X-rays from Hot Stars:

Stellar Astronomy Research with Swarthmore Students

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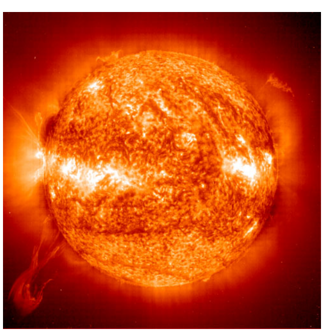

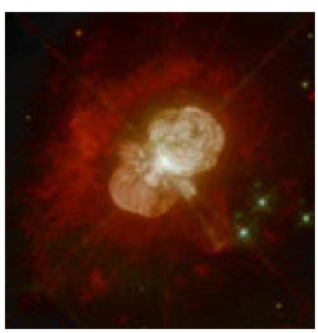

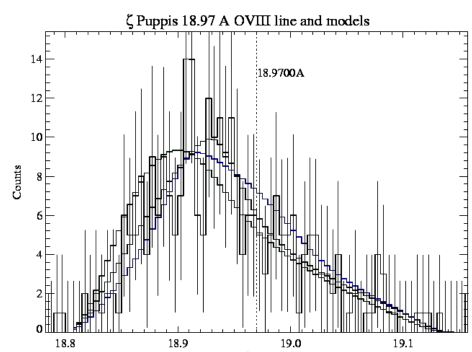

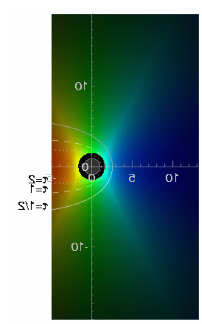

Presentation to the board of managers, December 3, 2004

For more information – and contact information – visit:

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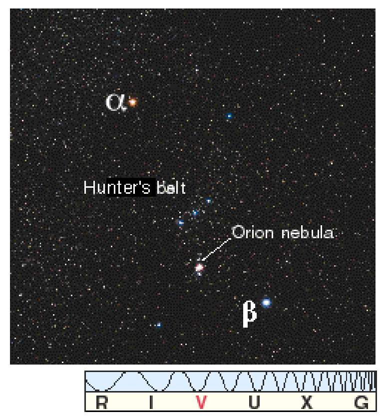
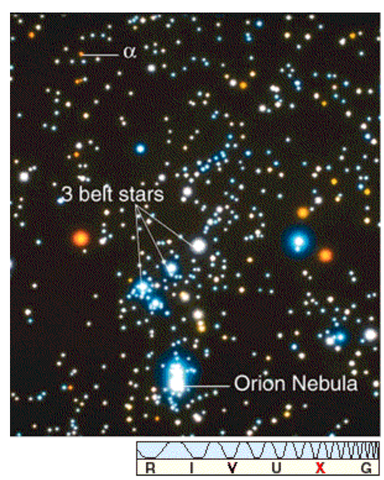
A 25-year-old *mystery*: Why and how do the galaxy's most massive, hot, and luminous stars produce x-rays?

The first x-ray telescopes unexpectedly discovered ubiquitous and strong x-ray emission from hot stars

Einstein X-ray Observatory (launched 1978): x-ray telescopes must be above the Earth's atmosphere.

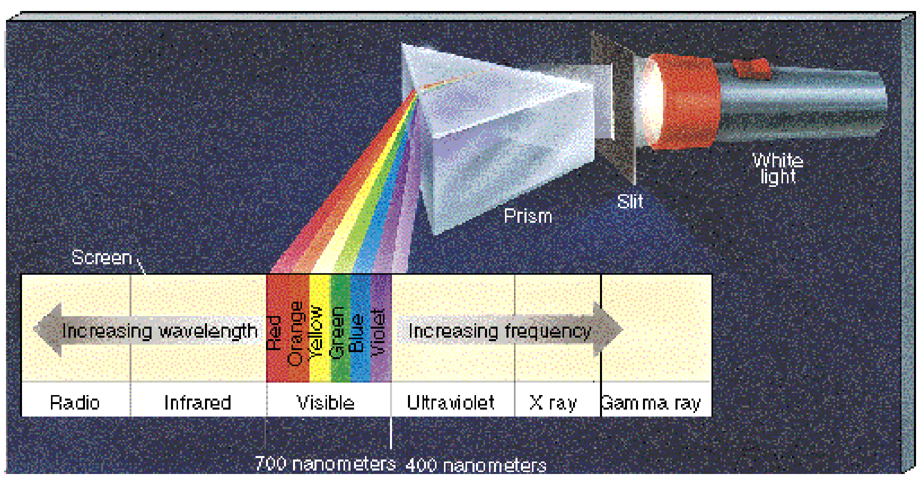




Hot stars in the constellation Orion are strong x-ray sources.

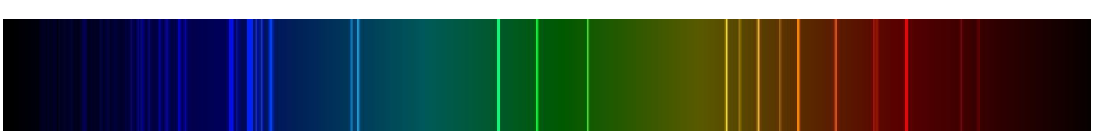
X-rays are electromagnetic radiation – light – but very, very energetic, short wavelength (beyond blue) light

Like visible light, X-rays have different wavelengths, or colors, that we can examine via *spectroscopy*



helium

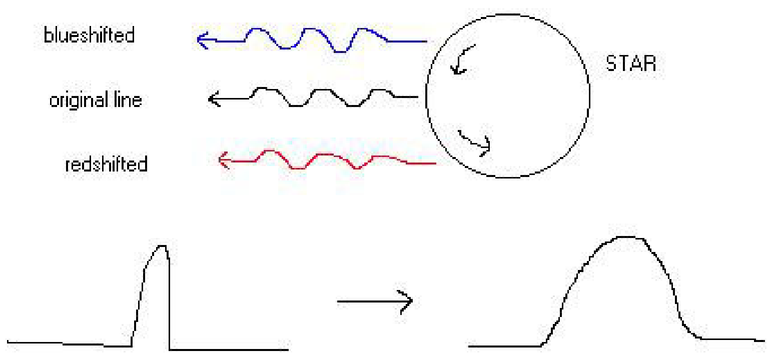
oxygen



Hot transparent gases have *emission line spectra*, with light emitted only over a few narrow wavelength ranges

Like any wave phenomenon, x-ray light is subject to the *Doppler shift* if the source of the light is moving

Light (including x-ray light) is blue-shifted if the source is approaching and red-shifted if it is receding.

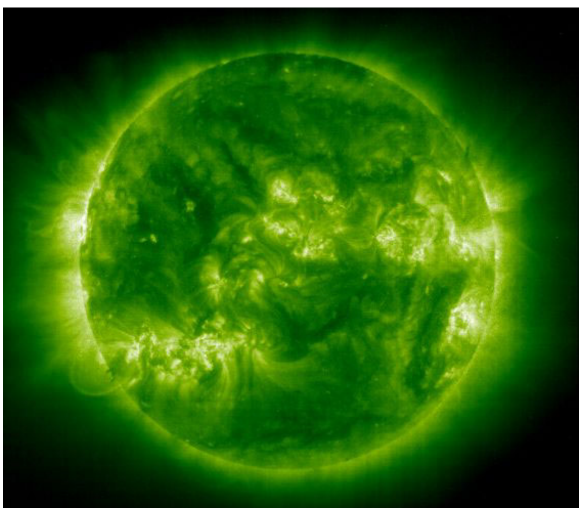


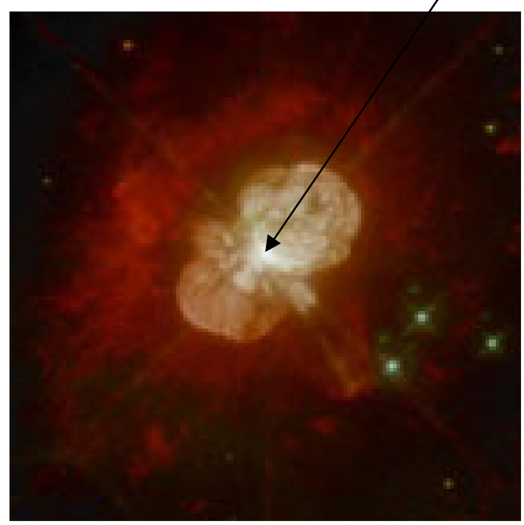
Here we see how the rotation of a star can lead to line broadening, but *any motion*, whatever its cause will also lead to line shifts that taken together produce a *broad spectral line*.

These are the underlying concepts – our scientific tools – how can we use them to solve the mystery of hot star x-ray emission?

There are two leading models – or hypotheses – of hot star x-ray emission:

The star itself is an unresolved point in the center.





The Sun's x-rays: plasma confined by magnetic fields → stationary → no Doppler shift → **narrow** emission lines

Hot stars*: massive outflows ("stellar winds") – are the x-rays associated with these winds? Moving plasma → large Doppler shift → **broad** emission lines

*This hot star (eta Carina) is unique in that we can actually take an image of its "wind nebula" – in all other cases, we infer the presence of a wind via spectroscopy; we can't see it directly.

Along with:

Roban Kramer ('03)

Stephanie Tonnesen ('03)

Genevieve de Messieres ('04)

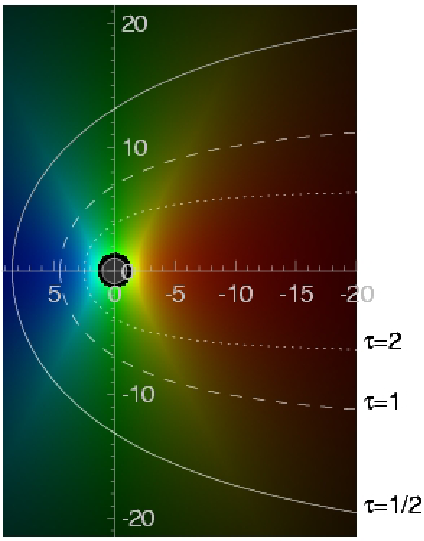
Mark Janoff ('04)

Casey Reed ('05)

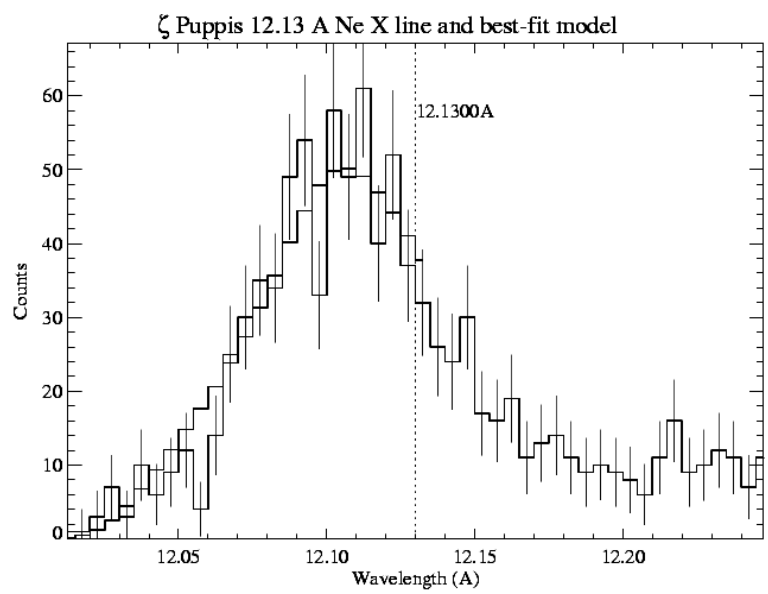
I obtained and analyzed x-ray spectra from several hot stars with the *Chandra X-ray Observatory*

to test the different theories of X-ray emission for hot stars.

Roban Kramer ('03) developed a model for fitting the detailed *shapes* of x-ray emission line profiles from hot star winds

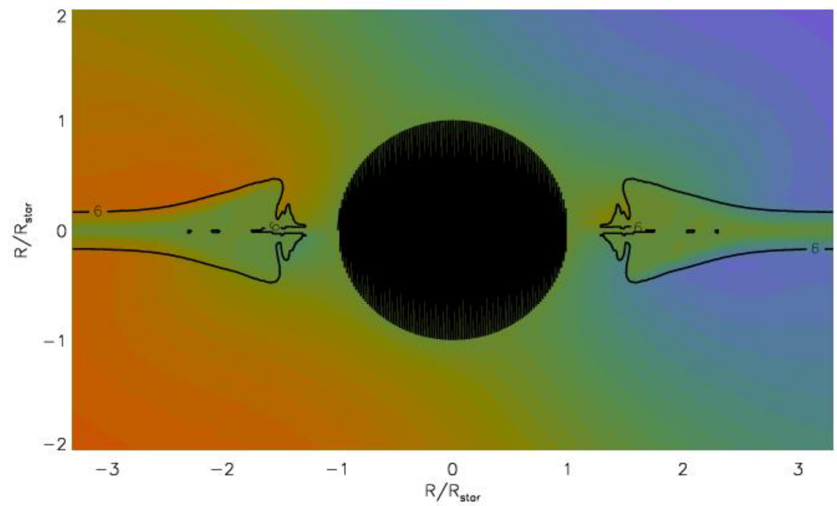


Details of the velocity structure of the wind, the spatial distribution of the x-ray emitting plasma, and the effects of x-ray absorption in the wind all affect the line shapes.

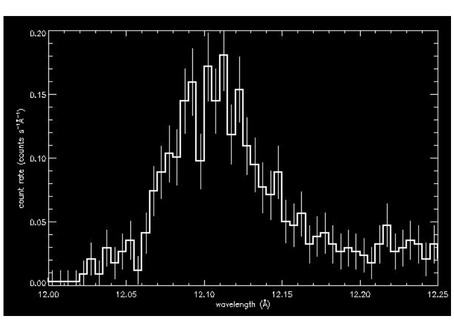


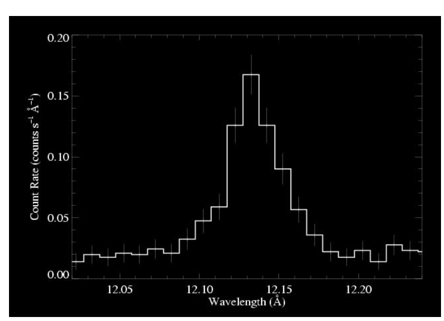
The very hot star, zeta Pup, with a strong stellar wind, does show broad lines…and Roban was able to fit the observed line shape in detail! Published in Kramer, Cohen, and Owocki, *Astrophysical Journal* (2003).

Stephanie Tonnesen ('03) modeled a hybrid situation, where winds and magnetic fields interact – this model is applicable to young hot stars, like theta Orionis, the star in the middle of the Orion nebula.



Stephanie calculated x-ray emission line widths from numerical simulations done by a collaborator of ours. Here she color-codes the wind flow according to its Doppler shift, as seen by an observer in the upper right. In the hybrid model, the hot plasma is confined to the equatorial plane of the star (inside the dark contour); it is moving but not very fast.





The same x-ray emission line in zeta Pup (Roban's star) on the left, and theta Ori (Stephanie's star) on the right. Theta Ori shows only modest Doppler broadening, as Stephanie's modeling predicts.

Conclusions

Scientifically: there is a diversity of results and behavior among hot stars; not a simple either-or result, but the observed phenomena are understandable through the application of physically meaningful models compared to quantitative data.

Educationally:

Students see how science is produced;

They get to interact with scientists from other institutions, attend meetings, present results, write papers;

They apply the knowledge and skills they learn in science, math, CS classes to the actual doing of science;

They take their understanding of the scientific process and the excitement of discovering something new back to the classroom (and grad school, teaching,…and their future professional lives).

For more information about my research, teaching, outreach and other professional activities – including the work of my student research group – please visit my website: `astro.swarthmore.edu/~cohen`