The strongest magnetic fields: magnetars

Dr Anna Watts
Astronomical Institute ‘Anton Pannekoek’
University of Amsterdam

Image: ESO/L.Calçada

Magnetar properties

- ~20 isolated neutron stars with
  - Slow spin periods (2-12s)
  - Rapid spin-down
  - Repeated gamma-ray bursts
- Luminosity too high to be powered by spin-down alone.
- Bursts are brighter than the Eddington limit for neutron stars
- Some appear to be located in supernova remnants

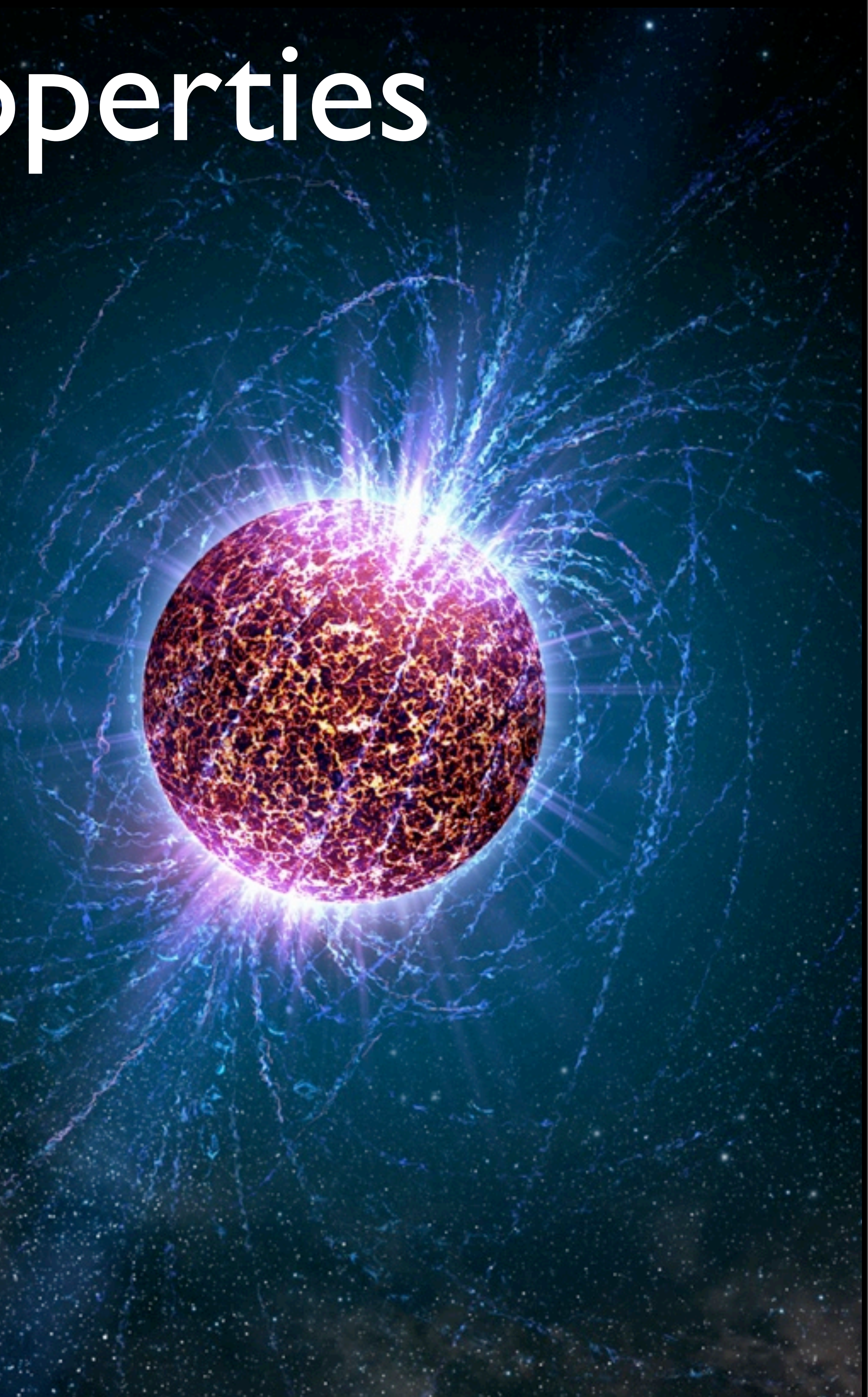
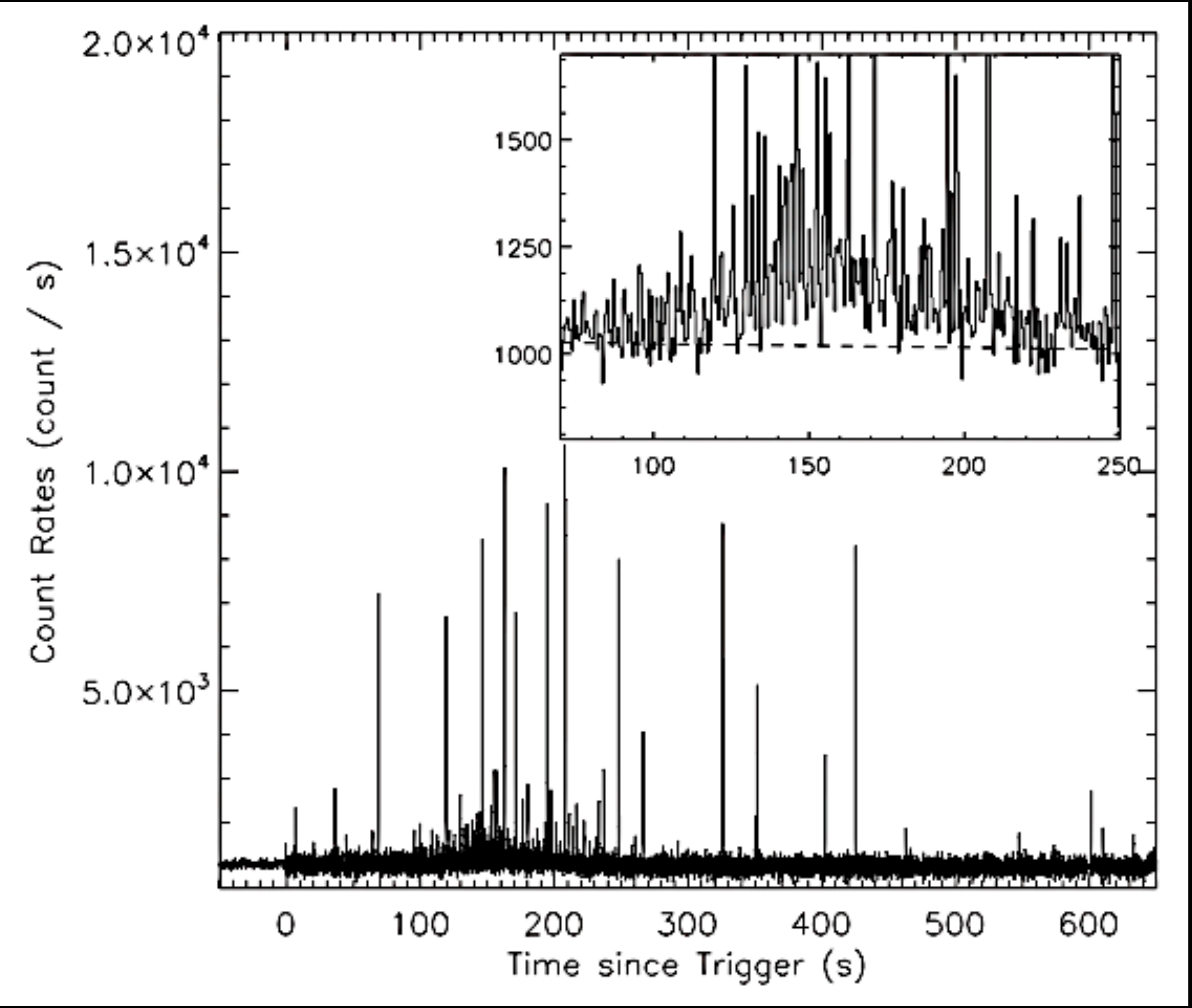
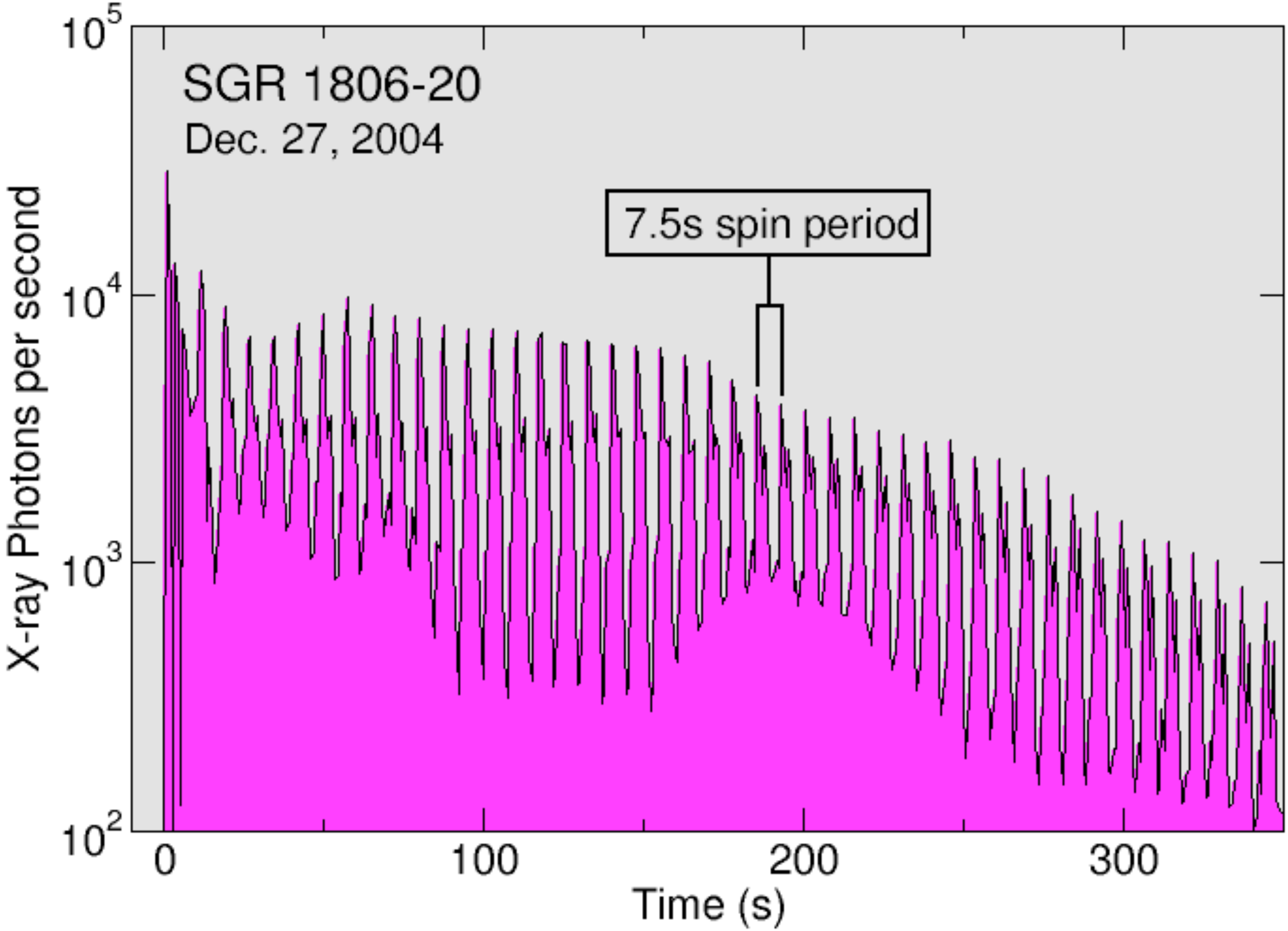


Image: Casey Reed/Penn State U



Kaneko et al. 2010

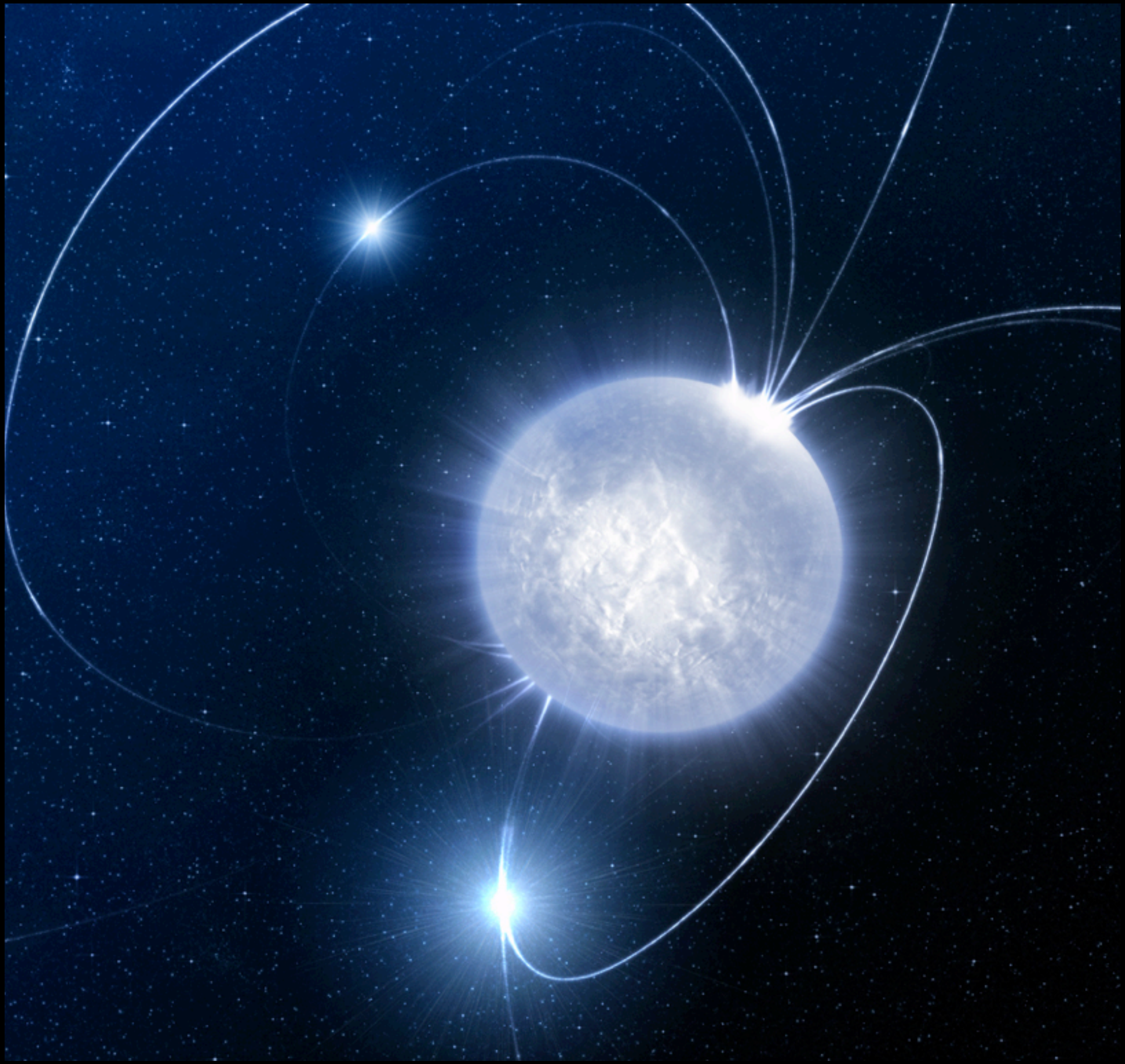


SGR 1806-20
Dec. 27, 2004
7.5s spin period
X-ray Photons per second
Time (s)
10^5
10^4
10^3
10^2
0
100
200
300

Source	Active period	Fermi GBM triggers
SGR 0501+4516	Aug-Sep 2008	26
SGR 1806-20	Nov 2008	1
SGR 1550-5418	Oct 2008 Jan-Feb 2009 Mar-Apr 2009	7 117 14
SGR 0418+5729	June 2009	2
1E 1841-045	Feb 2011	3
J1822.3-1606	July 2011	1
J1834.9-0846	Aug 2011	2

The magnetar model

- Developed initially by Rob Duncan and Chris Thompson in the 1990s.
- Magnetars are young neutron stars with ultra-strong ($>10^{14}$ G) magnetic fields.
- X-ray glow and gamma-ray bursts are powered by field decay.

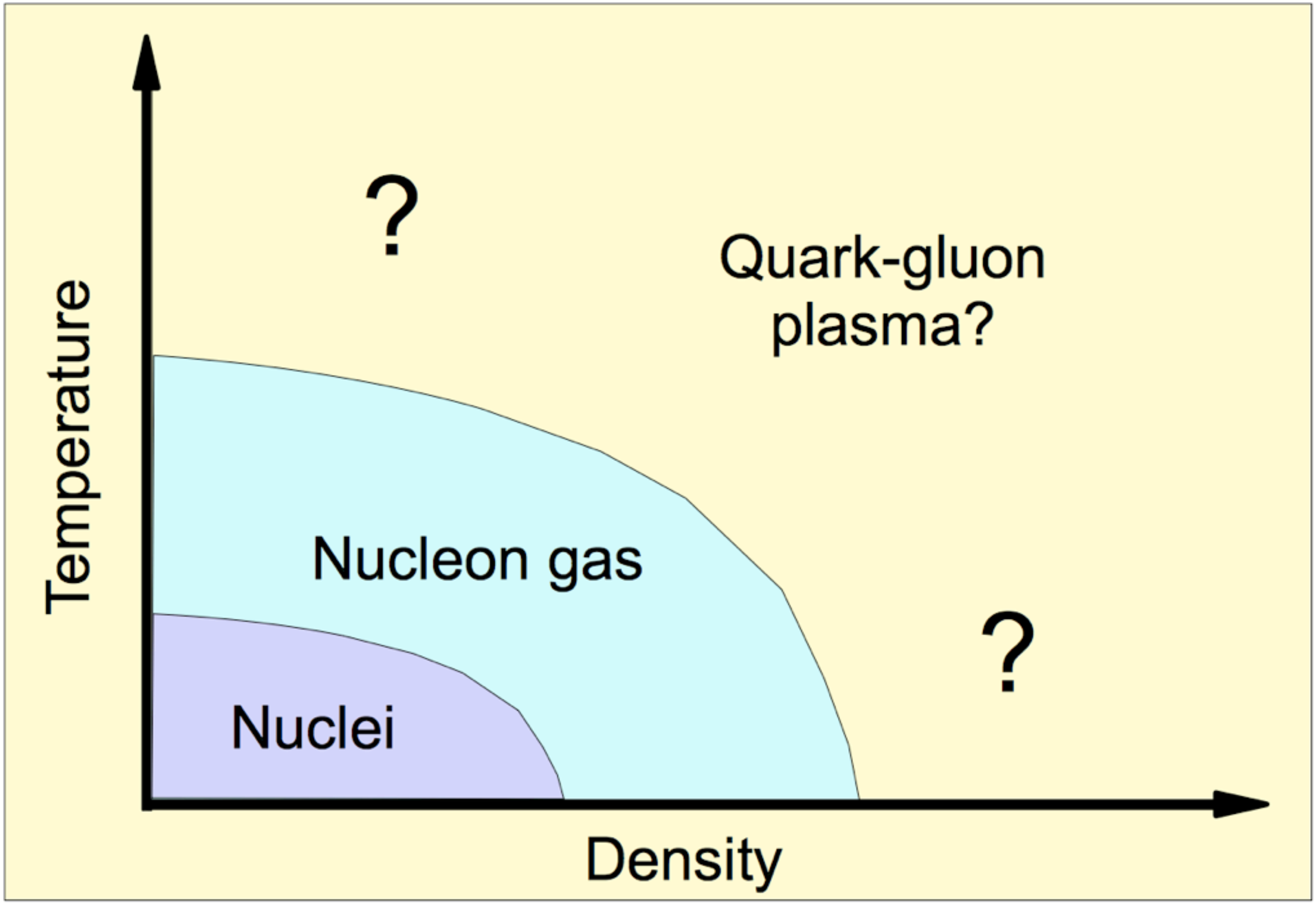


Some key questions

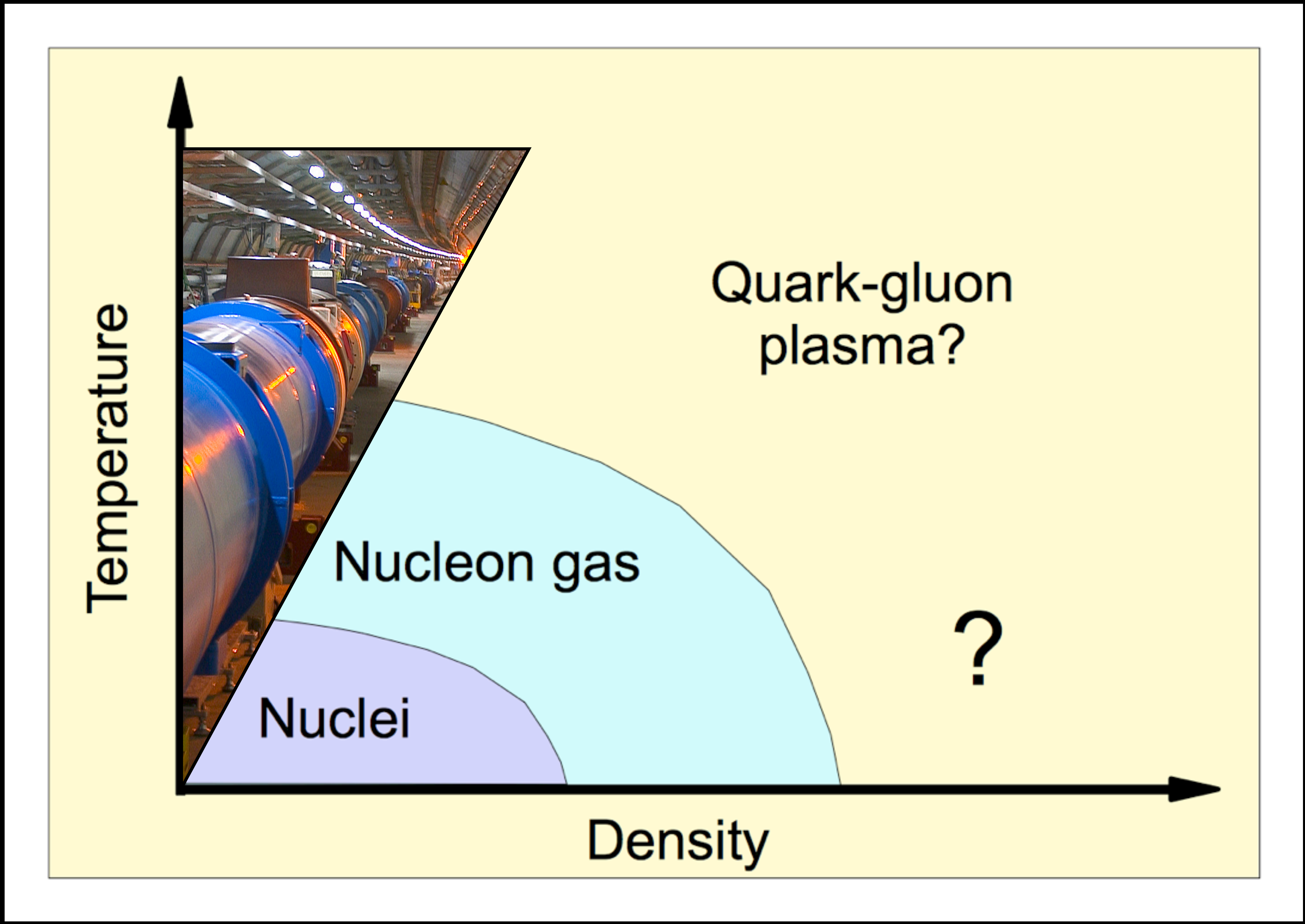
- What is the dense matter equation of state?
- How do you make a magnetar?
- What new physical processes occur once you have magnetic fields above the QED limit?

What is the dense matter equation of state?

Equation of state (EoS)

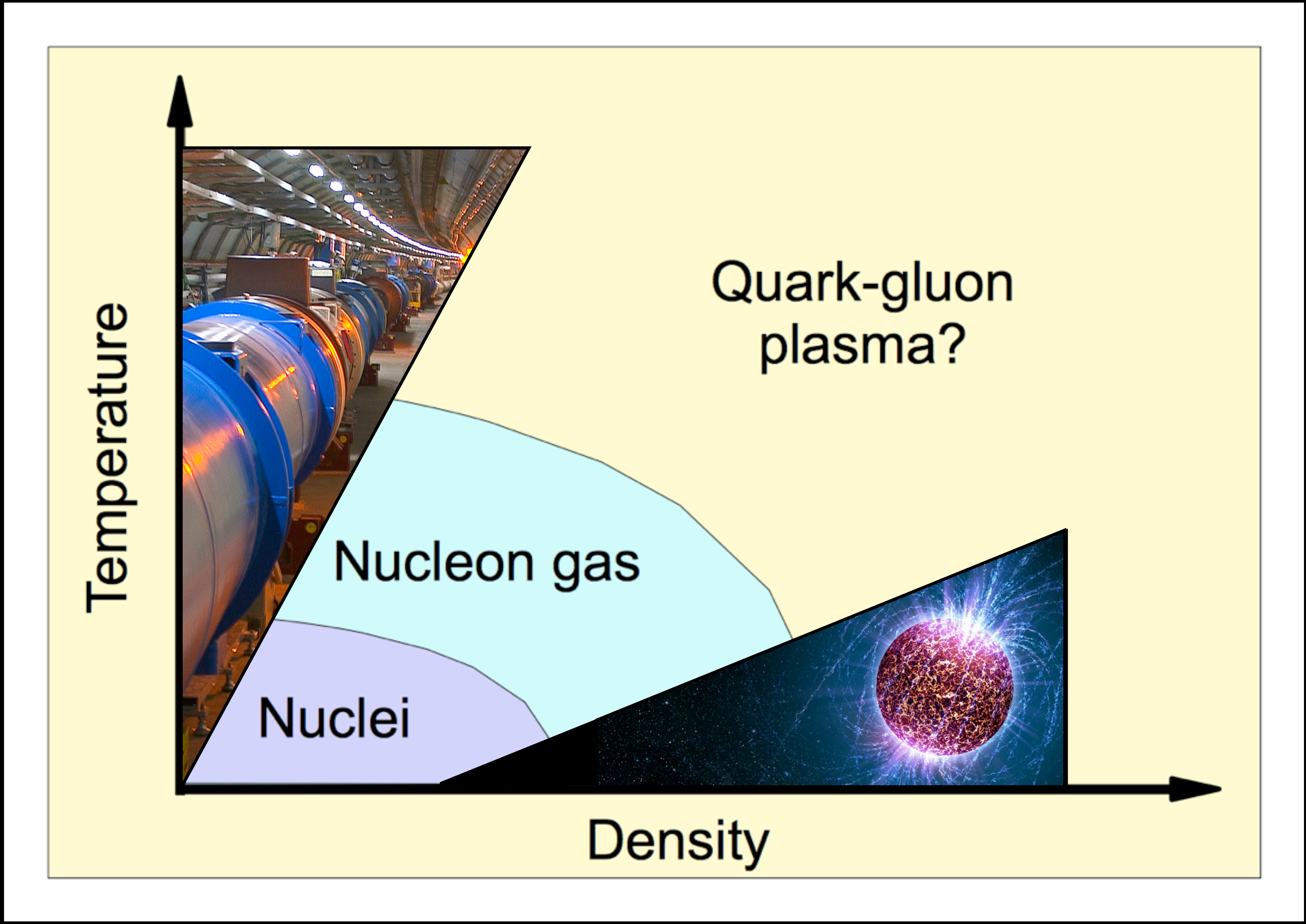


Equation of state (EoS)



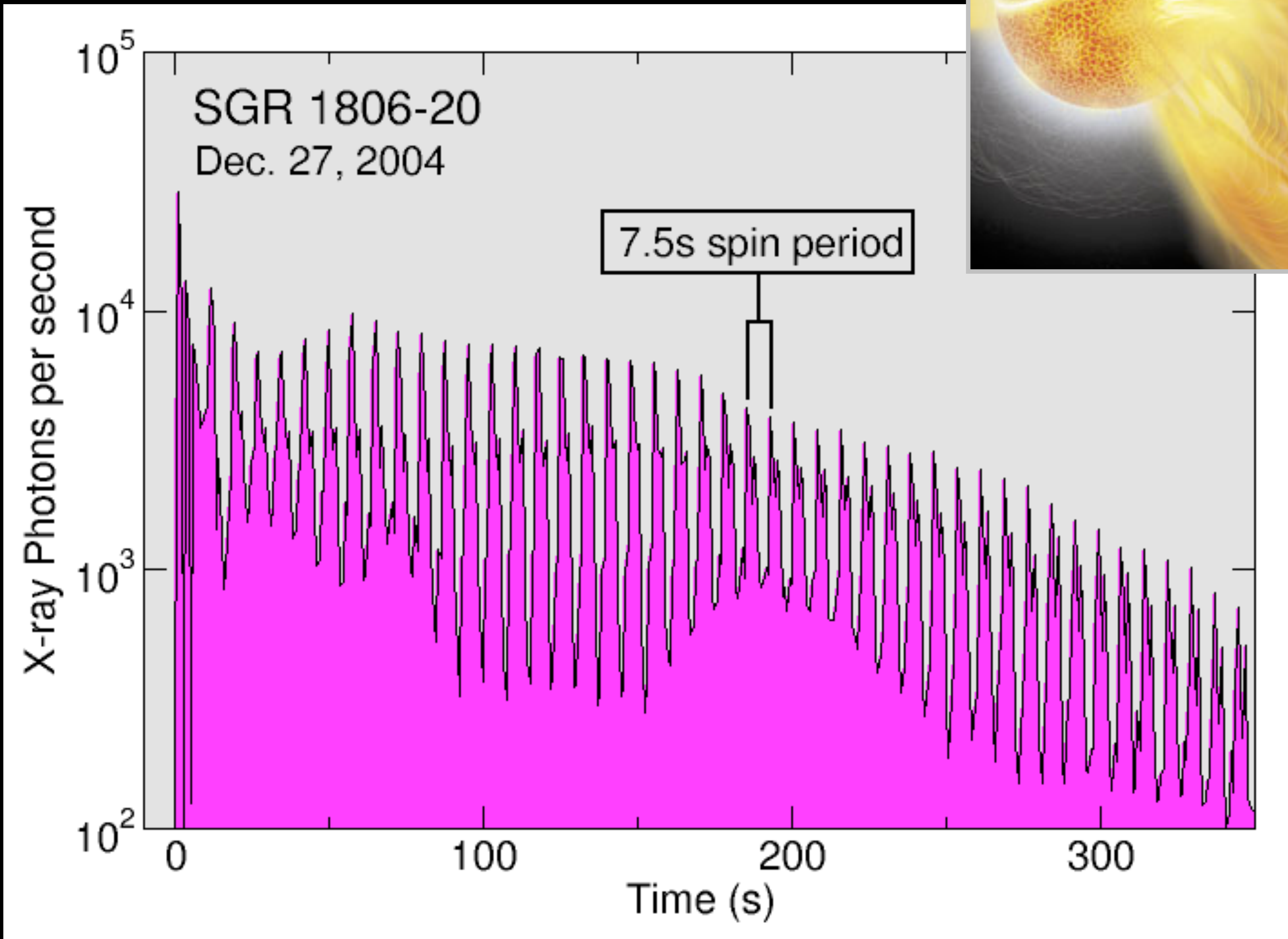
LHC image: CERN

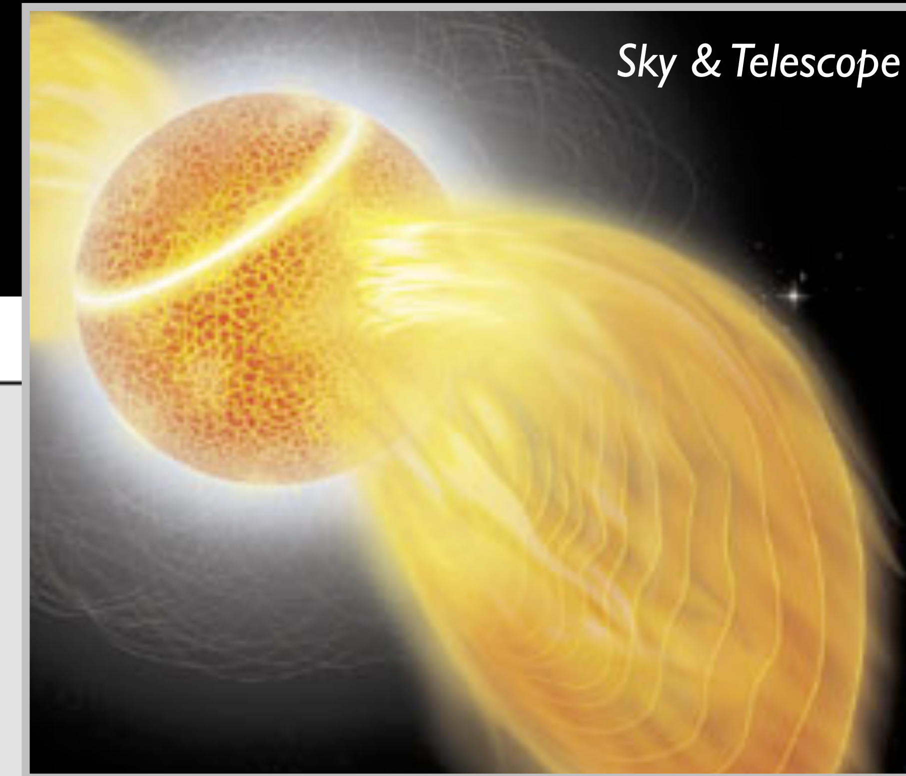
Equation of state (EoS)



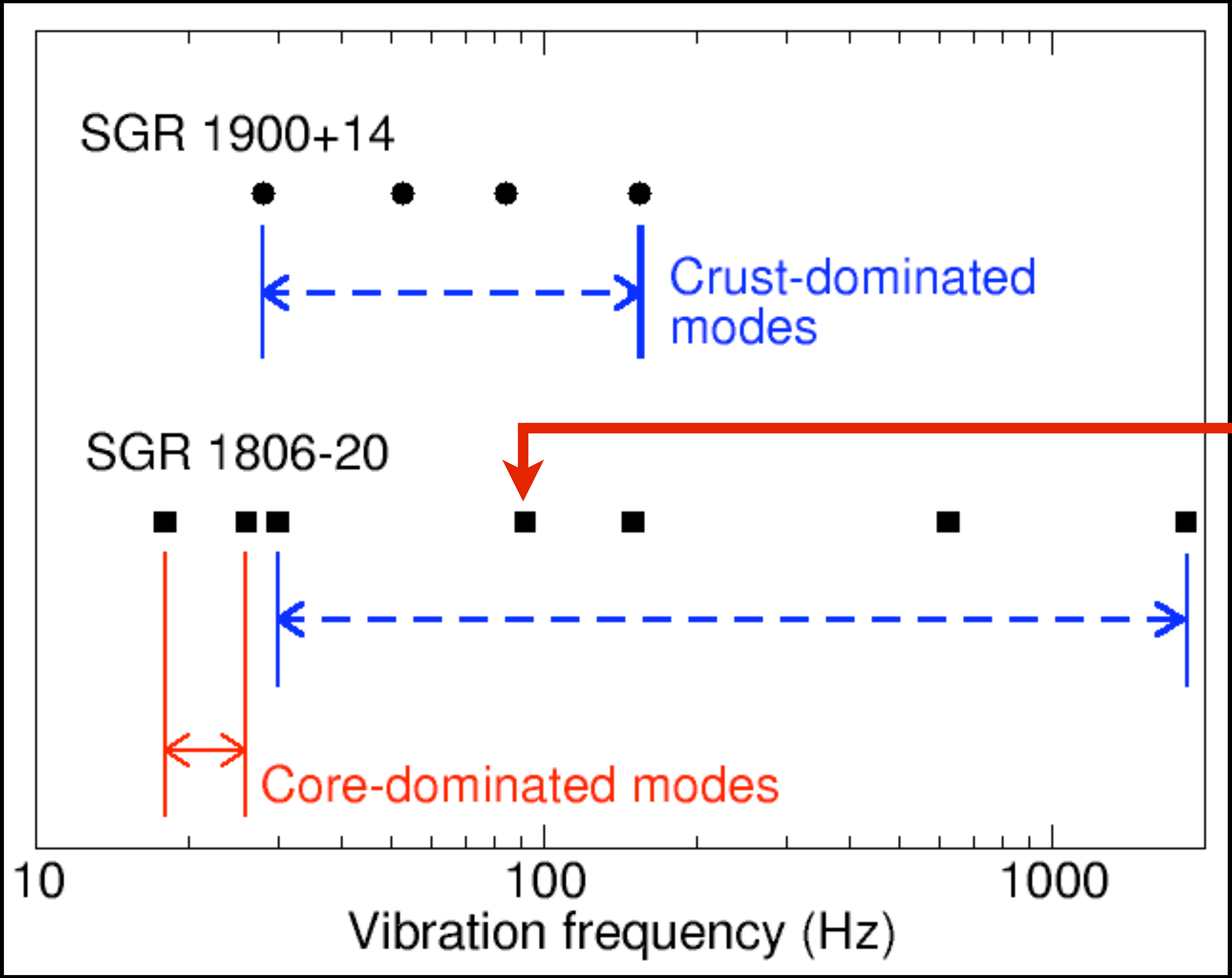
LHC image: CERN

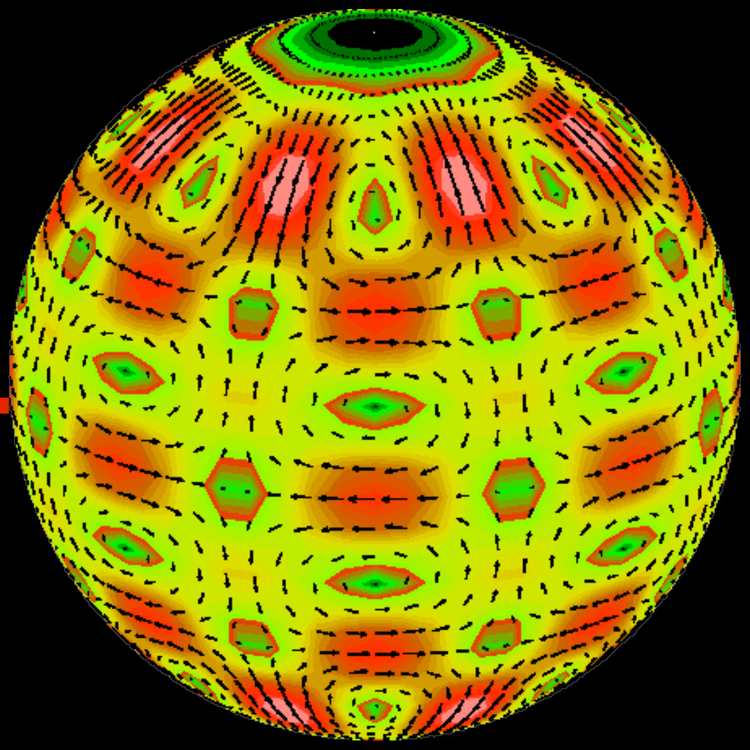
Giant flares





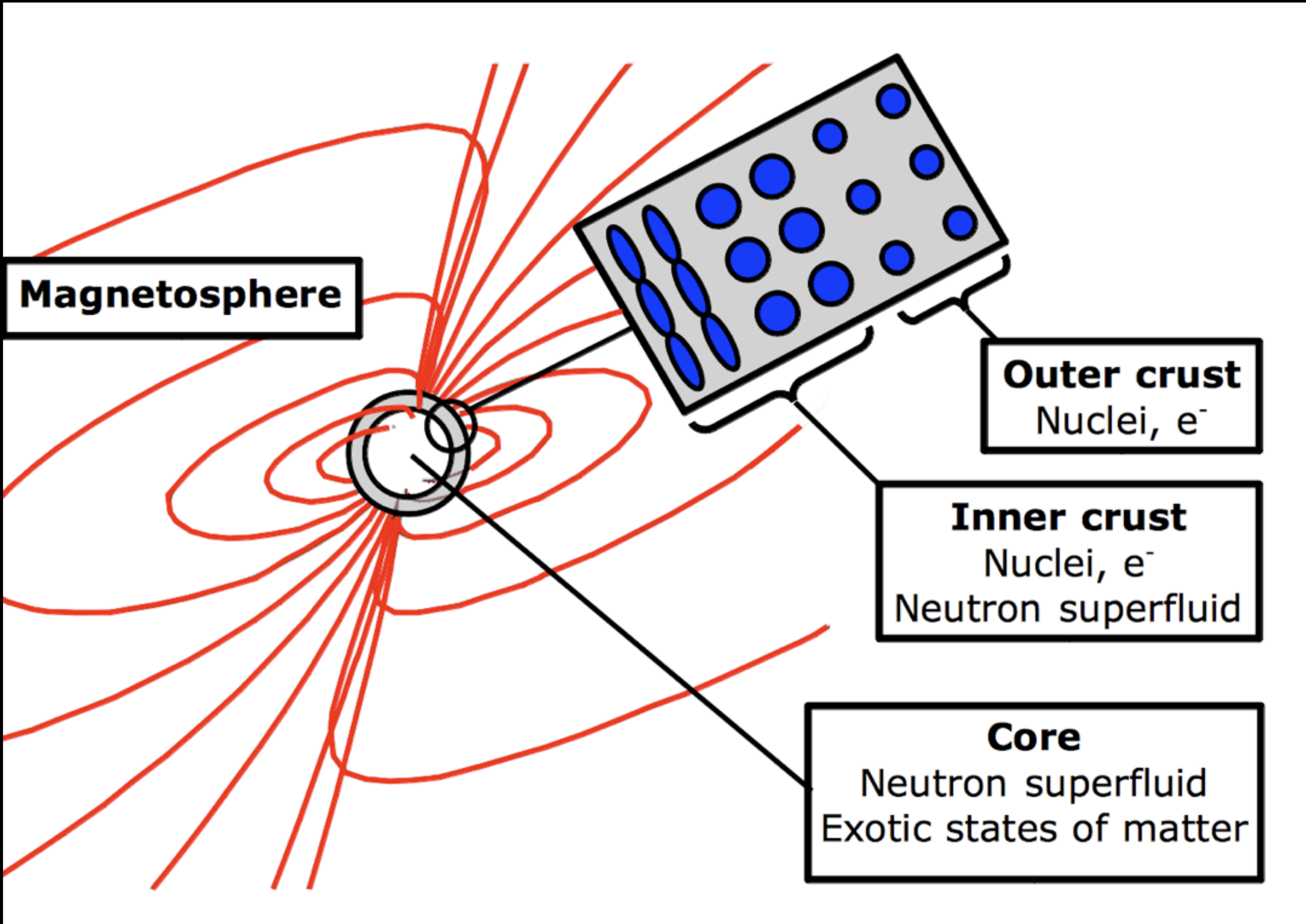
Giant quakes → global modes



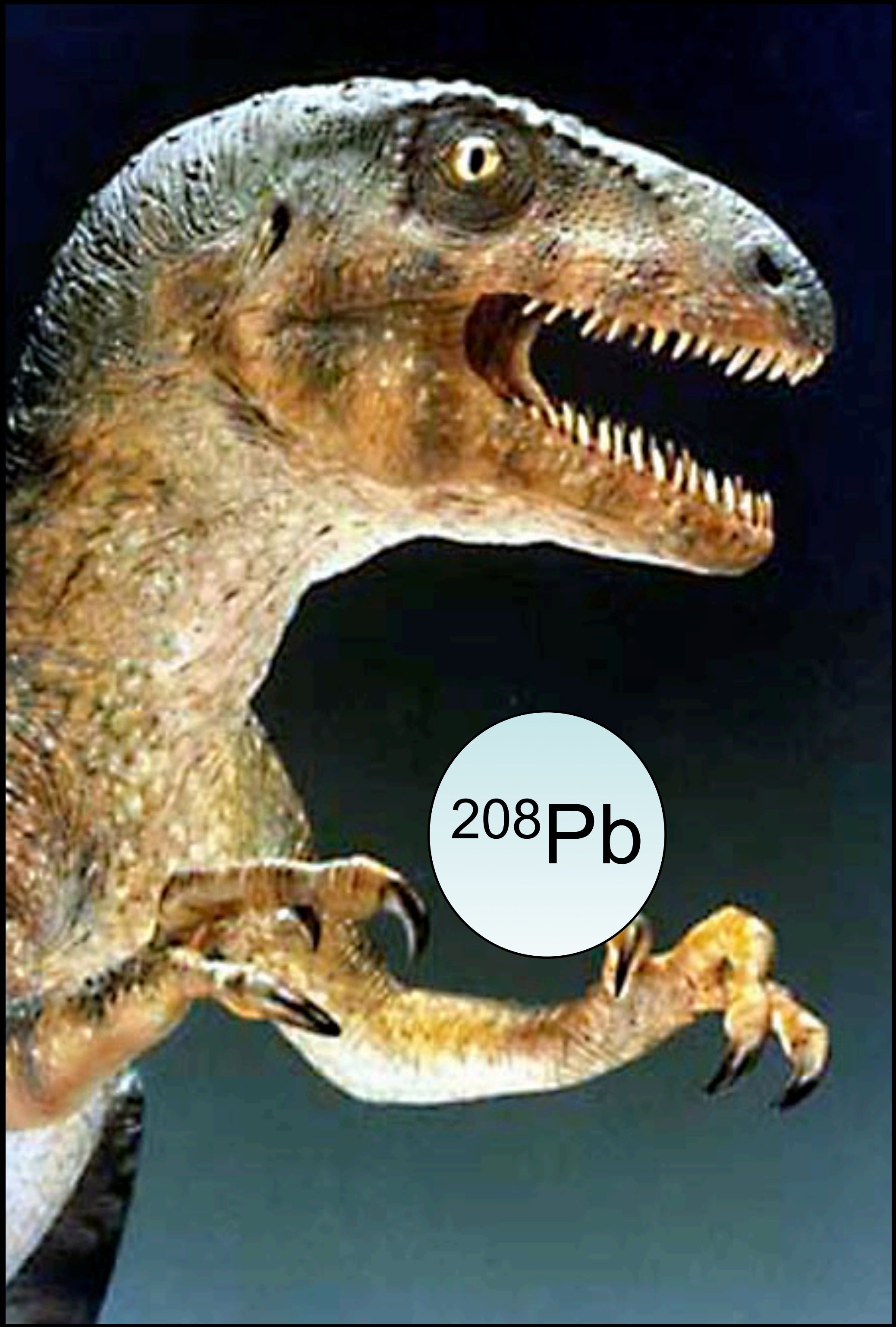


Each frequency has an associated mode of vibration

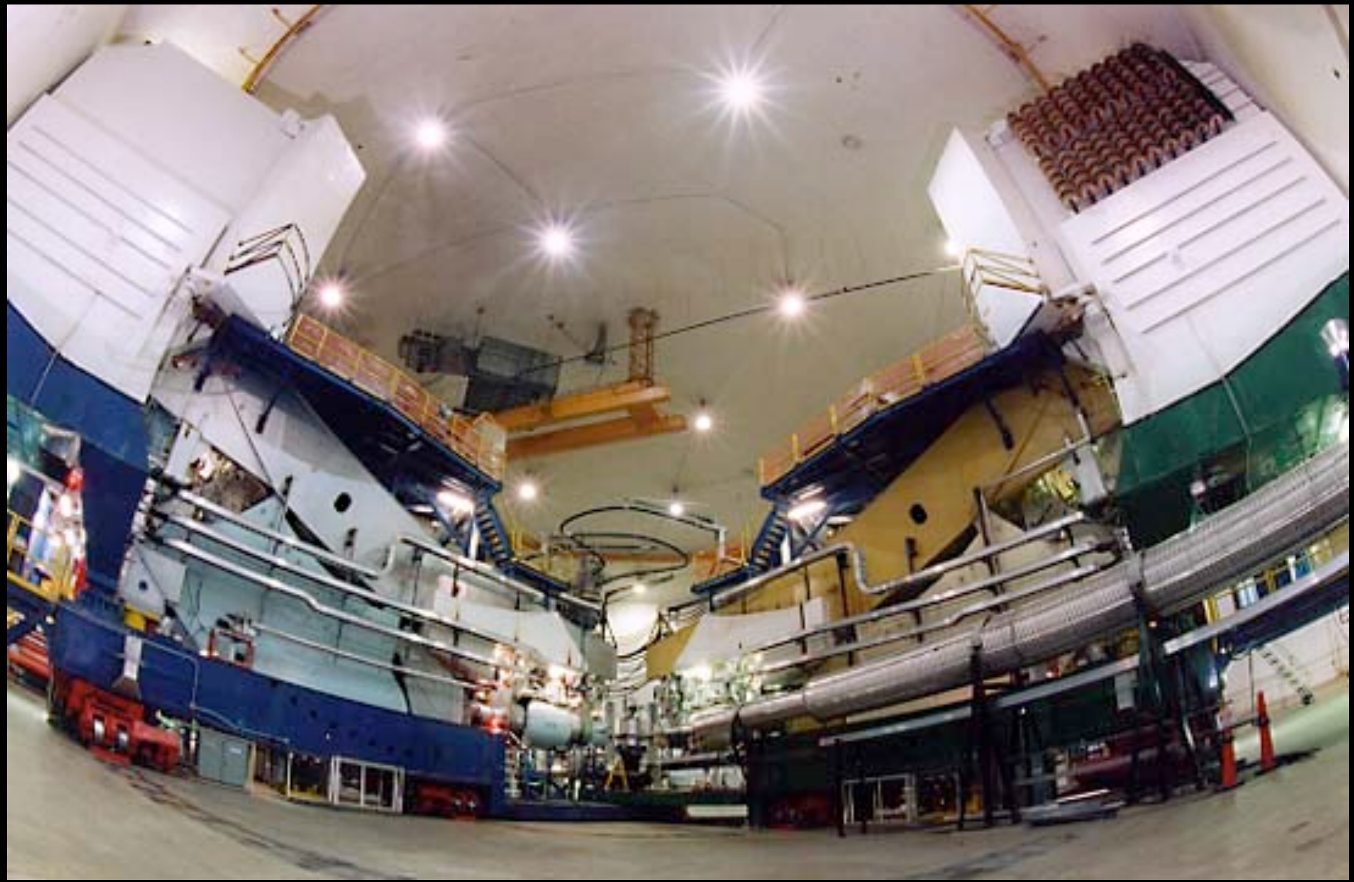
Israel et al. 05, Strohmayer & Watts 05, 06, Watts & Strohmayer 06, 07, Watts & Reddy 07


Magnetosphere
Outer crust
Nuclei, e⁻
Inner crust
Nuclei, e⁻
Neutron superfluid
Core
Neutron superfluid
Exotic states of matter

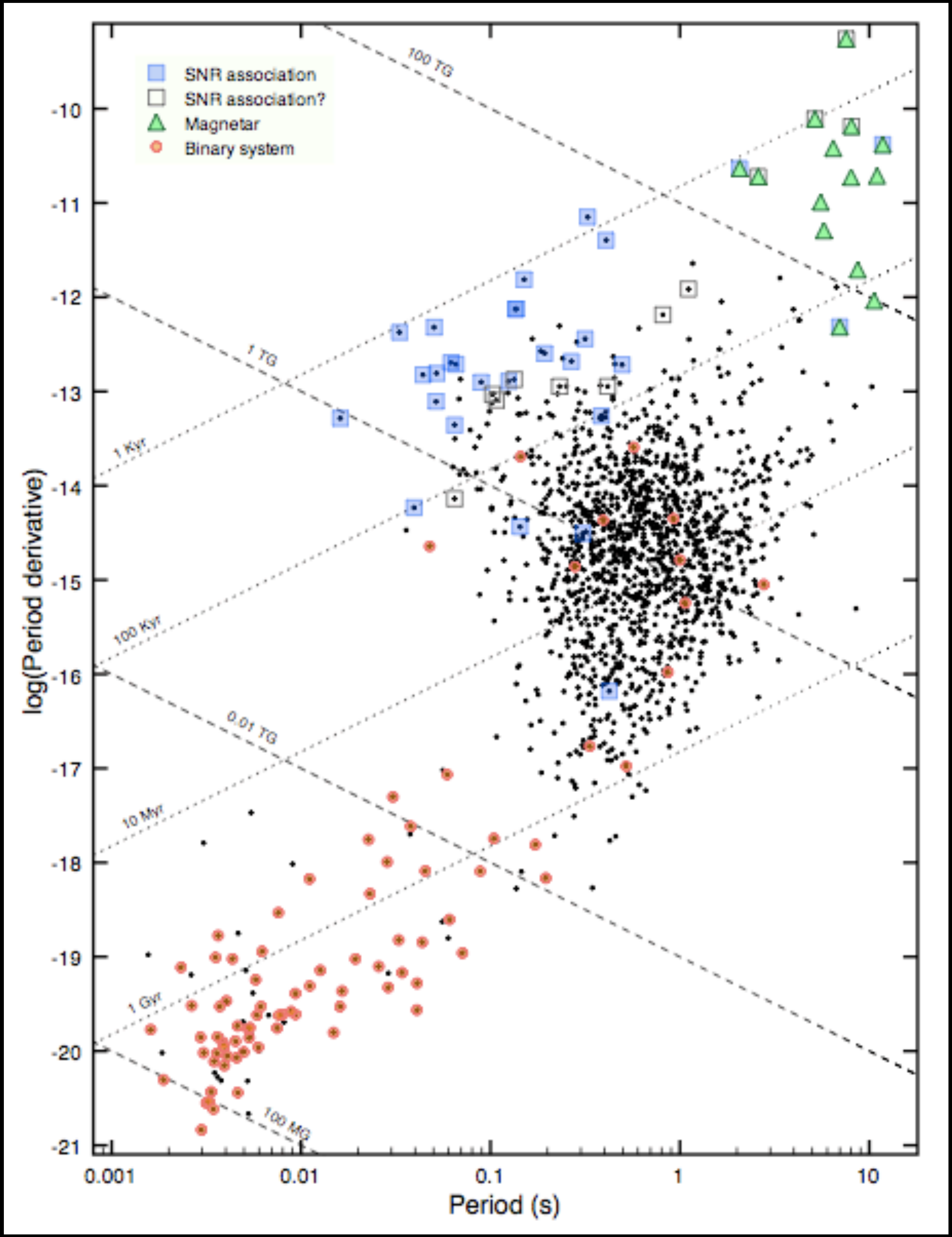
Links to laboratory experiments



- Crust composition depends on poorly known high density behaviour of symmetry energy (Steiner & Watts 2009).
- Links to experiments like PREX.



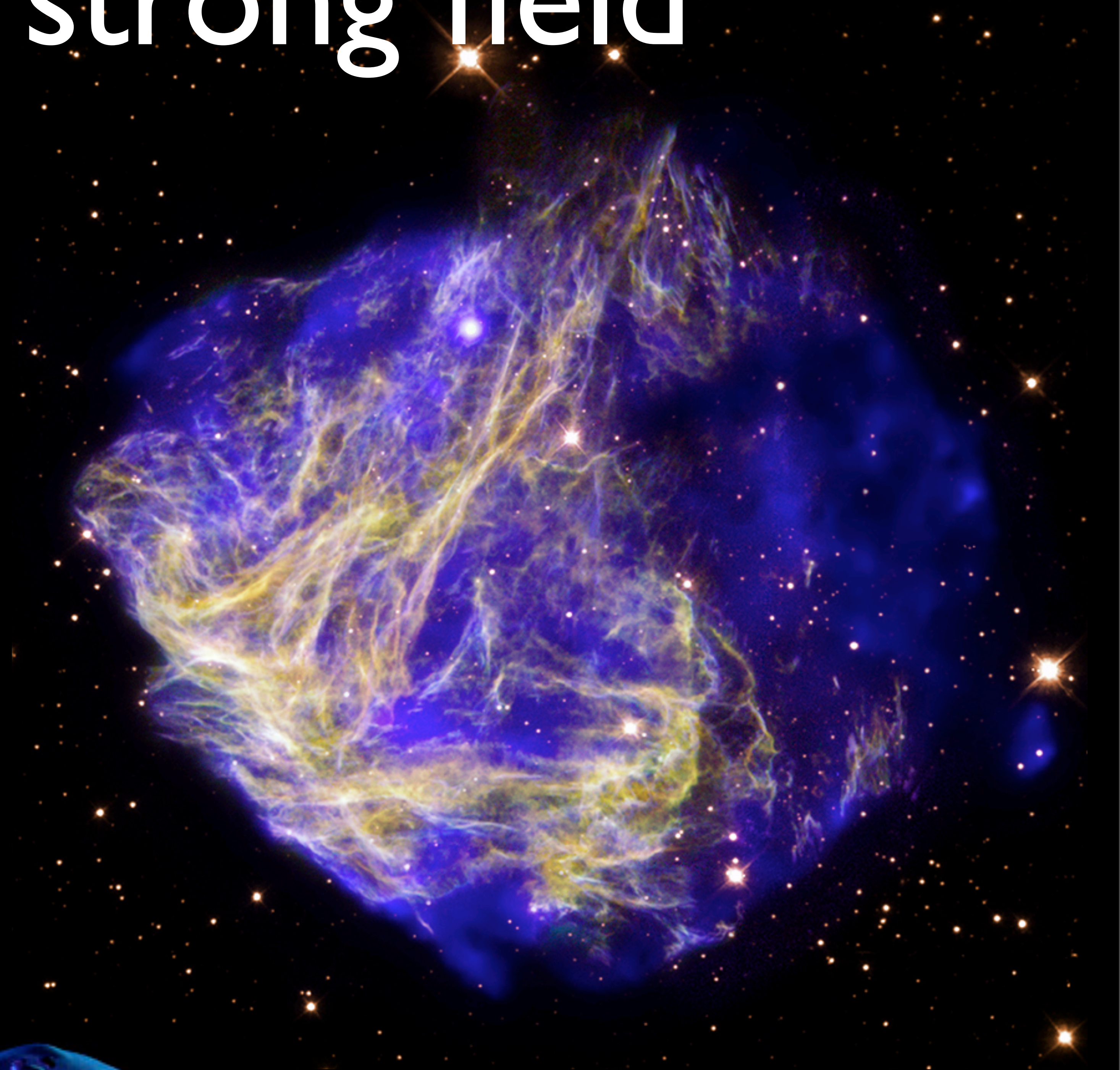
How do you make a magnetar?

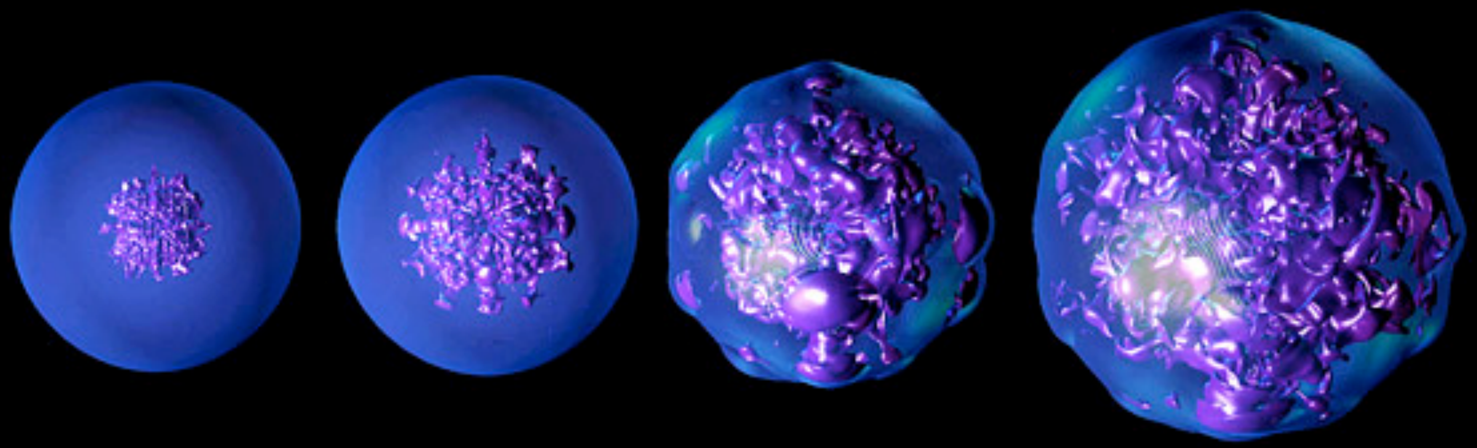


Courtesy of C. Espinoza

Making a strong field

- Dynamo action during the supernova?
- Unusual progenitor star properties?





Chandra/HST image of SNR N49 in the LMC

But is this enough?

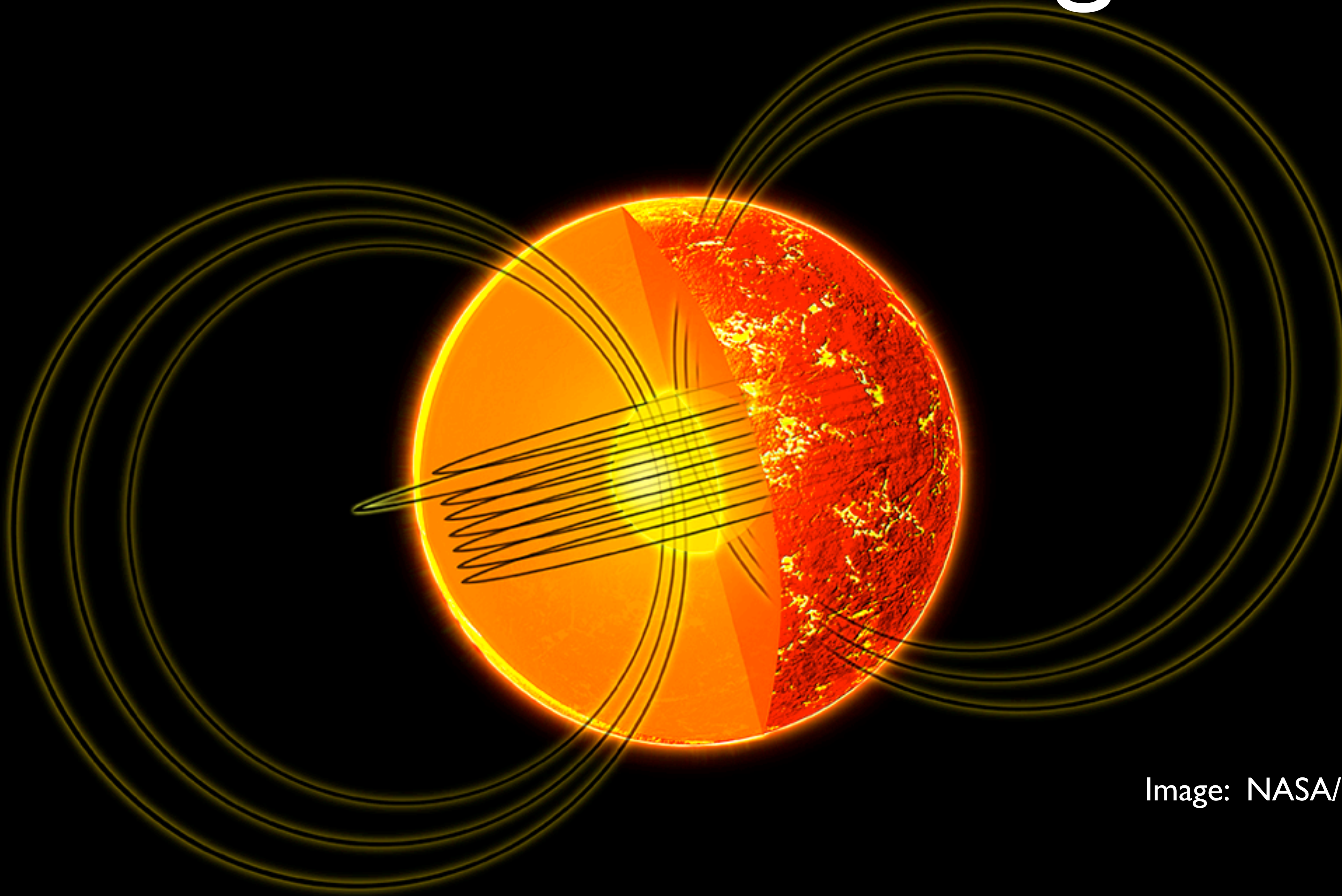
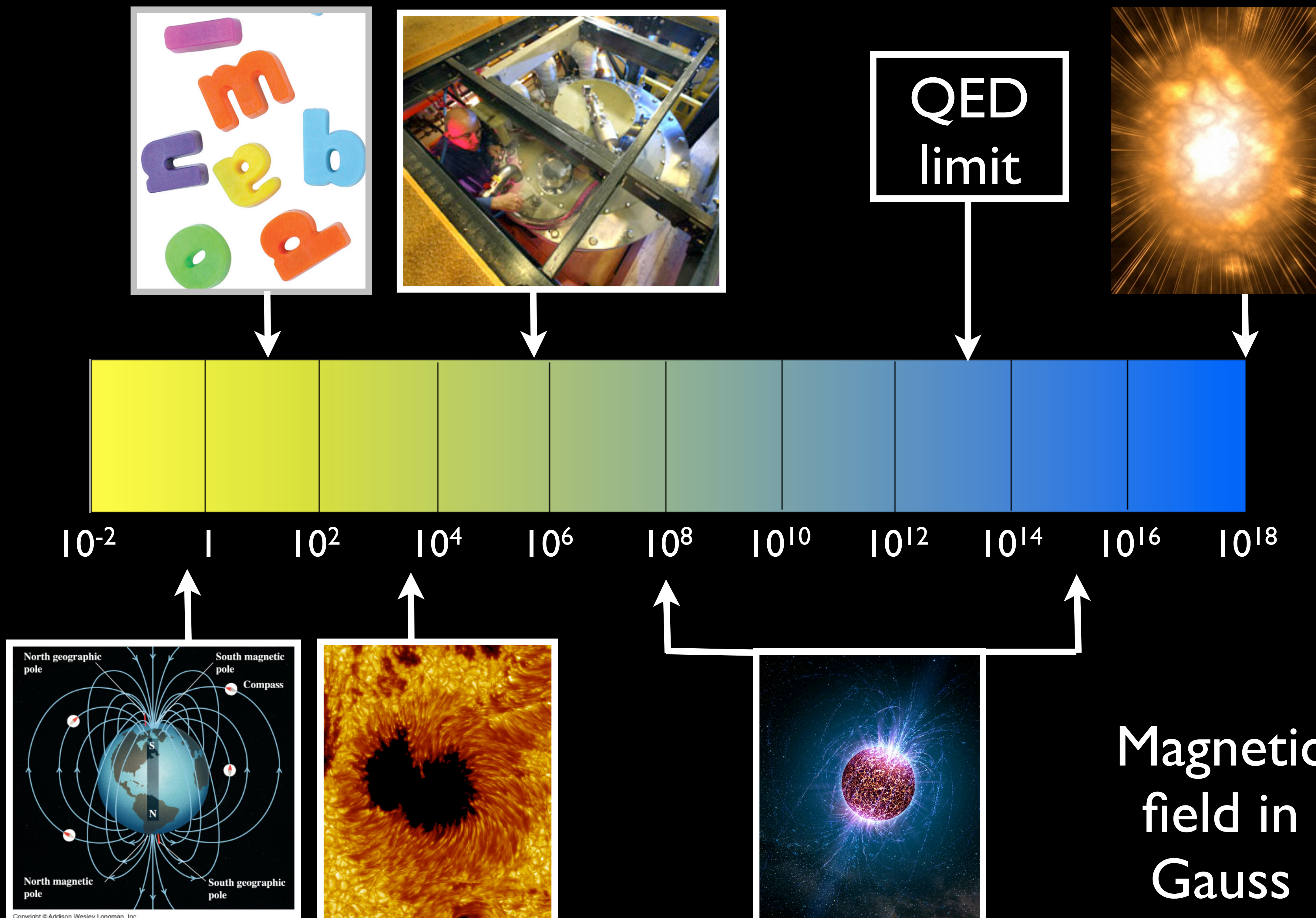


Image: NASA/CXC/M. Weiss

SGR 0418+5729 has standard magnetar bursts (van der Horst et al. 2010) despite having a dipole field < 10^{13} G (Rea et al. 2010).

What happens once you exceed the quantum critical field?

High magnetic field physics



High field radiative processes

- Fields above B_{QED} have strange effects on radiation and matter.
- Vacuum birefringence, photon splitting/ merging, reduced scattering, distortion of atoms....

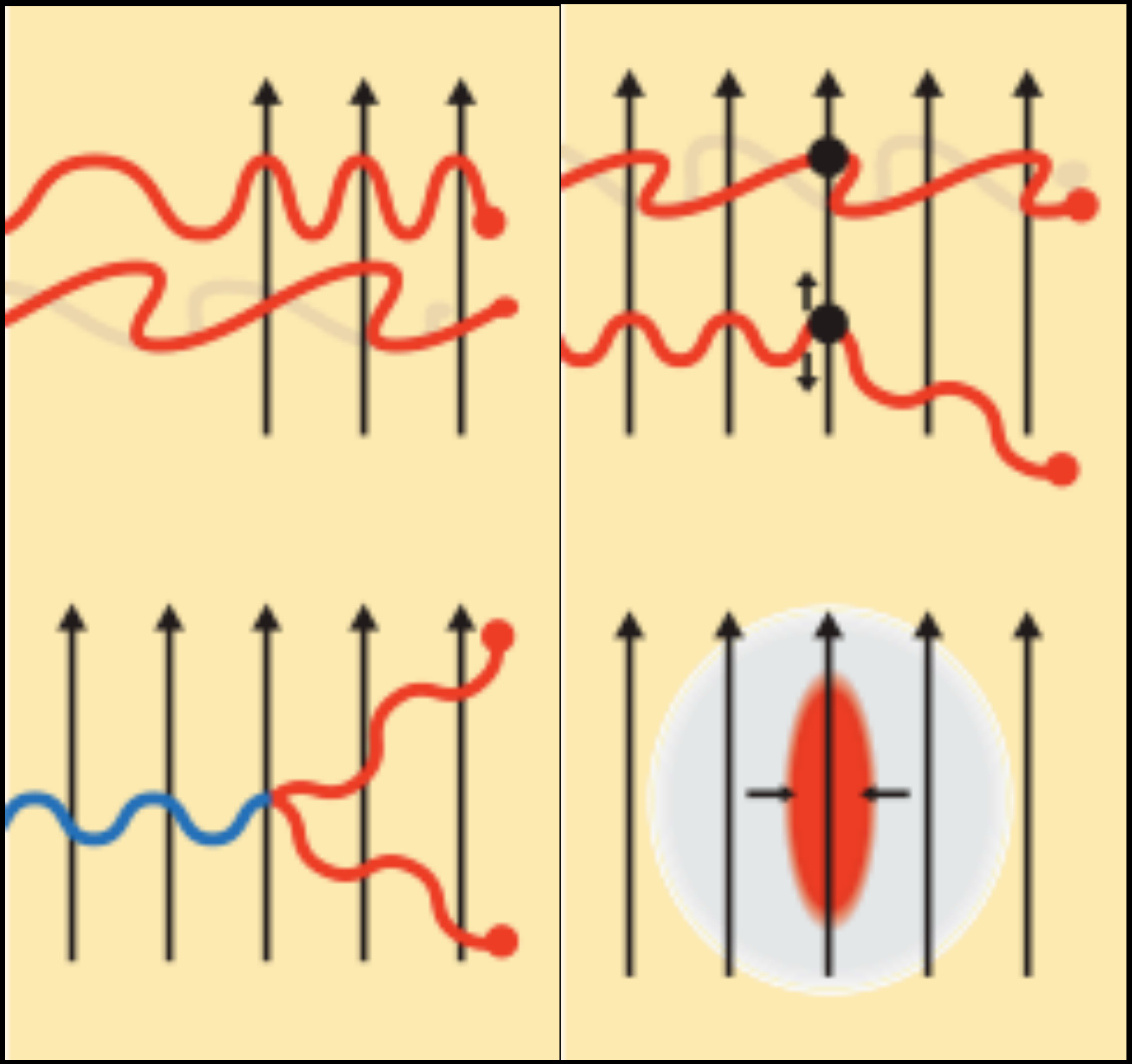
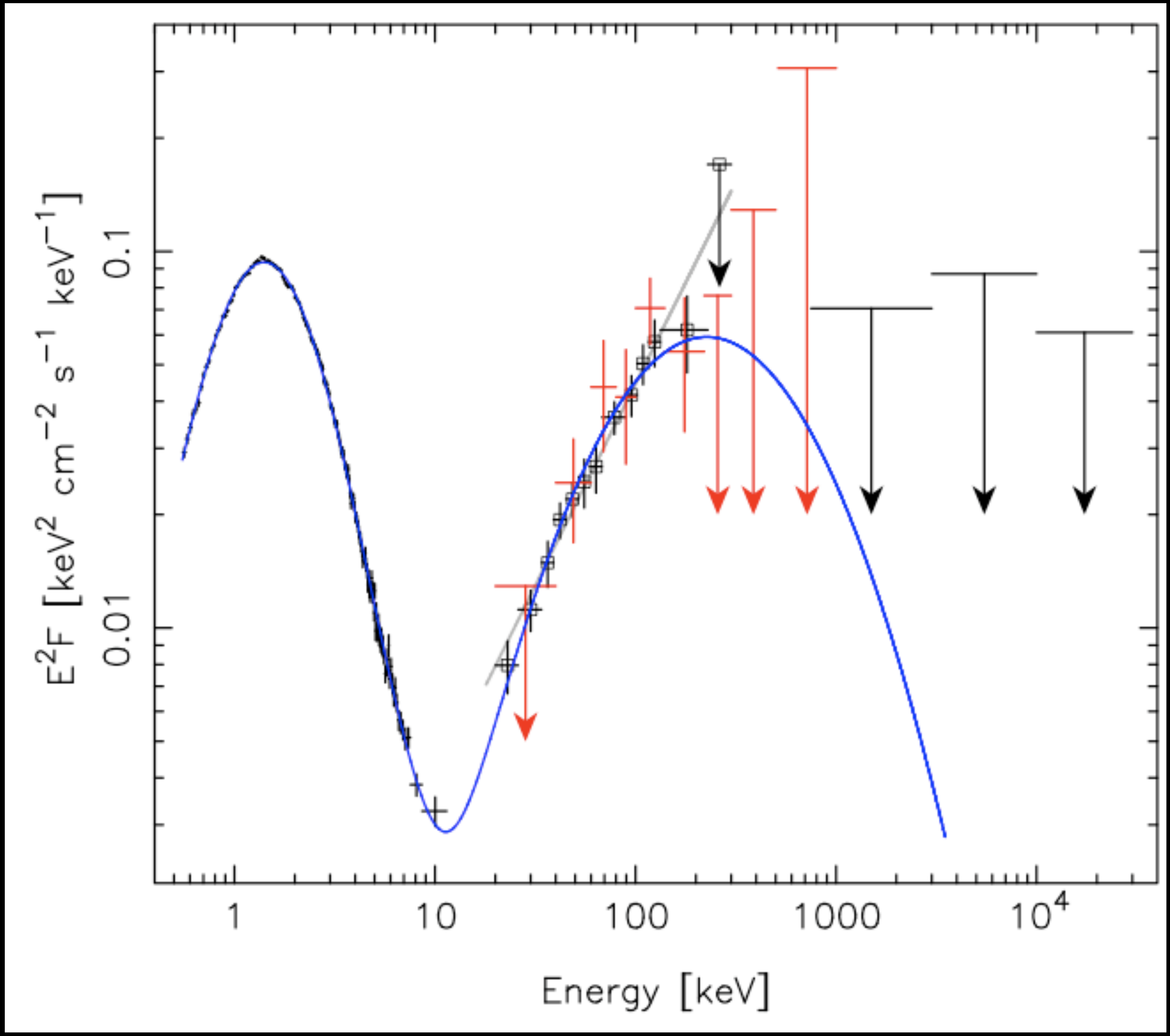


Figure from Kouveliotou et al. 2003

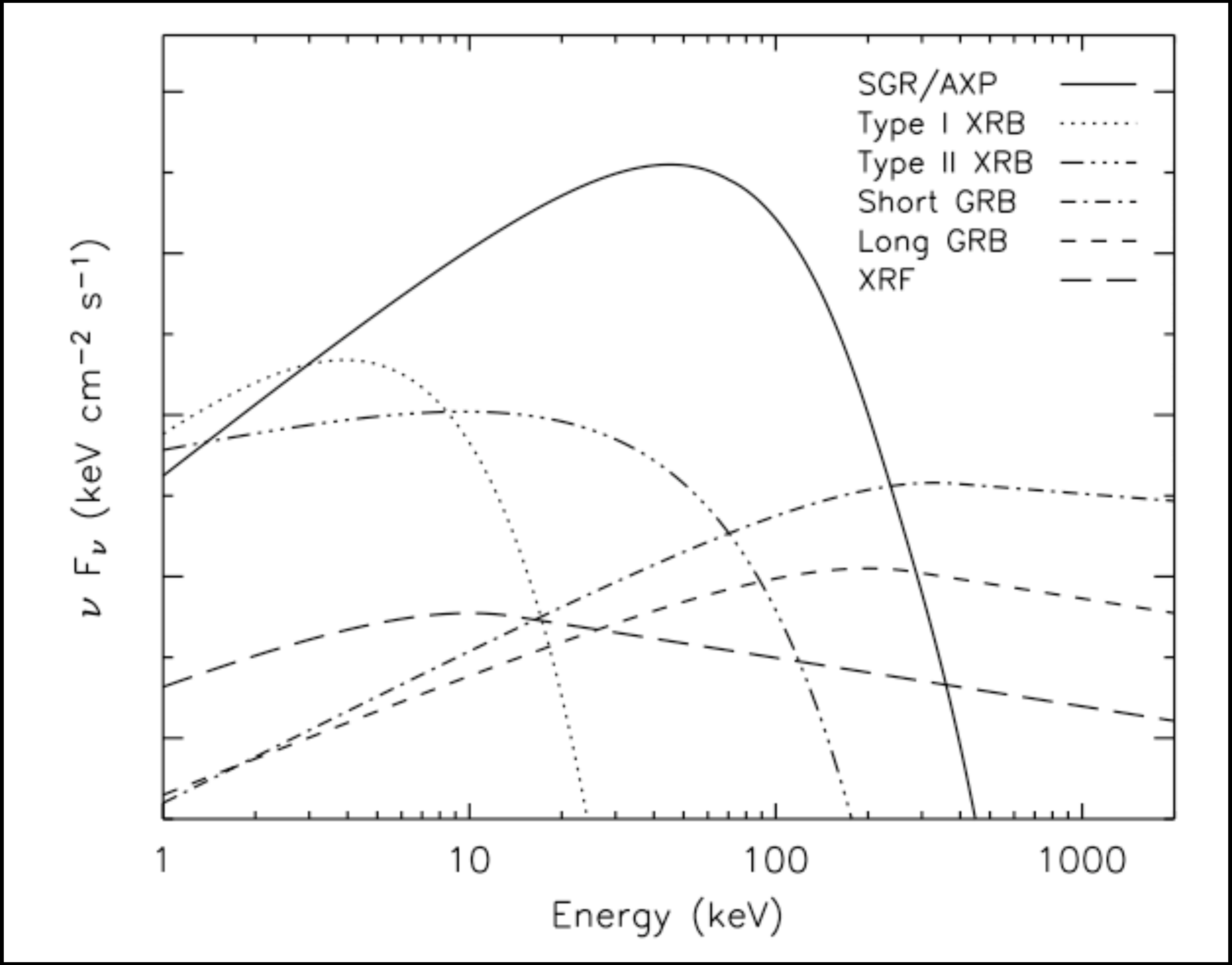
Quiescent spectra

- Multiple components
- Pulsed emission
- Huge theoretical effort over recent years to attempt to model quiescent emission.
- Now tying in to field evolution simulations.



Magnetar spectrum from den Hartog et al. 2008

Burst spectra

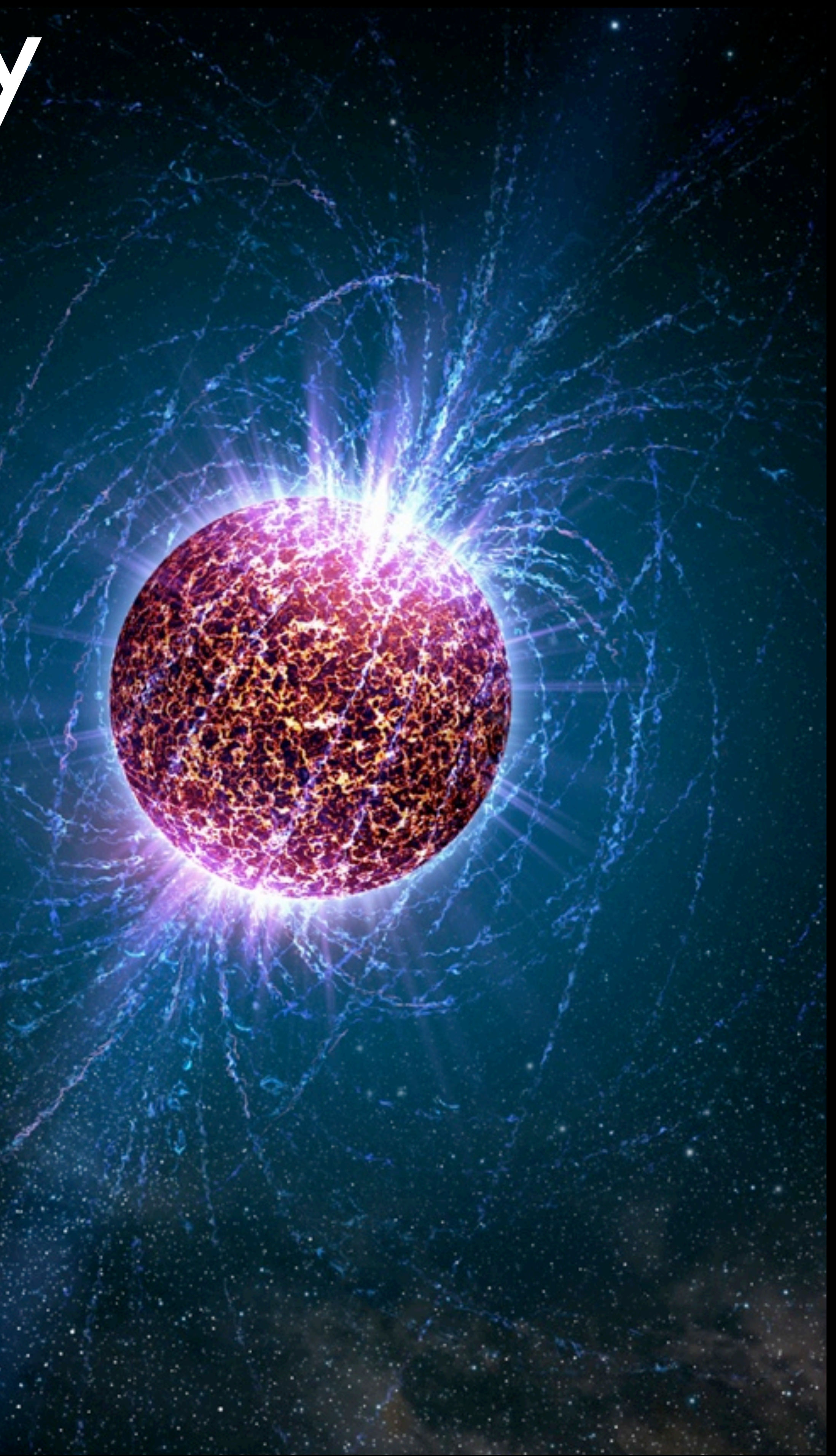


Woods & Thompson 2006

The magnetic Eddington limit

- Exceeds non-magnetic value (Paczynski 1992, Miller 1995)
- Can luminosity saturation of 2BB models of bright bursts be explained in terms of this limit (Israel et al. 2008)?
- Do bursts at the limit exhibit photospheric radius expansion (Watts et al. 2010)?
- An open question - but stability of emitting region is key!

Summary



- Magnetars have the strongest magnetic fields that we know of in the Universe.
- Their violent activity - powered by field decay - has led to the birth of observational neutron star asteroseismology.
- High field radiation processes are an active topic of research in a data-rich field.
- But we still do not know what it takes to make a magnetar!

Magnetar Vidi team Amsterdam

Anna Watts (PI), Caroline D'Angelo, Daniela Huppenkothen
Danai Antonopoulou, Thijs van Putten

Fermi GBM Magnetar key project

Chryssa Kouveliotou (PI), Alexander van der Horst (NASA/MSFC)
Ersin Gogus, Yuki Kaneko (Sabanci),
Vidi team (above), Ralph Wijers, Michiel van der Klis (Amsterdam)
Matthew Baring (Rice), Stefanie Wachter (Caltech)
Jonathan Granot (Hertfordshire), Enrico Ramirez-Ruiz (UCSC)
Vicki Kaspi (McGill), Andreas von Kienlin (MPE), Michael Kramer (MPIfR)
Neil Gehrels, Julie McEnery, Alice Harding (NASA/GSFC)
Peter Woods (Corvid Technologies), Sylvain Guiriec, Lin Lin (UAH)

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