The Nuclear EOS and QED in Astrophysics

What can observations of neutron stars tell us about fundamental physics?

CPU

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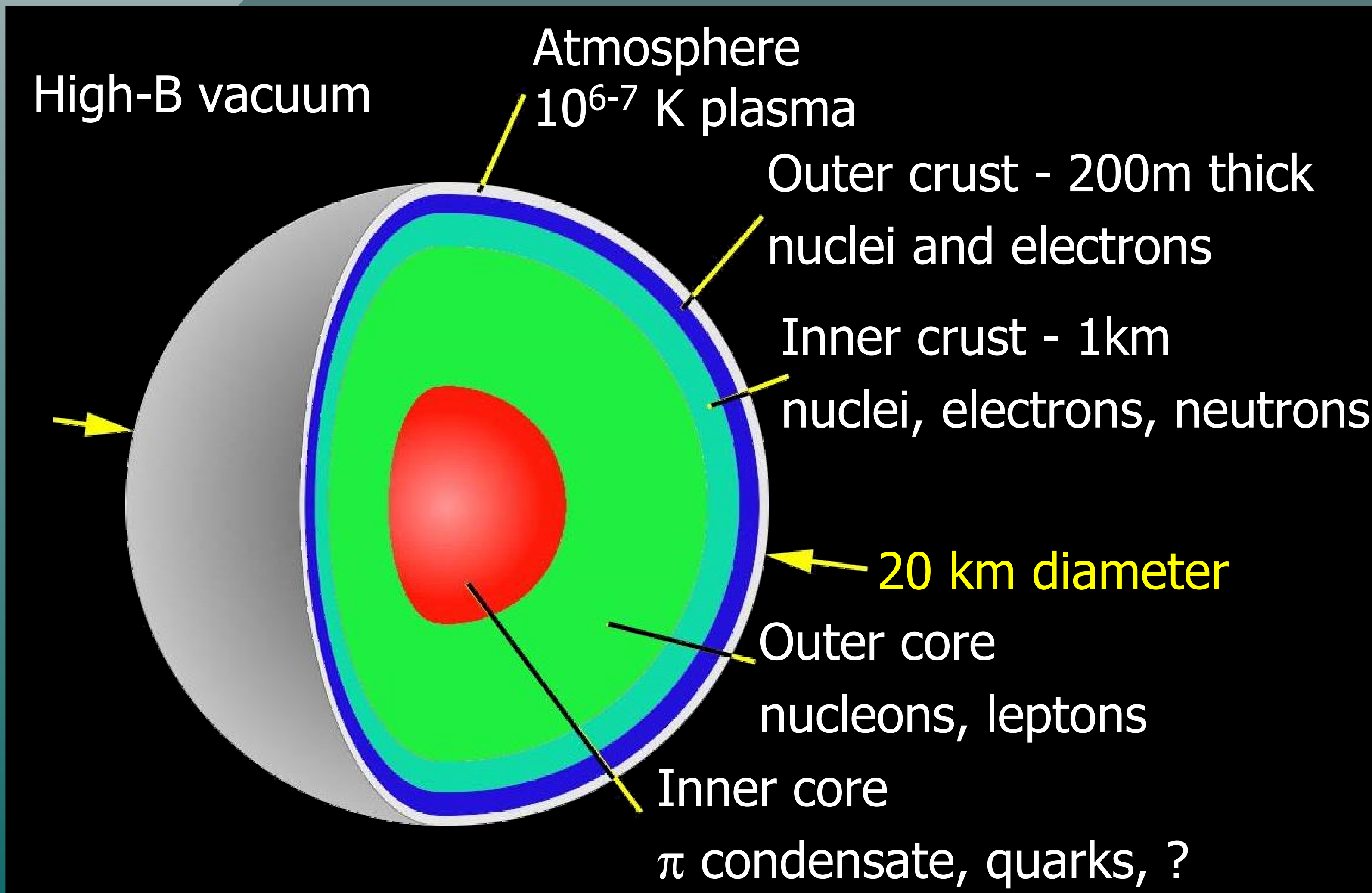
Introduction

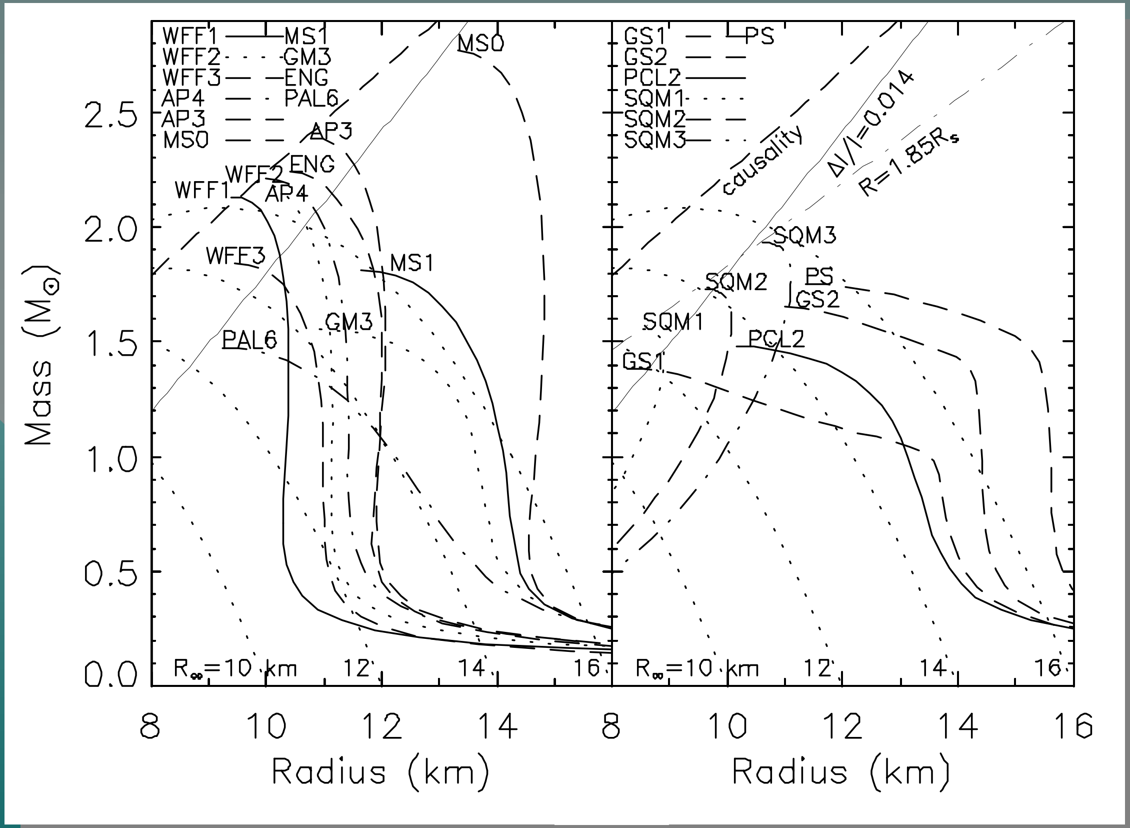
- The structure, cooling and observations of neutron stars probes all four forces in regimes inaccessible to Earthbound experiments. Neutron stars uniquely probe:
  - Nuclear physics at supranuclear densities
  - QED in ultrastrong magnetic fields

Neutron Star Structure



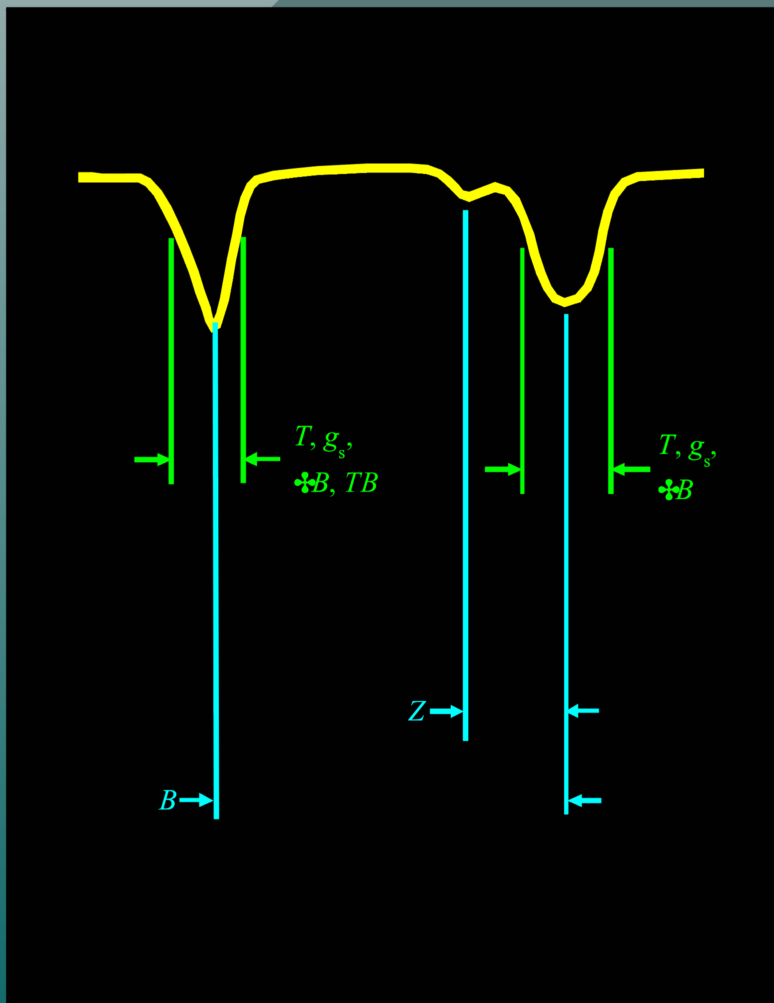
The Nuclear Equation of State

- Softer equations of state result in more compact stars.
  - Relativistic effects
  - Higher surface gravity
- Heat capacity and emissivity depends the composition of the core.



Lattimer & Prakash '01

Probing the EOS: Spectra



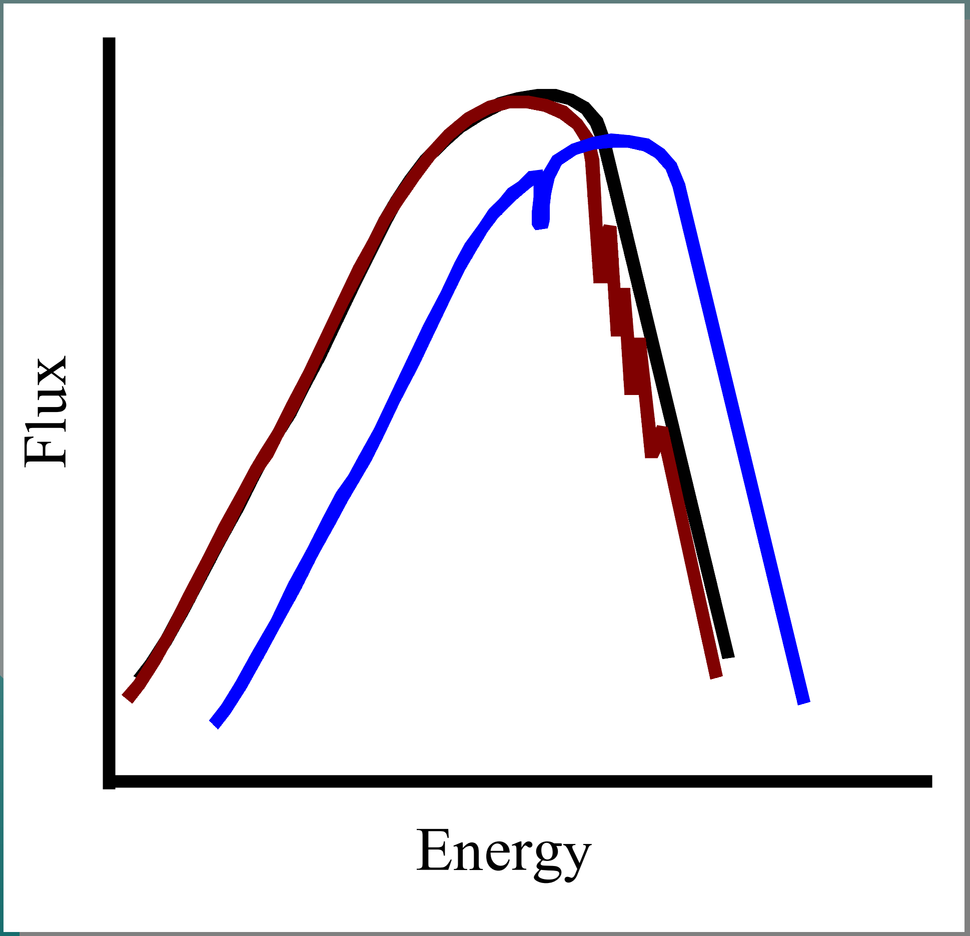
- Spectral lines from neutron-star surfaces: gravitational redshift and acceleration
- For light-elements wavelengths depend on the strength of the magnetic field.
- We haven’t seen any lines yet.

Probing the EOS: Variability

- Since light is bent by the strong gravitational field of a neutron star, we can see around the back.
- The emission from more compact stars varies less as they rotate.
- Variability also depends on the atmosphere and the structure of the magnetic field.

Probing the EOS: Total Flux

- A radius estimate may be off by a order of magnitude, if the wrong atmosphere model is used.
- Look at quiescent LMXBs in globular clusters: isotropic emission, low B-field, known distance, mass estimate.
- High-resolution, high signal-to-noise spectra are required to verify the models.

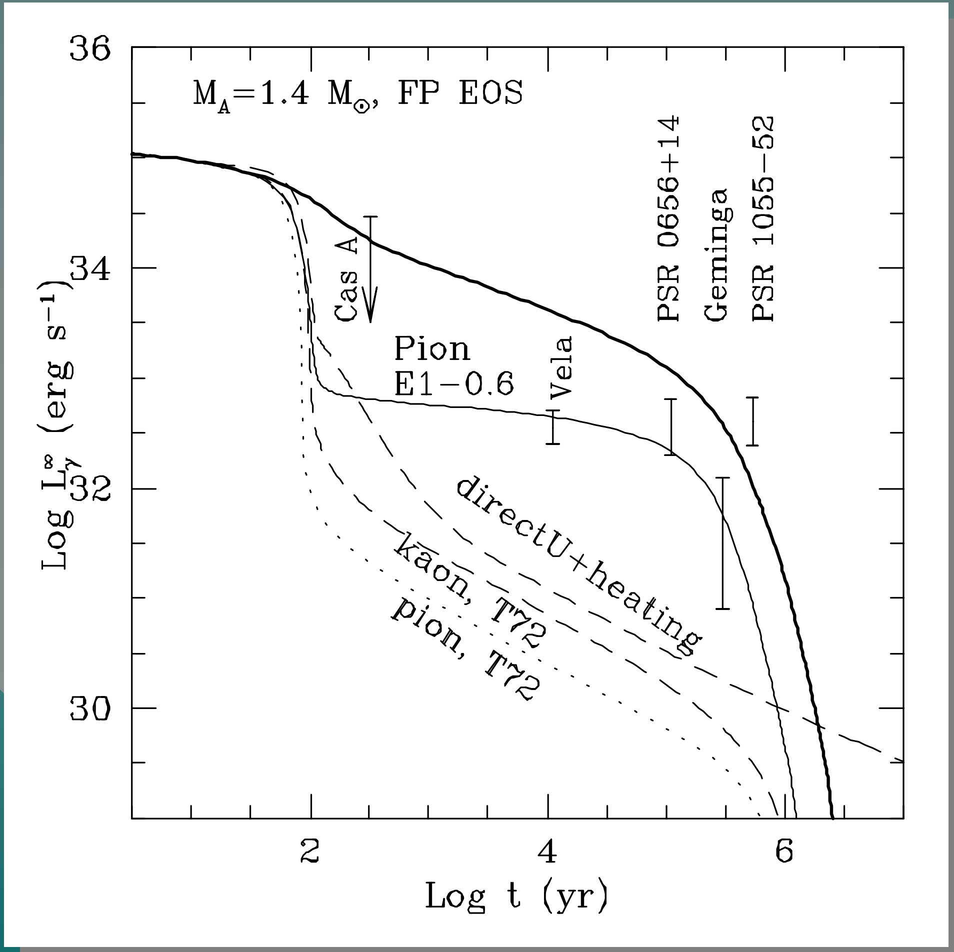


Probing the EOS: QPOs

- RXTE identified high-frequency QPOs in the emission from LMXBs.
  - Ω_K, Ω_K - Ω
- Low-frequency QPOs
  - hydrodynamic
  - Ω_{LT}
- The highest observed QPO frequency gives an upper limit to the radius of the star.
- If the low-frequency QPO is indeed Ω_{LT}, the frequencies constrain the moment of inertia.

Cooling: Young Neutron Stars

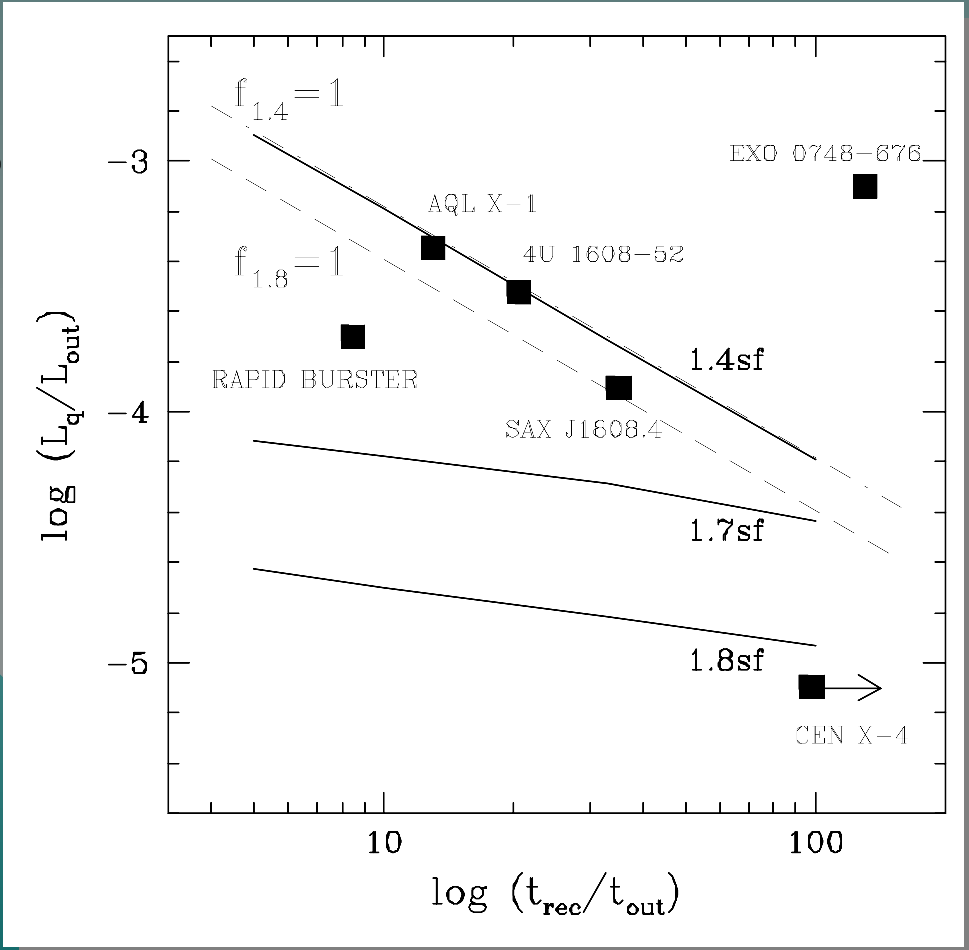
- If pions or quarks are present in the cores of young neutron stars, they cool much faster.
- How long it takes the surface to "find out" that the core is cooling quickly depends on the EOS.
  - 100 yr for soft EOS
  - 1000 yr for hard EOS



Umeda et al. '01

Cooling: Soft X-Ray Transients

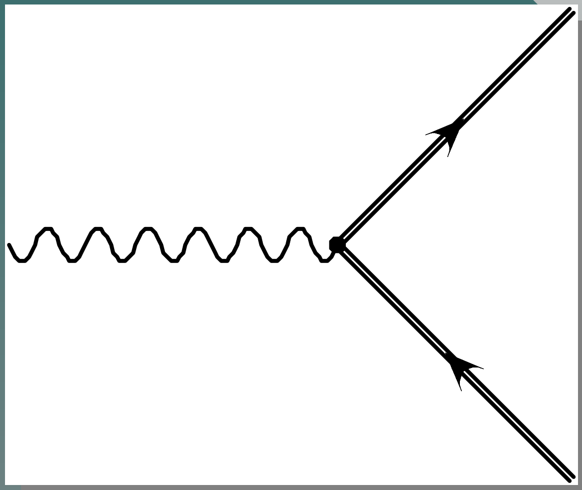
- If their quiescent emission is not due to accretion, then the EOS is unlikely to allow π or quarks.
- In quiescence the emission is from an unmagnetized H atmosphere (well understood).

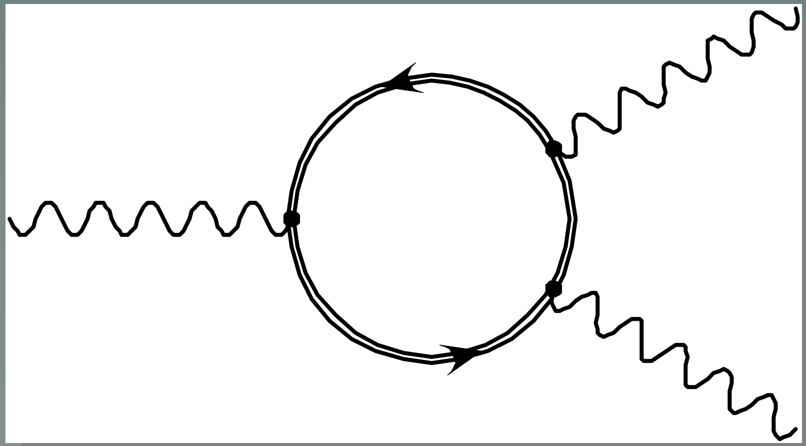


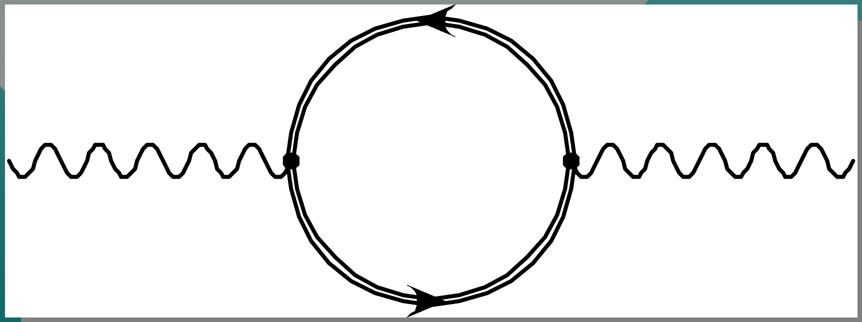
Possenti et al. '01

Strong-field QED

- In the magnetic field near a neutron star, many process may become important that we cannot otherwise probe.
- Tracers of these processes are generally polarized.

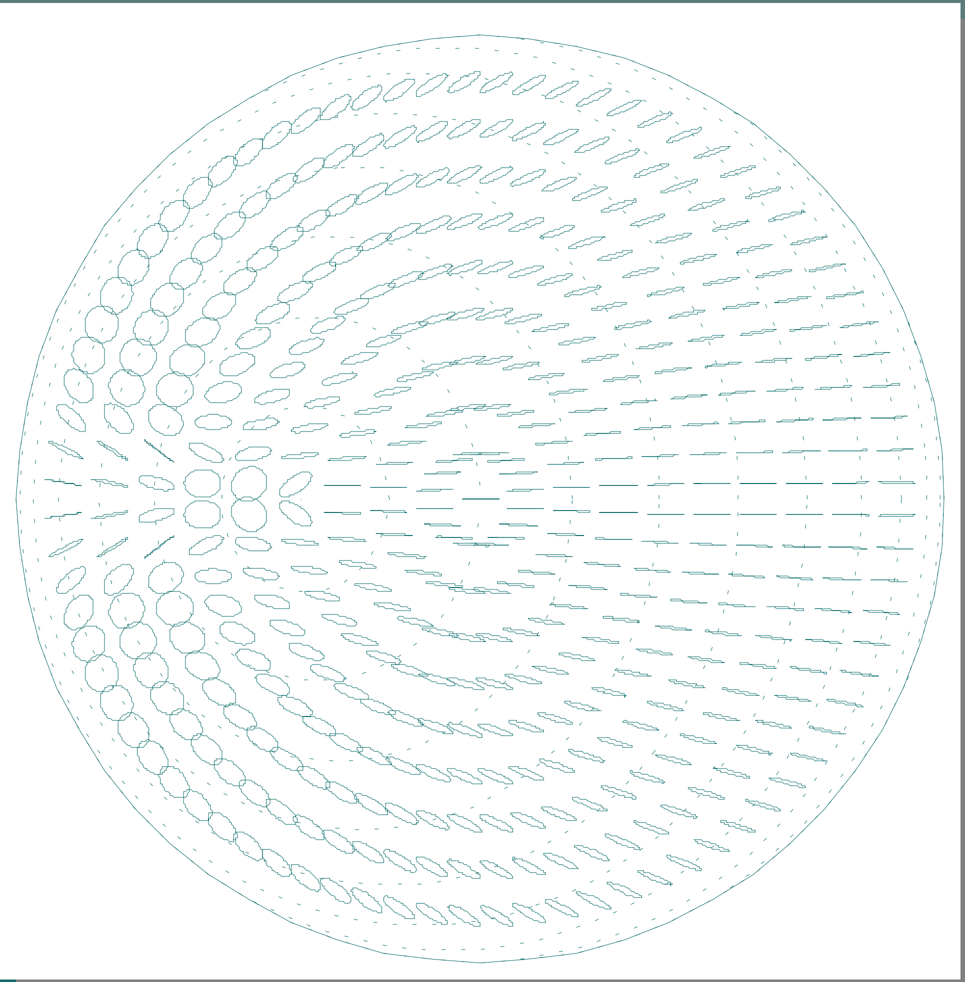






QED: Vacuum Polarization

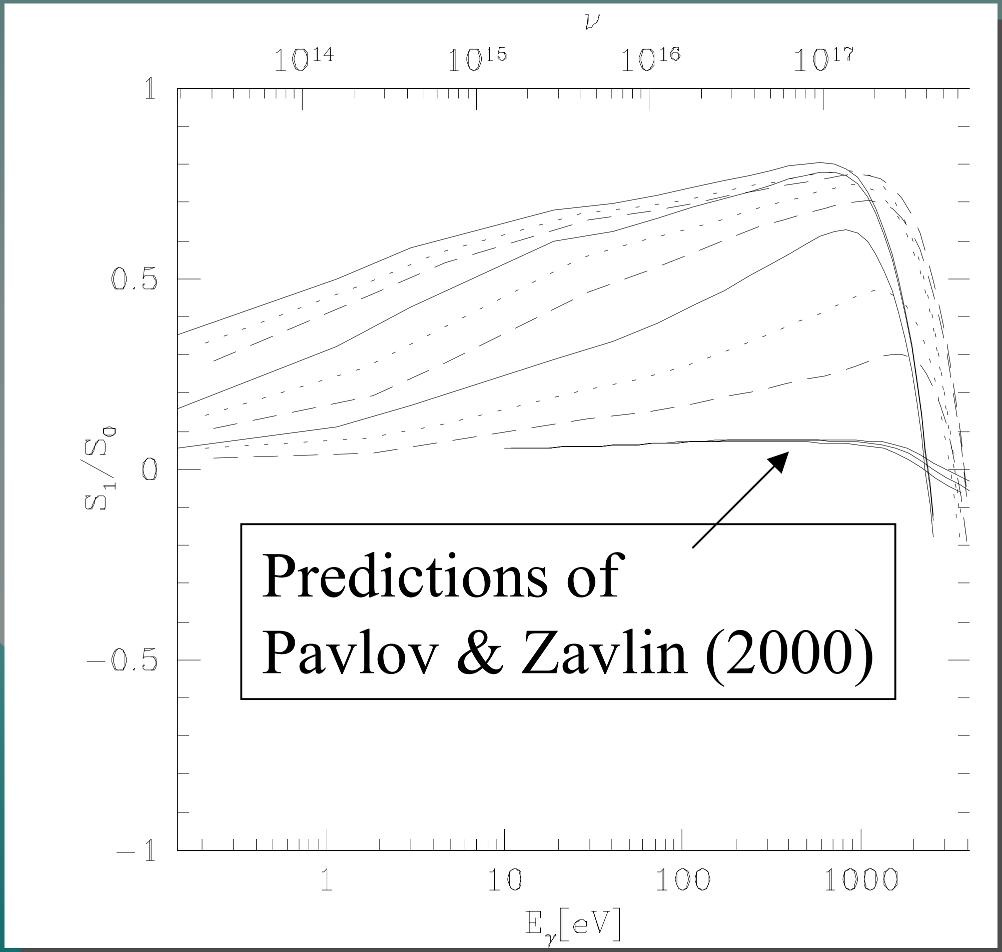
- The strong B-field surrounding a NS distorts our view of its surface.
- The polarization of photons travelling through the field tends to remained aligned with the field.



Heyl, Shaviv & Lloyd '01

QED: Observed Polarizations

- It dramatically affects the extent of polarization.
- Observations of polarized light in the optical would most sensitively probe the NS.
- X-ray data would probe QED.



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Close

- Constellation X and EXIST will provide a unique window into the interior of neutron stars.
  - If spectral lines from NS surfaces are not observed, we will have to use several complementary methods to constrain the EOS of nuclear matter. The more photons, the better.
- Probes of strong-field QED require polarization measurements but are otherwise straightforward.
  - Optical/UV polarimetry will constrain the EOS as well.
  - In the X-rays the signal is much stronger.