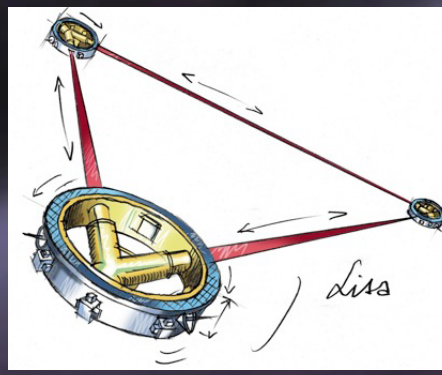
Gravitational wave astrophysics of compact Galactic binaries

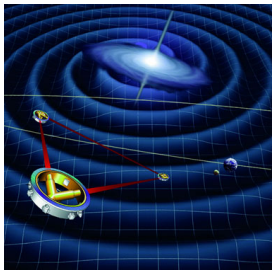
Sweta Shah

Collaborators: Gijs Nelemans, Marc v.d. Sluys

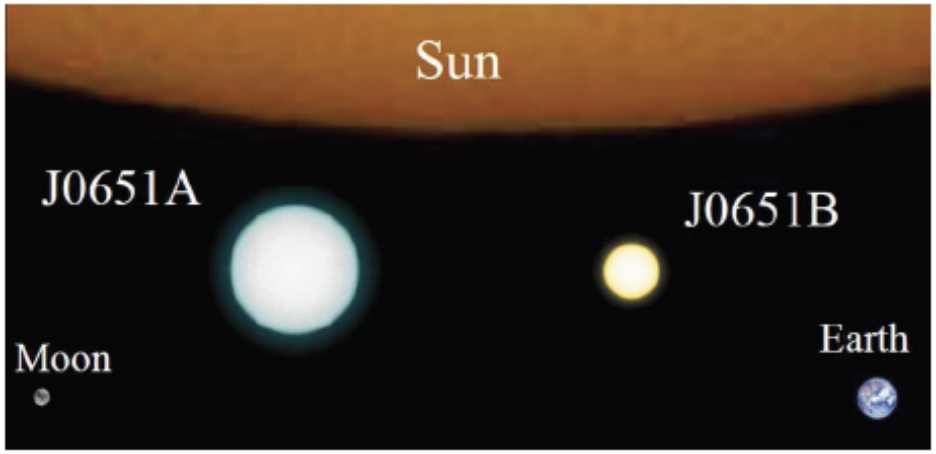
Radboud University Nijmegen



Verification binaries



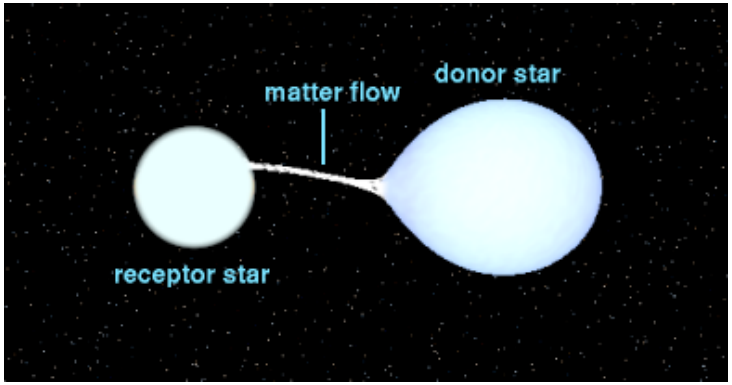
Detached White Dwarf binary (DWD)



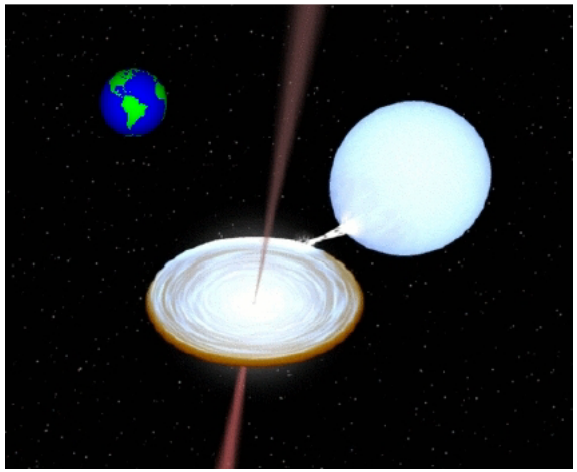
Jim Fuller

$P_{orb} < 5$ hrs

Interacting AM CVns



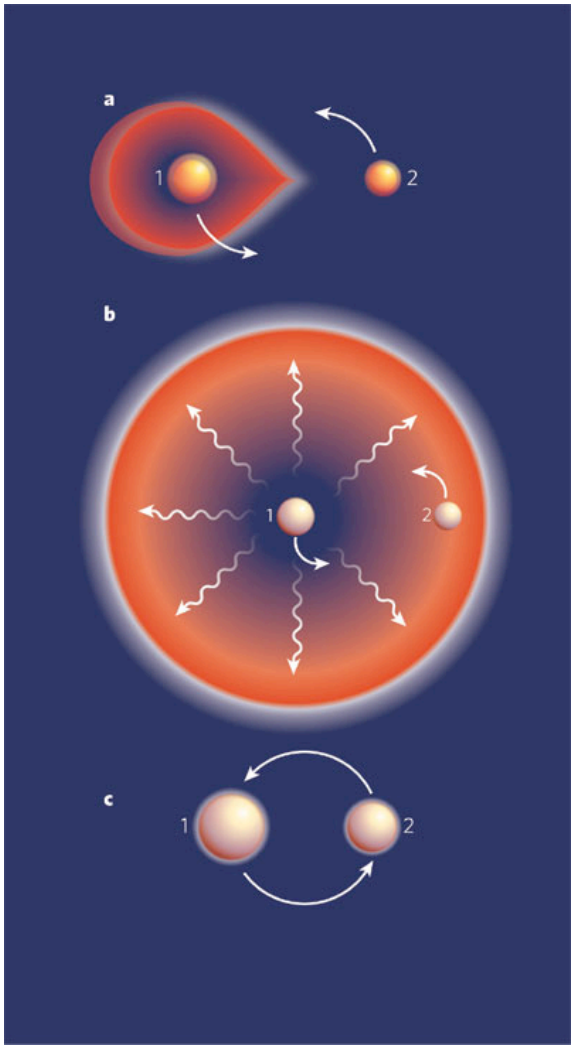
Ultra compact X-Ray binaries



Rob Haynes

Uncertainties in binary evolution

months- years



Example:
Common-envelope phase

Tomasz Bulik, *Nature*, 2007

The **Goals** …

Importance of masses, inclination, distance etc …

How to constrain binary parameters?

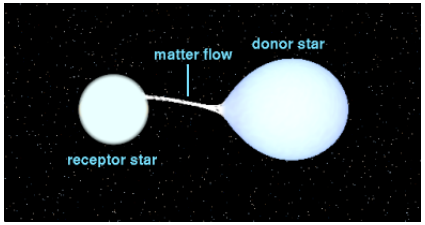
- By making use of EM parameters

Correlations between GW parameters?

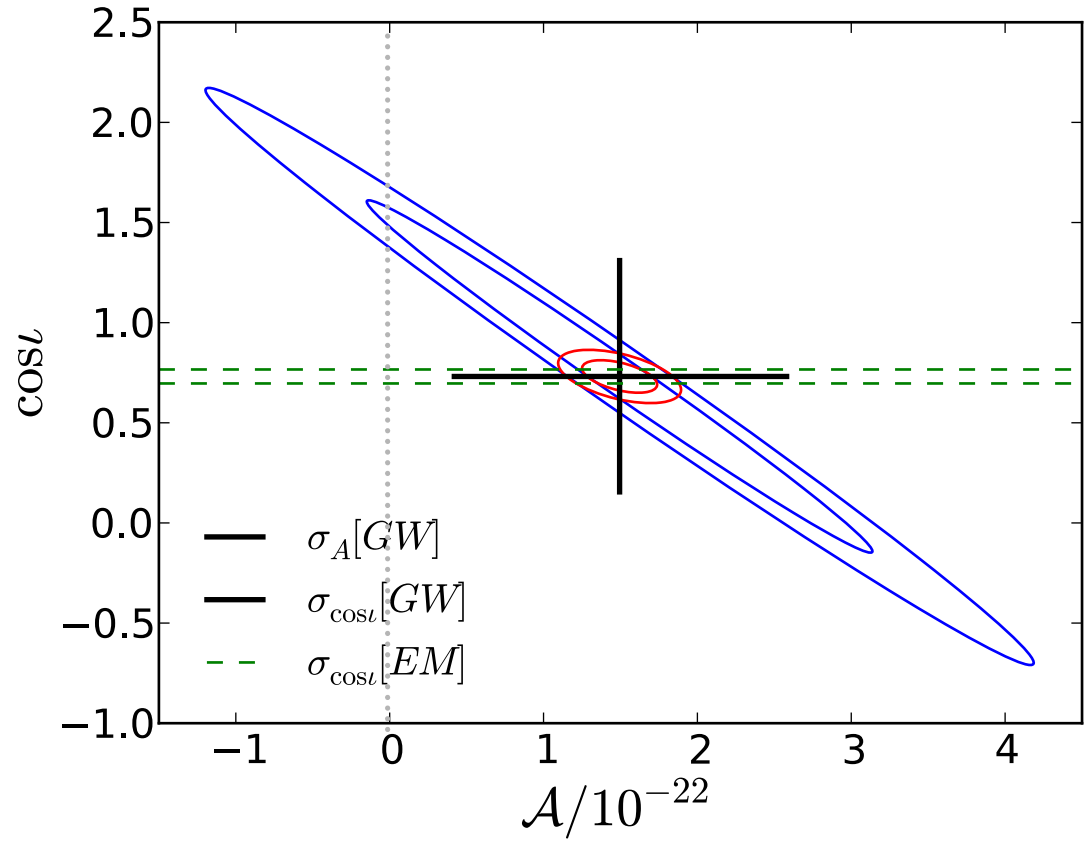
Develop strategic plans for EM observations

correlation $\mathcal{C}_{\mathcal{A}\iota}$ – AMCVn

0.71 0.31 $M_\odot$



17 min



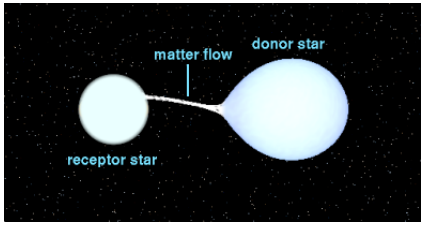
$$T_{\rm obs} = 2 \text{ years}$$
$$S/N = 11$$
$$\iota = 43^\circ$$

Fisher-analysis uncertainties:

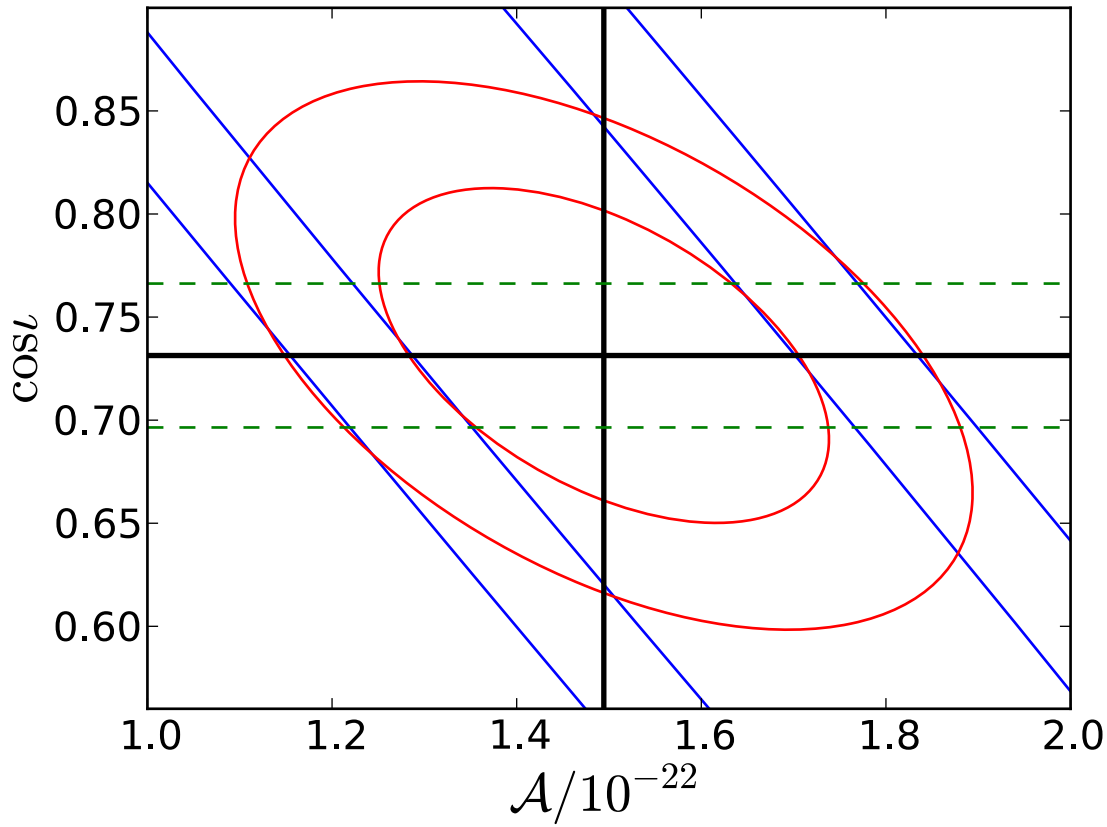
$$\sigma_\iota[\mathrm{GW}] = 49^\circ \qquad \sigma_{\mathcal{A}}[\mathrm{GW}] = 1.08 \times 10^{-22}$$

correlation $\mathcal{C}_{\mathcal{A}\iota}$ – AMCVn

0.71 0.31 $M_\odot$



17 min



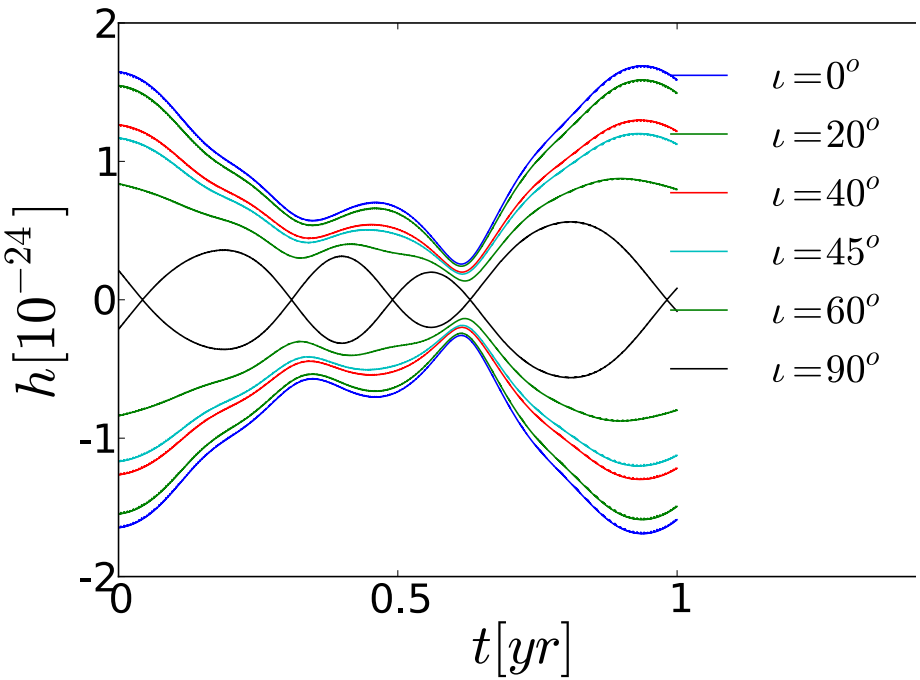
$$T_{\rm obs} = 2 \text{ years}$$
$$S/N = 11$$
$$\iota = 43^\circ$$

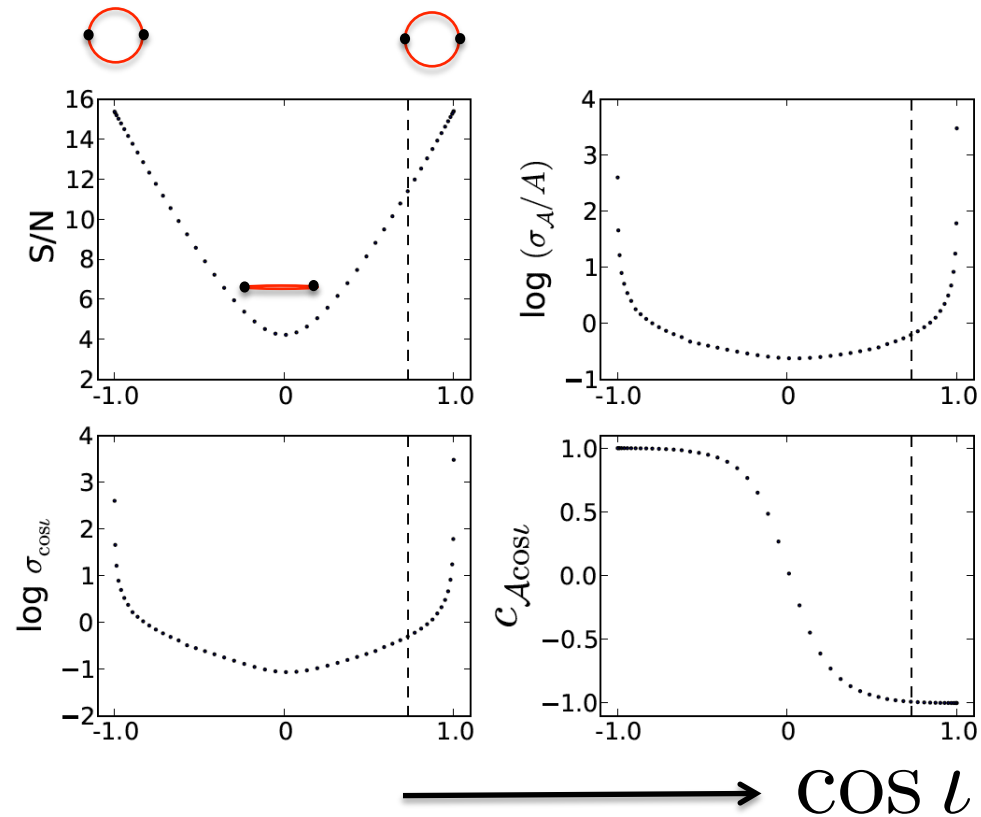
$$\sigma_\iota[\text{GW}] = 49^\circ$$
$$\sigma_\iota[\text{EM}] = 2^\circ$$

Roelofs et al 2007

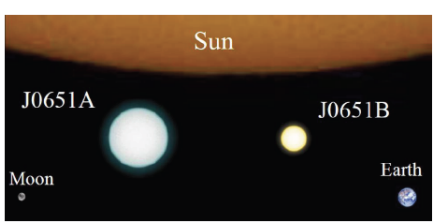
$$\sigma_{\mathcal{A}}[\text{GW}] = 1.08 \times 10^{-22}$$
$$\sigma_{\mathcal{A}}[\text{EM}] = 0.16 \times 10^{-22}$$

as a function of inclination – AMCVn





0.25 0.55 $M_\odot$



12 min

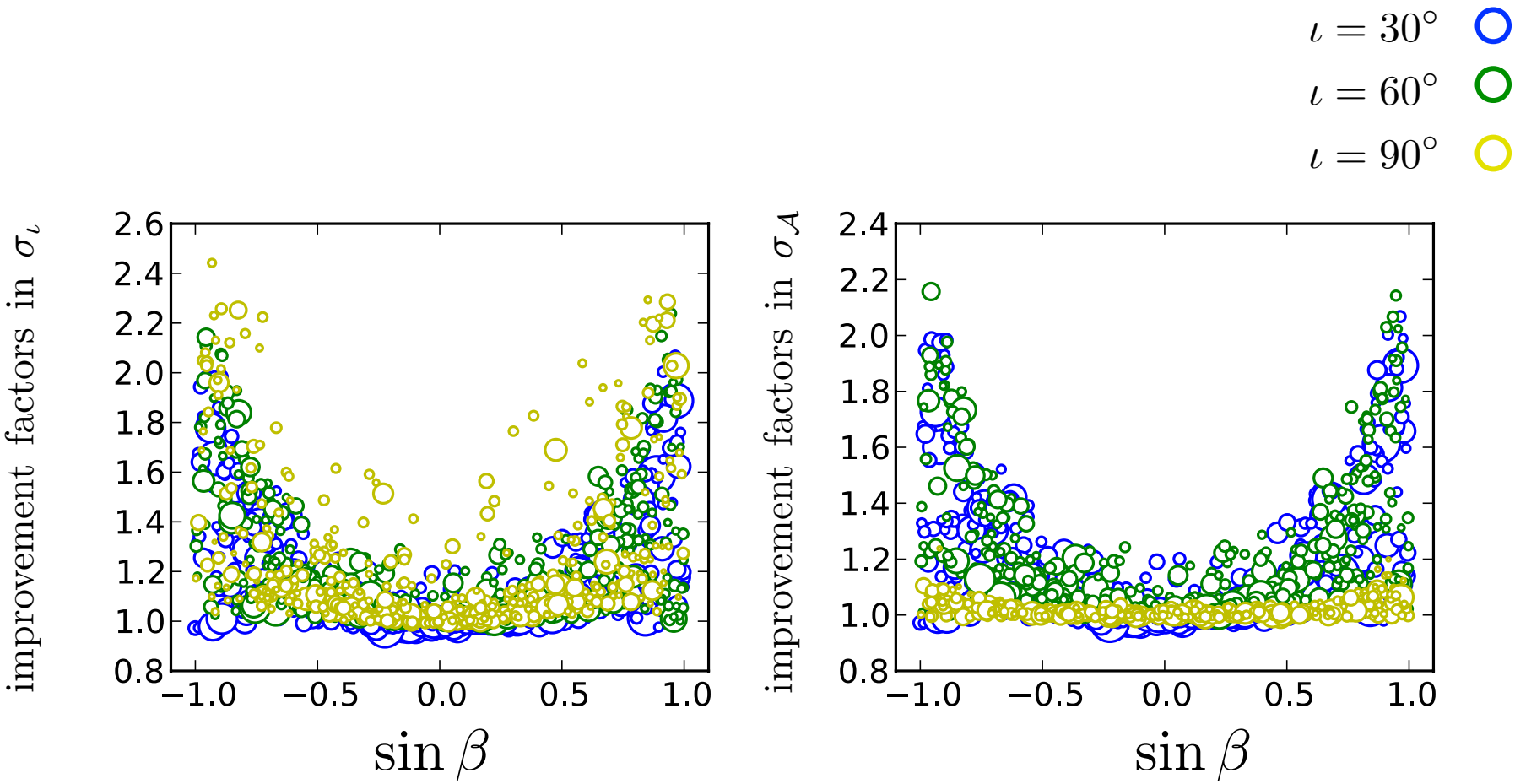
$$\iota \sim 89^\circ$$

$$S/N \sim 10 \rightarrow \sigma_\iota \sim 2^\circ$$

→ Finding **eclipsers**

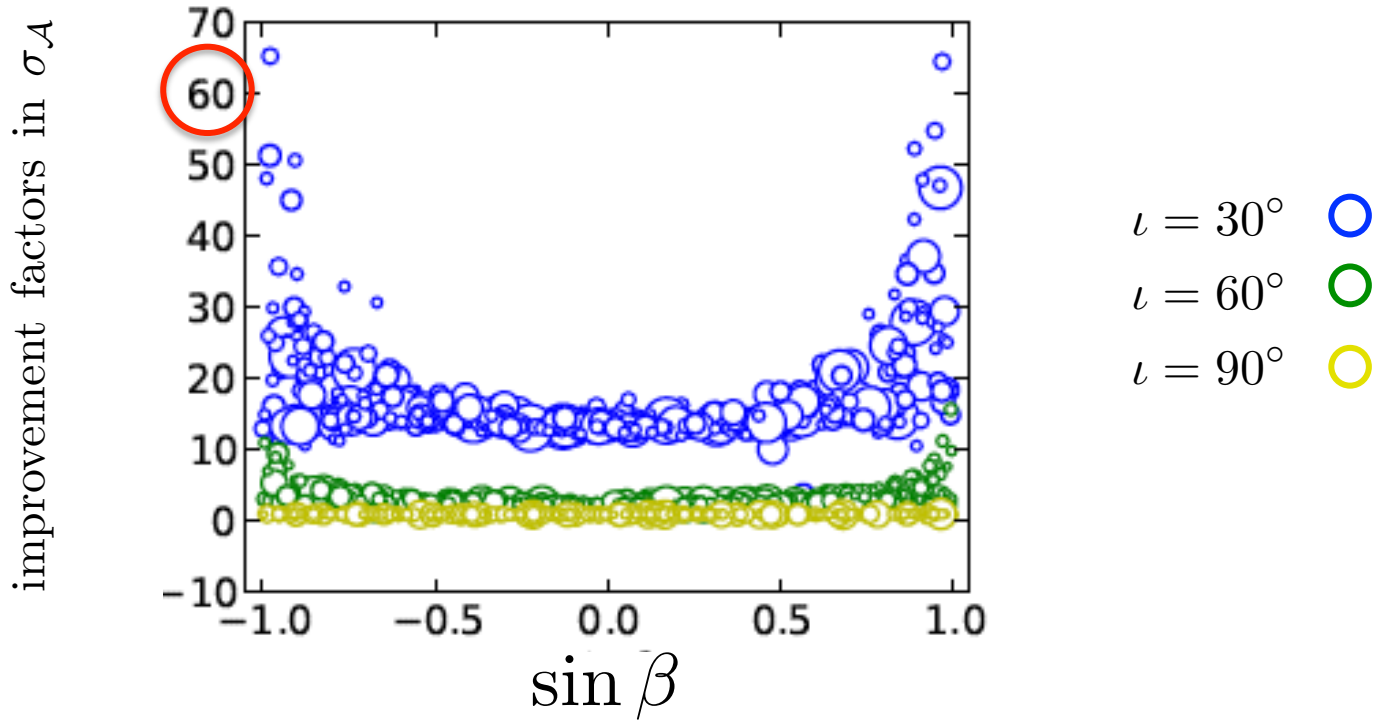
Other parameters in the **GW-EM** synergy

prior knowledge of **sky position**



Knowing sky position improves

prior knowledge of **sky position & inclination**

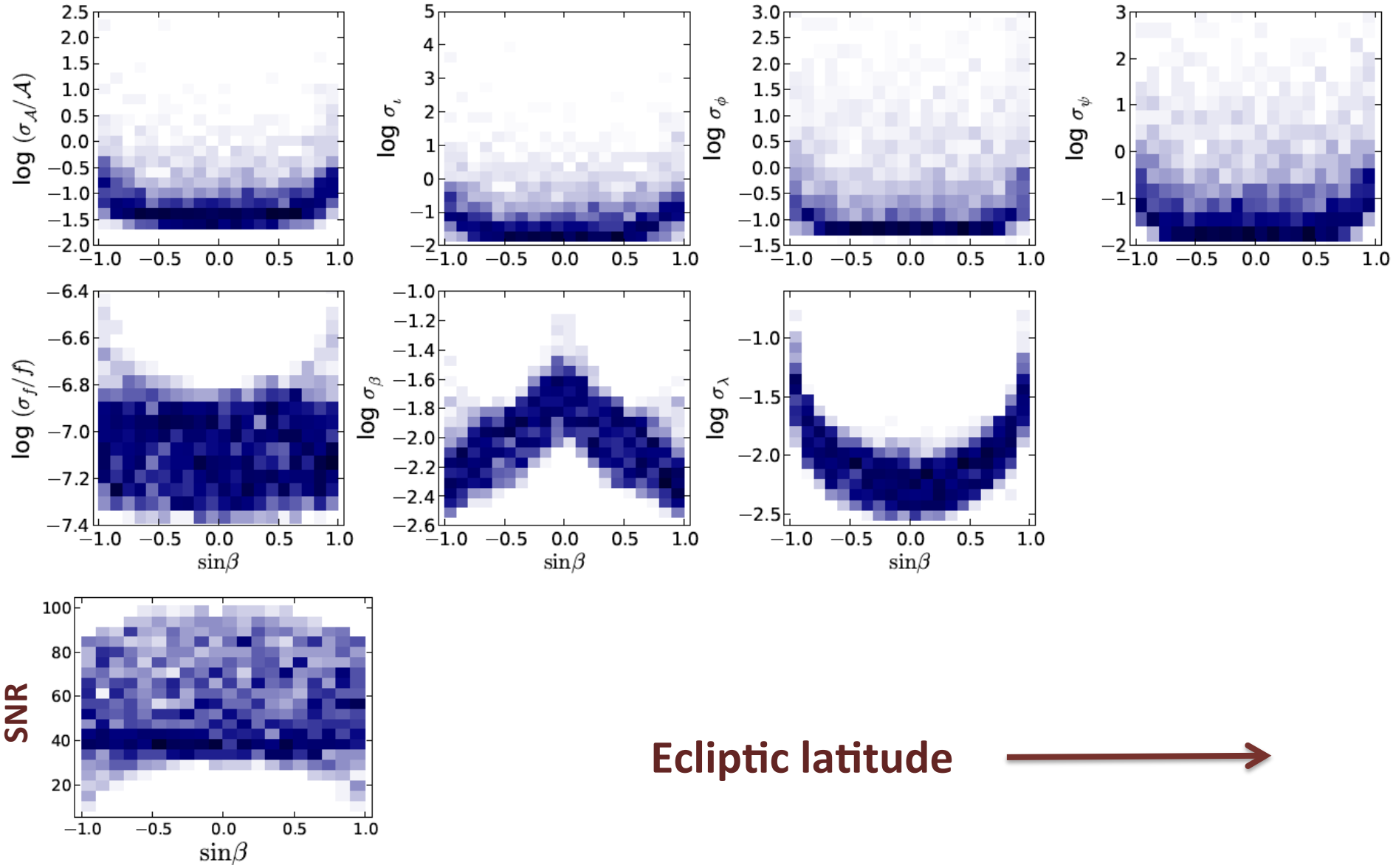


Knowing sky position **& inclination improves even more!**

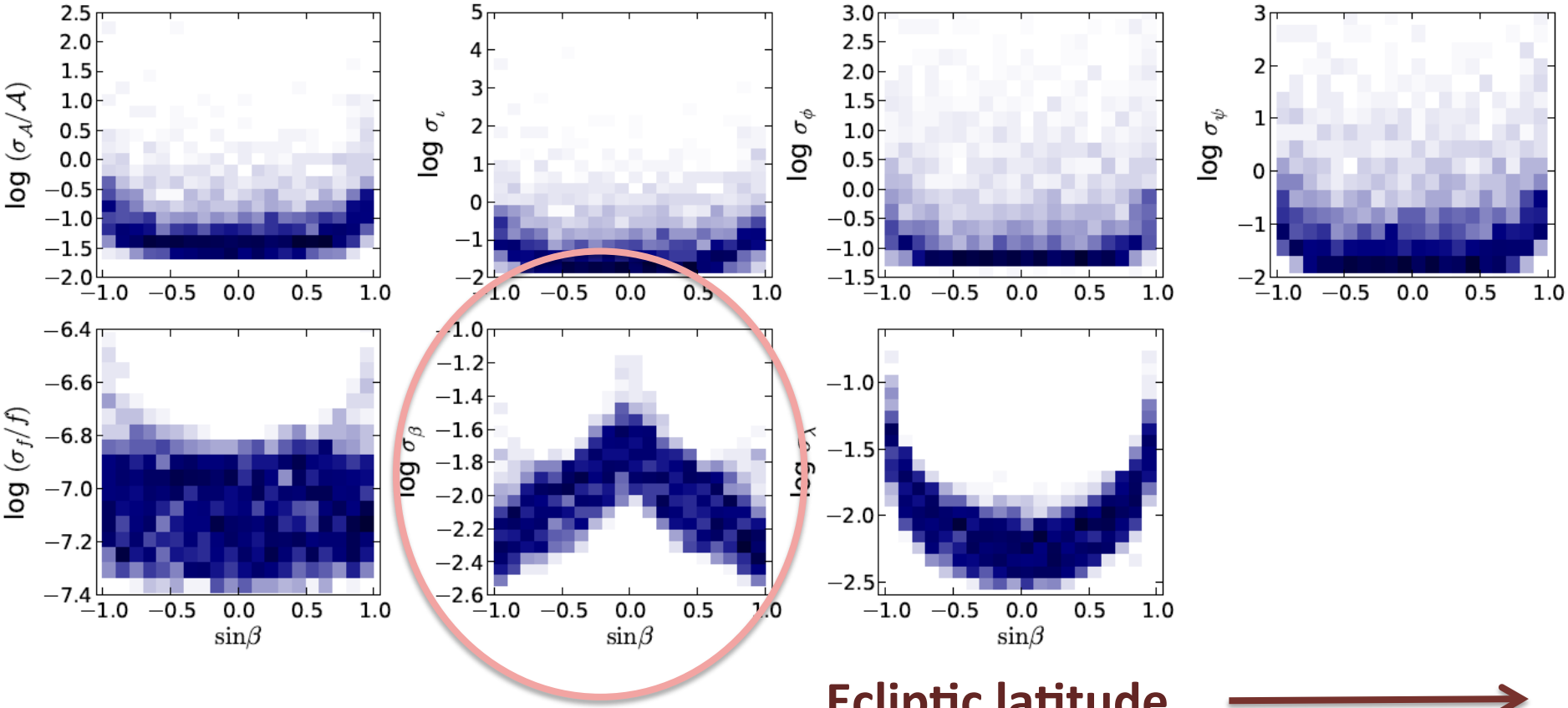
influence of the **orientation parameters**

inclination	strongest effect	ι
latitude	effects?	β
longitude		λ
polarization		ψ

Influence of ecliptic latitude



Influence of ecliptic latitude

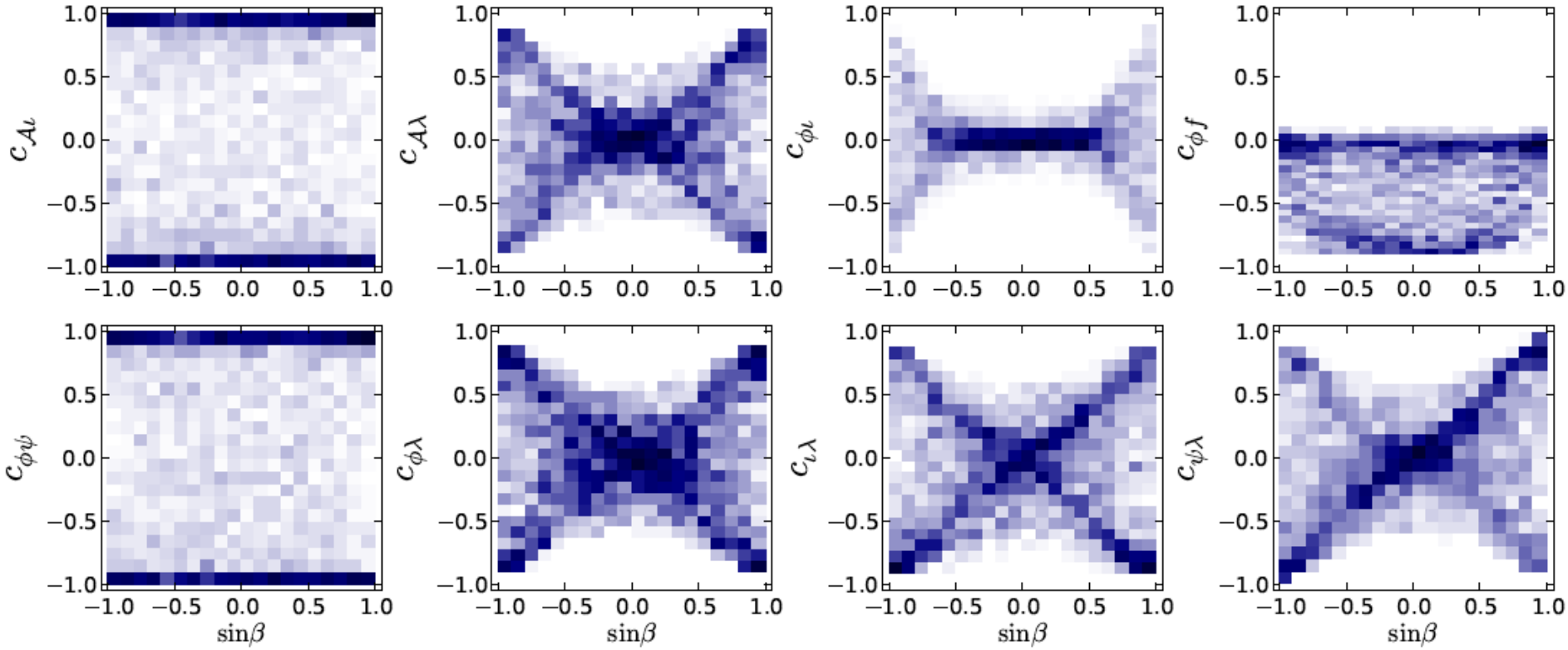


Ecliptic latitude →

$$\Phi_{\rm DM} \propto \cos\beta \qquad \frac{\partial \Phi_{\rm DM}}{\partial \beta} \propto \sin\beta$$

Cornish, Larson 2003

The **Strong** Correlations



Ecliptic latitude →

Putting everything together

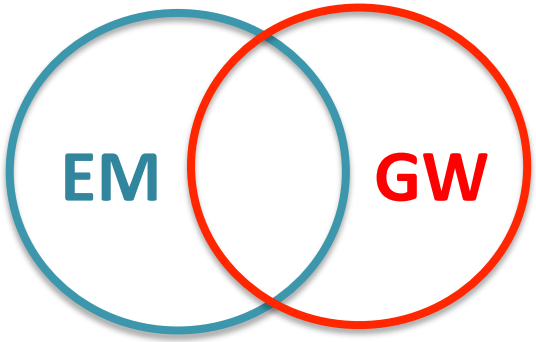
EM ← **Inclination**
Sky position → **GW**

m_i

$d[\mathrm{kpc}]$

$K_1[\mathrm{km/s}]$

$$\sin\iota \, \frac{m_2}{(m_1+m_2)^{2/3}} \left(\frac{2\pi\, G}{P_{\mathrm{orb}}}\right)^{1/3}$$



$$\mathcal{A} = \frac{2(G\,\mathcal{M}_c)^{5/3}}{c^4 d}\,(\pi f)^{2/3}$$

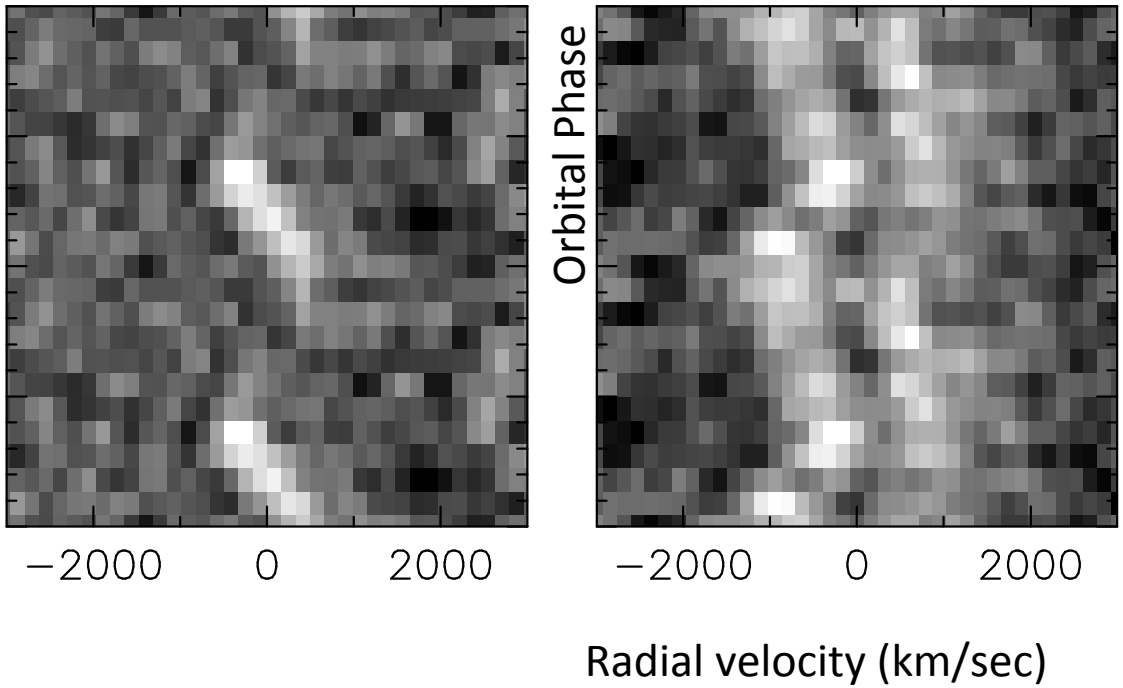
The EM measurements

I. Single line spectroscopic binary m_1, K_1

II. Double line spectroscopic binary

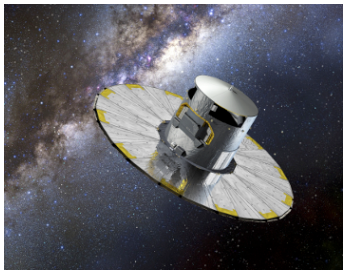
$m_{1,2},\ K_{1,2}$

Roelofs et al. 2010



III. Distance d

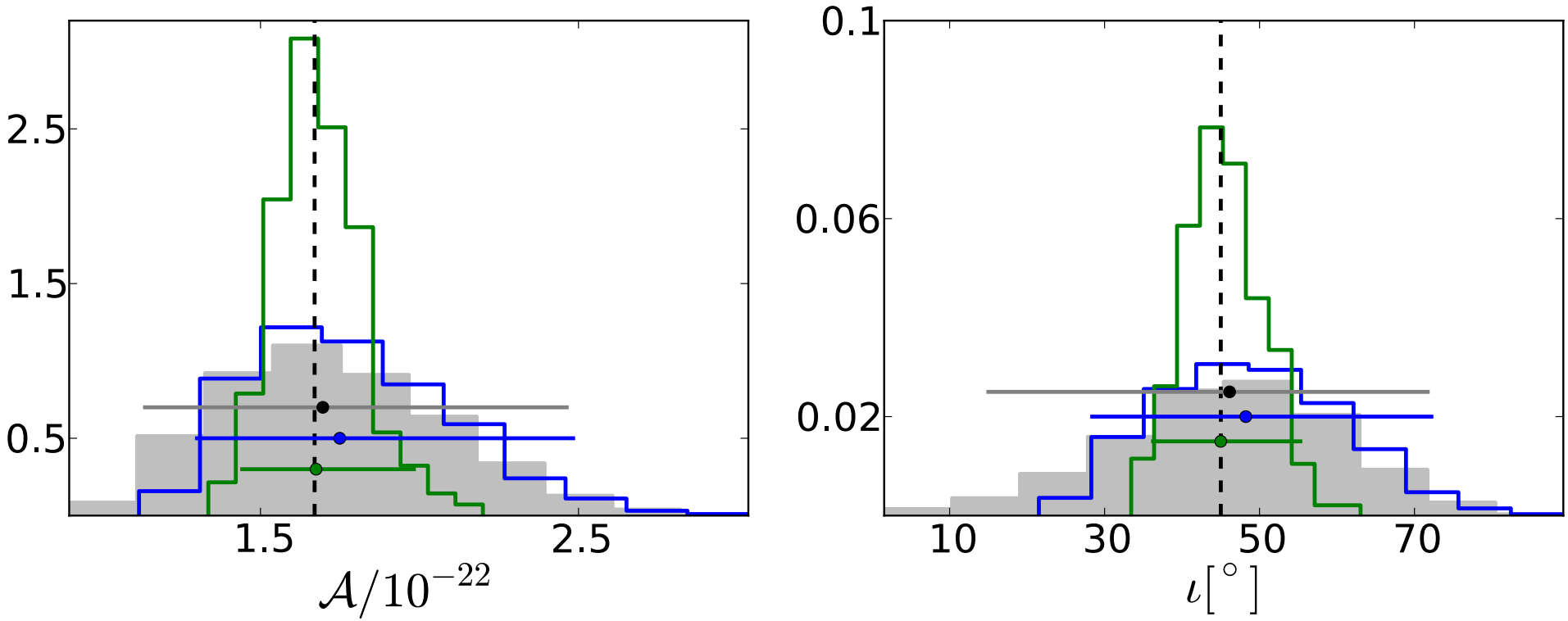
***Gaia* satellite**



ESA

GW($\mathcal{A}$, ι) + EM data – J0651

Case: Inclination = 45 degrees

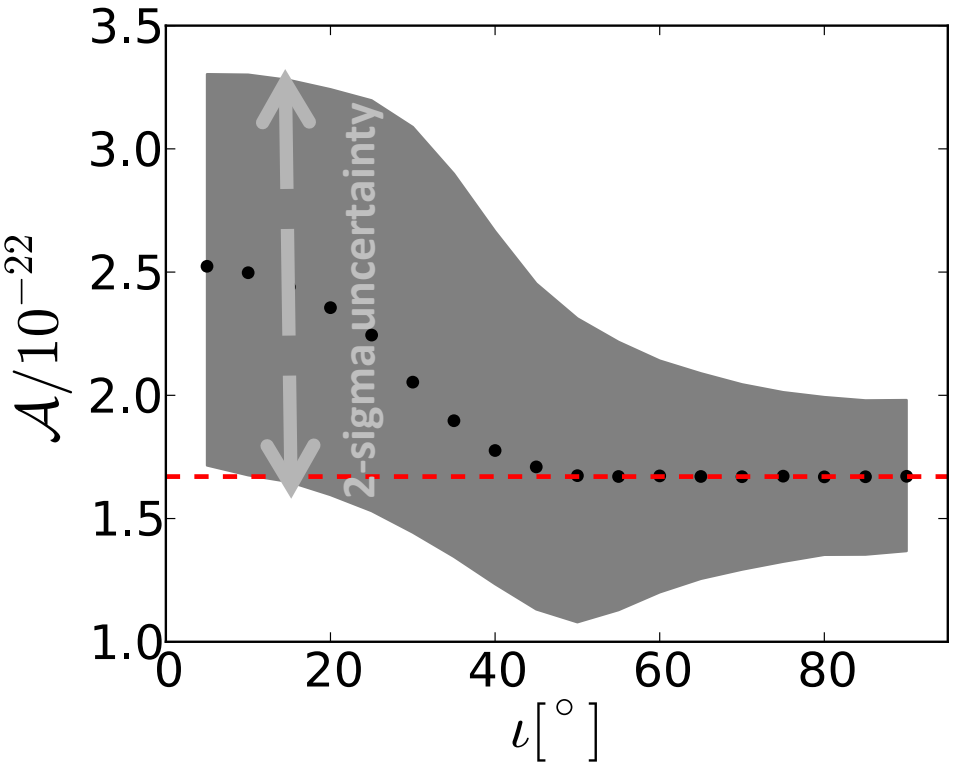


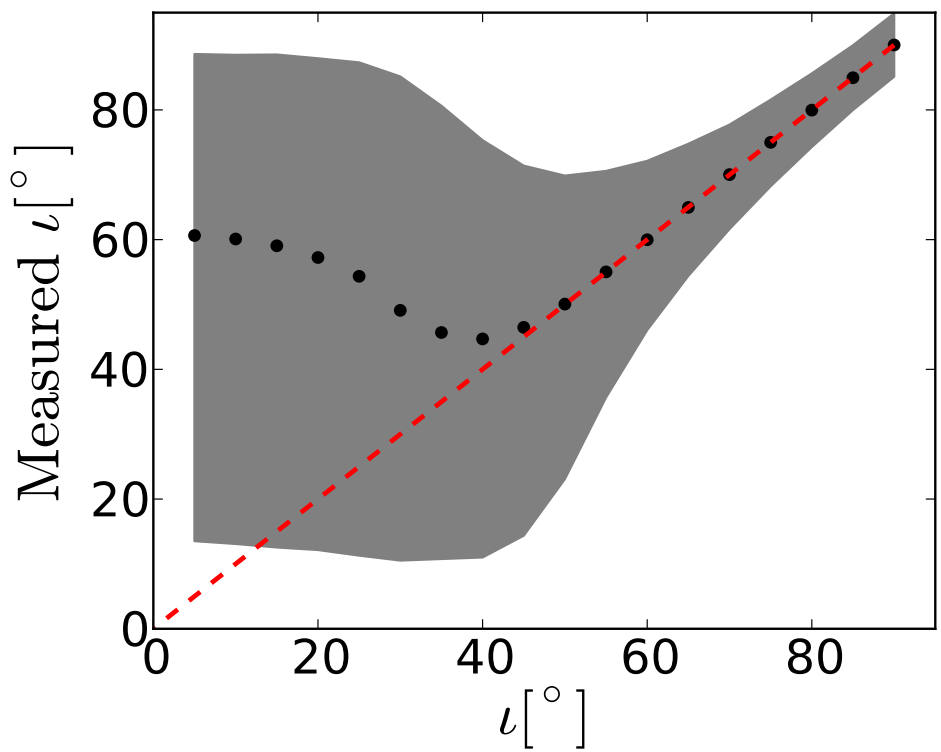
Only GW

GW + single-line

GW + single-line+dist

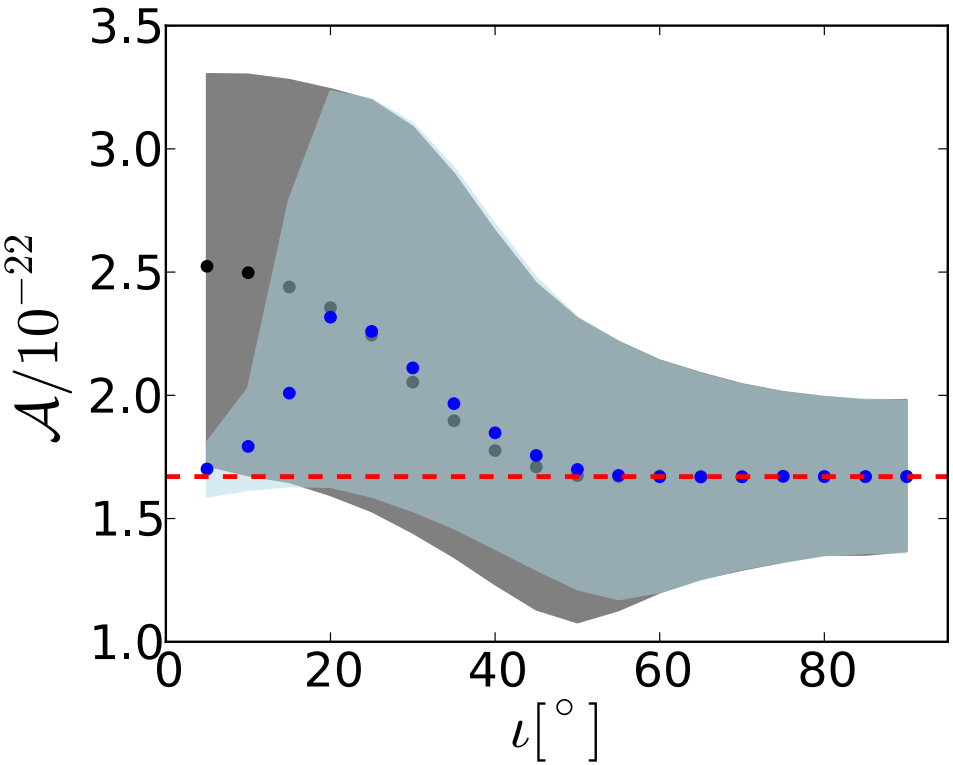
GW($\mathcal{A}$, ι) + EM data – J0651

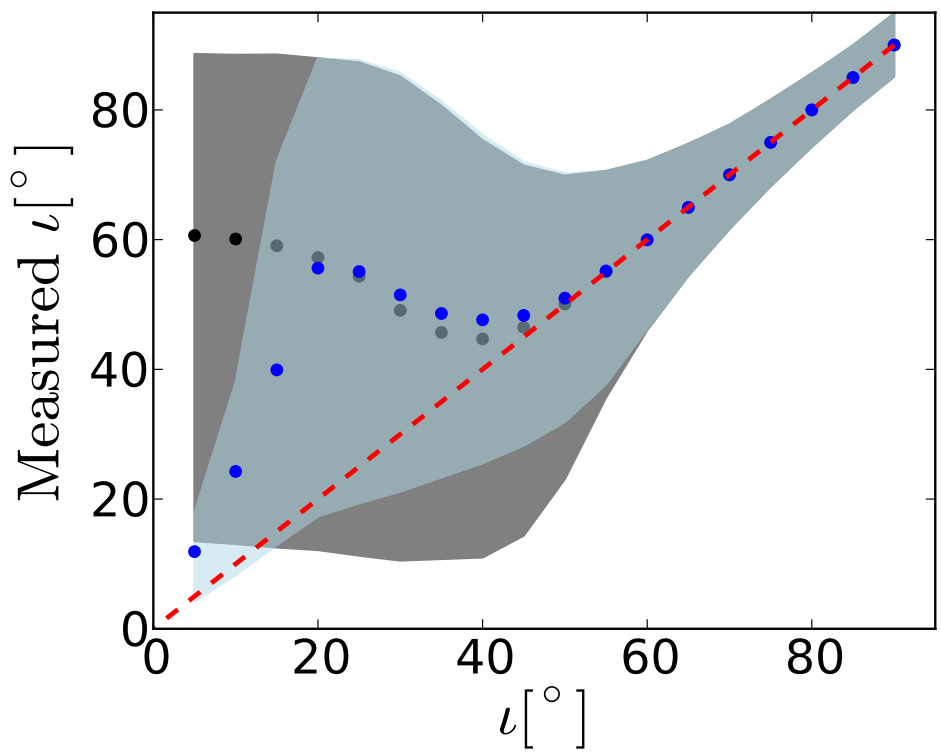




Only GW

GW($\mathcal{A}$, ι) + EM data – J0651

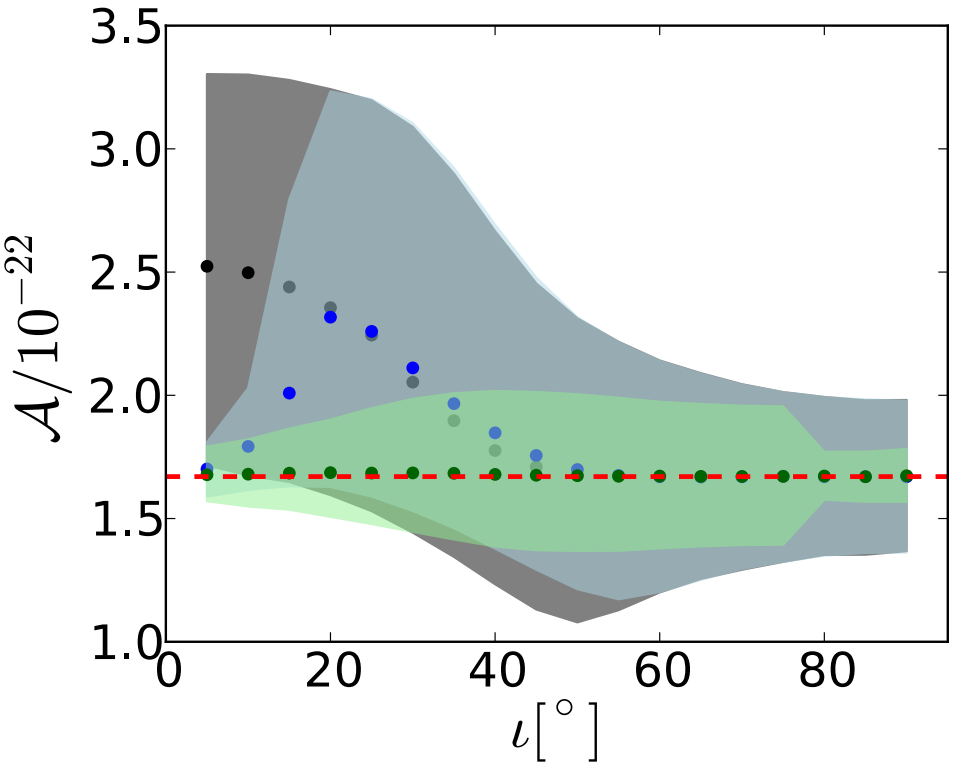


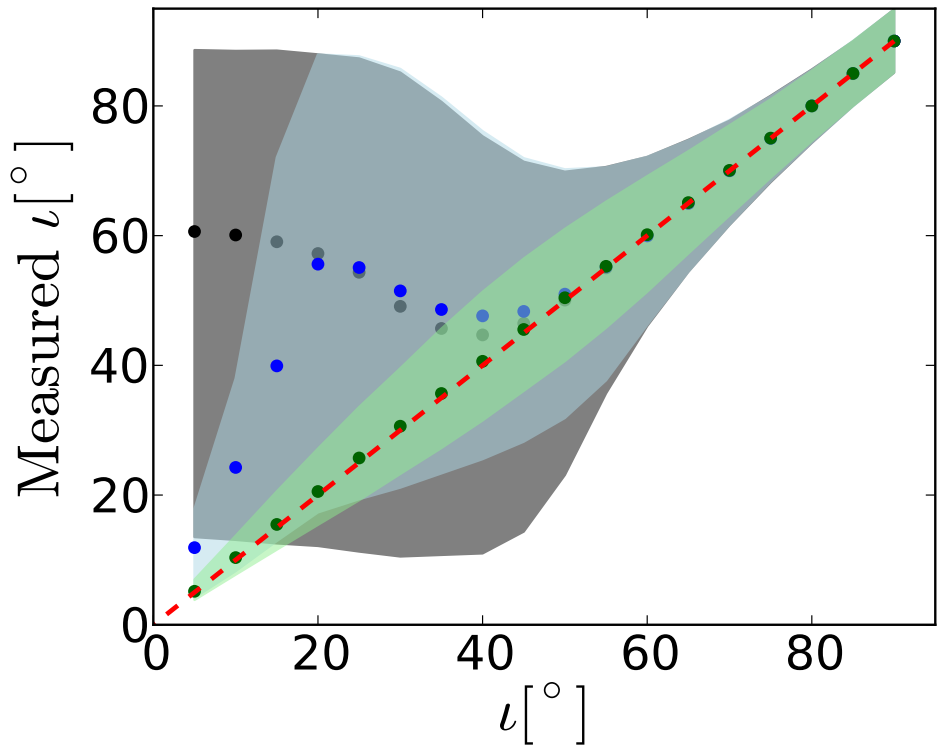


Only GW

GW + single-line

GW($\mathcal{A}$, ι) + EM data – J0651





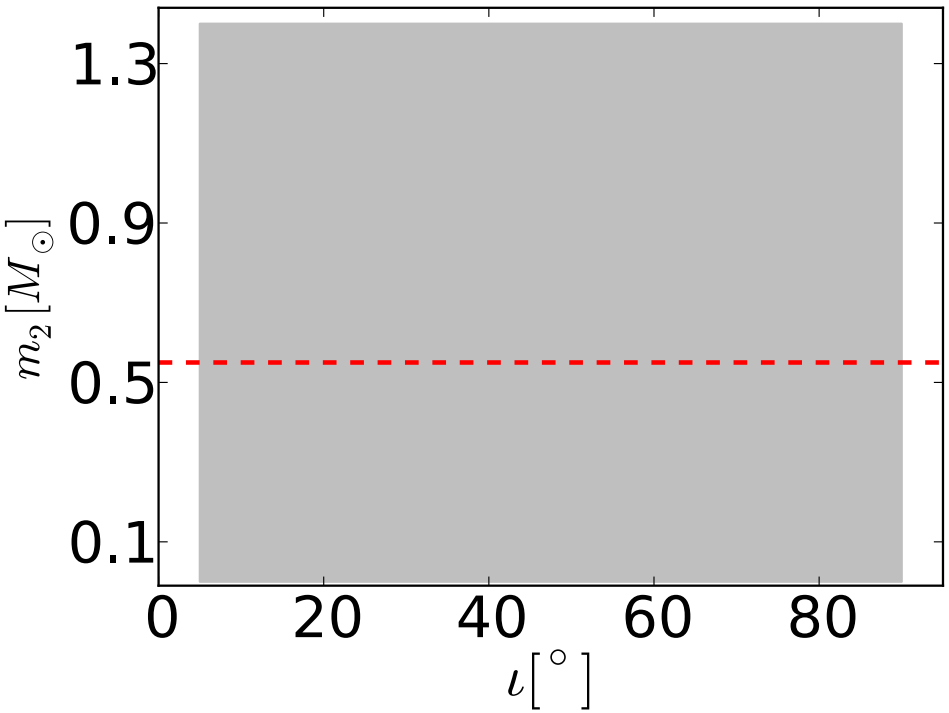
Only GW

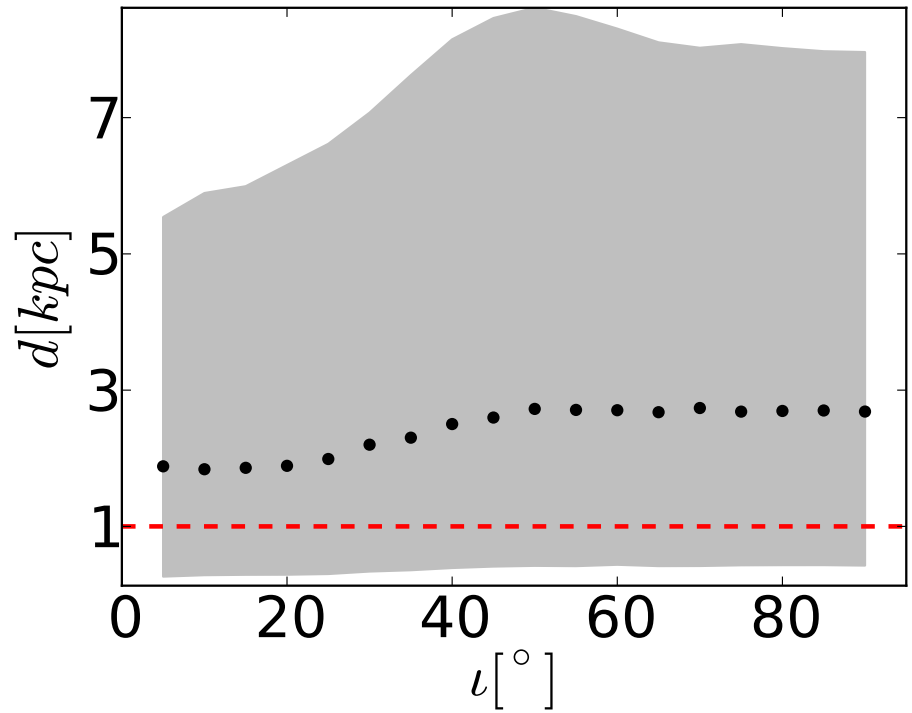
GW + single-line

GW + single-line+dist

GW($\mathcal{A}$, ι) + EM data – J0651

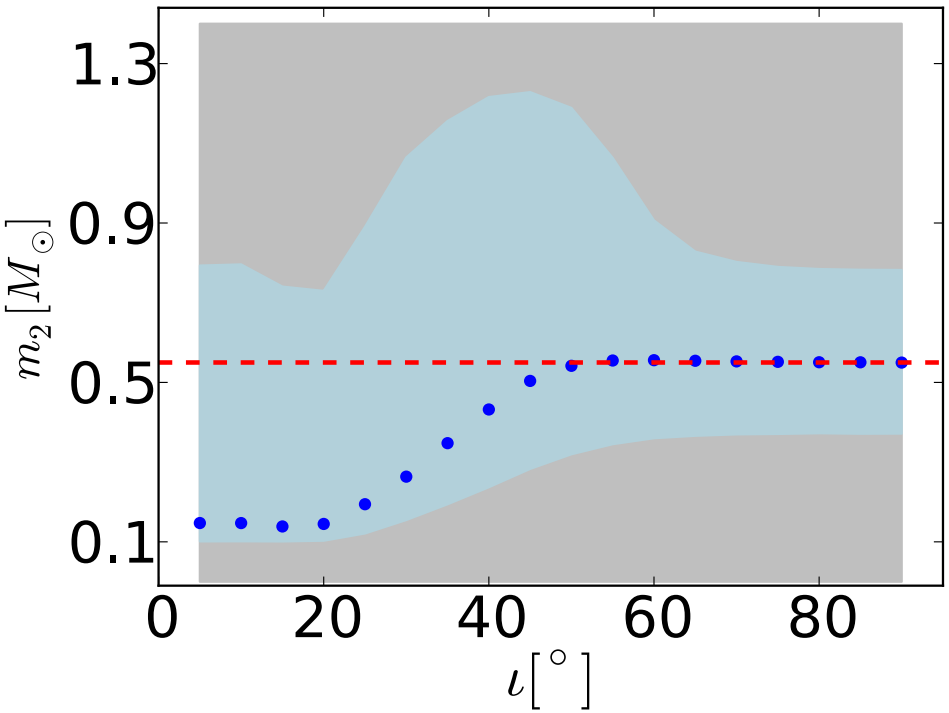
$$\mathcal{A} = \frac{2(G\,\mathcal{M}_c)^{5/3}}{c^4 d}\,(\pi f)^{2/3} \xrightarrow{m_1, m_2\ \epsilon[0.1, 1.4]M_\odot} d$$

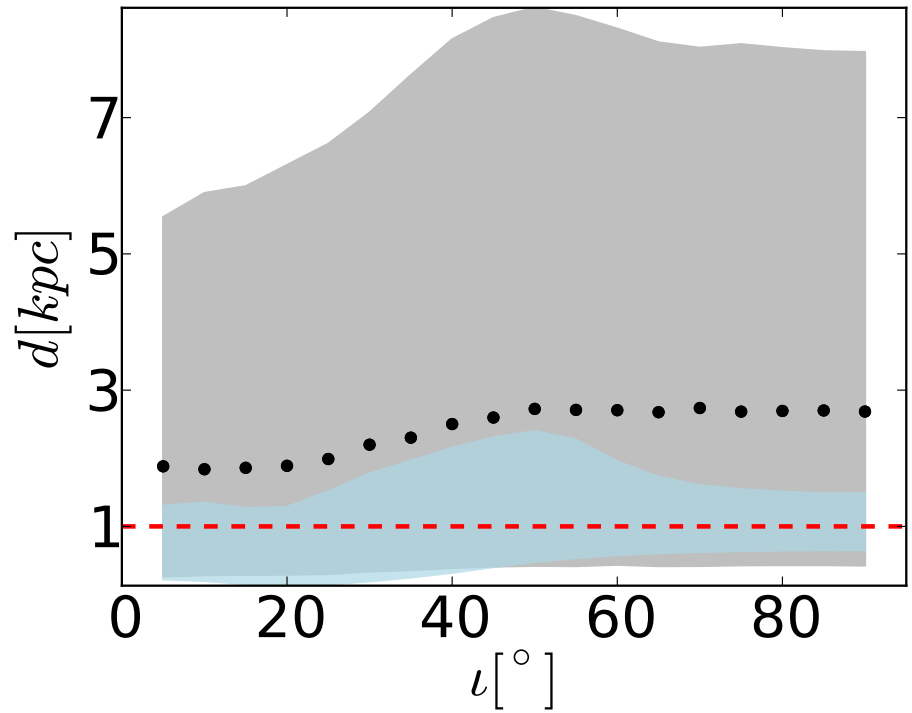




Only GW

GW($\mathcal{A}$, ι) + EM data – J0651

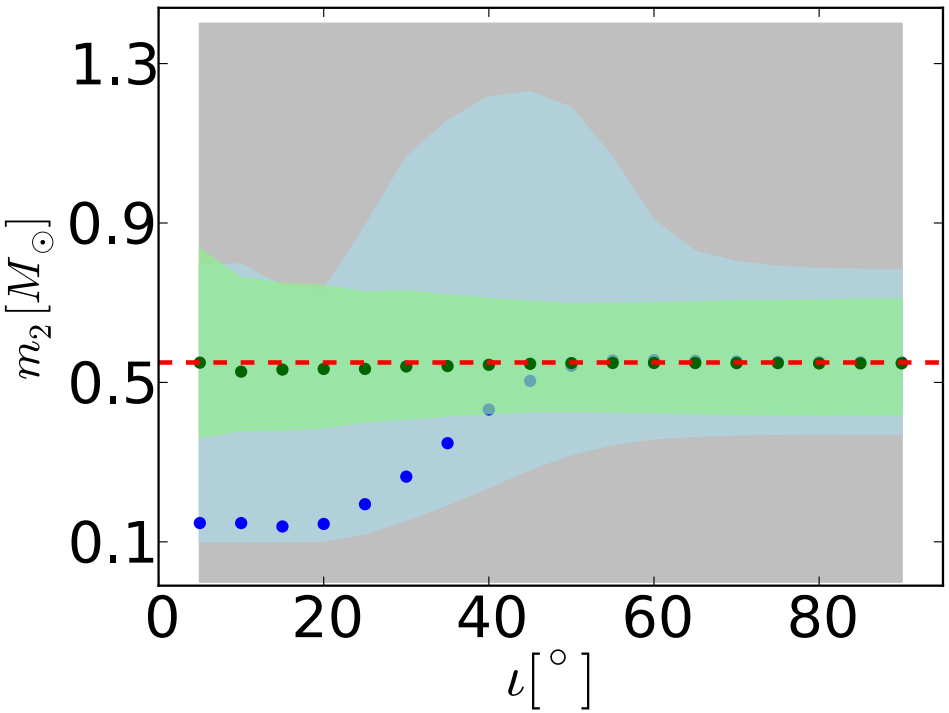


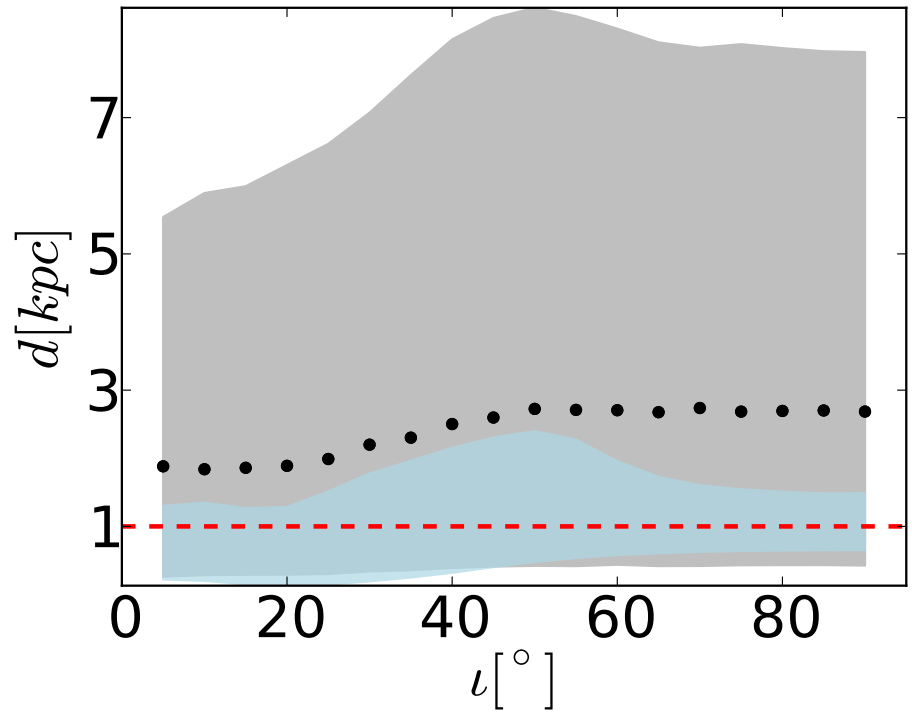


Only GW

GW + single-line

GW($\mathcal{A}$, ι) + EM data – J0651



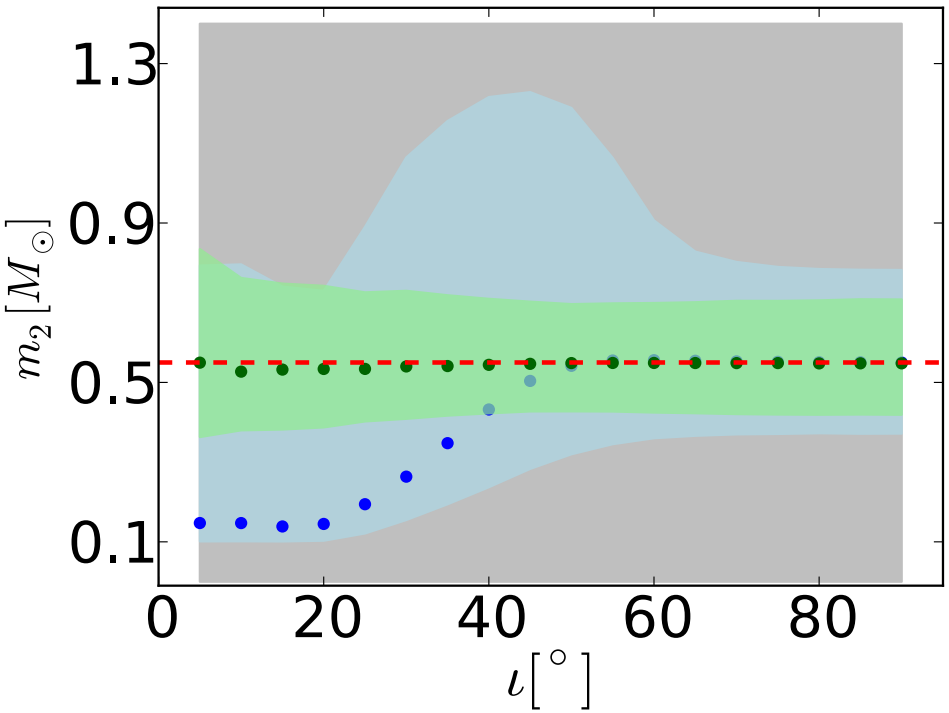


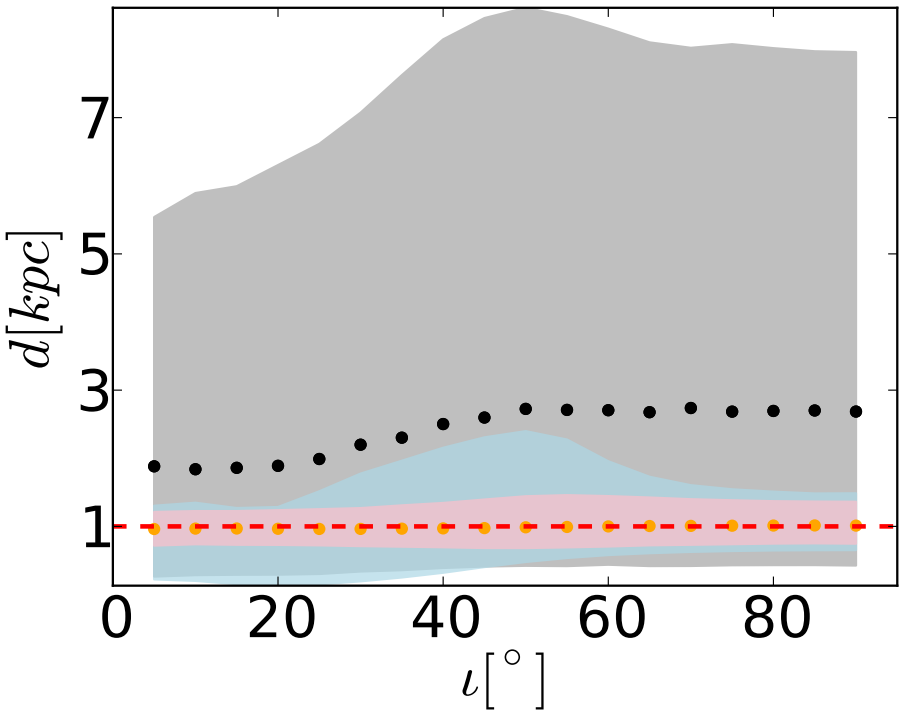
Only GW

GW + single-line

GW + single-line+dist

GW($\mathcal{A}$, ι) + EM data – J0651





Only GW
GW + single-line
GW + single-line+dist
GW + double-line

Including $\dot{f}$ $\ddot{f}$

Most → monochromatic binaries

What about chirping high-f sources?

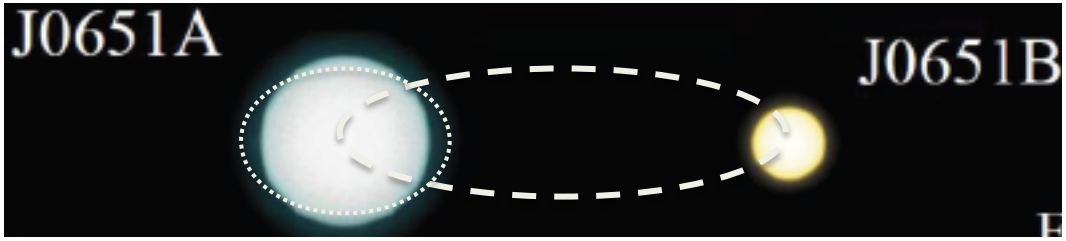
Will we have enough precision to do tidal astrophysics for eLISA binaries?

Tidal parameters

$$\dot{f}_{\rm total} = \dot{f}_{\rm GW} + \dot{f}_{\rm tide}$$

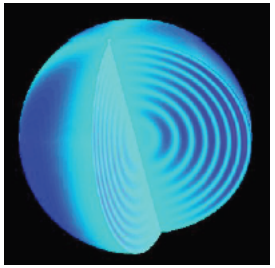
~ 5% e.g Benacquista 2012

Static tide



+

Dynamic tide



e.g. Fuller & Lai 2012
Burkart et al. 2013

GR prediction:

$$\left(\frac{\ddot{f}\,f}{\dot{f}^2}\right)_{\rm GW} := y = \frac{11}{3}$$

Webbink & Han 1998

EM/GW data accuracies

GW

Fisher studies → parameter uncertainties

EM

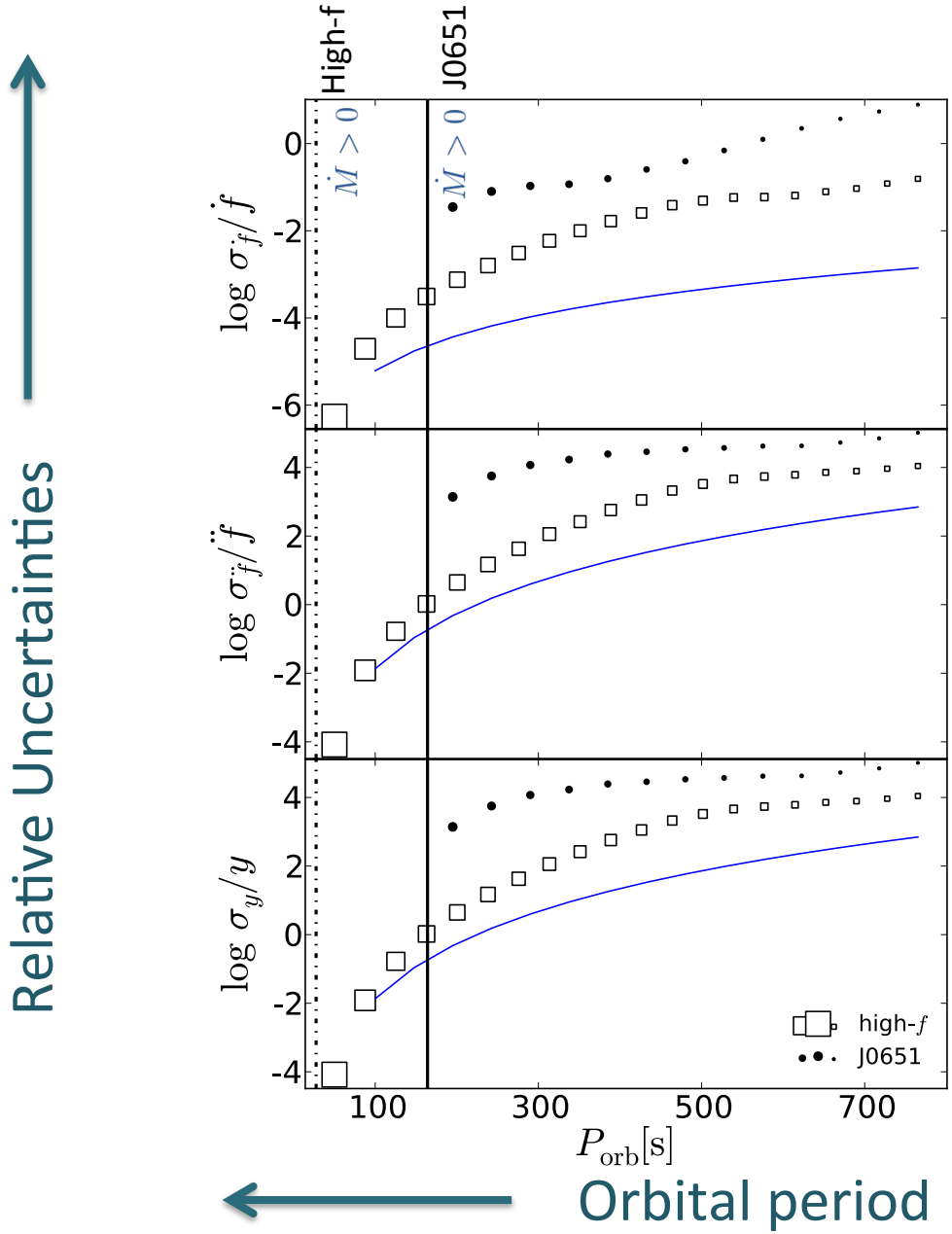
Taylor expansion of EM phase of the orbit,

$$\phi = \phi_0 \; + \; f\,(t - t_0) + \frac{\dot{f}}{2}\,(t - t_0)^2 \; + \; \frac{\ddot{f}}{6}\,(t - t_0)^3 \; + \; \ldots$$

Expectations:

$$\sigma_f \sim \frac{\sigma_\phi}{\mathrm{T_{obs}}} \quad ; \quad \sigma_{\dot{f}} \sim 2\frac{\sigma_\phi}{\mathrm{T_{obs}}^2} \quad ; \quad \sigma_{\ddot{f}} \sim 6\frac{\sigma_\phi}{\mathrm{T_{obs}}^3}$$

EM/GW data accuracies



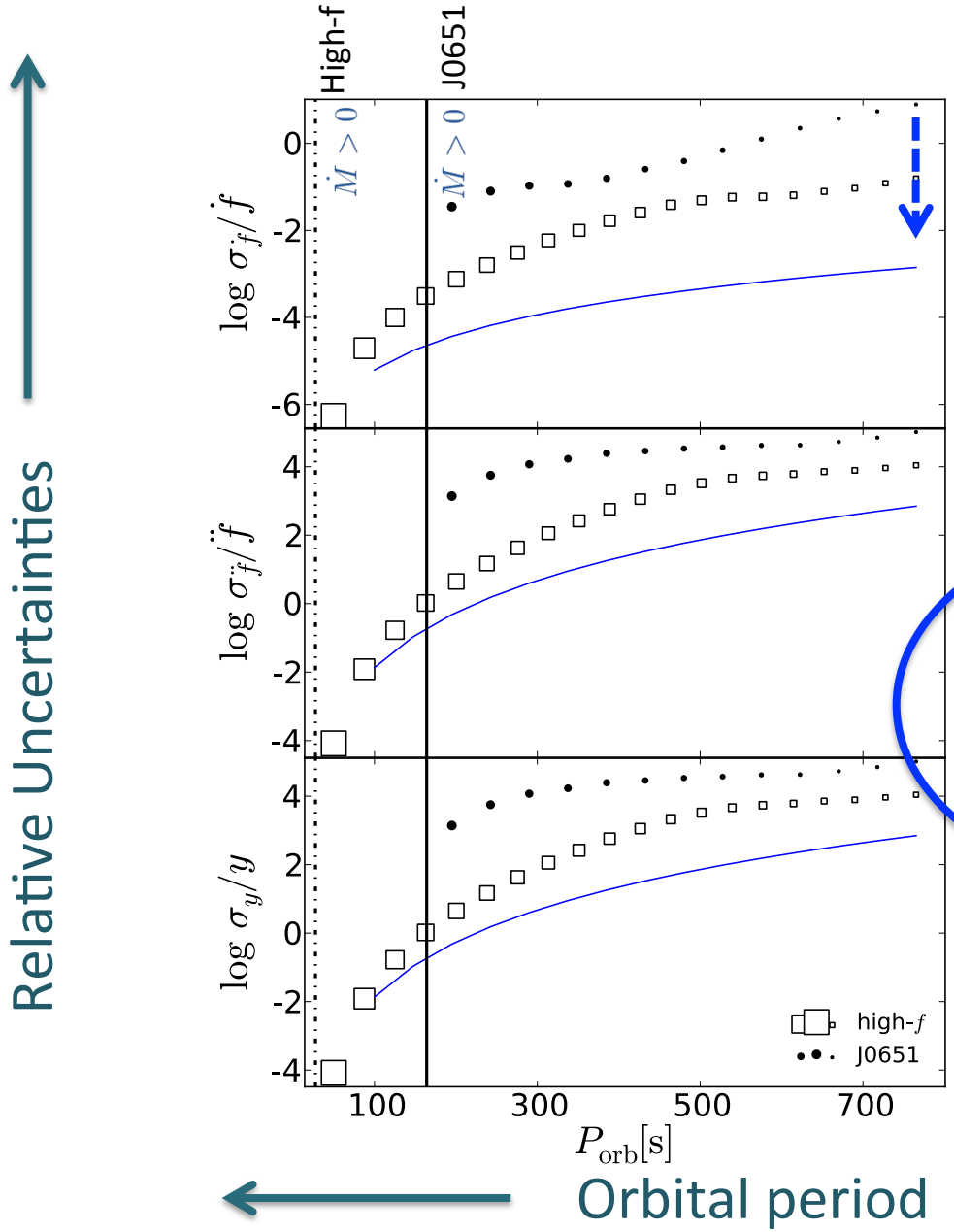
J0651 (**GW**)

High-f binary (**GW**)

J0651 (**EM; T_{obs} = 10 yrs**)

$$\left(\frac{\ddot{f}\,f}{\dot{f}^2}\right)_{\rm GW} := y = \frac{11}{3}$$

EM/GW data accuracies



J0651 (**GW**)

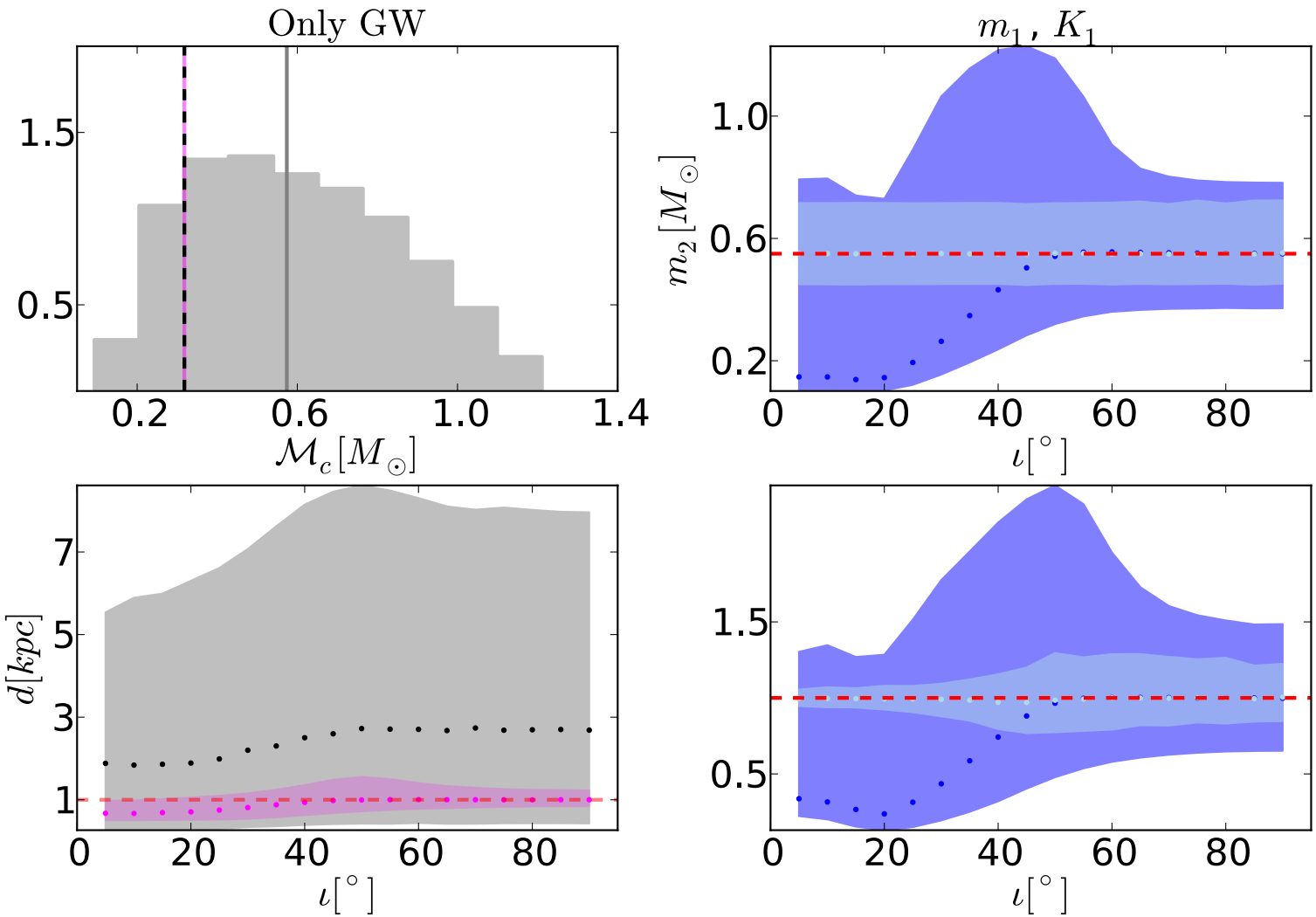
High-f binary (**GW**)

J0651 (**EM; T_{obs} = 10 yrs**)

EM accuracies win

$$\left(\frac{\ddot{f}\,f}{\dot{f}^2}\right)_{\rm GW} := y = \frac{11}{3}$$

Including $\dot{f}$ (from EM data)



Most important CONCLUSION

I am finishing my PhD thesis soon!

Work based on:

Shah et al 2012, 544, A&A
Shah et al 2013, 553, A&A
Shah & Nelemans, 2014, ApJ
Shah & Nelemans, ApJ (subm.)

Conclusions

We find **useful correlations** between GW parameters of Galactic binaries

Knowing **sky position, inclination and radial velocity** helps:

- Sky position (EM) → factors of 2
- Sky position + inclination → factors of 60
- Radial velocity → secondary mass and distance

Measuring **tidal deviations** in typical WD detached binaries may not be possible

Work based on:

Shah et al 2012, 544, A&A
Shah et al 2013, 553, A&A
Shah & Nelemans, 2014, ApJ
Shah & Nelemans, ApJ (subm.)