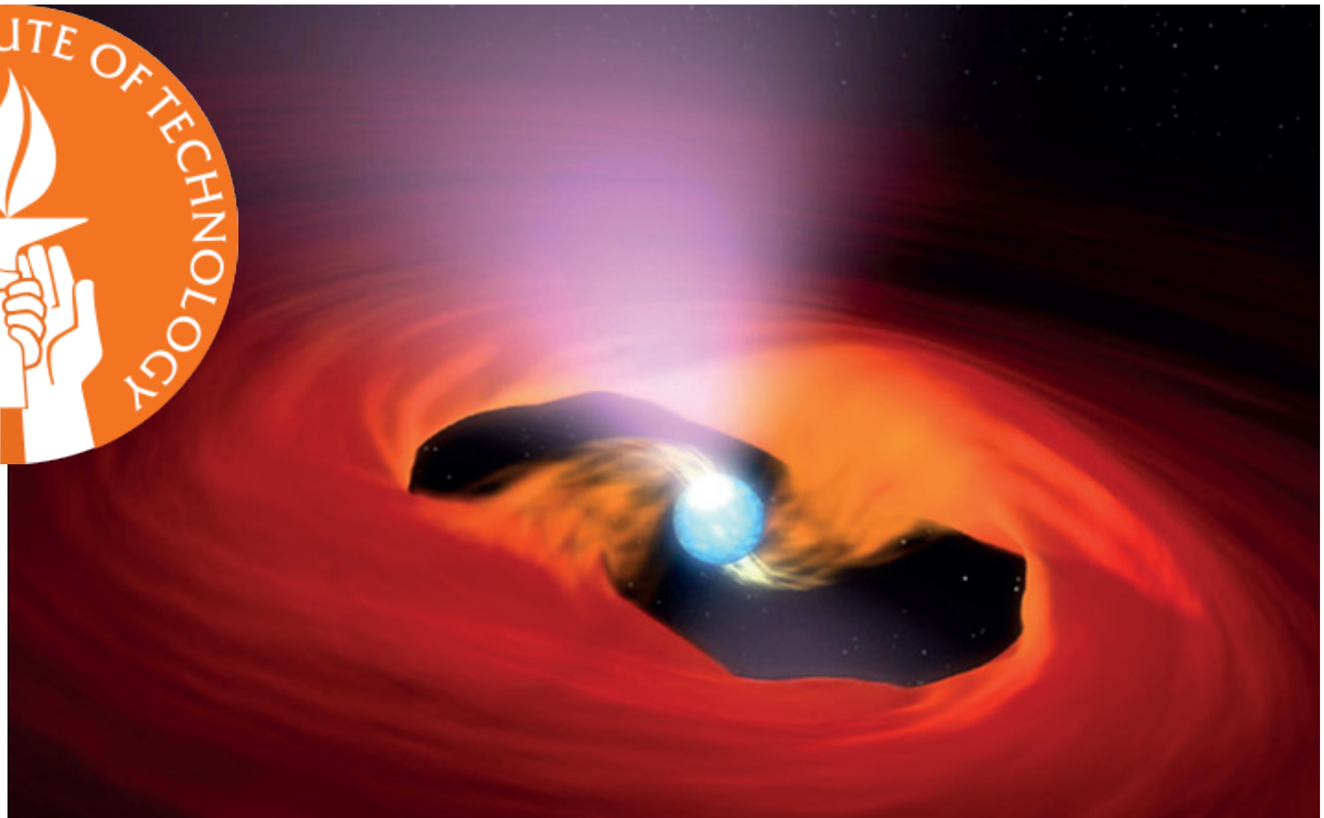
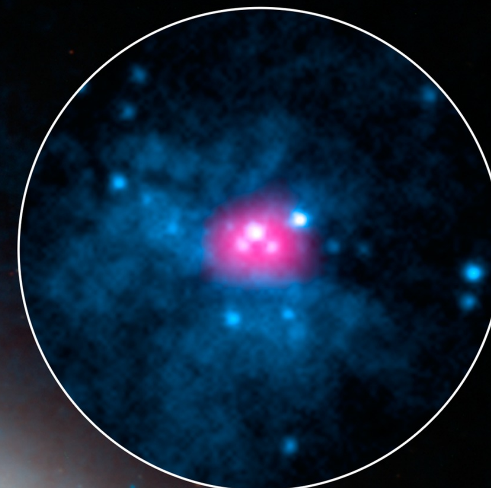
Uncovering and studying **neutron stars** powering **ultraluminous X-ray sources** with **high resolution** X-ray spectroscopy



Murray Brightman (Caltech)

Ultraluminous X-ray Sources

- Extra-nuclear X-ray sources in galaxies with observed $L_X > 10^{39}$ erg s^{-1}
- Discovered in the 1980s by Einstein X-ray observatory
- Once thought to be good IMBH candidates
- More recently though to be super-Eddington accreting, stellar-mass BHs

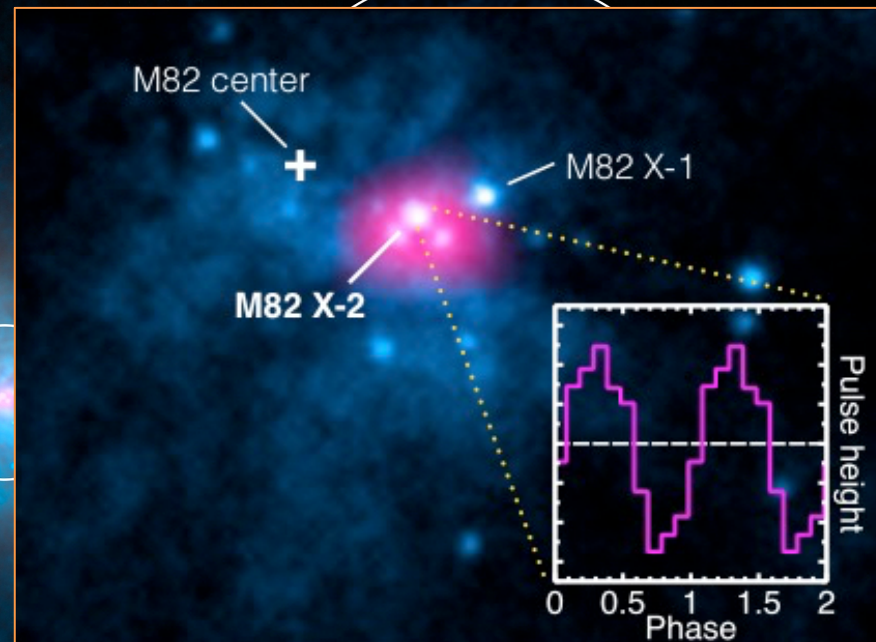


NuSTAR detects coherent pulsations from an ultraluminous X-ray source

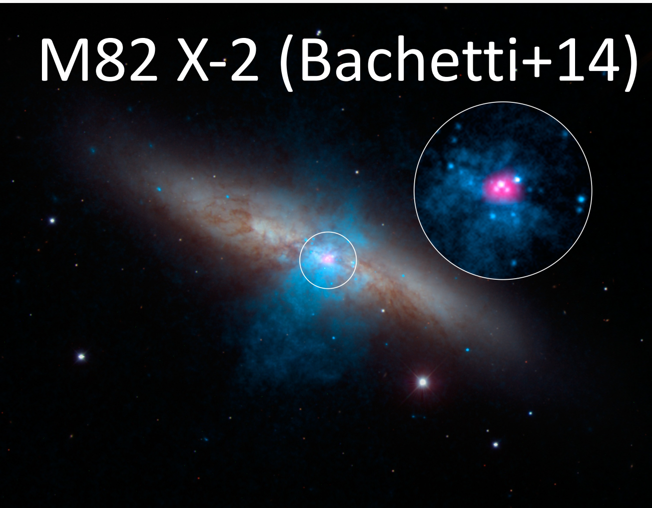
Bachetti+14

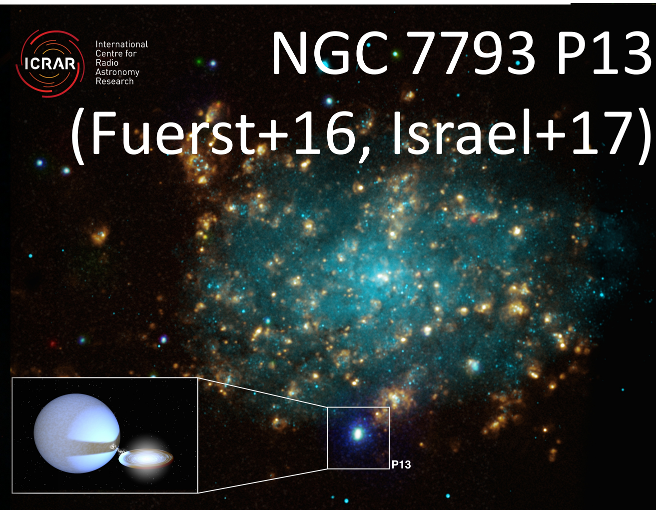
Can only be produced by a rapidly spinning, magnetized neutron star (black holes cannot produce these)

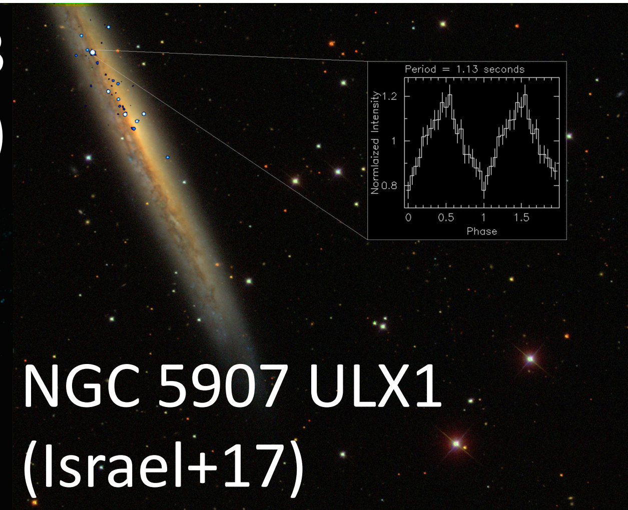
1.37-s period,
-2×10^{-10} s s^{-1} variable period derivative
2.5-day orbital period
5.2-M_{sol} minimum mass companion

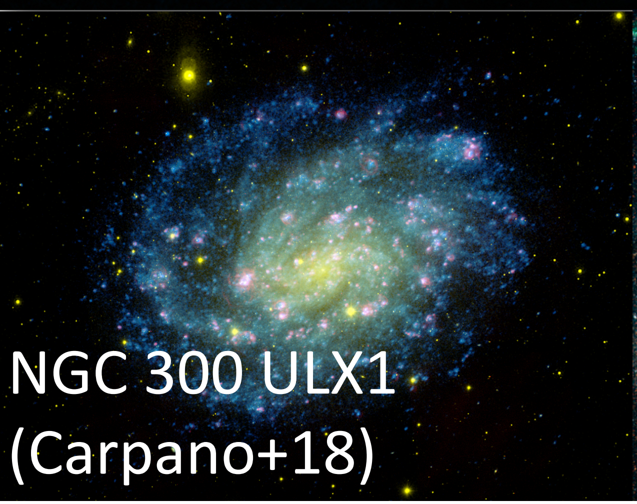


Ultraluminous X-ray Pulsars

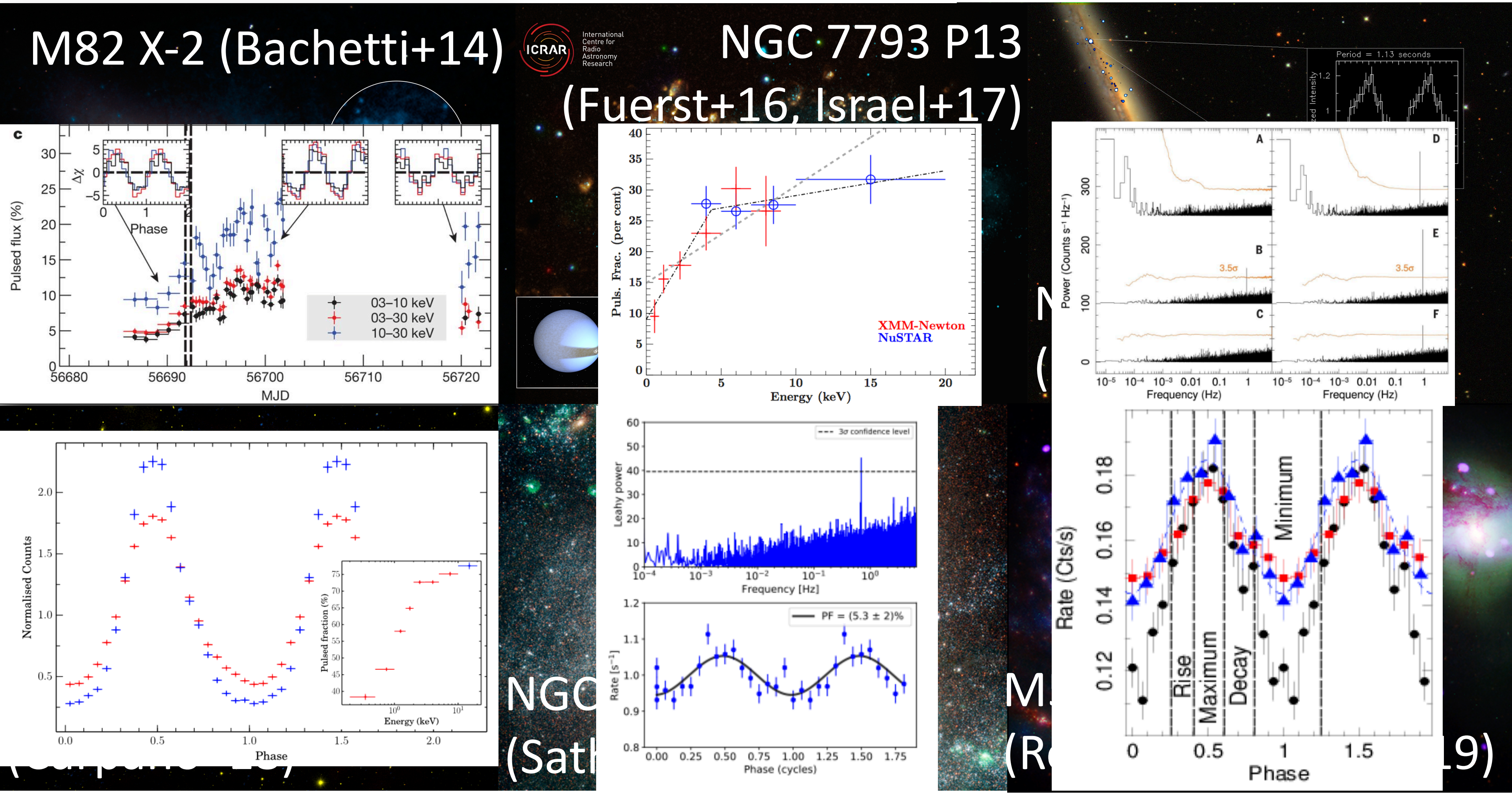






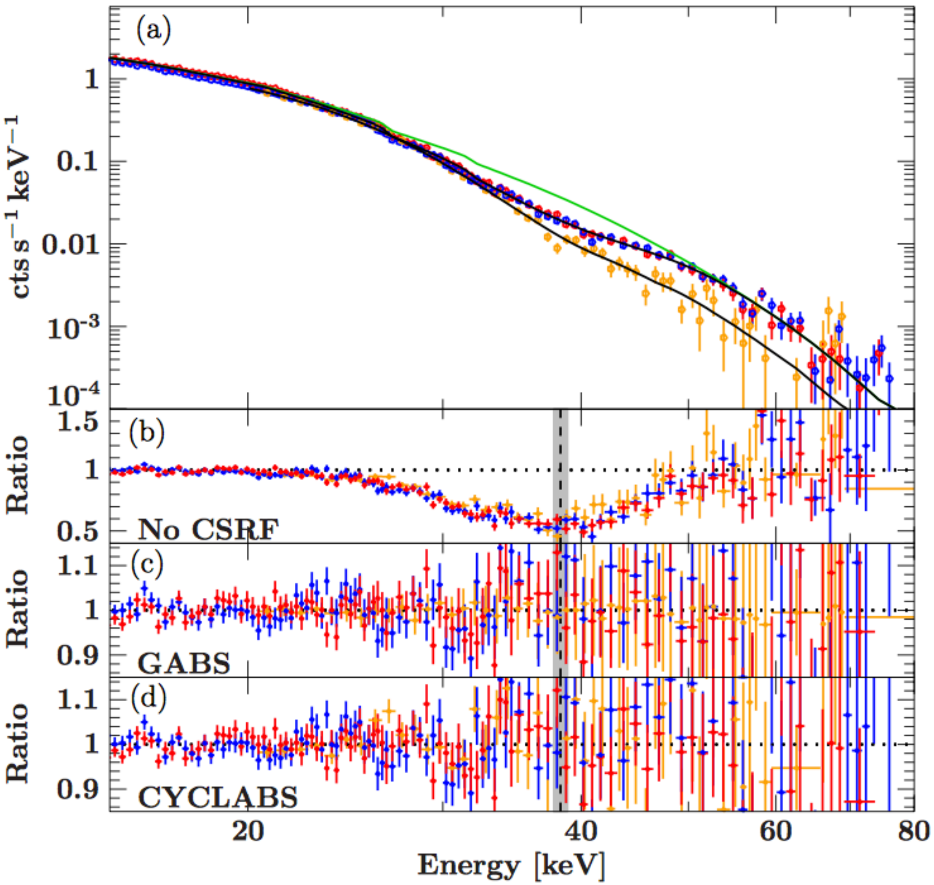


Ultraluminous X-ray Pulsars



Cyclotron lines

Hercules X-1, Fuerst et al. (2013)



Cyclotron resonance scattering features (CRSF).

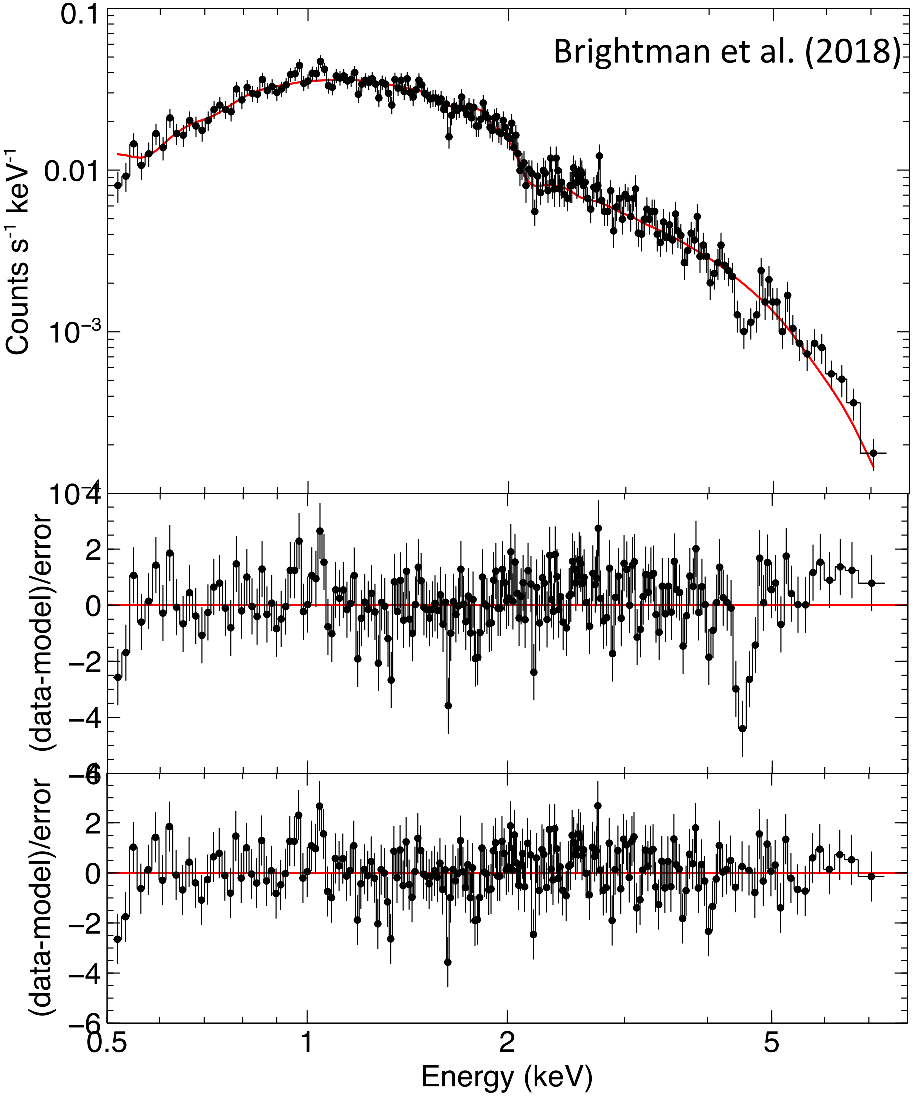
Caused by the transition of charged particles between Landau levels produced by a magnetic field.

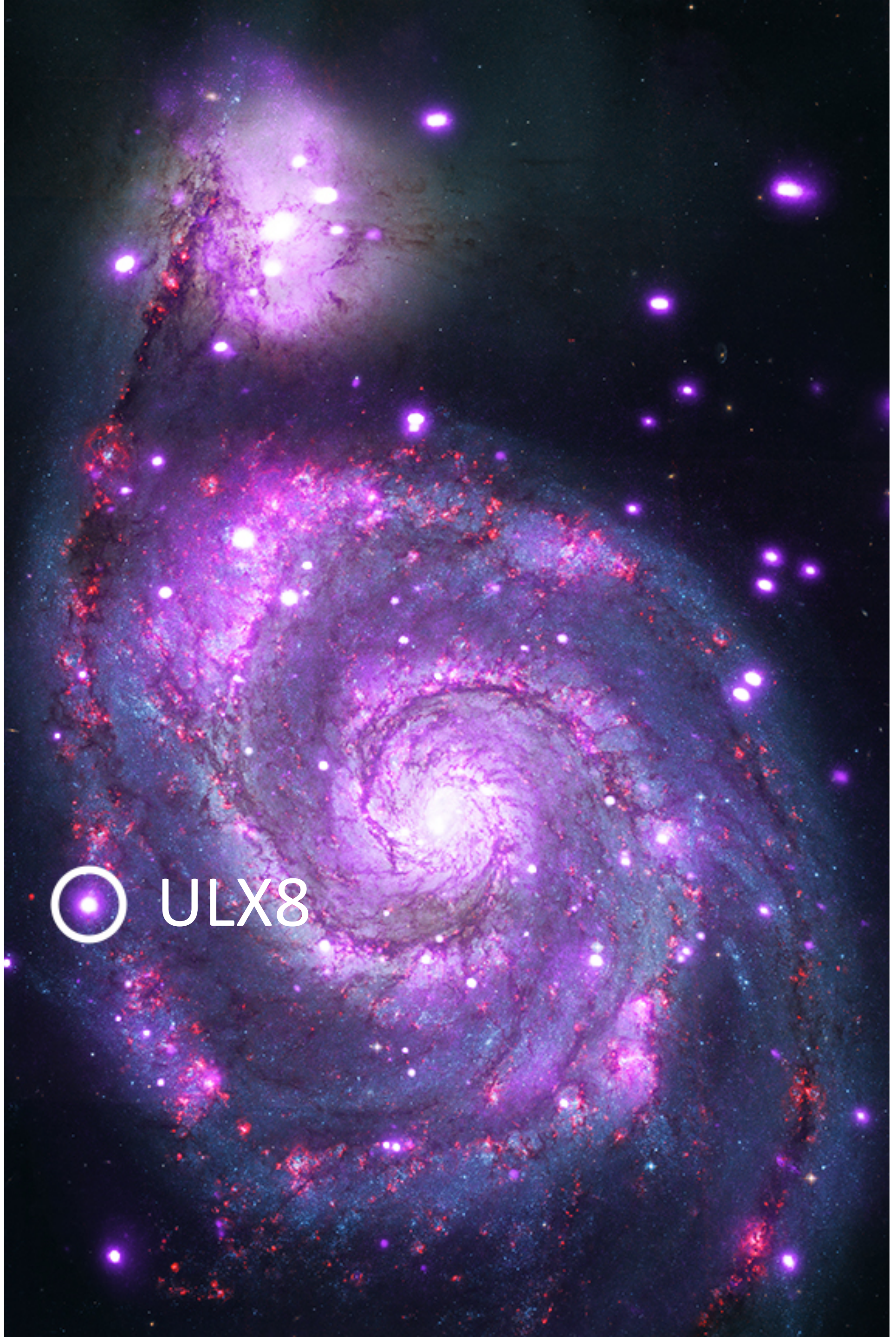
$$E_{cyc}=(\hbar e/mc)B$$

Not only implies the presence of a neutron star, but gives a direct measurement of its magnetic field strength.

ULX8 in M51

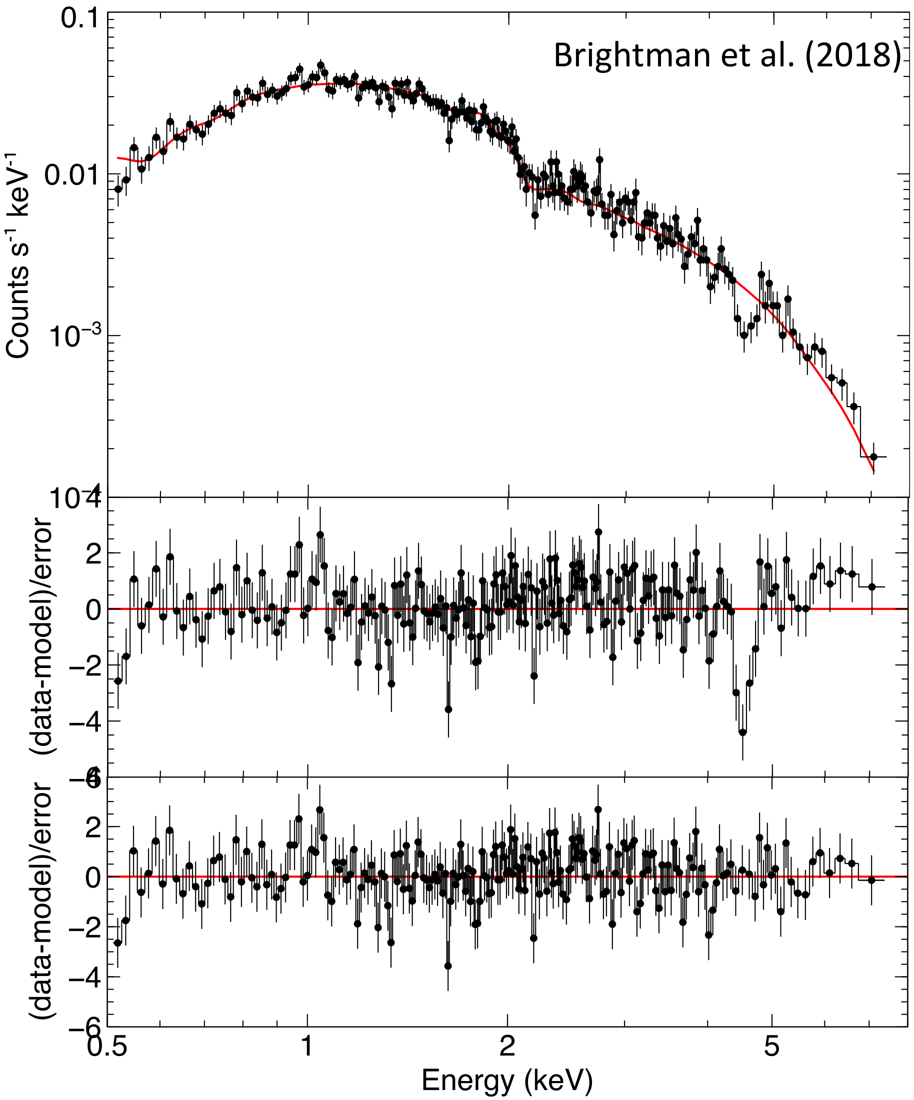
A spectral investigation of the ULXs in M51 with Chandra revealed a prominent absorption feature at 4.5 keV in ULX8





ULX8 in M51

A spectral investigation of the ULXs in M51 with Chandra revealed a prominent absorption feature at 4.5 keV in ULX8



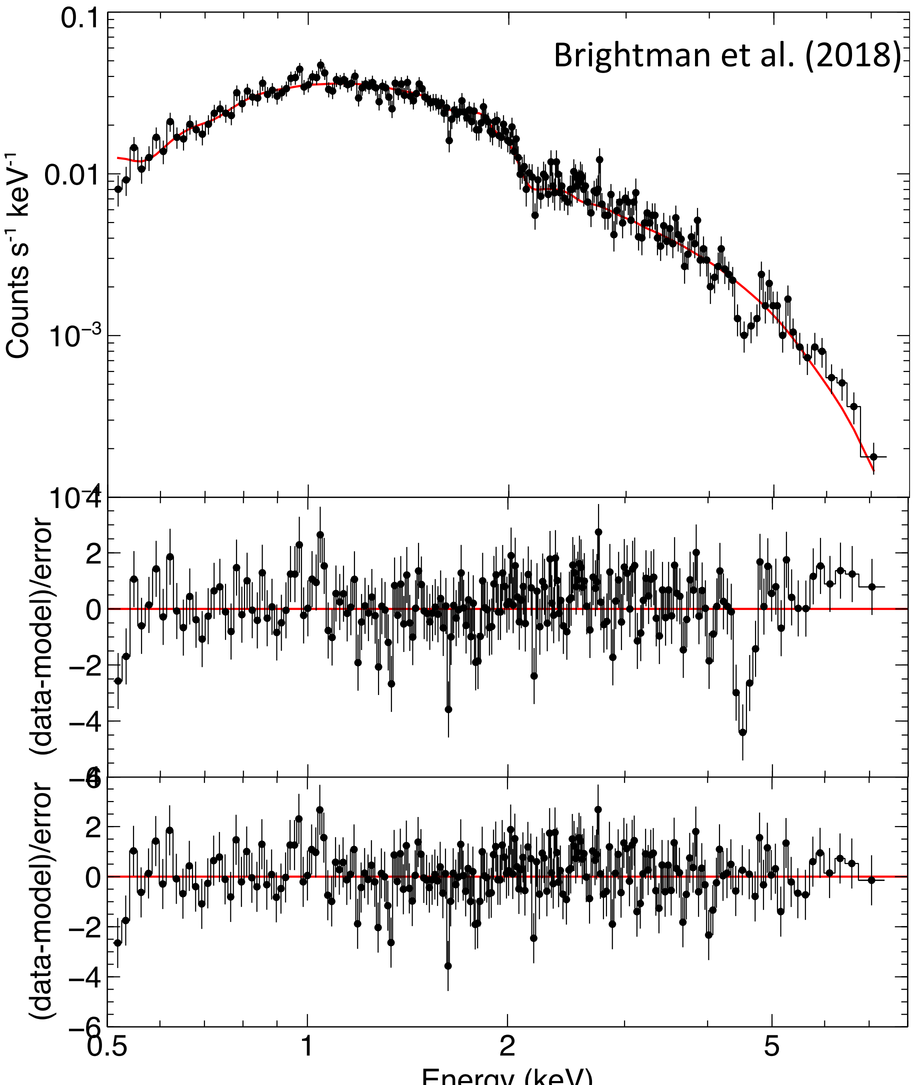
An absorption line at 4.5 keV

Simulations show not a statistical fluctuation and detected at 3.8σ

Not consistent with Chandra instrumental features

Not a known atomic transition. Extreme blue or redshift required to explain it

Cyclotron lines



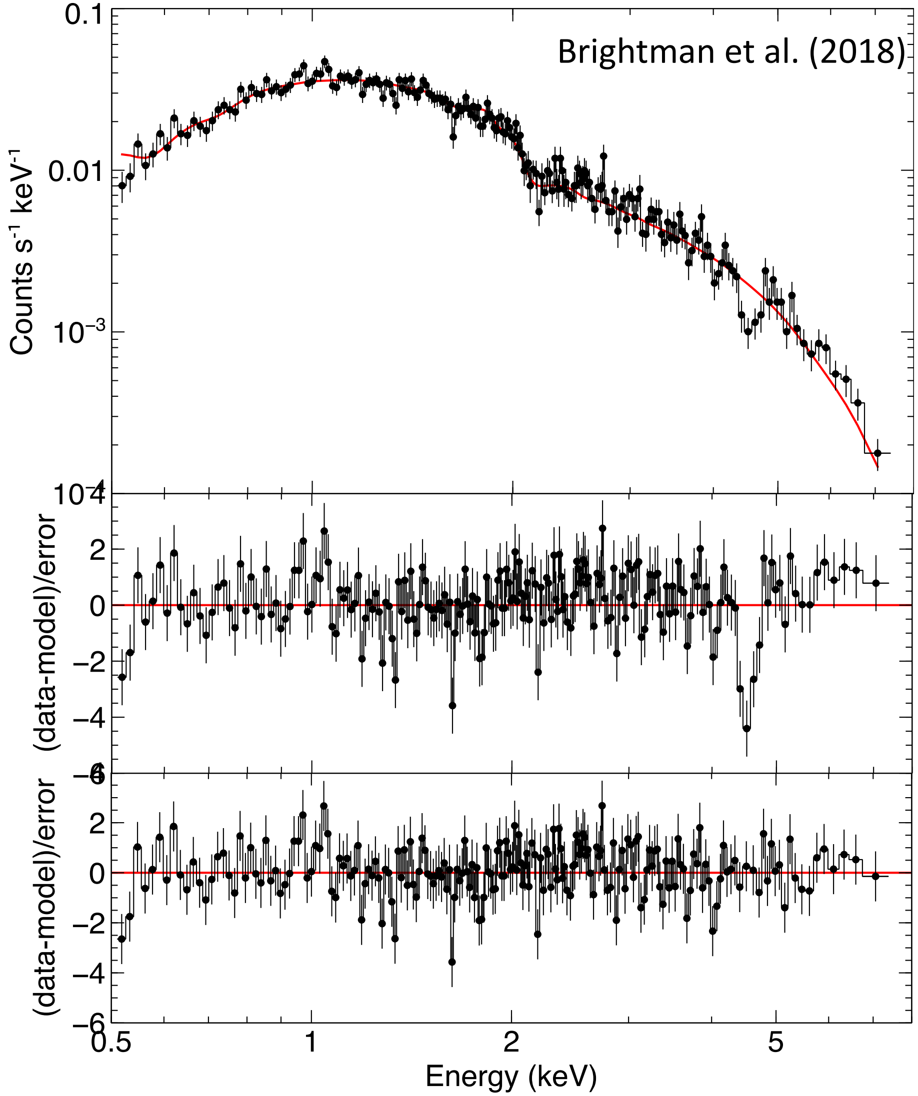
Cyclotron resonance scattering features (CRSF). Caused by the transition of charged particles between Landau levels produced by a magnetic field.

$$E_{cyc}=(\hbar e/mc)B$$

Not only implies the presence of a neutron star, but gives a direct measurement of its magnetic field strength.

Assuming an electron origin:
$B= 4(1+z)\times10^{11}$G

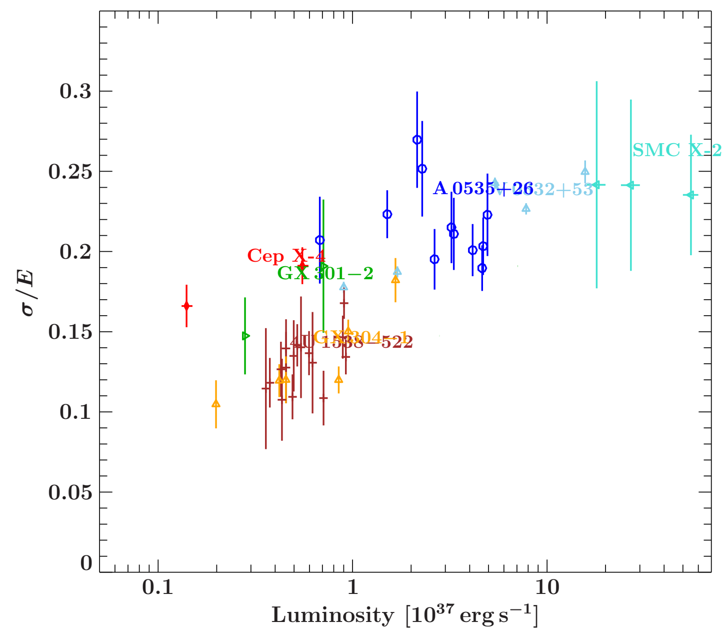
Cyclotron lines



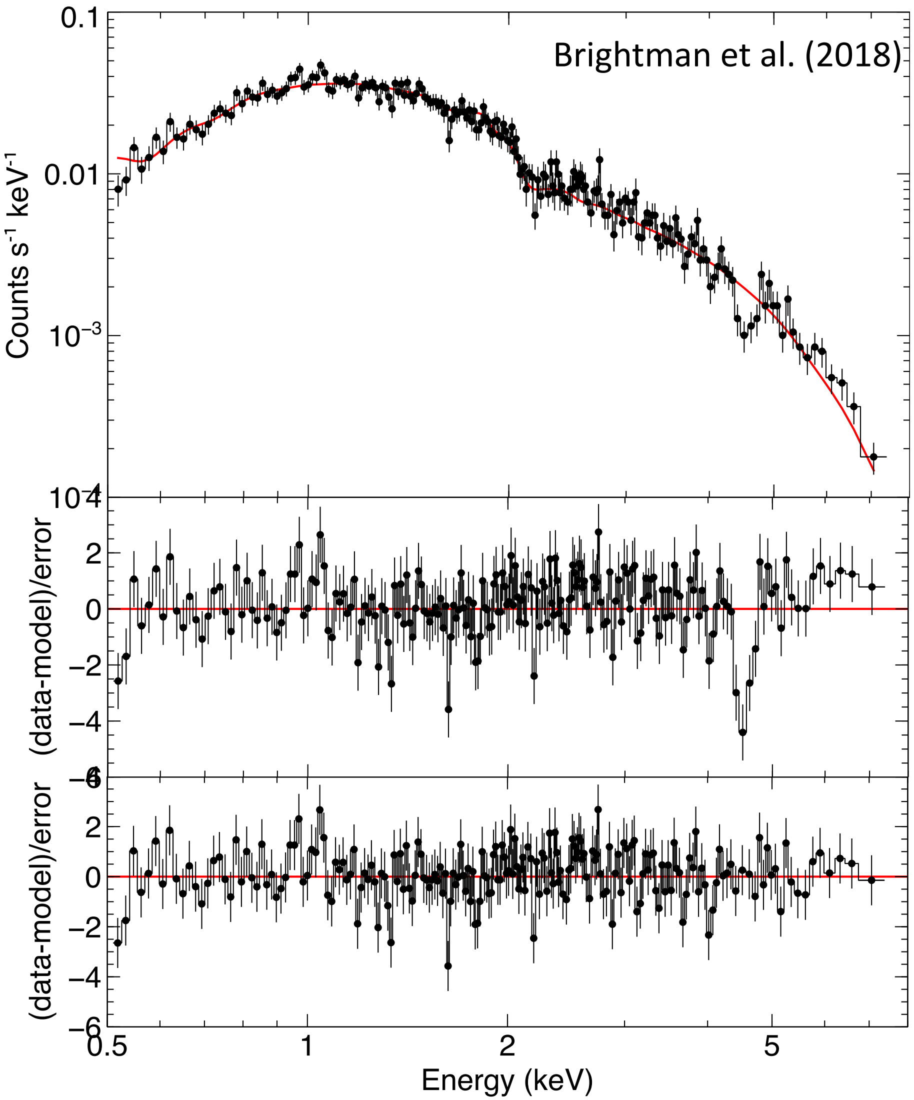
Broadening ratio:
ratio of intrinsic width to centroid energy =σ/E

For most observed CRSFs,
σ/E > 0.1

Observed line has
σ/E ~ 0.02



Cyclotron lines



Broadening ratio:
ratio of intrinsic width to centroid energy =σ/E

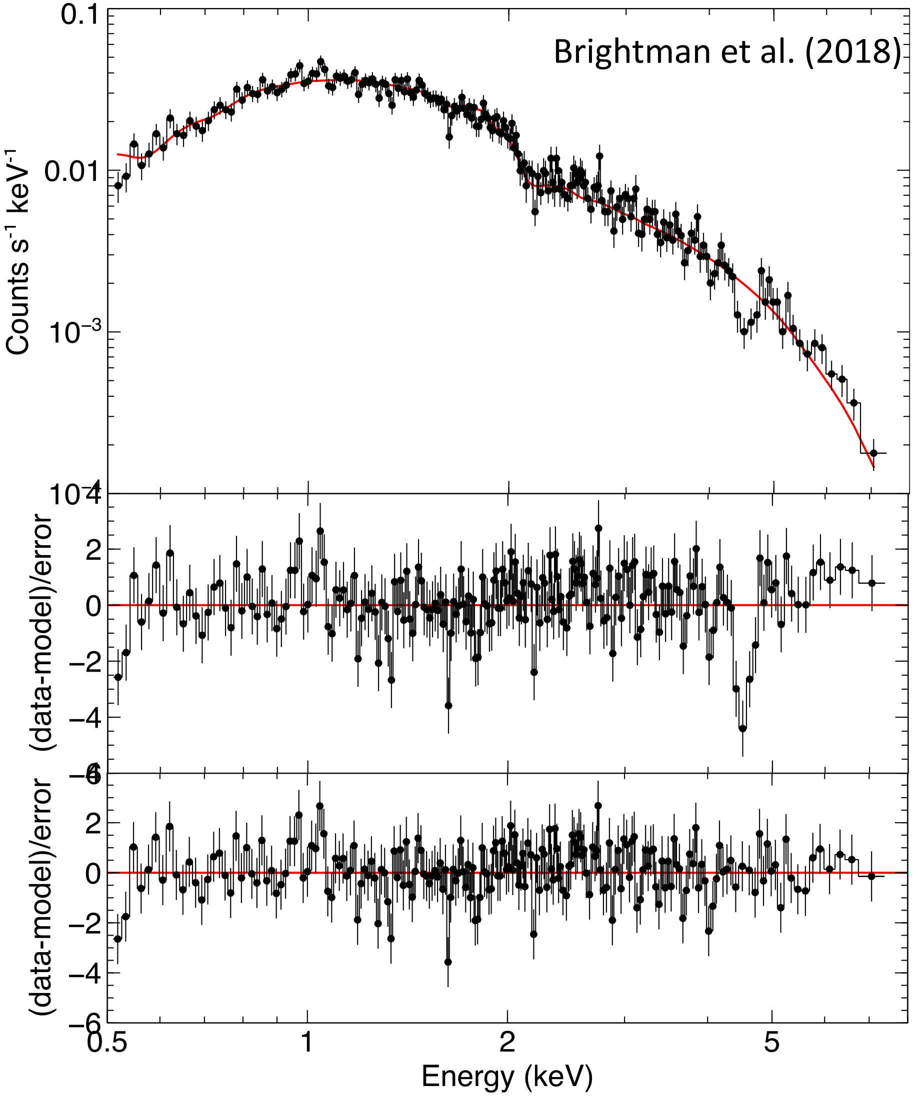
For most observed CRSFs,
σ/E > 0.1

Observed line has
σ/E ~ 0.02

Protons are more massive, and produce narrower lines.

Claimed in spectra of magnetar bursts: e.g. Ibrahim et al. (2002), Tiengo et al. (2013)

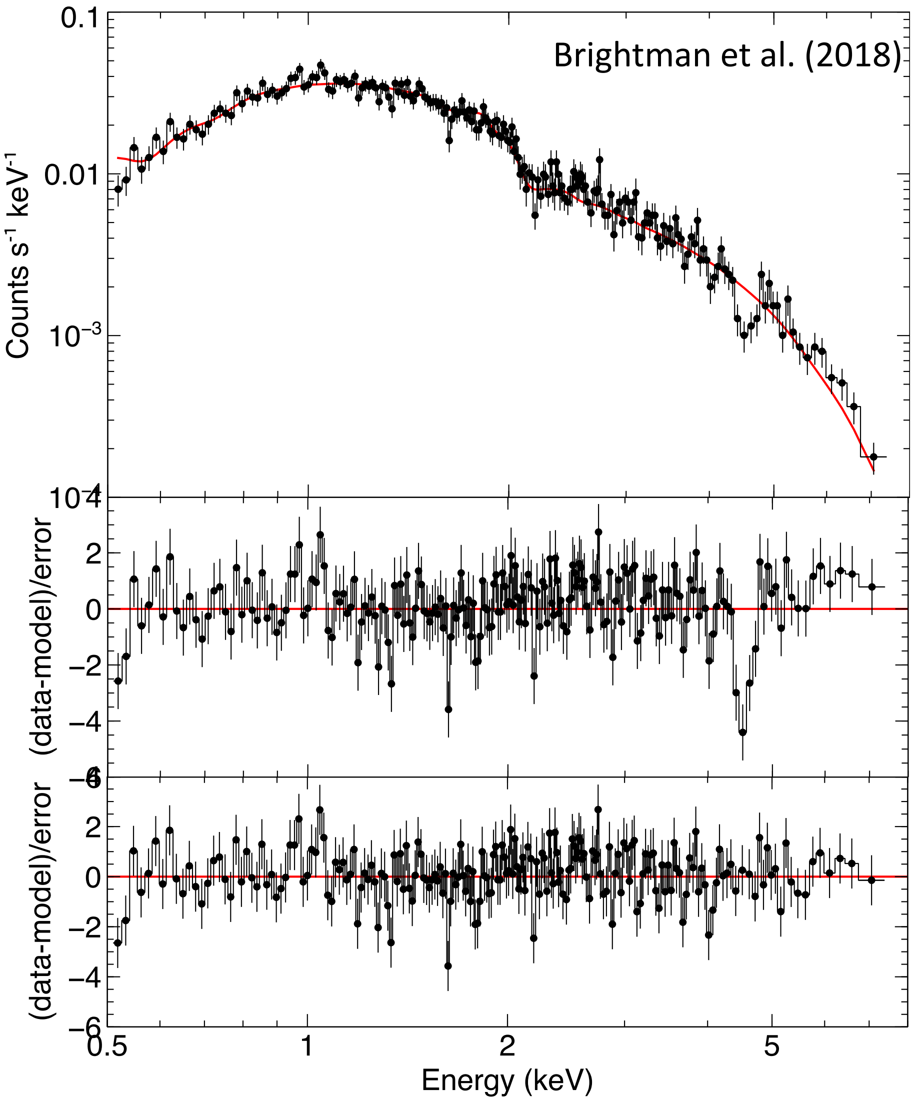
Cyclotron lines



E_{cyc}=($\hbar$e/mc)B

Assuming proton origin:
B= 7(1 + z) × 10^{14} G

Proton CRSF at 4.5 keV?



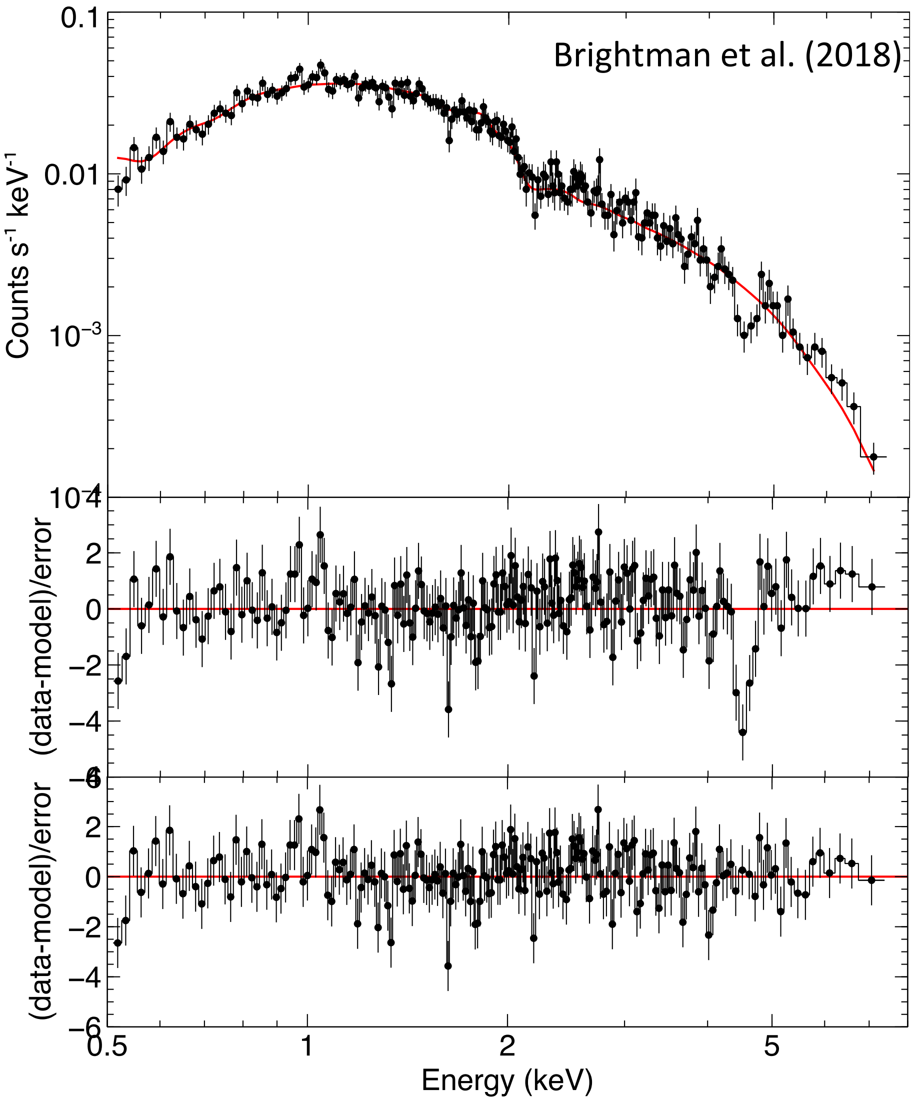
Implies an ultra-strong magnetic field strength close to the surface of the NS

Would significantly reduce electron scattering cross-section and increase Eddington luminosity

More data required

- Detect pulsations
- Detect harmonic lines

What can we learn from high resolution spectroscopy?



Obtain detailed line shape

- Yield clues regarding the magnetic field geometry

Detect harmonic lines

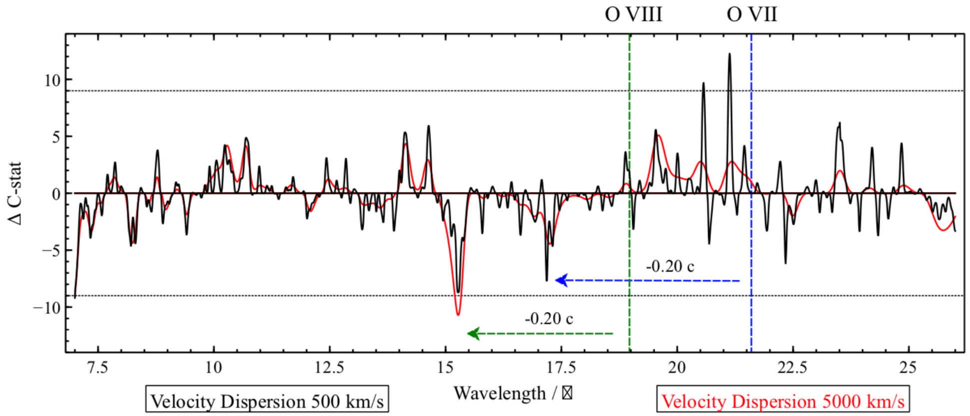
- Confirm electron/proton origin

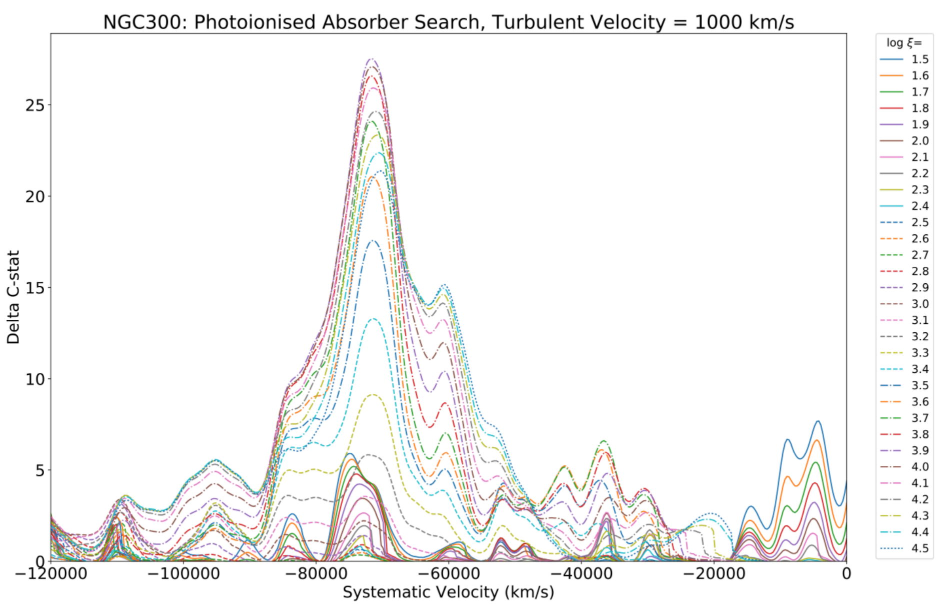
Detect similar lines in other sources that may be too narrow to detect with CCD resolution

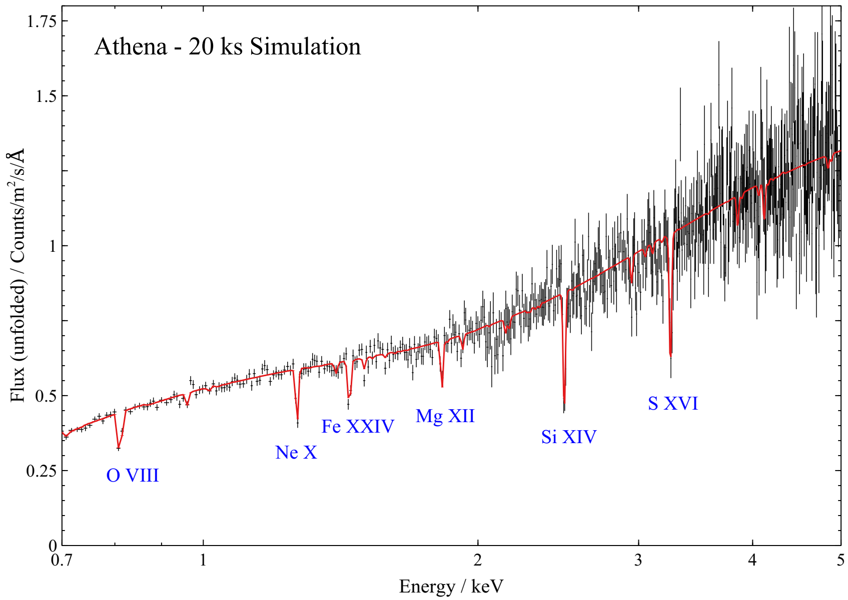
What can we learn from high resolution spectroscopy?

Measure ultra-fast outflows

NGC 300 ULX1 (Kosec et al. 2018)







Summary

- Neutron stars powering ultraluminous X-ray sources can be identified from the detection of cyclotron lines
- These lines may be narrow and observable with high-resolution spectrometers below 10 keV
- Line studies could potentially reveal details about the magnetic field strength and geometry