Black Hole Mergers: From Simulations to Detection

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Collaborations

Lazarus: J.Baker, B.Brügmann, M.Campanelli, R.Takahashi, C.L.

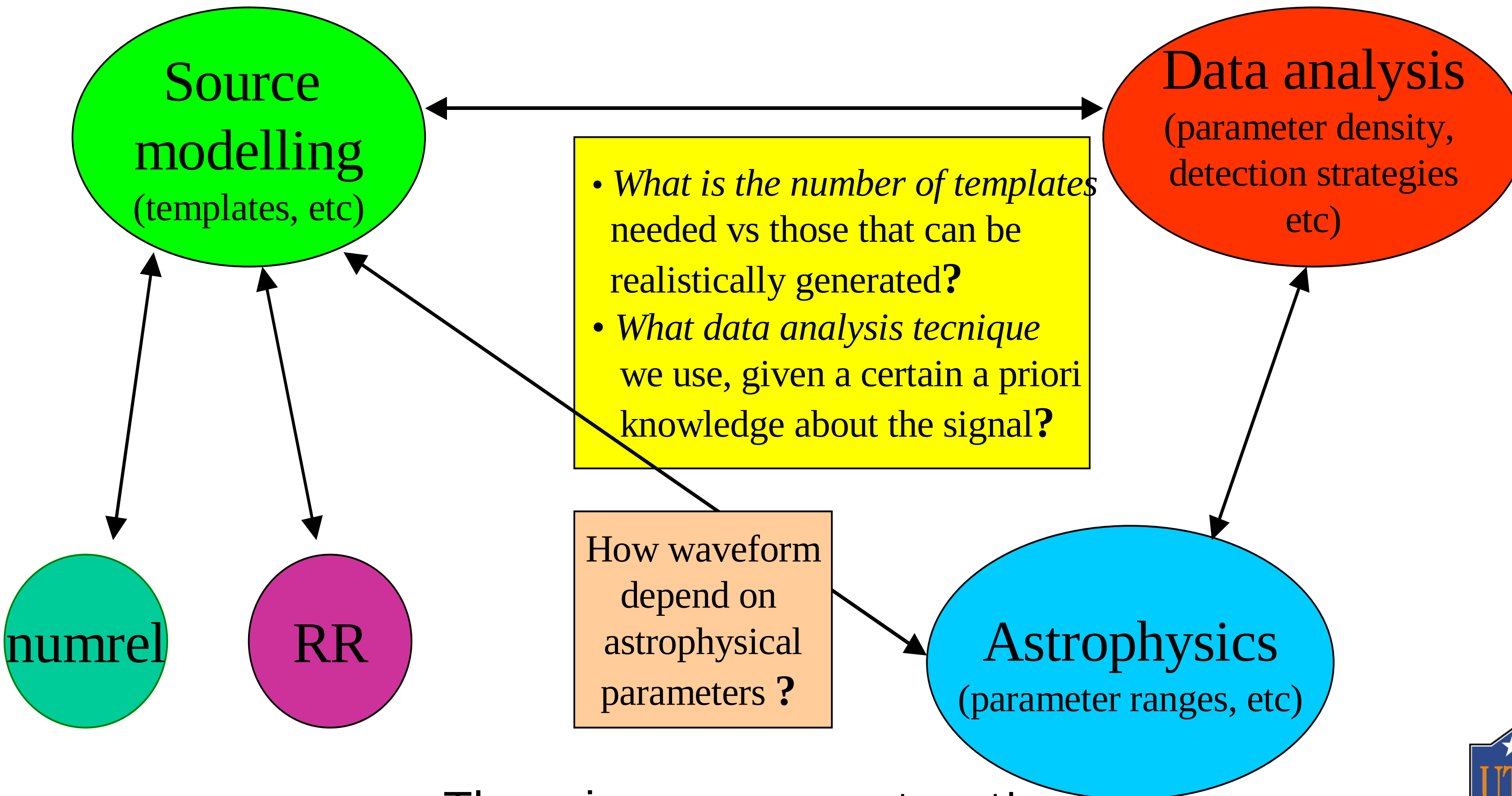
Kudu: Lazarus + W.Anderson, J.Creighton, C.Torres

Outline (Progress report)

- Kudu in a nutshell: Source simulations - Data analysis – Astrophysics connection
- Lazarus approach
  - Quasicircular orbits of BBH
- Time-frequency Maps of
  - Lazarus, PN, and Kludge waveforms
- Implement new search strategy

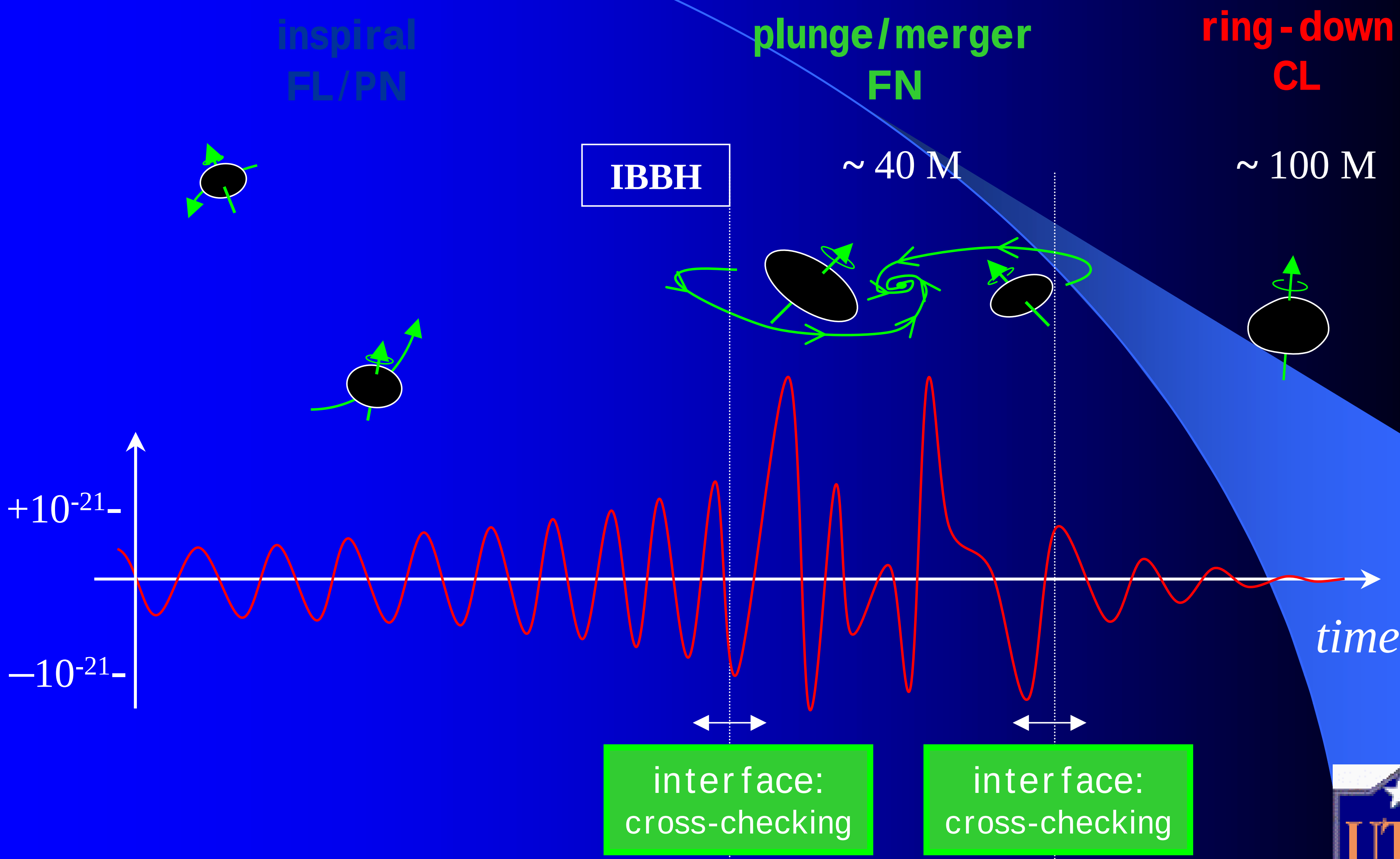
Black hole mergers: from simulation to detection

The Kudu Project:
A proposal to use Lazarus waveforms for a first small step in the interface between source modeling and data analysis. (a) Determine robust features of the waveforms. (b) Explore parameter space dependencies of the waveforms. (c) Design optimal detection strategies.



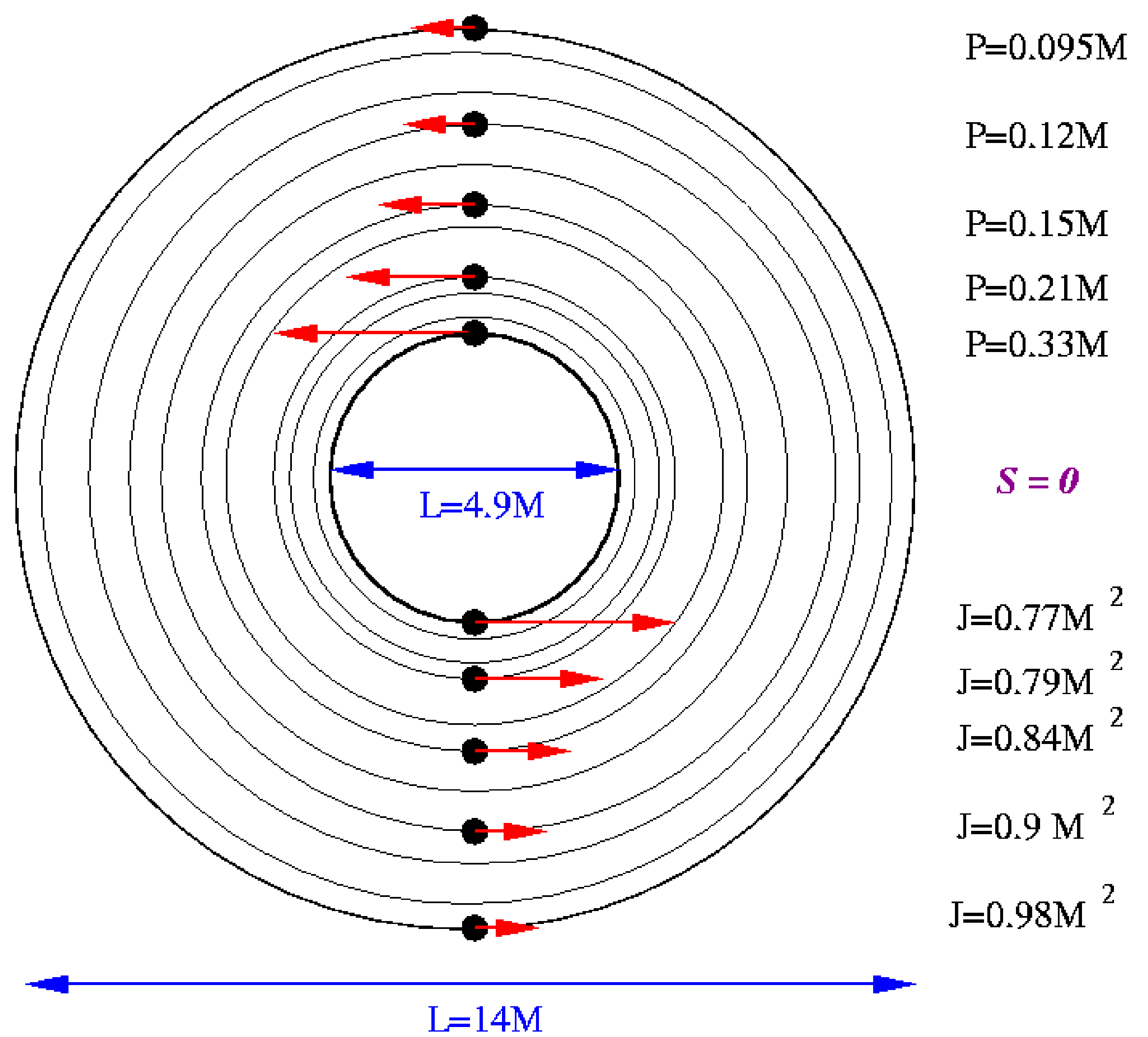
There is no one way street!

Lazarus = FL + interface + FN + interface + CL

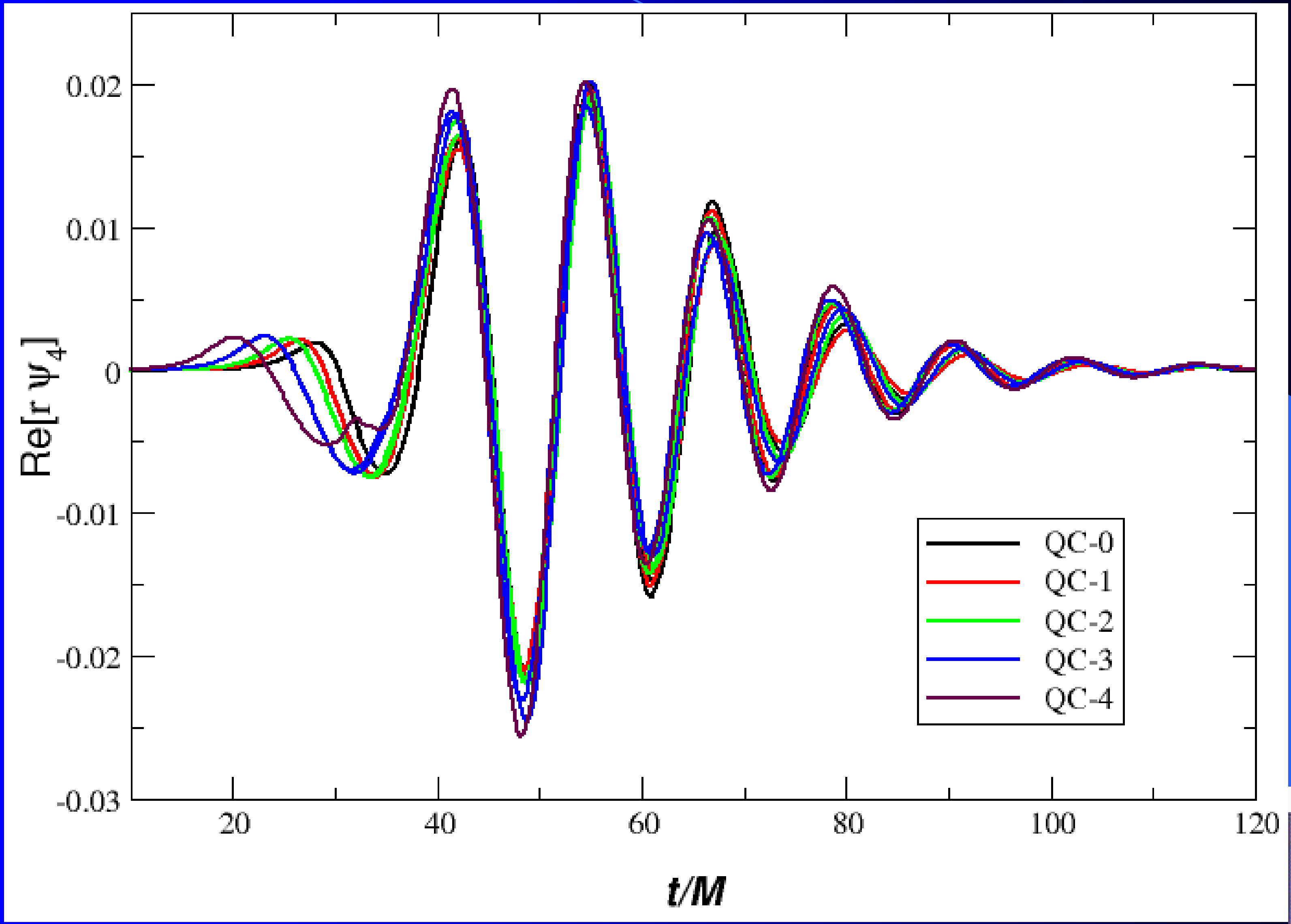


BH in Quasicircular orbits

- BY Data
- Effective Potential



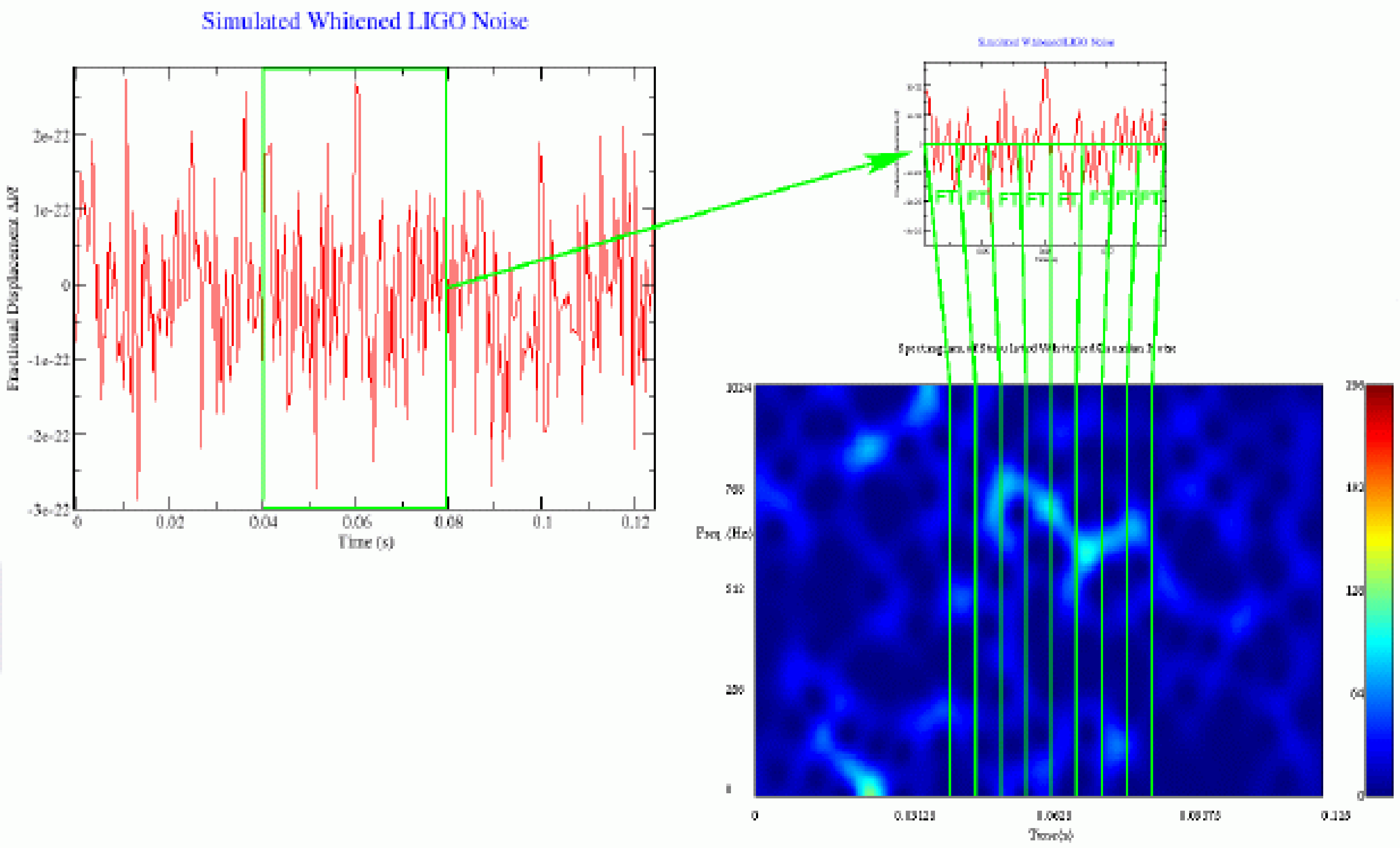
BH in Quasicircular orbits



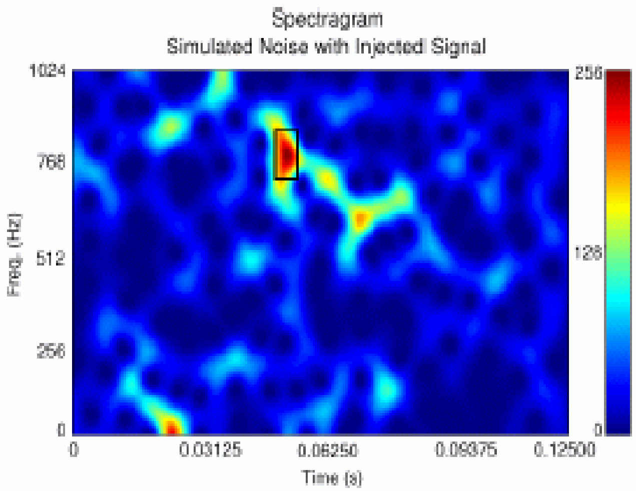
The Kudu project

- Our strategy: Forget about matched filtering and bank of templates use time-frequency Methods instead.
- We will focus on the merger signal: Highly visible in LIGO detectors for $M \sim 20 - 100\ M_{\odot}$
- Obtain `early' information for Data analysts
  - Identify robust features of the merger waveforms
  - Design optimal detection strategies based on this partial information
  - Implement this in LDAS
  - Assess theoretically the improvement of S/N

Time-Frequency Algorithms

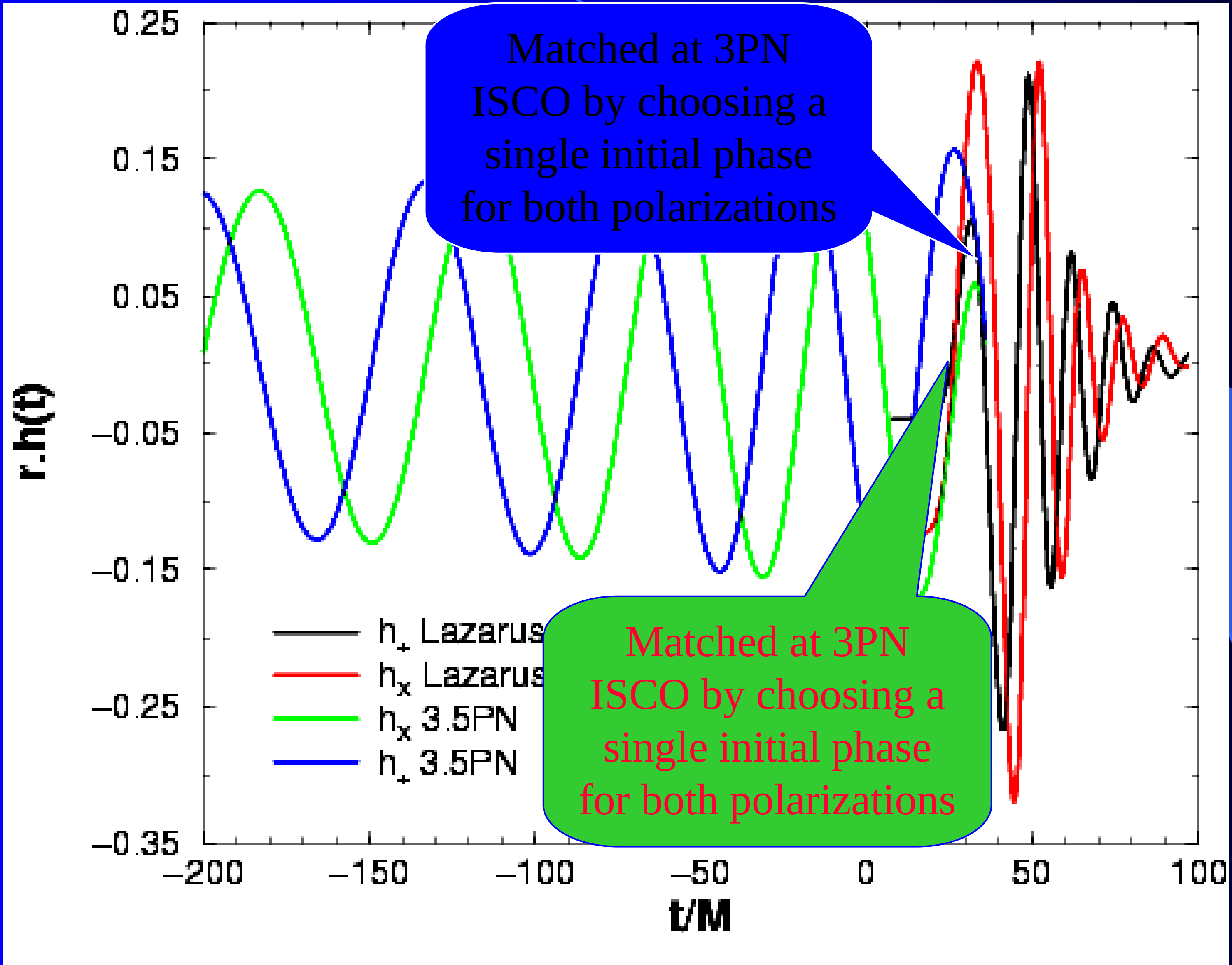


Power Statistic



- developed by Anderson, Brady, Creighton and Flanagan IJMPD 9, 303, (2000); PRD 63, 0402003, (2001) .
- Look for time-frequency areas with "too much power".
- Gaussian noise power is distributed as χ^2 .
- Set detection threshold to keep false alarm rate "low enough".
- Detection method is optimal given no information about signals.

3.5 PN + Lazarus



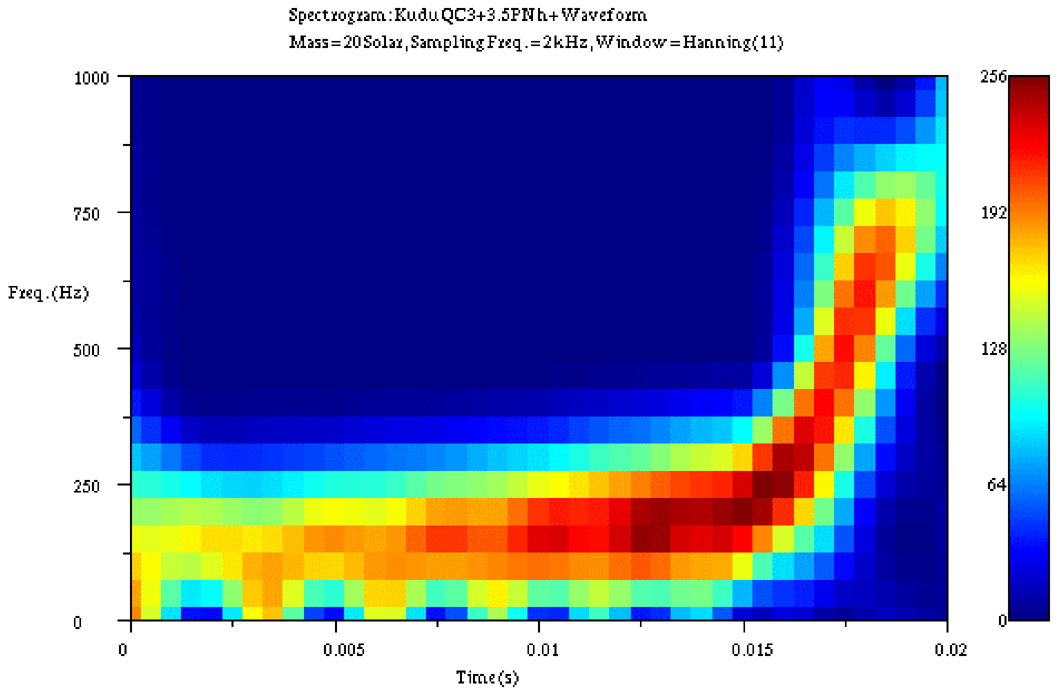
Match to a 3.5 PN Model

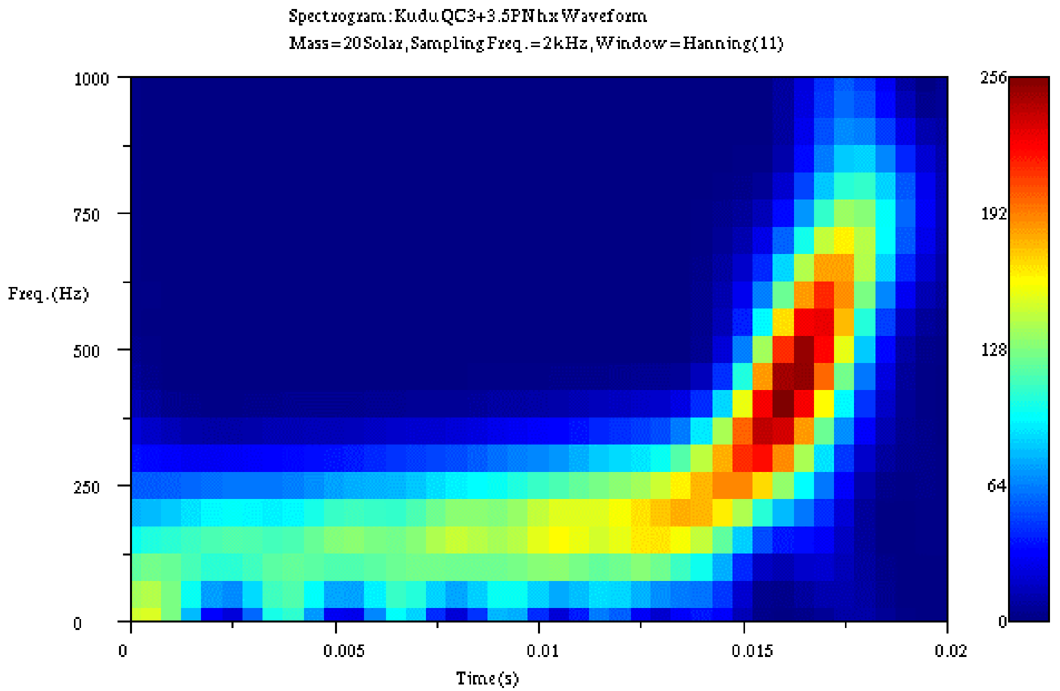
- Lazarus waveforms from 3PN-ISCO
- Blanchet (2002)
  - Give waveforms for ‘raw’ 3.5 PN:

$h_+ = (M\, d\varphi/dt)^{2/3} \cos(2\varphi)$

$h_X = (M\, d\varphi/dt)^{2/3} \sin(2\varphi)$

  - One unidentified 3.5 parameter, θ
  - D’Amour et al give range $-5 < \theta < 10$
    - We’ve chosen $\theta = 1.25$,
    - $t_0 = 50$ (instant of coalescense),
    - $\tau_0 = 0.01$ (initial phase)
- Matching useful to set the relative scale inspiral - merger in the time-frequency map.


Spectrogram: Kudu QC3+3.5PN h+ Waveform
Mass=20 Solar, Sampling Freq.=2kHz, Window=Hanning(11)
Freq.(Hz)
1000
750
500
250
0
0
0.005
0.01
0.015
0.02
Time(s)
256
192
128
64
0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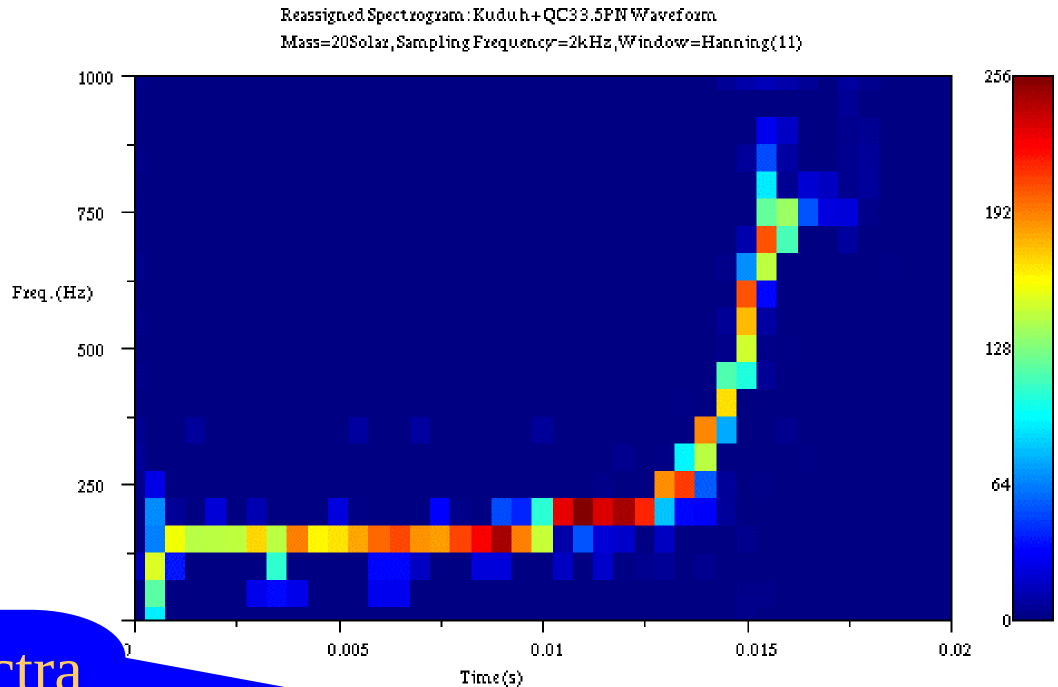
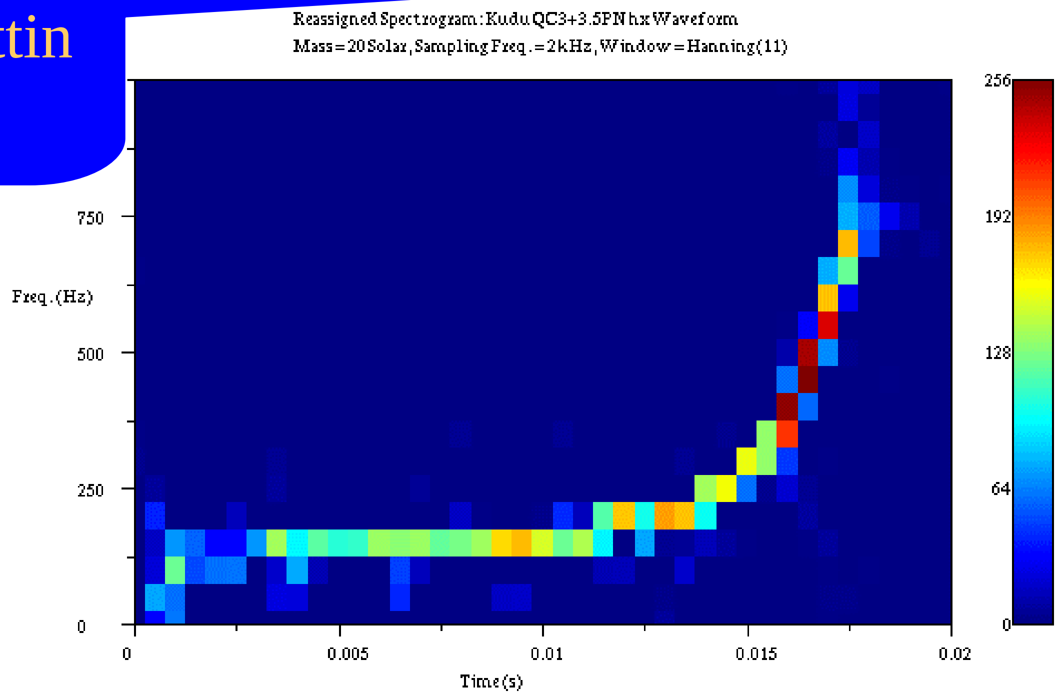
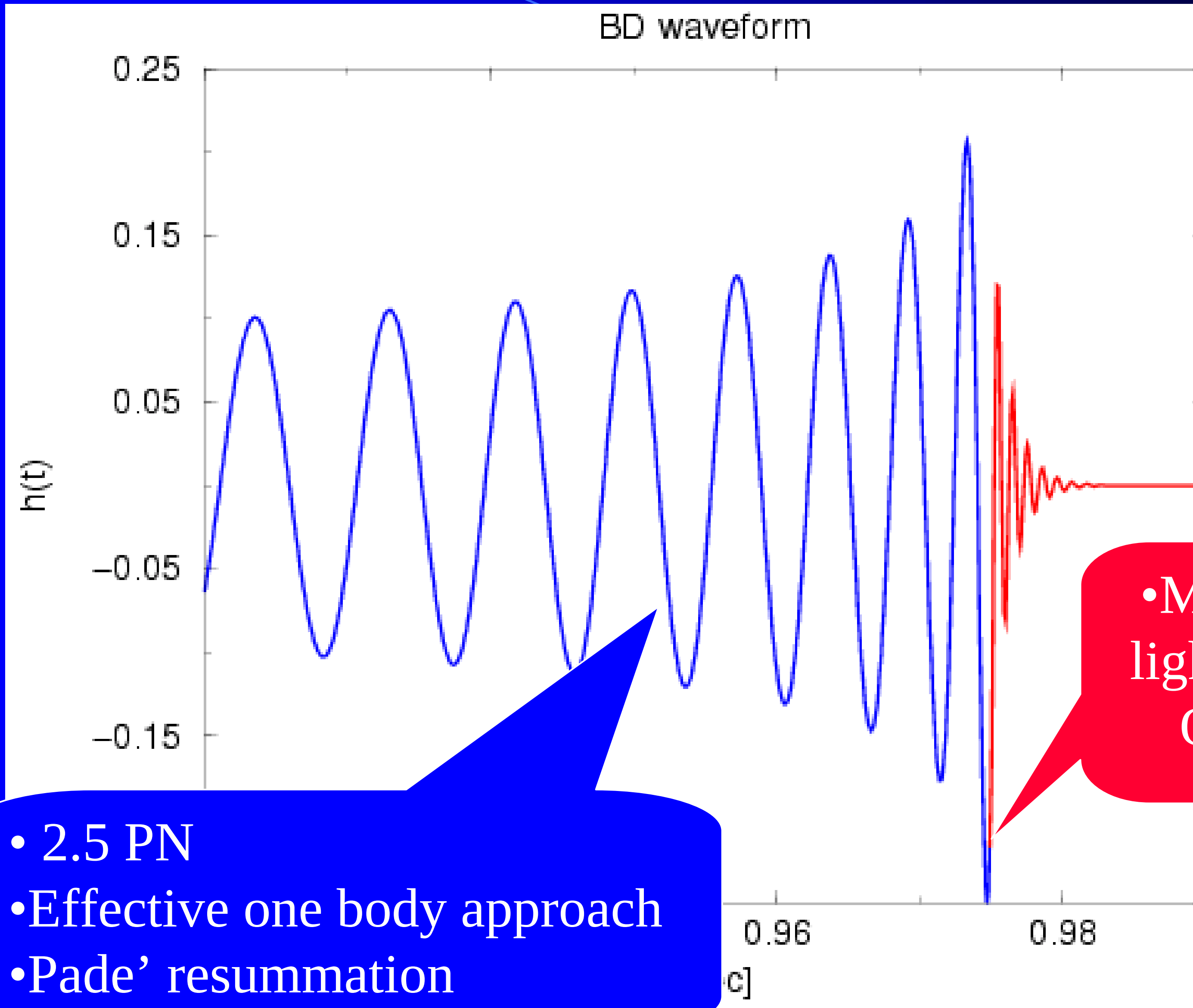


Reassigned spectra Chassande-Mottin et al



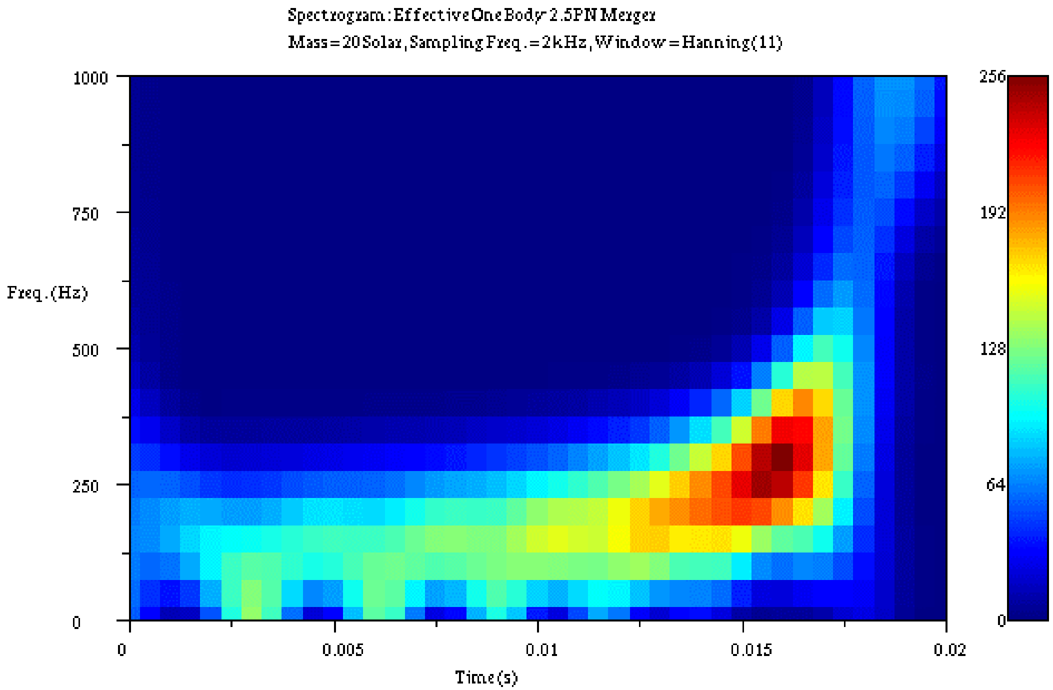
2.5 PN BD waveform



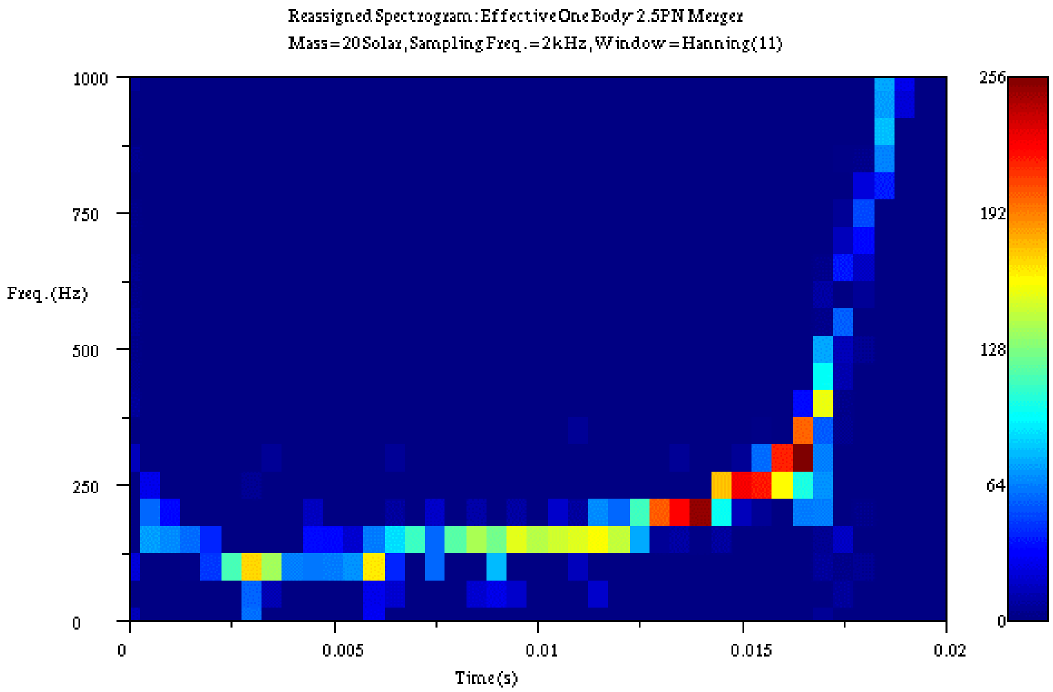
•Match at the light ring with QN mode

• 2.5 PN
•Effective one body approach
•Pade' resummation

Non
-reassigned



reassigned



The Kudu project

- Conclusions
  - Identify robust features of the waveforms
    - Monotonic curve (+ derivative info?)
  - Design optimal detection strategies based on this partial information
    - Reassigned spectra & suit window to merger waveforms
    - Track search (image processing technique to look for curvilinear features: Steger's algorithm) being implemented in LDAS
  - Next:
    - Adding colored Gaussian noise,
    - set a false alarm rate (~1/1000 yrs for two detectors)
    - Monte Carlo simulations (~10^6)
    - Compare track search to excess power statistics

      (factor 2 gain in S/N? First to detect BHs? E_rad ~ E_bin)
  - Physical parameter exploration: Spin, unequal masses