ALMA'S VIEW OF THE ARP 220 DISKS FROM 30 PC RESOLUTION OBSERVATIONS OF DENSE GAS TRACERS

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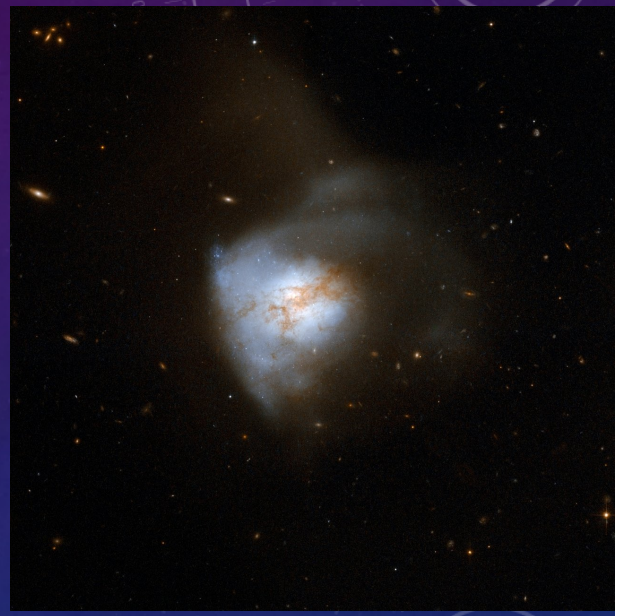
Arp 220

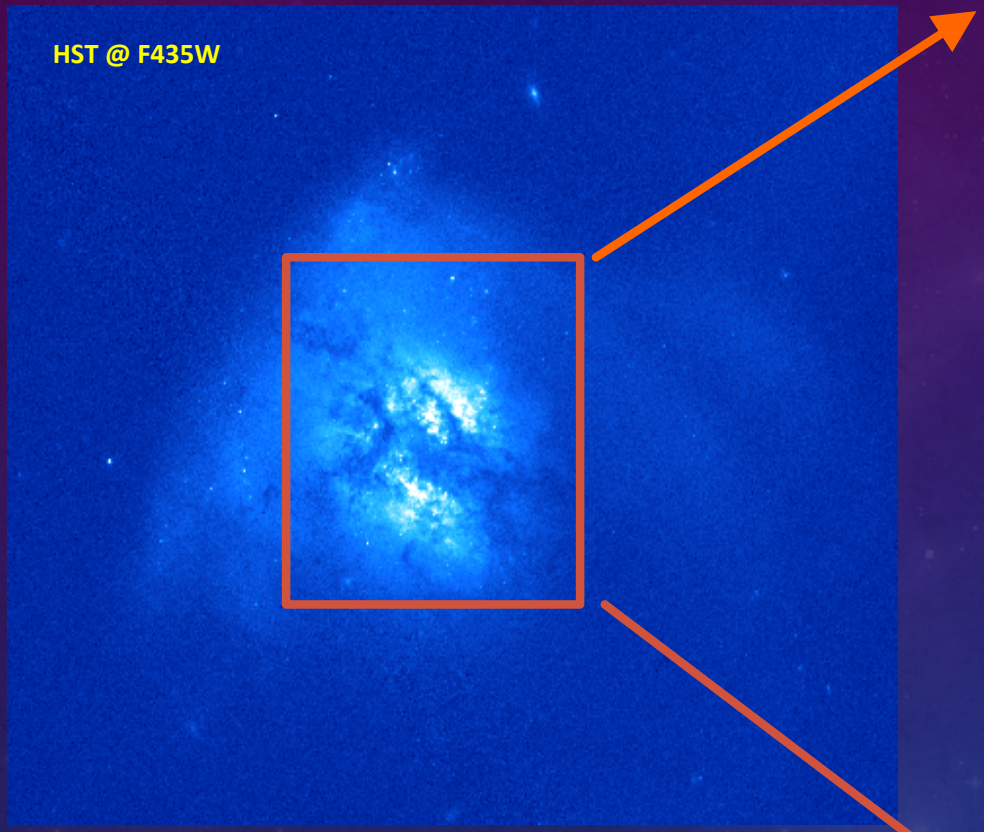
- D_L = 77 Mpc (1 arcsecond ~ 370 pc)
- L_{IR}[8-1000 μm] ~ $10^{12.2}$ $L_\odot$, SFR~ few 100 $M_\odot yr^{-1}$
- Av ~2000 mag towards the nuclei
- Late stage merger: Most of the emission concentrated within < 1 kpc. Compact system.
- Commonly used as a template for high z starbursts galaxies.
- Ideal combination of proximity and extreme environment.
- Able to test extreme physics of star formation, and galaxy evolution, in great detail.

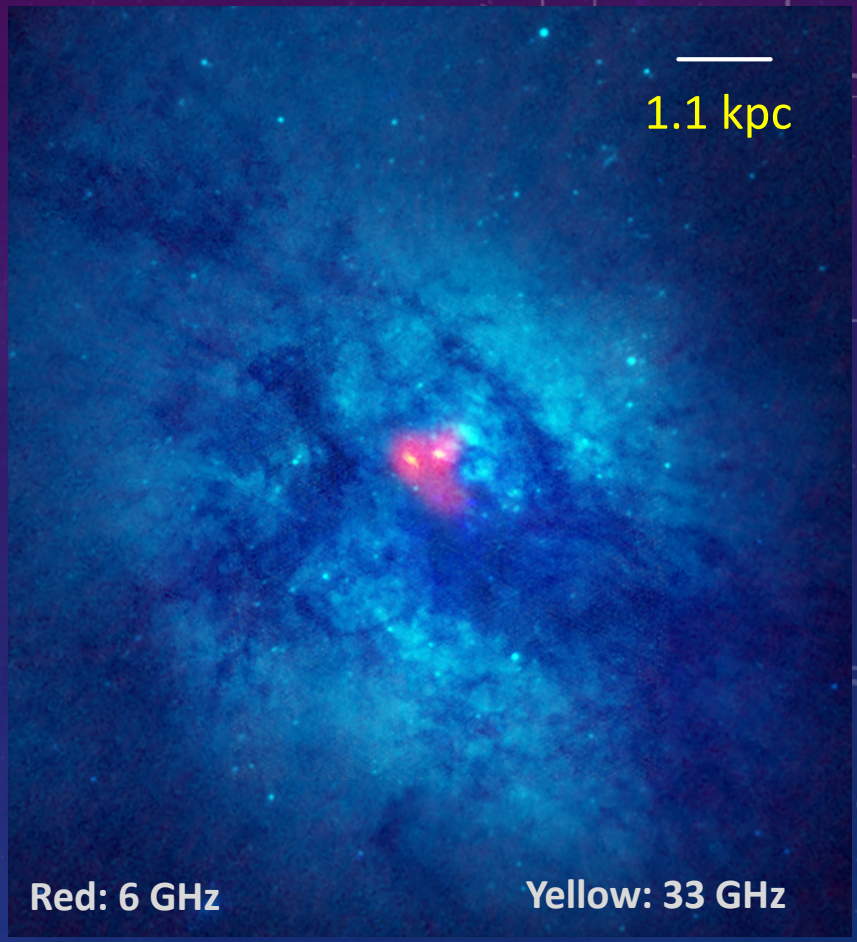


Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

Well studied, but still mysterious in many ways

The Need of cm/mm interferometry





Credit: B. Saxton NRAO/AUI/NSF

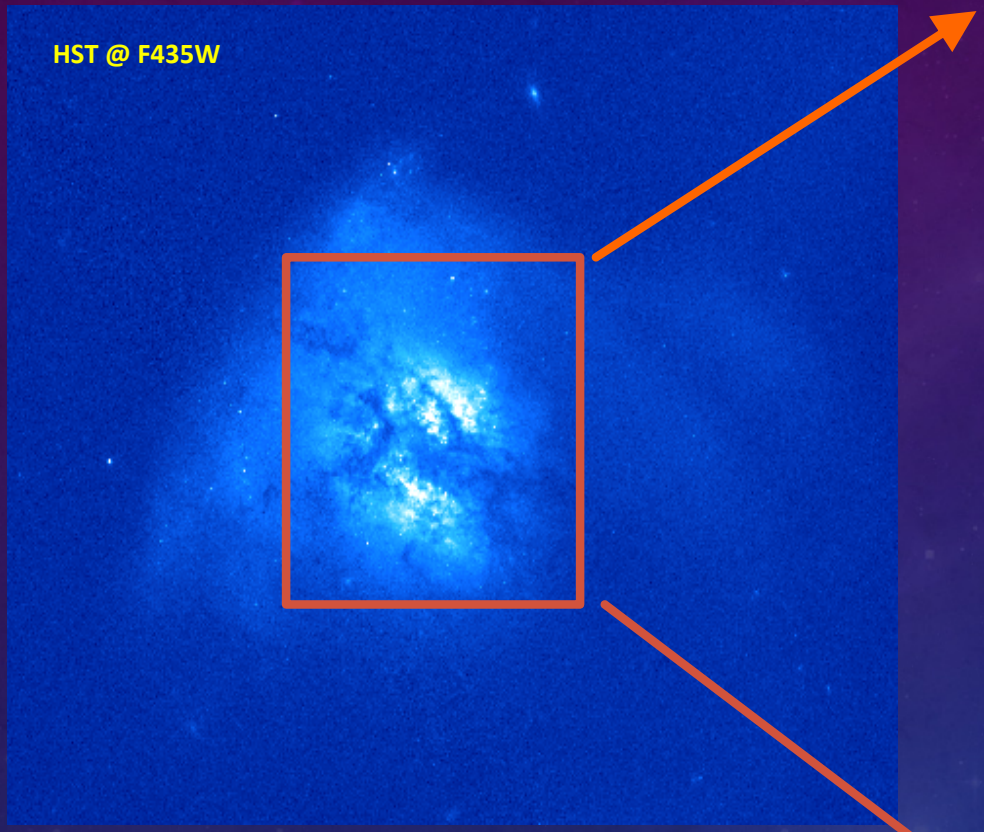
Large dust obscuration => need for cm/mm wavelength observations.

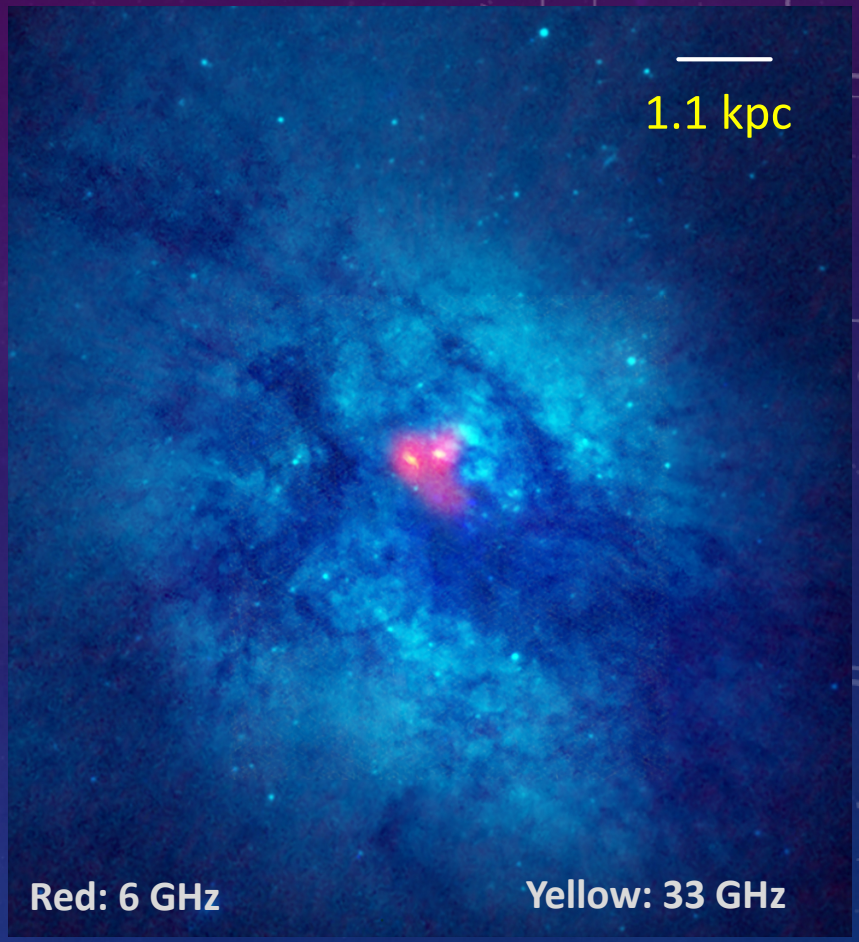
Compactness => Need high angular resolution => need for interferometric observations.

Arp 220 is optically thin from ~ 5-350 GHz

Barcos-Muñoz et al. (2015)

The Need of cm/mm interferometry





Credit: B. Saxton NRAO/AUI/NSF

Large dust obscuration => need for cm/mm wavelength observations.

Compactness => Need high angular resolution => need for interferometric observations.

Arp 220 is optically thin from ~ 5-~~350~~ 100 GHz

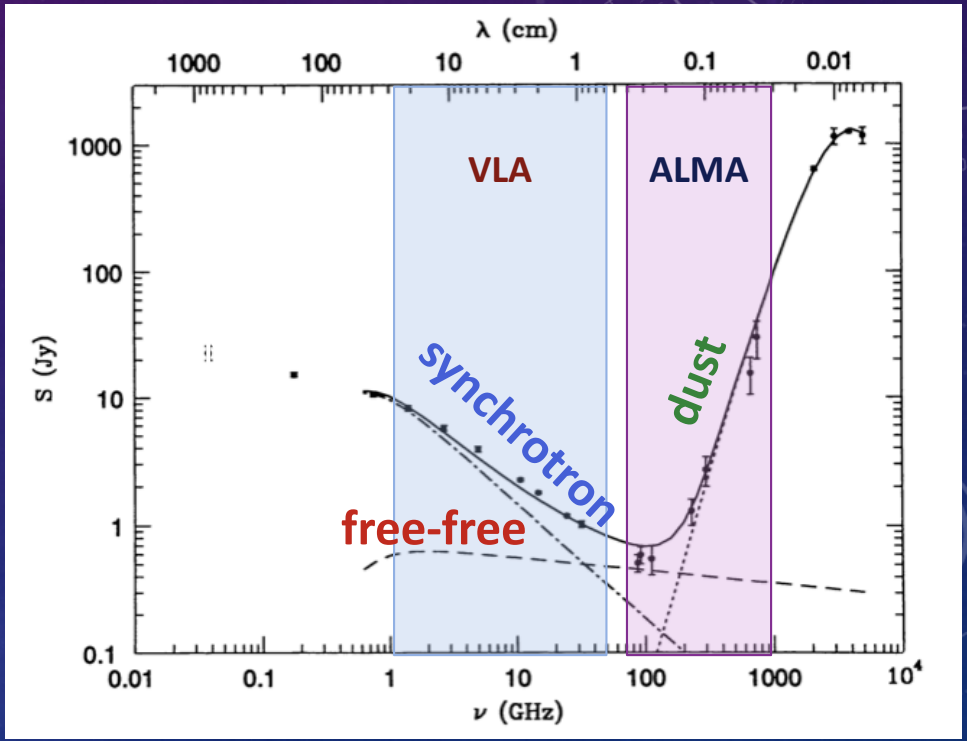
Barcos-Muñoz et al. (2015)

Radio continuum to the rescue

Types of radiation:

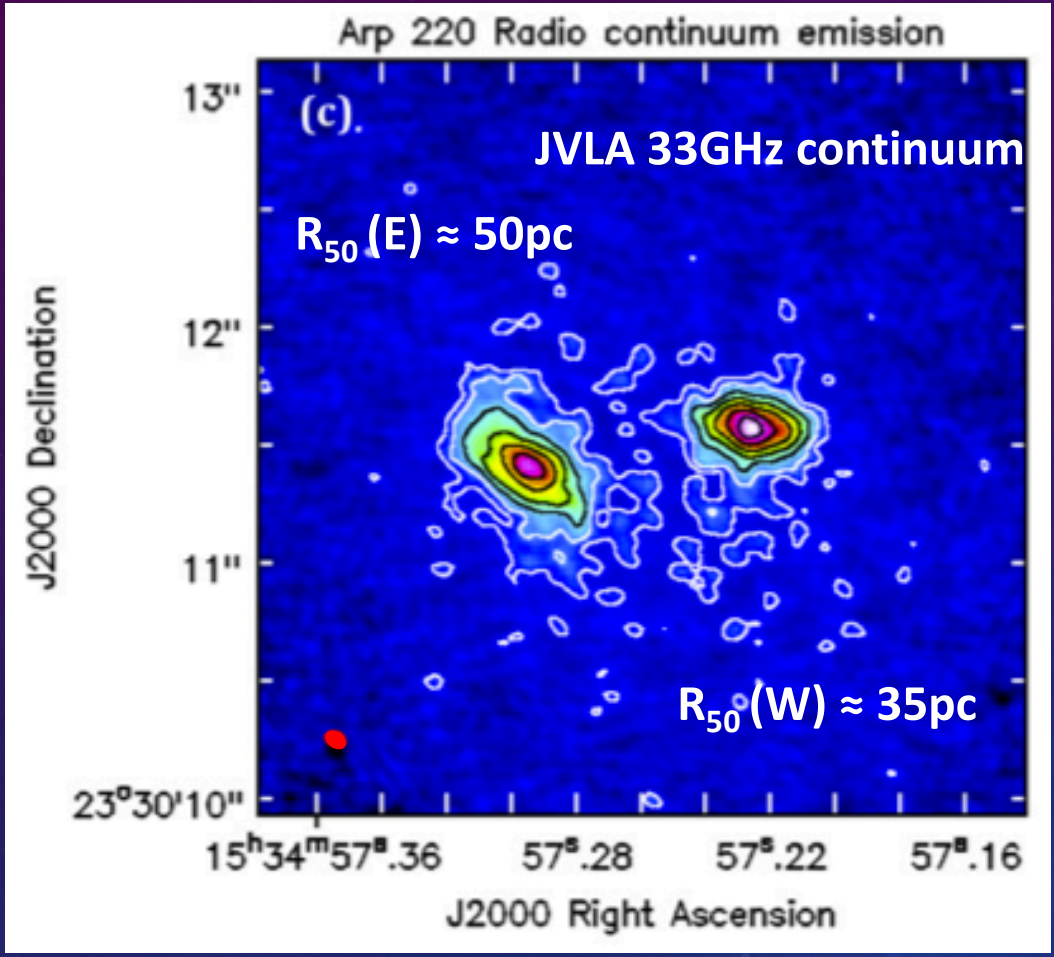
- Synchrotron emission (acceleration of CR e^- by SNR)
- Free-Free (ion-electron interaction in ionized gas, HII regions)
- Thermal dust (absorption of photons heat up dust)

Trace star formation



Spectra of M82 from Condon (1992)

Star Formation Distribution at 30 pc Scales at a distance of 77 Mpc



Highest values measured for any star-forming system

$\Sigma_{SFR}(W) \sim 10^{4.1}\ M_\odot\ yr^{-1}\ kpc^{-2}$

$\Sigma_{gas}(W) \sim 4.5 \times 10^{5}\ M_\odot pc^{-2}$

Barcos-Muñoz et al. 2015

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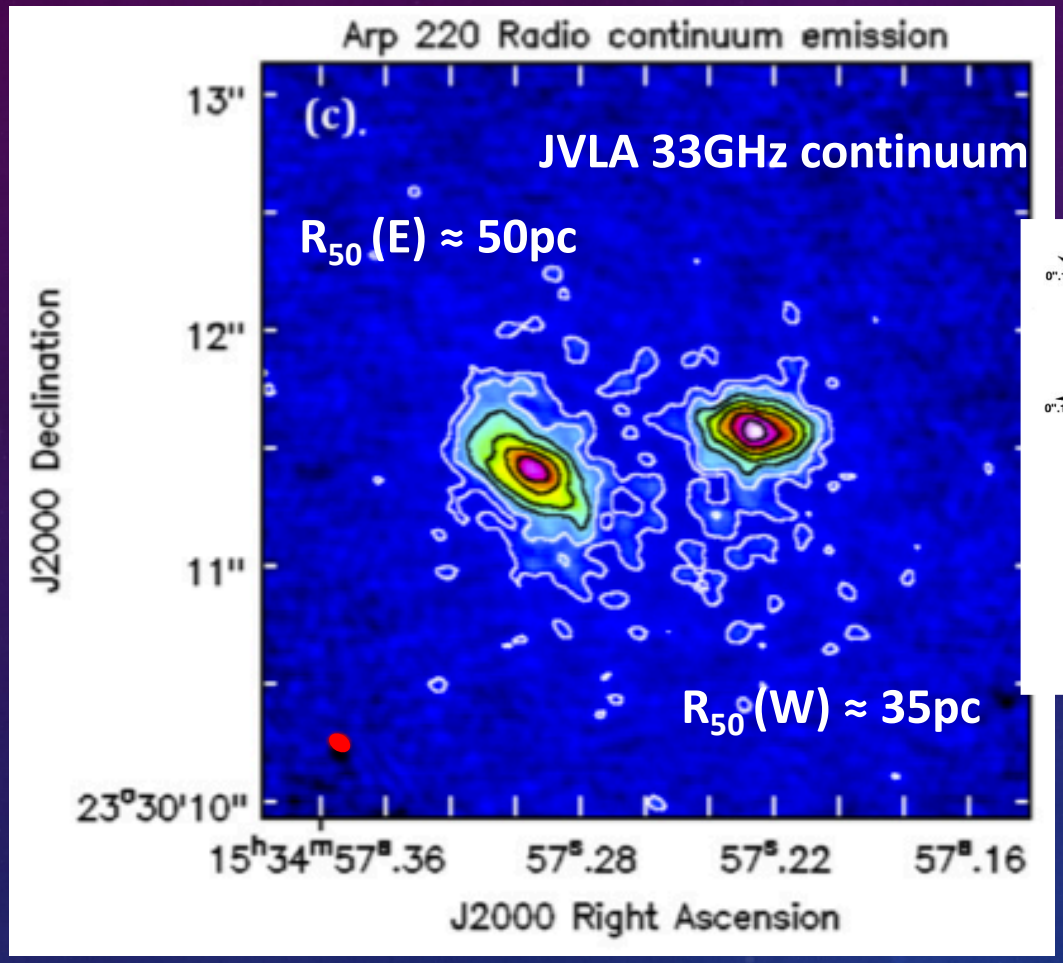

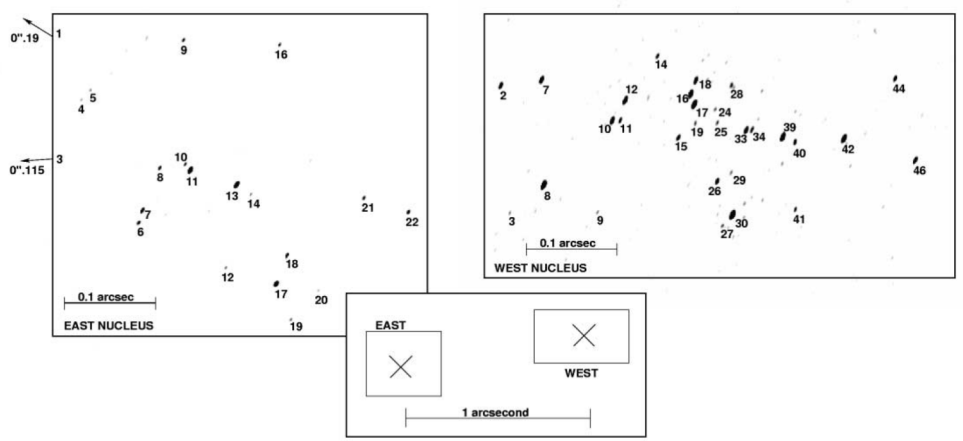

49 RSNe in the entire system with VLBI (Lonsdale+06)

See Varenius+17 arxiv for updated observations with 97 sources total.

Highest values measured for any star-forming system

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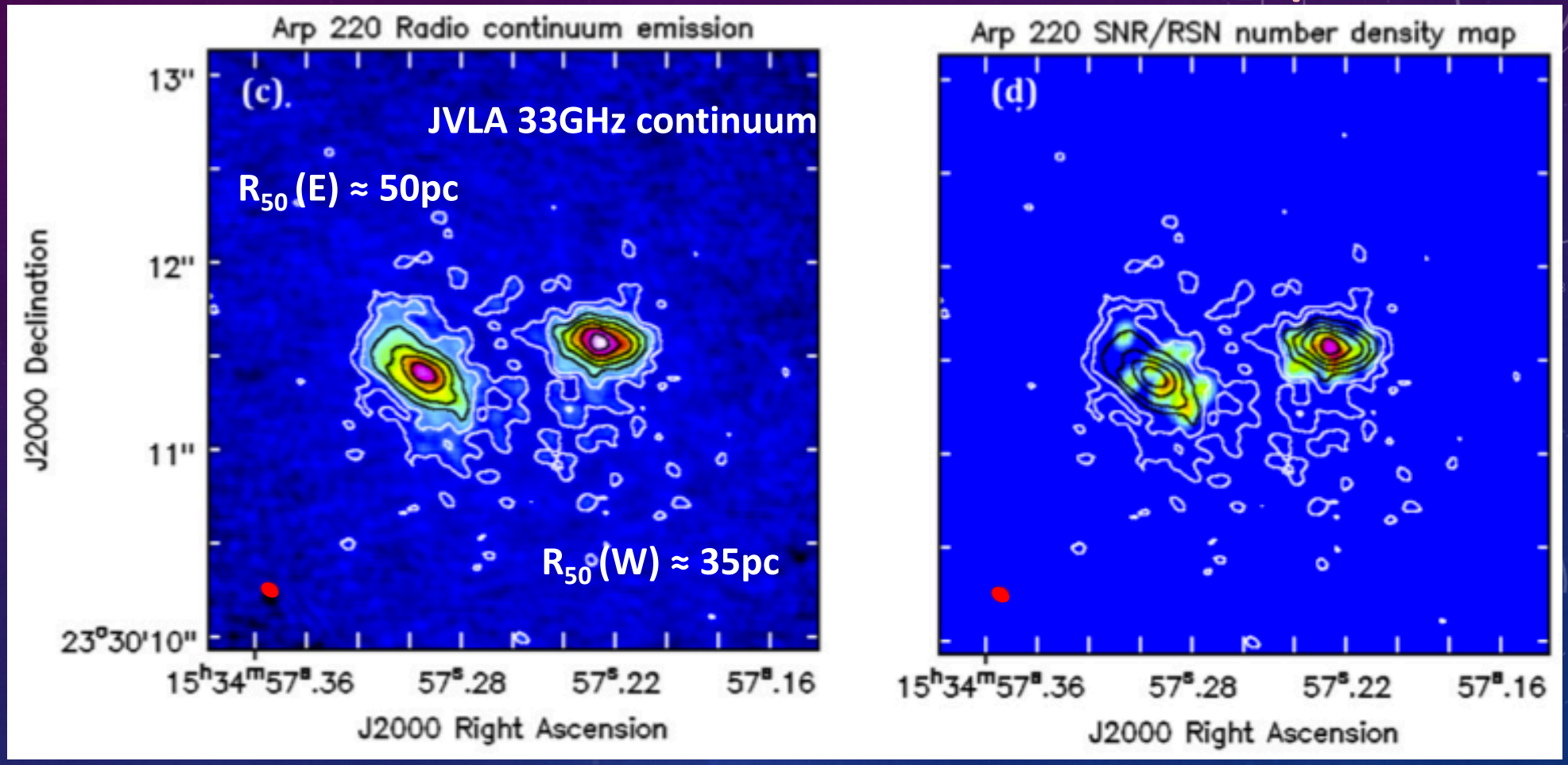


SNR distribution from Lonsdale+06

Highest values measured for any star-forming system

$\Sigma_{SFR}(W) \sim 10^{4.1}\ M_\odot\ yr^{-1}\ kpc^{-2}$

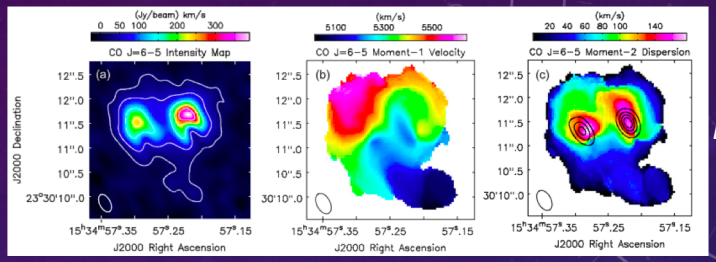
$\Sigma_{gas}(W) \sim 4.5 \times 10^5\ M_\odot pc^{-2}$

33 GHz tracing recent SF

Barcos-Muñoz et al. 2015

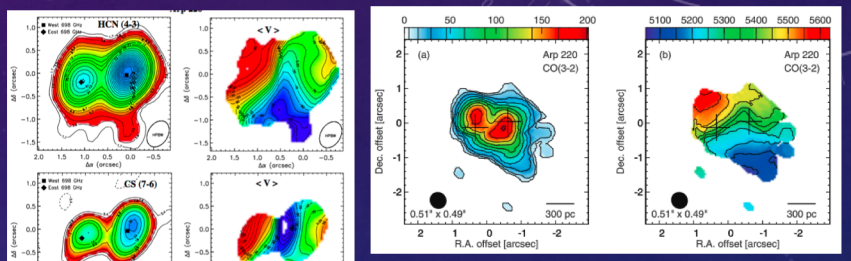
Submillimeter Observations of Arp 220

- ALMA has observed Arp 220 several times in an effort to determine gas and dust continuum properties (e.g., Wilson+14, Aalto+15, Rangwala+15, Scoville+15,16, Martin+16).
- Previous efforts with similar angular resolution include Sakamoto+99,08,09 with SMA.
- High angular resolution (0.1” < comparable to VLA at 33 GHz) available for the first time in Cycle 3.
- High resolution campaign to observe gas distribution and thermal dust continuum include Scoville+16 (CO (1-0)) and **Barcos-Muñoz+18, in prep. (e.g., HCN (1-0), HCO+(1-0), SiO(2-1))**

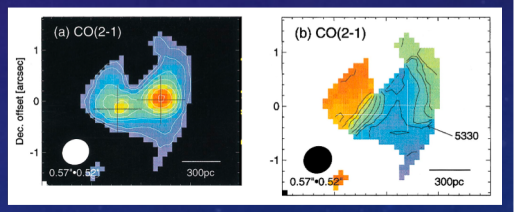


Rangwala+15

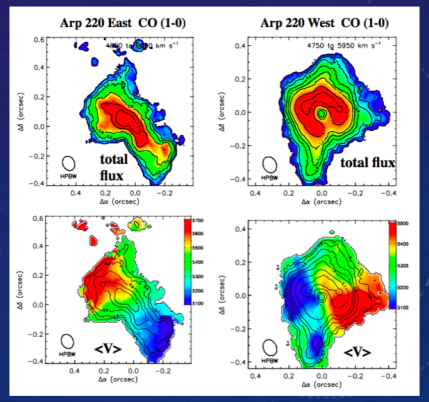
Sakamoto+08



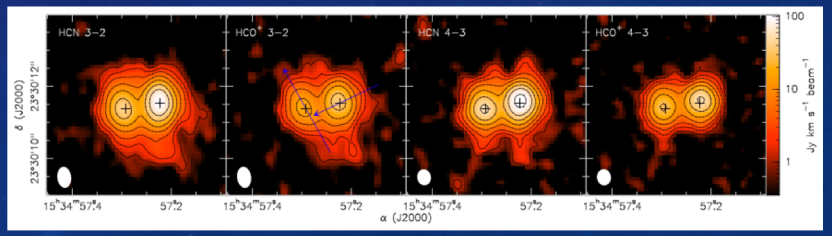
Scoville+15



Sakamoto+99

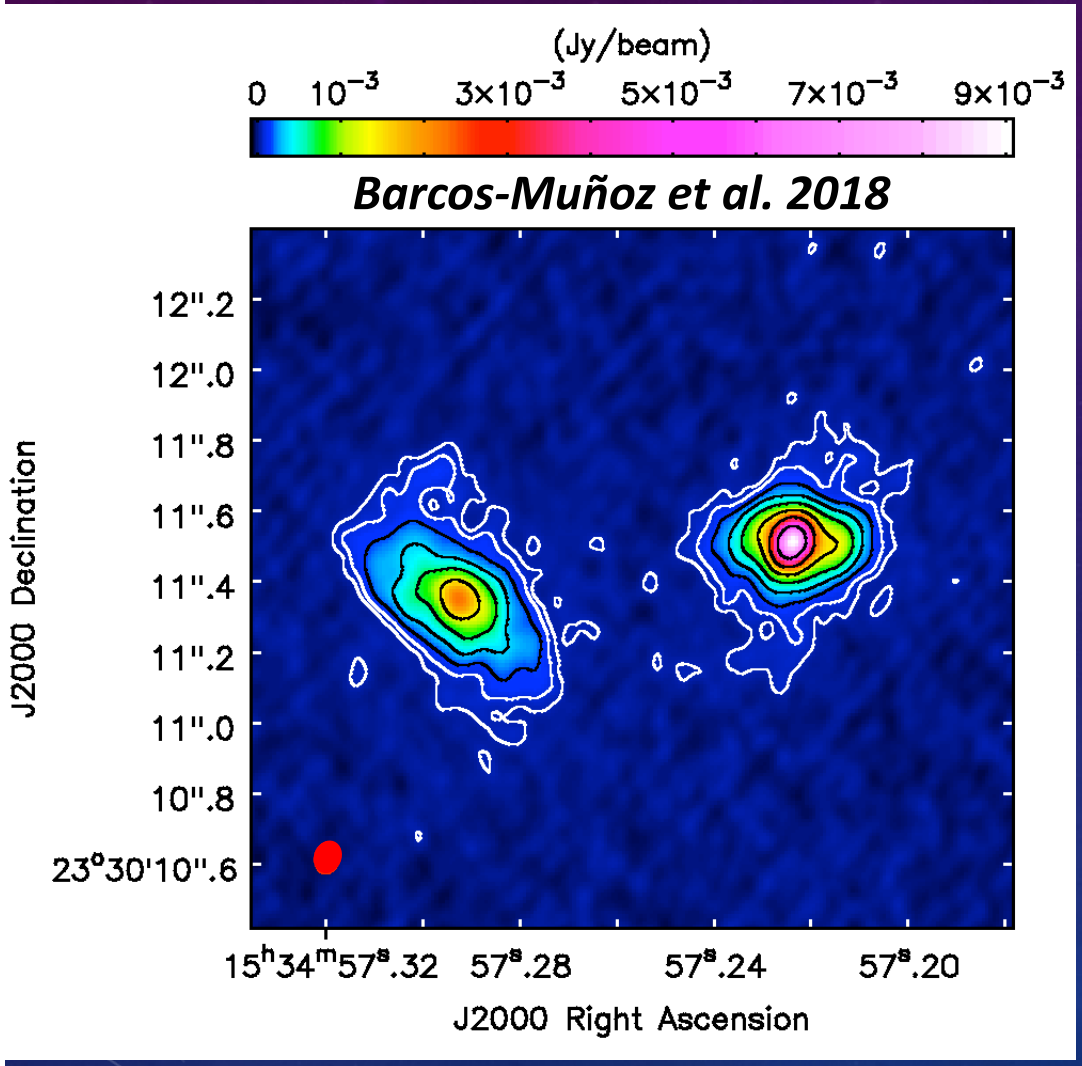


Scoville+17



Martín+16

Star Formation Distribution at 30 pc Scales at a distance of 77 Mpc



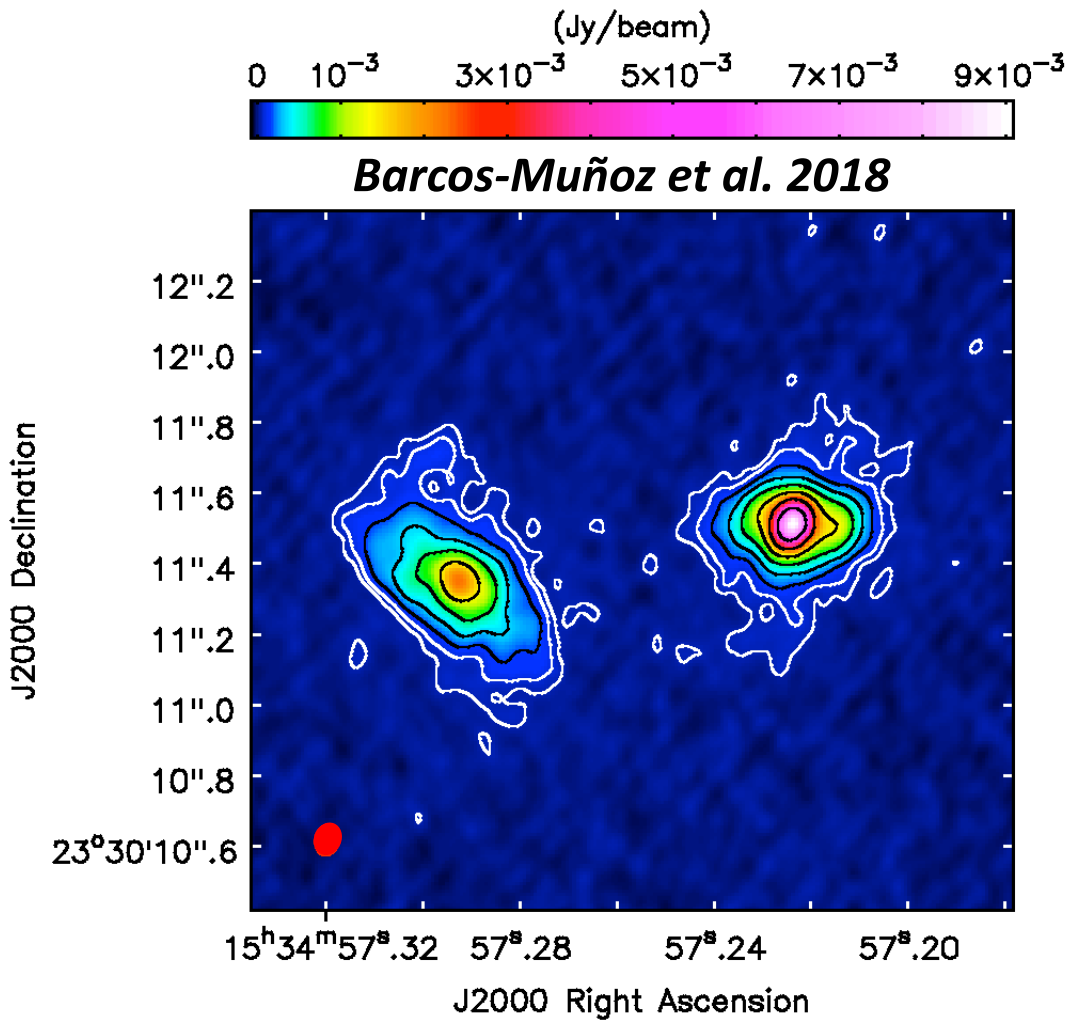
ALMA: 92 GHz

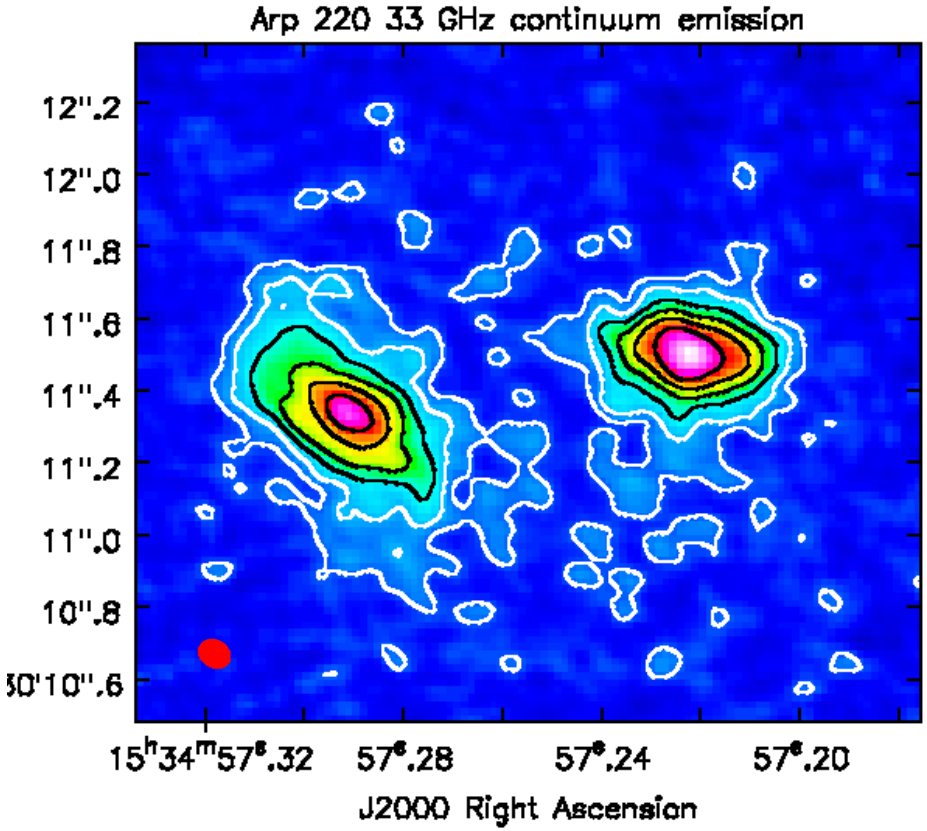
0.09” x 0.07” (33 x 26 pc)

92 GHz is optically thin. Traces star formation.

Star Formation Distribution at 30 pc Scales at a distance of 77 Mpc

33 and 92 GHz continuum emission similar





ALMA: 92 GHz

0.09” x 0.07” (33 x 26 pc)

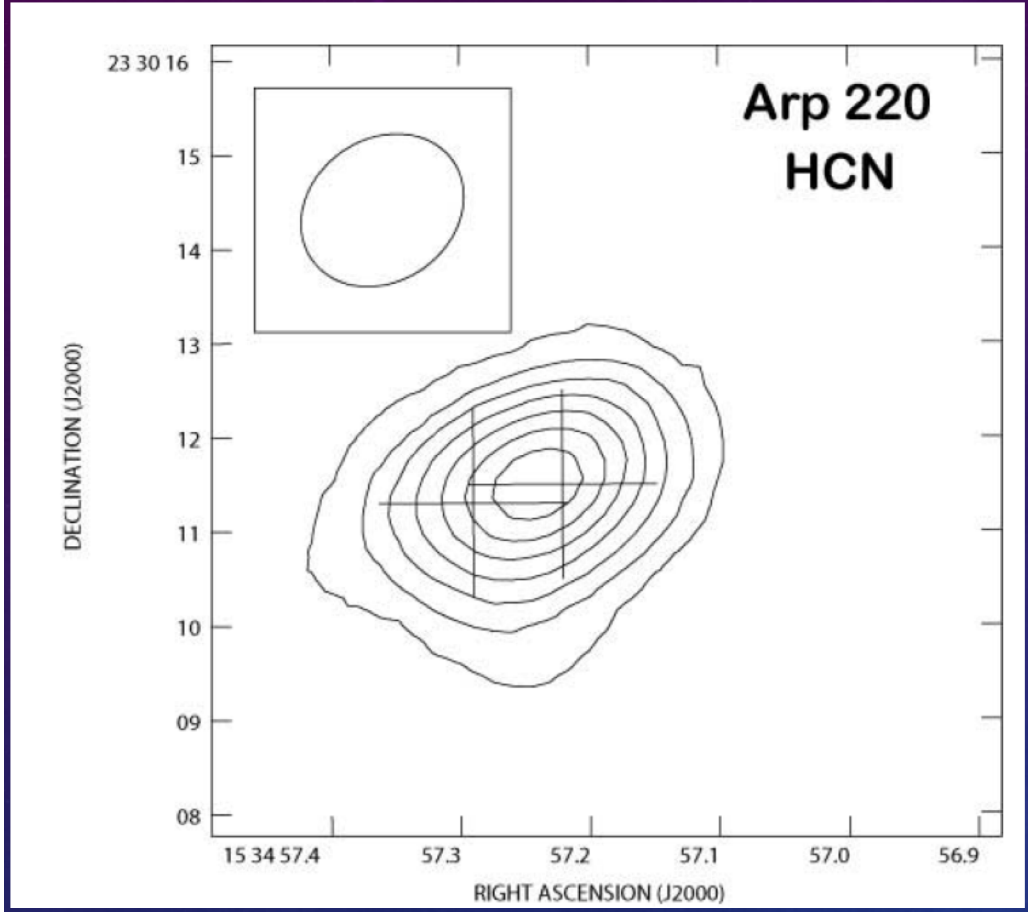
92 GHz is optically thin. Traces star formation.

VLA: 33 GHz

0.08” x 0.06” (30 x 23 pc)

33 GHz: recent SF

First HCN map at GMC scales for Arp 220



Imanishi+07

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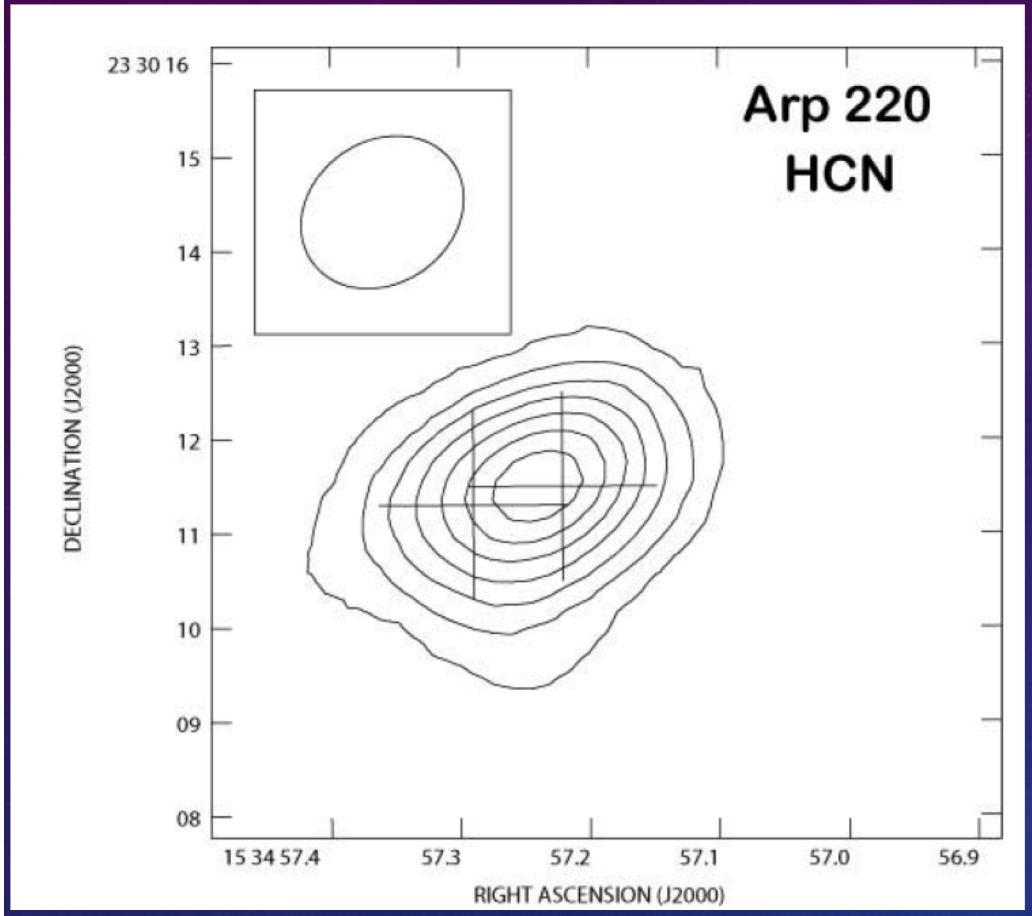
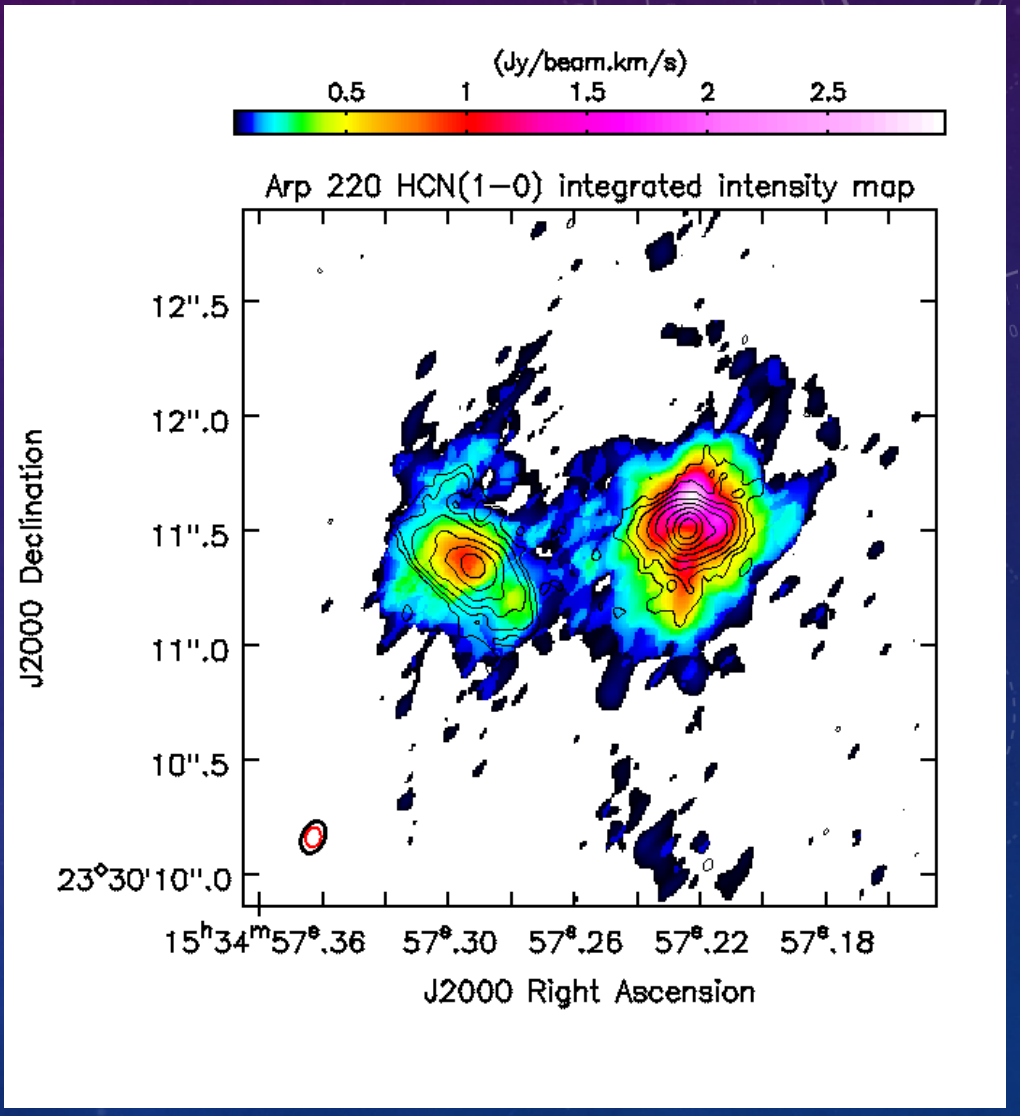
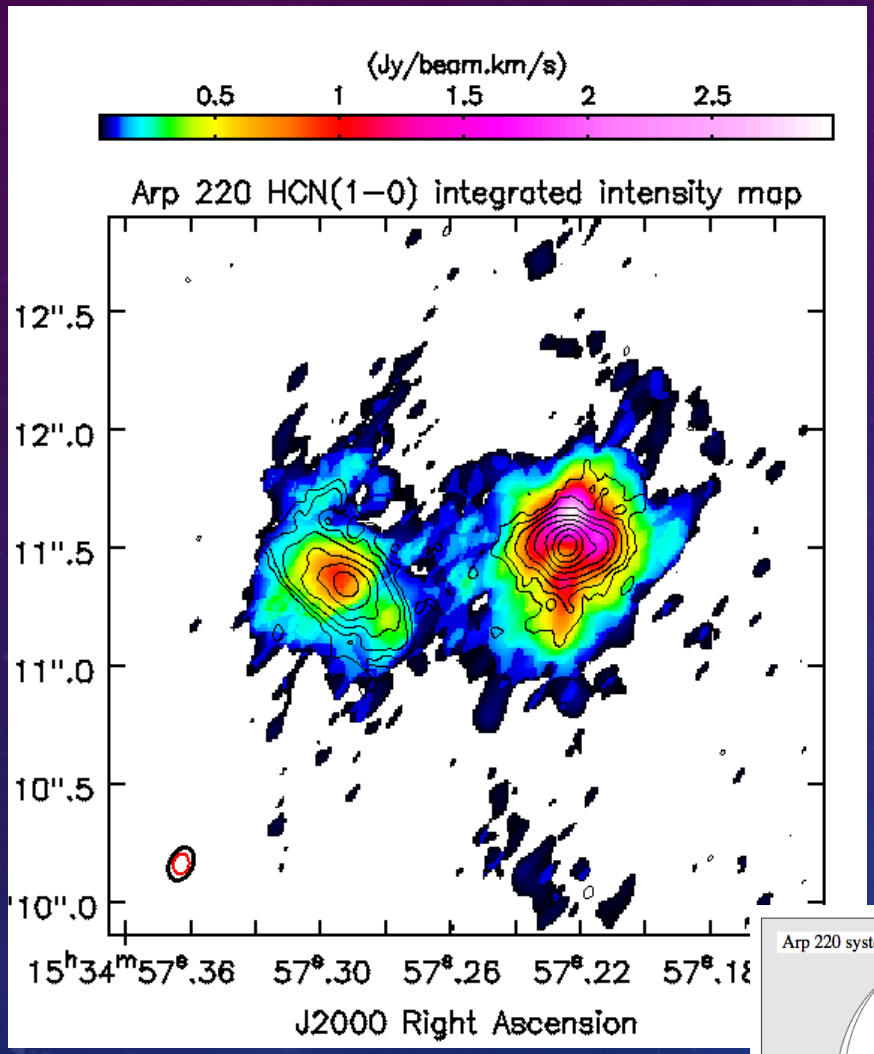


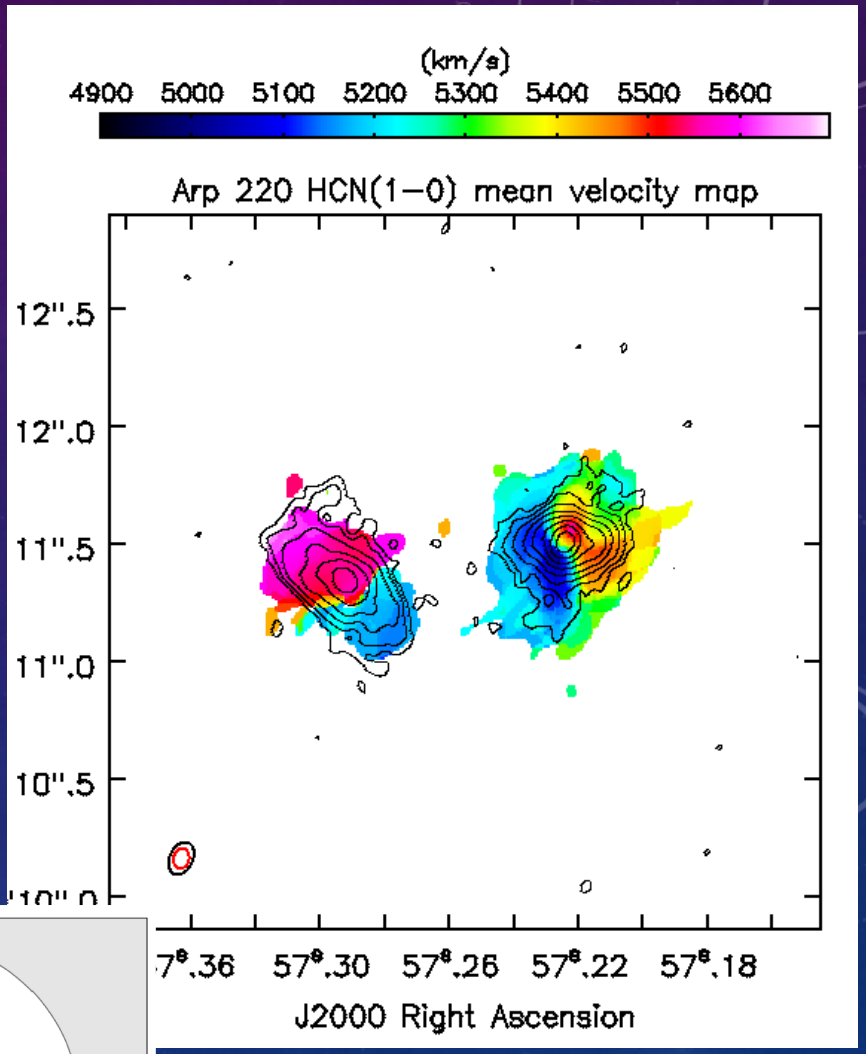
Imanishi+07

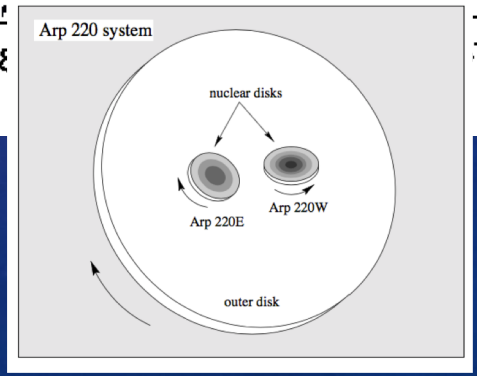


Barcos-Muñoz PhD thesis, in prep.

Dense Gas Distribution in Arp 220 at 30 pc scales







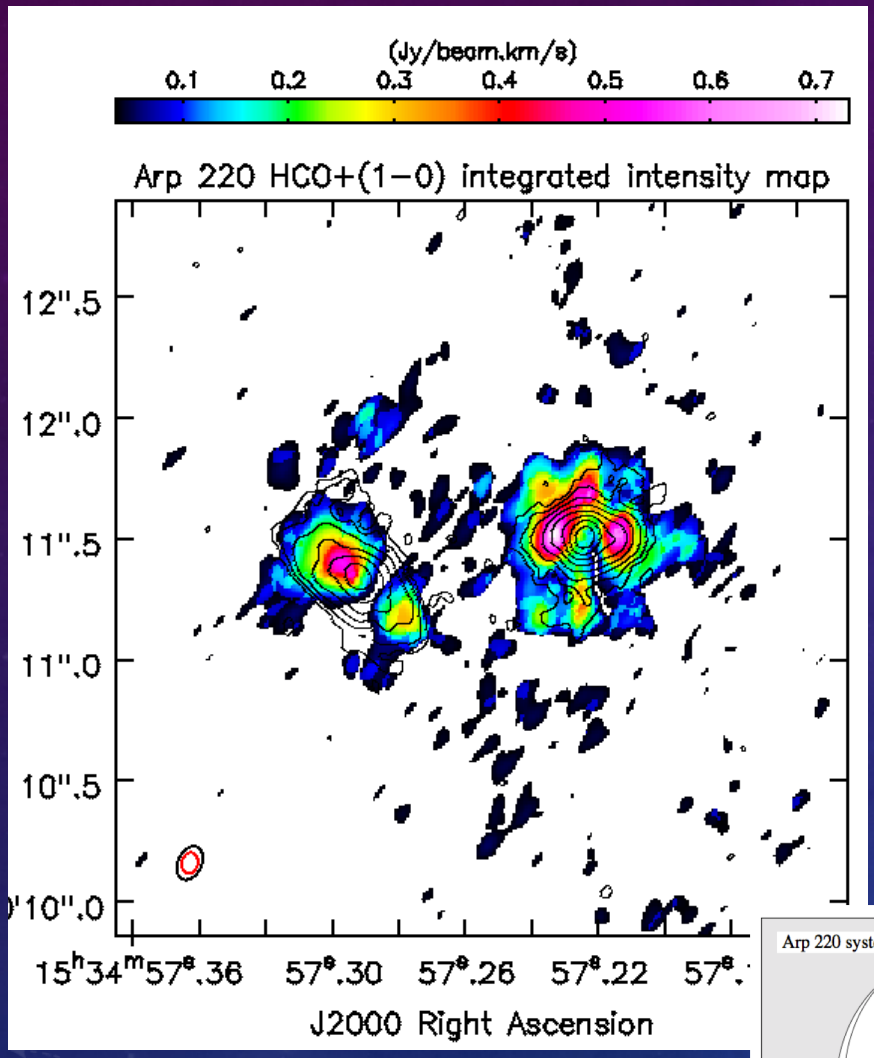
HCN (1—0)

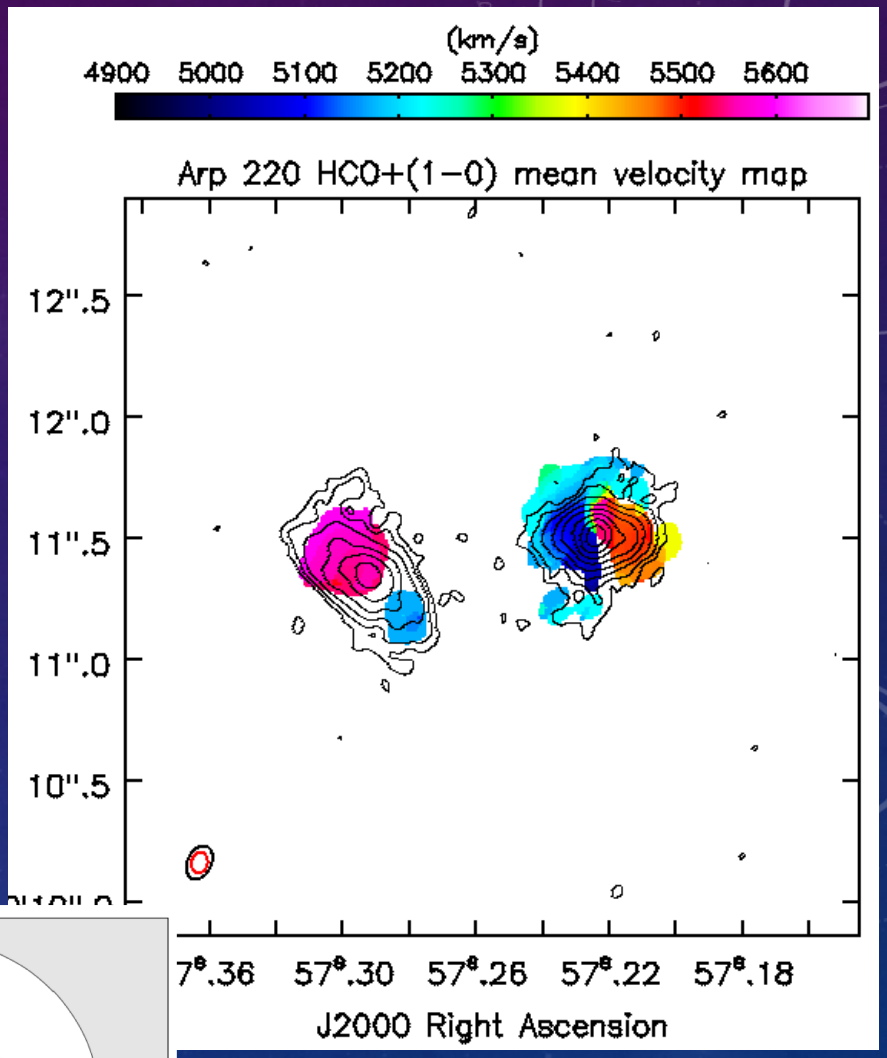
Barcos-Muñoz PhD thesis, in prep.

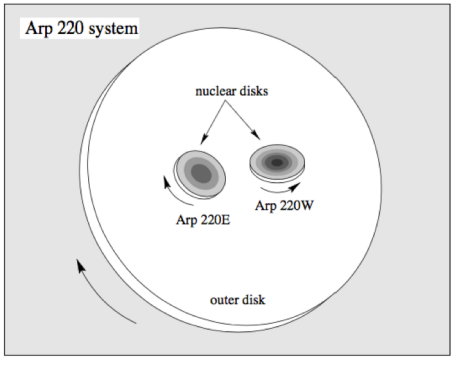
Sakamoto+99

Clear rotation of the gas

Dense Gas Distribution in Arp 220 at 30 pc scales







HCO⁺ (1—0)

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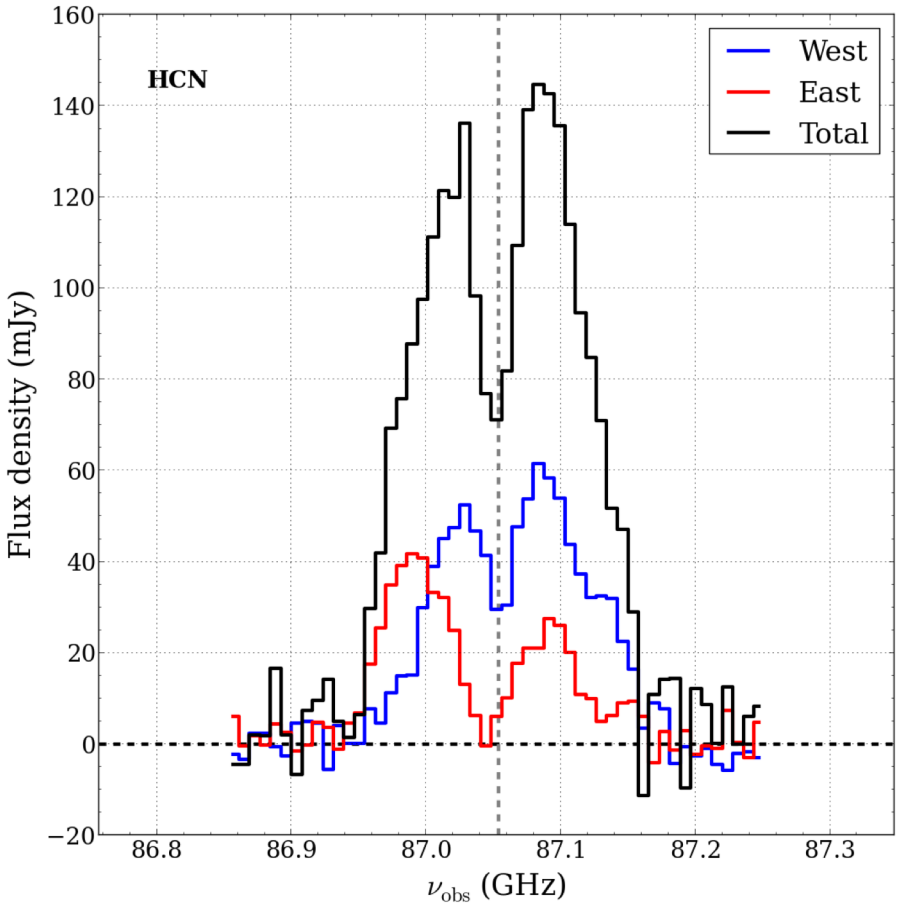
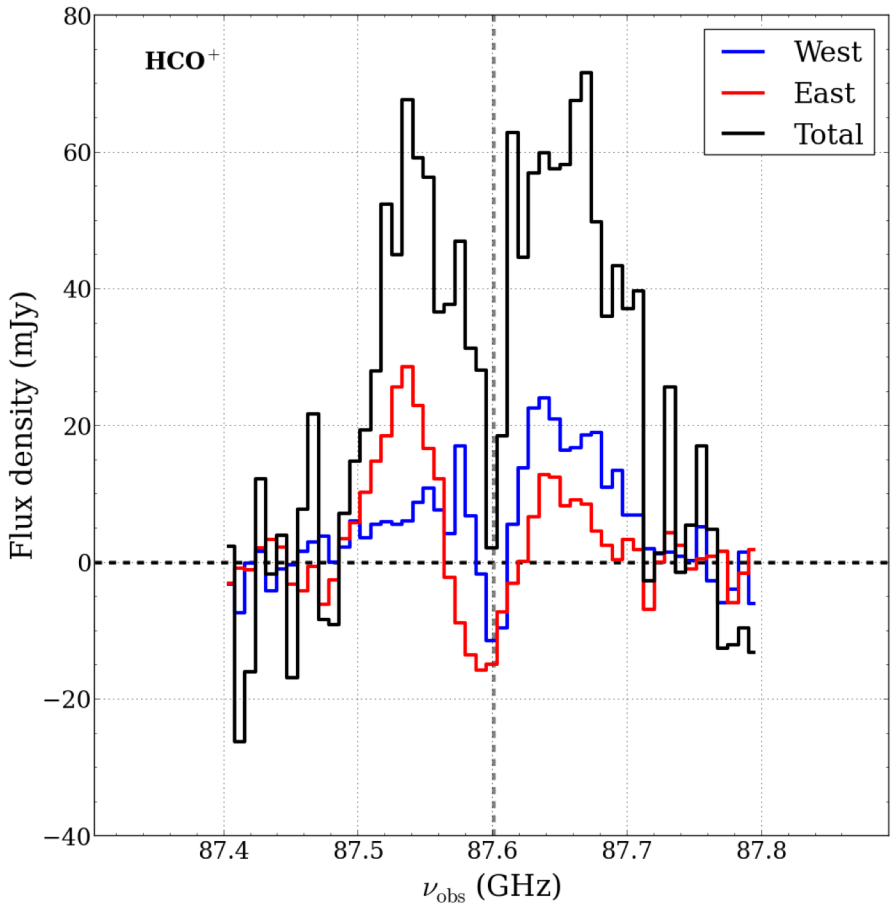
Sakamoto+99

Clear rotation of the gas

Dense Gas Distribution in Arp 220 at 30 pc scales

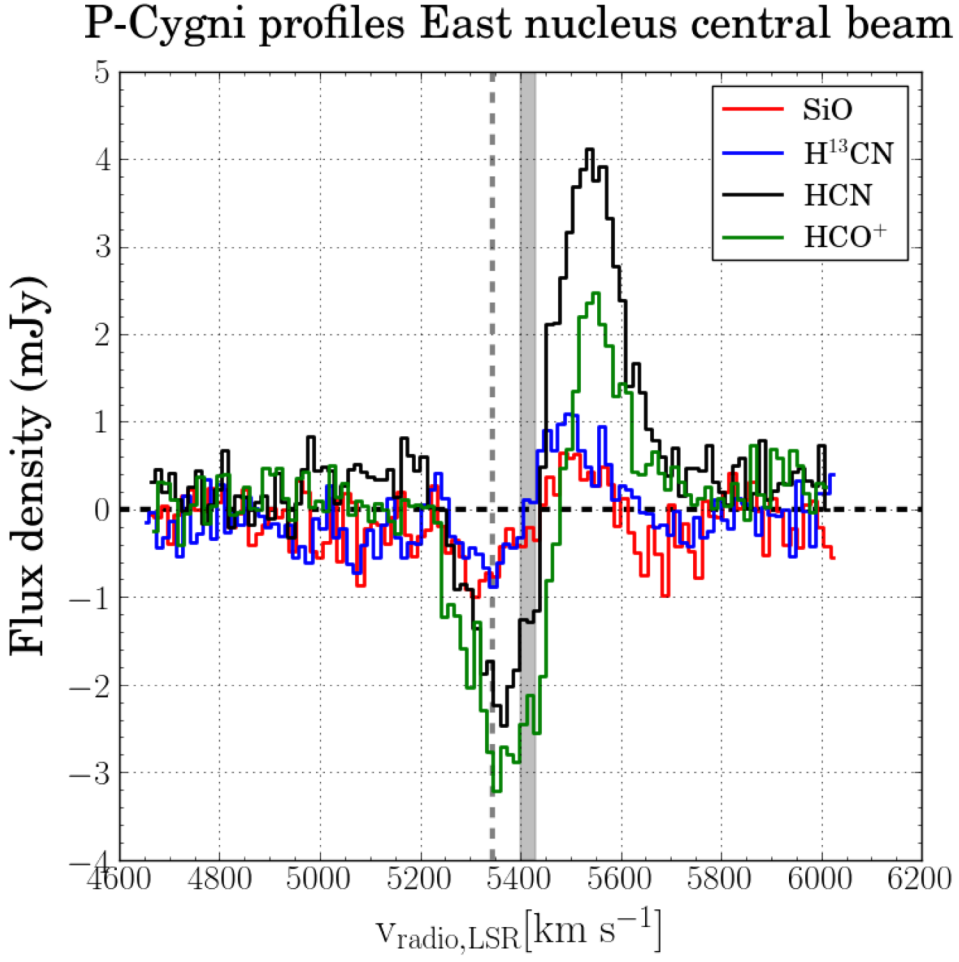


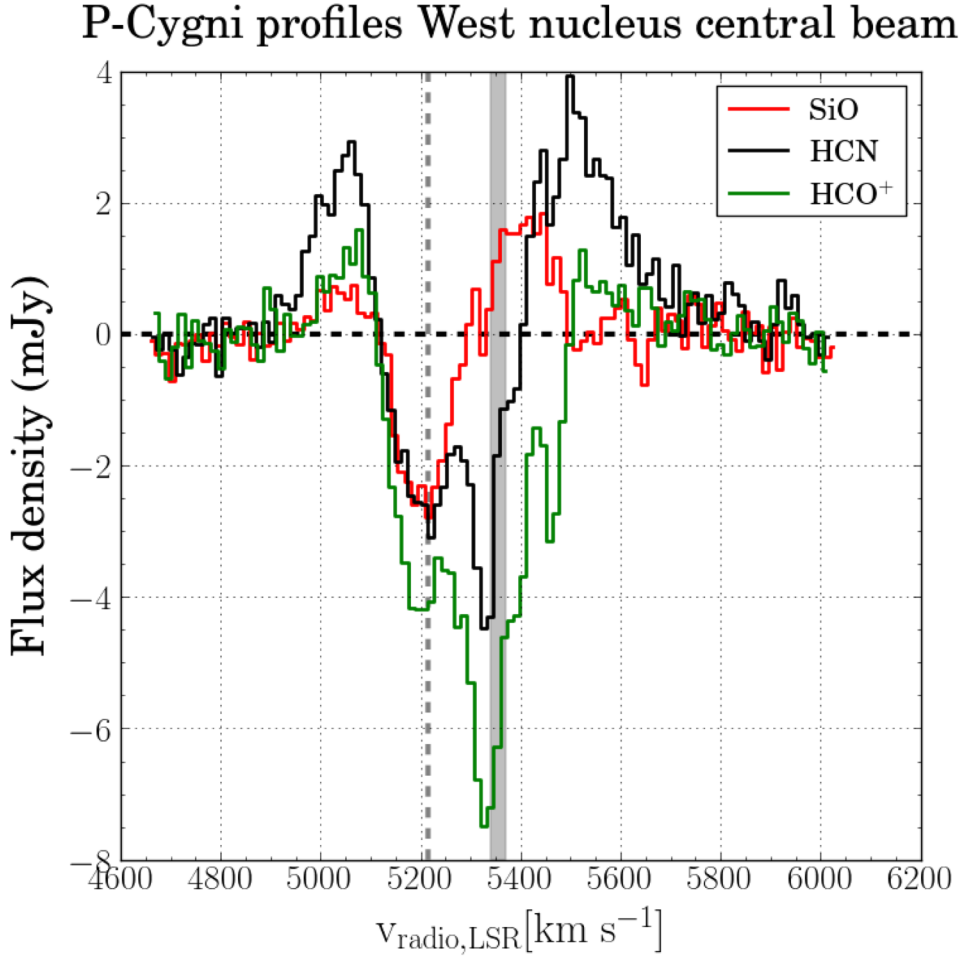


Recover 100% of total HCN emission: 37% in W, 23% in E, and 40% extended.

Barcos-Muñoz PhD thesis, in prep.

Dense Gas Distribution in Arp 220 at 30 pc scales





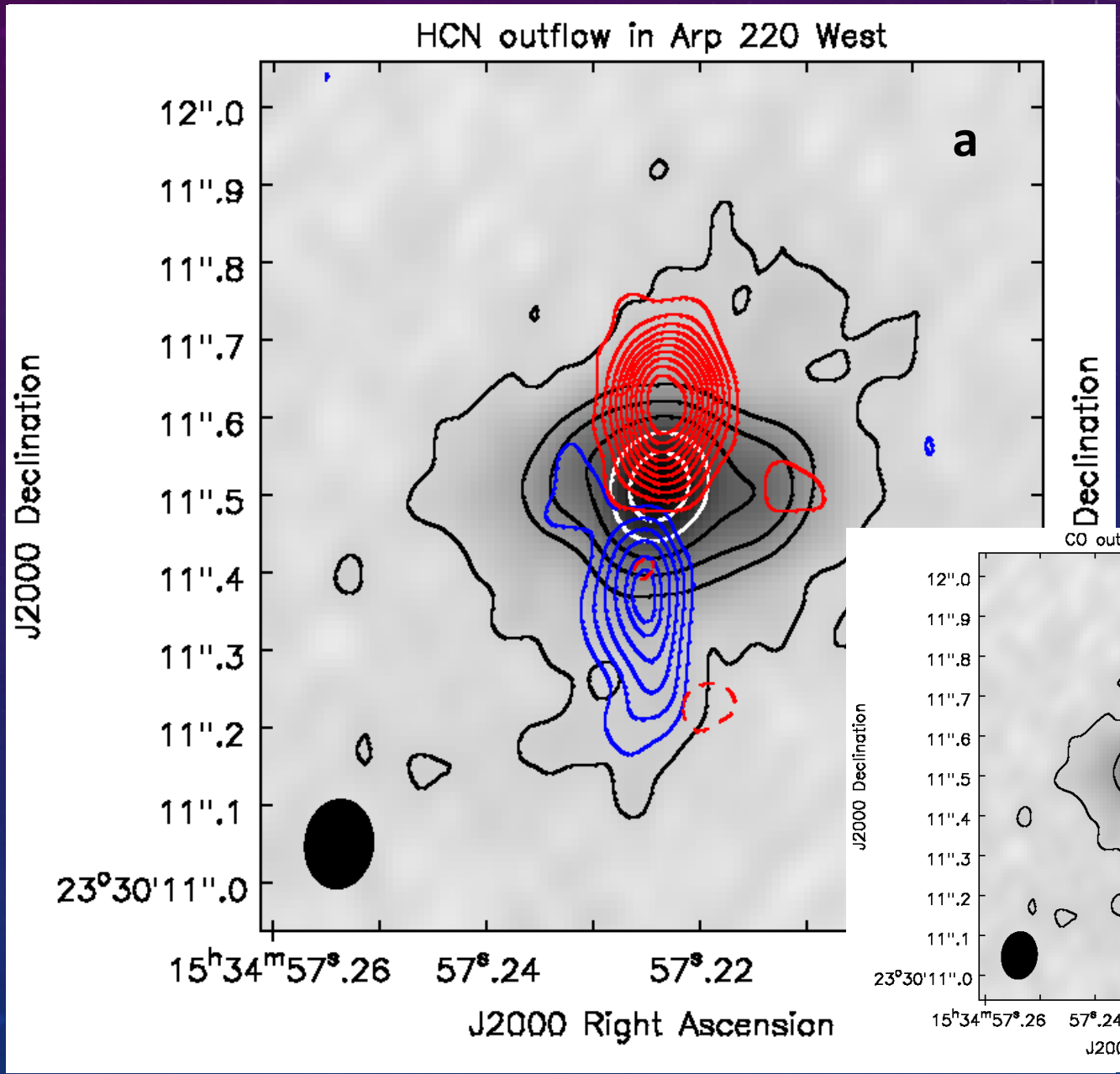
Outflow signature

Outflow signature + large obscuration

Barcos-Muñoz PhD thesis, in prep.

First 3D image of the molecular outflow in the western nucleus of Arp 220

Barcos-Muñoz et al. 2018



PI: Scoville

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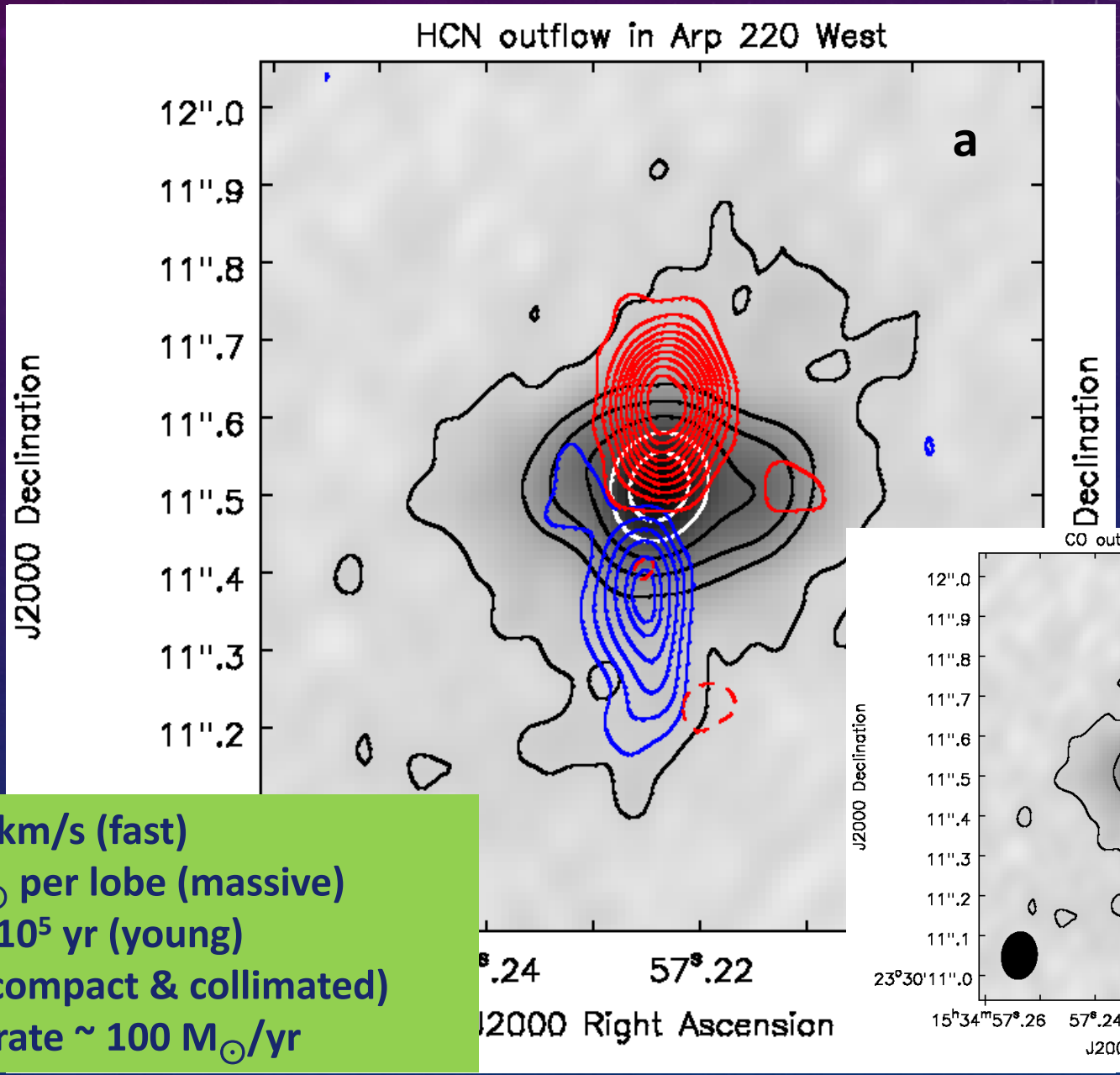
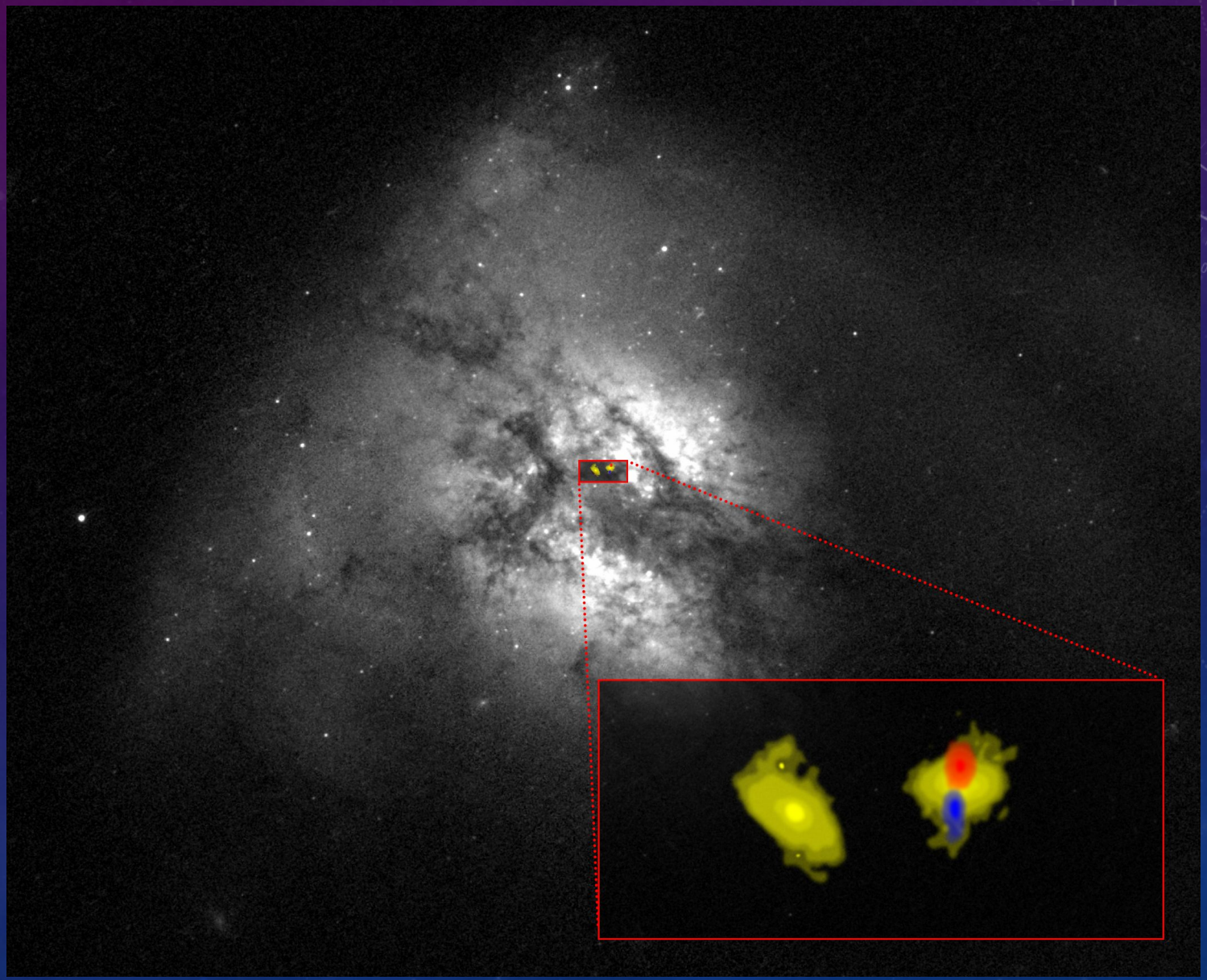


PI: Scoville

velocity ~ 850 km/s (fast)
Mass > 10^6 $M_\odot$ per lobe (massive)
outflow age ~ 10^5 yr (young)
size < 120 pc (compact & collimated)
Mass outflow rate ~ 100 $M_\odot$/yr

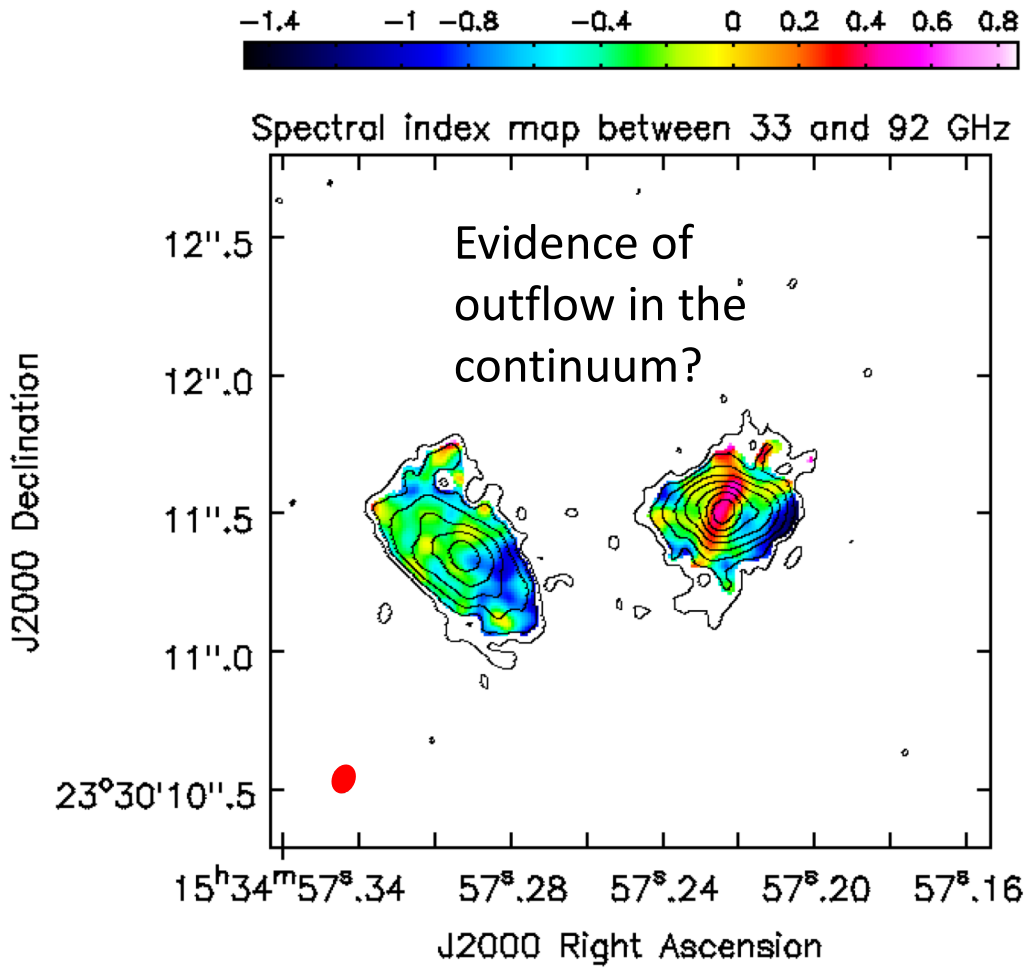
First 3D image of the molecular outflow in the western nucleus of Arp 220

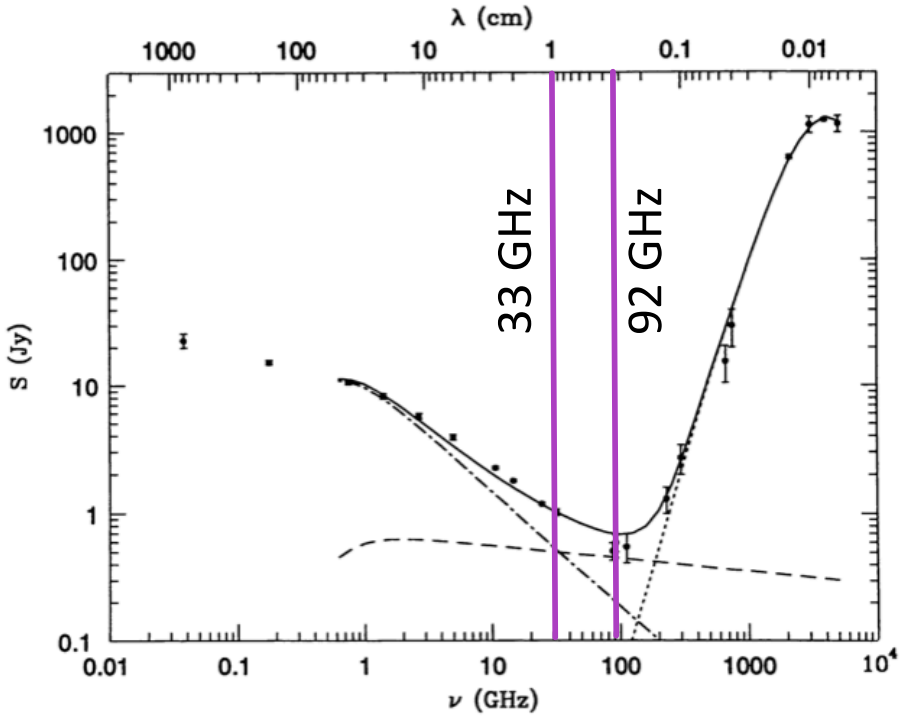


Credit: N. Lira (JAO), J. Pinto (JAO), and L. Barcos-Muñoz (JAO/NRAO)

Resolved spectral index map

Spatial distribution of thermal, non-thermal, and dust emission

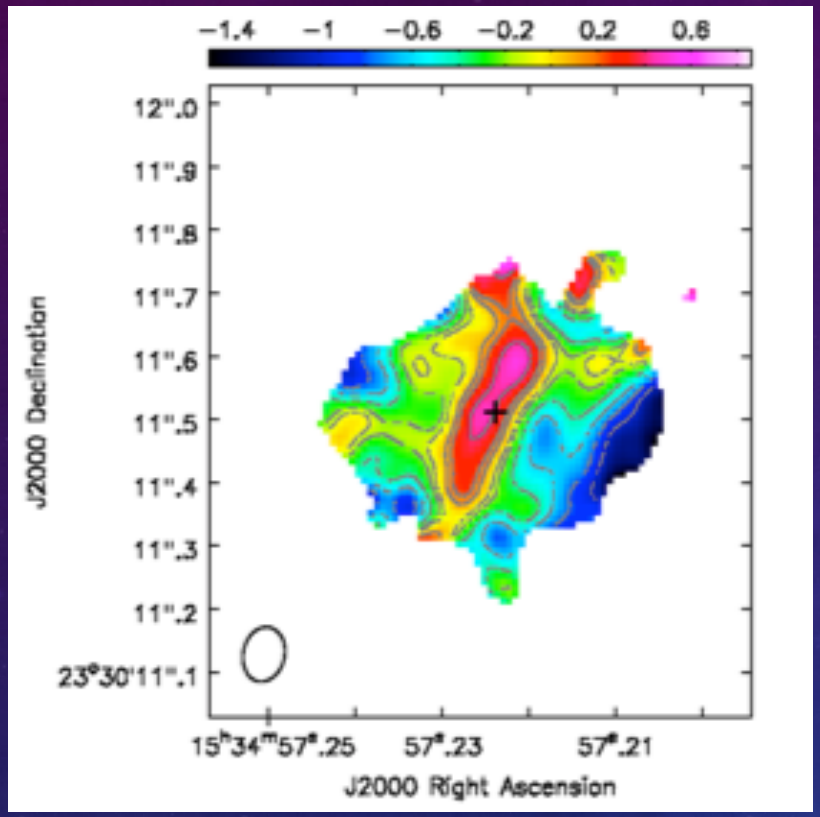




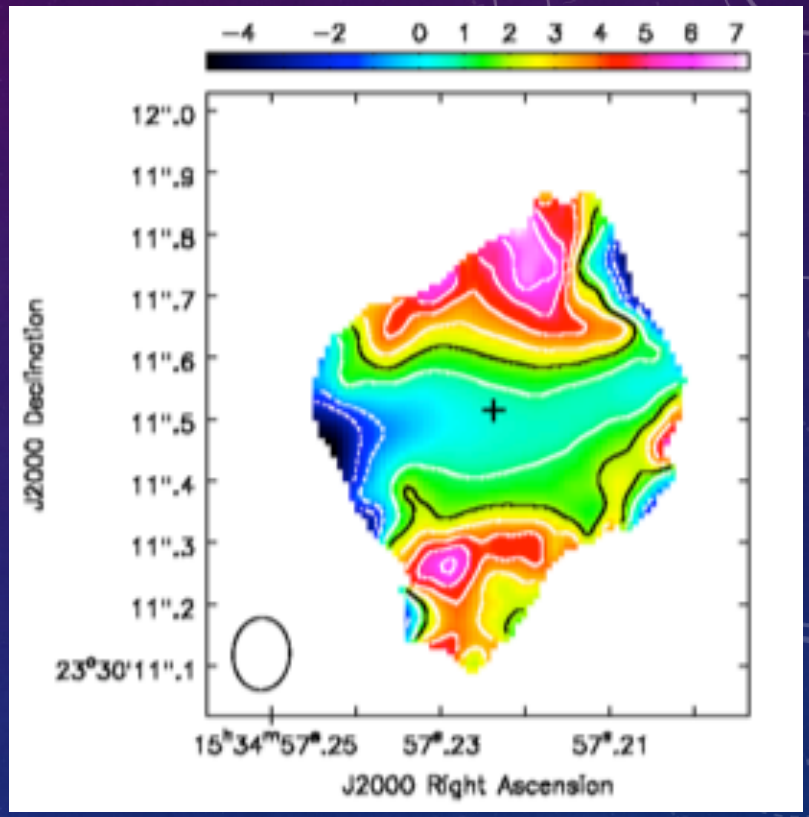
Spectral index maps: a powerful tool to unveil distribution of different emission mechanisms

NEED MULTIWAVELENGTH COVERAGE AT 0.1" RESOLUTION

First 3D image of the molecular outflow in the western nucleus of Arp 220



Spectral index map between 33 and 92 GHz

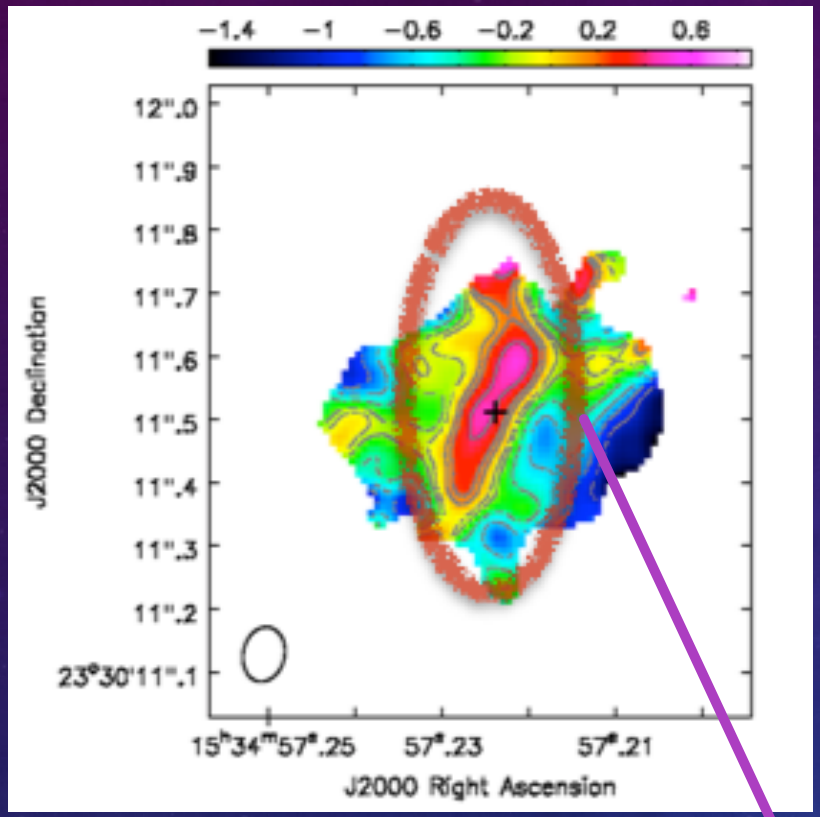


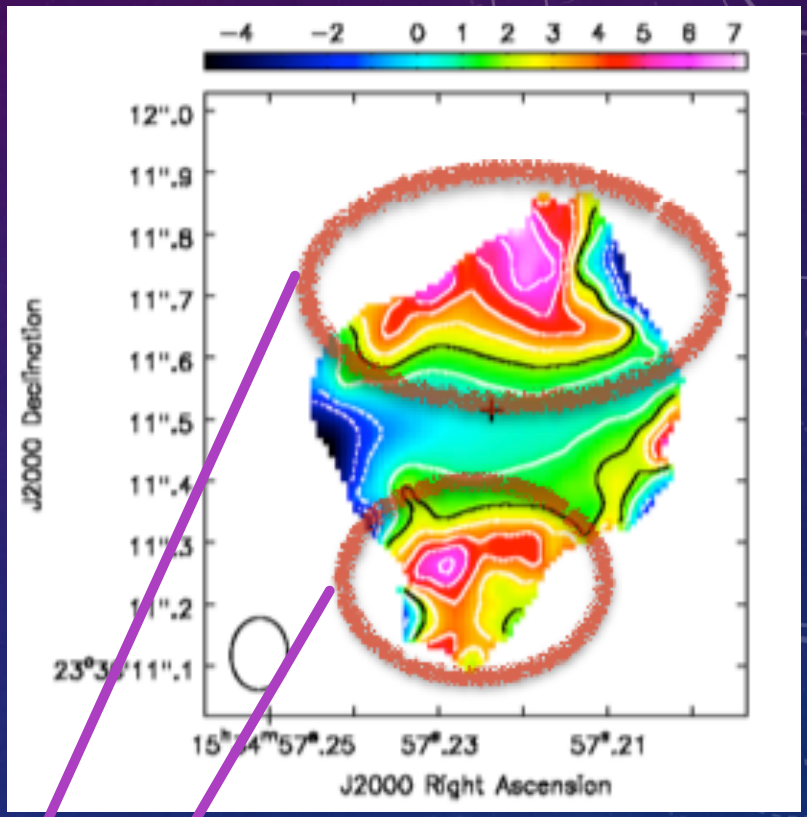
Spectral index map between 92 and 104 GHz

(Sakamoto et al. 2017)

Barcos-Muñoz et al. 2018

First 3D image of the molecular outflow in the western nucleus of Arp 220





Spectral index map between 33 and 92 GHz

Spectral index map between 92 and 104 GHz

Dust emission from the outflow!

Barcos-Muñoz et al. 2018 *(Sakamoto et al. 2017)*

High Resolution Survey of the Gas and Dust Distribution in Nearby Luminous Infrared Galaxies

- ALMA Cycle 5 PI project:
  - 6 local U/LIRGs selected from VLA survey
  - 0.1” resolution with LAS of 2”
  - Band 3 (continuum at 100 GHz + CO (1-0))
  - Band 7 (CO (3-2) + continuum at 350 GHz)
  - Goal is to have gas kinematics and dust continuum emission to be combined with VLA observations.
  - Data being delivered.

Stay tuned!

Conclusions

- Radio interferometry is the ideal tool to study obscured compact objects, such as Arp 220.
- Arp 220 has compact nuclei with half-light radii of 30 and 50 pc, implying extreme values of Σ_{SFR} and Σ_{mol}
- Arp 220 has extended dense gas distribution, from HCN. However, HCN emission is strongly absorbed in the center indicating unresolved measurements of HCN luminosity is probably underestimating total mass.
- First image of the molecular outflow in the W nucleus of Arp 220. Brighter in HCN than CO (chemistry involved? And/or dust obscuration?) Still unclear what is driving the outflow, but morphology indicates is similar to outflow from compact source, AGN?
- Arp 220 is one system with six more to come. Stay tuned!