Introduction to The LIGO Project

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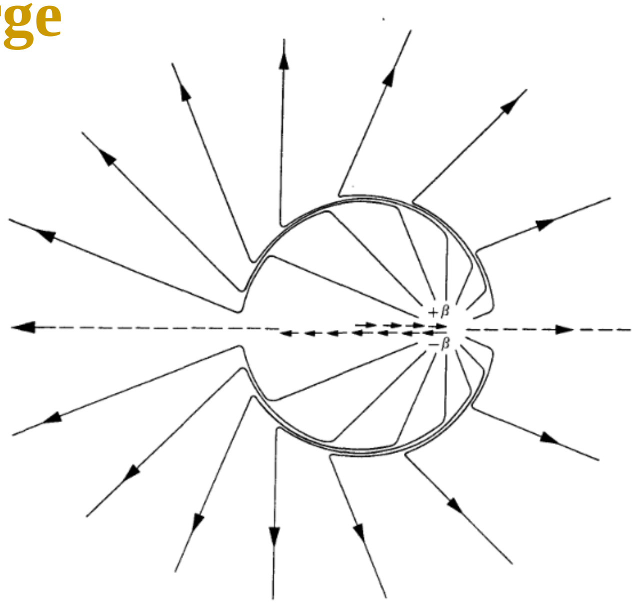
Classical Electrodynamics

ELECTRODYNAMICS

$$\Box A^{\alpha} = \frac{4\pi}{c} J^{\alpha}$$

Radiation from an Accelerating Charge



Classical Electrodynamics vs General Relativity

ELECTRODYNAMICS

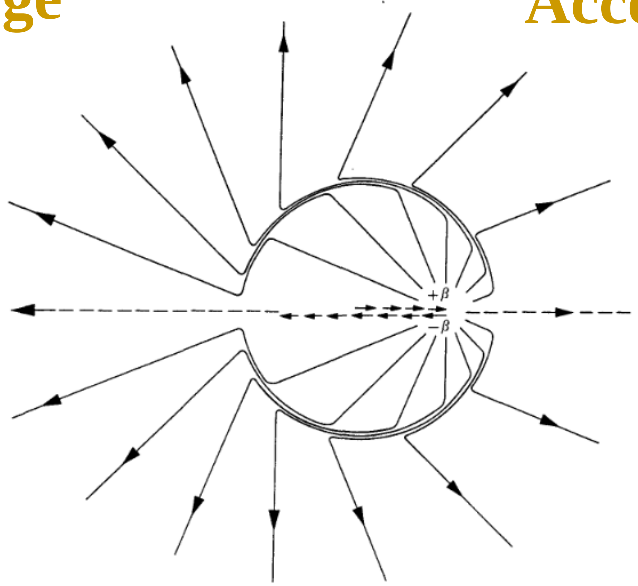
$$\Box A^{\alpha} = \frac{4\pi}{c} J^{\alpha}$$

Radiation from an Accelerating Charge

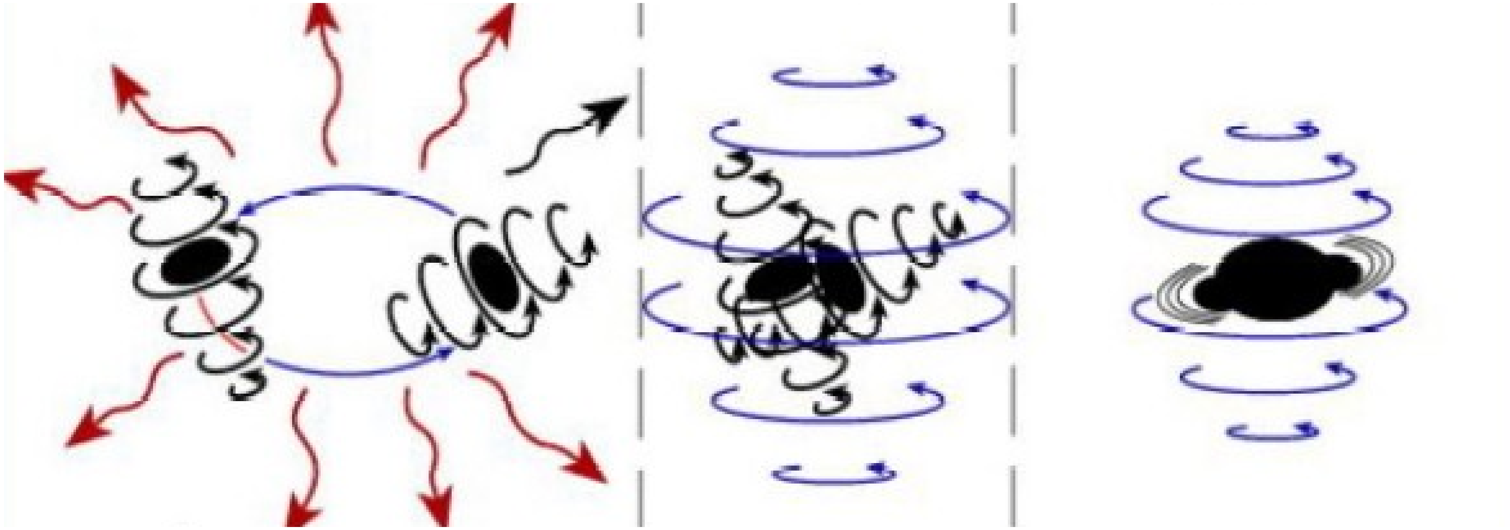
GENERAL RELATIVITY

$$\Box h_{\mu\nu} = 0$$

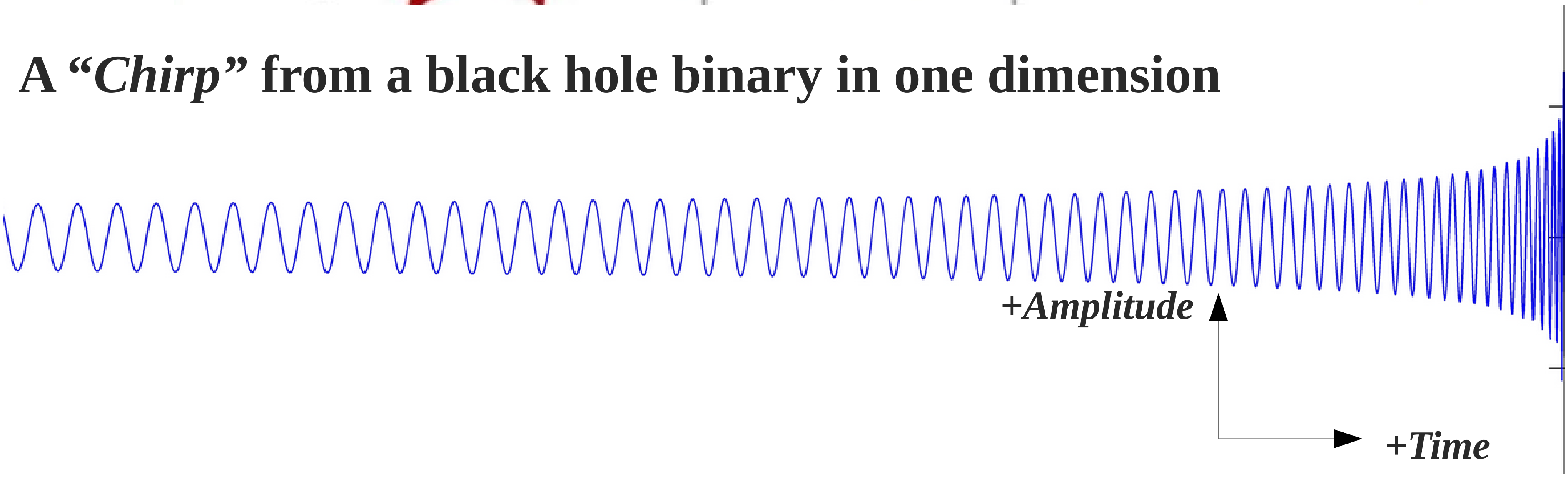
Radiation from an Accelerating Mass?



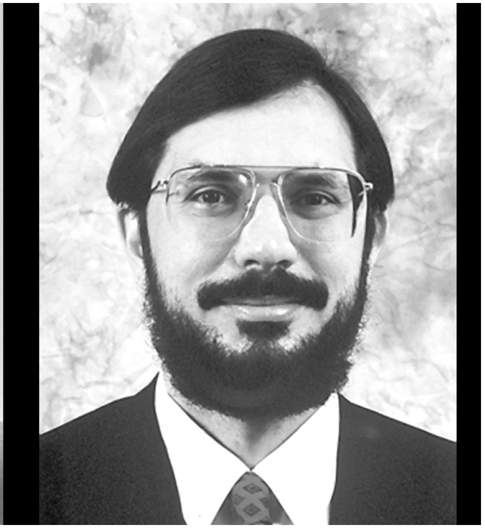
Chirps and Black Hole Binaries

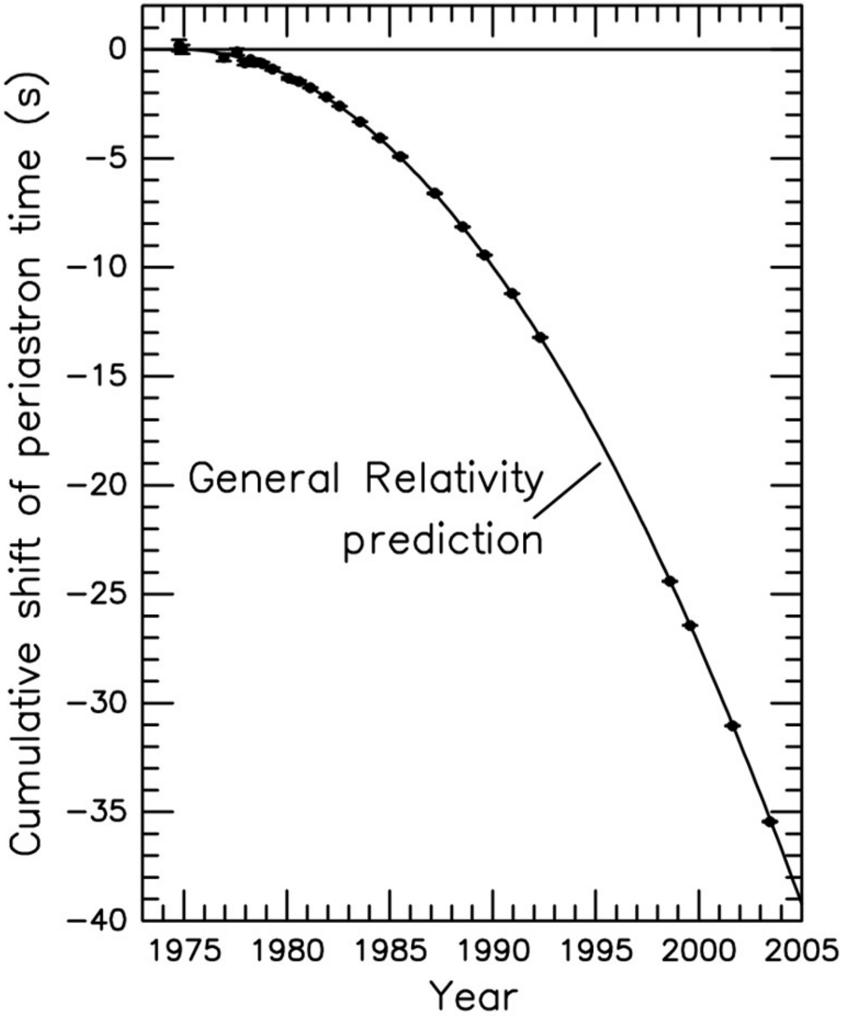


A "*Chirp*" from a black hole binary in one dimension



The Hulse-Taylor Binary Pulsar



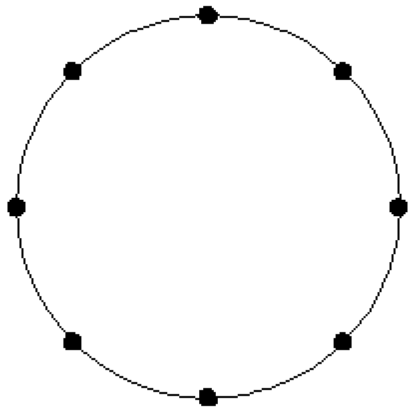


$$\frac{dP}{dt} = -\frac{96}{5}\pi 4^{\frac{1}{3}} \left(\frac{2\pi\mathcal{M}}{P}\right)^{\frac{5}{3}}$$

How does "*Gravitational Radiation*" Manifest Itself?

Waves go straight through matter.

Space between objects warped and stretched

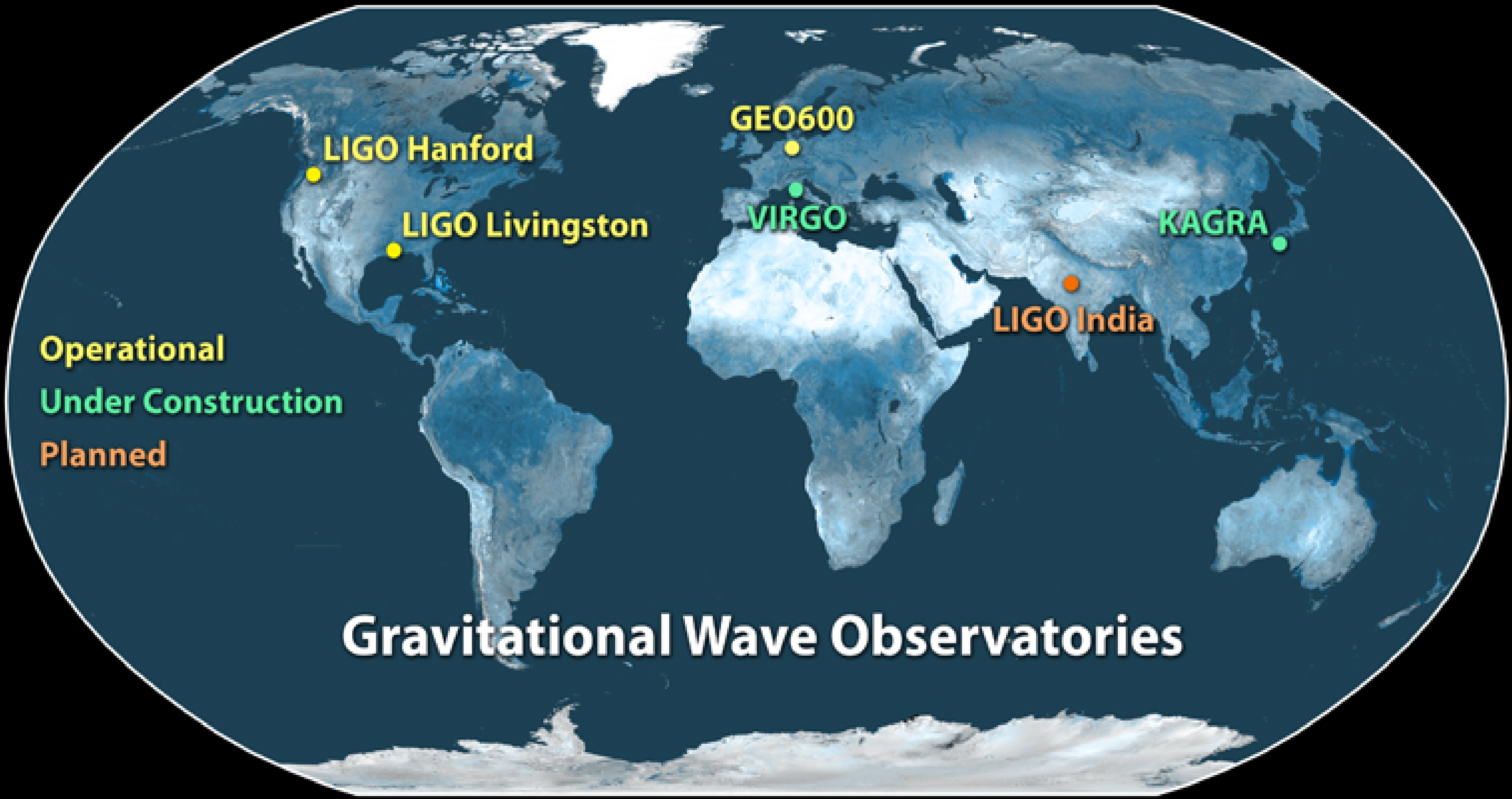


We need to measure the distances between things and look for changes and oscillations

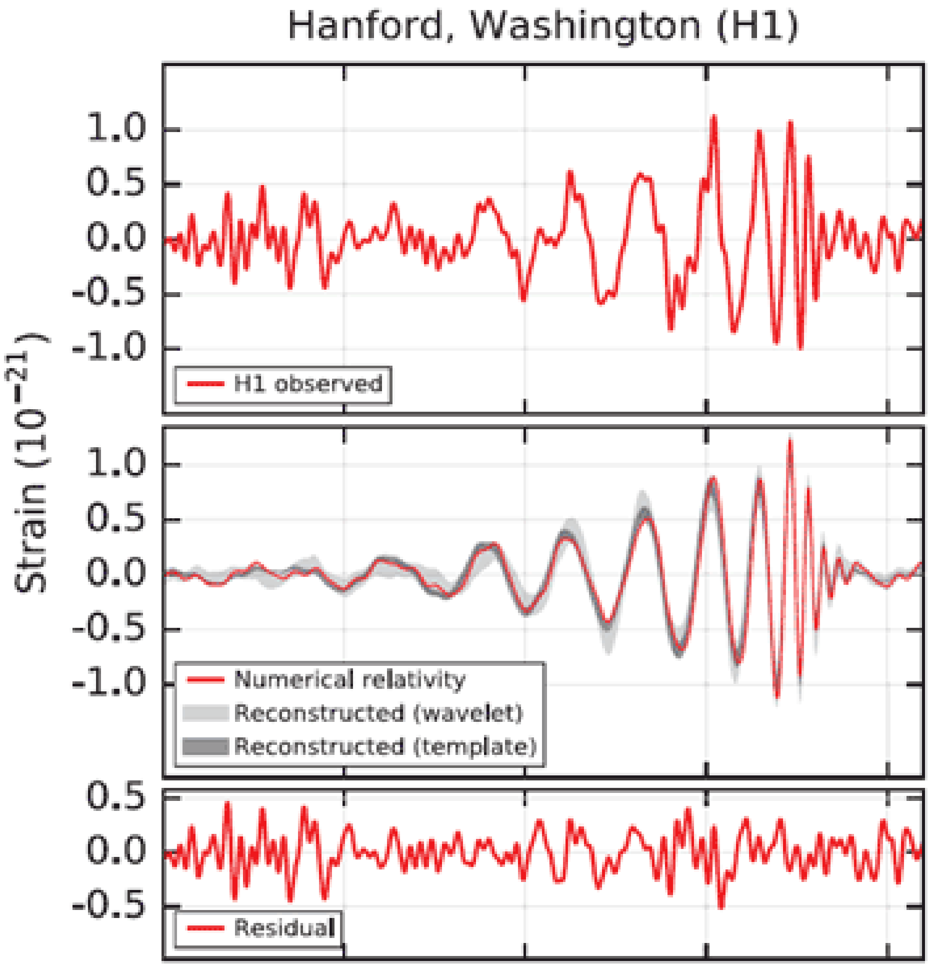
VERY tiny signal, ~ 10^{-23}

The LIGO Project

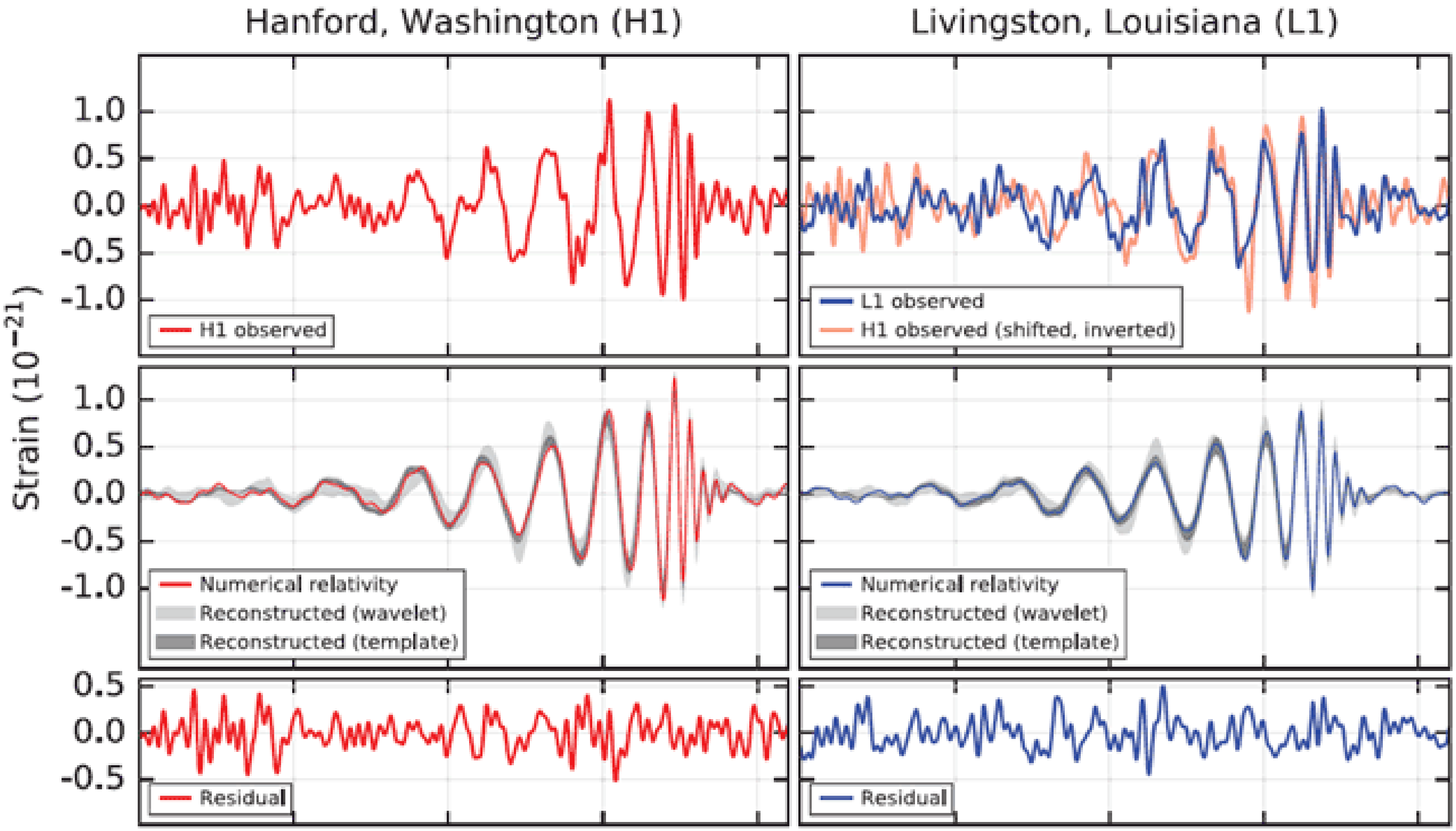
The LSC/VSC Detector Network



September 14th, 2015



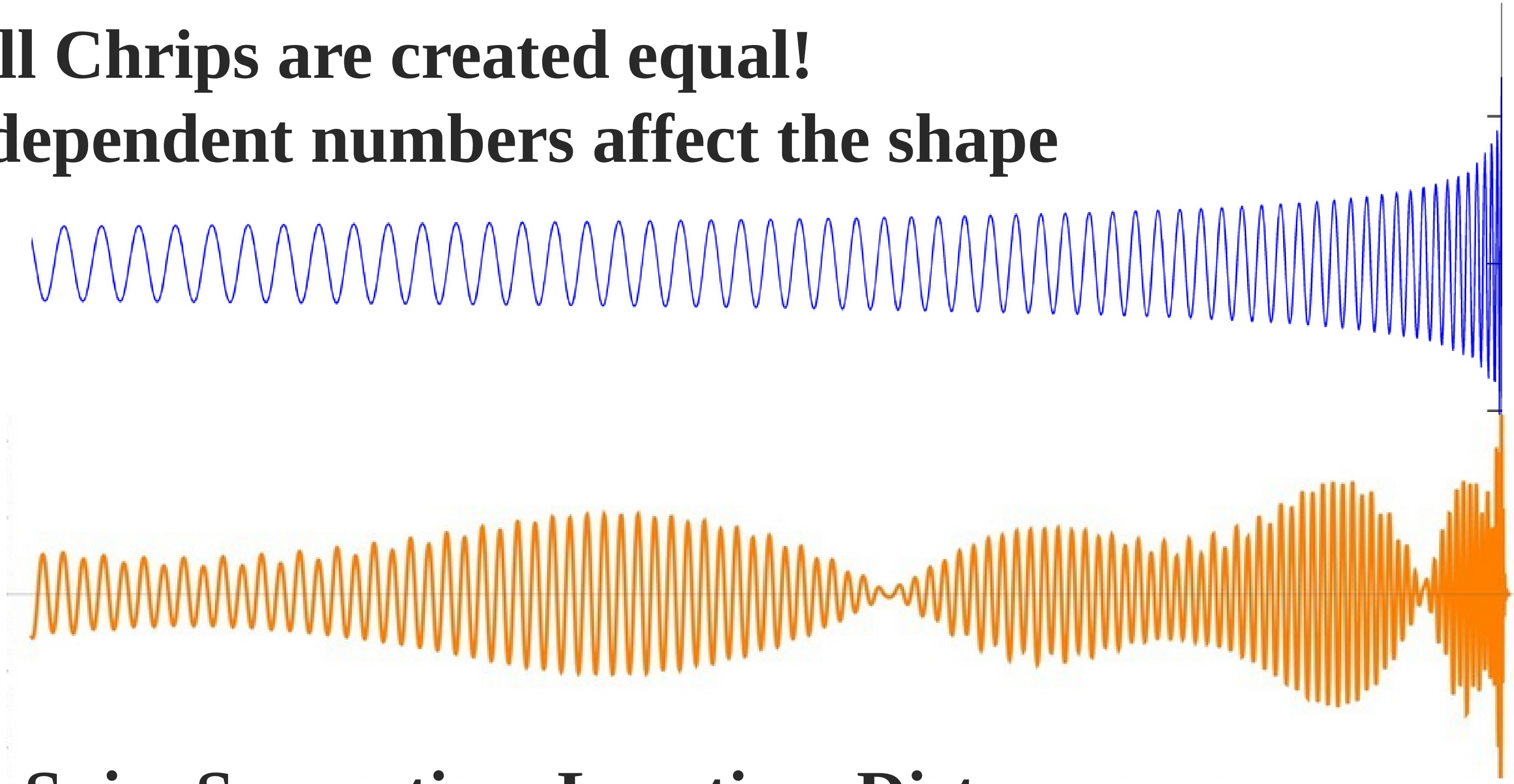
September 14th, 2015 – Success!



The Problem – Reverse Engineer the Parameters from the Signal

Not all Chrips are created equal!

15 independent numbers affect the shape

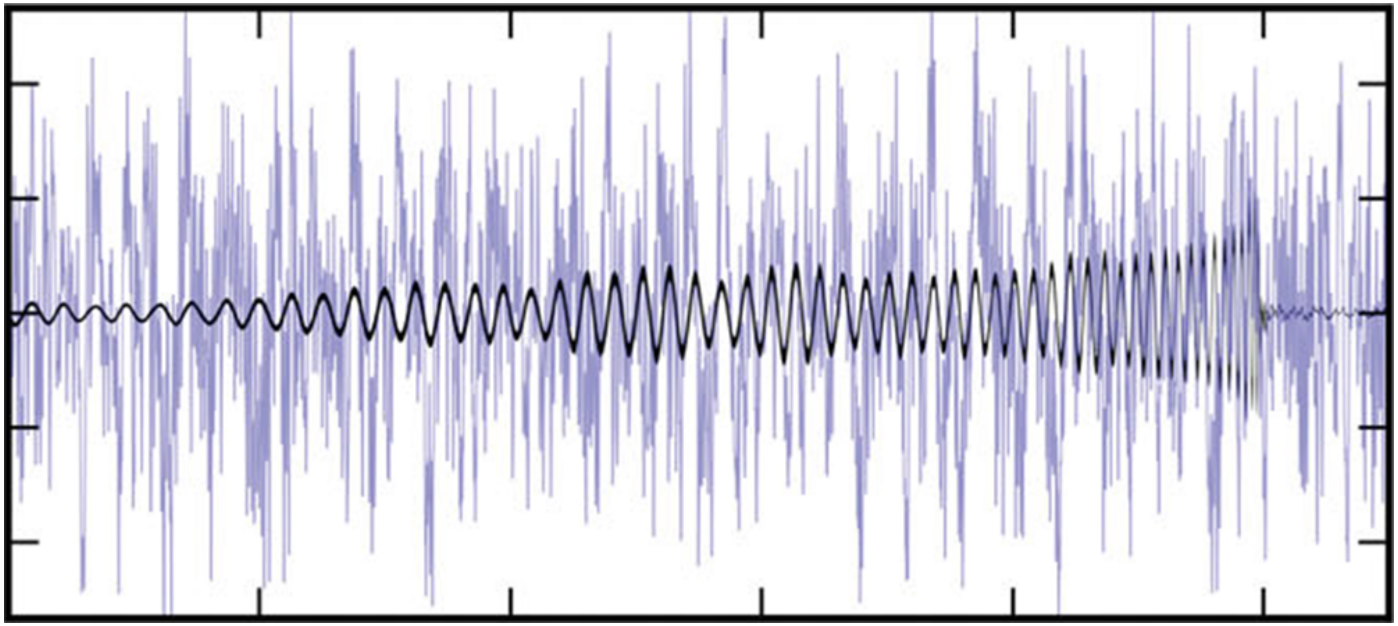


Mass, Spin, Separation, Location, Distance...

The list goes on!

What if there's noise? (there is)

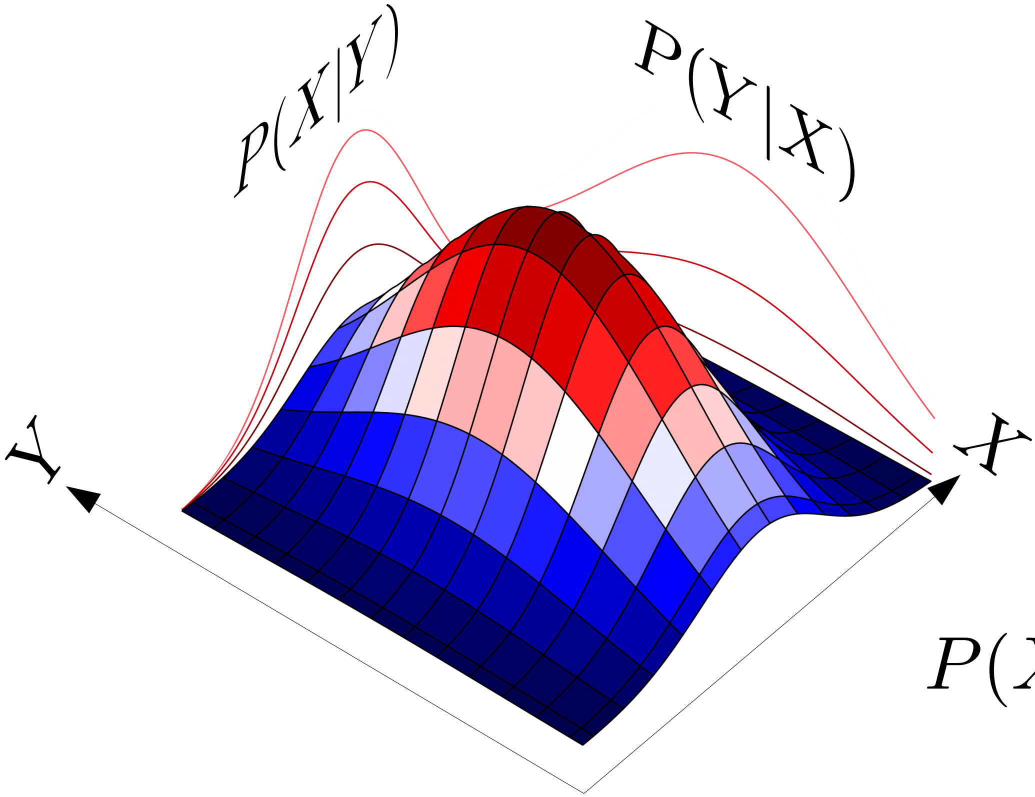
The real data (usually) looks something like this:



We need a way to make a quantitative statement about what parameters are the "best fit" while propagating through the uncertainty due to *noise*

A Bayesian Approach

Our main tool is thus the Bayesian Posterior:

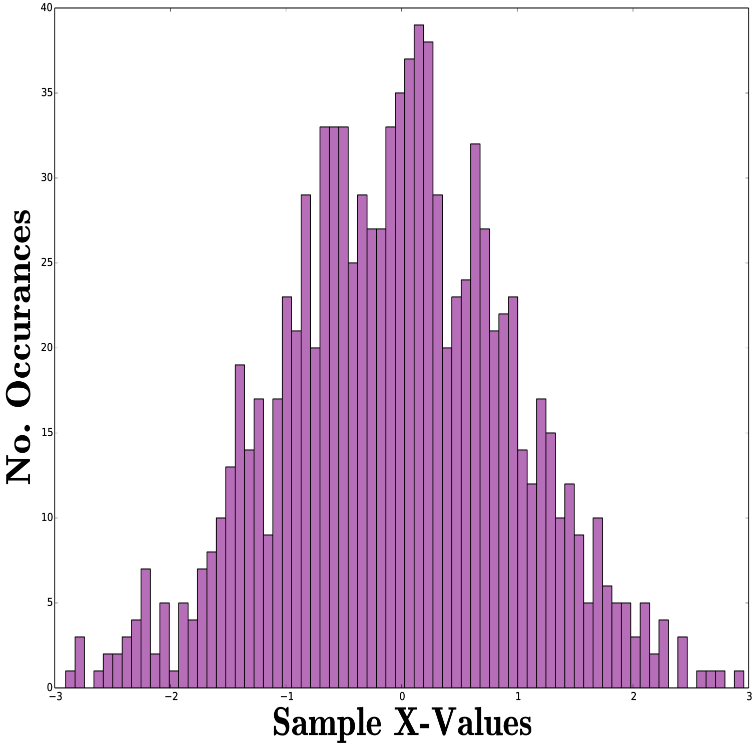


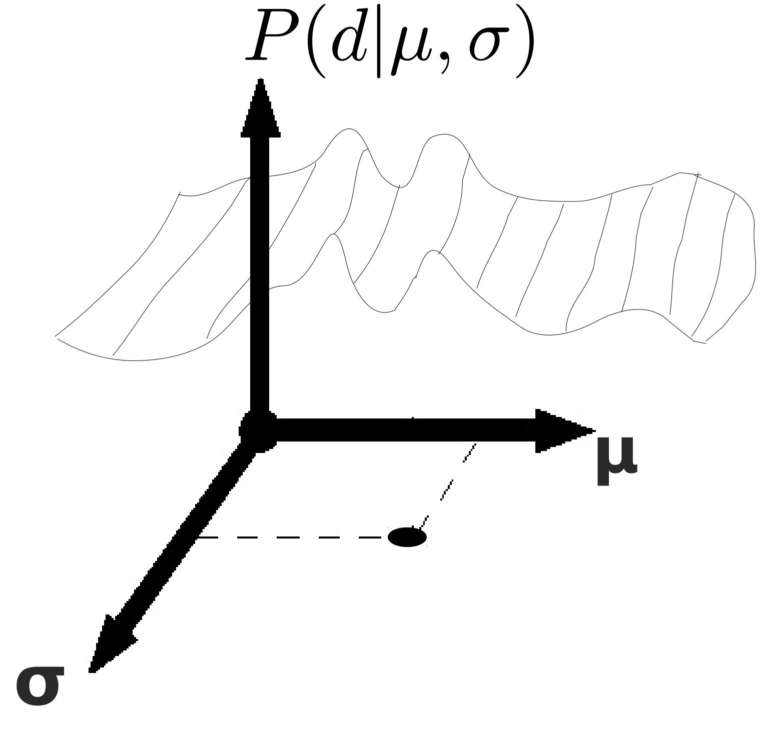
$$P(X|Y) = \frac{P(Y|X)P(X)}{P(Y)}$$

Bayes Theorem: Our Application

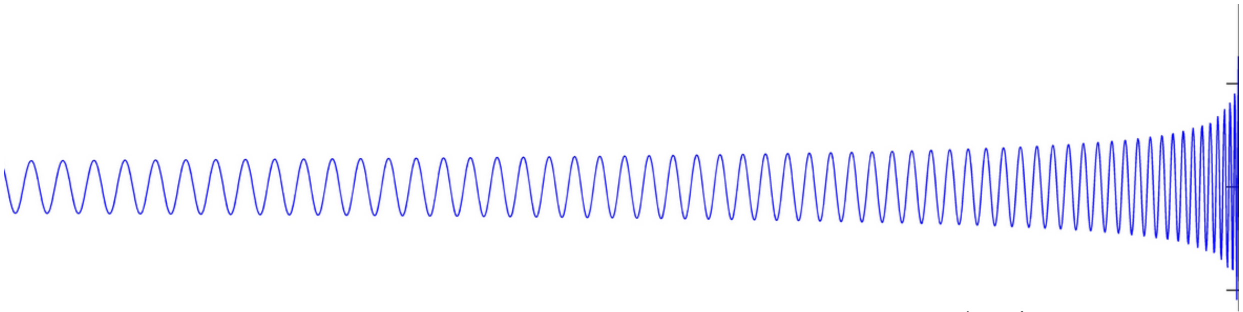
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Think of a *Gaussian!*

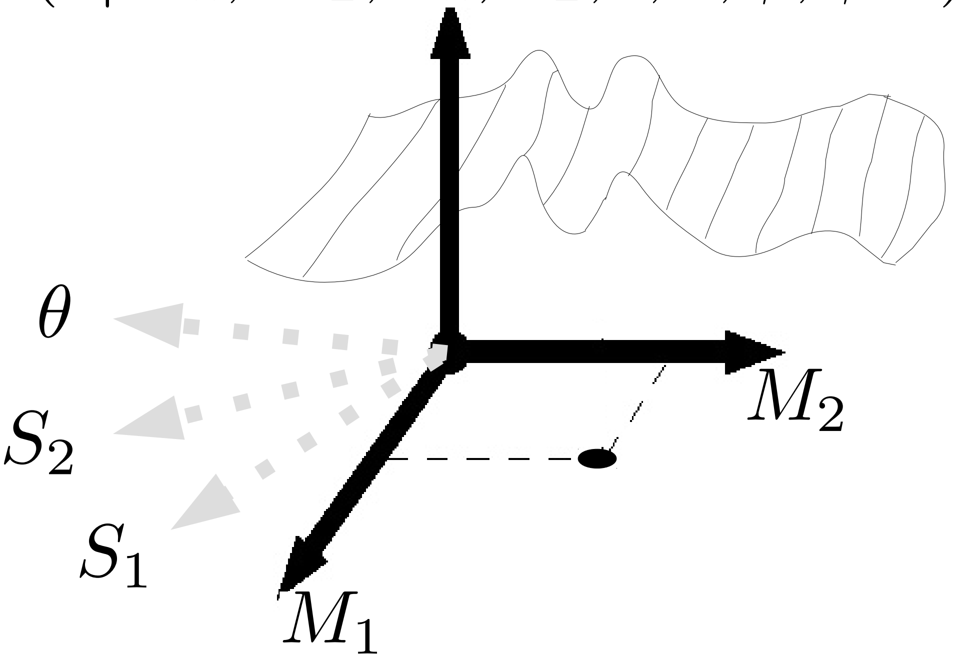




Bayes Theorem: Our Application

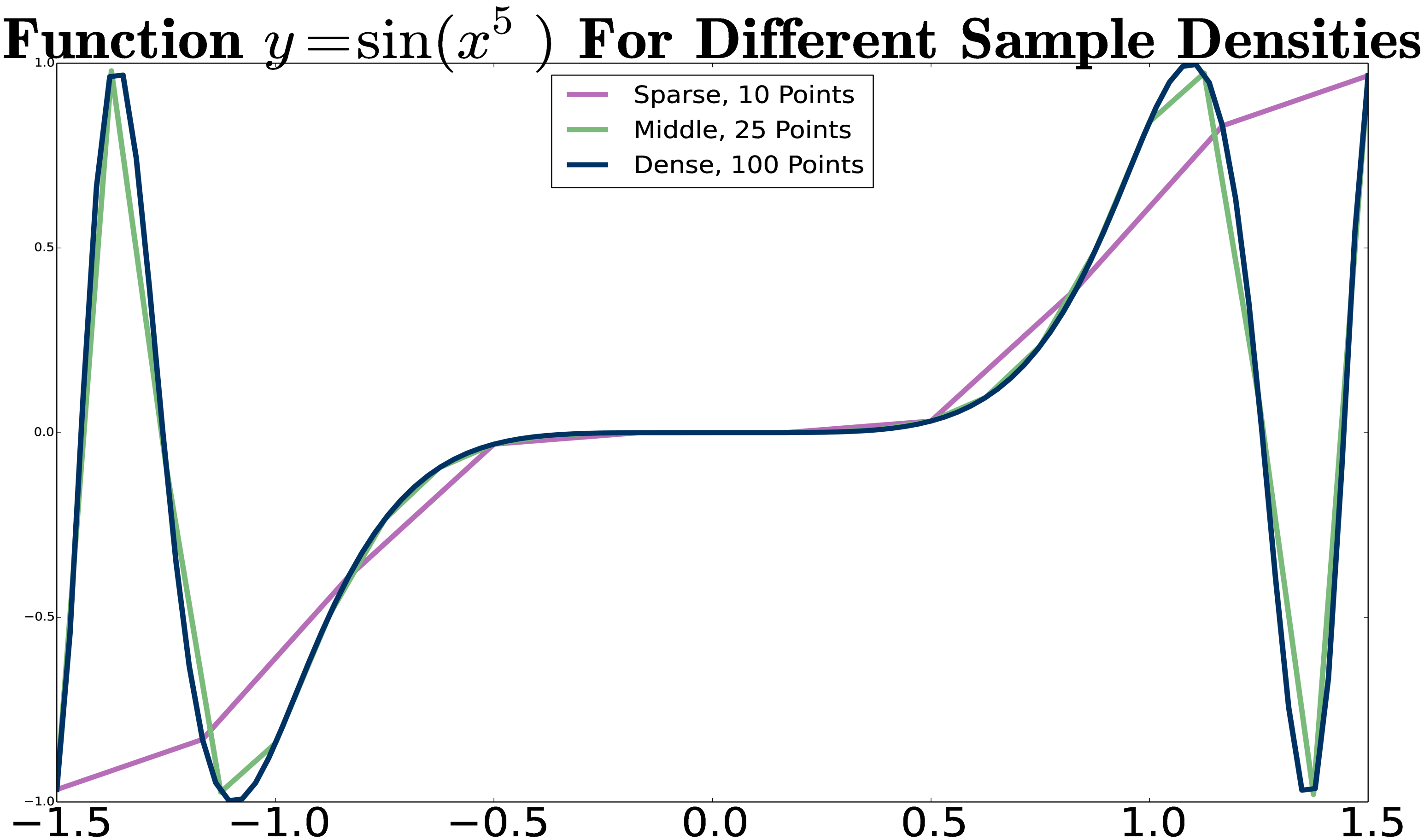


$$P(d|M_1, M_2, S_1, S_2, \iota, \theta, \phi, \psi ...)$$

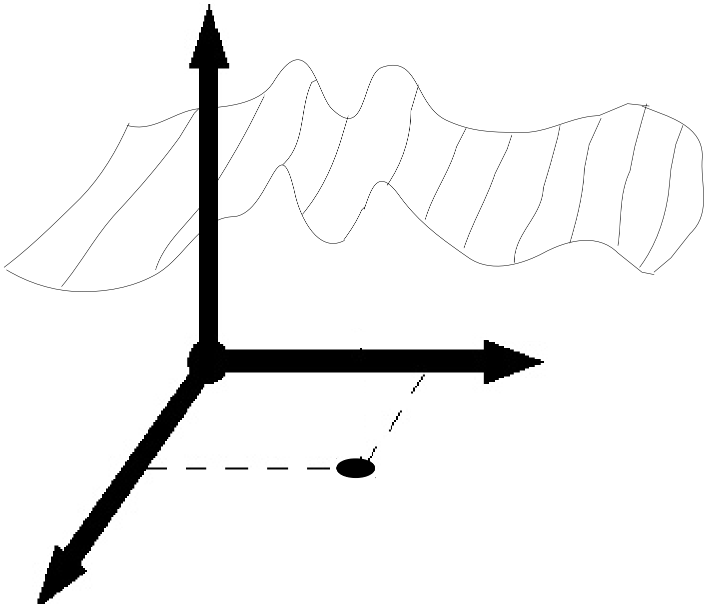


Problem: Posterior Narrow, Multimodal, and 15 Dimensional!

You can miss the peak, badly! Direct computation hard



One Solution: MCMC Sampling



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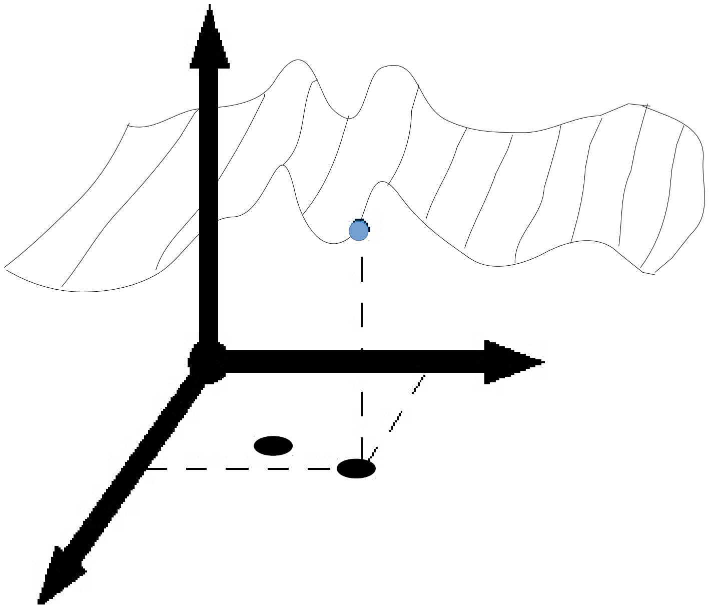

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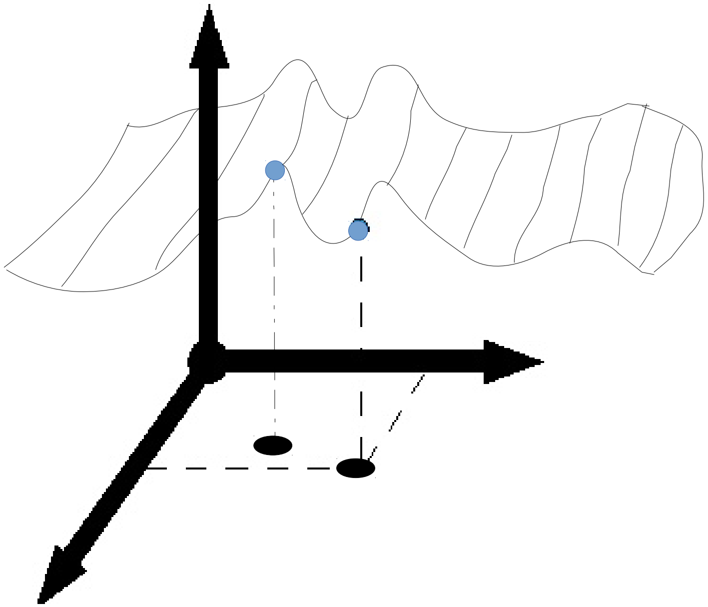

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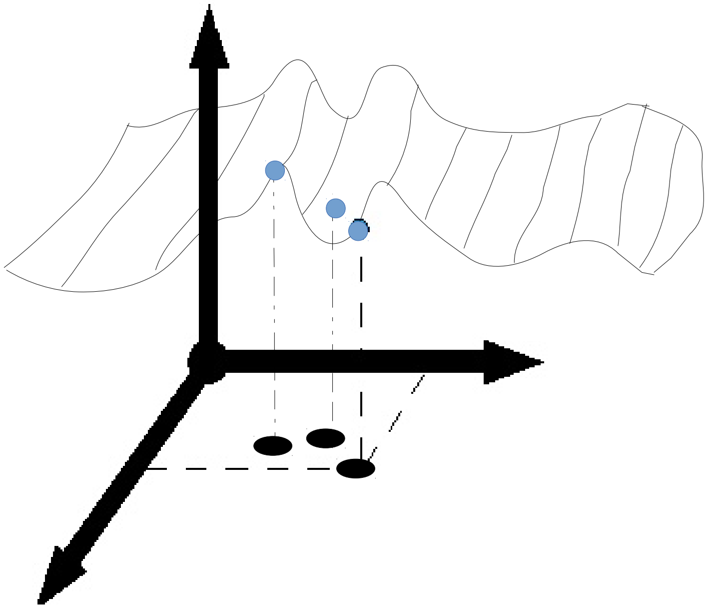

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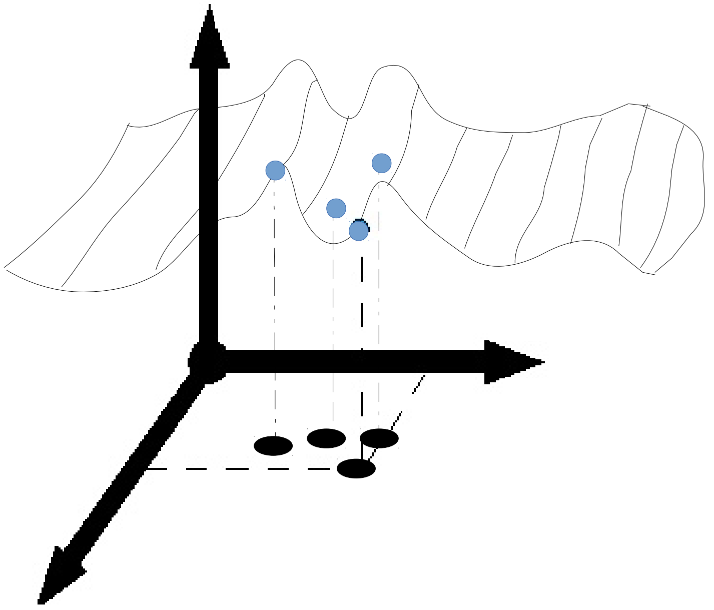
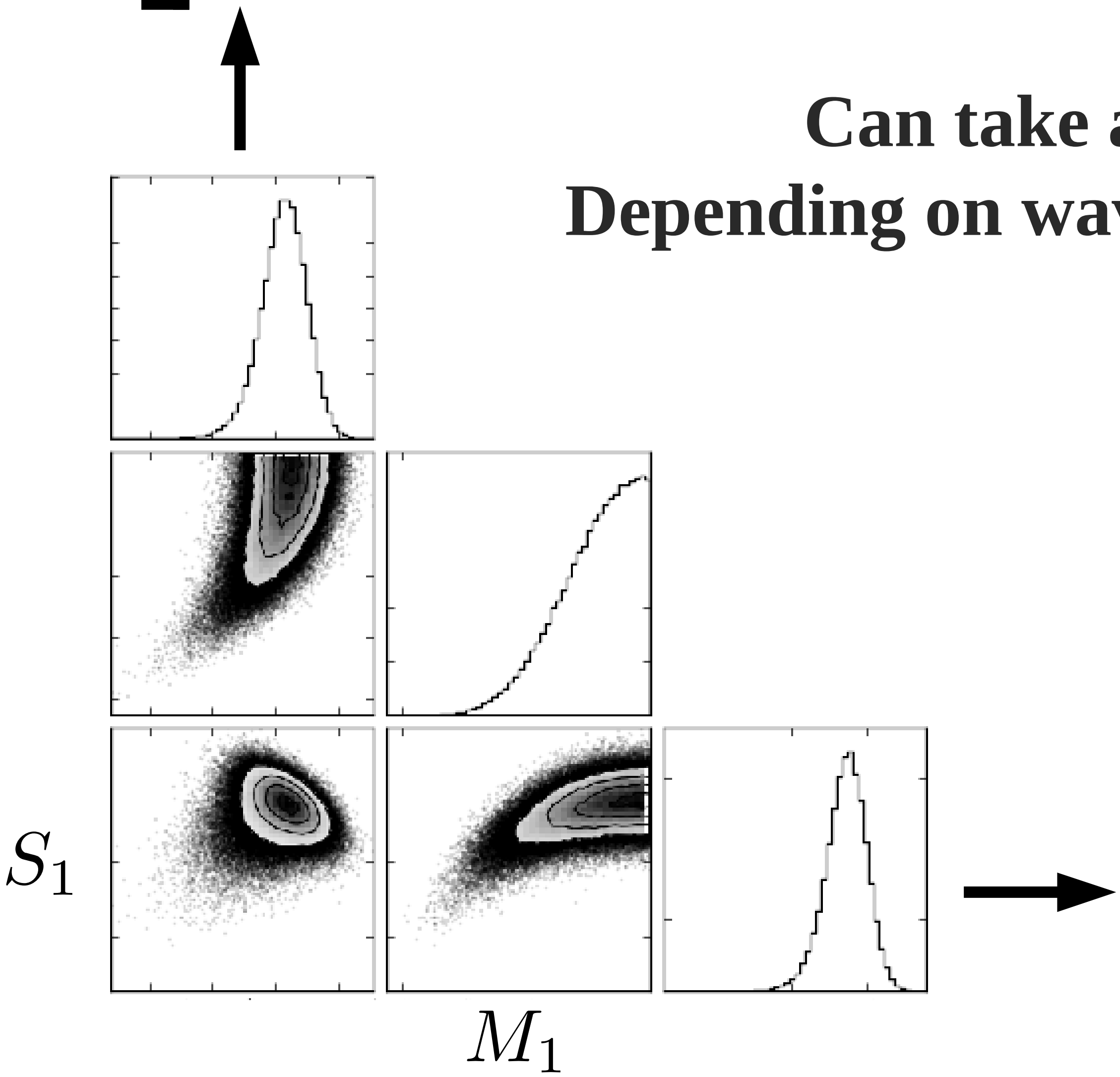
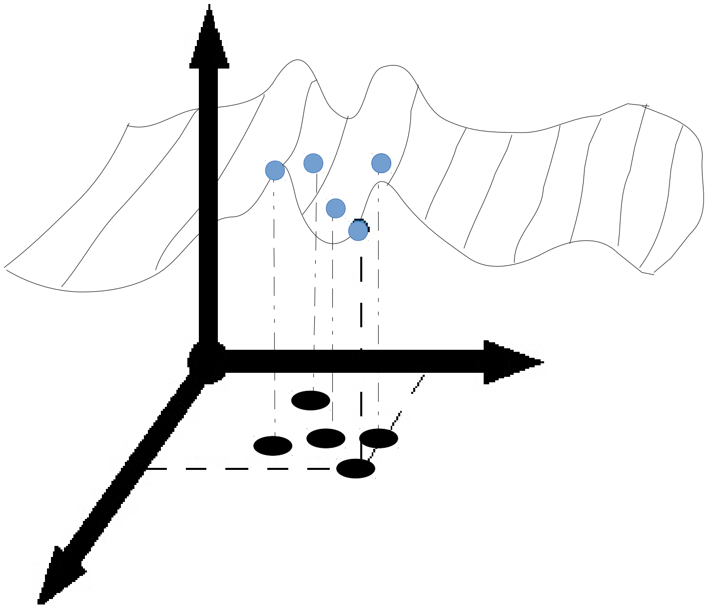


One Solution: MCMC Sampling

Can take a few days to converge
Depending on wave template, hardware

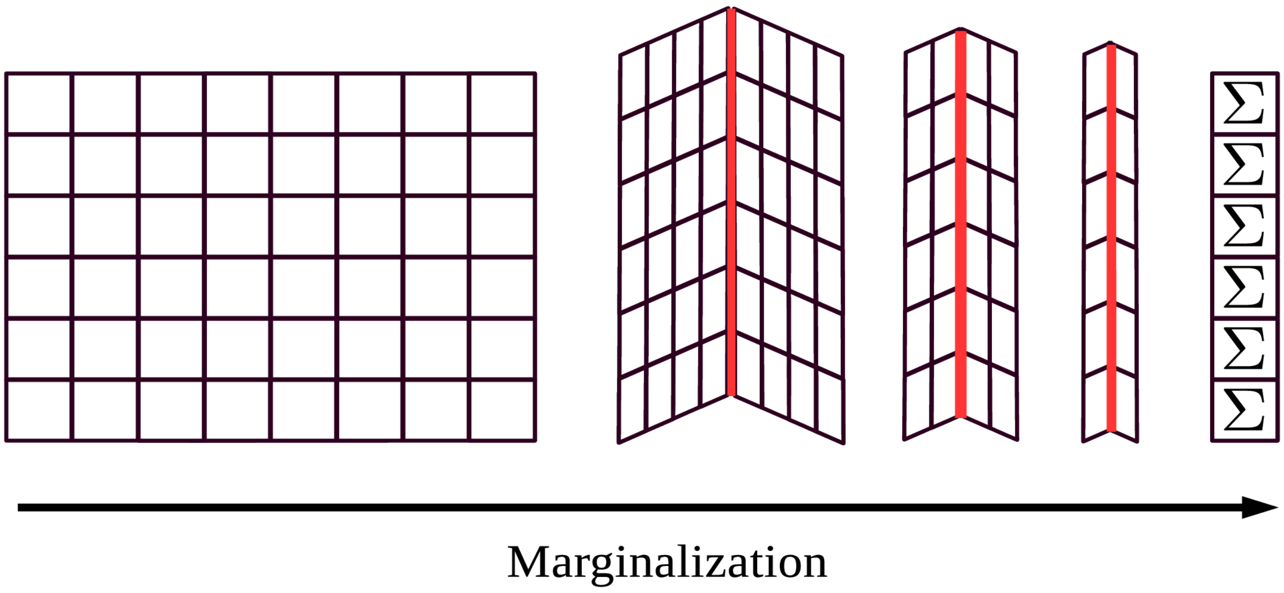




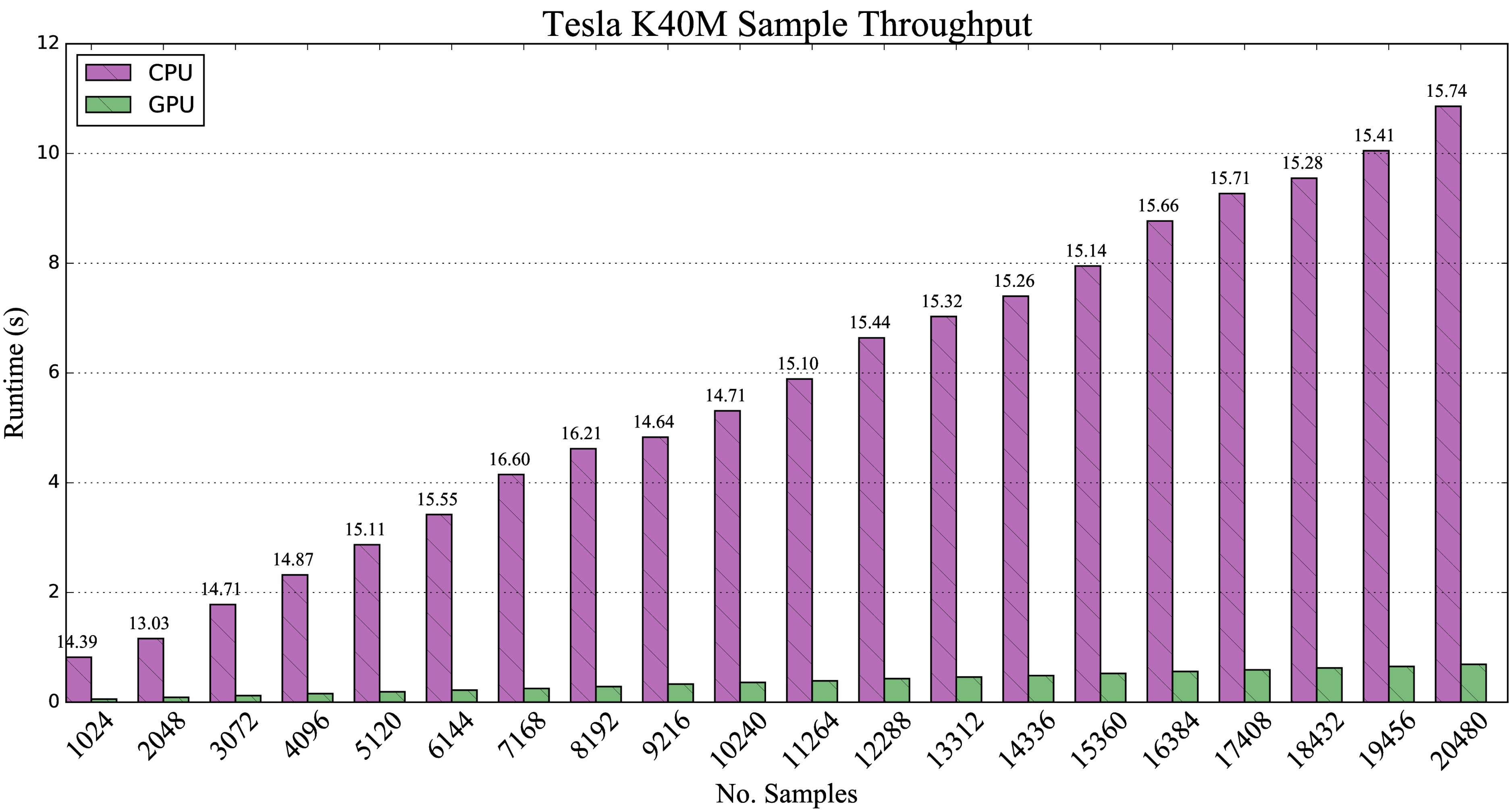
My Solution: GPU-based Direct Computation

Marginalizes out all the extrinsic parameters with a Large, brute force Monte-Carlo integration

Massively Parallel, scalable to multiple GPUs
Fully custom CUDA/PYCUDA



Results vs Fastest CPU Algorithm



A Brief Word About Why We Care

Low Latency Electromagnetic Follow-Up

Get the angles and orientations quickly and you can tell EM observatories where to look