Differentiating the Signal from the Noise

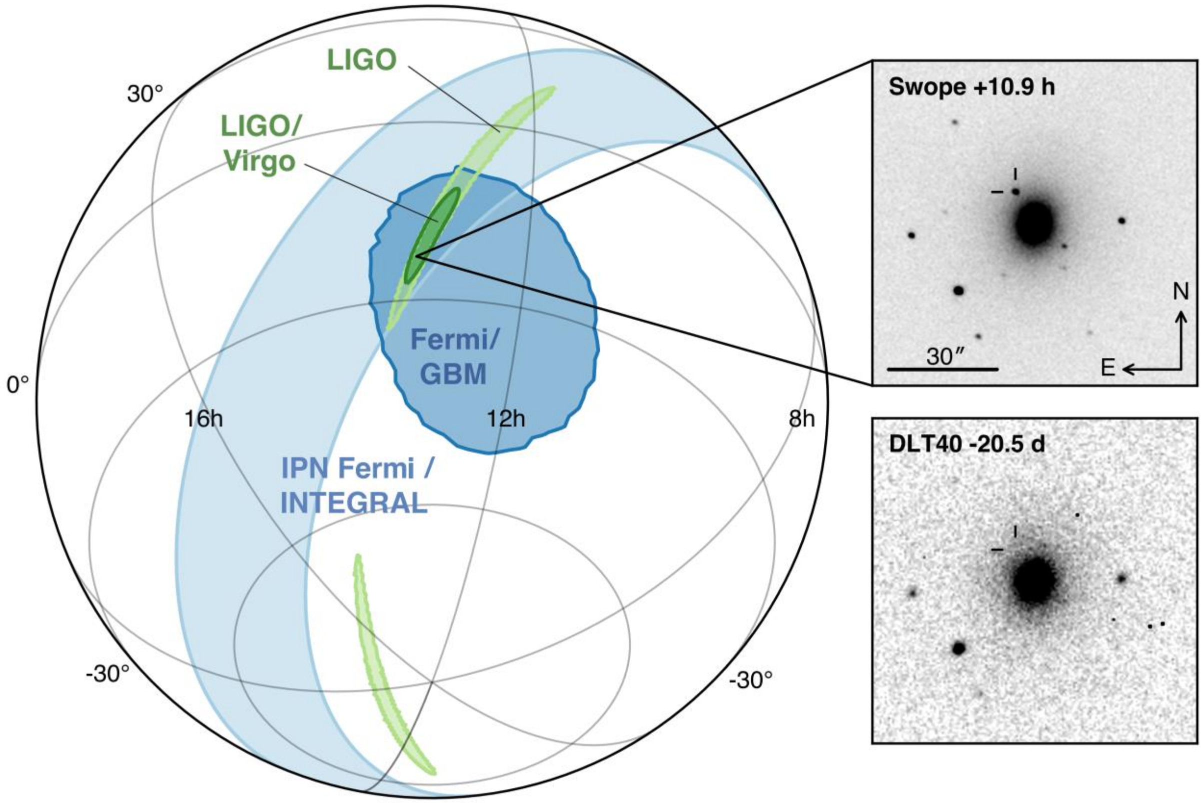
Towards Optimal Choices of Transient Follow-up

BETHANY SUTER

MENTORS: ALEX URBAN, MICHAEL COUGHLIN

Background

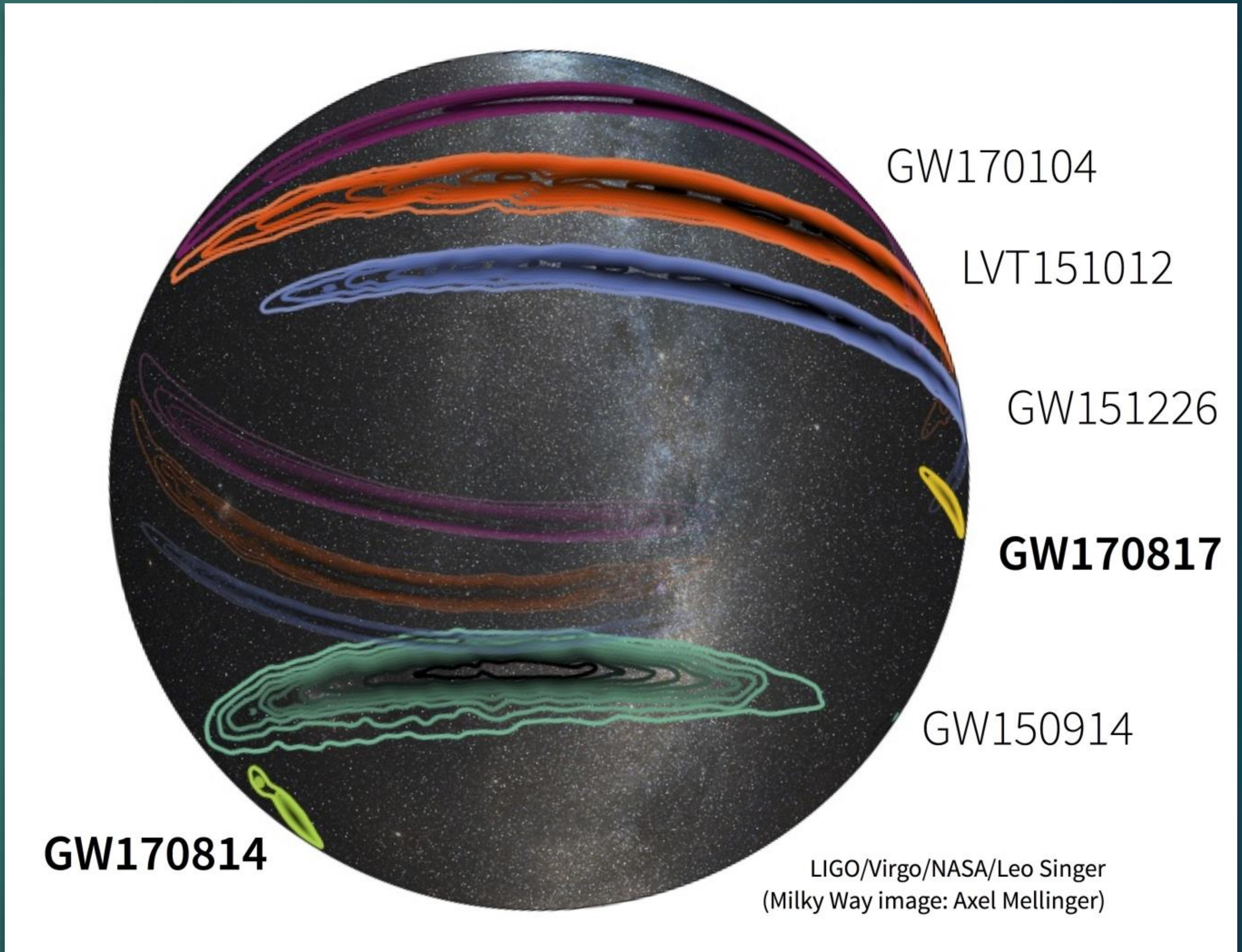
- GW170817 – first binary neutron star merger witnessed by LIGO
- GW170817 was optimal
  - Close
  - Strong signal
  - Unseen in VIRGO
  - Small localization region
  - EM counterpart



Credit: LSC/LIGO

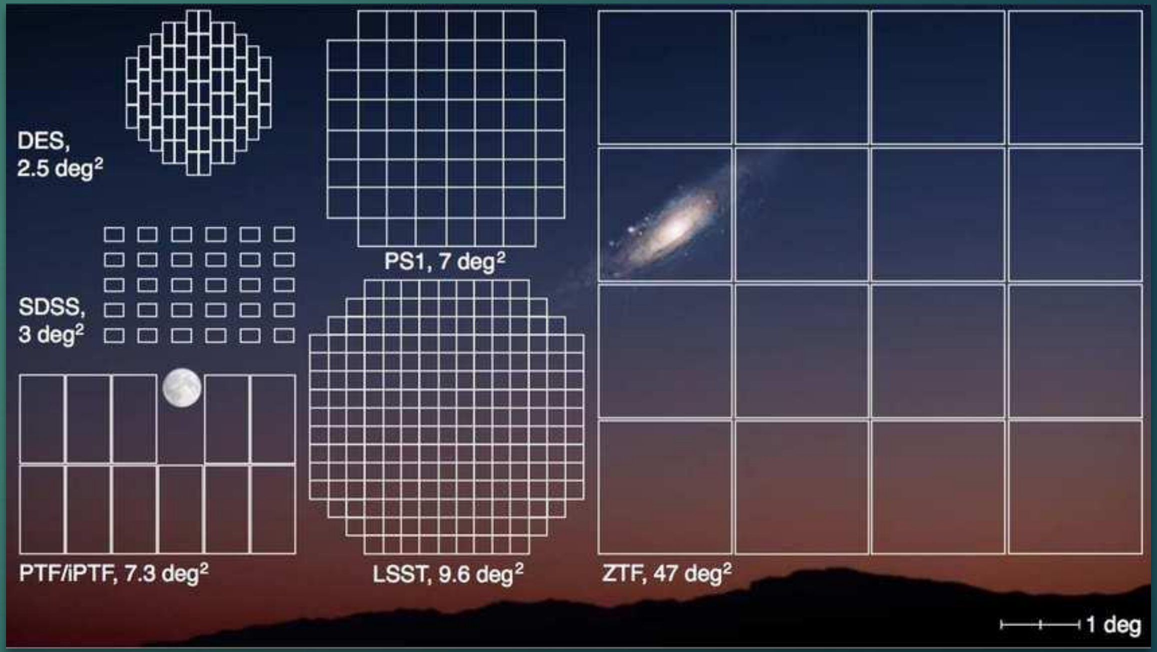
Background

- Third run of LIGO beginning soon, new discoveries expected
- Unlikely for new discoveries to be optimal like GW170817
- Large localization regions
- Binary neutron star (BNS) mergers require EM follow-up



Background

- Large Field of View Telescopes
  - ZTF – Zwicky Transient Factory
  - Other telescopes – Panstar, ATLAS, DECam
- Can cover night sky several times in one night
- Perfect for EM follow-up of BNS mergers

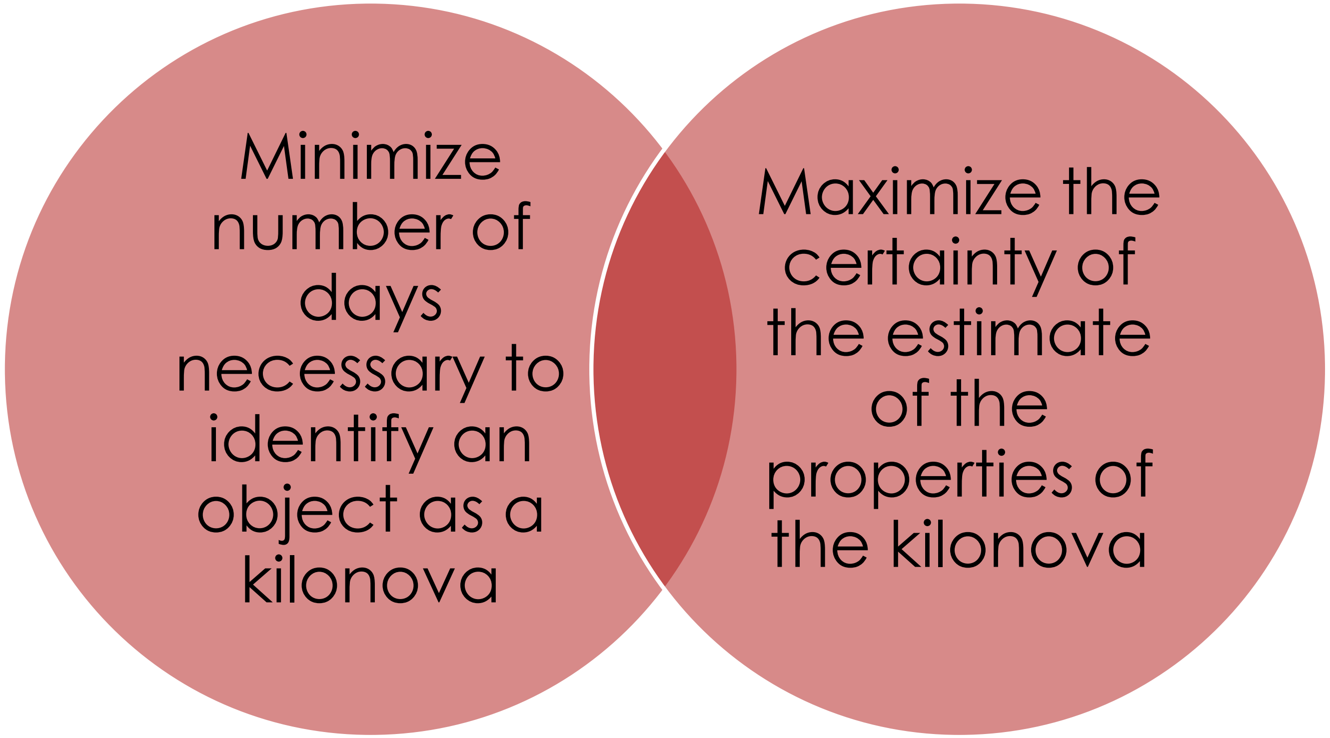


Credit: ResearchGate/Joel Johansson

Problem

- Even with large field of view telescopes, since telescope time is limited, we still need efficient follow-up of kilonova candidates.
- We must create prioritized lists based on the many identified candidates.

Goal


Minimize number of days necessary to identify an object as a kilonova
Maximize the certainty of the estimate of the properties of the kilonova

Methods

Photometry

Spectra

What is Photometry?

"**Photometry** is a technique in astronomy concerned with measuring the flux of an astronomical object's electromagnetic radiation over time."[1]

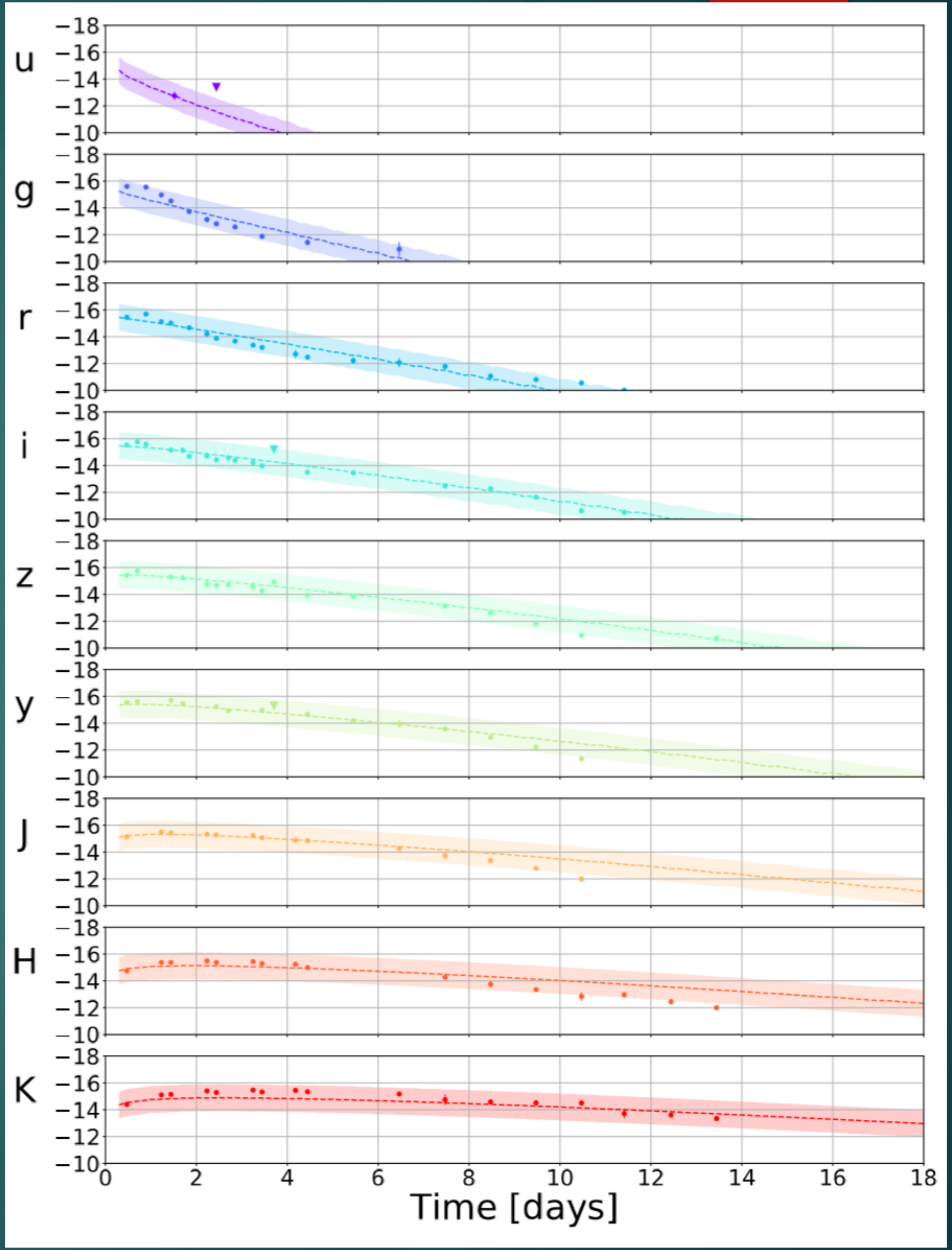
- Especially important for studies of transient objects like kilonovae
- Each type of transient has different characteristic lightcurves.
- Various means for objects to emit radiation – black body, synchrotron, Bremsstrahlung

[1]Credit: Wikipedia

Methods

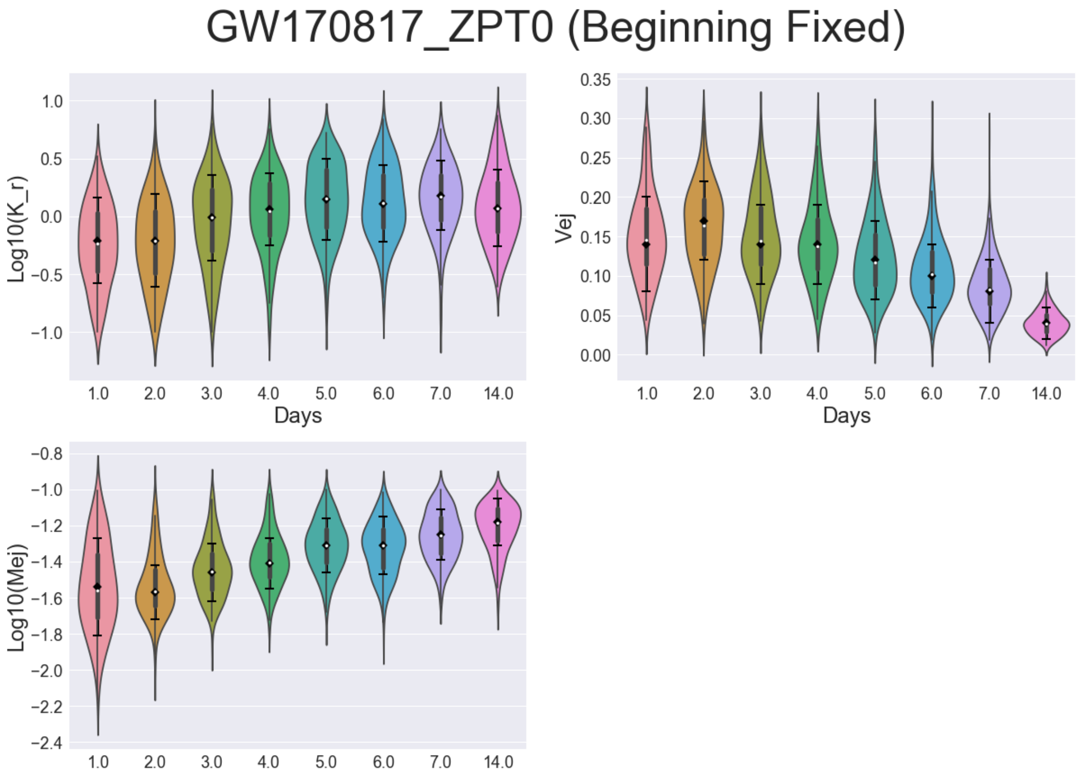
- Used Metzger 2017 model
  - Based on modeling the lightcurve of the ejecta as a black body
  - Determines mass of ejecta, velocity of ejecta, and lanthanide fraction
- Ran on GW170817 data, varying parameters
- Ran on various other transients – ATLAS18qqn, GRB090426 , GRB051221A

GW170817 Lightcurve
Passbands/filters: ugrizyHJK
14 days of data



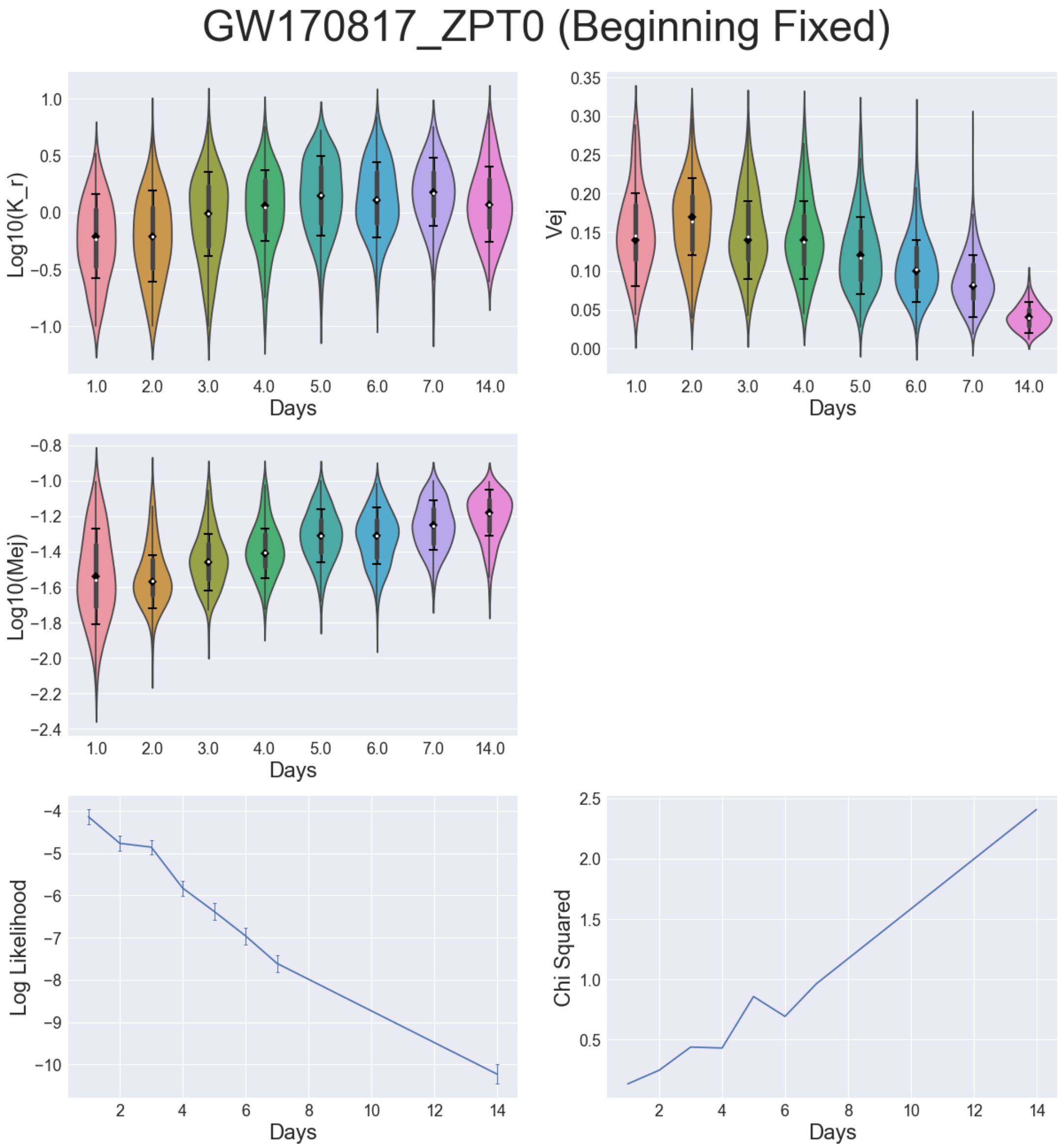
Methods

1. Varying number of days
2. Varying starting day
3. Varying zero point and T0
4. Varying cadences
5. Varying passbands



Varying Number of Days
§
GW170817

- X axis
  - the number of days of data used
  - Beginning fixed
- Y axis
  - the value of the parameter
- Violin plots
  - show the distribution of the parameter.
  - Shorter and fatter == better



Varying Number of Days
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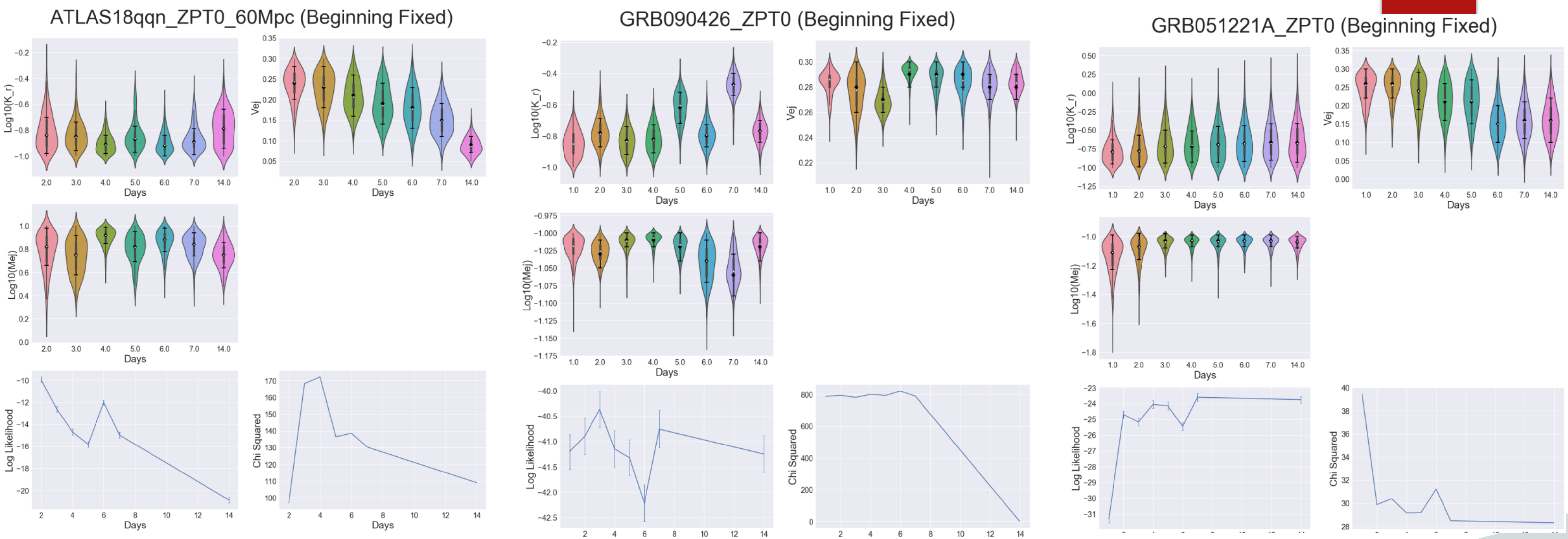
GW170817

- Log likelihood
  - Larger == better
- χ^2
  - Smaller == better
- Fit worse because of more data
- 4 day cutoff



Varying Number of Days
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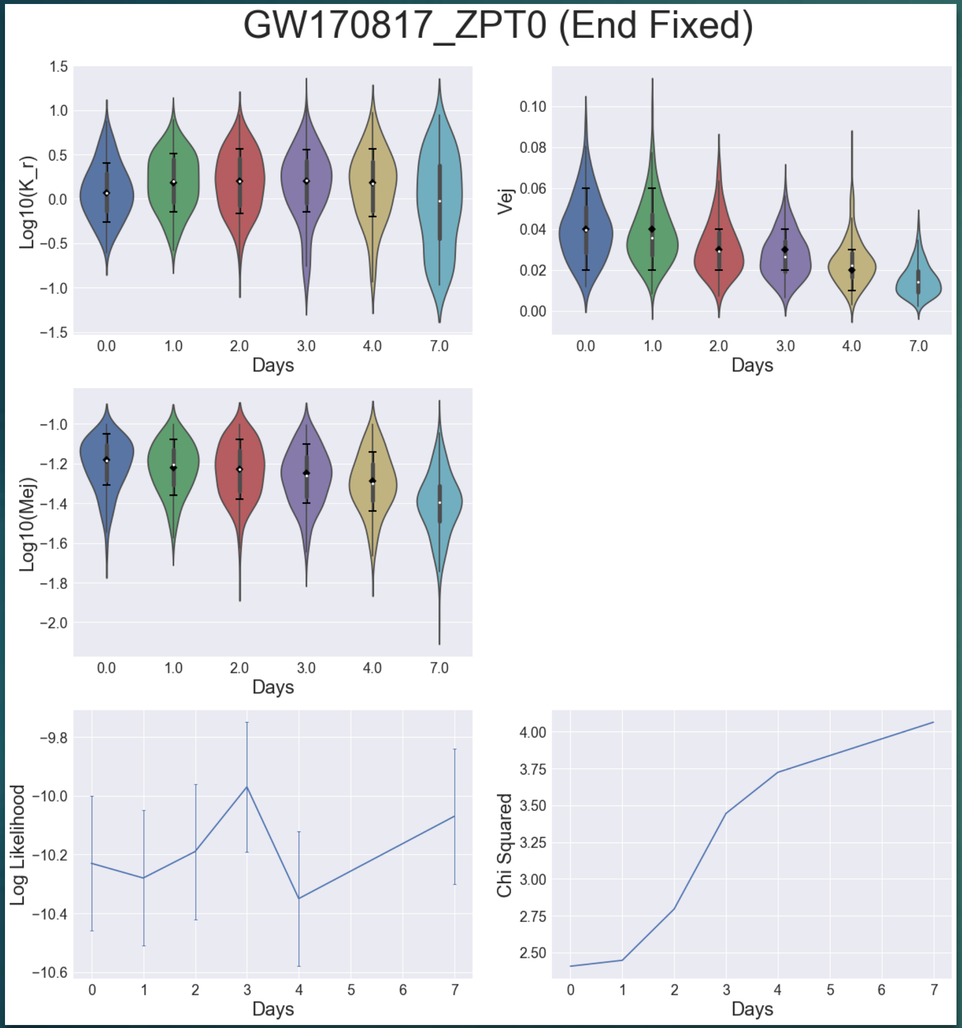
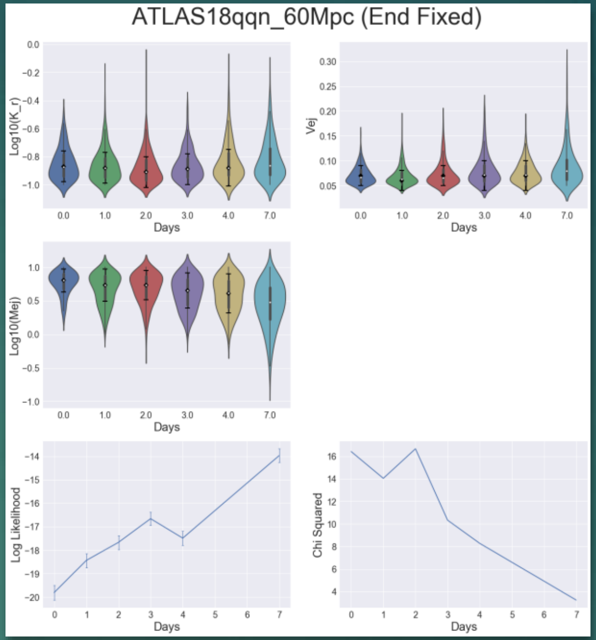
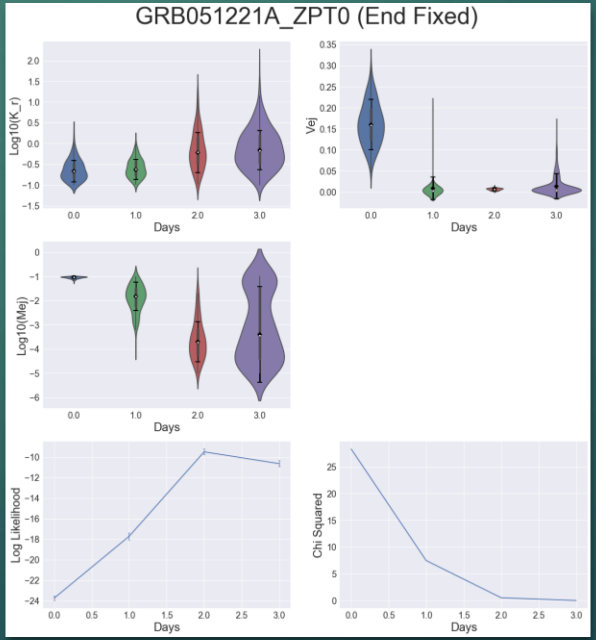
Other Transient Objects

- Types of transient objects
    - Possible supernova, GRBs
- Irregularity of properties
- Lowness of log likelihood



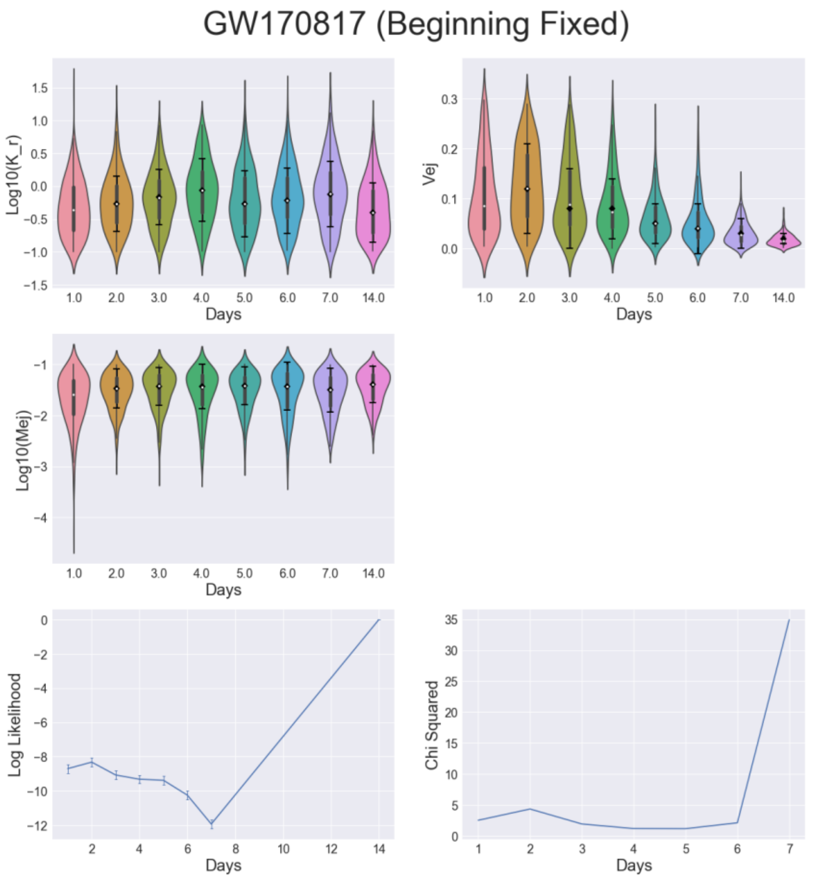


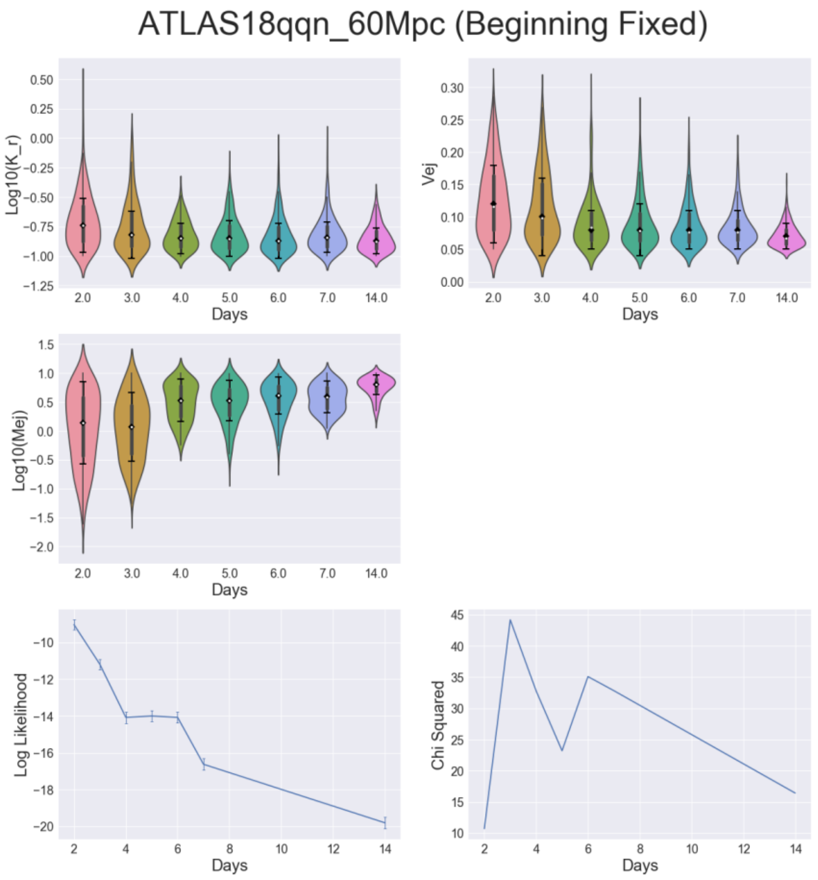


Varying starting day

- ATLAS18qqn
  - Regular properties
  - Low likelihood
- GRB051221A
  - Irregular properties
  - Low likelihood before 2 days after

Varying zero point and T0

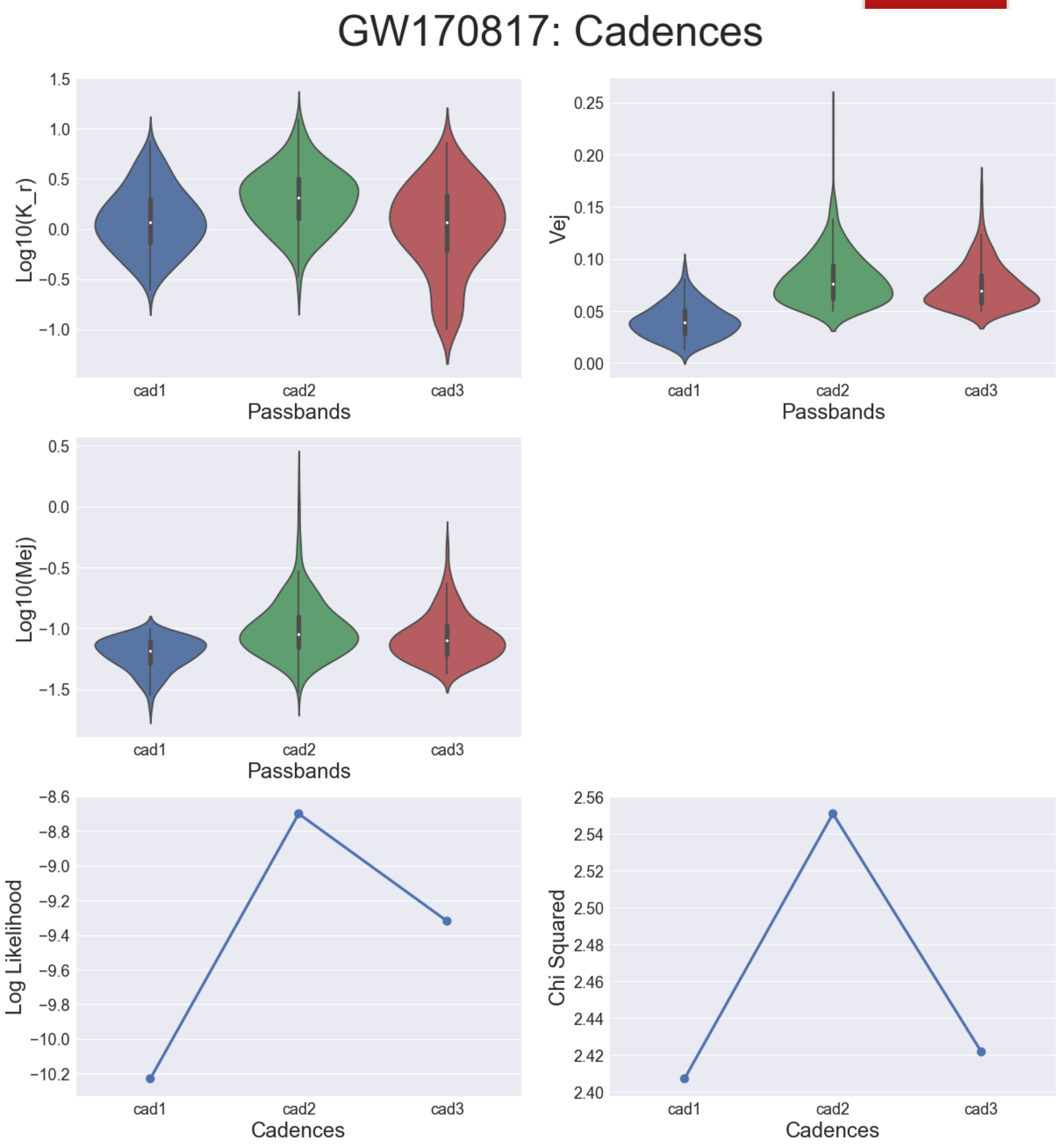


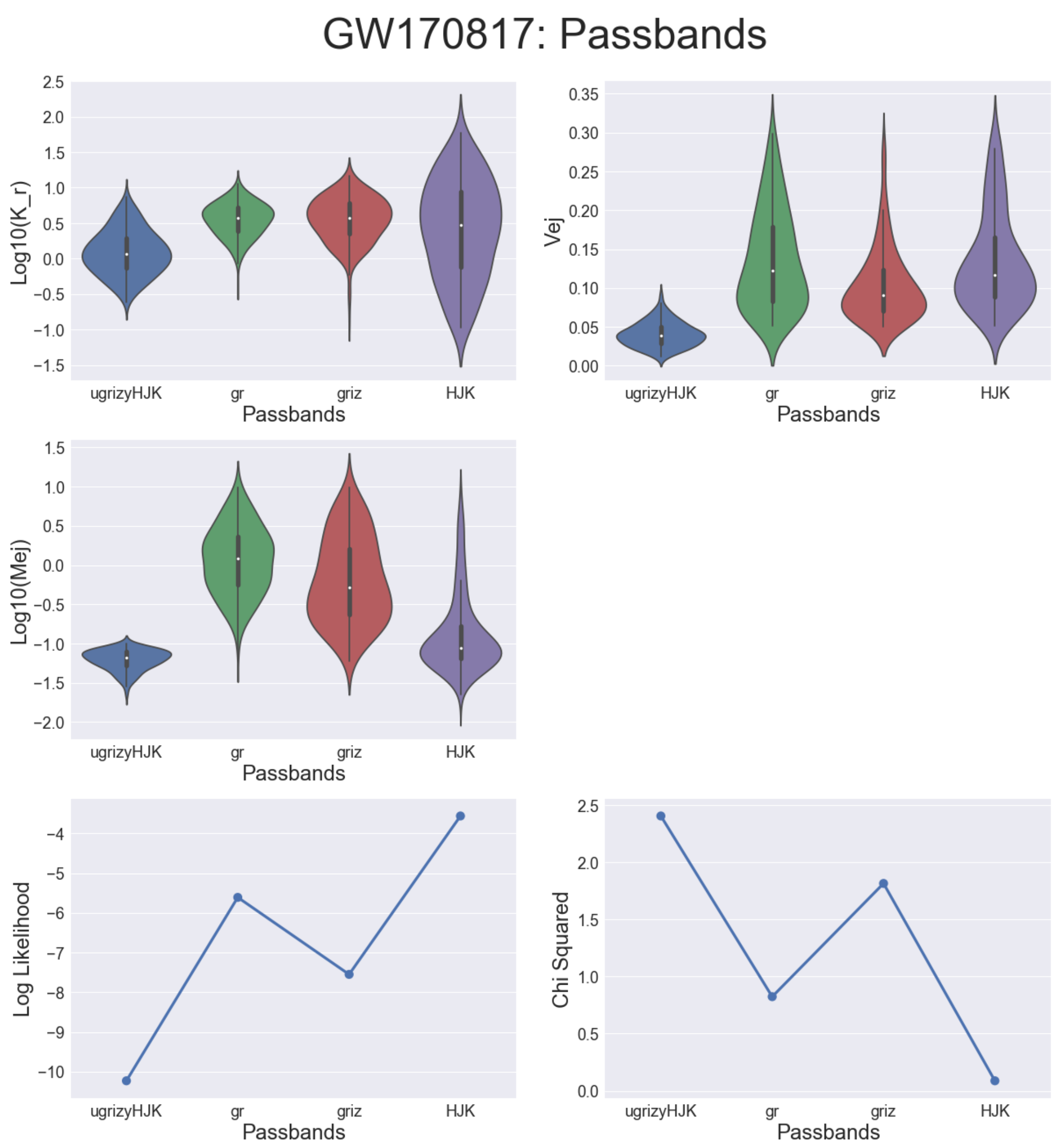


- Distance calculation errors
  - Causes lower relative magnitude
- ATLAS18qqn
  - Regular properties
  - Higher log likelihood

Varying Cadences

- X axis
  - Number of days in between data collection
  - Cad1 == every night
- Different cadences do not lose too much information
- Cad2 - rise in log likelihood due to less data
- Cad3 - fall in log likelihood due to poor fit





Varying Passbands

- X axis
  - Different combinations of various wavelength filters
- Clearly need all passbands to accurately determine properties
- Rise in log likelihood again due to less data

Discussion

- Determined best parameters to identify kilonovae
  - Log likelihood > -10
  - 4 days of data
- Other requirements
  - Need early data
  - Need to fix zero point and T0
  - Need to take data at least every other day
  - Need all passbands

Credit: Palomar Observatory

Spectra

Astronomical Spectroscopy is a method of astronomy which measures the spectrum of electromagnetic radiation which radiates from stars and other celestial objects in order to determine their various physical properties.[1]

- Used Kasen et al 2017 model
  - Based on modeling the spectra of the ejecta not only as a blackbody
  - Determines mass of ejecta, velocity of ejecta, and lanthanide fraction
- Created a whitening technique

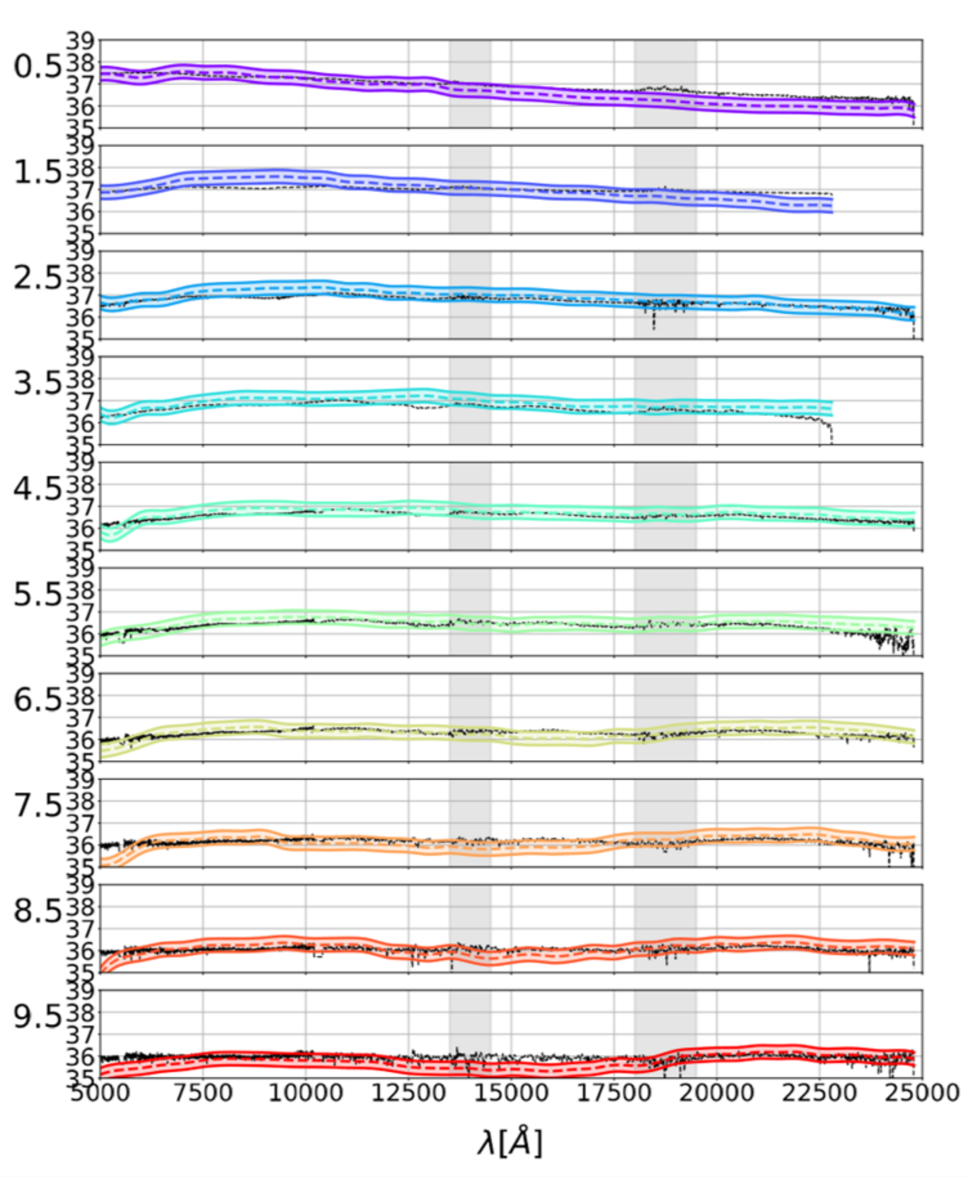
[1]Credit: Wikipedia

Whitening

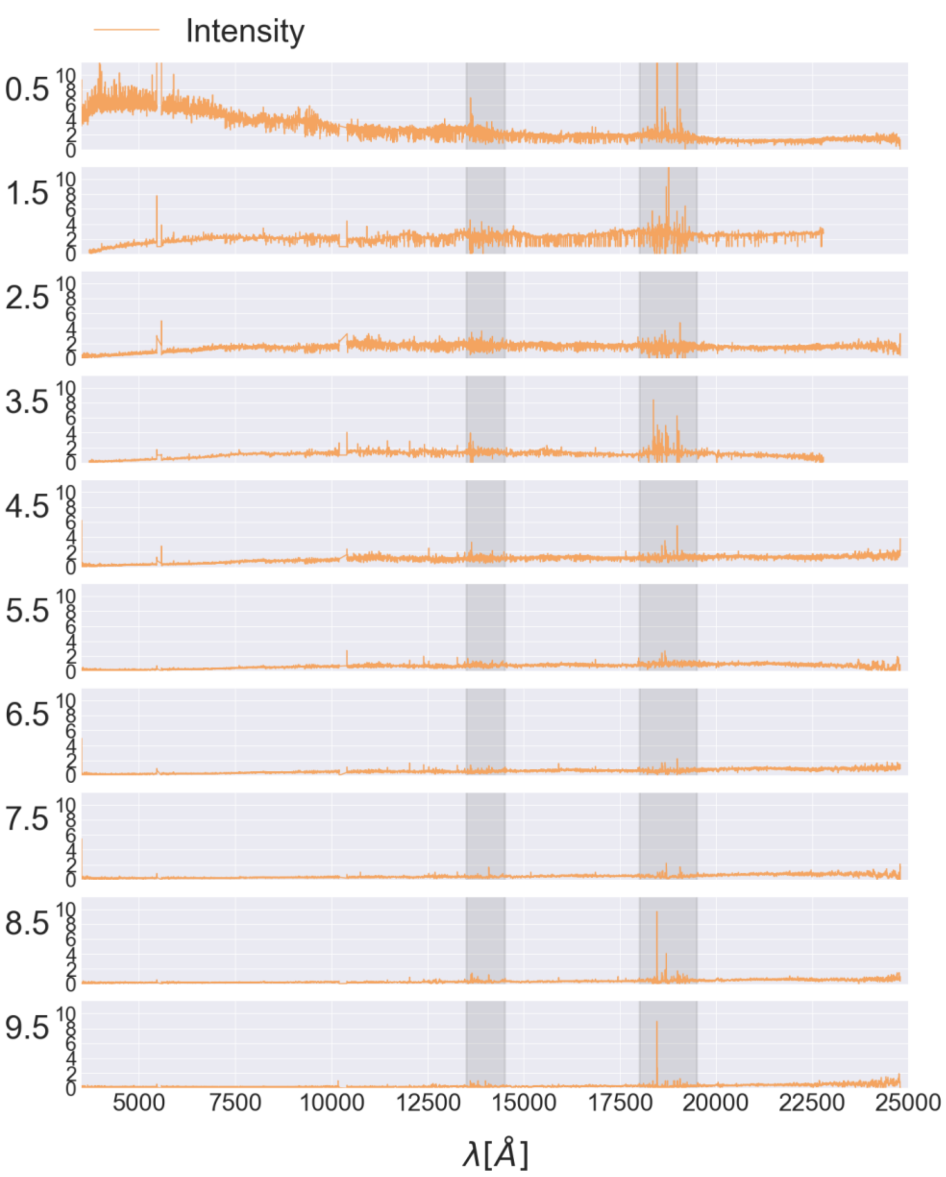
Whitening is a technique in which the average is divided out of a dataset.

- Our application
  - In each wavelength bin, take the average over the various days' spectra and then divide it out.
- Why?
  - Enhances the smaller features and lessens focus on overall magnitude
  - M_{ej} determines magnitude; V_{ej} and Lanthanide fraction determine bumps and wiggles
  - We want a better fit of all properties, not just M_{ej}

GW170817 (Without Whitening)
Log Likelihood: -76.28 ± 0.10



GW170817 (Whitened)
Log Likelihood: Unknown



Future Work

- Test spectra model with varying numbers of days of spectra
- Test spectra model on other types of transients
- Test setup with LIGO open public alerts
- Add other models for other transient objects
  - Compare log likelihoods instead of using a cutoff point

Acknowledgements

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