



# Black hole (g)astrophysics

**Rodrigo Nemmen**  
Universidade de São Paulo

# Goal of lectures

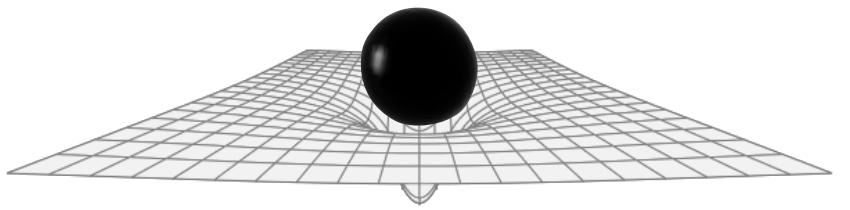
- General overview of black hole astrophysics
- Focus: understand observational  
manifestation in EM waves
- Primer on physics necessary for broad  
understanding of accreting black holes

# Disclaimer

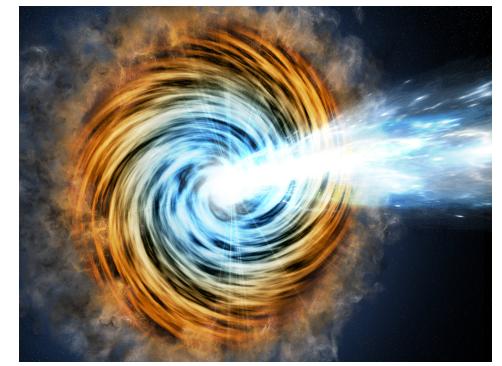
- Impossible to cover everything in 5 lectures
- Priority: *big picture*, basic concepts

# Outline of lectures

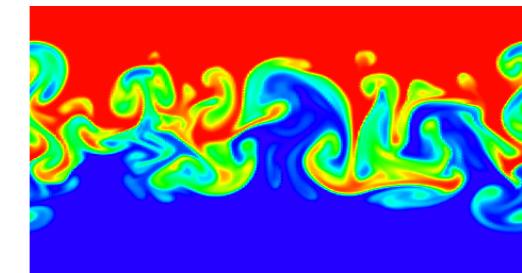
**1. GR, black holes**



**2. The *ins* and *outs* of BHs**



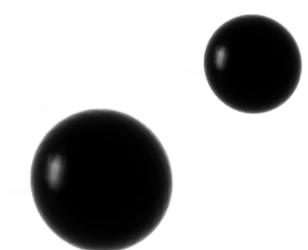
**3. Radiative processes**



**4. Phenomenology**



**5. Massive binary BHs**



**Website**

<https://tinyurl.com/bh-gastrophysics>

**Slides**

**References**



# Setting the stage

# Historically important *observations*

**1918:** "curious straight ray" in galaxy M87,  
"connected with the nucleus by a thin line of  
matter" (optical)

Curtis 1918

**1962:** bright cosmic X-ray sources (Cygnus X-1; X-rays)

Giacconi+1962

**1963:** strong point source at 3C 273 nucleus, looks  
like bright star, 800 Mpc away (optical, radio)

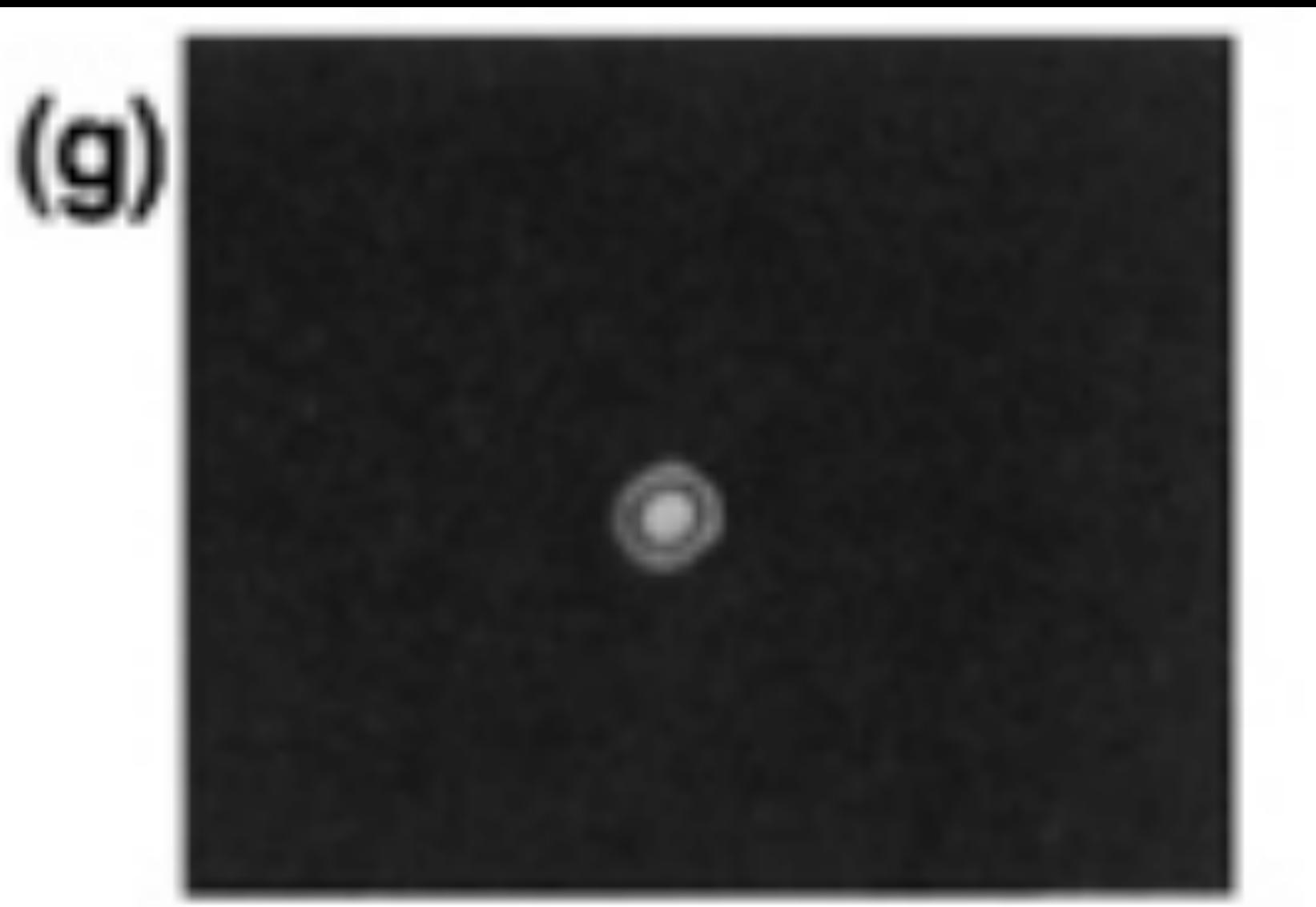
Schmidt+1963

**1967:** bright cosmic gamma-ray flashes found with  
military satellites

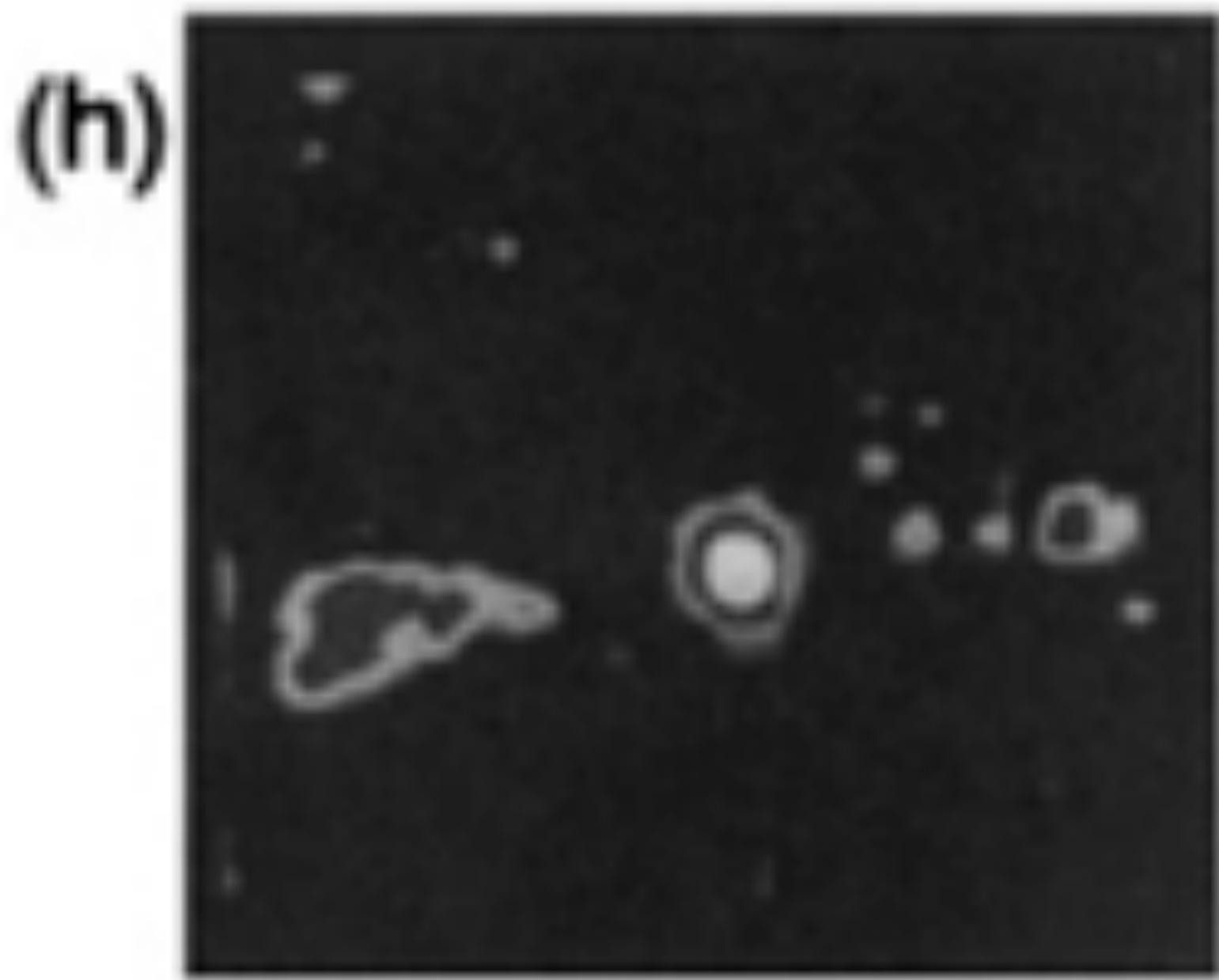
Klebesadel+1973

This image shows a radio galaxy, specifically M87, against a dark, star-filled background. A bright, white central source of light is visible, with a distinct horizontal jet extending to the right. The surrounding area is filled with numerous small, white stars of varying brightness.

radiogalaxy M87



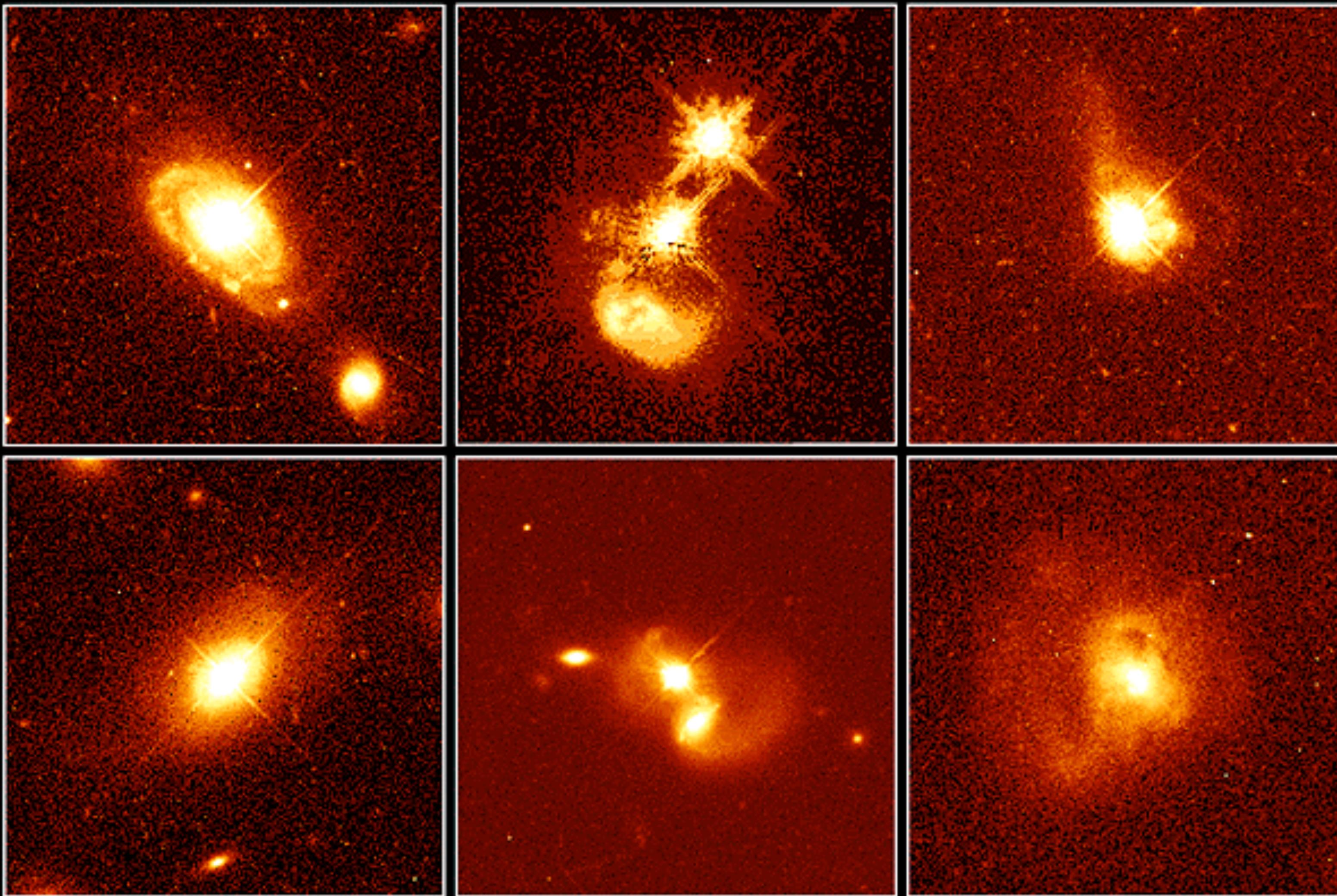
Cygnus X-1



SS 433

*Einstein* telescope  
courtesy: R. Giacconi

# Quasars in the centers of distant galaxies ( $z > 1$ ) outshine all stars in the host galaxy



Hubble Space  
Telescope  
Bahcall+97

this image:  $z \sim 0.2$   
 $d_L \sim 1$  Gpc

## Commonalities:

- \* New astronomical windows → Unanticipated discoveries
- \* Energy budget issue: *too much energy*, very hard to explain without relativistic phenomena and “creative” energy sources

# **Energy requirements of a quasar**



## Commonalities:

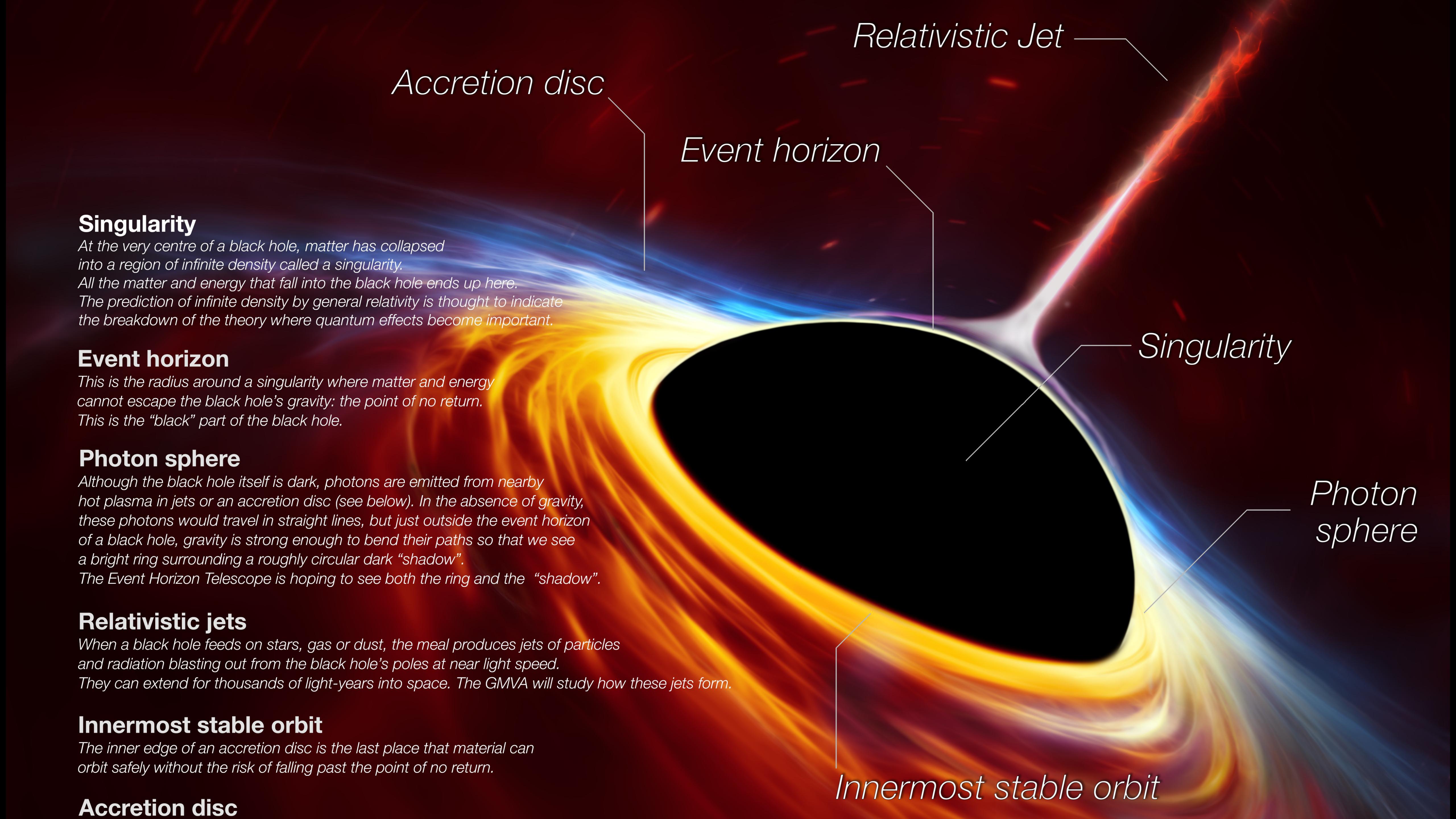
- \* New astronomical windows → Unanticipated discoveries
- \* Energy budget issue: *too much energy*, very hard to explain without relativistic phenomena and “creative” energy sources

One single picture emerged ...

# Unified picture: Accreting black holes

## One relativistic energy source to rule them all

- enormous free energy
- which can be extracted by free particles



## Singularity

At the very centre of a black hole, matter has collapsed into a region of infinite density called a singularity.

All the matter and energy that fall into the black hole ends up here.

The prediction of infinite density by general relativity is thought to indicate the breakdown of the theory where quantum effects become important.

## Event horizon

This is the radius around a singularity where matter and energy cannot escape the black hole's gravity: the point of no return.

This is the "black" part of the black hole.

## Photon sphere

Although the black hole itself is dark, photons are emitted from nearby hot plasma in jets or an accretion disc (see below). In the absence of gravity, these photons would travel in straight lines, but just outside the event horizon of a black hole, gravity is strong enough to bend their paths so that we see a bright ring surrounding a roughly circular dark "shadow".

The Event Horizon Telescope is hoping to see both the ring and the "shadow".

## Relativistic jets

When a black hole feeds on stars, gas or dust, the meal produces jets of particles and radiation blasting out from the black hole's poles at near light speed.

They can extend for thousands of light-years into space. The GMVA will study how these jets form.

## Innermost stable orbit

The inner edge of an accretion disc is the last place that material can orbit safely without the risk of falling past the point of no return.

## Accretion disc

## Accretion disc

## Relativistic Jet

## Event horizon

## Singularity

## Photon sphere

## Innermost stable orbit

# (magneto)hydrodynamics

[kinetic theory]

MHD

# general relativity

Kerr spacetime

## Singularity

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*Singularity*

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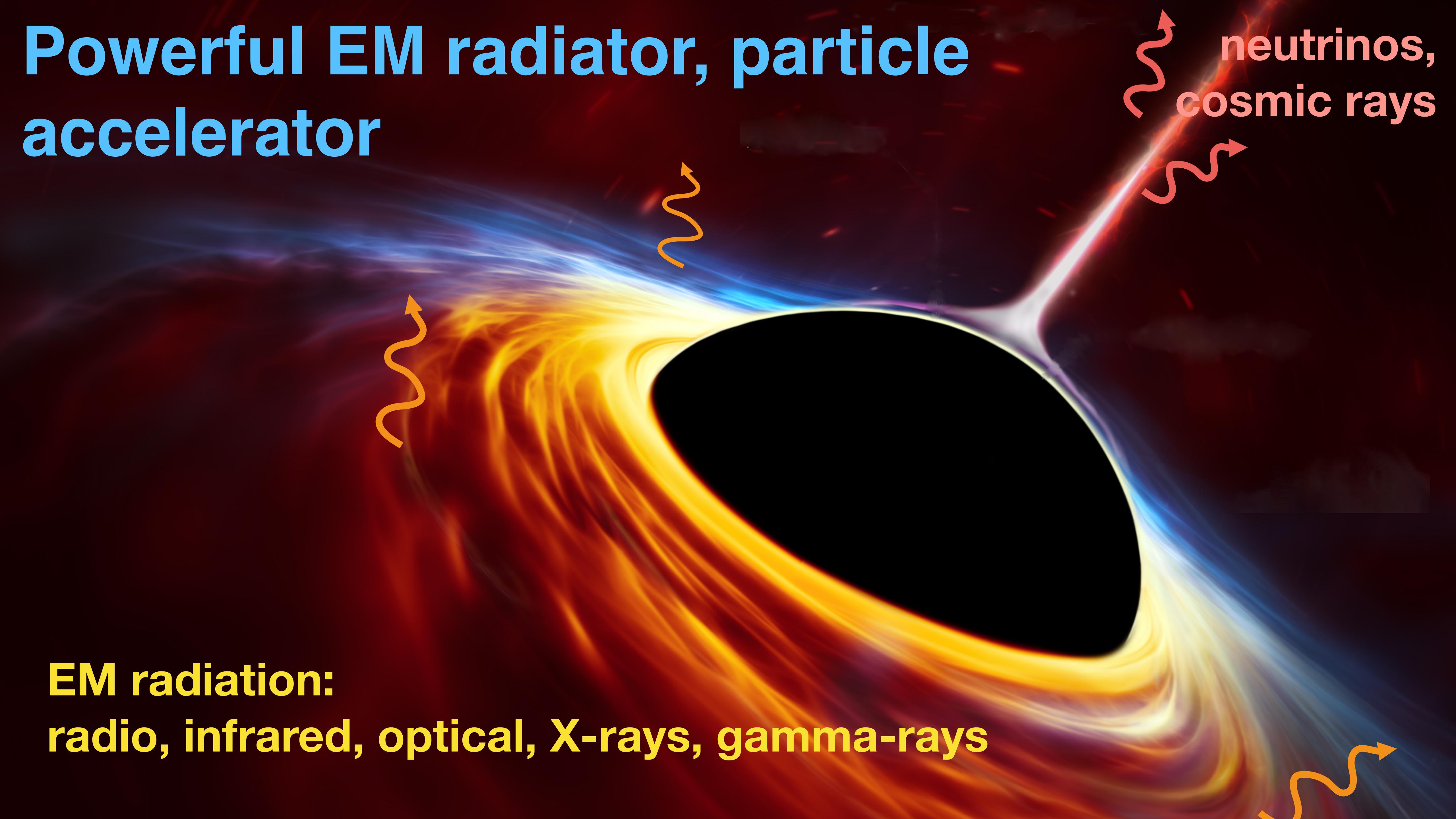
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*Innermost stable orbit*

## Accretion disc

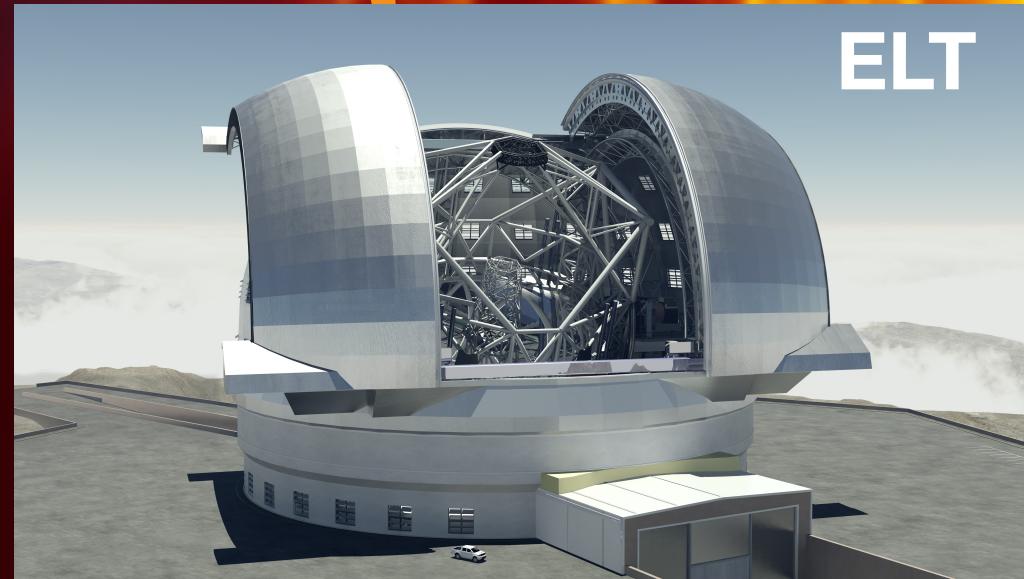
# Powerful EM radiator, particle accelerator

A black hole at the center of a galaxy, shown from a side-on perspective. A bright, multi-colored accretion disk swirls around it, transitioning from red at the outer edges to yellow and white near the center. Two powerful jets of particles are ejected perpendicular to the disk's plane, one extending upwards and the other downwards. Wavy arrows point from the text labels to these jets.

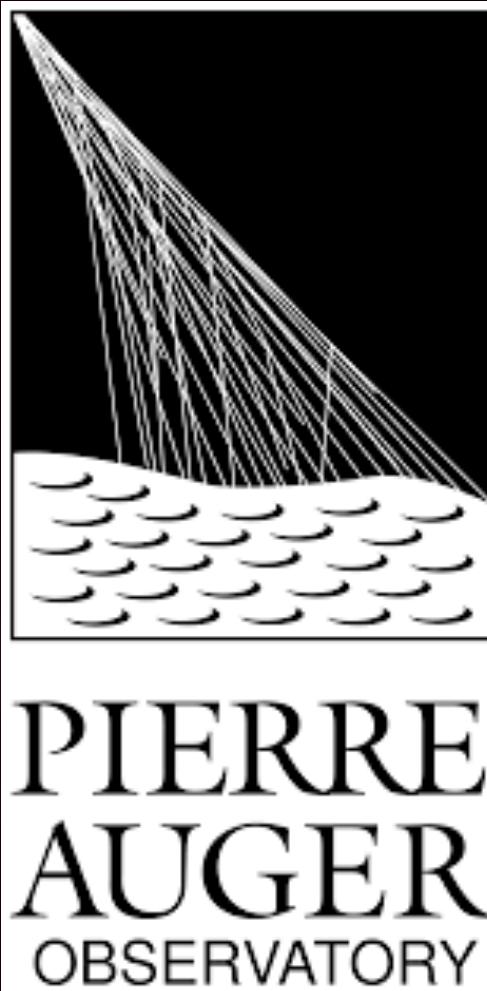
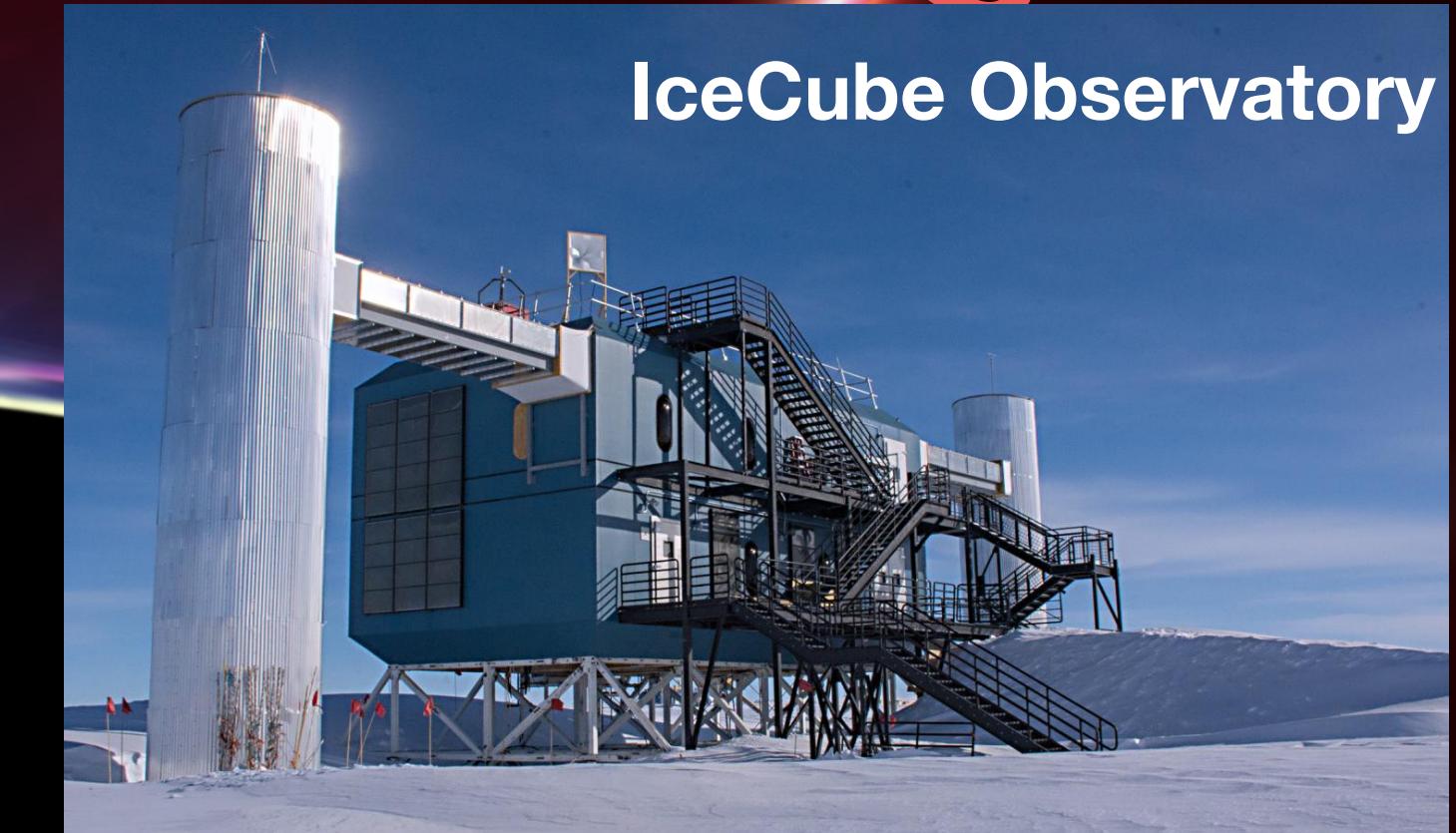
neutrinos,  
cosmic rays

**EM radiation:**  
**radio, infrared, optical, X-rays, gamma-rays**

# Powerful EM radiator, particle accelerator



**EM radiation:  
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neutrinos,  
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# Binary black hole systems

Gravitational  
waves

LISA

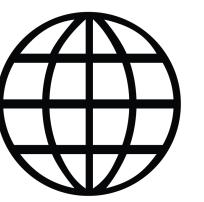
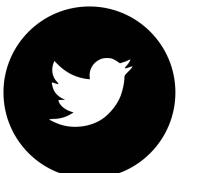
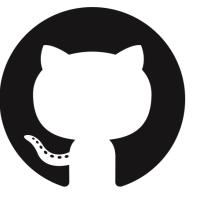
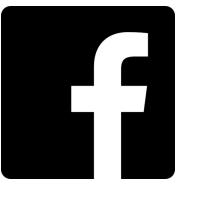
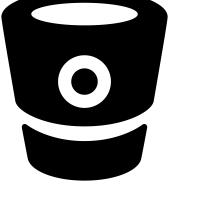
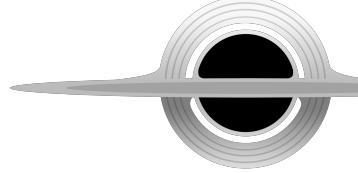
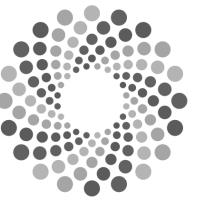
LIGO

We entered a new  
golden age of black  
hole (astro)physics

You can be part of this!

[blackholegroup.org](http://blackholegroup.org)

**Next: GR and black holes**

-  E-mail [rodrigo.nemmen@iag.usp.br](mailto:rodrigo.nemmen@iag.usp.br)
-  Web [rodrigonemmen.com](http://rodrigonemmen.com)
-  Twitter @nemmen
-  Github rsnemmen
-  Facebook [facebook.com/rodrigonemmen](https://facebook.com/rodrigonemmen)
-  Bitbucket nemmen
-  Group [blackholegroup.org](http://blackholegroup.org)
-  figshare [bit.ly/2fax2cT](https://bit.ly/2fax2cT)