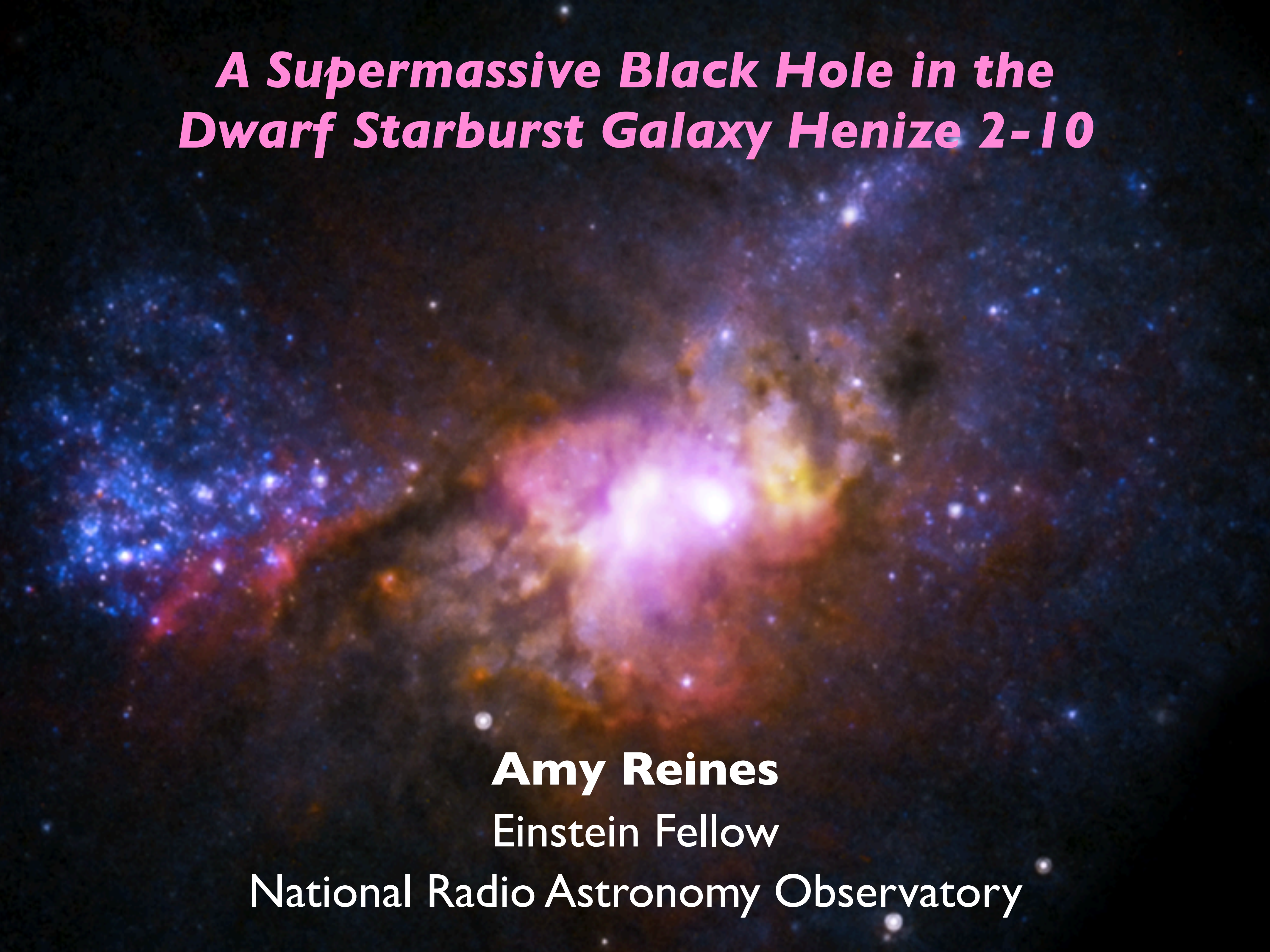


A Supermassive Black Hole in the Dwarf Starburst Galaxy Henize 2-10

Amy Reines

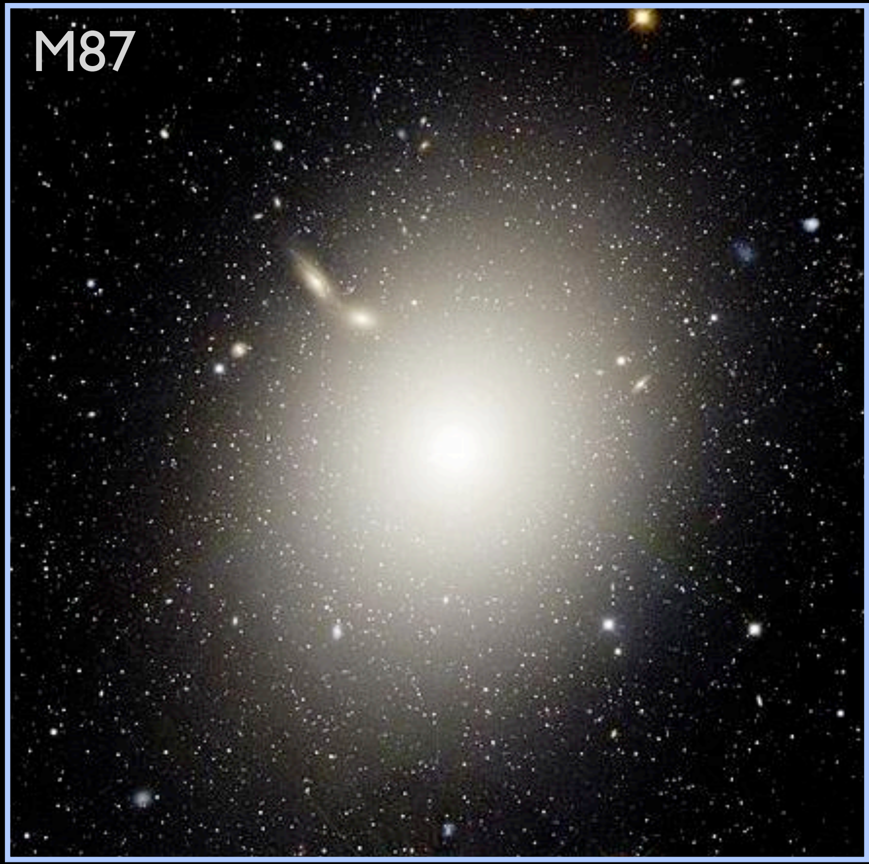
Einstein Fellow

National Radio Astronomy Observatory

Supermassive black holes and galaxy evolution

• Supermassive black holes reside in the nuclei of essentially all massive galaxies with a bulge
(e.g. Kormendy & Richstone 1995; Magorrian et al. 1998; Kormendy 2004)

$M_{BH} \sim 1.4 \times 10^8\ M_{sun}$ (Bender et al. 2005)



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Images from APOD

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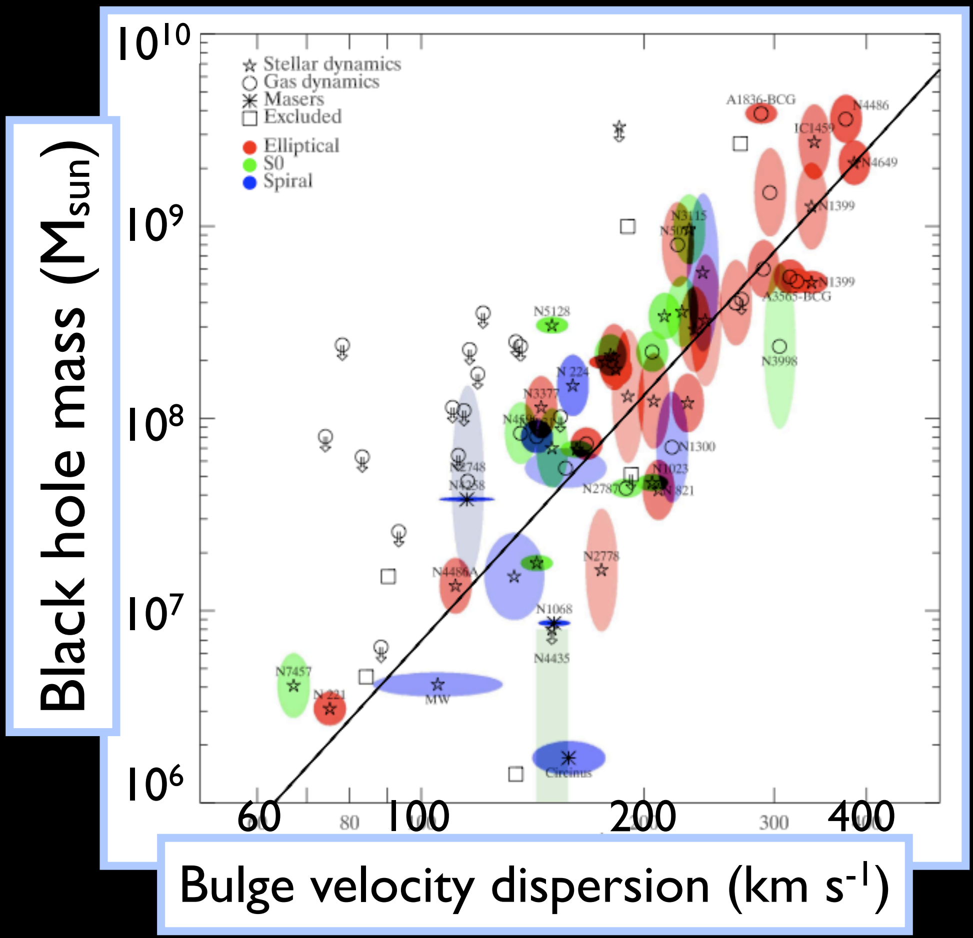

Gültekin et al. (2009)

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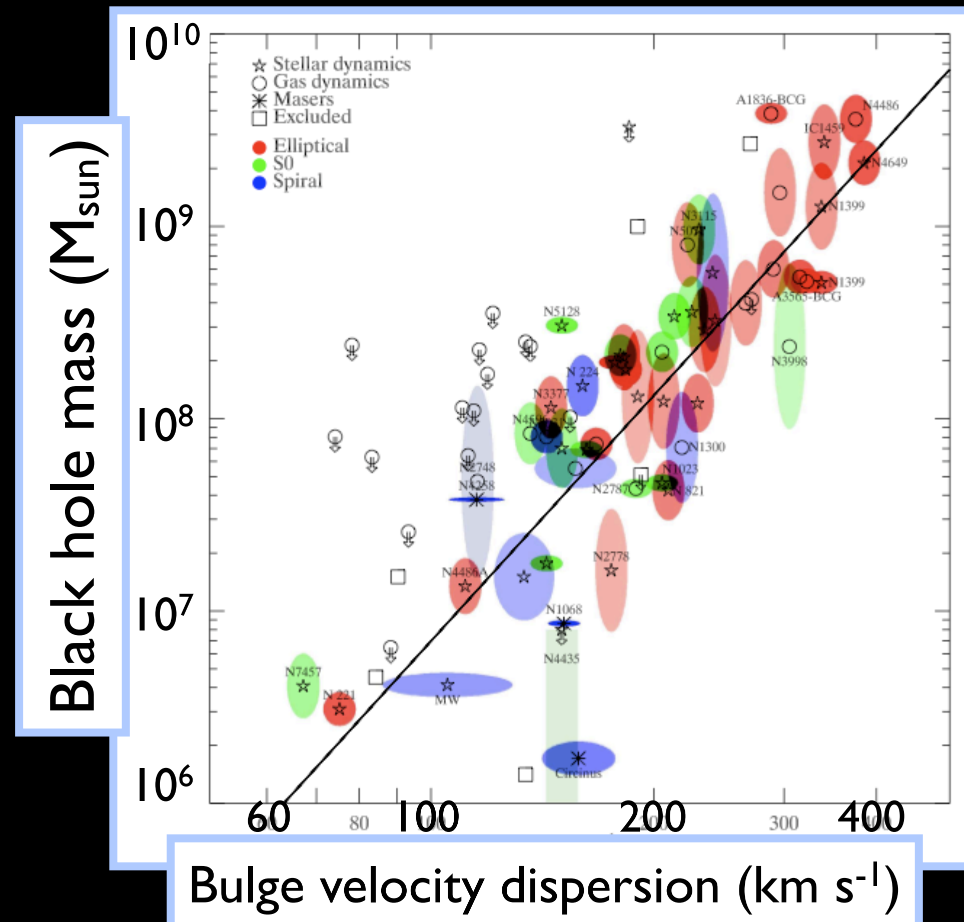

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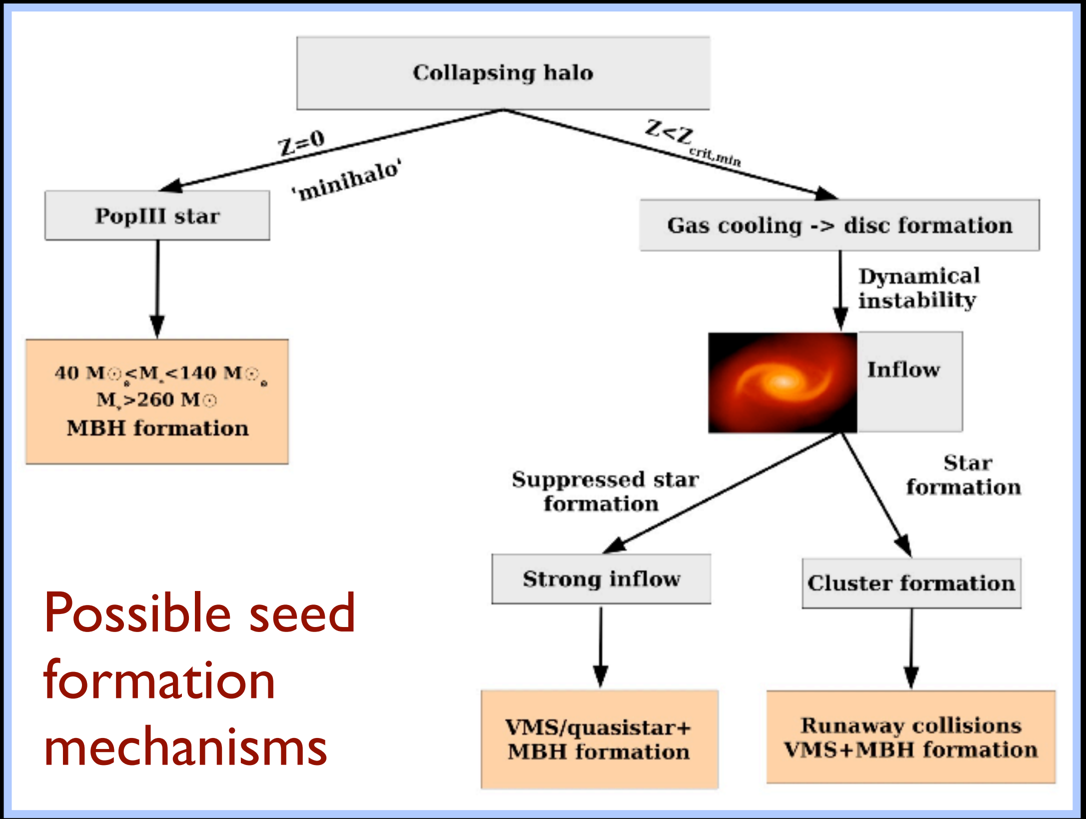

Volonteri (2010)

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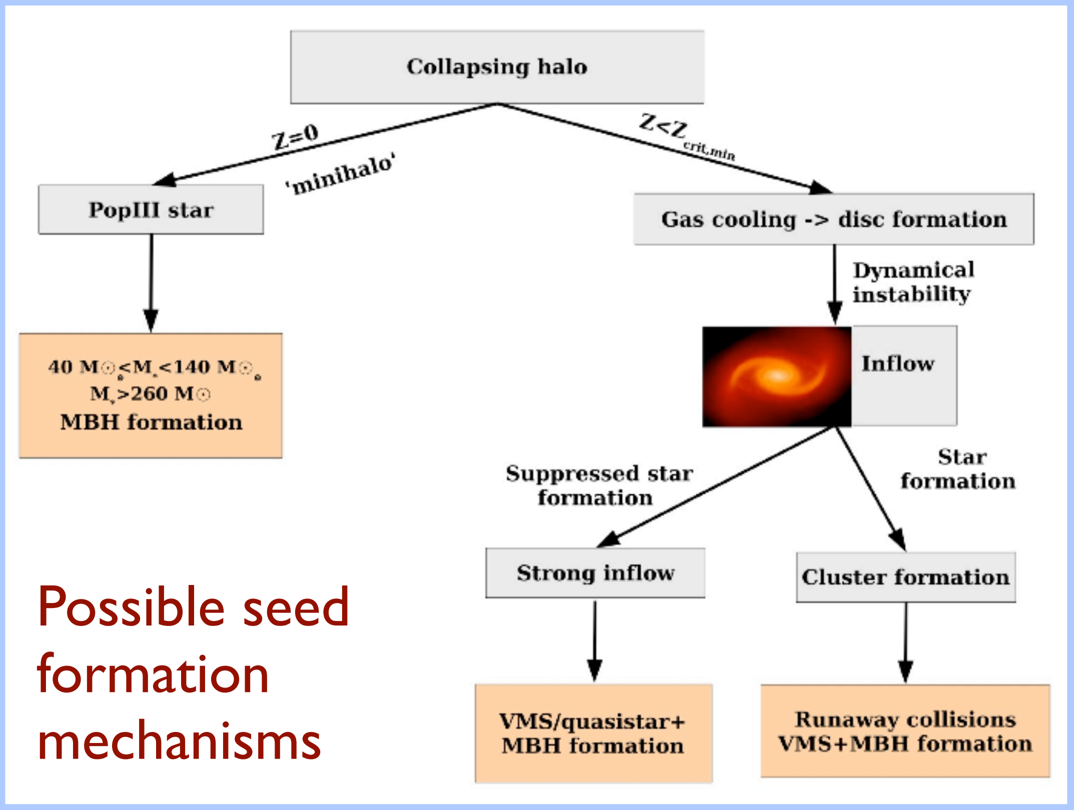

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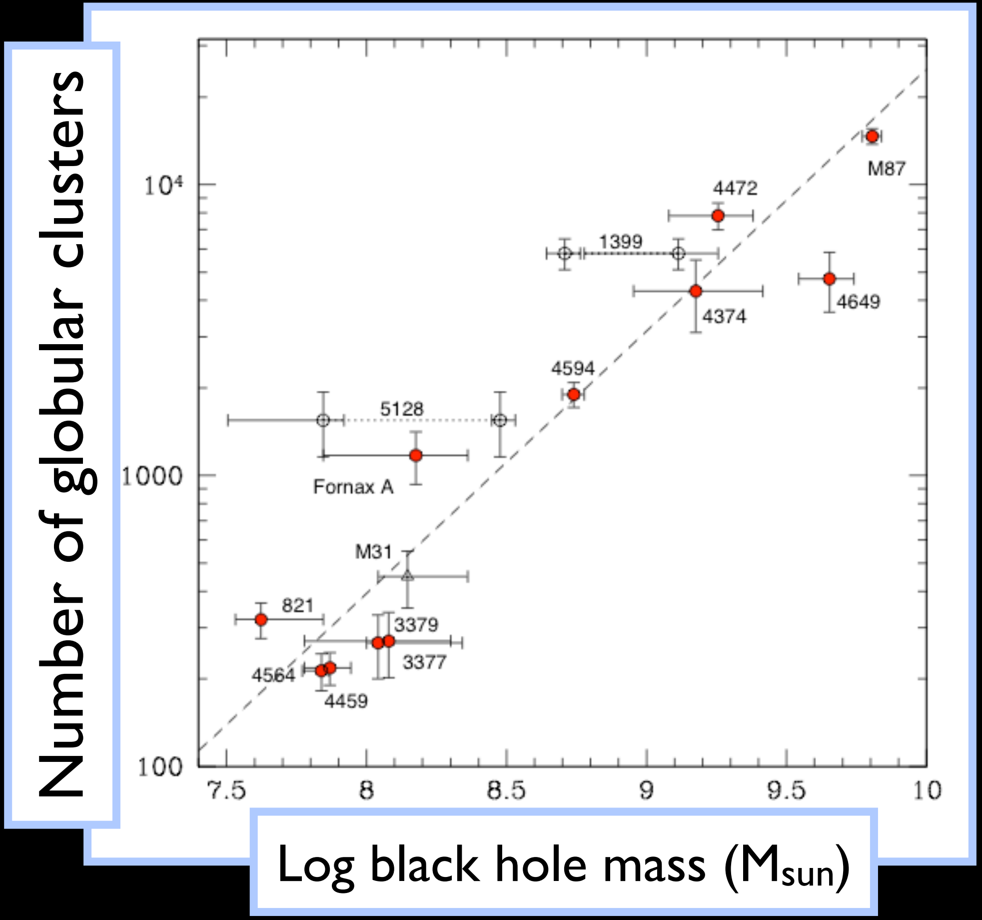
- What is the nature of the supermassive black hole - globular cluster connection?



Burkert & Tremaine (2010)

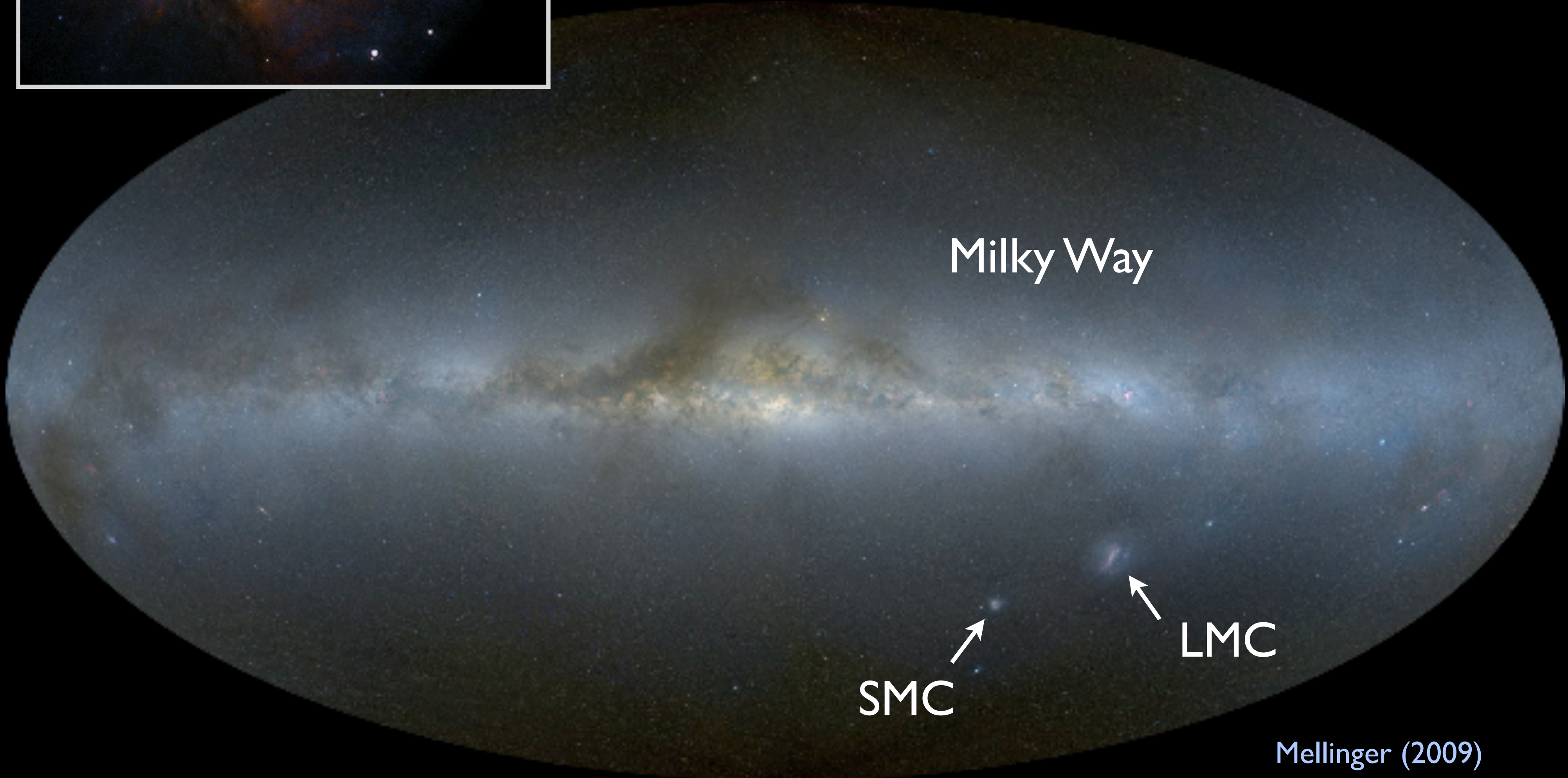

"An actively accreting massive black hole in the dwarf starburst galaxy Henize 2-10"
Reines, Sivakoff, Johnson & Brogan 2011, Nature, 470, 66
"Astrophysics: Big black hole found in tiny galaxy"
Greene 2011, Nature, 470, 45

Henize 2-10

- Nearby (D~9 Mpc) dwarf starburst galaxy (Allen et al. 1976)
- Compact (~ 1 kpc), irregular morphology
- Young super star clusters (proto-globular clusters) (e.g. Johnson et al. 2000)

Henize 2-10

- Nearby (D~9 Mpc) dwarf starburst galaxy (Allen et al. 1976)
- Compact (~ 1 kpc), irregular morphology
- Young super star clusters (proto-globular clusters) (e.g. Johnson et al. 2000)
- Main optical body is about half the size of the SMC
- SFR ~ 10 times the LMC but similar stellar and HI masses

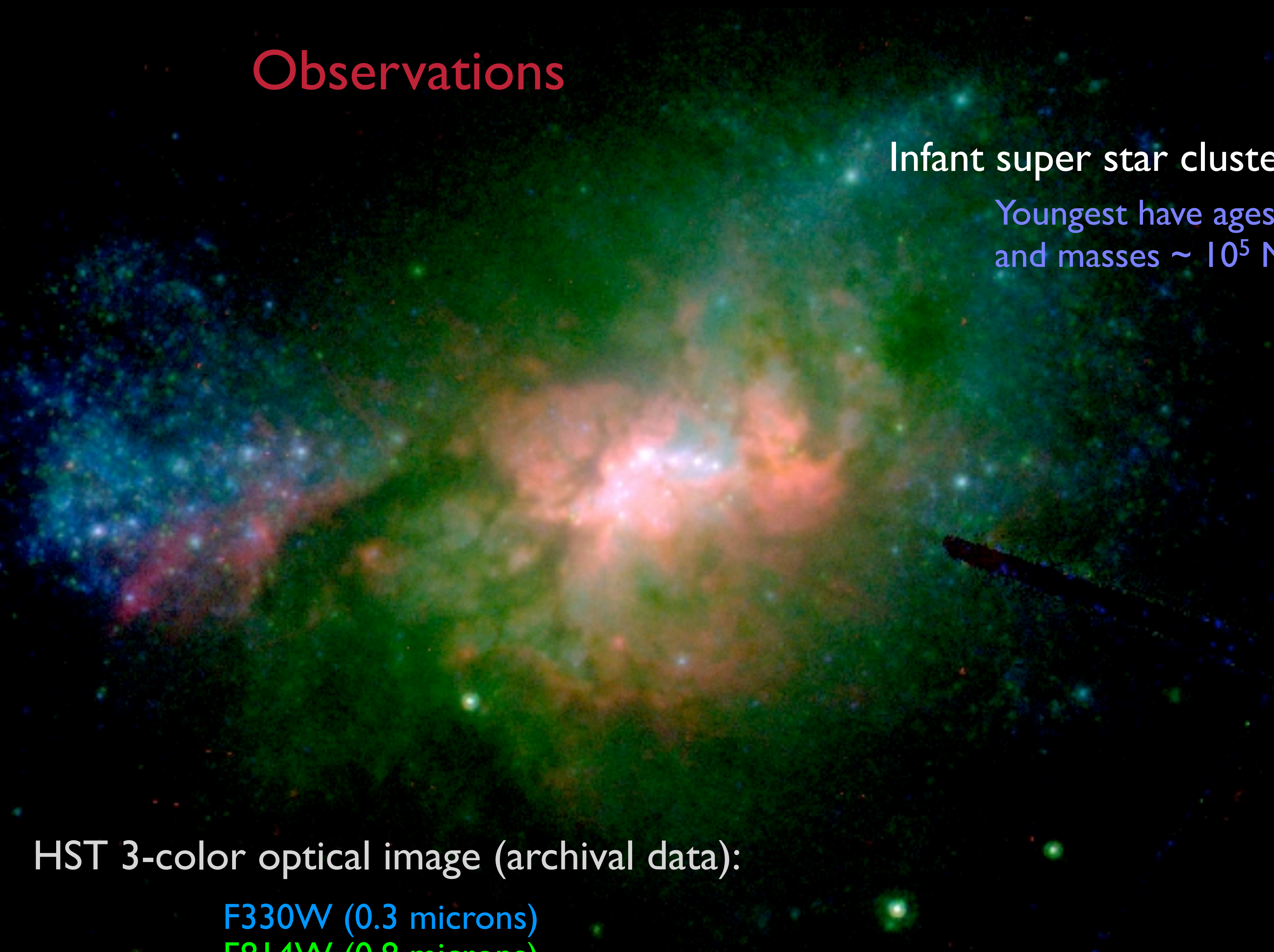


Mellinger (2009)

Observations

Infant super star clusters:

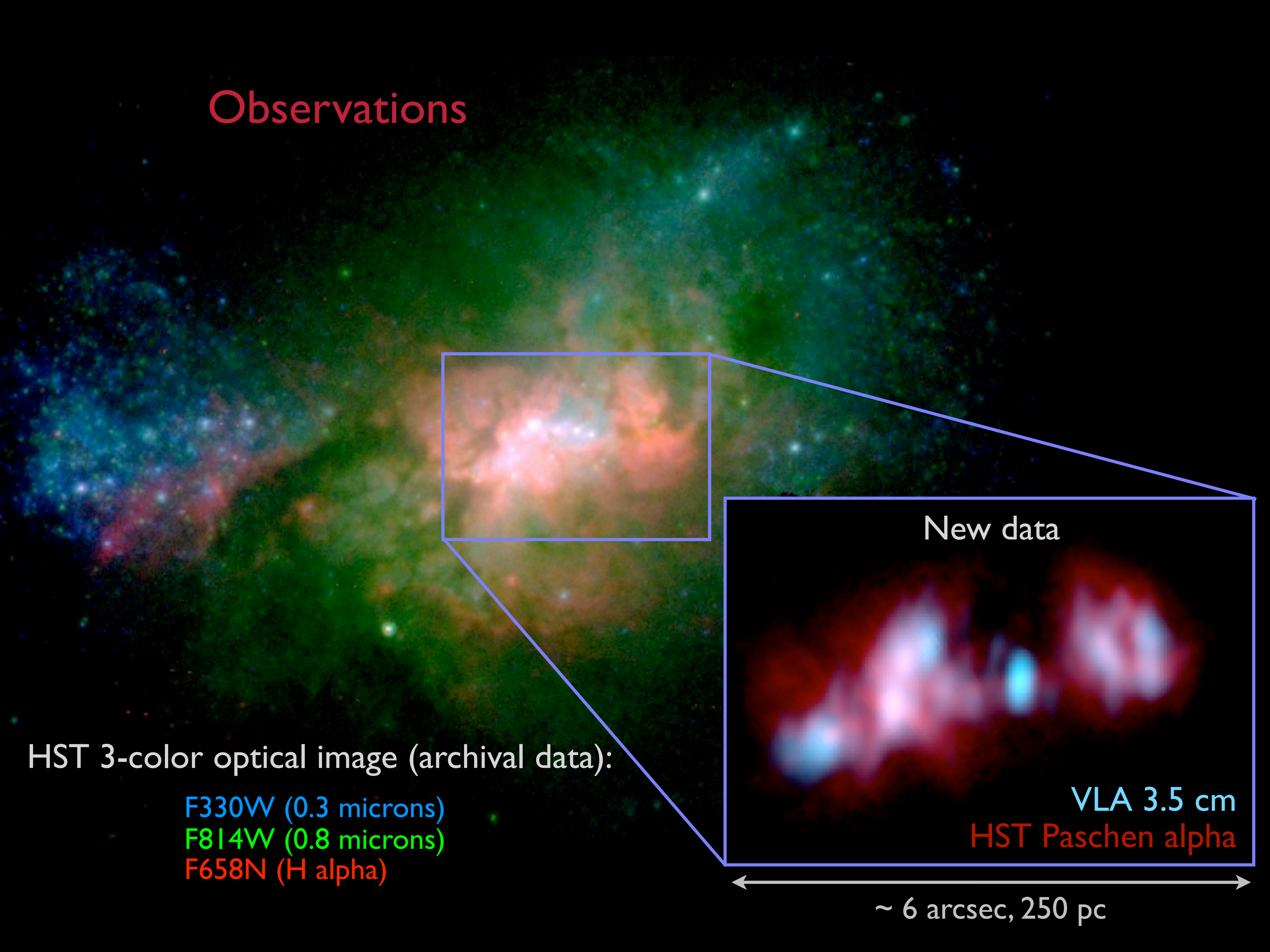
Youngest have ages $\lesssim$ few Myr
and masses ~ 10^5 M_{sun}

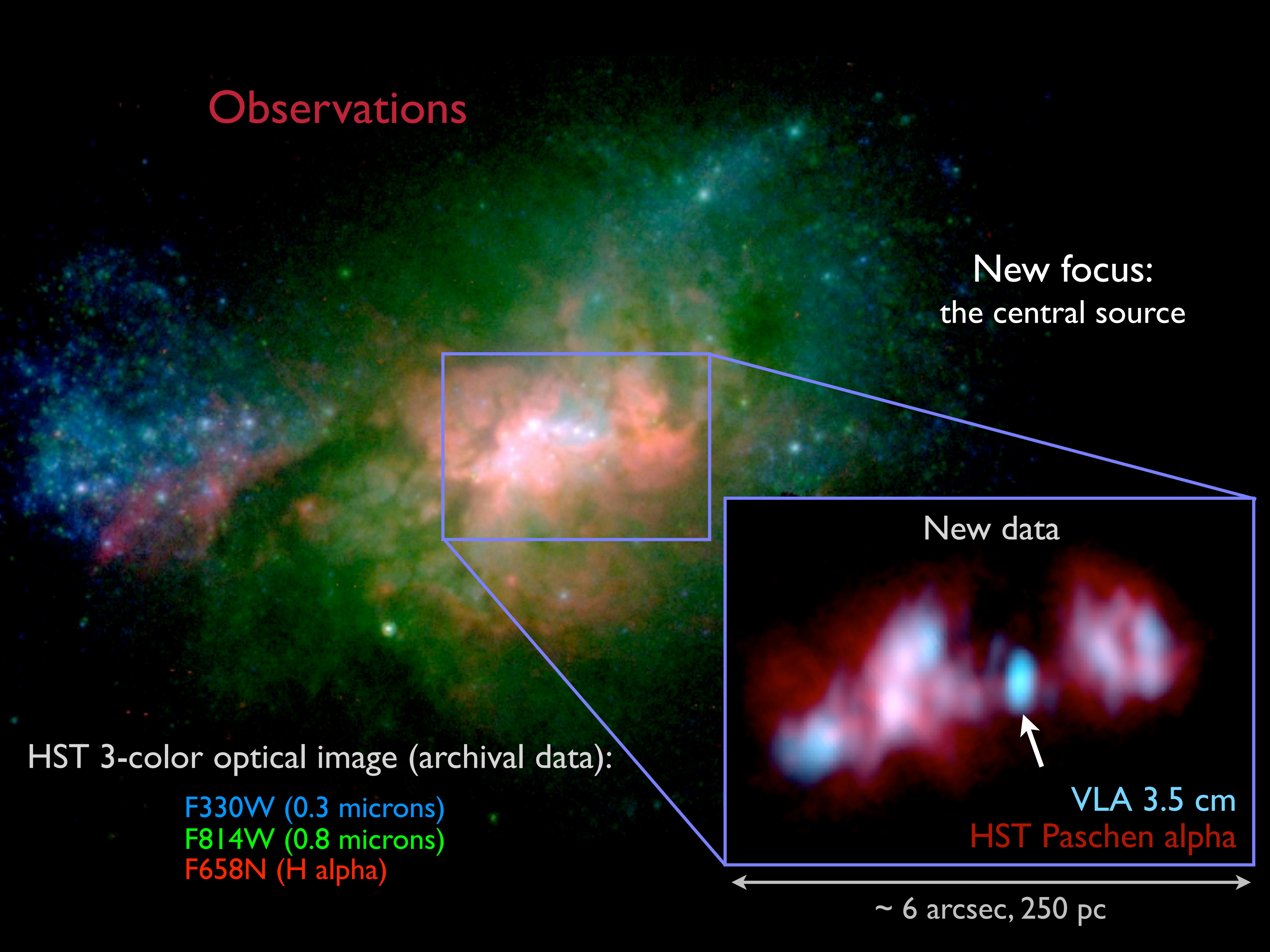


HST 3-color optical image (archival data):

F330W (0.3 microns)
F814W (0.8 microns)
F658N (H alpha)

Observations




Observations
New focus:
the central source
New data
VLA 3.5 cm
HST Paschen alpha
~ 6 arcsec, 250 pc
HST 3-color optical image (archival data):
F330W (0.3 microns)
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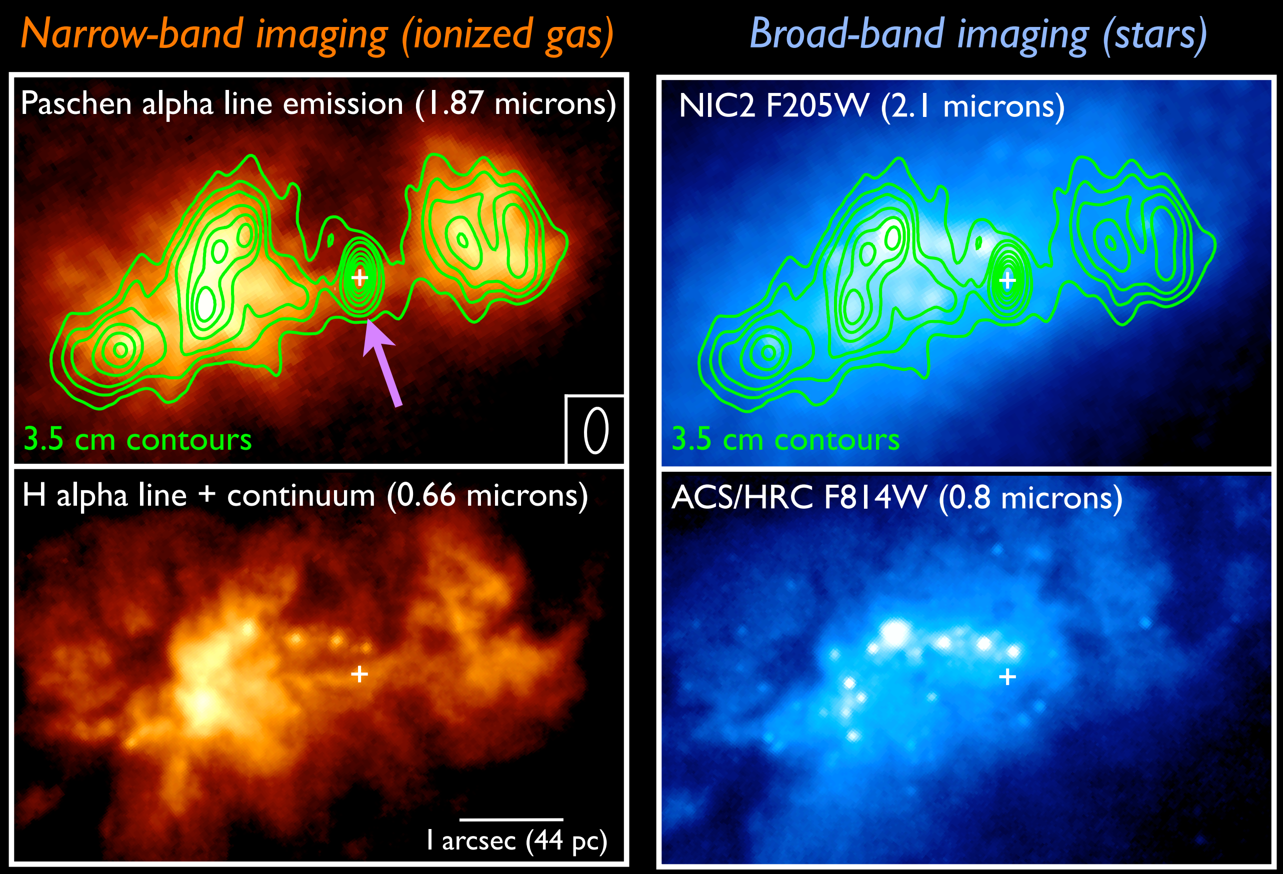
The central source in Henize 2-10



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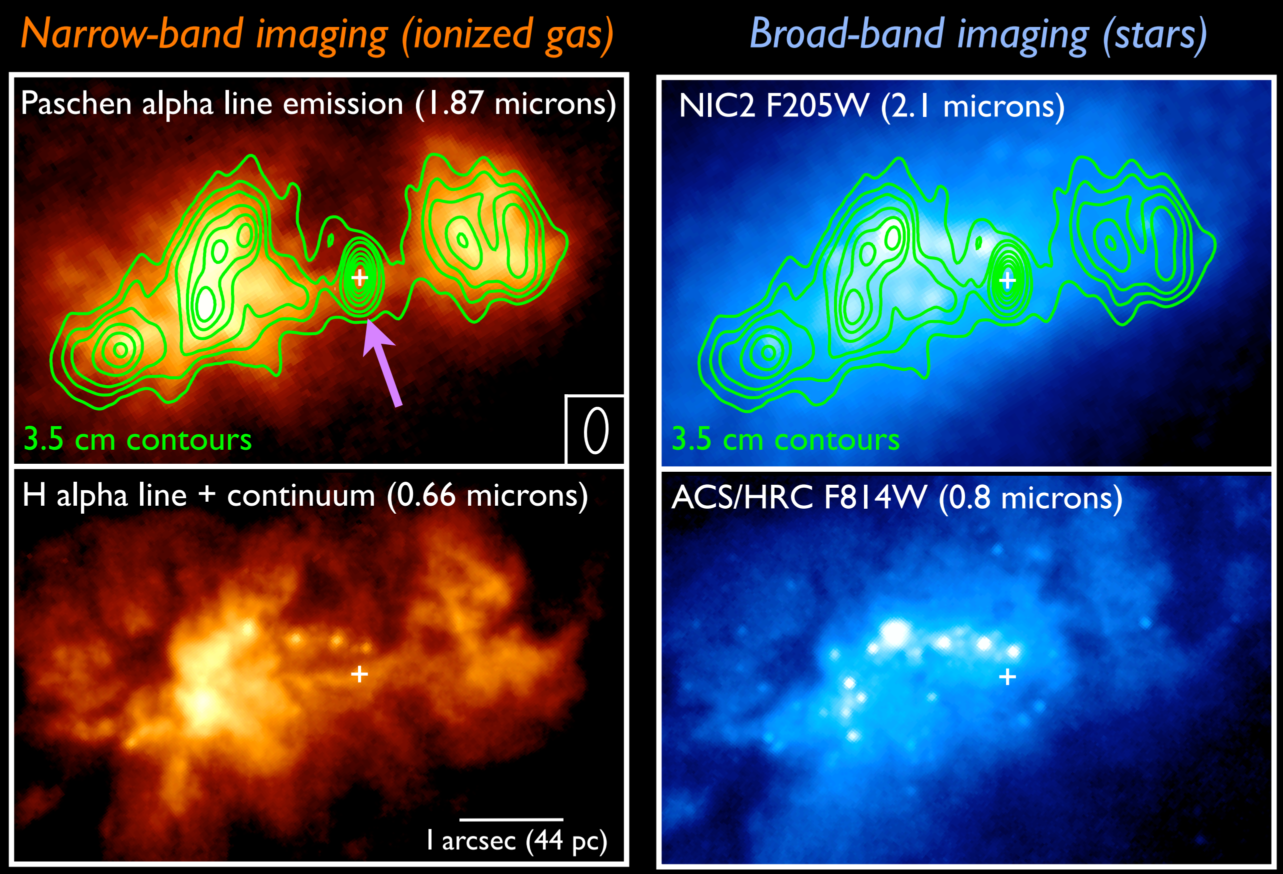

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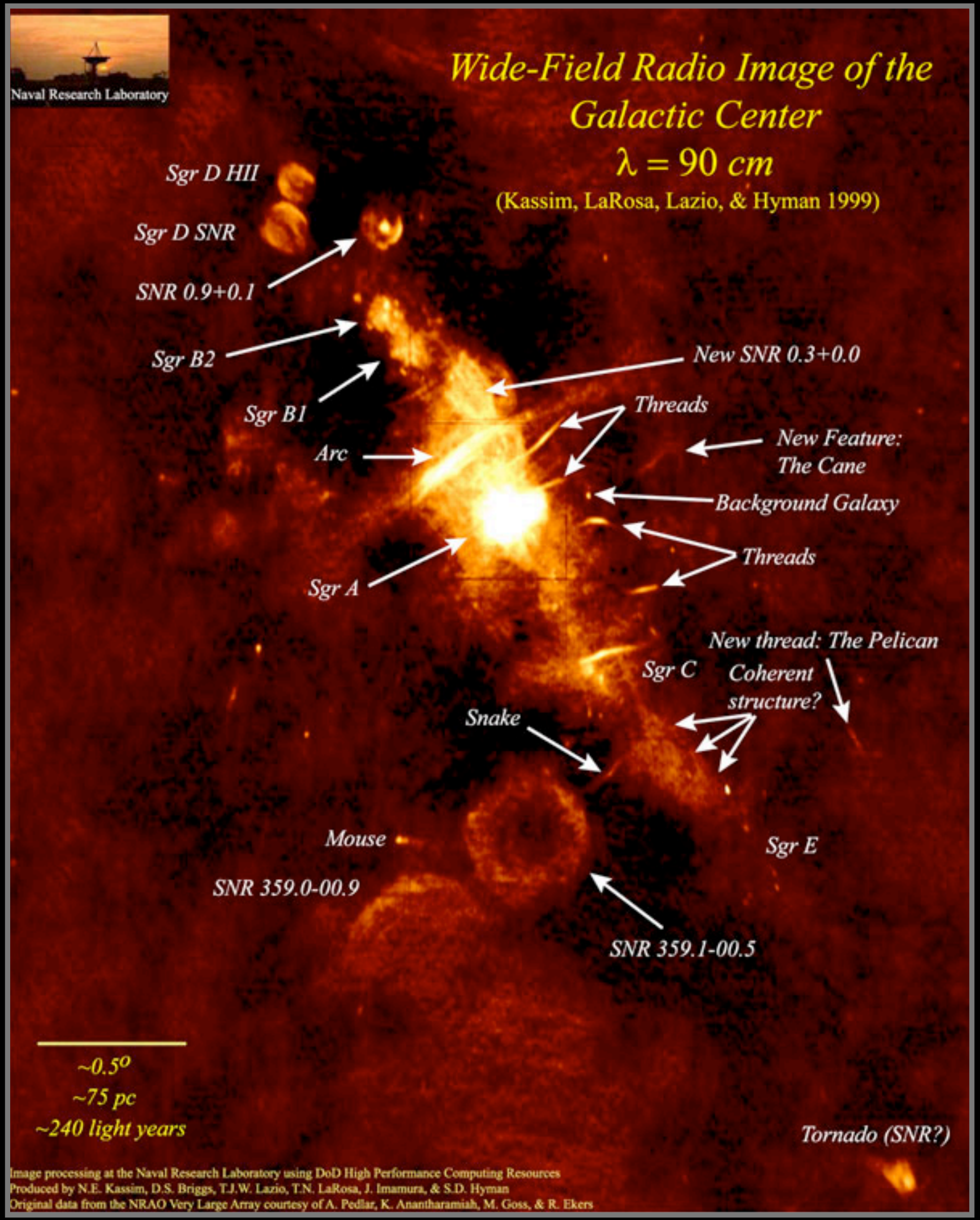
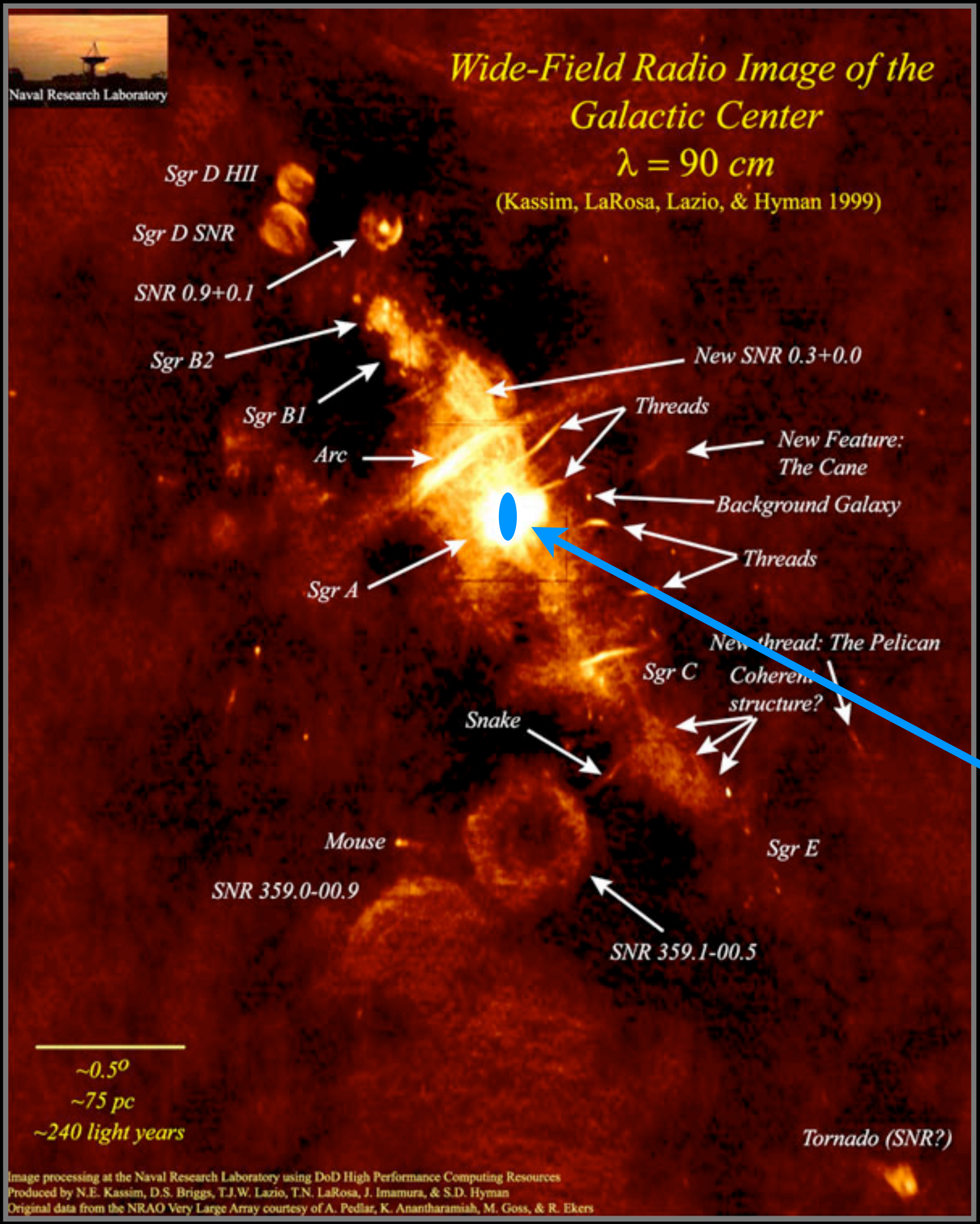


Radio image of the Galactic Center

The central source in Henize 2-10

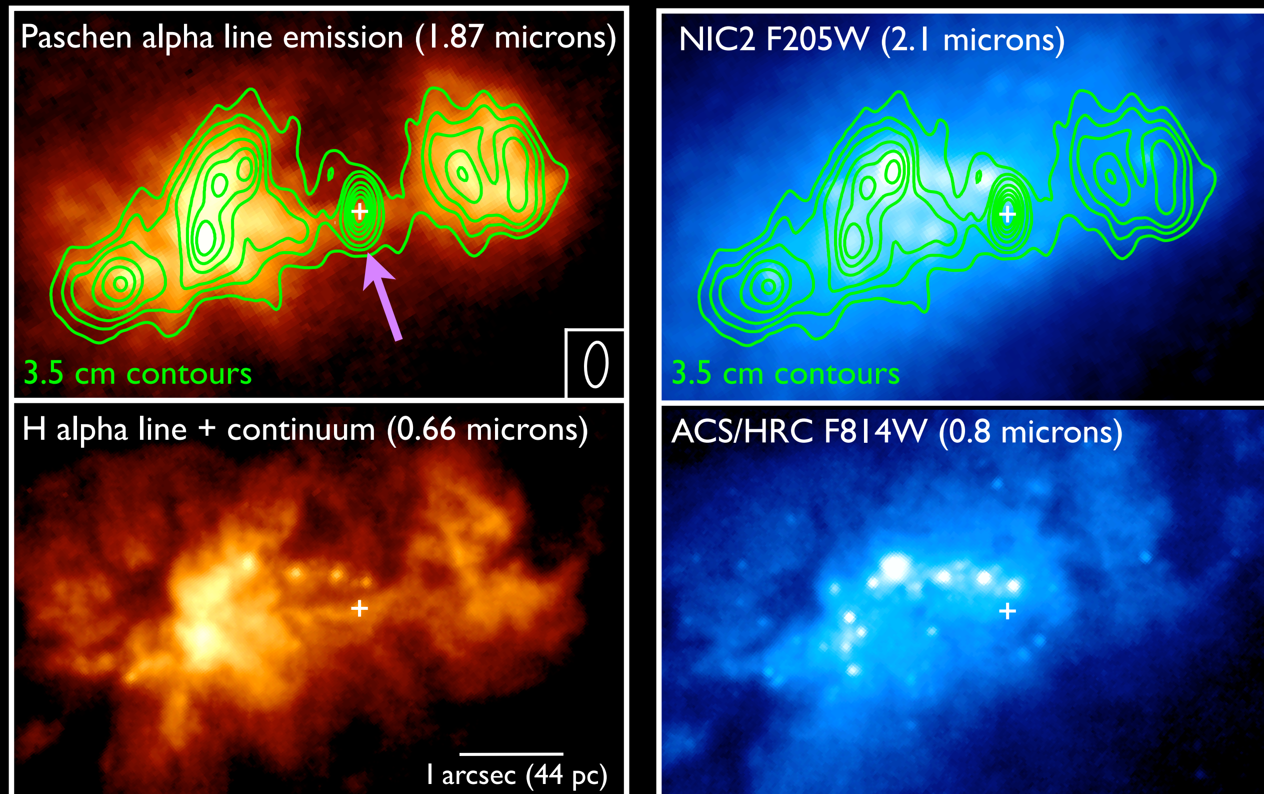


Radio image of the Galactic Center

24 pc x 9 pc beam

The central source in Henize 2-10

Narrow-band imaging (ionized gas) *Broad-band imaging (stars)*



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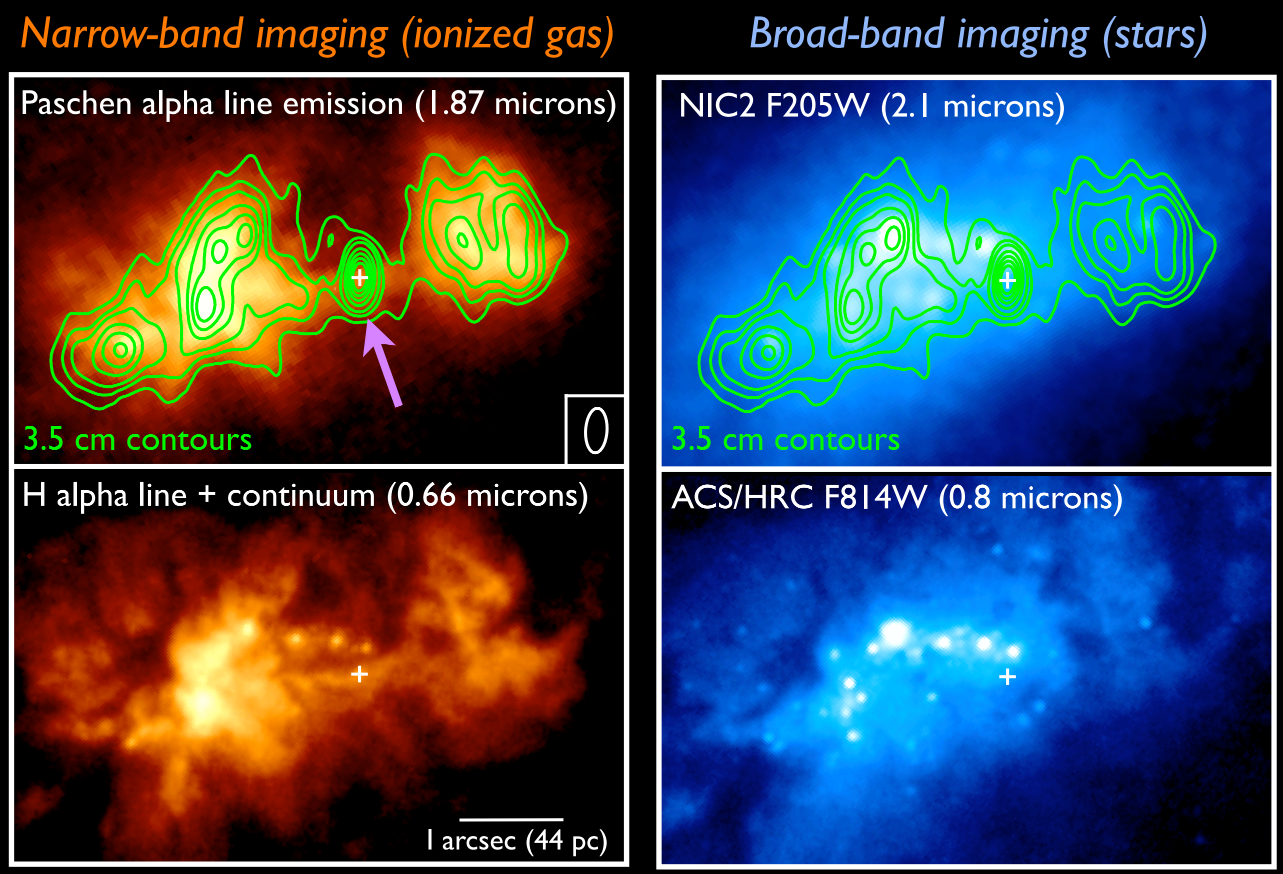
The central source in Henize 2-10



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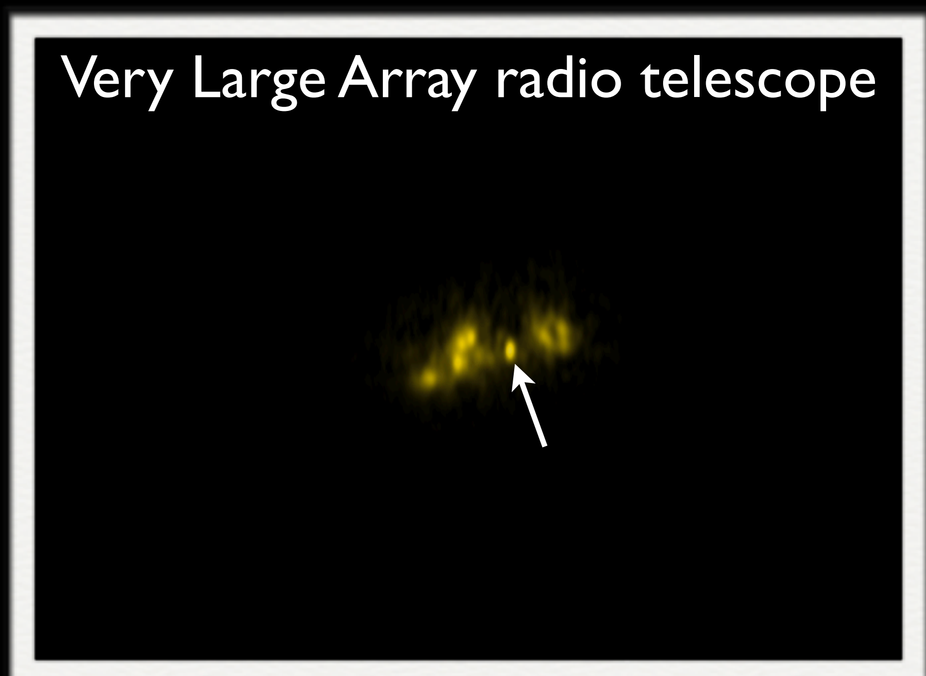
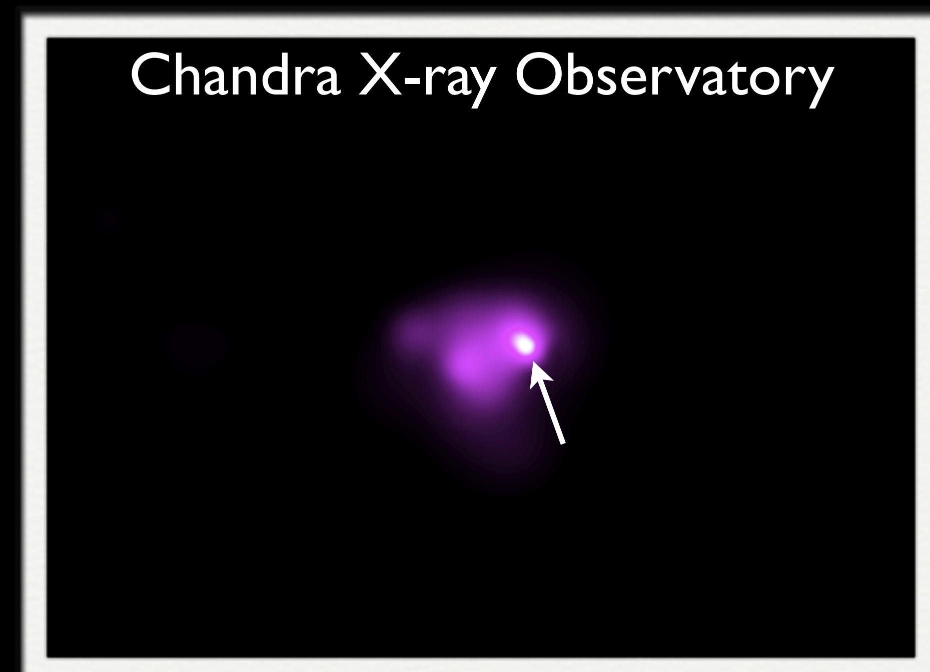
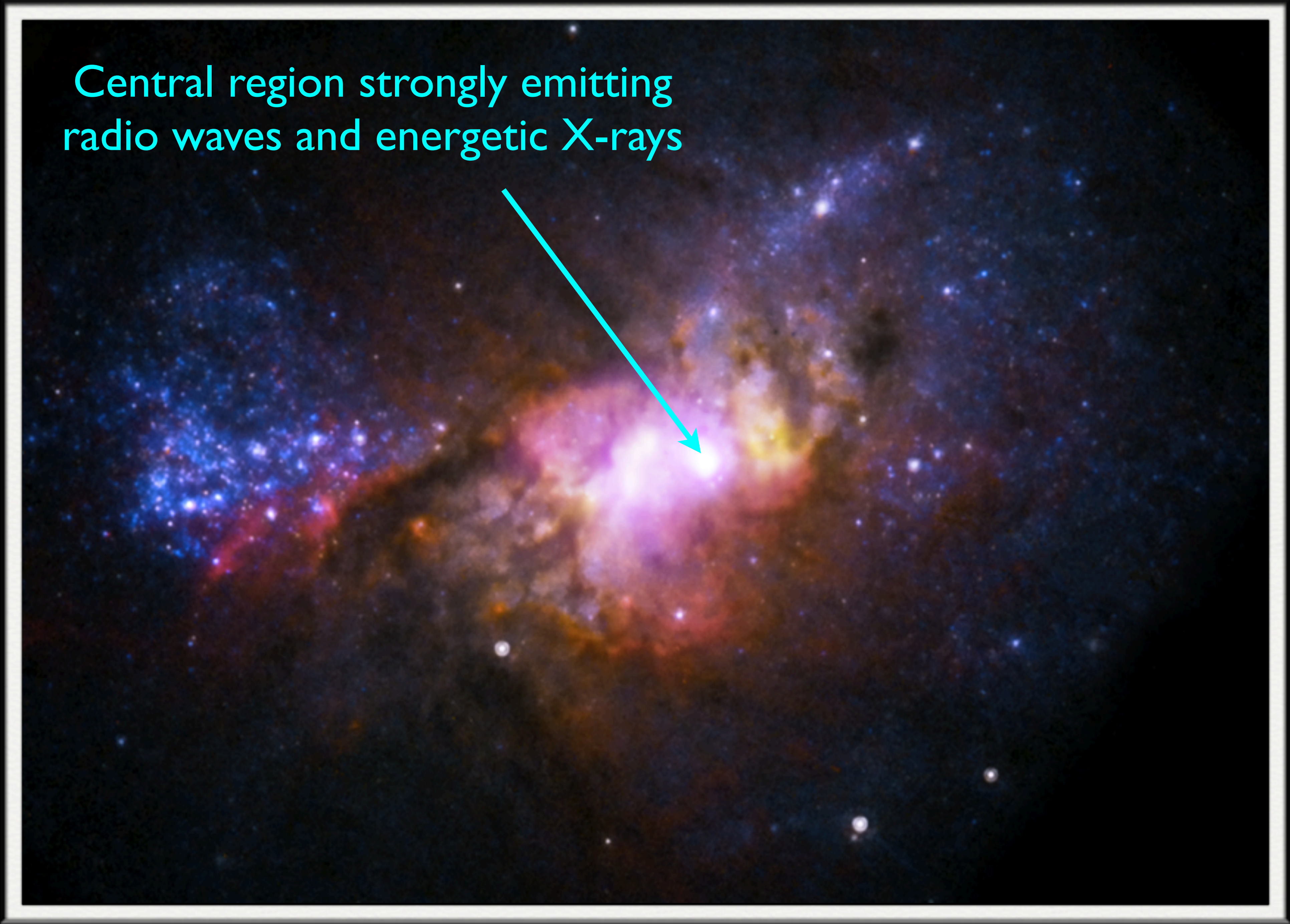




Images from http://chandra.harvard.edu/press



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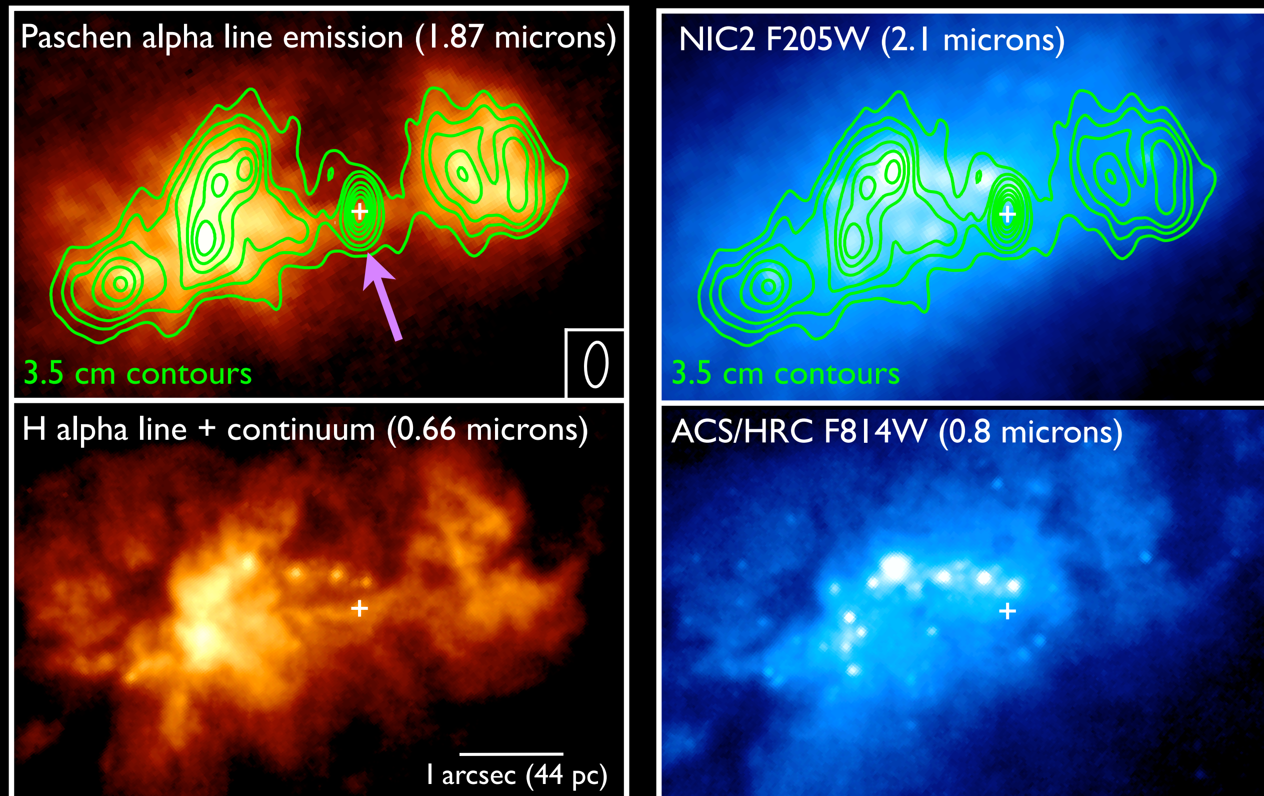
The central source in Henize 2-10

Narrow-band imaging (ionized gas)

Broad-band imaging (stars)



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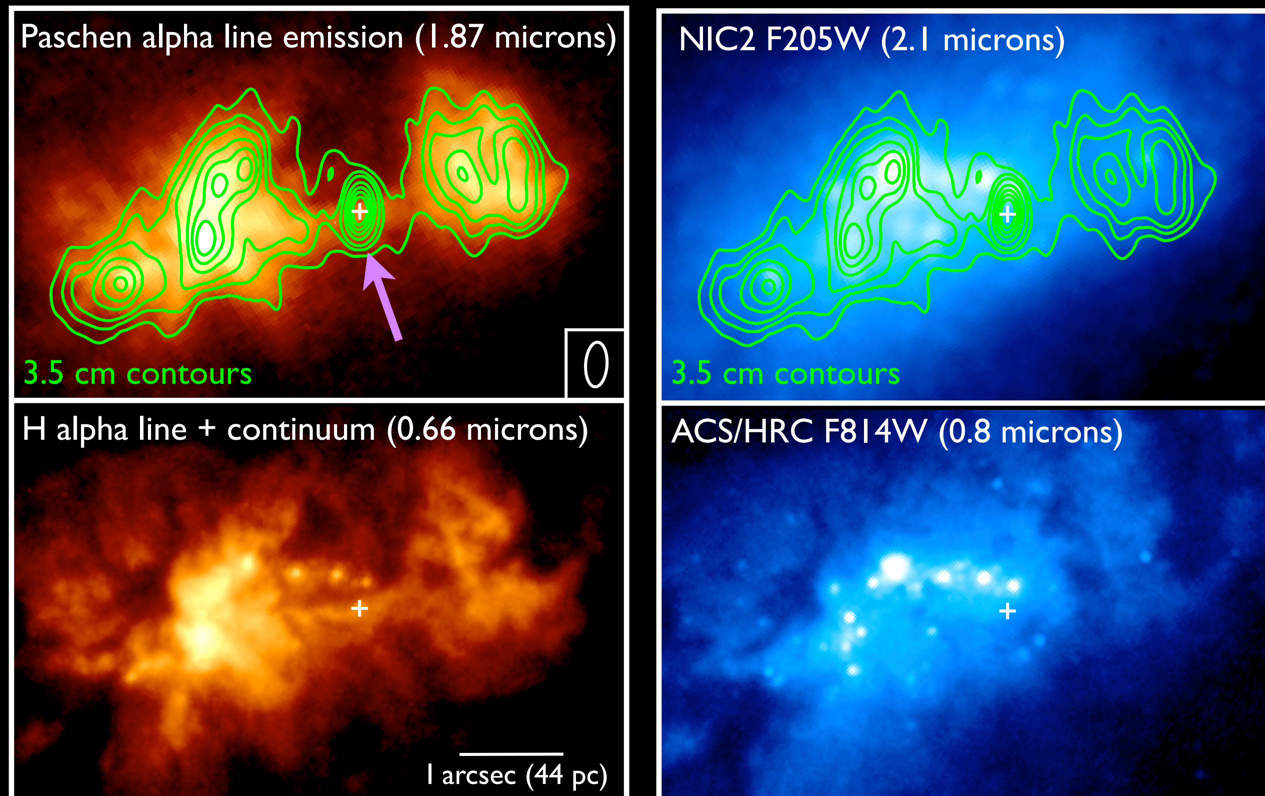

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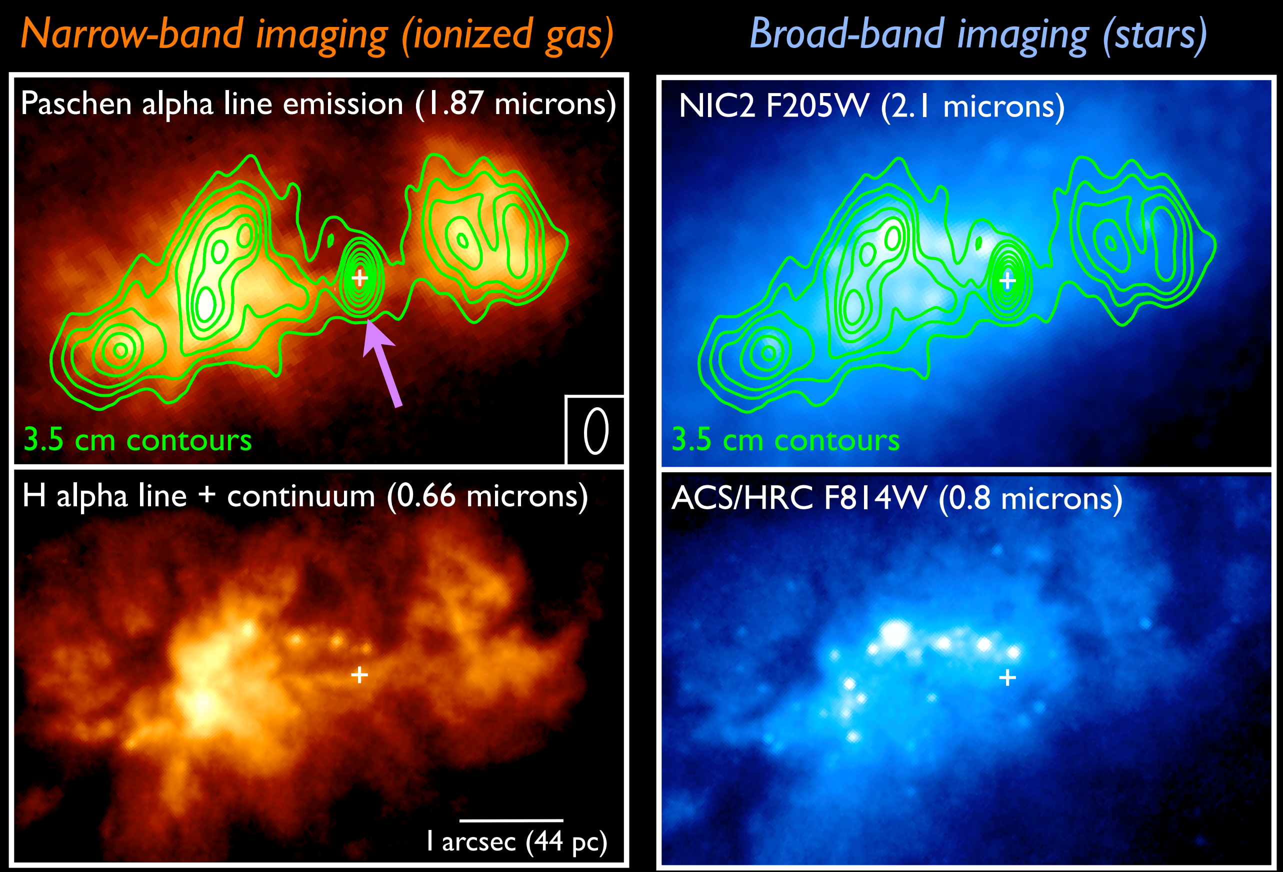

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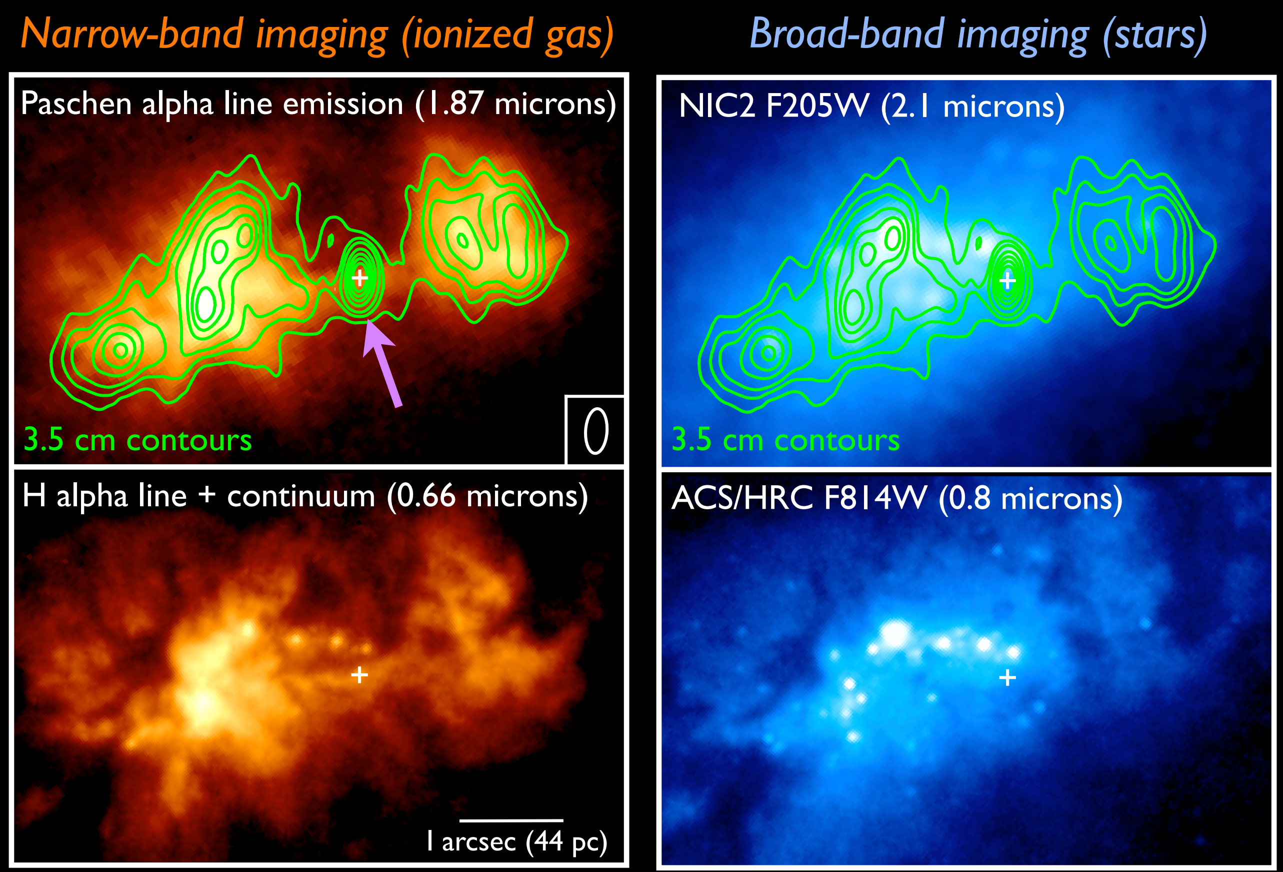

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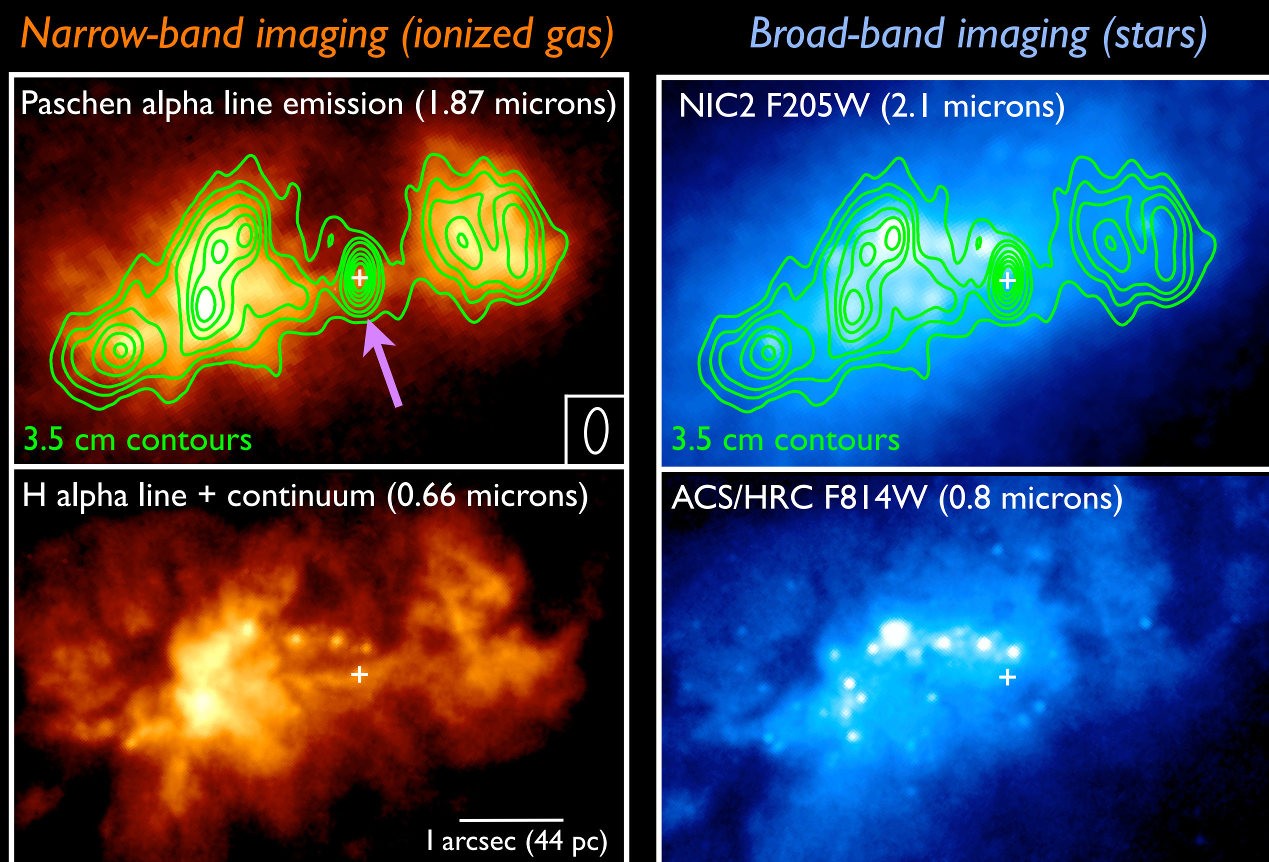

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→ Active Galactic Nucleus

Ruling out alternative explanations

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Radio luminosity	Hard X-ray luminosity
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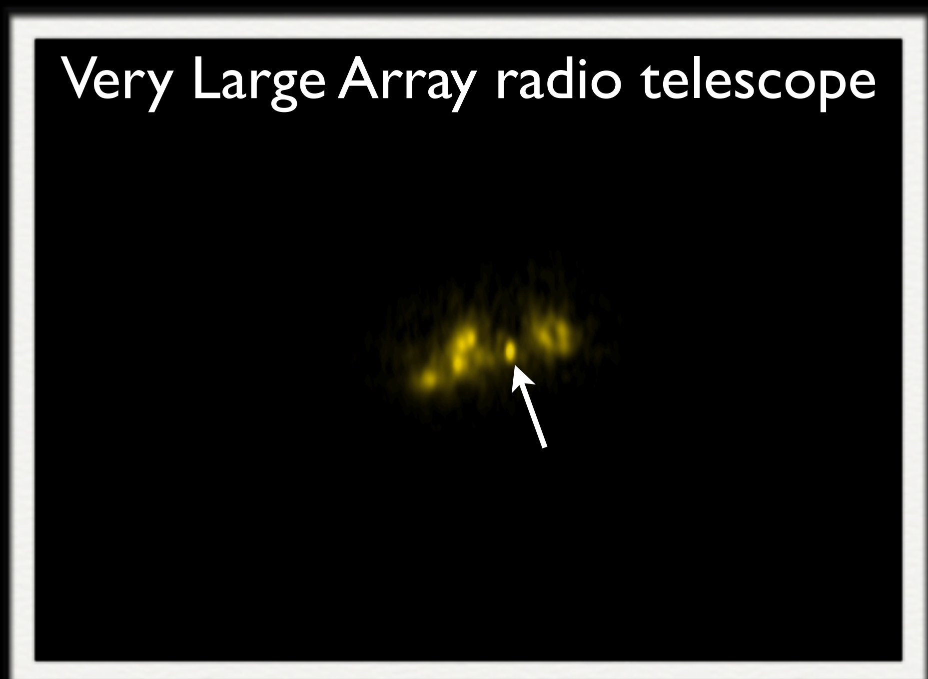

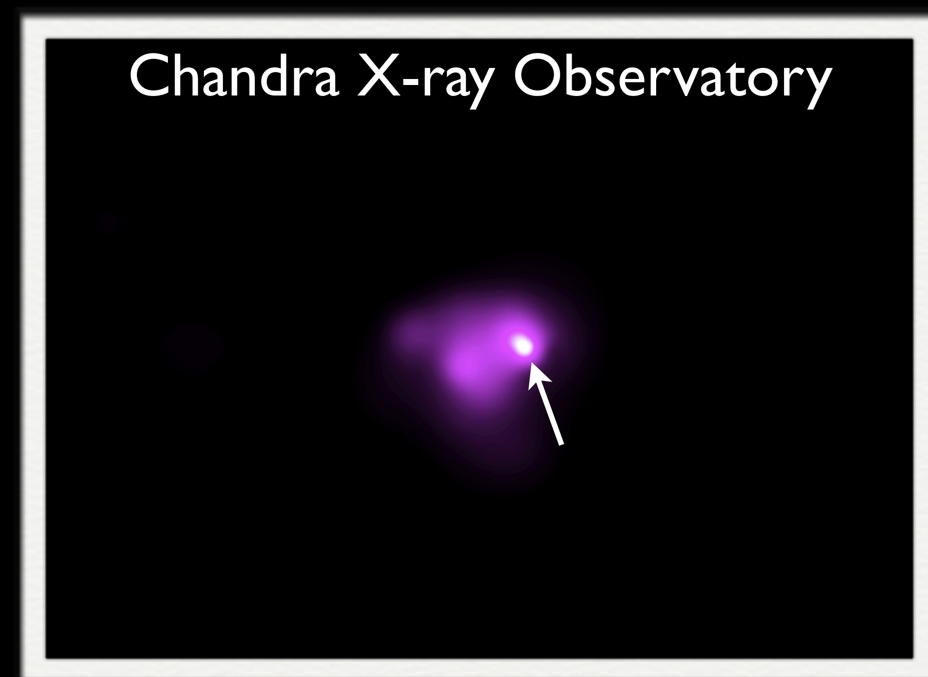

Ruling out alternative explanations

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Ratio of radio to X-ray luminosity:

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The central source in Henize 2-10:

$\log R_X \sim -3.6$

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Supernova remnants: too weak in hard X-rays
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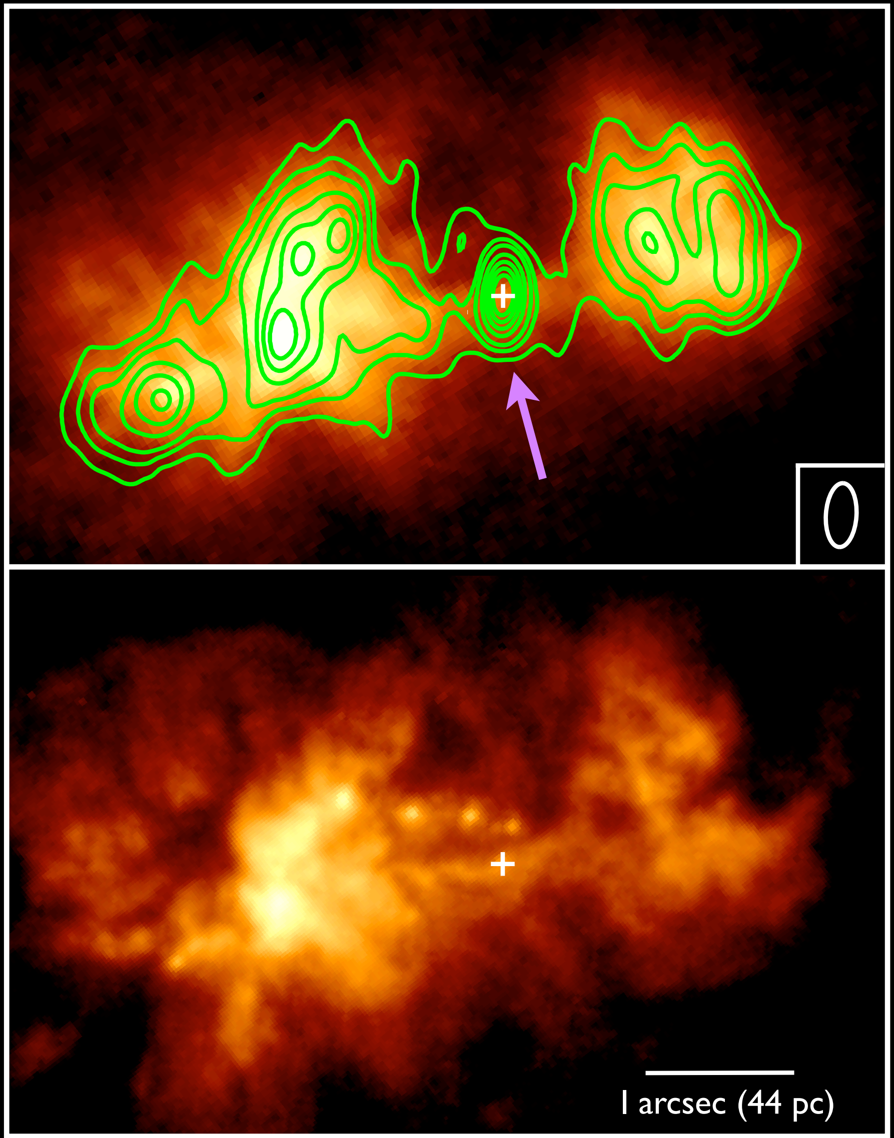
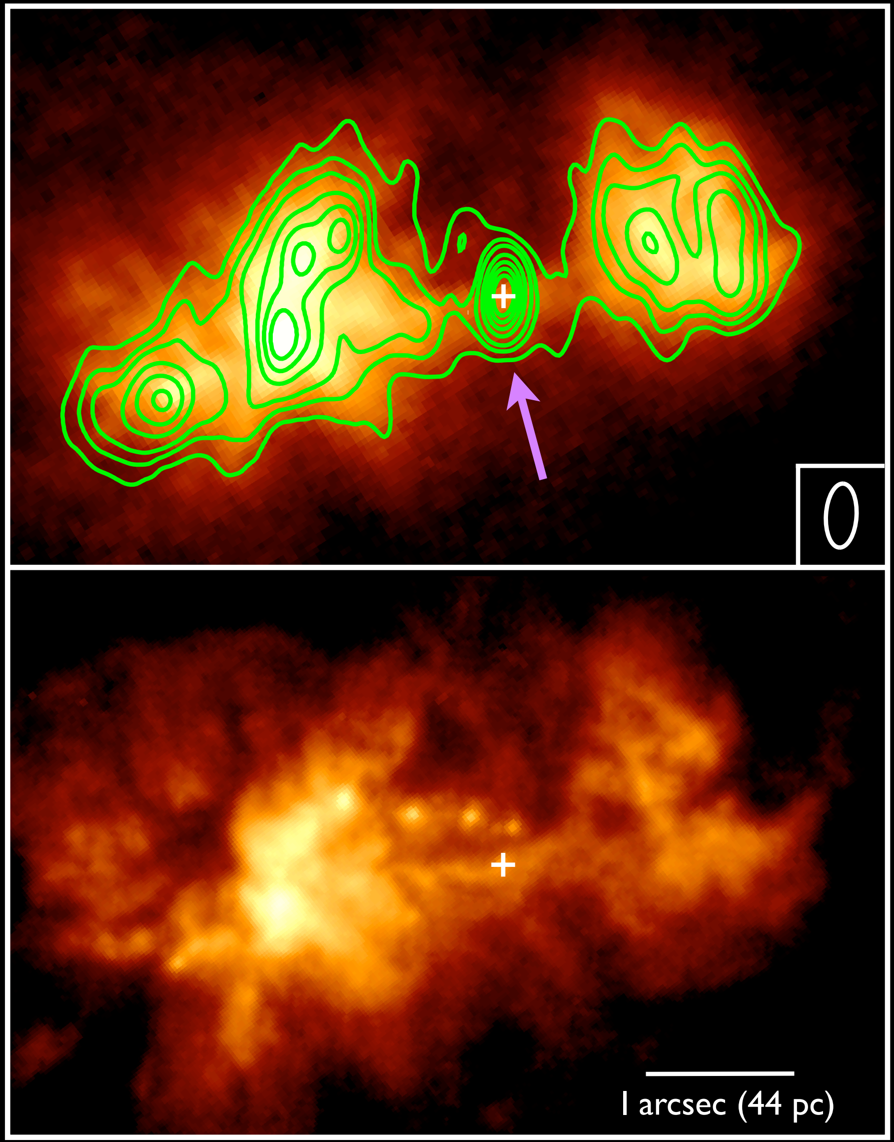
An actively accreting massive black hole



An actively accreting massive black hole

How massive?



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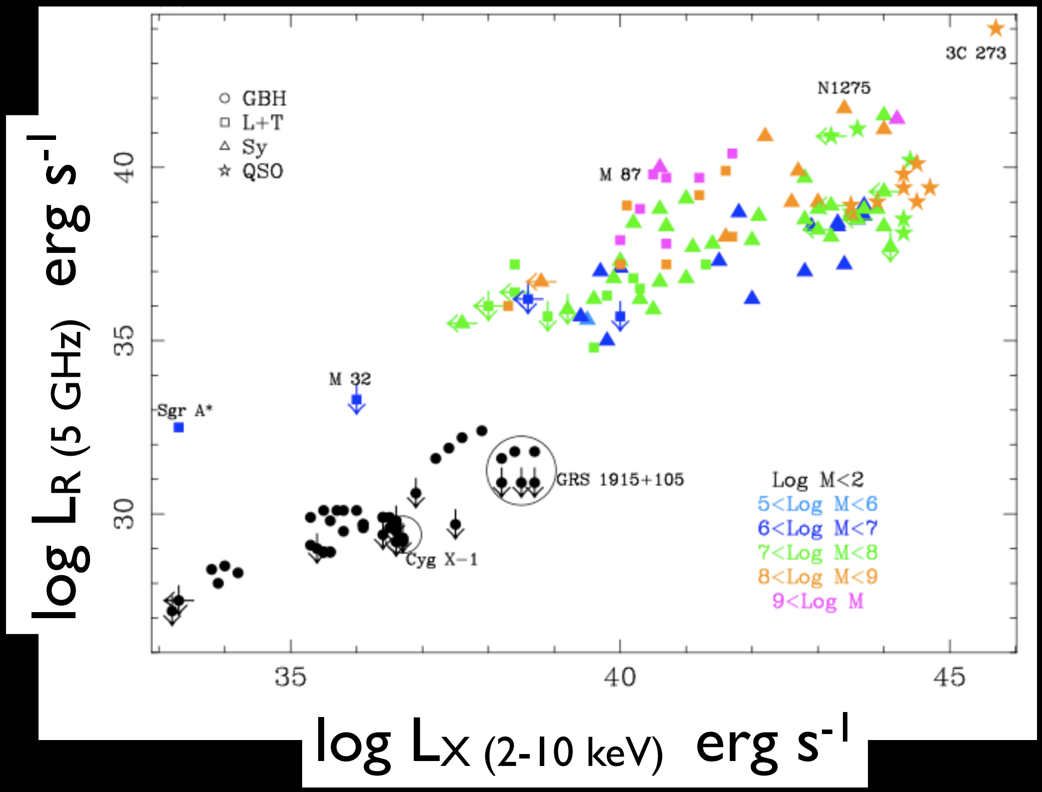
Merloni et al. 2003



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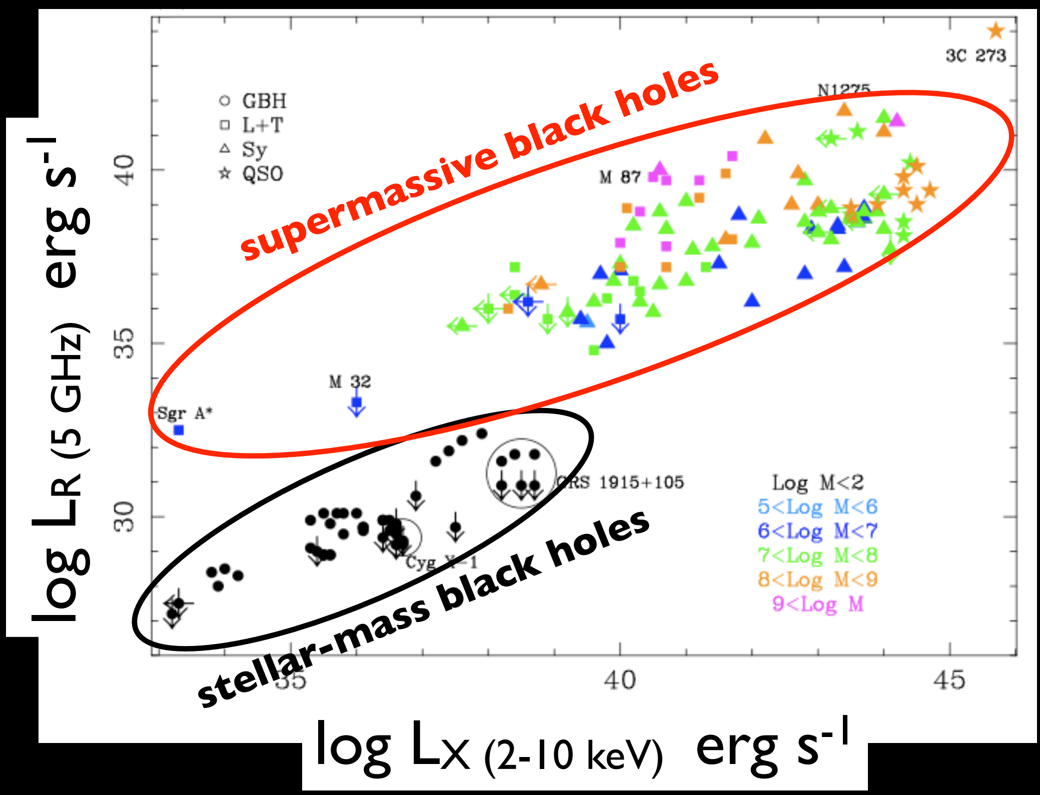

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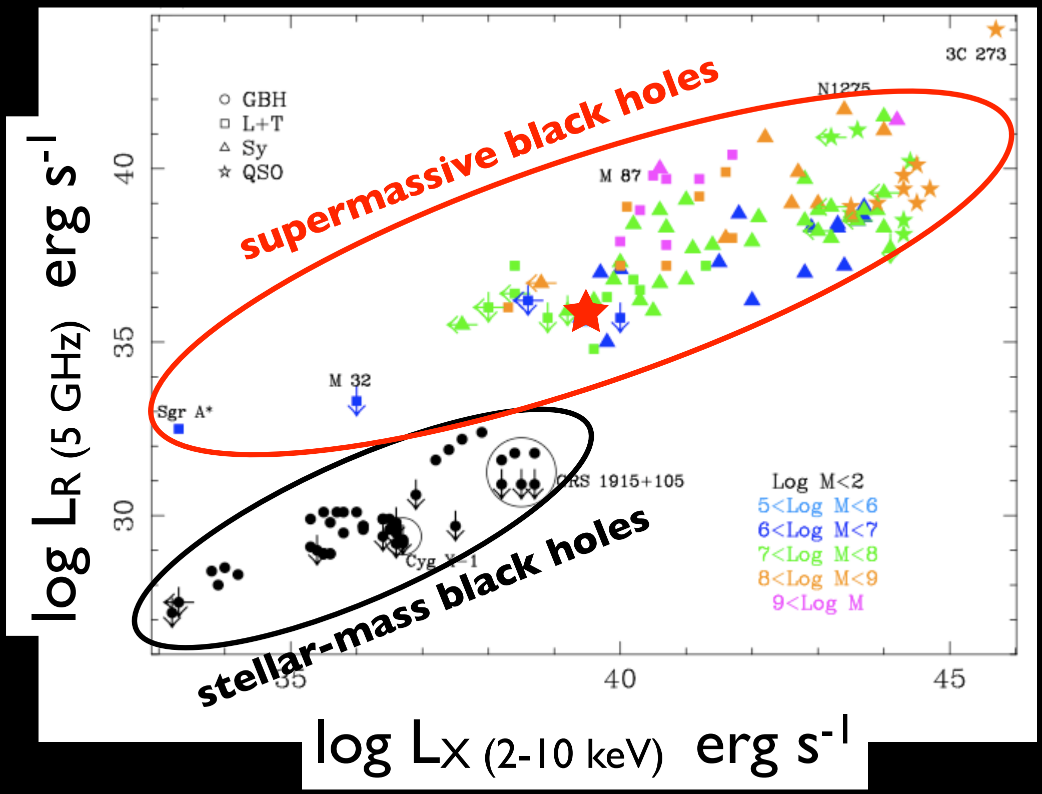

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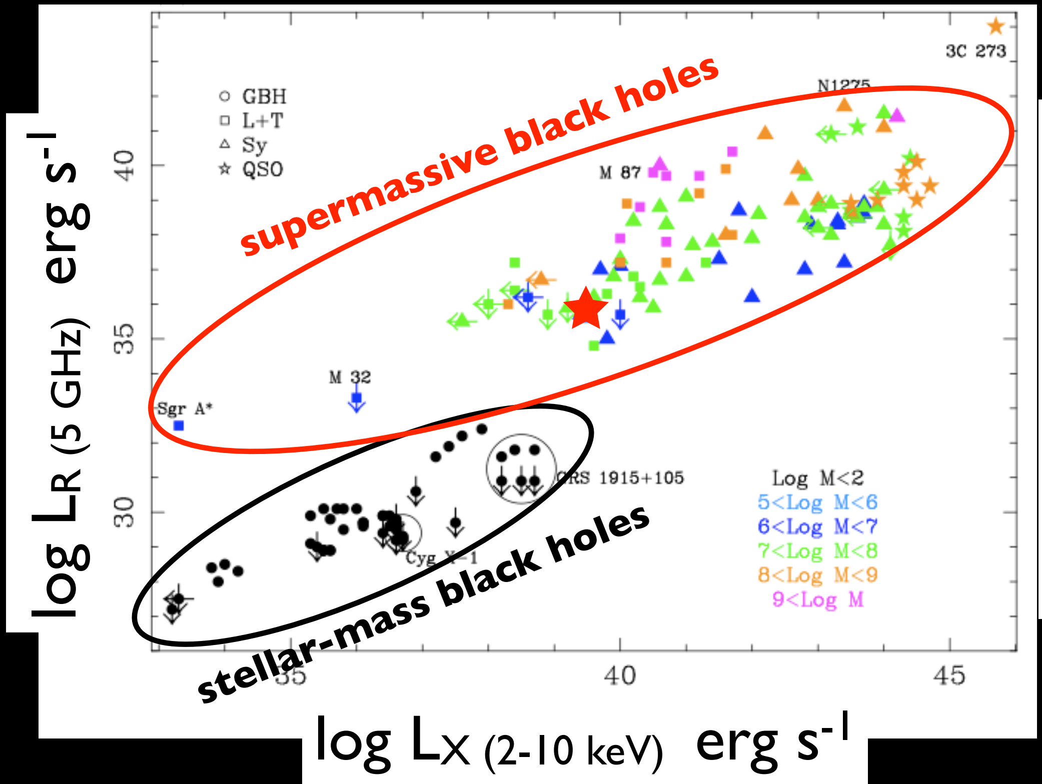

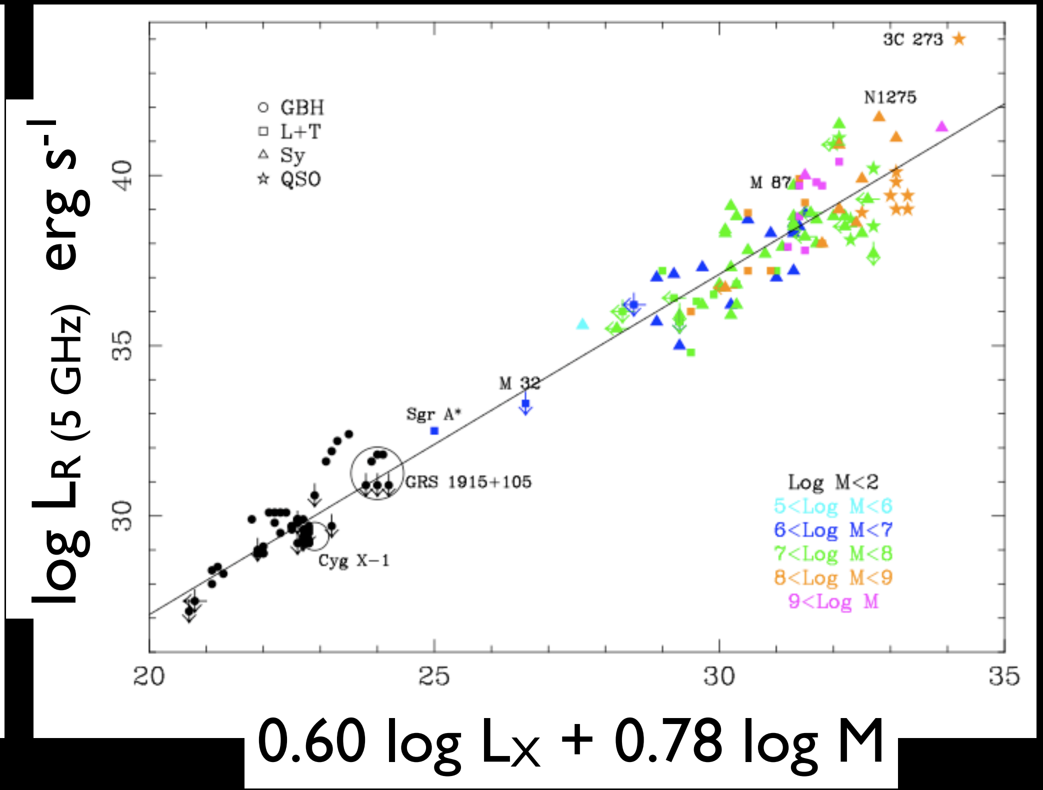

"fundamental plane of black hole activity"

$\log L_R = 0.60 \log L_X + 0.78 \log M + 7.33$

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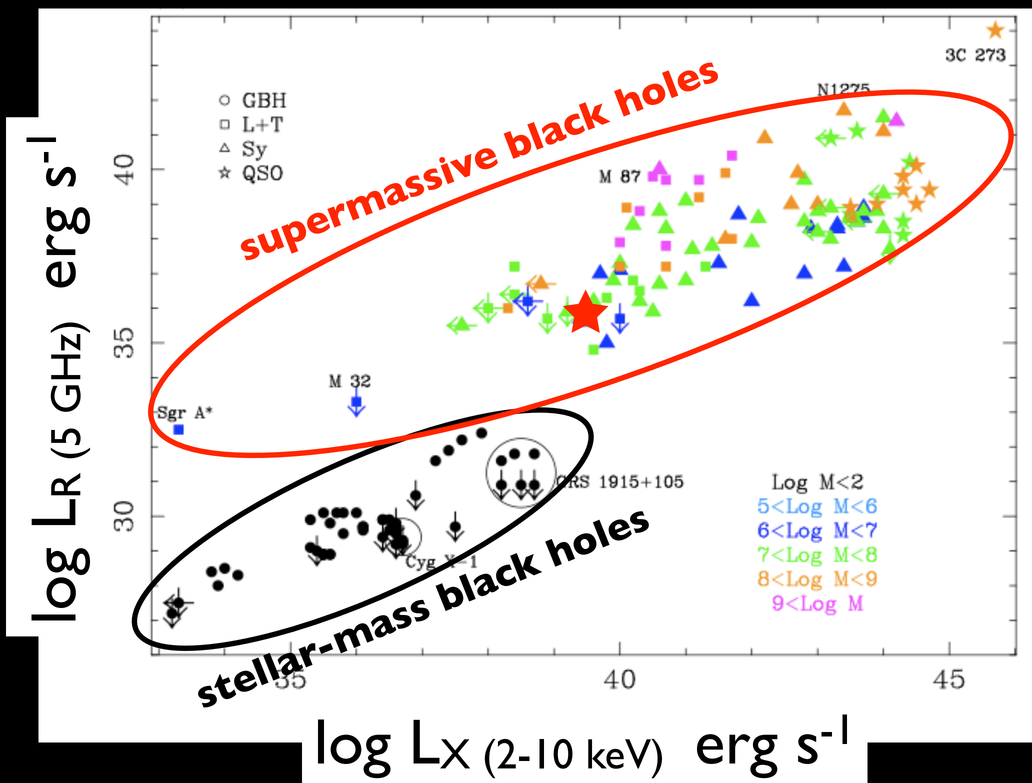
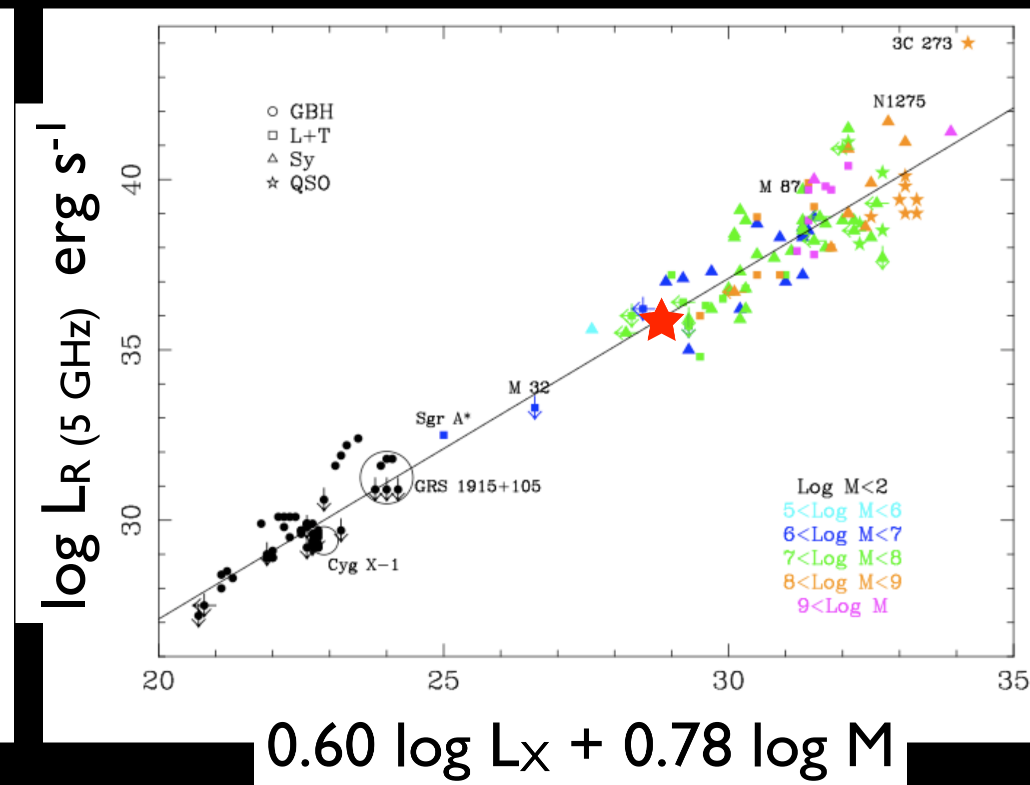
How massive?

Merloni et al. 2003





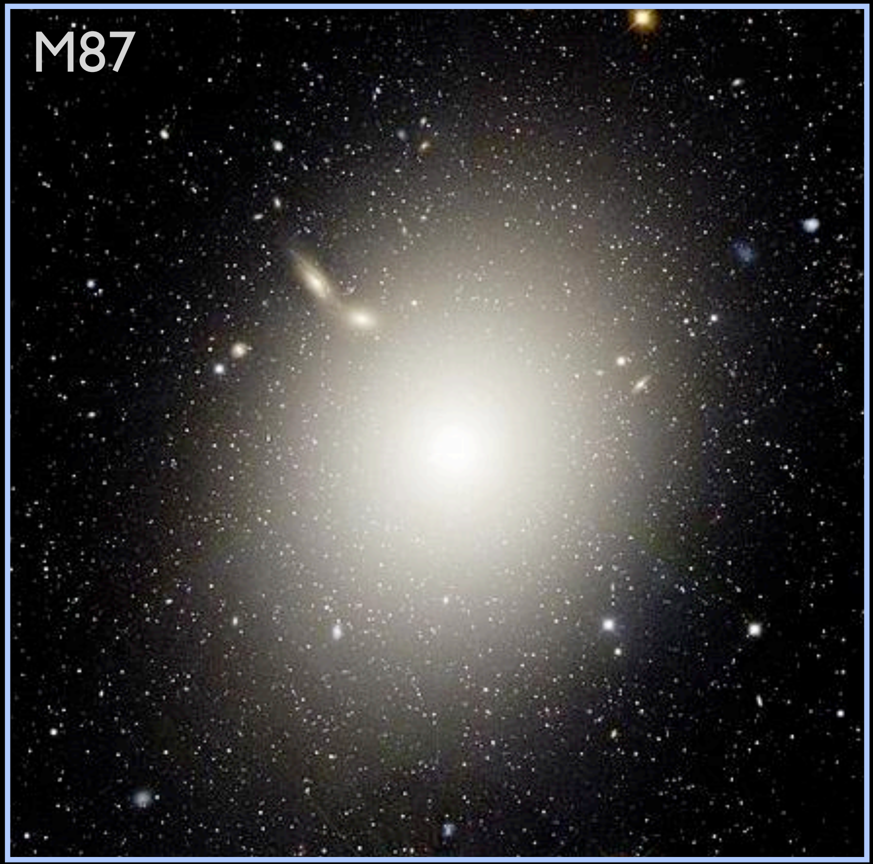
"fundamental plane of black hole activity"

$\log L_R = 0.60 \log L_X + 0.78 \log M + 7.33$

black hole in Henize 2-10 ⟶ $\log (M_{BH}/M_{sun}) = 6.3 \pm 1.1$

Supermassive black holes have typically been found in massive galaxies with bulges

$M_{BH} \sim 1.4 \times 10^8\ M_{sun}$ (Bender et al. 2005)



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Images from APOD

Supermassive black holes have typically been found in massive galaxies with bulges

But not always...

$M_{BH} \sim 1.4 \times 10^8\ M_{sun}$ (Bender et al. 2005)

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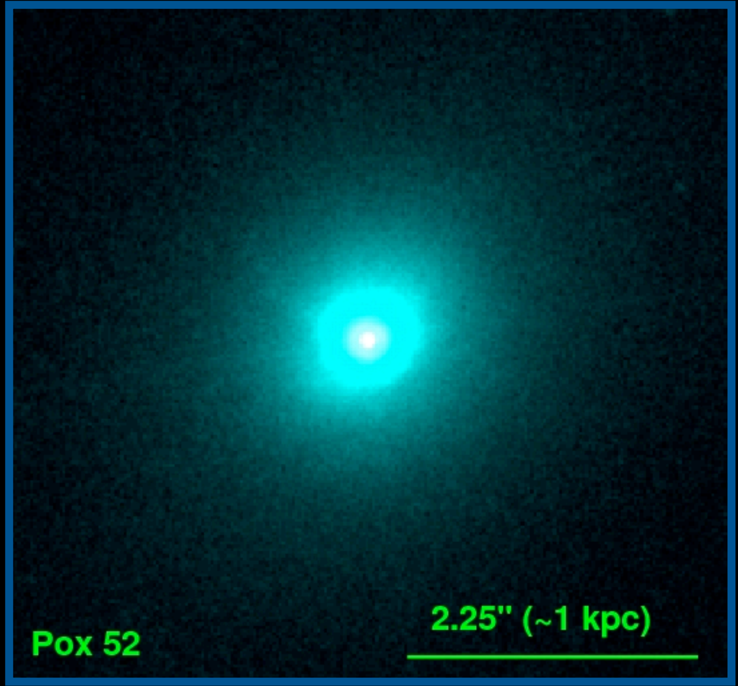
Images from APOD

The Low-Mass Regime: Putting Henize 2-10 in context

The Low-Mass Regime: Putting Henize 2-10 in context

Name	Type
NGC 4395	Sd
Pox 52	dE

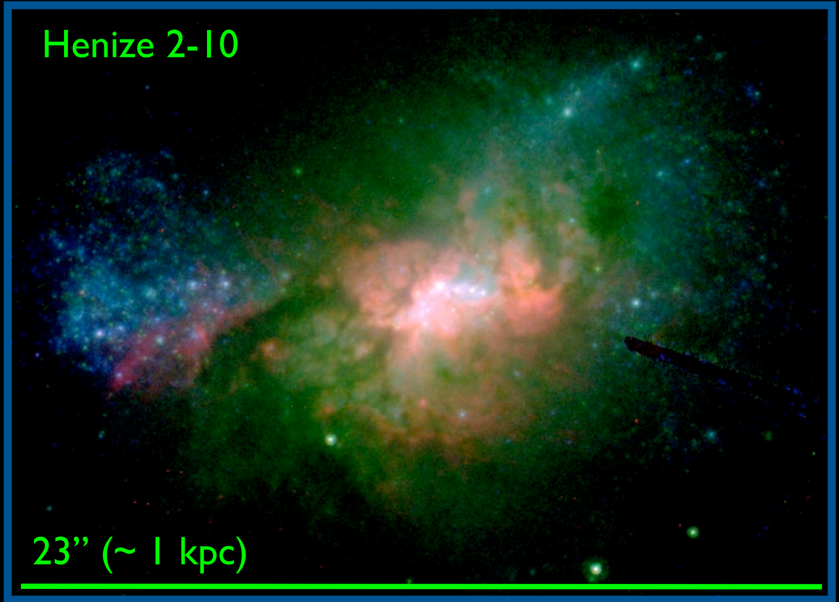
Filippenko & Sargent (1989)
Filippenko & Ho (2003)
Peterson et al. (2005)



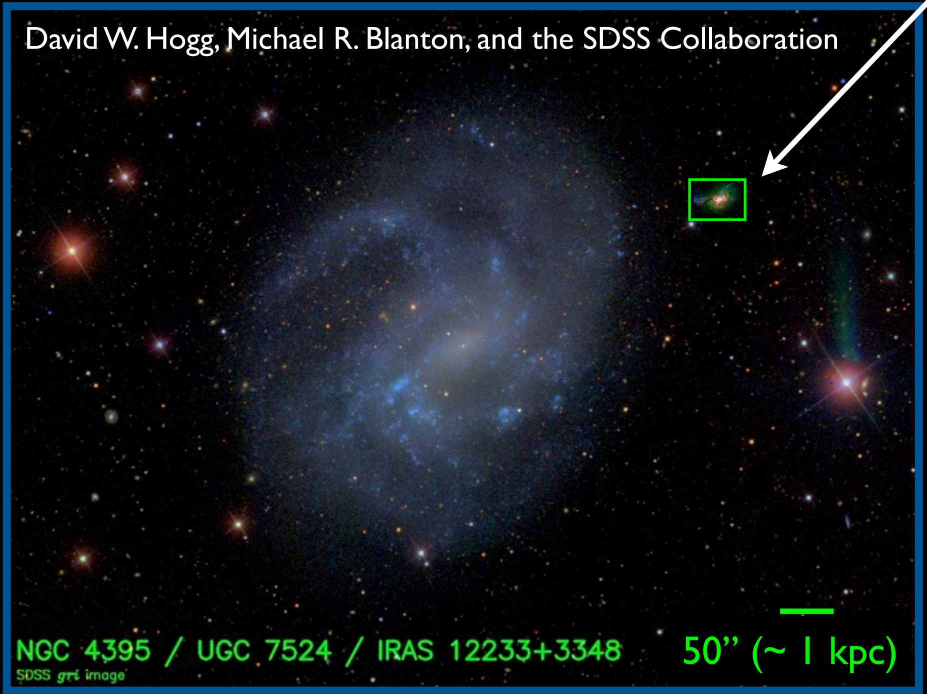
Kunth, Sargent & Bothun (1987)
Barth et al. (2004)
Thornton et al. (2008)

The Low-Mass Regime

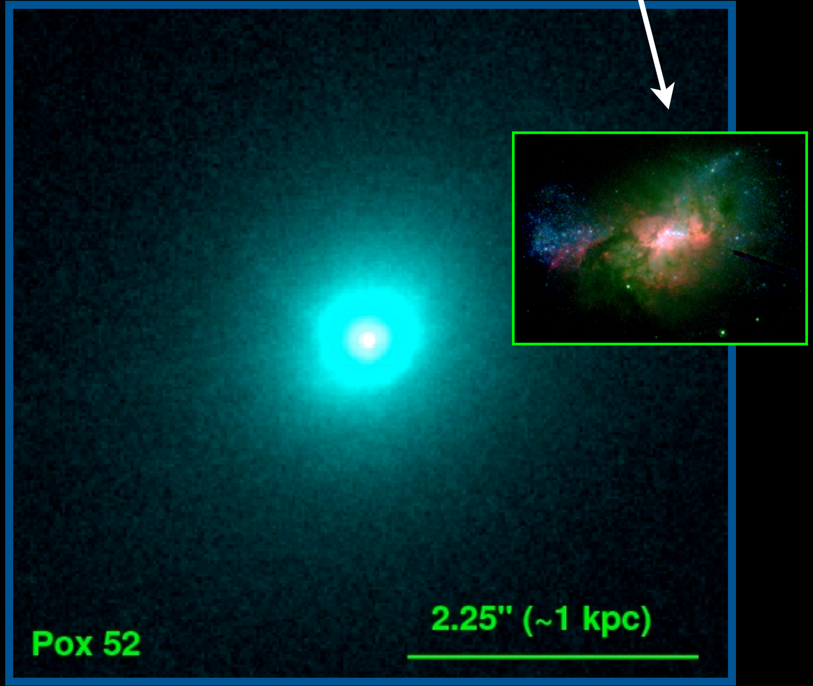
Name	Type
NGC 4395	Sd
Pox 52	dE
Henize 2-10	Blue Compact Dwarf



Reines et al. (2011)



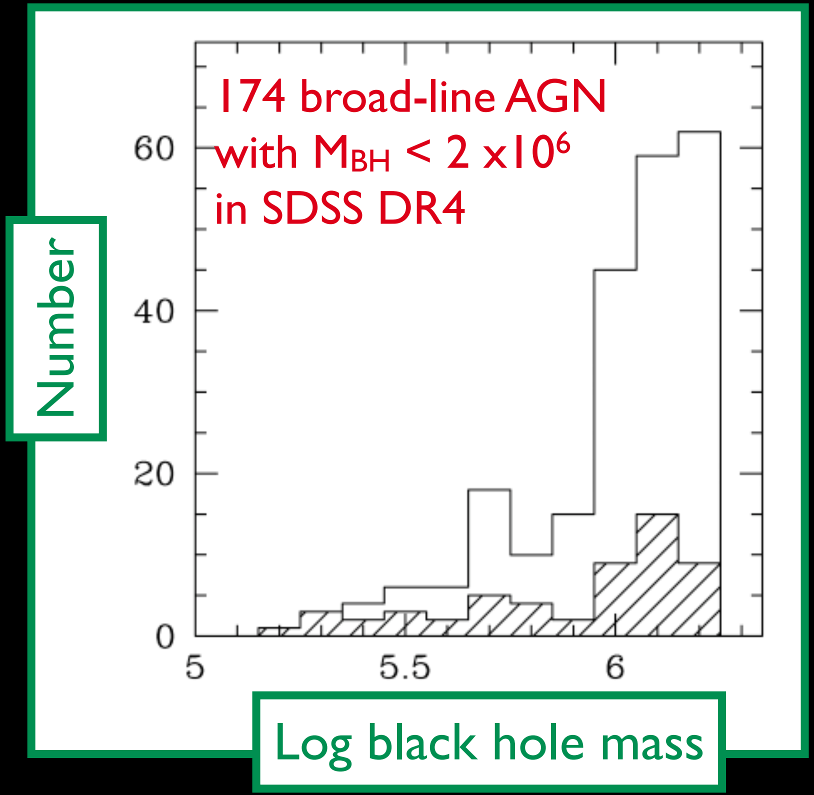
Filippenko & Sargent (1989)
Filippenko & Ho (2003)
Peterson et al. (2005)



Kunth, Sargent & Bothun (1987)
Barth et al. (2004)
Thornton et al. (2008)

The Low-Mass Regime: Putting Henize 2-10 in context

Greene & Ho (2004, 2007)



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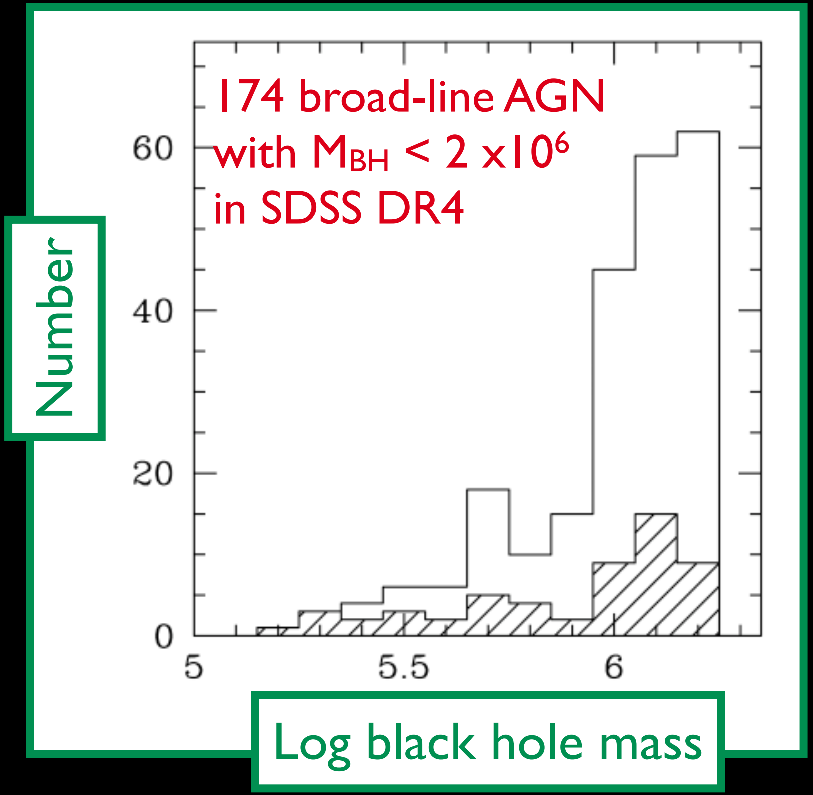
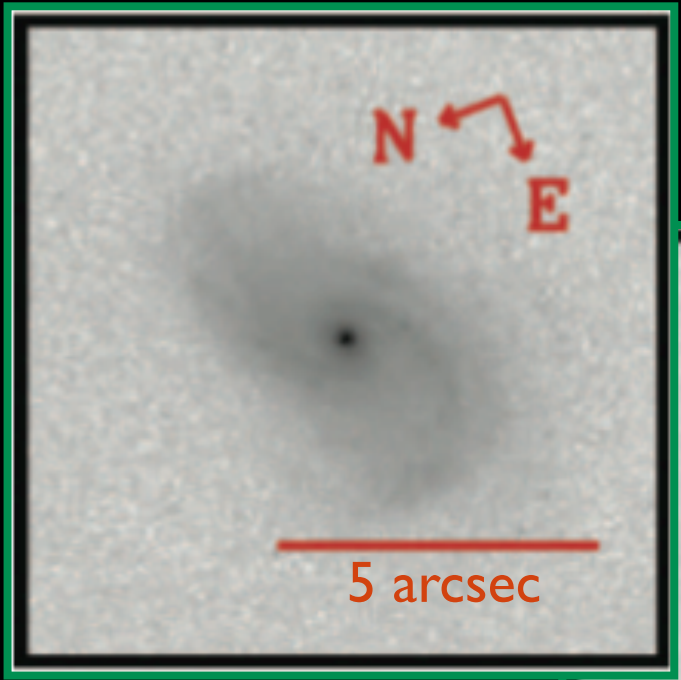
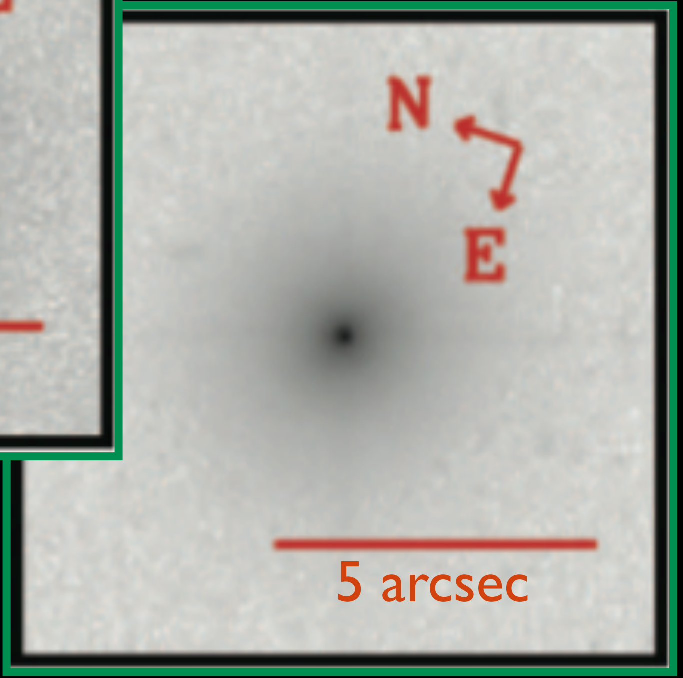


Host Galaxies

- Low-luminosity galaxies, ~ 1 mag below L*
- Well-defined optical nuclei



~ 93% extended disks (with pseudobulges)



~ 7% spheroidals

Greene et al. (2008); Jiang et al. (2011)

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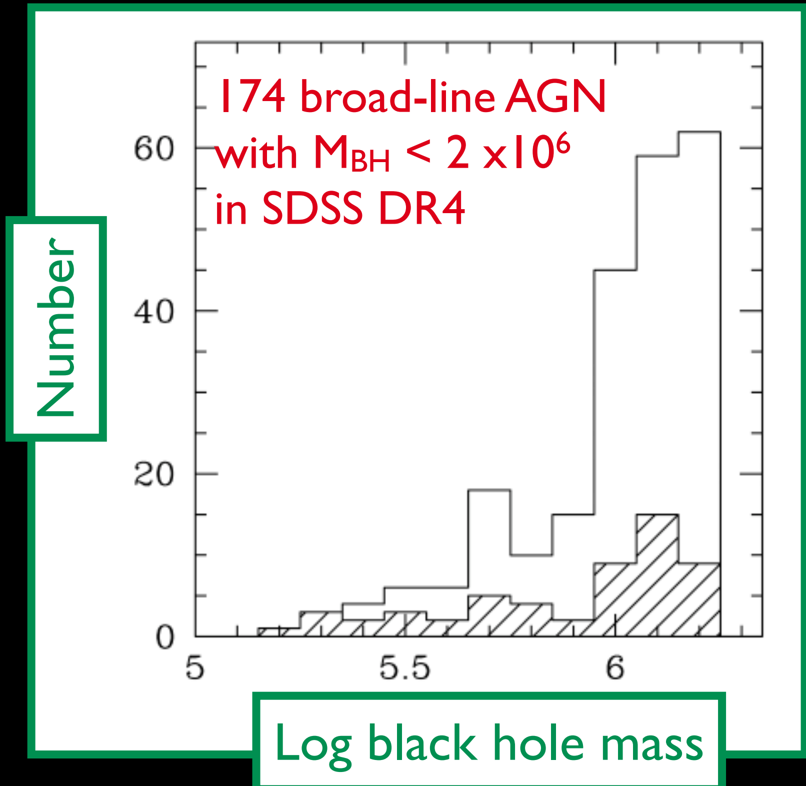
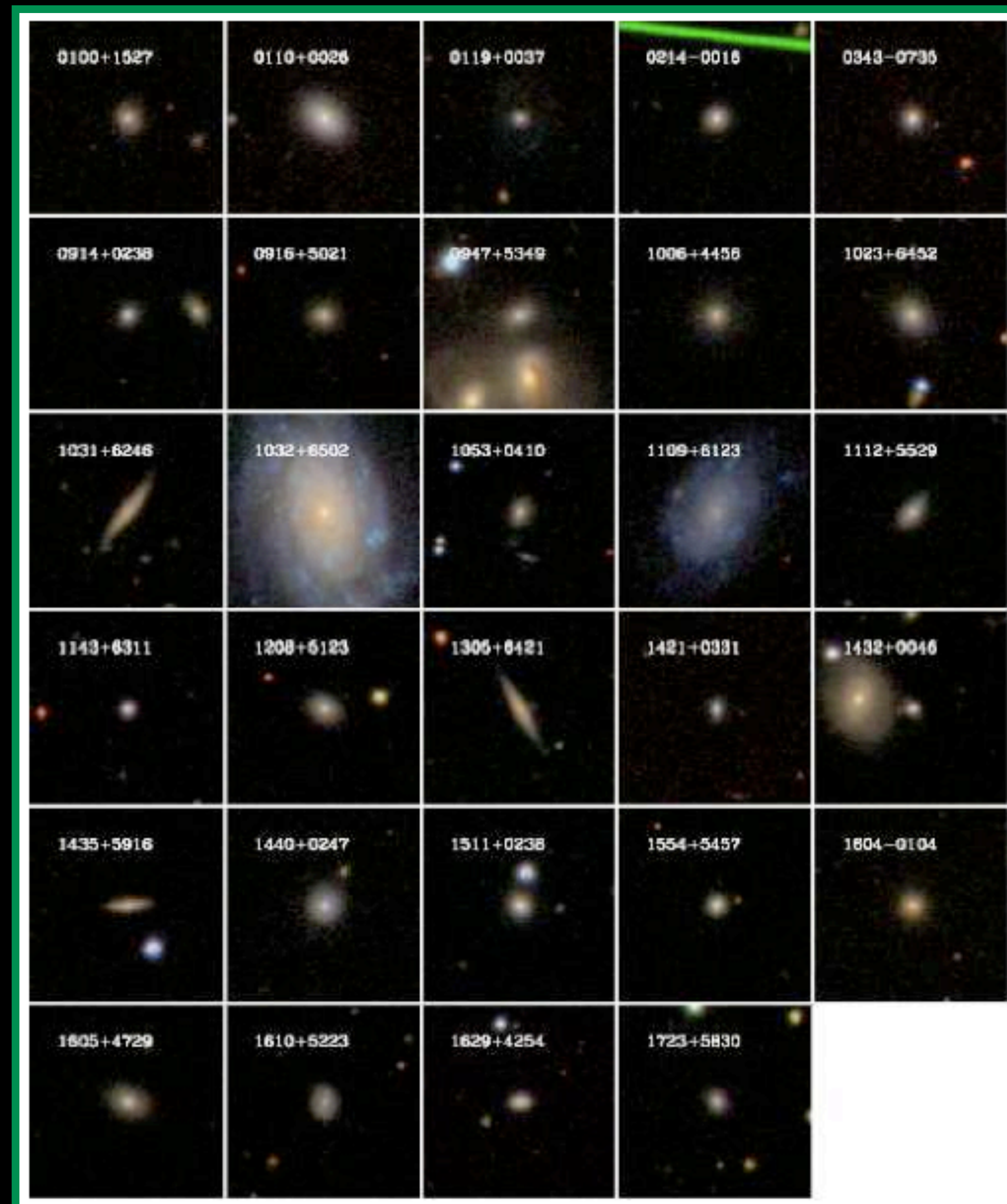


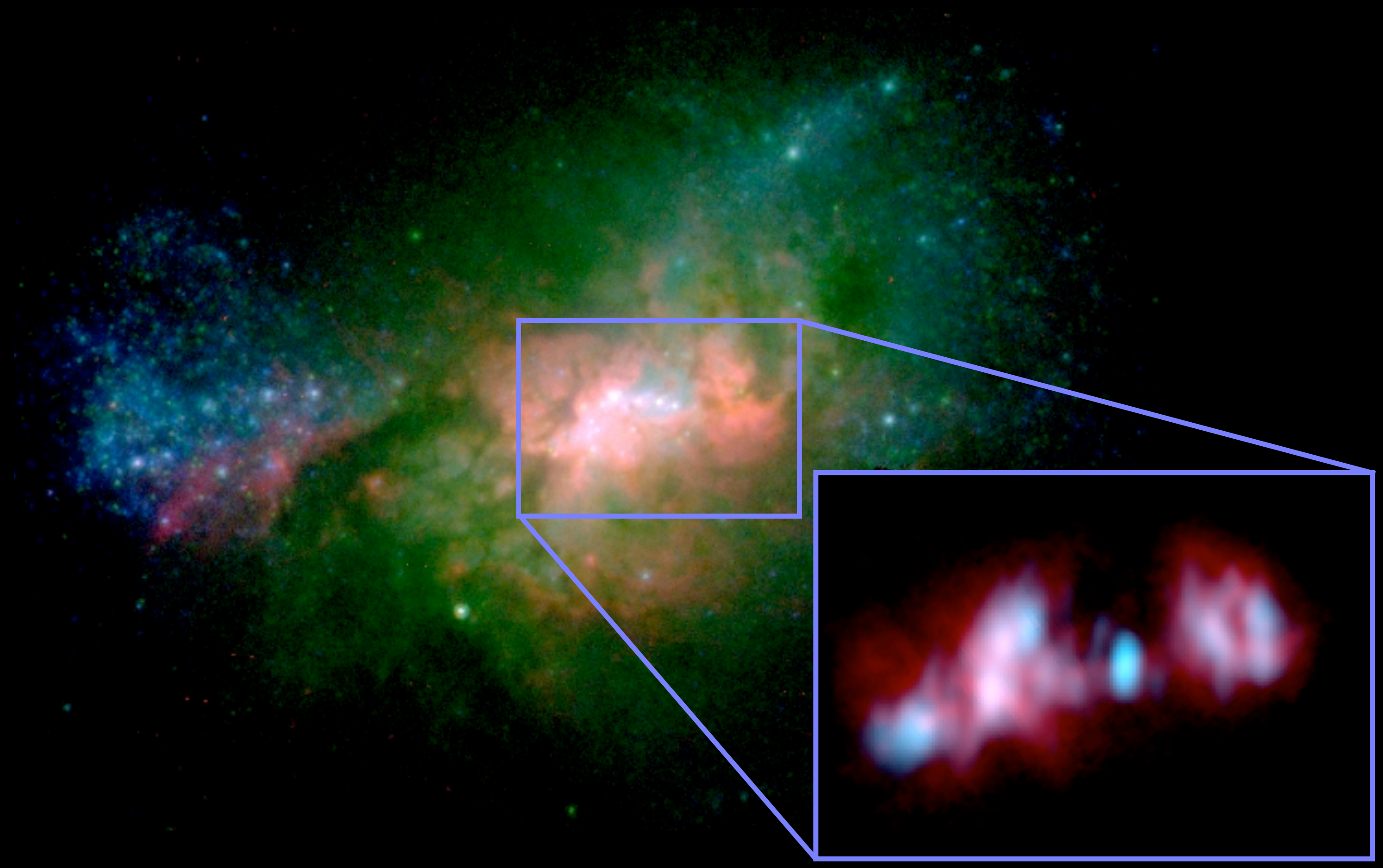


Barth et al. (2008)

- Type 2 counterparts to Greene & Ho sample
- 12 have stellar velocity dispersions < 60 km s^{-1} ($M_{BH} < 10^6$)

Henize 2-10 is *different*

- Dwarf starburst galaxy with newly formed globular clusters
- Irregular morphology without a well-defined nucleus



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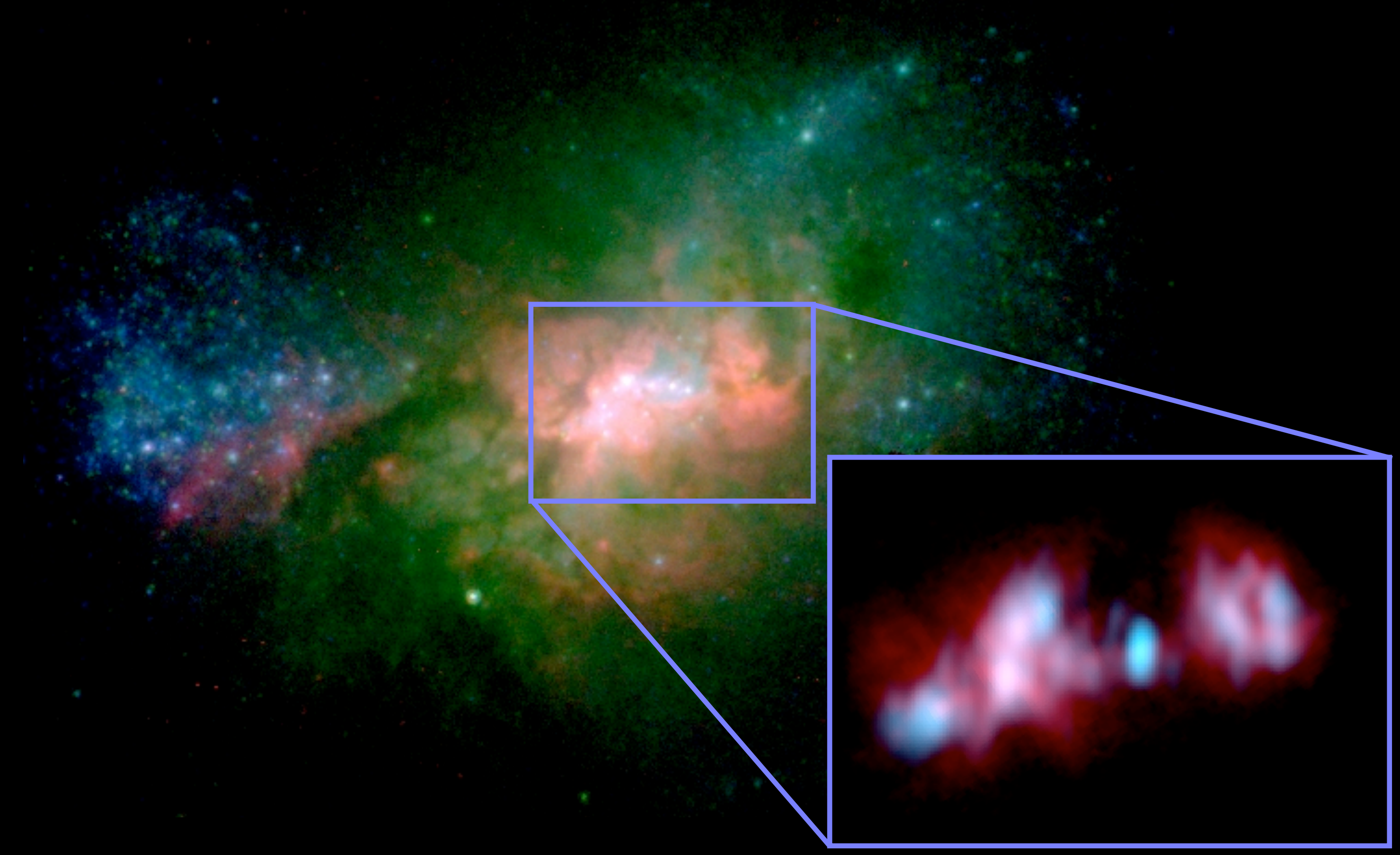

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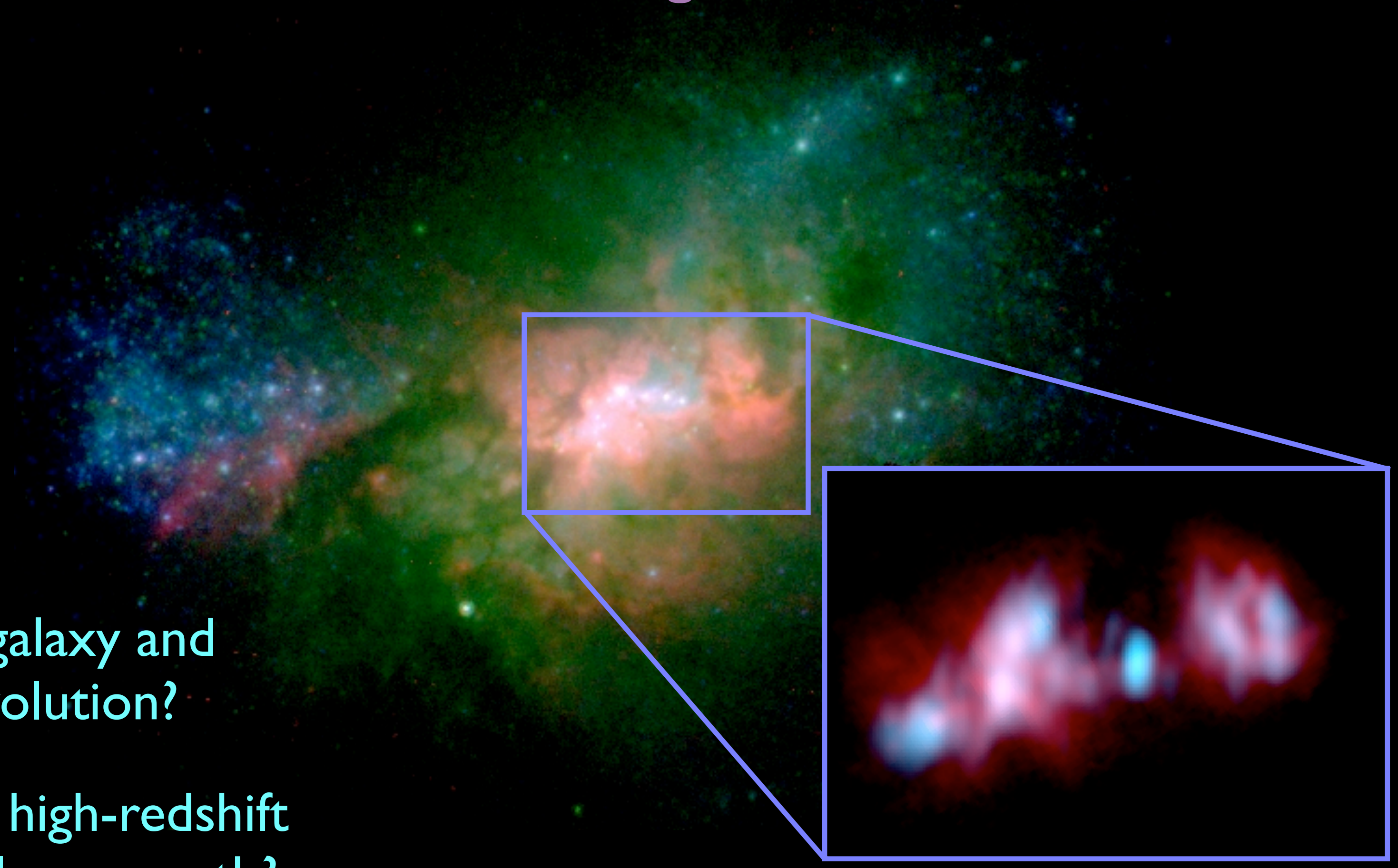
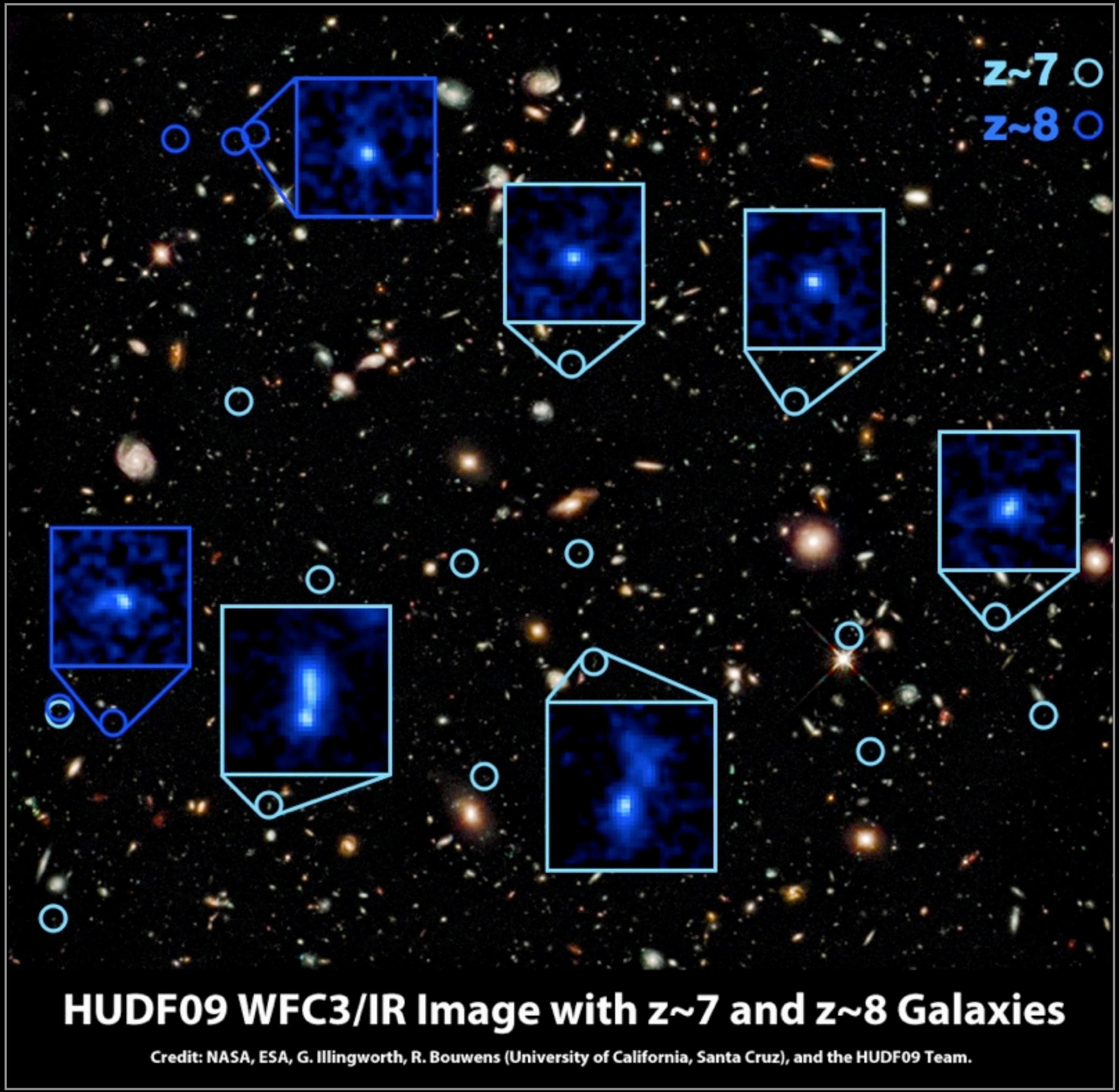


Early stage of galaxy and black hole evolution?

Local analogue to high-redshift black hole and galaxy growth?

The First Star-Forming Galaxies



- blue, compact galaxies 600-800 Myr after the Big Bang (Bouwens et al. 2010)
- intrinsic sizes $\lesssim$ 1 kpc (Oesch et al. 2010)
- masses ~ 10^9-10^{10} M_{sun} (Labbé et al. 2010)
- likely forming globular clusters
- likely host massive black holes (Treister et al. 2011)

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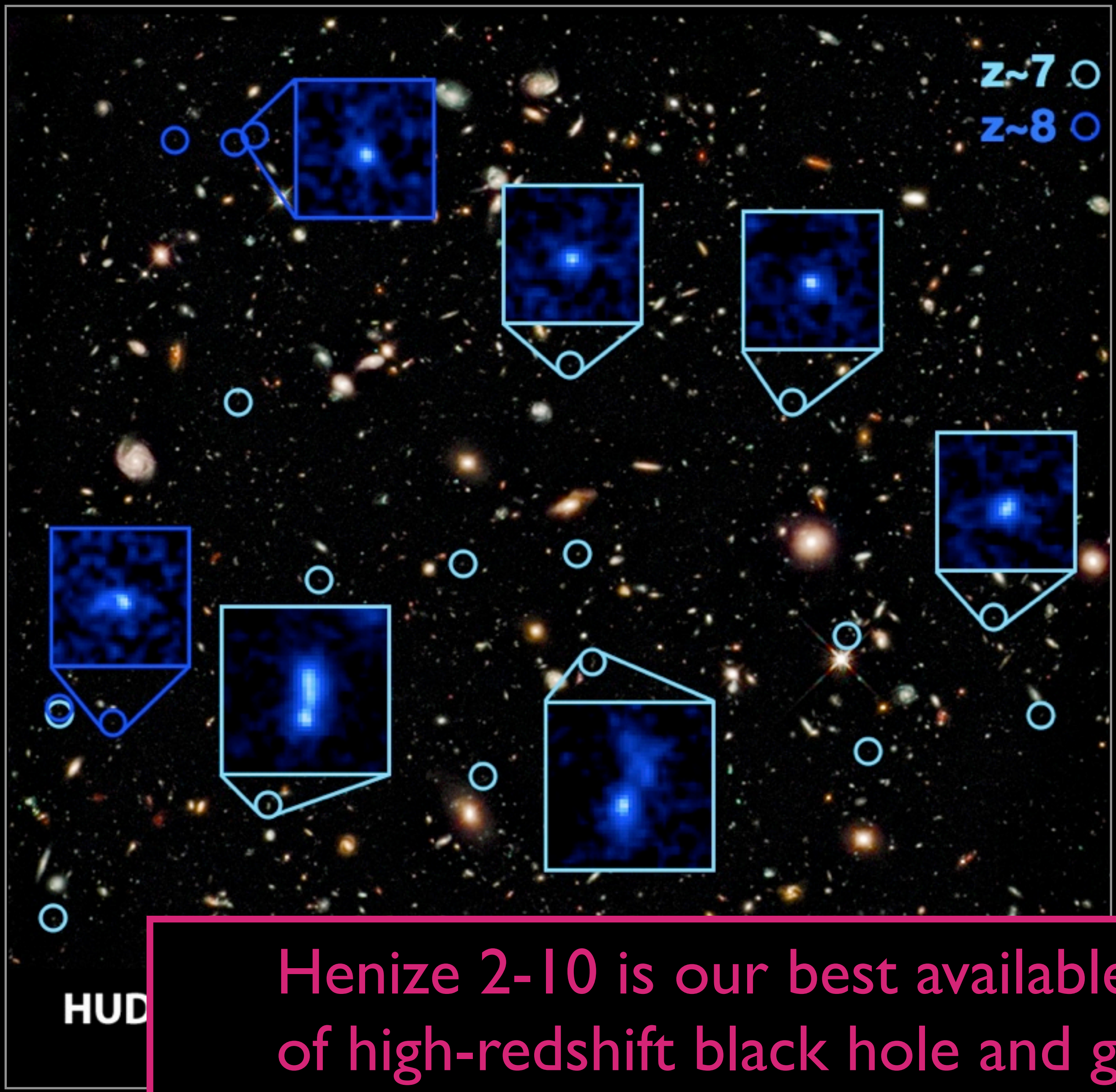

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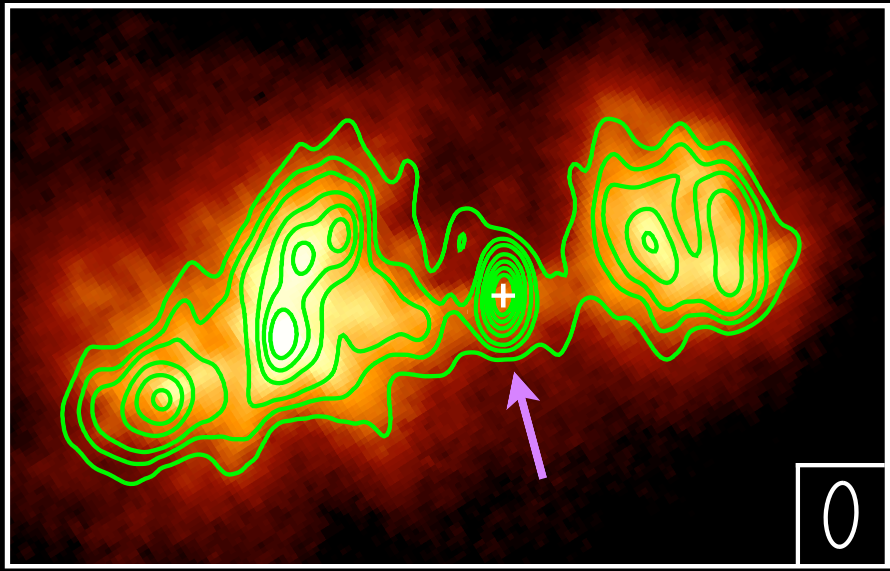
Henize 2-10 is our best available local analog of high-redshift black hole and galaxy growth

Main take-away points about Henize 2-10

- First example of a massive black hole in a local star-forming dwarf galaxy
- Nearby galaxy much like those in the earlier universe
- Best available analog of primordial black hole growth - opens up a new class of host galaxies to search for more
- No discernible bulge - black hole growth can precede the build-up of galaxy spheroids



Follow-up observations of Henize 2-10

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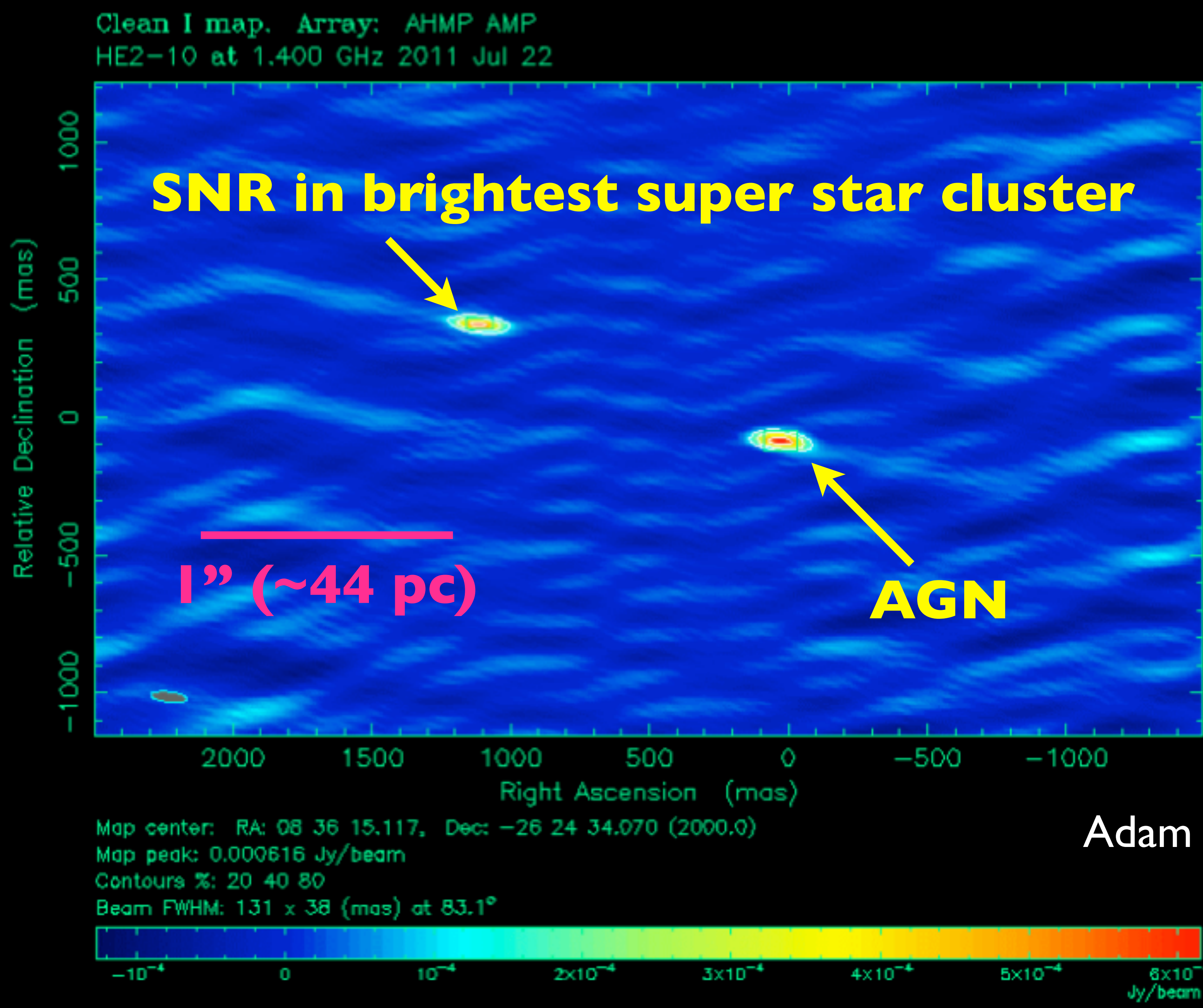
Accepted Proposals

- *HST/STIS* - Kinematics and ionization conditions near AGN
  P.I. Reines (w/ Whittle, Johnson)

- *XMM-Newton* - X-ray follow-up
  P.I. Hickox (w/ Greene, Reines, Sivakoff, Johnson, Alexander)

- *VLBI with the Long Baseline Array* - High-resolution observations at 1.4 GHz
  P.I. Reines (w/ Deller, Johnson)

New (yesterday!) VLBI data



Adam Deller

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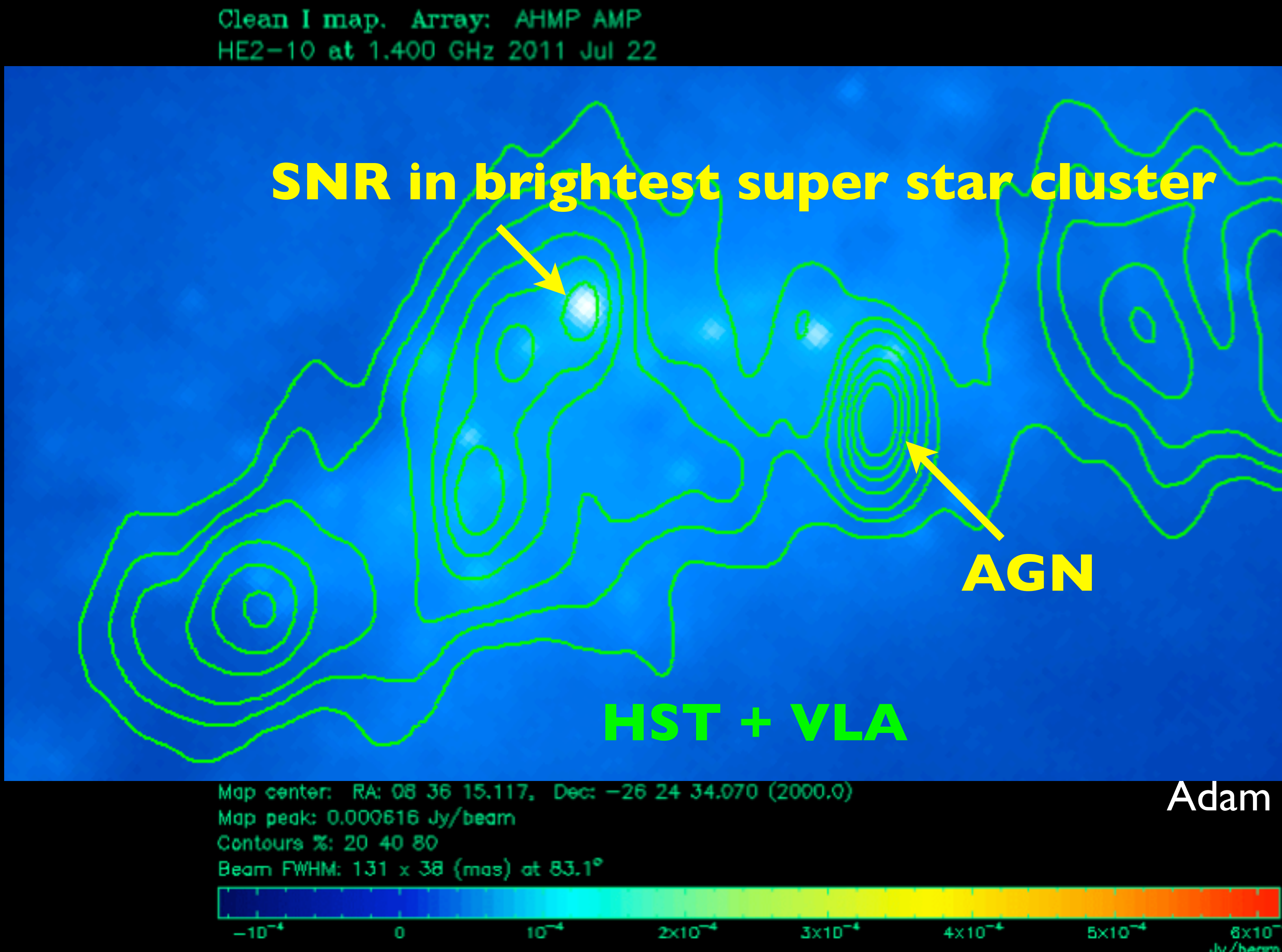

Adam Deller

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Submitted Proposals

- *EVLA* - Water maser observations
  P.I. Reines (w/ Darling, Brogan, Johnson)

- *ALMA* - Dense molecular gas
  P.I. Johnson (w/ Reines, Testi, Brogan, Vanzi, Wilner, Chen)

Searching for big black holes in little galaxies

Accepted Proposals

- Chandra + EVLA - mini survey of nearby star-forming dwarfs
  P.I. Reines (w/ Sivakoff, Condon)

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Starting to plan large-scale radio survey (w/ Jim Condon)

Discussion topics

1. Using the black hole fundamental plane to obtain masses

This is potentially a very powerful tool for obtaining black hole masses. How reliable is it (at low masses)? Would simultaneous X-ray and radio observations significantly reduce the scatter in the relationship?

2. The impact of metallicity on making “heavy” black hole seeds

Are extremely low metallicities required to make a massive seed? Can massive seeds form from direct collapse of enriched gas in the modern universe (e.g. Begelman & Shlosman 2009)?