Modeling Fe-Kα Fluorescence in the X-ray Spectra of γ Cas Stars

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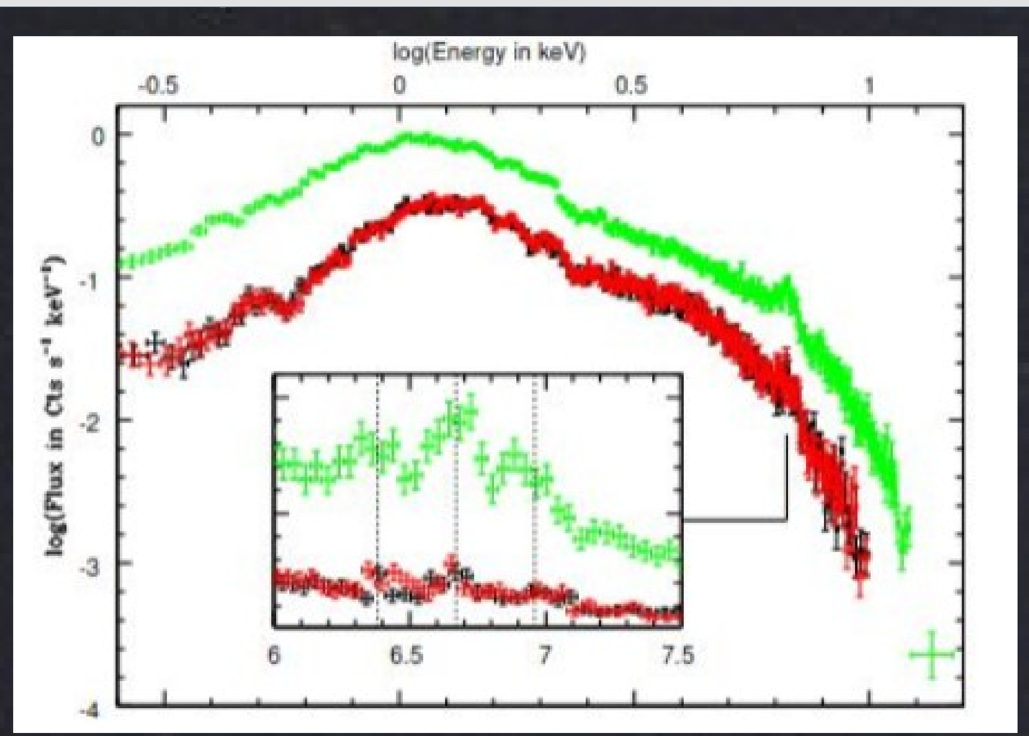
Abstract

Named after their prototype, γ Cas stars are a subset of Oe/Be stars emitting hard, bright and variable X-rays. The origin of these peculiar X-ray emissions is still in debate. Proposed scenarios include accretion onto a compact object, magnetic interaction of the Be star with its circumstellar disk, and collision between the wind of a stripped helium star companion and the Be disk. In this work, we model fluorescent Fe-K line emission from the rotating circumstellar disk and the photosphere of the Be star. The fluorescent Fe-K line is very sensitive to the physical conditions near the X-ray source. Thus, this line will help to better understand the geometry of the ionizing source and the X-ray emission mechanism in γ Cas stars. Athena/X-IFU will unveil the morphology of these lines, thereby offering robust diagnostics to distinguish between the various scenarios.

What are γ Cas stars?

- Named after their prototype γ Cas.
- Subset of Oe/Be stars.
- Emit hard (kT > 5 keV), bright and variable thermal X-rays.
- Feature fluorescent Fe-Kα line in their X-ray spectra along with FeXXV at 6.7 keV and FeXXVI at 6.97 keV, implying thermal nature of the emission.



EPIC spectra of π Aqr (Nazé et al. 2018)

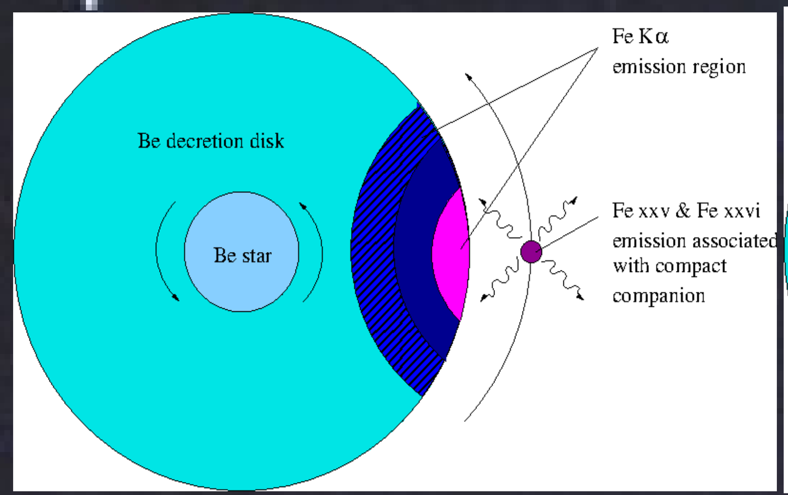
Goals of this project

- Investigate the origin of X-ray emissions in γ Cas stars by modeling fluorescent Fe-K line for various scenarios.
- Understand the role of Be stars in the evolution of massive stars.

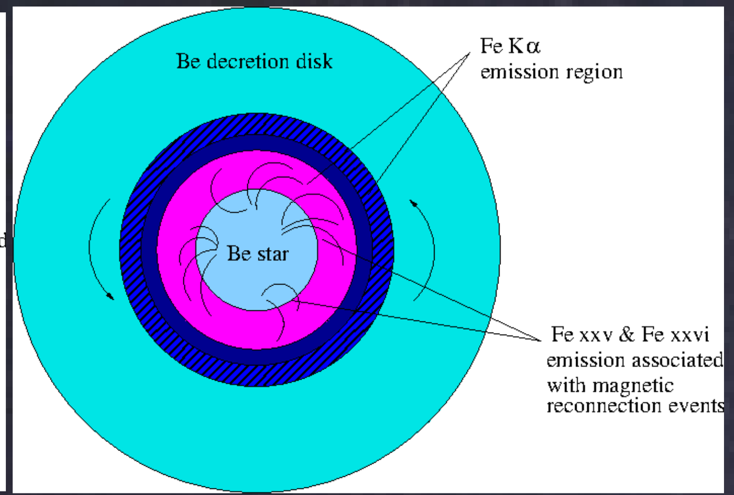
Why Fe-Kα line?

- Because it is sensitive to the physical conditions in the vicinity of the X-ray source. Hence, it helps to study the X-ray emission mechanism and ionizing source's geometry.

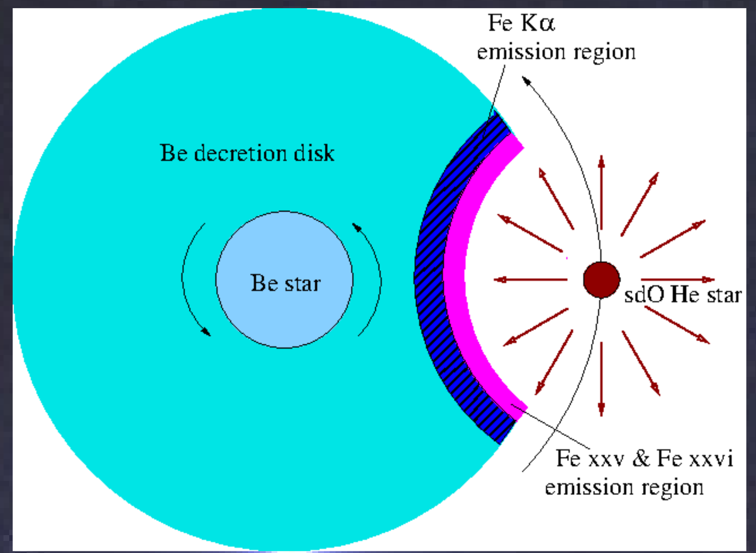
Proposed Scenarios



(a) Accretion onto a compact object (White et al. 1982; Postnov et al. 2017; Murakami et al. 1986; Hamaguchi et al. 2016)

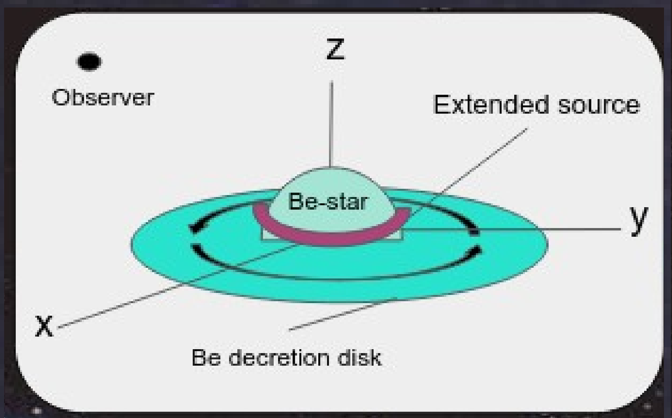


(b) Magnetic star-disk interaction scenario (Smith et al. 1998; Robinson et al. 2002; Smith et al. 2016)

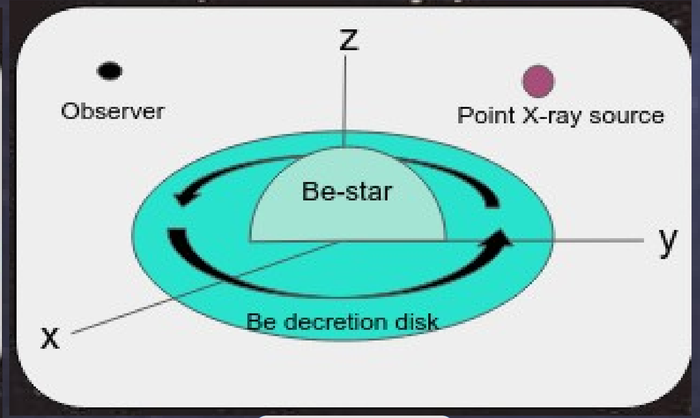


(c) Wind collision model (Langer et al. 2020)

Geometries



Case A



Case B

Fluorescence from Be disk

Assumptions in our model:

- Disk is optically thin vertically.
- Disk rotation is keplerian.
- Parameters adapted for γ Cas.

Equations: Line luminosity is given by:

$$L_{total} = \int_{volume} j_{K\alpha} dV \, obs$$

- where the emissivity $j_{K\alpha}$ is expressed as:

$$j_{K\alpha} = E_K w_K x_l vis \int_{E_{th}}^{\infty} \sigma_K F(E) dE$$

where σ_K = K-shell photoionization cross section, E_K = energy of fluorescent Fe-Kα line, w_K = fluorescent yield, x_l = relative abundance of a given Fe ion, *F(E)* = incoming flux at energy E, *vis* = visibility of X-ray source by disk element, *obs* = visibility of the disk element by observer, E_{th} = subshell ionization threshold energy of given Fe ion (Verner and Yakovlev (1995); Kallman et al. (2004)).

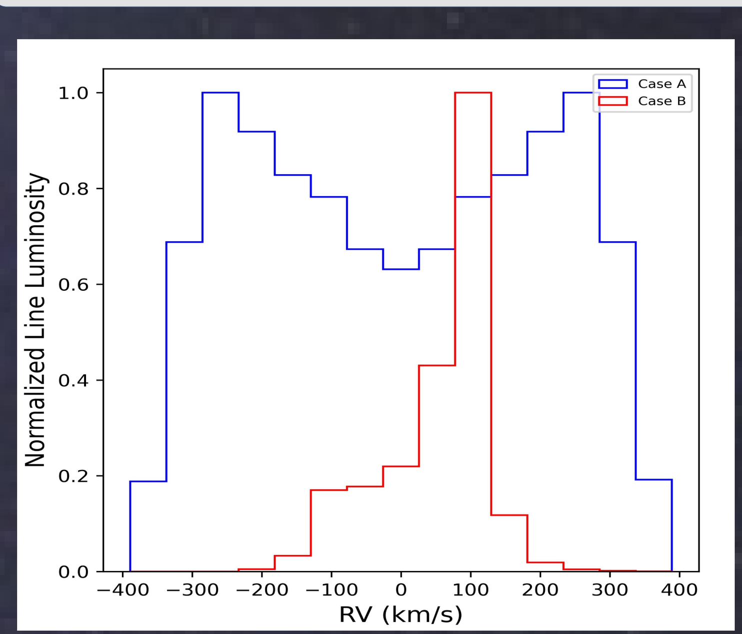
Fluorescence from Be photosphere

Since the overall ionization of the photosphere near $\tau_{Rosseland}$ = 1 is unaffected by the X-rays, we treat them as a small perturbation. We adopt:

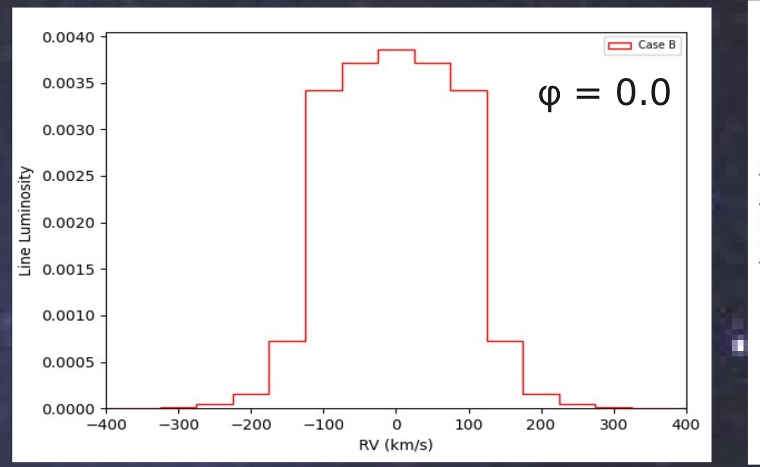
- Atmosphere structure of TLUSTY model (Lanz & Hubeny (2007)), and
- Feautrier scheme to solve the radiative transfer (Garcia et al. (2013)).

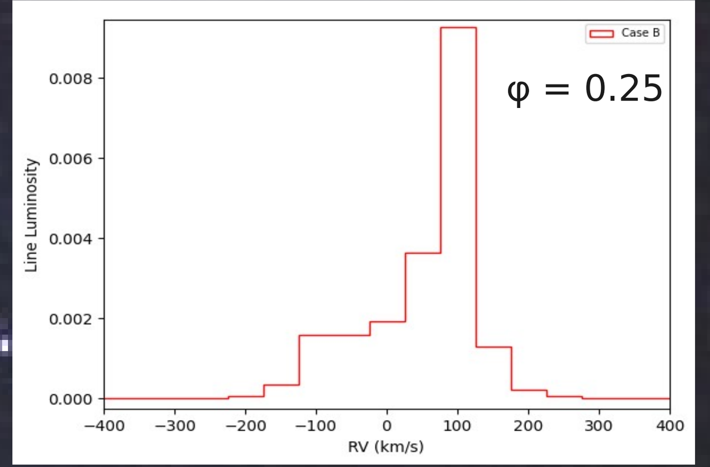
My Results

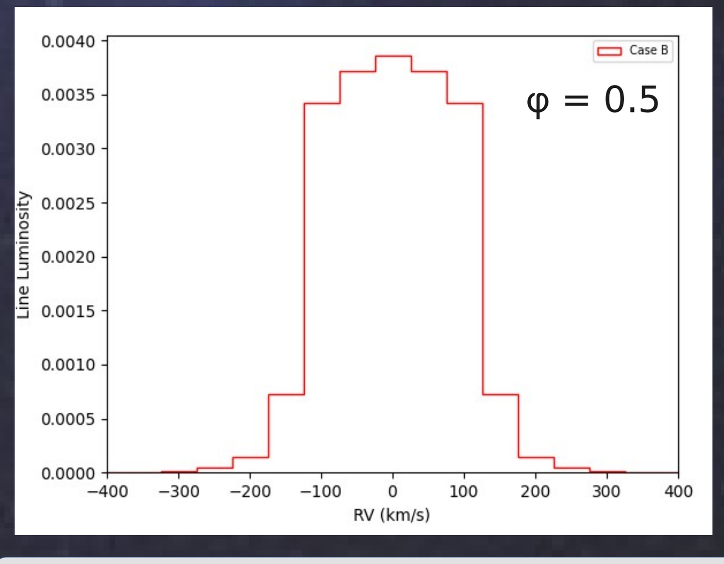
1) Fluorescence from Be disk:

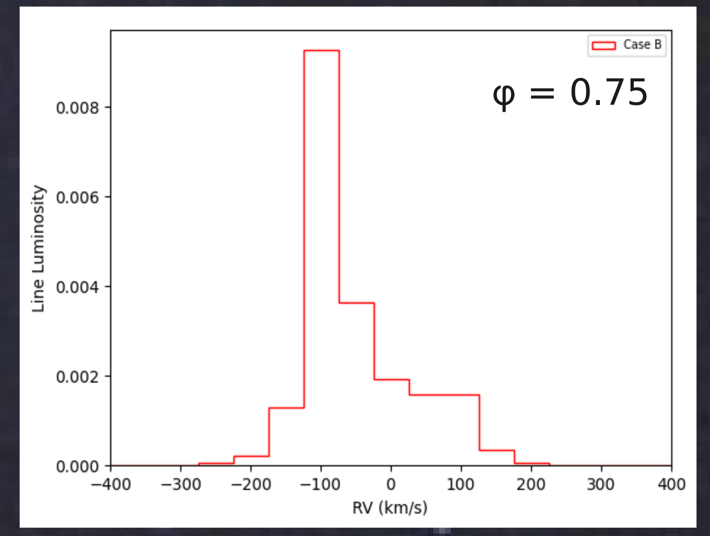


- $Flux_{Case\ A}$ > $Flux_{Case\ B}$
- Line profile stays symmetric in Case A but depends on orbital phase of the companion in Case B (as shown in the plots below).

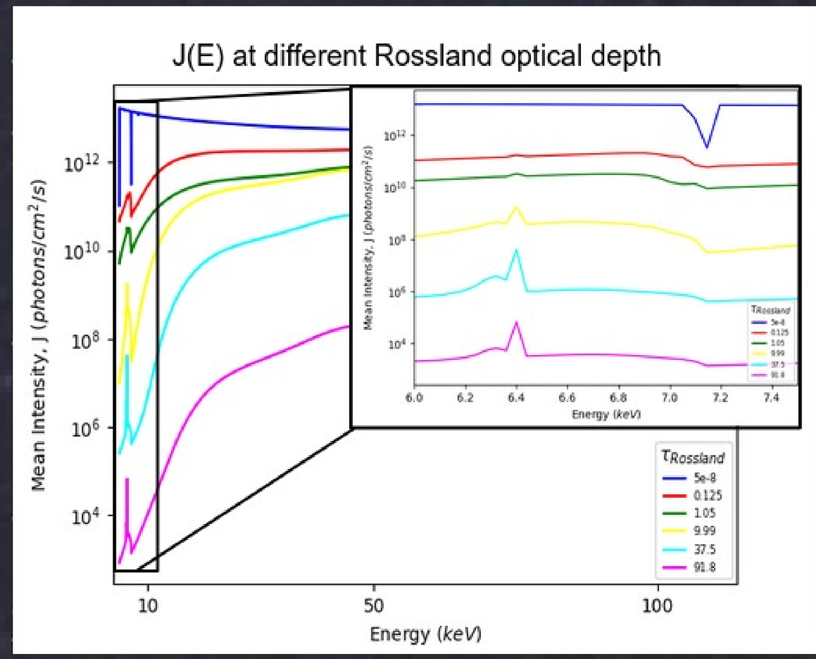








2) Fluorescence from Be photosphere:



- The shape of the energy distribution is determined by Compton scattering and photo-electric absorption.
- Fe-Kα line relatively stronger deep inside the photosphere as continuum weakens.