II Zw 40: A Test Case for Studying Baryon Cycling in the Nearby Universe

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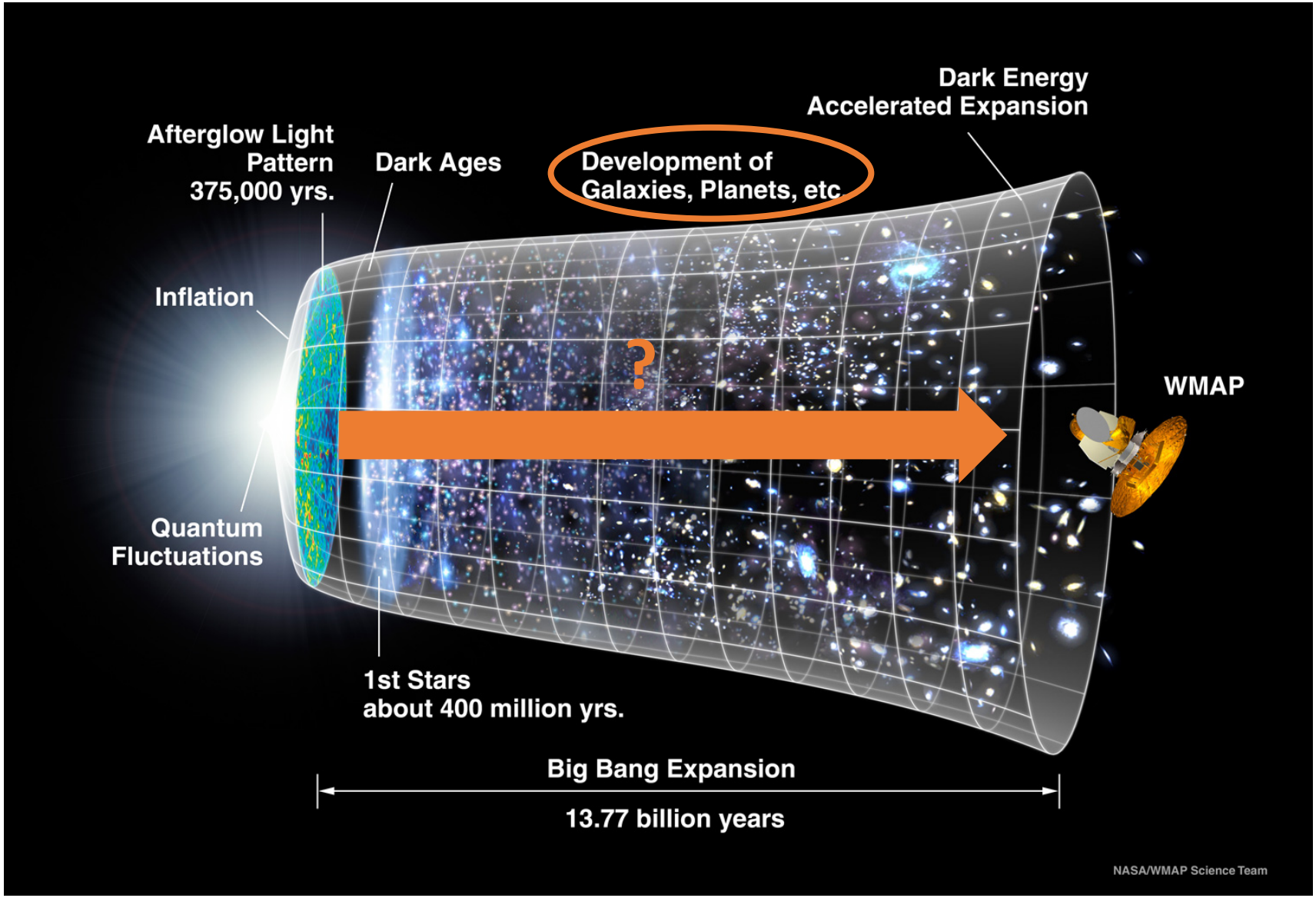
The History of the Universe in One Slide

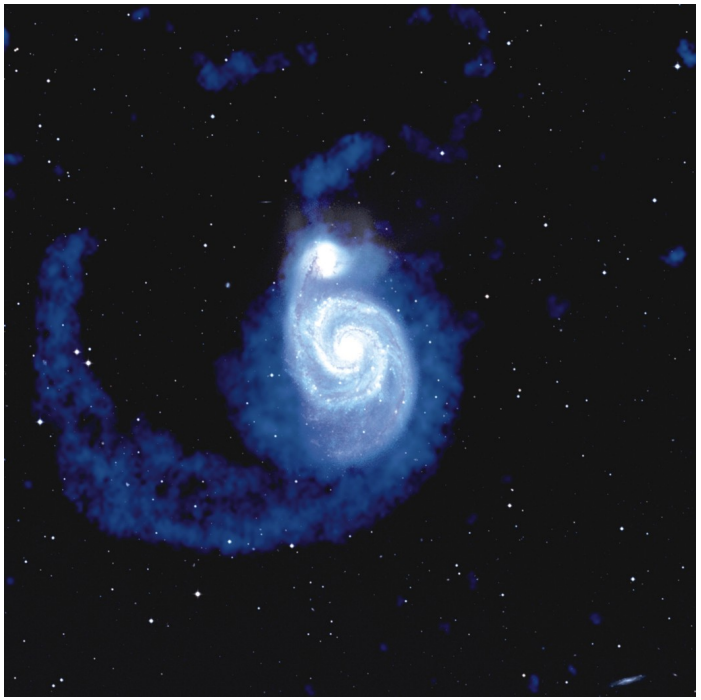


Time axis: logarithmic!!!

Credit: NASA / WMAP Science Team

Gravity

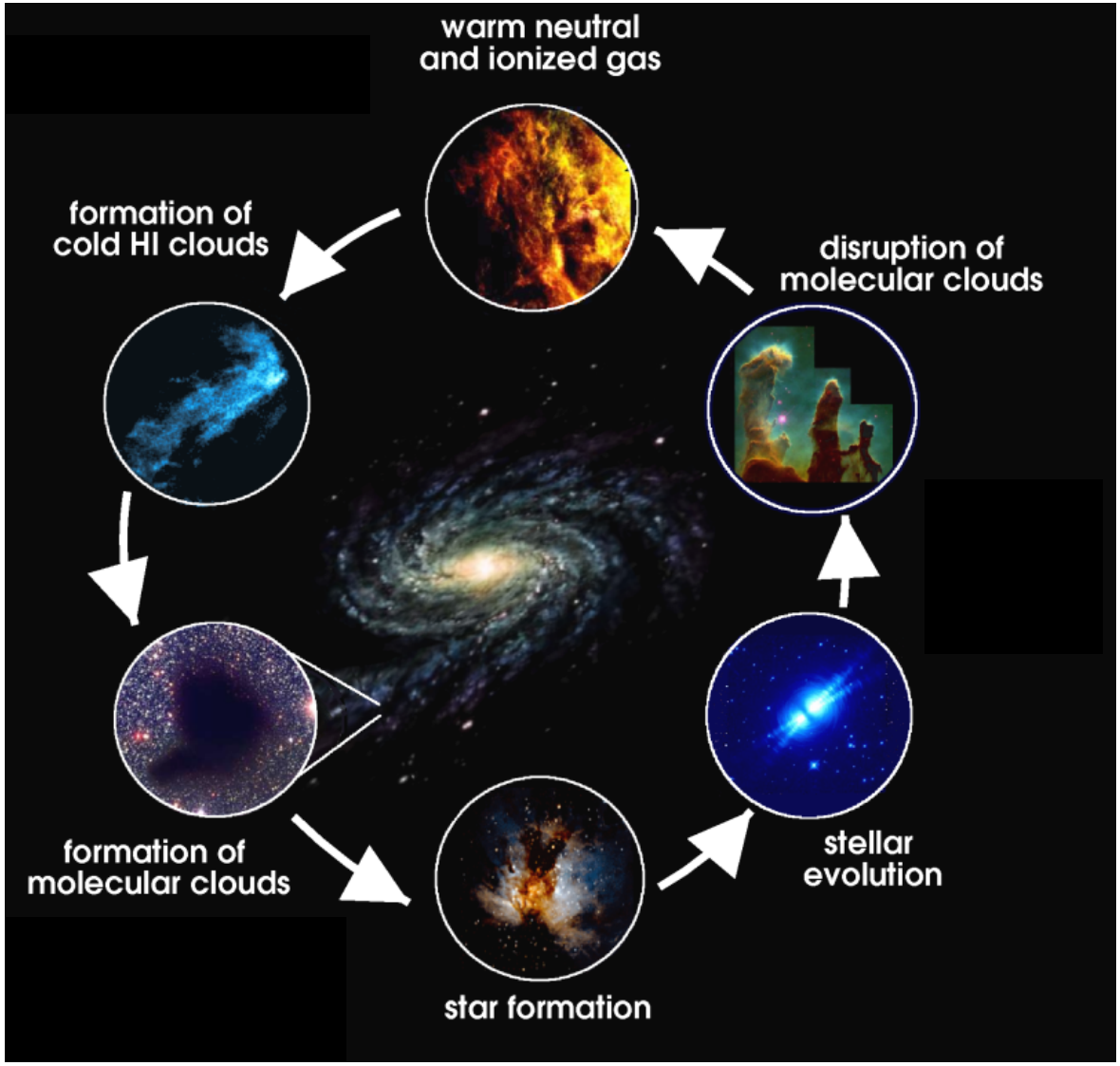
Expansion of the Universe



Interplay between gas and stars

(AKA baryon cycling)

Understanding the baryon cycle in galaxies is key for understanding their evolution.



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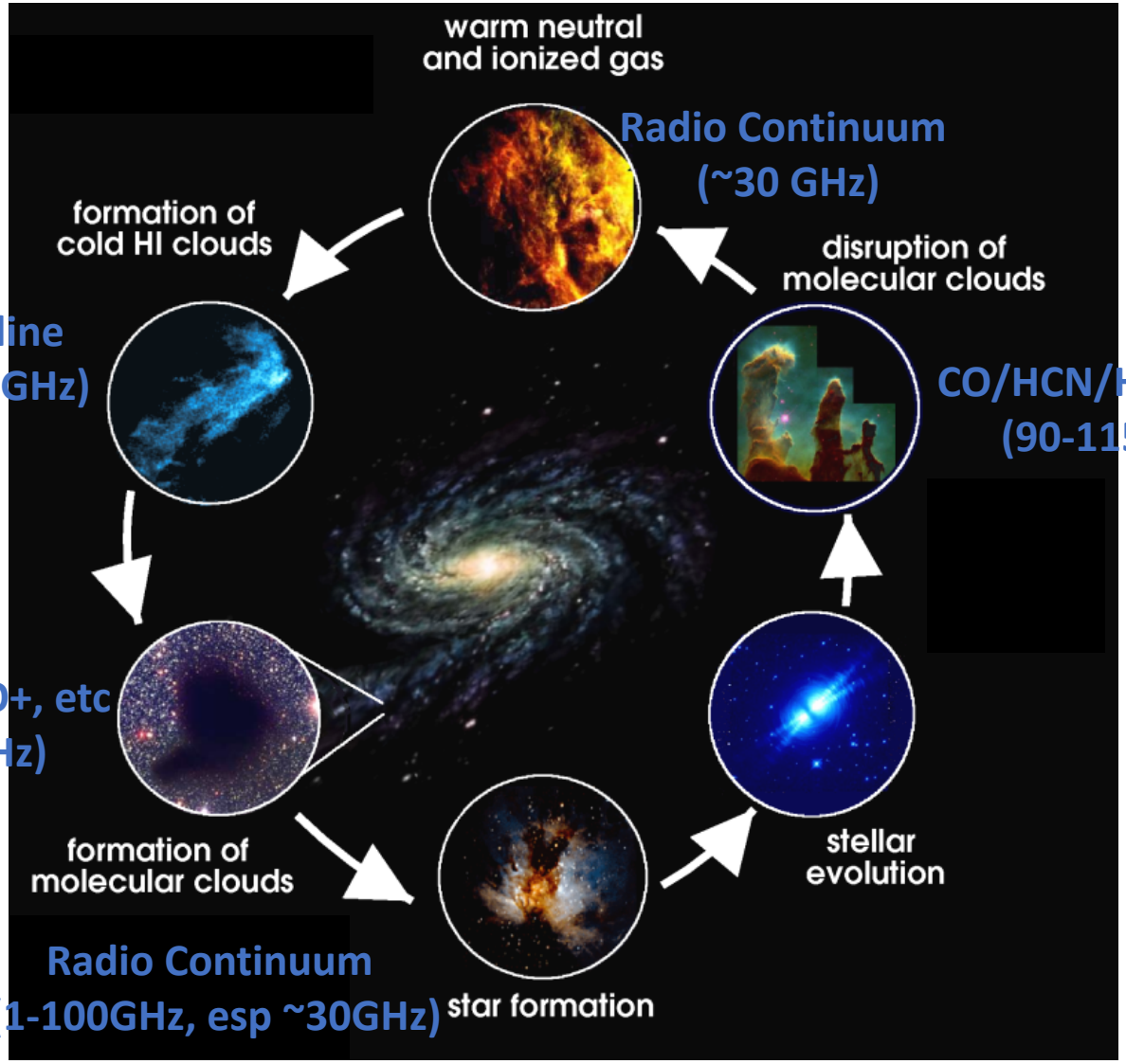
The VLA and ALMA provide access key gas and star formation tracers for this process.



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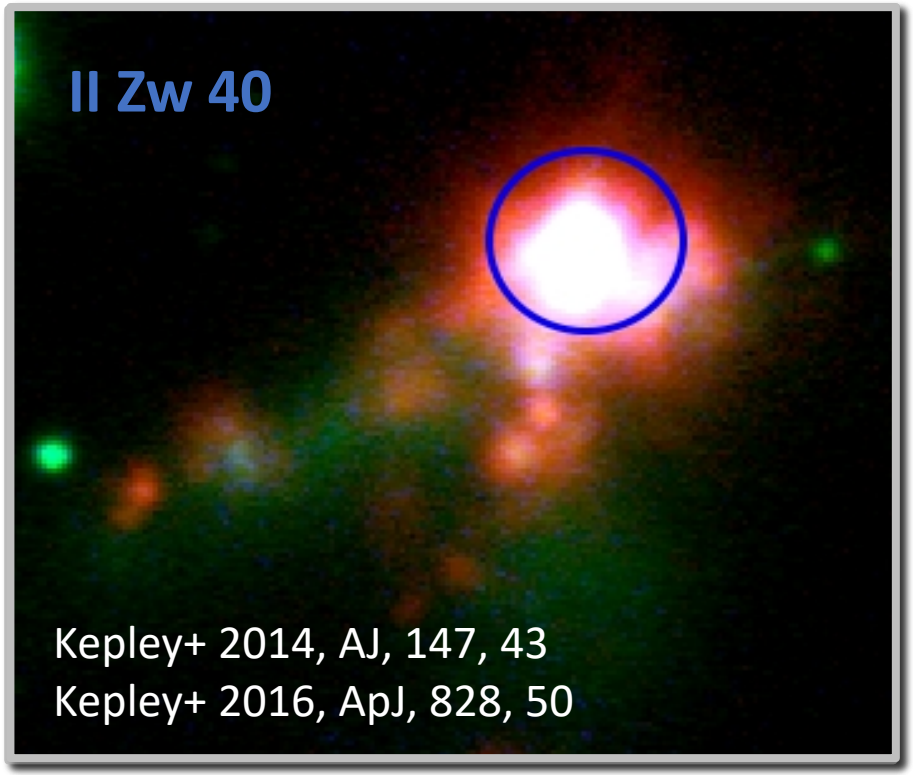
Results from the VLA and ALMA demonstrate the power of combining these tracers.



II Zw 40 probes star formation at very high Σ_{SFR} and moderate metallicity.

SFR = ~ MW (1 $M_\odot$/yr)

Size = ~20x smaller than MW (1.6 kpc)

SFR surface density ~ similar to that of a LIRG/ULIRG (500 $M_\odot$/yr/kpc^2)

Dynamical Mass = 1000x less massive than MW (6 x 10^9 $M_\odot$)

Metallicity = ~SMC (1/5 $Z_\odot$)

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Star formation may proceed differently at high Σ_{SFR} and low metallicity.

Star Formation Rate Surface Density (Σ_{SFR})

Higher radiation fields

Destruction of molecular gas

Higher external pressures

Metallicity (Z)

Reduced abundance of molecules

Less dust

Less shielding for CO

These conditions are similar to conditions in the early universe.

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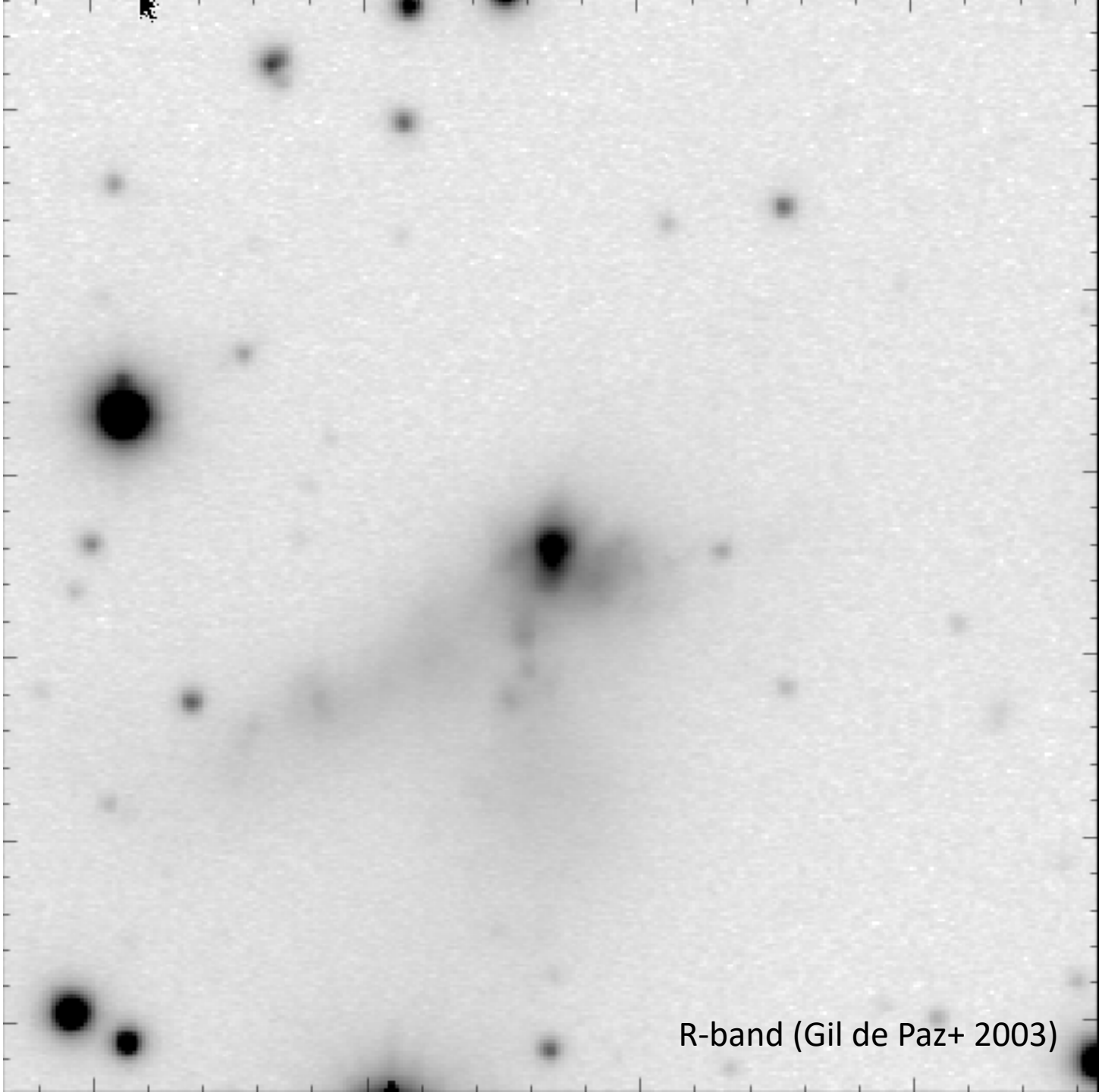
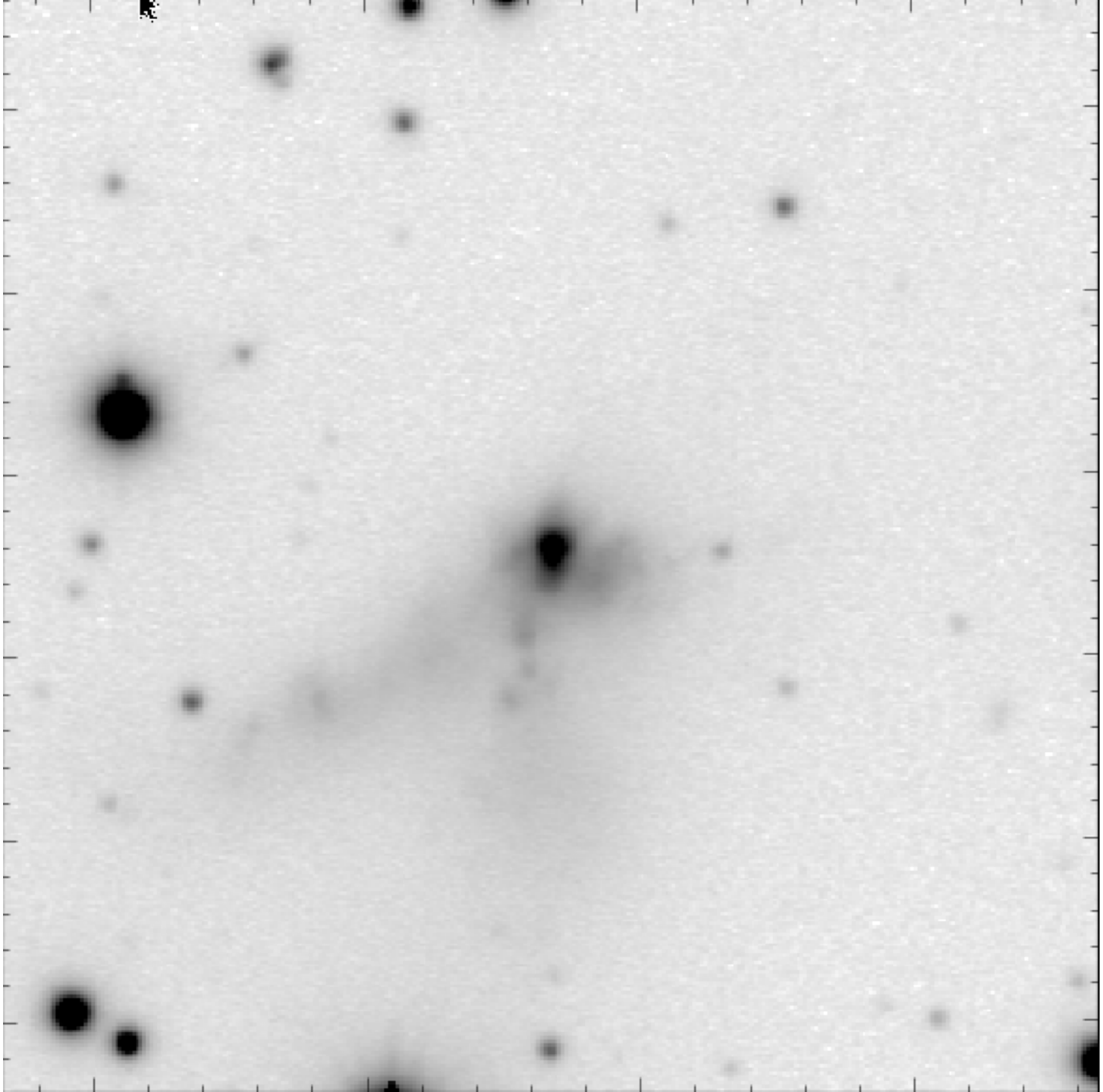
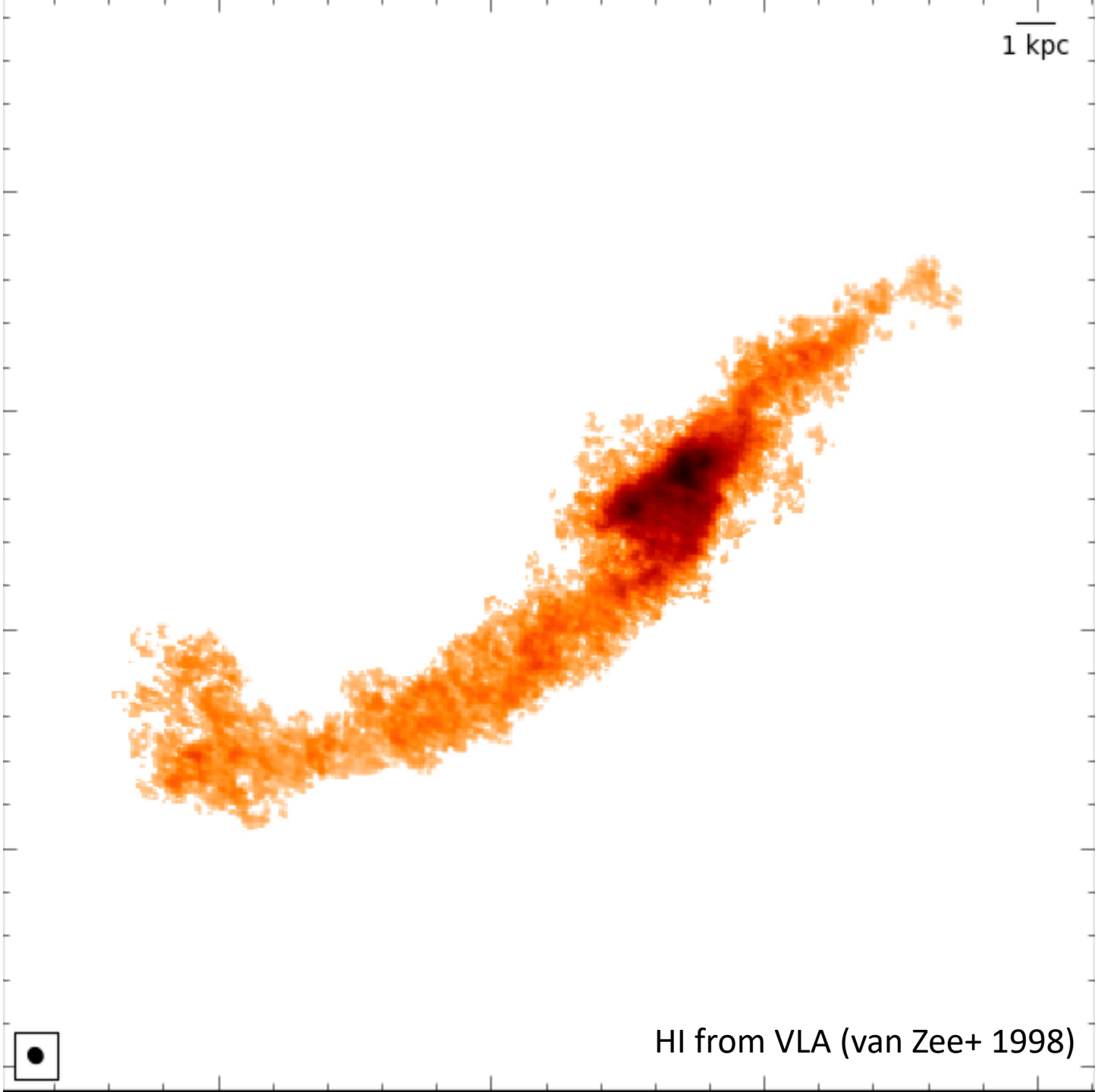
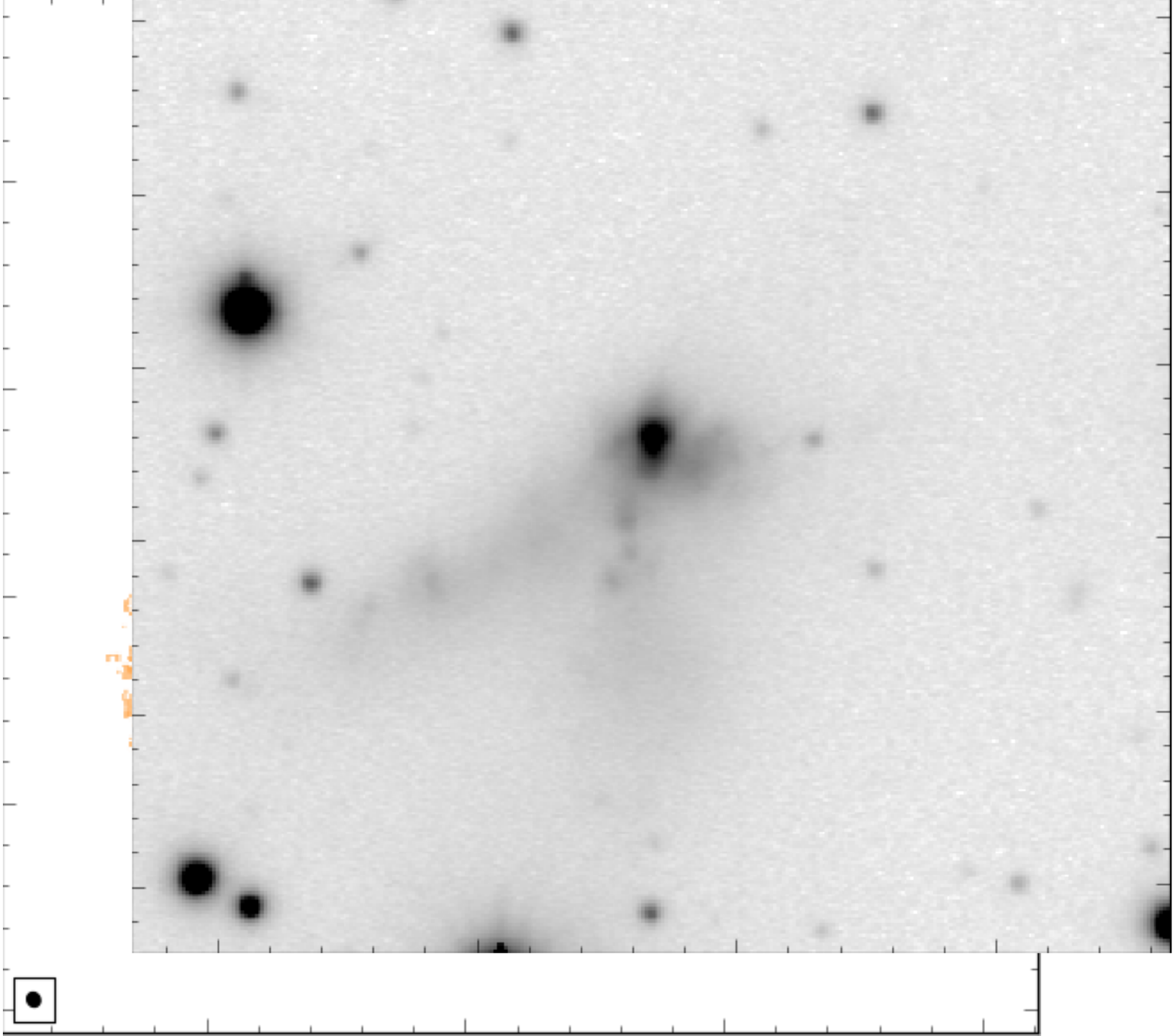
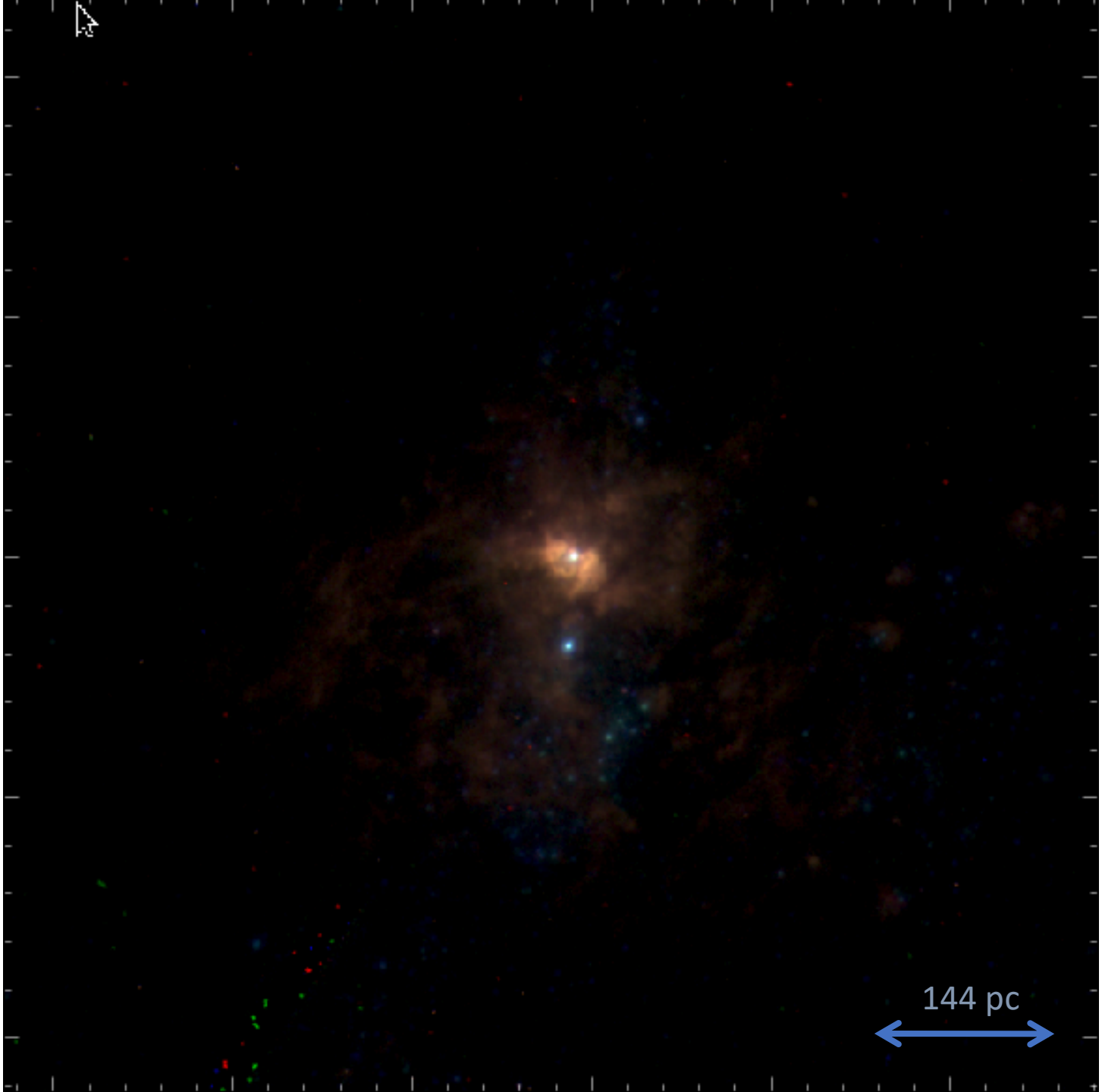

R-band (Gil de Paz+ 2003)

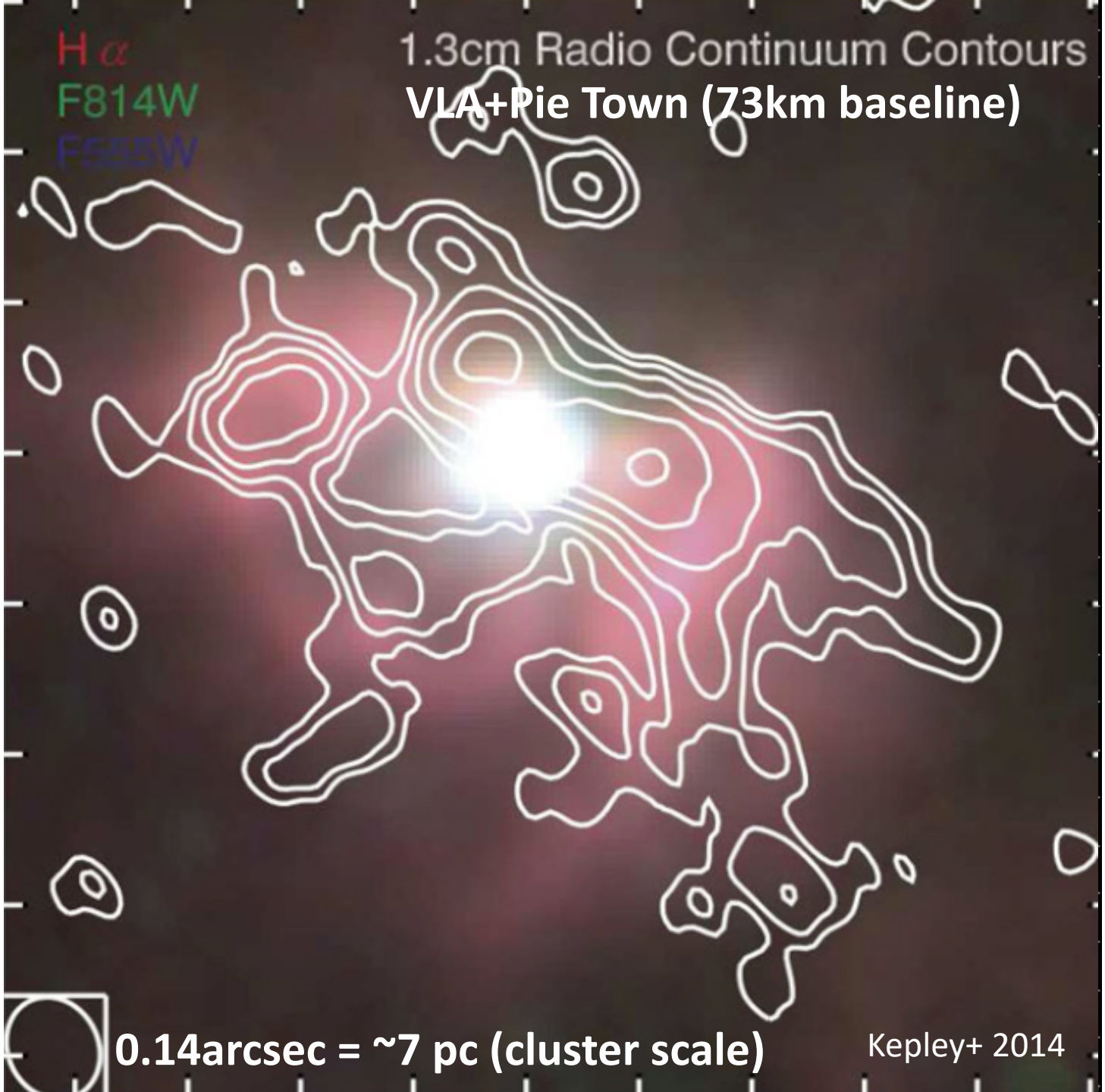




HI from VLA (van Zee+ 1998)

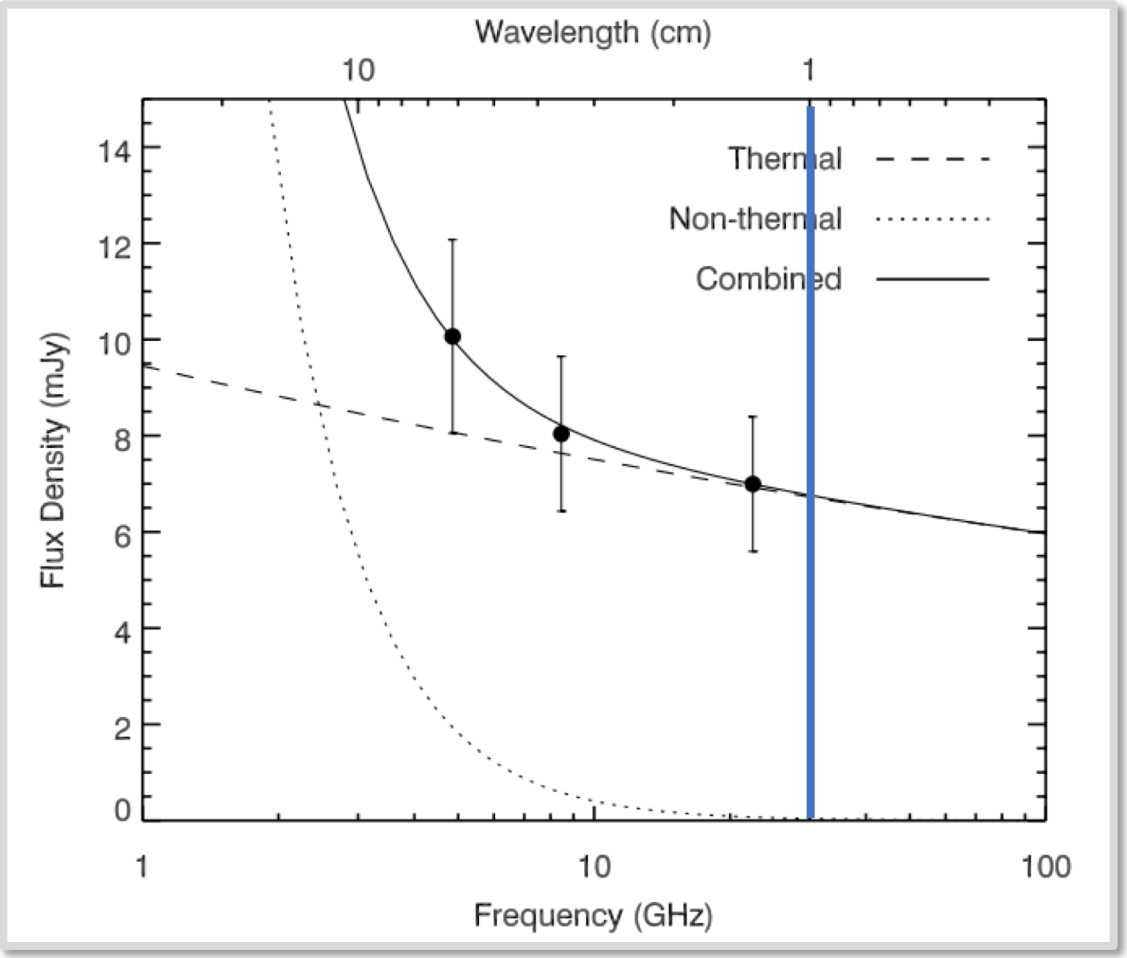



144 pc

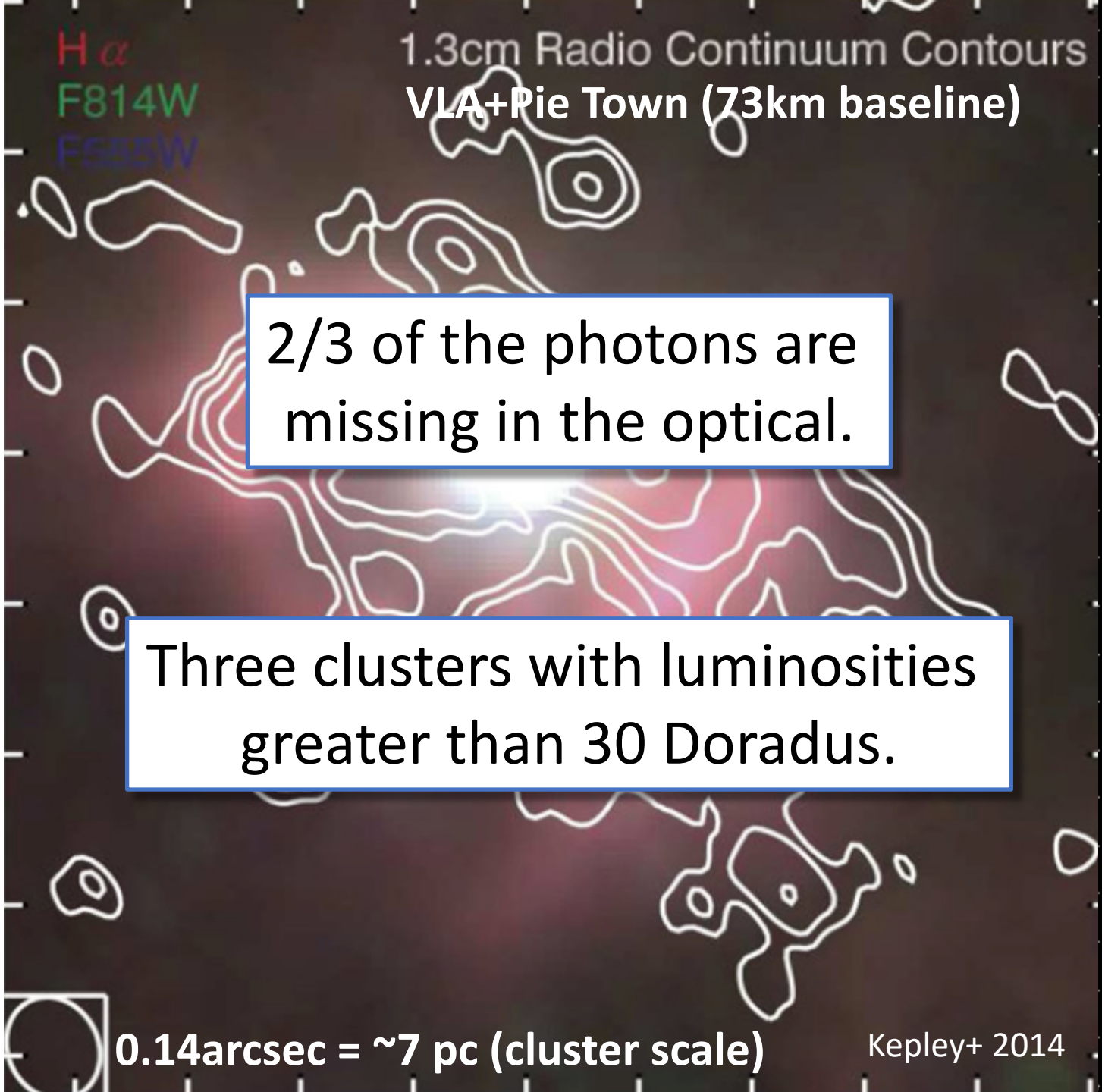

H α
F814W
F555W
1.3cm Radio Continuum Contours
VLA+Pie Town (73km baseline)
0.14arcsec = ~7 pc (cluster scale)

Kepley+ 2014

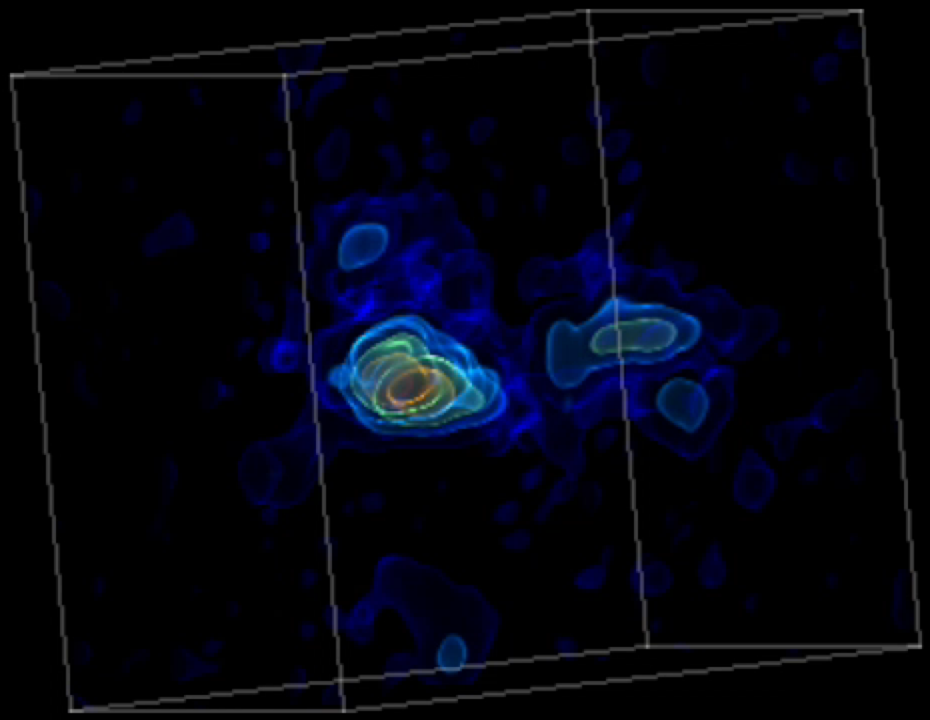
The 30 GHz continuum emission is dominated by free-free emission.



Kepley+ 2014

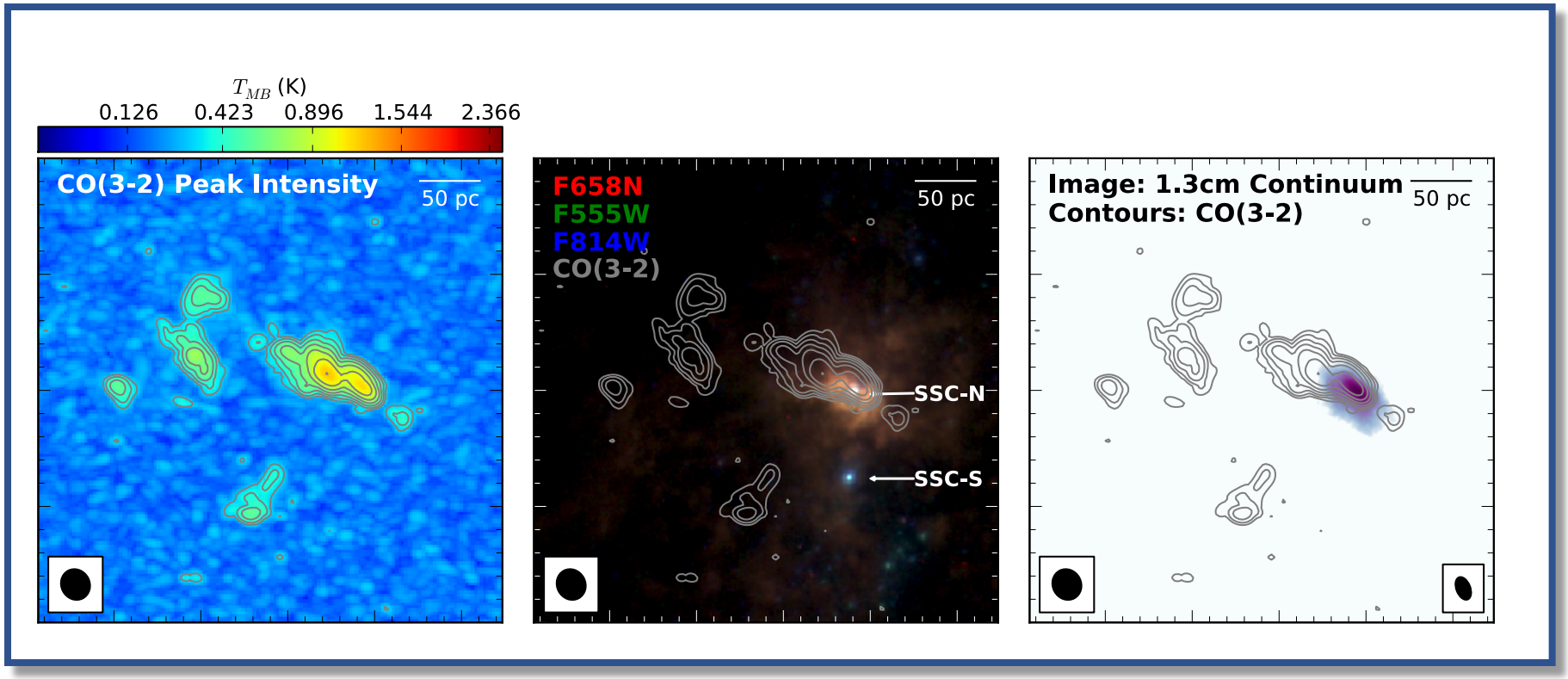

H α
F814W
F555W
1.3cm Radio Continuum Contours
VLA+Pie Town (73km baseline)
2/3 of the photons are missing in the optical.
Three clusters with luminosities greater than 30 Doradus.
0.14arcsec = ~7 pc (cluster scale)
Kepley+ 2014

ALMA CO(3-2)



Visualization by Kelsey Johnson

II Zw 40's molecular gas has a complex distribution and is mostly free of star formation.



Kepley+ 2016

24pc (GMC-scale) resolution!

2h with 19 antennas!

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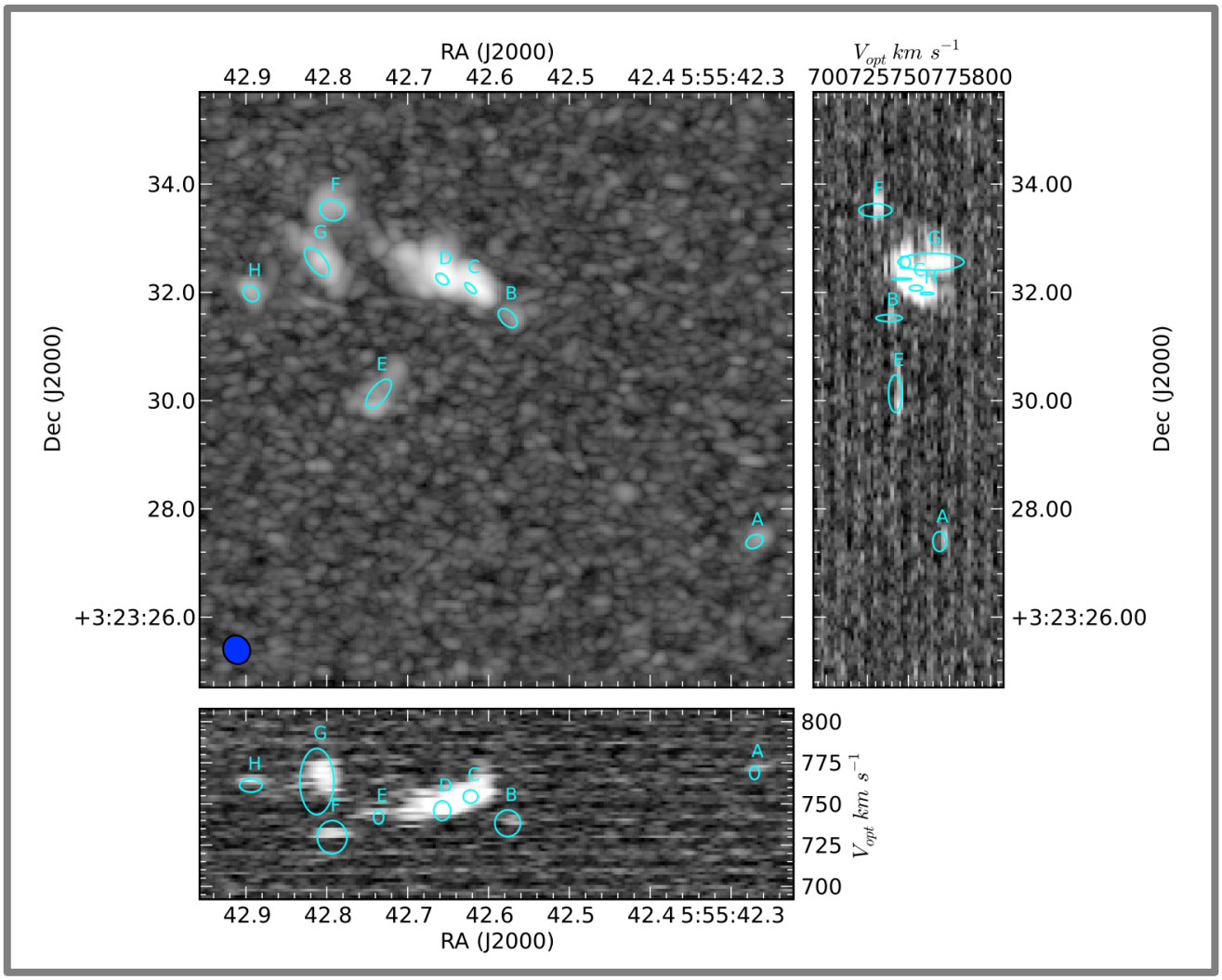
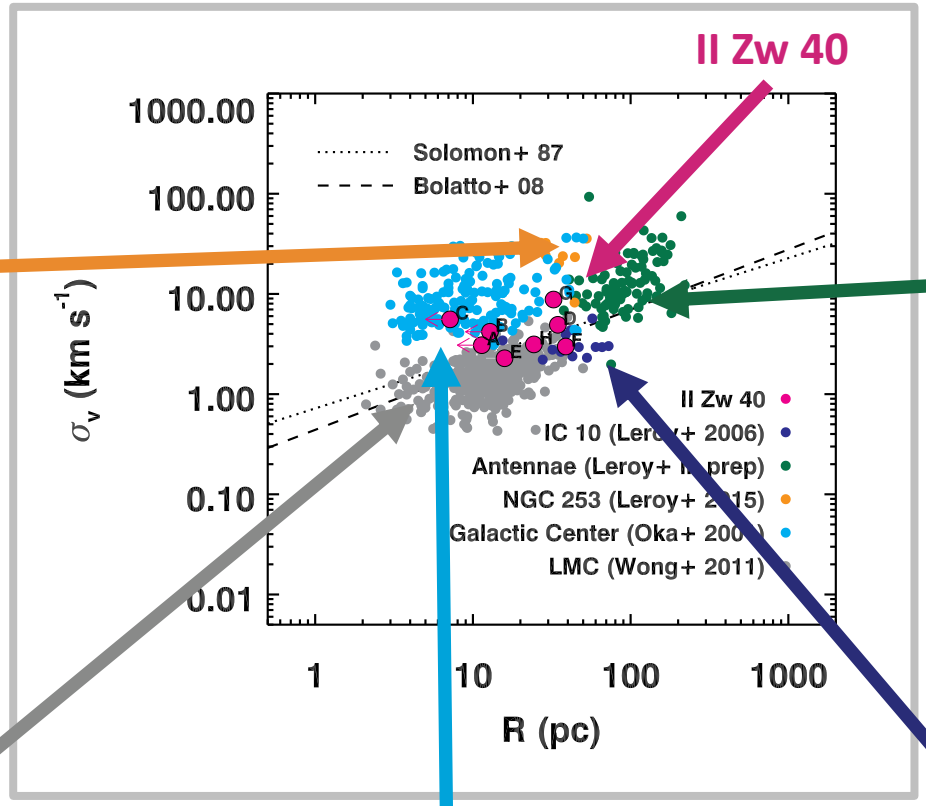
Now we can measure the properties of individual molecular clouds in II Zw 40.

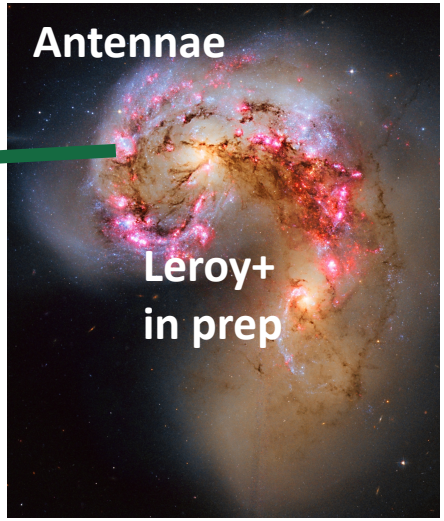


Cprops assignments shown. Other assignment algorithms provide similar results.

The clouds in II Zw 40 lie above the size-linewidth relationship.

Star Shadows Remote Observatory and PROMPT/CTIO





Hubble Legacy Archive, NASA, ESA

Carlos Fairbairn

ESO / Serge Brunier, Frederic Tapissier

Mike Siniscalchi

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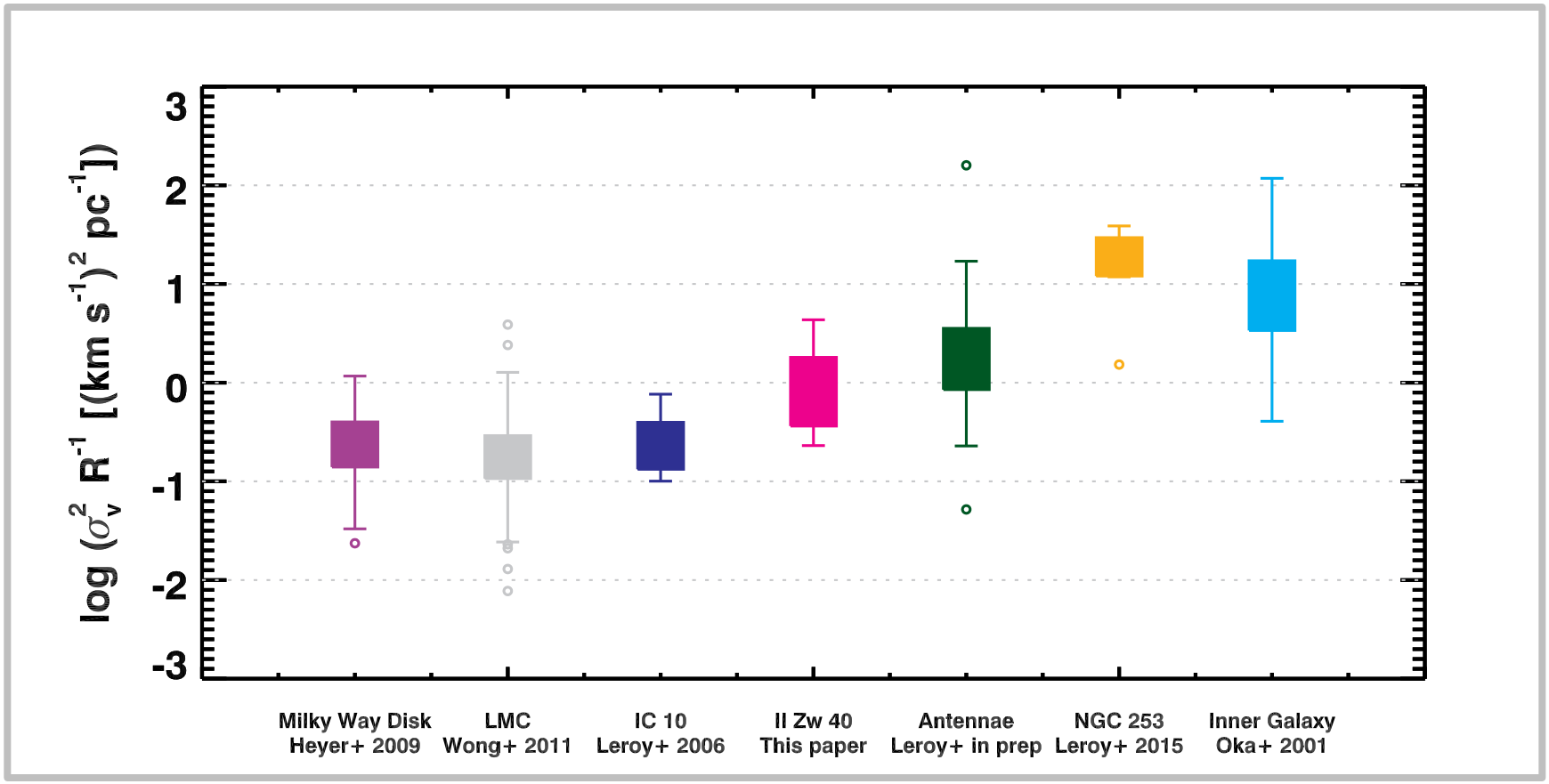
II Zw 40 has similar sizes and linewidths to the Antennae.



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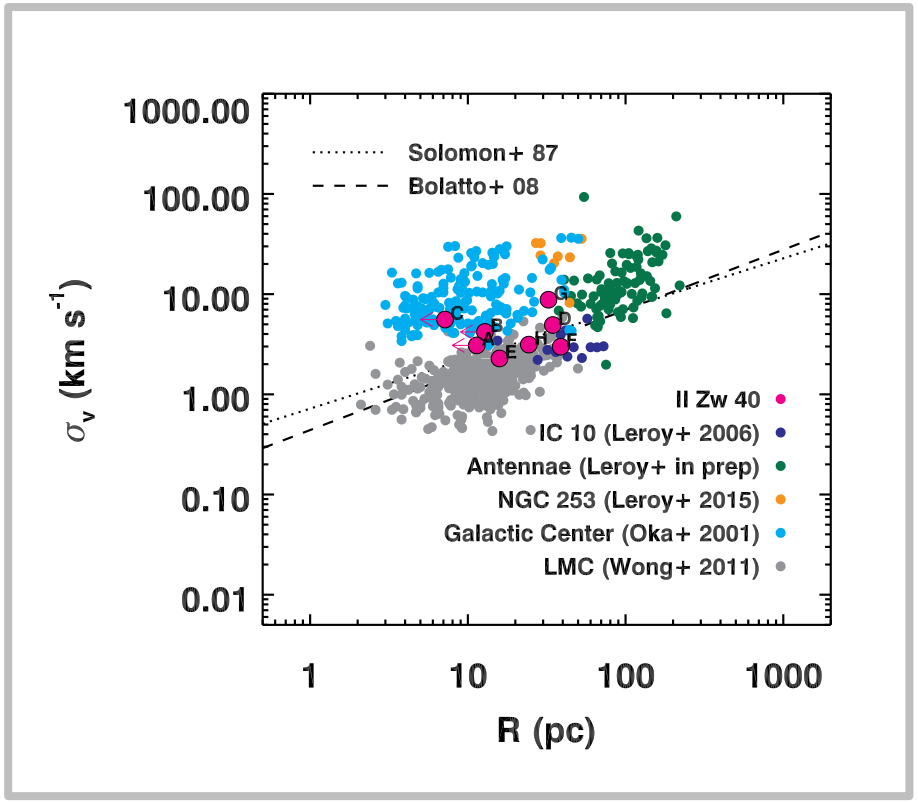
High external pressures and/or high surface densities can elevate points above line.



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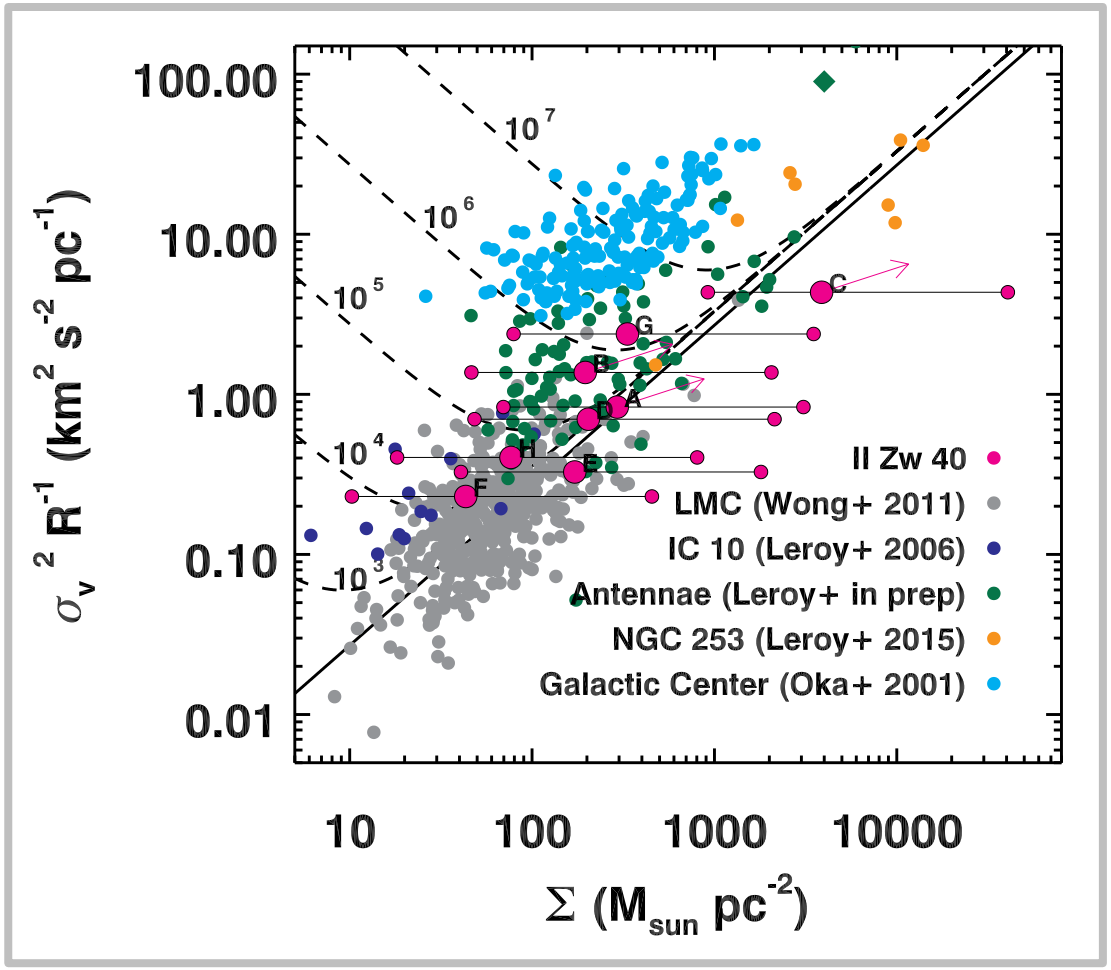
We can compare the virial and CO surface densities to distinguish these two scenarios.

Size-linewidth coefficient ~ Virial mass surface density



Molecular gas surface density from CO

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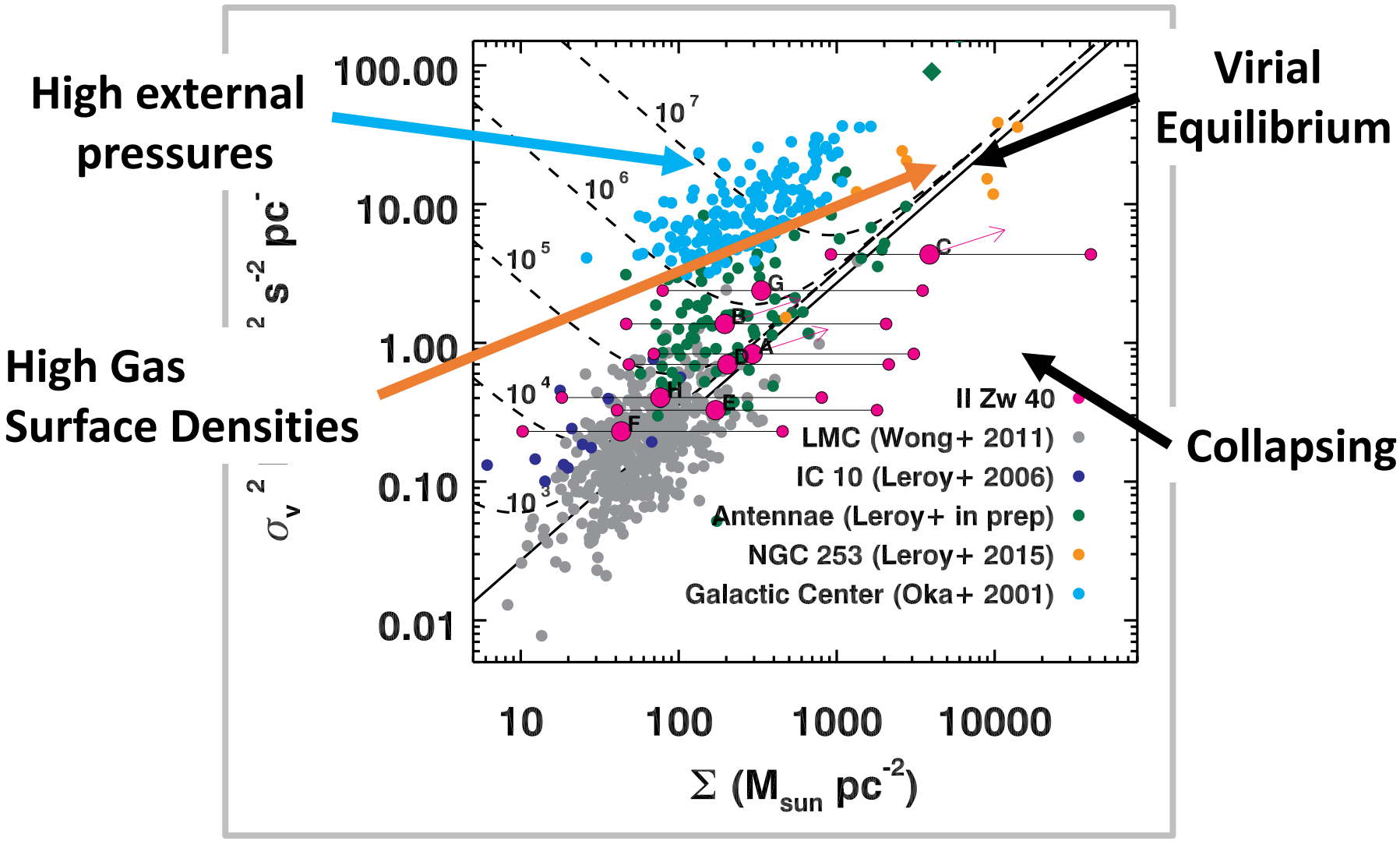
We can compare the virial and CO surface densities to distinguish these two scenarios.



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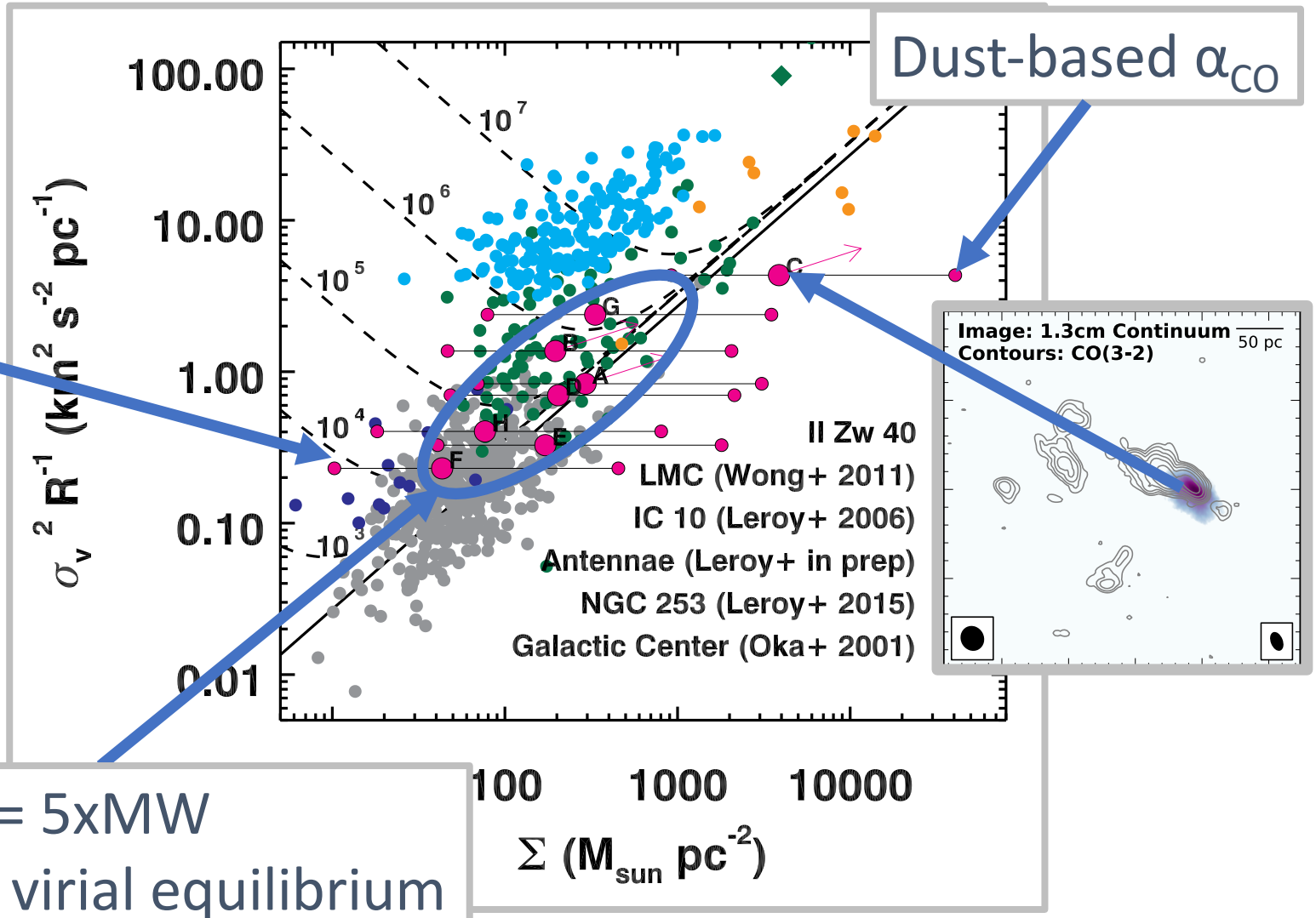
The elevated linewidths are most likely due to high molecular gas surface densities.



Used α_{CO} = 5xMW
Assuming virial equilibrium

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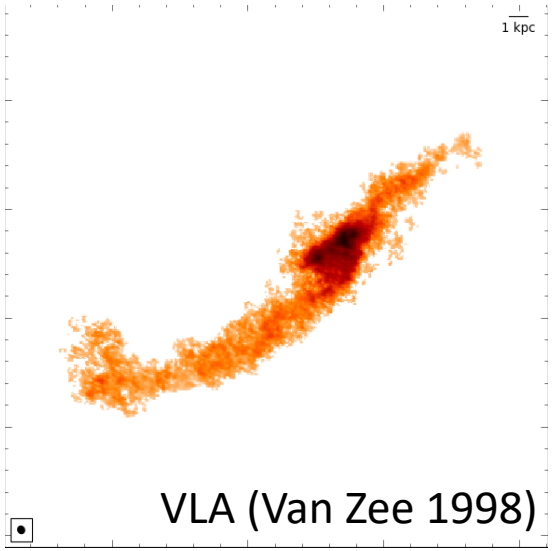
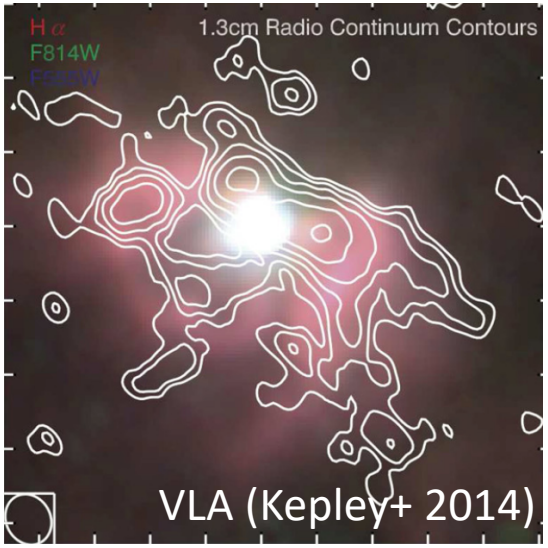
The star formation and molecular cloud properties of II Zw 40 are driven by its merger.

HI line
(cold atomic gas)



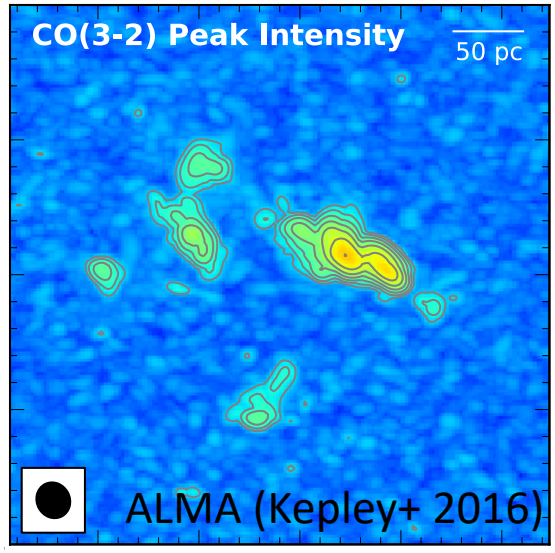
Large-scale gas kinematics are consistent with a late stage merger.

Radio Continuum
(young massive stars)



Central star-forming region has three clusters larger than 30 Doradus.

CO line
(bulk molecular gas)



Size-linewidth relationship consistent with that of the Antennae.

Only possible to make this conclusion when we have all the pieces of the puzzle!

Is II Zw 40 a special case or a prototype of a class of galaxies?

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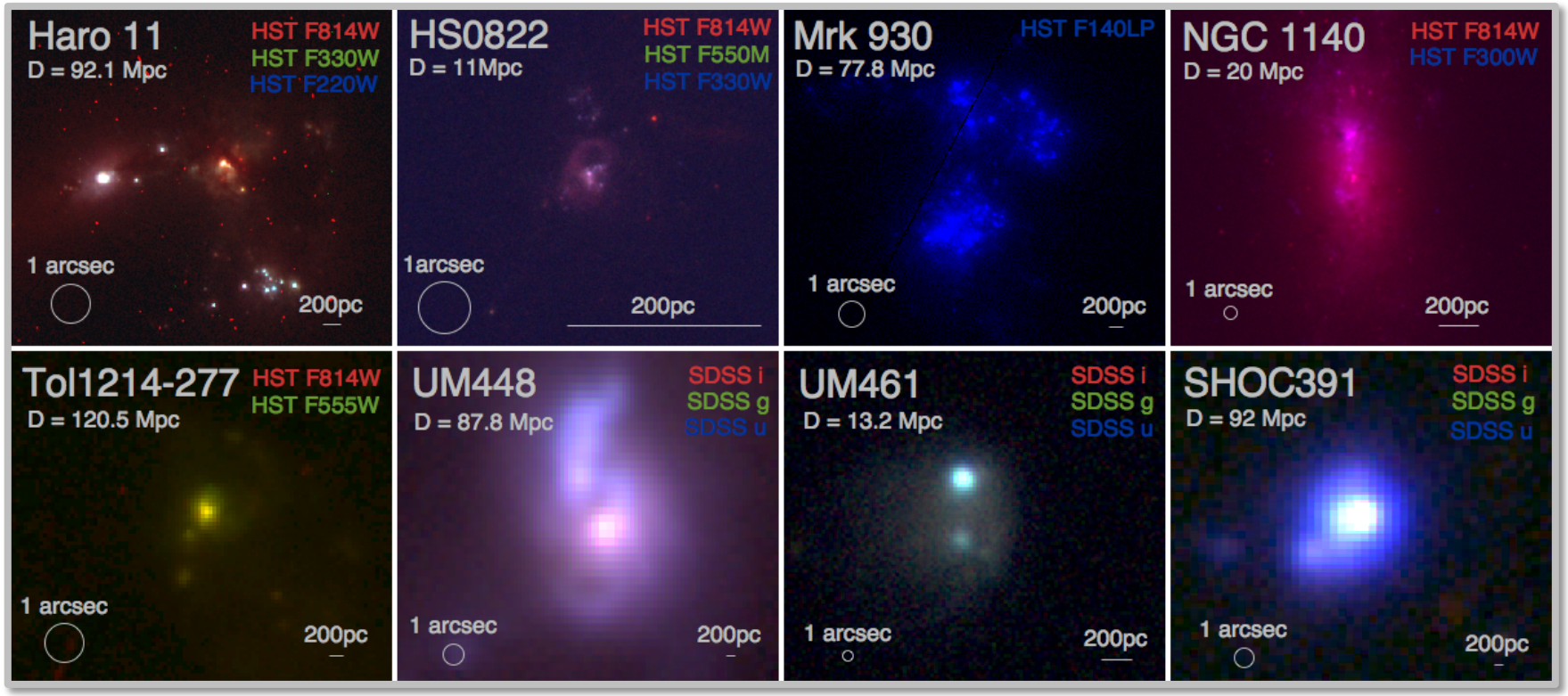
Fireflies

A survey of the stellar, dust, and molecular gas content of dwarf starburst galaxies



Thuan Trinh, Yuri Izotov, Kelsey Johnson,
Adam Leroy, Andreas Schruba

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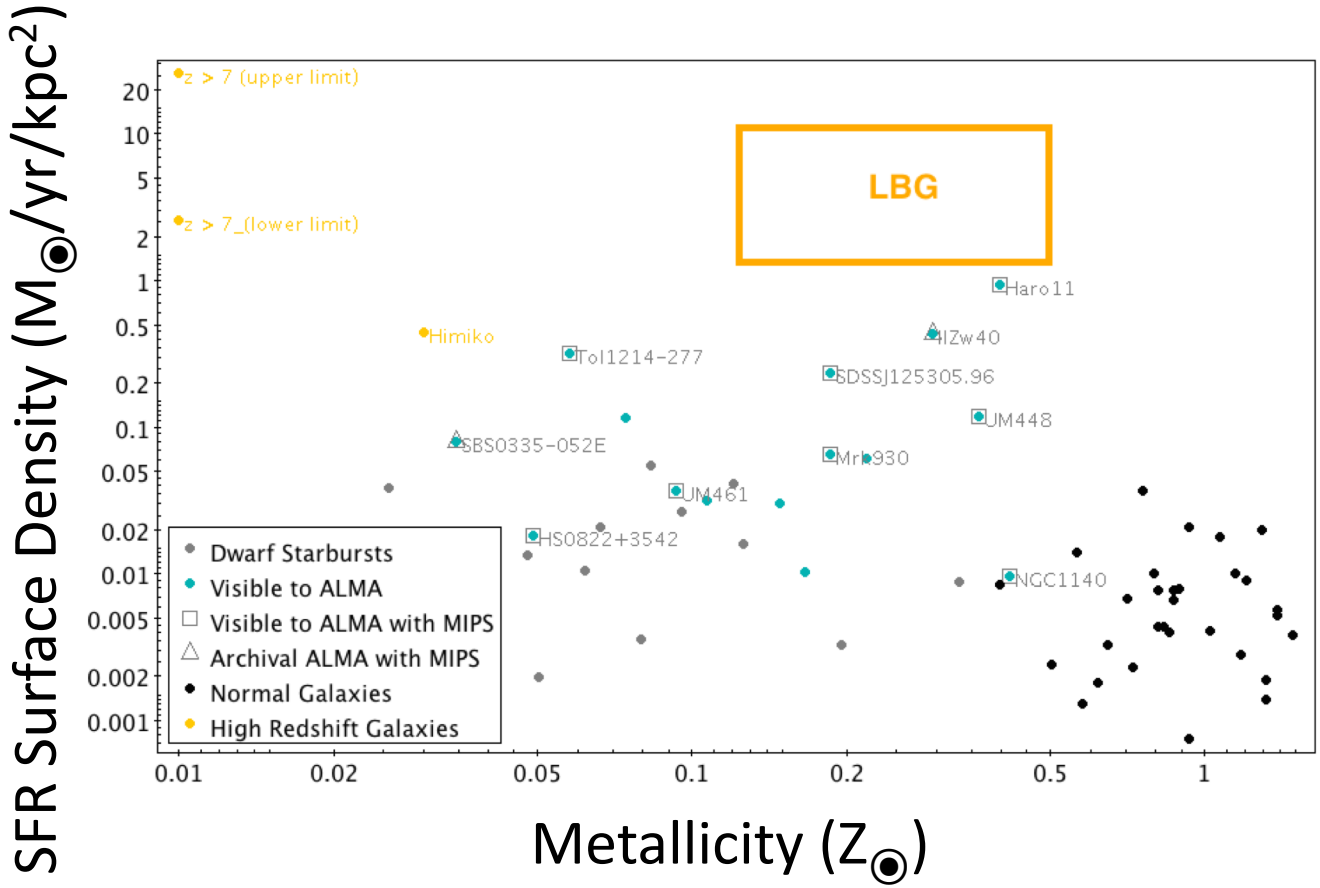
Sample selected to span a wide range of properties and have abundant ancillary data.

~ 2 orders of magnitude



Optical,
near-IR,
mid-IR,
far-IR
UV

+ 4 orders of magnitude in mass!

~ 1 order of magnitude

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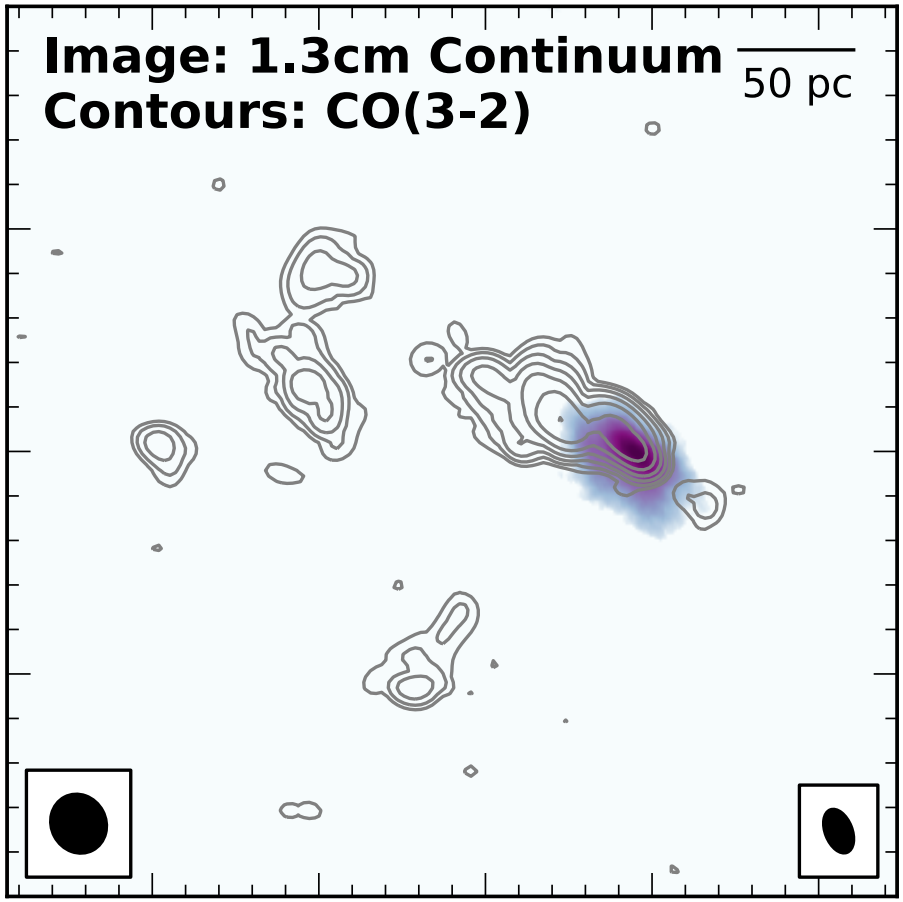
The JVLA+ALMA provides the missing pieces of the puzzle: molecular gas and young massive stars.



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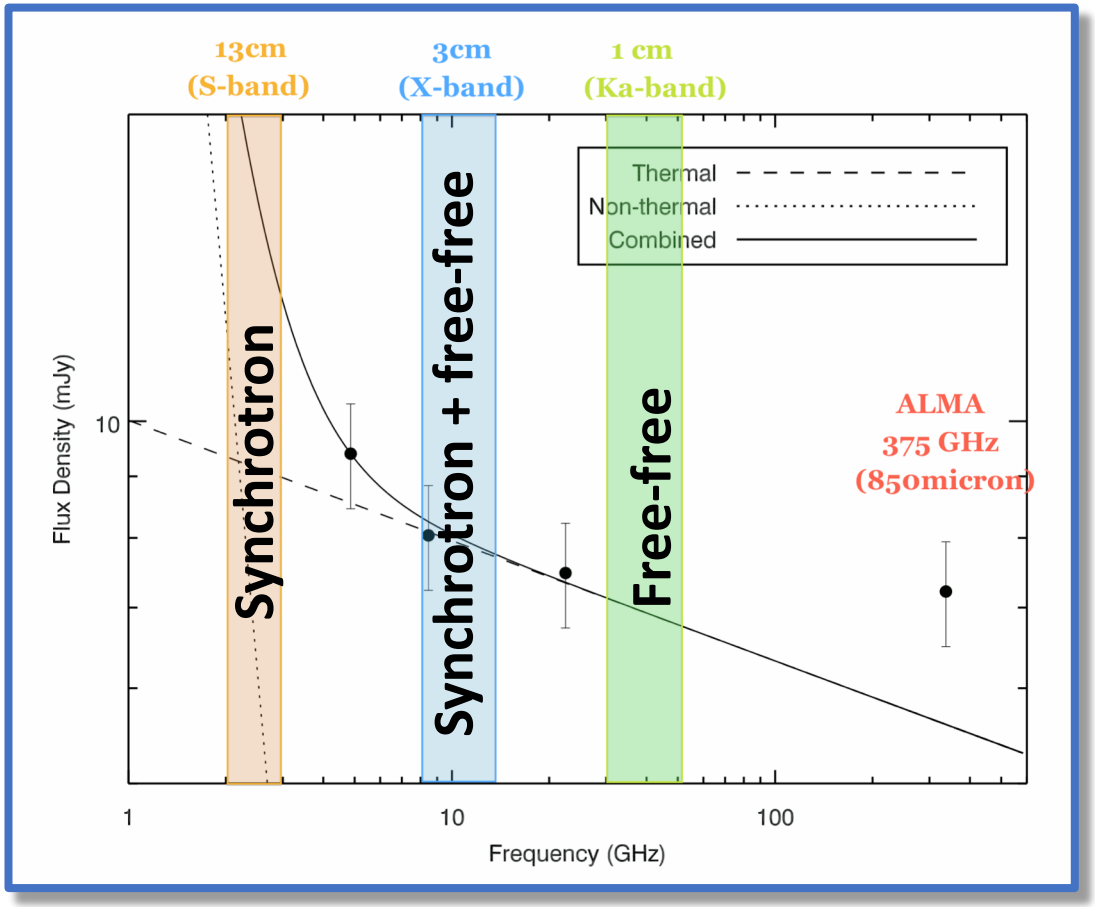
We can use deep JVLA continuum observations to model the spectral energy distribution.



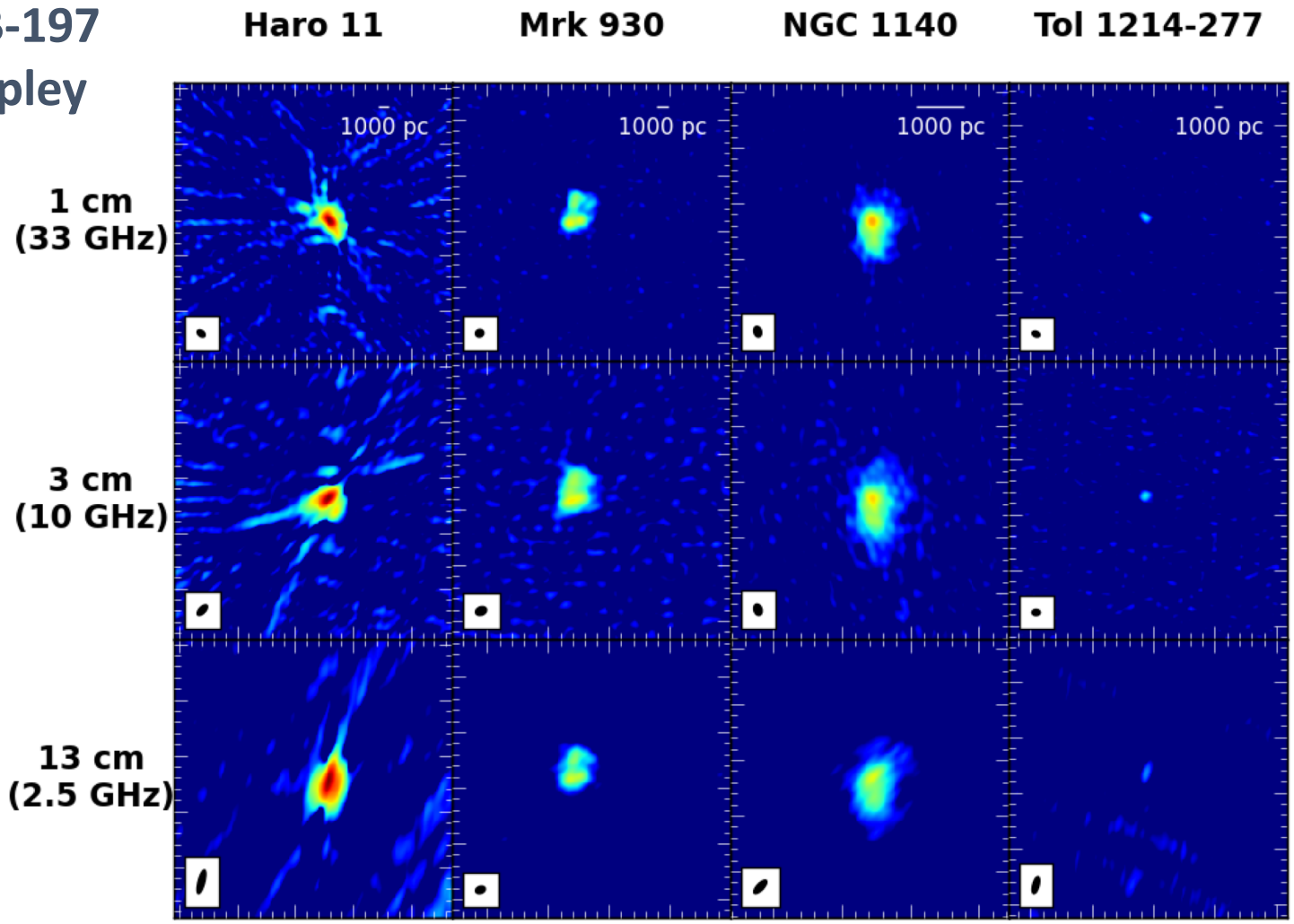
II Zw 40 spectrum from Kepley+ 2014

VLA/15B-197
PI: A. Kepley

1) What are ionizing photon fluxes and SFRs for the massive star-forming regions within these galaxies?
2) What drives the deficit of synchrotron emission in dwarf starburst galaxies?
3) Does the radio–far-infrared relation hold in dwarf starburst galaxies?

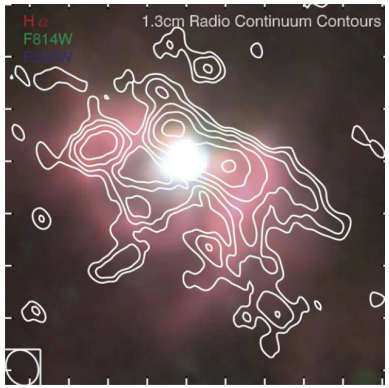
We have begun a JVLA program to quantify the obscured young massive star formation.

VLA/15B-197
PI: A. Kepley

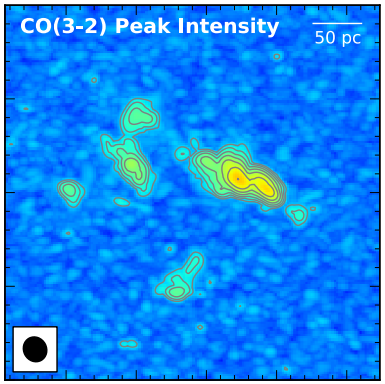


Preliminary images made from integrated pipeline output

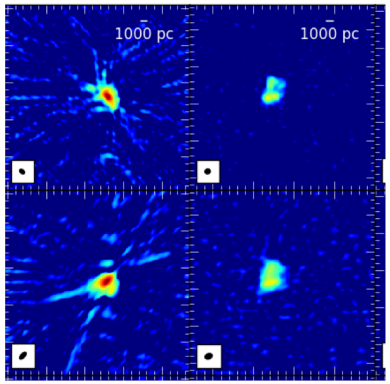
A. Kepley



- The 30GHz radio continuum emission from II Zw 40 is dominated by free-free emission.
- 2/3 of the ionizing photons from II Zw 40 are missing in the optical.
- The central star forming region has three clusters the size of 30 Doradus.



- The molecular clouds in II Zw 40 have high line widths for their sizes.
- The clouds are similar to what is found in the fiducial major merger, the Antennae.
- These large line widths are most likely driven by high gas surface densities driven by II Zw 40's merger.



- Larger systematic samples are needed to understand the young massive clusters and molecular gas in these systems as a population.
- Preliminary results from the Fireflies survey show that these faint galaxies can be easily detected in radio continuum by the JVLA.