Pulsars – Cosmic Laboratories for Extreme Physics

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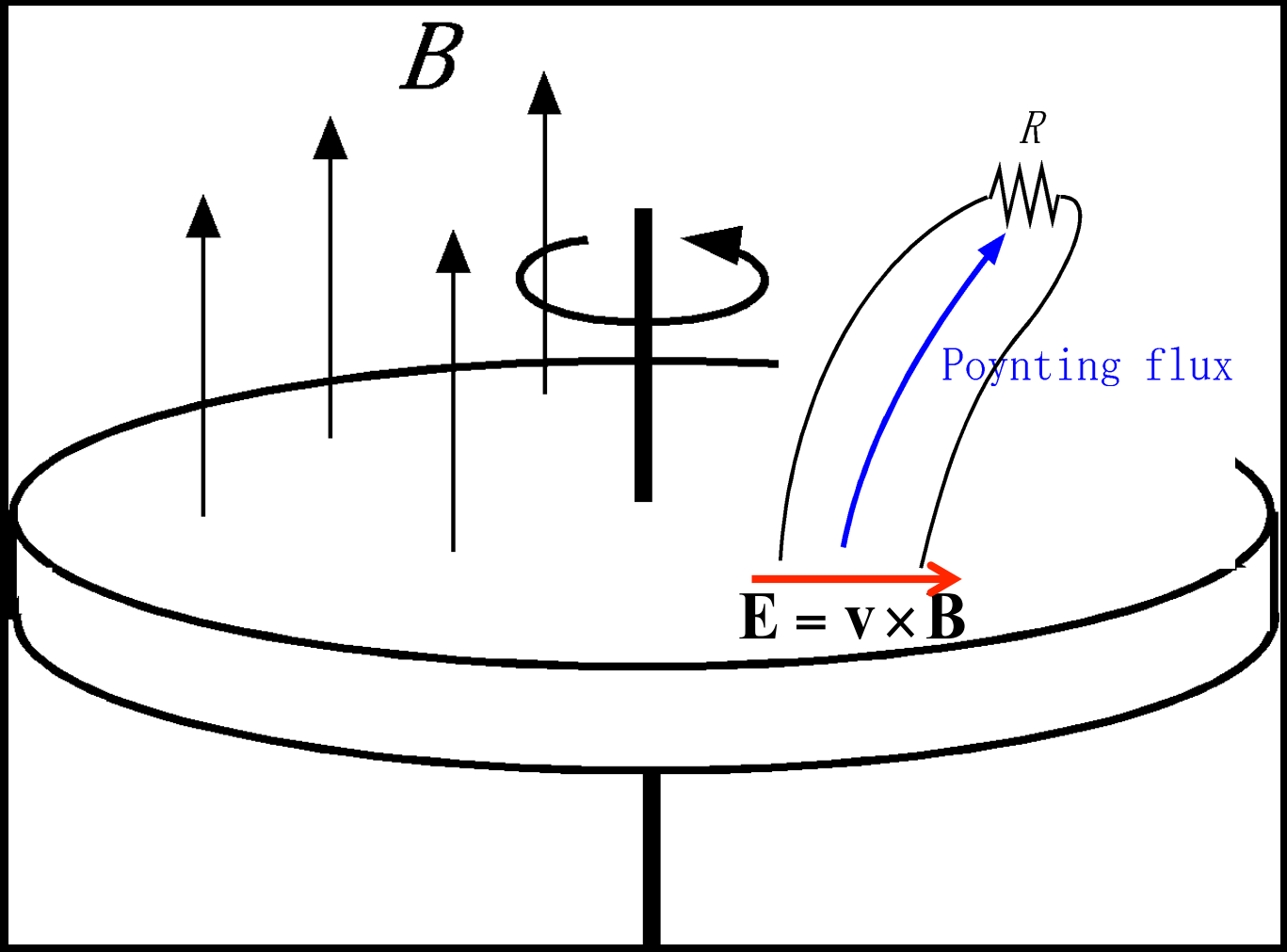
Pulsars as cosmic laboratories

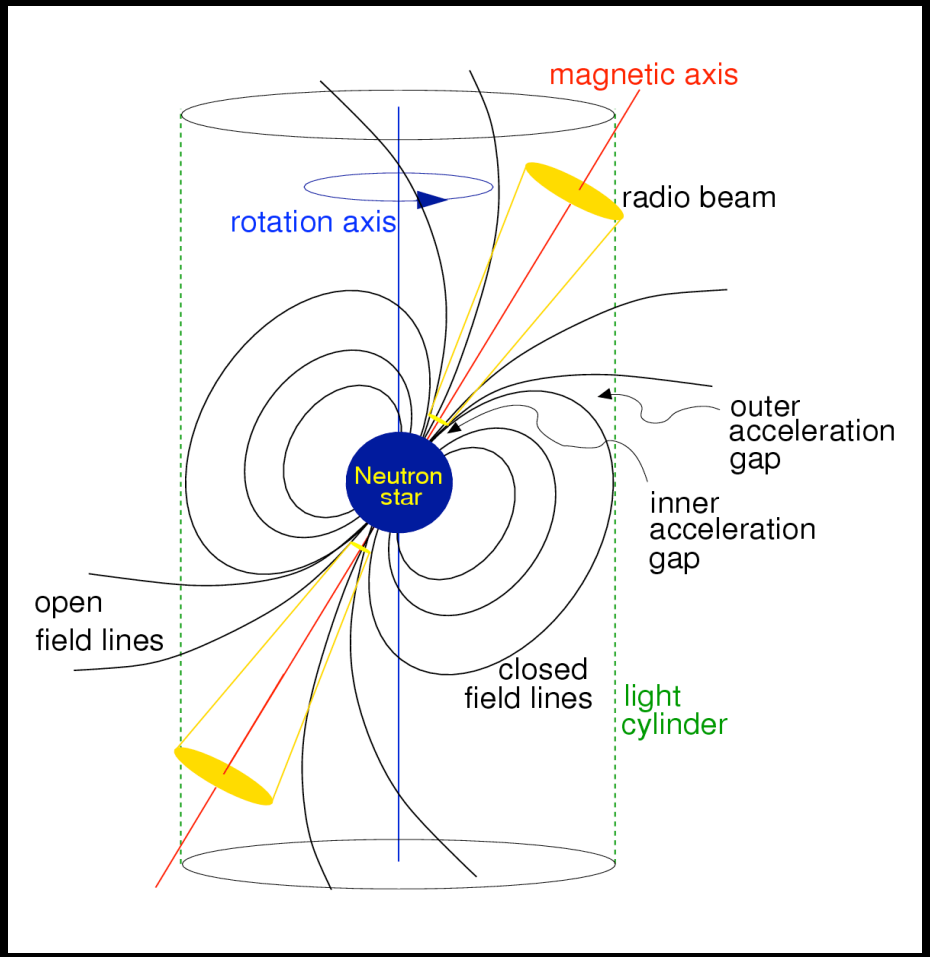
- High energy physics (e.g. particle accelerators)
- Shock physics, Magnetohydrodynamics
- Evolution of compact binaries
- Gravitation
- Physics of exotic matter

Pulsar as Unipolar Inductor



Electomotive force exerted on a spinning NS is the source that energize the particles.

Magnetospheric Accelerators

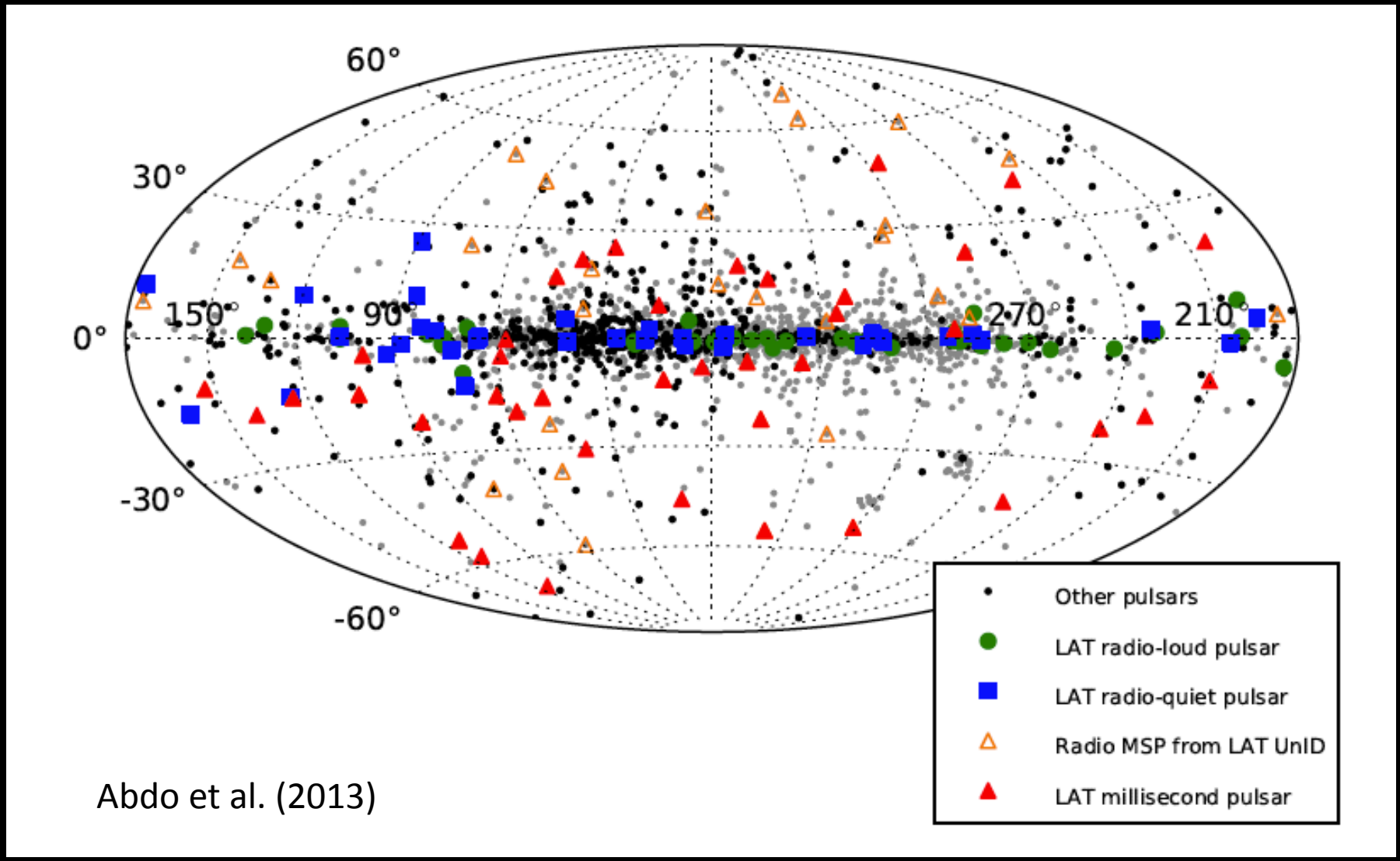


Acceleration of e^-/e^+ in the charge depletion regions (or gaps).

Attaining energies > 10^{15} eV

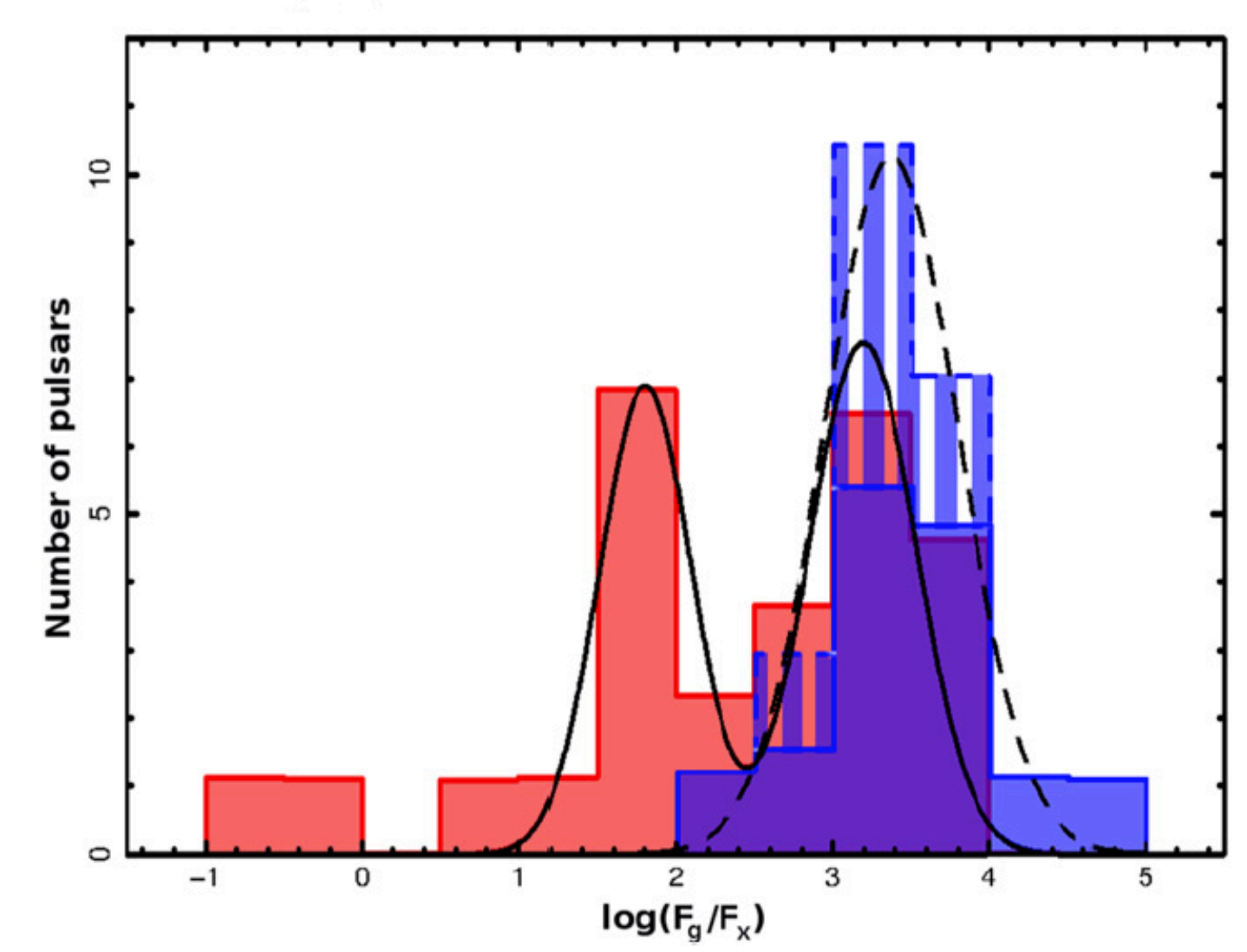
- **Polar cap model** - which have the non-thermal emission (e.g. radio) originated near the magnetic poles in the inner magnetosphere.
- **Outergap model** - which have the high energy radiation processes taking place in the outer magnetosphere.

Gamma-ray Pulsar Population in Fermi Era



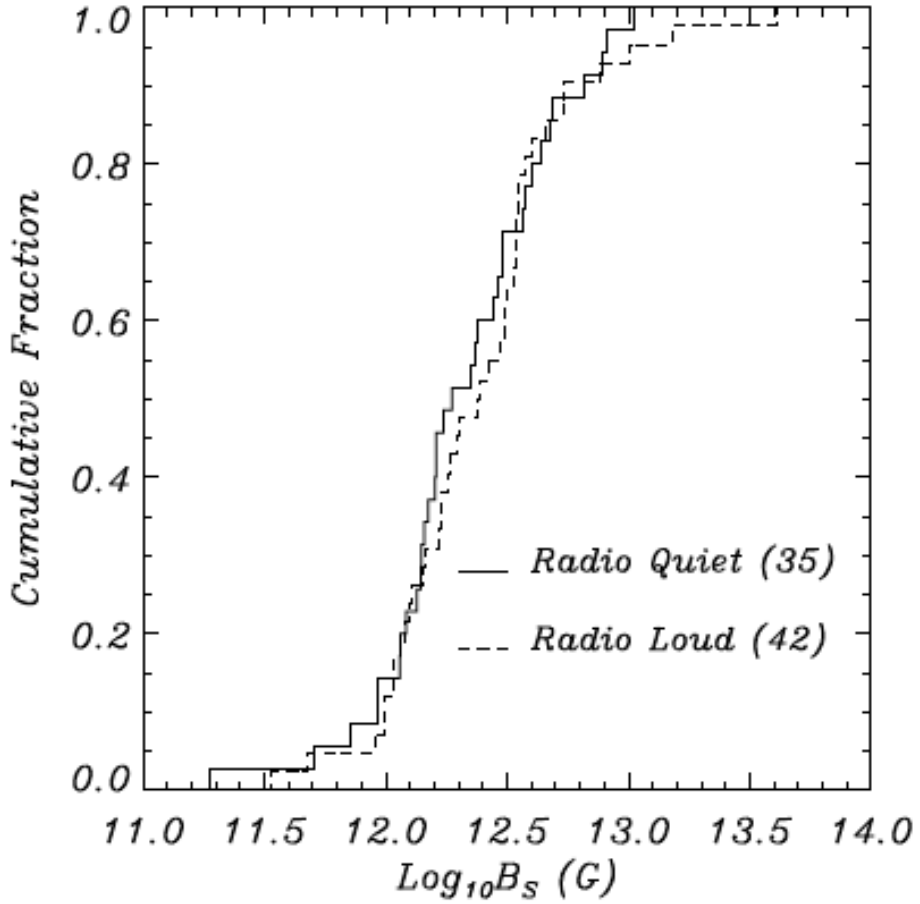
Abdo et al. (2013)

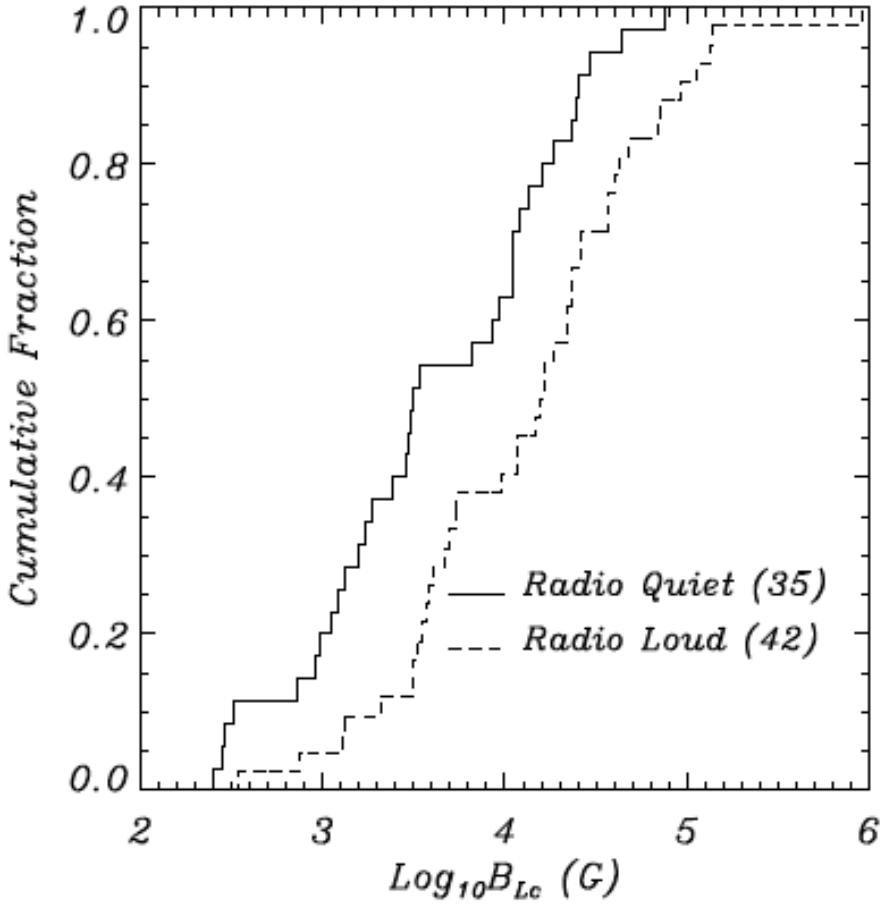
Radio-Quiet vs Radio-Loud



Marelli et al. (2015)

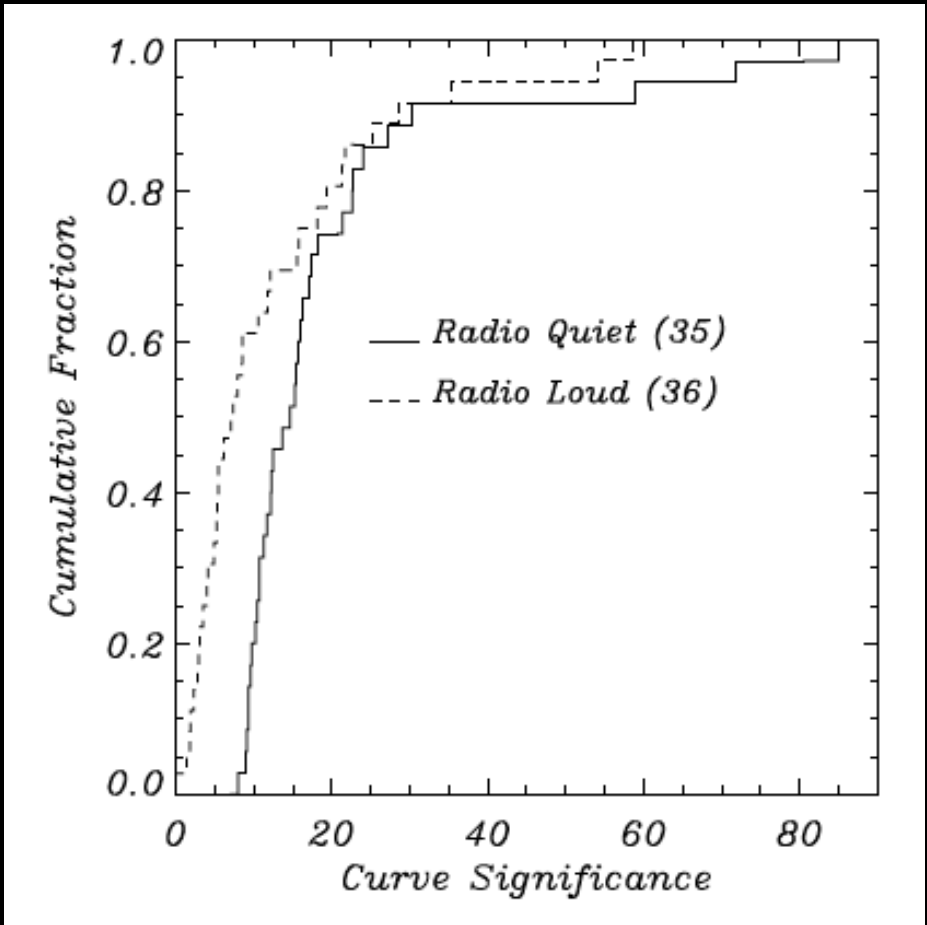
Radio-loud vs Radio quiet



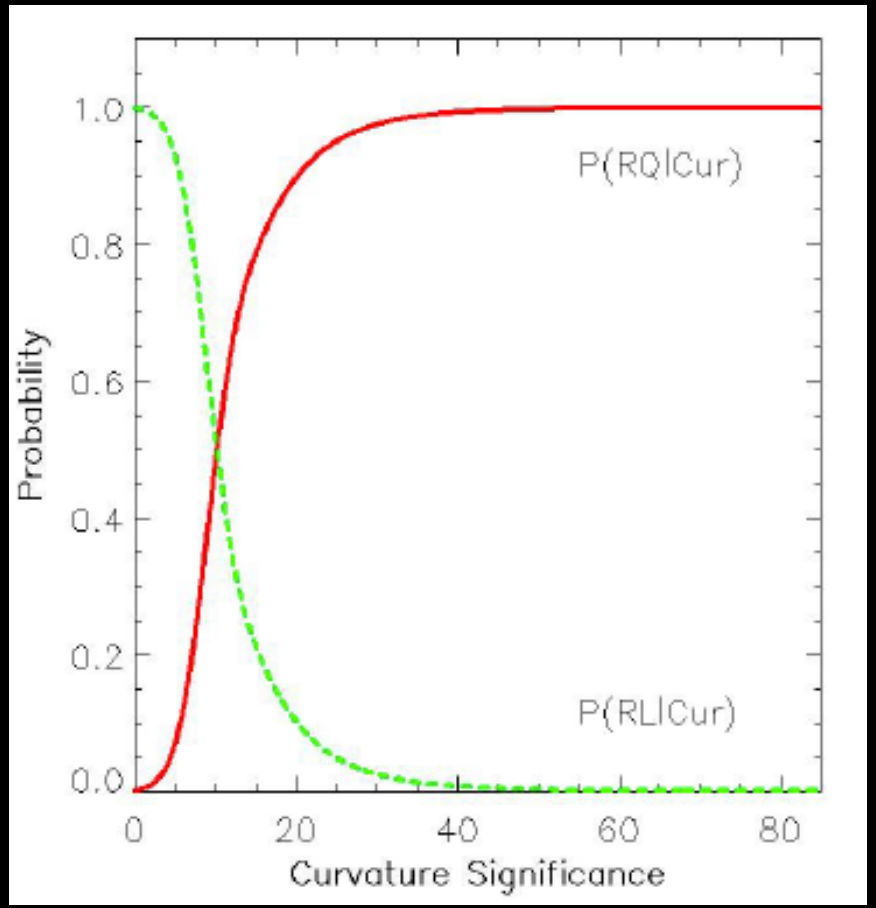


Hui et al. submitted

Radio-loud vs Radio quiet

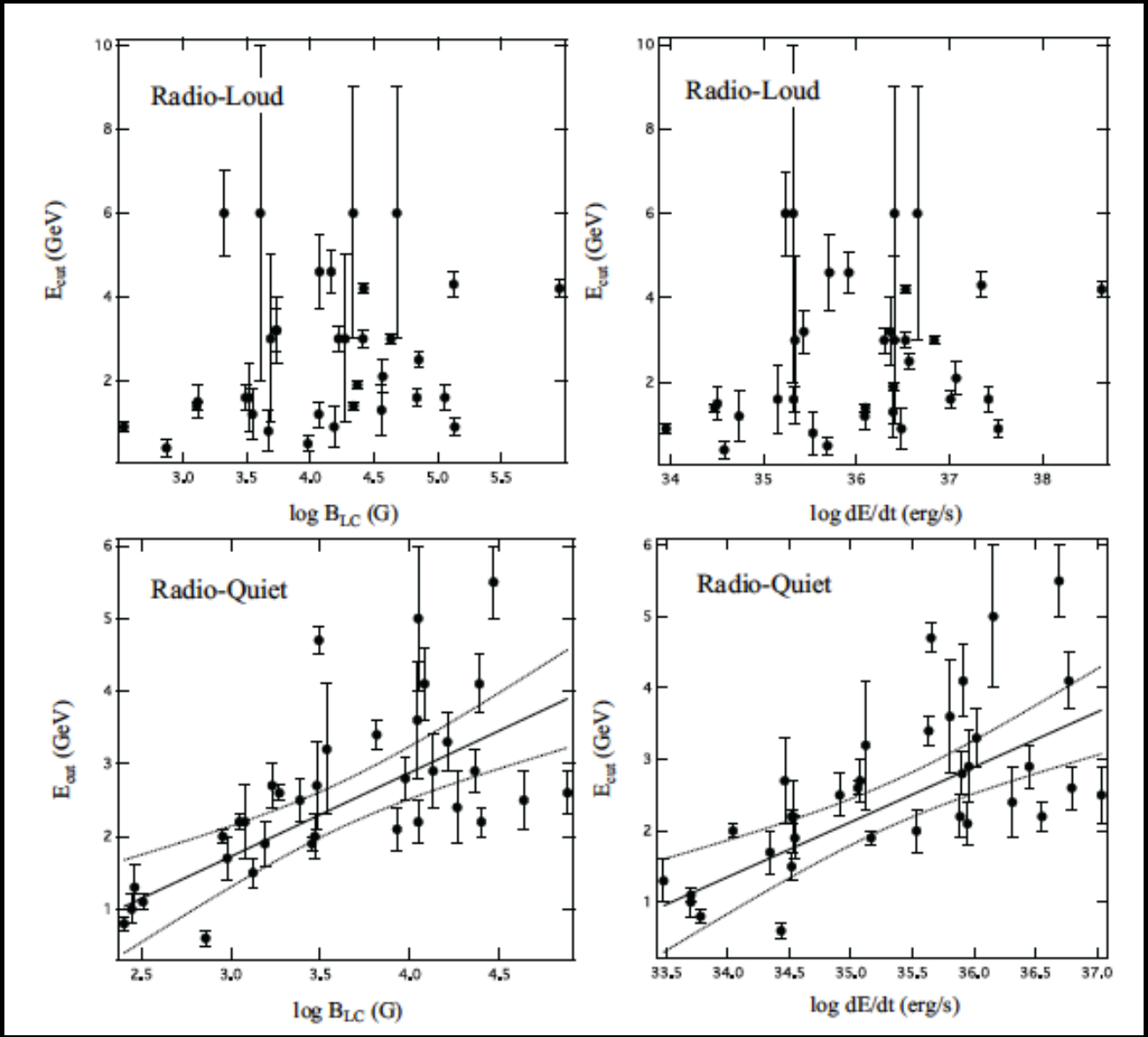


Hui et al. submitted



Hui & Lee (2016)

Radio-loud vs Radio quiet



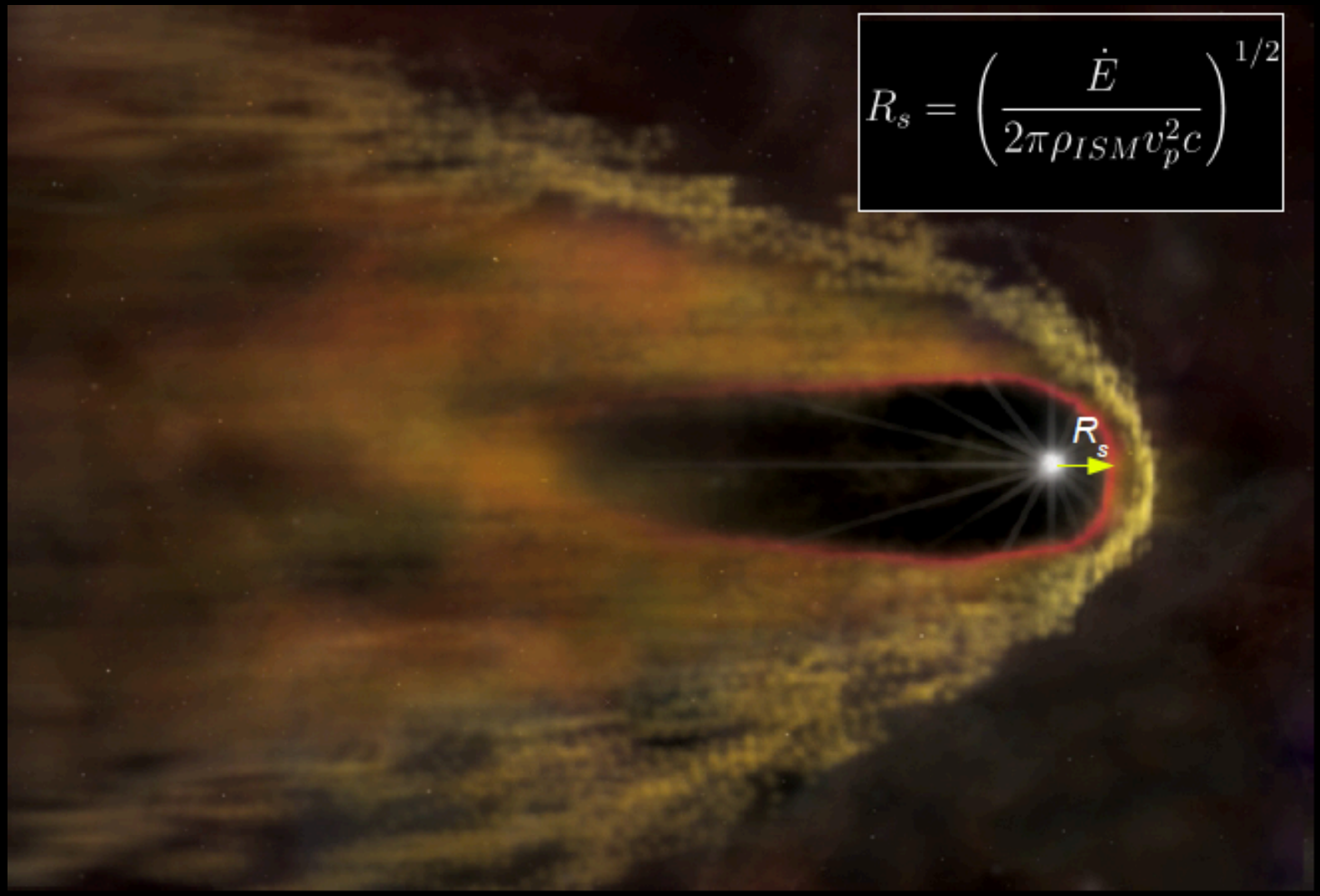
Hui et al. submitted

Pulsar Wind Nebula

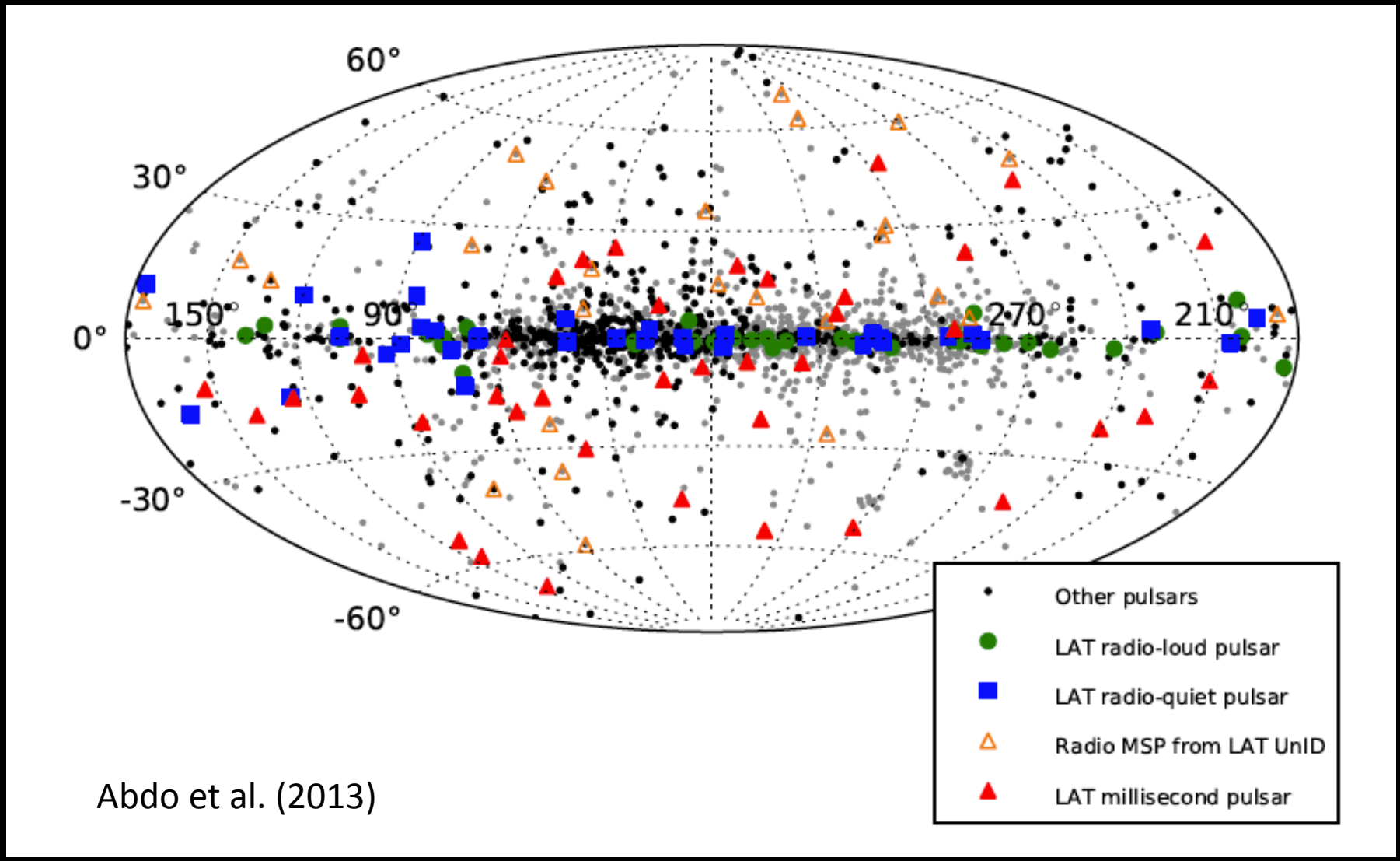
For powerful pulsar with subsonic motion

Pulsar Wind Nebula

- Pulsar in supersonic motion

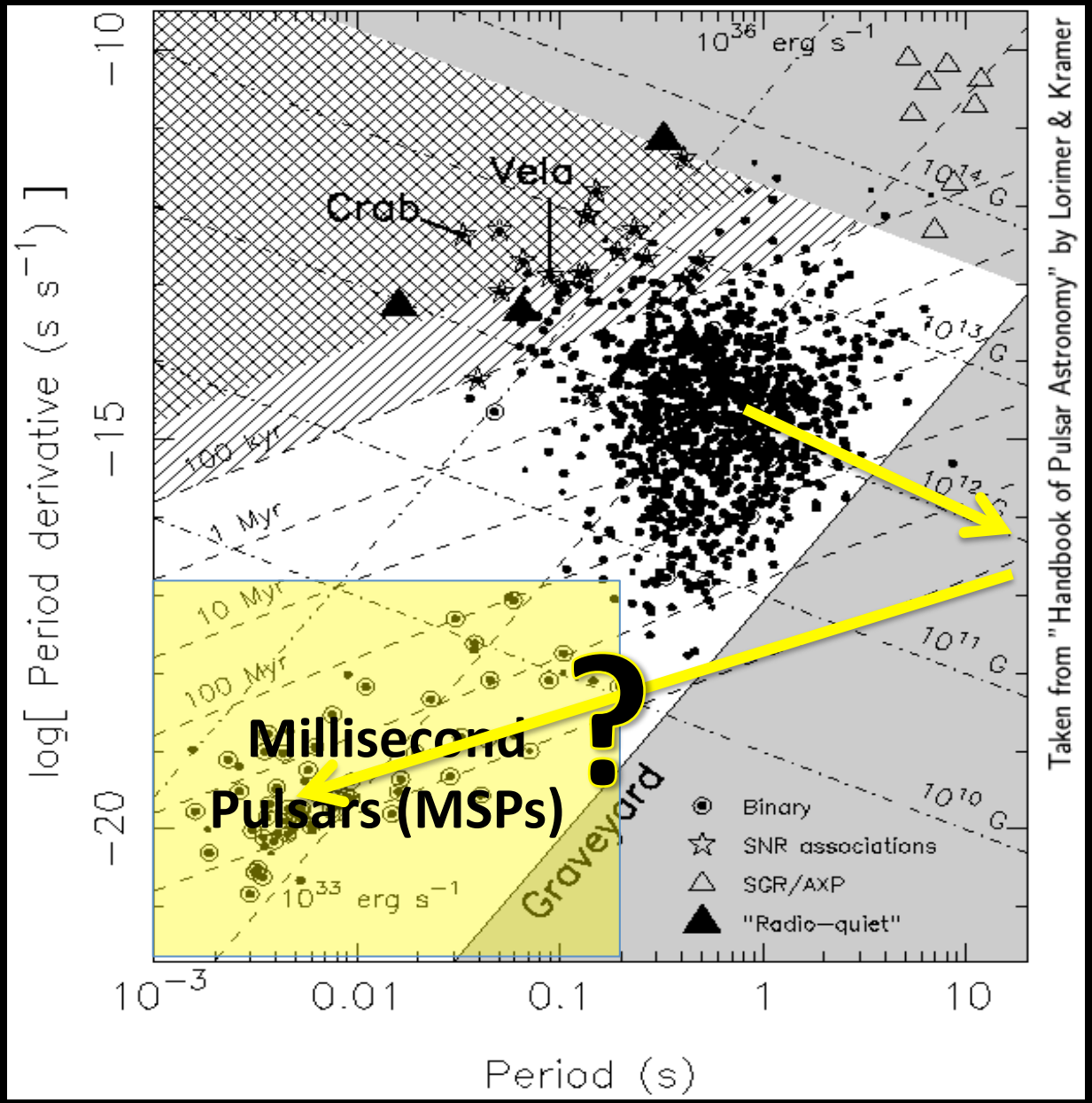


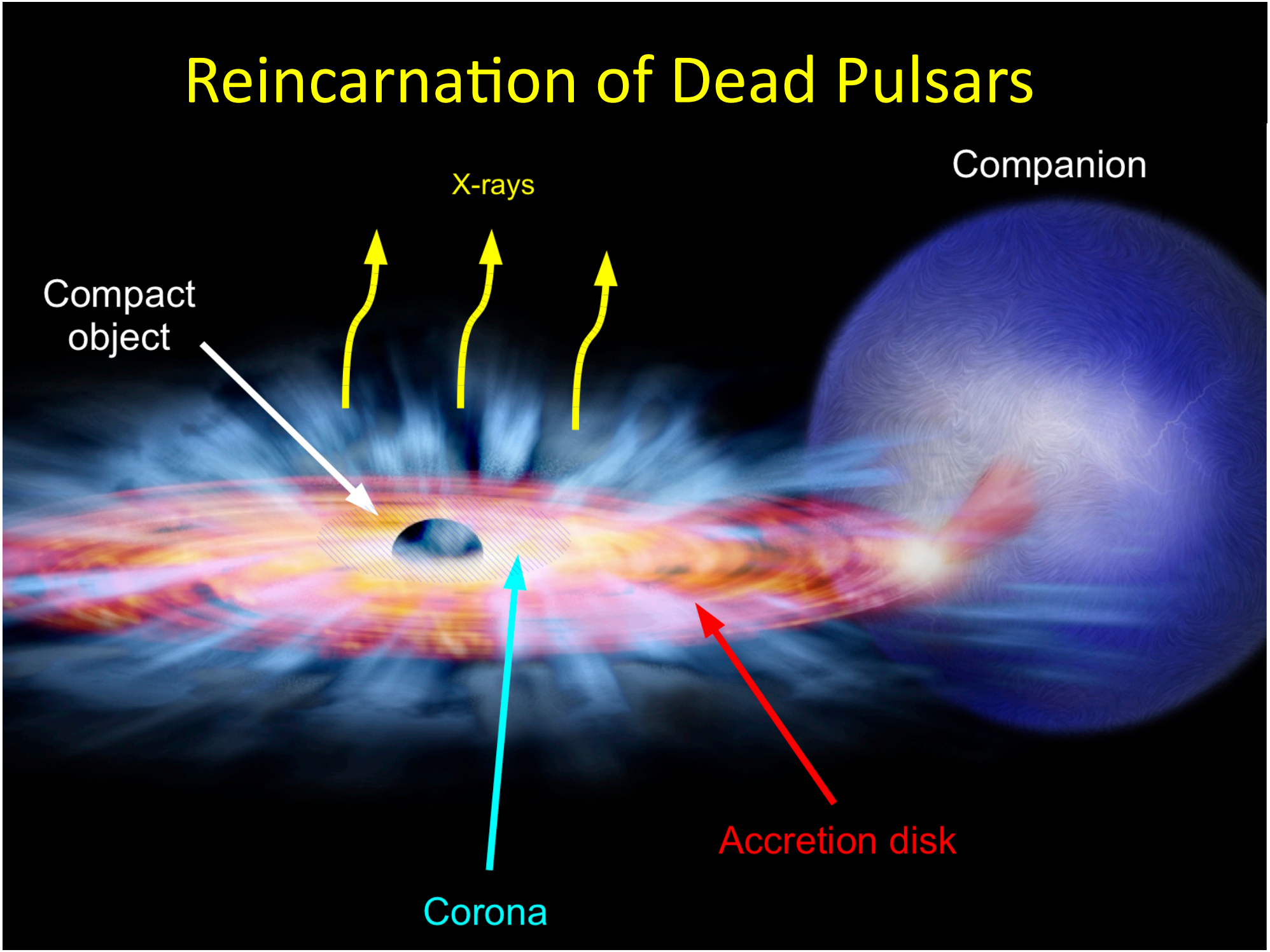
Gamma-ray Pulsar Population in Fermi Era



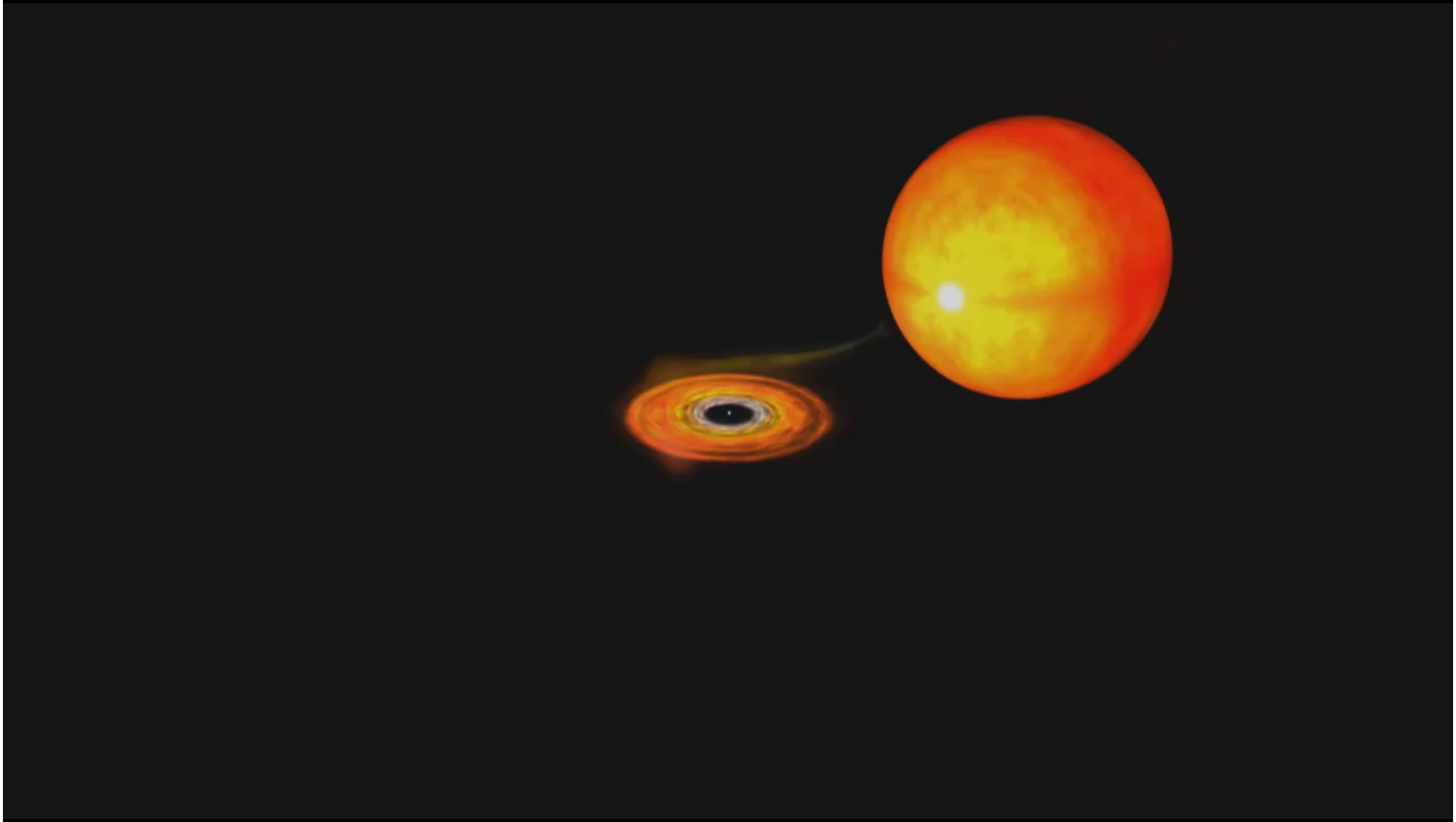
Abdo et al. (2013)

Evolution of Rotation-Powered Pulsars

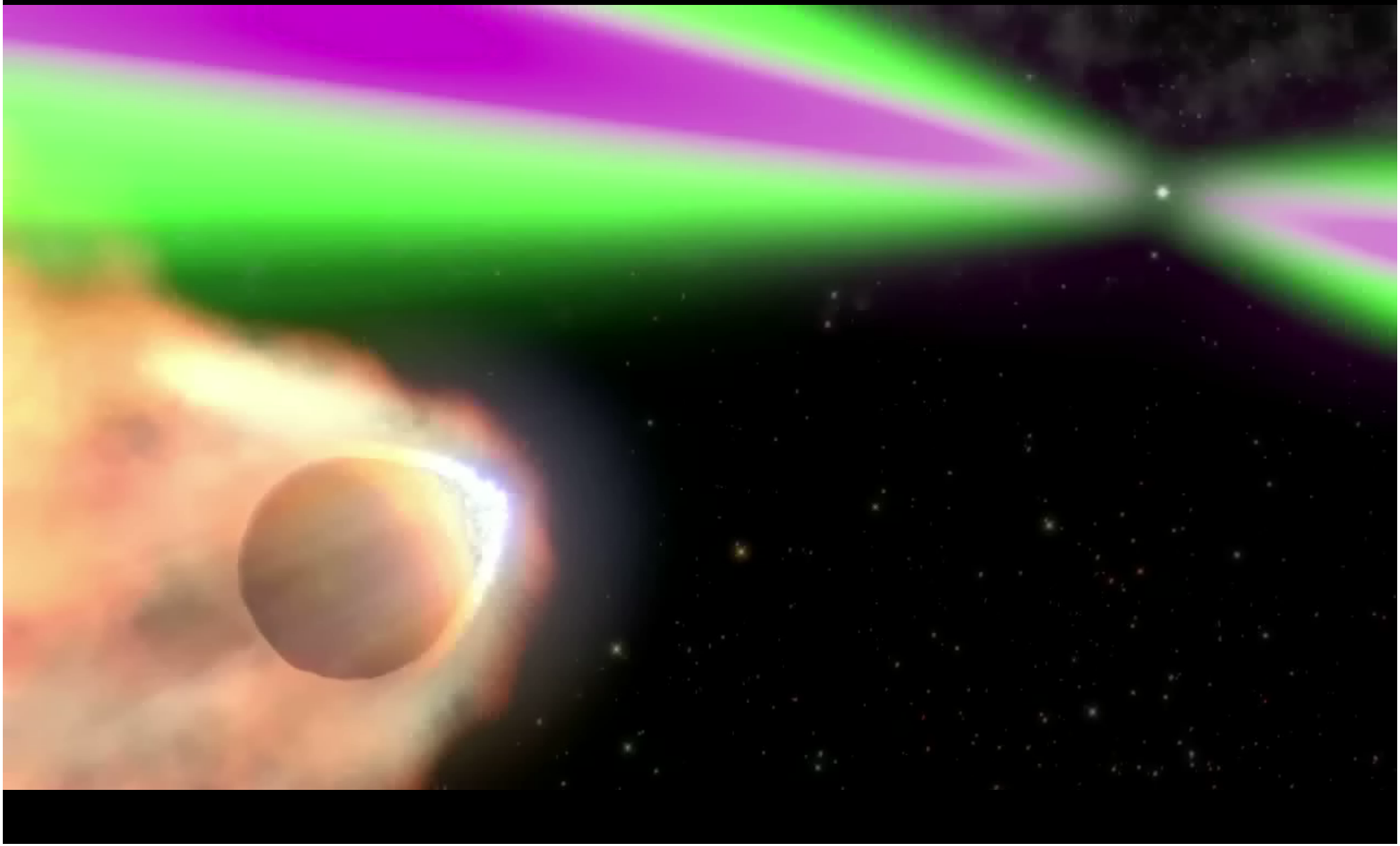



Reincarnation of Dead Pulsars
Companion
X-rays
Compact object
Corona
Accretion disk

LMXBs are progenitors of MSPs



The companion has been “evaporated” by the deadly MSPs in close binaries



Black Widow Pulsar

Isolated MSP can be a result of ablating their companions with their high energy radidation/relativistic pulsar wind particles.

Review Paper
J. Astron. Space Sci. 31(2), 101-120 (2014)
http://dx.doi.org/10.5140/JASS.2014.31.2.101

JASS Journal of Astronomy and Space Sciences

Spider Invasion Across the Galaxy

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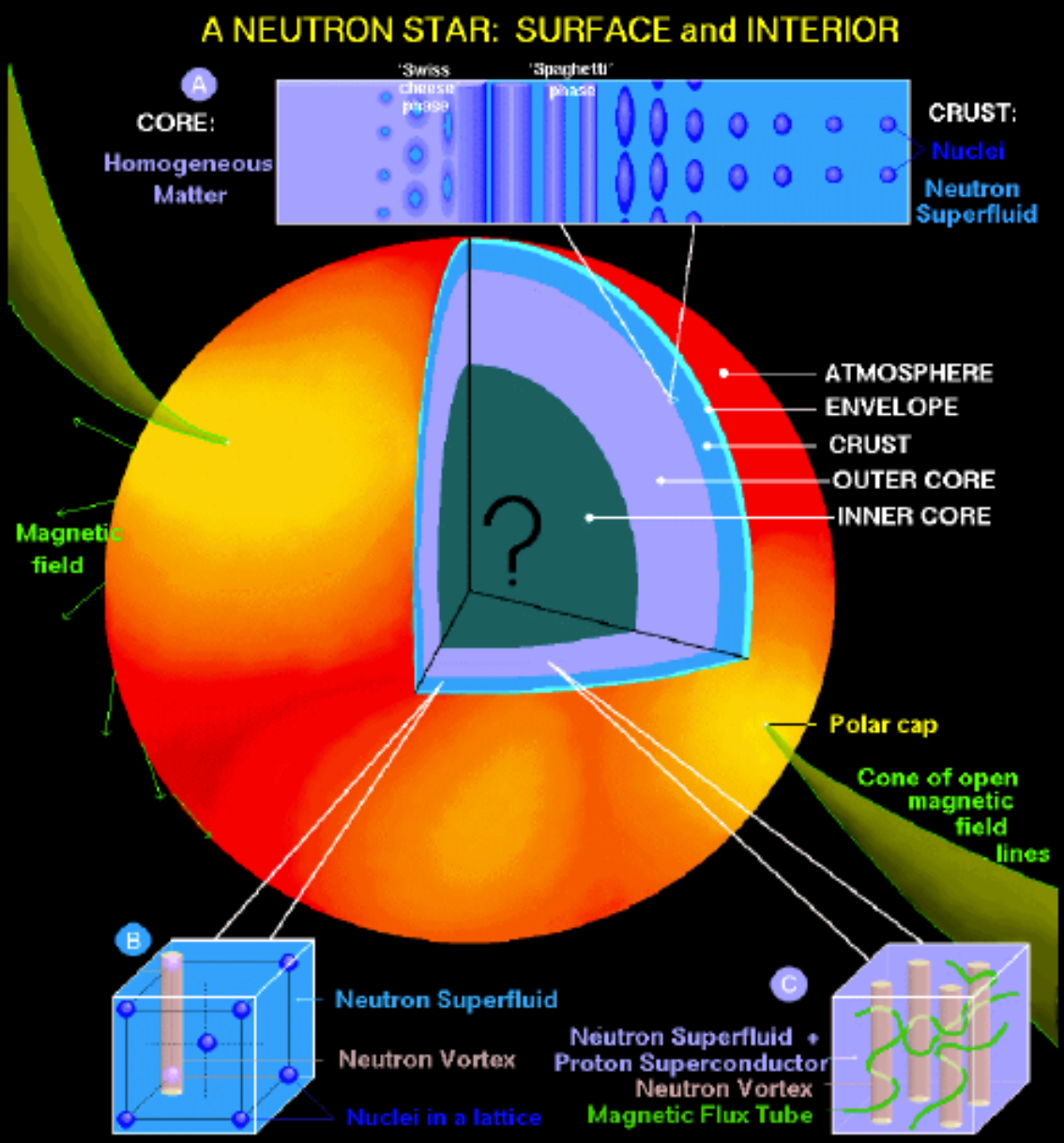
The nature of the exotic stellar corpses which reincarnate by consuming their companion is reviewed. Apart from sucking life from their partners, they are actually eating the doomed companions away by their deadly and powerful particle/radiation beams. Such situation resembles that a female "black widow" spider that eats its mate after mating. These celestial zombies are called - Millisecond pulsars (MSPs). In this review article, I will focus on the effort of *Fermi Asian Network* (FAN) in exploring these intricating objects over the last five years. Two special classes of MSPs are particularly striking. Since *Fermi* Gamma-ray Space Telescope has started surveying the gamma–ray sky, the population of "black widows" has been boosted. Another dramatic class is so-called "redbacks" (Australian cousin of "black widows") which has just emerged in the last few years. These MSPs provide us with a long-sought missing link in understanding the transition between accretion-powered and rotation-powered systems. The strategy of hunting MSPs through mulitwavelength observations of the unidentified *Fermi* objects is also reviewed.

Composition of NS



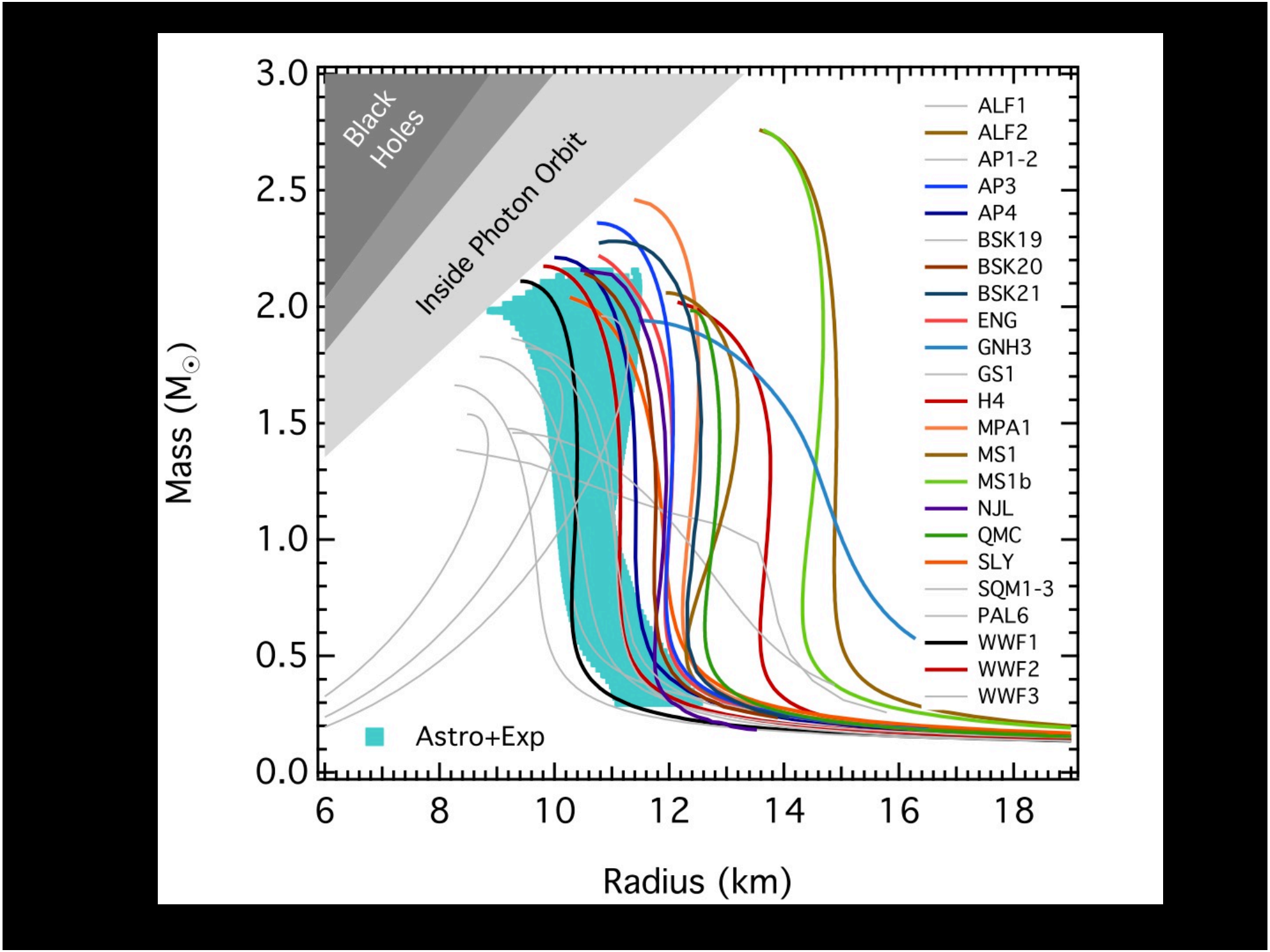
Atmosphere: ~ 0.1-10 cm
modify emergent spectrum

Envelope: ~ 10 m
Thermal Transport

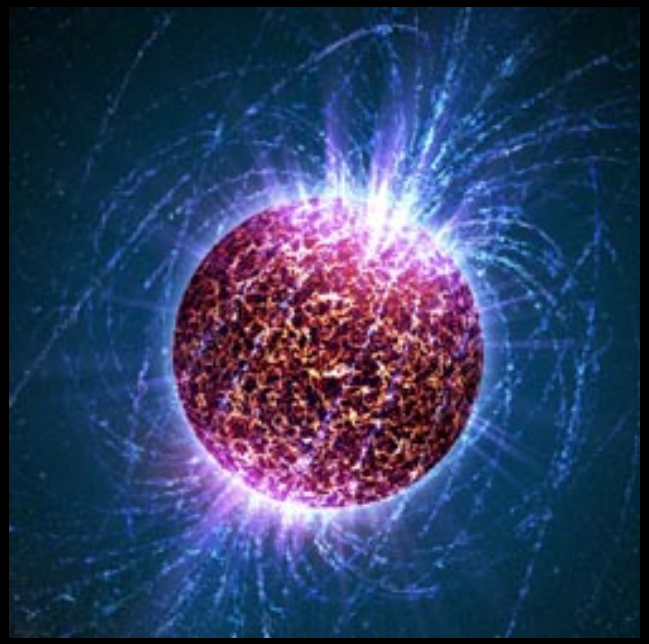
Crust: ~1-2 km
Neutron superfluid and normal matter coexist

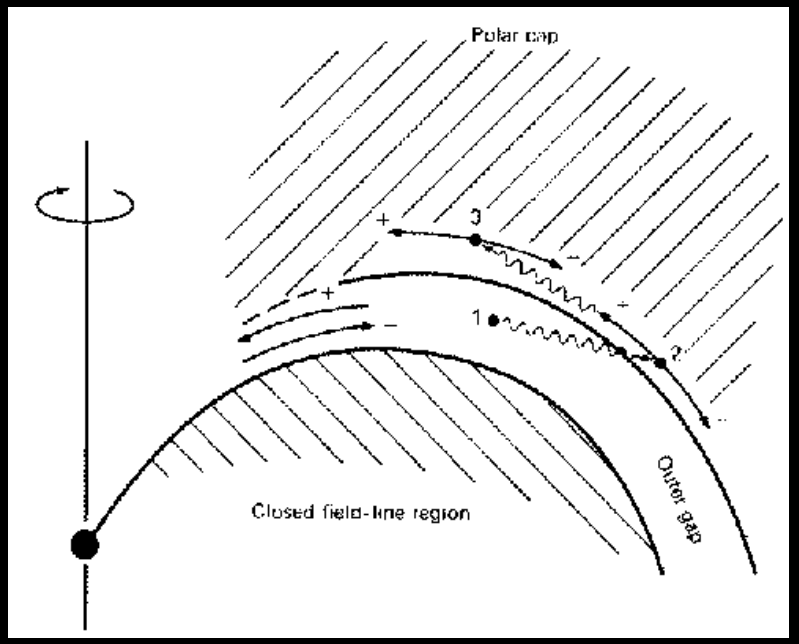
Outer Core: Homogeneous
Neutron superfluid
Proton Superconductivity

Inner Core: ????
Hyperon (e.g. Strange particles in baryon octet)
Bose-condensate (e.g. pion)
Deconfined quark matter.....


Black Holes
Inside Photon Orbit
Astro+Exp
ALF1
ALF2
AP1-2
AP3
AP4
BSK19
BSK20
BSK21
ENG
GNH3
GS1
H4
MPA1
MS1
MS1b
NJL
QMC
SLY
SQM1-3
PAL6
WWF1
WWF2
WWF3
Mass (M⊙)
Radius (km)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
6
8
10
12
14
16
18

Modeling the X-ray Pulsations

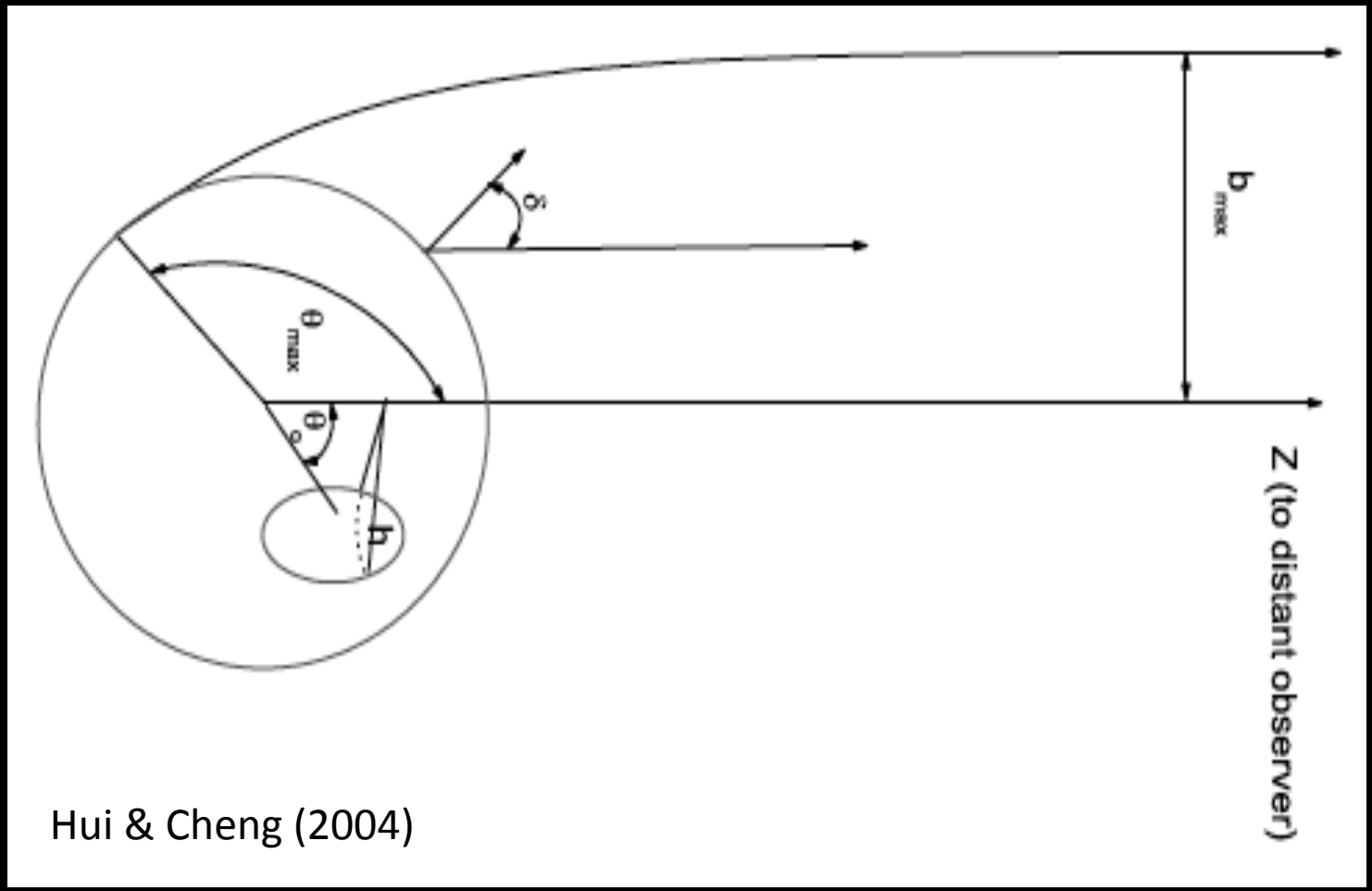




• Polar cap on the NS surface can be heated by the return current from the outer gap.

• When the hot polar cap sweeps across the line-of-sight, modulation in soft X-ray regime will be seen.

Effect of gravitational light bending on neutron star surface



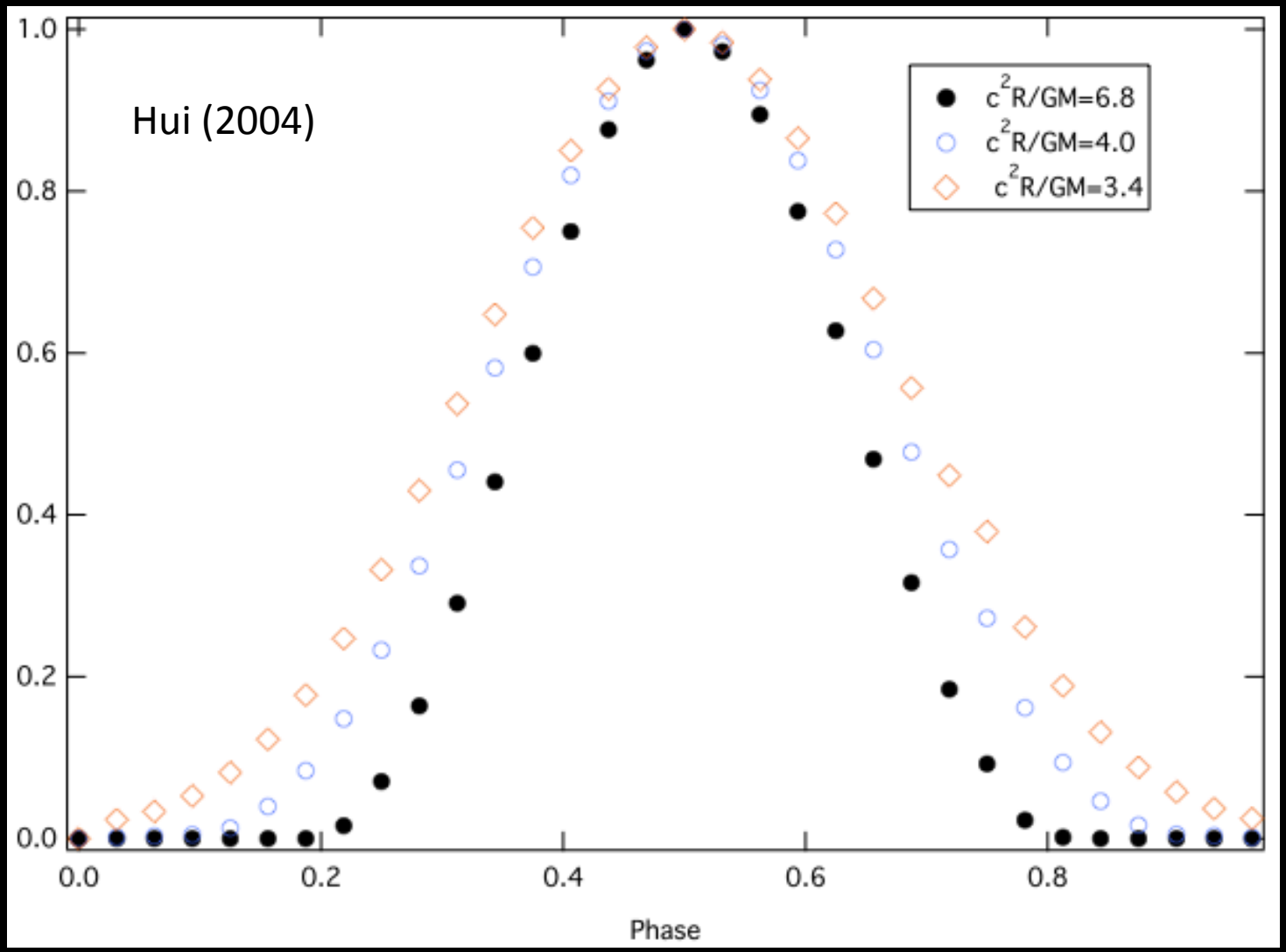
Hui & Cheng (2004)

Effect of gravitational light bending on neutron star surface

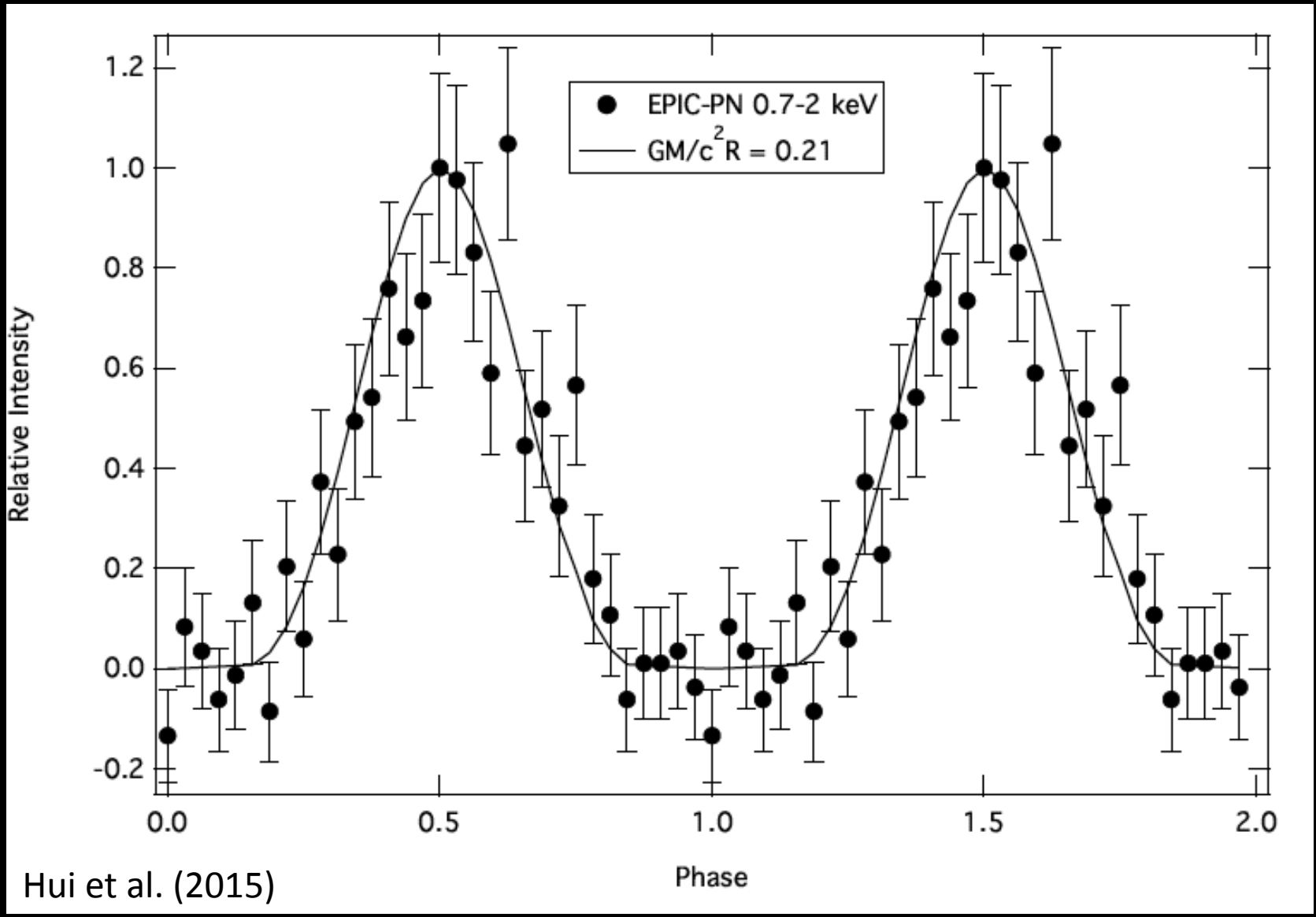
Flat Spacetime

Curved Spacetime

Effect of gravitational light bending on neutron star surface



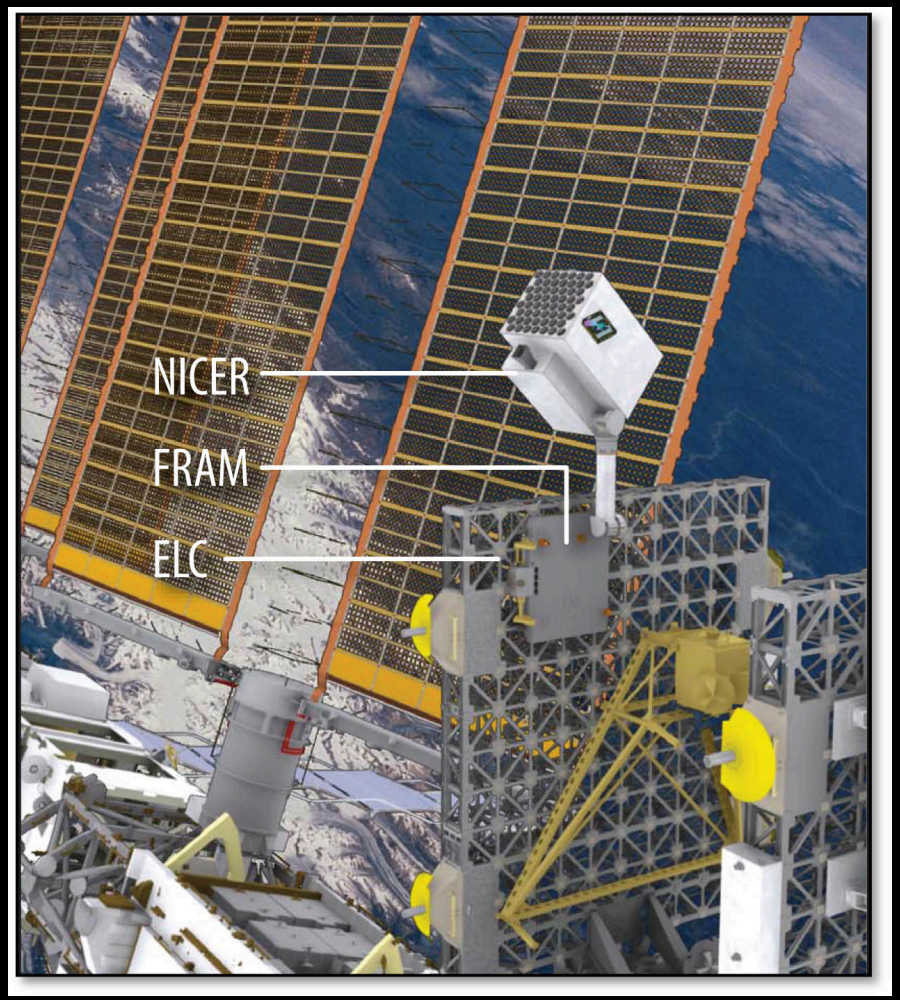
Modeling the X-ray Pulsations



Hui et al. (2015)

NICER

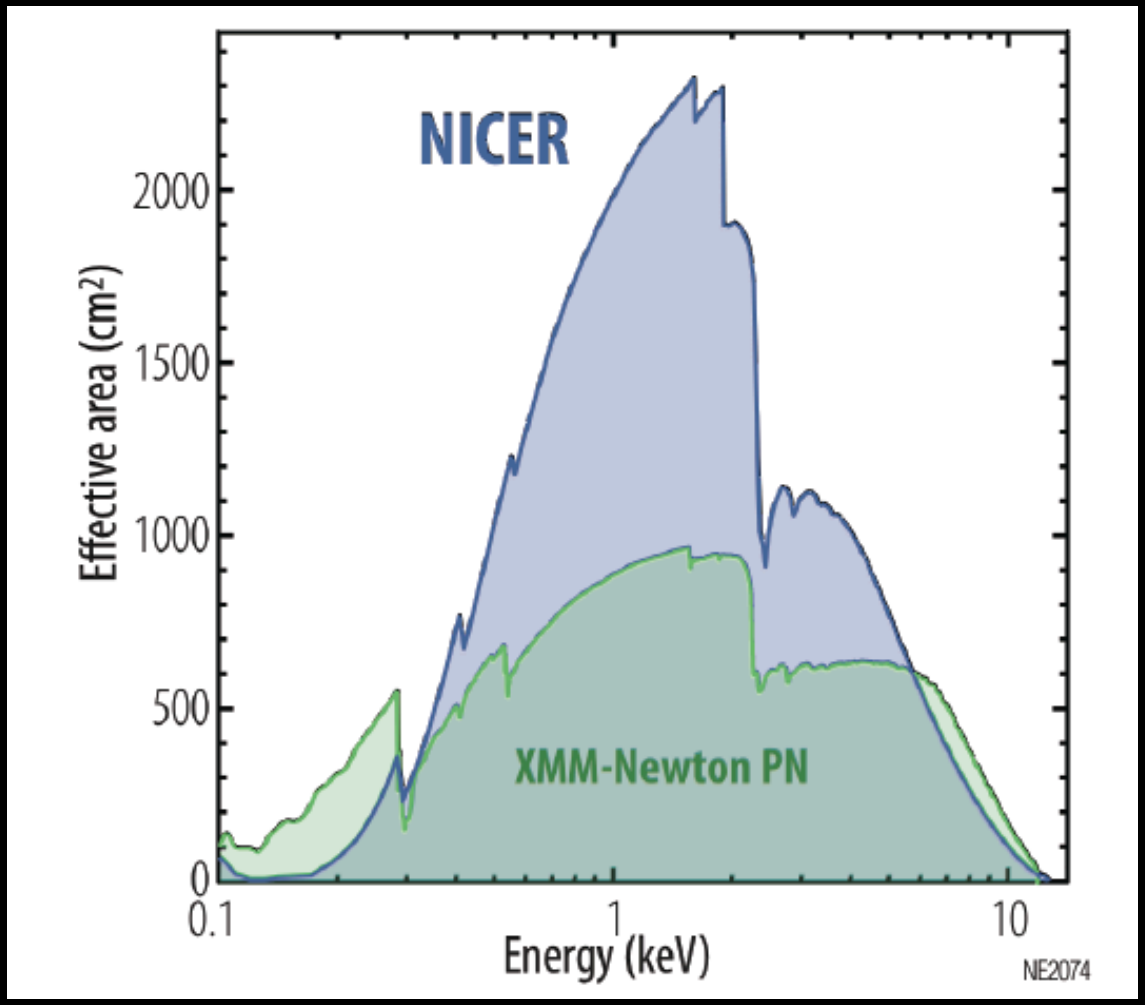
Neutron star Interior Composition ExploreR



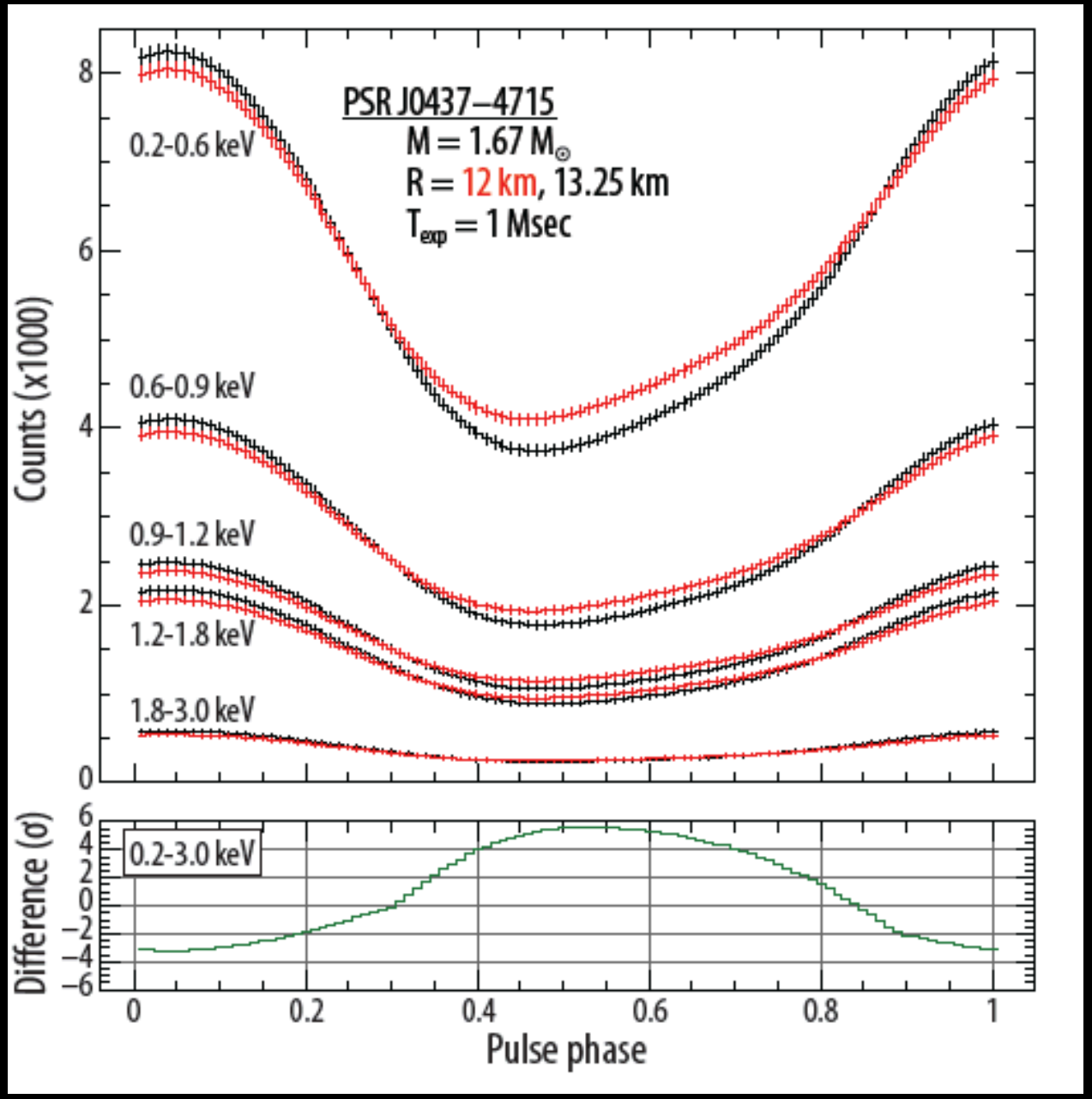
Launch: Early 2017

Primary Mision Duration: 18 months, with an additional 6 months long Guest Observer program

Instrument: X-ray (0.2-12 keV) "concentrator" optics and silicon-drift detectors. GPS position and absolute time reference to better than 300 ns.



Gendreau et al. (2012)



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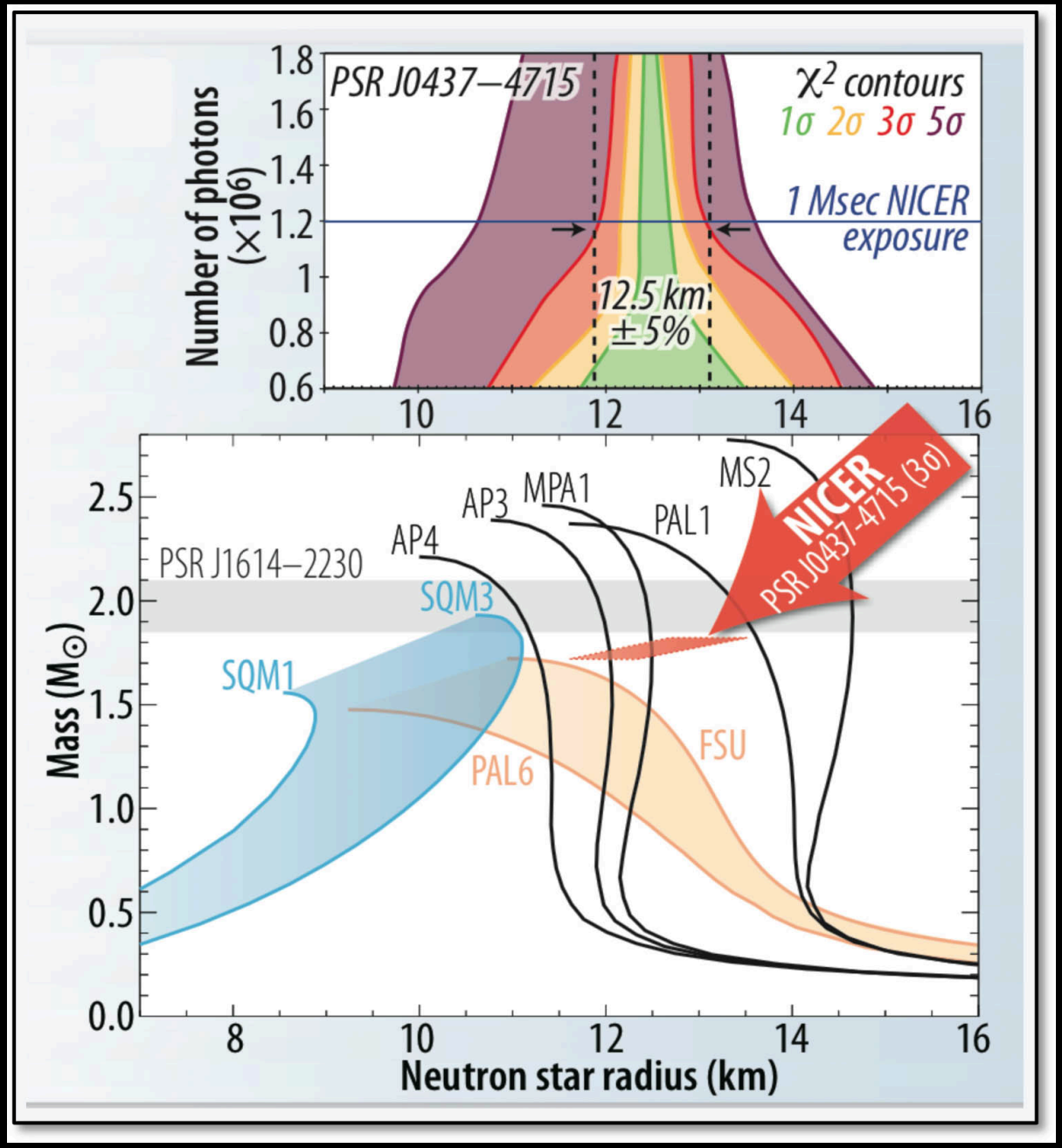

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