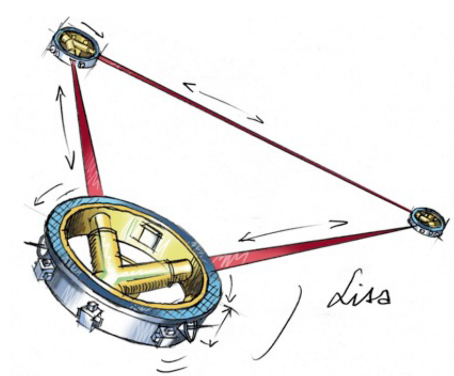
Synergy between EM and GW measurements
(for Galactic binaries)

Sweta Shah
Radboud University Nijmegen
Gijs Nelemans
Marc v. d. Slyus



the project …

For the Galactic Binaries,

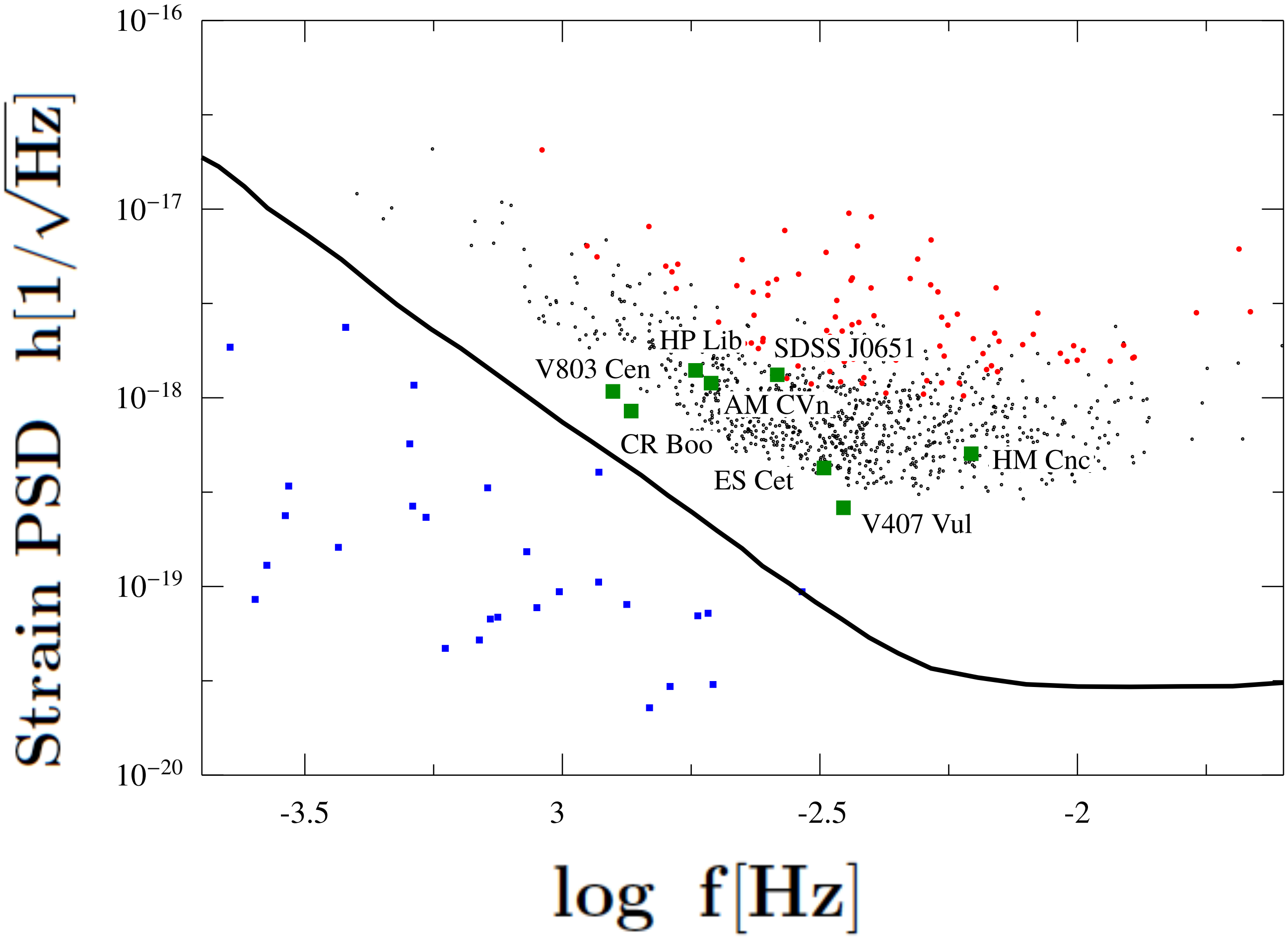
Can we get the most out of GW parameter estimates?

Do EM parameters correlate with GW parameters?

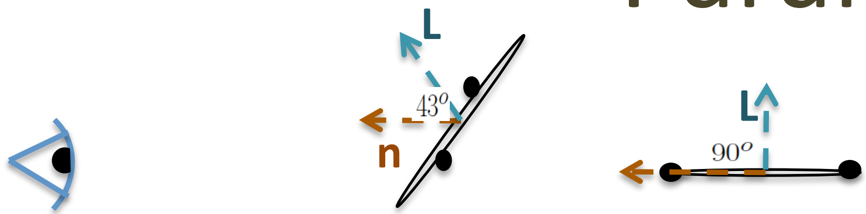
Develop strategic plans for EM measurement

Do the GW parameters correlate and if so how well?

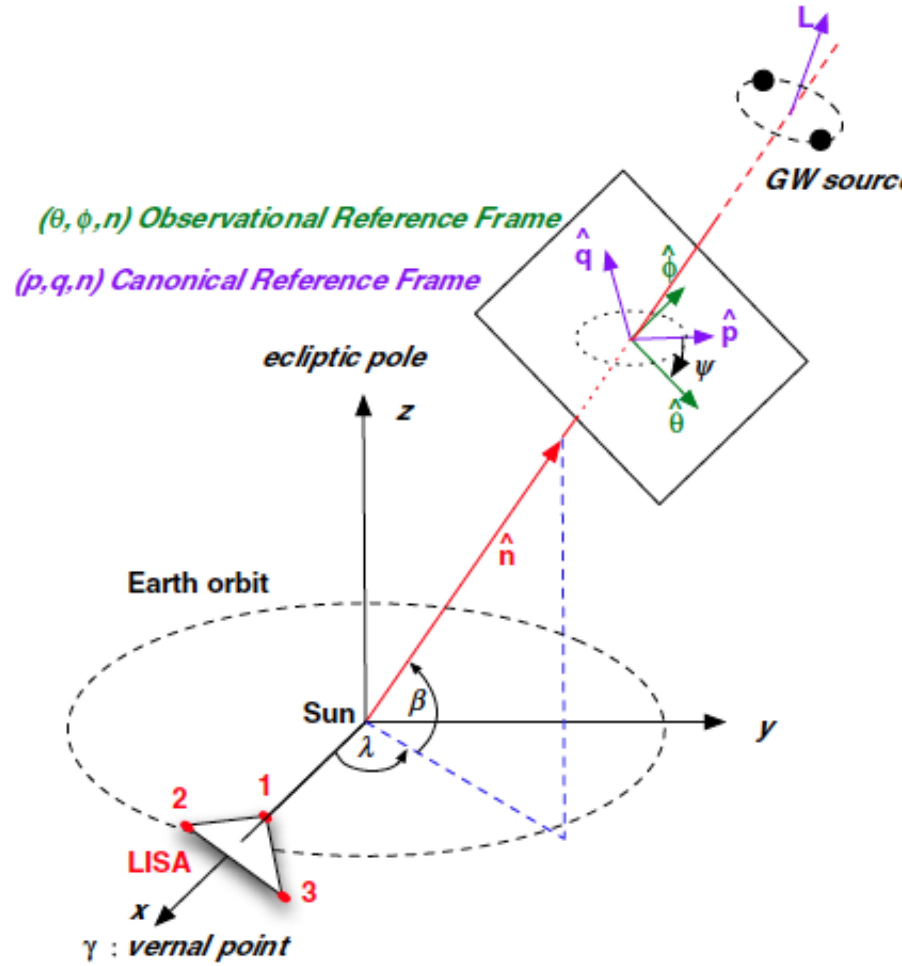
Verification Binaries



Parameters



		AMCVn	SDSS
EM info	$\mathcal{A}(m_1, m_2, d, f)$	1.494×10^{-22}	1.670×10^{-22}
	f	1.944×10^{-3}	2.61×10^{-3}
	ι	0.75 (43^o)	1.56 (89.6^o)
	β	0.65	0.10
	λ	2.97	1.77
chosen	ϕ	π	π
	ψ	$\pi/2$	$\pi/2$
	$m_1[M_\odot]$	0.71	0.55
	$m_2[M_\odot]$	0.13	0.25
	$d[kpc]$	0.606	0.1



Lisacode
Petiteau, 2008

x = {parameters of the signal}

Fisher Matrix Studies

Given a signal, $h(t, \boldsymbol{x})$, for SNR >> 1 & Gaussian noise

$$p(\Delta \boldsymbol{x}) = \left(\frac{det(\Gamma)}{2\pi}\right)^2 e^{-(1/2)\Gamma_{ij}\Delta x_i \Delta x_j}$$

$$\mathcal{C} = \Gamma^{-1}$$

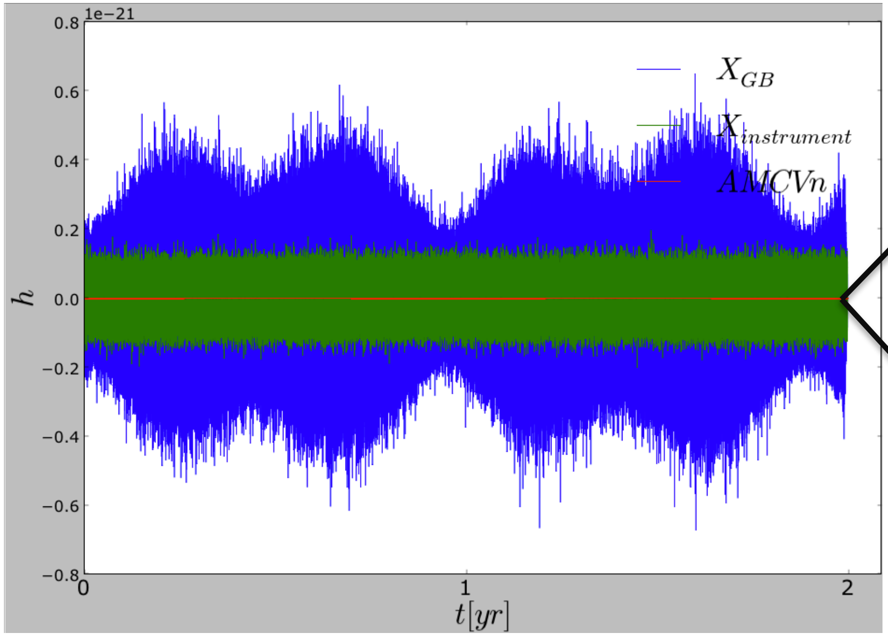
Normalised correlation (off-Diagonals)

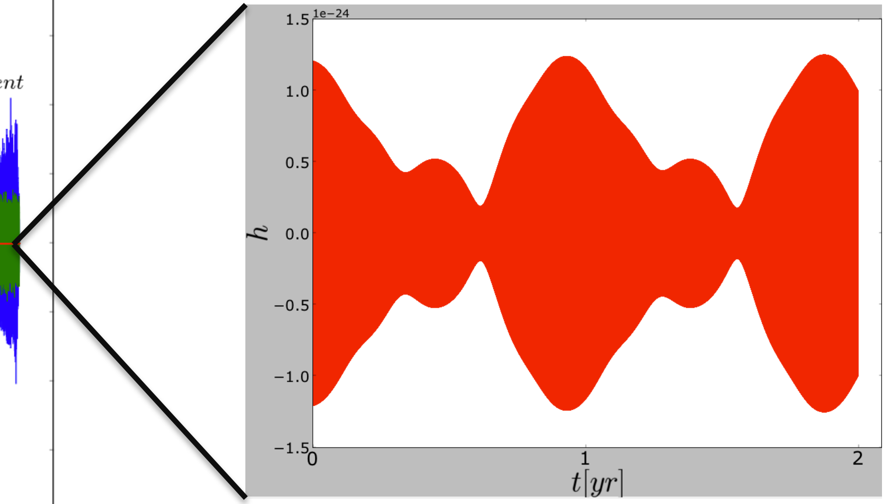
$$c_{ij} = \frac{\mathcal{C}_{ij}}{\sqrt{\mathcal{C}_{ii}\mathcal{C}_{jj}}}$$

Parameter accuracy (Diagonals)

$$c_{ii} = \sqrt{\mathcal{C}_{ii}}$$

Simulations

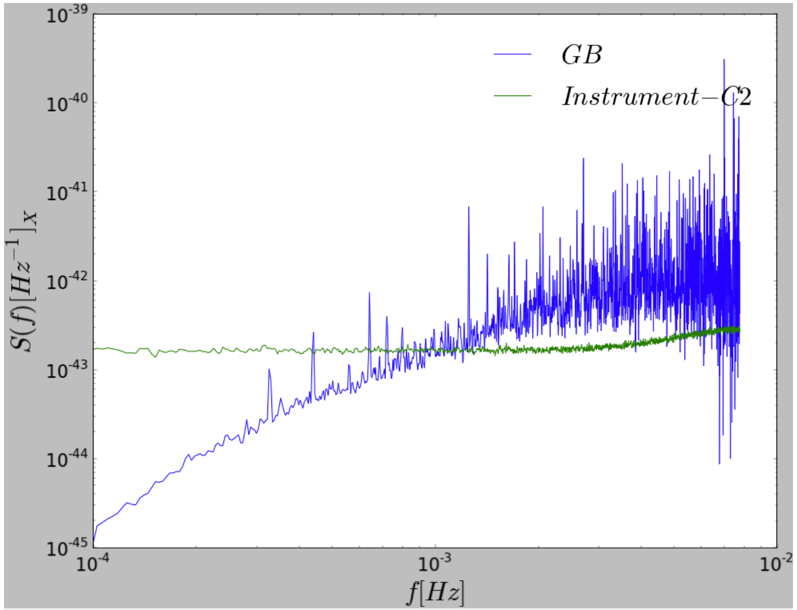




Synthetic LISA
Vallisneri, 2006

$$T_{\text{obs}} = 2 \text{ years}$$

$$\#\text{DWDs} > 2.7 \times 10^7$$

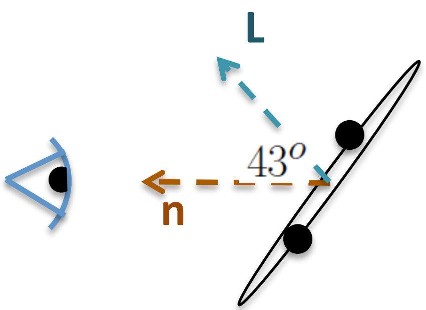


Lisasolve
Vallisneri

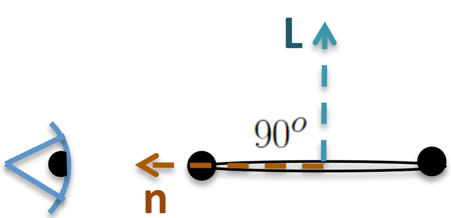
AMCVn & SDSS J0165+..

(8.18) (4.22)

$$\mathrm{SNR} = \rho = \sqrt{(h|h)}$$



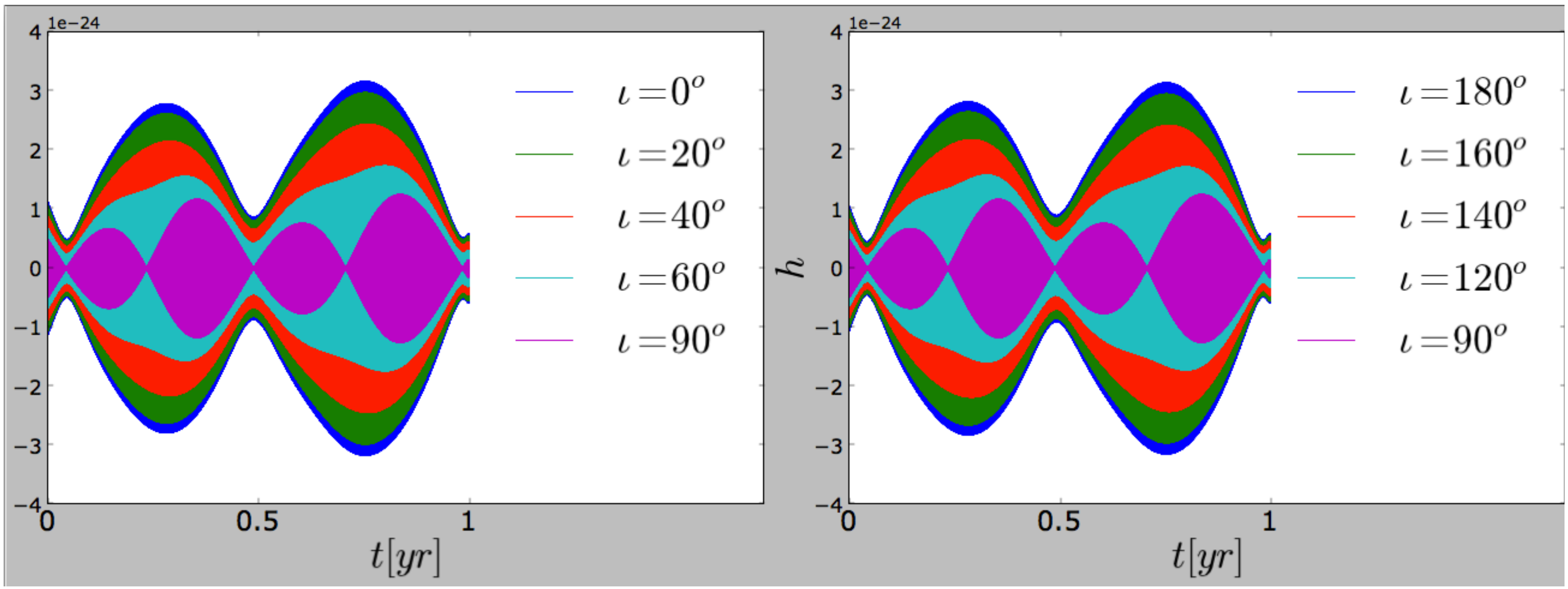
	$\mathcal{A}$	ϕ	ι	f	ψ	β	λ
$\mathcal{A}$	1.492×10^{-22}	0.29	0.99	−0.06	−0.3	−0.03	−0.60
ϕ		3.218	0.27	−0.03	−0.996	0.25	−0.44
ι			1.171	−0.06	−0.28	−0.04	−0.60
f				9.377×10^{-10}	−0.03	−0.11	−0.19
ψ					1.614	−0.27	0.03
β						0.051	0.03
λ							0.055



	$\mathcal{A}$	ϕ	ι	f	ψ	β	λ
$\mathcal{A}$	3.976×10^{-23}	0.01	0.05	−0.02	0.03	0.03	−0.08
ϕ		0.526	0.01	−0.89	−0.02	0.13	−0.13
ι			0.11	−0.01	−0.02	0.07	−0.33
f				2.119×10^{-9}	0.01	−0.17	0.16
ψ					0.103	−0.03	−0.07
β						0.176	−0.07
λ							0.49

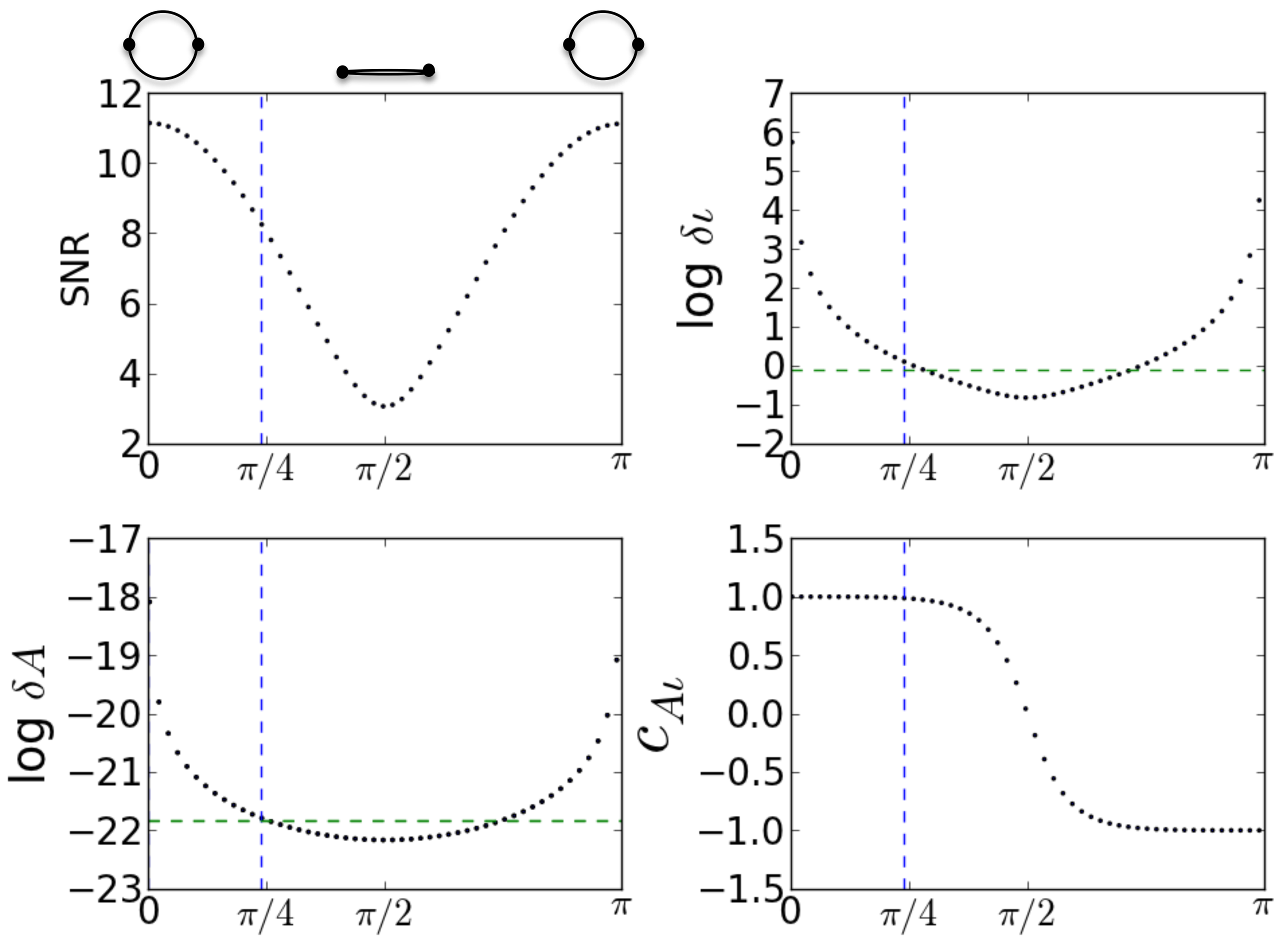
structure of the signals

Signals in time domain

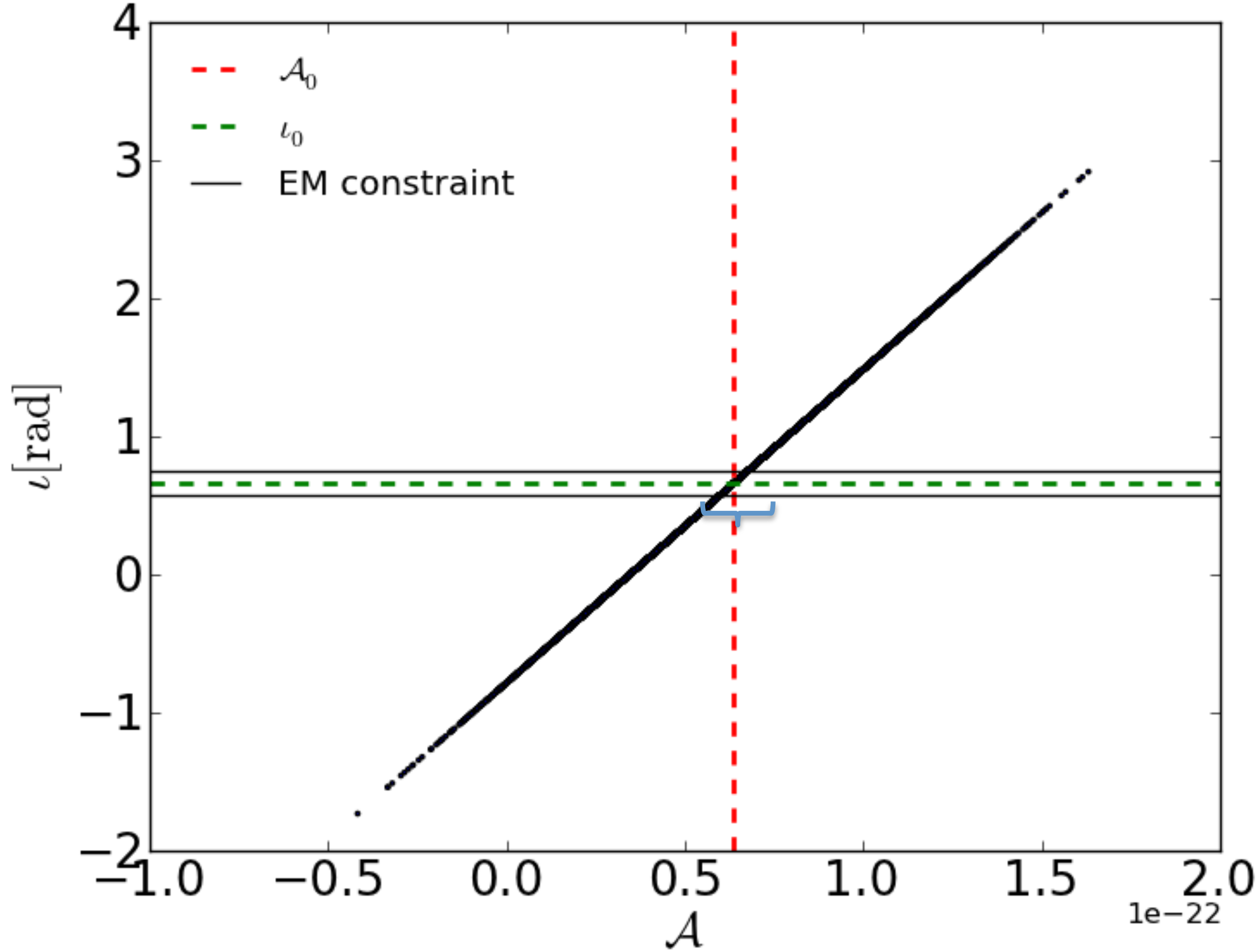


as a function of inclination

AMCVn



Correlation AMCVn $\mathcal{C}_{\mathcal{A}\iota}$



Including mild chirp

EM info

$\mathcal{A}$	6.3783×10^{-23}
f	6.2202×10^{-3}
$\dot{f}$	-7.255×10^{-16}
ι	$0.663 \ (38^o)$
β	-0.082
λ	2.102

chosen

ϕ	π
ψ	$\pi/2$

RX J0806… or HM Cancri
SNR = 20.50

$m_1[M_\odot]$	0.55
$m_2[M_\odot]$	0.27
$d[kpc]$	5.0

$\Delta\theta$		2.4038×10^{-23}	1.782	0.541	4.409×10^{-10}	-	0.884	0.034	0.004
		$\mathcal{A}$	ϕ	ι	f	$\dot{f}$	ψ	β	λ
2.4165×10^{-23}	$\mathcal{A}$		0.01	0.99	-0.01	–	-0.01	-0.11	-0.07
1.761	ϕ	0.003		0.01	-0.14	-	-0.99	-0.17	0.07
0.544	ι	0.99	0.003		-0.01	-	-0.01	-0.11	0.08
1.8582×10^{-9}	f	-0.004	-0.13	0.01		-	-0.09	0.29	-0.06
5.422×10^{-17}	$\dot{f}$	0.01	0.1	-0.01	-0.97		-	-	-
0.872	ψ	0.003	0.995	0.004	-0.04	0.03		0.15	-0.06
0.035	β	0.16	-0.02	0.16	-0.07	0.16	-0.01		-0.06
0.004	λ	-0.07	-0.04	-0.07	-0.28	0.28	-0.06	0.1	

conclusions

Accuracy is worst for (almost) face-on binaries compared to edge-on ones

In general, correlations depend on inclination

Strong correlation is only useful for non-edge on binaries

Binaries with mild chirp does not really help

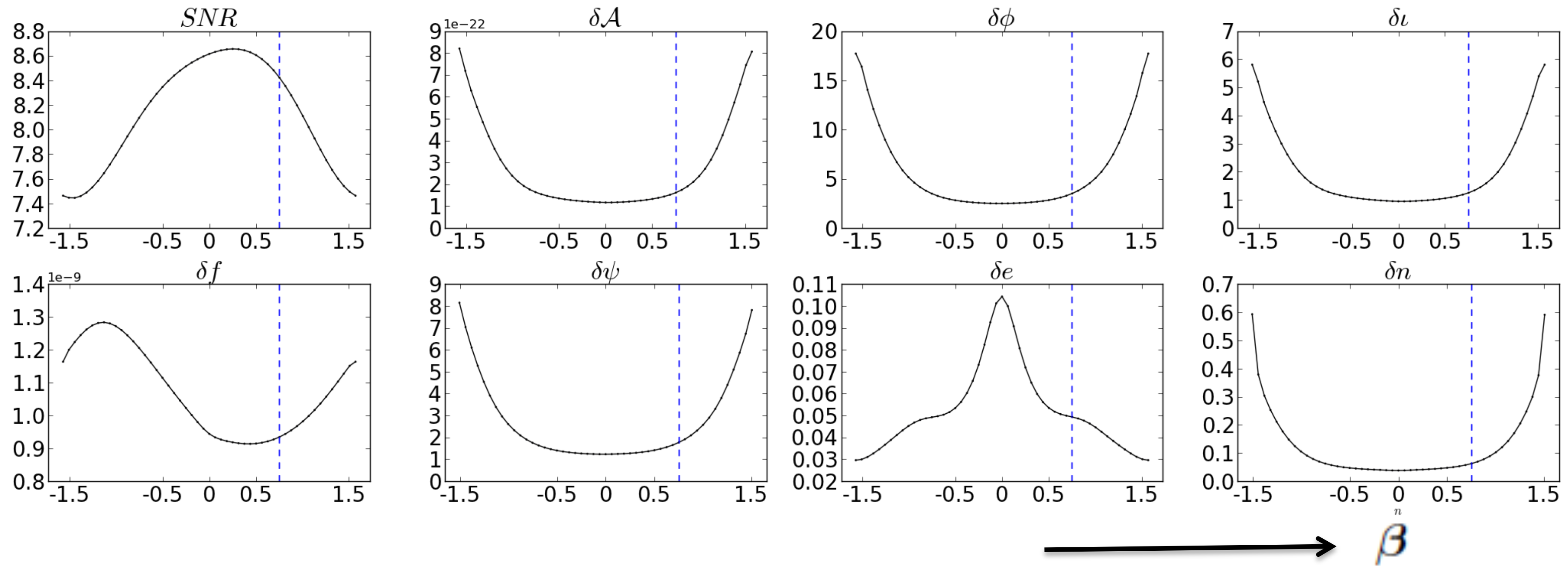
Next steps …

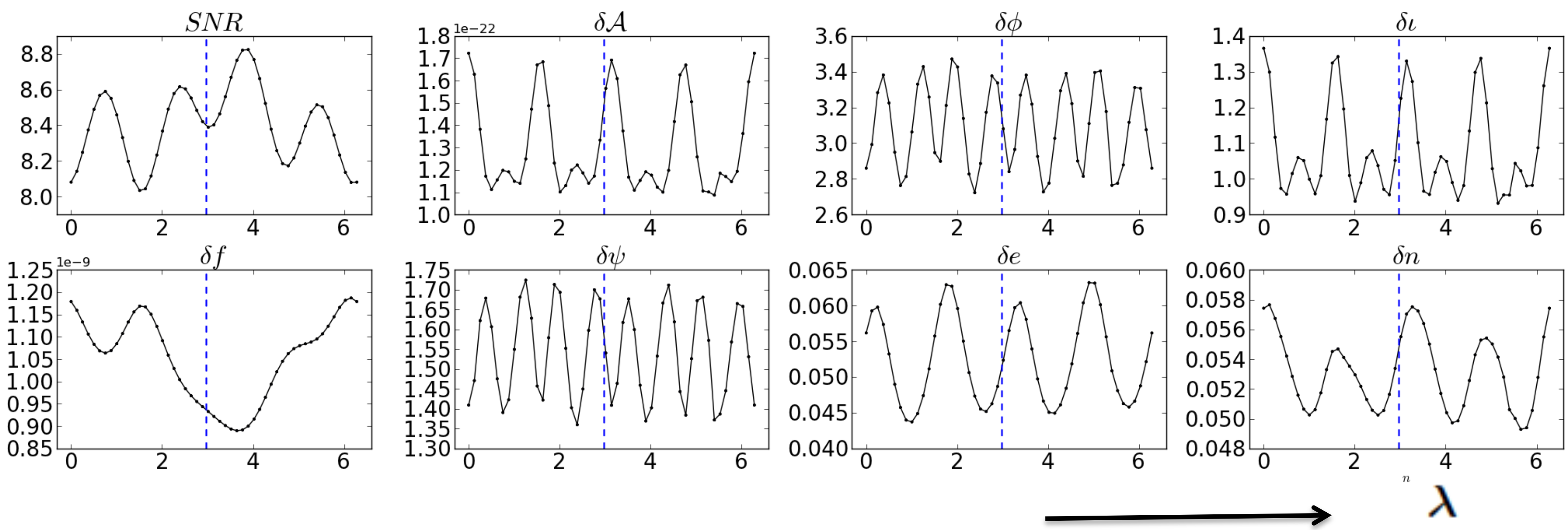
Interpret correlations as a function of sky positions

Develop strategic plans for EM follow ups

Do the same for VIRGO (Marc)

as a function of sky positions





Including mild chirp - SDSS

EM info

$\mathcal{A}$	1.670×10^{-22}
f	2.61×10^{-3}
$\dot{f}$	-1.078×10^{-17}
ι	$1.56 \ (89.6^o)$
β	0.10
λ	1.77

chosen

ϕ	π
ψ	$\pi/2$

SNR = 4.22

$m_1[M_\odot]$	0.55
$m_2[M_\odot]$	0.25
$d[kpc]$	1.0

$\Delta\theta$		3.976×10^{-23}	0.526	0.11	2.119×10^{-9}	-	0.103	0.176	0.49
		$\mathcal{A}$	ϕ	ι	f	$\dot{f}$	ψ	β	λ
3.679×10^{-23}	$\mathcal{A}$		0.01	0.05	−0.02	-	0.03	0.03	−0.08
0.84	ϕ	−0.01		0.01	**0.89**	-	−0.02	−0.13	−0.13
0.102	ι	−0.01	0.01		−0.01	-	−0.02	−0.07	−0.33
8.753×10^{-9}	f	0.01	**−0.91**	−0.01		-	0.01	−0.17	0.16
2.431×10^{-16}	$\dot{f}$	−0.01	**0.81**	0.01	**−0.97**		-	-	-
0.095	ψ	0.03	0.01	0.02	−0.01	0.01		−0.03	−0.07
0.163	β	0.02	0.11	−0.07	−0.08	0.04	−0.02		−0.07
0.46	λ	−0.06	0.09	0.33	−0.15	0.19	−0.04	0.07	

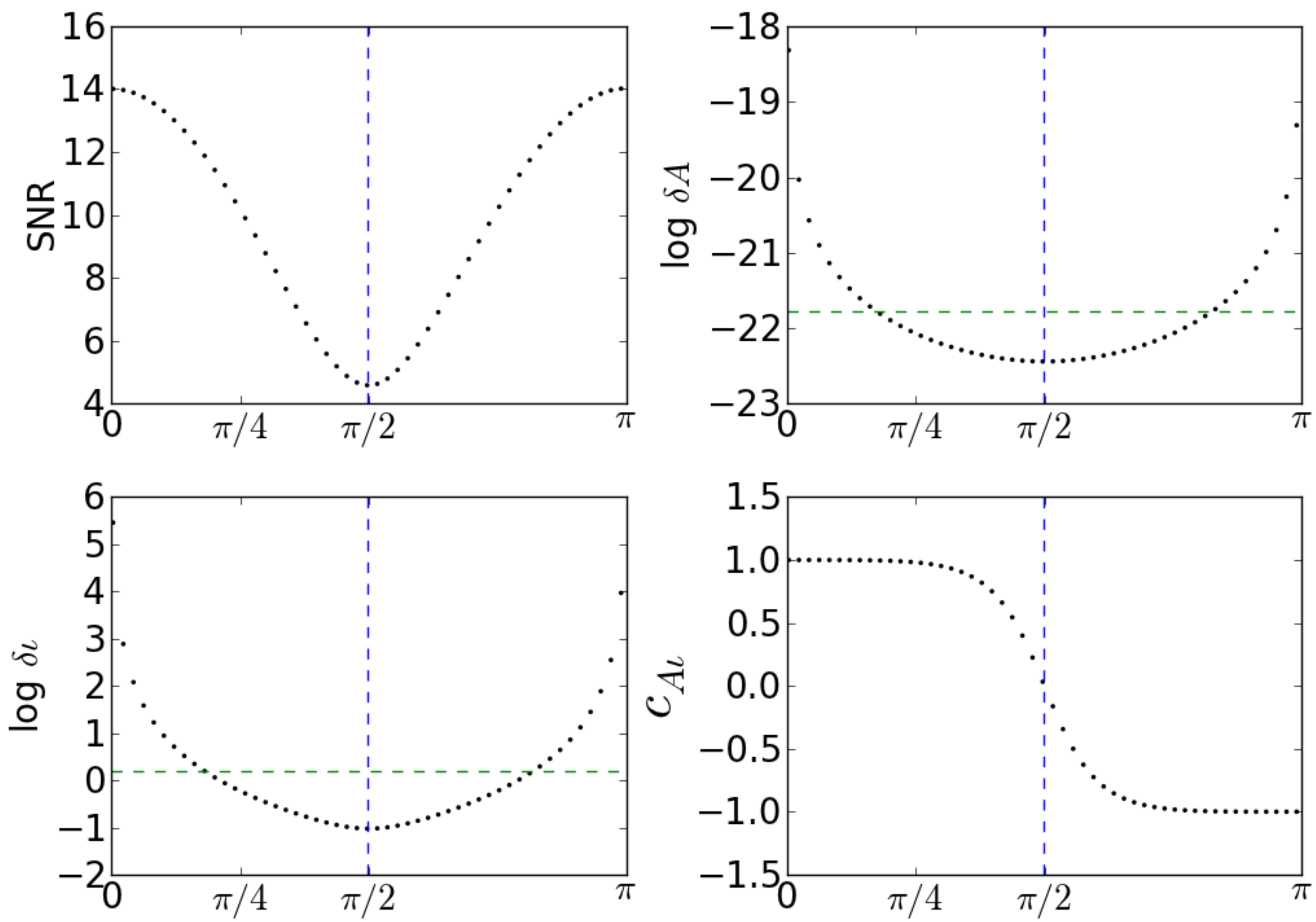
Stabilising FIM, AMCVn

$$c_{ii} = \sqrt{\mathcal{C}_{ii}}$$

$\times x$	$\Delta\mathcal{A}$	$\Delta\iota$	Δf	$\Delta\psi$		$\Delta\phi$	$\Delta\lambda$	$\Delta\beta$
$10^{-4}\times\sqrt{\epsilon}$	$2.13563e-23$	0.16	$9.5765e-10$	0.194	10^{-6}	0.475	0.05	0.042
$10^{-3}\times\sqrt{\epsilon}$	$1.181829e-22$	0.93	$9.601e-10$	1.263	10^{-5}	2.528	0.052	0.05
$10^{-2}\times\sqrt{\epsilon}$	$1.523703e-22$	1.196	$9.6112e-10$	1.648	10^{-4}	3.286	0.052	0.057
$10^{-1}\times\sqrt{\epsilon}$	$1.529117e-22$	1.2	$9.6113e-10$	1.654	10^{-3}	3.298	0.052	0.057
$\sqrt{\epsilon}$	$1.529084e-22$	1.2	$9.6115e-10$	1.654	10^{-6}	3.298	0.052	0.057
$10\times\sqrt{\epsilon}$	$1.520324e-22$	1.193	$9.6339e-10$	1.657	10^{-2}	3.311	0.054	0.059
$10^{2}\times\sqrt{\epsilon}$	$1.286394e-22$	1.019	$1.214e-09$	1.385	10^{-1}	3.382	0.208	0.179

as a function of inclination

SDSS



64 s, T = 2years, Xm time = 10 s

32 s, T = 2years, Xm time = 20 s

16 s, T = 2years, Xm time = 40.5 s

8 s, T = 2years, Xm time = 82 s = 1.4 m

4 s, T = 2years, Xm time = 158 s = 2.6 m

2 s, T = 2years, Xm time = 330 s = 5.5 m