Gravitational Wave Astronomy

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Statistics for inductive inference

- Inductive Inference: OED says
  - *The process of inferring a general law or principle from the observation of* particular *instances (opposed to deduction)*
  - Corollary: You can't make an inference without making an assumption
- How do we use our gravitational observations to draw conclusions about astrophysics or the fundamental physics of gravity?

Examples

- We bound the rate of coalescing compact binaries signals as a function of mass: what can we surmise of binary synthesis and evolution?
- We bound the amplitude of gravitational waves from a pulsar: how can we choose among models for the nuclear EOS?
- We observe a gravitational wave burst associated with a gamma-ray burst: what can we say about the GRB central engine?

Surmise, choose, say: quantitative

Regimes of interest

- Today’s expectations
  - Ground-based detectors: Weak (low snr) & rare (serendipitous) signals
- Tomorrow’s expectations
  - Next generation ground-based detectors: Strong signals at moderate rate (1/wk ~ 1/mo)
  - Space-based detectors: Strong & (over-)abundant signals: confusion from superposition in some bands

We Observe Signals, not Sources

- Stochastic
  - Continuous in time, possibly modulated, unknown spectrum
- Periodic
  - Known frequency, amplitude and phase modulation
  - Unknown frequency, known amplitude and phase modulation
  - Unknown frequency, amplitude and phase modulation
- Bursts
  - Characterized by, e.g., waveform, (time-)frequency spectrum, energy spectrum, amplitude, bandwidth, duration, etc.

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Multi-layered Data Analysis

- Data conditioning
  - Regression, vetoes, whitening (flat-fielding), etc.
- Signal identification & characterization
  - Amplitudes, durations, (time-)frequency spectra, location, bandwidths, waveforms, rates, etc.
  - Classification: identifying signals of same, different type
- *Interpretation of signals as sources*
  - Source: e.g., mass, spin, differential rotation, etc.
  - Process: e.g., hypernova or binary coalescence?, neutrino opacity, common envelope efficiency, etc.
  - Population: e.g., mass function, spatial distribution (within/without a model), luminosity function, evolution, etc.

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Where are we now?

- Analysis today is focused on signal identification and characterization
  - We have not yet seriously tackled interpretation
- Statistical tools used for id & characterization:
  - Confidence interval construction on rates (bursts, stochastic)
  - Extreme value statistics (inspiral)
  - Bayesian credible sets (periodic signals)

Pressing, open questions

- Do/did we see (strong) evidence for gravitational waves? Quantify strong.
- How do we go about carrying-forward knowledge gained from earlier investigations?
  - How to incorporate prior knowledge or experience without closing our mind to discovery?
  - When and how may we "re-analyze" data? I.e., carry-out an improved analysis, incorporate new information, etc.

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- How do we go about classifying signals (and infer source classes)?
- How do we go about selecting among physical models for phenomena?
- How do we go about inferring population properties from incomplete & biased samples?
- How do we go about comparing or combining results from different experiments? When are observations/inferences (in)consistent?