Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Coronal Mass Ejection Oscillations

INAM 2018, Birr

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Research Fellow

Date 06/09/18

Outline

1. What are CMEs and how are they observed?

2. Why are CMEs / CME oscillations interesting?

3. Analysis

4. Results

5. Conclusions

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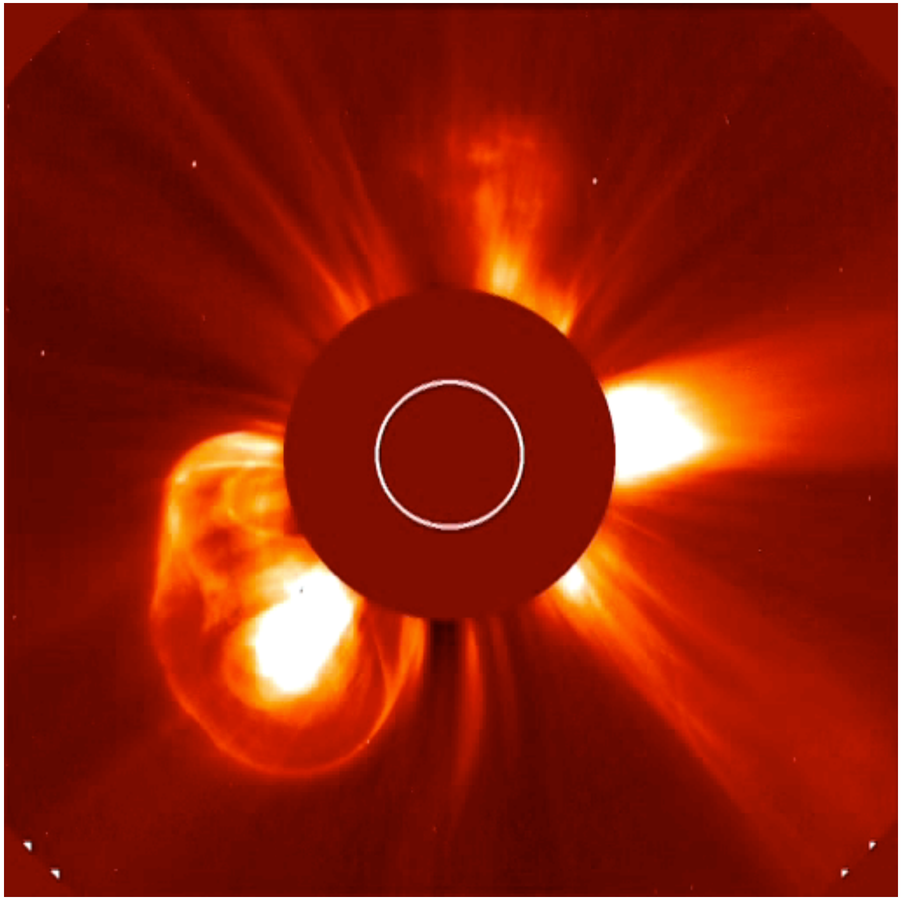
1. What are CMEs and how are they Observed?

- Large scale eruptions of plasma and magnetic field
- Mass ~ 10^{15} g
- Velocity 100 - 3500 km/s
- Kinetic Energy ~ 10^{31} ergs
- Magnetic flux ropes



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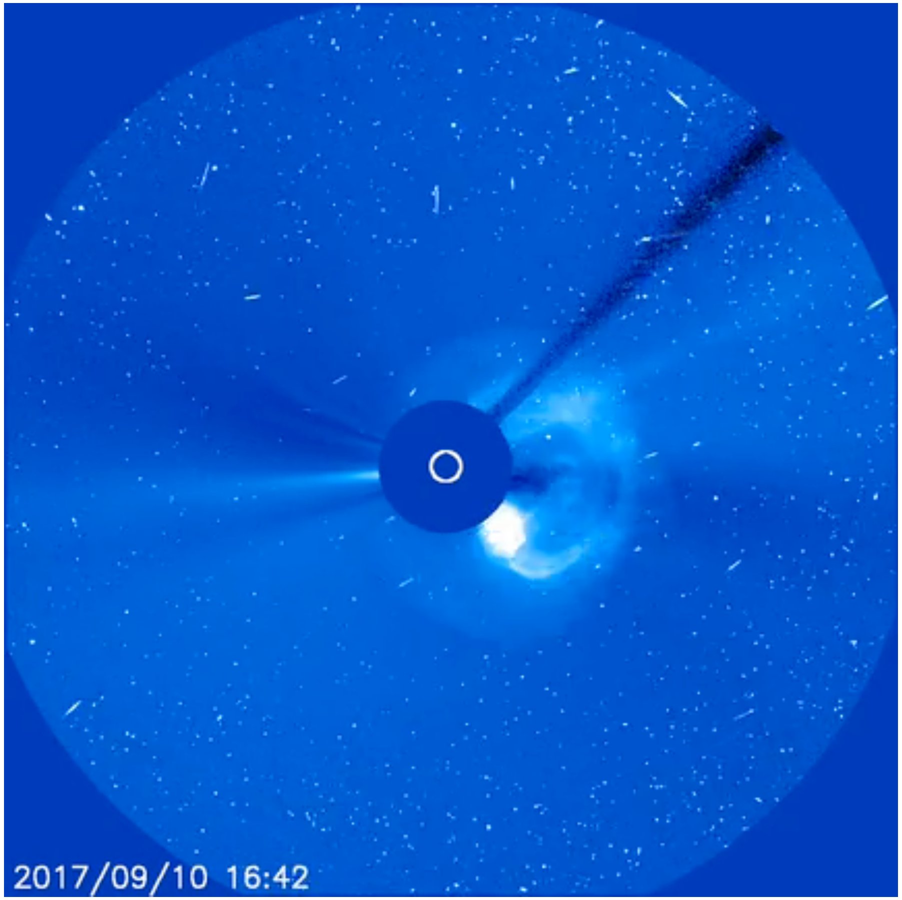
2. What are CMEs and how are they Observed?

- Coronagraphs (white light)
- Thomson scattered light from the photosphere

$$I \propto n_e$$

- Plane of sky projected
- Polarisation
  - Can infer distance from plane of sky



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3. Why are CMEs / CME oscillations interesting?

- CMEs are some of the most energetic events on the Sun

- CMEs are the main drivers of adverse space weather affects
  - CME velocity and magnetic (B) field key factors

- Flux ropes structures present in many astrophysical systems

- Understand the details of entire flare CME system

3. Why are CMEs / CME oscillations interesting?

- What is a CME oscillation?
  - semi-periodic signal in velocity-time profiles

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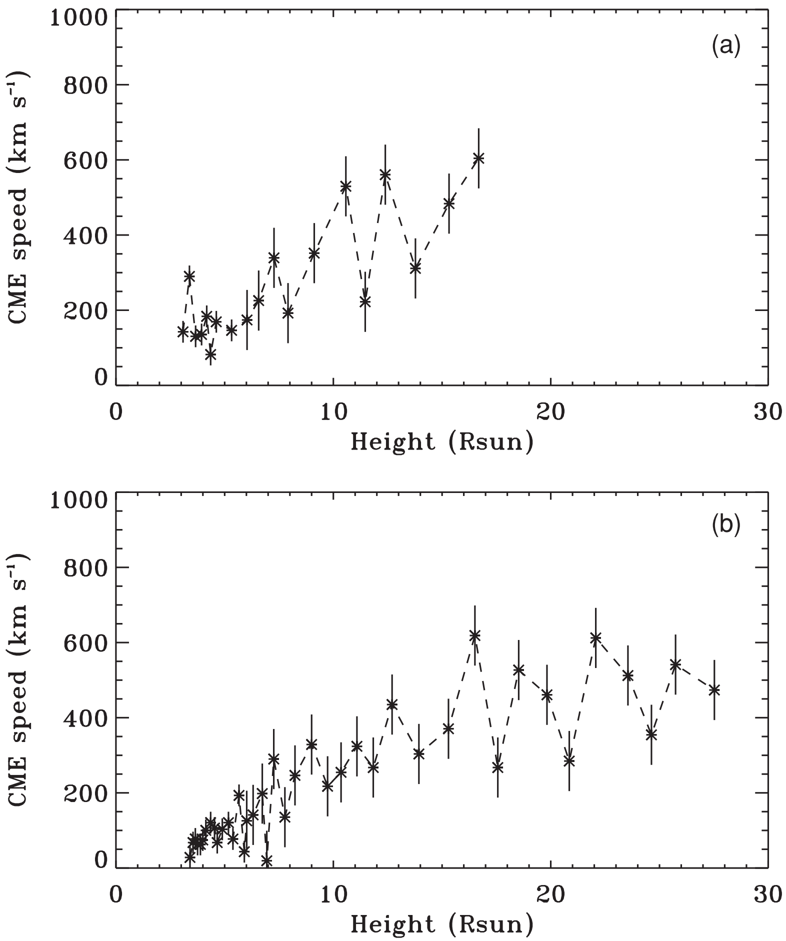
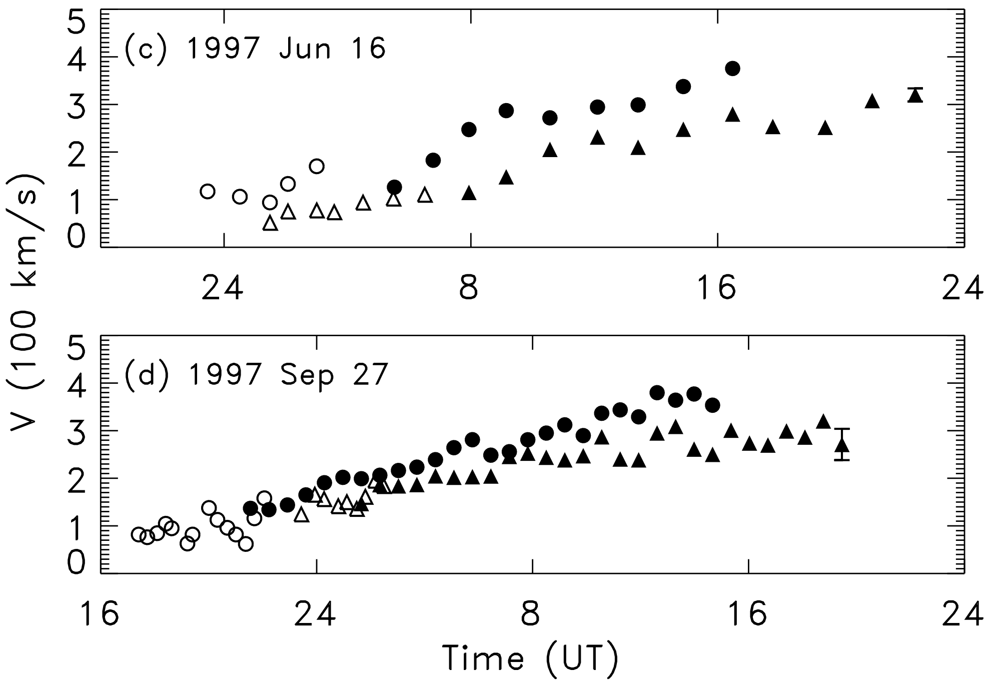
3. Why are CMEs / CME oscillations interesting?



Shanmugaraju et al. (2010)



Krall et al. (2001)

3. Why are CMEs / CME oscillations interesting?

- What is a CME oscillation?
  - semi-periodic signal in velocity-time profiles

- What could cause CME oscillations?
  - MHD waves
    - Coronal seismology -> get an estimate of B field and other properties

$$P = \frac{2\pi}{c_A}\left(al\right)^{1/2} \qquad c_A = f(B)$$

~220 min

  - Modulation of magnetic reconnection rate

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4. Analysis

Data

- CDAW LASCO CME catalogue 1996 - present (29,000 CMEs)
  - Manual point-and-click
  - Metadata and height-time

```
#VERSION=3
#DATE-OBS: 2017/10/18
#TIME-OBS: 05:48:05
#DETECTOR: C2+C3
#FILTER: Orange(C2)  Clear(C3)
#OBSERVER: michalek
#FEAT_CODE: 1=LE
#IMAGE_TYPE: RUNNING DIFF
#YHT_ID: 20171018.054805.p137g
#ORIG_HTFILE: 20171018.054805.pa137.ht
#ORIG_WDFILE: 20171018.054805.pa137.wd
#UNIVERSAL: 1
#WDATA:    2.82 2017/10/18 07:24:05 346.5    C2    9    282.0    365.0
#WDATA:    2.93 2017/10/18 07:24:05 265.6    C2    9    374.0    244.0
#WDATA:    2.93 2017/10/18 07:24:05 266.1    C2    9    374.0    245.0
#HALO: 1
#ONSET1: 2017/10/18 05:24:03
#ONSET2: 2017/10/18 05:30:03
#ONSET2_RSUN:  1.00
#CEN_PA: HALO
#WIDTH:  360
#SPEED: 1576
#ACCEL:  -44.5
#FEAT_PA: 137
#FEAT_QUAL:  3.0
#QUALITY_INDEX: 5 (Excellent)
#REMARK:
#COMMENT:
# HEIGHT   DATE      TIME    ANGLE  TEL  FC    COL     ROW
```

```
#COMMENT:
# HEIGHT    DATE       TIME    ANGLE   TEL   FC    COL     ROW
   3.49 2017/10/18 05:48:05 139.0    C2    1    162.0   146.0
   5.54 2017/10/18 06:00:05 142.0    C2    1    116.0    75.0
   6.78 2017/10/18 06:06:07 139.1    C3    1    220.0   221.0
   8.71 2017/10/18 06:18:05 139.3    C3    1    209.0   208.0
  10.51 2017/10/18 06:30:05 141.2    C3    1    201.0   194.0
  11.30 2017/10/18 06:42:05 139.9    C3    1    195.0   190.0
  13.67 2017/10/18 06:54:06 135.7    C3    1    175.0   180.0
  14.95 2017/10/18 07:06:05 135.6    C3    1    167.0   172.0
  17.05 2017/10/18 07:18:06 135.6    C3    1    154.0   159.0
  18.09 2017/10/18 07:30:07 135.8    C3    1    148.0   152.0
  20.11 2017/10/18 07:42:06 134.1    C3    1    132.0   143.0
  21.24 2017/10/18 07:54:05 134.2    C3    1    125.0   136.0
  22.54 2017/10/18 08:06:05 133.8    C3    1    116.0   129.0
  24.64 2017/10/18 08:18:06 133.5    C3    1    102.0   117.0
  25.94 2017/10/18 08:30:06 134.0    C3    1     95.0   108.0
```

4. Analysis

Numerical Derivatives

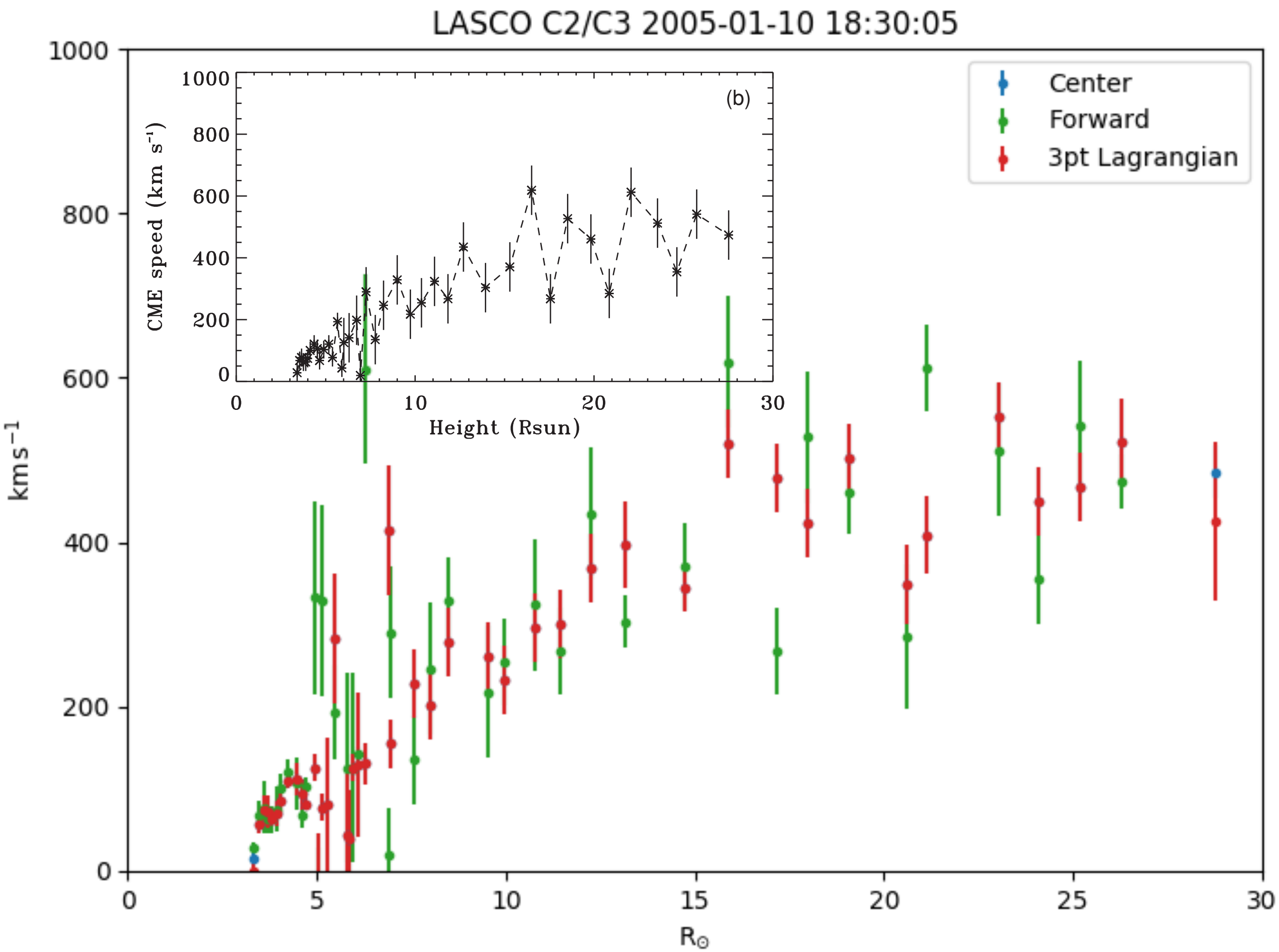
- Oscillations *visible* in velocity-time data need numerical differentiation to calculate from observed heights and times

  - Error propagation and approximation to a derivative

  - Different techniques give different results

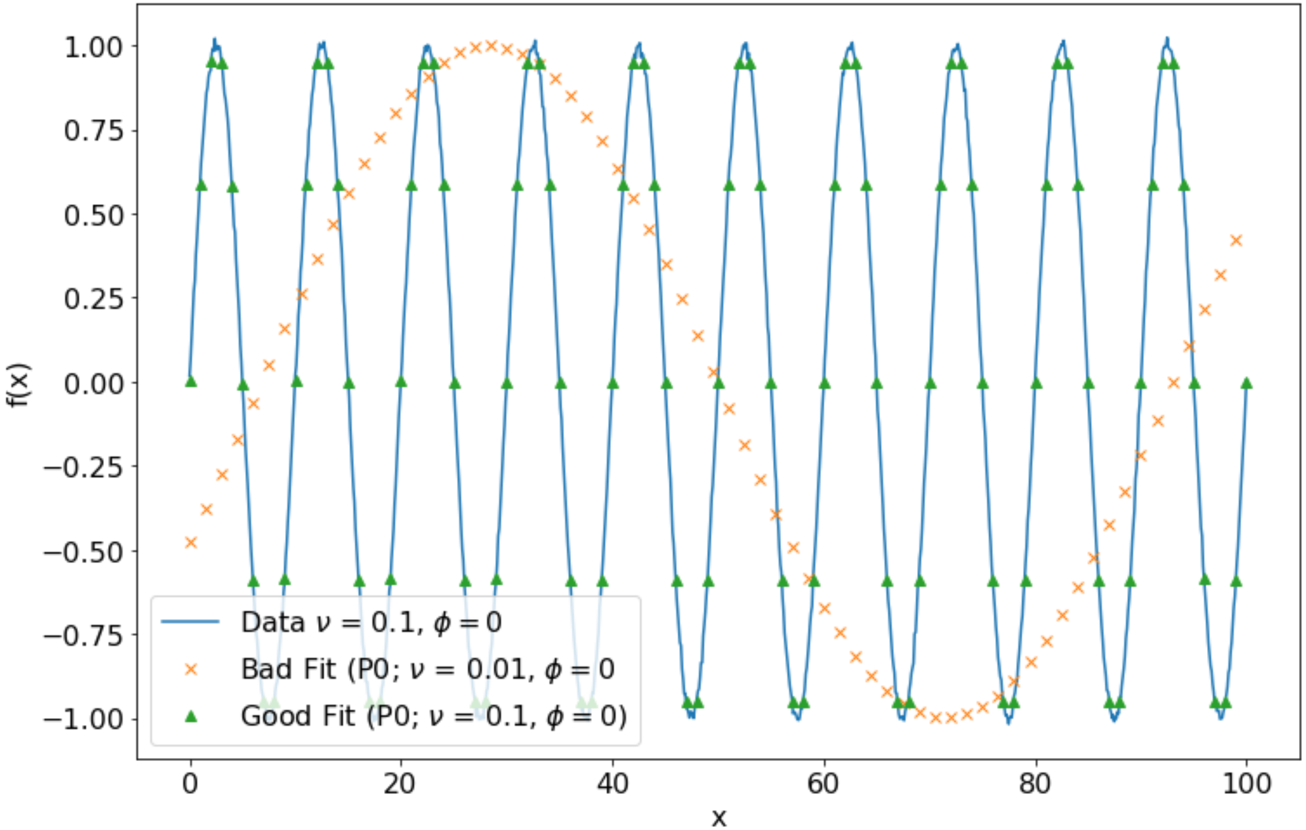
4. Analysis

Numerical Derivatives



4. Analysis
Fitting

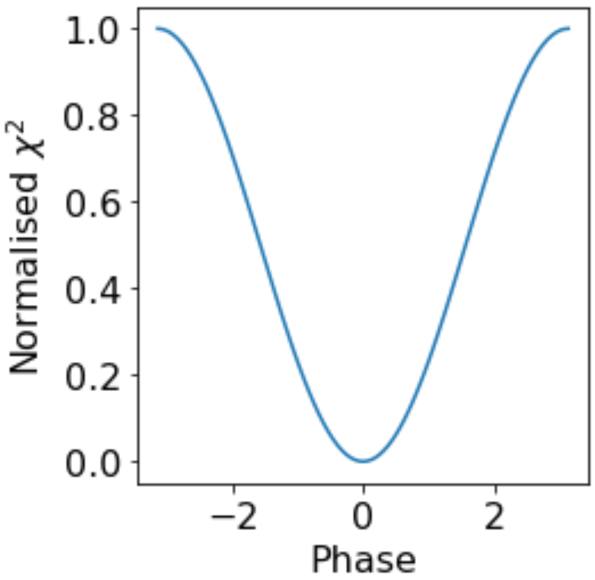
- Fitting even simple oscillatory functions leads to issues $f(x) = sin(2\pi\nu x + \phi)$



4. Analysis

Fitting

– Objective function or minimisation landscape



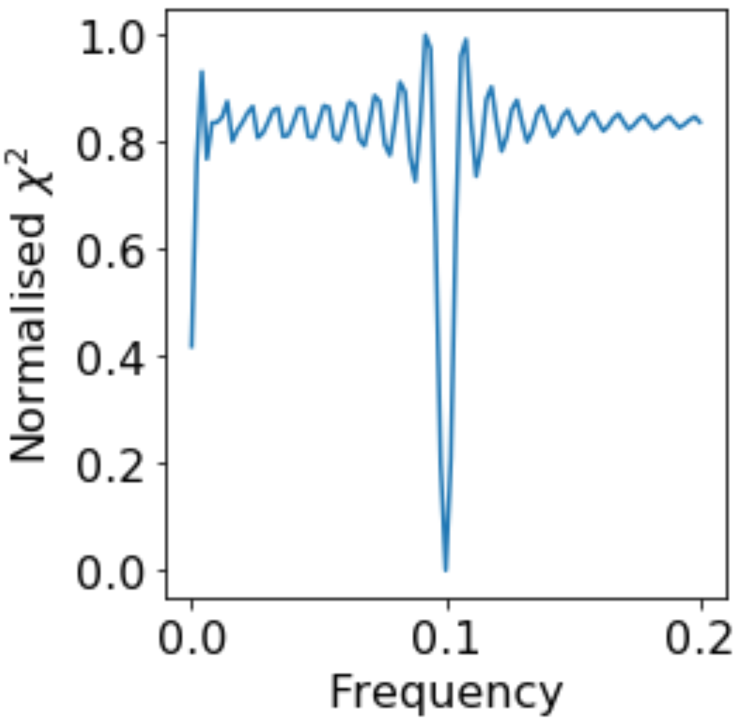
– Fix phase at correct value evaluate frequency dependance

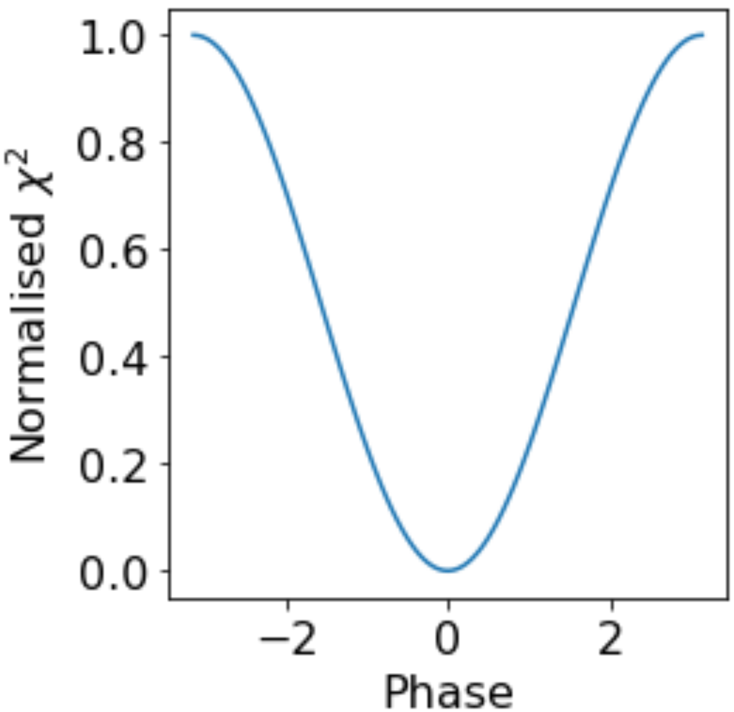
– Fix freq at correct value evaluate phase dependance

4. Analysis

Fitting

- Monte Carlo method - uniformly sample the initial condition space (Michalek et al. 2016)





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4. Analysis

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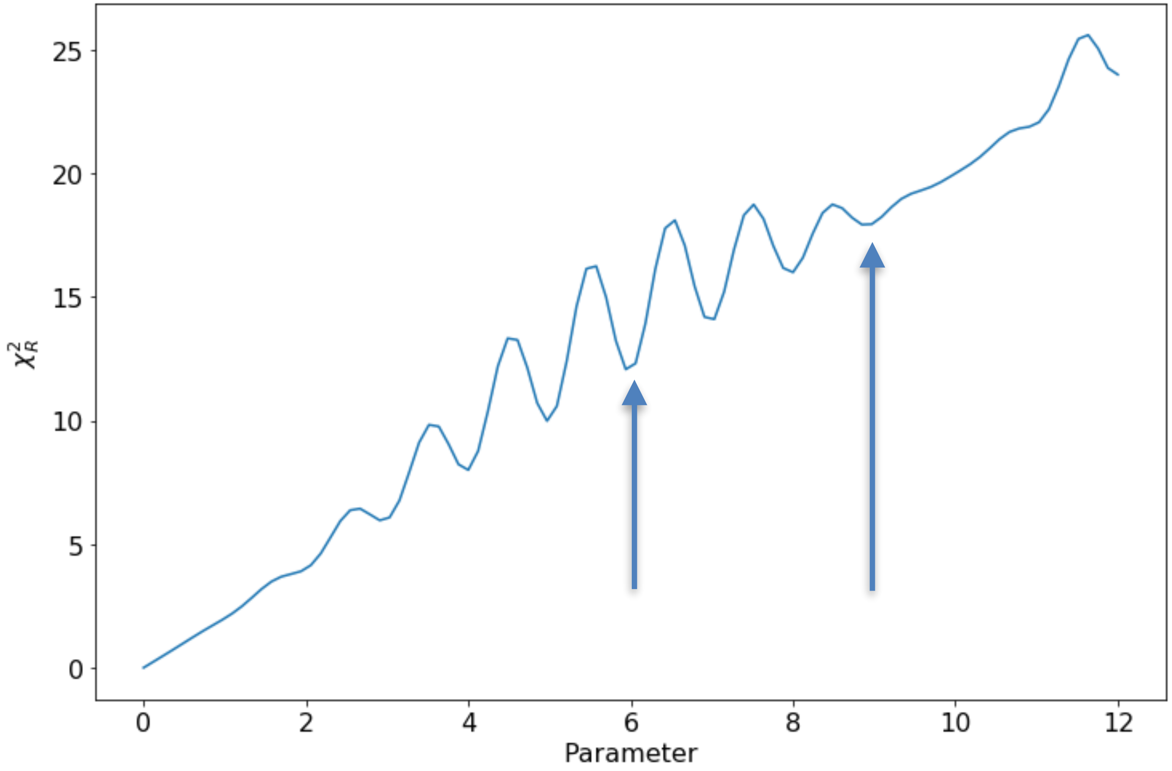
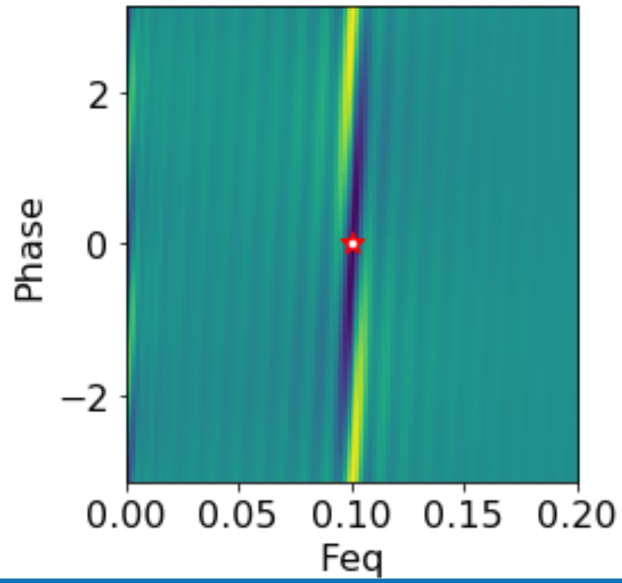


4. Analysis
Fitting

- Monte Carlo method - uniformly sample the initial condition space (Michalek et al. 2016)

- Grid Search - evaluate the initial condition on a grid



4. Analysis

Fitting

- Monte Carlo method - uniformly sample the initial condition space (Michalek et al. 2016)

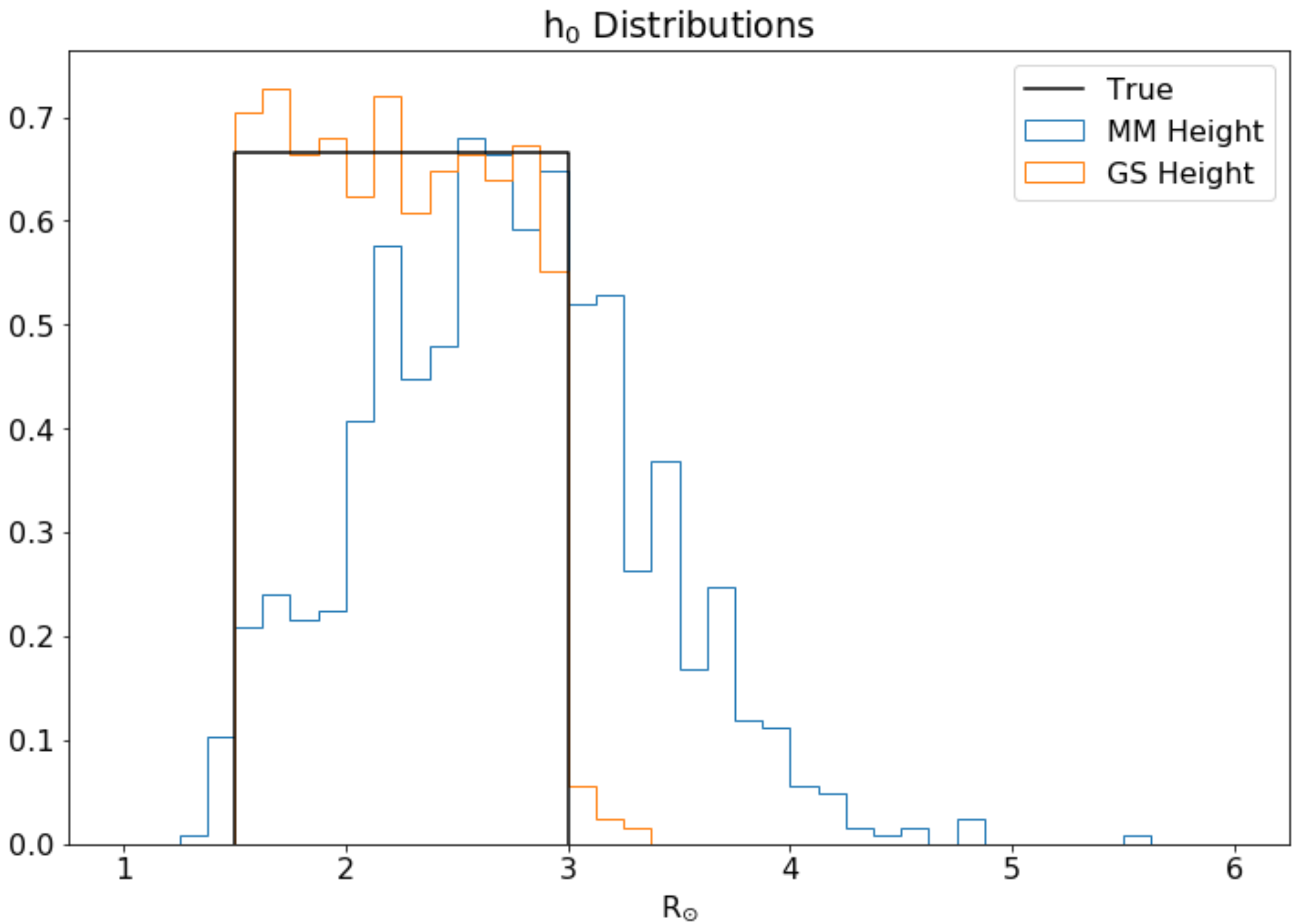
- Grid Search - evaluate the initial condition on a grid

- Simulate CMEs with parameters from sampled from known distributions and compare results from the methods

$$h = h_0 + v_0 t + \frac{1}{2} a_0 t^2 - \frac{A2\pi}{P} cos\left(\frac{2\pi t}{P} + \phi\right)$$

5. Results

Simulated Data



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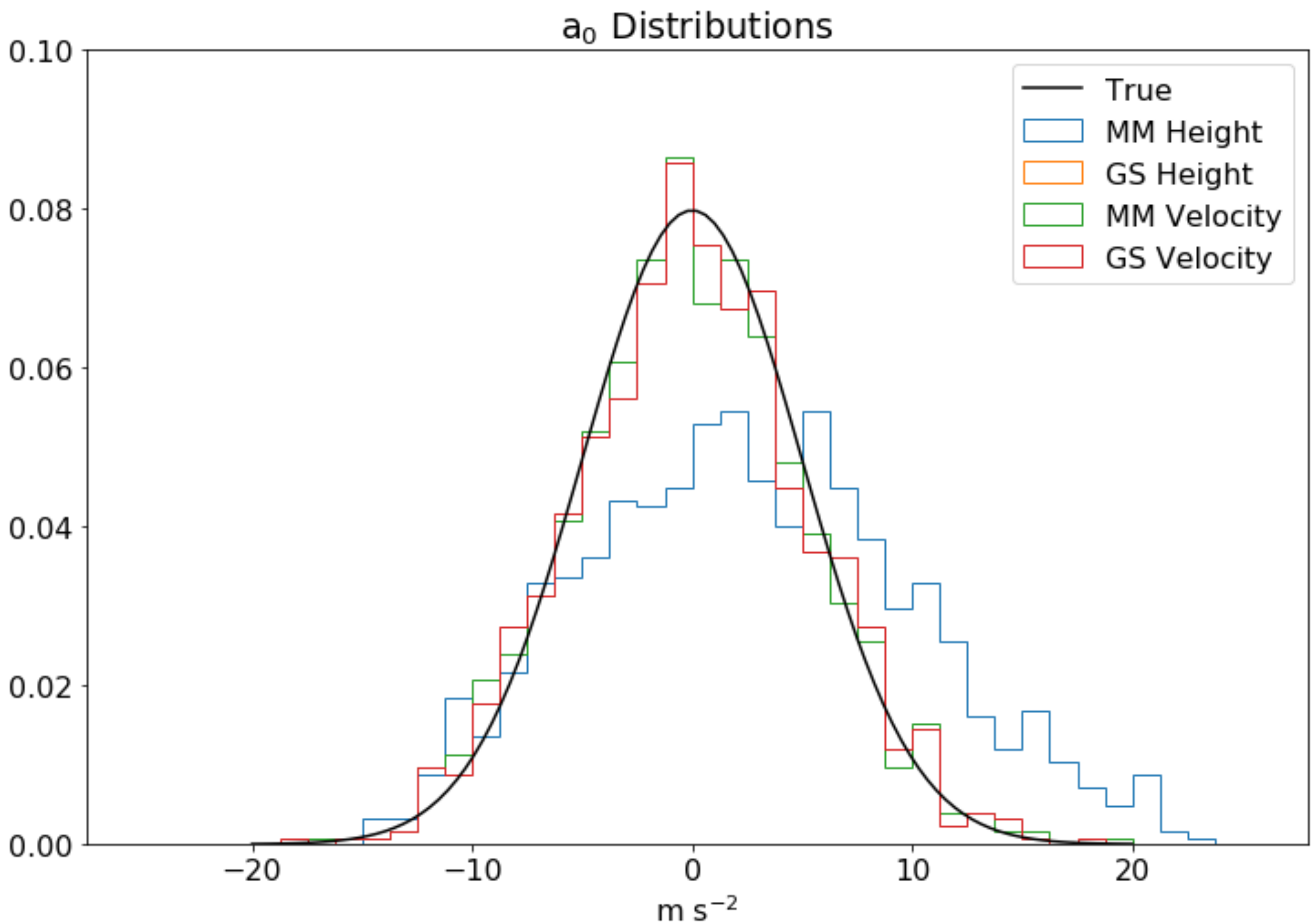

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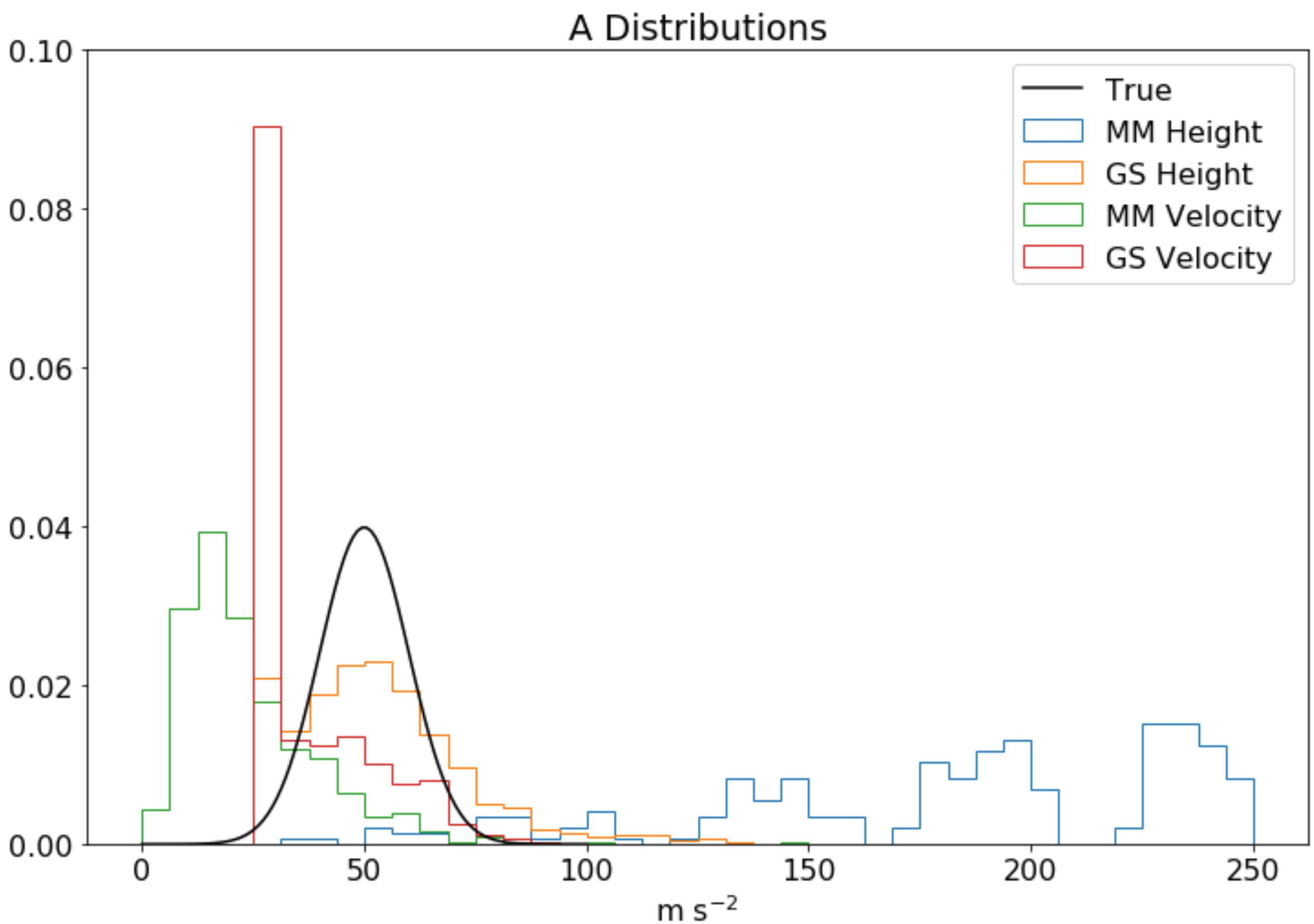

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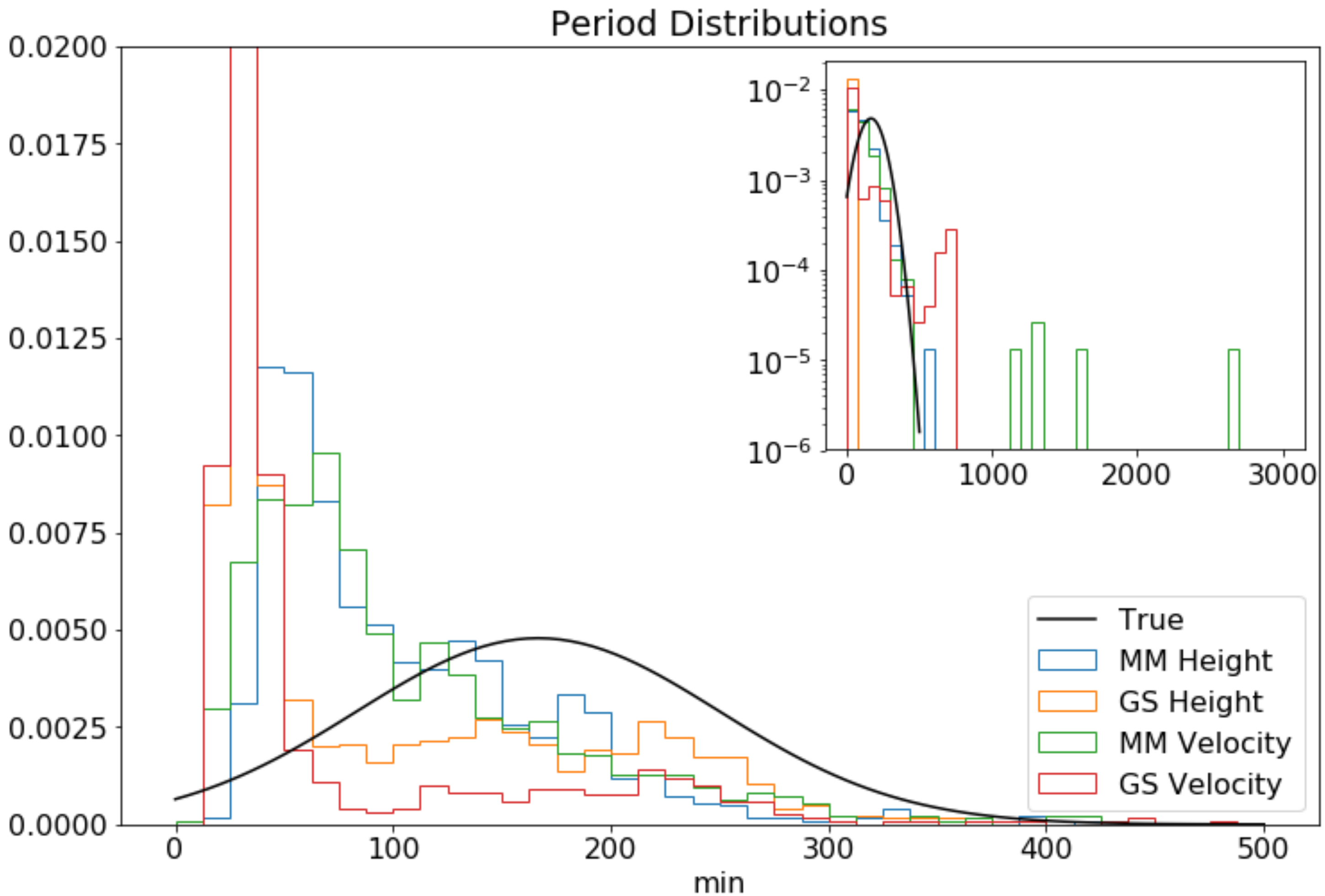
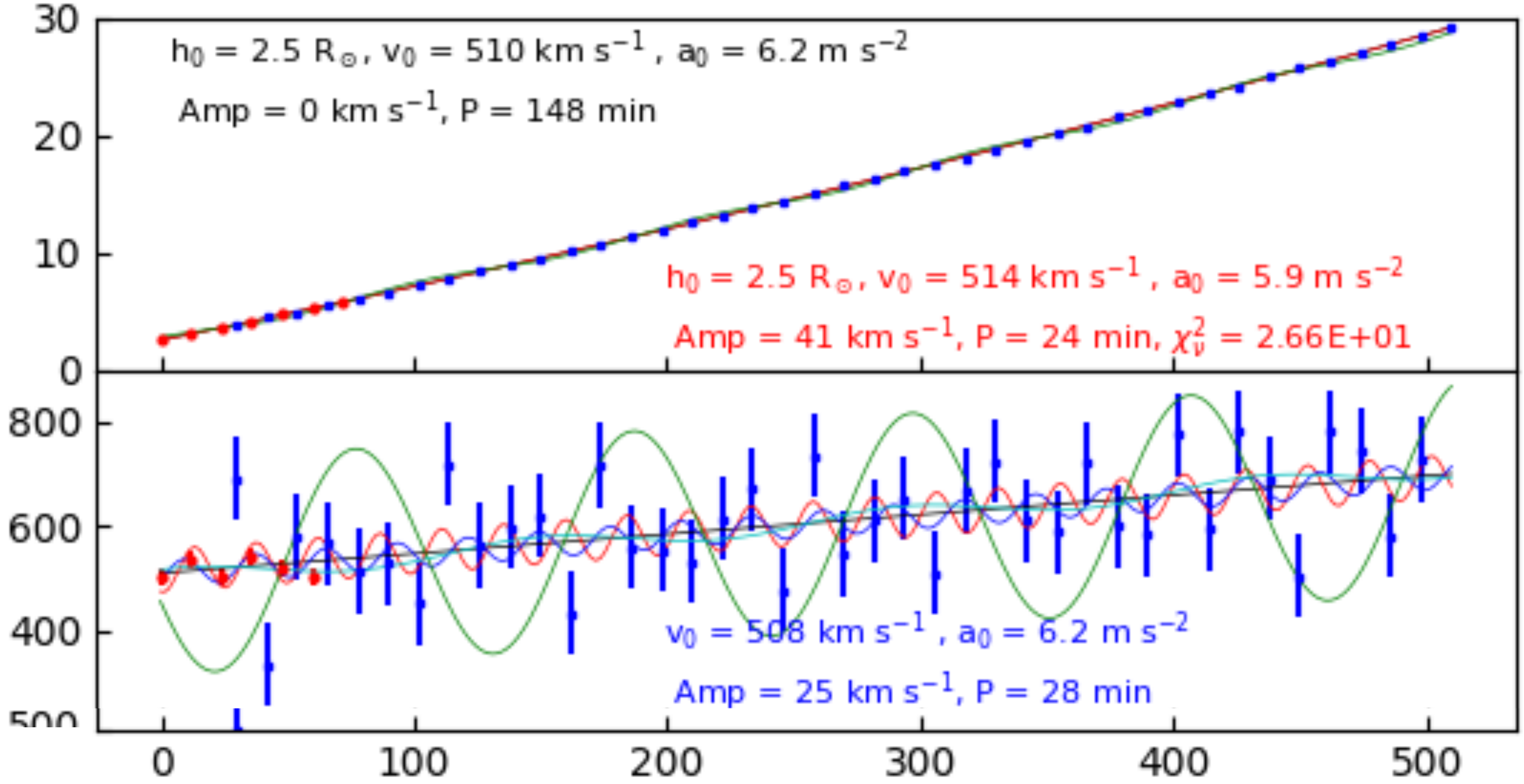


5. Results

Simulated Data

Simulated CME



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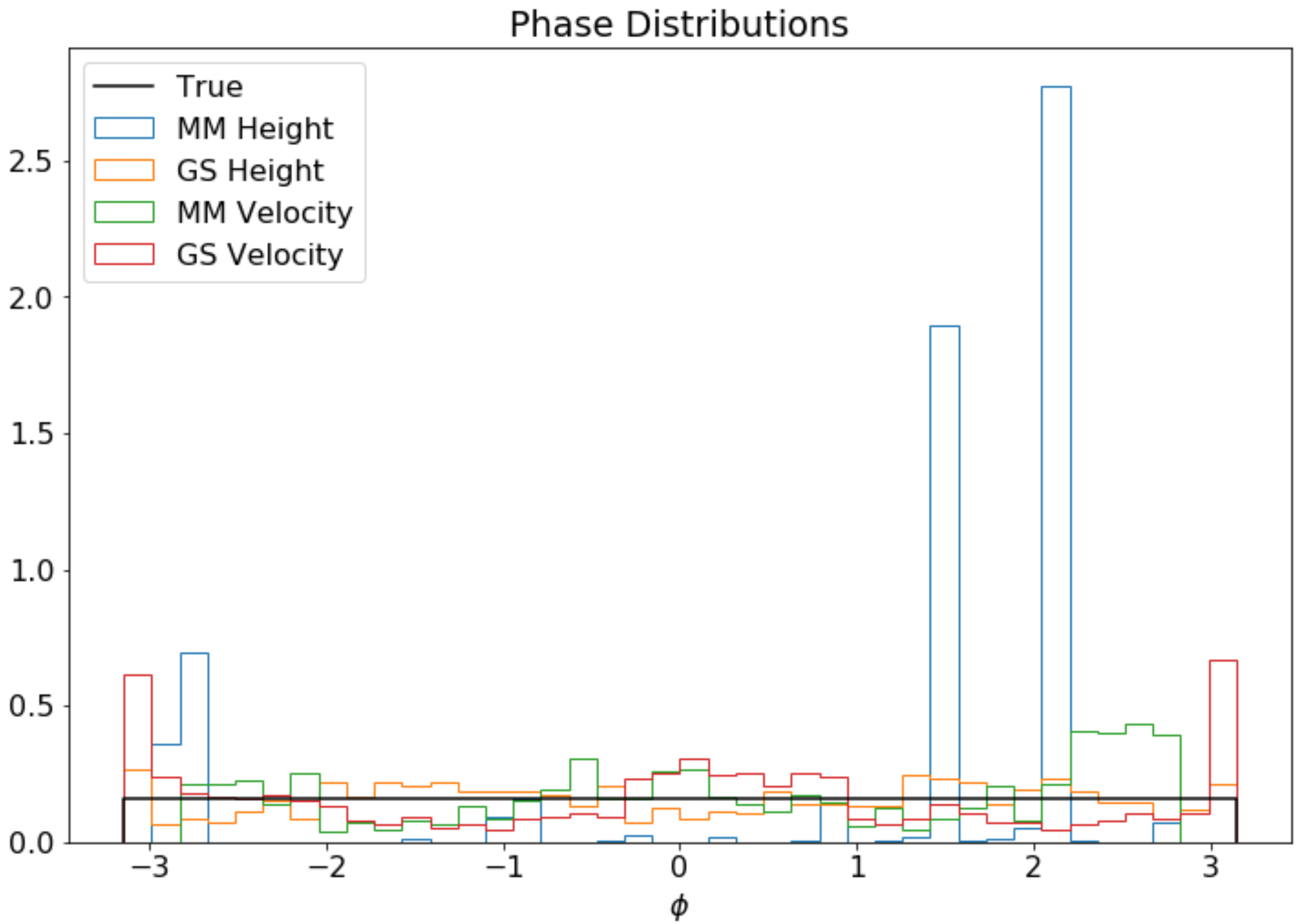

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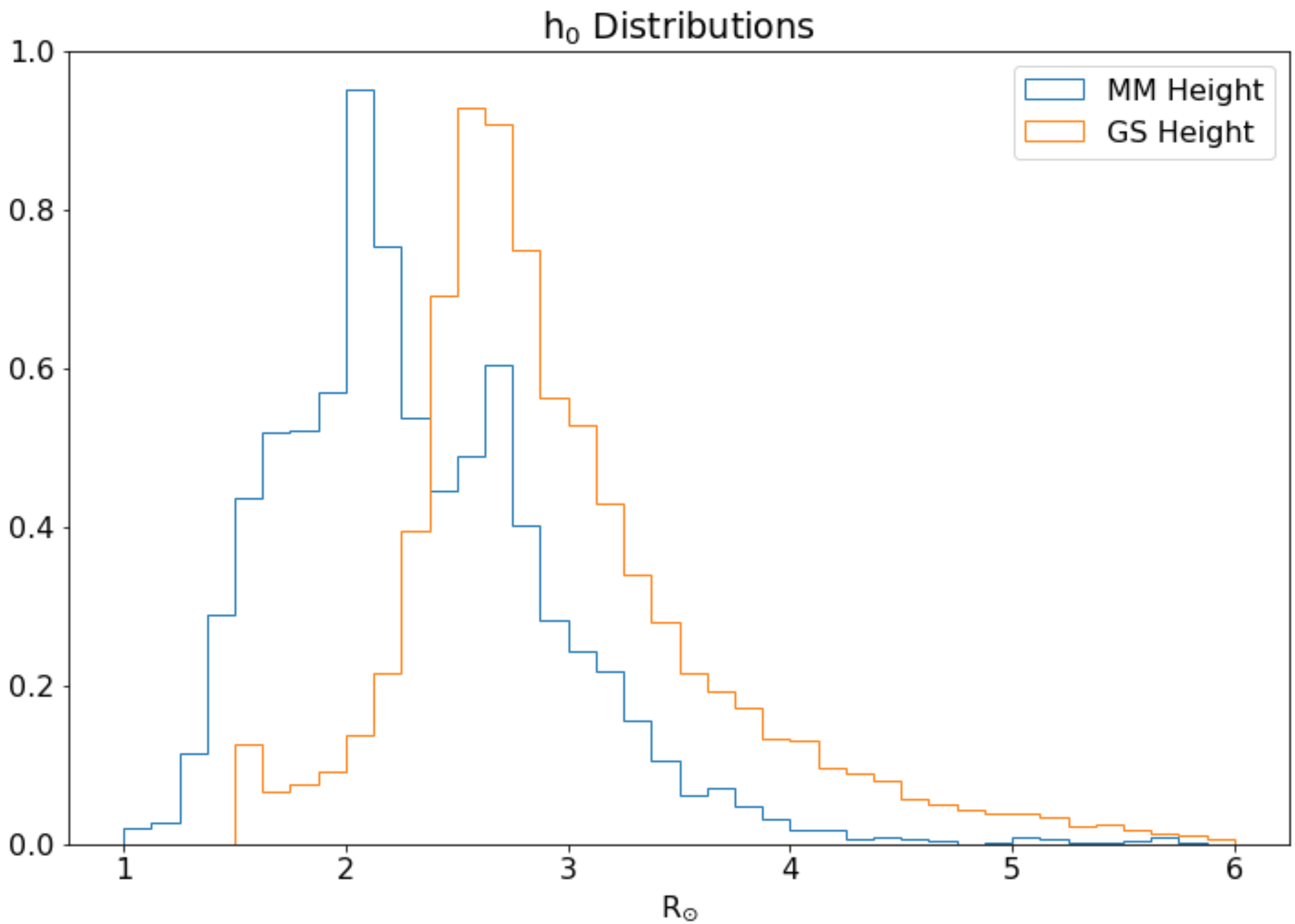
5. Results

LASCO CME Catalogue



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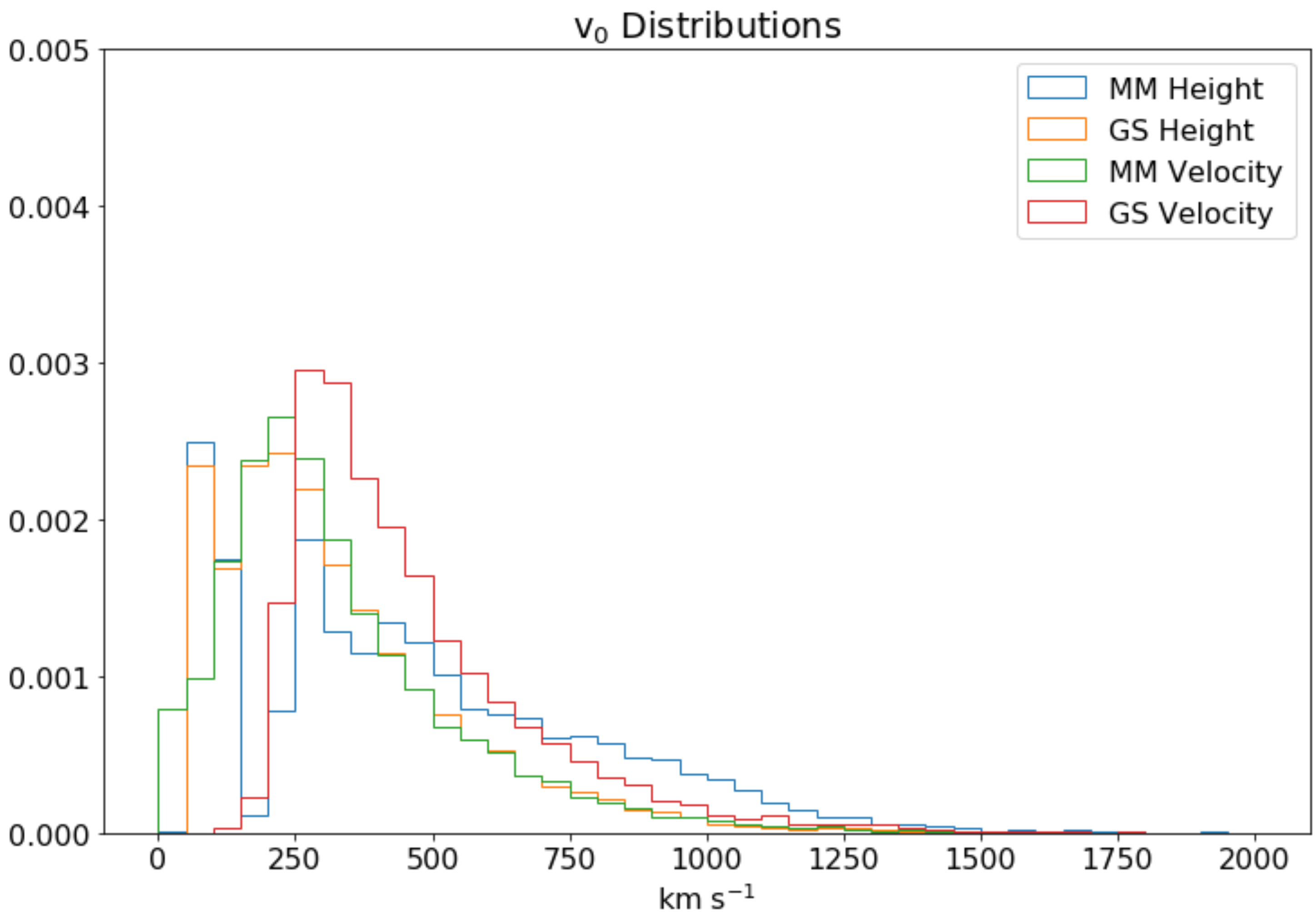

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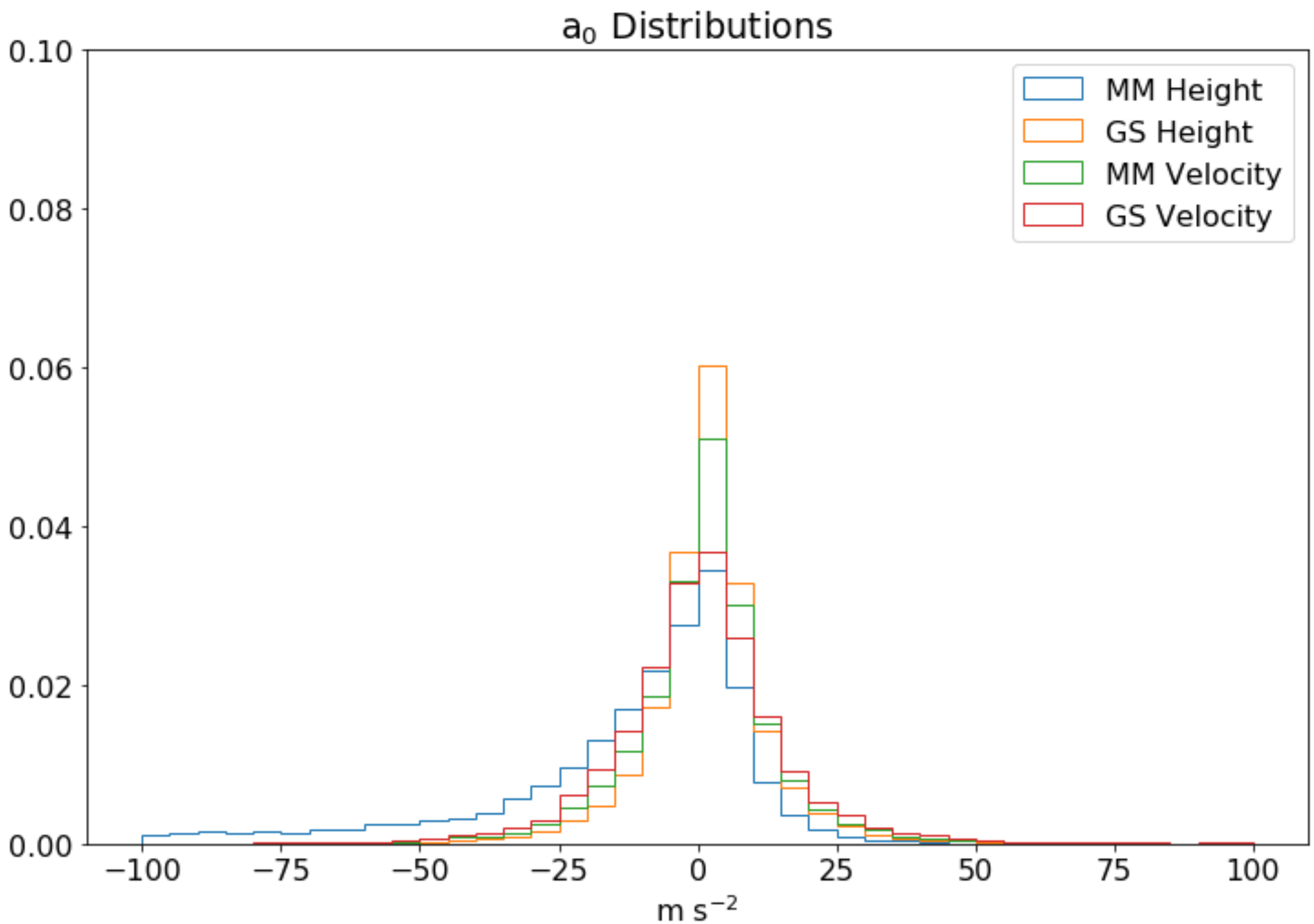

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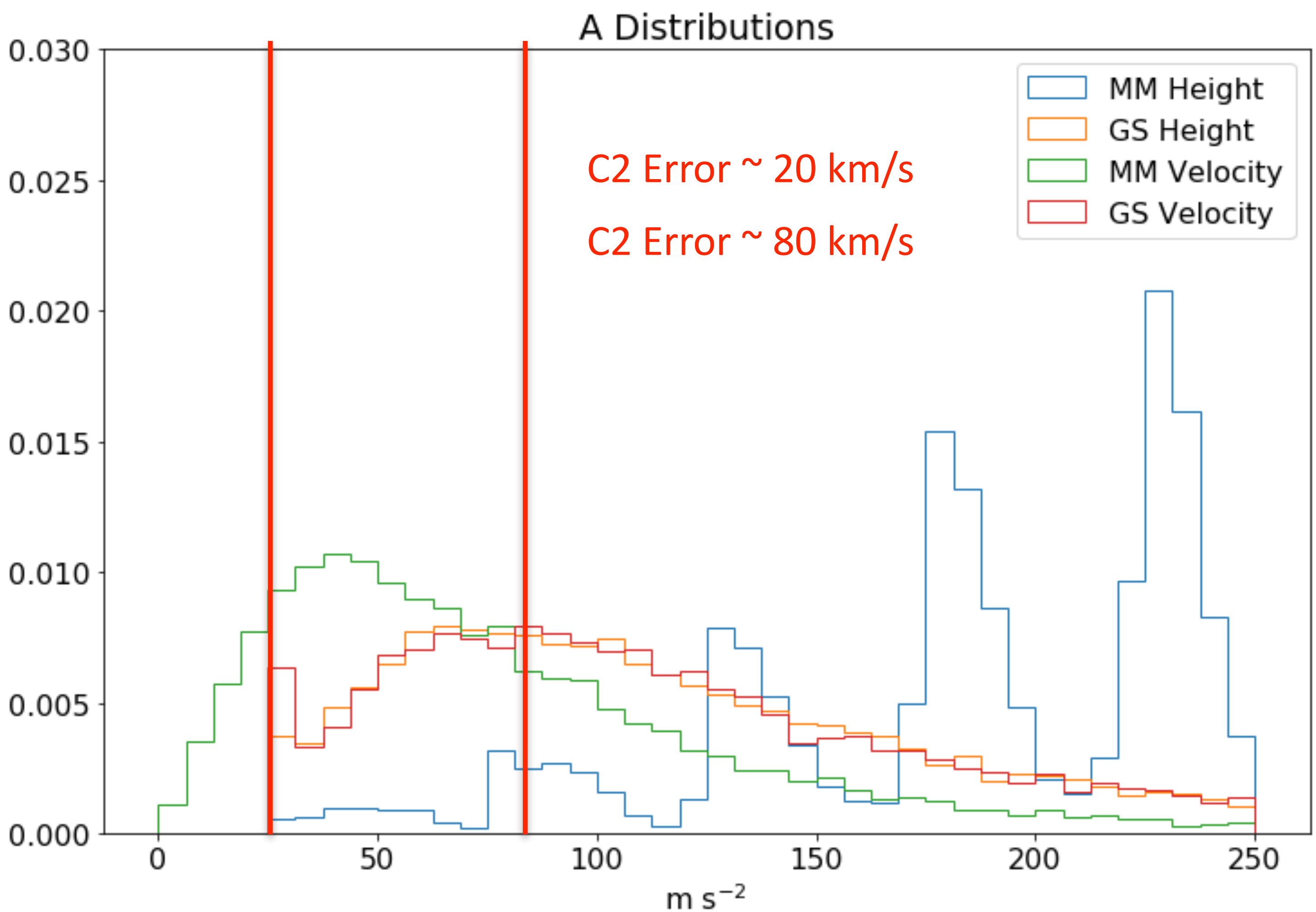

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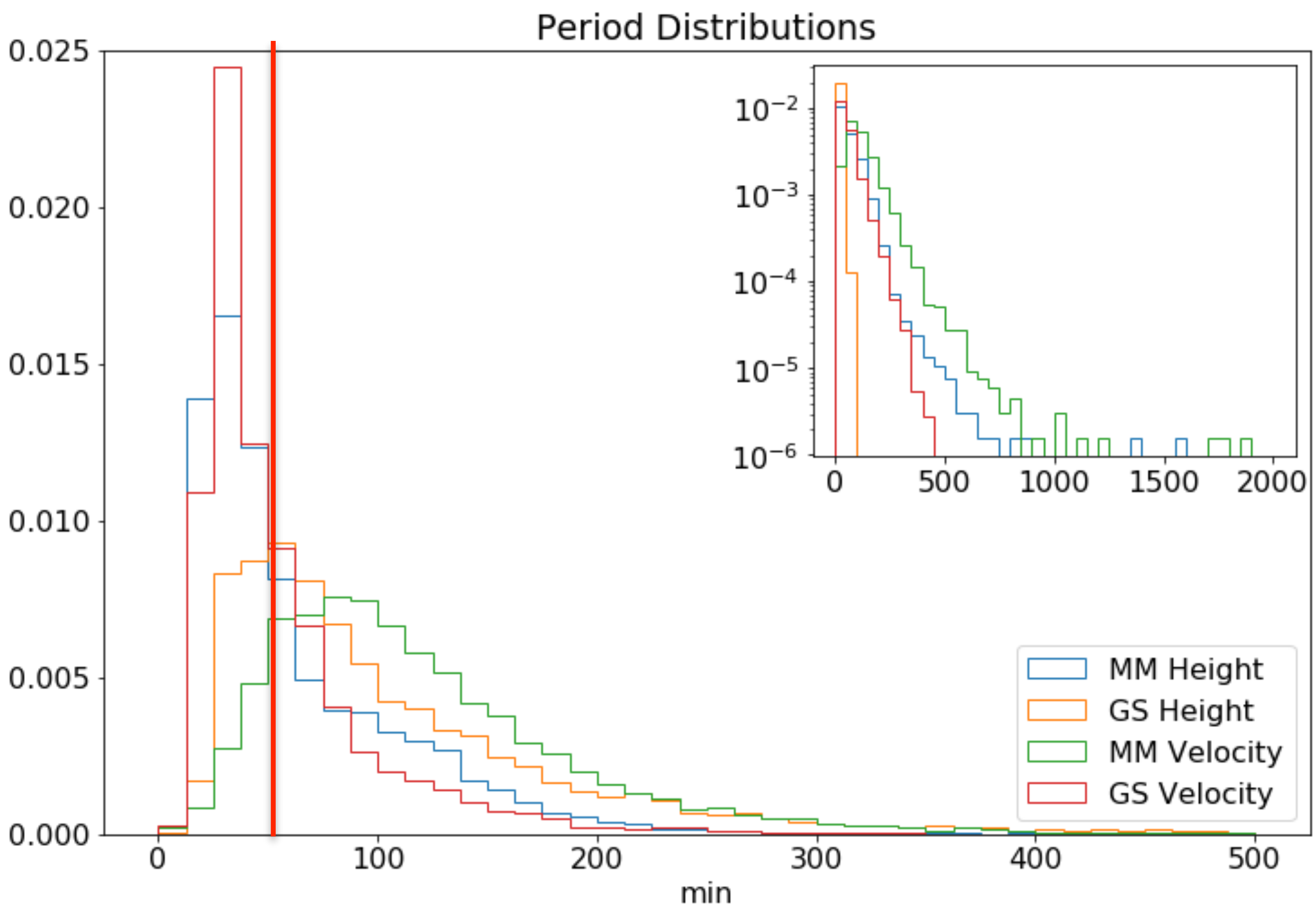

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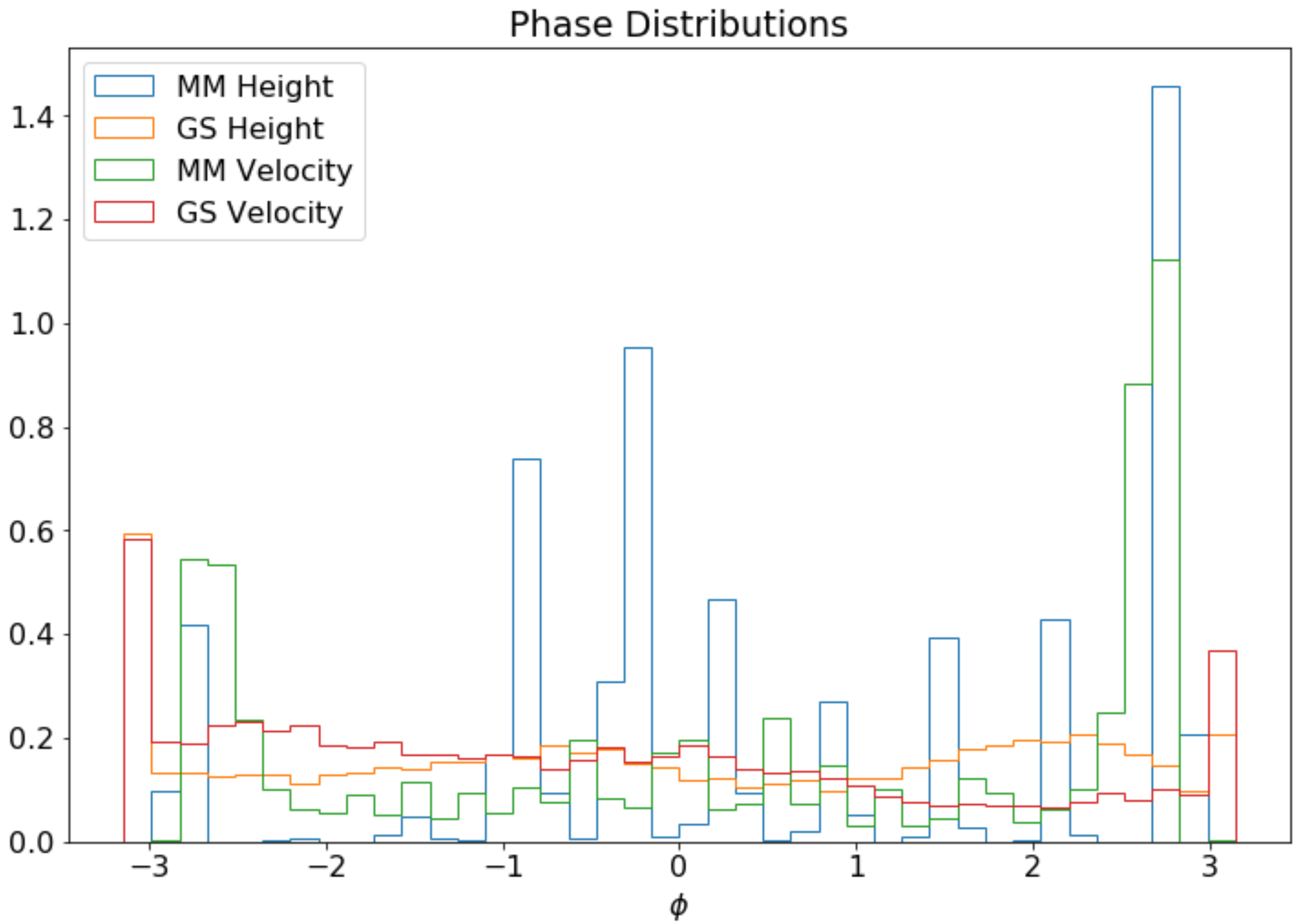

6. Conclusions

- Unclear if oscillatory signatures are statistically significant.
- Grid search method seems marginally more stable and accurate.
- Chose between models -> closest χ_R^2 to 1?
- Bayesian methods
  - Marginalise unimportant parameters
  - Bayesian Information Criterion to choose model