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Testing the Impact of Surface Temperature Inhomogeneities on Quiescent NS's Mass/Radius Determinations

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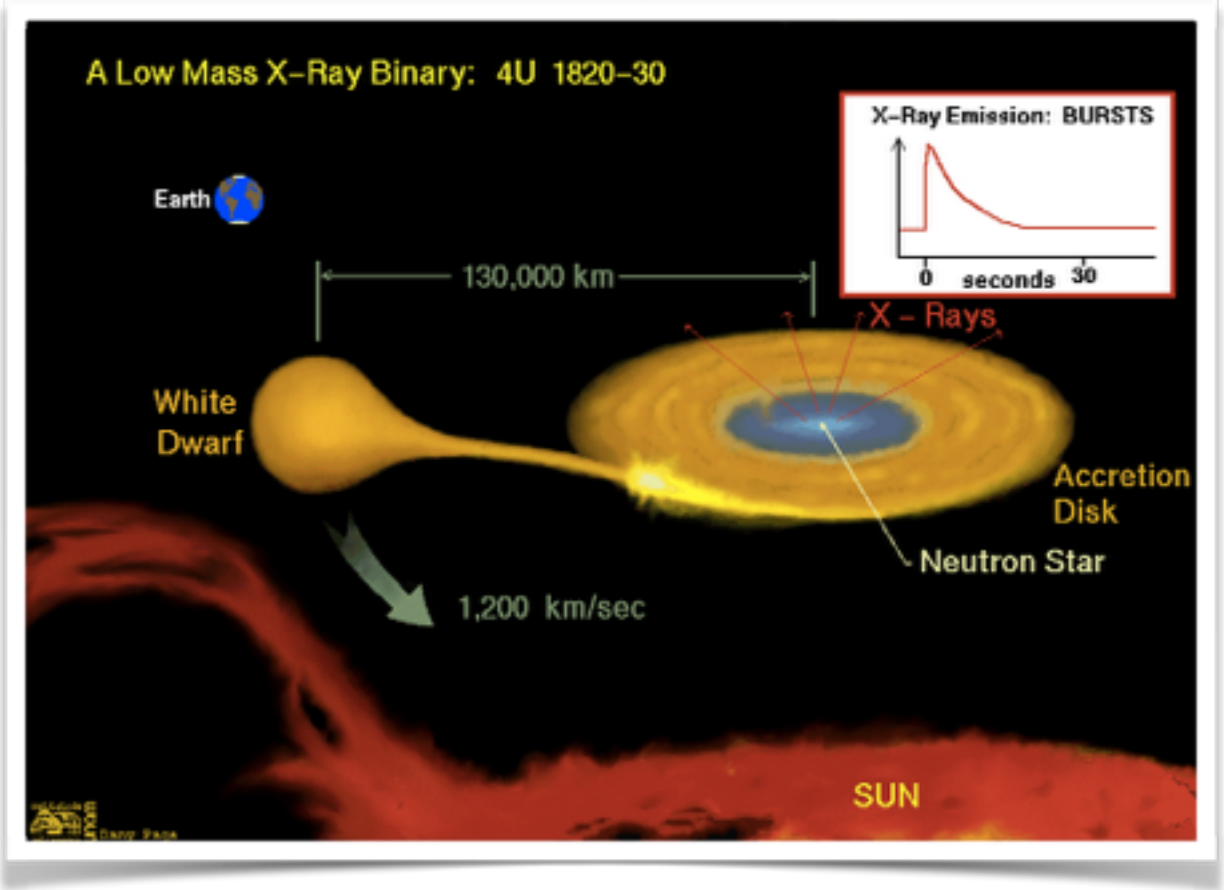
Quiescent low mass X-ray binaries (qLMXBs)

- *M* and *R* of NSs can be constrained spectroscopically if *T*, *d*, atmosphere composition are known.
- Transient LMXB in quiescence can fulfill these requirements.
- qLMXBs in globular clusters are great candidates, as their distance is well-known.
- Their spectra are generally composed of soft and *possibly* a harder component



Courtesy: D. Page

Hydrogen Atmosphere

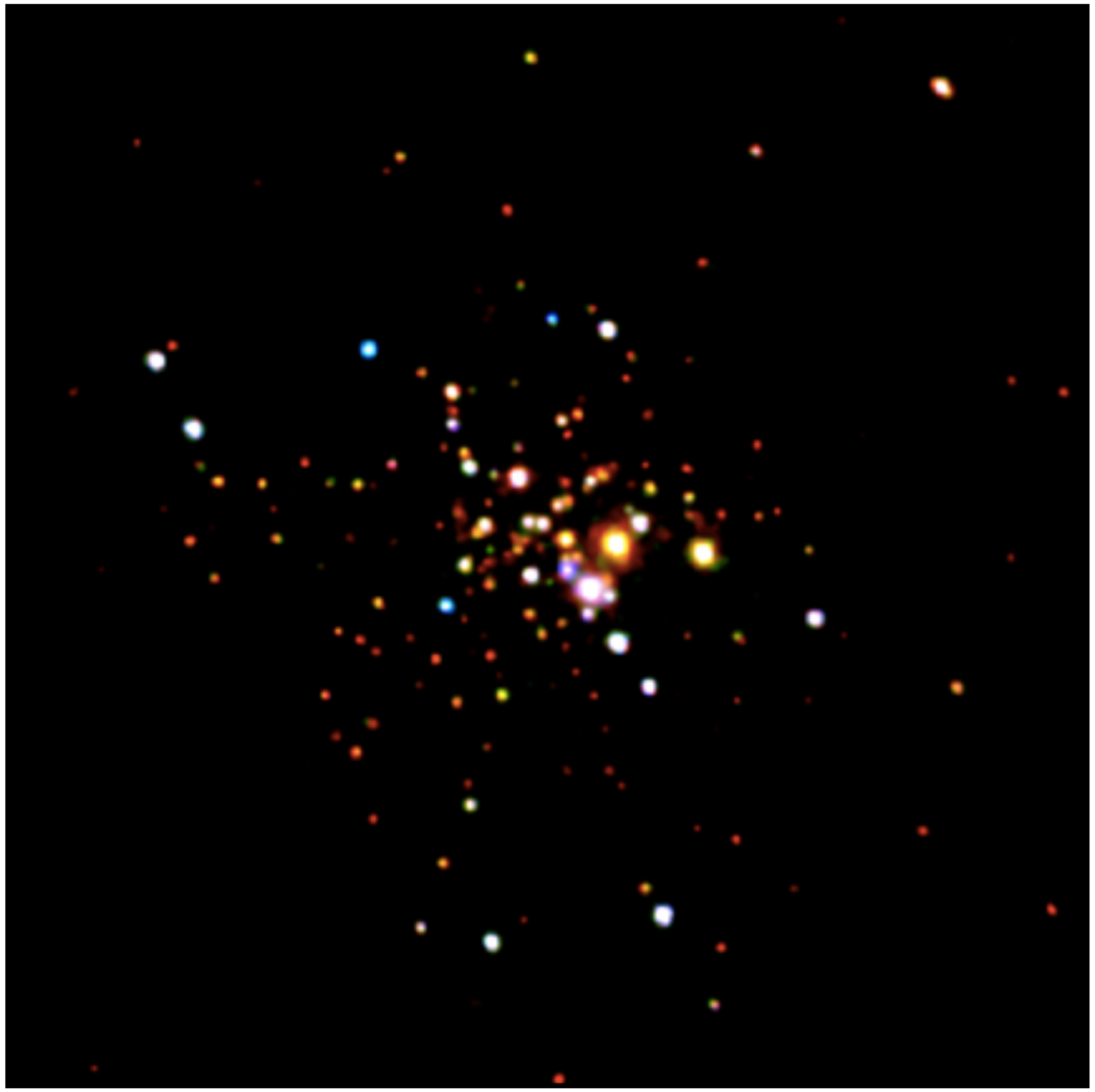
- Thermal component of spectra fitted with BB produces *too small* radii for a NS.
- The NS in qLMXB can develops a thin H-atmosphere, as the heavier metals settle out.
- Hydrogen atmosphere will *shift* the peak of the emitted radiation to higher frequencies. (Strong frequency dependence of free-free absorption). [Heinke+06], [Zavlin+96]
- Hydrogen atmosphere will concentrate the emitted radiation into the normal direction, causing *limb-darkening.*
- Therefore; H-atmosphere should result in a *greater* pulsed fraction than BB!

Polar Caps

- *Q:* What if we add hot spot(s) on the NS?
- Can be formed by heated spots from accretion.
- This leads to temperature inhomogeneities on the NS surface.
- *Q:* What is the effect of this, combined with H-atmosphere, on what we see observationally?

47 Tucanae

- Distance is highly constrained (4.6 ± 0.2 kpc , low reddening (*E(B-V)*=0.024 ± 0.004)) [Richer +13]
- 23 known MSPs in 47 Tuc [Freire +03].
- Two interesting bright quiescent LMXBs (X5 and X7). Pulsation limits from deep 800 ks HRC Chandra observation.



Courtesy: CXO

X5 and X7 in 47-Tuc

3σ upper limits on the pulsed fraction

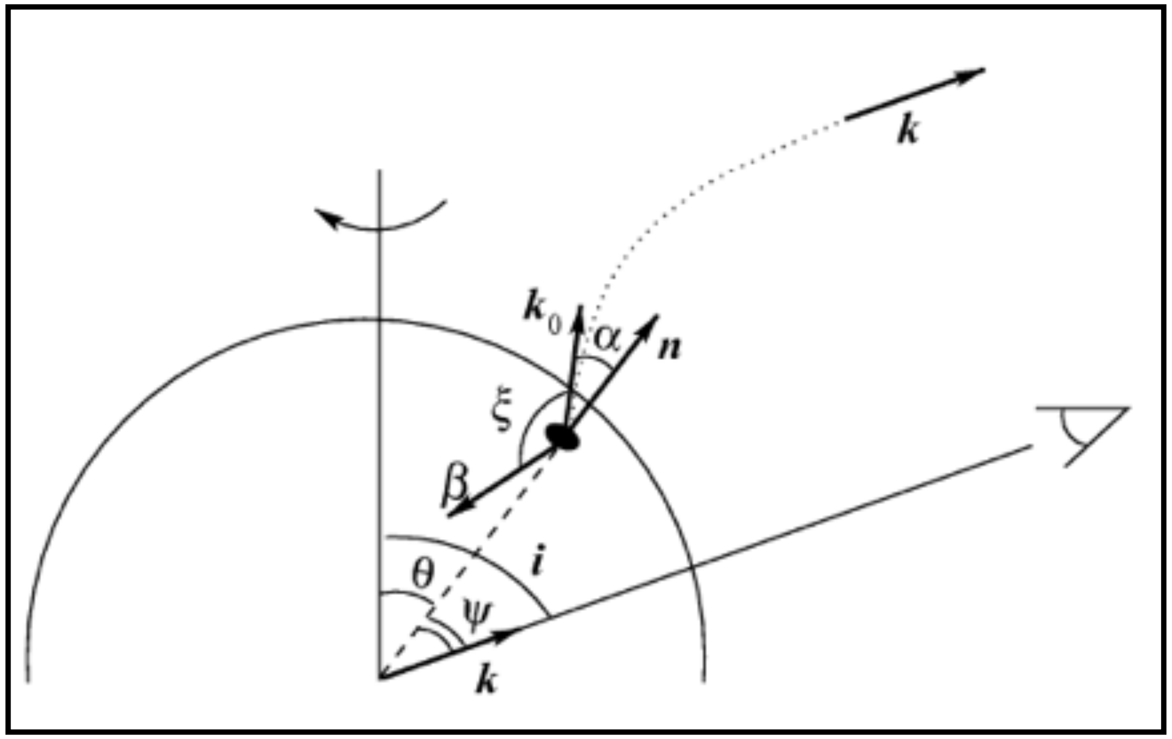
	X5		X7	
	W/O Acc.	***W/ Acc.***	***W/O Acc.***	***W/ Acc.***
	17.4%	18.9%	16.1%	17.5%

$$PF = \frac{F(\phi)|_{\mathtt{max}} - F(\phi)|_{\mathtt{min}}}{F(\phi)|_{\mathtt{max}} + F(\phi)|_{\mathtt{min}}}$$

- based on the 800 ks HRC data [Cameron+07], including acceleration searches.
- For spin periods >2 ms, the upper limits decrease to 17 & 16%, respectively.

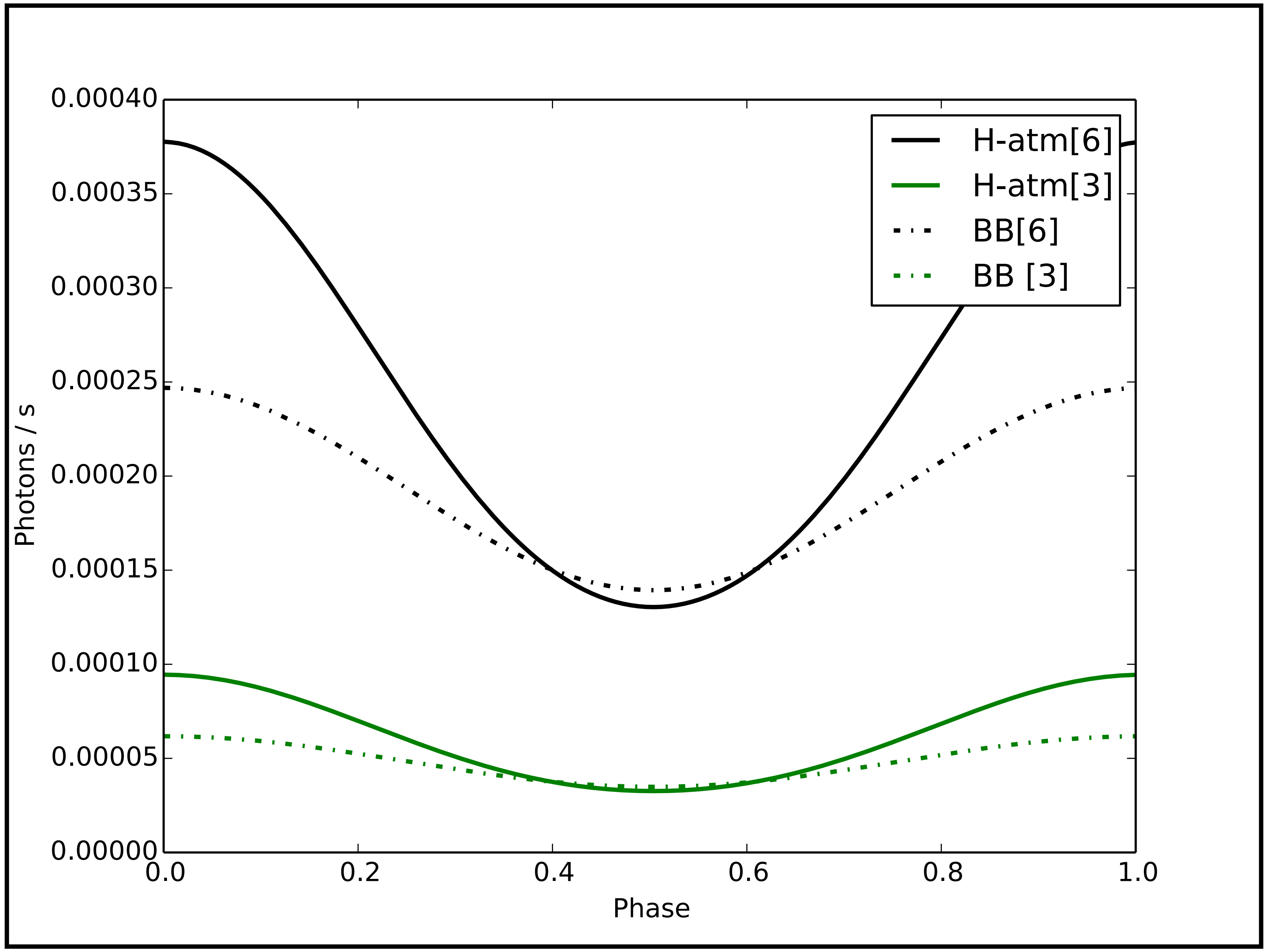
Simulation Method

- Assume photons originate at the NS surface.
- Specify radiation spectrum and angular dependence (H-atmos) in the co-rotating frame.
- Follow photon trajectories in Schwarzschild metric to a non-rotating observer at infinity.
- We account for SR effects, gravitational redshift and light-bending.



[Poutanen&Gierlinski 03]

H-atmosphere Light Curves



$M = 1.6\ M_s$

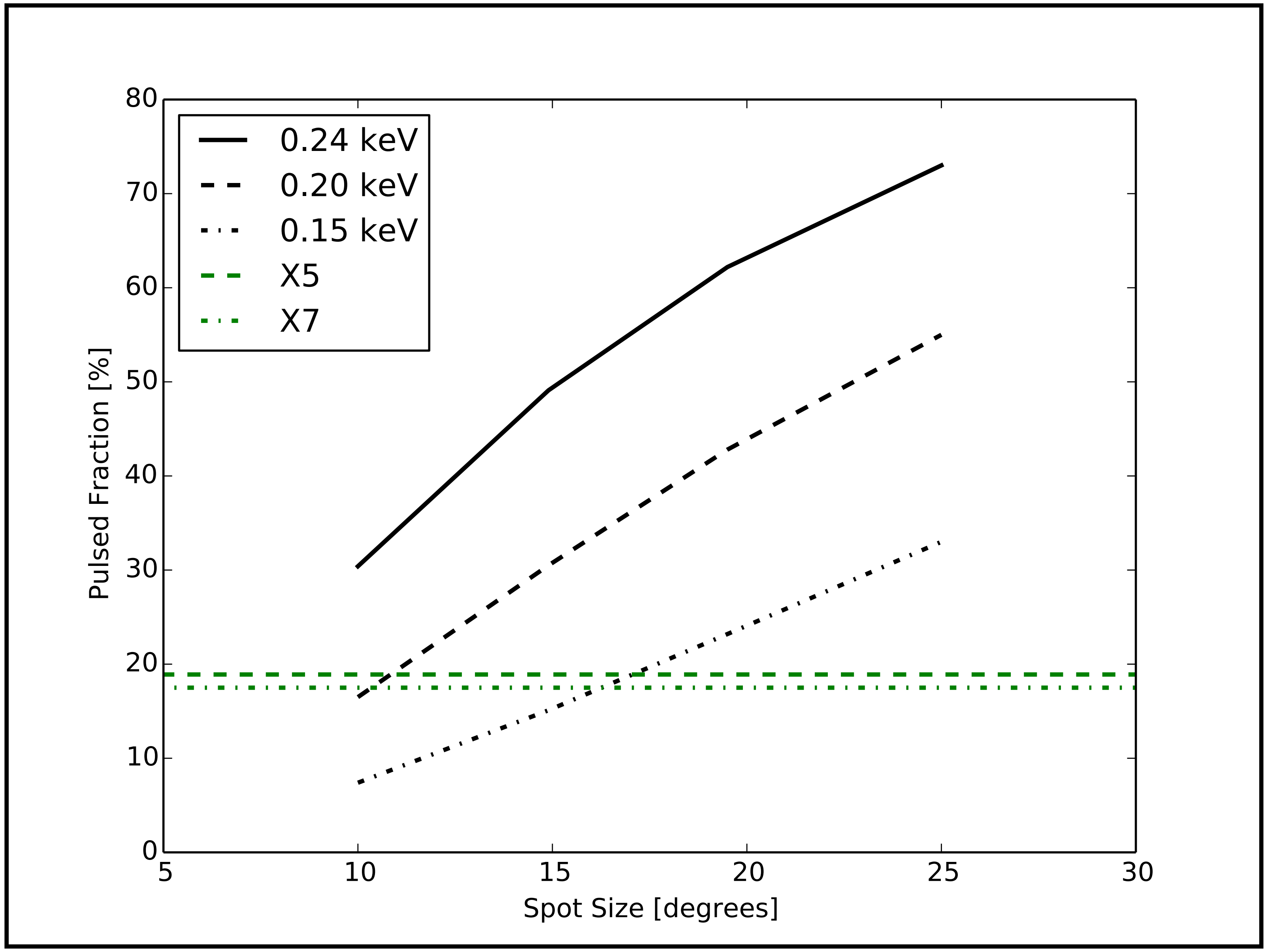
$R = 12$ km

$T = 0.1$ keV

$f = 1$ Hz

- Comparison between BB and H-atmos light curves for different emission region sizes.
- Measure the maximum pulsed fractions, for different choices of the inclination, colatitude angles.

Preliminary Results



$M = 1.6\ M_s$

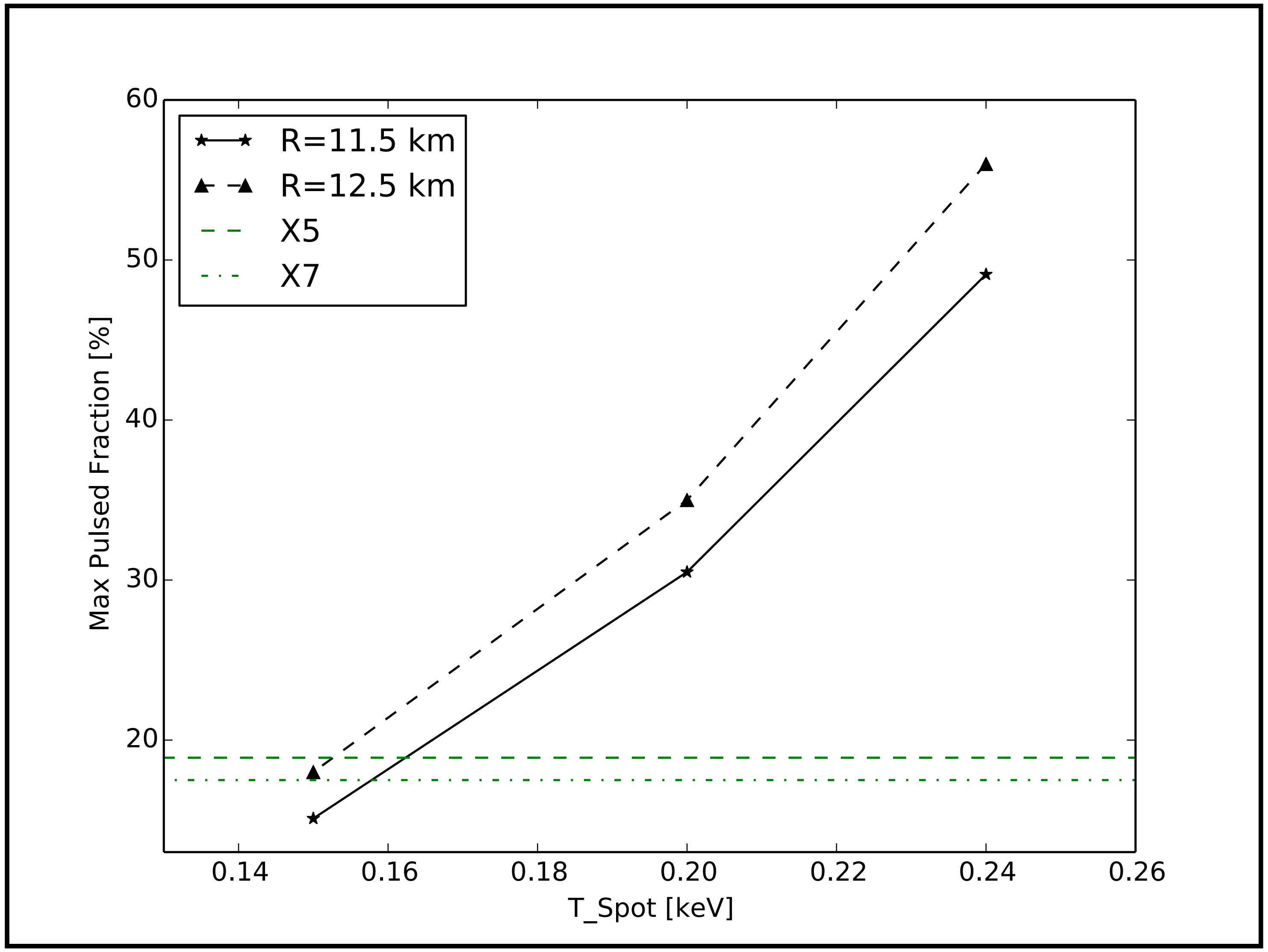
$R = 11.5$ km

$T\_NS = 0.1$ keV

$f = 500$ Hz

- Using simulation over 460 choices of i and θ, we computed the maximum pulsed fraction obtained for various spot temperature, for $T_{NS} = 0.1$ keV.
- However, should be interpreted with caution!

Preliminary Results



M = 1.6 M_s

R = 11.5,12.5 km

T_NS = 0.1 keV

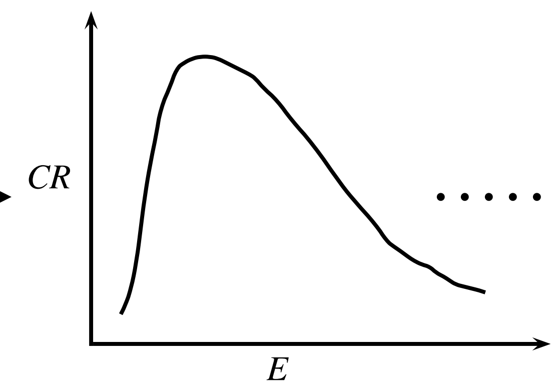
f = 500 Hz

Spot = 15°

- Increasing *R* decreases the gravitational light bending, which leads to slightly higher PF.

Comparing spectra and inferred *M, R*

M, R, ΔT, f ⋯ *i,θ* ⋯▸



⋯ *fitting* ⋯▸ *M, R ??*

- How do the spectra and the inferred *(M,R)* differ between spectra with hot spots on the surface, vs. those without hot spots?

Conclusion

- It's an *ongoing* work!
- H-atmosphere significantly *increases* the pulsed fraction.
- *Test* the results from more than one hot spot.
- *Test* the results for an oblate NS.