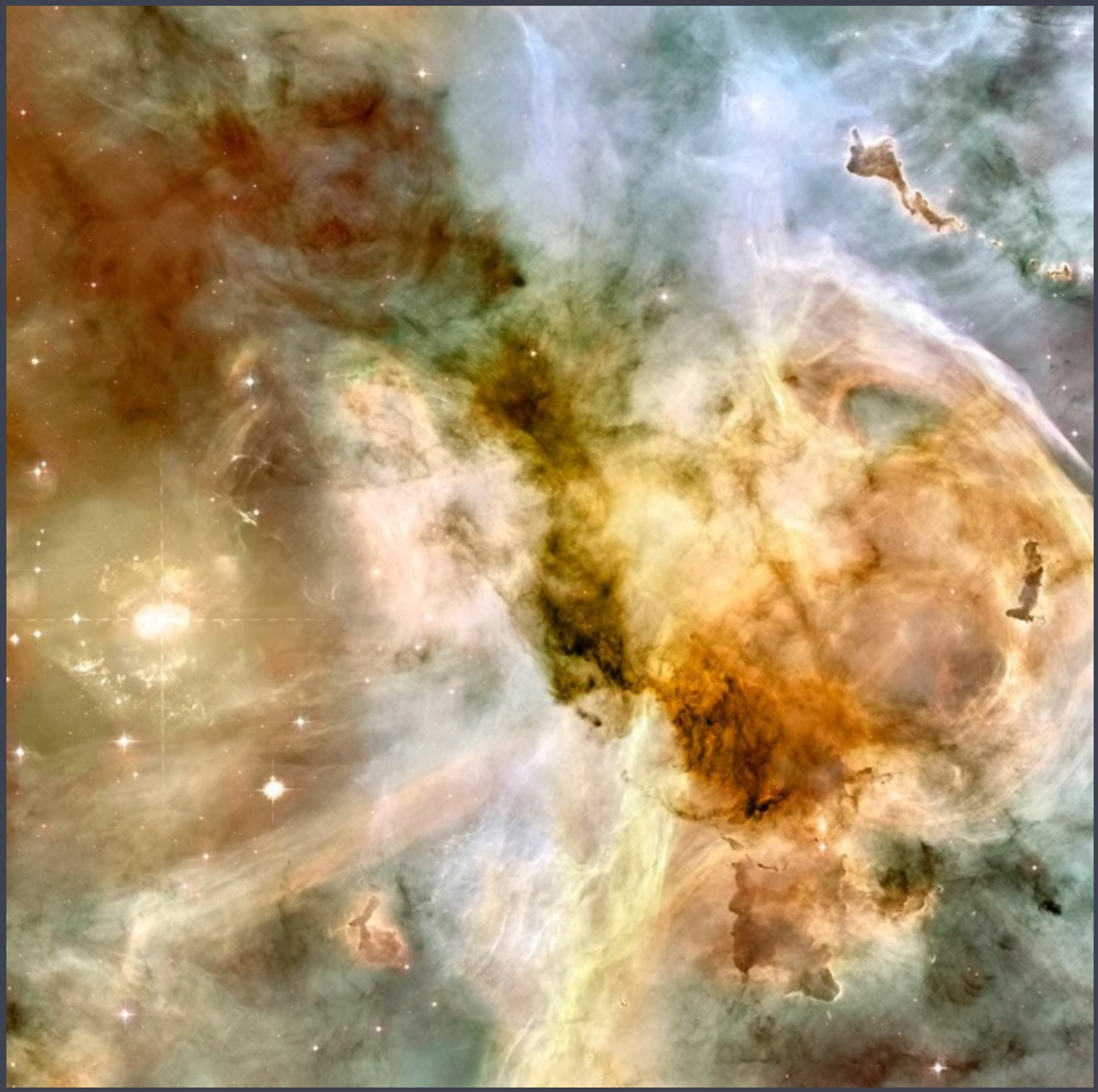
Carina Nebula: star formation region, *d* ~ 7000 light years

HST: Carina Nebula

Prof. David Cohen: SC 124

energized by the few dozen most massive & luminous stars



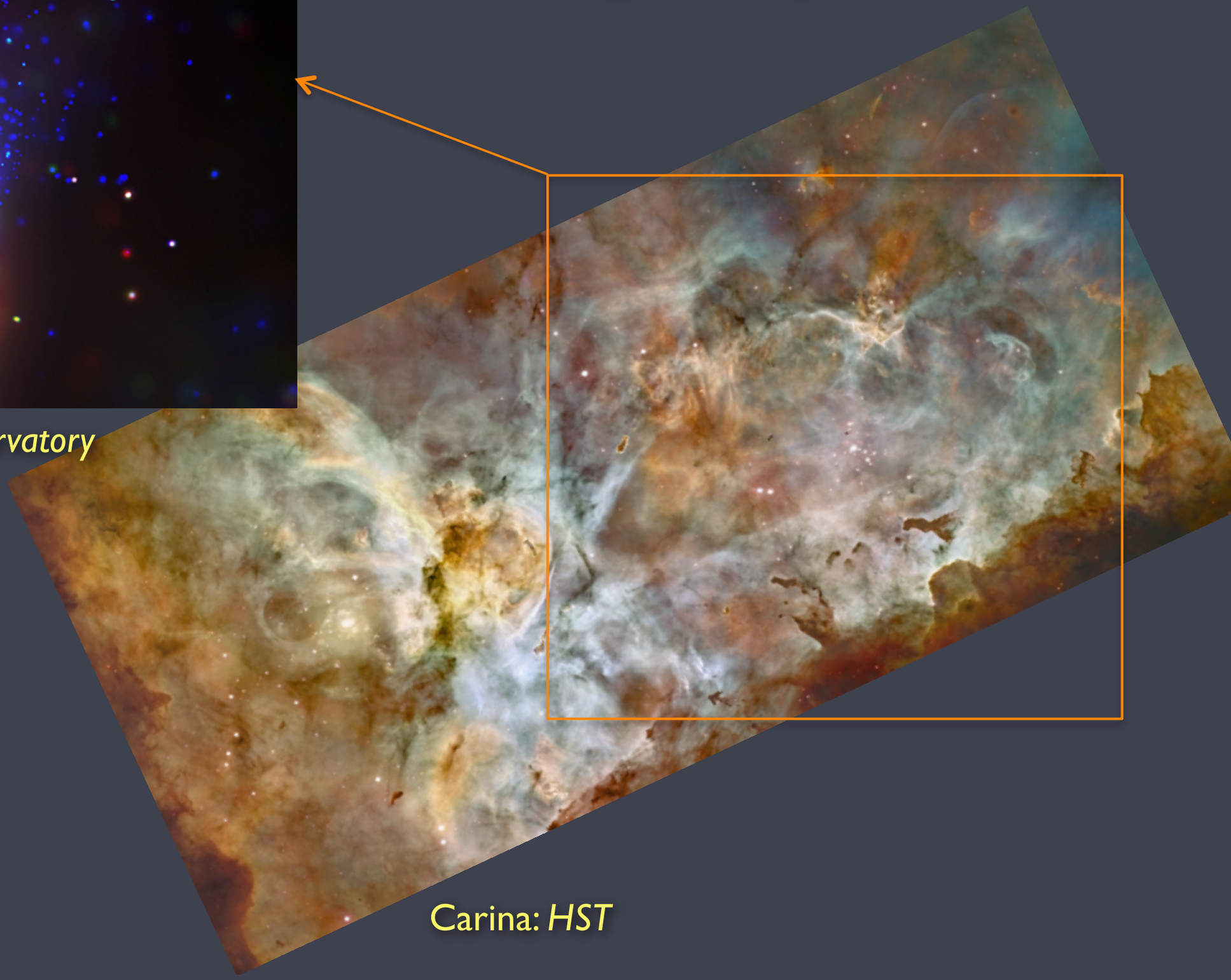
HST: Carina Nebula

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*

I am an astrophysicist

I work mainly on massive stars,
especially their radiation-driven winds

I study them mainly with X-ray spectroscopy

HST: Carina Nebula

I work with a medium-sized group of scientists and students (Swarthmore, U. Delaware, Goddard Spaceflight Center, Space Telescope Science Institute)

Sometimes I work on detailed studies of one star

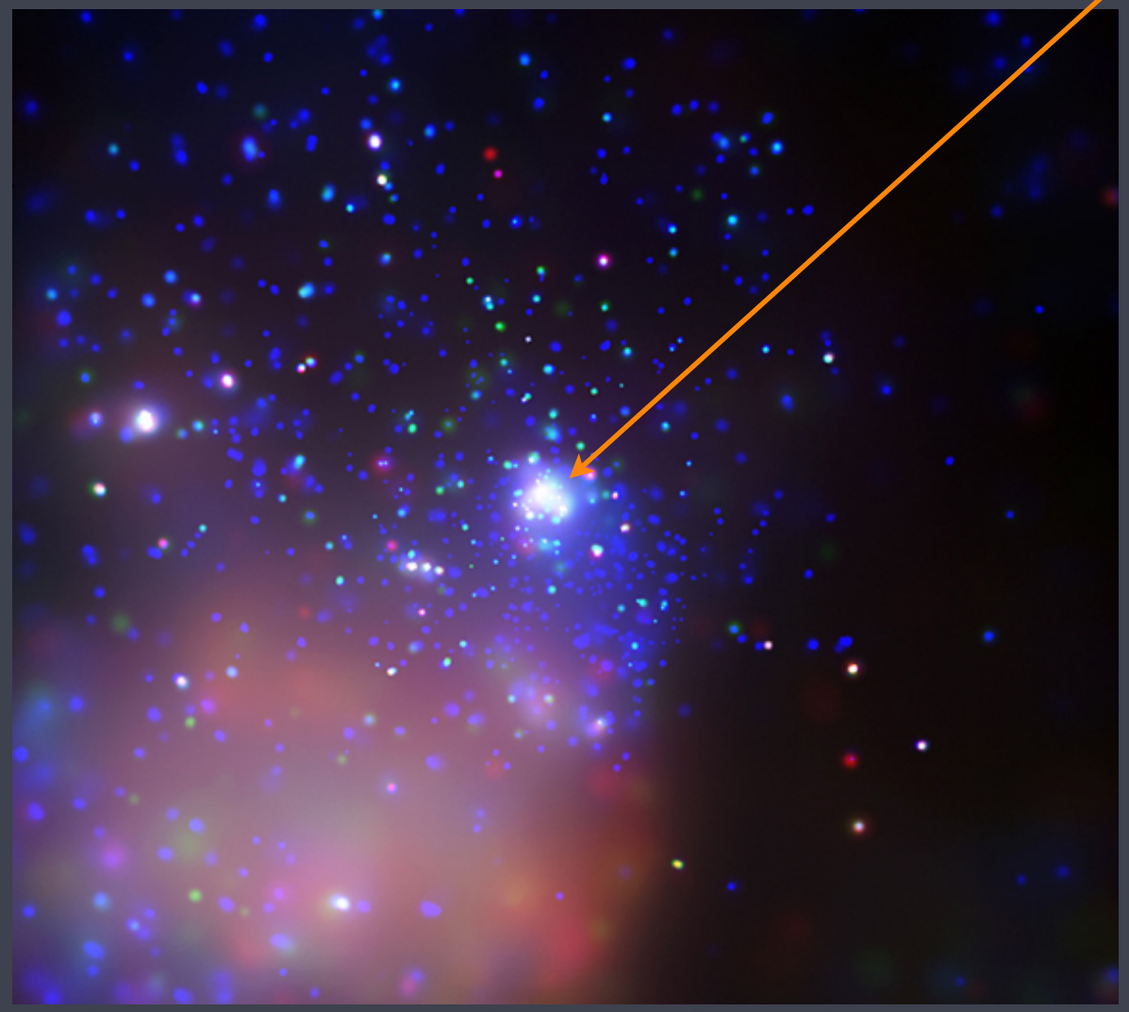
HST: Carina Nebula

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

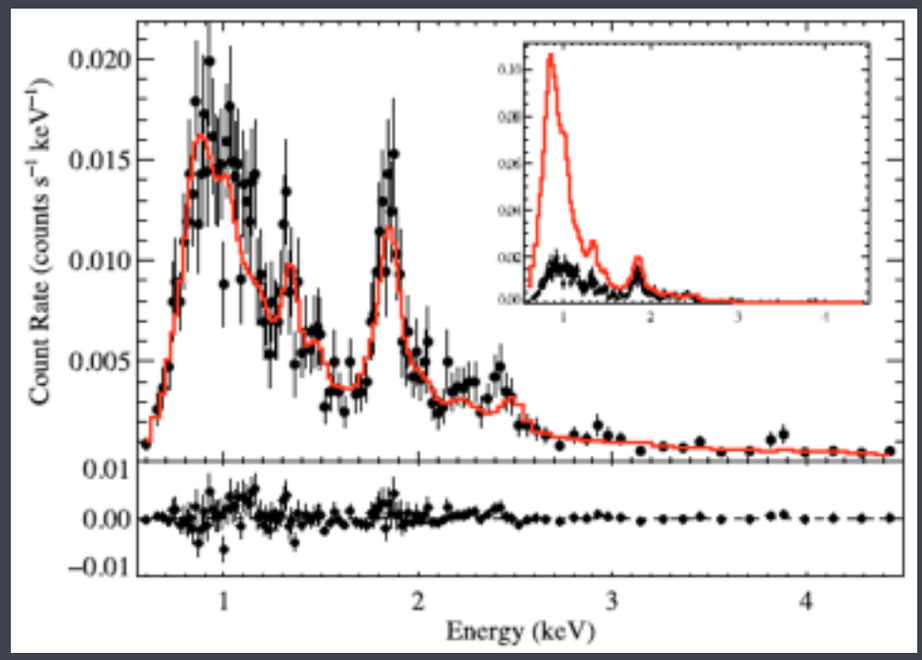
David H. Cohen,[1★] Marc Gagné,[2] Maurice A. Leutenegger,[3,4] James P. MacArthur,[1] Emma E. Wollman,[1,5] Jon O. Sundqvist,[6] Alex W. Fullerton[7] and Stanley P. Owocki[6]

[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 provides new information about this star's wind



I work with a medium-sized group of scientists and students (Swarthmore, U. Delaware, Goddard Spaceflight Center, Space Telescope Science Institute)

Sometimes I work on large surveys of hundreds of stars

HST: Carina Nebula

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 194:5 (26pp), 2011 May doi:10.1088/0067-0049/194/1/5

CARINA OB STARS: X-RAY SIGNATURES OF WIND SHOCKS AND MAGNETIC FIELDS

MARC GAGNÉ[1], GARRETT FEHON[1], MICHAEL R. SAVOY[1], DAVID H. COHEN[2], LEISA K. TOWNSLEY[3], PATRICK S. BROOS[3], MATTHEW S. POVICH[3,10], MICHAEL F. CORCORAN[4], NOLAN R. WALBORN[5], NANCY REMAGE EVANS[6], ANTHONY F. J. MOFFAT[7], YAËL NAZÉ[8,11], AND LIDA M. OSKINOVA[9]
[1] Department of Geology and Astronomy, West Chester University, West Chester, PA 19383, USA
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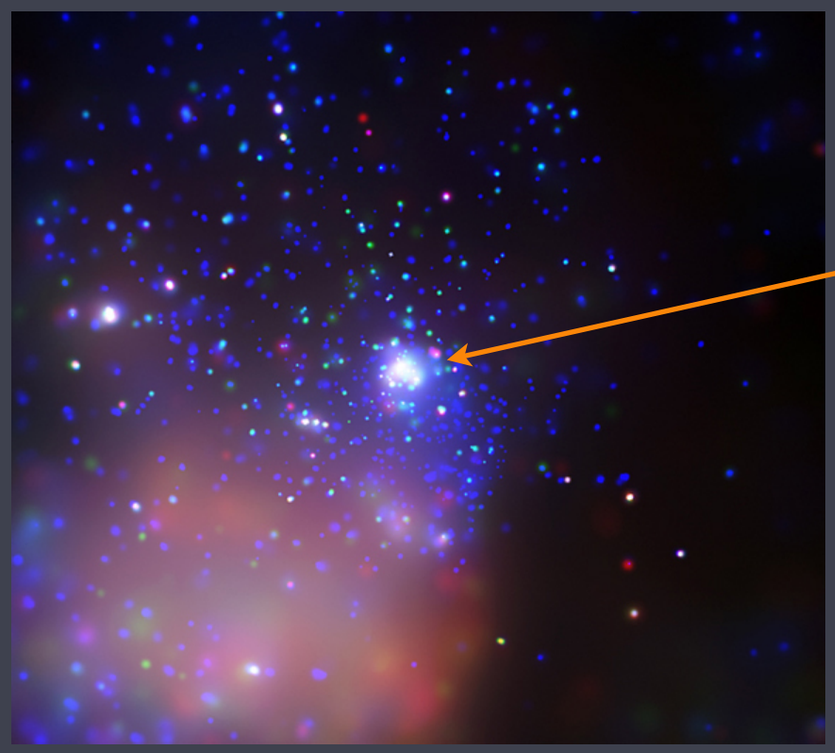
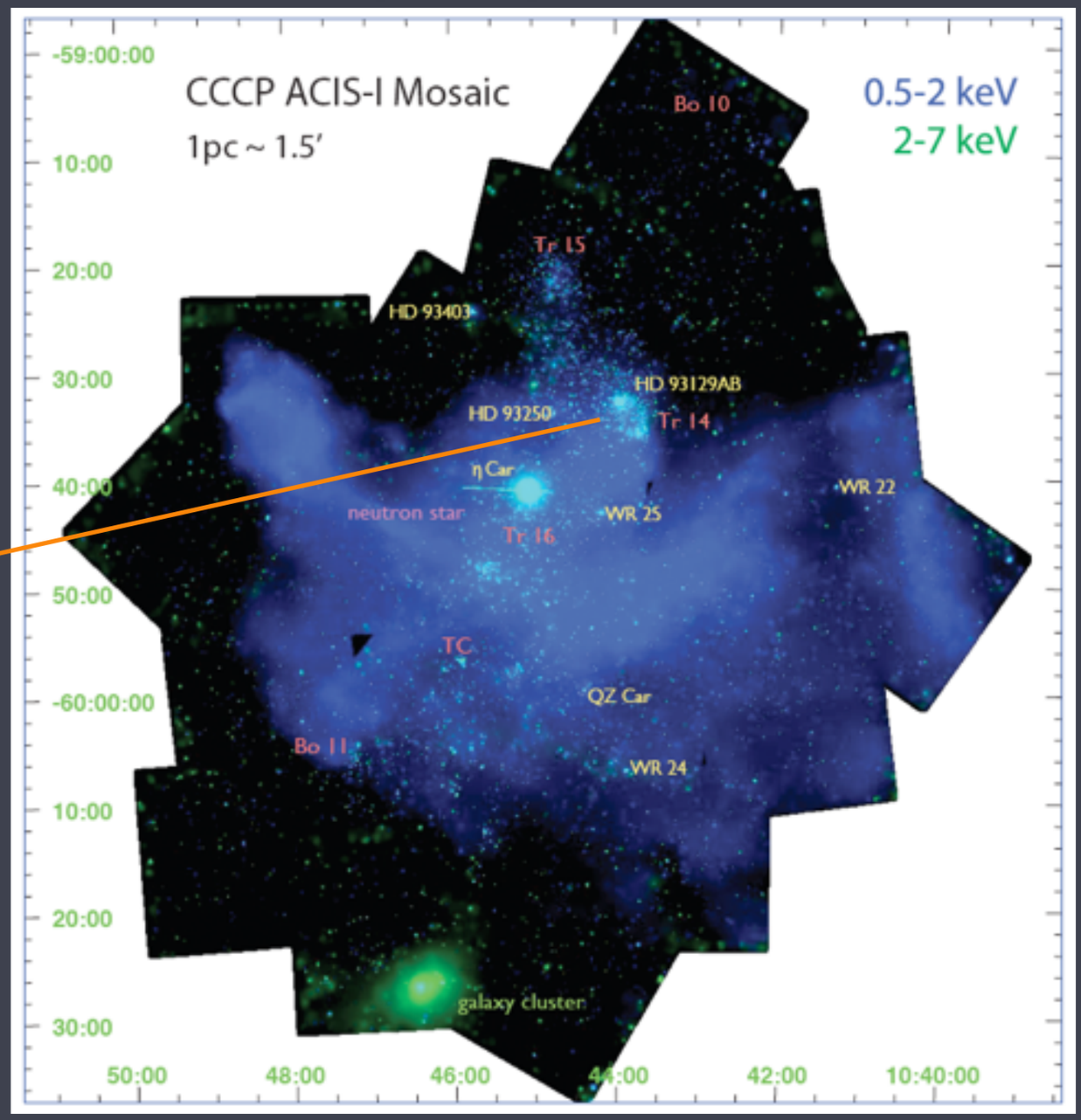
Study the X-ray properties of 100s of massive stars in Carina



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

Chandra X-ray survey of the Carina Nebula



I like research!

You get to decide what's interesting,
figure out ways to find out things people don't already know,
talk to people about it,
learn things

HST: Carina Nebula

research learning is very different from
classroom learning

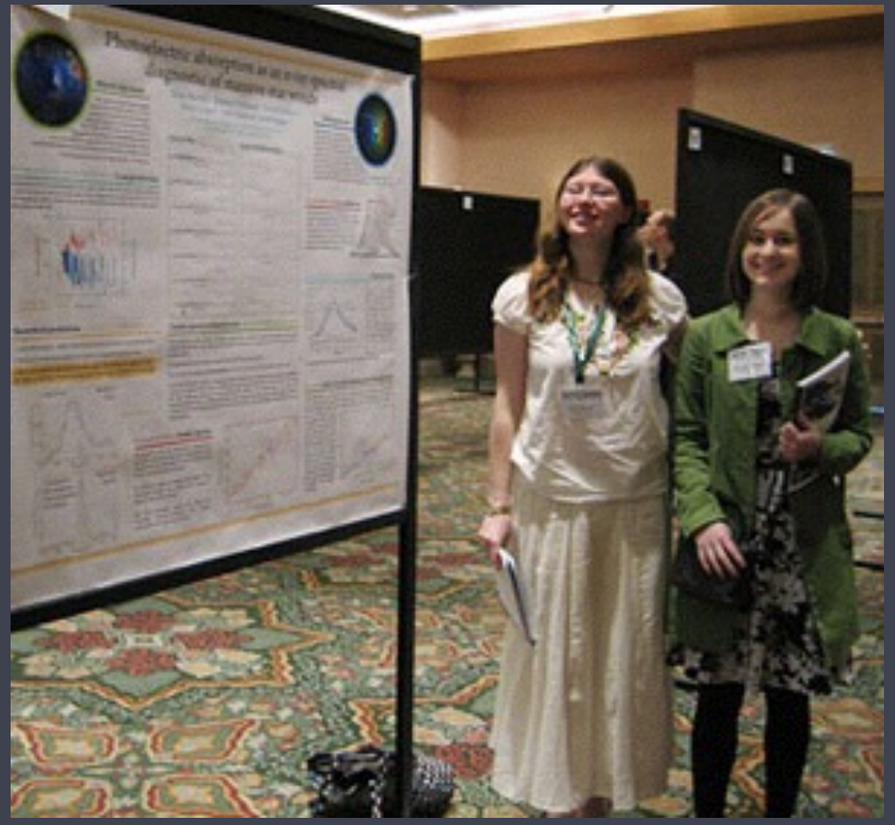
but you will get to see how the concepts you've learned in the classroom are applied in the real (!) world

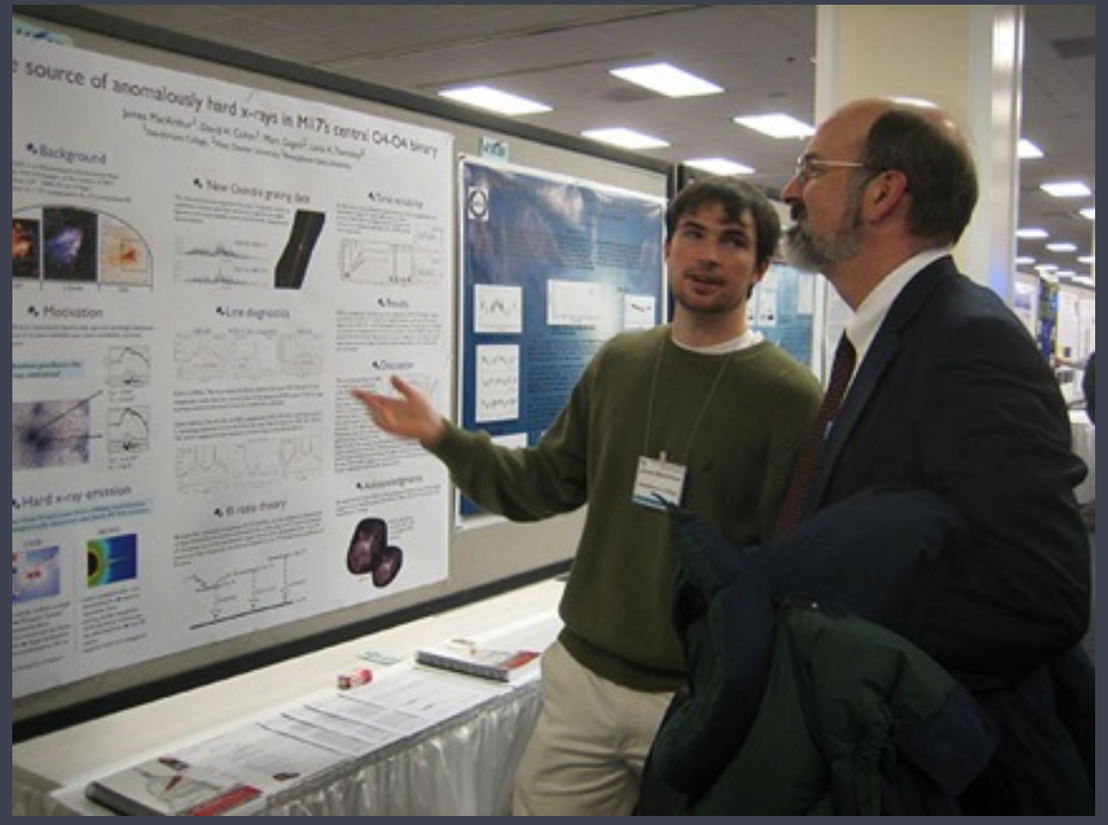
HST: Carina Nebula

Working in David's research group will require:

1. Willingness to work a lot with computers - some programming, a lot of using software written by others.
2. Enthusiasm for trying things until you find something that works.
3. But also then carefully applying a 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.
6. Enthusiasm for communicating your work to others.

science is a
social activity





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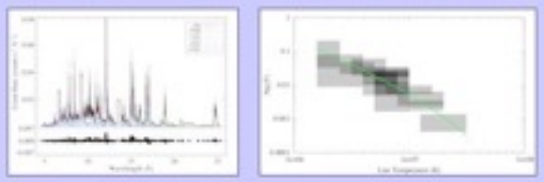

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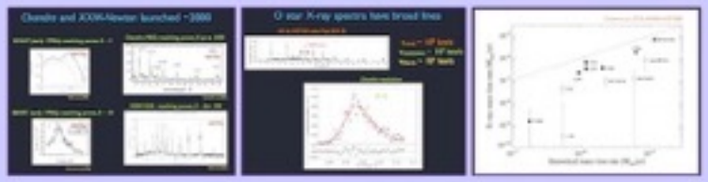

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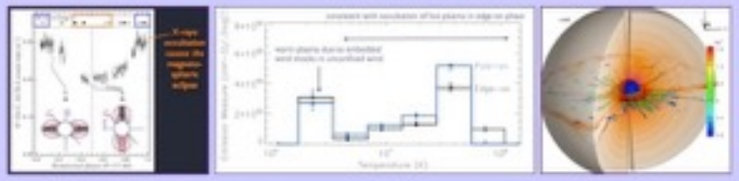


In September, 2013 I gave the Astronomy Department colloquium at Penn State, entitled "X-ray Spectroscopy of O Supergiant Winds: Shock Physics, Clumping, and Mass-Loss Rates" [pdf].

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

Four 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)?
3. How clumpy or smooth are the winds?
4. What effect to magnetic fields have on the winds and X-rays?

observational X-ray astronomy

X-ray spectroscopy with the Chandra X-ray Telescope

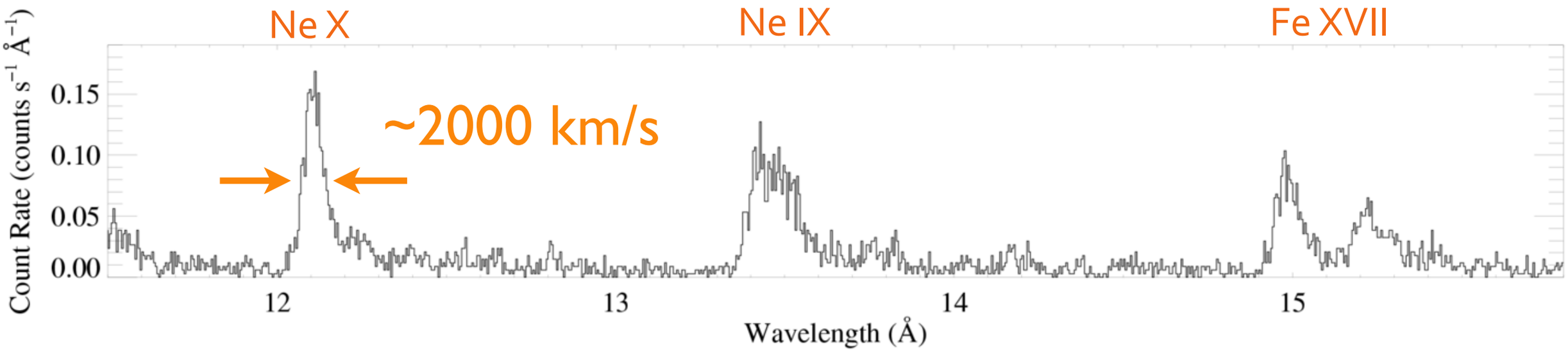
Chandra in the Space Shuttle cargo bay

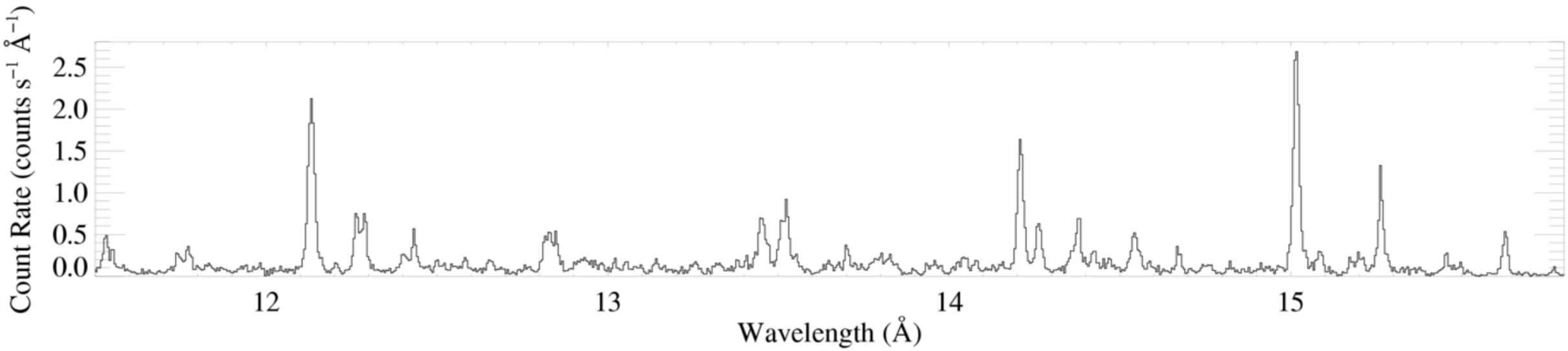
Chandra in orbit

massive stars' X-ray emission lines are broad

Chandra spectra

ζ Pup (O4If)



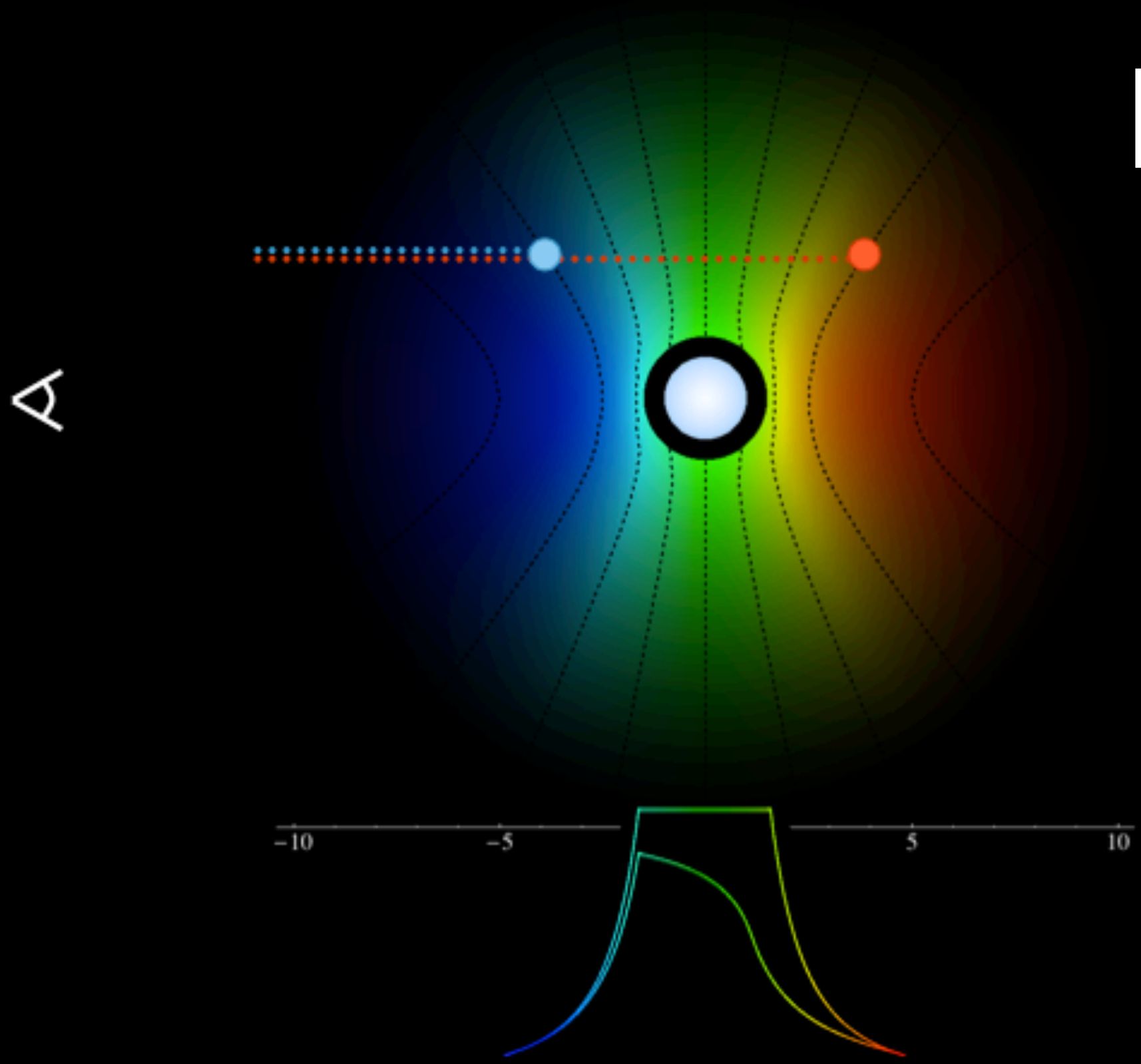


Capella: G star for comparison (narrow lines)

we make models

Line Asymmetry

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

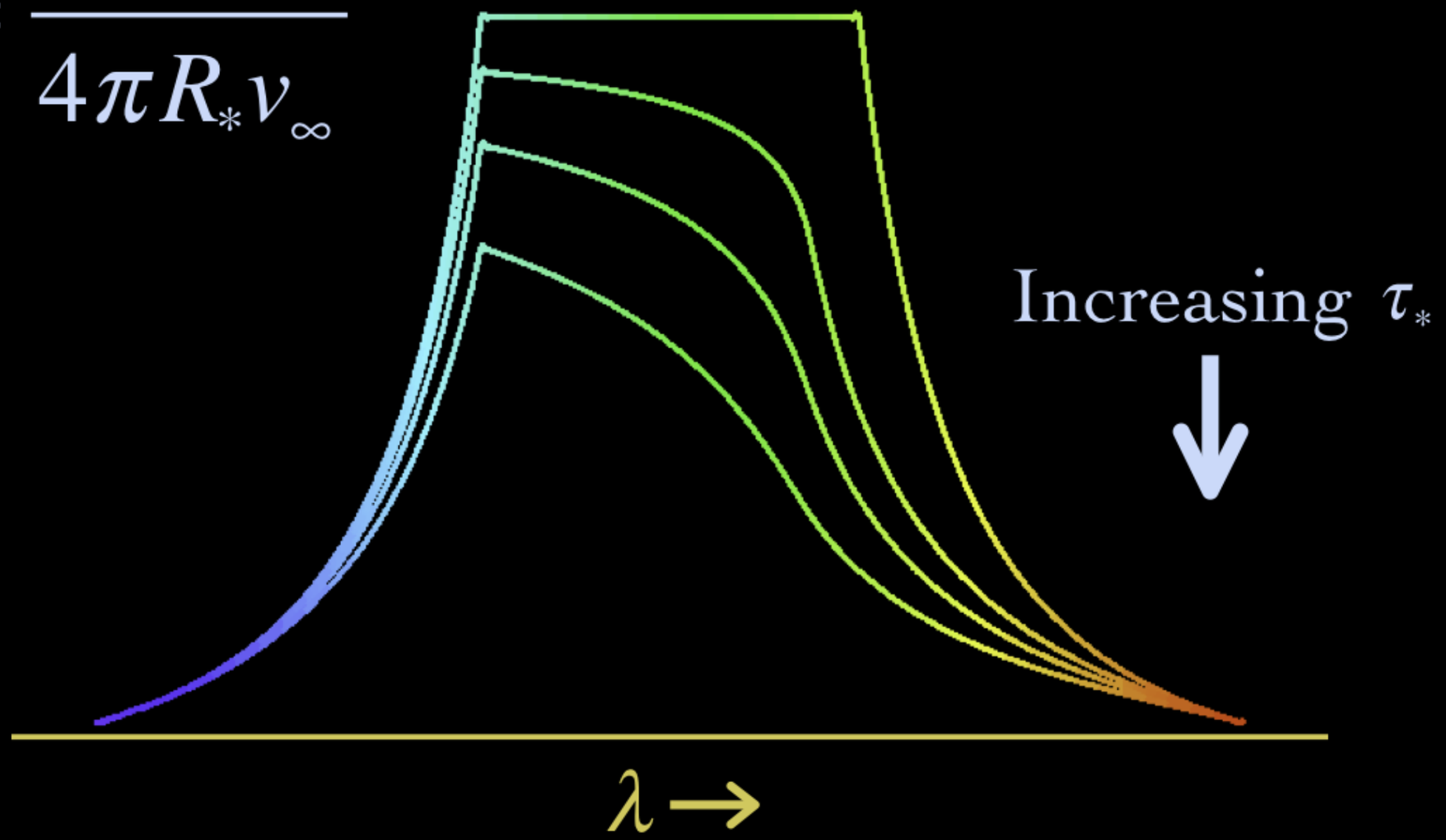


models make predictions

Wind Profile Model

wind mass-loss rate

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



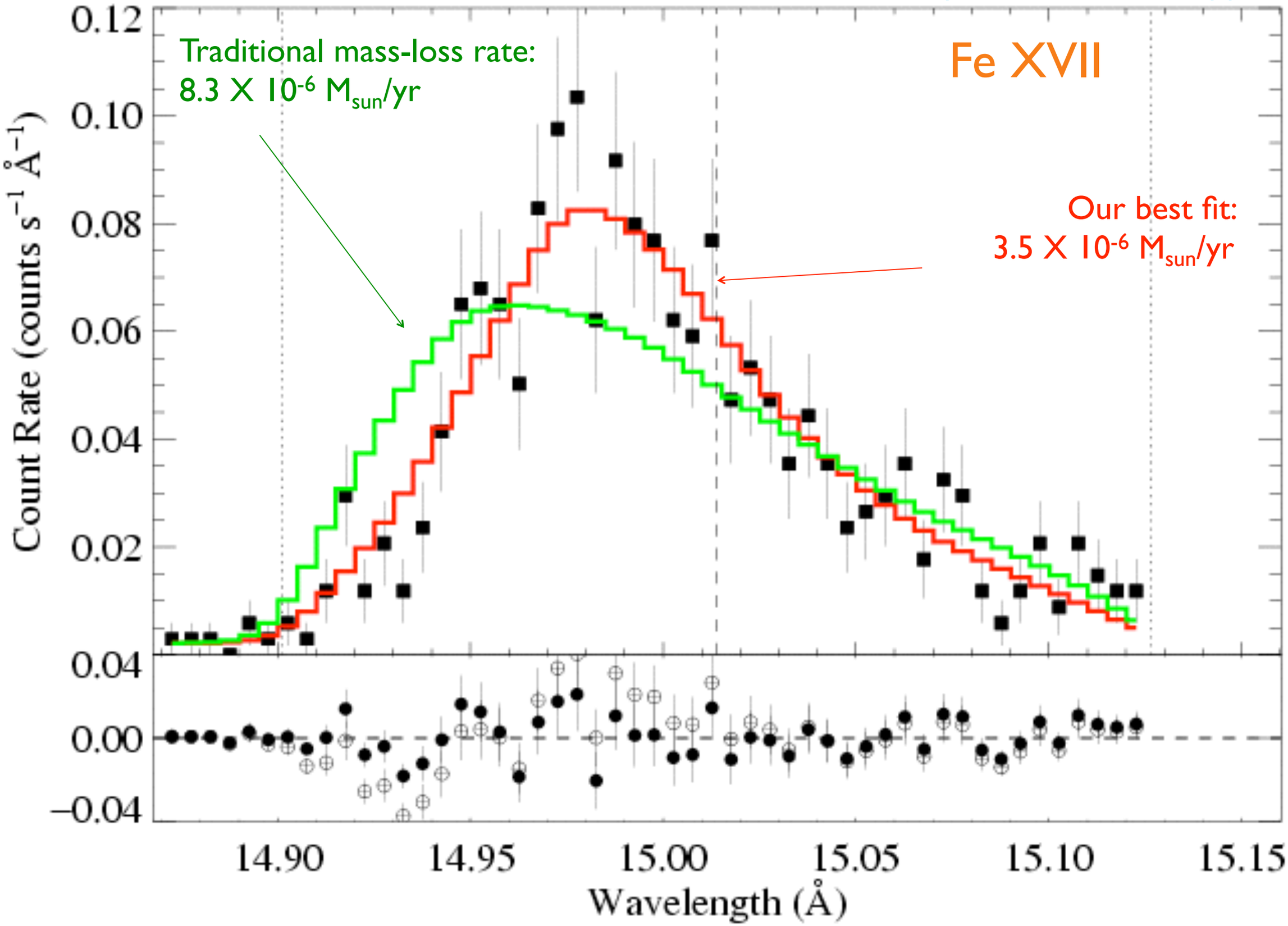
we compare these predictions to data

Chandra spectrum of zeta Puppis

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

Fe XVII

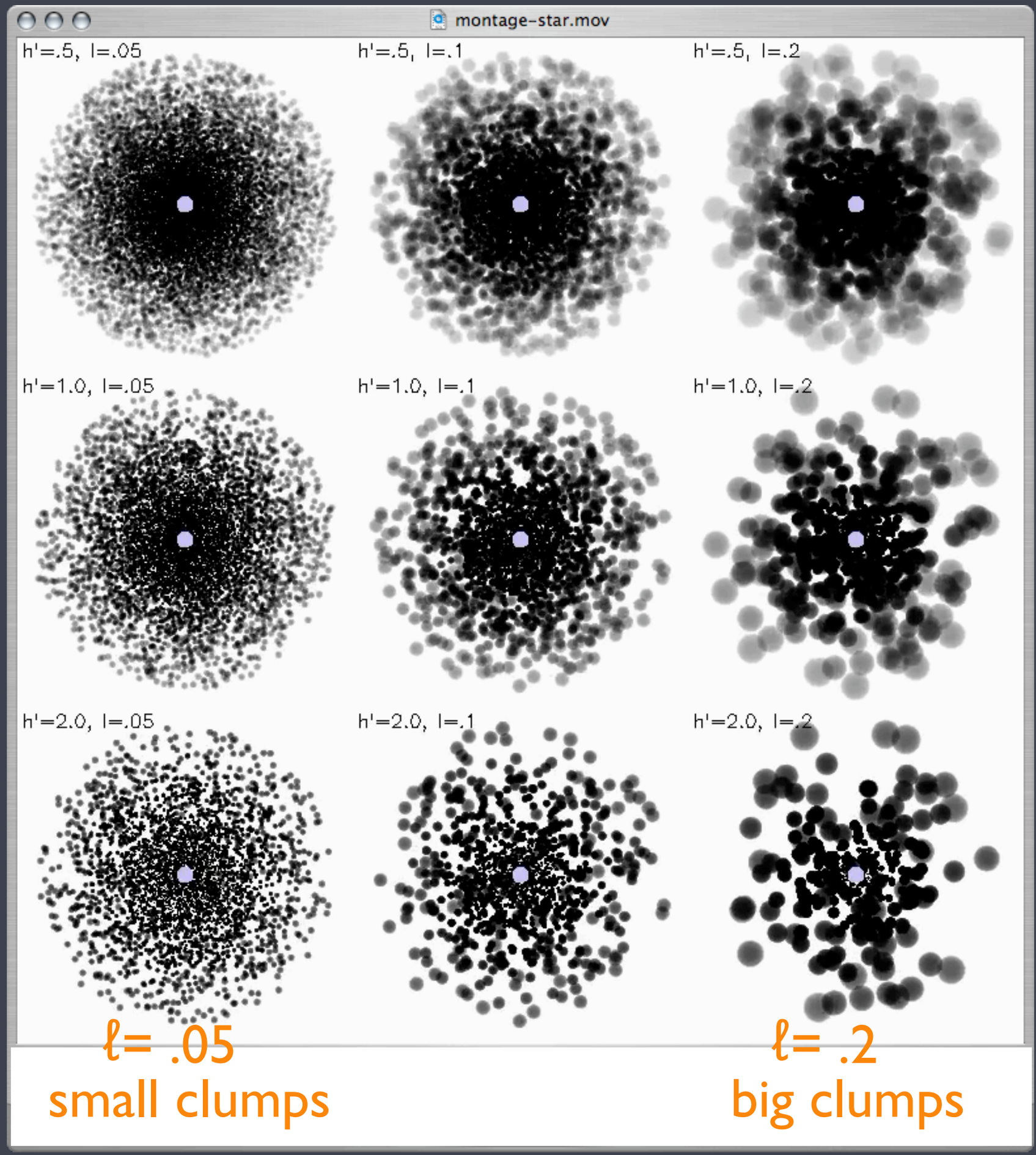
Our best fit:
3.5×10^{-6} M_{sun}/yr



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

less porous

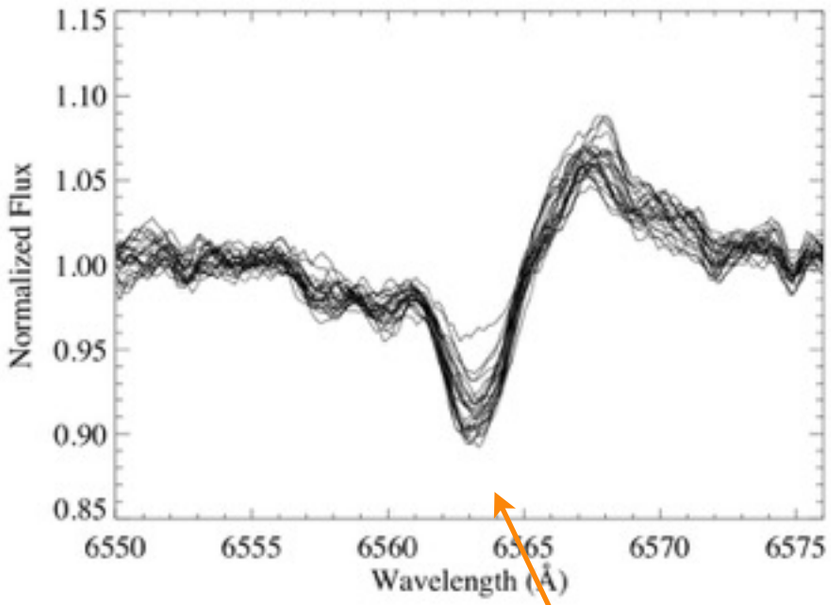
more porous



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

Four outstanding questions

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to try to answer these questions

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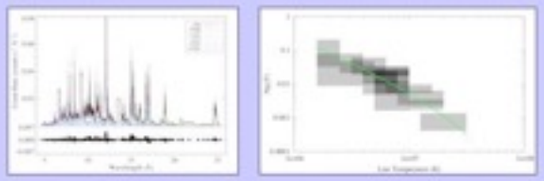

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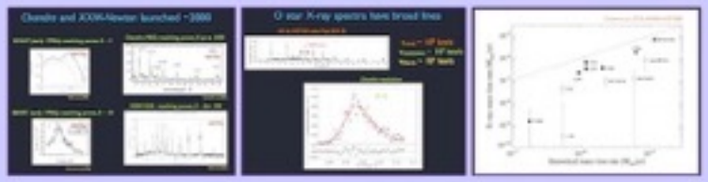

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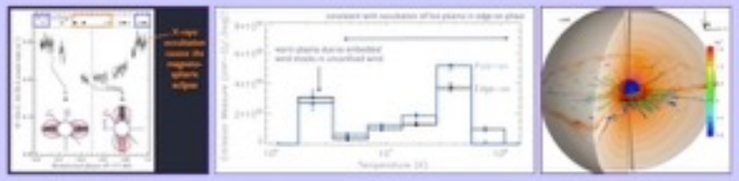

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