



YSOVAR: Variability in ρ Oph



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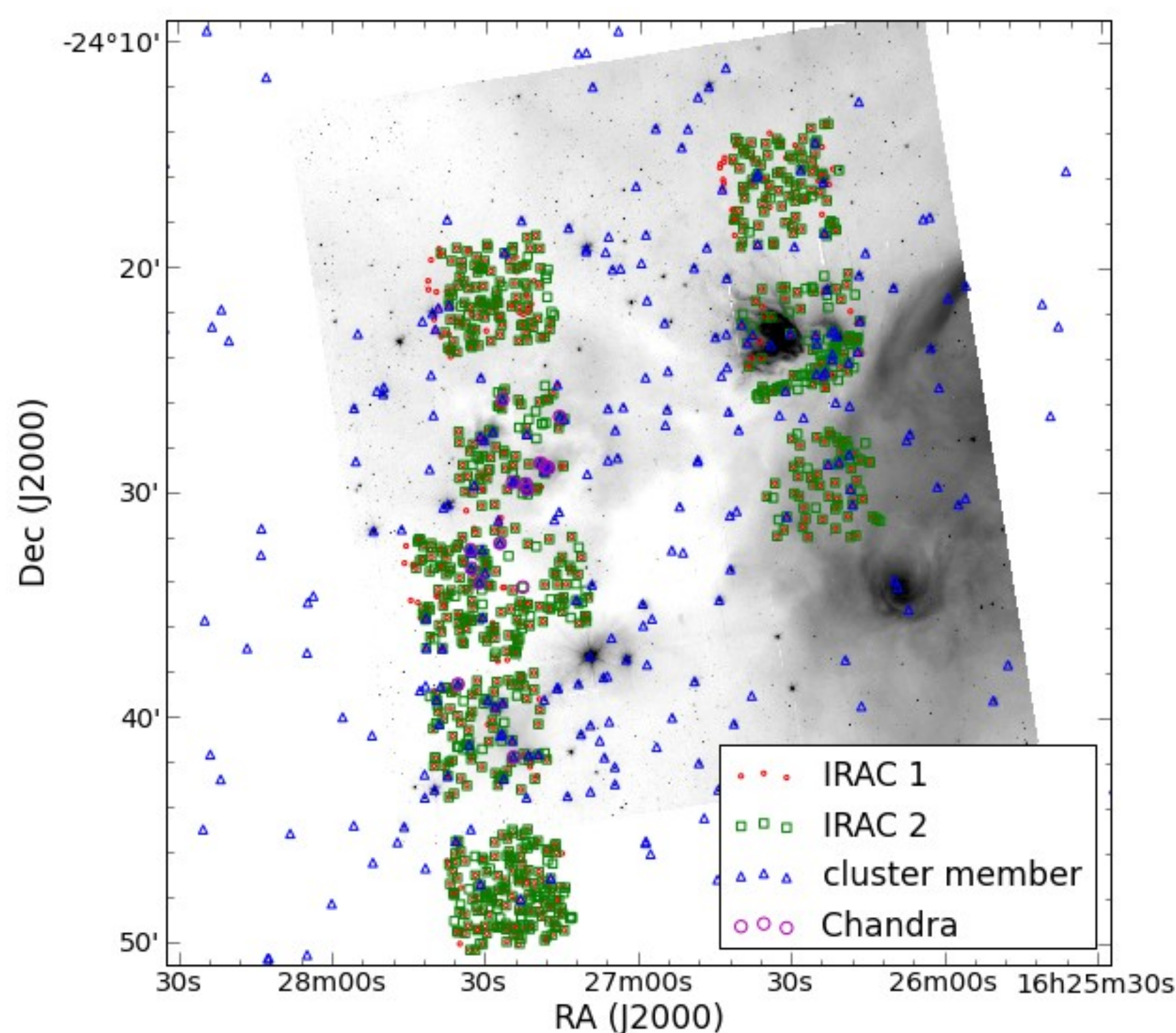
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YSOVAR: Young Stellar Object VARIability

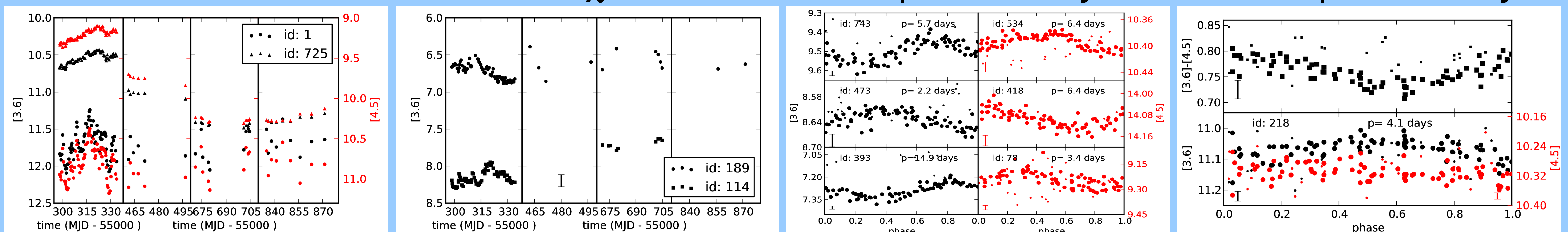
The YSOVAR project (Morales-Calderon et al. 2011) monitored about a dozen star forming regions in 3.6 μ m and 4.5 μ m using the warm mission capabilities of *Spitzer*. The sampling varies with the region, but most star forming regions were observed 50-100 times, on scales of hours to months. Here, we present results for the L1688 cloud in ρ Oph.



Young stellar objects (YSOs) are intrinsically variable on a wide range of time scales and in almost all wavelength regions. In fact, YSOs were originally discovered by their optical variability. The sources observed in L1688 can be divided into several groups by their SED (class I, flat-spectrum (F), II and III) or by the properties of the lightcurve. We show examples of variable lightcurves as classified by the Stetson index (Stetson 1996), a χ^2 test and a period-finding algorithm. The time evolution for each source can be traced on the color-magnitude diagram and this allows us to distinguish variability caused by changes in accretion or extinction or by spots on the star. We show how the variability changes in the IR through different stages of YSO evolution. Since the L1688 cloud is near-by and much better studied compared to other clusters monitored by the YSOVAR project, we can take advantage of the reasonably complete membership list (Wilking et al. 2008) and present an almost complete census of the IR variability in a young cluster. We find that YSOs are variable in the mid-IR as long as they have disks (class I, F and II), but in the class II stage the variability is already much weaker. Most stars are variable due to variable extinction, but for young stars we also see variable accretion.

Left: Sources observed in L1688 by the YSOVAR project. Sources with at least 5 points in the lightcurve of IRAC1 and IRAC2 are marked, those which are detected by *Chandra* as well are highlighted. The background image is an inverse gray-scale IRAC1 image from the *Spitzer* cold mission. For comparison we also mark cluster members (Wilking et al. 2008).

Exemplary lightcurves of variable objects, where variability is found by: Stetson index >0.9 red. $\chi^2 > 5$ periodicity color periodicity

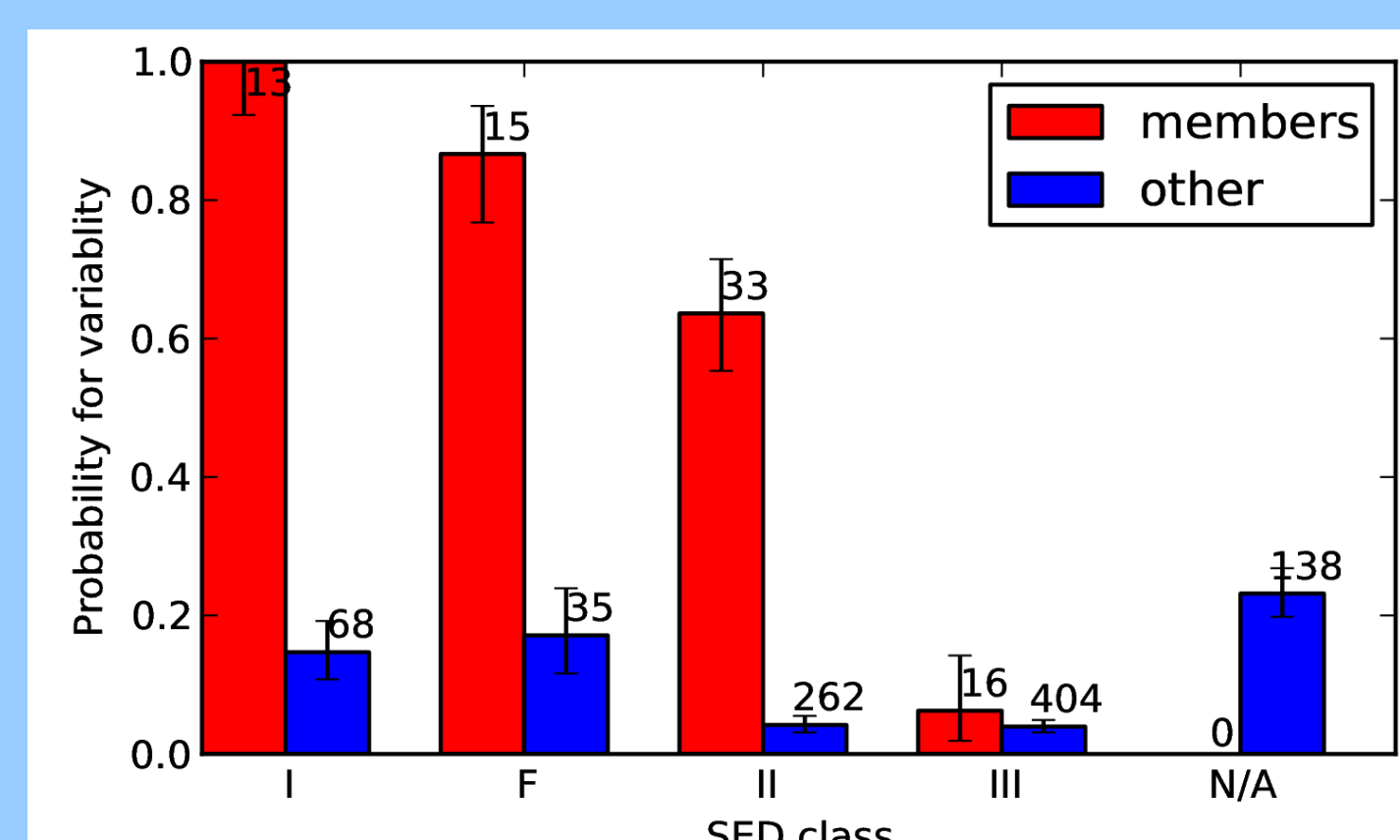


Lightcurves for exemplary sources. Data for [3.6] are shown in black, for [4.5] in red. Errorbars are indicated, if larger than plot symbols. Periodic sources: Large dots are datapoints taken in the first season, small dots are observed at other times.

The Stetson index measures correlated variability in two bands. We use a χ^2 test, if only one band is available. Variability is seen within one season as well as between seasons.

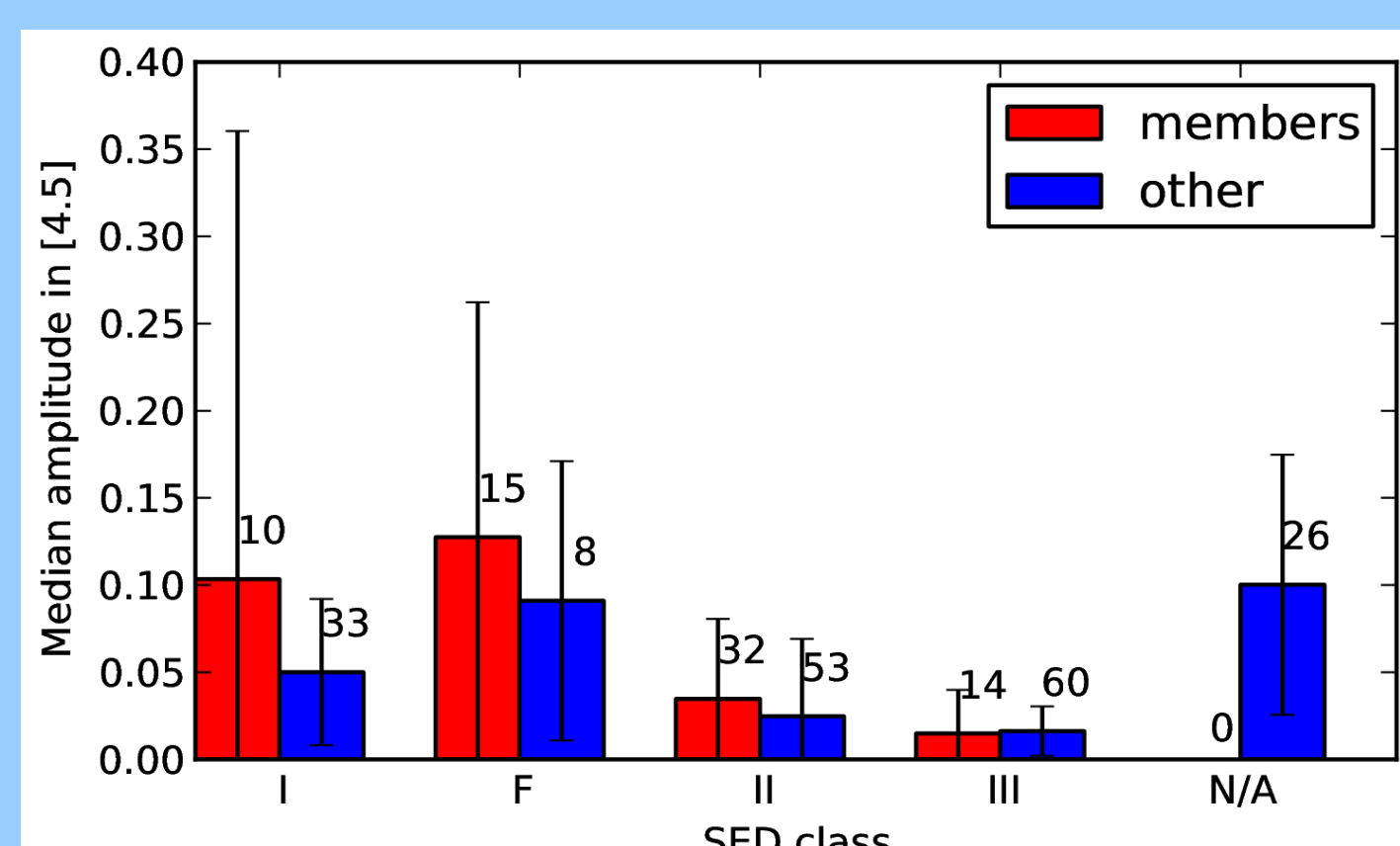
Right: Lightcurves for source 218 in each band separately (bottom) and as [3.6]-[4.5] color (top), folded by the period. The periodicity is best seen in the color lightcurve.

Younger sources are more often and more violently variable



Fraction of variable sources in each evolutionary class. Classes are determined from the slope if the spectral energy distribution (SED). The numbers give the total number of sources in that class.

Basically, sources are IR variable, as long as they accrete from their disk (classes I, F and II).

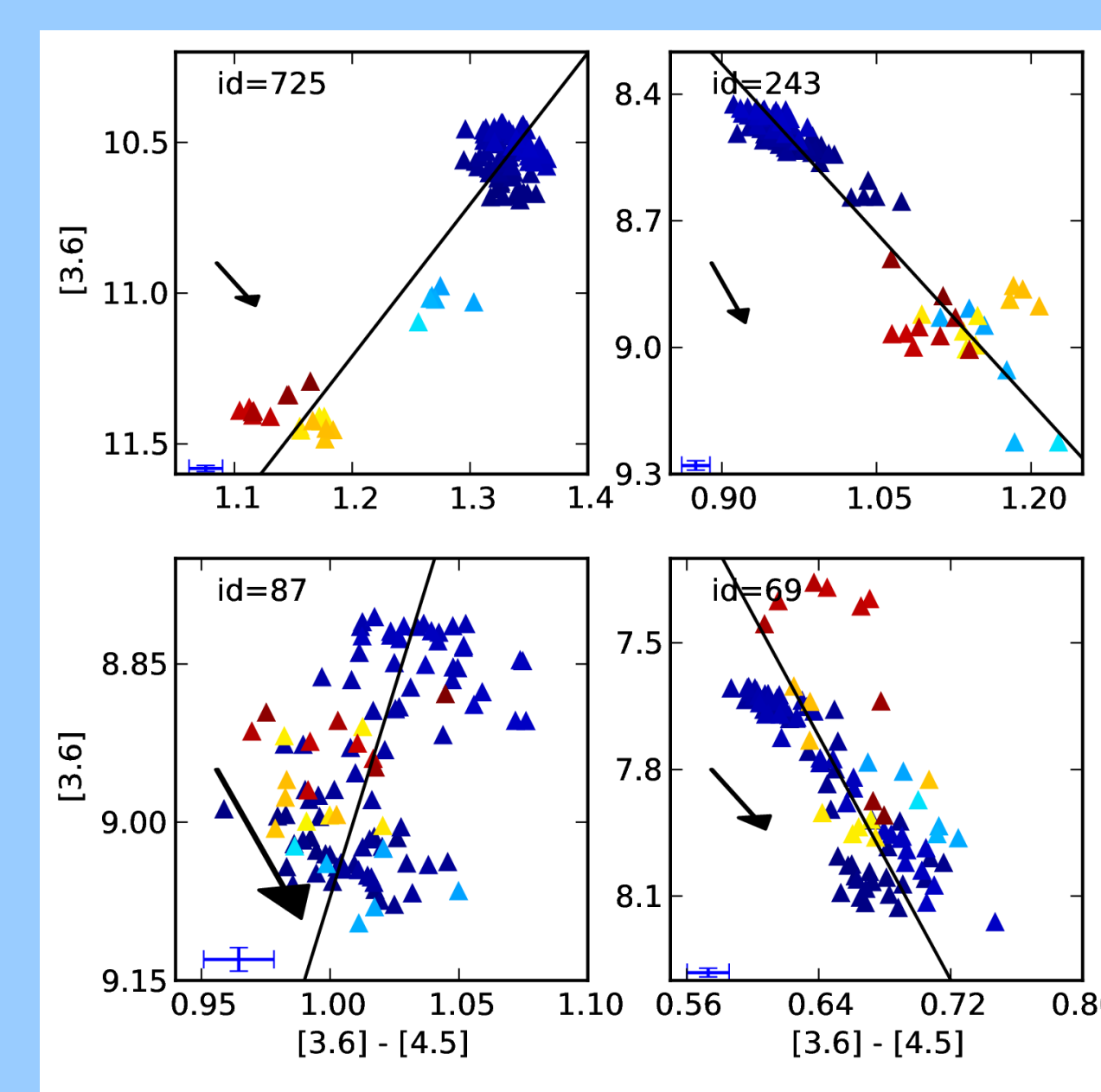


Median amplitude of lightcurves in each class. The value for the amplitude is the difference between the 10% and the 90% quantile for each lightcurve. The errorbars show the standard deviation of the amplitude.

The numbers give the total number of sources in that class. The variability is strongest for sources with massive, young disks (classes I and F).

YSOs are IR variable as long as they have disks, but the amplitude decreases with disk mass

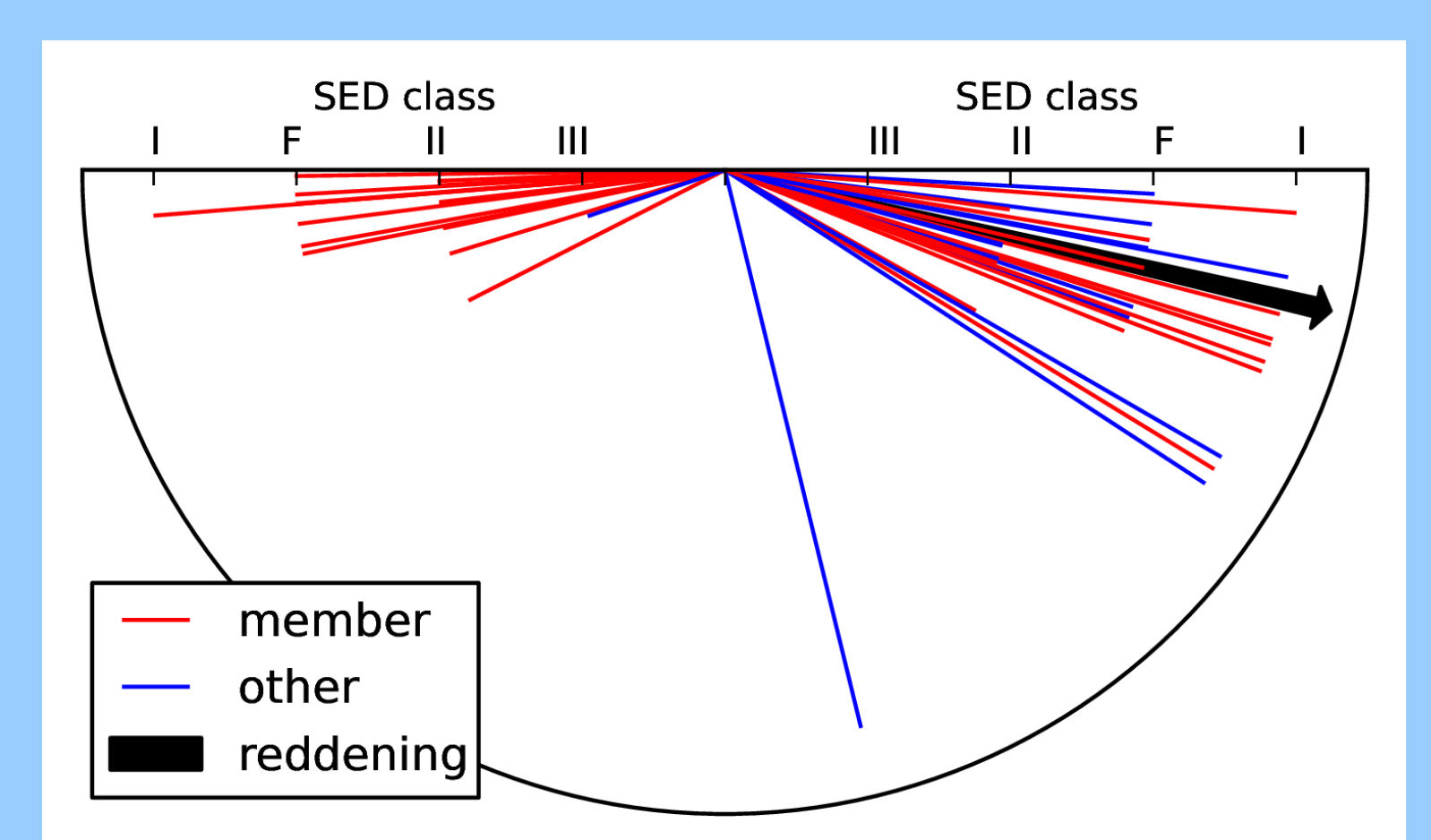
Variable extinction or accretion?



Color-magnitude diagrams (CMDs) for exemplary sources. Symbols in different color are from different seasons. The arrow shows $A_K = 0.2$ mag.

Color variability can happen both between seasons (top) or within a season (bottom).

Some sources show a slope in the CMD that is close to ISM reddening (right), others appear more blue when they faint (left).



Angles of the best fit slope (black line in the left figures, note that x and y axis have different scales in those plots) in the CMD. The length of each line marks its class.

The black arrow indicates the ISM reddening slope. Non-member sources and most members cluster around this slope in the CMD, indicating that their color changes are caused by variable extinction. In contrast, only cluster members have slopes where the source becomes more blue as it fades.

Class I: extinction
Class II: Either / or (but not both)