Wandering Massive Black Holes in Dwarf Galaxies

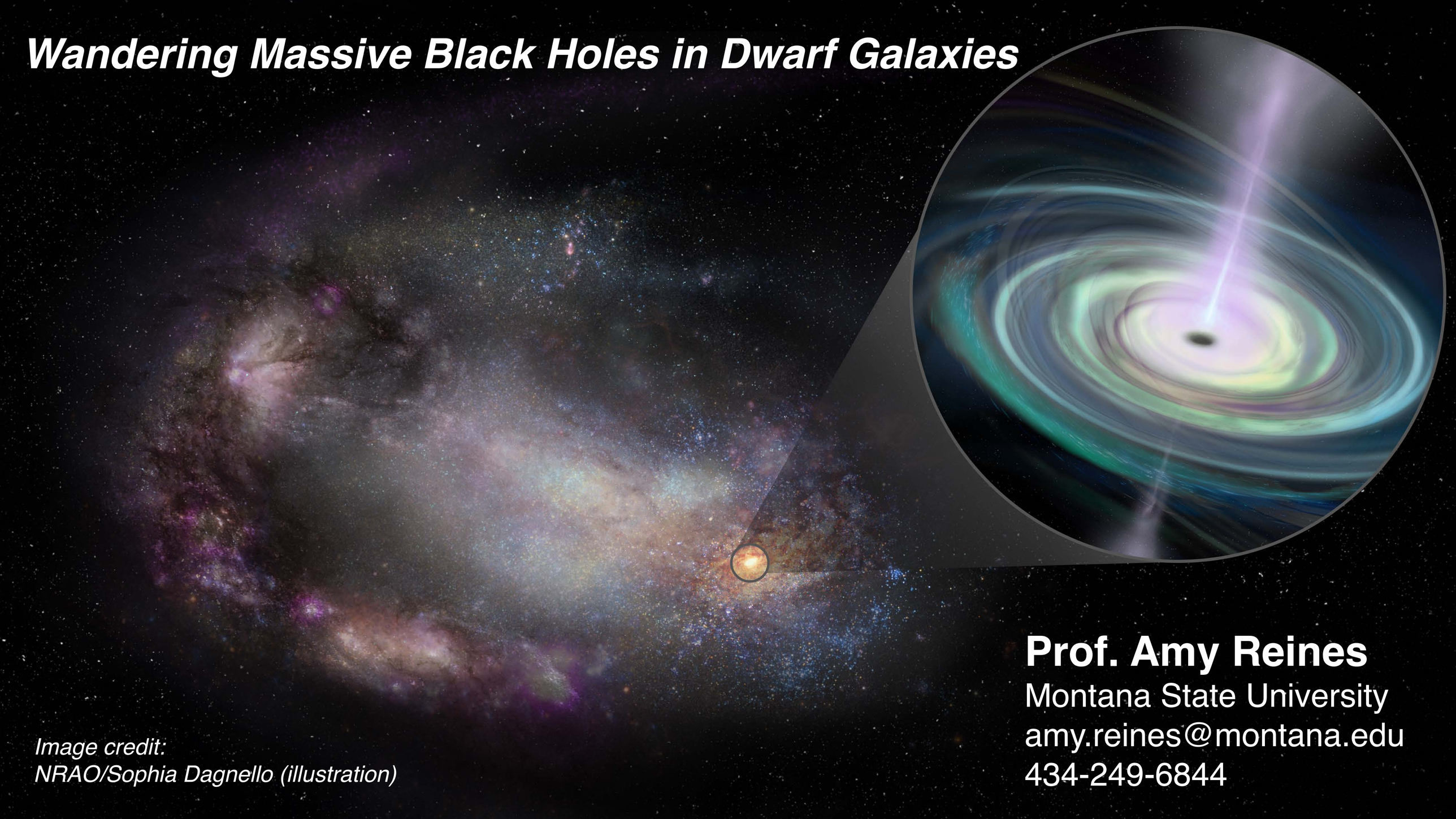

Image credit:
NRAO/Sophia Dagnello (illustration)

Prof. Amy Reines
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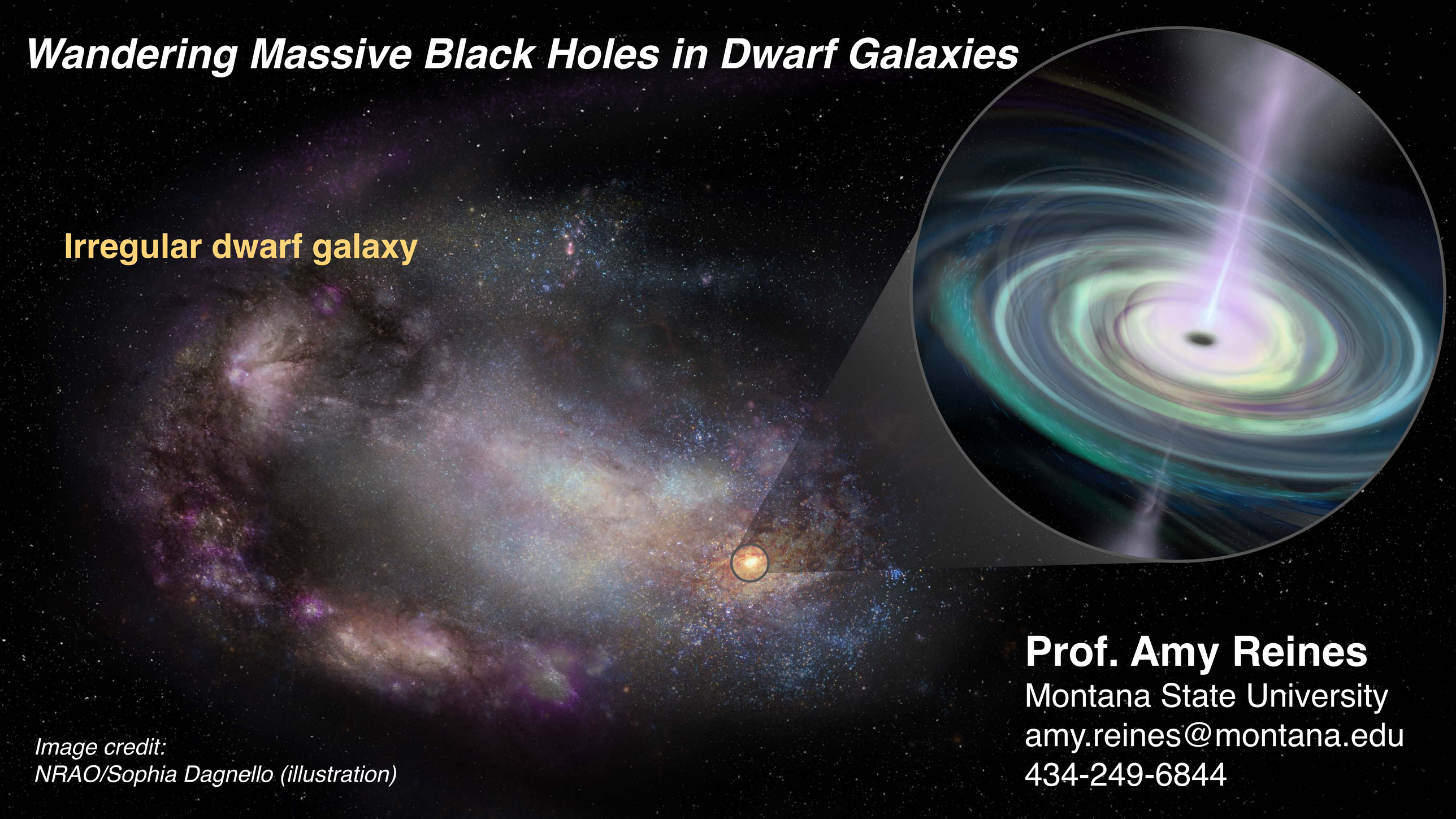

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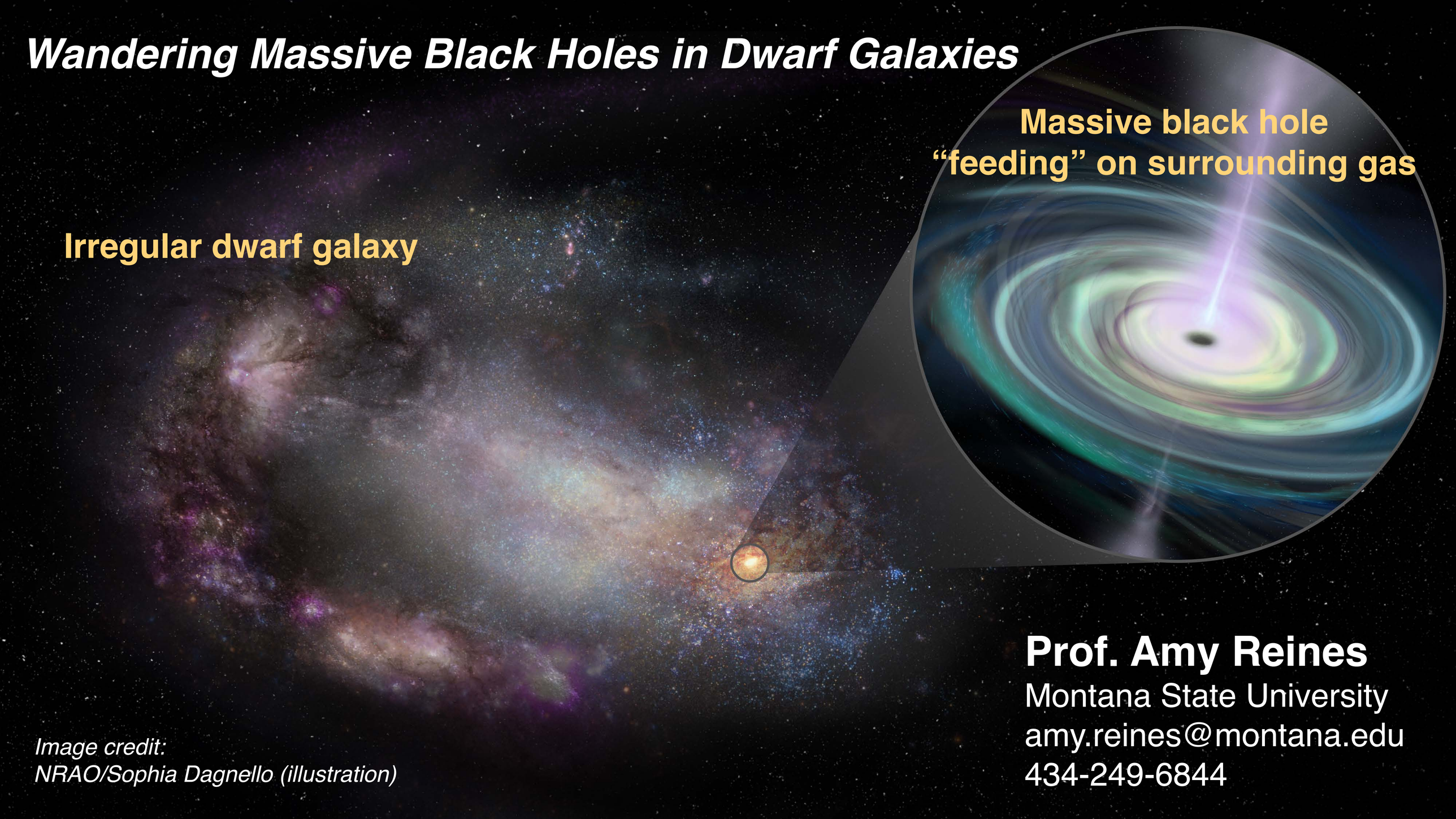

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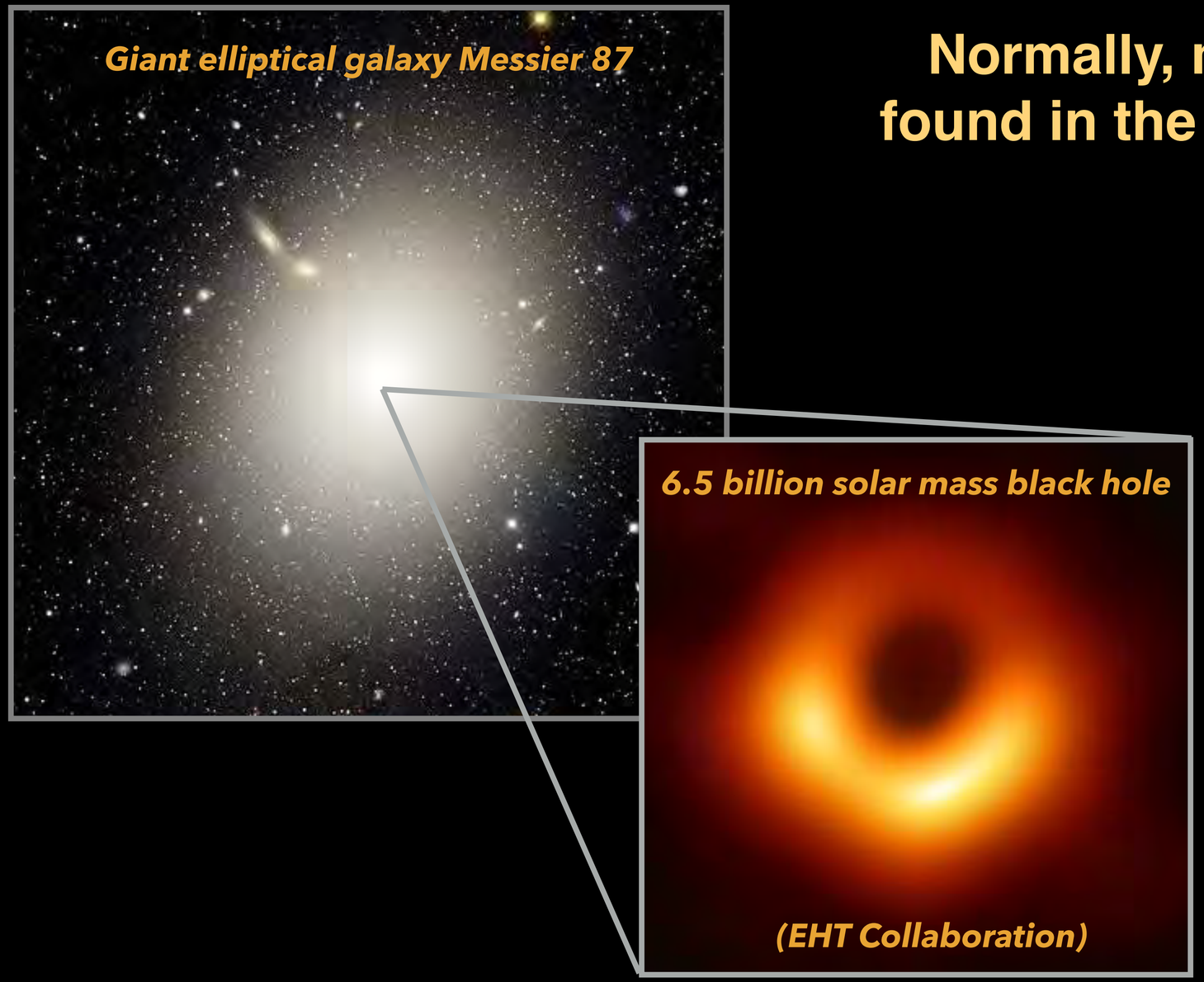
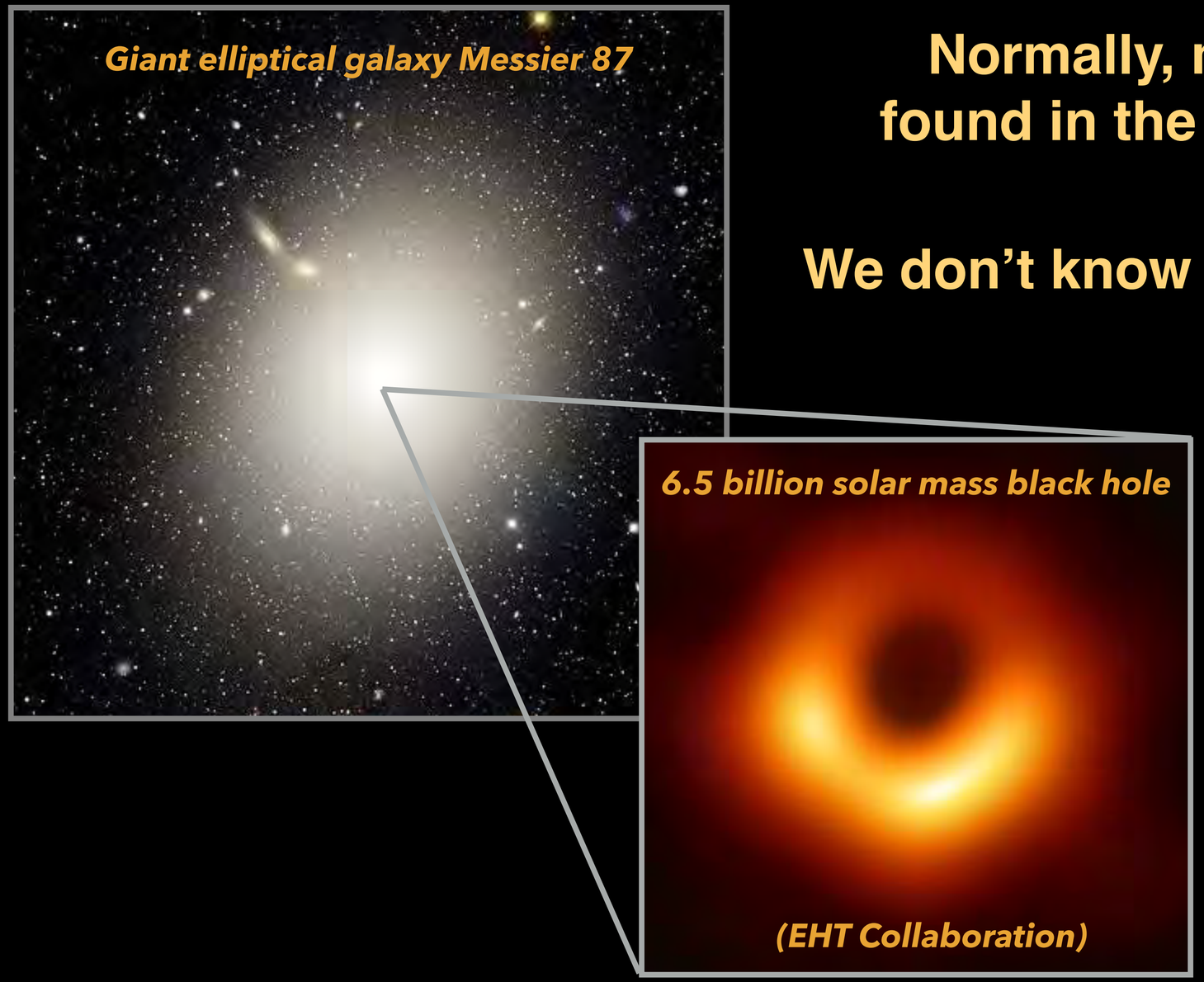


Normally, massive black holes are found in the centers of giant galaxies.

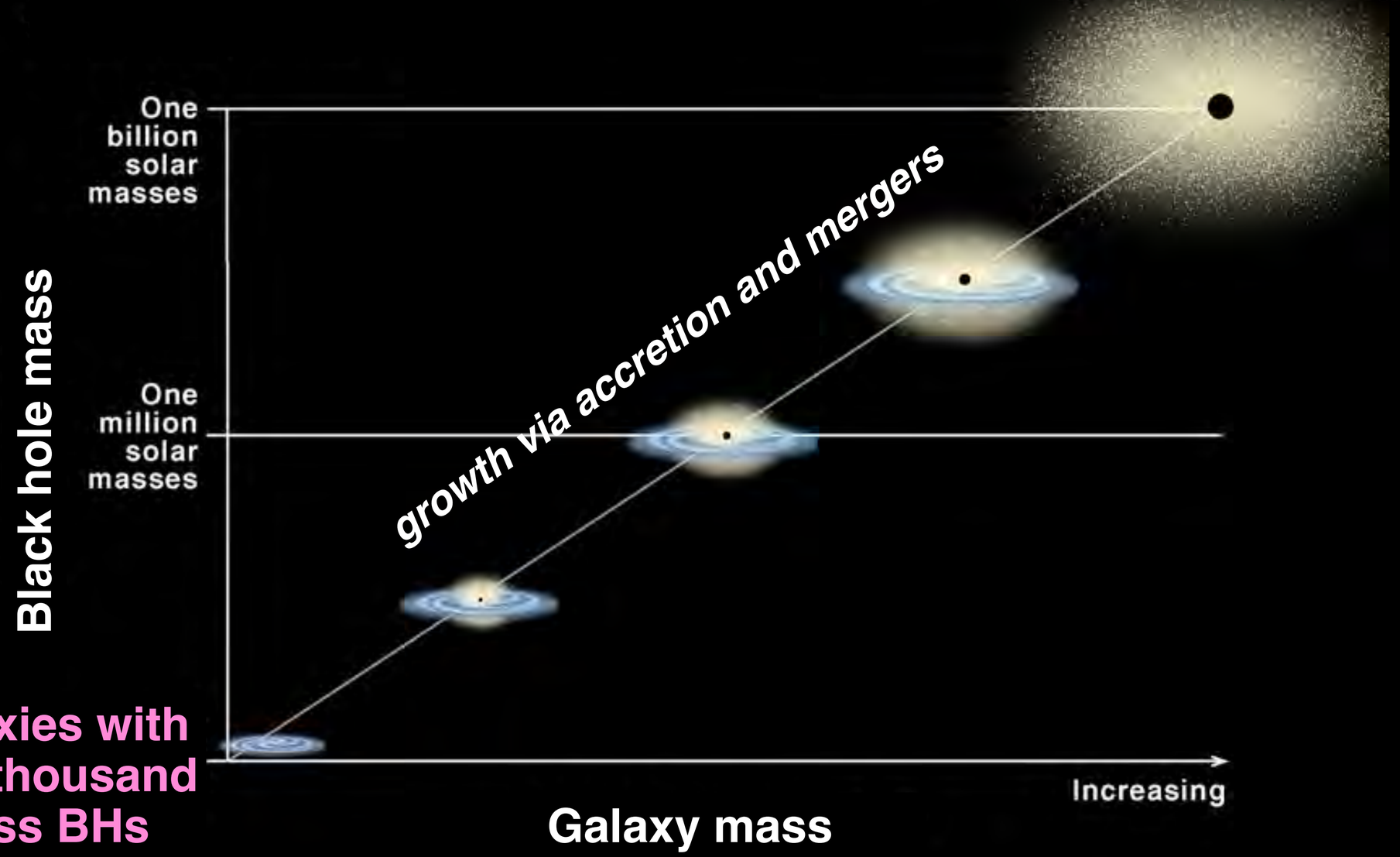
Wandering Massive Black Holes in Dwarf Galaxies



Normally, massive black holes are found in the centers of giant galaxies.

We don’t know how these black holes form!

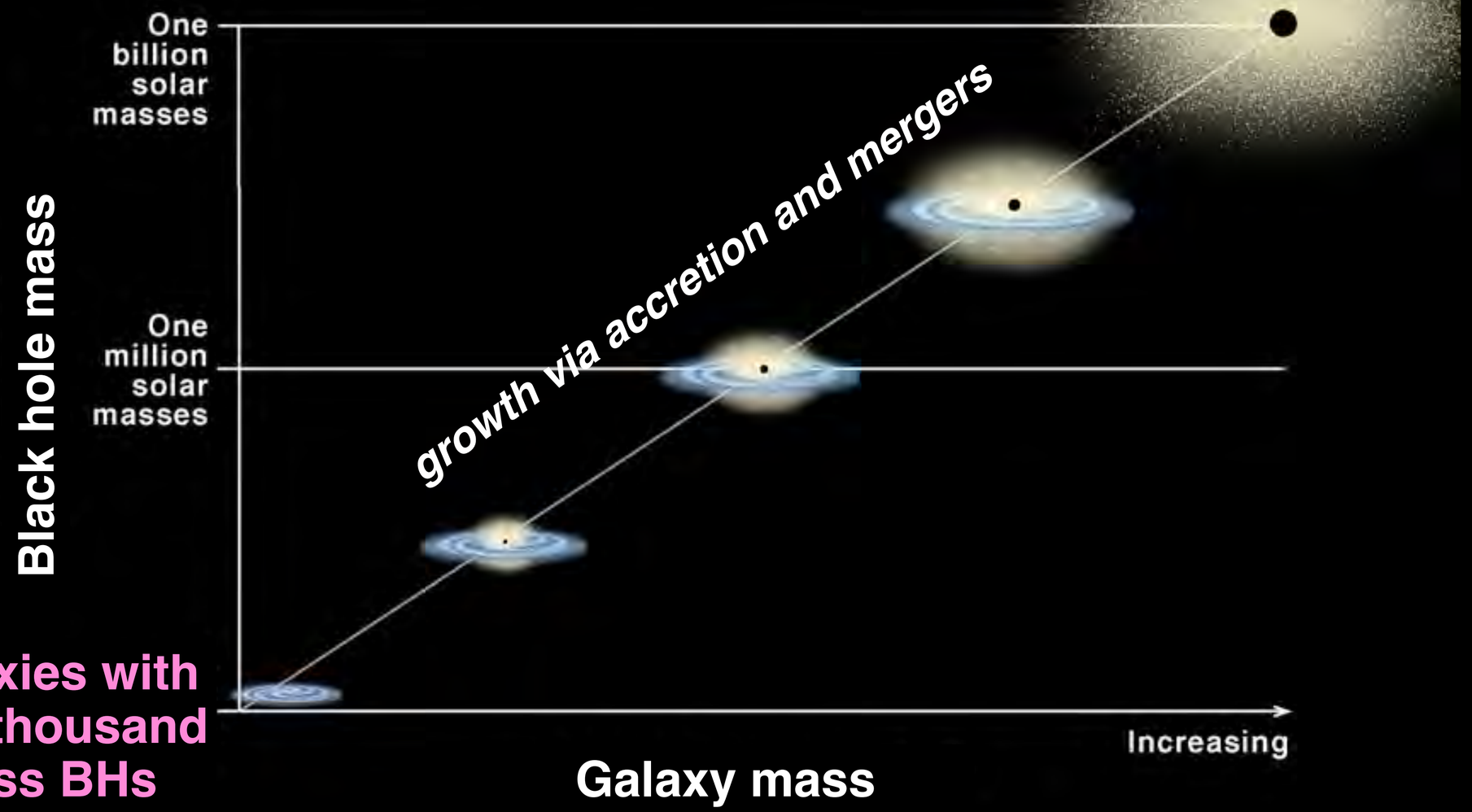
Wandering Massive Black Holes in Dwarf Galaxies



Wandering Massive Black Holes in Dwarf Galaxies

Dwarf galaxies provide clues to the origin of massive black holes

Giant galaxies with > billion solar-mass BHs



Dwarf galaxies with < hundred thousand solar-mass BHs

Wandering Massive Black Holes in Dwarf Galaxies

Optical Searches

- **Lots of progress in recent years**

> 100 dwarfs with massive black holes
(Reines et al. 2013)

~ 50,000 M_{sun} black hole
(Baldassare, Reines et al. 2015)

- **Optically-selected black holes just the tip of the iceberg**

Wandering Massive Black Holes in Dwarf Galaxies

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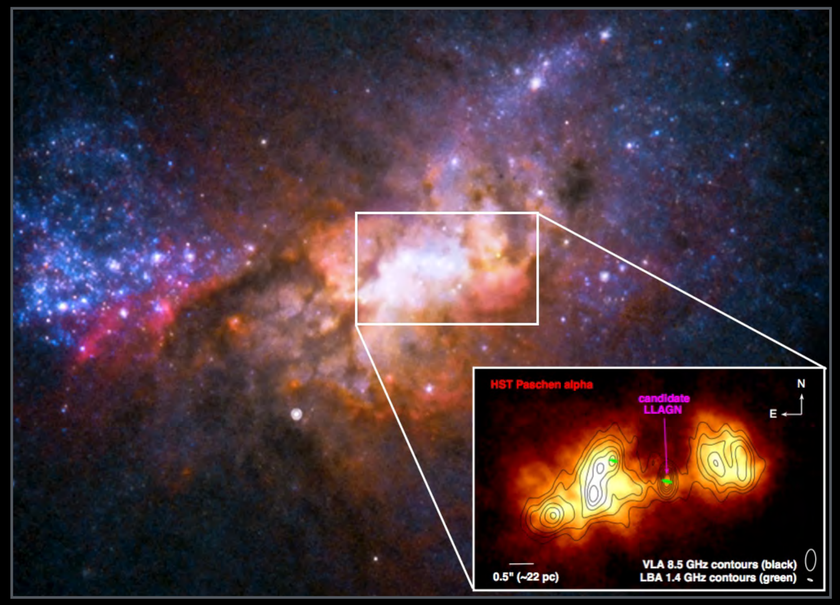
Radio Searches

- **Potential for new discoveries**



A massive black hole in the dwarf starburst galaxy Henize 2-10
(Reines et al. 2011, *Nature*)

Wandering Massive Black Holes in Dwarf Galaxies

First large-scale radio survey for massive black holes in dwarf galaxies

NSF's Karl G. Jansky Very Large Array (VLA)

"A New Sample of (Wandering) Massive Black Holes in Dwarf Galaxies from High-resolution Radio Observations"

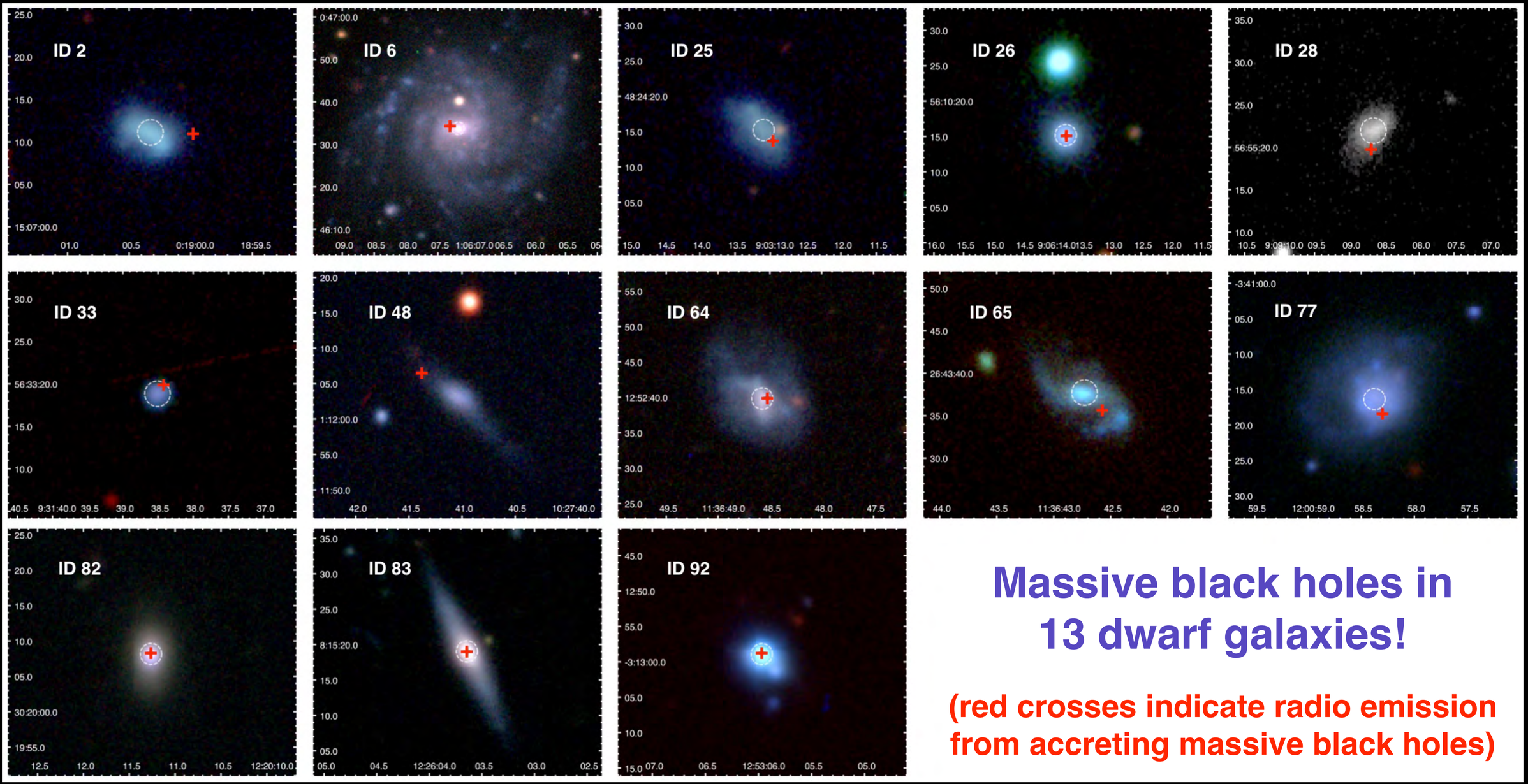
Reines, Condon, Darling & Greene 2020, *The Astrophysical Journal*, 888,1 (arXiv:1909.04670)

Wandering Massive Black Holes in Dwarf Galaxies

First large-scale radio survey for massive black holes in dwarf galaxies

- VLA observations of 111 dwarf galaxies
- Previously detected in FIRST radio survey at low angular resolution (origin of radio emission is unclear)
- New observations have much higher angular resolution and are also much more sensitive (can help distinguish between massive black holes and star formation)

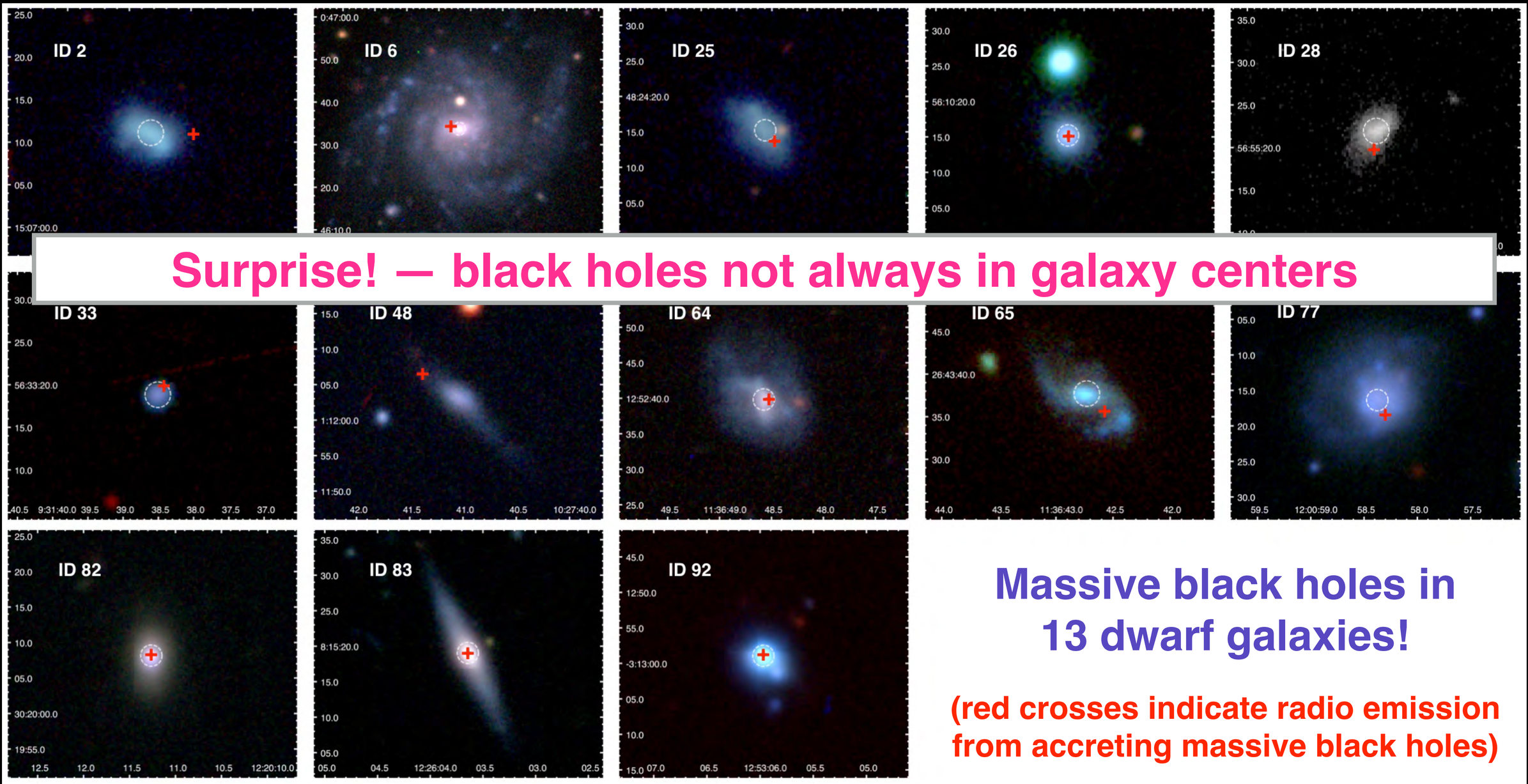
Wandering Massive Black Holes in Dwarf Galaxies



Massive black holes in 13 dwarf galaxies!

(red crosses indicate radio emission from accreting massive black holes)

Wandering Massive Black Holes in Dwarf Galaxies



Surprise! — black holes not always in galaxy centers

Massive black holes in 13 dwarf galaxies!

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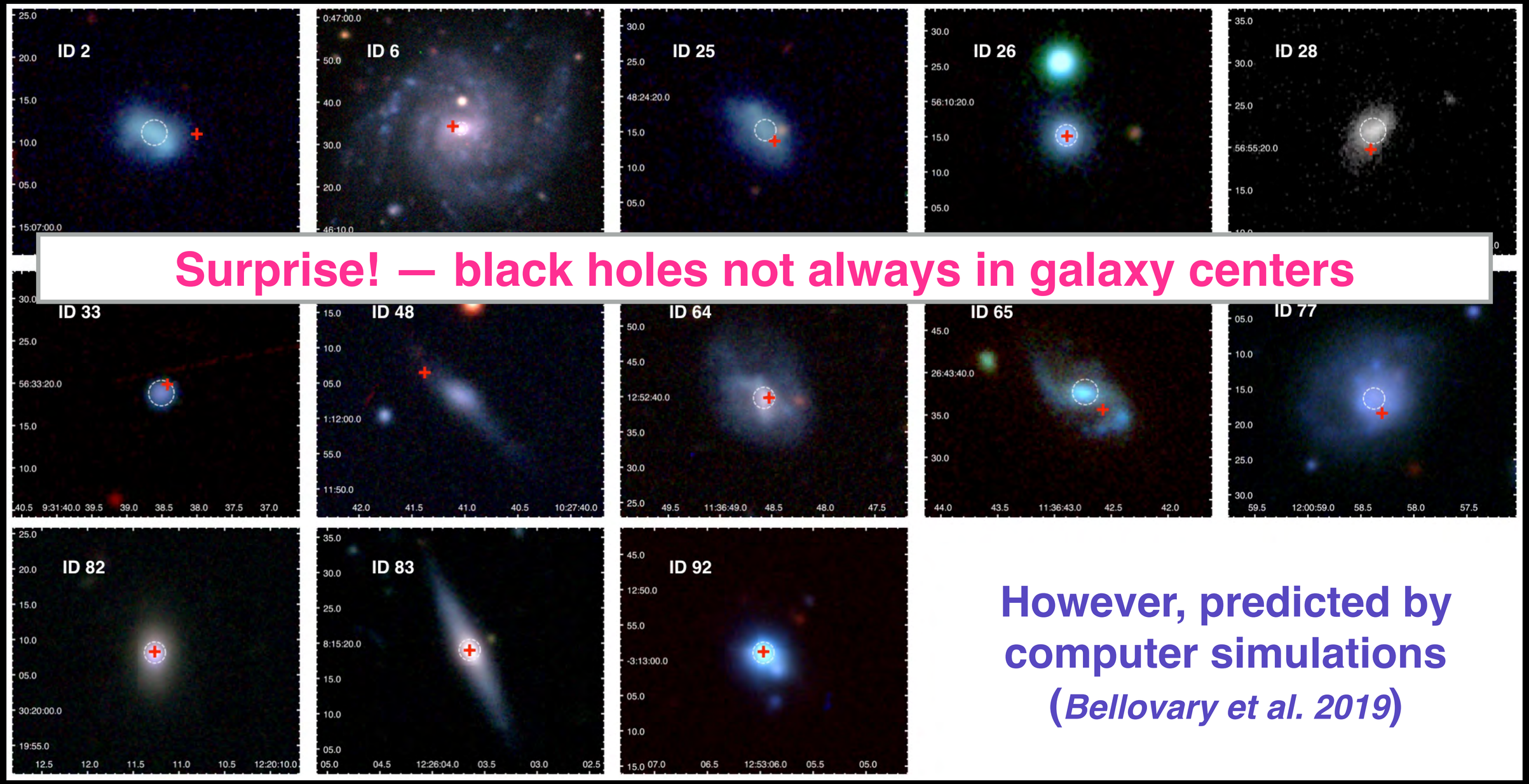
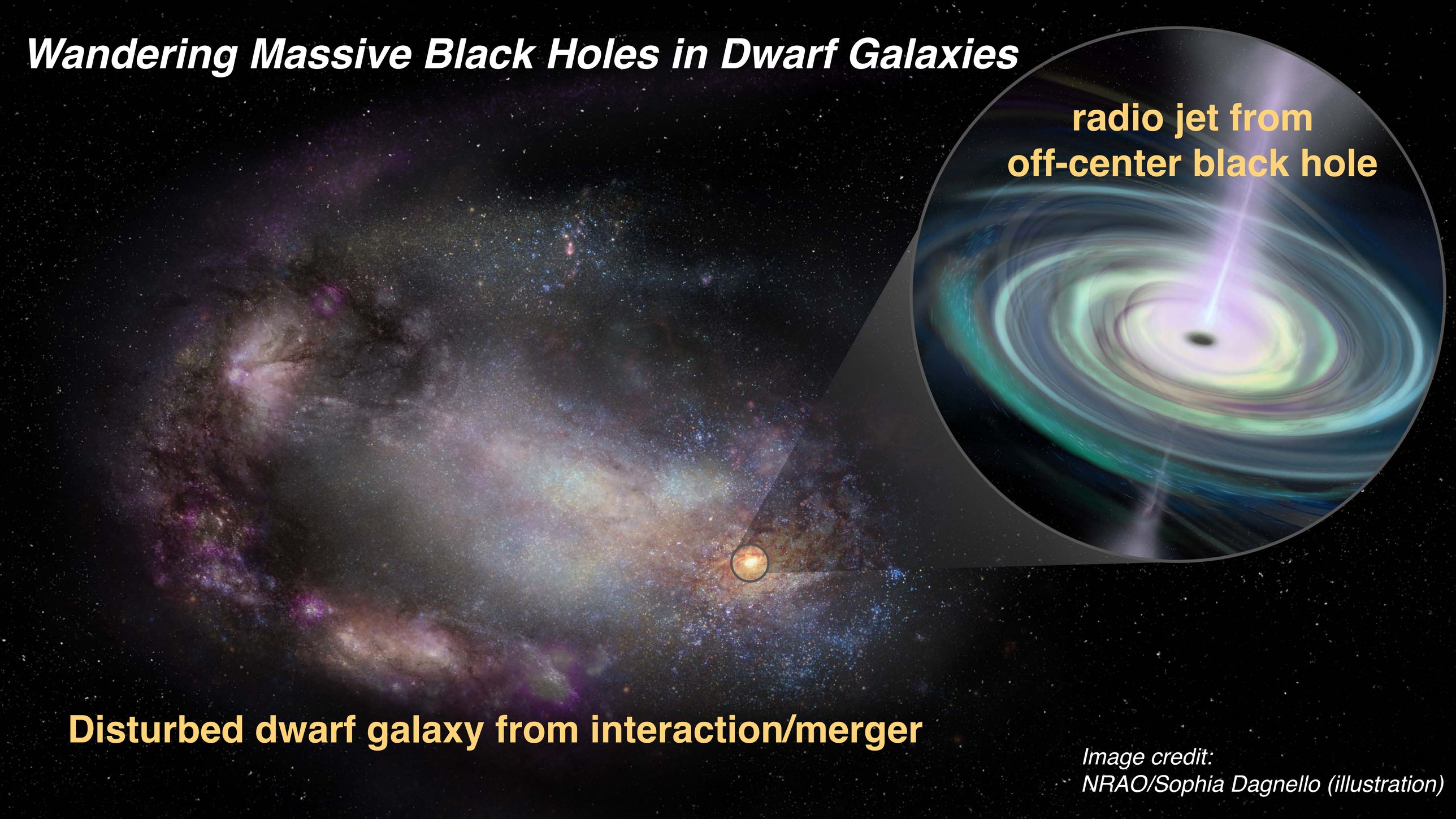


Surprise! — black holes not always in galaxy centers

However, predicted by computer simulations (*Bellovary et al. 2019*)

Wandering Massive Black Holes in Dwarf Galaxies



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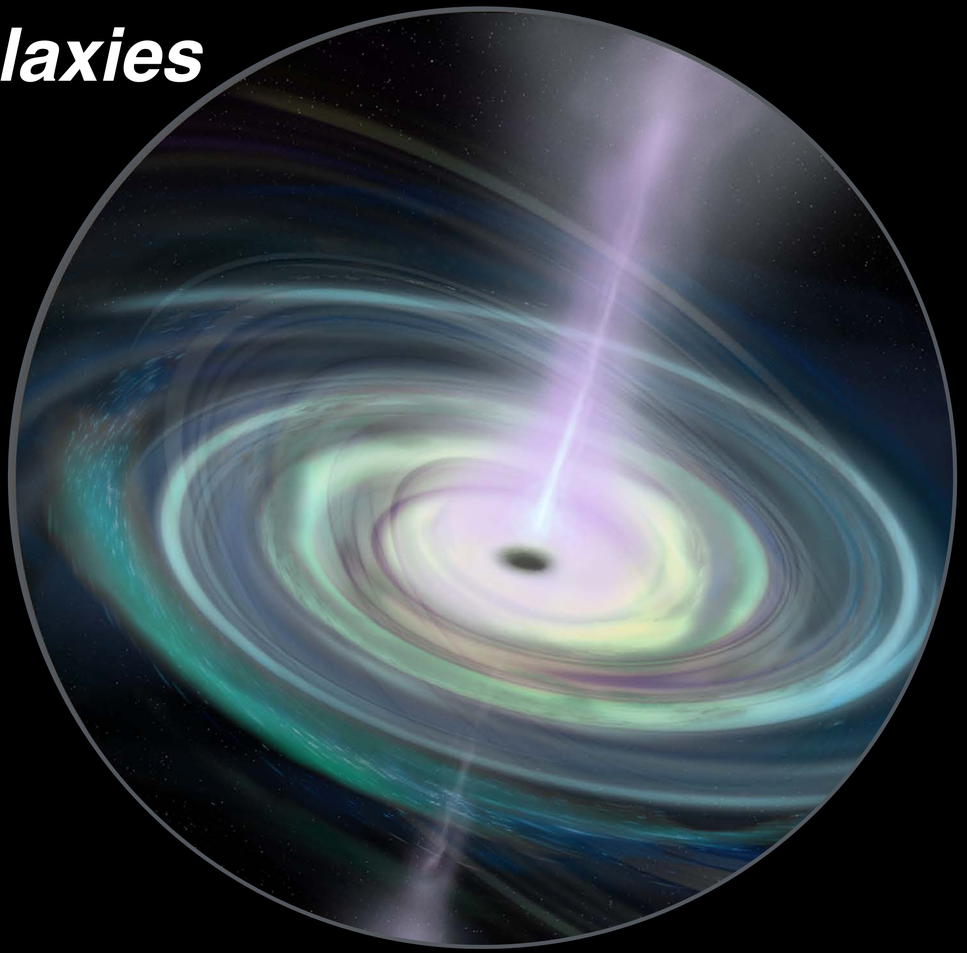

Recap:

- Used the VLA to search for radio signatures of massive black holes in dwarf galaxies
- Discovered 13 dwarfs with massive black holes
- Surprise! black holes not always in the center
- Consistent with computer simulations
- Must broaden our searches beyond dwarf galaxy nuclei to constrain the formation of massive black holes

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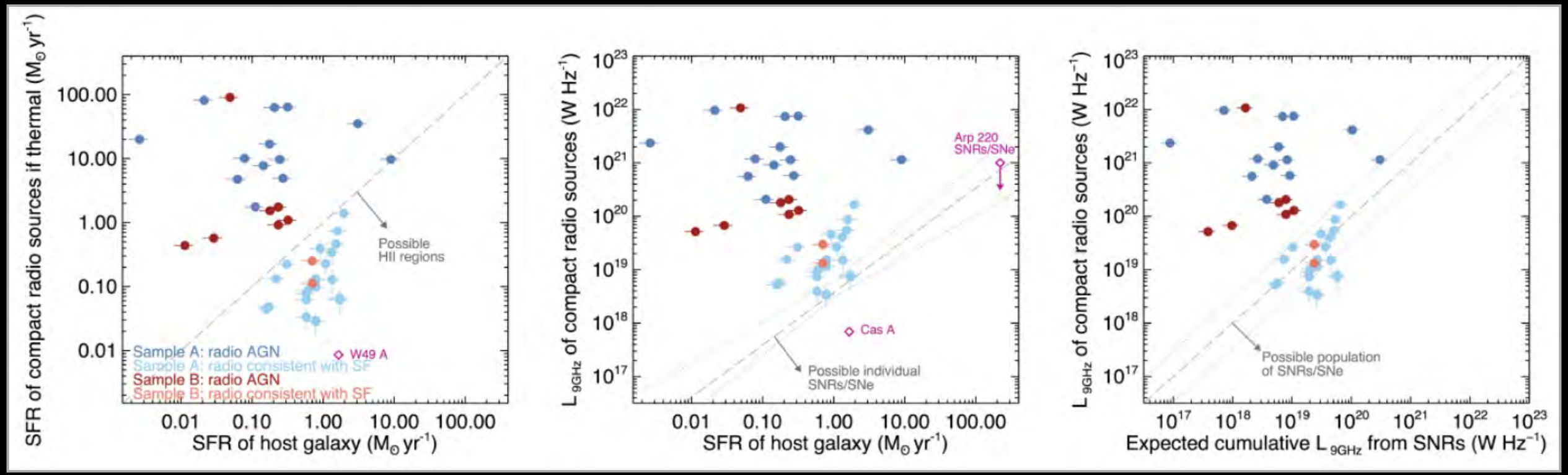
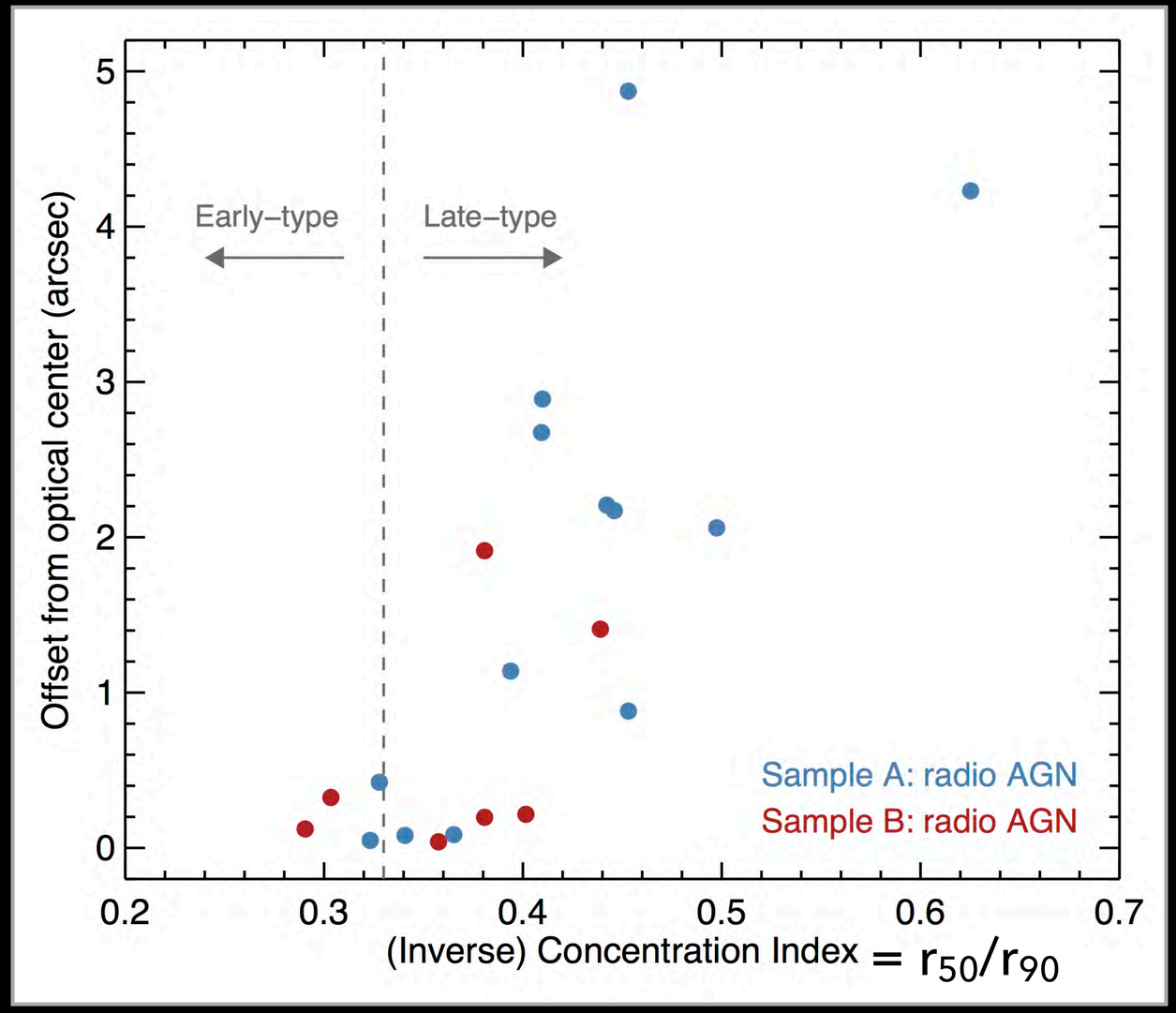
A new sample of (wandering) massive black holes in dwarf galaxies from high-resolution radio observations

Reines et al. 2020



- Considered various possible origins for the compact radio emission including thermal HII regions, SNRs, populations of SNRs and younger radio SNe, and AGNs.
- AGNs are almost certainly responsible for the compact radio emission in *at least 13* of my target dwarf galaxies.

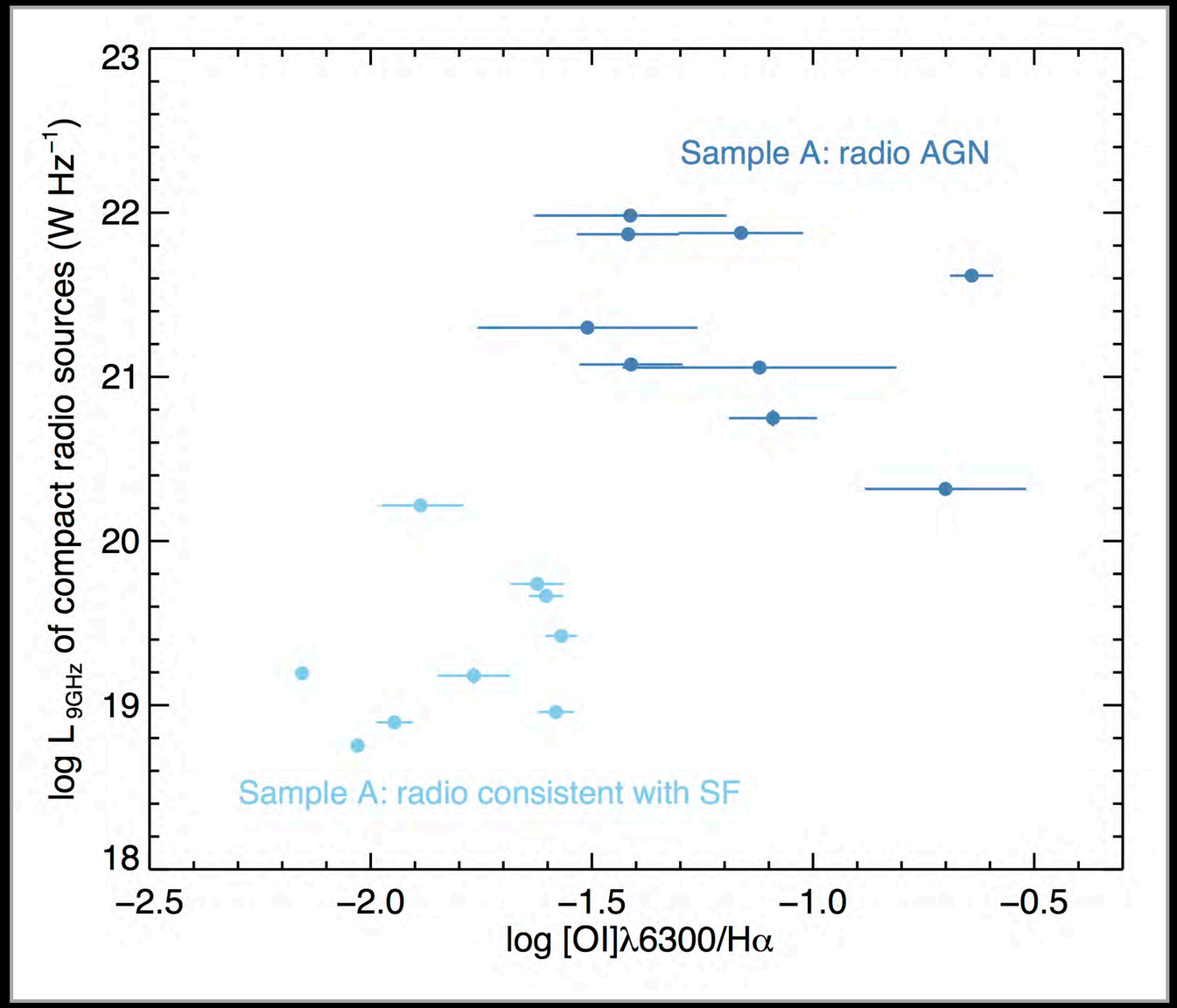
Wandering Massive Black Holes in Dwarf Galaxies



Extended/disturbed/ later-type galaxies tend to have more offset BHs

Regular/nucleated/ earlier-type galaxies tend to have more central BHs

Wandering Massive Black Holes in Dwarf Galaxies

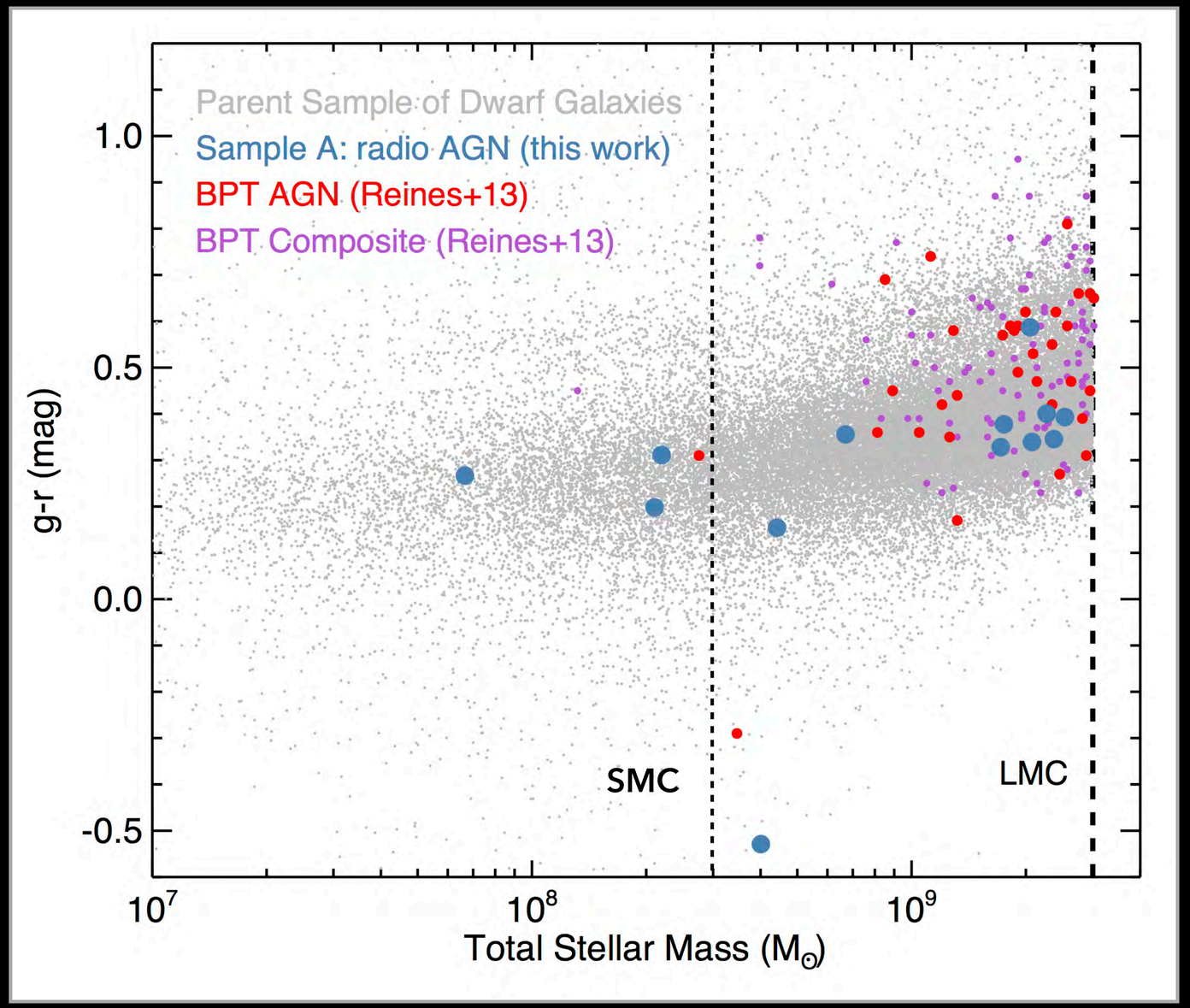


The radio AGNs have relatively high [OI]/Hα ratios…

- Radio AGNs are associated with the galaxies producing the line emission
- Unlikely to be background interlopers

Wandering Massive Black Holes in Dwarf Galaxies

Radio AGNs found in lower-mass and bluer galaxies than optical samples



A new sample of (wandering) massive black holes in dwarf galaxies from high-resolution radio observations

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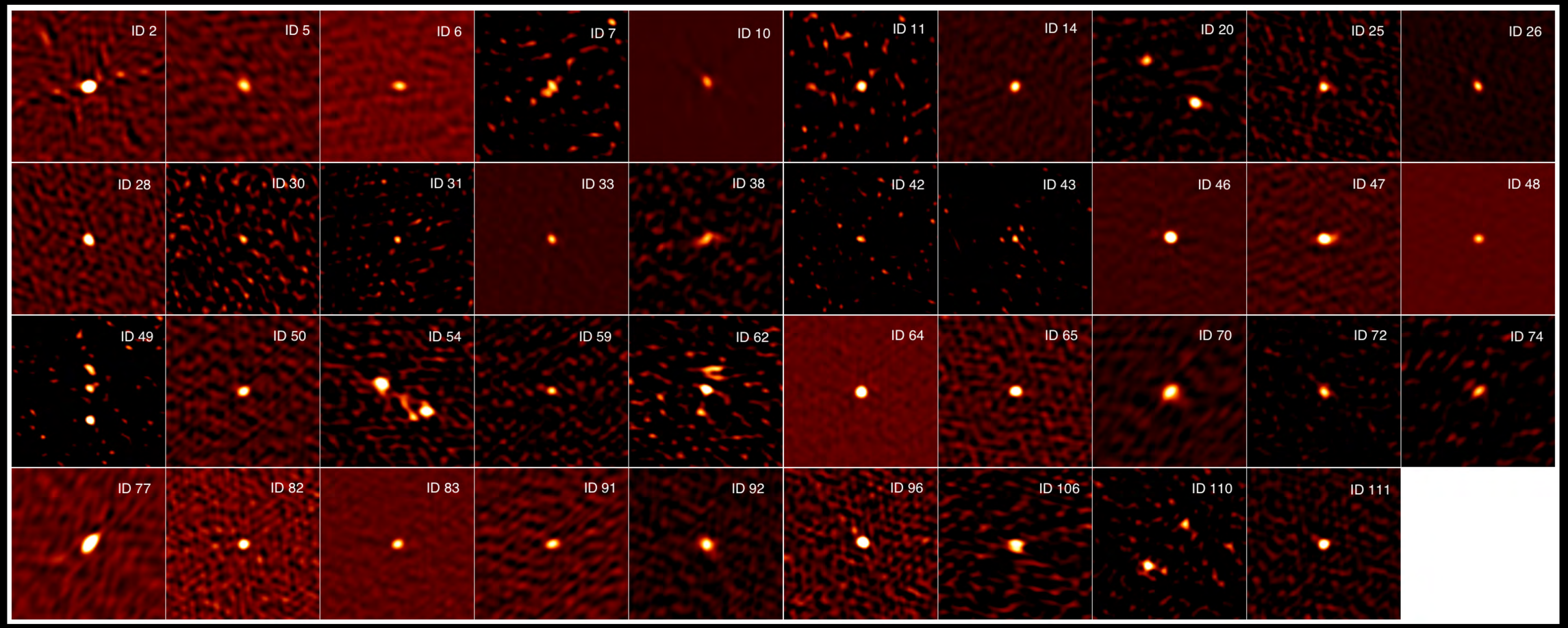
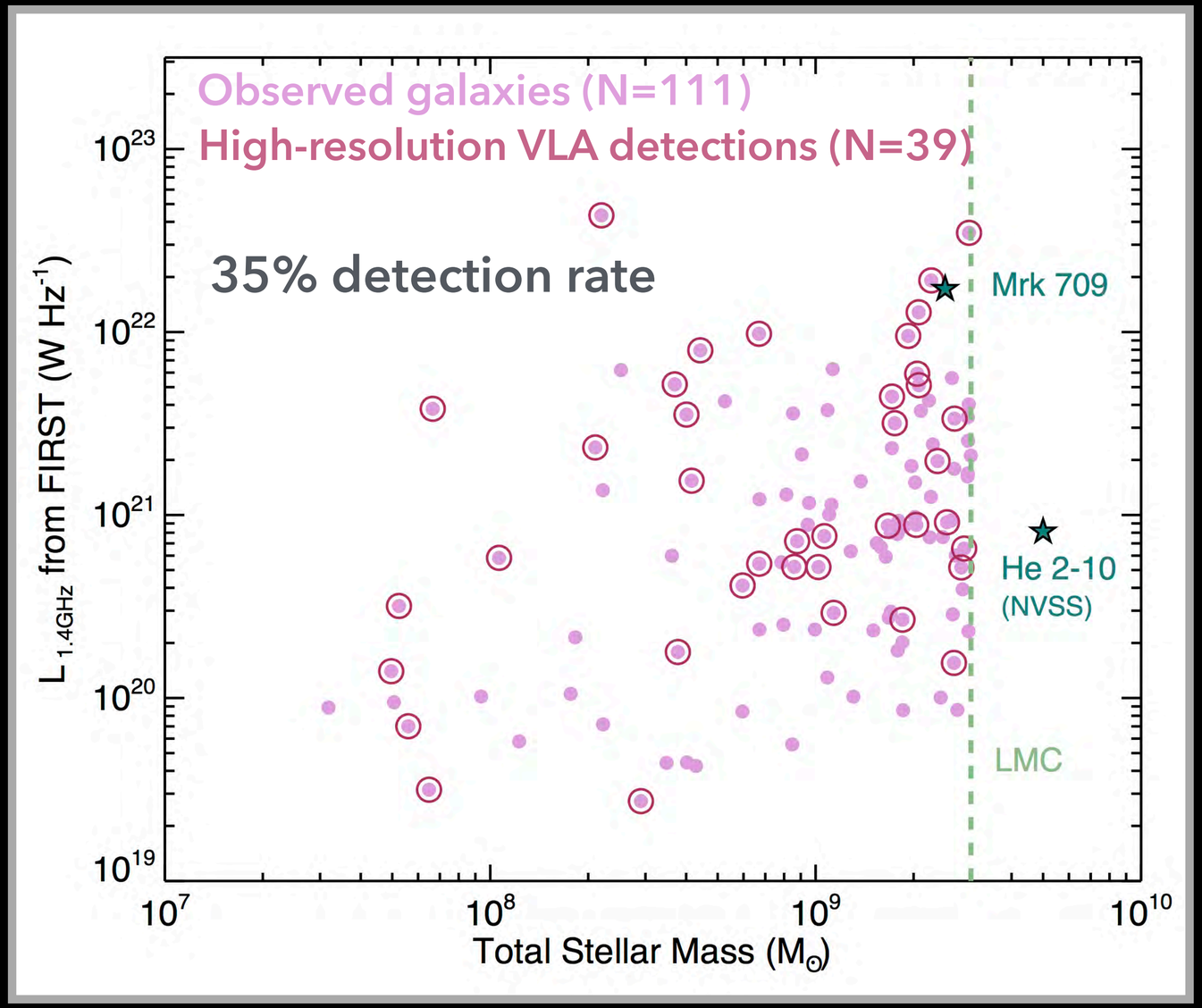


VLA – 4″ x 4″ cutouts

39 galaxies with compact radio source detections

A new sample of (wandering) massive black holes in dwarf galaxies from high-resolution radio observations

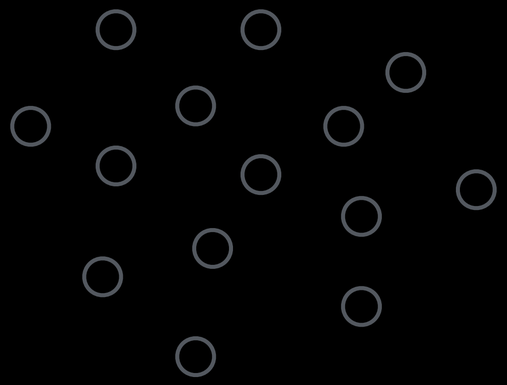
Reines et al. 2020



How do the “seeds” of supermassive BHs form?

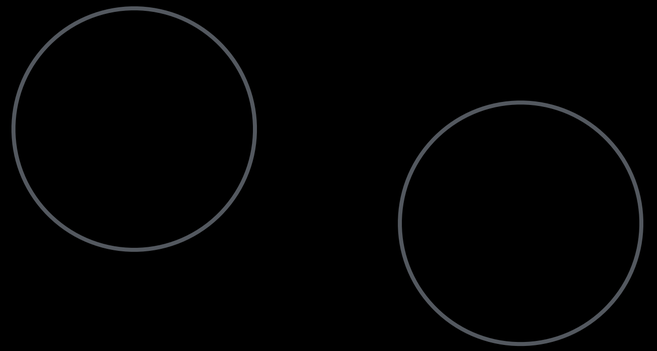
Theory: Possible BH seed formation mechanisms

Remnants from first generation of massive stars



- M_{BH} ~100 M_{sun}
- abundant

Direct collapse of dense gas

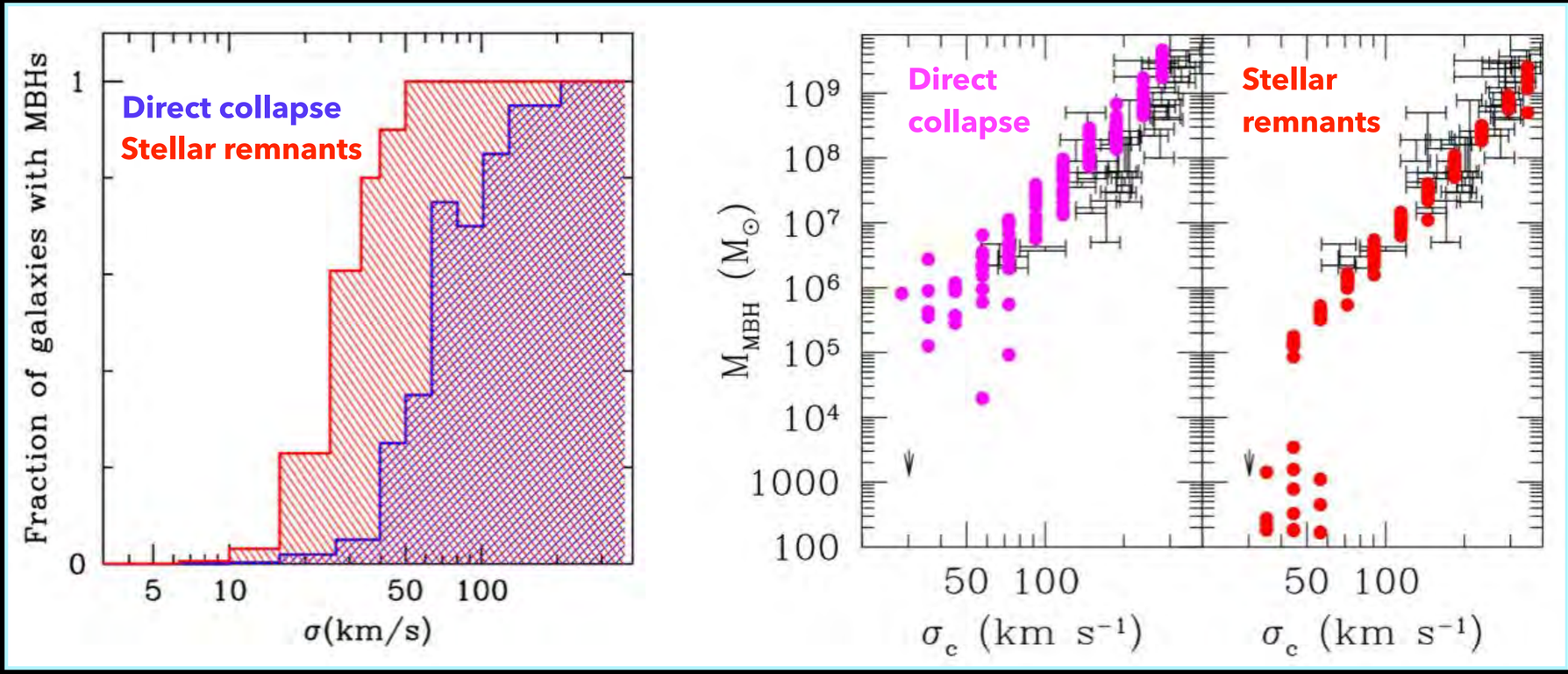


- M_{BH} ~10^5 -10^6 M_{sun}
- rare

for reviews, see e.g., Volonteri (2010); Natarajan (2014); Johnson & Haardt (2016); Latif & Ferrara (2016)

Models of BH growth in a cosmological context predict that the observational signatures indicative of seed formation are strongest in dwarf galaxies

predictions at z=0



BH occupation fraction

M_{BH}-host galaxy relations

Volonteri et al. (2008); van Wassenhove et al. (2010); also see Ricarte & Natarajan (2018)