NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
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IRMOS Spectroscopy of the Orion Nebula Cluster

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
We propose to use IRMOS to perform an infrared spectroscopic survey of the Orion Nebula Cluster (ONC). We will target Pre-Main Sequence (PMS) objects too red to have their spectra taken at shorter wavelengths. At the same time, the multi-object capability of IRMOS will allow us to classify hundreds of PMS objects across the full range of stellar masses. This survey ideally complements the HST Treasury Program on the ONC we have recently completed. Coupling the exquisite accuracy of the optical and near-IR HST photometry with the IRMOS spectral classifications, we will build the most accurate HR diagram ever made for the low-mass end of the PMS. This will allow us to attack fundamental questions of star formation from a firm, quantitative assessment of the physical parameters of each stellar source, e.g. luminosity, mass, age, accretion rates. We will analyse the star formation history of the cluster (age and age-spread vs. position) and the structure and variation of the IMF. Probing into the brown-dwarfs regime, we will classify low luminosity sources spread across the Great Orion Nebula while confirming their actual membership. The survey will also provide a unique dataset for studying the structure and evolution of the inner disks around hundreds of nearly coeval stars of different mass. This study is timely and highly needed, considering the amount of observing time recently dedicated to the ONC by several facilities, including HST, Spitzer and Chandra, and the general need for accurate spectral classification of PMS in Orion.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	KP-4m	IRMOSM	8	bright	Nov - Jan	Nov - Jan
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Our understanding of star formation is critically based on the nearest massive star-forming region, the Orion Nebula and its associated stellar cluster (ONC). According to the current paradigm, dense, rich clusters dominated by a few massive OB stars represent the typical Galactic star-forming environment. The ON is a harsh environment, characterized by winds and ionizing radiation, multiple outflows, close dynamical encounter and substantial X-ray emission. The canonical scenario developed in the last two decades for isolated low mass ($M < 1M_\odot$) stars forming in sparse clusters like Taurus-Auriga may not adequately describe all passages of early stellar evolution.

Several near-IR imaging surveys of the ONC have been carried out in recent years (Luhman et al 2000, Hillenbrand & Carpenter 2000, Lucas & Roche 2000, Muench et al 2002). These studies, based on the observed JHK colors, magnitudes and source counts, have shown that the IMF of the Trapezium cluster spans a significantly greater range of mass than any other IMF determination, either for field stars or other clusters (Kroupa 2002). The shape of the IMF has also been relatively well defined, with a Salpeter slope above 0.6 $M_\odot$, a broad peak between 0.3 $M_\odot$ and the hydrogen burning limit, and a decline into the substellar regime.

On the other hand, these near-IR imaging surveys only provide statistical averages. Since it is not possible to reliably convert JHK fluxes and colors of individual stars into parameters like bolometric luminosity and mass, even the shape of the IMF remains somewhat uncertain (Lada & Lada 2003). For a deeper and more complete understanding of the ONC we would like to know for each member the stellar mass, age, extinction, presence and relevance of disk and accretion, etc. Considering that our current understanding of the star formation process (e.g. IMF) is largely built upon the ONC, it is clear that these observational uncertainties represent a major limitation.

To carefully place a star in the HR diagram we need both precise photometry and spectroscopy. Photometry is better obtained in the visible, where the contribution of circumstellar emission (disks) is negligible. For this reason, we have recently carried out the definitive photometric survey of the ONC using all imagers (ACS, WFPC2 and NICMOS) onboard the HST (HST Orion Treasure Program, P.I. M. Robberto). The sensitivity of HST allowed us to measure with exquisite precision the colors of almost all ONC sources at $\lambda > 7{,}000$ Å (approximately 3500 sources, with an expected 5% of field star contribution in the core and up to 50% in the outskirts). Concerning spectroscopy, in the visible Hillenbrand (1997) obtained spectral types for about 1000 sources that are above the hydrogen burning limit and not too deeply embedded. In general, however, the majority of the cluster members, in particular all substellar objects, remain a very difficult target for visible spectroscopy even at 10m class telescopes. For them infrared spectroscopy is the way to go. We are proposing to perform the definitive IR spectroscopic survey of the ONC using IRMOS at the KPNO 4m telescope.

Coupling our HST photometry with optical and near-IR spectroscopy, we will build the richest HR diagram of pre-main sequence objects ever, nearly free from observational biases and errors. With ~ 2000 points we shall be able to bin sources by location, mass, age, etc. looking for trends that may disclose important clues on the star formation history in this cornerstone region. We will understand if the IMF varies with the distance from the cluster center, or if shows spatial trends that may be traced back to a triggering mechanism. Our preliminary analysis of the HST data indicates a remarkably well defined isochrone in the M43 subregion of the cluster. Is this a distinct episode? We shall also address the distribution and frequency of brown dwarfs, the possible contamination of foreground objects belonging to the older Orion stellar associations, the structure of the inner disk, the mass accretion rates, etc. The proposed survey, combined with the HST Treasury Program, will provide a long lasting contribution to our understanding of star formation.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

The richness and density of the ONC make it an ideal, and unique, target for multi-object near-IR spectroscopy with IRMOS. IRMOS will allow us to reach with 3600s integration time sources at $J, H \simeq 14^m$ with SNR=20 on the continuum and resolution R=1000. The sensitivity in the K' band is lower due to the higher thermal background, but we (IRMOS team) are considering reducing the temperature of the micromirror, with beneficial effects especially in K. In any case, K' may be the band of choice for highly reddened targets. In Orion, objects at $J \simeq 14^m$ are approximately at the hydrogen burning limit assuming a 1Myr old isochrone. Since most of the sources in the cluster are in the 0.6-0.05 $M_\odot$ range, we will optimize our observations for PMS with spectral types from late K to L.

The J band contains a large number of temperature and luminosity sensitive feature. It is the most promising for IR spectroscopy of sources in Orion, since at longer wavelengths the circumstellar emission may become overwhelming. (cfr. Slesnick et al. 2004). The brightest features are the strong KI pairs at 1.169 and 1.177 μm and at 1.243 and 1.252 μm. Their strength increases with later spectral type, but is also highly dependent on surface gravity, becoming fainter with decreasing surface gravity. Therefore their absence may be used to confirm cluster membership.

Among the molecular absorption lines, the FeH feature at 1.20μm, with a bandwidth of 130Å is the most important. This is an excellent index for the M3-L0 spectral types. If weather conditions allow, the H_2O index built upon the 1.34 μm absorption feature is an excellent indicator of low mass spectral types. Its strength decreases with spectral type across the entire range M0-L0, with typical errors $\sim$ 1.54 spectral subtypes. With an equivalent width of 100Å, it remains well measurable also after resampling the spectra for SNR improvement, allowing some extra gain in sensitivity on the faintest objects.

The effects of veiling due to circumstellar material and reddening will be taken into account. Both affect in different ways the band-to-continuum ratios, and can be be easily modeled. Besides, we plan to solve for their effect taking into account the optical color in the I-z band, which is nearly insensitive to stellar variability and veiling.

In the K'-band we will be able to use a molecular absorption features commonly utilized for classification of low mass stars: the very broad absorption feature that affects the spectra from the short-wavelength end of the band at 1.90μm through 2.1μm. The strength of this feature decreases with decreasing spectral type, similar to the behavior in the J-band, with good correlation for objects later than M2.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

a) As explained in the Scientific Justification, the proposed observations represent the ideal complement to the HST Treasury Program on the Orion Nebula Cluster, awarded with 104 orbits of HST time in Cycle 13 and led by the PI of this proposal. The treasury program is supported by an extremely qualified team of co-investigators which includes PIs or co-Is of other major programs on Orion carried out with space or ground-based telescopes. We envision, for example, that the HST+IRMOS results will allow to precisely compare the X-ray luminosity measured with Chandra (COUP) with the stellar bolometric luminosity, or isolate X-ray sources of the cluster from background objects like QSOs. It will also allow to measure the mid-IR excess detected by Spitzer, by removing the contribution of the underlying stellar photosphere.

To complement our HST observations, which saturate at relatively low flux levels, we have also performed a unique ground-based survey of the cluster, obtaining *simultaneous* broad-band imaging in the UBVIzJHK filters using WFI at the 2.2m telescope of La Silla and ISPI at the 4m telescope of KPNO. In this way the photometry at the bright end of the cluster has been measured removing the uncertainties due to stellar variability. The PI, in collaboration with L. Hillenbrand, has also an ongoing program at WYIN to obtain spectra of ONC sources at visible wavelengths.

Finally, we are aware that FLAMINGO has been used in the past to collect data also on the Orion Nebula Cluster. These observations have great interest for us, but we cannot assess at the moment their value in terms of sensitivity, spectral coverage and number of sources. If the Flamingo data become eventually available, we will fine tune our target selection taking into account what has already been done. We remark that with respect to Flamingo, IRMOS offers a much simpler slit positioning system. This provides a substantial increase in observing efficiency with an overall gain in survey speed.

b) We will use for this program funds allocated for the ground support of the HST Treasury program on the Orion Nebula.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

1) One of us (JM) is the PI of IRMOS, and all of us have contributed to the project participating to the commissioning runs at the KPNO 2.1m and 4m in 2005. A few fields in Orion have been observed at the 4m in October 2005 with short exposure times. These data are presently being analyzed (see also Technical Description)

2) We have performed in January 2005 (2 nights) a wide-field JHK survey of the Great Orion Nebula using ISPI at CTIO. One of us (KS) is actively reducing the data. Preliminary results have been presented last summer at the Protostar & Planets V conference in Hawaii.

Observing Run Details for Run 1: KP-4m/IRMOSM

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

During the engineering runs performed in the Fall of 2005, we have probed a number of fields in Orion with relatively short exposure times in a variety of filters. These observations have contributed to the optimization of the IRMOS observing strategy and give us great confidence about the success of this extensive project. Our experience indicates that it is possible to take more than 15 spectra simultaneously with IRMOS, depending on the relative position and density of the sources. Flat field and spectral calibration must be made for each slit pattern immediately after the science data acquisition. With 1hr on source integration time, and accounting for another hour for overheads and calibration, we estimate that 4 fields can be observed per night. We will use our CTIO JHK band wide-area mosaic to fine tune the exact location of our fields, optimizing on the basis of the source brightness, optical and IR color, density, and accepting a mix of objects with and without previous spectral classification. In general, however, we will try to cover an area as wide as possible in order to probe sources in different environments, out of the usual 5×5 arcminutes inner field centered on the Trapezium. Our request is thus for 8 nights, which will allow us to cover 32 fields and probe up to 200 square arcminutes. In what concerns our main targets, the sources in the vicinity of the hydrogen burning limit, the best candidates are stars with J magnitude in the range 13-14 with relatively moderate near-IR colors. We estimate that there are approximately 100 sources across the Great Orion Nebula ($\simeq 30 \times 30$ arcmin field), with significant clustering at the center, that meet these criteria. We should be able to classify almost all of them.

Instrument Configuration

Filters: J,H	Slit: 0.6	Fiber cable:
Grating/grism: 1000	Multislit: yes	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 5 to 5

Dec. range of principal targets (degrees): -5 to -5

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

NOAO observing proposal LaTeX macros v2.12.