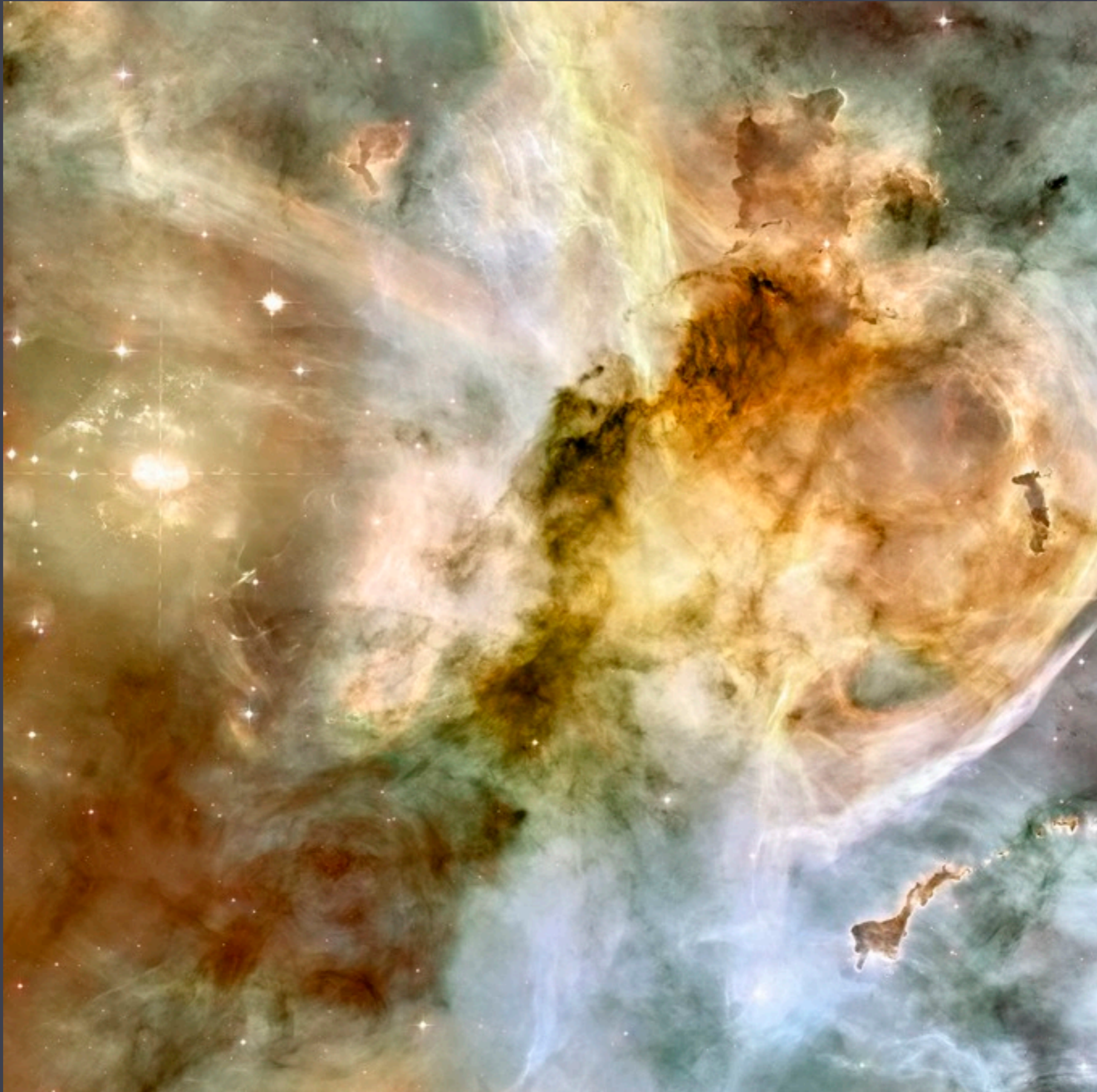


Carina Nebula: star formation region, $d \sim 7000$ light years



HST: Carina Nebula

energized by the few dozen most massive & luminous stars



massive stars produce heavy elements and return them to the Galaxy via their stellar winds

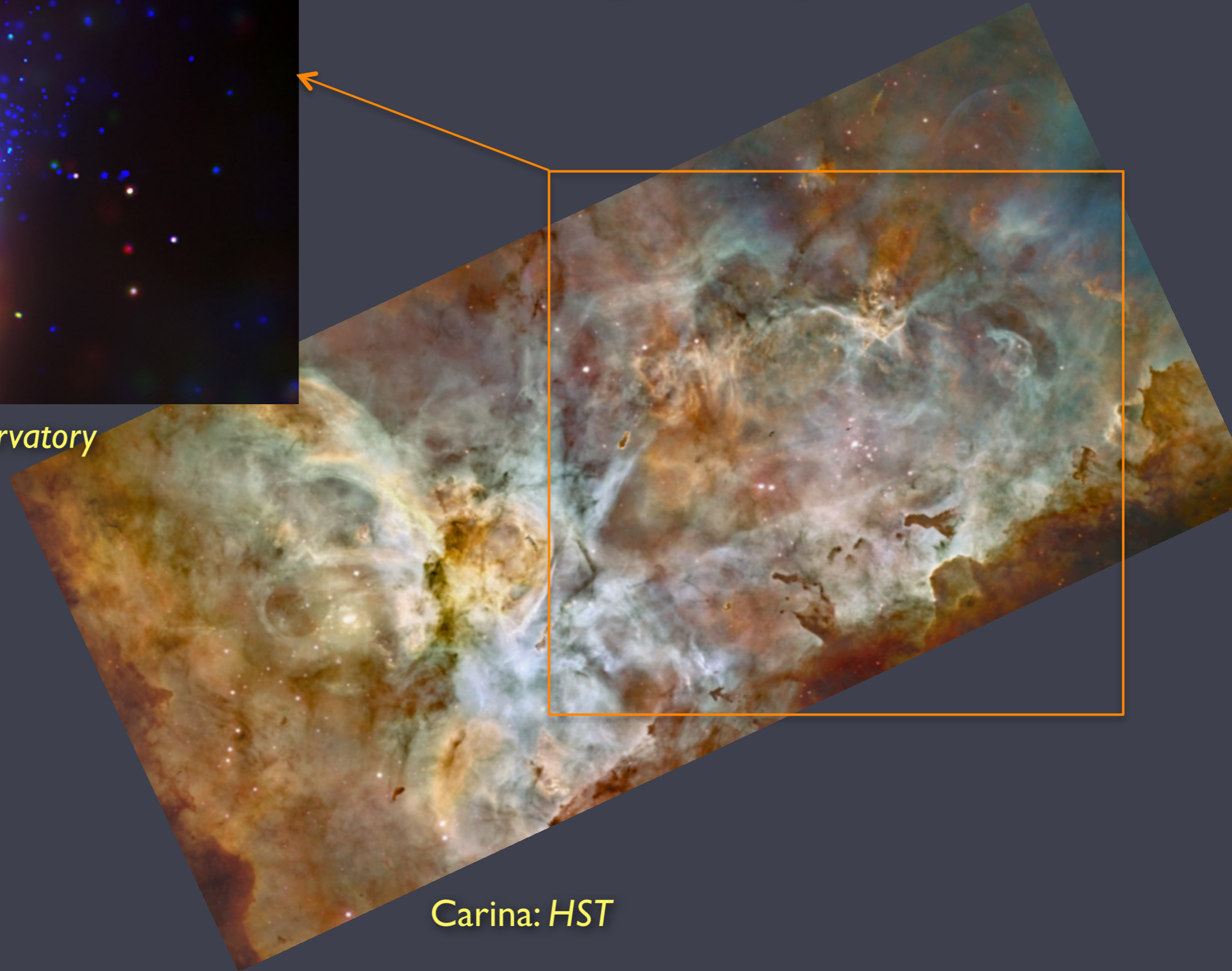


eta Carina

The massive stars are also
strong X-ray sources



Tr 14: Chandra X-ray Observatory



Carina: HST

***Chandra* X-ray spectroscopy of the very early O supergiant HD 93129A: constraints on wind shocks and the mass-loss rate**

David H. Cohen,^{1*} Marc Gagné,² Maurice A. Leutenegger,^{3,4} James P. MacArthur,¹ Emma E. Wollman,^{1,5} Jon O. Sundqvist,⁶ Alex W. Fullerton⁷ and Stanley P. Owocki⁶

¹*Department of Physics and Astronomy, Swarthmore College, Swarthmore, PA 19081, USA*

²*Department of Geology and Astronomy, West Chester University, West Chester, PA 19383, USA*

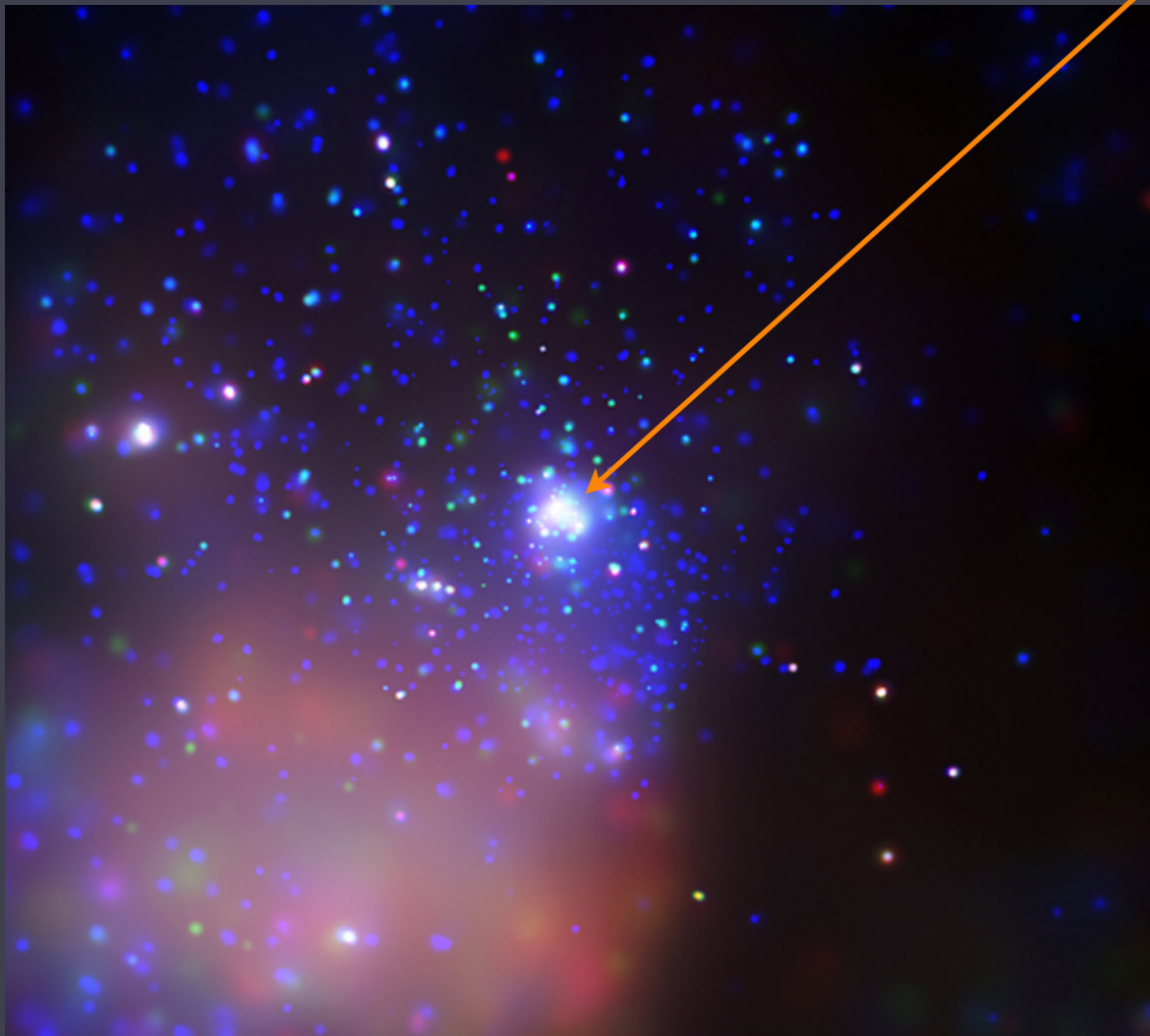
³*NASA/Goddard Space Flight Center, Code 662, Greenbelt, MD 20771, USA*

⁴*CRESST and University of Maryland, Baltimore County, MD 21250, USA*

⁵*Department of Physics, Caltech, 1200 East California Boulevard, Pasadena, CA 91125, USA*

⁶*Bartol Research Institute, University of Delaware, Newark, DE 19716, USA*

⁷*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA*



X-ray spectroscopy of the most massive star in the cluster has already yielded new information about this star's wind

Tr 14 in Carina: *Chandra* X-ray Observatory

Two outstanding questions

1. How do massive stars produce their strong X-ray emission?
2. How strong are their stellar winds (what are their mass-loss rates)?

observational X-ray astronomy

X-ray spectroscopy with the Chandra X-ray Telescope



Chandra in the Space Shuttle cargo bay

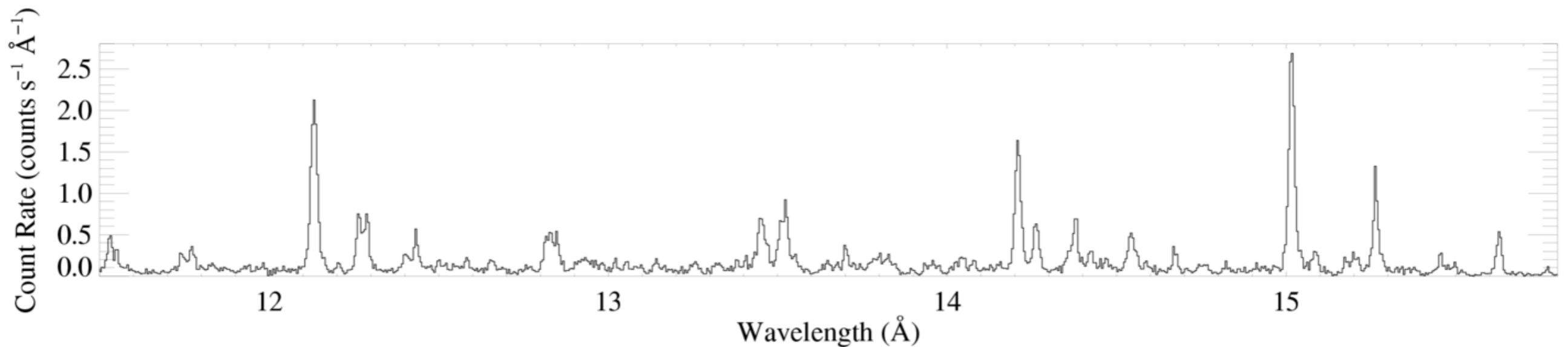
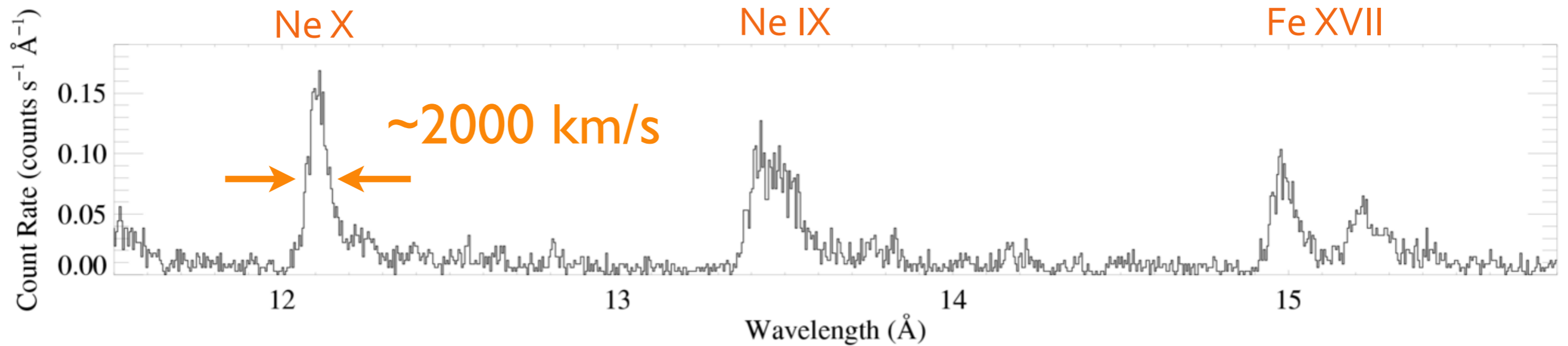
Chandra in orbit



massive stars' X-ray emission lines are **broad**

Chandra spectra

ζ Pup (O4If)



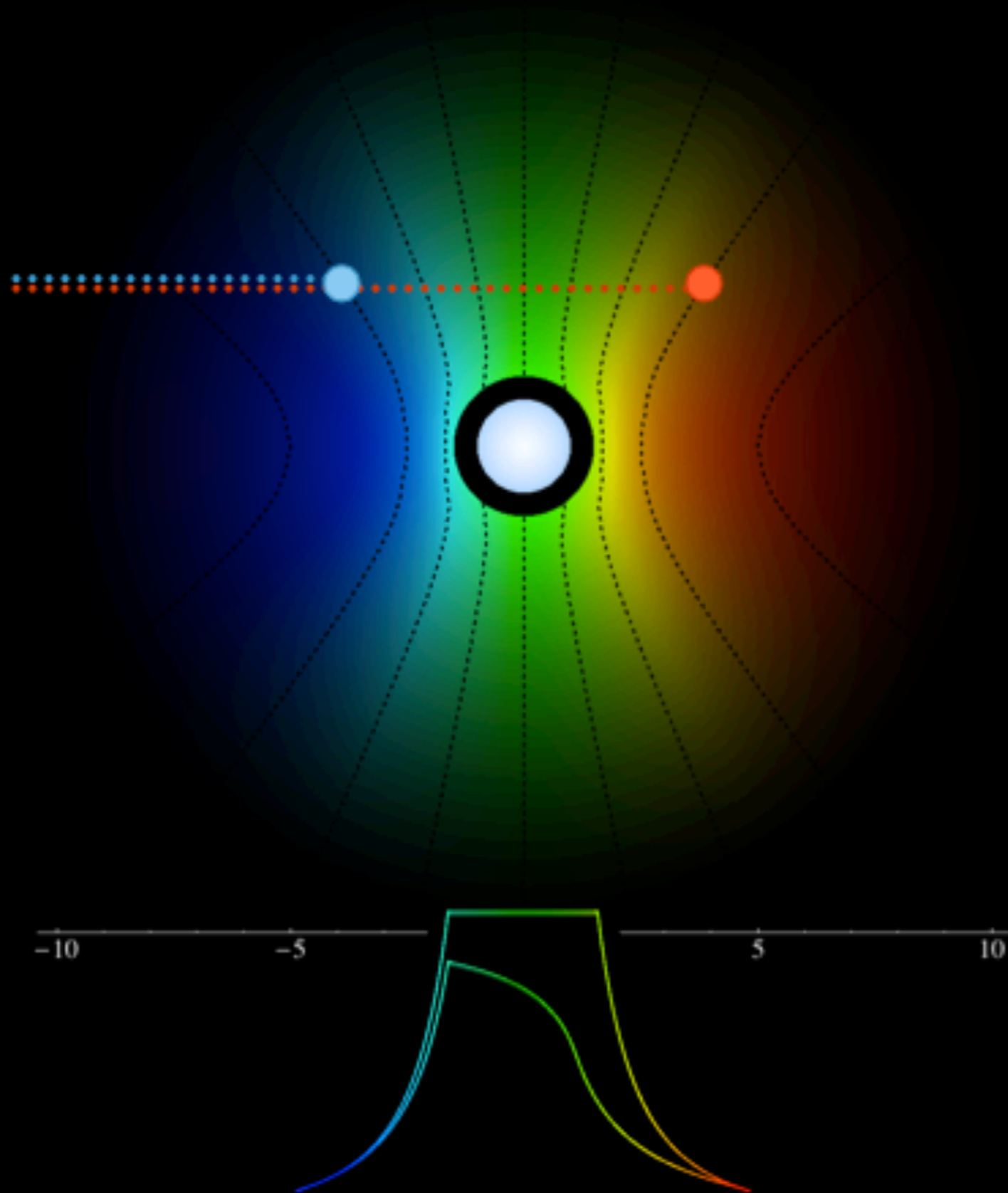
Capella: G star for comparison (narrow lines)

we make models

Line Asymmetry

$$\tau = \tau_* \int_z^\infty \frac{R_* dz'}{r'^2 (1 - R_*/r')^\beta}$$

A

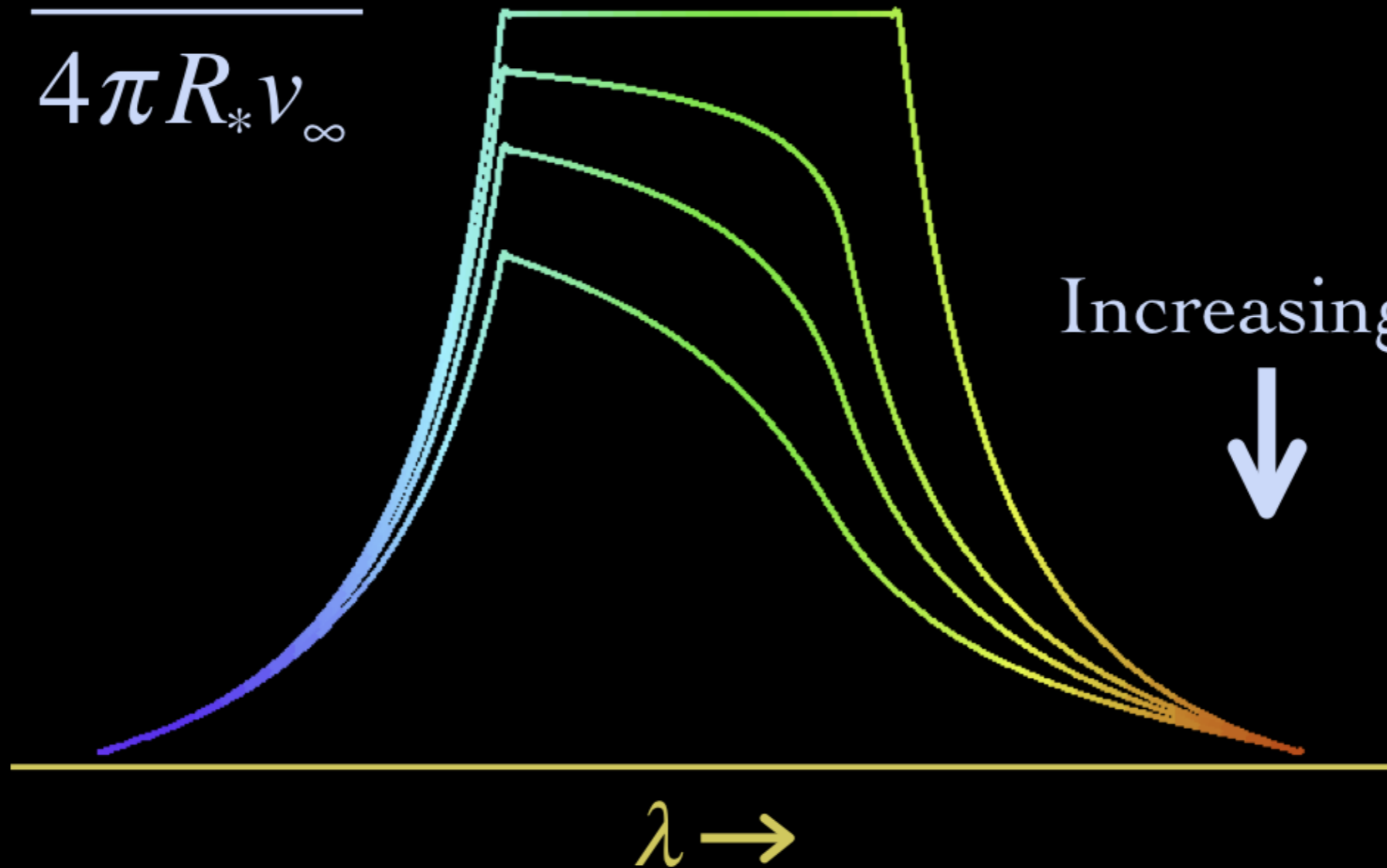


models make predictions

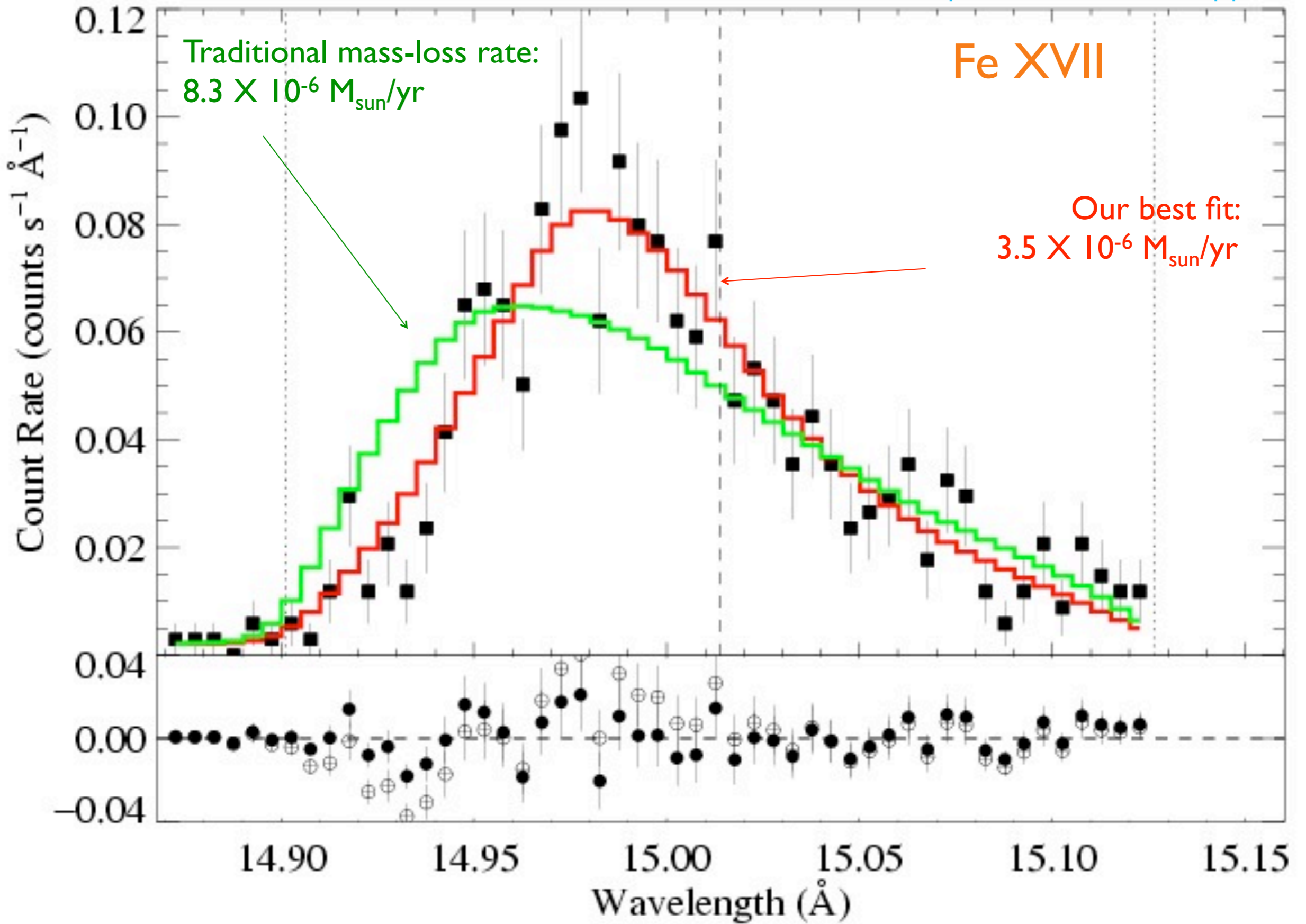
Wind Profile Model

wind mass-loss rate

$$\tau_* = \frac{\kappa \dot{M}}{4\pi R_* v_\infty}$$



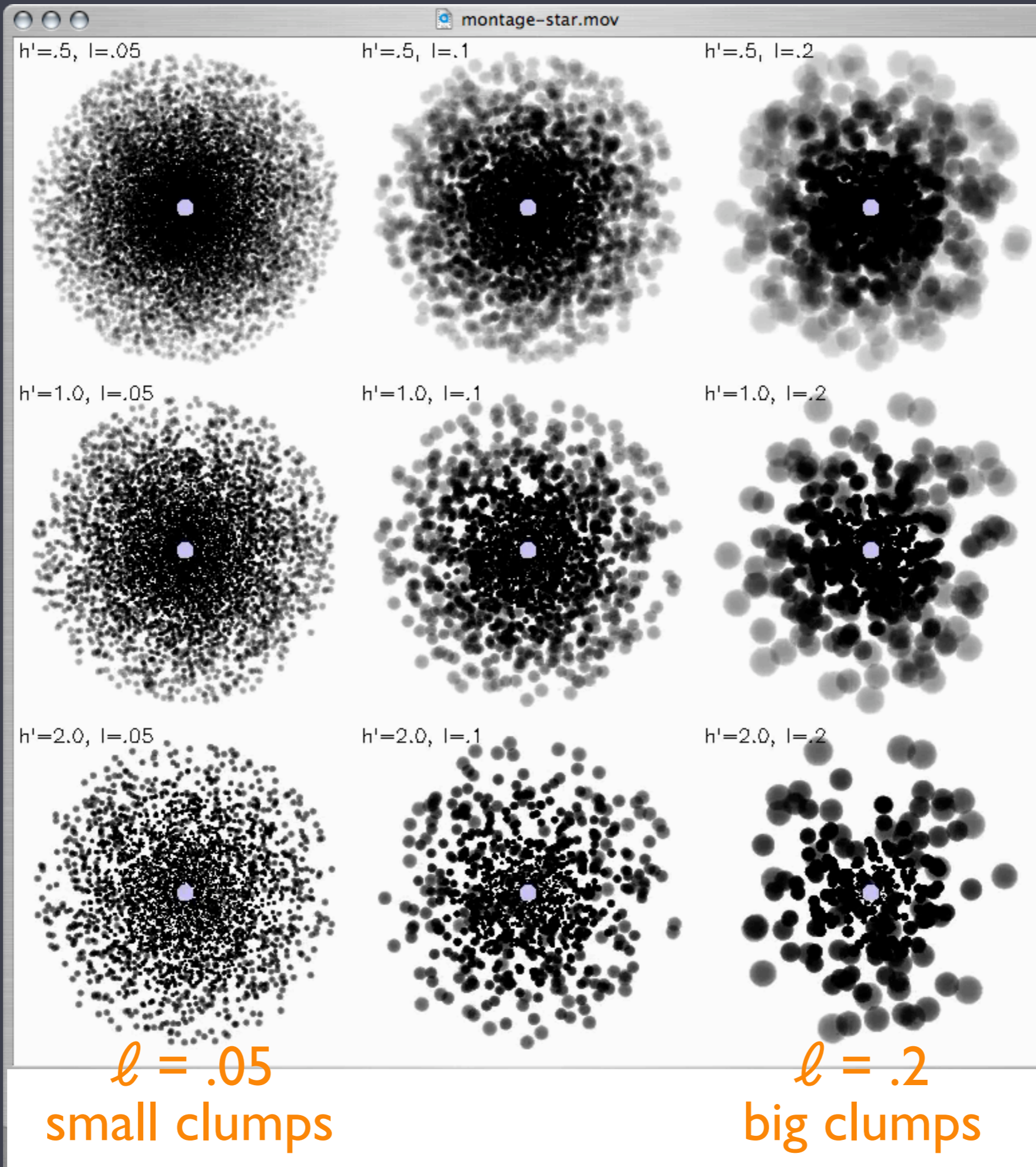
we compare these predictions to data



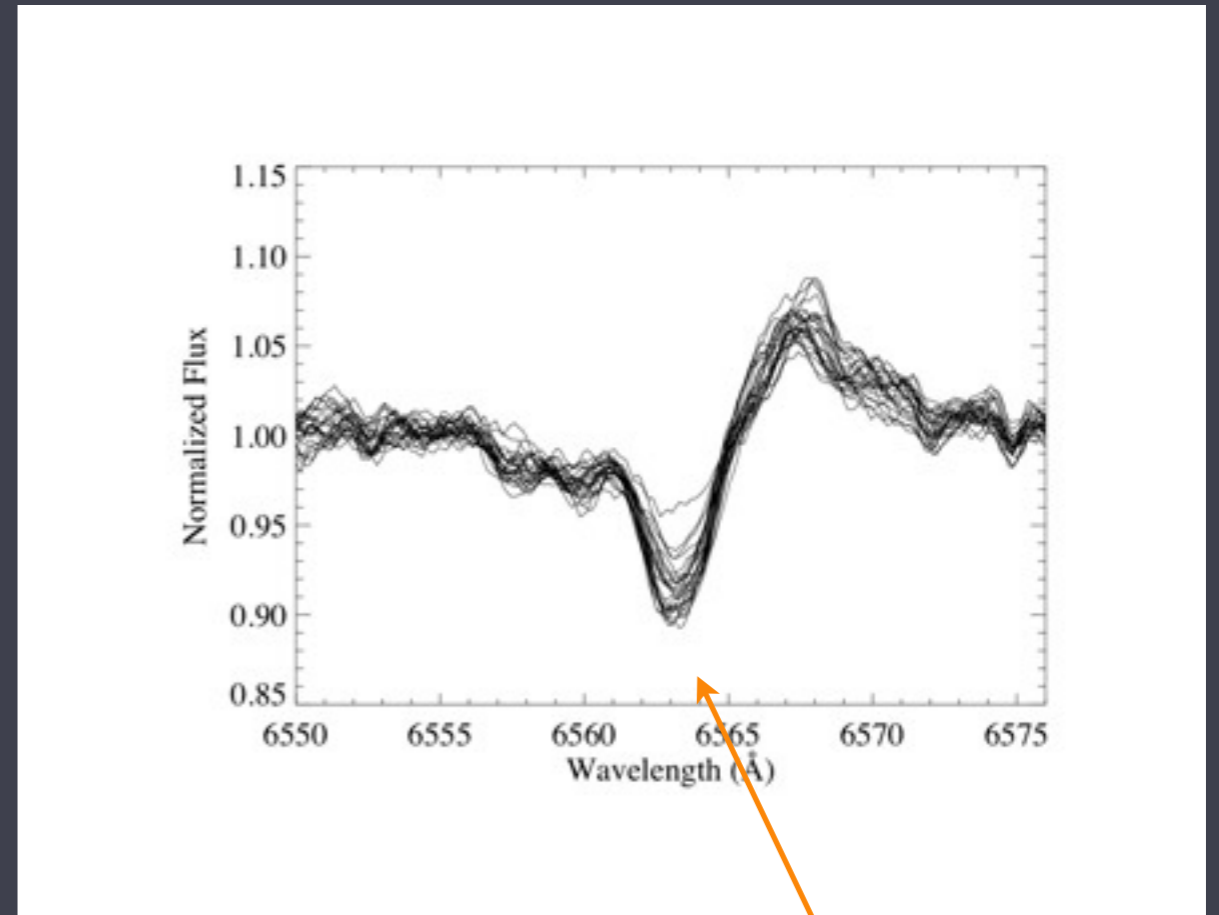
sometimes we contemplate X-ray propagation
through a clumpy and porous medium

less
porous

more
porous



sometimes we make complementary observations
with our telescope on the roof



hydrogen abs/em spectral line
in zeta Ori



Two outstanding questions

1. How do massive stars produce their strong X-ray emission?
2. How strong are their stellar winds (what are their mass-loss rates)?

to try to answer these questions

more information on my website

astro.swarthmore.edu/~cohen

Student Research Group

Summer Research 2011

Sierra Eckert ('14) and Jackson Goodman ('13) have started working on projects involving X-ray emission line profiles in massive stars. Neither of them were on campus this summer, but they're continuing their projects in the fall.

Summer Research 2010

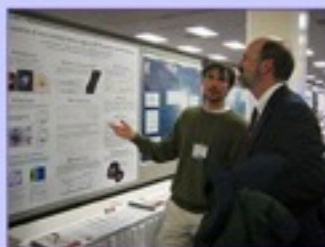
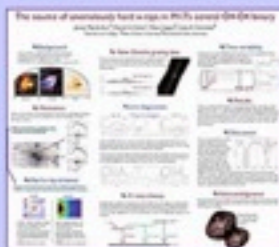
Tzitzily Barajas (Cal. State Los Angeles, '12) worked with the Peter van de Kamp Observatory here on campus to study Bp and other magnetic massive stars. While James MacArthur ('11) worked on a new project: using the curve of growth technique to measure the column density and ionization balance in X-ray photoionized neon plasma we're studying at the Z-Machine facility at Sandia National Lab.

To get a sense of other student projects that my student-based research group will be working on in the future, you can check out [this brief presentation](#) about potential projects I gave in February 2009. The project on the laboratory astrophysics experiments and modeling is described in the poster by my old student, Michael Rosenberg, who did some preliminary work on the project two summers ago.

Summer Research 2009

James MacArthur ('11), a physics major, worked with some new *Chandra* observations this summer, with his project continuing into the semester. He presented his preliminary research results at the American Astronomical Society meeting in January (*see below*). We're working - along with Marc Gagné at West Chester and Leisa Townsley at Penn State - on trying to understand the strong X-ray emission from a pair of binary stars in M17.

Jan. 2010: James MacArthur has presented his preliminary research results at the American Astronomical Society meeting in Washington, DC, with a poster entitled, "The Source of Anomalously Hard X-rays in M17's Central O4-O4 Binary".



Research Links

Our research group's presentations page
Poster-making advice

Astrobetter - lots of useful information about the nitty-gritty of astronomical research

ADS
astro-ph
SIMBAD
Astronomical Catalogs
SkyView

Chandra X-ray Center
XMM Guest Observer Facility
HEASARC

ATOMDB atomic database

physical and astronomical constants
astrophysical constants and data

Graphics

Historical graphics
Edward Tufte
Infographics News
Visualizing Astronomy at the CfA
Information Aesthetics

Student Travel and Research Funding

HHMI travel funding
Sigma Xi travel funding
(these two will fund travel to meetings)

Sigma Xi grants in aid of research
National Geographic Young Explorers
(things like travel to an observatory are eligible)

DoD SMART scholarships
NDSEG graduate student scholarship

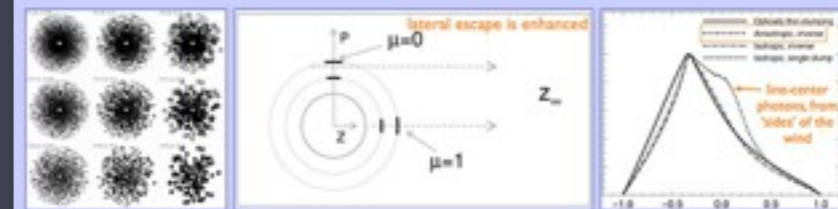
Grad School Information

Recent Presentations

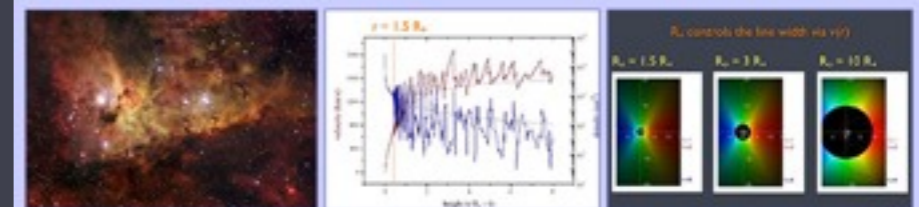
Many of these presentations involve student research. You can [get information](#) about student research in the Department of Physics and Astronomy here at Swarthmore College. You can also see [what else my research group is up to](#).

Refereed papers are archived [here](#).

My colleagues, Stan, Jon, and Maurice and I have put together a new talk, on *clumping and porosity* [pdf]. I gave it in October, 2011, at the University of Liège, while visiting Yael Nazé's group.



During October 2011, I gave a colloquium at the Institute Anton Pannekoek, the astronomy department, at the University of Amsterdam. The talk provided an overview of our X-ray based wind mass-loss rate measurements, using both individual X-ray emission line profile shapes and also the broadband X-ray spectral energy distributions [pdf].



At the meeting to honor Tony Moffat, in Lac Taureau, Quebec, I gave a talk on HD 93129A, one of the most massive stars in the Galaxy [pdf of talk and pdf of paper].

