# Where do X-rays come from in hot massive stars? The case of delta Orionis

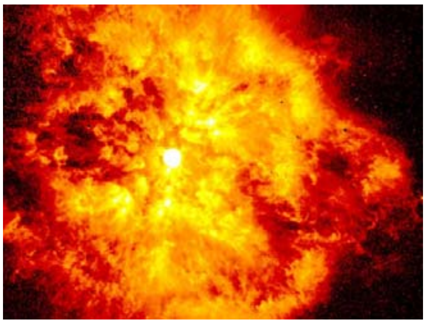
## Call for supplementary ground-based observations

## Abstract

In addition to scheduled observing runs from space using Chandra (http://chandra.harvard.edu/) for X-rays (professional team led by M. Corcoran, NASA) and MOST (http://www.astro.ubc.ca/MOST/) for precision optical photometry, we make a plea to the astronomical community to obtain simultaneous complementary ground-based optical observations of the key bright hot binary star delta Orionis (Mintaka, one of the belt stars) in the period between mid December 2012 and early January 2013. Both multi-band photometry and especially spectroscopy would be most welcome.

## Introduction

Massive O-type stars, though rare, are a primary driver behind the chemical, ionization and pressure evolution of the interstellar medium. Evolution of these stars from main sequence to supernova is driven significantly by stellar-wind mass loss. Understanding this important connection in individual stars requires a good understanding of the physical stellar parameters (mass, radius, luminosity, temperature) combined with detailed understanding of the outflowing wind (mass-loss rate, wind acceleration and structure in the form of density inhomogeneities or clumps). Our best estimates of mass, radius and luminosity come from direct dynamical analysis of photometric and radial velocity variations in massive, eclipsing binaries. But because massive stars are rare, and massive binaries rarer still (of the 2386 systems listed in the $9^{th}$ Catalog of Spectroscopic Binaries, only 82 of them have an O-type component), dynamical determinations of stellar parameters are only known for a few systems.



A massive W0olf-Rayet star with clumps in its interacting wind (HST image).

Our uncertainties regarding mass loss are even worse. For most of the star's life the dominant mode of mass loss is through radiatively-driven stellar winds at mass-loss rates of a solar mass in 100 000 to a million years. (These rates may seem minuscule, but recall that during the 3-10 mega-year O-star lifetime these stars can lose a significant fraction - typically ~30% - of their original mass via a stellar wind.) But these mass-loss rates are, in the majority of cases, estimated using an idealized smooth, spherically symmetric wind. Because the radiative driving force is inherently unstable, stellar winds are not smooth, and the resulting dense structures (clumps) which form in the wind play an important role in determining the overall mass-loss rate. More realistic models and observational evidence suggest that wind clumping may reduce established mass-loss rates by a factor of a few. Important questions such as the onset radius of clumping, the fraction of the wind that is clumped and the radial distribution of clumps through the wind have not yet been answered.

## The project

One of the best ways to constrain these dense clumps is via the associated hot, shocked X-ray emitting gas they produce. Massive, mass-losing hot stars are strong sources of X-ray emission ranging up to a full solar luminosity just in X-rays (!), produced by the collisions of fast streams with the clumps, generating shocked parcels of gas at thermal temperatures above a million degrees Kelvin embedded in and distributed through the wind. With the goal to quantify the origin of the X-ray emission **we have obtained 475 ksec (5.5 days – quite a large project for this large and exotic telescope!) of observing time with the NASA Chandra X-ray satellite** to follow a complete orbit of the eclipsing binary system delta Orionis Aa, containing a rather bright O9.5II primary and fainter B? type secondary in a 5.73 day period. (A third star Ab located 0.3" away from Aa and thus usually inseparable from Aa) is of type O9IV and thus contributes less than 10% to the total light.) The secondary acts as a probe blocking an *a priori* known volume from which the X-rays are coming, mainly from the dominating wind of the primary star. By following the behaviour of the X-ray spectrum with time around the orbit, we will be able to reconstruct exactly where the X-rays come from and what their properties are. This is the first time anything like this has been attempted! It should produce unique results that confine once and for all where the X-rays originate in luminous hot stars, something which has frustrated astronomers ever since X-rays were first observed from space starting several decades ago.

delta Orionis is the nearest massive, single-lined eclipsing binary. System parameters are given in Table 1 and a sketch of the system is presented in Fig.1. It is an important system and serves as one of the fundamental calibrators of the mass-radius-luminosity relation in the upper Hertzsprung-Russell diagram where massive stars are found. **It is also the only eclipsing O-type binary which is bright enough to be observable with the Chandra diffraction gratings (i.e. for X-ray spectroscopy in the 5-25A range!) in a reasonable time.**

While the Chandra observations are tentatively scheduled in the intervals 16-21 and 24-29 December 2012, we also have overlapping observations firmly scheduled in high-precision optical photometric mode using the Canadian MOST satellite from **17 Dec 2012 through 7 Jan 2013**. These latter observations in a single ~2000 Å wide filter centred on the V band will be allow us to correlate the X-ray fluctuations with optical variations and thus further constrain the origin of the X-rays from the ubiquitous wind clumps in del Ori, with implications for all hot luminous stars. Furthermore, the MOST photometry, of extremely high precision and long duration, will allow us to determine a more definitive eclipse curve and hence better constrain the stellar parameters. The best previous results for del Ori, all based on ground-based data, is found in the study of Mayer et al. (2010, A&A, 520, 89).

## Need for additional ground-based observations

We are looking for complementary ground-based repeated optical photometric observations in more than one filter. Although not obligatory, such data should be extensive and at least be partly simultaneous with the Chandra/MOST data.

Even more important is to obtain **frequently repeated high-resolution optical spectra** of del Ori – especially including **H-alpha 6562A** and **HeI 6678A** - overlapping with the Chandra and MOST data. We also need **observations of a telluric standard** (e.g. broad-line A-type star of similar magnitude) for **the H-alpha HeI 6678 region**.

Although this is during the holiday season when the weather is less likely to be favourable in the Northern Hemisphere, we are hoping that a sufficient number of interested parties, **especially amateur**, at different sites will be able to contribute. For such a bright object, it should be easy to obtain high S/N spectra >~ 200 with a spectral resolving power of R >~10 000 in reasonably short times (< 30 minutes) covering a large part of the optical spectrum from ~4000-7000A.

**If you are interested, please contact the optical coordinator for this campaign, Tony Moffat (moffat@astro.umontreal.ca) at the Université de Montréal. Each useful data contribution will result in co-authorship in the ensuing refereed publication.**

**Table 1: Parameters for delta Ori**

RA(2000) 05:32:00.40
DEC(2000) -00:17:56.7
V = 2.41
B-V = -0.40
Spec. type of component Aa1 = O9.5 II
Spec. type of component Aa2 = B?
P(days) = 5.732436
Radius of component Aa1 = 17 solar radii
Radius of component Aa2 = 4-7 solar radii
Major half axis = 44 solar radii
Inclination = 67°
Excentricity = 0.09
Mass loss rate of component Aa1 = $10^{-6}$ solar masses per year
Mass loss rate of component Aa2 < $10^{-7}$ solar masses per year

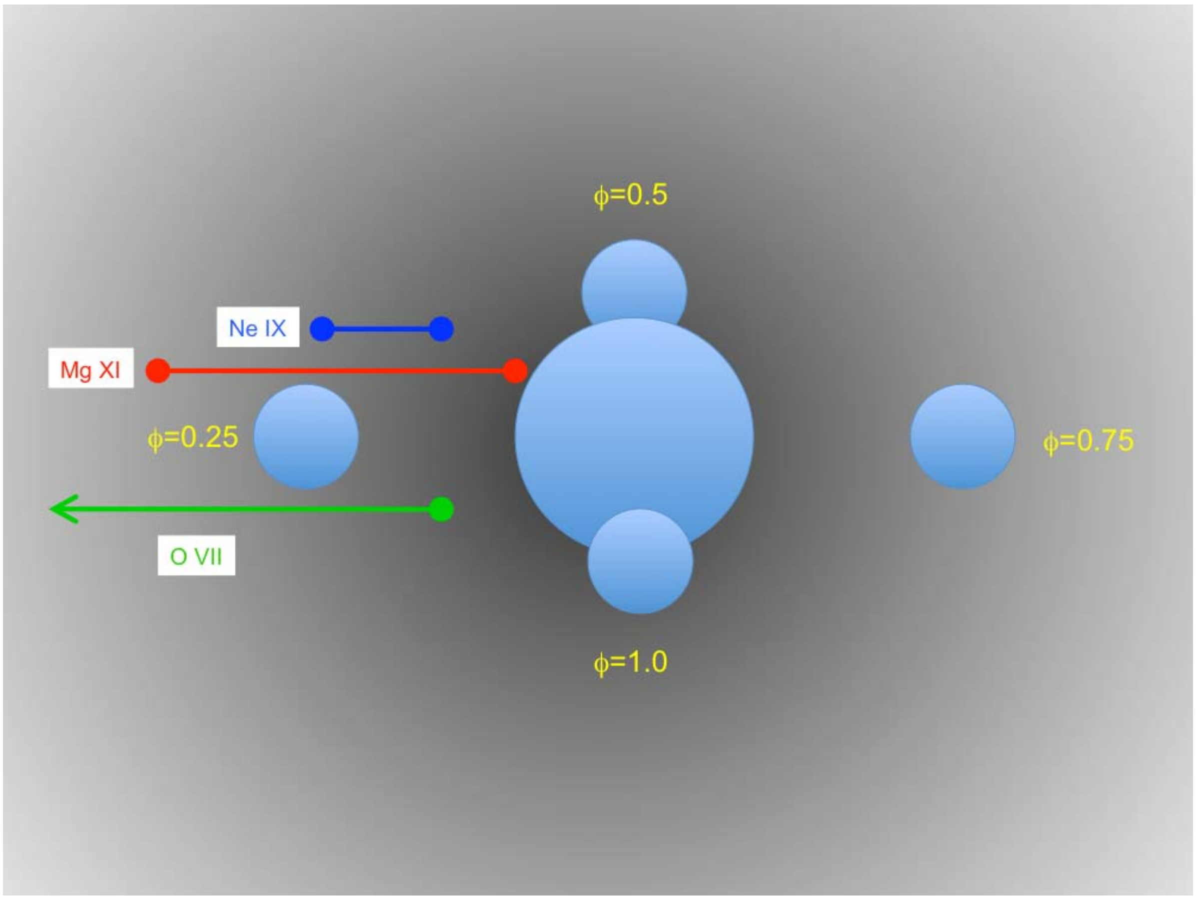



Fig.1 Sketch of the Aa delta Orionis binary system as seen on the sky to scale (although unresolved at 1" resolution) at both quadratures and conjunctions. The larger sphere represents the O9.5II primary (arbitrarily taken here as fixed). The coloured bars show the expected regions of formation of different (very-high ionization!) X-ray lines from the primary's wind. These will be progressively eclipsed by the smaller secondary and allow one to trace the geometric origin of the X-rays.