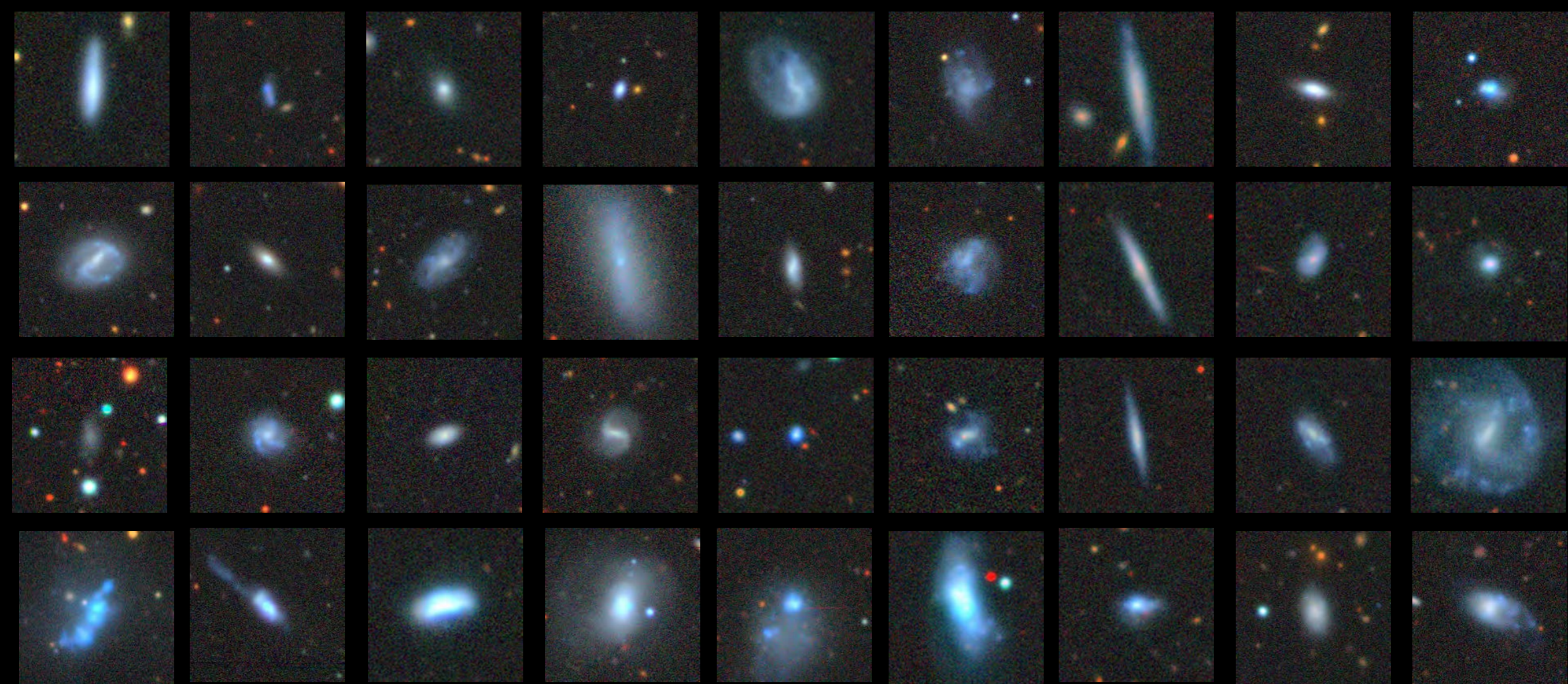


# A New Population of Supermassive Black Holes in Dwarf Galaxies



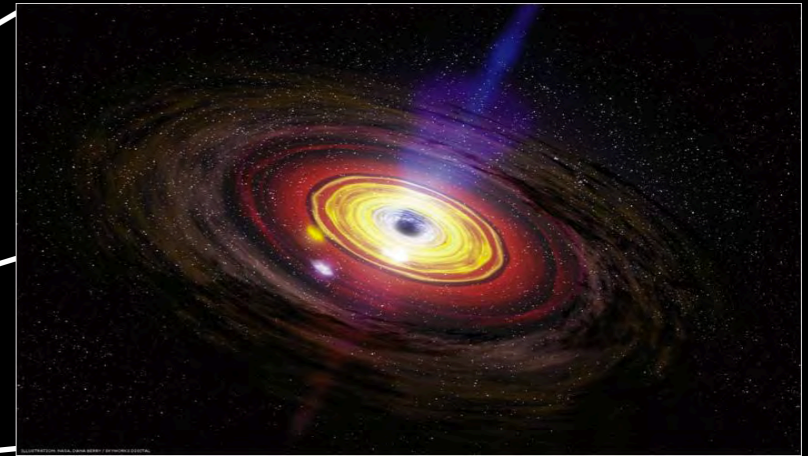
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# Galaxies are a collection of different astronomical objects



A supermassive black hole resides in the center of most massive galaxies.

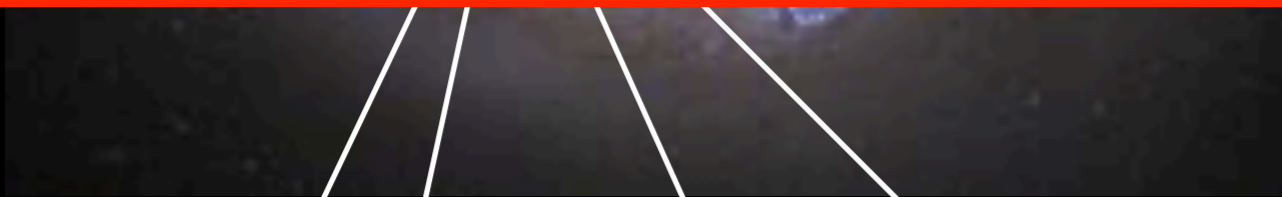


Outside of the center there are stars, dust and gas.

# Galaxies are a collection of different astronomical objects



**How did the first black holes form in the early Universe?**



of most massive galaxies.



Outside of the center there are stars, dust and gas.



# Detecting the first generation of black holes in the early universe is not currently possible

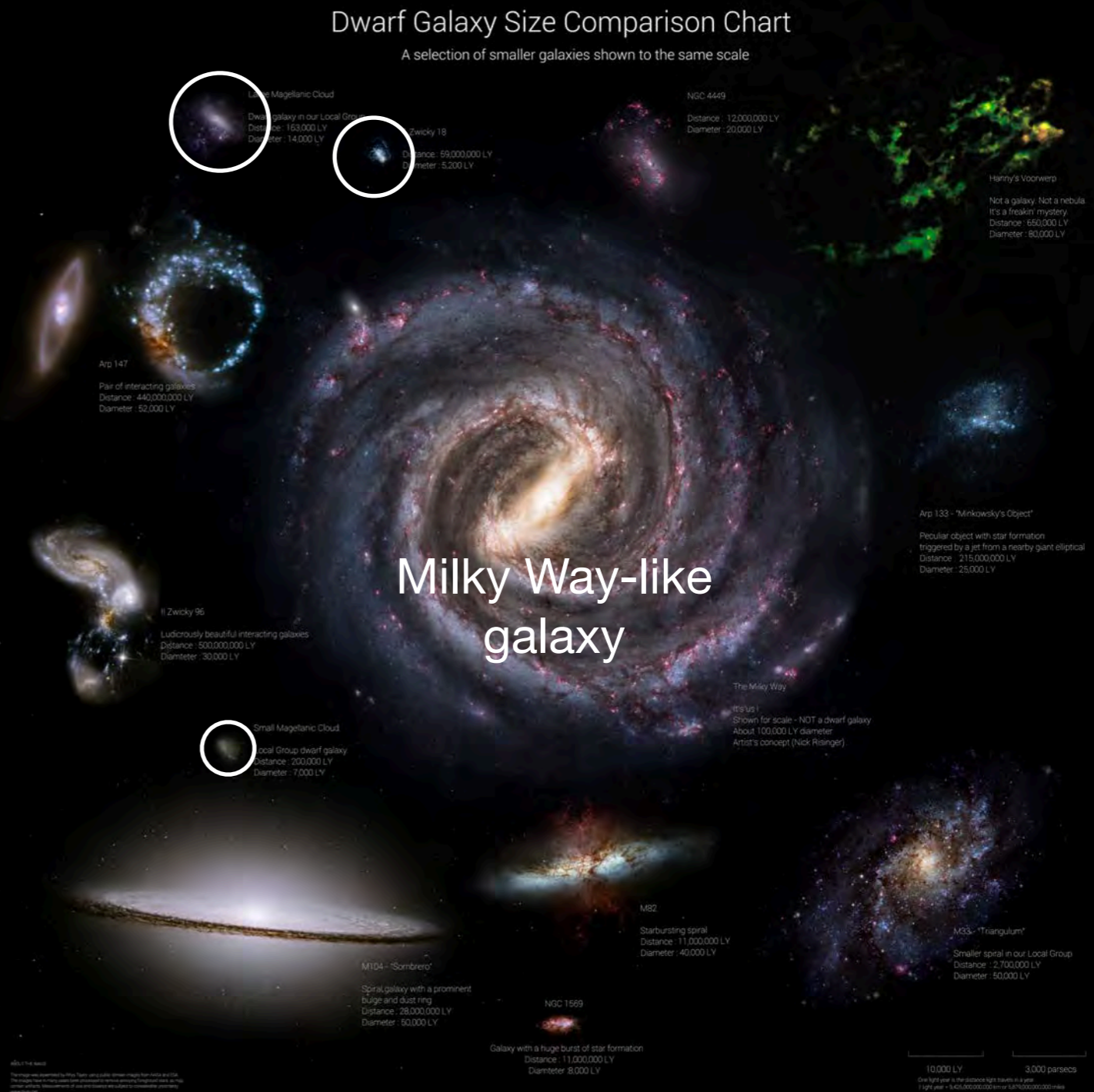
We can only detect ***the total*** light from galaxies in the early universe.



Only quasars, with  $\sim 1$  billion solar mass black holes that ***outshine their entire galaxy***, are confidently detected.

# Supermassive black holes in nearby dwarf galaxies provide clues about the first generation of black holes

- Dwarf galaxies are 10–100 times smaller than Milky Way
- Dwarf galaxies are relatively untouched over cosmic time
- The supermassive black holes found in dwarfs are typically 100,000 solar masses





# Supermassive black holes in nearby dwarf galaxies provide clues about the first generation of black holes

- Dwarf galaxies are 10–100

**Since supermassive black holes in dwarf galaxies are *smaller and less luminous*, they are harder to detect**

found in dwarfs are typically 100,000 solar masses

Dwarf Galaxy Size Comparison Chart

A selection of smaller galaxies shown to the same scale



Small Magellanic Cloud

Local Group dwarf galaxy  
Distance: 200,000 LY  
Diameter: 7,000 LY

The Milky Way  
It's us!  
Shown for scale - NOT a dwarf galaxy  
About 100,000 LY diameter  
Artist's concept (Nick Risinger)

M104 - "Sombrero"  
Spiral galaxy with a prominent  
bulge and dust ring  
Distance: 28,000,000 LY  
Diameter: 50,000 LY

M82  
Starbursting spiral  
Distance: 11,000,000 LY  
Diameter: 40,000 LY

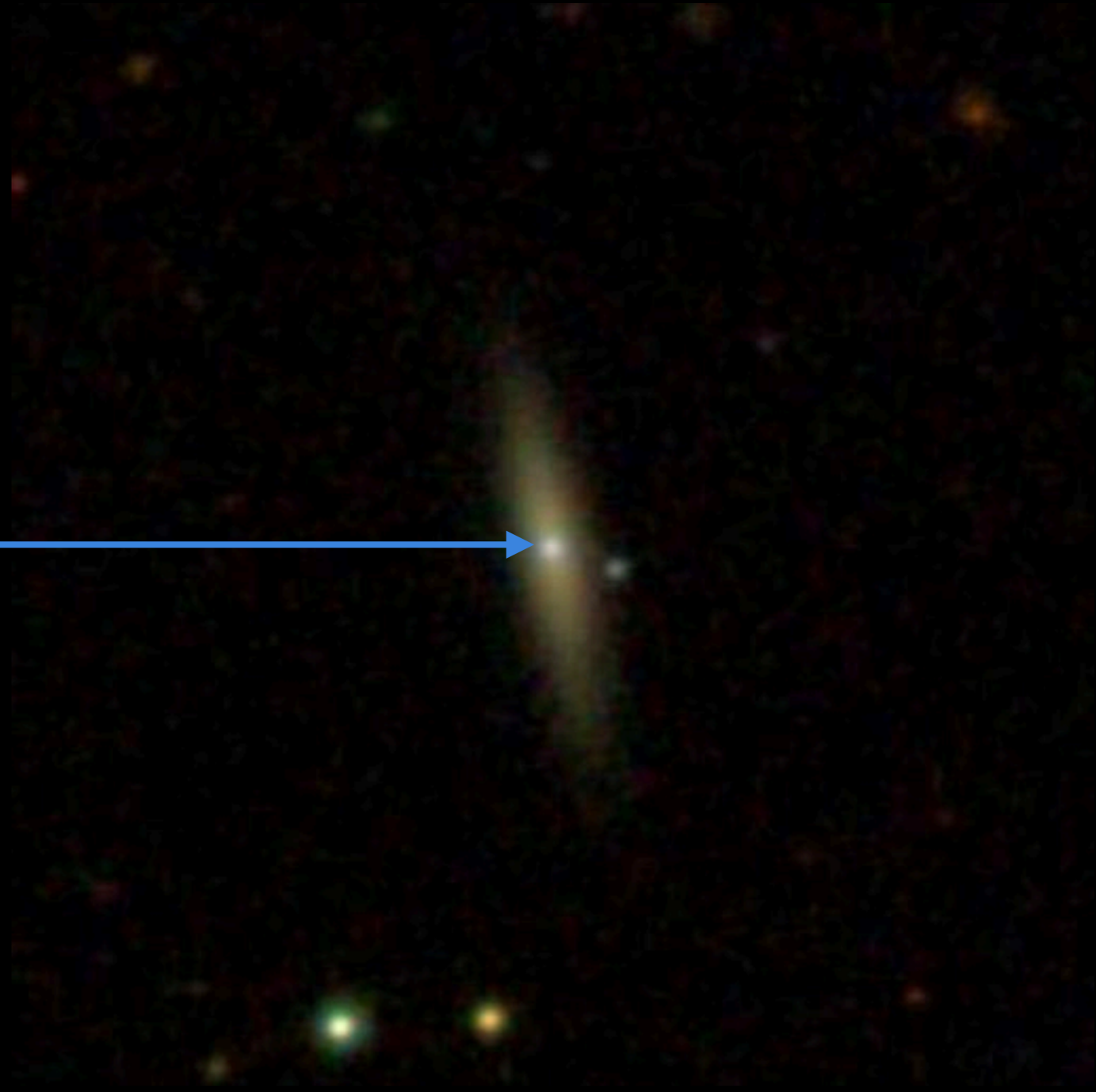
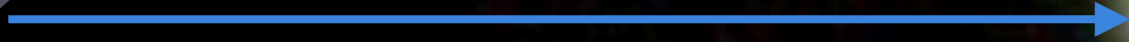
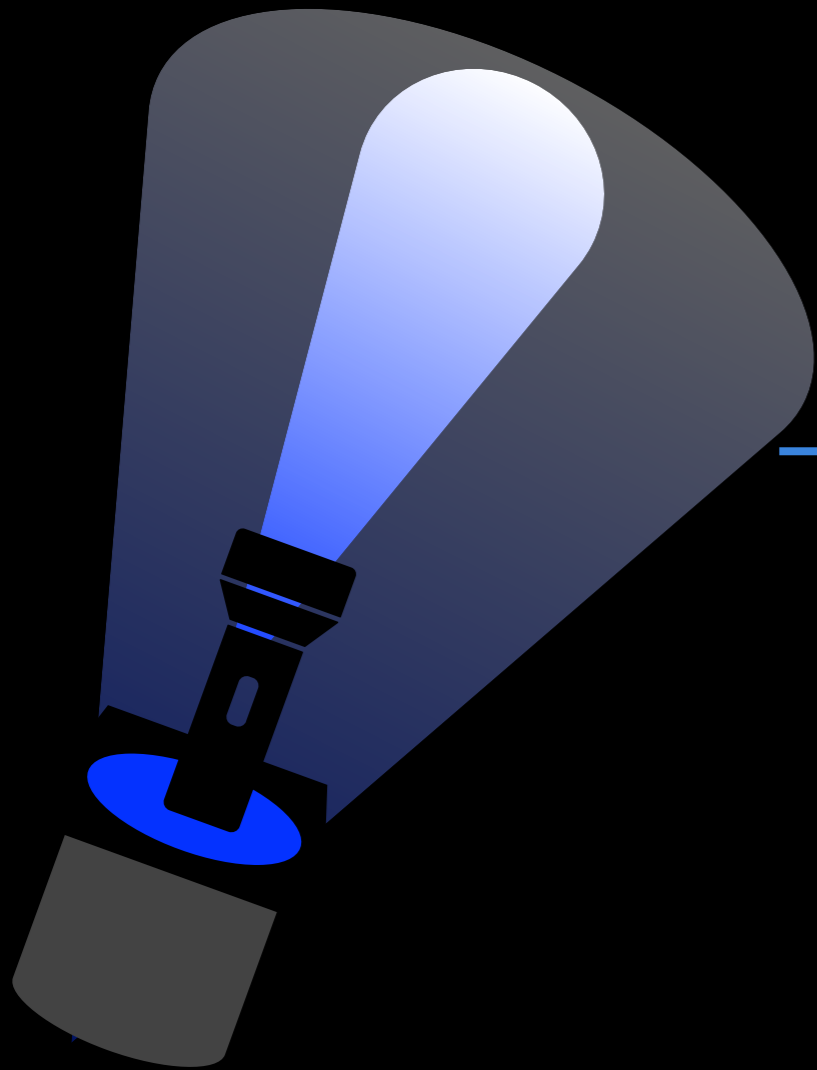
NGC 1569

Galaxy with a huge burst of star formation  
Distance: 11,000,000 LY  
Diameter: 8,000 LY

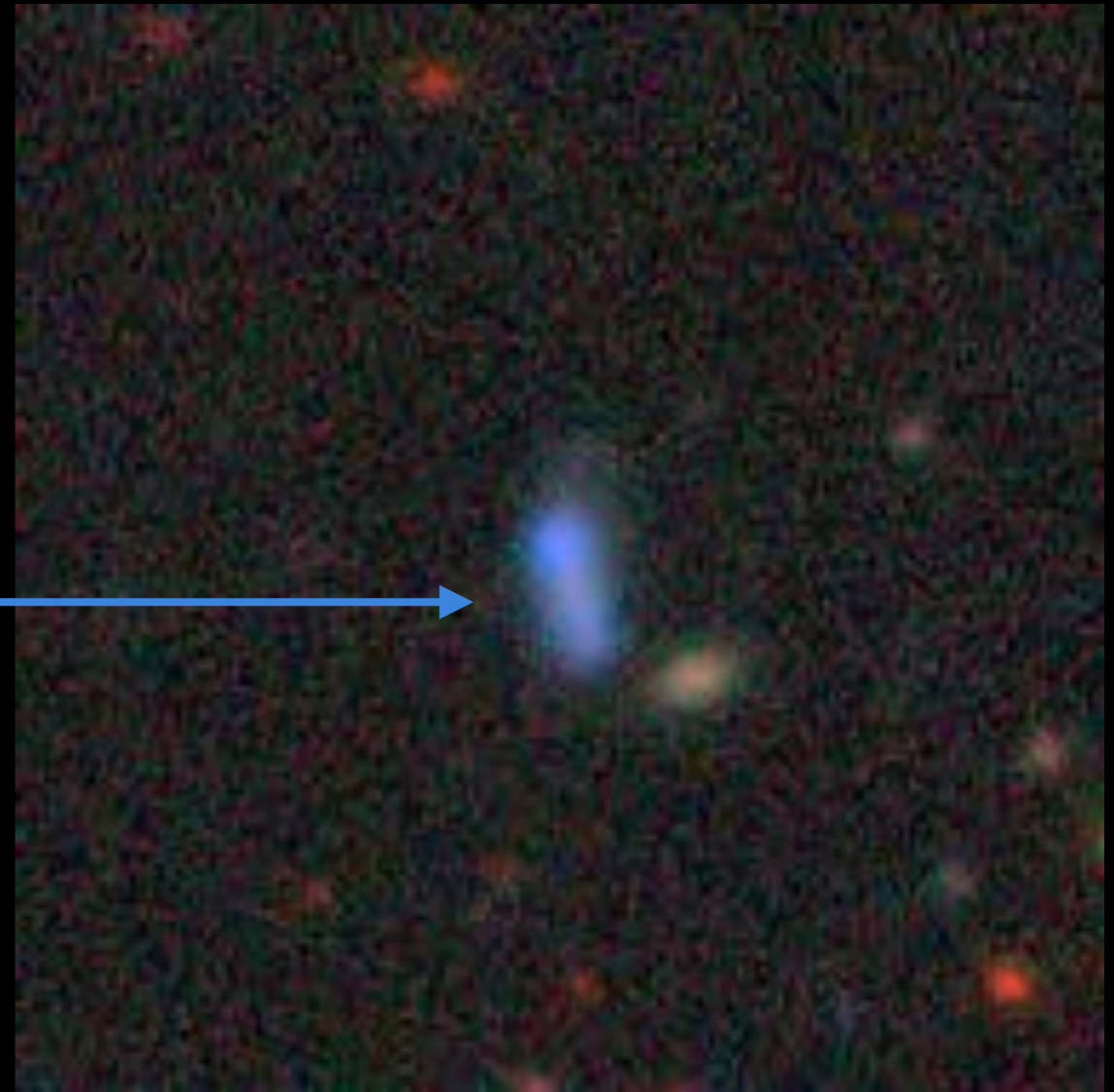
M33 - "Triangulum"  
Smaller spiral in our Local Group  
Distance: 2,700,000 LY  
Diameter: 50,000 LY

10,000 LY      3,000 parsecs  
One light year is the distance light travels in a year  
1 light year = 9,460,800,000,000 m or 5,878,625,370,000 miles

Traditional Optical Methods look for Supermassive Black Holes that can outshine the host galaxy



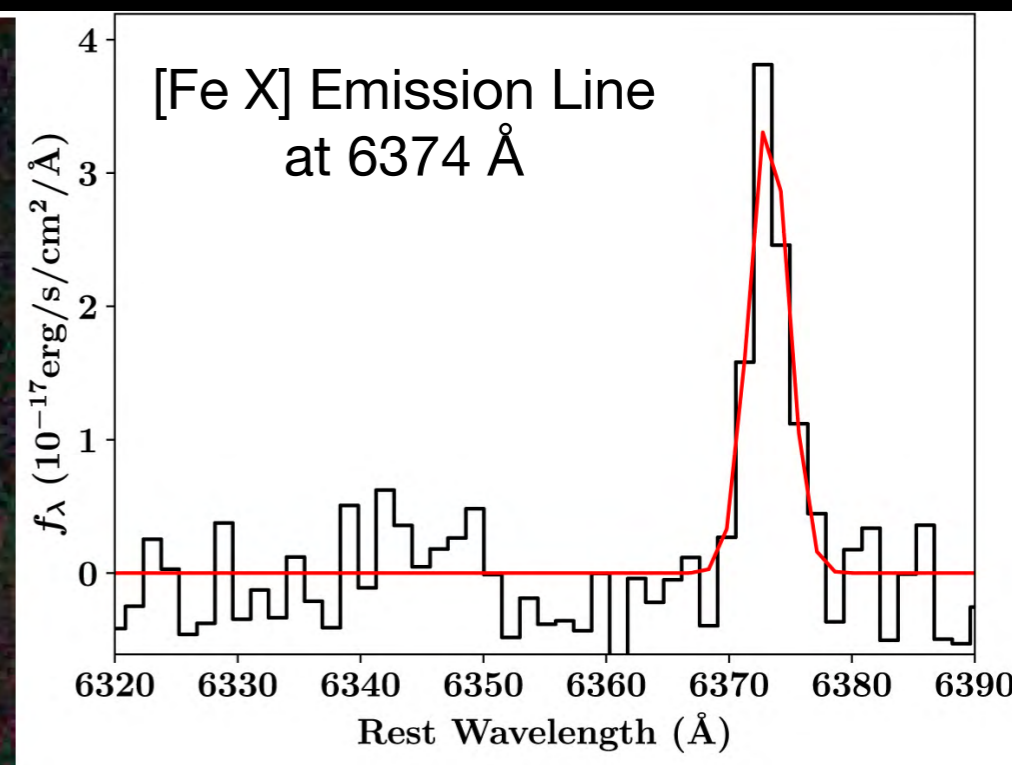
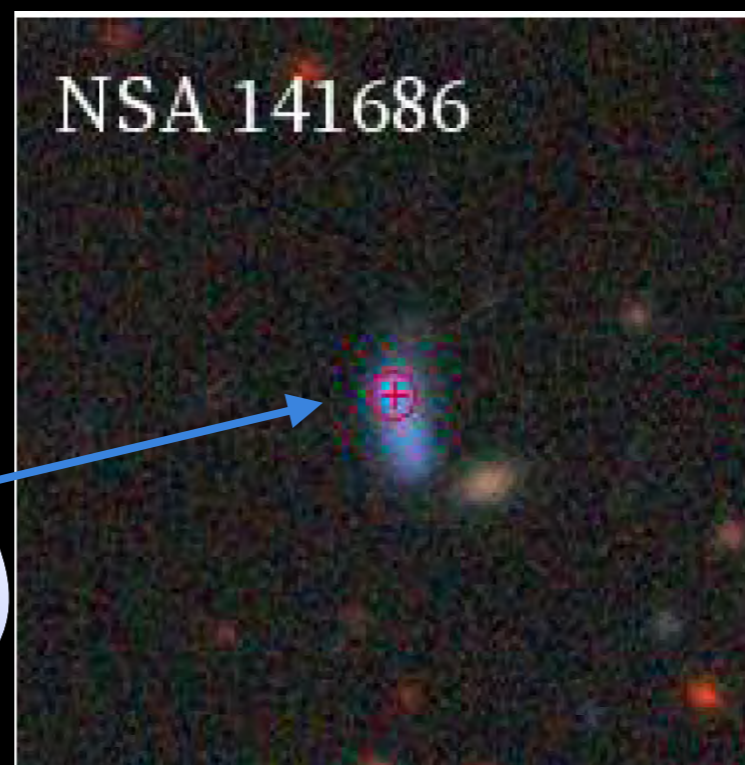
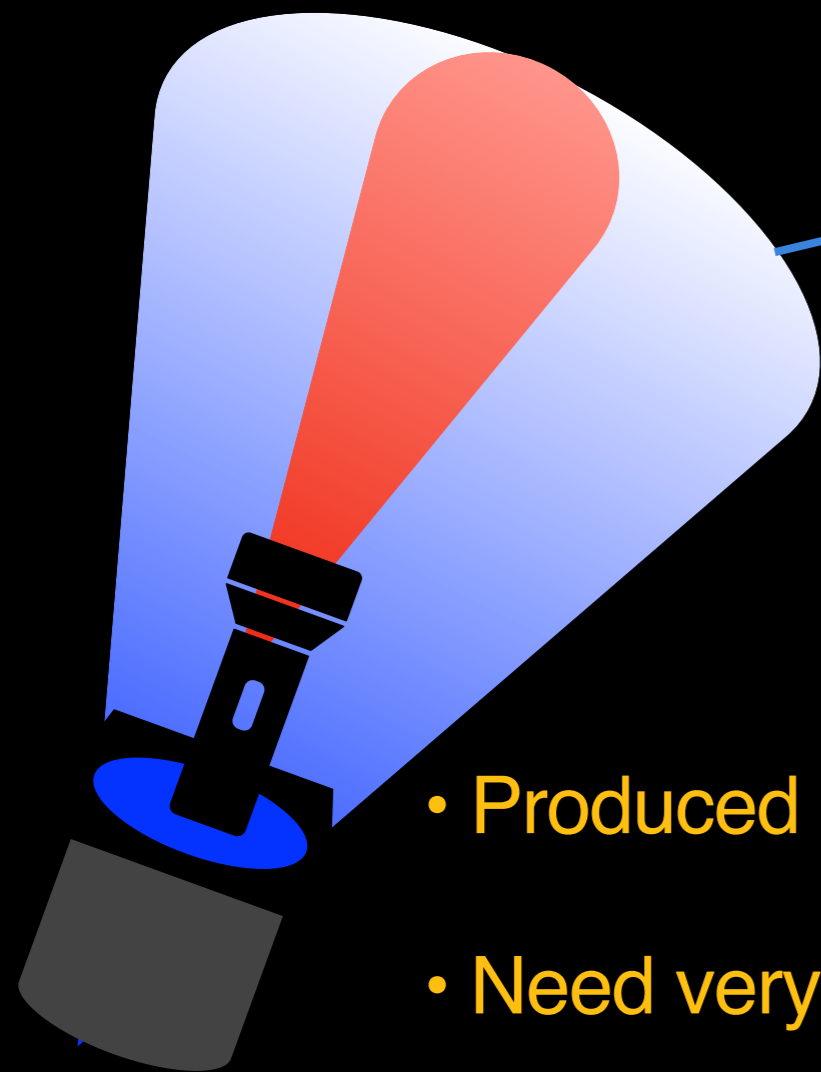
When the star formation is too high, we can't see the signal from the black hole



*Is there a way to cut through that star formation to find black holes in these galaxies?*



# Coronal Line [Fe X] $\lambda$ 6374: A New Method to search for Black Holes in Dwarf Galaxies



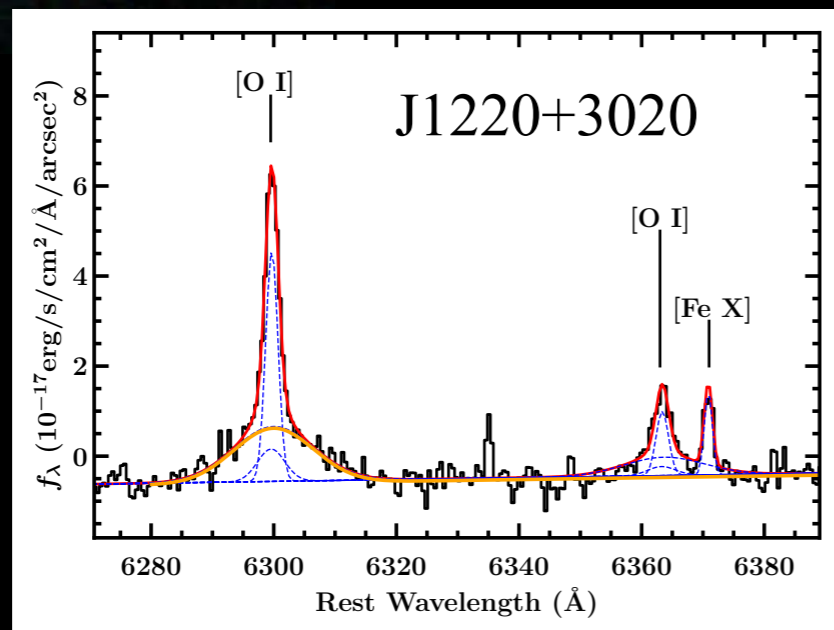
- Produced by hot X-rays or outflowing winds from black hole
- Need very high energy photons not easily produced by stars
- Previously seen in spectra of two black holes in dwarfs

# [Fe X] detected in two galaxies where the black hole missed by traditional optical techniques

J1220+3020



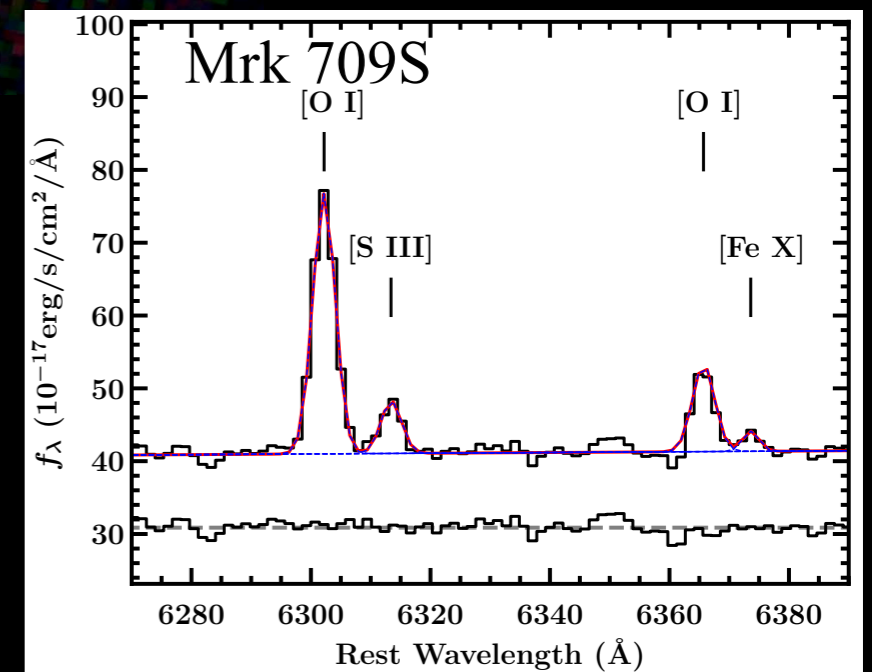
Left: Reines et al. (2020)  
Bottom: Molina et al. (2021a)



Mrk 709 N

Mrk 709 S

Left: Reines et al. (2014)  
Bottom: Kimbro et al. (2021)



**Could [Fe X] help us find black holes in dwarf galaxies otherwise hidden by star formation?**



# First Systematic Search for [Fe X] in Dwarf Galaxies



Used Optical Data from the Sloan Digital Sky Survey

Identified **81 black holes** in dwarf galaxies with detected [Fe X] emission.

*"A Sample of Massive Black Holes in Dwarf Galaxies Detected via [Fe X] Coronal Line Emission: Active Galactic Nuclei and/or Tidal Disruption Events"*

Molina, Reines, Latimer, Baldassare & Salehirad 2021,  
*The Astrophysical Journal*, 922, 2 (arXiv: 2108.09307)

# First Systematic Search for [Fe X] in Dwarf Galaxies



Almost all had [Fe X] emission too bright for stellar processes

[Fe X] emission is consistent with an accreting supermassive black hole

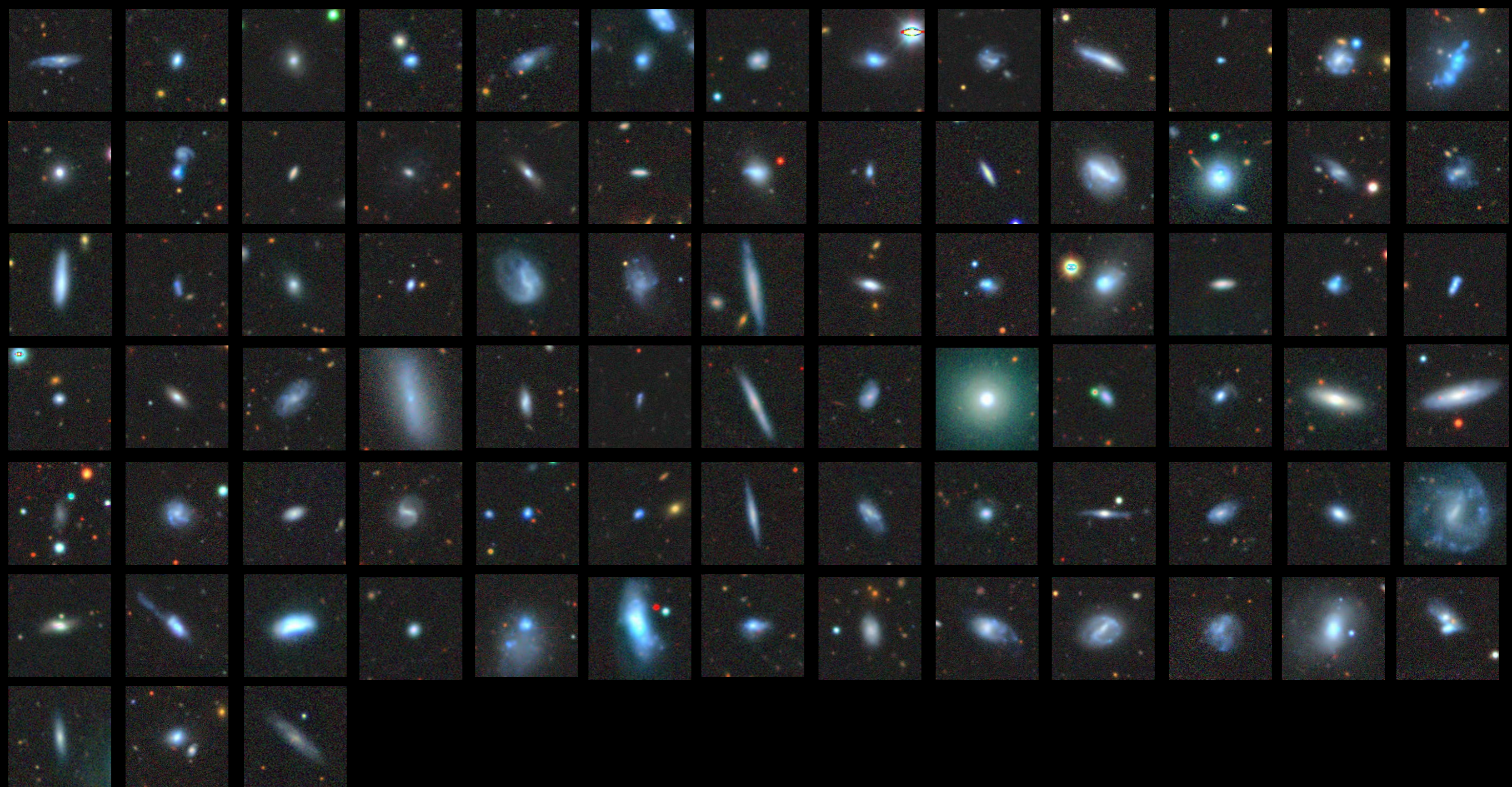
About 50% showed additional signatures of black hole activity

*"A Sample of Massive Black Holes in Dwarf Galaxies Detected via [Fe X] Coronal Line Emission: Active Galactic Nuclei and/or Tidal Disruption Events"*

Molina, Reines, Latimer, Baldassare & Salehirad 2021,  
*The Astrophysical Journal*, 922, 2 (arXiv: 2108.09307)



# [Fe X]-Selected Black Holes Found in Blue (Actively Star-Forming) Dwarf Galaxies

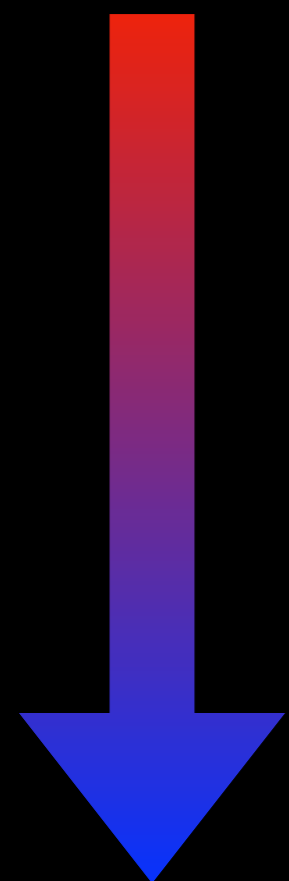
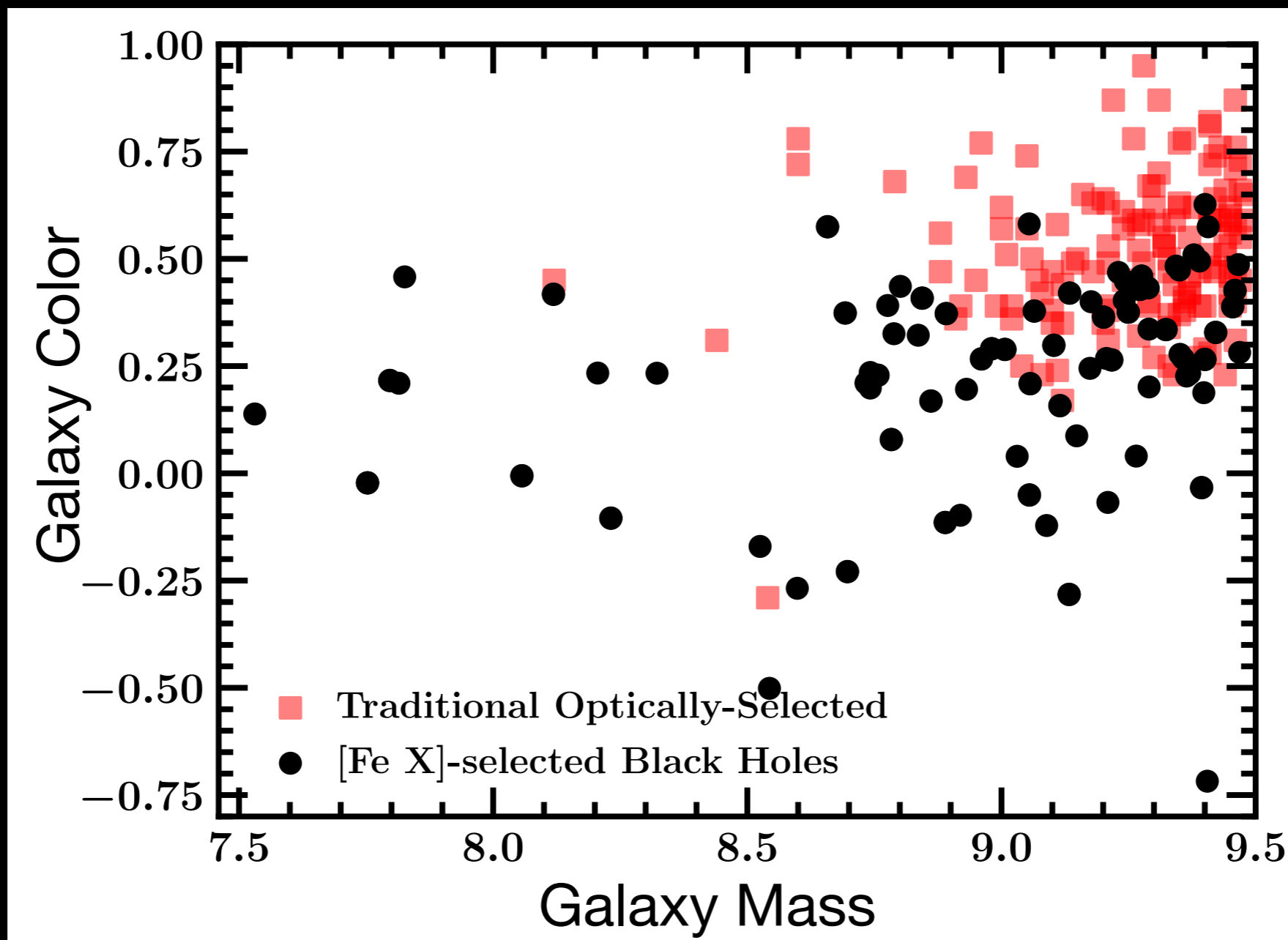




# [Fe X]-Selected Black Holes Found in Bluer (Actively Star-Forming) Lower-Mass Dwarf Galaxies

Redder  
Galaxy

Low Star  
Formation



Bluer  
Galaxy

High Star  
Formation

Less Massive Galaxy

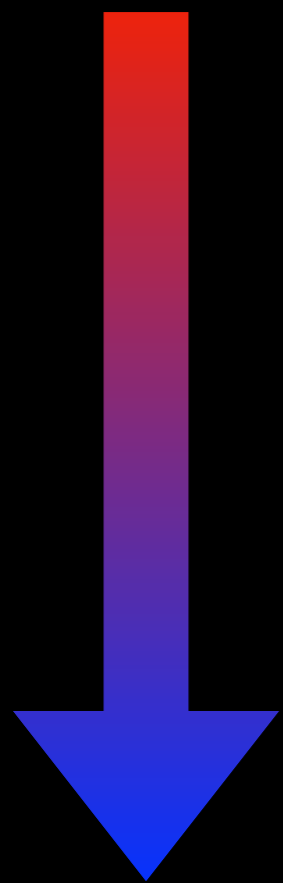


More Massive Galaxy



# [Fe X]-Selected Black Holes Found in Bluer (Actively Star-Forming) Lower-Mass Dwarf Galaxies

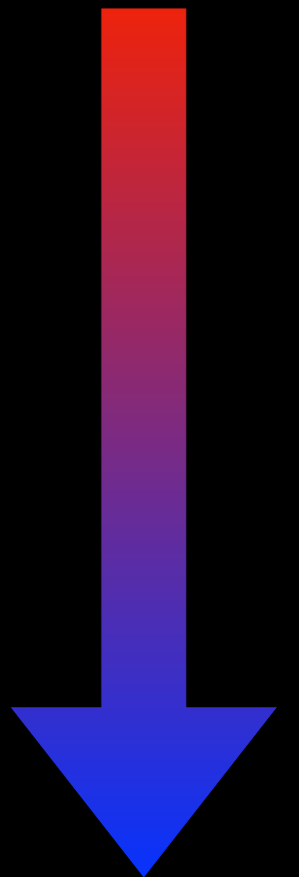
Redder  
Galaxy



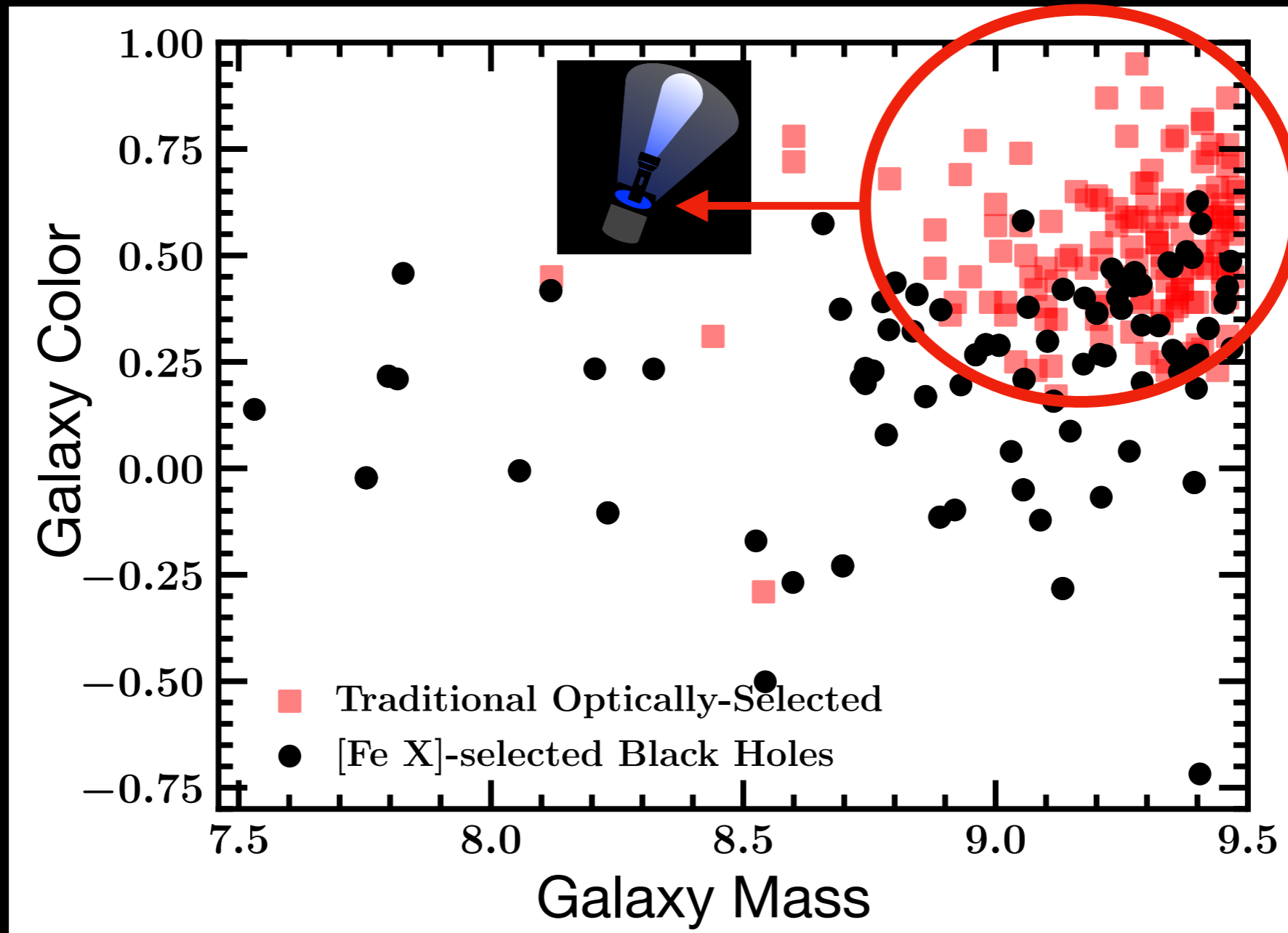
Bluer  
Galaxy

Red and Massive

Low Star  
Formation



High Star  
Formation



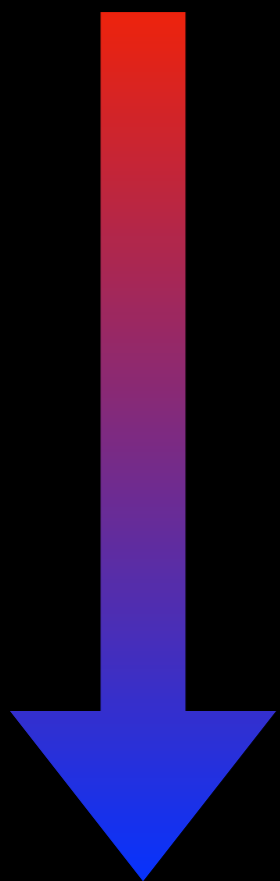
Less Massive Galaxy



More Massive Galaxy

# [Fe X]-Selected Black Holes Found in Bluer (Actively Star-Forming) Lower-Mass Dwarf Galaxies

Redder Galaxy



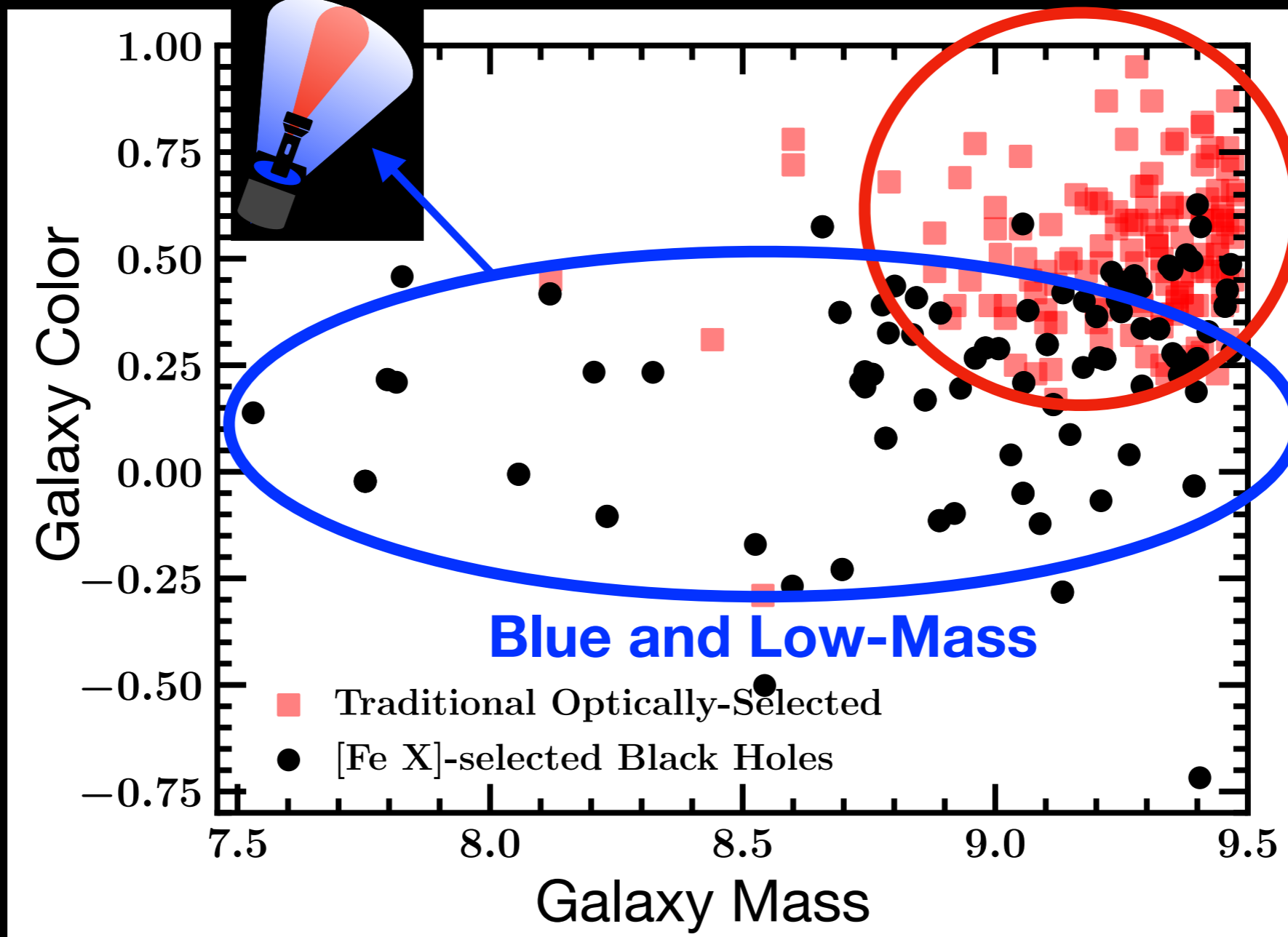
Bluer Galaxy

Red and Massive

Low Star Formation



High Star Formation



Less Massive Galaxy



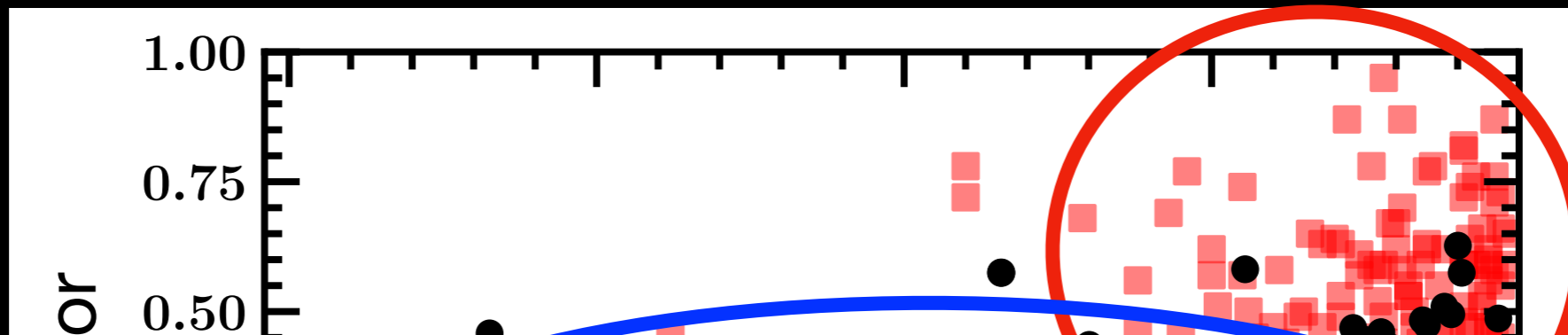
More Massive Galaxy



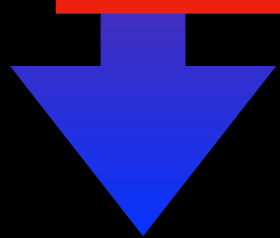
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Redder Galaxy

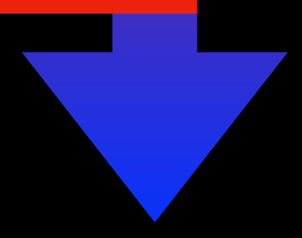
Low Star Formation



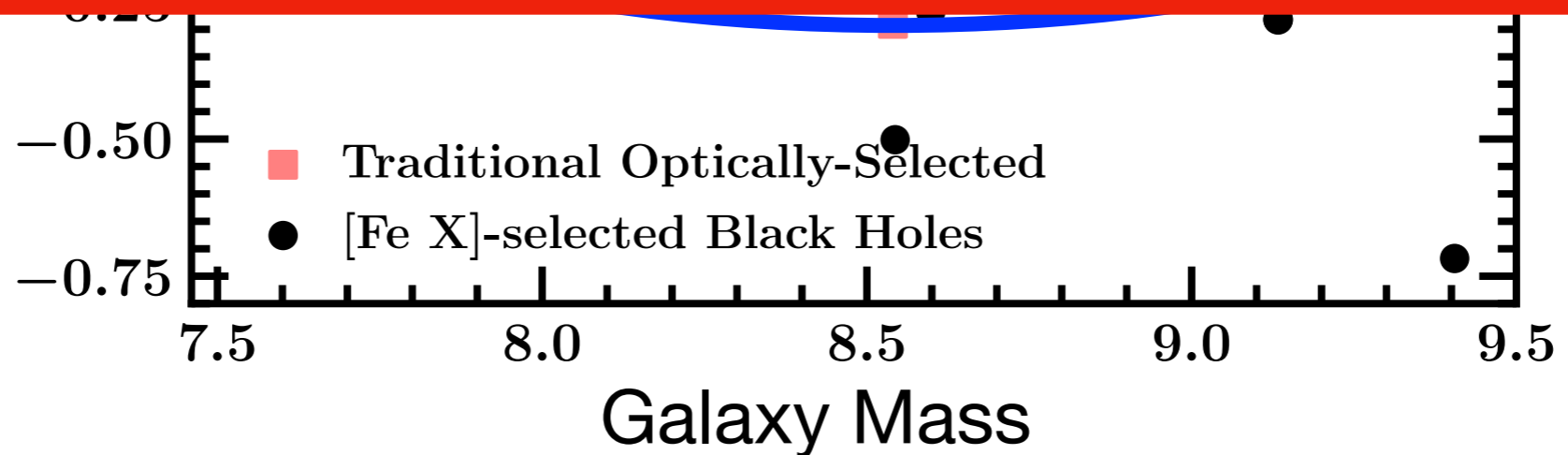
The [Fe X] Selection technique opens a whole new population of black holes previously inaccessible with optical methods



Bluer Galaxy



High Star Formation



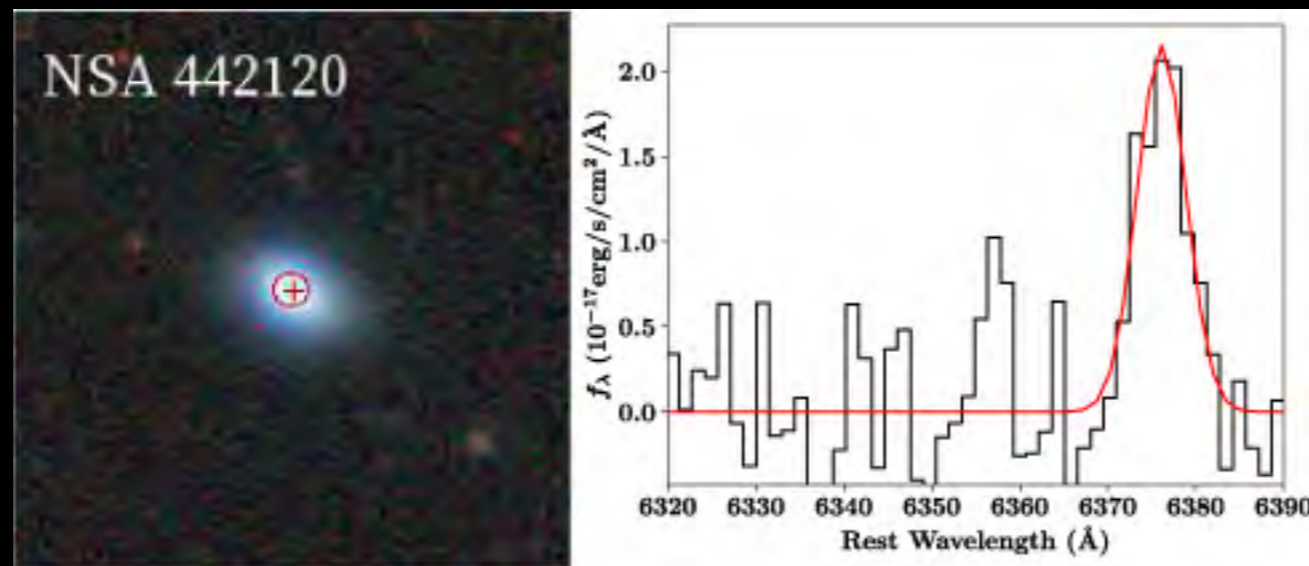
Less Massive Galaxy



More Massive Galaxy

# Summary

- First systematic search for coronal-line [Fe X] in dwarf galaxies
- Identified 81 dwarfs with supermassive black holes
- A new population of black holes inaccessible with traditional methods
- Stronger, new constraints on the origins of supermassive black holes



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