Galaxies

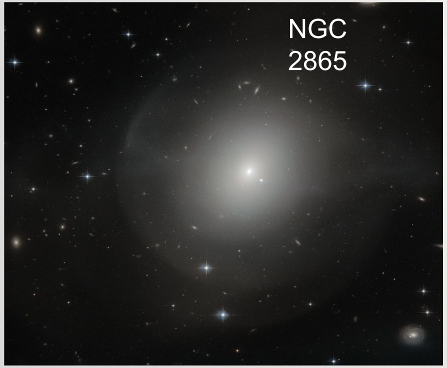
Spiral

Giant rotating pin-wheels with a pancake-like disk, a central bulge , and spiral arms.

Credit: NASA, ESA, K. Kuntz (JHU), F. Bresolin (University of Hawaii), J. Trauger (Jet Propulsion Lab), J. Mould (NOAO), Y.-H. Chu (University of Illinois, Urbana) and STScI; CFHT Image: Canada-France-Hawaii Telescope/J.-C. Cuillandre/Coelum; NOAO Image: G. Jacoby, B. Bohannan, M. Hanna/NOAO/AURA/NSF

Elliptical

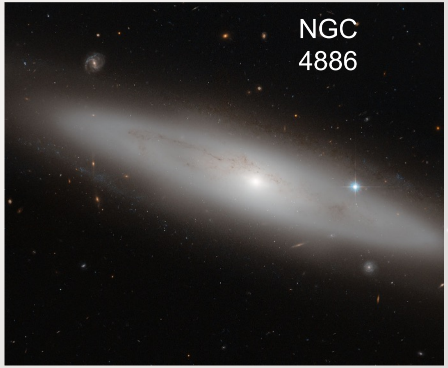
From completely round to oval. Less common than spiral galaxies.



Credit: ESA/Hubble & NASA.
Acknowledgement: Judy Schmidt

Lenticular

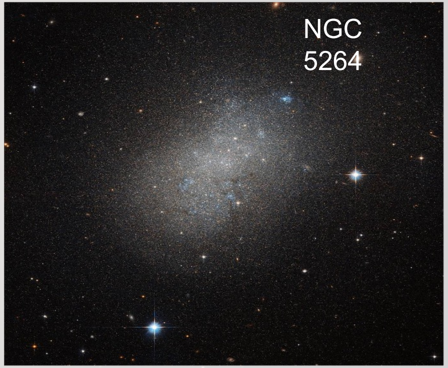
Mix between spirals and ellipticals. Central bulge & disk of spiral galaxies but no arms.



Credit: ESA/Hubble & NASA.
Acknowledgement: Gilles Chapdelaine

Irregular

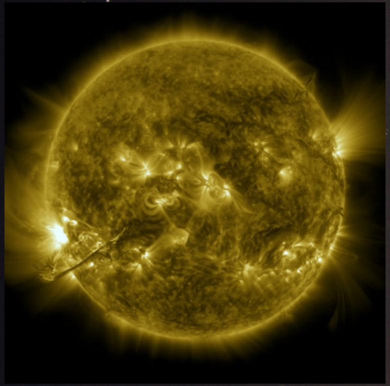
Unusual shapes.



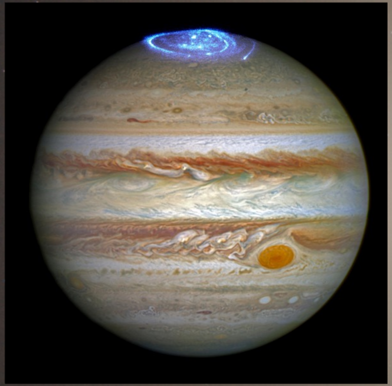
Credit: ESA/Hubble & NASA

Galaxies

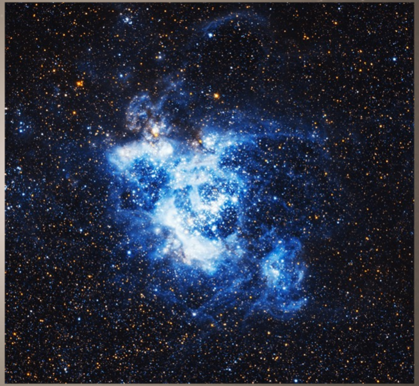
Galaxies consist of stars, planets, and vast clouds of gas and dust, all bound together by gravity.



Credit: NASA's Scientific Visualization Studio/SDO



Credit: NASA, ESA, and J. Nichols (University of Leicester)

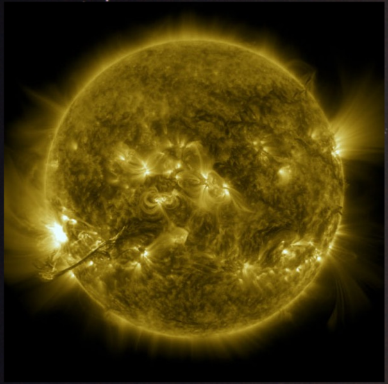


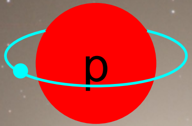
Credit: NASA, ESA, and M. Durbin, J. Dalcanton, and B. F. Williams (University of Washington)

Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)
Acknowledgment: P. McCullough (STScI)

Sun-like Stars ($M < 10\ M_{sun}$)

Stars are giant balls of hot gas (mostly hydrogen, some helium and tiny bits of heavier elements). They are real-life fusion reactors : they burn hydrogen and create helium, this balances the gravity that is pulling the envelop together.





Hydrogen atom
= 1 proton
+ 1 electron

4x

Hydrogen nuclei
= 1 proton

Helium nuclei =
2 protons +
2 neutrons

+ Other things
(2 positrons
2 neutrinos
2 photons)

Sun-like Stars (M < 10 M_{sun})

Stars are giant balls of hot gas (mostly hydrogen, some helium and tiny bits of heavier elements). They are real-life fusion reactors : they burn hydrogen and create helium, this balances the gravity that is pulling the envelop together.

In the case of the Sun and similar stars: the atmosphere keeps expanding until it is blown away

Core of the star

sure from fusion

Gravity

What is left of the core is dense, hot material that will cool down to become a White Dwarf.

The intermediate stage is called the planetary nebula phase.

The Helix nebula, credit NASA/JPL-Caltech
Credit: NASA Goddard Space Flight Center/Chris Smith (KBRwyle)

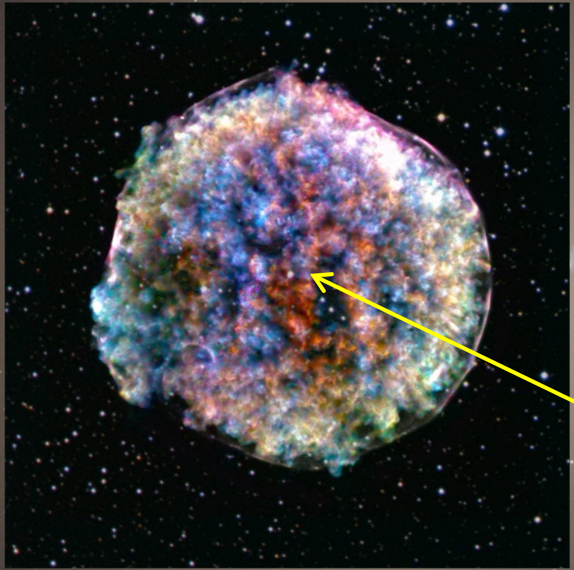
White Dwarf facts

- The remaining cool core is ~ 0.5 M_{sun}
- The size is ~ size of Earth
- It is very dense: like putting an elephant in a teaspoon

Heavier Stars

In the case of massive stars: fusion continues until gravity cannot hold it anymore.

The core collapses then it bounces off and creates a shock wave, with a big explosion and pushes away the remaining material: this is called a supernova.



Credit: X-ray: NASA/CXC/RIKEN & GSFC/T. Sato et al; Optical: DSS

Image of the remaining of a supernova observed in 1572. Supernovaes can be so bright that they are visible with bare eyes, even during the day.

Somewhere in there is a Neutron Star, what remains from the original core of the star

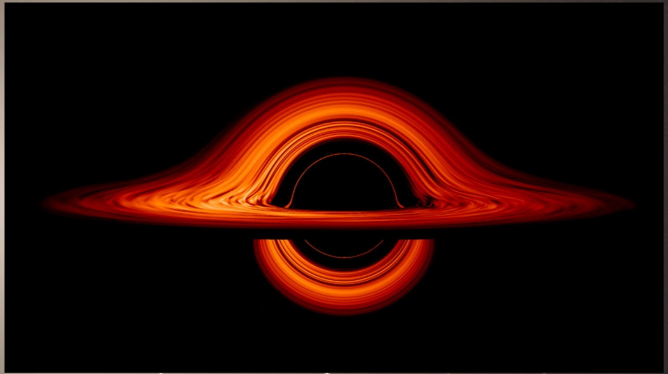
Neutron Star facts

- The remaining cool core is ~ 1.5 M_{sun}
- The size is ~ 10km (a city)
- It is even denser: like putting 900 Great Pyramids of Giza in a teaspoon

Very very heavy Stars
(M > 20 M_{sun})

If the remaining core is more than ~ 3-4 M_{sun}, it cannot hold anymore, and a black hole forms.

Fun fact: if the Sun was a black hole of the same mass, gravity on Earth would be the same (although we would be frozen)



Credit: NASA's Goddard Space Flight Center/Jeremy Schnittman

Black Hole facts

★The "No-Hair Theorem", black holes are only defined by:

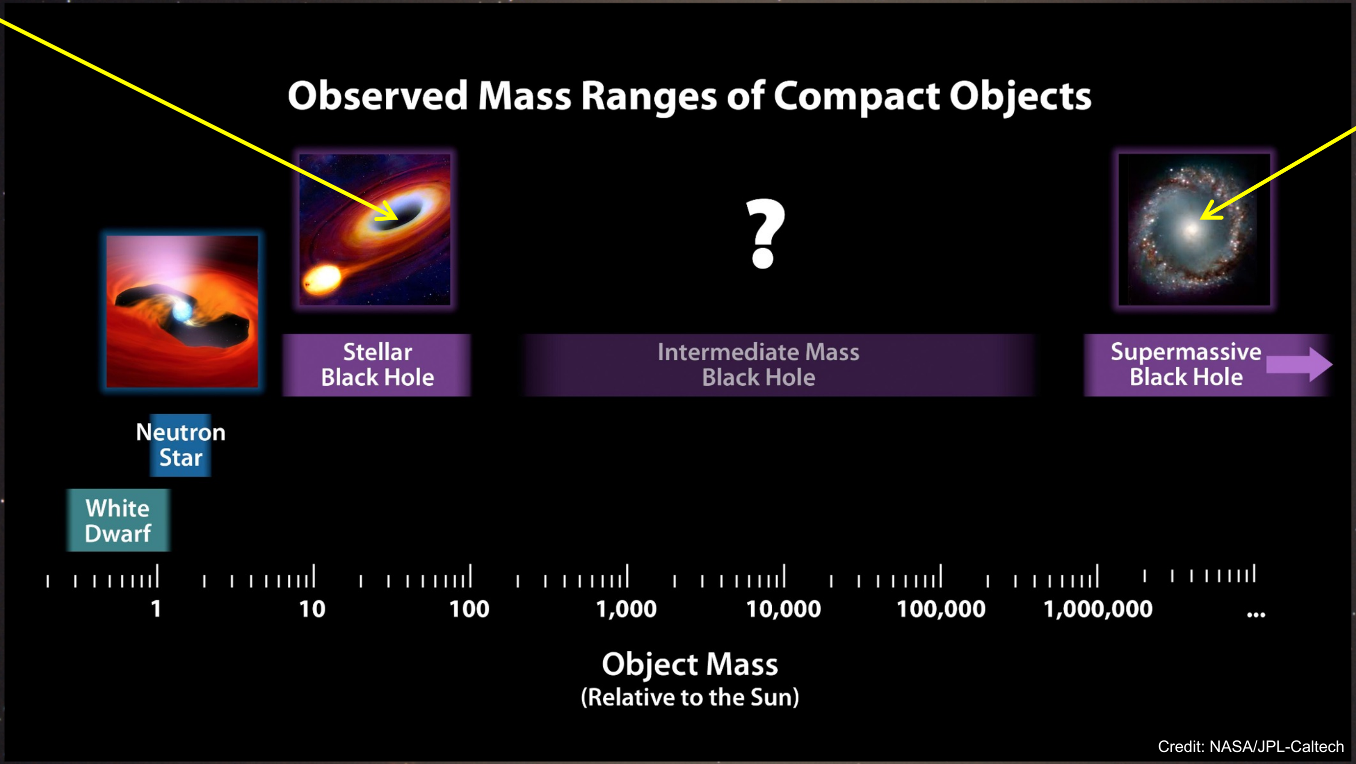
- Their mass
- Their angular momentum (how fast they rotate)
- Their electric charge

★Cygnus X-1, a galactic source discovered in 1964, became the first astronomical object commonly accepted to be a black hole.

★There are only 2 black holes that were directly imaged: M87* (2019) and Sagittarius A* (2022)

Supermassive black holes?

The ones I explained



The ones that are interesting for active galaxies

Active Galaxies

Around 10% of known galaxies are active: their center appears more than 100 times brighter than the combined light of their stars!

- ⭐Why is that?
- ⭐What makes them so bright?

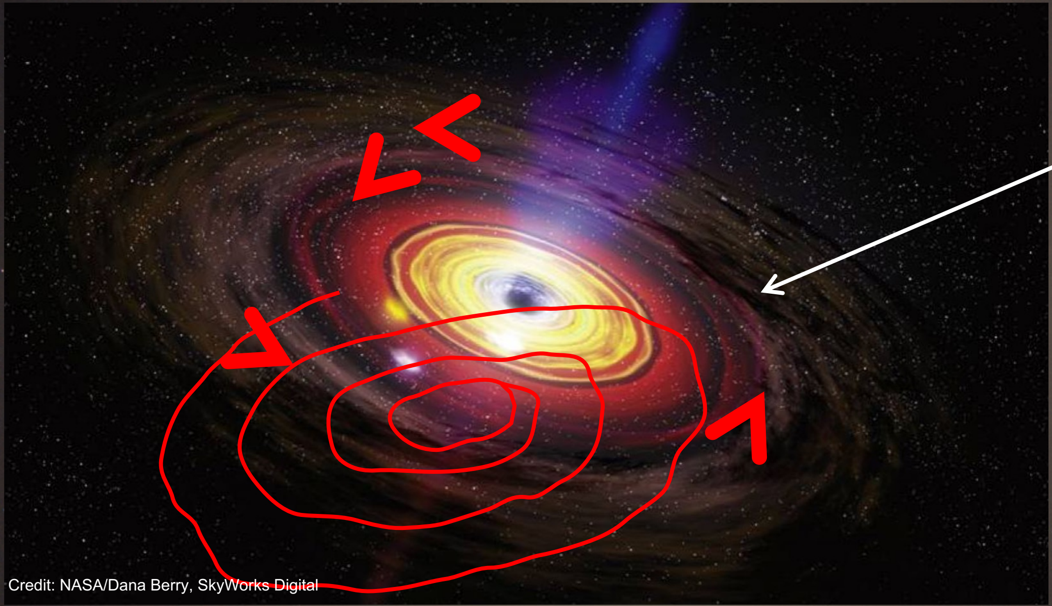

Credit; EHT Collaboration

In Active Galaxies, the supermassive black hole is accreting material present in the central region

This, is M87, a galaxy with an active core

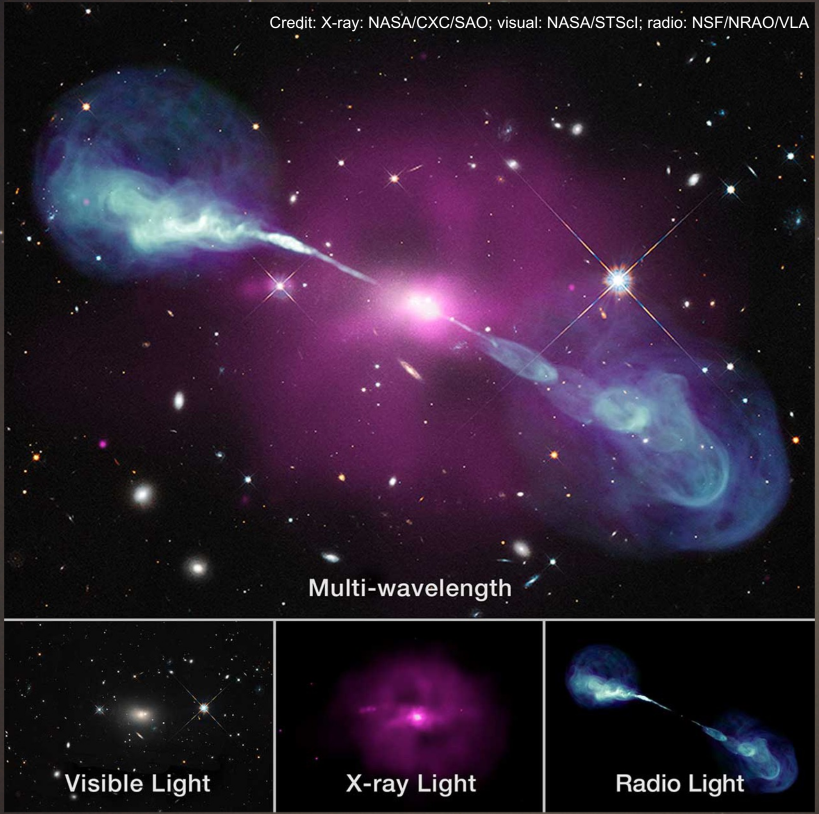
Active Galaxies

As matter spirals towards the black hole: it heats up and forms a disk


Credit: NASA/Dana Berry, SkyWorks Digital

Gas and dust coming the surrounding stars and clouds

Active Galaxies



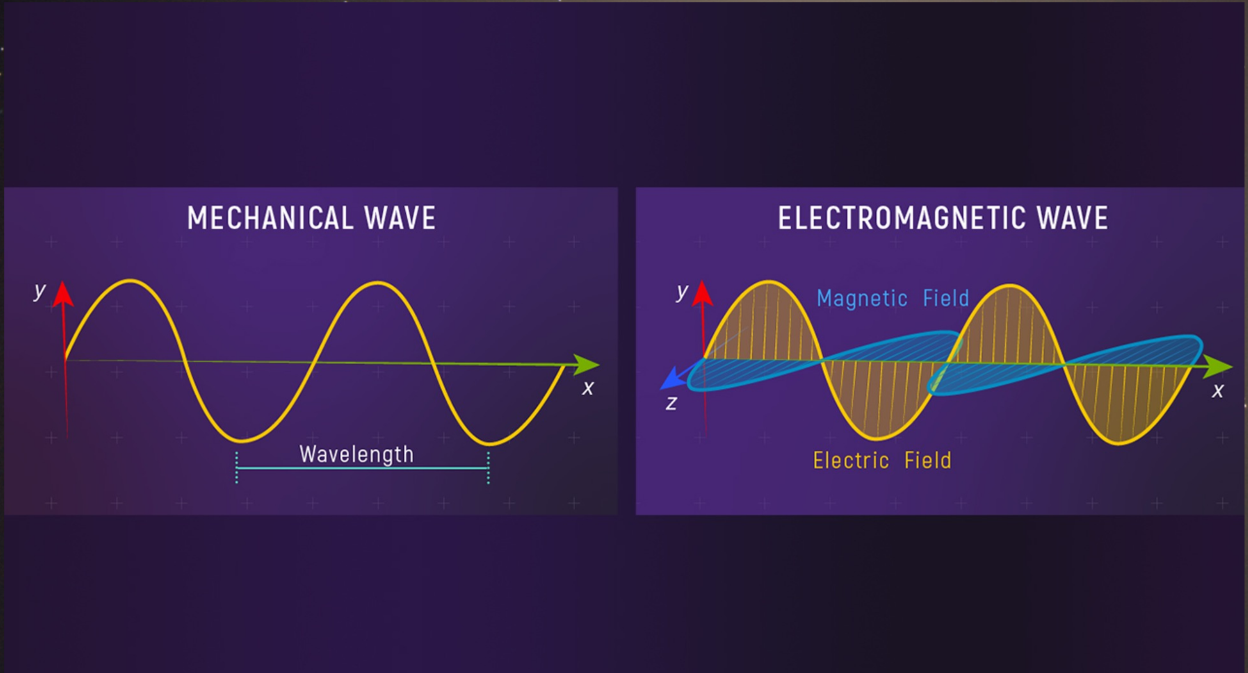
As matter spirals towards the black hole: it heats up → it releases some energy by radiating → it emits light (here X-rays, in pink)

Jets are narrow beams of energetic particles ejected outward in opposite directions away from the disk. The jets are characterized by their radio wave emission.

Sometimes (in 10% of the cases), with the help of the magnetic field, the accretion disk and the black hole, jets can b

Electromagnetic spectrum

What’s this story about X-rays, radio etc?



Credit: NASA, ESA, Leah Hustak (STScI)

A mechanical wave is a propagation of energy through matter.
Ex: waves on a rope.

Light waves (electromagnetic waves) are oscillations of electric and magnetic fields.

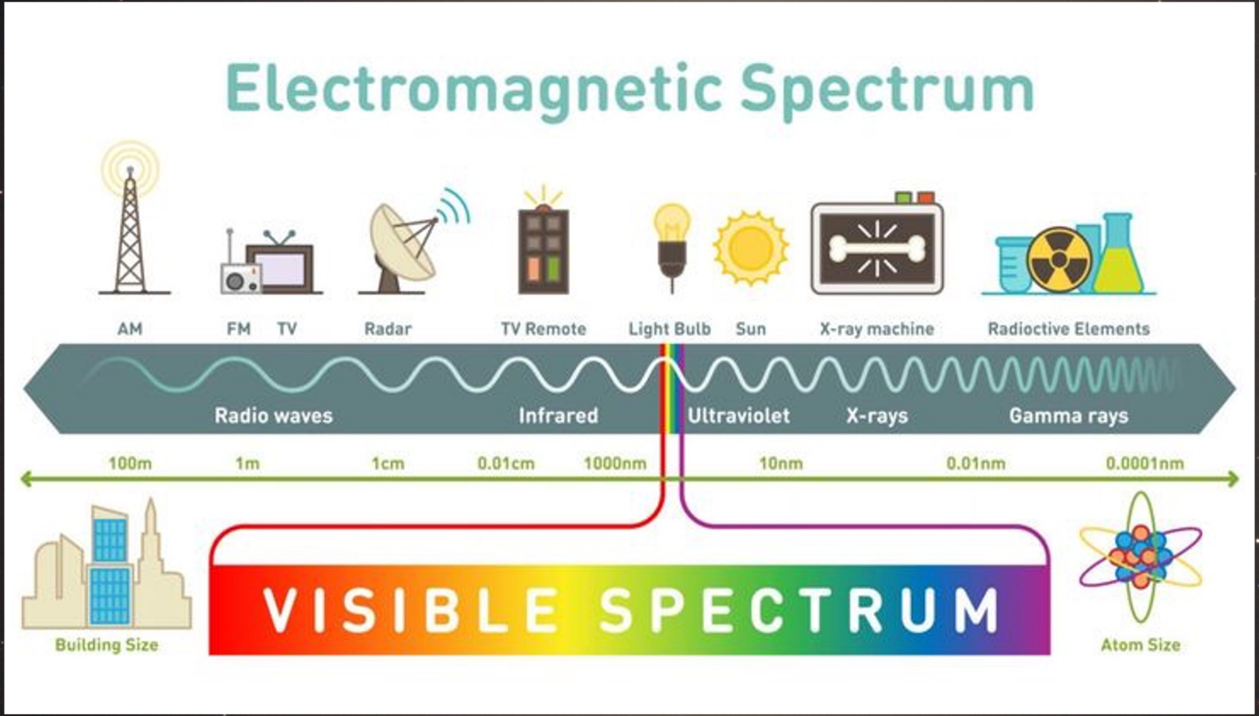
Electromagnetic spectrum

What’s this story about X-rays, radio etc?

The runner runs always at the same speed. If she was a light wave, her speed would be 300 000 km/s.
She changes direction regularly. If she was a radio wave, she would change direction 1 million times per second.

Electromagnetic spectrum

What's this story about X-rays, radio etc?



What type of object of our everyday life uses that "light"

Interval between two wave oscillations at the speed of light

Active Galaxies

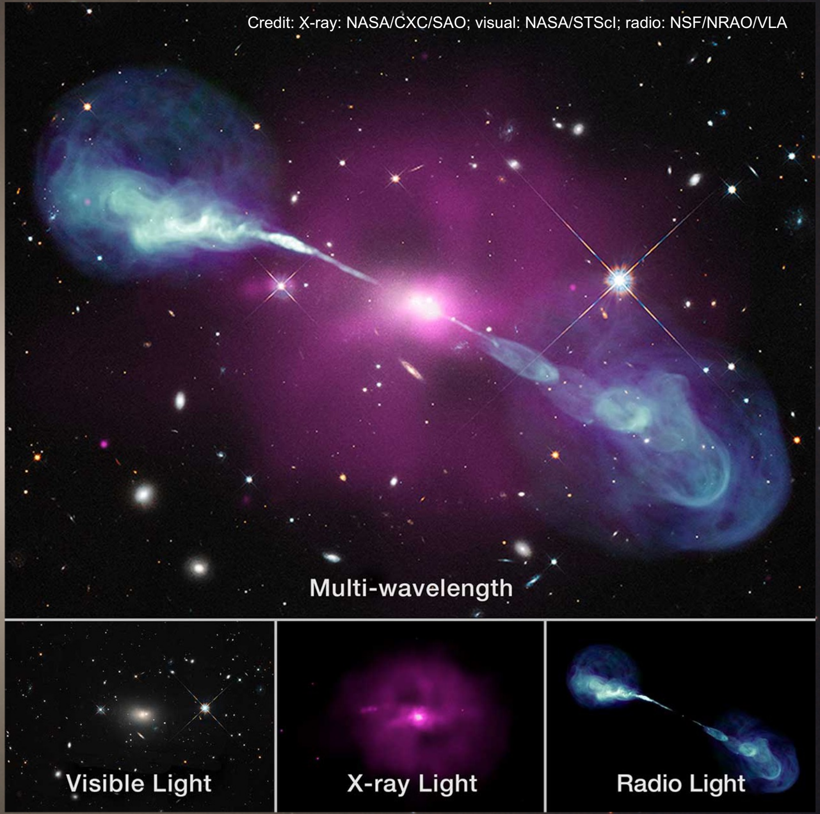
Why do different parts emit at different wavelengths?

★It depends what type of particle there is.

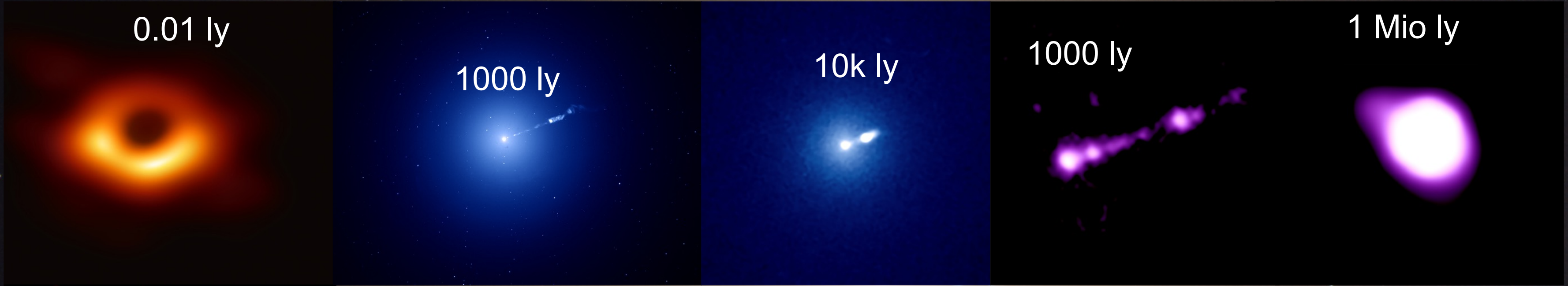
★It depends how energetic the particles are.

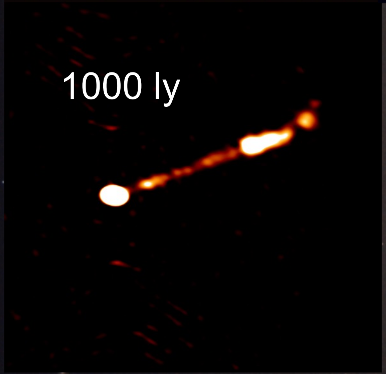
★It depends on the temperature of that region.

★It depends on how dense the region is.



M87: the typical



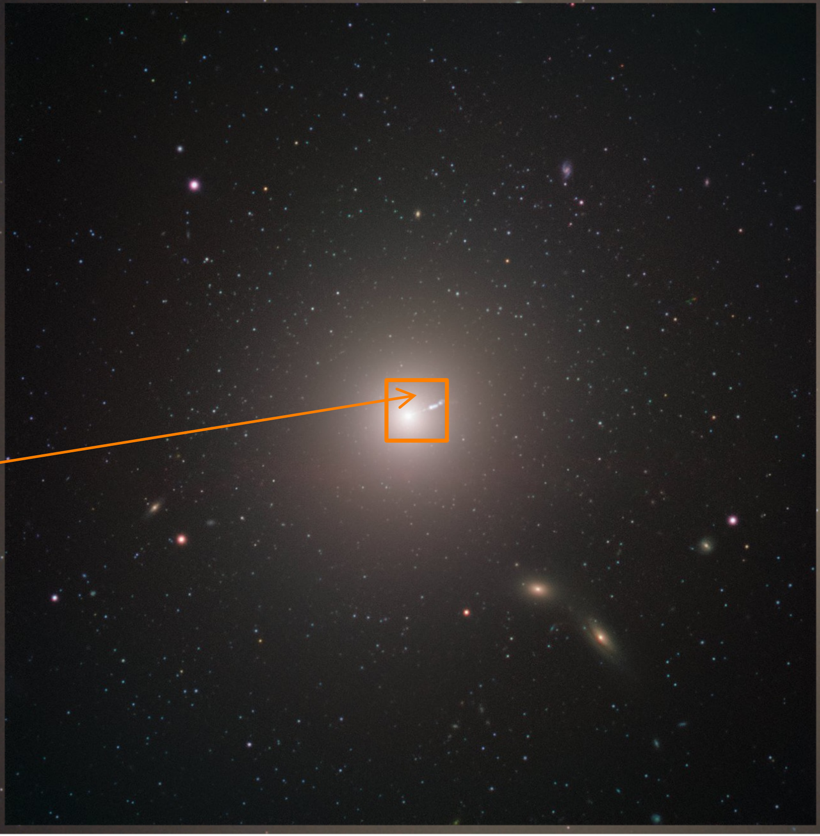


This is M87 (again) in different lights. This gives indications about "where is the emission at a certain wavelength coming from?"

These observations were taken in 2017, nearly simultaneously during 3 months. This is the perfect set-up to study what happens in the core of an active galaxy when it is in a quiet state.

Example: in gamma rays, we cannot know, we only see a blob of light. But in radio, we see that the region closest to the black hole is bright.

M87: the galaxy

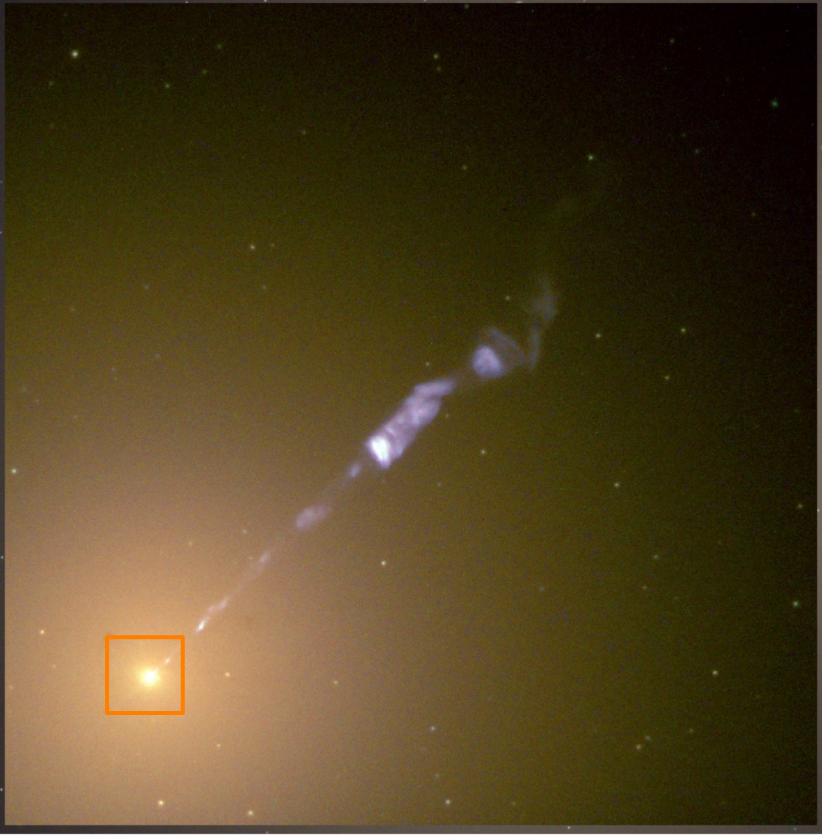


- Lives in the Virgo constellation
- Its jet extends up to 5000 light years! Outside of the galaxy
- Real name: Messier 87
- Discovered in 1779 by Charles Messier
- “close to Earth” (500 billion of billion of km… 50 Mio light years!)

M87: the jet

⭐The jet is moving with relativistic speed (meaning nearly at the speed of light)

⭐Because of this, it is possible that when we observe it, it looks like the material is travelling actually faster than light…



⭐It is one of the best-studied jet

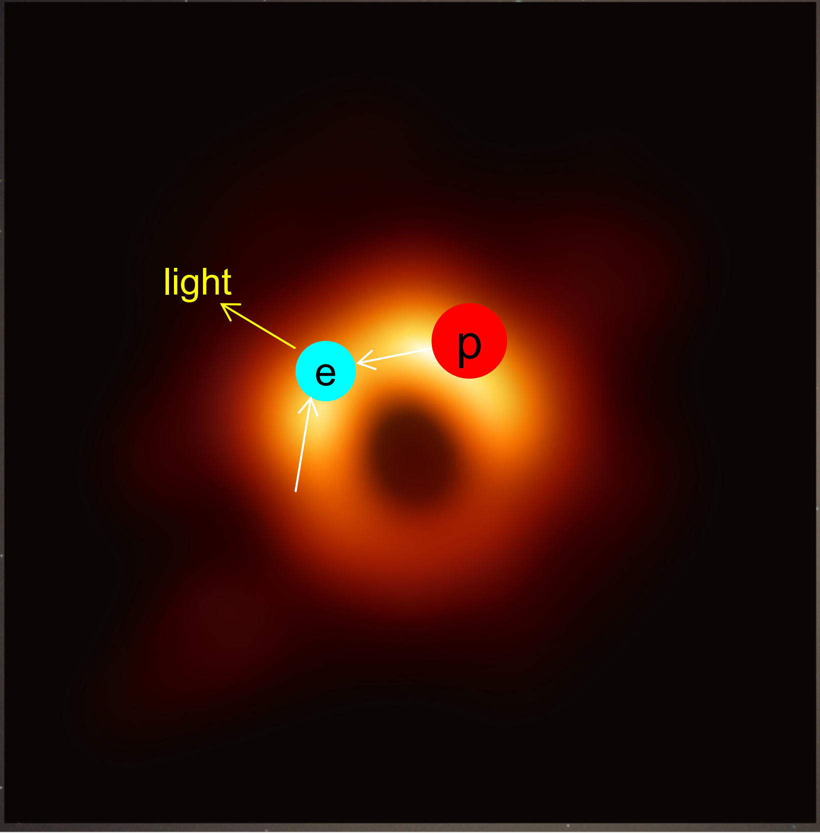
⭐We see the jet inclined, not directly pointing at us, but also not completely perpendicular

M87: the black hole

- This image is the first-ever direct image of a black hole.
- Observing the matter so close to the black hole at this distance is equivalent to look at a credit at the surface of the Moon.

- What we actually see: the heated plasma (gas) orbiting around the black hole.
- The black hole here is 6 billion times heavier than the Sun!

M87: the accretion flow



This image is taken in the radio domain: it means that the particles around the black hole must emit radio light. How?

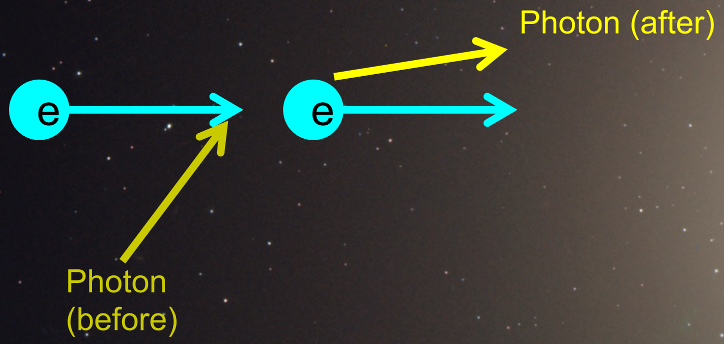
Synchrotron radiation

When an electron passes by a magnetic field:

- It spirals along the field lines.
- It is a charged particle so it emits light
- The wavelength of the emission depends on the magnetic field strength and on the electron energy

This phenomenon happens in the accretion flow and in the jet.

Inverse Compton scattering

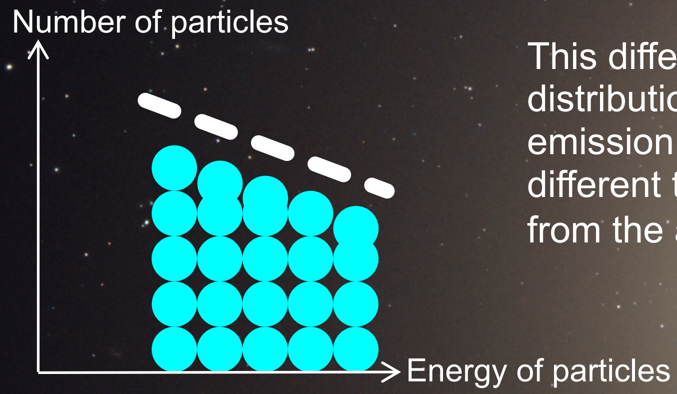


When a high-energy electron collides with a low-energy photon:

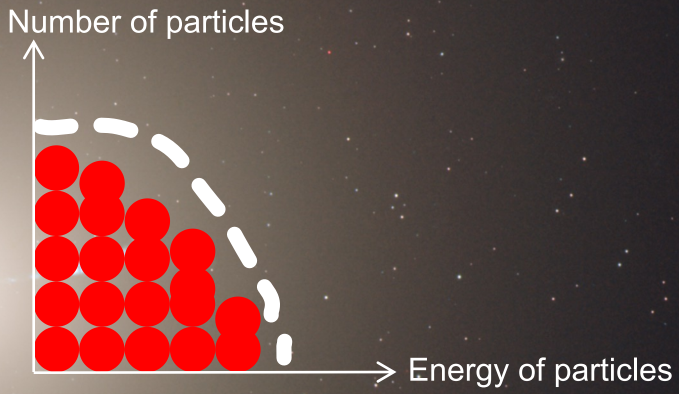
- The photon gains energy → we say it is upscattered
- It is a charged particle so it emits light
- The wavelength of the emission depends on the photon density and on the electron energy

This phenomenon happens in the accretion flow and in the jet. It is usually responsible for the X-ray or even gamma-ray emission in the source.

Difference between the particles of the jet and of the accretion disk



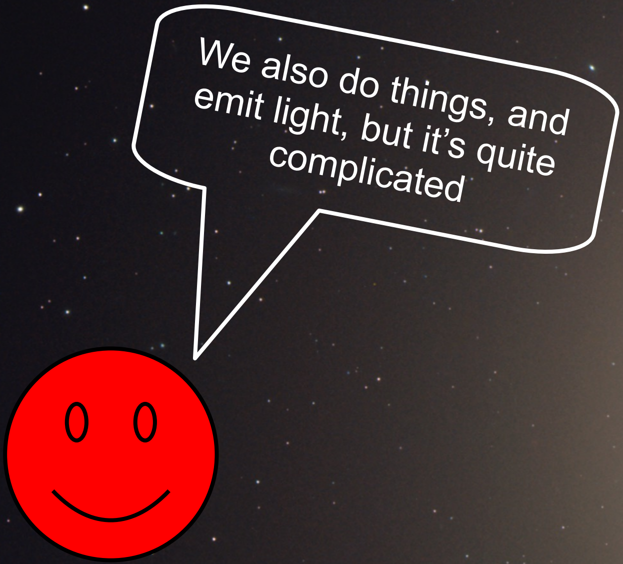
This difference in the distribution makes the emission from the jet look different than the one from the accretion disk



In the jet: particles are accelerated somehow → they are thought to follow a power law

In the disk: particles are not accelerated → they are "thermal" and their distribution is defined by the temperature

Protons



- ⭐Protons interactions in the jet lead to the emission of very-high-energy light…
- ⭐… if they have sufficient energy themselves!
- ⭐It is not clear whether there are high-energy protons in the jets

In our model we consider that something is able to accelerate protons

Real data!

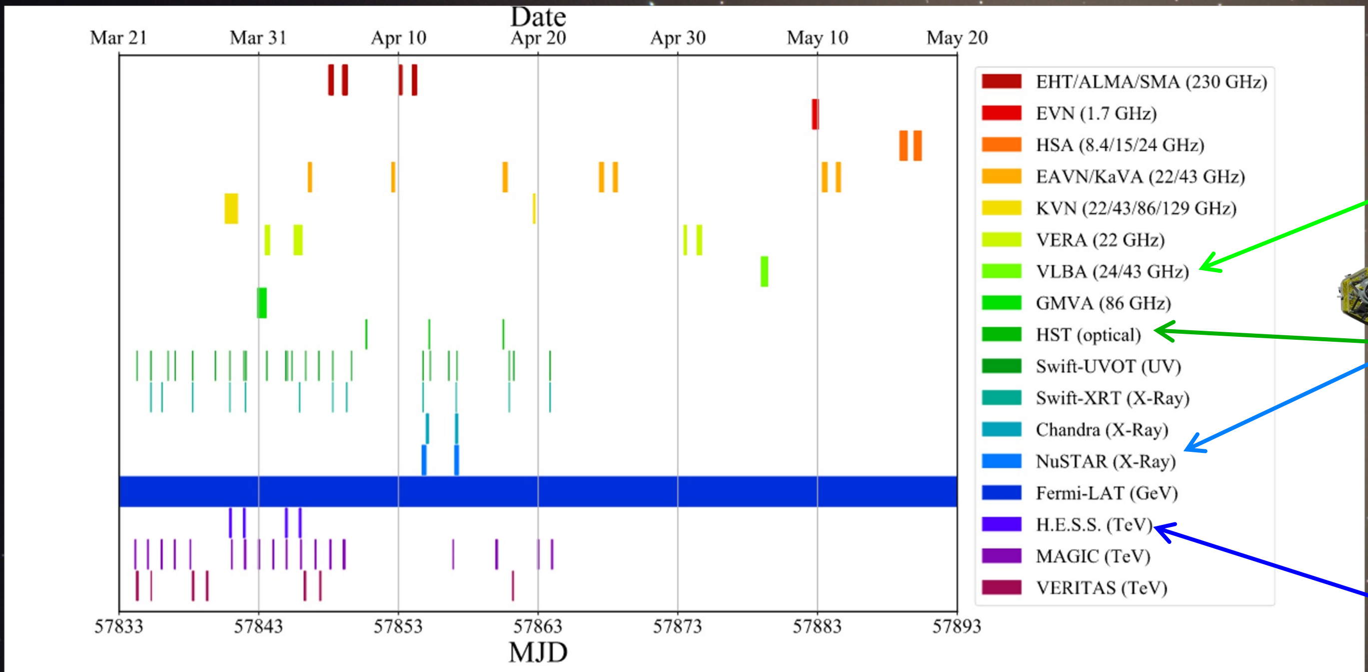
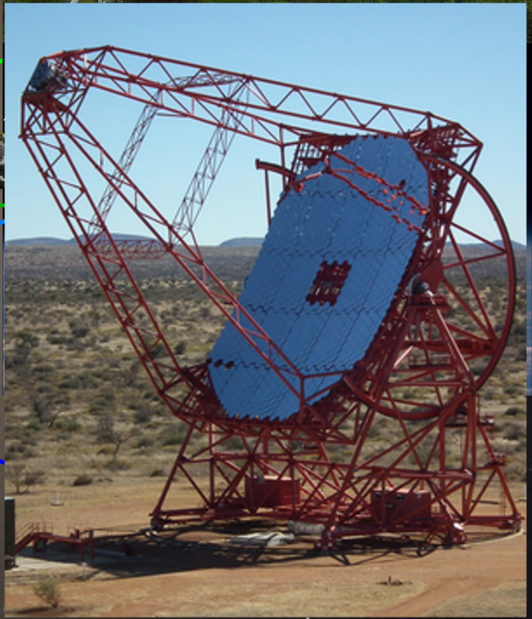
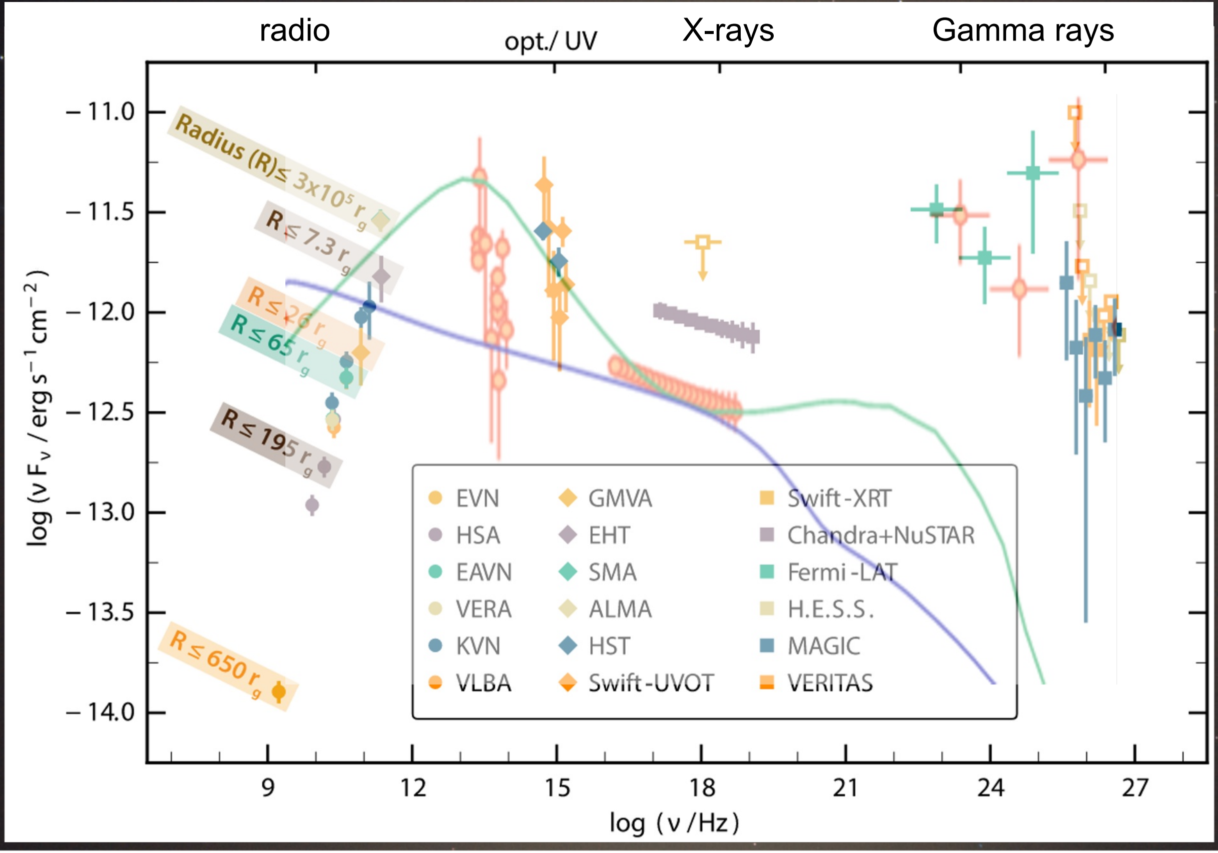


Figure 1. Instrument coverage summary of the 2017 M87 MWL campaign, covering MJD range 57833–57893. (Made with the `MWLGen` software by J. Farah.)

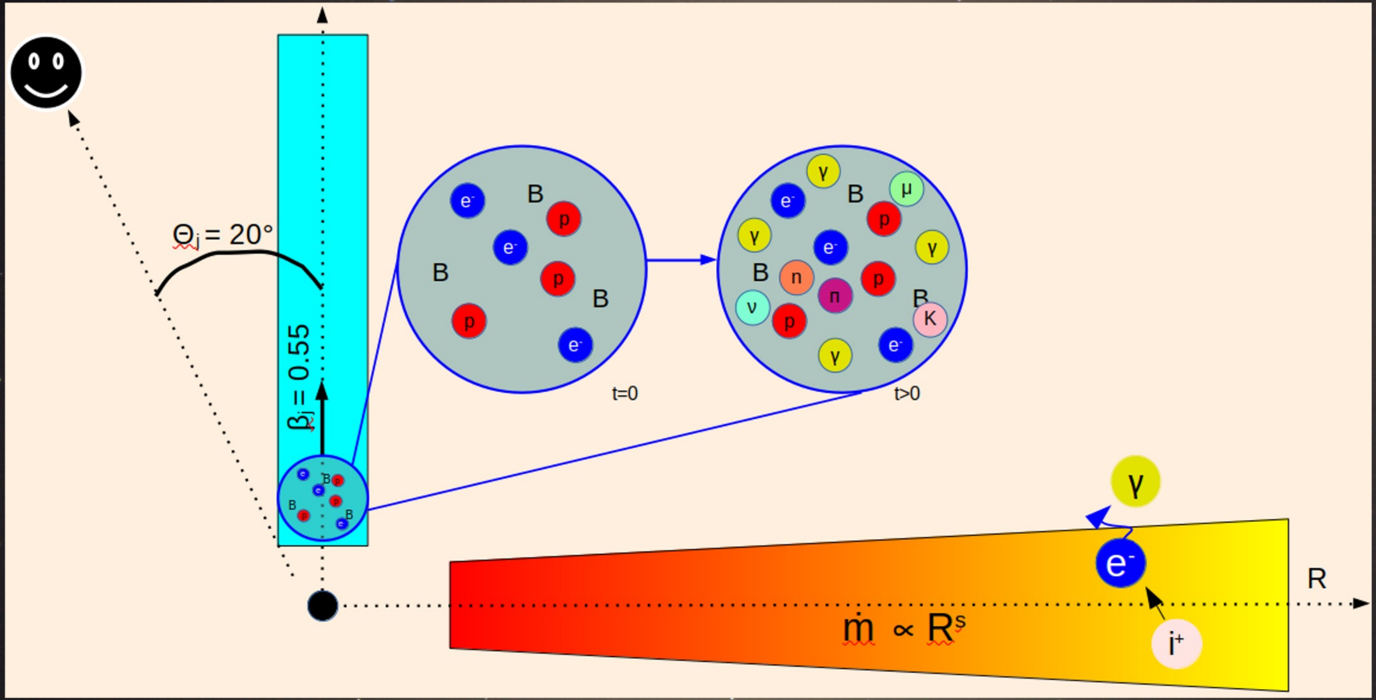


Real data!



This shows us how bright the source is, when seen from Earth, depending on the frequency of the light (the wavelength)

The model

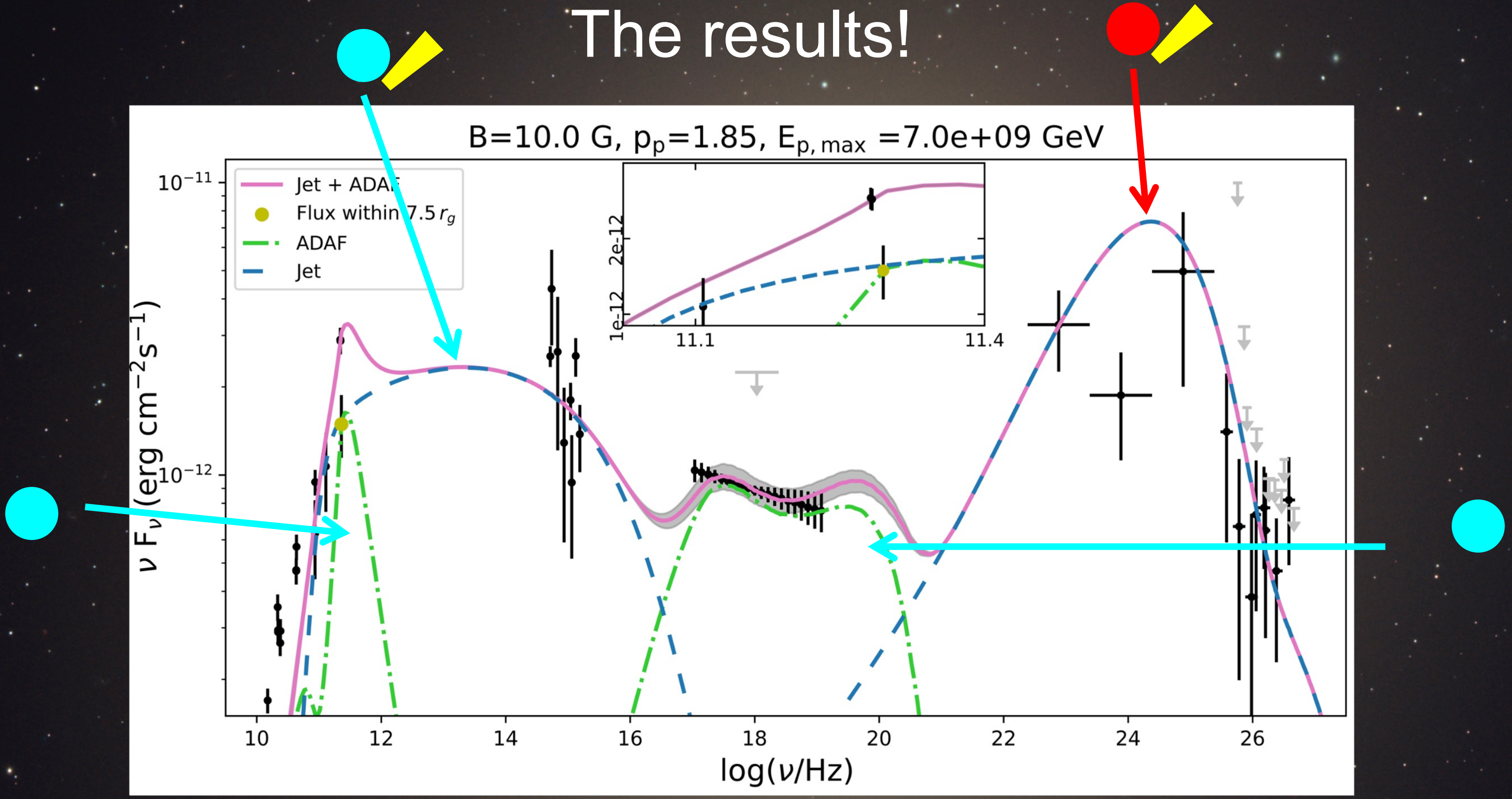


Now we wait...

- Simulations need time to run
- I need time to figure out what bug there is in my code
- Then I need to think whether the parameter values I use make sens not
- We discuss these in meetings
- I adjust the code

TADAM

The results!



B=10.0 G, p_p=1.85, $E_{p,max}$ =7.0e+09 GeV
Jet + ADAF
Flux within 7.5 r_g
ADAF
Jet
νF_ν (erg cm^{-2}s^{-1})
10^{-11}
10^{-12}
log(ν/Hz)
10
12
14
16
18
20
22
24
26
2e-12
1e-12
11.1
11.4

The results!

Happy astrophysicists!

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