Mid-IR emission of circumstellar disks in the Orion Nebula

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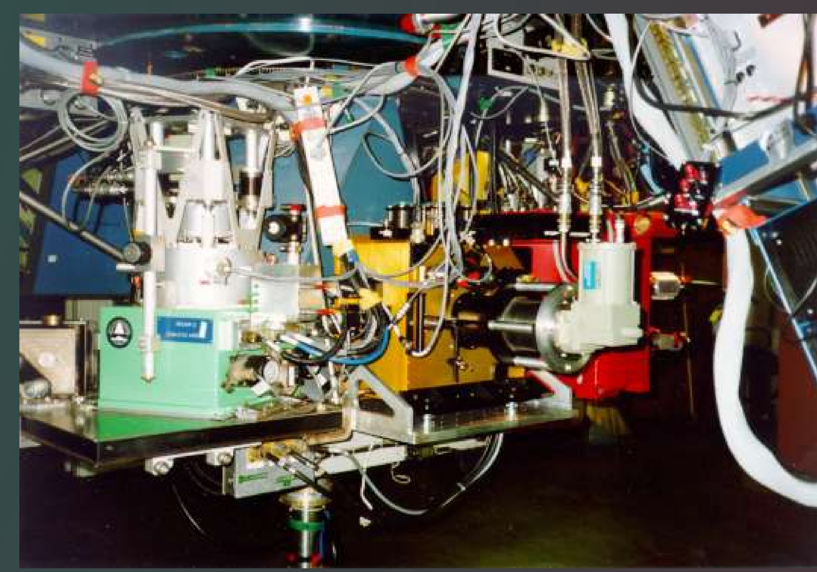
ABSTRACT

We present results from an extensive study of the Orion Nebula at mid-IR wavelengths perfomed with the MAX camera on UKIRT. The data include spectacular wide field mosaics at 10 and 20 micron and deep images of selected fields. A new model addressing the effects of the nebular environment on the disk thermal emission is also presented.

MAX on UKIRT



The data presented in this poster have been collected at the UKIRT telescope using MAX, a MID-IR camera developed at MPIA in Heidelberg.

MAX is equipped with a Rockwell Si:AS BIB 128x128 detector array. The optics deliver a scale of ~0.27arcsec/pixel and ~34x34 arcsec field of view.

MAX benefits from the tip-tilt secondary mirror of UKIRT and reaches routinely diffraction limited performances at wavelengths longer than 8micron.

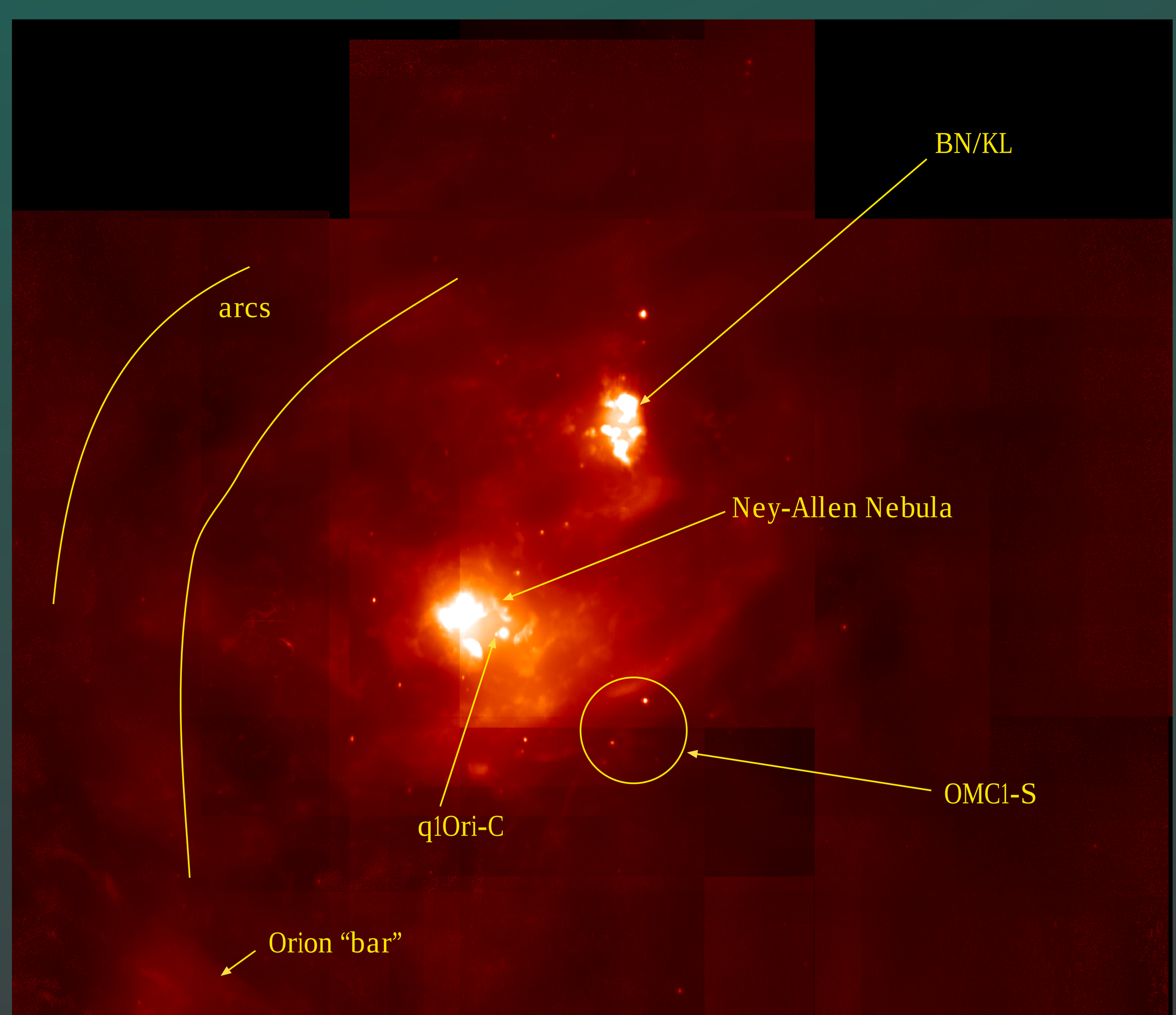
First light of MAX occurred in November 1995. Since then, MAX has been operated for ~100 nights until the last run in November 2000.

For more information see Robberto and Herbst, Proc. SPIE 3354, p.711 (1998).

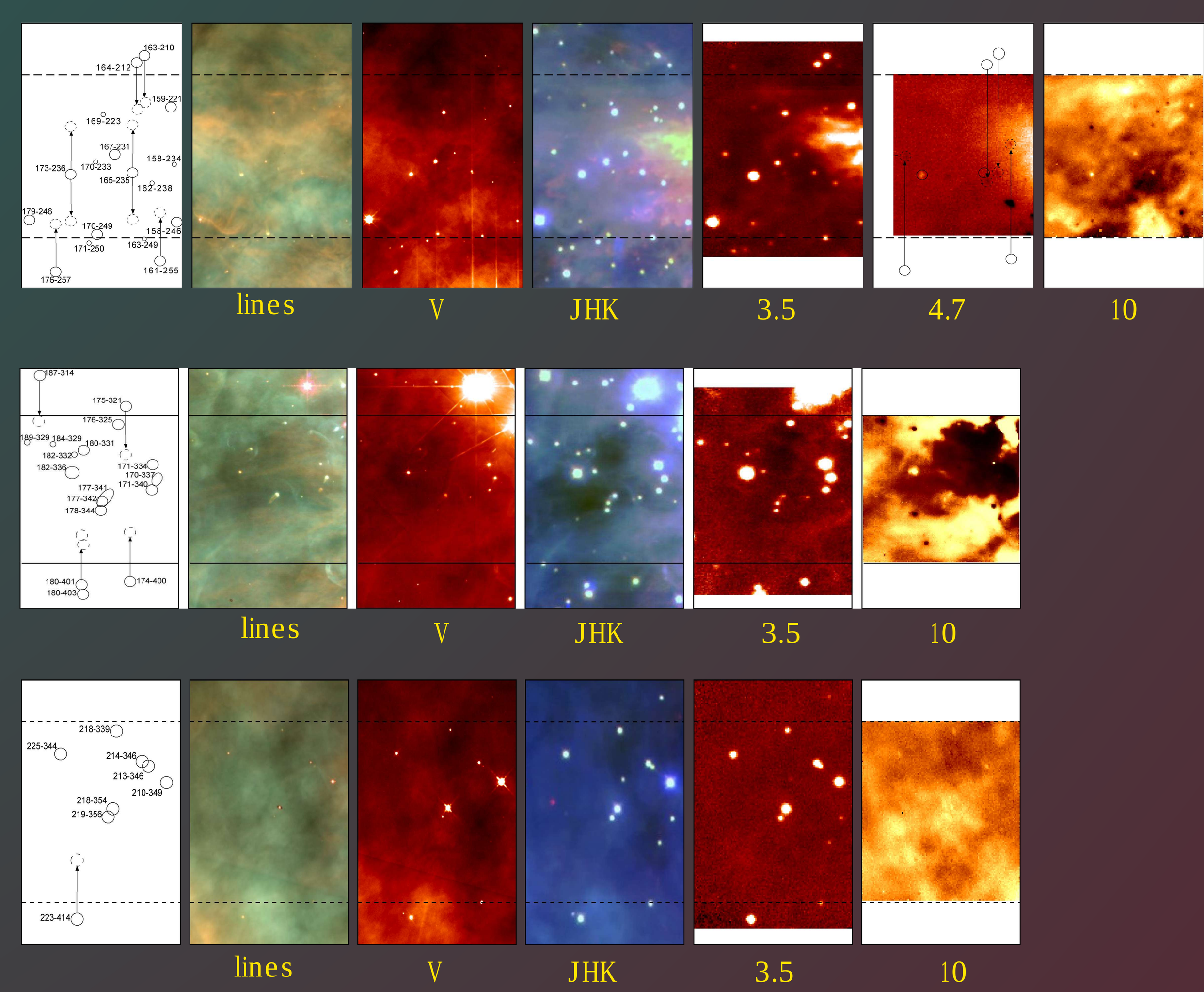
1. Wide field imaging of the Orion Nebula

We imaged the Orion Nebula at 10 and 20 micron in order to search for sites of star formation embedded in the underlying molecular cloud, and to obtain the first sub-arcsecond map of warm dust in a HII region.
To attain the highest sensitivity we did scans with the standard chopping and nodding technique. The chopping throw of the UKIRT telescope, constrained by the range of the secondary mirror adaptive actuators, is limited to 30". In the case of a bright and extended source like the Orion Nebula, this small amplitude introduces negative counterparts due to the presence of the source in the offset beam. We have developed a new restoration method based on the projected Landweber method, which iteratively searches for the positive solution of minimal norm in the space of possible solutions. To eliminate a number of artifacts originated by the mathematical structured the problem, multiple images with different chopping throw and orientation must be taken and recombined (see Bertero, Boccacci and Robberto, PASP 112, 1121 (2000))

The image we are presenting, still preliminar, has been obtained at 10micron and shows a ~5'x5' field centred between the Trapezium and BN/KL. It has been produced by combining three mosaics taken in December 1999 and November 2000 under excellent weather conditions. Total integration time is ~5min. The image is dominated by the Ney-Allen Nebula, in fact a system of arc-like structures pointing to q1C, and of BN/KL. We detect several point sources, most of them previously identified at shorter wavelengths. A number of sources are new and represent deeply embedded objects in the OMC1 cloud. In particular, we identify a group of IR sources ~100" S of BN, in correspondence of the OMC1-South peak. Two large arc of emission encircle the nebula to the E, possibly tracing the ionization front.



2. Deep survey of selected fields



We obtained deep 3.6 (with TUFTI), 4.7 and 10.1micron images (with MAX) of 9 fields centered on a sample of prominent dark silhouettes and photoionized clouds in the Orion Nebula.

A total of 49 sources has been detected at 10micron, corresponding to ~1/3 of the cluster members falling within our fields, with detections down to the M5 spectral type. All sources have been cross-identified using data from O'Dell and Wong (1996), the most recent version of the Hillenbrand (1997) and Hillenbrand et al. (1998) tables, and the H- and K-bands survey of Hillenbrand and Carpenter (2000).

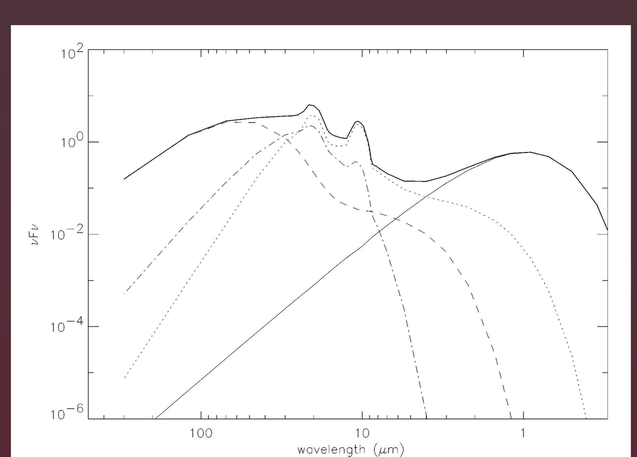
In most cases, the observed thermal emission is in excess with respect to the stellar photosphere. Sources with mid-IR excesses are statistically compatible with a typical sample of the cluster population. Our data provide conclusive evidence that YSO's in Orion are normally surrounded by disks.

Spectral types are known for 45 mid-IR sources. This allows us to search for correlations between the disk emission and both the observed (e.g. luminosity, effective temperature, extinction) and inferred (e.g. mass, age) stellar parameters (Robberto et al., in prep.).

The images presented to the left represent 3 fields in the Orion Nebula. From top to the bottom:
1. The field centered on the prominent photoionized proplyd 177-341 (HST1), in the vicinity of the Trapezium stars.
2. The field centered on the dark silhouette disk 167-231
3. The field centered on the dark silhouette disk 218-354.
From left to right, the images represent the identification map, the HST emission-line composition, the HST V-band image, the Subaru JHK image, and the TUFTI/MAX mid-IR images.

3. The IR SED of disks in a HII region

We have modelled the infrared flux emitted by a circumstellar disk embedded in an HII region photoevaporated by an external source of ionizing radiation.
The model applies to the proplyds in the Orion Nebula, most of which are illuminated by q1Ori-C. We assume the disk surrounded by a spherical, homogeneous dusty globule that thermally re-radiates the energy absorbed from the disk central star and from the nebular environment. The disk model is based on the model of Chiang and Goldreich (1997), and treats the hydrostatic and radiative equilibrium of passive (non-accreting) reprocessing disks in a self-consistent fashion.
The inner disk, emitting in the far-infrared, is encased between two optically thin layers of superheated dust grains. We improve over the treatment of Chiang and Goldreich by following the propagation of the various radiation fluxes (ionizing, Ly-a and grazing from the disk's central star) through the thin layer. We distinguish between the disk's side facing the ionizing source and the other side exposed to the nebular flux only, mostly Ly-a.
The presence of ionizing radiation causes the disk flaring angle to be different on the two sides of the disk. The resulting geometrical distortion has clear signatures in the resulting spectral energy distribution. Depending on the optical depth of the envelope, the ionizing photons are absorbed in the envelope before reaching the disk or at the disk surface. In both cases the heated dust produces a peak of emission at mid-IR wavelengths. This may explain the high fraction of 10micron sources we have recently found in the Orion nebula.

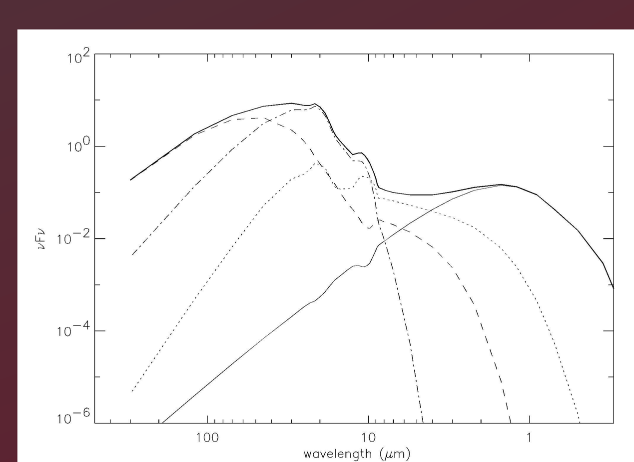


envelope radial optical depth t=0.3

Calculated SED of a proplyd in the Orion Nebula.
The main parameters are:

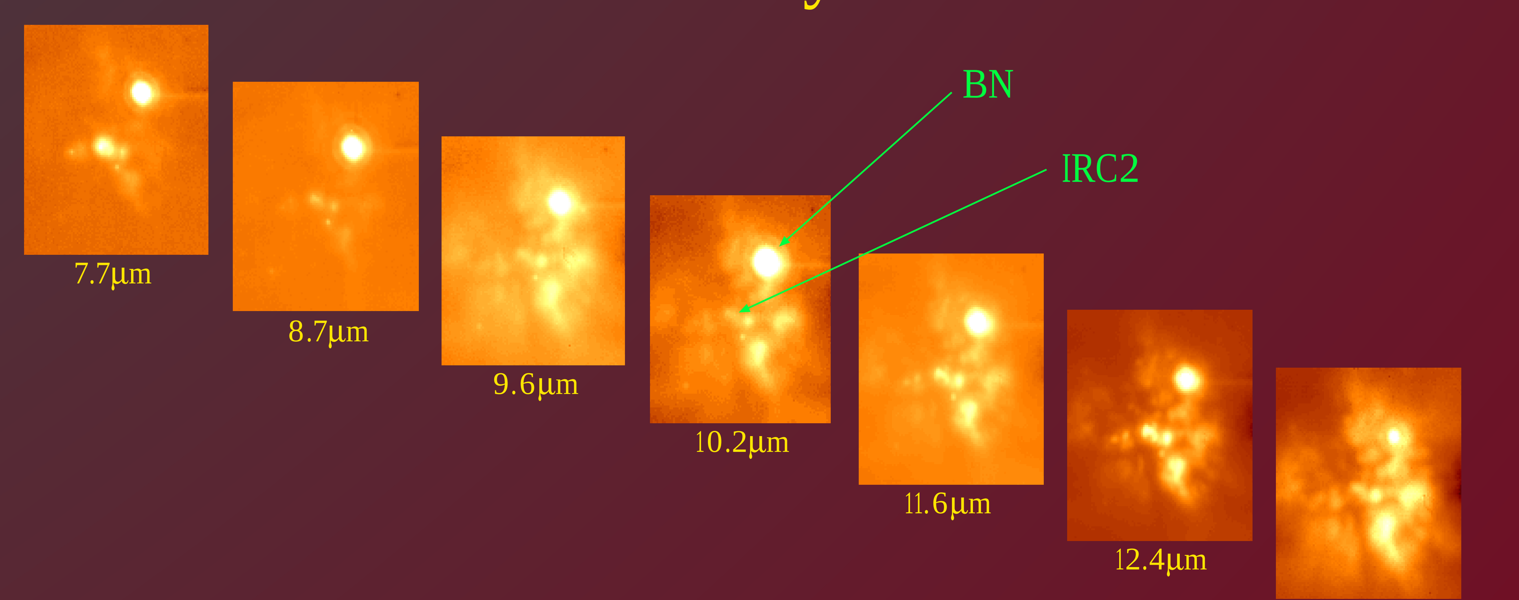
distance from q1C: 40arcsec.
disk tilt angle with respect to q1Ori-C: 30deg
Tstar=4,000 K
Rstar=2.5Rsun
Mstar=0.5Msun
outer disk radius=100 AU
inner disk radius=0.1 AU
Observer view: front side, 30deg tilt

Legend:
continuous line: stellar photosphere
dotted line: disk atmosphere
dashed line: inner disk
dot-dashed line: ionized envelope (dust emission)



envelope radial optical depth t=3

4. A case study: IRC2



We have collected a remarkable set of mid-IR images of the Becklin-Neugebauer/Kleinman-Low (BN/KL) region. The images show a number of structures either entirely new or previously detected at shorter wavelengths. In particular, we resolve the source IRc2 into a clumpy structure comparable to the four components resolved at 3.8micron by Dougados et al (1993). We also detect to the south-west of the KL nebula a striking group of equally spaced knots aligned on a circle centred on the IRc2/IRc7 sources. Our data suggest that IRc2 traces the northern edge of a dense equatorial toroid surrounding a deeply embedded central source, most probably associated with the compact HII region detected at radio wavelengths. This is in agreement with the most recent molecular line maps, and is predicted by radiative transfer models of IR radiation from massive, optically thick disks.
The estimates of the IRc2 luminosity based on mid-IR color temperature cannot provide reliable results. Our data support a scenario in which the BN/KL region is a cluster of embedded young stars experiencing a major mass outflow episode from one of its members located in the vicinity (south of) IRc2. The outflow axis is oriented at P.A.~160 deg. and is tilted with respect to the line of sight with the northern side pointing toward us. The outflow is poorly collimated, and is currently eroding the confining circumstellar toroid, with streams of material close to the equatorial plane visible even at mid-IR wavelengths.