# Jet Precession in SGRBs: a Discriminant Between NS-NS and BH-NS Mergers

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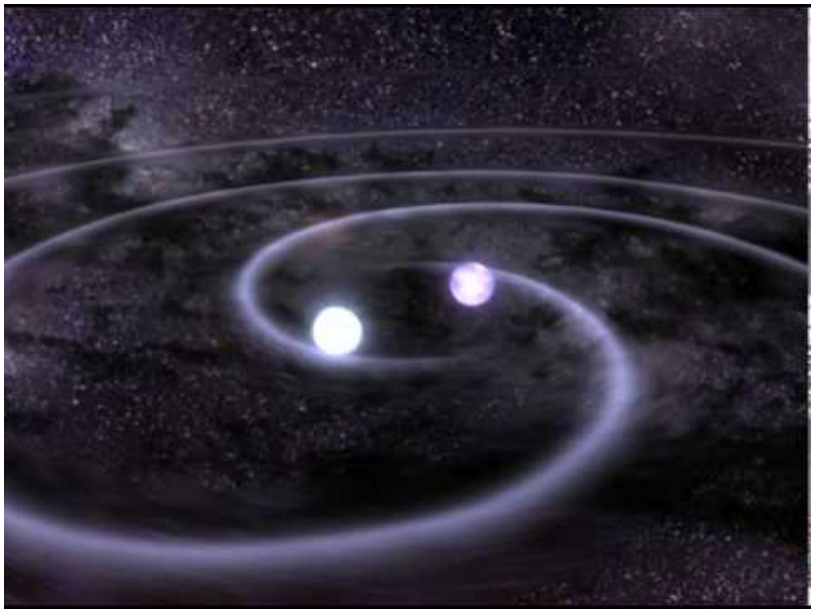
# Compact Object Mergers

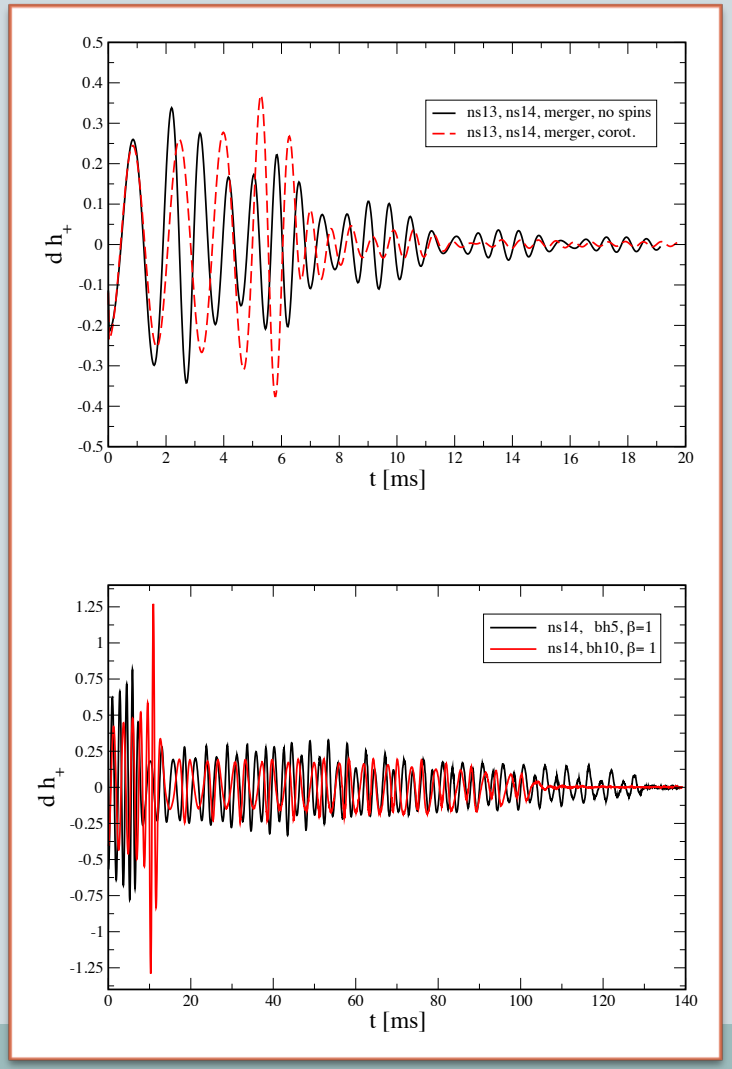
- Increasing observational evidence of compact object merger progenitors for SGRBs
- Open question: BH-NS or NS-NS?
  - Relative rates uncertain
- BH-NS rates very interesting
  - ALIGO rate informs binary evolution, stellar dynamics
  - SGRB/ALIGO rate ratio informs NS radii, BH spin distributions



(Wikimedia)

# Compact Object Mergers: Differences

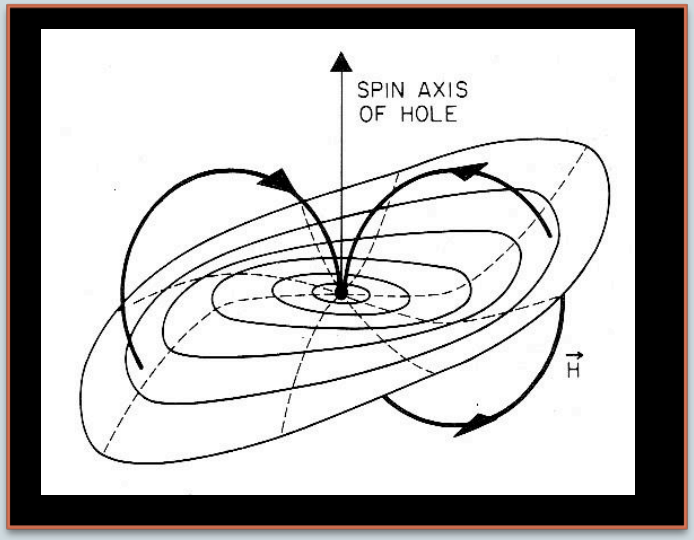
- Dynamical ejecta (Piran+13)
  - NS-NS ~0.01 $M_\odot$
  - BH-NS ~0.05 $M_\odot$
- Supramassive NS (Özel+10)
- GW signal (e.g. Rosswog+13)
- Offset distribution (natal kicks)
  - Statistical/hypothetical probe (Belczynski+ 06)
- Our proposal: jet precession




(Rosswog+13)

# Tilted Disks

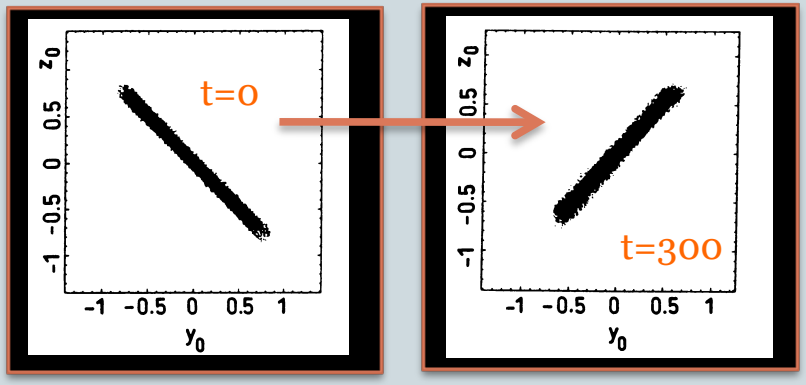
- Kerr metric => frame-dragging
- Differentially precessing mass annuli: $d\mathbf{J}/dt \propto r^{-3}$
- Warp evolution depends on $(H/R)/\alpha$
  - Thin disks: warp propagation diffusive, shear viscosity aligns inner regions (Bardeen-Petterson effect)
  - Thick disk: warp propagation wavelike



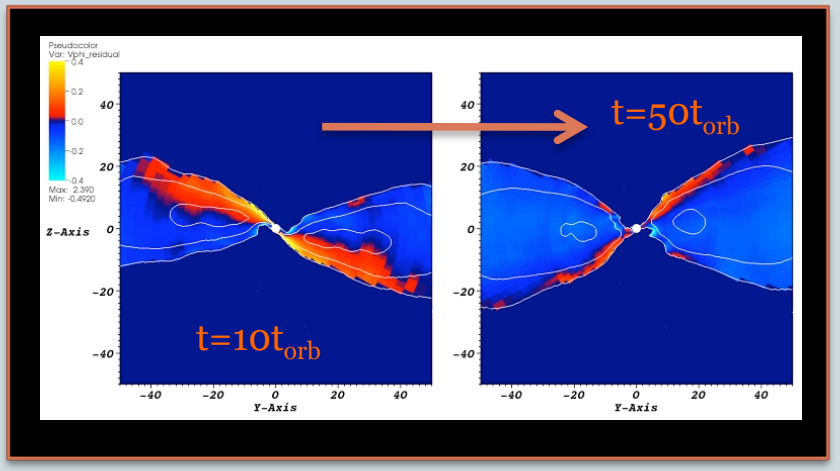

(Gravity Probe B)

# Precessing Disks

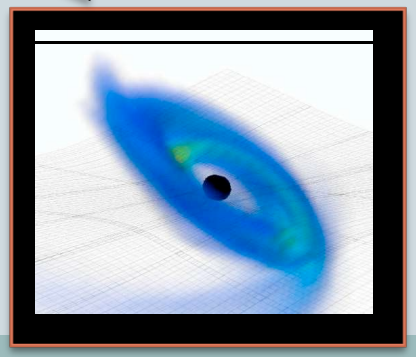
- Inclined thick disks precess like solid body rotators when torqued
  - Specifically, if $H/r > \alpha$
- Seen in various tilted disks:
  - Protoplanetary
  - BH disk
  - BH-NS remnant
- Open question: where does jet point?
  - $J_{BH}$?
  - $J_{disk}$?




(Larwood+ 96)



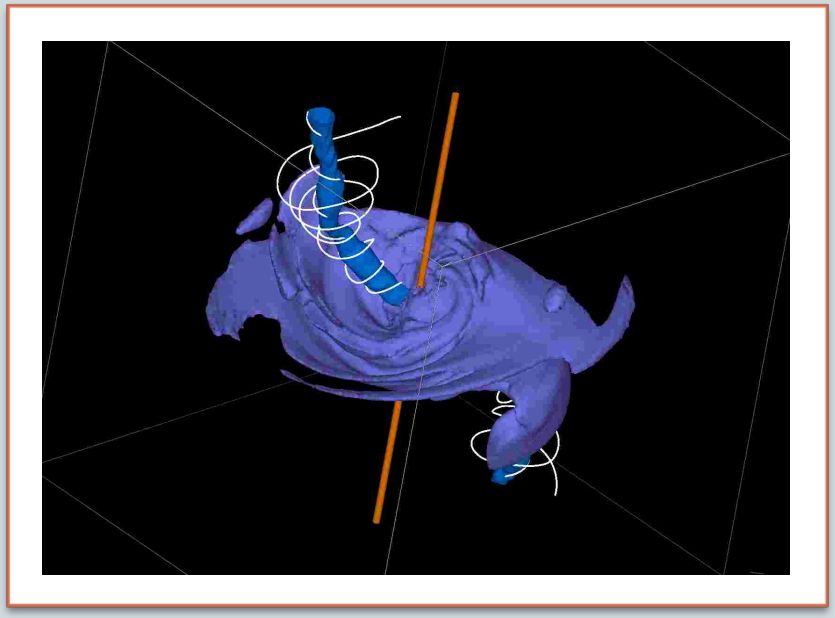

(Fragile & Blaes 08)



(Foucart+ 11)

# Precessing Jets

- Theory:
  - Force-free: aligns with $\mathbf{J}_{\rm disk}$ (Palenzuela+10)
  - GRMHD: $\mathbf{J}_{\rm disk}$, but ambiguous (McKinney+13)
- Observations:
  - Microquasars: LSI+61°303 indicates $\mathbf{J}_{\rm disk}$ alignment (Massi+12)
  - Tidal disruption events: Swift J1644+57 indicates $\mathbf{J}_{\rm BH}$ alignment (Stone & Loeb 12), but possible $\mathbf{J}_{\rm disk}$ alignment at early times



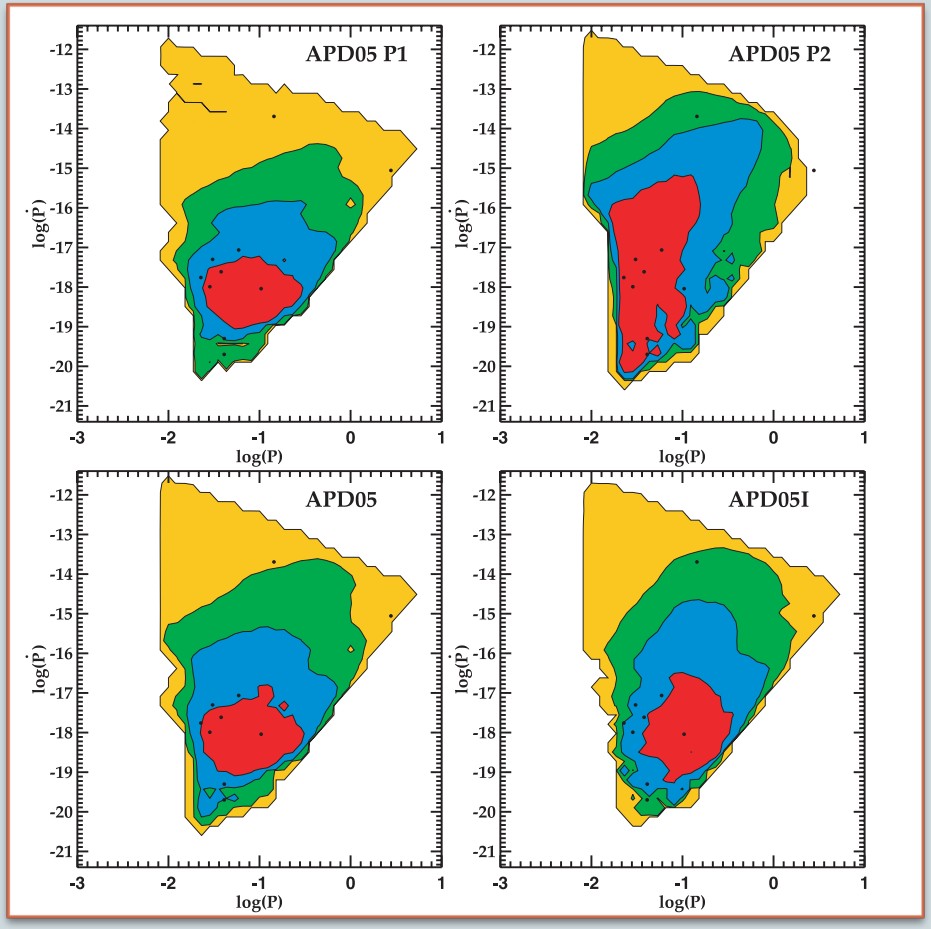
(McKinney+13)

# Past Work – Precessing SGRB Jets

- Older SGRB models (Blackman+ 96)
- CO merger
  - Thick steady-state disks, LT torques, jets aligned with $\mathbf{J}_{\rm disk}$ (Reynoso+ 06)
  - Lightcurves (Lei+ 07)
- We calculate for the first time:
  - Large Monte Carlo sample of merger events with realistic prescriptions for postmerger spin, misalignment, etc
  - Distributions of $T_{\rm prec}$, $\psi_{\rm d}$
  - Evolution of QPO
  - Requirements for disk tilt

# Which SGRB Disks are Tilted?

- NS-NS: no
  - $\psi_d$<1°, generally <<1°
  - Compare to $\theta_{jet}$~5°
- BH-NS: often
  - $\psi_d$~25°




(Oslowski+10)

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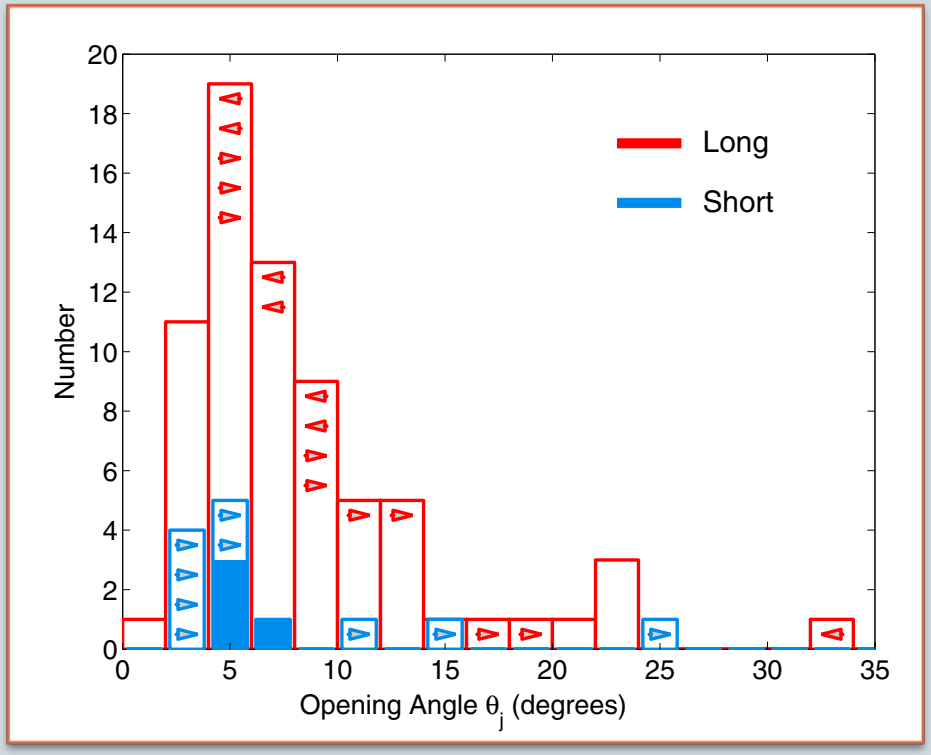
- BH-NS: often
  - $\psi_d$~25°
- Important caveat – many BH-NS mergers can't produce SGRBs
  - Small $M_{BH}$, large $a_{BH}$, large $R_{NS}$ help




(Fong+14)

# BH-NS 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°**
  - Fully isotropic (<180°)

Results largely independent of progenitor choices

Except for this one!

# BH-NS Merger Prescriptions

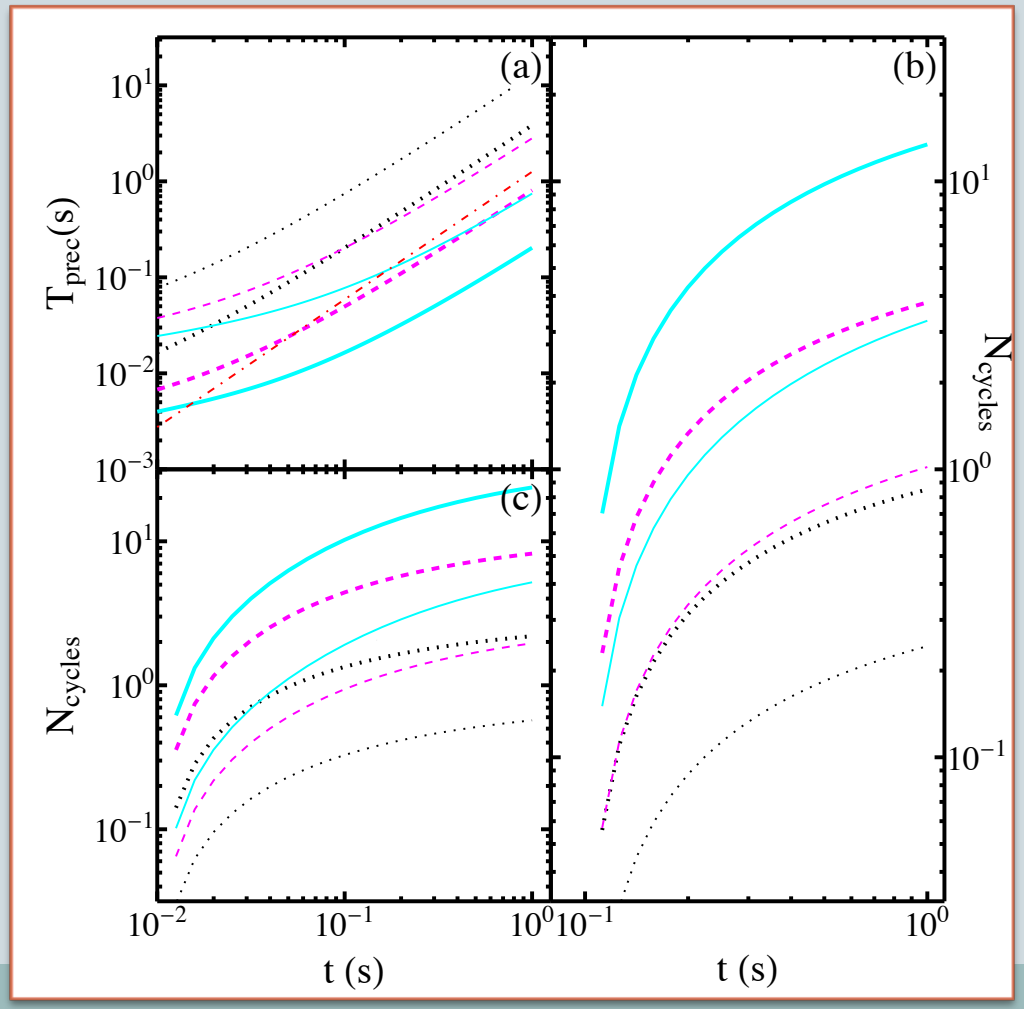
- PN fitting formula used for postmerger mass $m_f$, spin $a_f$
  - Lousto+ 11 – surprisingly accurate!
- Tidal disruption criteria
  - Calibrated from numerical relativity (Foucart 12)
  - Effective spin modification for misaligned BH-NS
- Precession timescale, amplitude
  - $T_{prec}=2\pi\sin(\psi_d)(J/\tau)$, so for $\Sigma = \Sigma_0 (r/r_0)^{-\zeta}$,

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

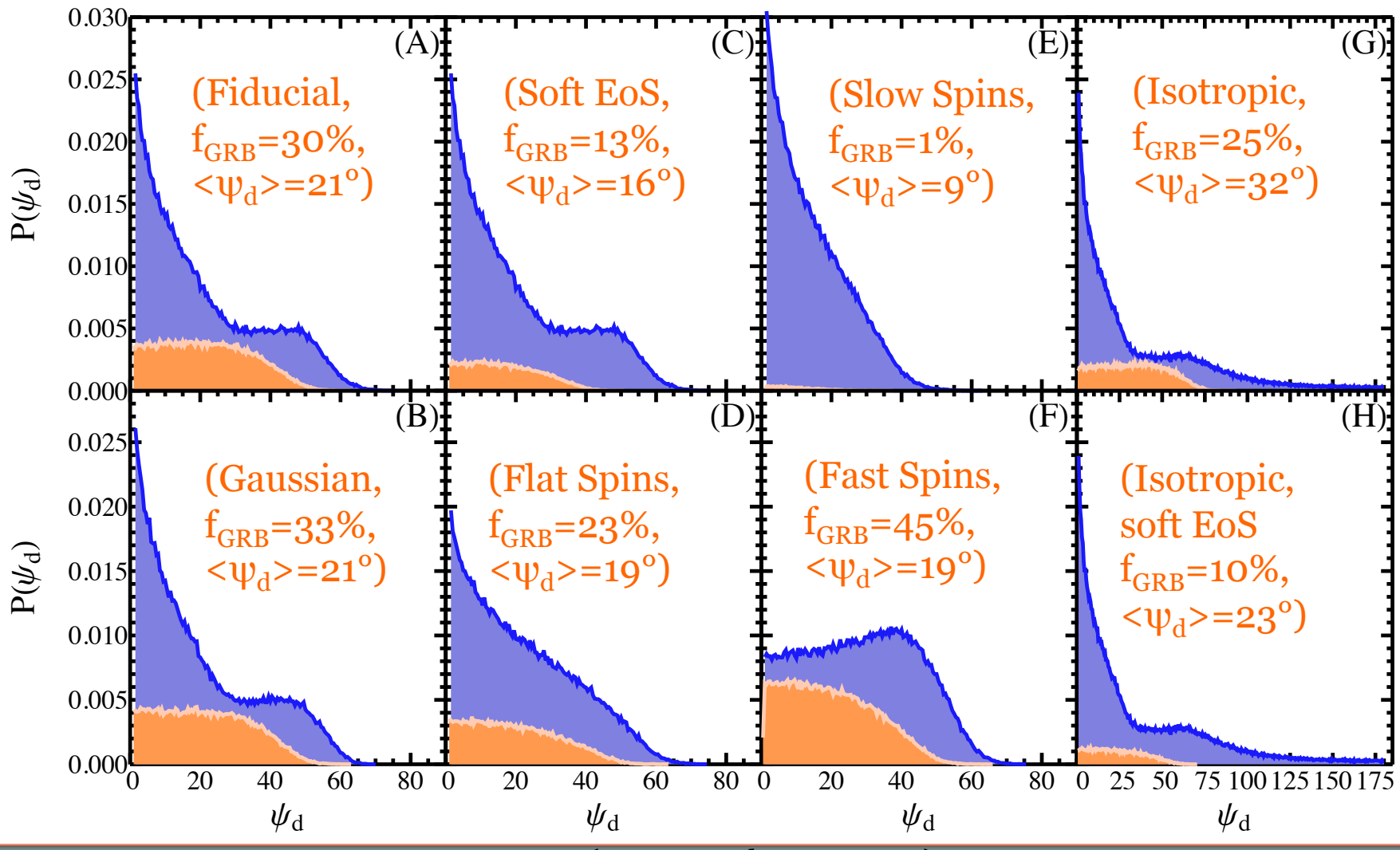
# Timescale Evolution

- Analytic solution for spreading disk (Metzger+ 08)
- Self-similar expansion: $T_{prec} \propto t^{4/3}$
- Results sensitive to $\alpha$
  - Need $\alpha \leq 0.1$ for $N_{cycles} > 1$
  - Need $\alpha \leq 0.01$ for $N_{cycles} > 10$

(**Stone**, Loeb & Berger 13)

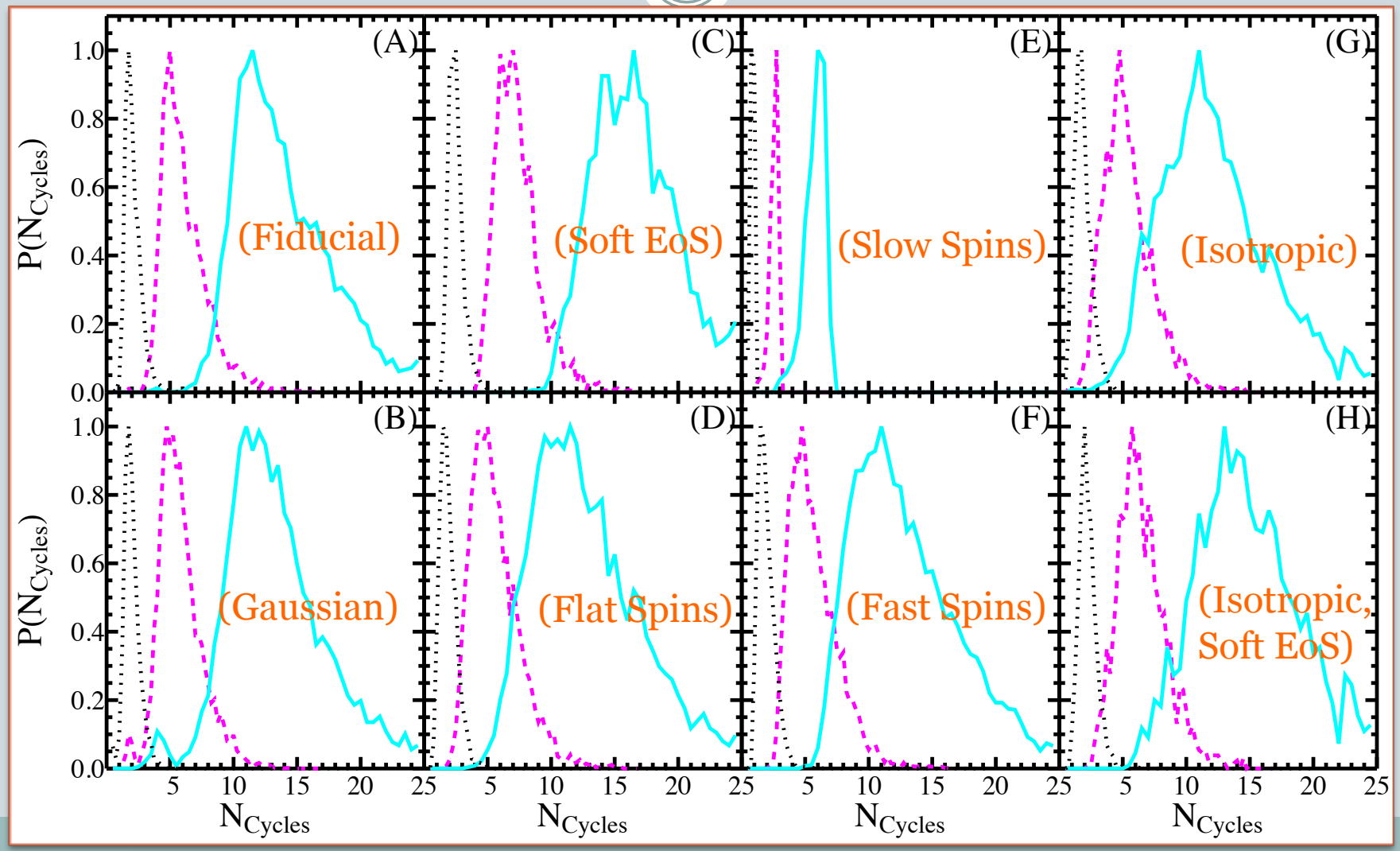


# Results – Misalignment, $f_{GRB}$



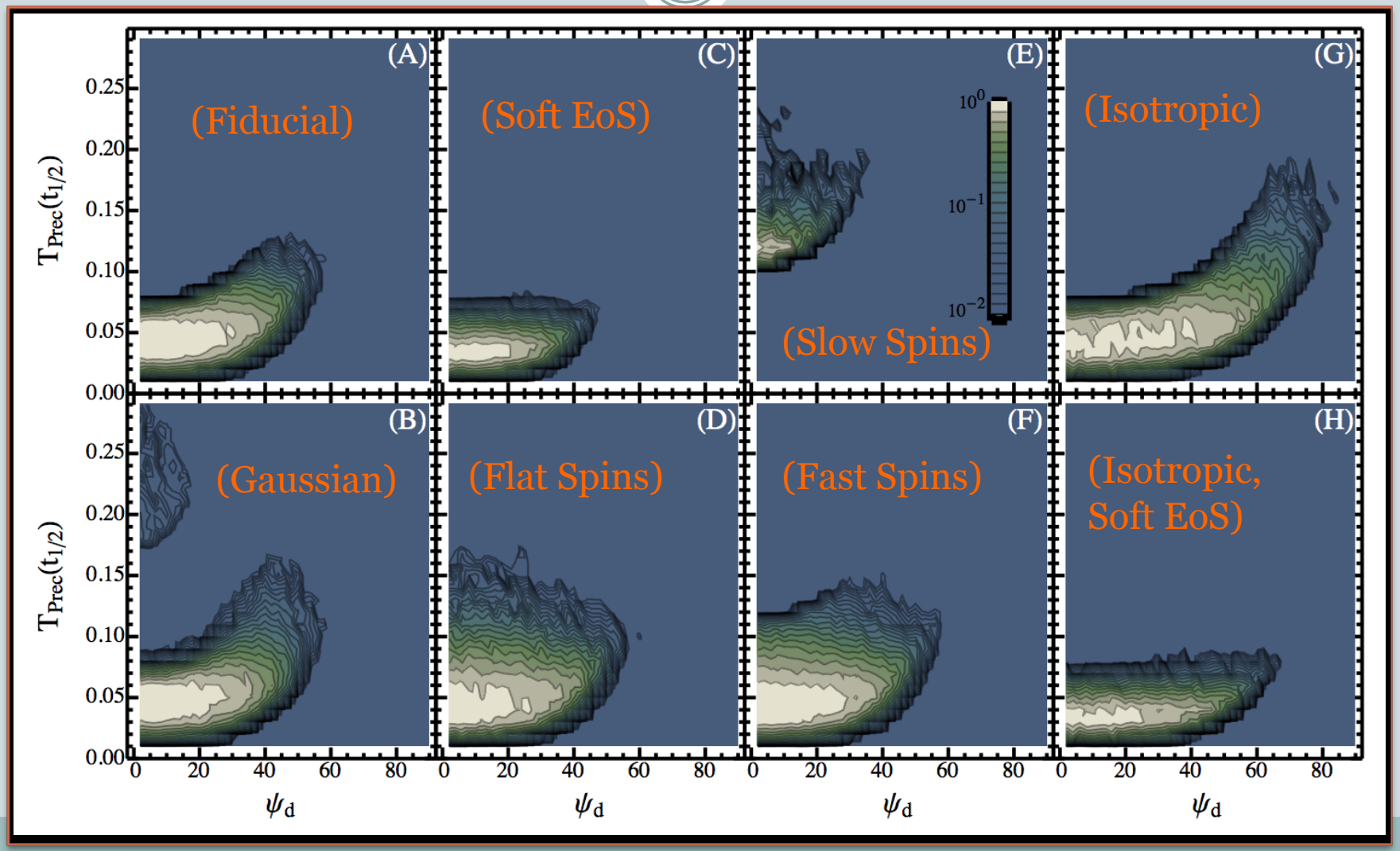

(**Stone**, Loeb & Berger 13)

# Results – Cycle Accumulation




(**Stone**, Loeb & Berger 13)

# Results – Precession Timescales



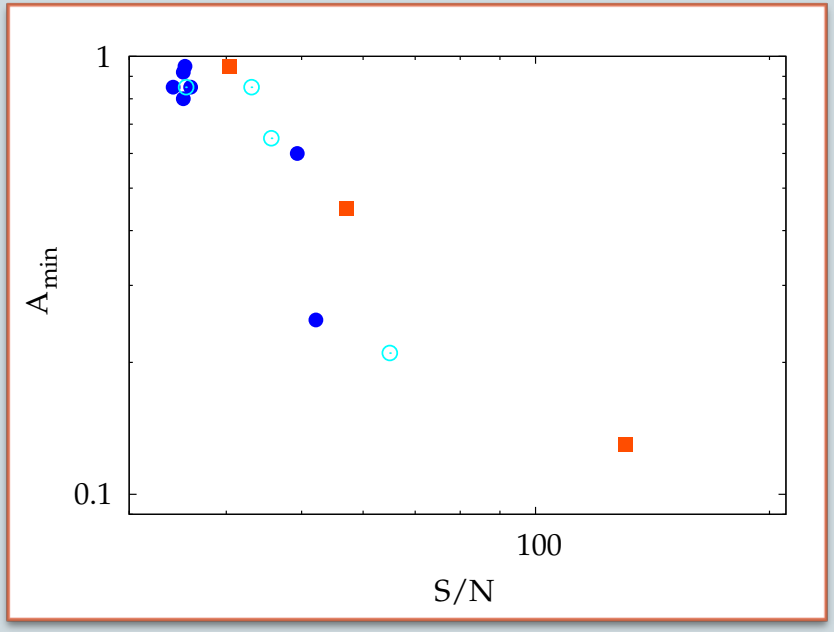

(**Stone**, Loeb & Berger 13)

# Evolution and Observability

- Observability:
  - $T_{prec}$>10 msec >> $\Delta t$
  - Limited by photon counting statistics
- Two theoretical uncertainties
- 1. 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
- 2. How does disk spread viscously outward?
  - I.e. how does $T_{prec}$ grow in time?

# Observational Searches

- BATSE archival search: 2203 GRBs, no periodicity detected (Kruger+02)
- Followup search by Dichiara+13
  - Examined 44 SGRBs with SNR>20, no periodicity found in power spectra
  - 14/44 have sufficient SNR to search for $T_{prec}$ α $t^{4/3}$ : no QPOs found
  - Constraint on BH-NS fraction?




(Dichiara+13)

# Conclusions – SGRB Jet Precession

- Post-merger BH-NS disks will have large tilts $\psi_d \sim 25°$, initially short $T_{prec} \sim 0.01\text{-}0.2s$
  - Post-merger NS-NS disks have $\psi_d < 1°$
- Results generally independent of assumptions on progenitor population
- Larger uncertainties physical:
  - Jet alignment direction?
  - Viscous spreading of disk? I.e. $\alpha < 0.1$ needed for $N_{cycles} >> 1$
- Implications:
  - QPO in prompt emission
  - Larger solid angle for jet/outflows in BH-NS
  - Precession nondetections (Dichiara+ 13) may indicate low BH-NS fraction in SGRBs

# Questions?