

Galaxy-Black Hole Co-Evolution



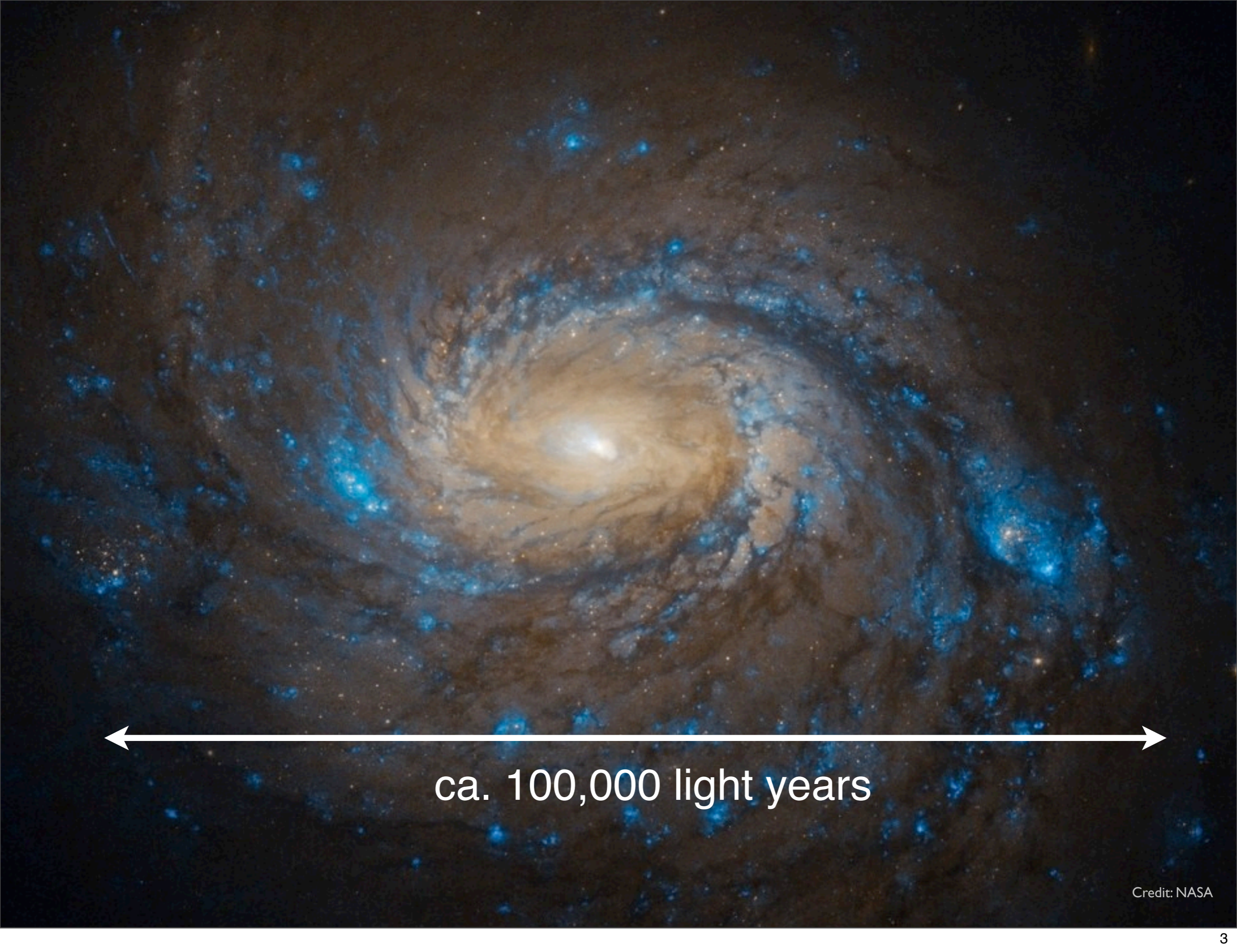
Kevin Schawinski
Institute for Astronomy
ETH Zurich

 @kevinschawinski





Credit: NASA



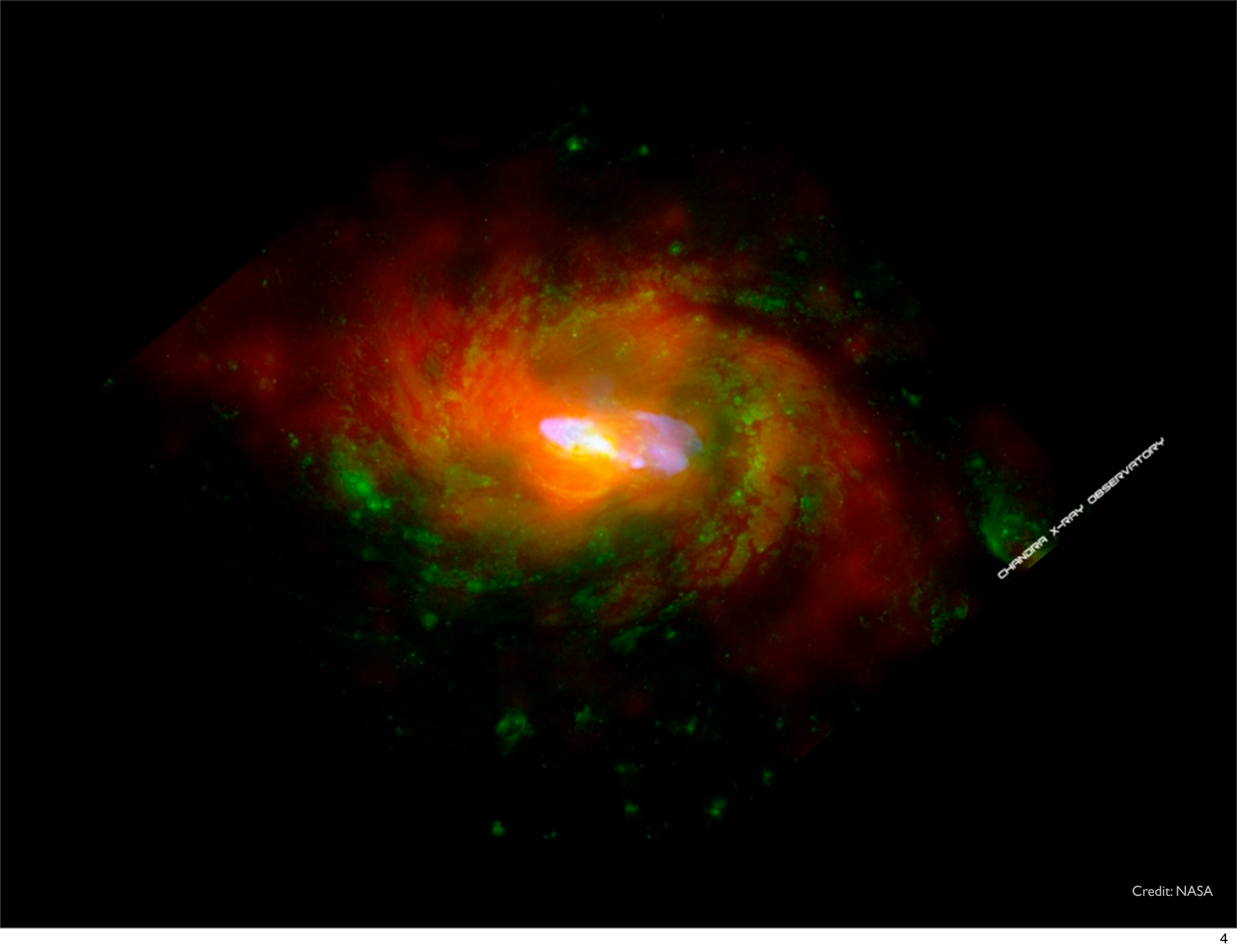
ca. 100,000 light years



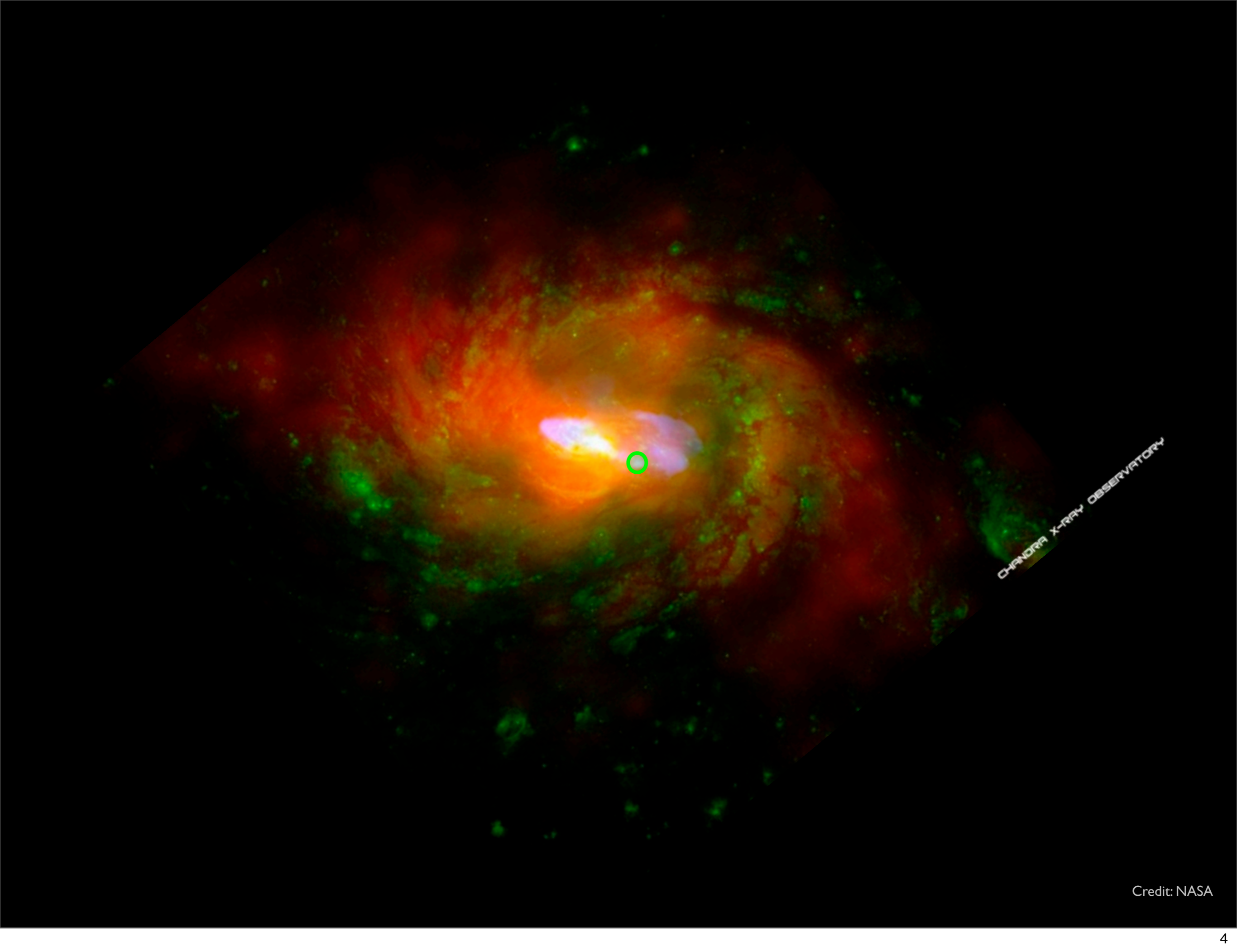
Credit: NASA



Credit: NASA



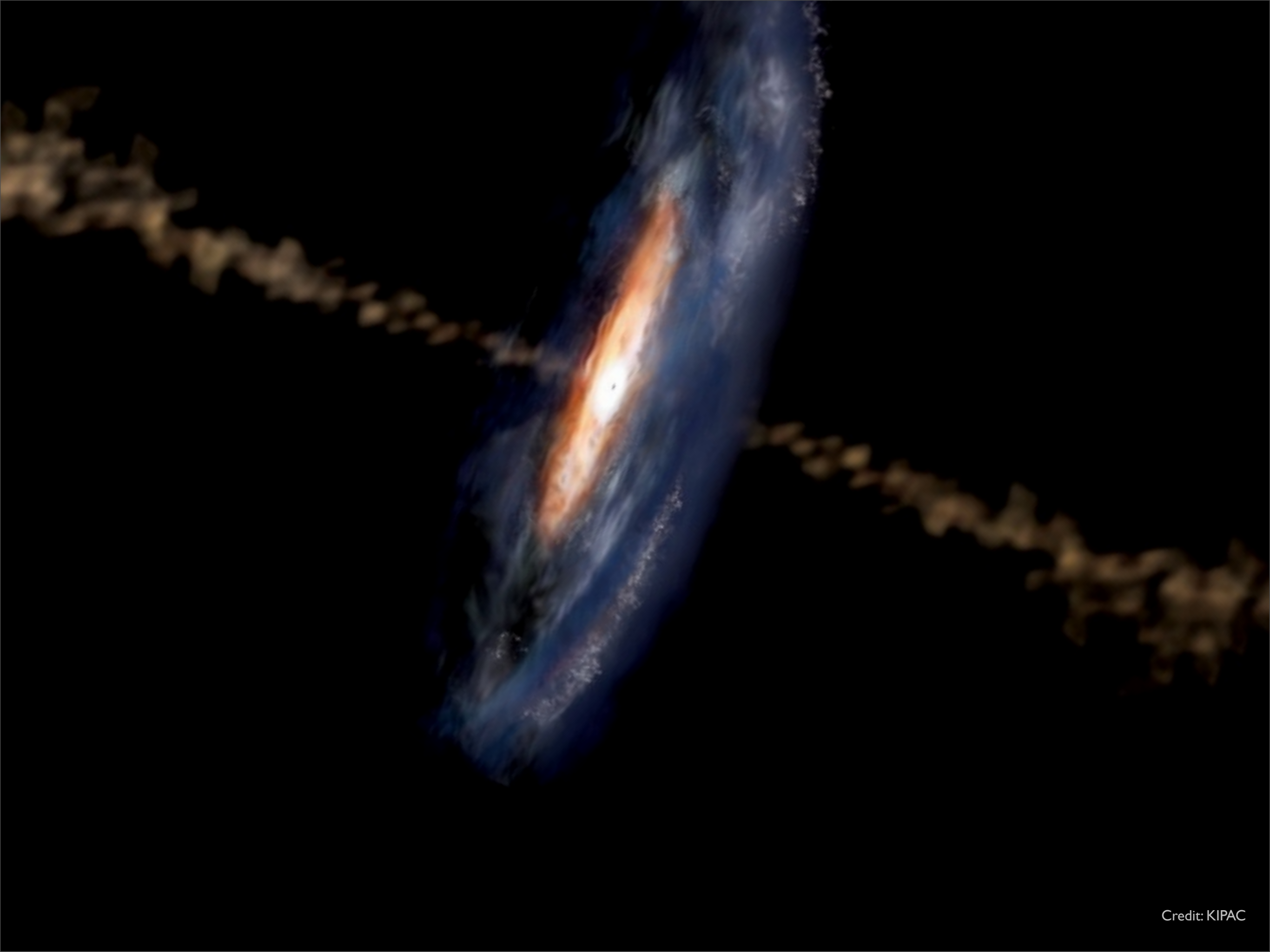
CHANDRA X-RAY OBSERVATORY



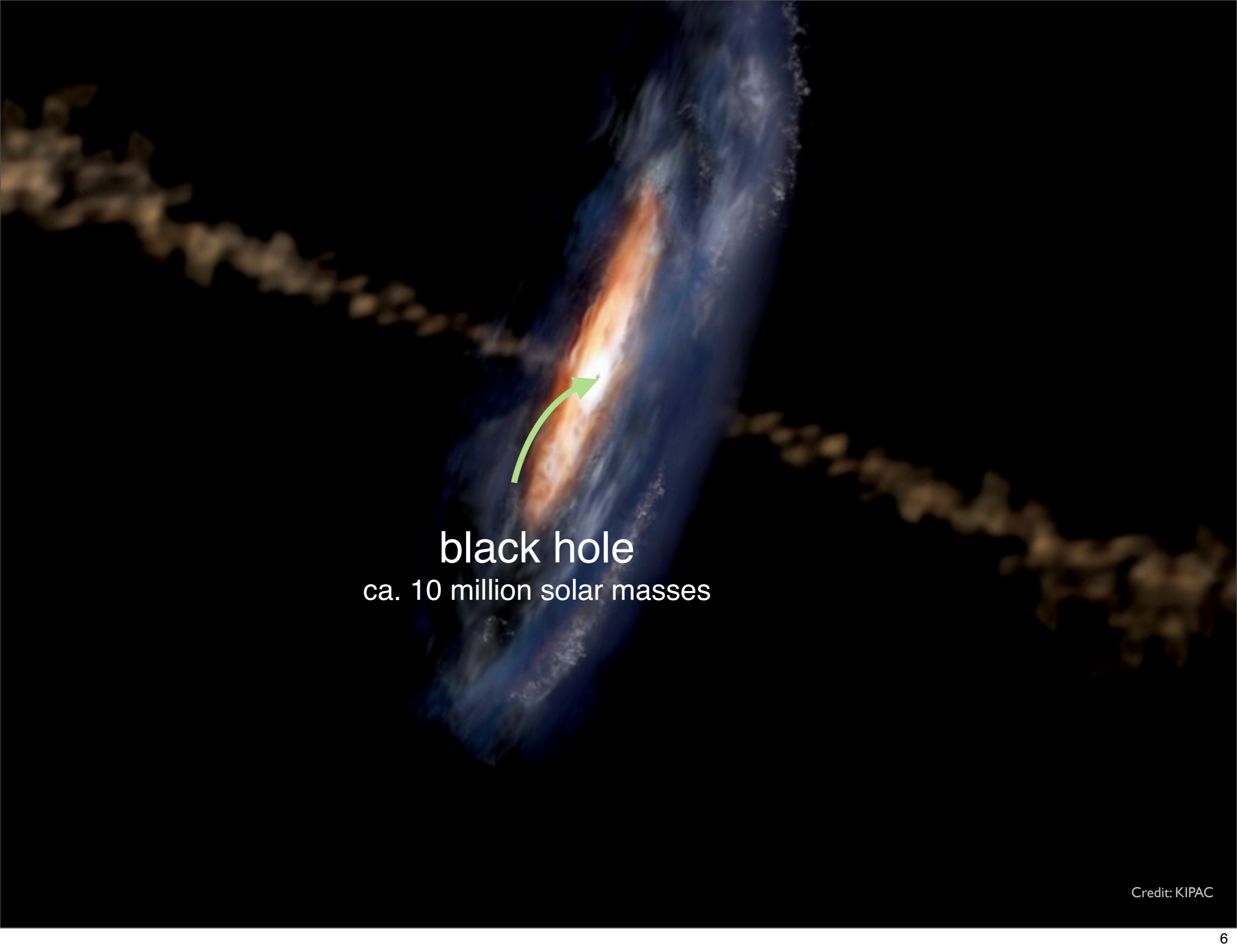
CHANDRA X-RAY OBSERVATORY



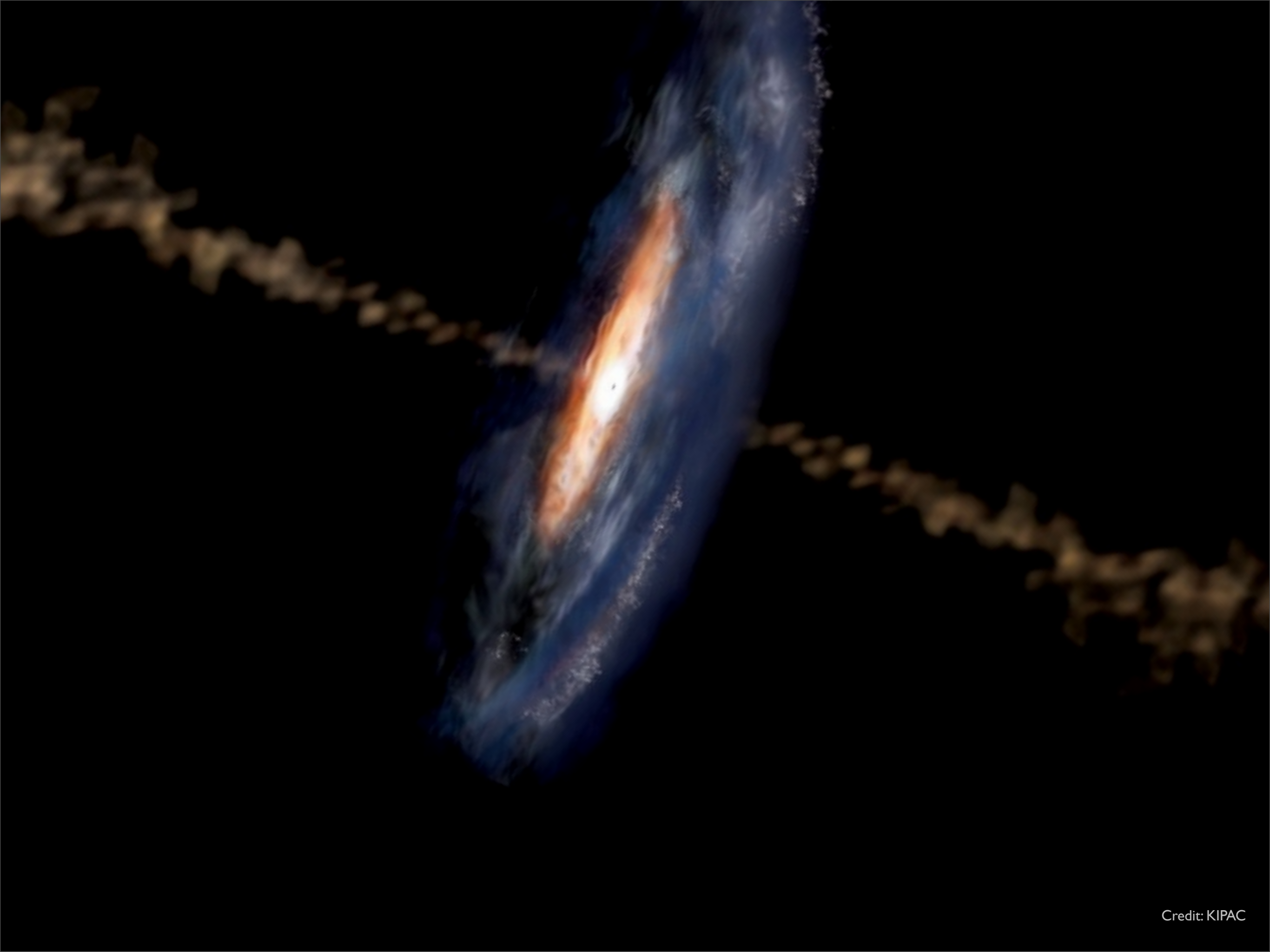




Credit: KIPAC

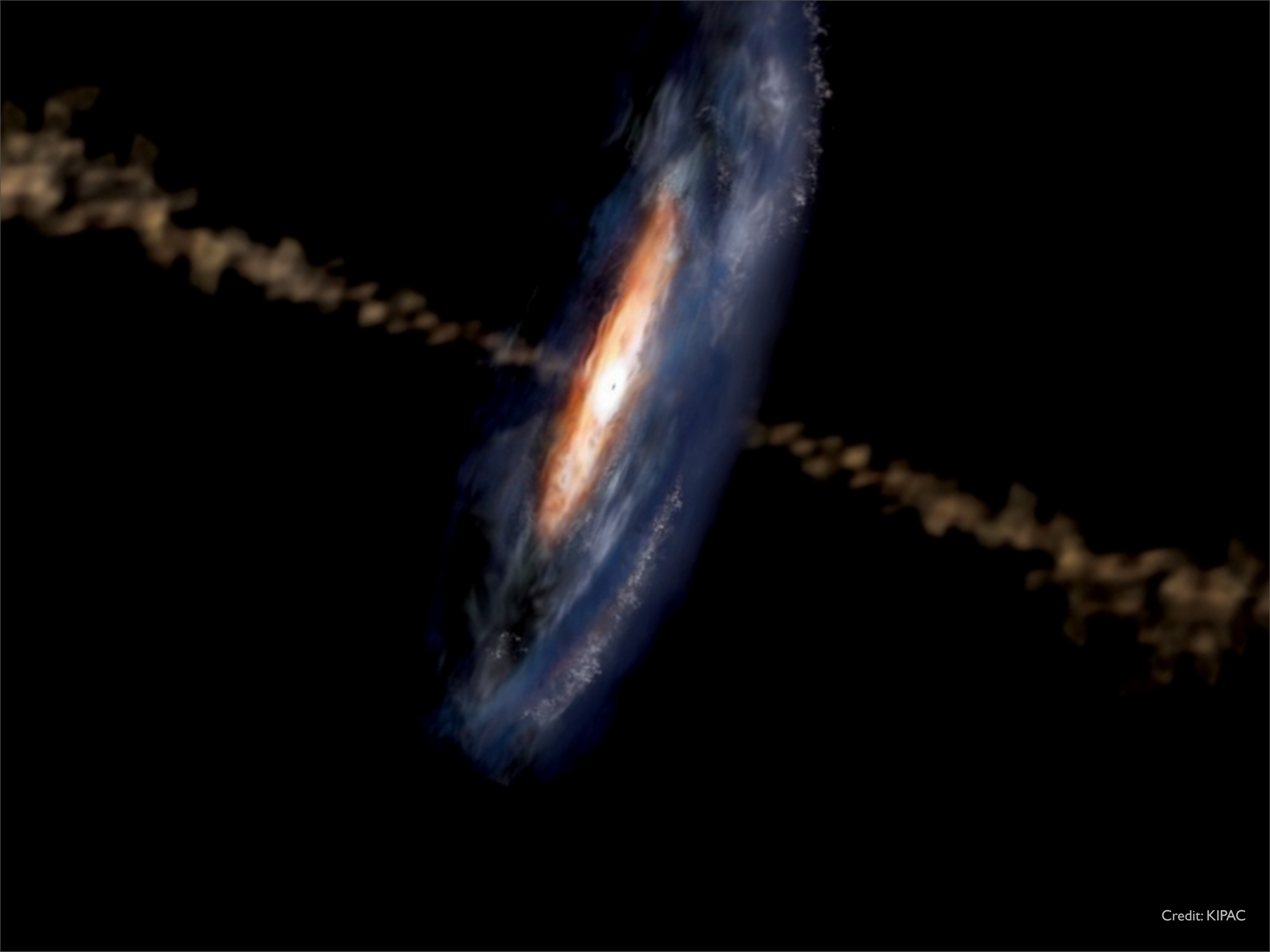


black hole
ca. 10 million solar masses





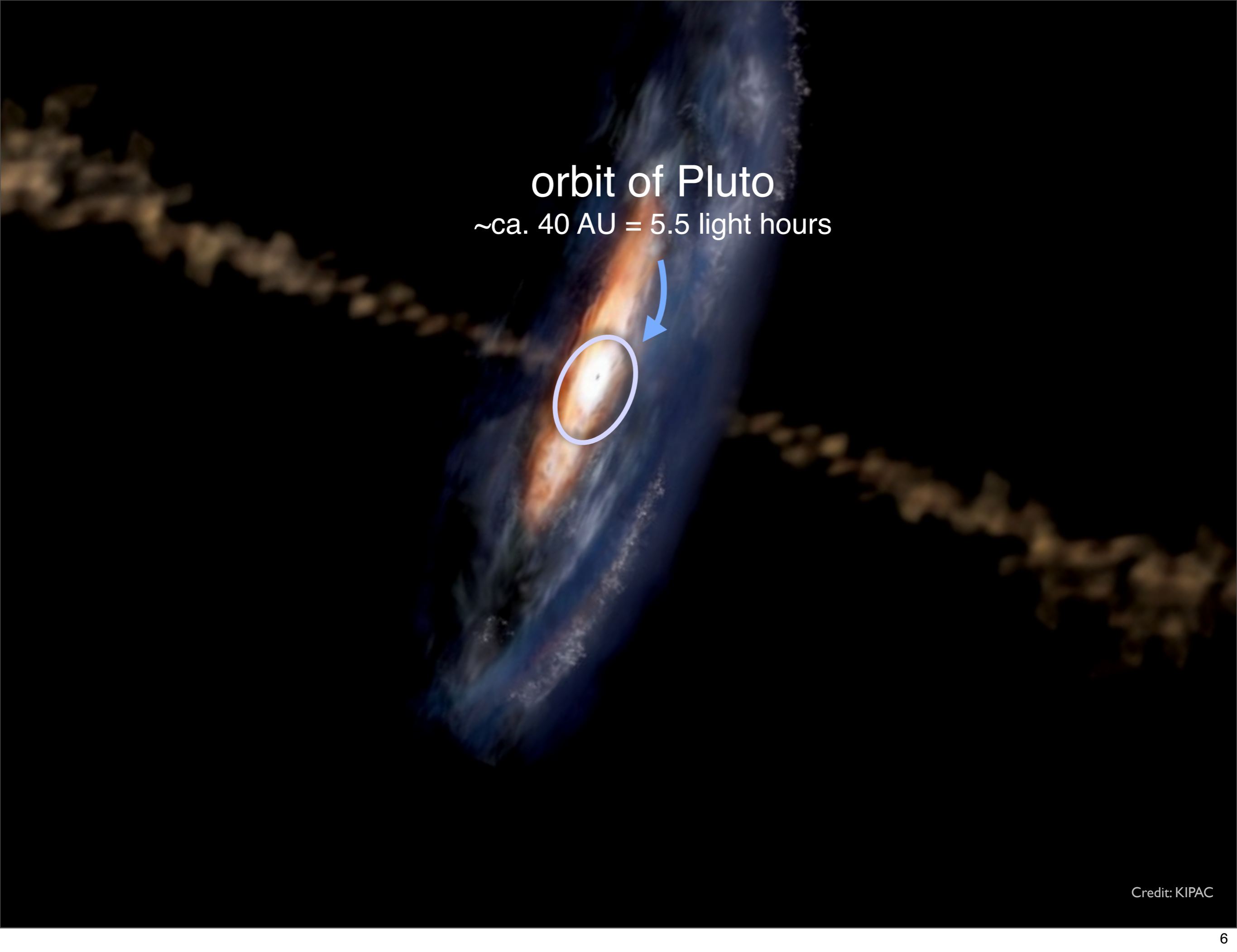
angular momentum

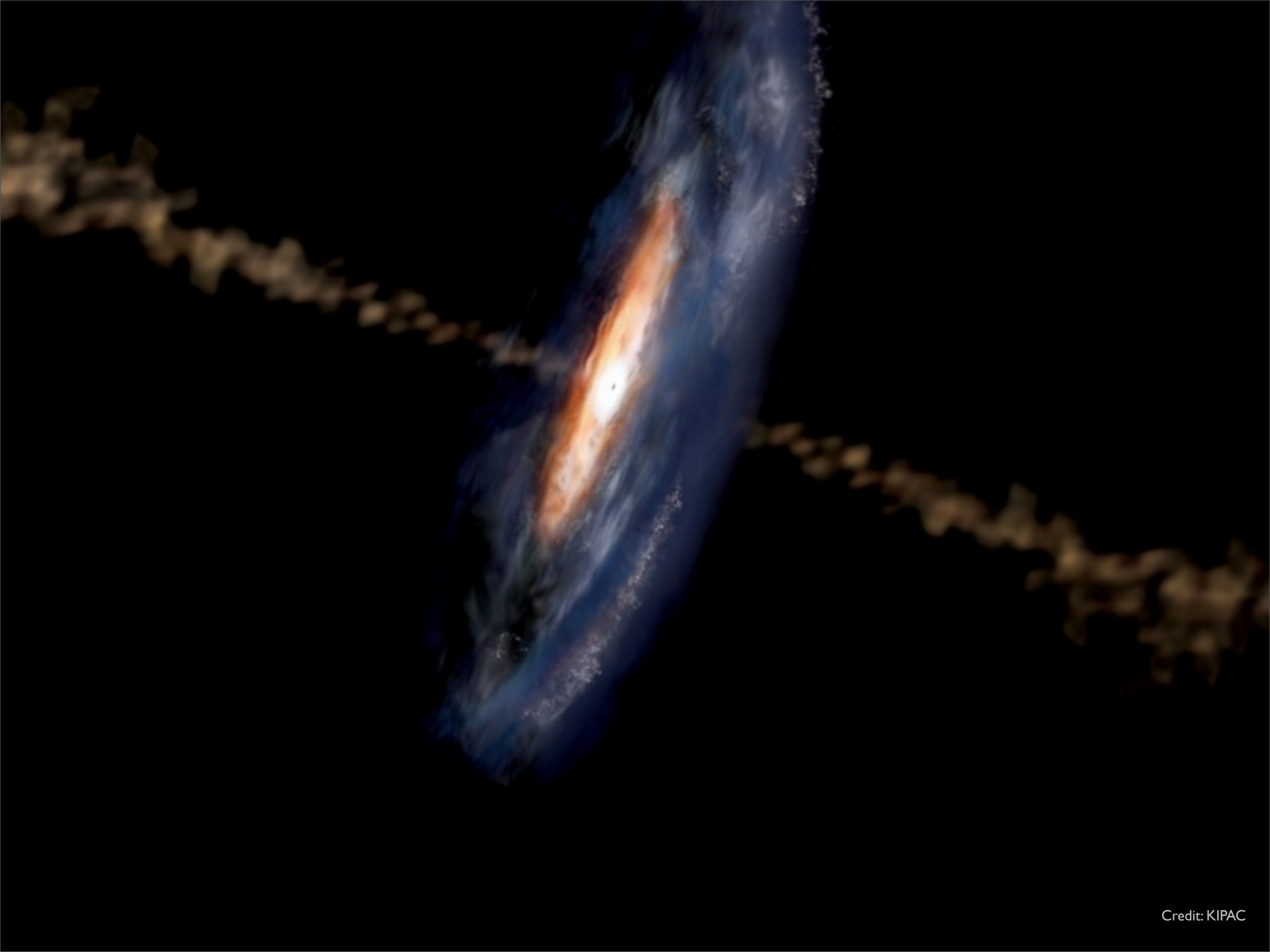


Credit: KIPAC

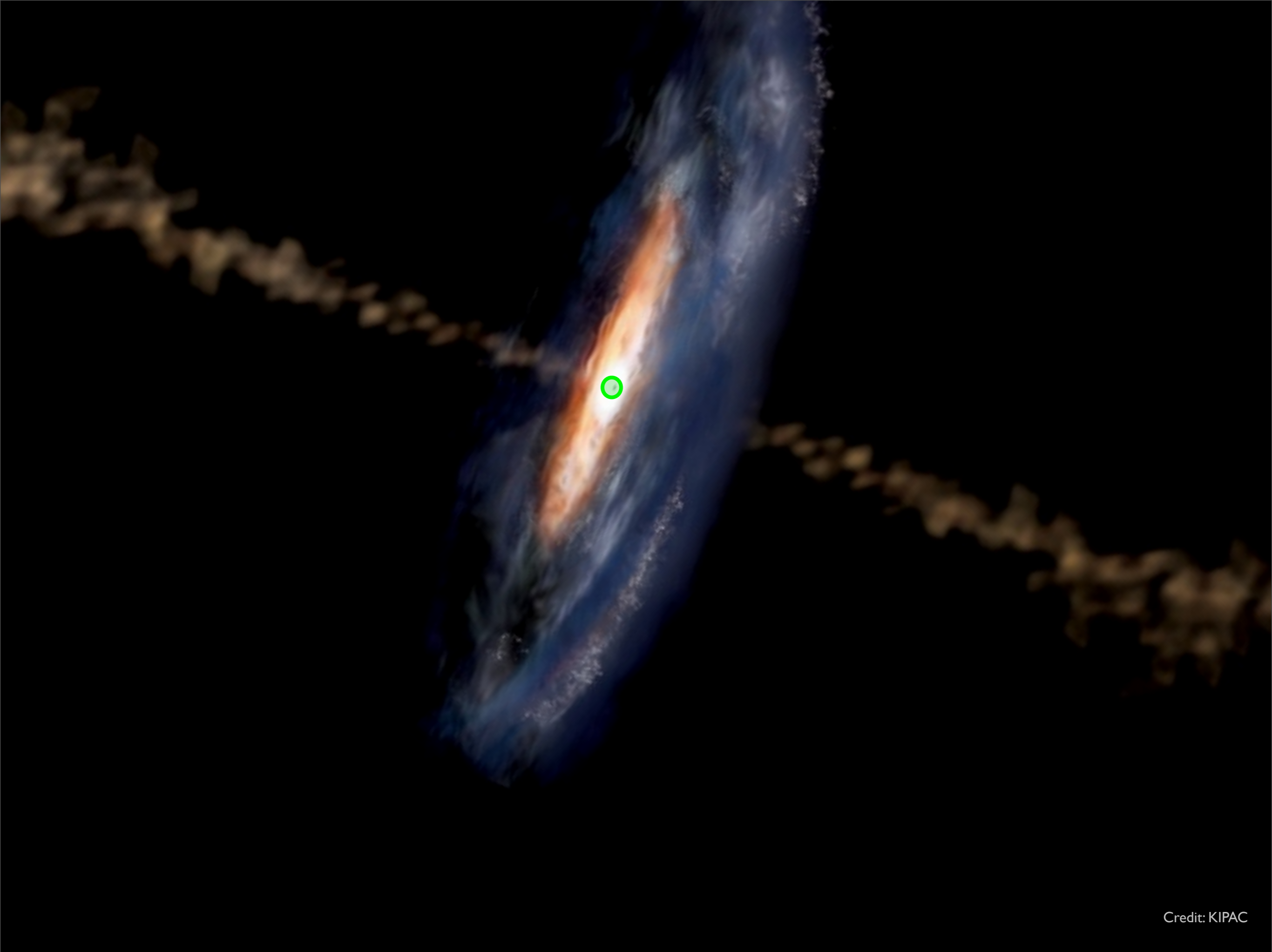
orbit of Pluto

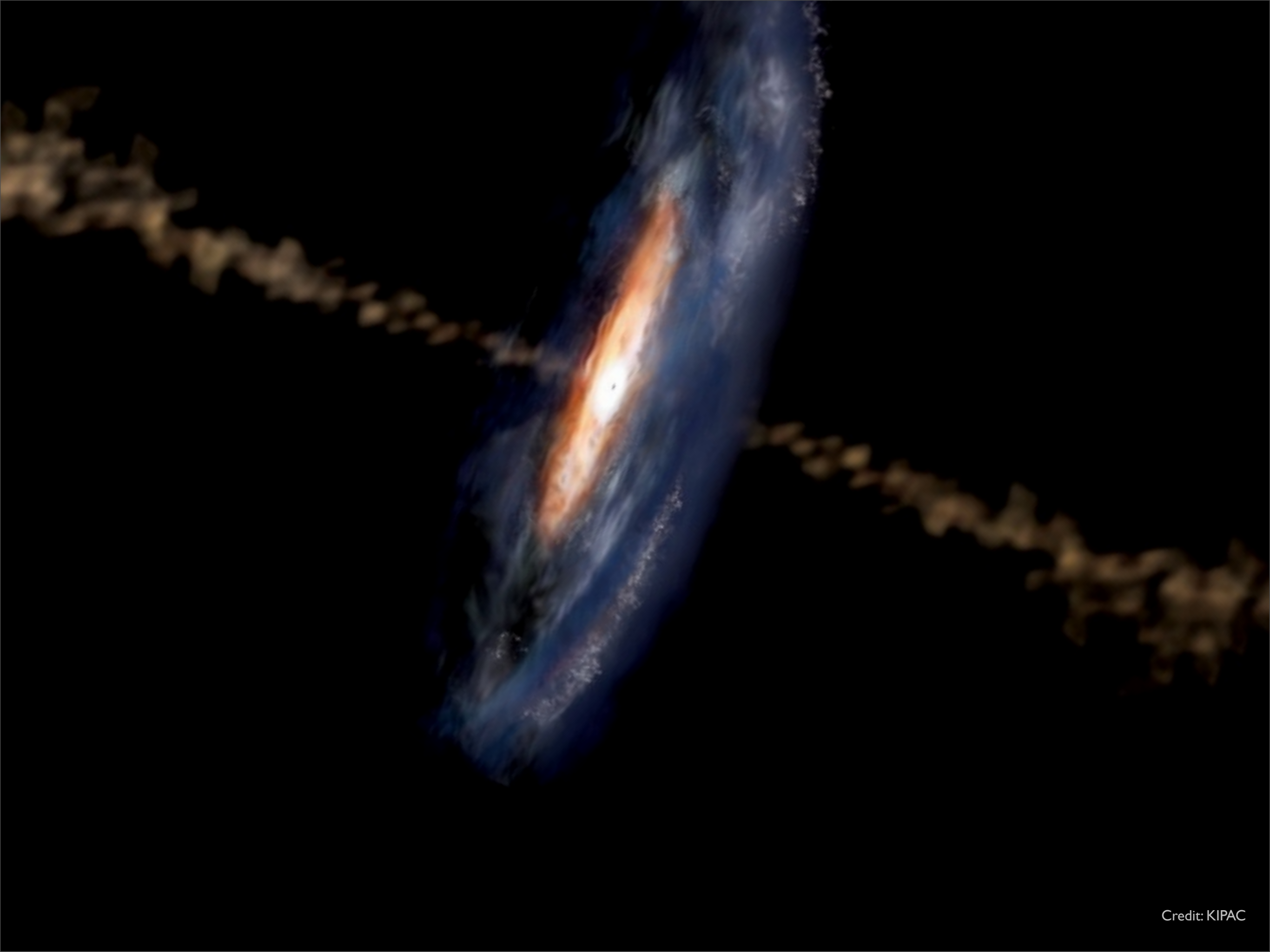
~ca. 40 AU = 5.5 light hours





Credit: KIPAC





Credit: KIPAC

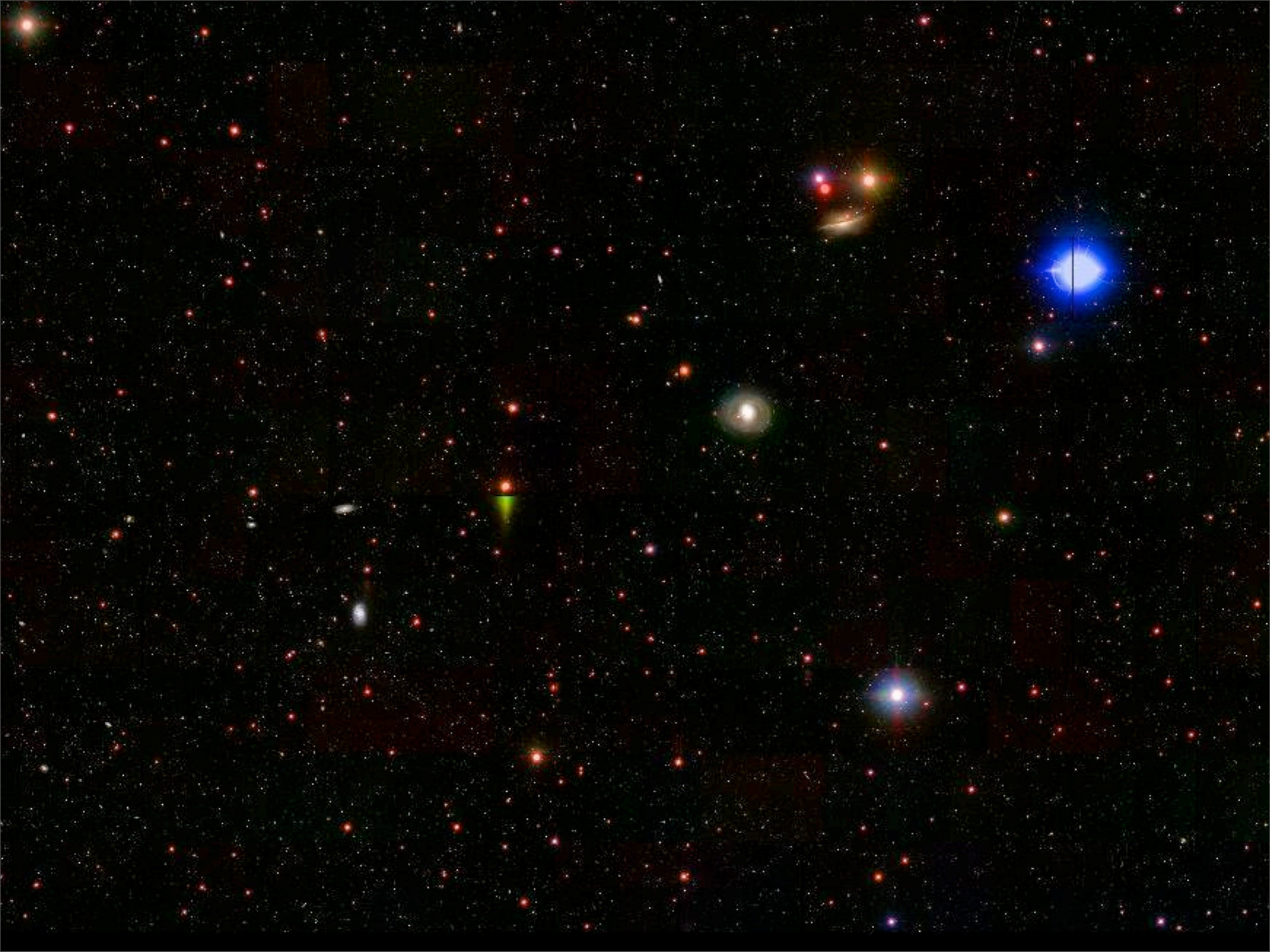


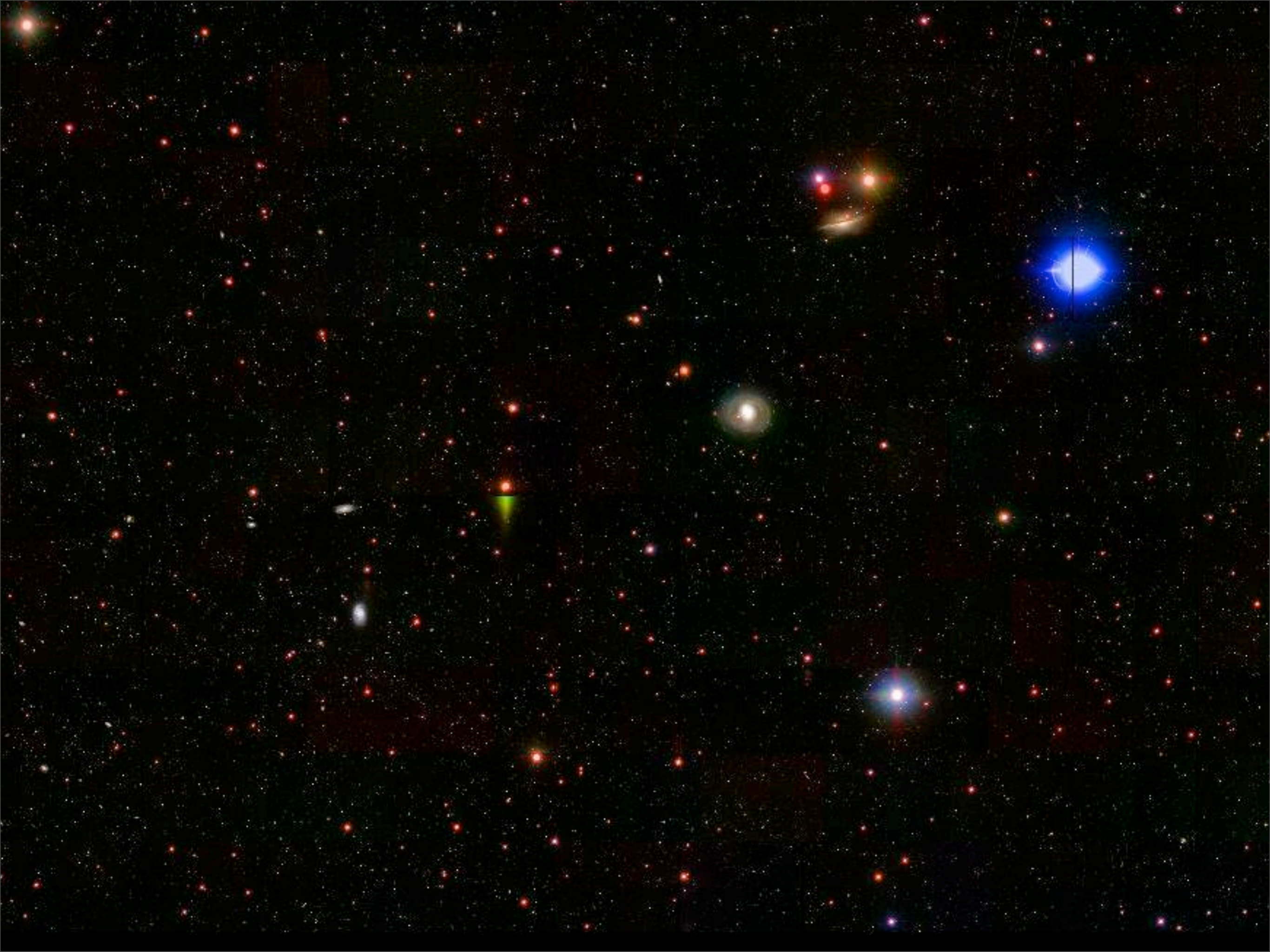


Credit: NASA









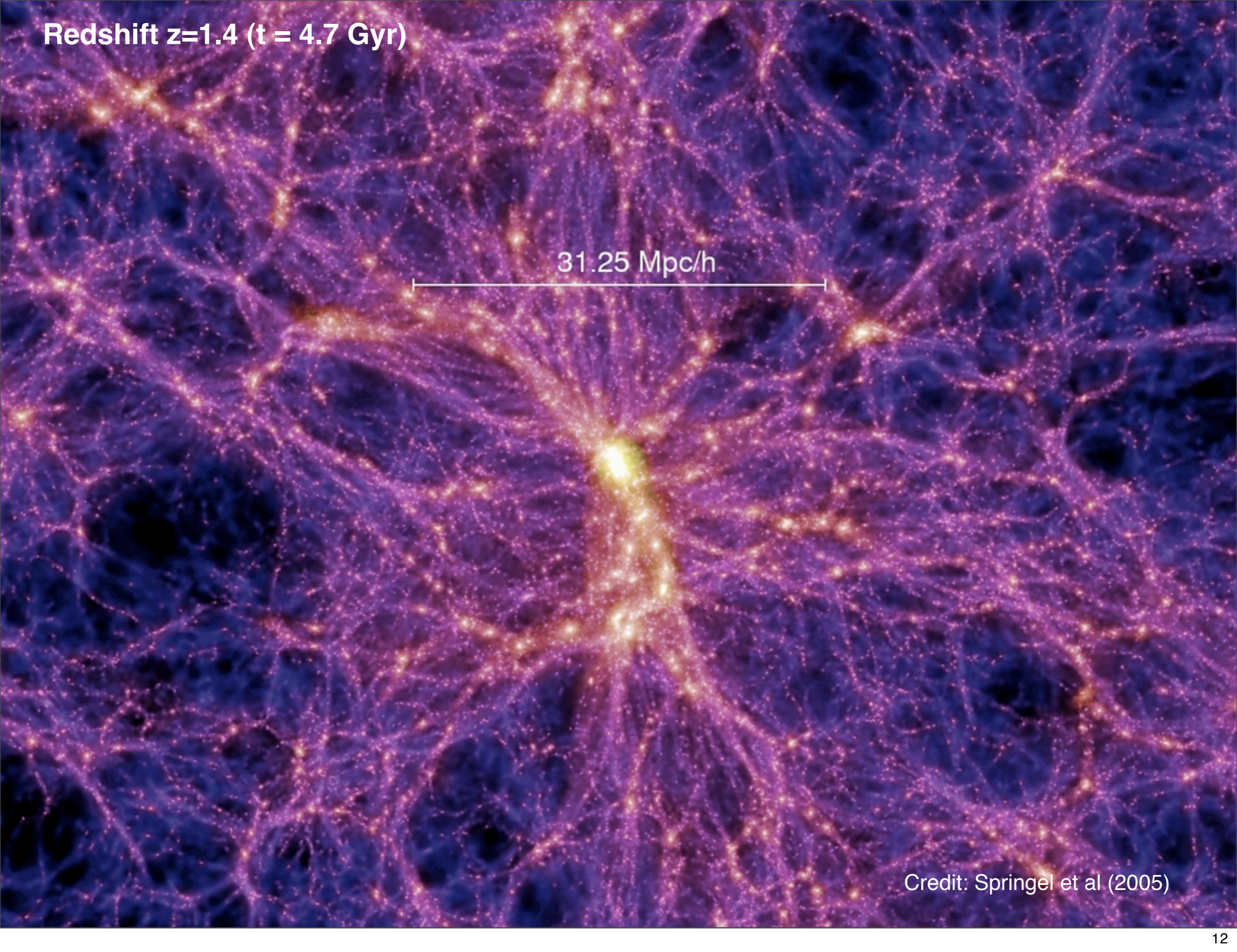
Redshift $z=0$ ($t = 13.6$ Gyr)

31.25 Mpc/h

A visualization of the cosmic web at redshift z=0, showing a complex network of dark matter filaments and galaxy clusters. The filaments are colored in shades of purple and blue, while the galaxy clusters are highlighted in yellow and orange. A central, bright yellow-green cluster is the most prominent feature. A horizontal scale bar with tick marks at each end is positioned in the upper-middle part of the image, labeled "31.25 Mpc/h".

Credit: Springel et al (2005)

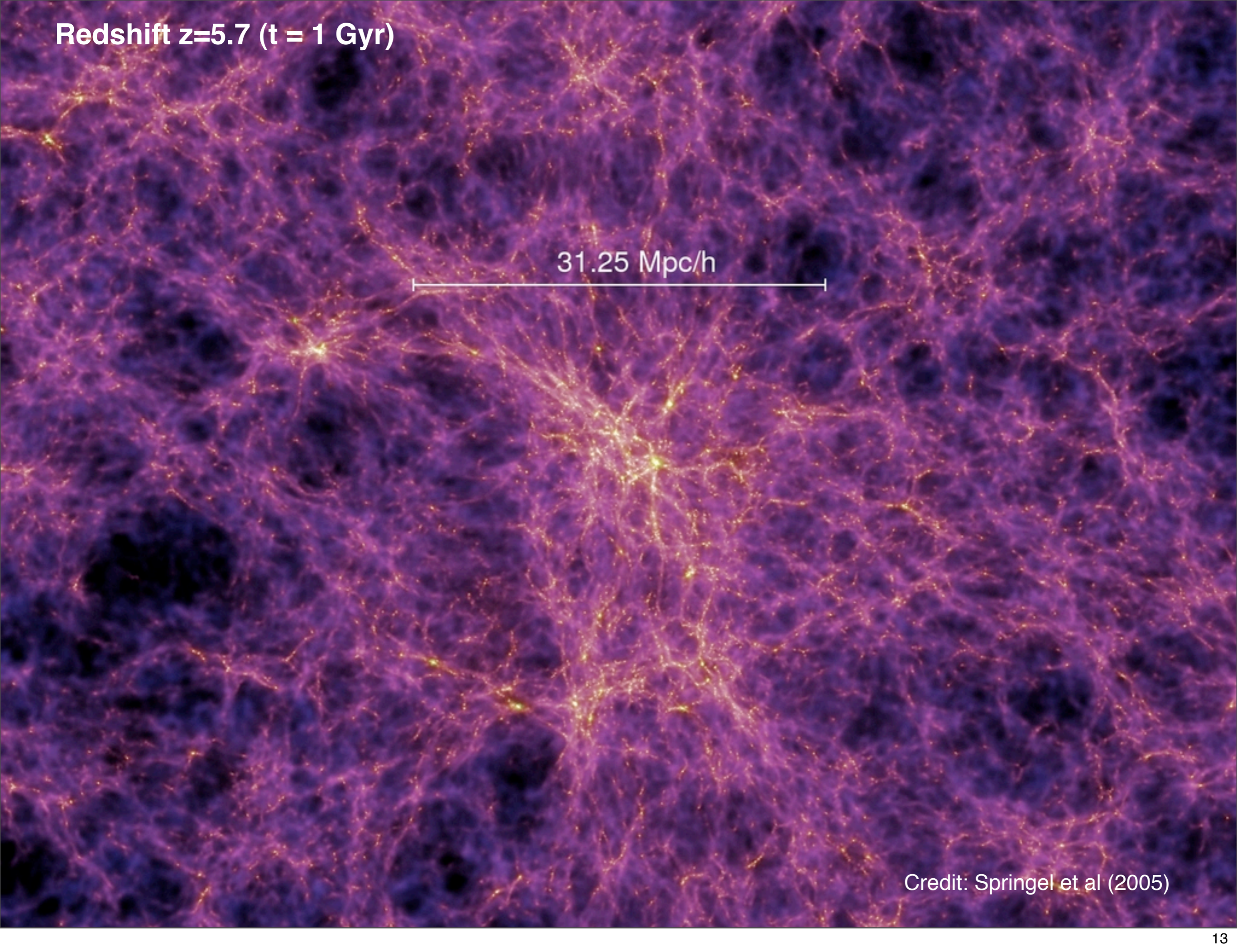
Redshift $z=1.4$ ($t = 4.7$ Gyr)



31.25 Mpc/h

Credit: Springel et al (2005)

Redshift $z=5.7$ ($t = 1$ Gyr)

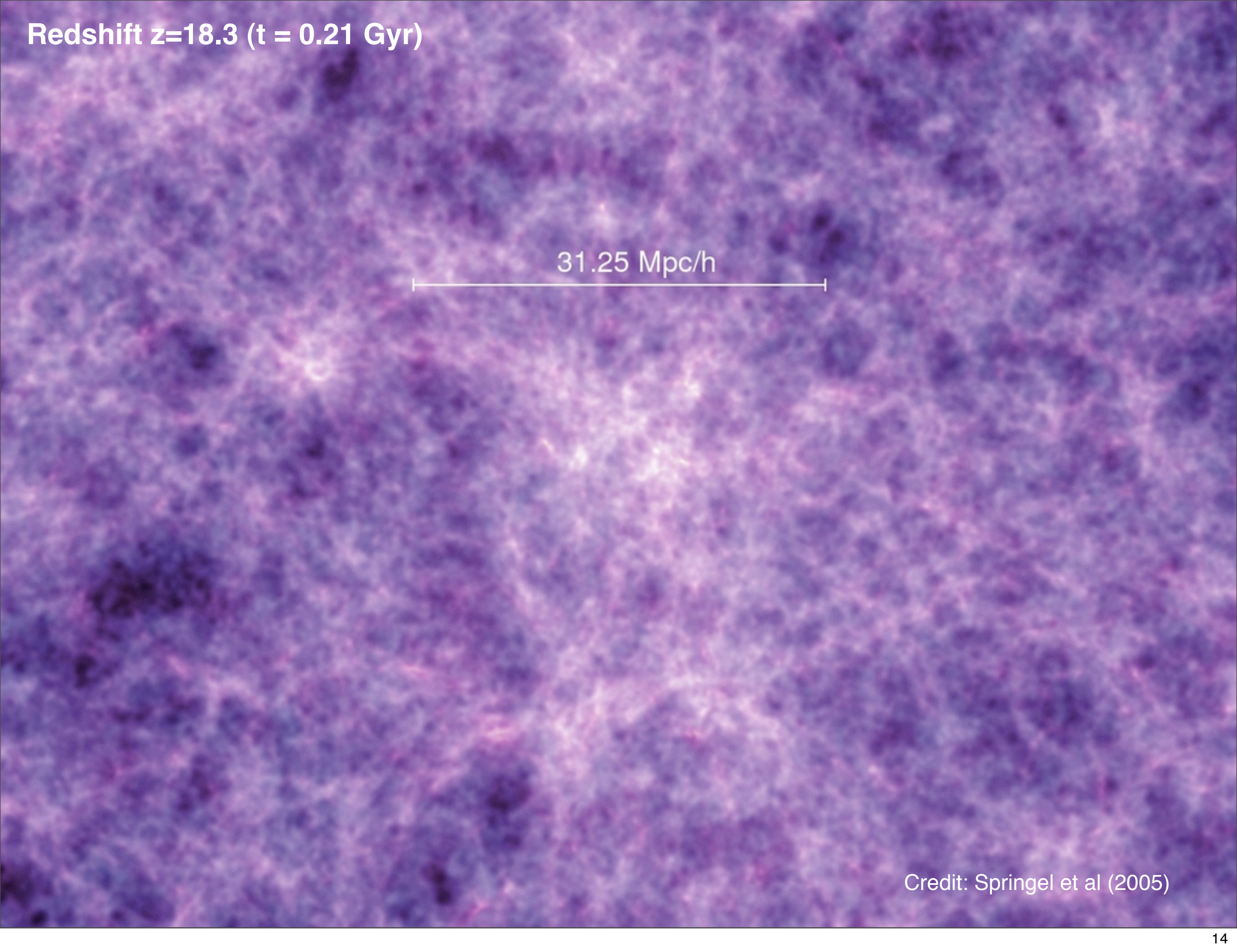


31.25 Mpc/h

Credit: Springel et al (2005)

Redshift $z=18.3$ ($t = 0.21$ Gyr)

31.25 Mpc/h

A visualization of the cosmic web at redshift $z=18.3$ ($t = 0.21$ Gyr). The image shows a complex network of filaments and nodes, with a color gradient from dark purple to bright yellow. A horizontal scale bar is positioned in the upper-middle section, labeled "31.25 Mpc/h".

Credit: Springel et al (2005)

gas+astrophysics = gastrophysics

e.g. White & Rees (1978)

gas+astrophysics = gastrophysics

Dark matter haloes collapse under gravity

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Baryonic matter (gas) collapses to disks
due to angular momentum

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Gas that cools enough becomes
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Galaxies “form”
(rather, become visible due to stars emitting light)
and grow due to mergers and accretion

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Gas that cools enough becomes
the fuel for star formation

Galaxies “form”
(rather, become visible due to stars emitting light)
and grow due to mergers and accretion

“Feedback” somehow regulates this process
(Supernovas, schwarze Löcher)

e.g. White & Rees (1978)

Cold Gas
($\log T < 4.5$ K)

Warm Gas
($4.5 \log T < 5.5$ K)

Hot Gas ($\log t$
 > 5.5 K)

Stars

$z = 10.270$

Cold Gas
($\log T < 4.5$ K)

Warm Gas
($4.5 \log T < 5.5$ K)

Hot Gas ($\log t$
 > 5.5 K)

Stars

Credit: Richard Bower and the EAGLE collaboration (Durham University)

5.000 Mpc

Energy liberated by a
black hole growing via
accretion

$$E_{bh} \sim \eta_{acc} M_{bh} c^2$$



Credit: ESA

Energy liberated by a black hole growing via accretion

$$E_{bh} \sim \eta_{acc} M_{bh} c^2$$



Credit: ESA

Gravitational binding energy of a galaxy

$$E_{grav} \sim \frac{3GM^2}{5R} \\ \sim M_{bulge} \sigma^2$$



Credit: NASA

Energy liberated by a black hole growing via accretion

$$E_{\text{bh}} \sim \eta_{\text{acc}} M_{\text{bh}} c^2$$



Credit: ESA

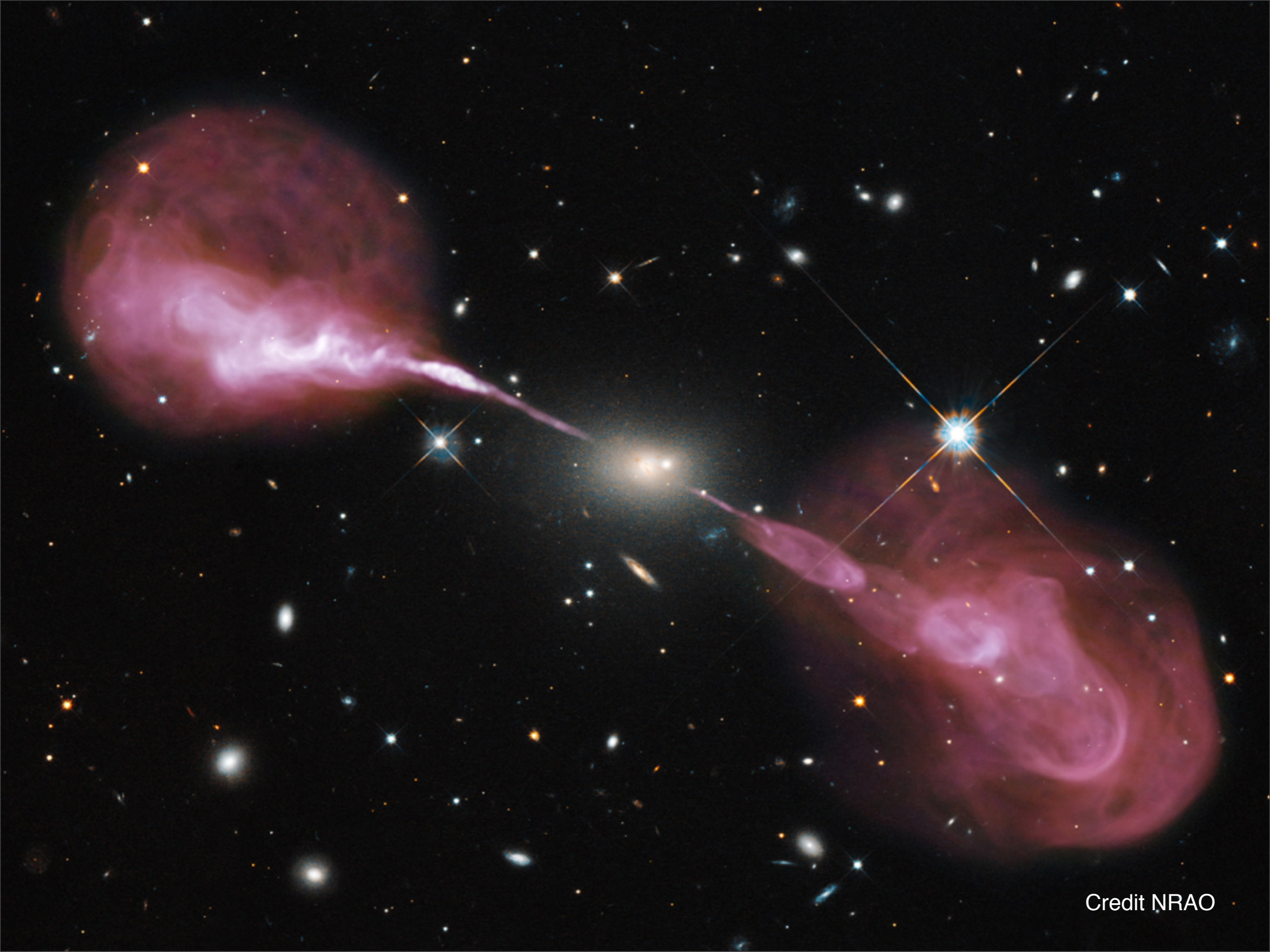
Gravitational binding energy of a galaxy

$$E_{\text{grav}} \sim \frac{3GM^2}{5R} \\ \sim M_{\text{bulge}} \sigma^2$$



Credit: NASA

$$E_{\text{bh}} \gg E_{\text{grav}}$$



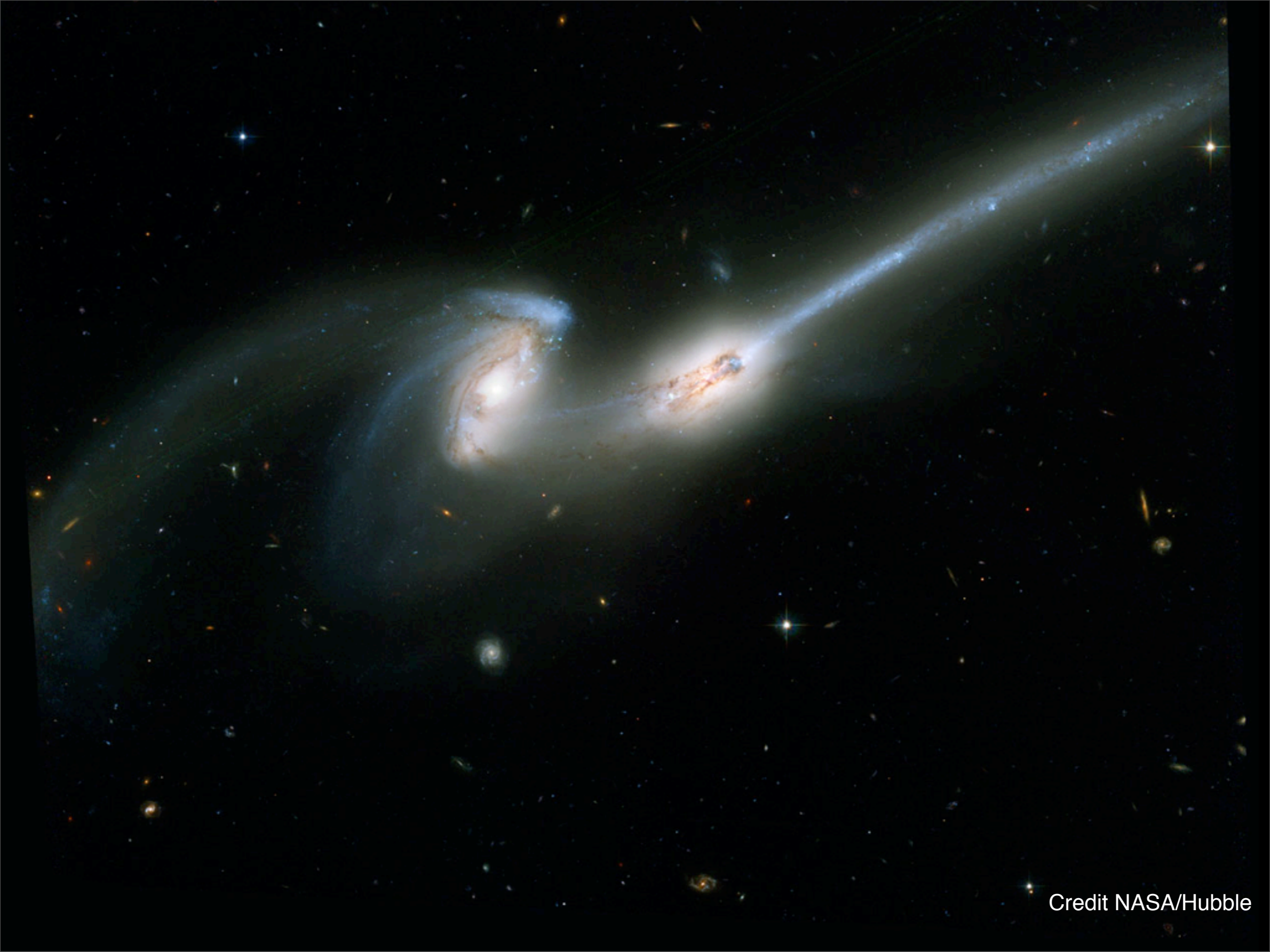
Credit NRAO

Redshift $z=0$ ($t = 13.6$ Gyr)

31.25 Mpc/h

A visualization of the cosmic web at redshift z=0, showing a complex network of filaments and clusters of galaxies. The central region is the most dense, with a bright yellow-green core. Filaments of galaxies extend outwards, becoming sparser as they move away from the center. The color gradient ranges from dark purple in the sparsest regions to bright yellow in the densest. A horizontal scale bar is positioned in the upper-middle part of the image, indicating a distance of 31.25 Mpc/h.

Credit: Springel et al (2005)



Credit NASA/Hubble

Gas

(blue=cool, red=hot)

Stars

(blue=young, red=old)

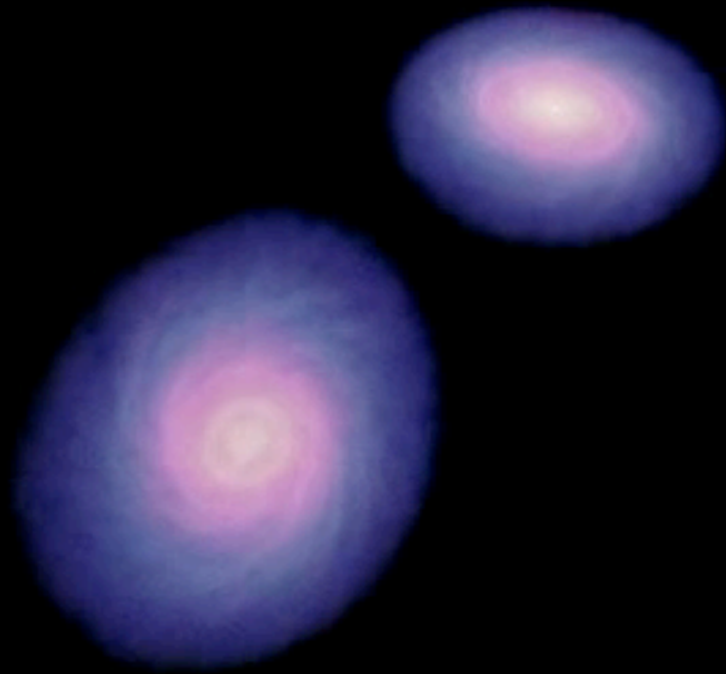
Credit Phil Hopkins (Caltech)

Gas

(blue=cool, red=hot)

T = 210 Myr

Gas



face on view

Stars

(blue=young, red=old)

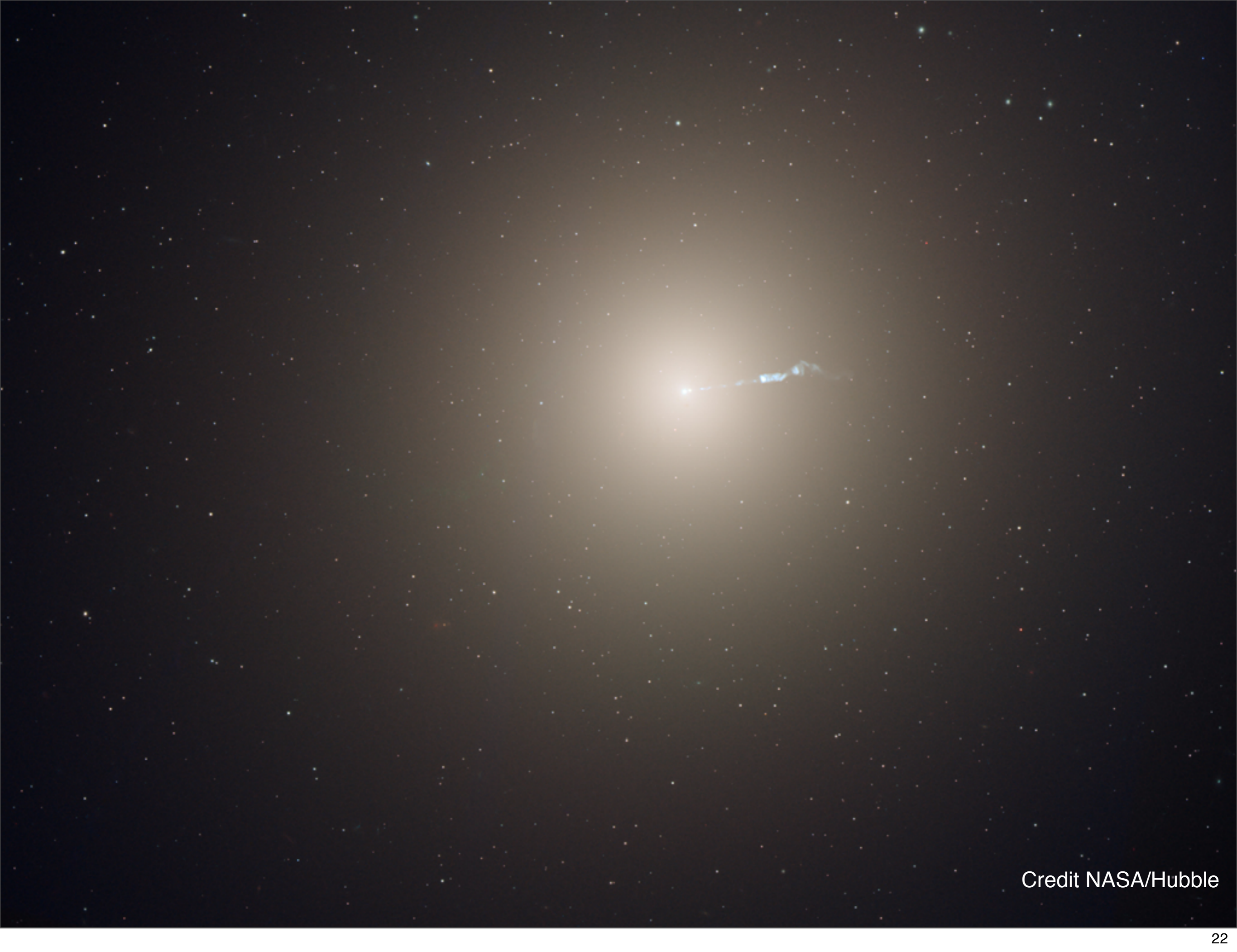
T = 210 Myr

Stars



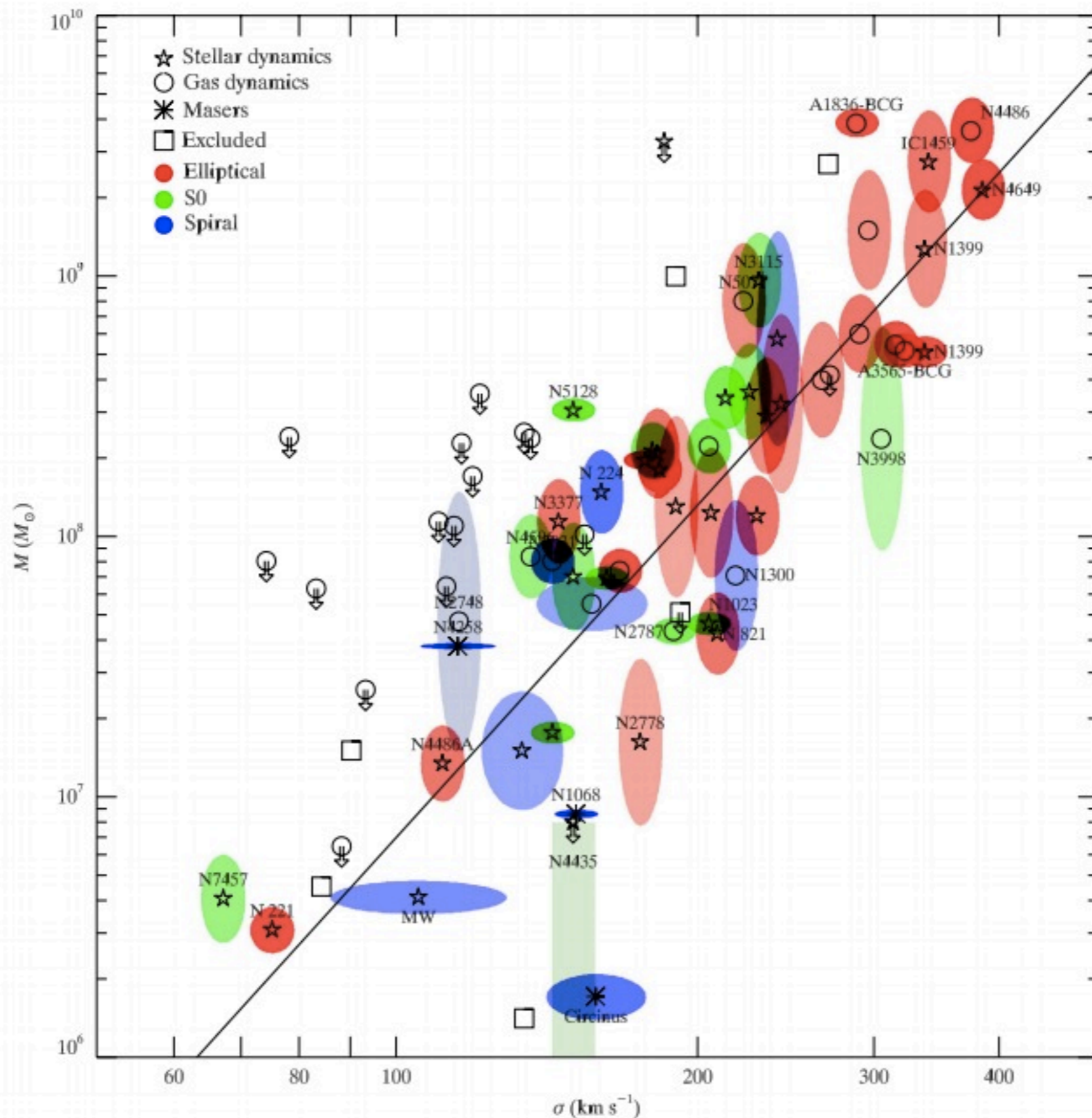
face on view

Credit Phil Hopkins (Caltech)



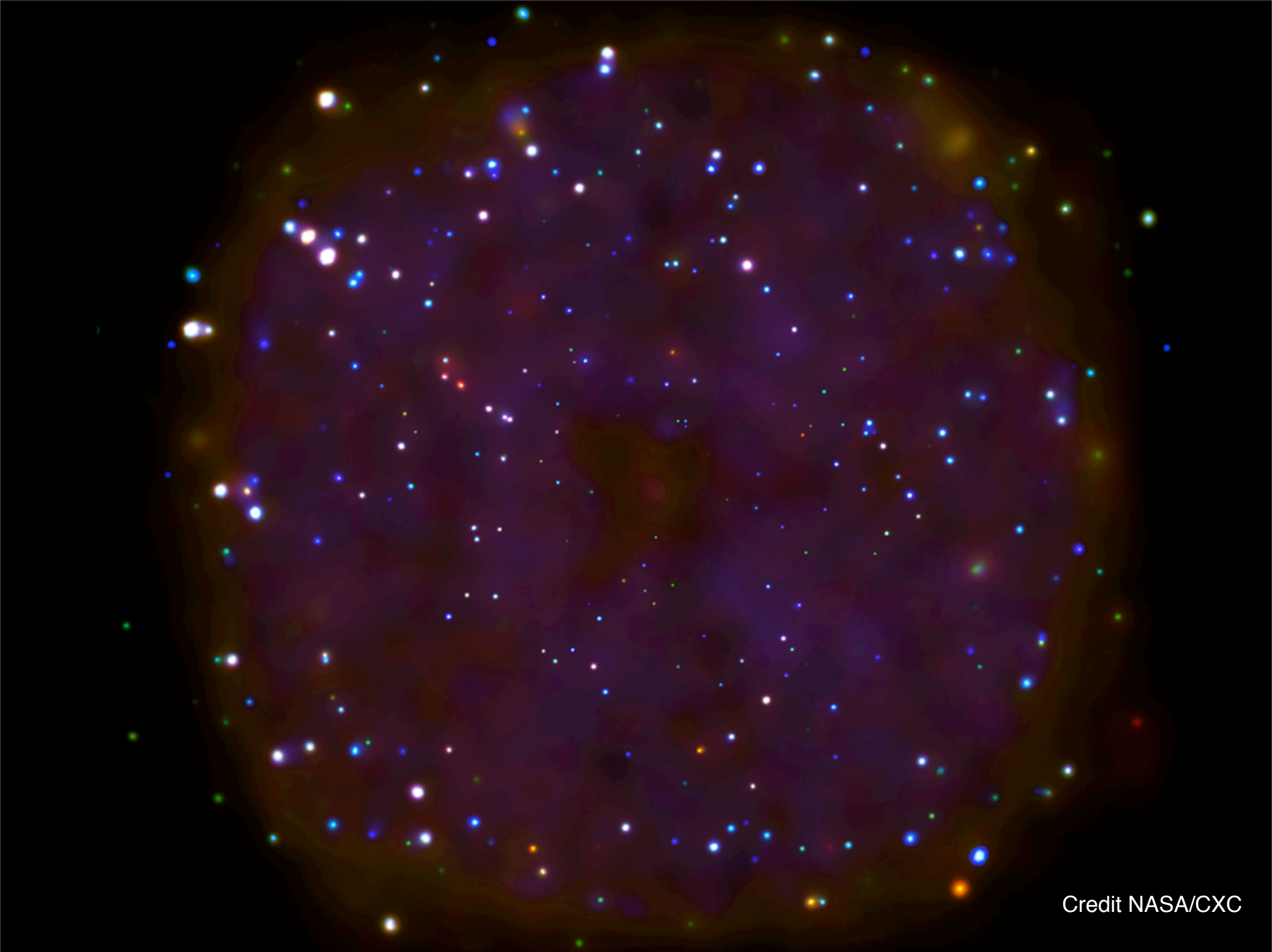
Credit NASA/Hubble

Black hole mass (solar masses)



Velocity dispersion of the bulge (km/s)

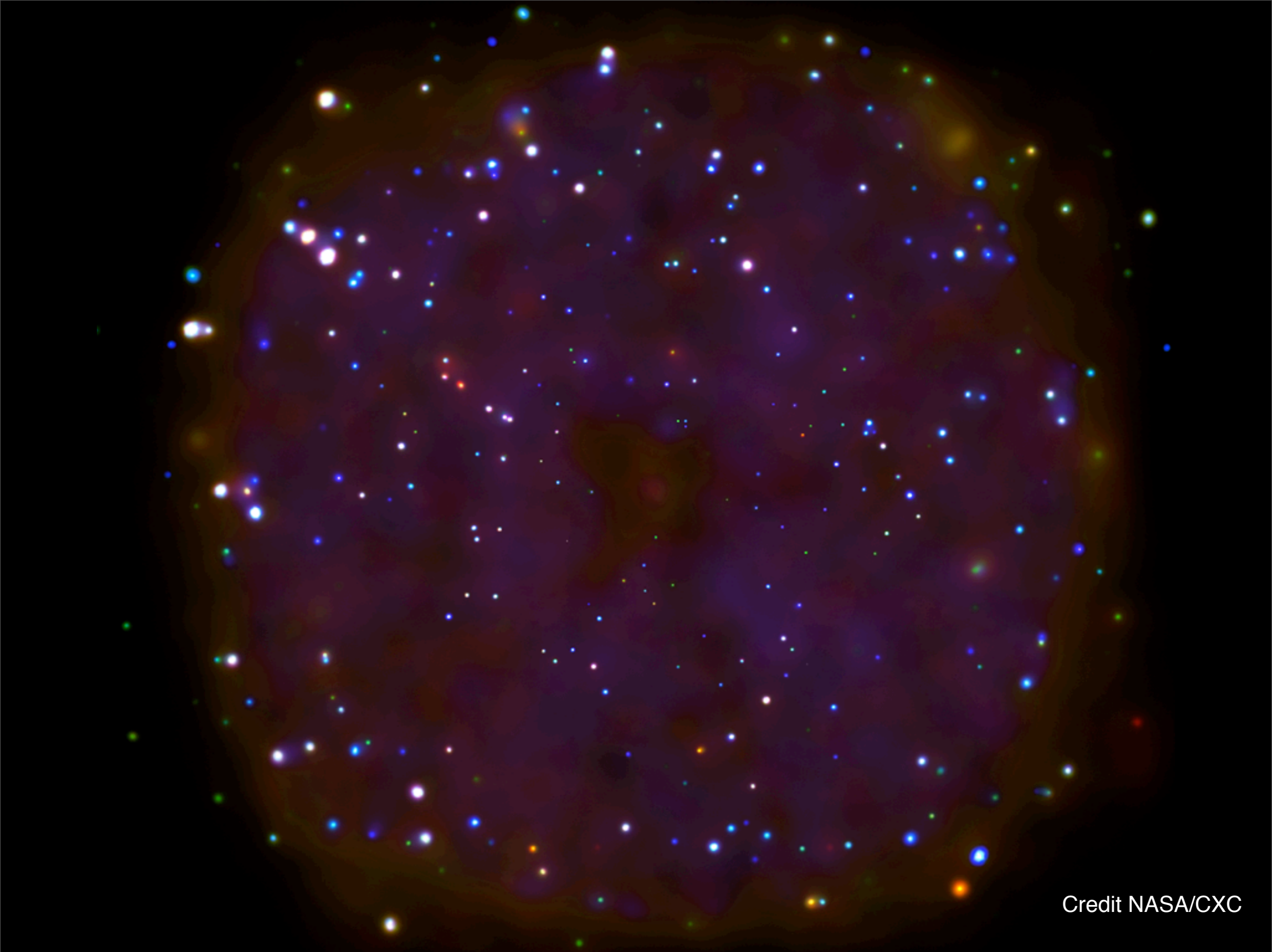
from: Gultekin+2009; see also: Gebartd+2000; Ferrarese & Merritt 2000



Credit NASA/CXC



Credit NASA/CXC



Credit NASA/CXC

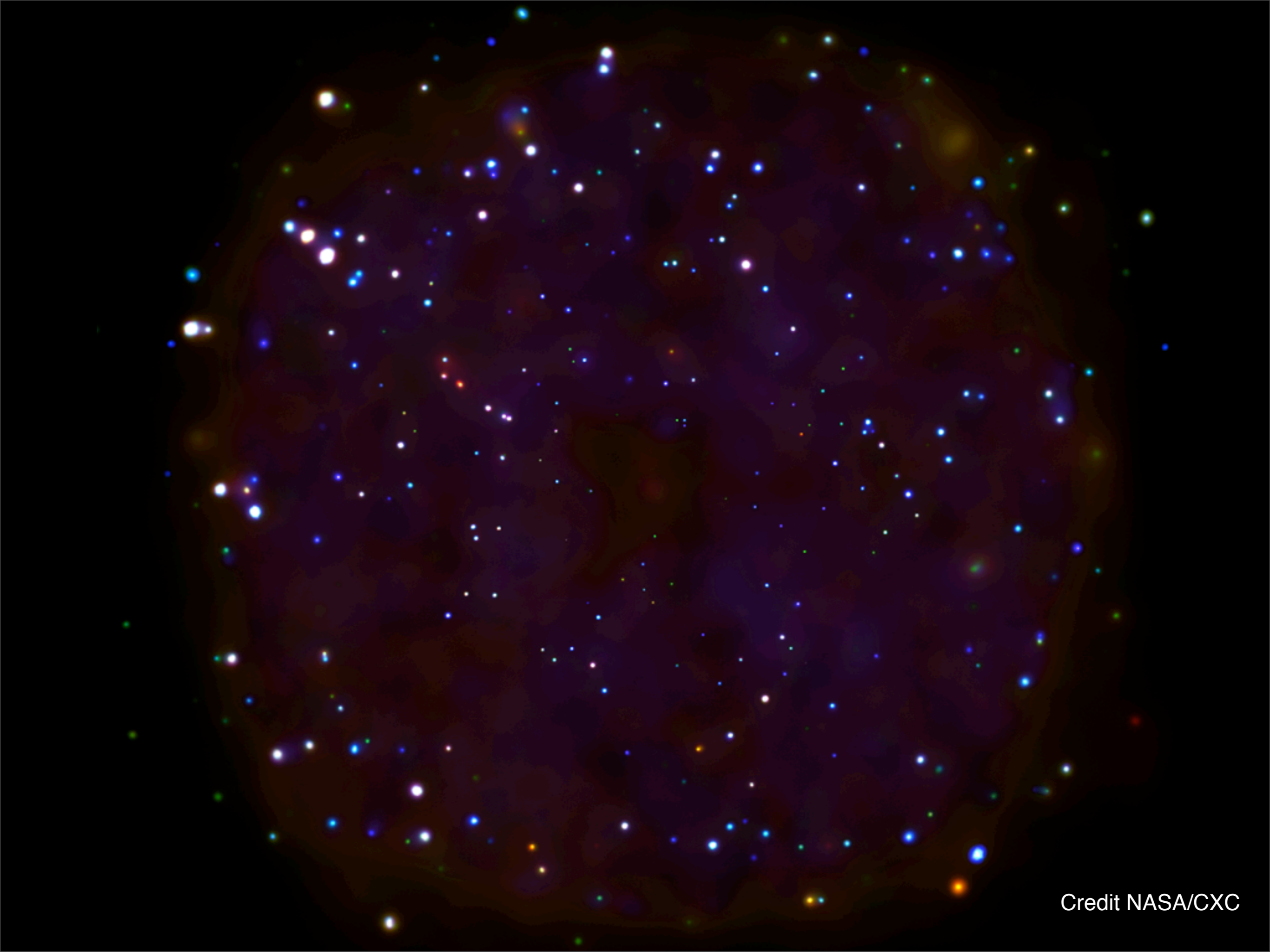
In what kind of galaxies do black holes grow?

What effect does this growth have on the evolution of the host galaxy?

1. Is the hypothesis correct that black holes grow in galaxy collisions?

2. Can we observe the effect of “feedback” directly?”

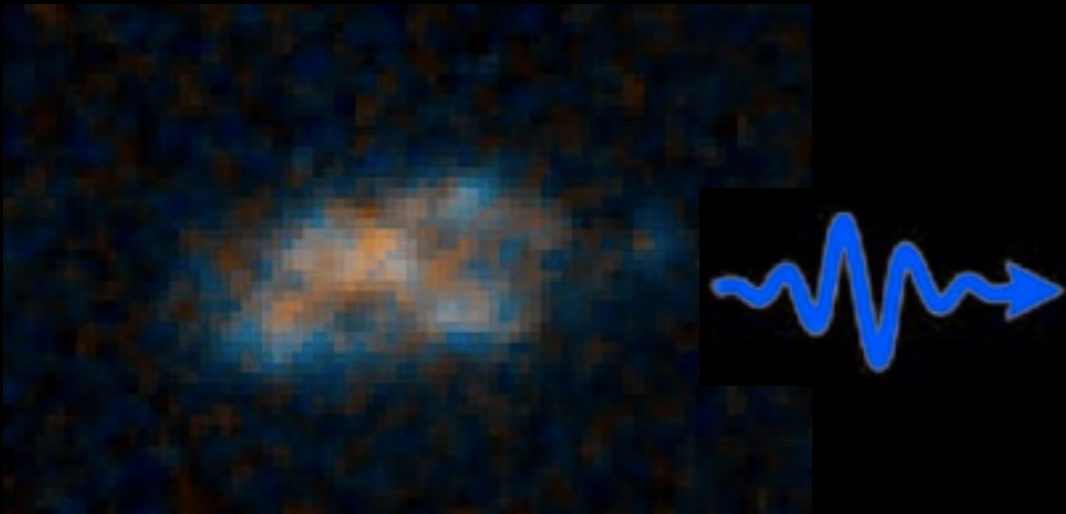
3. Woher kommen denn die schwarzen Löcher in den Zentren von Galaxien?

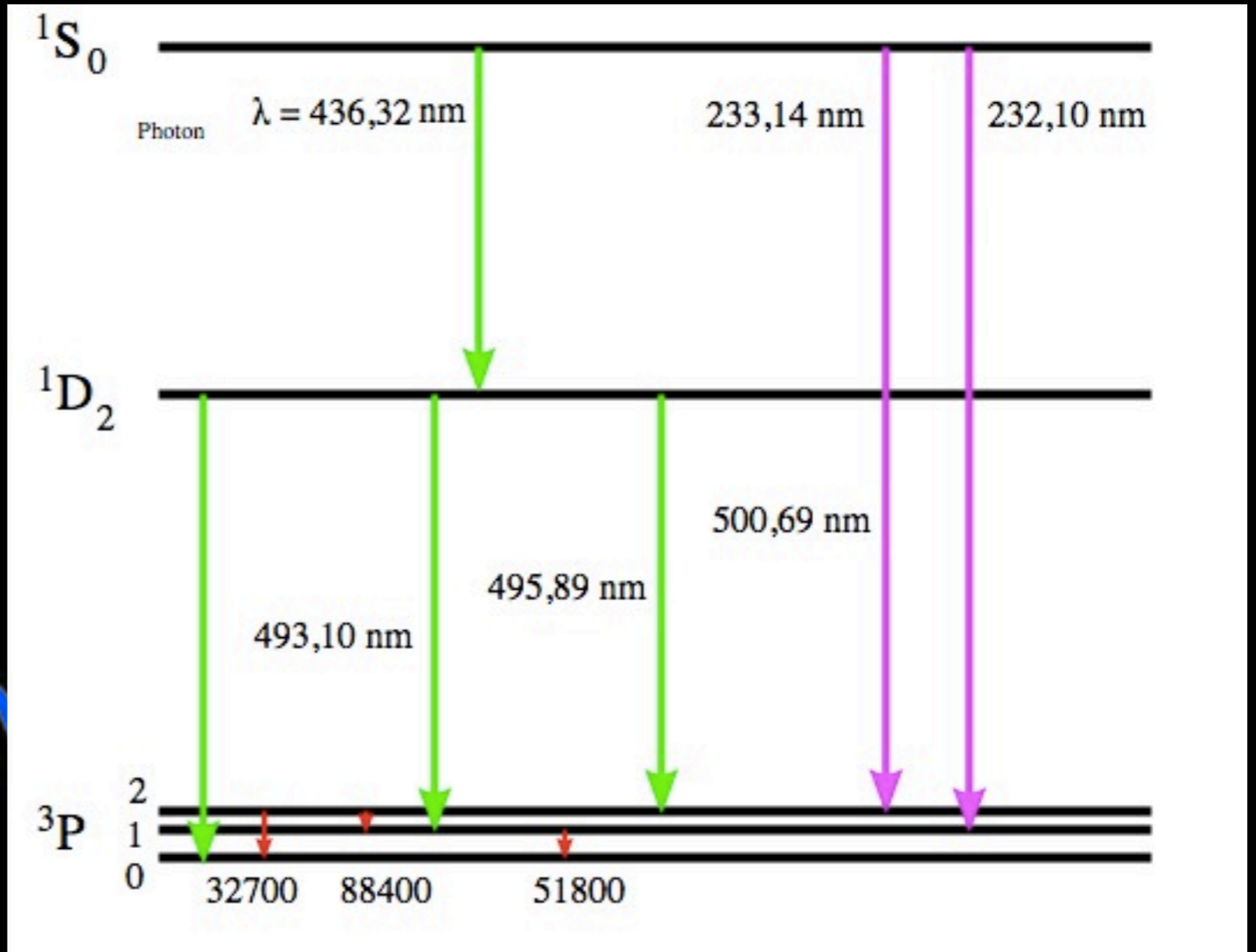
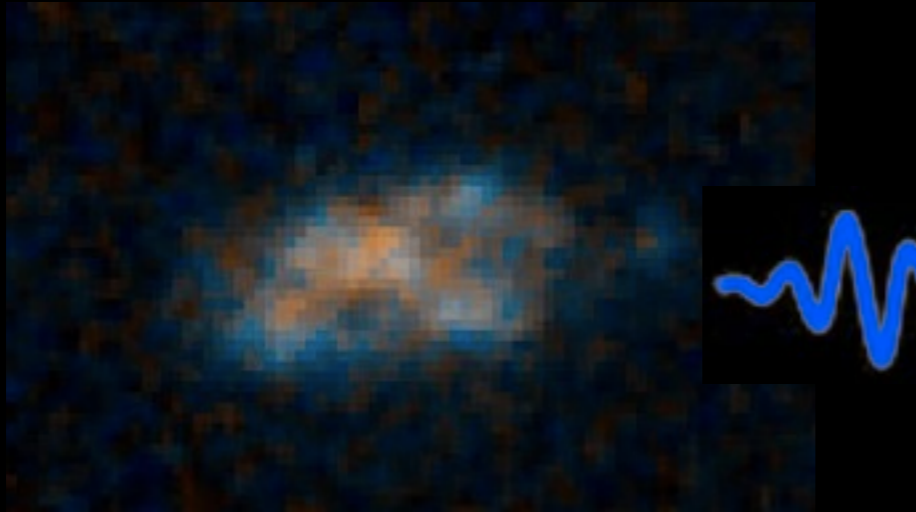


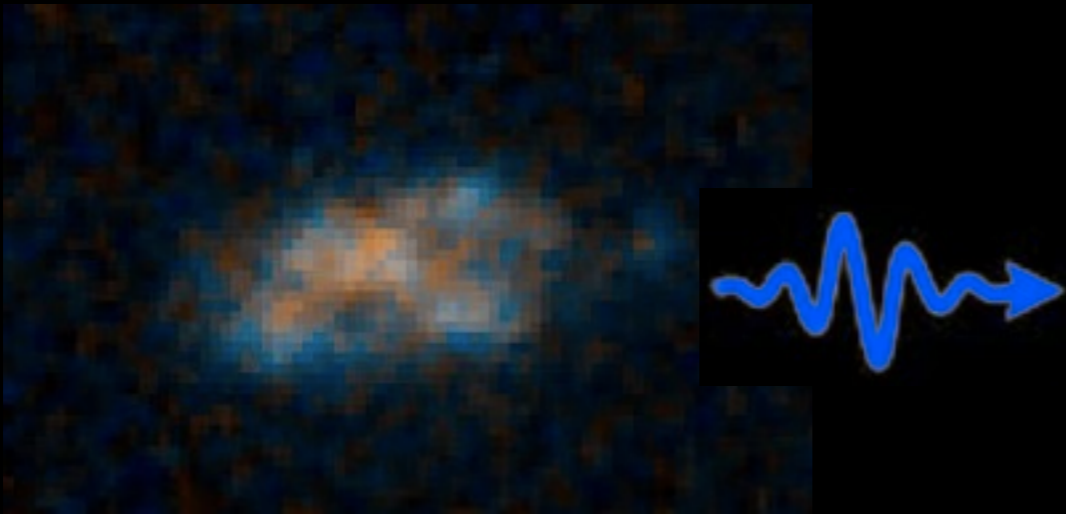
Credit NASA/CXC



Credit: Keck











Credit: NASA



Credit: NASA



SAOImage ds9

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

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Object: HD 240171

Value:

WCS:

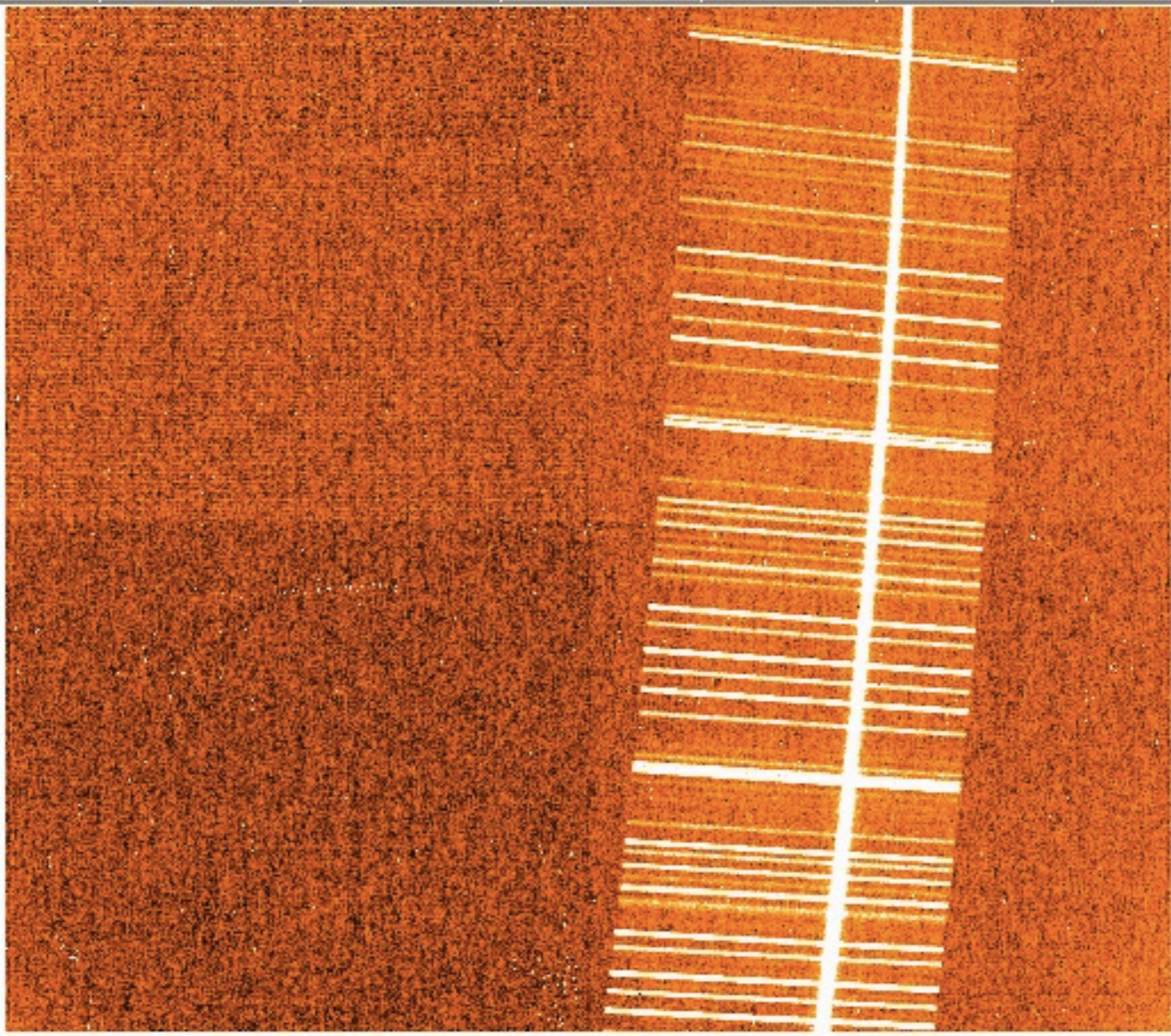
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Image X: Y:

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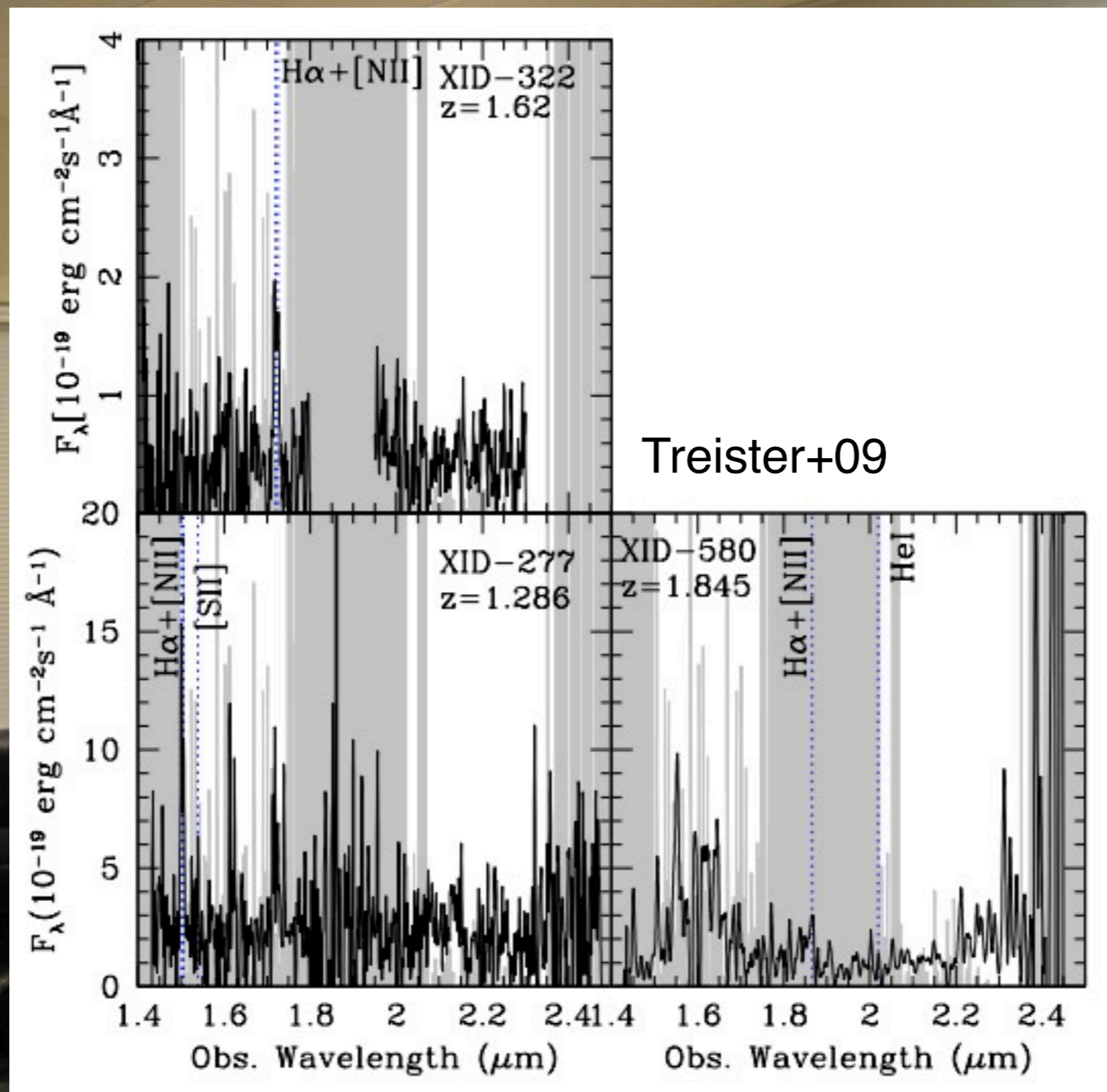
file edit view frame bin zoom scale color region wcs help

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-7.4 -3.7 -0.074 3.6 7.2 11 14 18 22





Treister+09

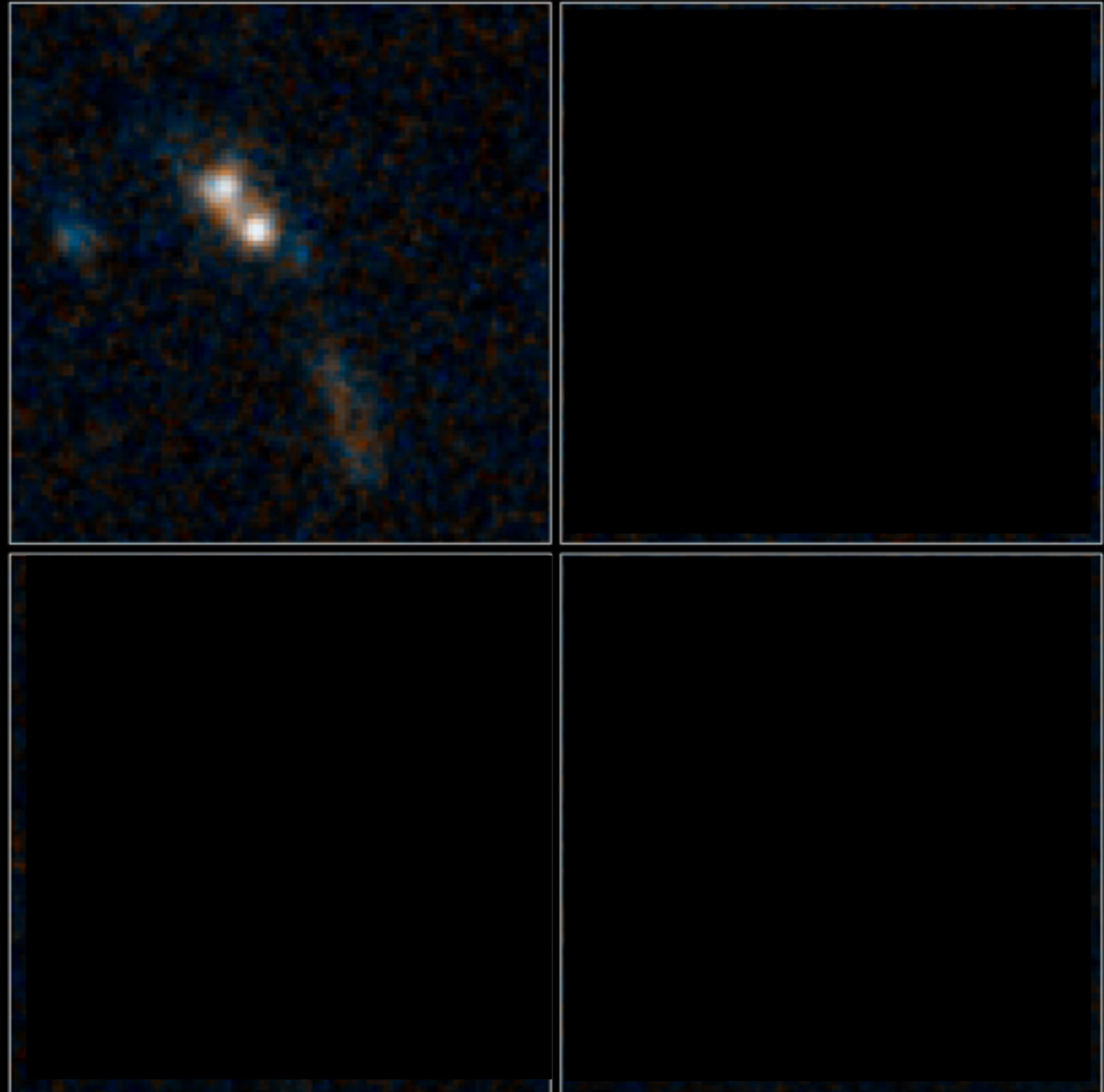
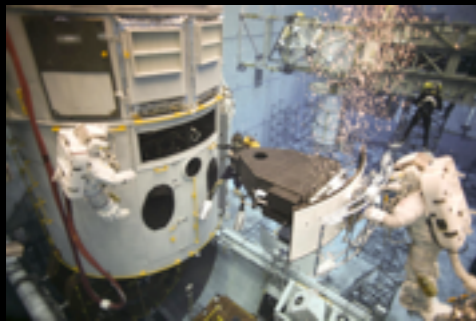


4

Normal Quasars

$z \sim 2$, ca. 3 Billion years after the Big Bang

Distant, Obscured Quasars • *Hubble Space Telescope* • WFC3/IR

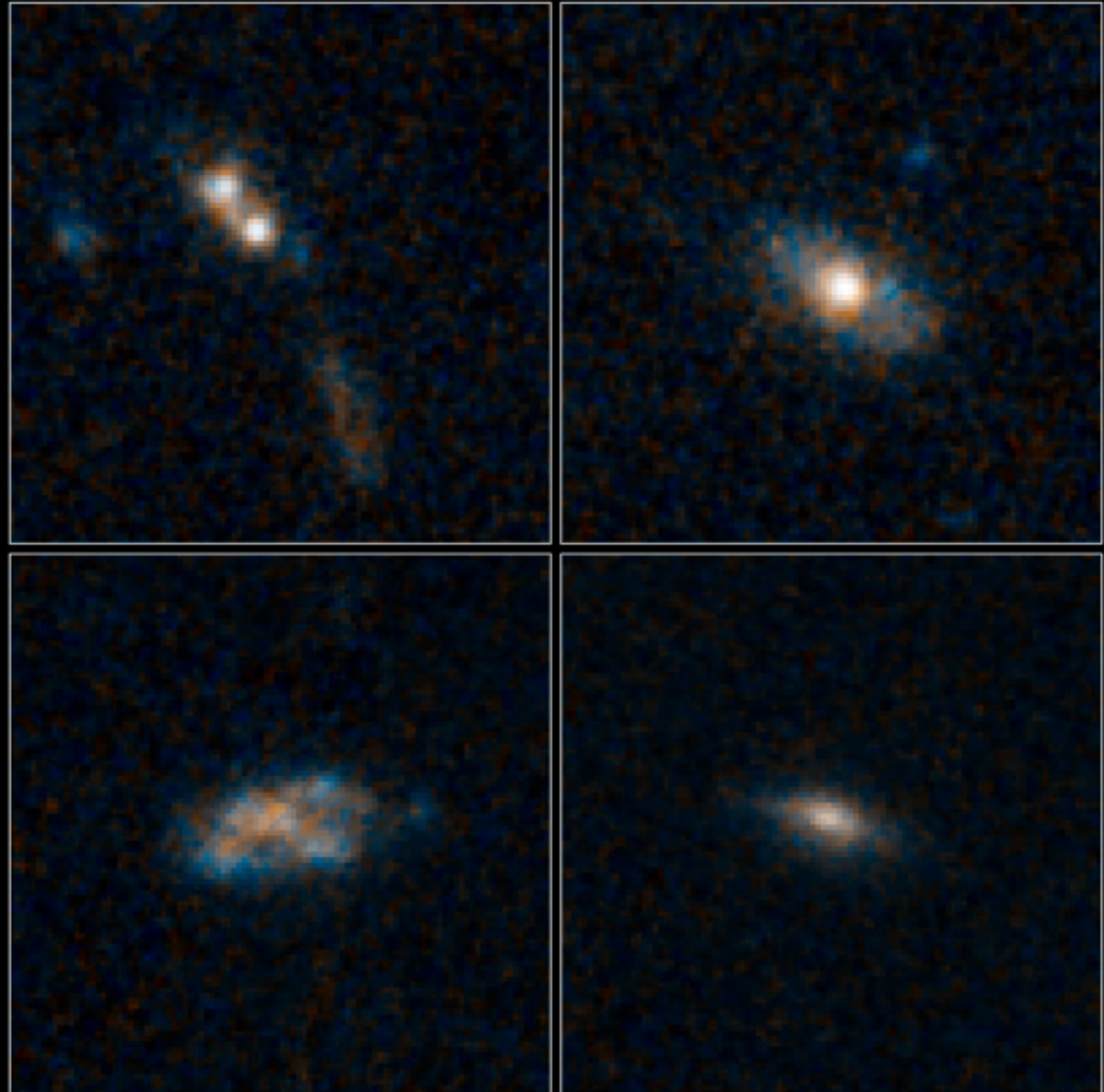
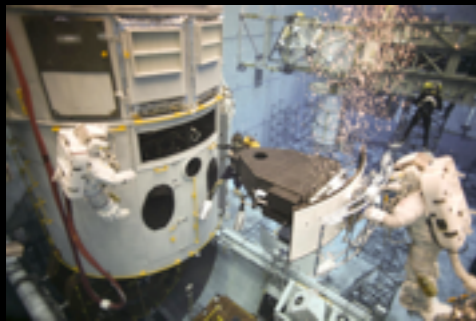


NASA, ESA, and K. Schawinski (Yale University) • STScI-PRC12-27a

Normal Quasars

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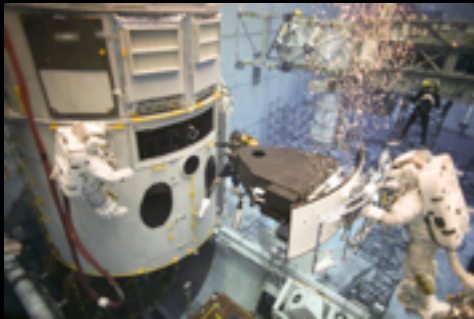
Distant, Obscured Quasars • Hubble Space Telescope • WFC3/IR



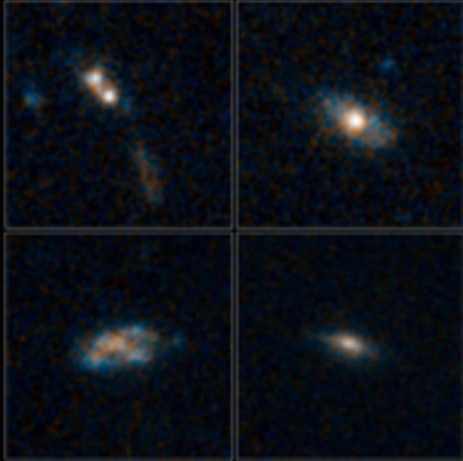
NASA, ESA, and K. Schawinski (Yale University) • STScI-PRC12-27a

Normal Quasars

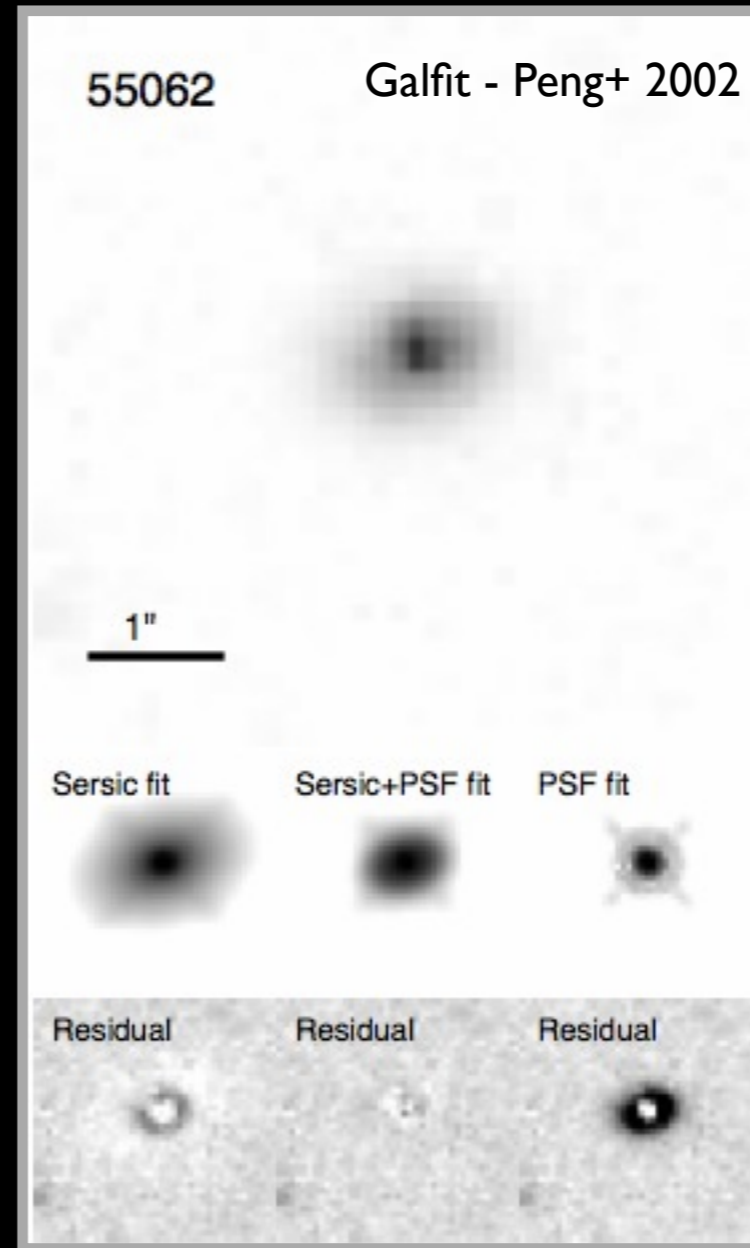
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Distant, Obscured Quasars - Hubble Space Telescope - WFC3/IR



MGA, ESA, and R. Schaefer (Yale University) - STS07-IRCL-27a

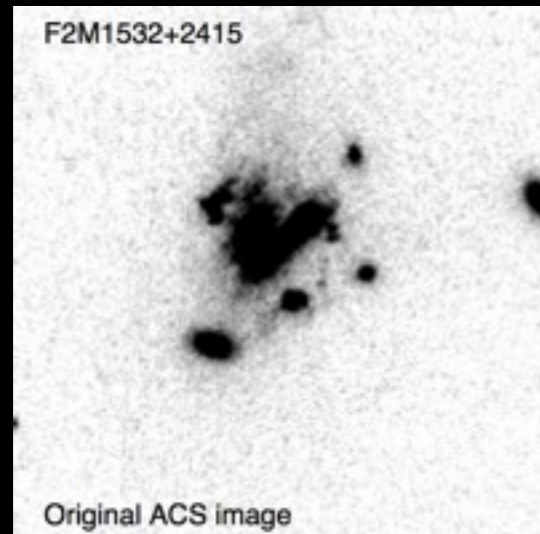
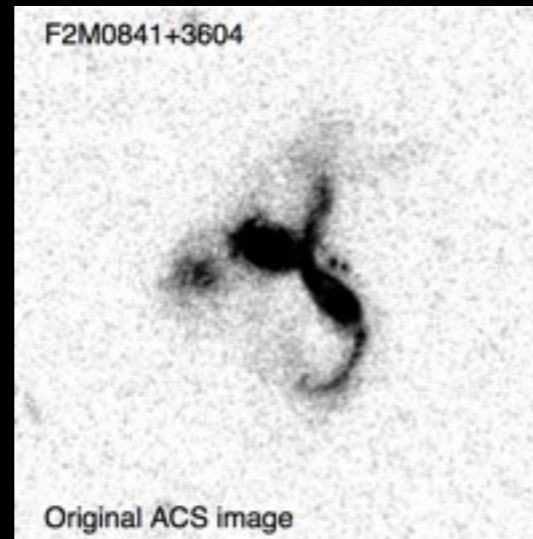
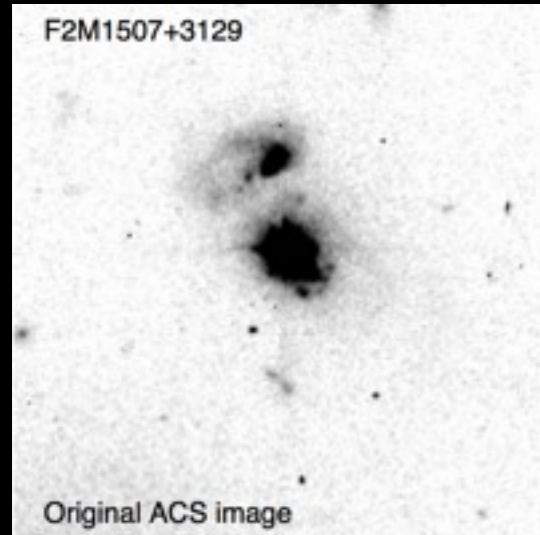


The Brightest Quasars in the Universe

$z \sim 0.5-2$, ca. 3-9 Billion years after the Big Bang

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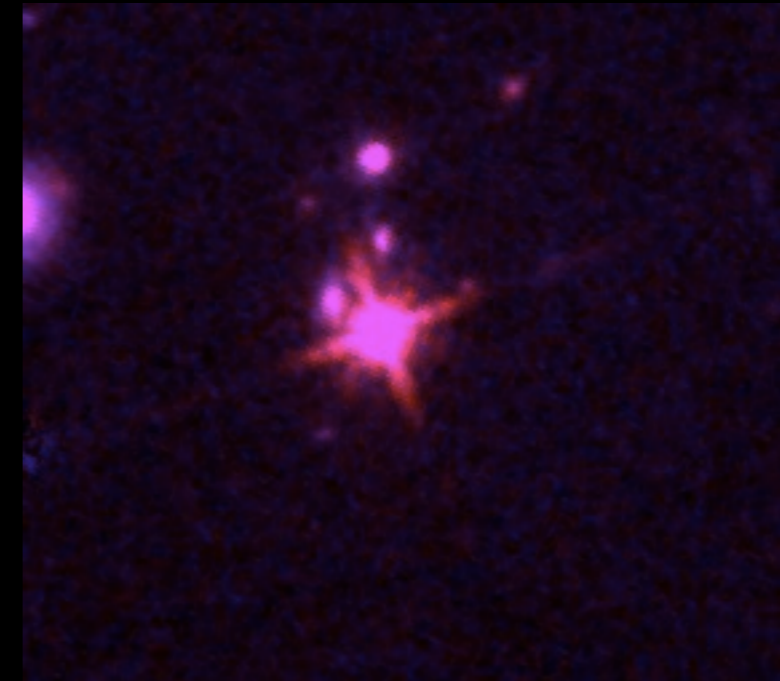
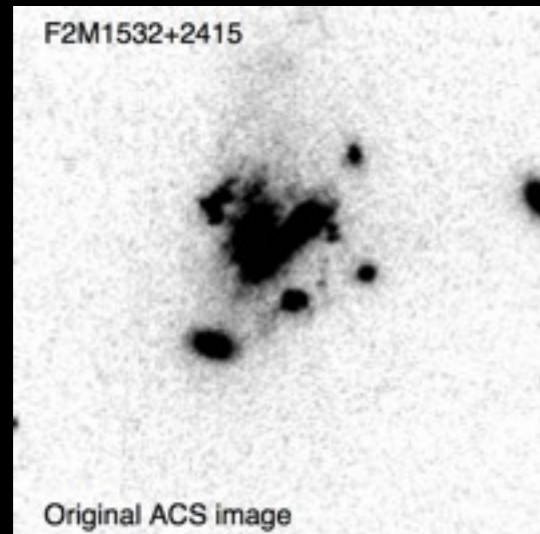
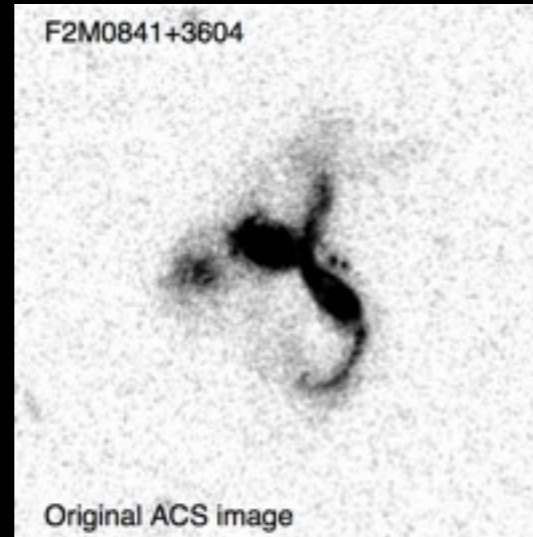
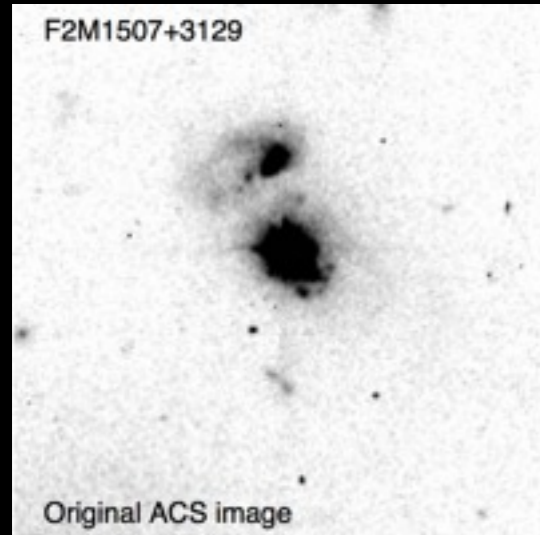
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Hubble images of low- z “red” quasars
Urrutia+07

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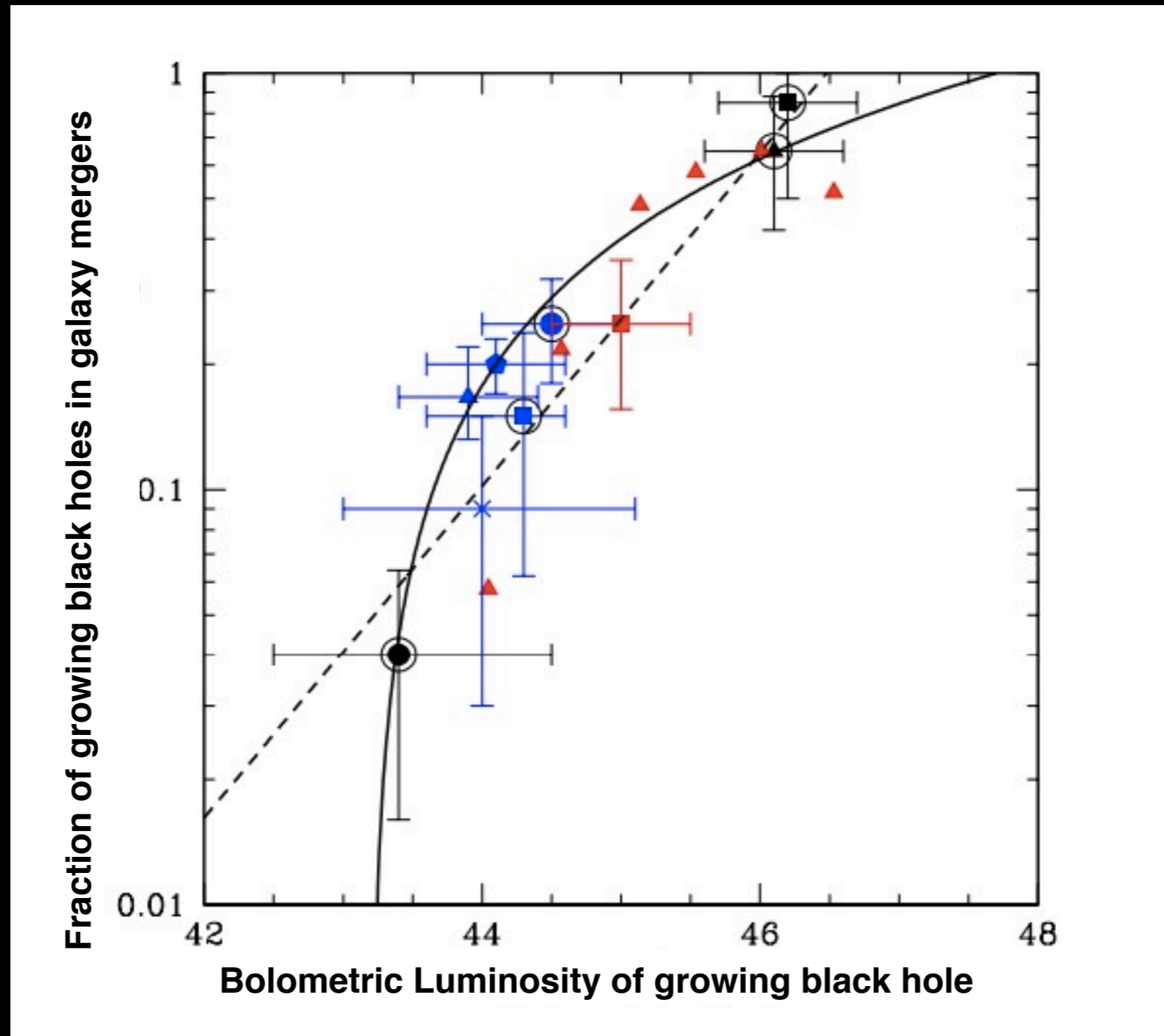
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Hubble images of low- z “red” quasars
Urrutia+07

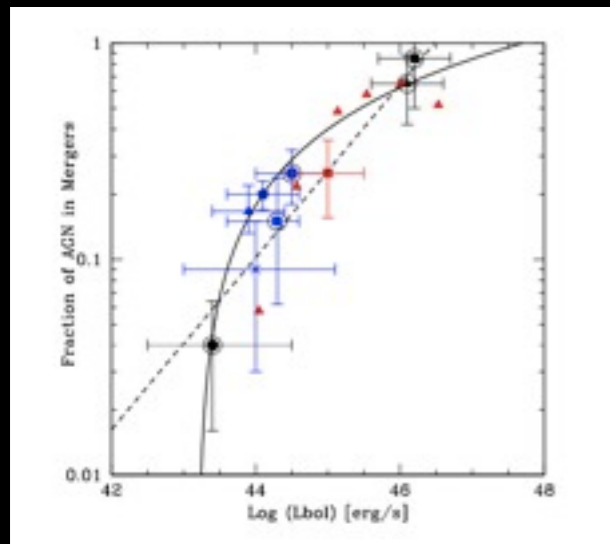
Hubble images of high- z “red” quasars

Are black hole growth episodes triggered by galaxy mergers?

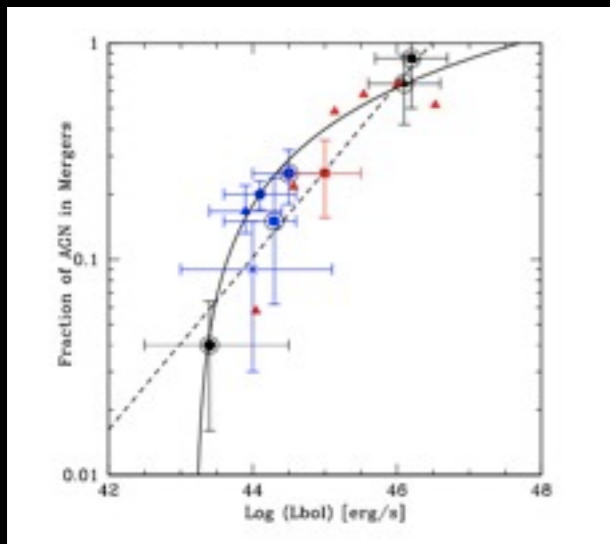


Treister, Schawinski, Simmons & Urry 2013

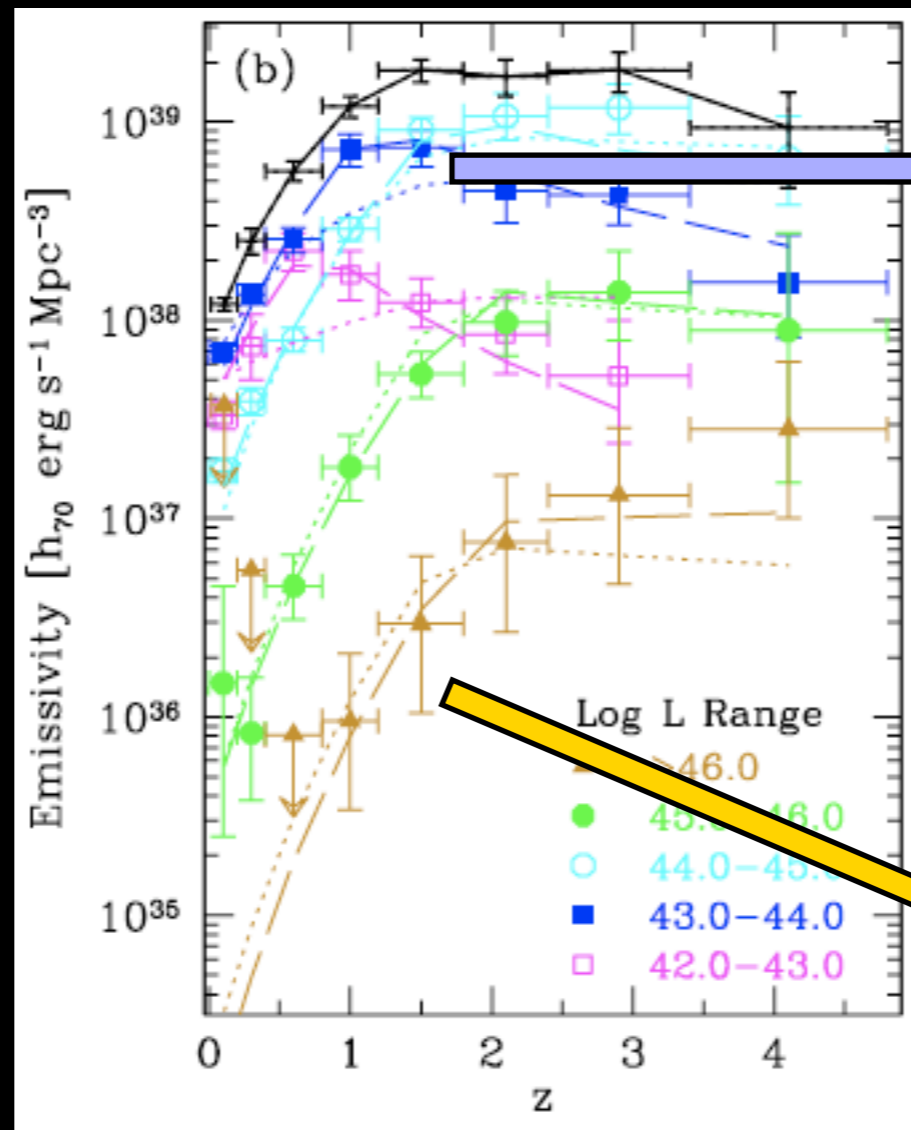
How and where do black holes grow?



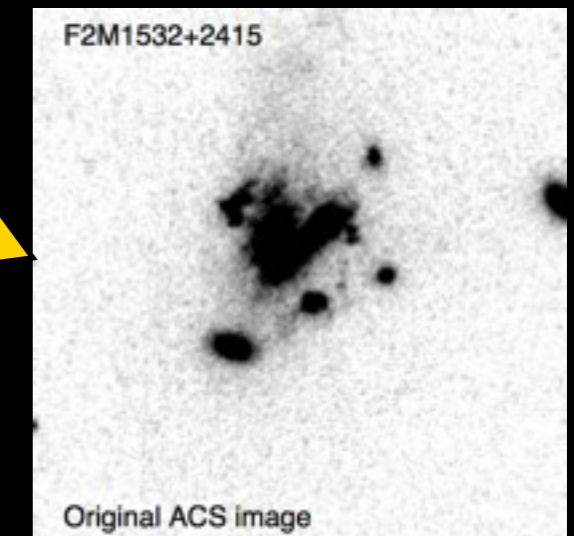
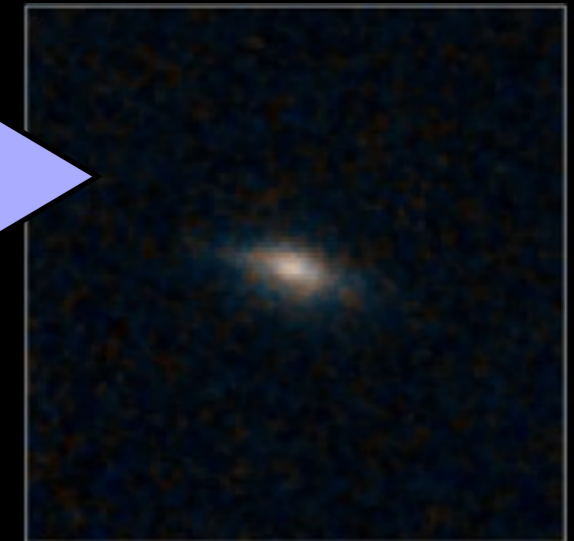
How and where do black holes grow?



+

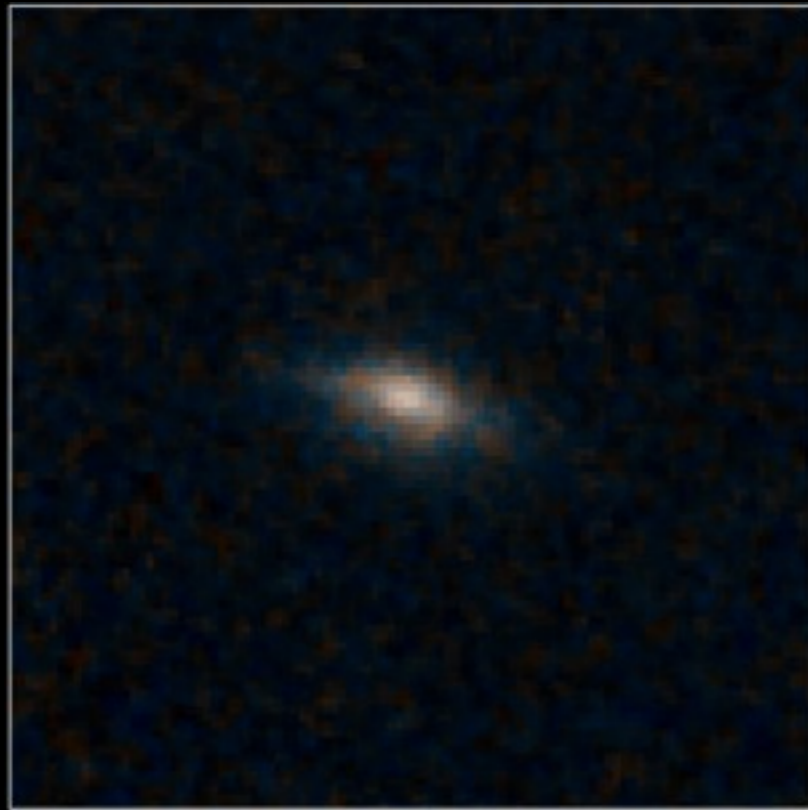


Hasinger+2005



How and where do black holes grow?

“normal” growing
black holes



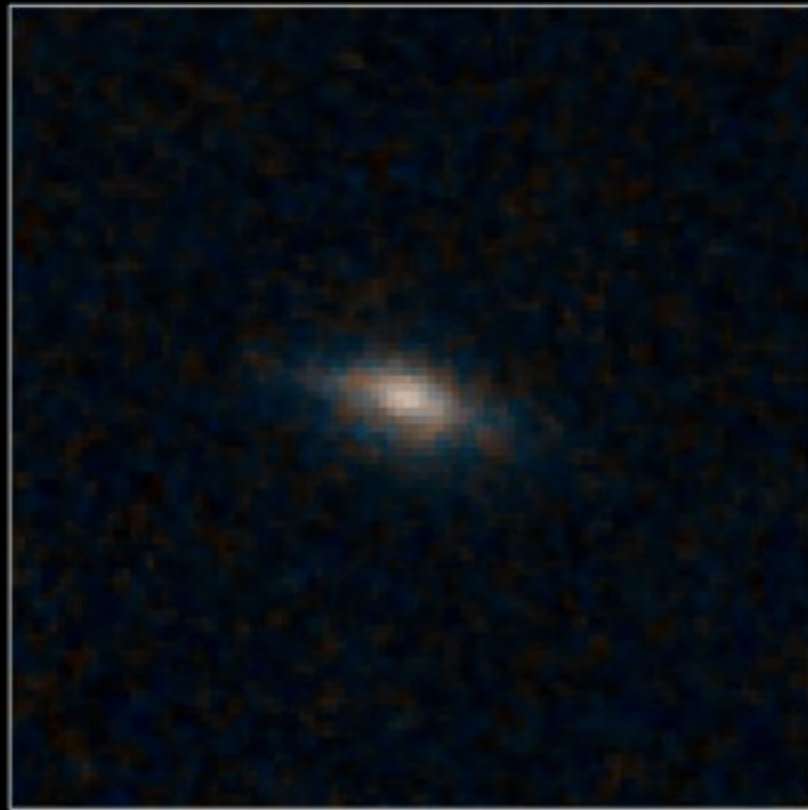
90% by space density
50% of mass accreted

the brightest quasars
in the universe

10% by space density
50% of mass accreted

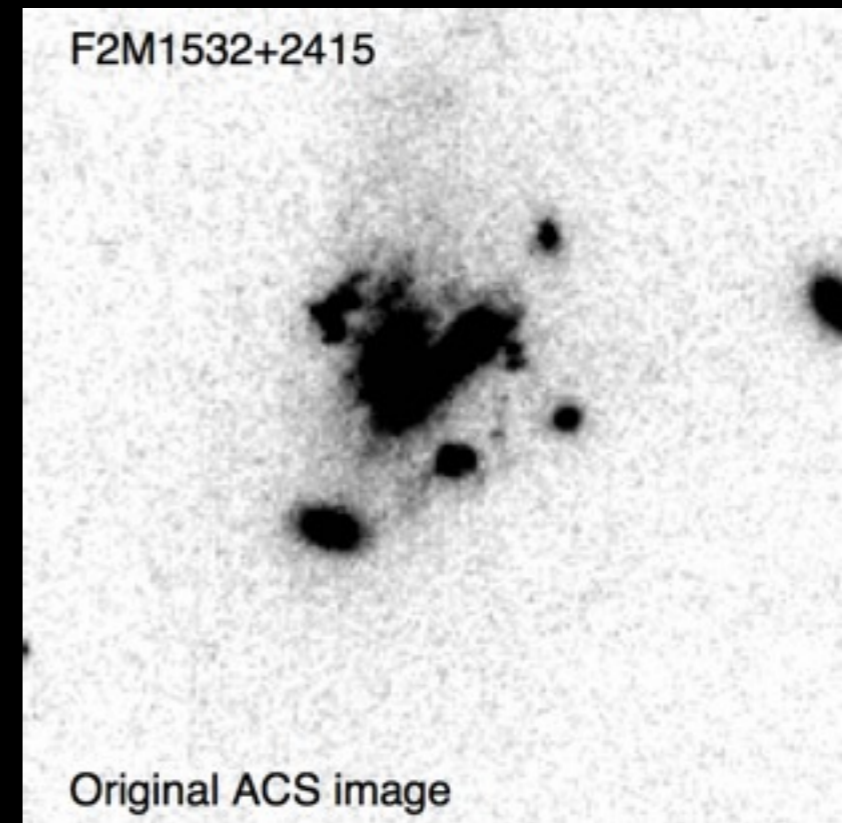
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1. Is the hypothesis correct that black holes grow in galaxy collisions?

2. Can we observe the effect of “feedback” directly?”

3. Woher kommen denn die schwarzen Löcher in den Zentren von Galaxien?

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Discovered by citizen scientist Hanny van Arkel in 2007

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- Galaxy Tutorial
- Galaxy Analysis
- Galaxy Zoo - Thank You

Galaxy Analysis

Welcome to Galaxy Zoo's view of the Universe. If you're here you should already have seen the [Tutorial](#), but feel free to go and remind yourself. There's no need to agonise for too long over any one image, just make your best guess in each case.



Galaxy Ref:
587741816777277606

Choose the Galaxy Profile by clicking the buttons below


CLOCK ANTI EDGE ON / UNCLEAR
SPIRAL GALAXY

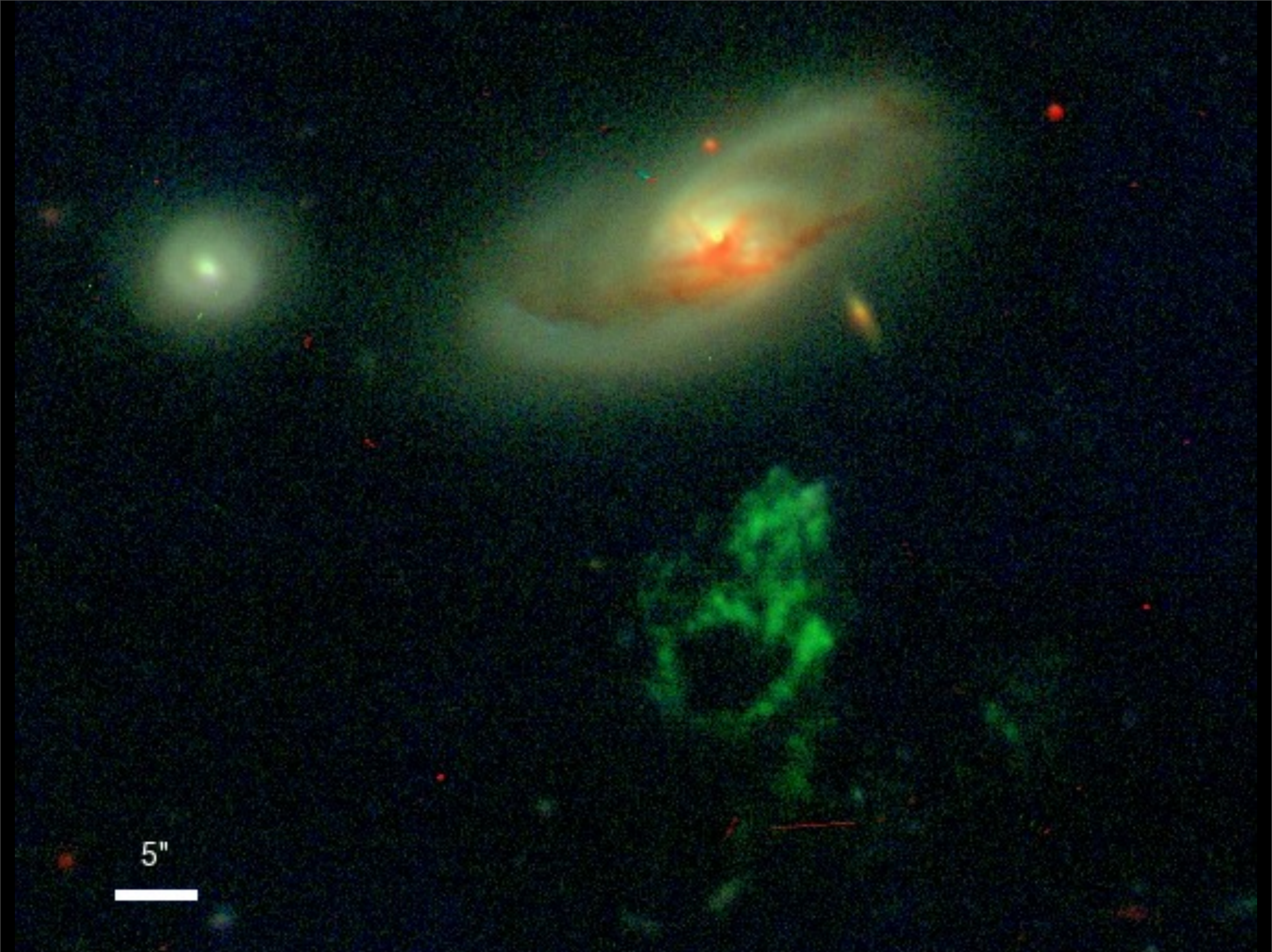
ELLIPTICAL GALAXY

STAR / DIRT / KNOW MERGERS

Show Grid Overlay on the next Image

Show Grid Overlay on the next Image







1.4 GHz continuum

$10^9 M_{\text{sun}}$ of HI

From: WSRT, Jozsa et al. (2010)



Quasar - $L_{\text{bol}} \sim 10^{46}$ erg/s!

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SUZAKU | ASTRO-EII



Quasar - $L_{\text{bol}} \sim 10^{46}$ erg/s!



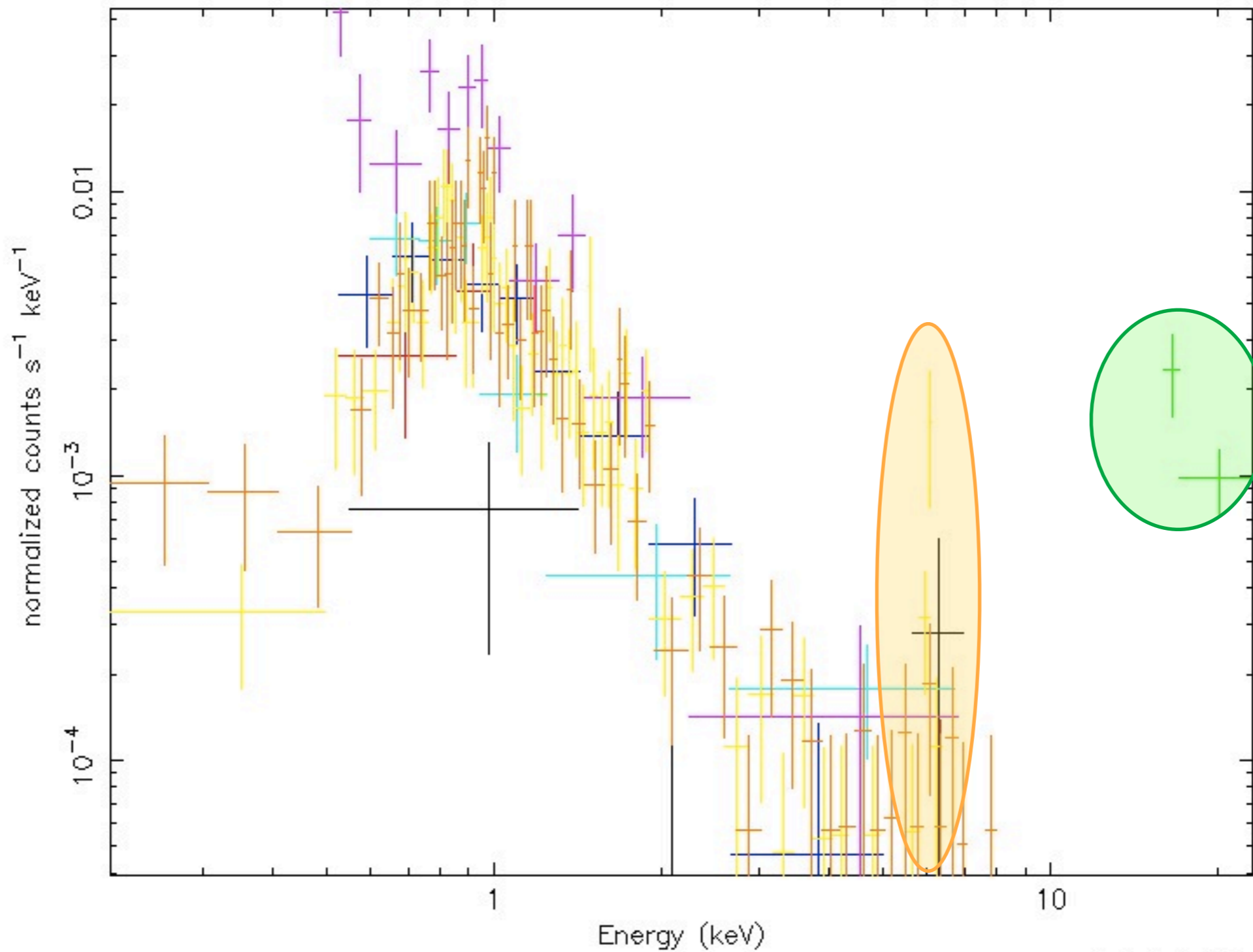
Quasar - $L_{\text{bol}} \sim 10^{46}$ erg/s!





Quasar - $L_{\text{bol}} \sim 10^{46}$ erg/s!

data



keyinschawinski 24-Jun-201

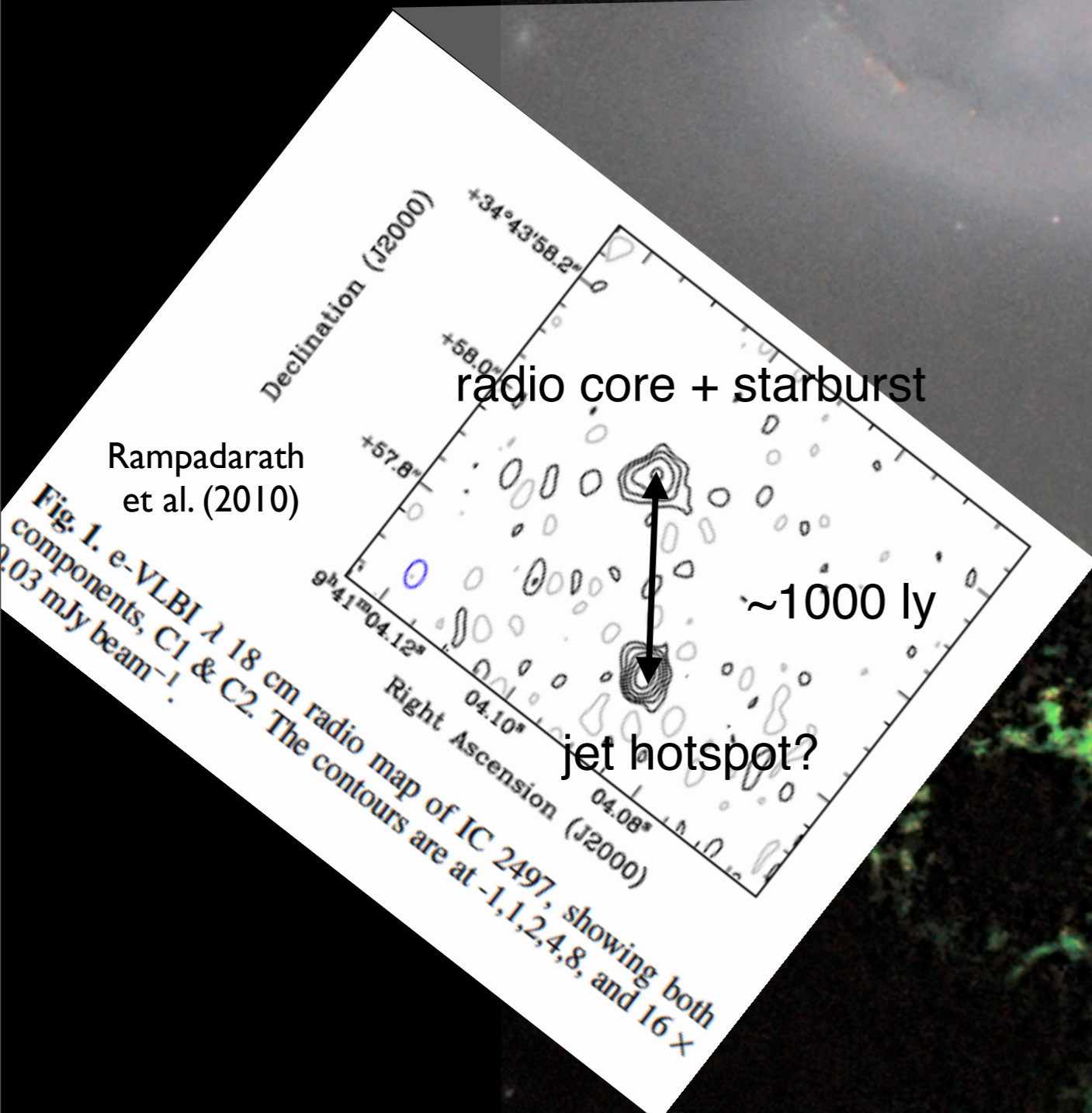


Quasar - $L_{\text{bol}} \sim 10^{46}$ erg/s!

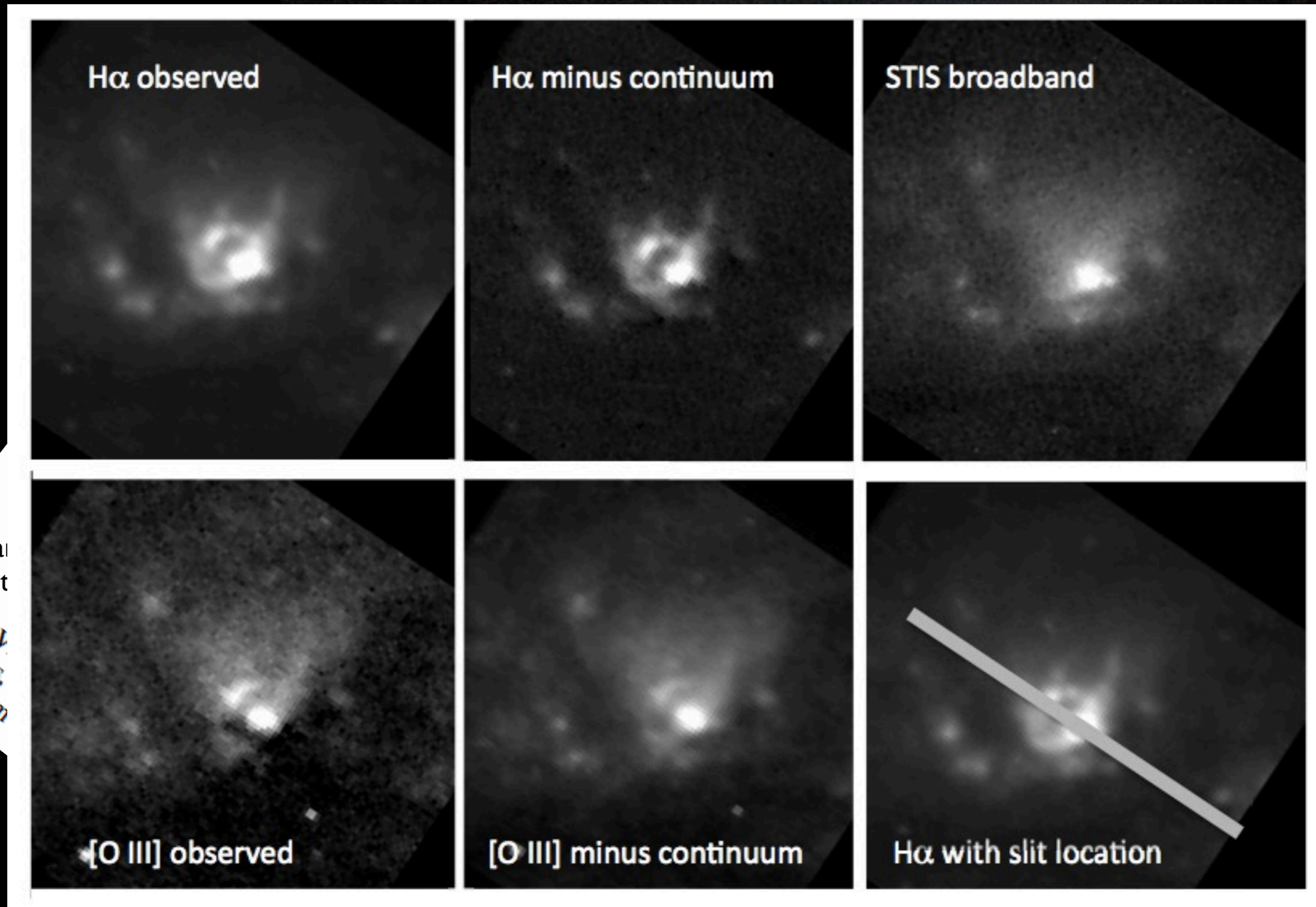
A better view of the heart of a quasar



A better view of the heart of a quasar



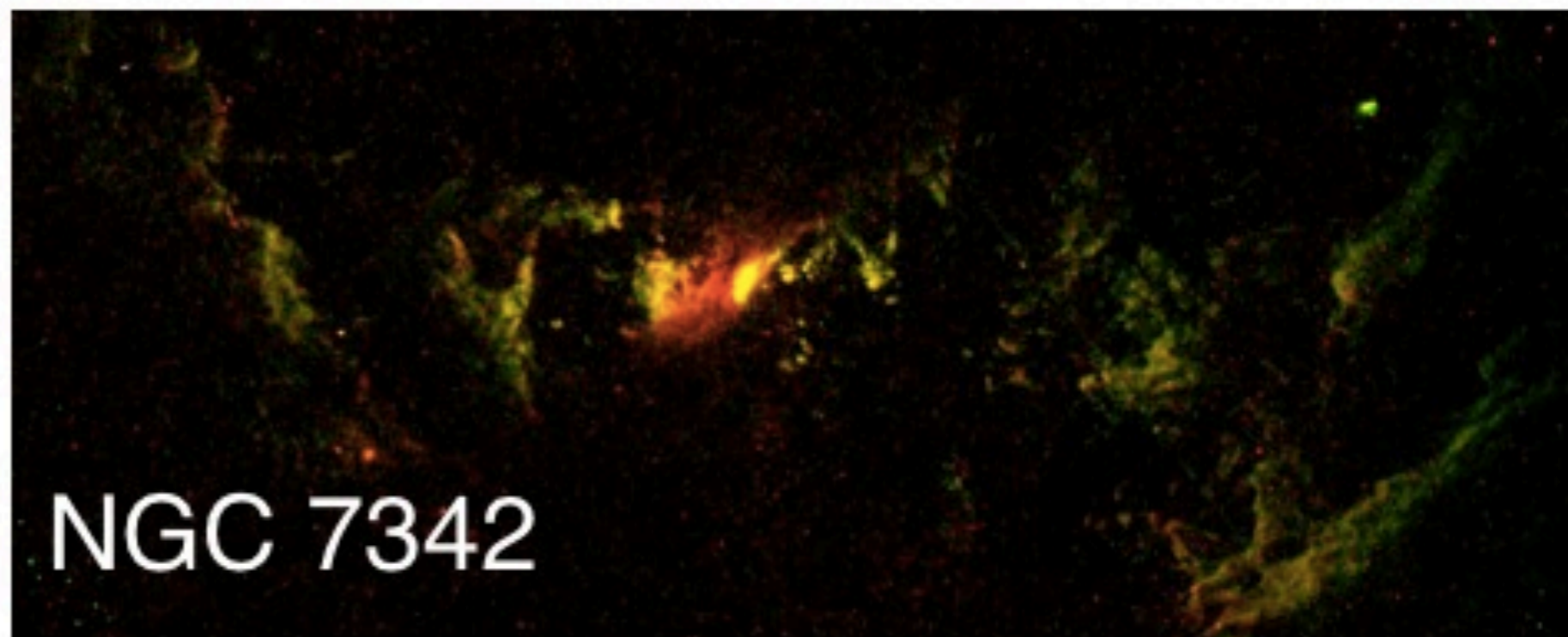
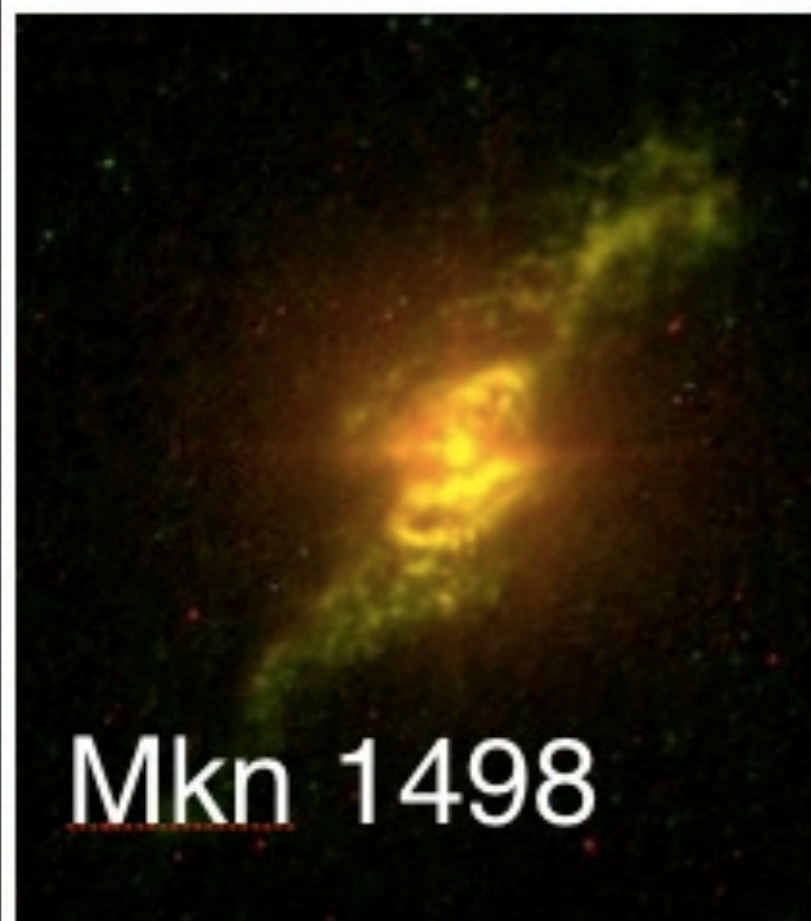
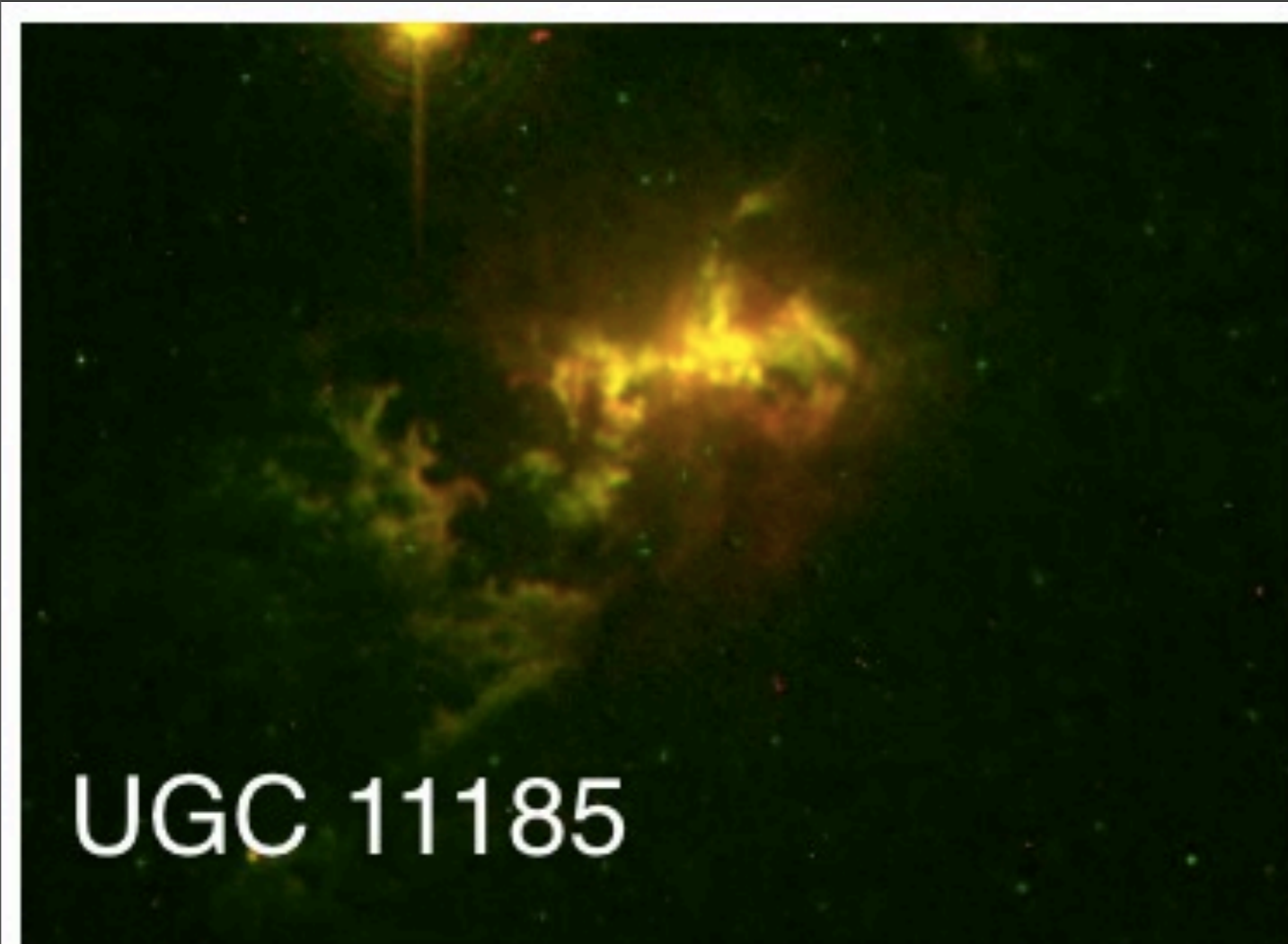
A better view of the heart of a quasar



Rai
et

Fig. 1. e-v
components,
0.03 mJy beam

showing both
2, 4, 8, and 16 x



Galaxy-Black Hole Co-evolution

Accreting black holes may regulate galaxy evolution and shape the galaxy population

We don't really know how this works, but we'd love to know.

CLASSIFY

SCIENCE

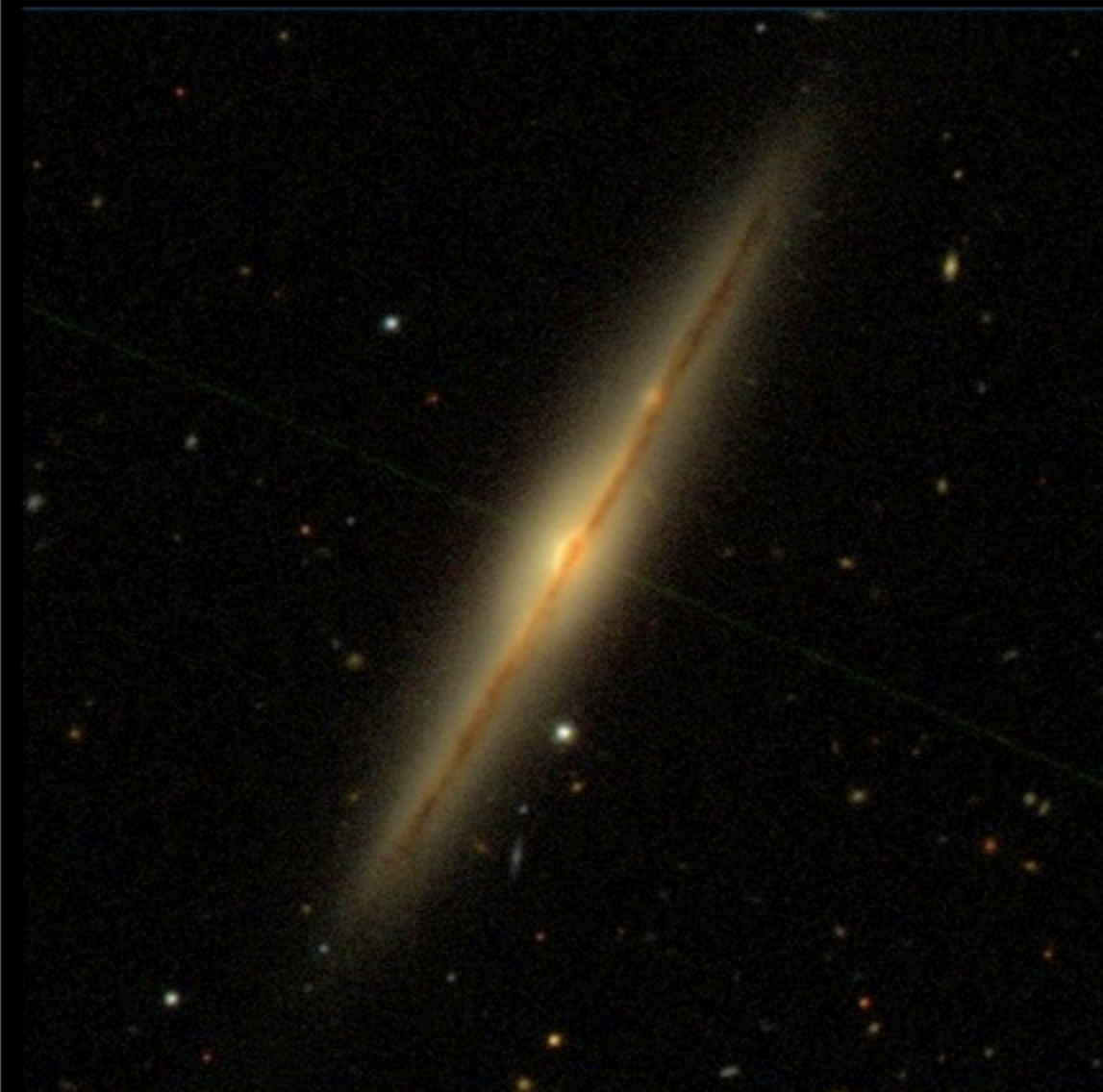
STORY



ASTRONOMERS

DISCUSS

PROFILE



Classify



SDSS



Invert

Help

Restart

SHAPE

Is the galaxy simply smooth and rounded, with no sign of a disk?



Smooth



Features or disk



Star or artifact

My path

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Maths, more maths, physics, chemistry at A level (UK)

Also: be a computer geek!

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Faculty:

ETH Zurich (Switzerland)

Also: get students to do work as admin takes over???