Fanning the Flames: X-ray Burst Probes of Neutron Star Properties

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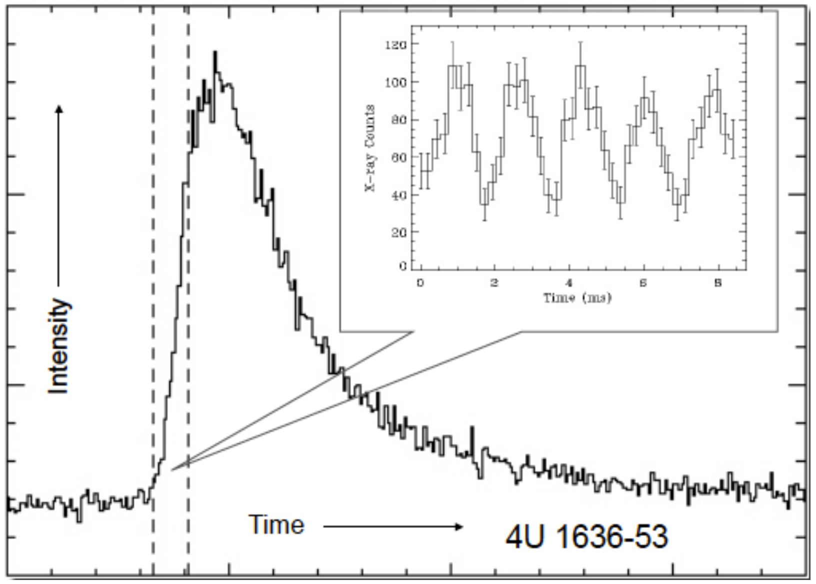
X-ray bursts oscillations

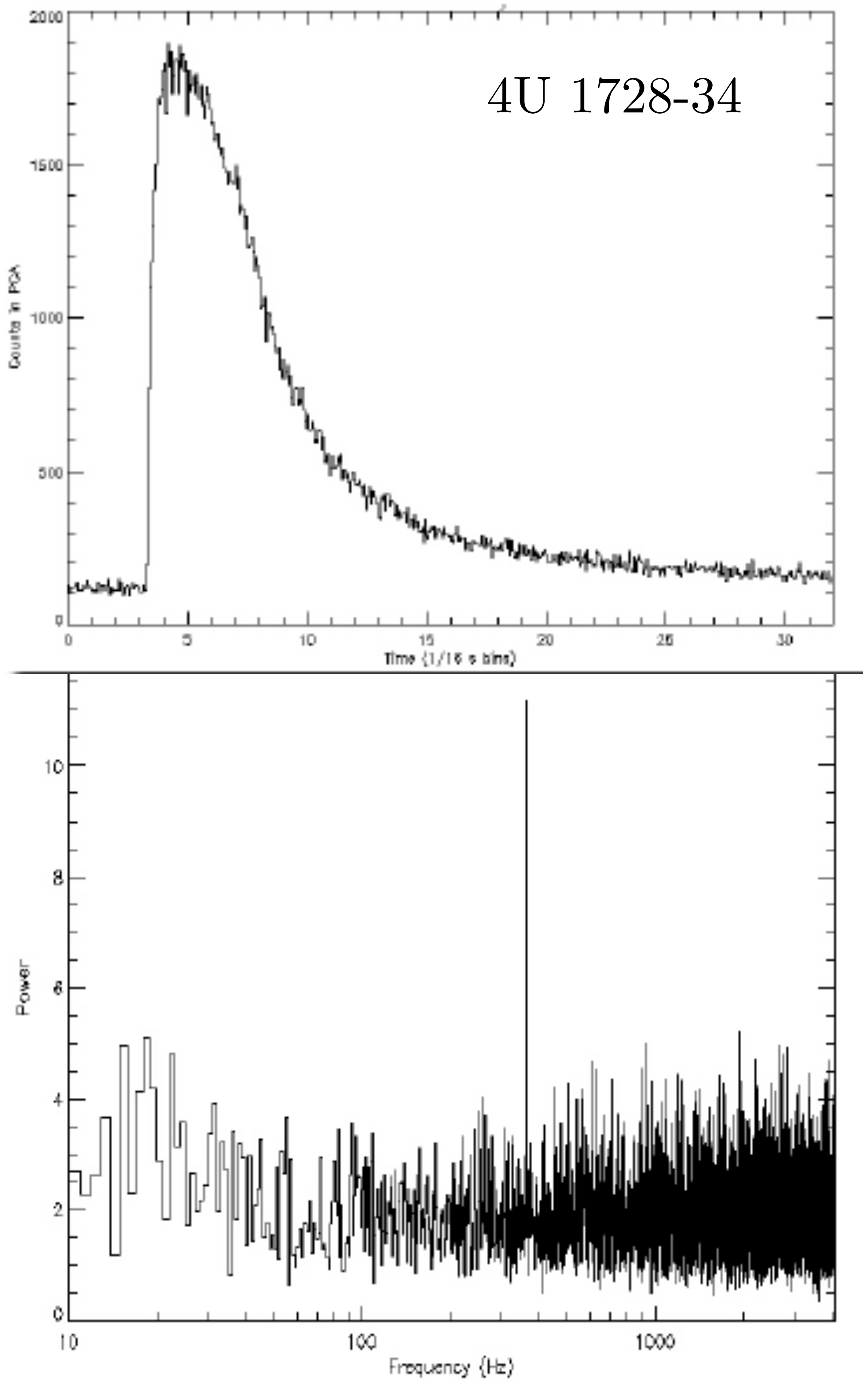
- Rise time ~ 1-10 sec.
- Decay time ~ tens to hundreds of seconds.

- X-ray spectrum consistent with a black-body of temperature T_{bb}=2-3 keV.

- Burst oscillations, in about 10% of the bursts observed with high time resolution detectors.

- Oscillations observed both during the rise and decay of the burst.



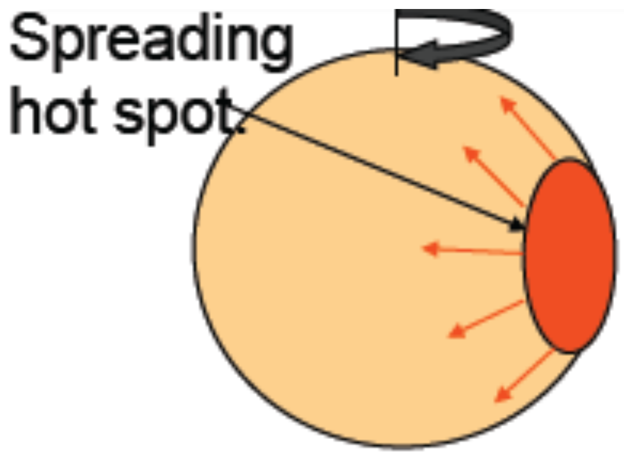


Strohmayer et al. 1996; Strohmayer & Bildsten 2006
Reviews: Galloway et al. 2008; Watts 2012

Current models for burst oscillations

- Hot-spot model

Spreading hot spot
(Strohmayer et al. 1996; Nath, Strohmaye & Swank 2002; Bhattacharyya et al. 2005)

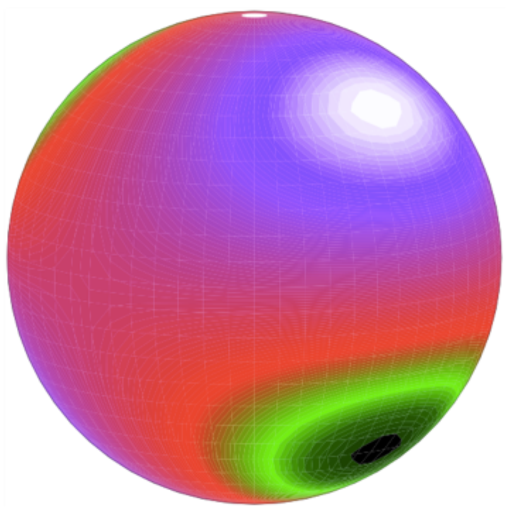


Coriolis force effects
(Spitkovsky, Levin & Ushomirsky 2002; Maurer & Watts 2008; Cavecchi et al. 2012, 2014)

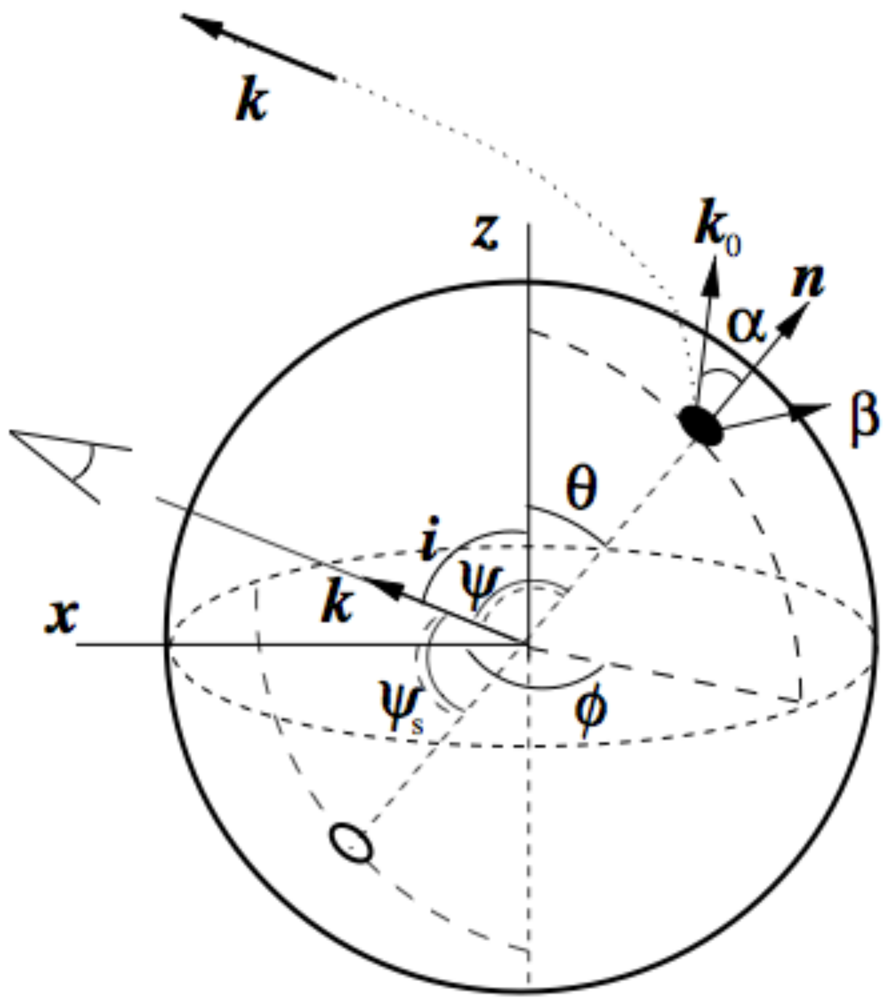
- Surface modes

(Bildsten et al. 1996; Heyl 2004; Piro & Bildsten 2005; Cumming 2005; Lee & Strohmayer 2005)

g-modes
buoyant r-modes
Kelvin modes
l=2, m=1 buoyant r-mode (Heyl 2004)



Modeling X-ray emission from a rotating neutron star

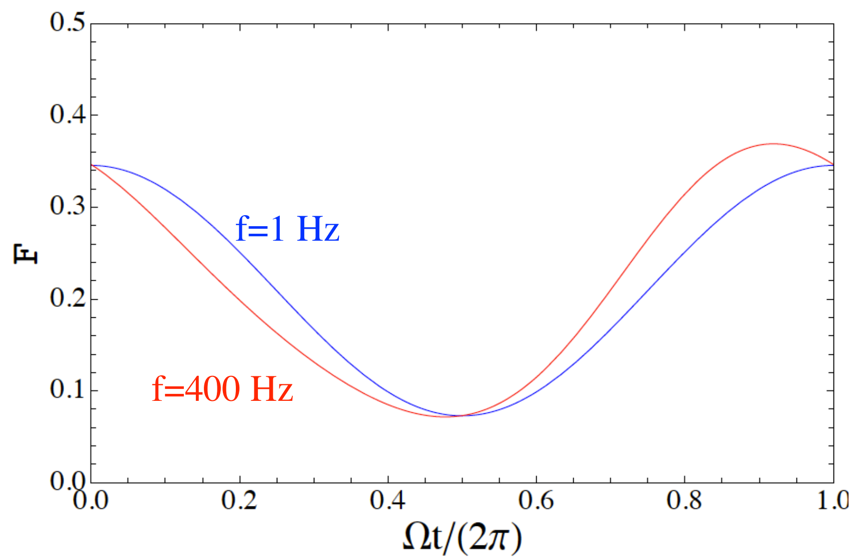


Viironen &Poutanen (A&A 2004)

- Rotating star
- X-ray emitting hot-spot
- Relativistic effects:

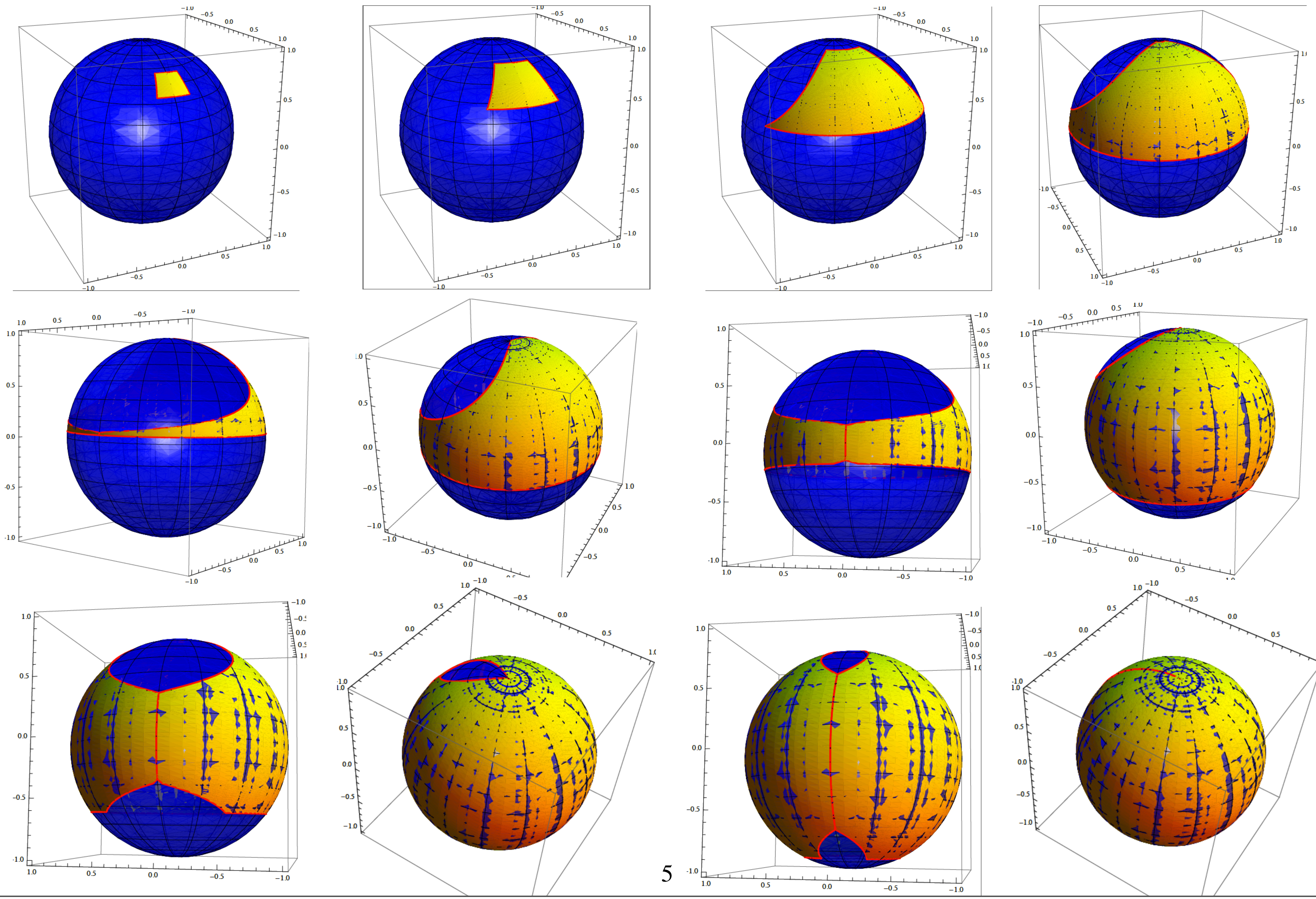
  Light bending in a Schwarzschild geometry
  Gravitational redshift
  Doppler shifts
  Relativistic aberration

(Beloborodov 2002; Poutanen & Gierlinski 2003; Poutanen & Beloborodov 2006; Morsink et al. 2007; Lo et al. 2013)



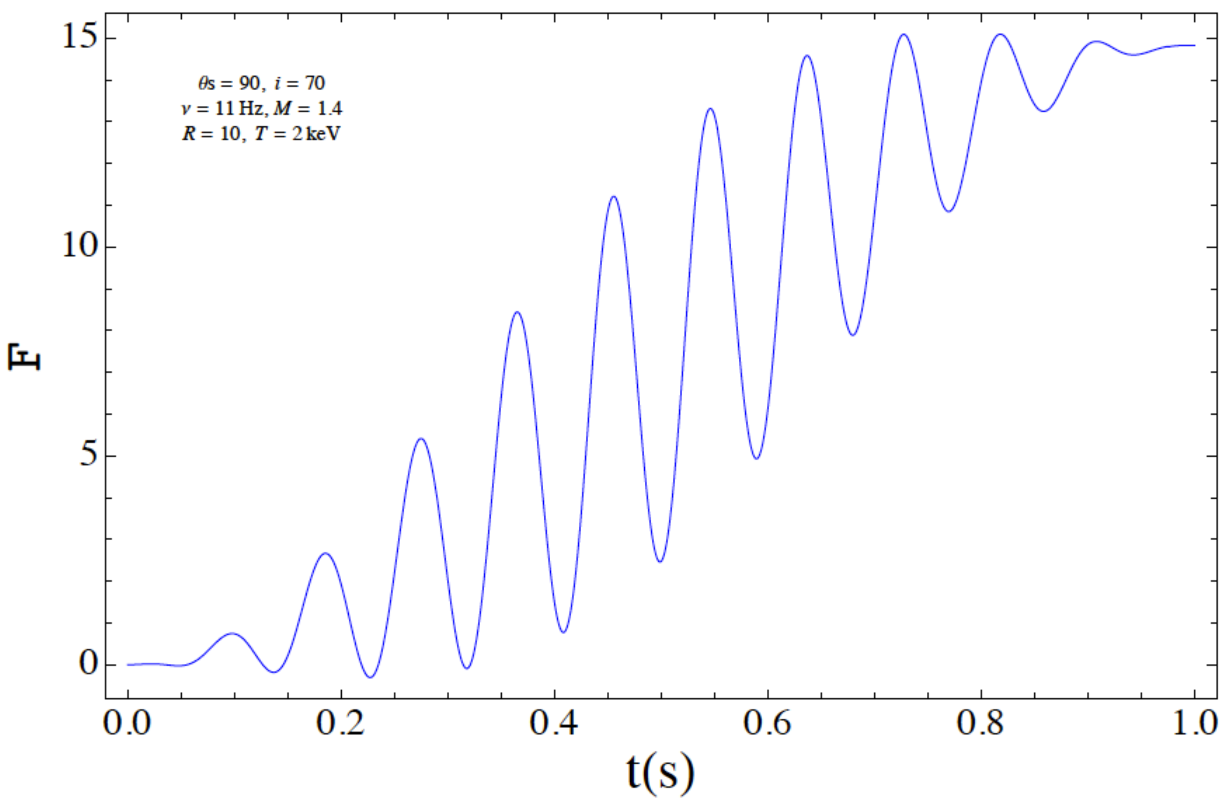
Pulse profiles consistent with the results of the LOFT Science Working Group on Dense Matter.
(Poutanen, Lamb et al., Morsink, Psaltis et al.)

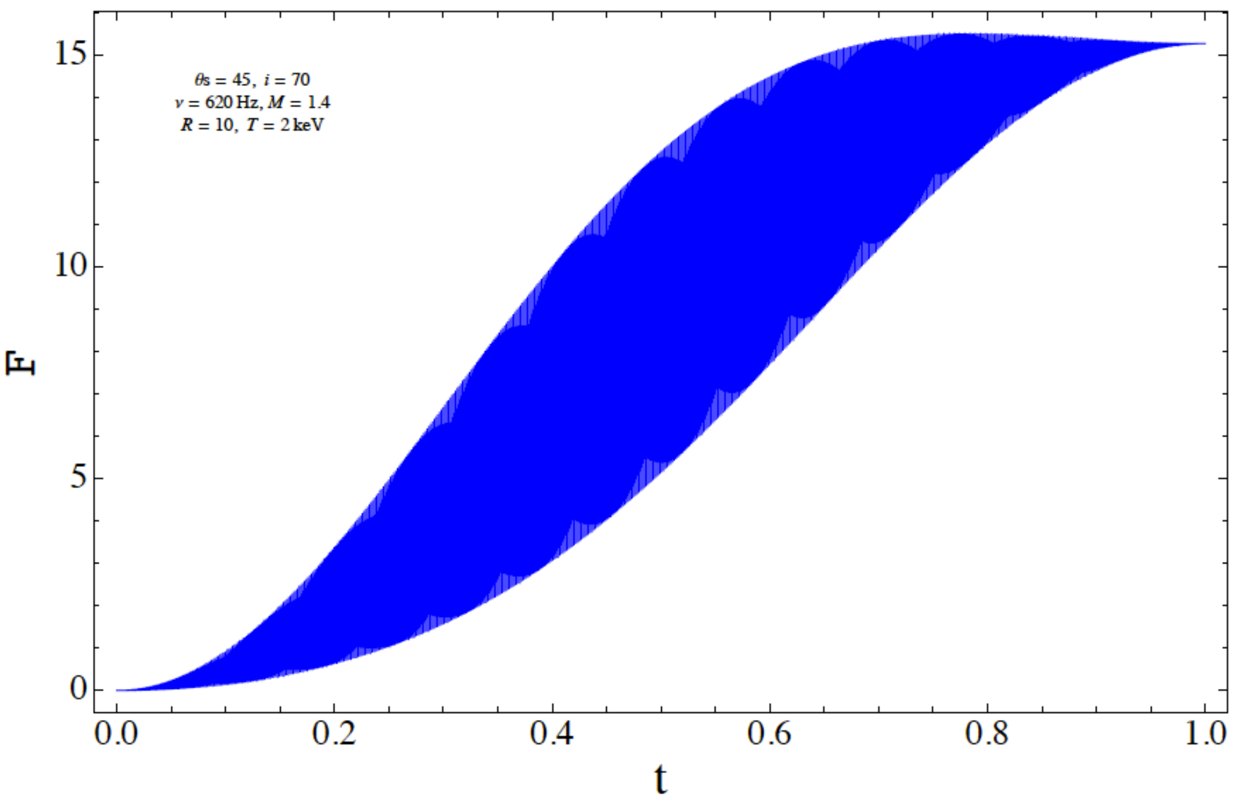
Evolution of the hot spot (i=70°, θ=45°, t=1s)



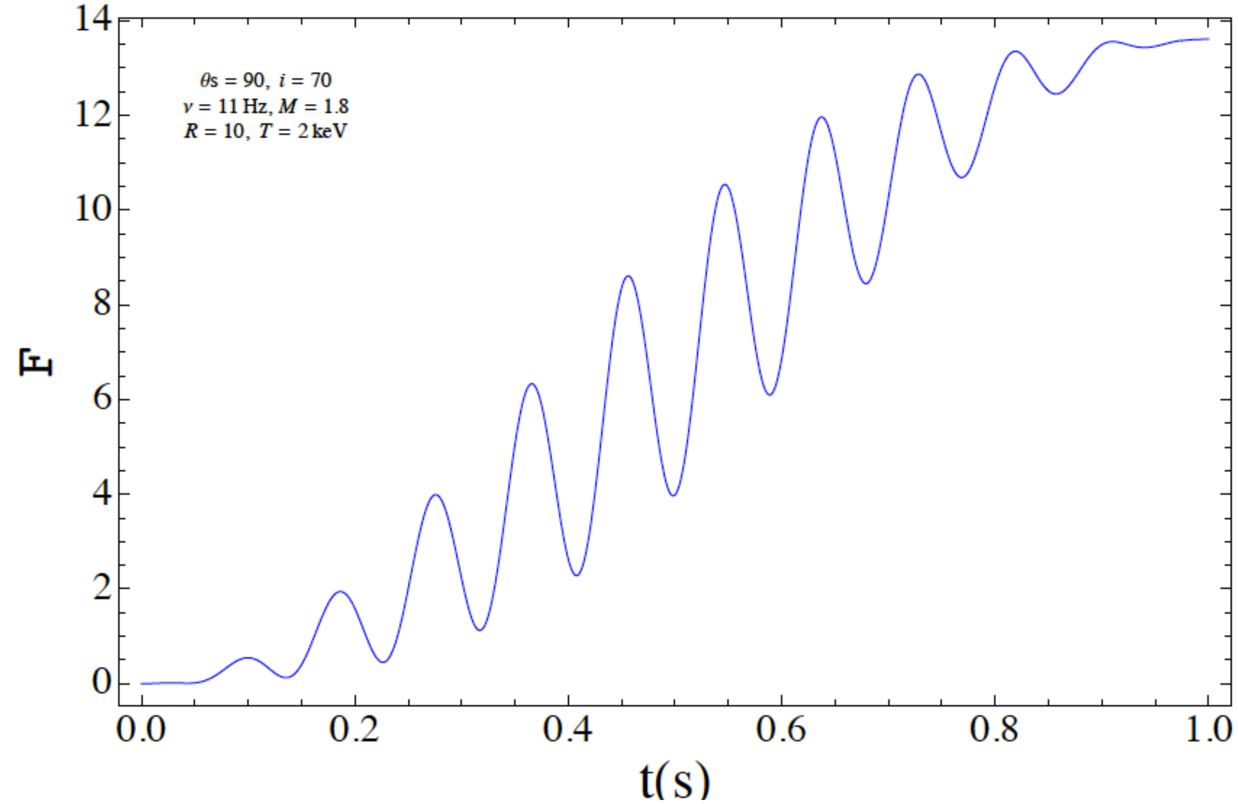
Model light curves during the rise (Different Masses)

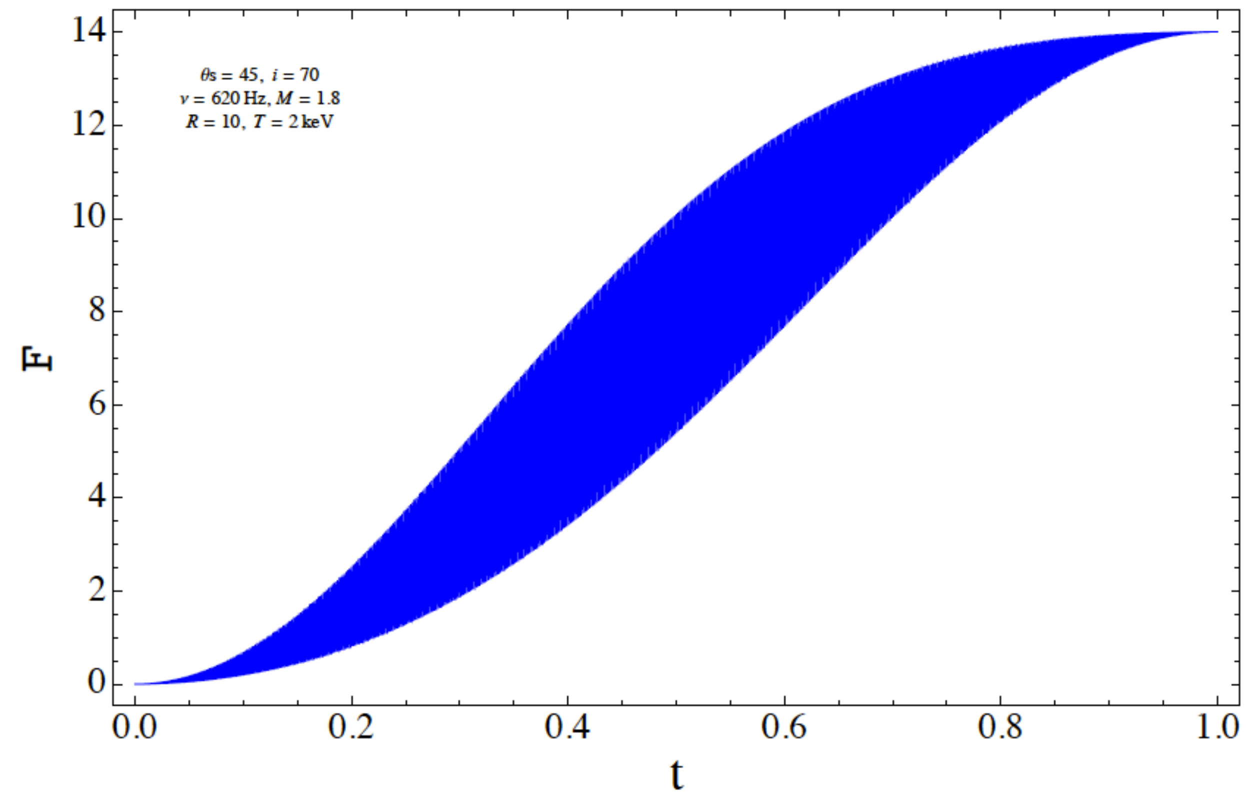
$M = 1.4 M_\odot$



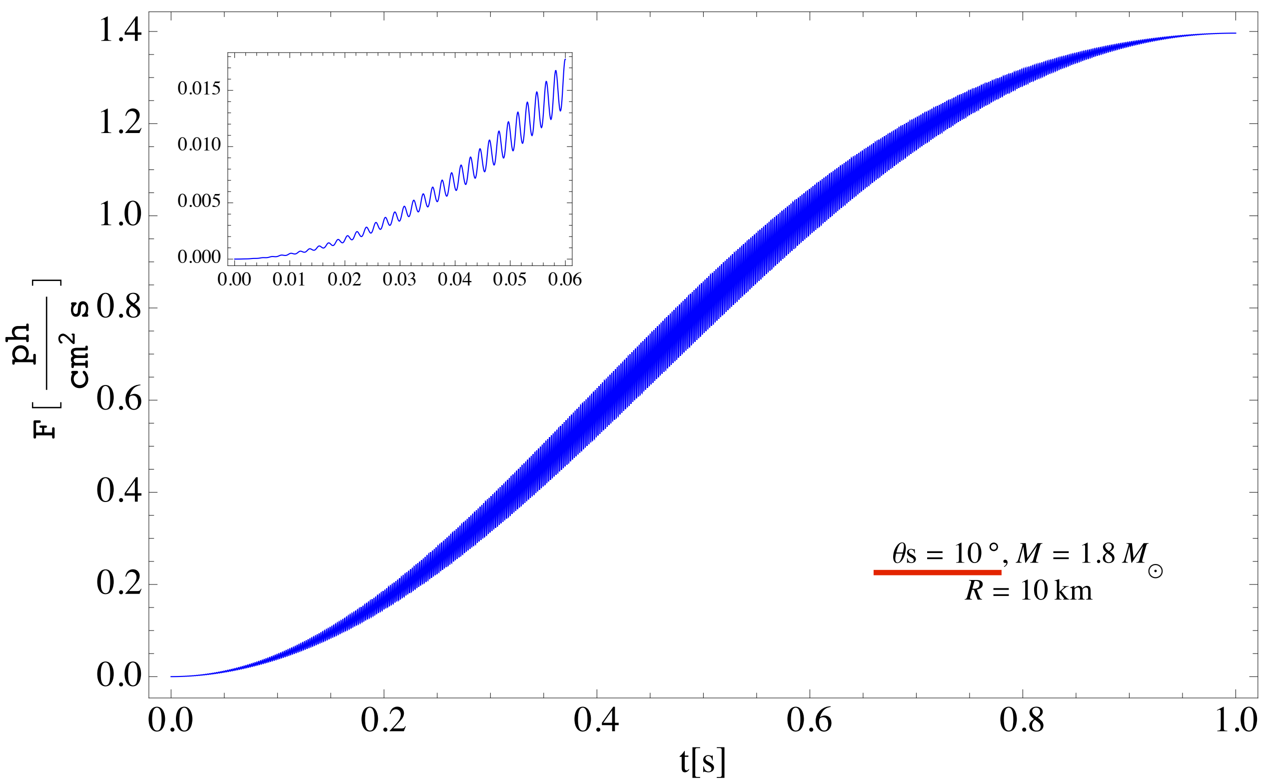


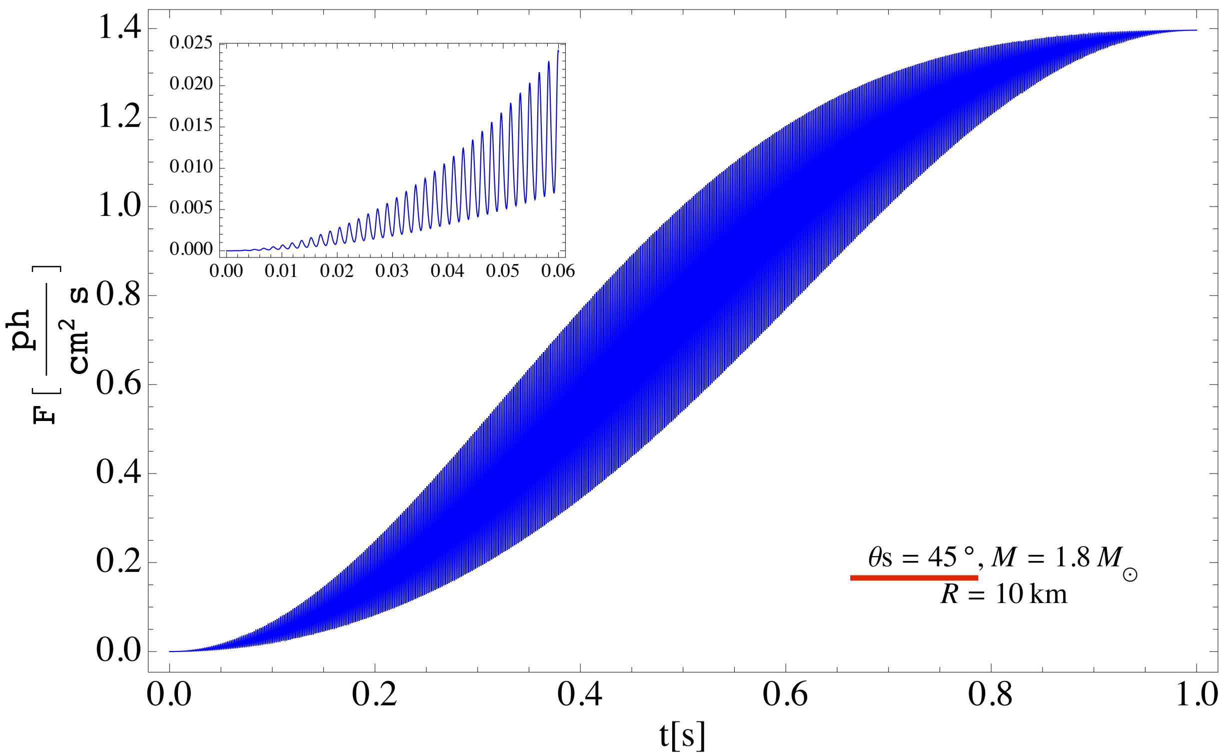
$M = 1.8 M_\odot$

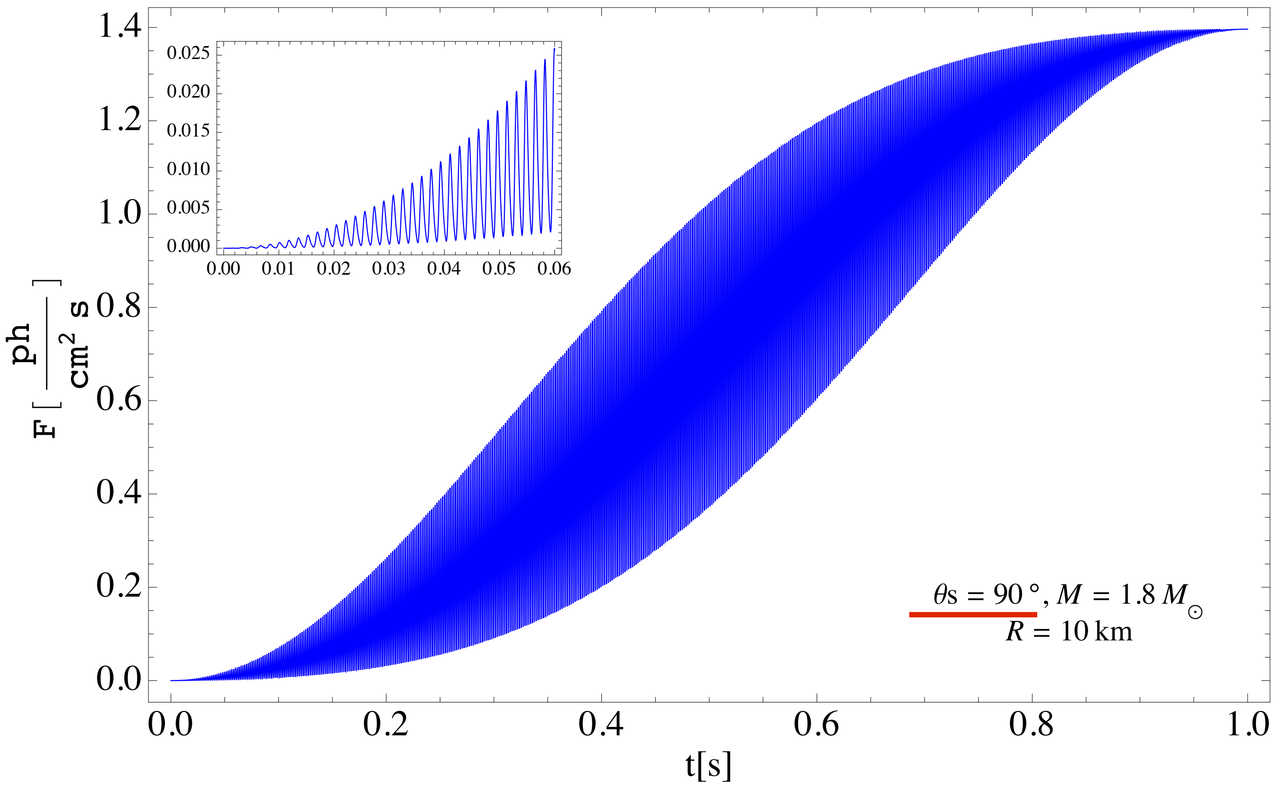


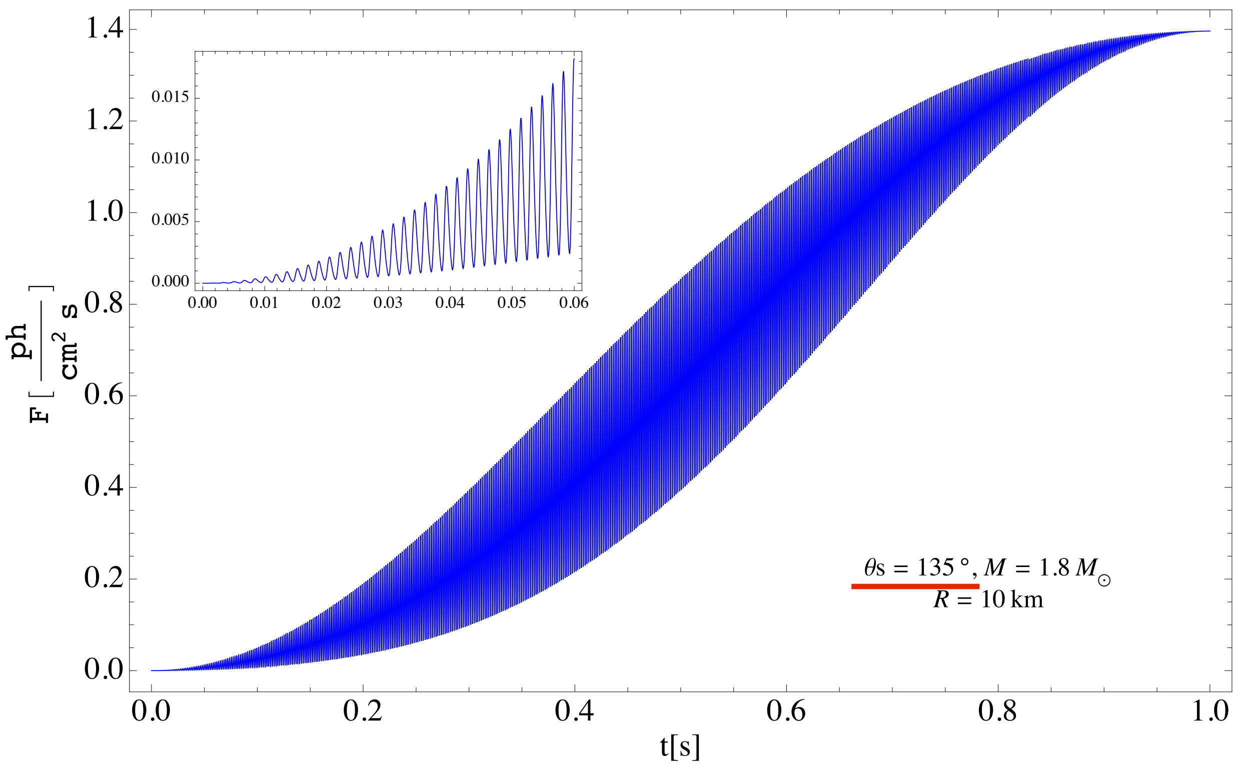


Different ignition latitudes

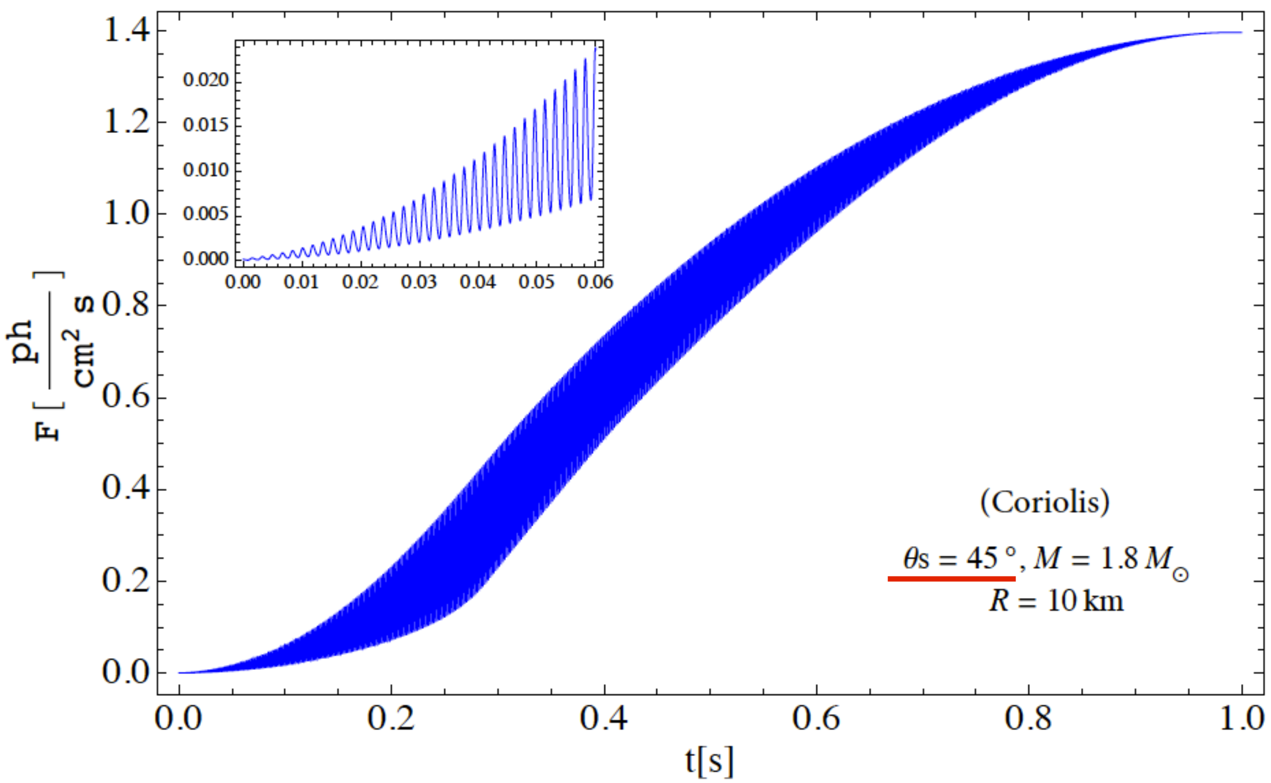


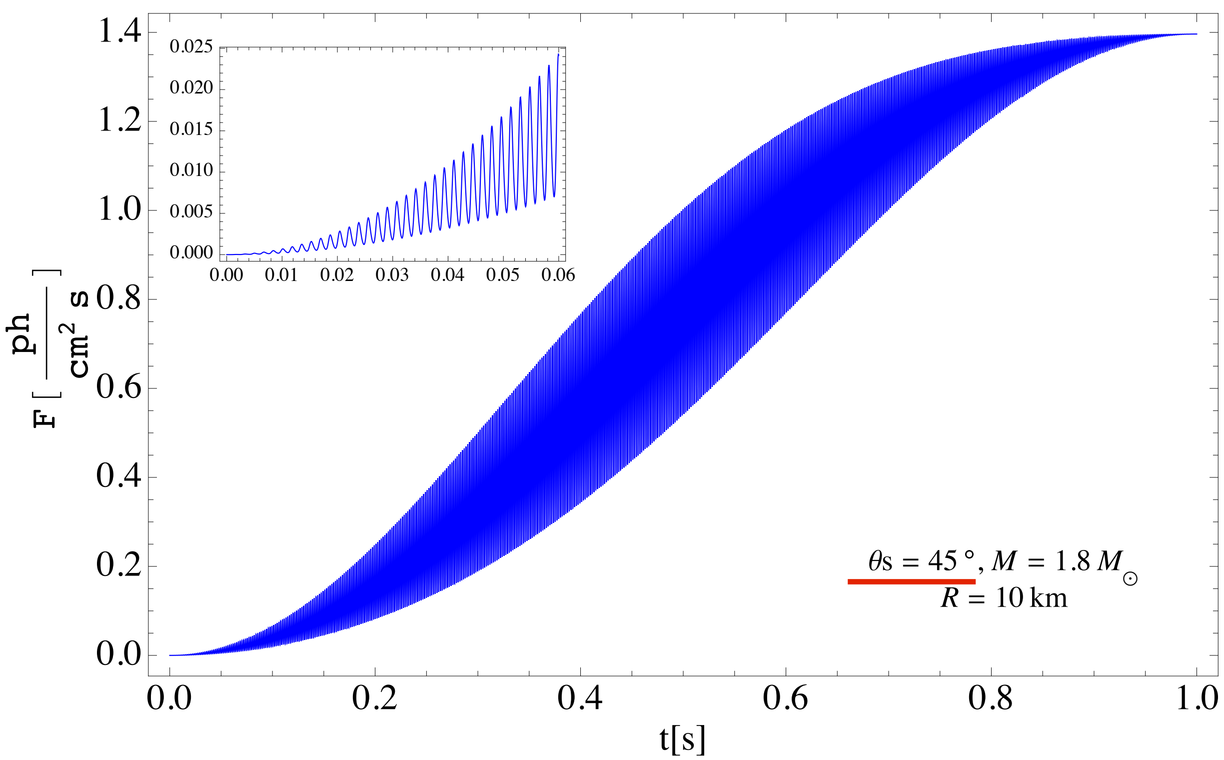


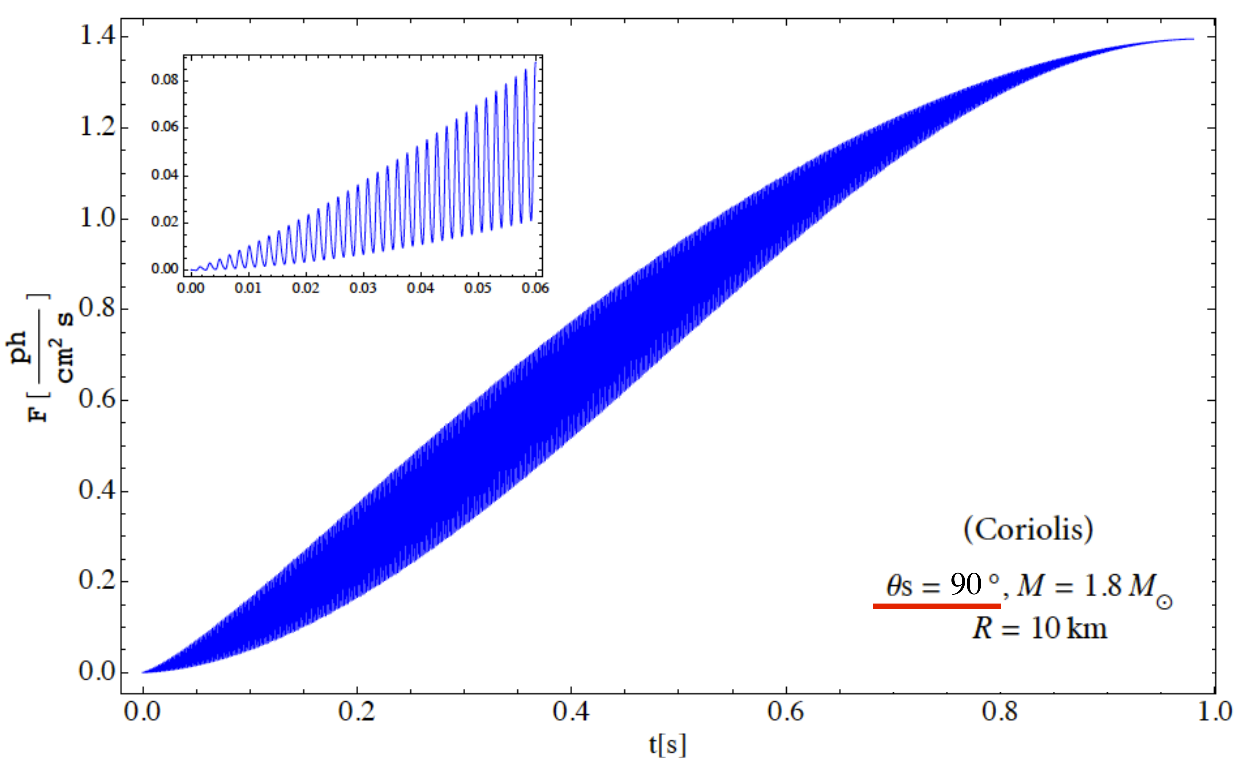


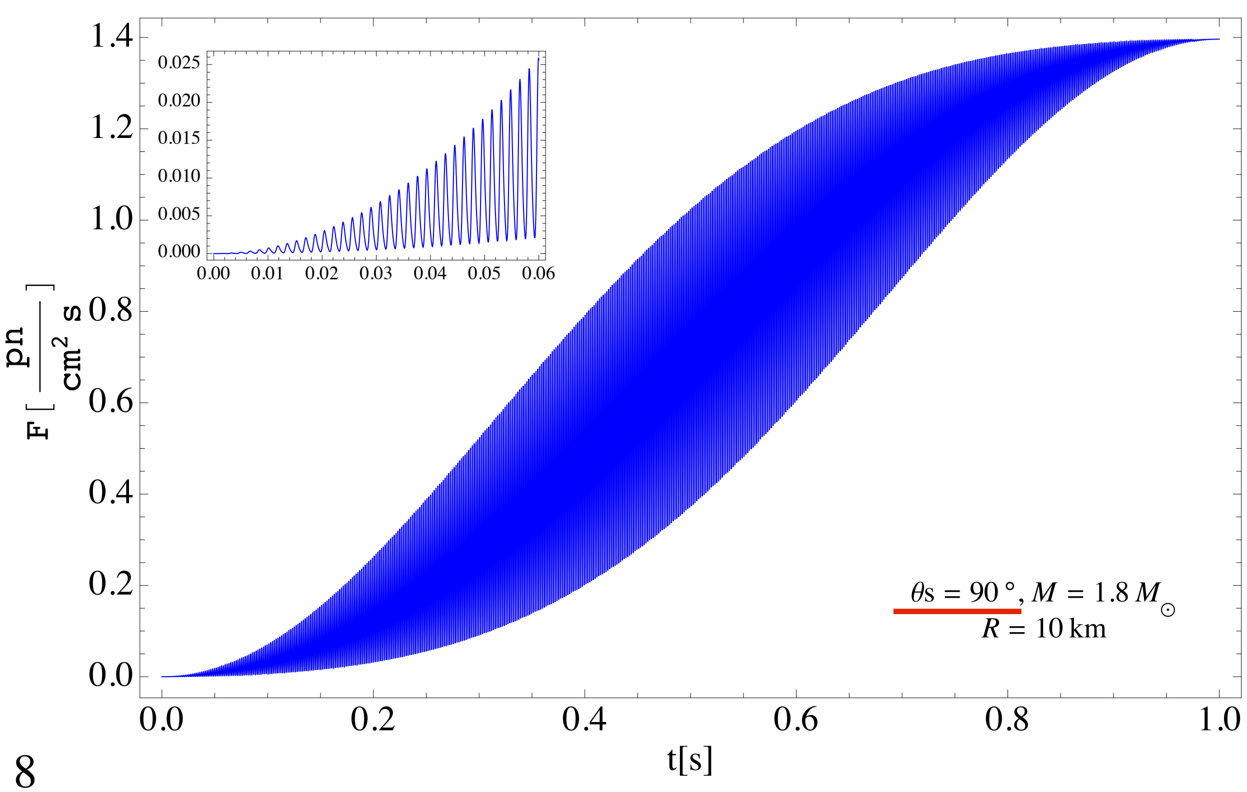


Coriolis force effects

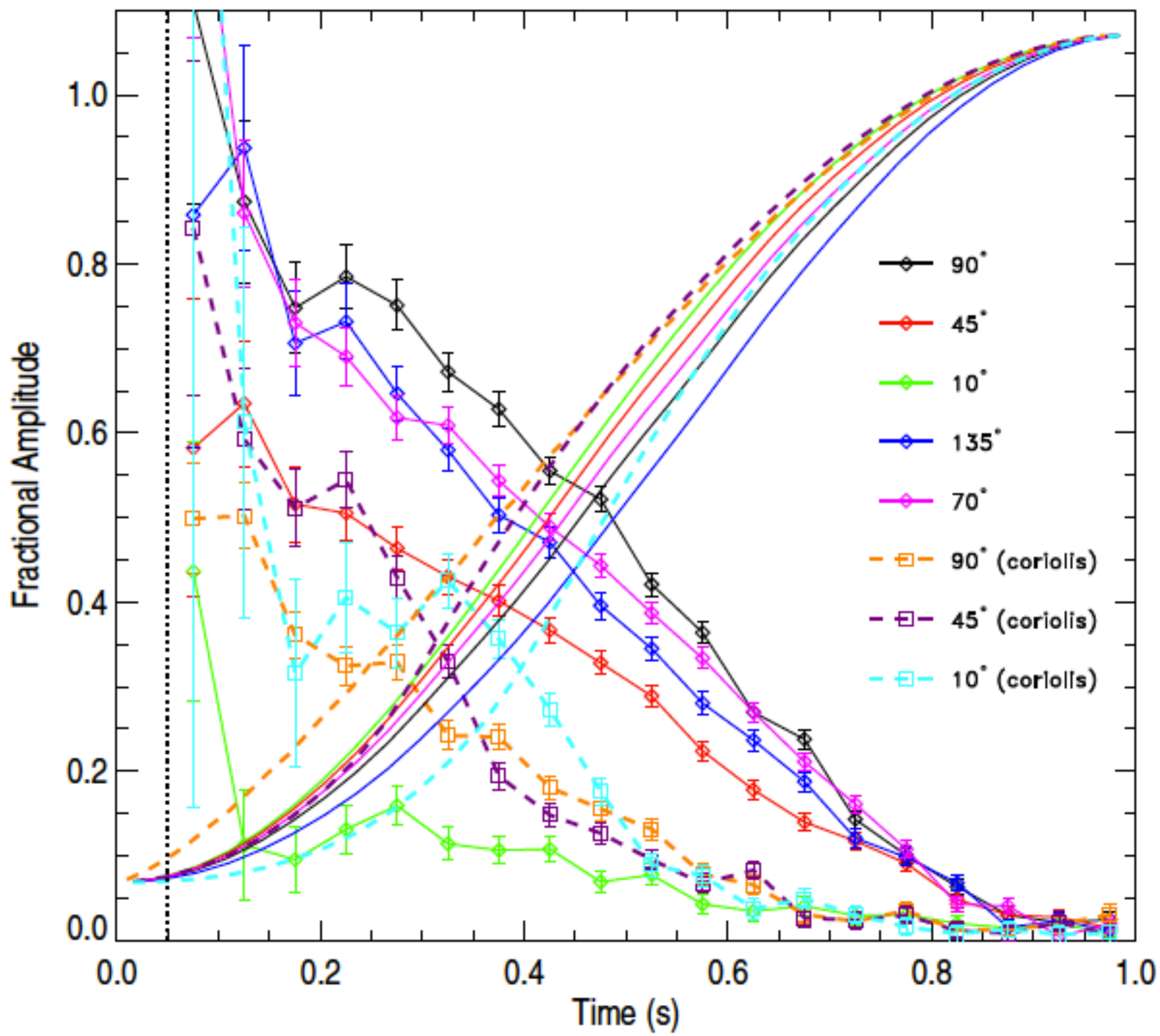






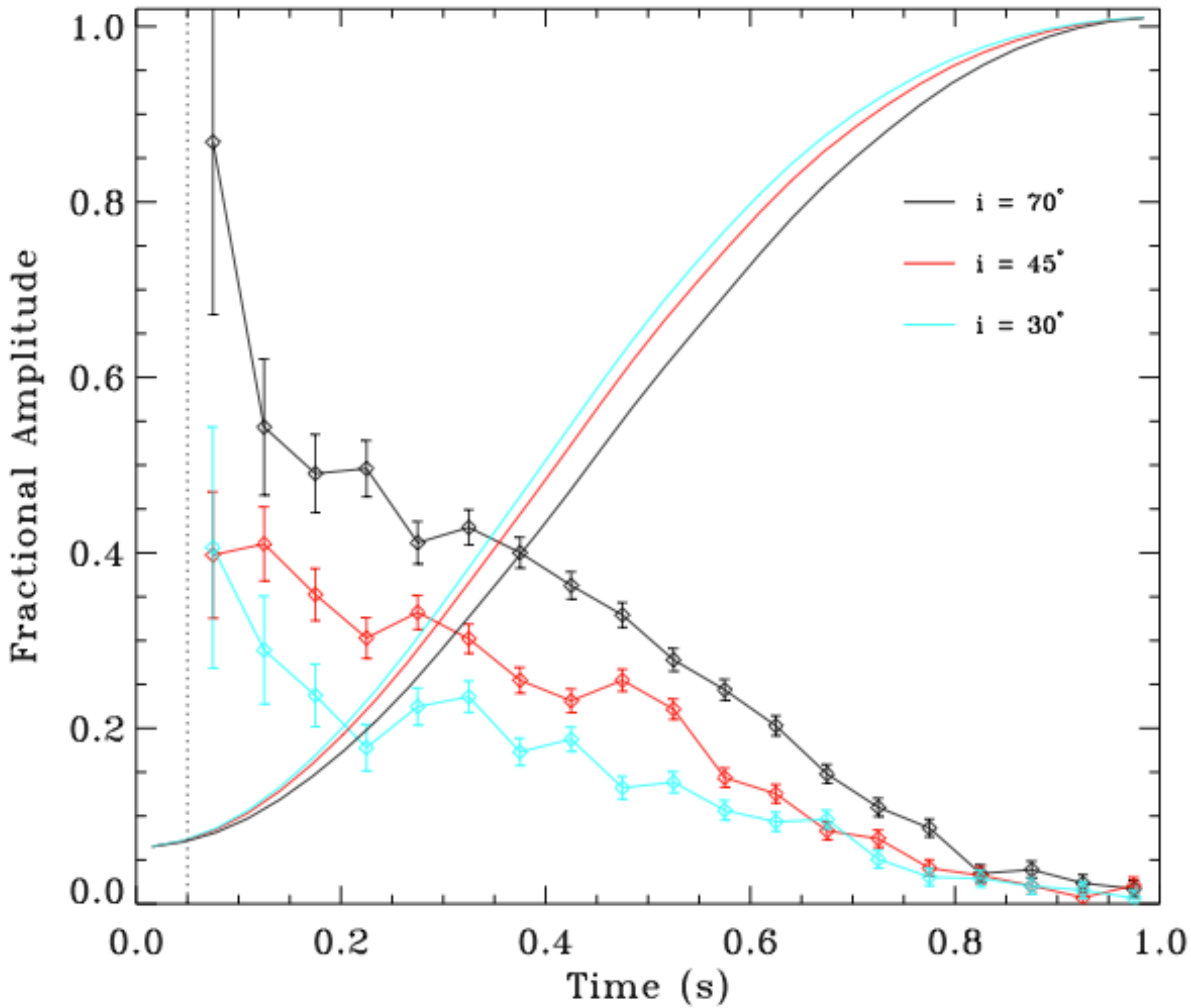


Evolution of the fractional amplitude (LOFT Simulation) (Varying ignition latitude)



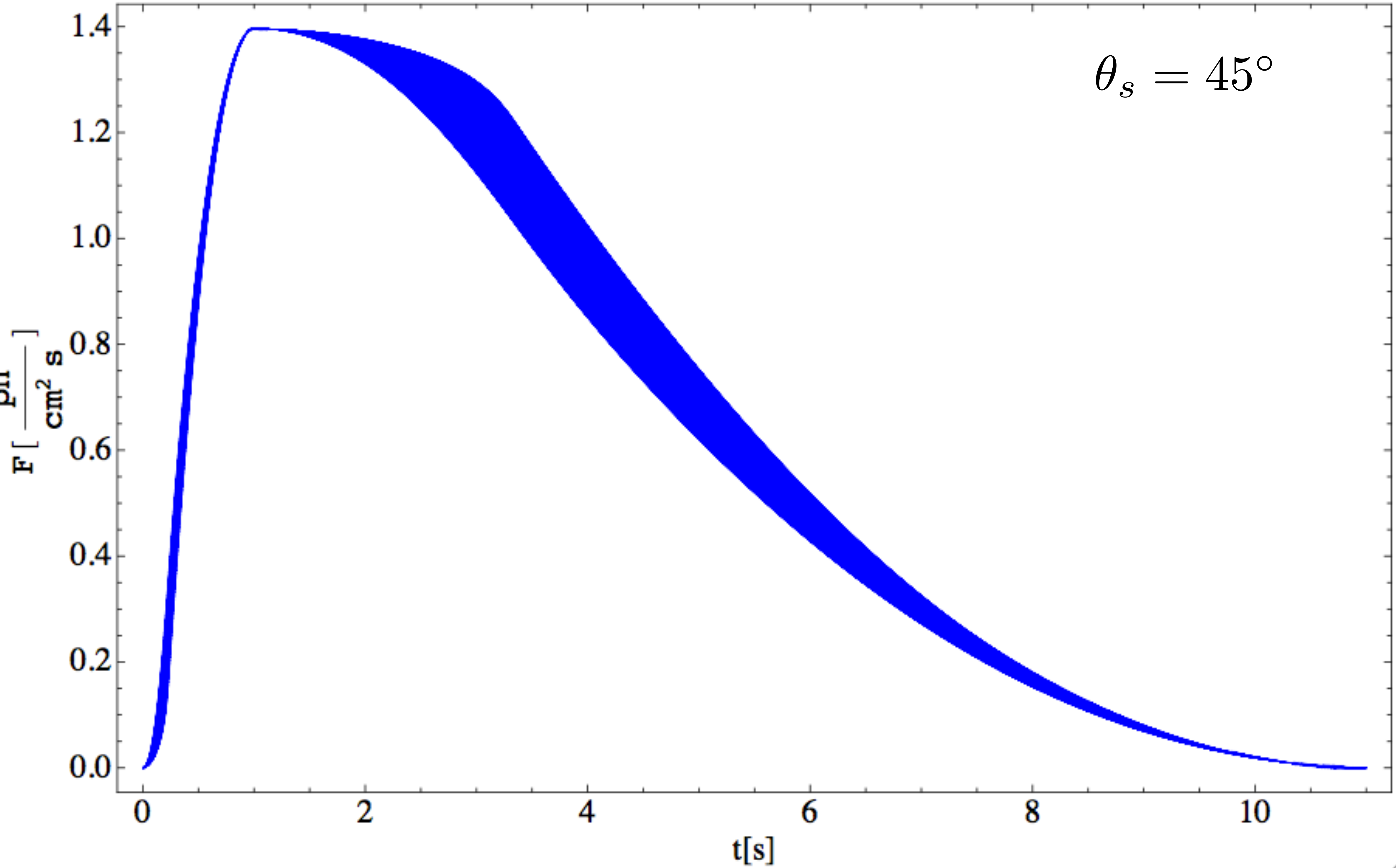
For a light curve that varies as $\mathrm{A}+\mathrm{B}\ \sin(2\pi\nu t)$ the fractional amplitude here is defined as B/A.

Evolution of the fractional amplitude (LOFT Simulation) (Varying inclination angles)

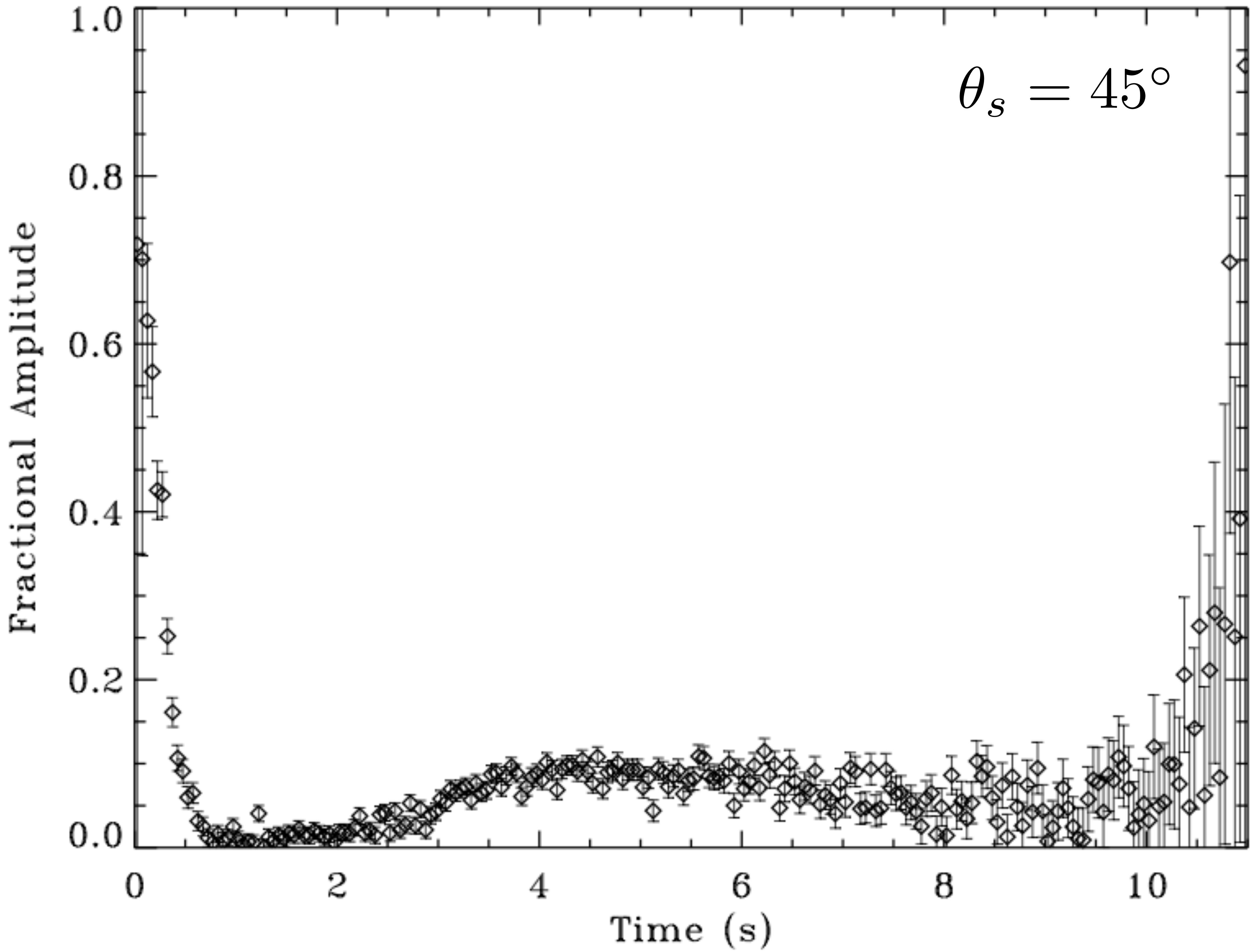


Light curve varies as $A+B\ \sin(2\pi\nu t)$, the fractional amplitude is defined as B/A.

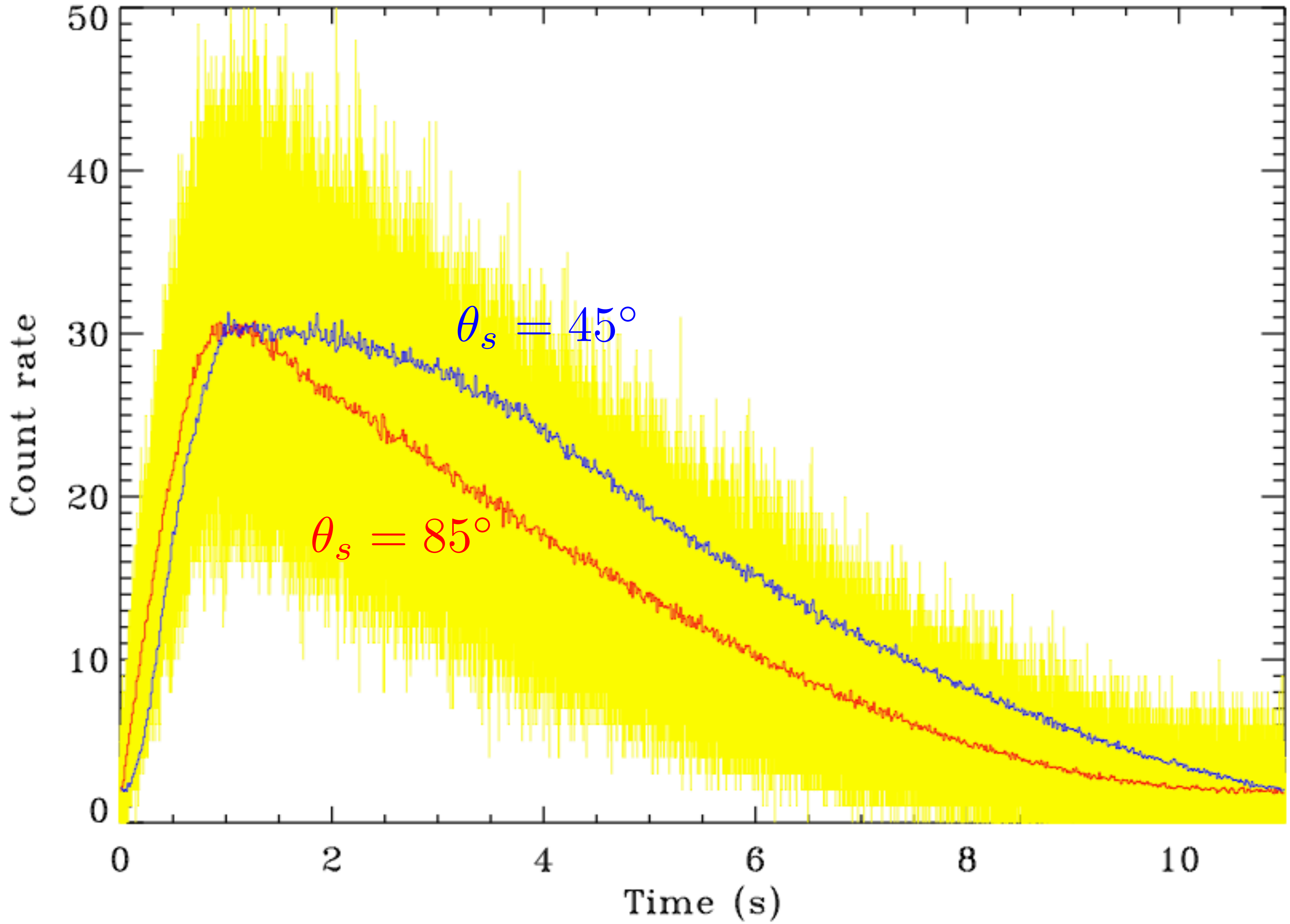
Model light curve for the rise and decay (cooling wake)



Fractional amplitude (LOFT Simulation)



Light curves for $\theta_s = 45^\circ$ vs 85° (LOFT Simulation)



Conclusion

- Burst oscillations can be used as probes of NS properties.
  - M & R (Pulse profile modeling; several active groups)
  - NS spin frequency
  - Ignition latitude

- Theoretical explanation of why and how burst oscillations develop is still an open question.

- The combination of the fractional amplitude evolution and the light curve will enable:
  - The confirmation of the expanding hotspot model for burst oscillations during the rise
  - Determination of ignition latitude for a number of bursts
  - Measuring the effect of the Coriolis force on flame propagation

- Future capabilities: NASA's NICER and ESA's LOFT

  LOFT white paper on neutron star thermonuclear bursts (J. in 't Zand et al. 2015)