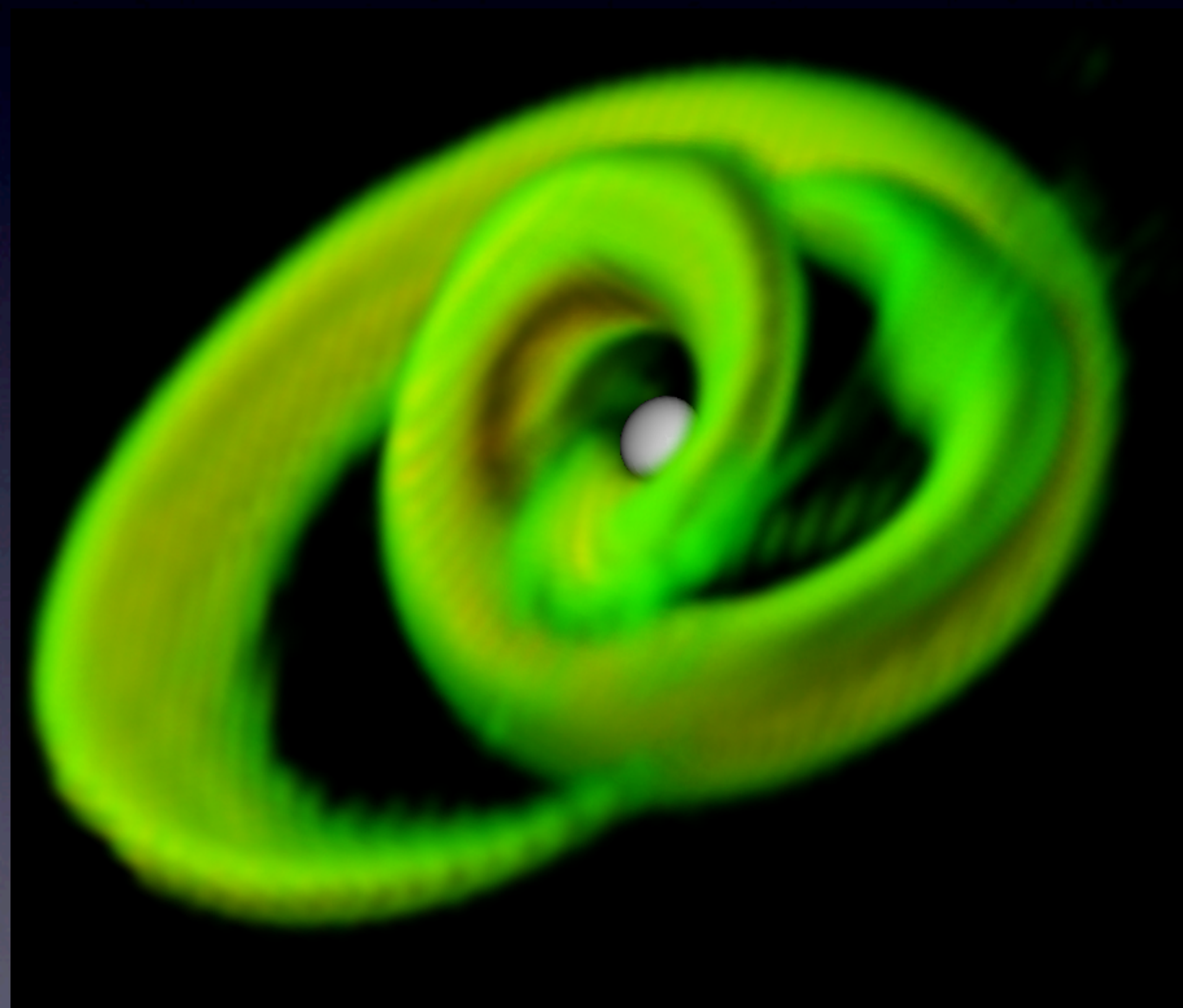
Black Hole-Neutron Star Binaries at Realistic Mass Ratios



Francois Foucart (CITA)

SXS Collaboration

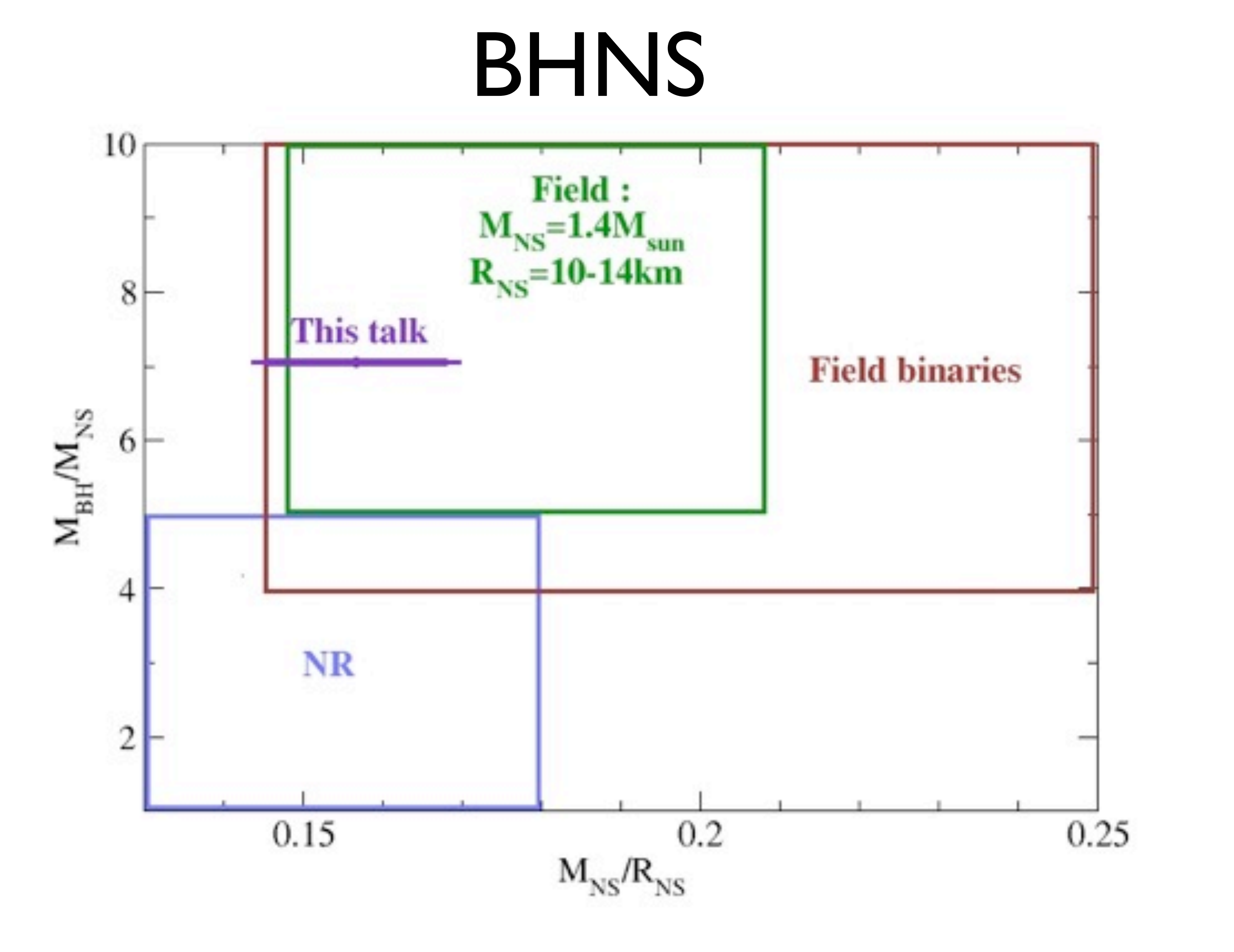
Collaborators

- CITA: Harald Pfeiffer, Abdul Mroue, Serguei Ossokine, Ilana MacDonald
- WSU: Matt Duez, Brett Deaton
- Cornell: Saul Teukolsky, Larry Kidder, Geoffrey Lovelace, Mike Boyle, Curran Muhlberger, Dan Hemberger
- Caltech: Christian Ott, Mark Scheel, Bela Szilagyi, Roland Haas, Jeff Kaplan, Nick Taylor, Christian Reisswig

BHNS Parameter Space

Important binary parameters at merger:

$$q = \frac{M_{\rm BH}}{M_{\rm NS}}, \chi_{\rm BH} = \frac{a_{\rm BH}}{M_{\rm BH}}, C_{\rm NS} = \frac{M_{\rm NS}}{R_{\rm NS}}$$



For Post-Merger :

- Microphysics
- MHD
- Ejecta

To also explore :

- Large Spins
- Precessing binaries

Numerical Simulations

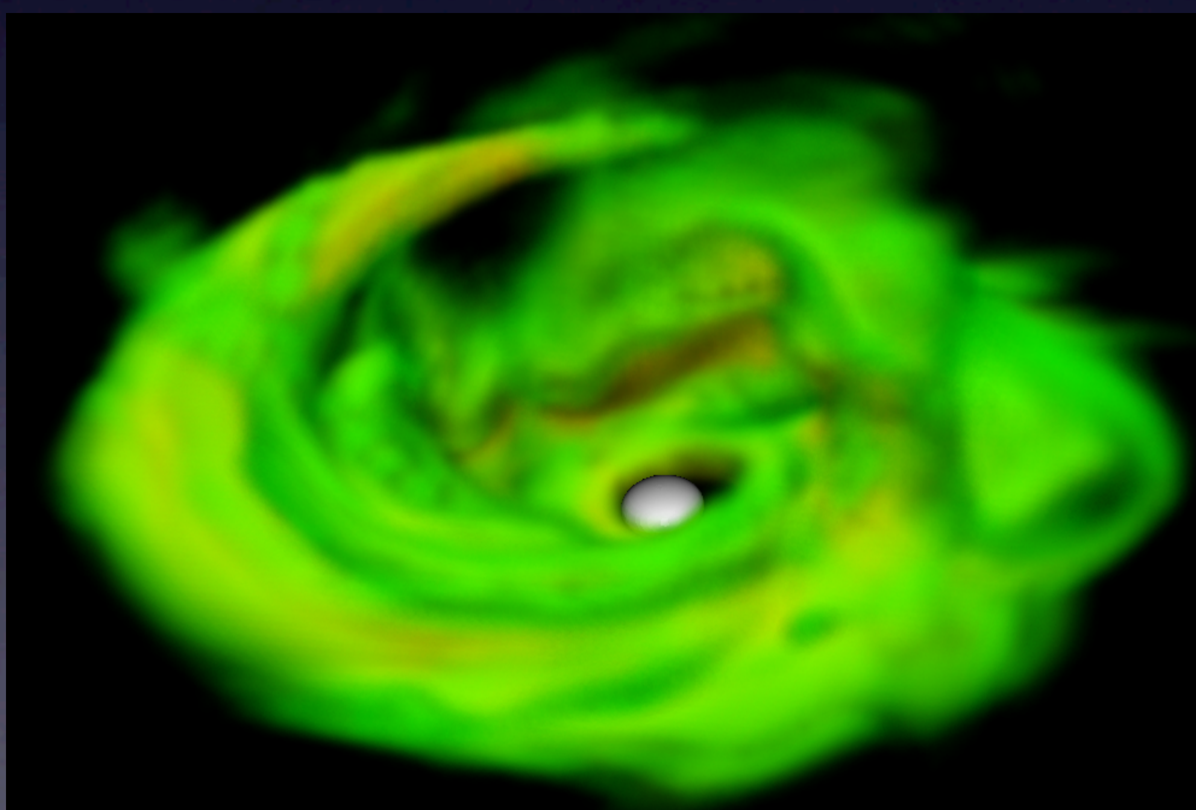
- Study q=7 for polytropic equations of state (Γ=2)
- Vary :
  - BH spin amplitude ($\chi_{\rm BH}$ = 0.5 - 0.9)
  - BH spin inclination (up to 60°) for $\chi_{\rm BH}$ = 0.9
  - Neutron star radius (R_{NS} = 12 - 14 km) for $\chi_{\rm BH}$ = 0.9
- Objectives:
  - Describe post-merger remnant : Disk mass, Tidal Tail, ... (Unbound mass only approximately determined)
  - Study gravitational waves

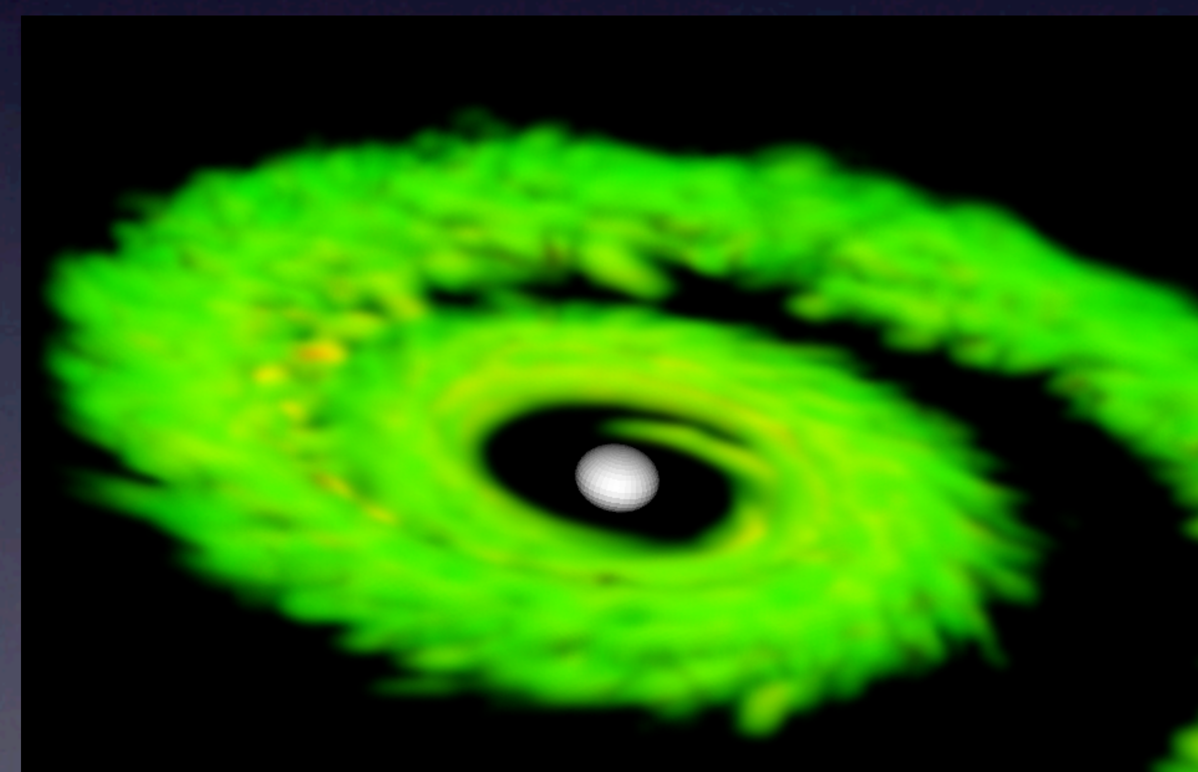
Black Hole Spin

$a_{BH}/M_{BH}>0.7$ required to form a disk!

Left: $a_{BH}/M_{BH}=0.9 \Rightarrow M_{remnant} \approx 0.30 M_{NS}$ (~1/2 in tail)

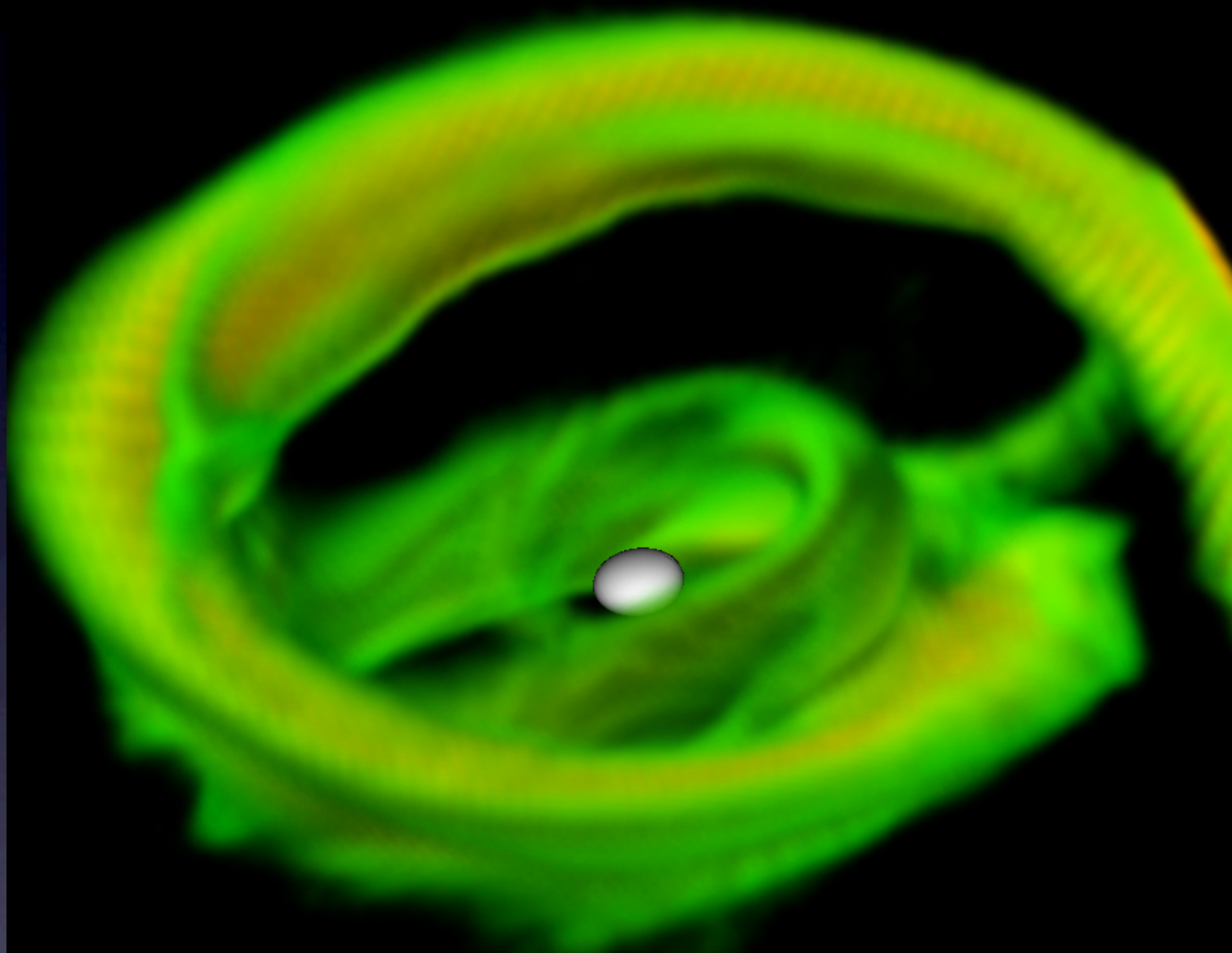
Right: $a_{BH}/M_{BH}=0.7 \Rightarrow M_{remnant} \approx 0.05 M_{NS}$ (~1/2 in tail)

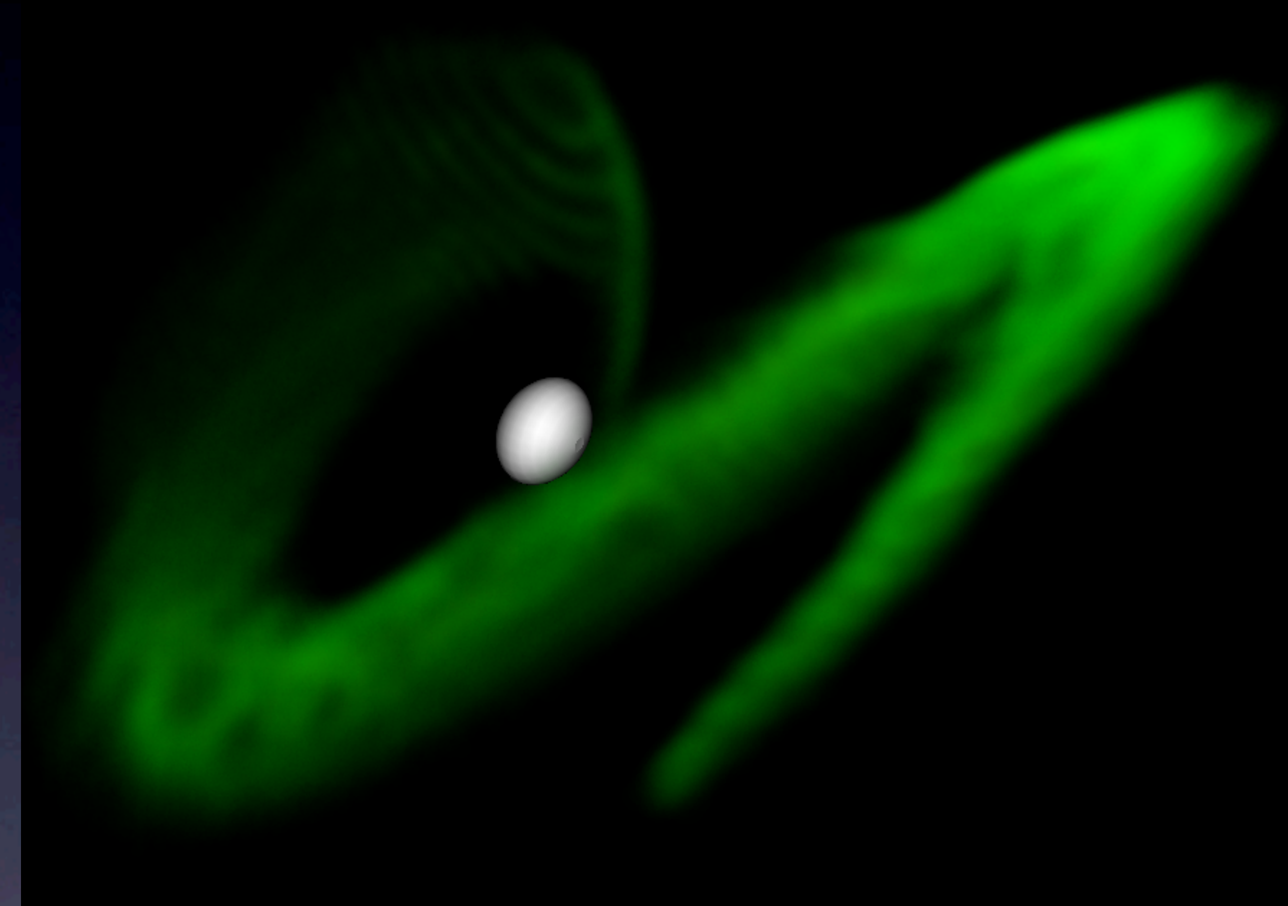




F. Foucart et al. (2012), Phys Rev D85 044015

Precessing Binaries





Disk formation up to 40o misalignment

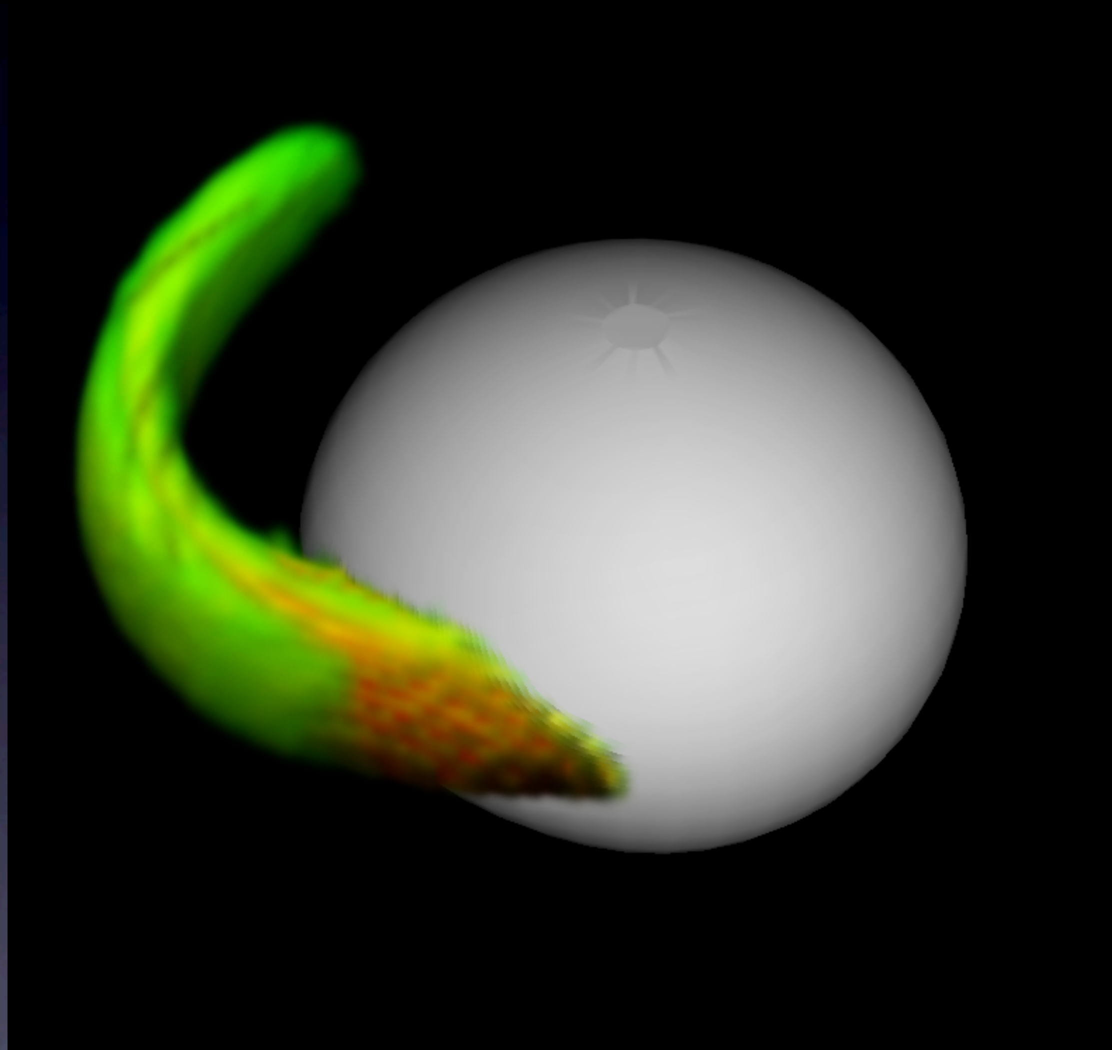
Left: 40o misalignment ⇒ Mremnant≈0.15MNS (>1/2 in tail)

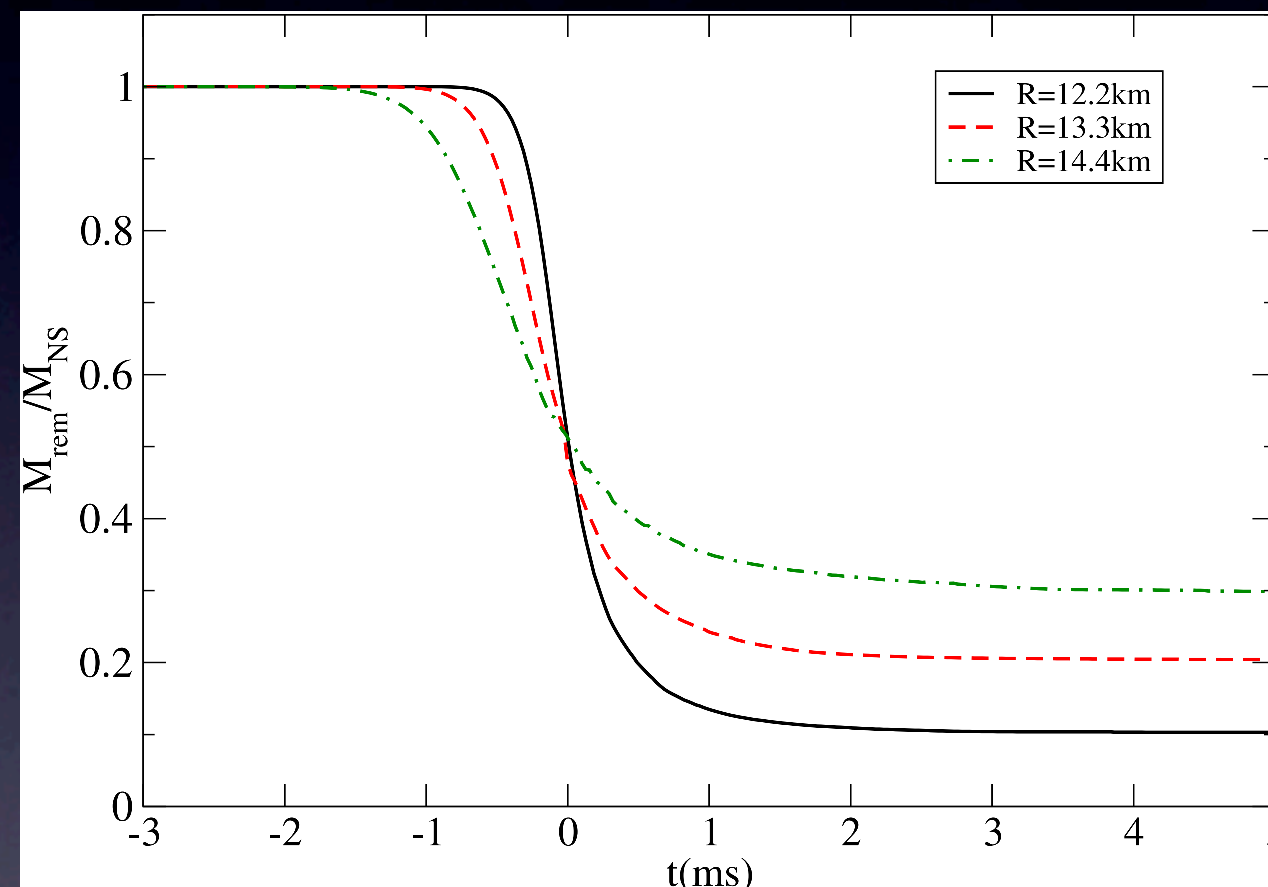
Right: 60o misalignment ⇒ Mtail<0.05MNS (no disk after 5ms)

=> Important for disk mass only if large inclinations are common

Other effects : see Nick Stone's talk

Equation of State





- *Left:* Smaller star (R=12.2km) disrupts very late
- *Right:* Rapid decay of the remnant mass with R_{NS}

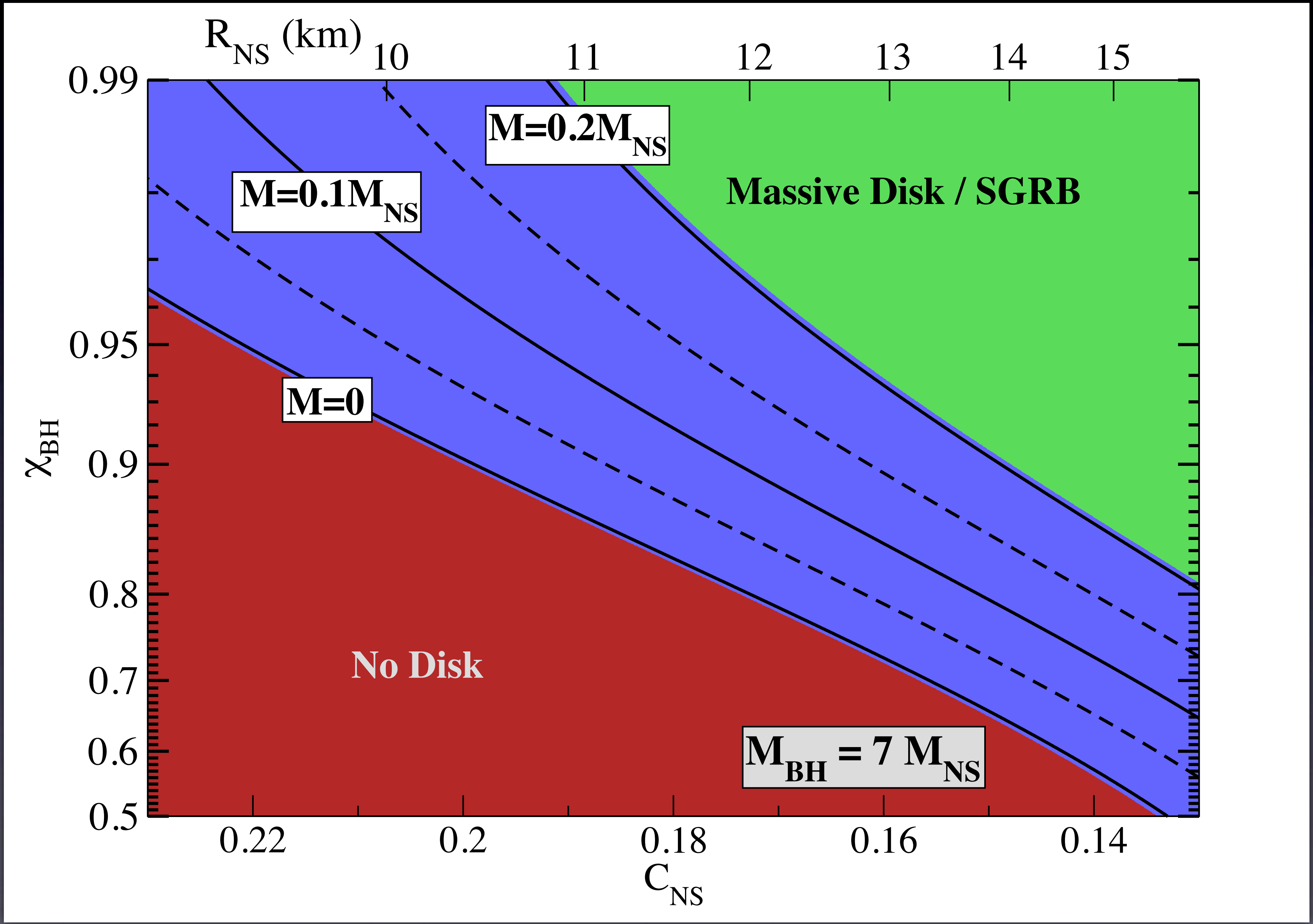
Remnant Mass

- $M_{\rm remnant} = M_{\rm disk} + M_{\rm tail} + M_{\rm ejecta}$
- Assume remnant mass depends on:
  - Tidal disruption radius
  - Innermost stable circular orbit

$$M_{\rm remnant} = \alpha \left(\frac{M_{\rm BH}}{M_{\rm NS}}\right)^{1/3} (1 - 2\frac{M_{\rm NS}}{R_{\rm NS}}) - \beta \frac{R_{\rm ISCO}}{R_{\rm NS}}$$

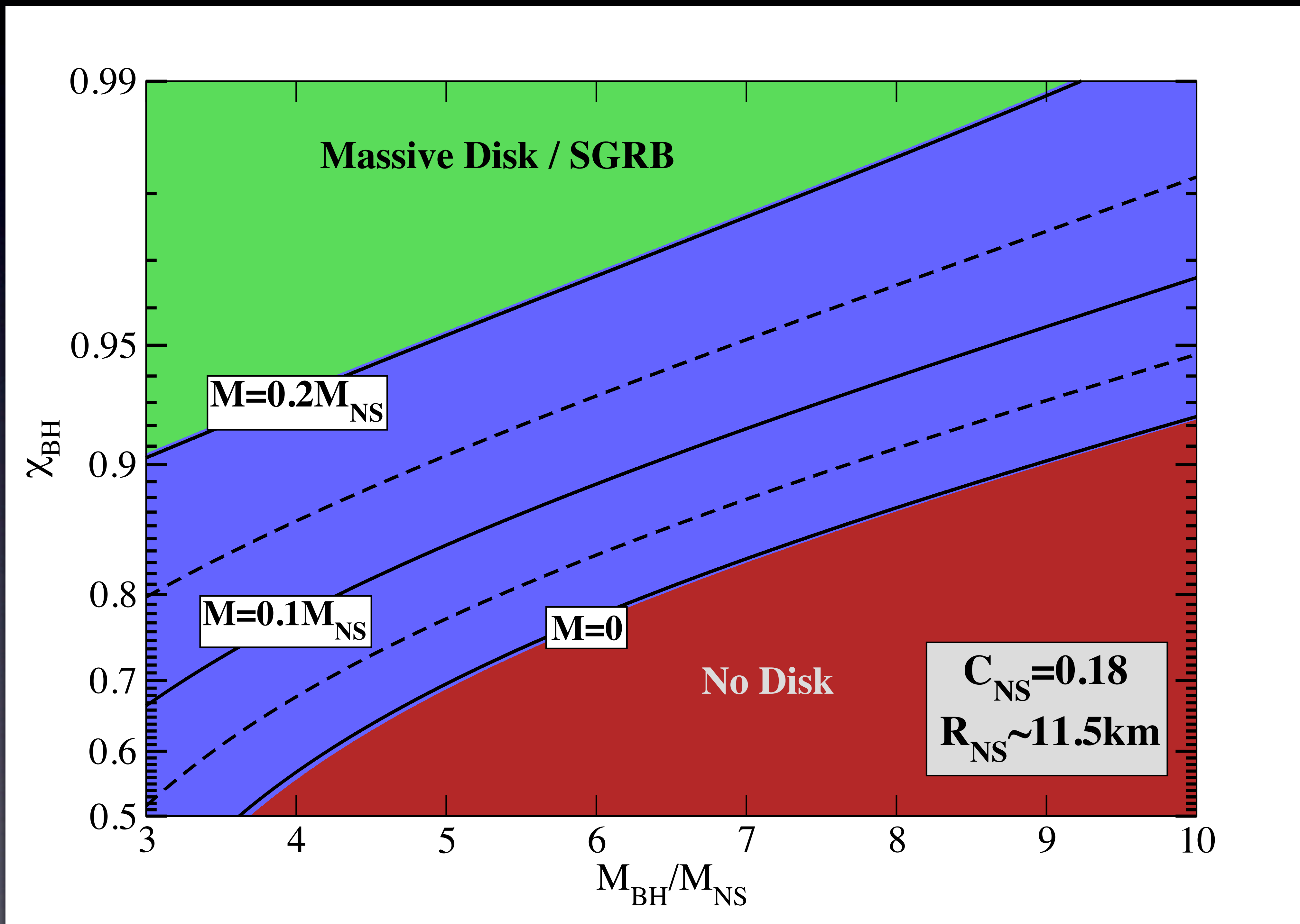
- Fit to numerical simulations [Kyutoku et al.(2012), Etienne et al. (2010), Foucart et al.(2011 & 2012)] : α=0.29,β=0.15
- ΔMremnant~0.02M_{NS} for $M_{remnant}$<0.2M_{NS}, no precession

Remnant Mass



F. Foucart (2012), arXiv:1207.6304

Remnant Mass



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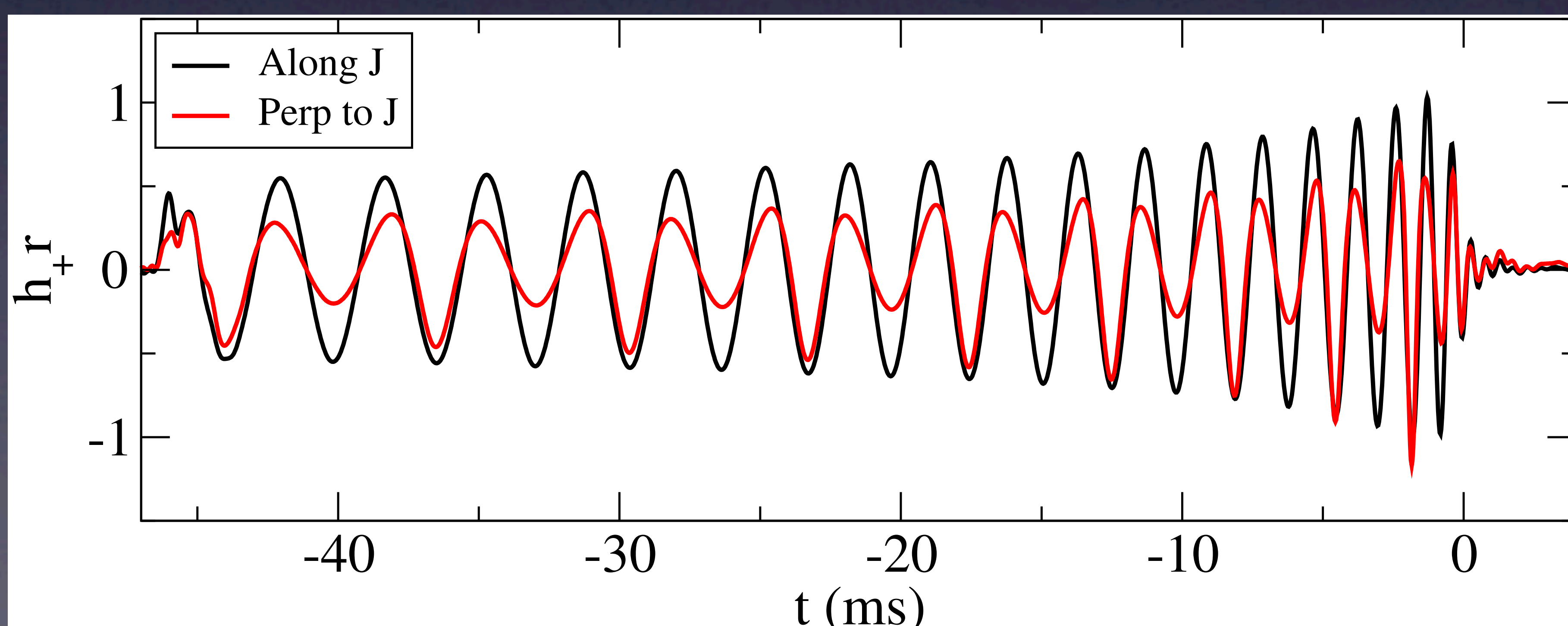
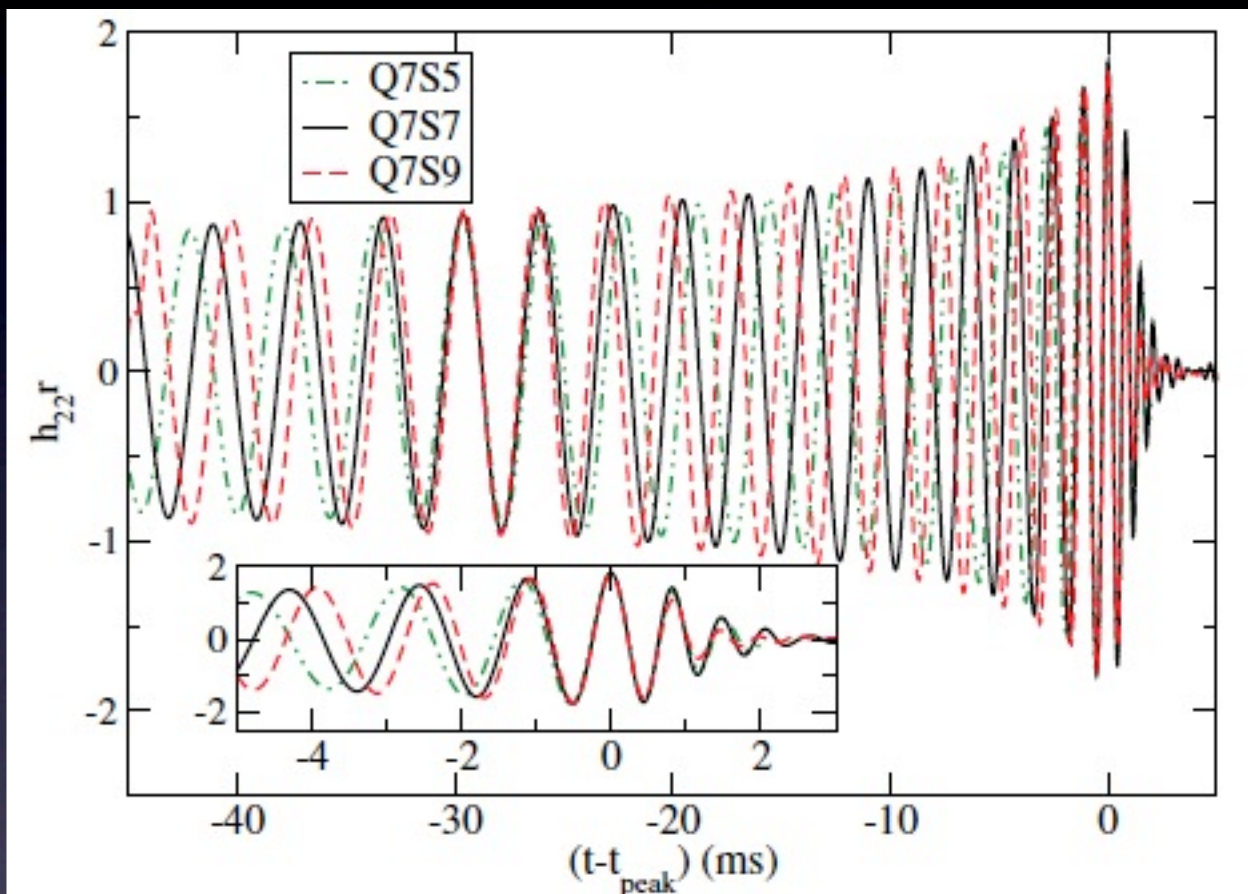
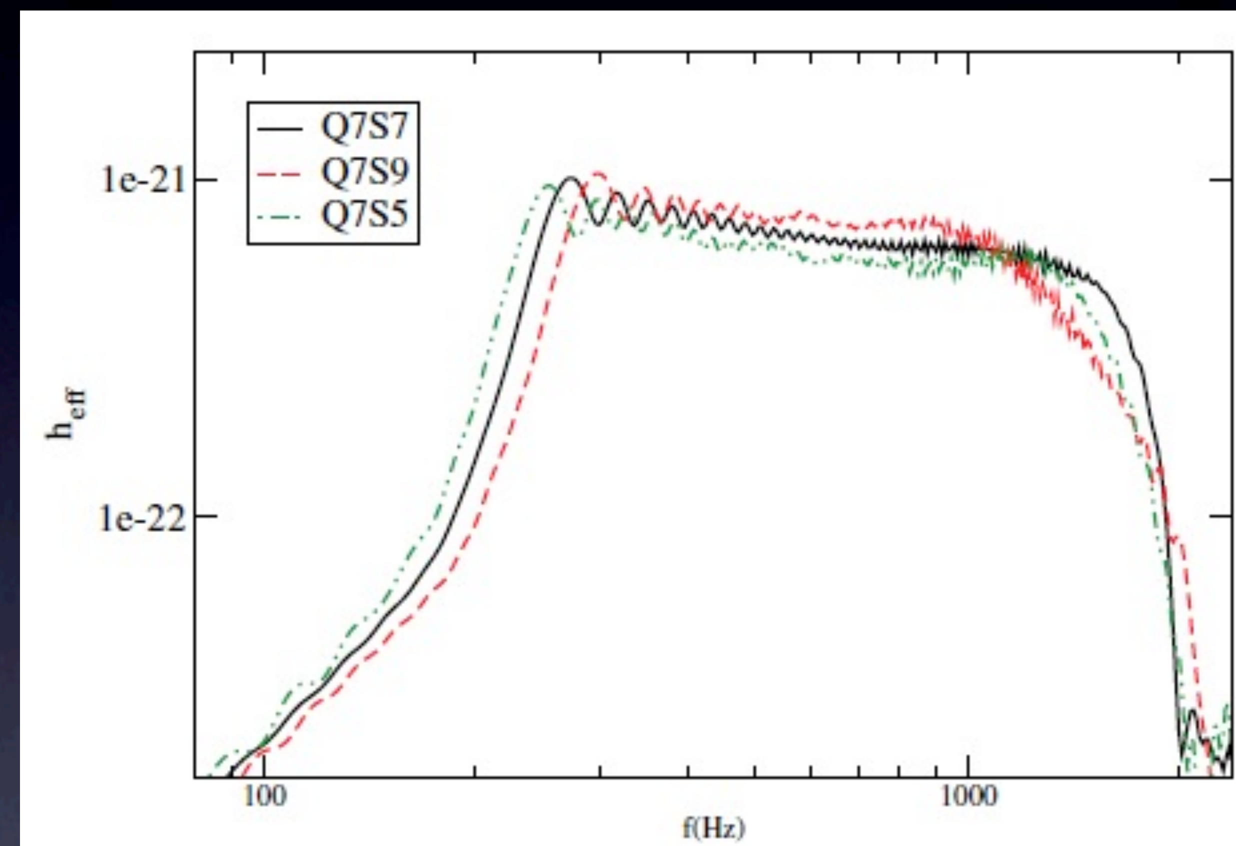
Gravitational Waves

- 15-20 cycles waveforms for all simulations
- Numerical error : $\delta\varphi$~0.2*rad* (inspiral)
- Extrapolation error : $\delta\varphi$<0.1*rad* (inspiral)



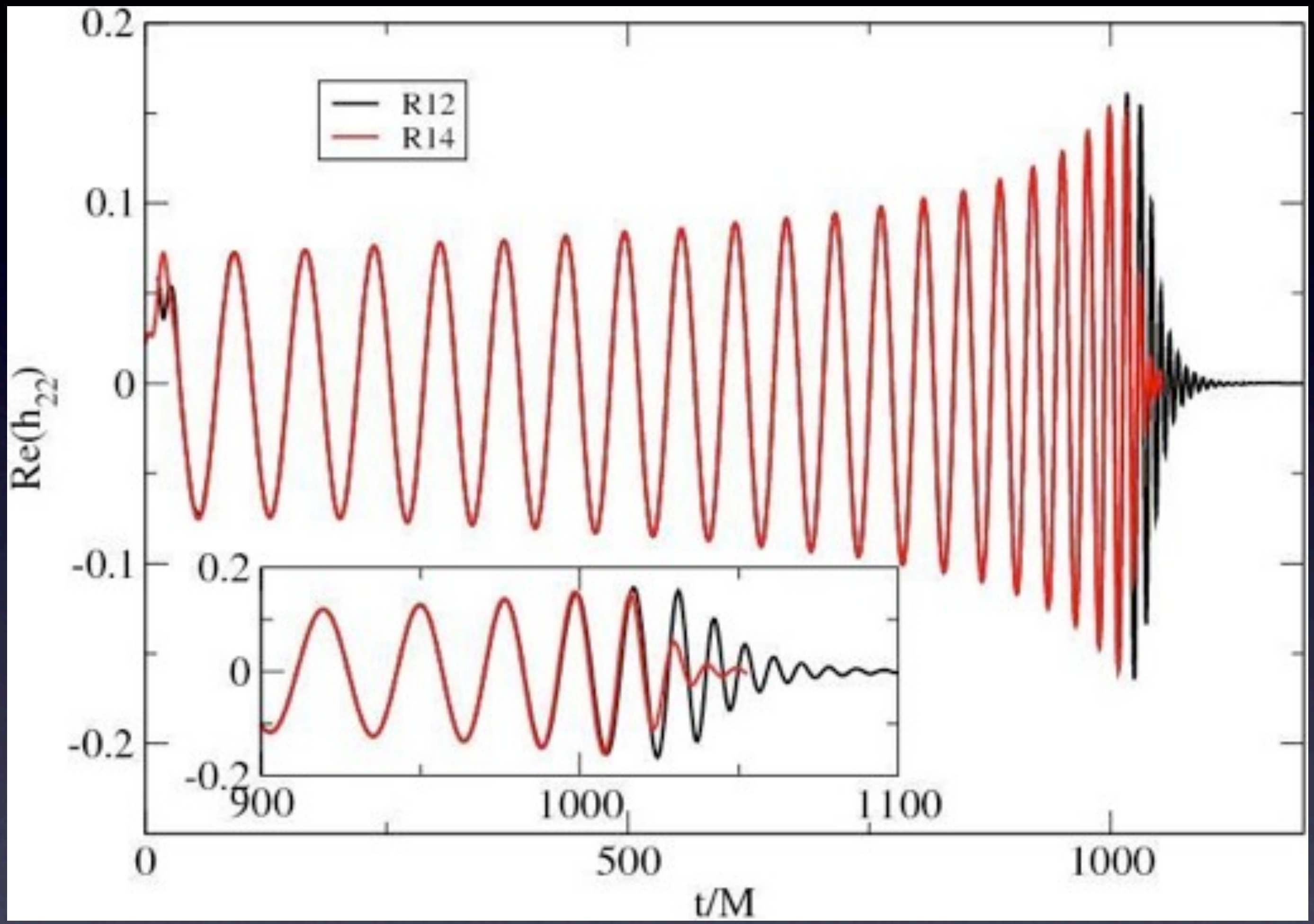
GW: Spin Effects

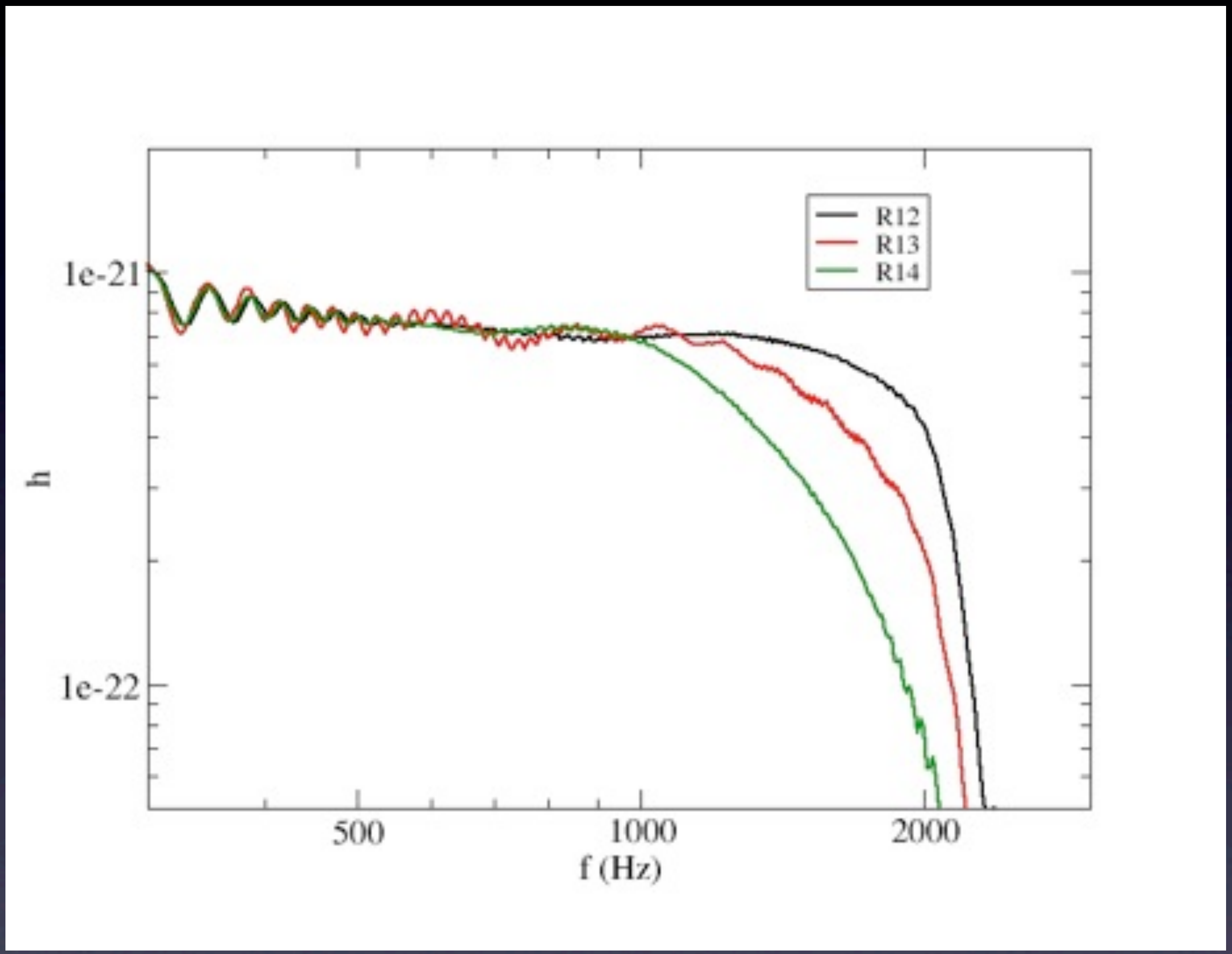




- Orbital hangup main observable spin effect
- Small differences in cutoff frequency due to disruption farther/closer to BH

GWs: EoS Effects





- Waveforms indistinguishable up to merger
- Cutoff frequency shifts: f_{cut} =1kHz →2kHz

Conclusion

- Disk formation only possible for large NS and/or quasi-extremal spins
- Equation of State effects on waveforms:
  - Small during inspiral
  - Large difference in f_{cutoff} (...if NS disrupt!)
- Mass predictions available in most of the astrophysical range of parameters

References:

F. Foucart et al. (2012), Phys Rev D85 044015
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