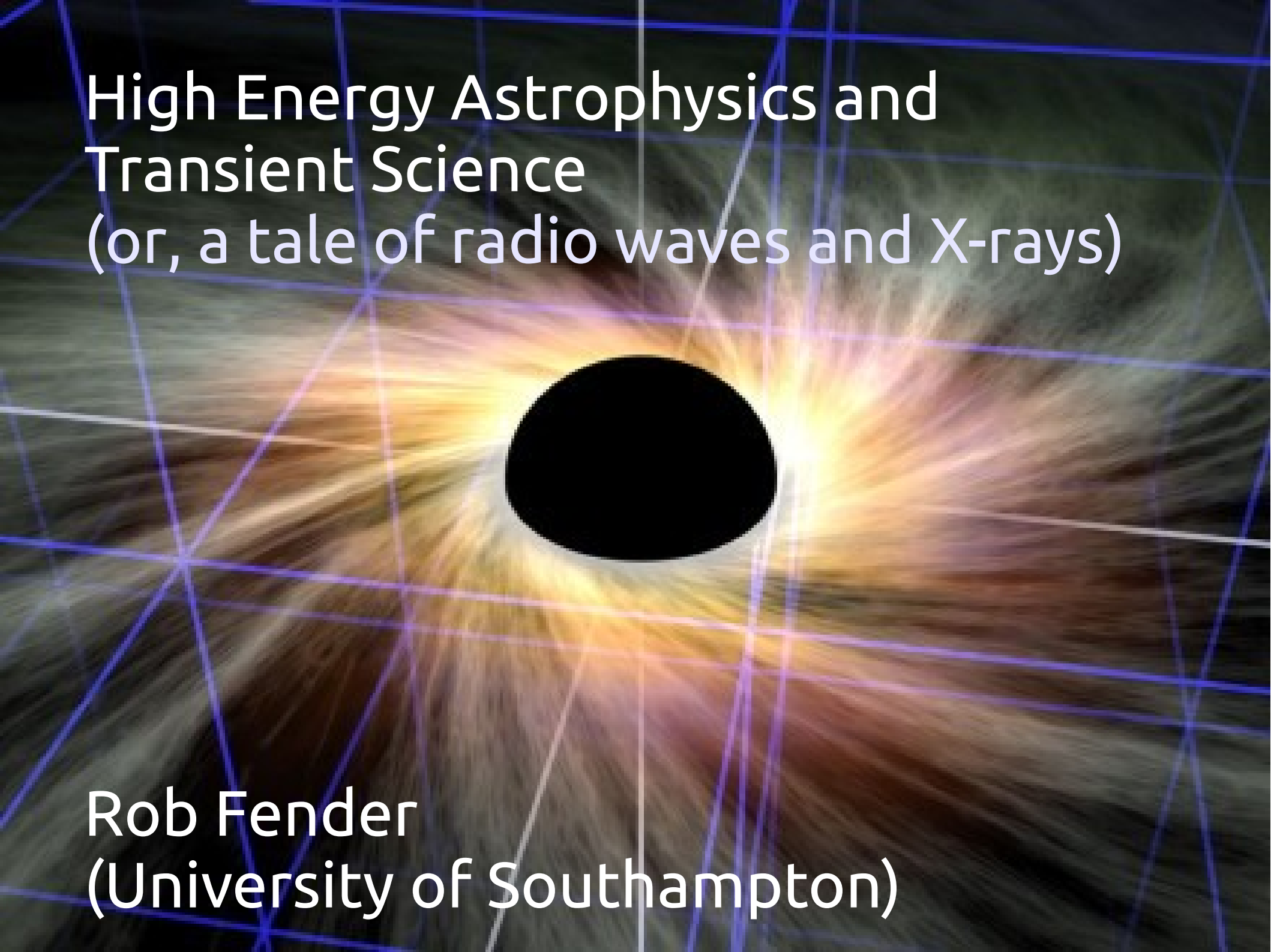
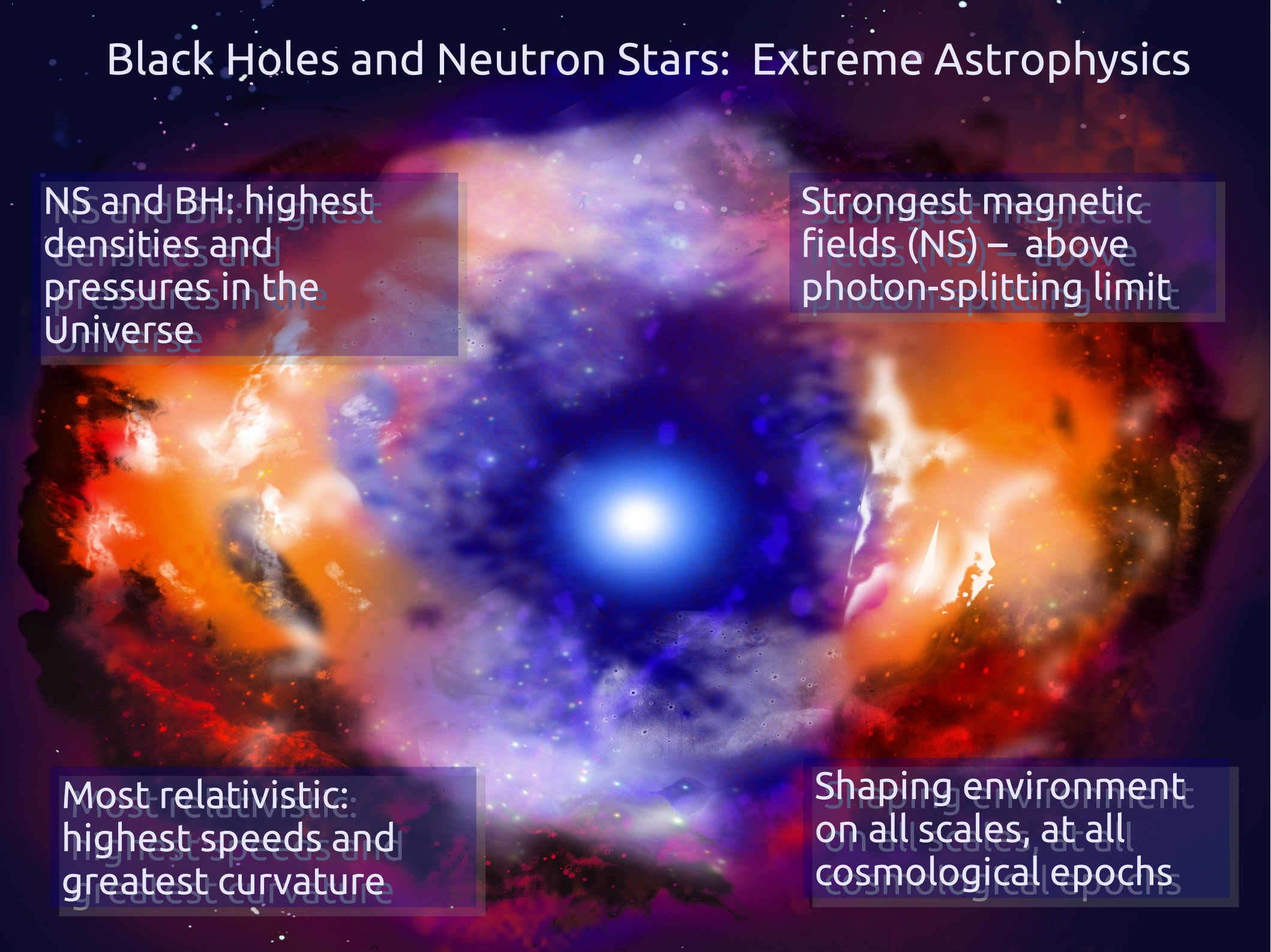
High Energy Astrophysics and Transient Science
(or, a tale of radio waves and X-rays)



Rob Fender
(University of Southampton)

Black Holes and Neutron Stars: Extreme Astrophysics



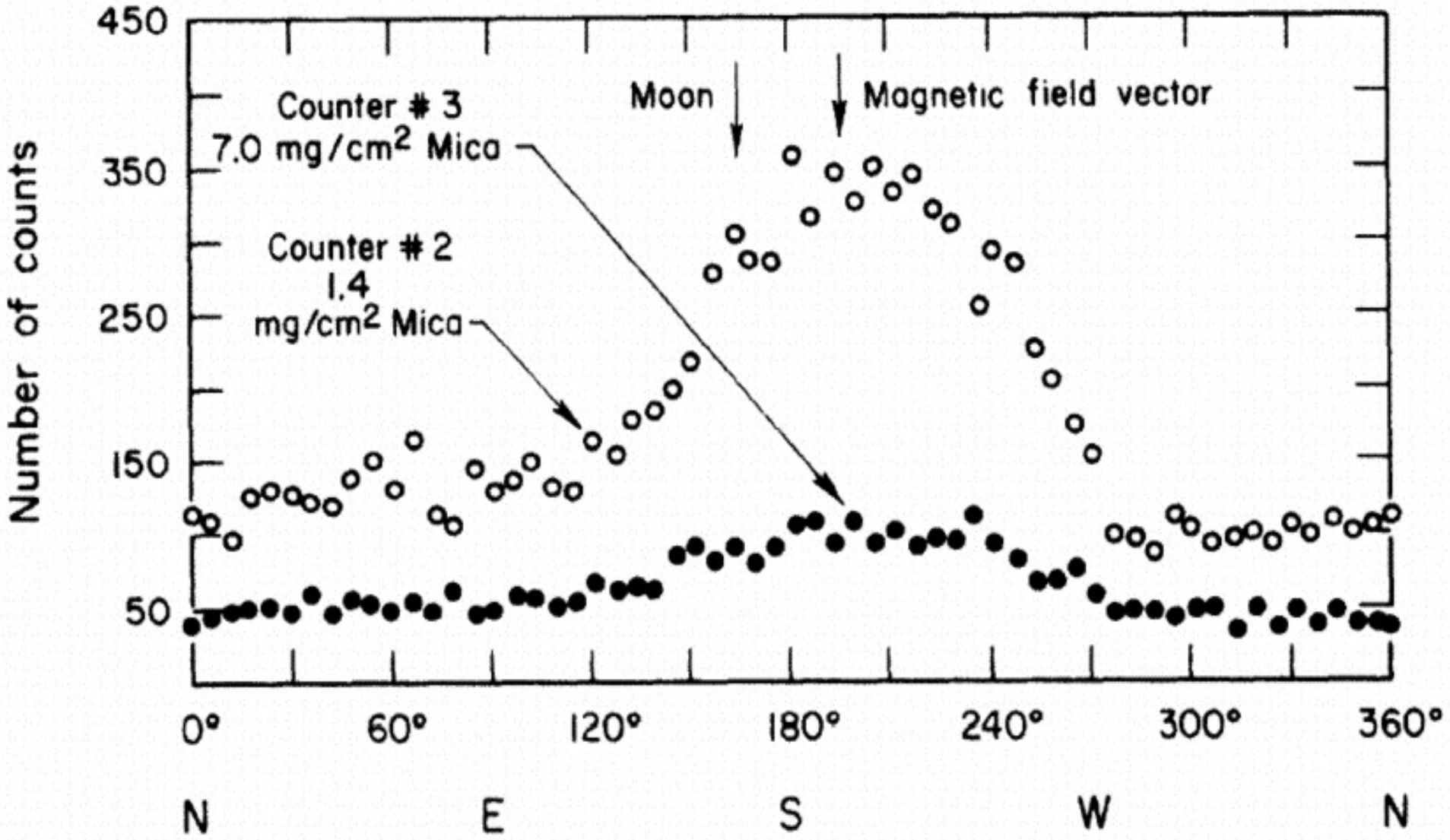
NS and BH: highest densities and pressures in the Universe

Strongest magnetic fields (NS) – above photon-splitting limit

Most relativistic: highest speeds and greatest curvature

Shaping environment on all scales, at all cosmological epochs

1962



The discovery of X-ray binaries (Giacconi et al. 1962)

1968

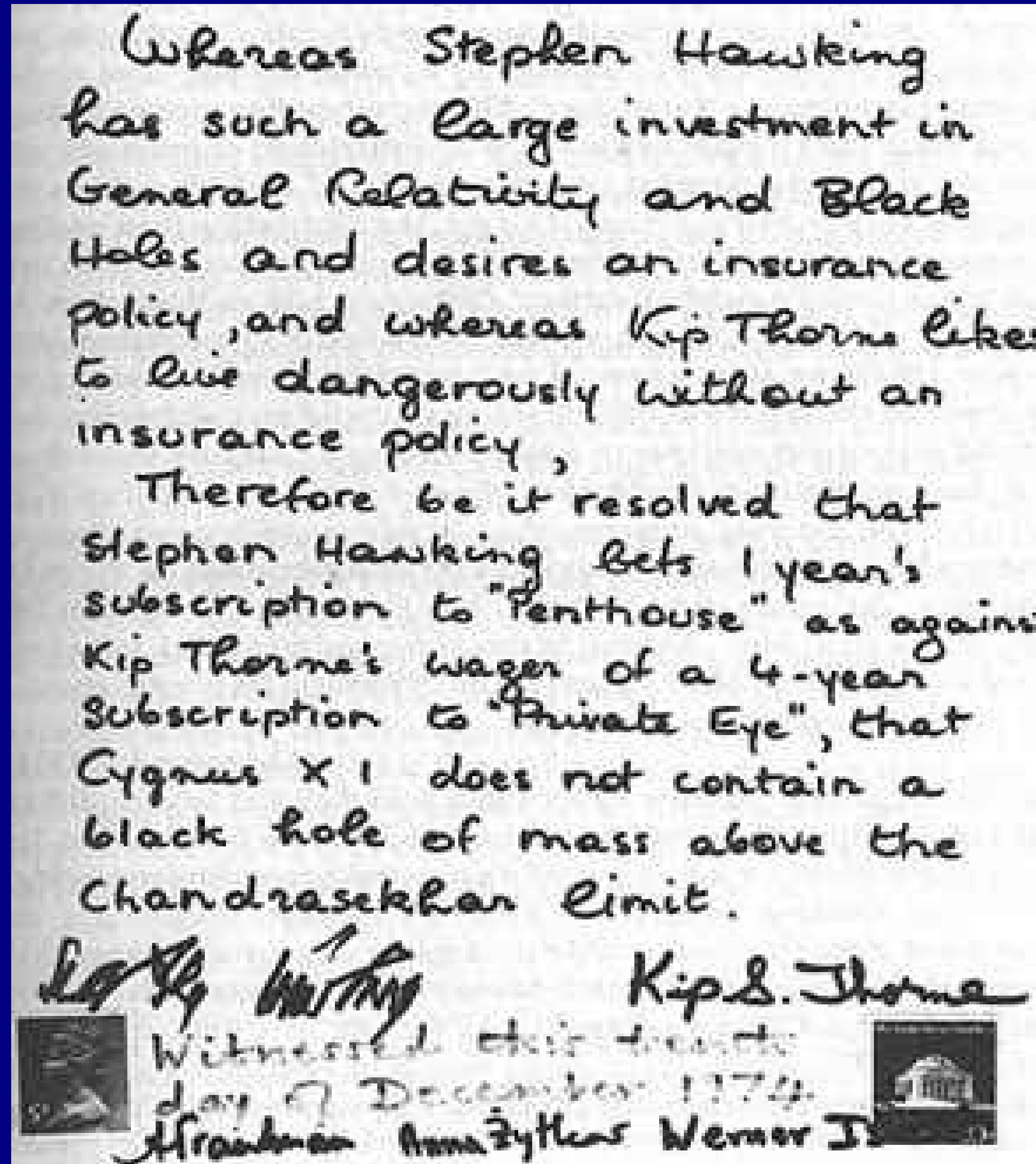
The discovery of radio pulsars (Hewish, Bell et al. 1968)

1974

Black holes, Penthouse and Private Eye

Bet made in 1974

“Conceded” by Hawking in 1990

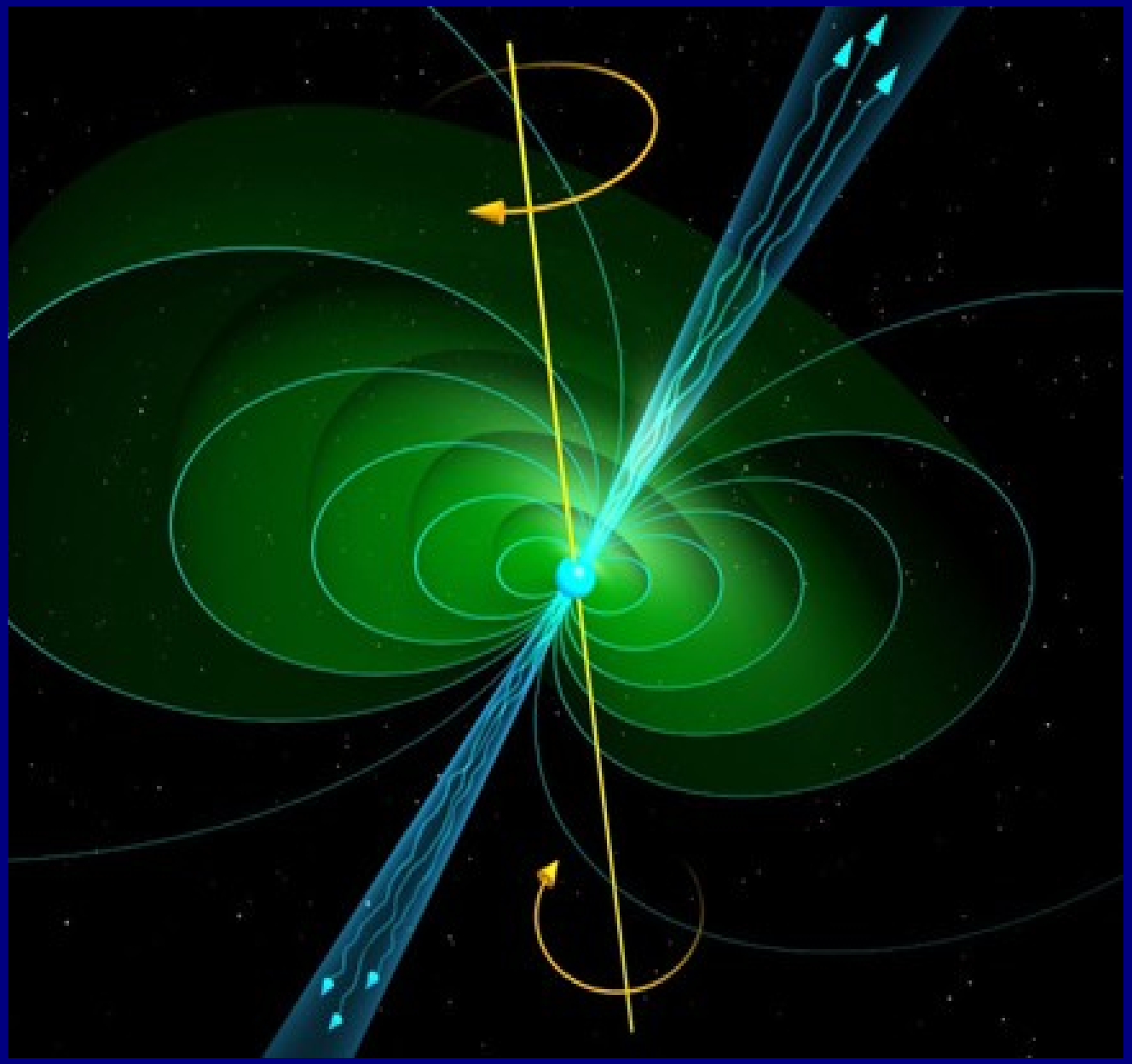


Whereas Stephen Hawking has such a large investment in General Relativity and Black Holes and desires an insurance policy, and whereas Kip Thorne likes to live dangerously without an insurance policy,

Therefore be it resolved that Stephen Hawking bets 1 year's subscription to "Penthouse" as against Kip Thorne's wager of a 4-year subscription to "Private Eye", that Cygnus X1 does not contain a black hole of mass above the Chandrasekhar limit.

Kip S. Thorne

Witnessed this tenth day of December 1974.



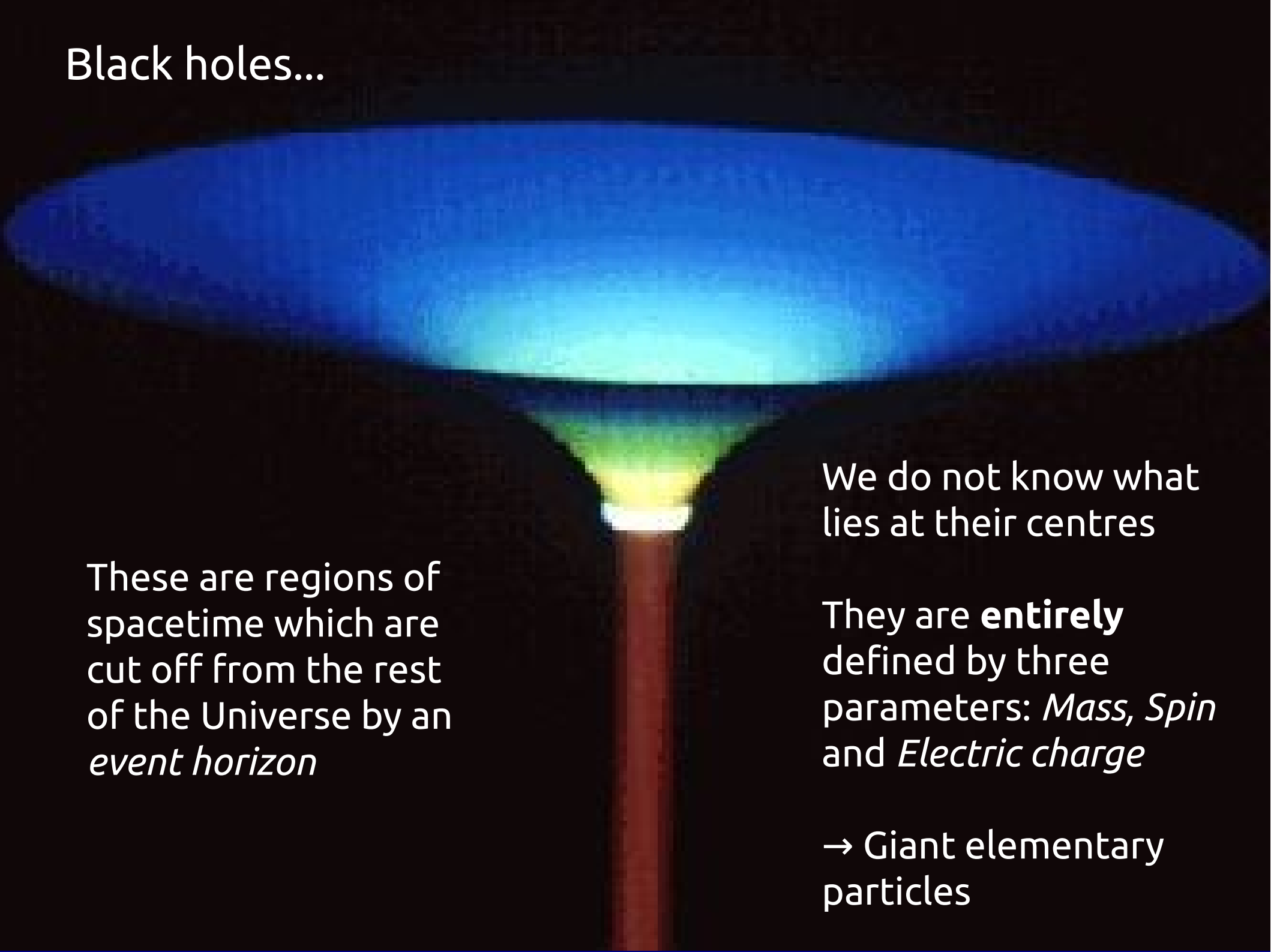
Neutron stars

1-2 solar masses in a star 10-20 km across

Density comparable to atomic nucleus

Sometimes extremely highly magnetised

Black holes...



These are regions of spacetime which are cut off from the rest of the Universe by an *event horizon*

We do not know what lies at their centres

They are **entirely** defined by three parameters: *Mass*, *Spin* and *Electric charge*

→ Giant elementary particles

The black hole at our own galactic centre

Stars orbiting a large unseen mass at the centre of our galaxy

Genzel et al. / Ghez et al.

The black hole at our own galactic centre

Worth seeing a second time..

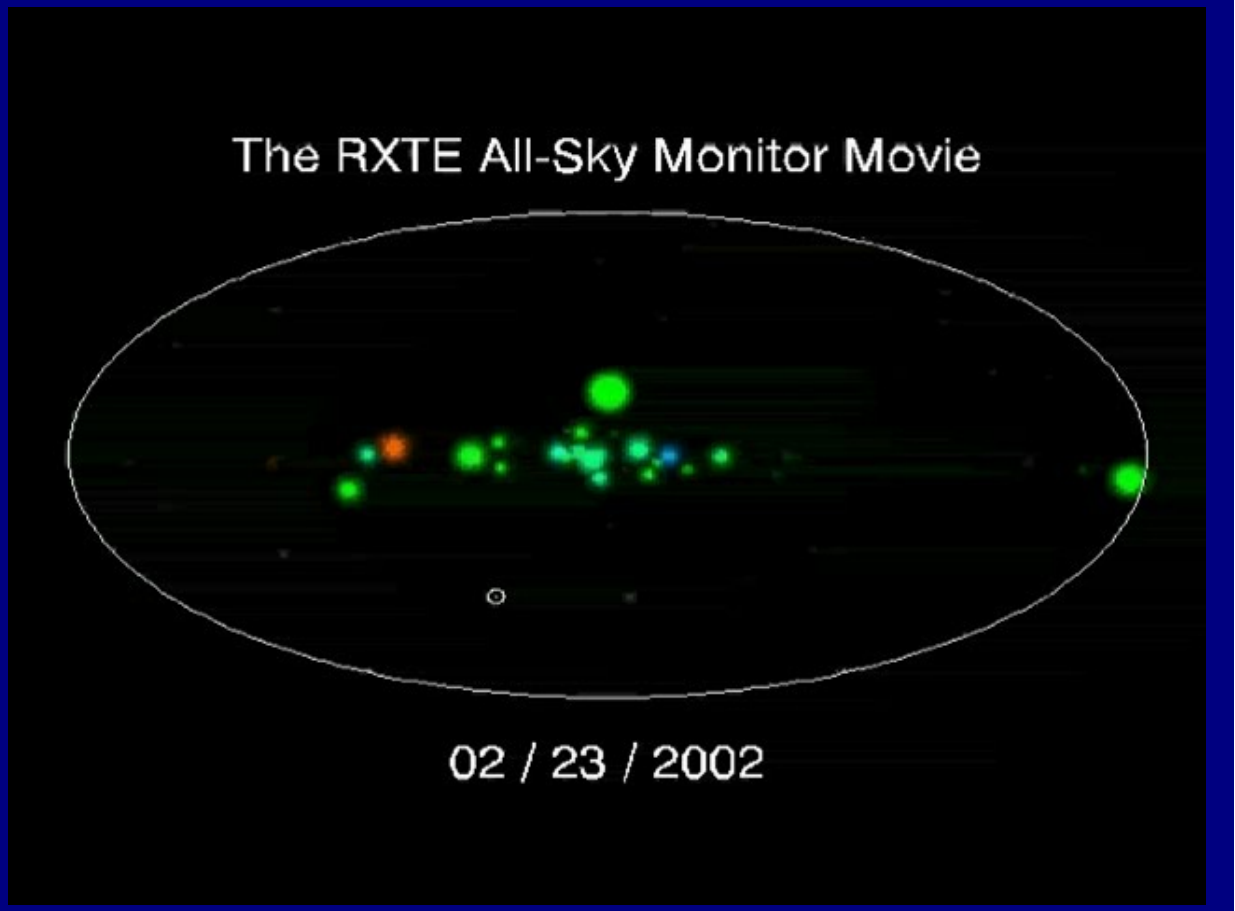
Genzel et al. / Ghez et al.

The X-ray sky : revealing a violent universe

‘soft’ X-ray spectrum

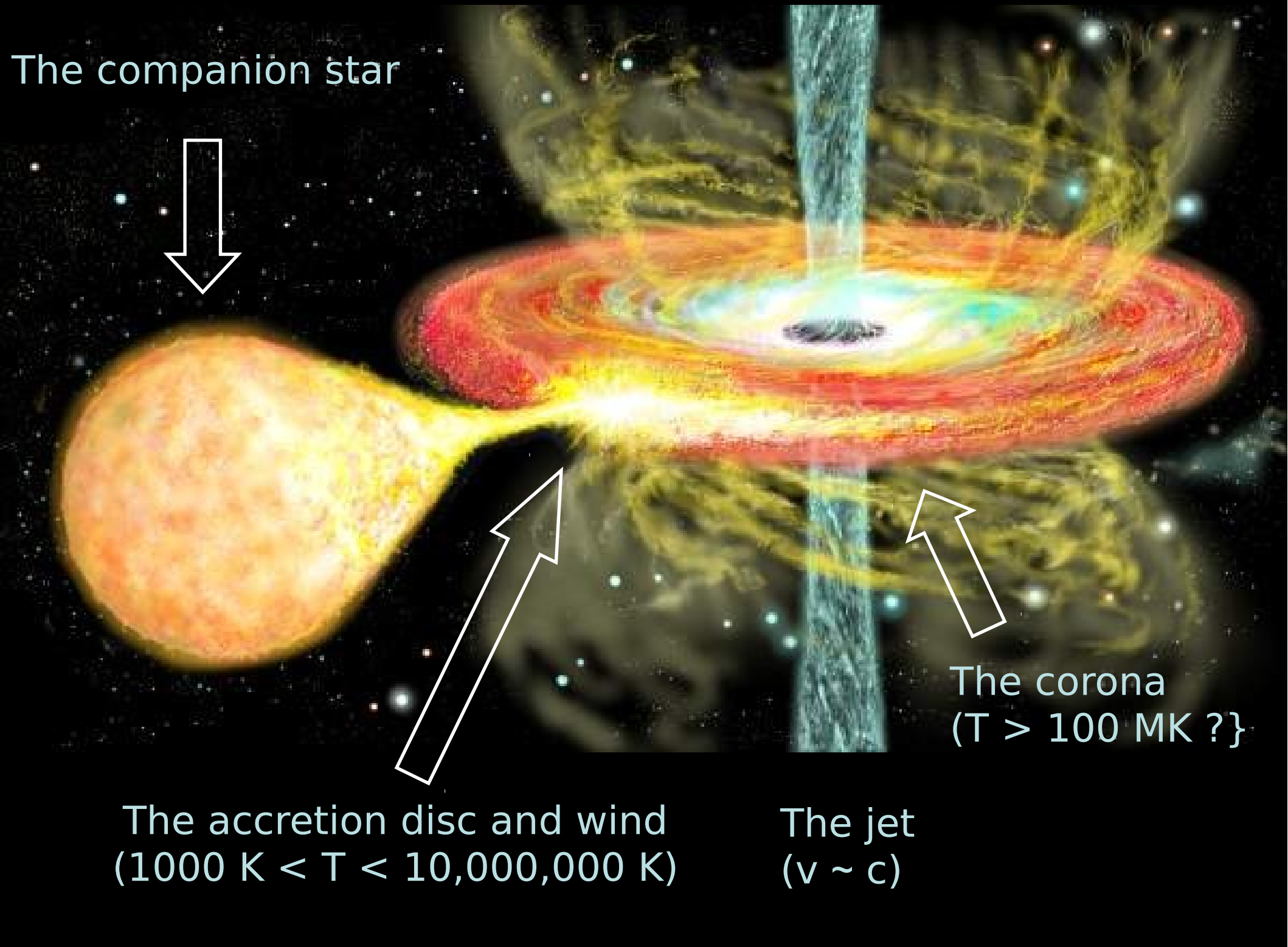
‘hard’ X-ray spectrum

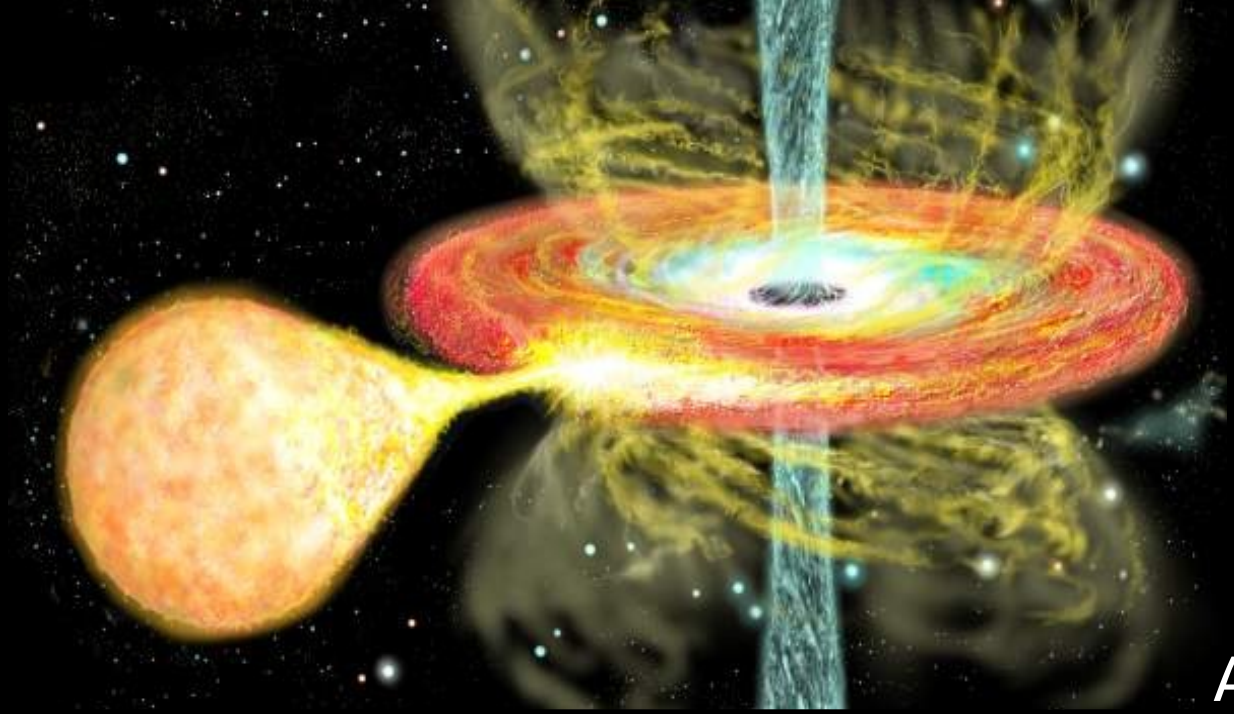
All the objects in the movie have X-ray luminosities greater than 10^{36} erg/s and are at large (kpc) distances



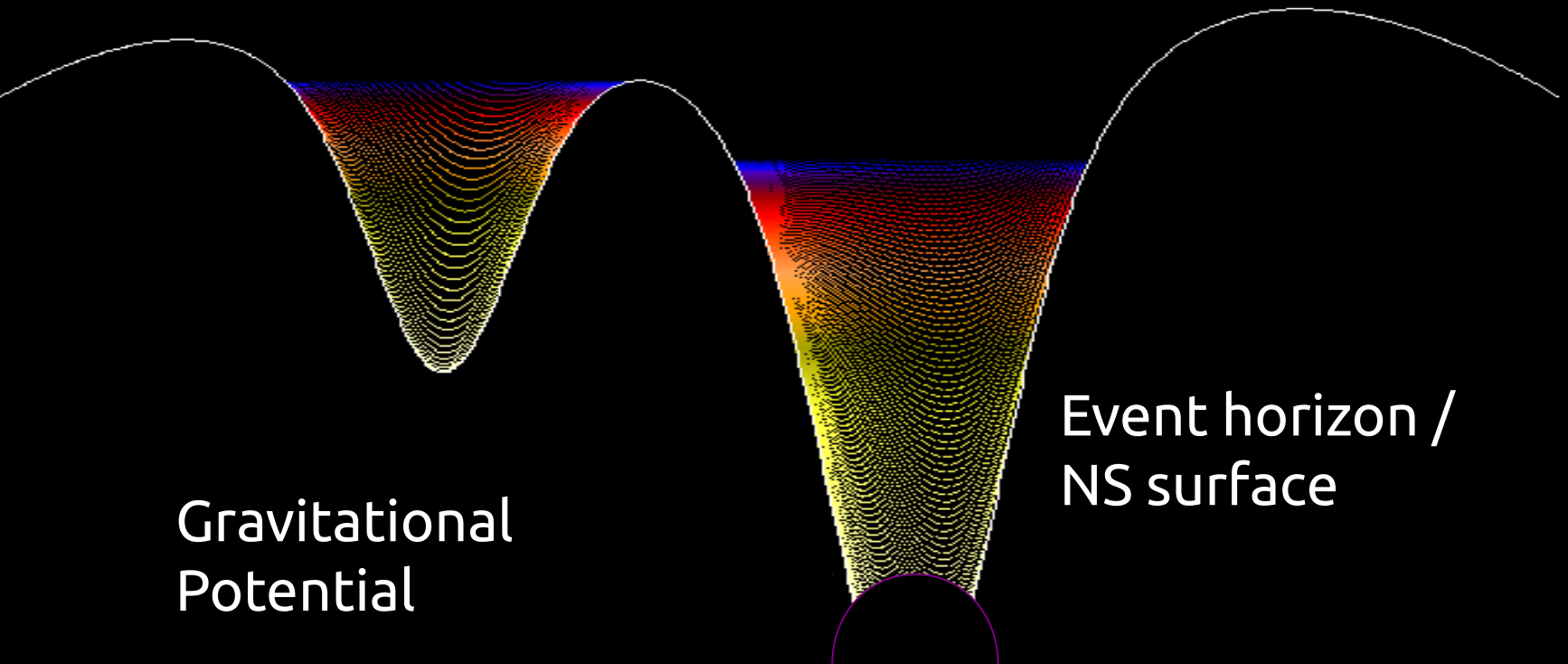
The X-rays originate from regions with temperatures $>10^{7}$ K and sizes 10—100 km ...

... they are accreting neutron stars and stellar mass black holes in X-ray binary systems


The companion star
The corona
(T > 100 MK ?}
The accretion disc and wind
(1000 K < T < 10,000,000 K)
The jet
(v ~ c)

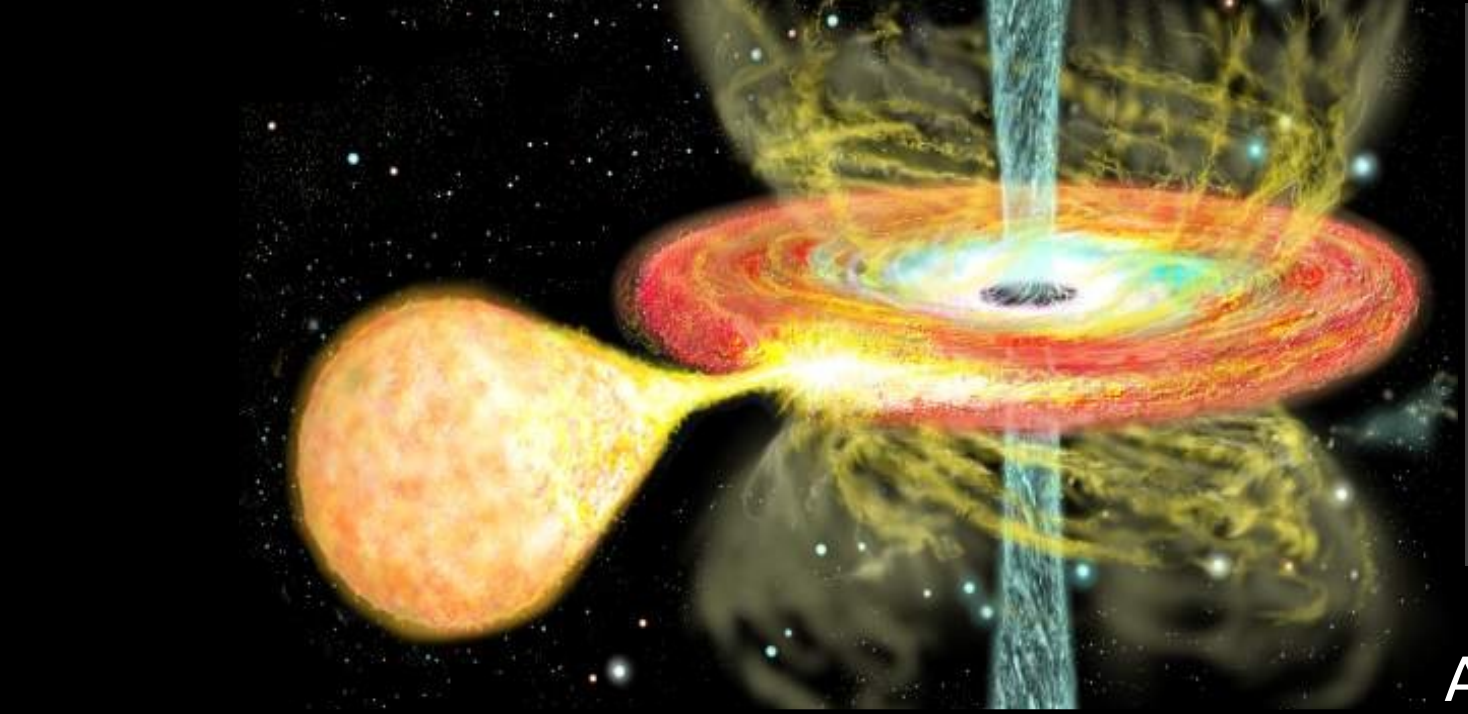


Angular momentum
results in disc



Gravitational
Potential

Event horizon /
NS surface



Angular momentum
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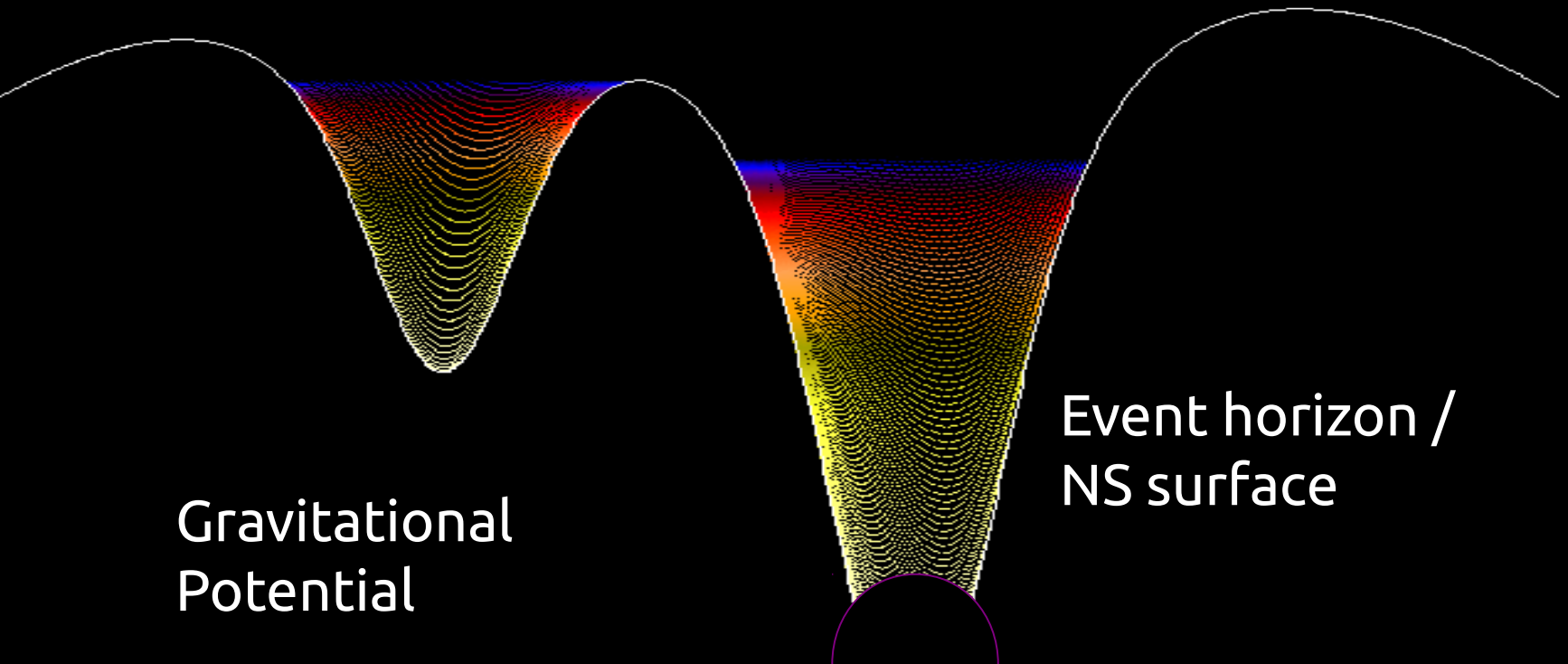
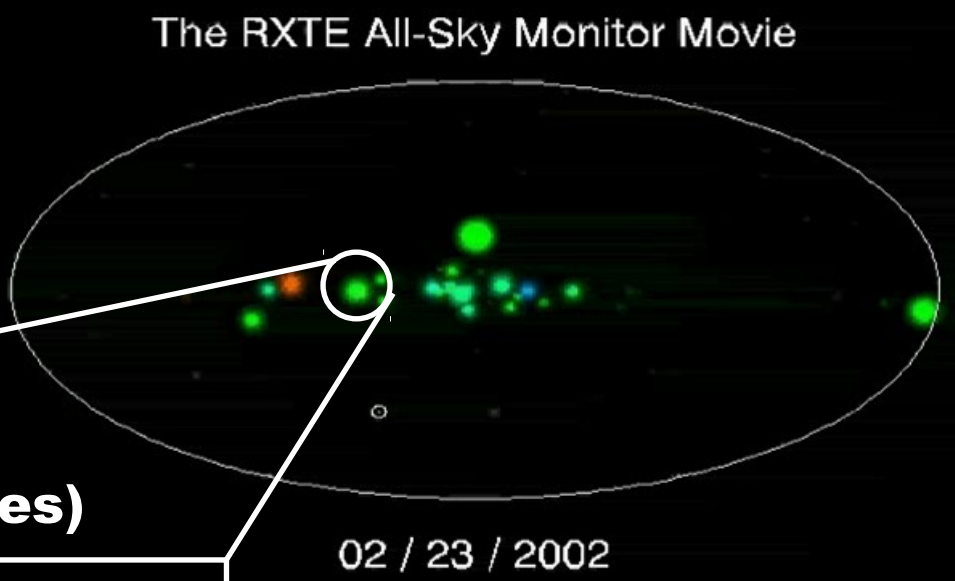


Event horizon /
NS surface

Gravitational
Potential

These objects are sources of highly relativistic (Γ>5) jets



MERLIN (daily images)

This source is **not unique** but rather at an extreme of the spectrum of X-ray binary properties (very high accretion rate)

GRS 1915+105:

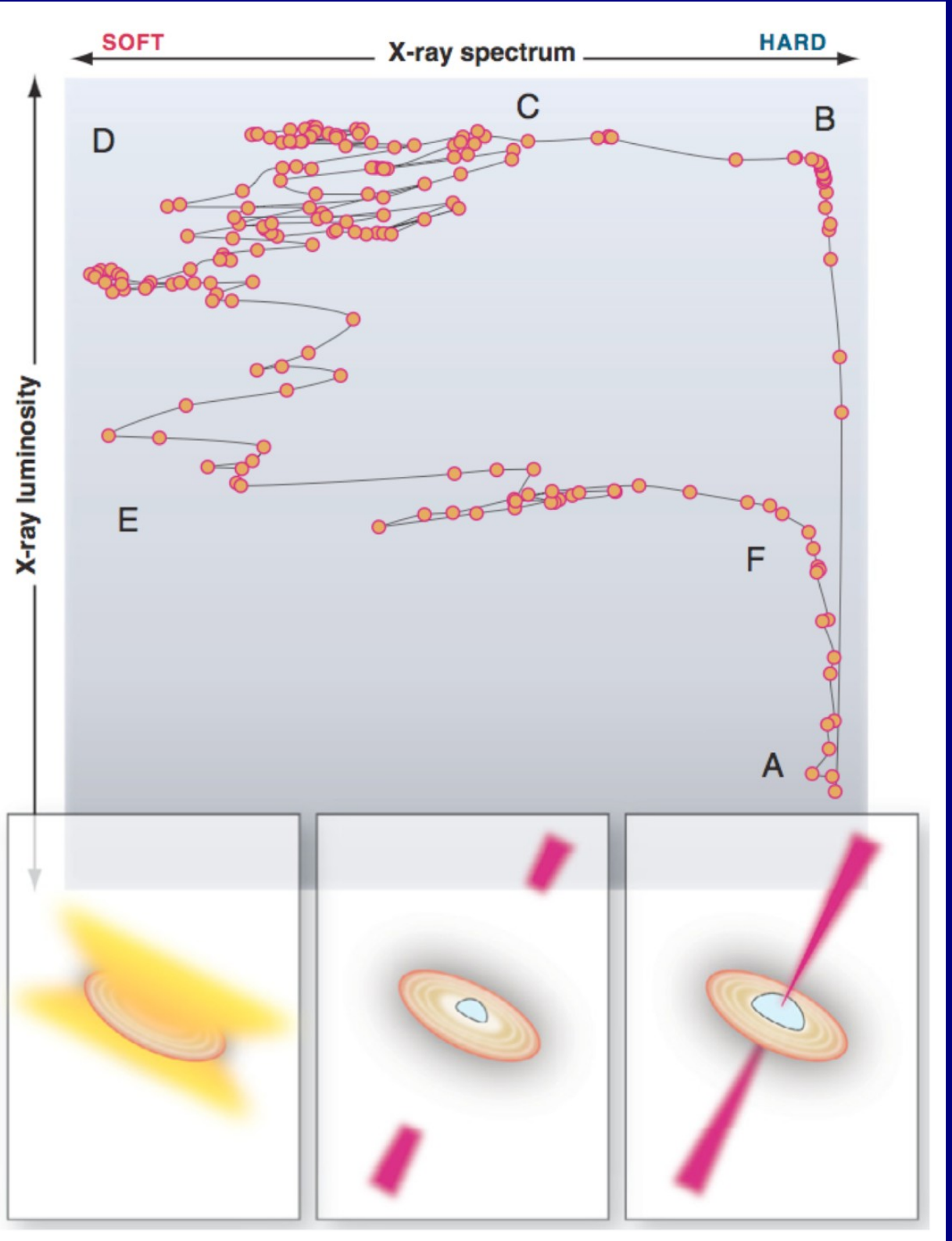
~15 solar mass black hole in 33 day orbit

Jets moving at >0.99c

Associated with outbursts

Carrying a large fraction of accretion power

This side has strong disc with disc wind, no jet



This side has strong corona and relativistic jet

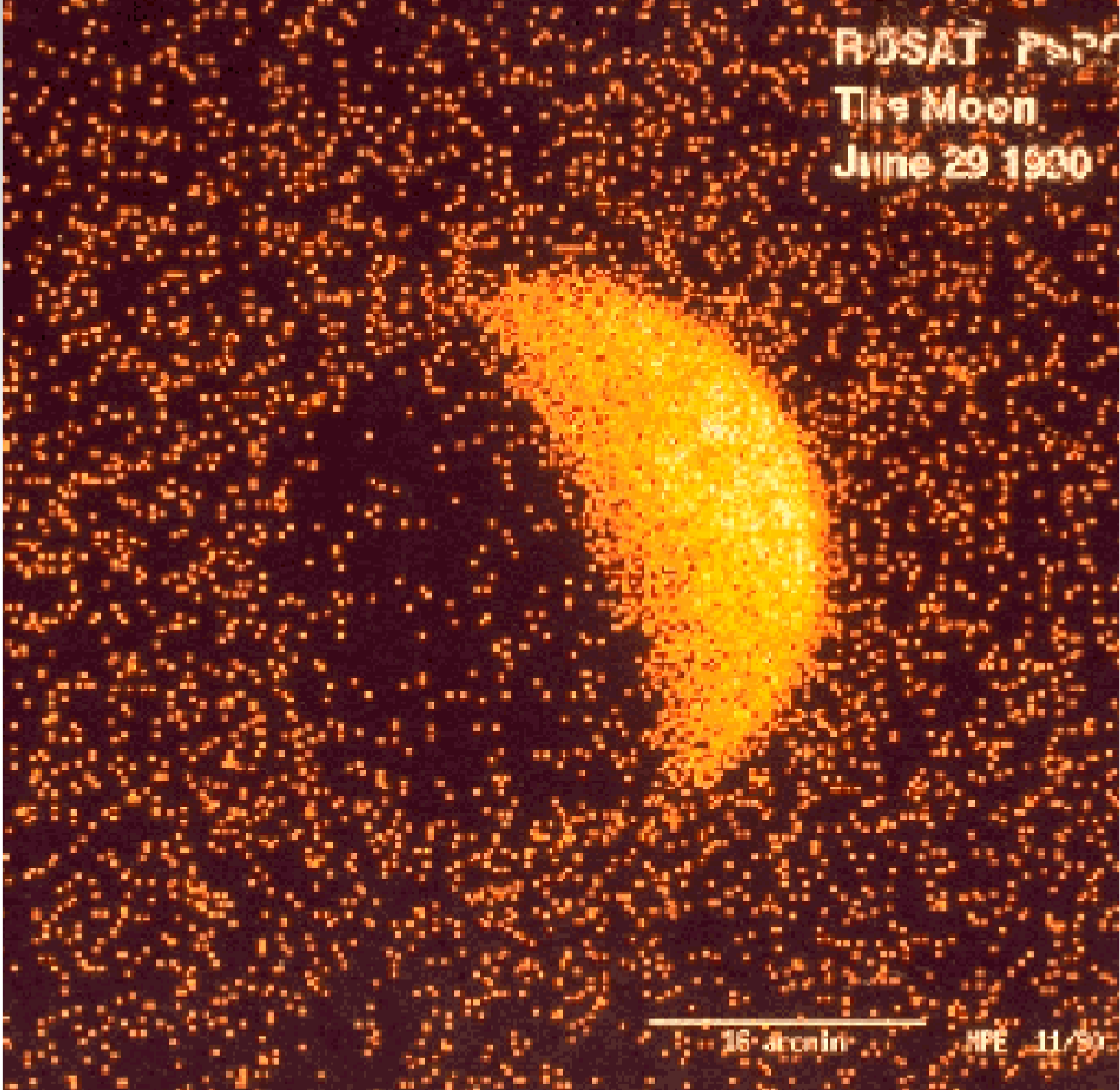
Fender & Belloni 2012

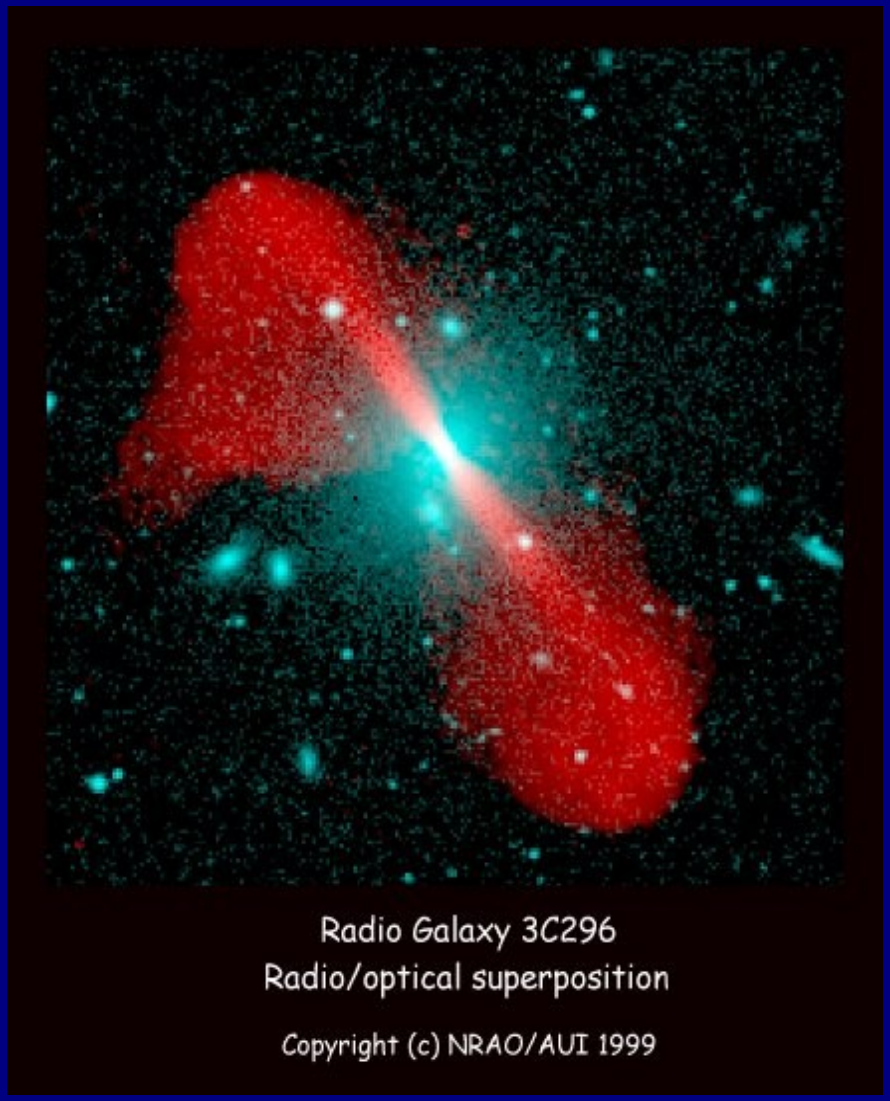
We know how the radio (jets) and X-rays (accretion) are coupled

Fender, Belloni & Gallo (2004) / Fender & Belloni 2012

These patterns of behaviour turn out to be applicable (broadly) also to SMBH in AGN.

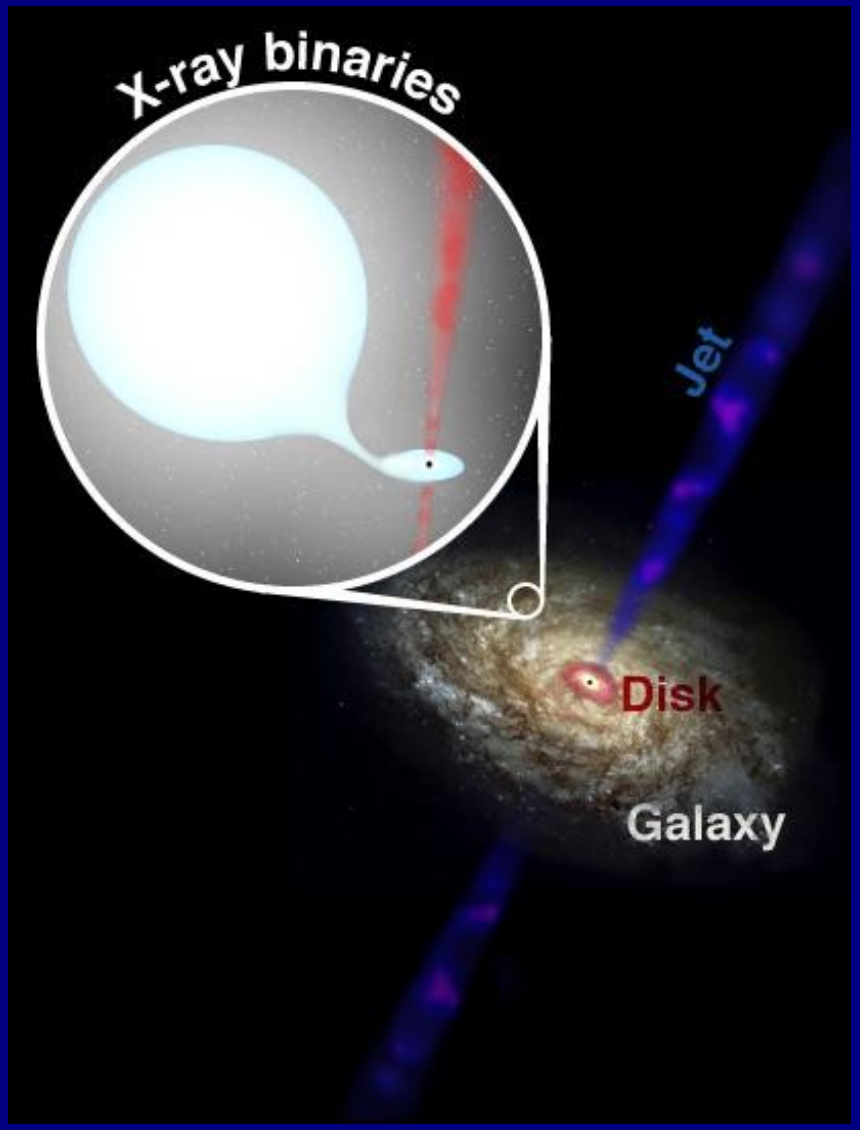
Can you see them?





Radio Galaxy 3C296
Radio/optical superposition

These objects are small-scale analogs of supermassive black holes



We can use them to study the evolution of feedback and galaxy formation over cosmic time

The cutting edge / future prospects

Wide-field searches for radio transients

Black hole spin – does it power jets?

Watching Sgr A* come to life

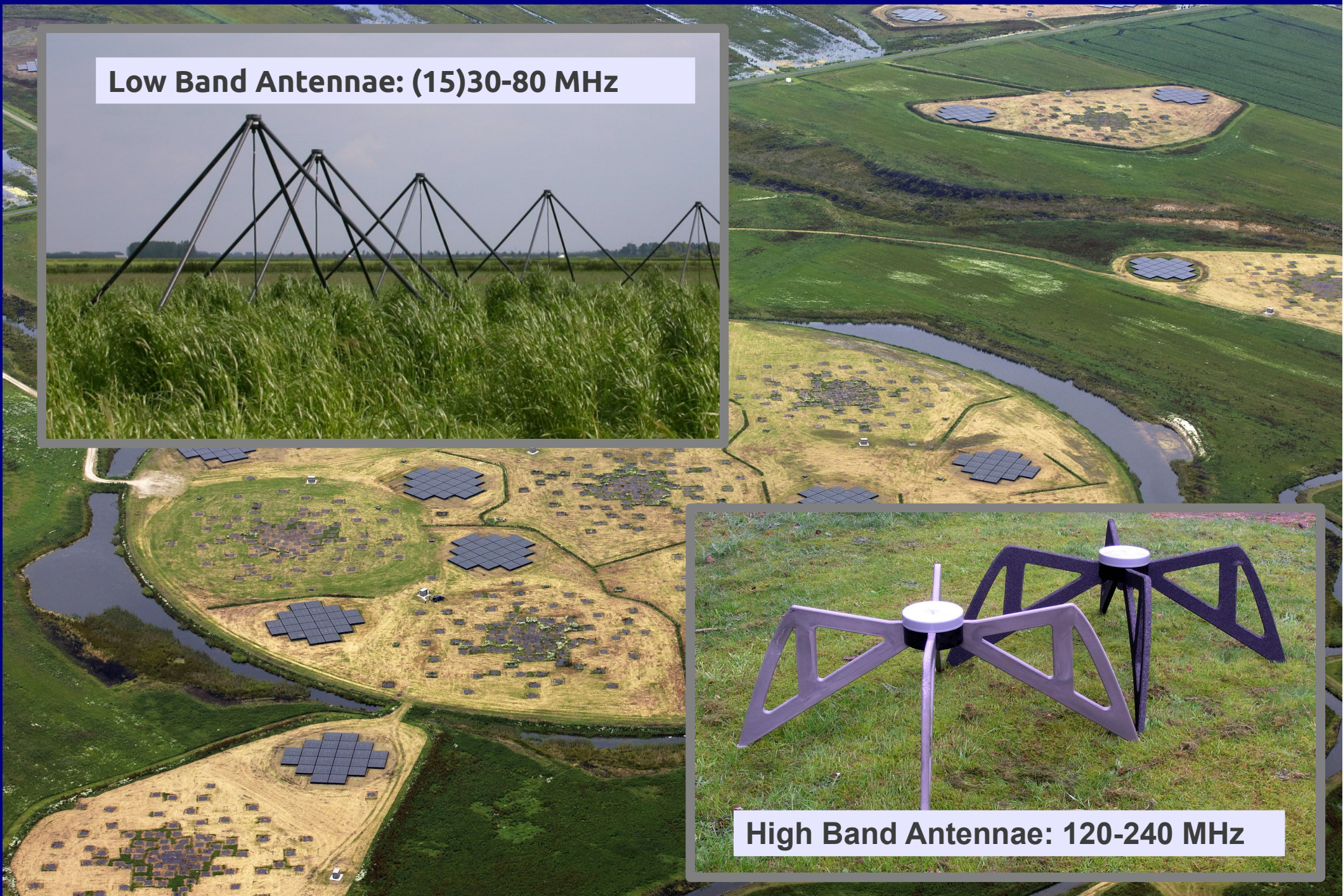
Wide field searches for transients in the radio band

Reber's 9m dish

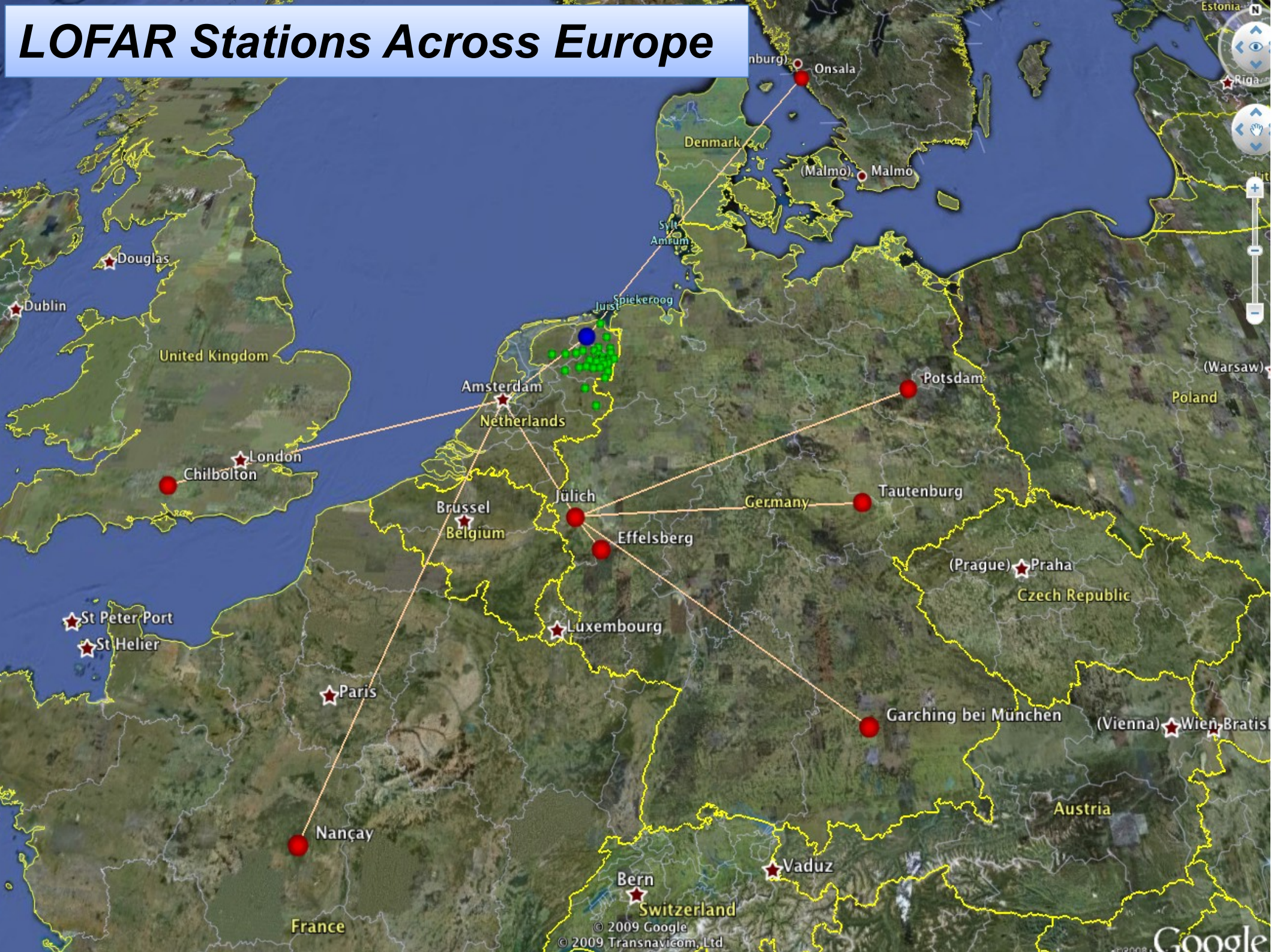
The Lovell Telescope at Jodrell Bank 76m

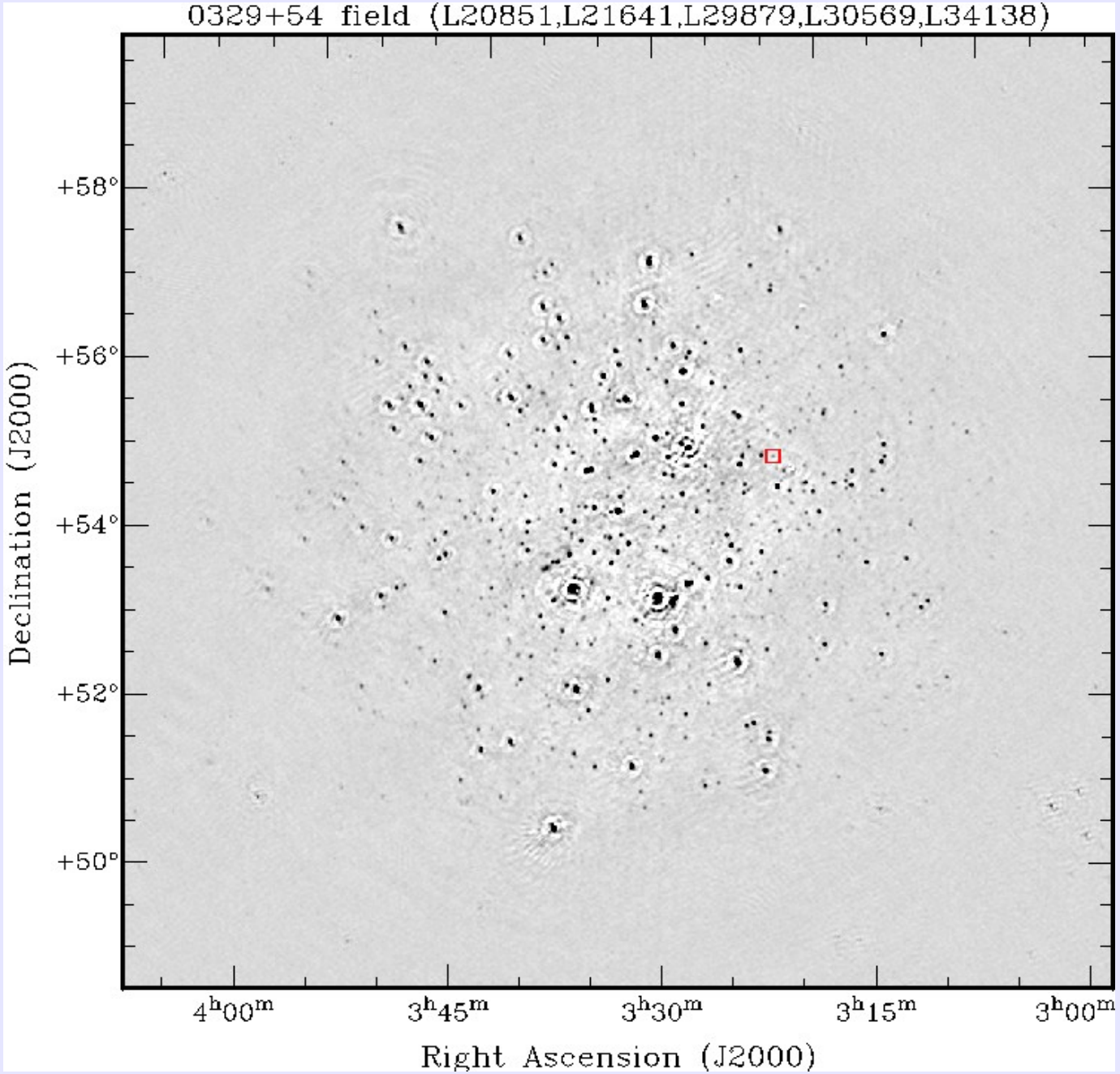
Orders of magnitude more sensitive.. but smaller field of view

LOFAR: The Low Frequency Array (30-240 MHz)



LOFAR Stations Across Europe





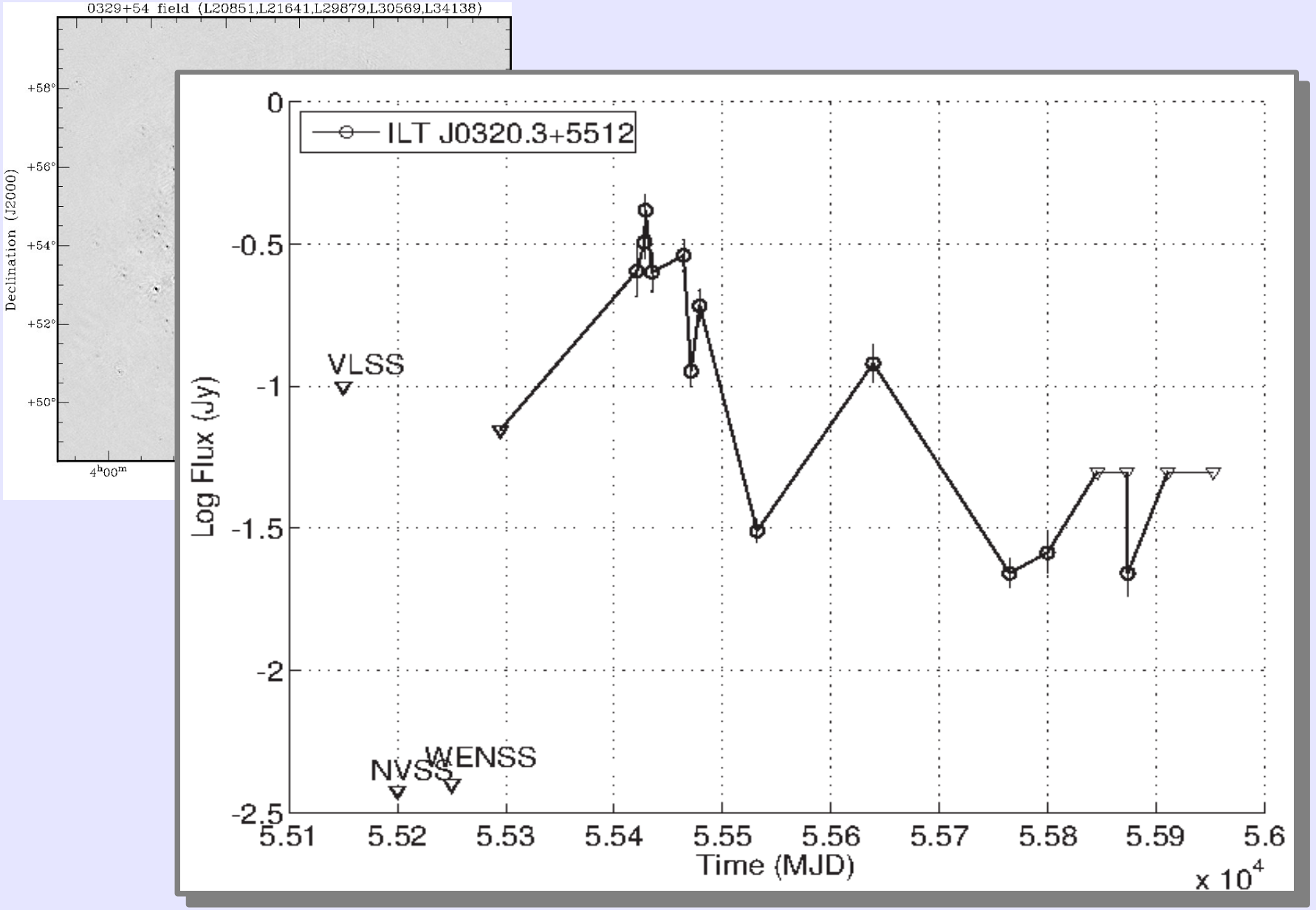
Zenith field transient: 0329+54

Bright (few x 100 mJy) source varying by factor ≥ 10

Not present in previous radio surveys (nor in some other radio observations we've made)

Broderick, Bell et al.

140 MHz band, σ ~3 mJy



Bell, Broderick et al.

What is this object?

Large network of multiwavelength (radio, IR, optical, X-ray, γ-ray, GW) partner facilities.

Multiple optical observations made, also X-ray upper limits from RXTE ASM and MAXI

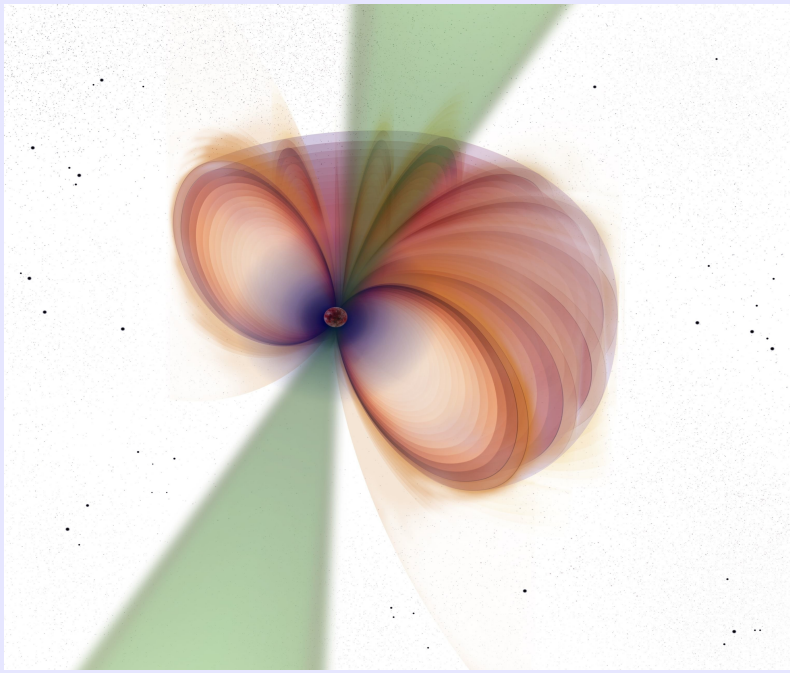
No optical counterpart to (stacked) m ~22.5. No bright X-ray counterpart.

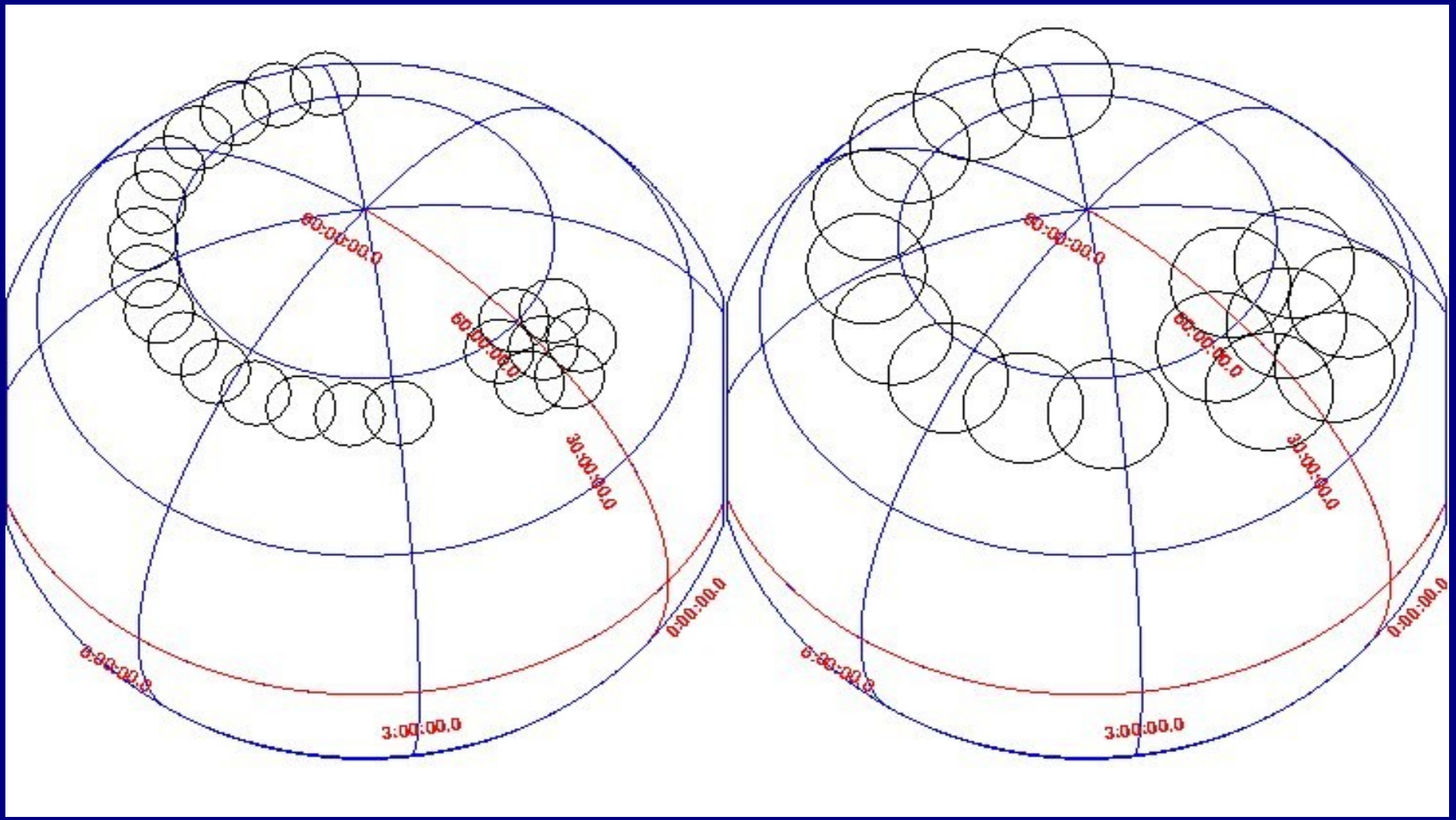
These limits rule out: accreting binary (CV, X-ray binary), AGN

What is left?
Some flavour of neutron star?

However, there are no pulsations

New class of transient ??



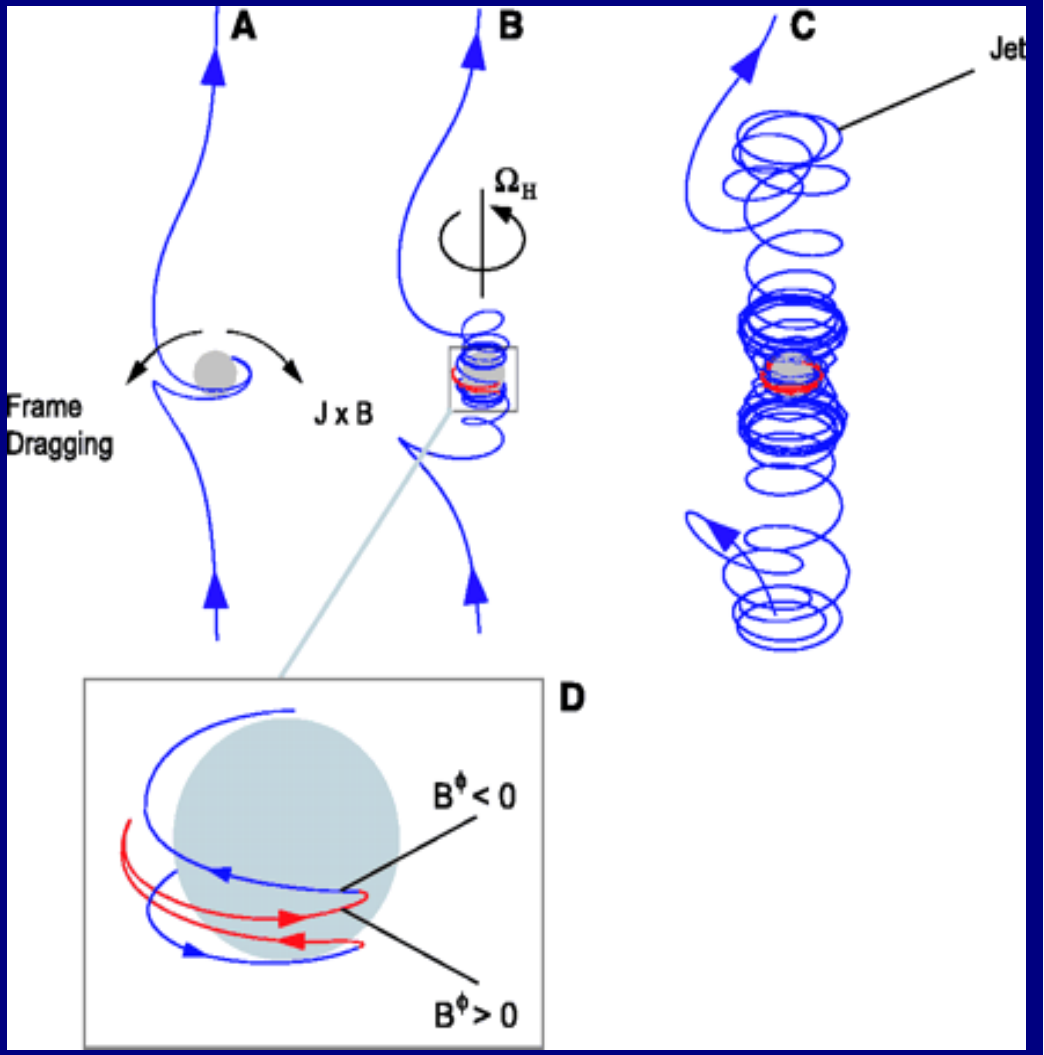


LOFAR observation cycle zero starts in January, over one quarter of all observing time is transient searches – whatever the LOFAR transient is, we should find 10s – 100s of them..

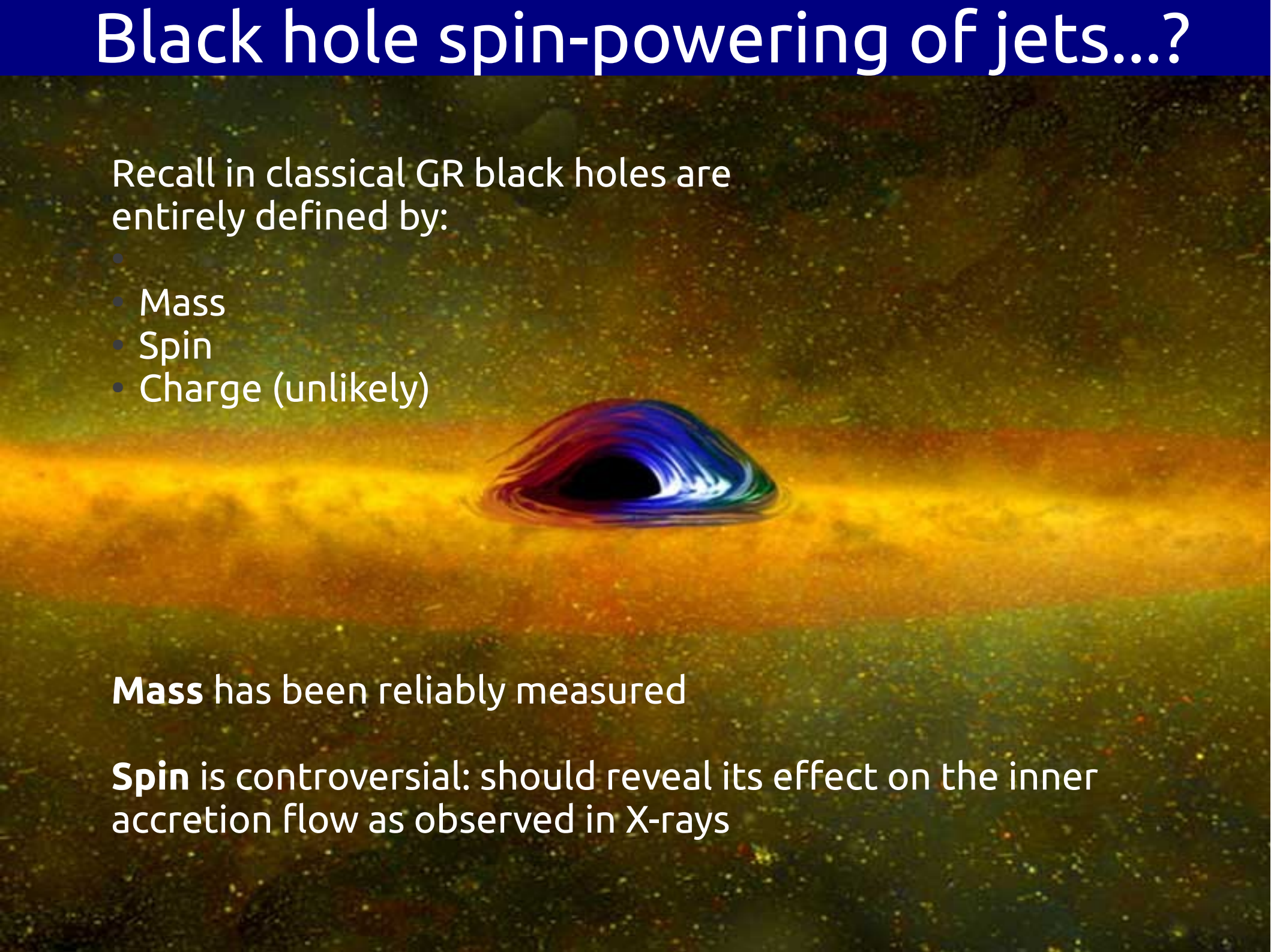
Black hole spin-powering of jets...?

Penrose (69), Christodolou (70) showed that you can extract up to ~30% of the mass-energy of a maximally rotating black hole

- Blandford & Znajek (77) … McKinney (05++) showed how a disc could allow this energy to be extracted and to drive a powerful relativistic jet,
- Essentially **all** current GRMHD simulations of relativistic jet formation focus on a rotating black hole to produce the most relativistic jets



Black hole spin-powering of jets...?



Recall in classical GR black holes are entirely defined by:

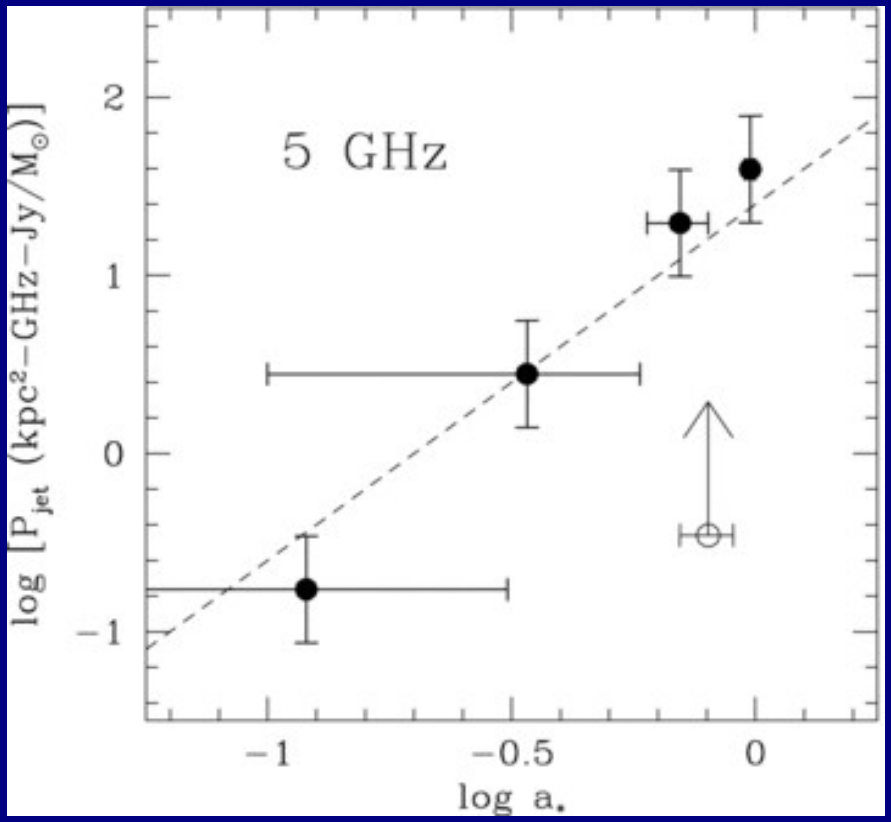
- Mass
- Spin
- Charge (unlikely)

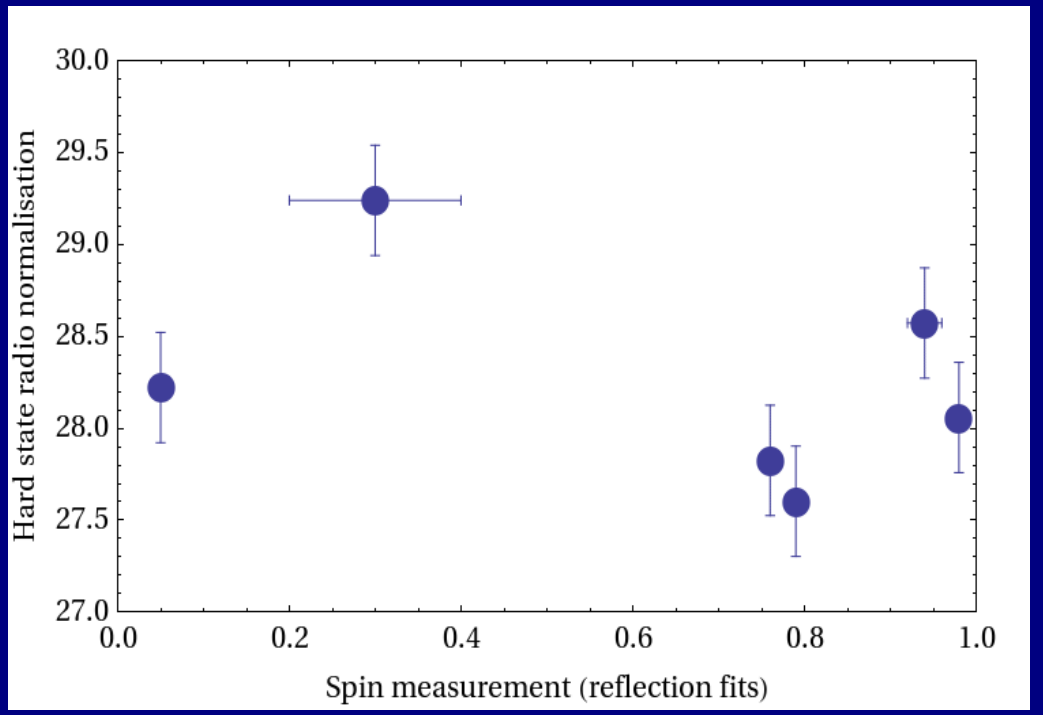
Mass has been reliably measured

Spin is controversial: should reveal its effect on the inner accretion flow as observed in X-rays

There is no correlation between the power of the steady hard state jet and reported spins

(Fender, Gallo & Russell '10)

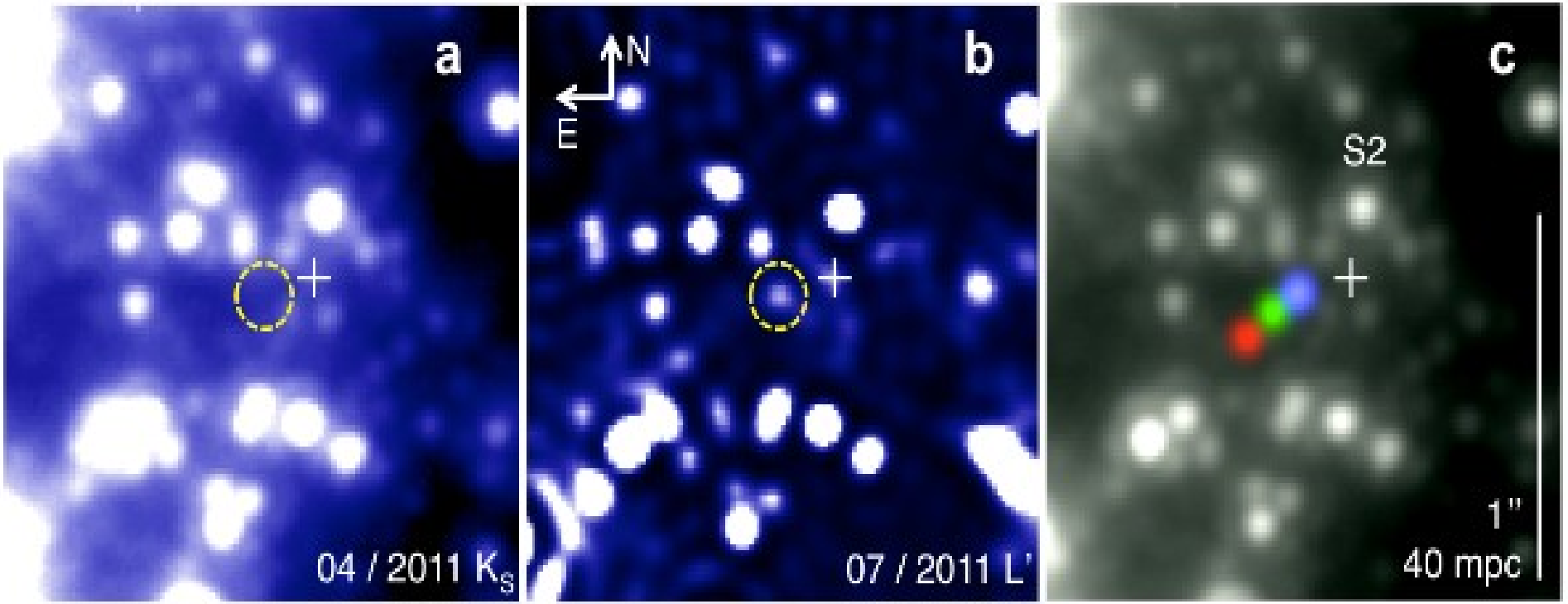




… **but** there is a report of a correlation between reported spins (of one flavour) and radio flare peaks

(Narayan & McClintock '12)

2013: black hole reborn



Gillenson et al. (2012)

In mid-2013 the infalling gas cloud will fall to within 36 light hours of the supermassive black hole and accretion (→ X-rays) should commence

Gillenson et al. (2012)

Summary

High energy astrophysics studies the most extreme conditions in the entire universe, orders of magnitude beyond anything we can (ever) achieve on Earth

Radio and X-ray astronomy are excellent tools for studying these phenomena, moreso when used together

There are many open and exciting challenges, and the relevance is broad

Watch Sgr A* in 2013 !