Desenvolvimento de Metodologias em Análise de Dados no Estudo de Detectores e Fontes de Ondas Gravitacionais

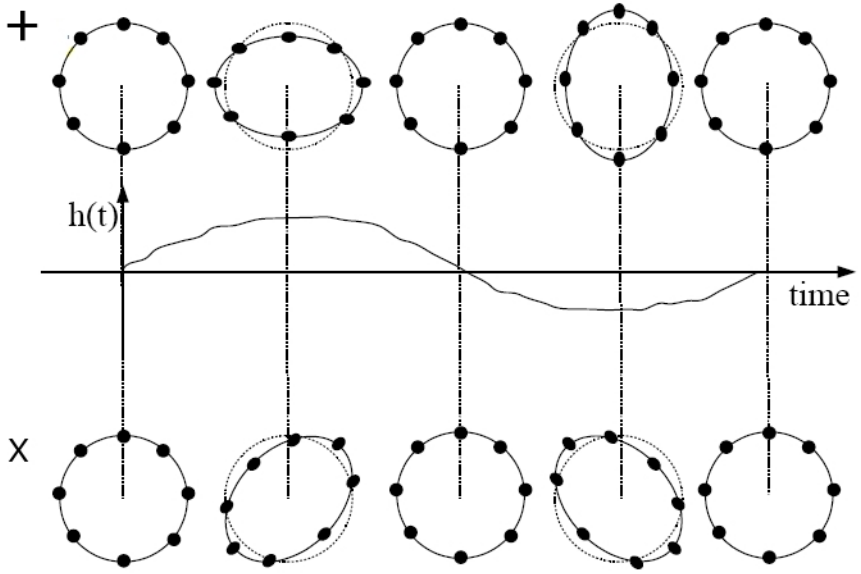
Cesar Costa

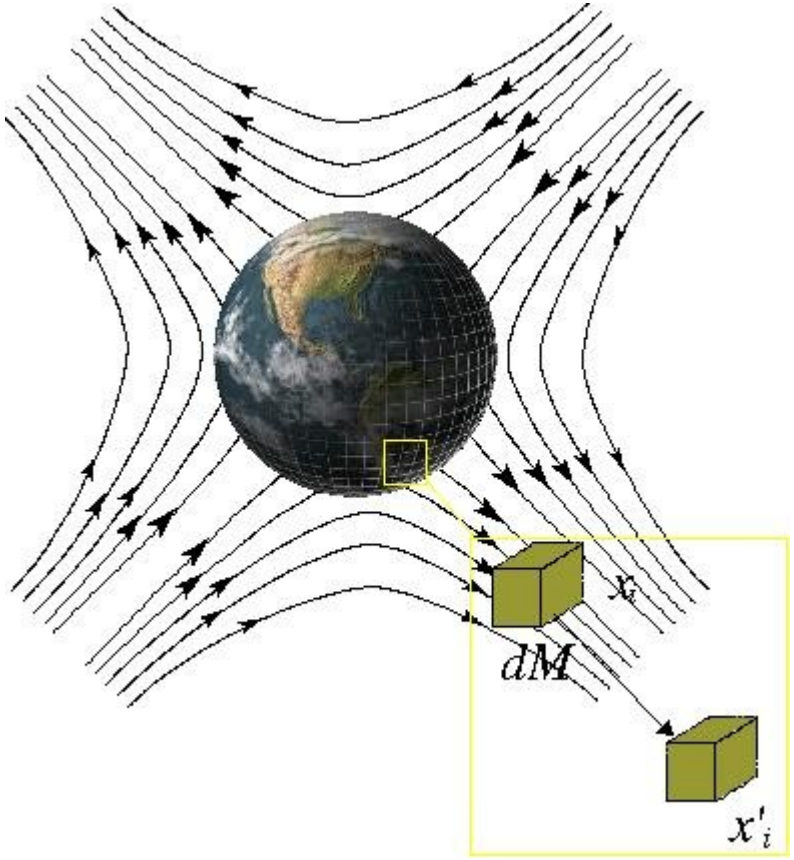
Supervisor: Odylio Denys Aguiar

CNPq/MCTI/INPE
VIII Workshop PG-AST/DAS
Abril, 2015

- Histórico
  - Mestrado e Doutorado em Astrofísica – DAS/INPE
    - Modelagem matemática do detector de ondas gravitacionais Mario Schenberg
    - Resposta do detector a fontes astrofísicas
  - Pós-Doutorado USP (FAPESP)
    - Implementação do sistema de aquisição de dados
  - Pós-Doutorado LSU-LIGO (NSF)
    - Caracterização instrumental e ambiental do LIGO (Data Quality)
    - Desenvolvimento pipeline para análise de canais auxiliares
  - Bolsa PQ-DA (INPE-CNPq)
  - Pós-Doutorado Sênior (INPE-CNPq)
    - LIGO Detchar
    - Schenberg
    - PTA
  - Onde me encontrar : SALA 41 – CEA I / Ramal 7220
- Colaborações:
  - LSU, UTB, UNESP, UNIFESP, JPL/NASA

measuring gravitational waves





Gravitational Waves Astronomy

Gravitational wave detectors will study sources characterized by extreme physical conditions: strong non-linear gravity and relativistic motions, very high densities, temperatures and magnetic fields.

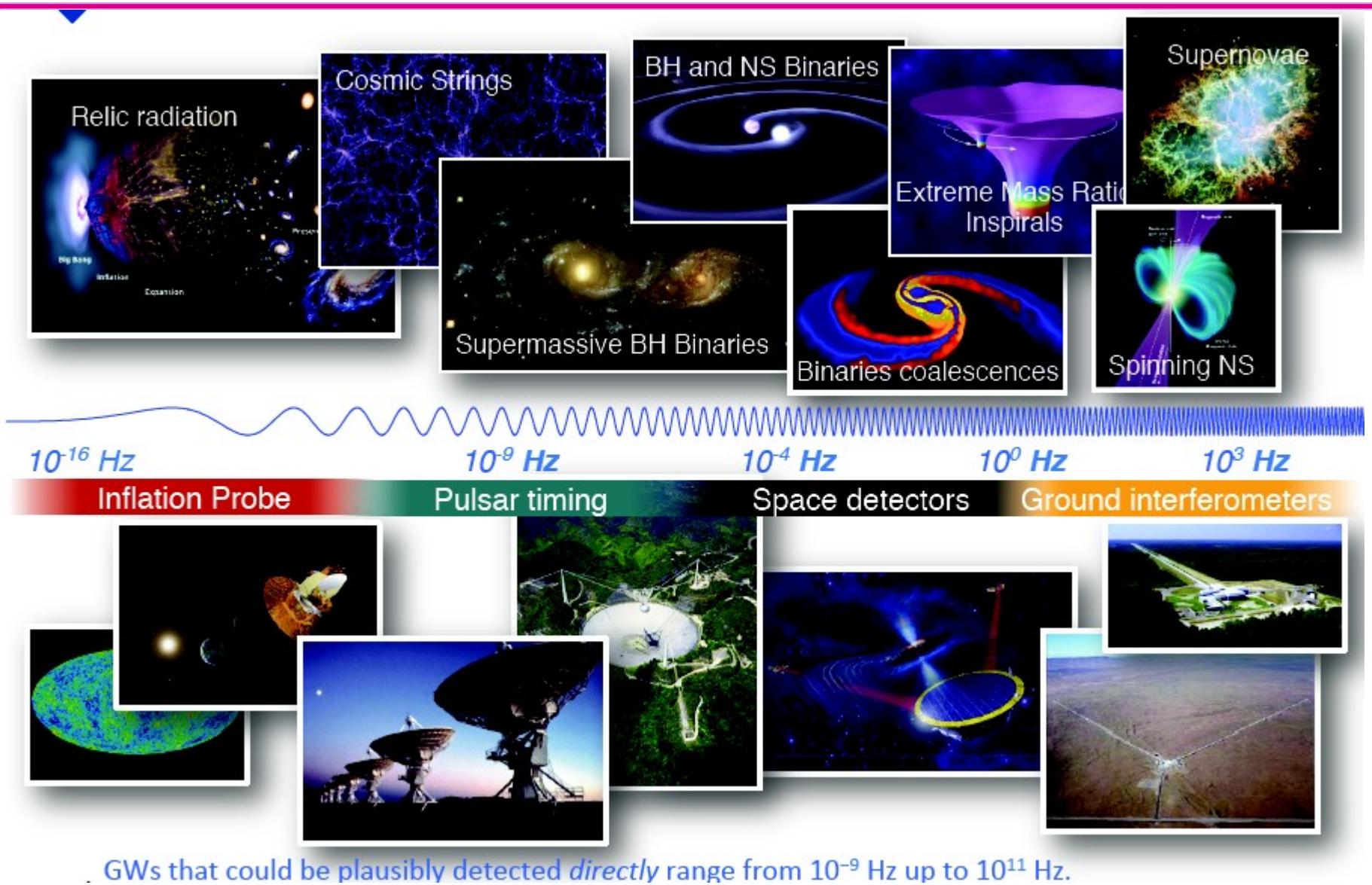
Some of the key scientific questions to which answers will be sought:

fundamental physics:
• What are the properties of gravitational waves?
• Is General Relativity still valid under strong-gravity conditions?
• Are nature's black holes the black holes of General Relativity?
• How does matter behave under extremes of density and pressure?

cosmology:
- What is the history of the accelerating expansion of the Universe?
- Were there phase transitions in the early Universe?

Astrophysics:
• How abundant are stellar-mass black holes?
• What is the mechanism that generates gamma-ray bursts?
• What are the conditions in the dense central cores of galactic nuclei dominated by massive black holes?
• Where and when do massive black holes form, and what role do they play in the formation of galaxies?
• What happens when a massive star collapses?
• How do compact binary stars form and evolve, and what has been their effect on star formation rates?

GW Spectrum

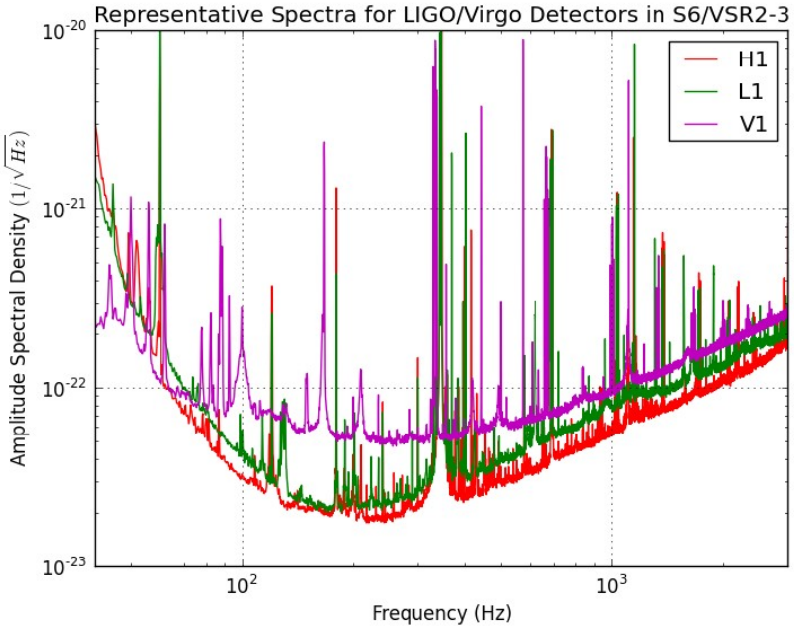


GWs that could be plausibly detected *directly* range from 10^{-9} Hz up to 10^{11} Hz.

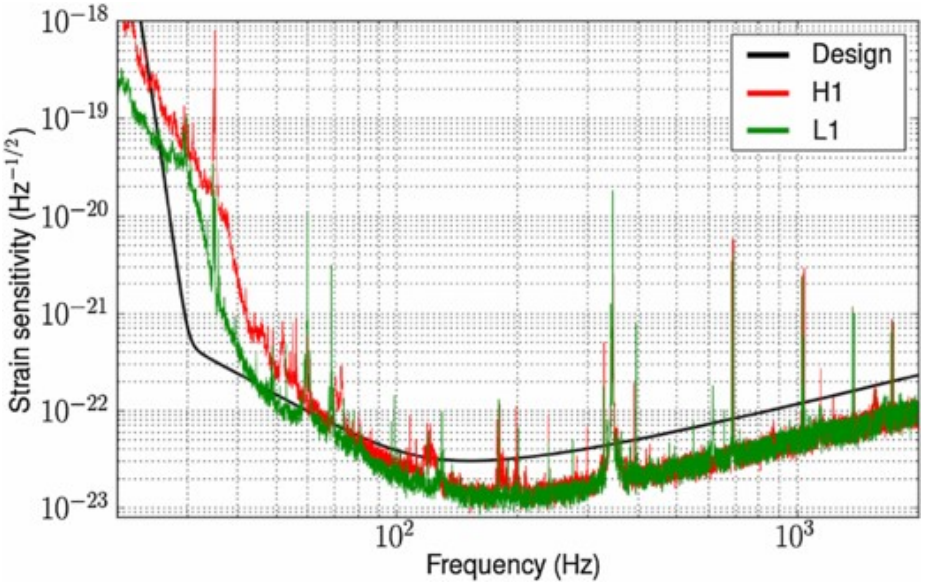
LIGO/VIRGO

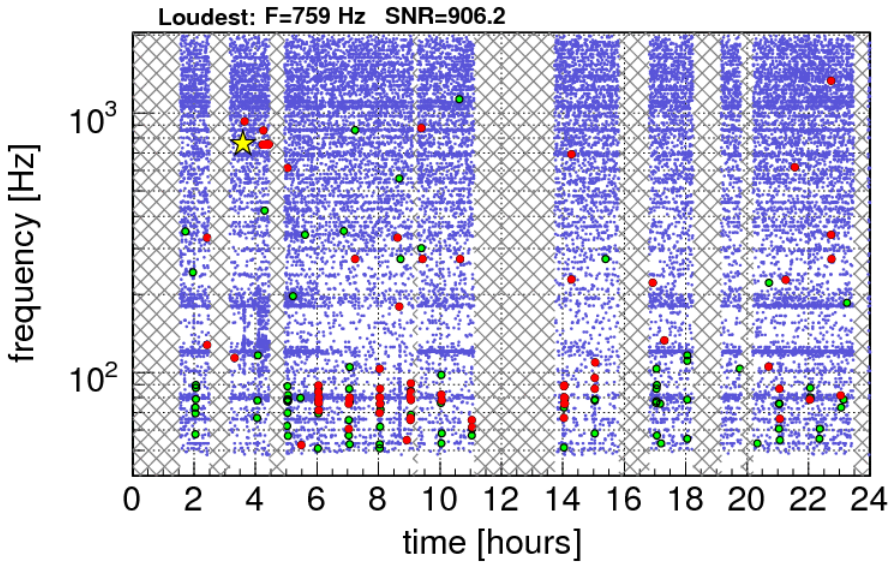


- **L**aser **I**nterferometric **G**ravitational Wave **O**bservatory (LIGO)
  - Two detectors (Hanford, WA, and Livingston, LA)
- VIRGO (Cascina, Italy – near Pisa)
- Michelson Interferometer with 4km long arms (Virgo - 3km)
- Fabry-Pérot cavity stores ~1kW of “light”
- Intended to be an inertial referential frame on Earth.



Noise and transients

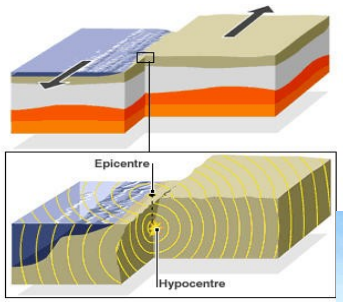


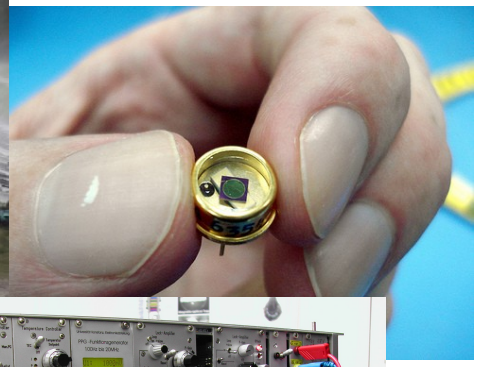


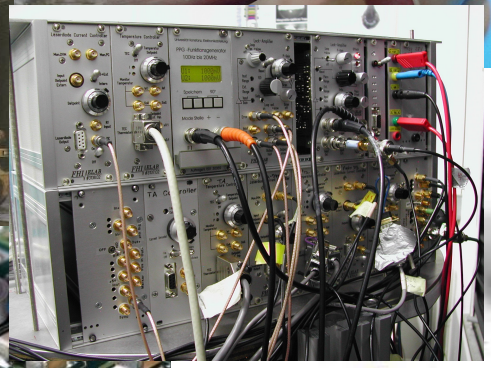
- **Sensitivity curve**
  - Stationary PSD
  - Well known physics
    - seismic,residual gas, thermal noise, “shot noise”, etc

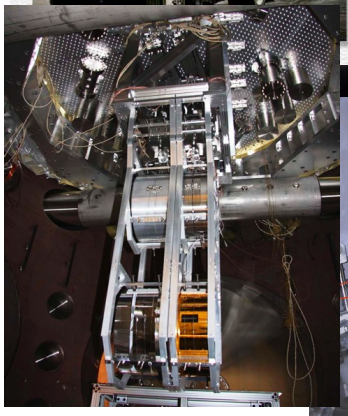
- **Transients (Glitches)**
  - Non-gaussian artifacts
  - Due to ambient and instrument culprits
  - Undesired effects on data analysis and sensitivity

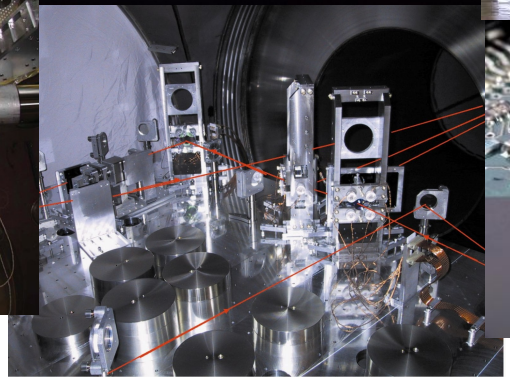
Instrumental and Environmental Couplings

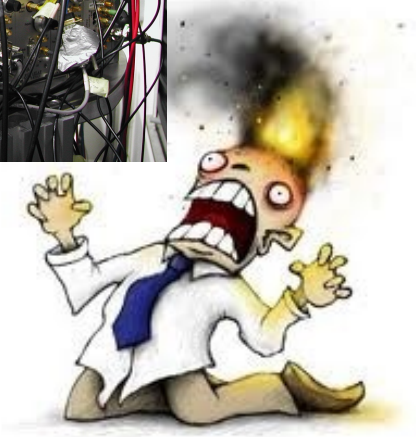






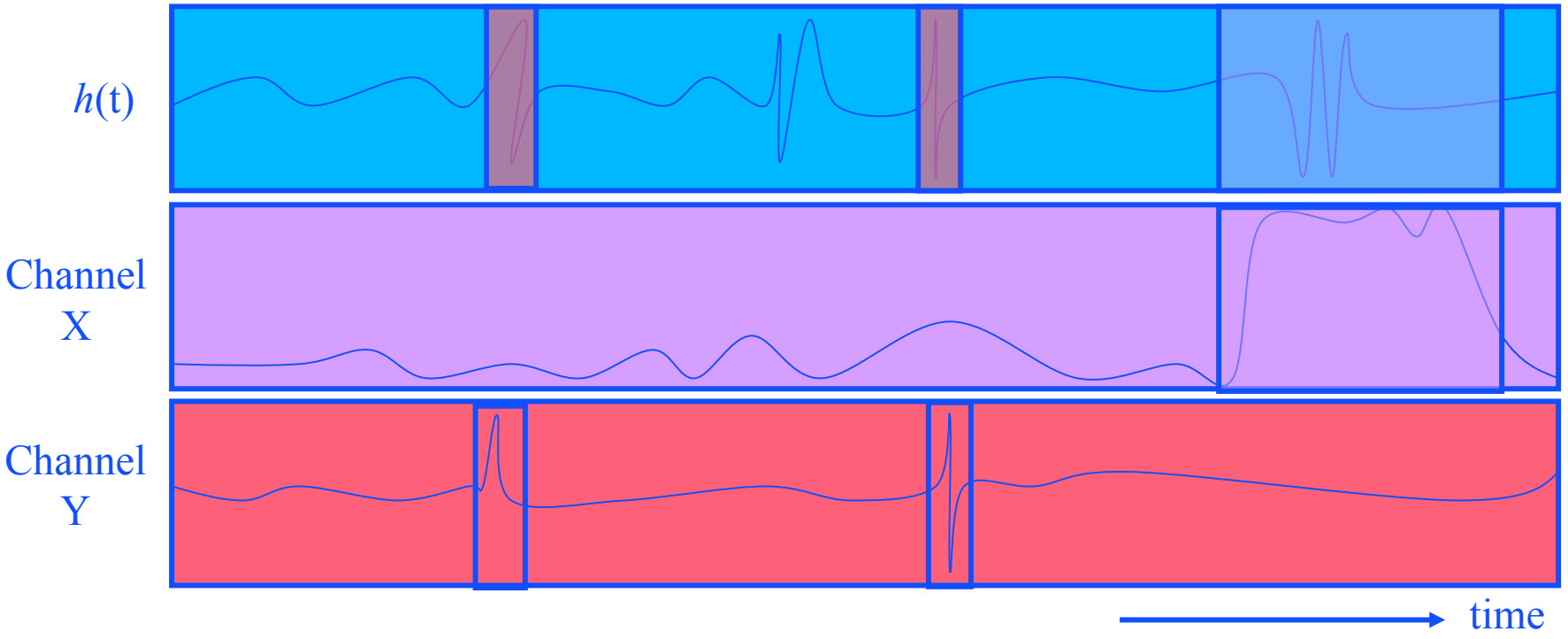






Data Quality

- Compare h(t) (DARM_ERR) to auxiliary channels.
  - Time coincidences point do probable culprits
- "Data quality flags" isolate misbehaving times.



Motivation

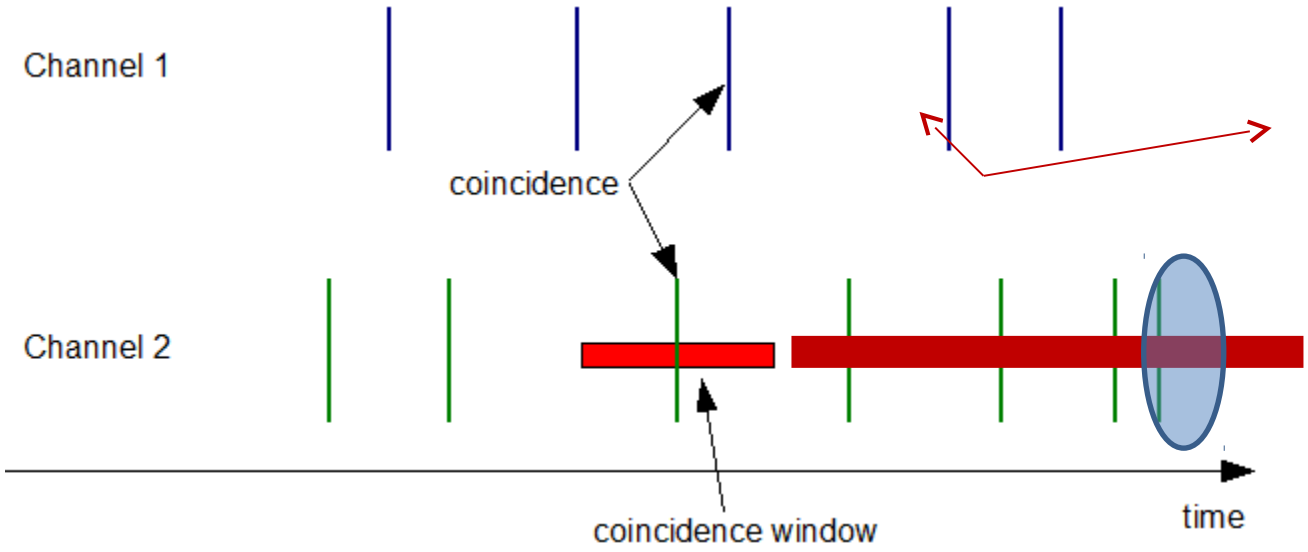
LIGO White Paper

- Signal searches
  - Integrate DQ information into search
  - “clean 99% of single detector transients”
- Instrumental
  - Identify couplings, properties and pathways
  - Give better information to instrumentalists
  - Fast identification

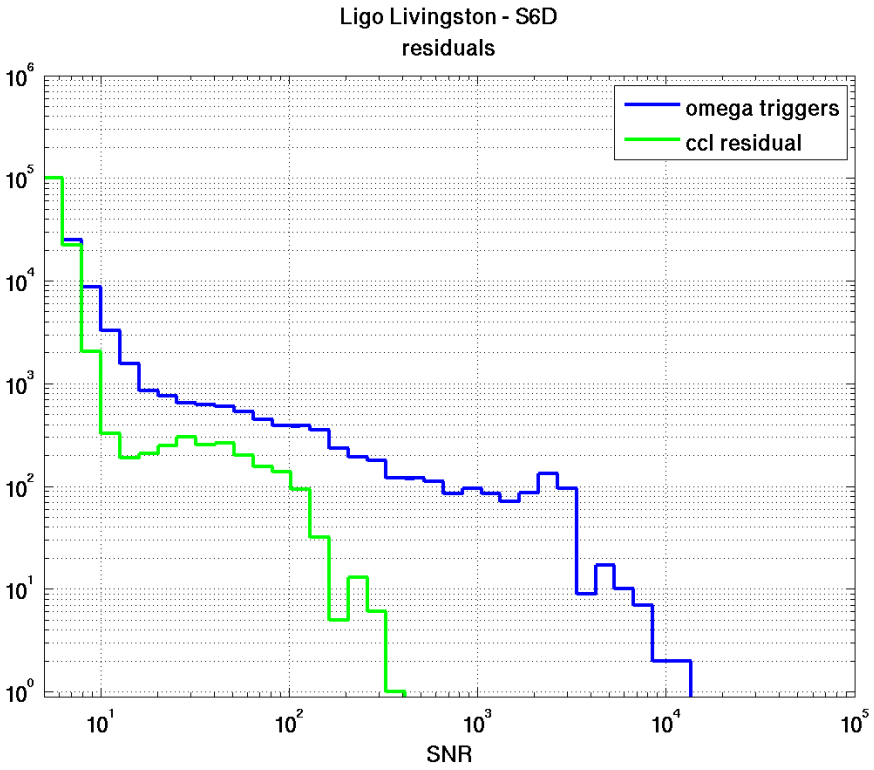
Applying methods to data sets

- Collections of transient properties are compared
  (gpstime, amplitude, snr, frequency band, duration, etc)
- Statistical methods must be applied and developed

$$Y = y_1, y_2, \ldots, y_n \qquad X = x_1, x_2, \ldots, x_n$$



Critical Coupling Likelihood

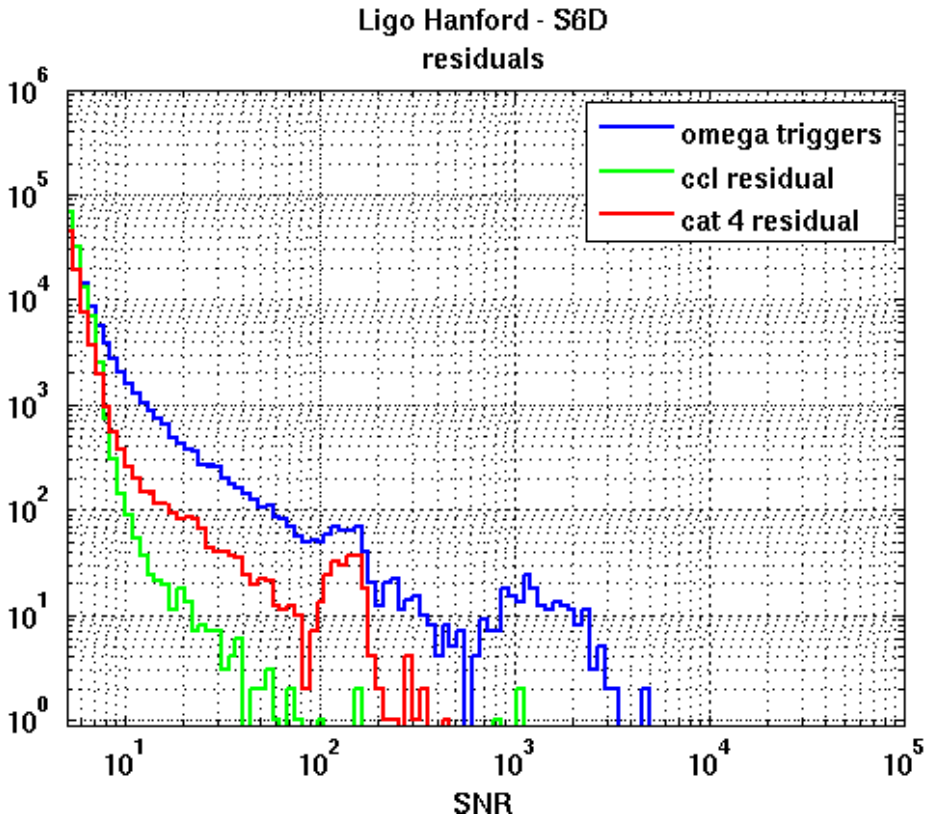


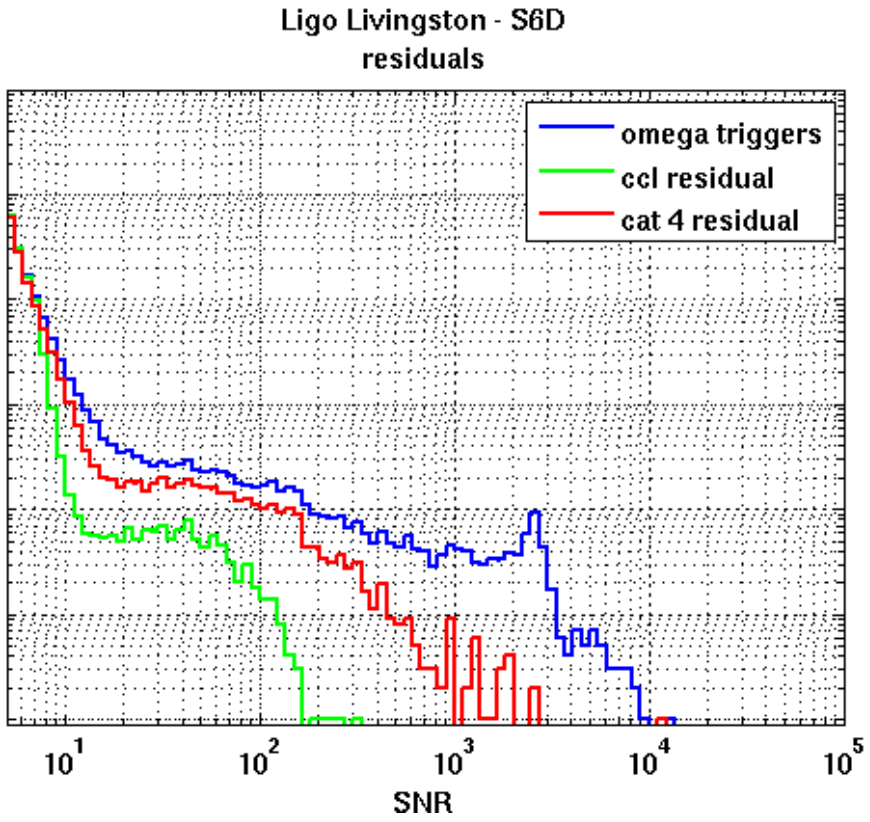
- Desempenho
  - Deadtime: 13.9%
    - Upper limit
  - SNR>8 : ~ 85%

Livingston	CCL > 1
SNR (>)	%
5	14.44%
8	84.26%
10	88.83%
20	86.77%
50	92.42%
100	98.00%

Critical Coupling Likelihood

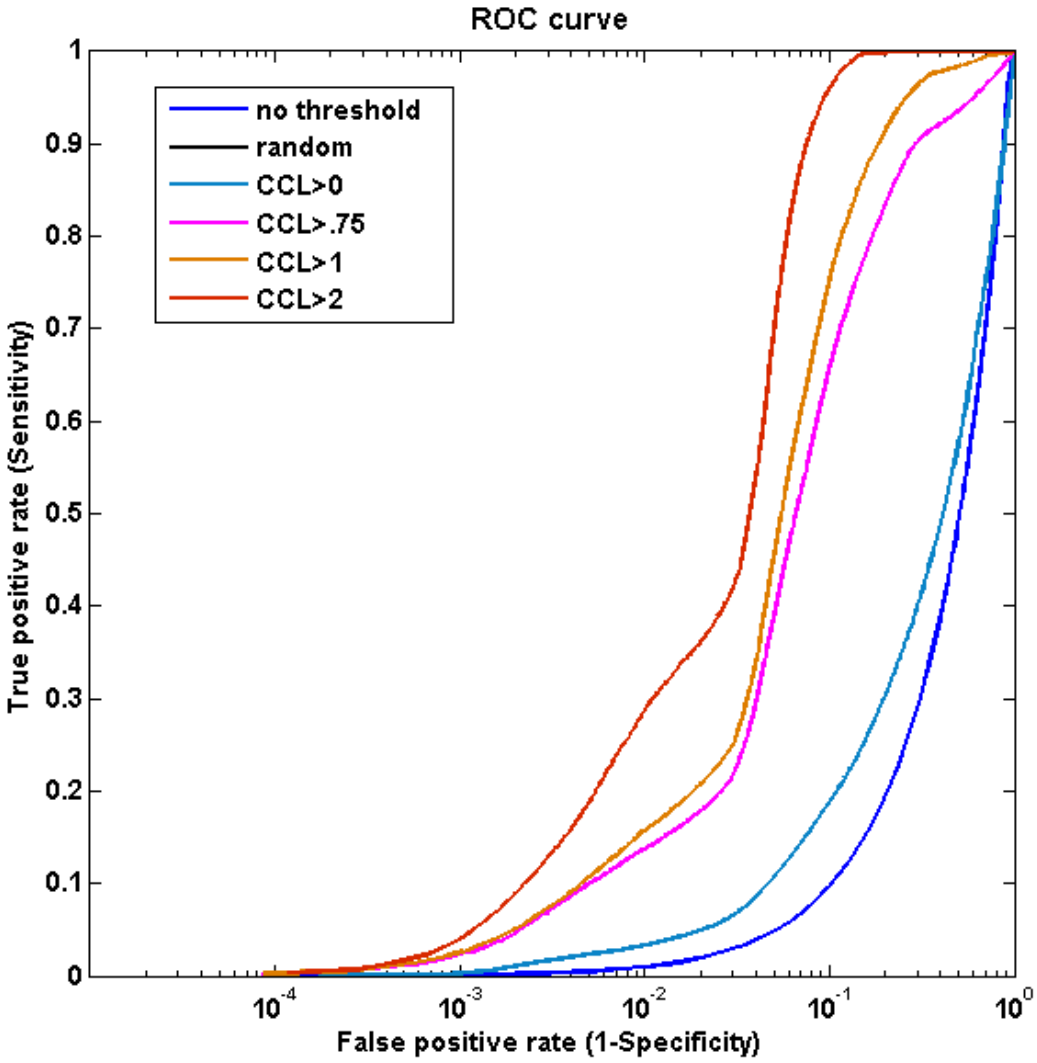
performance vs. Cat 4

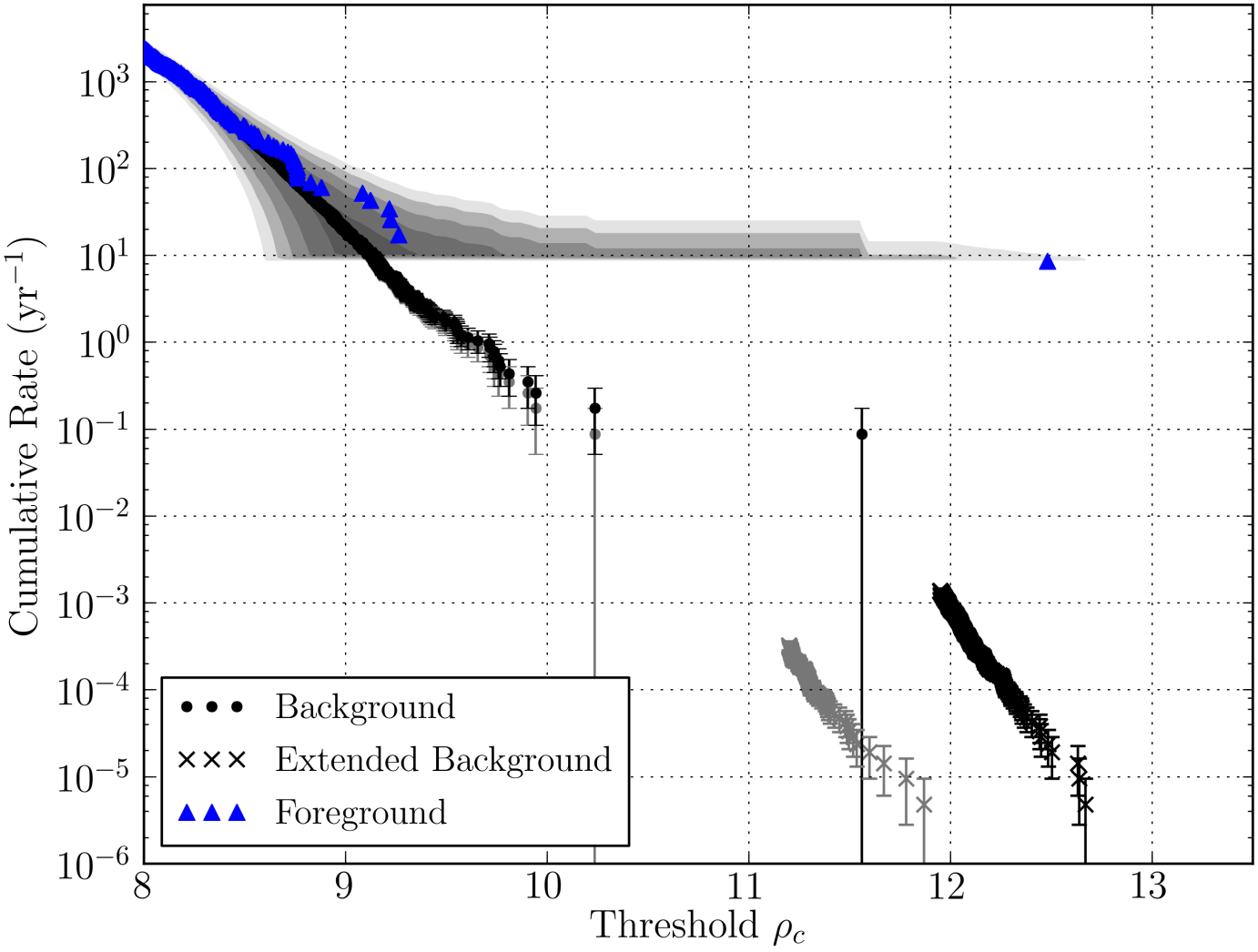




Critical Coupling Likelihood

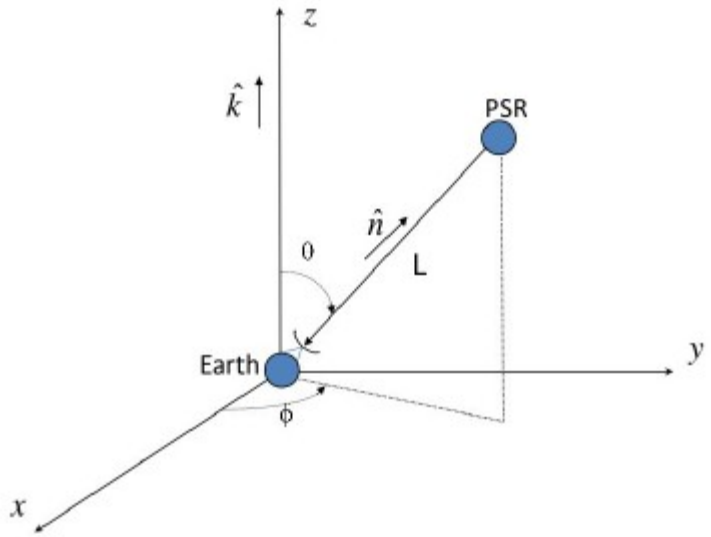
ROC

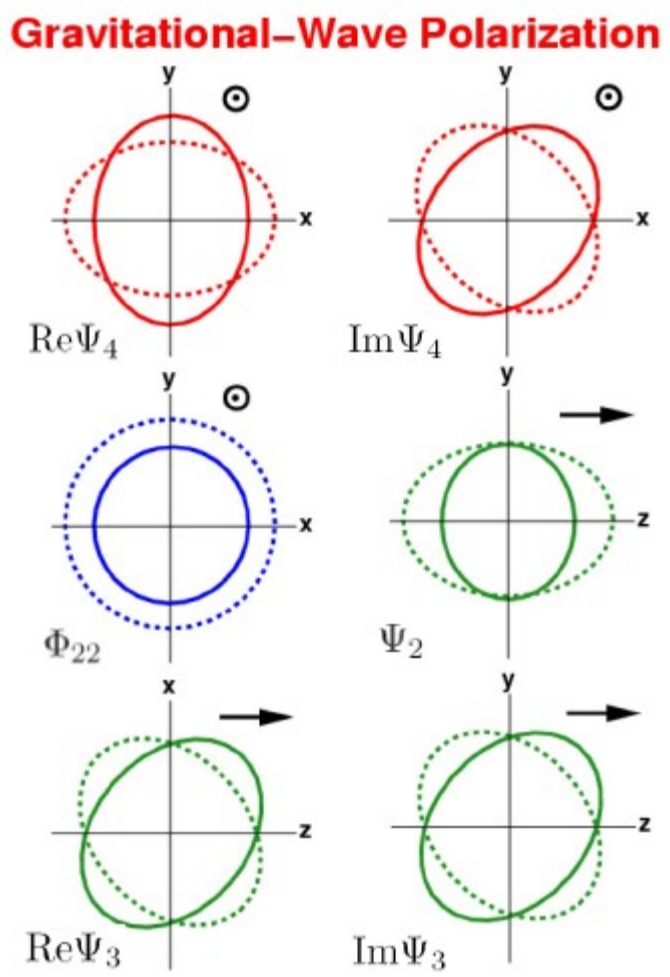



Cumulative Rate (yr^{-1})
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
8
9
10
11
12
13
Threshold ρ_c
Background
Extended Background
Foreground

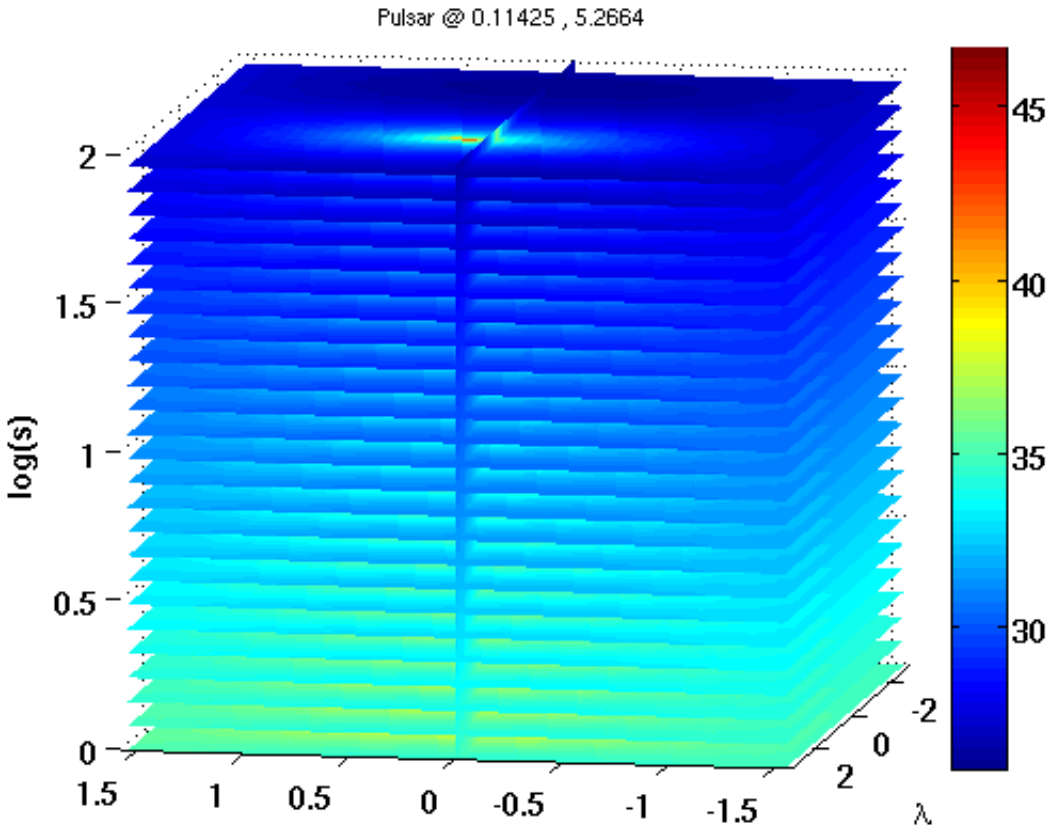
Bayesian Detection of Alternative GW Polarizations by using Pulsar Timing Array

- Colaboration
  - Márcio Alves (Unesp/SJC)
  - Massimo Tinto (JPL/NASA)





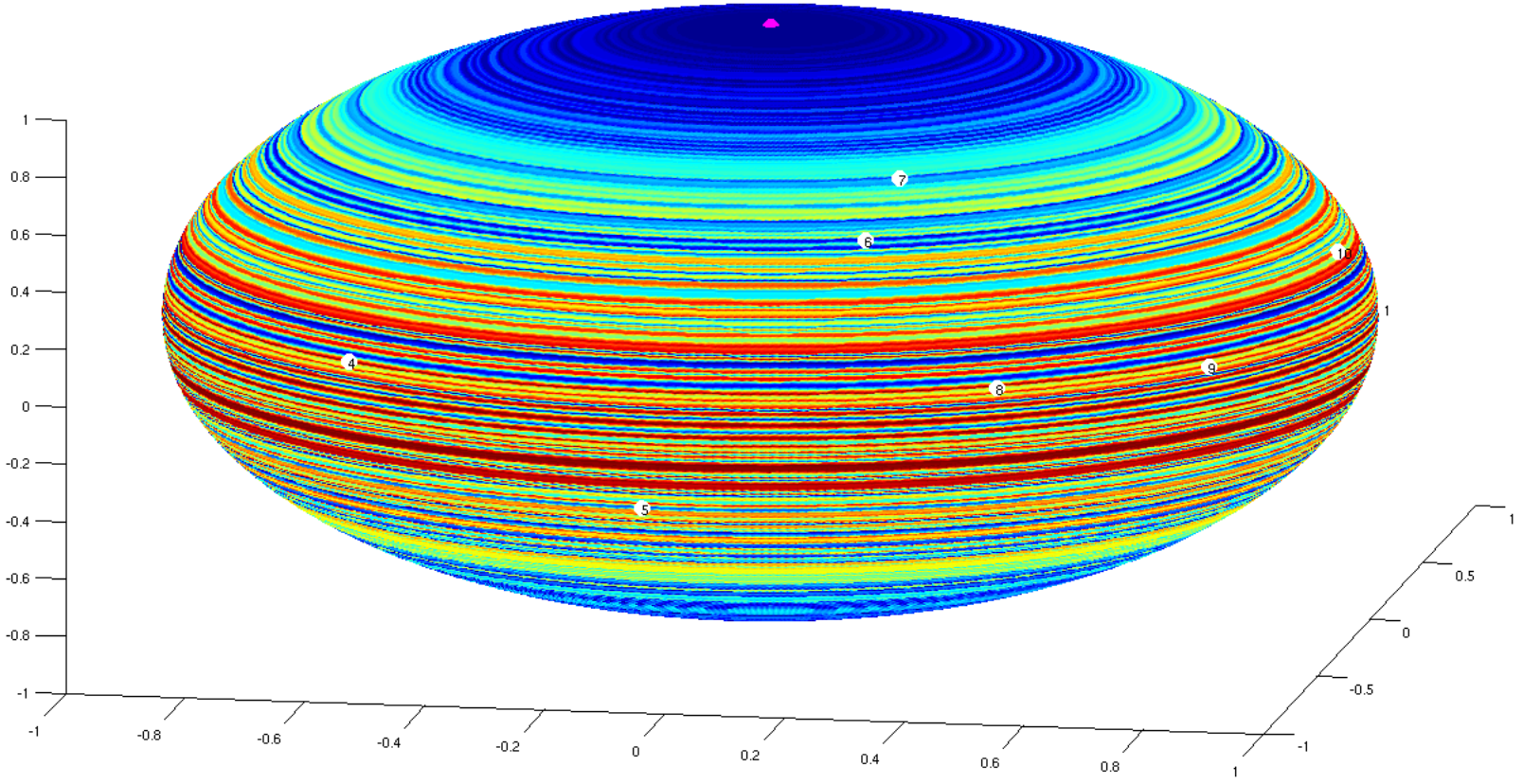
Likelihoods



$$P(D|H_r,\theta,\phi,\{s\},\sigma) \approx \{\det[\mathbb{I}-\mathbb{K}(\{\hat{\omega}\})]\}^{\frac{1}{2}} \frac{\Gamma(\frac{M}{2})}{2\ln(R_\gamma)} \left(\pi M\overline{\omega^2}\right)^{-\frac{M}{2}}$$

$$\times \quad (2\pi\sigma^2)^{-\frac{(N-M)}{2}} [\det(\mathbb{B})]^{-\frac{1}{2}} \exp\left[-\frac{N\overline{d^2}-2n\overline{q^2}(\{\hat{\omega}\})}{2\sigma^2}\right]$$

SNR vs relative sky position



Sky location