STAR FORMATION IN THE VICINITY OF THE NORTH AMERICAN AND PELICAN NEBULAE

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WHY STUDY YET ANOTHER STAR-FORMING REGION?

- The North American / Pelican Nebulae (d $\approx$ 600 pc) are the closest region of recent massive star formation after the Orion clouds (d $\approx$ 480 pc).
- Efficiency of massive star formation *appears* to be $\sim$ 20 times higher than in Orion.
- Except for photographic Hα surveys and Vilnius photometry of the brightest stars, the region is relatively unexplored.
- Our goals:
  - Determine clustering properties of the cloud
  - Derive age and age spread of stellar population
  - Construct stellar mass function
  - Investigate diagnostics of circumstellar disks
  - Look for trends in disk diagnostics with stellar mass and/or age

WHAT THE LITERATURE TELLS US

- A nearly spherical HII region (W80) is located between the two nebulae and requires ionizing photons from 2-3 stars of spectral type O6 or ∼8 stars of type O8-B0 (Wendeker; 1968, 1983)
- Lack of systematic variations in Hα velocities or line widths suggests a classic ionization-bounded nebula (Fountain, Gary, & O'Dell; 1983)
- The cloud is highly fragmented, with a mass of $\sim 5 \times 10^4 M_\odot$, and contains an expanding molecular shell ∼12 pc in diameter (Bally & Scoville; 1980)
- At least 300 $H\alpha$ emission stars are known, including ∼50 Herbig Ae/Be star analogs (Herbig; 1958, Weilin; 1972, Shevchenko; 1988)
- The extinction rises to >1 mag at the distance of the cloud (Straizys *et al.*; 1993)

OUR DATA SET

- BVI/Hα imaging over $\sim 1.75 \times 1.75$ deg^2 (KPNO)
  $\Rightarrow$ photometry for 1.9×10^4 B-band selected stars
  and $> 10^5$ I-band selected stars

- JHK imaging over $\sim 3.75 \times 6$ deg^2 (2MASS survey)
  $\Rightarrow$ photometry for 5×10^5 K-band selected stars

- $\sim 5,000 - 10,000$Å spectroscopy (WIYN)
  $\Rightarrow$ spectral types for $\sim 1 \times 10^3$ stars

- ^{12}CO and ^{13}CO imaging (FCRAO)
  $\Rightarrow$ column density maps

DIFFICULTIES IN ANALYSIS

- Location
  - Galactic latitude ≈ -0.5 deg
    ⇒ *significant* foreground and background
    (models predict ∼ 2000 stars deg^{-2})
  - Galactic longitude ≈ 85 deg
    ⇒ tangent point in velocity
- Appreciable and spatially variable extinction

STEP 1: IDENTIFY ASSOCIATED STARS

- Assuming stars associated with the cloud are relatively young, some portion of the population can be identified from:
  - $H\alpha$ or CaII emission
  - near-infrared continuum excess
  - high extinction
- However, not all stars will have these diagnostics and statistical analysis is required. We plan to:
  - Construct a column density map from the molecular data
  - Compare the observed star counts with an appropriately reddened two-dimensional Galactic model
  - Derive probabilities of physical association with the cloud as a combined function of magnitude and color

NEXT STEPS

- Understand photometric and spectroscopic completeness limits (should be sensitive to all masses M> $0.08 M_\odot$ for $\tau < 10$ Myr and $A_V < 1$ mag, and for $\tau < 1$ Myr and $A_V < 5$ mag)
- Quantify stellar clustering properties of the cloud
- Construct HR diagram
- Derive stellar masses and ages, mass and age distributions
- Investigate disk frequency with stellar mass and age

WHAT WE KNOW SO FAR

- Extinction through the cloud exceeds 10 mag with a peak value of $\sim$ 30 mag.
- *Most* of the stars projected on the region are not associated with the cloud at 600 pc.
- The degree of stellar clustering is low. In particular, 3-20$M_{\odot}$ stars do not appear associated with dense clusters, as they are in the Orion clouds. However, there are two groupings of B- and A-type stars located outside the main area of the cloud.
- An age range from 0.1-10 Myr is suggested from color-magnitude diagrams.
- Stars which have Hα in emission also tend to have near-infrared excess.

Fig. 1.— The North American / Pelican Nebulae region. *Right panel* is a Schmidt photograph (roughly R band) from Welin (1972); x's and o's indicate Hα emission objects. Solid square outlines are the regions imaged at B,V,I$_C$,Hα. Dashed square outlines are the regions mapped in ^{12}CO and ^{13}CO J=1-0. *Left panel* contains the right panel, and shows the 2MASS (JHK) 6-degree scans in this region.

Fig. 2.— A 1 x 1 deg^2 portion of the North American / Pelican Nebulae region. The *right panel* shows visible wavelengths (POSS image) while the *left panel* shows infrared wavelengths (2MASS mosaic constructed by Gene Kopan). Contours show ^{13}CO intensity integrated over -5 - 10 kms^{-1}, beginning at 5σ above the background.

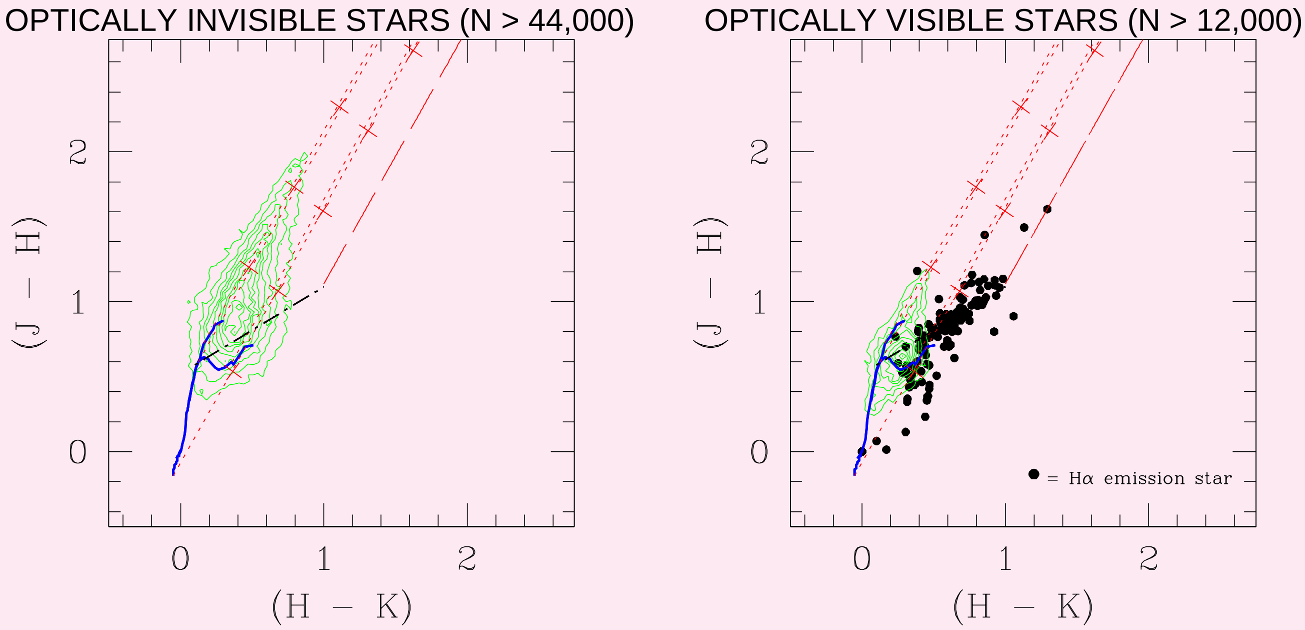

Fig. 3.— $J - H$ vs $H - K_s$ for a $\sim 1.75^\circ \times 1.75^\circ$ region (including the area shown in Figure 2). Green contours indicate the density distribution of optically visible (*right panel*) and optically invisible (*left panel*) stars. Blue lines are the locus of colors expected for dwarf and giant stars while red lines indicate reddening vectors. Black dash-dot line is the locus of colors populated by de-reddened classical T-Tauri stars. The two main peaks in these distributions correspond to reddened giant stars (extending to $J - H \approx 2$), and reddened main sequence stars (extending to $J - H \approx 0.7$). Dots on the optically visible plot denote stars with strong Hα emission; these stars clearly define a different color sequence than the majority of the stars projected onto the cloud, and are consistent with those expected from low-mass stars still surrounded by circumstellar disks.

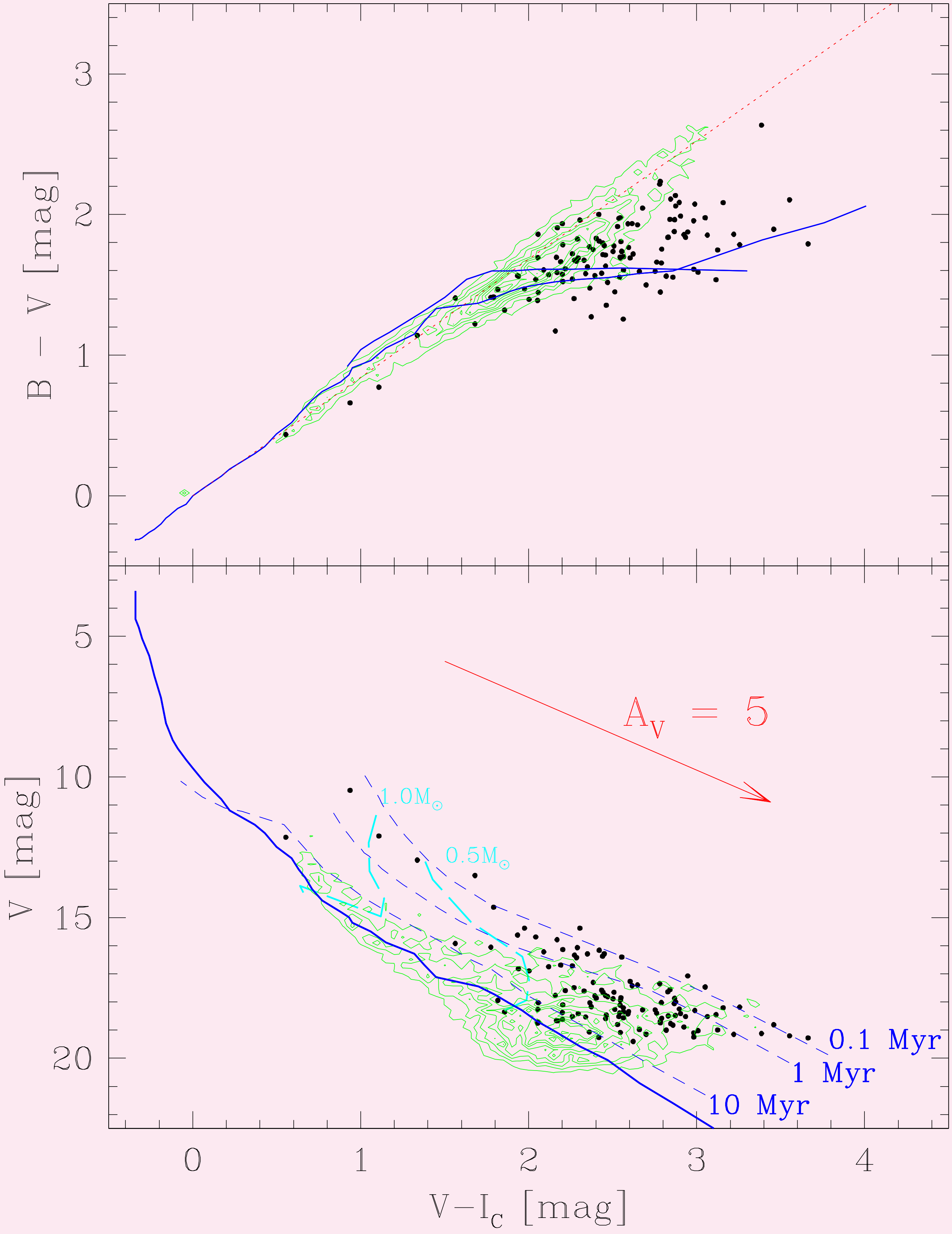

Fig. 4.— $B-V$ vs $V-I_C$ (*top panel*) and V vs $V-I_c$ (*bottom panel*) diagrams. Green contours represent the density distribution of colors for all stars projected onto this $\sim 1.75° \times 1.75°$ region of the cloud. Dots denote stars with Hα strongly in emission. Blue and red lines in the upper panel are as in Figure 1. Blue and cyan lines in the lower panel represent the pre-main sequence isochrones and evolutionary tracks from D'Antona & Mazzitelli (1994), as labelled.

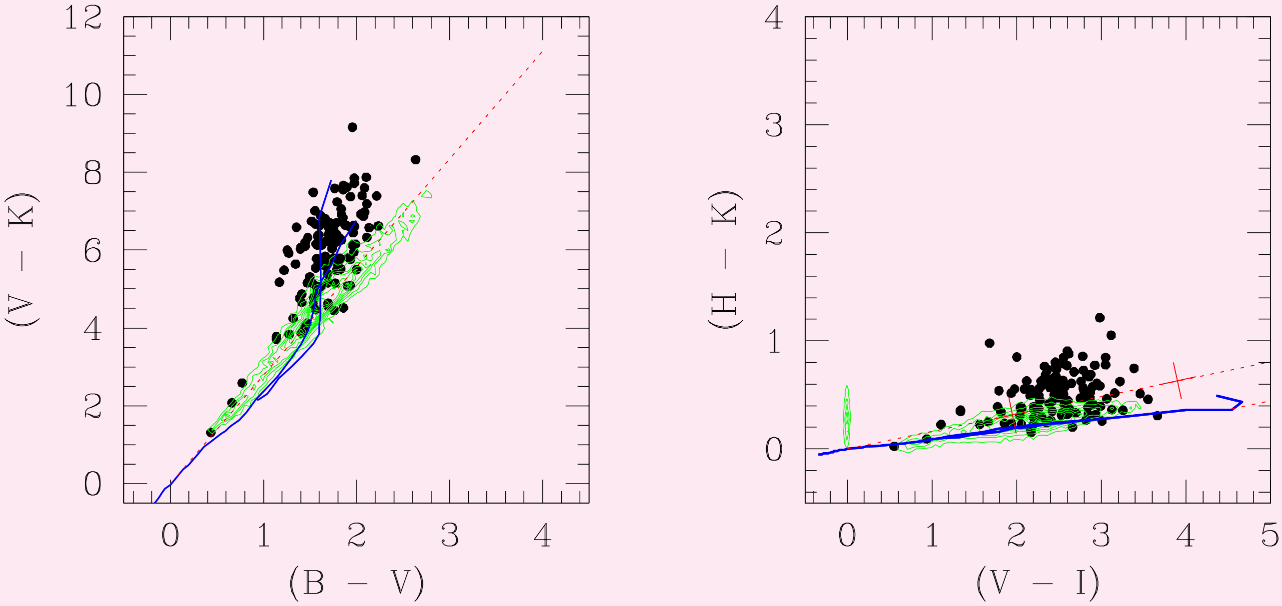

Fig. 5.— $V - I_C$ vs $H - K_s$ (*right panel*) and $B - V$ vs $V - K_s$ (*left panel*) diagrams. Contours represent the density distribution of all stars projected on the region while dots are stars with strong Hα emission.