# Isolated Neutron Stars as seen by *Athena*


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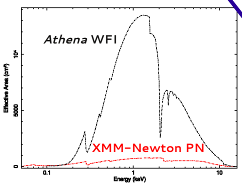
## Improvements in INS science expected thanks to *Athena*

### *Athena* will provide:

- much higher sensitivity (WFI)
- very good spectral resolution (X-IFU)
- superb time resolution (~8 μs, WFI,X-IFU)




### Thus, *Athena* will enable:

- very accurate phase-resolved spectral analysis and therefore disentangling of NS emission geometries
- investigation of line features in NS spectra and their shifts over phase
- studying the faint end of (e.g.,) thermal NSs which are currently not accessible due to high absorption or faintness (e.g., old pulsars)

### *Athena* constraints on the science of Isolated Neutron Stars

**Chemical composition of NS surface layers**

- constrain NS atmosphere models by disentangling chemical properties and geometric effects caused by varying magnetic fields using broad-band spectra *(see below)*
- confirm, identify and find new line features in NS surface emission

**Fundamental physics**

- constrain the equation of state (EoS) of superdense matter by radius measurements
- constrain the EoS of superdense matter by measuring NS thermal evolution
- constrain deviations from spherical shape by finding free precession and thus derive predictions for expected gravitational waves

**Neutron Star Evolution**

- constrain magnetic field distributions in different NS populations by studying changes of spectral lines/features with rotational phase
- check buried-magnetic field hypothesis for CCOs by identifying CCOs with hotspots
- constrain particle acceleration mechanism by investigating the X-ray-radio connection suggested for the heated polar caps of old pulsars

**Current puzzling NS findings**

- suspected (phase-dependent)proton cyclotron lines in Magnificent Seven and magnetars
- narrow absorption feature, originating in a "slab" of relatively dense ambient medium around one of the Magnificent Seven

## *Athena* vs XMM-*Newton* Xspec simulations for NS atmospheres

### Model choices:

NS magnetic atmosphere model (NSMAXG; e.g., Ho et al. 2014)

- H – $B\,[10^{12}$ G] = 0.01, 0.1, 7, 30; $g = 2.4{\times}10^{14}$ cm s$^{-2}$
- C – $B\,[10^{12}$ G] = 1, 10; $g = 2.4{\times}10^{14}$ cm s$^{-2}$
- O, Ne – $B\,[10^{12}$ G] = 1; $g = 2.4{\times}10^{14}$ cm s$^{-2}$

- H – B $[10^{12}$ G]=7; $g = 2.4{\times}10^{14}$ cm s$^{-2}$ and $1.6{\times}10^{14}$ cm s$^{-2}$
- H – B varying over surface, inclination angles 0° and 90° (angle between B and observer)

all model spectra:

- distance=1 kpc, whole NS is emitting
- ISM absorption (tbabs) with $N(H) = 5{\times}10^{20}$ cm$^{-2}$
- unredshifted effective surface temperature $\log T = 6.0$

### Responses & Background:

*Athena* WFI response & background

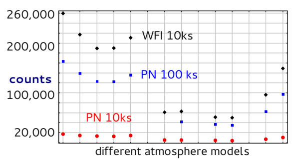
- athena_wfi_1190_onaxis_w_filter_v20150326
- athena_wfi_1190_bkgd_sum_psf_onaxis_w_filter_20150327.pha

XMM-*Newton* EPIC PN response & background

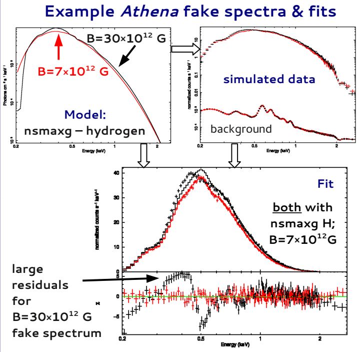
- from recent flare-free observation on target position on CCD 4

Fake spectra for:

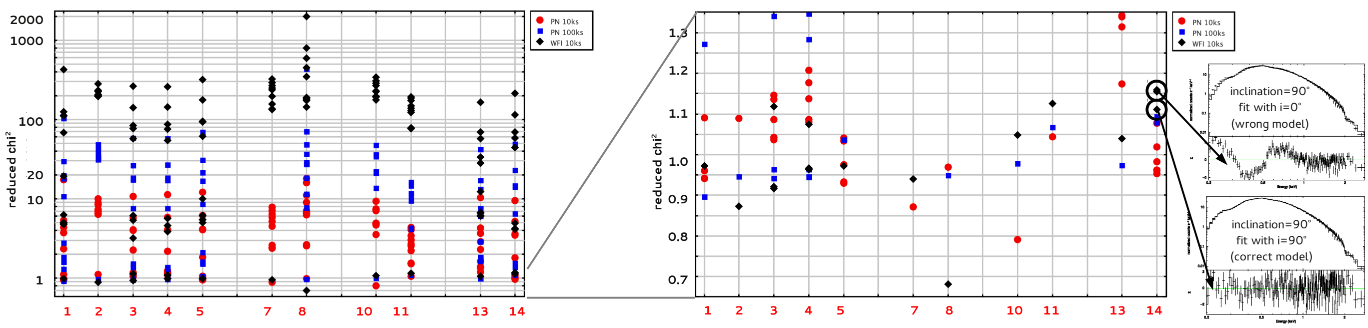
- 10 ks and 100 ks PN
- 10 ks *Athena* WFI




### Example *Athena* fake spectra & fits




### Fit all simulated fake spectra with all chosen NS atmosphere models




(if not noted otherwise $g_{14}$=2.4 ) 1 H $B_{12}$= 0.01, 2 H $B_{12}$= 1, 3 H $B_{12}$= 7, 4 H $B_{12}$= 7, $g_{14}$=1.6, 5 H $B_{12}$= 30, 7 C $B_{12}$= 1, 8 C $B_{12}$= 10, 10 O $B_{12}$= 1, 11 Ne $B_{12}$= 1, 13 H θ=0°, $g_{14}$=1.6, 14 H θ=90°, $g_{14}$=1.6

based on our chi$^2$-fit of broad-band (!)spectra,

- 10 ks XMM observations can already differentiate between H, C, O, and Ne atmospheres
- 10 ks XMM observations cannot differentiate between hydrogen atmospheres with different magnetic fields B; 100ks XMM and 10ks *Athena* WFI are sensitive to B
- First tests indicate that with 10 ks *Athena* WFI observations it is difficult to differentiate between two surface gravity values $g$ for hydrogen atmospheres
- only *Athena* WFI observations (10ks) can differentiate between inclination angles 0° and 90° if the B-field (realistically) varies over the NS surface (H atmosphere) while neither 10 ks nor 100ks XMM observations can do this

***Athena* WFI observations will disentangle geometric and magnetic field ambiguities and allow one to determine the chemical composition of NS atmospheres**

Stay tuned – still ongoing tests to what accuracy *Athena* can constrain the surface gravity (or mass/radius) from broad-band spectral fits . . .


nsmaxg references: Ho, W.C.G., Potekhin, A.Y., & Chabrier, G. (2008, ApJS, 178, 102), Mori, K. & Ho, W.C.G. (2007, MNRAS, 377, 905); Ho, W.C.G. (2014, Proc. of IAUS 302)