Stellar-Mass Black Holes and Pulsars

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Work group 2 leader
(ESO ALMA fellow)

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Overview of Work Group 2

Stellar-mass black holes and pulsars

- Two work group leaders:
  - Anthony Rushton (Accretion)
  - Robert Ferdman (Pulsars)

Overview of Work Group 2

- Accretion on to stellar-mass black holes.
- Pulsar timing in the orbit of a black hole.
- Synergies with other WGs:
  - Using pulsars to detect gravitational waves from super-massive black holes.
  - Microquasars to Quasars: Scale invariants, intermediate-mass BHs and their growth/evolution.

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High energy stellar-mass accretion: X-ray binaries

- Binary systems with a *compact object* and a *companion star*.

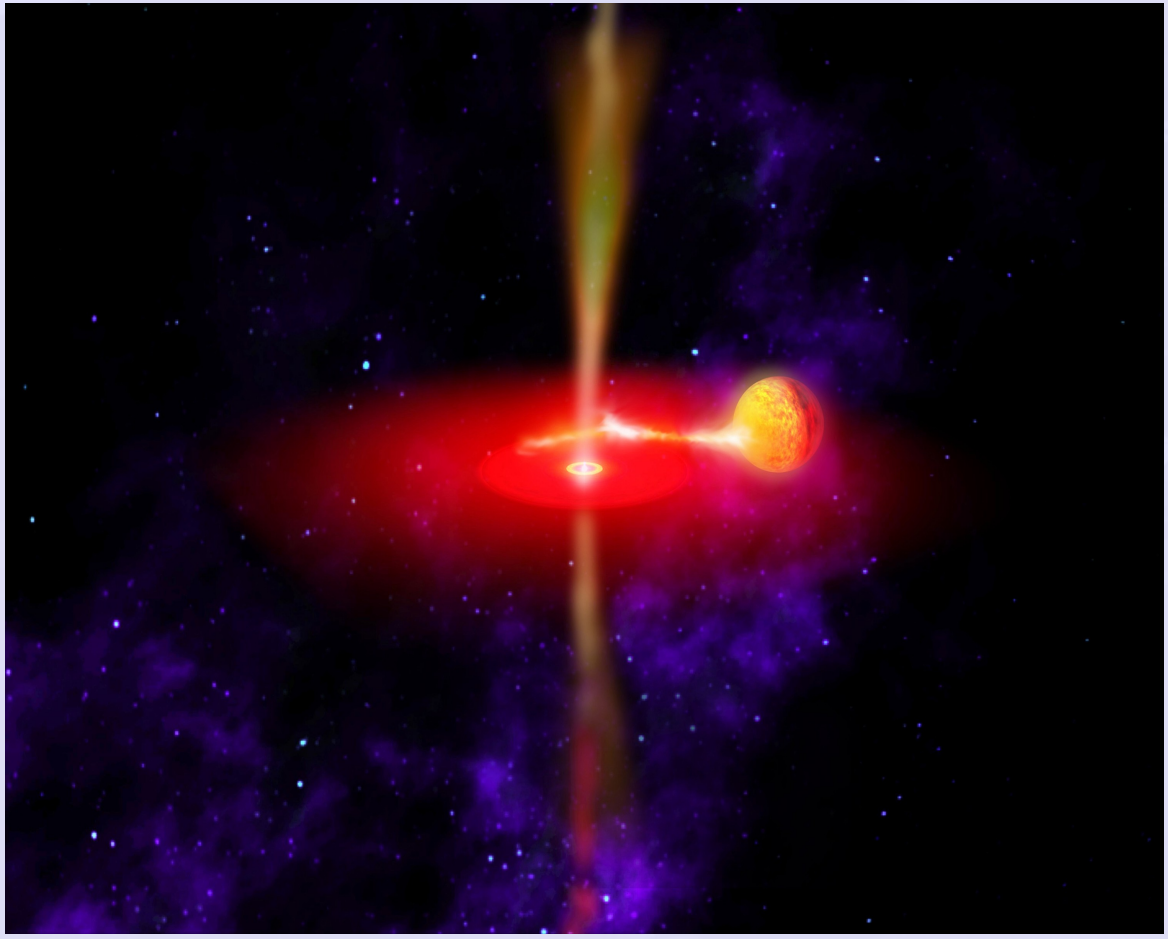
- The companion star maybe:
  - High-mass star
  - Low-mass star

} Determines the rate of mass-transfer onto the accretion disk

Companion stars: High-mass XRBs

- Mass-transfer via stellar wind
- Accretion rate determined by:
  - cross-section of the disk
  - Asymmetry of the outflowing wind
- Short life-time and found across Galactic plane.

Companion stars: Low-mass Stars



- Mass-transfer via a Lagrangian point in Roche lobe
- Longer life-time and located towards galactic centre / globular clusters

High energy stellar-mass accretion: X-ray binaries

- Binary systems with a *compact object* and a *companion star*.

- The companion star maybe:
  - High-mass star
  - Low-mass star

  } Determines the rate of mass-transfer onto the accretion disk

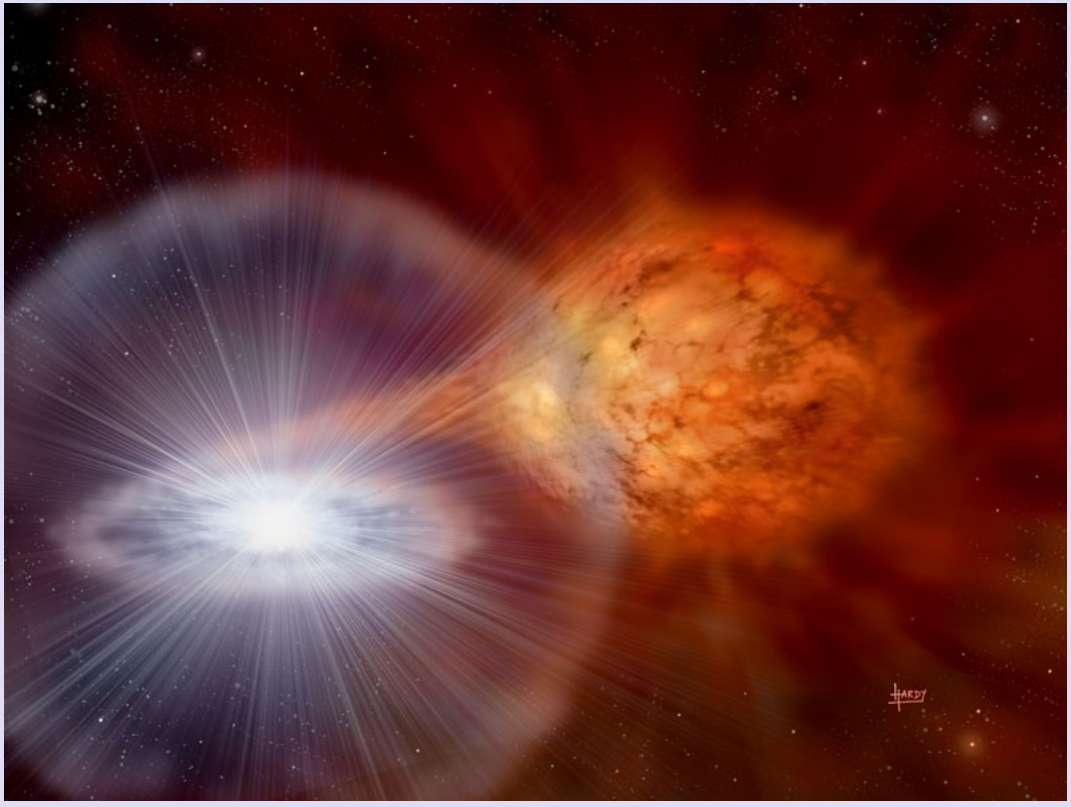
- The compact object maybe:
  - White Dwarf
  - Neutron star (possibly a pulsar)
  - Stellar-mass **Black Hole**

  } Determines the mode of accretion with the disk

Types of XRBs

- We need to study different types of XRB to determine what physics is unique to black hole progenitors:

White Dwarf – (Cataclysmic variable stars)

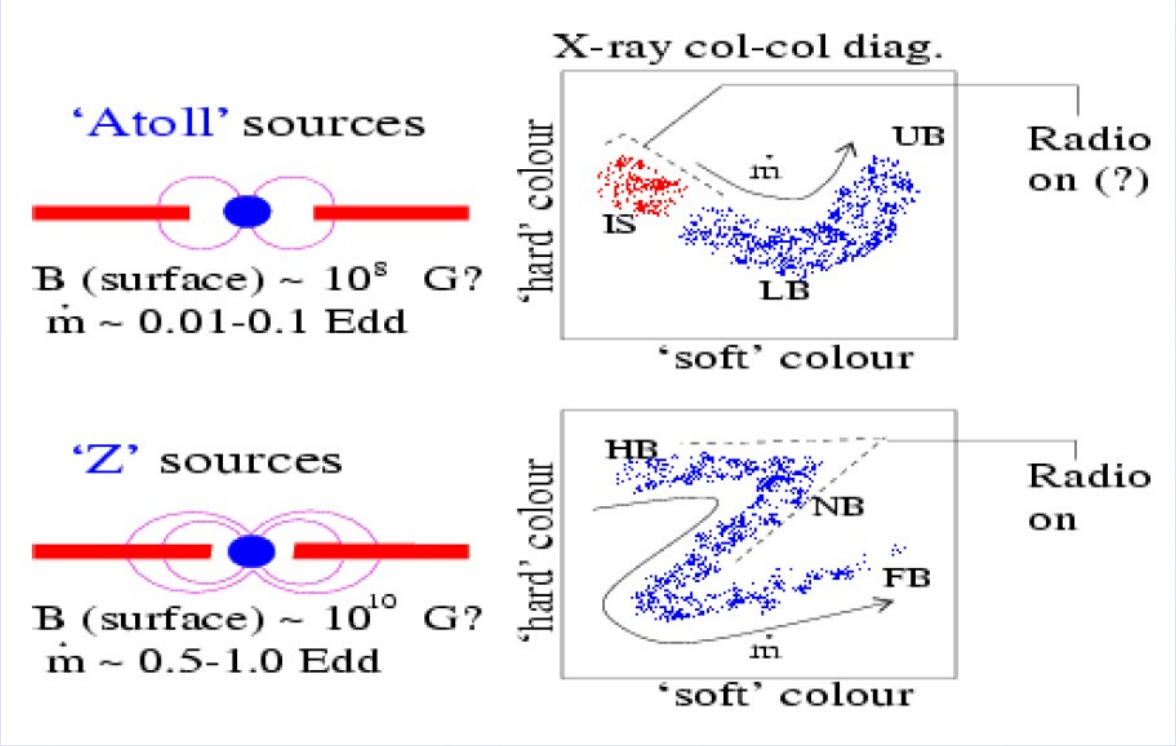


- As matter accretes onto the White Dwarf it can ignite runaway carbon fusion and trigger a Type Ia supernova explosion
- However, 'dwarf nova' might be instability in the accretion disk

Types of XRBs

- We need to study different types of XRB to determine what physics is unique to black hole progenitors:

Neutron star XRBs

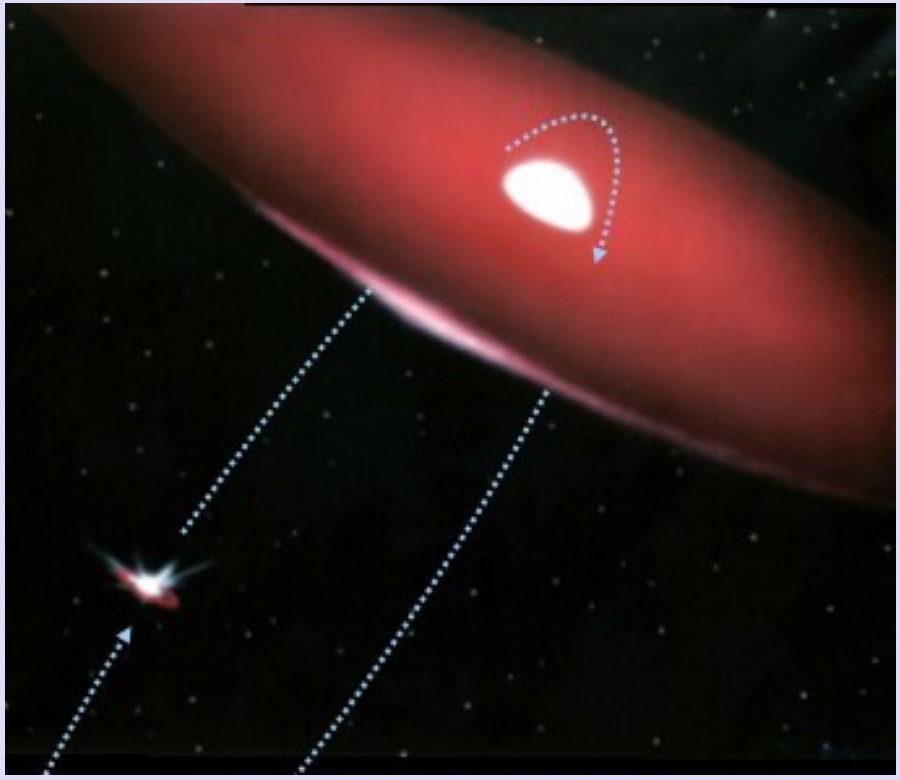


- Some similar X-ray properties to black hole XRBs
- Relatively radio weak
- Accretion is radiatively efficient

Types of XRBs

- We need to study different types of XRB to determine what physics is unique to black hole progenitors:

X-ray pulsars

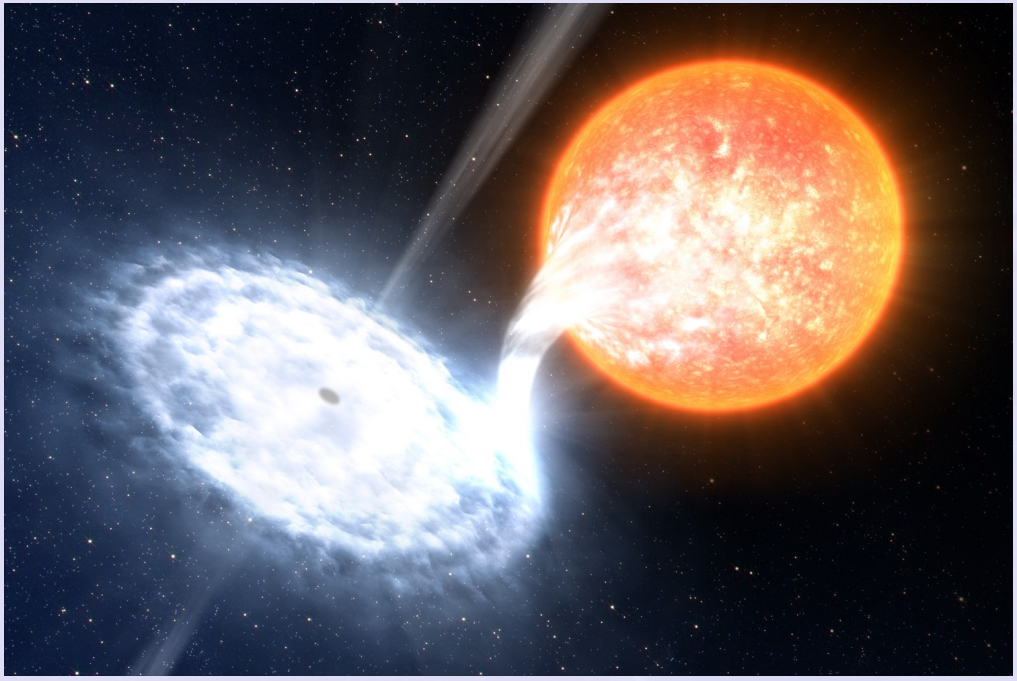


- High magnetized pulsar
- Be type star with equatorial outflowing disk
- When the pulsar's orbit intersects the outflow there is a strong X-ray outburst
- X-ray pulse period of a ~ few seconds

Types of XRBs

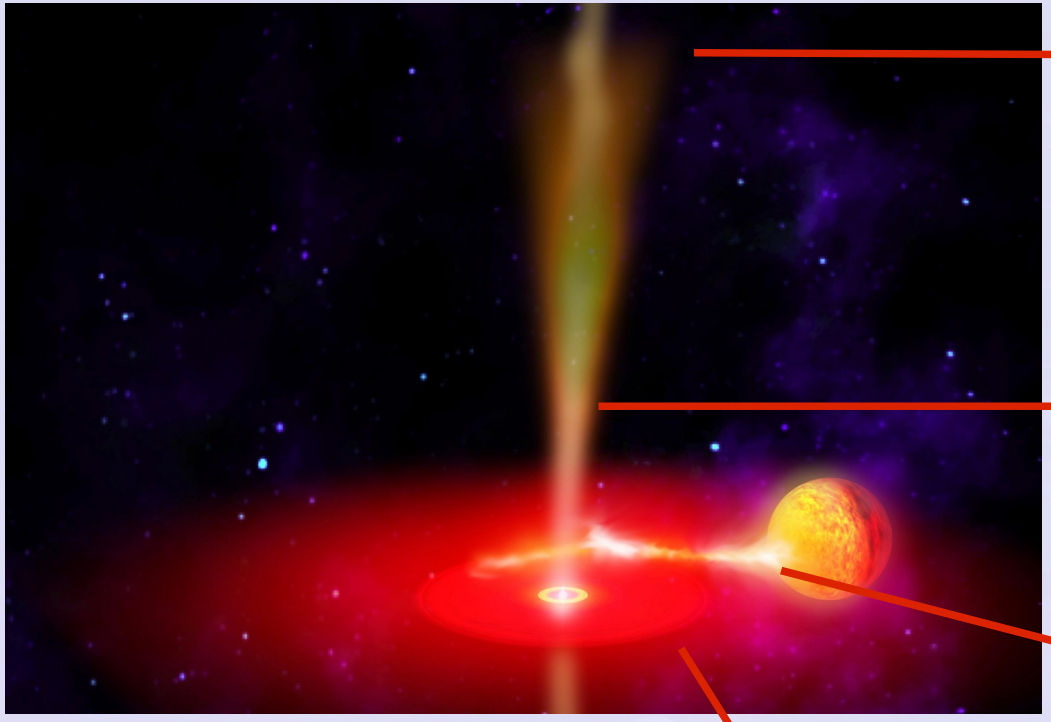
- We need to study different types of XRB to determine what physics is unique to black hole progenitors:

Black hole XRBs



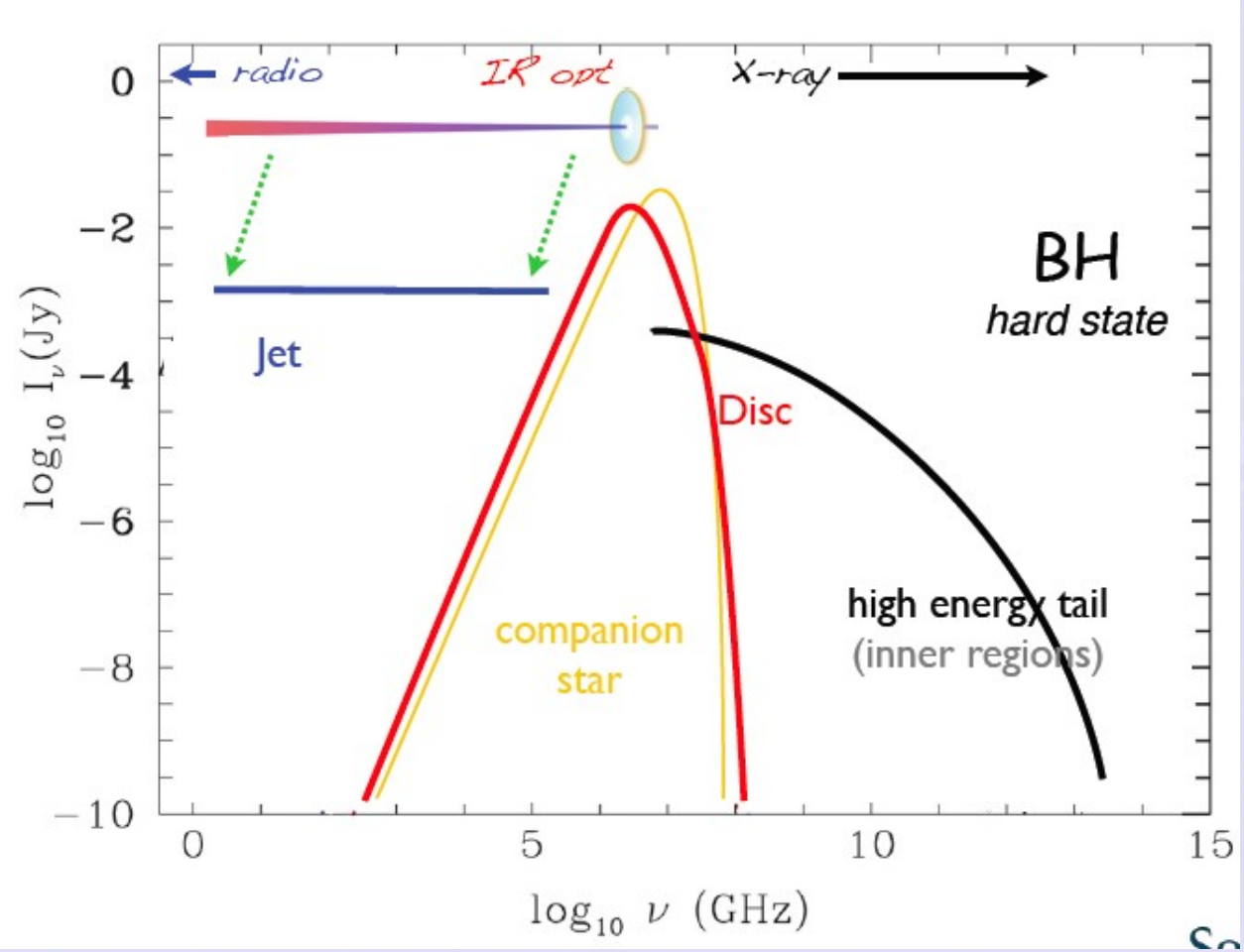
- Complex and highly variable X-ray spectrum
- Sometimes strong radio jets are produced (i.e. “microquasars”)
- Accretion maybe radiatively inefficient (i.e. advection accretion) due to the presence of a BH

Multi-wavelength field



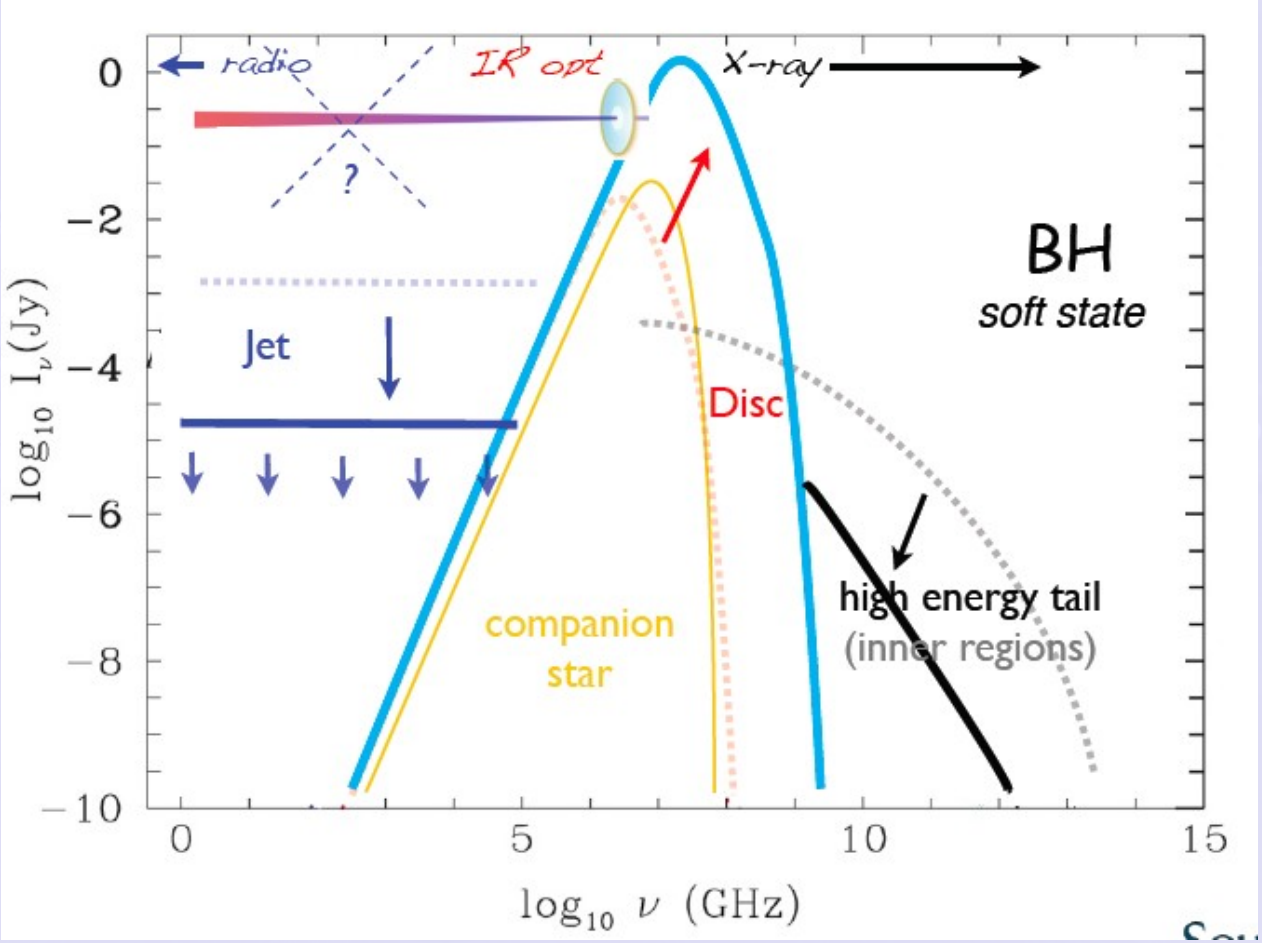
Introduction – XRB SED

(low) *Hard-state* for black holes



Introduction – XRB SED

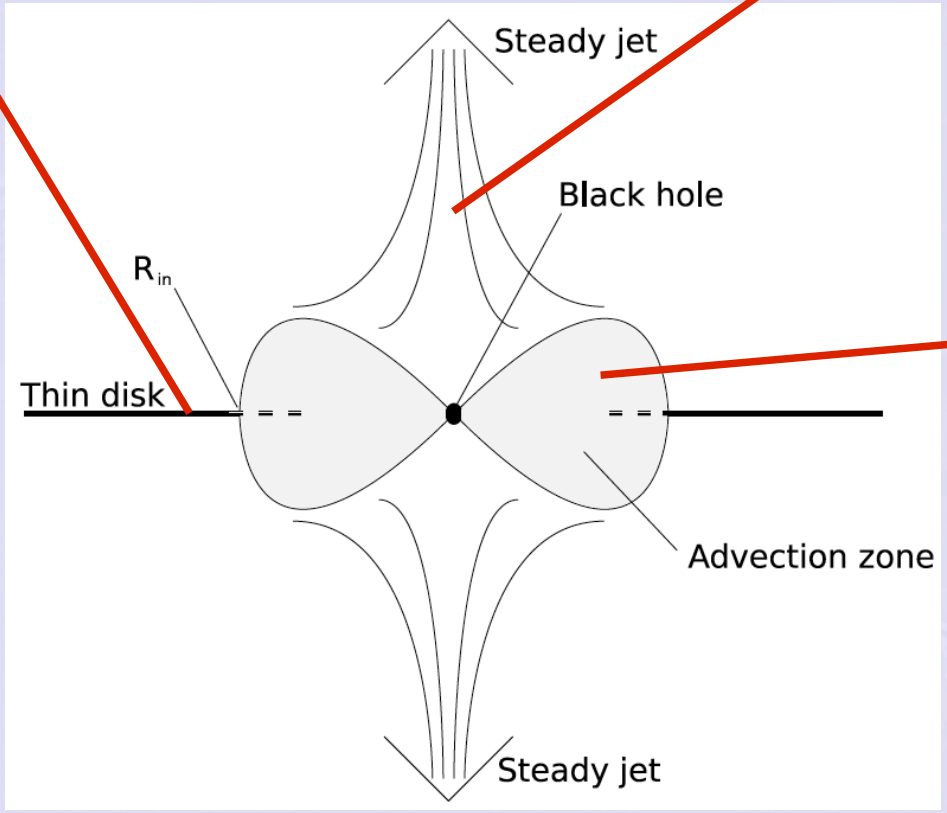
(high) *Soft-state* for black holes



The X-ray binary emission models

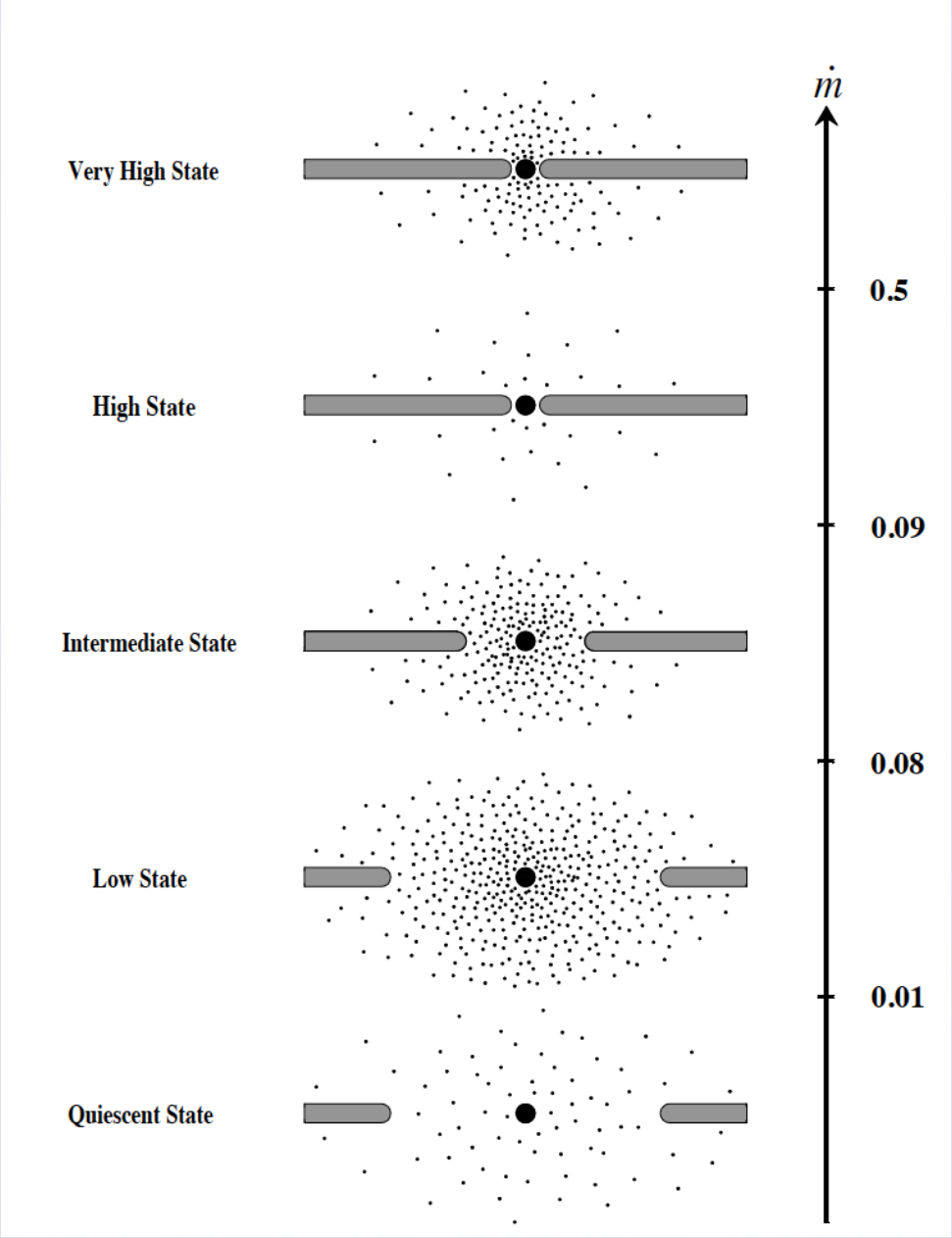
Thermal emission
(soft X-rays)

Synchrotron
emission (radio)



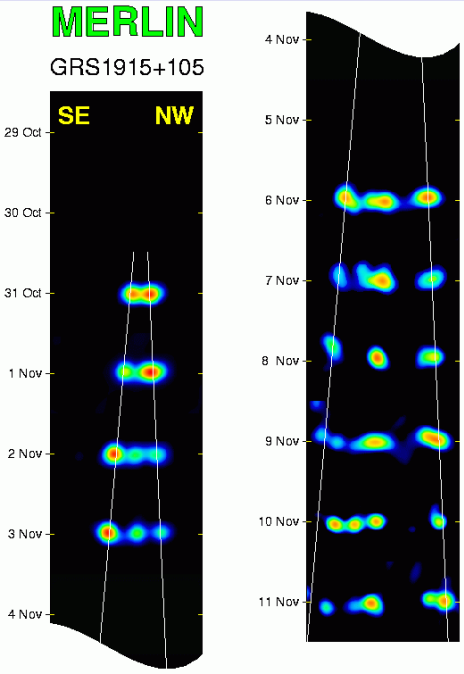
Non-thermal
emission
(hard X-rays)

Mass-accretion rate maybe related to the *'state'*

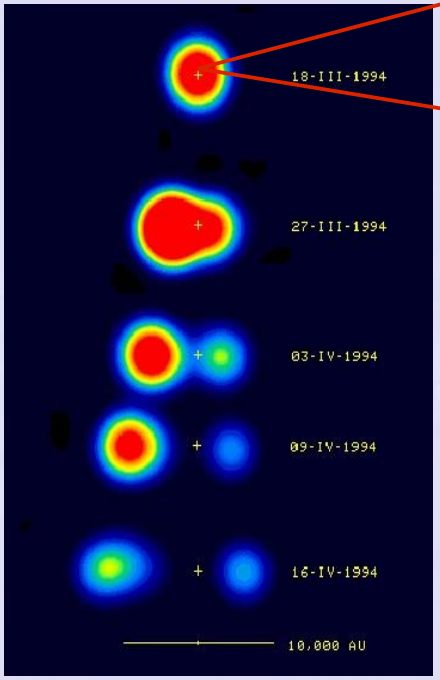


State transition – discrete 'knots'

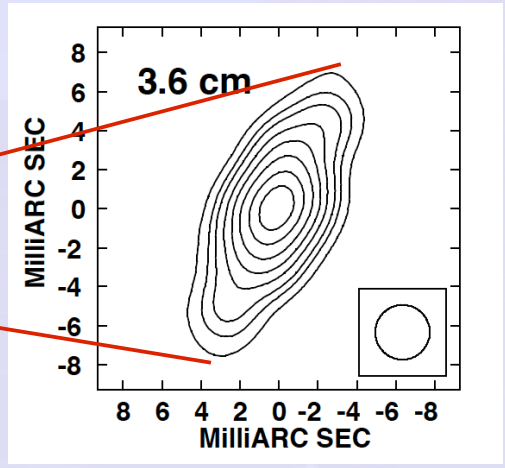
GRS 1915+105



Fender et al. (1999) MERLIN



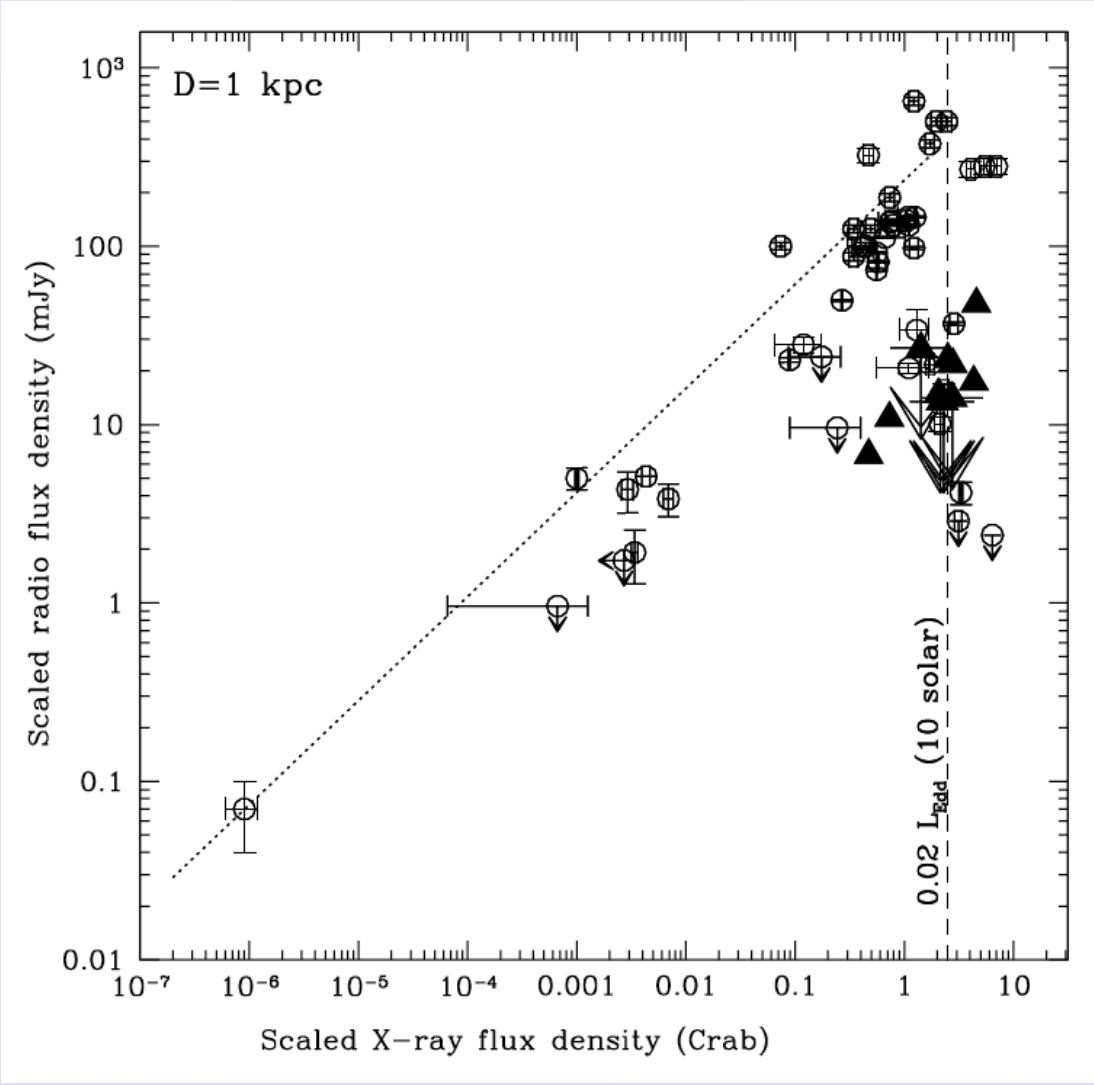
Mirabel & Rodríguez (1994) VLA



- Superluminal motion
  - Ejected knots ~ 0.9c
  - Occurs after a state change

    low/hard → high/soft

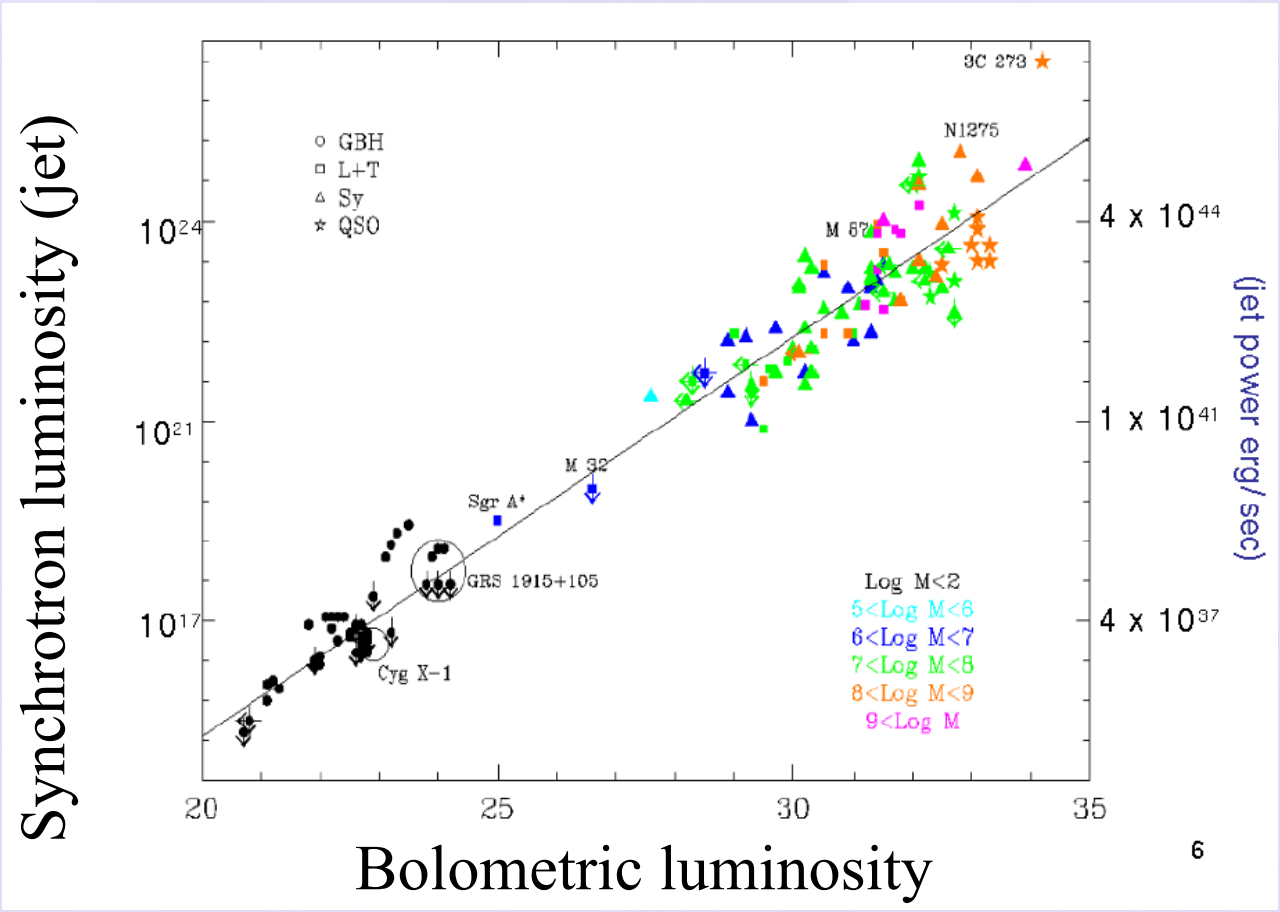
Universal correlation of BH XRBs in the low state



$$L_{\rm radio} \propto L_{\rm X-ray}^{0.71\pm0.1}$$

Corbel et al. (2003)
&
Gallo et al. (2003)

Fundamental plane of black holes



$$L_{\rm radio} \propto L_{\rm X-ray}^{0.6} M^{0.8}$$

Merloni et al. (2003)
&
Falcke et al. (2004)

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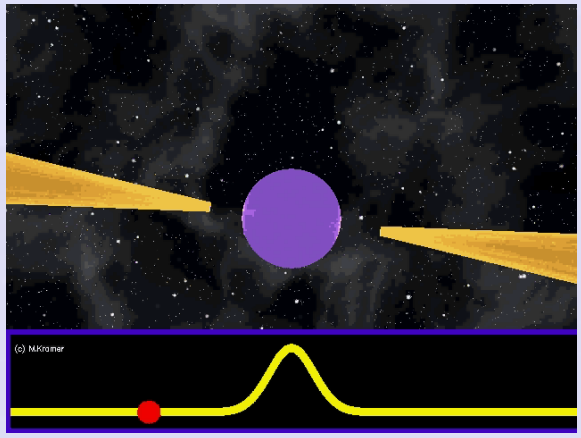
Pulsars are extreme objects…

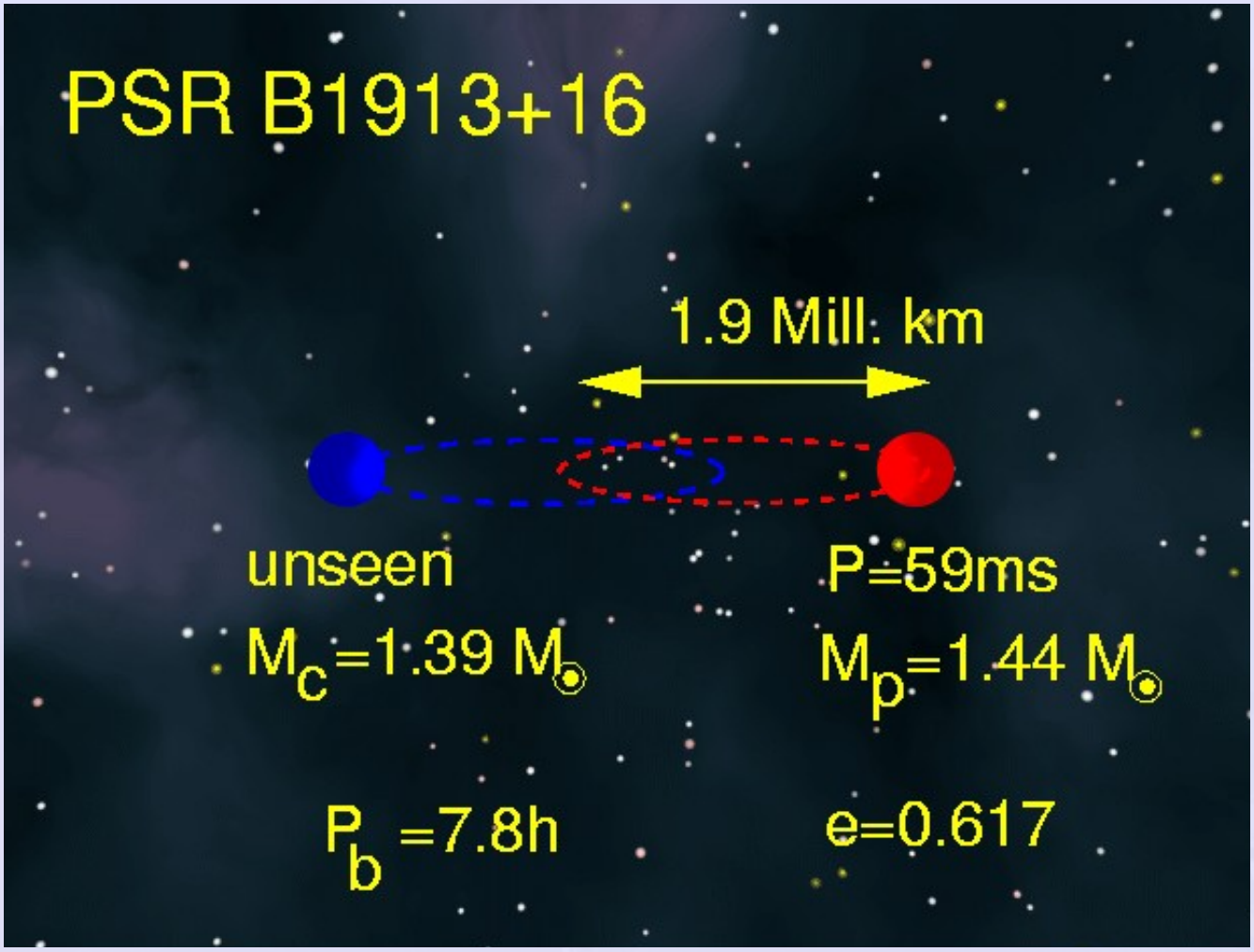


- Cosmic lighthouses …
- Precise clocks …
- Almost Black Holes …
- Objects of extreme matter …
  - 10x nuclear density
  - $B \sim B_q = 4.4 \times 10^{13}$ Gauss
  - Voltage drops ~ 10^{12} V
  - $F_{EM} = 10^{10\text{-}12}\ F_g$
  - High-temperature & superfluid superconductor
- Massive stable flywheels & superb cosmic clocks
  e.g. period of B1937+21:

$$P = 0.00155780649243 27 \pm 0.000000000000004 \text{ s}$$

Precision tools for a wide range of fundamental physics and astrophysics

The first binary pulsar



Hulse & Taylor (1974)

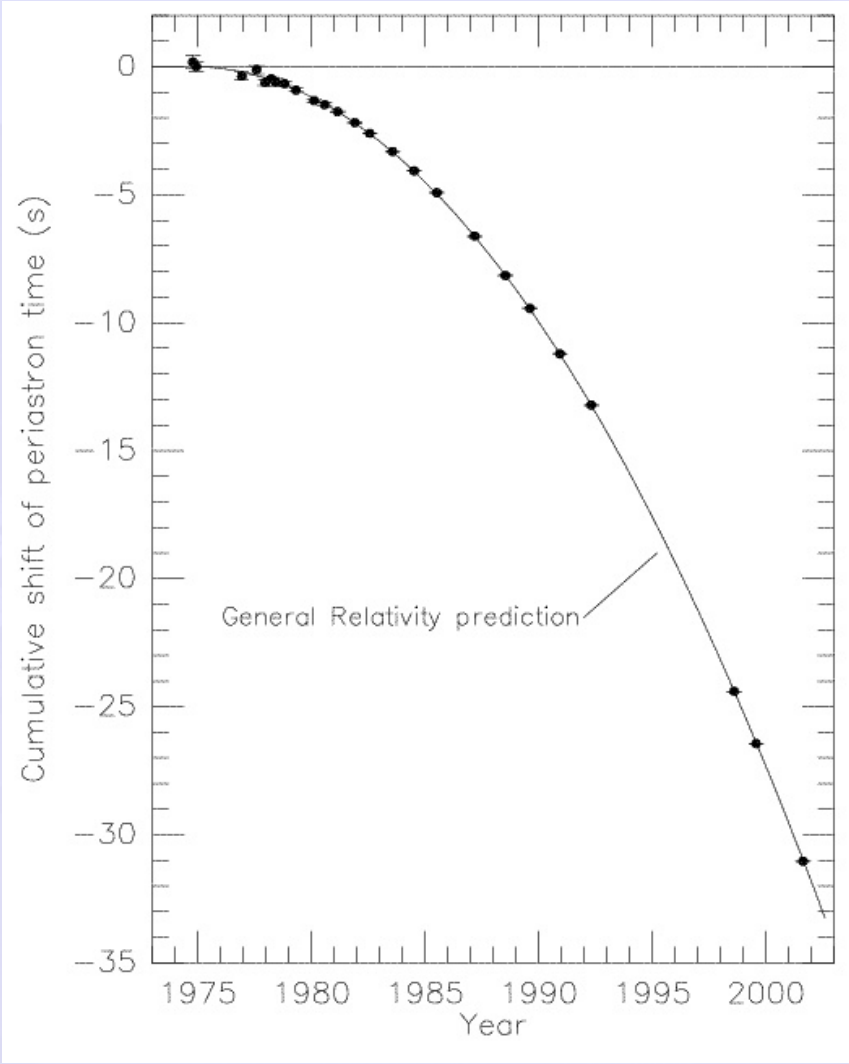
- **Orbit shrinks every day by 1cm**
- **Confirmation of existence of gravitational waves**

Evidence for gravitational waves

• In 1974, J. Taylor and R. Hulse discovered the first pulsar in a binary system, PSR B1913+16 (orbital period ~8 hours).

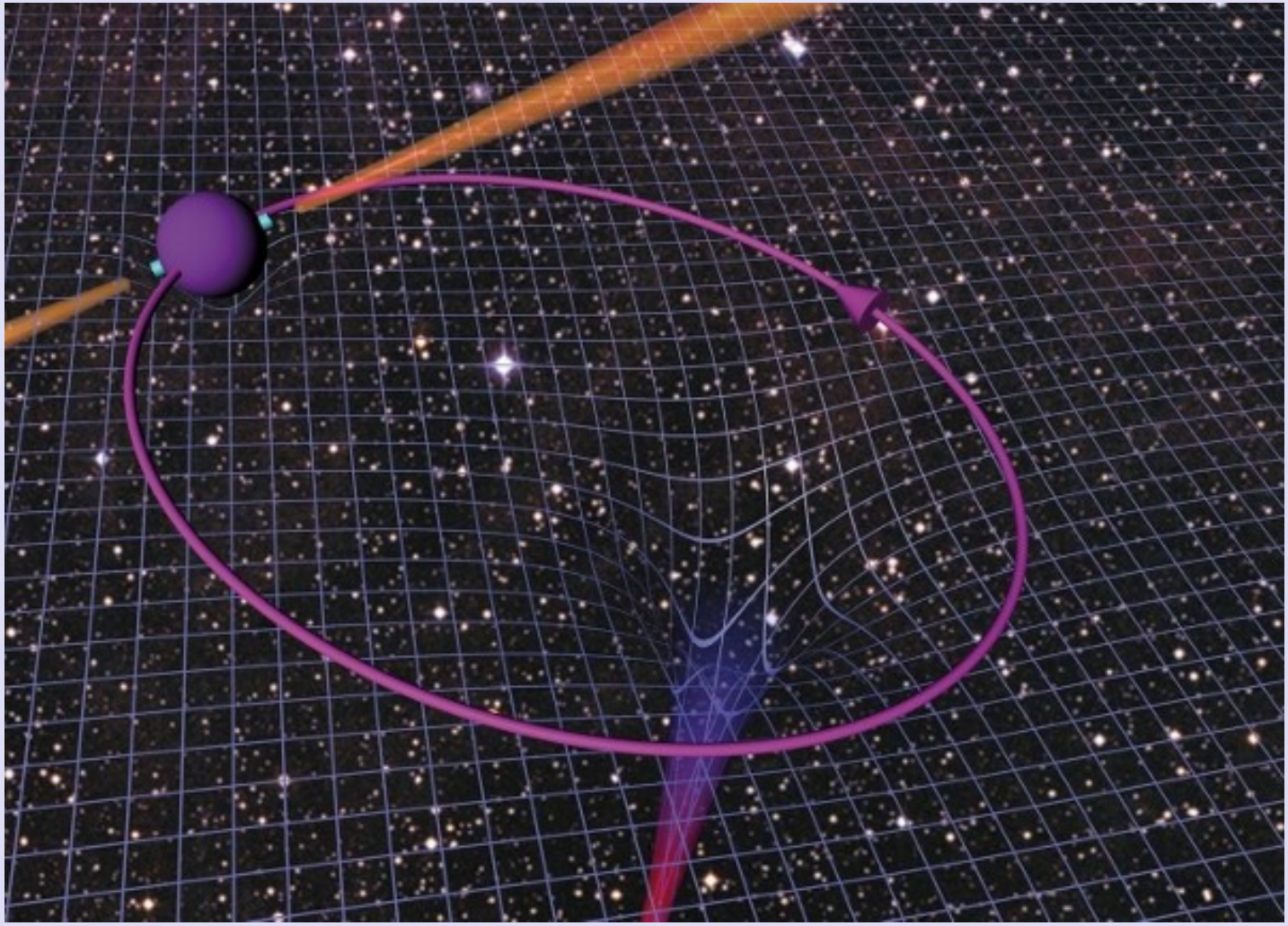
•GR emission of gravitational radiation, causing the orbit to continually contract as it loses orbital energy.

• Observations confirm this prediction: *providing the first ever evidence of the existence of gravitational waves*



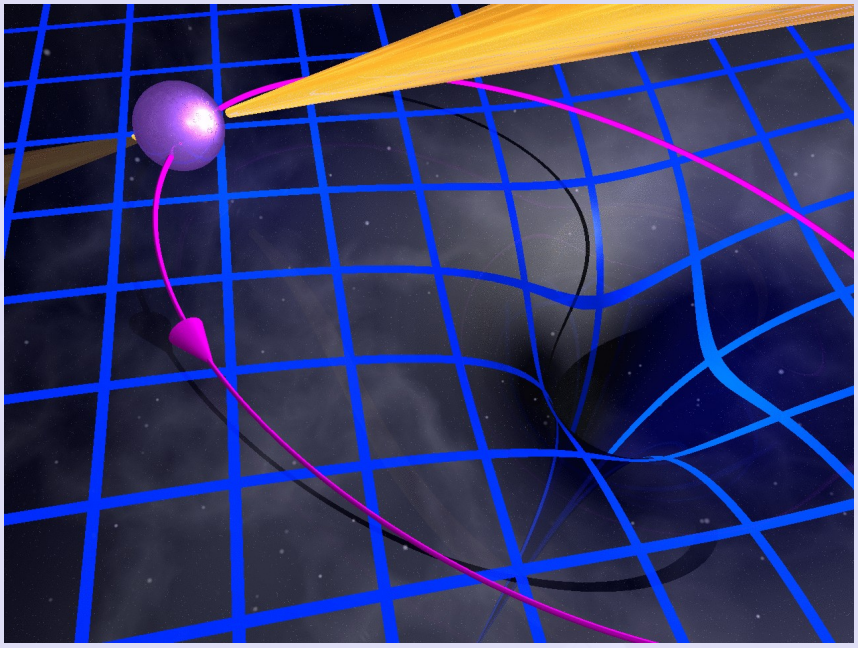
(Weisberg & Taylor 2003)

Pulsar around a black hole



Pulsar around a black hole

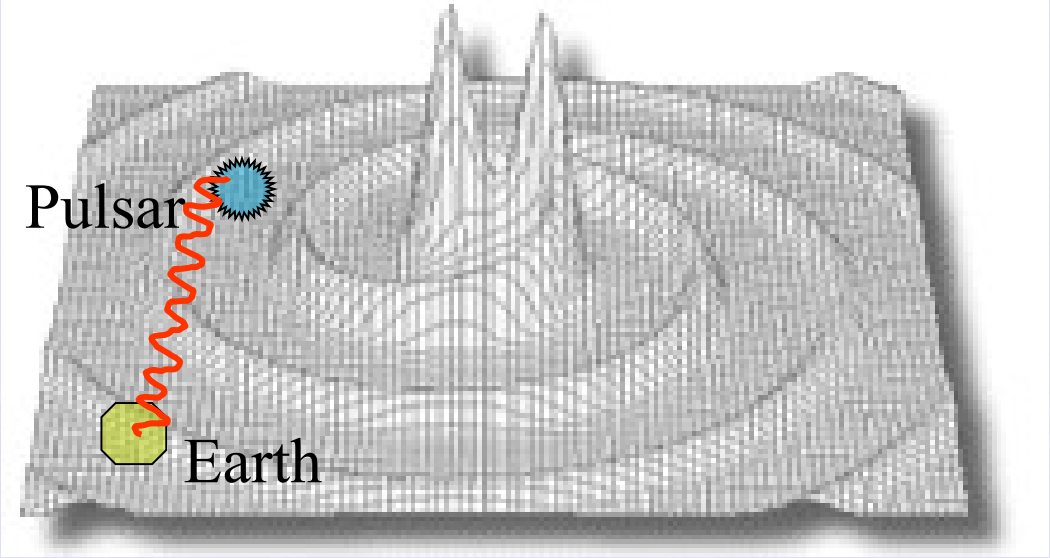
- **The remaining "holy grail": a pulsar – black hole system!**
- **Wanted: millisecond pulsar around black hole**



"...a binary pulsar with a black-hole companion has the potential of providing a superb new probe of relativistic gravity. The discriminating power of this probe might supersede all its present and foreseeable competitors..."

(Damour & Esposito-Farese 1998)

Pulsar timing of gravitational waves

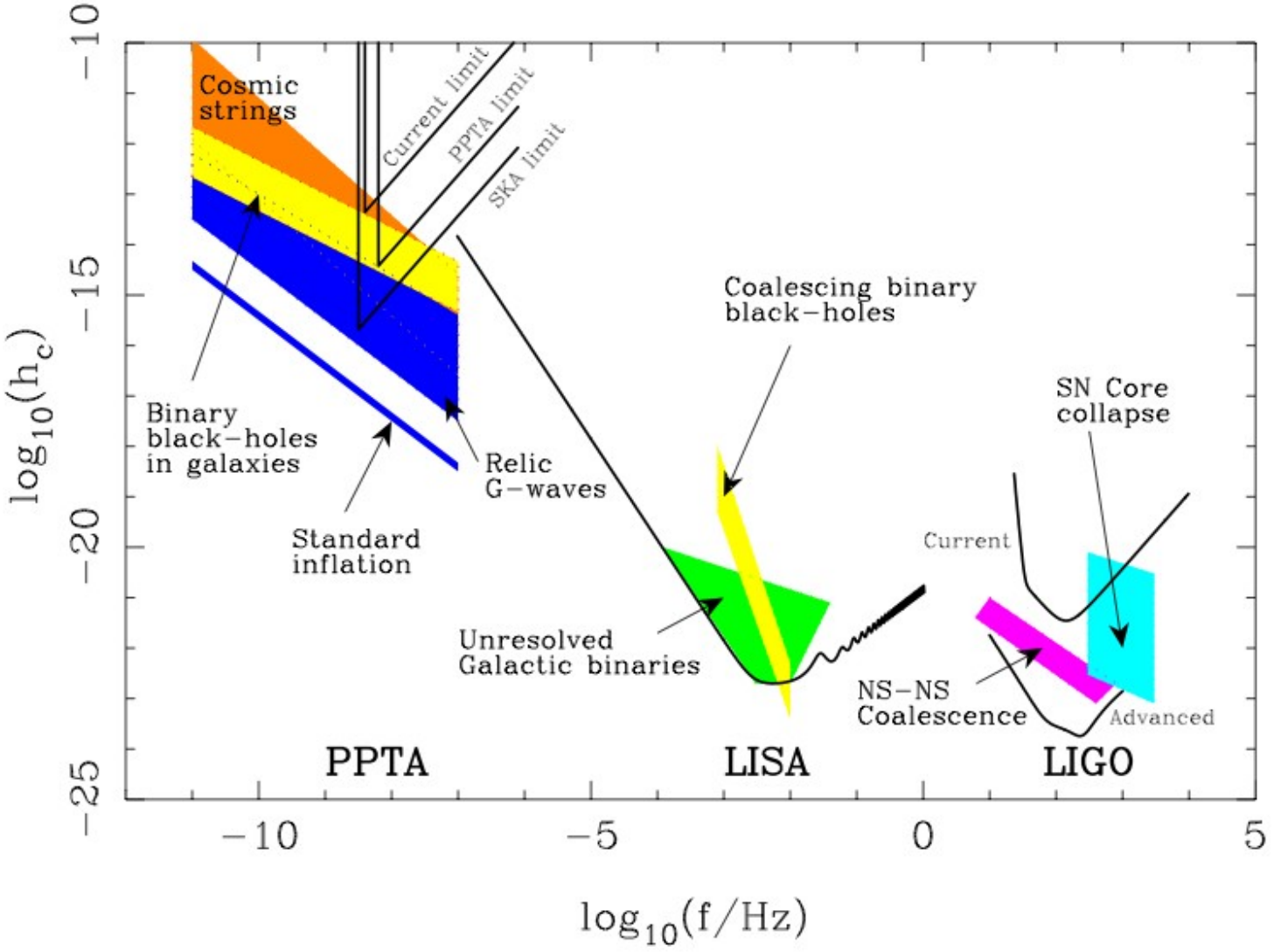


- Pulsars can be used to make a direct detection of low frequency gravitational waves
- Can see the effect of gravitational waves in the timing of 1 pulsar, but …
- Require observations of ~20+ pulsars to make a definitive detection

Pulsar timing of gravitational waves

- Pulsar timing experiments may allow detection of gravitational wave signals - stochastic background or single sources
- Observations of pulsars will allow us to detect low-frequency (nano-Hz) gravitational waves
- Limits on low-frequency gravitational waves are already of astrophysical interest

Pulsar timing of GWs is complementary



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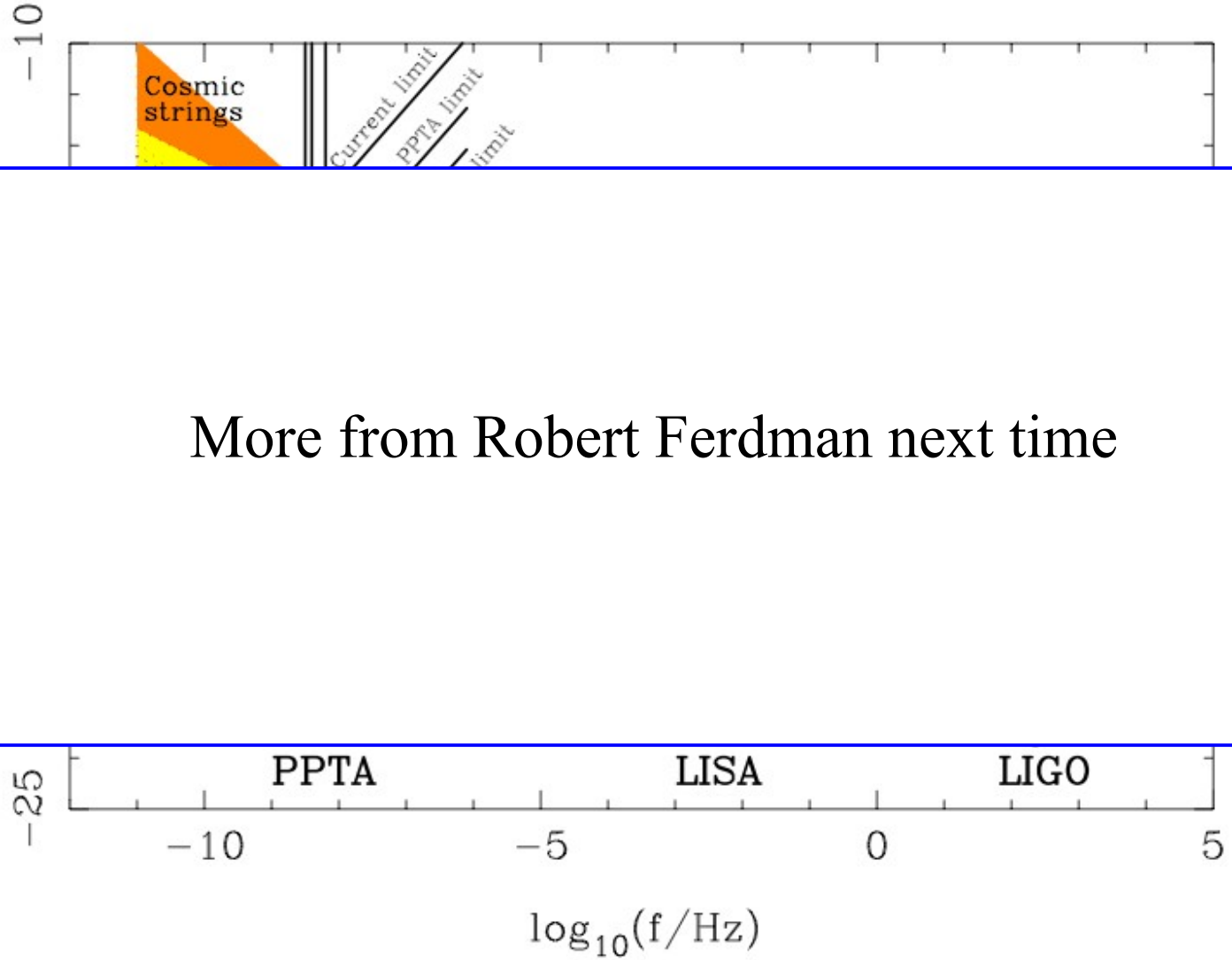

More from Robert Ferdman next time

The End