



# YSOVAR: Variability in $\rho$ Oph



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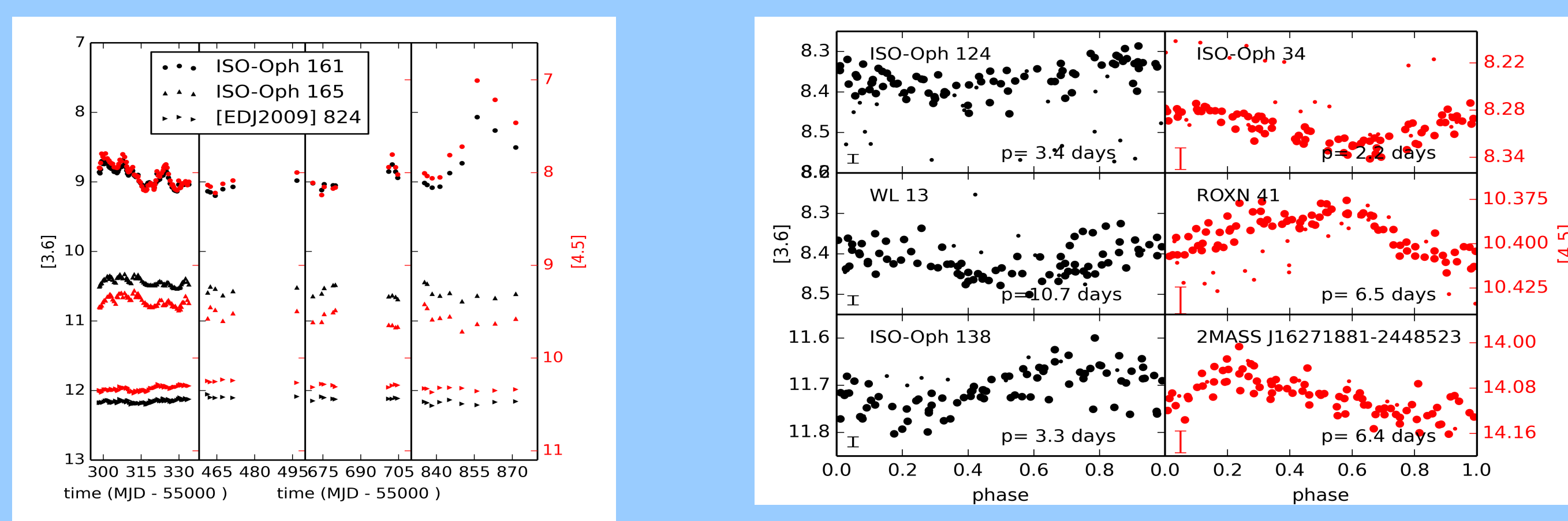


## YSOVAR: Young Stellar Object VARIability

The YSOVAR project (Morales-Calderon et al. 2011, Rebull et al. in prep) monitored a dozen star forming regions in 3.6  $\mu$ m and 4.5  $\mu$ 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  $\rho$  Oph.

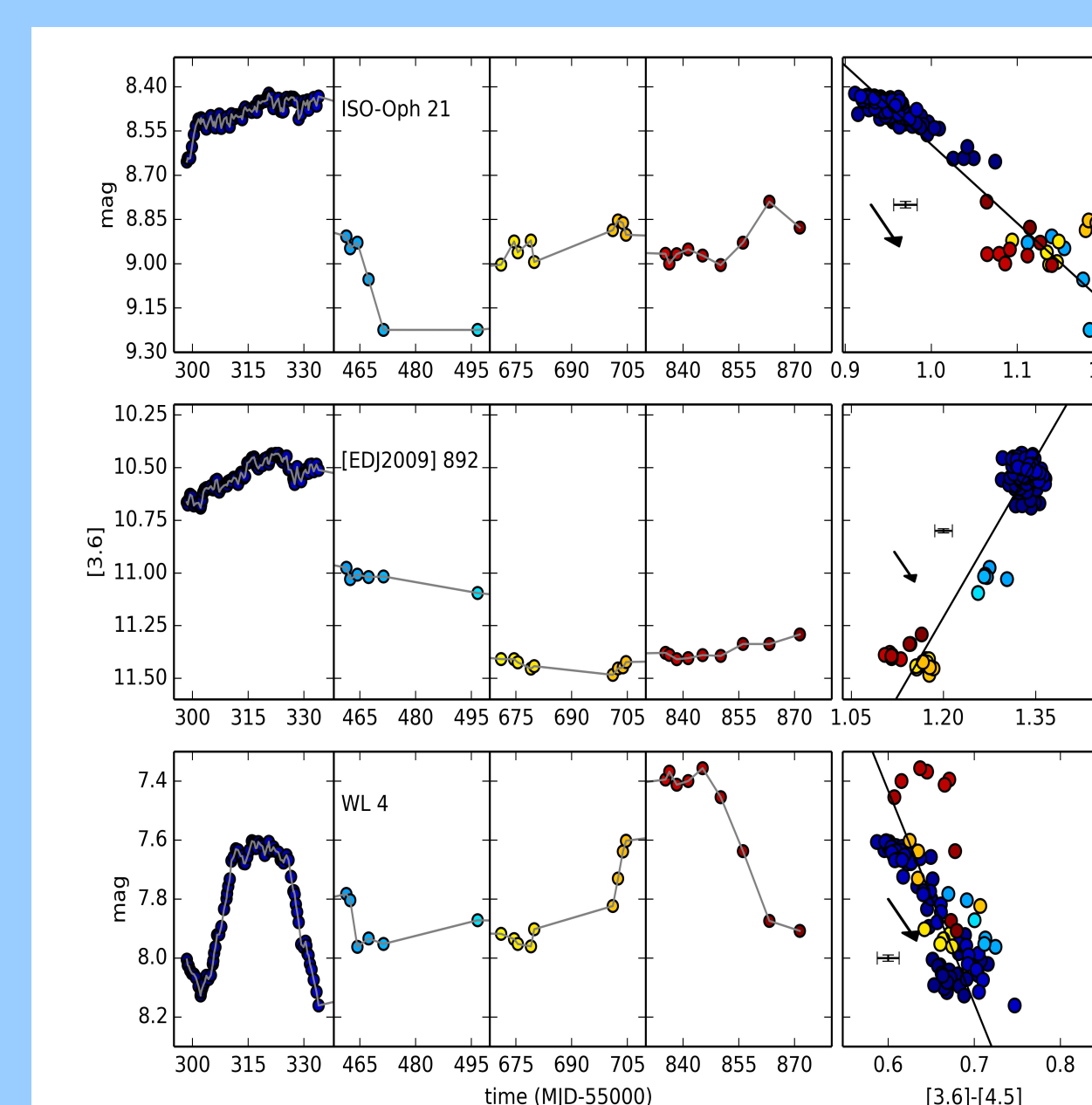
The emission from young stellar objects (YSOs) in the mid-IR is dominated by the inner rim of their circumstellar disks. We present an IR-monitoring survey in the direction of the Lynds 1688 (L1688) star forming region over four visibility windows spanning 1.6 years using the *Spitzer* space telescope in its warm mission phase. Among the lightcurves, 57 sources are cluster members identified based on their spectral-energy distribution and X-ray emission. Almost all cluster members show significant variability. The amplitude of the variability is larger in more embedded YSOs. Ten out of 57 cluster members have periodic variations in the lightcurves with periods typically between three and seven days, but even for those sources, significant variability in addition to the periodic signal can be seen. No period is stable over 1.6 years. Non-periodic lightcurves often still show a preferred timescale of variability which is longer for more embedded sources. About half of all sources exhibit redder colors in a fainter state. This is compatible with time-variable absorption towards the YSO. The other half becomes bluer when fainter. These colors can only be explained with significant changes in the structure of the inner disk. No relation between mid-IR variability and stellar effective temperature or X-ray spectrum is found.

## Exemplary variable objects Stetson index $> 0.9$ periodicity

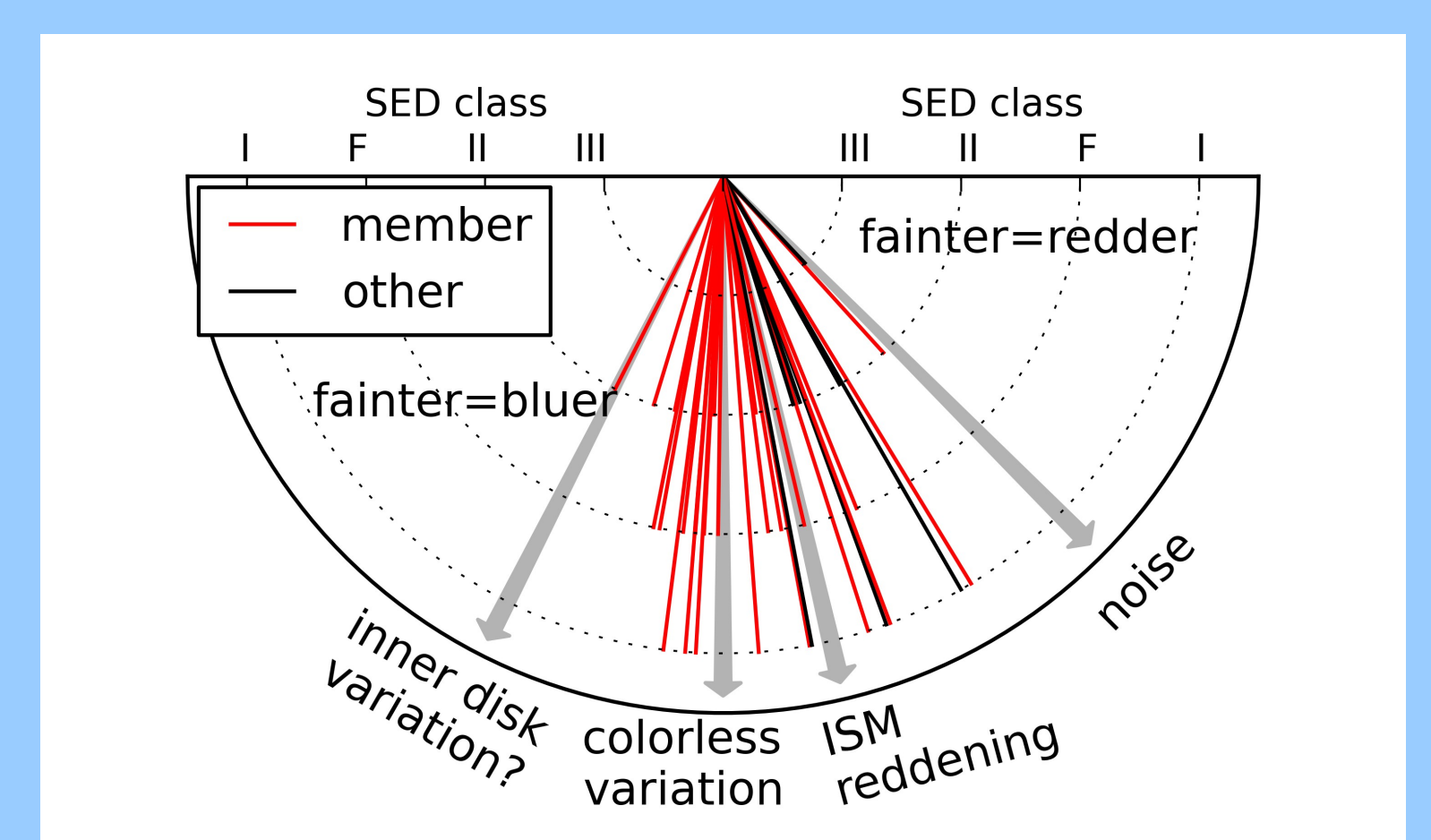


Lightcurves for exemplary sources. Data for [3.6] are shown in black, for [4.5] in red. Errorbars are indicated, if larger than plot symbols. Periodic sources: Large dots are datapoints taken in the first season, small dots are observed at other times. The Stetson index measures correlated variability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

## Variable extinction or accretion?

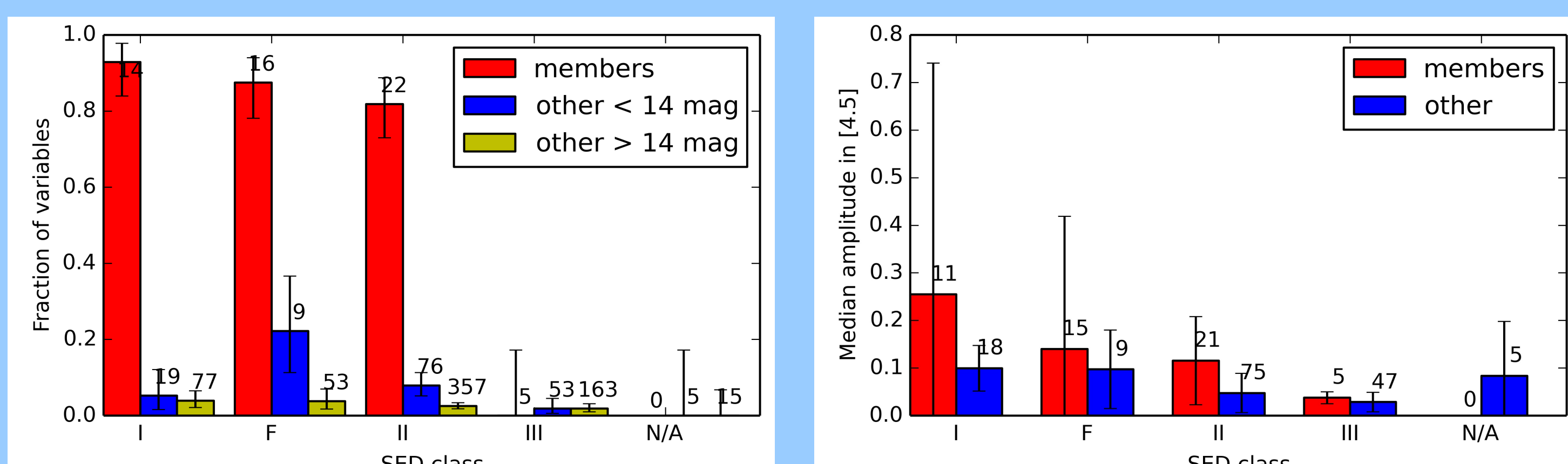


Color-magnitude diagrams for exemplary sources. Symbols in different color are from different seasons. The arrow shows  $A_K = 0.2$  mag. Color variability can happen both between seasons (top) or within a season (bottom). Some sources show a slope in the CMD that is close to ISM reddening (top and bottom), others appear more blue when they faint (middle).



Angles of the best fit slope (black line in the left figures) in the CMD. The length of each line marks its class. Non-member sources and many cluster members are found around the reddening slope in the CMD, indicating that their color changes are caused by variable extinction (reddening). In contrast, only cluster members have slopes where the source becomes more blue as it fades (bluening). A change in the inner disk radius can cause this. As material comes closer to the star, the temperature rises and at the same time the emitting area reduces.

## Younger sources are more often and more violently variable

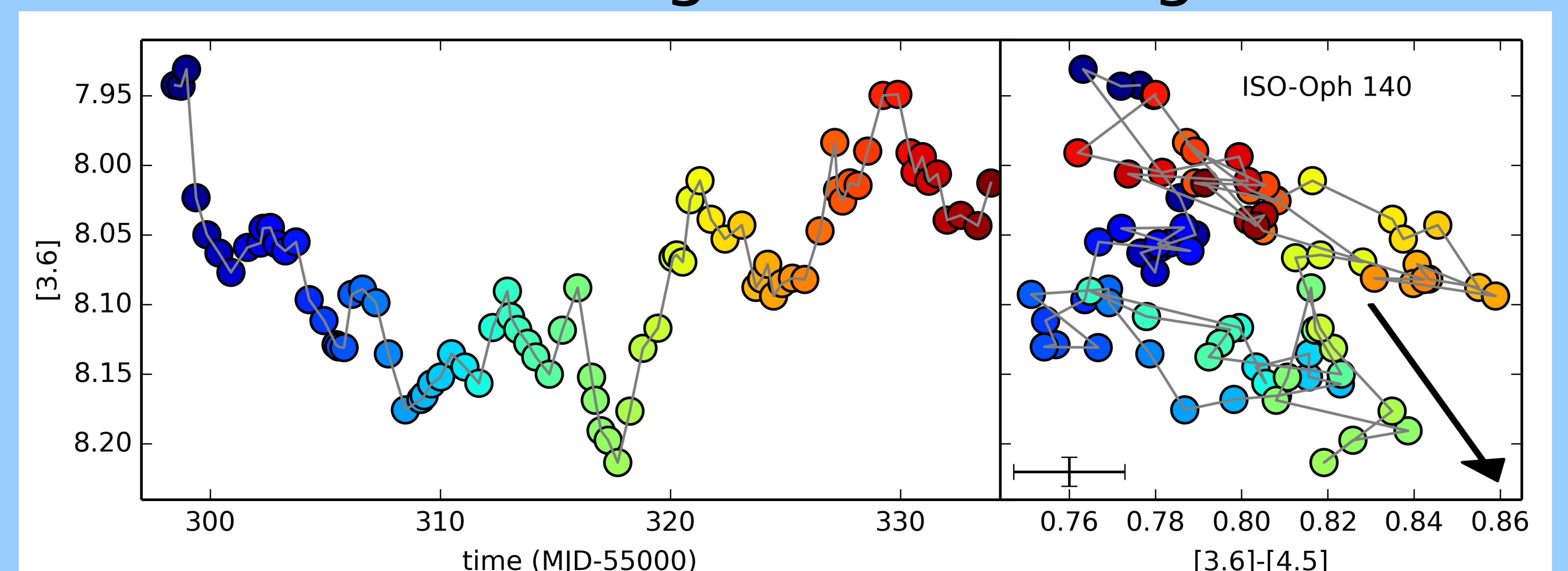


Fraction of variable sources in each evolutionary class. Classes are determined from the slope of the spectral energy distribution (SED). The numbers give the total number of sources in that class. Basically, sources are IR variable, as long as they accrete from their disk (SED classes I, Flat and II).

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 mid-IR variable as long as they have disks, but the amplitude decreases with disk mass.

## Example: Color slope changes between reddening and bluening



Lightcurve (left) and color-magnitude diagram (CMD - right) for ISO-Oph 140 in the first observing visibility window. The color of the symbols in the CMD shows their position on the lightcurve. There is no single slope in the CMD. Initially, the luminosity drops sharply, while the color becomes slightly bluer. The behavior changes around MJD 55305. For the next 15 days, the source becomes redder and dimmer. Then, the brightness increases again. In the last 10 days, the source again has a slope close to the ISM reddening law.

Mid-IR variability is not as simple as you think.

A paper based on these results is submitted to *AJ*. Please contact [hguenther@cfa.harvard.edu](mailto:hguenther@cfa.harvard.edu) if you are interested in pre-referee draft versions. The analysis is based on *Astropy* ([www.astropy.org](http://www.astropy.org)) and our own python pYSOVAR code ([www.github.com/YSOVAR](http://www.github.com/YSOVAR)).

This work is funded by NASA/ Spitzer contract #1416591. References: Morales-Calderon, Stauffer et al., *ApJ*, 733, 50 (2011)