

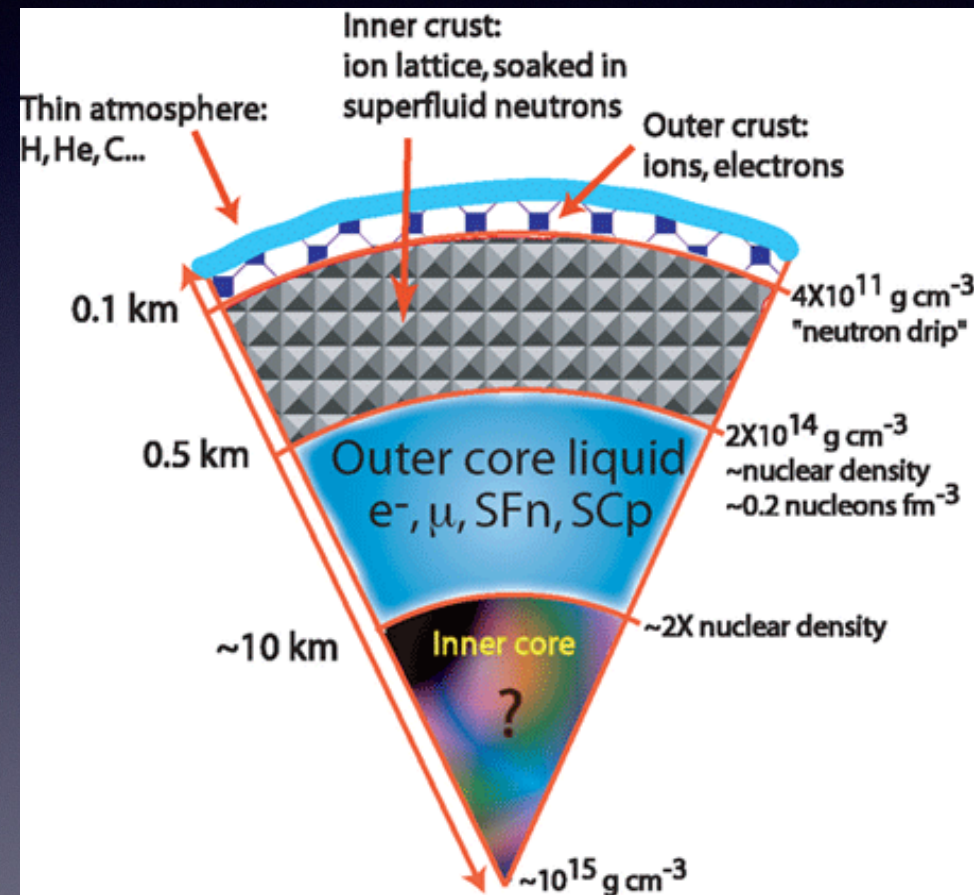
Prospects for measuring the neutron star equation of state with high resolution spectroscopy

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University of Alberta
XCALIBUR 2019, Winchester, UK

Physics of Dense Matter

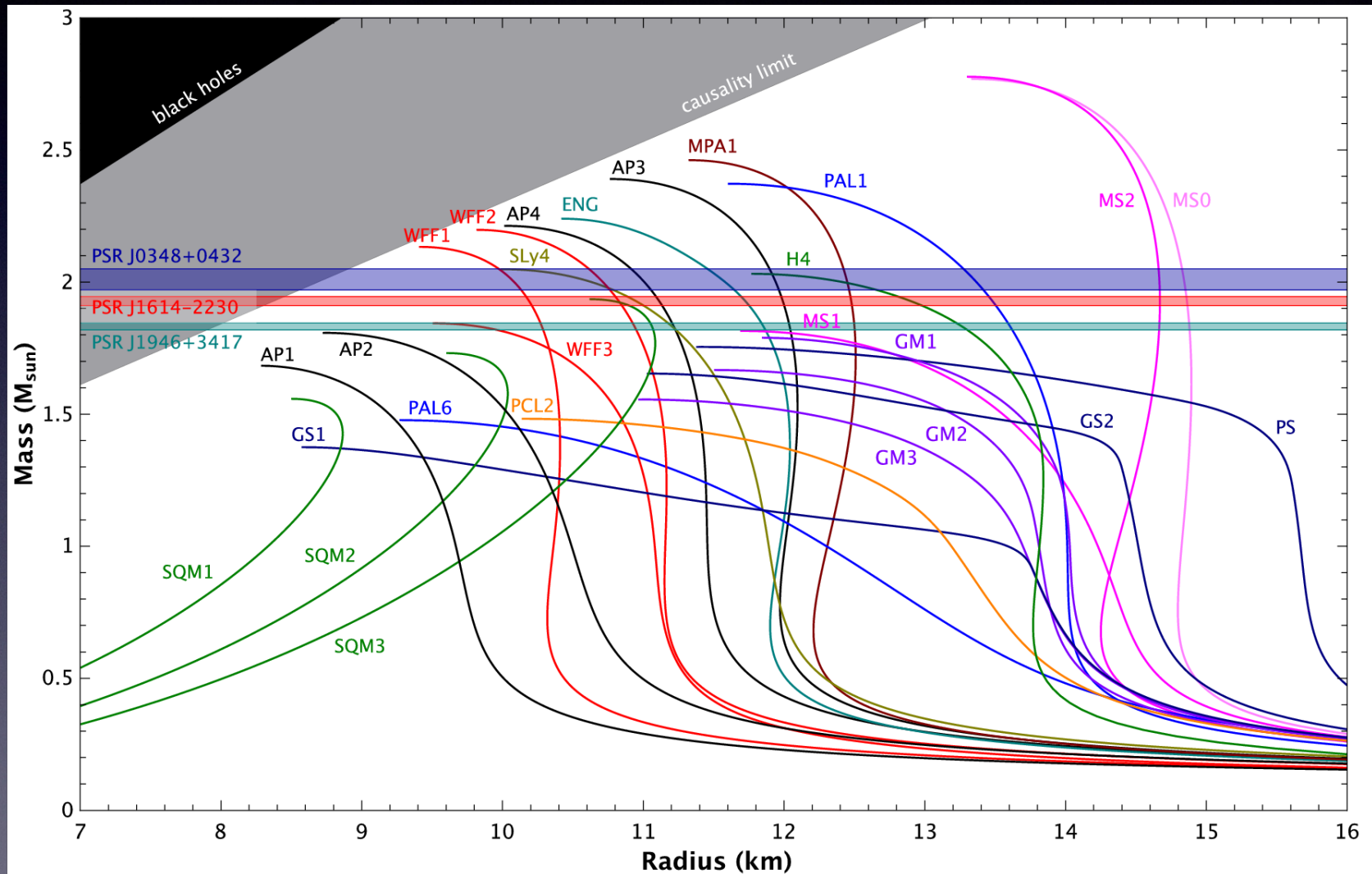
- Behavior of quarks at high densities unclear;
“stiff” repulsion?
Rearrange into exotic particles (pions, hyperons)?
Dissolve hadrons in sea of free quarks?
- Need experiments; NSs only option

Neutron Star Structure



by Bennett Link

Equations of state



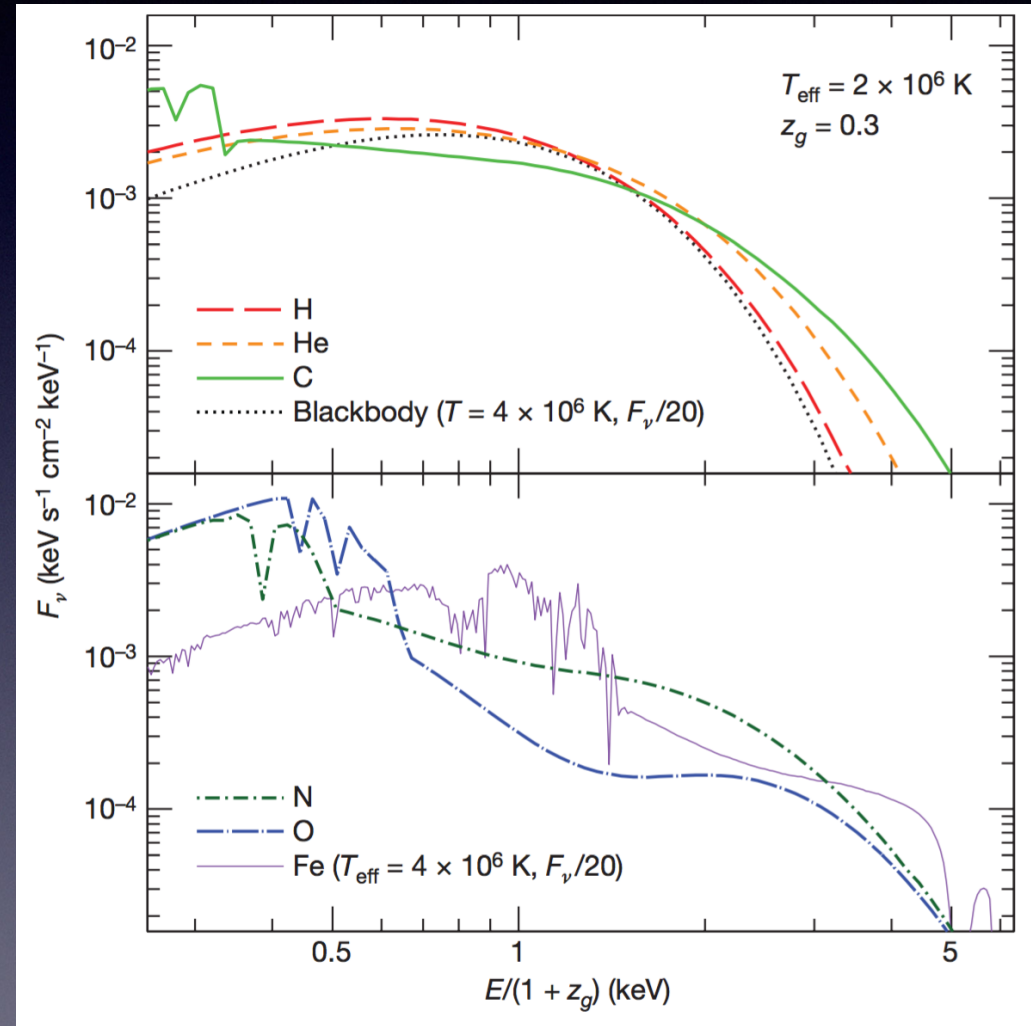
N. Wex

How to get NS radius?

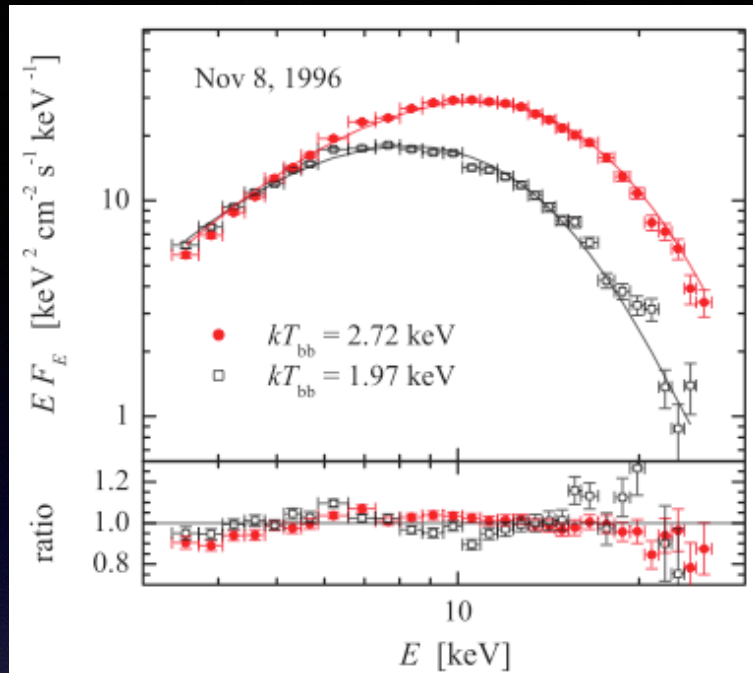
- Blackbody-like radiation: temp, emitting angle (X-ray bursts, quiescent NSs)
- Pulse profile; lensing (NICER)
- Moment of inertia (double pulsar)
- NS 'squeeze'-ability (LIGO/VIRGO)
- Redshift of spectral lines or edges

Atmosphere spectra

- Atmosphere rapidly stratifies, lightest on top
- Light element lines not easily accessible
- Stir up atmosphere for heavy elements?

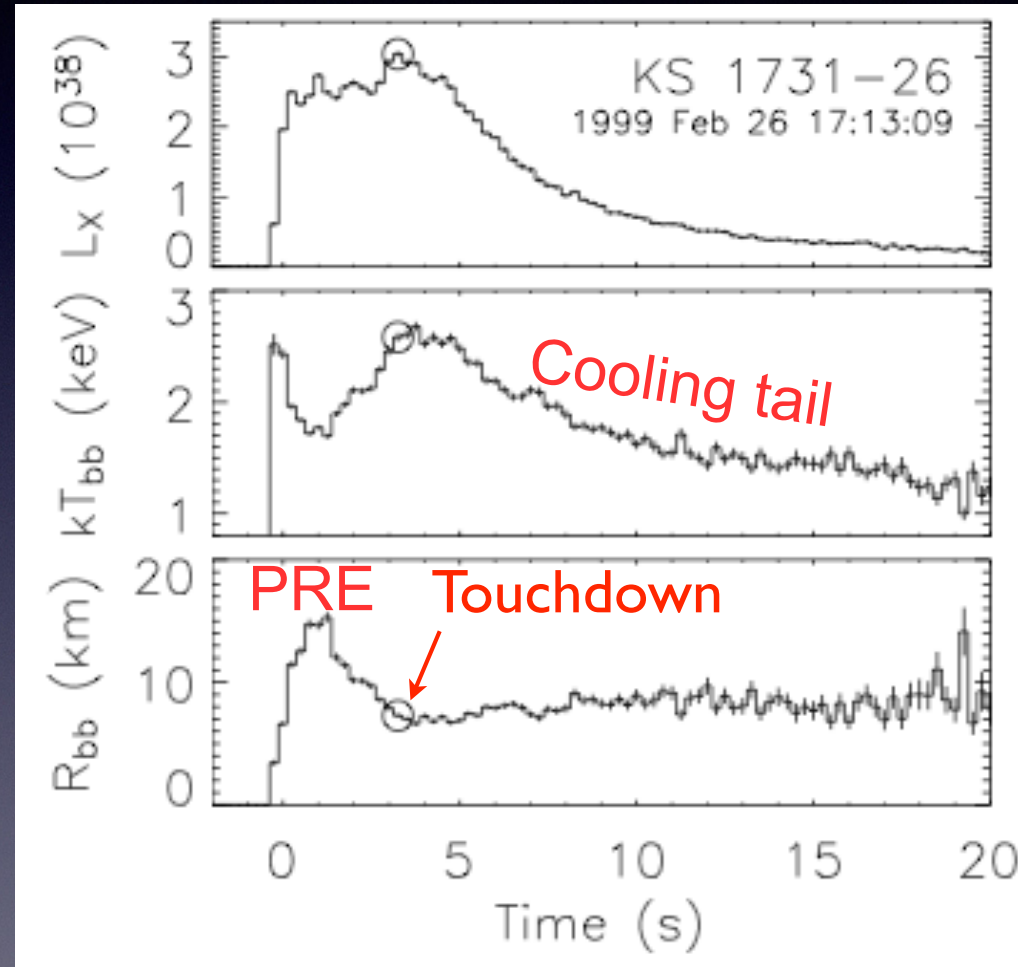


Ho & CH 2009



- Burning of He and/or H to heavy elements
- Blackbody-like spectrum
- If L high, radiation pressure expands photosphere.

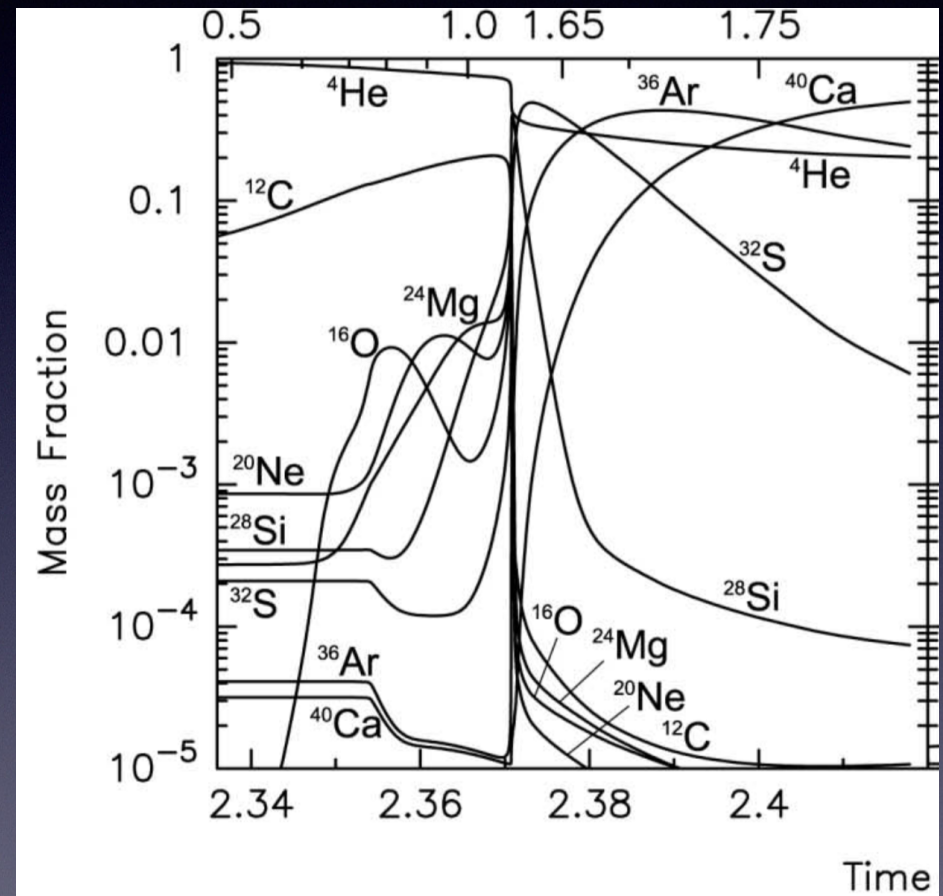
X-ray bursts



Galloway+08

Nuclear burning products

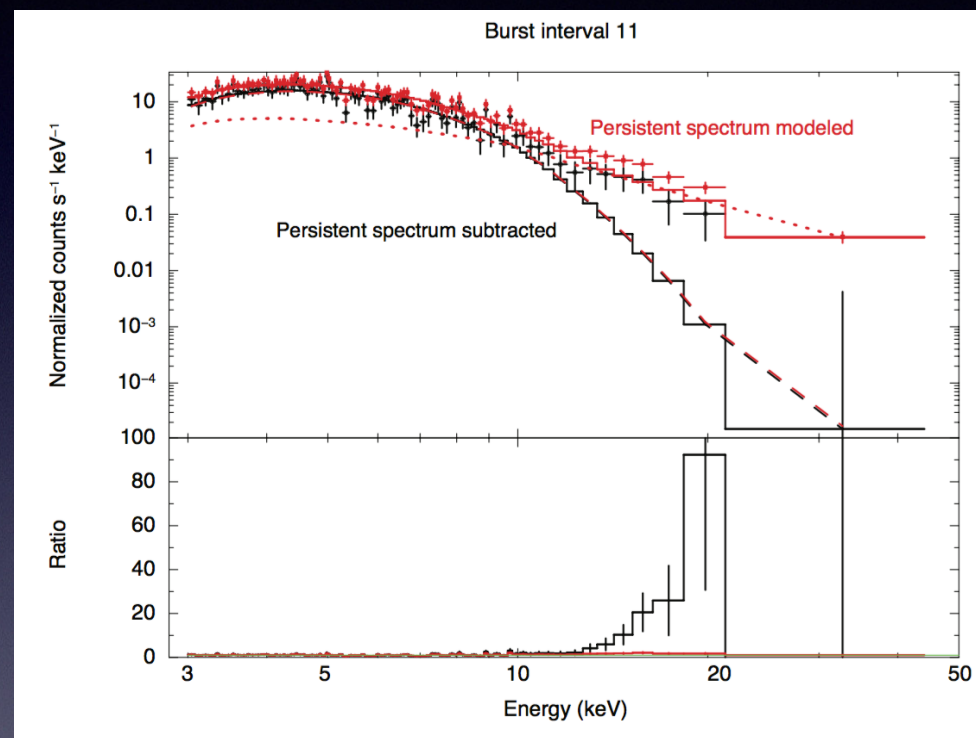
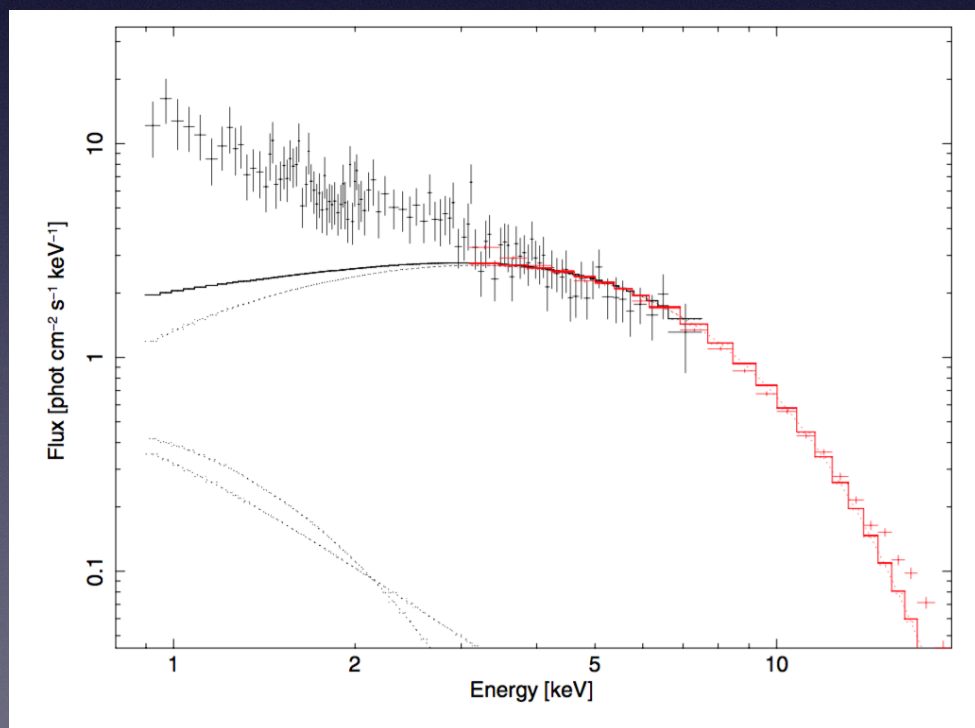
- Burst produces heavy elements
- Various models; predict $A \sim 20-30$ (Si, S, Ar, Ca) & $A \sim 50-60$ (Fe, Zn)
- Mostly hidden; burst convection may bring up to surface



Weinberg+06, burst
composition

Complexities: Accretion

- Changes in accretion flux during burst (Worpel+13)

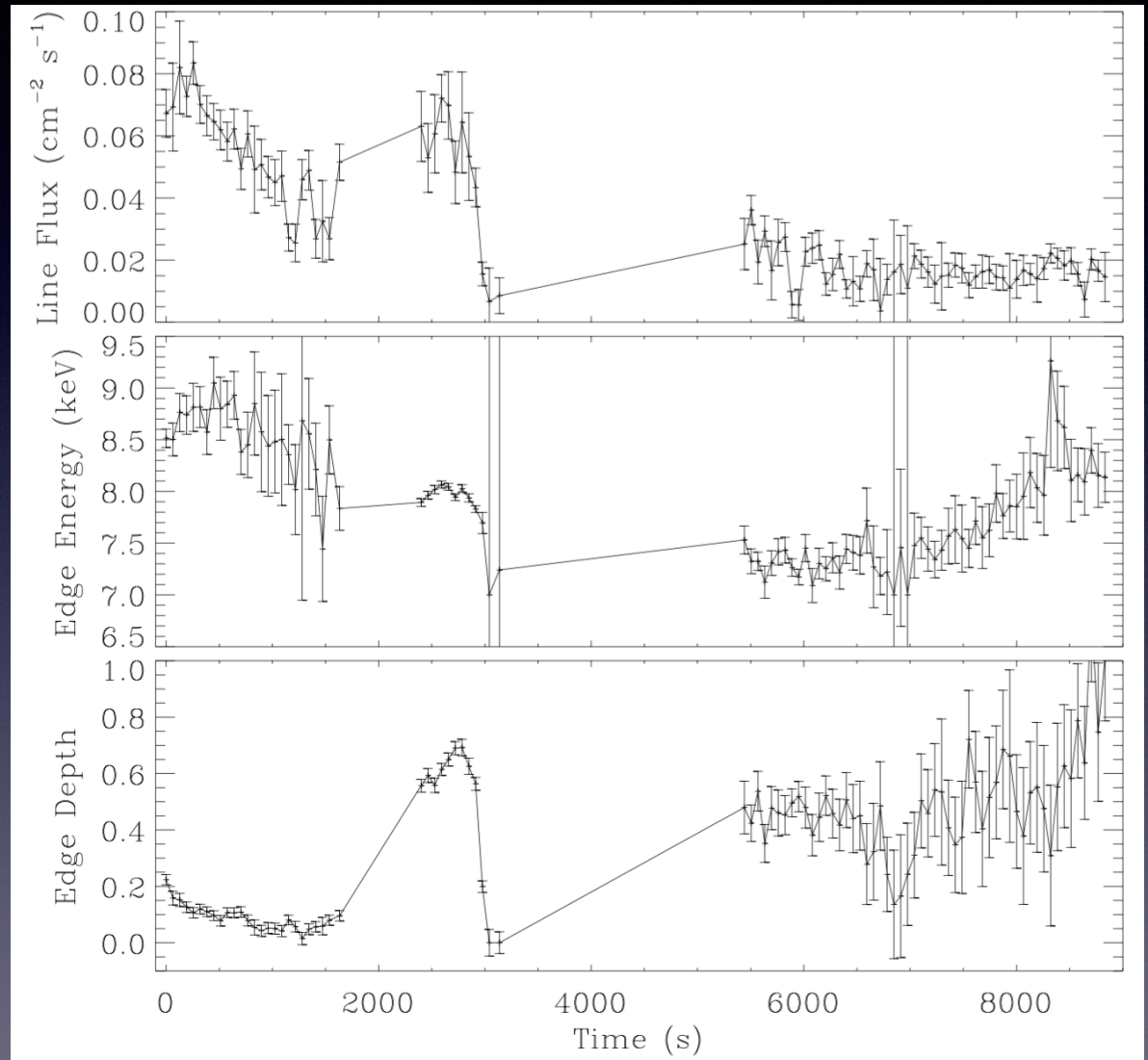


Degenaar+16

in 't Zand+13,
fit burst w/BB

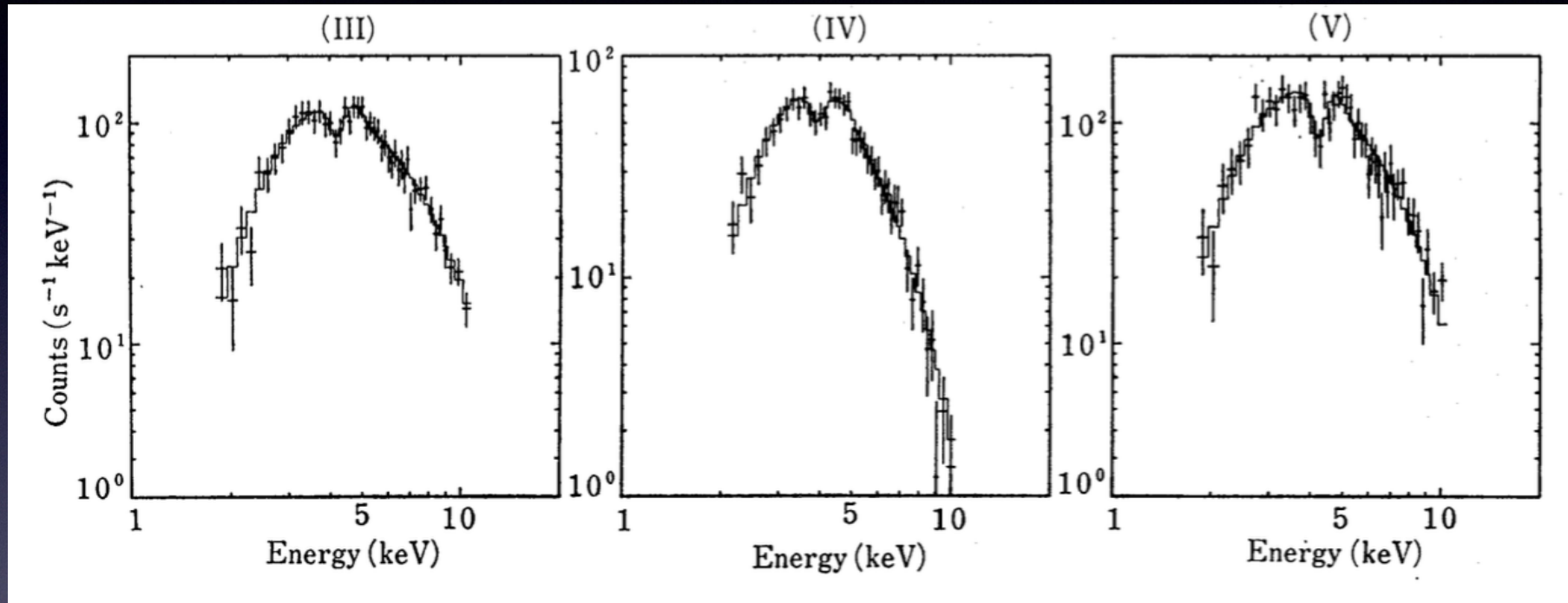
Complexities: Reflection

- Reflection features change;
Day+Done91,
Ballantyne04



Strohmayer+Brown02

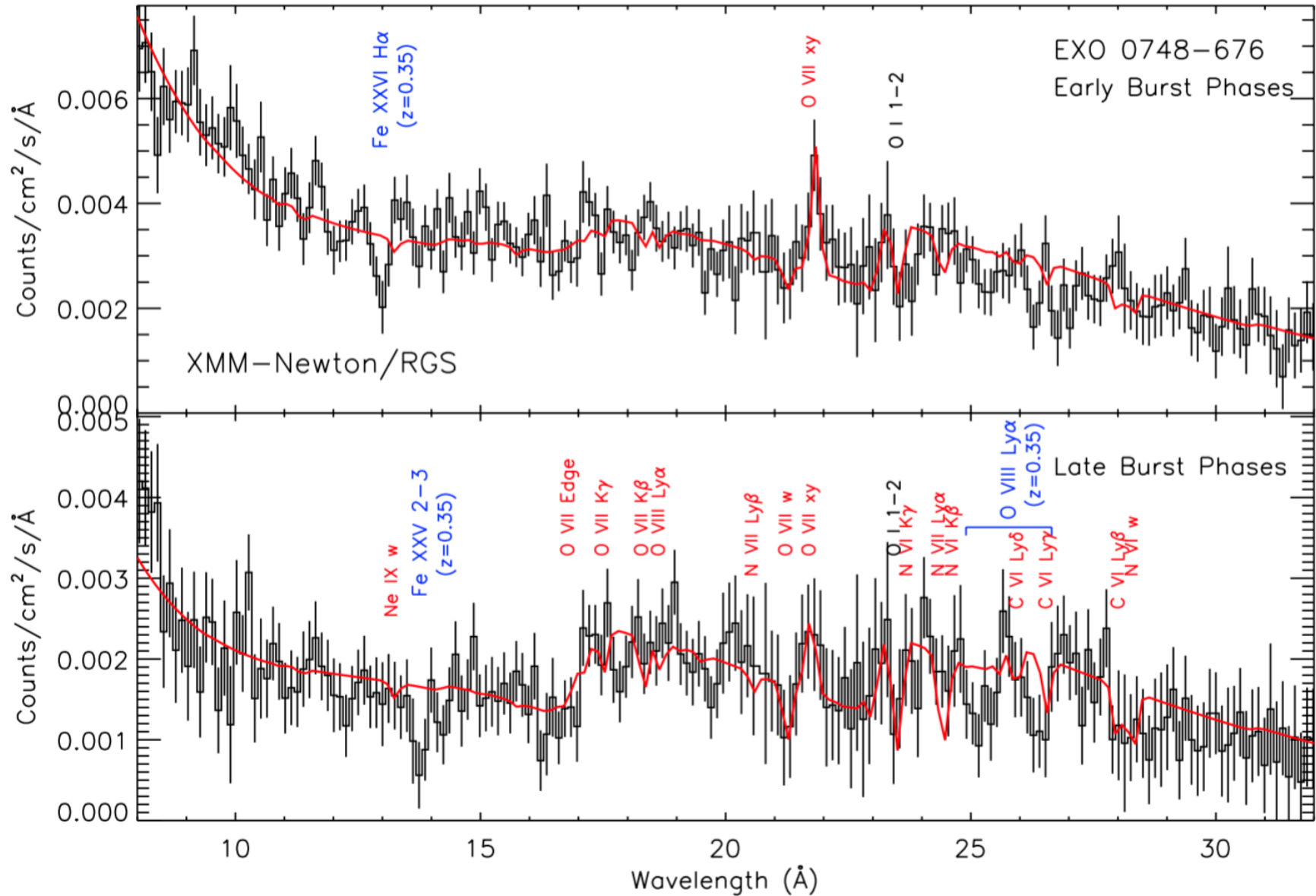
Lines in bursts?



Waki+84, Tenma on 4U 1636-536

Not seen in later ASCA burst data
(Asai+98)

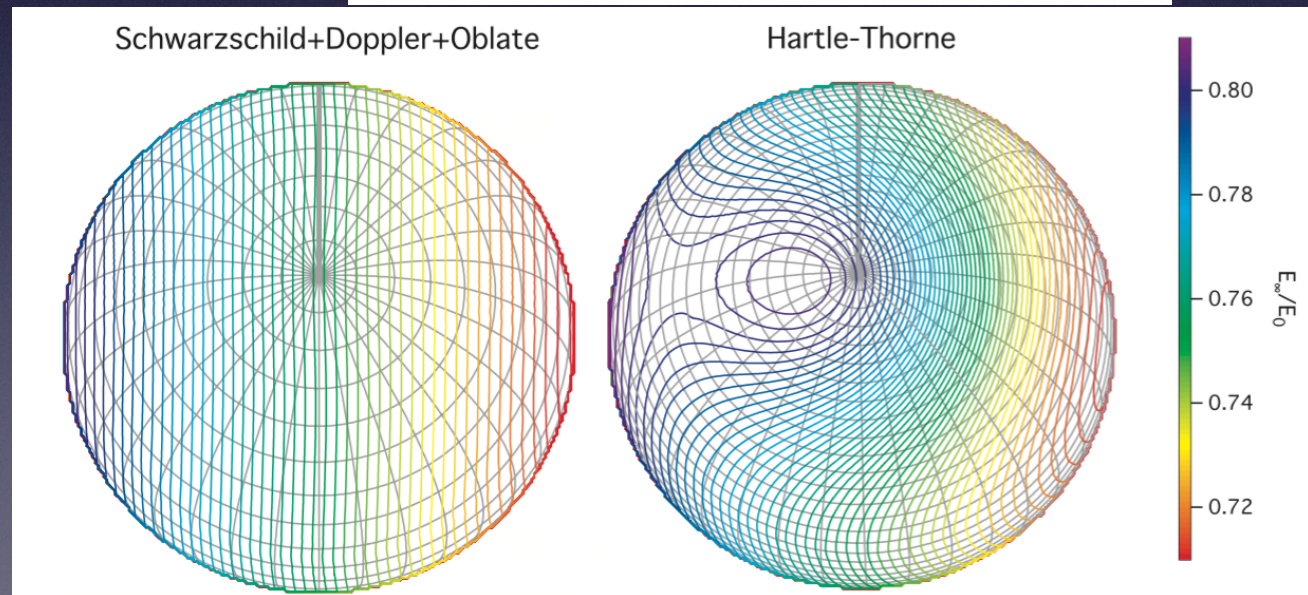
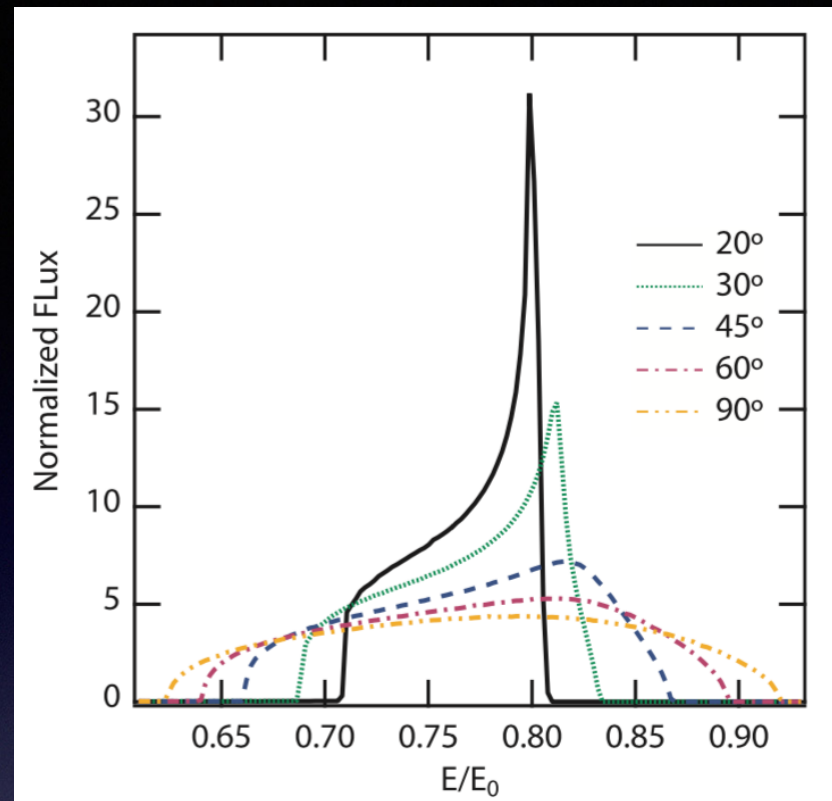
Lines in bursts?



Cottam+03

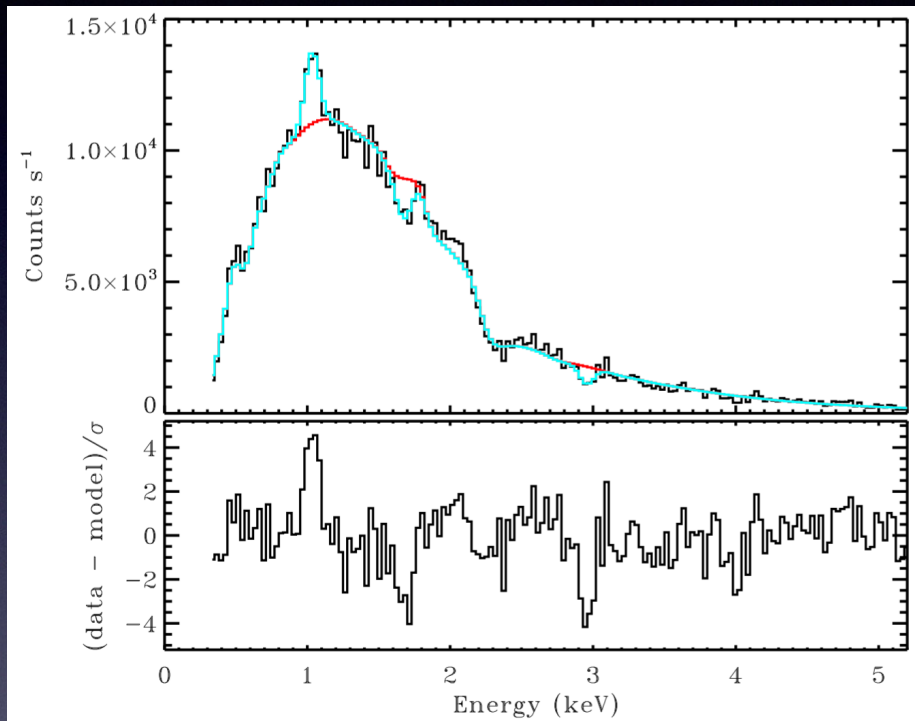
Line shape

- NS rotation broadens;
+/-25% @700 Hz
- But, narrow core appears at low i



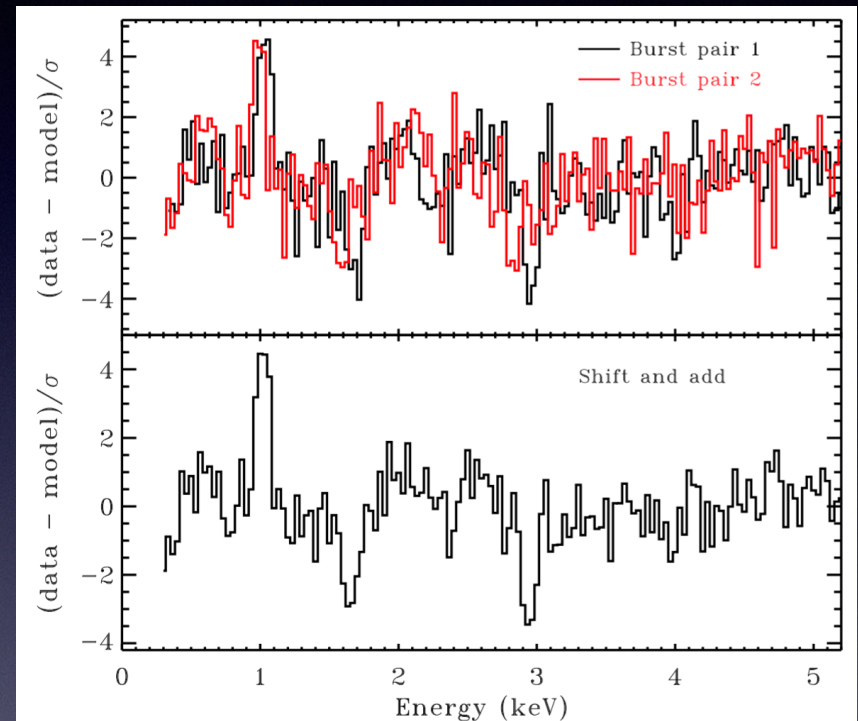
Baubock et al. 2013; 700 Hz NS

Lines in bursts!



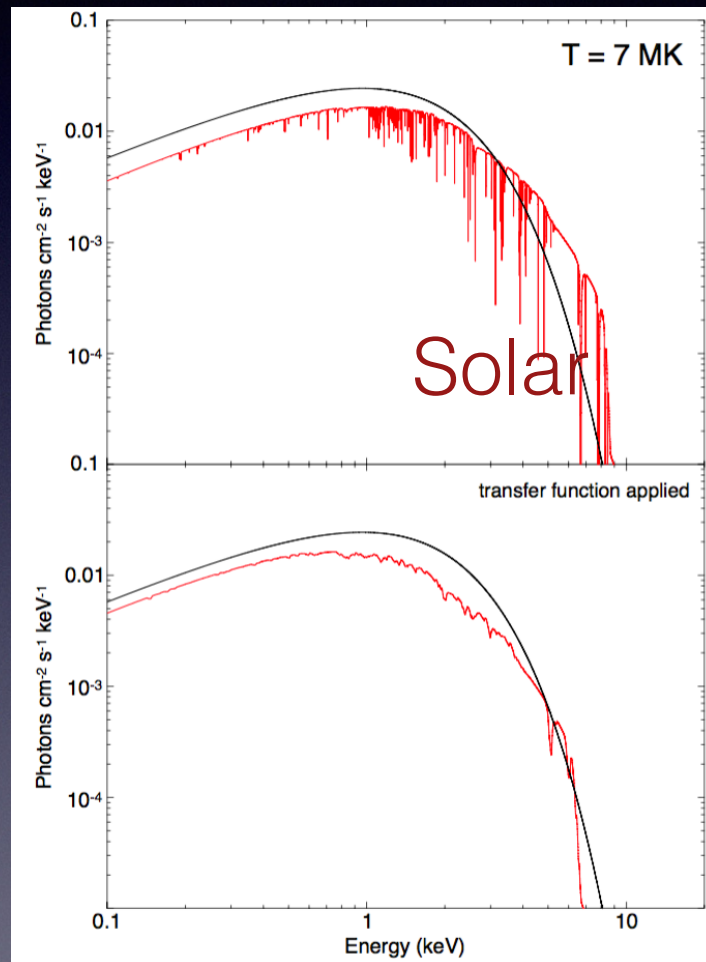
Strohmayer+19, NICER;
4U 1820-30 burst peaks

Winds? 1 keV Fe or Ne?; 1.7 S?; 2.9 Fe?

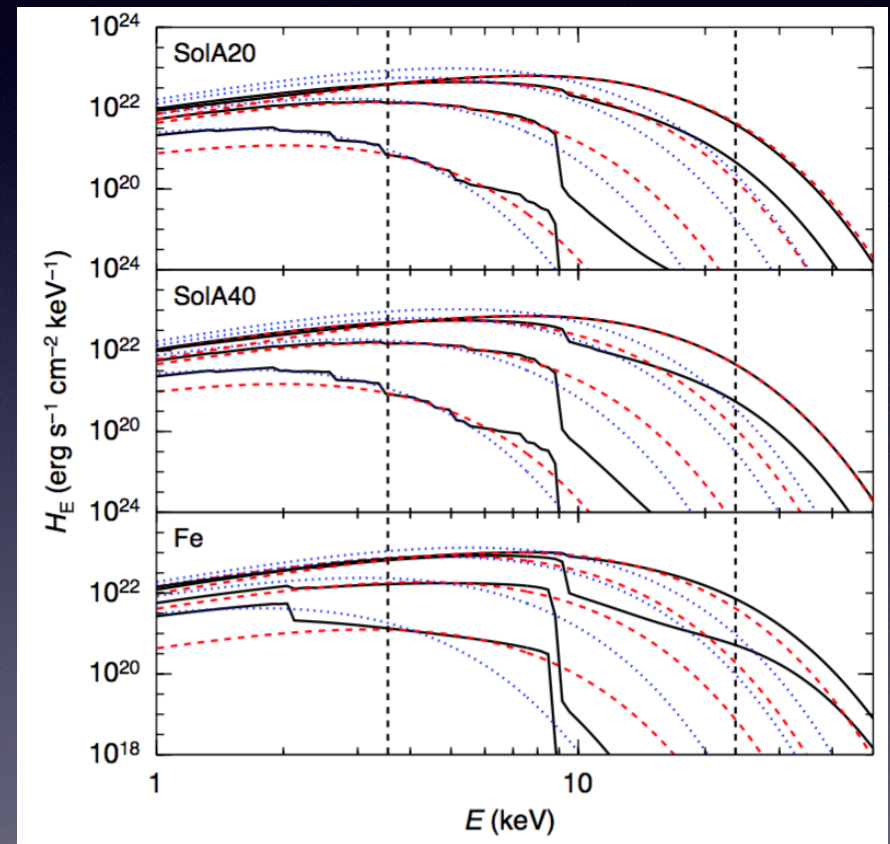


Strohmayer+19; lines
in many bursts; E shift

Model atmospheres

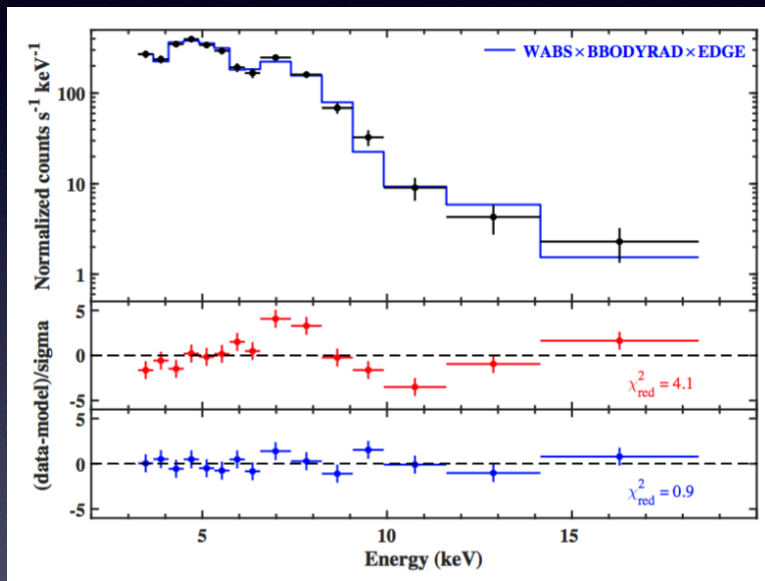


Yoneda+17

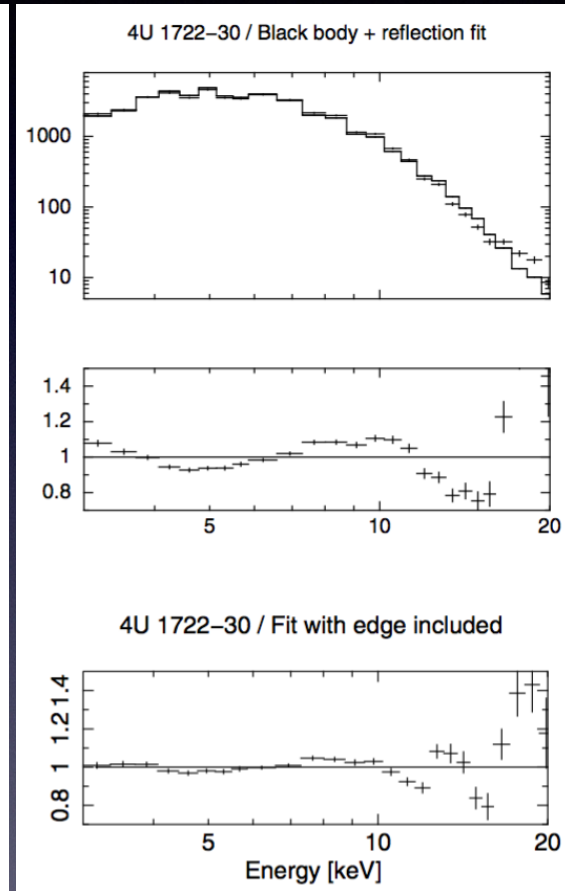
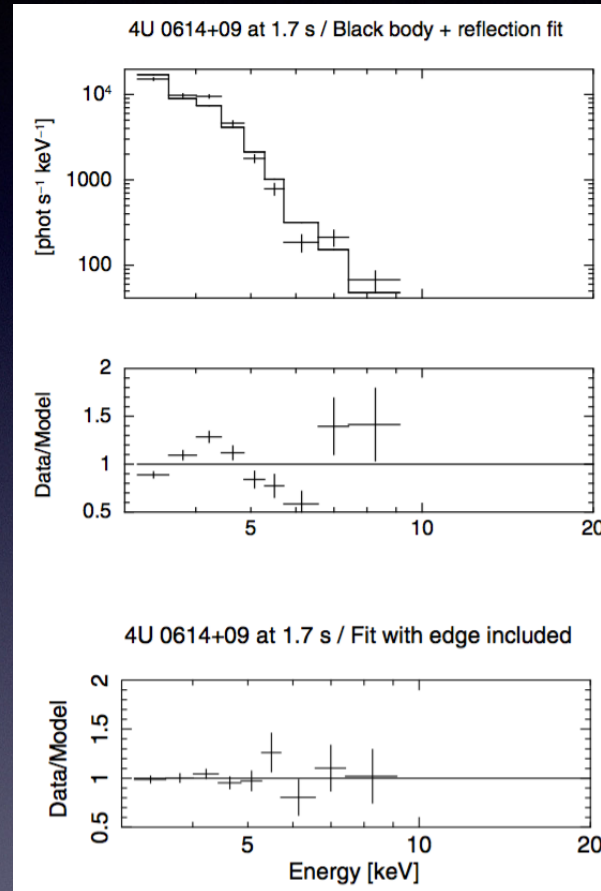


Nattila+15

Nuclear burning ashes?



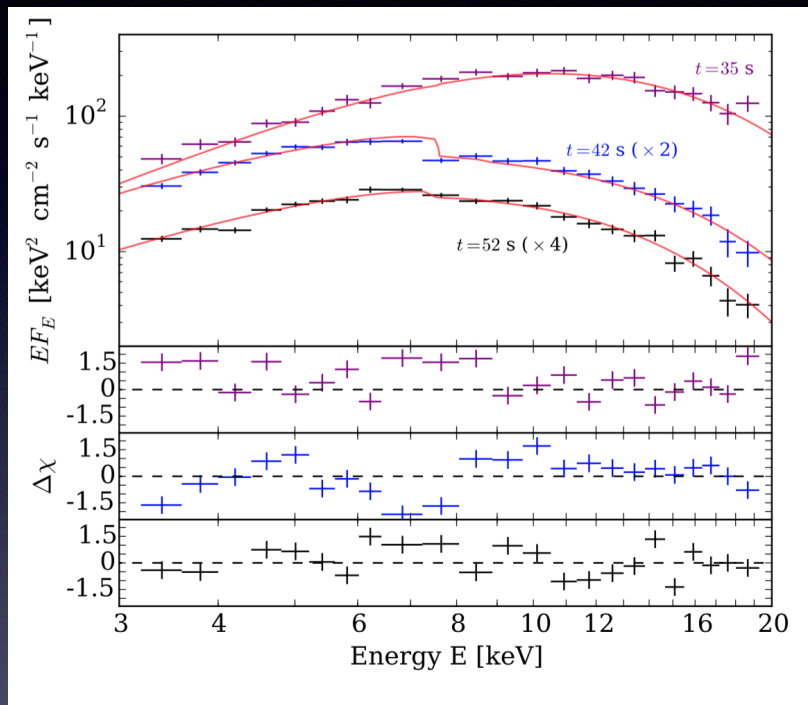
Li+18, Terzan 6
BB (red), w/edge (blue)



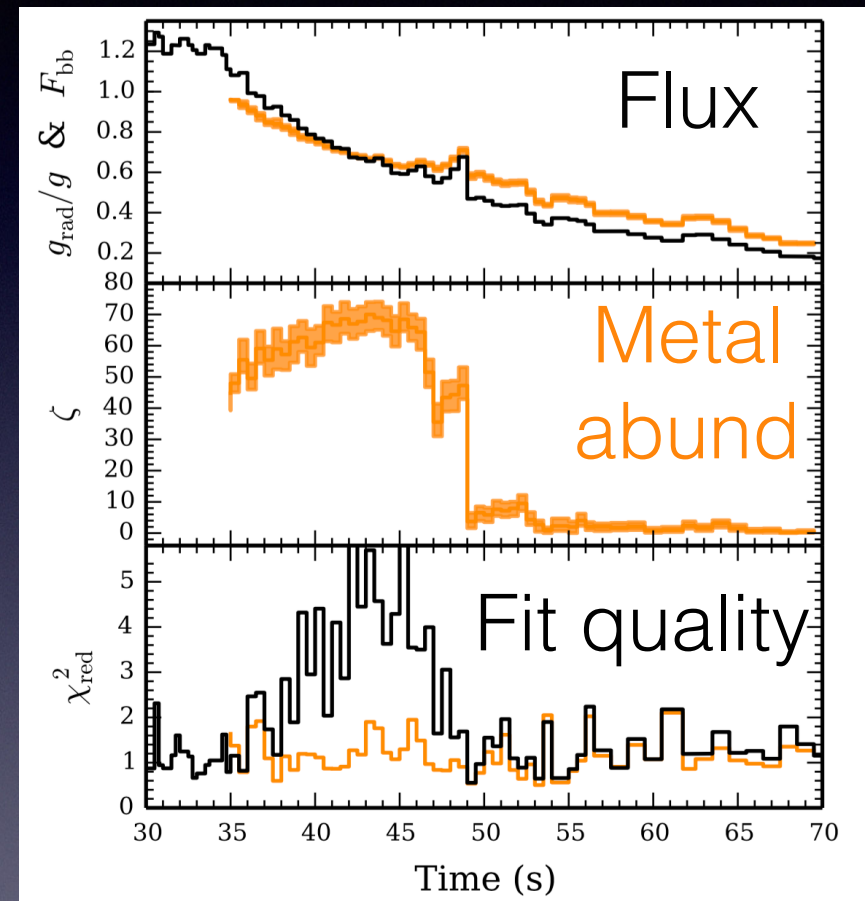
in 't Zand+10

Edges evolving $\sim 6-11$ keV; common in strongest bursts

Nuclear burning ashes?



Kajava+16; burst spectra
HETE J1900.1-2455



Kajava+16, burst models

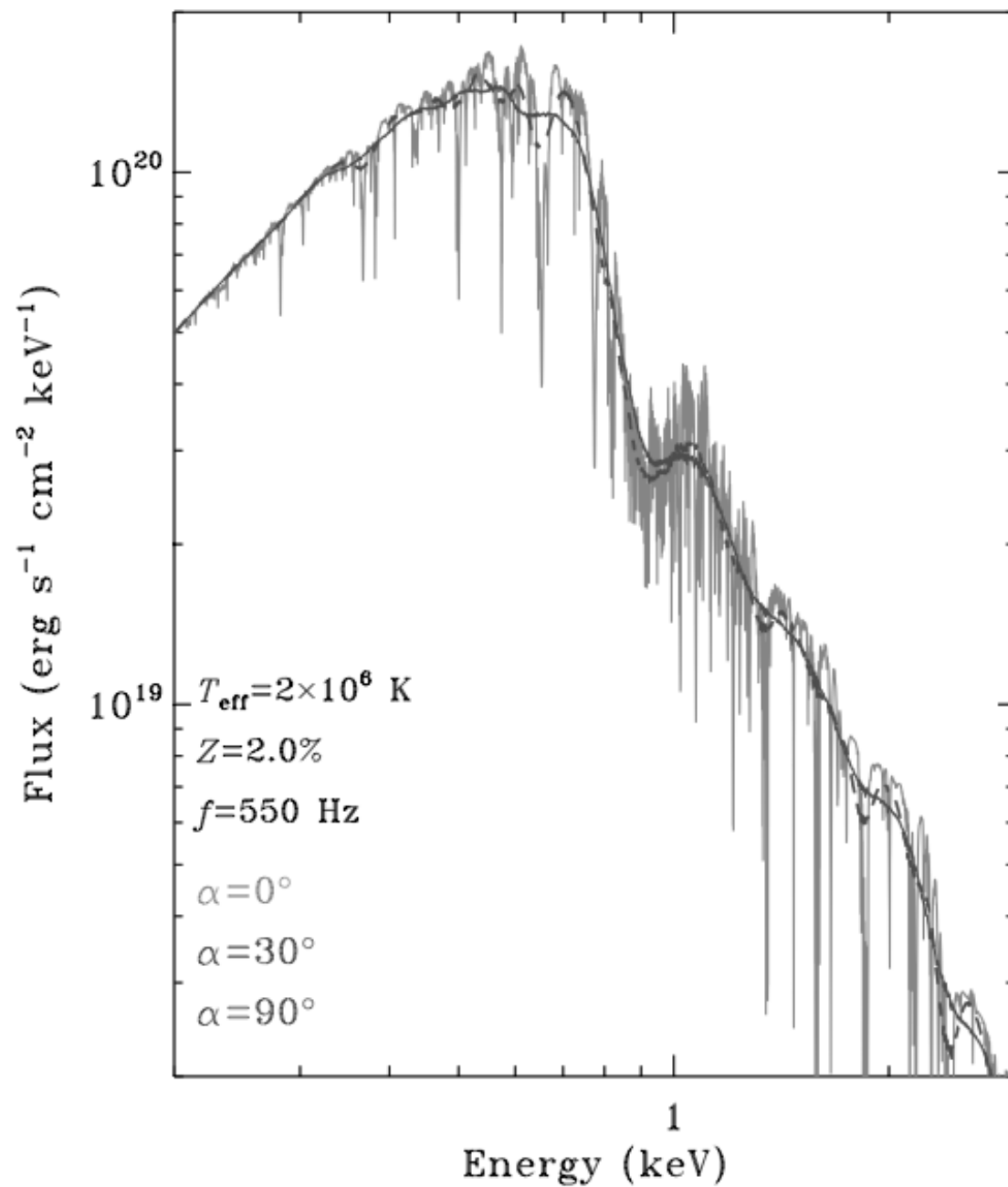
Future

- High-res spectra:
Multiple lines & edges identify elements
Measure redshift, constrain R
- Chandra, XMM eff. area too low
- Rate too high for XRISM
- ATHENA, Colibri
Need to catch rare bursts

Conclusions

- Lines, edges from NS surface constrain dense matter
- Some X-ray bursts show lines & edges
- Need higher spectral resolution, lots of observing time, high data rates

Extra slides



Rutledge+02a, solar-metallicity model
of quiescent LMXB

Study with HETG?

- Resolve 1.7 keV feature in HETG spectra?
- Simulated 7 s (5 bursts, 2 MEG arms); 50-200 ks?

