LIGO Discovery of Gravitational Waves: What does it mean for Astrophysics?

Prof. Rogier Windhorst (ASU)

(1) LIGO first observed Gravitational Waves on Sept. 14, 2015.

(2) These were caused by two merging (29 + 36 solar mass) black holes!

- $E=Mc^2$: 3 solar masses converted to energy in fraction of second!

(3) BLACK HOLES EXIST !! General Relativity is the law-of-the-land!

(4) Cannot see blackholes directly through electromagnetic radiation (light).

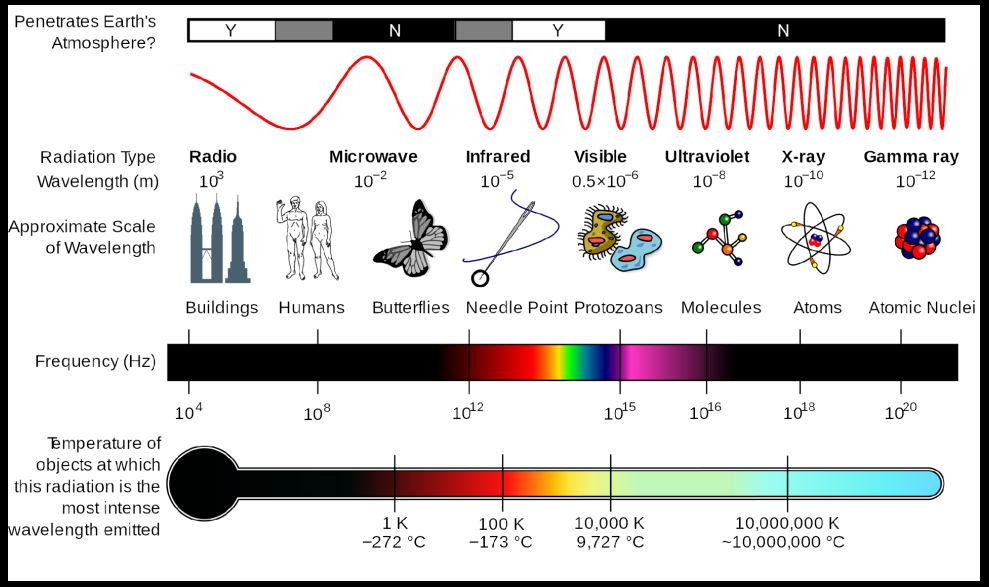
- But can see them through gravitational radiation (space-time ripples).

Waves that happen in Nature — Sounds Waves:

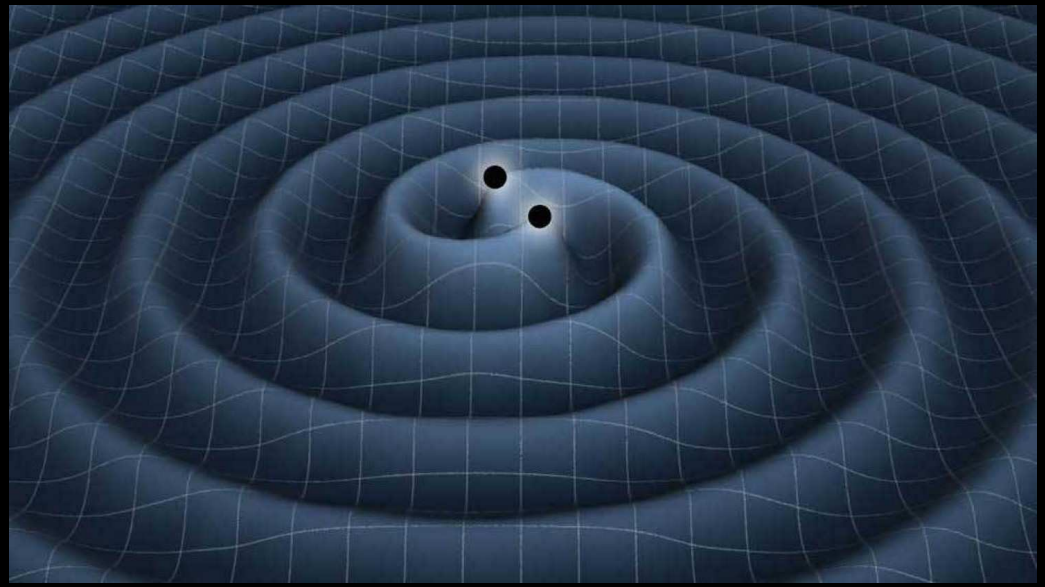
In solids: Earthquakes

In liquids: Surf!

In gasses: Sound

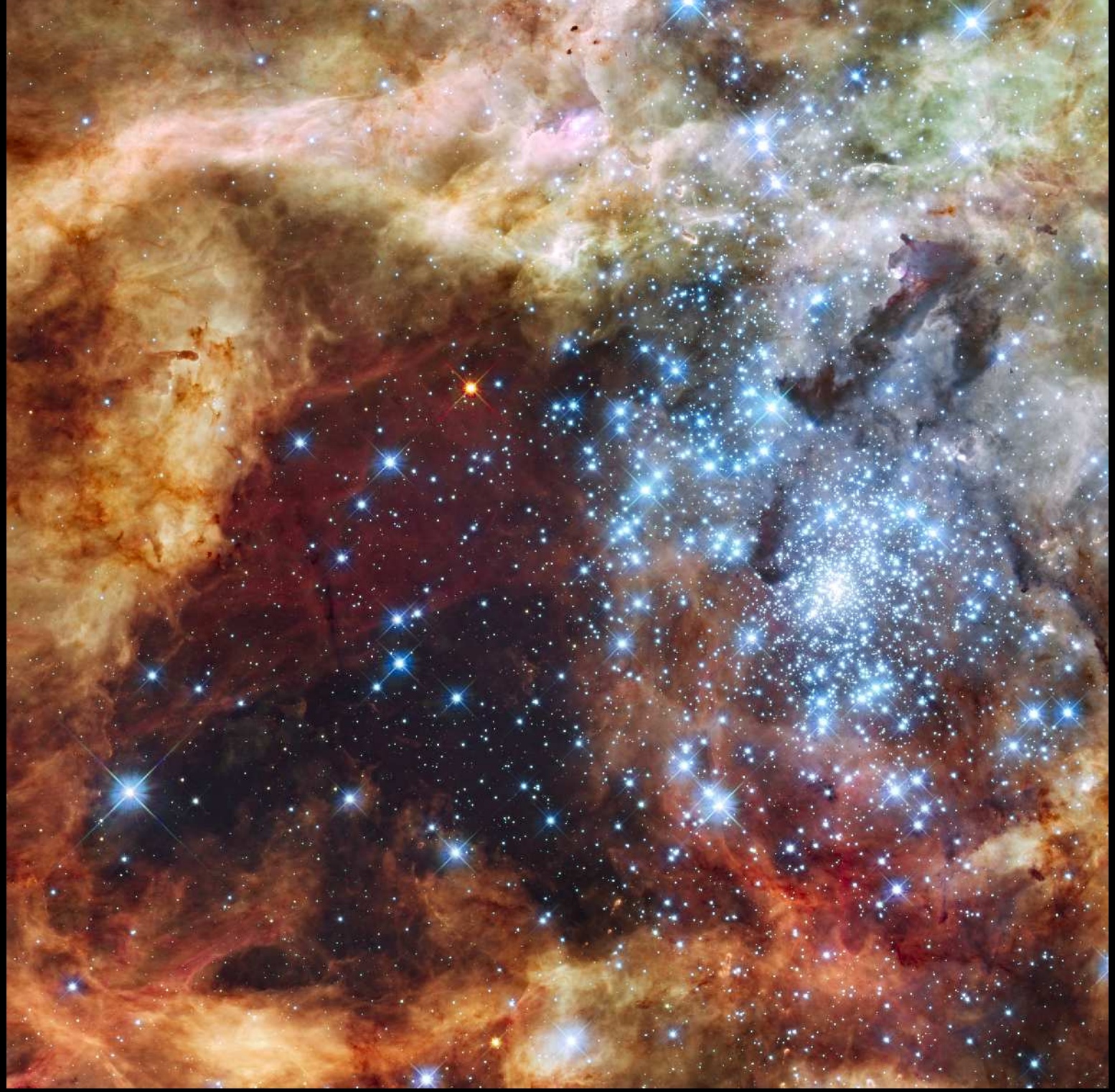


Electromagnetic Waves



In space-time: Gravity Waves

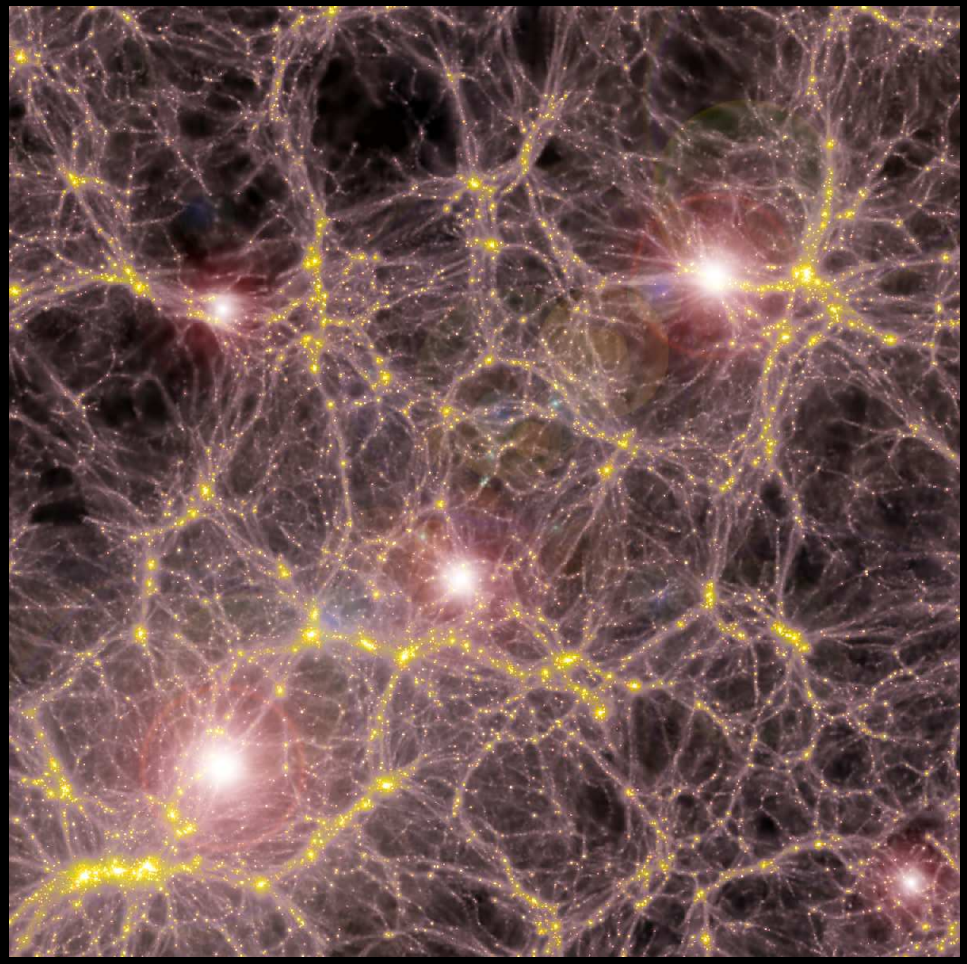
LIGO just added Gravitational Waves as a new way to observe Nature!

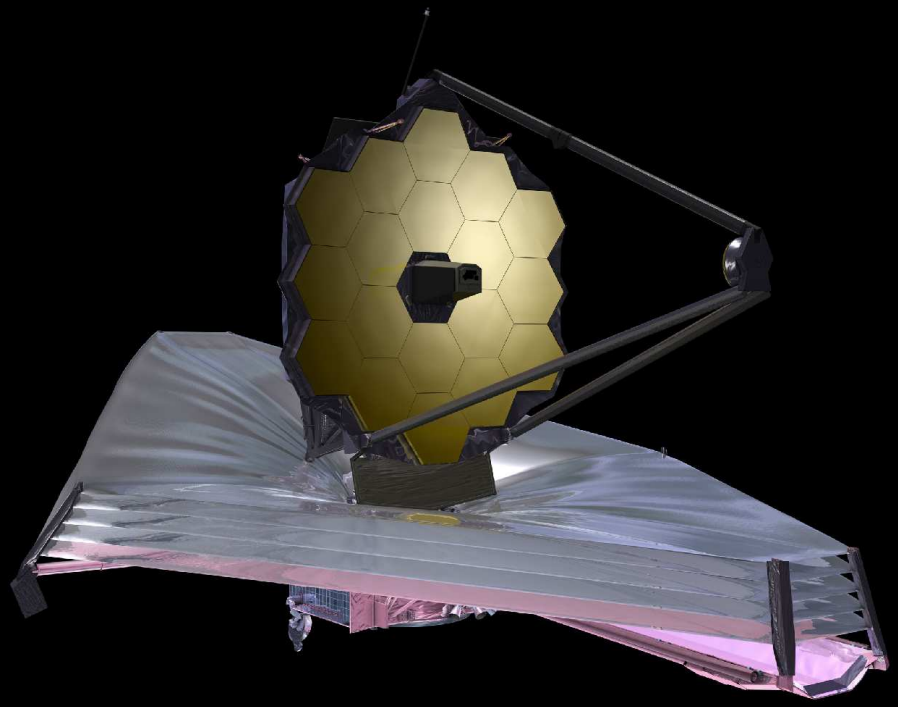


Ordinary stars (8–30 solar masses) leave modest black holes (3–12 solar).

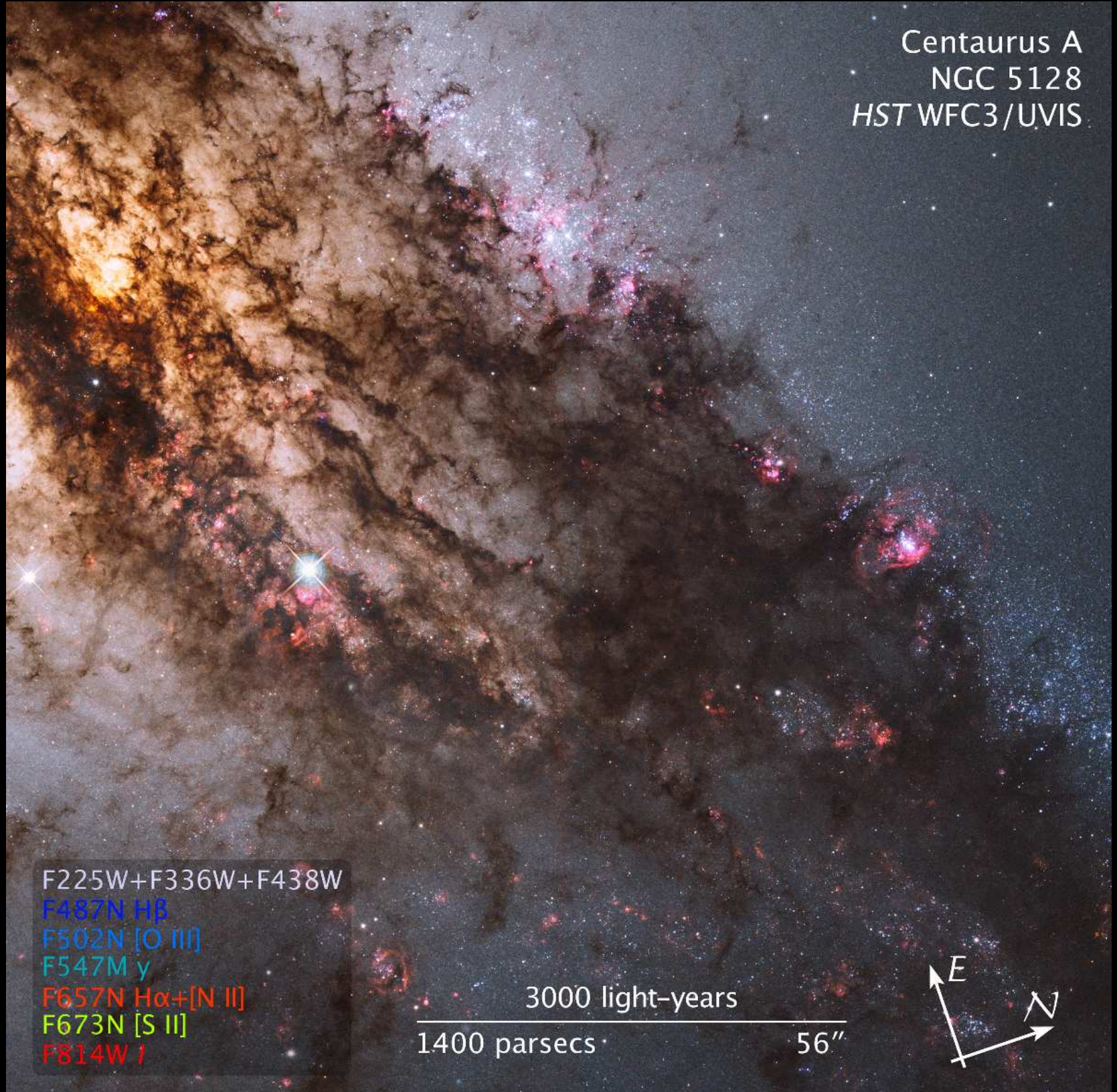
Conclusion 1: Most low-mass black holes today are small, slow eaters:

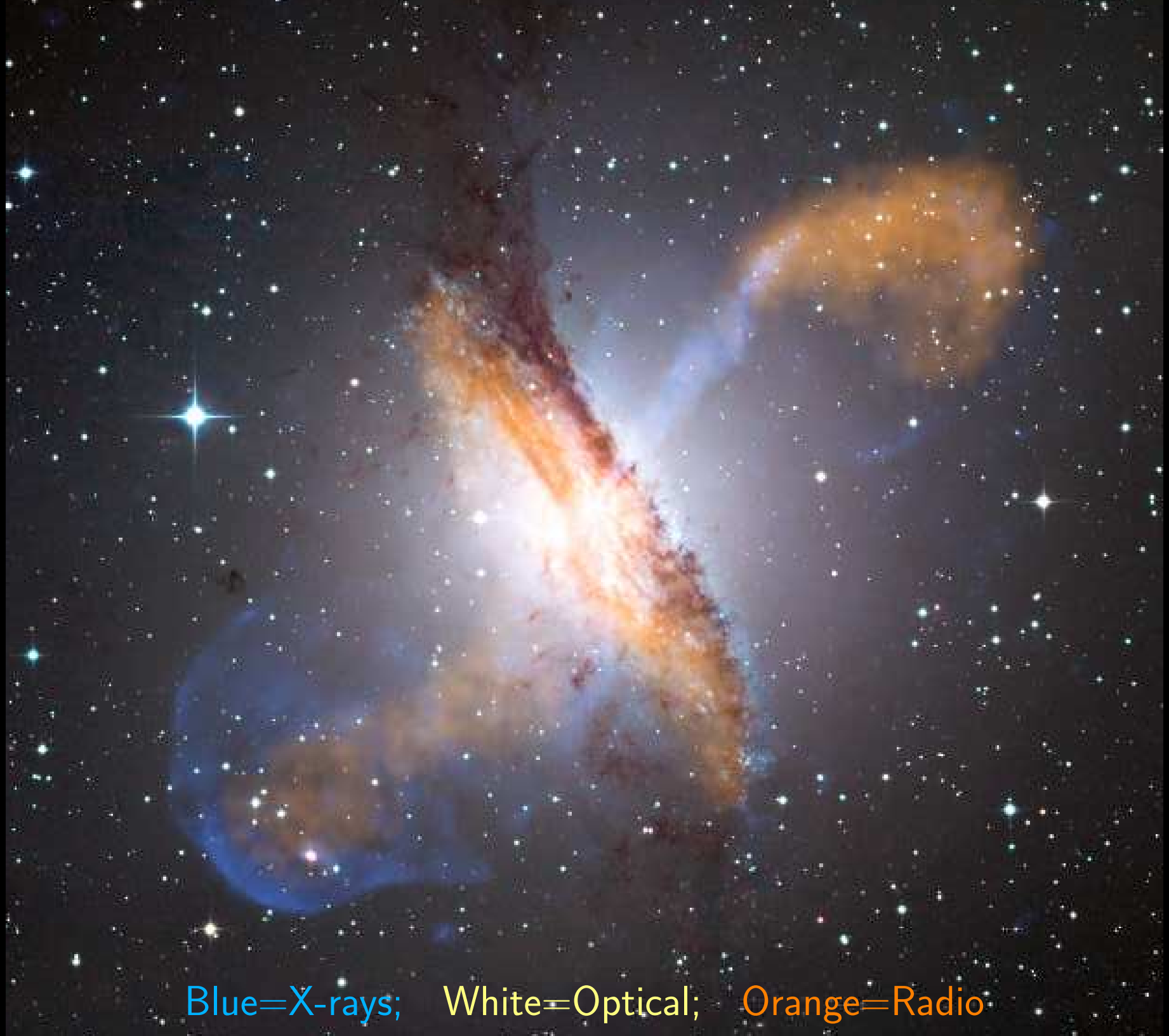
- 29–36 solar mass blackholes likely leftover from First Stars (first 500 Myr).
  - Too massive to be leftover from ordinary Supernova explosions.
  - How come only now seen merging by LIGO (12.5 Byr after BB)?
  - They were likely not fast & efficient eaters, but slow and messy ...



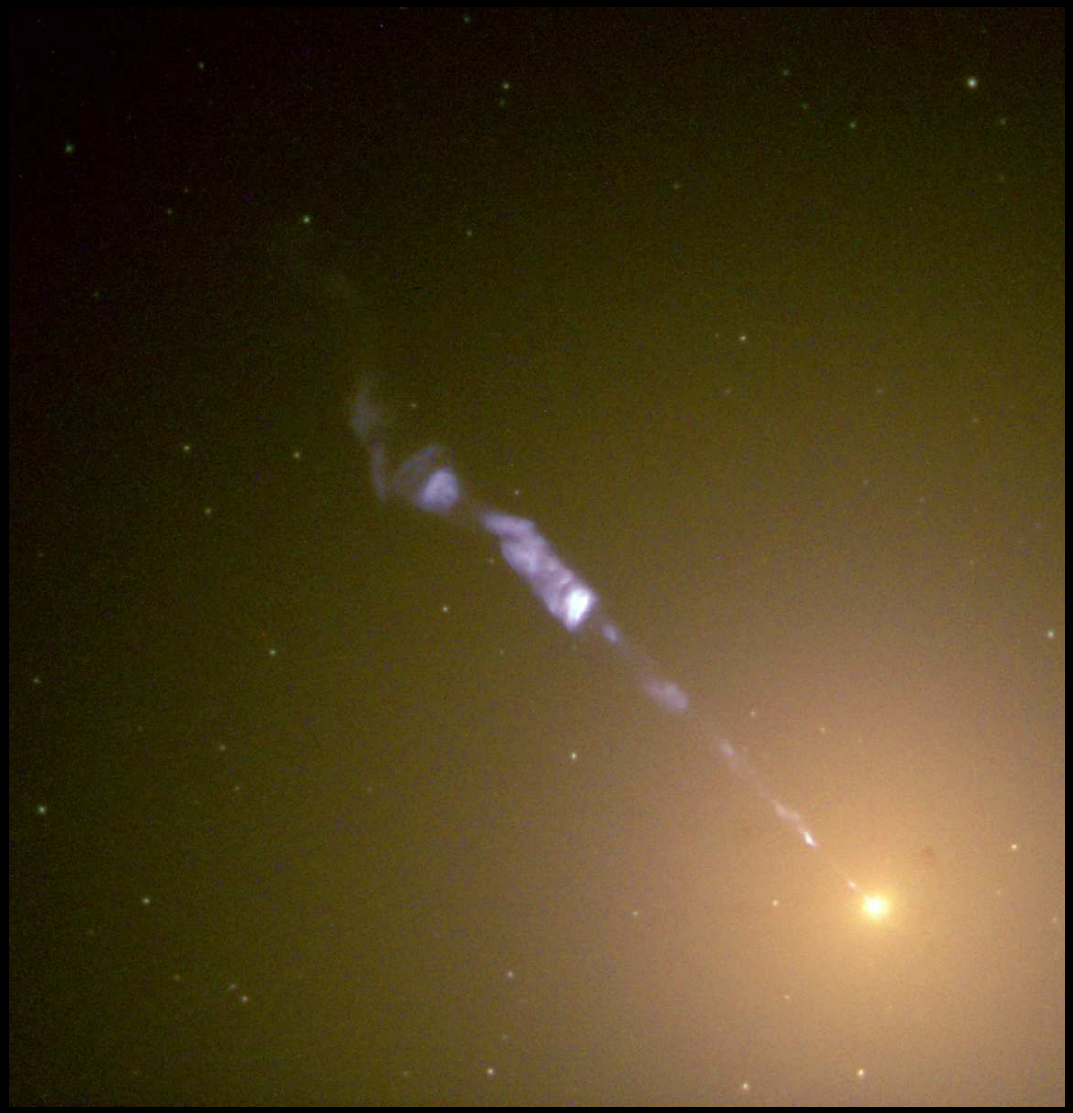


- Very first stars likely born in the first 500 Myr after the Big Bang.
- They were likely 80–200 solar masses, lived fast, & died young (1 Myrs!)
- They could have left 30–80 solar mass black holes behind, as LIGO saw.
- But how come LIGO only sees these leftovers merge today (1 Byrs ago)?
- The James Webb Space Telescope will observe First Light after 2018.


Centaurus A
NGC 5128
HST WFC3/UVIS
F225W+F336W+F438W
F487N Hβ
F502N [O III]
F547M y
F657N Hα+[N II]
F673N [S II]
F814W *I*
3000 light-years
1400 parsecs
56″
E
N


Blue=X-rays; White=Optical; Orange=Radio

Elliptical galaxy M87 with Active Galactic Nucleus (AGN) and relativistic jet:



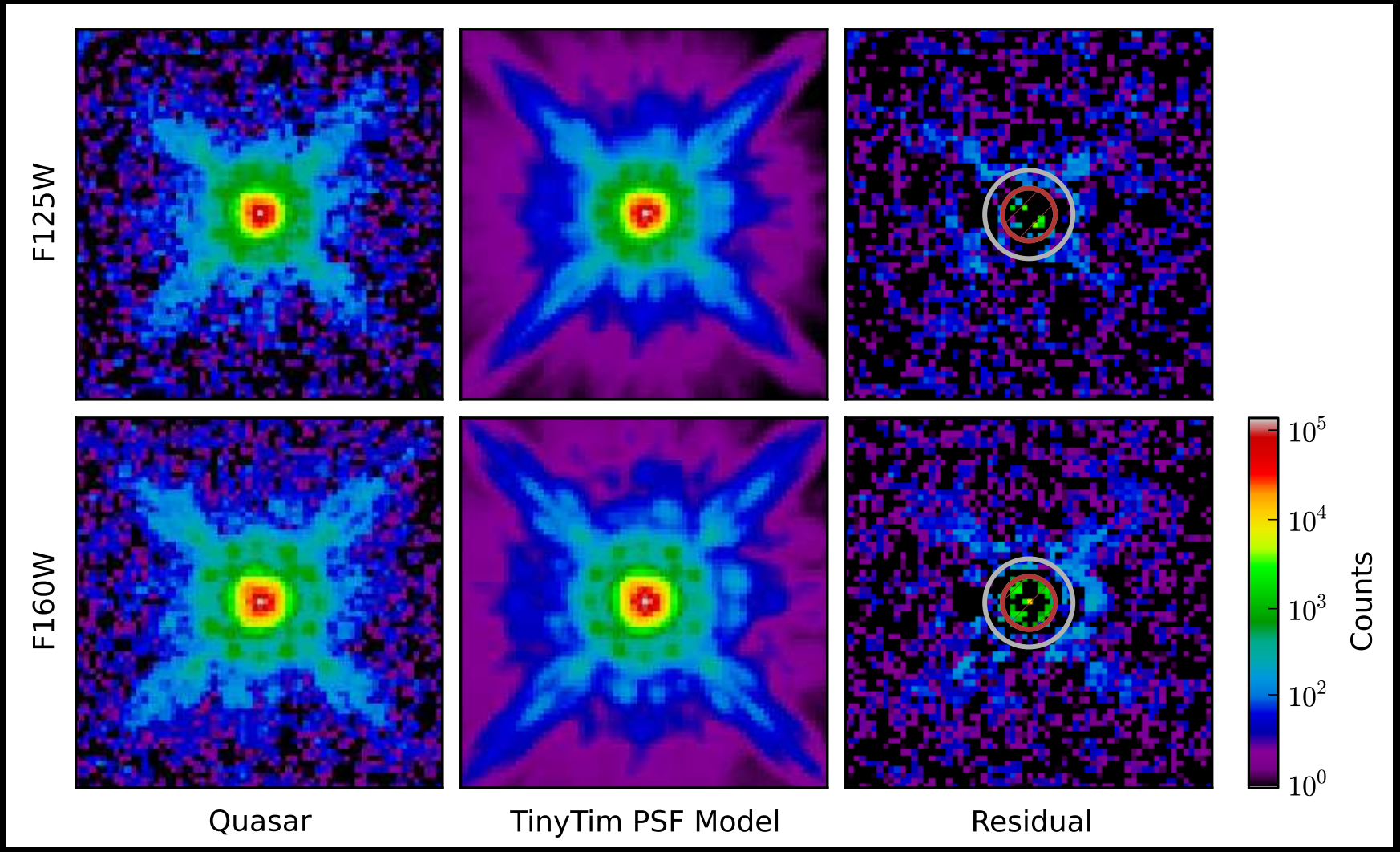
"For God's sake, Edwards. Put the laser pointer away."

The danger of having Quasar-like devices too close to home ...

They are EXTREMELY bright sources if viewed "down-the-pipe".

Children: Please do NOT do this at home!

- Quasars: Centers of galaxies with feeding supermassive blackholes:



- Hubble IR-images of the most luminous Quasar known in the universe.
- Seen at redshift 6.42 (universe 7.42× smaller than today), 900 Myr old!
- Contains 10^{14} solar luminosities within a region as small as Pluto's orbit!
- A feeding monster blackhole ($>3\times10^9$ solar mass) 900 Myr after BB!

Conclusion 2: Supermassive black holes started early & were very rapid eaters:

- All massive galaxies today contain a super-massive blackhole, no exceptions!
  - Masses 3×10^9 solar, leftover from the First Stars (first 500 Myr)?
  - Must have fed enormously rapidly in the first 1 Byr after the Big Bang.
  - Were eating cat-astrophically (and secretly) until they ran out of food ...

Future LIGO's to see frequent blackhole-mergers from epoch of First Light.

Illustration Sequence of the Milky Way and Andromeda Galaxy Colliding

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger ▪ STScI-PRC12-20b

Will this ever happen to our own Galaxy?

YES! Hubble showed no lateral motion:

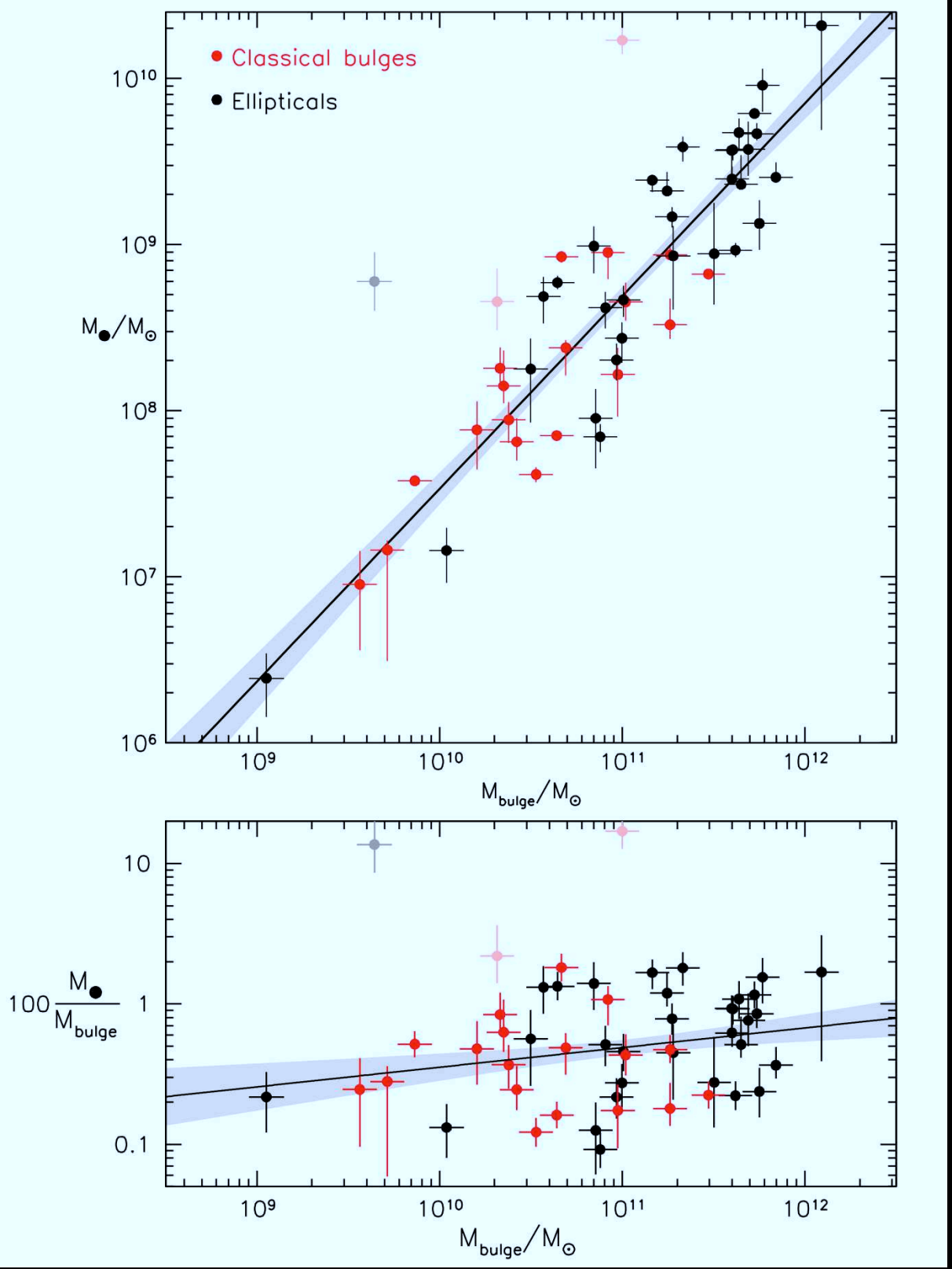
Approaches at –110 km/s.

Hence, Andromeda will merge with Milky Way!

The two blackholes (10^6–10^7 suns) will also merge!

Not to worry: only 4–5 Byr from today!

SPARE CHARTS



SuperMassive BlackHole mass vs. Galaxy Bulge Mass

(For elliptical galaxies only)

0.5% of total galaxy mass makes it into SMBH!

SMBH=cosmic garbage disposal: Messy leftover of galaxy formation!

(Kormendy & Ho, 2013 An Rev A&Ap 51, 511)

Active Galactic Nuclei: powered by supermassive blackholes (10^6–10^{10} M_{sun})

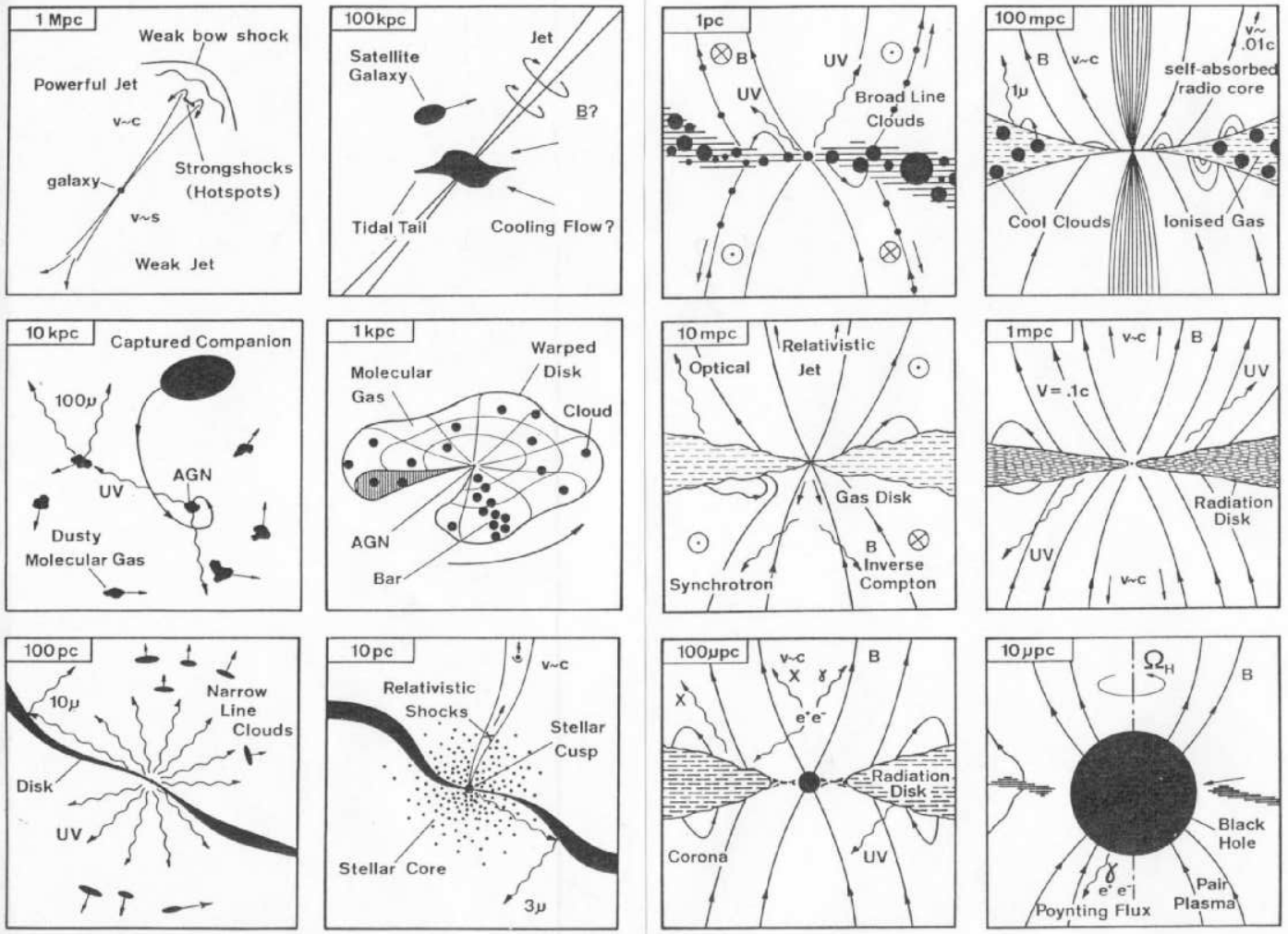


Fig. 7.1. Montage of scales exhibiting some effects of accretion onto a black hole over 12 successive decades of radius ranging from ~ 1Mpc to $\sim 3\times10^{13}$cm. This is scaled to a black hole of mass $\sim 10^8 M_\odot$. We comment upon the individual frames in the text.

Blackhole affects surroundings over 10^{12} in size: from AU to 6 Mlyr:

or from General Relativistic Singularity (AU) to Relativistic Jets (Mlyr).

If jet shines in face $\Rightarrow$ Quasars: $\lesssim 10^{15} L_\odot$ coming from several AU!