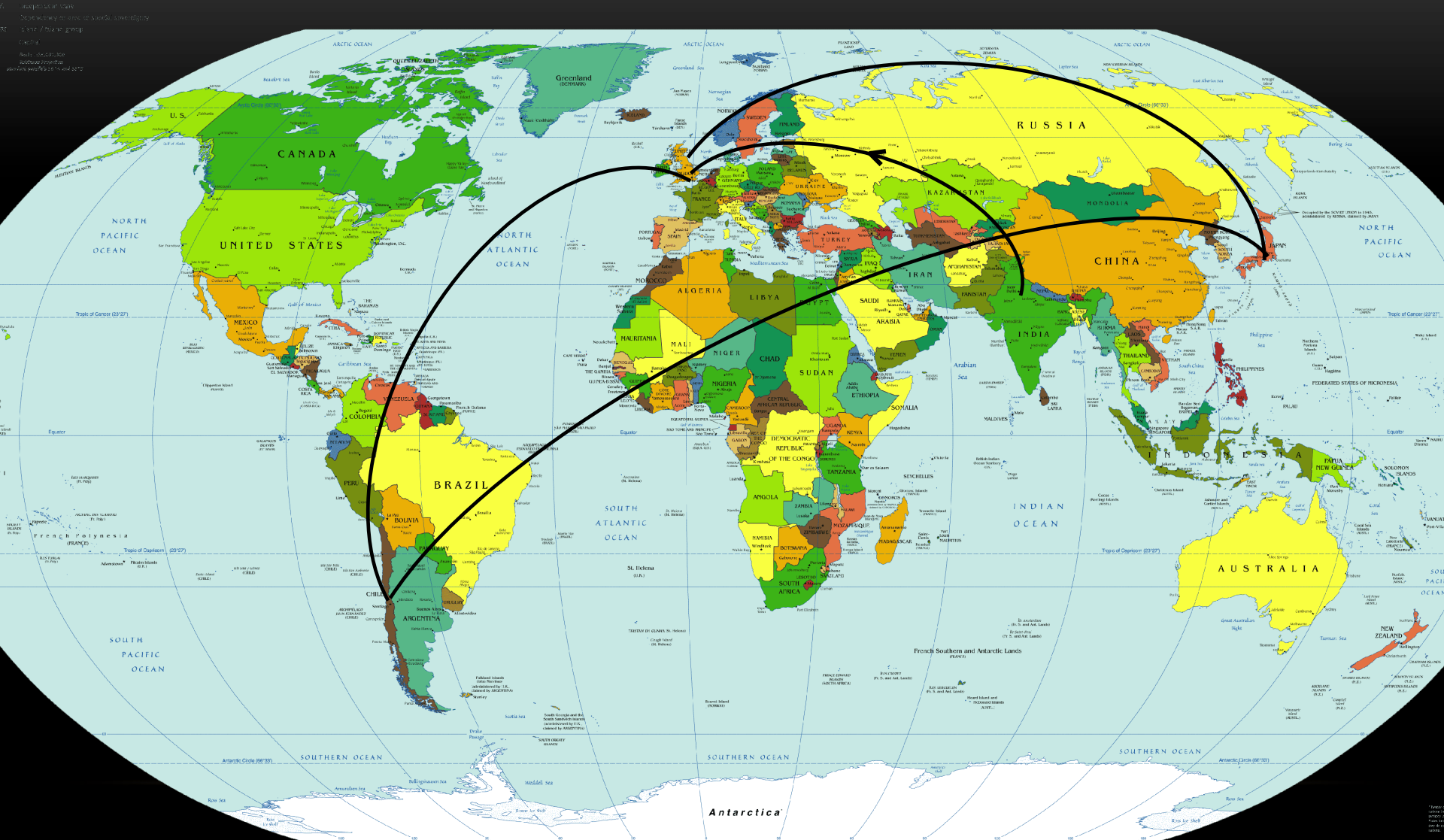


Black holes that go bump in the night

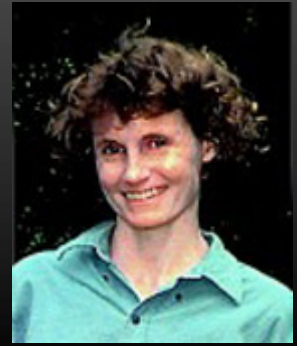
Dr. Poshak Gandhi
(University of Southampton)

Nomadic life of an astronomer

Map of the World, April 2006



“We Astronomers”



*Dr. Rebecca Elson
(1960-1999)*

We astronomers are nomads,
Merchants, circus people,
All the earth our tent.

We are industrious.
We breed enthusiasms,
Honour our responsibility to awe.

...

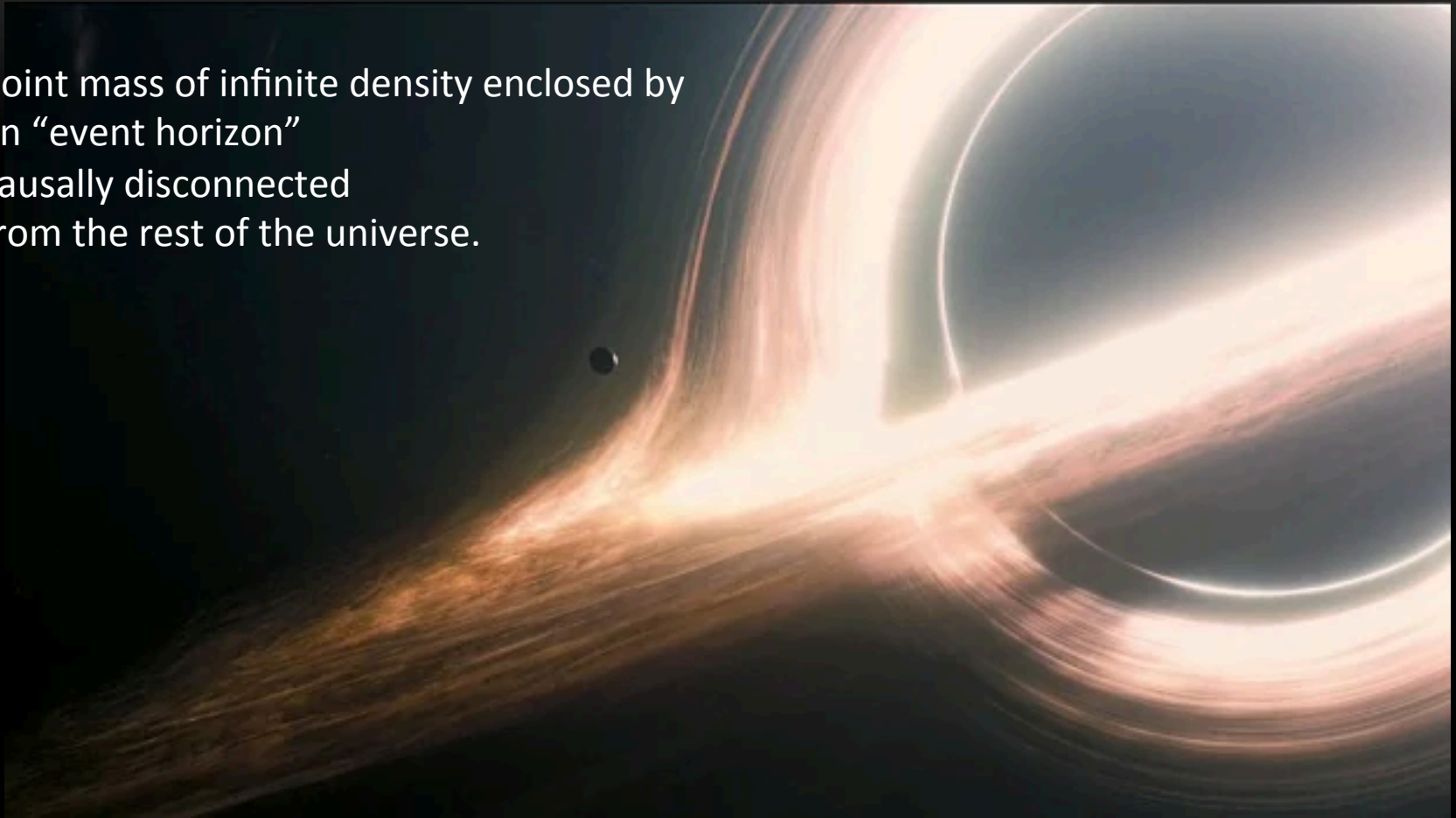
*"Responsibility to Awe", Oxford Poets, Carcanet Press (2001)
Estate of Rebecca Elson; Anne Berkeley and Angelo di Cintio*

Black holes: the Whys and the Wherefores...

- What are Black holes holes?
- Why are they interesting?
- Where are they located?
- How do we (and how can you) study them?

What is a black hole?

Point mass of infinite density enclosed by an “event horizon” causally disconnected from the rest of the universe.



Interstellar ; Christopher Nolan



Chandra Deep Field South image
(Optical)

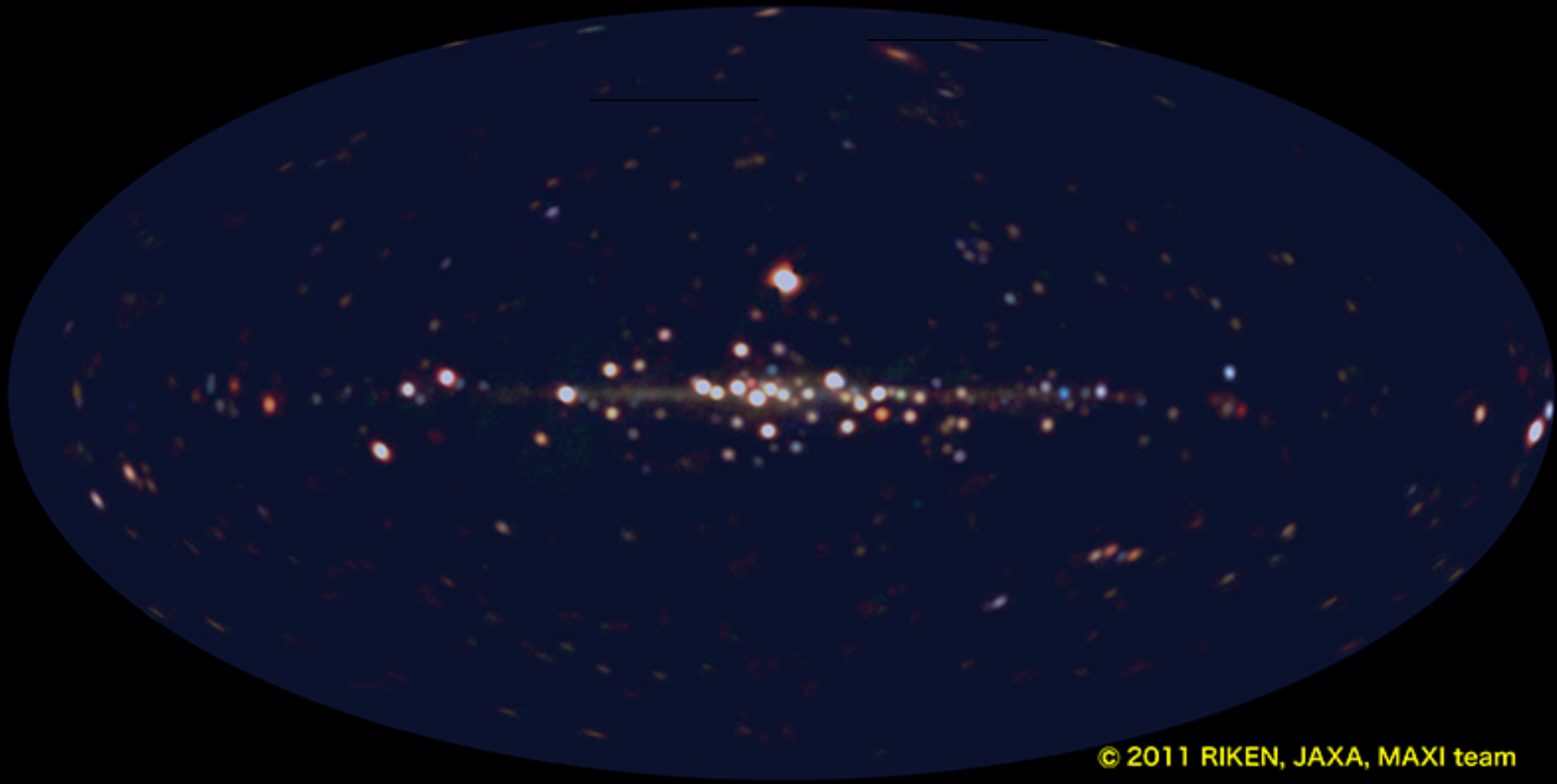
UBR composite.
14x21 arcmin wide
(Credit ESO)

The image is a deep field of X-ray emissions from the Chandra X-ray Observatory, showing a vast field of distant galaxies. The galaxies are represented by numerous small, multi-colored points of light against a dark background. The colors of these points represent different energy levels of the X-rays they emit. The text is overlaid on the upper left portion of the image.

Chandra Deep Field South image
(X-ray emitting Supermassive Black Holes in distant galaxies)

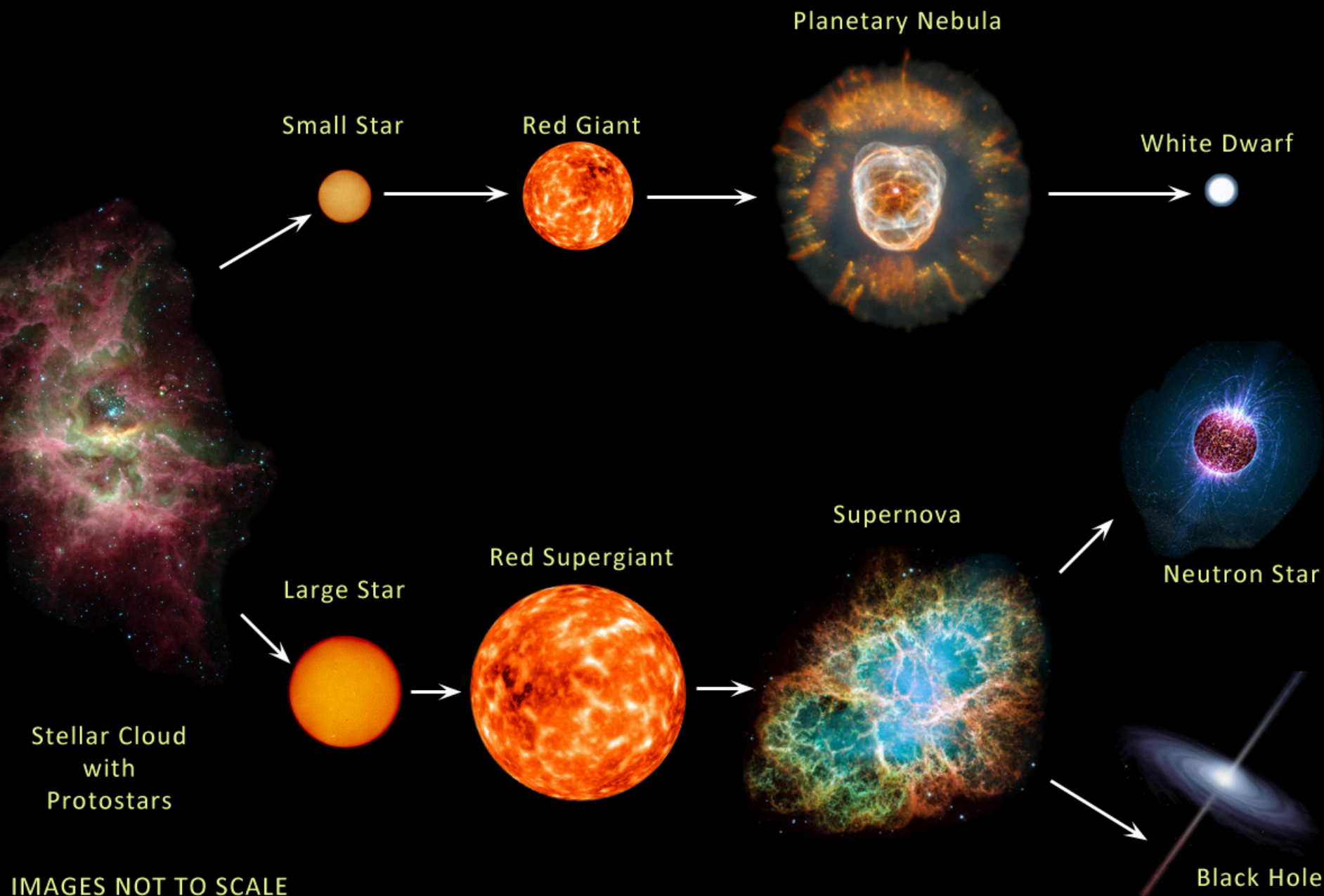
Red=low energy
Blue=high energy
(Credit NASA)

Stellar-mass black holes in the Milky Way



← 100,000 light years →

EVOLUTION OF STARS

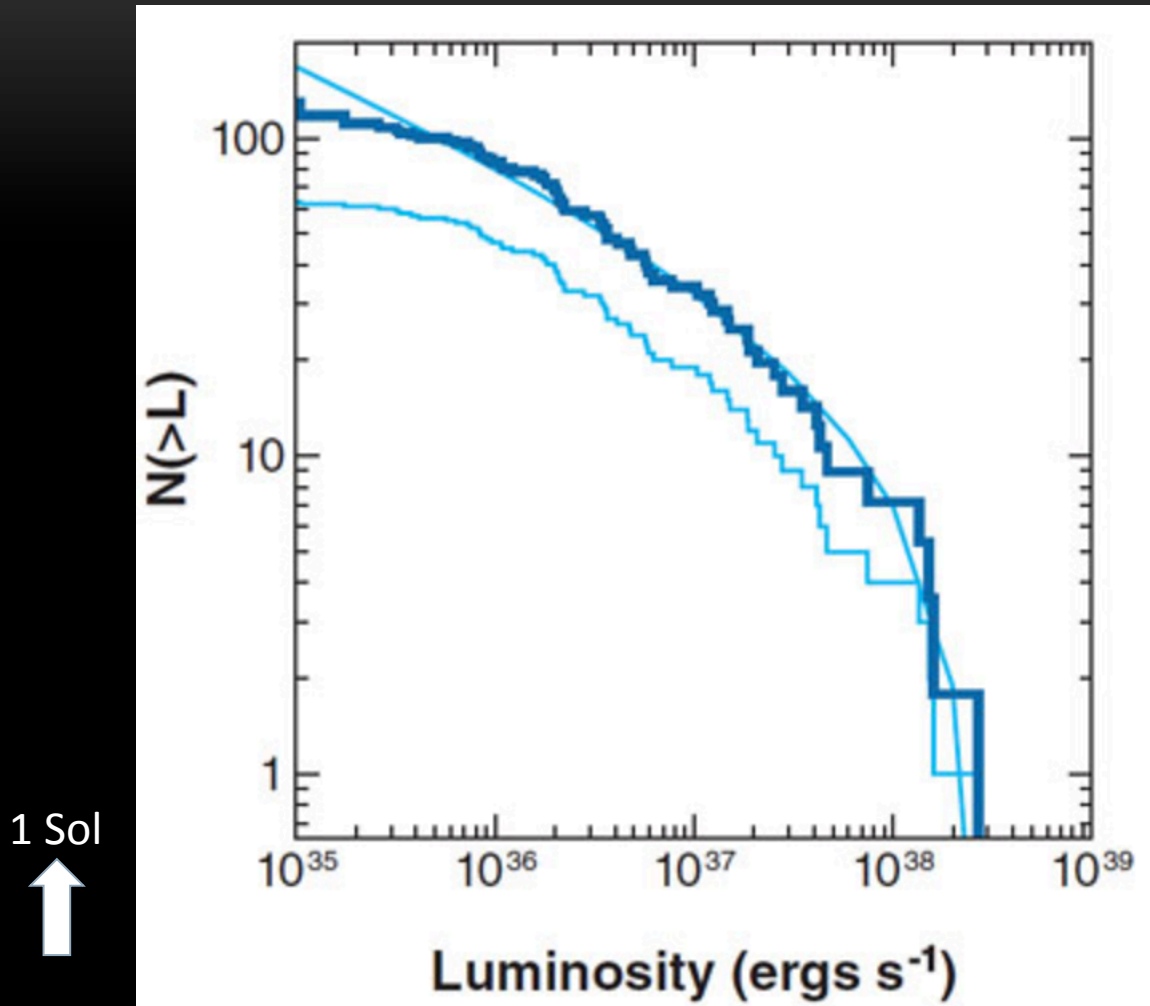


Black hole binaries



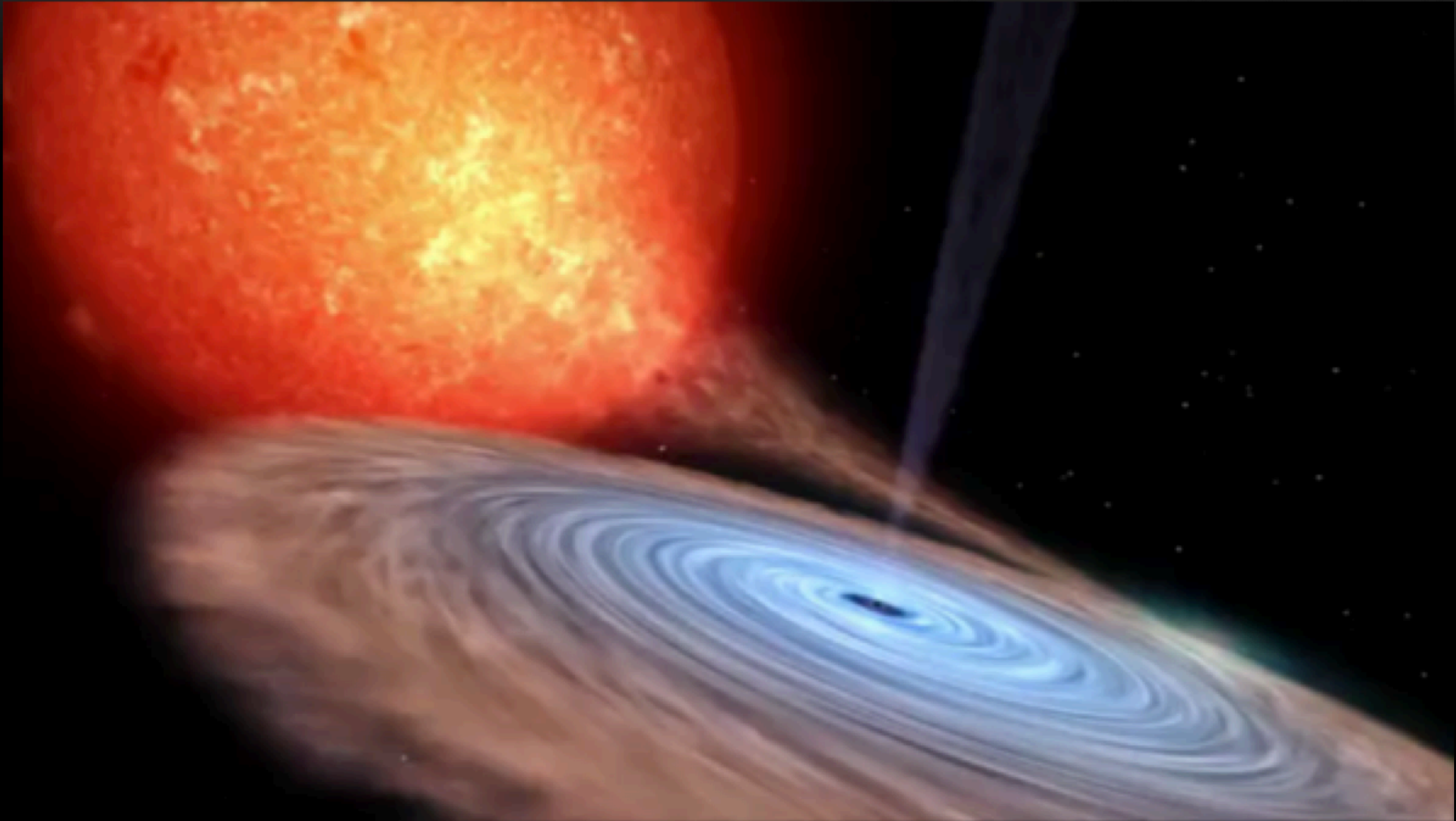
(Credit: IAC; Munoz-Darias et al. 2016)

Why are they interesting?



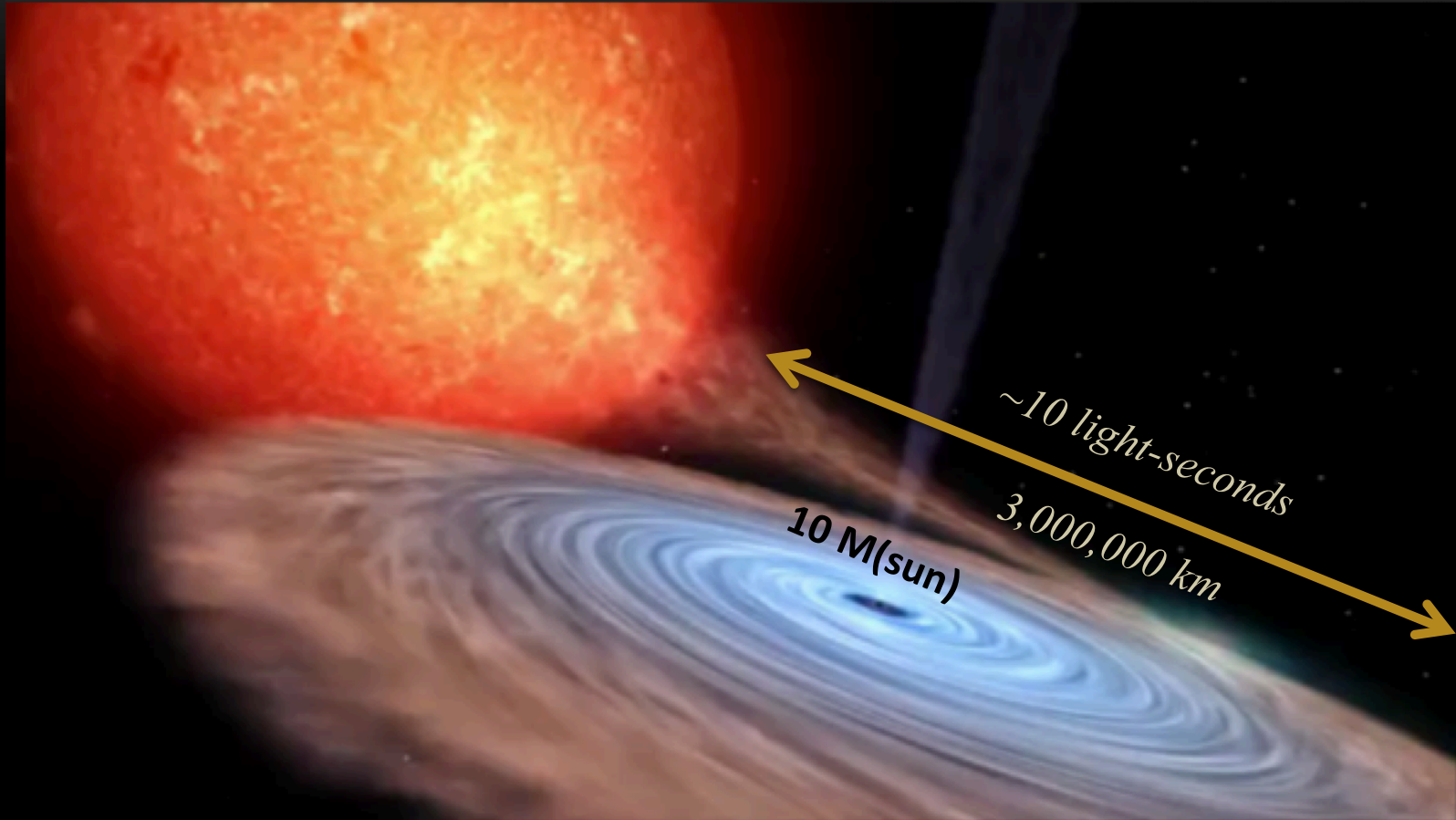
(Credit: Grimm, Gilfanov & Sunyaev 2002)

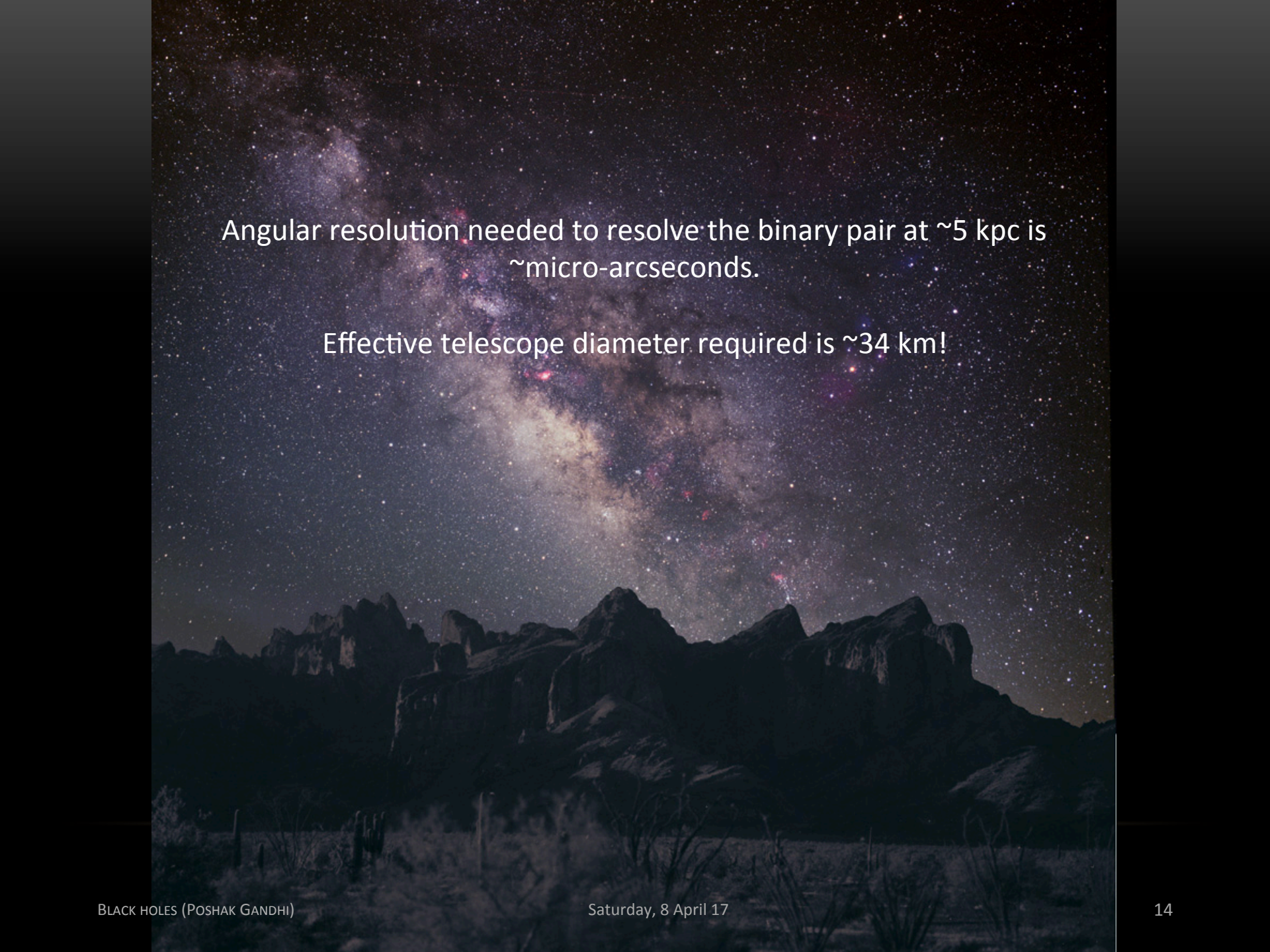
How big are such binary systems?



(Credit: IAC; Munoz-Darias et al. 2016)

How big are such binary systems?

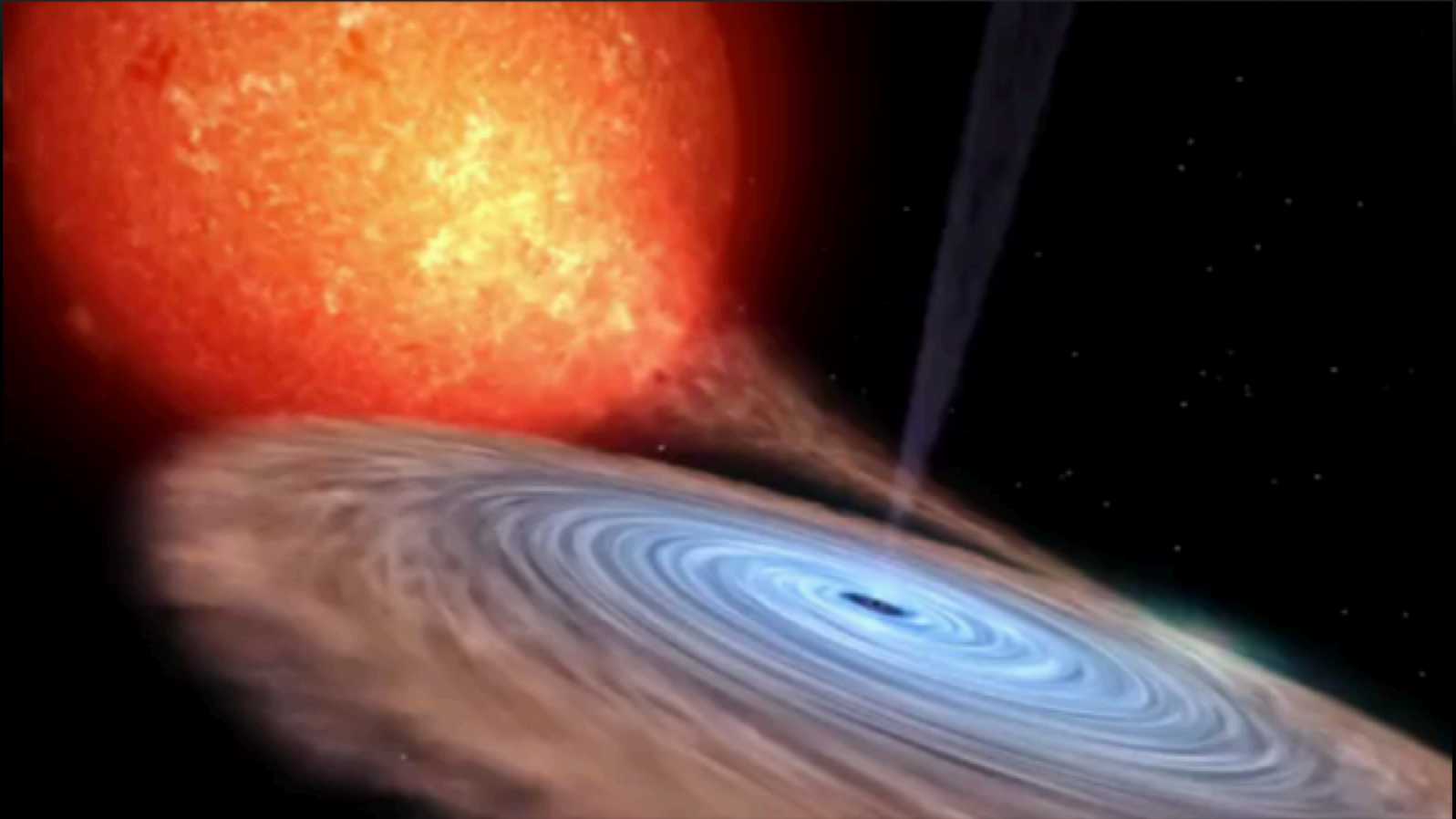




Angular resolution needed to resolve the binary pair at ~ 5 kpc is
 \sim micro-arcseconds.

Effective telescope diameter required is ~ 34 km!

How do we measure black hole masses?



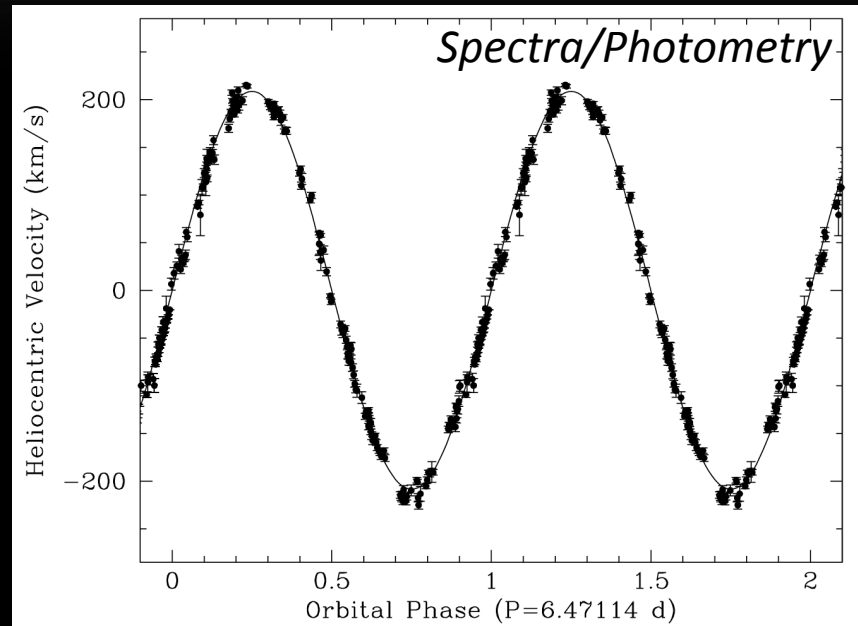
(Credit: IAC; Munoz-Darias et al. 2016)

How do we measure black hole masses?



Philip A. Charles (1950-)
Univ. of Southampton

First robust black hole mass measurement
using binary orbital radial velocity changes.

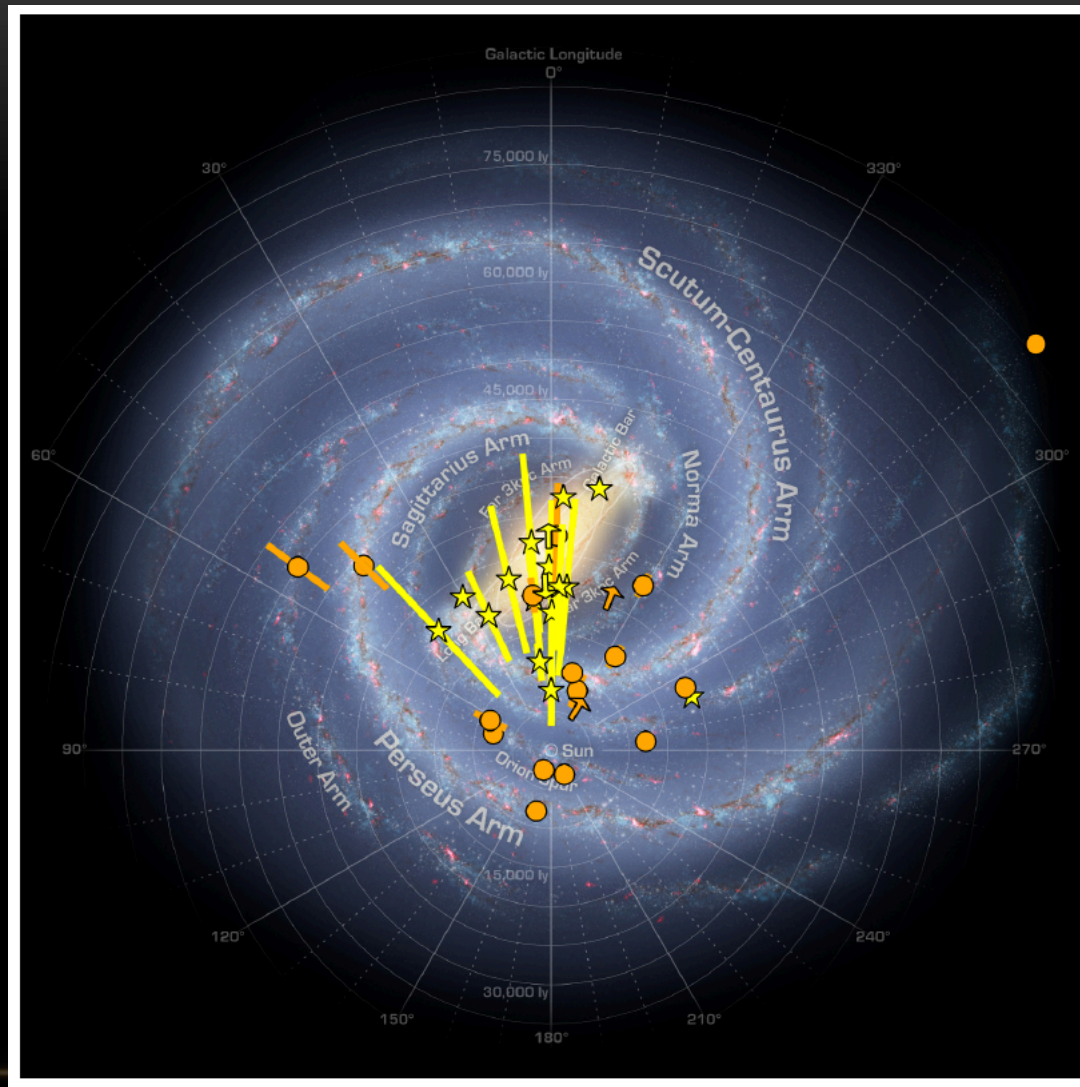


Minimum mass (V404 Cygni) $> 6.3 M(\text{sun})$

(Casares, Charles & Naylor 1992)

Where are they located?

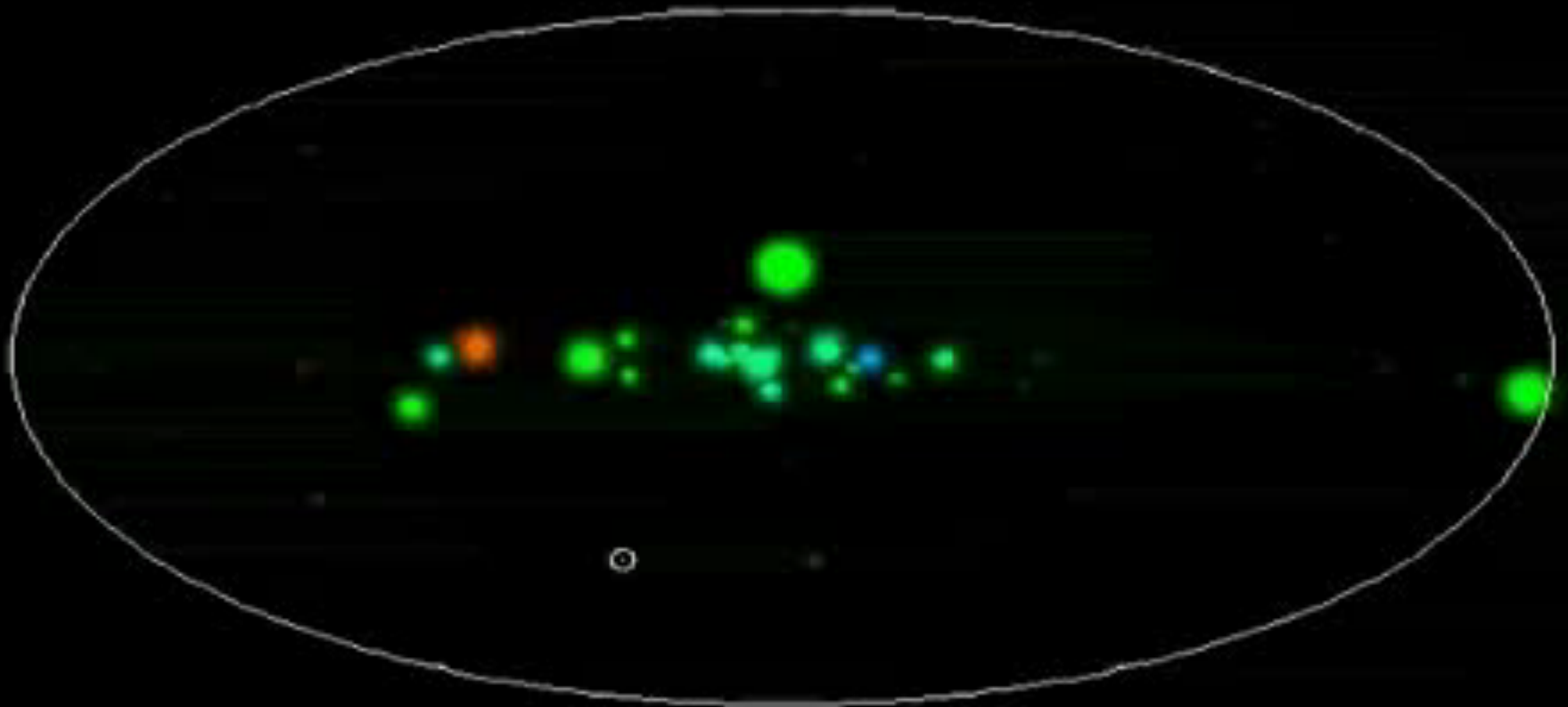
Where are they located?



(Credit: Corral-Santana et al. 2016)

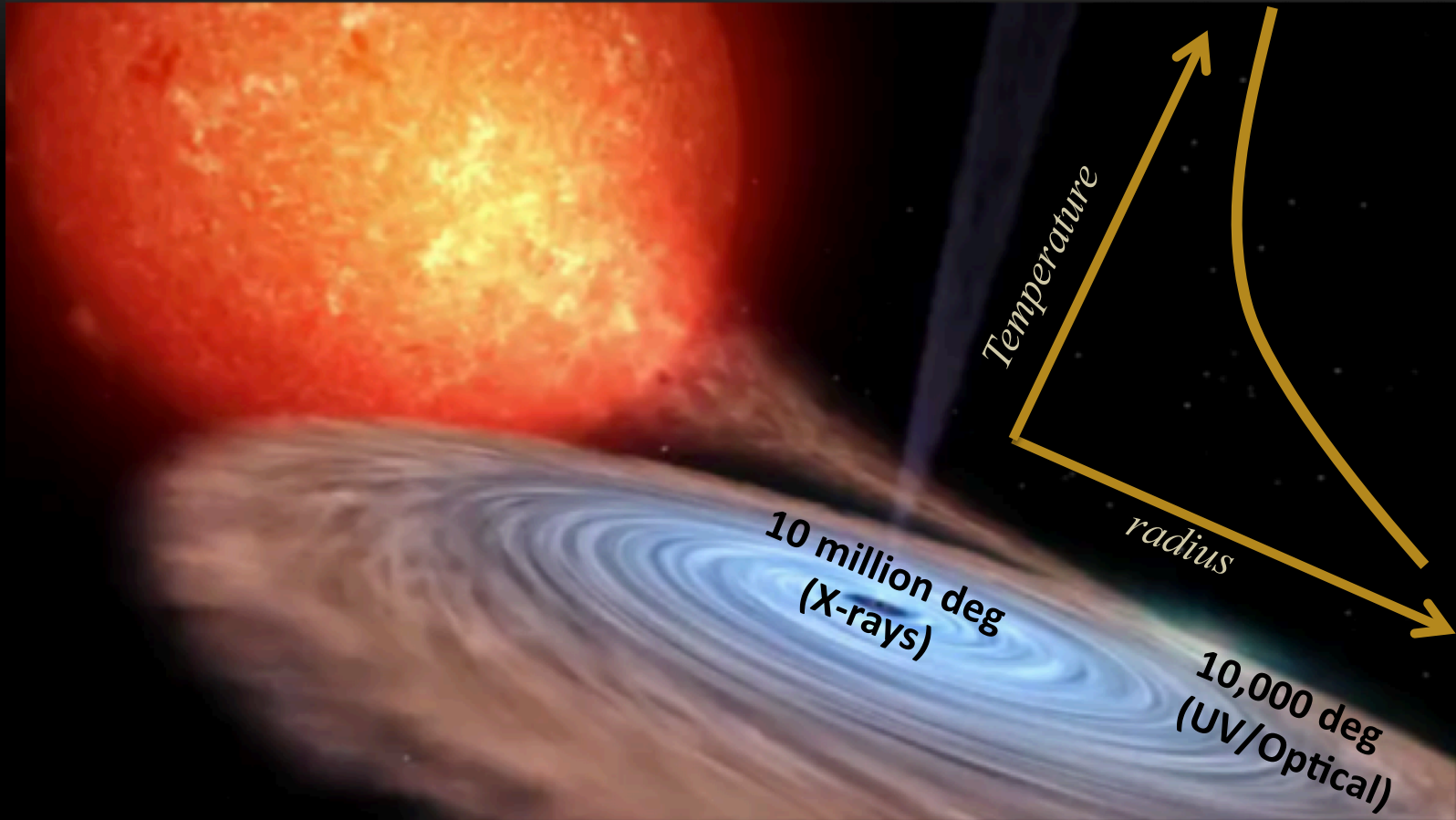
X-ray flashes in the night

The RXTE All-Sky Monitor Movie

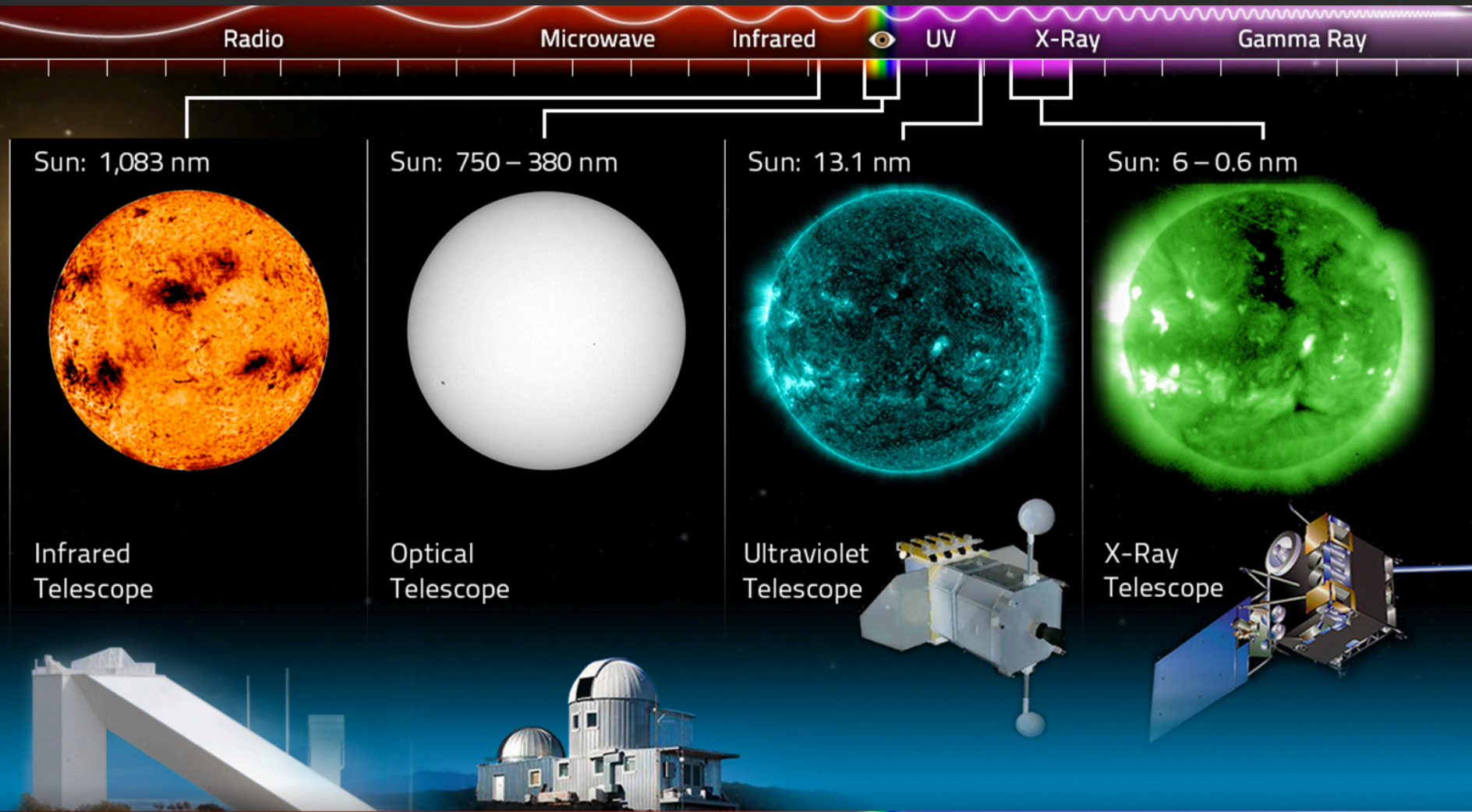


02 / 23 / 2002

The need for multiple wavelengths



Learn something new at each wavelength



Pioneer of “X-ray astronomy”

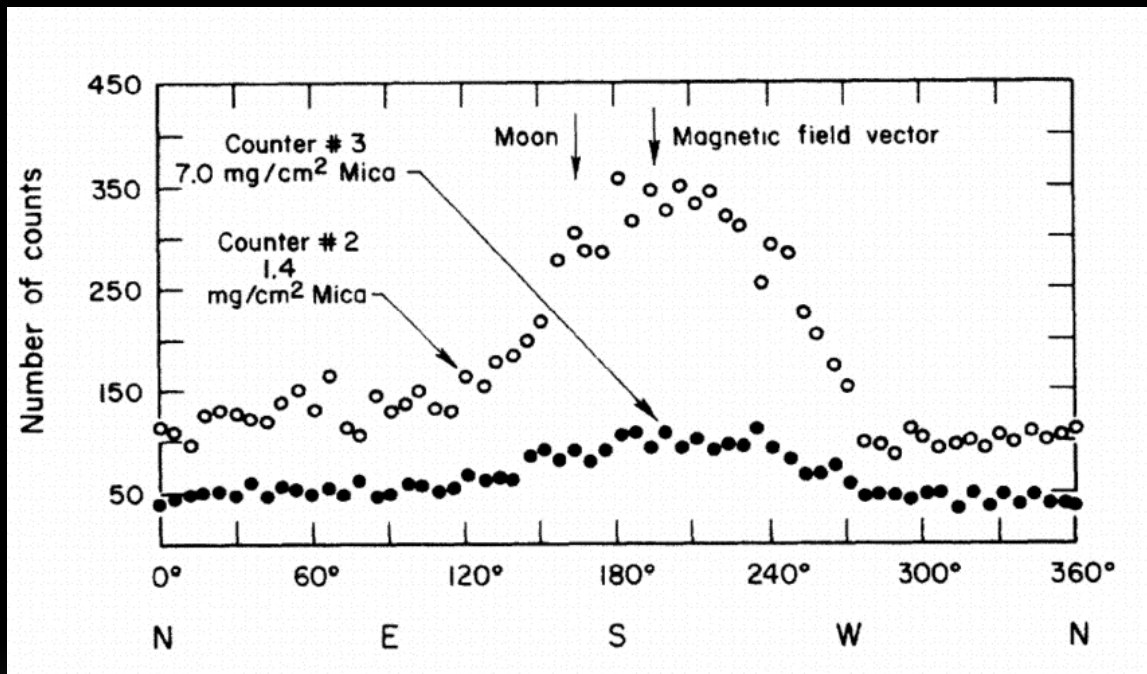


Nobel 2002

Riccardo Giacconi



(1931-)

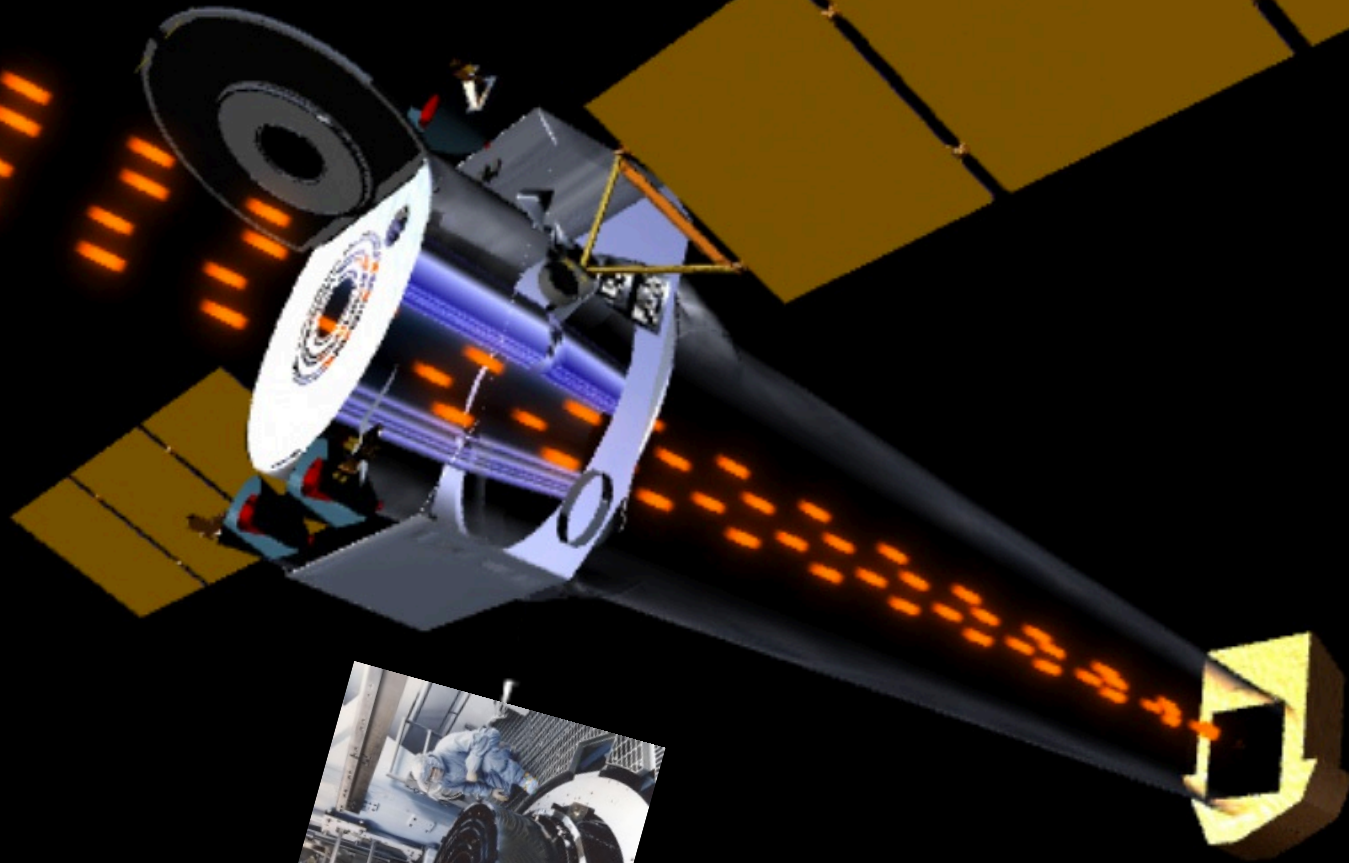


(Discovery of X-rays from space; 1962)

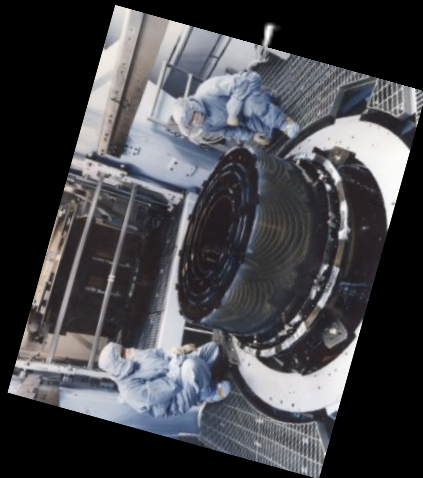
X-ray telescopes: Grazing Incidence



X-ray focusing telescopes



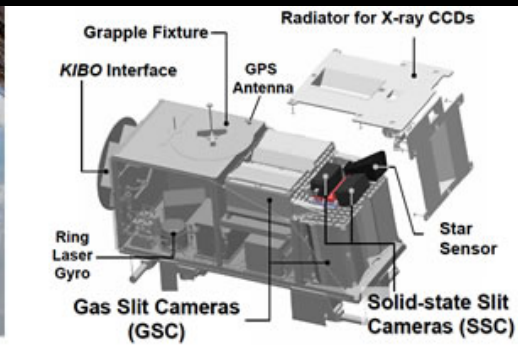
Chandra X-ray telescope



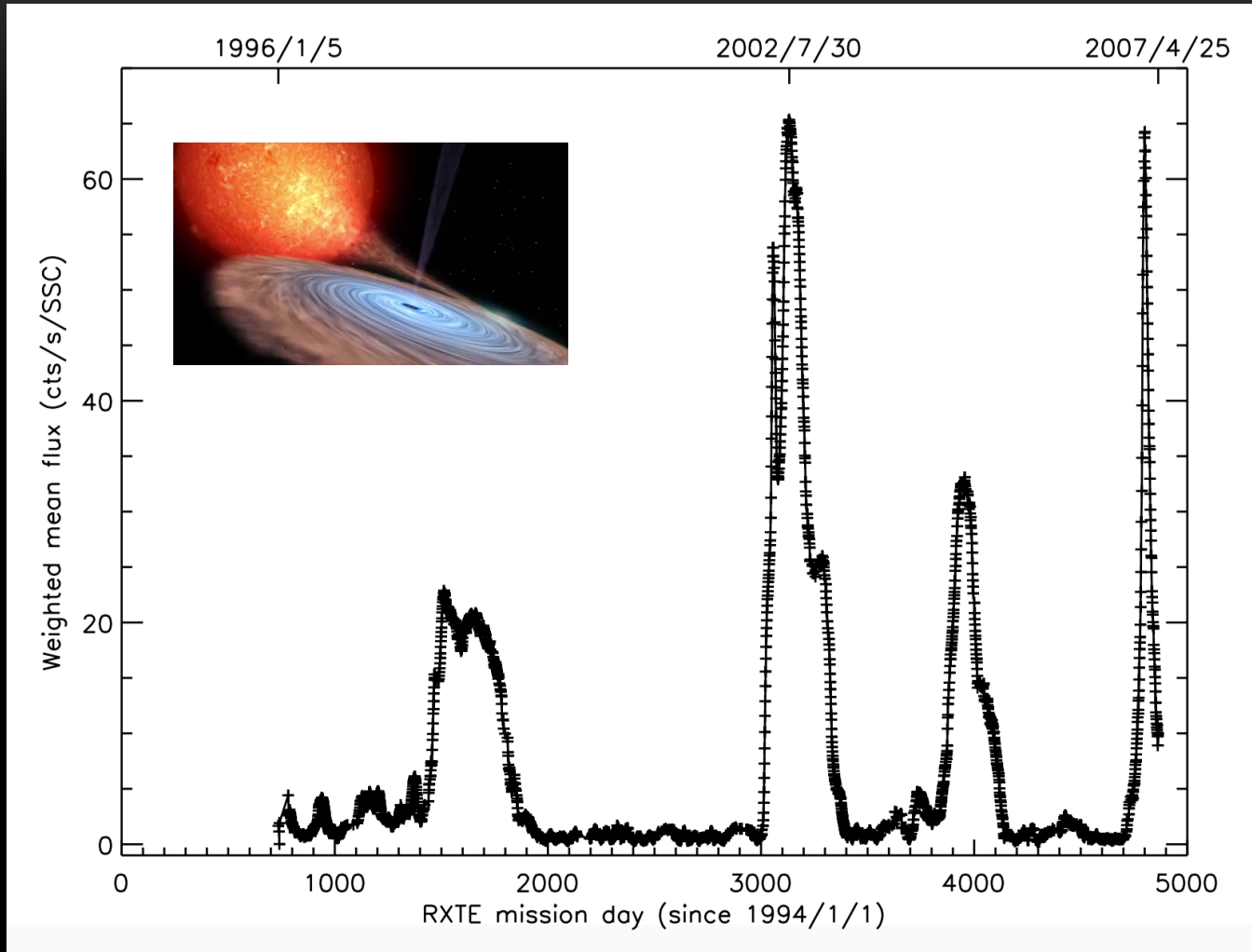
X-ray camera on the ISS



MAXI X-ray all-sky scanning camera

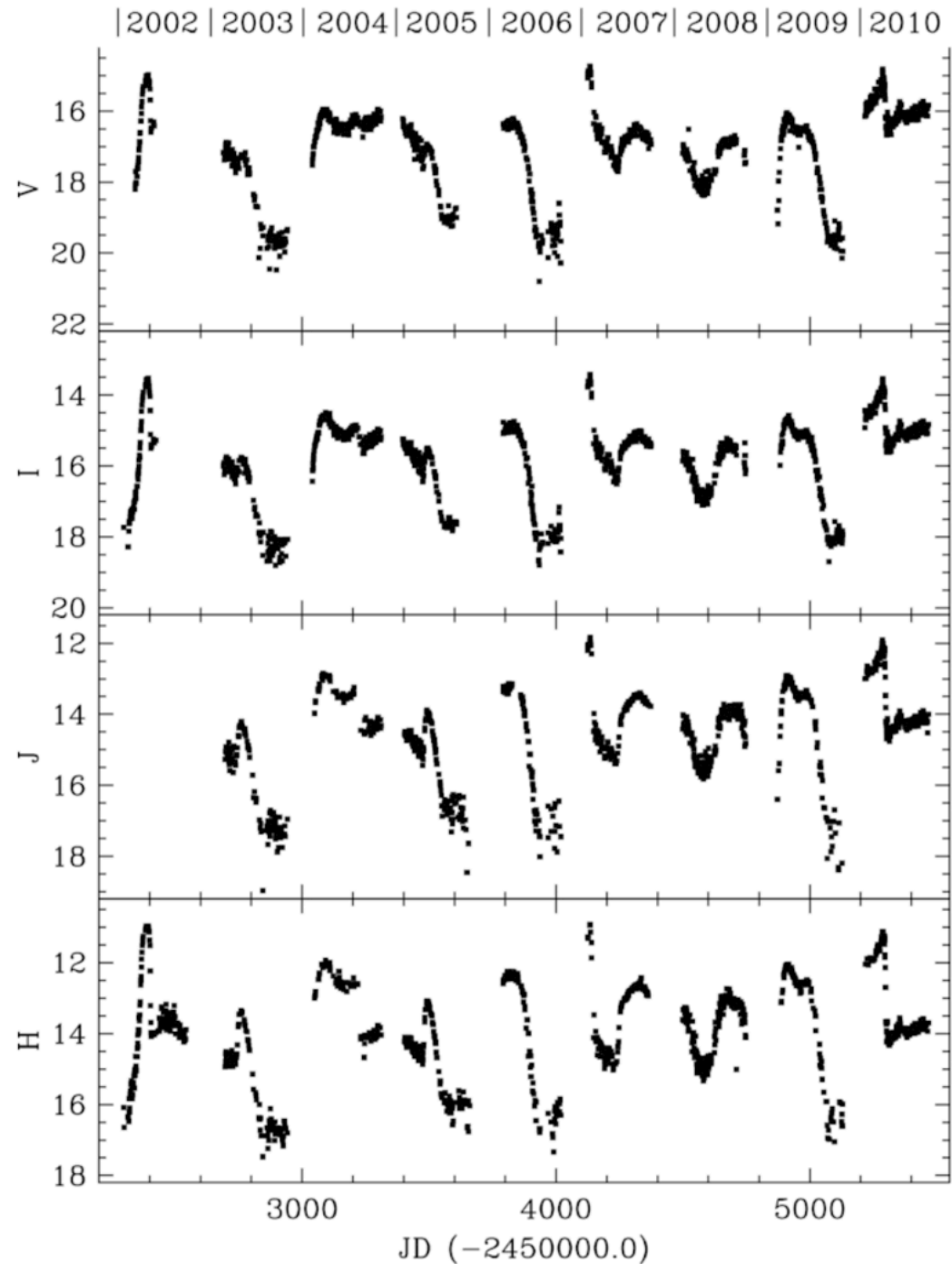


Long-term X-ray light curve of GX 339-4 (V821 Ara)

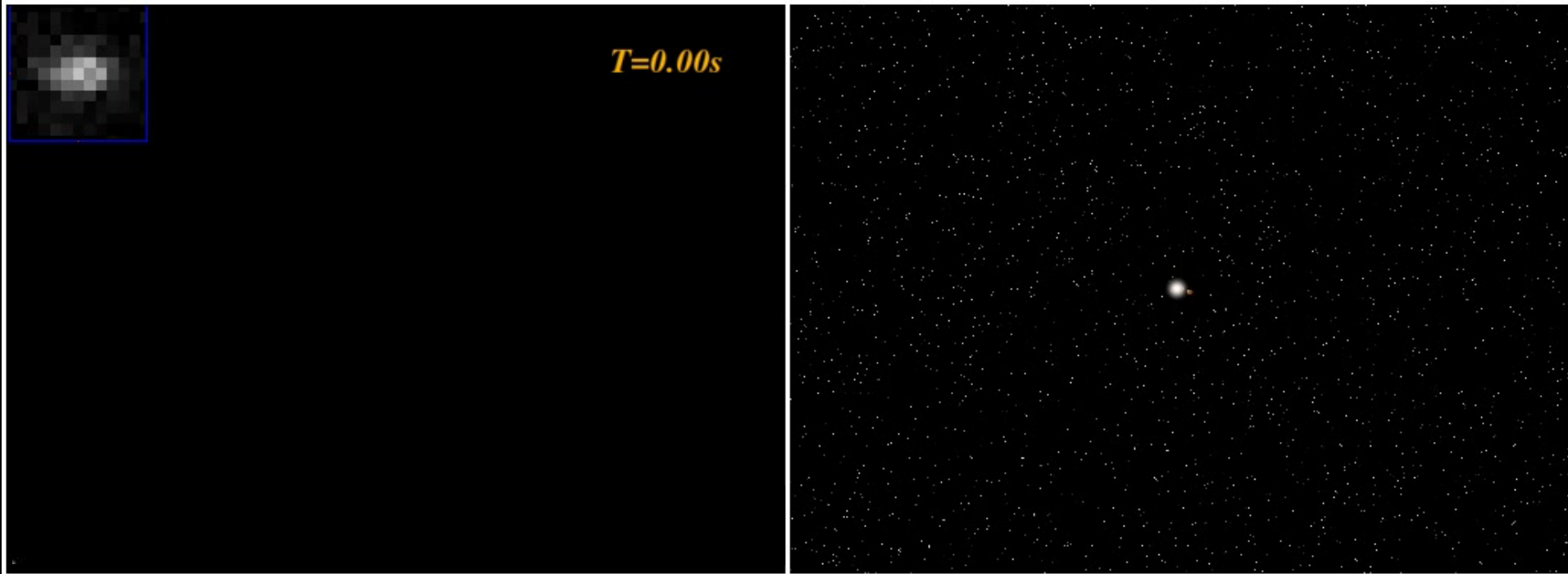


Long-term optical light curves of V821 Ara

Typical brightening
~5 mag in a few weeks



Rapid (sub-second) optical variability in black holes



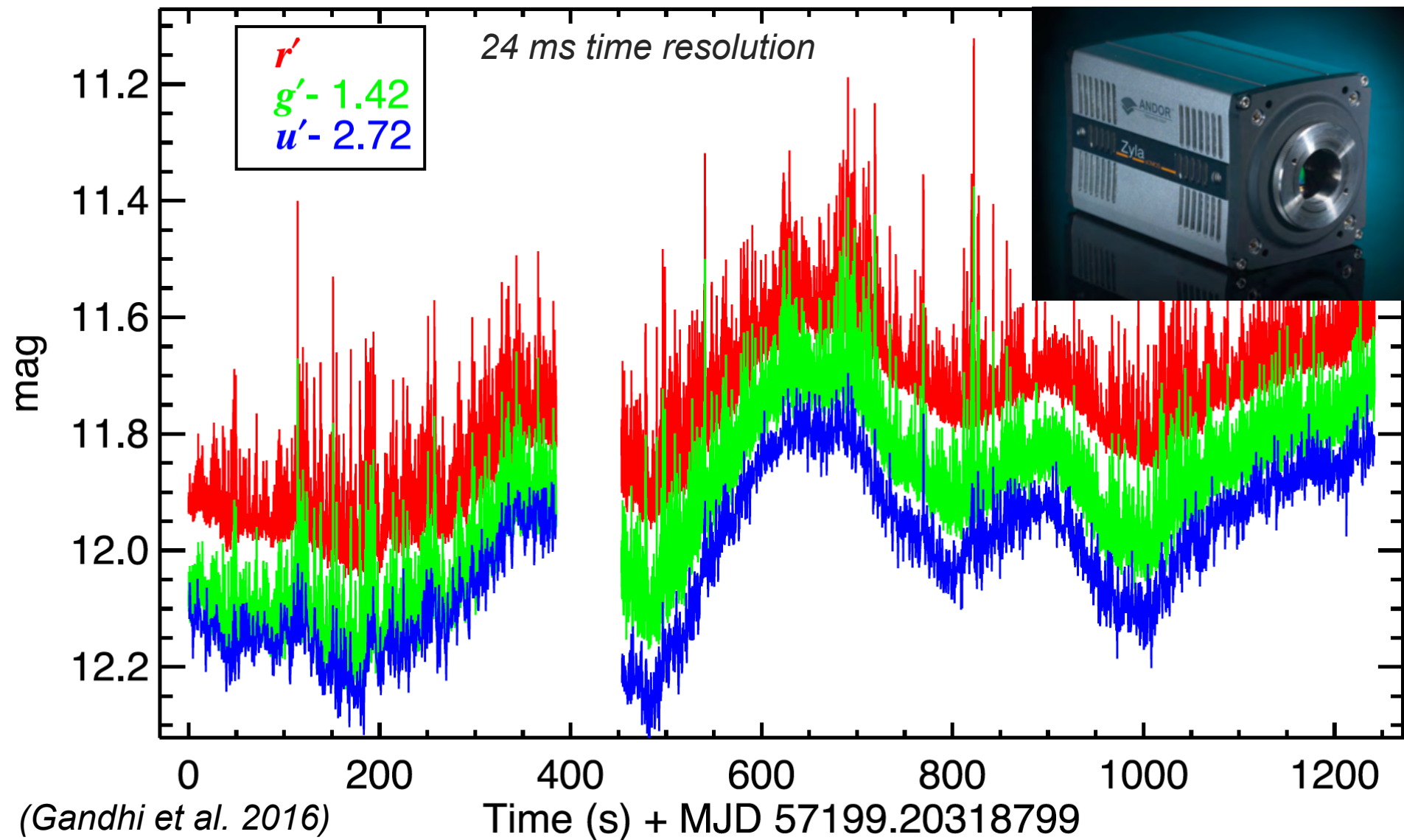
50 ms time resolution

Animation: binsim

V821 Ara
with VLT/ULTRACAM
(Gandhi et al. 2008, 2010)

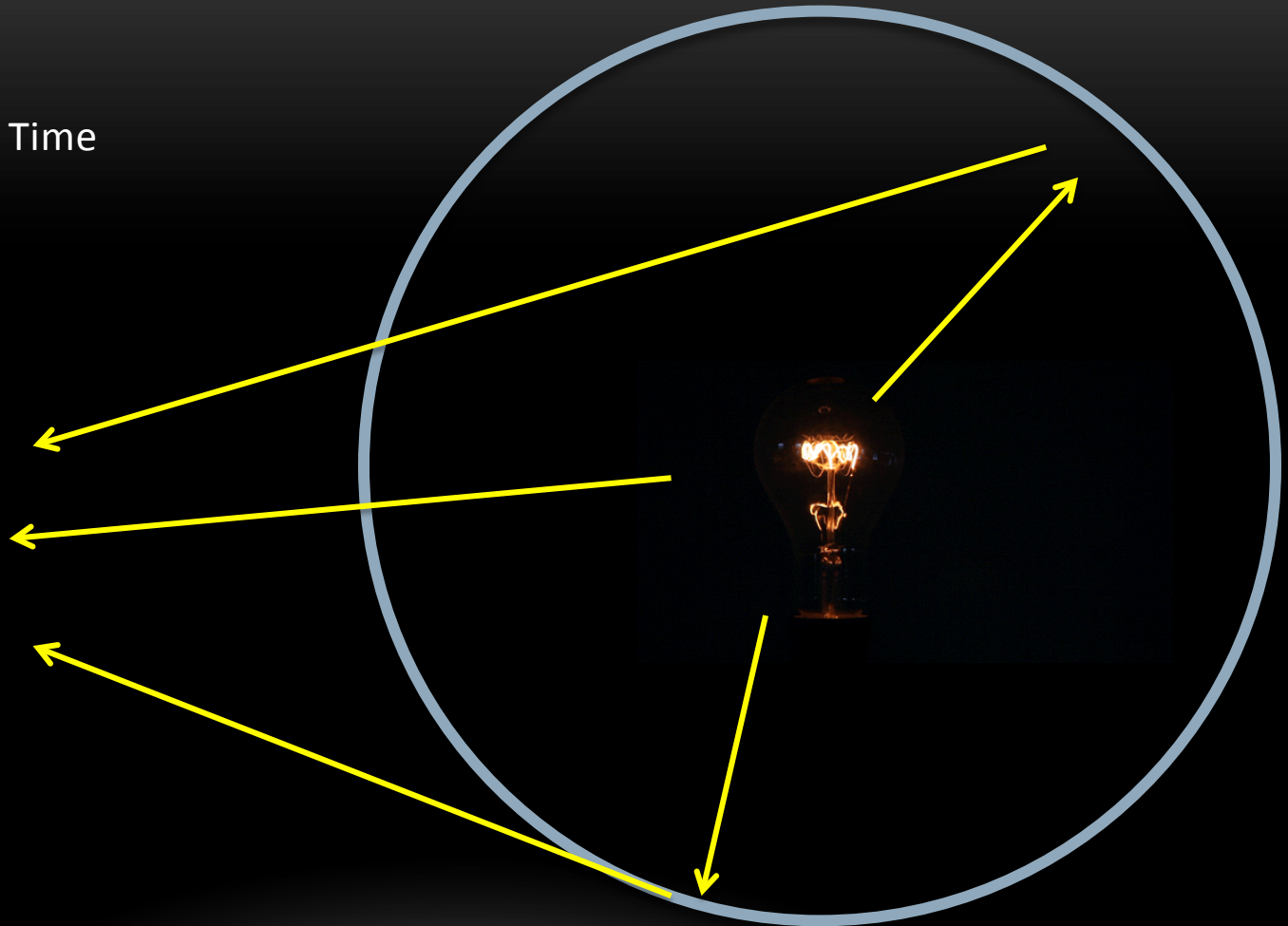


Spectacular optical variations in V404 Cygni



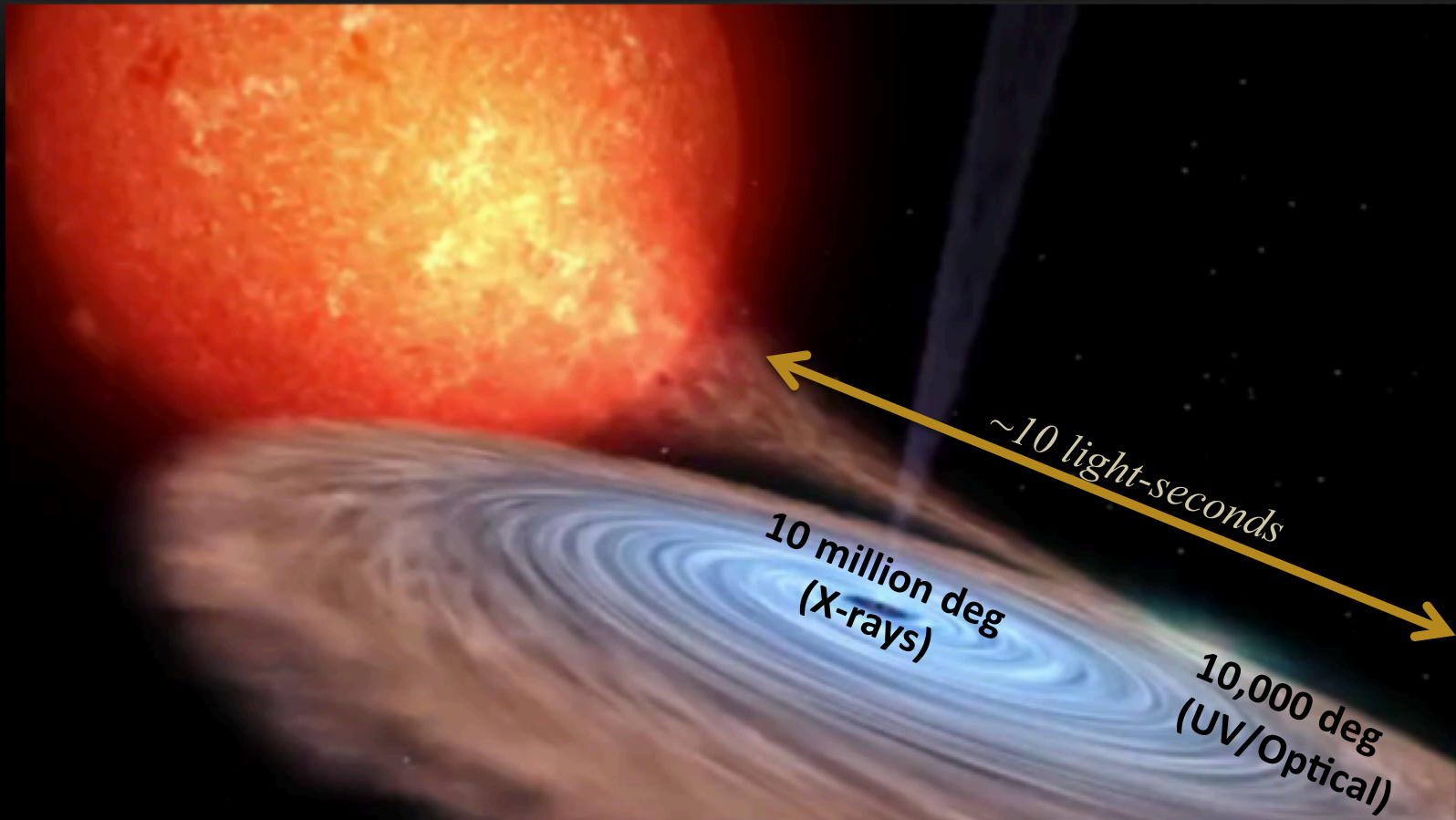
Variability tells us characteristic size

$$\text{Size} < c \times \text{Time}$$



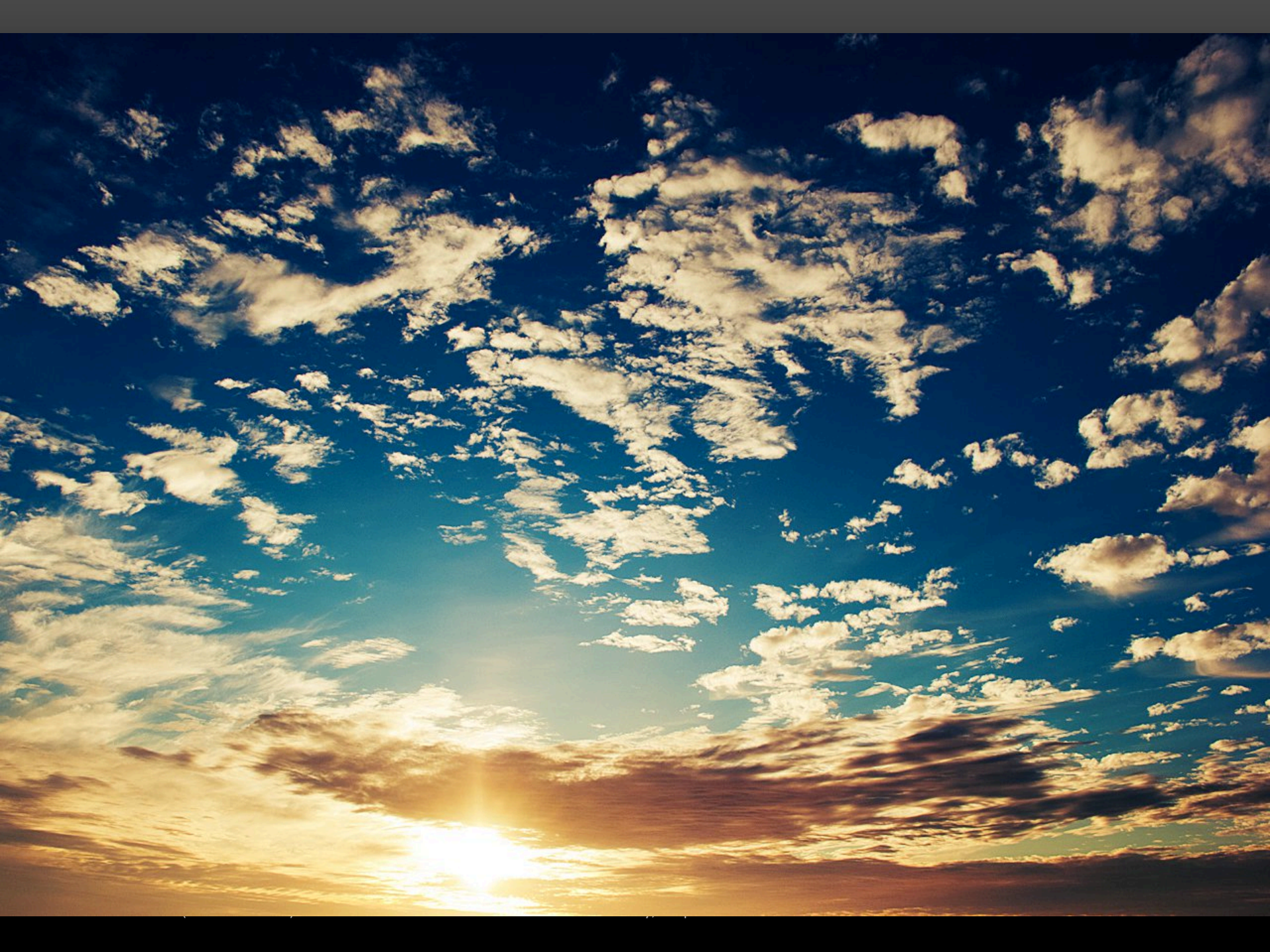
Larger size => Effective variability will be smoothed and longer

Optical variability much faster than expected



Fast optical flashes reveal black hole jets

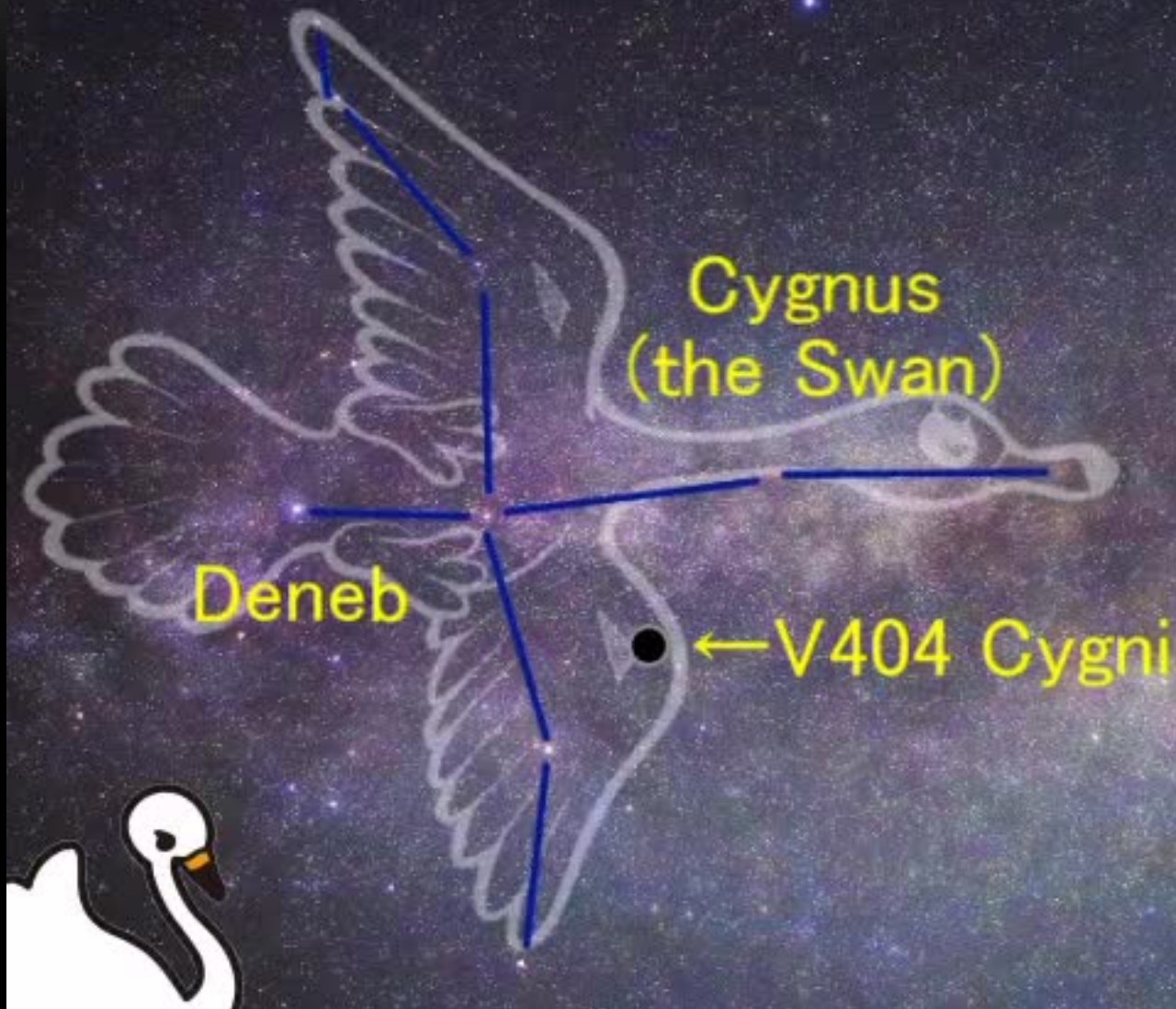








V404 Cygni variability from small telescopes



(Kimura et al. 2016)

Summary

- Light variations from accreting black holes provide fundamental information on the sizes and physical processes that cannot otherwise be resolved. These can range from \sim milliseconds to \sim years.
- Simultaneous data from across the electromagnetic spectrum is important for obtaining a complete understanding of these systems.
- Long term accurate monitoring by amateur astronomers is highly valuable to the astronomy community.