Probing cosmic-ray driven winds with deep radio observations

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Reasons to care about cosmic rays:

(a very incomplete list)

They are a significant and important component of the energy density in galaxies.

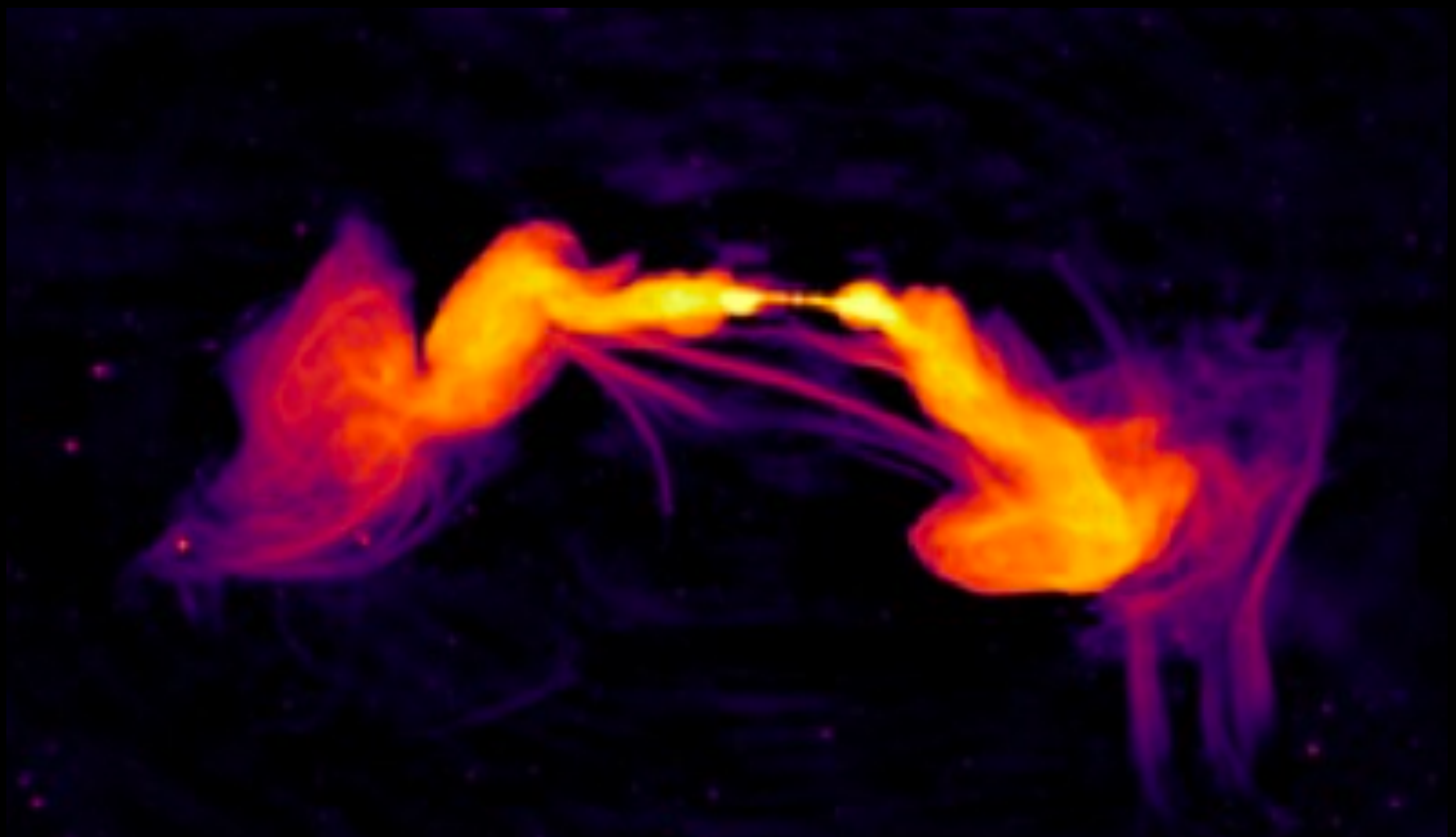
Essential for understanding the FIR/radio correlation and how radio emission ties to star formation.

“The impact of cosmic rays is one of the largest uncertainties in understanding feedback in galaxy formation.” -*Astro2020 Decadal Survey*

Cosmic ray feedback is especially important in normal galaxies.

Image credit: Hubble and Chandra Composite image

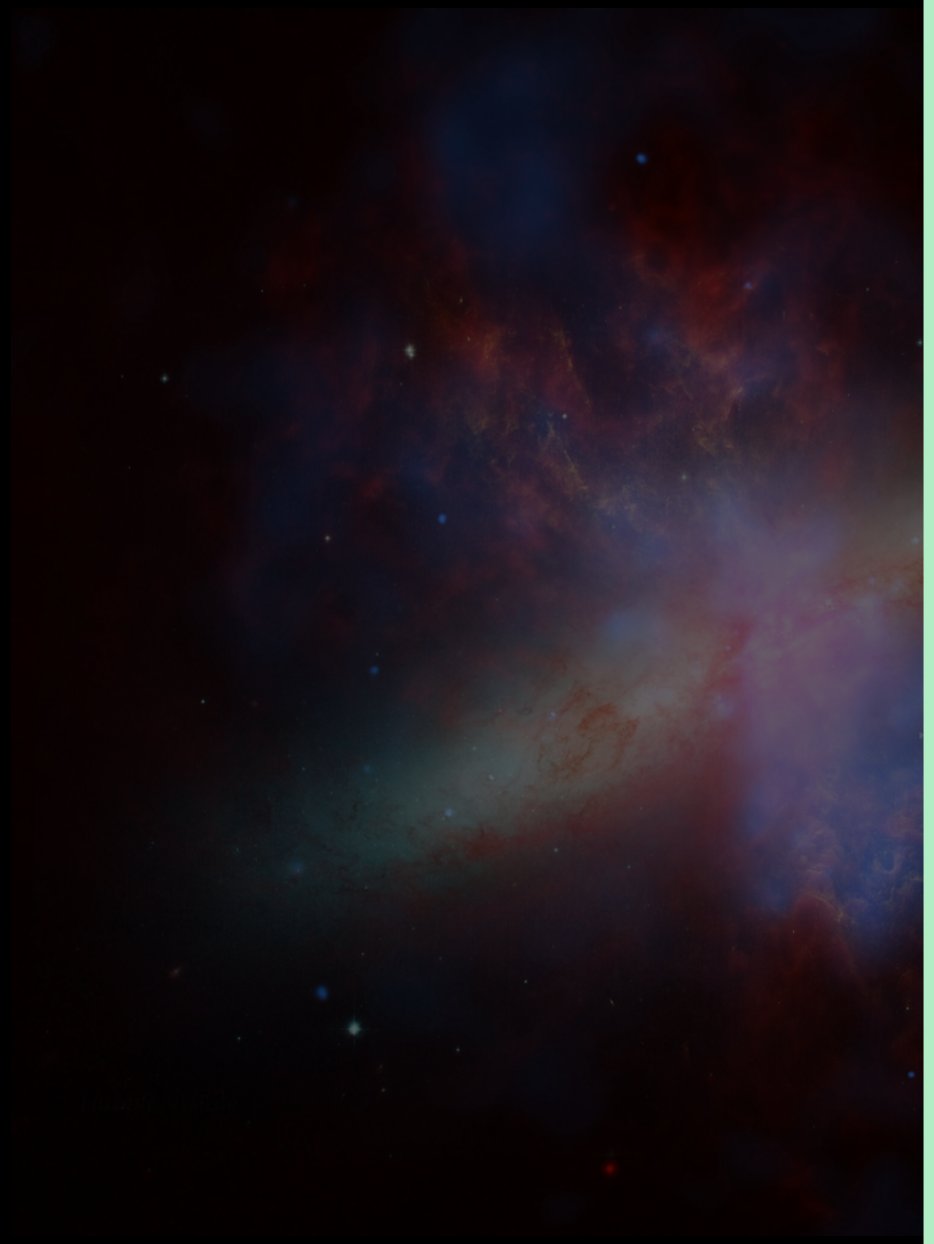
The dense ISM of M82 results in strong hadronic losses, yielding dynamically weak CR pressures (Buckman+2020).

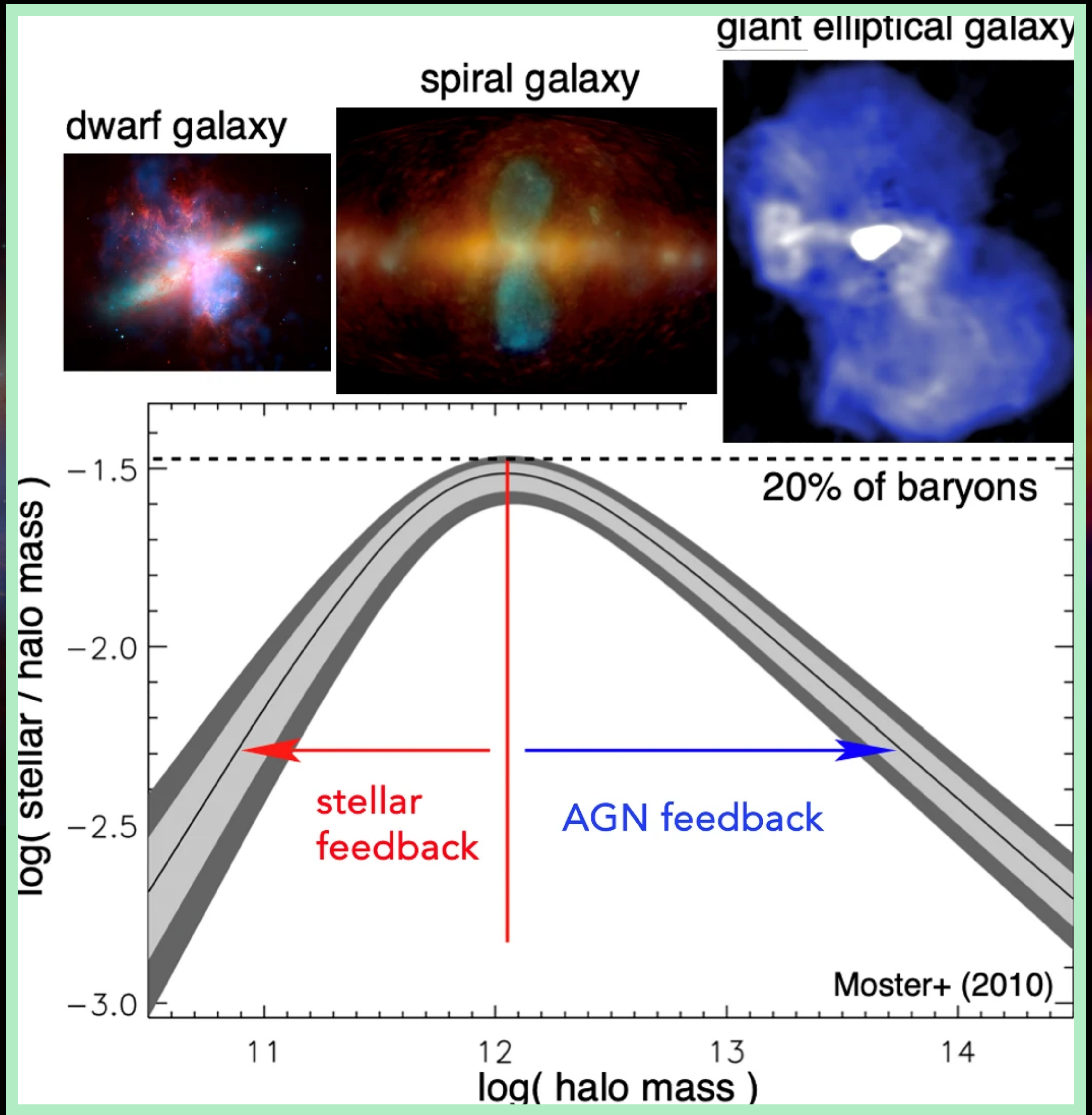


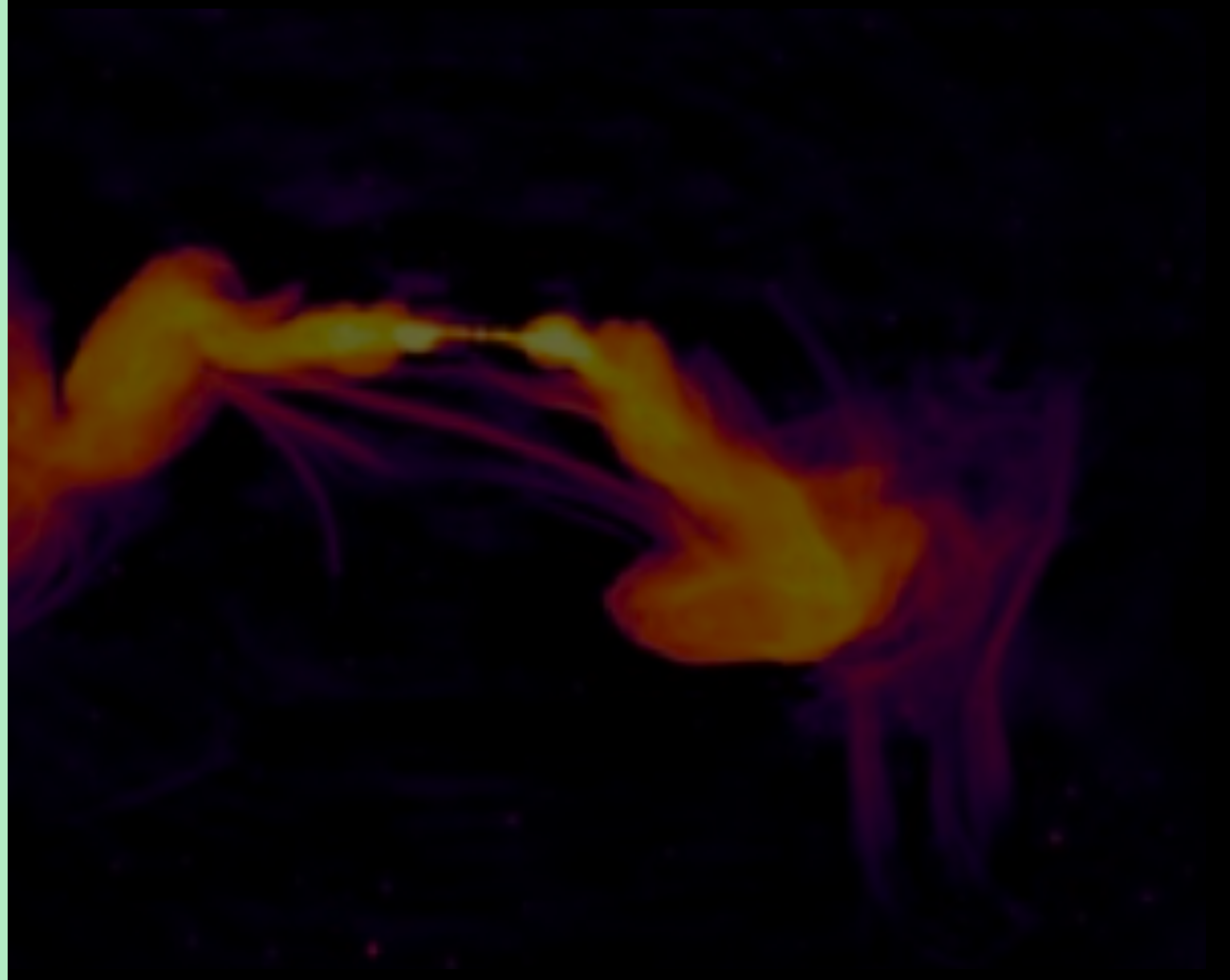
ESO137-006. Credit: Rhodes University, INAF and SARAO

Supermassive black holes are excellent at expelling/heating up.

Cosmic ray feedback is especially important in normal galaxies.



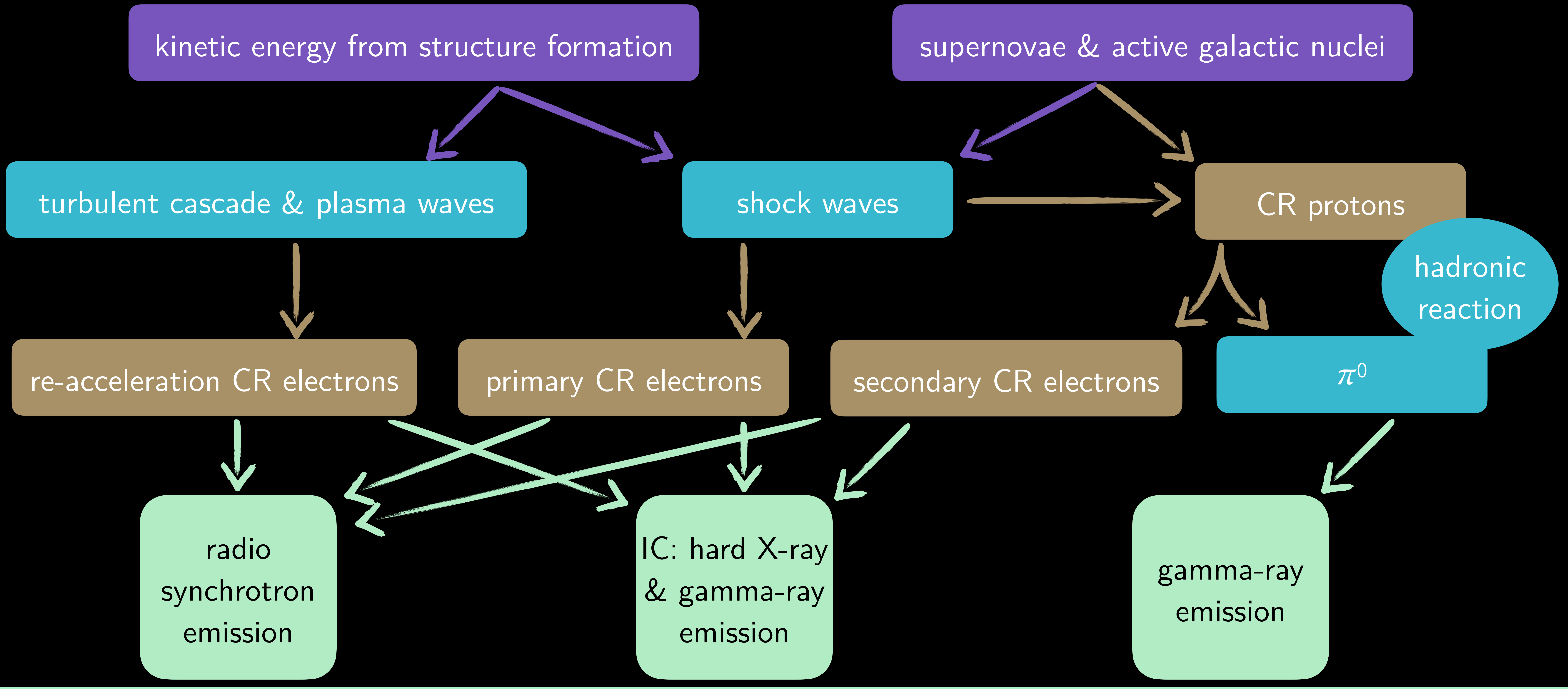




Ruszkowski & Pfrommer (2023)

Adapted from Ruszkowski & Pfrommer (2023), Pfrommer et al. (2008)

Radio observations are the most accessible probe of CRs.



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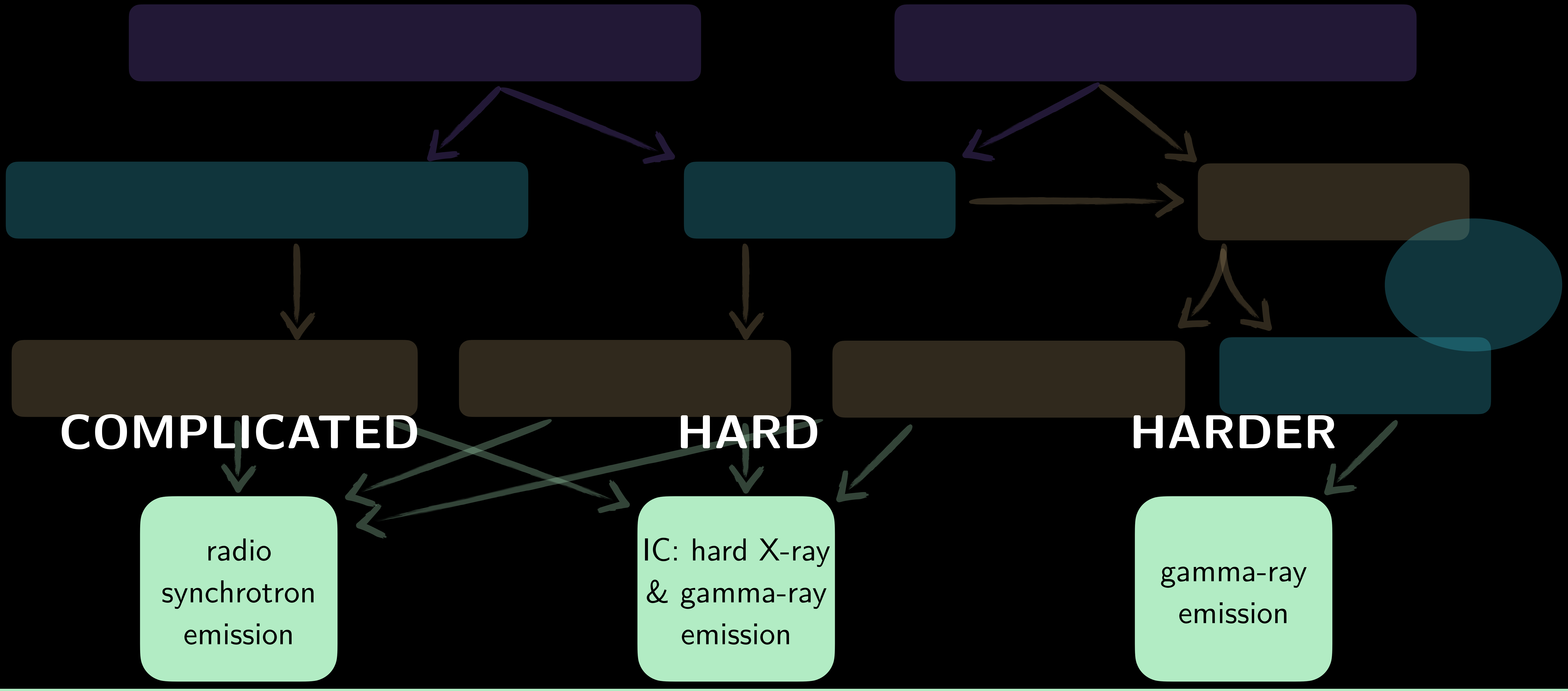
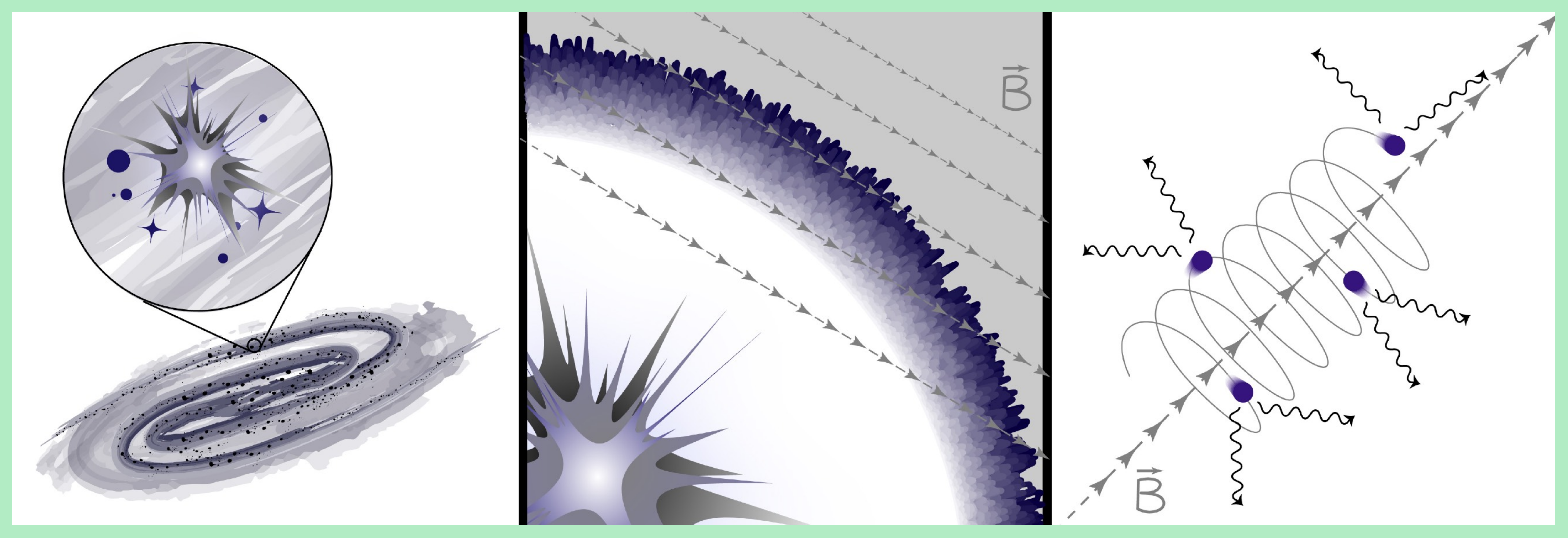


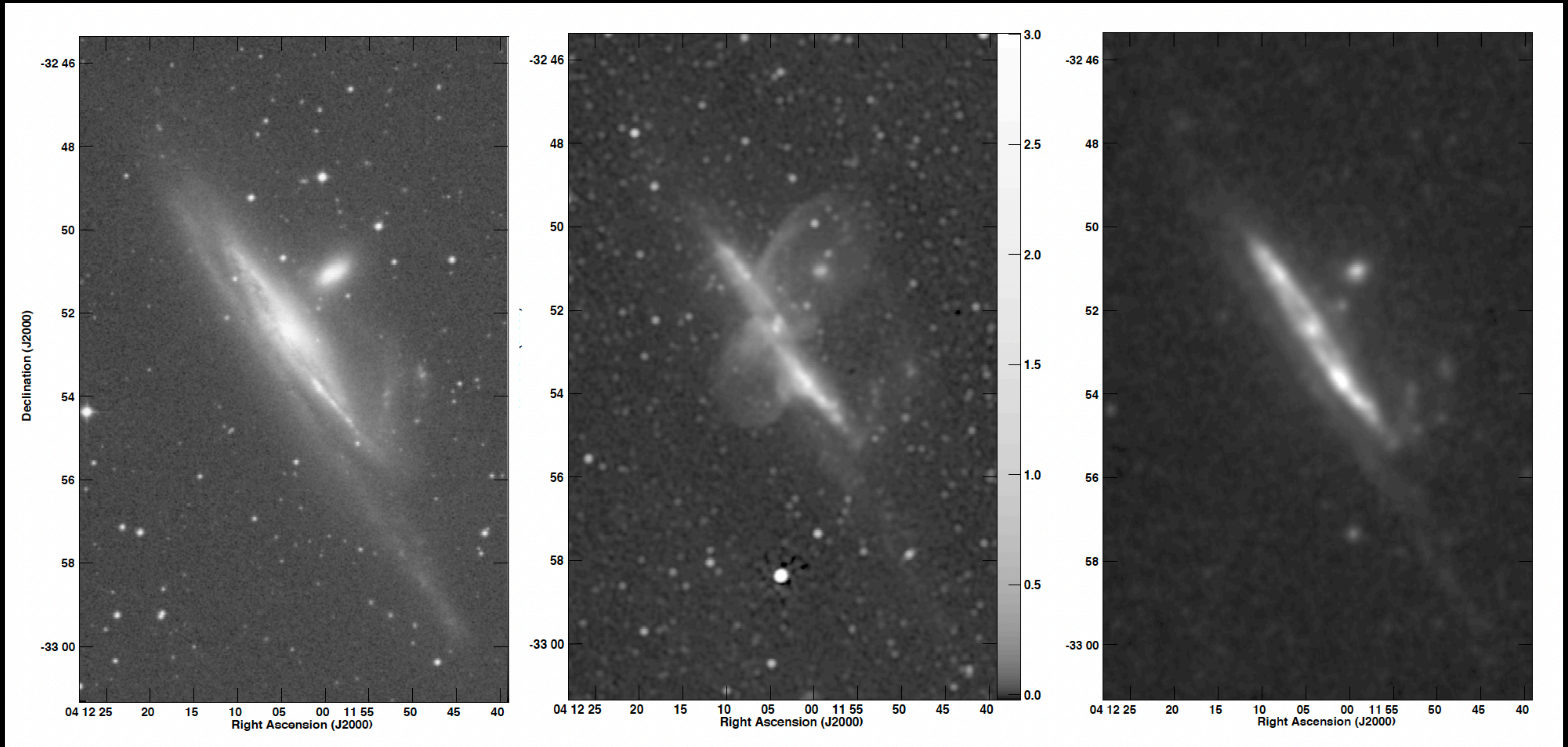
Radio emission is complicated and depends on both cosmic ray transport and magnetic fields.



The most effective way forward is for theorists and observers to tackle these problems together.

NGC 1532: an exciting surprise.

During a MeerKAT survey of southern IRAS Revised Bright Galaxy Survey (RBGS) sources (Condon+2020), we stumbled upon something unexpected.



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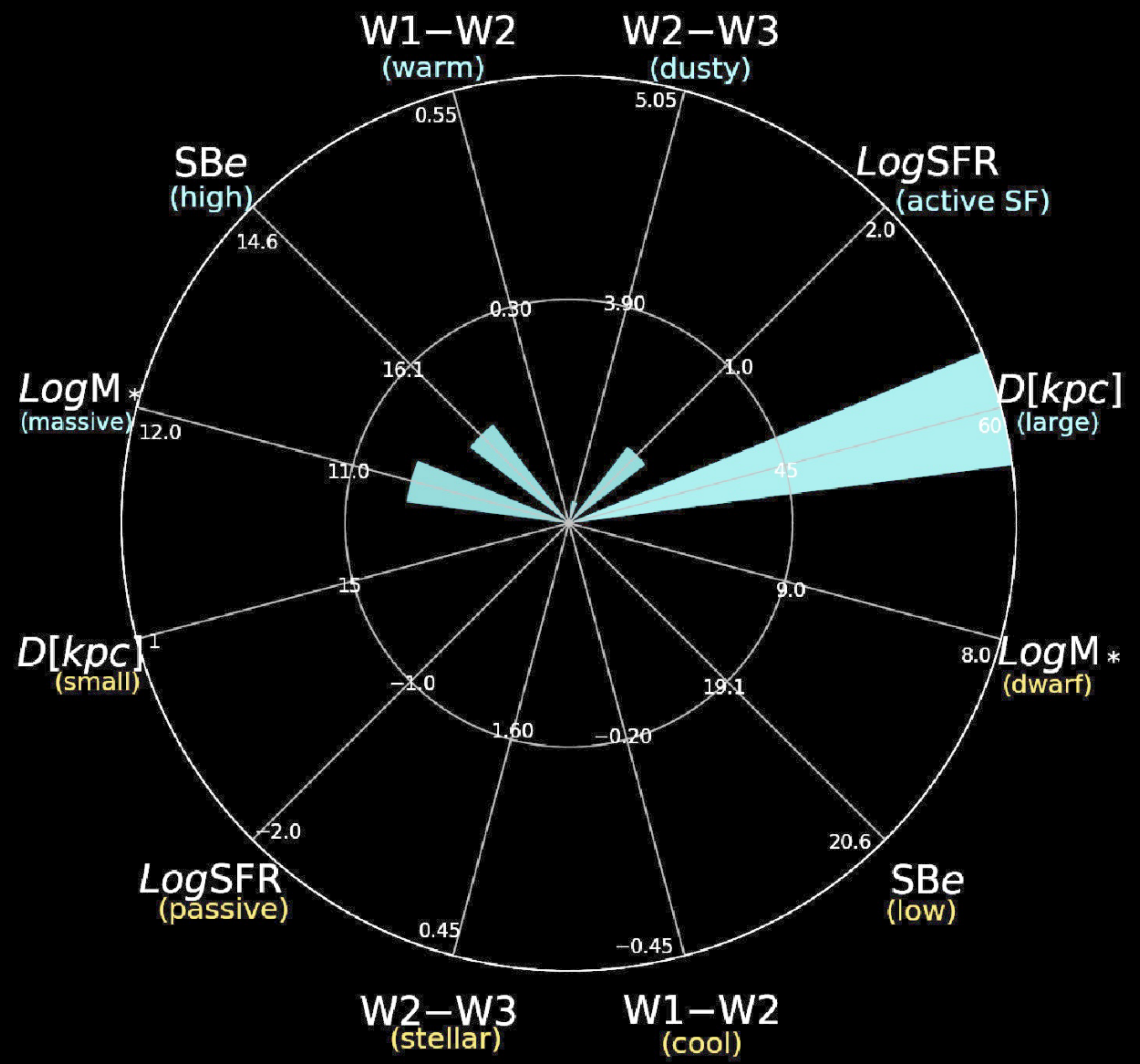
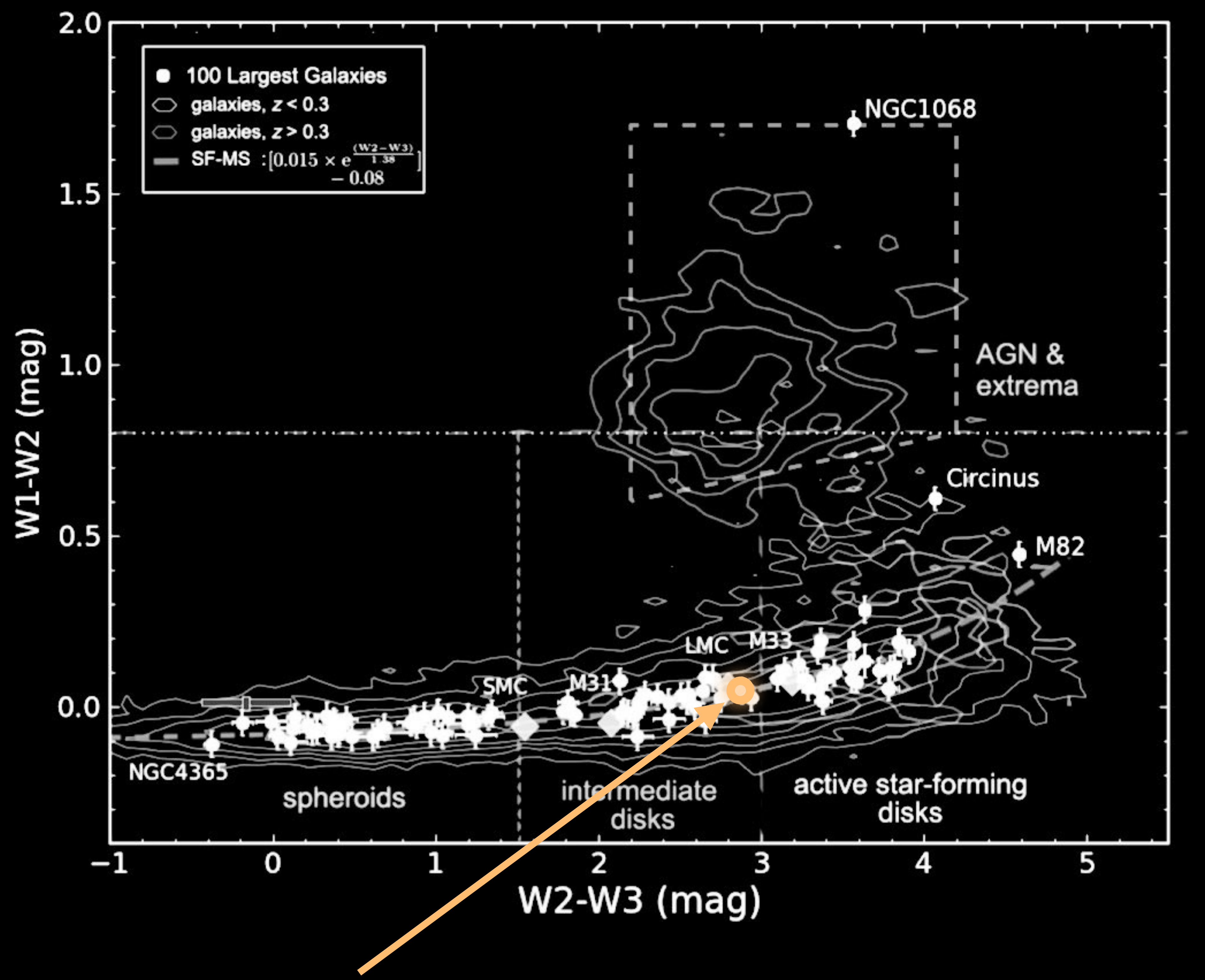
NGC 1532: a sweet spot for cosmic ray driven outflows.

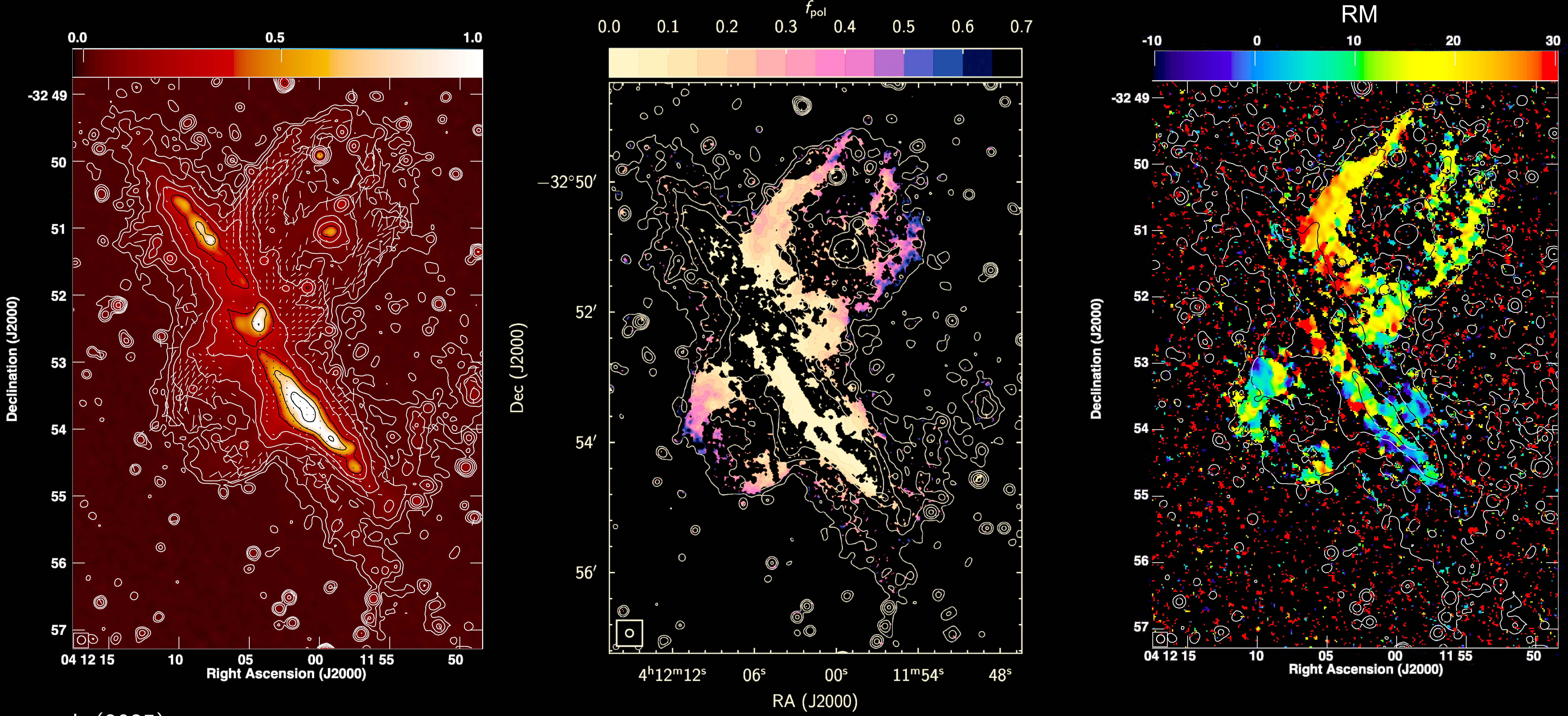




NGC 1532 lies directly on the "star-forming main sequence."

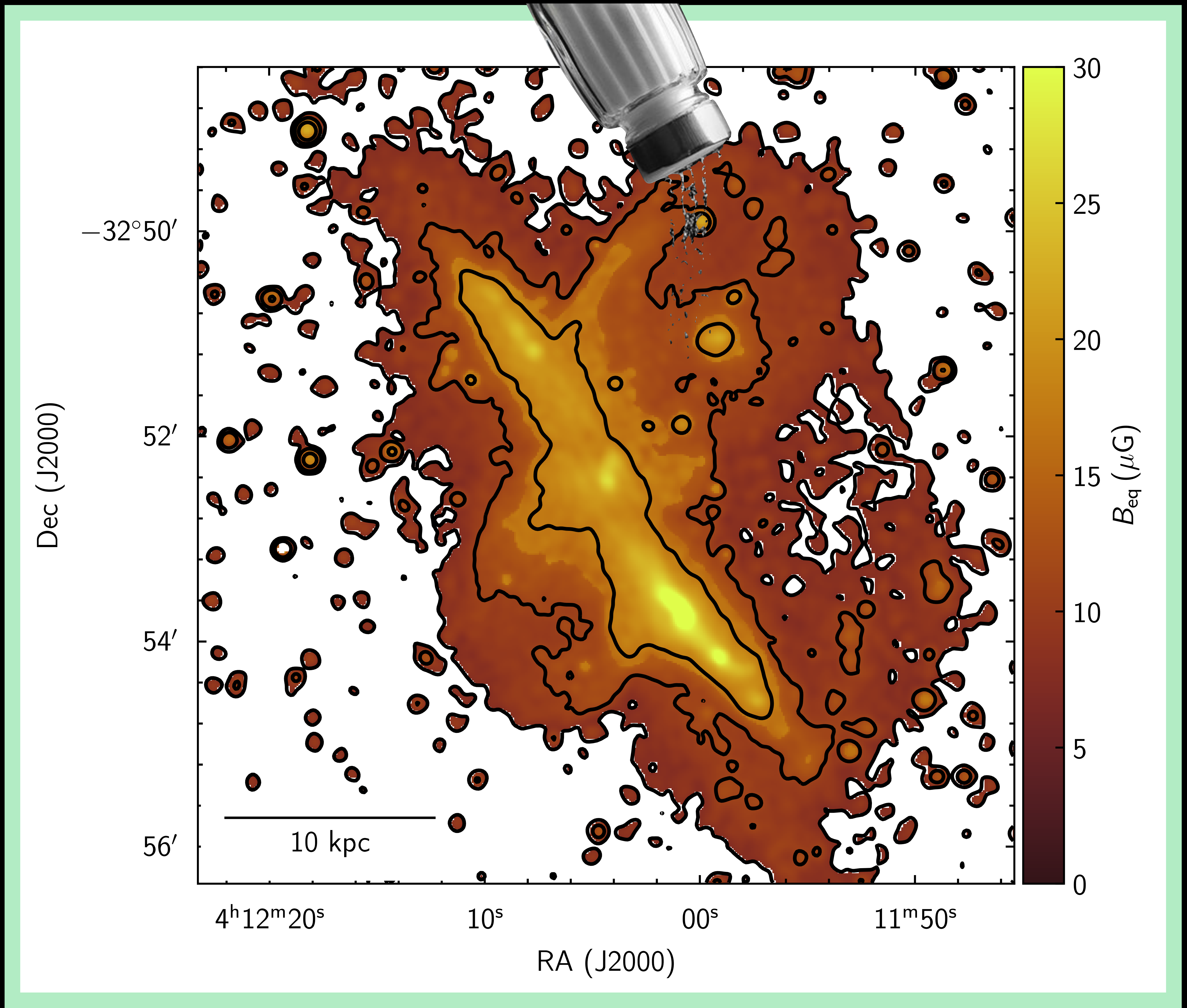
Jarrett et al. 2019

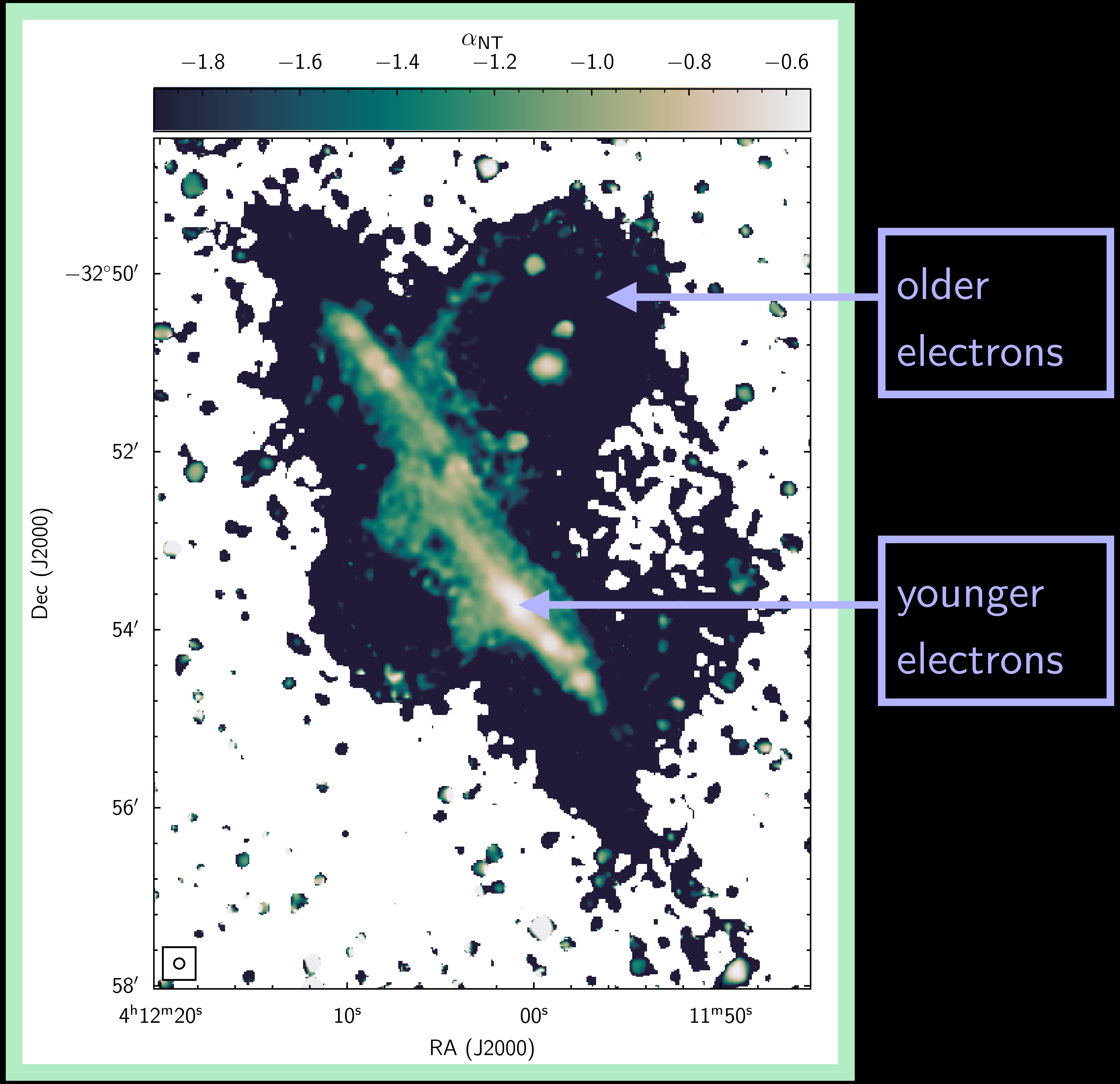
NGC 1532: a heavily magnetized wind.



Matthews et al. (2025)

NGC 1532: strong magnetic field in the disk.





Matthews et al. (2025)

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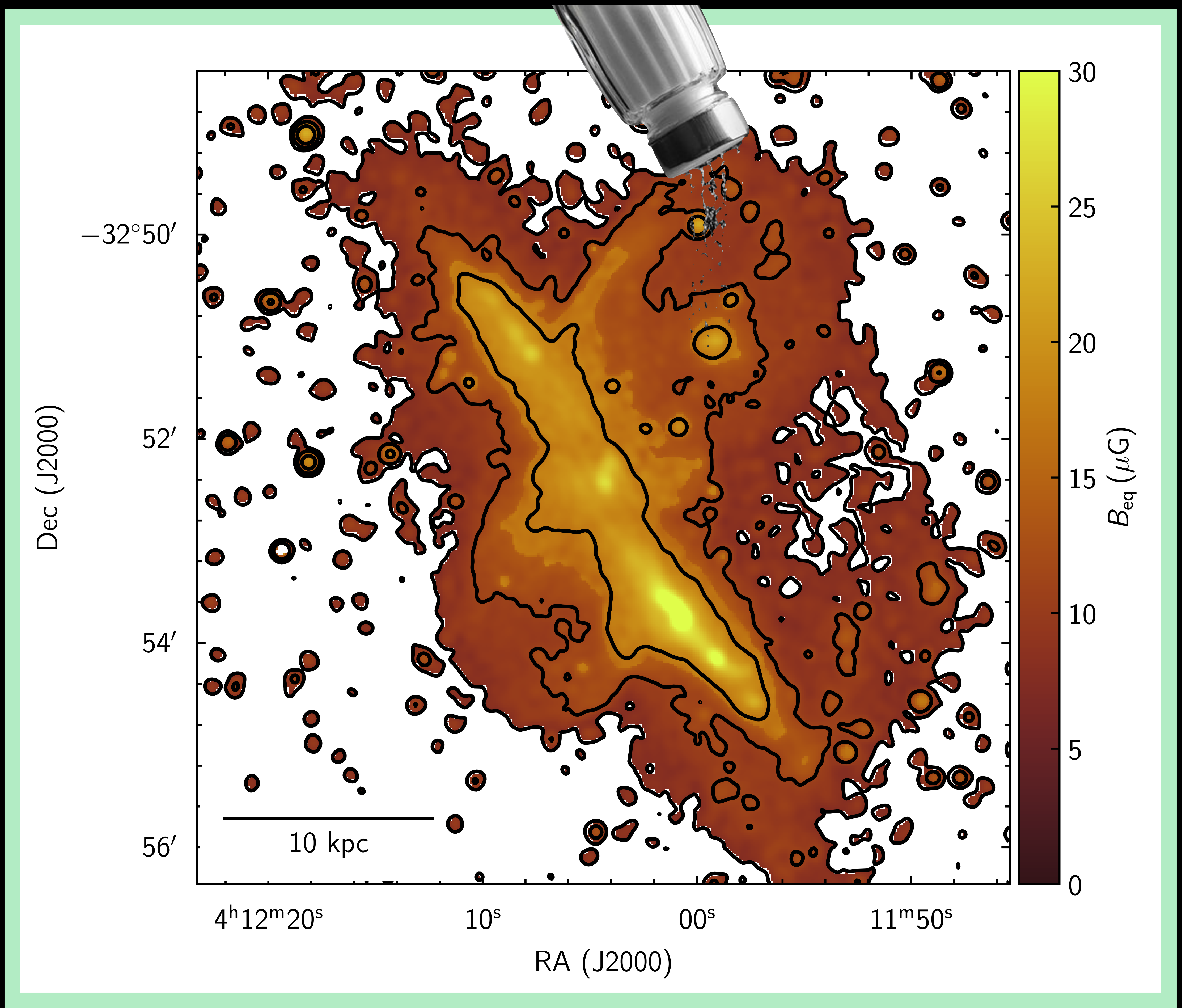

Matthews et al. (2025)

The CHANG-ES survey finds typical magnetic field strengths between **10-20 μG in the disk** and **5-10 μG in the halos**.

Krause+ (2018), Irwin+(2019), Mora-Partiarroyo+(2021)

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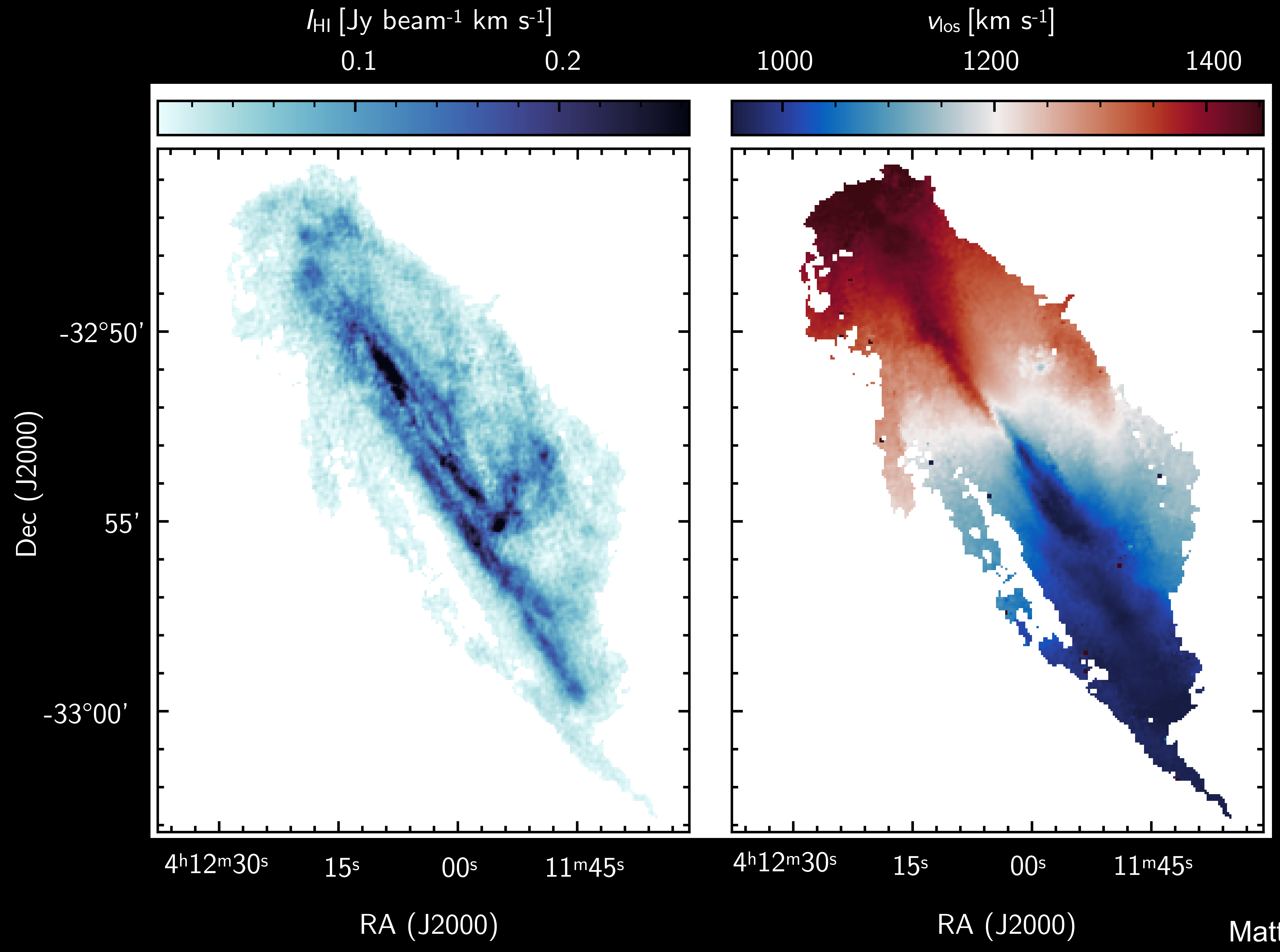
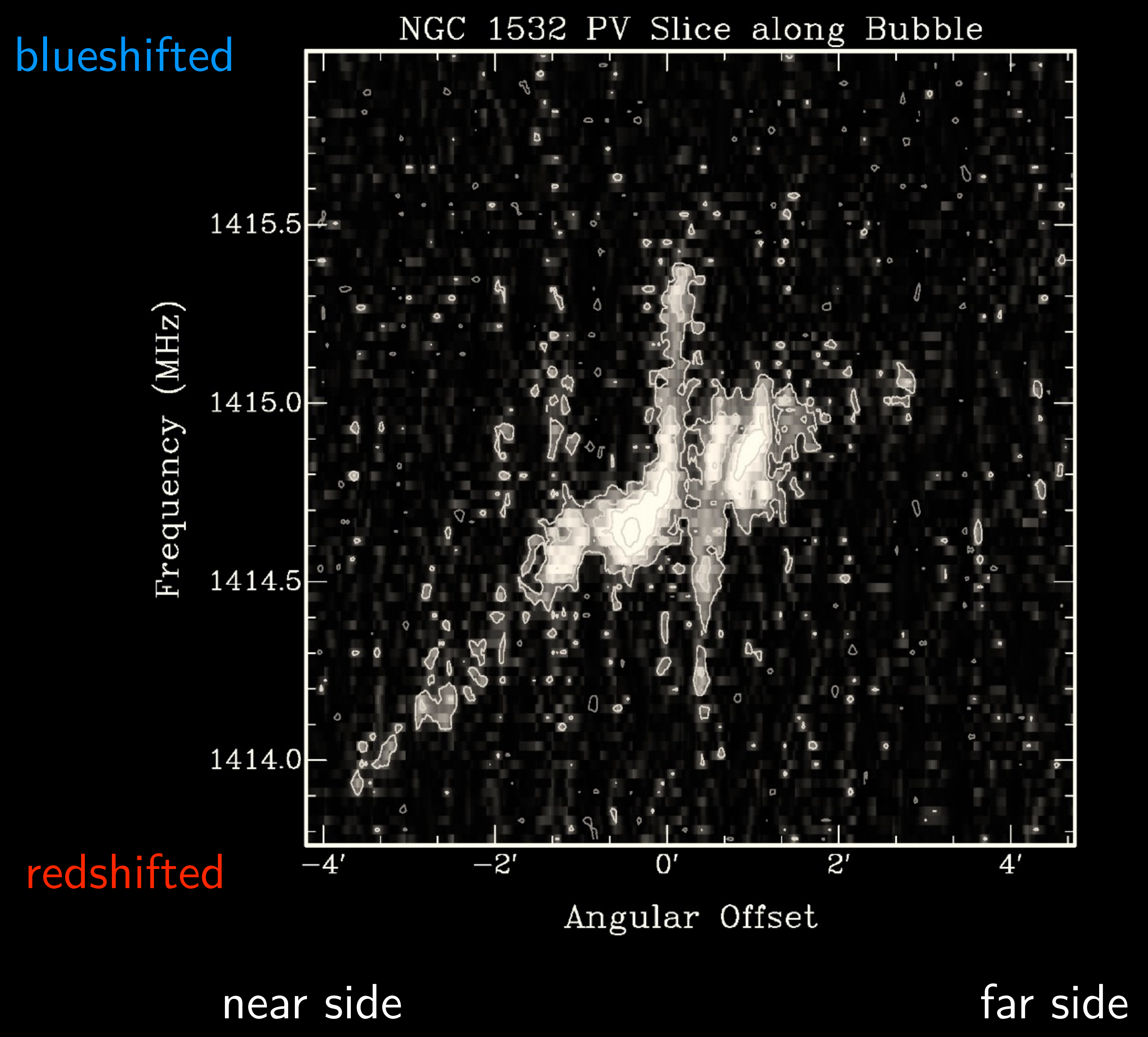
NGC 1532: the neutral gas is rotating ~normally.



Evidence for HI outflows.



Matthews et al. (in prep)

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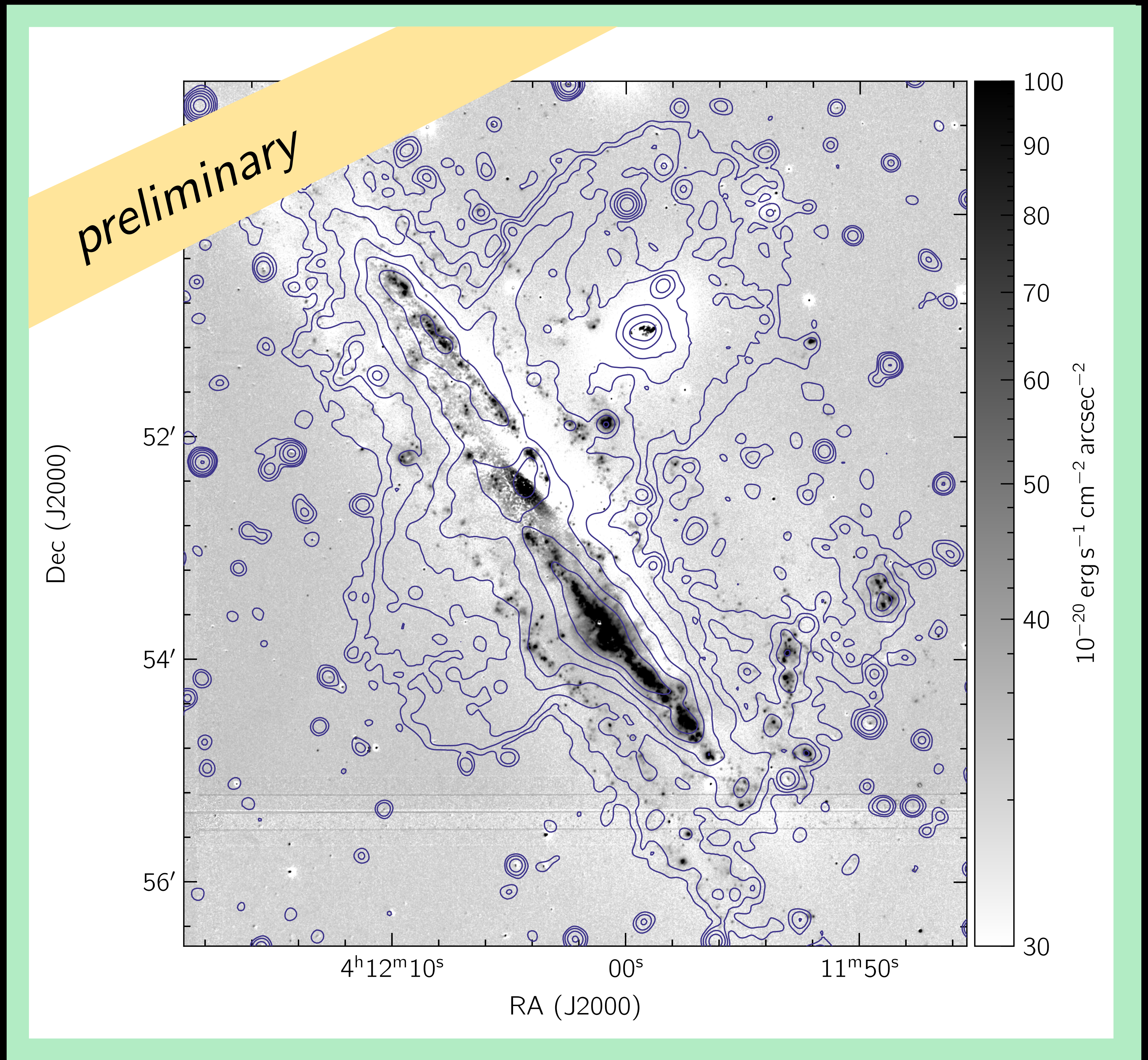
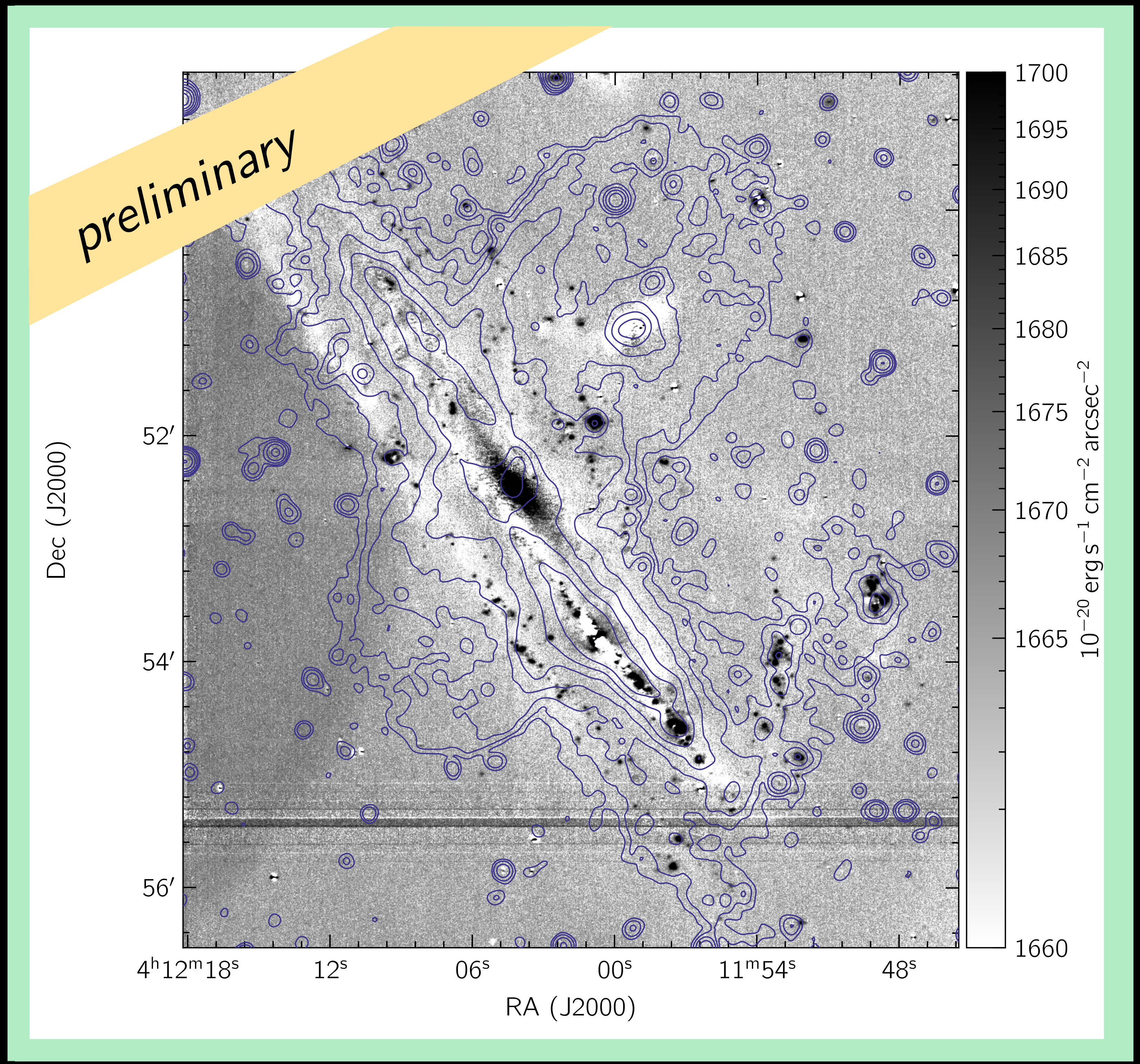
NGC 1532: the ionized gas shows signs of outflows outside the nucleus.

Hα narrowband image



OIII narrowband image



Matthews et al. (in prep)

Are NGC 1532's outflows primarily driven by cosmic rays?

Maybe!

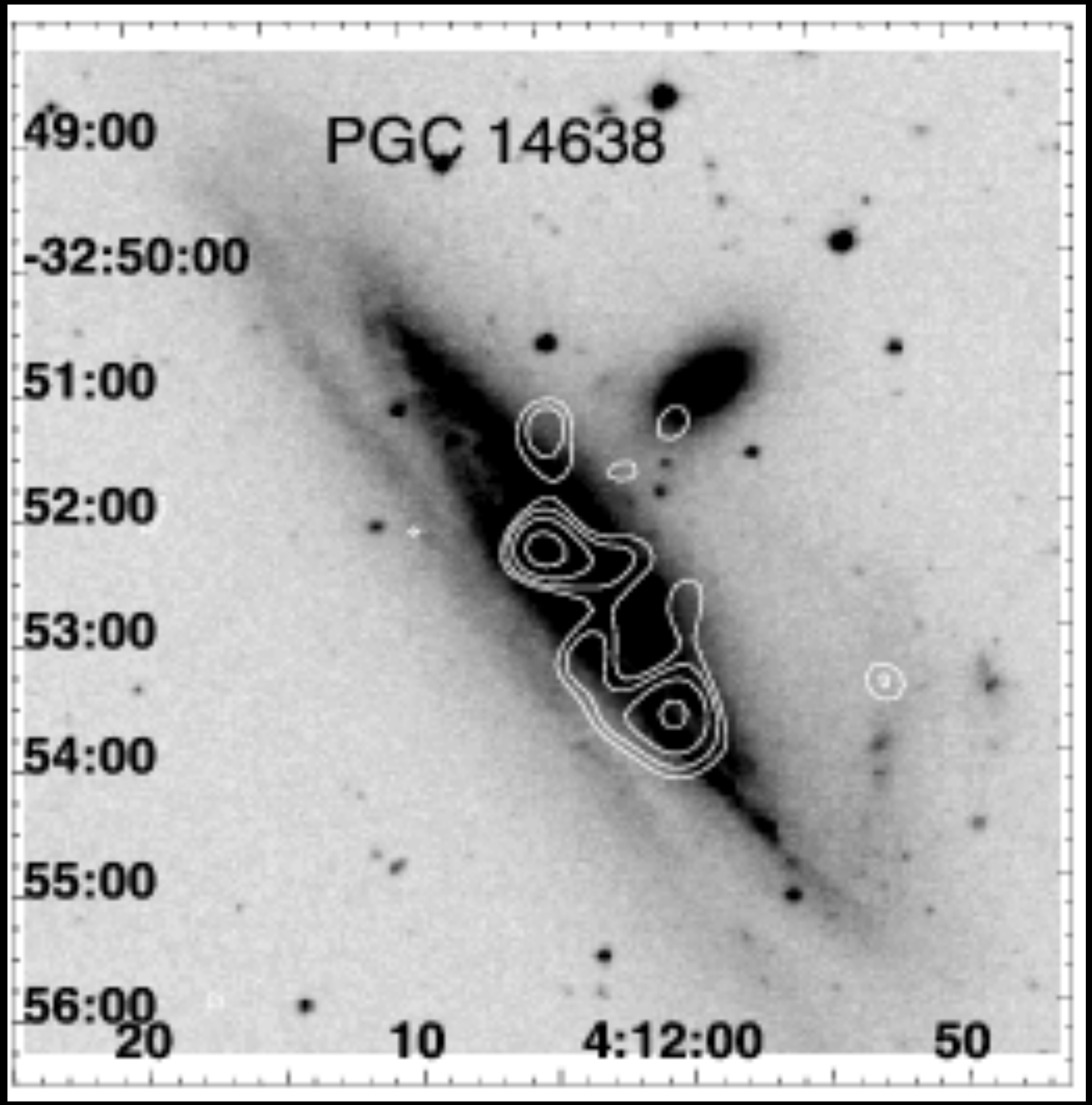
Incoming data in the form of soft X-rays and integral-field spectroscopy will help determine the thermal energy density and warm-ionized gas dynamics.

Question: what measurements of NGC 1532 would be most helpful in constraining the physics of cosmic rays and their role in outflows? Radio intensity as a function of scale height?

Discussion topic: The increased surface brightness sensitivity + angular resolution of MeerKAT makes it an excellent telescope for surveying galaxies for CR-driven outflows. What galaxy properties would make for good targets?

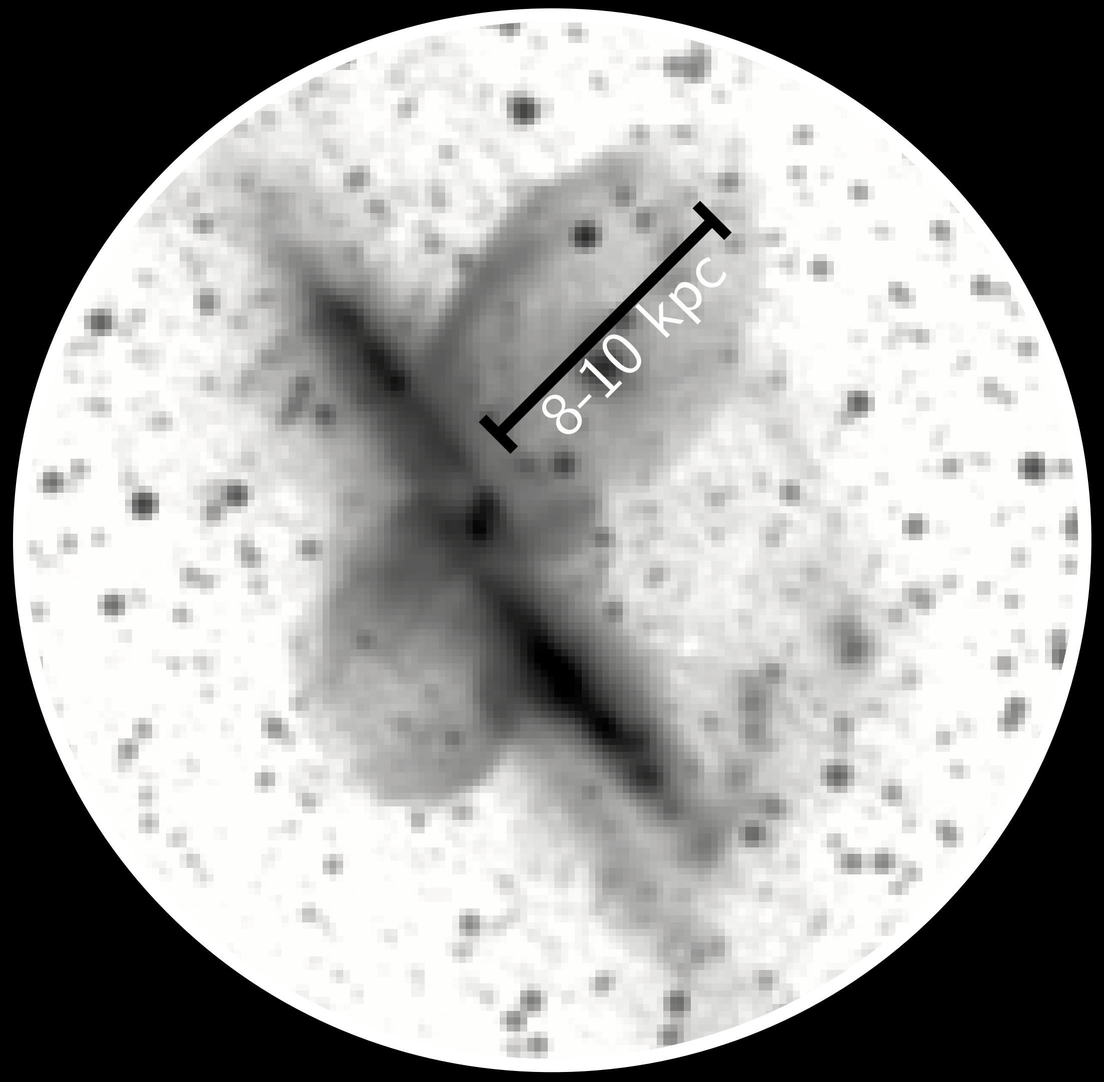
Back up slides

ROSAT data on NGC 1532

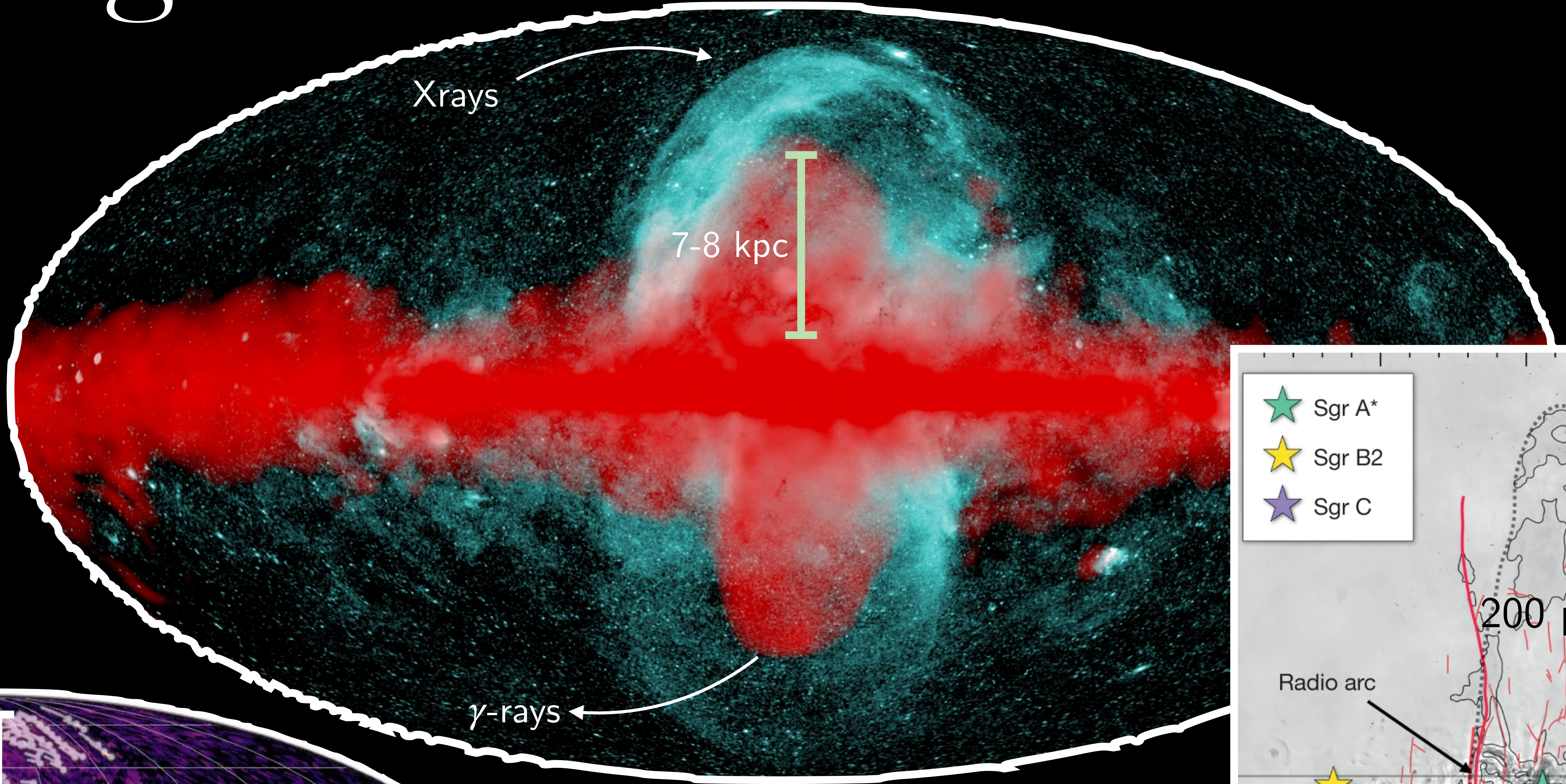


Tajer et al. (2005)

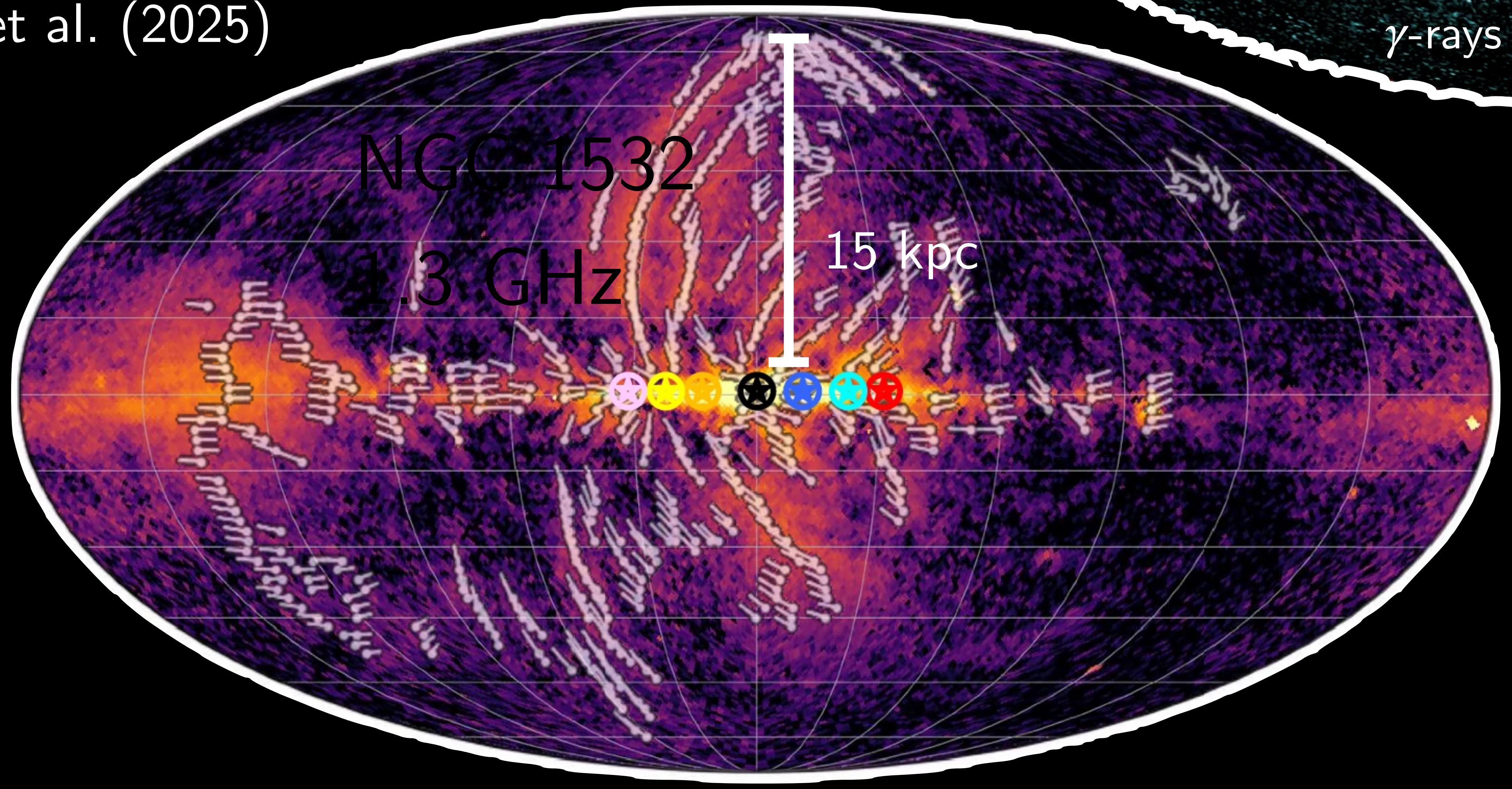
Are they extragalactic Fermi bubbles?



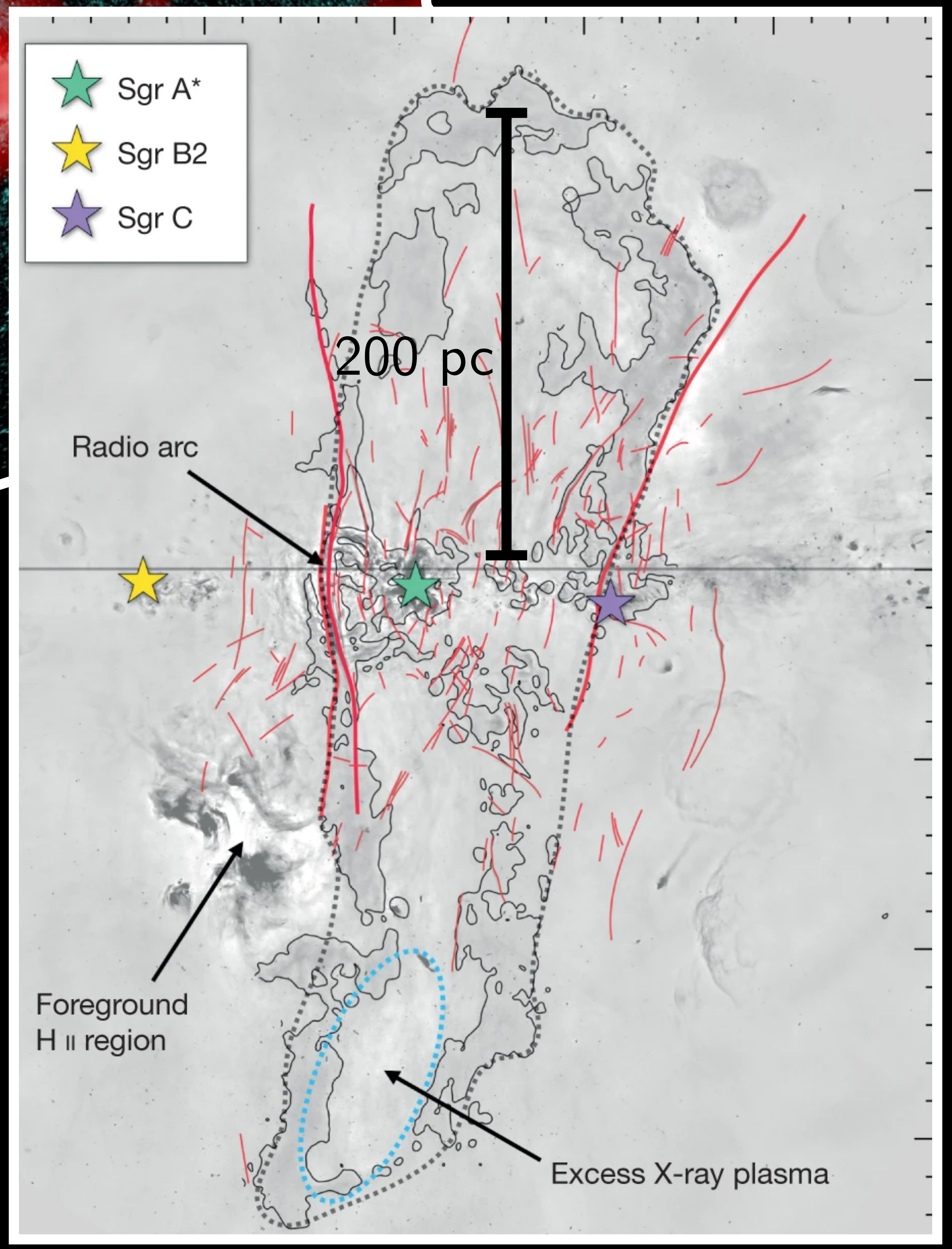
Matthews et al. (2025)



Predehl et al. (2020)



Zhang et al. (2024)



Heywood et al. (2019)