Wandering Massive Black Holes in Dwarf Galaxies

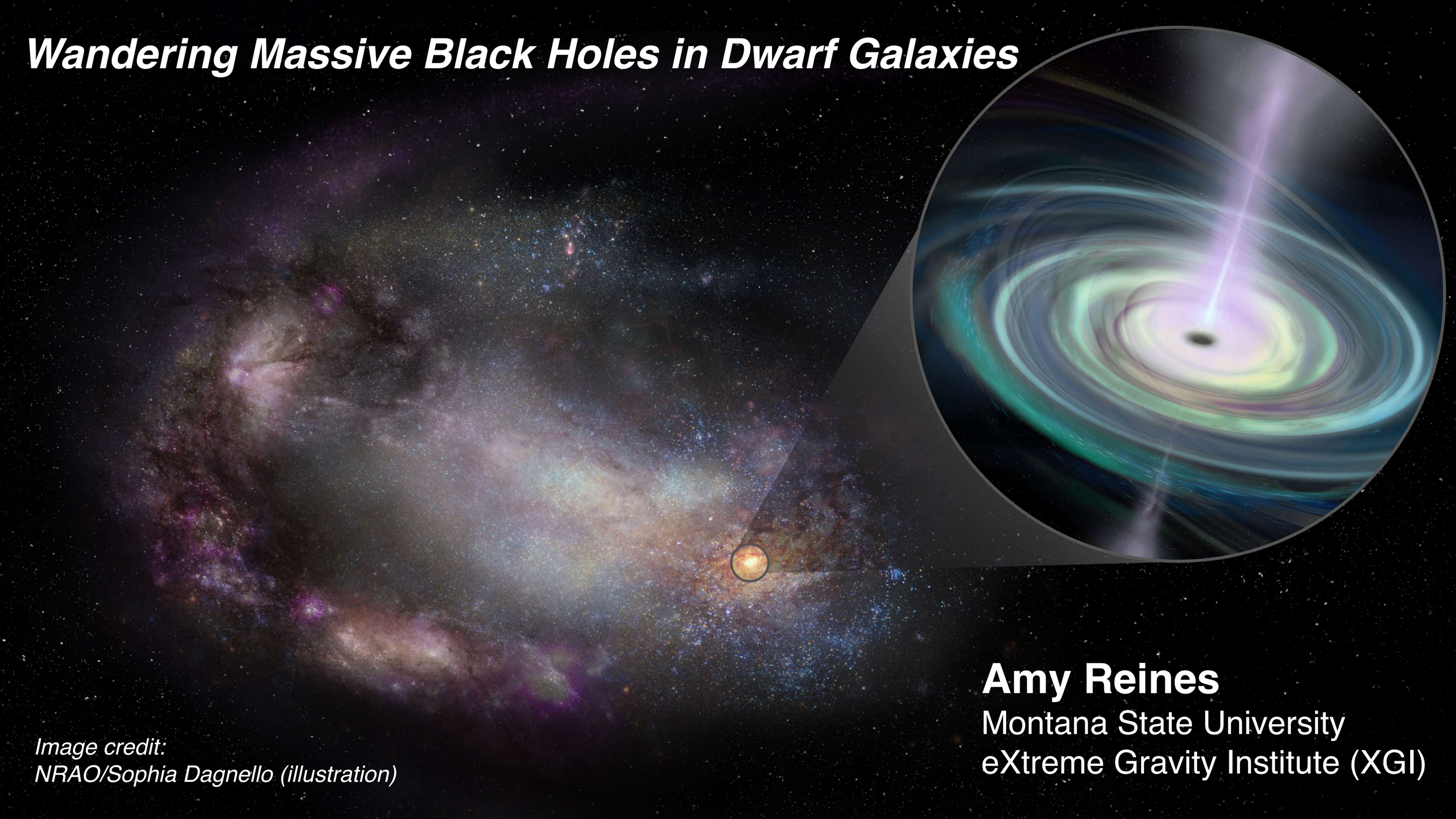
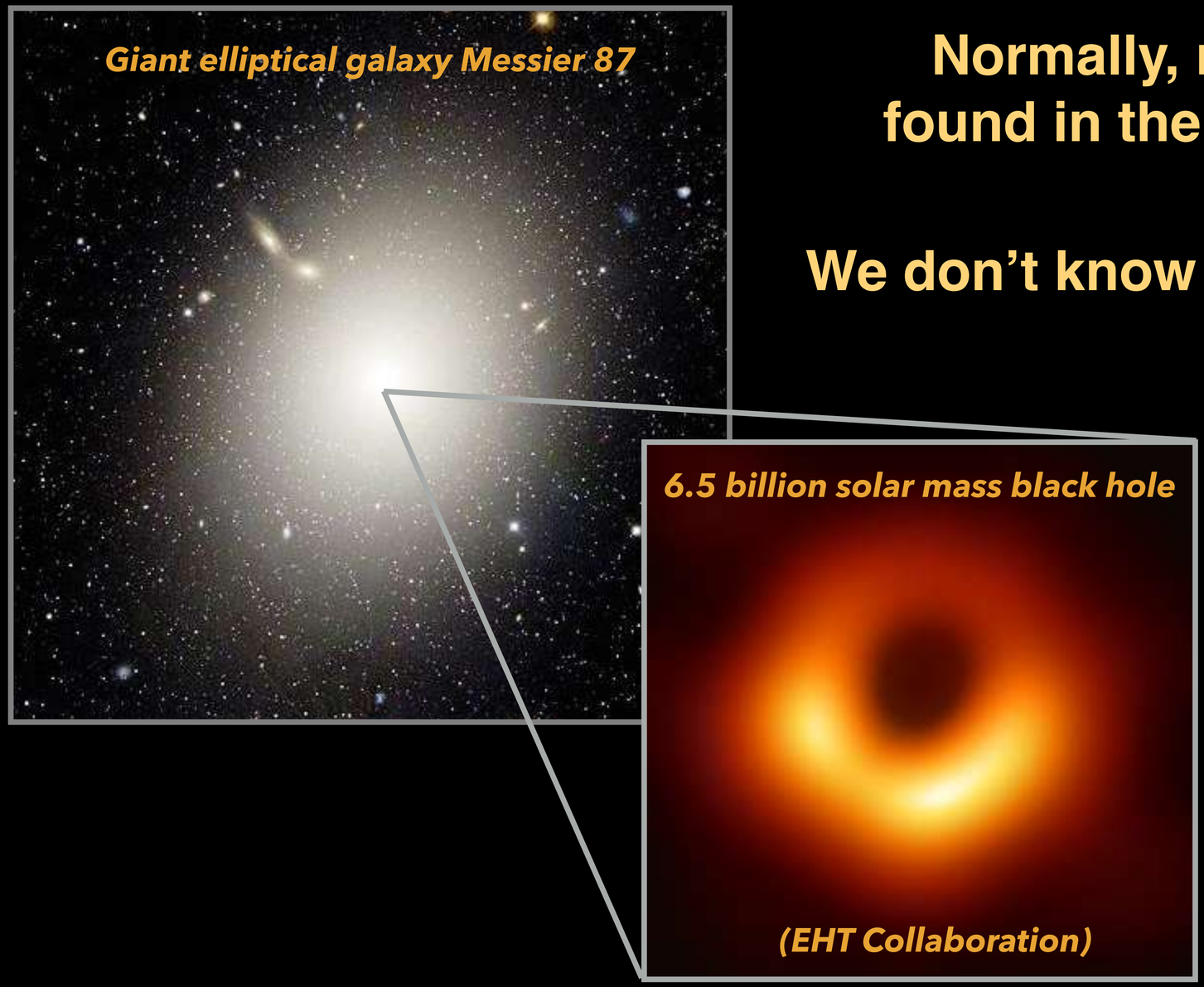


Image credit:
NRAO/Sophia Dagnello (illustration)

Amy Reines
Montana State University
eXtreme Gravity Institute (XGI)

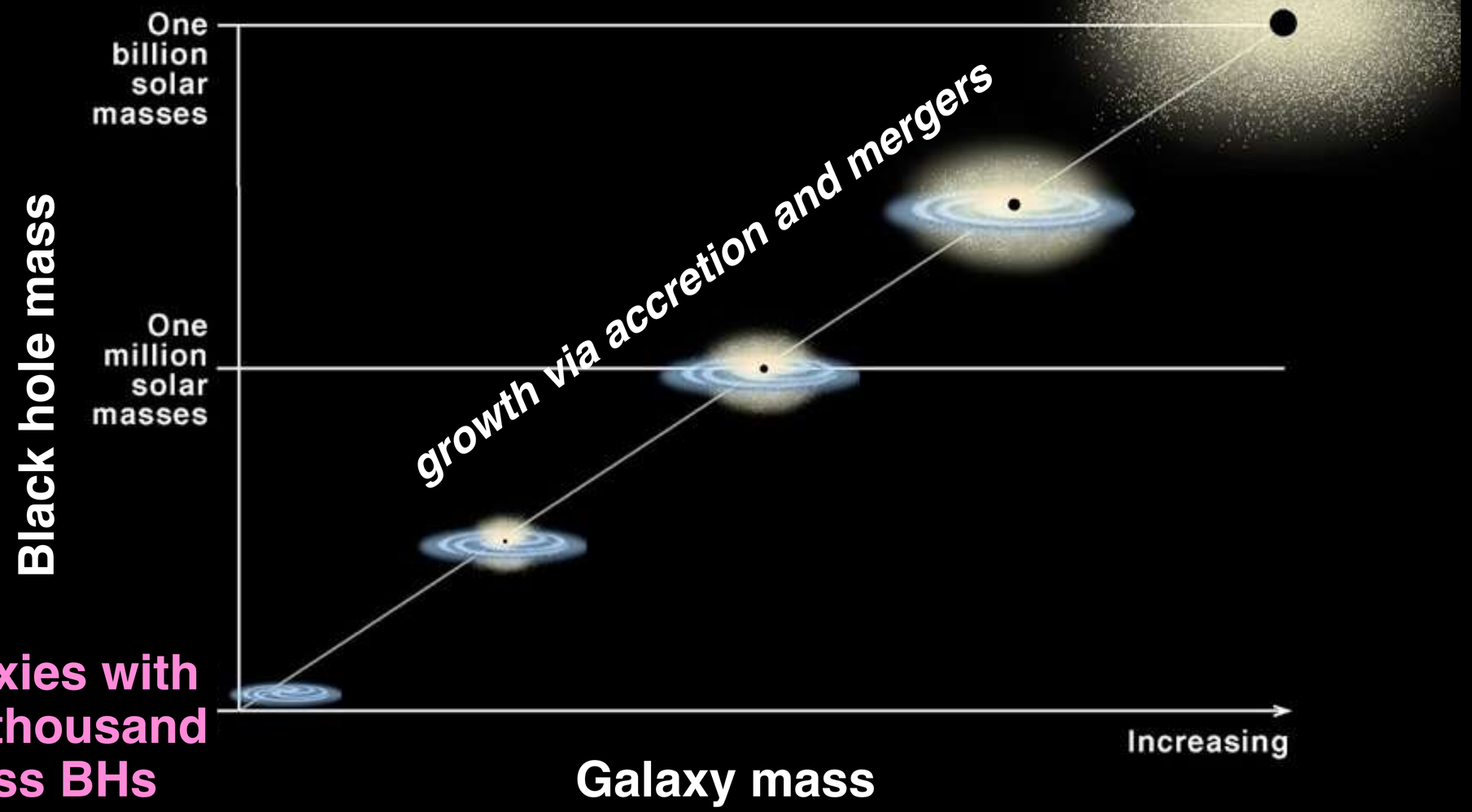


Normally, massive black holes are found in the centers of giant galaxies.

We don’t know how these black holes form!

How massive were the first black hole seeds?

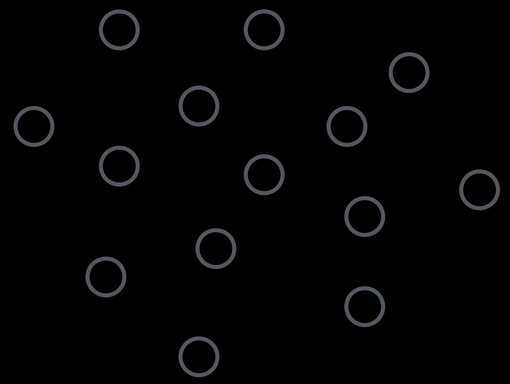
Giant galaxies with
> billion solar-mass BHs



Dwarf galaxies with
< hundred thousand
solar-mass BHs

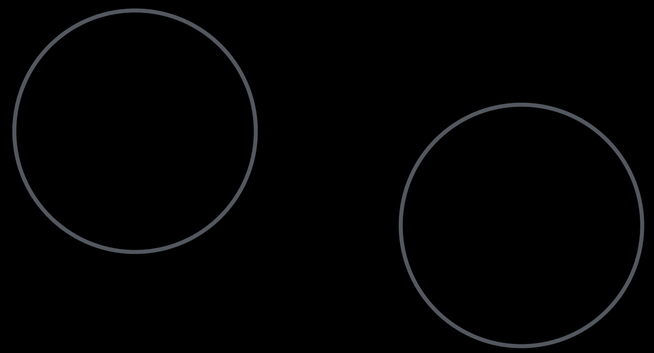
Theory: Possible black hole seed formation mechanisms

Remnants from first generation of massive stars



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

Direct collapse of dense gas

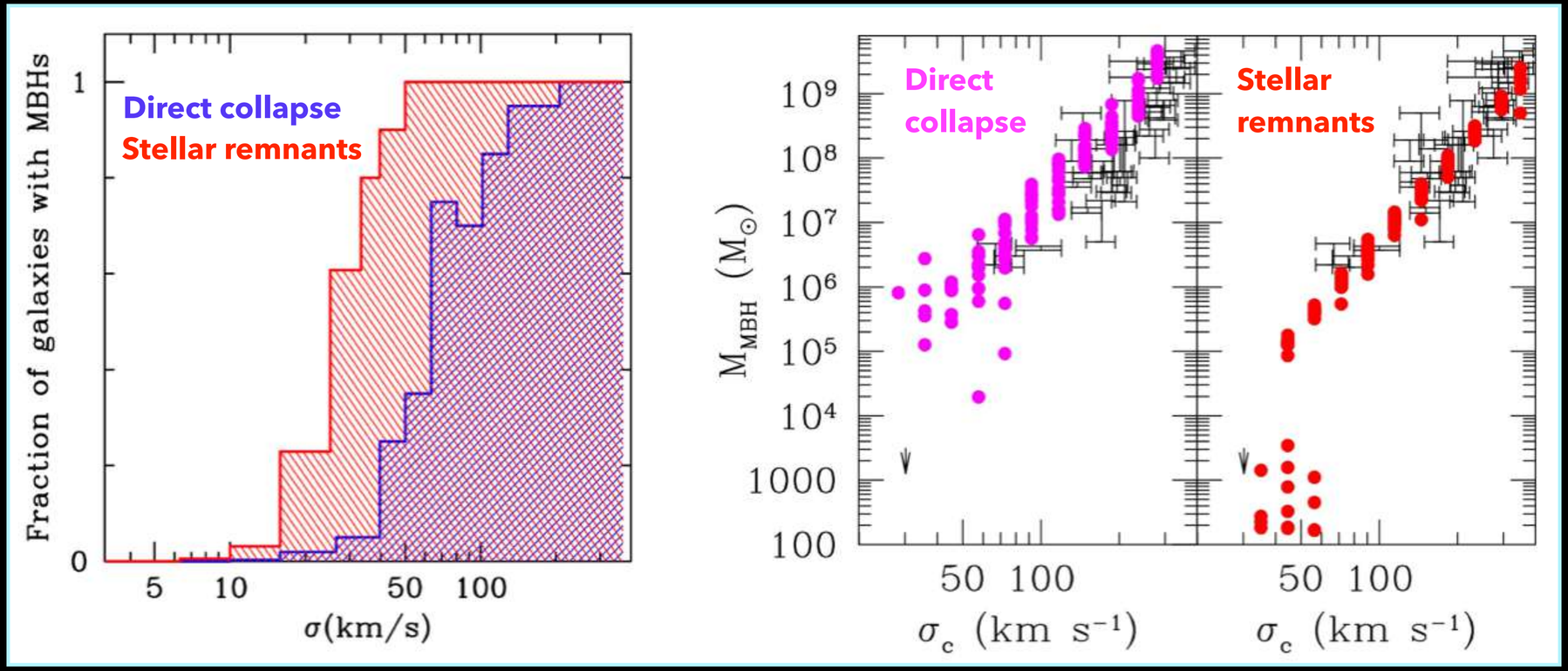


- M_{BH} ~10^5 -10^6 M_{sun}
- rare

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

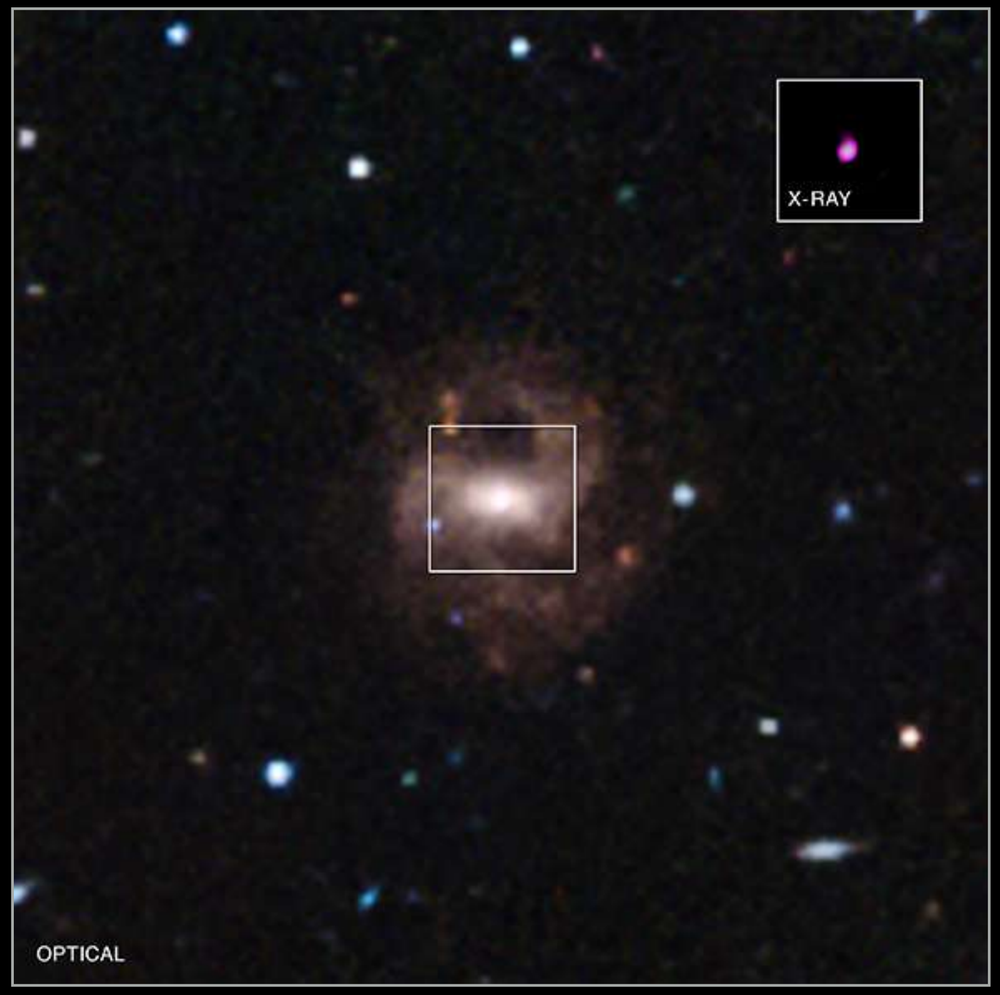


BH occupation fraction

M_{BH}-host galaxy relations

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

Observations: The smallest BHs in dwarf galaxies place the most concrete limits on the masses of BH seeds.



RGG 118:
Dwarf galaxy with
M_{BH} ~50,000 M_{sun}

Baldassare, Reines, Gallo & Greene (2015, 2017)

The focus of my research is to search for and study massive black holes in dwarf galaxies.

This is currently our best observational probe of the origin of massive black holes.

Optical Searches

- **Lots of progress in recent years**

For example:

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

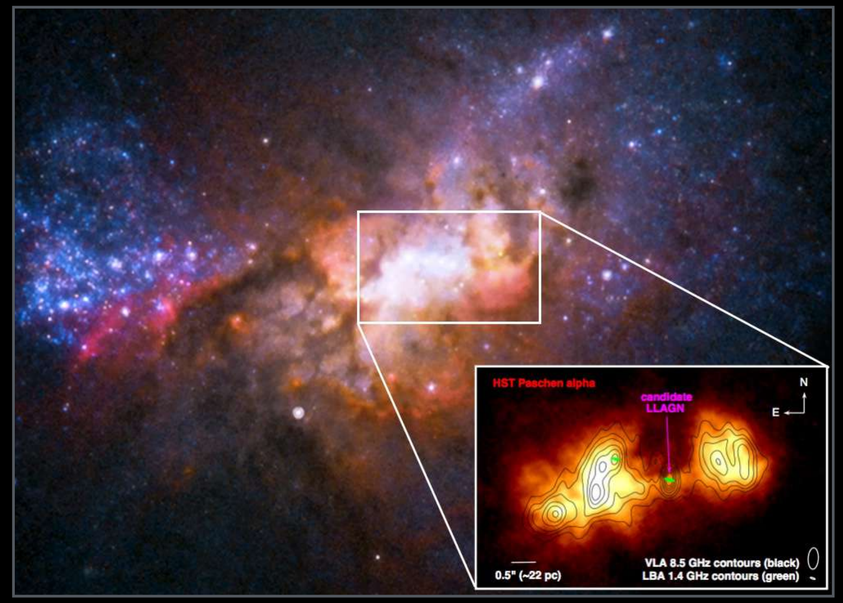
~ 50,000 M_{sun} black hole in RGG 118
(Baldassare, Reines et al. 2015)

M_{BH} — M_{bulge} relation including dwarfs
(Schutte, Reines & Greene 2020)

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

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

"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)

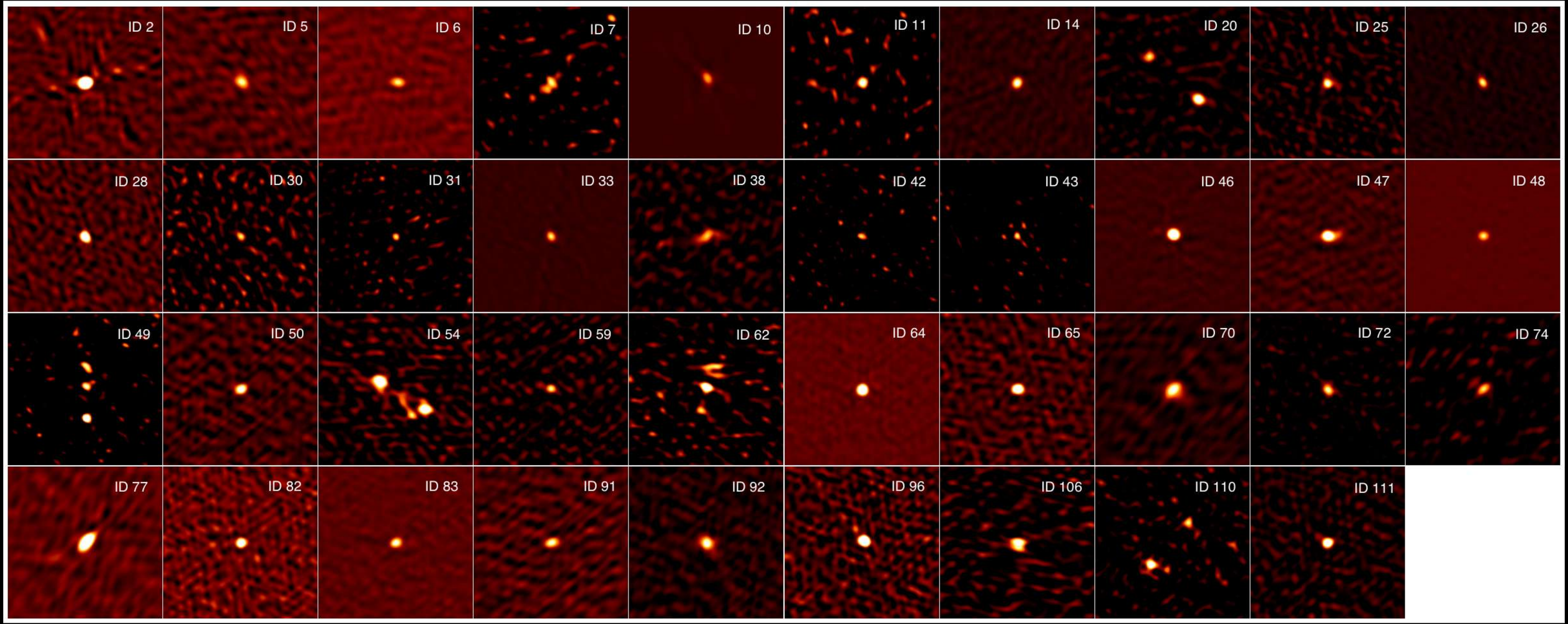
Wandering Massive Black Holes in Dwarf Galaxies

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

- VLA observations of 111 dwarf galaxies with $M_{star} < 3 \times 10^9 M_{sun}$, $z<0.055$
- Previously detected in FIRST radio survey at low angular resolution (origin of radio emission is unclear)
- New observations have much higher angular resolution (0.25") and are also much more sensitive (rms ~ 15 uJy), which can help distinguish between massive black holes and star formation

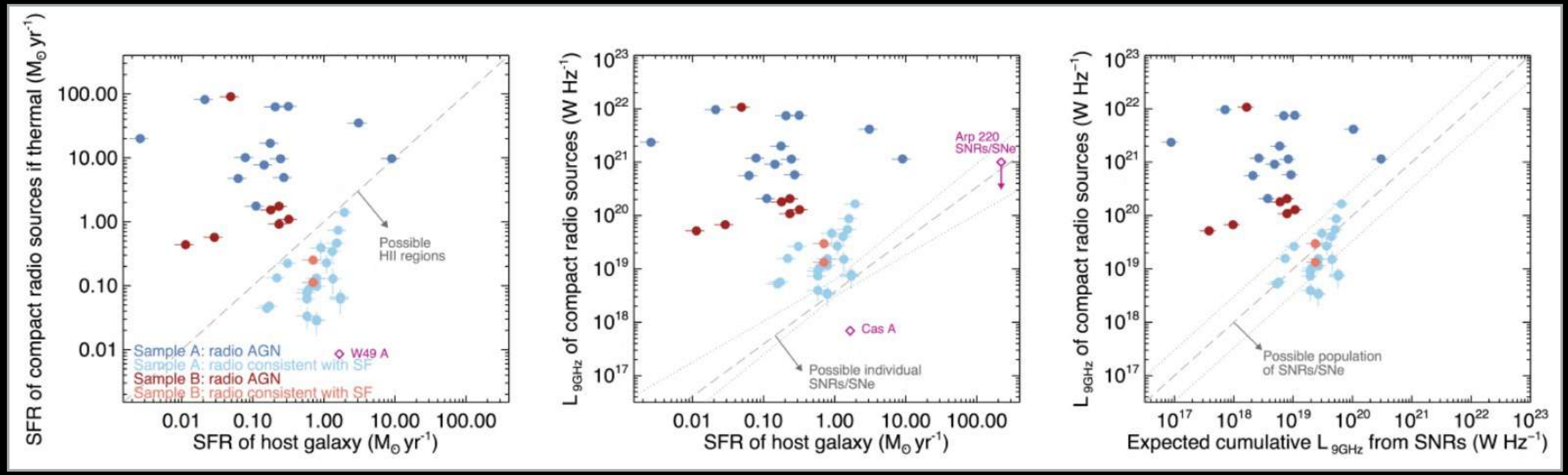
Wandering Massive Black Holes in Dwarf Galaxies

VLA – 4″ x 4″ cutouts



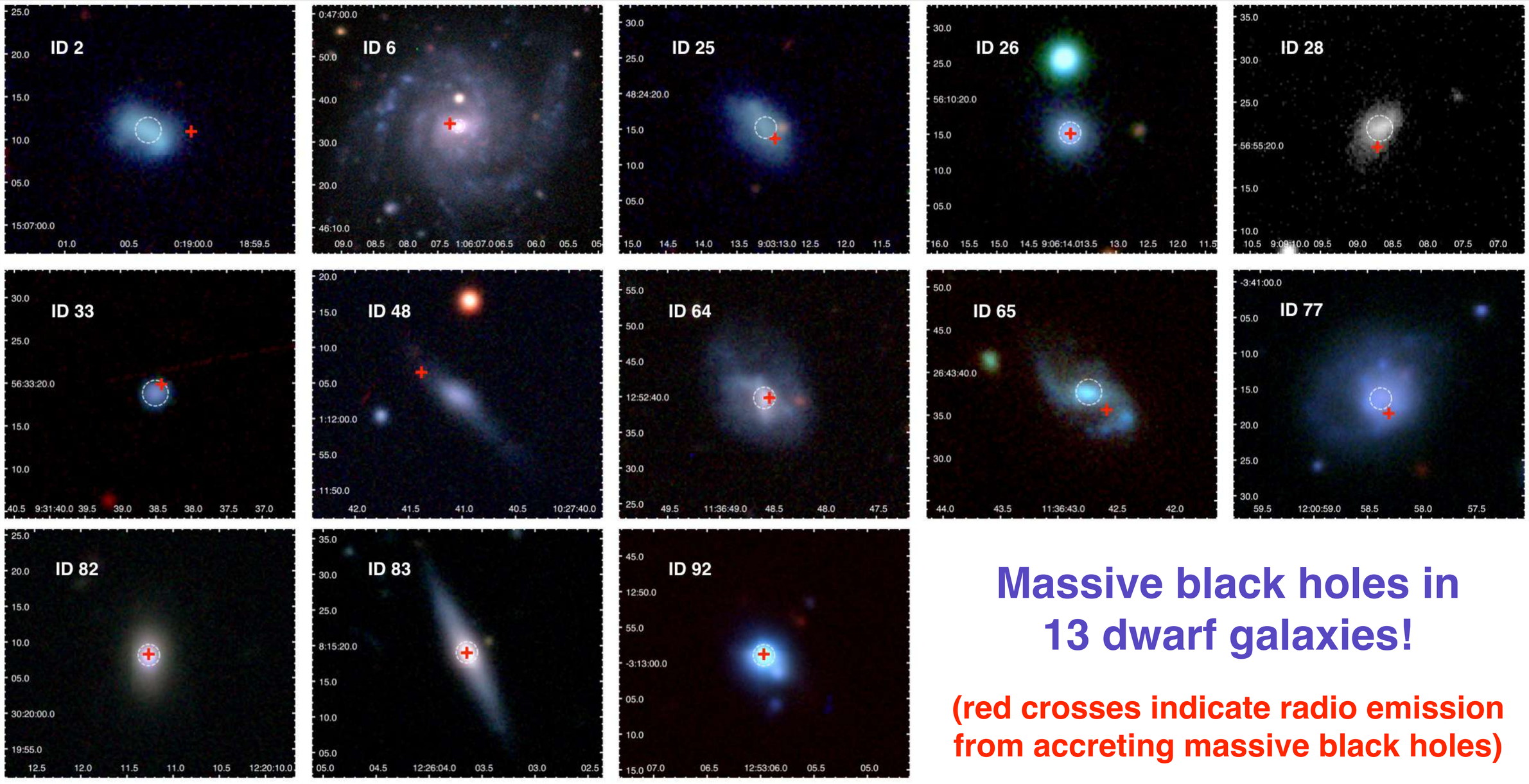
39 out of 111 galaxies with compact radio source detections
(35% detection rate)

Wandering Massive Black Holes in Dwarf Galaxies



- 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.

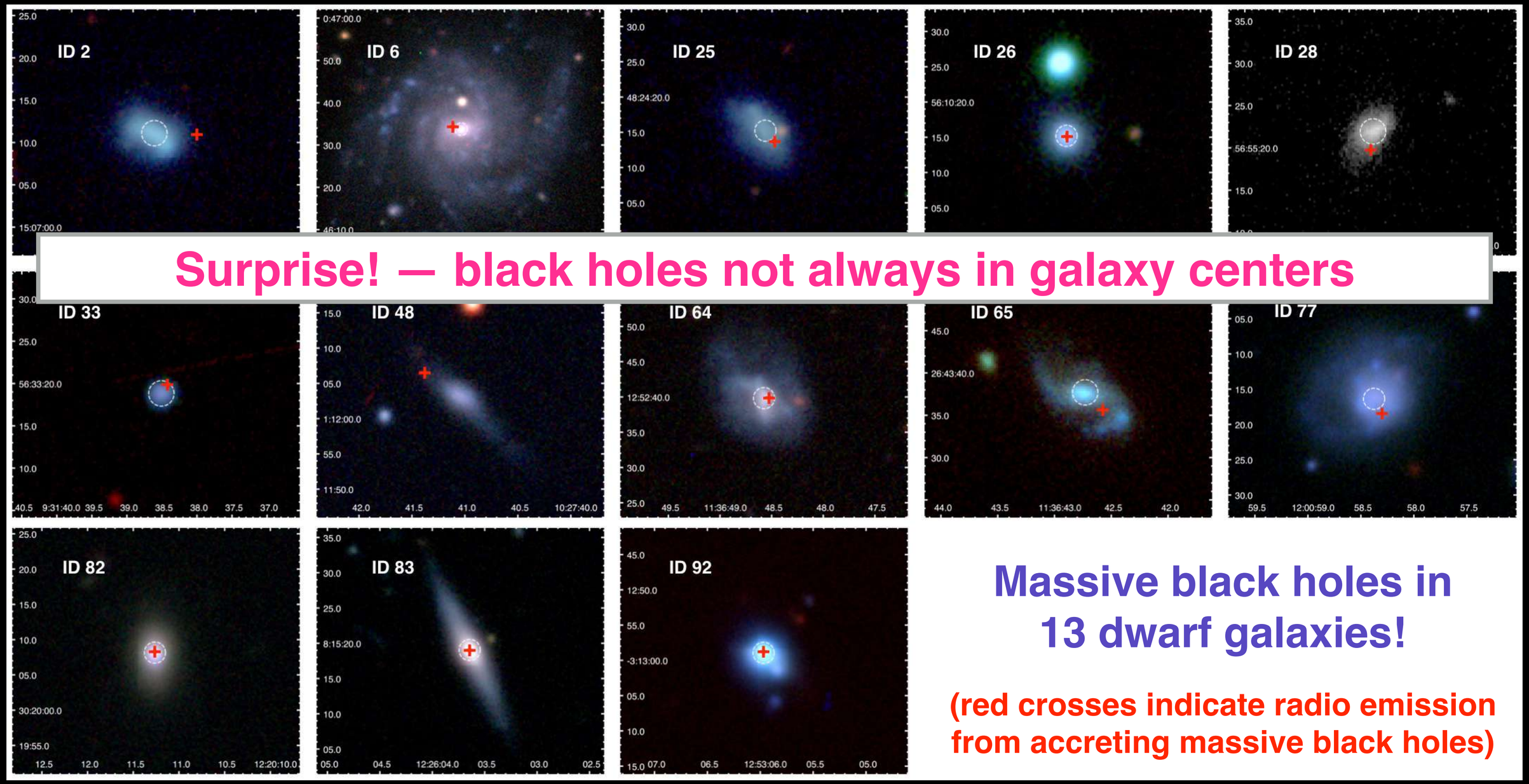
Wandering Massive Black Holes in Dwarf Galaxies



Massive black holes in 13 dwarf galaxies!

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

Wandering Massive Black Holes in Dwarf Galaxies

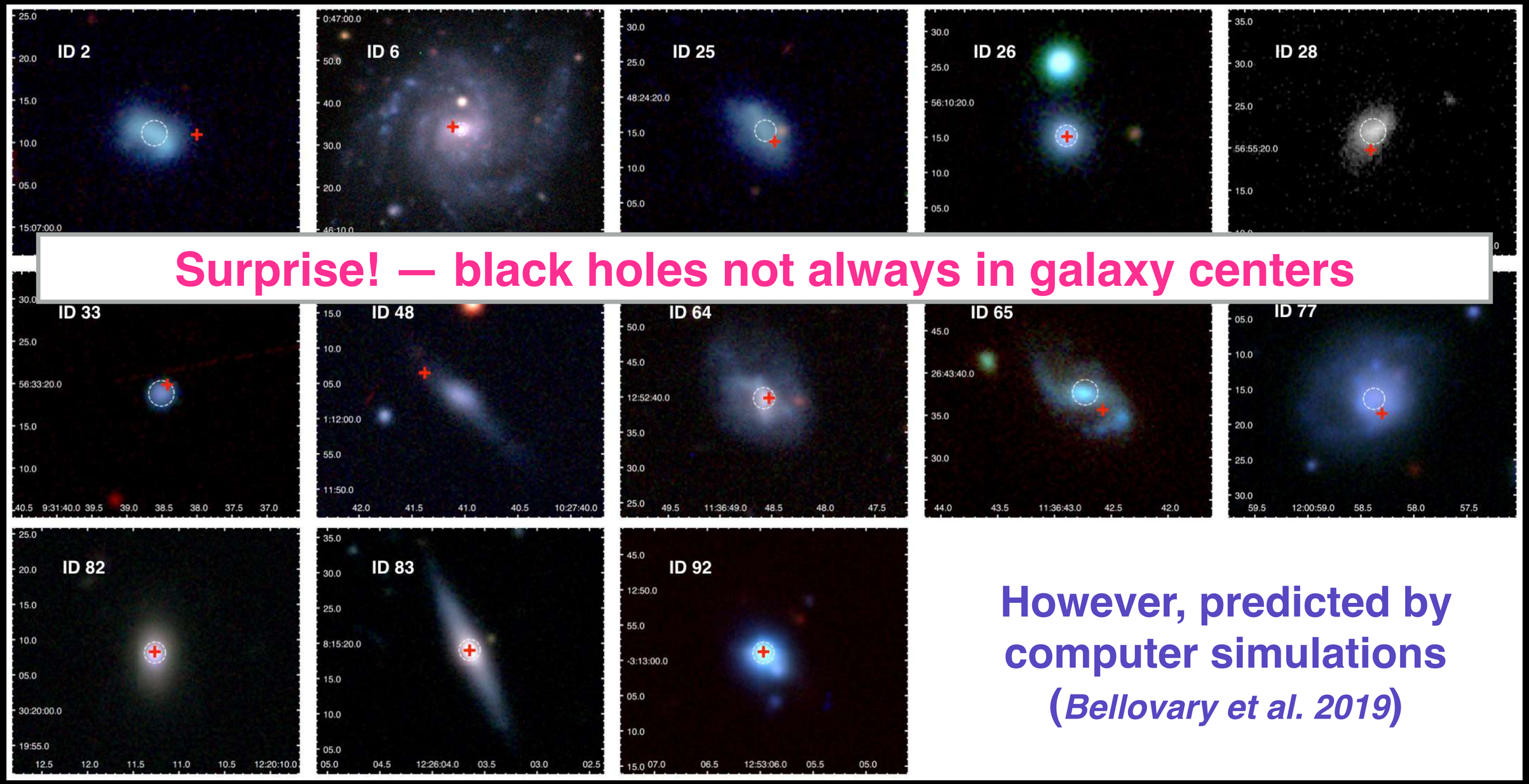


Surprise! — black holes not always in galaxy centers

Massive black holes in 13 dwarf galaxies!

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

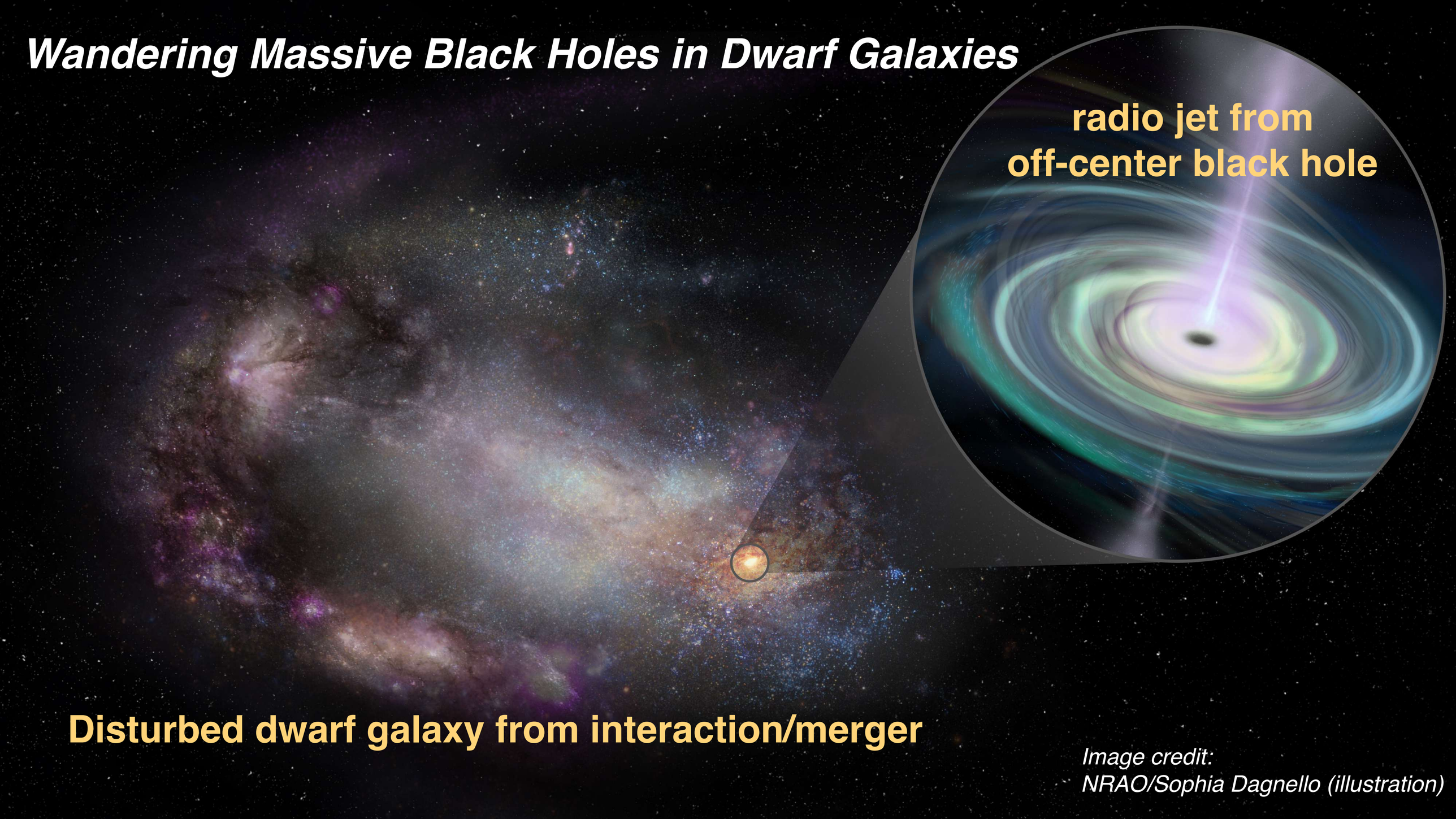
Wandering Massive Black Holes in Dwarf Galaxies



Surprise! — black holes not always in galaxy centers

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

Wandering Massive Black Holes in Dwarf Galaxies



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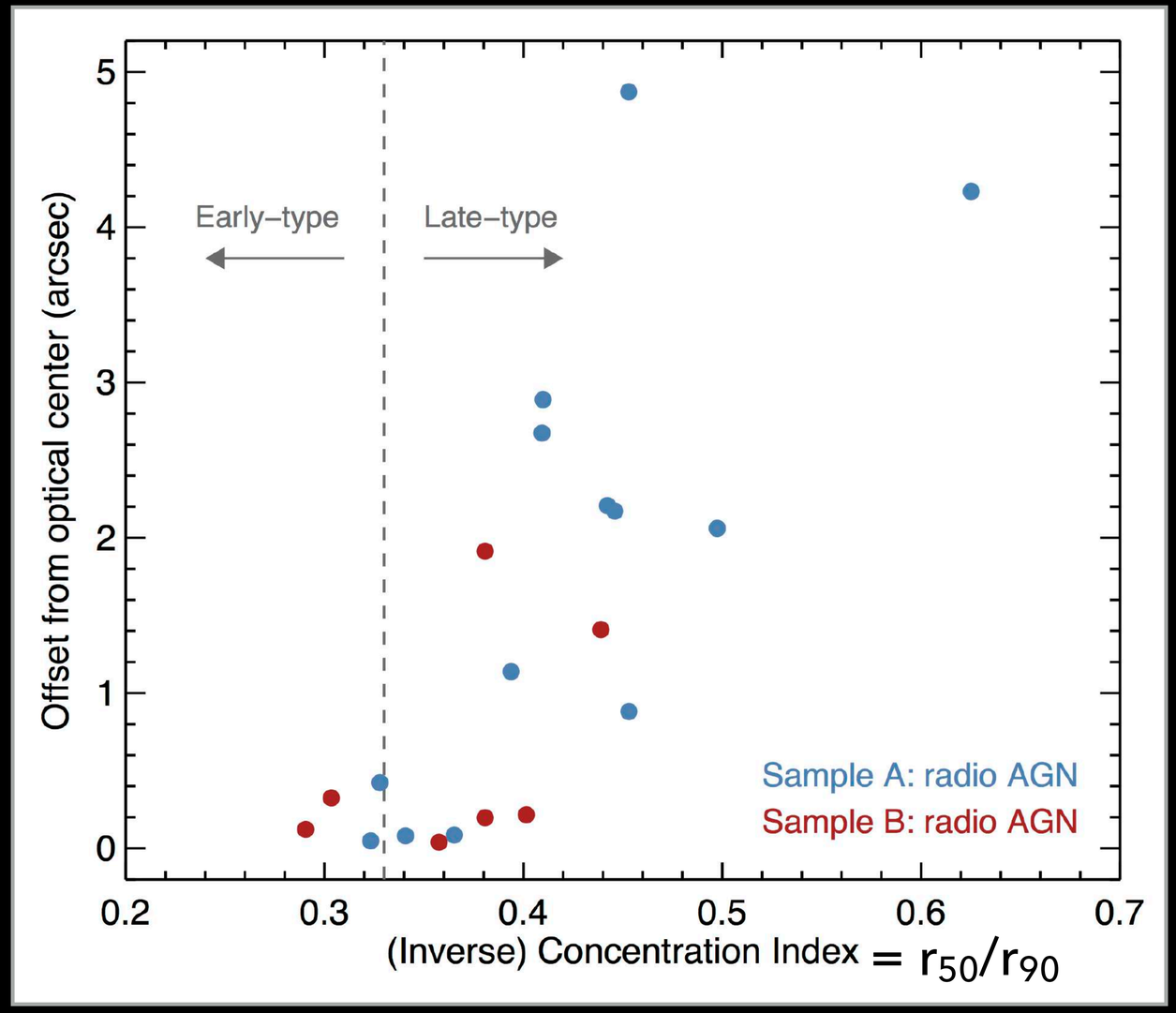
Wandering Massive Black Holes in Dwarf Galaxies

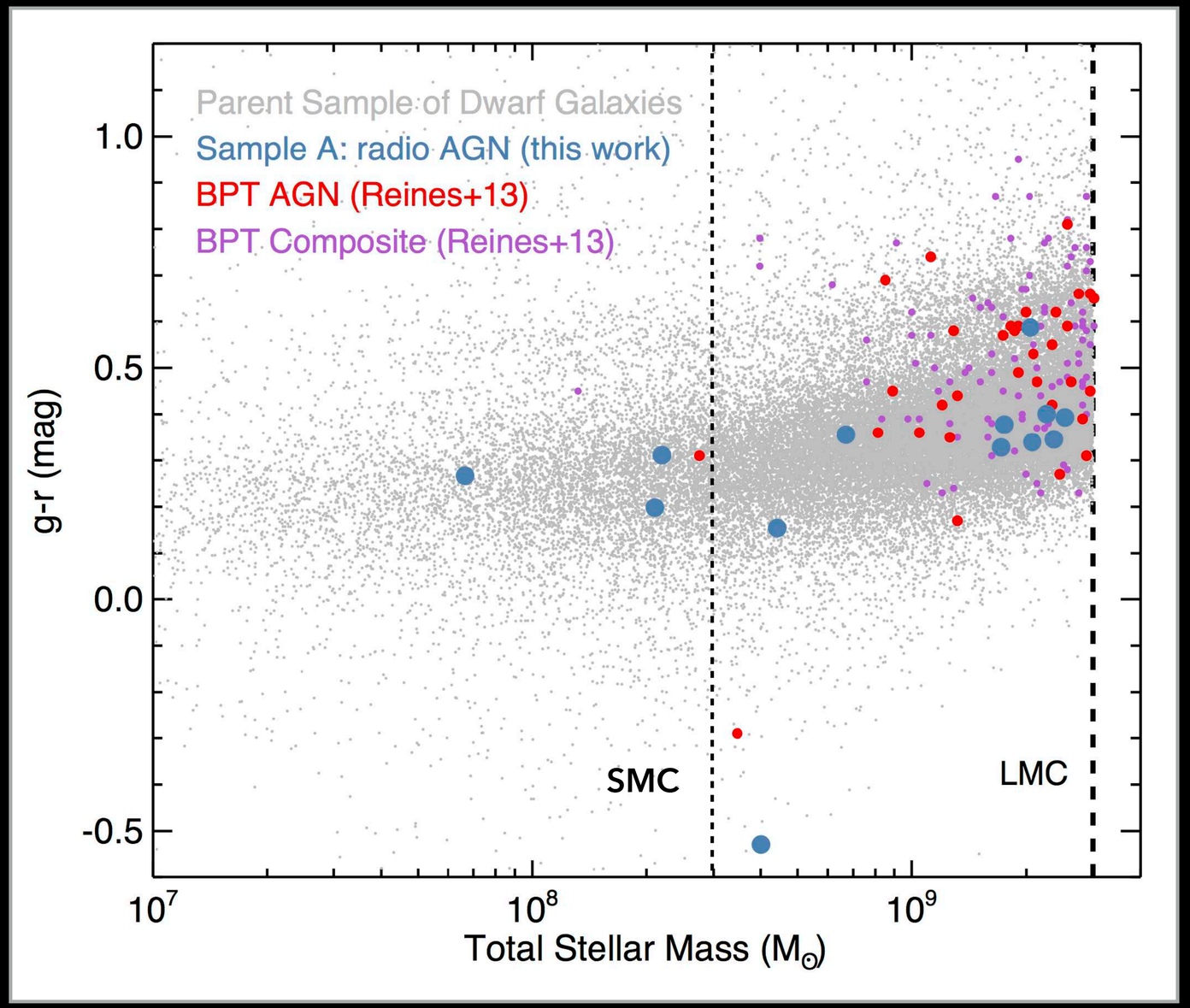


Extended/disturbed/ later-type galaxies tend to have more <u>offset</u> BHs

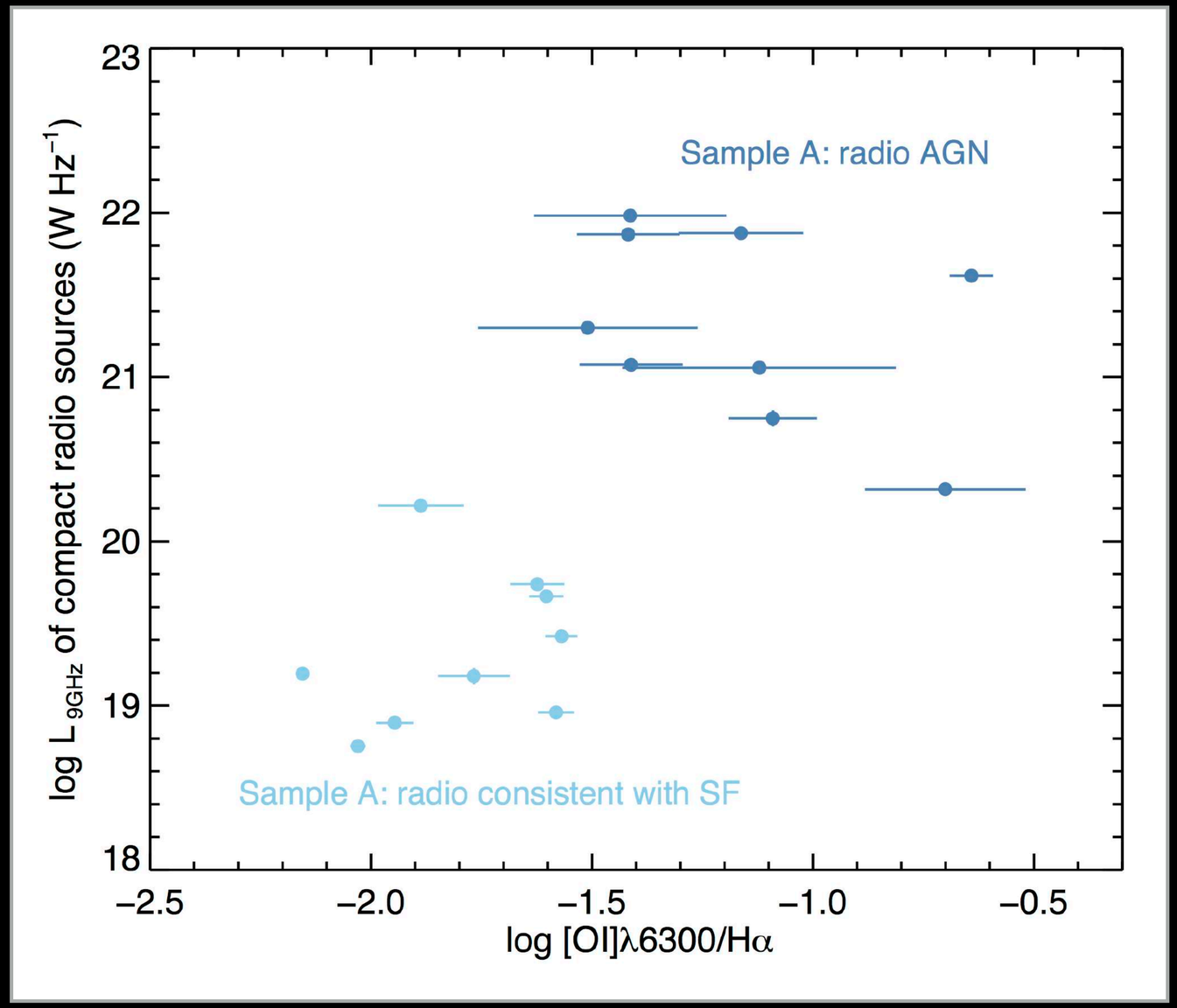
Regular/nucleated/ earlier-type galaxies tend to have more <u>central</u> BHs

Wandering Massive Black Holes in Dwarf Galaxies

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



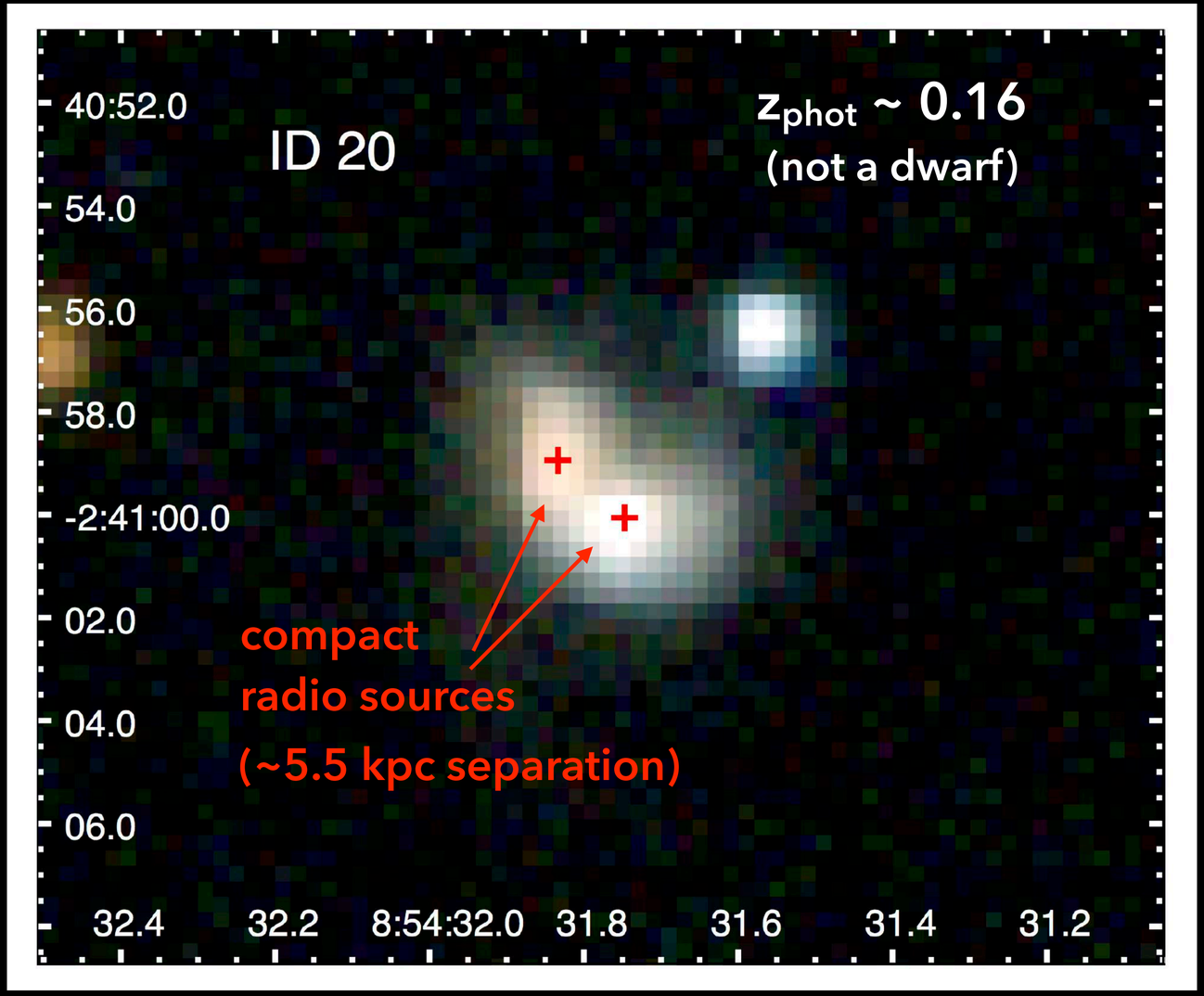
Wandering Massive Black Holes in Dwarf Galaxies



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

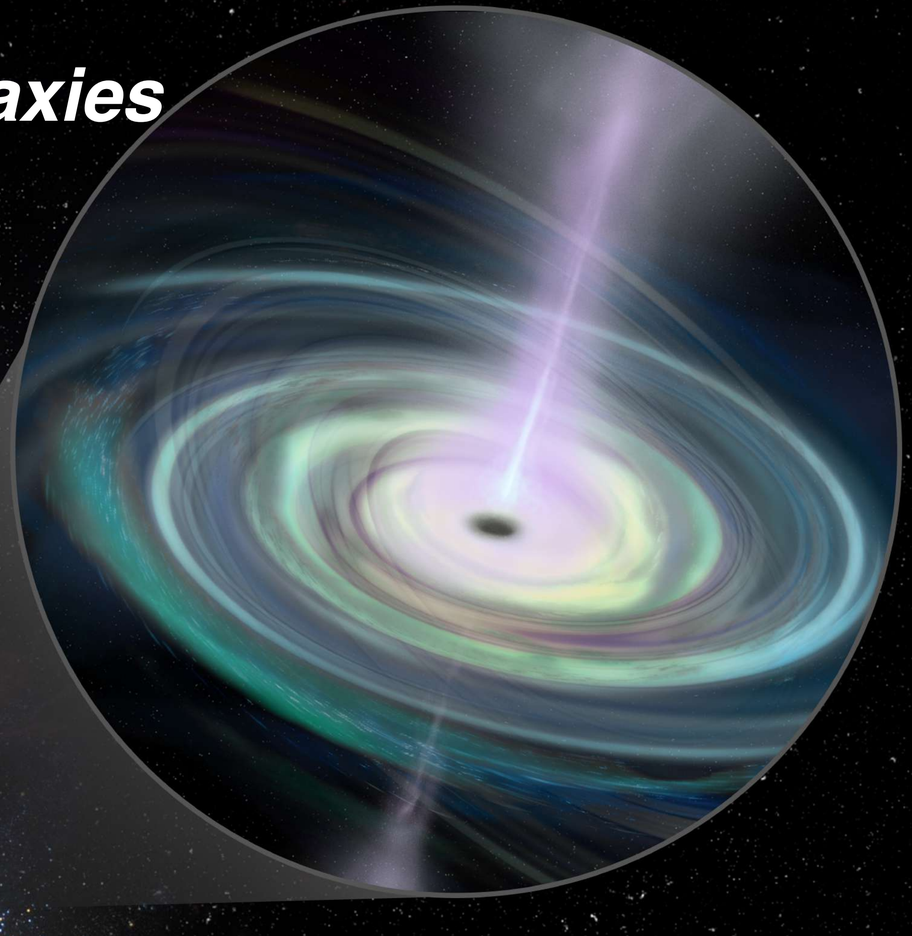
- Radio AGNs are associated with the galaxies producing the line emission
- Unlikely to be background interlopers

Serendipitous discovery of a dual AGN candidate in a more massive galaxy system



Wandering Massive Black Holes in Dwarf Galaxies

Reines et al. 2020, ApJ, 888, 1
(arXiv:1909.04670)



- Found massive BHs wandering around dwarf galaxies, as predicted by simulations.
- Searches attempting to constrain BH seed formation using dwarf galaxies need to account for such a population of ‘wandering’ BHs in the outskirts of their hosts.
- This work highlights the potential of deep, high-resolution radio observations (e.g., with an ngVLA) to make further progress in this field *(e.g., Plotkin & Reines 2018)*.

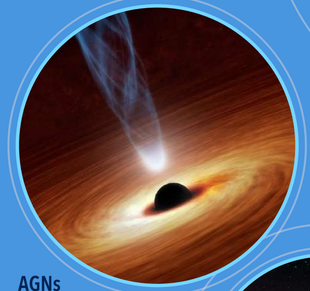
MONTANA STATE UNIVERSITY

DEPARTMENT OF PHYSICS & EXTREME GRAVITY INSTITUTE (XGI)

Gravitational Waves

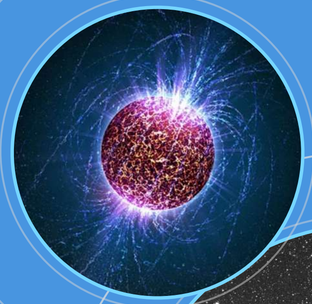
Astrophysics Research

- Gravitational Waves
- Extragalactic Astronomy
- Galactic Astronomy
- Solar Physics
- Space Physics
- Physics/Astro Education



AGNs

Neutron Stars



Small Bodies in the Solar System

The Milky Way
and its Satellite Galaxies

Galaxies, Black Holes and Star Formation

Department Info

- 19 faculty (4 women, 6 junior faculty)
- ~70 graduate students
- Women+ in Physics Group
- Friendly environment and regular social activities

Life in Bozeman

- Picturesque town surrounded by beautiful mountains
- Easy access to world-class skiing, hiking, rafting and more
- 90 minutes to Yellowstone National Park
- Vibrant downtown with excellent restaurants, locally-owned shops, galleries and theaters