The Millimeter Valley Between Dust and Synchrotron Emission in Nearby Galaxies

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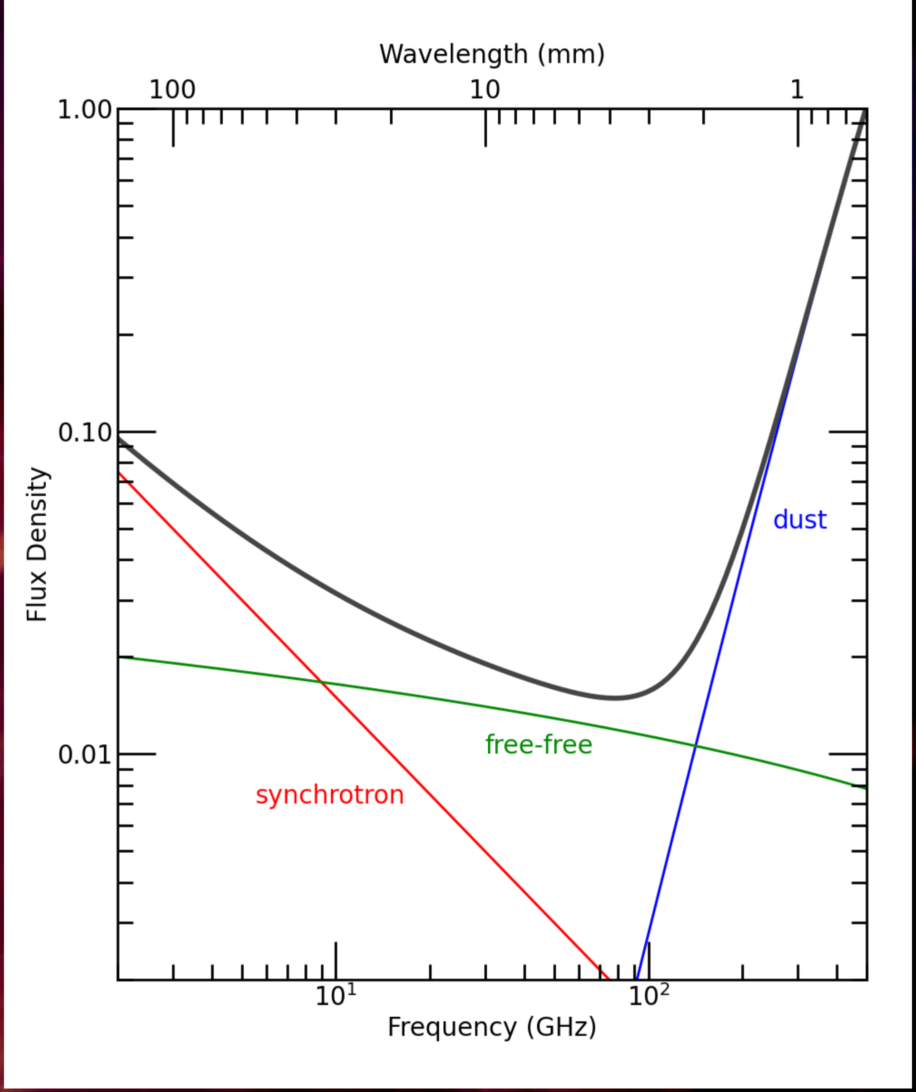
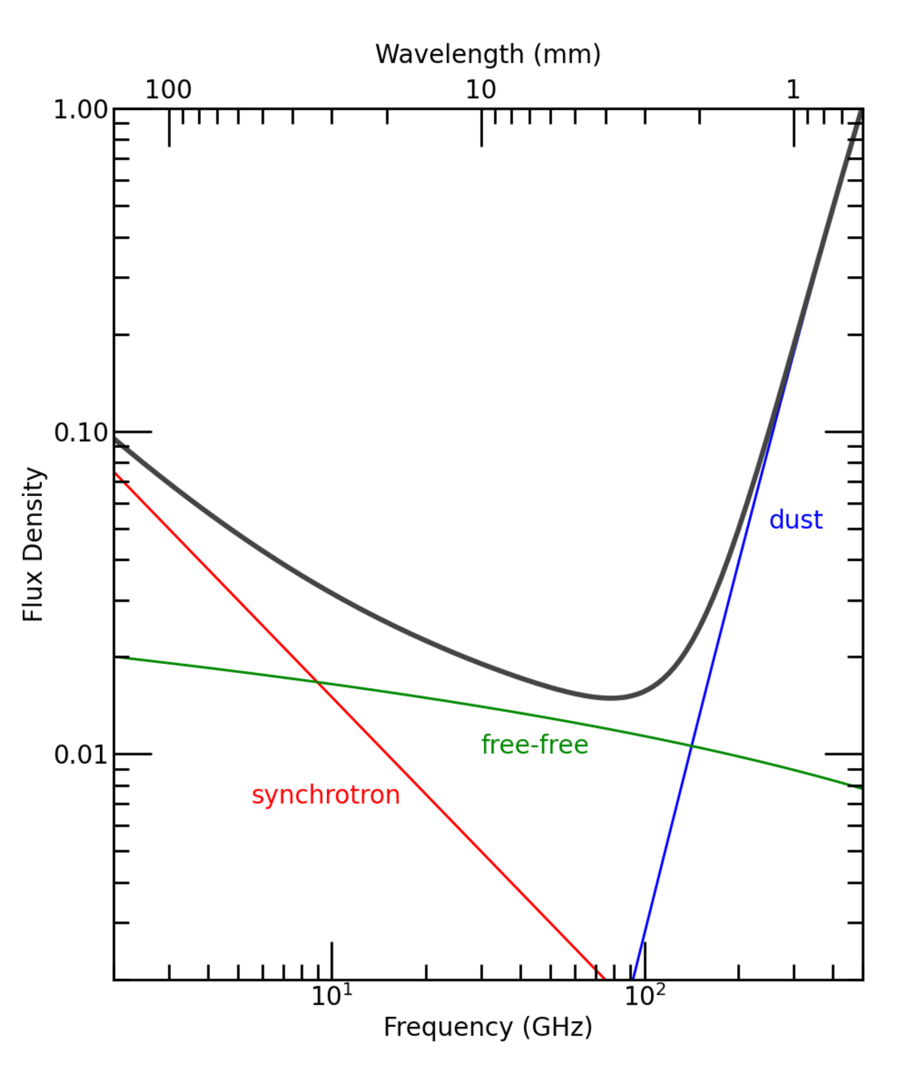
For galaxies, the millimeter /submillimeter part of the electromagnetic spectrum represents a transition from one source of emission through a second source of emission to a third.

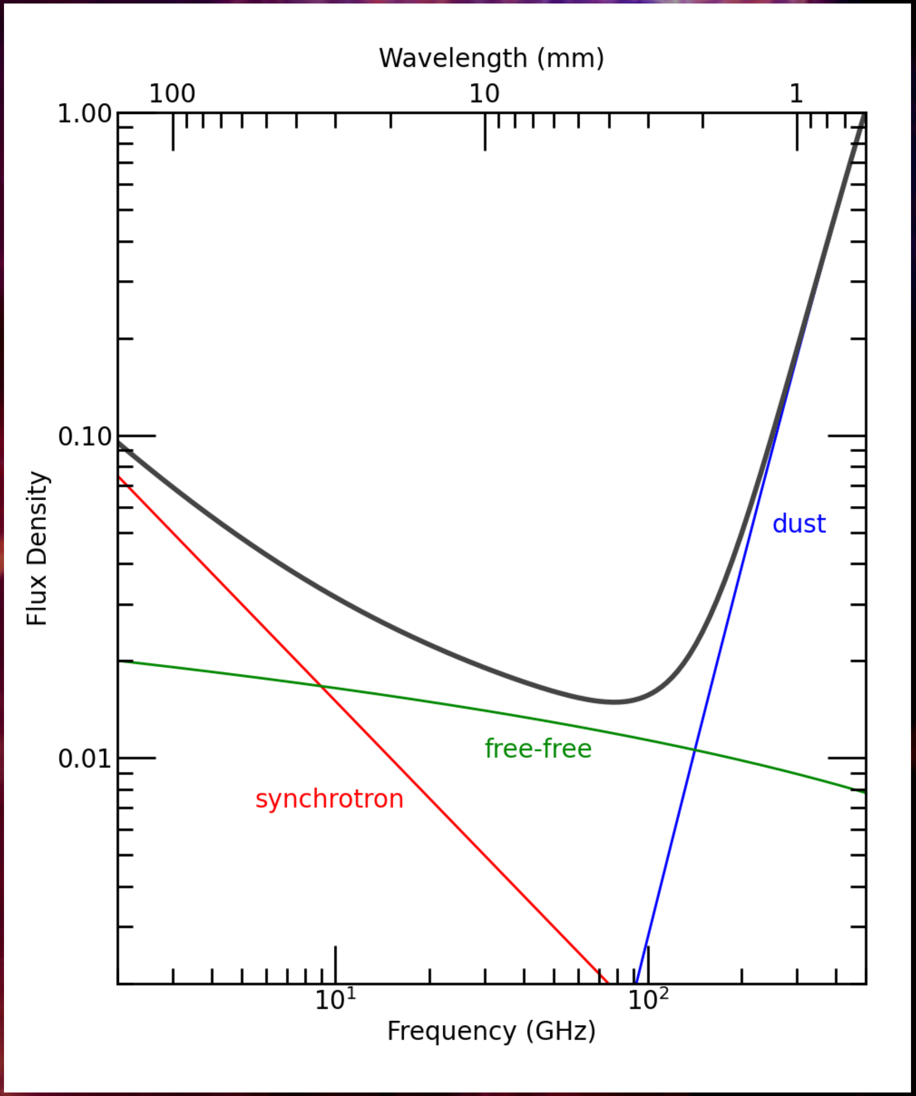


- Thermal dust emission ($\propto \nu^{4}$)
- Free-Free emission ($\propto \nu^{-0.1}$)
- Synchrotron emission ($\propto \nu^{-0.8}$)



All three of these sources of emission can be related to star formation. The free-free emission may be the best.

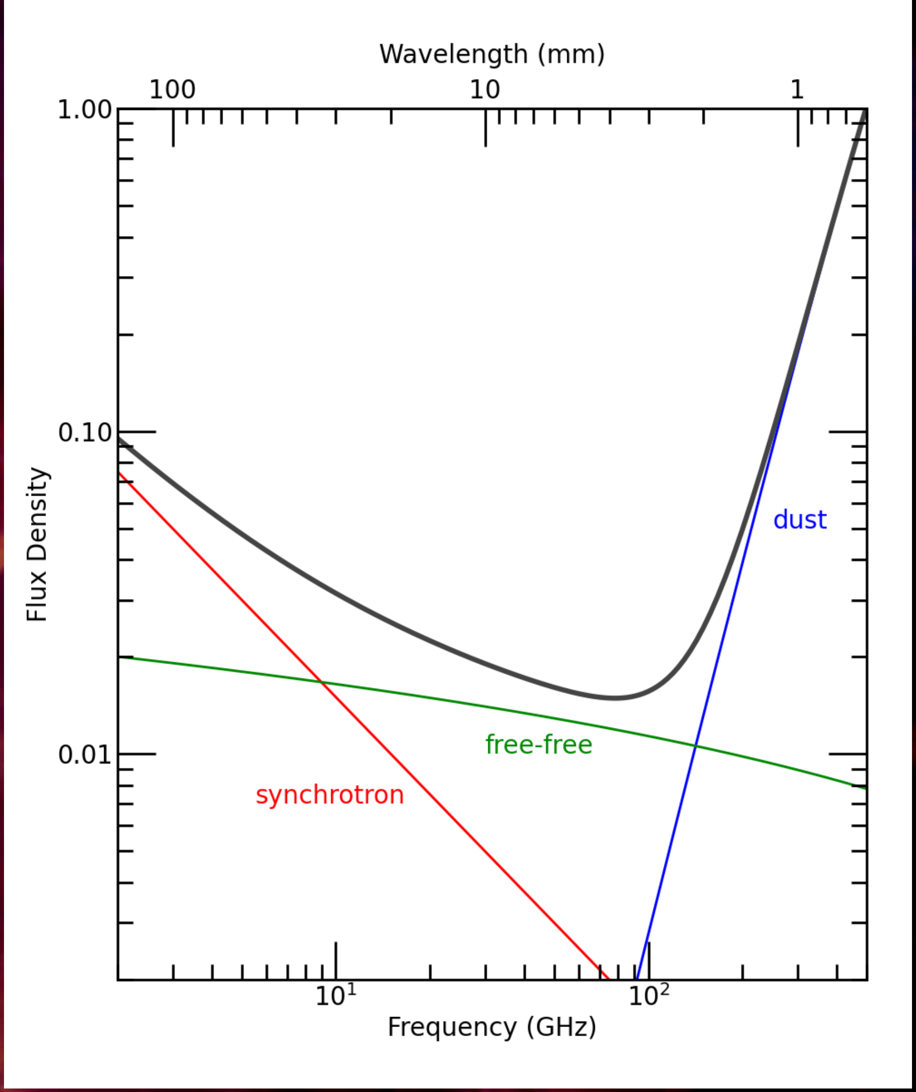
Additionally, the synchrotron emission itself should be higher than the other components in galaxies with AGN.

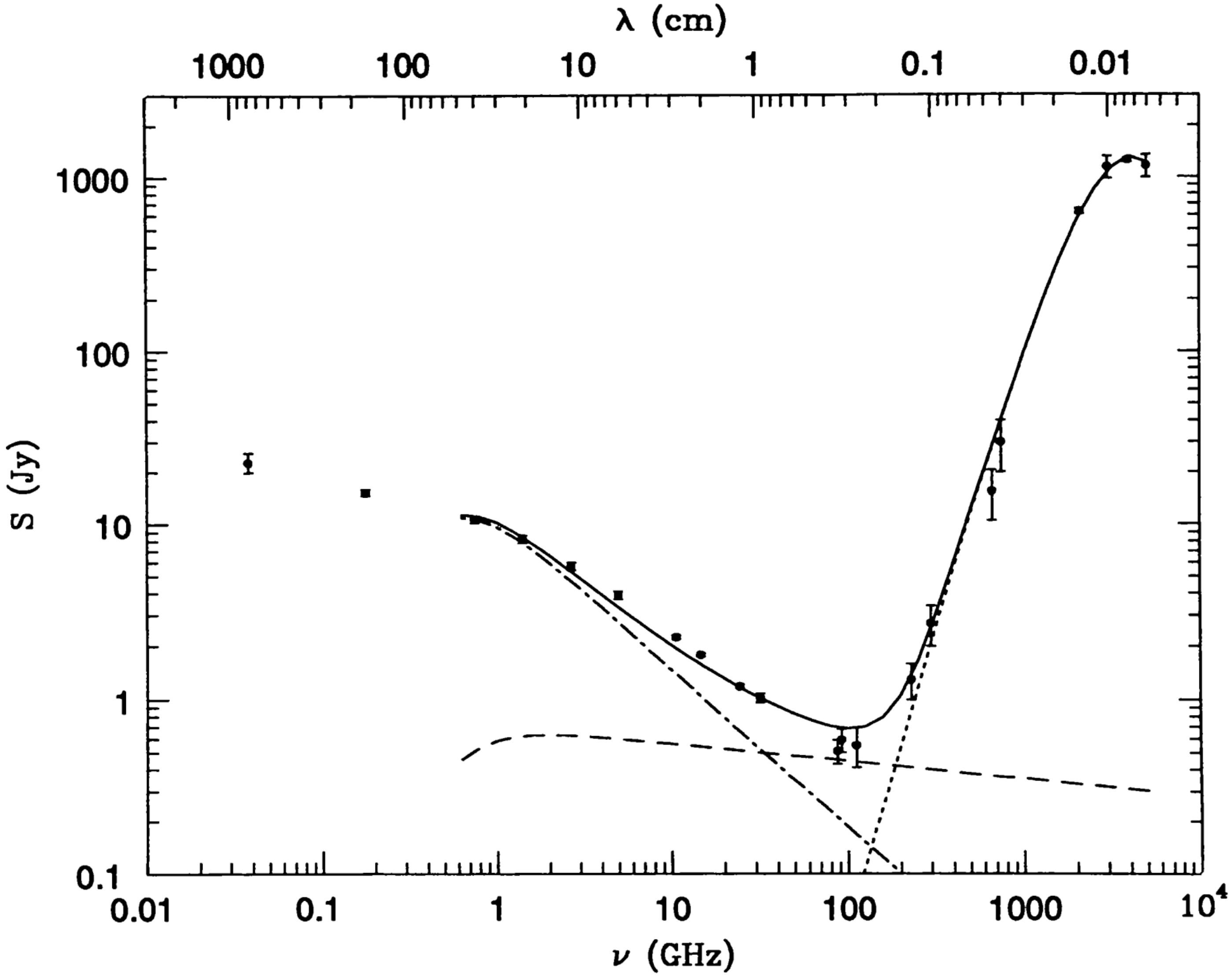


Unfortunately, the research into the spectral energy distributions in this wavelength range has been piecemeal.

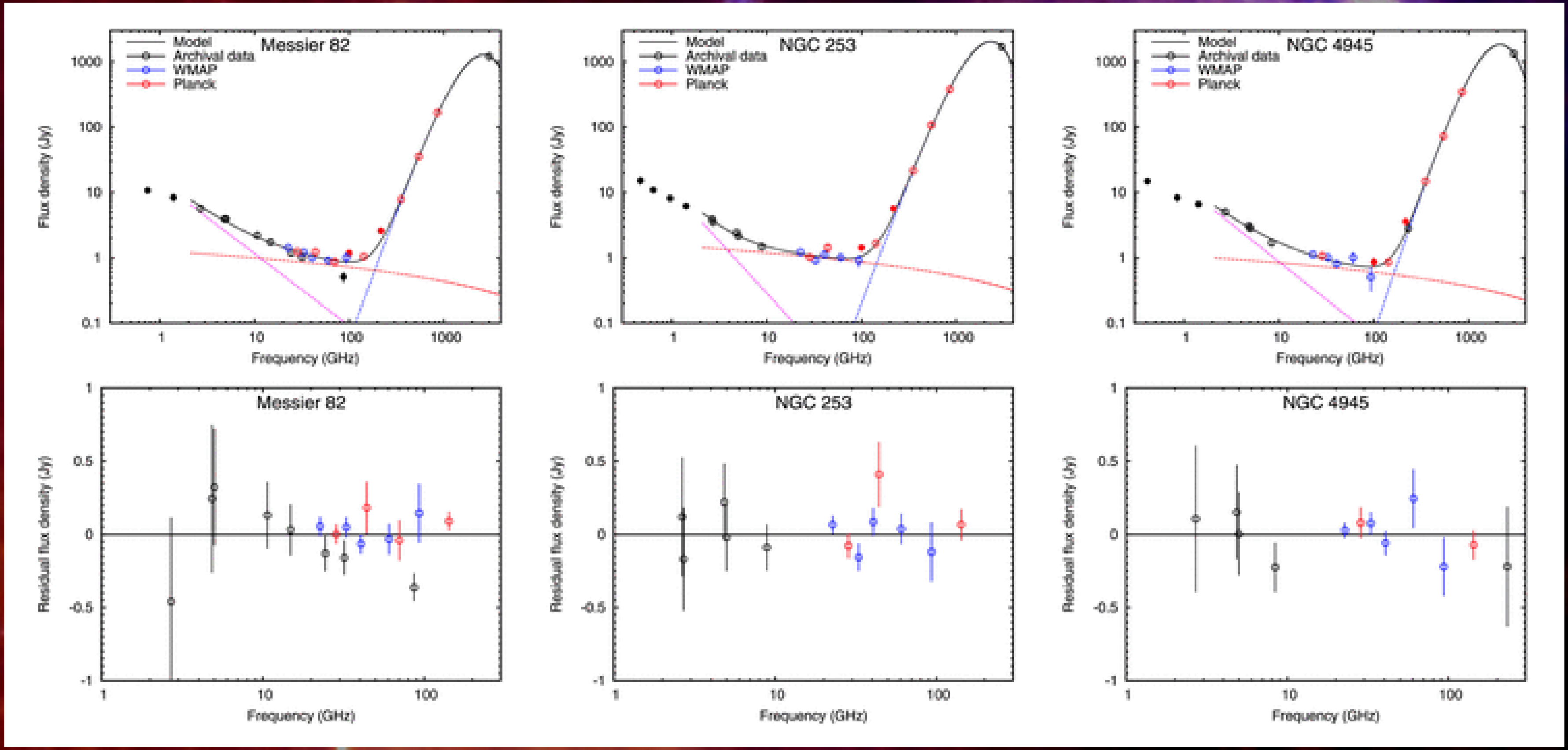
In infrared, optical, ultraviolet, and X-ray bands, it is possible based on surveys of hundreds or thousands of galaxies to identify the dominant emission source from a galaxy at any given wavelength/frequency and the stellar population connected to that emission.

In the millimeter regime, we hardly know what we are looking at, and we only have a few examples.

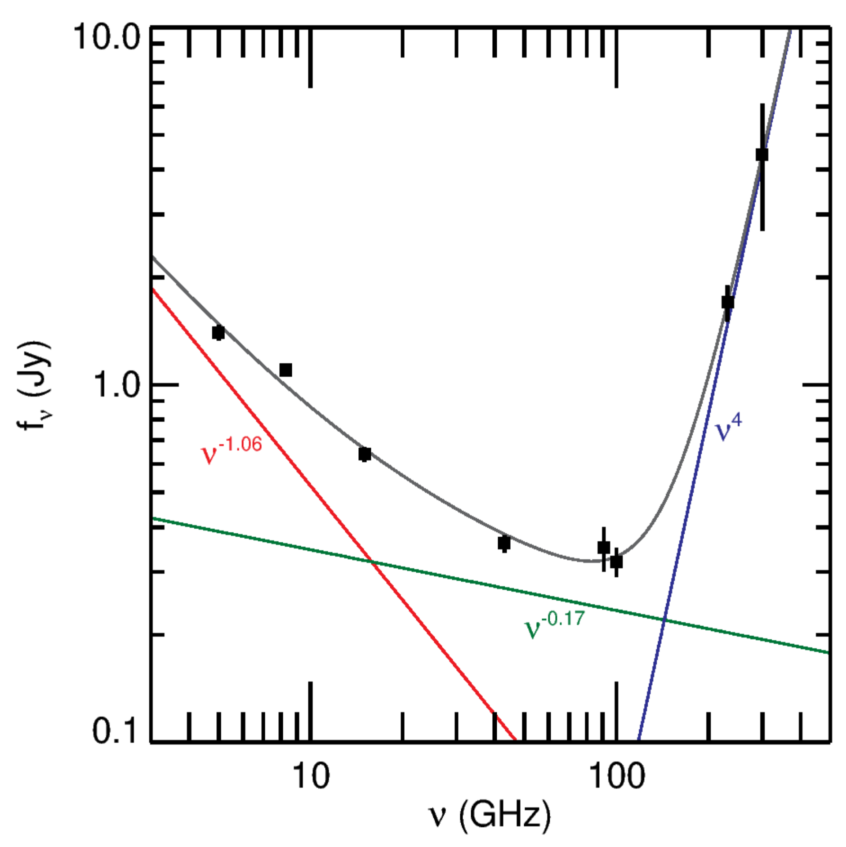




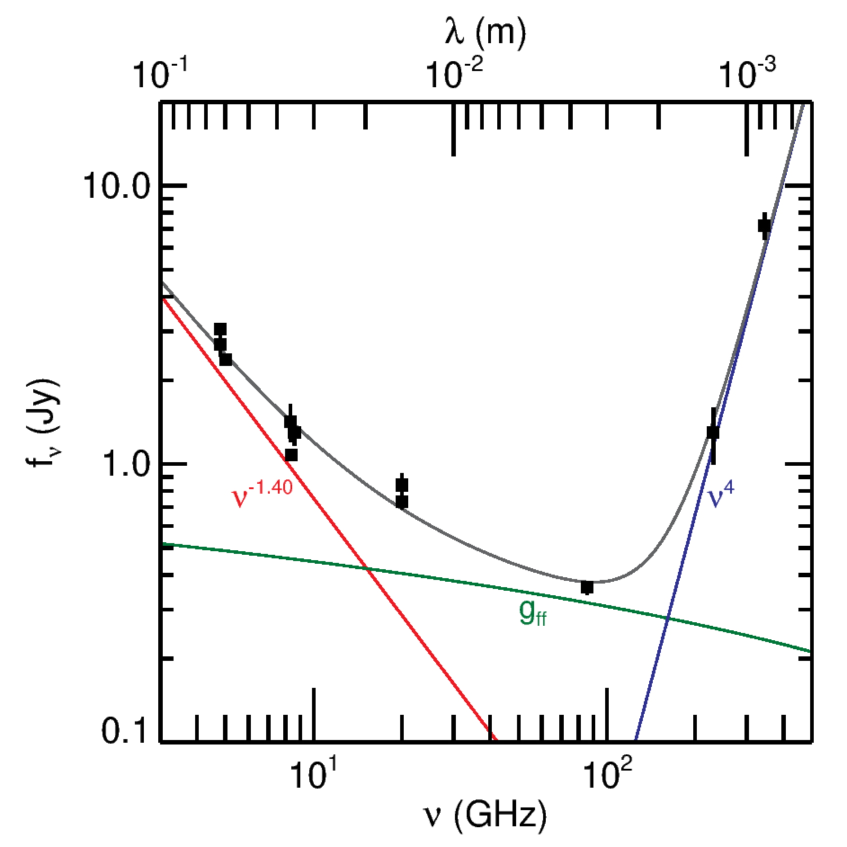
M82
(Condon, 1992, ARA&A, 30, 575)



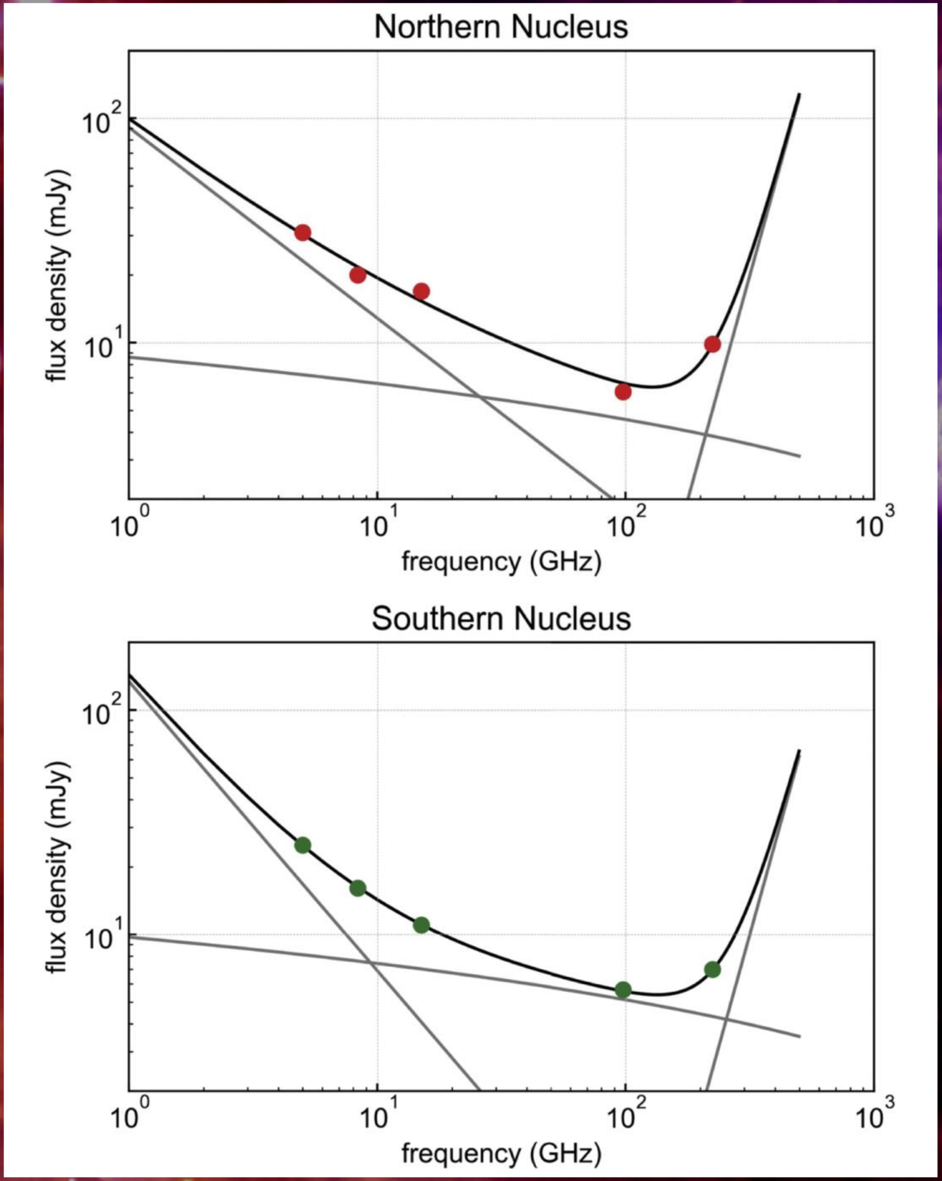
(Peel et al., 2011, MNRAS, 410, 2690)



NGC 253 central starburst
(Bendo et al., 2015, MNRAS, 450, L80)



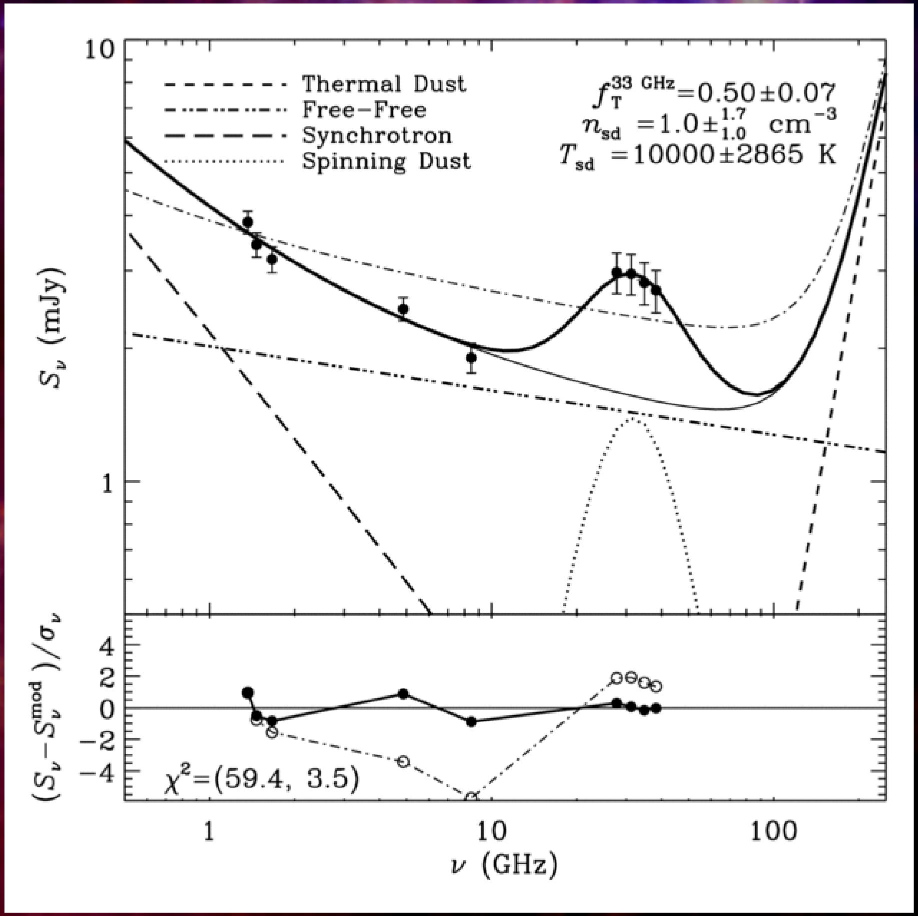
NGC 4945 central starburst
(Bendo et al., 2016, MNRAS, 463, 252)



NGC 3256
(Michiyama et al., 2020, ApJ, 895, 85)

Other sources of emission can appear in the millimeter /submillimeter bands:

- Anomalous microwave emission (from spinning dust)
- Submillimeter excess emission
- Optically-thick dust emission



Extranuclear region in NGC 6946
(Murphy et al., 2010, ApJ, 709, L108)

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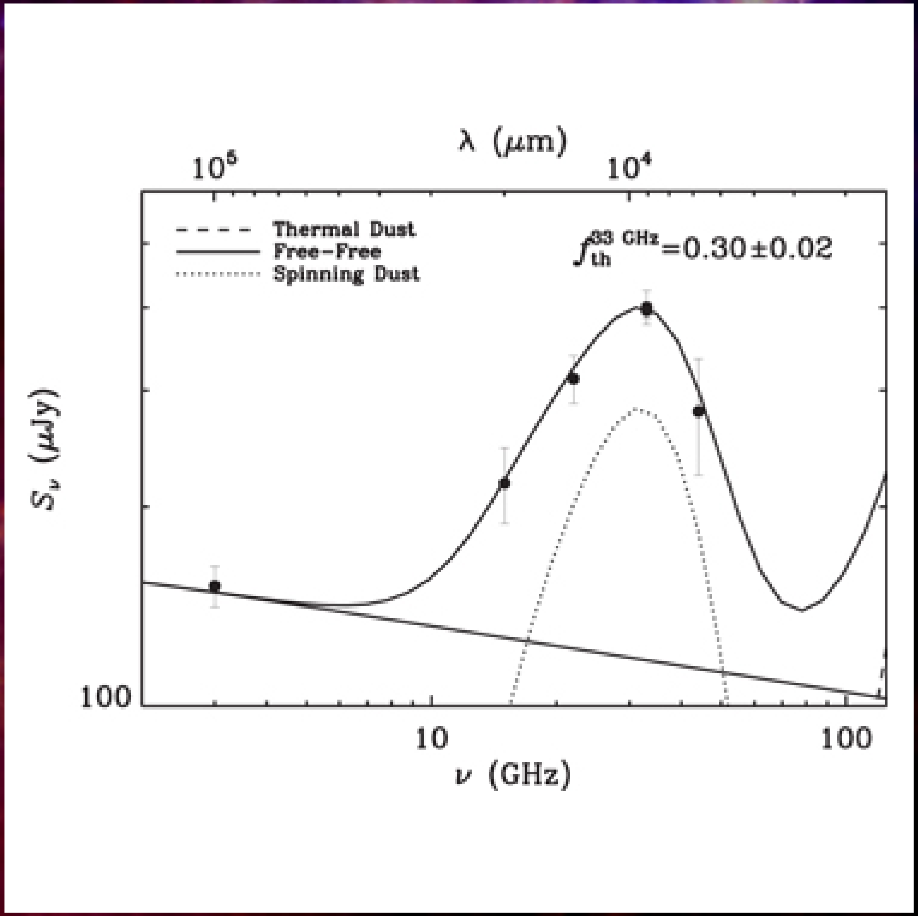

Extranuclear region in NGC 4725
(Murphy et al., 2018, ApJ, 862, 20)

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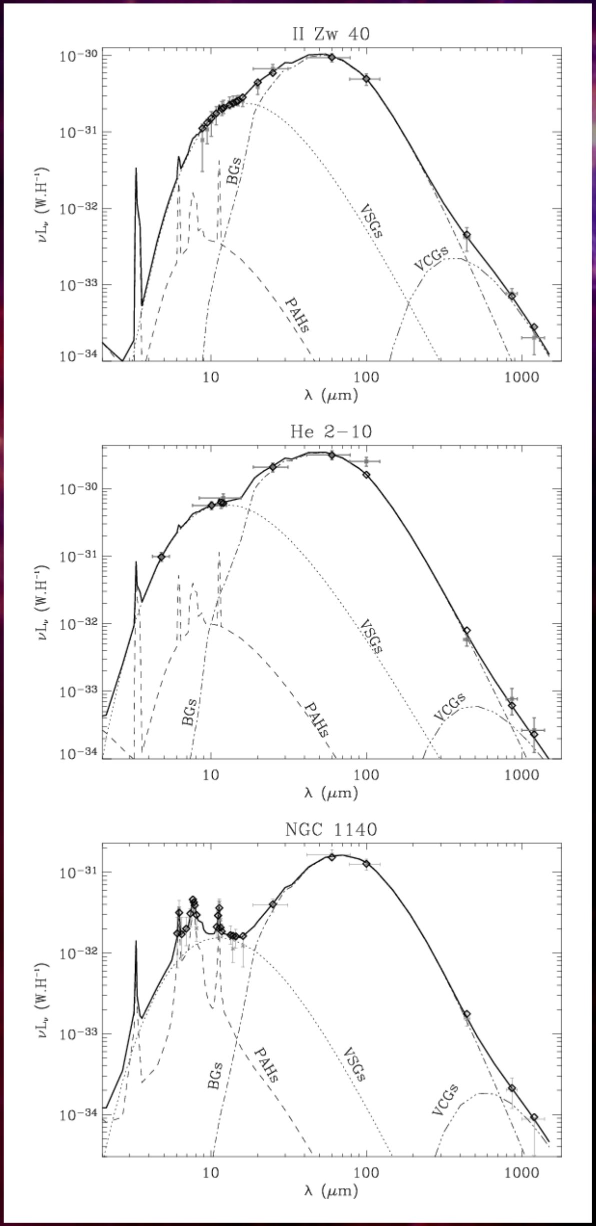

(Galliano et al., 2005, A&A, 434, 867)

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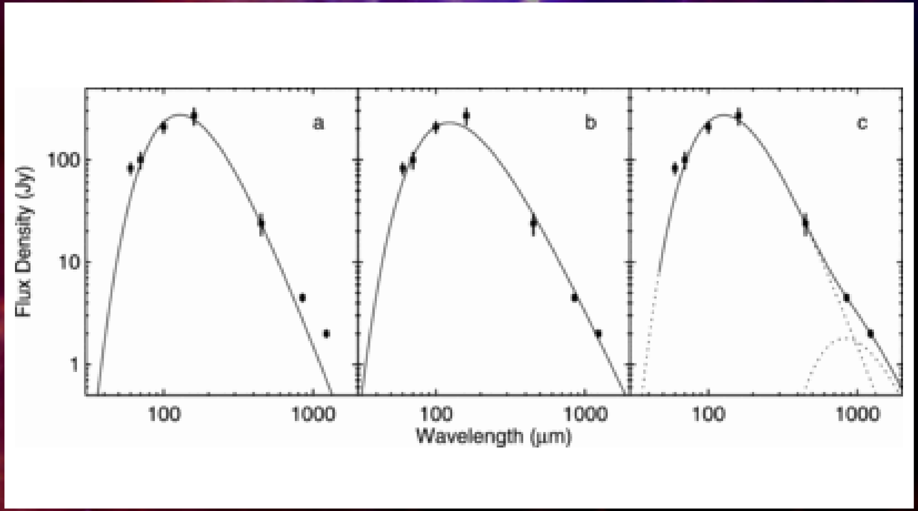

NGC 4631
(Bendo et al., 2006, ApJ, 652, 283)

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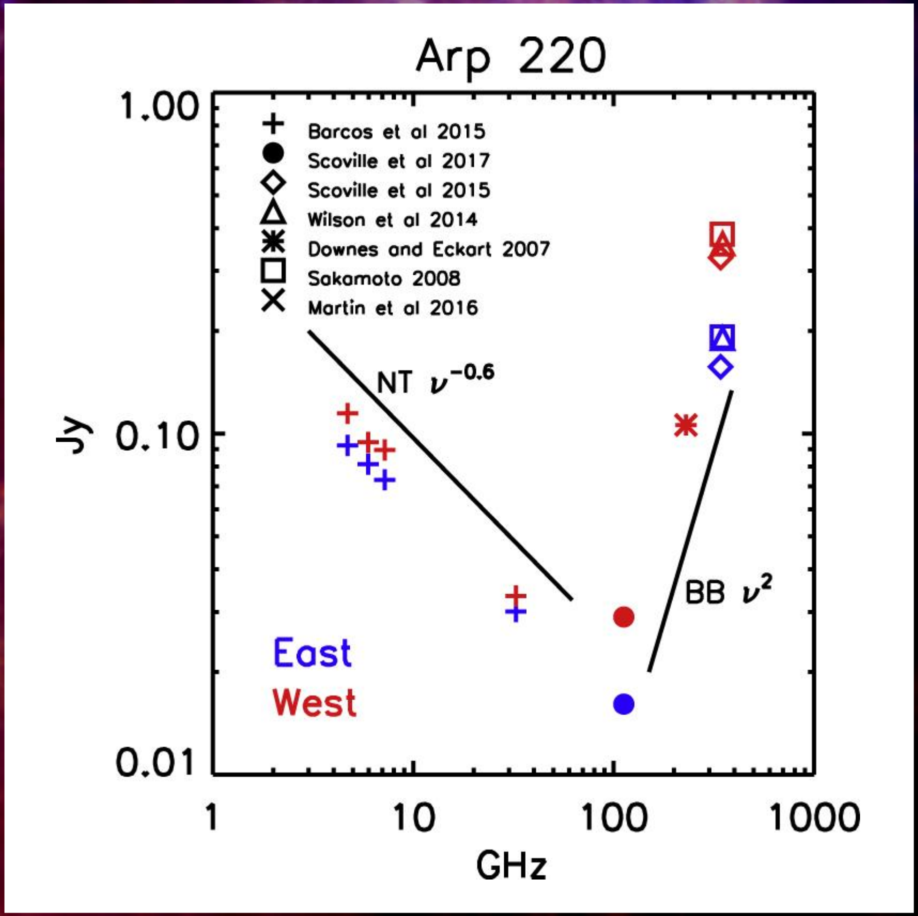
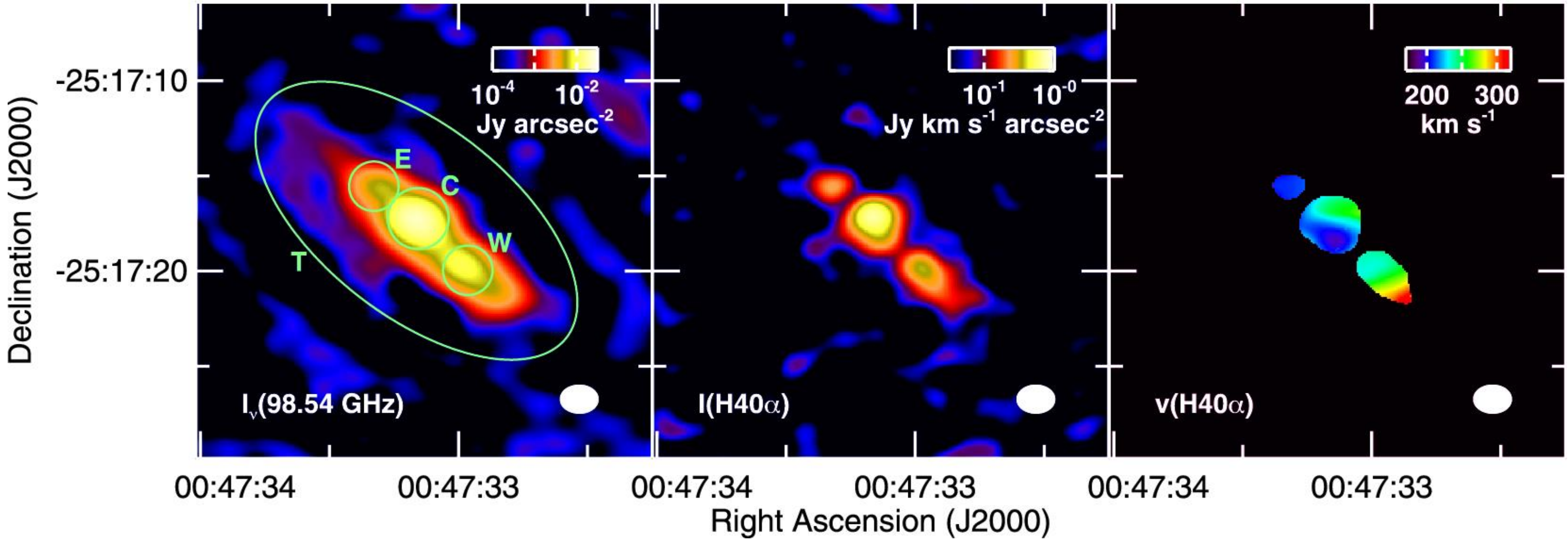


(Scoville et al., 2017, ApJ, 836, 66)

Free-free emission (when it can be separated from other emission sources) can be a very good tracer of star formation.

Additionally, millimeter recombination line emission at the same frequencies can be used as an additional star formation tracer.

- Both directly trace photoionizing stars (unlike infrared or radio emission).
- Both are unaffected by dust extinction (unlike Hα or ultraviolet emission).



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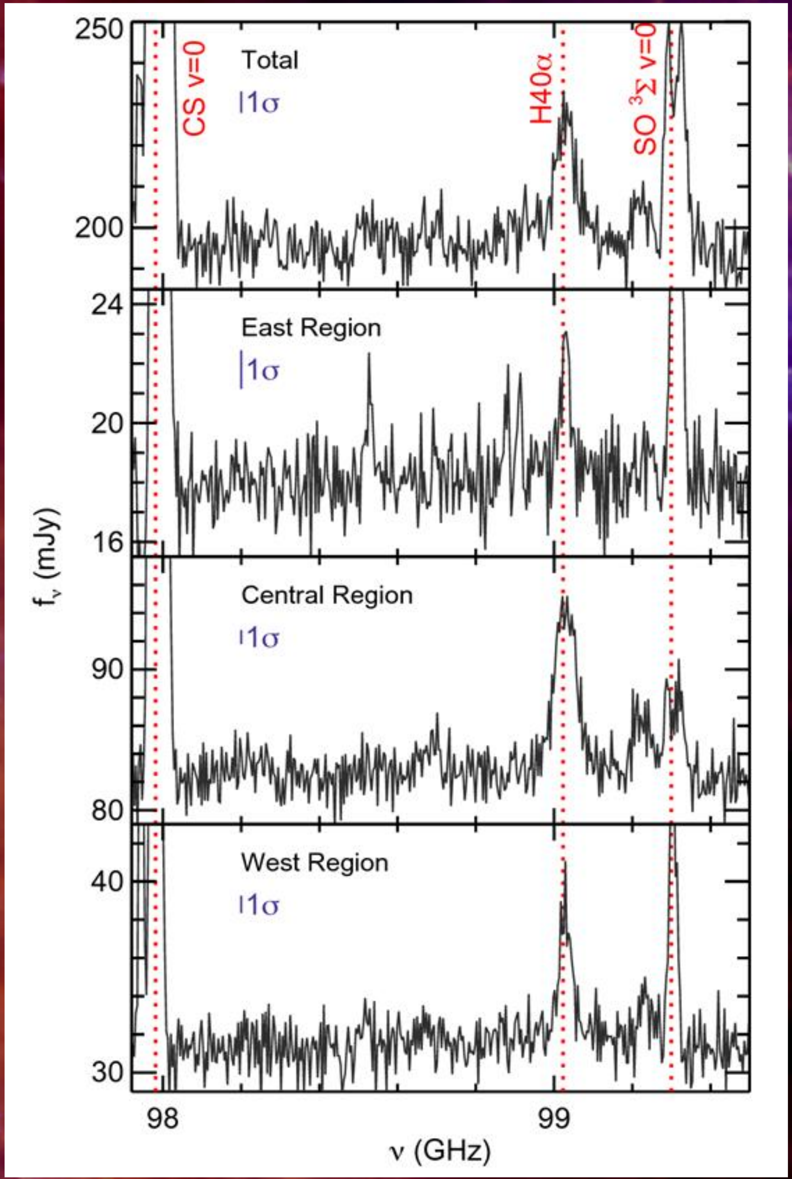

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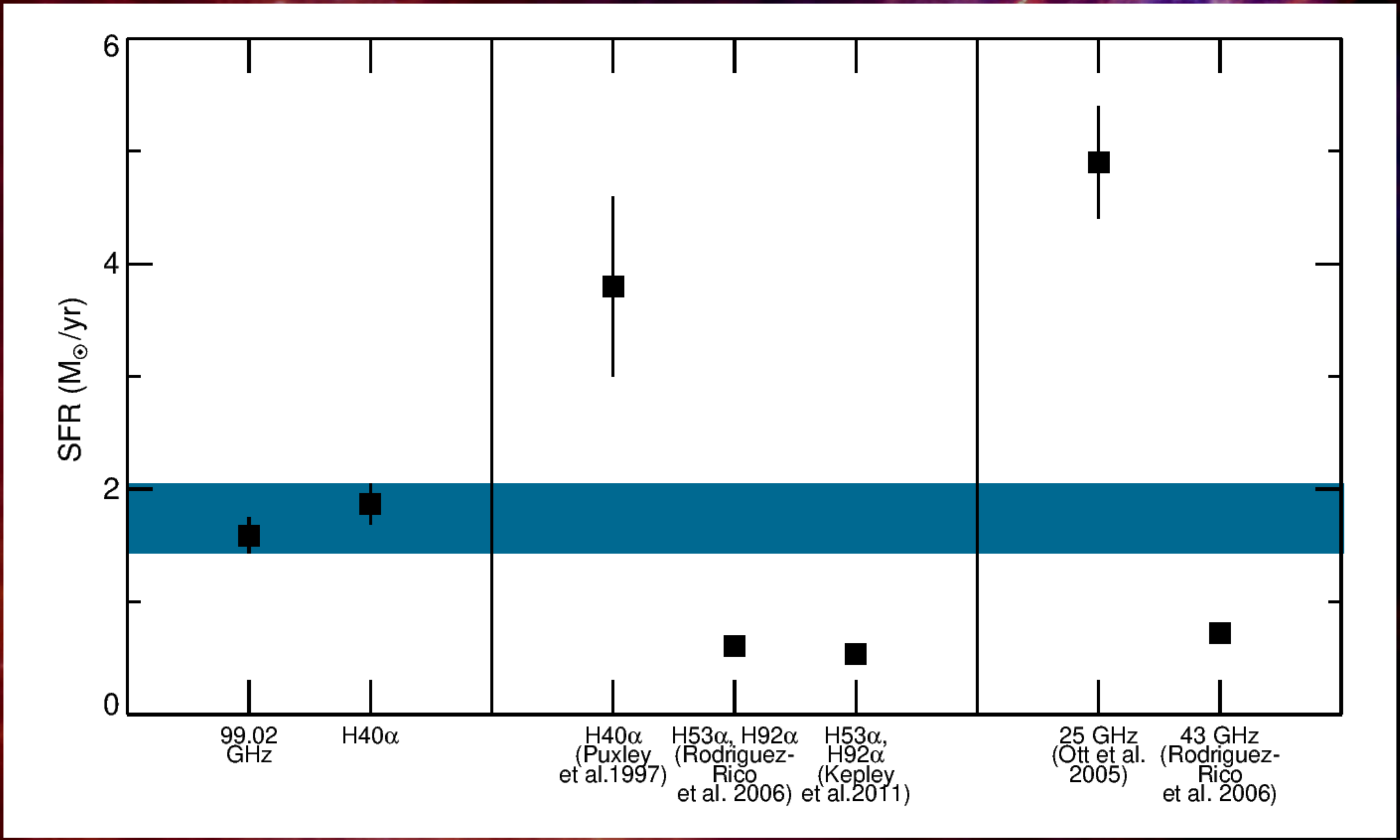

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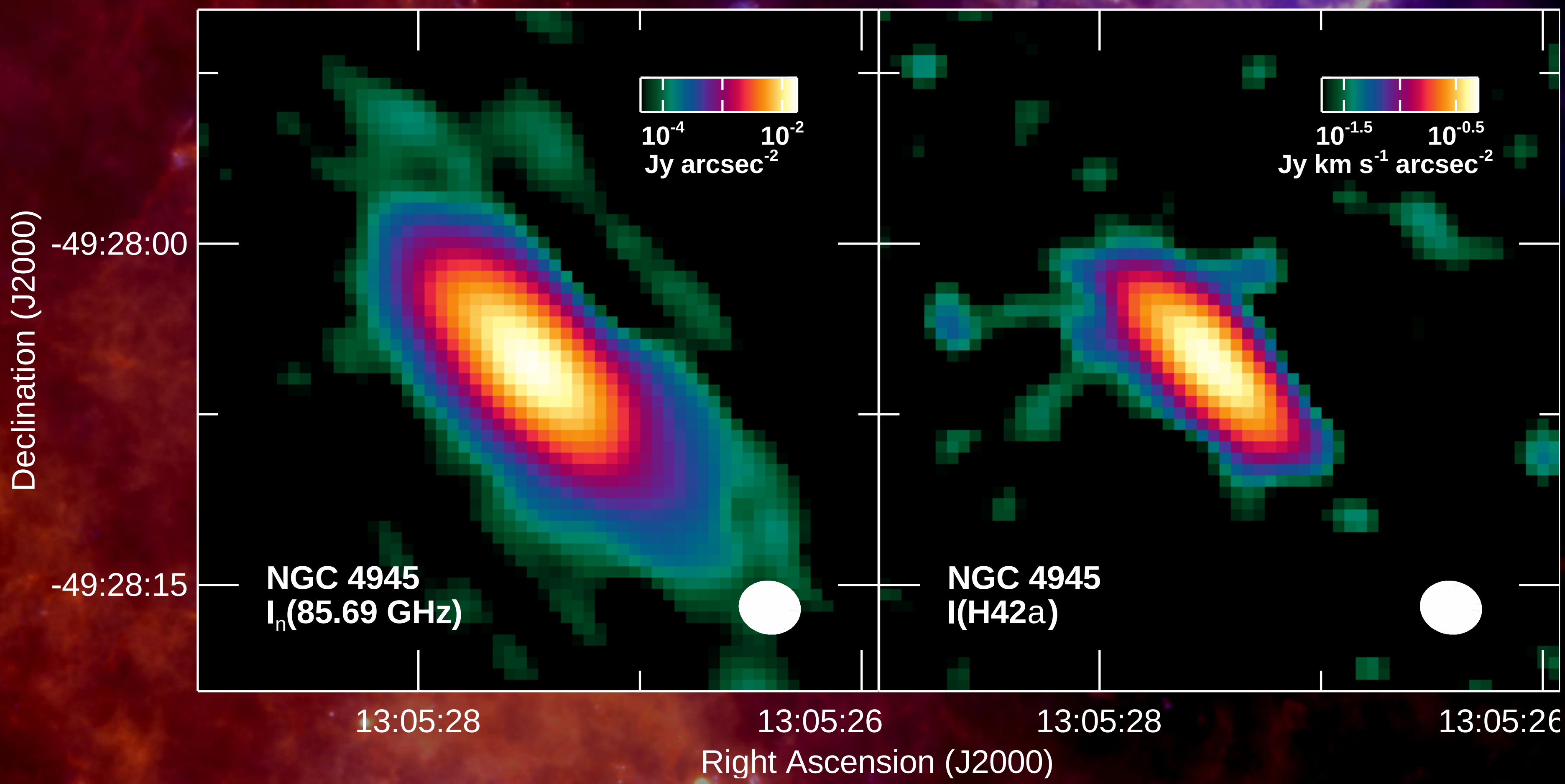

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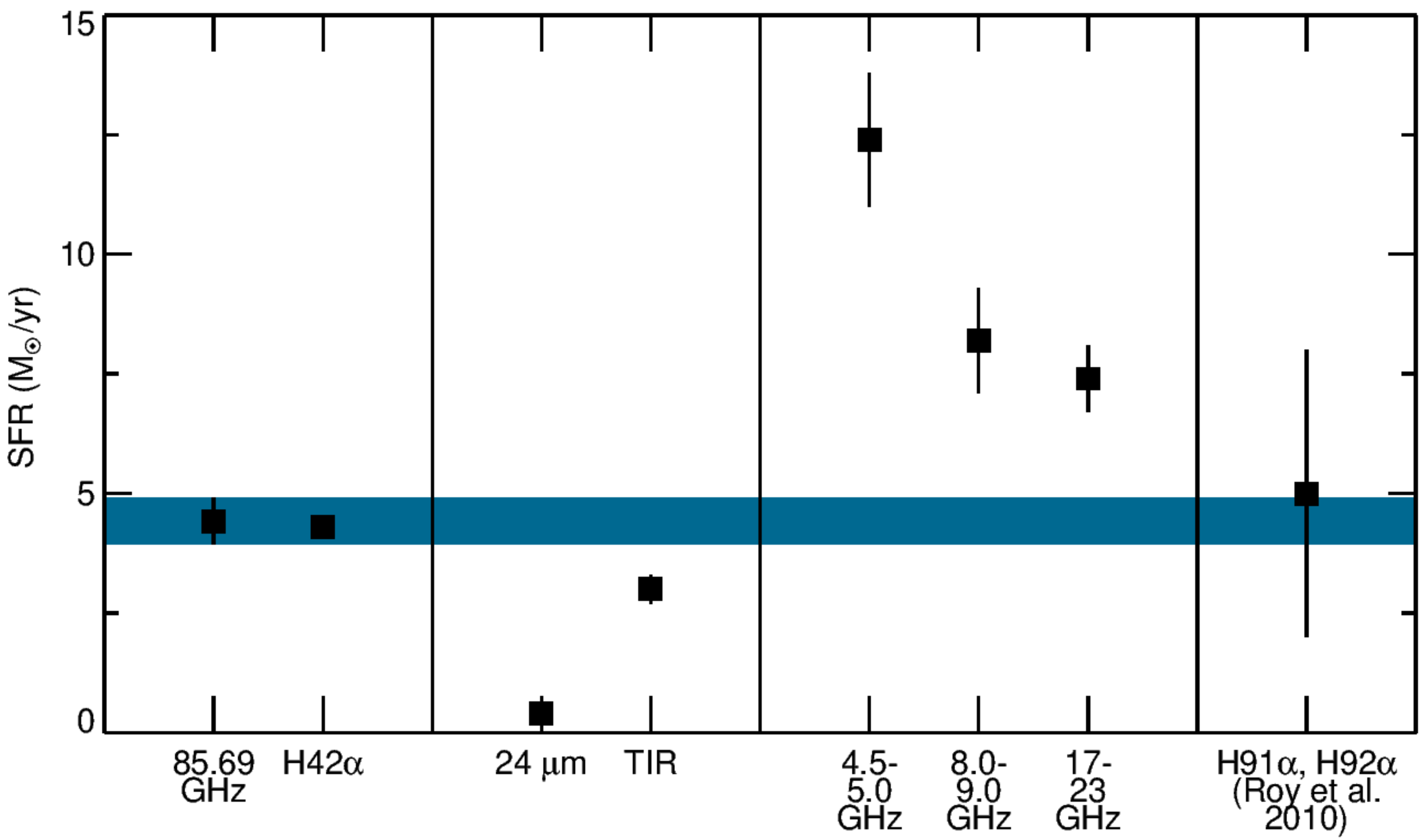

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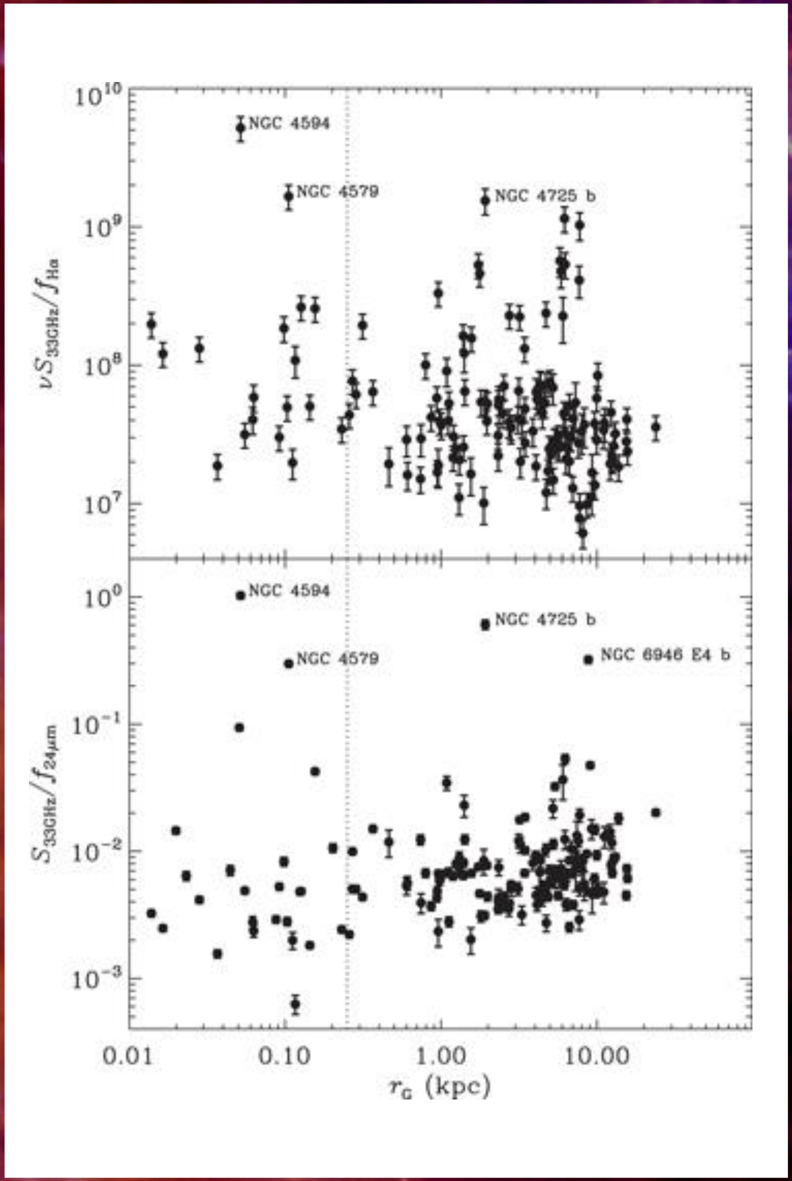
(Bendo et al., 2016, MNRAS, 463, 252)

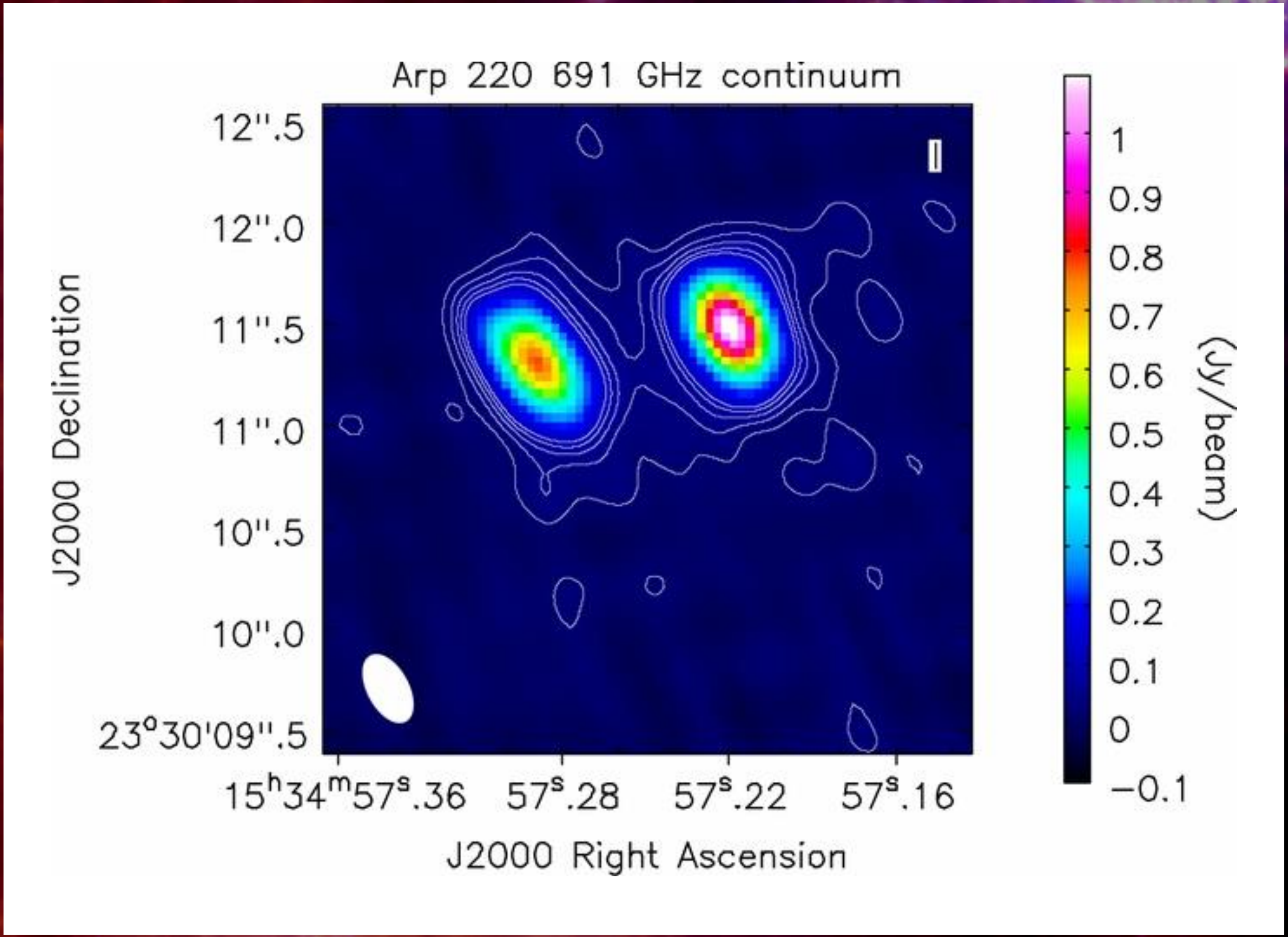


(Murphy et al., 2017, 234, 24)

Millimetron's extragalactic science is currently oriented towards high-redshift sources or VLBI observations of nearby AGN.

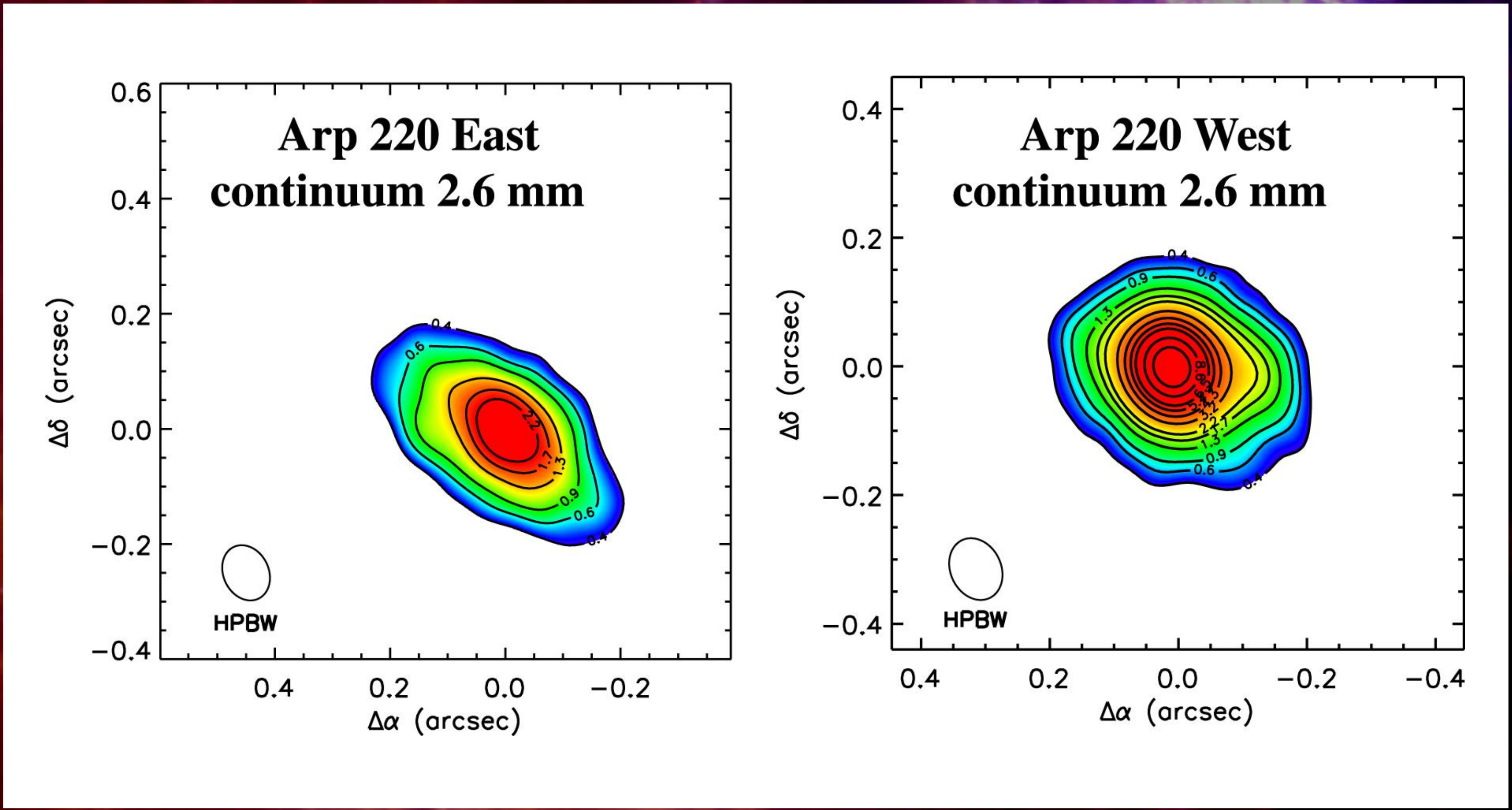
However, WG3 will be looking very specifically at Arp 220.

Arp 220 is the closest ULIRG to Earth and is treated like the archetype of the class.



(Wilson et al., 2014, ApJ, 789, L36)

The galaxy contains two nuclei. The west nucleus contains an AGN. Additionally, the dust is optically thick up to 2.6 mm (115 GHz).



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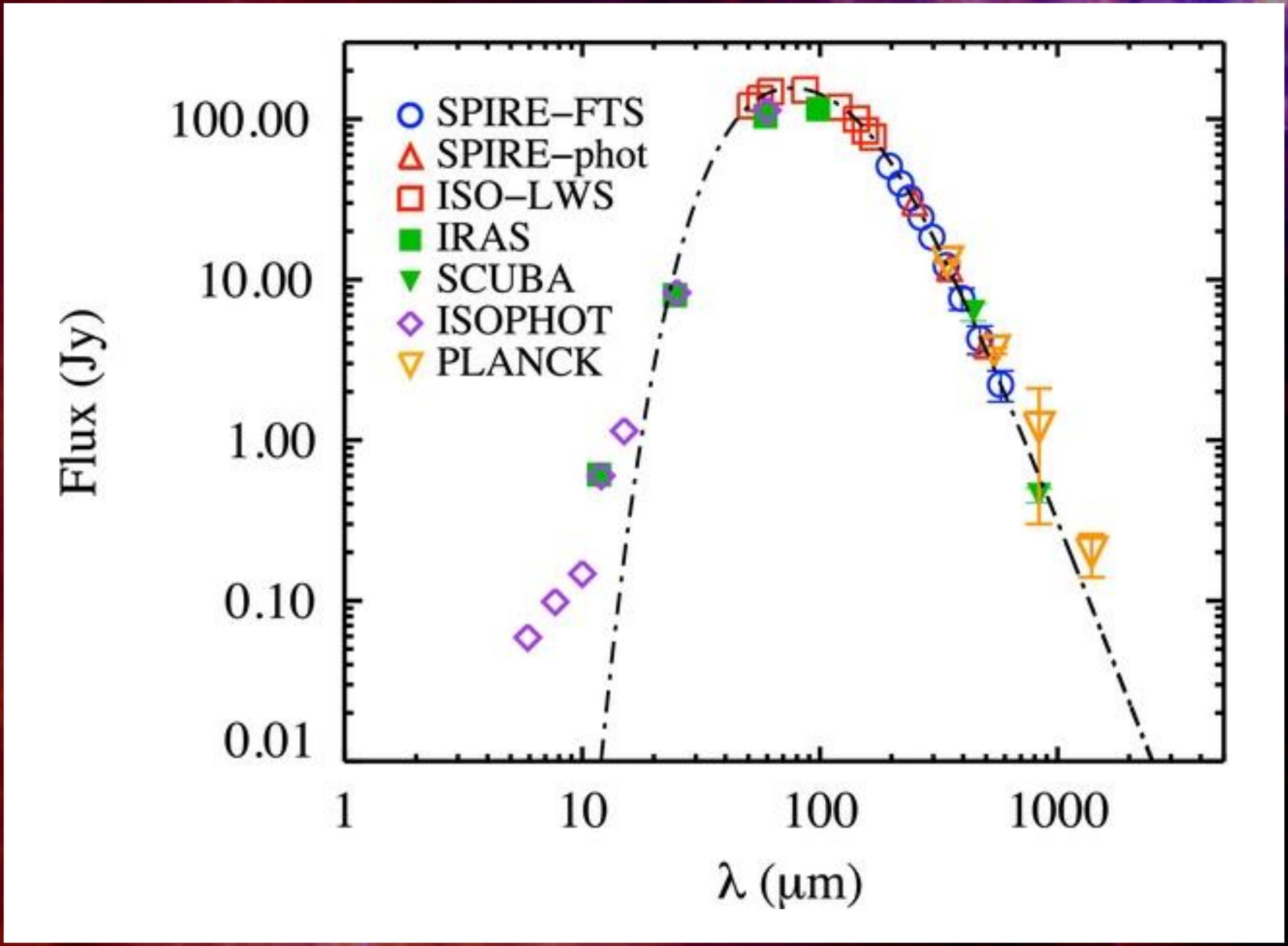

(Rangwala et al., 2011, ApJ, 743, 94)

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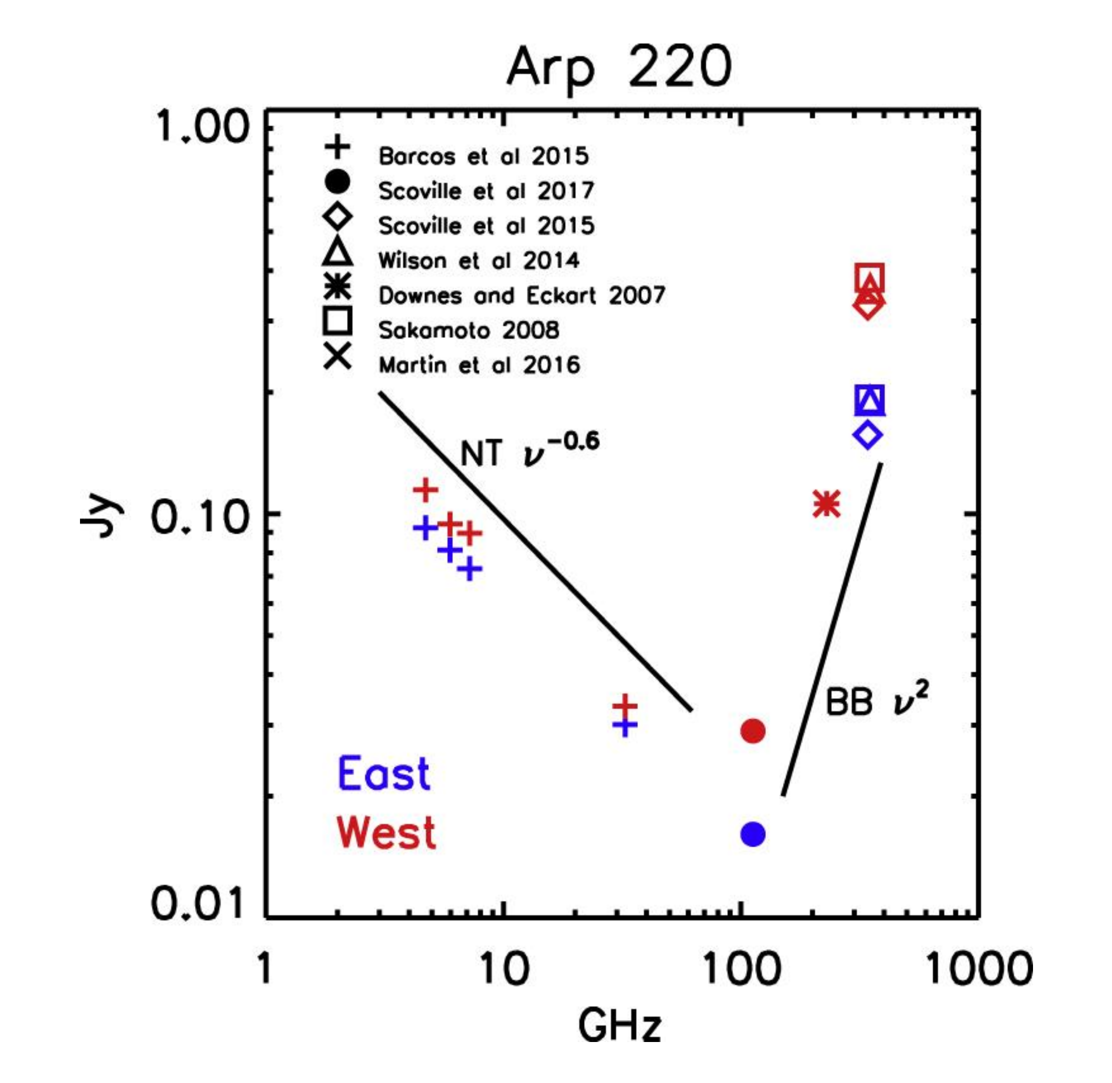
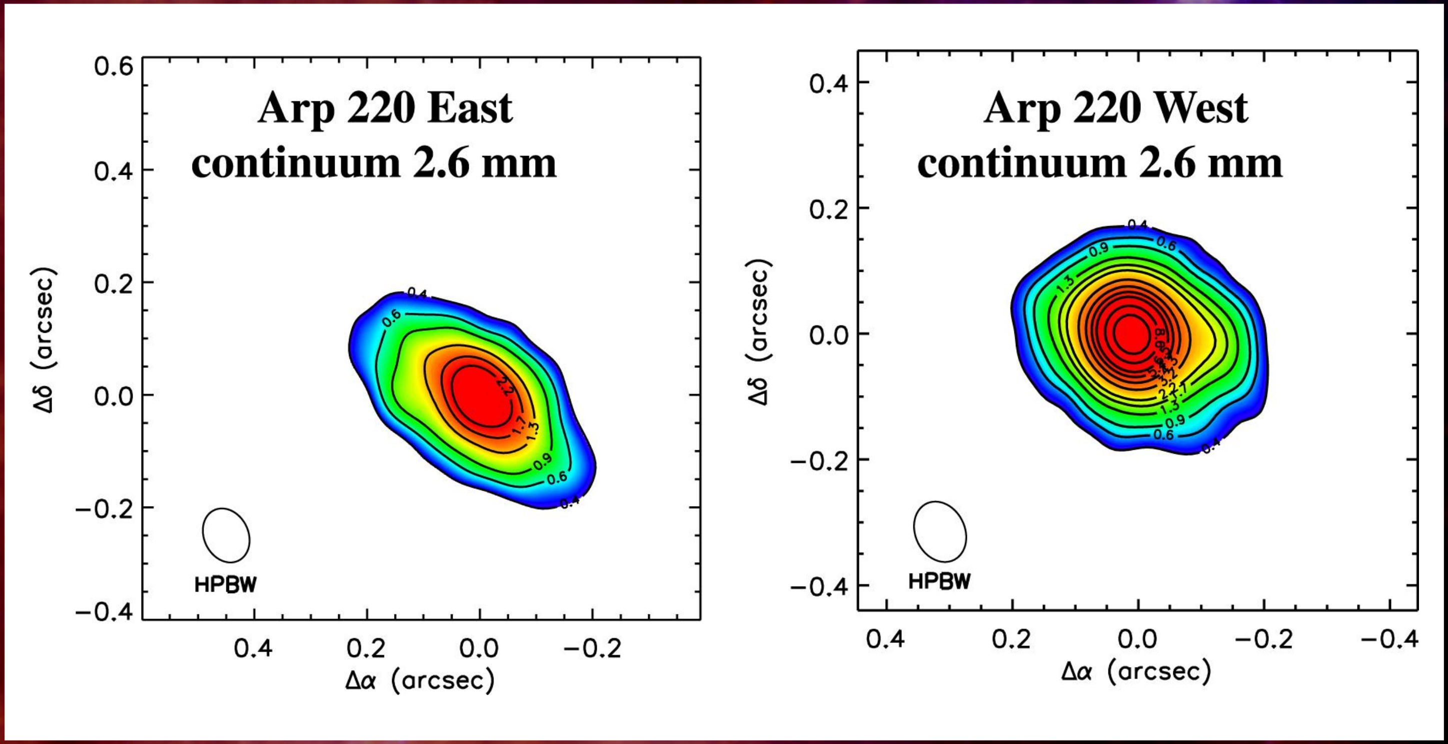


(Scoville et al., 2017, ApJ, 836, 66)

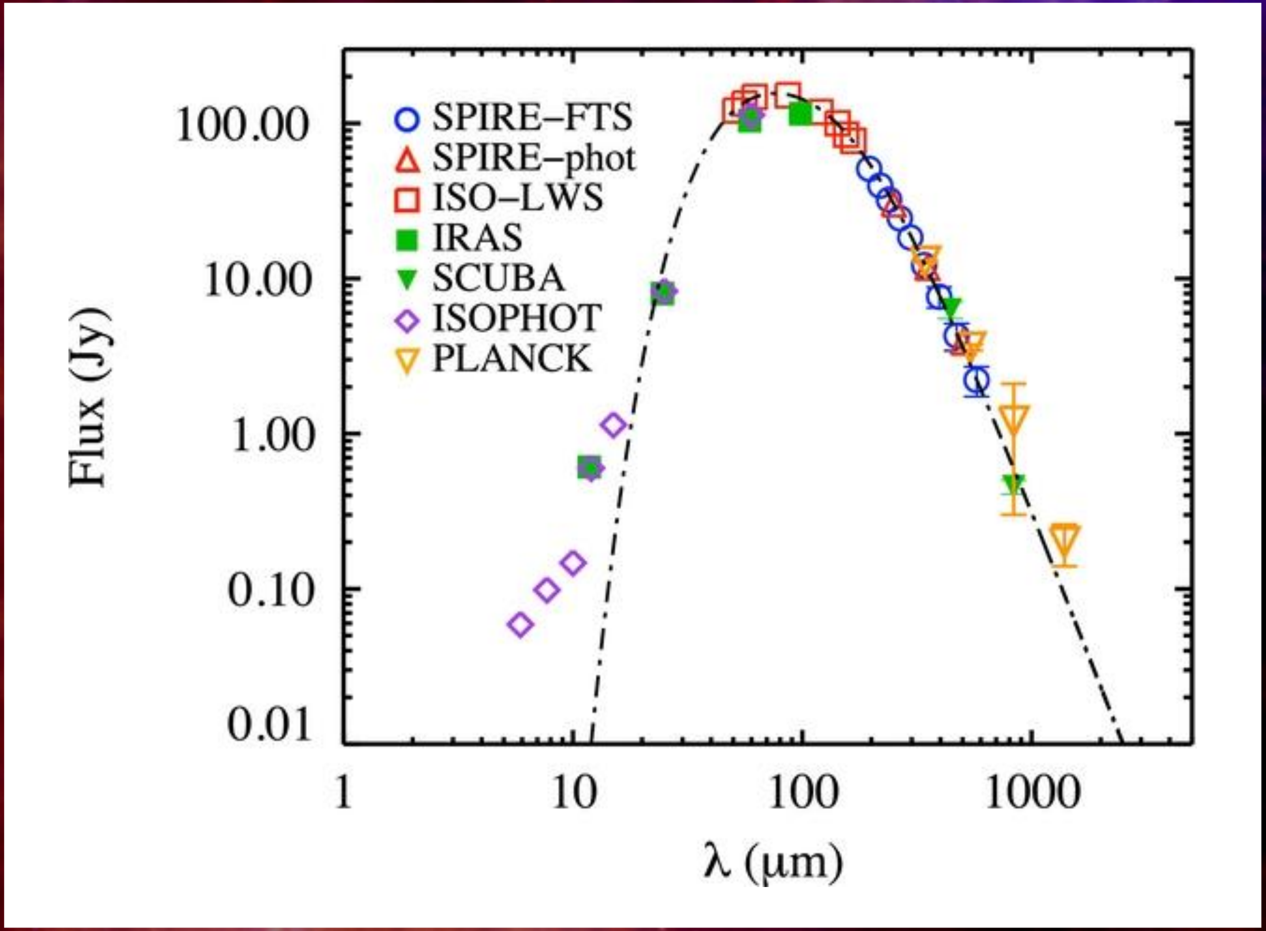
The ALMA images resolved structures on scales of ~40 pc, revealing the overall structures of the dust discs.

VLBI observations between Millimetron and ALMA could resolve structures of 20-200 AU, revealing the structures near the event horizons of any potential black holes.



(Scoville et al., 2017, ApJ, 836, 66)

Additionally, Millimetron by itself can be used to compile spectra of Arp 220 from 100 µm to 1000 µm. The exact shape of this spectrum can be used to construct a detailed model of the radial structure of the dust densities and temperatures.



(Rangwala et al., 2011, ApJ, 743, 94)

The spectral energy distributions of nearby galaxies remain poorly characterized in the millimeter/submillimeter regime.

However, this part of the electromagnetic spectrum can be used to discover new and exotic phenomena and to measure highly accurate star formation rates.

Millimetron in particular will be very important for this work, especially in Arp 220.