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

Cesar Costa

Supervisor: Odylio Denys Aguiar

PCI/MCTI/INPE
VII Workshop PG-DAS
Abril, 2014

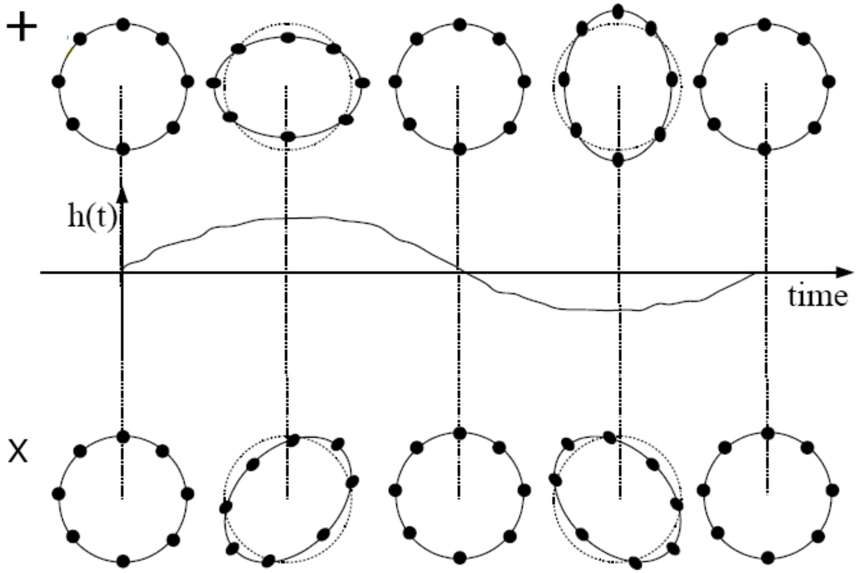
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

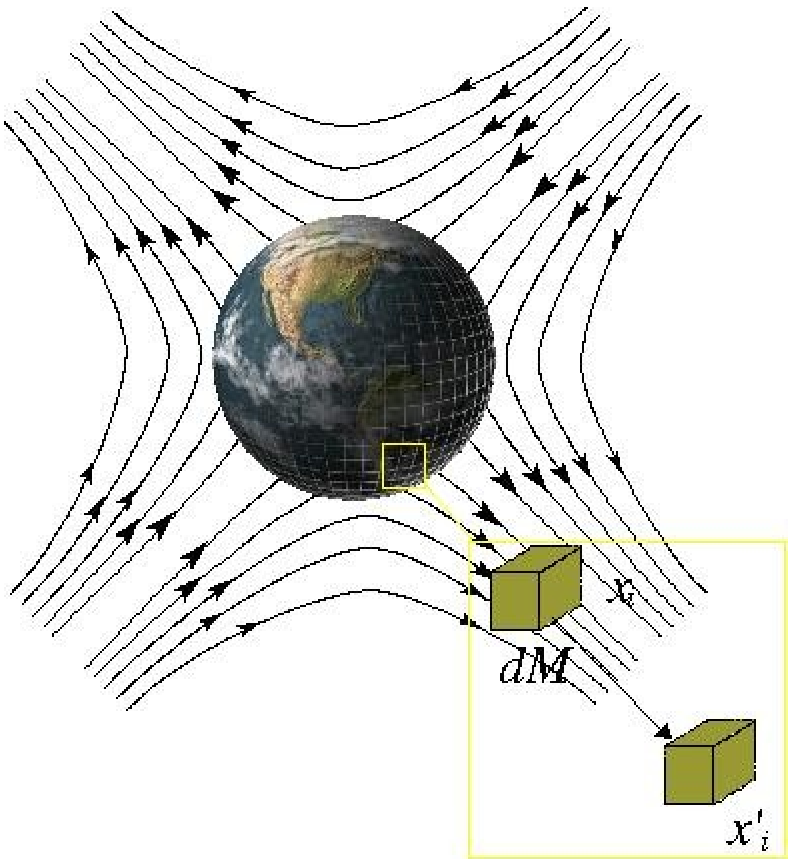
Ministério da Ciência, Tecnologia e Inovação

GOVERNO FEDERAL BRASIL PAÍS RICO É PAÍS SEM POBREZA

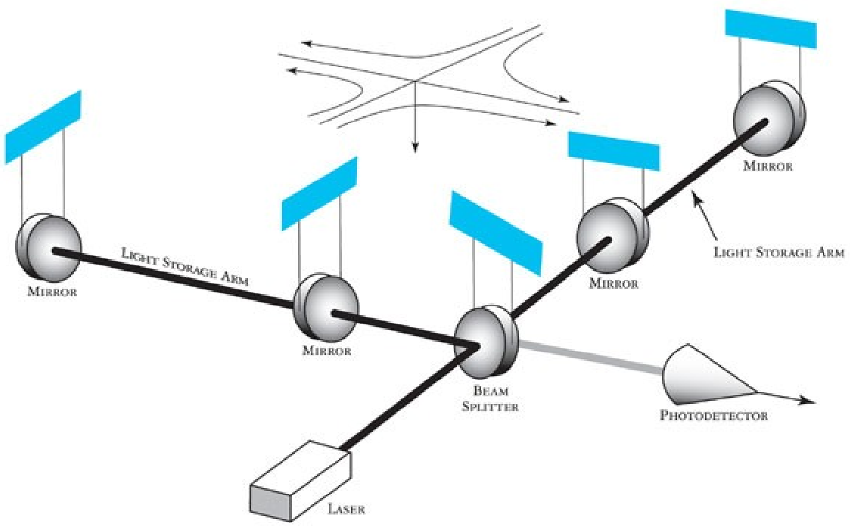
- Histórico
  - Mestrado e Doutorado em Astrofísica – DAS/INPE
    - Modelagem matemática do detector de ondas gravitacionais Mario Schenberg
    - Resposta do detector a fontes astrofísicas
  - Pós-Doutorado USP (FAPESP)
    - Implementação do sistema de aquisição de dados
  - Pós-Doutorado LSU-LIGO (NSF)
    - Caracterização instrumental e ambiental do LIGO (Data Quality)
    - Desenvolvimento pipeline para análise de canais auxiliares
  - Bolsa PQ-DA (INPE-CNPQ)
- Colaborações:
  - LSU, UTB, UNIFEI, JPL/NASA

Medindo Ondas Gravitacionais



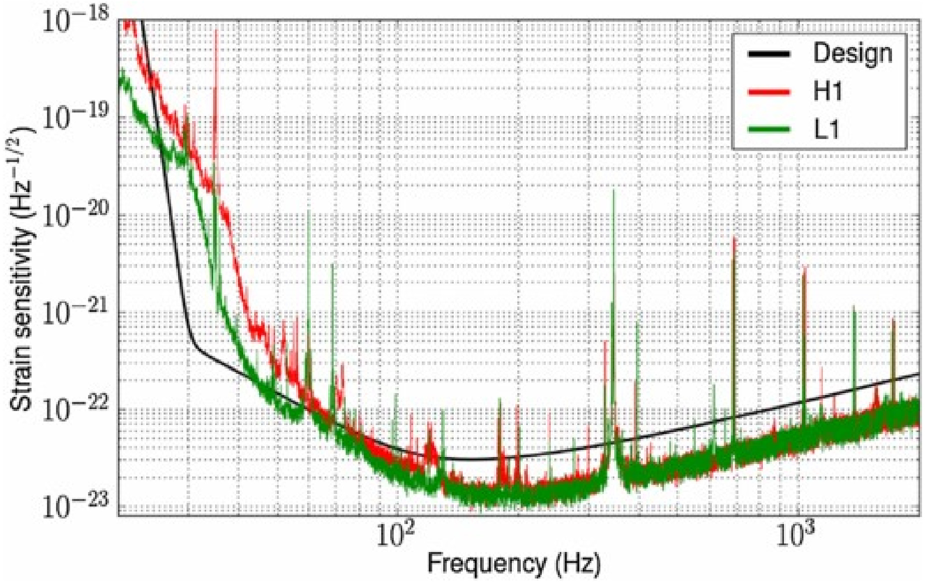


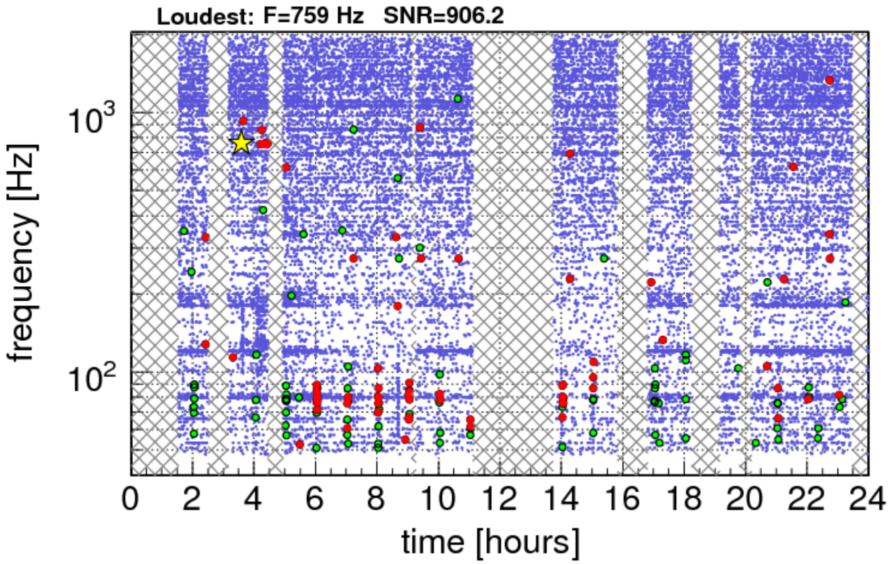
LIGO



- **L**aser **I**nterferometric **G**ravitational Wave **O**bservatory (LIGO)
- Dois detectores (Hanford, WA, and Livingston, LA)
- Interferômetro Michelson com braços de 4km
- Cavidades Fabry-Pérot armazena ~1kW
- Construído para ser um referencial inercial na Terra.

Ruído e Transientes





- **Curva de Sensibilidade**
  - Espectro Estacionário
  - Física conhecida
    - Sísmico, gás residual, ruído térmico, "shot noise", etc

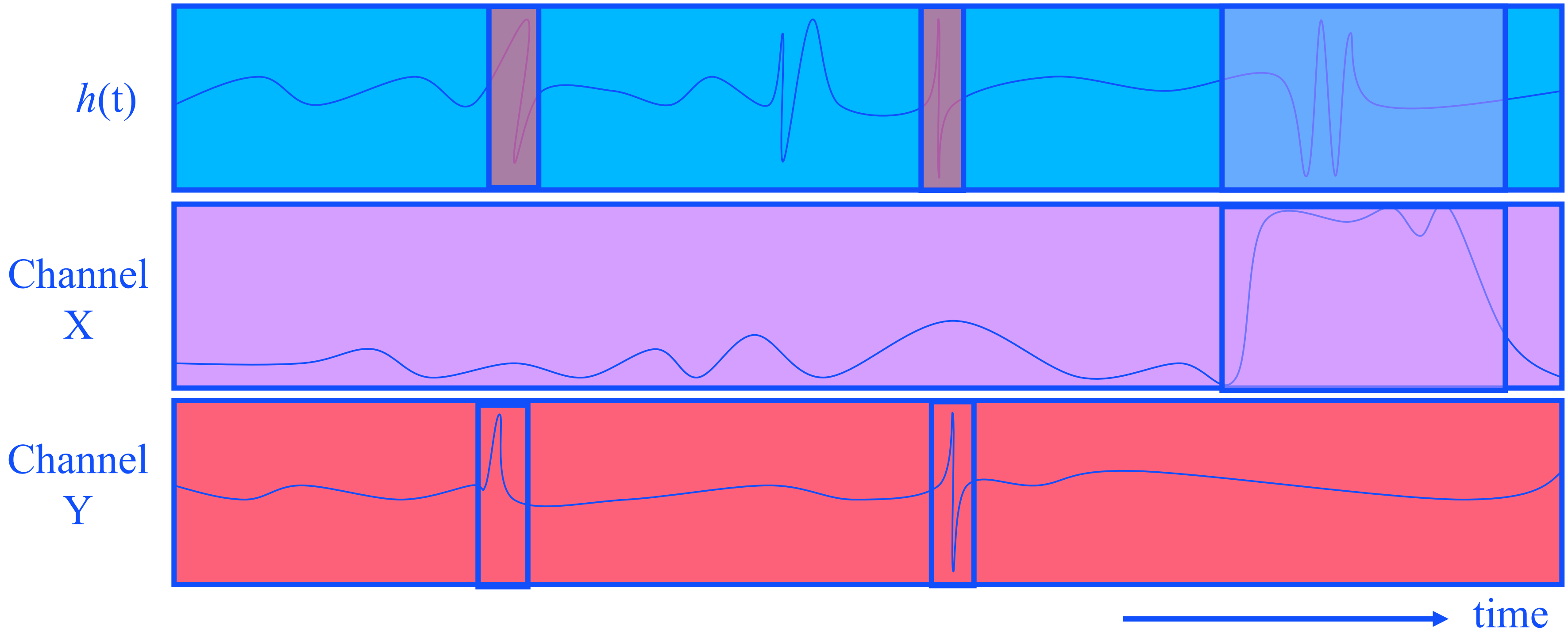
- **Transientes (Glitches)**
  - Transientes não-gaussianos
  - Devido a efeitos de origem instrumental ou ambiental
  - Efeitos indesejáveis na sensibilidade do instrumento

LIGO

Acoplamento Instrumental e Ambiental

Qualidade de dados (Data Quality)

- Compara h(t) (ou, DARM_ERR) com canais auxiliares.
  - Coincidências temporais apontam para prováveis culpados
- "Data quality flags" isola alguns tempos de mal comportamento.



Critical Coupling Likelihood

Motivação

Cumprir as expectativas relatadas no White Paper do LIGO

- Objetivos para Busca por Sinais
  - Integrar informação de DQ information into search
  - “limpar 99% dos transientes de detector isolados”

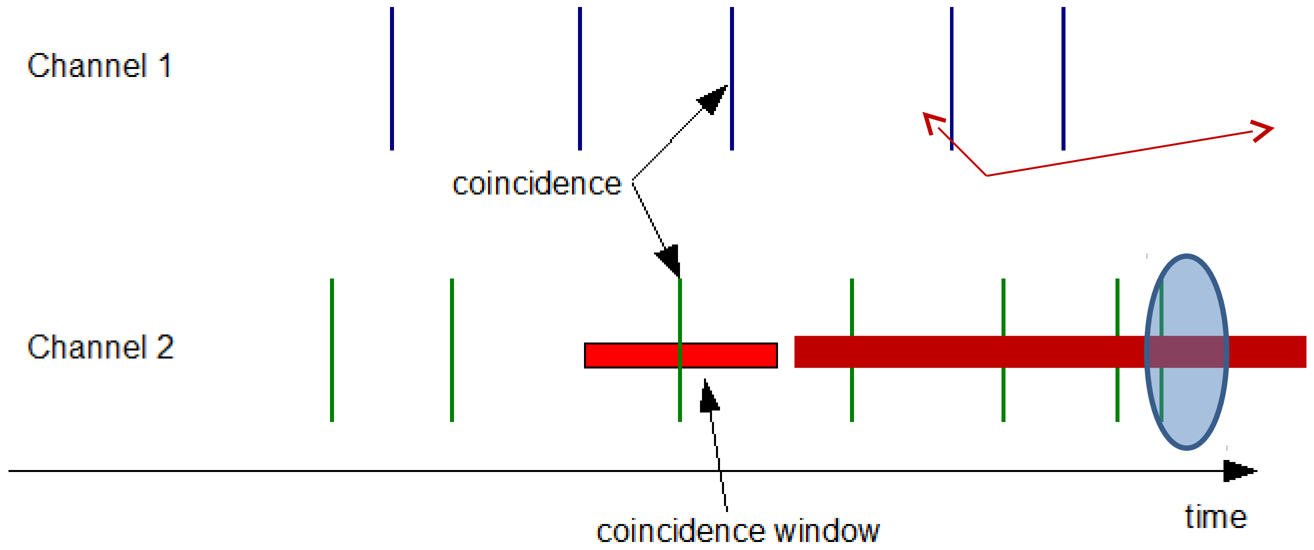
- Objetivos Instrumentais
  - Identificar acoplamentos e propriedades
    - Melhorar a informação passada aos instrumentalistas
  - Identificação de rápida problemas

Colaboração: Dra. Cristina Torres (UTB), LSU, LSC

Critical Coupling Likelihood
Conjunto de Dados

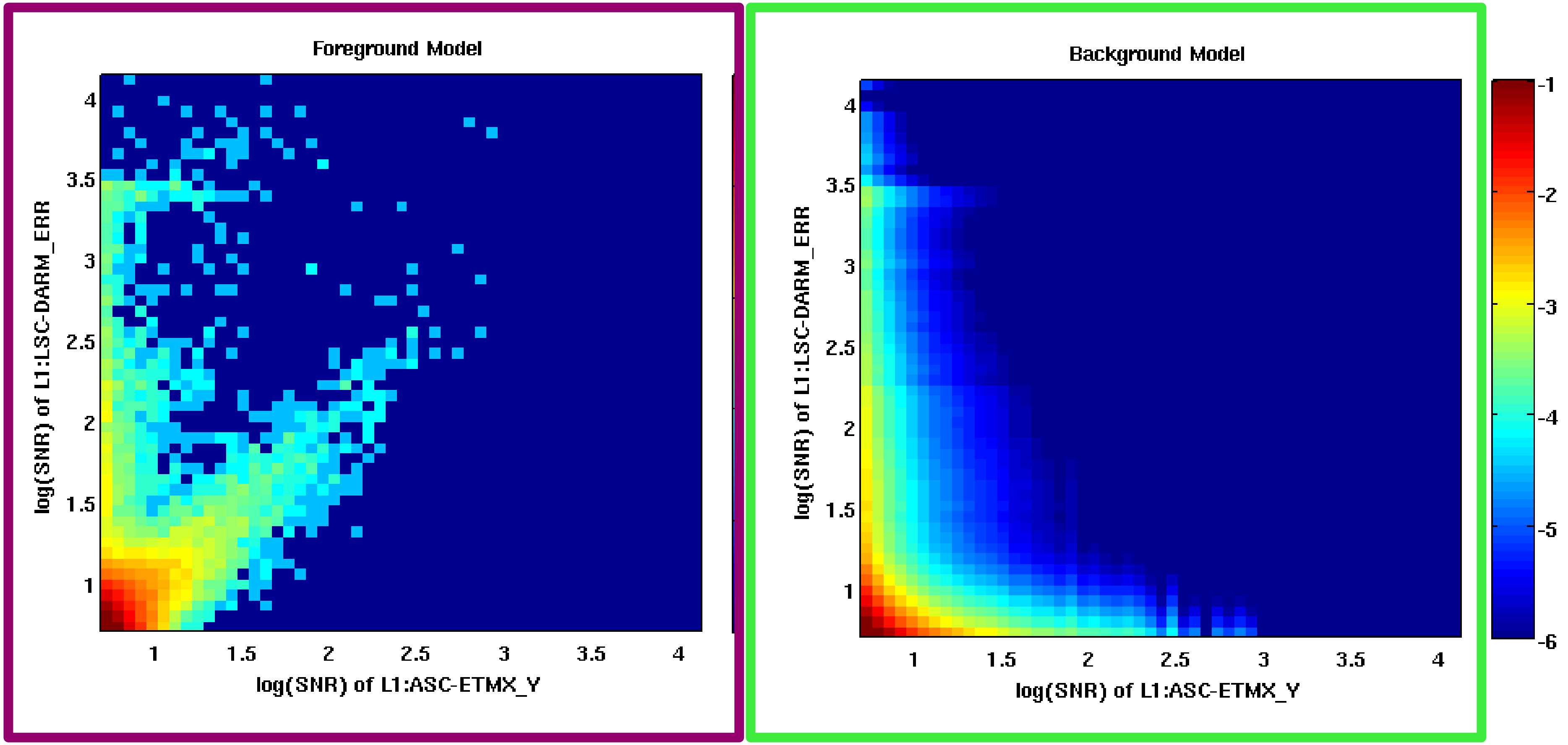
Dois coleções de transientes com respectivas características (gpstime, amplitude, snr, frequency band, duration, etc)

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



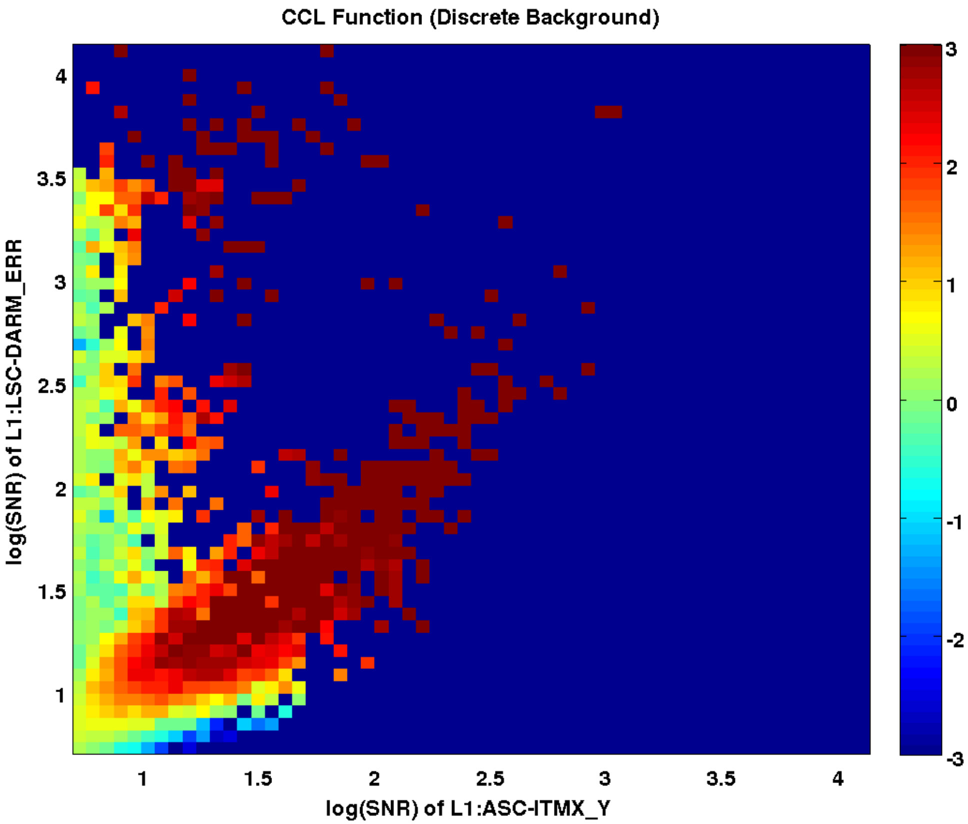
Critical Coupling Likelihood

Modelos



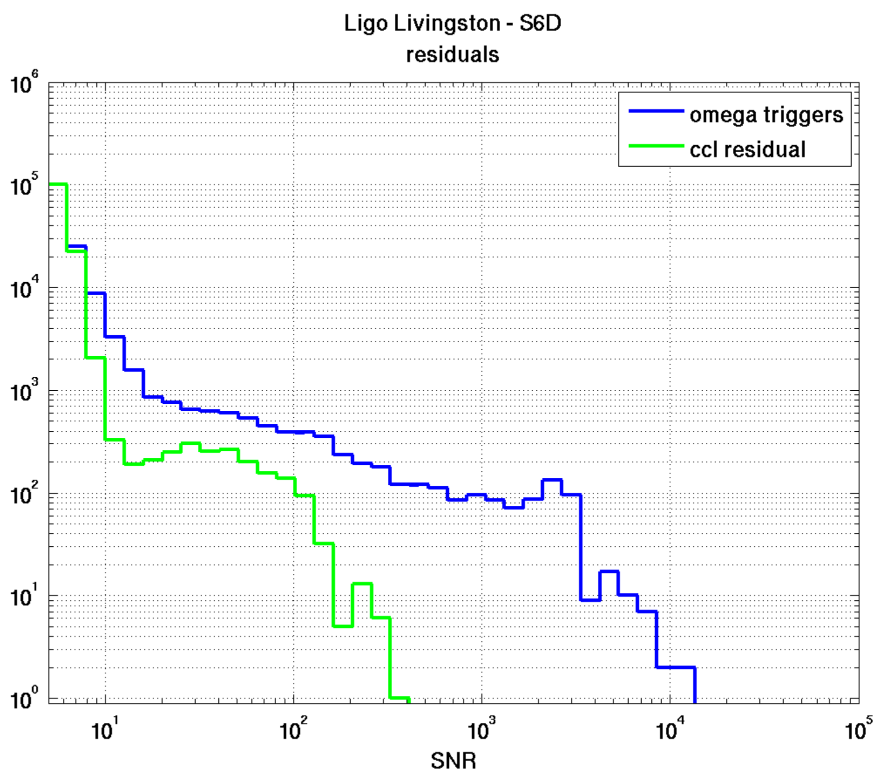
$$CCL = 2\log\left(\frac{P(Y \cap X, \theta_f)}{P(Y \cap X, \theta_b)} \frac{P(X, \theta_b)}{P(X, \theta_f)}\right)$$

Critical Coupling Likelihood
Visão Geral



- Teste de Verossemelhança
  - H1: coincidência temporal real
  - H0: coincidência tempral acidental
- Construção dos modelos
  - Foreground
  - Background
- Região **Critica** CCL > 1 define como X (canal aux.) é mapeado em Y (DARM_ERR)
  - Pares de transientes dentro desta região tem alta probabilidade de estarem relacionados (**acoplados**)

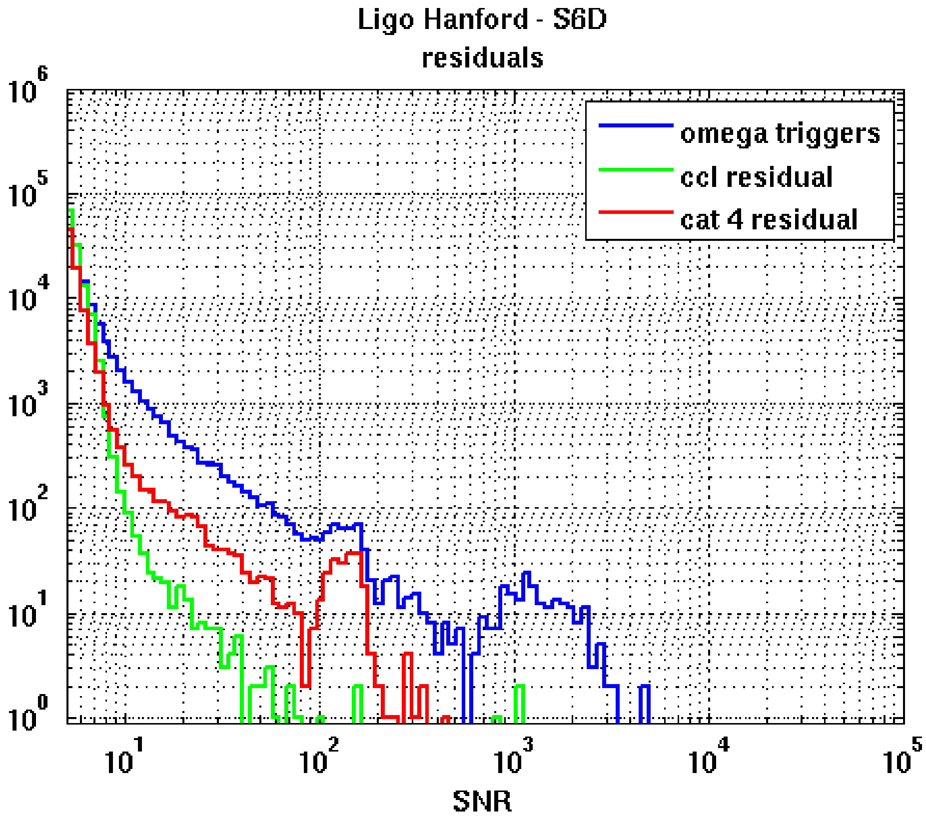
Critical Coupling Likelihood
Desempenho

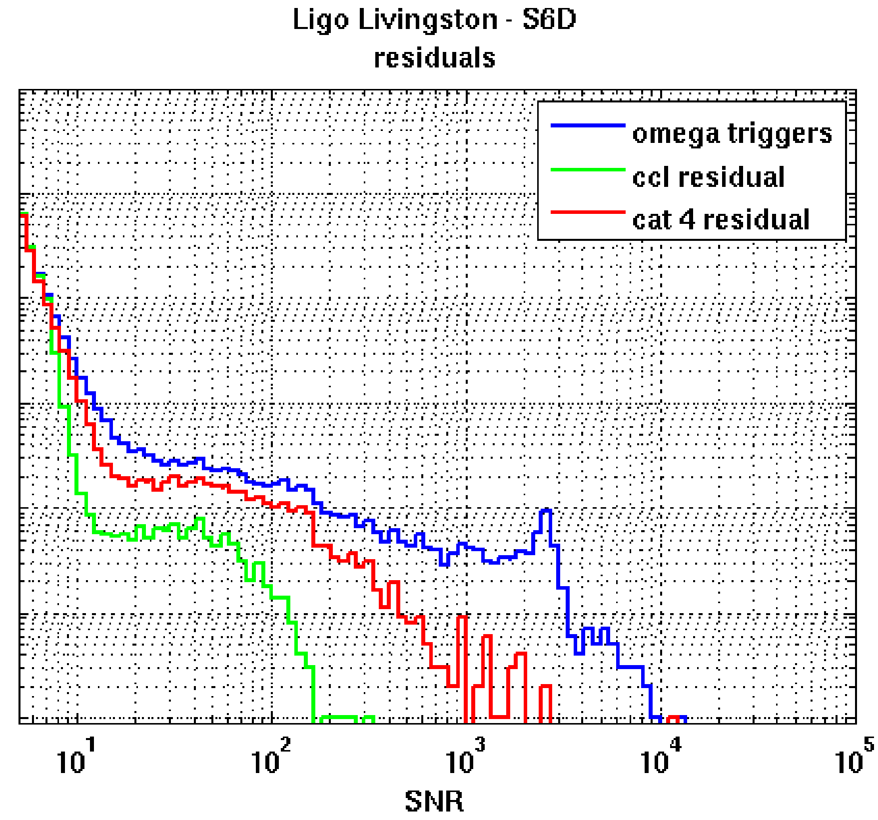


- Desempenho
  - Deadtime: 13.9%
    - Limite superior
  - SNR>8 : ~ 85%

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

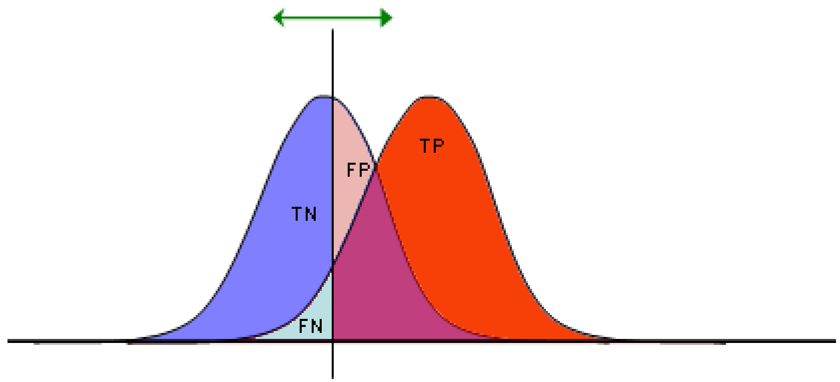
Critical Coupling Likelihood
Desempenho vs. Cat 4



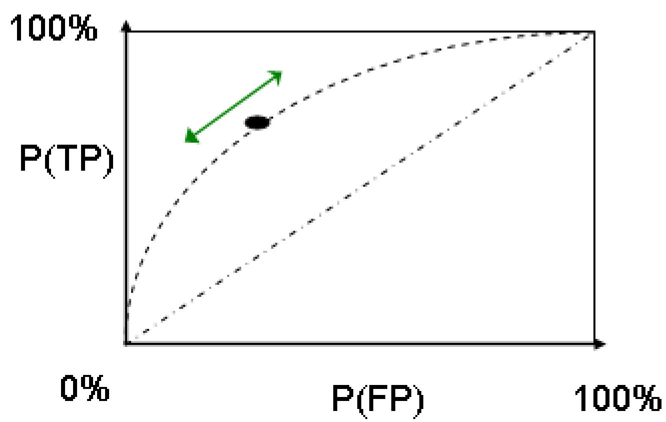


Característica de Operação do Receptor

Receiver Operating Characteristic (ROC)

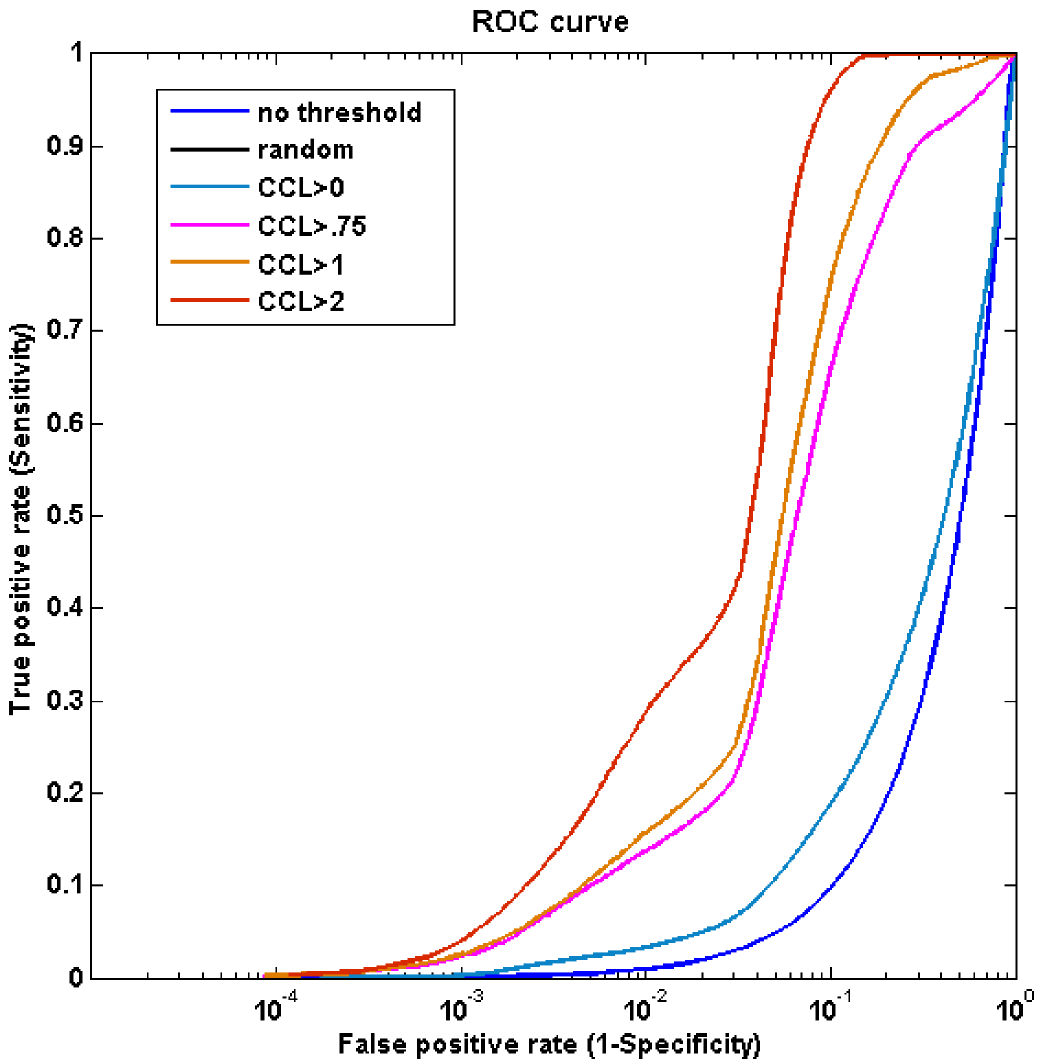


TP	FP
FN	TN
1	1

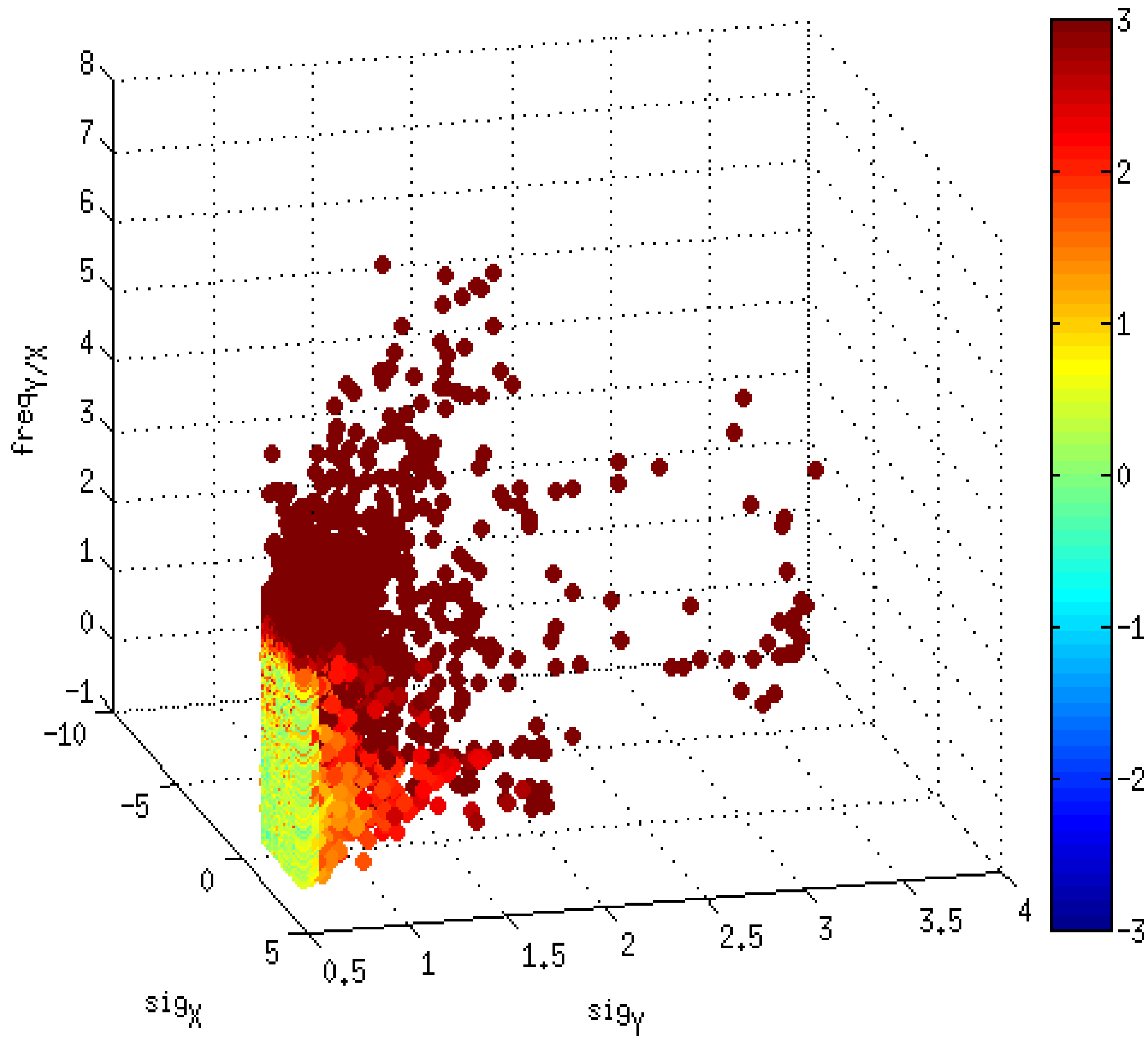


Critical Coupling Likelihood

ROC

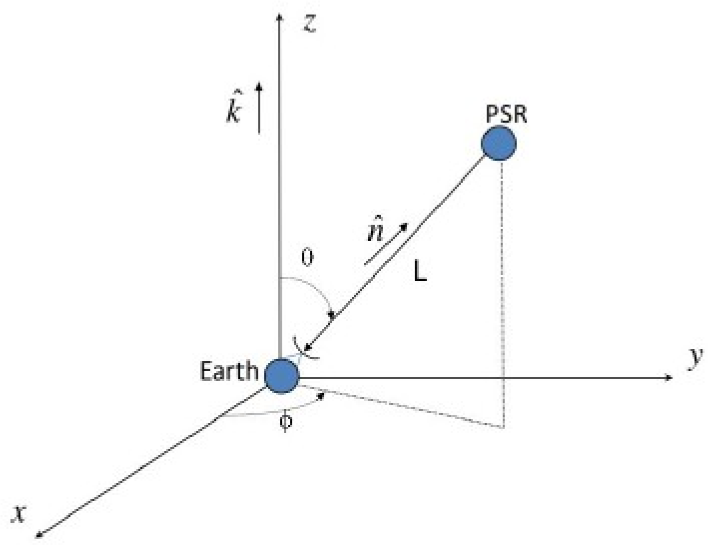


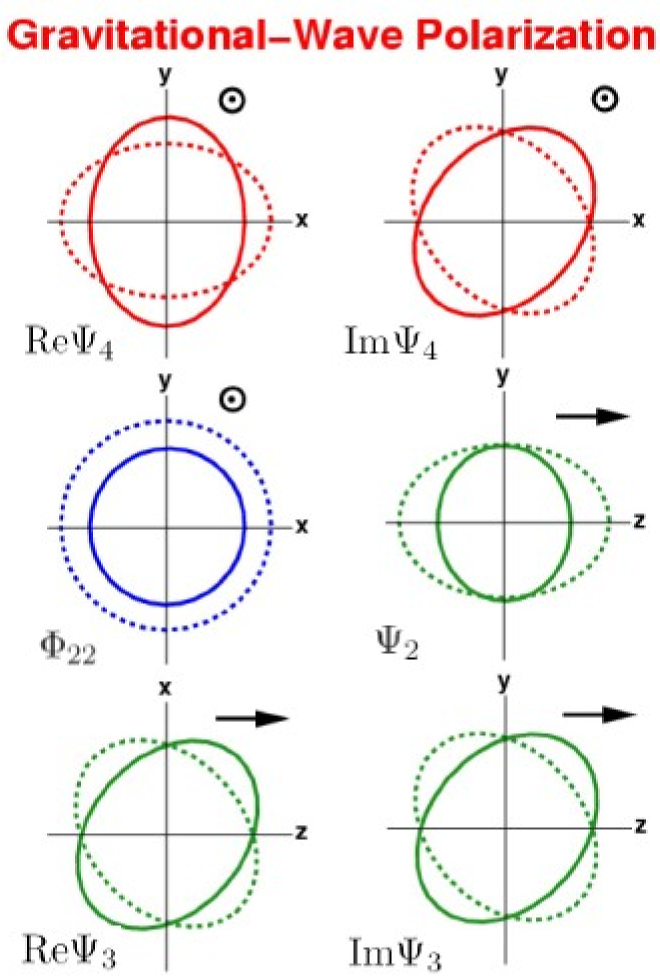
Critical Coupling Likelihood
Multidimensional



Detecção Bayesiana de modos de polarização utilizando Pulsar Timing

- Colaboração
  - Márcio Alves (Unifei)
  - Massimo Tinto (JPL/NASA)





Cálculo das Verossemelhanças

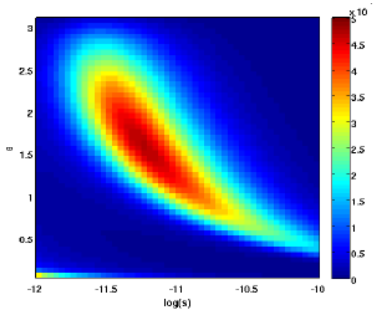


Figure: Modos tensoriais.

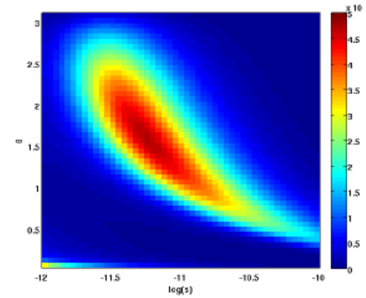


Figure: Modo escalar-transverso.

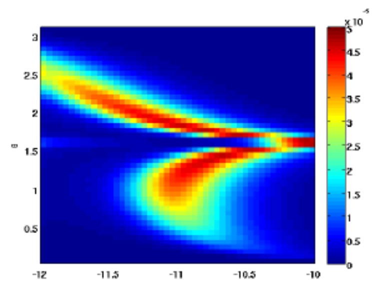


Figure: Modos vetoriais.

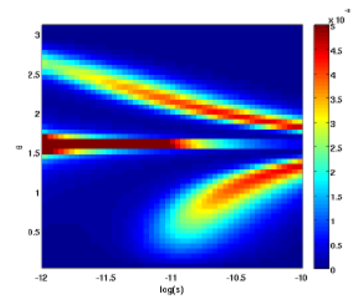


Figure: Modo escalar-longitudinal.

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

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

Publicações

- COSTA, C.F.S ; **COSTA, C. A.** ; AGUIAR, O. D . Low-latency data analysis for the spherical detector Mario Schenberg. Classical and Quantum Gravity (Print), v. 31, p. 085012, 2014.
- AASI, J. , et al. **COSTA, C. A.**; FIRST SEARCHES FOR OPTICAL COUNTERPARTS TO GRAVITATIONAL-WAVE CANDIDATE EVENTS. The Astrophysical Journal. Supplement Series, v. 211, p. 7, 2014.
- AASI, J. , et al. **COSTA, C. A.**; Search for gravitational waves from binary black hole inspiral, merger, and ringdown in LIGO-Virgo data from 2009 2010. Physical Review. D. Particles, Fields, Gravitation, and Cosmology), v. 87, p. 022002, 2013.
- Aasi, J ; et al ; **Costa, C A** . Einstein@Home all-sky search for periodic gravitational waves in LIGO S5 data. Physical Review. D. Particles, Fields, Gravitation, and Cosmology (Online), v. 87, p. 042001, 2013.
- ADRIÁN-MARTÍNEZ, et al. **COSTA, C. A**.; A first search for coincident gravitational waves and high energy neutrinos using LIGO, Virgo and ANTARES data from 2007. Journal of Cosmology and Astroparticle Physics, v. 2013, p. 008-008, 2013.
- AASI, J. , et al. **COSTA, C. A.** ; Enhanced sensitivity of the LIGO gravitational wave detector by using squeezed states of light. Nature Photonics (Print), v. 7, p. 613-619, 2013.
- AASI, J. , et al. **COSTA, C. A**. ; Parameter estimation for compact binary coalescence signals with the first generation gravitational-wave detector network. Physical Review. D, Particles, Fields, Gravitation, and Cosmology, v. 88, p. 062001, 2013.
- Abadie, J. ; et al ; **COSTA, C. A.** . Implementation and testing of the first prompt search for gravitational wave transients with electromagnetic counterparts. Astronomy & Astrophysics, p. A124, 2012.
- Aasi, J ; et al ; **COSTA, C. A.** . The characterization of Virgo data and its impact on gravitational-wave searches. Classical and Quantum Gravity (Print), v. 29, p. 155002, 2012.
- **Costa, Cesar A** ; Torres, Cristina V . The critical coupling likelihood method: a new approach for seamless integration of environmental and operating conditions of gravitational wave detectors into gravitational wave searches. Classical and Quantum Gravity, v. 29, p. 205018, 2012.
- Aguiar, O D et al. **COSTA, C. A.**; Status Report of the Schenberg Gravitational Wave Antenna. Journal of Physics. Conference Series, v. 363, p. 012003, 2012.