

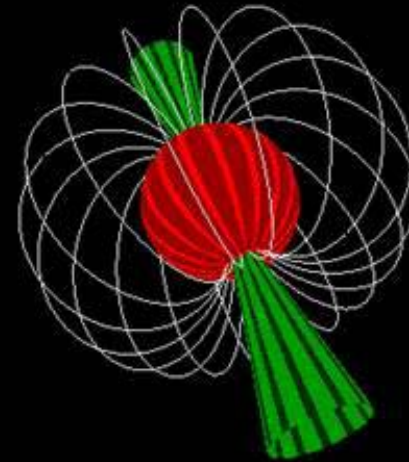
# The Evolving Violent Universe

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- **Outline:**
  - New physics with neutron stars and black holes
  - Evolution and environmental impact of black holes
  - Exploding stars and gamma ray bursts

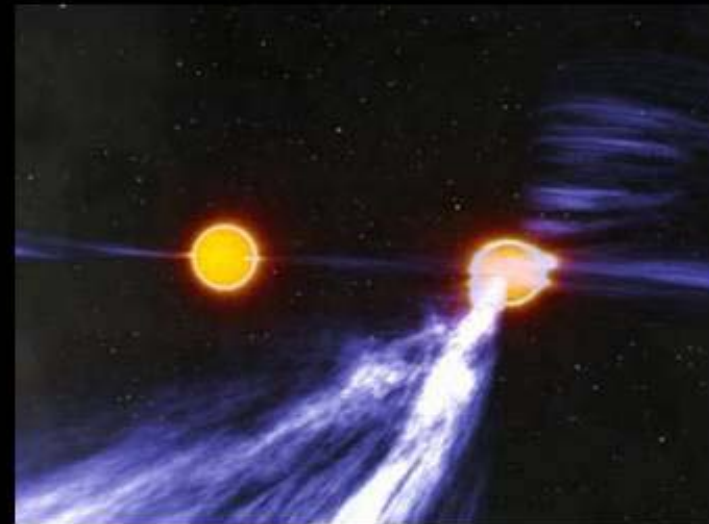
## Compact Objects: Neutron Stars

Radio Pulsars (rotation power)



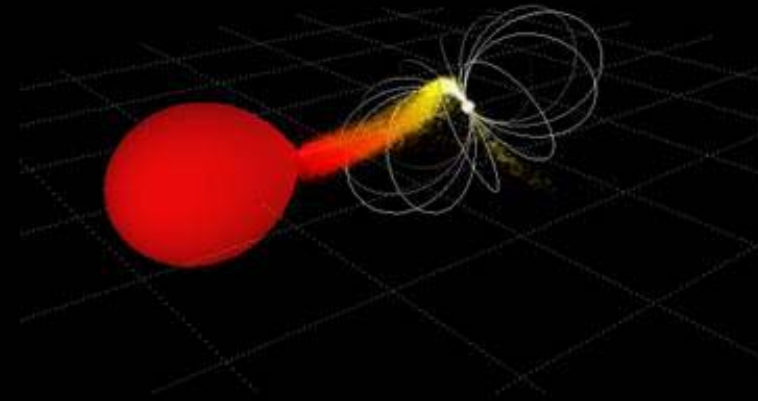
Relativistic binary radio pulsars

- Accurate gravity
- Direct measurements at  $R \sim 10^6 - 10^7$  Schwarzschild radii

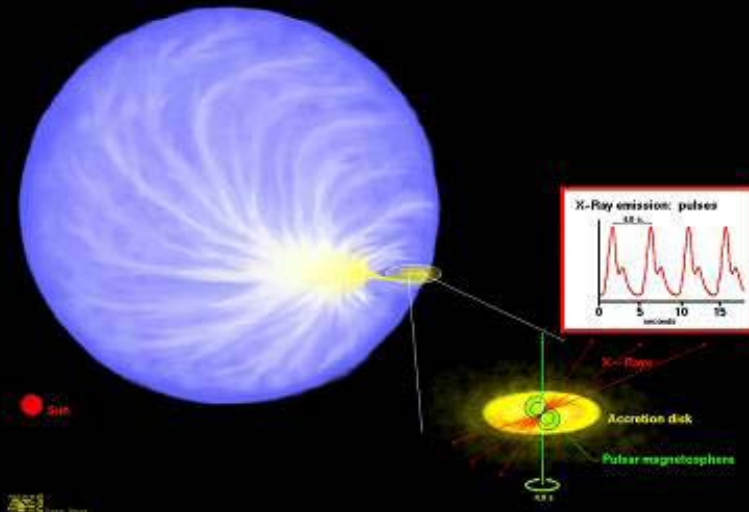
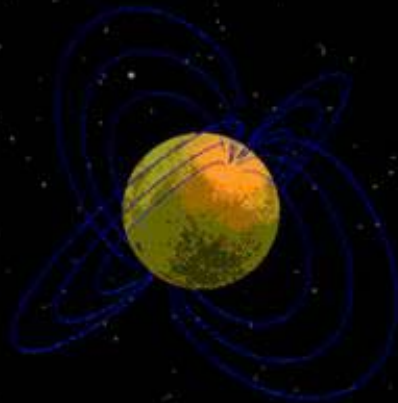


# Neutron Stars

- Accreting neutron stars (accretion power)
- Accretion onto magnetic poles: pulsations
- Magnetars and supercritical magnetic fields ( $B \sim 10^{15} \text{G}$ ) (magnetic power)



CENTAURUS X-3: A HIGH MASS X-RAY BINARY



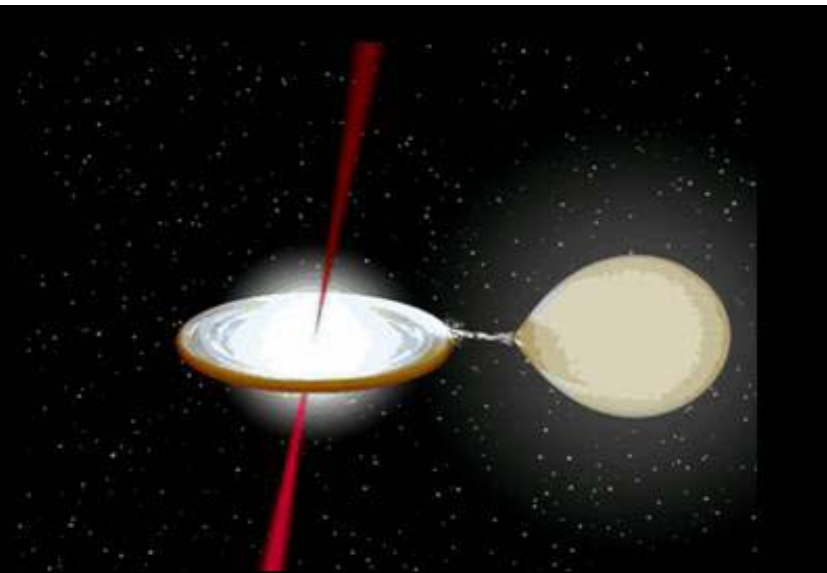
## Black Holes

- Stellar mass Black holes in X-ray binaries (5-15  $M_{\odot}$ )

Mass criterion: compact star  
with  $M > 3.2 M_{\odot}$

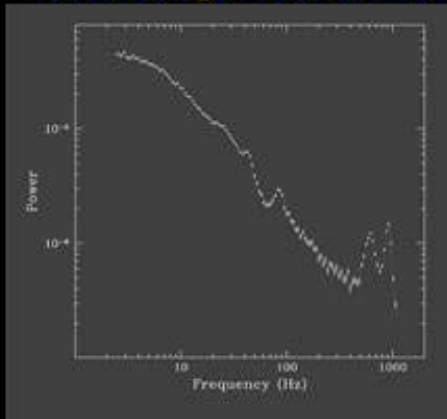
- Supermassive black holes in  
galactic nuclei ( $10^6$ - $10^9 M_{\odot}$ )  
Active Galactic Nuclei (AGN)

- Accretion power
- Rotation power ?

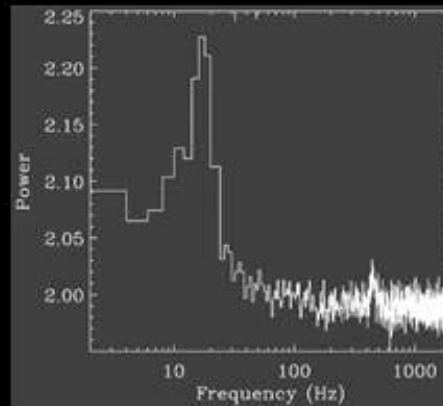


## Probing strong gravitational fields with Quasi Periodic Oscillations (QPOs)

### Accreting neutron star

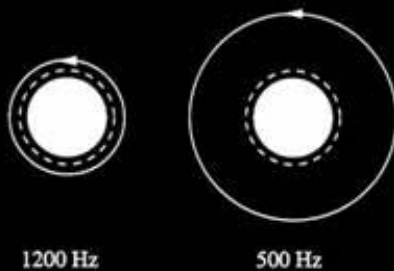


### Accreting black hole



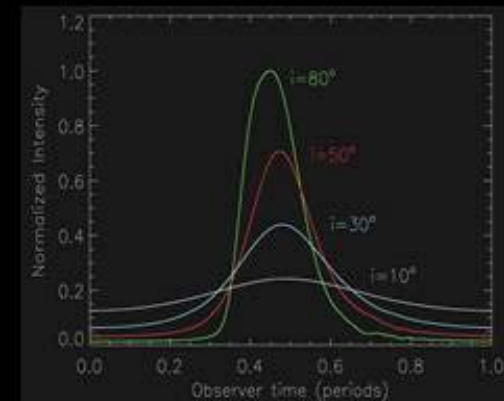
- revealed through broad peaks in the power spectrum of the X-ray intensity fluctuations.
- related to frequencies of particle motion in the strong gravitational field regime (few  $R_s$ )

10 km radius,  
1.4  $M_{\odot}$  neutron star



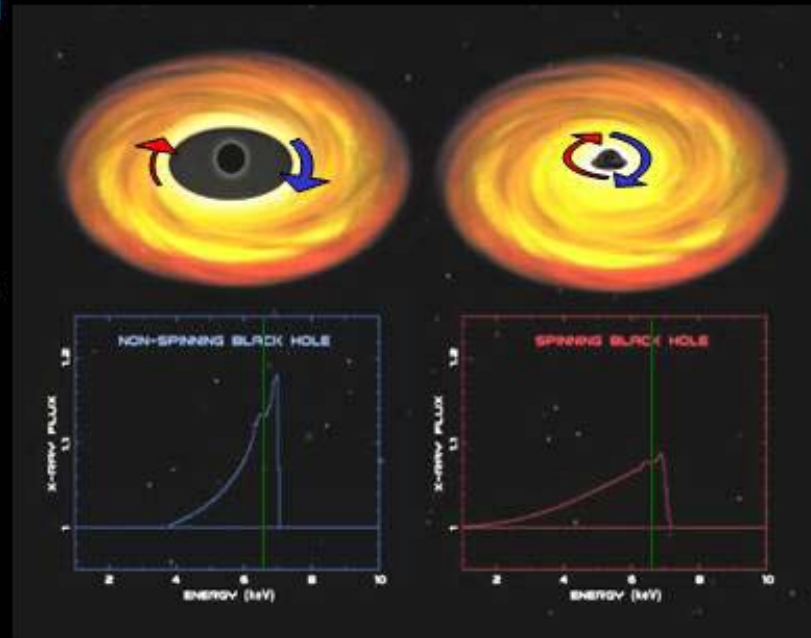
If individual wave trains could be seen, then:

- gravity close to event horizon
- black hole mass and spin
- neutron star radii and mass distribution; equation of state of ultradense matter



## Probing strong gravitational fields with X-ray Fe-lines from accretion disks

- Very broadened line profiles from innermost regions of accretion disks
- Strong field relativistic effect: Doppler shifts and boosting, gravitational redshift, strong field lensing
- Observed in several Active Galactic Nuclei



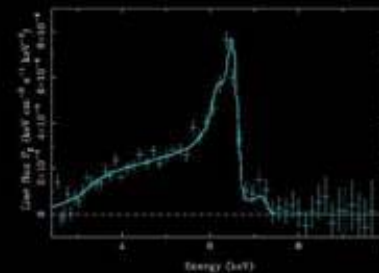
**Line profile and time variability**  
black hole mass and spin

**Polarisation**

strong field deflection  
geometry

**In situ probing of strong field gravity (~few  $R_s$ )**

XMM MCG 6-30-15



## Probing physics of very strong magnetic fields with X-ray polarimetry

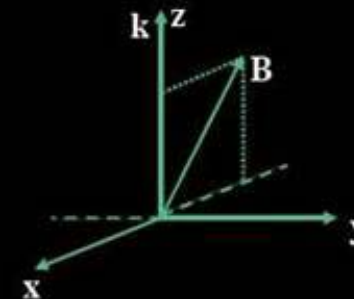
Neutron stars with  $B \sim 10^{12} - 10^{15} \text{ G}$

- Polarisation degree and angle as a function of energy and phase:
  - Gravitational light deflection**
  - Emission geometry**
- Two modes of propagation of photons:
  - Ordinary (O) and extraordinary modes (X)



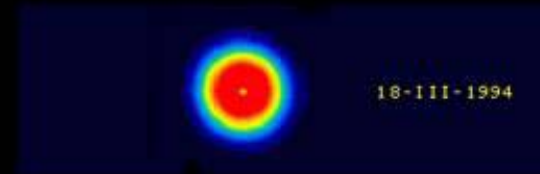
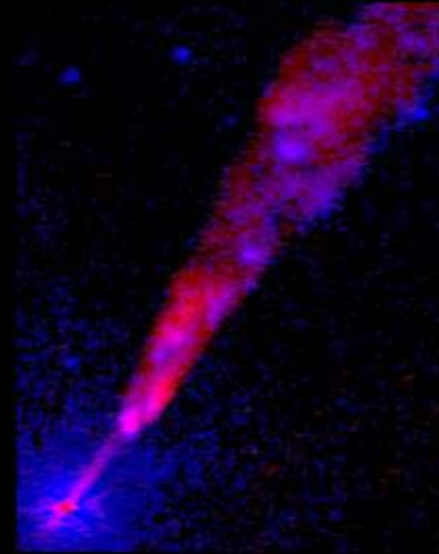
**Strong-B field radiative transfer**

**Signature of strong B-field QED at 1-10 keV:**  
Vacuum polarization-induced mode changes



## Probing the Central Engine: accretion disks and jets

- Jets from massive black holes  
pointing away from us  
pointing toward us
- Jets in neutron stars and black  
hole binary systems
- **Jet production mechanism**
- **Interplay with accretion disk**
- **Accretion vs extraction of  
rotational energy**





## Black holes and galaxies

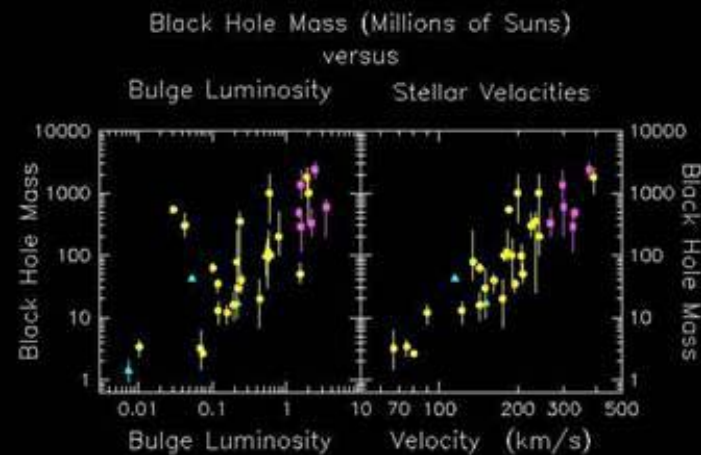
- **Intermediate mass black holes** ( $M \sim 100\text{-}1000 M_{\odot}$ ) in regions of intense star formation in nearby galaxies?

- **Massive black holes** in the nucleus of galaxies:

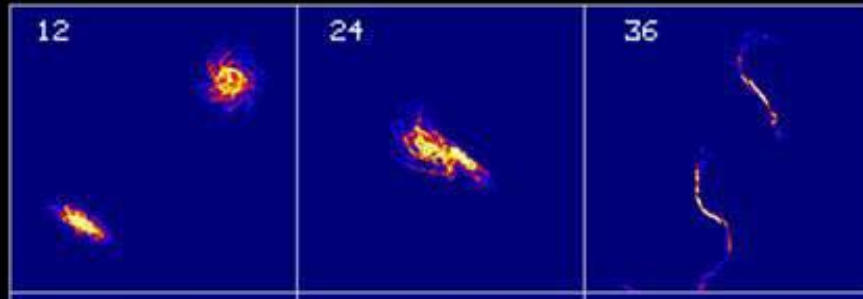
Very common

Only a few active (AGN)

Black hole mass related to galactic bulge properties

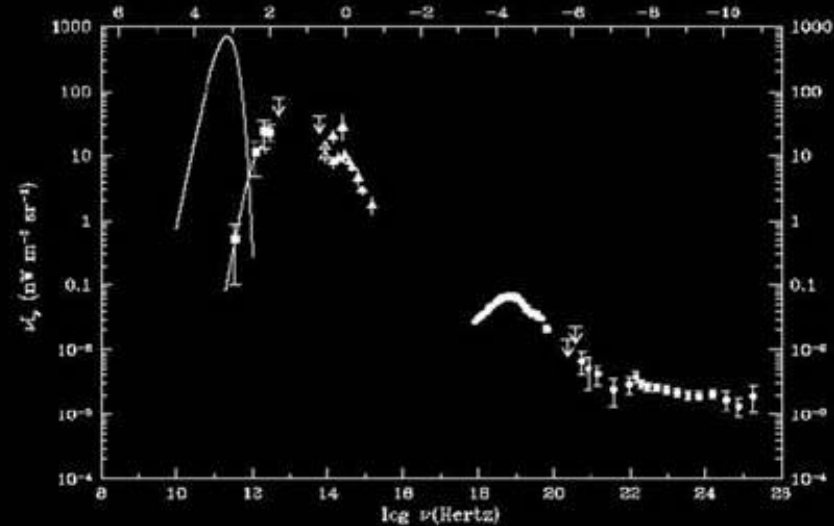


## Black holes: evolution and environmental impact



- Interplay of black hole and galaxy evolution: AGN activity vs Starbursts, triggered by galaxy encounters?
- 1<sup>st</sup> generation of very massive stars as black hole seeds
- mass and spin evolution of black holes
- Evolution of "accretion power" and the cosmic X-ray and gamma-ray background

Spectral energy distribution of extragalactic background radiation



## Most violent stellar explosions and stellar collapse: Supernovae

- Production and dispersion of metals in intergalactic and interstellar media
- Give birth to neutron stars and black holes
- How do supernovae work?  
Impact on:

**Massive star formation  
and evolution (rotation,  
metallicity)**

**ISM feed back**

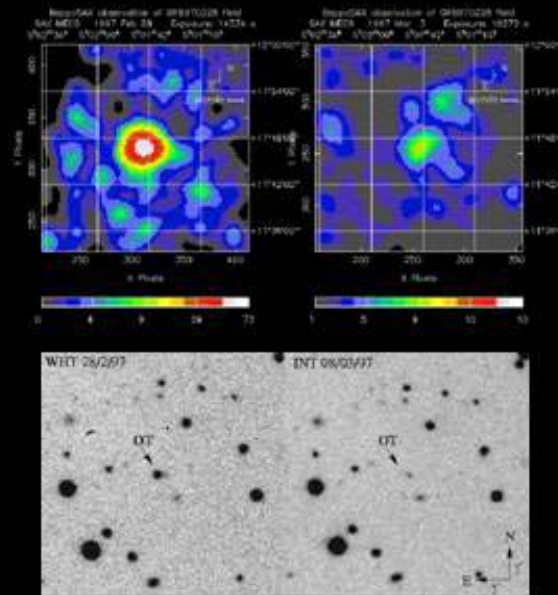
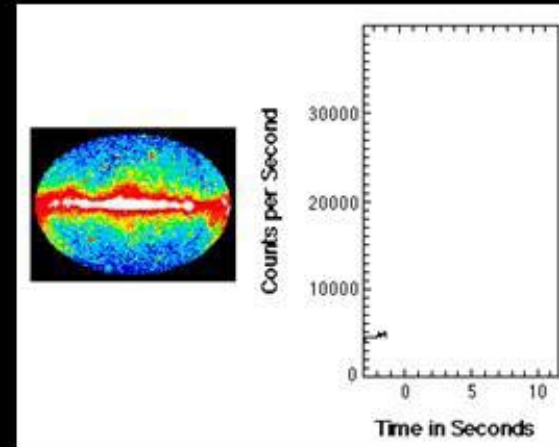


## Gamma ray bursts

- X-ray, optical, radio afterglows
- ~ 1 GRB/day in the whole universe
- A very distant class of astronomical objects: very high  $z$  in the near future ?
- Association to peculiar Supernovae
- Powerful high redshift cosmic beacons, shining through the matter along the line of sight

Galaxies in the age of star-formation

The warm intergalactic medium



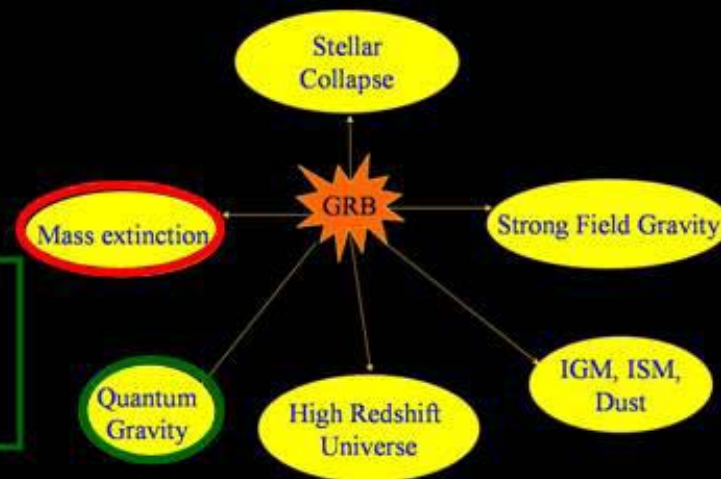
## Physics of Gamma ray bursts

### Hypernova model:

- Massive star collapse to black hole + ultradense torus
- Beamed fireball produced
- Internal shocks generate Gamma-rays
- X-ray, optical, radio Afterglow from interaction of fireball with the ISM

1 GRB with 1 kpc pointing toward the earth every  $10^8$ - $10^9$  yr  
Gamma and X-ray destroy ozone layer  
Increased UV depletes lower food chain  
Candidate: Ordovician mass extinction ?

Speed of light changes with frequency ?  
Sharp onset of GRBs ( $< 1$  s), then light travelled for  $\sim 10^{10}$  yr  
Constraints on quantum gravity !



## Conclusions

- Probing strong field gravity with measurements at a few  $R_s$
- Physics of extreme regimes with compact objects
- Formation and growth of first black holes
- Feedback between black hole growth/activity and galaxy evolution
- Understanding the most violent explosions since the big bang:  
SNe and GRBs