Institut de Física d'Altes Energies

EXCELENCIA SEVERO OCHOA

Barcelona Institute of Science and Technology

ESCAPE
European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

Active Galaxies with Jets

and their radiative processes

Pizza Seminar 2/12/2020

Cosimo Nigro

Outline

> Observational history (images)

> Emission Mechanisms (spectra)

> Advertisement

Observational History

"Our path leads us past Murasaki 312, a quasar-like formation..."

The Galileo Seven

https://youtu.be/msiBWGDsEYQ

“Our path leads us past Murasaki 312, a quasar-like formation, vague, undefined.”

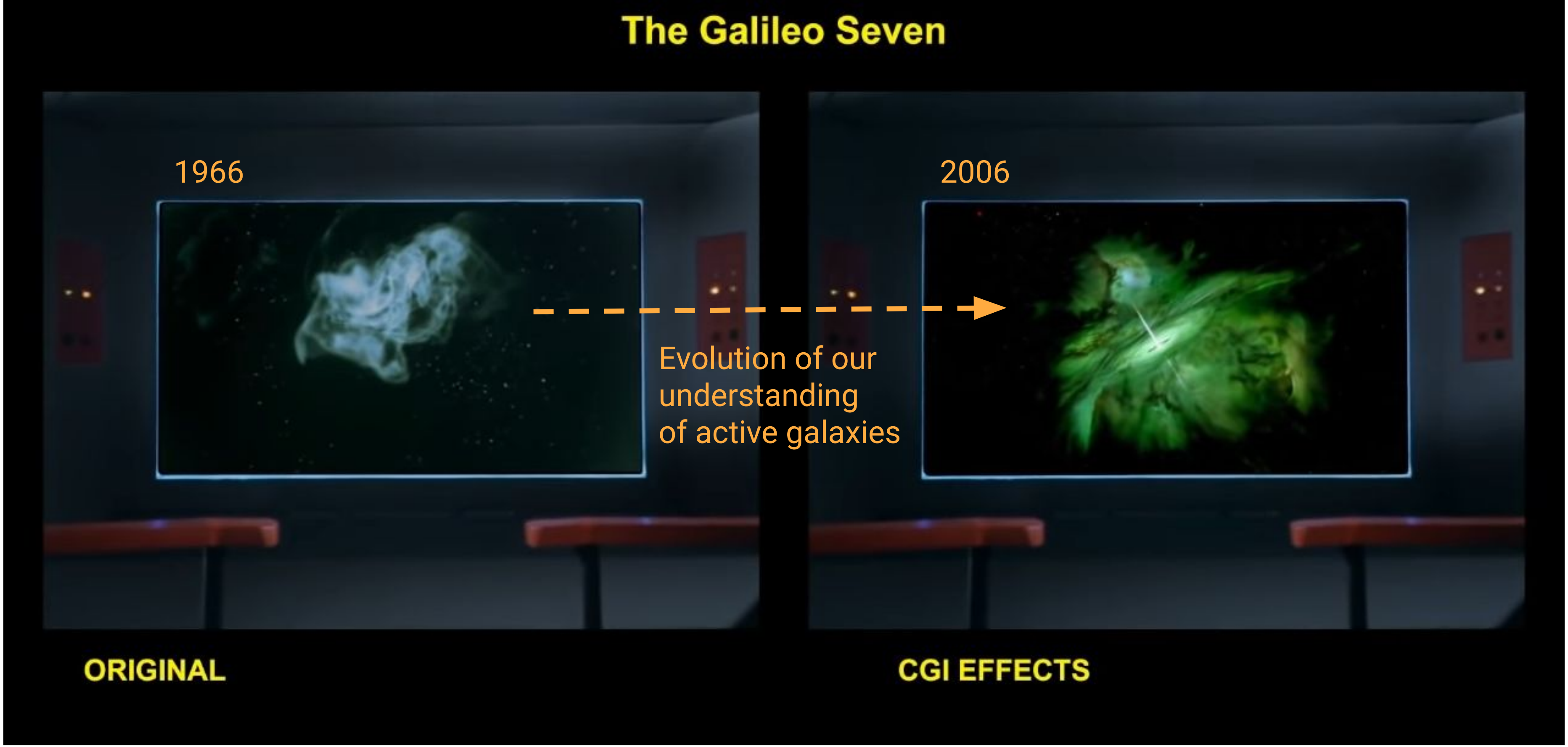
The Galileo Seven

ORIGINAL

CGI EFFECTS

https://youtu.be/msiBWGDsEYQ

“Our path leads us past Murasaki 312, a quasar-like formation, vague, undefined.”

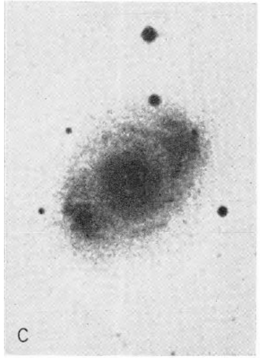


https://youtu.be/msiBWGDsEYQ

Early Optical Observations of AGN

> **18th century - early 20th century**: considered as nebulae;

NGC 4151

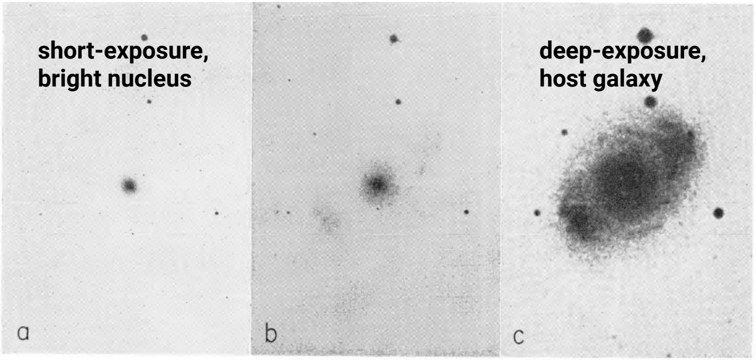


Early Optical Observations of AGN

> **18th century - early 20th century**: considered as nebulae;

> **1910s**: some nebulae show a **very bright nucleus**

NGC 4151

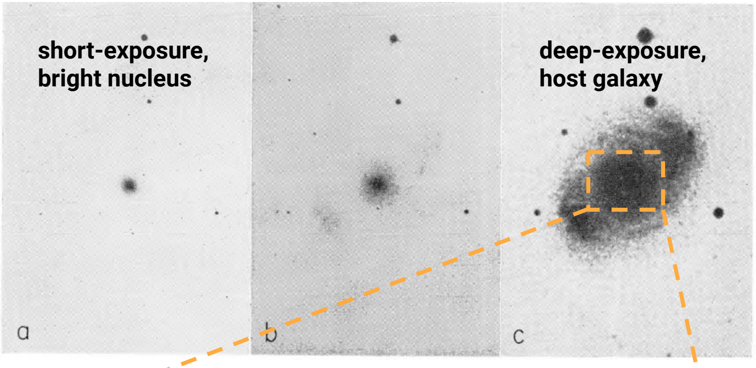


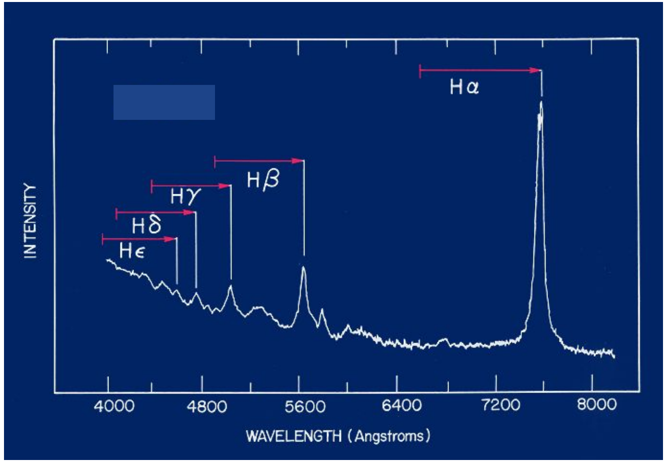
Early Optical Observations of AGN

> **18th century - early 20th century**: considered as nebulae;

> **1910s**: some nebulae show a **very bright nucleus** and **broadening of optical lines** compatible with motion at speeds ~10 000 km/s;

NGC 4151





$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta v}{c}$$

Early Optical Observations of AGN

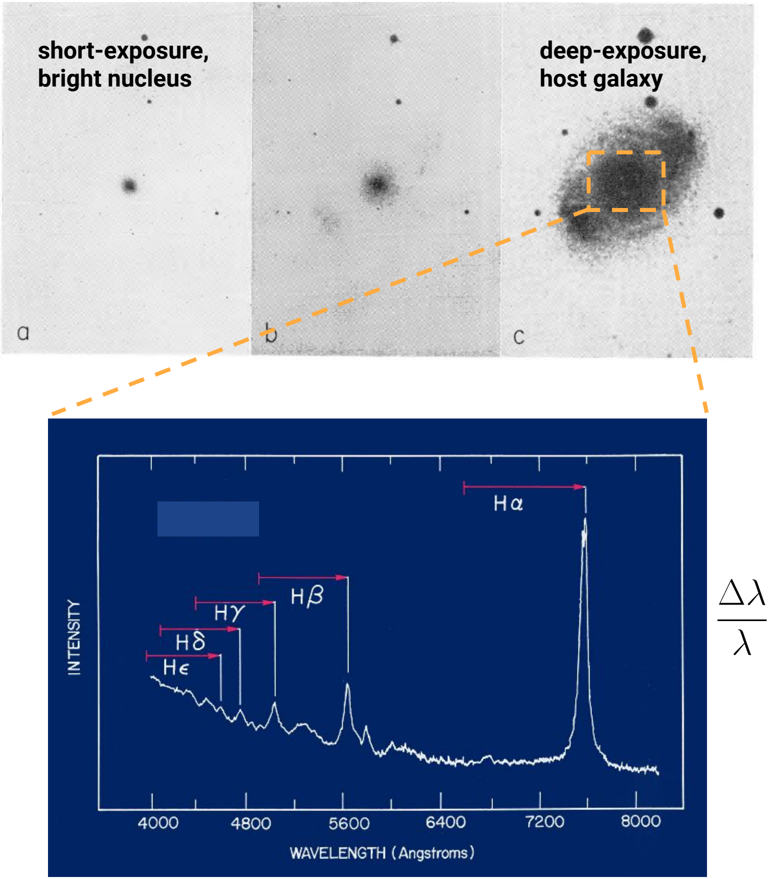
> **18th century - early 20th century**: considered as nebulae;

> **1910s**: some nebulae show a **very bright nucleus** and **broadening of optical lines** compatible with motion at speeds ~10 000 km/s;

> **1920s**: Hubble measures their distances, not compatible with galactic size;

> **1943** Seyfert distinguishes two types of *galaxies*:
- **Seyfert 1** with **Broad Lines**, $\Delta v \gtrsim 10^4$ km/s,
- **Seyfert 2** with **Narrow Lines**, $\Delta v \lesssim 10^3$ km/s;

NGC 4151



$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta v}{c}$$

Early Optical Observations of AGN

> **18th century - early 20th century**: considered as nebulae;

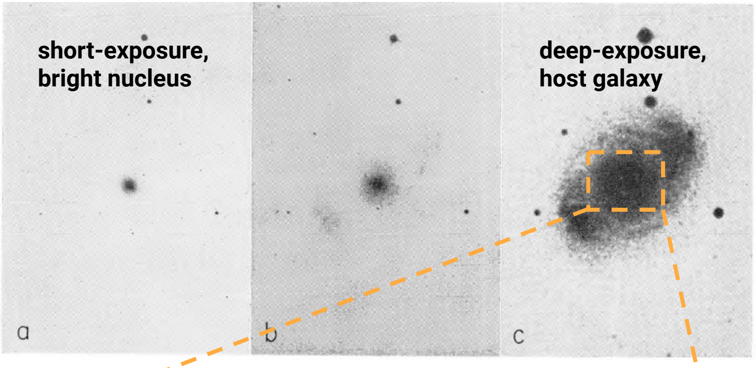
> **1910s**: some nebulae show a **very bright nucleus** and **broadening of optical lines** compatible with motion at speeds ~10 000 km/s;

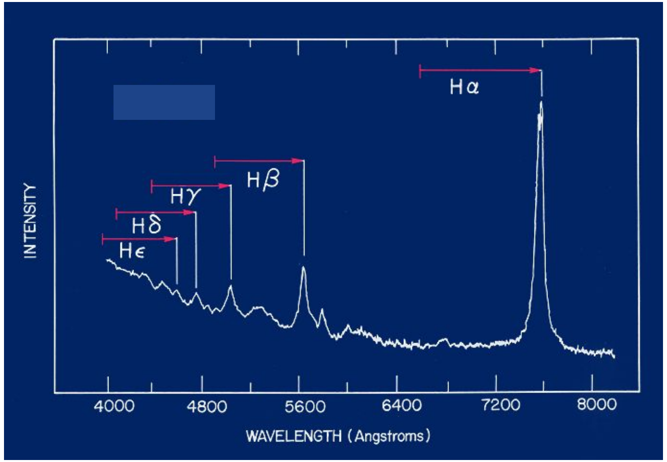
> **1920s**: Hubble measures their distances, not compatible with galactic size;

> **1943** Seyfert distinguishes two types of *galaxies*:
- **Seyfert 1** with **Broad Lines**, $\Delta v \gtrsim 10^4$ km/s,
- **Seyfert 2** with **Narrow Lines**, $\Delta v \lesssim 10^3$ km/s;

> **global picture in the early 1960s**:
- central **bright engine** L $\gtrsim 10^{46}$ erg/s (10^{39} W);
- ionises fastly moving gas (orbital motion 10^9 $M_\odot$?);
- region ~ 0.01 pc ($3 \cdot 10^{16}$ cm) emitting Broad Lines;
- region ~ 100 pc emitting Narrow Lines;

NGC 4151

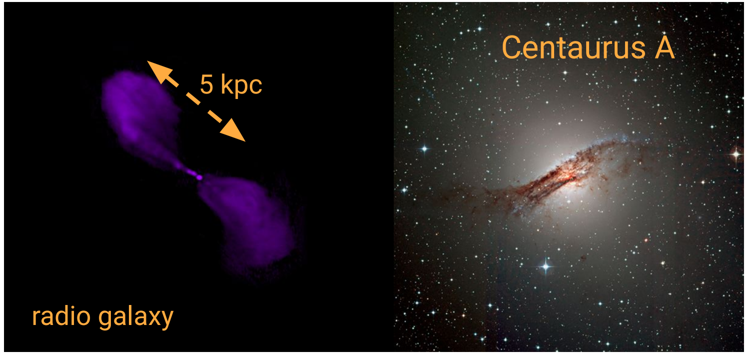




$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta v}{c}$$

Radio Observations of AGN

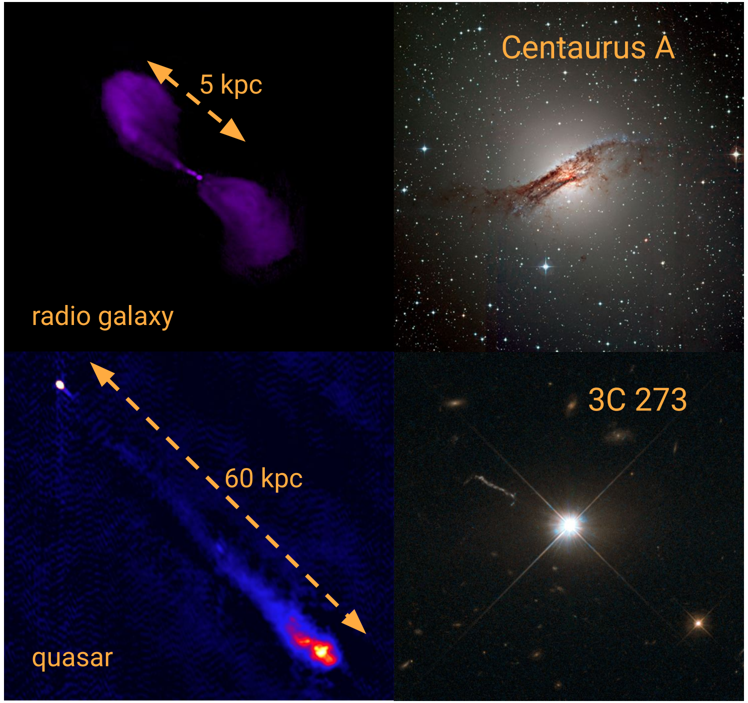
> **1950s : 1/10** active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;



Radio Observations of AGN

> **1950s : 1/10** active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;

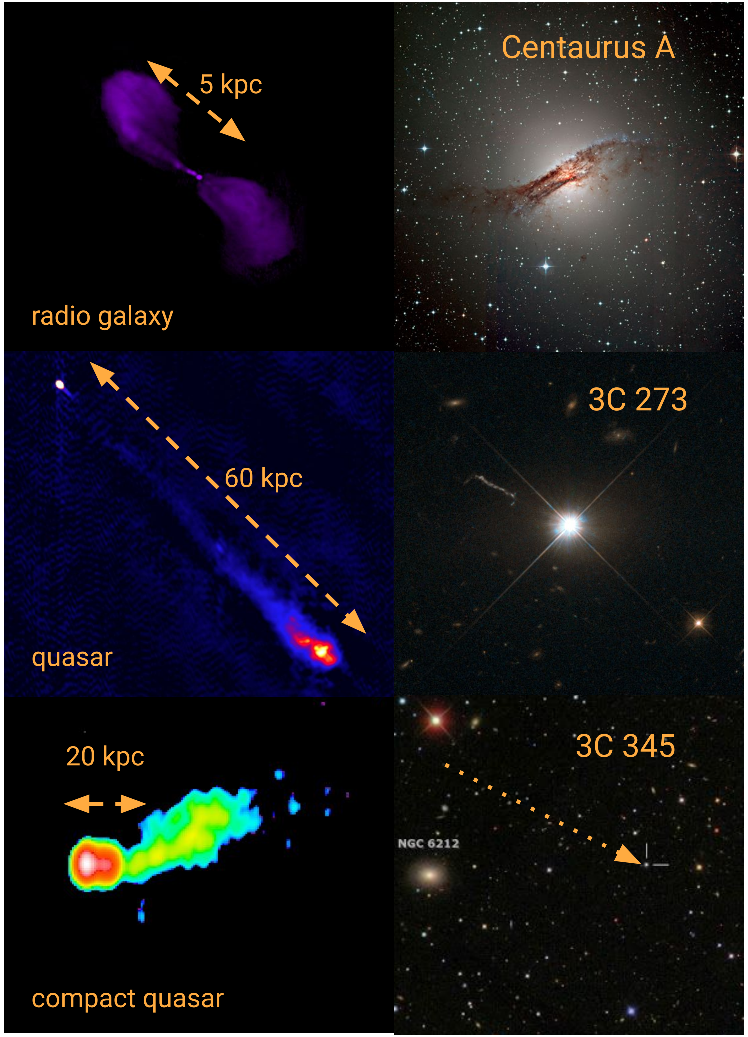
> **1960s**: first radio survey of the northern sky (3C):
   - some jetted radio sources do not match optical galaxies, quasi-stellar counterpart: *quasar*;



Radio Observations of AGN

> **1950s : 1/10** active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;

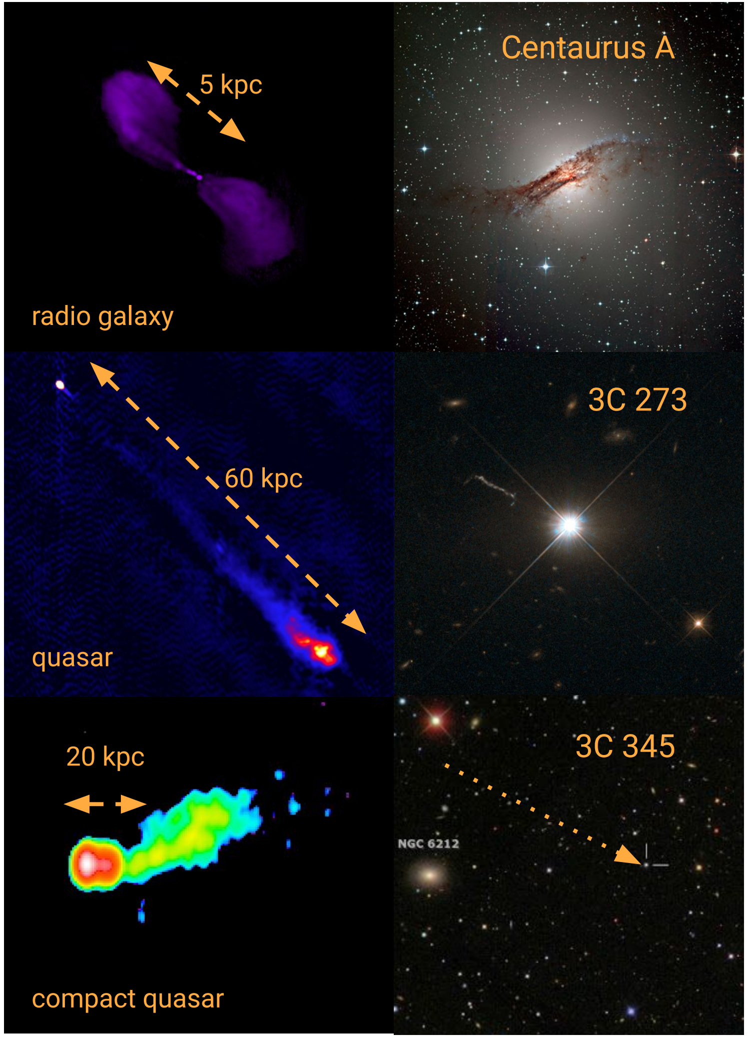
> **1960s**: first radio survey of the northern sky (3C):
- some jetted radio sources do not match optical galaxies, quasi-stellar counterpart: *quasar*;
- many quasars are compact, unresolved at VLBI;



Radio Observations of AGN

> 1950s : 1/10 active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;

> 1960s: first radio survey of the northern sky (3C):
- some jetted radio sources do not match optical galaxies, quasi-stellar counterpart: *quasar*;
- many quasars are compact, unresolved at VLBI;
- **quasars** very far ($z \geq 0.2$) and very bright L_{radio}~10^{44}-10^{46} erg/s, they show **broad lines**;
- are they isolated engines (w/o host galaxy)?

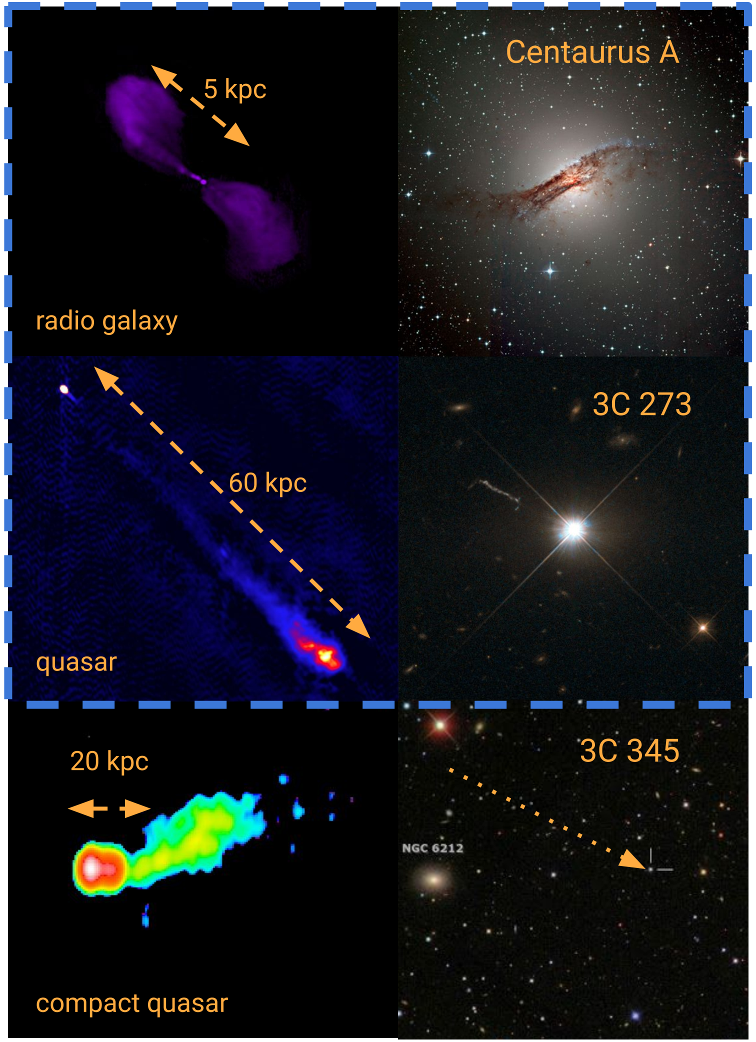


Radio Observations of AGN

> 1950s : 1/10 active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;

> 1960s: first radio survey of the northern sky (3C):
- some jetted radio sources do not match optical galaxies, quasi-stellar counterpart: *quasar*;
- many quasars are compact, unresolved at VLBI;
- **quasars** very far ($z \geq 0.2$) and very bright $L_{radio} \sim 10^{44}$-10^{46} erg/s, they show **broad lines**;
- are they isolated engines (w/o host galaxy)?

> 1970-80 unification by brightness contrast:
- galaxy-like density profile resolved for low-z quasars: bright nucleus outshining the host;



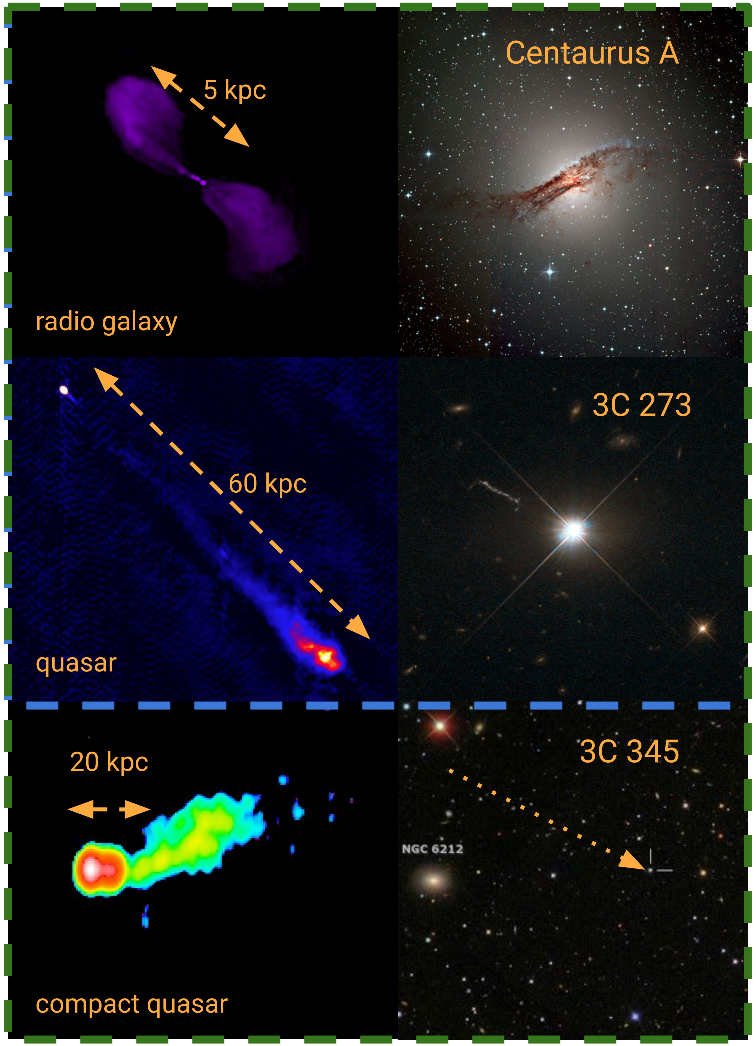
Radio Observations of AGN

> **1950s : 1/10** active galaxies present a extended jetted radio emission, dumbbell shape, they emit narrow lines;

> **1960s**: first radio survey of the northern sky (3C):
- some jetted radio sources do not match optical galaxies, quasi-stellar counterpart: *quasar*;
- many quasars are compact, unresolved at VLBI;
- **quasars** very far ($z \geq 0.2$) and very bright $L_{radio} \sim 10^{44}$-10^{46} erg/s, they show **broad lines**;
- are they isolated engines (w/o host galaxy)?

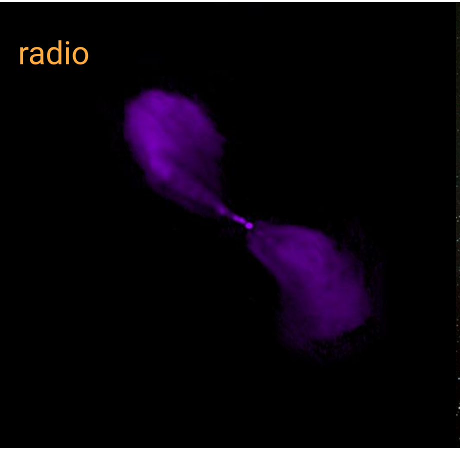
> **1970-80 unification by brightness contrast**:
- galaxy-like density profile resolved for low-z quasars: bright nucleus outshining the host;

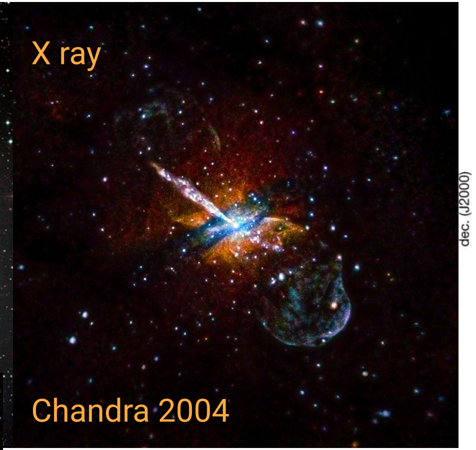
> **1979 unification by viewing angle**:
- compact and extended radio sources differ only by the viewing angle.

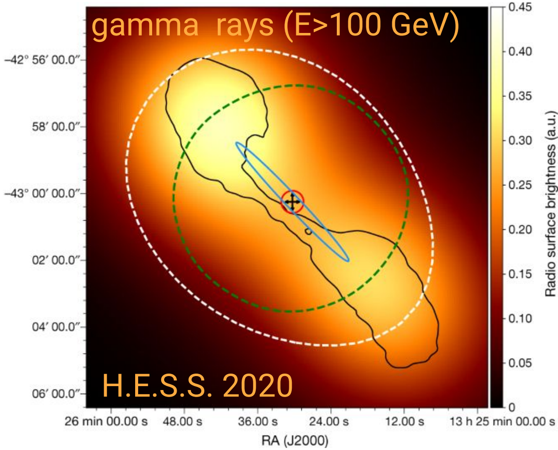


X-ray and Gamma-ray Observations of Jetted AGNs

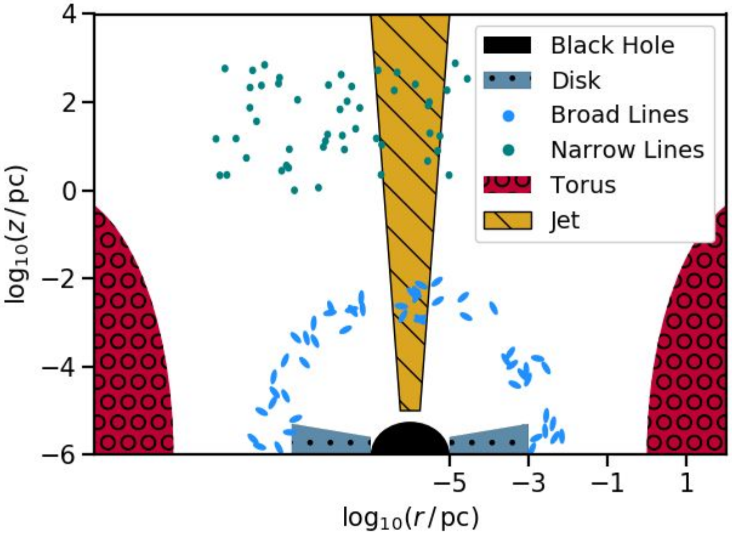
> **1978**: the first imaging x-ray satellite is launched;
> **1990s**: operation of space and ground-based gamma-ray telescopes.



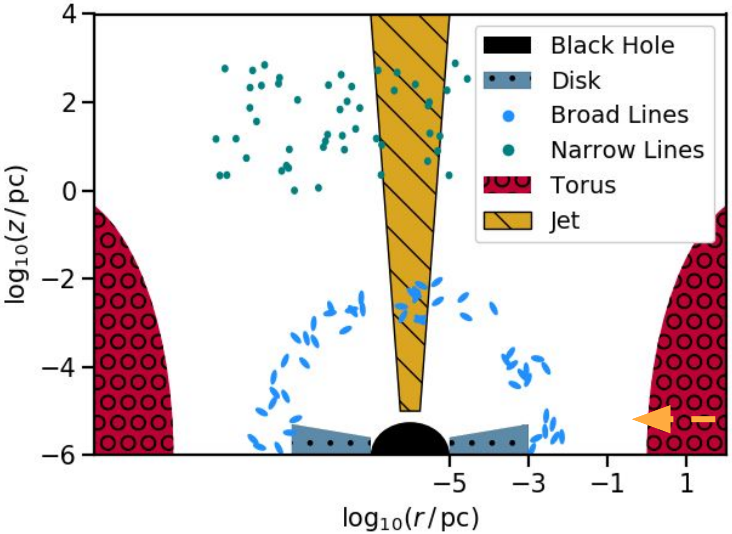


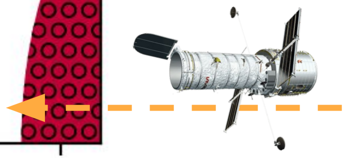


Unified Scheme Active Galaxies with Jets



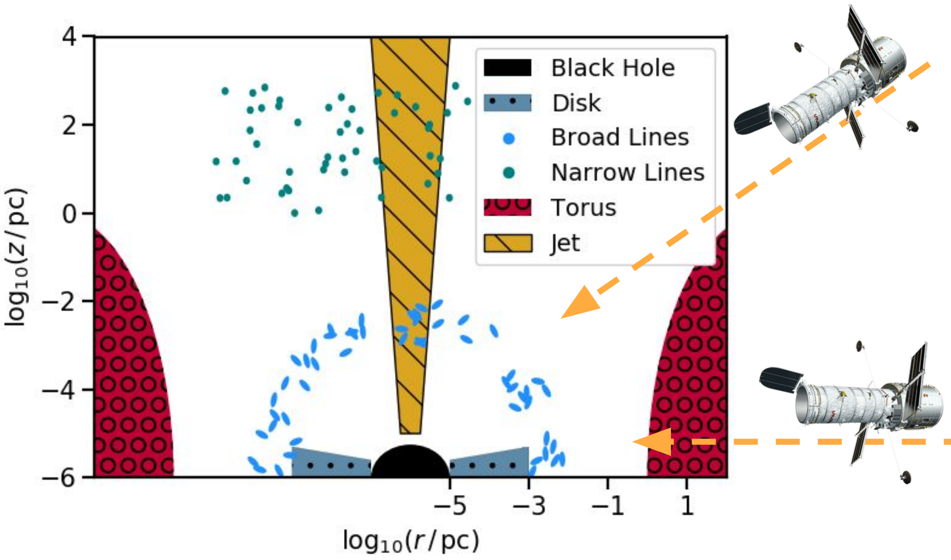
Unified Scheme Active Galaxies with Jets





jet: extended (dumbbell) radio galaxy + narrow lines
no jet: Seyfert 2
broad line emission obscured

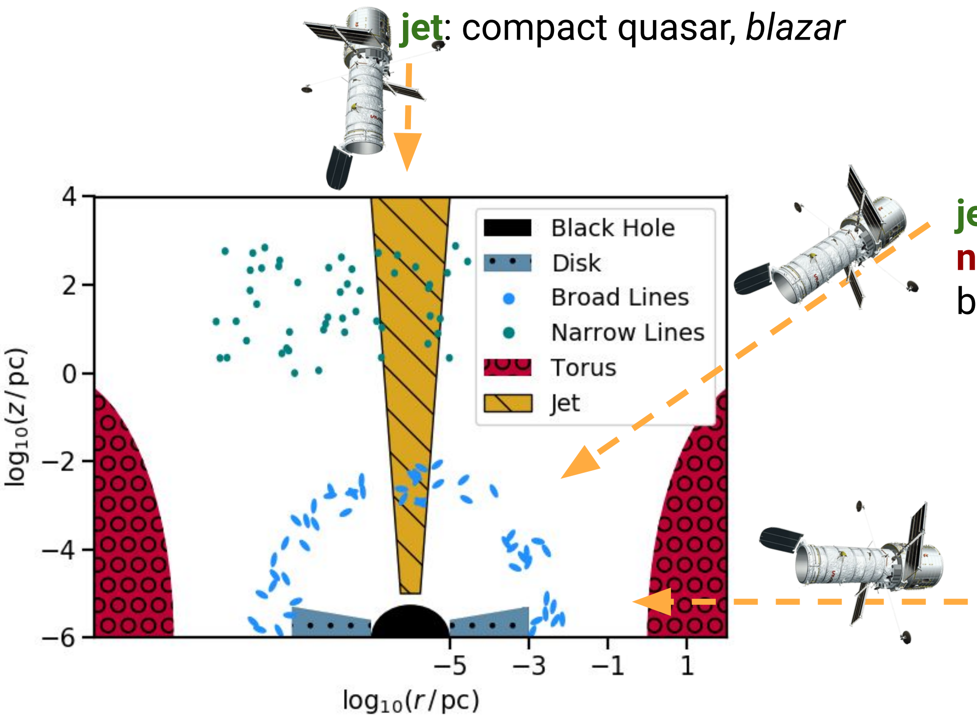
Unified Scheme Active Galaxies with Jets



jet: extended radio galaxy + broad lines
no jet: Seyfert 1
broad line emission not obscured

jet: extended (dumbbell) radio galaxy + narrow lines
no jet: Seyfert 2
broad line emission obscured

Unified Scheme Active Galaxies with Jets



jet: compact quasar, *blazar*

jet: extended radio galaxy + broad lines
no jet: Seyfert 1
broad line emission not obscured

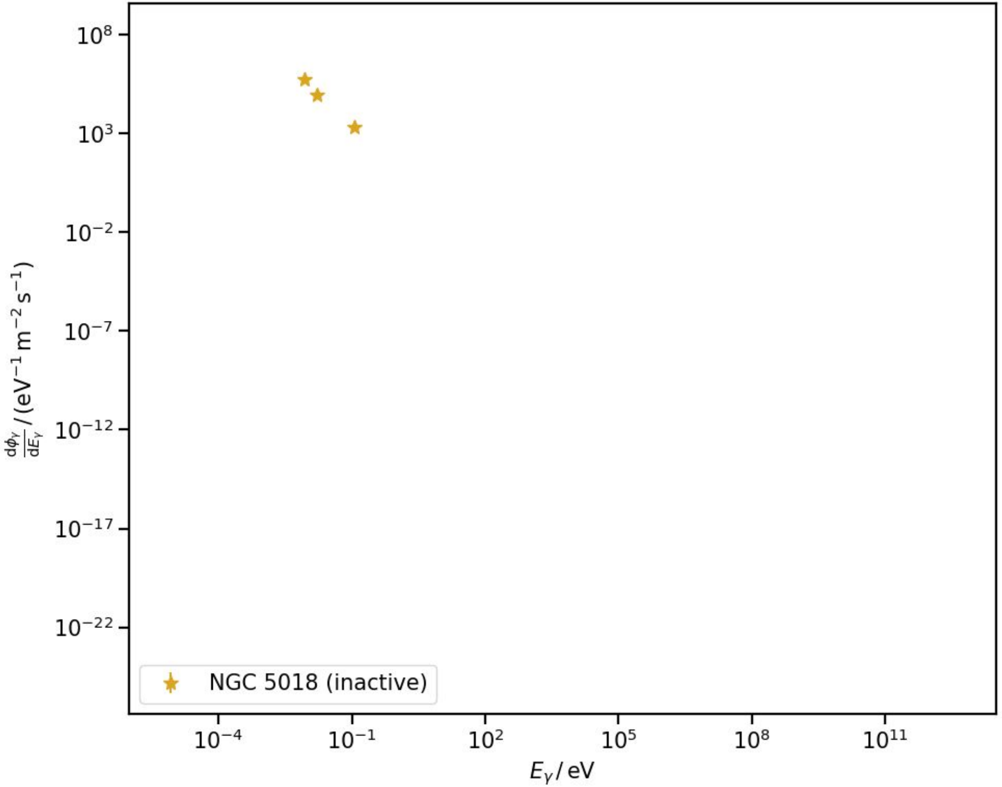
jet: extended (dumbbell) radio galaxy + narrow lines
no jet: Seyfert 2
broad line emission obscured

Jetted sources have doppler-boosted emission: $L_{\rm obs} = \delta_D^4 L_{\rm em}$

$$\delta_D = [\Gamma_{\rm jet}(1 - \beta_{\rm jet}\cos\theta)]^{-1}$$

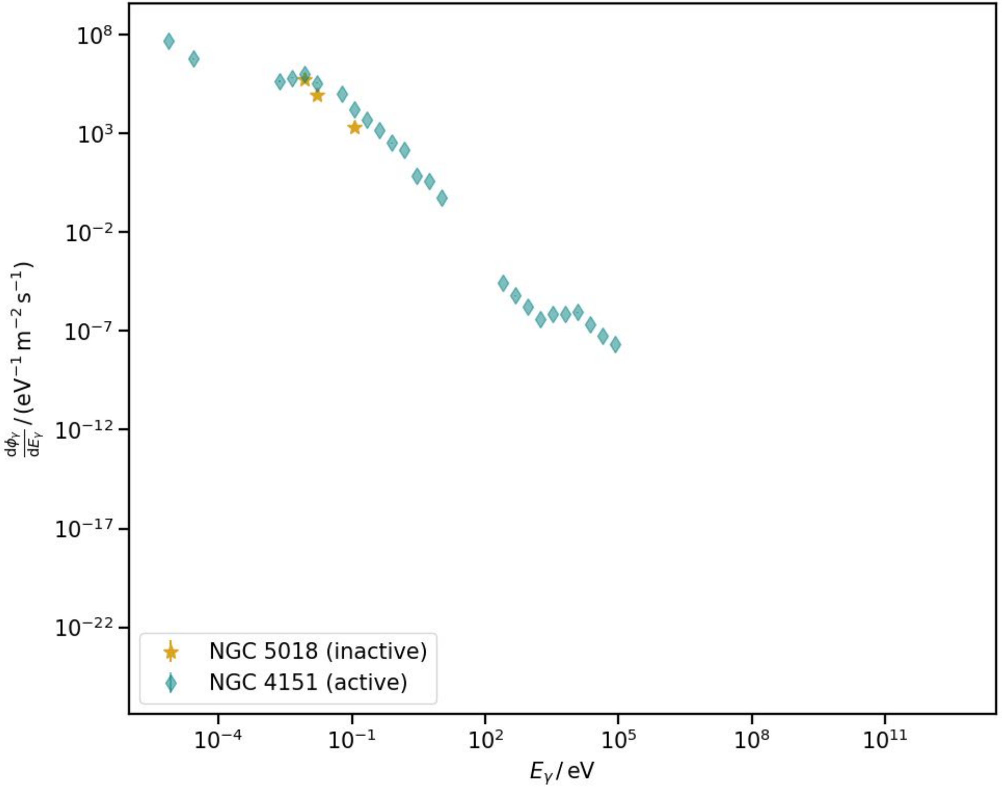
Emission Mechanisms

Broad-band Emission



> the emission of a **normal galaxy** is **thermal**, cumulative stellar black-body emission;

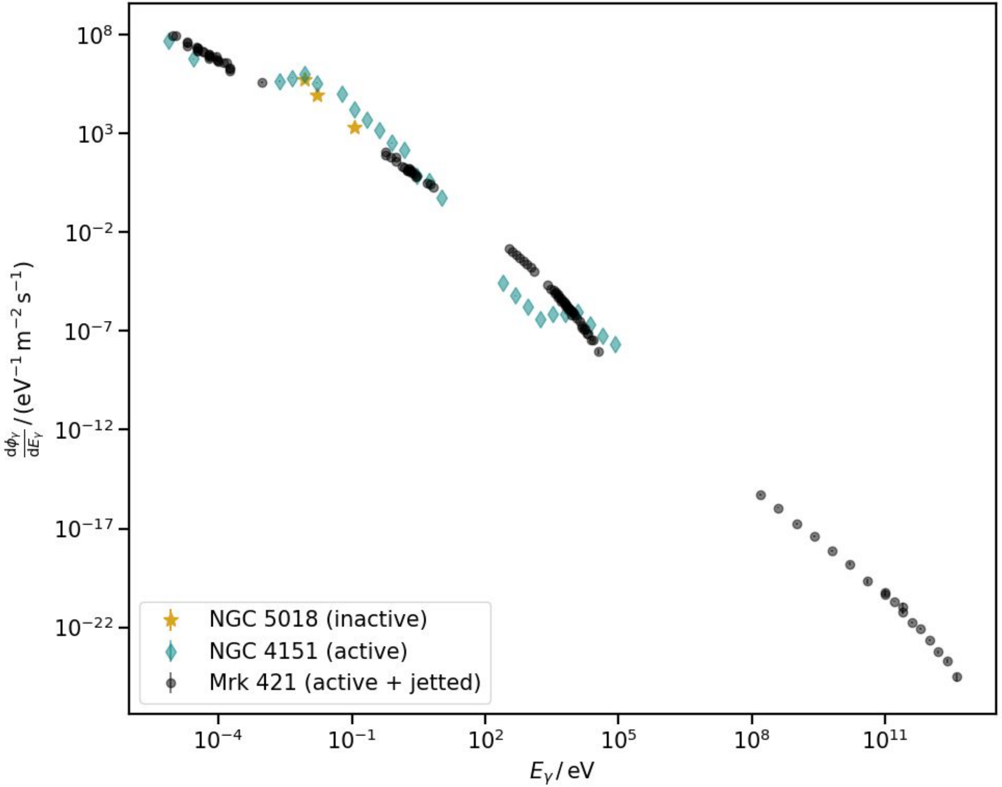
Broad-band Emission



> the emission of a **normal galaxy** is **thermal**, cumulative stellar black-body emission;

> the emission of an **active galaxy**, still **thermal**, is mostly due to its accretion disk;

Broad-band Emission

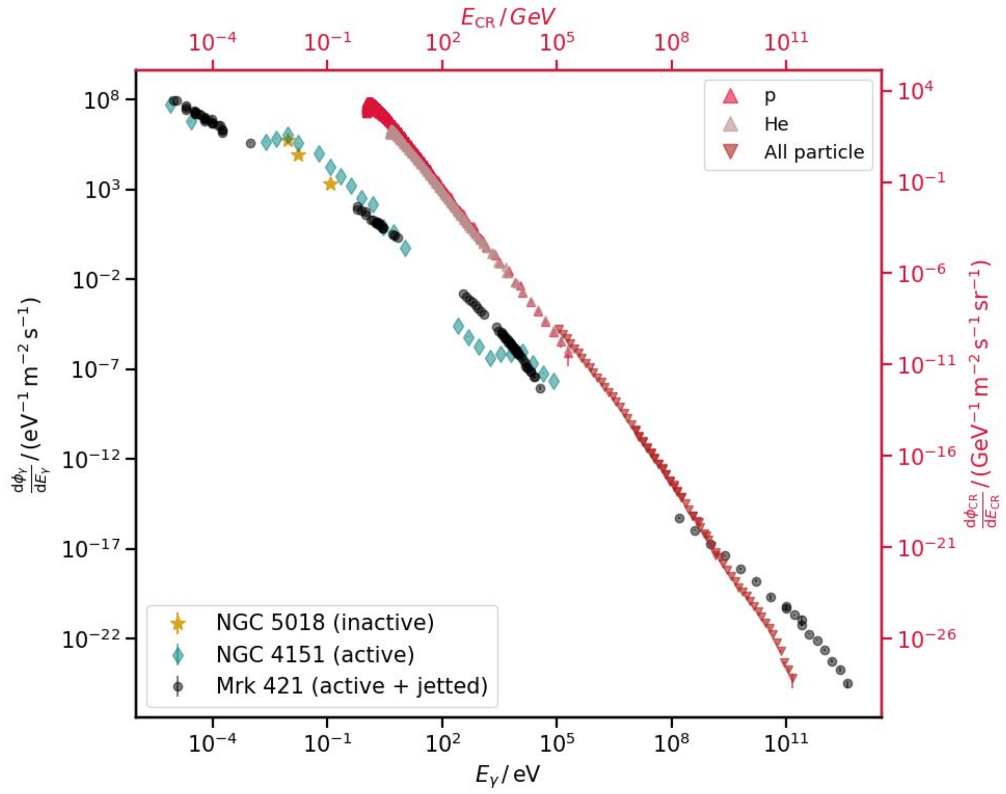


> the emission of a **normal galaxy** is **thermal**, cumulative stellar black-body emission;

> the emission of an **active galaxy**, still **thermal**, is mostly due to its accretion disk;

> a **jetted active galaxy** emits **non-thermal radiation** $d\Phi/dE \sim E^{-\Gamma}$ from radio to gamma-rays;

Broad-band Emission: Cosmic Fluxes



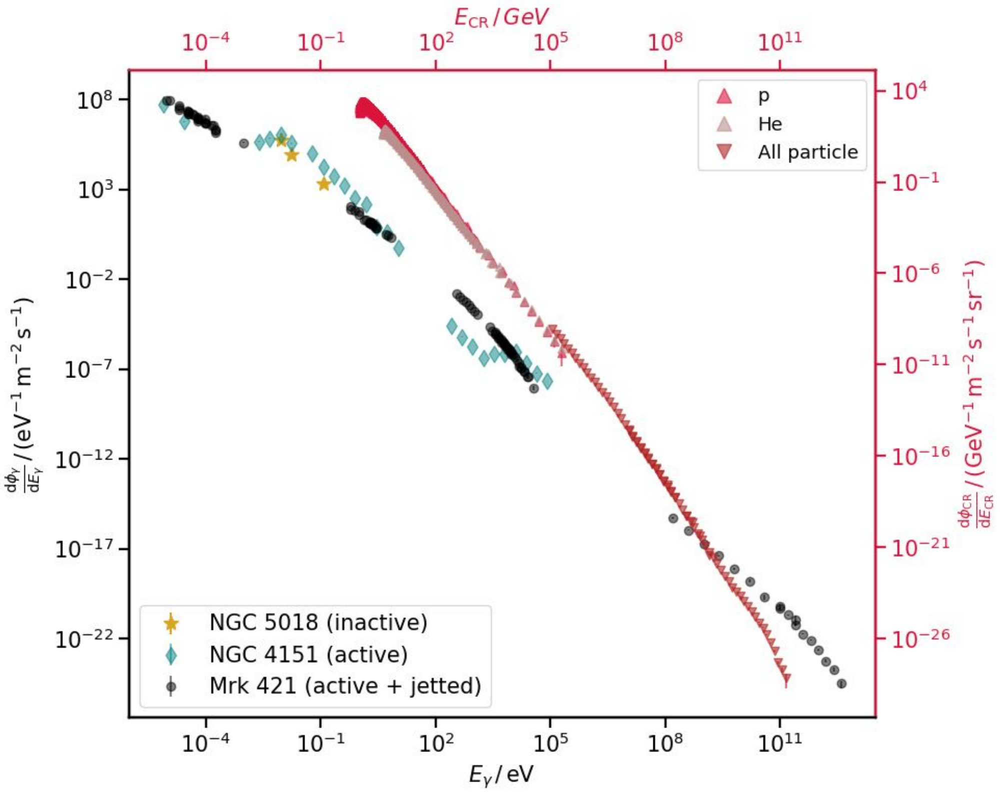
> the emission of a **normal galaxy** is **thermal**, cumulative stellar black-body emission;

> the emission of an **active galaxy**, still **thermal**, is mostly due to its accretion disk;

> a **jetted active galaxy** emits **non-thermal radiation** $d\Phi/dE \sim E^{-\Gamma}$ from radio to gamma-rays;

> radiative processes of power-law of relativistic charged particles;

Broad-band Emission: Cosmic Fluxes



> the emission of a **normal galaxy** is **thermal**, cumulative stellar black-body emission;

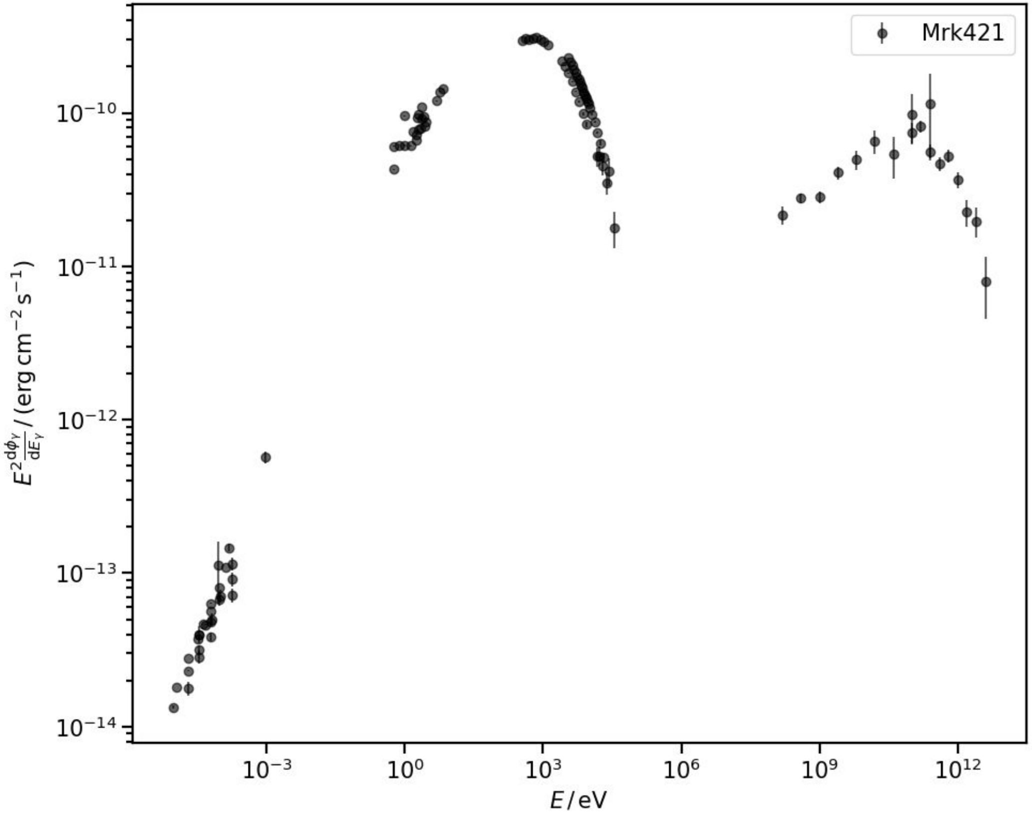
> the emission of an **active galaxy**, still **thermal**, is mostly due to its accretion disk;

> a **jetted active galaxy** emits **non-thermal radiation** $d\Phi/dE \sim E^{-\Gamma}$ from radio to gamma-rays;

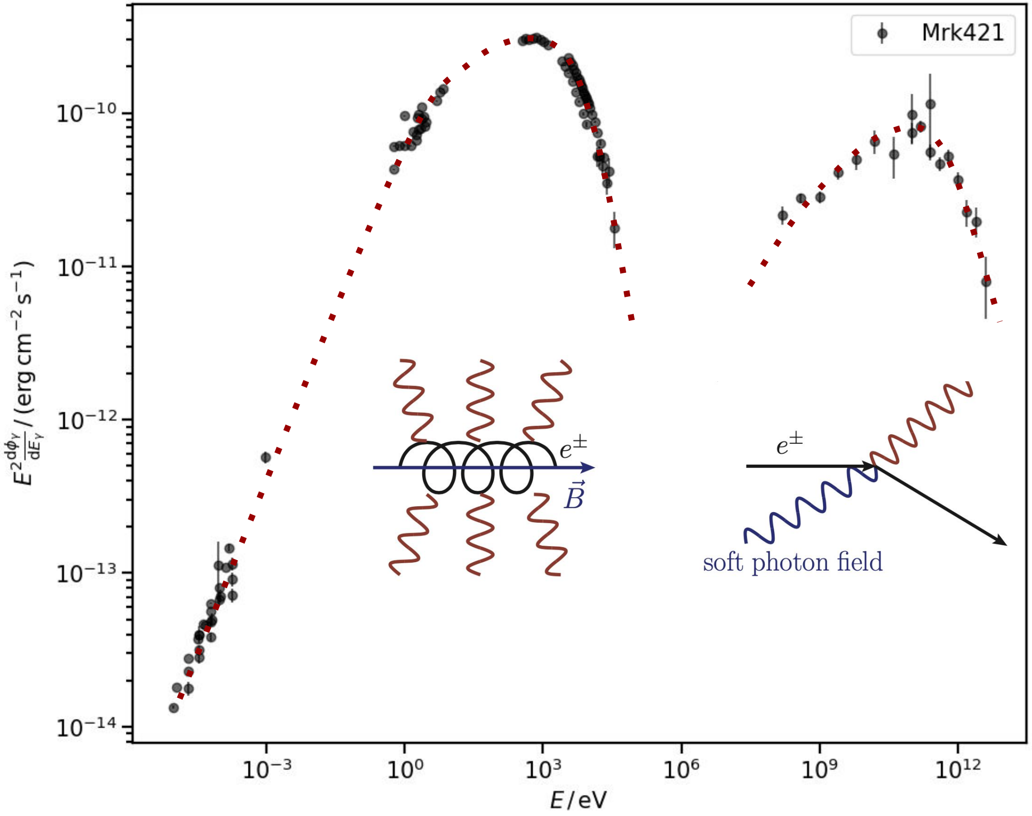
> radiative processes of power-law of relativistic charged particles;

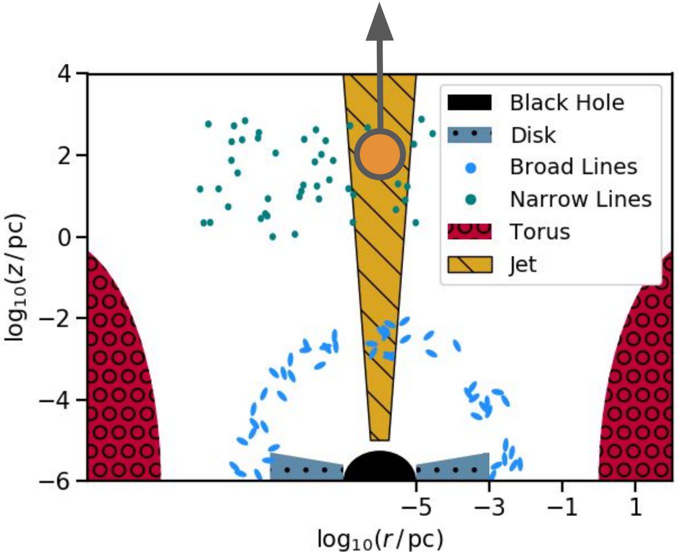
> **jets are the loci of particle acceleration**.

Spectral Energy Distribution



Spectral Energy Distribution





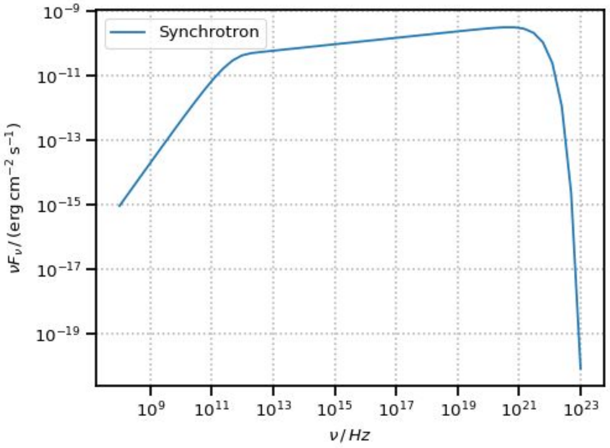
> a plasmoid streams along the jet and accelerates e$^\pm$ (*one-zone model*);
> low energy bump: ***synchrotron radiation***;
> high energy: ***Inverse Compton***
- on its own synchrotron photons (*synchrotron self-Compton*);
- on thermal / line radiation fields (*external Compton*).

Advertisement

agnpy

- I have created an open-source python package **modelling the broad-band emission of jetted active galaxies**;
- the package is built in the numpy + astropy ecosystem (increasingly dominant in astrophysics);
- the code is hosted on [GitHub](), the documentation on [readthedocs]();
- the idea is that with a few lines of python code one can obtain the spectrum due to a given radiative process.

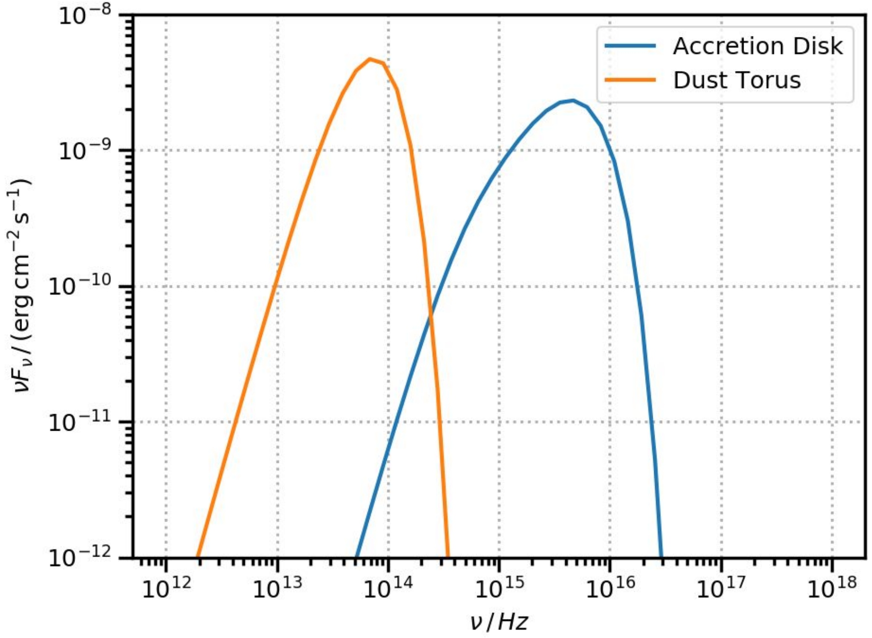
```python
import numpy as np
import astropy.units as u
from agnpy.emission_regions import Blob
from agnpy.synchrotron import Synchrotron
from agnpy.utils.plot import plot_sed
import matplotlib.pyplot as plt

# define the emission region and the radiative process
blob = Blob()
synch = Synchrotron(blob)
# compute the SED over an array of frequencies
nu = np.logspace(8, 23) * u.Hz
sed = synch.sed_flux(nu)
# plot it
plot_sed(nu, sed, label="Synchrotron")
plt.show()
```



agnpy

> the code contains also **classes describing the components emitting line and thermal radiation** (CMB, accretion disk, broad line region, dust torus);

> the spectrum due to their thermal emission can be evaluated;

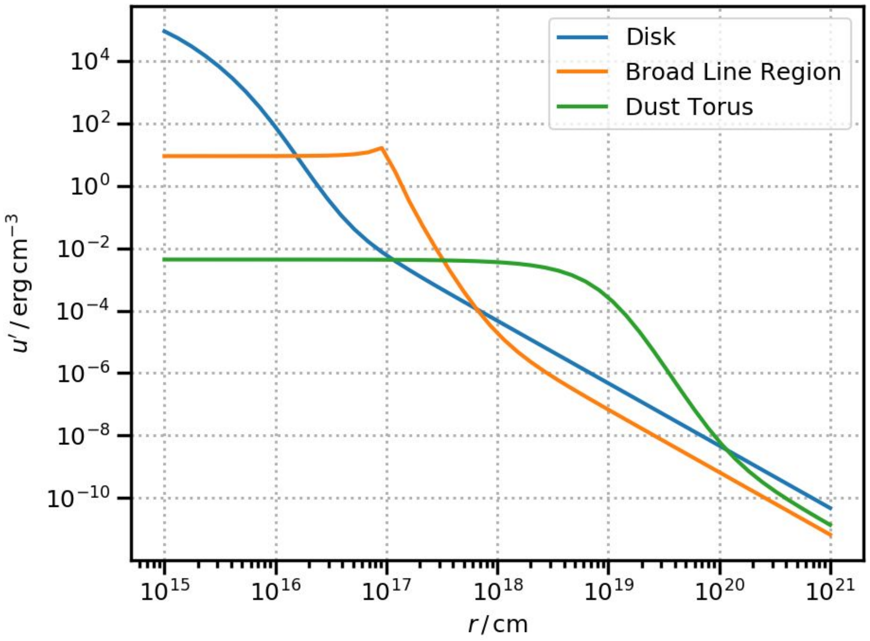


agnpy

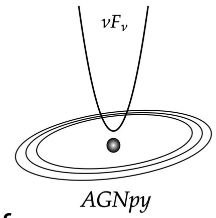
> the code contains also **classes describing the components emitting line and thermal radiation** (CMB, accretion disk, broad line region, dust torus);

> the spectrum due to their thermal emission can be evaluated;

> the density of their photon fields as a function of the distance along the jet can be evaluated;



agnpy



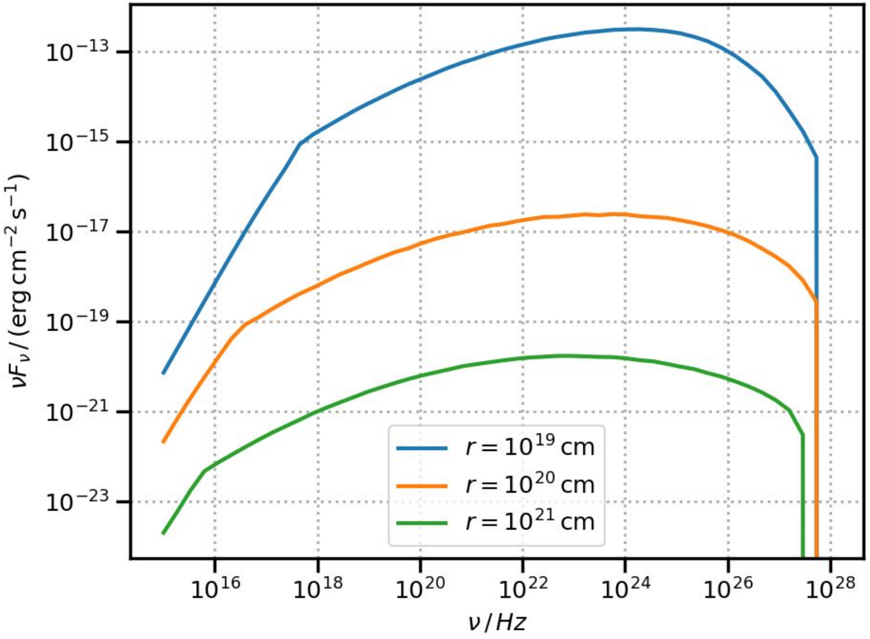
> the code contains also **classes describing the components emitting line and thermal radiation** (CMB, accretion disk, broad line region, dust torus);

> the spectrum due to their thermal emission can be evaluated;

> the density of their photon fields as a function of the distance along the jet can be evaluated;

> they can be used as a target for inverse Compton scattering;

External Compton of a power-law of electrons on dust torus photons



agnpy

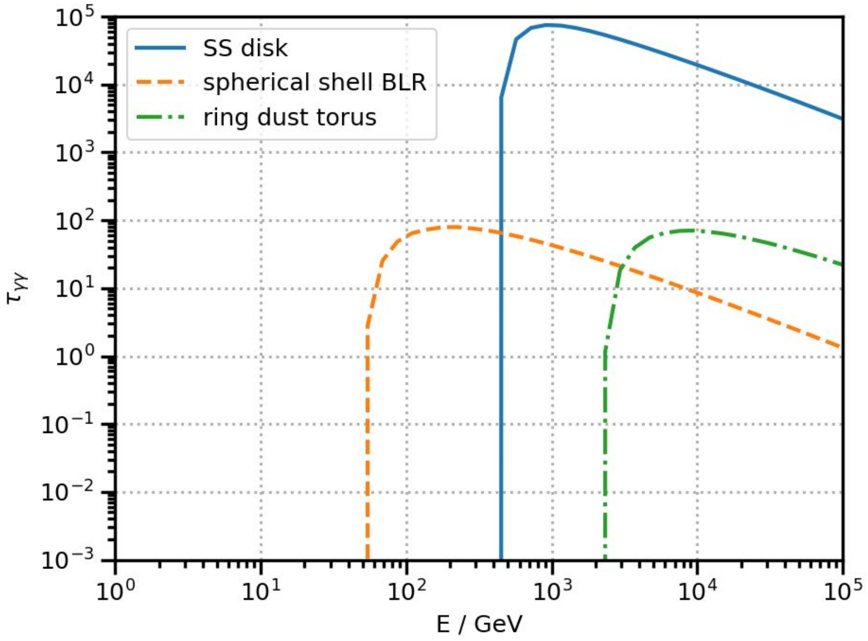
> the code contains also **classes describing the components emitting line and thermal radiation** (CMB, accretion disk, broad line region, dust torus);

> the spectrum due to their thermal emission can be evaluated;

> the density of their photon fields as a function of the distance along the jet can be evaluated;

> they can be used as a target for inverse Compton scattering;

> one can estimate the absorption their soft photon fields produce on the highest energy photons via gamma-gamma pair production.



Conclusions

- Jetted AGN are the most powerful, persistent, sources in the universe;
- extragalactic jets are the sites of cosmic particle acceleration;
- the broad band emission of jetted active galaxies can be accounted for with a non-thermal distribution of electrons radiating via synchrotron and inverse Compton;
- I have created a code modelling the emission of jetted active galaxies, I hope you consider its usage for your work.