A UKIDSS-based search for very low-mass stars, brown dwarfs and planetary-mass objects in outer parts of young star-forming regions

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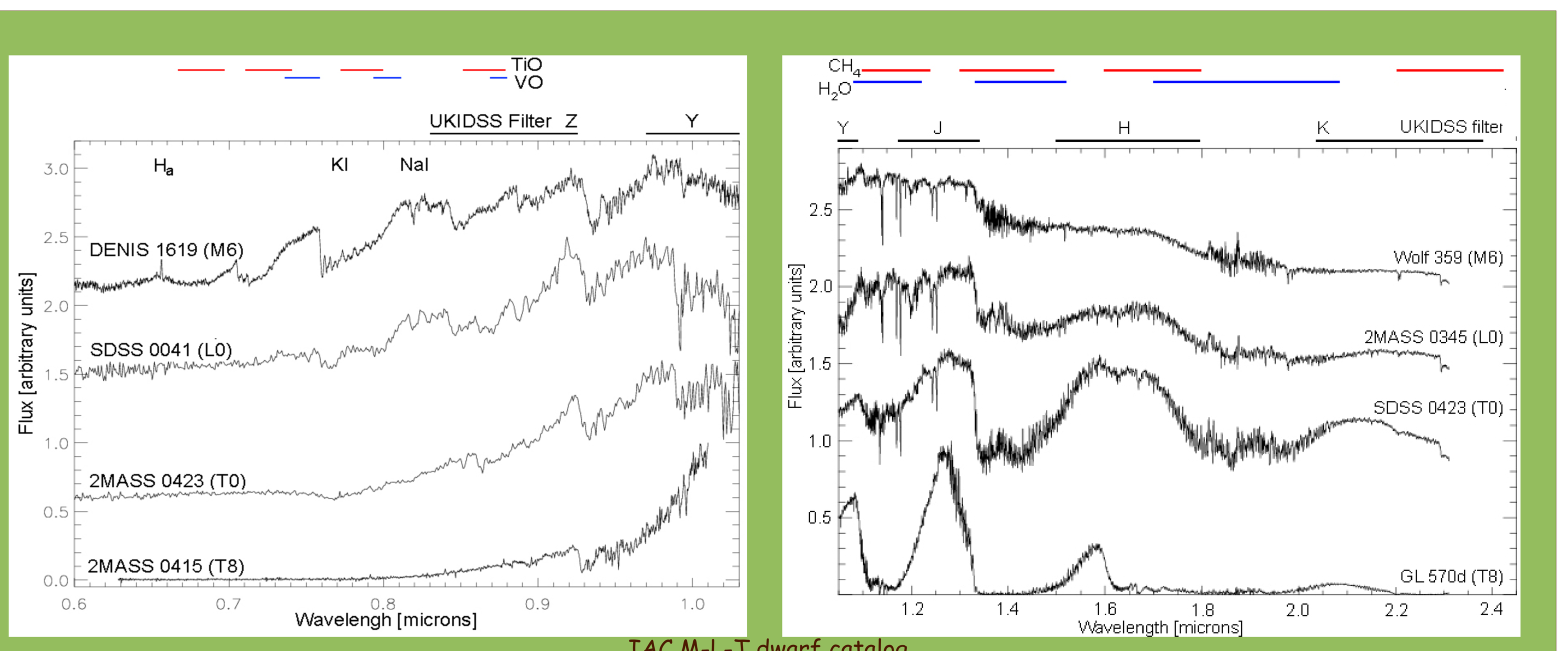
Summary

We have conducted a search for brown dwarfs in yet unexplored parts of Taurus and Orion. Both are very young, nearby and large star-forming regions but show different fractions of substellar to stellar objects, possibly proportional to their different stellar densities. Until today it remains unclear, if the mass function in the low-mass range is universal. Recent star-forming models include the proposition, that brown dwarfs could have been ejected during their birth and should therefore be located further away from the main clusters. Up to date, no searches for brown dwarfs were applied there, neither in Taurus, where a dearth of brown dwarfs is observed, nor in Orion. If we will confirm many low-mass objects, we might contribute to the interesting question for the brown dwarf formation and the form of the mass function. Our candidates have been selected from the UKIDSS Galactic Cluster Survey using photometric criteria. For brighter sources we calculated proper motions, via cross-correlation with 2MASS data, in order to apply membership criteria. After calculating near-infrared extinction maps, we located small stellar clumps in an area in between Orion's main clusters. In Taurus, the GCS covered region remains entirely unexplored until now, except a small part observed with IRAC/Spitzer. There, we found indications for transition disks by constructing the spectral energy distributions from 0.8 to 11.5 µm. Furthermore, we found highly probable long-time variables, possibly connected to binarity or accretion disks. The candidates will be observed by optical spectroscopy and near-infrared imaging, respectively, to assign spectral type, estimate surface gravity and to derive new number frequencies. The observations are on the way on various telescopes.

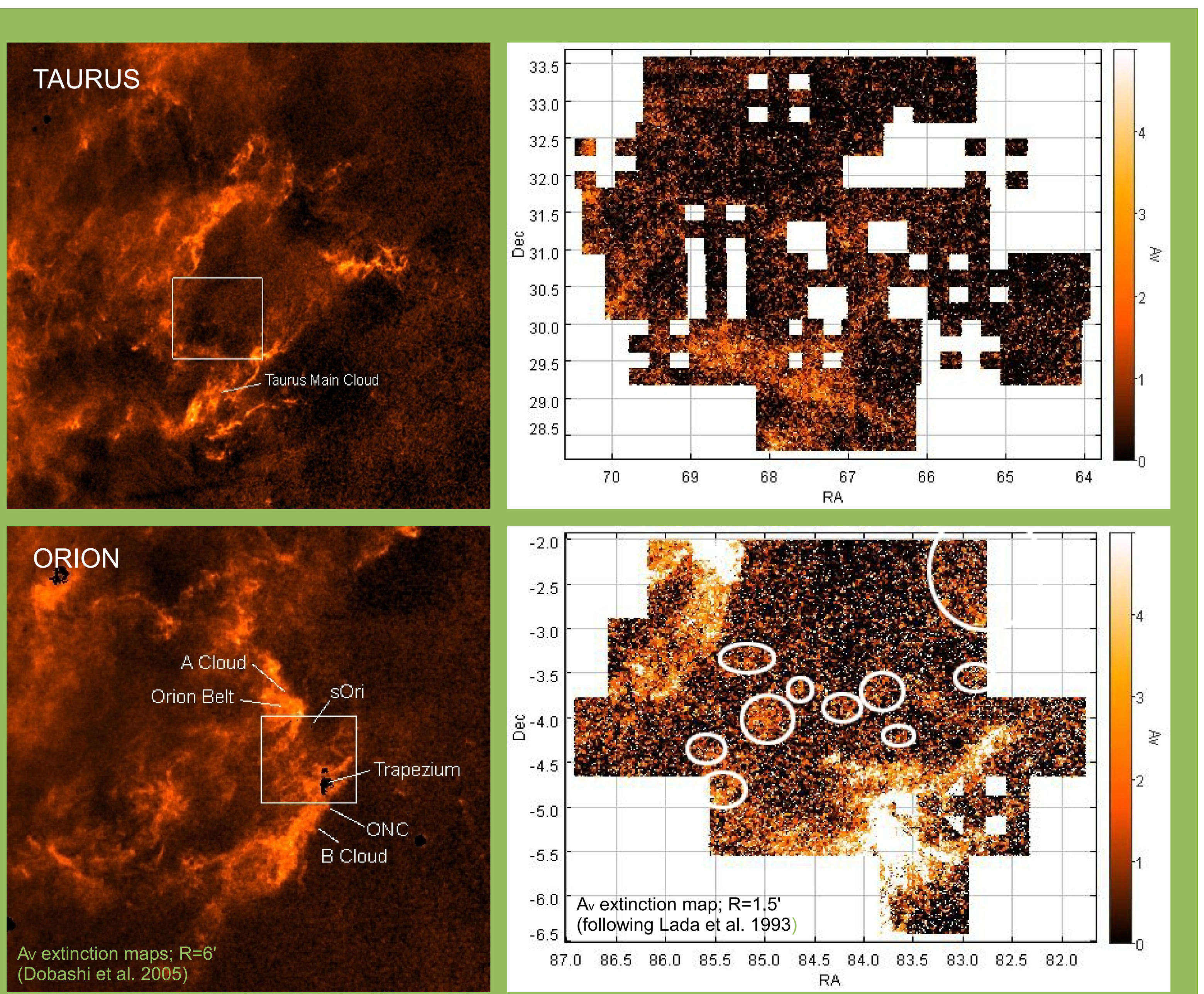
Photometry and Spectra of Brown Dwarfs



IAC M-L-T dwarf catalog

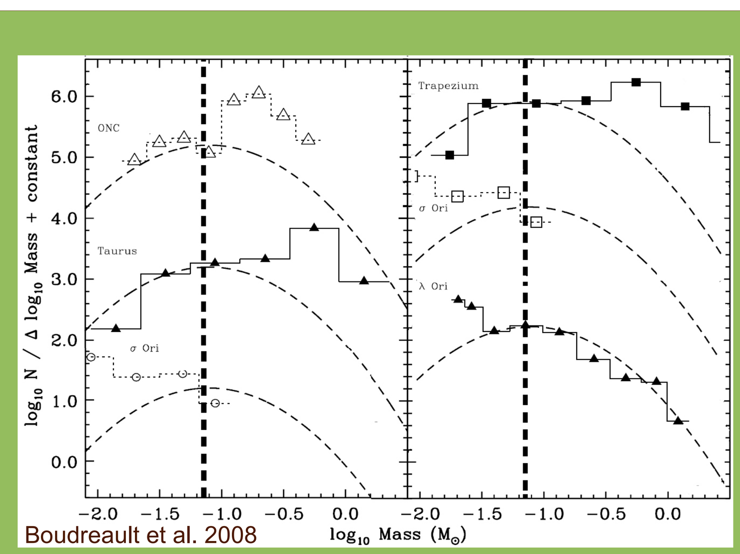
M-, L- and T type brown dwarfs are faint objects with cool and dusty atmospheres and spectra dominated by large absorption bands of e.g. Titaniumoxide (TiO) and Vanadiumoxide (VO; Pavlenko et al. 2005) and masses of 0.072 to 0.013 M_{Sun} (Basri 2000). Generally, they show red near-infrared colors, but as the temperature decreases, the spectra get more influenced by large methane (CH_4) absorption bands until the colors of T type dwarfs turn blue (Pinfield et al. 2008). Large samples are needed to improve the statistical significance of their properties. **The photometric properties form excellent selection criteria for those low-mass objects.**

Taurus, Orion, and the Calculation of Extinction Maps



The Taurus- and the Orion star-forming regions are both very young (~1 Myrs), nearby, and cover huge areas of ~300 deg² (e.g. Perryman et al. 1997). As young dwarfs are brighter and the detection probability therefore higher, extensive searches were already conducted in the main clusters such as σOrionis, Trapezium and the Taurus-Main-Cloud (e.g. Luhman et al. 2006b, Weights et al. 2009). But, in respect to high-density regions such as Orion (1000 M_{Sol}), the low-density Taurus-Auriga star-forming region (250 M_{Sol}) shows a dearth of low-mass objects. On the other hand, the finding of young cluster T dwarfs remains however very scarce with only one yet confirmed object (sOri70; Zapatero Osorio et al. 2008).
To investigate this further, we calculated high resolution (R=1.5') near-infrared extinction maps following Lada et al. (1993). Thereby, we located small stellar clumps inbetween the Orion Belt and the Orion Nebula Cluster. In Taurus the completely unexplored region covered by the GCS is located north of the main cloud. **Our new 'hunting grounds' have therefore remained unexplored until now.**

Brown Dwarf Formation Models



- **A** compression and fragmentation of a dense molecular cloud (Luhman et al. 2007a)
- **B** accretion process interrupted by photoevaporation (Hester et al. 1996)
- **C** ejection by gravitational disk instability or binary disruption (Whitworth & Stamatellos 2006)
- **D** early ejection from its accretion envelope or embryo ejection model (Bate et al. 2003)

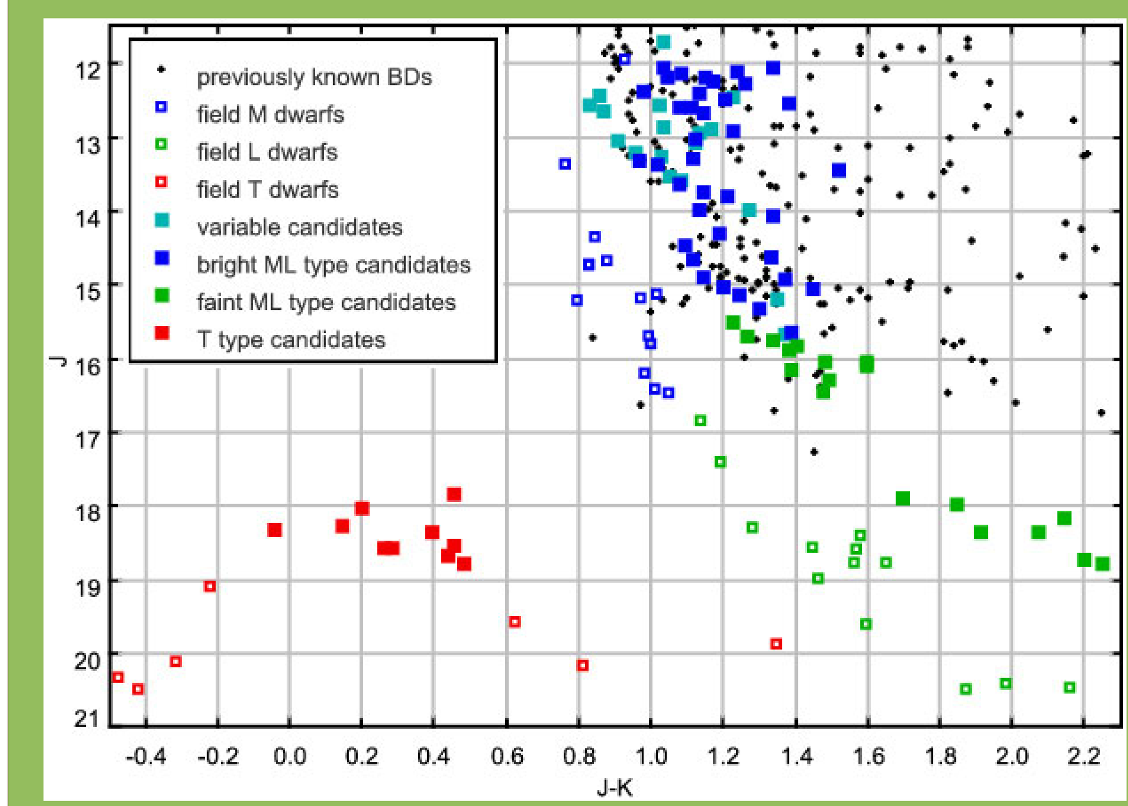
It is discussed controversially, if the BD frequency with respect to stars is proportional to the stellar density of a cluster (e.g. Briceño et al. 2002). It is therefore of key importance to investigate areas away from the main clusters and to constrain a better approximation of their disk and binary frequency.

Data Sets

We use the UKIRT Infrared Deep Sky Survey (**UKIDSS**; Lawrence et al. 2007) for our search, which is a deep wide-field near-infrared survey conducted with **WFCAM** on UKIRT (Hawaii). The project has three world-wide (EDR, DR1, DR2)- and **ESO**-wide releases (DR3, DR4, DR5). One of its three shallow surveys is the Galactic Cluster Survey (**GCS**) which will cover 1000 deg² in ZYJHK filters (Hewett et al. 2006) in ten star-forming regions and open clusters. A typical 5σ completeness limit is J=19.7 mag, 3 to 4 magnitudes deeper than **2MASS** (Cutri et al. 2003). The GCS will also provide second epoch K band data for proper motions. We received JHK-, and partly ZY photometry in regions north of Taurus' main clouds (~30 deg²), and inbetween the Orion Belt and the Orion Nebula Cluster (~20 deg²). For brighter sources we received 2MASS JHK data, which divided our dataset into a bright and a faint sample (J_{2MASS}<15.9 mag). By cross-correlating the two datasets, we calculated proper motions. For ages of 1 to 3 Myrs and distances of 140 pc for Taurus and 450 pc for Orion, the survey reaches until 30 and 45 M_{Jup}, respectively (Baraffe et al. 1998).

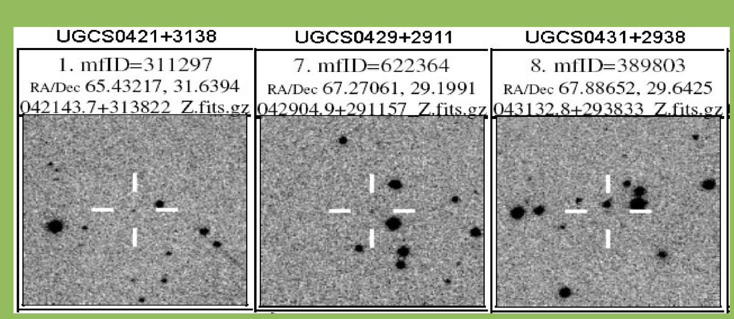
Search Criteria

Proper motion membership for sources sharing same movement as T Tauri stars (Gomez et al. 1992, Kharchenko et al. 2005)

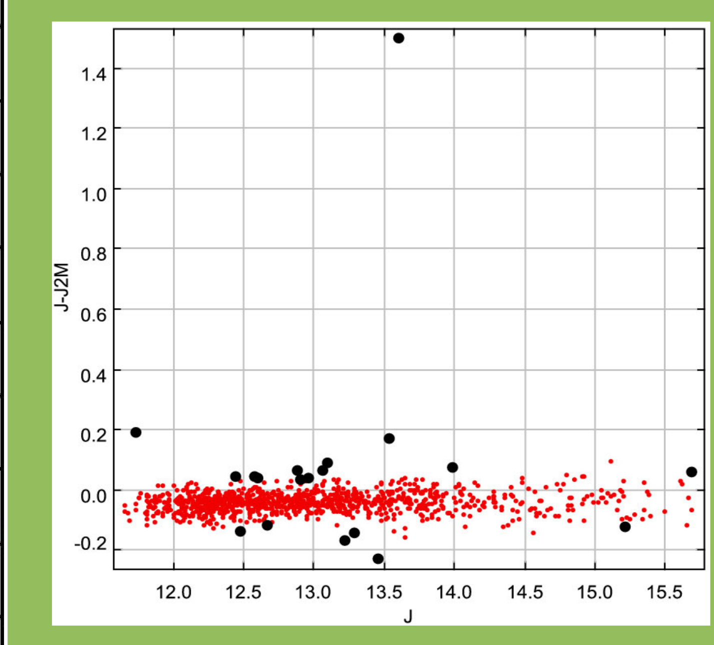


M- and L type dwarfs: location in various color-magnitude and color-color diagrams with respect to known brown dwarfs (e.g. Luhman 2006a, Peterson et al. 2008) and field dwarfs (Hewett et al. 2006) for observed and dereddened magnitudes

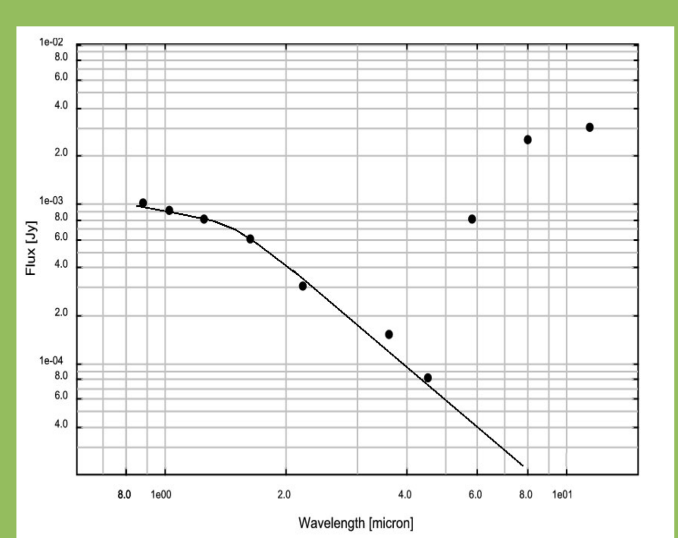
T dwarfs: color and magnitude limits (e.g. Burgasser et al. 2006); YJHK detection, Z non-detection and absence of optical counterparts



Search for misidentification, artefacts and counterparts via UKIDSS, IRAS, CFHT and ROSAT databases



~yearly timescale variability of low-mass objects: J_{GCS}-J_{2MASS} color greater than 3σ (99.5% confidence level) in 0.5 mag bins of J_{GCS}



Transition disks in UKIDSS/GCS-Spitzer/ IRAC overlap in Taurus: spectral energy distributions from 0.8 to 11.3 µm

Results, Future- and Ongoing Work

We selected candidates in yet unexplored regions away from the main clouds of the young star-forming regions Taurus-Auriga and Orion. We have candidates for M- and L type low-mass stars and brown dwarfs and some objects in Taurus showing infrared excess possibly related to transition disks. Those candidates will be observed with **optical spectroscopy** at **CAHA/CAFOS**, **CAHA/TWIN**, **NOT/ALFOSC**, **GTC/OSIRIS** and **VLT/FORS2**. We will be able to assign spectral type, confirm membership and to measure the equivalent width of the KI and NaI doublets (proxy of surface gravity; Martin et al. 2004). As well, we can detect variability by measuring the Hα emission line (e.g. Barrado y Navascues et al. 2004) indicating chromospheric activity or the presence of a companion. Additionally, we have T type brown dwarf candidates and various sources showing indications for long-term variability. We will observe those objects with **near-infrared imaging** at **CST/CAIN3** and **WHT/LIRIS**, calculate the H-CH_4 color (Tinney et al. 2005) and access new photometry in month-separated epochs. The relation between variability and accretion disks will be proved. If confirmed as bona-fide T dwarfs those candidates will be observed later spectroscopically. Thereby, we might discover the first T dwarf in Taurus! With the observations we will be able to derive the masses and ages of the sources and access new number frequencies with respect to stars. We can investigate the form of the low-mass luminosity and mass functions and compare them to other star-forming regions. But over all, we are interested in probing recent star-forming models. This work combined with what is known in the literature will provide a general picture of the results of the star-forming processes in large areas of Taurus and Orion. We plan to pursue this program to extend in coverage and in depth previous studies in those benchmark star-forming regions from high-mass brown dwarfs down to planetary-mass objects.

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