Classification and Analysis of Ophiuchus YSOs from IRS Spectra

M. K. McClure (U. Michigan), D. M. Watson (U. Rochester), E. Furlan (JPL, Caltech), P. Manoj (U. Rochester), K. Luhman (Penn State), W., Forrest (U. Rochester), N. Calvet, C. Espaillat, L. Hartmann (U. Michigan)

Sample and Classification

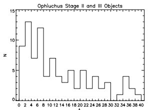
Ophiuchus

Distance	120 pc, radial extension
Age	core 0.3-1Myr, surface population ~2 Myrs
Av	>50 mag in the core
Clouds	L1688 (main), L1689, L1709
Size	5 deg^2, <1 deg^2 for each cloud

(Loinard et al. 2008; Luhman & Rieke 1999; Wilking et al. 2005; Wilking & Lada 1983; Rydgren, Strom, & Strom 1976)

Sample

Spatial distribution of our sample of 136 objects with a histogram of the extinction toward the Stage III & II objects (median A_V=10.2).



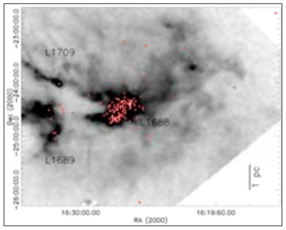
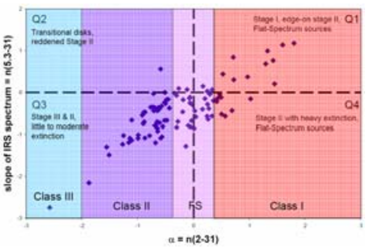


Image Credit: COMPLETE 2MASS extinction map

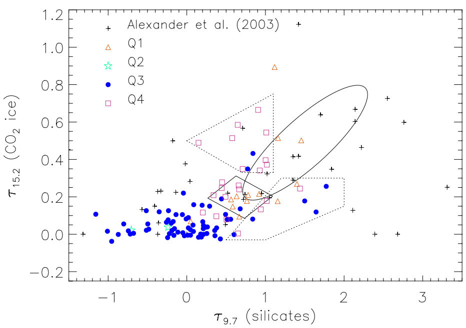
Classification

Traditional observational "classes" base on the slope from 2-25 μm, α, do not distinguish between intrinsically red objects and objects extinguished by line-of-sight extinction, including geometry effects. Robataille et al. (2006) suggest classifying objects with their known evolutionary "stage" as well as "class". We adopt a two step approach to arrive at the "stages" of our objects.



First, we compared the slope over the IRS spectrum, n(5.3-31) with α calculated from 2-31μm.

Then, we calculated the optical depths of silicates and CO_2 ice. Objects that we would classify as Stage II and III seem to cluster near the (0,0) and in prongs on either side, FS sources are indicated by the solid box, Stage I by the solid ellipse. Dotted lines delineate objects with anomalously high ice or silicate optical depths.



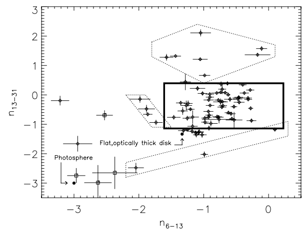
Abstract

We present the results of our guaranteed-time IRS survey of the Ophiuchus star forming region, which includes objects in the heavily embedded core region, L1688, and a smaller subset of objects in the other clouds and off-core regions. Analysis of young stellar objects is complicated by extinction along the line of sight and the inclination of each object. Using optical depths of the silicate and ice features, as well as the n2-31 and n5.3-31 micron spectral indices, we classify these objects by evolutionary stages. To apply extinction corrections to the Stage II and III objects, we determine empirical extinction curves for Av = 3-47 based on IRS spectra of K giants behind star forming regions. For Av<8 the curves lie close to the Mathis (1990) extinction curve, but for Av>8, they lie closer to the Weingartner & Draine (2001) Rv = 5.5 case B curve, a result which is consistent with that of Flaherty et al. (2007). After applying extinction corrections to the Stage II and III spectra, we determine spectral indices for each stage, study other indicators of disk evolution and discuss emergent trends.

Results

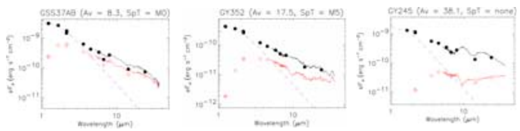
Stage II/III

To identify interesting objects, we computed the n(6-13) and n(13-31) indices described in Furlan et al. (2006) (see below). The solid box represents the area covered by the D'Alessio et al. (2006) accretion disk models. The dotted lines enclose outliers. Side note: most of the sources with n(6-13) < -2.3 are Stage III sources.



Examples

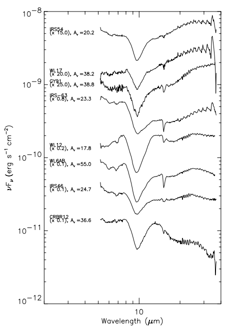
The following are examples of spectra that we classified as Stage II and that lie inside the box covered by the D'Alessio models. Objects that are outliers are discussed in other posters/presentations (E. Furlan, P. Manoj). Red data are original, while black data have been corrected for extinction.

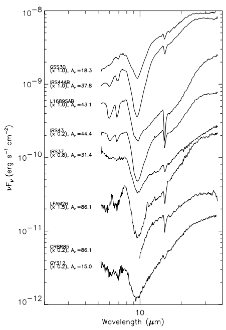


Flat Spectrum

Stage I

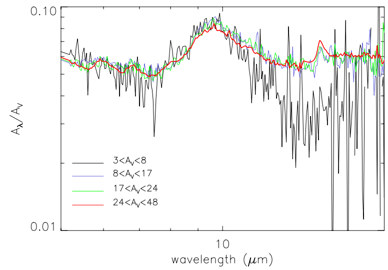
The plots below contain the flat-spectrum and Stage I sources in our sample. Potentially, some of these could be edge-on Stage II disks, but most of those should have been culled through the classification process.





New MIR Extinction Law and Correction

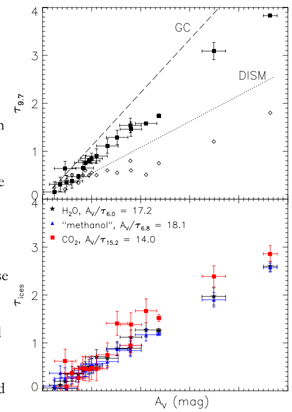
To correct our targets for extinction, we derived new median MIR extinction curves from G0-M4 III stars behind molecular clouds with A_V between 3 and 48 mag. They are shown separated into bins of Av below. **Importantly, the shape of the extinction curve changes with A_V!**



To compare the shape of the silicate feature with others found in the literature, we calculated the optical depth, $\tau = -\ln(F_{source}/F_{continuum})$.

Top: Total optical depth of the 9.7 μm silicate absorption feature. The data are well fit with $A_V/\tau_{9.7}$~12.5, between 18 for the ISM and 9 for the galactic center. Data from Chiar et al. 2007, calculated relative to the continuum absorption, are plotted as diamonds.

Bottom: Total optical depths of the 3 ice absorption features. These optical depths correlate with the difference between $\tau_{9.7}$ we calculated and that calculated by Chiar et al. (2007). Possibly signify coagulated ice-coated grains.



Comparing this new extinction curve with others from the literature, we see that our extinction curves are in excellent agreement with IRAC extinction curves for molecular clouds! Our extinction curves seem to be in transition between a more standard ISM curve and the observed IRAC curve. Significantly, Chapman et al. (2008, accepted) see this change in more detail at lower extinctions. Note: WD01 refers to Weingartner & Draine (2001).