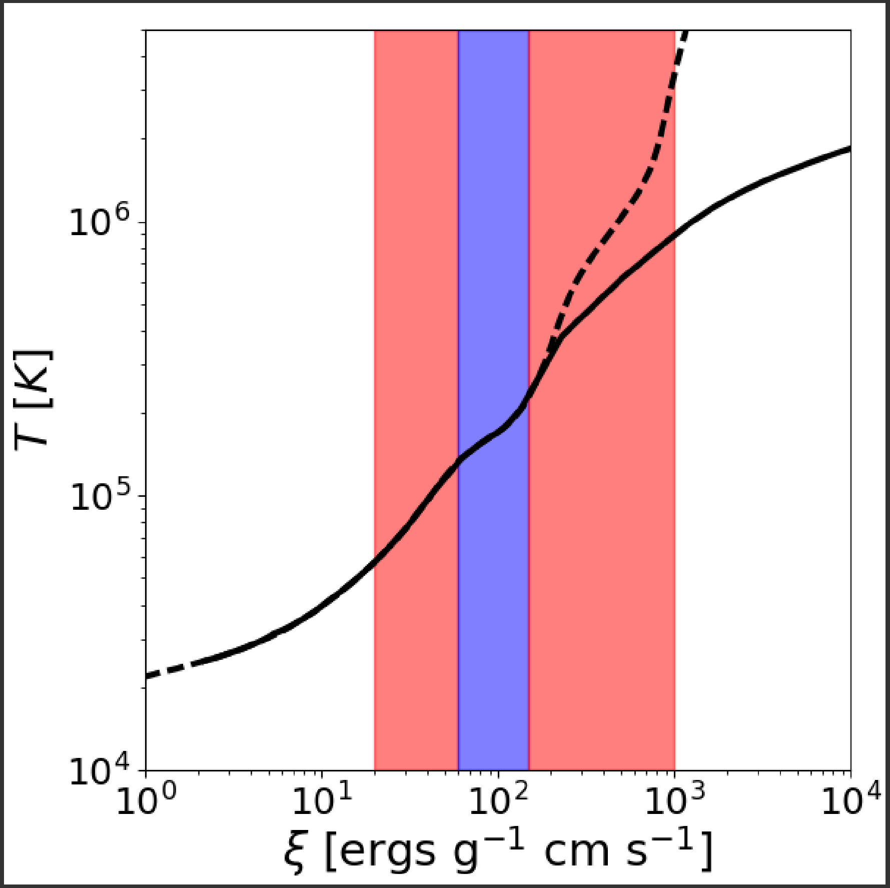
$$\xi \sim \frac{1}{\rho}$$

AMD = Column density of gas at a certain ionization

Holczer, Behar, Kaspi, ‘07

Absorption Measure Distribution (AMD)





Equilibrium Curve (shape, thermal instability??)

Adiabatic Processes (fall of equilibrium curve)

Dyda et al. ‘17

Conclusions & Future Work

Wind driving mechanism
(macrophysics)

ξ T

Spectra (microphysics)

Conclusions & Future Work

Wind driving mechanism
(macrophysics)

ξ T

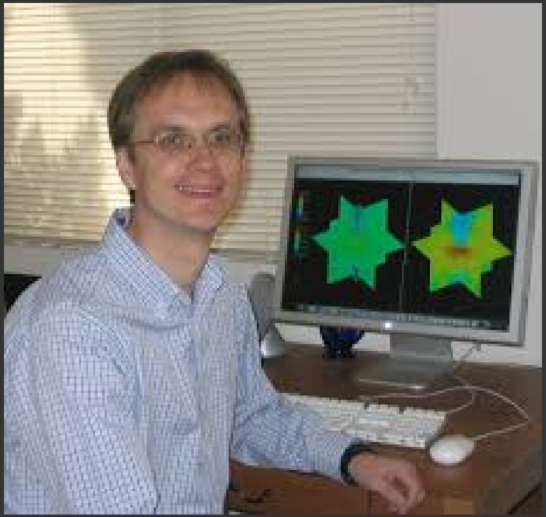
Spectra (microphysics)

Hydrodynamics
(Athena++)

Self Consistent

Photoionization (XSTAR)

Acknowledgments



D. Proga

T. Waters

R. Dannen

athena++ athena++

NASA

UNLV