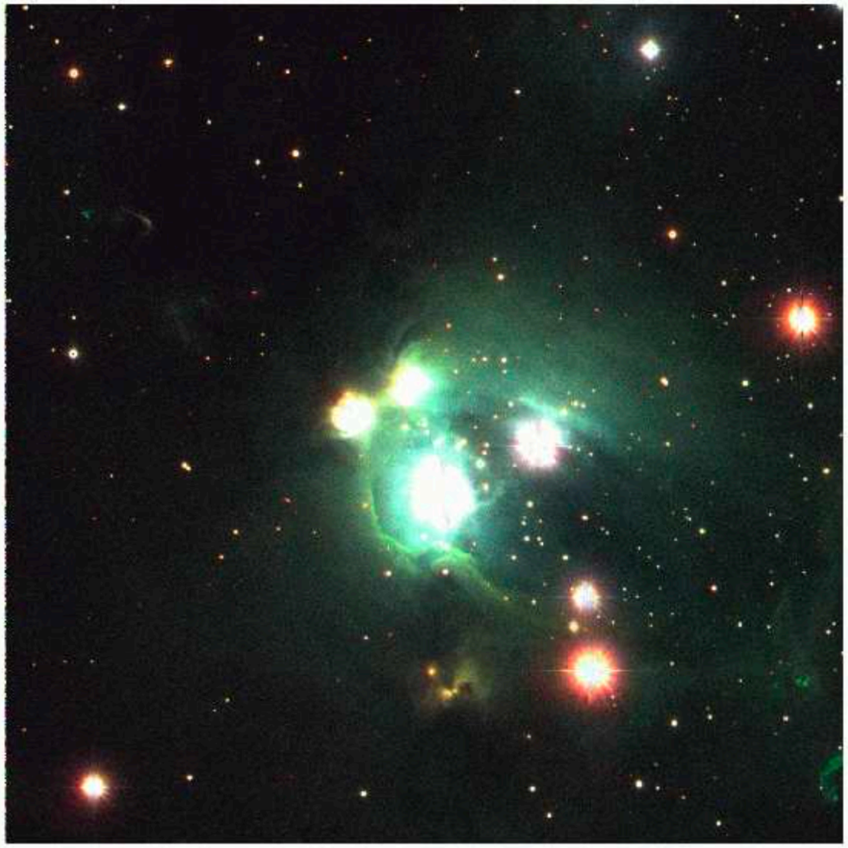


STAR FORMATION AND THE YOUNGEST STELLAR POPULATIONS

lynne a. hillenbrand | (caltech)

THE LMC

- nearby (~50kpc) proxy for high-z star formation, illustrating standard HII region emission line diagnostics

- c.f. galactic star forming regions at <1-2-8 kpc where spectra of individual stars are feasible.

SOME FAVORITE GALACTIC REGIONS ARE WELL-SUITED FOR JWST

d ~8kpc

Lu (2019)

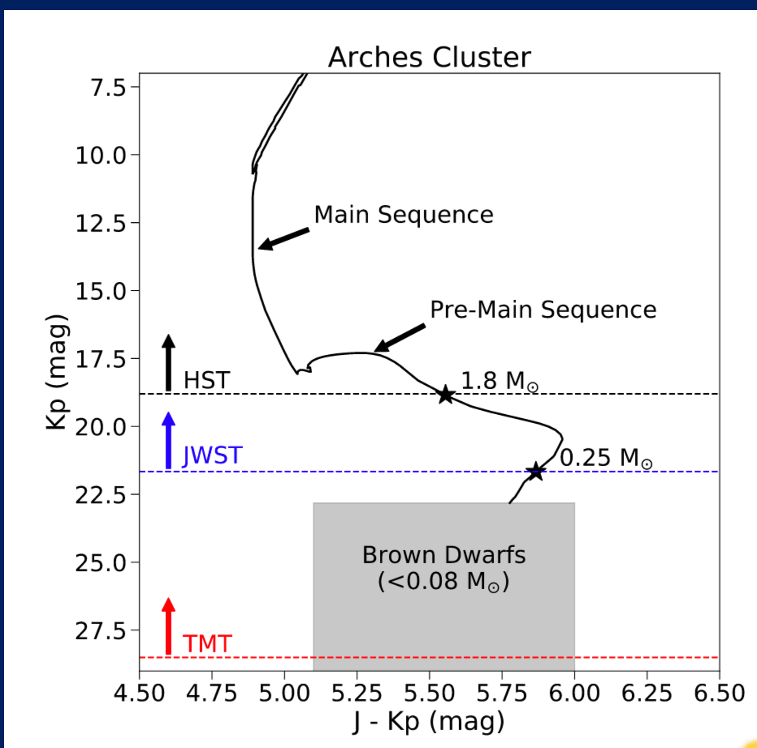


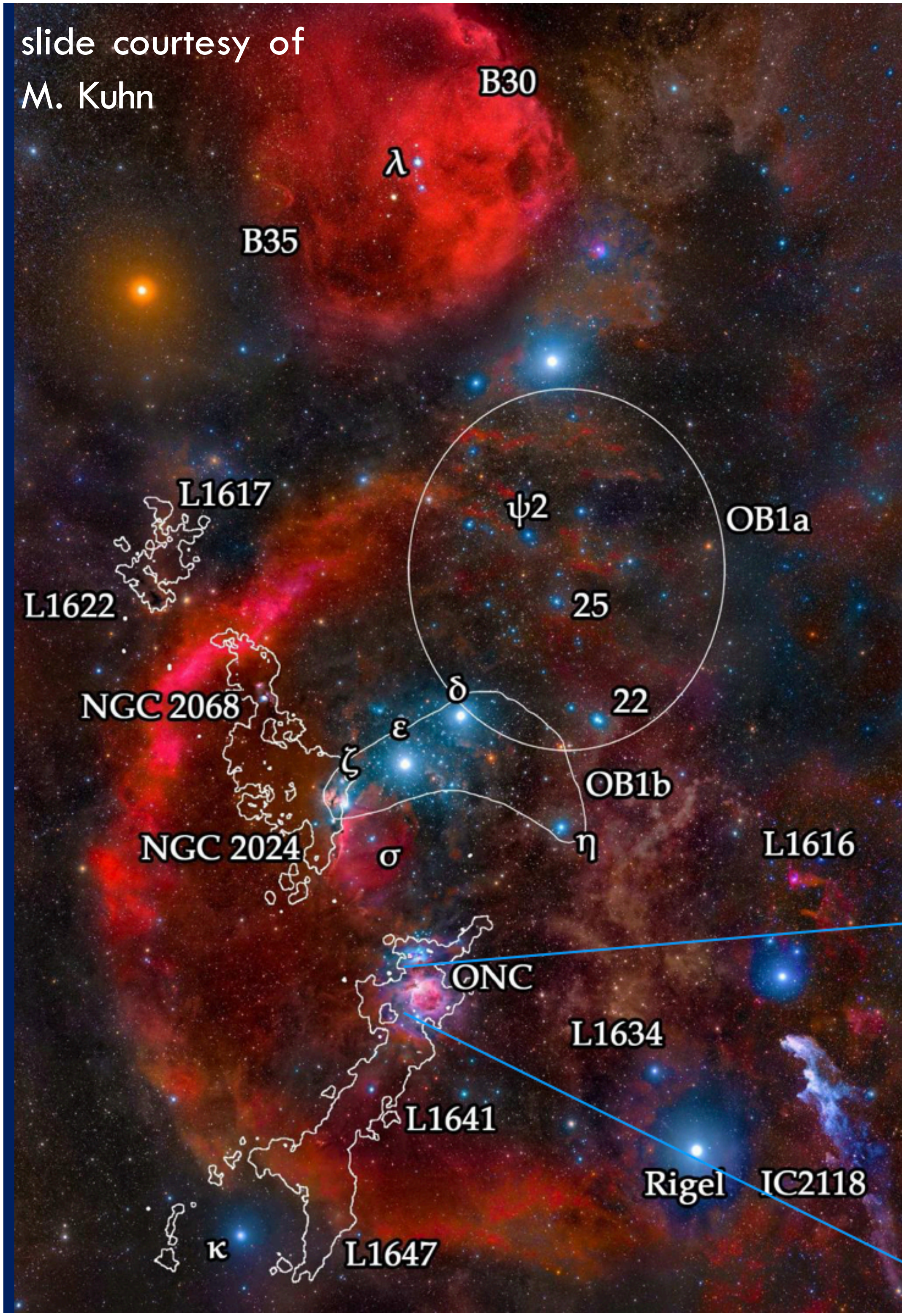
Fig. 3.2 Zoomed infrared images of the Arches Cluster (*left*), Quintuplet Cluster (*middle*), and the Young Nuclear Cluster (*right*). The extreme stellar density and patchy extinction are evident. This false-color image shows infrared light ranging from 1 to 1.6 μm from the NICMOS camera on the Hubble Space Telescope. The centers of both the Arches and YNC are so dense that only a handful of the brightest young stars can be individually resolved with HST and ground-based adaptive optics images on 8–10 m class telescopes are required. The images are oriented with North up and East to the left and are 80″ (3.2 pc at a distance of 8 kpc) on a side

~2-6 Myr old

Each cluster has ~100-150 O-type stars and contains total stellar mass >10^4 Msun.

Spatial resolution, sensitivity, infrared all required. Currently sampled to only 1.8 Msun.

Hosek et al. (2019, DSWP)



GALACTIC STAR-FORMING COMPLEXES

- Stars are born mainly in clusters/groups, within GMCs.

- Spatial-temporal star formation scenarios are complex.

- In massive star-forming regions, UV radiation from the most massive stars can have significant effects on the environment.

d ~0.4kpc

STILL OPEN QUESTIONS REGARDING:

Cluster formation/dispersal timescales.

Gas expulsion processes.

Connection between gas kinematics and young star kinematics

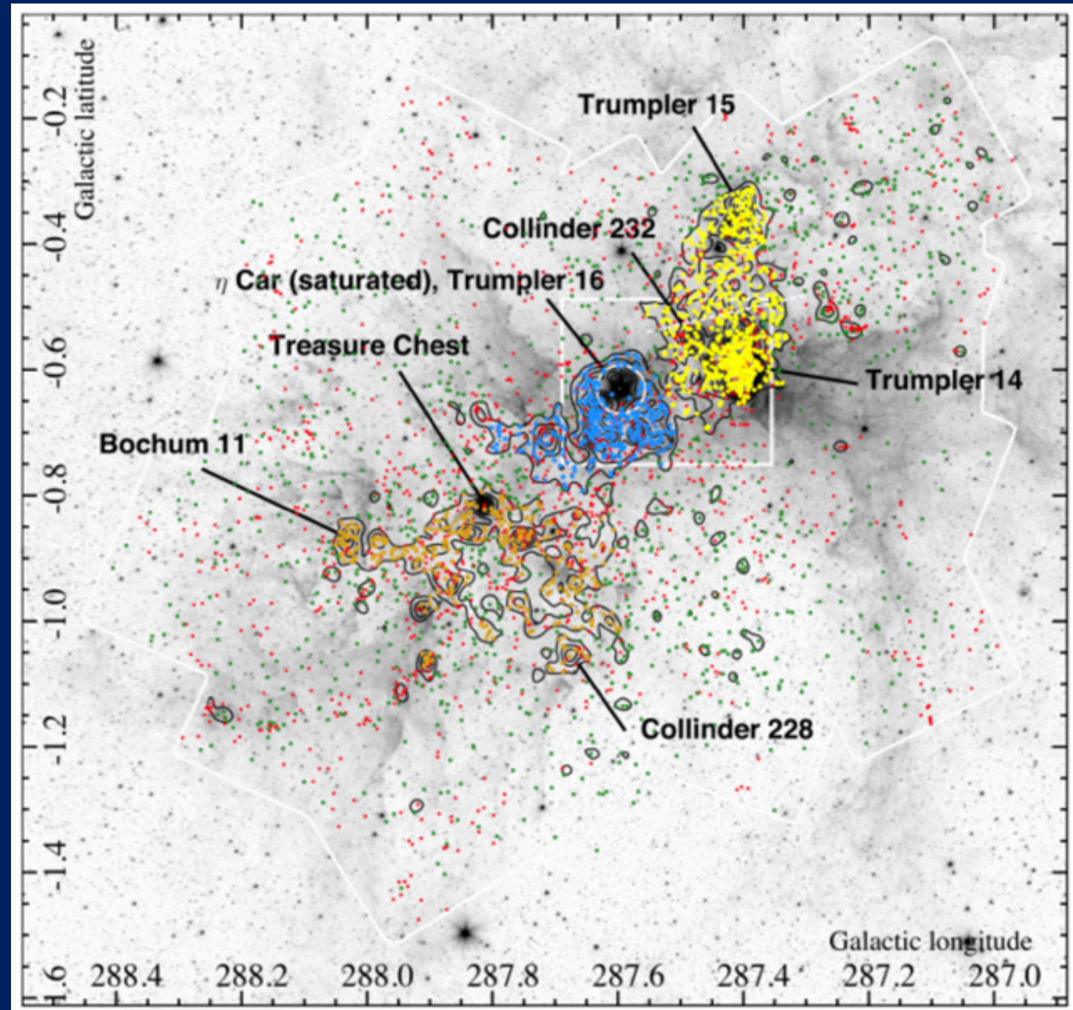
Fraction of clusters that remain bound.

Age spreads and sequencing of s.f.

IMF and variations.

Mass segregation.

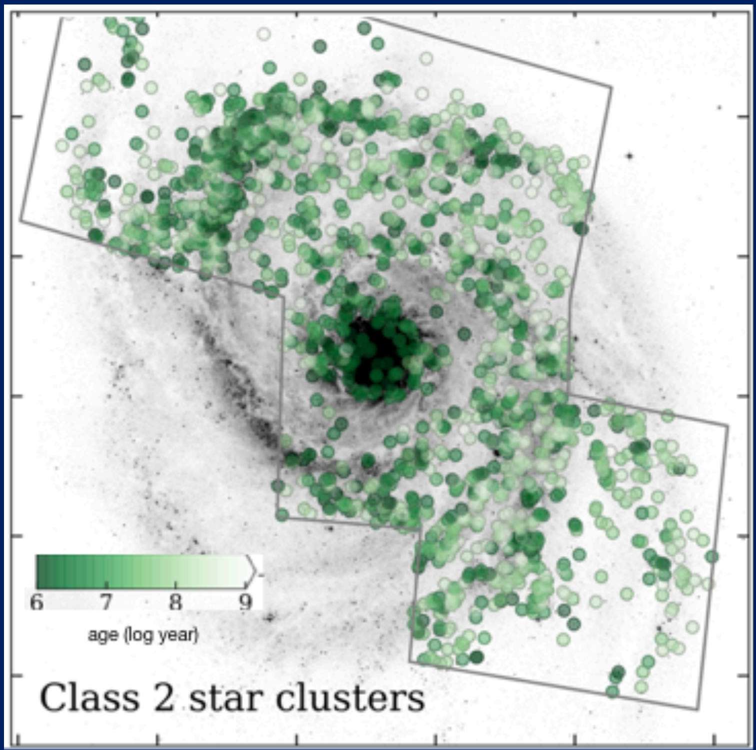
Multiplicity fractions and binary parameters.



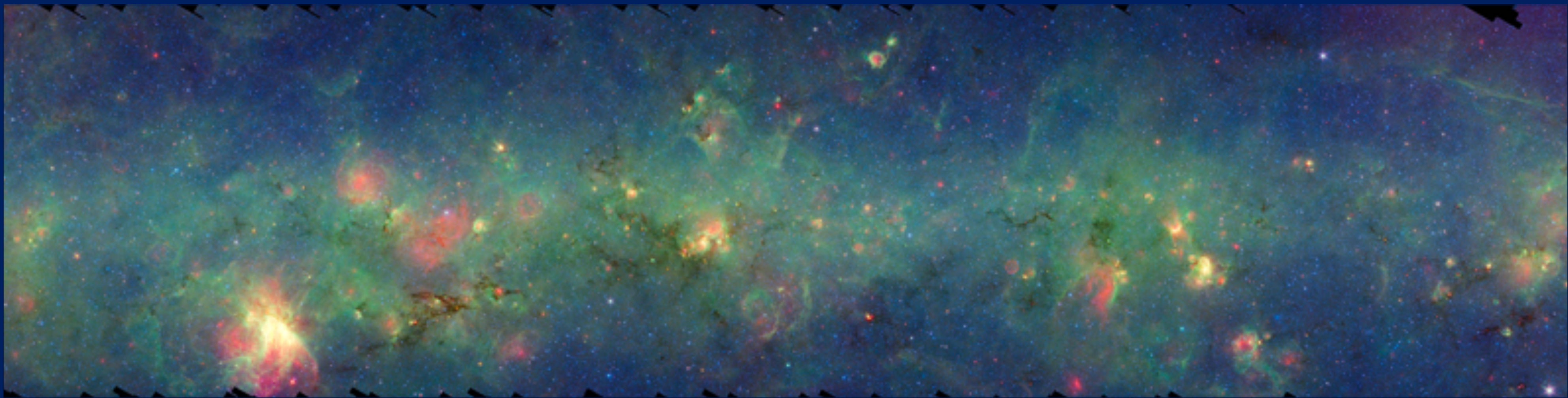
Povich et al 2019

d ~2.7kpc

WE HAVE A NON-IDEAL VANTAGE FROM WHICH TO UNDERSTAND GALACTIC STAR FORMATION

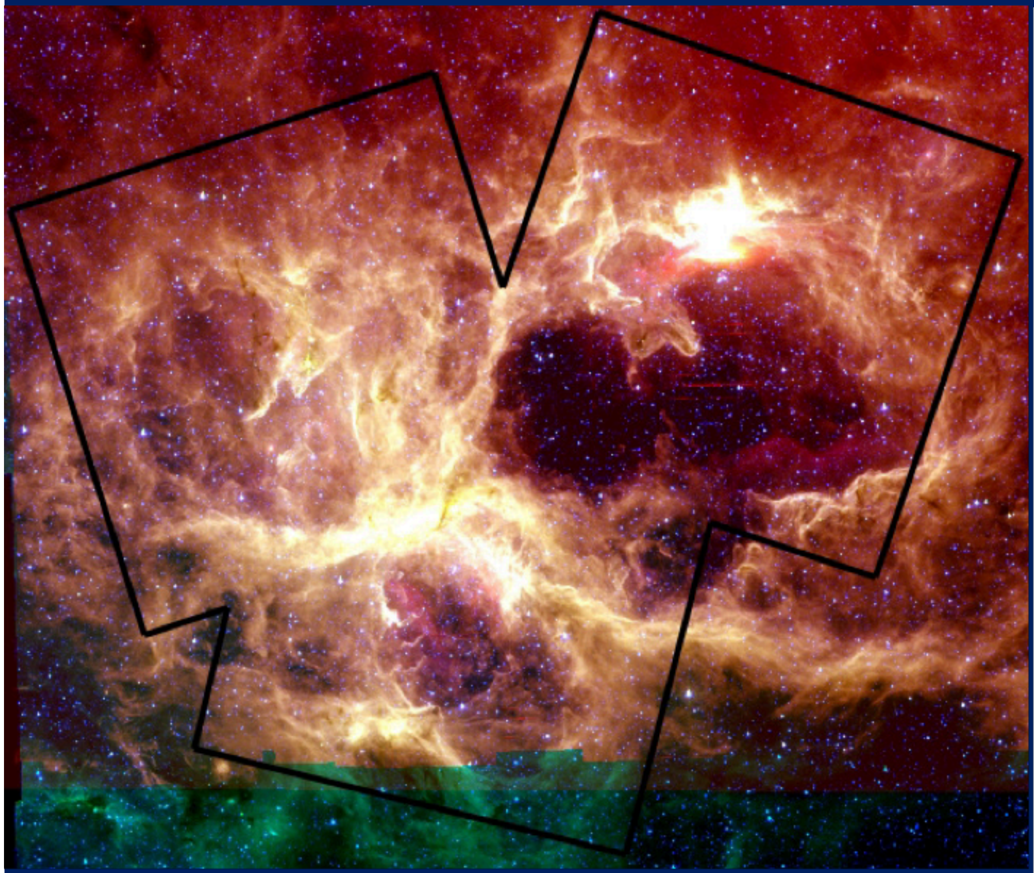


LEGUS HST image of M51 (Grasha+2019)

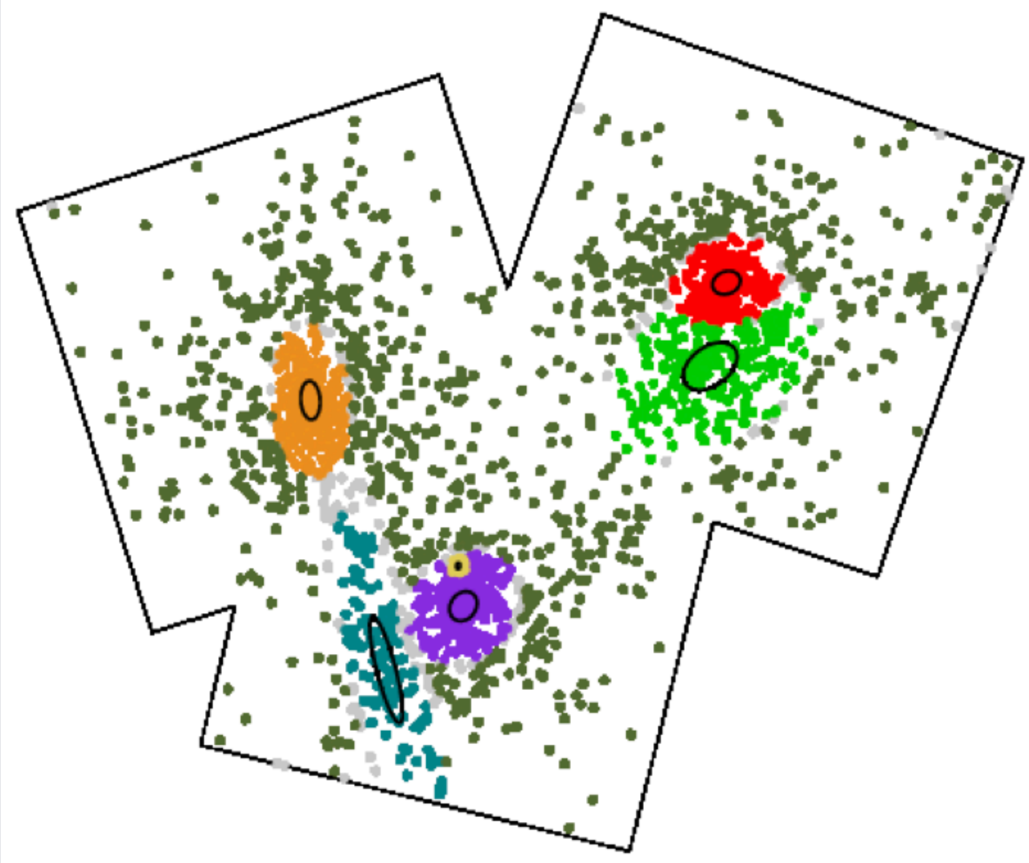


Spitzer's GLIMPSE survey of the midplane (Benjamin+03; Churchwell+06)

TRADITIONAL SURVEYS COVER ONLY SMALL TO MODERATE FIELDS OF VIEW



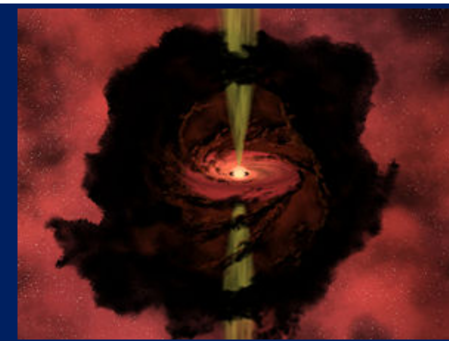
Spitzer/IRAC 3.6 (blue), 5.8 (green), 8.0 (red) micron



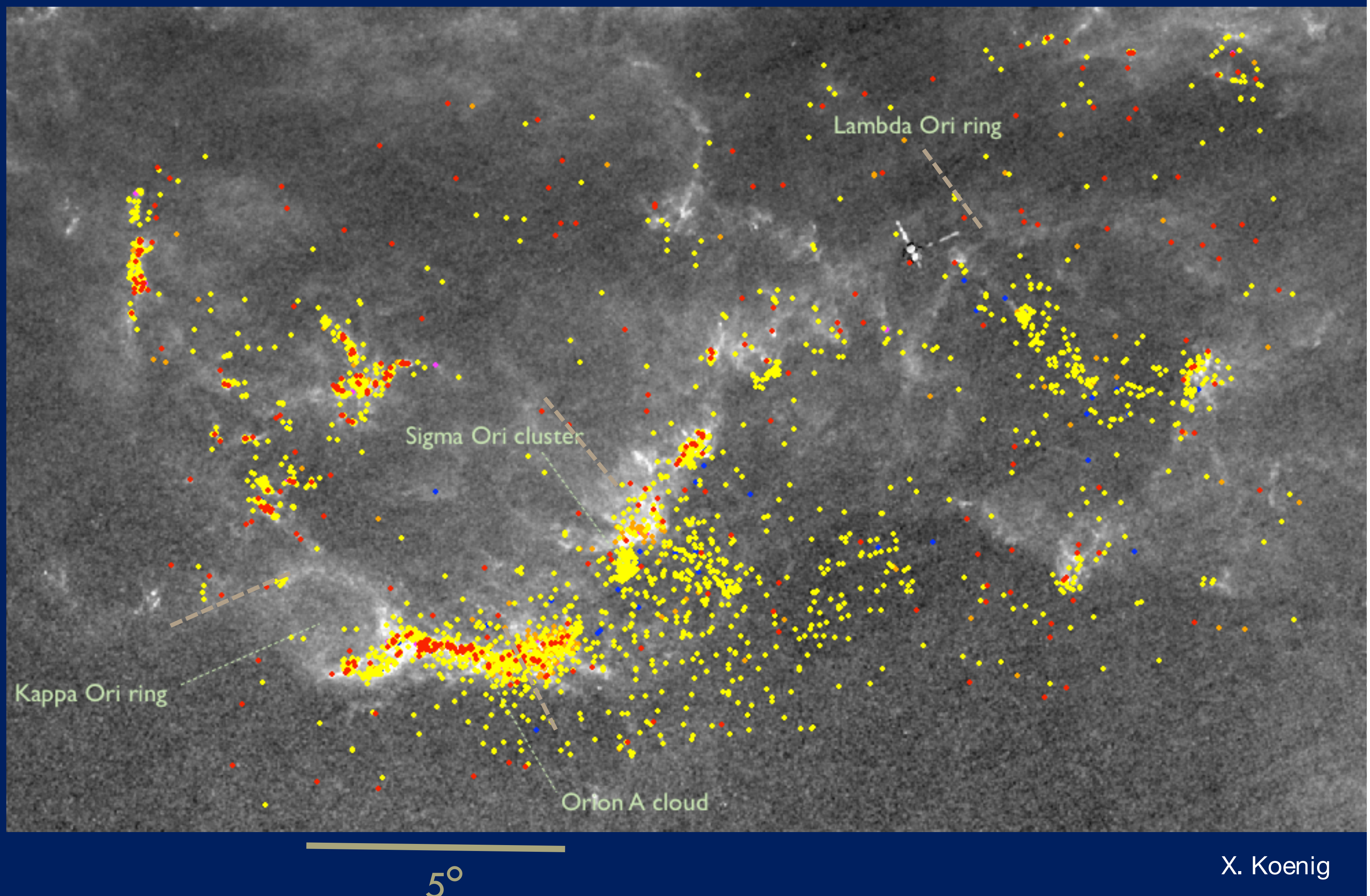
Spatial distribution of YSOs

Kuhn et al.

WIDE-FIELD AND ALL-SKY SURVEYS HAVE IDENTIFIED EXTENT OF YSOS

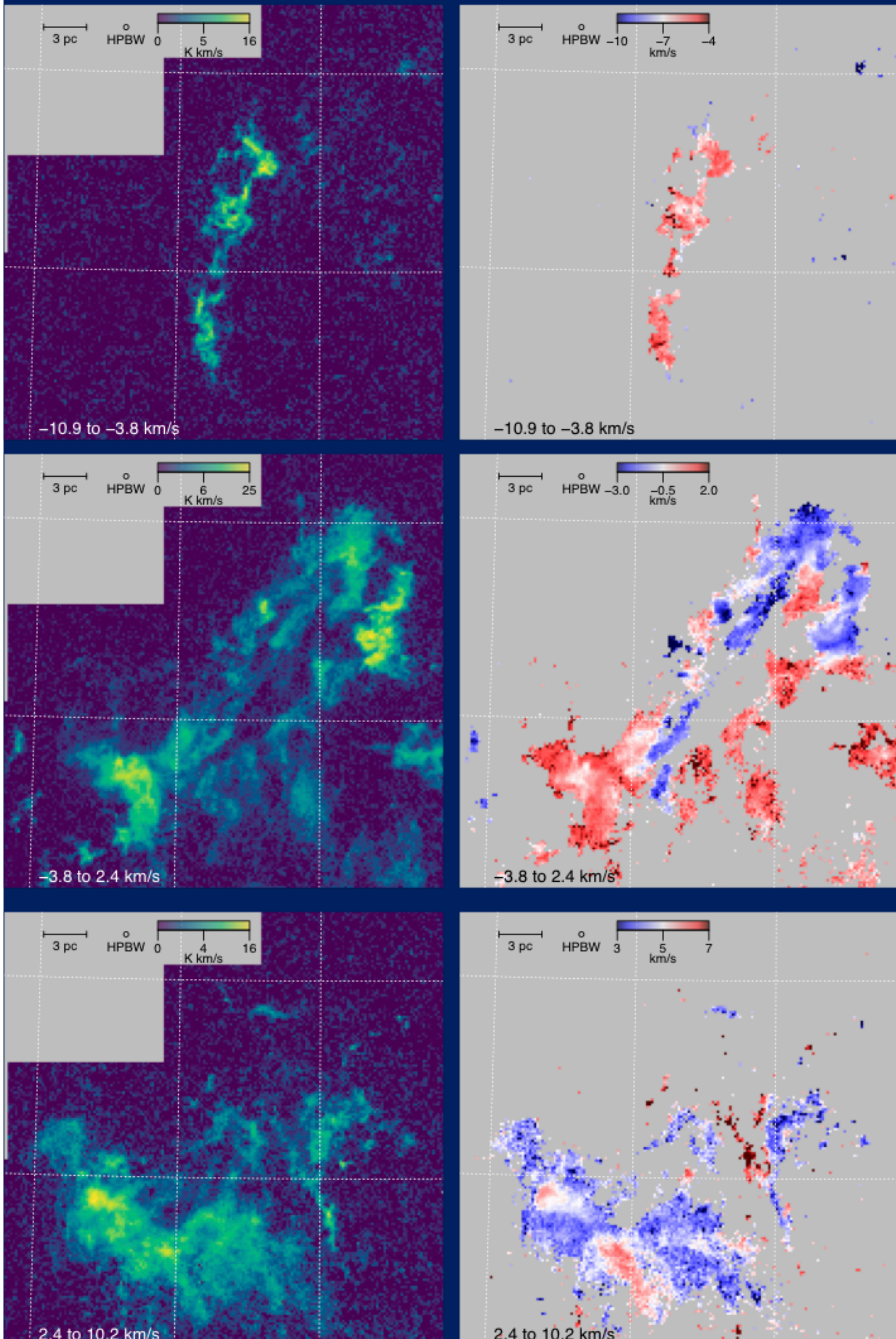


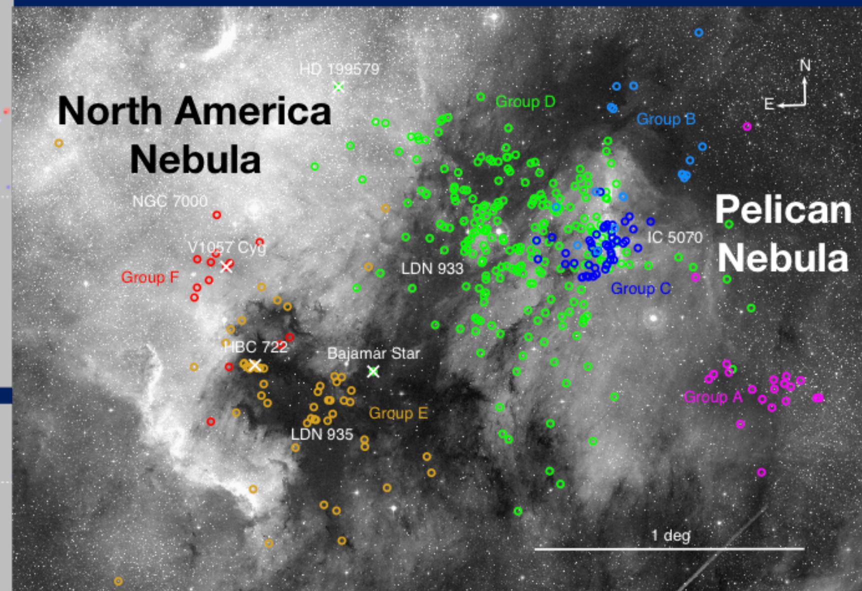
- Infrared excess
- Photometric variability
- Halpha emission
- X-ray emission
- CMDs

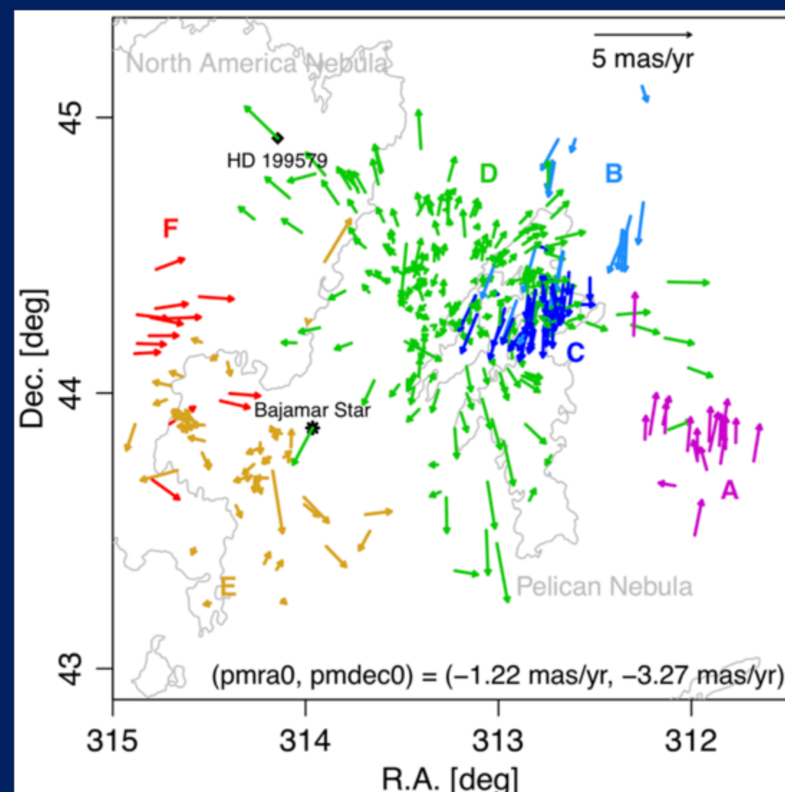


X. Koenig

KINEMATICS NOW TOO!



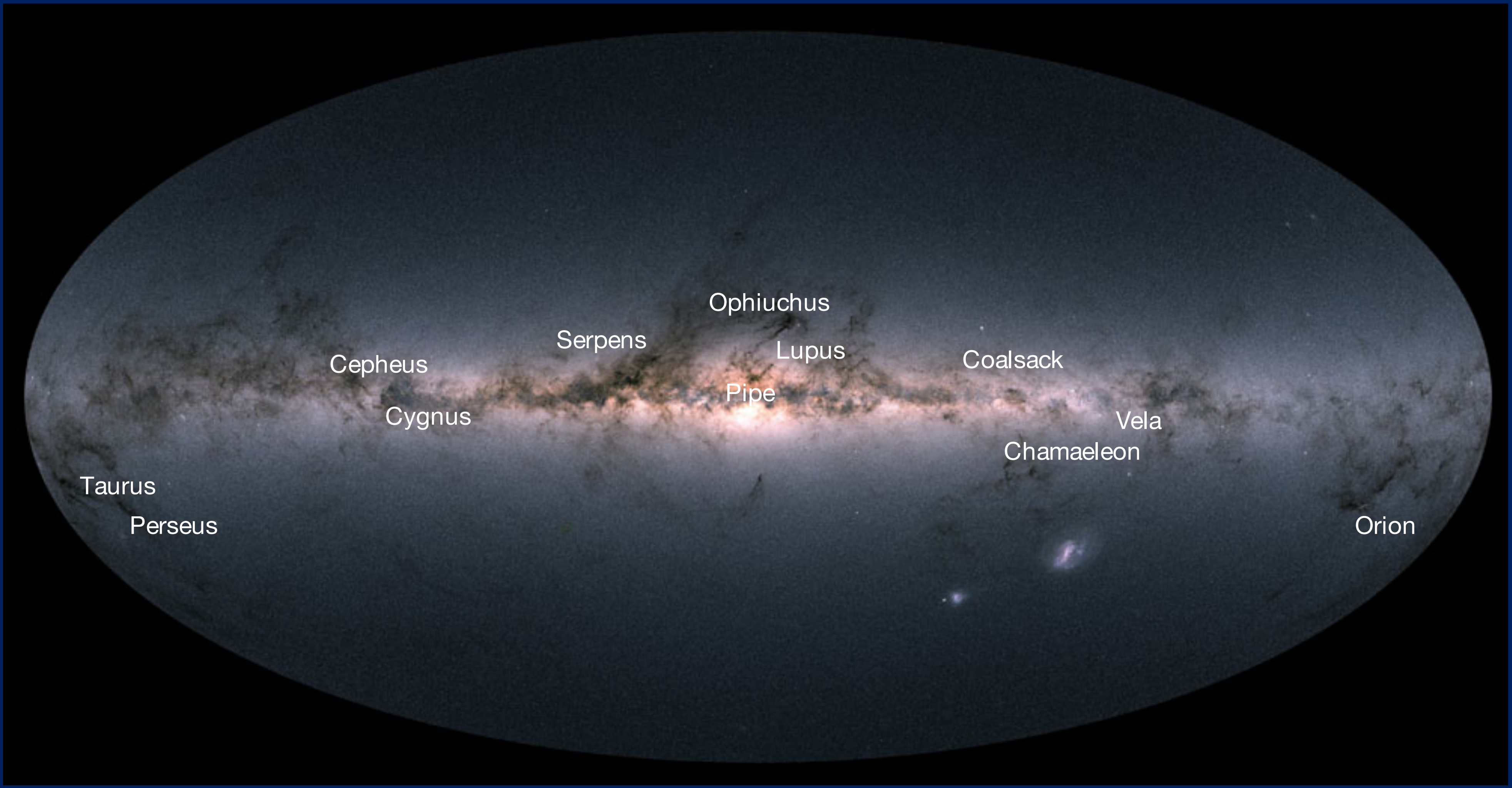




Kuhn et al 2020

INSATIABLE APPETITE FOR WIDE-FIELD

THE ASTROMETRIC BOUNTY OF GAIA



ESA/Gaia

2-4 X PI FIELDS NOW AVAILABLE

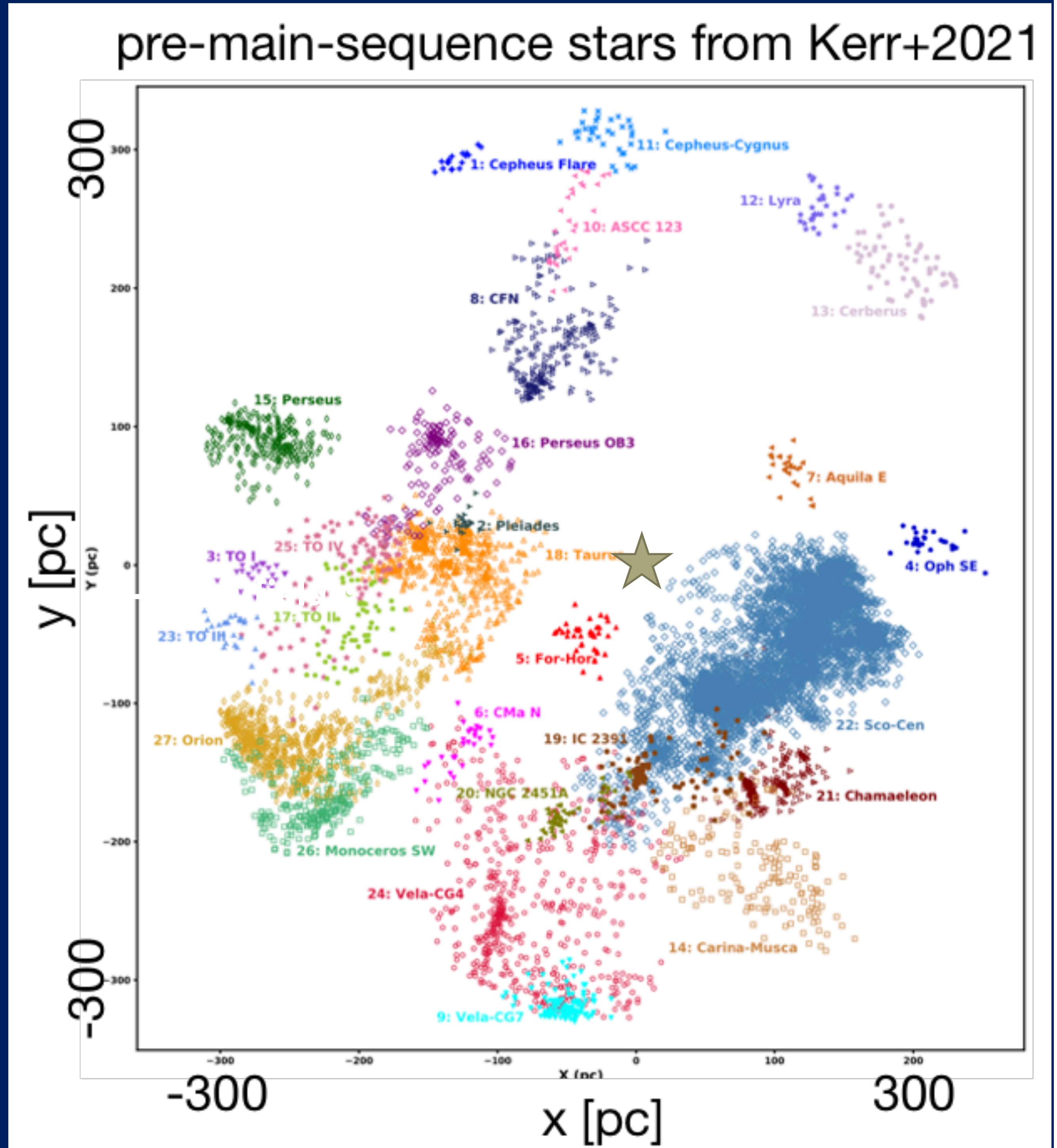
-Photometric surveys

- WISE – mid-IR
- 2MASS – near-IR
- K2/ZTF/VVV - variability
- PanSTARRS – red optical
- Gaia – blue optical
- GALEX – UV

-Astrometric capabilities of Gaia

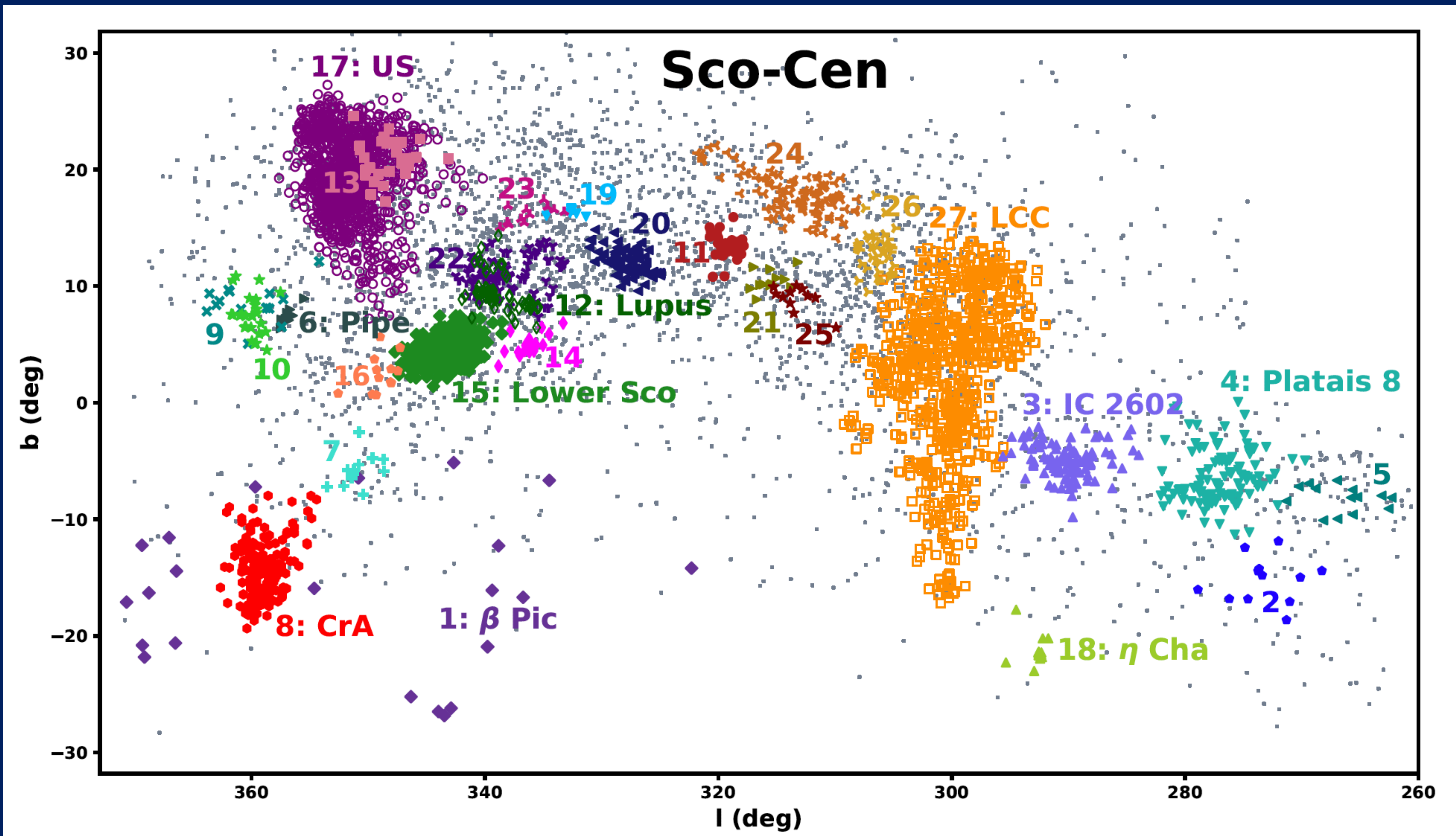
- proper motions
- parallaxes
- radial velocities

Statistical methods e.g. UPMASK, HDBSCAN used to identify kinematically associated and evolutionarily related sources.



THE EXTENT AND POPULATION STATISTICS OF THE NEAREST OB ASSOCIATION ARE STILL BEING DISCOVERED

d ~0.15kpc



Kerr+ 2021

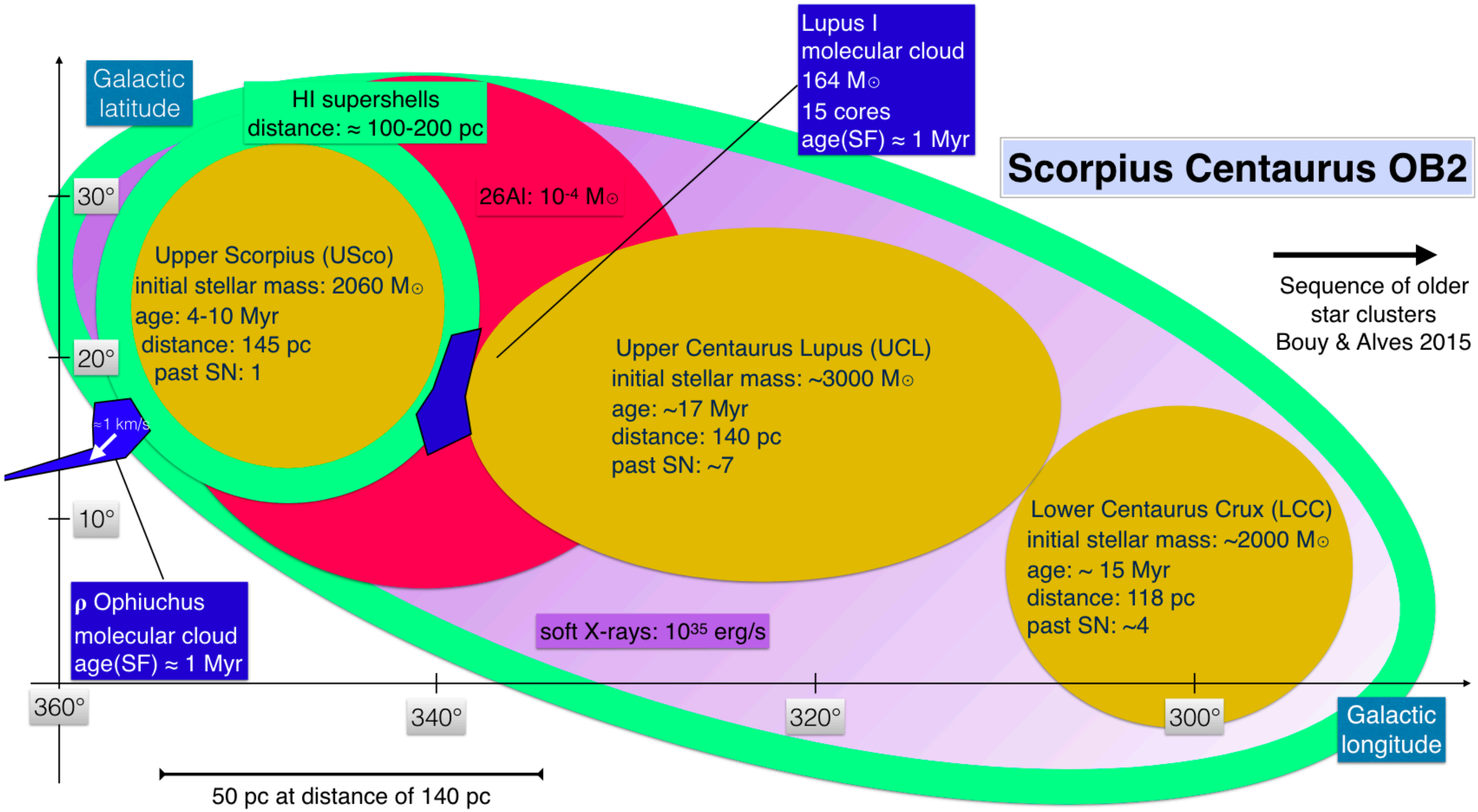
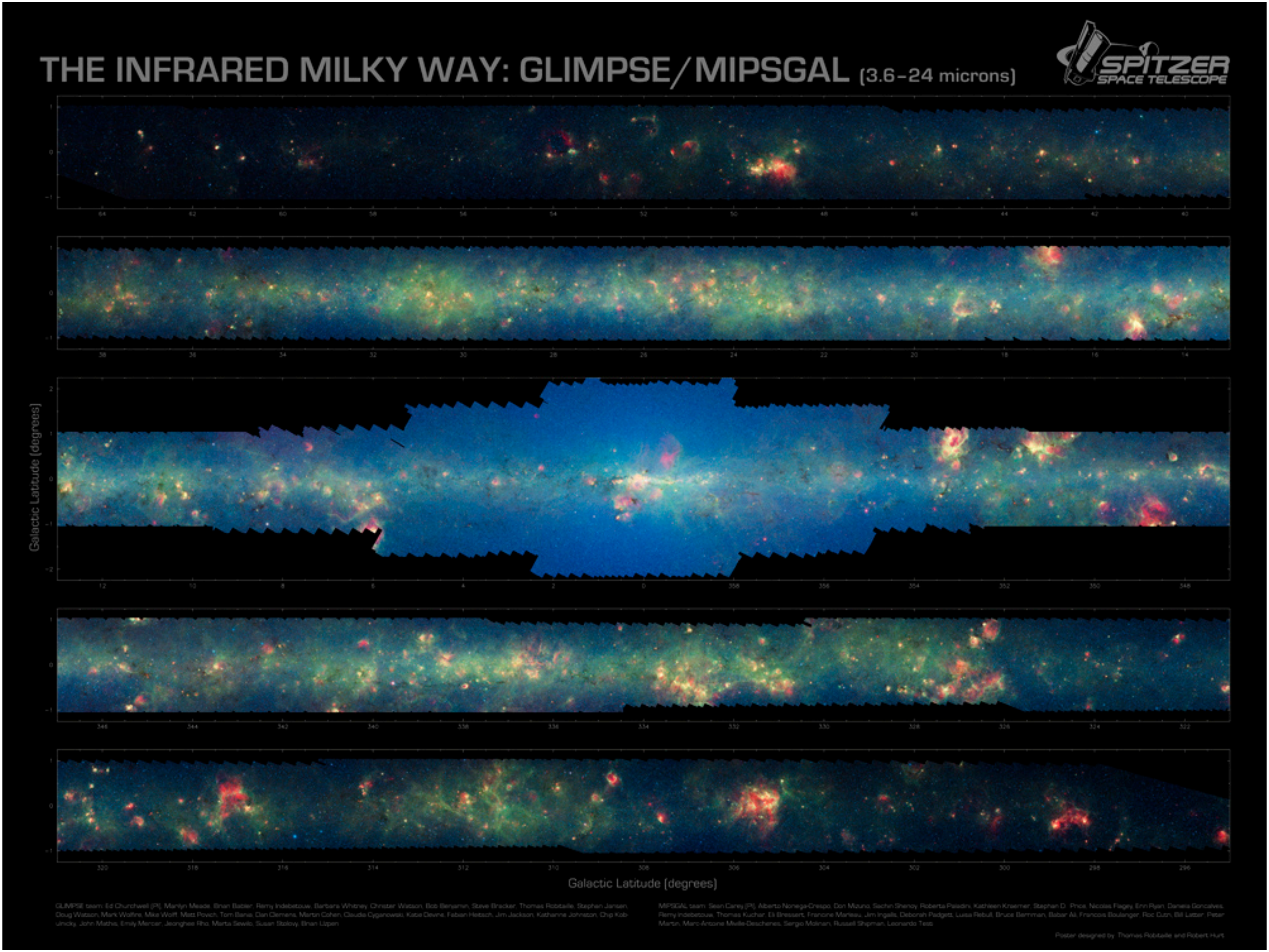


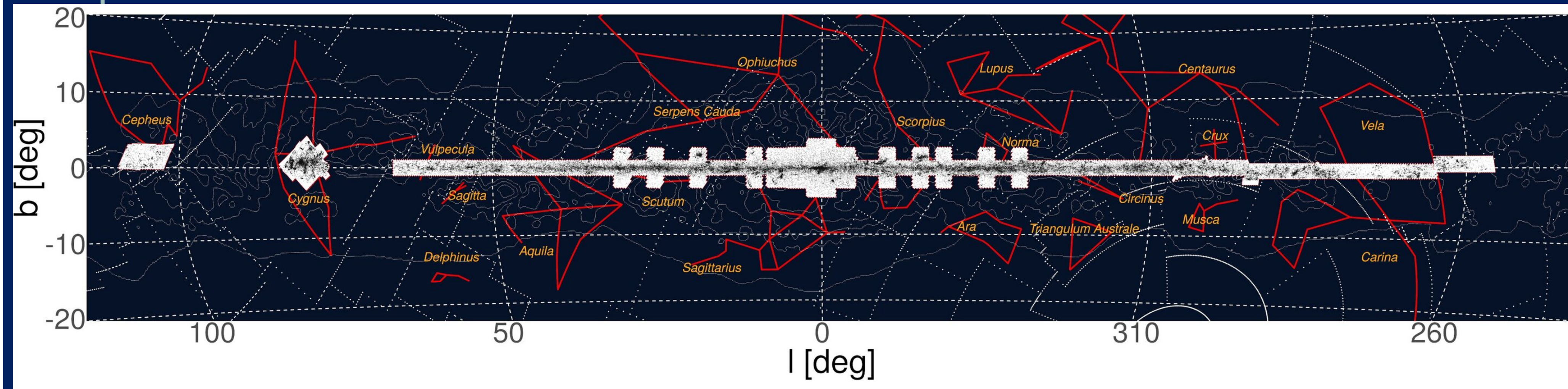
Fig. 1. Summary sketch of observational information on the Scorpius–Centaurus region. The OB-association Sco–Cen OB2 has three subgroups of ≈2000 $M_\odot$ each, formed over the last ≈15–20 Myr. Stars are currently forming in the ρ Ophiuchus (moving away from USco at about 1 km s^{-1}) and Lupus I (part of an expanding HI loop around USco) molecular clouds. See Table 1 for more details on the stars. HI shells are detected around the youngest OB subgroup, USco, and around the entire region. Diffuse soft X-ray emission is detected towards the superbubble at a level of 10^{35} erg s^{-1}. One of the detected signatures of massive star winds and supernova explosions is ^{26}Al, towards USco.

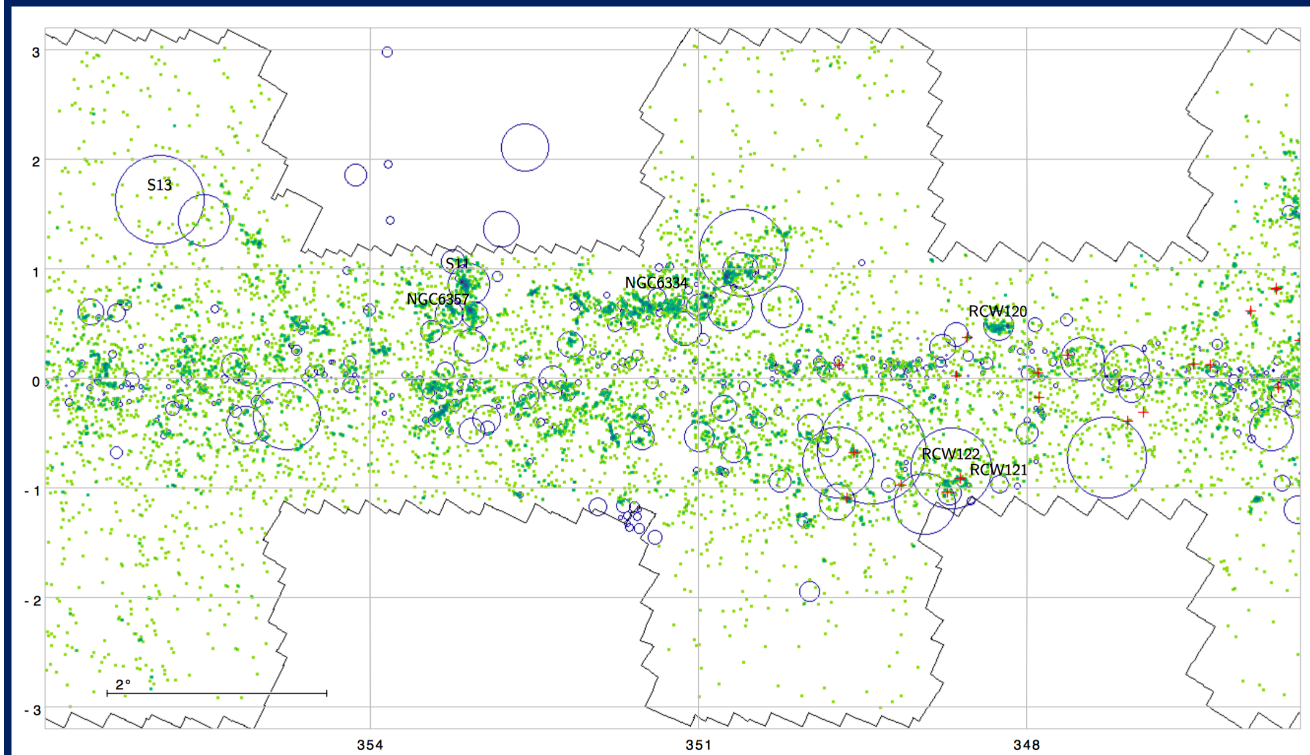
Krause, Burkert

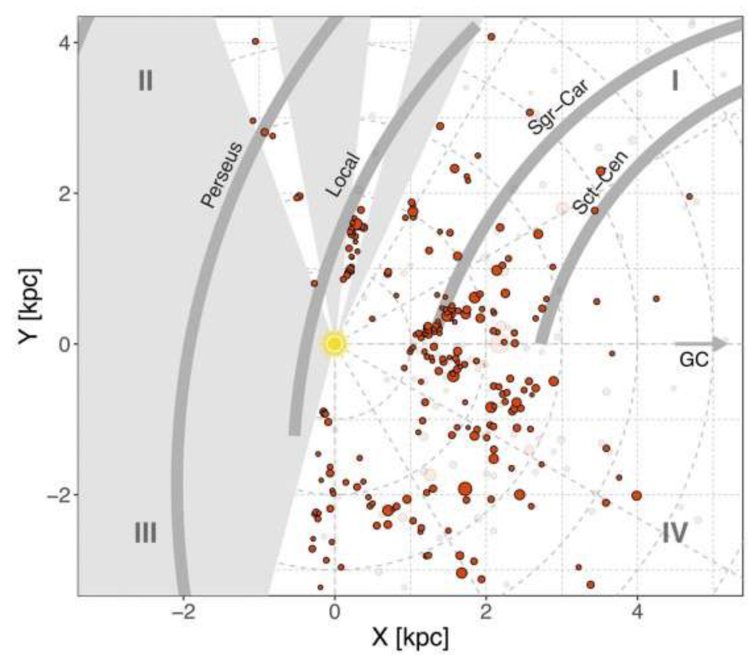

THE INFRARED MILKY WAY: GLIMPSE/MIPSGAL (3.6–24 microns)
SPITZER SPACE TELESCOPE
Galactic Latitude (degrees)
Galactic Latitude (degrees)
GLIMPSE team: Ed Churchwell (PI), Marilyn Meade, Brian Babler, Remy Indebetouw, Barbara Whitney, Christer Watson, Bob Benjamin, Steve Bracker, Thomas Robitaille, Stephan Jansen, Doug Watson, Mark Wolfire, Mike Wolff, Matt Povich, Tom Bania, Dan Clemens, Martin Cohen, Claudia Cyganowski, Katie Devine, Fabian Heitsch, Jim Jackson, Katharine Johnston, Chip Kobulnicky, John Mathis, Emily Mercer, Jeonghee Rho, Marta Sewilo, Susan Stolovy, Brian Uzpen
MIPSGAL team: Sean Carey (PI), Alberto Noriega-Crespo, Don Mizuno, Sachin Shenoy, Roberta Paladini, Kathleen Kraemer, Stephan D. Price, Nicolas Flagey, Erin Ryan, Daniela Goncalves, Remy Indebetouw, Thomas Kuchar, Eli Bressert, Francine Marleau, Jim Ingalls, Deborah Padgett, Luisa Rebull, Bruce Berriman, Babar Ali, Francois Boulanger, Roc Cutri, Bill Latter, Peter Martin, Marc-Antoine Miville-Deschenes, Sergio Molinari, Russell Shipman, Leonardo Testi
Poster designed by Thomas Robitaille and Robert Hurt

NEW CATALOG OF >10^5 YSOS

Kuhn, de Souza et al. 2021

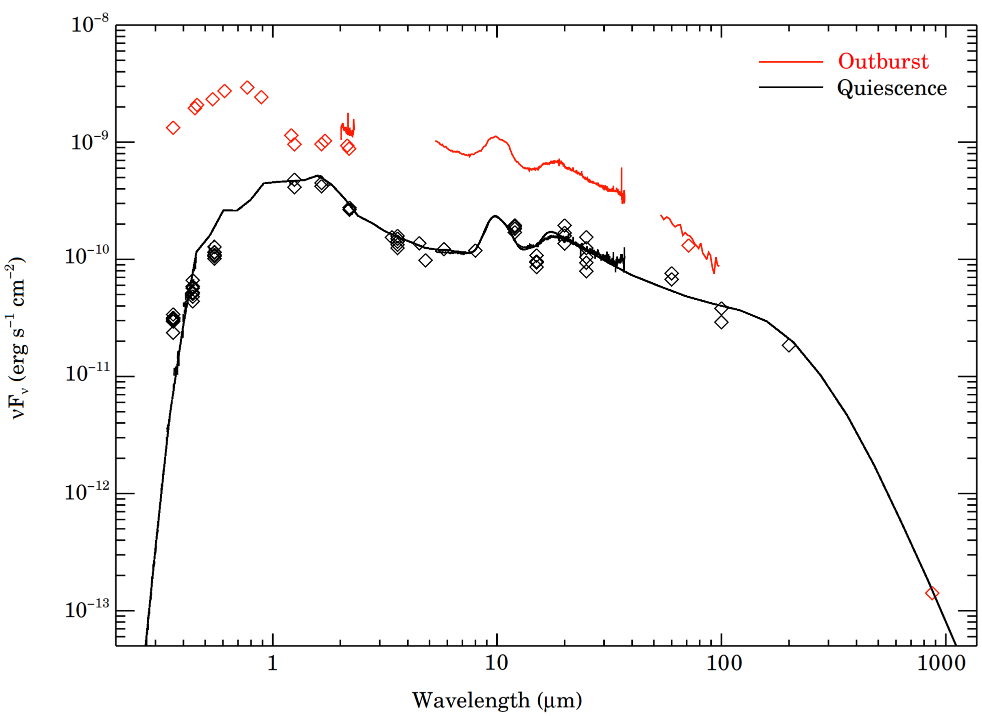


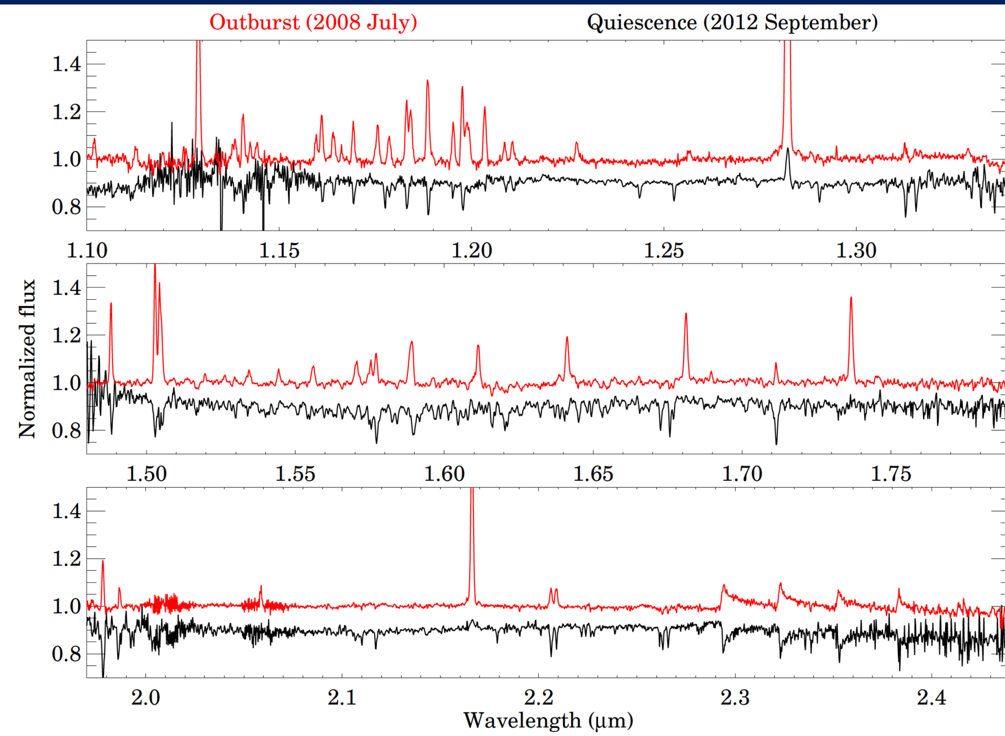




BOTTLENECK IS STILL SPECTROSCOPY

photometry ➔ SEDs (cheap) spectroscopy ➔ physics (expensive)





A. Kospal

PRE-MS EVOLUTIONARY THEORY

Amard et al.: Grid of rota

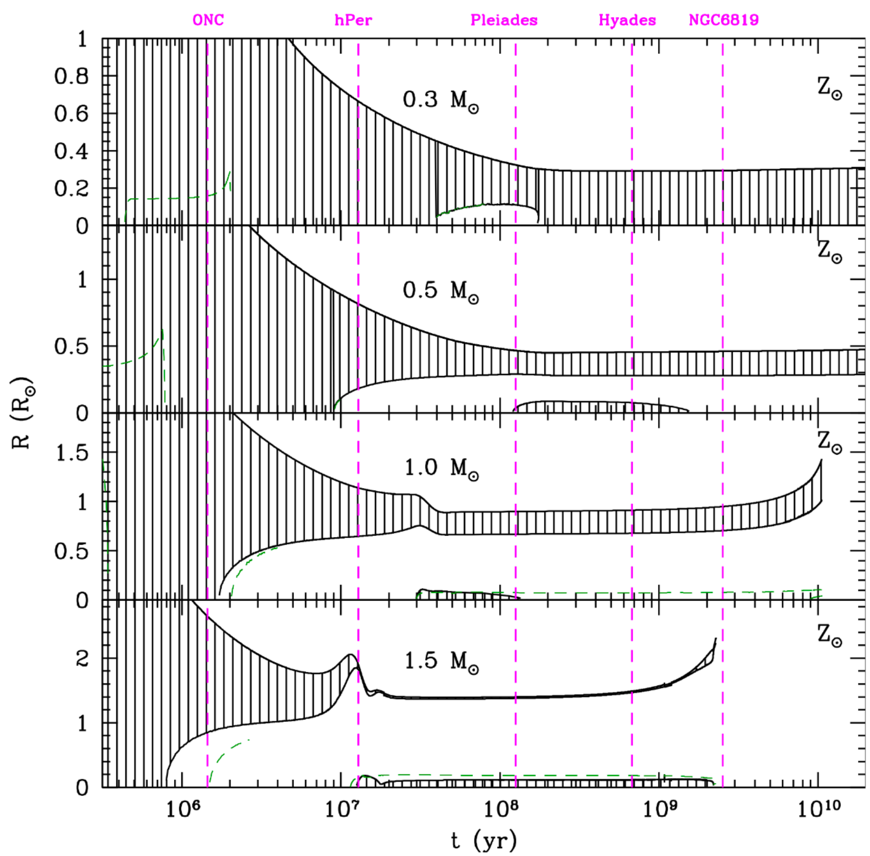


Fig. 5. Kippenhahn diagram showing the evolution of the internal structure of the non-rotating solar metallicity models of 0.3 (top), 0.5, 1.0 and 1.5 $M_\odot$ (bottom) from the PMS up to the end of the main sequence. The upper line represents the surface radius and hatched areas refer to convective regions. The green line displays the H-burning limit. The five pink vertical lines indicate the ages of open clusters used as markers of the evolution.

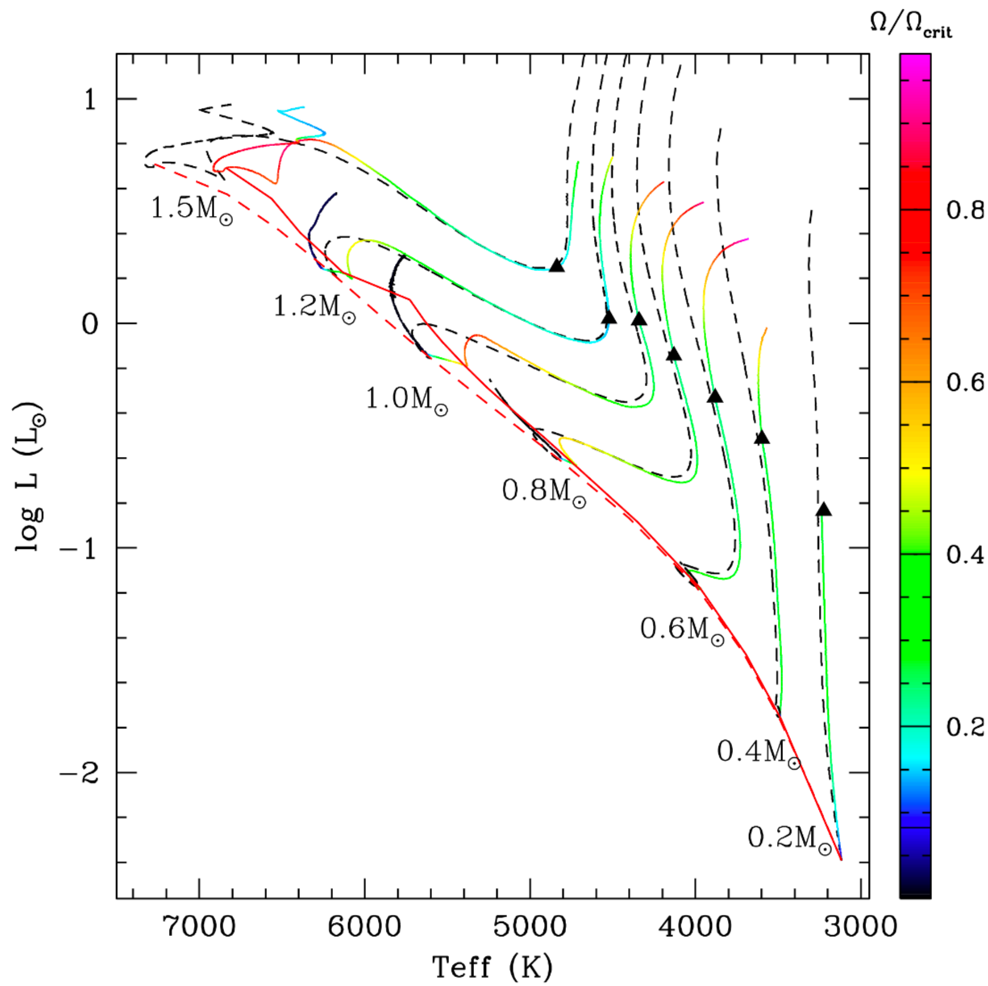
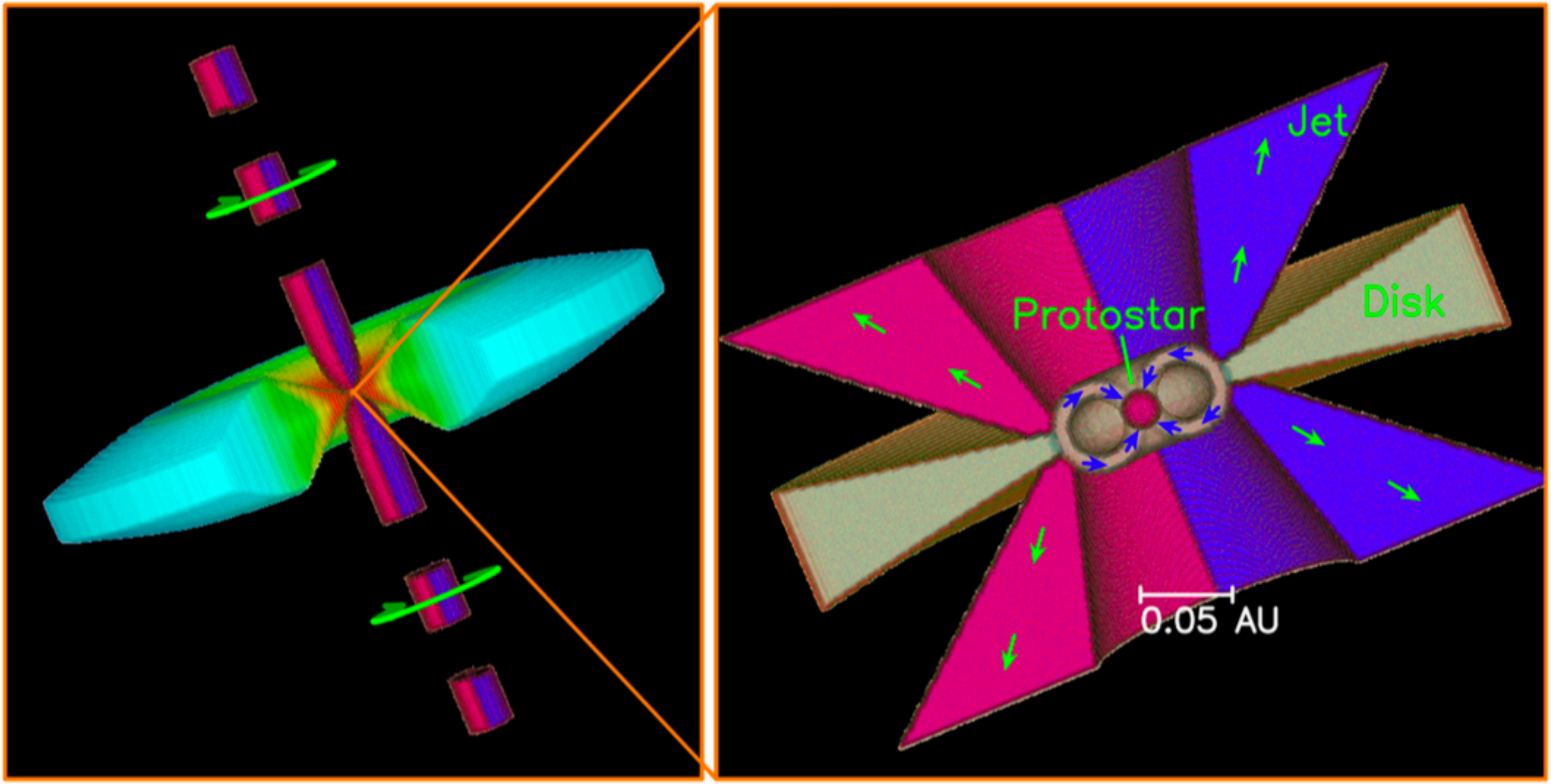


Fig. 4. HR diagram of solar metallicity models without (dashed black line) and with rotation (solid colored lines; here we show the fast rotators). The values of the surface velocity normalized to the break-up value (Ω/Ω_{crit}) increase from blue to red as shown on the right color bar. The black triangles indicate when the rotating models are released from their disc. The red lines indicate the standard (dashed) and rotating (solid) ZAMS.

CARTOON OF AN INDIVIDUAL YOUNG STAR ACCRETION/OUTFLOW SYSTEM



YSO SEDS CONSIST OF UNDERLYING STELLAR PHOTOSPHERE + CIRCUMSTELLAR DUST/GAS

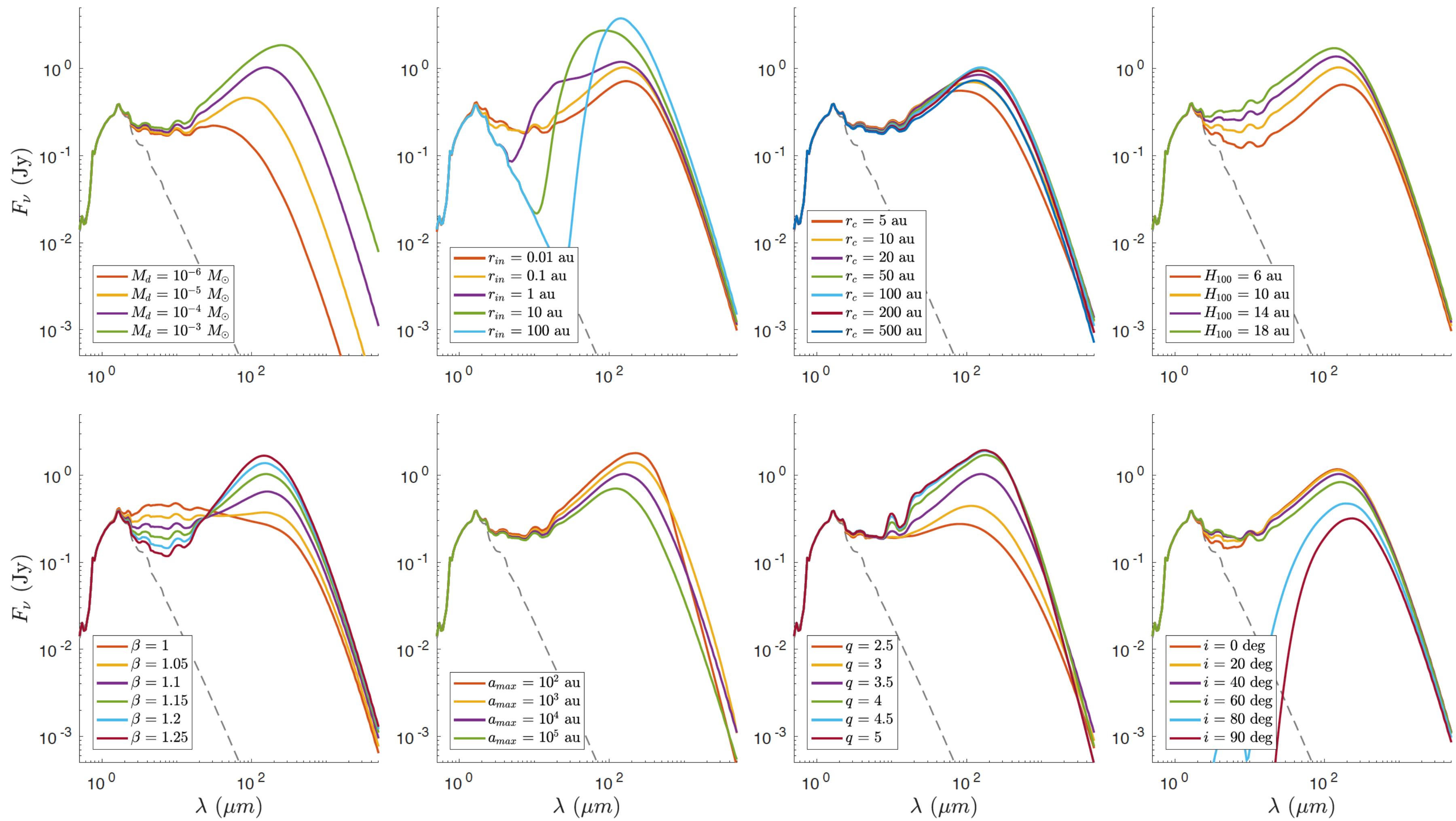


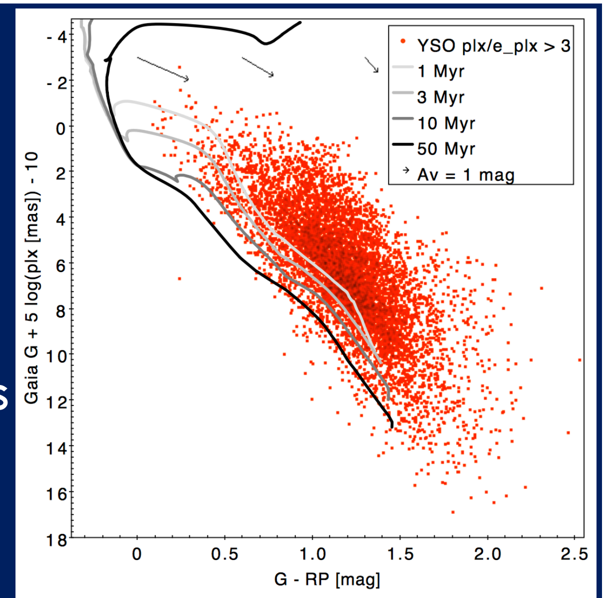
Figure 1. A demonstration of the effect on the model SED by varying each of the eight free parameters from the fiducial model. The dashed gray line in each plot is the stellar photosphere.

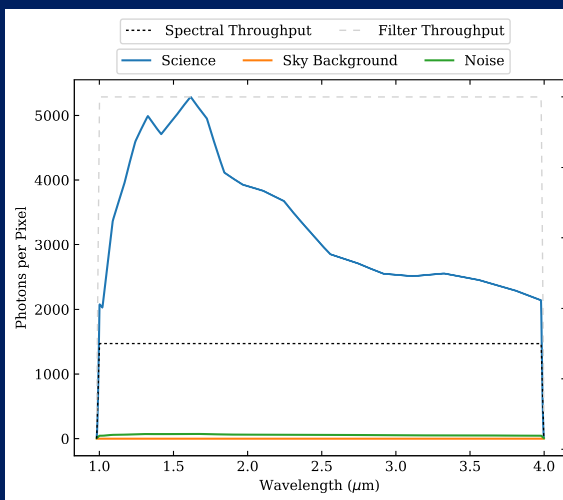
WHAT CAN ATLAS DO?

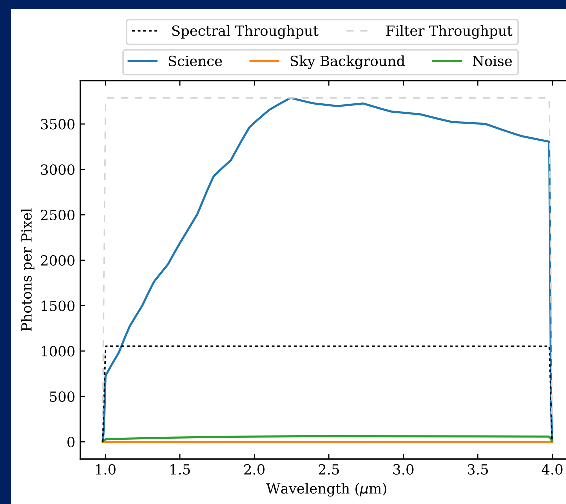
1-4 um spectrophotometry

R = 1000 spectroscopy ➔ spectral typing; emission lines

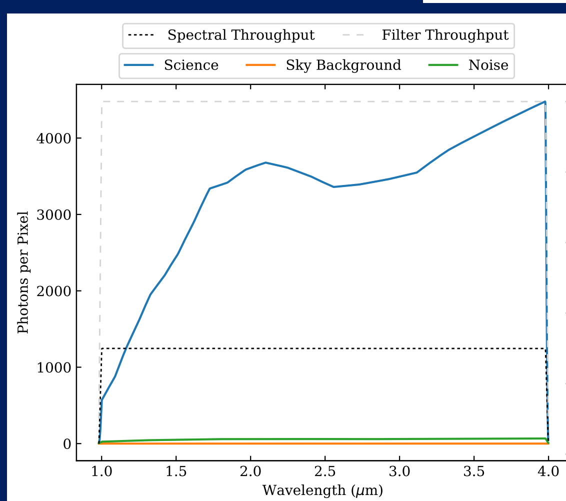
YSOs at SNR=60 out to beyond 2.5-3 kpc!

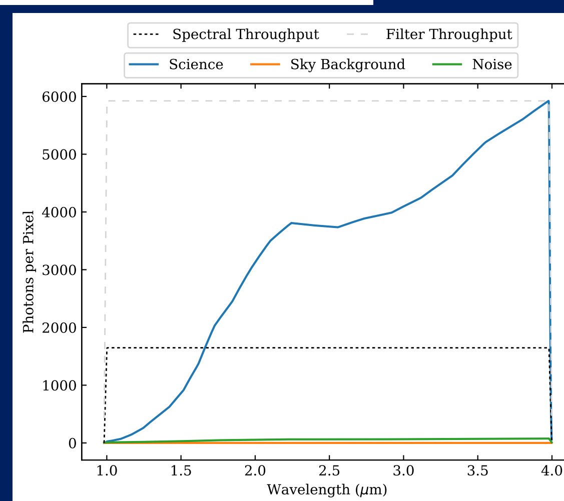


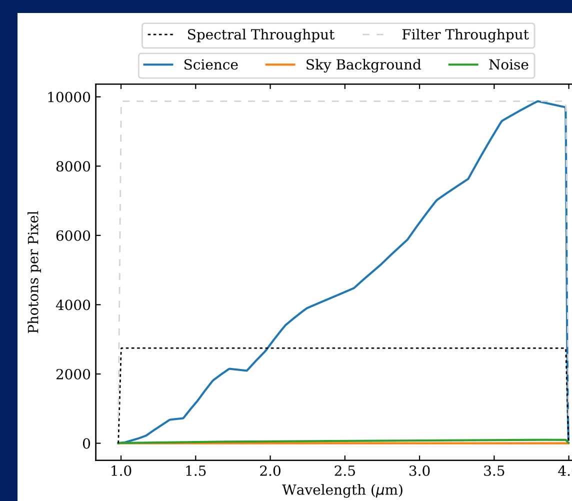




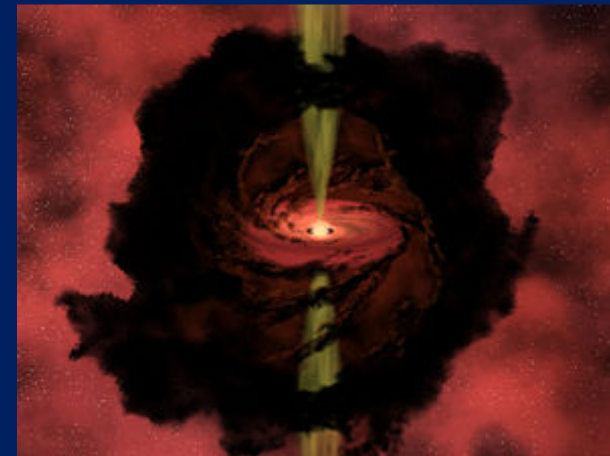
range of SED shapes at K=14 mag (current sample limited by Gaia sens.)

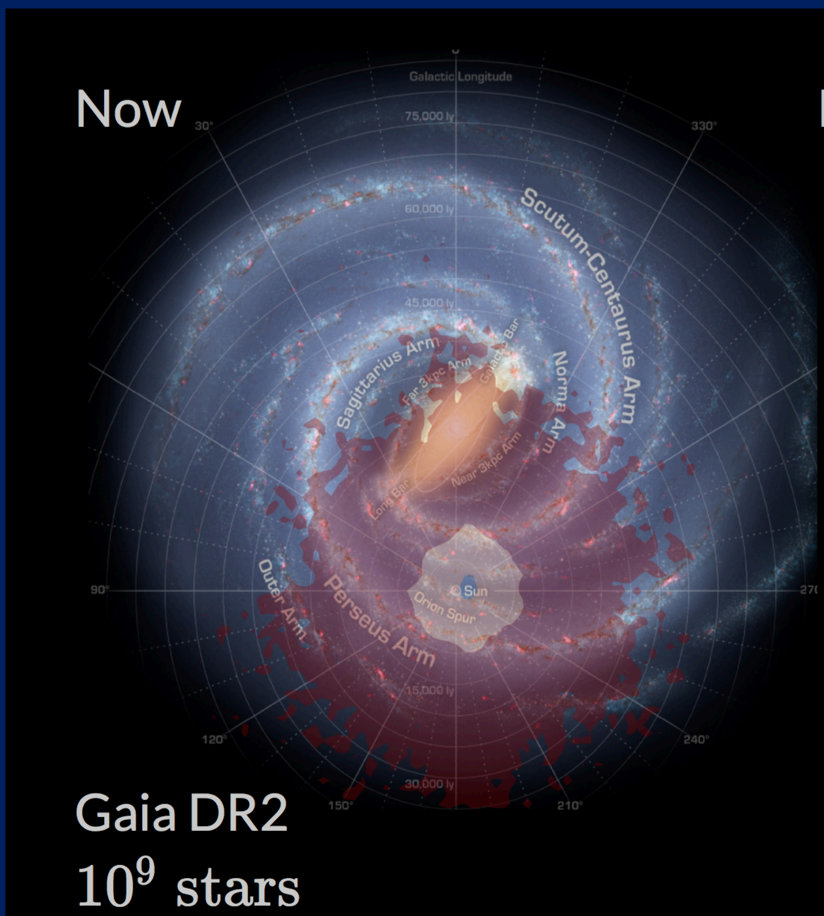






BUILDING HR DIAGRAMS FOR YOUNG STARS





Spectral type from optical or infrared spectra used to estimate photospheric temperature.

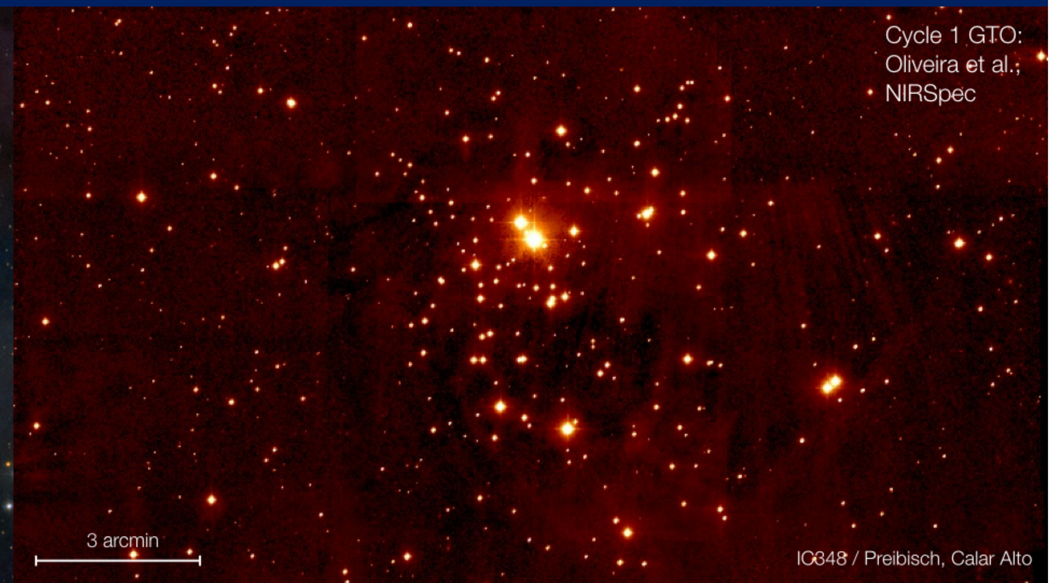
Accretion effects need to be taken into account.

De-reddened photometry plus bolometric correction *and distance* allows luminosity estimate.

Few months of ATLAS with multiple DMD reconfiguations per pointing to survey entire galactic plane.

graphic courtesy of Y.-S. Ting

COMPLEMENTS JWST-TARGETTED NEARBY STAR FORMING REGIONS



graphic courtesy of M. McCaughrean