Chandra X-Ray Spectroscopy of DoAr 21: The Youngest PMS Star with a High-Resolution Grating Spectrum

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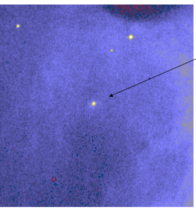
hat is DoAr 21? It is a Pre-Main Sequence (PMS) tar, a star that is still in the process of forming.

ne of the brightest X-ray sources in the Ophiuchus star-forming region, DoAr 21 is approximately 45 parsecs, or 423 light years, away.



mage from an optical telescope

We know DoAr 21 is a young star because:

--young stars form from interstellar gas in star-forming regions (notice the hazy blue gas surrounding DoAr 21)

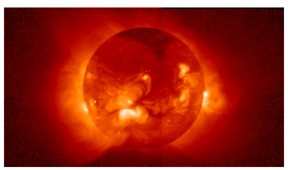
--young stars have more X-rays

--young stars have more lithium, thus their lithium absorption line, which can be seen in the reddish part of the optical spectrum, is stronger.

hat are X-Rays?

-rays are photons that are too energetic for the uman eye to see, much like some pitches in usic are too high for the human ear to hear. hile we see visible light at around 5000 ngstroms (Å), the X-rays from DoAr 21 are etween 1 and 25 Å.

-rays are emitted by gas that is at least a few illion degrees Kelvin. Stars like DoAr 21, hich is younger than our Sun, produce more X-ays than our Sun for two reasons:



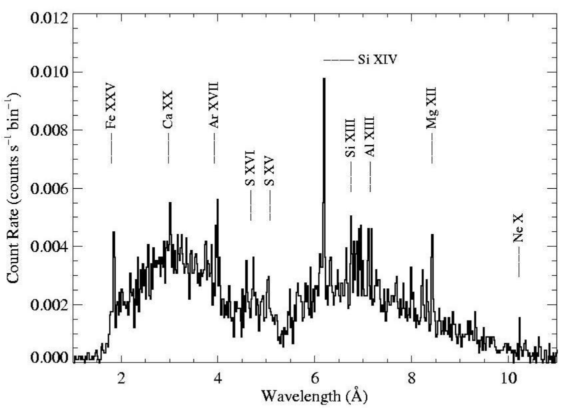
X-Ray picture of the Sun

.) Younger stars have stronger magnetic fields and they rotate faster (the mechanical and agnetic energy is turned into heat, which is emitted in the form of X-Rays)

.) Younger stars may also still have an accretion disk (surrounding the star and contributing to the rmation of the star by falling onto its surface) that can contribute to X-Ray emission. Does oAr 21's accretion disk affect its X-ray emission?

hat is Spectroscopy?

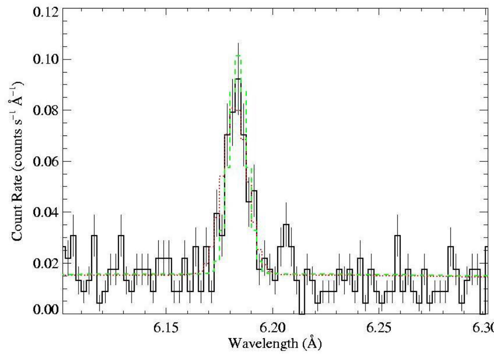
pectroscopy is the study of light that has been split into its various wavelengths, exactly as a rism separates visible light into its various colors.



The High Energy Grating Spectrum of DoAr 21, binned by a factor of five, where the size of one bin is 0.0125 Å. Strong lines are identified by the element's ionization stage.

Emission Lines

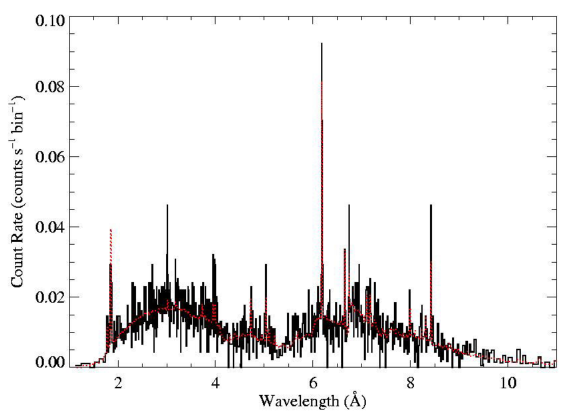
Each individual emission line comes from an element that has been ionized in the hot X-ray emitting plasma. An emission line can be broad due to the Doppler shift: photons will be bluer or redder depending on their direction of motion, resulting in an overall broad line. We care about the Doppler shift because the width of an emission line indicates the speed at which the X-ray emitting plasma is moving. If the material is moving, then it would most likely be emitted from a disk surrounding the star. If the plasma is stationary, the X-rays come from the stationary star. The amplitude of the emission line yields the abundance of the element causing the X-ray emission.



Above is an example of an individual emission line. We fit a model to the strongest emission line in our spectrum, Si XIV. Si XIV is a silicon atom with 13 of its electrons stripped. The red model is our best fit Gaussian model, and it indicates a velocity of about 450 km/s. The green model has been frozen at a velocity of 0 km/s for comparison.

The Entire Spectrum

In addition to using the individual emission lines to gain more information about DoAr 21, it is also useful to look at the spectra as a whole by fitting thermal models to these spectra. Through these thermal models, we can then determine the dominant temperatures of the plasma, and the elemental abundance values through relative line strengths.



Our best fit two-temperature model (red) overplotted on the High Energy Grating spectrum (black). Both model and data are binned so that each bin has at least 20 counts per bin. The model uses chi squared statistics for its fit.

Temperatures and Elemental Abundances

Our final results indicate that a two temperature model, with temperature components of 17 million Kelvin and 65 million Kelvin and abundance values of about a third of the Sun's abundance values, best fit the data of our spectra. Compared to the temperature of the plasma on the Sun, 2 million Kelvin, this is very hot. The term *abundance* is used by astronomers to describe the amount of heavy elements relative to hydrogen.

Flare Analysis

Flares occur when magnetic energy is suddenly released, resulting in an increase in brightness and temperature. During our observation, DoAr 21 experienced a flare that caused its X-ray brightness to increase by a factor of 3.

Applying temperature diagnostics to the separated pre-flare and flare spectra reveals that temperatures increased during the flare from about 10 million and 25 million Kelvin to 17 million and 65 million Kelvin. Much like we see on DoAr 21, when solar flares occur, the temperature of the X-ray emitting plasma of the Sun increases. Compared to flare temperatures of 10 million degrees Kelvin on the Sun, this is very hot plasma.

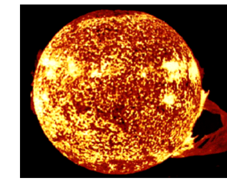
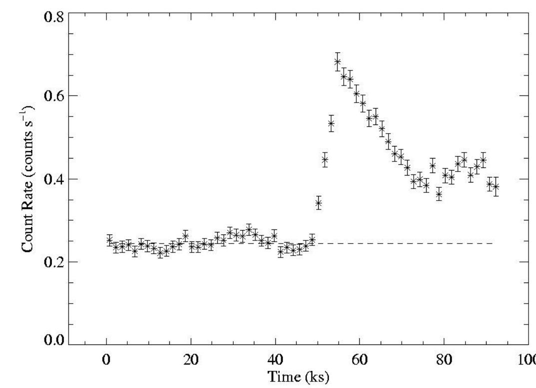


Image of a Solar flare. Is the flare we detected on DoAr 21 similar?



The light curve of DoAr 21, clearly depicting the giant flare that occurred at around 50 kiloseconds (ks) into our observation. The bin size of the light curve is 1500 seconds, and the dashed line represents the average count rate for the quiescent phase

Conclusions

DoAr 21's basic X-ray properties are similar to the Sun's. Because it is a young star, DoAr 21's X-ray properties do differ from the Sun's in key areas:

1.) the X-rays are harder, indicating higher temperatures than the Sun, and there are more of them

2.) the non-zero width of the Si XIV line indicates that an accretion disk may have some role in DoAr 21's X-ray emission

3.) the giant X-ray flare seen on DoAr 21 indicates stronger magnetic activity than compared to the Sun.