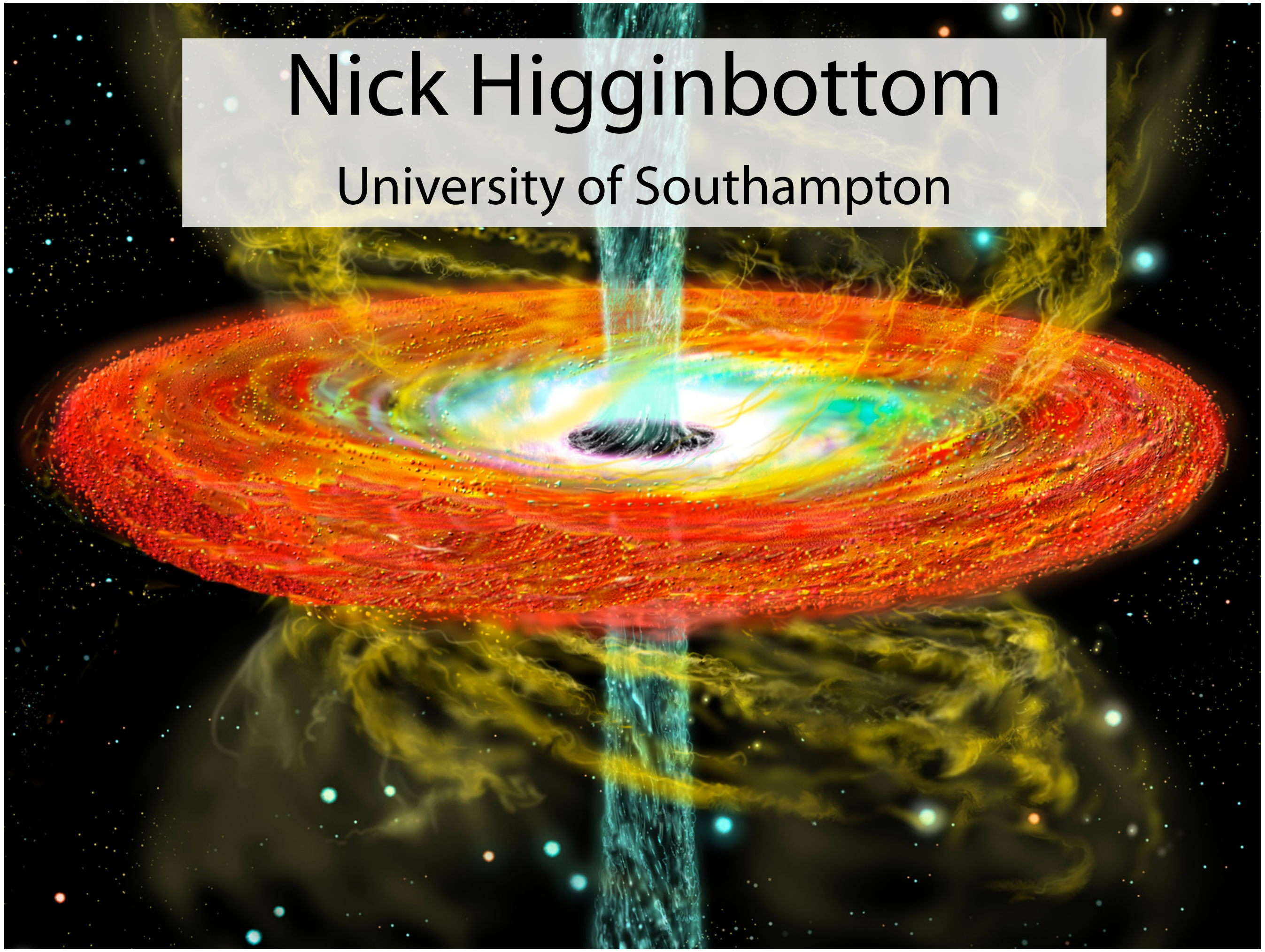
University of Southampton
School of Physics & Astronomy

Radiation-Hydrodynamic Simulations of Disk Winds in X-ray Binaries

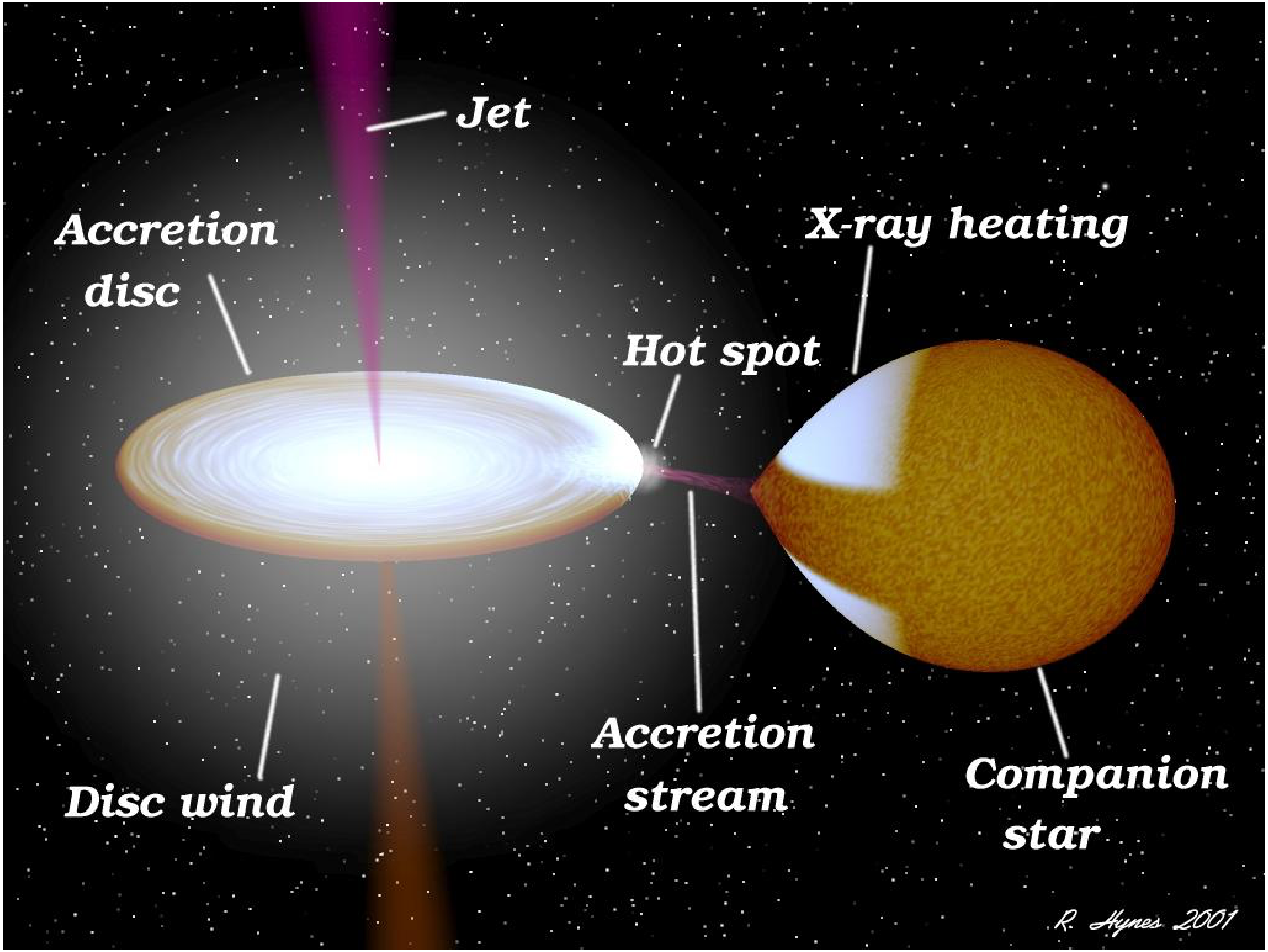


Nick Higginbottom
University of Southampton

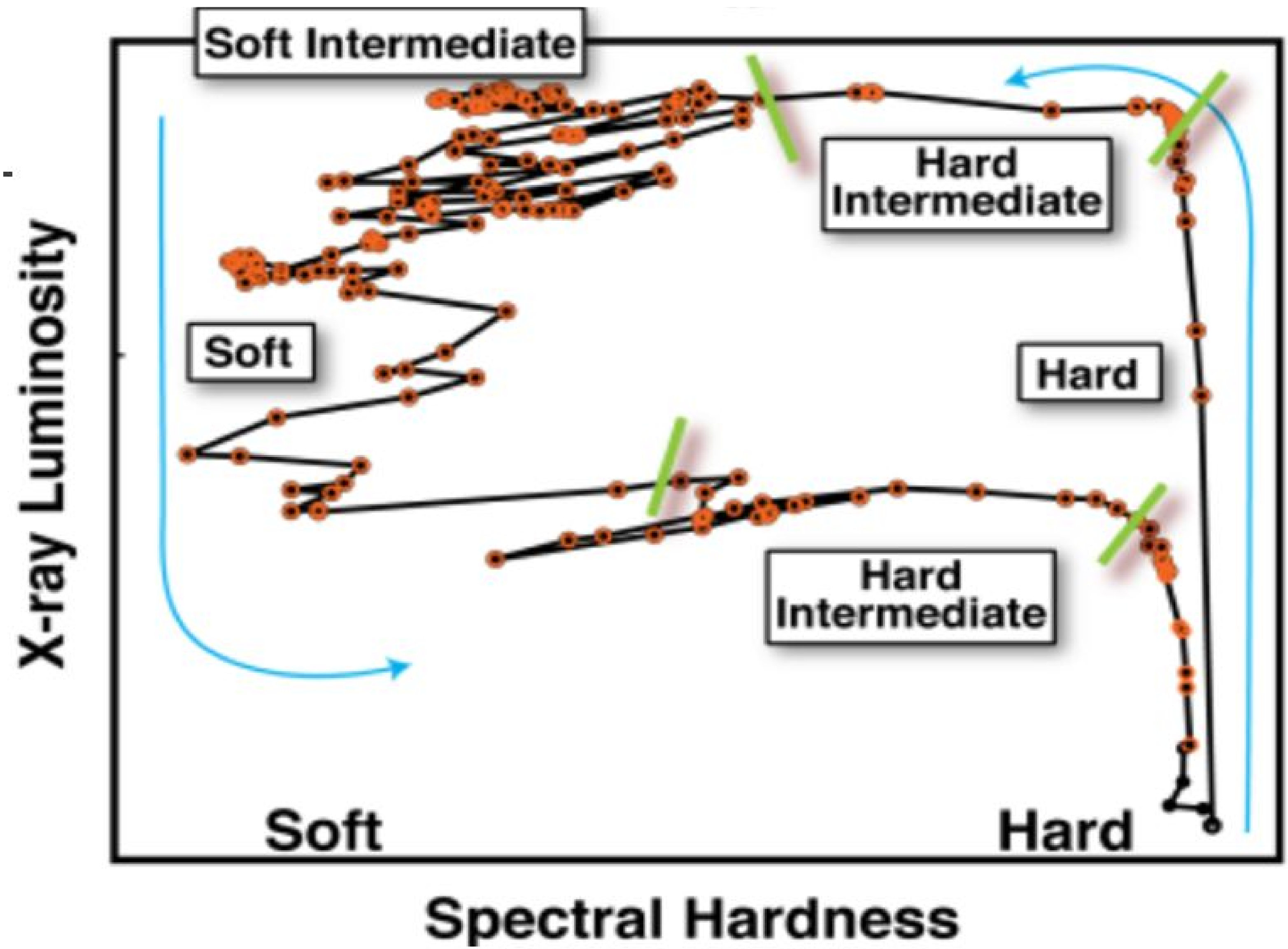
Christian Knigge

Knox Long, Daniel Proga, James, Matthews, Stuart Sim, Mandy Bailey, Sam Mangham

The Structure of X-ray Binaries

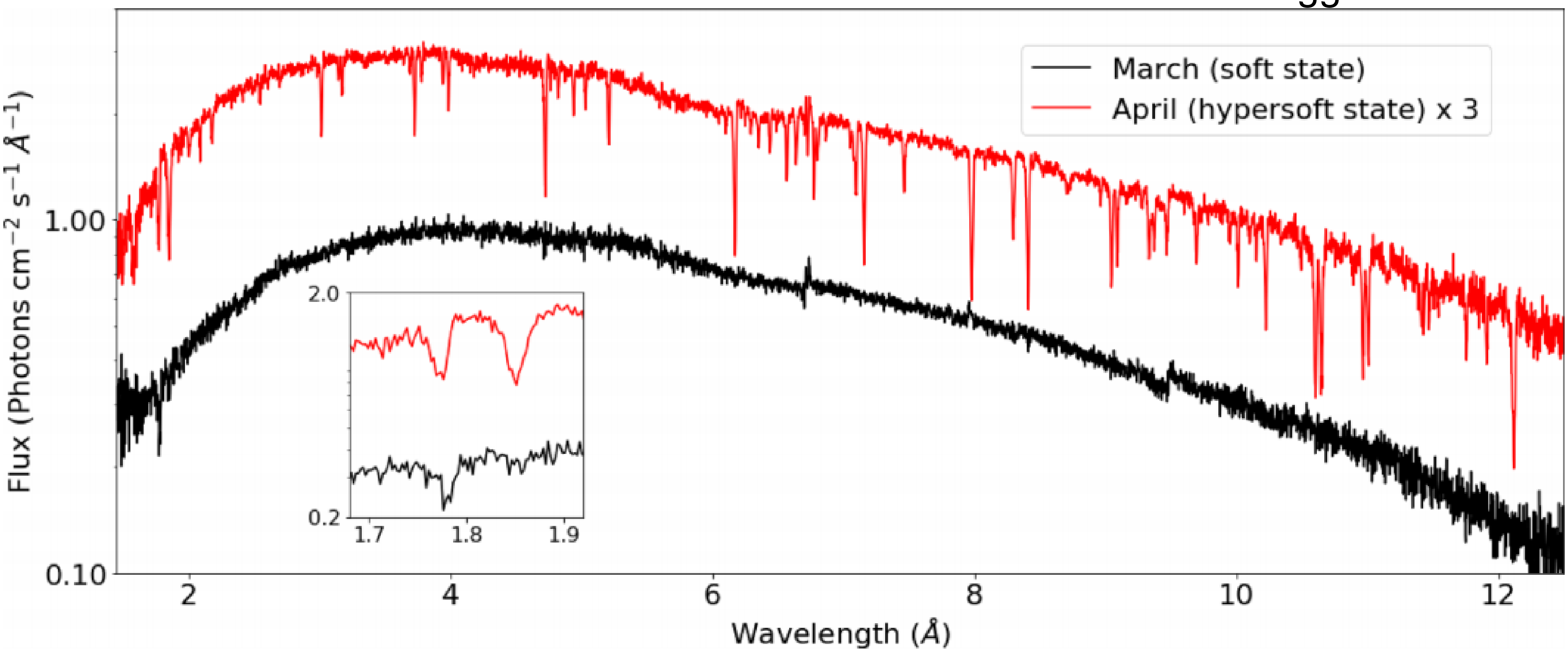


Outbursts of X-ray Binaries



Evidence for Disk Winds

Higginbottom+18



XRBs in outburst exhibit blue-shifted absorption in X-ray lines!

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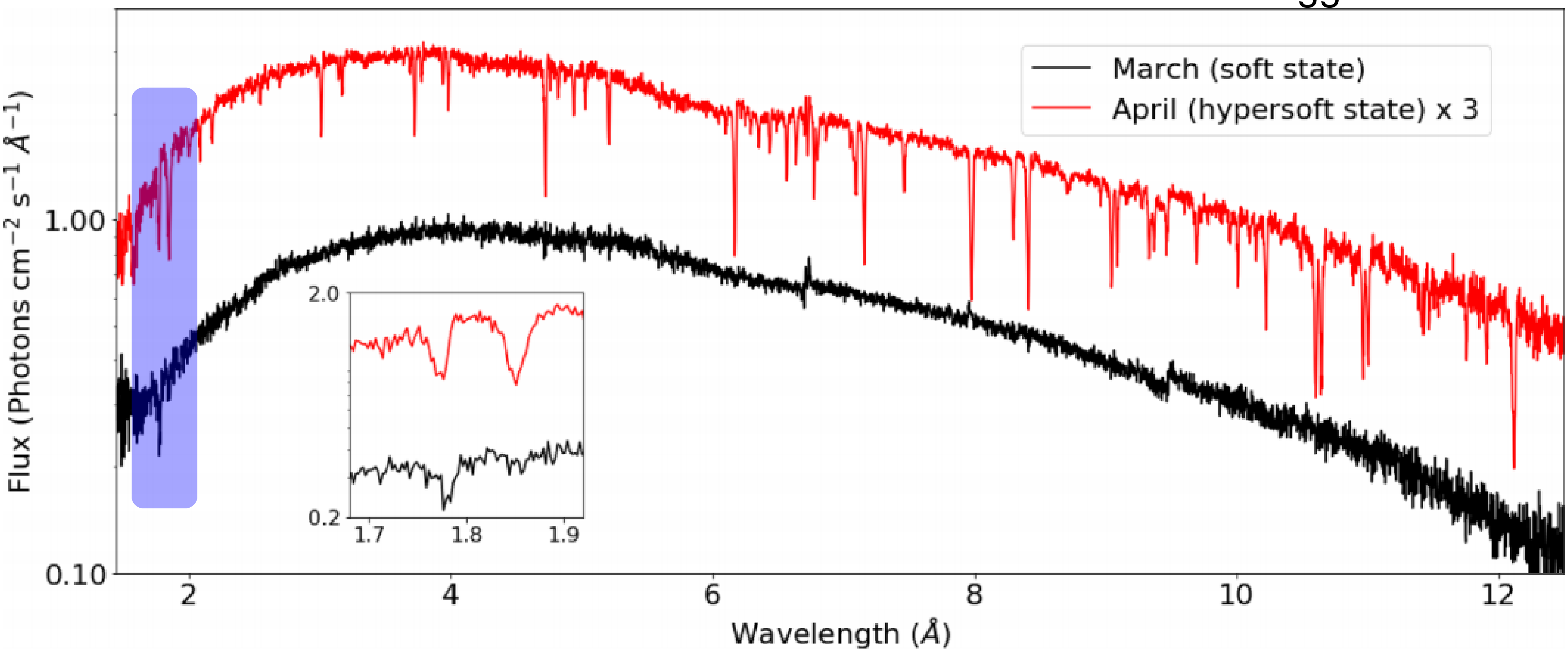
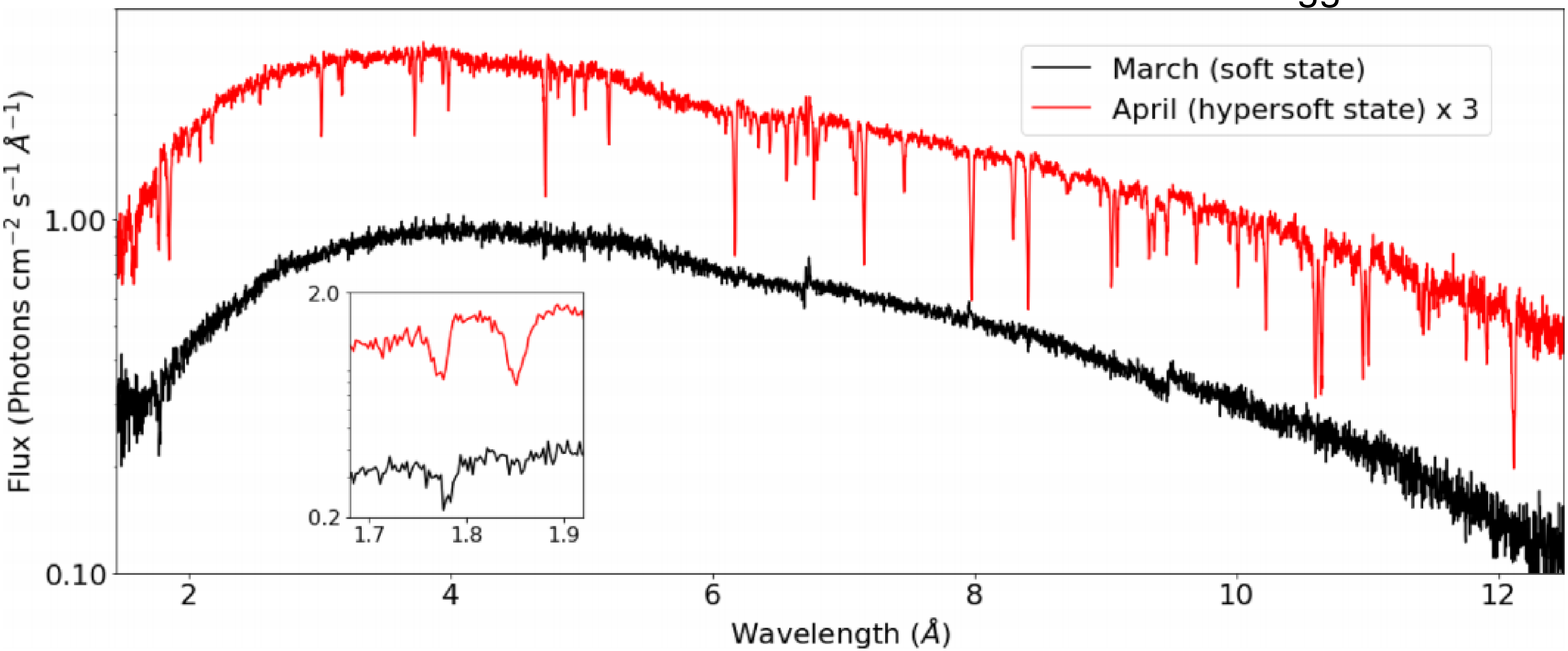


XRBs in outburst exhibit blue-shifted absorption in X-ray lines!

- always see H/He-like Iron lines
- $v_{wind} \approx$ 300 - 3000 km s^{-1}

Evidence for Disk Winds

Higginbottom+18



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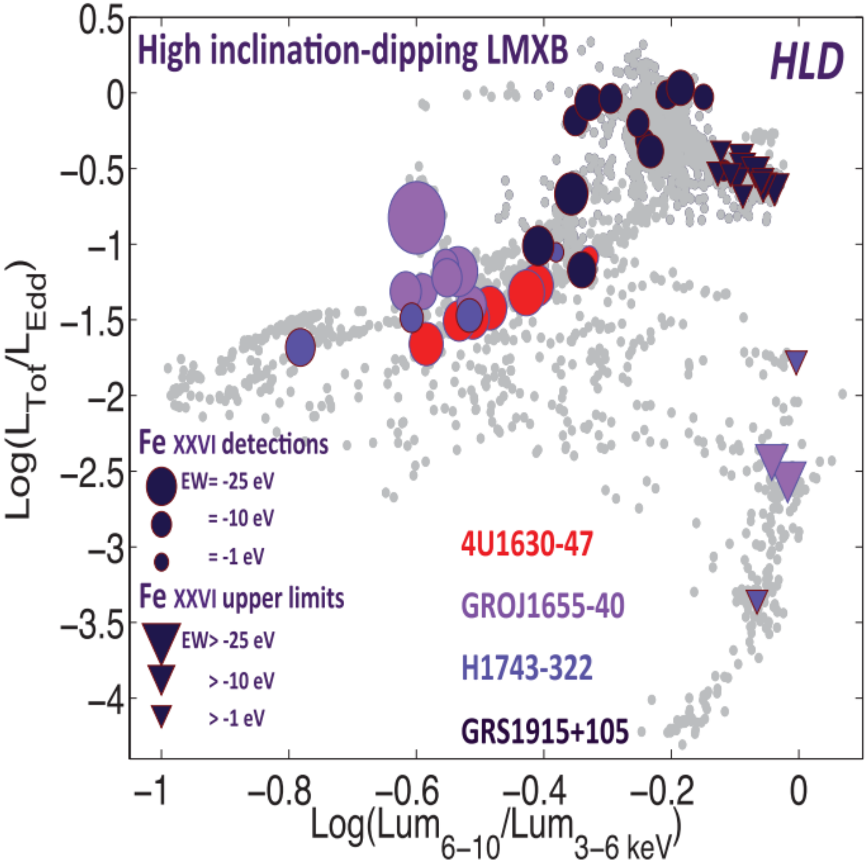
Outflow!

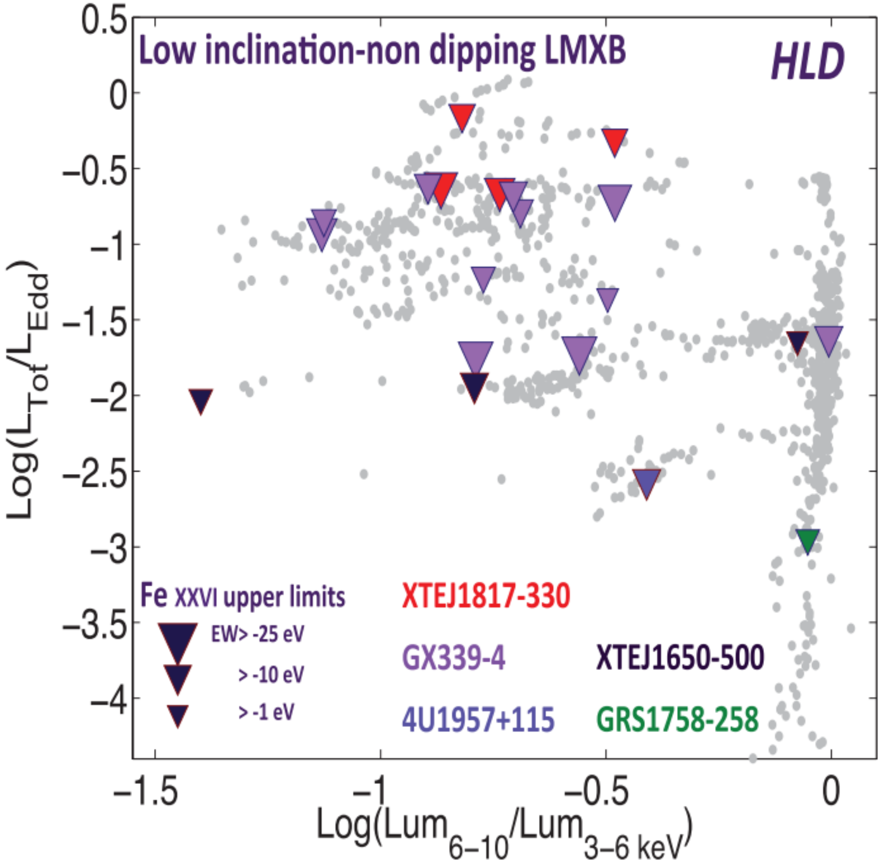
Evidence for Disk Winds

Only observed...

...in the soft state

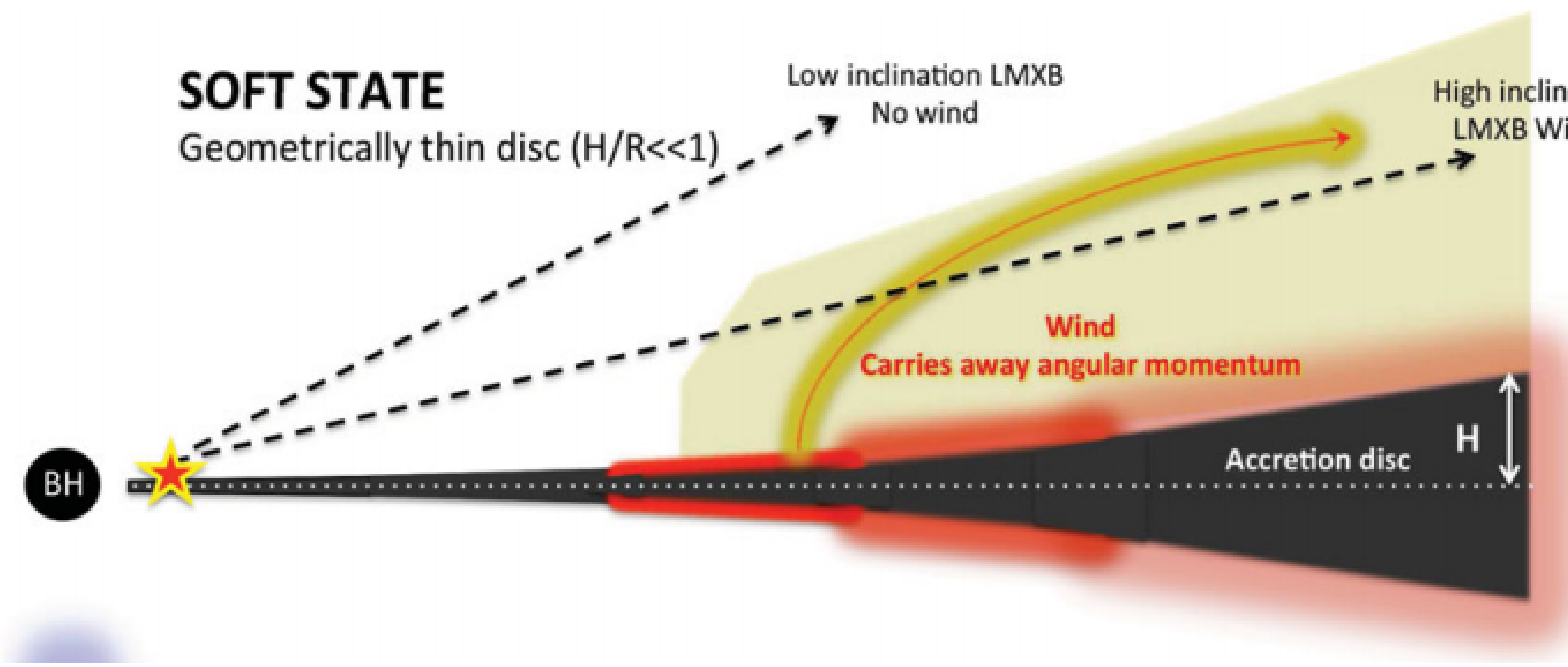


...in edge-on systems



Ponti+2012

Interpretation



Ponti+2012

Motivation: Why Should You Care?

- XRB disk winds are powerful: $\dot{M}_{wind} > \dot{M}_{acc}$
  - Accretion
    - disk winds may remove significant amounts of angular momentum
  - Veiling
    - all of our observations are viewed ***through*** the outflow
  - State changes and radio jets
    - disk winds might be involved in triggering state transitions

Driving Mechanisms

- Magneto-centrifugal acceleration
  - "Bead-on-a-wire" (Blandford & Payne 1982)

- Radiation pressure
  - Continuum → but usually $L < L_{edd}$
  - Lines → too ionized

- Thermal driving
  - Disk atmosphere is irradiated by X-rays → $T_{top} \simeq T_{Compton}$
  - Mass loss is inevitable at large radii → $v(T_{Compton}) > v_{esc}(R)$
  - Defines the "Compton Radius"

$$R_{IC} = \frac{GM_{BH}\mu m_H}{k_B T_{IC}}$$

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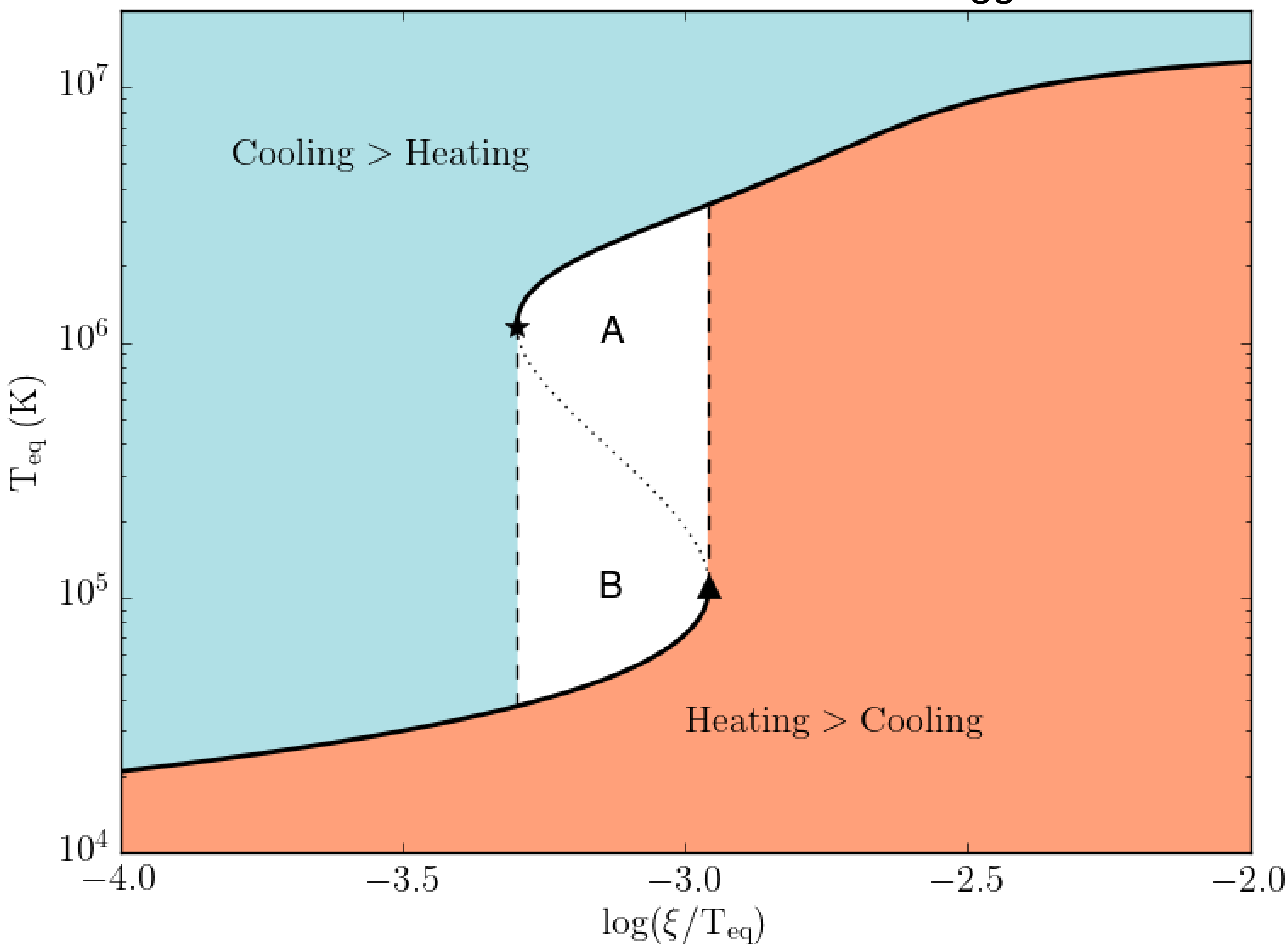
Thermal Instability

Higginbottom+16



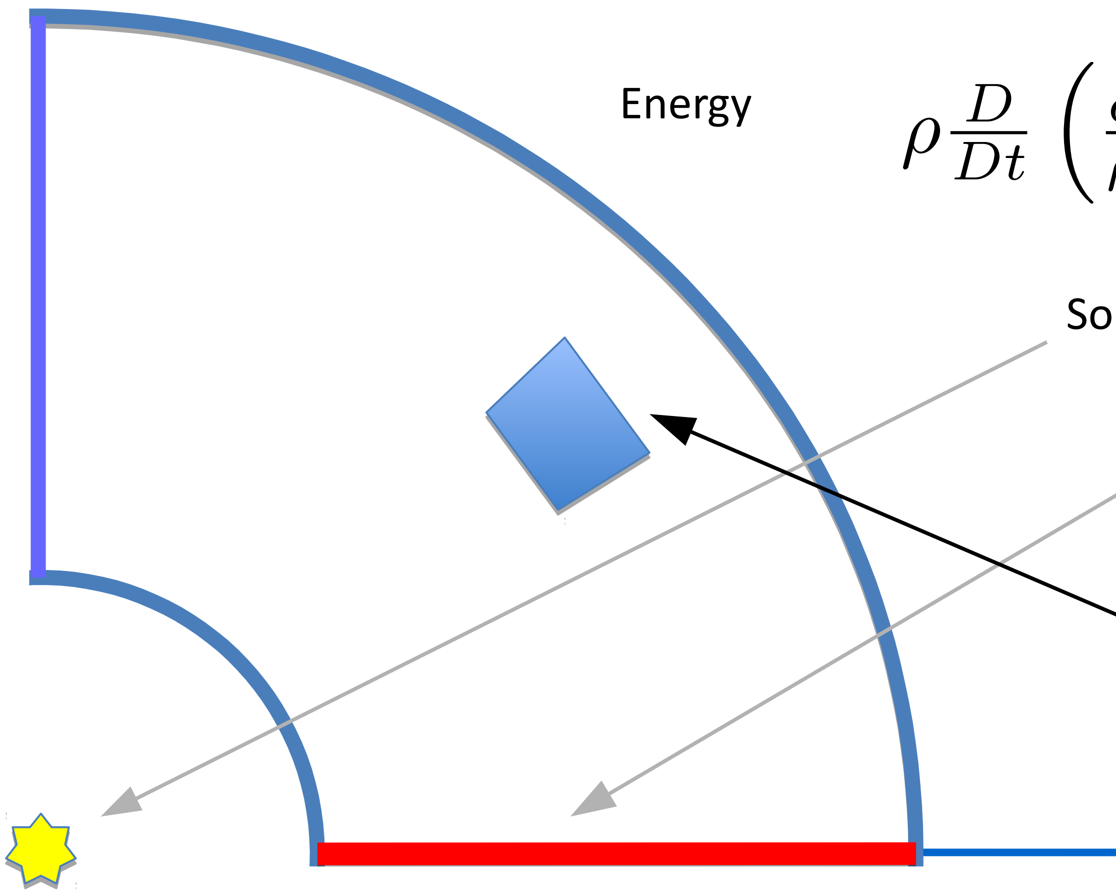
The Physics of Thermally-Driven Disk Winds Hydrodynamics

ZEUS (Stone, Proga,...)

Mass $$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{v} = 0$$

Momentum $$\rho\frac{D\mathbf{v}}{Dt} = -\nabla P + \rho\mathbf{g}$$

Energy $$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla\cdot\mathbf{v} + \rho\mathcal{L}(\xi,\mathcal{T})$$



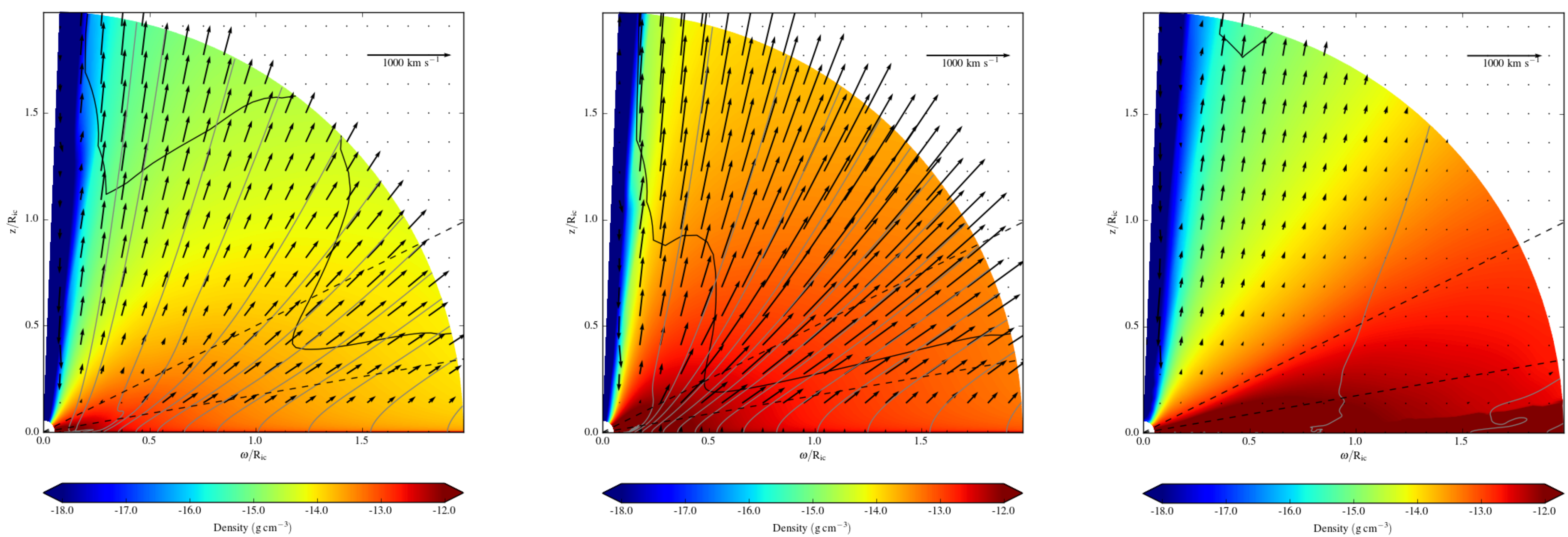
Source of ionizing radiation L_X

Fixed density boundary $\rho(r) = \rho_0\left(\frac{r}{R_{IC}}\right)^{-2}$

For a given cell, we need the radiative heating/cooling rate

The Physics of Thermally-Driven Disk Winds
Previous Work

- Heating and cooling rates matter!
  Higginbottom & Proga 2015; Higginbottom et al. 2016
- But all work to date neglected radiation transport
  - Should <u>at least</u> account for attenuation of X-rays in the outflow itself!
- Need to couple hydrodynamics with radiative transfer: ZEUS + PYTHON
  e.g. Long & Knigge 2002; Higginbottom+13+14; Matthews+15+16; Mangham+17



RHD vs HD: 5x Lower Mass-Loss Rate (but this is still 2x $\dot{M}_{acc}$)

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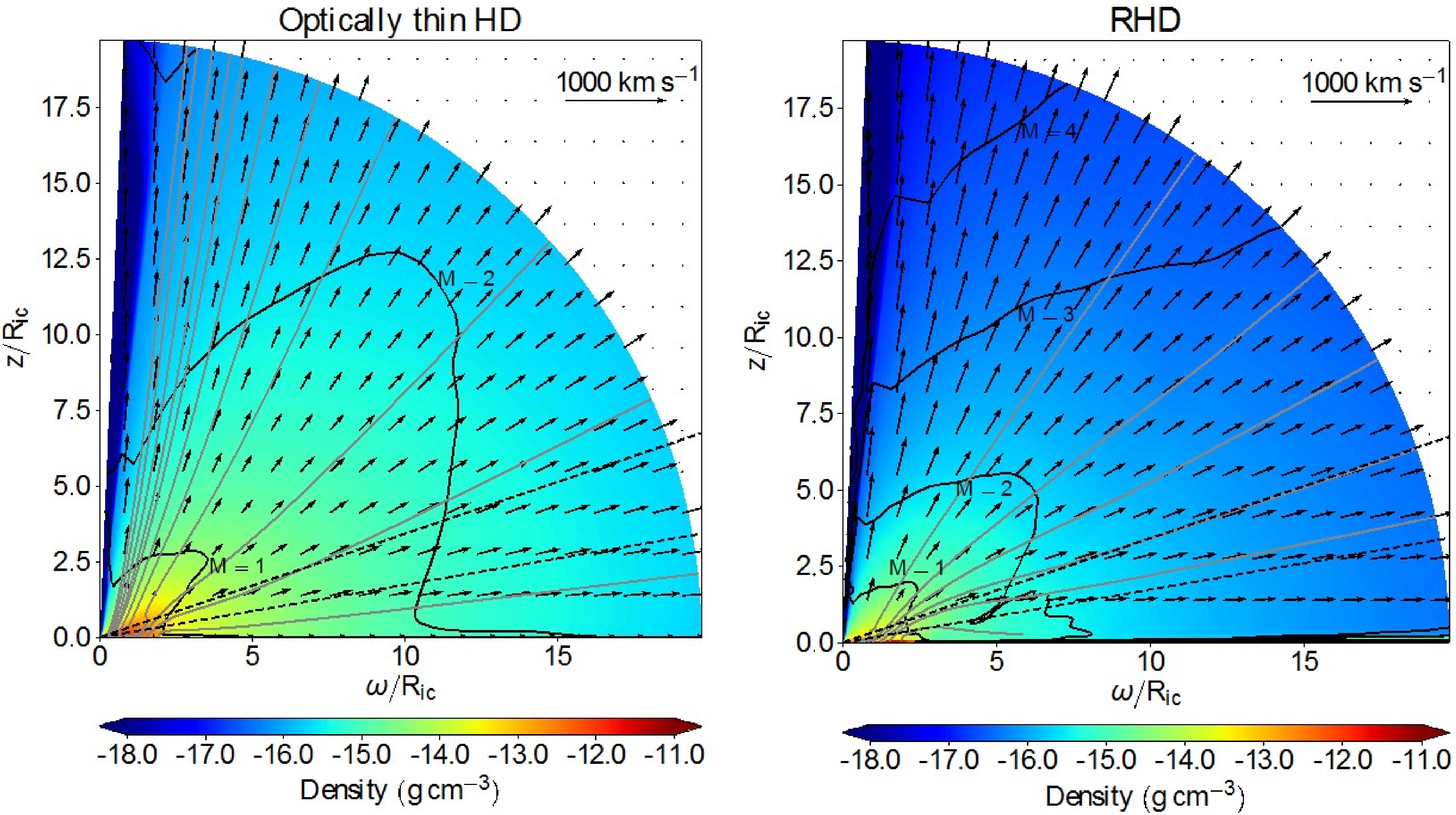

Higginbottom+18

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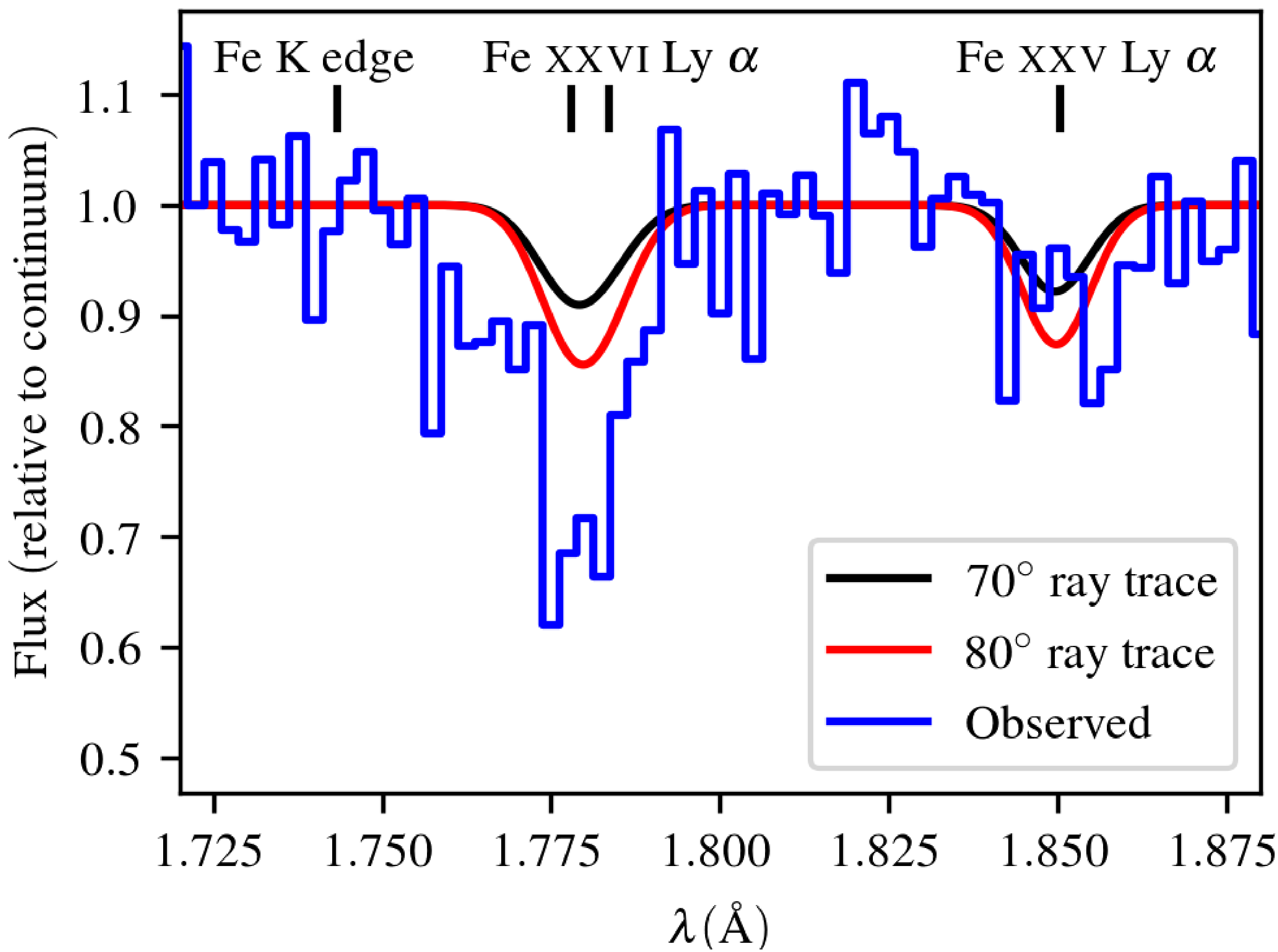
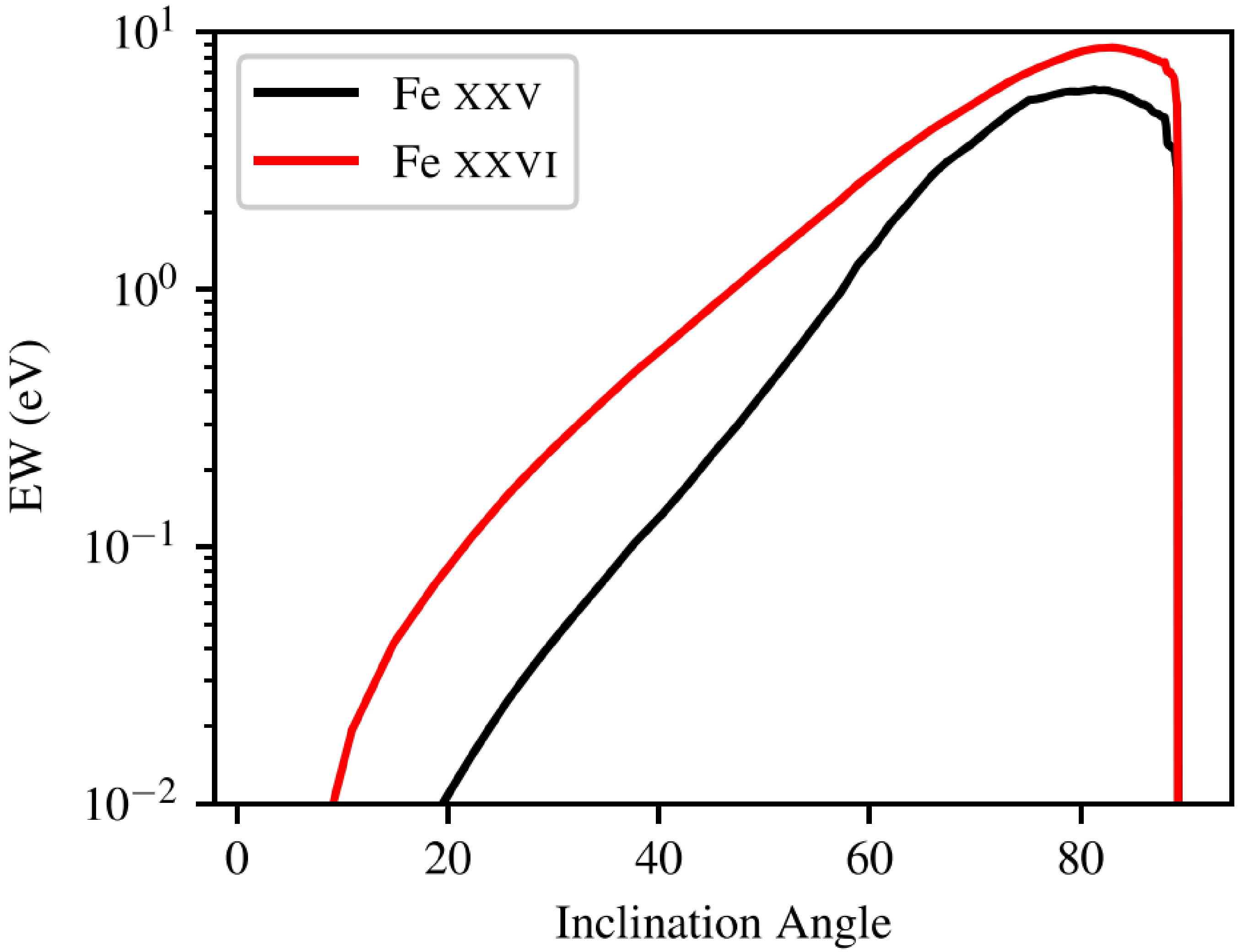
Comparison to Chandra Observations of J1655



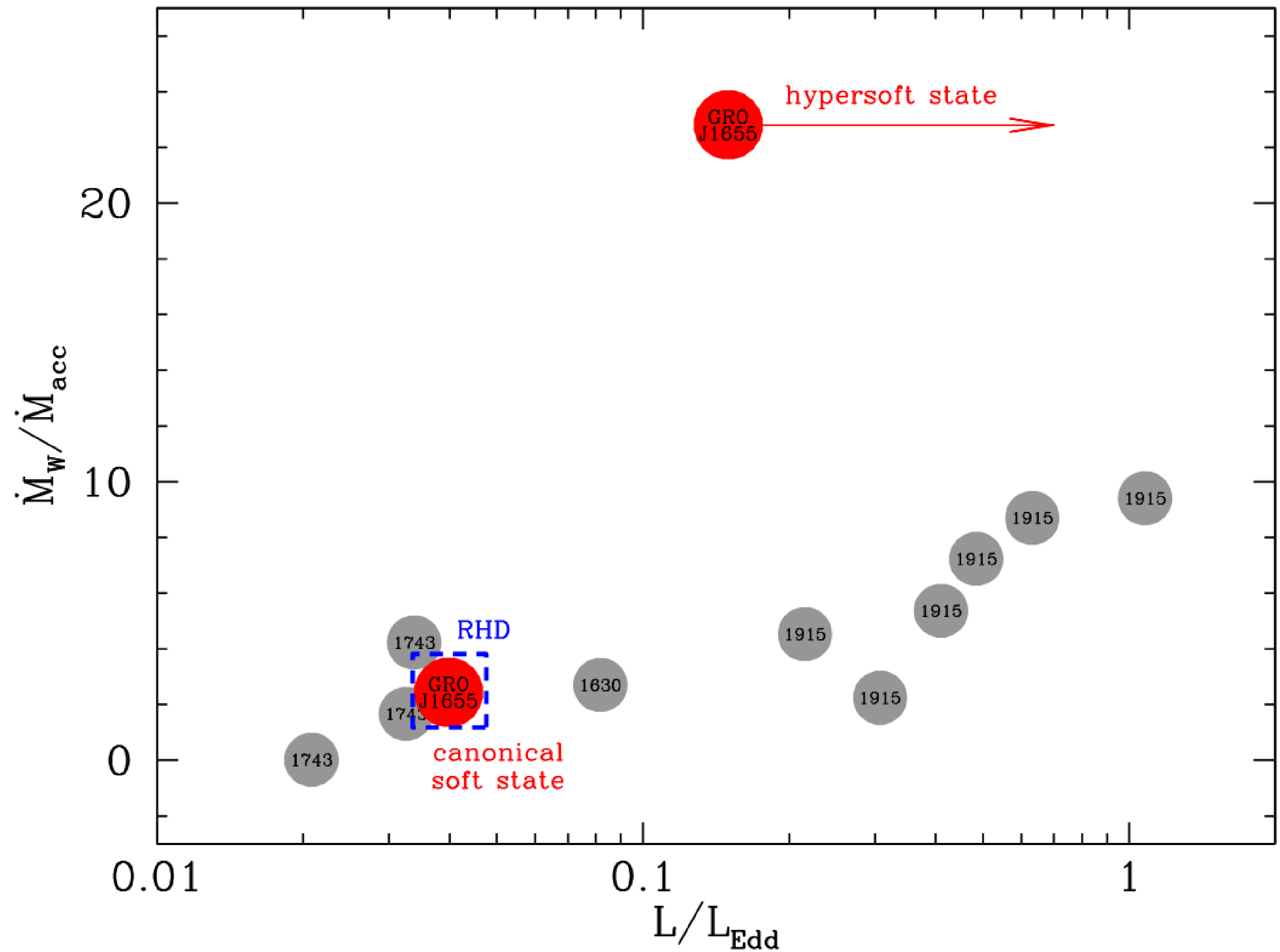
Inclination Dependence

Higginbottom+2018



"Efficiency": $\left(\dot{M}_{wind} / \dot{M}_{acc}\right)$

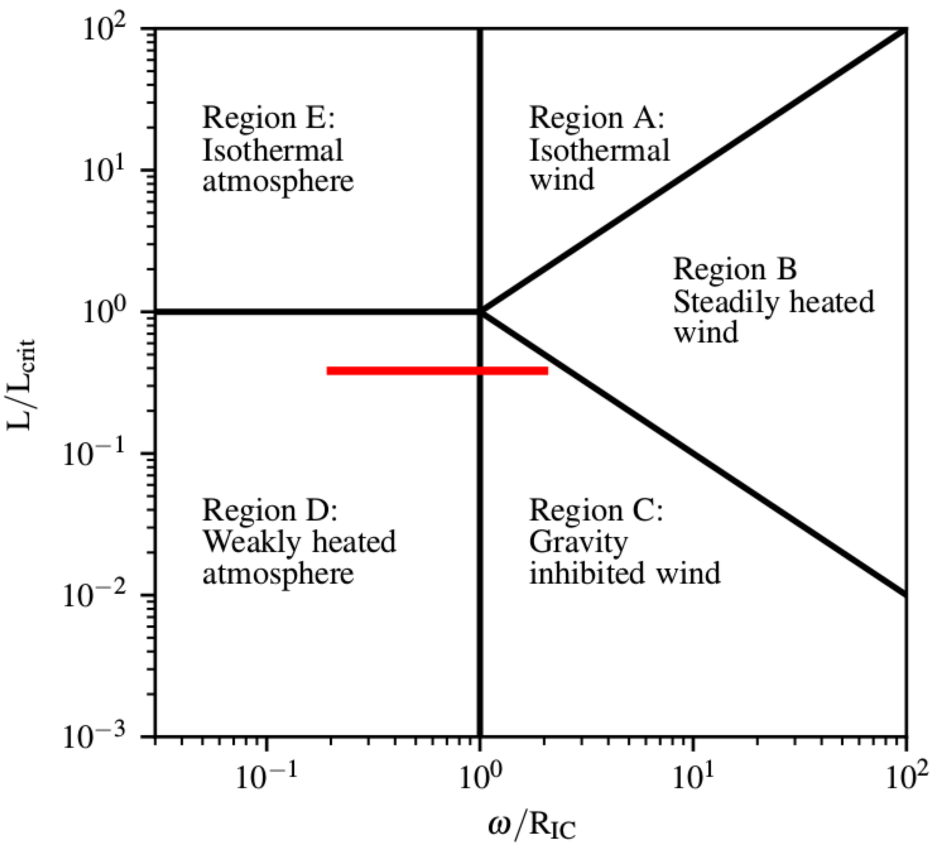
Higginbottom+18



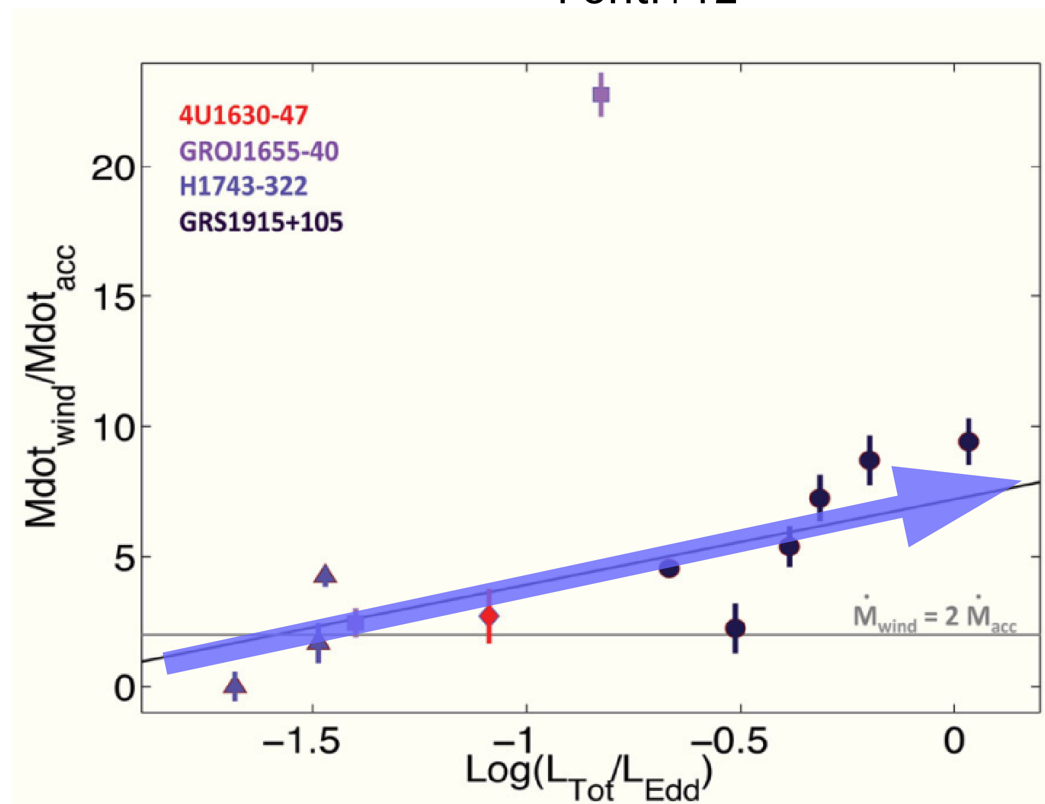
Data from Ponti+2012

Luminosity Dependence

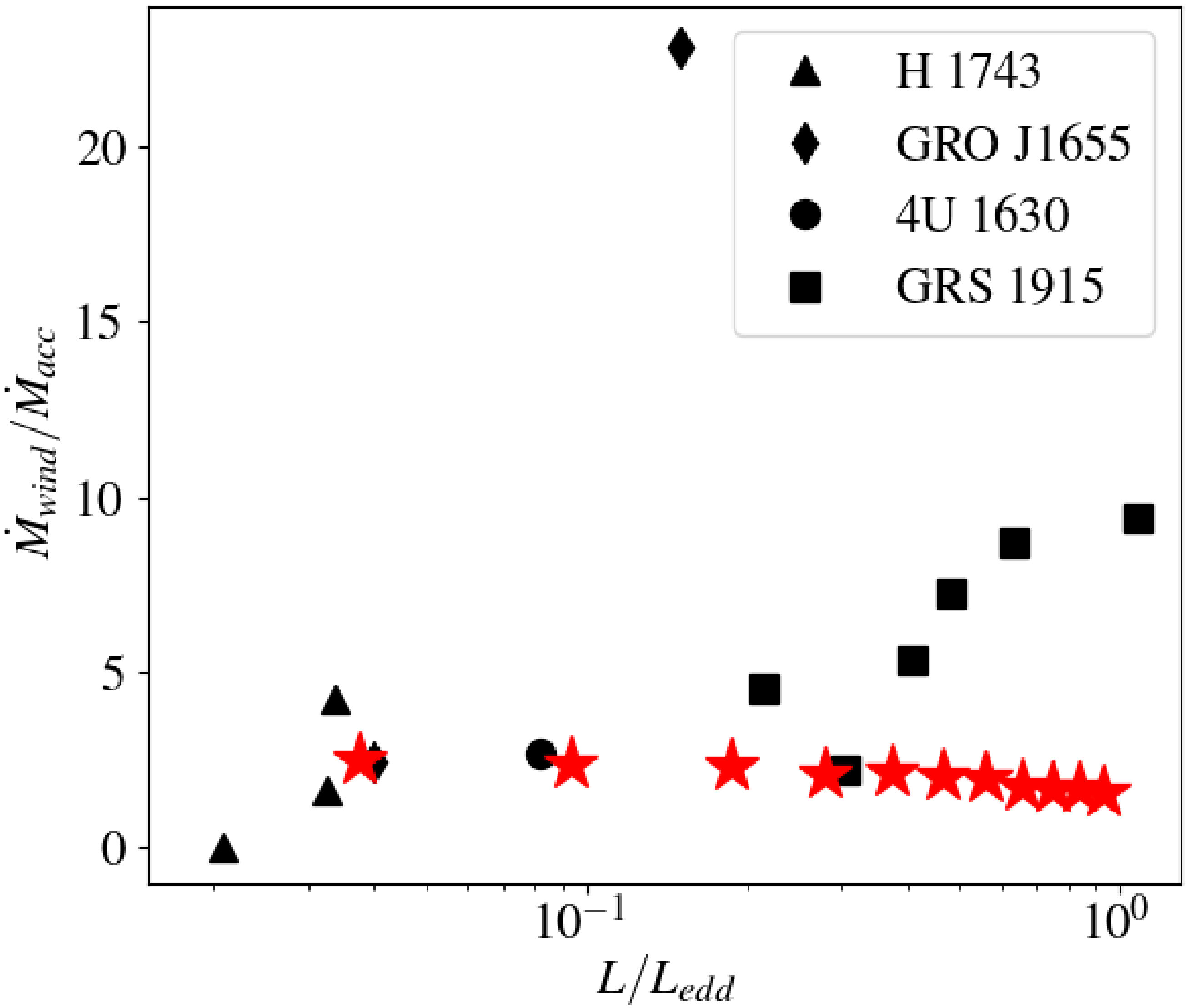
Theoretical
Begelman+83



Empirical
Ponti+12



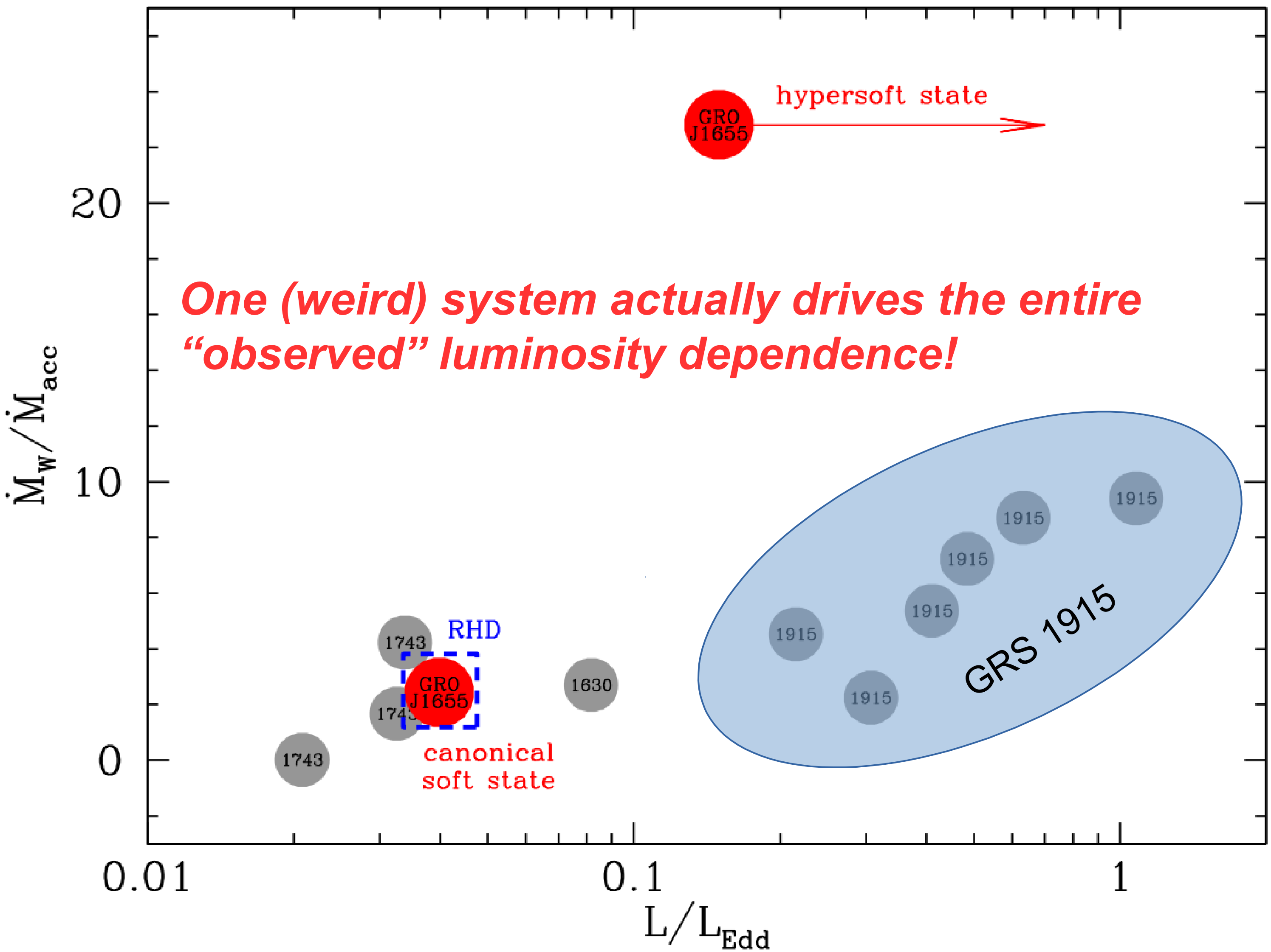
Luminosity Dependence
RHD Results



Efficiency stays ~constant

Consistent with Done+18

Luminosity Dependence
Is this a Problem?



Luminosity Dependence
Wind Speed and Line Profiles