Can Jet Precession in SGRBs Distinguish NS-NS from BH-NS Mergers?

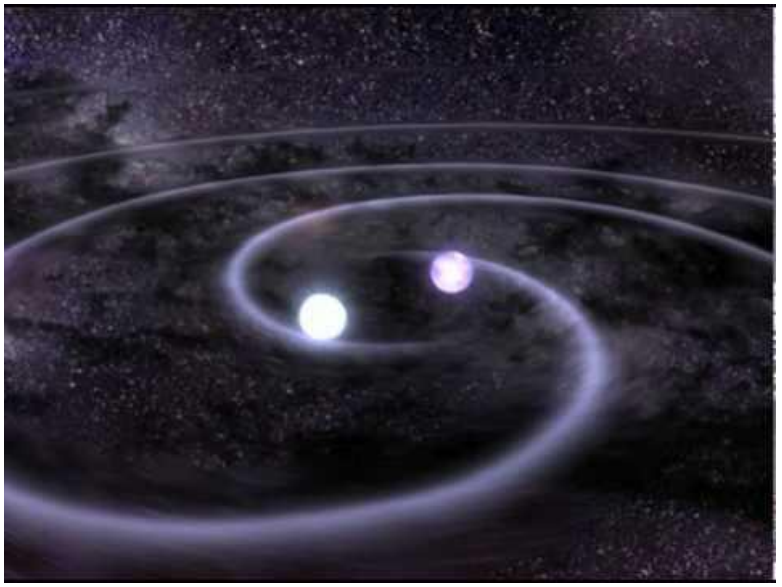
NICK STONE – 8/2/12

IN COLLABORATION WITH AVI LOEB & EDO BERGER

HARVARD UNIVERSITY ASTRONOMY DEPARTMENT

Compact Object Mergers

- Increasing observational evidence of CO merger progenitors for SGRBs
- Open question: BHNS or NSNS?
  - Could be answered by GWs
- But EM method would be good too!
  - ALIGO still years away
  - Combined GW signal + precession [non]detection very informative



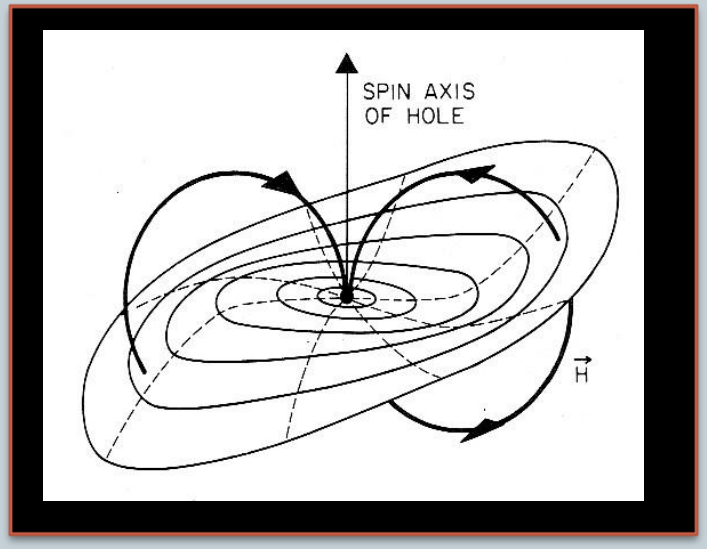
Past Work – Precessing SGRB Jets

- Older SGRB models (Blackman+ 96, Portegies-Zwart+ 99)
- CO merger
  - Thick steady-state disks, LT torques, jets aligned with $\mathbf{J}_{disk}$ (Reynoso+ 06)
  - Lightcurves (Lei+ 07)

- We calculate for the first time:
  - Distributions of T_{prec}, ψ_d
  - Evolution of QPO

Tilted Disks

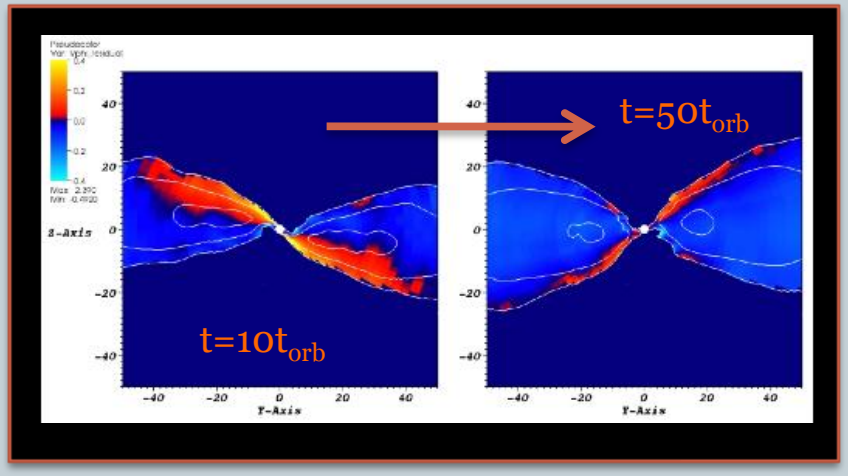
- Kerr metric=> frame-dragging
- NSNS postmerger disks unlikely to have large tilt
  - Generic to BHNS disks
- Differentially precessing mass annuli
- Thin disks: competition between differential Ω_{prec} and shear viscosity aligns inner disk (Bardeen-Petterson)



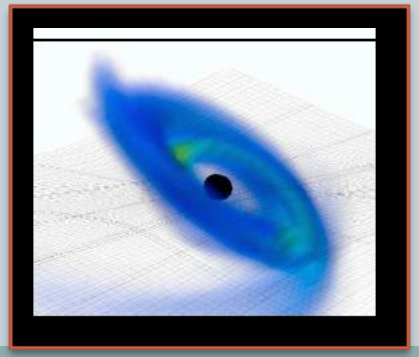
(Gravity Probe B website)

Precessing Disks

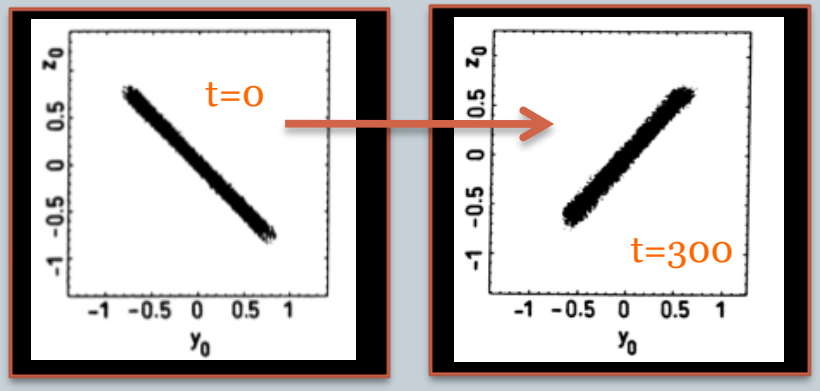
- Inclined thick disks torqued precess like solid body rotators
  - Specifically, if H/r>α
- Seen in various tilted disks:
  - Protoplanetary (Papaloizou & Terquem 94, Larwood+ 96)
  - BH disk (Fragile+ 07, 08)
  - BHNS (Foucart+ 11)
- Open question: where does jet point?
  - $\mathbf{J}_{BH}$?
  - $\mathbf{J}_{disk}$?



(Fragile & Blaes 08)



(Foucart+ 11)



(Larwood+ 96)

BHNS Progenitor Properties

- BH mass functions:
  - **Özel+ 2010 exponential w/ cutoff**
  - Farr+ 2011 Gaussian
- BH spin functions:
  - **Bimodal**
  - Flat
  - Fast
  - Slow
- NS mass/radii:
  - **Stiff EoS (R_{NS}=13.5 km)**
  - Soft EoS (R_{NS}=11 km)
- Spin-orbit misalignment ψ:
  - **Isotropic < 90°**
  - <45°, fully isotropic

Results largely independent of progenitor choices

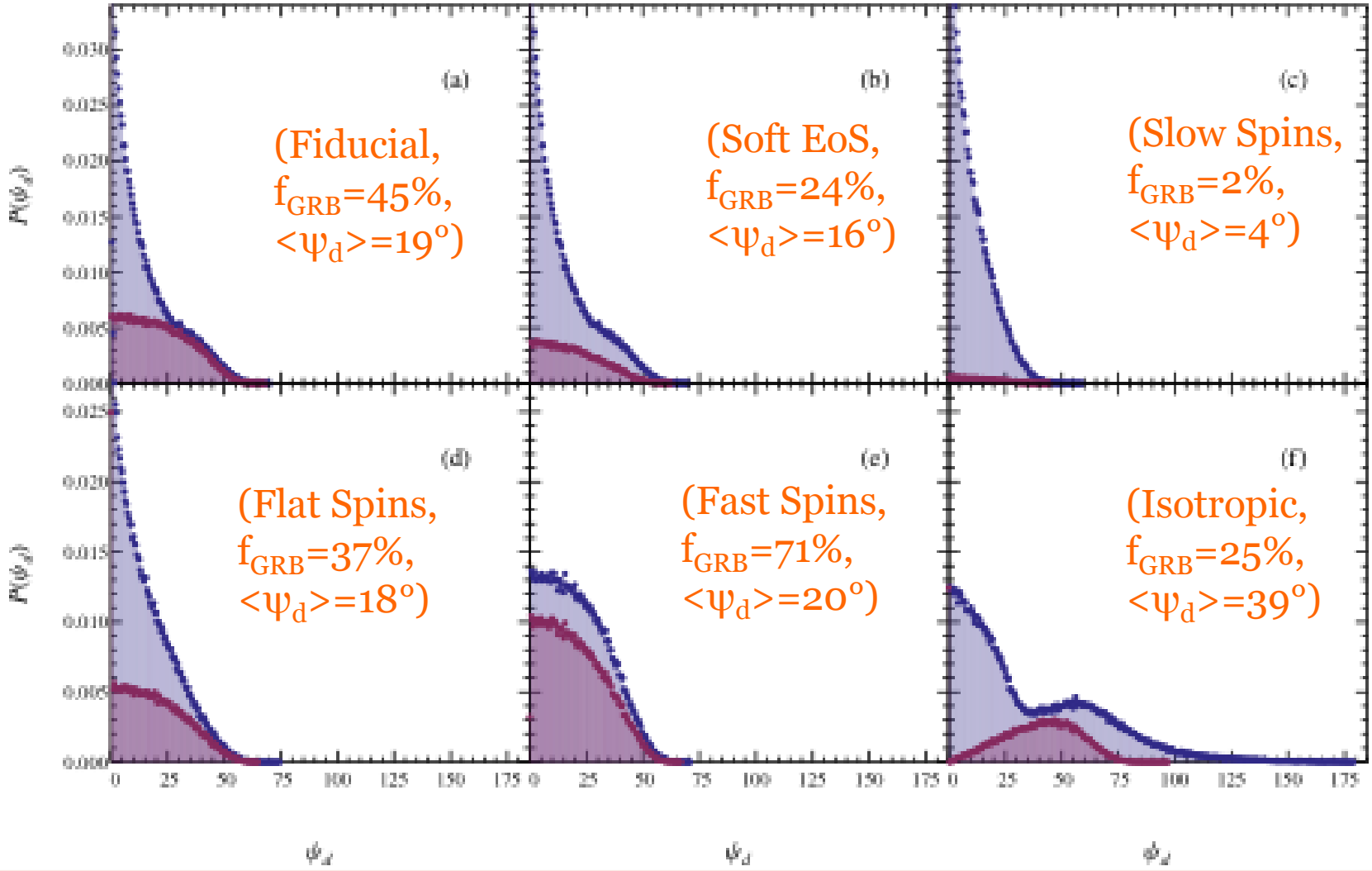
Except for this one!

BHNS Merger Prescriptions

- PN fitting formula used for postmerger mass m_f, spin a_f
  - Lousto et al. 11 – surprisingly accurate!
- Tidal disruption criteria
  - Newtonian?
  - Calibrated from NR (Foucart 12)
- Precession timescale, amplitude
  - $T_{prec}=2\pi\sin(\psi_d)(J/\tau)$, so for $\Sigma = \Sigma_0 (r/r_0)^{-\zeta}$,

$$T_{prec} \approx 0.3\,\mathrm{sec} \times \left(\frac{r_0}{50\,r_G}\right)^{5/2-\zeta} \times \left(\frac{r_i}{10\,r_G}\right)^{1/2+\zeta} \times \left(\frac{M_{BH}}{M_{Sun}}\right) \times \left(\frac{a_{BH}}{0.9}\right)^{-1}$$

Results – Misalignment



(Fiducial, f_{GRB}=45%, $\langle\psi_d\rangle$=19°)

(Soft EoS, f_{GRB}=24%, $\langle\psi_d\rangle$=16°)

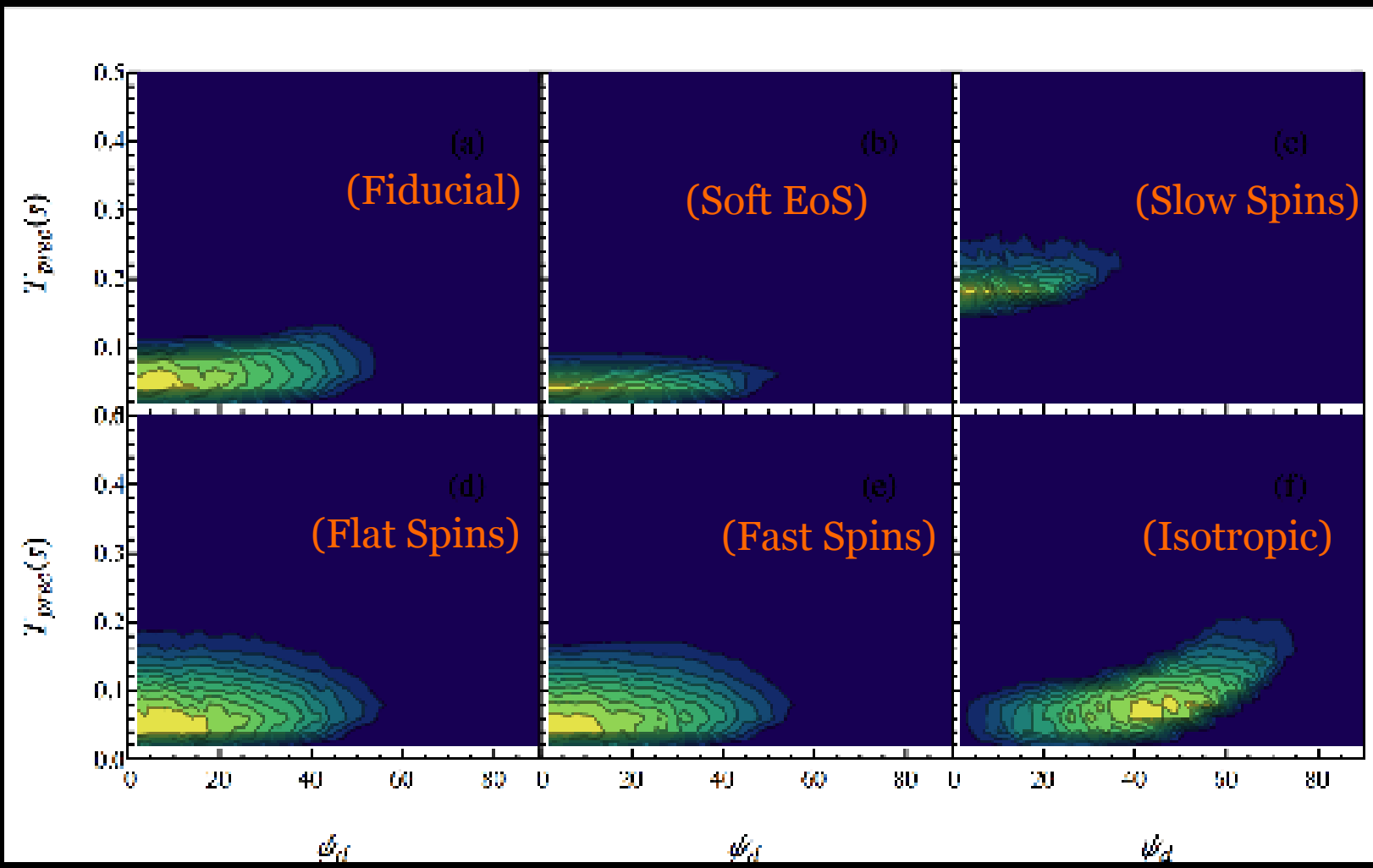
(Slow Spins, f_{GRB}=2%, $\langle\psi_d\rangle$=4°)

(Flat Spins, f_{GRB}=37%, $\langle\psi_d\rangle$=18°)

(Fast Spins, f_{GRB}=71%, $\langle\psi_d\rangle$=20°)

(Isotropic, f_{GRB}=25%, $\langle\psi_d\rangle$=39°)

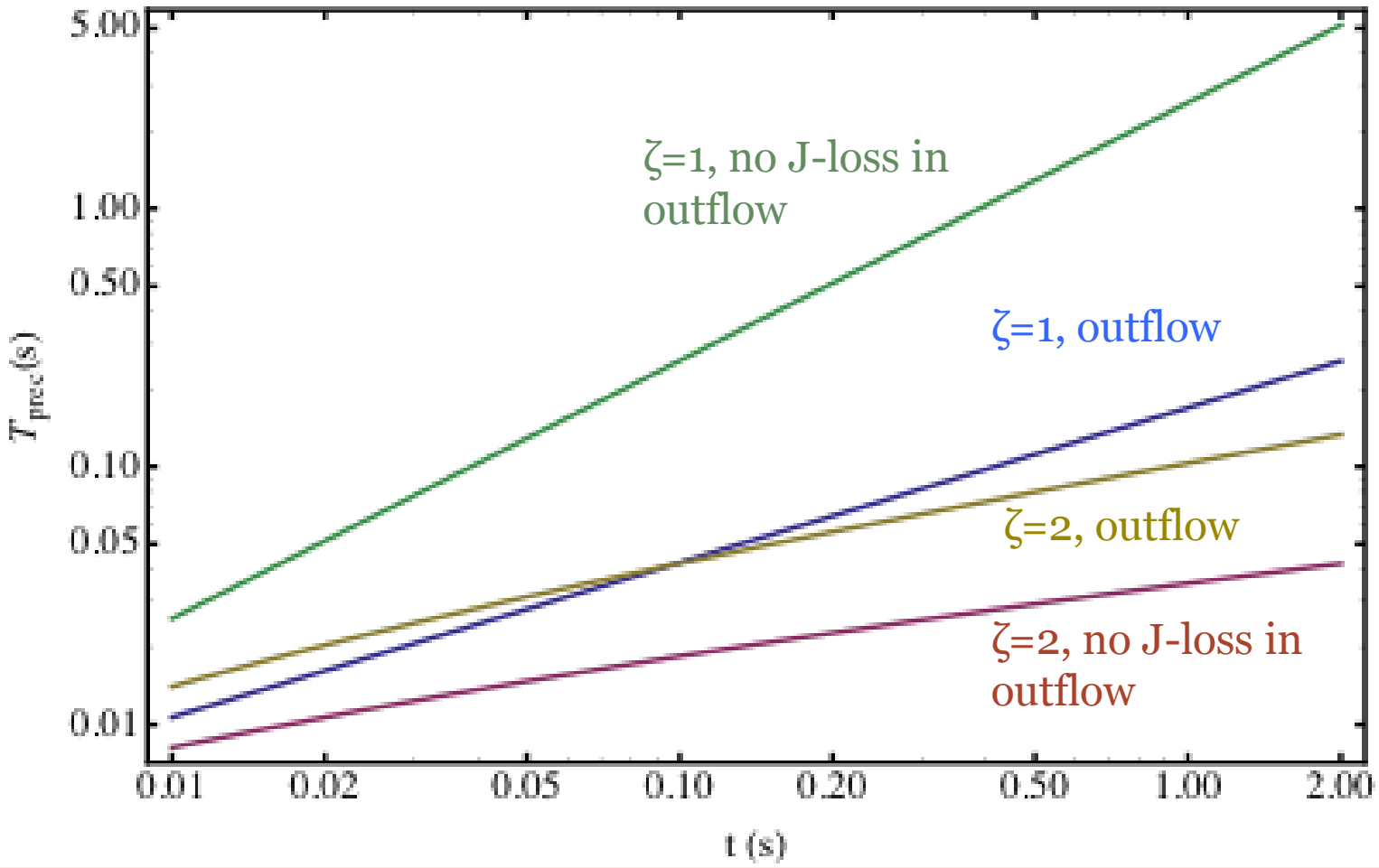
Results – Precession Timescales



Evolution and Observability

- Observability:
  - T_{prec}>10 msec >> Δt
  - Limited by photon counting statistics
- Two major uncertainties
- Does jet align with $\mathbf{J}_{BH}$ or $\mathbf{J}_{disk}$?
  - If $\mathbf{J}_{disk}$, then $\psi_d \sim 25°$ is the precession angle
  - If $\mathbf{J}_{BH}$, then $(J_{disk}/J_{tot})\psi_d < 5°$ is the precession angle
- How does disk spread viscously outward?
  - I.e. how does T_{prec} grow in time?

Timescale Evolution



Theoretical Uncertainties

Is there a persistent QPO?

	Jet $\|\|$ $\mathbf{J}_{disk}$ (Fireball, BZ?)	Jet $\|\|$ $\mathbf{J}_{BH}$ (BZ?)
ζ=2	**Yes, $\langle\psi_{prec}\rangle \sim 25^\circ$**	**Yes, $\langle\psi_{prec}\rangle \sim 5^\circ$**
ζ=1	Marginal, $\langle\psi_{prec}\rangle \sim 25^\circ$	Marginal, $\langle\psi_{prec}\rangle \sim 5^\circ$
ζ=1, disk winds	Yes, $\langle\psi_{prec}\rangle \sim 25^\circ$	No

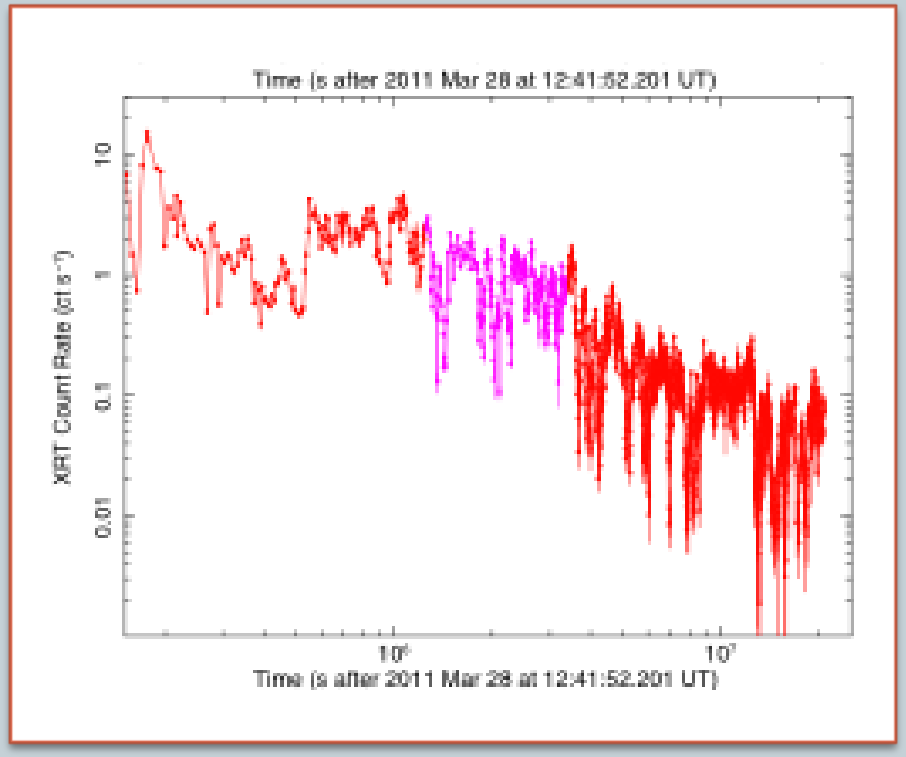
Conclusions

- Post-merger BHNS disks will have large tilts $\psi_d \sim 25°$, initially short $T_{prec} \sim 0.01\text{-}0.2s$
- Results generally independent of assumptions on progenitor population
- Larger uncertainties physical:
  - Jet alignment direction?
  - Viscous spreading of disk?
- Implications:
  - QPO in prompt emission
  - Larger solid angle for jet/outflows

Questions?

Precessing Jets

- Not well-constrained theoretically
- Handful of observational constraints:
  - Microquasar LSI+61°303=> jet aligns with disk (Massi+ 12)
  - Swift 1644+57 => jet aligns with BH spin (Stone & Loeb 12)
- But jet launching mechanism may vary between systems!



(Saxton+ 12)