



Observations of (Galactic) HII Regions

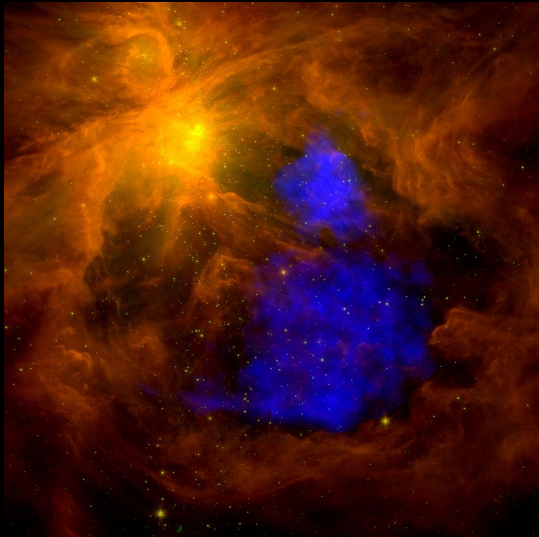
Loren Anderson
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October 29, 2024
TOSCA



HII Region Properties

- ~10,000 in the Milky Way (Armentrout et al., 2021)
- Diameter ~few pc (full range ~0pc-100pc)
- Temperature $\sim 10^4\text{K}$ (5000K-12000K)
- Emission
 - Bright bound-bound lines from recombination (e.g., H α) or collisions (e.g., [OIII]).
 - Bremsstrahlung from radio to X-ray
- Bounded by a photodissociation region (PDR)
 - Bright in molecular lines, [CII], infrared continuum, polycyclic aromatic hydrocarbons (PAHs)





PDR

Molecular lines
FIR continuum
[CII]
PAHs



Ionized gas

Radio Continuum, X-ray
H α , Radio recombination
lines (RRLs)



PDR

Molecular lines

[CII]

PAHs



Ionized gas

Radio Continuum, X-ray
H α , Radio recombination
lines (RRLs)



- $\sim 10 \mu\text{m}$: Mainly PAH emission; traces photodissociation regions
- $\sim 20 \mu\text{m}$: Hot ($\sim 100 \text{ K}$) small grain emission; traces massive stars

All HII regions look like this! $\sim 20\mu\text{m}$ surrounded by $\sim 10\mu\text{m}$

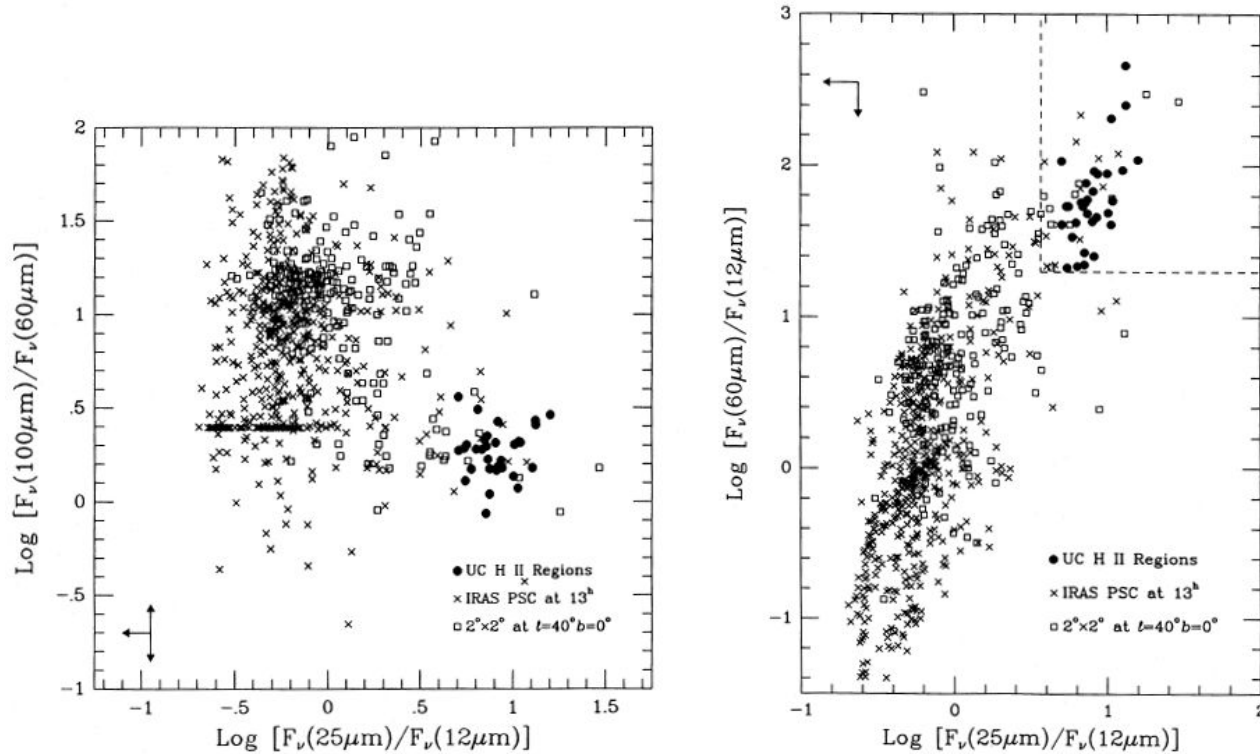
HII Region Observations

HII Region Observations - Photometry

Get flux, sky location, angular size

- **Naked eye**
 - Messier (1774), 5 HII regions out of 110 northern objects (M16, M17, M20, M42, M43)
- **H α photometric images**
 - Sharpless (“Sh”; 1953, “Sh-2”; 1959), 312 northern HII regions
 - Rodgers, Campbell & Whiteoak (“RCW”; 1960), 182 southern HII regions
 - Gum (1955), 84 southern “emission nebulae”
- **Radio continuum**
 - Westerhaut (1958), 82 northern objects (really 79), about half are HII regions (e.g., W3, W4, W5, W43, W49, W51)

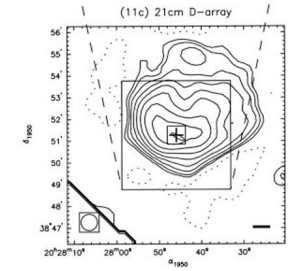
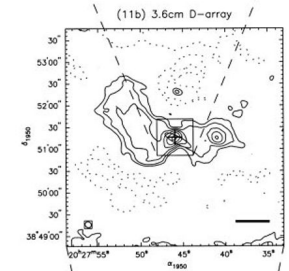
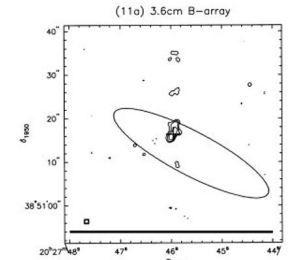
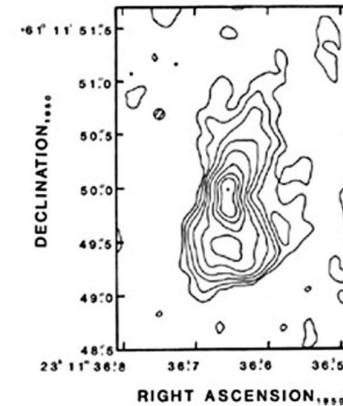
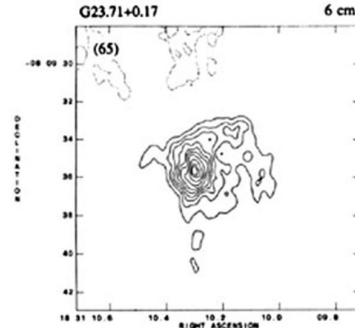
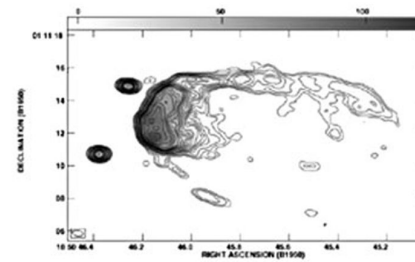
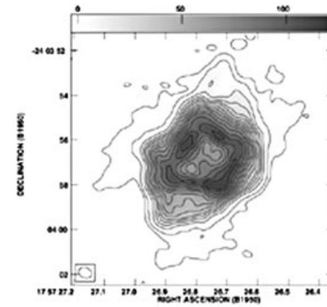
IRAS color-color selection of “Ultracompact” HII regions



Wood & Churchwell (1989)

VLA observations of “Ultracompact” HII regions

- Wide range of morphologies
- Ionizing sources derived from luminosities are small ($\sim B2$), but actual stars are larger because of missing flux (Kim & Koo, 2001)

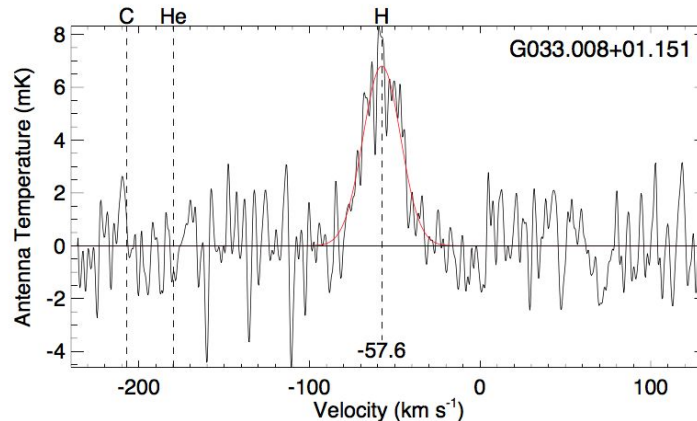


HII Region Observations - Radio Spectroscopy

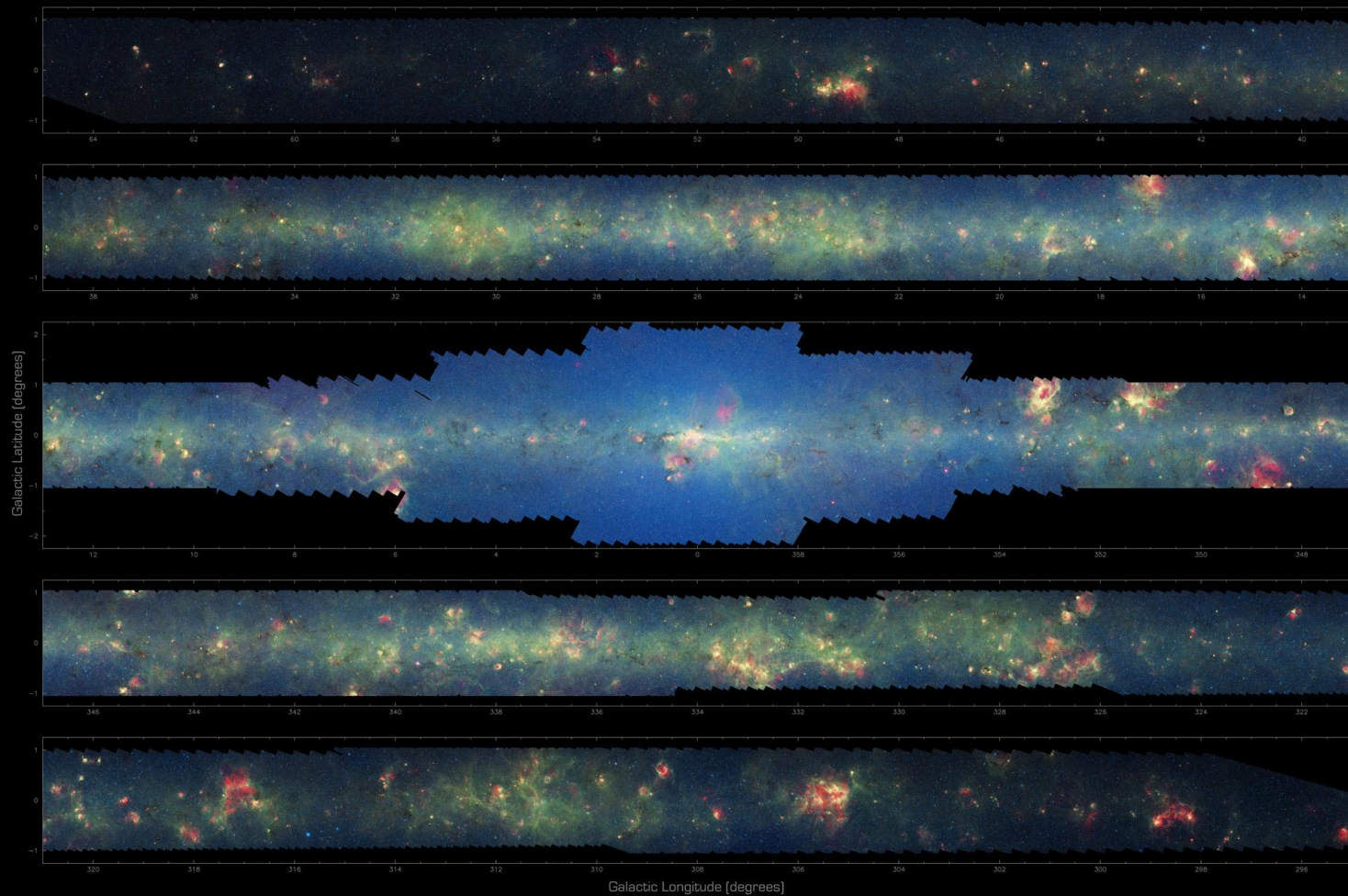
Can derive distances and average electron densities.

Fluxes -> luminosities, angular sizes -> physical sizes

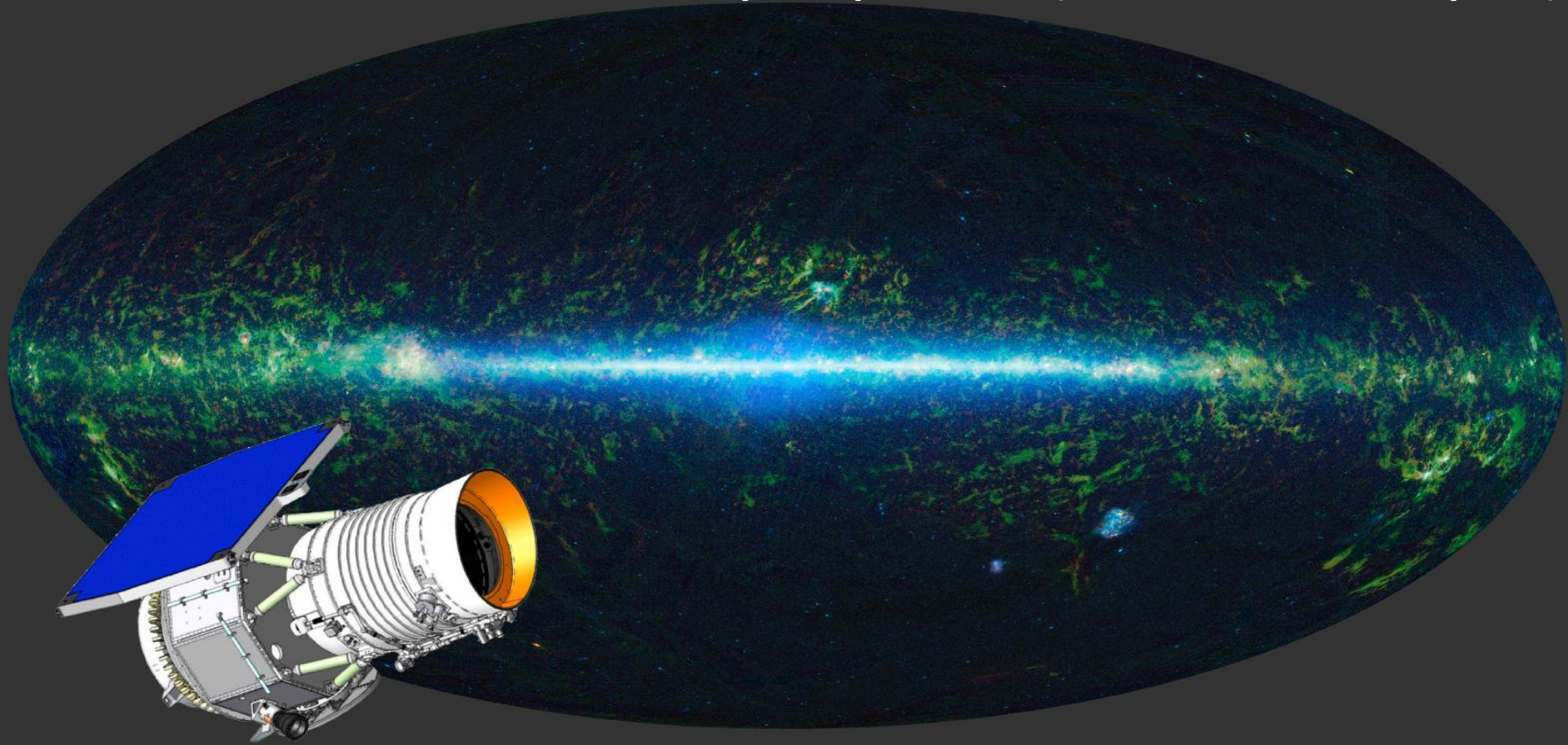
- **First Radio Recombination Line (RRL) observations**
 - Hoglund & Mezger (1965), 11 H II regions including M17 and Orion
- **Pointed RRL surveys**
 - Downes (1980), Caswell & Haynes (1985), Lockman (1989), Lockman (1996)



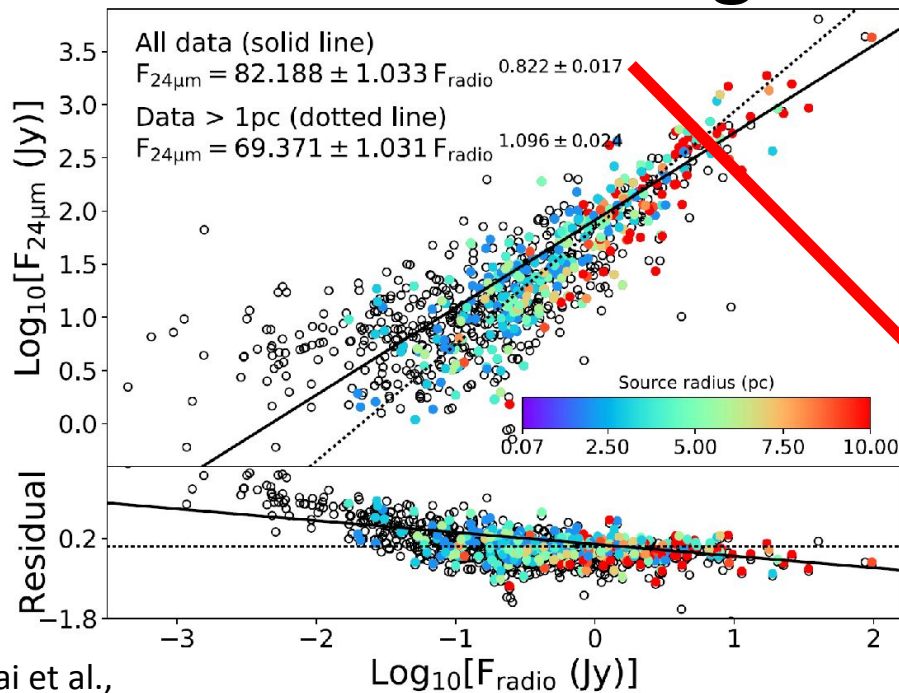
THE INFRARED MILKY WAY: GLIMPSE/MIPSGAL (3.6–24 microns)



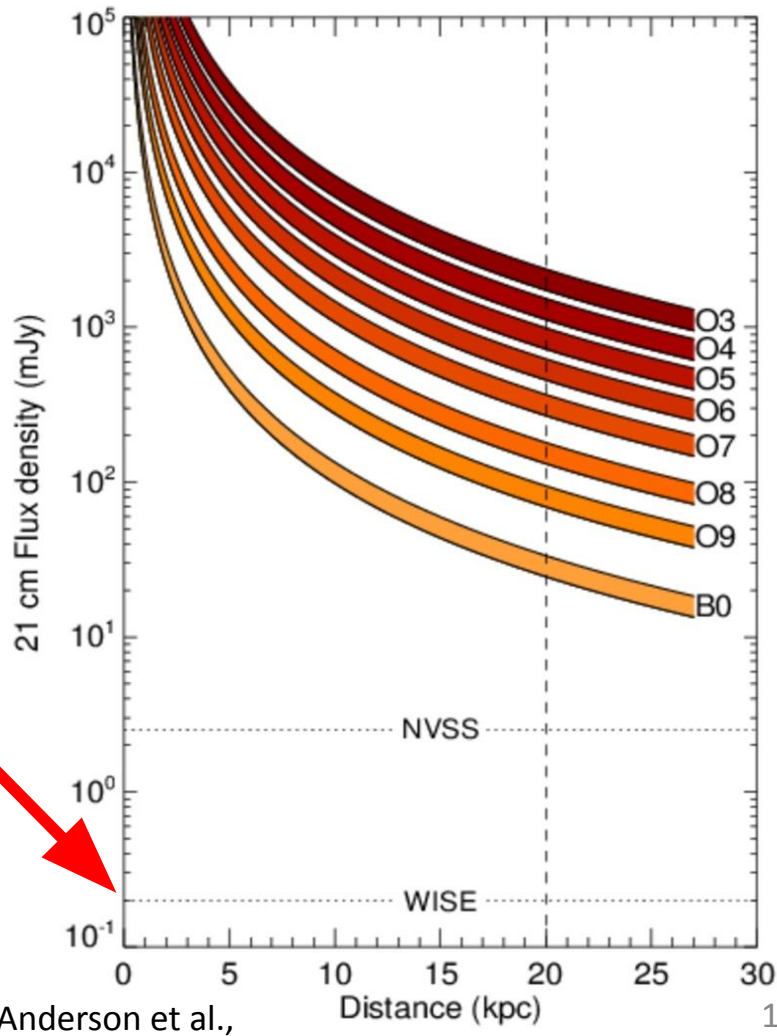
Widefield Infrared Survey Explorer (WISE; 3.4-22 μm)



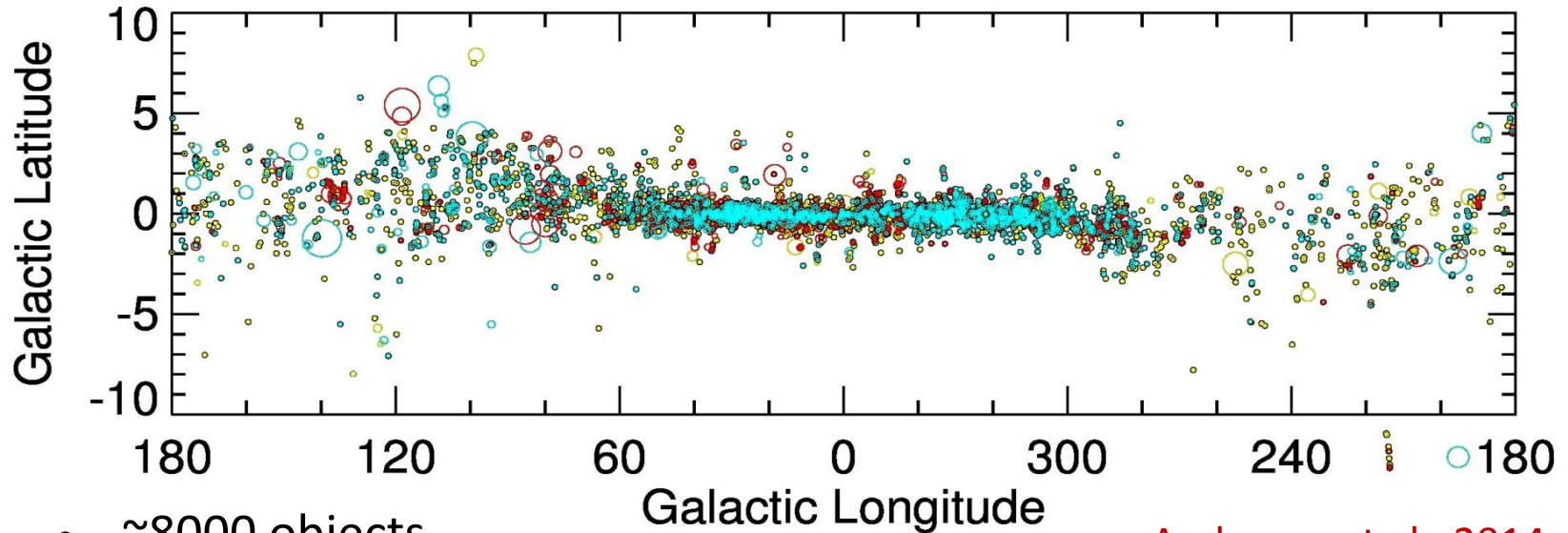
WISE (and Spitzer) can in principle detect all Galactic HII regions!



Makai et al.,



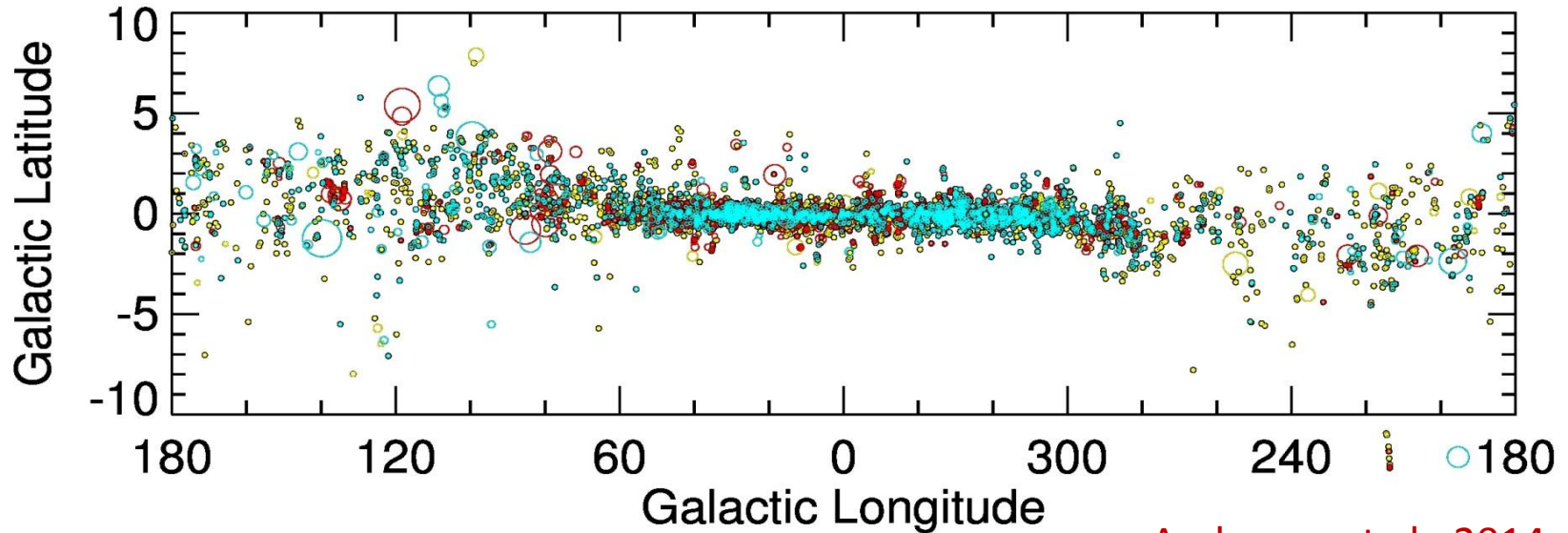
The WISE Catalog of Galactic HII Regions



Anderson et al., 2014

- ~8000 objects
- ~2000 known HII regions (red)
 - ~1500 with distances
- ~2000 HII region candidates (cyan)
- ~4000 radio quiet candidates (yellow)

The WISE Catalog of Galactic HII Regions

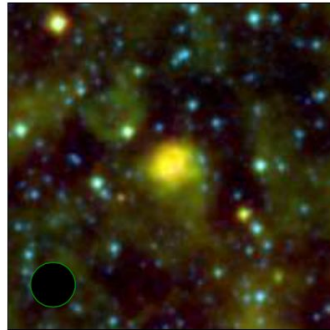


Anderson et al., 2014

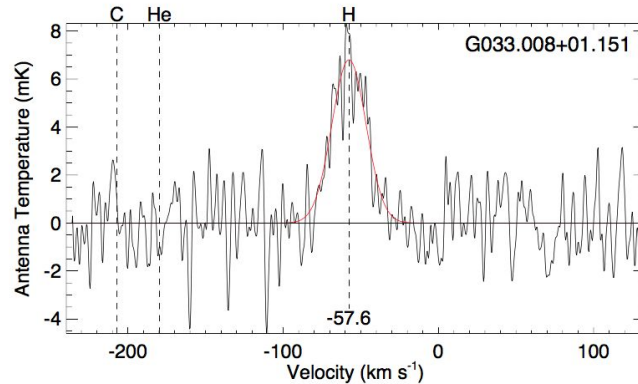
- Most distances are “kinematic”, ~ 100 from maser parallax, ~ 100 from other arguments
- Sizes are from infrared
- < 1000 IR and radio luminosities, from Makai et al. (2017)

HII Region Discovery Survey (HRDS)

- Radio Recombination Line (RRL) observations
 - From electrons cascading to ground state
 - Average spectra from H87 α (8.05 GHz) to H93 α (9.82 GHz)
- RRL detections definitively show a candidate is an HII region
 - Turning *WISE candidate* HII regions into *known* HII regions
- **95% of sources** observed with this characteristic mid-IR morphology were detected in RRL emission



WISE Image



RRL Detection

HII Region Observations - Radio Spectroscopy

Can derive distances and average electron densities.

Fluxes -> luminosities, angular sizes -> physical sizes

- **First Radio Recombination Line (RRL) observations**
 - Høglund & Mezger 1965, 11 H II regions including M17 and Orion
- **Pointed RRL surveys**
 - Downes (1980), Caswell & Haynes (1985), Lockman (1989), Lockman (1996)
 - “HII Region Discovery Survey” - Anderson et al. (2011), Bania et al. (2013), Anderson et al., (2015), Wenger et al. (2019, 2021)

Wenger et al., 2019, 2021



Anderson et al.,
2015



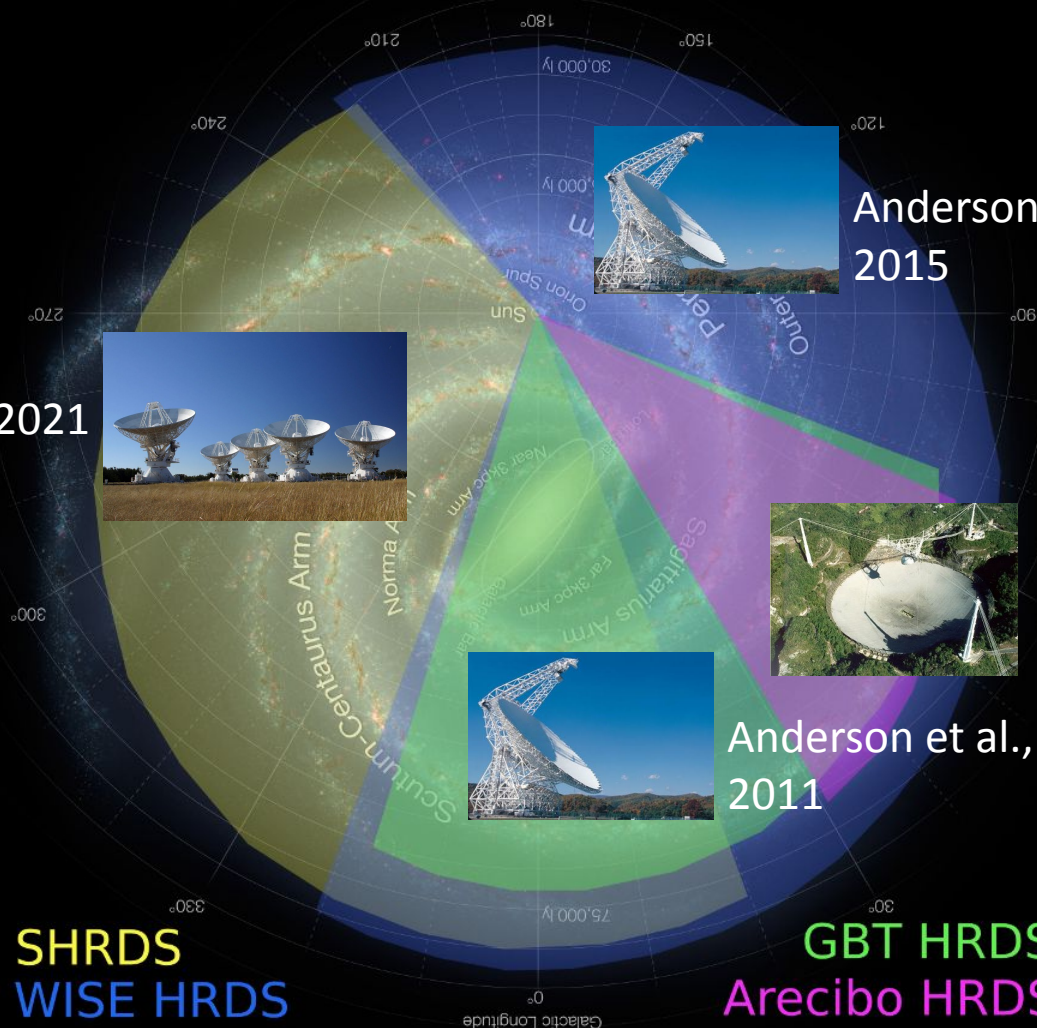
Bania et al.,
2013



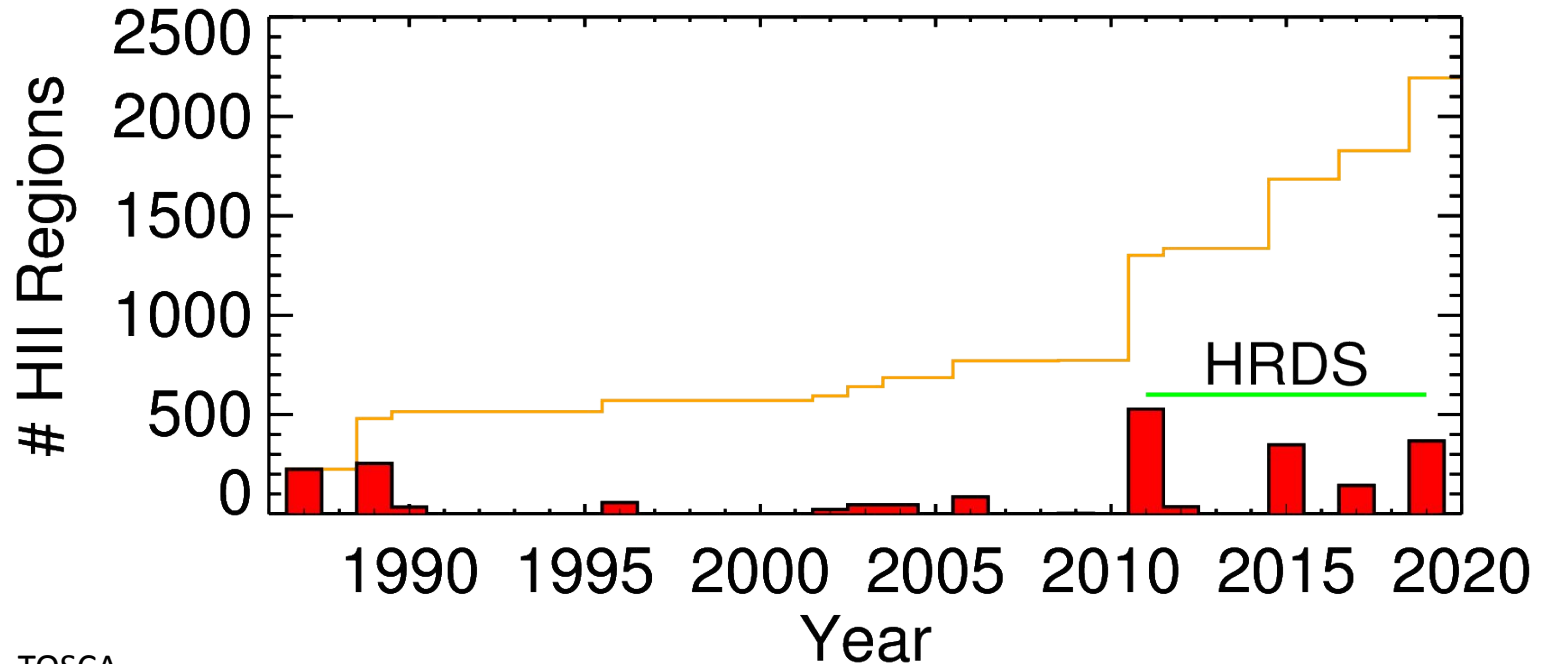
Anderson et al.,
2011

SHRDS
WISE HRDS

GBT HRDS
Arecibo HRDS



The HRDS doubled the known Galactic HII region population

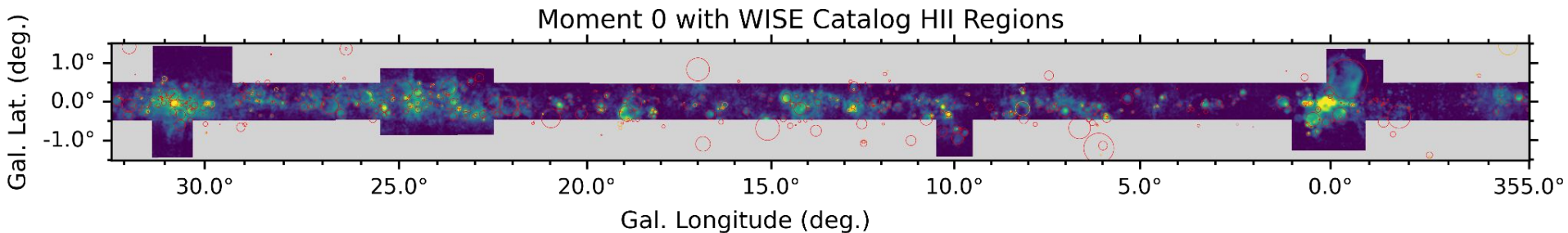


HII Region Observations - Radio Spectroscopy

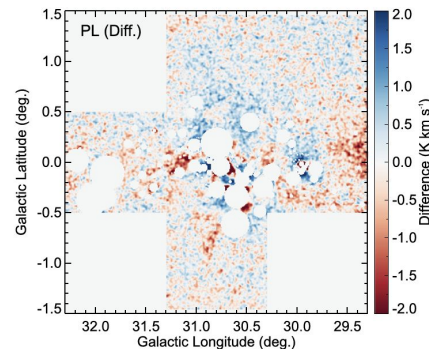
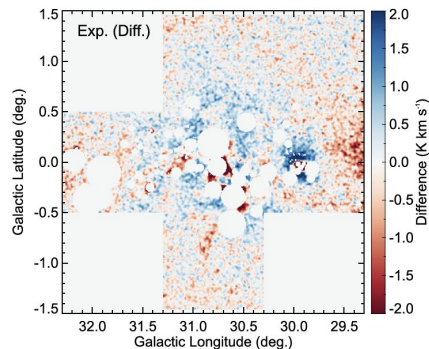
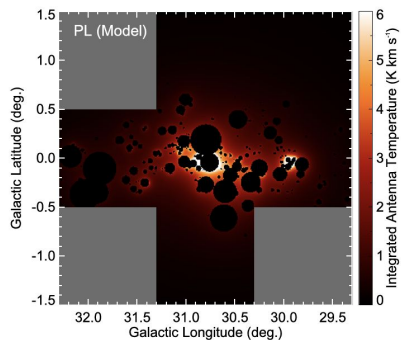
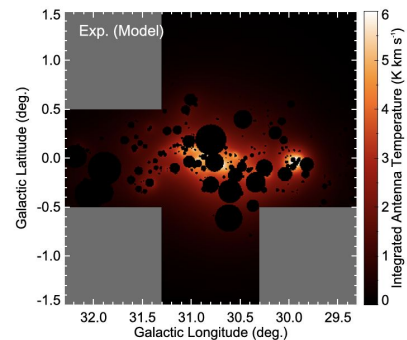
Can be used to derive distances, and hence luminosities and physical sizes

- **First Radio Recombination Line (RRL) observations**
 - Hoglund & Mezger 1965, 11 H II regions including M17 and Orion
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 - “HII Region Discovery Survey” - Anderson et al. (2011), Bania et al. (2013), Anderson et al., (2015), Wenger et al. (2019, 2021)
- **Large-scale RRL surveys**
 - HI Parkes All Sky Survey (HIPASS; Alves et al. 2012, 2015)
 - Survey of Ionized Gas in the Galaxy, Made with the Arecibo Telescope (SIGGMA; Liu et al. 2013, 2019)
 - GBT Diffuse Ionized Gas Survey (GDIGS; Luisi et al. 2020; Anderson et al. 2021; Linville et al. 2023)
 - FAST RRL survey “piggybacking” the Galactic Plane Pulsar Snapshot (GPPS. 2022)

GDIGS - Emission explained with photon leakage



Anderson et al., 2023

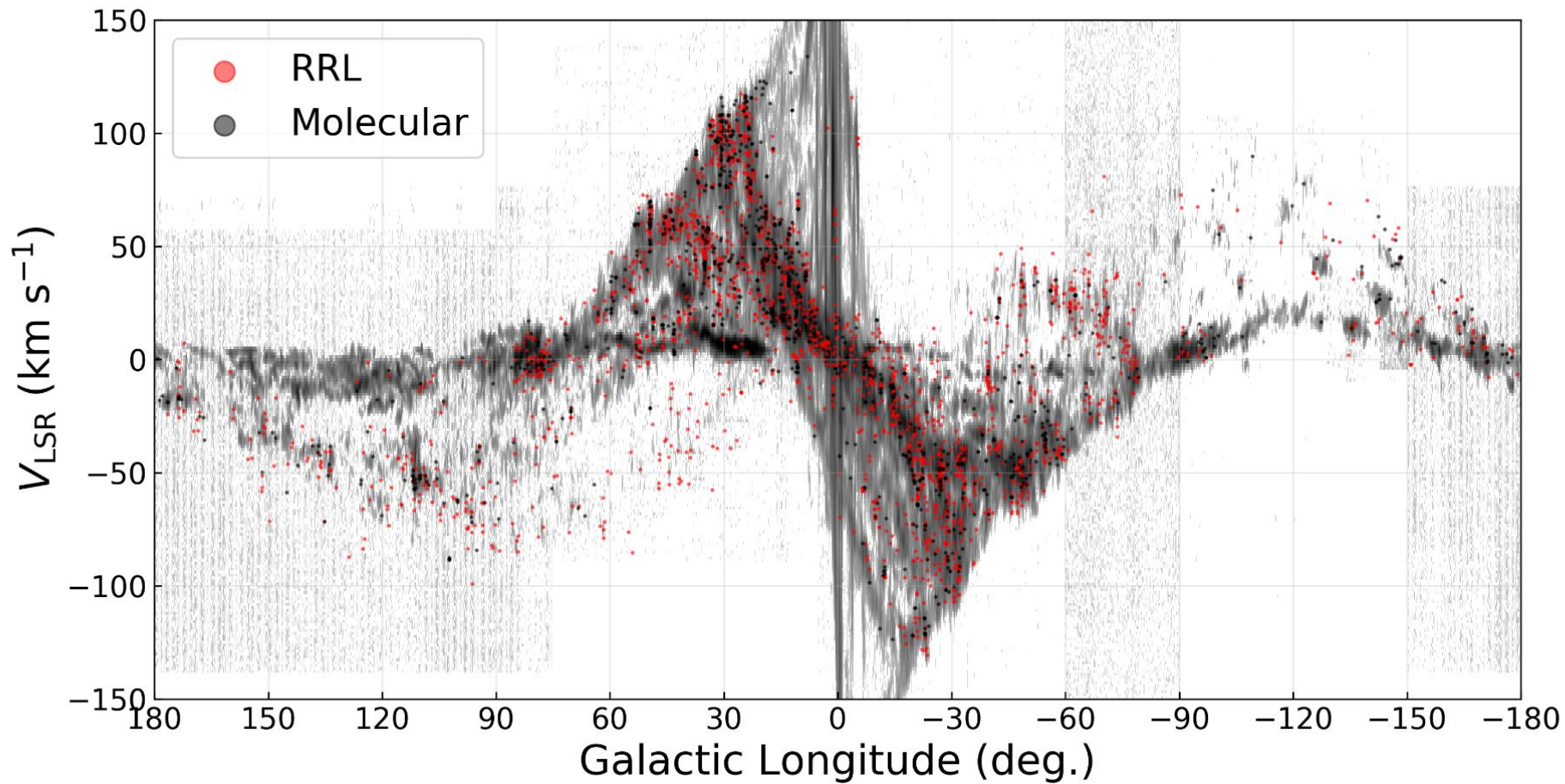


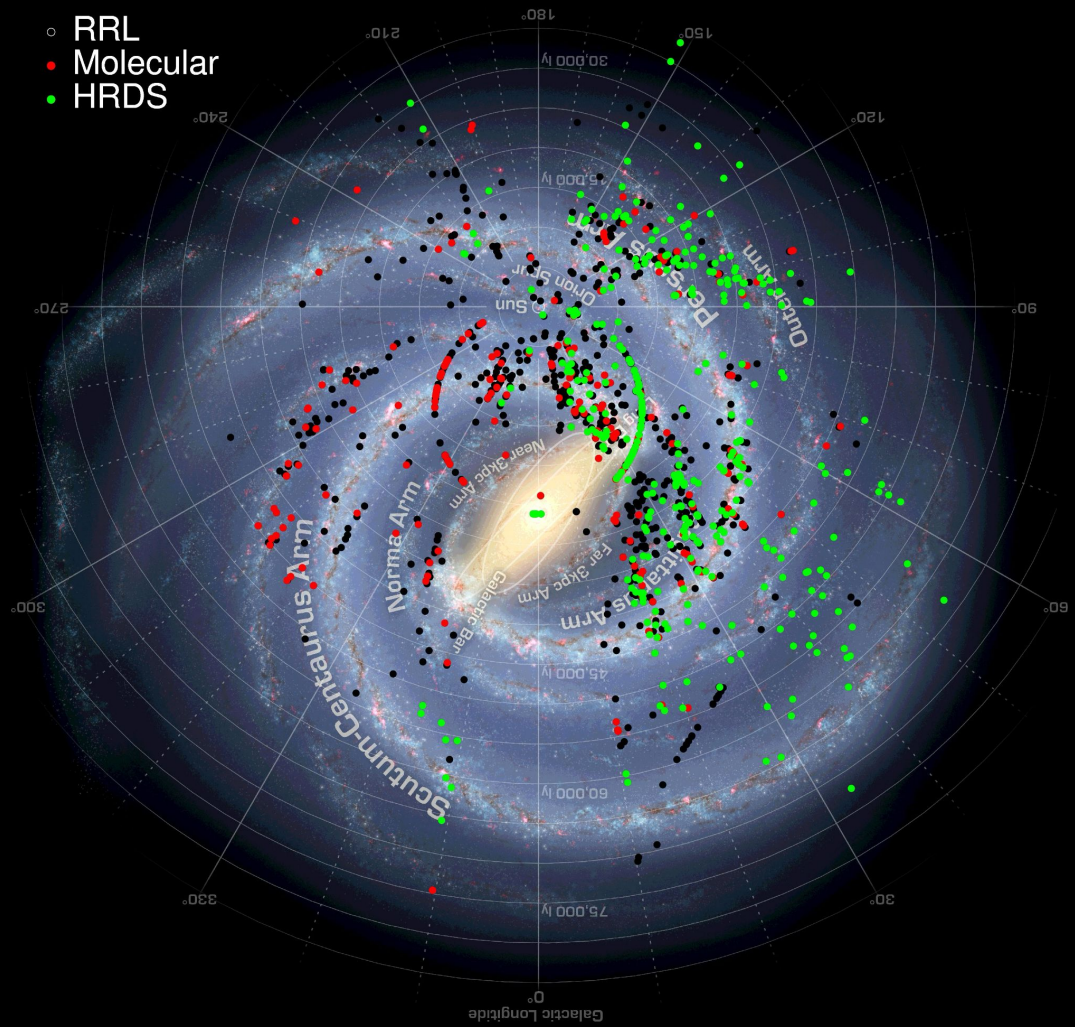
Anderson - TOSCA

Luisi et al., 2021

HII Region Properties

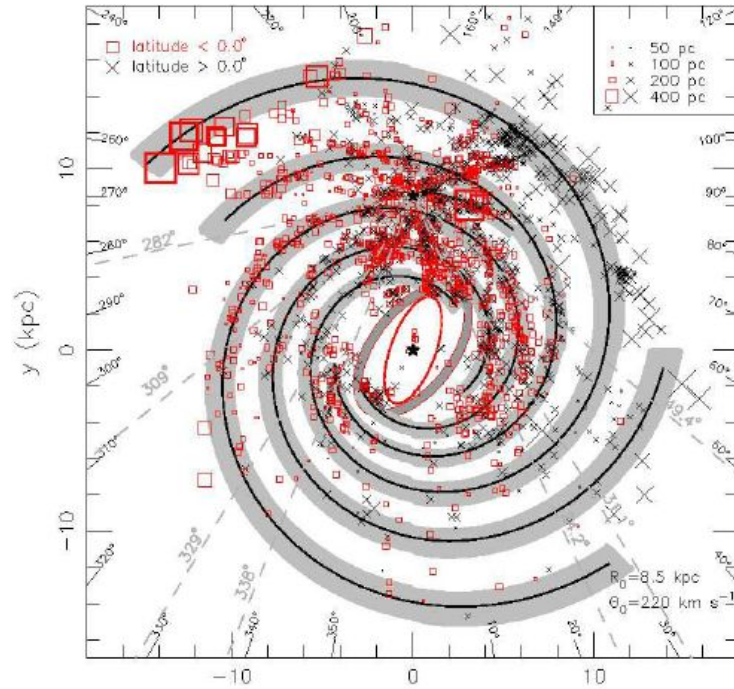
Distribution





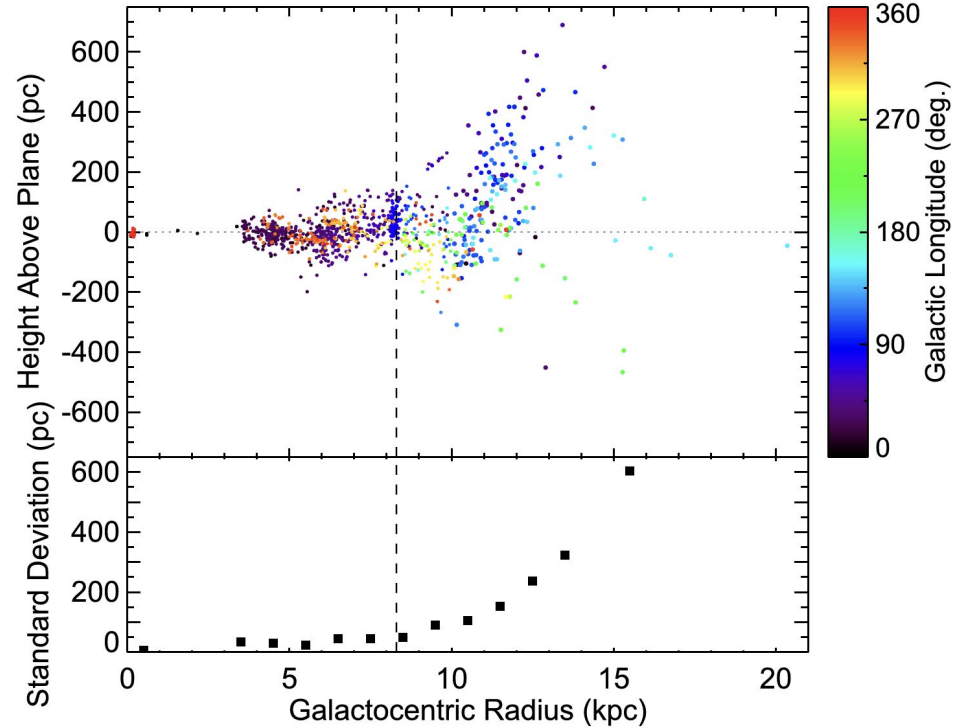
- RRL
- Molecular
- HRDS

Distribution - Warp and Flaring



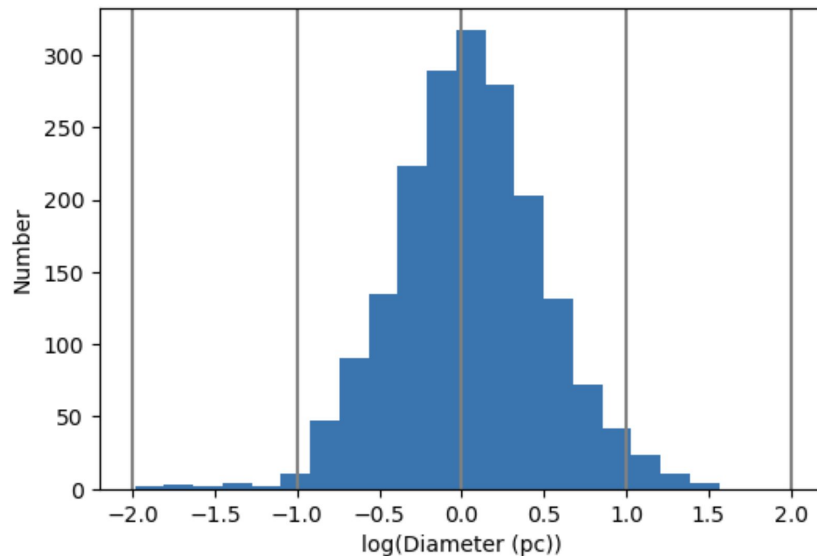
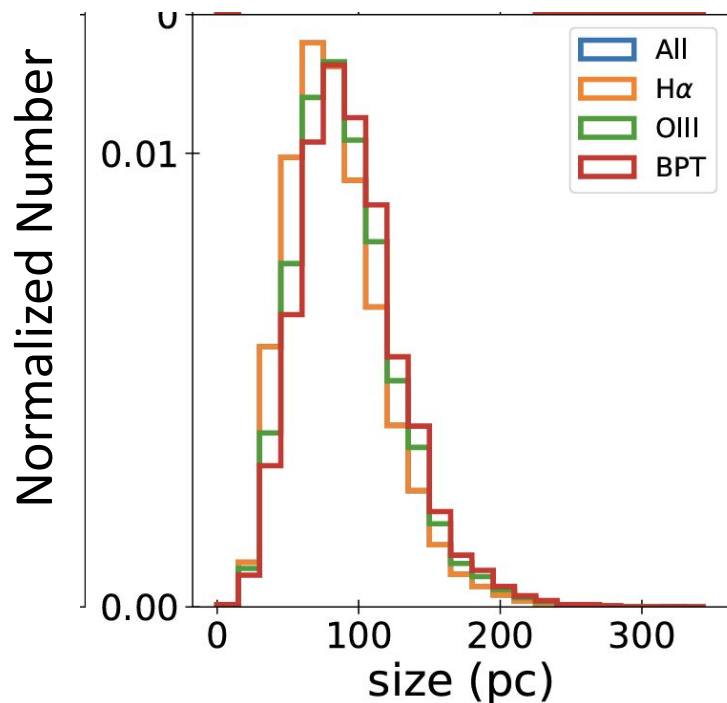
Hou & Hahn (2014) x {kpc}

Anderson - TOSCA



Anderson et al. (2019)

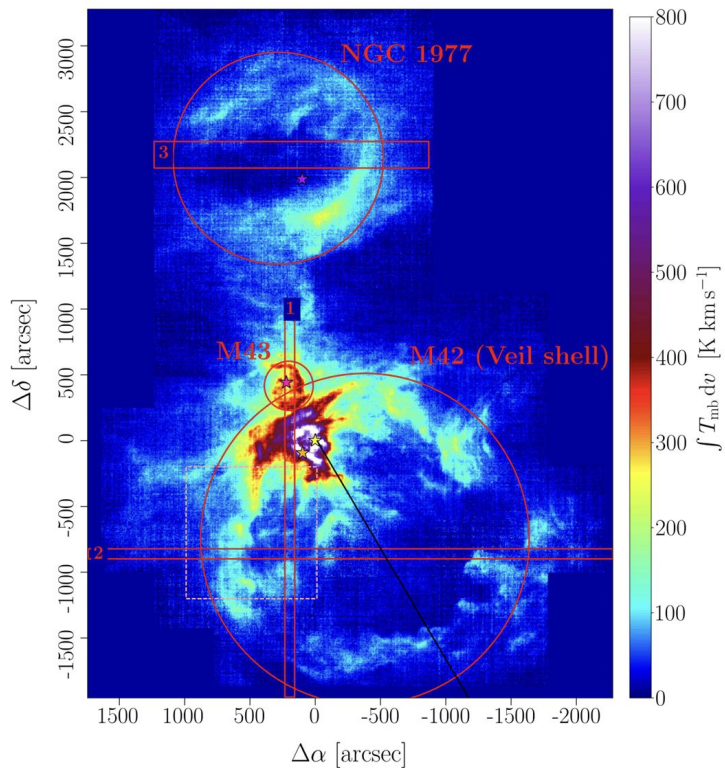
Size - extragalactic are larger



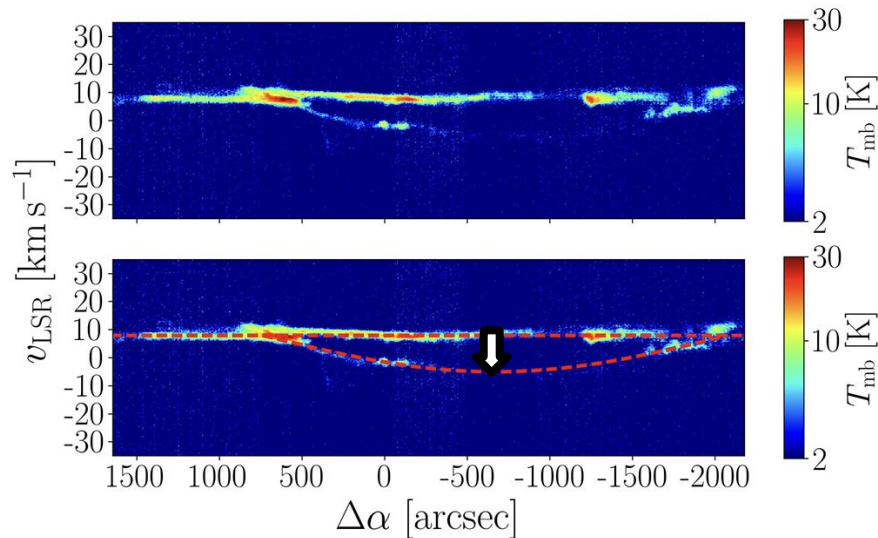
Congiu et al. (2023) - 19 galaxies from PHANGS

WISE Catalog

Expansion - Orion in [CII]

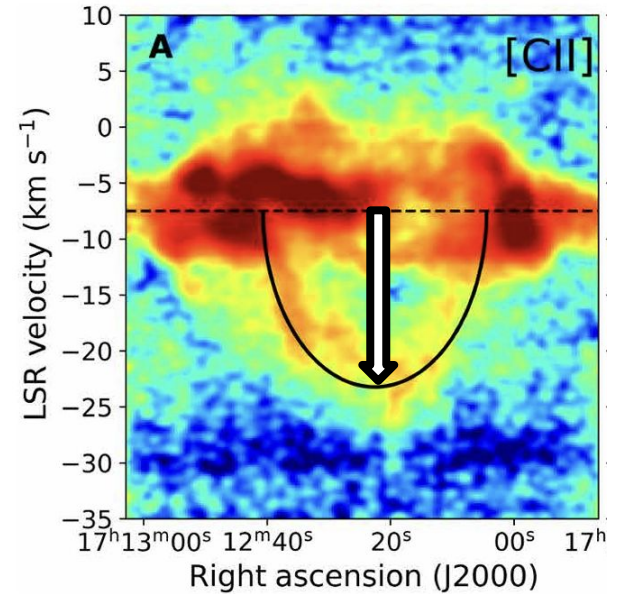
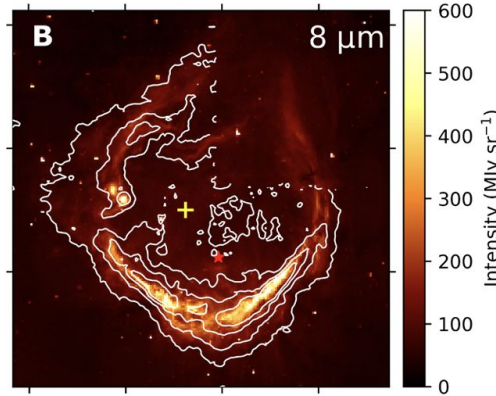
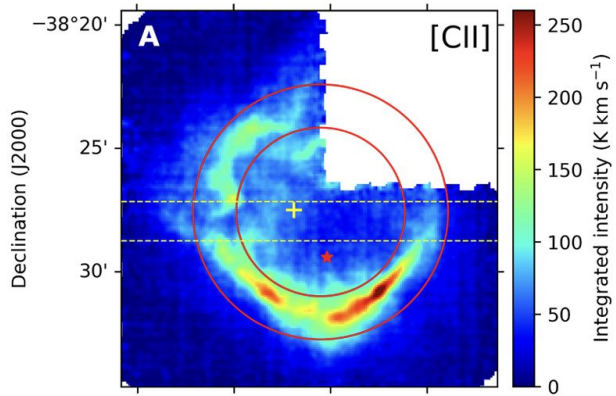


”The bubble blown by the O7V star θ^1 Ori C in the Orion Nebula expands rapidly, at 13 km/s.”



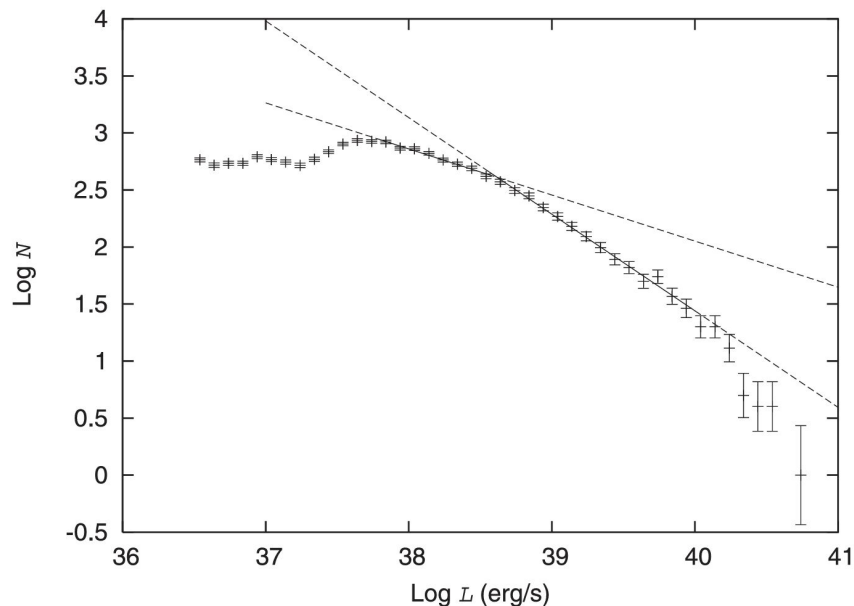
Pabst et al. (2020)

Expansion - RCW120



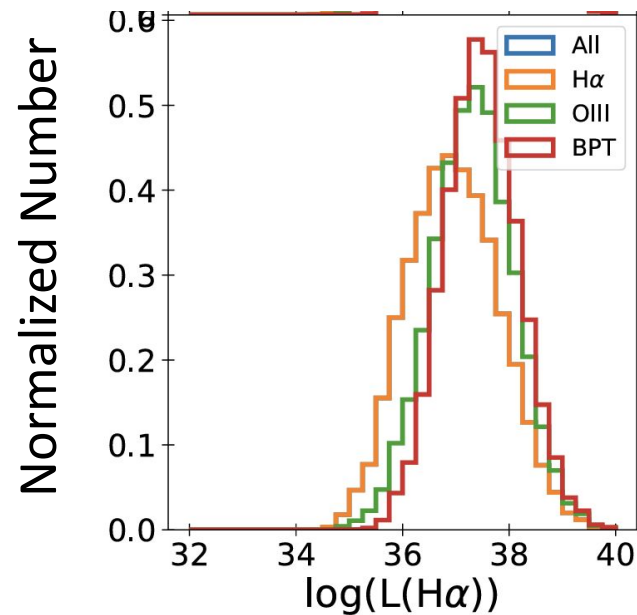
- “...observations from the SOFIA program FEEDBACK of [...] RCW 120 in the [CII] 1.9-THz fine-structure line [reveals] a gas shell expanding at 15 km/s.”
- **~half of all HII regions observed in [CII] by SOFIA show organized expansion (Faerber et al., 2024, in prep.), averaging ~10 km/s, more commonly blueshifted**
 - **Very short dynamical ages! ($\ll 1\text{Myr}$)**

Luminosities



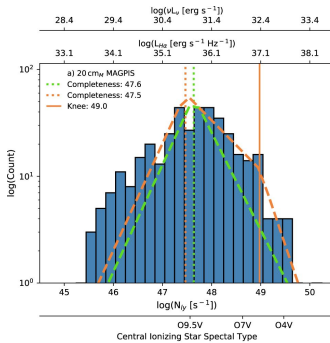
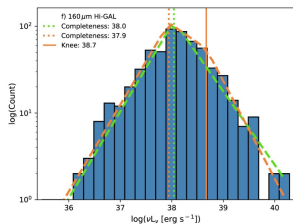
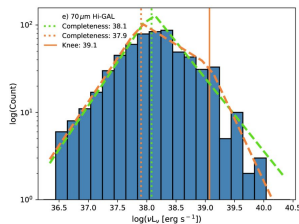
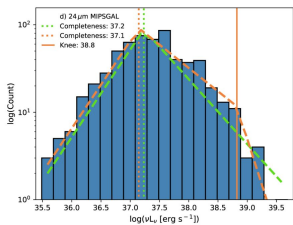
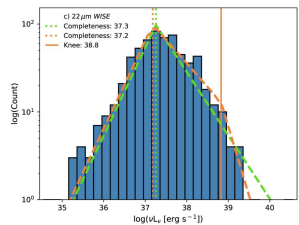
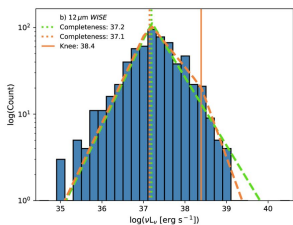
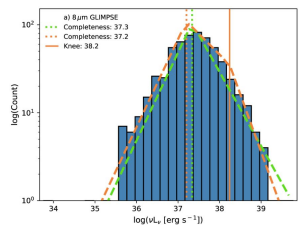
Bradley (2006) - 53 galaxies

Anderson - TOSCA



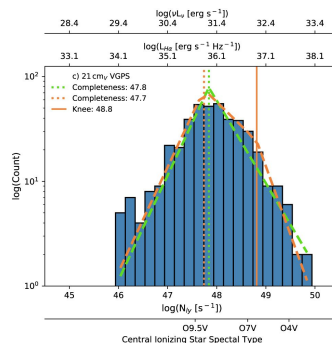
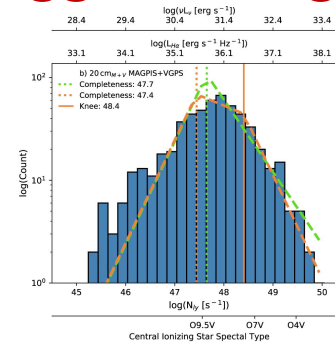
Congiu et al. (2023) - combined
from 19 galaxies from PHANGS

Luminosities - $8\mu\text{m}$ to 21cm



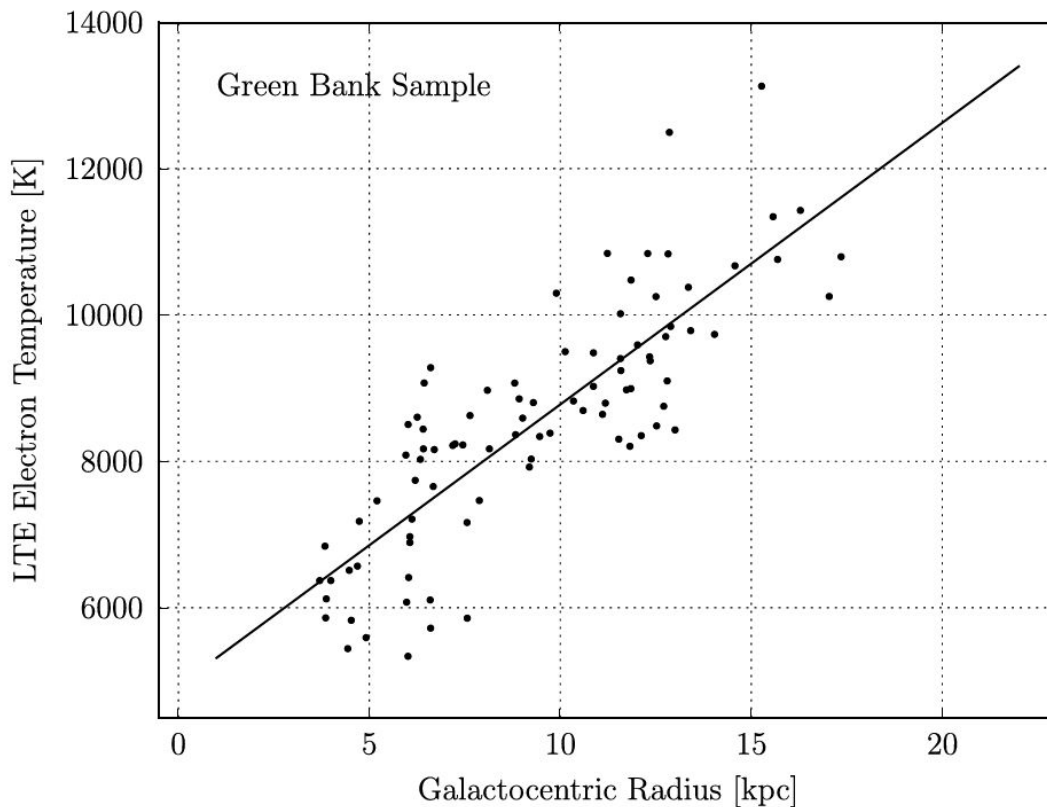
33

38

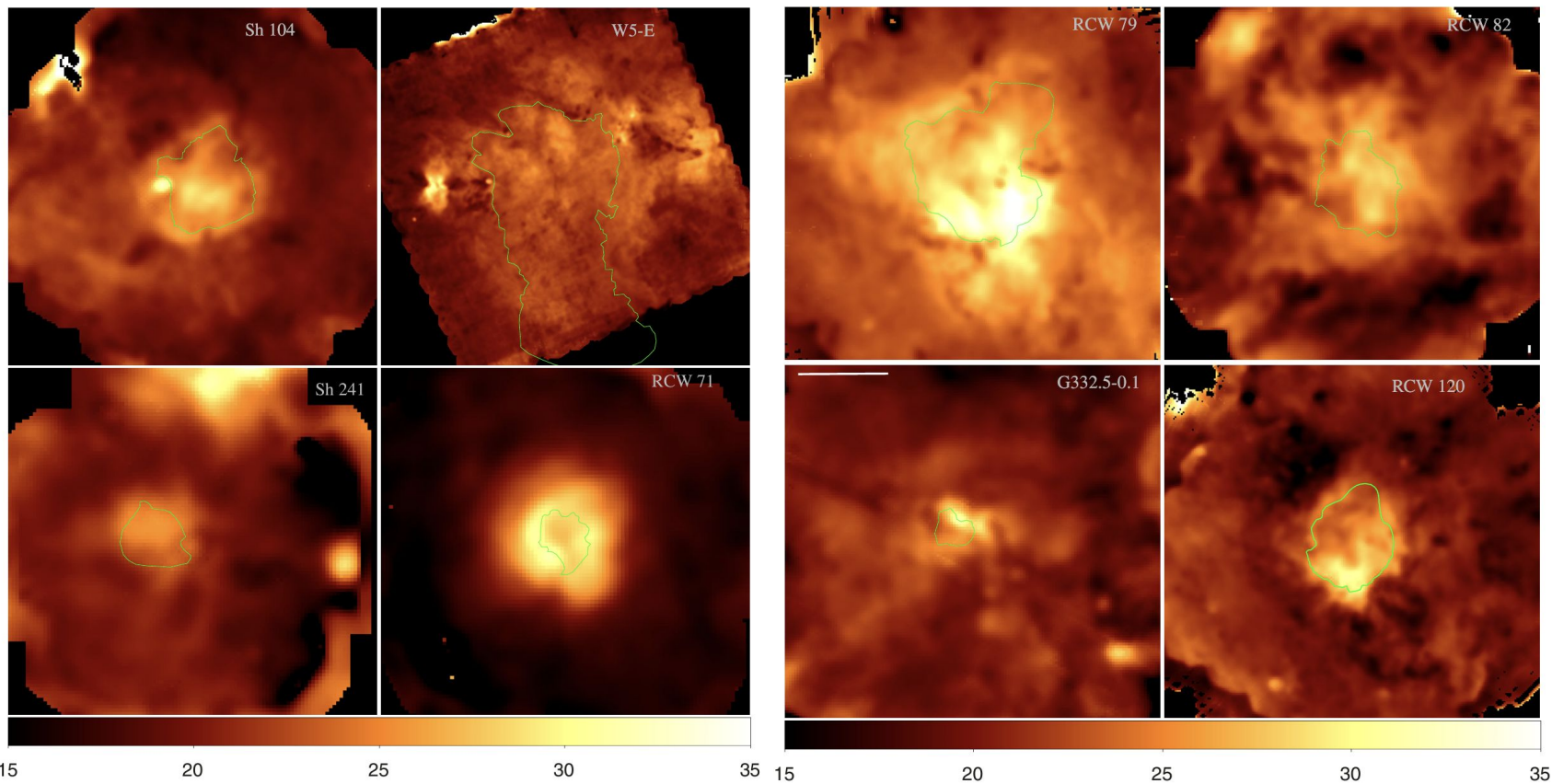


“Averaging the results from all wavelengths, the mean of the best-fit single power law index is $\langle\alpha\rangle = -1.75 \pm 0.01$.”

Ionized Gas Temperature



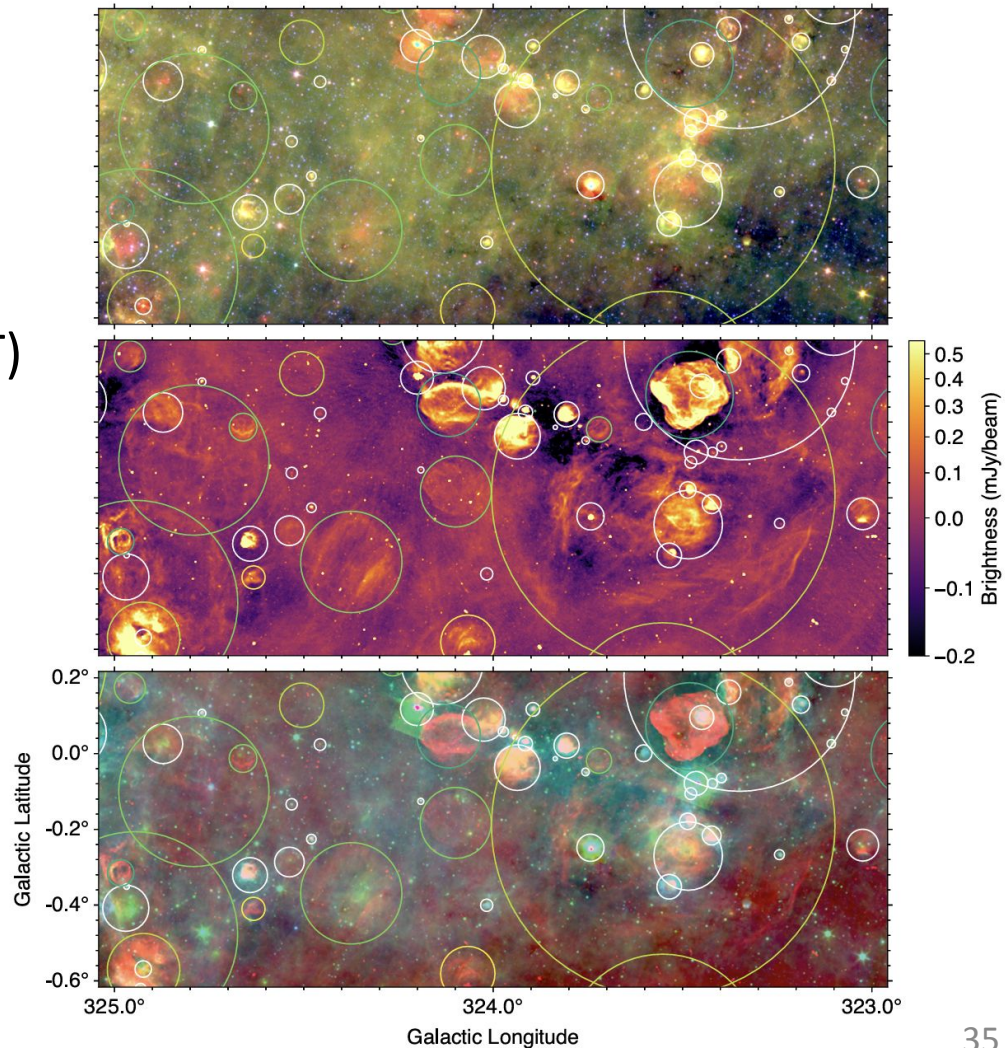
Dust Temperature $\sim 30\text{K}$



SNRs!

~300 known

~400 candidates (273 from MeerKAT)



Future Directions

- HII region expansion
 - Need PDR tracers but SOFIA is gone.....
- Associating OB stars and HII regions
- Future large-scale RRL surveys will give velocities (and hence distances) to ~1000s more HII regions
 - SKA, ngVLA, FAST
- Roman Galactic Plane Survey, SDSS Local Volume Mapper
- Updated WISE Catalog?

