ASTRO 461 Sp19 MDM OBSERVING PROPOSAL

TITLE: Constraining the Origins of Massive Stars Away from the Galactic Plane

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ABSTRACT:

We seek to learn about the formation and dynamical evolution of high-mass stars through studying their kinematics and multiplicity. We will do this by measuring the spectra of 15 O- and B-type stars located away from the galactic plane to determine their radial velocities, which will allow us to compute their space velocities and understand more about their runaway status. Furthemore, we will learn about the multiplicity of the individual systems by taking photometric images of the target stars in order to help determine the presence of a nearby stellar binary, which can then be confirmed through spectroscopy. Constraining the fraction of high galactic latitude OB stars which are runaways and the fraction which are in multiple systems will help us learn more about massive star formation and evolution in the Milky Way (Chini et. al. 2012; de Wit et. al. 2005; Hoogerwerf et. al. 2000).

1.3-m + B4K CCD	Request	2.4-m + CCDS	Request
Filters	R, I, H-alpha +13A	**Wavelength range**	440 - 515 nm
Number of hours	4.5	**Number of hours**	4.5
Time range	21:00 - 1:30	**Time range**	21:00 - 1:30

Notes about observing setup:
Our OB stars are so bright (mag < 8) that for S/N > 100 we only need minimal exposure times for each detection. We will take both photometry and spectroscopy of our targets. We will observe targets with V-band magnitudes less than 3 with the H-alpha +13A filter and all others with the R and I filters. If a candidate companion is revealed from photometric images, we will immediately follow up with spectroscopy of the target and secondary stars.

SCIENTIFIC MOTIVATION.

Just as early astronomers observed and catalogued the skies, we are now in a position to study the properties of millions of nearby stars with the unprecedented accuracy provided by the *GAIA* space telescope's second data release (DR2). Regarding the most massive and brightest stars known to exist, OB stars, one question that astronomers have tried to answer it: How and where do OB stars form? Extensive research has led us to understand that giant hydrogen molecular clouds (GMCs) collapse due to self-gravity, forming protostars which if massive enough can become OB stars. Although this theory is generally accepted and accurate, there still remain many questions. Do OB stars always form amongst other OB stars, condensing from the same GMC? Could OB stars form from less dense regions of gas, and therefore amongst fewer stars? After OB stars form, will they remain gravitationally-bound in their birth cluster? In fact, photometric studies have found many OB stars that do not belong to any such star cluster. These massive stars are isolated from other massive companions, and are thus said to exist in the "field," the sparsely populated region outside of star clusters. To better understand the formation and dynamical evolution of massive stars, we must explain this population of massive field stars.

There are two possible explanations for a massive star to exist in the field: (1) it could have formed outside of the existing star clusters, so called *in situ* formation, and (2) it could have been ejected from its birth star cluster into the field, becoming a runaway star. A runaway star can be produced via two possible ejection mechanisms: (1) close dynamical interactions between two or more stars in a dense region of a cluster, and (2) the slingshot effect from the supernova explosion of a companion star in a binary system. A 3-D velocity greater than about 30 km/s is generally accepted to be the velocity at which a star is considered a runaway (Leonard & Duncan 1988). The goal of our work is to constrain the number of OB stars located at high Galactic latitude which are likely runaways. We have chosen 15 OB stars which are both visible from Kitt Peak and are at least 20° above the plane of the Milky Way in order to observe as many field OB stars as possible. We will use the *GAIA* DR2 proper motions and perform spectroscopy to measure the radial velocities for our 15 OB stars in order to determine their 3-D velocities. We will also image the stars to identify possible faint wide-binary companions. Doing so will inform us of the multiplicity of field OB stars and allow us to make connections between the dynamical ejection scenario and *in situ* formation, based on the velocities of the stars we are able to obtain.

TECHNICAL AND SCIENTIFIC FEASIBILITY.

In order to confirm whether or not a massive star is a runaway, we must estimate their total space velocities. While one component of this, the transverse velocity, is available from GAIA DR2, we must measure the second component, the radial velocity. The radial velocity of each target star can be measured by obtaining its spectrum and comparing this to the known rest spectrum. The difference in wavelength of certain spectral features will allow us to compute a radial velocity. We will therefore be able to find the space velocity which will help us determine whether the star is a runaway or formed in situ.

For our study of runaway star multiplicity, we will first reference GAIA DR2 to find if any of our target stars have confirmed companions. For the targets which do not, visual inspection of photometric images of these systems in the I, R, and H-alpha +13A bands will aid us in detecting a potential companion. An apparently-nearby star is considered to be a companion if it is within 10% of the distance of the target star. We will compute the distance by comparing the apparent magnitude of the star with its intrinsic magnitude. A star's spectral type is indicative of its intrinsic magnitude, so we will therefore also need to take spectra of any companion candidates.

We are also interested in learning more about the population of confirmed multiple systems that we observe, namely the companion mass ratio distribution and orbital separation distribution. The mass estimates of both the primary and secondary star can be determined by their mass-luminosity relationships. We can make an initial guess for the mass of the stars from their spectral types, and use this to decide which coefficient of the mass-luminosity relationship will be most appropriate. Luminosity can be determined using the flux and distance of each star. In order to determine the separation between the primary and secondary bodies of the system, we can use the angular separation between the two and their distance.

Obtaining the information we require to conduct the analysis described above necessitates photometric data of the target star and its surrounding region as well as spectroscopic data of the target star and any potential companion. Due to the low visual magnitudes of these massive stars, these observations will be feasible to conduct. We will use the 2.4-m telescope with the CCDS for the retrieval of the necessary spectra, and the 1.3-m telescope with the 4k Imager for photometric observations. The spectral resolution of the 2.4-m telescope's CCDS is sensitive to wavelength differences of 0.19 nm, which will enable us to detect radial velocity shifts of 110 km/s over our wavelength regime of interest. We will seek to observe any shift in spectral features over the wavelength range of 440 - 515nm, which includes prominent spectral features of O and B stars such as ionized helium (454.1nm) and neutral helium (447.1nm). Fitting multiple lines will help aid us in improving this sensitivity. The angular resolution of the 1.3-m telescope's 4K Imager will be seeing-limited to 1-2", which will allow us to detect binary systems wider than 3,000AU separations for the average distance to our targets of about 1.6kpc. We will observe in I, R, and H-alpha +13A bands, which will enable us to detect companions fainter than our target stars. Due to the brightness of our targets, higher levels of seeing will not prohibit these observations.

TARGET LIST.

Object ID	RA (hh:mm:ss)	DEC (dd:mm:ss)	Confirmed Companion RA/DEC	V mag	Exposure Time (s)	Transverse Velocity*** (km/s)
HD 69686	08:18:22.97	+09:09:05.07	NA	7.08	1-2	161.40 +/- 0.3
HD 91316	10:32:48.671	+09:18:23.71	NA	3.870	1-2	19.54 +/- 2.5
HD 93521	10:48:23.512	+37:34:13.09	NA	7.03	1-2	16.00 +/- 2.2
HD 97991	11:16:11.7	-3:28:19.0914	NA	7.41	1-2	165.62 +/- 1.0
HD 104337?	12:00:51.16	-19:39:32.33	NA	5.264	1-2	43.46 +/- 1.1
HD 108767	12:29:51.855	-16:30:55.5525	NA	2.94**	1-2	31.19 +/- 0.2
HD 119608	13:44:31.31	-17:56:13.22	NA	7.53	1-2	1032.92[a] +/- 25
HD 120086	13:47:19.20	-02:26:36.62	NA	7.82	1-2	9.19 +/- 0.8
HD 129956	14:45:30.2060	+00:43:02.179	NA	5.665	1-2	34.55 +/- 0.4
HD 142096?	15:53:20.055	-20:10:01.442	NA	5.027	1-2	13.44 +/- 0.5
HD 142378*	15:55:00.365	-19:22:58.5127	NA	5.957	1-2	20.14 +/- 2.9
HD 144218?	16:05:26.572	-19:48:06.8625	NA	4.89	1-2	15.92 +/- 0.5
HD 144470*	16:06:48.4269	-20:40:09.090	NA	3.97	1-2	15.10 +/- 0.7
HD 149757	16:37:09.539	-10:34:01.529	NA	2.56**	1-2	37.70 +/- 1.9
HD 150100!	16:36:11.421	+52:54:00.167	16:36:12.2/ +52:54:8.64	5.52	1-2	19.45 +/- 0.1

* = Identified as in an OB association by Hipparcos (de Zeeuw et. al. 1999)

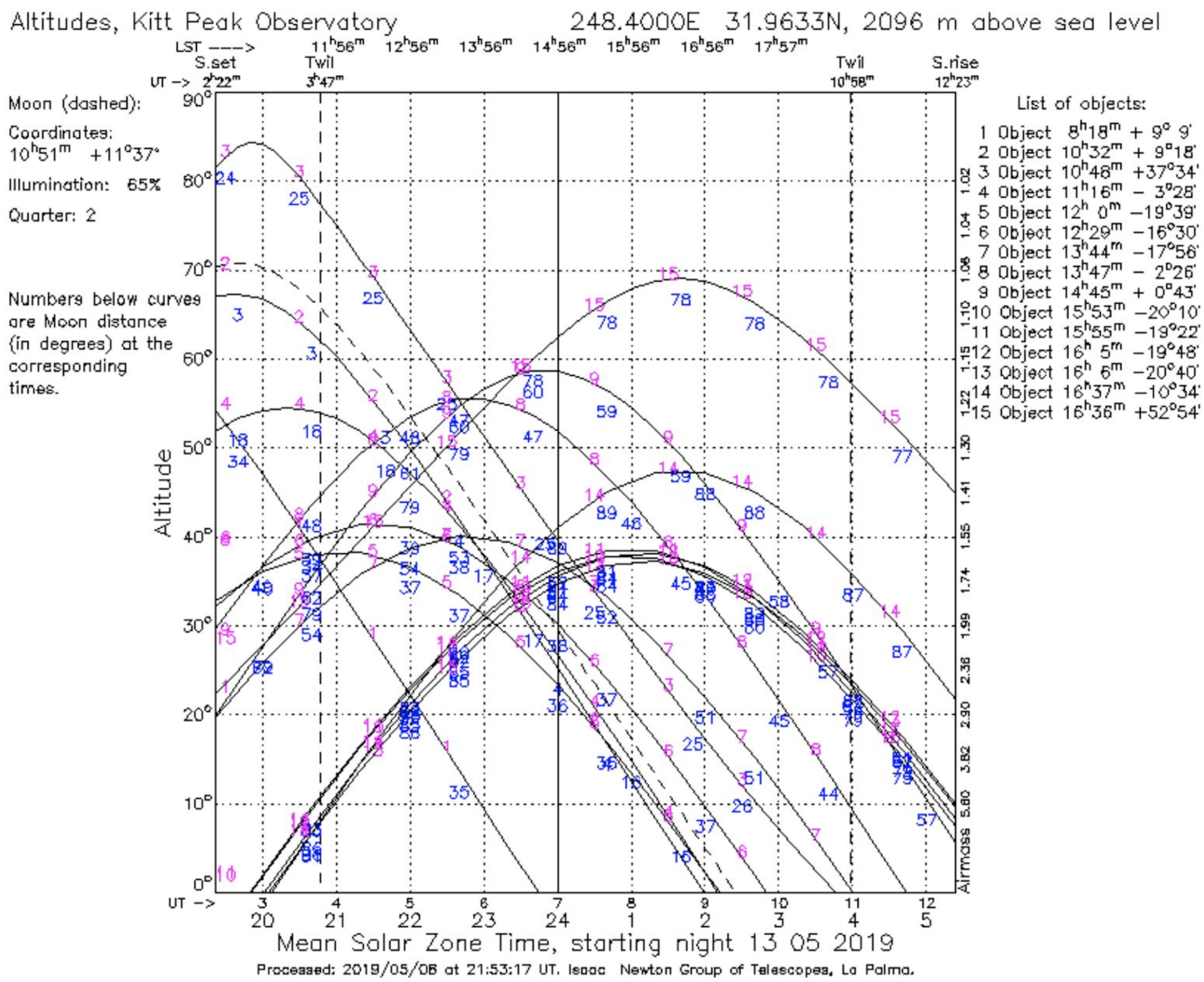
** = Stars to be observed using H-alpha +13A filter

*** = Calculated from GAIA DR2 proper motion and distance data

a = High transverse velocity comes from highly uncertain GAIA DR2 parallax data
! = Confirmed by GAIA DR2 to have a companion (Companion parallax within 10% of target's parallax and separation less than 10,000 AU), NA if no confirmed companion
? = Identified as binary system by SIMBAD but not supported by GAIA DR2 (missing parallax data)

Note: According to GAIA DR2, there are numerous stars with similar positions as many of our targets but with no recorded parallax. For this reason, we believe it is worthwhile to conduct follow-up companion surveys.

Observing Guide



Works Cited

Chini et. al. (2011). A Spectroscopic Survey on the Multiplicity of High-Mass Stars. *Mon. Not. R. Astron. Soc.* (000 2011), 1-6.

de Wit et. al. (2005). The Origin of Massive O-Type Field Stars. *Astron. & Astrophys.* (437), 247-255.

de Zeeuw et. al. (199). A Hipparcos Census of the Nearby OB Associations, *The Astron. Journal* (117), 354-399.

Hoogerwerf et. al. (2000). The Origin of Runaway Stars. *The Astrophys. Journal* (544), 133-136

Leonard & Duncan (1988). Runaway Stars from Young Star Clusters Containing Initial Binaries I. Equal-Mass, Equal-Energy Binaries. *The Astron. Journal* (96), 1-11.

*This work has made use of data from the European Space Agency (ESA) mission Gaia (*https://www.cosmos.esa.int/gaia*), processed by the Gaia Data Processing and Analysis Consortium (DPAC,* https://www.cosmos.esa.int/web/gaia/dpac/consortium*). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.*