$\mathcal{F}$-Statistic Searches for White Dwarf Binaries in the Mock LISA Data Challenges

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Outline

1. Methods
   - $\mathcal{F}$-Statistic Search for Periodic Gravitational Waves
   - Our Reductionist Approach
2. Results
   - Parameter Recovery
   - Pipeline Efficiency
3. Outlook
   - Future/Ongoing Work

$\mathcal{F}$-Statistic Basics

WD Binaries $\longrightarrow$ periodic signals; search w/$\mathcal{F}$-stat
Jaranowski, Królak, Schutz PRD **58**, 063001 (1998)
Params $\mathcal{A} \equiv \{h_0, \cos\iota, \psi, \phi_0\}$ & $\theta \equiv \{\lambda, \beta, f, (\dot{f}, \ldots)\}$

$$x(t; \mathcal{A}_0, \theta_0) = n(t) + \mathcal{A}_0^\mu h_\mu(t; \theta_0)$$

$$x_\mu(\theta) = (x|h_\mu(\theta)); \qquad \mathcal{M}_{\mu\nu}(\theta) = (h_\mu(\theta)|h_\nu(\theta))$$

$$2\ln\Lambda(\mathcal{A}, \theta) = -\mathcal{A}^\mu \mathcal{M}_{\mu\nu}(\theta)\mathcal{A}^\nu + 2\mathcal{A}^\mu x_\mu(\theta)$$

$$\mathcal{A}^\mu_{\mathrm{MLE}}(\theta) = \mathcal{M}^{\mu\nu}(\theta) x_\nu(\theta); \qquad 2\mathcal{F}(\theta) = x_\mu(\theta)\mathcal{M}^{\mu\nu}(\theta)x_\nu(\theta)$$

$\mathcal{M}_{\mu\nu}$ is a metric on amp param space

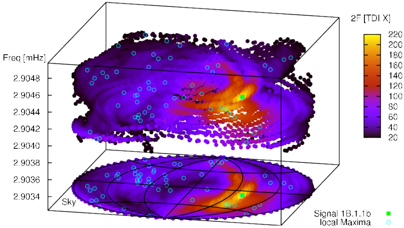
Keeping It Simple

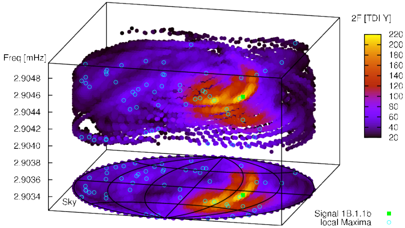
- Re-use LIGO (LAL/LALApps) $\mathcal{F}$-stat code where possible
- Search for individual signals (reductionist, not holistic)
- Use a grid (sorry Neil!) & refine hierarchically
- Convert TDIs to equivalent strain

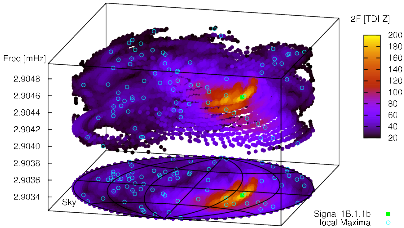
$$R(f)\widetilde{X}(f) = \widetilde{h}(f) = \overleftrightarrow{h}(f) : \overleftrightarrow{d}^X(f, \widehat{k})$$

- Can use $\overleftrightarrow{d}^X_{\text{LWL}}$ or $\overleftrightarrow{d}^X_{\text{RAA}}(f, \widehat{k})$
- LISAsim and synthLISA just have different $R(f)$s

Secondary Maxima (Orientation of the Vorlon)

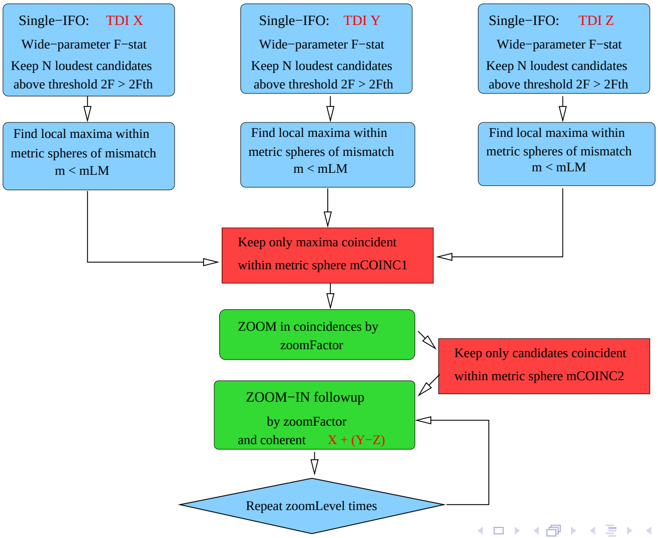




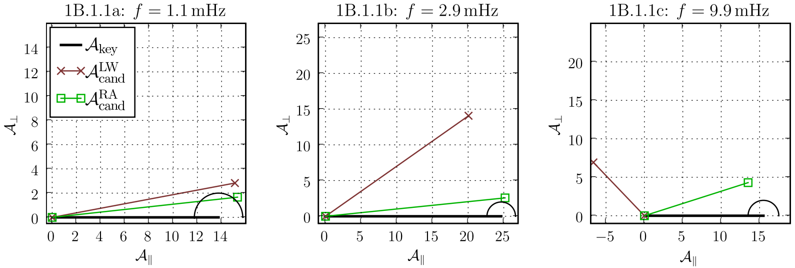


- Spurious local $2\mathcal{F}$ maxima
- 2ndary maxima in diff places in diff TDI vars
- Our pipeline requires coïncidence

Pipeline for Prix/Whelan/Khurana MLDC Searches



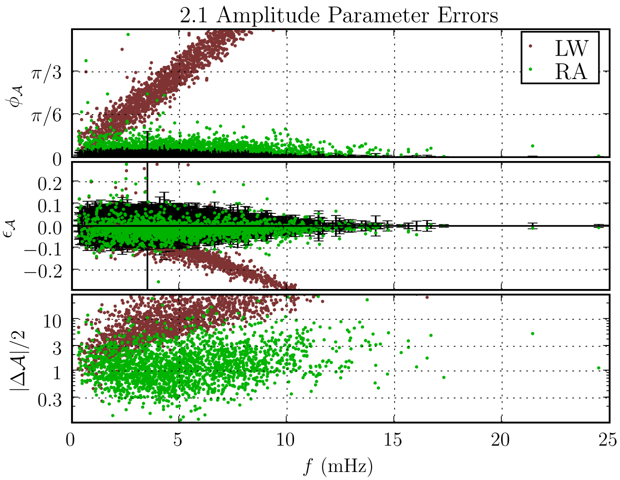
Challenge 1(B).1.1: Isolated Binaries



	f (mHz)	Δf(nHz) LW	RA	ϕ_{sky}(mrad) LW	RA	ϵ_θ LW	RA
a	1.1	−0.7	−0.7	61.9	46.1	0.5	0.3
b	2.9	0.9	0.9	12.3	7.7	1.1	0.9
c	9.9	1.8	1.8	5.1	7.5	0.4	0.5

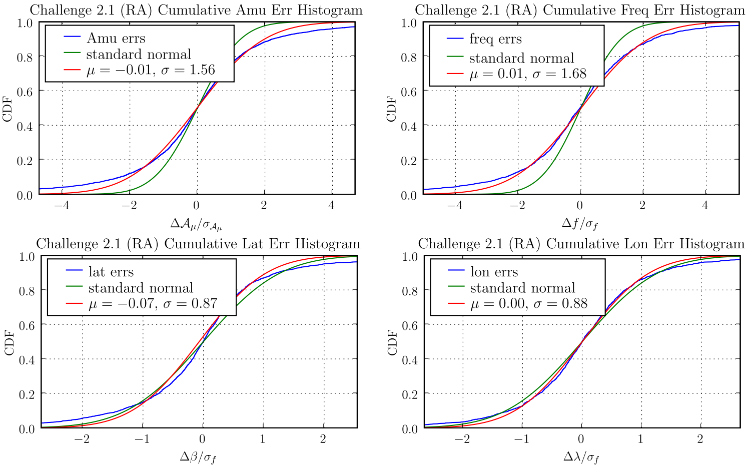
Good sky position even w/approx long-wavelength response
More accurate Rigid adiabatic resp needed for amp params

Amplitude Accuracy w/RA



Amp param errors comparible to statistical expectations

Cumulative Histograms: Err/Sigma



Statistics of Galactic Signals Recovered

Focus on sources w/expected $2\mathcal{F} > 40$

Freqs	Signals ($\|\mathcal{A}\|^2 > 40$)	Found LW	Found RA	False LW	False RA
0–5 mHz	4443	982	1025	1	2
5–10 mHz	1966	652	822	5	3
10–15 mHz	163	68	133	1	0
15–20 mHz	7	2	7	0	0
20–27 mHz	3	0	2	2	0
Total	6582	1704	1989	9	5

Improved response improves efficiency
Find $\sim$ 10% as many signals as Crowder et al;
limitation of reductionist approach?

Current Status and Future Directions

- Might need to subtract bright signals & iterate (more like multi-signal approach)
- Would like to produce our own residuals advocate option to submit for MLDC3
- MLDC3 has $\dot{f}$; underlying code already handles this, still playing with pipeline & infrastructure
- Implementing A, E, T TDI vars; final coherent step could be done w $X \oplus (Y - Z)$ or $A \oplus E$ or $A \oplus E \oplus T$ (Suspect difference only matters at high freq)

Prix/Whelan/Khurana Papers:

- MLDC1 paper: P&W CQG **24**, S565 (2007) (arXiv:0707.0128)
- MLDC1B paper: W,P&K arXiv:0805.1972
- Longer paper, incl MLDC2: W,P&K on arXiv soon!