The Athena Science Working group SWG3.3
“End points of Stellar Evolution”

E. Bozzo
(ISDC, University of Geneva)

on behalf of the Athena SWG3.3

The SWG3.3 organization and activities

- SWG3.3 has been reshaped early this year
- Members of the SWG have been registered in late 2014 and confirmed by mid 2015
- At present the SWG3.3 comprises 58 members (chairs: A. Schwope and E. Bozzo)
- Full list of members available at: http://www.cosmos.esa.int/web/athena/community-wg
- Wide range of scientific expertises ranging from neutron star/black hole/white dwarf binaries to pulsar wind nebulae and magnetars

- Past and on-going ctivities:
  - Present status of the Athena science requirements and presentation to the entire SWG
  - First revision of the Athena Mock observing plan
  - Revision of the science requirements assigned to the SWG3.3
  - Discussions about missing requirements for several classes of sources
  - Preliminarily formulations of the new science requirements to be proposed to the SWG3 chairs and ASST
  - Plans for simulations (some simulations already carried out for a few science cases)

The SWG3.3 assigned science requirements

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- Two Athena science requirements were originally assigned to the SWG3.3

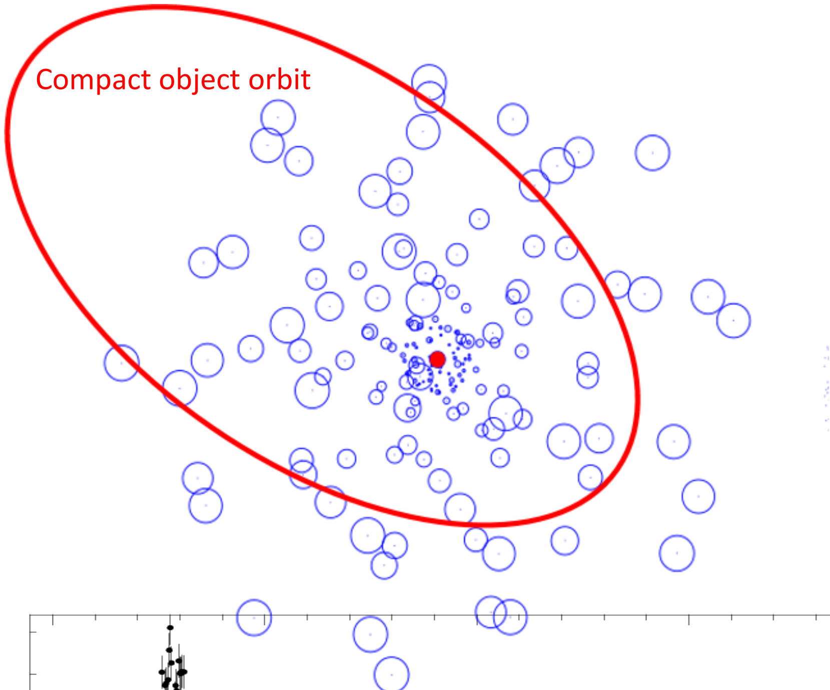
R-SCIOBJ-332	Athena shall determine the geometry, porosity and mass loss-rate of stellar wind structures of isolated massive stars, especially in the presence of magnetic fields, through phase spectroscopy for a sample of objects. Time resolved spectral analysis of X-ray emission from a sample of high mass X-ray binaries hosting supergiant and hypergiant companions shall be carried out to seek independent estimates of massive star wind properties.

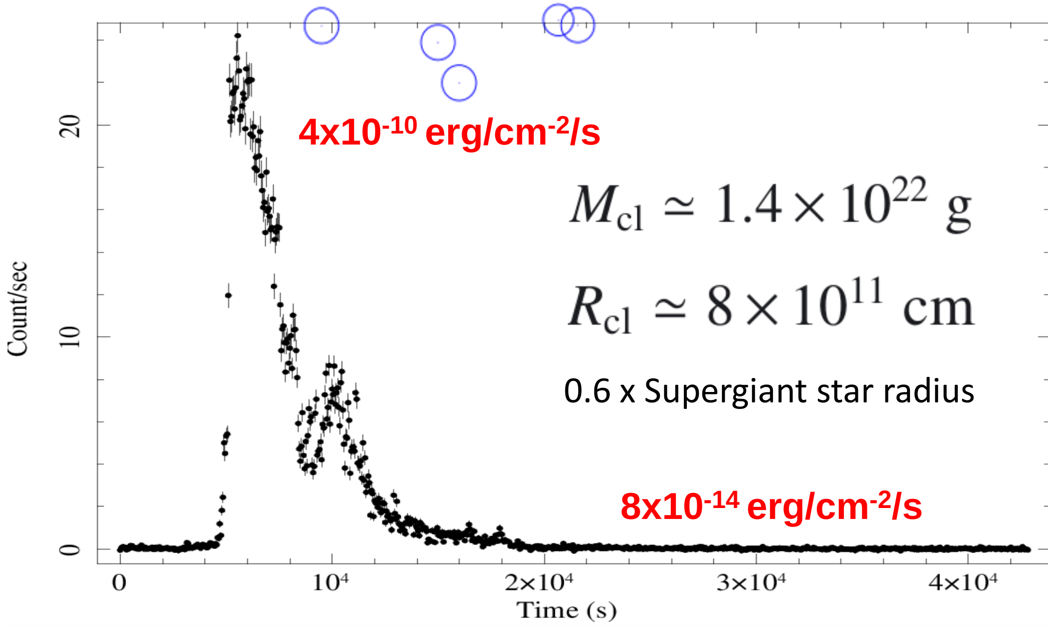
Shared requirement with the SWG3.2: star formation and evolution

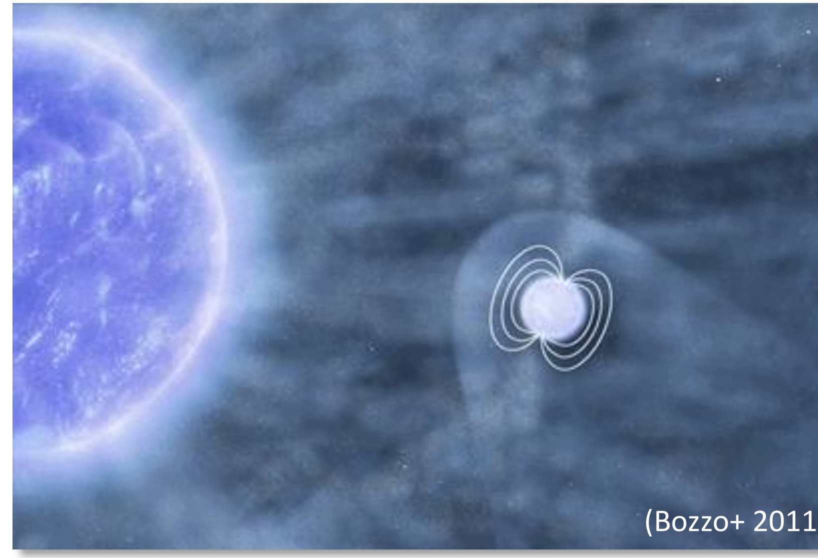
R-SCIOBJ-331	Athena shall constrain the equation of state of neutron stars by: 1. Obtaining X-ray spectra of 20 quiescent X-ray binaries with a good distance estimate. 2. Obtaining energy dependent folded light curves of a selected sample of millisecond pulsars. 3. Performing high-resolution X-ray spectroscopy of neutron star surface absorption lines. 4. Searching for narrow absorption lines in type I X-ray bursts.

R-SCIOBJ-332: accreting massive star X-ray binaries

- Clumpy winds: the case of high mass X-ray binaries






(Bozzo+ 2011)

- Clumps accreting onto the compact object → variable absorption & X-ray flares
- Clumps passing along the line of sight → absorption events
- Rapid changes (100 s) in the absorption column density measured with the **Athena/WFI** → get clump physical parameters

(Sako+ 2003)

R-SCIOBJ-332: accreting massive star X-ray binaries

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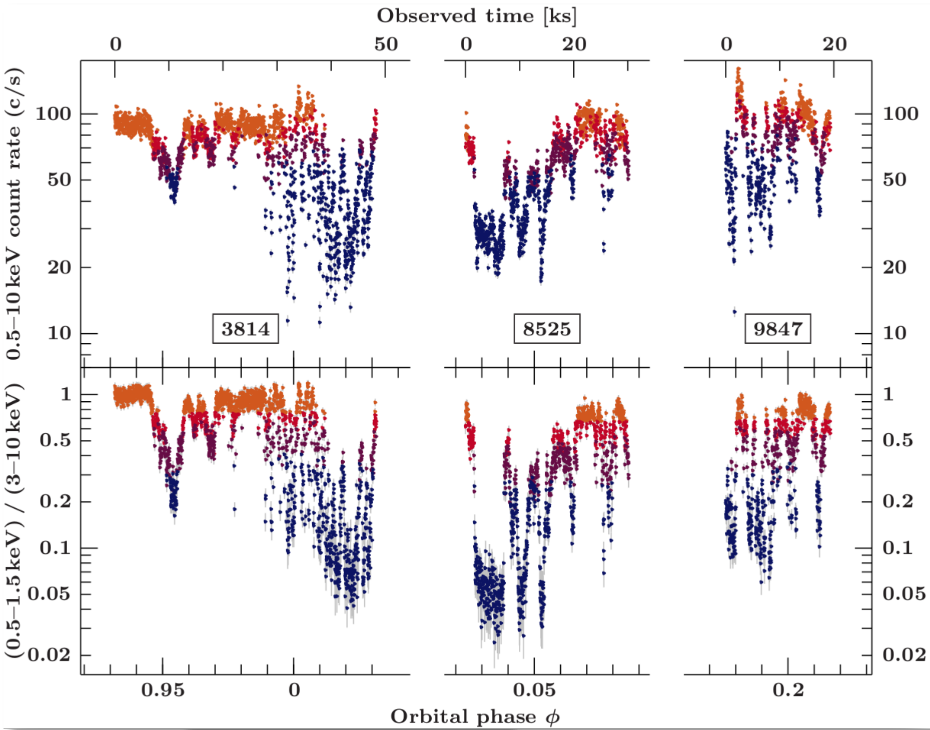
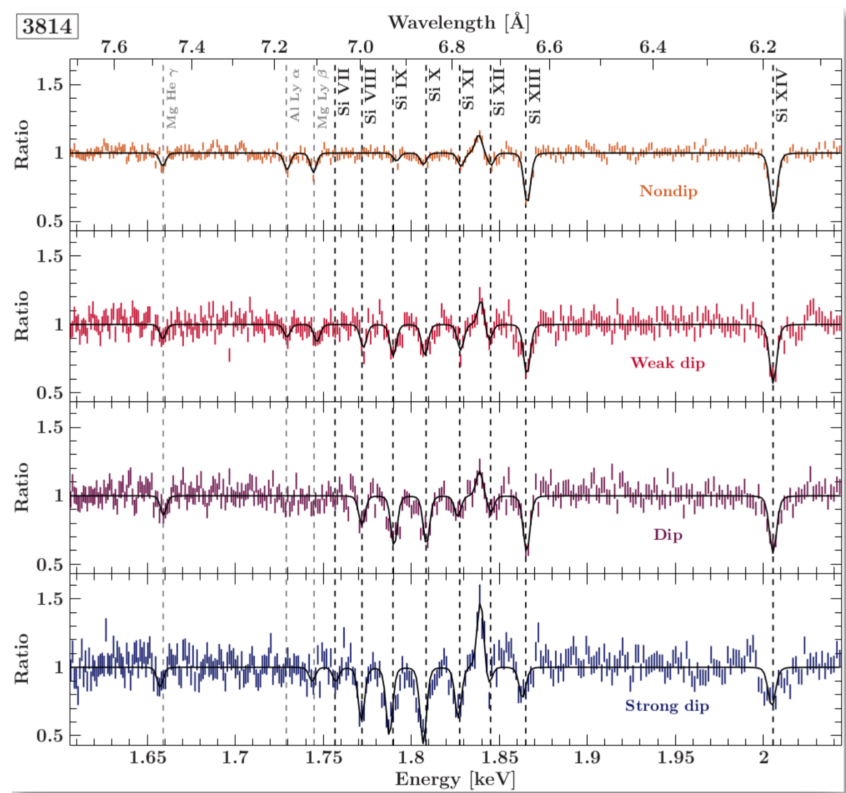
- Clumps along the line of sight and obscuration events: the focused wind in Cyg X-1



(Hirsch et al. 2015, in prep.)

Measure the response of clumps to the X-ray illumination → reveals intrinsic properties of the clump composition and physical properties

(Courtesy of Grinberg)



Athena/X-IFU observations will permit to:

- Study properties of INDIVIDUAL clumps
- Perform similar studies on much fainter (1/10 – 1/100) dipping HMXBs
- Study the response of INDIVIDUAL clumps to irradiation in bright sources

R-SCIOBJ-332: accreting massive star X-ray binaries

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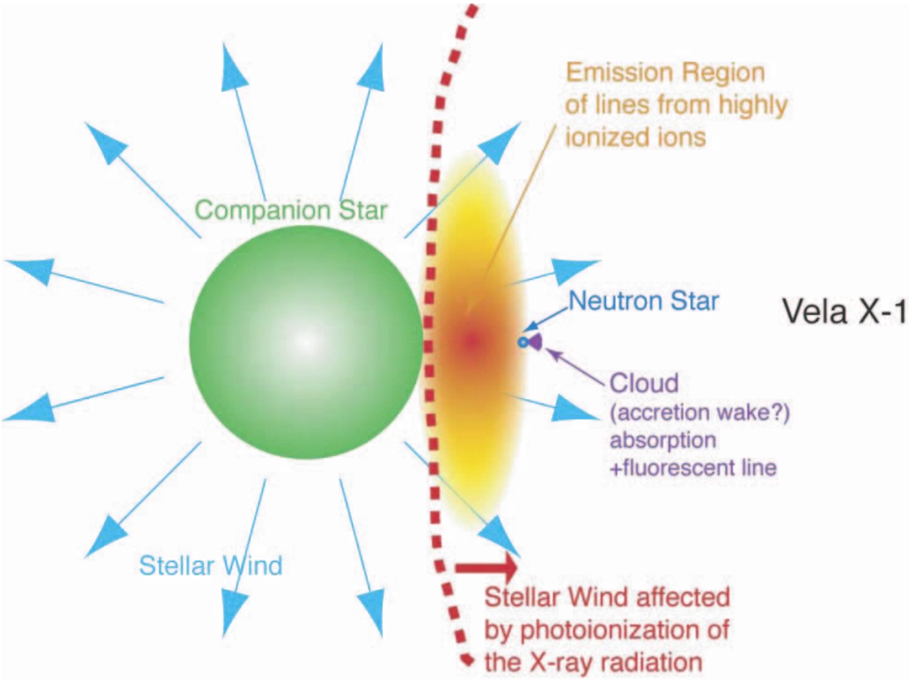
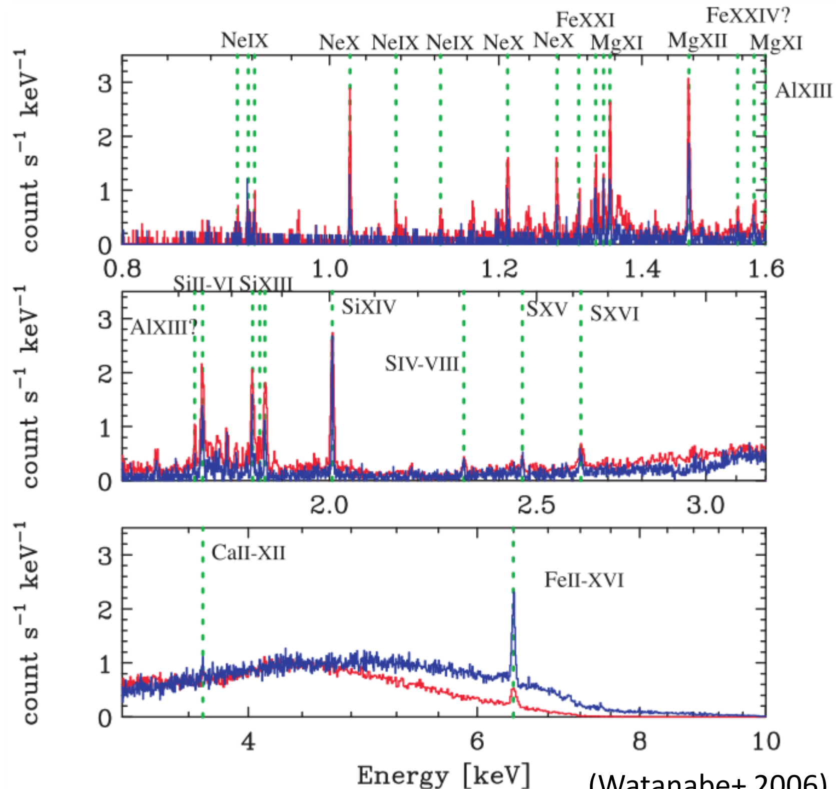
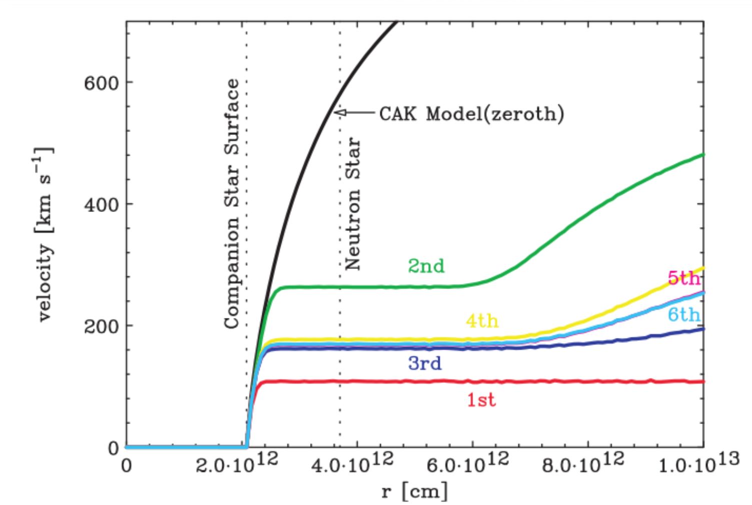
- X-ray feedback on the stellar wind: measuring wind properties through high resolution X-ray spectra





(Watanabe+ 2006)



Vela X-1: **emission lines** from H- and He-like ions by **photoionization** + **fluorescent emission lines** from several elements in lower charge states.

Highly ionized ions: between NS and supergiant
Fluorescent lines: stellar wind, reflection off the stellar photosphere, and the accretion wake.

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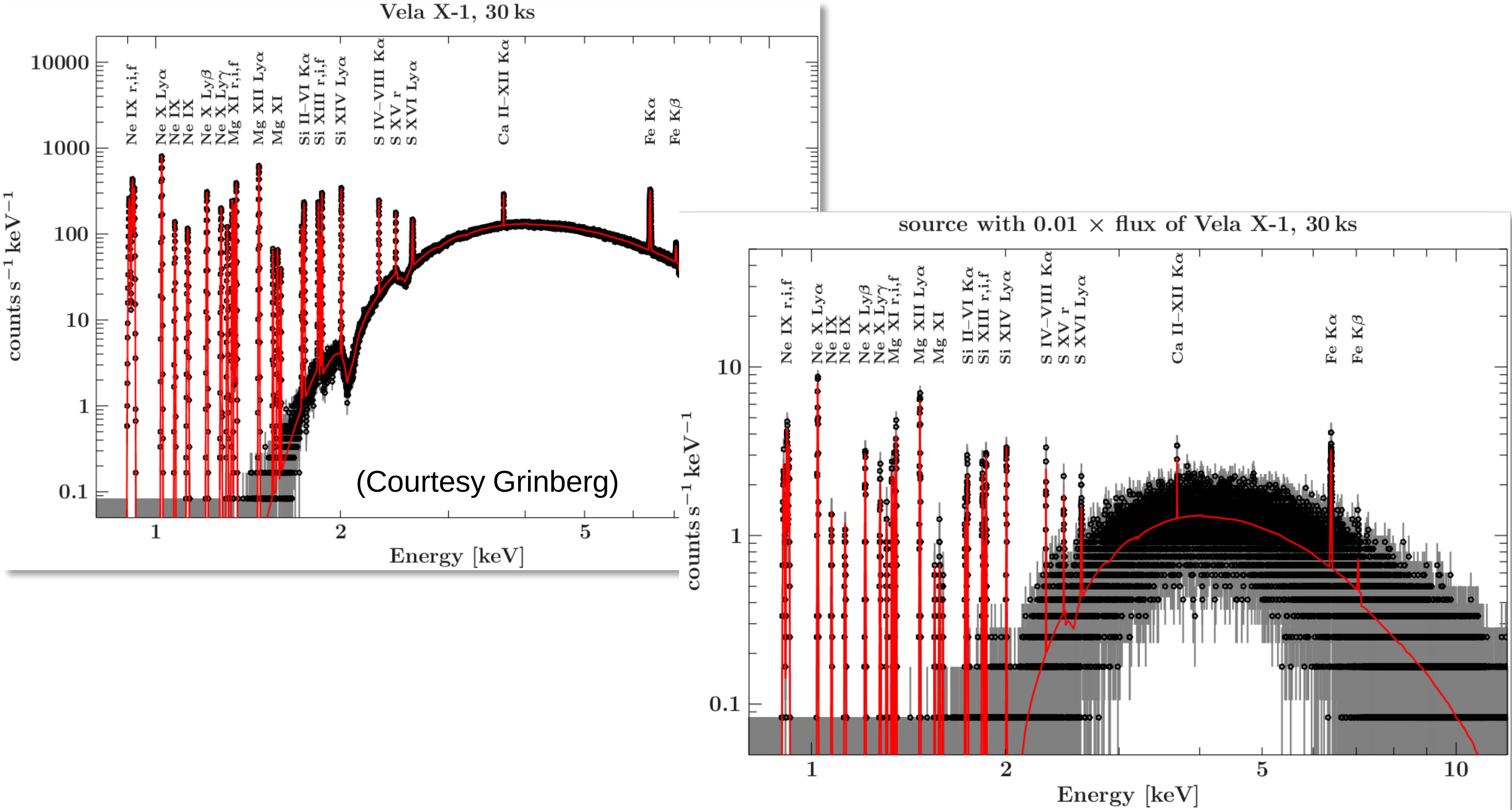

Athena/X-IFU will permit similar studies on the entire class of known HMXBs, going to limiting fluxes of 1/100 – 1/1000 lower than Vela X-1

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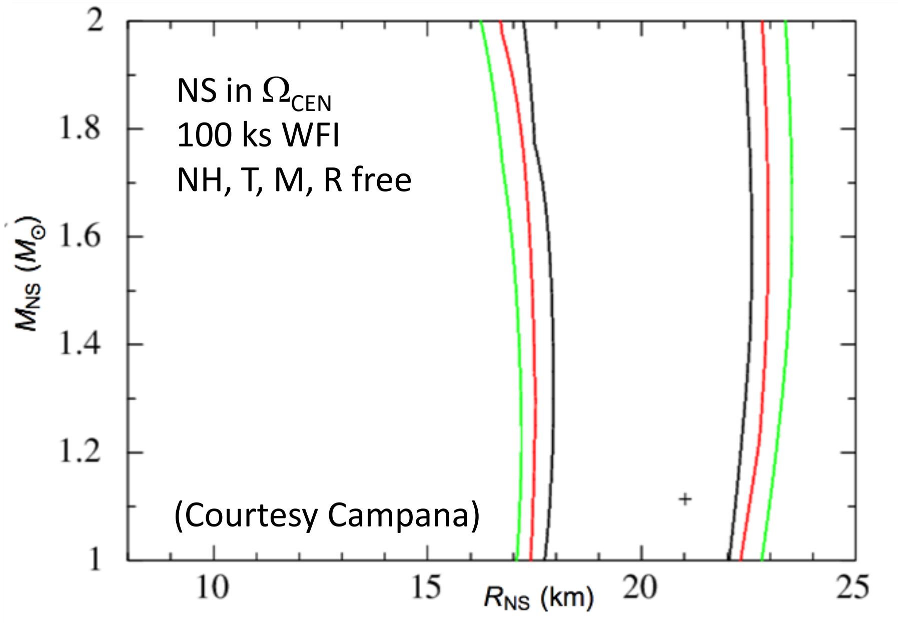
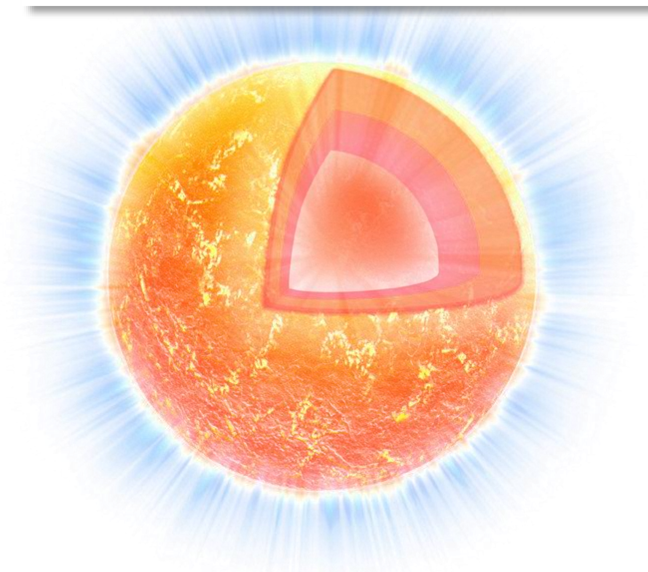
R-SCIOBJ-333: the neutron star equation of state

- Observations of quiescent neutron star X-ray binaries with a good distance estimate

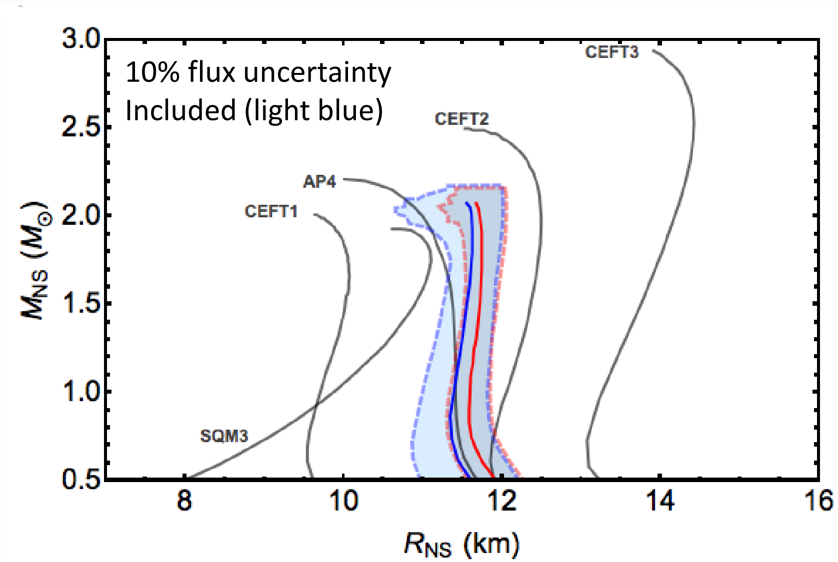


The spectrum of a (non accreting) quiescent NS has a shape dependent from the NS Mass and Radius → high quality data should be able to constrain M and R from the spectral fit.
Uncertainties on the source distance, N_H, Athena absolute flux calibrations (10%) have a major impact on the results obtained with this method

Possible improved method:
- use more accurate GAIA distances
- simulate M-R contours from known NS
- invert M-R with TOV equation to get EoS



(Courtesy Guillot)
See poster!



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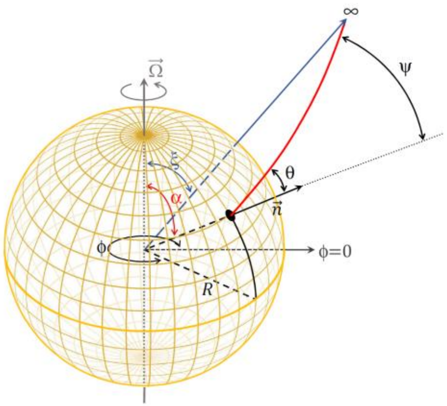
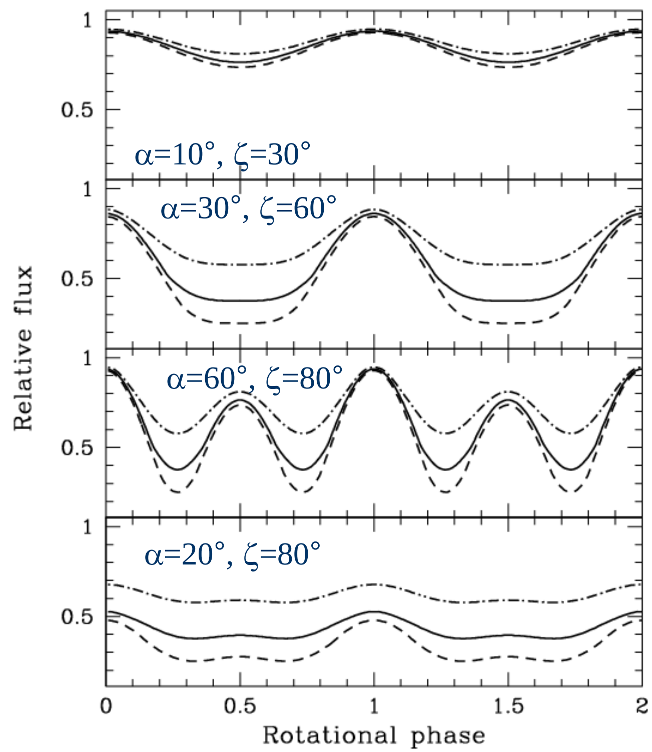
- Energy dependent folded light-curves of accreting X-ray pulsars



9 km
12 km
16 km
for $M = 1.4\ M_\odot$



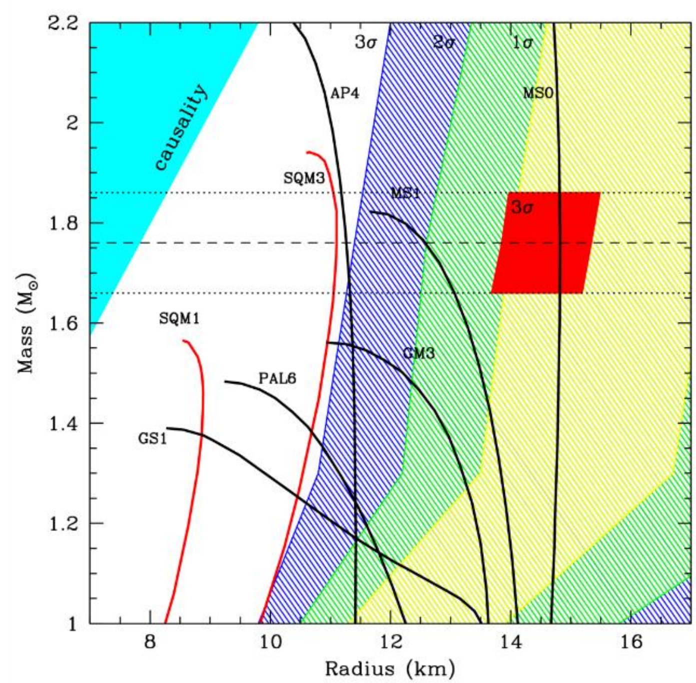
(Bogdanov+ 2007)

Thermal X-ray pulsations from rotation-powered pulsars very sensitive to NS M/R due to relativistic light bending

Detailed numerical modeling can constrain NS M/R

Existing models already incorporate all important General + special relativistic effects plus H atmosphere emission (Bogdanov+ 2007, 2008)

(Courtesy Bogdanov)



PSR J0437-4715

D = 156.3±1.3 pc (Deller+ 2008)

M_{PSR} = 1.76±0.20 $M_\odot$ (Verbiest+ 2008)

PSR J1614–2230

D = 1.8 kpc

M_{PSR} = 1.97±0.04 $M_\odot$ (Demorest+ 2010)

- Detecting narrow absorption lines during thermonuclear bursts
  - The most difficult part to simulate: we don’t have similar securely detected features so far and thus simulations have to rely only on models
  - A sub-working group is being set-up within the SWG3.3, led by Jean in’t Zand

Science perspectives:

Most (>95%) thermonuclear bursts observed with detectors sensitive only >2 keV and with low spectral resolution (despite typical k$T \leq$ 2.5 keV) → discovery space

Some numbers:

Peak count rates (burst from SAX J1808.4-3658)

RXTE/PCA	Chandra/LETGS	XMM/RGS	Athena/WFI
84,300 c/s	2,500 c/s	140	66,300 c/s

Workgroup tasks:

- X-IFU high-resolution spectra
  - Employ simulated NS atmosphere spectra at various T
  - Include in model dredge up of heavy ashes
  - Compton scattering
- Continuum spectra: deviations from black body (in 't Zand et al. 2013)

(Courtesy in’t Zand)

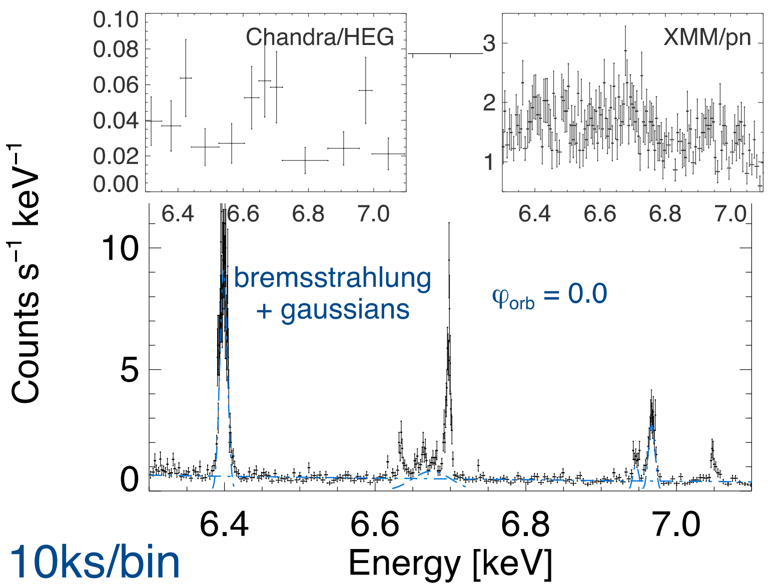
R-SCIOBJ-333: accreting white dwarfs

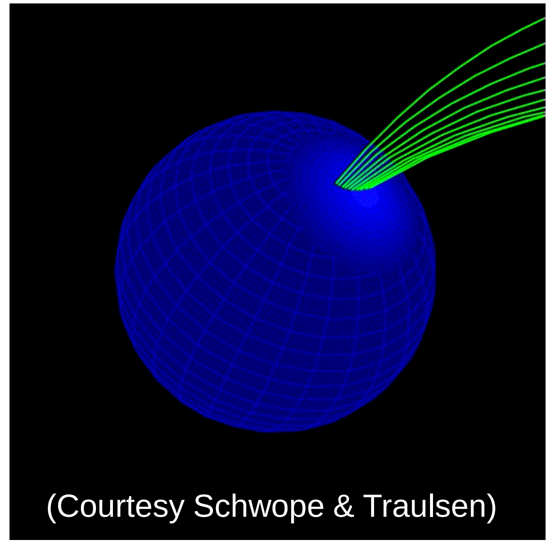
The first 'freshly' added science requirement: white dwarfs in binaries

R-SCIOBJ-333	Athena shall determine the M/R ratio of accreting white dwarfs in cataclysmic binaries of different kinds within 15% accuracy, resolve their accretion regions to probe the magneto-ionospheric or inner disk interaction regions, and constrain processes of energy release (e.g. hydrodynamic accretion models)

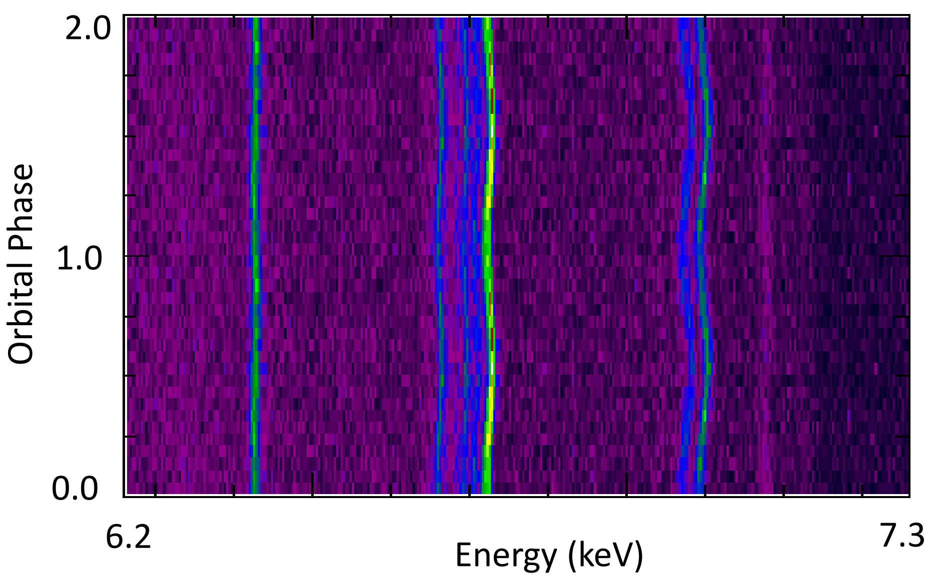
R-SCIOBJ-333: accreting white dwarfs

- The first ‘freshly’ added science requirement: white dwarfs in binaries





Constrains on the WD mass are obtained by detecting the Fe Kα line produced by reflection of the X-rays onto the NS surface at different spin phases.



Fe Ka (Reflection)
Grav redshift (15% 100ks)
+ Orbital motion

Fe XXV and XXVI (Plasma)
GR & Orbital motion +
streaming bulk motion

(Courtesy Schwope & Traulsen)

The radial velocities of plasma lines in the accretion columns can disentangle different accretion models

Missing science requirements?

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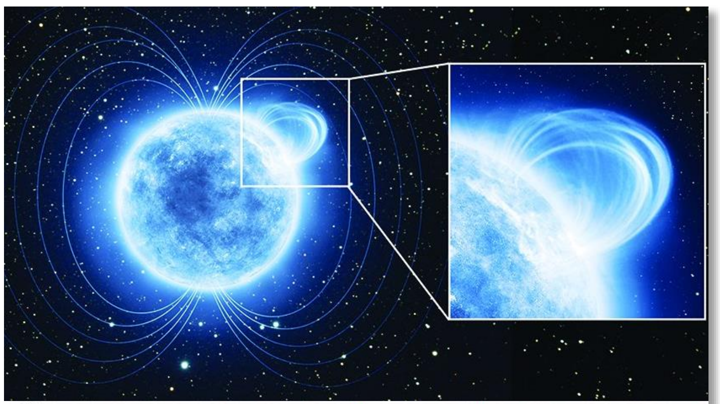
- Missing science requirements: several classes of X-ray sources not yet fully considered
- Athena will provide breakthrough contributions to the science of:
  - Magnetars
  - Pulsar wind nebulae
  - Novae
  - Double degenerates systems
  - Gamma-ray binaries
  - Isolated Neutron Stars

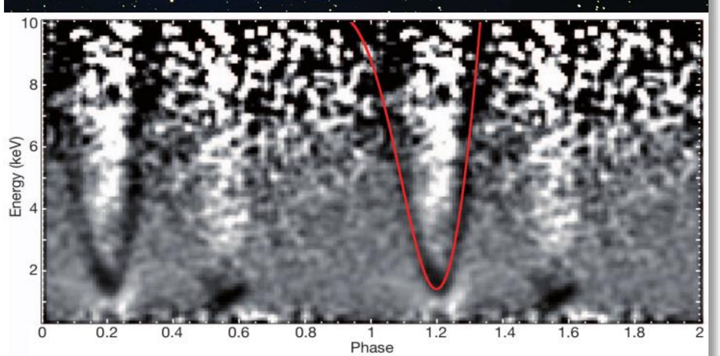
Magnetars

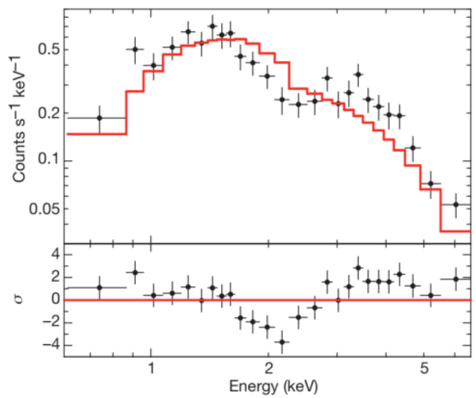
<u>L1 requirement</u>: Athena shall constrain the geometry of the magnetar surface magnetic field by detecting energy and phase-dependent proton cyclotron lines resulting from resonant scattering of its emission in the presence of magnetic structures close to the compact object surface

<u>L2a requirement</u>: The geometry of magnetars' surface magnetic field will be constrained by performing spin-phase resolved spectral analysis of proton cyclotron lines, measuring their energy dependence at different phases. This study will be carried out on both quiescent and outbursting magnetars. Observations of X-ray Dim Isolated Neutron Stars will also be carried out to unveil the origin of the spectral lines discovered so far and possibly confirm their proton cyclotron origin.

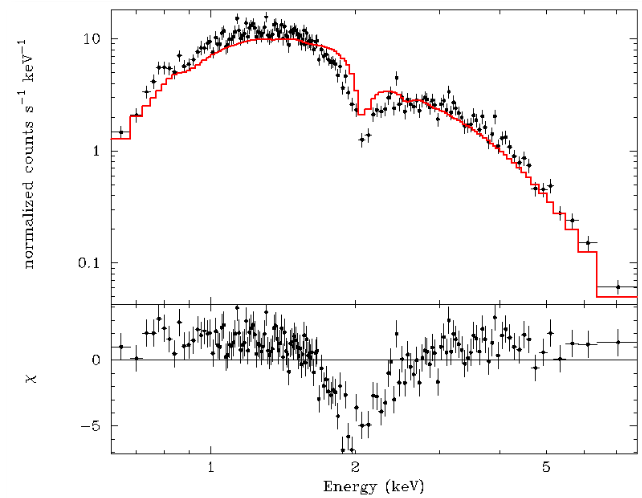
<u>L2b requirement</u>:
Athena/WFI shall observe the XDINS RX J0720.4-3125 and RX J1308.6+2127 for XXX ks and XXX ks, respectively. **Athena/WFI** observations of the persistent magnetars 1RXS J170849.0-400910 and XTE J1810-197 shall be carried out for XXX ks and XXX ks, respectively. An **Athena/X-IFU (?)** observation of the source XXX is also requested to probe the presence of thinner lines that might have gone undetected so far. In case a new magnetar in outburst is detected during the Athena life time, XXX observations with the **Athena/WFI** are requested during the course of the outburst to monitor the change in the magnetic twist (the expected spacing of the observations is XXX days). Assuming a representative distance of XXX for the outbursting magnetar, the expected average duration the observations is XXX ks. In case of a closer-by (more distant) magnetar in outburst, the value of the exposure time shall be decreased (increased) by a factor of (d/XXX)^2, where d is the distance to the outbursting source. A single **Athena/X-IFU (?)** observation shall be carried out as closer as possible to the onset of the outburst to test the presence of thin spectral lines.







SGR 0418+5729
EPIC-pn (613 s)
(Tiengo+ 15)



Athena/WFI
(613 s)

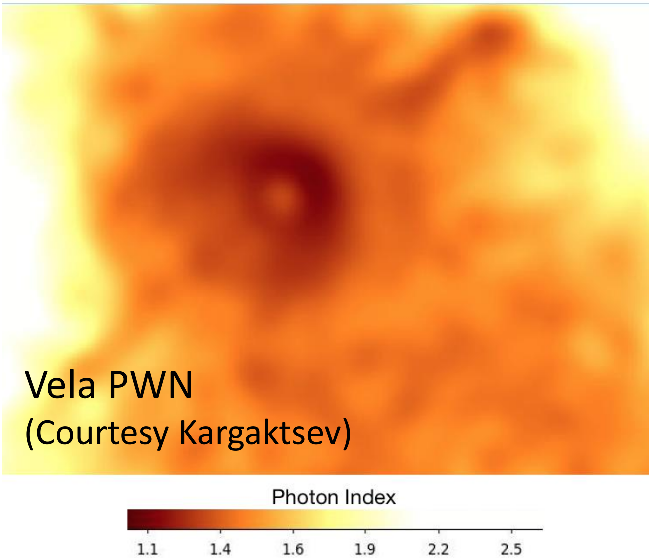
Measure energy + phase dependence of magnetar proton cyclotron lines

Pulsar wind nebulae

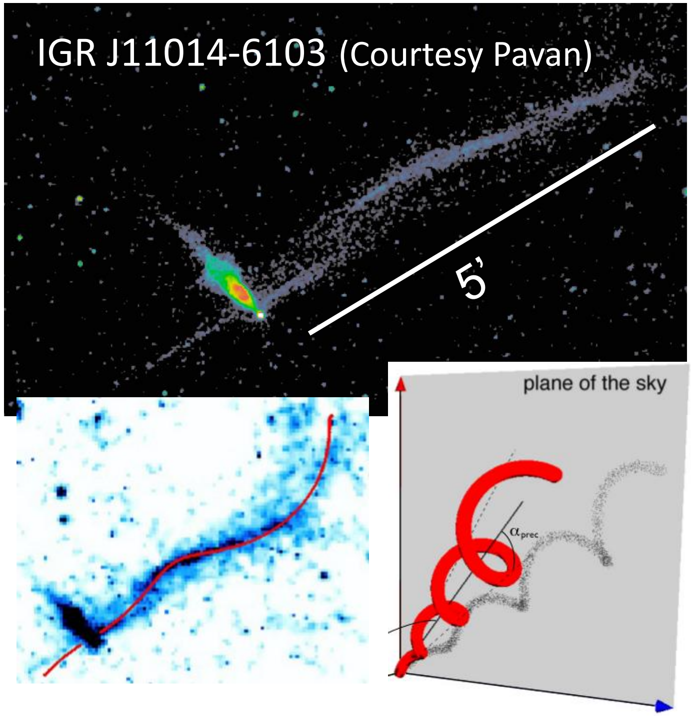
L1 requirement: Athena shall constrain transport and particle acceleration mechanisms and the magnetization of ultra-relativistic plasmas, together with the progenitors and energetics of supernova explosions making pulsar-wind nebulae, through observations of extended and relatively bright PWNe

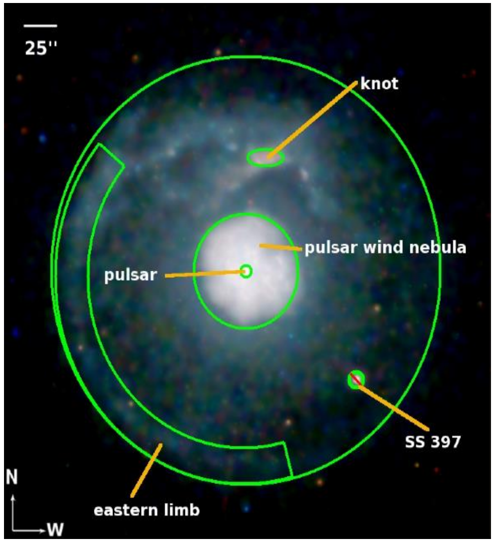
L2a requirement: The required constraints will be achieved by: (i) accurately mapping spectral morphologies of large structures in bright PWNe, (ii) accurately mapping spectral morphologies of PWNe interacting with the surrounding SNR, (iii) measuring synchrotron spectra of TeV emitting regions associated with `relic' PWNe, (iii) searching for thermal X-ray emission in the outer regions of shell-less PWNe, and (iv) accurately determine the thermal plasma properties that are needed to constrain the intrinsic properties of the SN explosion (including its progenitor star) in those PWNe with already detected thermal X-ray emission

L2b requirement:
Athena/WFI should perform a single deep observation of the Vela PWN, G320.4-1.2, 3C58, PSRs J1509-5850, B0355+54, PSRs B2224+65, and IGR J1101-6101, PSR J0357+3205. The required exposure times are XXX ks, ..., and XXX ks, respectively.
Athena/WFI/X-IFU? should perform a single deep observation of the Vela relic PWN and MSH 15-52 (G327.1-1.1 also?). The required exposure times are XXX ks and XXX ks, respectively.
Athena/WFI should perform a single deep observation of the PWNe around PSR B1823-13, PSR J1809-1917, and PSR J0007+7303. The required exposure times are XXX ks, ..., and XXX ks, respectively.
Athena/X-IFU should perform a single deep observation of the PWNe G21.5-0.9 and 3C58. The required exposure times are XXX ks, ..., and XXX ks, respectively.



Spectral map binned to 10’’ resolution. This spectral photon index map would be obtained by the **Athena/WFI** in <10 ks





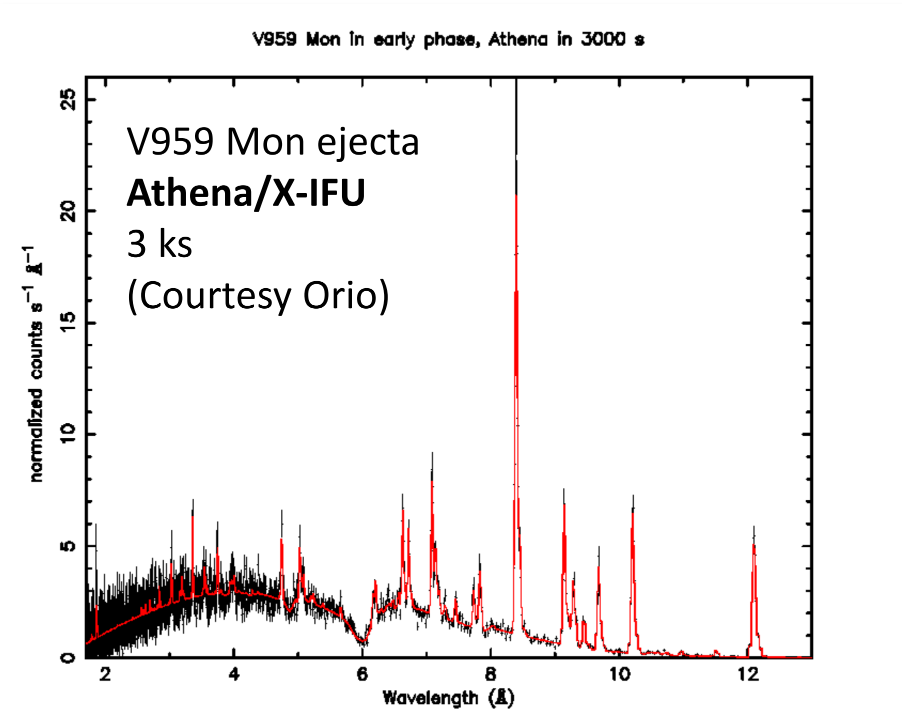
G21.5-0.9 X-ray image (Matheson+ 2010)

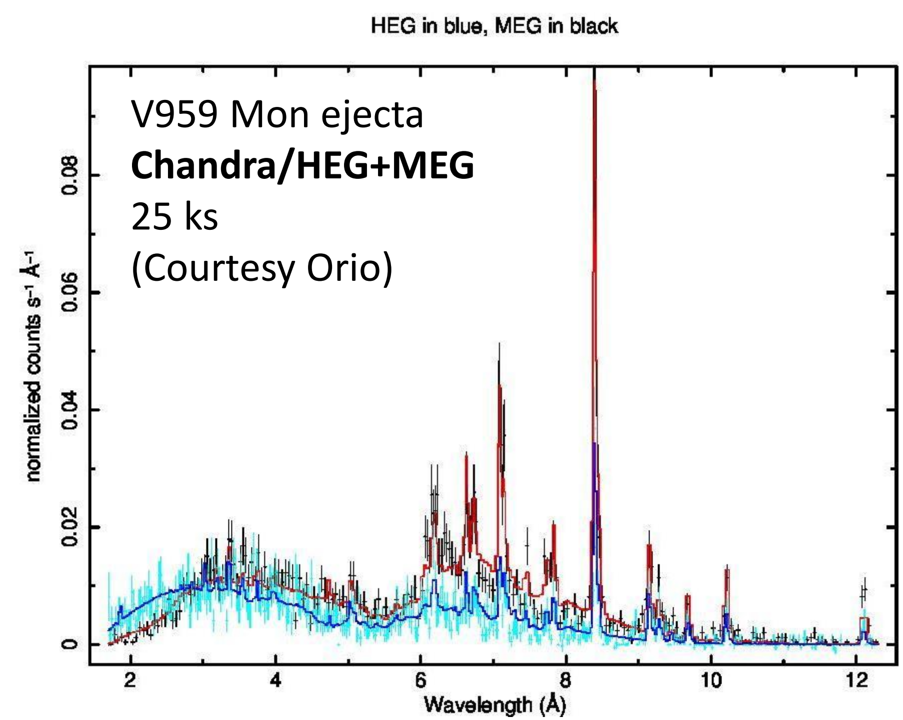
See Kargaktsev poster!

L1 requirement: Athena shall measure the chemical composition of Novae ejecta, testing SN type Ia progenitor scenarios via the single-degenerate channel and determining the corresponding chemical enrichment of the Galaxy

L2a requirement: The chemical composition of Novae ejecta will be determined by unambiguously identifying emission lines of O, Ne, Ar, Si, S. The measure of line velocities will be crucial to understand the ejection process and to infer the mass loss and to provide key test on the single-degenerate channel for the production of type Ia SNe.

L2b requirement: **Athena/X-IFU** shall observe at least XXX Novae going off during the Athena mission lifetime, in order to have a meaningful statistical sample. XXX (XXX) observations of XXX (XXX) ks shall be carried out during the fastest (slowest) evolving Novae by using an average spacing time of XXX days in order to properly study the properties of the ejecta.



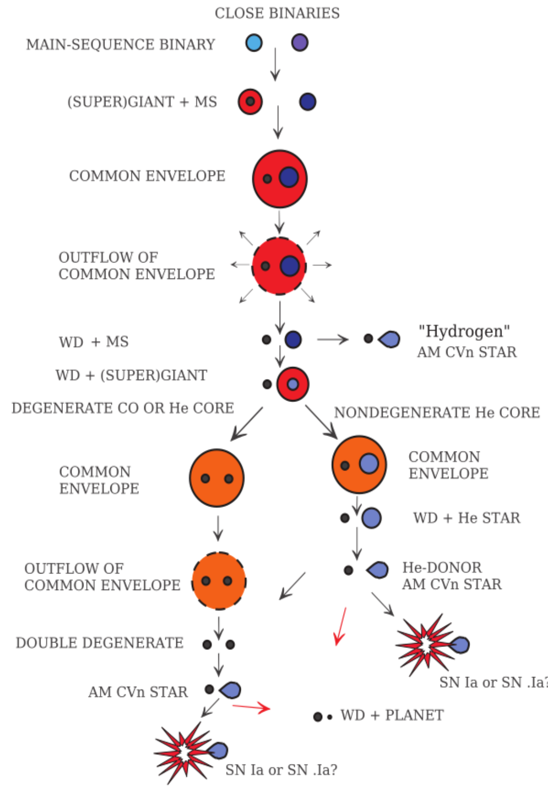


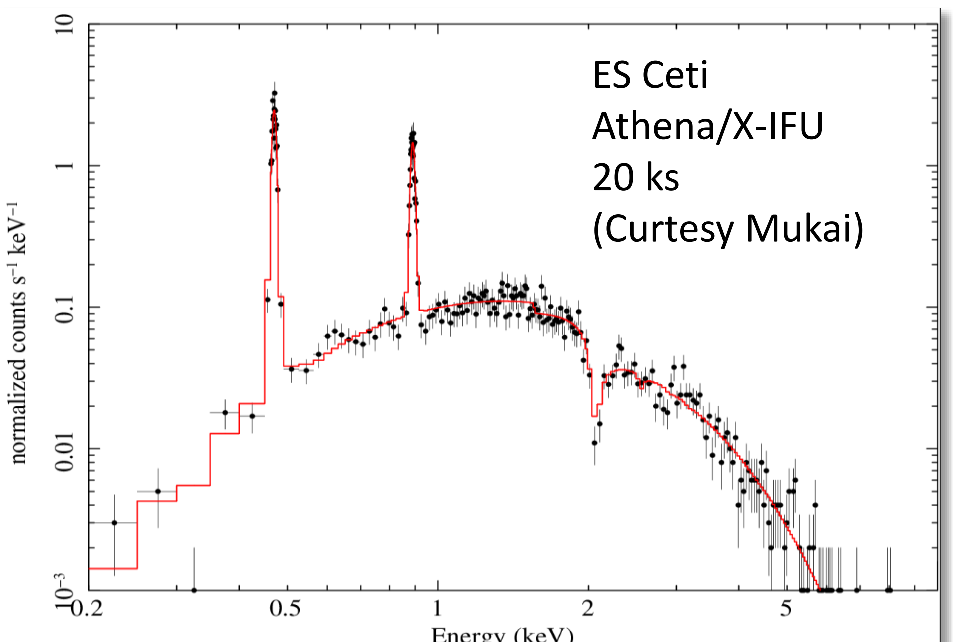
Double Degenerates

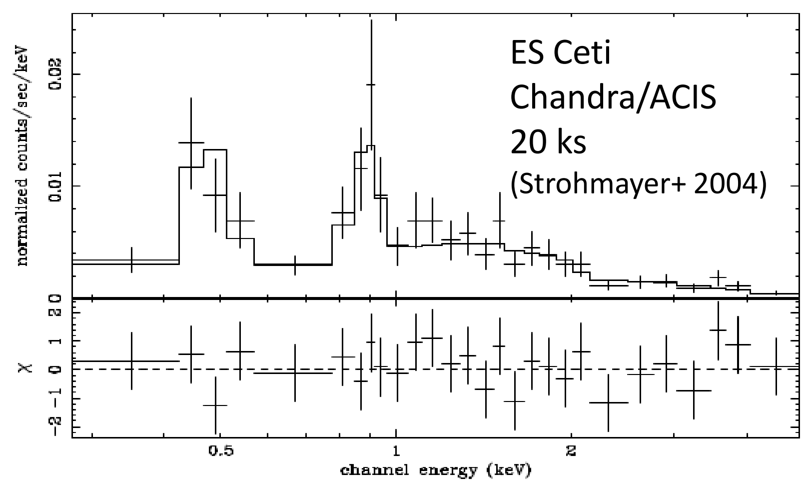
L1 requirement: Athena shall test different evolutionary scenarios for double degenerate binaries and identify the most promising gravitational wave sources and Type Ia Supernova progenitors among these systems.

L2a requirement: The different evolutionary scenarios will be investigated by identifying and study the spin/energy dependence of the He-like and H-like lines of N, O, Ne, Mg, Si, Ca and Fe. The proposed evolutionary scenarios for these systems predict different element abundances to be tested with X-ray spectroscopy (Nelemans+ 2010, MNRAS 401, 1347)

L2b requirement: **Athena/X-IFU** shall observe GP Com, HP Lip, Cr Boo, CP Eri, V406 Hya for a total exposure time of XXX ks, …., XXX Ks, respectively. An **Athena/WFI** observation shall be carried out for 100 ks on a type Ia supernova exploding at a distance < 25 Mpc from the Earth in order to provide a key test on the double degenerates against single degenerates scenarios.

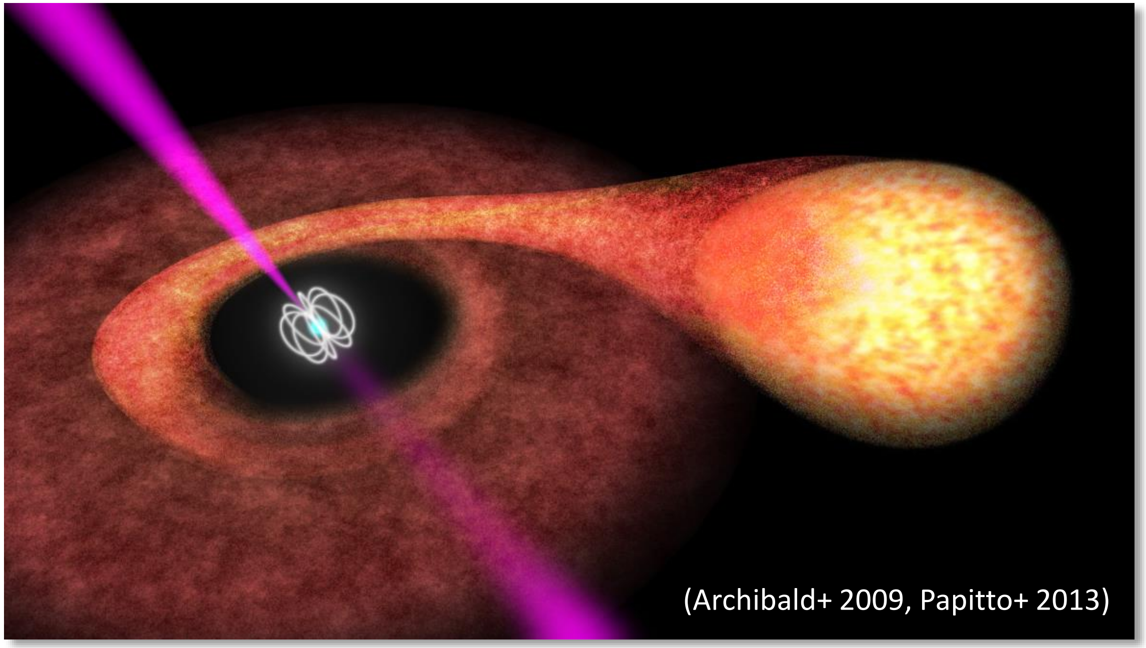






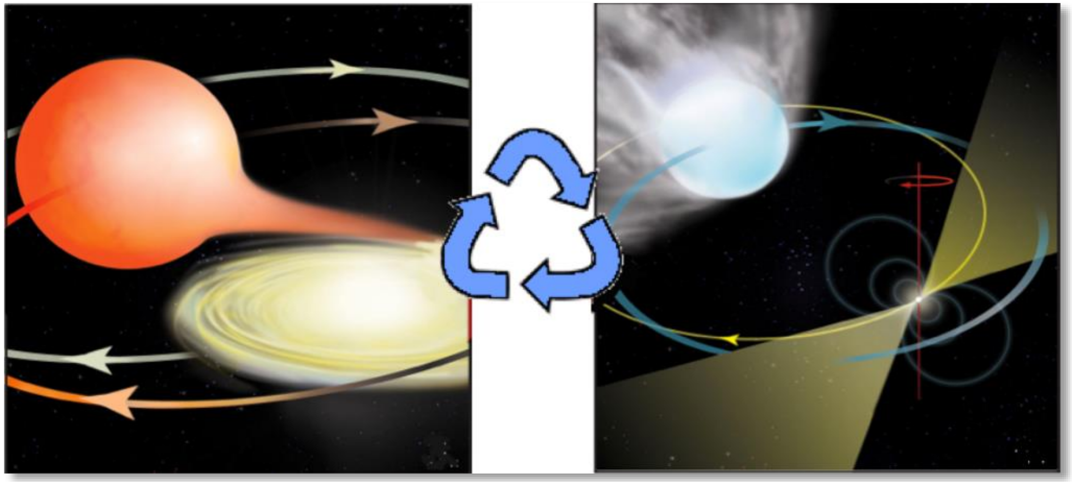
Gamma-ray binaries

- Still under discussion



Athena/WFI observations of Transitional pulsars

Switch between accretion and rotational powered pulsations

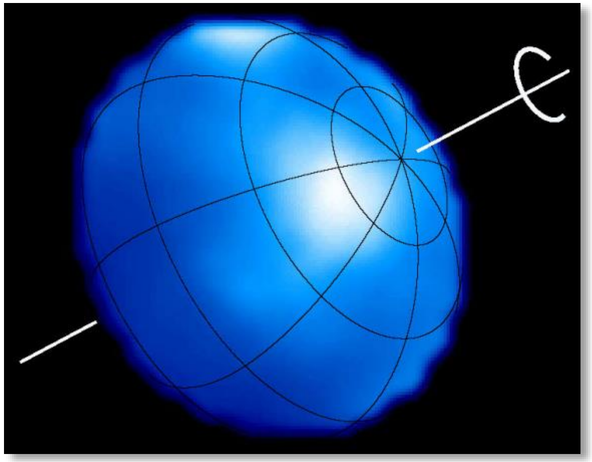


$L_{0.1\text{-}10\ GeV} \approx 10^{34}$ erg/s
x10 brighter with respect to the level observed during the rotation powered state, and not detected by Fermi/LAT from other accreting NS in low-mass X-ray binaries

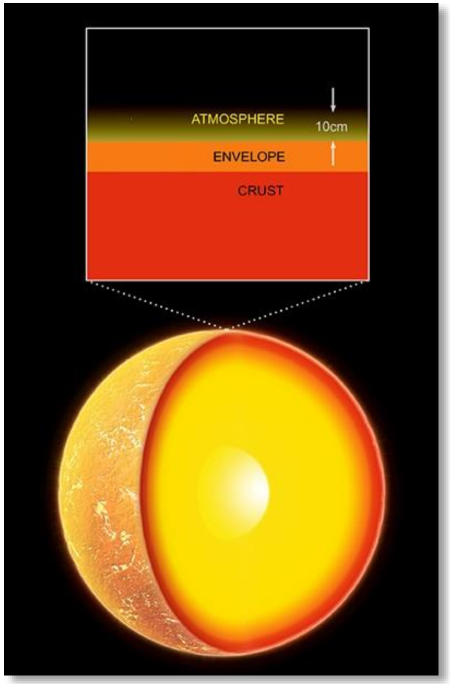
(Courtesy Papitto/De Martino)

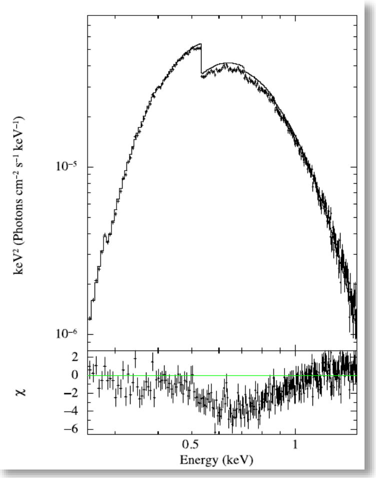
Isolated Neutron Stars

- Still under discussion

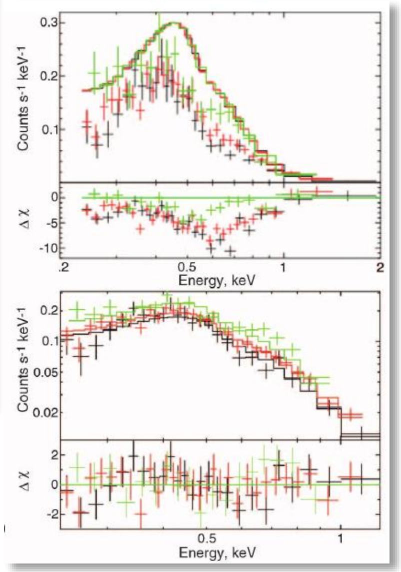


Test the existence of oblate NSs (through detection of long term changes in the timing properties of isolated NSs) and the possibility that these objects are promising Gravitational Waves emitters





(Vigano+ 2014)



(Kargaltsev+ 2012)

Probe Isolated NS and CCOs atmospheres through, e.g. detection of absorption lines
Test uniformities/differences in the atmospheres in isolated and binary NSs

See B. Posselt poster!

To do list and timeline

To do:

- Complete simulations and consolidated required exposure time for each considered source
- Consolidate science requirements for each source (depending on the available observational time)
- Revise and optimize the Mock observing plan

To be delivered:

- Prepare a detailed document to be delivered to the SWG3 chairs and to the ASST to support the science cases with the required simulations.
- Finalized Mock observing plan for the SWG3.3

Timeline:

- Deadline: end of 2015 (TBD)