Introduction to The LIGO Project

Brandon B. Miller

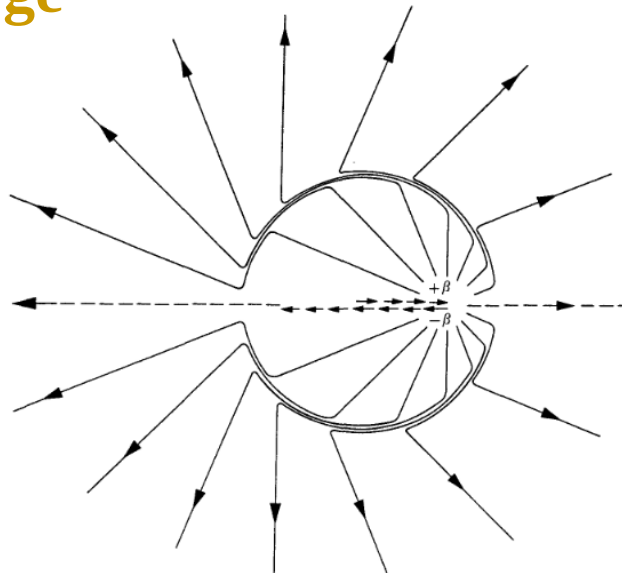*Allstate*

9/1/2016

Classical Electrodynamics

ELECTRODYNAMICS

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

Radiation from an Accelerating Charge

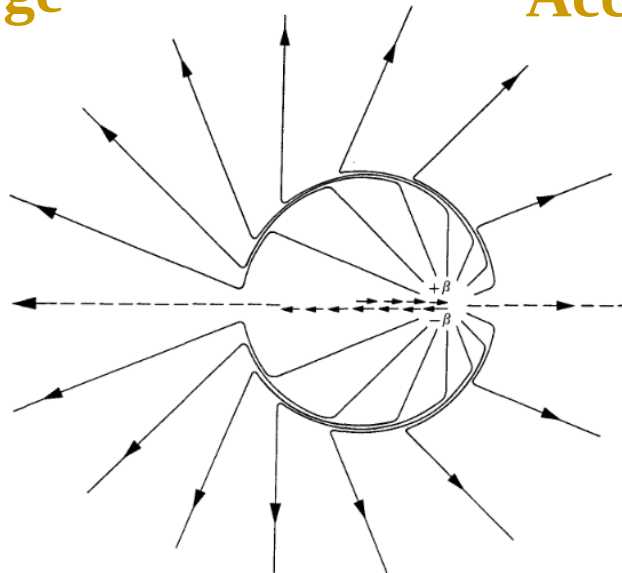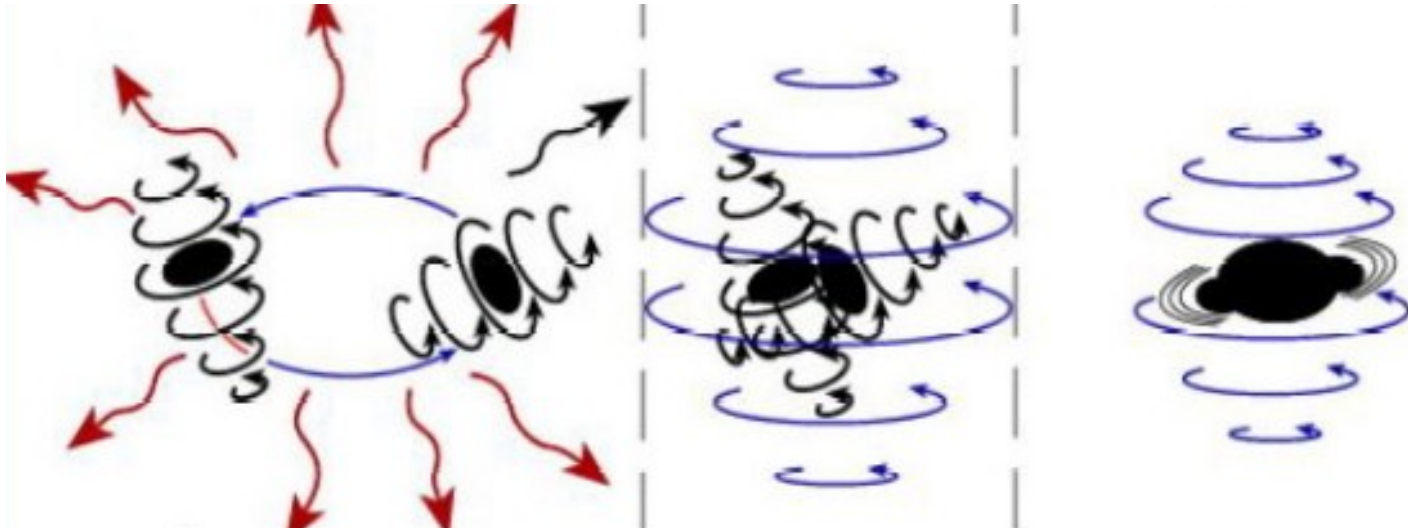# Classical Electrodynamics vs General Relativity

ELECTRODYNAMICS

GENERAL RELATIVITY

$$\Box A^\alpha = \frac{4\pi}{c} J^\alpha$$
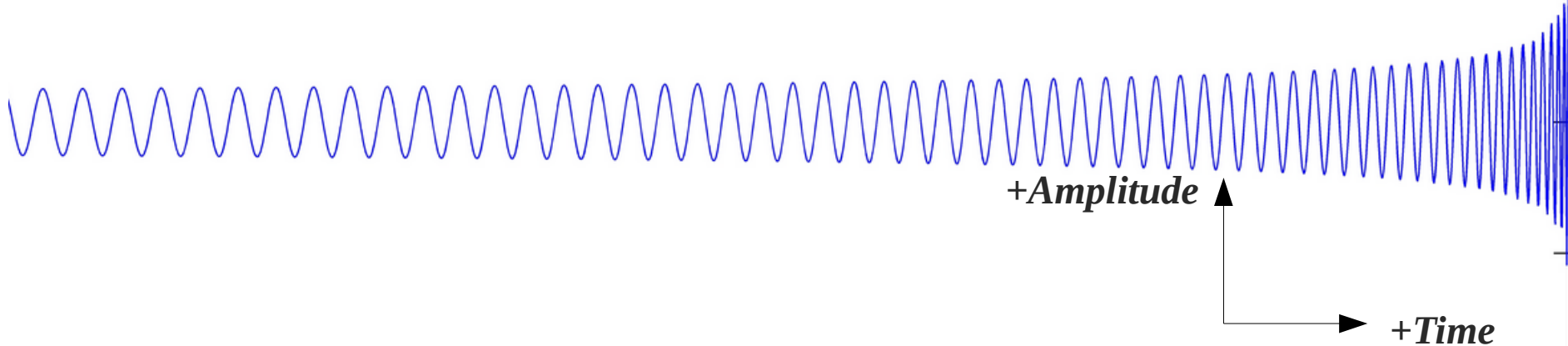
$$\Box h_{\mu\nu} = 0$$

Radiation from an Accelerating Charge

Radiation from an Accelerating Mass?

Chirps and Black Hole Binaries

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

+Amplitude

+Time

How does *"Gravitational Radiation"* Manifest Itself?

Waves go straight through matter.
Space between objects warped and stretched
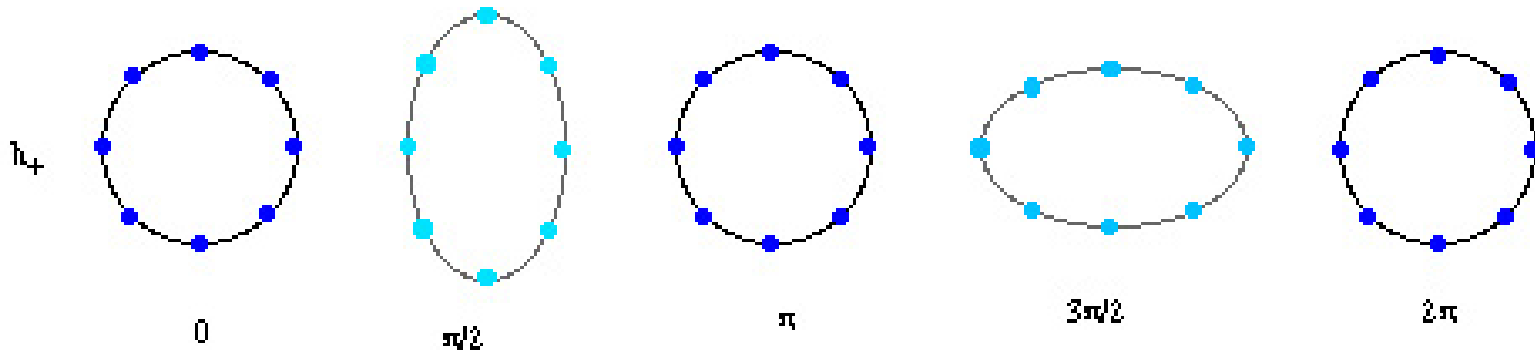
We need to measure the distances between things and look for changes and oscillations

VERY tiny signal, ~ 10^{-23}

Hulse and Taylor

The LIGO Project

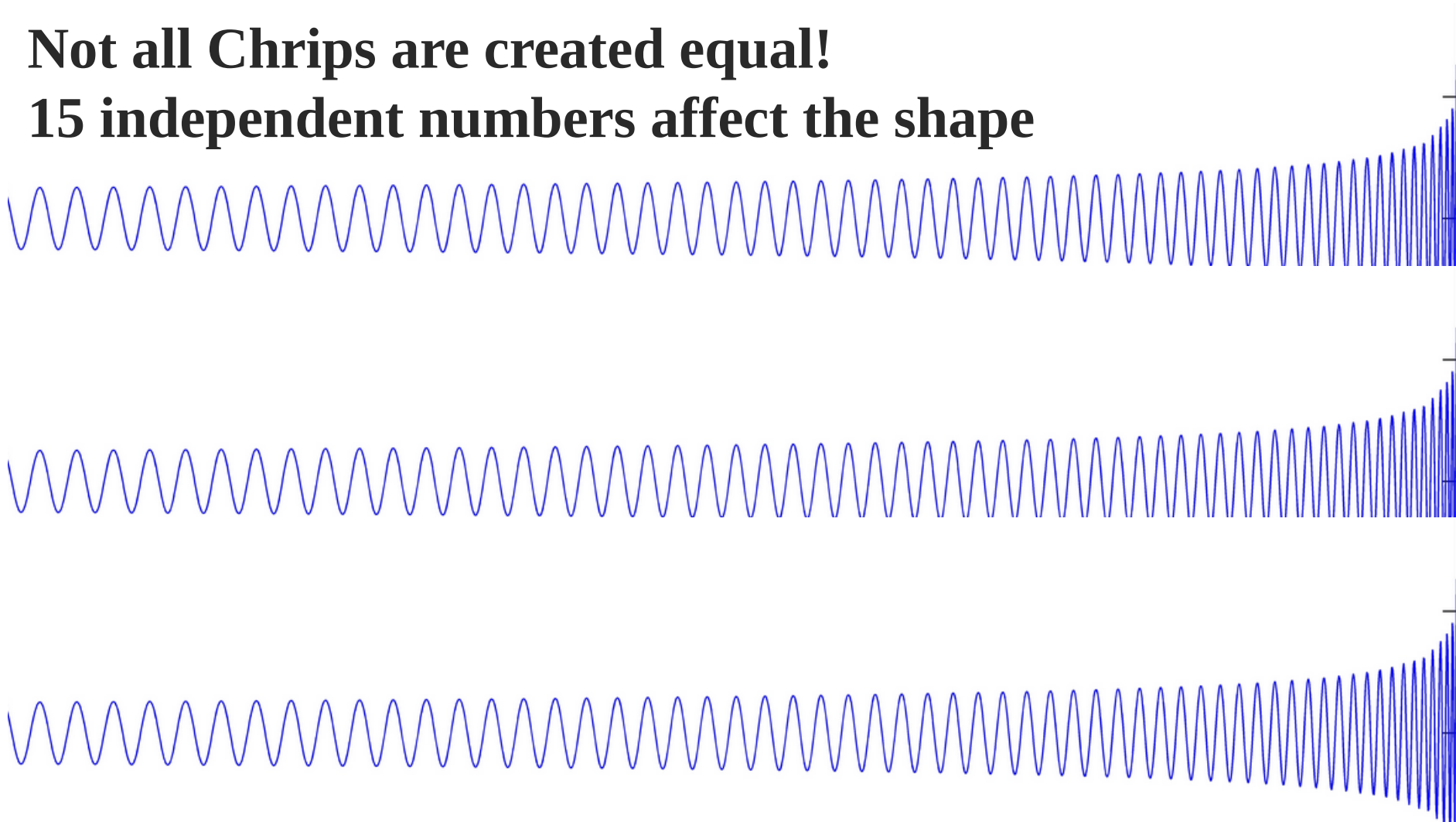# The LSC/VSC Detector Network

September 14th, 2015

September 14th, 2015 – Success!

The Problem – Reverse Engineer the Parameters from the Signal

Not all Chrips are created equal!
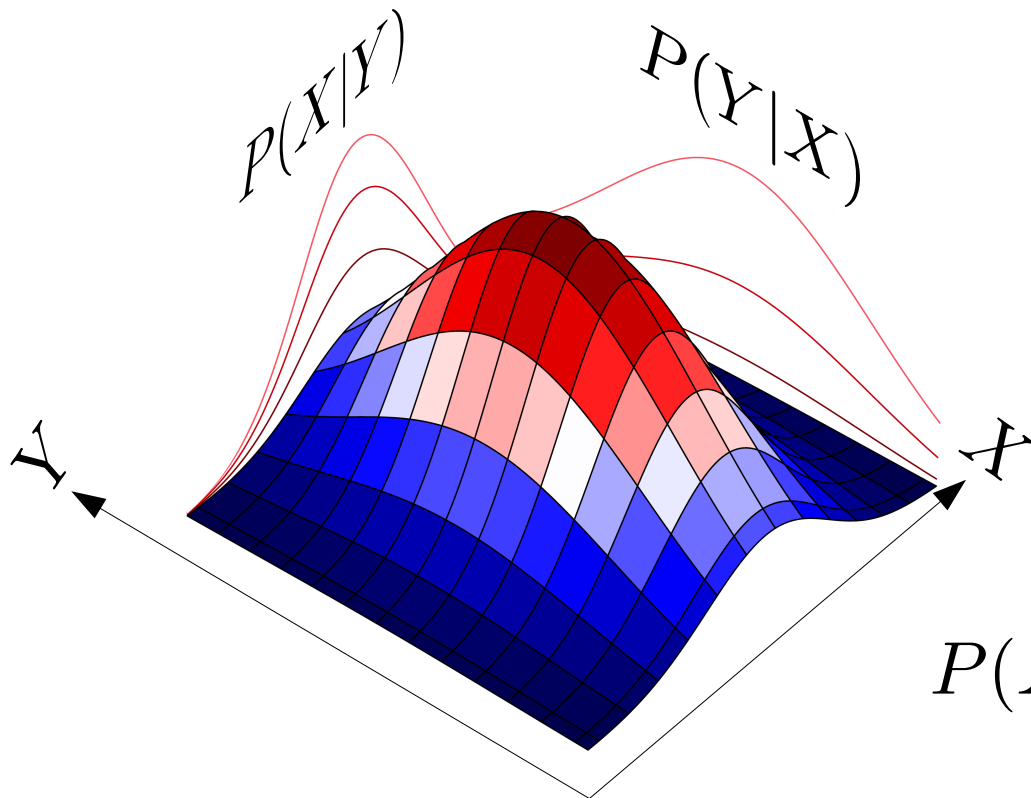**15 independent numbers affect the shape**

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*
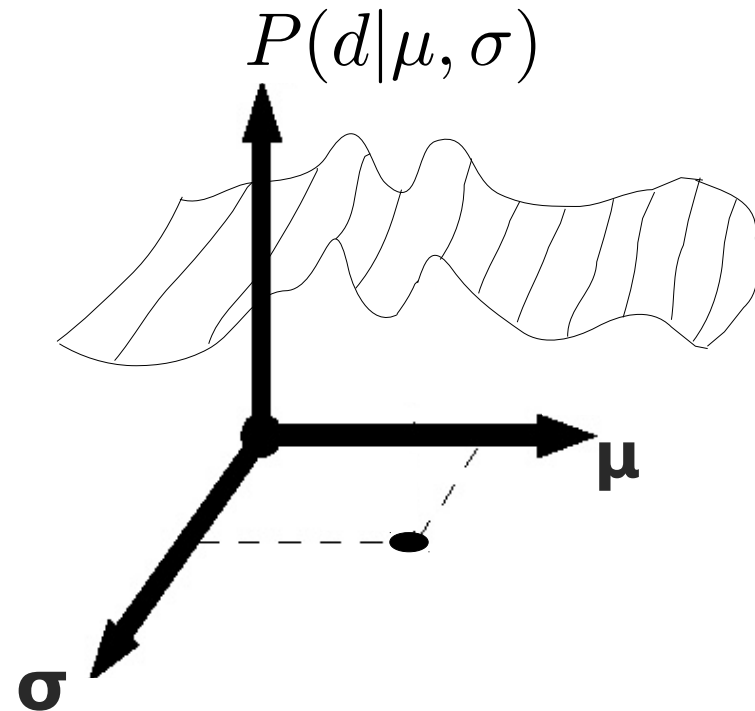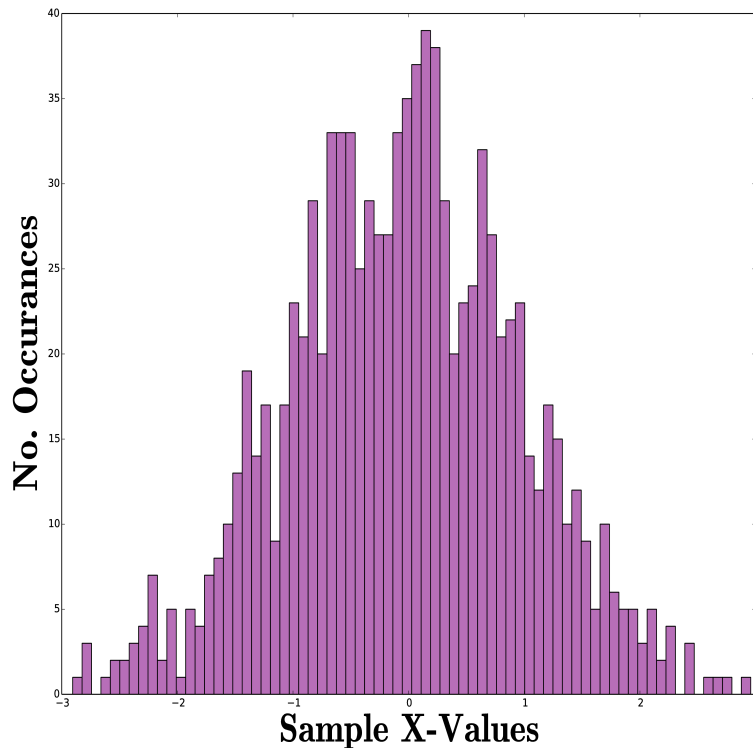
A Bayesian Approach
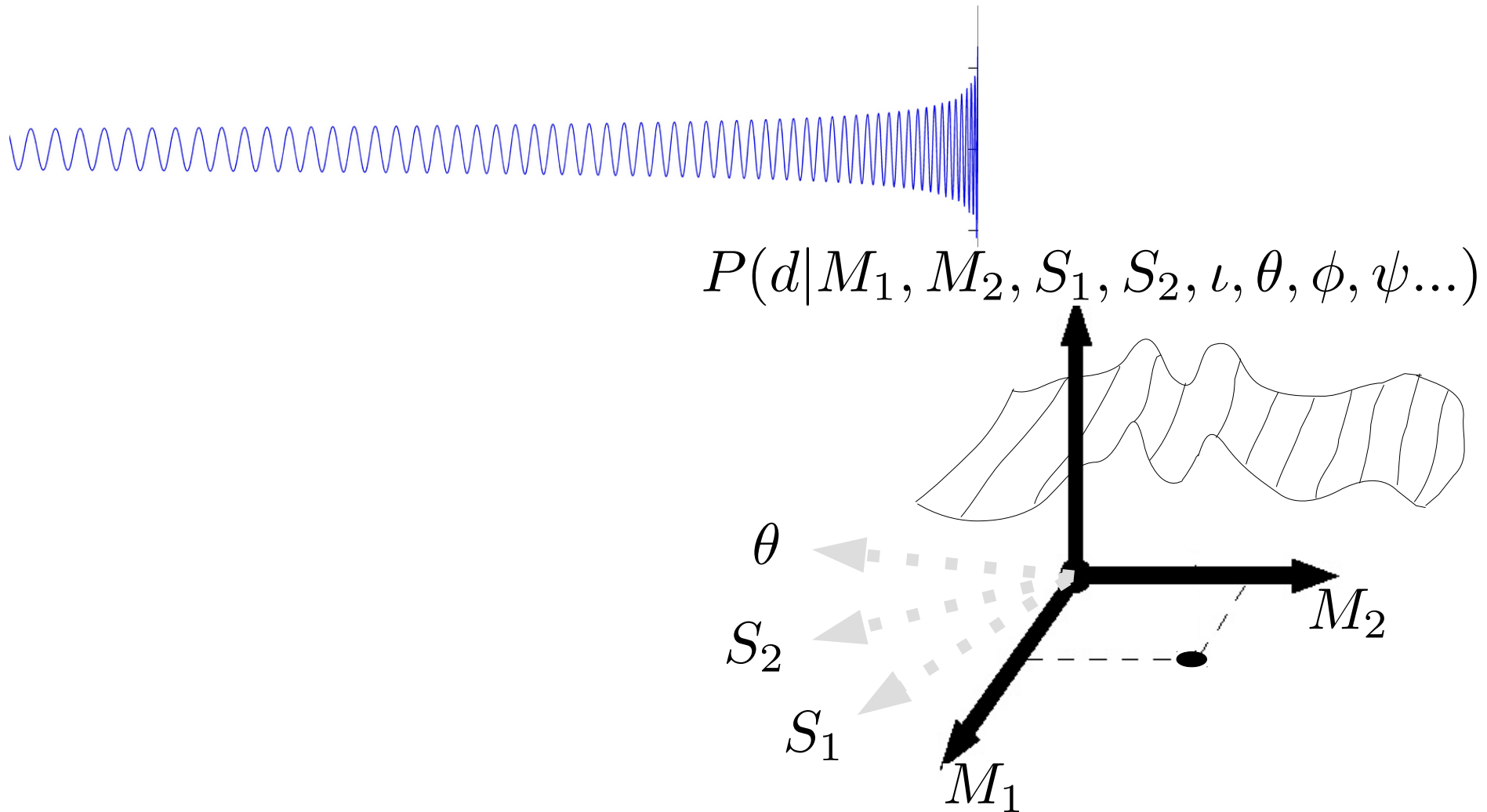
Our main tool is thus the Bayesian Posterior:

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

Bayes Theorem: Our Application

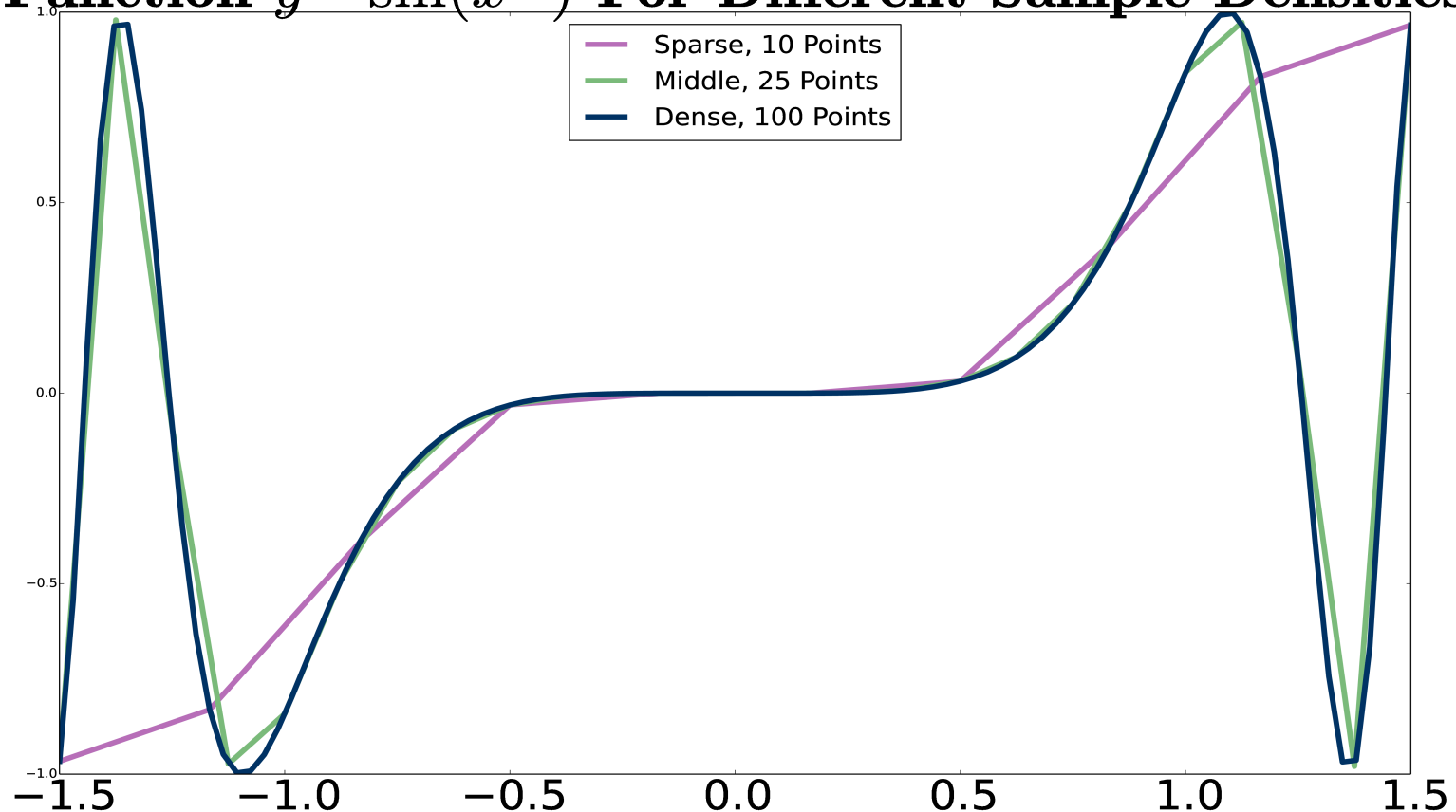$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$ $\longrightarrow$ **Think of a *Gaussian!***

No. Occurances

Sample X-Values

$P(d|\mu, \sigma)$

μ

σ

Bayes Theorem: Our Application

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

θ
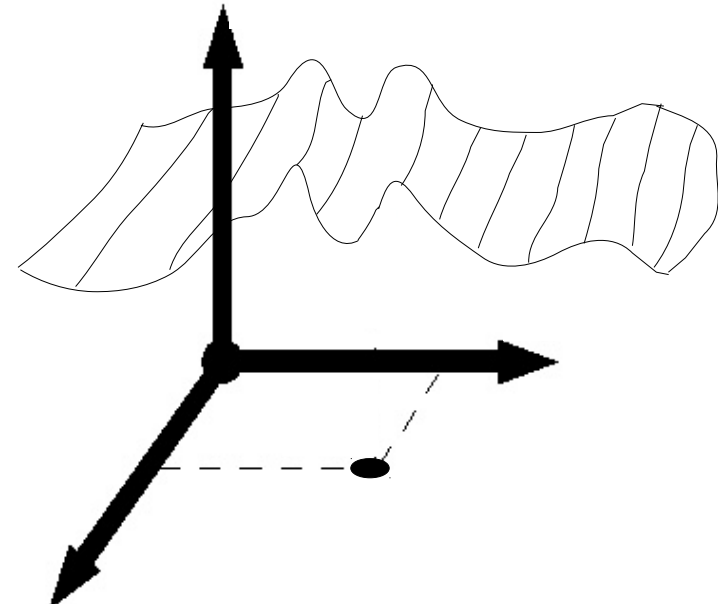
S_2

S_1

M_2

M_1

Problem: Posterior Narrow, Multimodal, and 15 Dimensional!

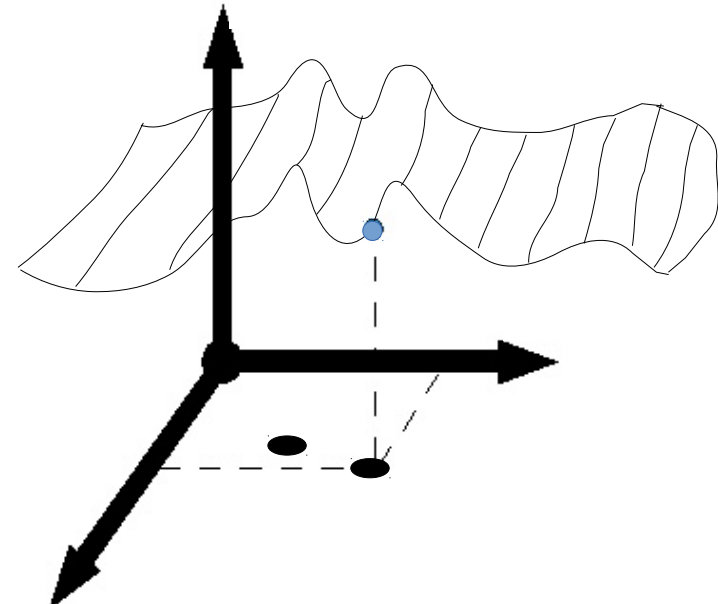**You can miss the peak, badly! Direct computation hard**

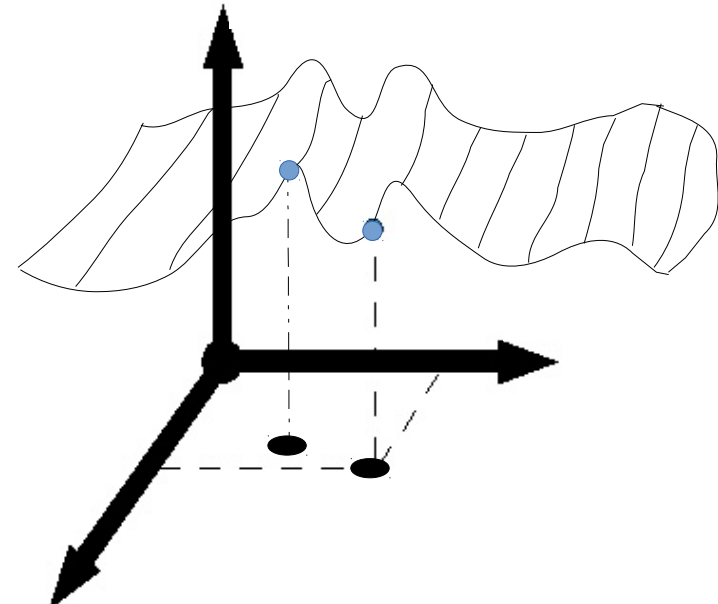**Function $y = \sin(x^5)$ For Different Sample Densities**
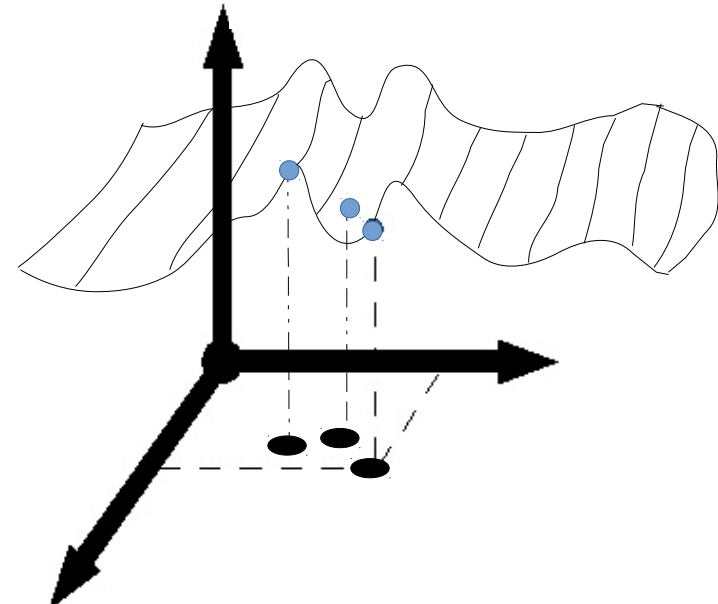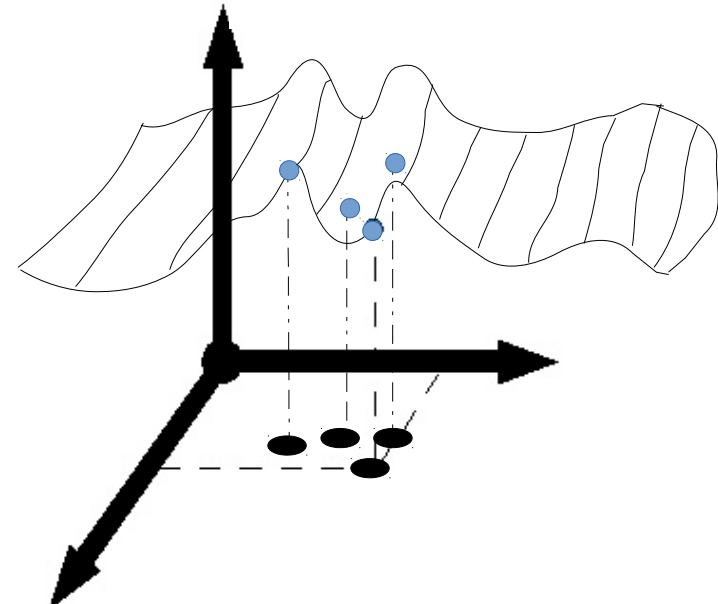
One Solution: MCMC Sampling

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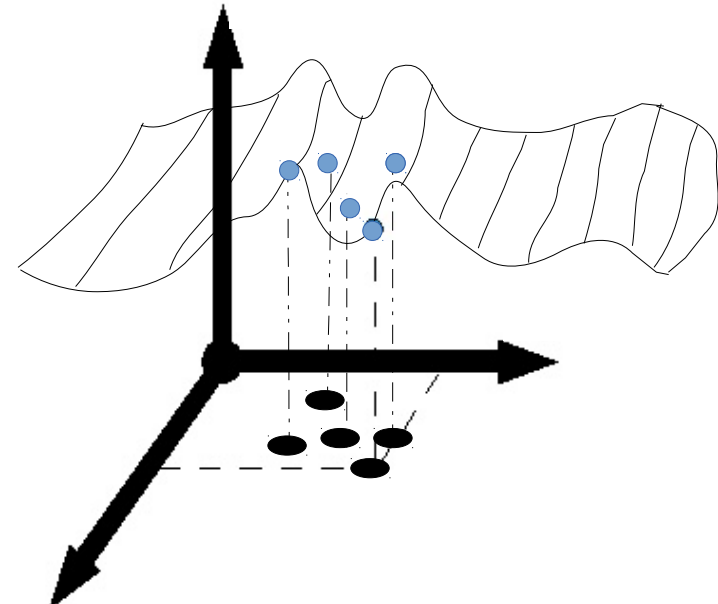
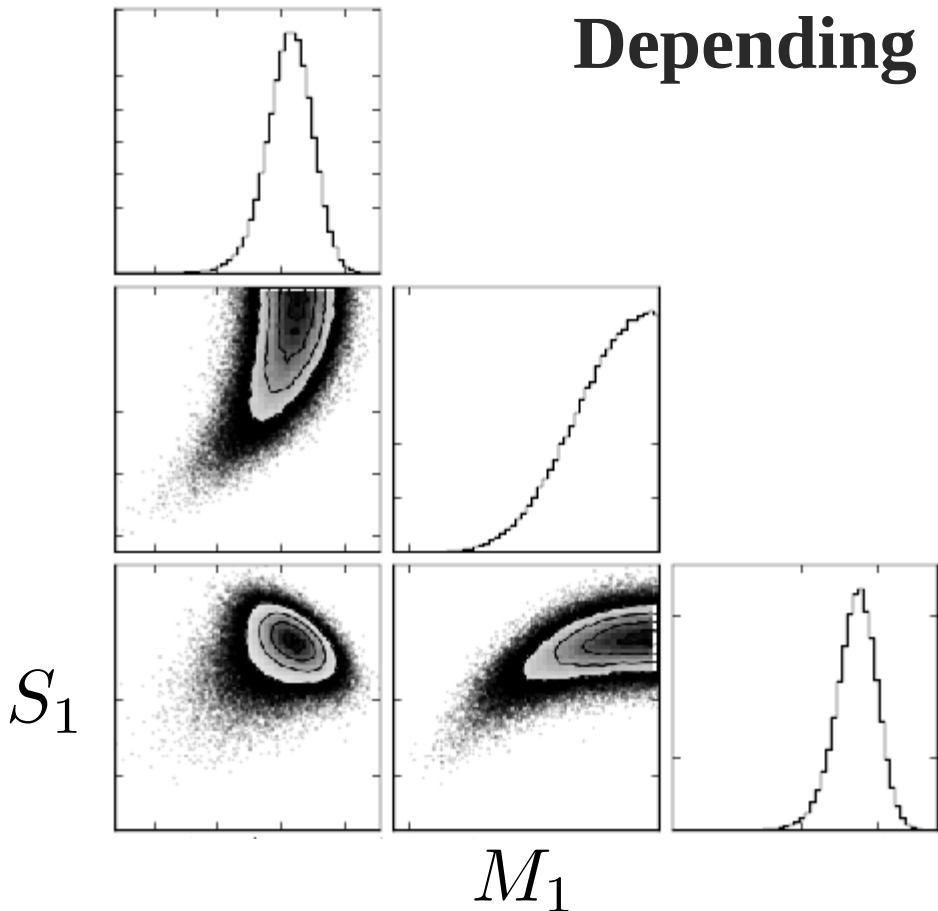# One Solution: MCMC Sampling

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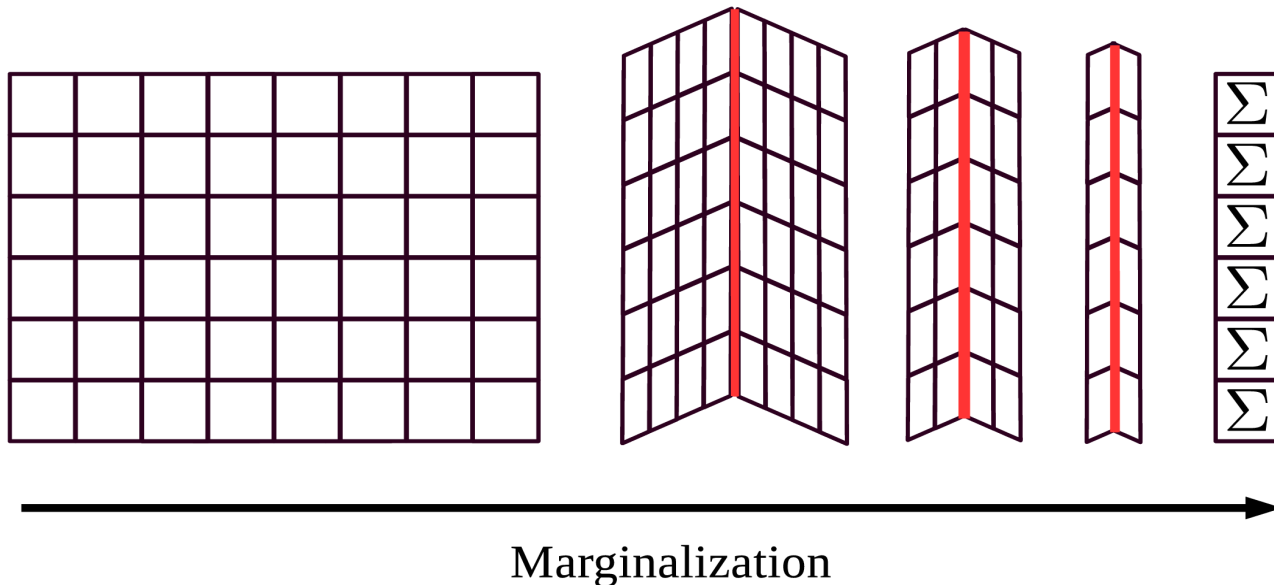
One Solution: MCMC Sampling

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

S_1
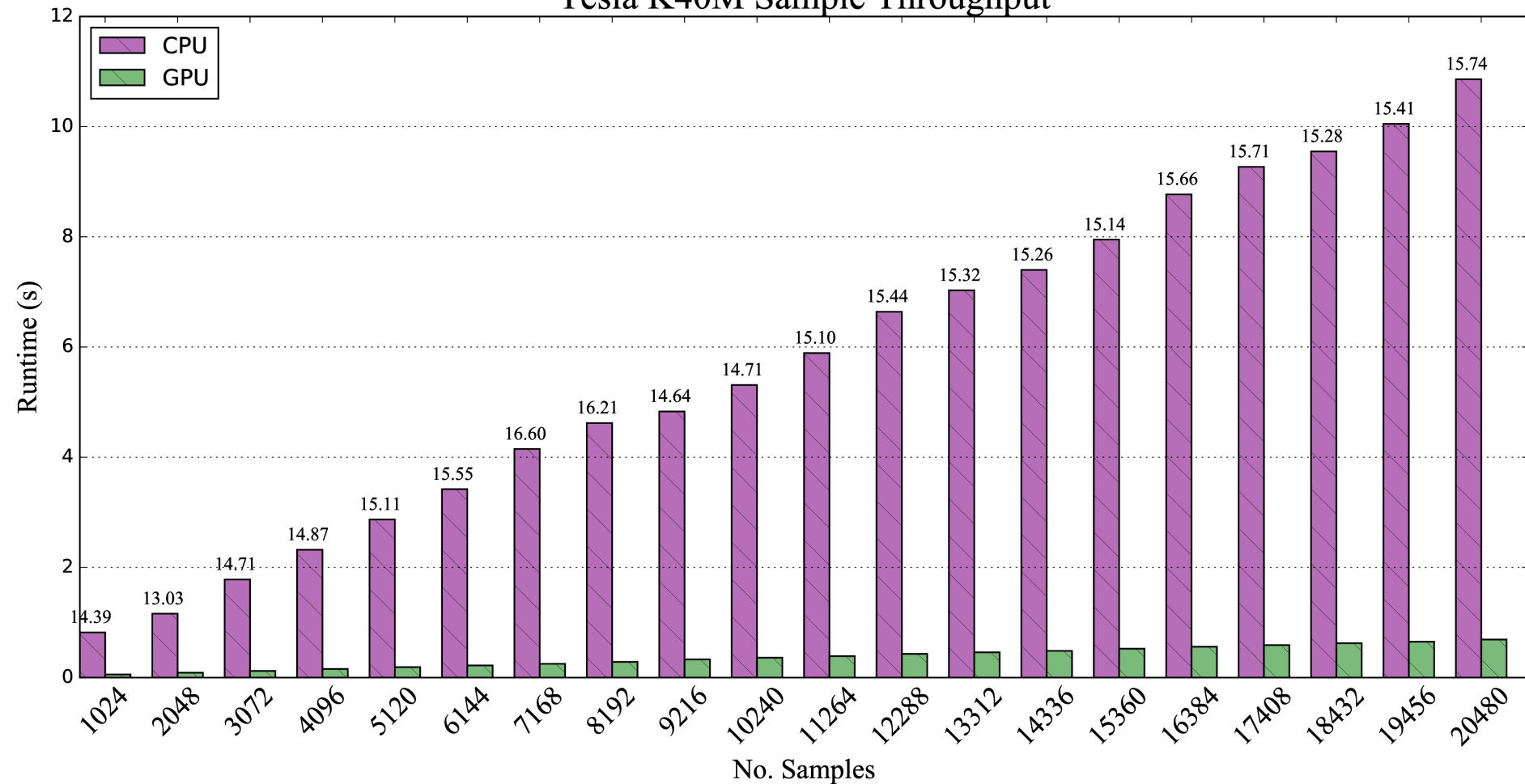
M_1

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

Marginalization

Results vs Fastest CPU Algorithm

Tesla K40M Sample Throughput

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

$+t$