



Black Holes at Work

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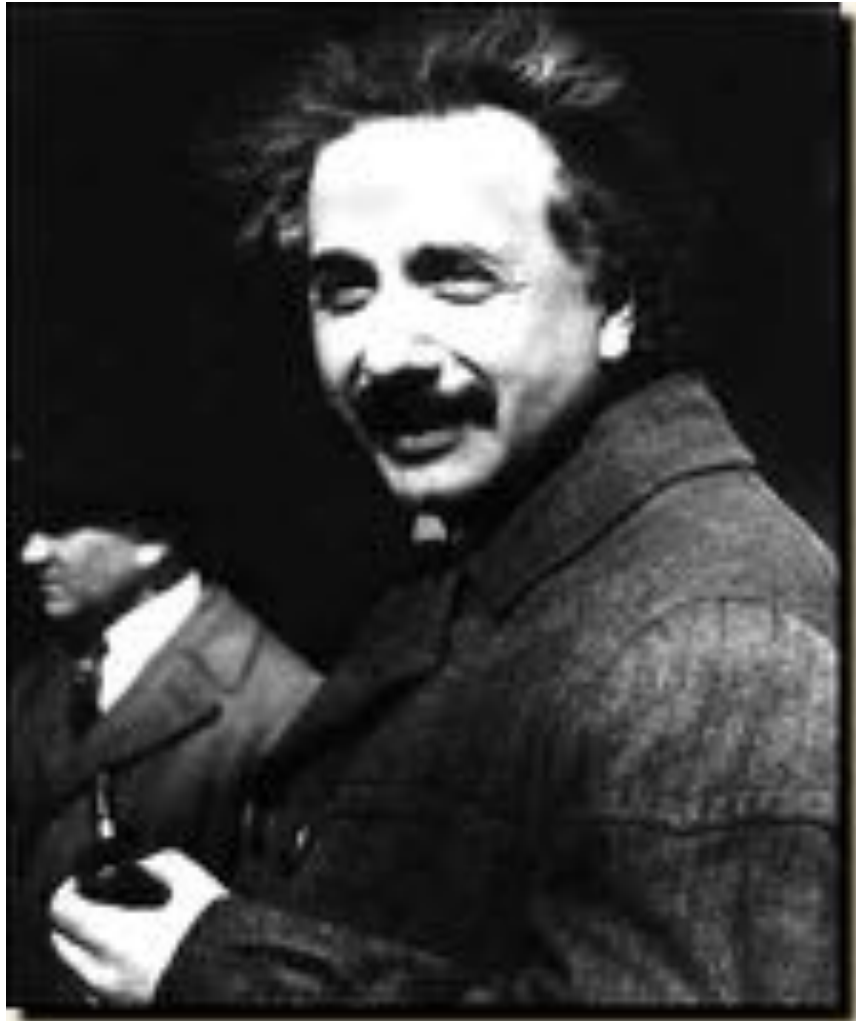


European Research Council
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JOHN MICHELL ~1784

- SUN' s escape velocity is 600 km/s
- Velocity of light is 300,000 km/s
- Escape velocity from 10^8 Suns stacked together = velocity of light
- HOW COULD WE SEE SUCH A “DARK STAR”?
- By influence on neighbouring stars

ALBERT EINSTEIN



Zürich 19.8.12

Aus
 Koch geachteter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfeld eine ^{ger. Abl.} Deviation erfahren.

Lichtstrahl

An Sonnensande müsste diese Ablenkung $0,84''$ betragen und wie $\frac{1}{R}$ abnehmen (R = Sonnenradius).

10000

Es wäre deshalb von größter Interesse, bis zu wie grosser Sonnen-^{helle} nahe ^{gerade} Fractions bei Anwendung in stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

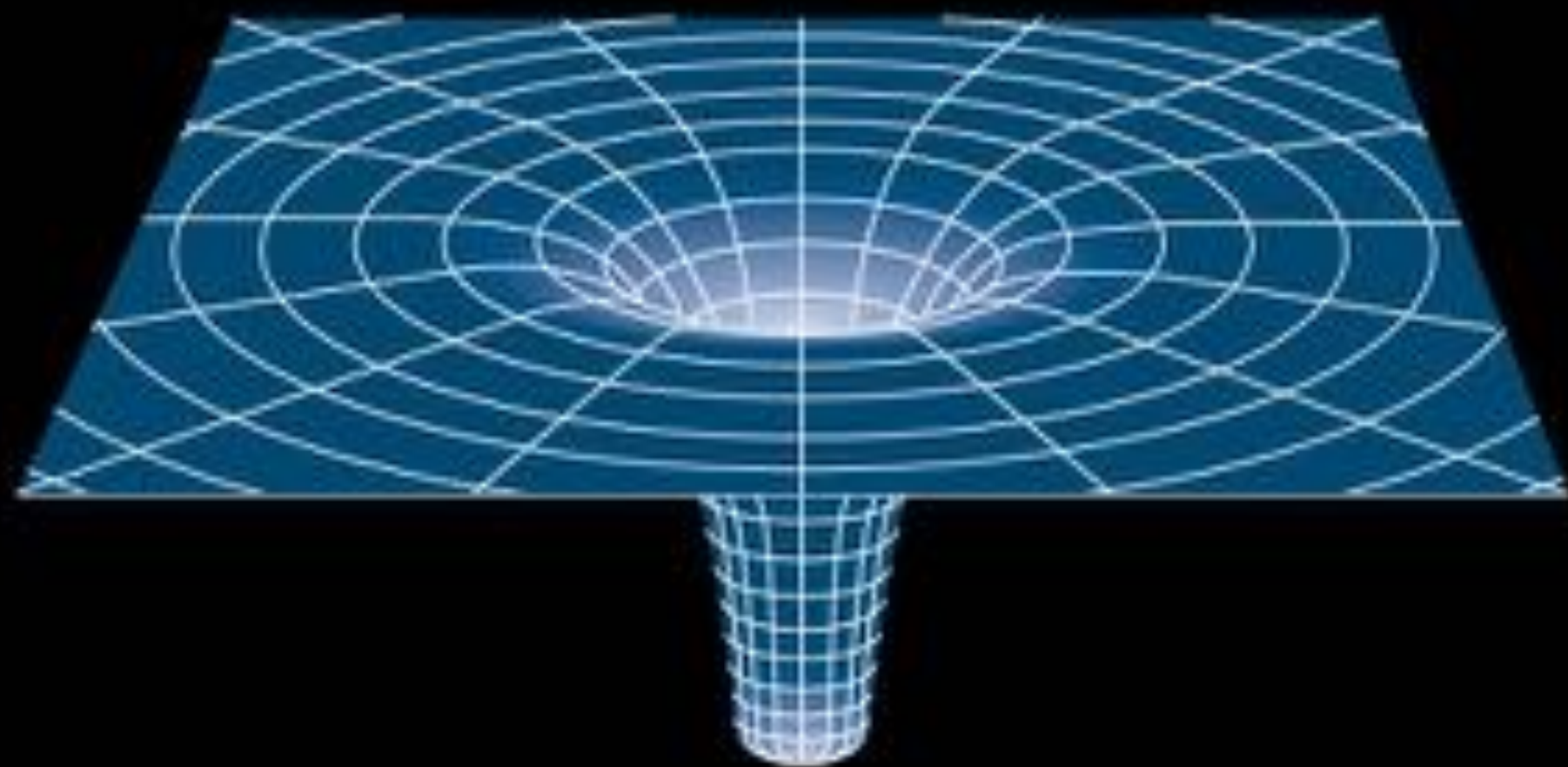
BLACK HOLES



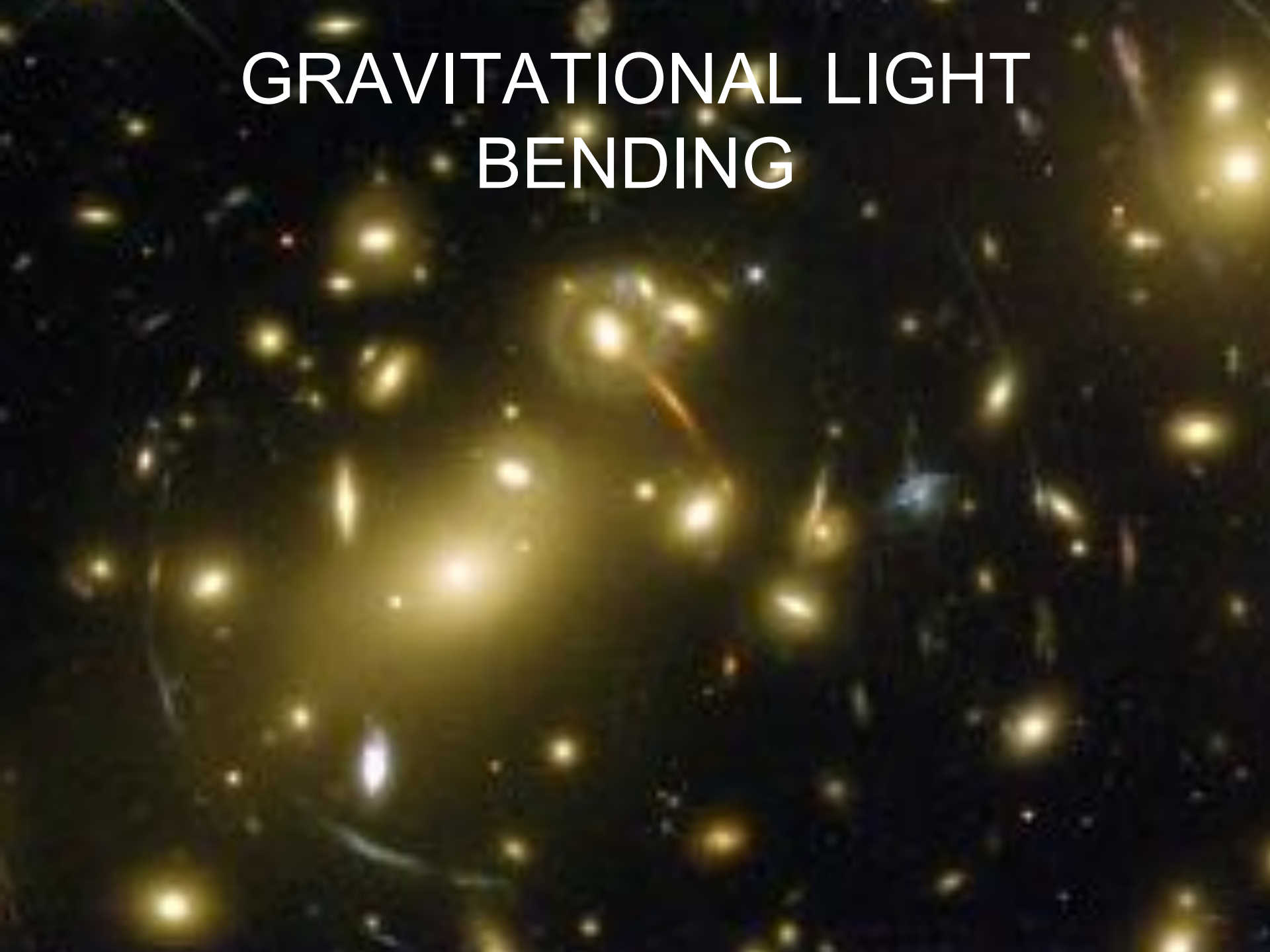
Karl Schwarzschild



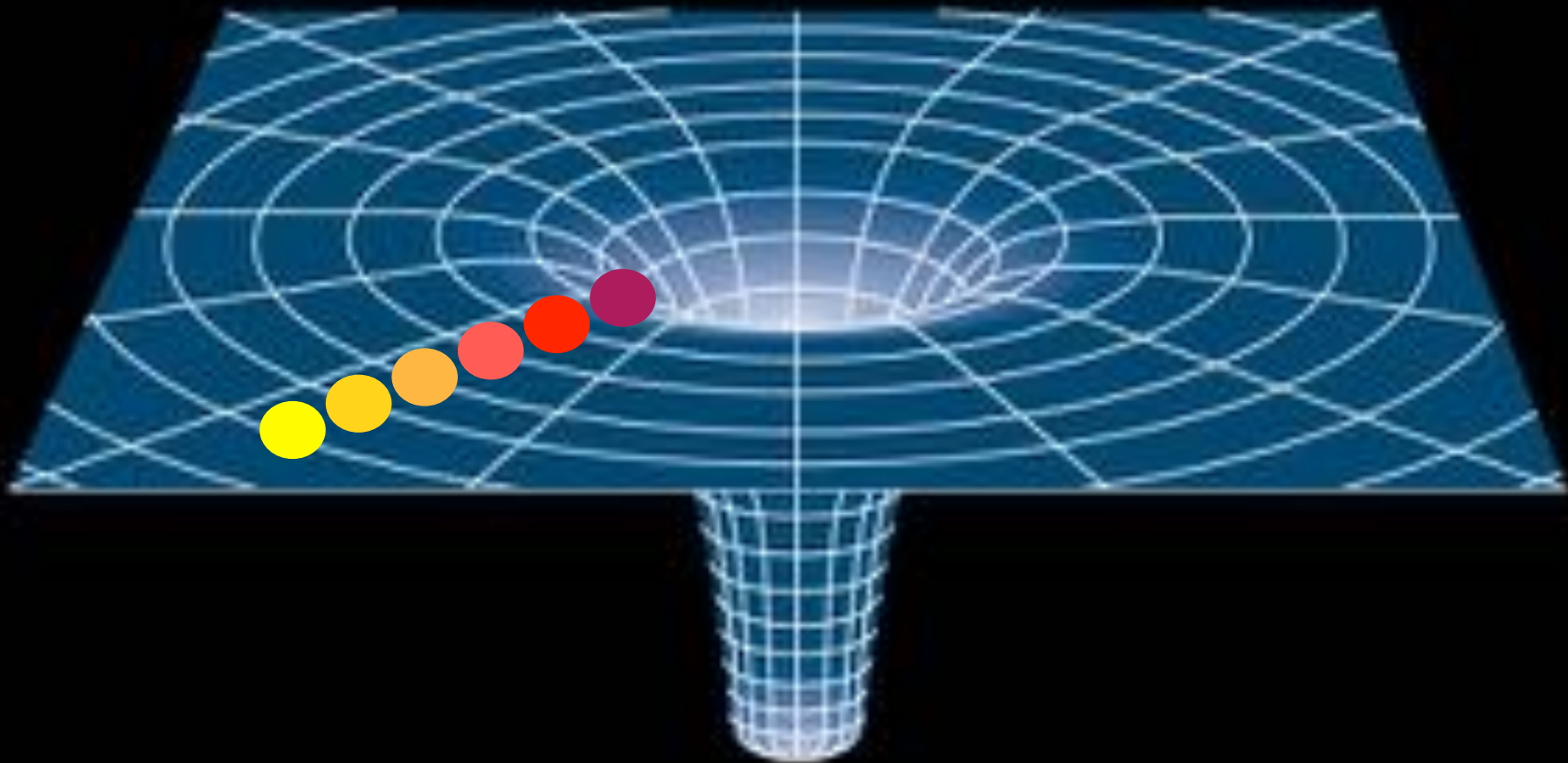
Roy Kerr



GRAVITATIONAL LIGHT BENDING

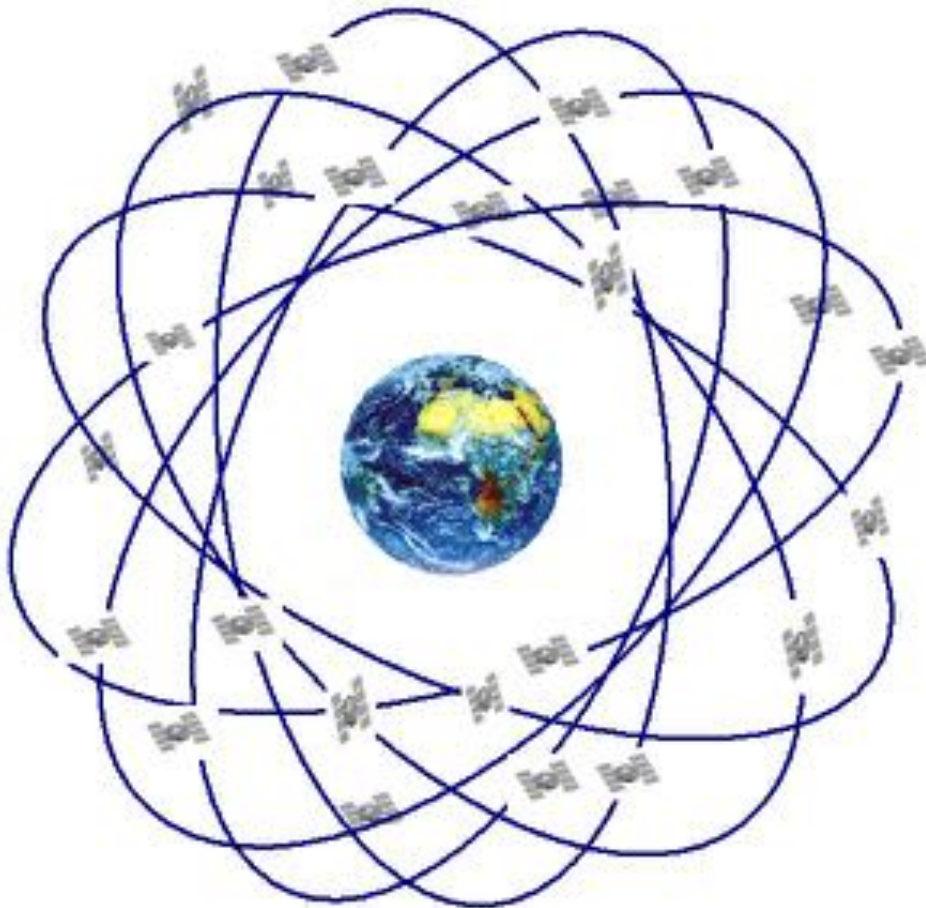






GPS

GR=45microsec/day
(or ~10km/day)



GRAVITATIONAL REDSHIFT

Astrophysical Black Holes have only

MASS and SPIN

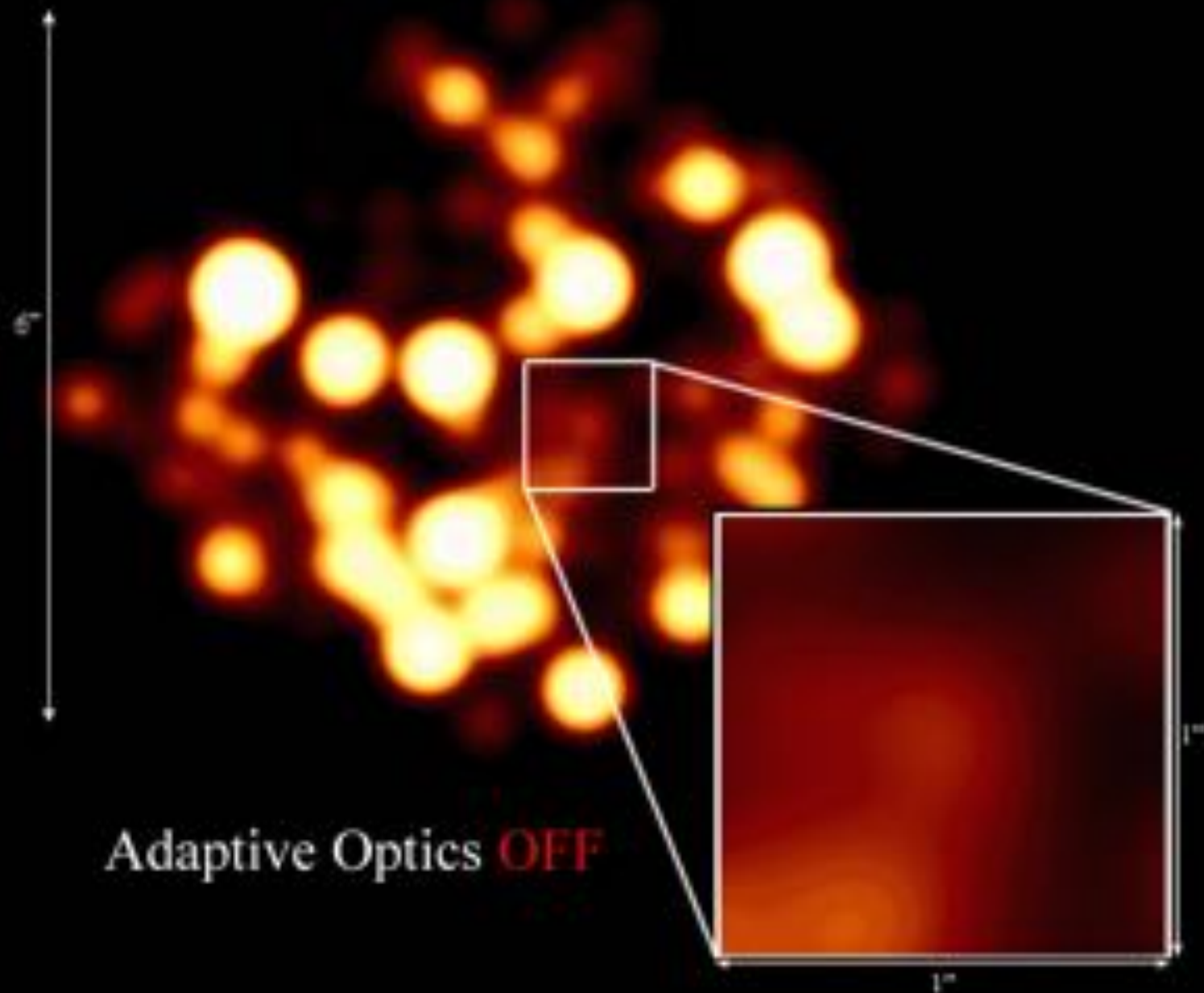
Astrophysical Black Holes have only

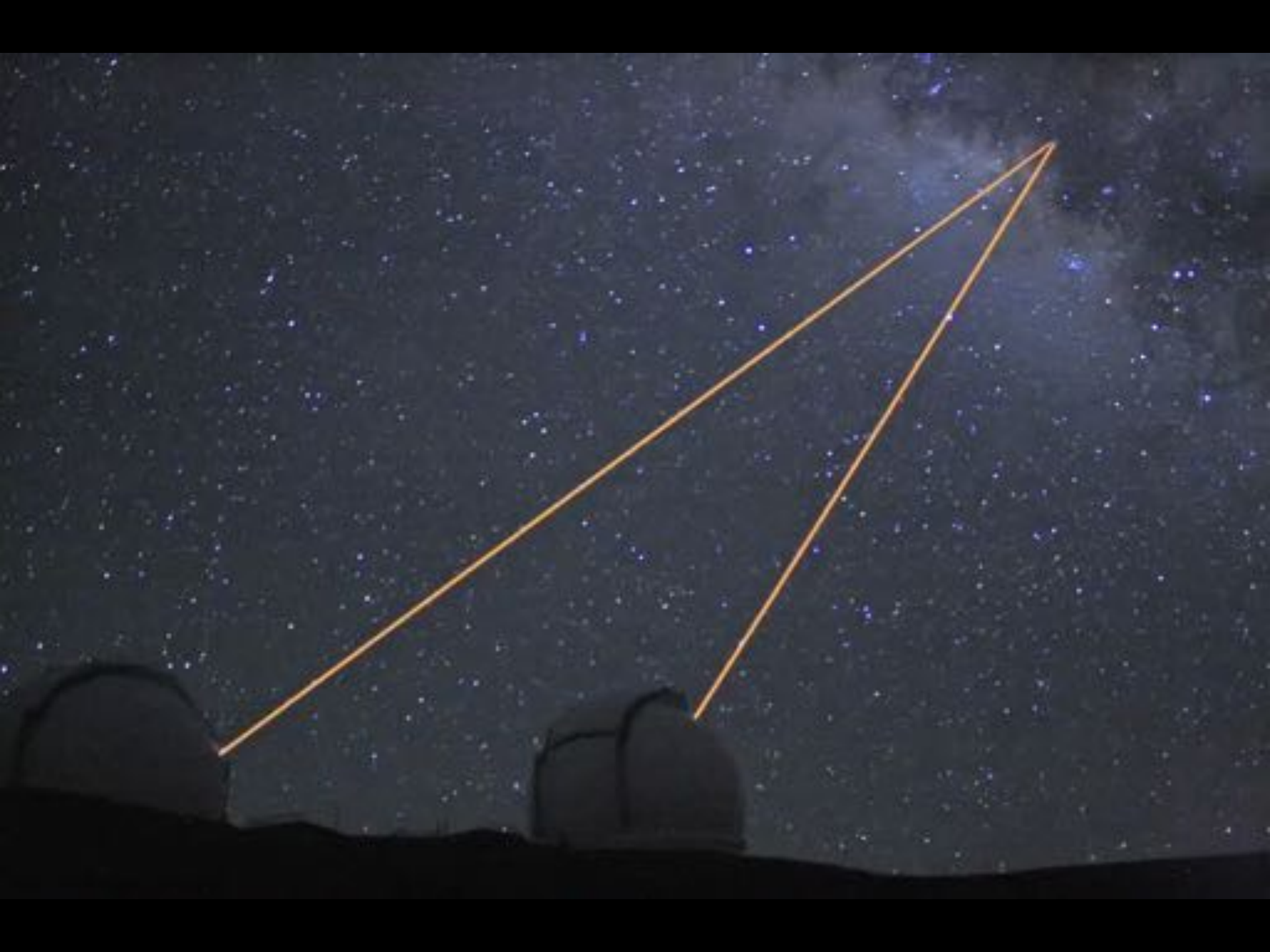
MASS and SPIN

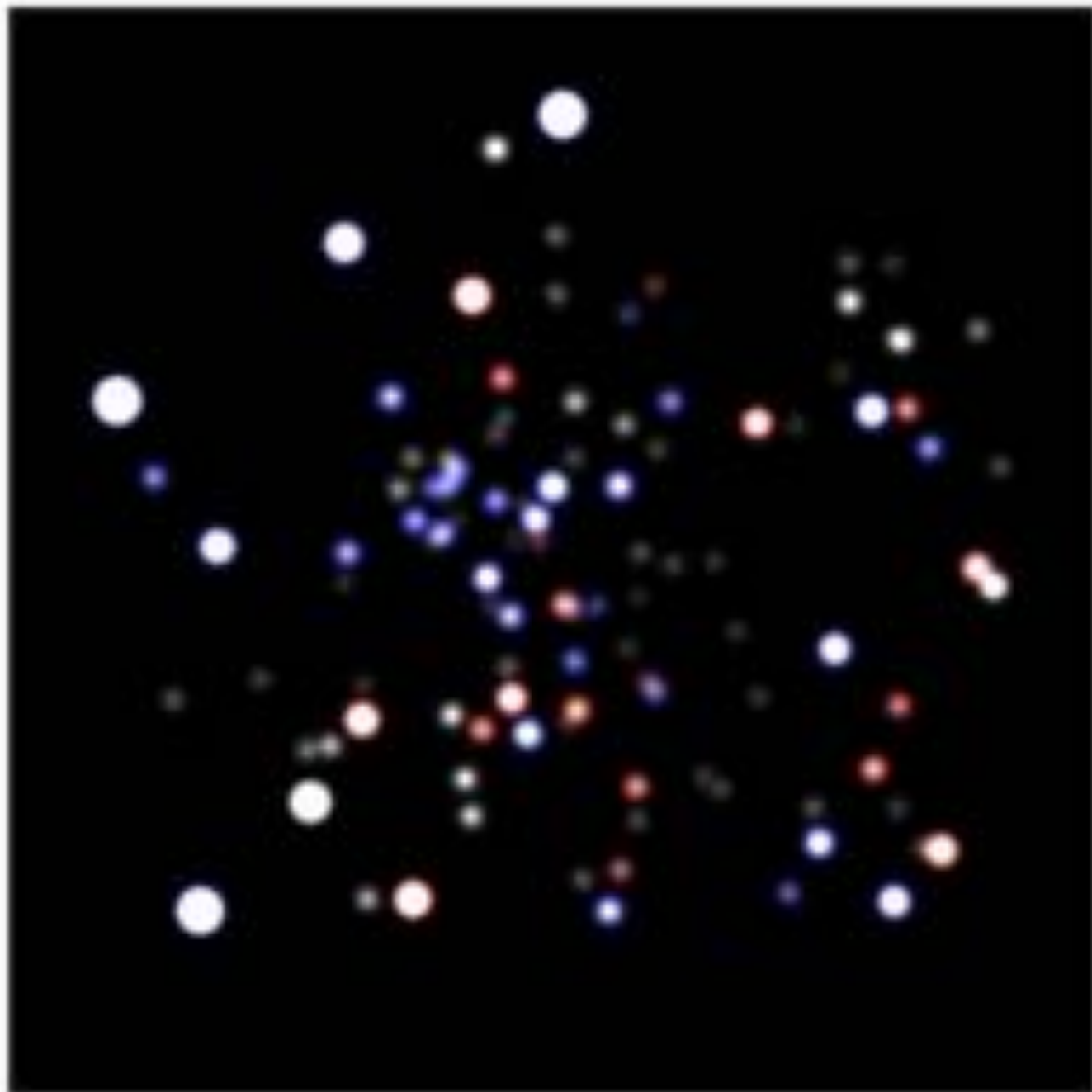
Event horizon radius is 3 km per Solar mass

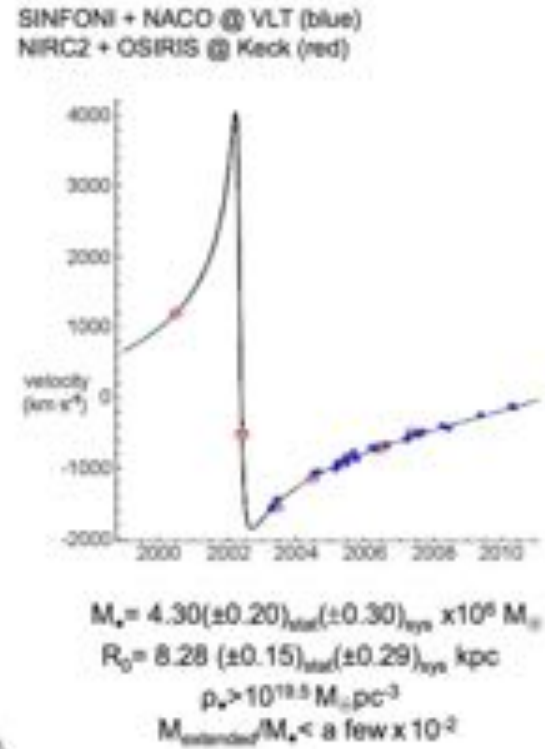
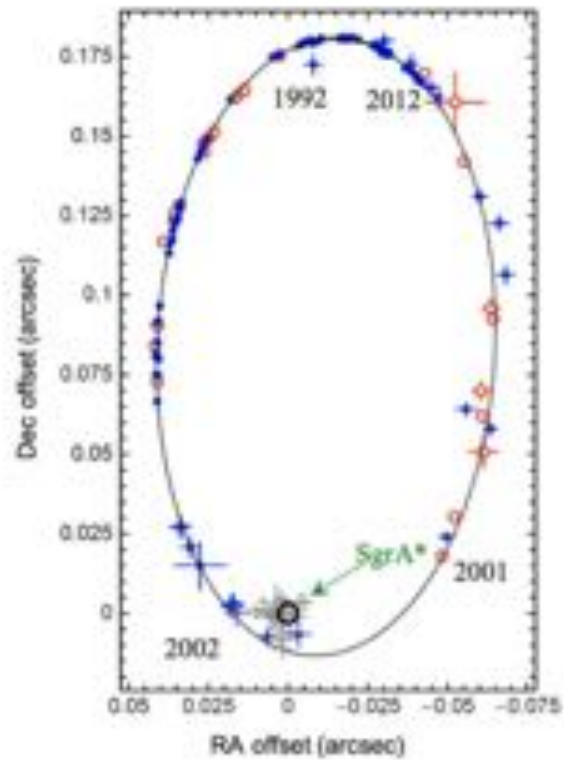
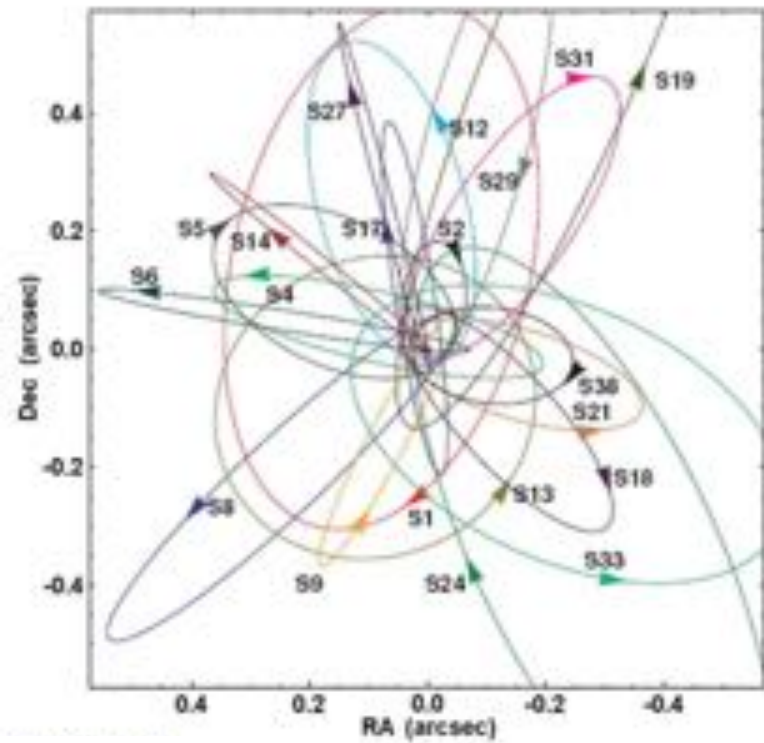


The Galactic Center at 2.2 microns



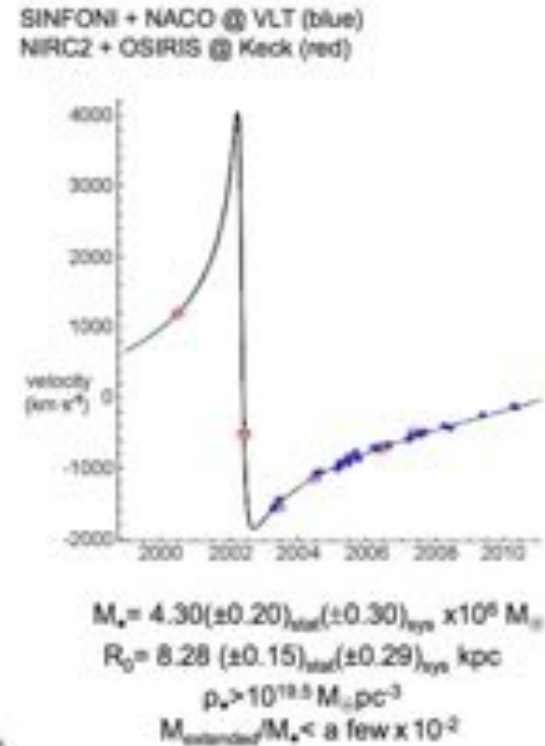
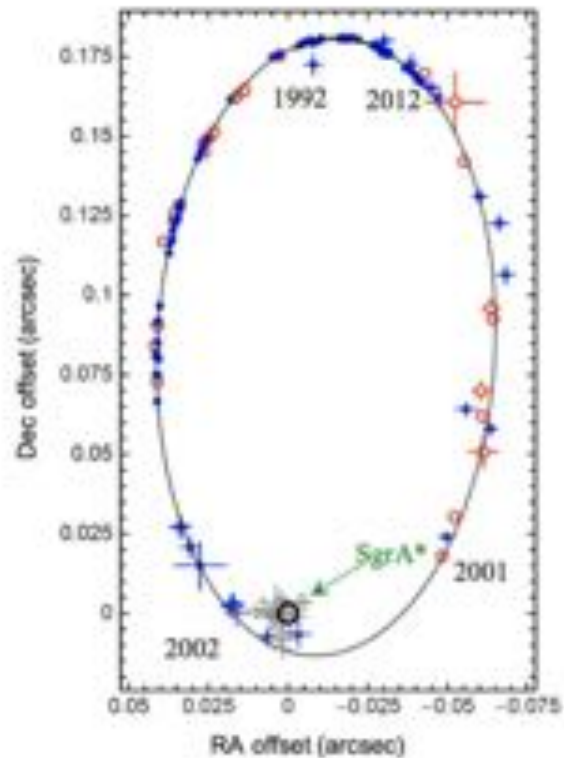
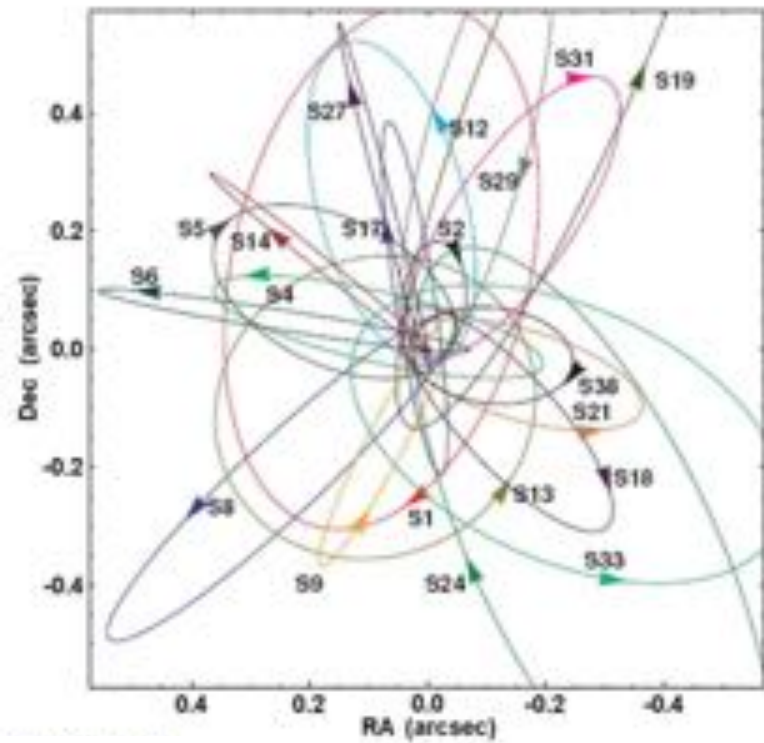






$$M = 4.3 \times 10^6 M_{\text{sun}}$$

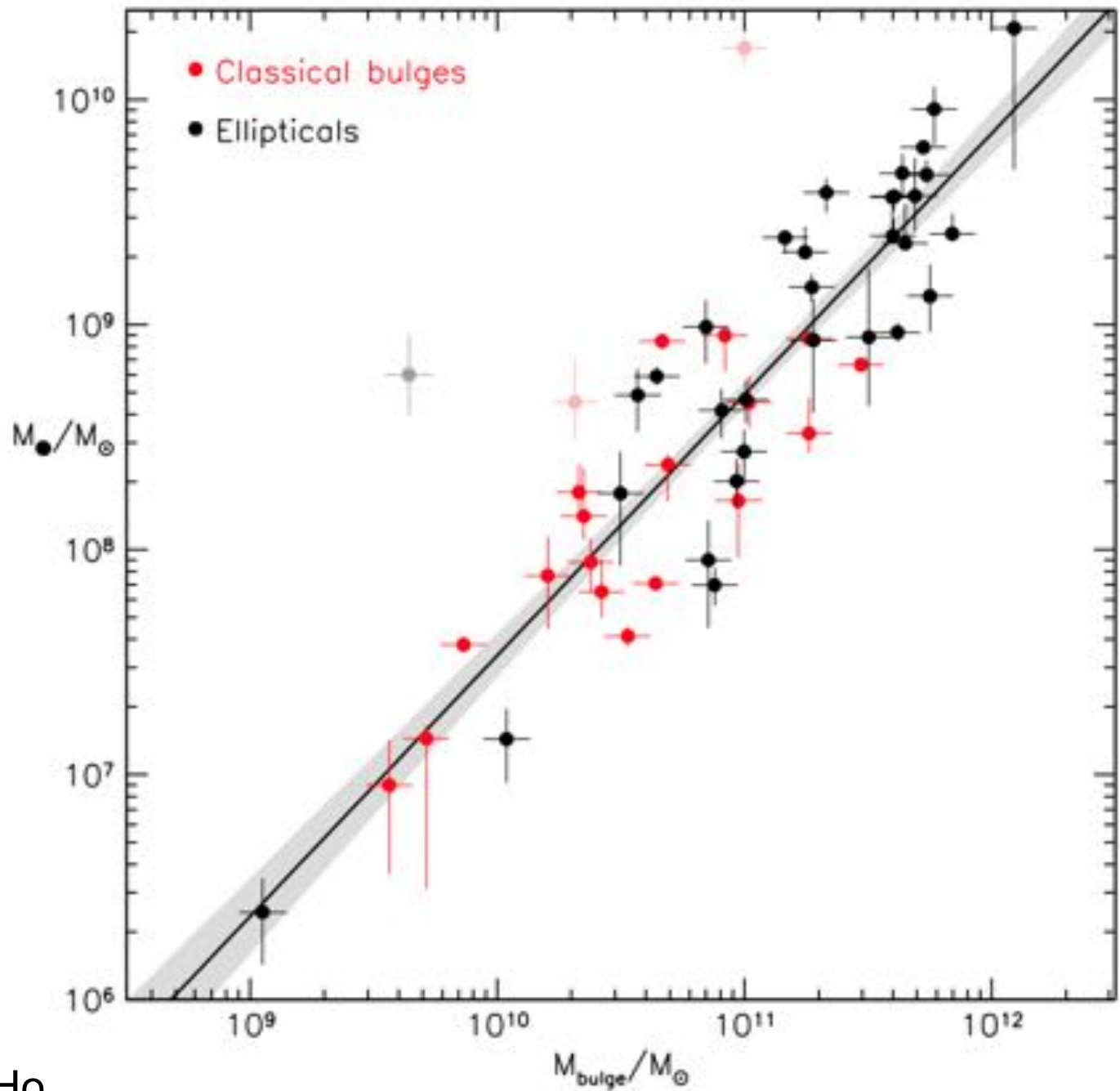
Adapted from Genzel + Ghez by Kormendy+Ho

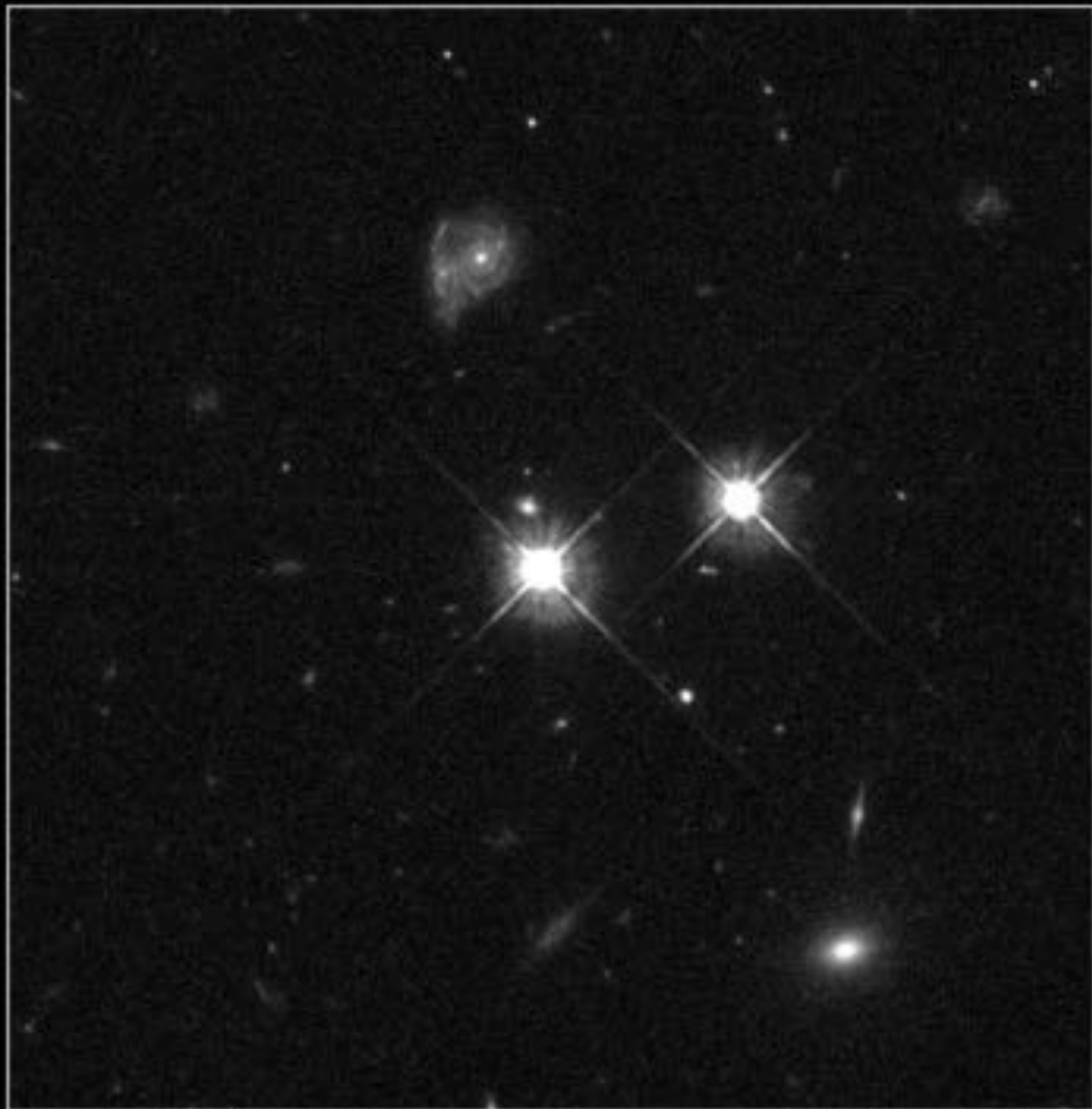


Density $> 10^{19.5} \text{ Sun pc}^{-3}$

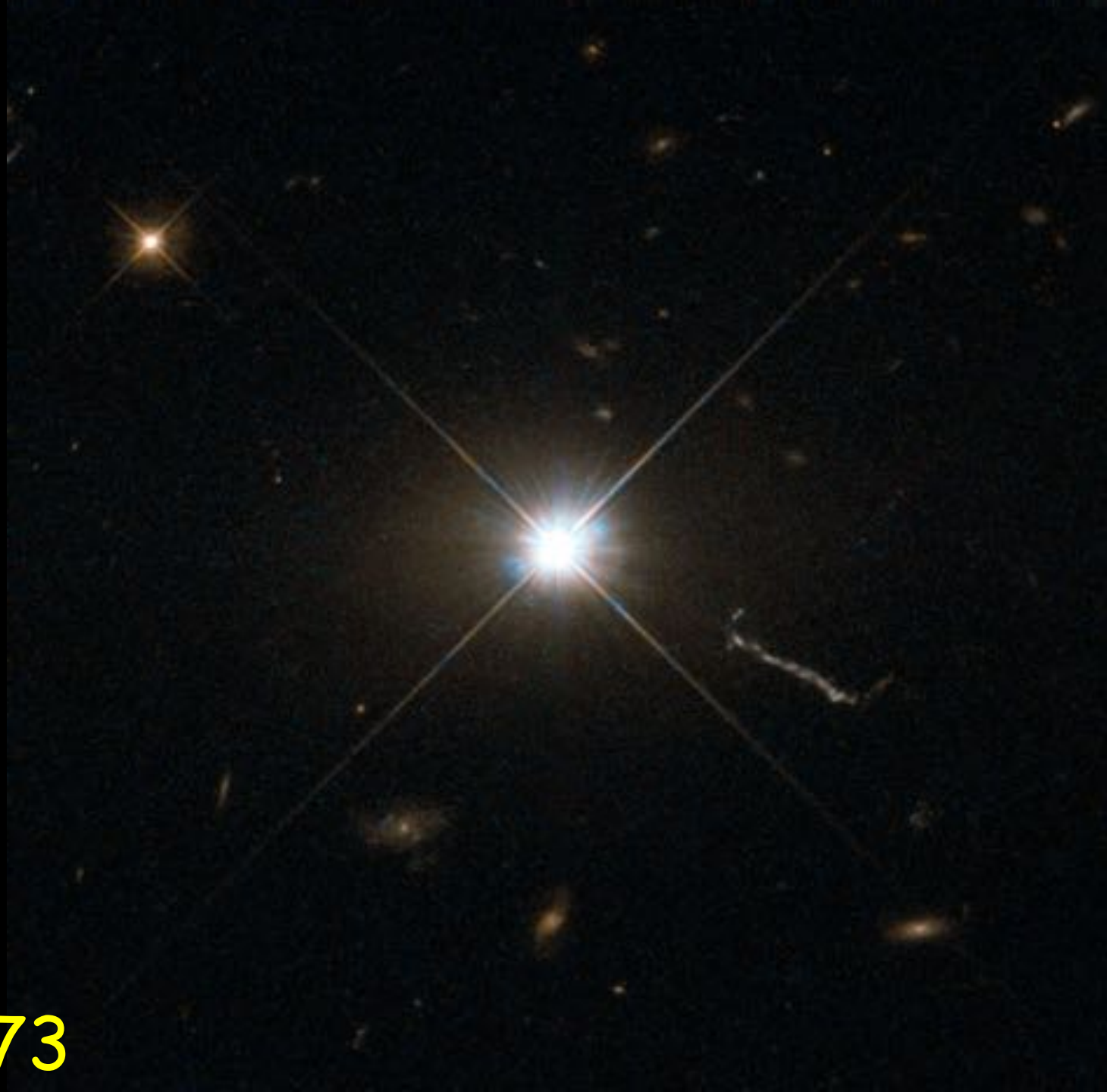
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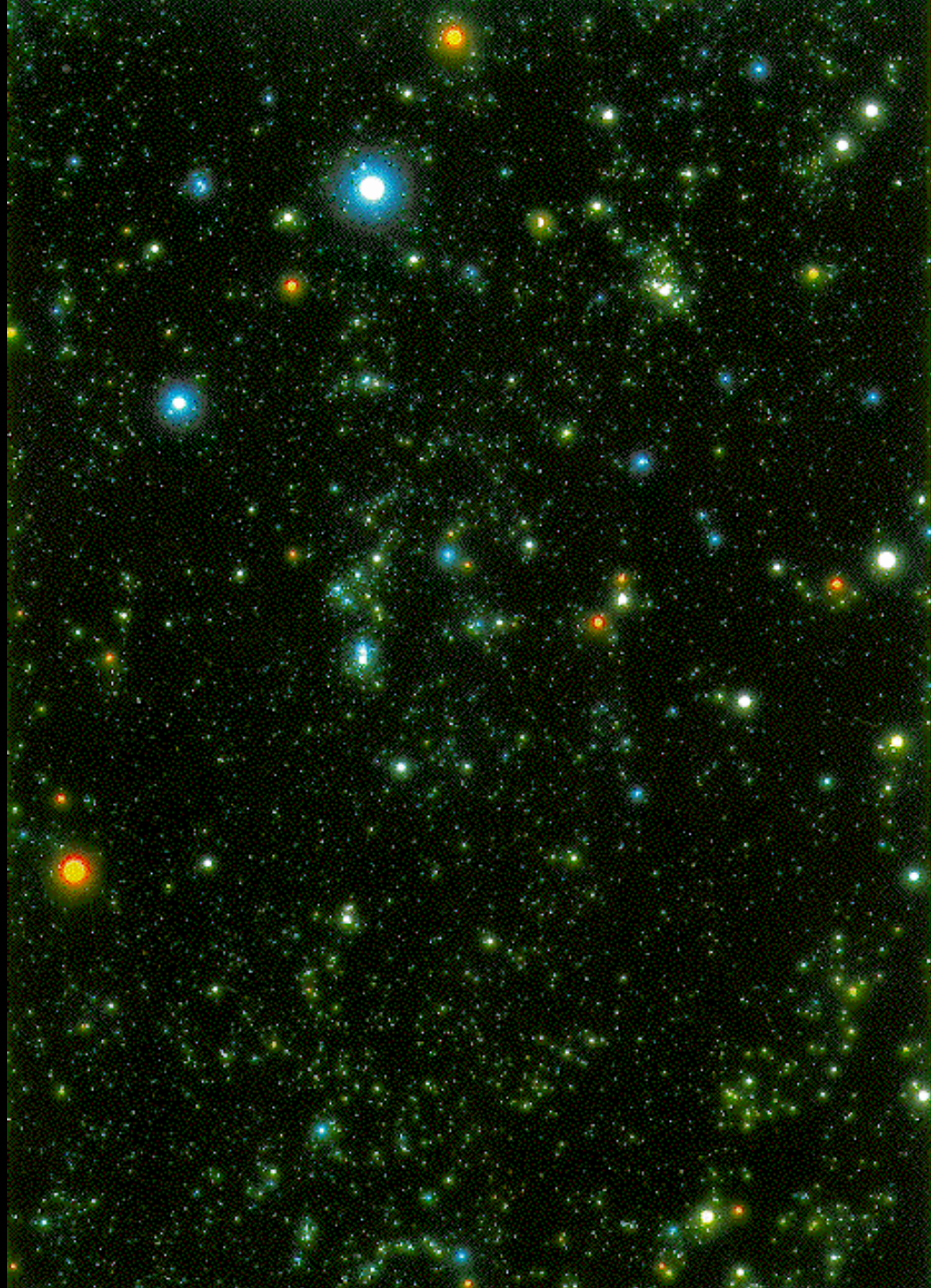






3C273

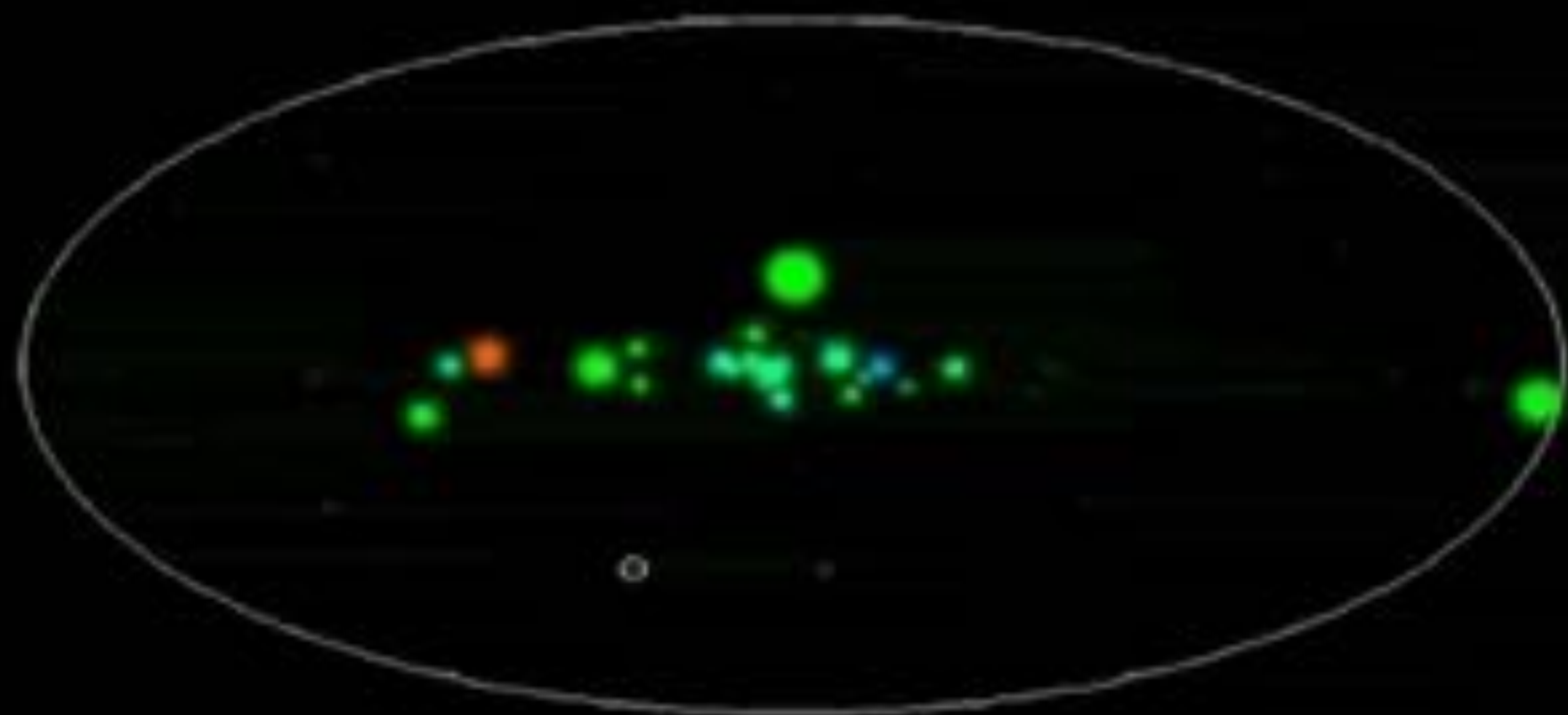




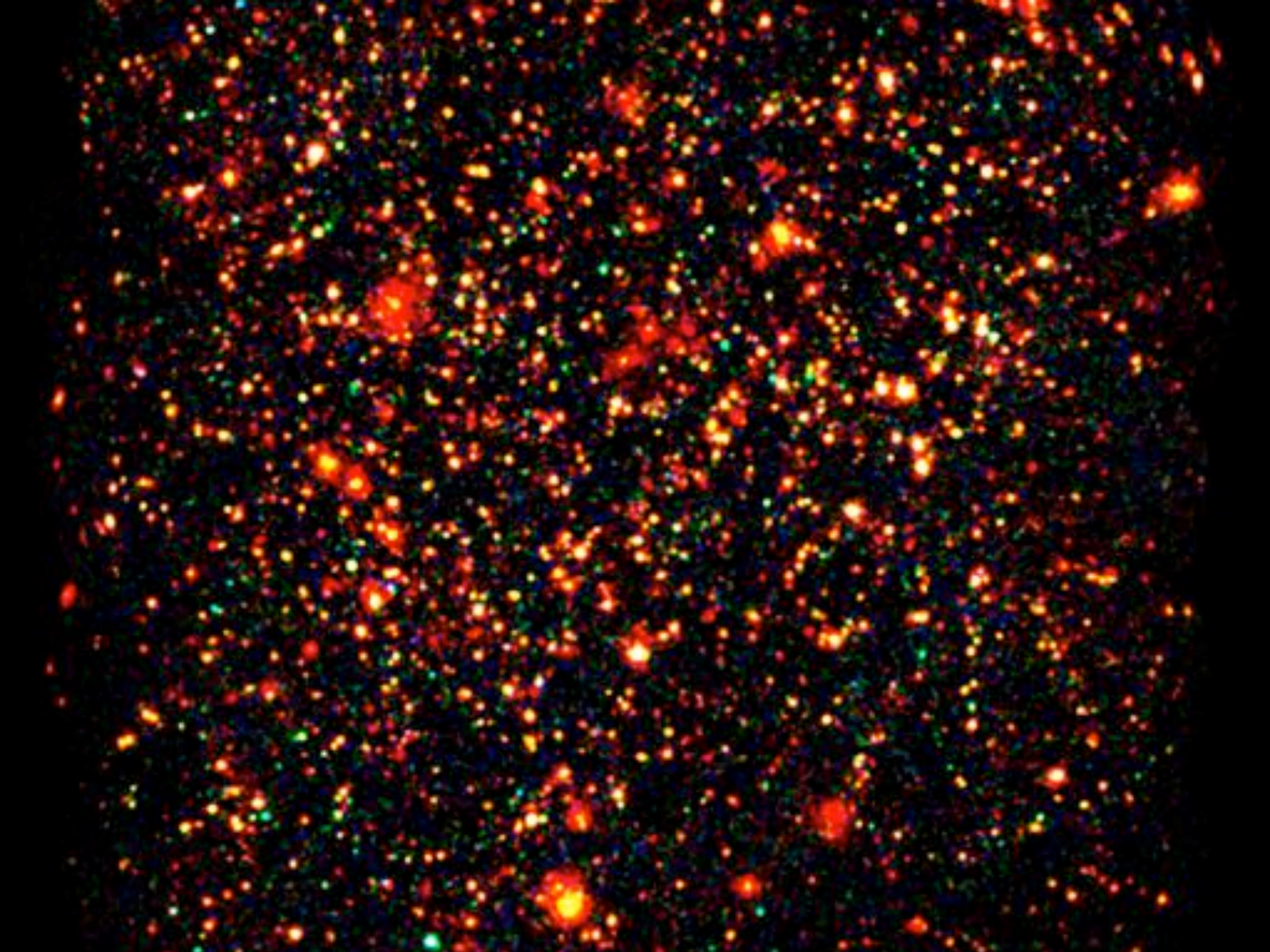
visible

X-rays

The RXTE All-Sky Monitor Movie



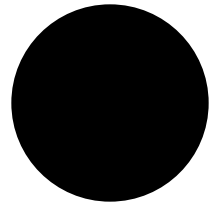
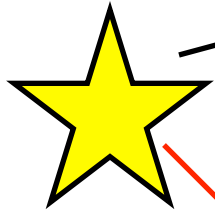
02 / 23 / 2002





Direct Power-law

To observer



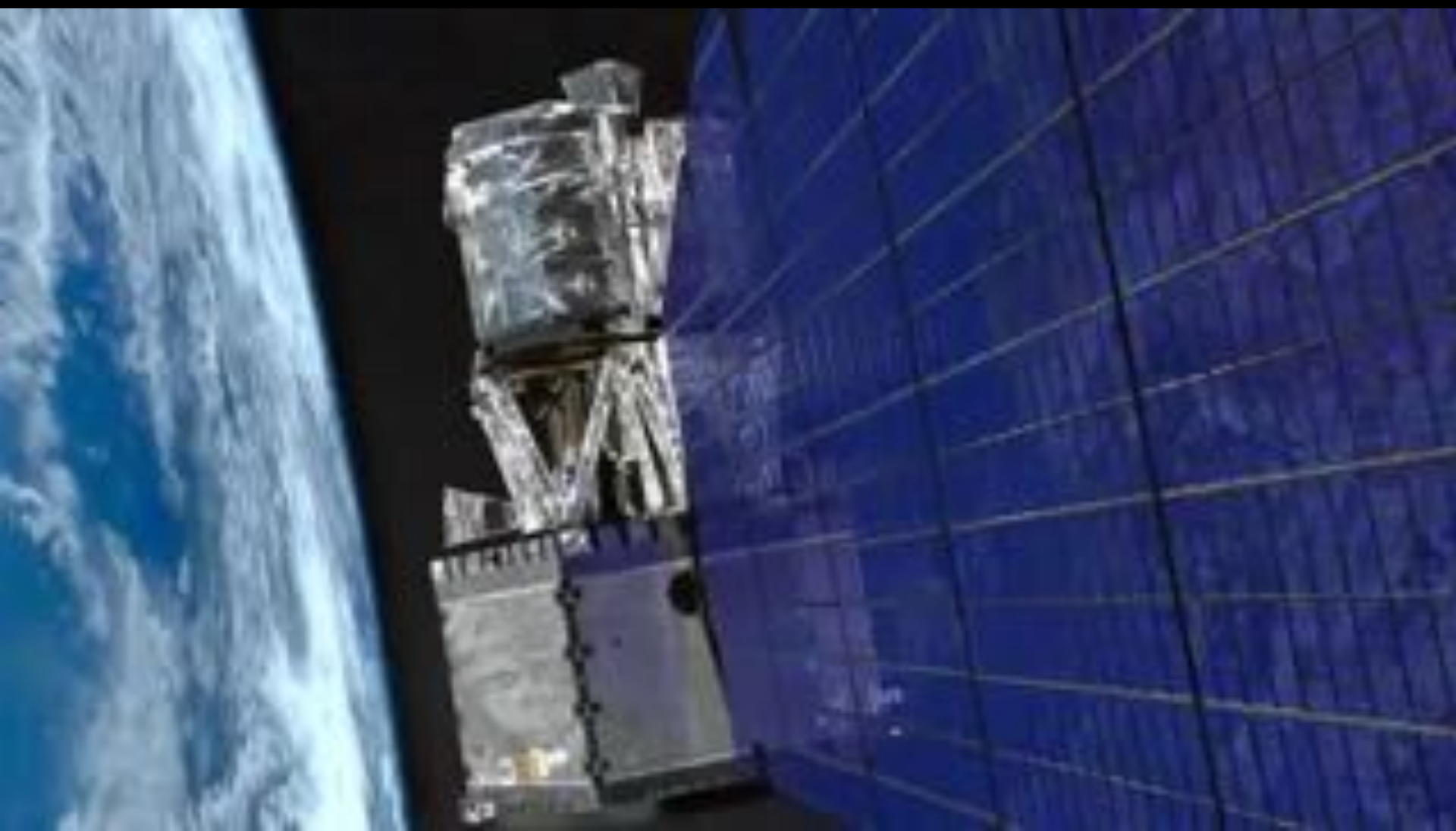
“Reflection” spectrum

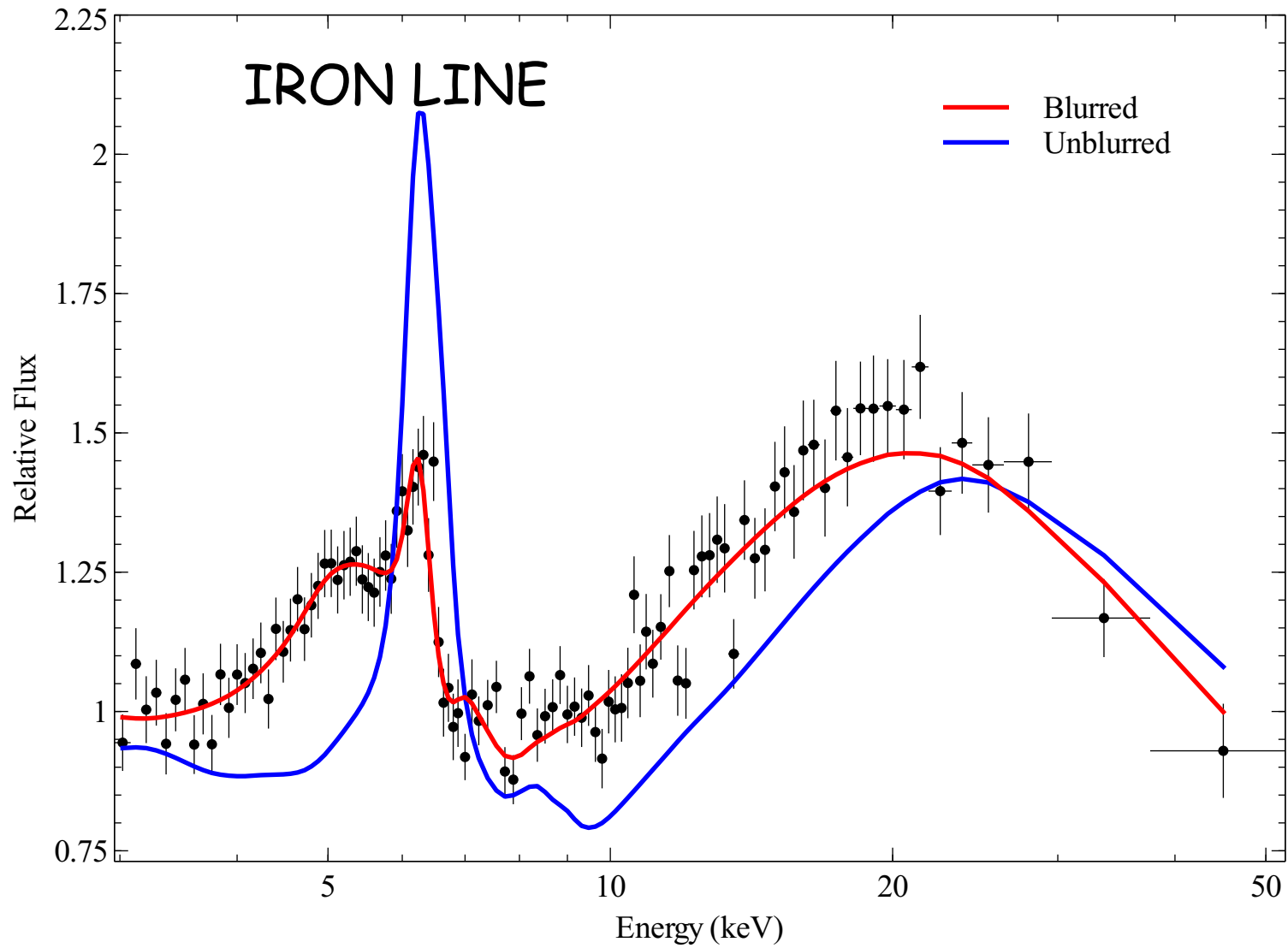
Accretion disc

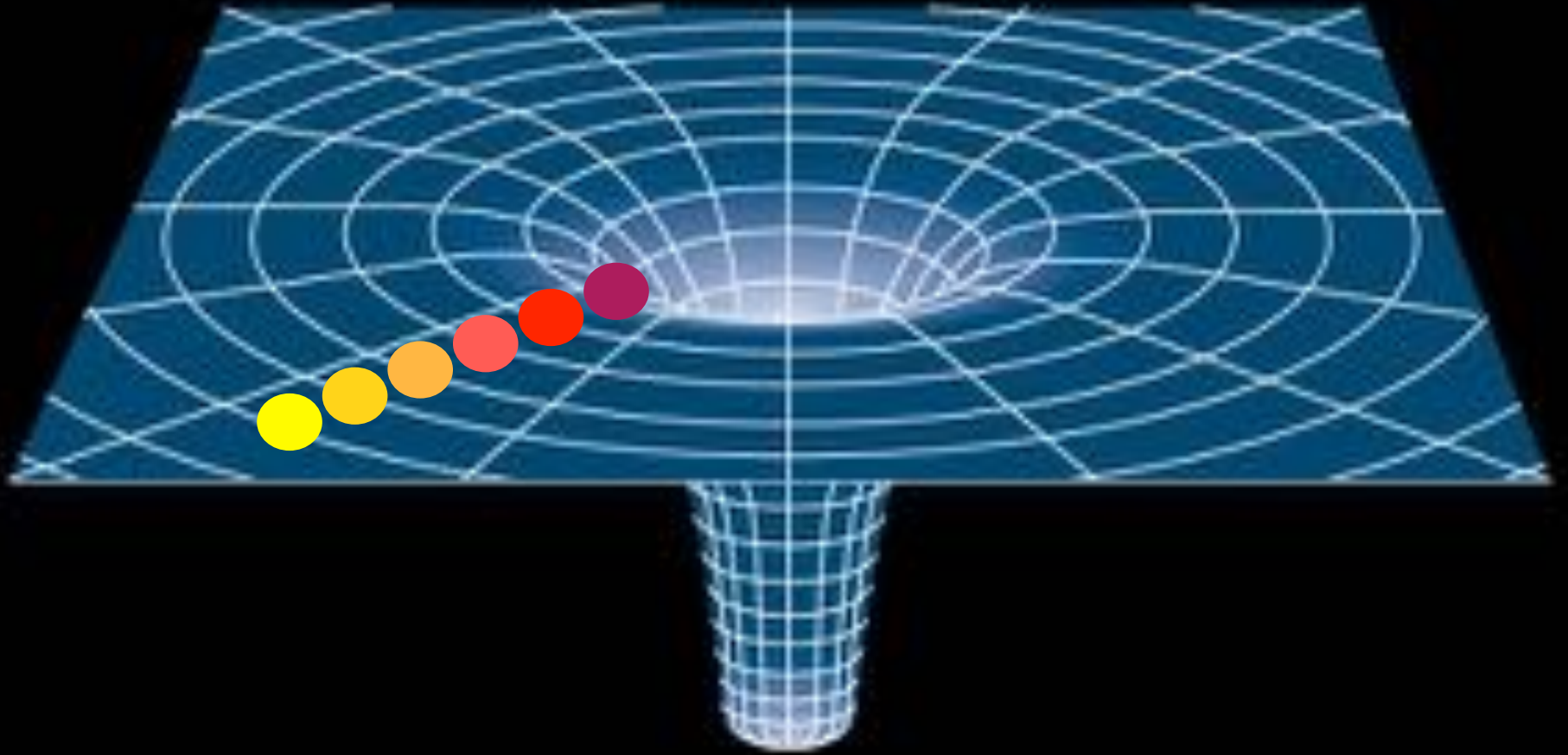


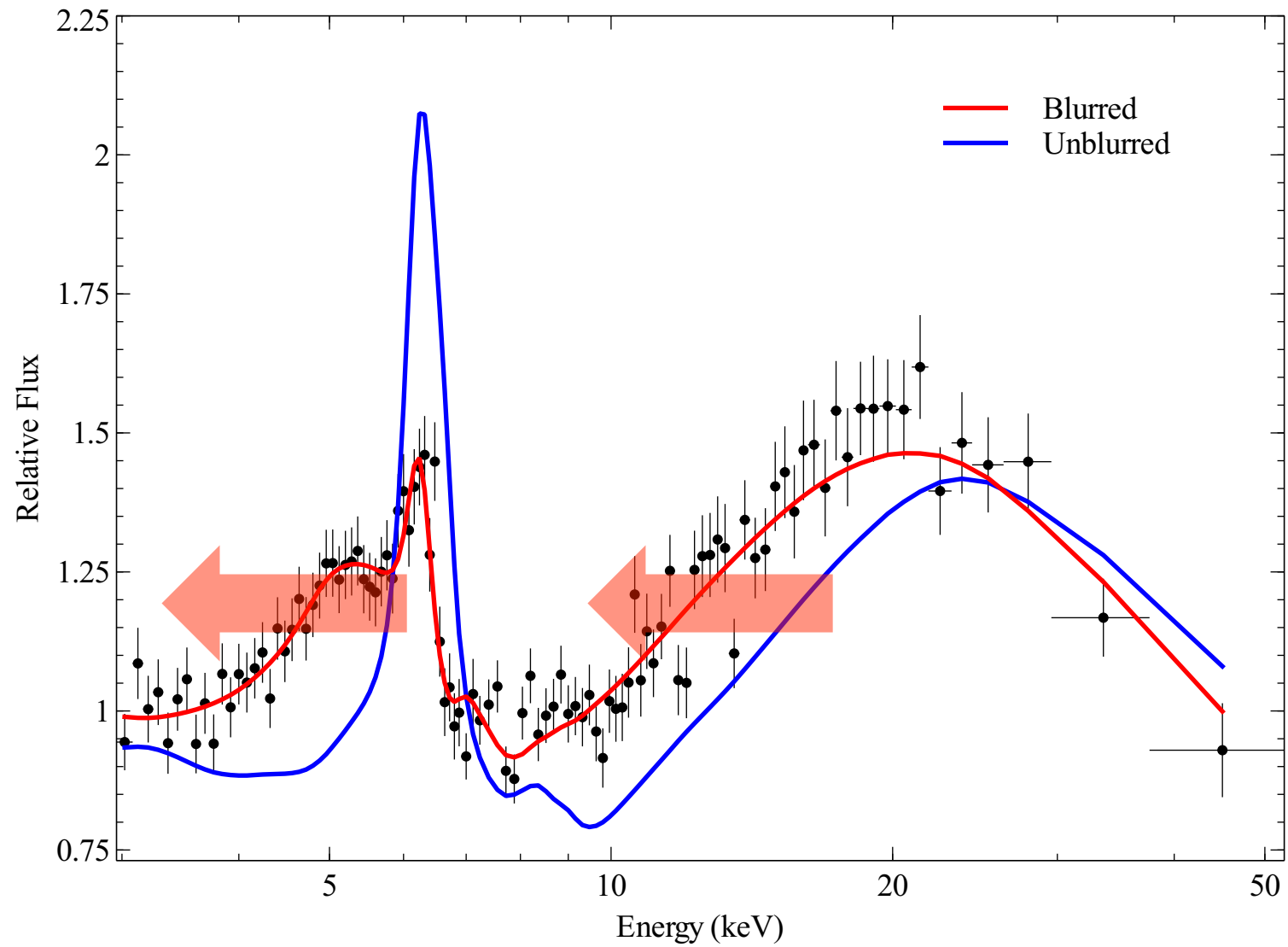
NuSTAR had a Pegasus Launch











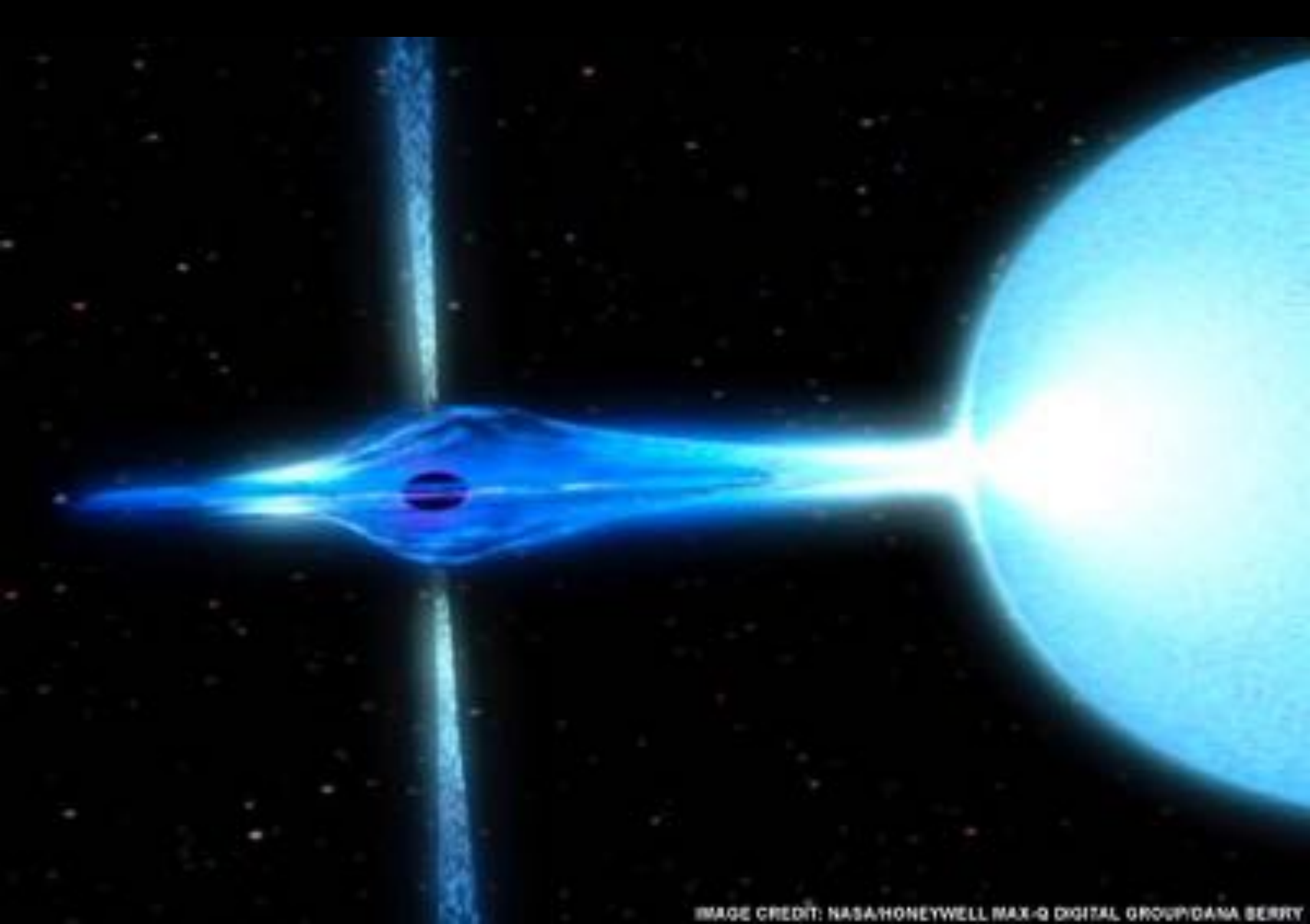
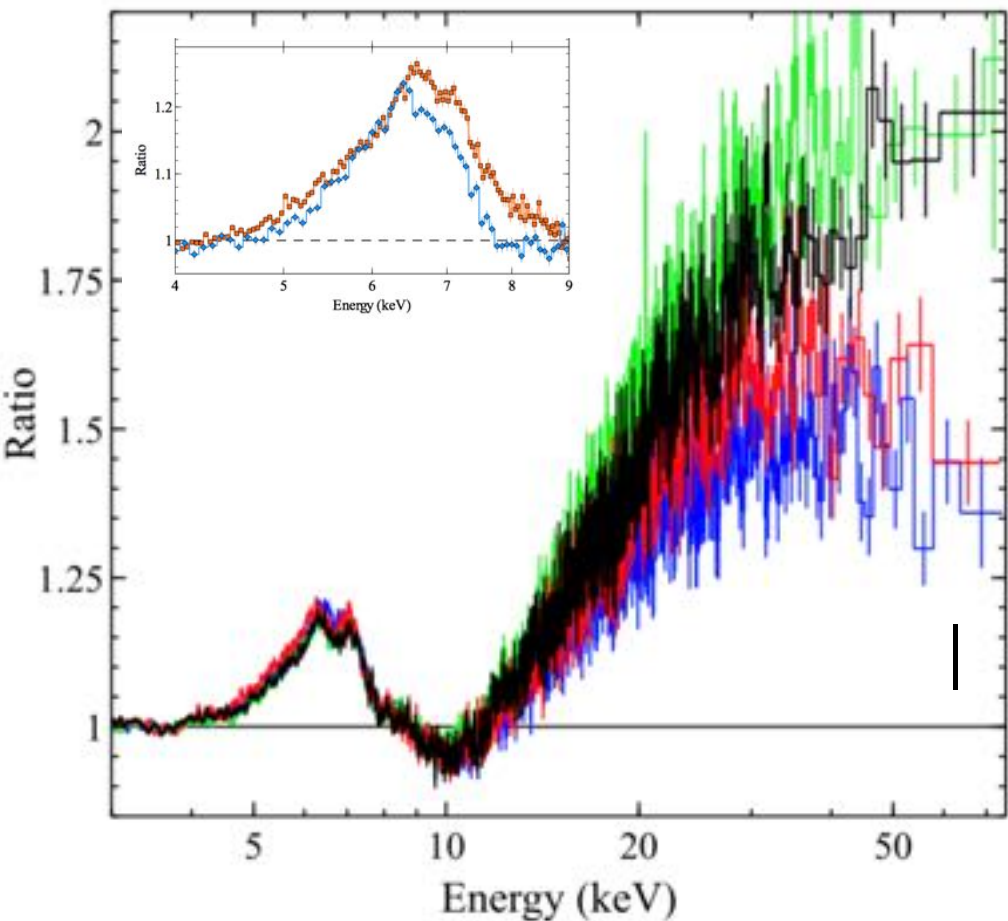


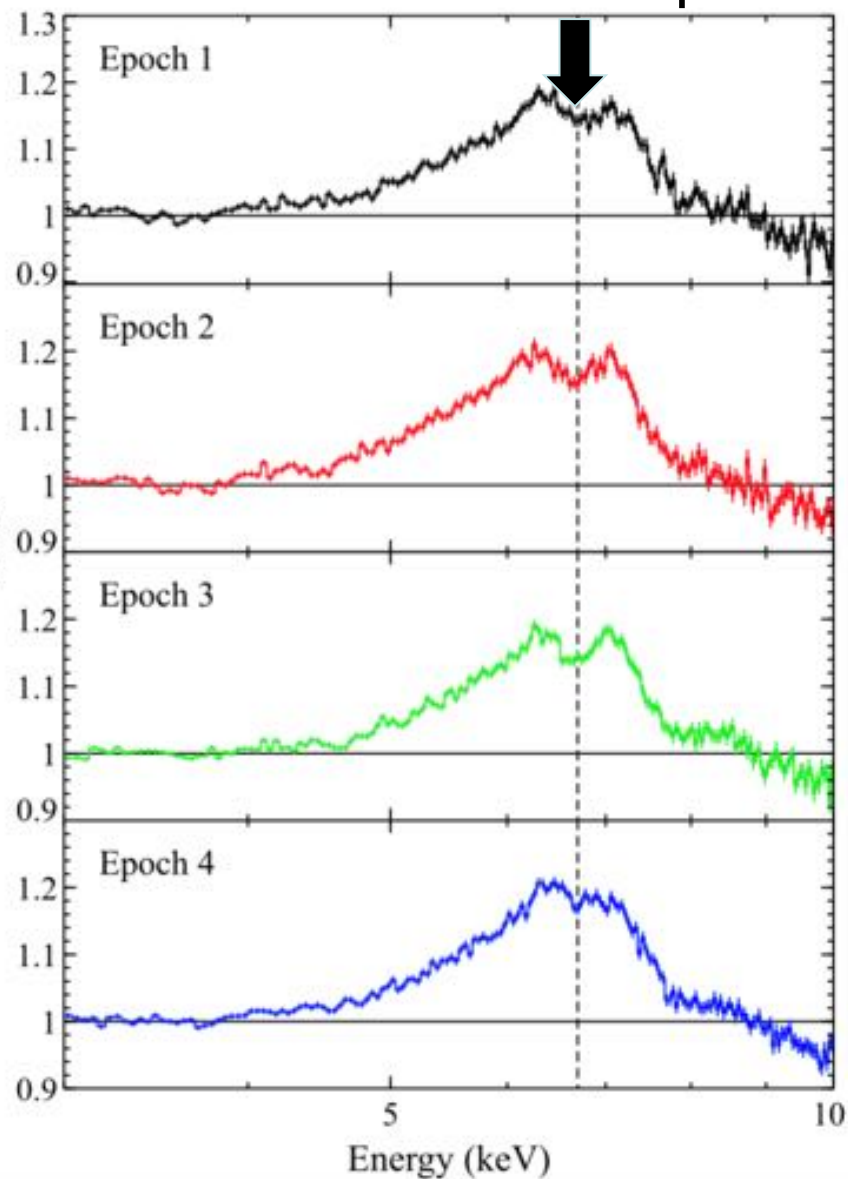
IMAGE CREDIT: NASA/HONEYWELL MAX-Q DIGITAL GROUP/DANA BERRY

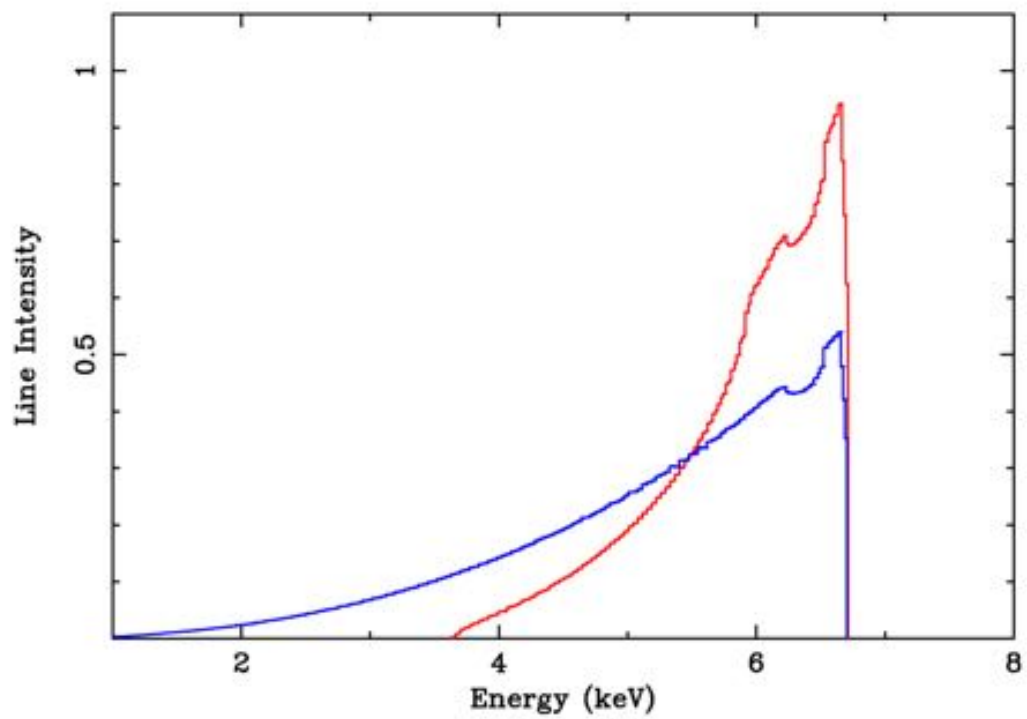
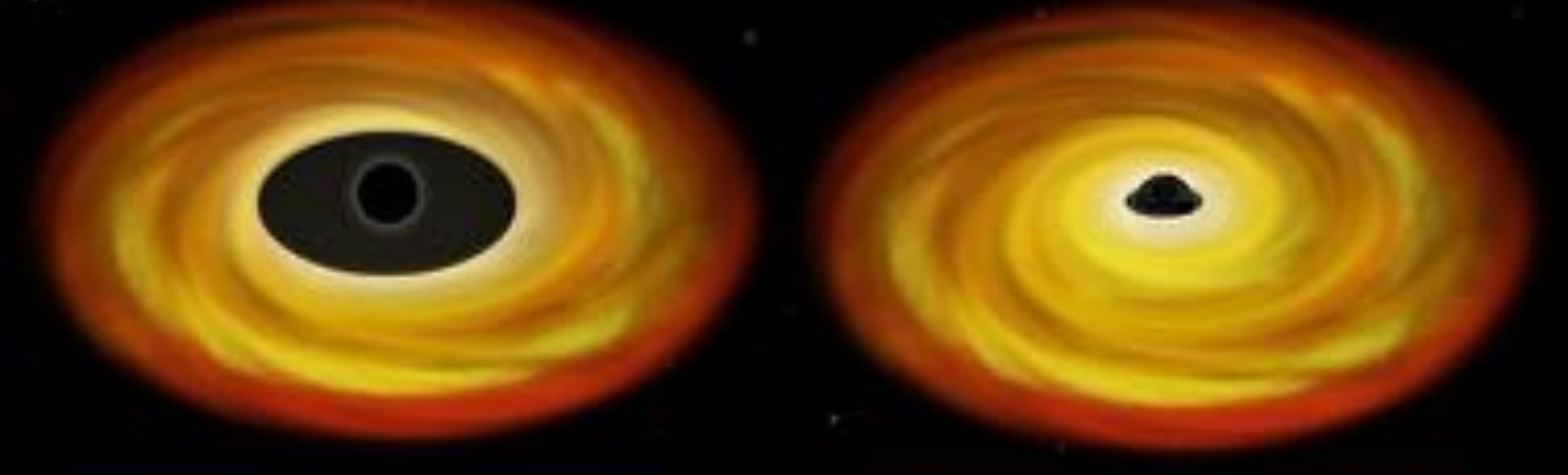


Cygnus X-1 $a > 0.93$

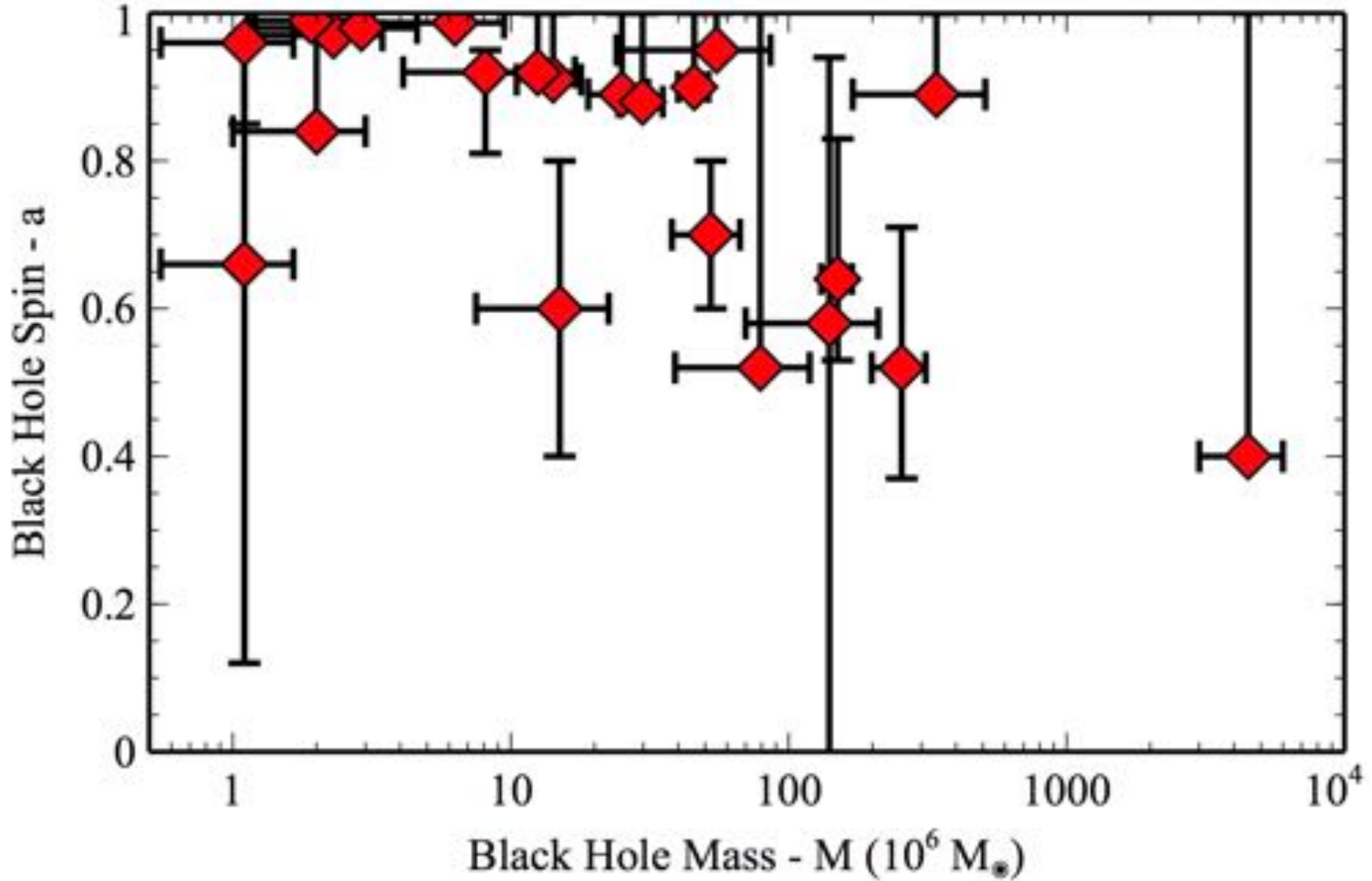
Walton+16, Parker+15

Wind absorption





Black Hole Spin from Reflection Spectrum



Black Hole Feedback

$$E = 5 \times 10^{-11} Mc^2$$

Petrol

100 million

$$E = 0.005 Mc^2$$

Nuclear fusion

20

$$E = 0.1 Mc^2$$

Black Hole Accretion

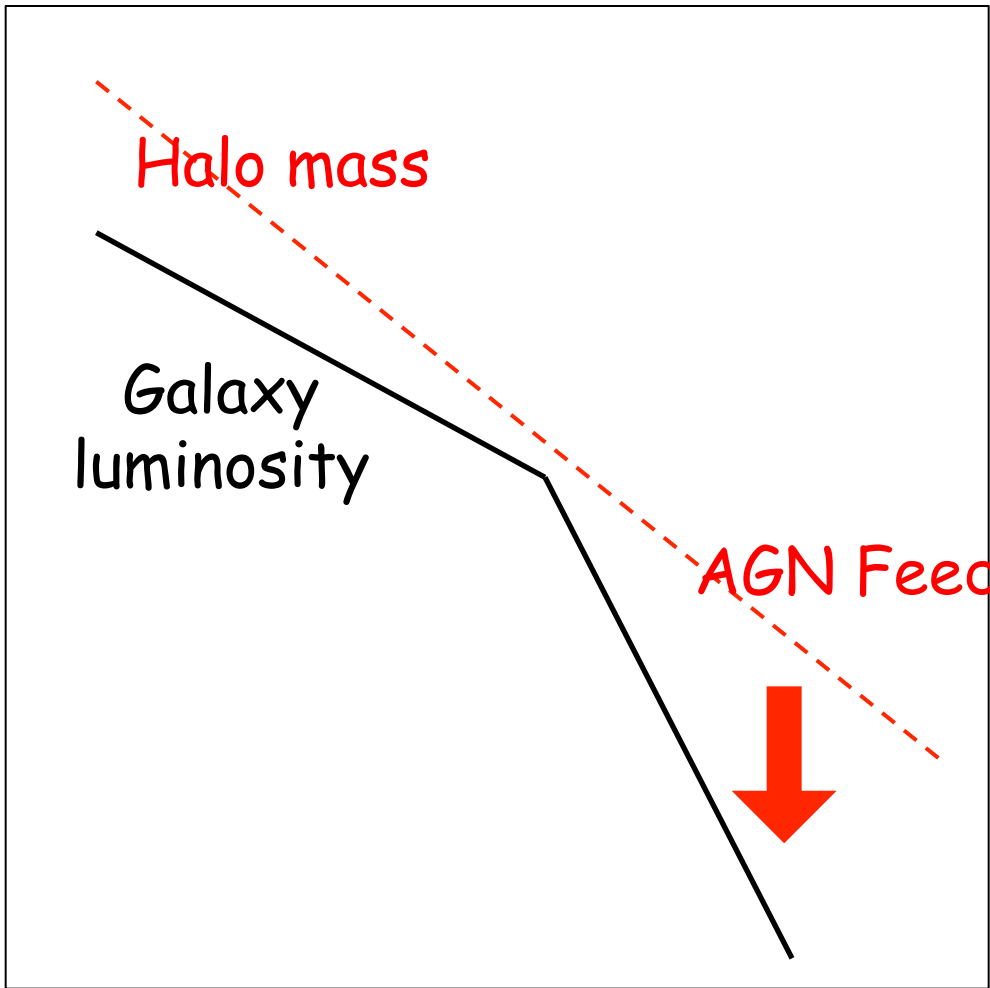
Possible effect of central black hole on galaxy

$$E_{BlackHole} > 100 \times E_{Galaxy}$$

↑
Energy released by
growth of Black Hole

↑
Gravitational Binding
Energy of Host Galaxy

log
Number density
of galaxies

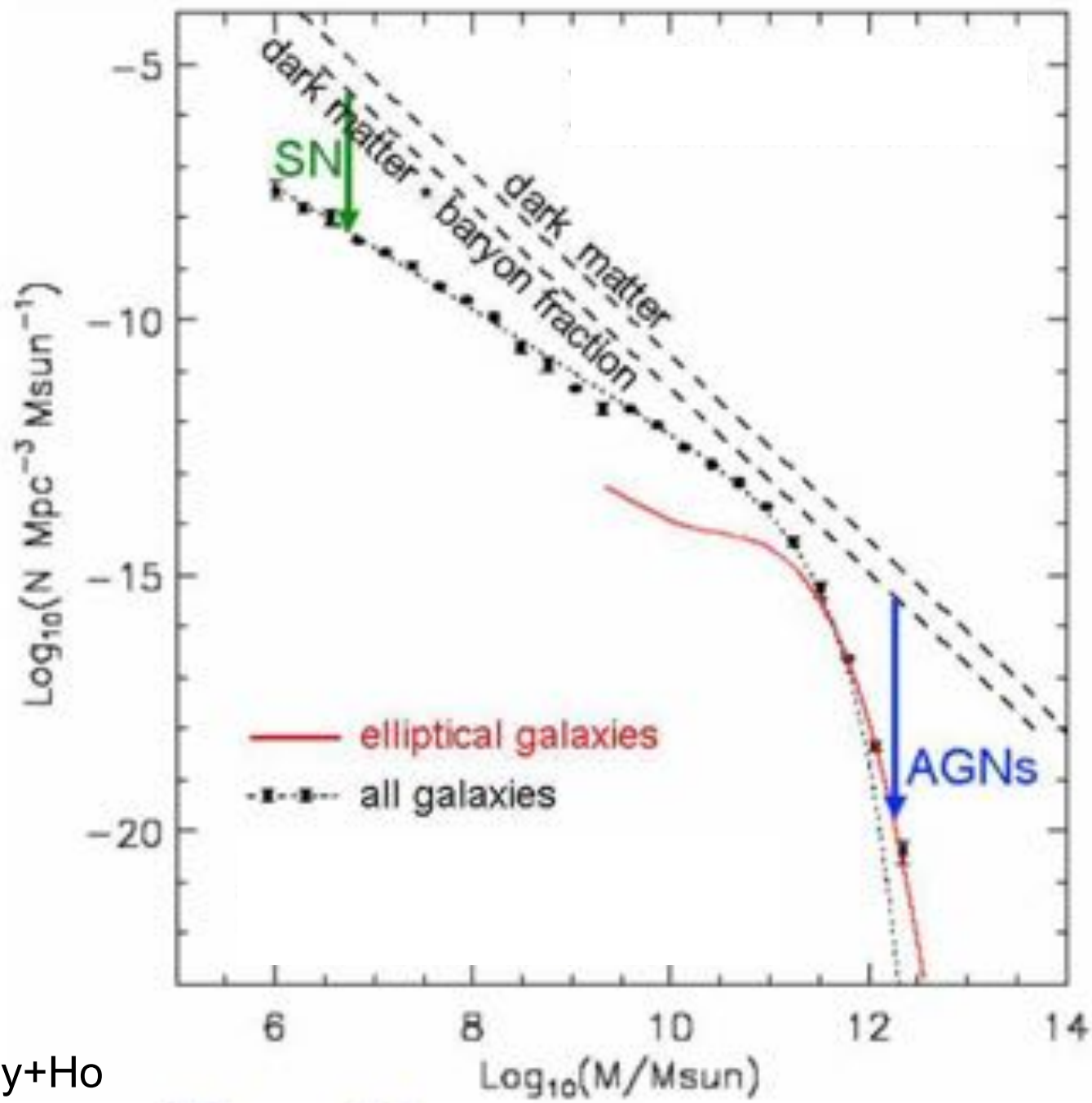


Halo mass

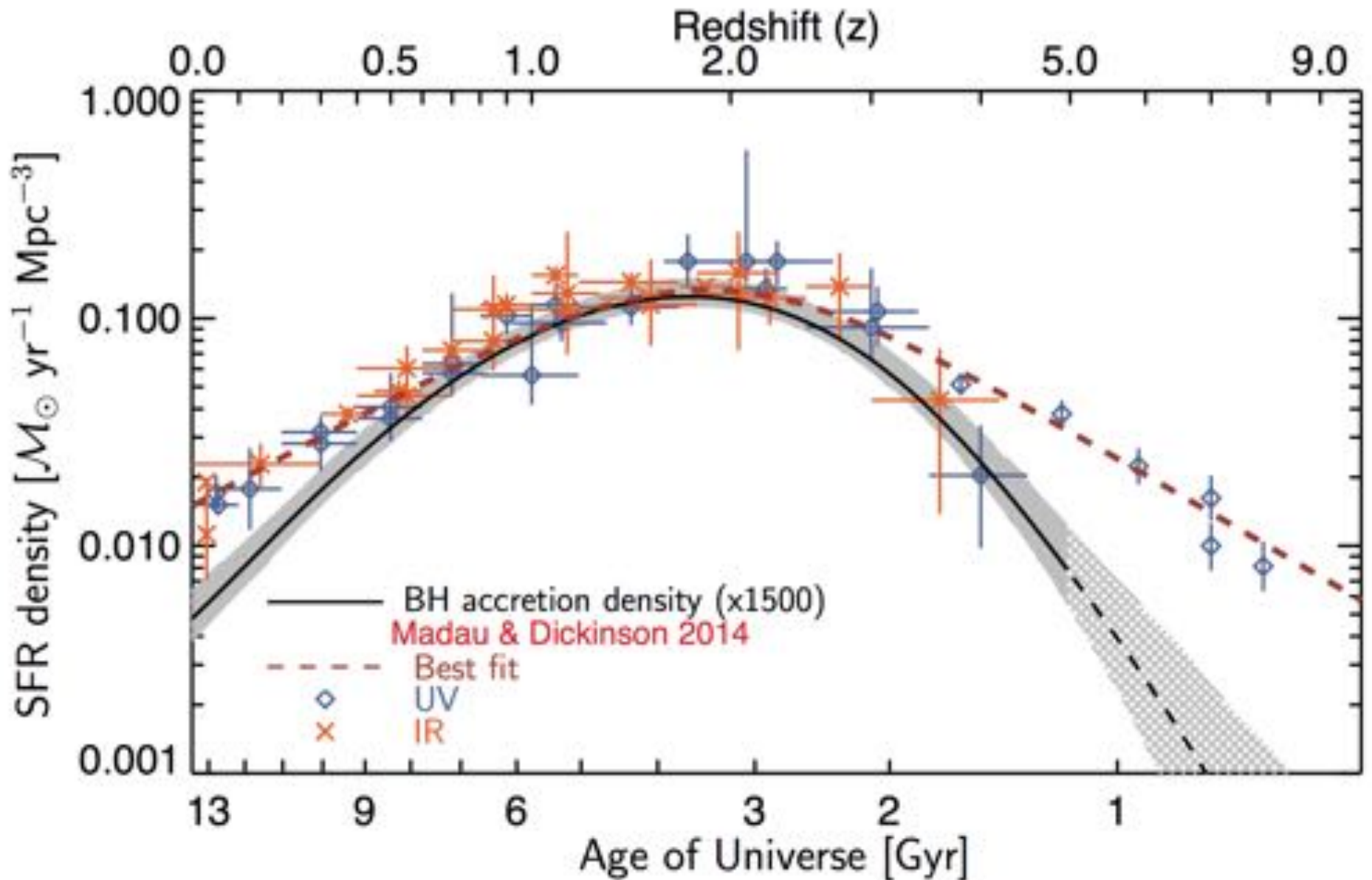
Galaxy
luminosity

AGN Feedback

Log Luminosity/Mass



Growth of Stars and Black Holes with time







Elliptical galaxies are now red and dead





Ion tail

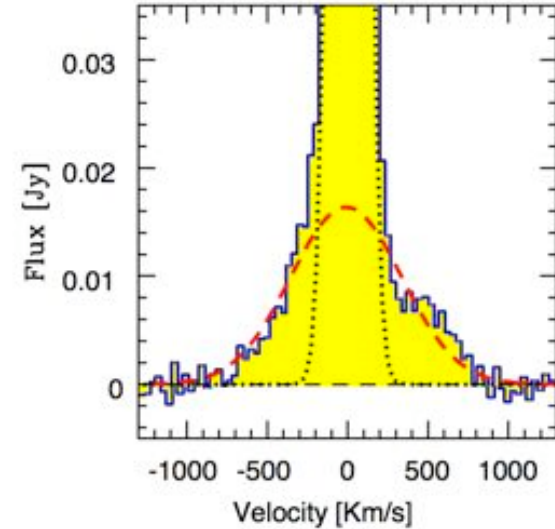
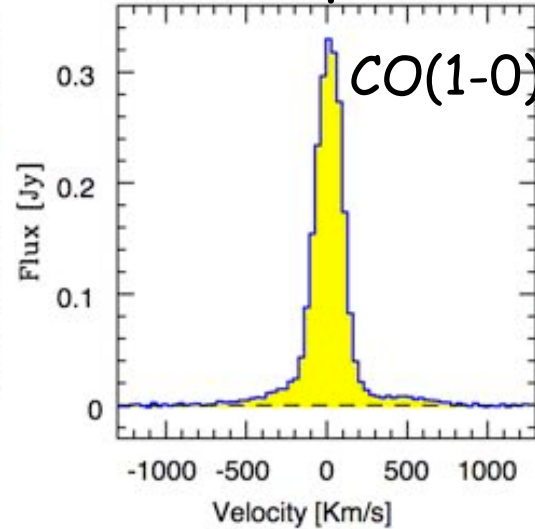
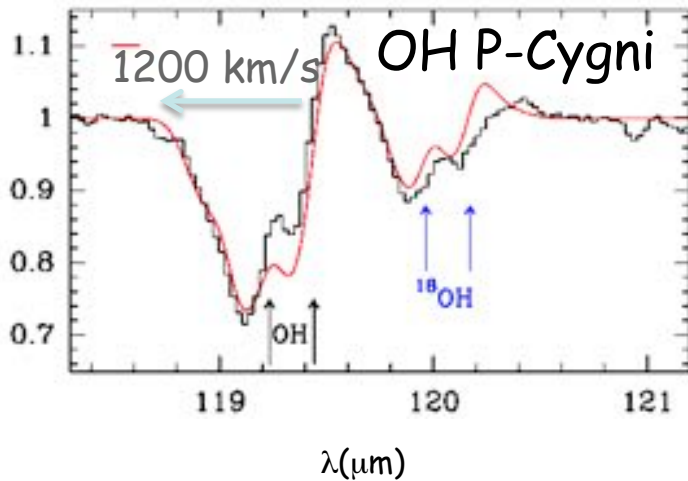
<- to Sun

Dust tail

Effects of radiation pressure and winds

Large amount of high velocity MOLECULAR gas observed in galactic outflows (especially in quasar-driven outflows)

Mrk231 (the closest quasar)



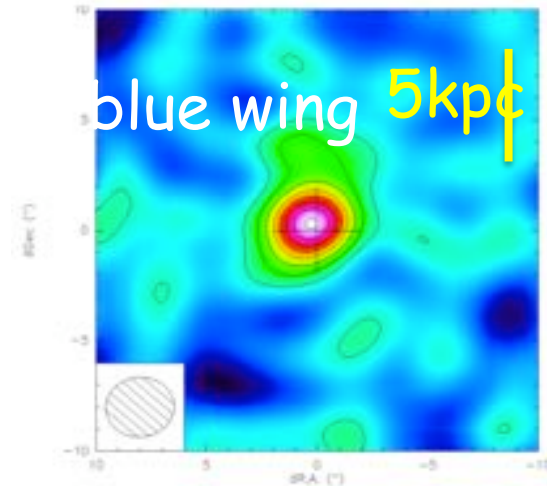
Massive molecular outflows ($\sim 1000 M_{\odot}/\text{yr}$)
 Extended on kpc scales

Fischer+10
 Sturm+11

Feruglio+10, 13
 Aalto+11, 15

Cicone+14

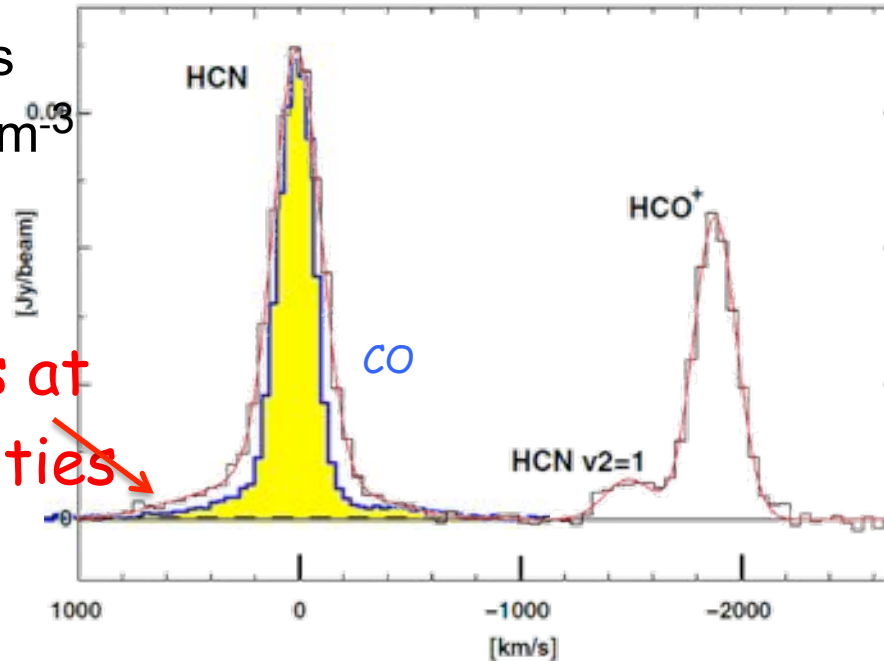
Gracia-Burillo+15
 Combes+14
 Sakamoto+14



A large fraction of the outflowing gas is very dense

HCN: tracer of gas
with $n \sim 10^6 \text{ cm}^{-3}$

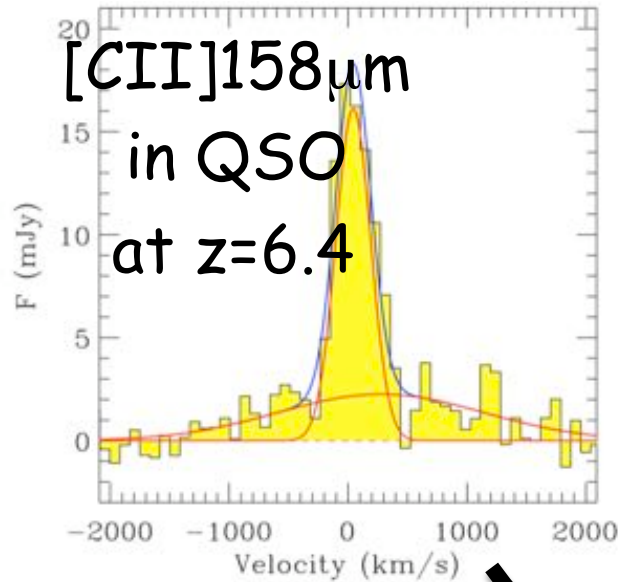
dense gas at
high velocities



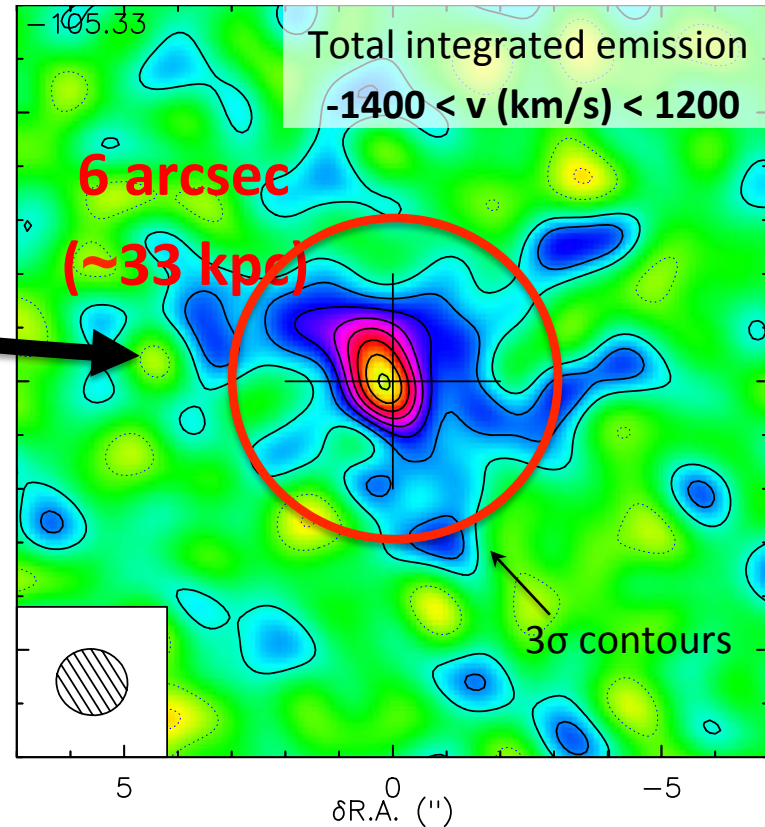
Aalto+15

The fraction of dense/diffuse molecular gas in the outflow is higher than typically observed in galaxies

Extremely extended quasar-driven outflows of cold gas at high-z

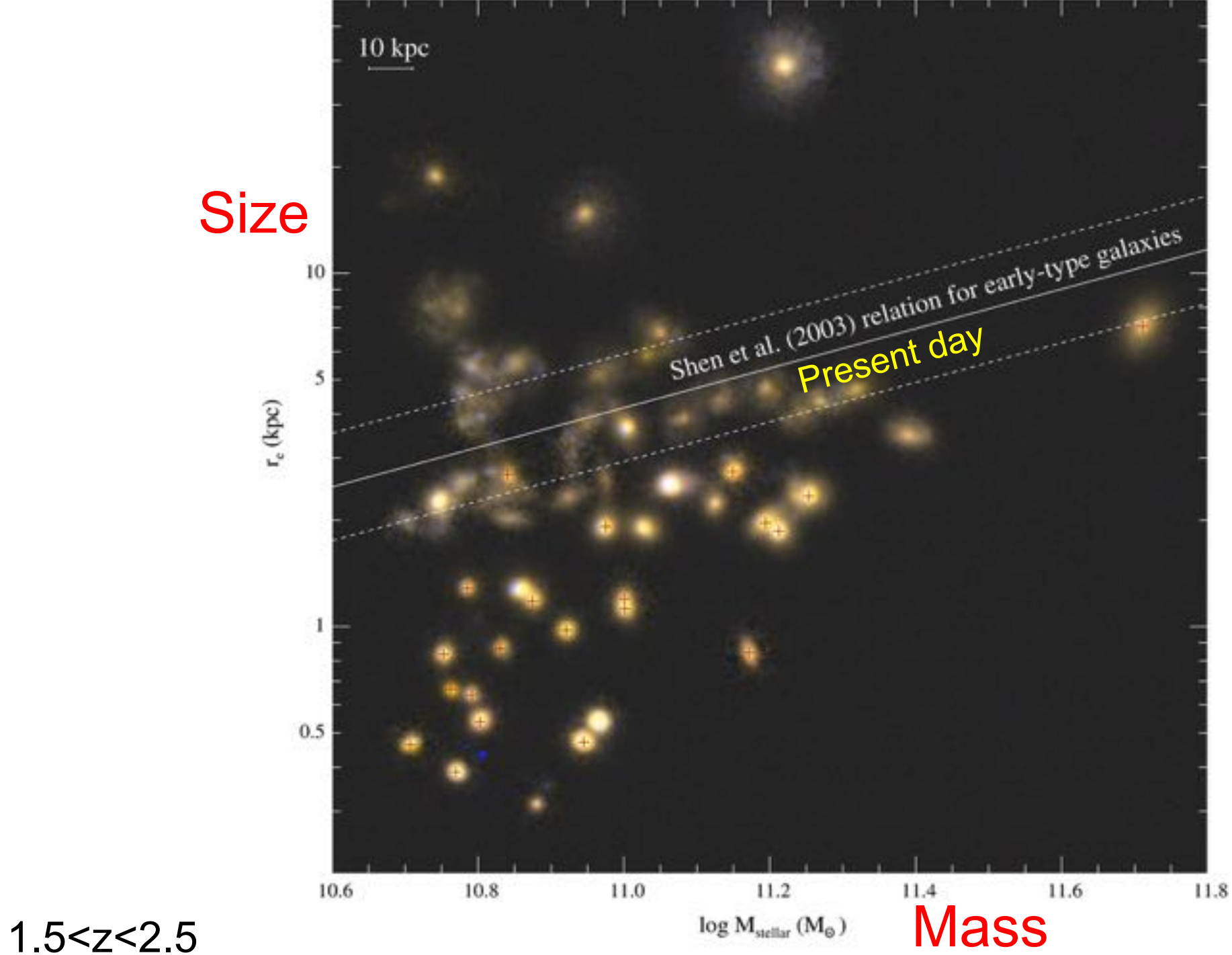


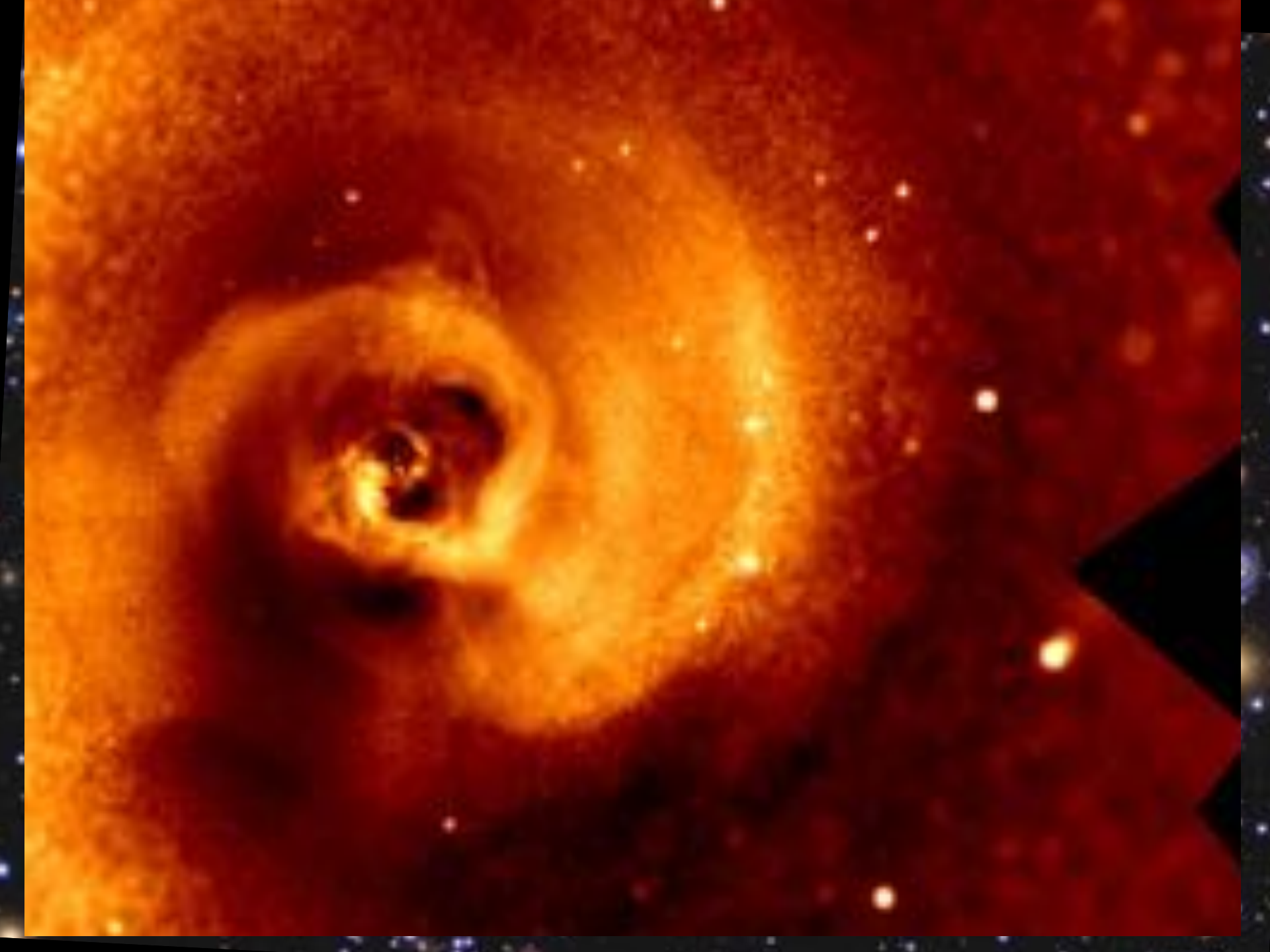
Maiolino+12

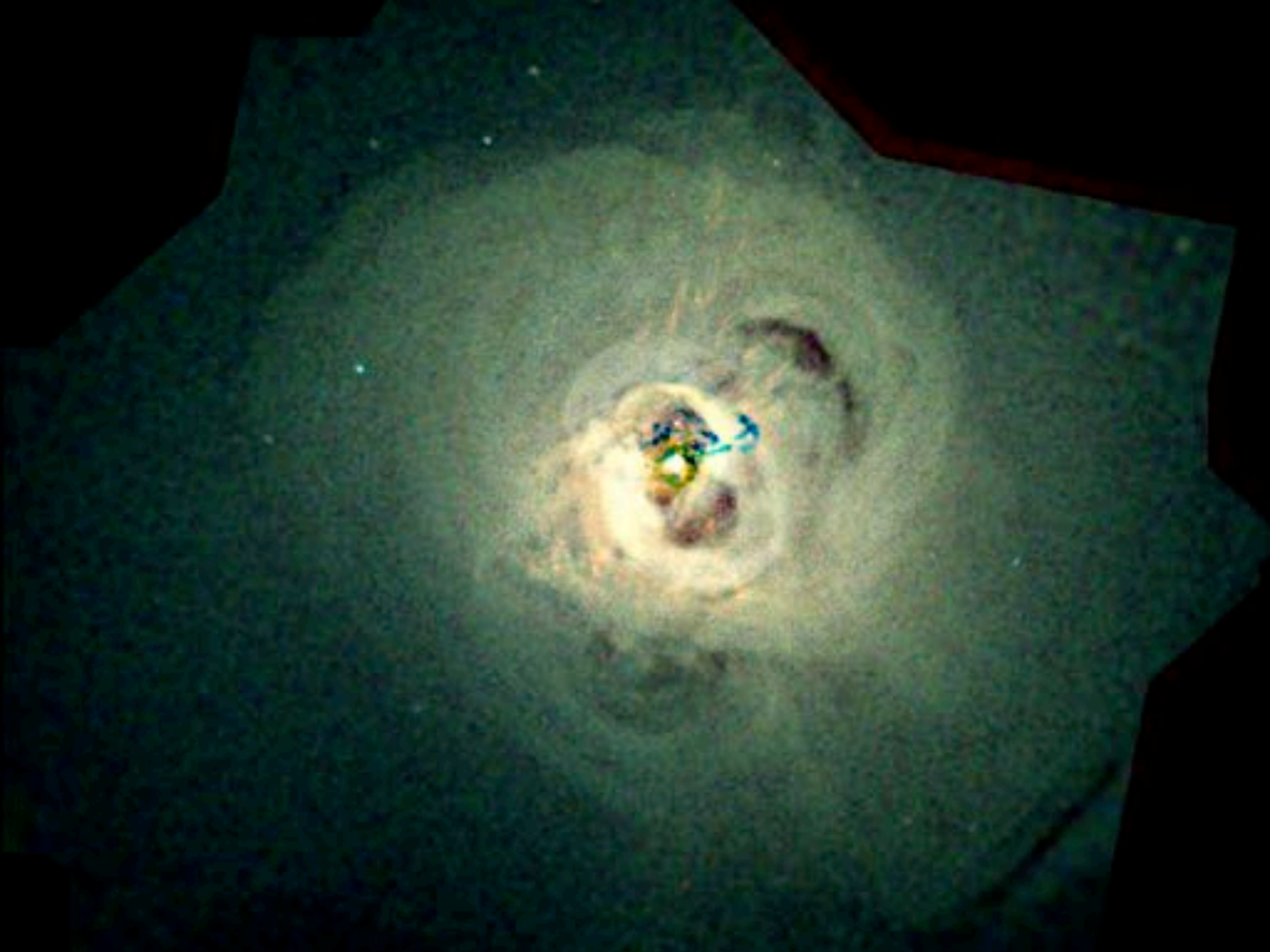


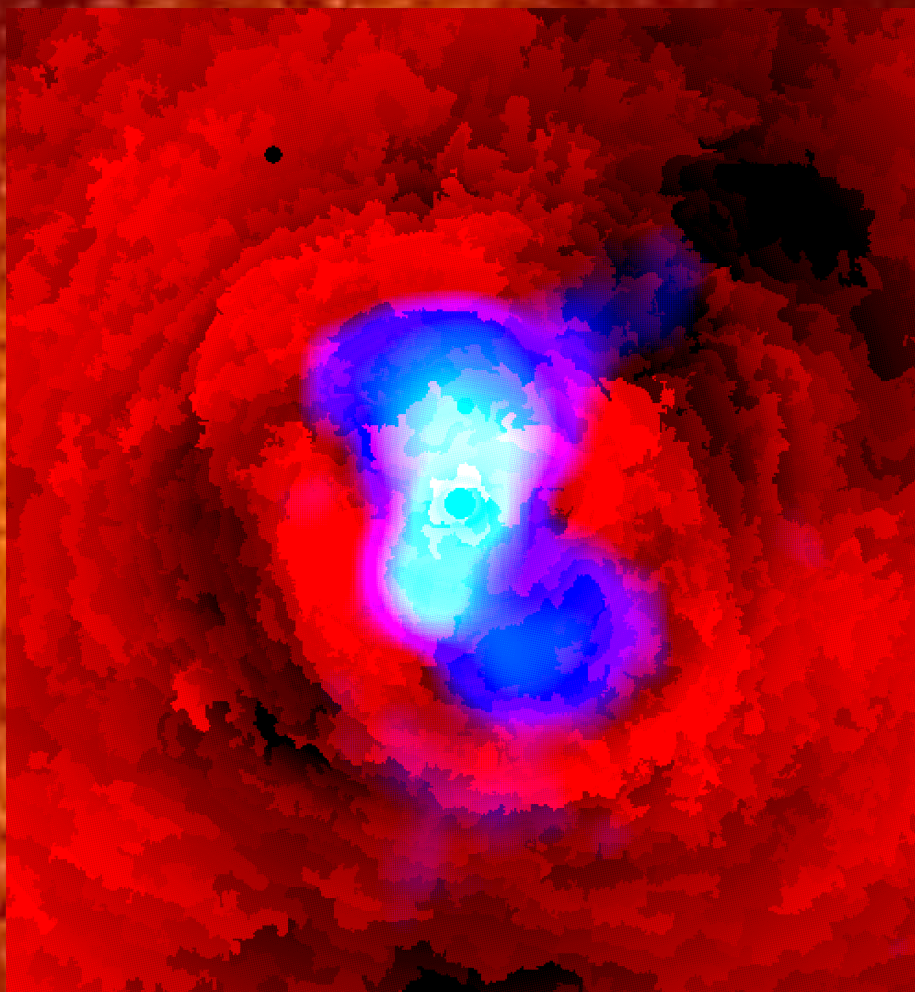
Cicone+15

High velocity outflow
extending on 30 kpc scales







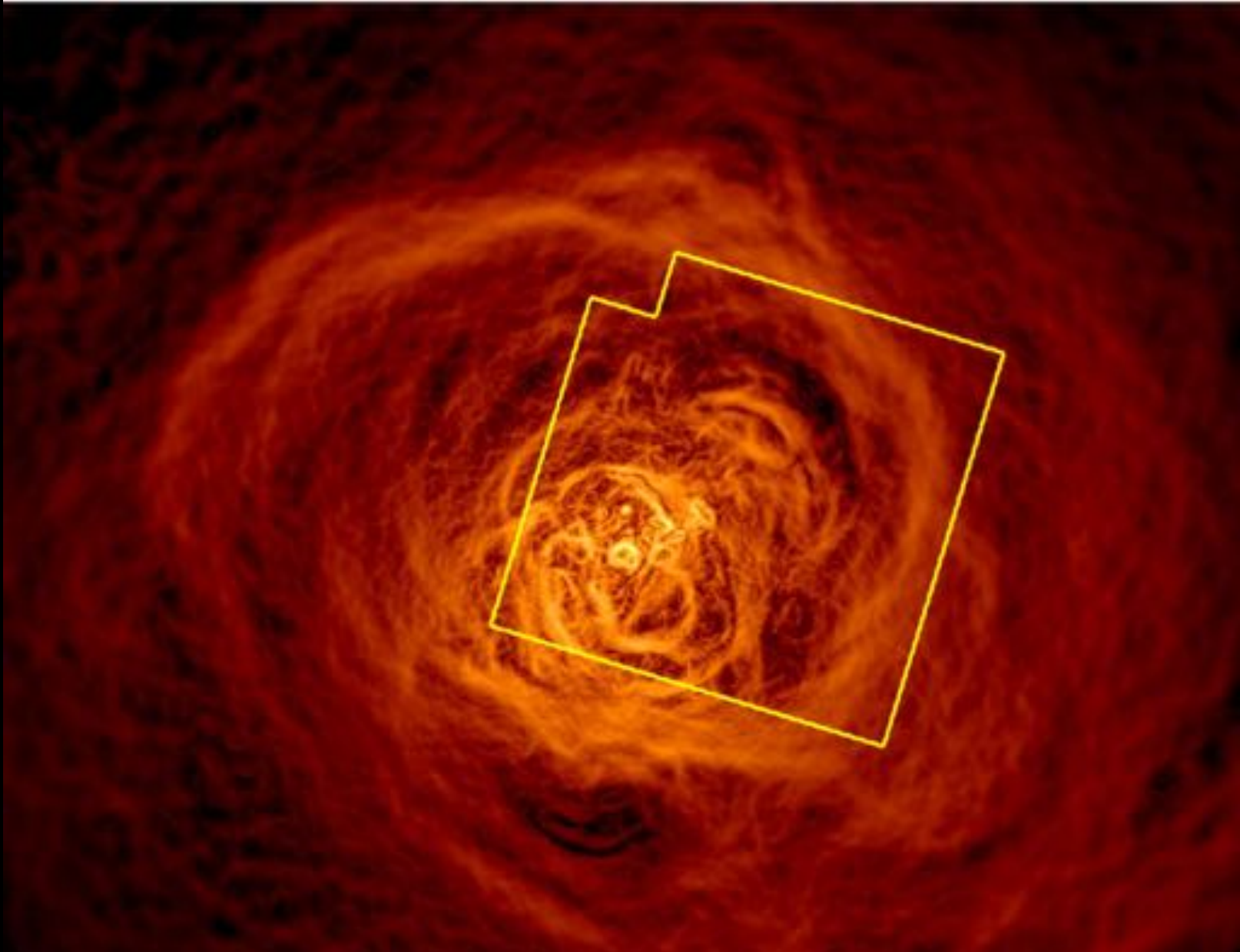


Feb 17 2016



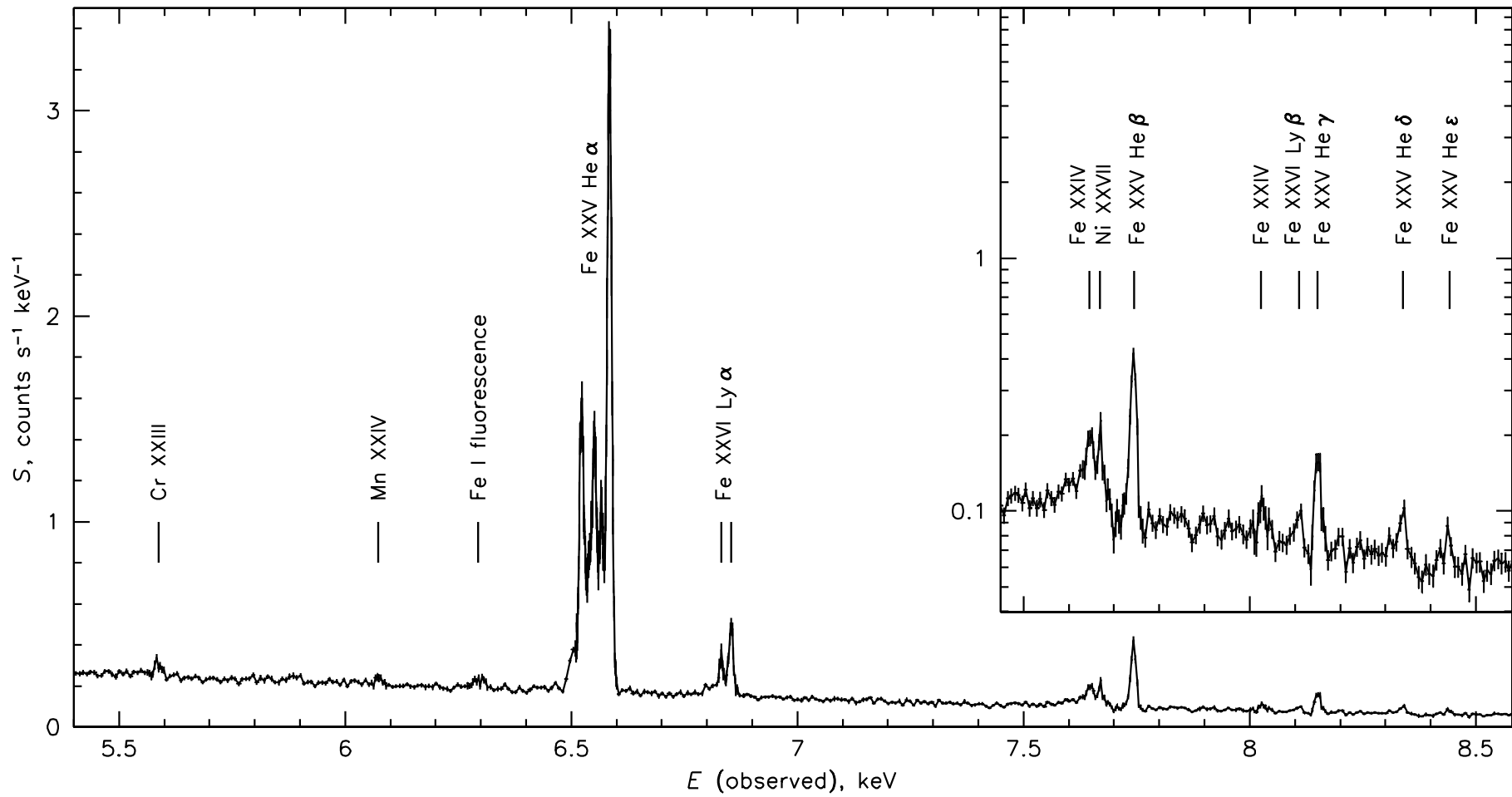
Final inspection before closing

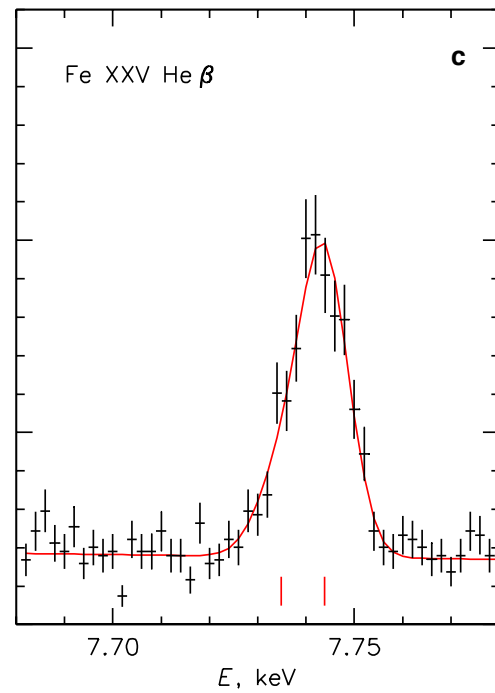
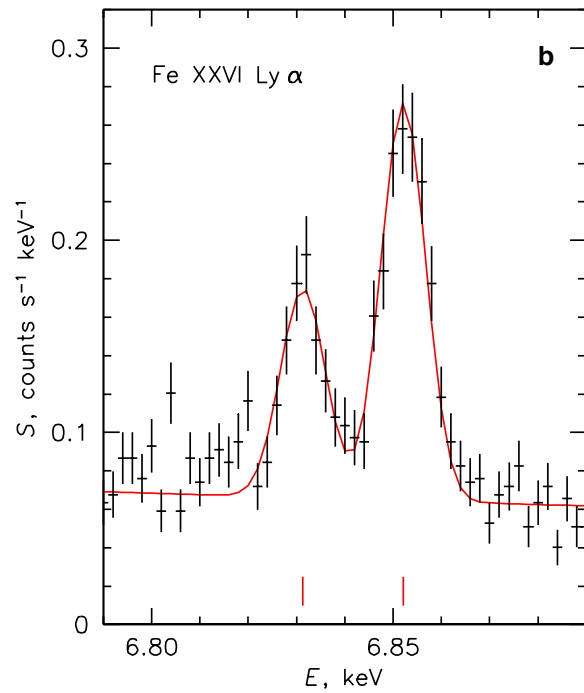
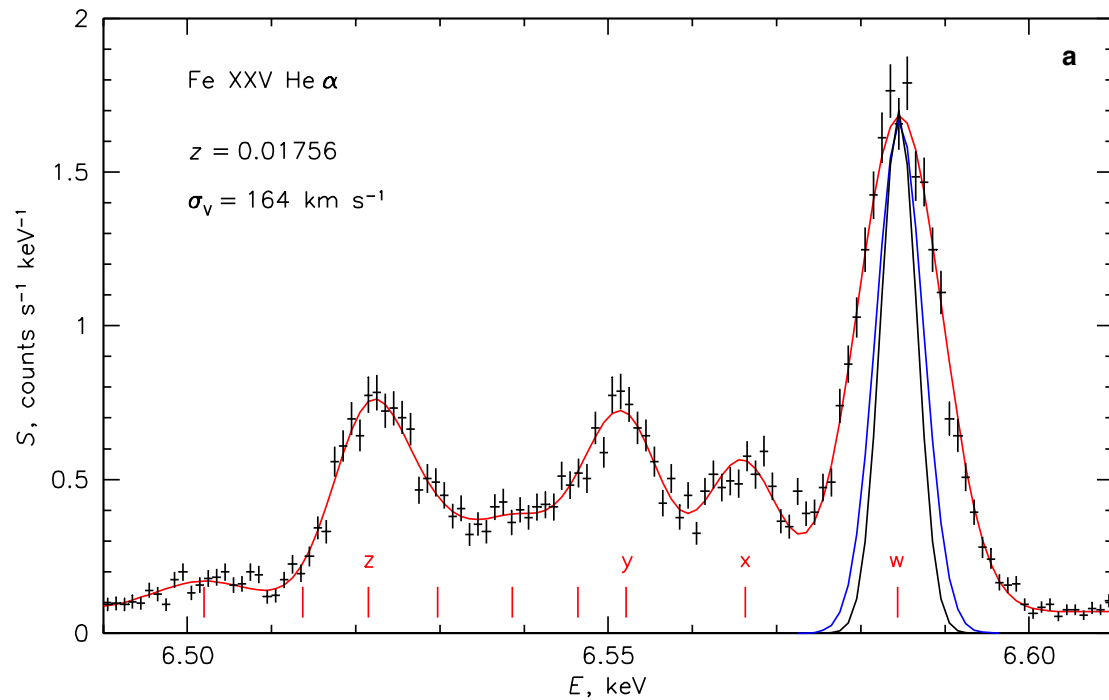


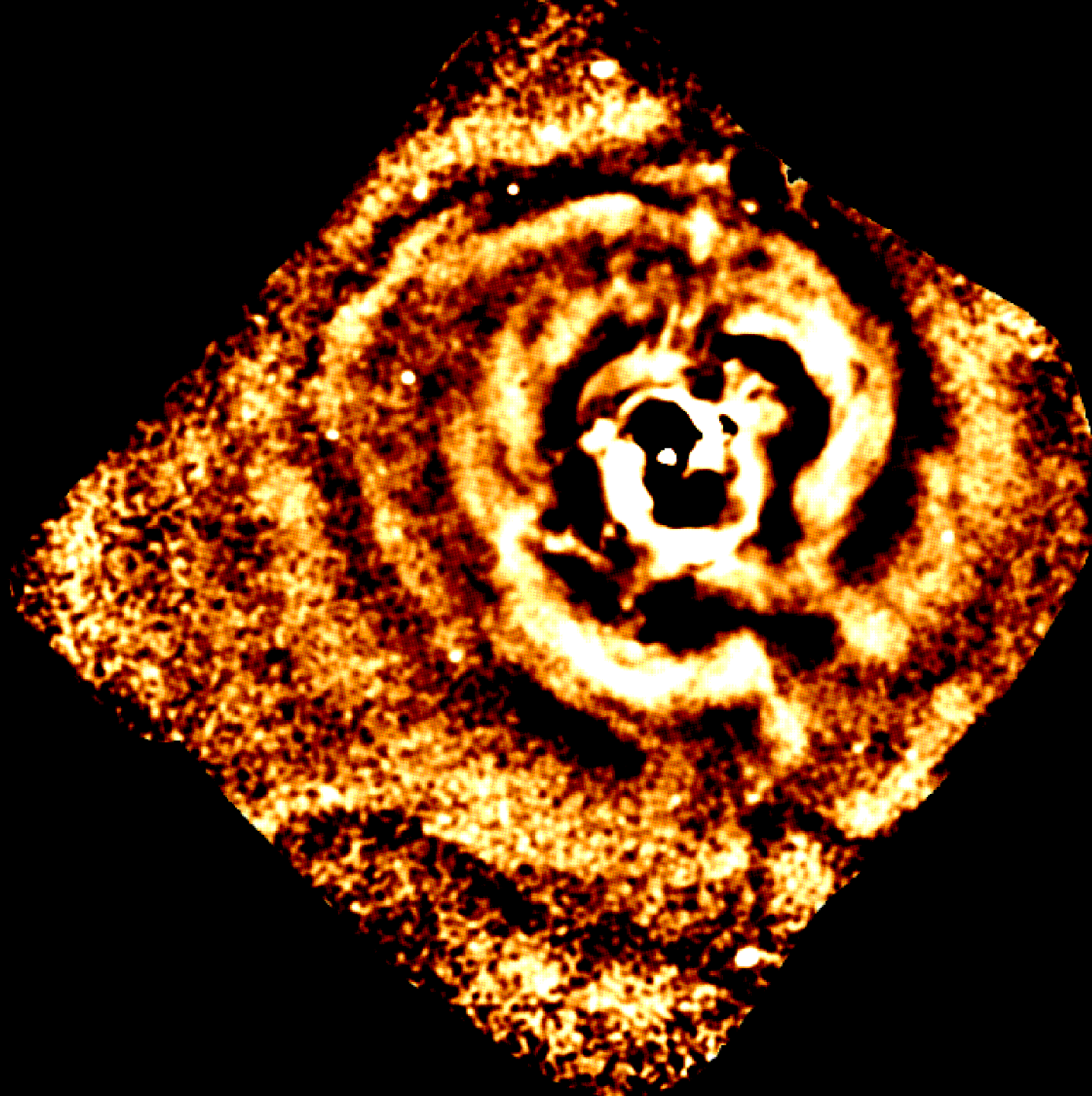


A. C. Fabian et al. MNRAS 2017;464:L1-L5

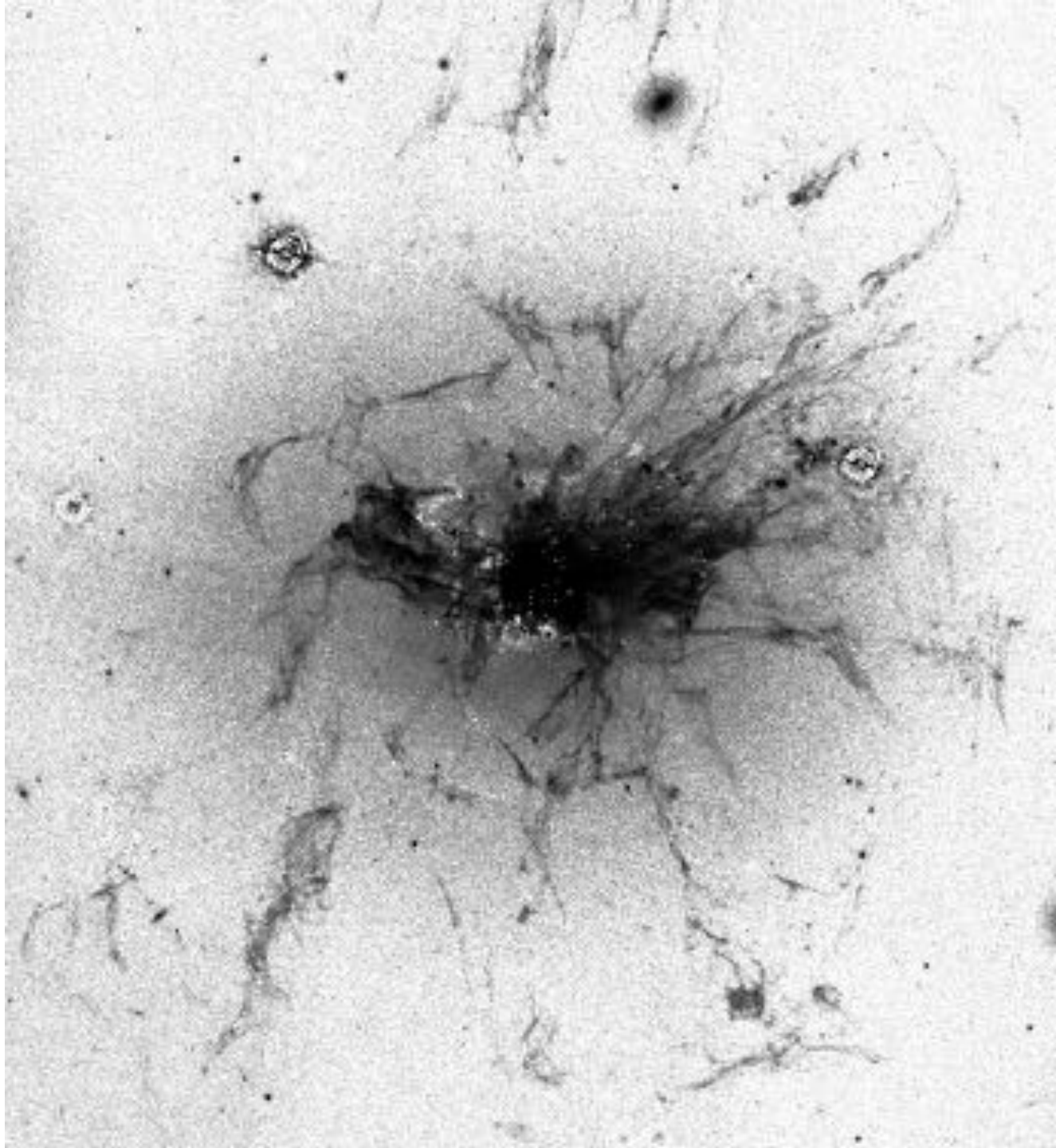


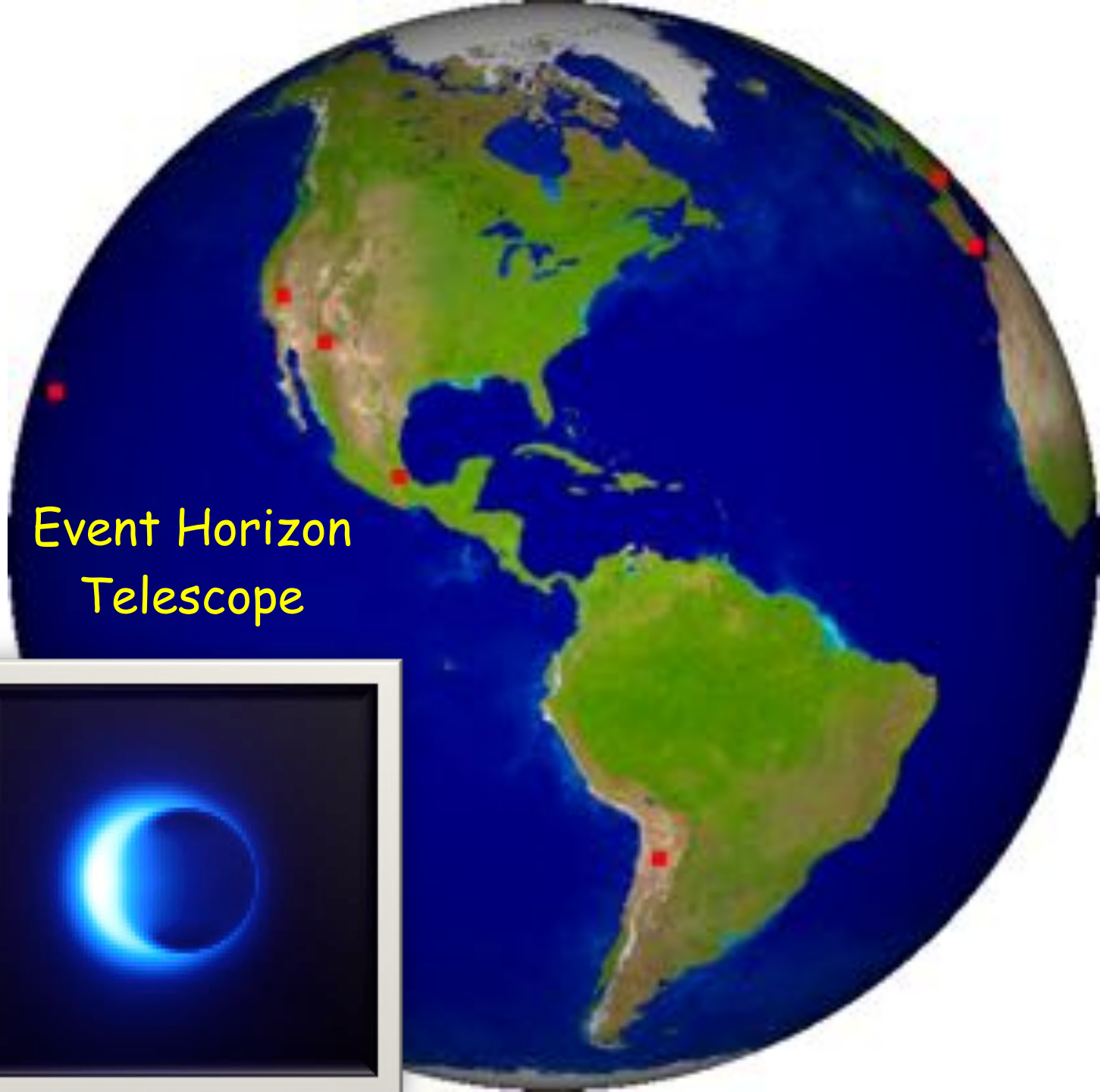












Event Horizon
Telescope



ATHENA

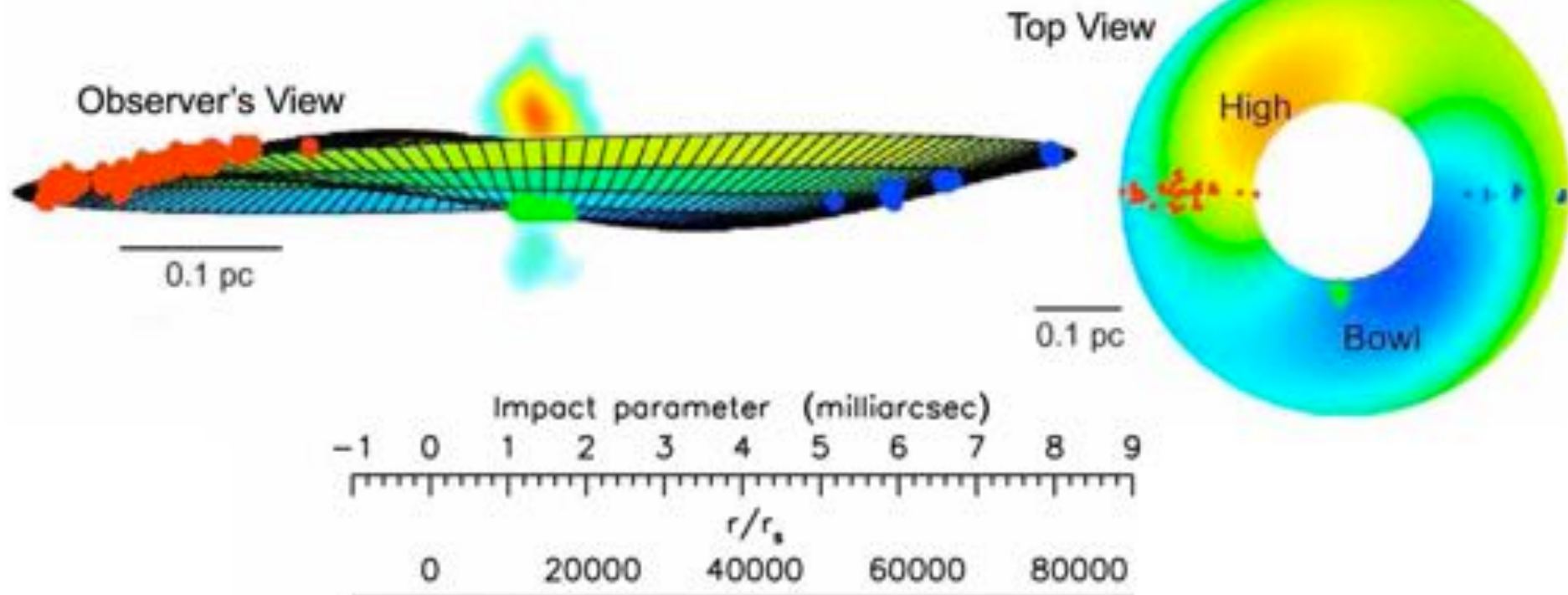
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How to find a black hole

Large mass in small radius

Earth mass in 1 cm;

Sun's mass within 3 km;

Billion solar masses within orbit of Uranus

How to find a black hole

Large mass in small radius

Earth mass in 1 cm;

Sun's mass within 3 km;

Billion solar masses within orbit of Uranus

Large luminosity varying rapidly

Million solar luminosities in a few millisec

Billion solar luminosities in a few minutes

Trillion Solar luminosities in a few days