The *Chandra* Carina Complex Project:
A Spatially Resolved X-ray and Infrared Study of the Nearest Galactic Starburst Region

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CCCP Collaboration

16 papers published in a **May 2011** Special Issue of ApJS!
Available at http://cochise.astro.psu.edu/Carina_public/special_issue.html

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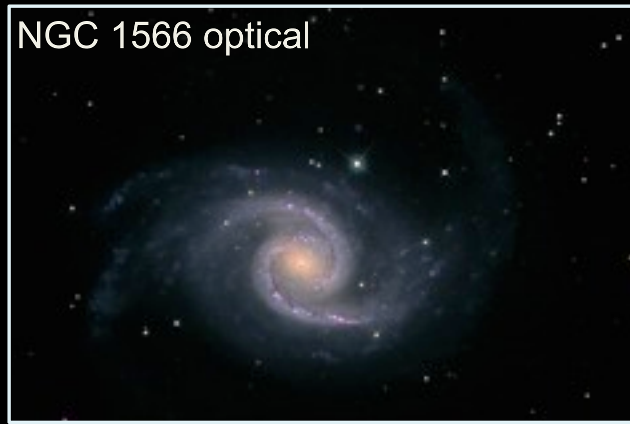
PLUS: About 50 other people!

Motivation: H II Regions as Tracers of Star Formation

- *Extragalactic (see Kennicutt 1998)*
  - Broadband UV/optical colors
  - Optical/near-IR recombination lines (and forbidden lines)
  - **IR continuum** (alone or combined with Hα; Calzetti et al. 2007; Kennicutt et al. 2009)
- *Galactic*
  - **Thermal radio continuum** (Smith, Biermann, & Mezger 1978; Schraml & Mezger 1982; Murray & Rahman 2010)
  - Global IR continuum (Misiriotis et al. 2006)
  - Supernova rate (Diehl et al. 2006)



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All of the above employ *indirect* observational tracers sensitive *only* to the most massive <1% of stars!

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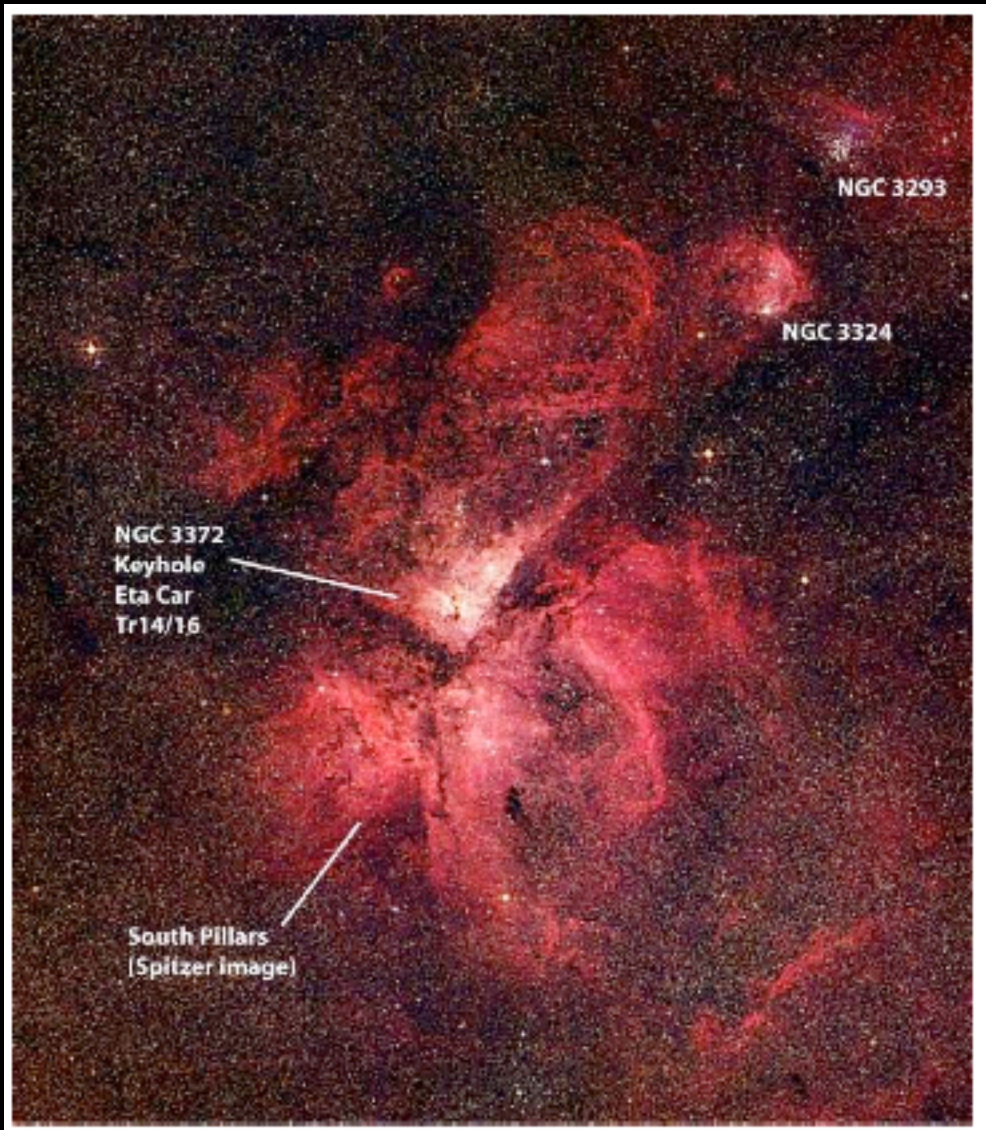
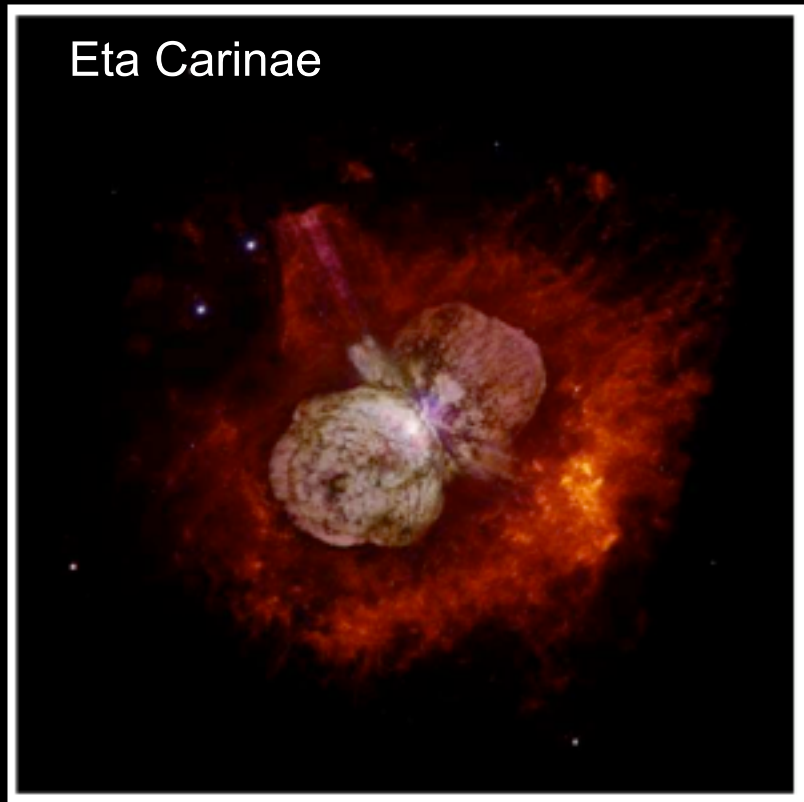
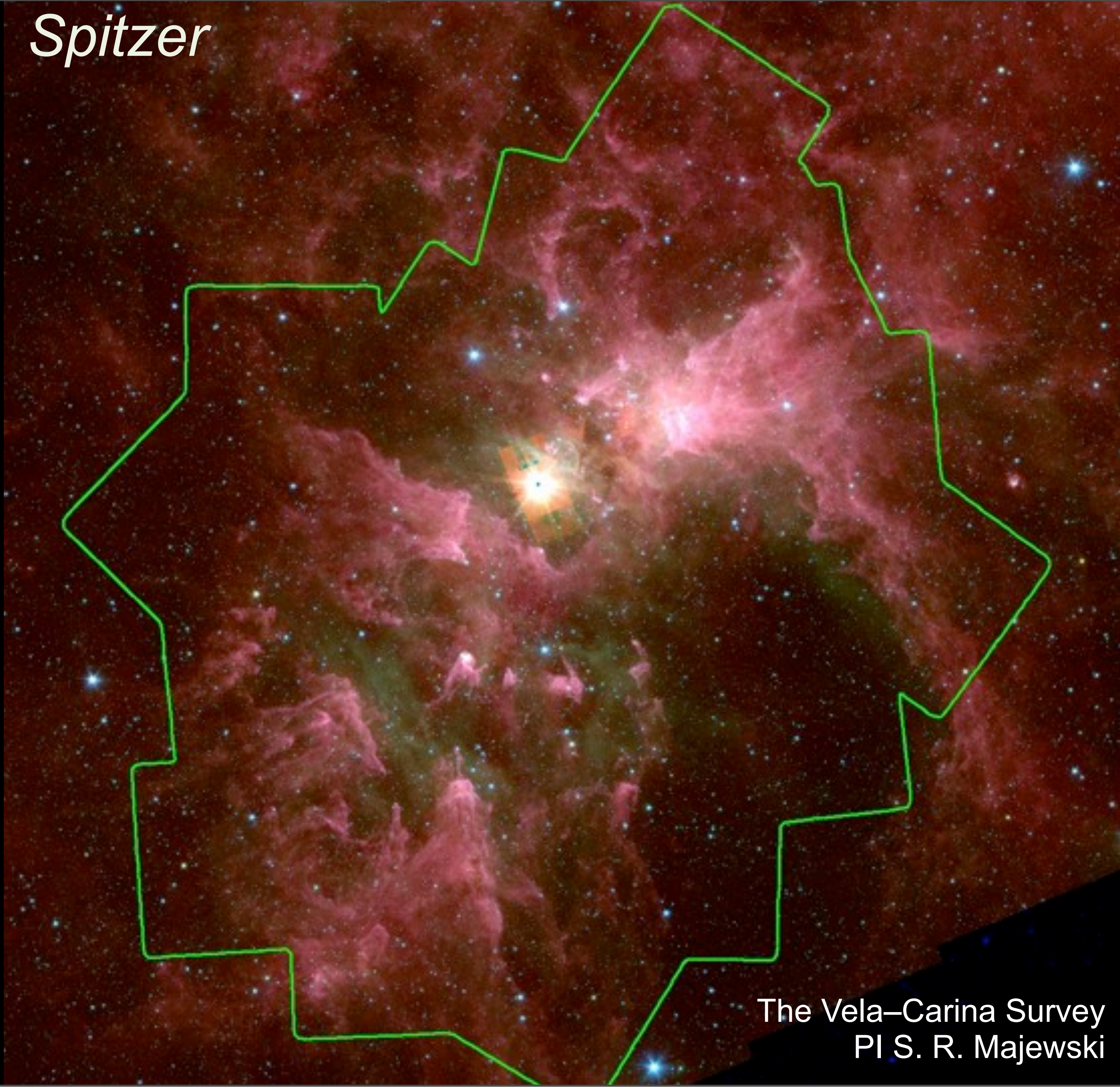
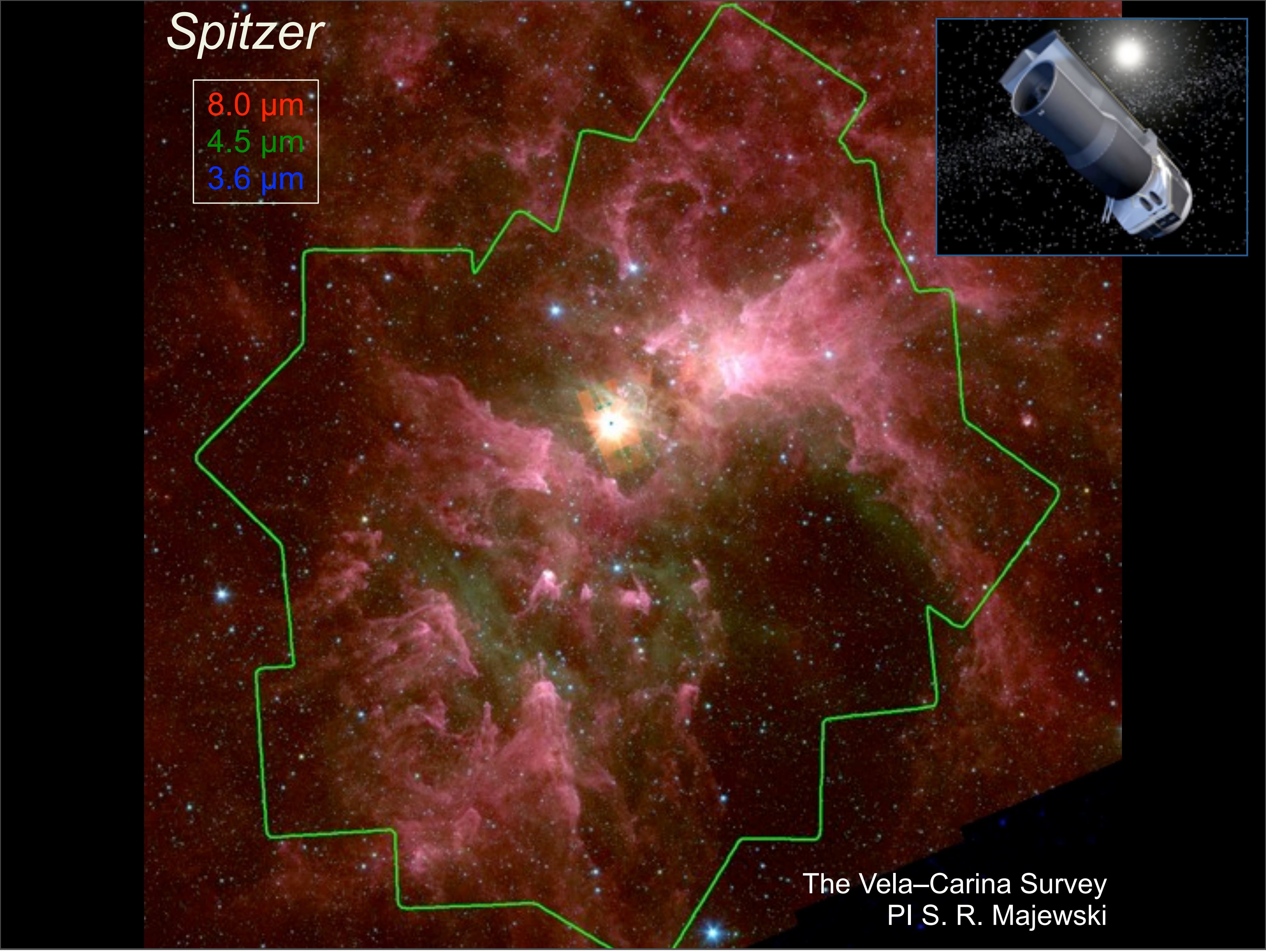
- Why Carina?
  - Nearest analog of extragalactic "starburst" regions.
  - Because we're masochists…

The Great Nebula in Carina






Spitzer
The Vela–Carina Survey
PI S. R. Majewski


Spitzer
8.0 µm
4.5 µm
3.6 µm
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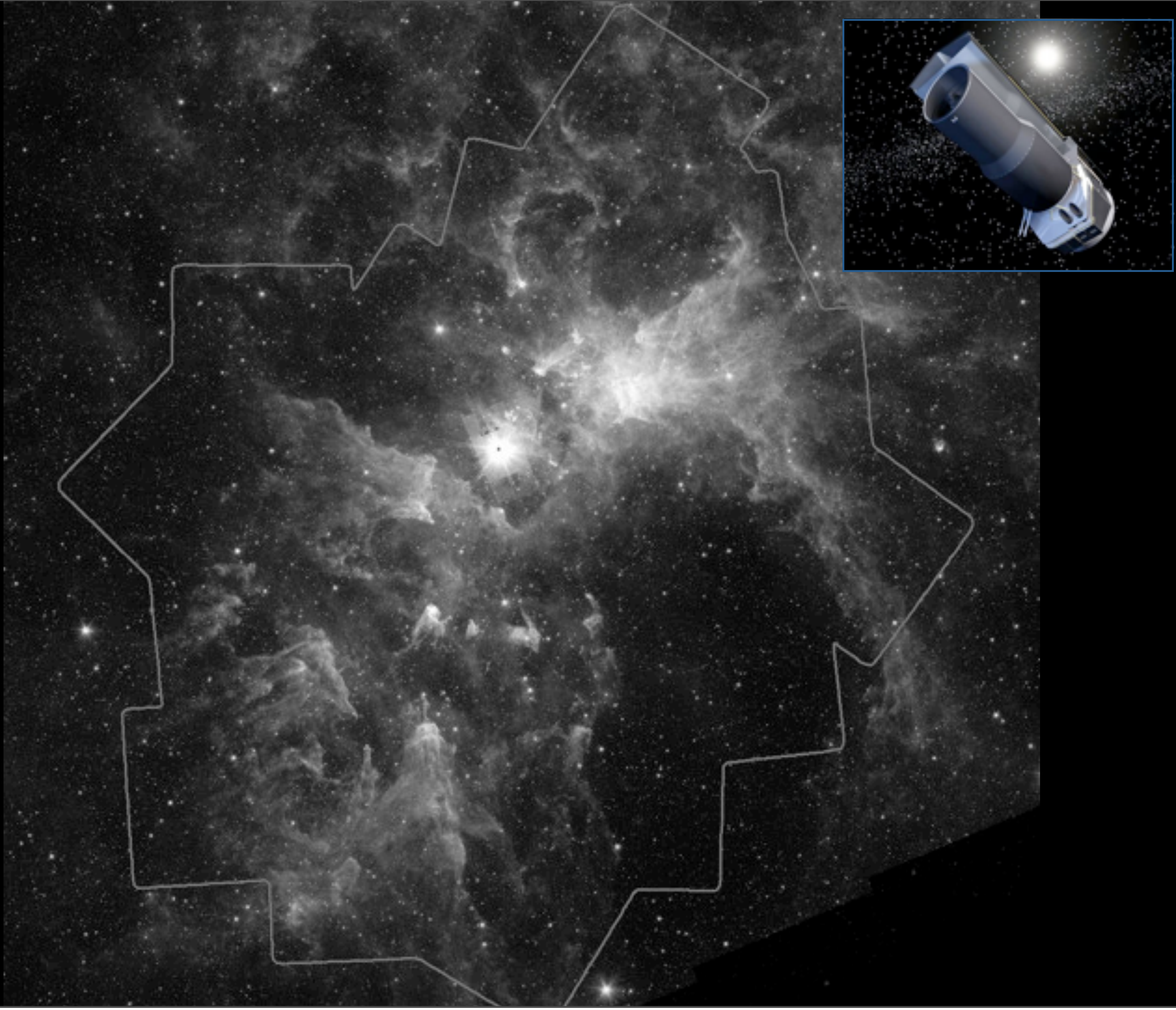
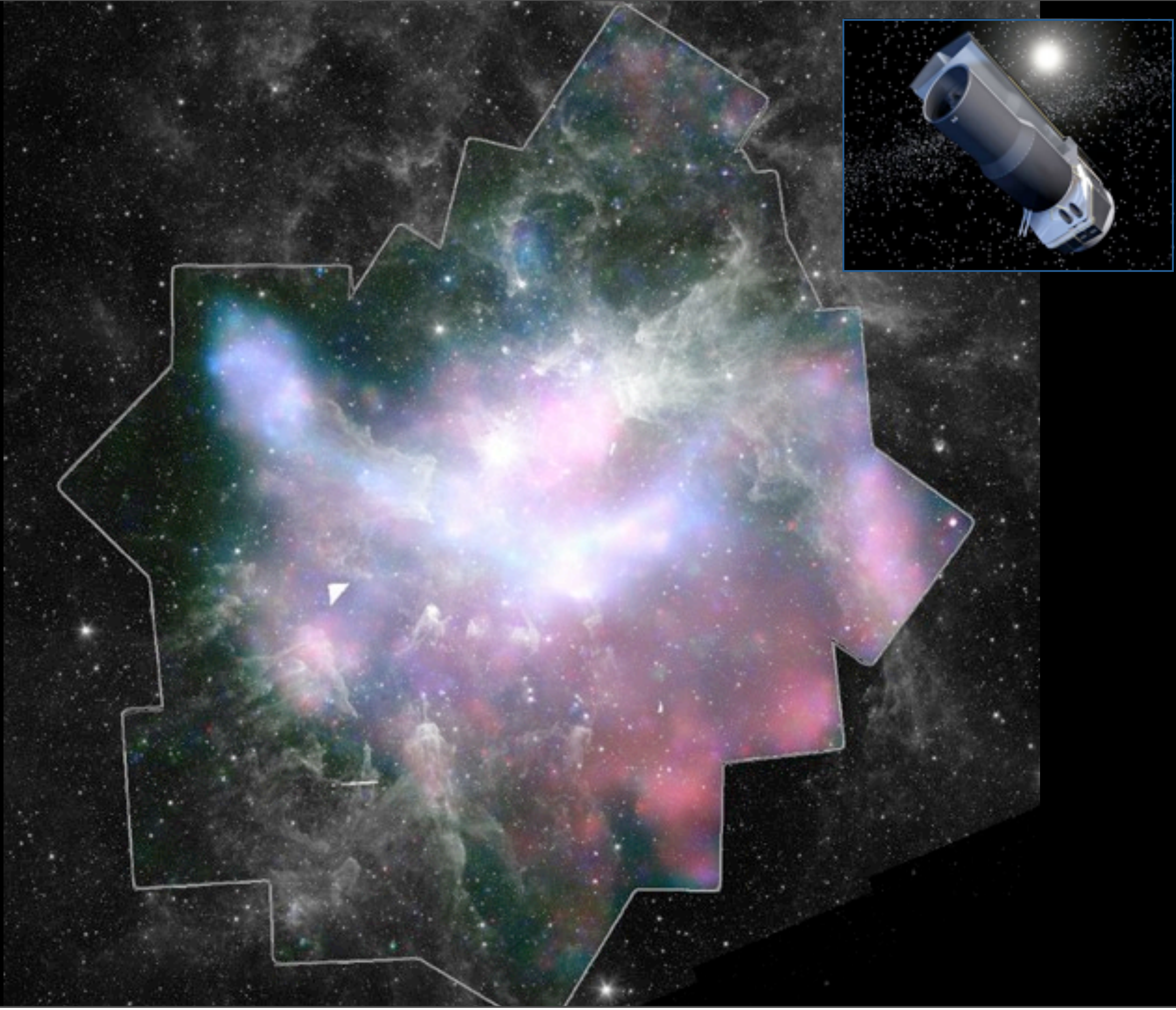
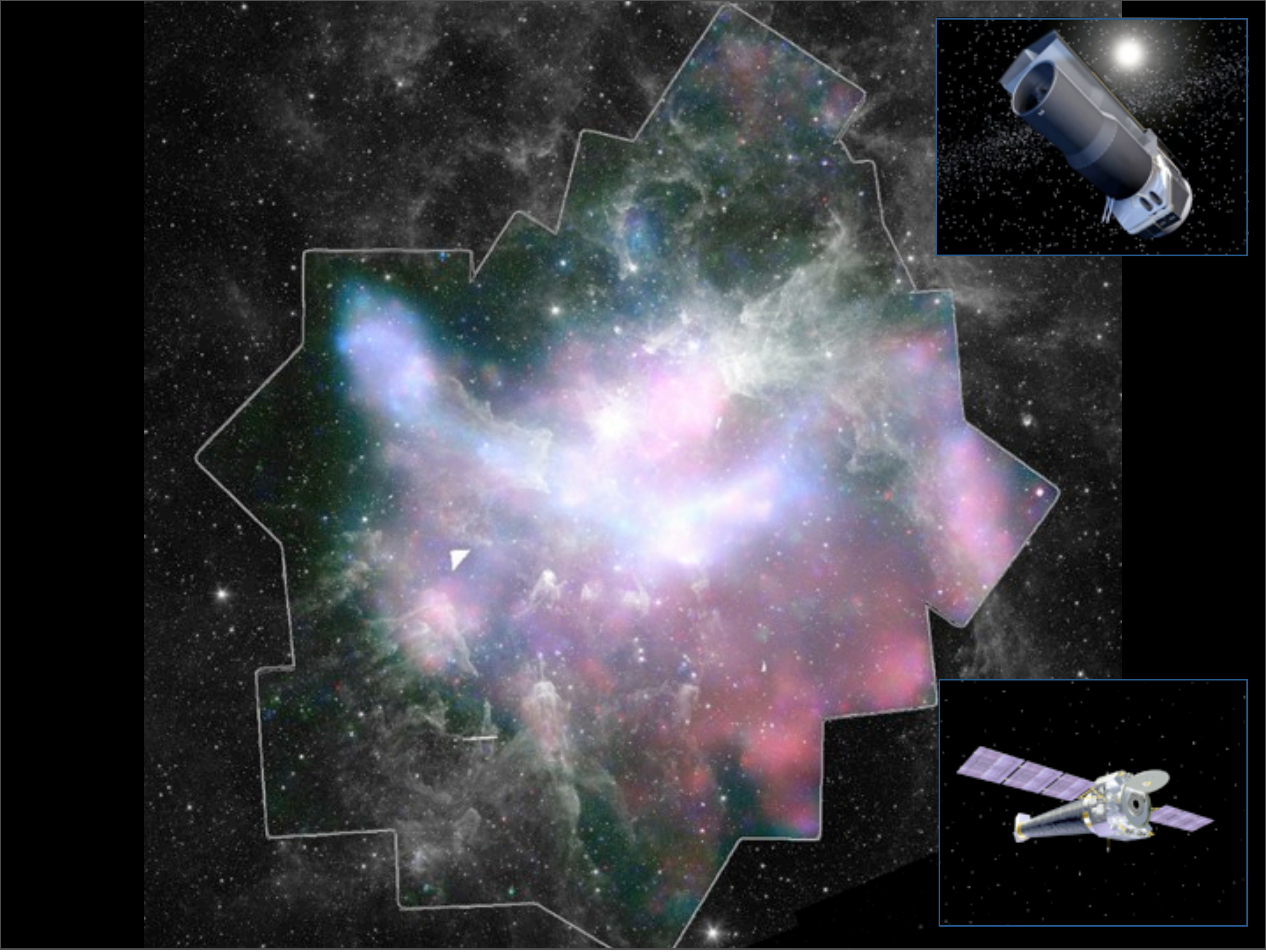
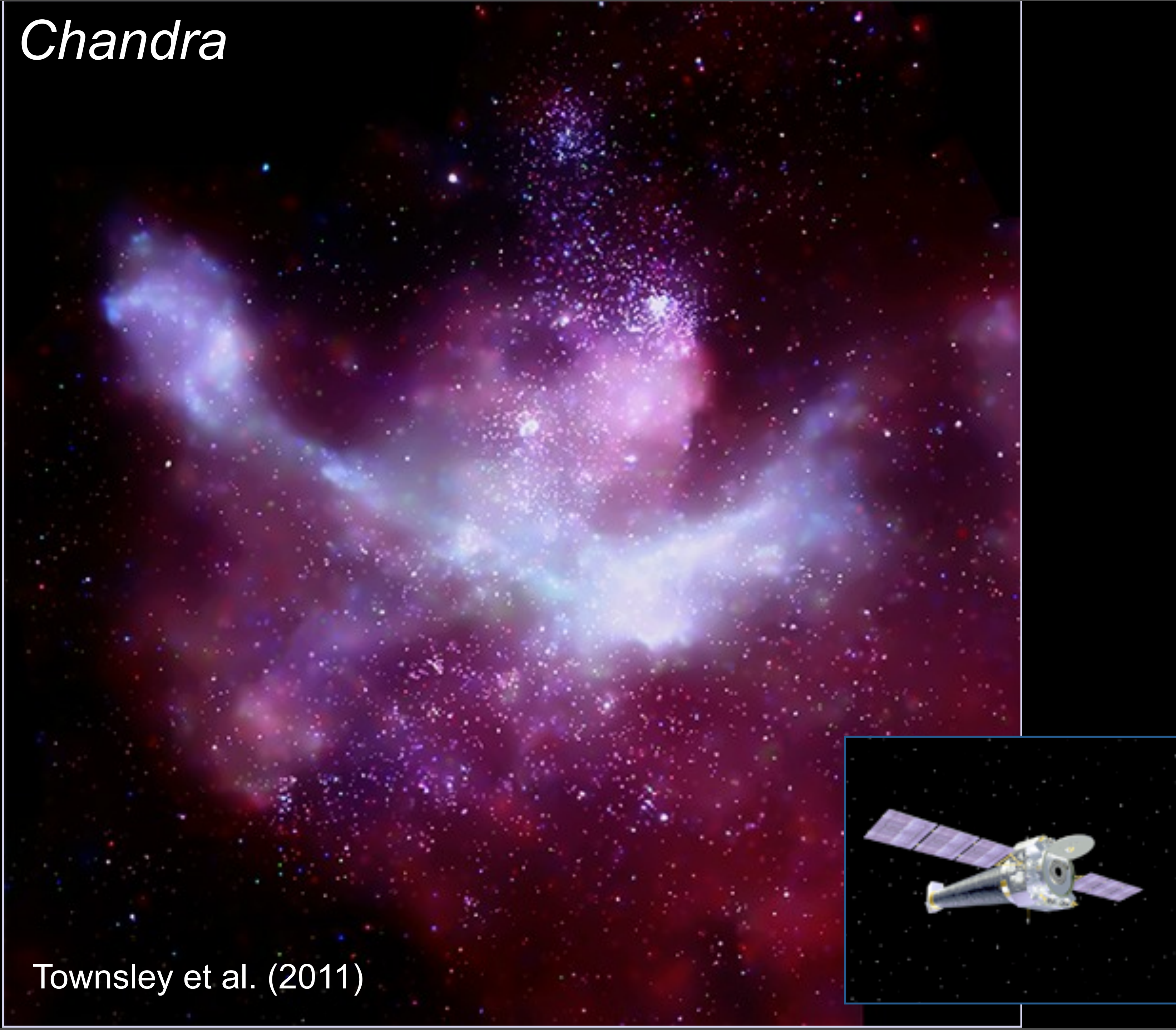
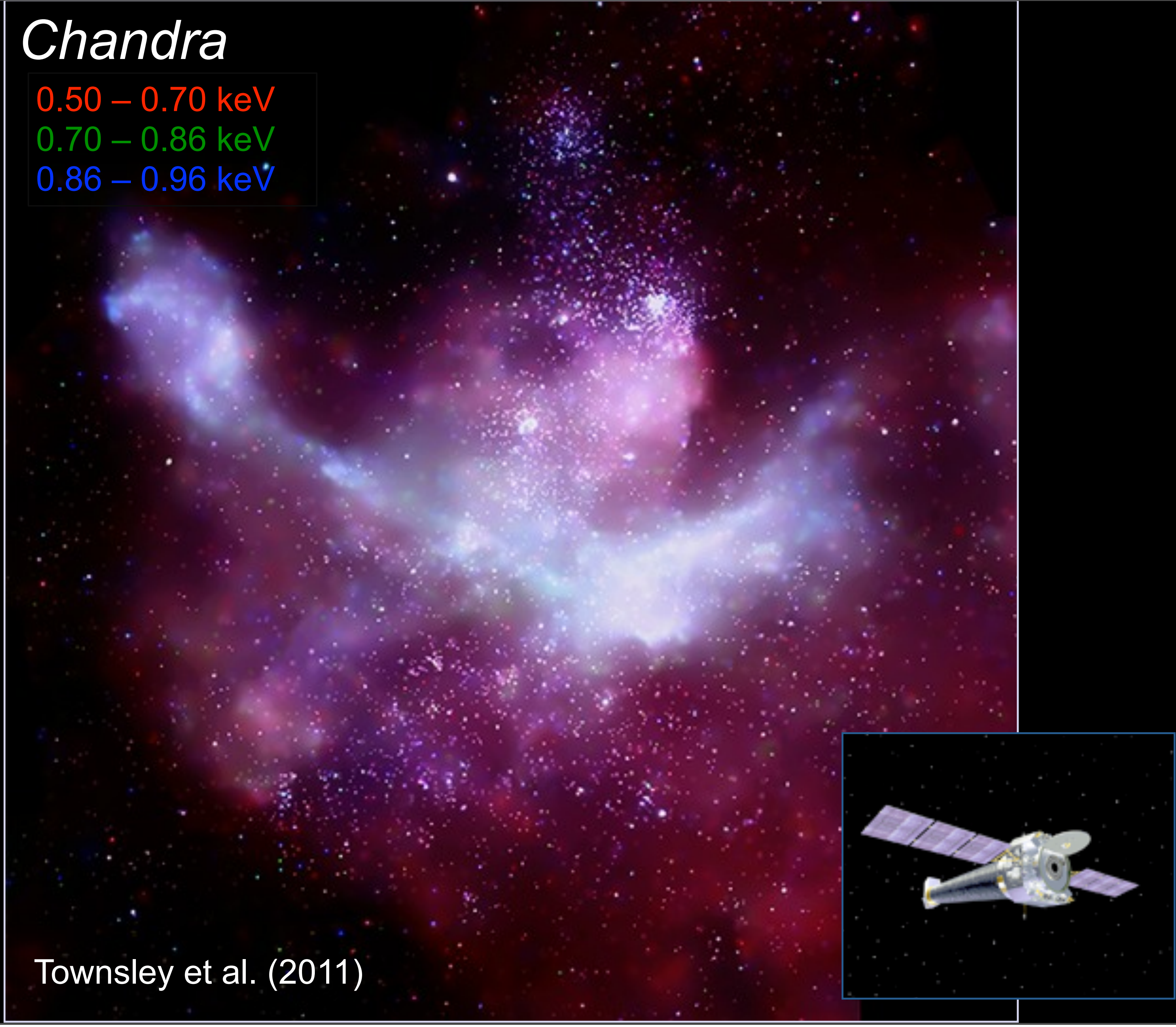






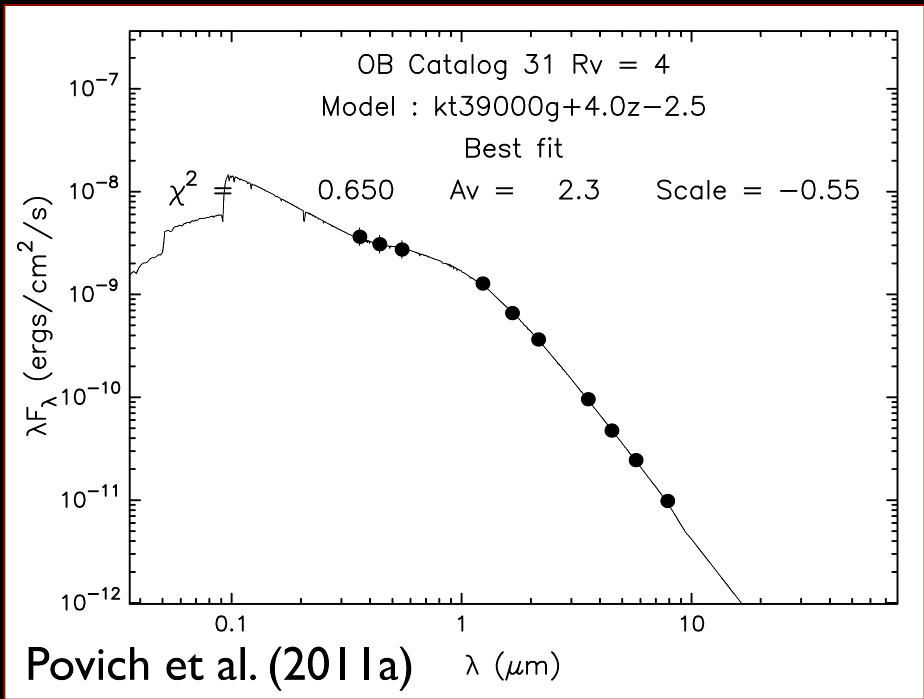

Chandra
Townsley et al. (2011)


Chandra
0.50 – 0.70 keV
0.70 – 0.86 keV
0.86 – 0.96 keV
Townsley et al. (2011)

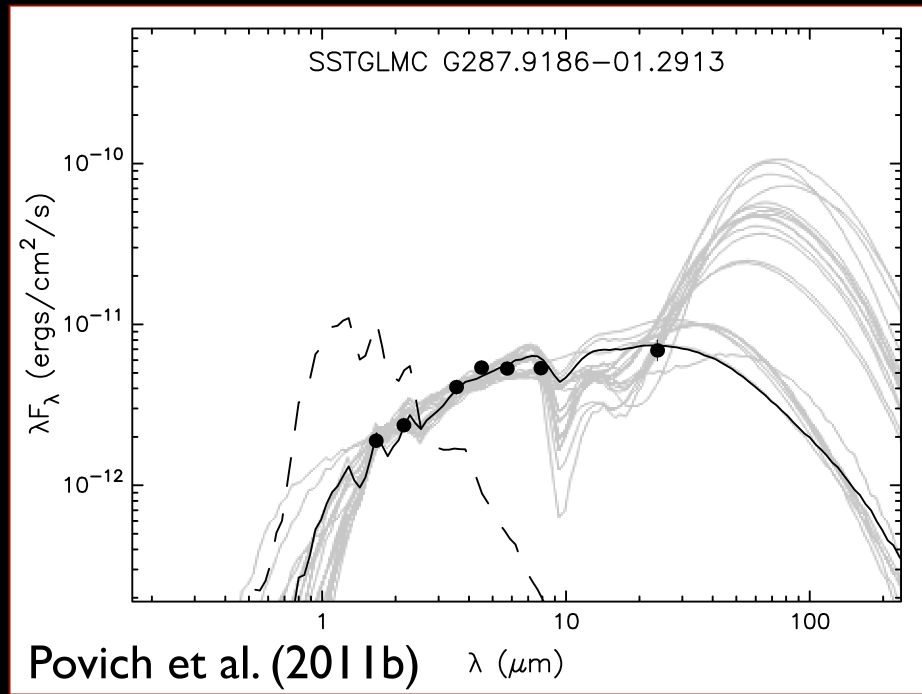
X-rays from Young Stars

- Pre-main-sequence (PMS) stars
  - Magnetic reconnection flares produce hard (>2 keV) X-rays (e.g. Preibisch et al. 2005).
- Massive stars (O and early B types)
  - "Microshocks" in strong stellar winds produce soft (<1 keV) X-rays (Lucy & White 1980).
  - More exotic mechanisms (Colliding wind binaries? Magnetically channeled wind shocks?) produce hard (>1 keV) X-rays (e.g. Gagné et al. 2011).
- Intermediate-mass main-sequence stars
  - No known source of strong X-ray emission (no convection-driven dynamos to produce flares, winds are not strong enough).
  - X-ray emission associated with intermediate-mass stars is usually attributed to the presence of a lower-mass companion (e.g. Evans et al. 2011).

Infrared Spectral Energy Distribution (SED) Fitting Analysis



Povich et al. (2011a)

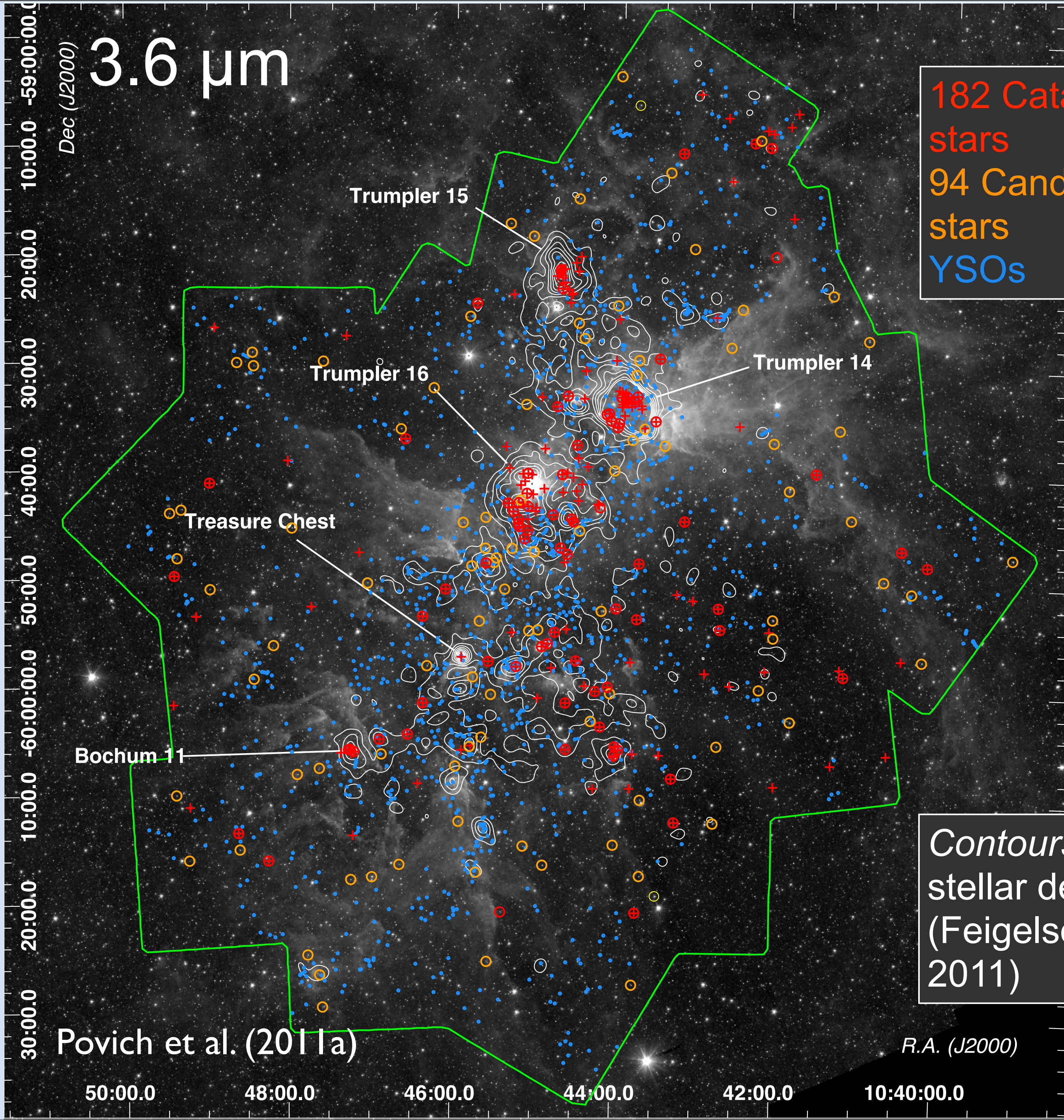


Povich et al. (2011b)

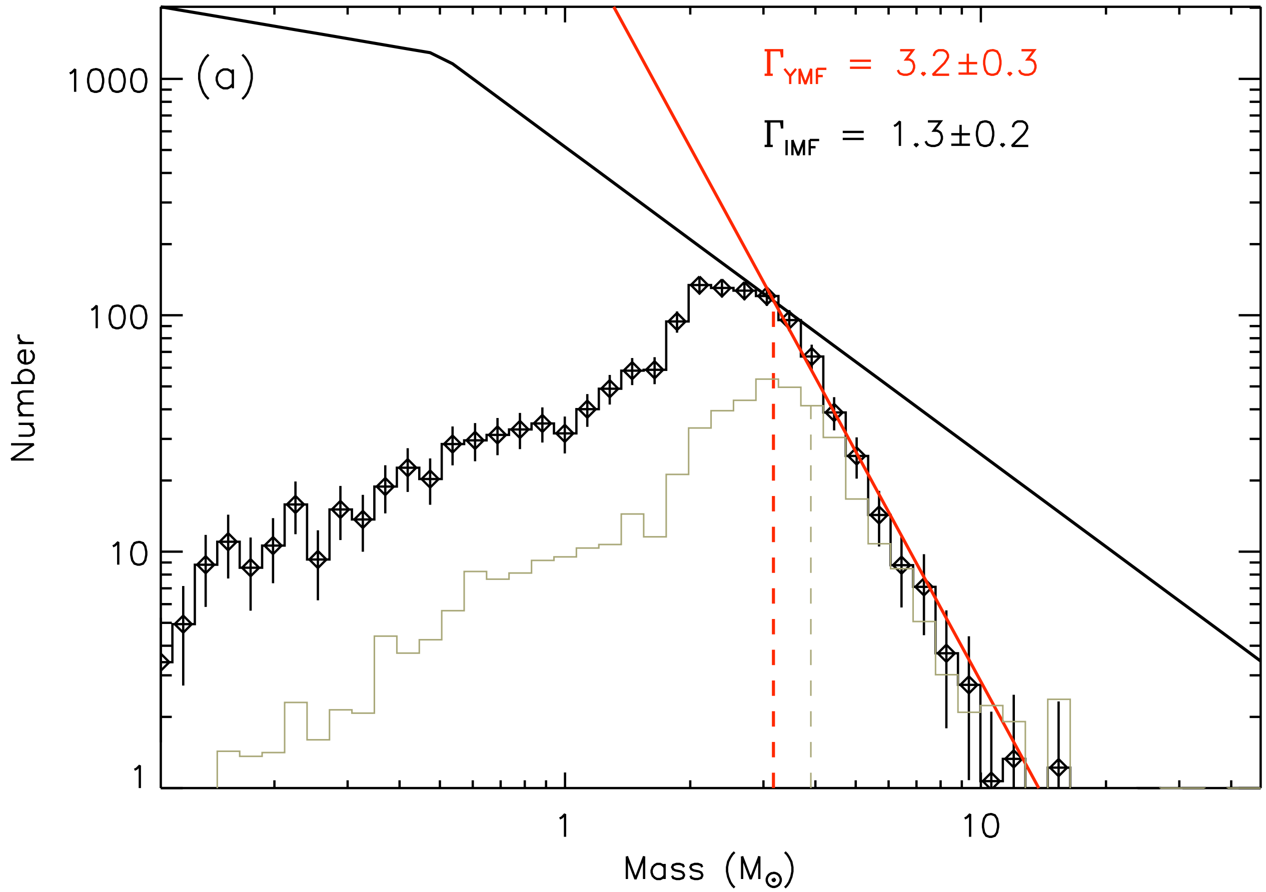
O-type star:
No IR excess emission

Young Stellar Object (YSO):
Stage 0/I, strong IR excess emission

Primary references: Robitaille, Whitney, et al. (2006, 2007)


3.6 µm
Dec (J2000)
-59:00:00.0
10:00.0
20:00.0
30:00.0
40:00.0
50:00.0
-60:00:00.0
10:00.0
20:00.0
30:00.0
Trumpler 15
Trumpler 16
Trumpler 14
Treasure Chest
Bochum 11
182 Cataloged OB stars
94 Candidate OB stars
YSOs
Contours: CCCP stellar density (Feigelson et al. 2011)
Povich et al. (2011a)
R.A. (J2000)
50:00.0
48:00.0
46:00.0
44:00.0
42:00.0
10:40:00.0

YSO Mass Function (YMF)



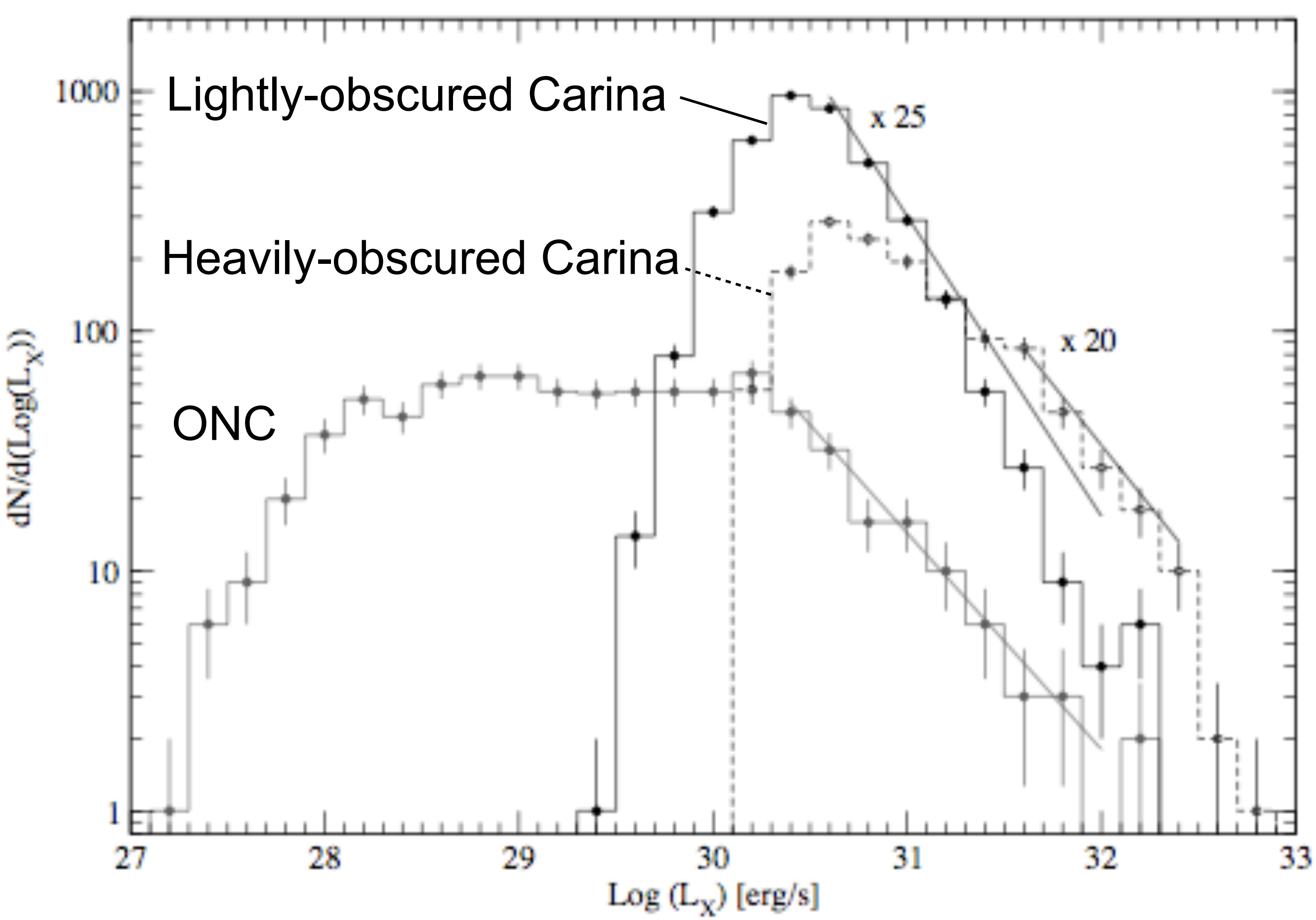
1439 YSOs *detected*, incomplete for *m* < 3.1 M_{Sun}

>20,000 YSOs *predicted*, with TOTAL mass >16,000 M_{Sun}, extrapolated to *m* ≥ 0.1 M_{Sun}

Present-Day SFR: >0.008 M_{Sun}/yr

Black curve: Stellar initial mass function (IMF; Kroupa 2001)
Red curve: Best-fit power law to intermediate-mass YMF (Povich & Whitney 2010; Povich et al. 2011b)

X-ray Luminosity Function (XLF)



Povich et al. (2011b)

Scaling XLF from 840 stars in the Orion Nebula Cluster (ONC) to match Carina XLFs gives an estimate of total stellar population

>38,000 *diskless* PMS stars *predicted*, extrapolated to $m \geq 0.1$ M$_{Sun}$

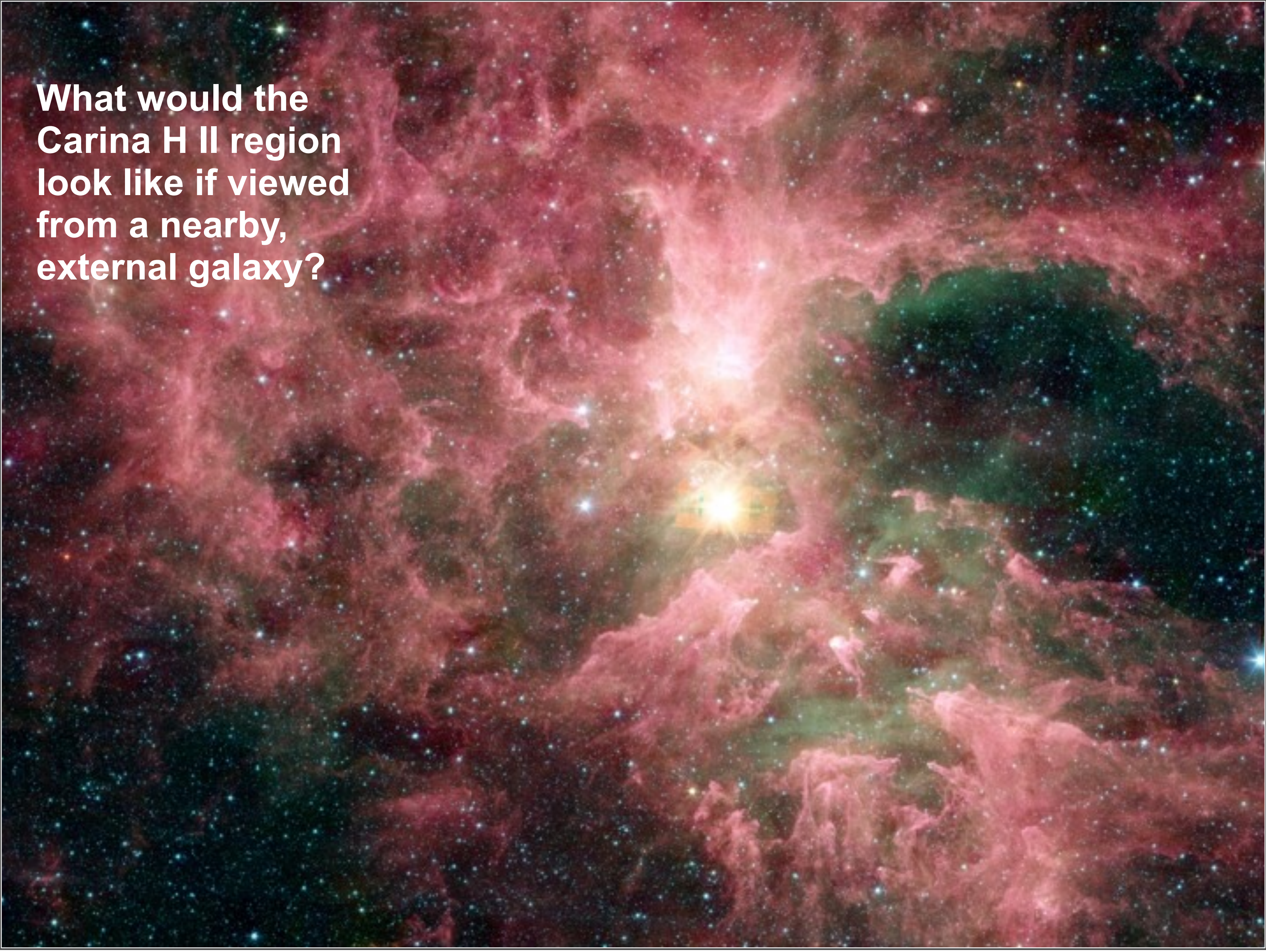
Combination Mid-IR and X-ray Analysis of Carina Nebula Population

- *Global* population: 5.8–7.4 × 10^4 stars, containing 4.6–5.9 × 10^4 M_{Sun} total mass.
- SFR: 0.009–0.012 M_{Sun}/yr, *averaged* over past 5 Myr, punctuated by more intense bursts.
- Global circumstellar disk fraction (mid-IR excess fraction) = 30%.

Lessons from the CCCP

- Extrapolating IMF from known massive star content of Carina Nebula *underestimates* total stellar population.
- Candidate obscured, X-ray-emitting OB stars could increase known massive stellar population by up to a factor of ~2.
- Approximately constant SFR averaged over past ~5 Myr, representing ~0.5% of the total Milky Way SFR.

[and we're not *quite* done...]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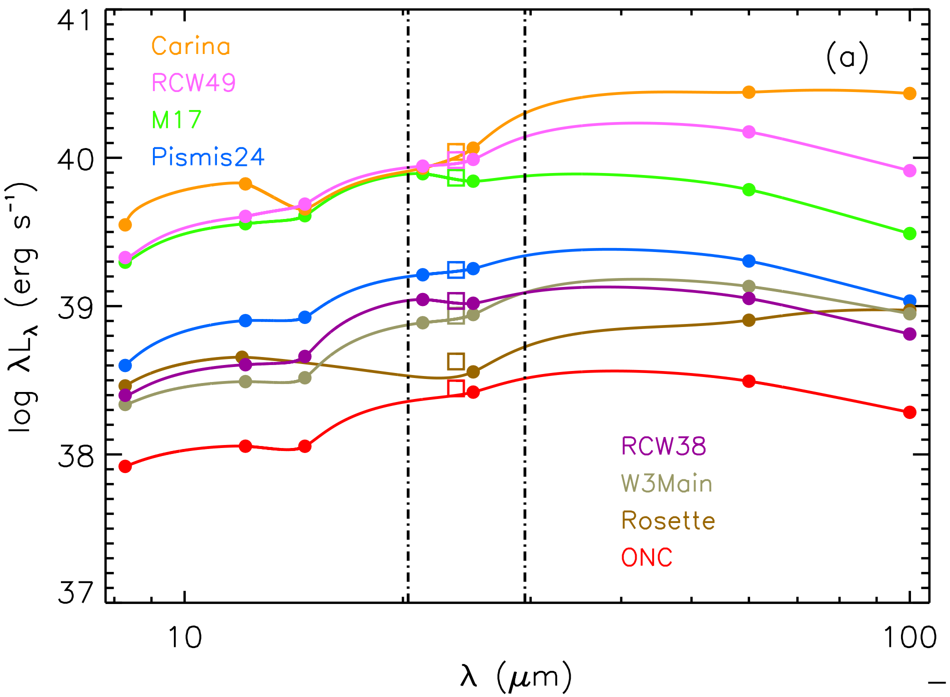
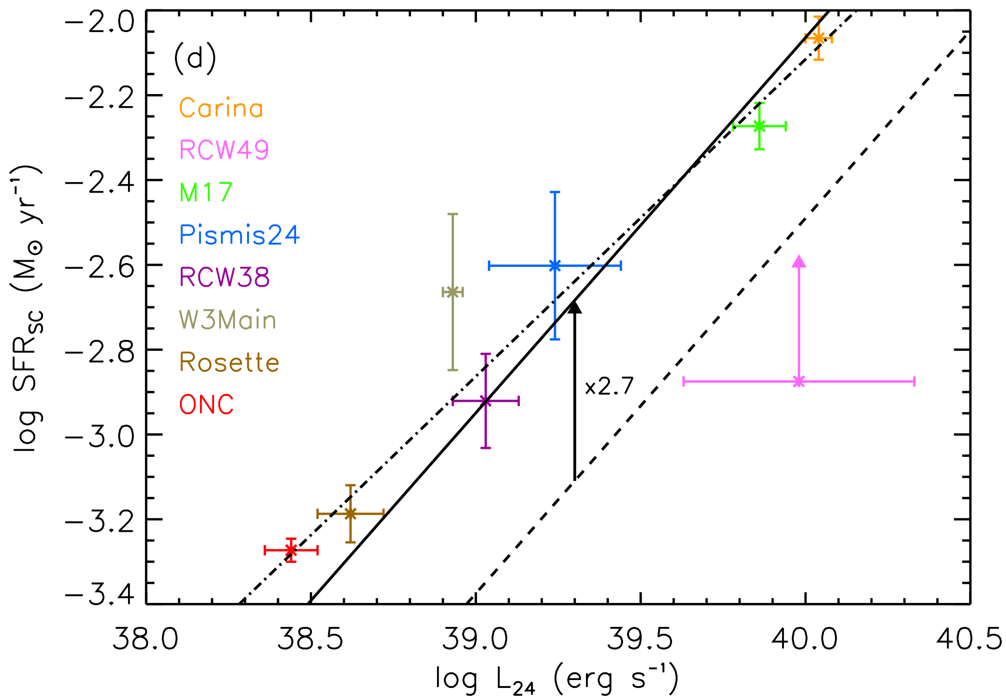
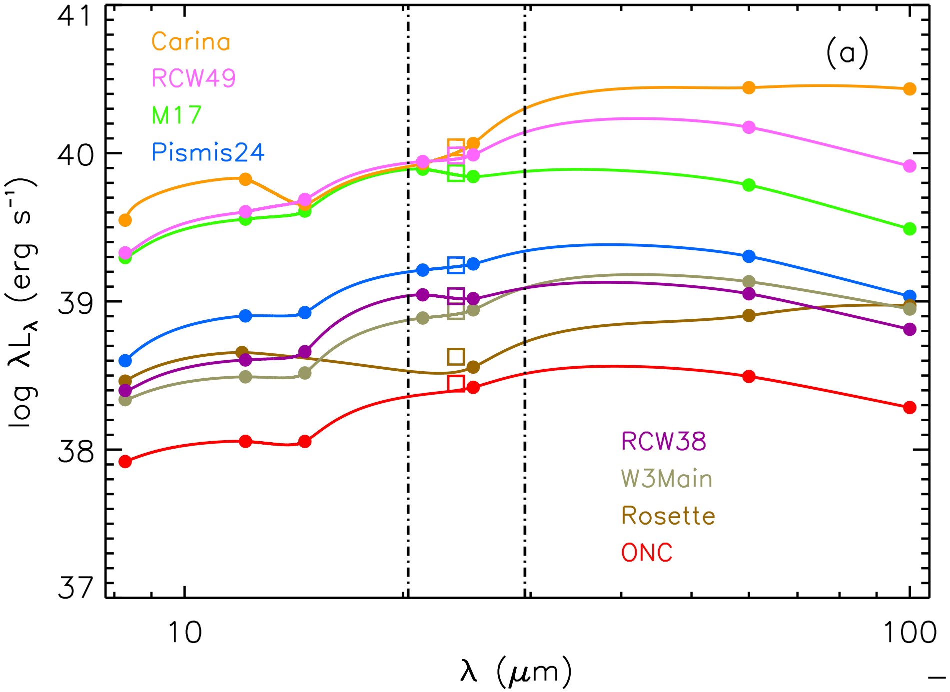


Treat Galactic H II regions as single sources by extracting flux densities using large apertures on *MSX* and *IRAS* images. Then interpolate their IR SEDs to measure luminosities.

Plot SFR derived from the X-ray + IR “star counts” methods against equivalent *Spitzer*/MIPS 24 μm luminosity. *Note the significant, systematic discrepancy between this relation and the Calzetti et al. (2007) extragalactic calibration (dashed line).*



Chomiuk & Povich (submitted)



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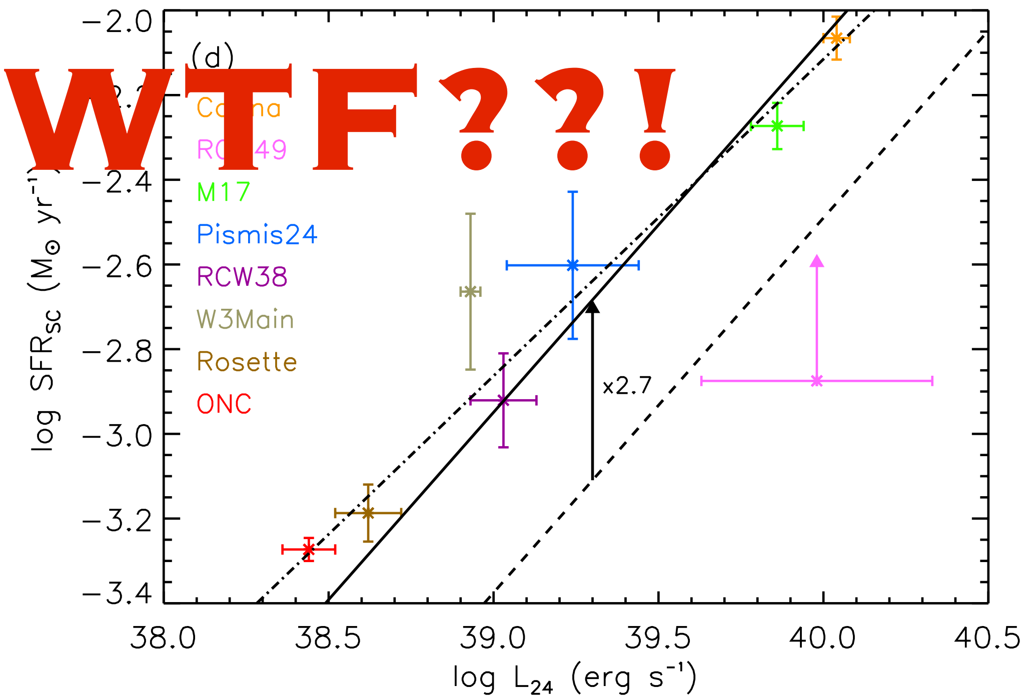


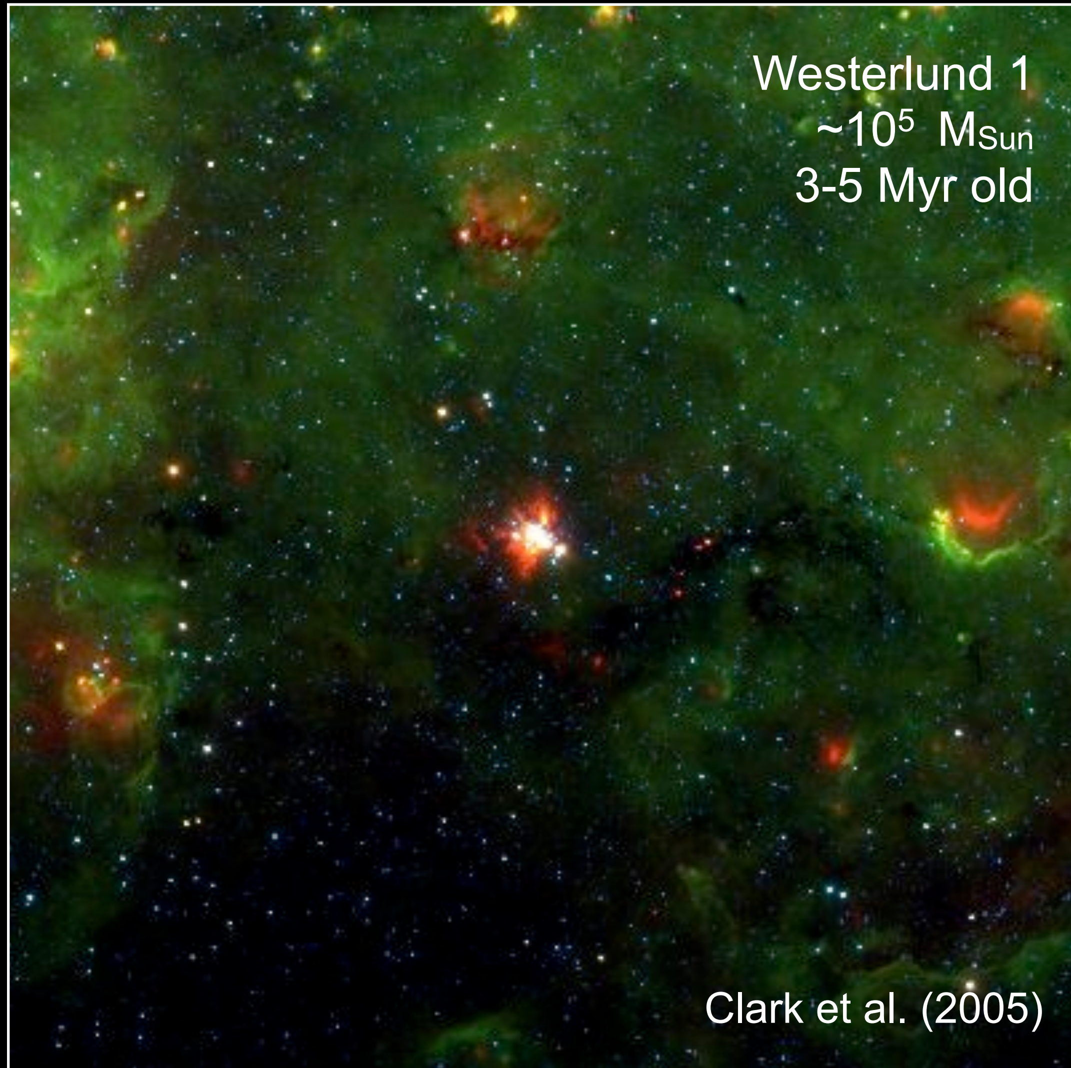
Chomiuk & Povich (submitted)

Are ages of sampled H II regions biased by IR selection criteria?

M17
~8000 M_{Sun}
~1 Myr old

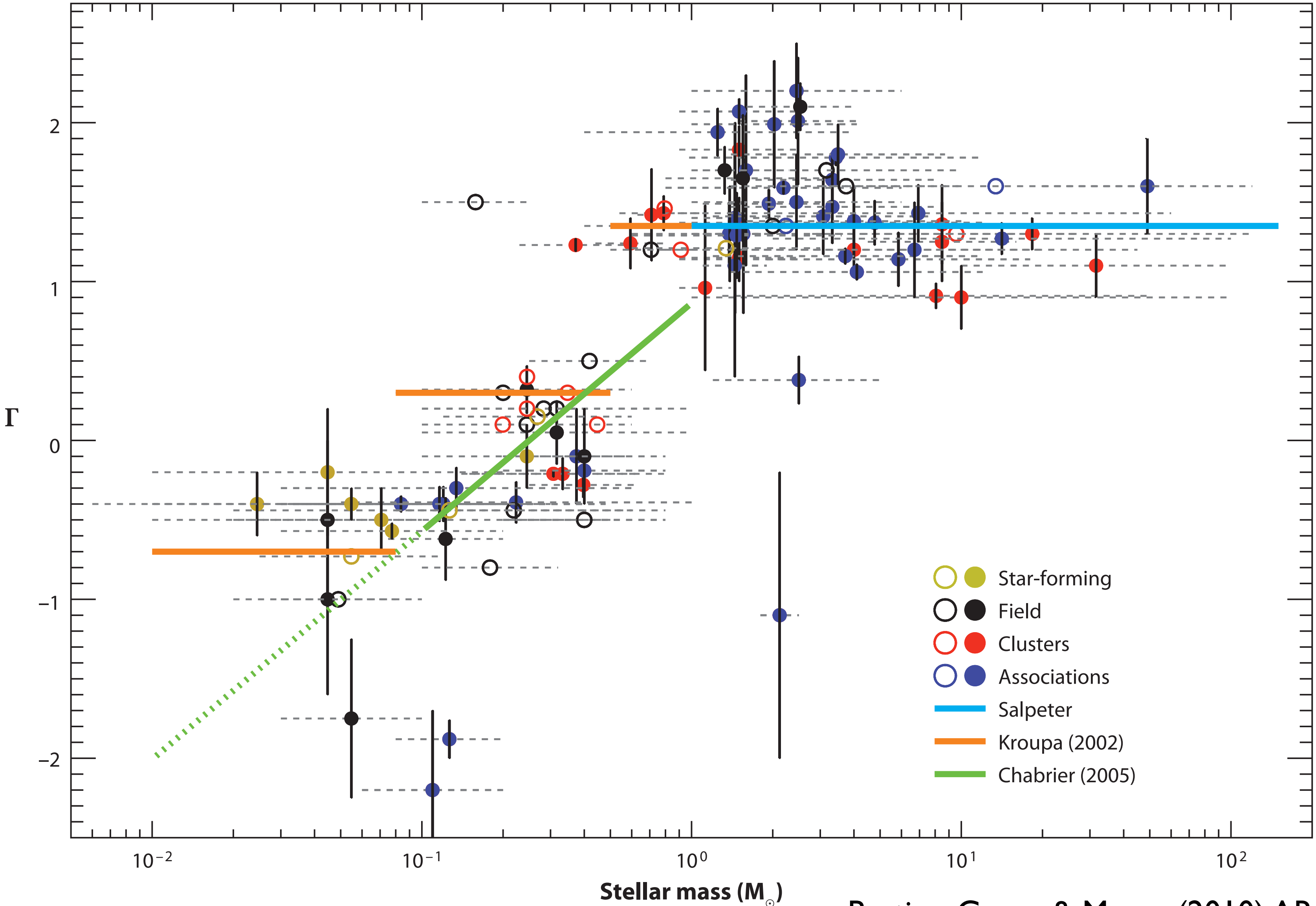
Povich et al. (2009)

24 µm
8.0 µm
4.5 µm



Clark et al. (2005)

Is the intermediate-mass IMF *actually* Salpeter's?



Bastian, Covey & Meyer (2010) ARA&A

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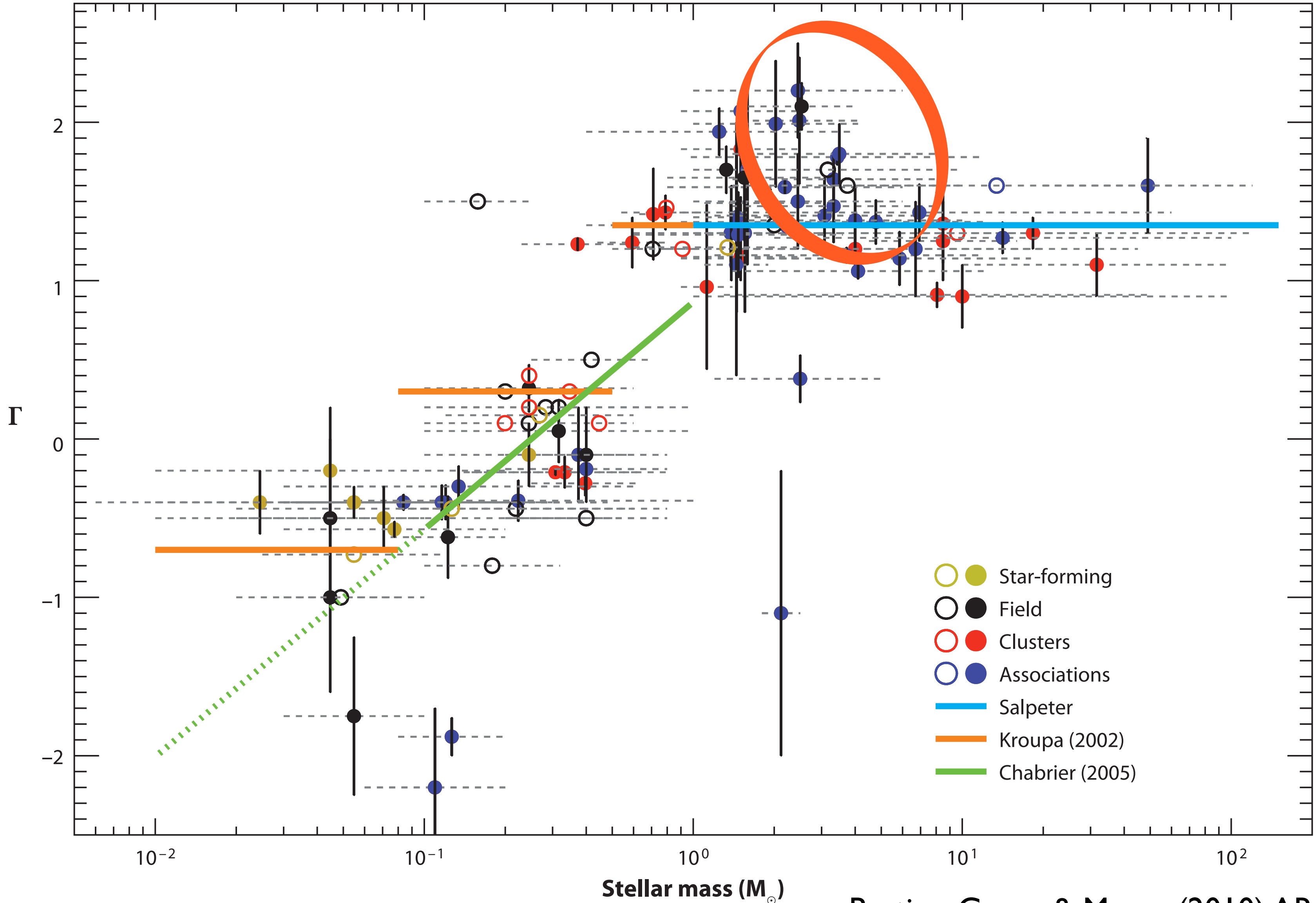

Bastian, Covey & Meyer (2010) ARA&A

Conclusions

- The combination of X-ray and IR observations of resolved young stellar populations provides a powerful method for exploring star formation in Galactic H II regions.
- We can now start calibrating SFRs versus nebular emission tracers *without* invoking stellar population synthesis models.
- Initial comparisons suggest that calibrations based on population synthesis models may systematically *underestimate* SFRs (by factors of >2.5).