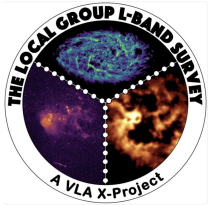
Where do stars explode in the interstellar medium?

Sumit K. Sarbadhicary
CCAPP Fellow (OSU)



Collaborators: Adam Leroy, Eric Koch, Ness Mayker Chen, Jordan Wagner, Erik Rosolowsky, Kathryn Neugent, Natalia Lahen, Chang-Goo Kim, Laura Chomiuk, LGLBS+PHANGS collaboration

Supernova feedback drives major physical processes in galaxies

Outflows

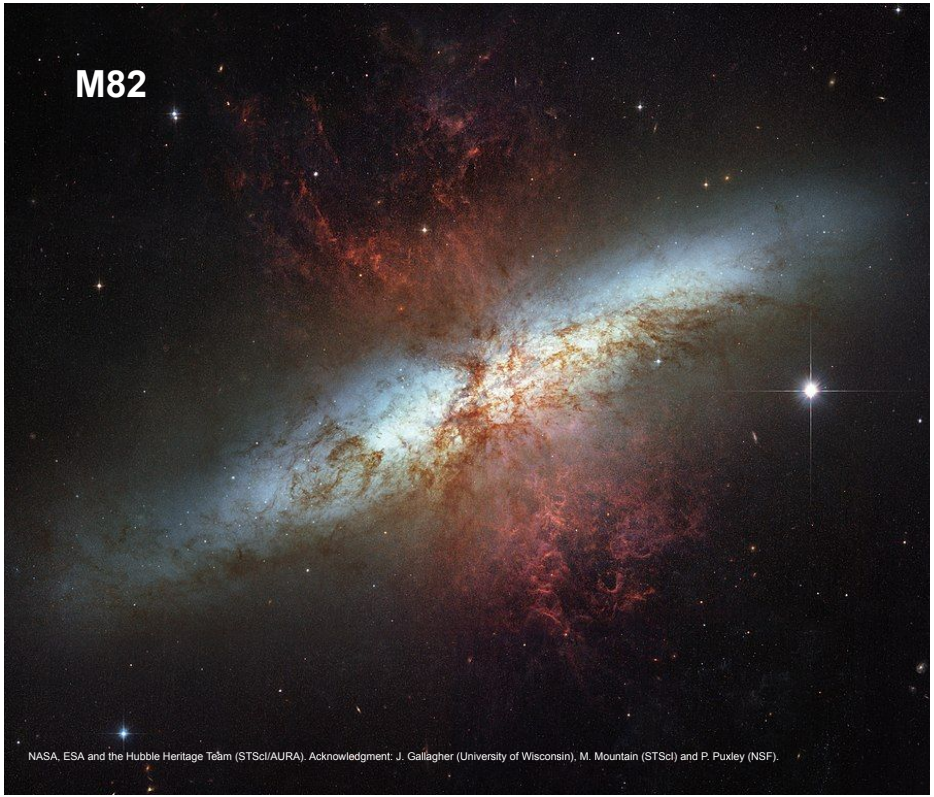
Interstellar turbulence

Hot gas

Cosmic rays

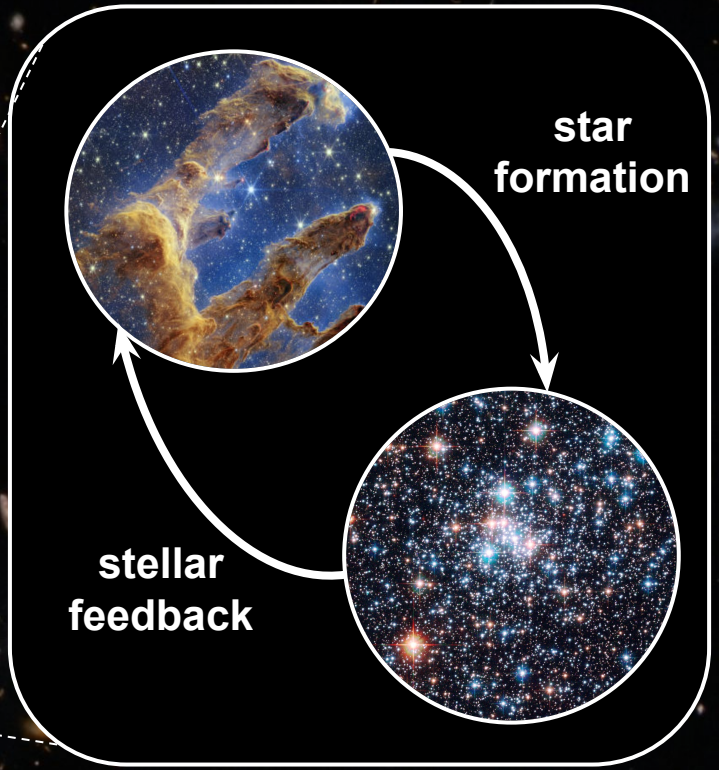
Metal cycling

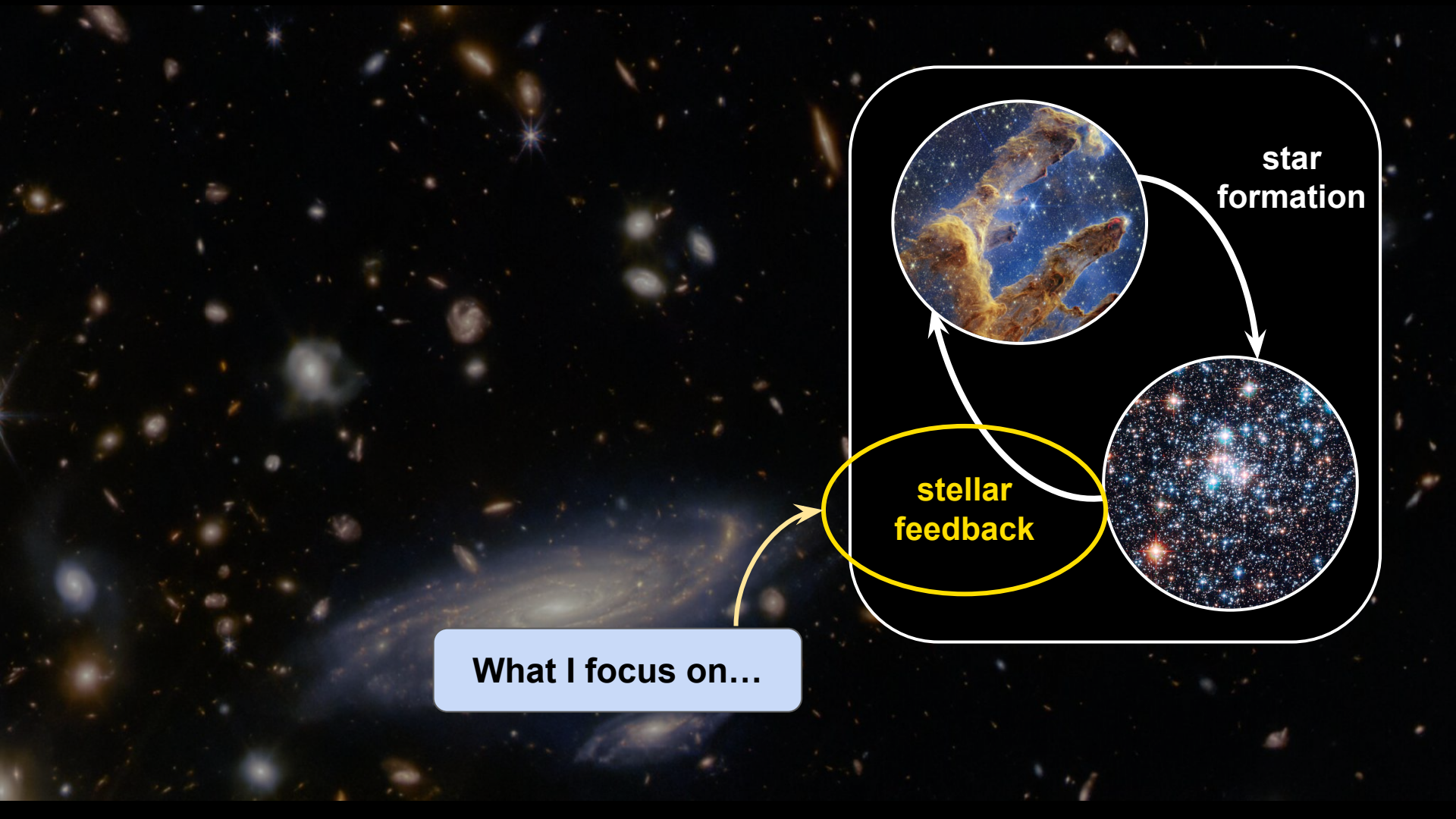
Molecular cloud destruction




How do galaxies evolve?
LEDA 2046648
ESA/Webb, NASA & CSA, A. Martel

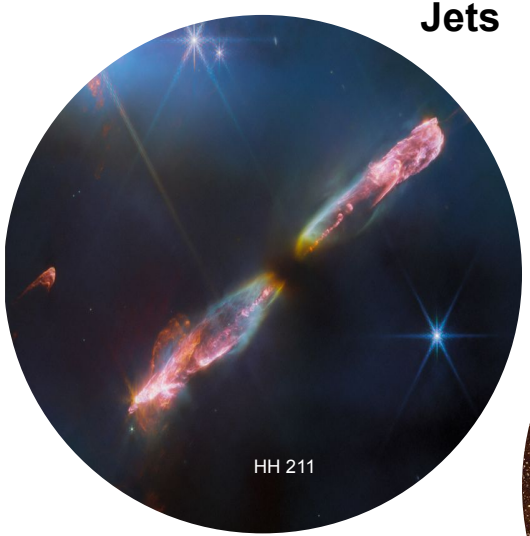
Star-formation + stellar feedback physics is crucial



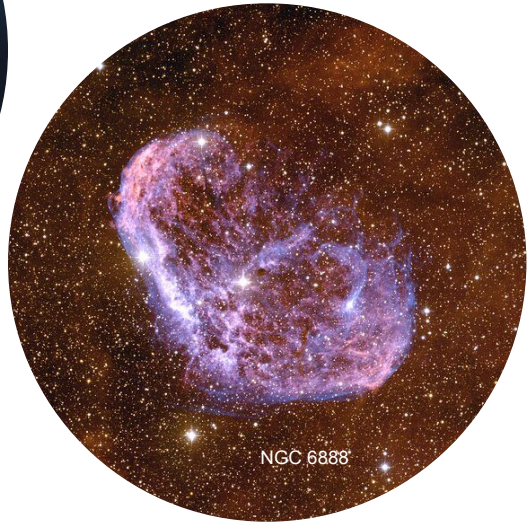

star formation
stellar feedback
What I focus on…

Types of stellar feedback

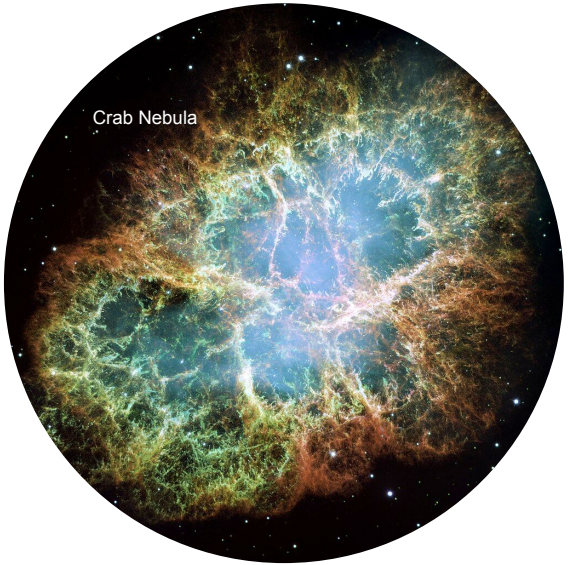
Jets



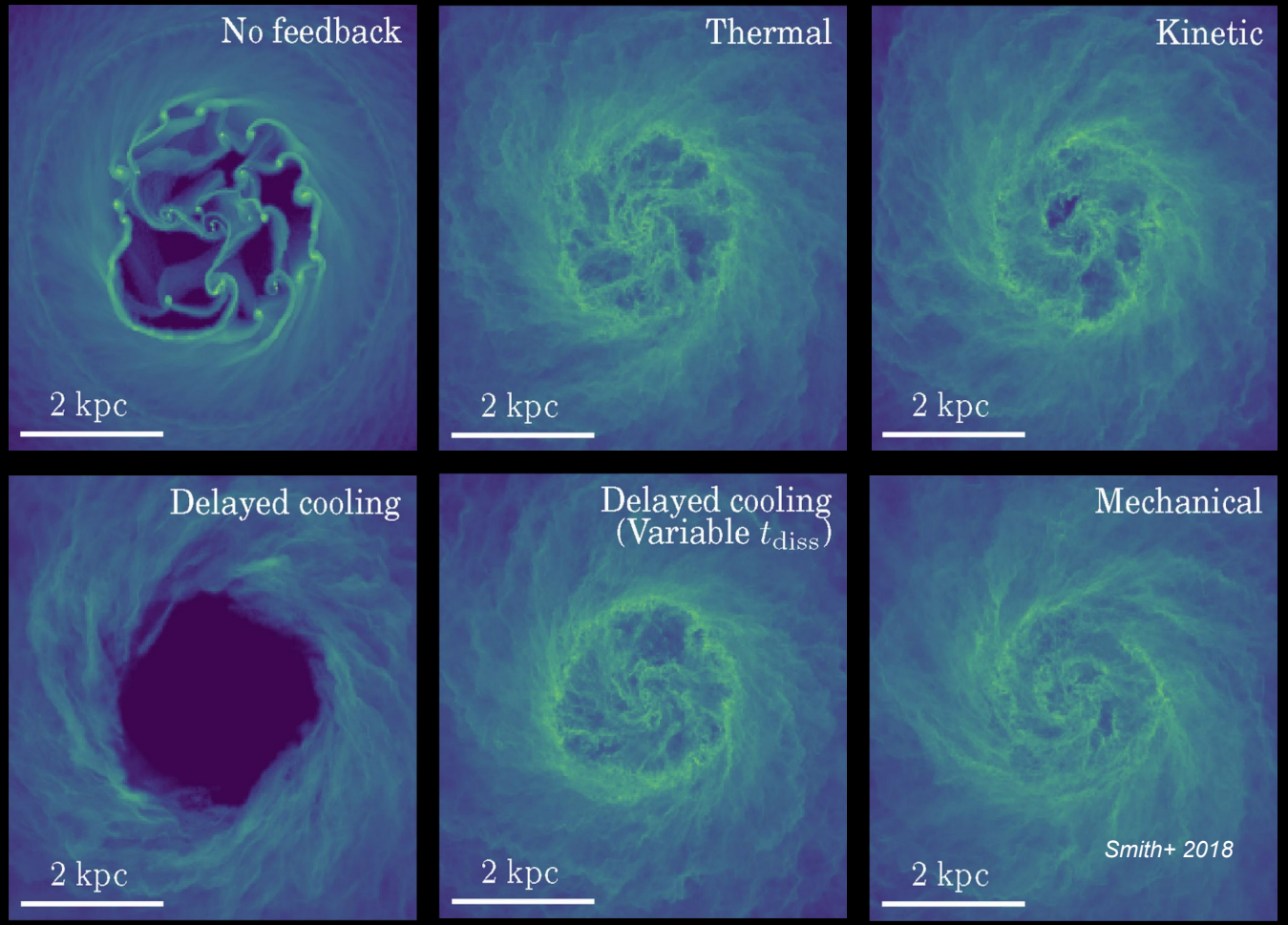
Winds + Ionizing photons



Supernovae

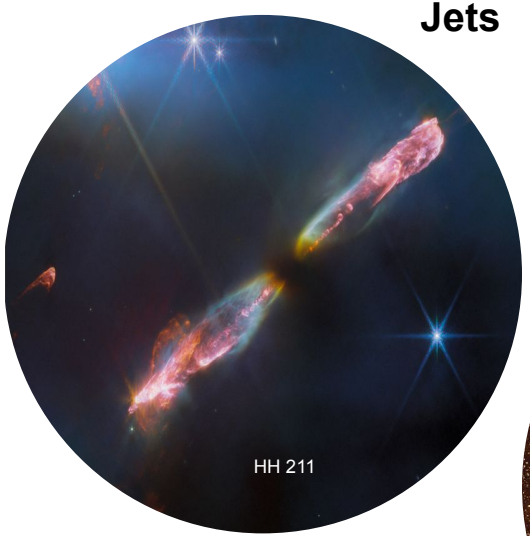


Galaxy properties significantly vary with stellar feedback physics

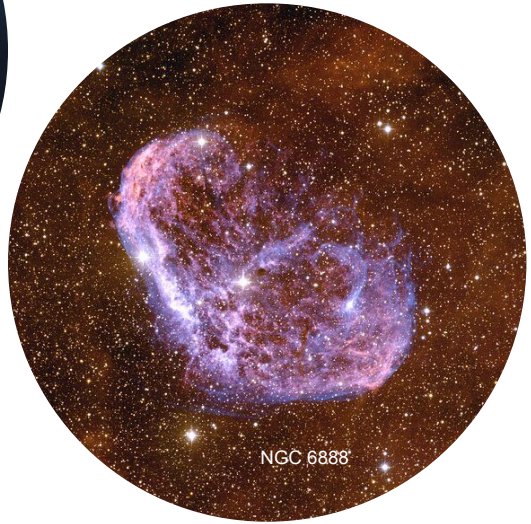


Types of stellar feedback

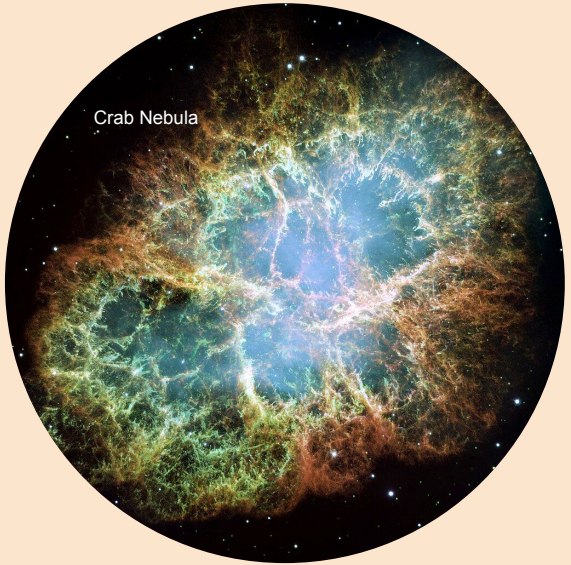
Jets



Winds + Ionizing photons



Supernovae

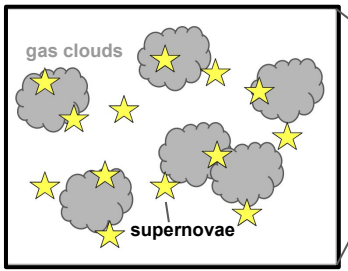


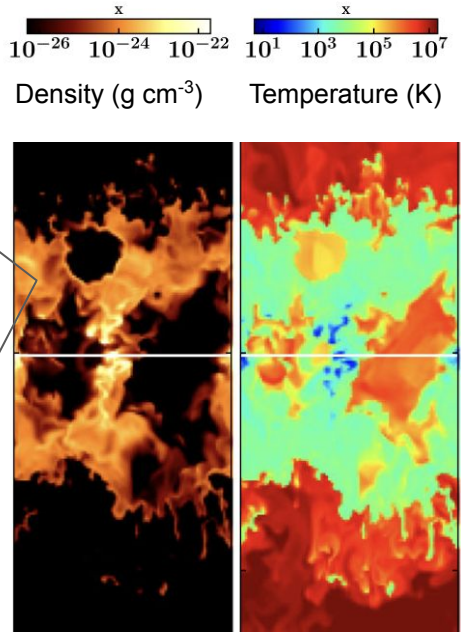
Critical factor

Ambient Density

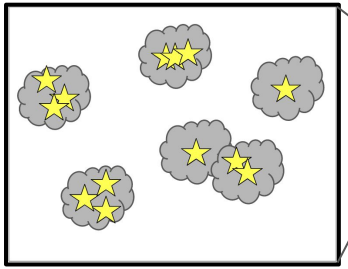
ISM properties significantly vary with “where” stars explode

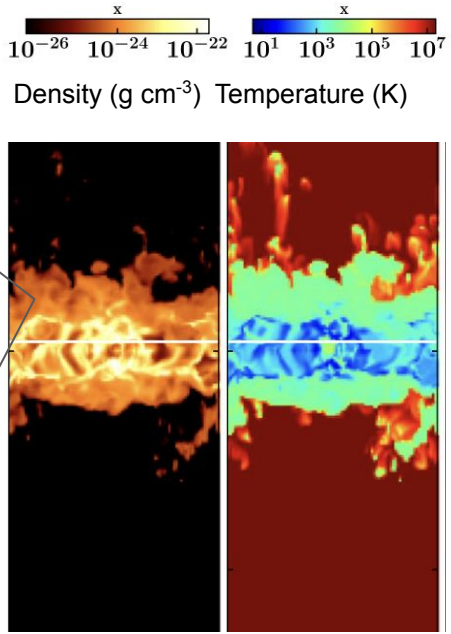
Stars exploding randomly





Stars exploding in dense gas





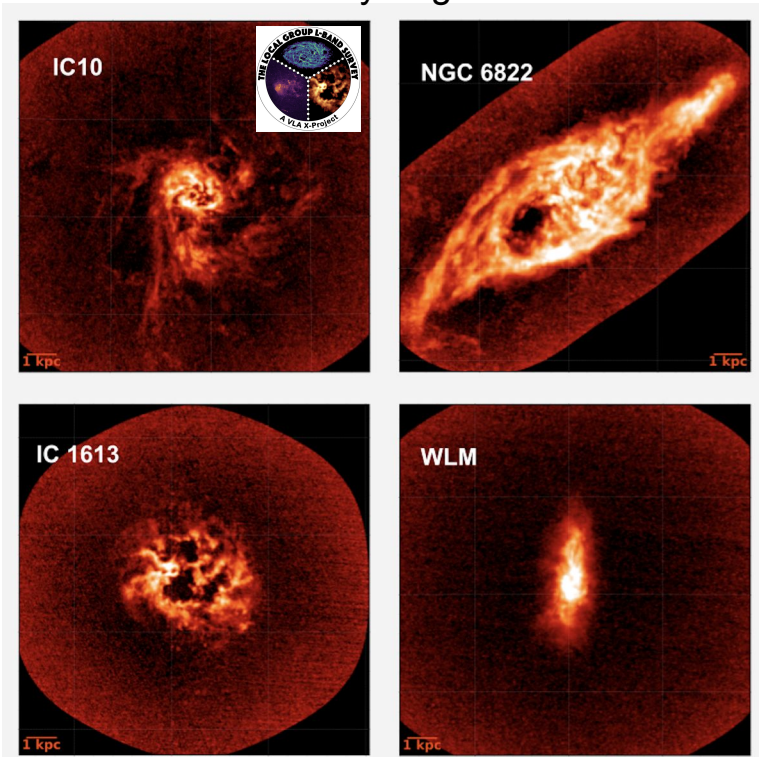
SILCC simulations (Girichidis+ 2016)

Where do stars explode in the ISM?

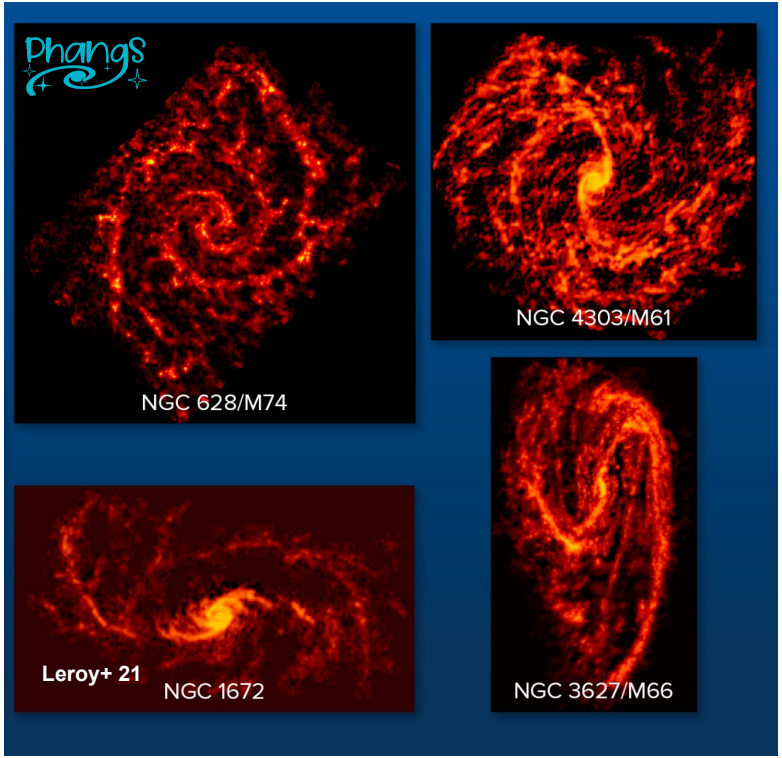
Characterise from observations

High-resolution maps of multi-phase ISM with VLA, ALMA, MUSE, JWST

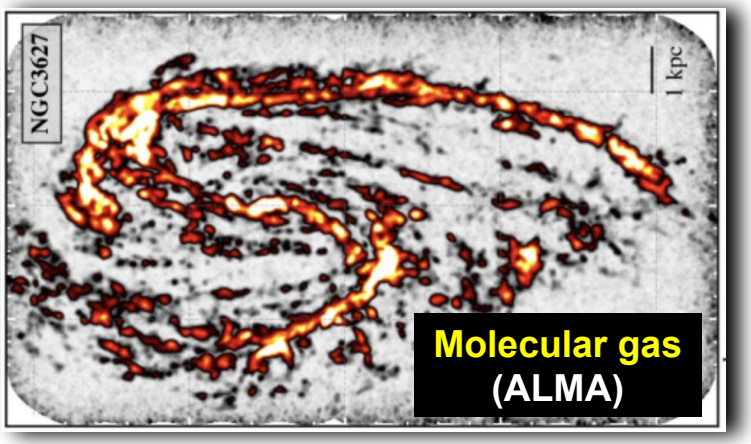
Atomic Hydrogen



Molecular hydrogen

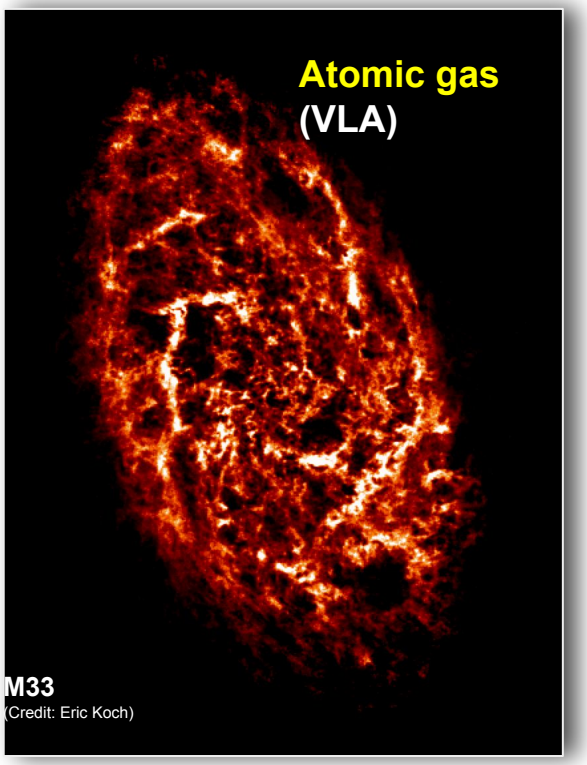


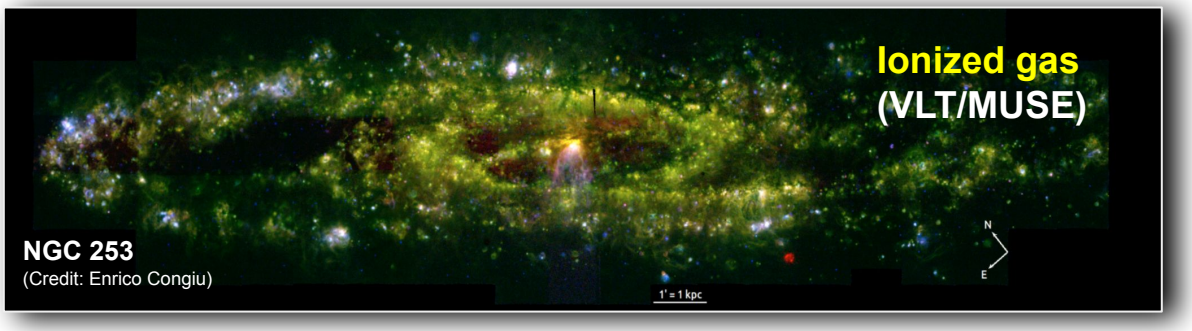
Era of high-resolution gas maps of nearby galaxies



Phangs

THE LOCAL GROUP L-BAND SURVEY
A VLA X-Project

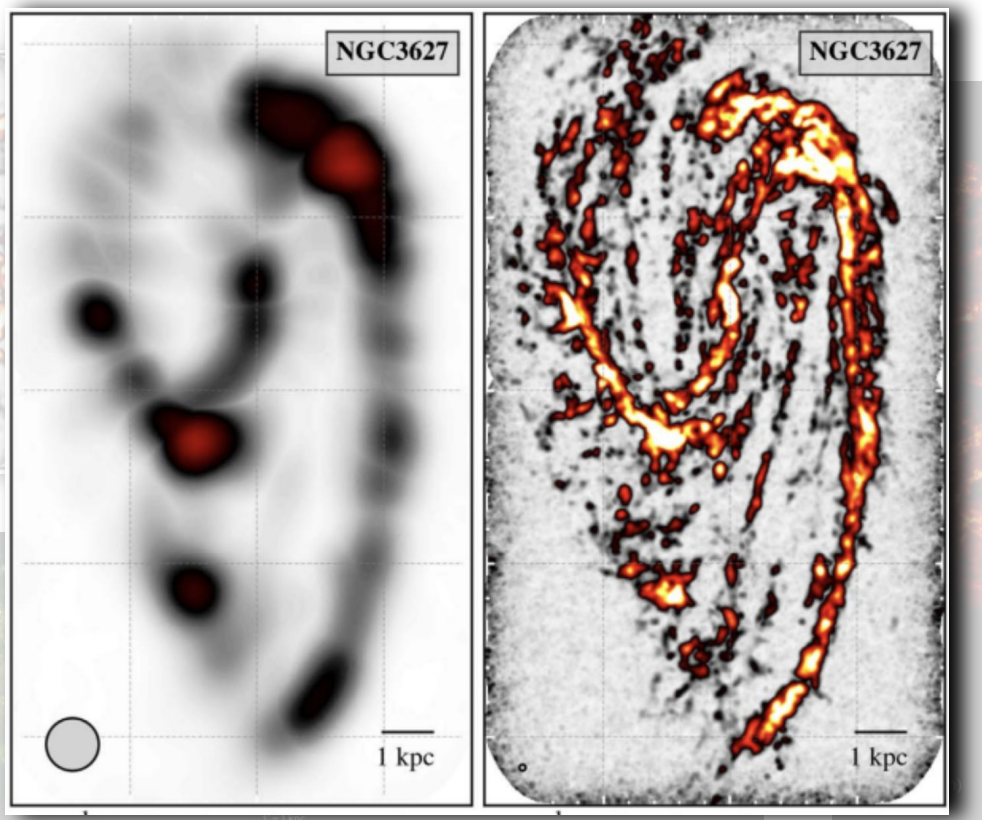




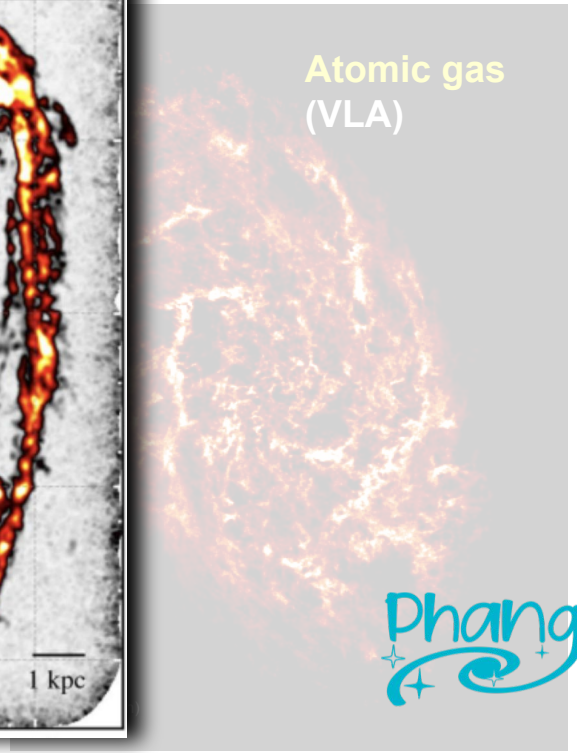
Era of high-resolution gas maps of nearby galaxies

Before ALMA…

After ALMA…



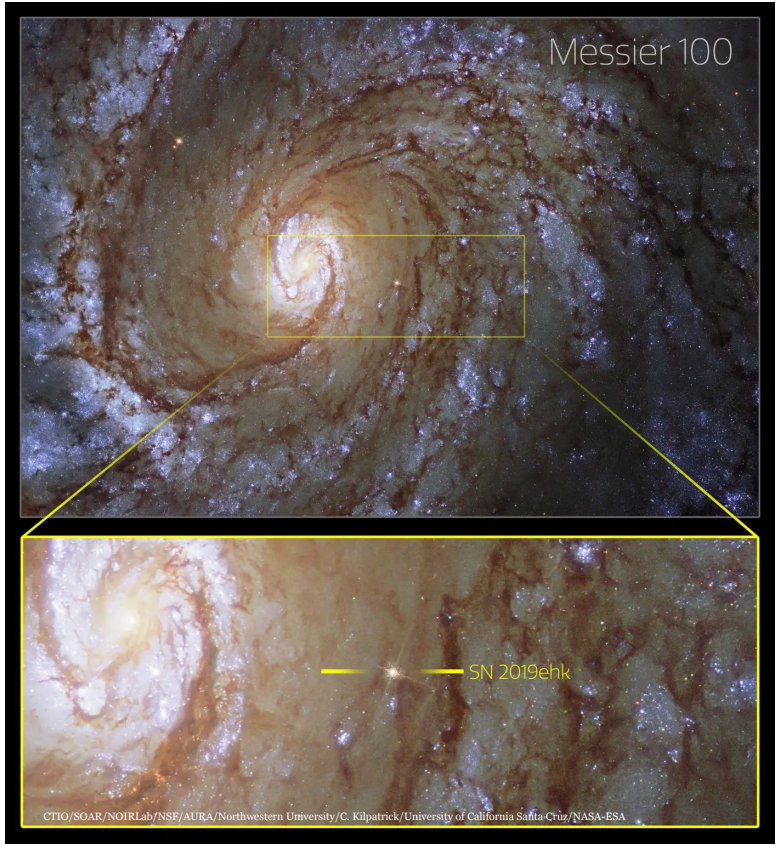
NGC 253
(Credit: Enrico Congiu)



Atomic gas
(VLA)

PHANGS

Observing dense gas around nearby supernovae



63 supernovae

31 galaxies (<20 Mpc)

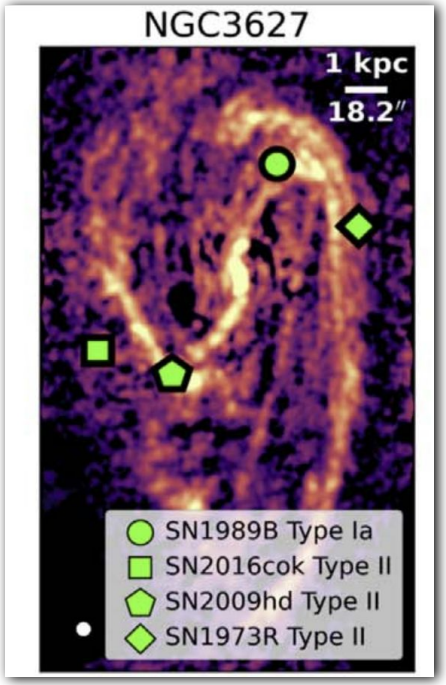
60-150 pc resolution

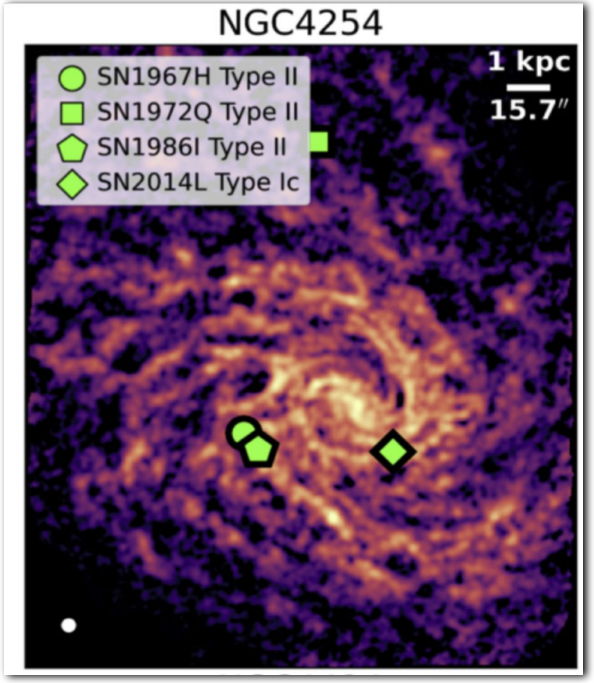
Ness Mayker Chen (OSU)

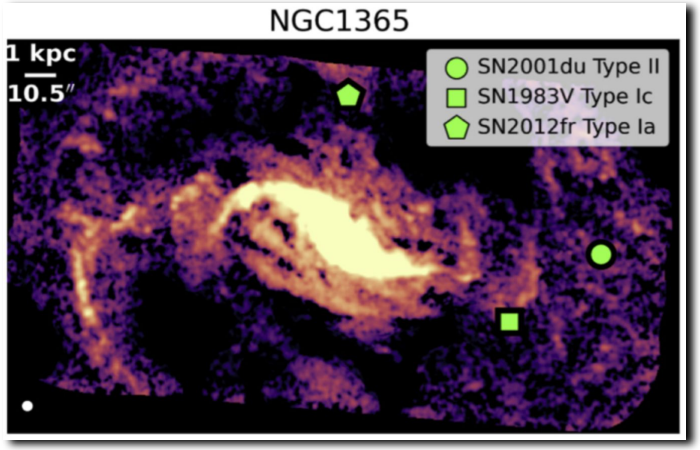
*Mayker Chen+ (incl. **SKS**) 2022*
ApJ 944:110

PHANGS

Observing dense gas around nearby supernovae





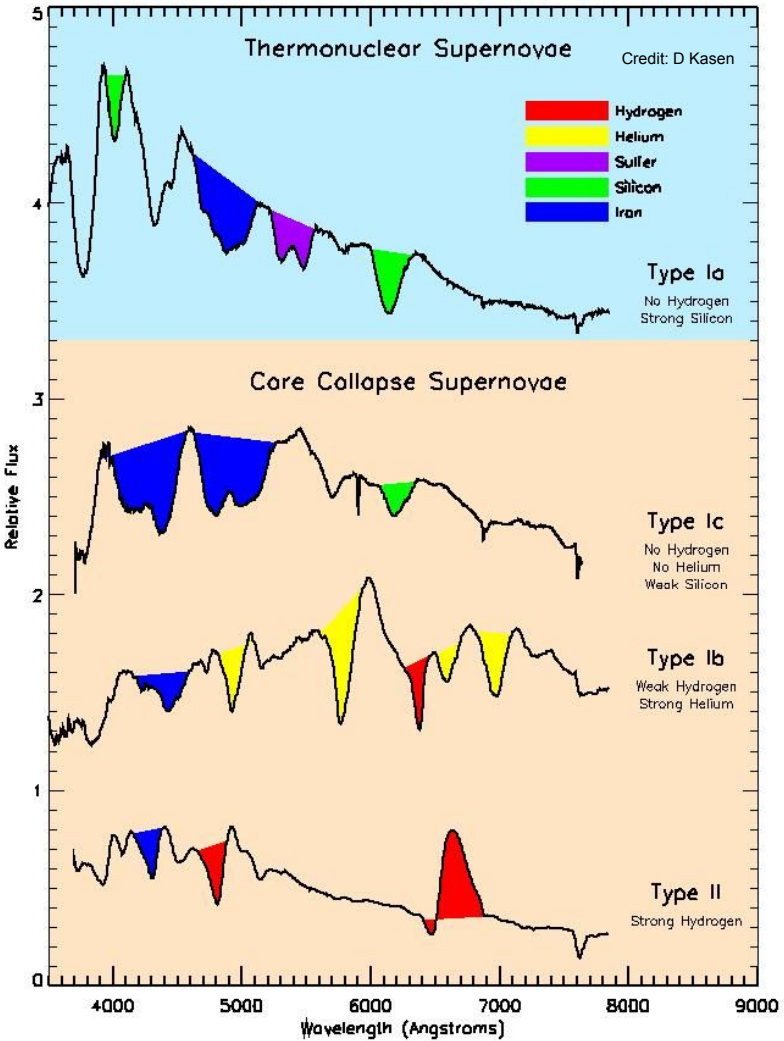


Ness Mayker Chen (OSU)

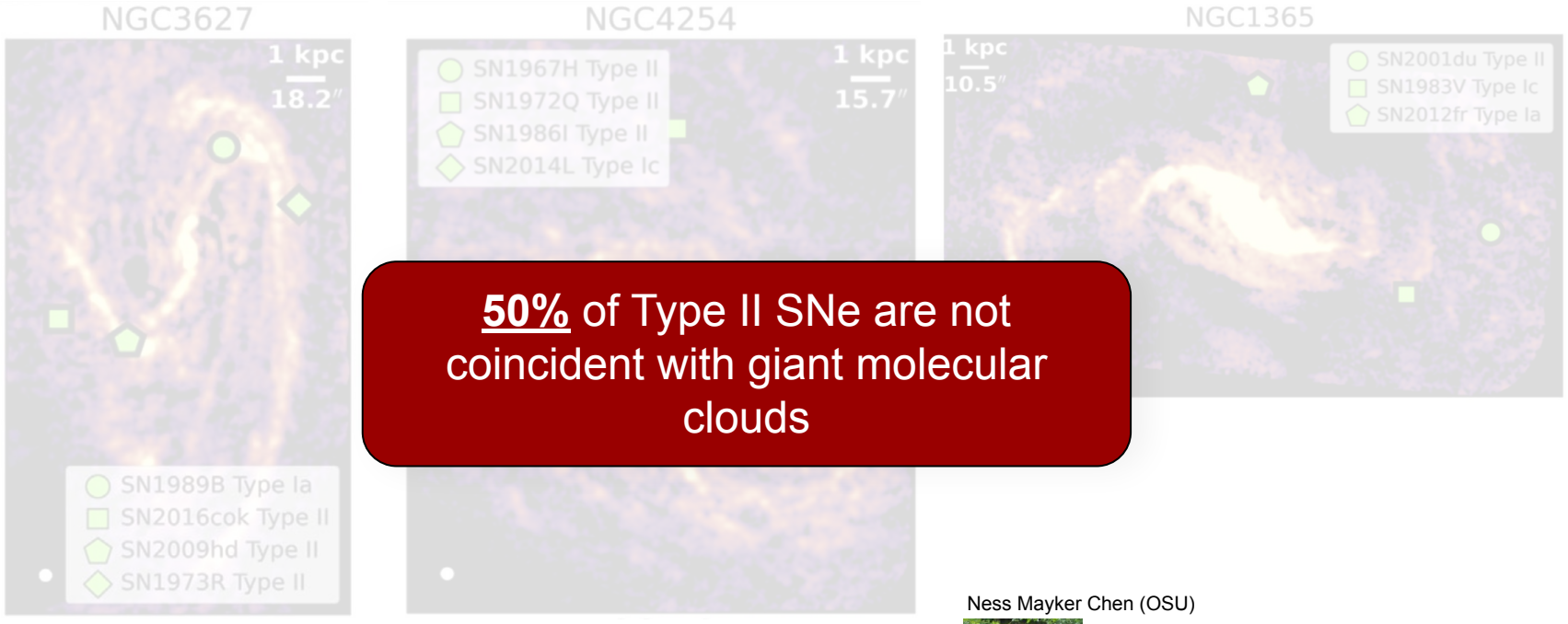
*Mayker Chen+ (incl. **SKS**) 2022*
ApJ 944:110

PHANGS

Observing dense gas arour



Observing dense gas around nearby supernovae



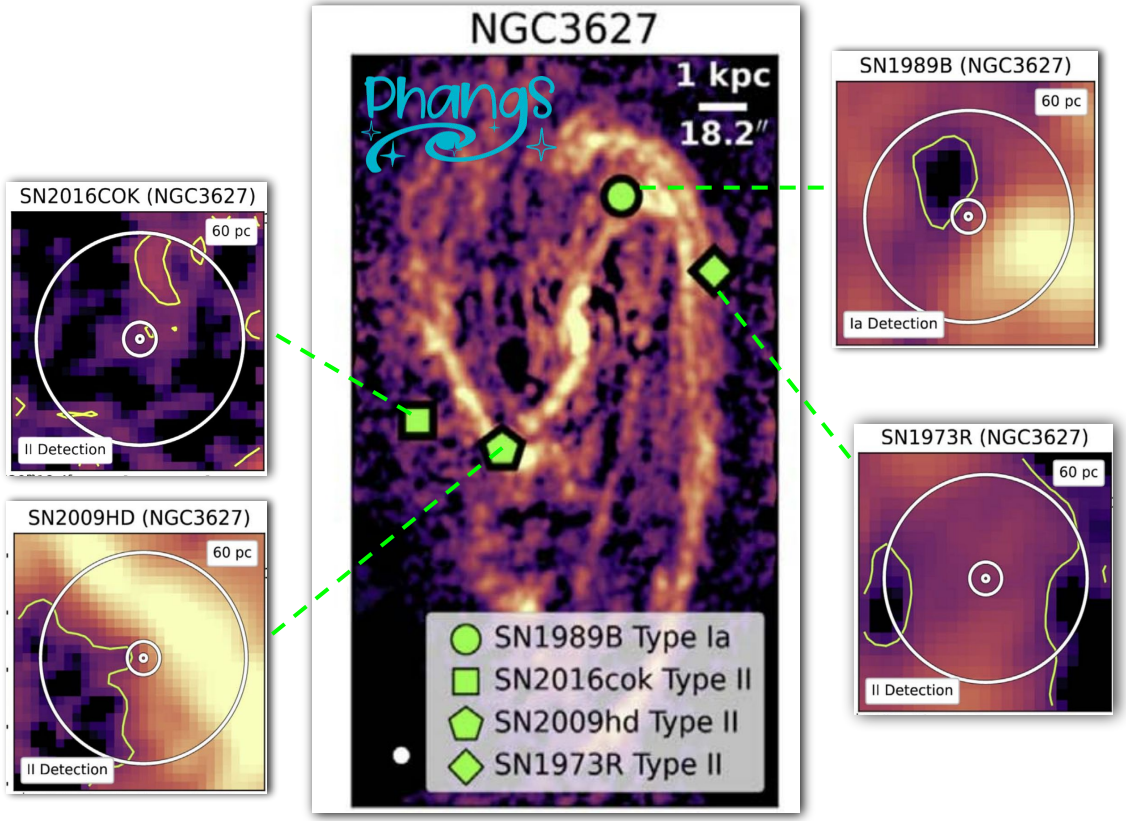
<u>50%</u> of Type II SNe are not coincident with giant molecular clouds

Ness Mayker Chen (OSU)

*Mayker Chen+ (incl. **SKS**) 2022*
ApJ 944:110

PHANGS

Observing dense gas around nearby supernovae



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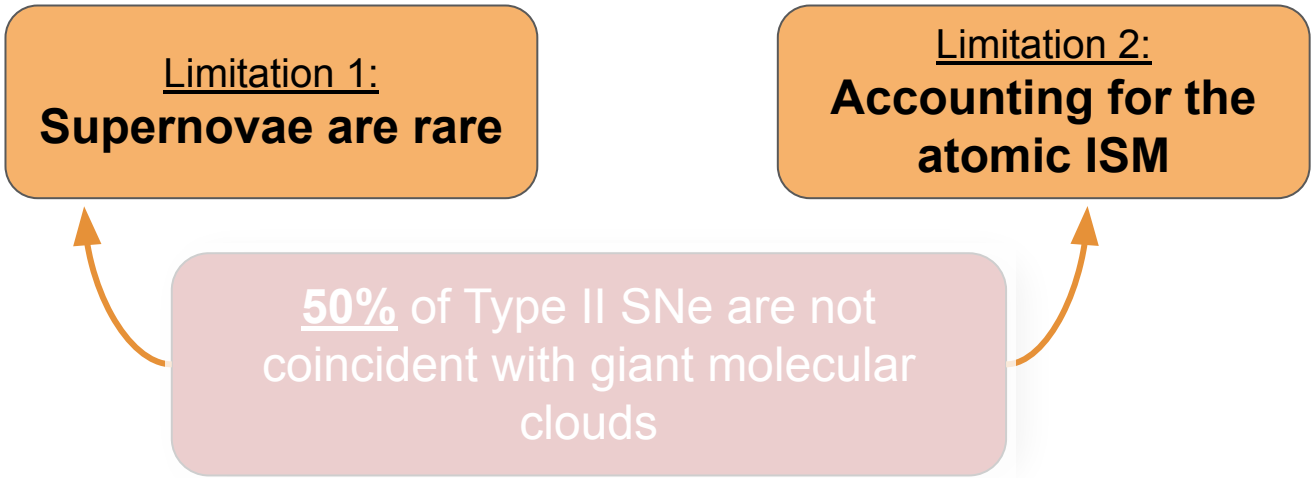
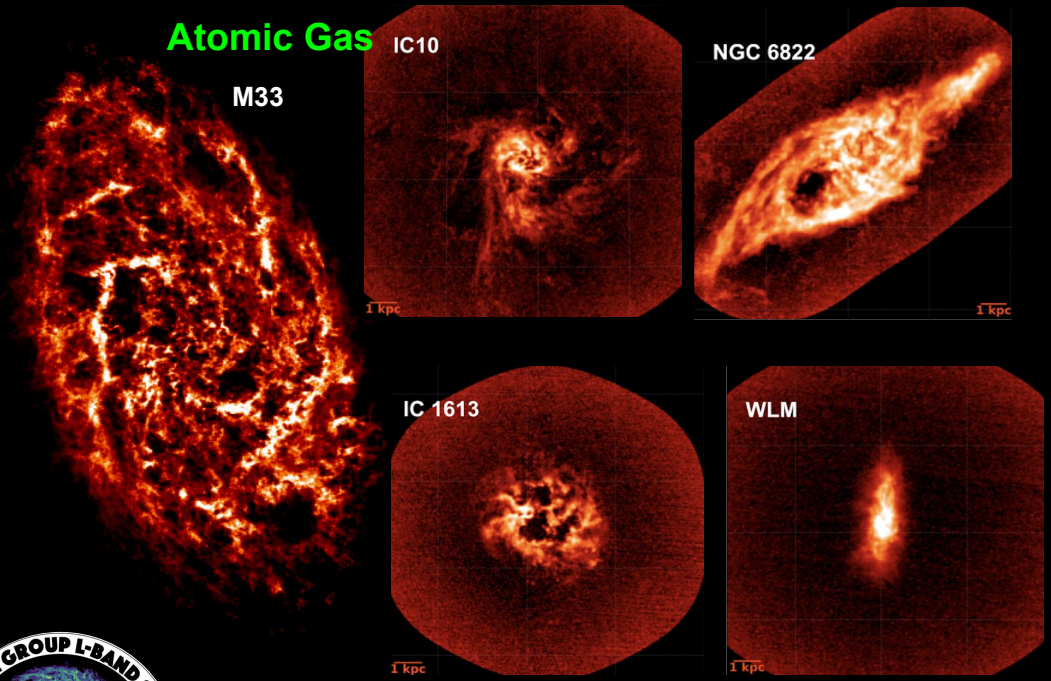
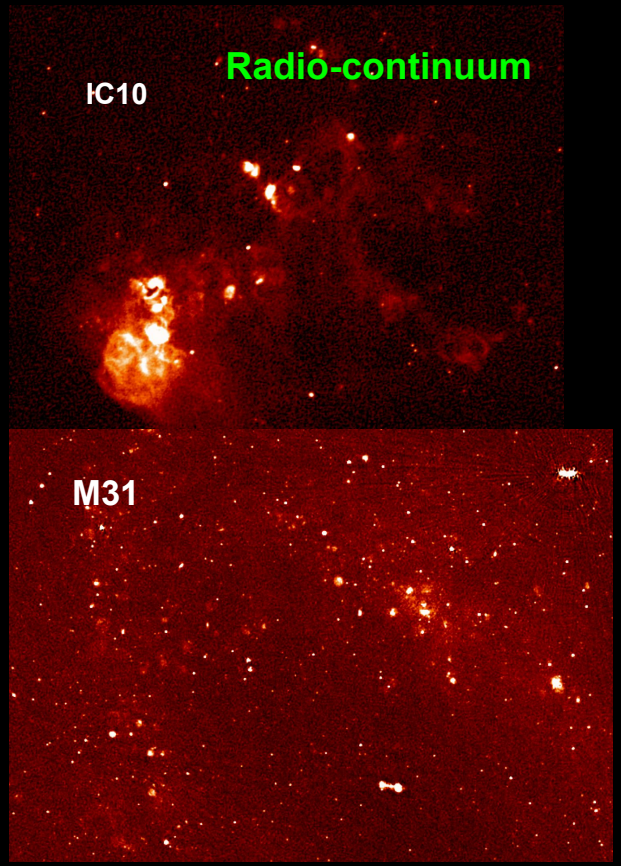
Observing dense gas around nearby supernovae



Alternative: Local Group galaxies!

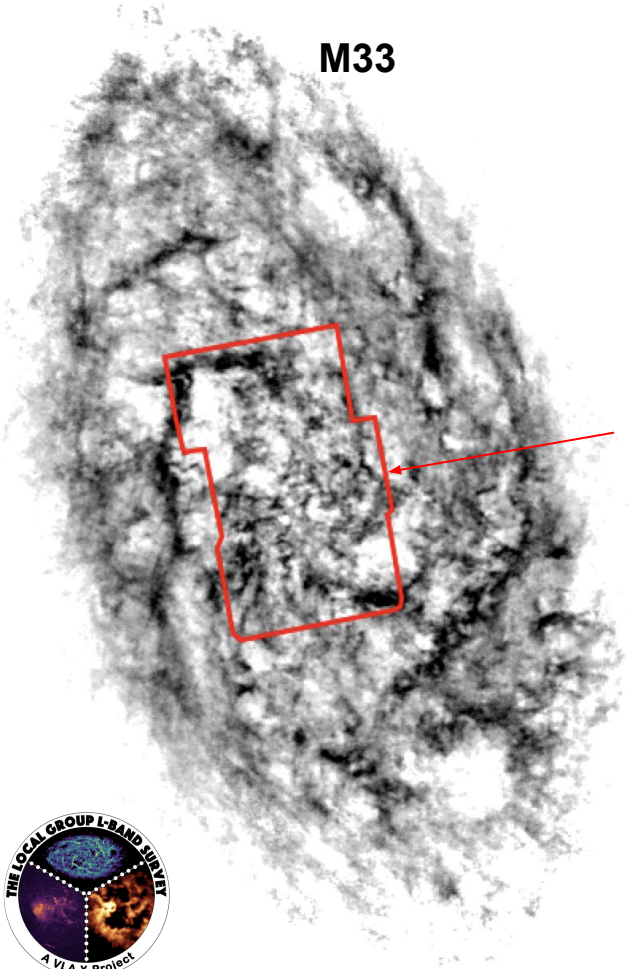




THE LOCAL GROUP L-BAND SURVEY
A VLA X-Project

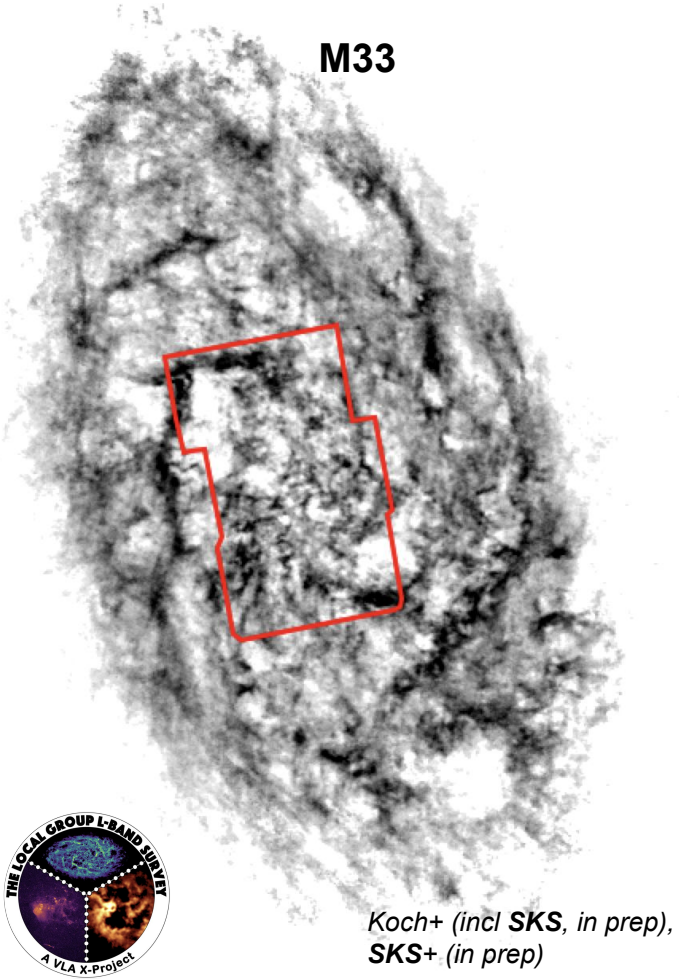
Spectral lines: Eric Koch, Nick Pingel, Adam Leroy, Erik Rosolowsky
Continuum: ***Sumit Sarbadhicary***, Erik Rosolowsky, Preshanth Jagannathan

Pilot study in M33



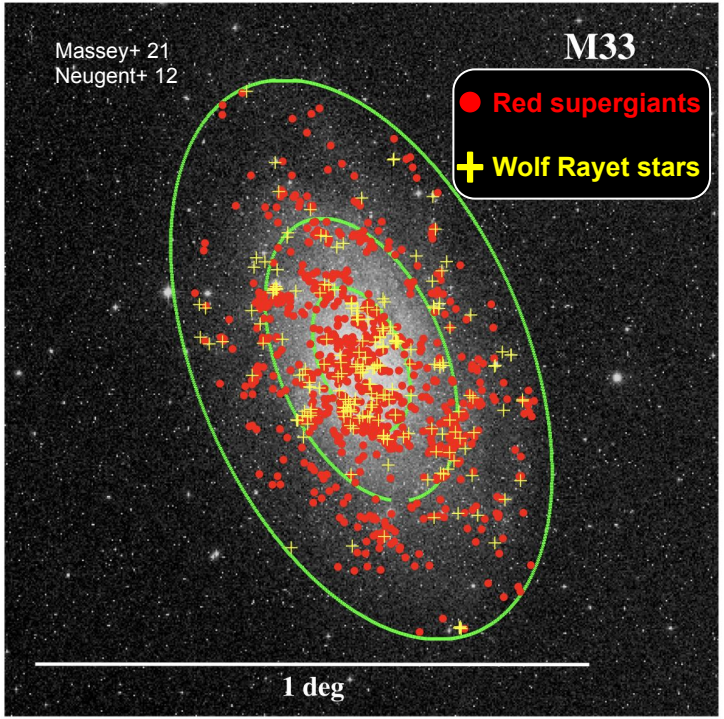
Ongoing ALMA ACA survey
(Koch+ in prep)

Jordan Wagner
(SURP '22, OSU)



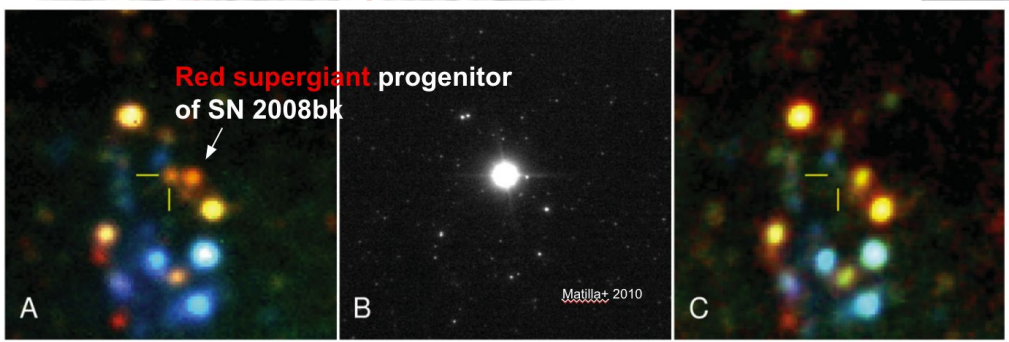
*Koch+ (incl **SKS**, in prep),*
***SKS**+ (in prep)*

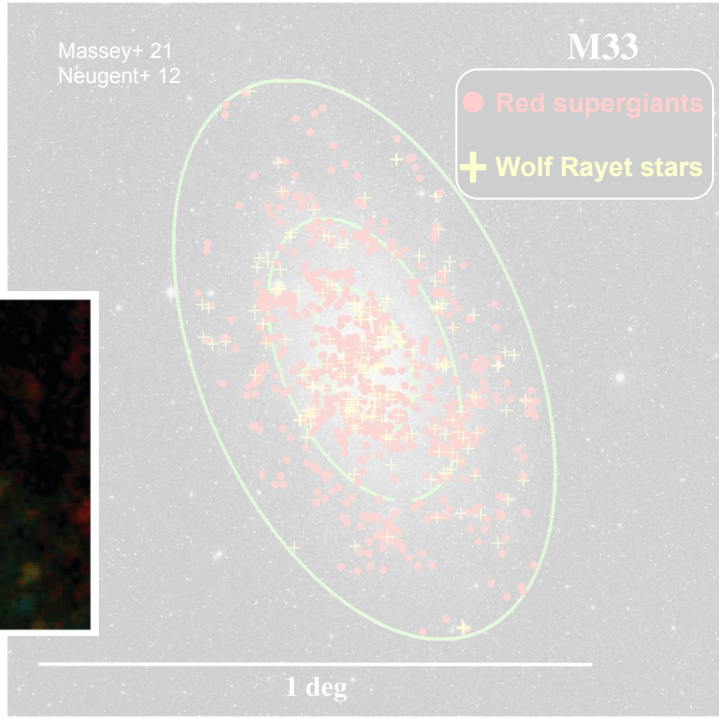
Evolved massive stars as “future” supernovae.



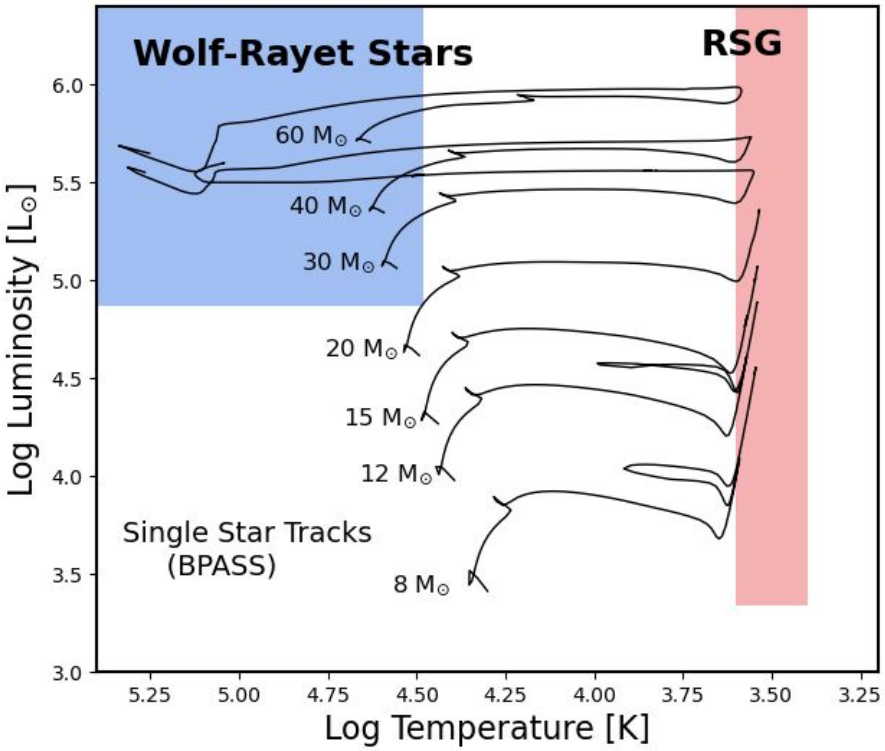
M33

Evolved massive stars as “future” supernovae.



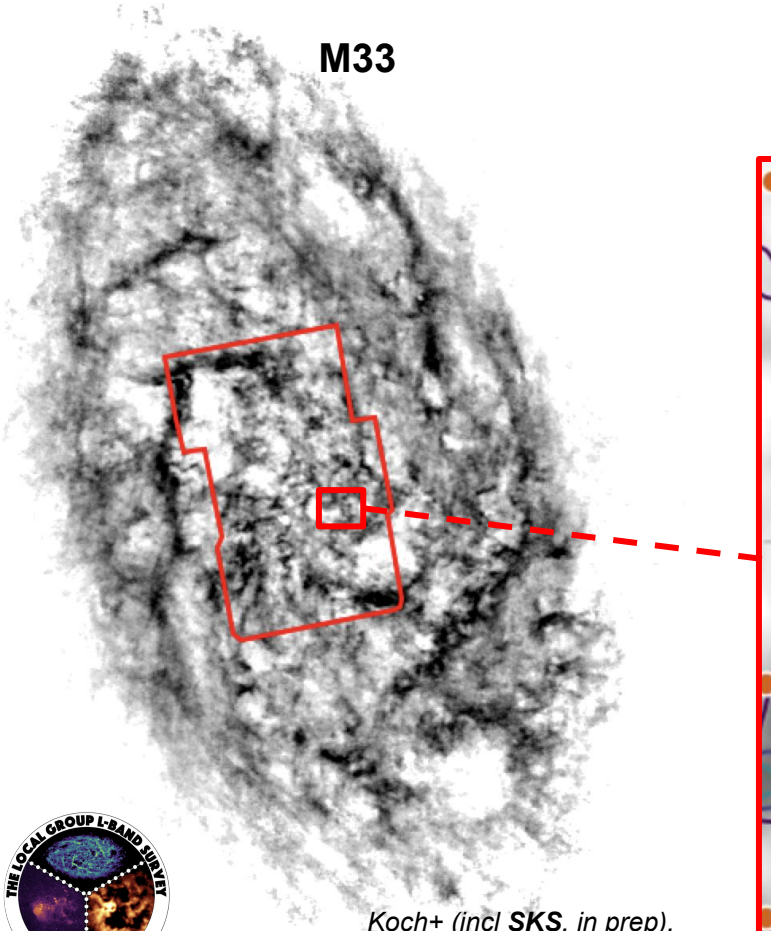


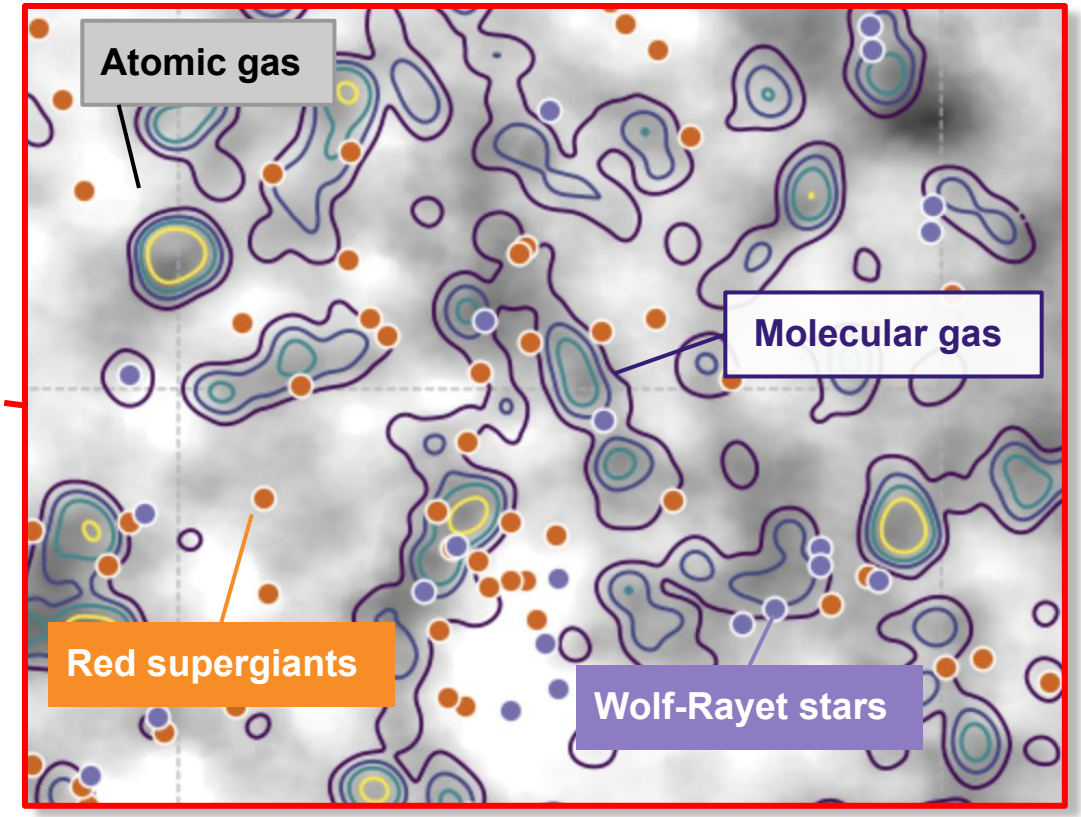
*Koch+ (incl **SKS**, in prep),*
***SKS**+ (in prep)*



Evolved massive stars as “future” supernovae.

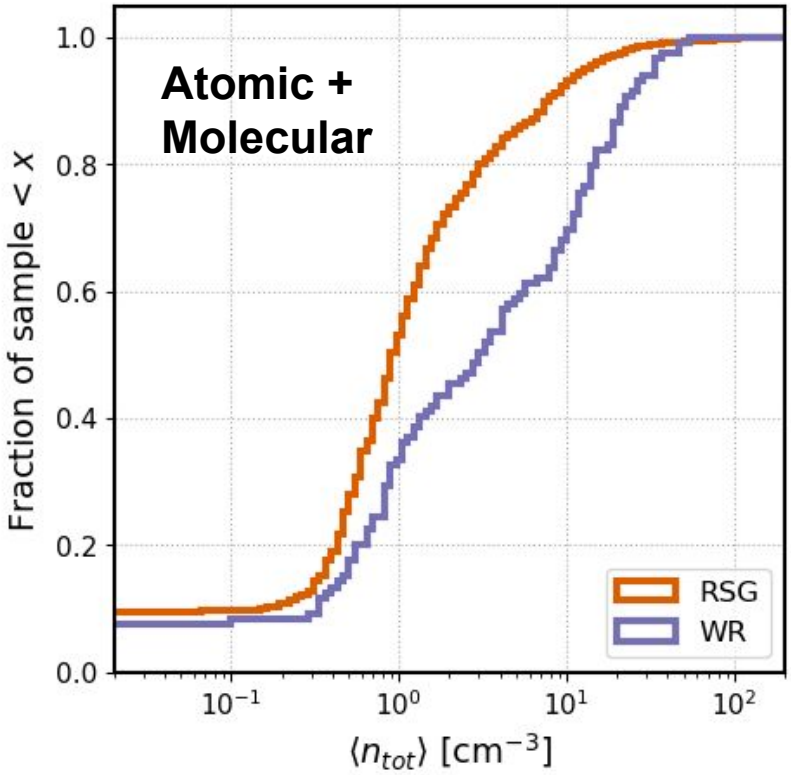
Cold ISM around “future” supernovae



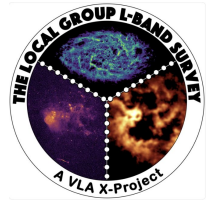


*Koch+ (incl **SKS**, in prep),*
***SKS**+ (in prep)*

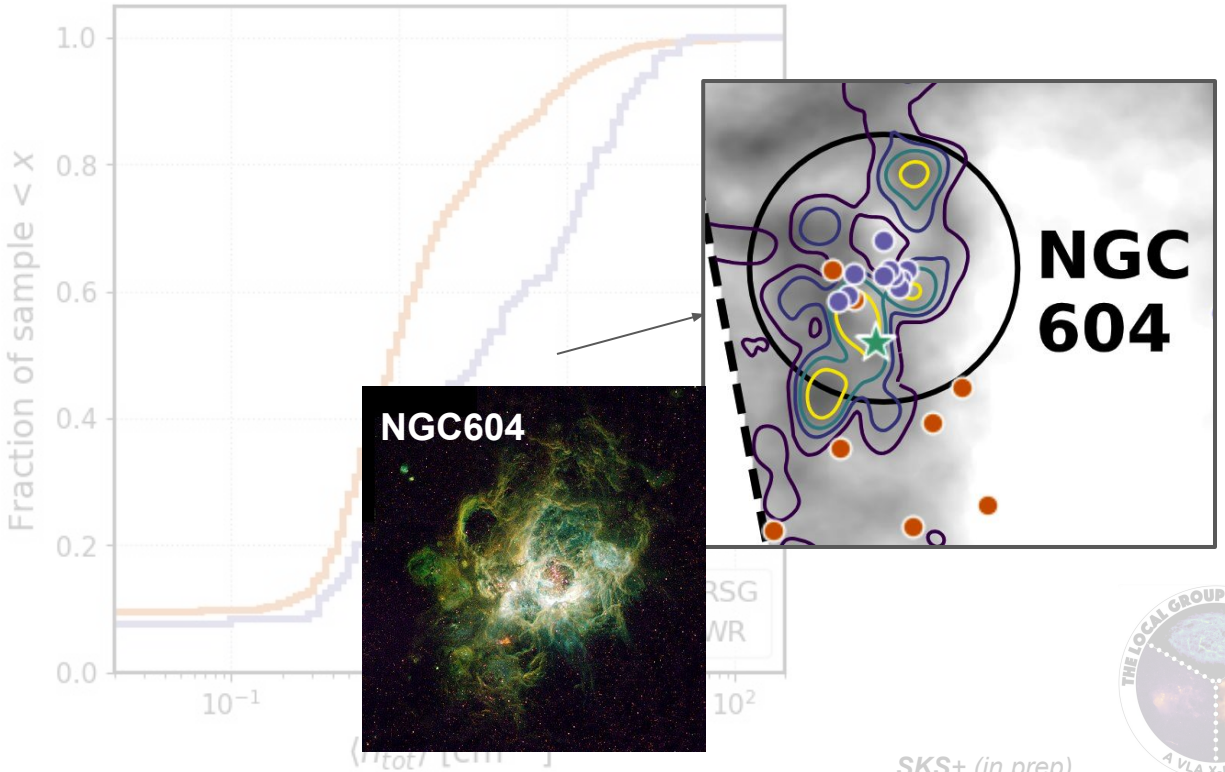
Younger massive stars explode in denser ISM



***SKS+** (in prep)*

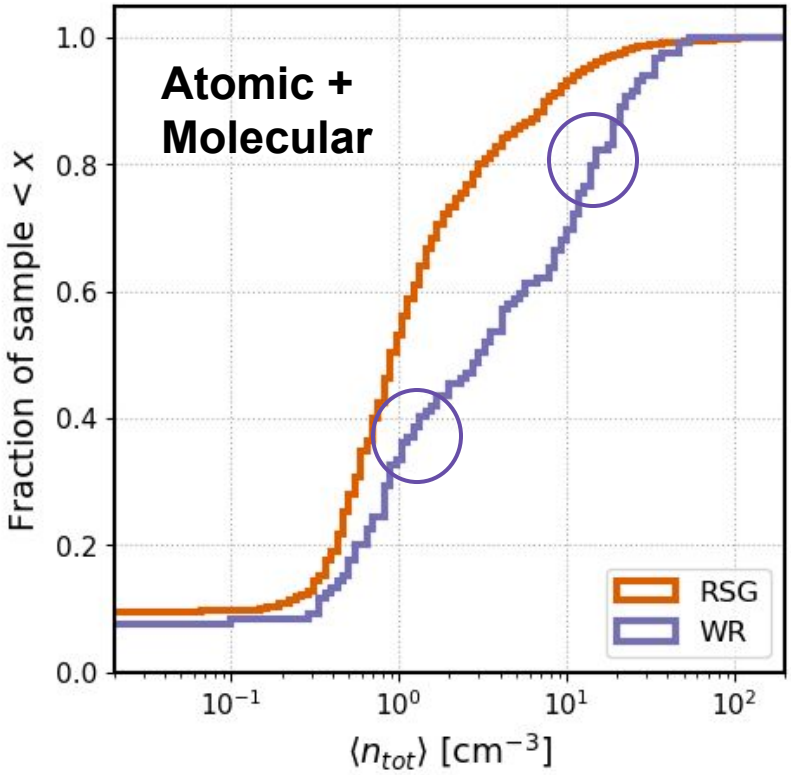


Younger massive stars explode in denser ISM



SKS+ (in prep)

Younger massive stars explode in denser ISM



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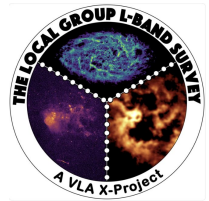
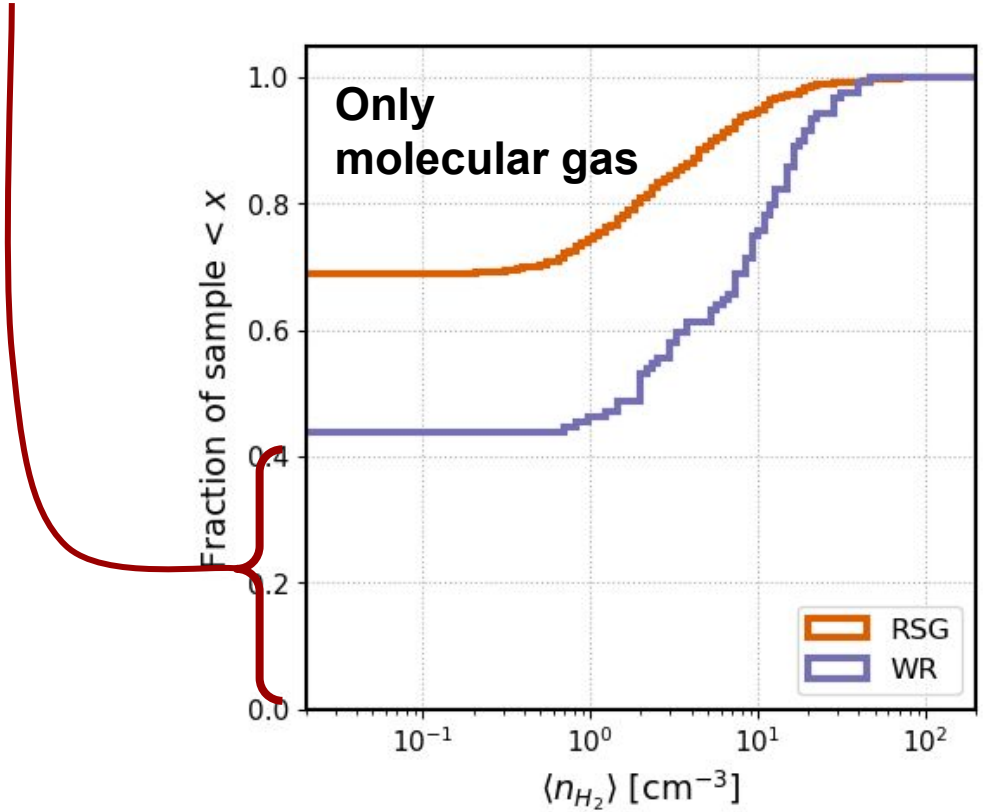
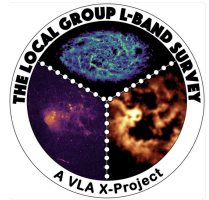
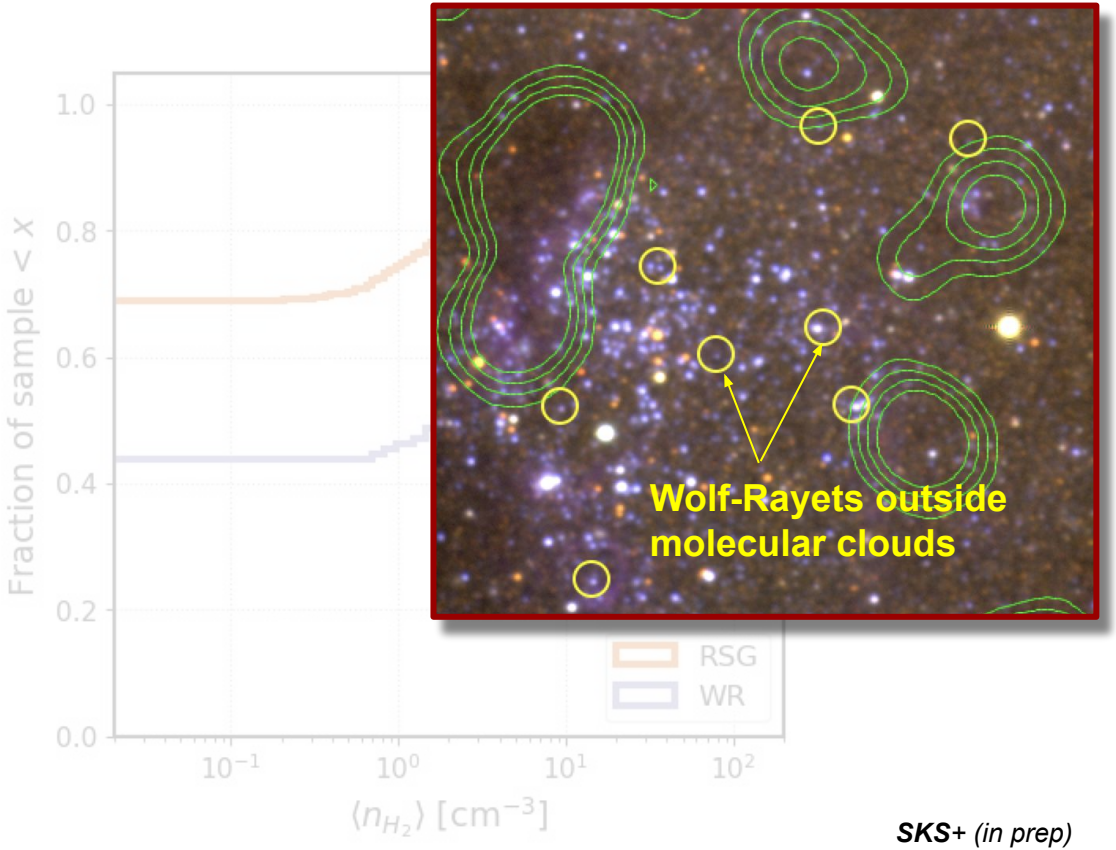


…But a significant fraction explodes outside molecular clouds



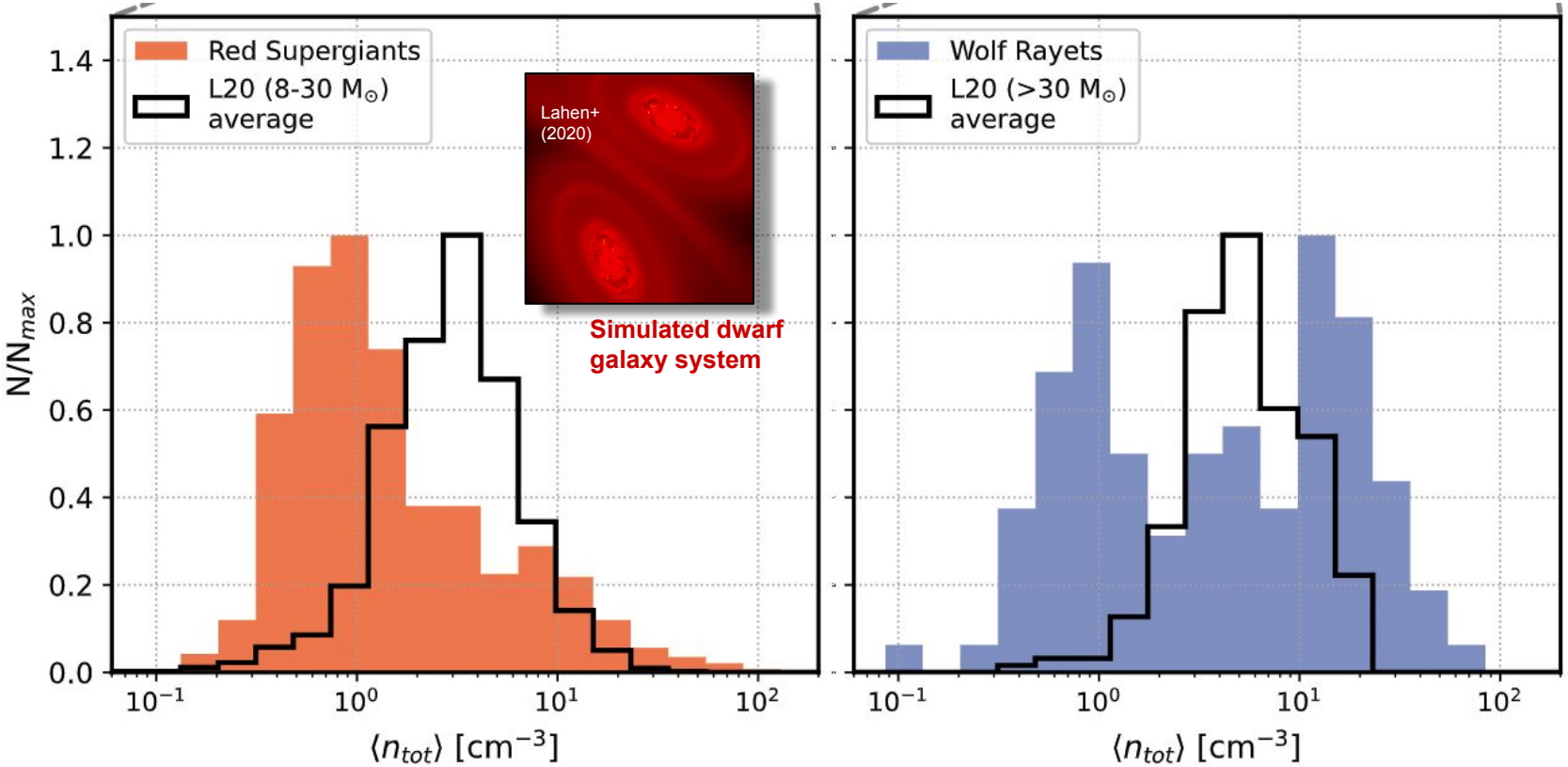
***SKS+** (in prep)*



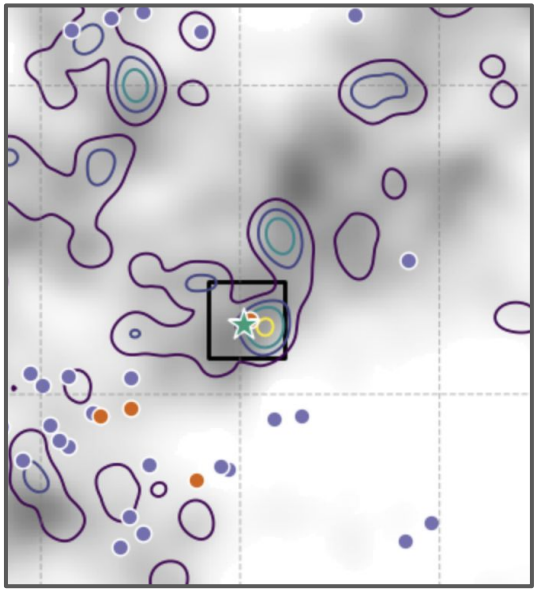

Wolf-Rayets outside
molecular clouds
Fraction of sample < x
1.0
0.8
0.6
0.4
0.2
0.0
RSG
WR
10^{-1}
10^{0}
10^{1}
10^{2}
$\langle n_{H_2} \rangle$ [cm^{-3}]

***SKS+** (in prep)*

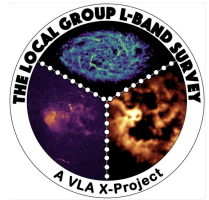
A new way to observationally constrain feedback models in simulations



Higher-resolution can reveal detailed substructure



SKS+ *(in prep)*



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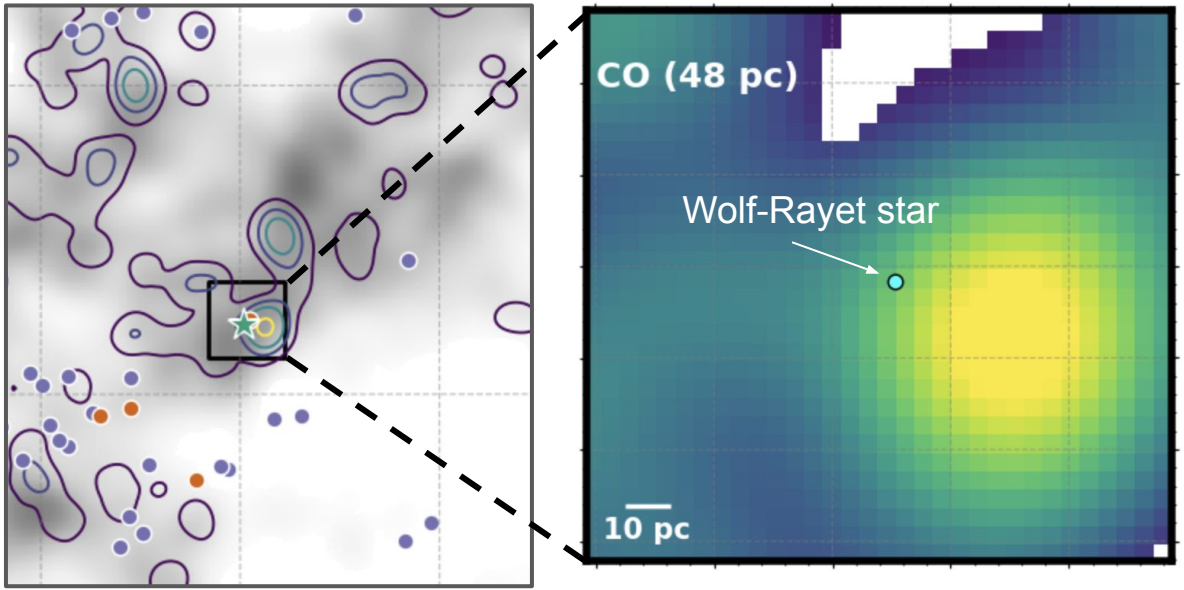
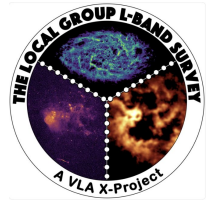
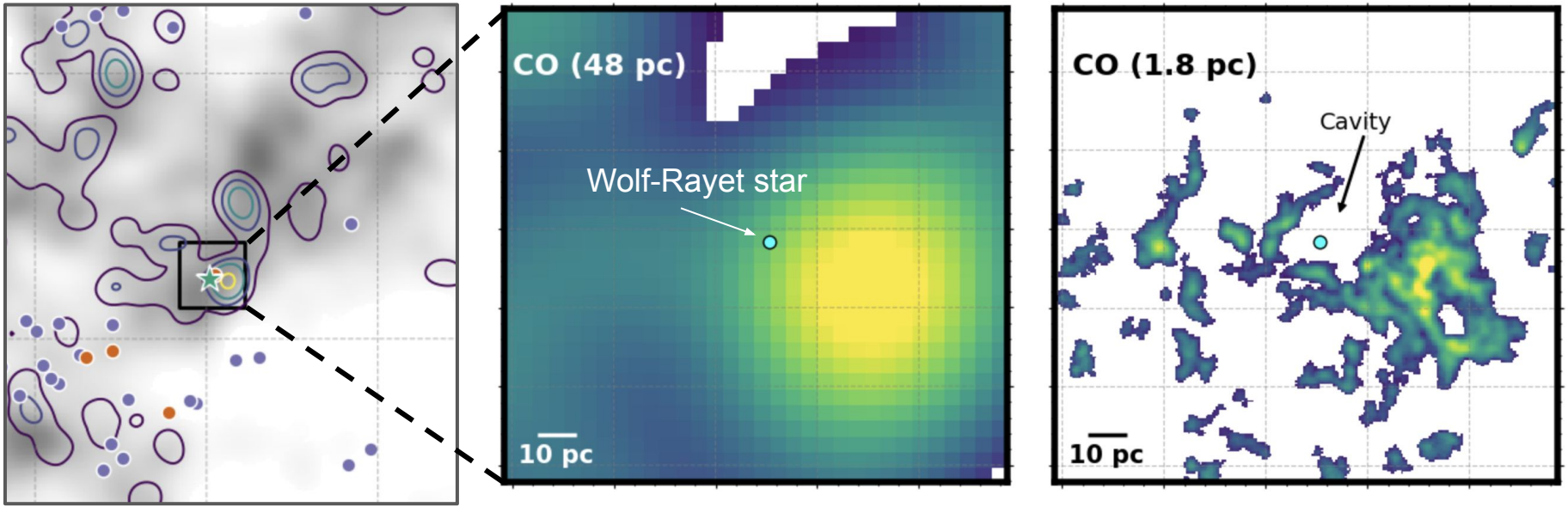


SKS+ *(in prep)*

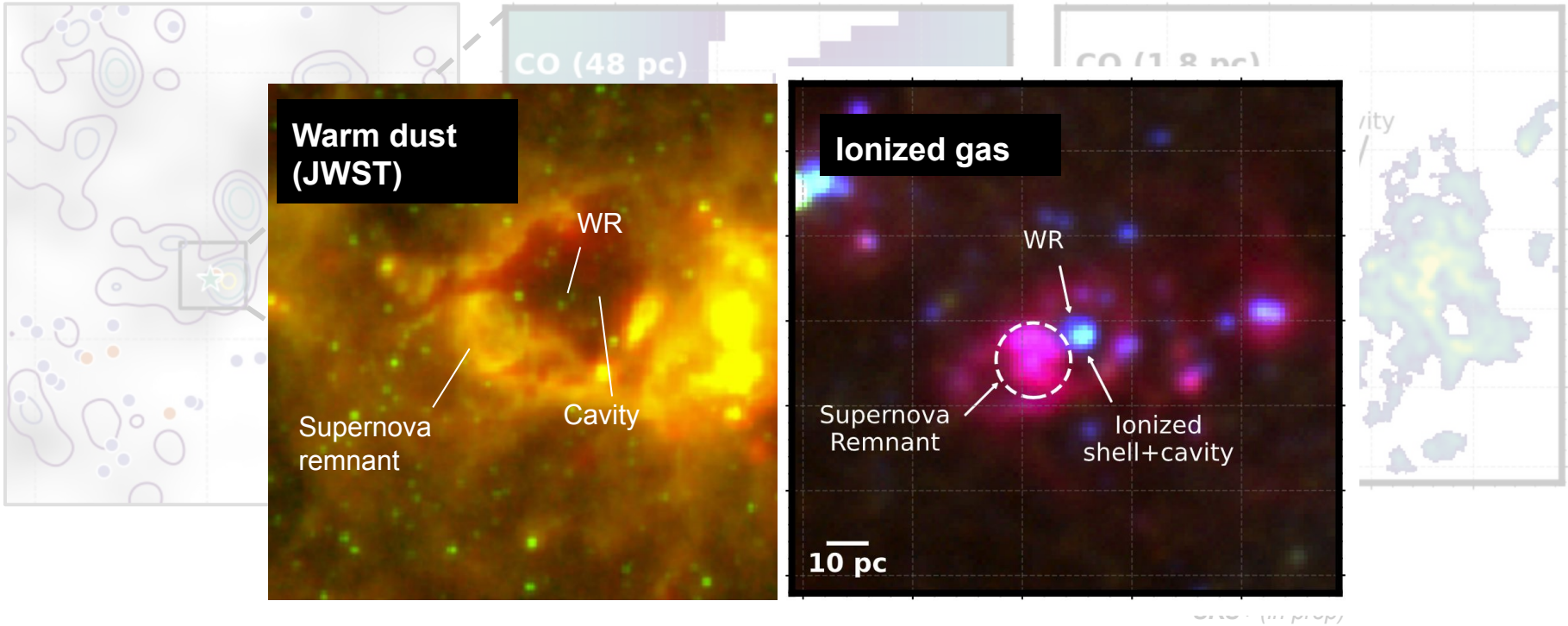


Higher-resolution can reveal detailed substructure



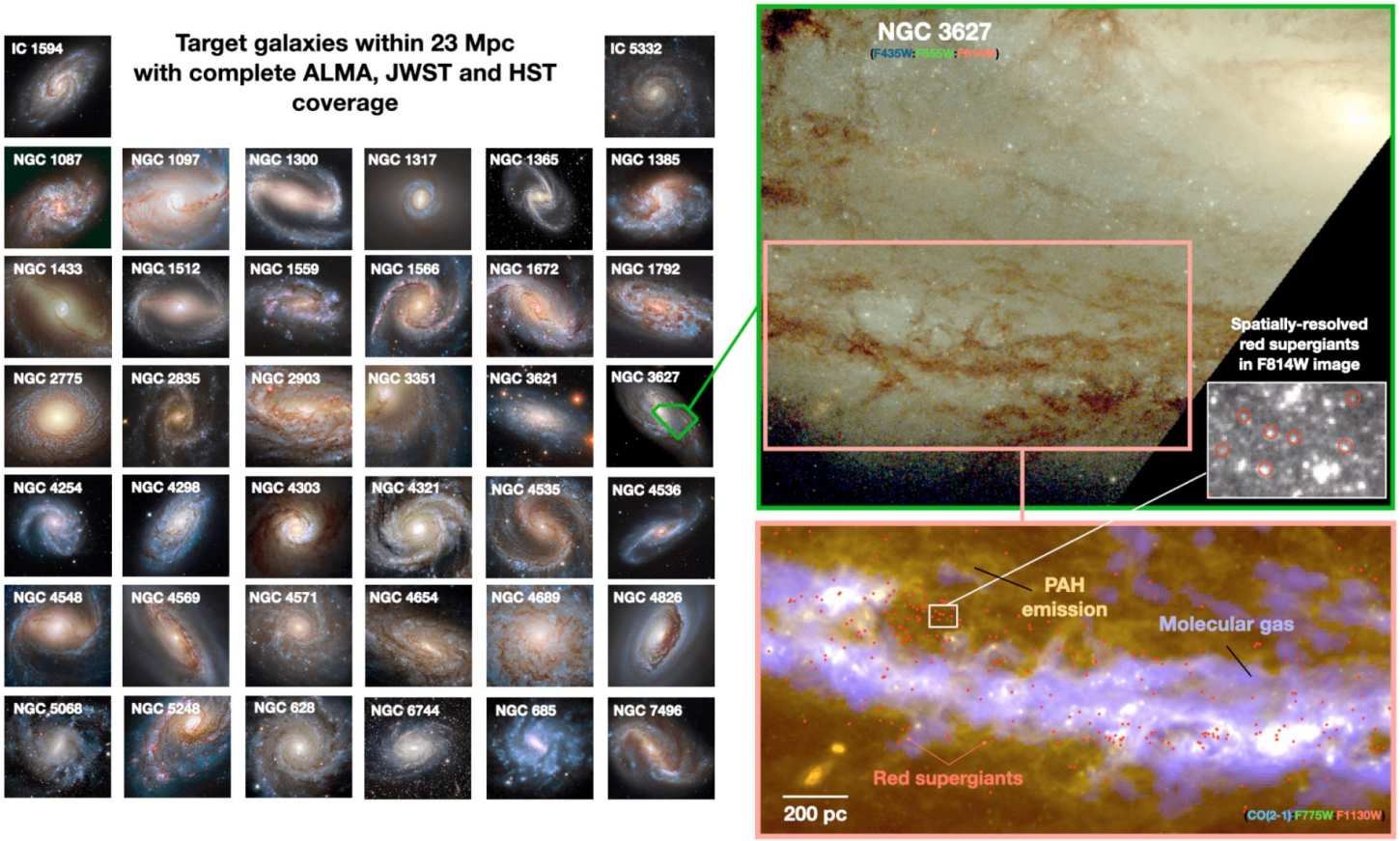
***SKS+** (in prep)*

Higher-resolution can reveal detailed substructure

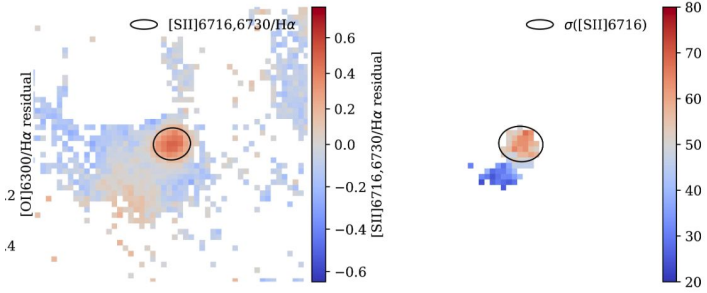


Ongoing/future work

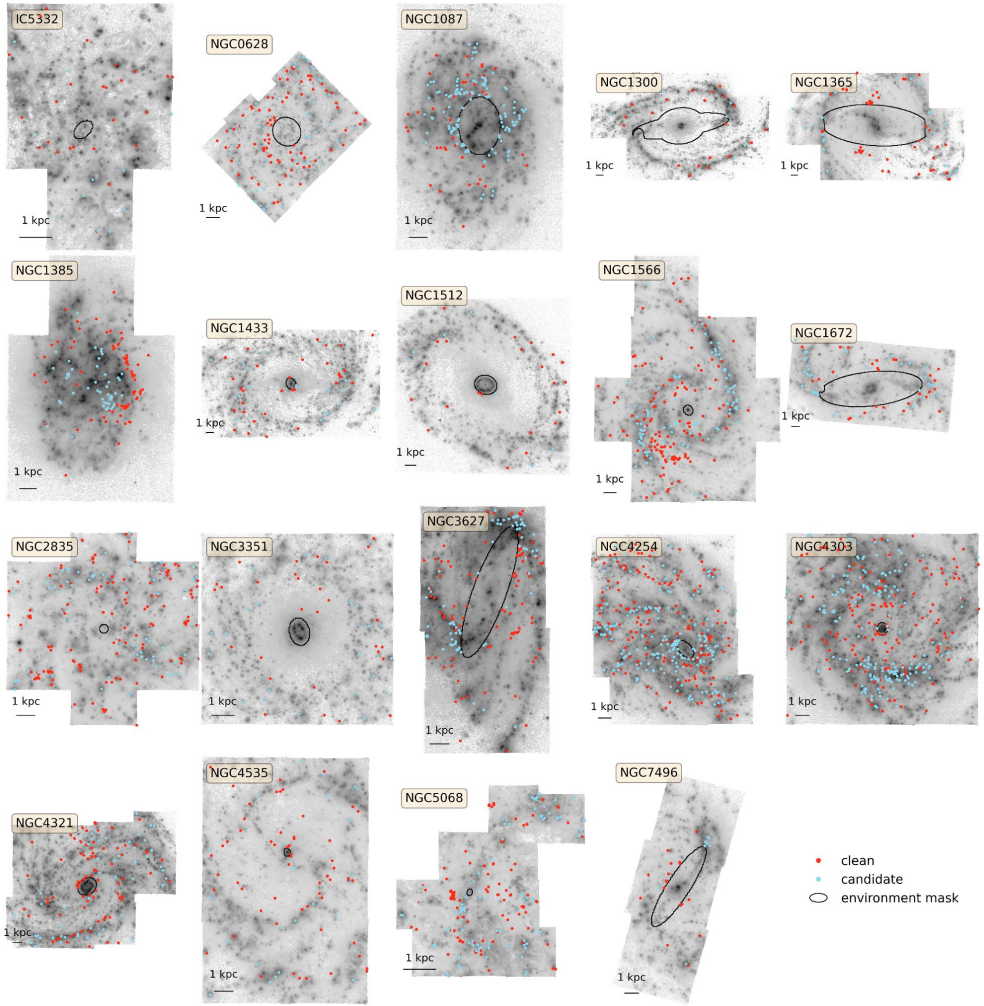
Supernova progenitors in 38 nearby galaxies with HST (AR 17572)



~2400 new supernova remnants in 19 galaxies with MUSE spectroscopy



Jing Li (ZAH Heidelberg)

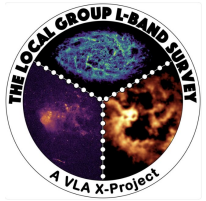


SUMMARY

Where do stars explode in the ISM?

- Dense molecular gas more common near more massive progenitors.
- 42-70% (depending on mass) explode outside molecular clouds.
- Measurements can directly constrain feedback models in simulations.

Exciting use case for modern/upcoming observatories (e.g. JWST, Roman, ELTs, ngVLA)



**SKS+ (in prep)*

Phangs