MAD Science Demonstration Proposal

Title: The Orion Trapezium Cluster ultra deep field

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Abstract:

In order to map the core of the Orion Nebula Cluster with unprecedented sensitivity and high spatial resolution, we wish to obtain very deep JHK images of all stellar fields near the Orion Trapezium Cluster that allow to fully exploit the capabilities of MAD. These data shall be sensitive enough to study the full dynamic range of the IMF, down to the planetary-mass regime. The superb spatial resolution that will be obtained ($\leq 0.1''$), as estimated by our simulations, allows us to perform the first binary survey among brown dwarfs and planetary-mass objects in the Orion Trapezium Cluster. With an expected number of detections of >30 so-called free floating planetary-mass objetcs, we will a) substantially increase the census of extremely low-mass objects in the Orion Nebula Cluster, b) significantly contribute to the statistics of the binary fraction for planetary-mass objects.

Scientific Case:

The shape of the initial mass function (IMF) at substellar masses ($< 0.075\mathrm{M}_\odot$), and particularly in the regime of planetary-mass bodies ($< 0.012\mathrm{M}_\odot$) is observationally not well constrained yet. Only recently very deep imaging surveys and follow-up spectroscopy began to record the full census of extremely low-mass objects in young stellar clusters (e.g. Greissl et al. 2007, Caballero et al. 2007, Lucas et al. 2006, Lucas et al. 2005, Slesnick et al. 2004, Muench et al. 2002.). Such in-depth investigations at the lowest mass end of the IMF are mandatory to understand the formation process of substellar bodies, which is a key topic of today's astrophysical research. If indeed a minimum mass limit at $3-5\mathrm{M}_{Jup}$ exists for object formation via molecular core fragmentation, as predicted by theory (e.g. Low-Lynden-Bell 1976, Silk 1977), then this should be reflected in the very low-mass IMF. Similarly, the properties of young brown dwarf/planetary-mass binaries are tightly linked to their formation process and must, therefore, be thoroughly studied. Some formation models predict a low binary frequency and a paucity of wide pairs at the lowest masses (Bate et al. 2002, 2003). On the other hand, Close et al. (2007) find that very-low mass binary systems (having component separations of ≥100AU) are much more frequent in very young clusters and associations than among the Galactic field population. The mechanism for the "evaporation" of pairs is likely to be dynamical interactions within the young dense stellar cluster environment. However, to date, binary sample sizes as well as achieved sensitivities are not yet sufficient to unambigiously constrain theories of brown dwarf/planetary-mass object formation (Burgasser et al. 2007).

The Orion Trapezium Cluster (OTC) is located at the core of the Orion Nebula cluster (ONC), which is the most populous young stellar cluster within 1 kpc and serves as a benchmark to study the full dynamic range of the IMF. Although the ONC is extensively studied, there is still an ongoing debate on the shape of its IMF and on its dynamical state (e.g. Pflamm-Altenburg & Kroupa 2006, Kumar & Schmeja 2007). The role and abundance of stellar/brown dwarf ejections in the dense stellar cluster environment, and the gravitational state of the OTC in general (bound or unbound) are far from being understood (e.g. van Altena et al. 1988, Gomez et al. 2005, Kraus et al. 2007).

With MAD we wish to obtain high spatial resolution ultra-deep JHK-images of a significantly large area of the OTC. Our goal is to detect substellar binaries and extremely low-mass objects, down to the planetary mass level at $\sim 3\mathrm{M}_{Jup}$. The proposed MAD observations will be complementary to the large dataset obtained with high sensitivity by the HST (the HST Treasury Program on the Orion Nebula, Robberto et al. 2005) and the Chandra Orion Ultradeep Project (COUP, Getman et al. 2005). In combination with the high accuracy HST data it will also be possible to constrain the velocity dispersion of cluster members down to the sub-stellar limit, and to identify high velocity run-away candidates (Poveda et al. 2005). With the superb spatial resolution that will be obtained ($\leq 0.1''$, which corresponds to ∼45AU in the OTC) we will be able to resolve close brown dwarf binary or even planetary mass systems. As several tens of potentially very low luminosity targets are expected to be detected in our images, this will define the very first binary survey among brown dwarfs and planetary-mass objects in the Orion Trapezium Cluster. Concerning other near-infrared datasets, ultra-deep but seeing-limited JHK observations in the *outer* regions of the Orion Nebula Cluster have been performed by Lucas et al. (2005) using Gemini. They identified 33 planetary mass candidates with M=3-12M_{Jup} and K=18-19mag. Although the area studied by Lucas et al. (26arcmin^2) is larger than the area we can study with MAD (10-12arcmin^2), we expect to detect roughly 1.3 times more sources, due to the steep radial stellar density profile of the Orion cluster. Hence, we will get more than sufficient statistics for a reliable comparison with the results derived by Lucas et al. for the outer parts of the cluster. The predicted brightness of a 3M_{Jup} mass object, assuming a distance of 450pc to the Trapezium Cluster, an average extinction of $A_V \approx 5$ mag, and an age of ∼1Myr, is J≈21.5 mag, H≈20.5 mag, Ks≈19 mag (Baraffe et al. 1998, Chabrier et al. 2000). Several hours of integration time, particularly at J-band, are needed to reach such faint levels. However, employing MAD imaging has several advantages over seeing-limited observations, like those with ISAAC (of which very deep unpublished observations of the Trapezium Cluster exist, but as said, with typical FWHM of $0.5'' - 0.8''$): The capability of MAD providing $\leq 0.1''$ spatial resolution over the full $1' \times 1'$ field, and over $2' \times 2'$ in very good seeing conditions, greatly improves the sensitivity to point-sources and separating those from the nebular background is easily possible. Moreover, close binary systems can be resolved. A preliminary correction performance for our target fields has been computed by one of us using the YAO simulation software adapted to the MAD optical configuration. The guide stars asterisms has been reproduced with correct positions and magnitudes and closed loop simulations have been carried out for a correction frequency of 200-400Hz. The seeing has been taken to be 0.8 arcseconds (at 0.55 um). The results of 2 representative asterisms are shown in the contour plots of Fig.1 and consist of the Strehl ratio maps in K band, PSF shape variation in the field and associated FWHM (values next to the color bar). Based on these performance simulations we plan our mosaic pointings in the 5 target fields (only areas with good expected correction, i.e. FWHM $\leq 0.1''$, are considered for mapping).

It should be noted that the inner $1' \times 1'$ of the Trapezium Cluster has been observed with MAD already during a MAD-commissioning run in early April 2007 and the results will be included in our analysis. With the MAD SV observations we intend to extend the observations from commissioning to *all* fields of the Trapezium Cluster that can be observed with MAD (i.e. where 3 bright stars for wavefront sensing are available), and to go as deep as possible to detect potential planetary mass objects. Certainly, any planetary mass *candidate* that will result from our photometric survey will have to be confirmed through follow-up spectroscopy in future studies.

Targets and integration time

Target	**RA**	**DEC**	**Filter**	**Magnitudes**	**Total integration time** (sec)	**Field** (arcmin)
TC center field	05 35 16.864	-05 23 07.20	J,H,Ks	JHK> 4.4^m	K: 850 H: 5132 J: 7698	$2\times1'$ mosaic template DIT=1s
TC field 1	05 35 18.775	-05 22 09.78	J,H,Ks	JHK> 7.5^m	K: 2160 H: 8288 J: 12432	$3\times1'$ mosaic template DIT=1s
TC field 2	05 35 18.713	-05 21 17.44	J,H,Ks	JHK> 5.8^m	K: 2160 H: 8288 J: 12432	$3\times1'$ mosaic template DIT=1s
TC field 3	05 35 28.485	-05 25 33.47	J,H,Ks	JHK> 6.2^m	K: 2880 H: 11050 J: 16576	$4\times1'$ mosaic template DIT=1s
TC field 4	05 35 24.496	-05 25 19.19	J,H,Ks	JHK> 4.8^m	K: 2160 H: 8288 J: 12432	$3\times1'$ mosaic template DIT=1s

Guide stars list and positions

Target: TC center field			
	$\mathbf{RA}''_{rel}$	$\mathbf{DEC}''_{rel}$	**V Mag**
GS1/Par1910	+16.38	+21.78	11.39
GS2/Par1864	-16.44	-2.86	11.10
GS3/Par1889	+5.76	-9.49	6.7
Target: TC field 1			
GS1/Par1956	+27.52	+25.76	9.62
GS2/Par1885	-28.42	+24.76	10.55
GS3/Par1910	-12.28	-35.64	11.39
Target: TC field 2			
GS1/Par1923	+6.25	+38.44	11.89
GS2/Par1956	+28.45	-26.58	9.62
GS3/Par1885	-27.49	-27.58	10.55
Target: TC field 3			
GS1/Par2031	-32.48	+33.16	6.41
GS2/Par2085	+42.97	+17.55	8.24
GS3/Par2058	-2.48	-46.35	9.47
GS4/Par2032	-33.68	-6.25	11.97
Target: TC field 4			
GS1/Par2031	+27.36	+18.88	6.41
GS2/Par2032	+26.16	-20.53	11.97
GS3/Par1993	-24.99	+21.92	5.07

Time Justification:

It is mandatory for our proposed survey to obtain images at all 3 near-infrared bands, as we need to make a photometric selection of brown dwarf and planetary mass candidates from color-color and colour-magnitude diagrams. Best sensitivity can be obtained at K-band, because extremely low-mass objects are intrinsically red, extinction is less significant, and Strehl ratios are highest at K-band. Using the commissioning images taken of the Trapezium center field in April 2007 as a reference, we extrapolate the exposure times needed for the additional MAD images we propose here. Hence, in $\sim$ 12min a 5σ point-source detection of Ks$\approx$19mag per $1' \times 1'$ field is achieved at K-band. At H-, and J-band significantly more time is needed, because all the effects mentioned above (spectral energy distribution of the source, extinction etc.) are much less favourable. We expect to reach, under good conditions, with the total exposure times as specified in the table above, a 5σ point-source limit of H(J)$\approx$20mag(20.5mag), not reached so far by any other published near-infrared survey of the Trapezium cluster. The images of the Trapezium center from the April commissioning run will also be included and therefore reduce the additional time required for the center field. The sum of integration times in the table above, plus 21min per field acquisition overhead, plus 1hour per field for offset sky images amount to $\sim$ 38.5hrs total time. If this cannot be accomodated in the MAD SV schedule, imaging of only those 3 fields that continously sample the Trapezium Cluster center (target TC center field, TC field 1, TC field 2) is also an option, which decreases the requested time to $\sim$ 18hours.

Figure 1: Near−infrared image of the OTC with 2´x2´ MAD fields overplotted
The contour plots for 2 of the MAD fields show the expected AO performance.