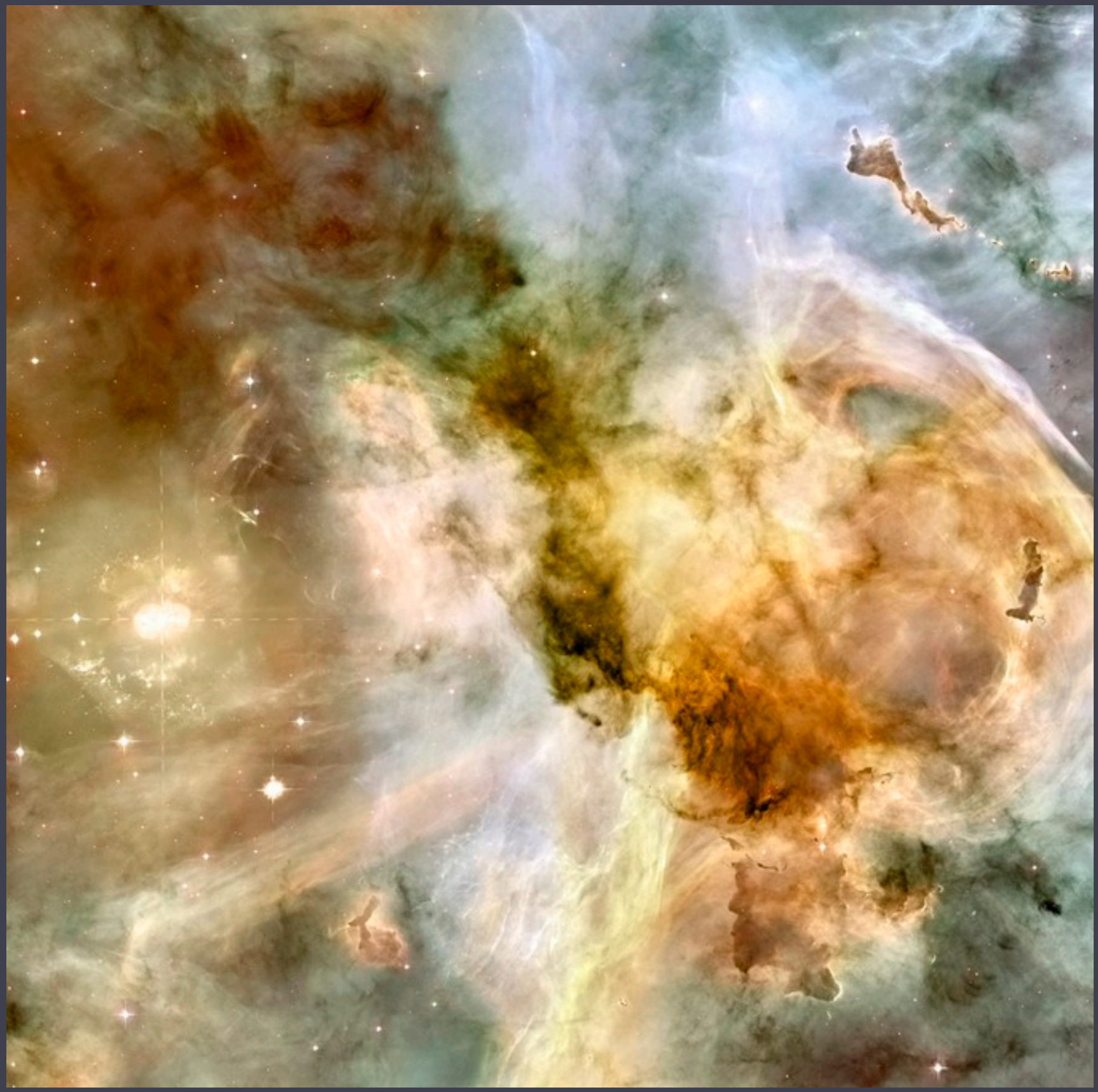
Carina Nebula: star formation region, *d* ~ 7000 light years

HST: Carina Nebula

energized by the few dozen most massive & luminous stars



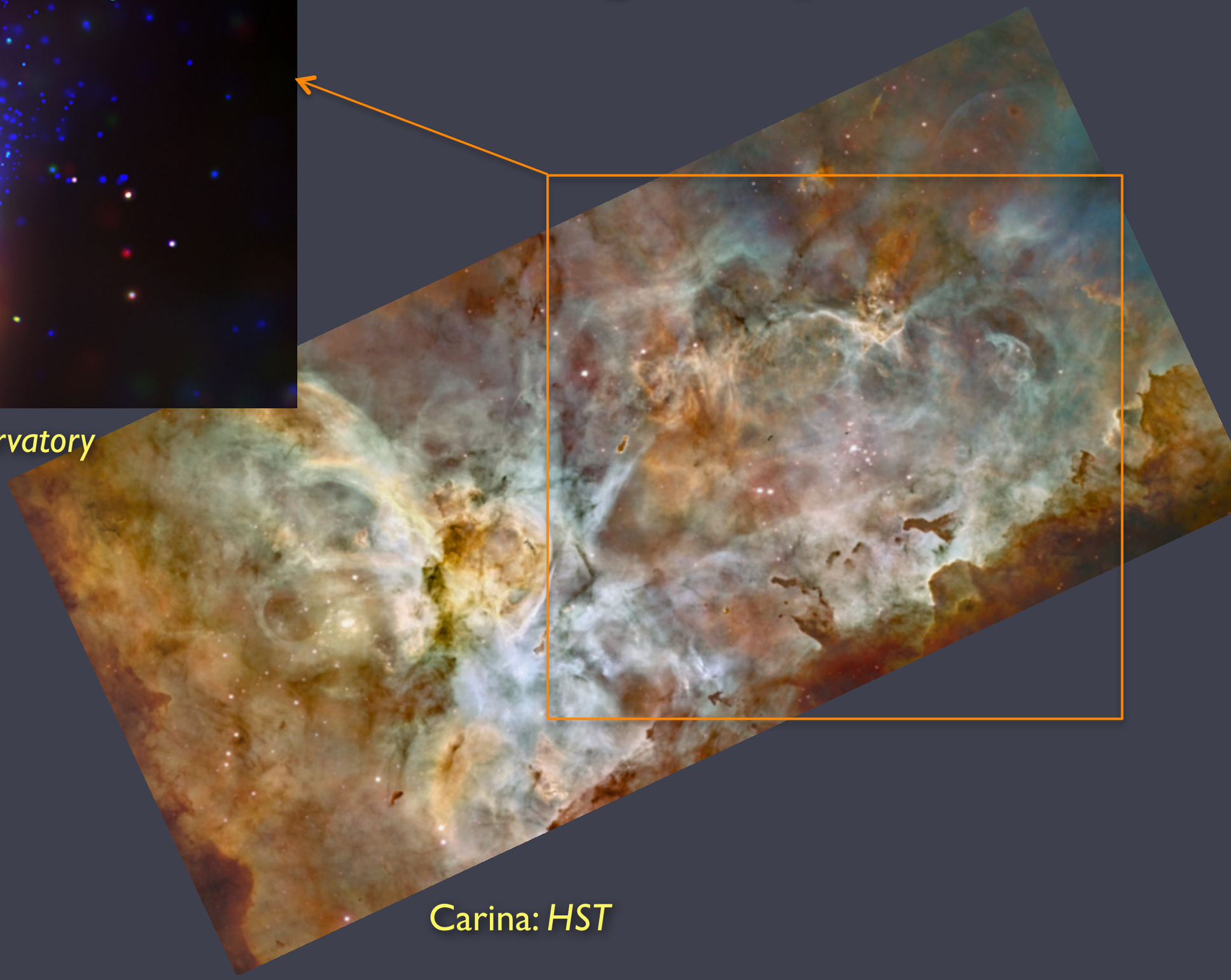
HST: Carina Nebula

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*



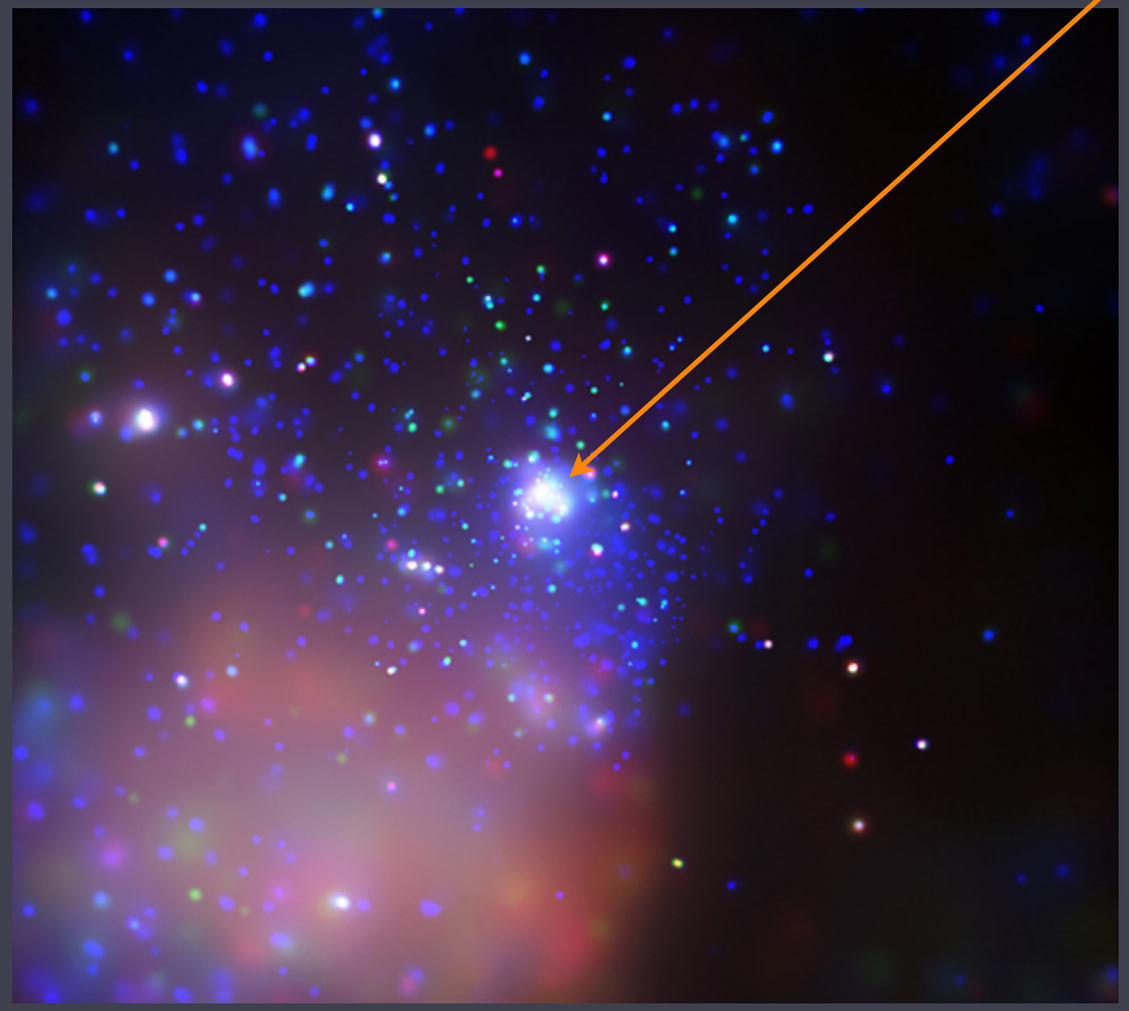
Carina: *HST*

Mon. Not. R. Astron. Soc. **415,** 3354–3364 (2011) doi:10.1111/j.1365-2966.2011.18952.x

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. Fullerton[7] and Stanley P. Owocki[6]

[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*



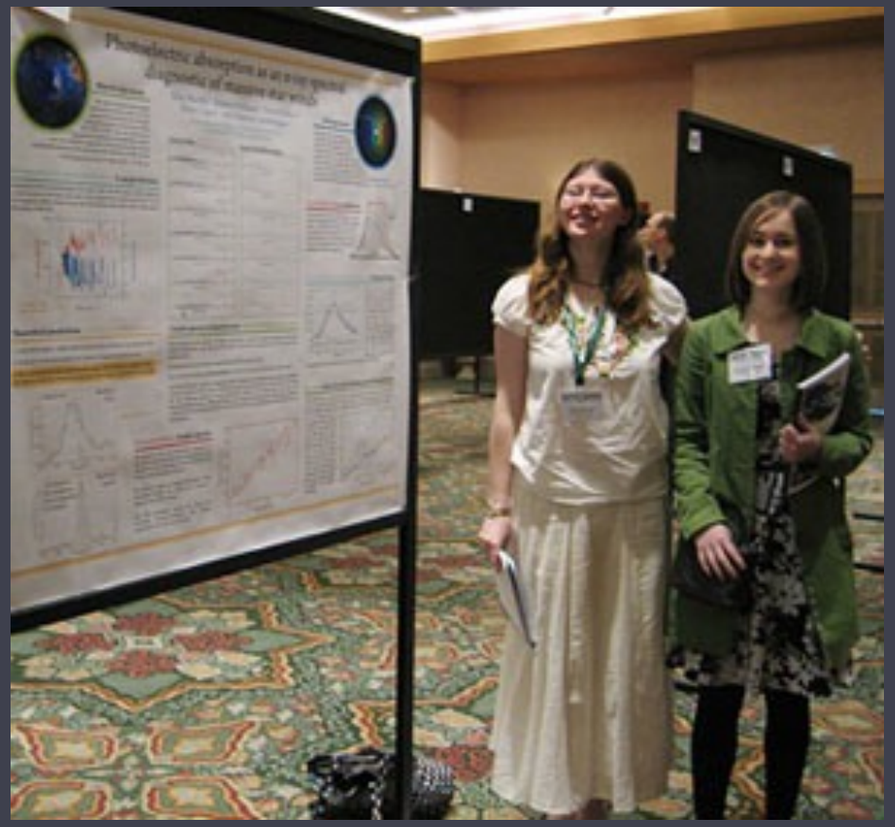
Tr 14 in Carina: *Chandra X-ray Observatory*

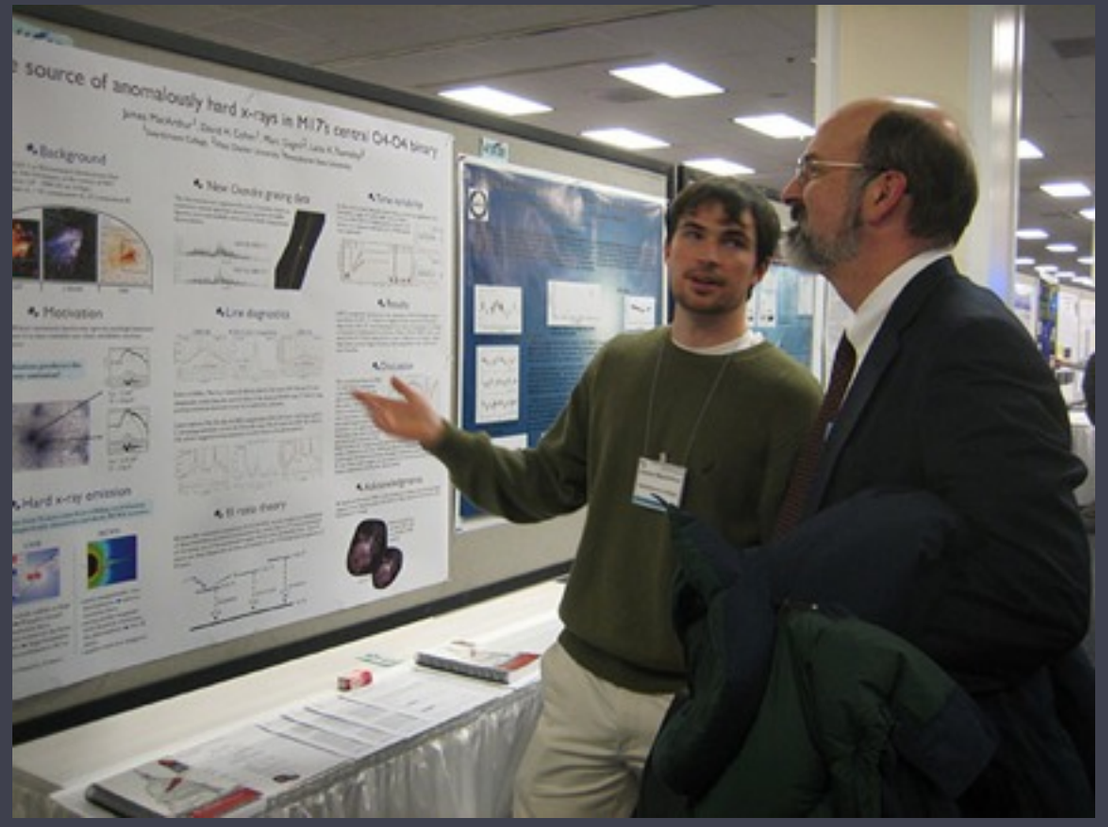
X-ray spectroscopy of the most massive star in the cluster has already yielded new information about this star's wind

Working this summer will require:

1. Willingness to work a lot with computers - some programming, a lot of using hard-to-use programs.
2. Enthusiasm for trying things until you find something that works.
3. But also then carefully applying the useful technique and being very organized about it.
4. Dedication to getting things right.
5. Motivation to read papers, learn about the context of the problems you're working on.

science is a
social activity

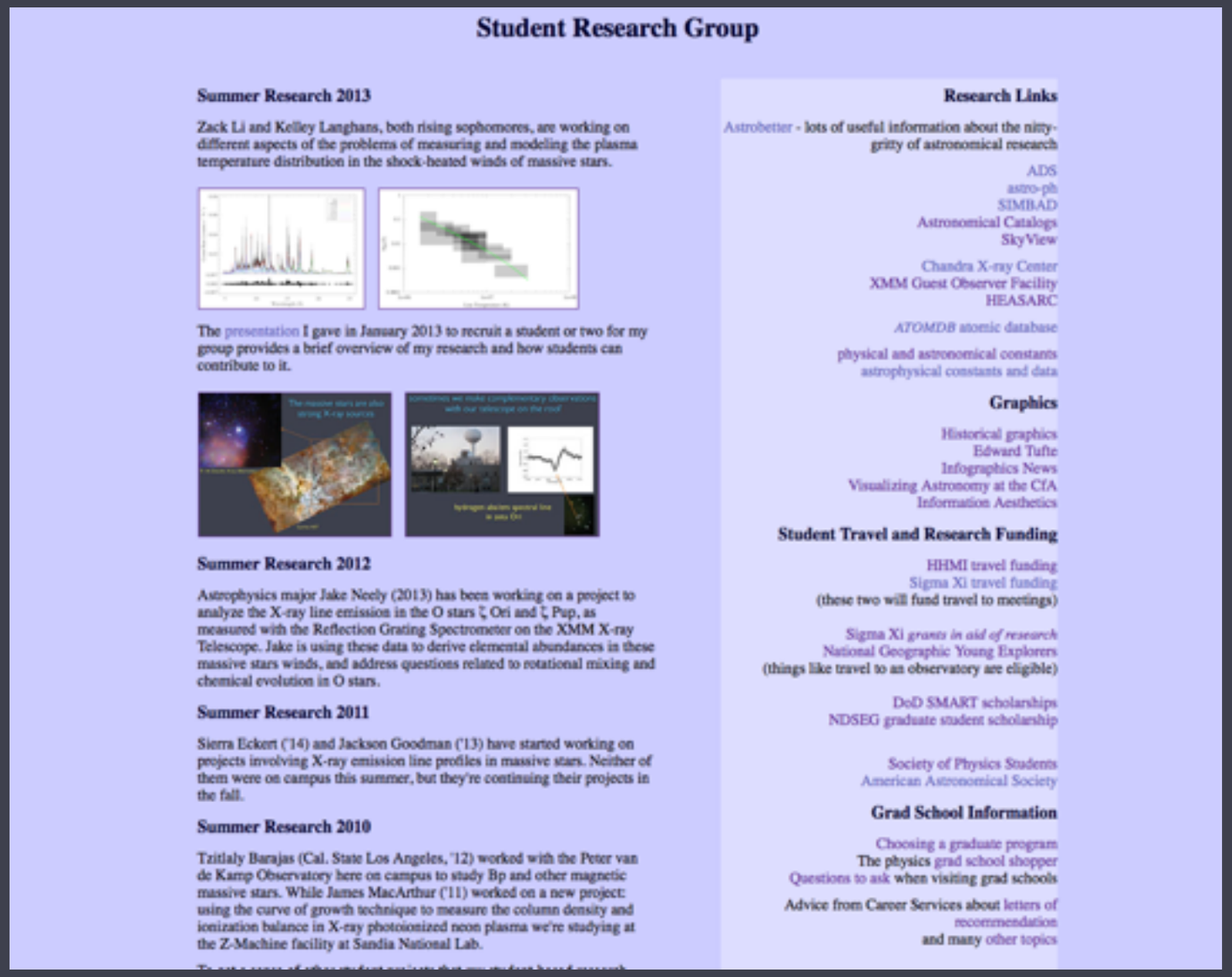




more information on my website

astro.swarthmore.edu/~cohen

all faculty websites are listed on the dept site



Student Research Group

Summer Research 2013

Zack Li and Kelley Langhans, both rising sophomores, are working on different aspects of the problems of measuring and modeling the plasma temperature distribution in the shock-heated winds of massive stars.

The presentation I gave in January 2013 to recruit a student or two for my group provides a brief overview of my research and how students can contribute to it.

Summer Research 2012

Astrophysics major Jake Neely (2013) has been working on a project to analyze the X-ray line emission in the O stars ζ Ori and ζ Pup, as measured with the Reflection Grating Spectrometer on the XMM X-ray Telescope. Jake is using these data to derive elemental abundances in these massive stars winds, and address questions related to rotational mixing and chemical evolution in O stars.

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

Tzitlaly 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.

Research Links

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)

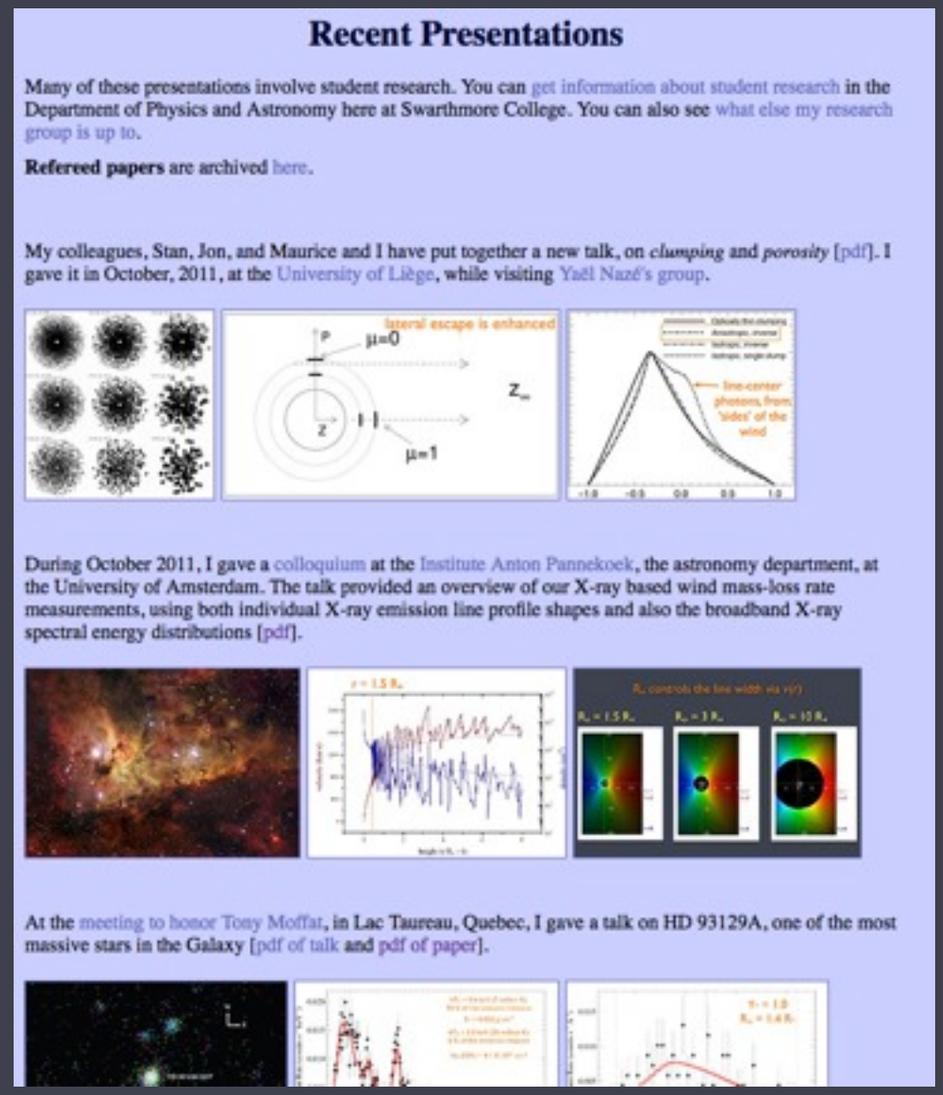
DoD SMART scholarships
NDSEG graduate student scholarship

Society of Physics Students
American Astronomical Society

Grad School Information

Choosing a graduate program
The physics grad school shopper
Questions to ask when visiting grad schools

Advice from Career Services about letters of recommendation
and many other topics



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 Yaël 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].

...and there are a few more slides with examples of the kinds of problems we work on (and sometimes solve) following this slide

Two outstanding questions

1. How do massive stars produce their strong X-ray emission? What's the physics of the wind shocks?
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

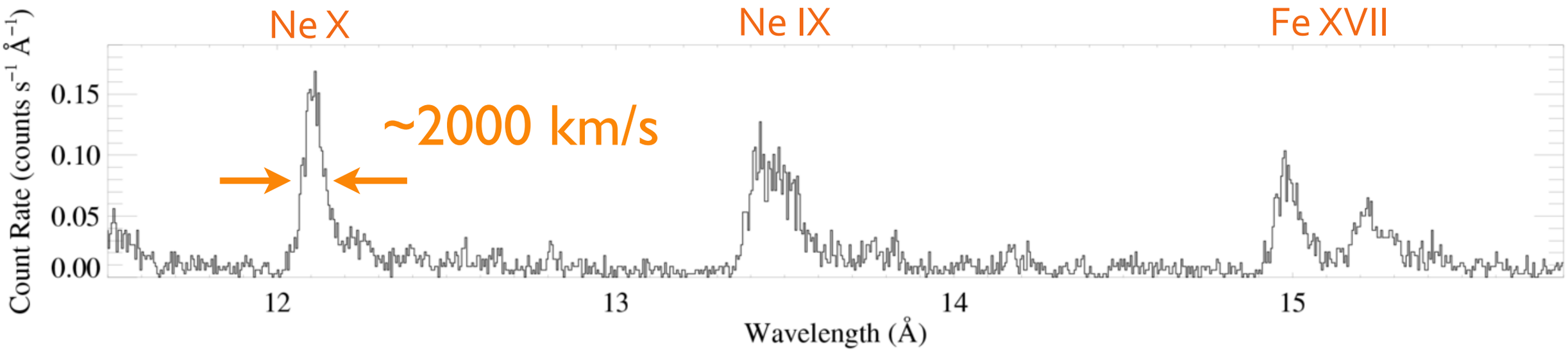
Chandra in the Space Shuttle cargo bay

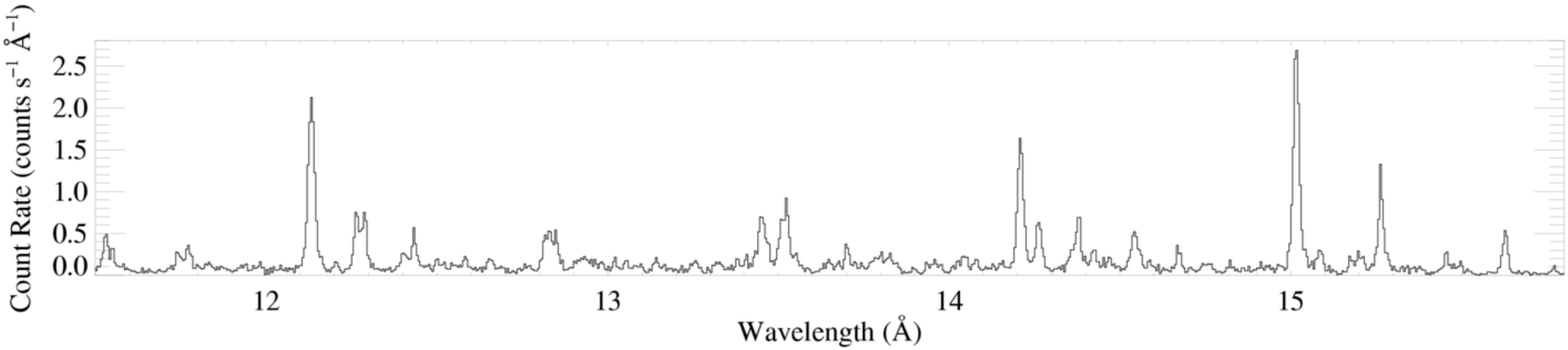
Chandra in orbit

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

Chandra spectra

ζ Pup (O4If)



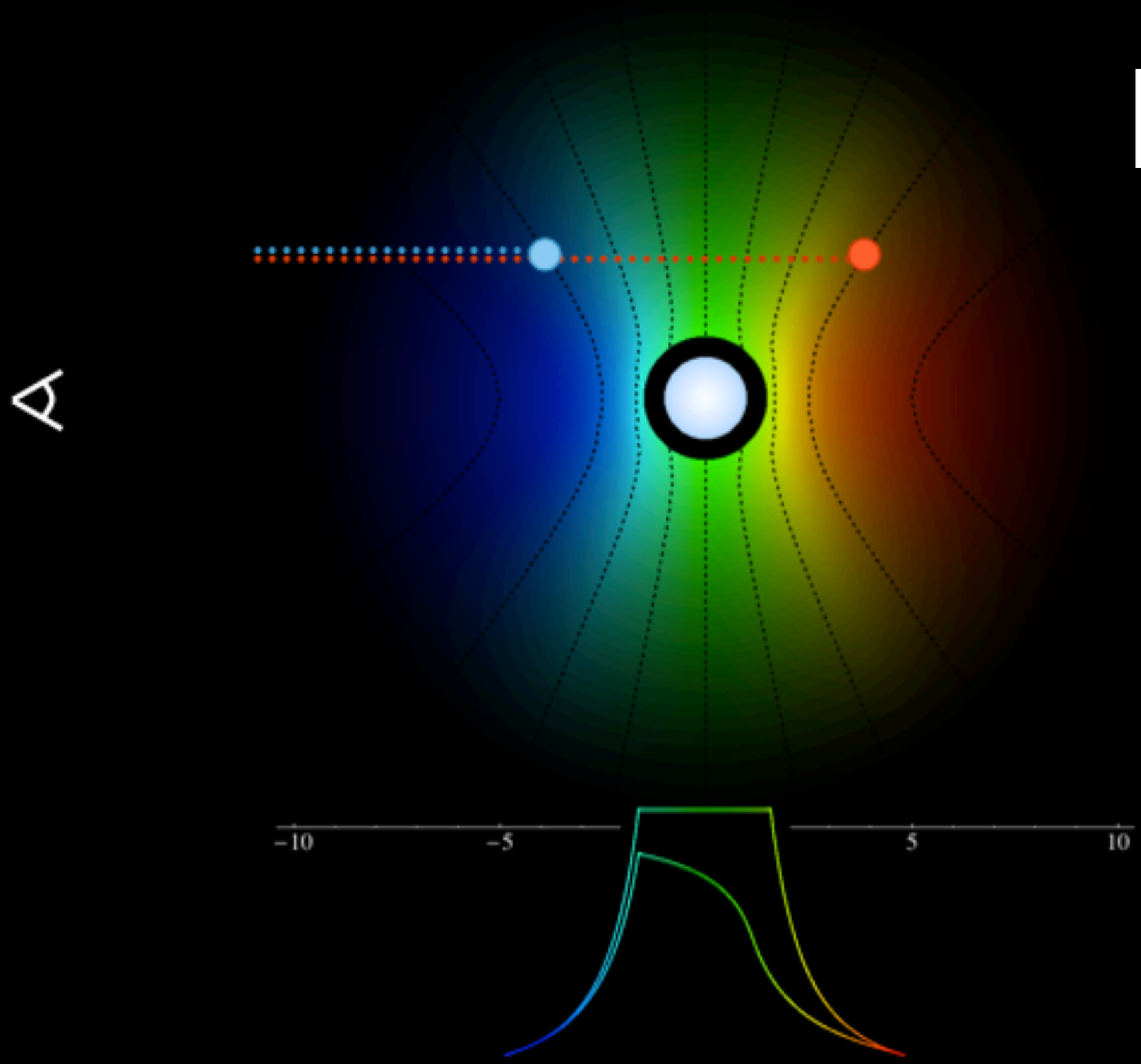


Capella: G star for comparison (narrow lines)

we make models

Line Asymmetry

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

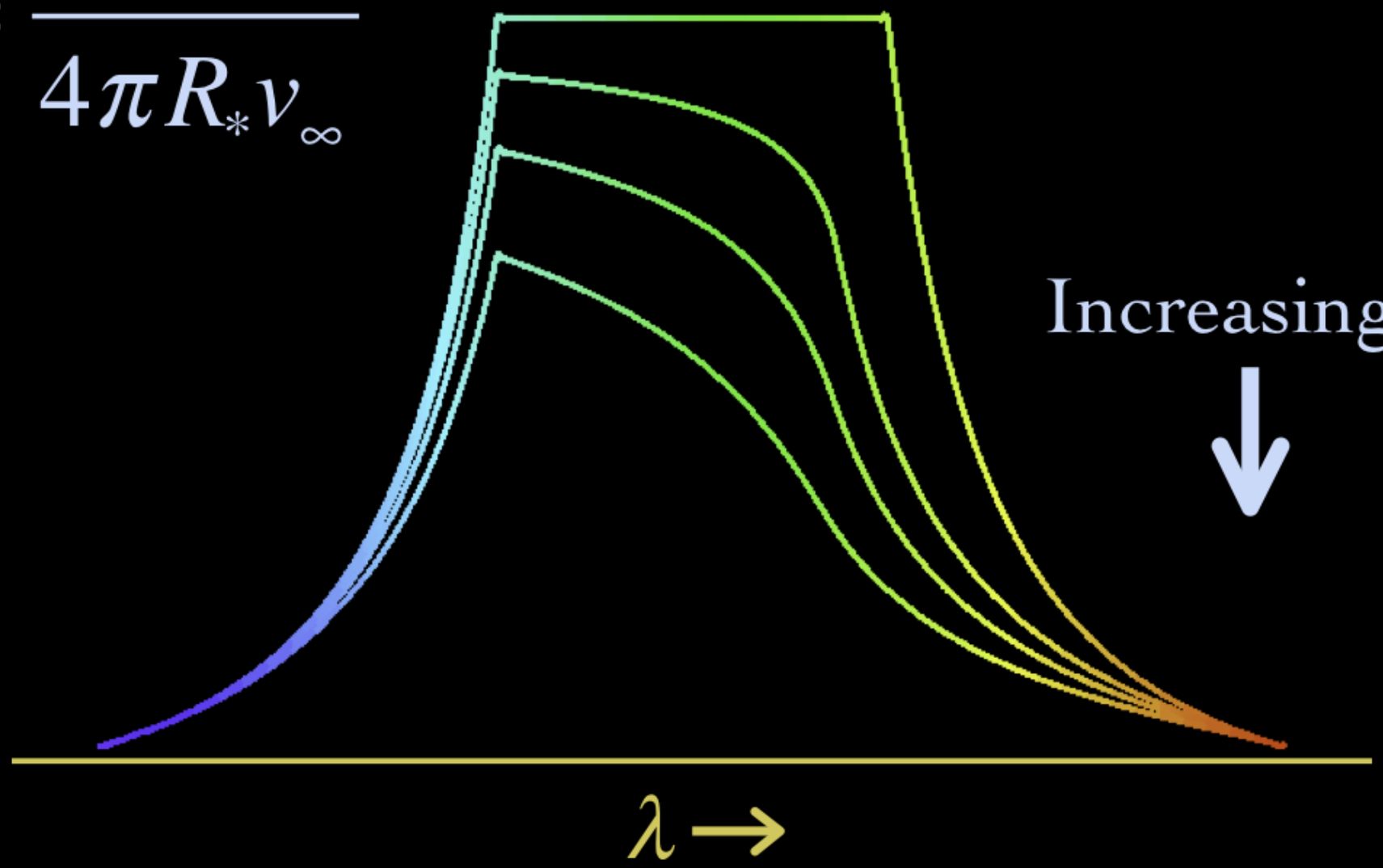


models make predictions

Wind Profile Model

wind mass-loss rate

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



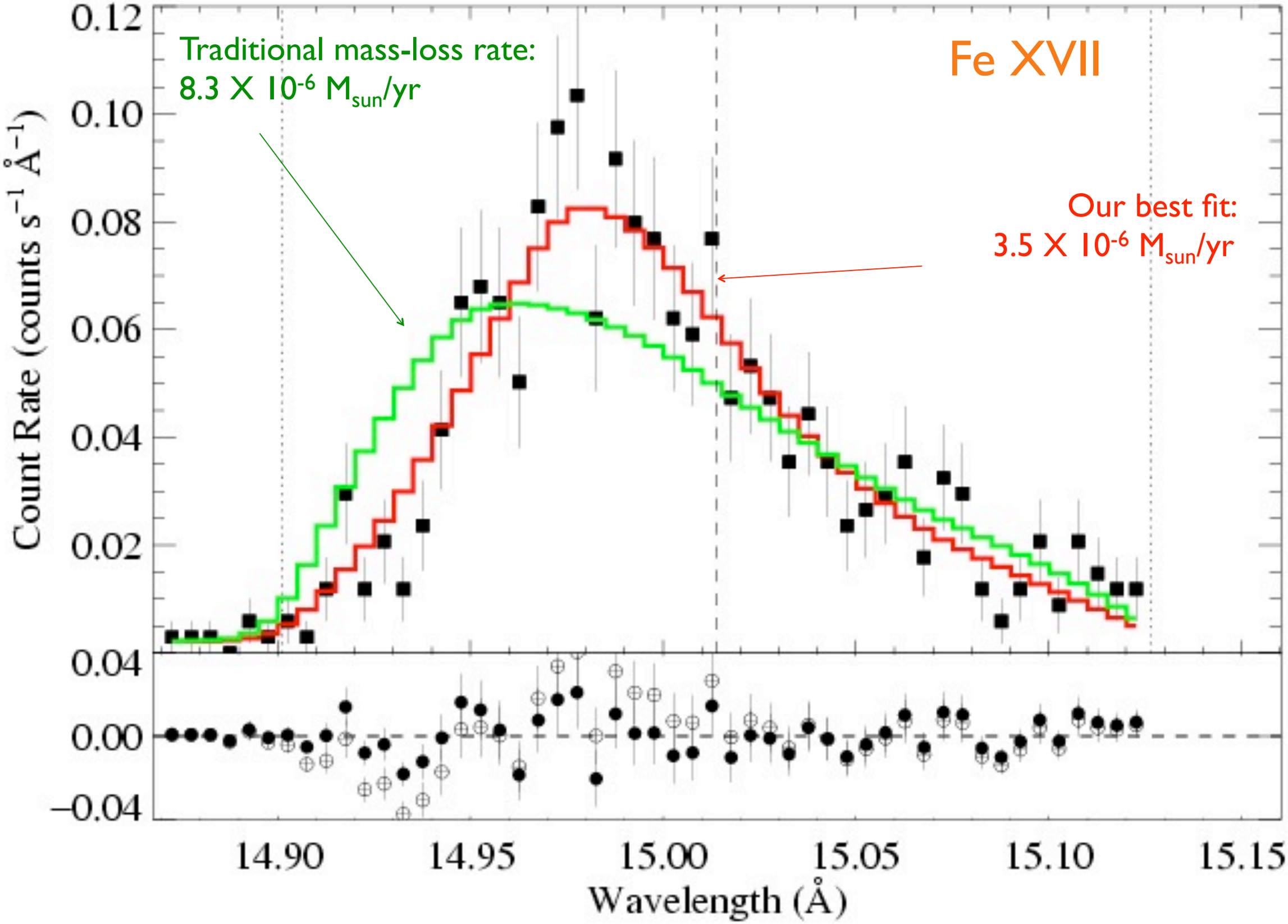
we compare these predictions to data

Chandra spectrum of zeta Puppis

Traditional mass-loss rate:
8.3×10^{-6} M_{sun}/yr

Fe XVII

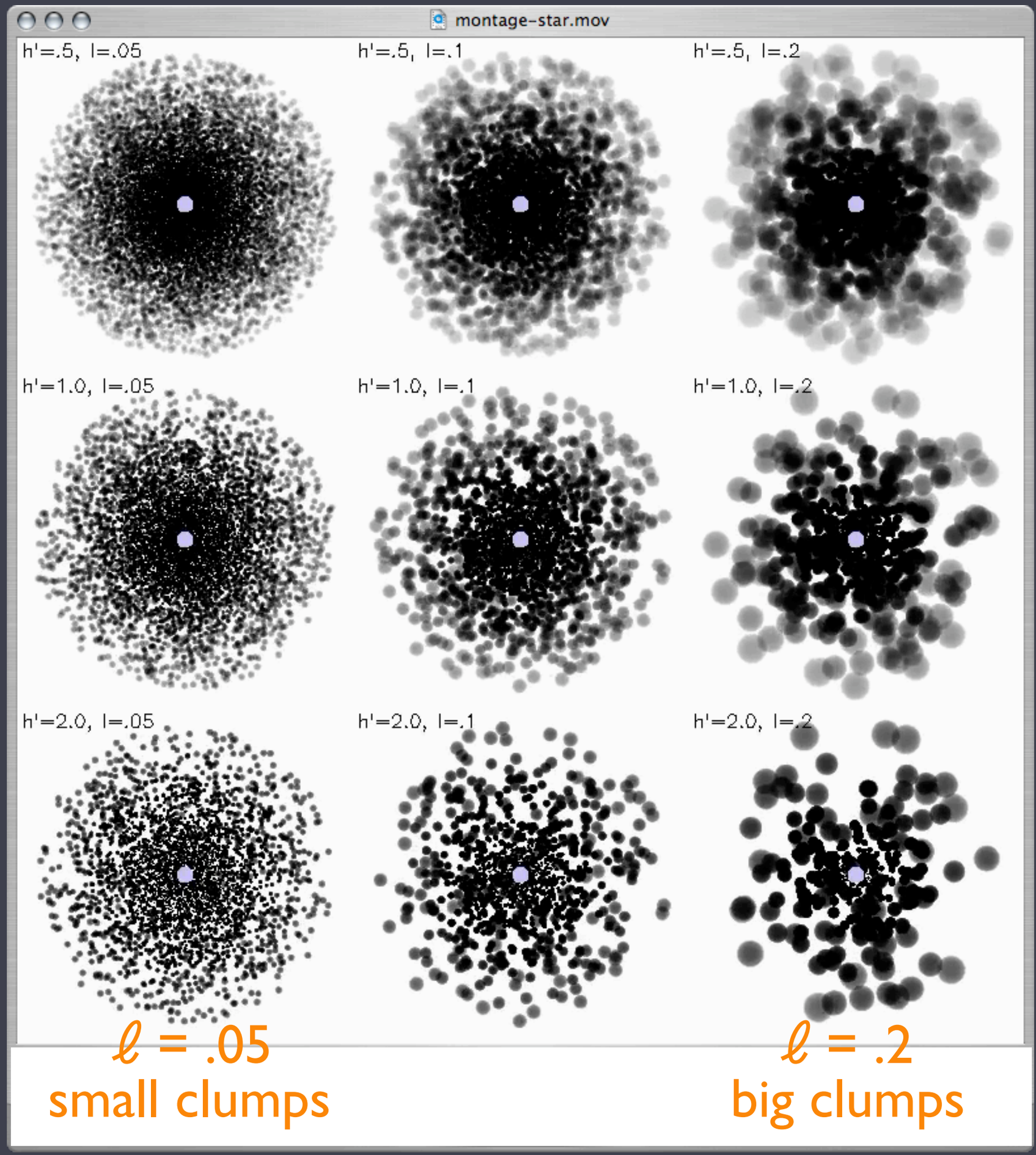
Our best fit:
3.5×10^{-6} M_{sun}/yr



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

less porous

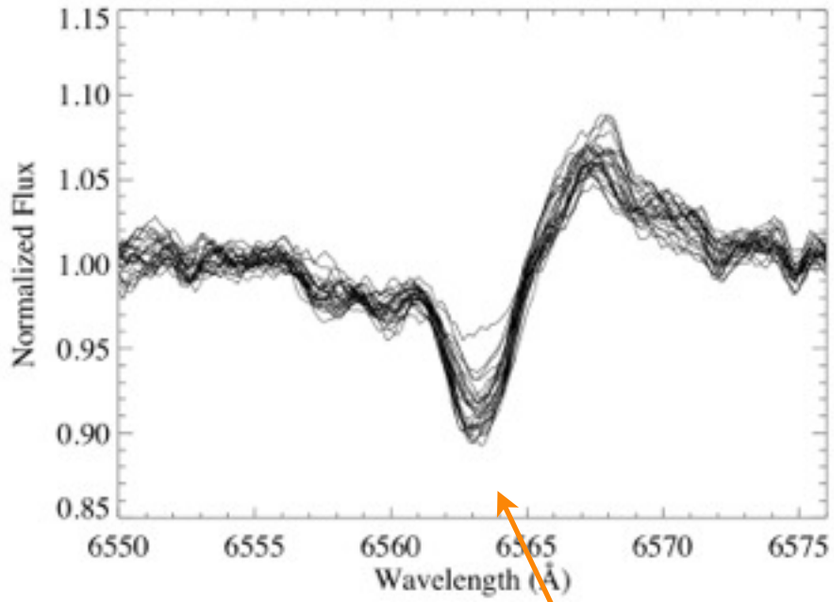
more porous



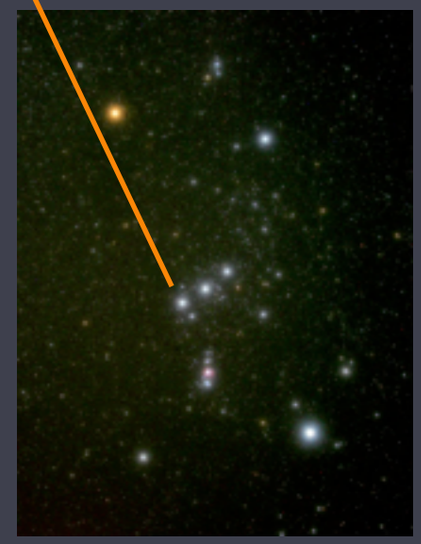
ℓ = .05
small clumps

ℓ = .2
big clumps

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

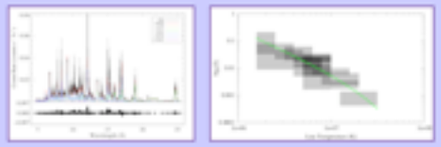
astro.swarthmore.edu/~cohen

all faculty websites are listed on the dept site

Student Research Group

Summer Research 2013

Zack Li and Kelley Langhans, both rising sophomores, are working on different aspects of the problems of measuring and modeling the plasma temperature distribution in the shock-heated winds of massive stars.



The presentation I gave in January 2013 to recruit a student or two for my group provides a brief overview of my research and how students can contribute to it.

Summer Research 2012

Astrophysics major Jake Neely (2013) has been working on a project to analyze the X-ray line emission in the O stars ζ Ori and ζ Pup, as measured with the Reflection Grating Spectrometer on the XMM X-ray Telescope. Jake is using these data to derive elemental abundances in these massive stars winds, and address questions related to rotational mixing and chemical evolution in O stars.

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

Tzitlaly 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.

Research Links

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

Society of Physics Students
American Astronomical Society

Grad School Information

Choosing a graduate program
The physics grad school shopper
Questions to ask when visiting grad schools

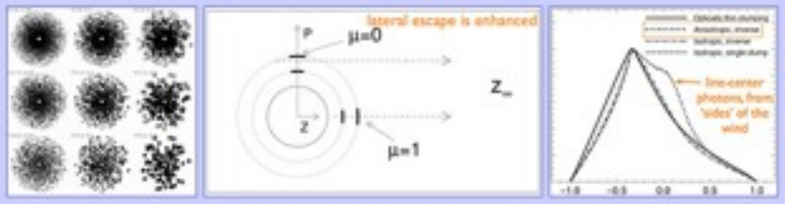
Advice from Career Services about letters of recommendation
and many other topics

Recent Presentations

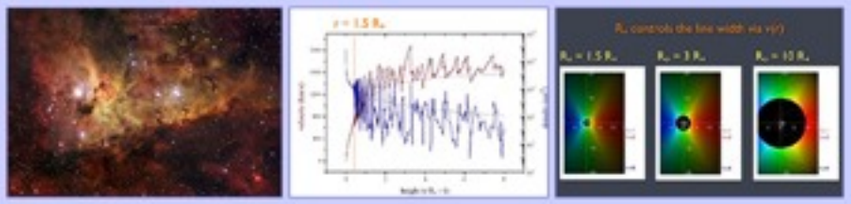
Many of these presentations involve student research. You can get information about student research in the Department of Physics and Astronomy here at Swarthmore College. You can also see what else my research group is up to.

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 Yaël 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].