

# Signal Synchronization Strategies and Time Domain SETI

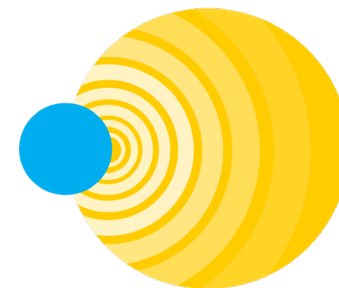
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Yale University



UNIVERSITY *of*  
WASHINGTON

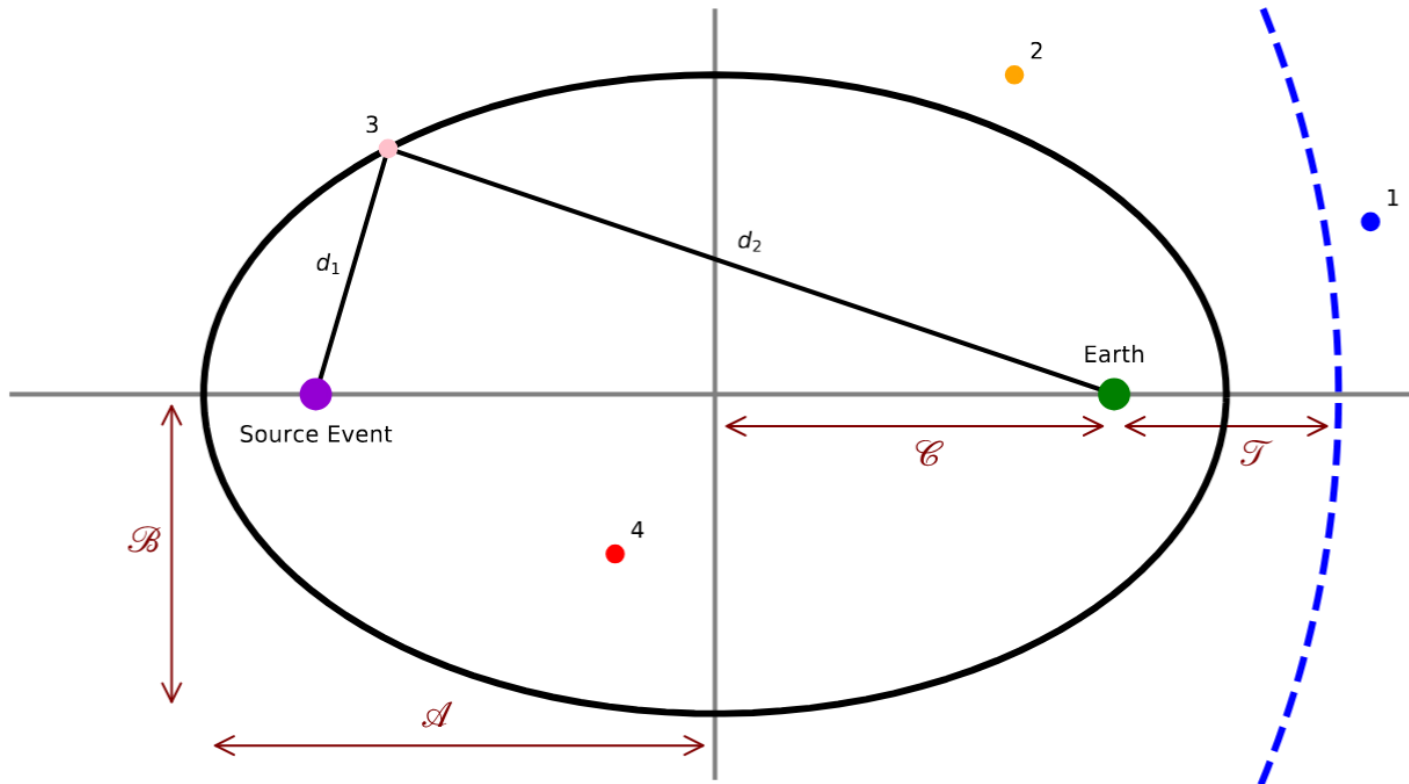


**BERKELEY SETI**  
RESEARCH CENTER

# Schelling Points in SETI

- Coordination **without prior communication**
- What to observe
  - Magic frequencies
    - 21cm line
    - Planck frequencies (Wright 2020)
    - Pulsar rotational frequencies (Heidmann et al. 1992), etc.
- Where + when to observe
  - Transits (Kipping & Teachey 2016)
  - Signal synchronization strategies (SETI Ellipsoid, Seto methods)

# SETI Ellipsoid



## SETI Ellipsoid:

$$d_1 + d_2 = D + \mathcal{T} = D + cT$$

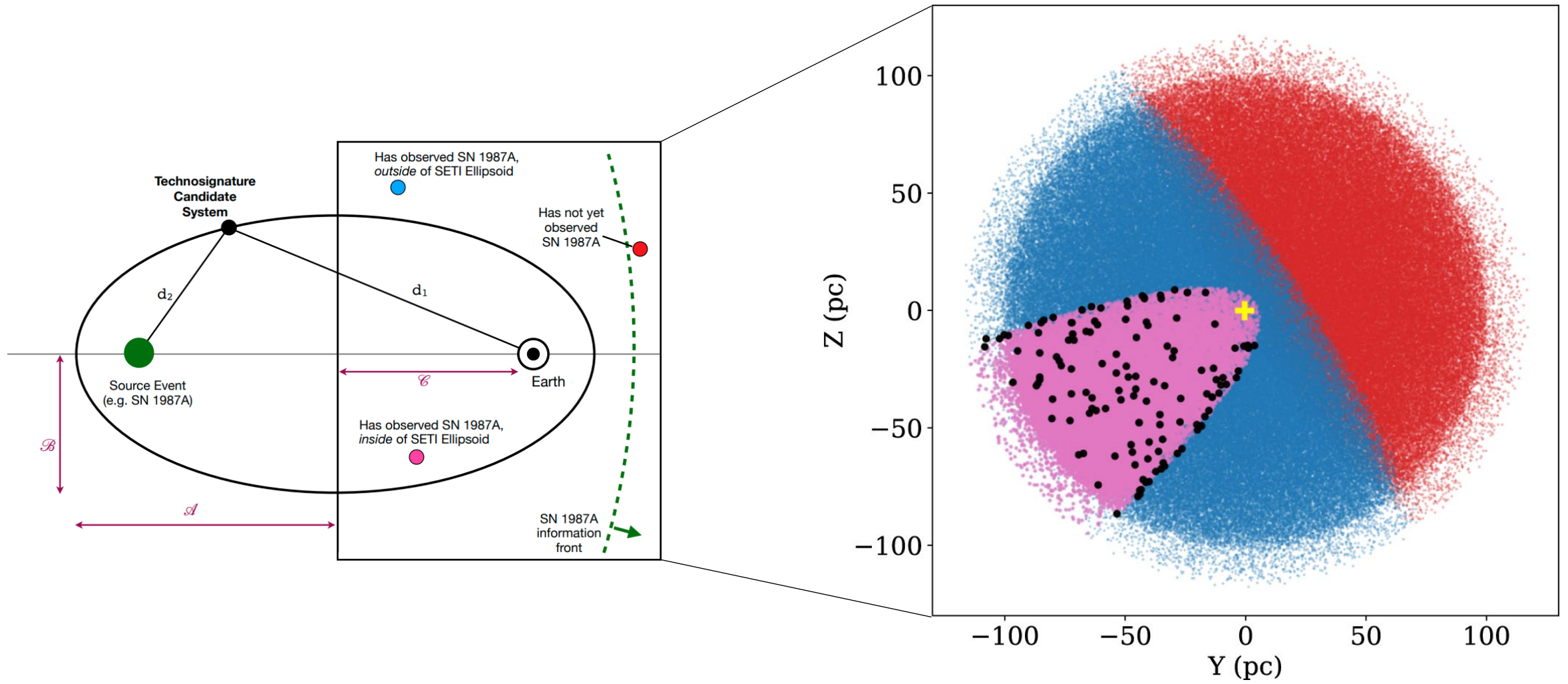
## Star Classes

- 1:  $d_1 > D + cT$
- 2:  $d_1 < D + cT, d_1 + d_2 > D + cT$
- 3:  $d_1 + d_2 = D + cT$
- 4:  $d_1 + d_2 < D + cT$

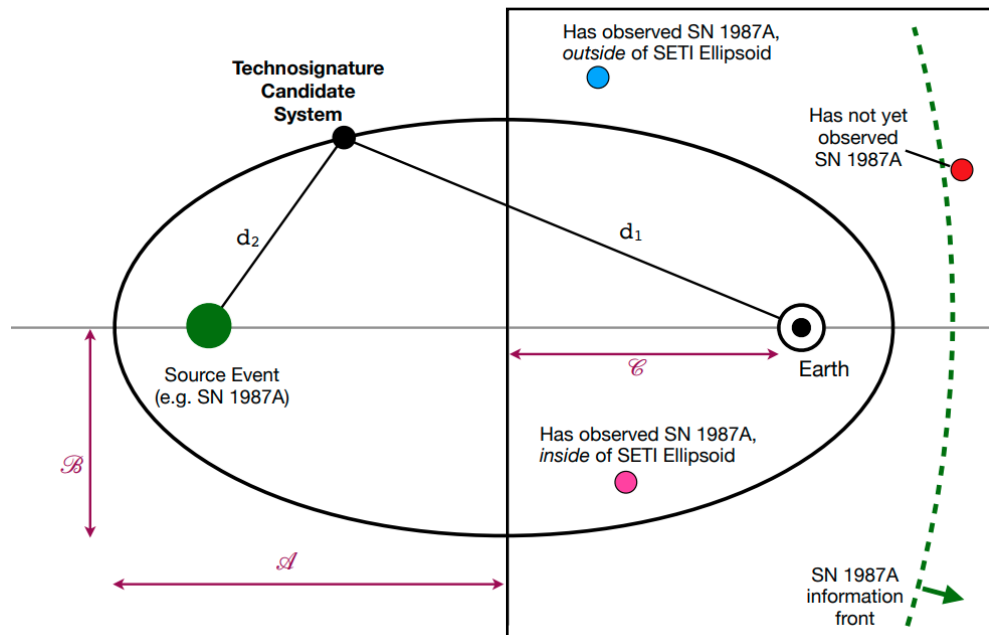
## Crossing Time:

$$T_x = \frac{d_1 + d_2 - D}{c}$$

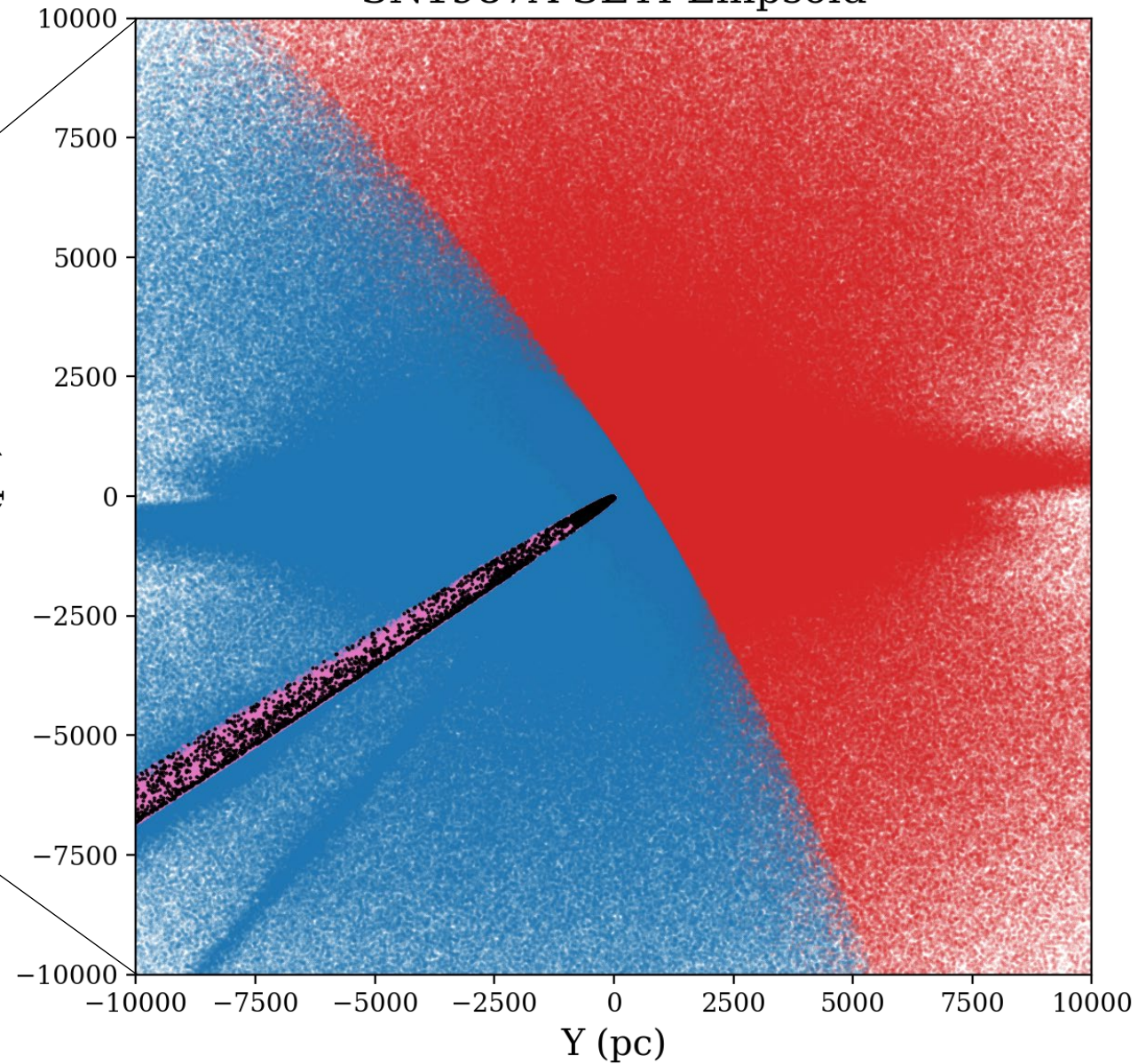
# SETI Ellipsoid with Gaia



# SETI Ellipsoid with Gaia DR3



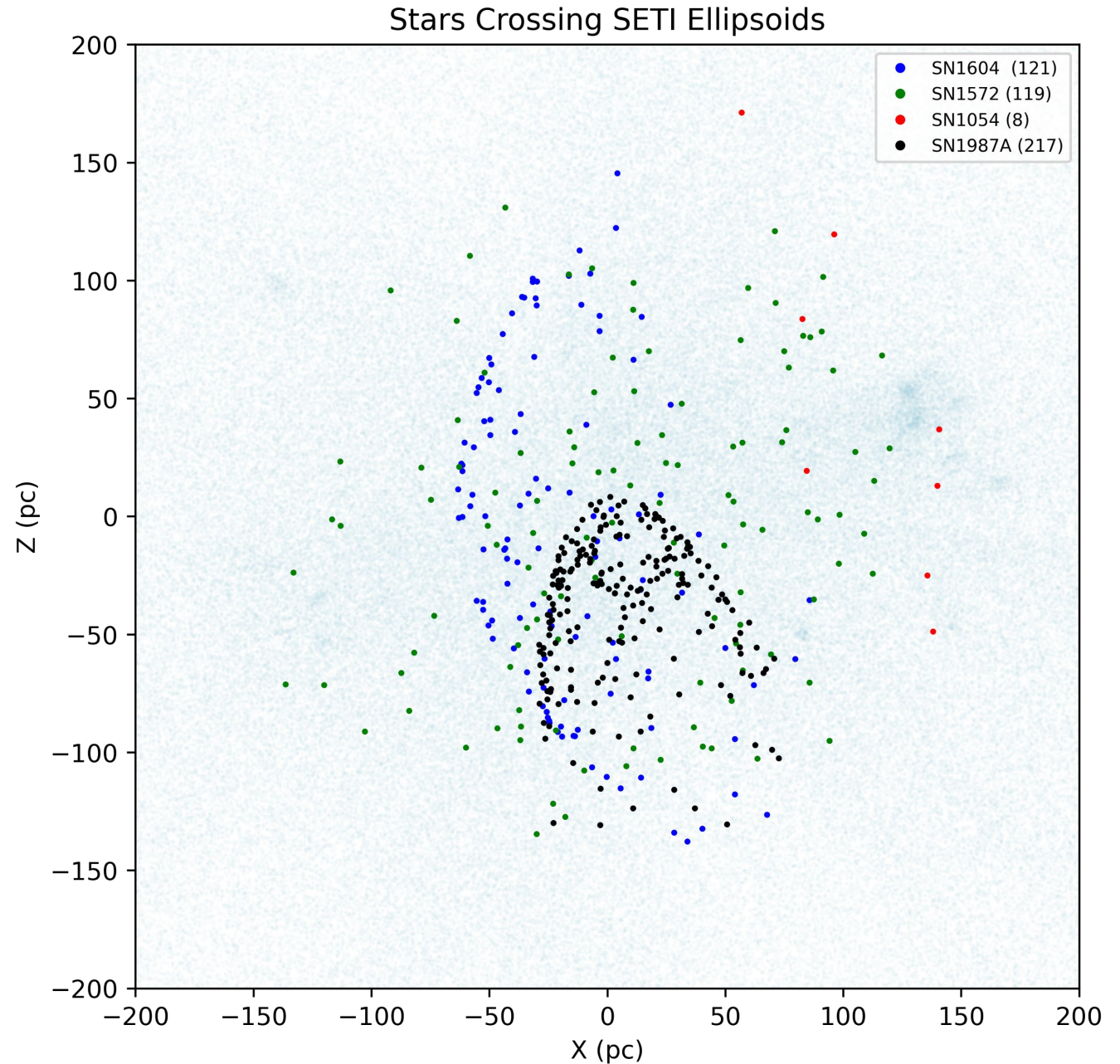
## SN1987A SETI Ellipsoid



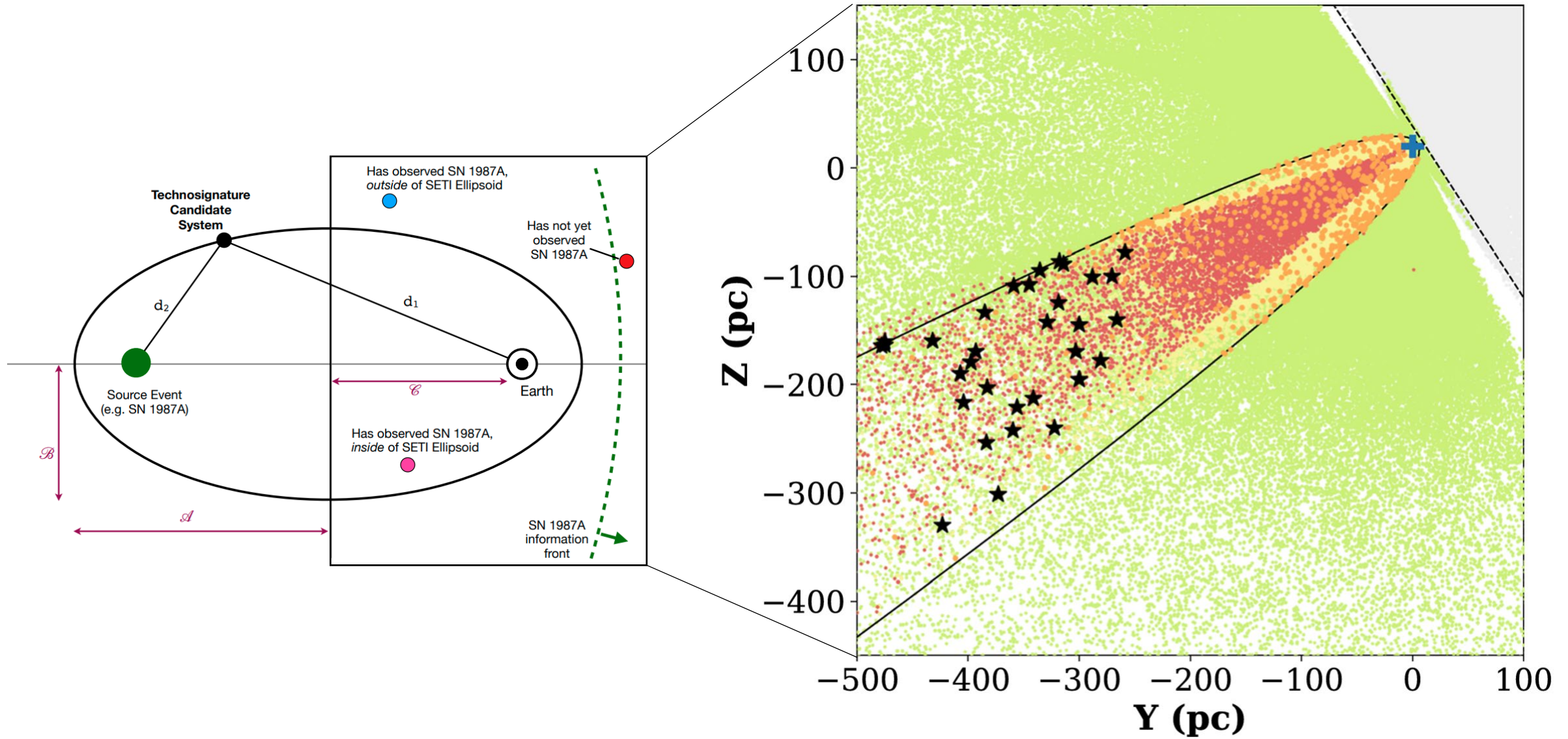
# SETI Ellipsoid with Gaia DR3

465 stars crossed the SETI Ellipsoids for SNe 1987A, 1604, 1572, or 1054 between 2014 and 2017

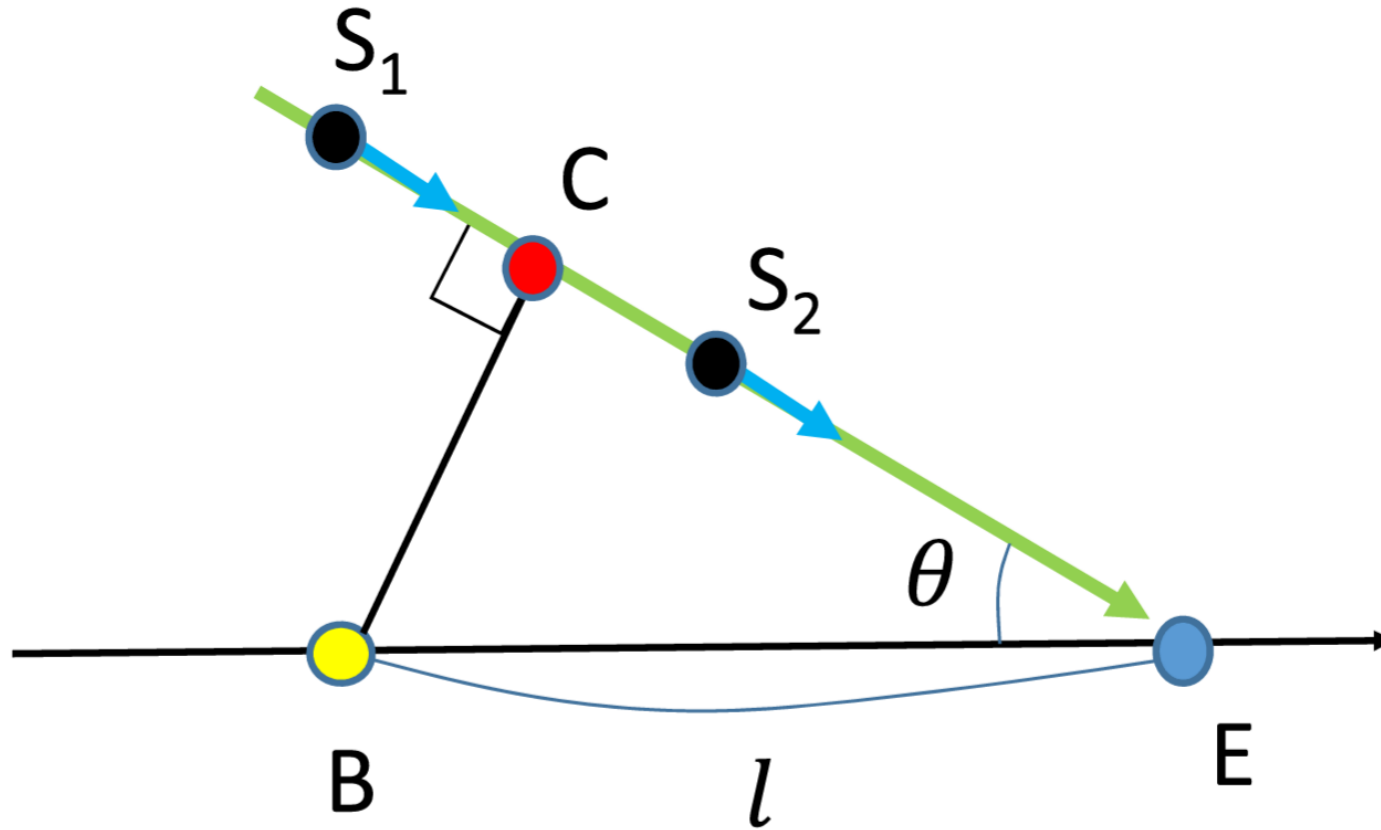
(Nilipour et al. 2023)



# SETI Ellipsoid with TESS



# Seto (2021) Signaling Scheme



Unique Reference Point for Each Angle:

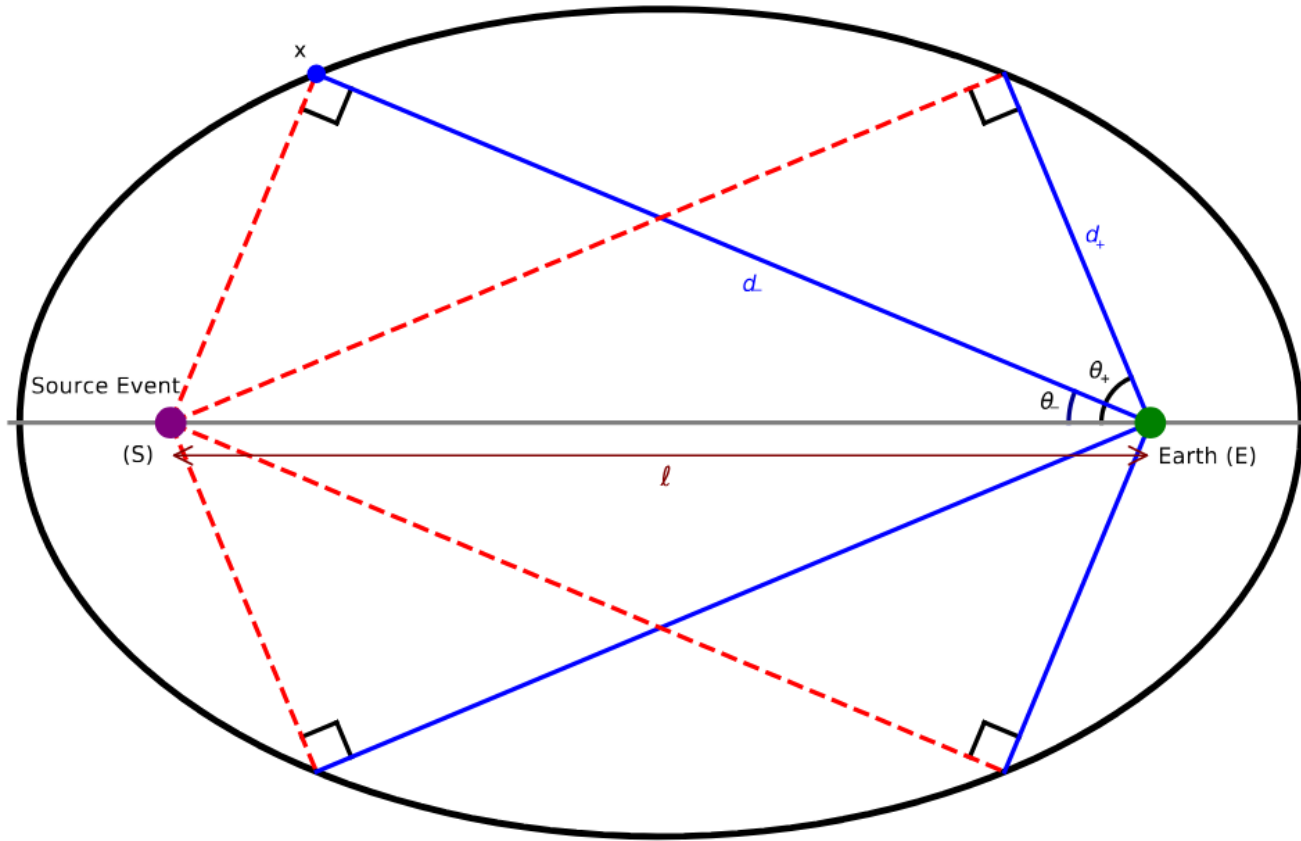
$$(C, t_0 + \frac{l \sin \theta}{c})$$

Seto Crossing Time:

$$T_E(\theta) = \frac{l}{c} (\sin \theta + \cos \theta - 1)$$



# Seto (2021) Signaling Scheme



Seto Normalized Crossing Time:

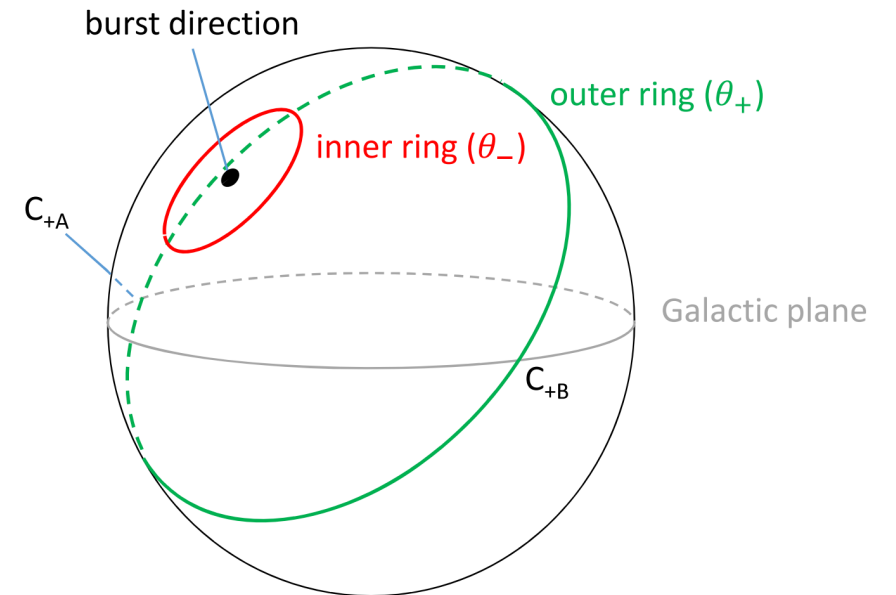
$$\tau_E(\theta) = \sin\theta + \cos\theta - 1$$

Seto Search Angles:

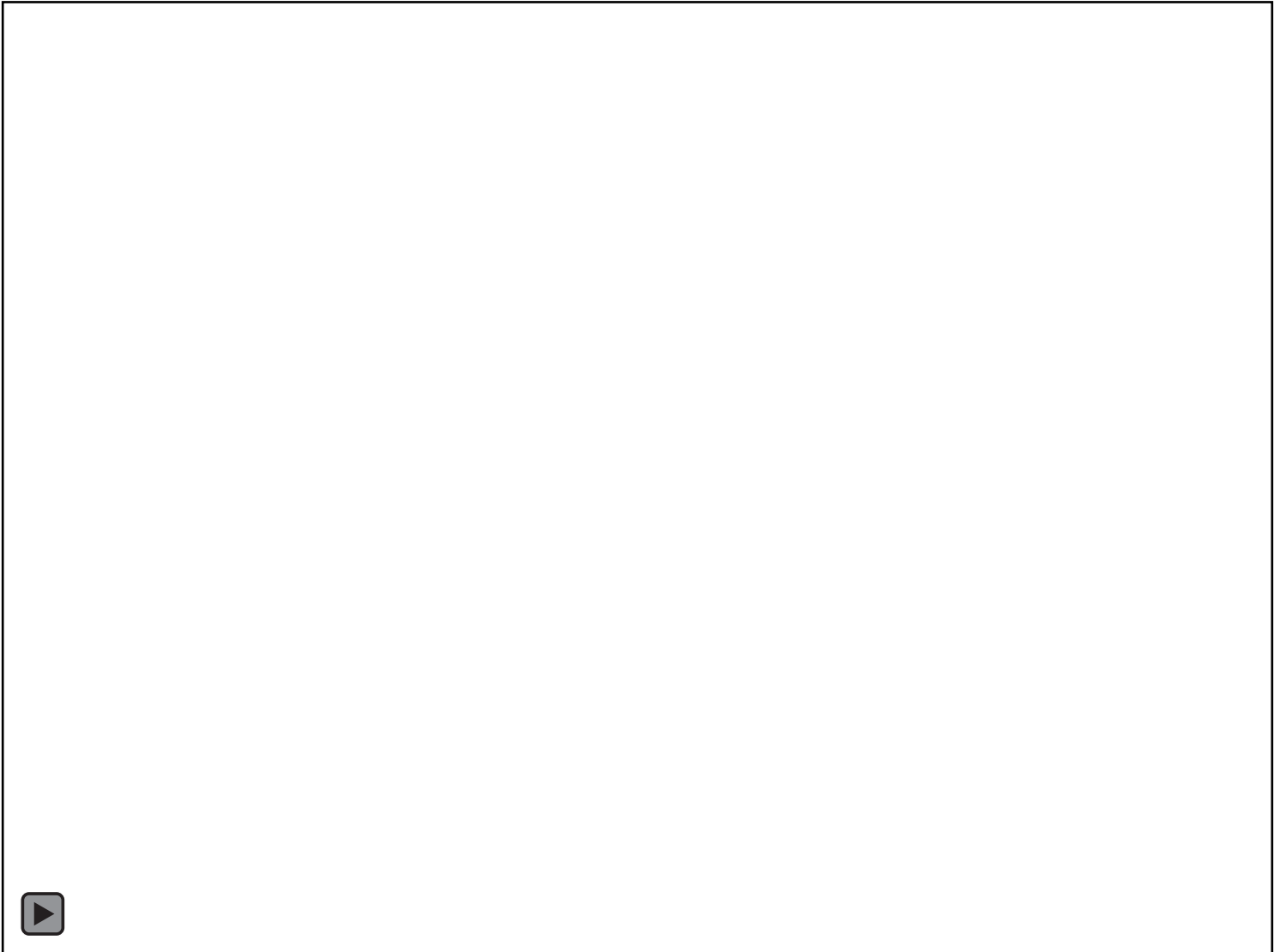
$$\theta_{\pm}(\tau_E) = \frac{\pi}{4} \pm \cos^{-1}\left(\frac{\tau_E + 1}{\sqrt{2}}\right)$$

Seto Closing Time:

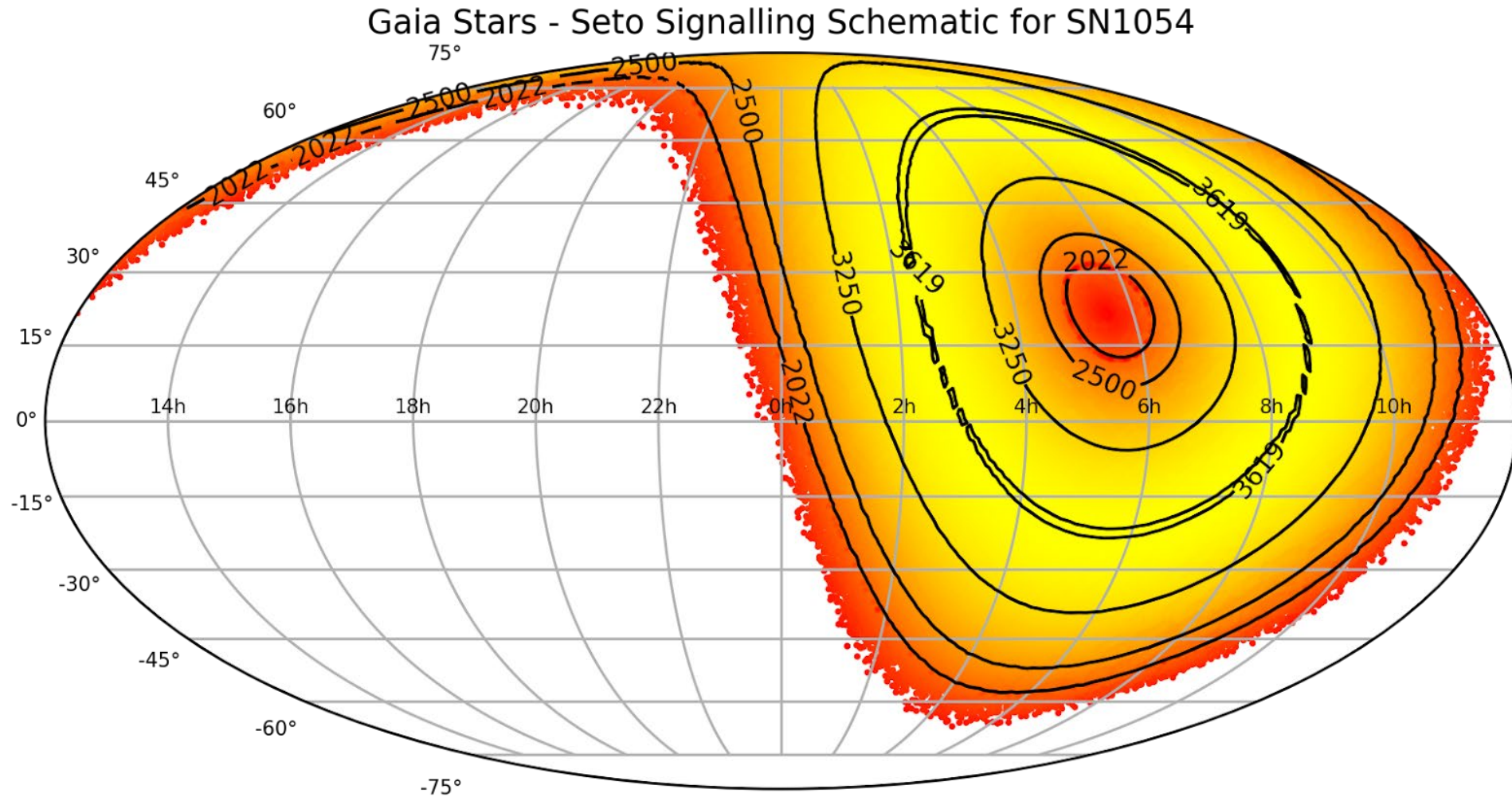
$$\tau_E = \sqrt{2} - 1$$



# Seto (2021) Signaling Scheme

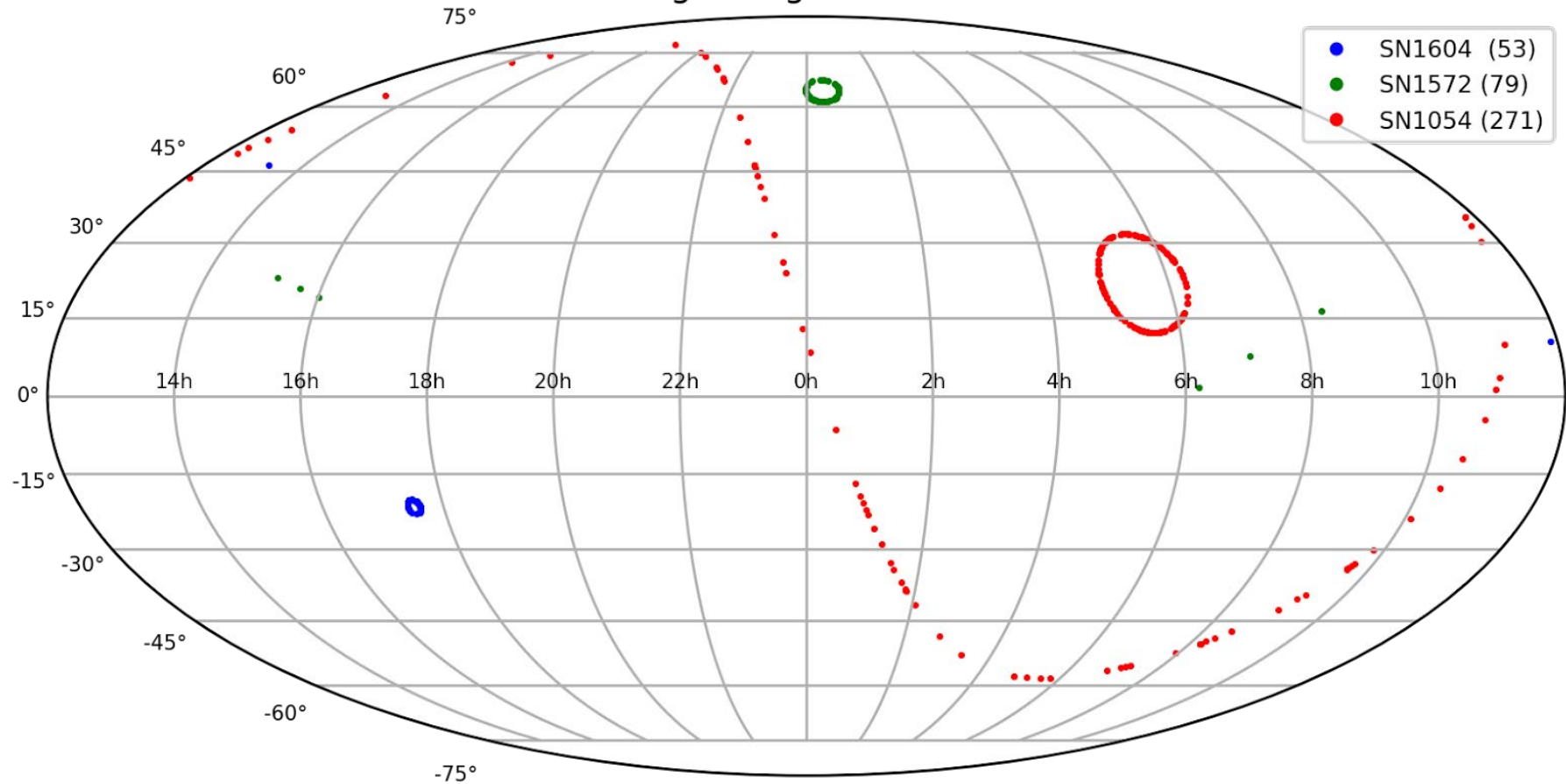


# Seto (2021) Scheme with Gaia DR3



# Seto (2021) Scheme with Gaia DR3

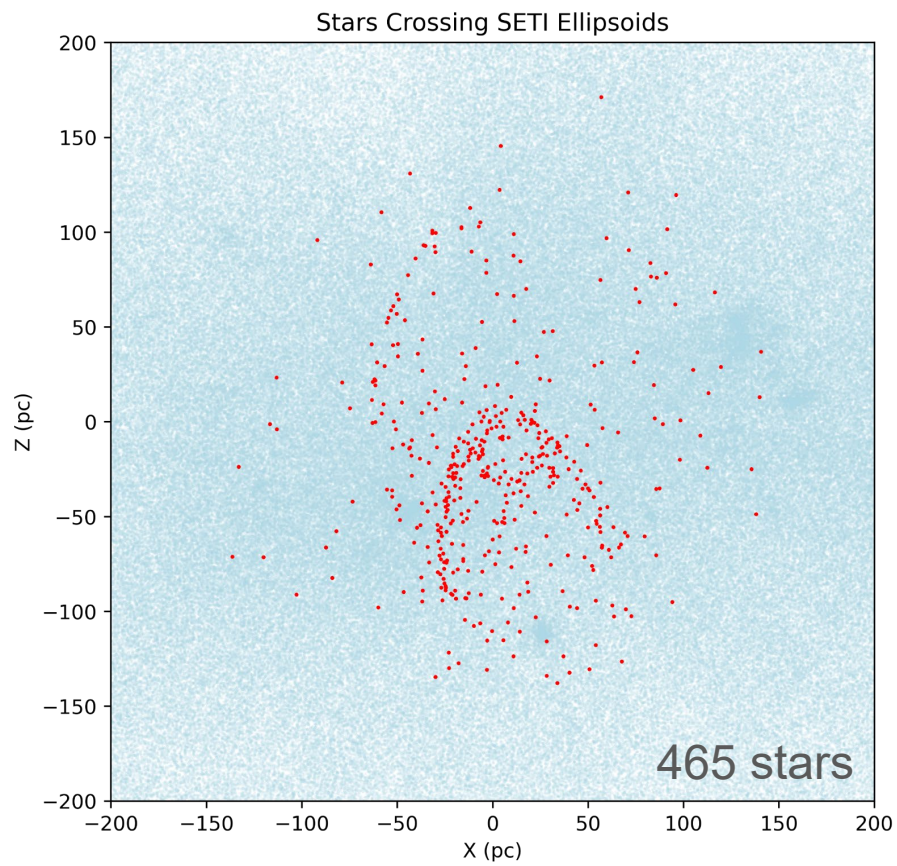
Gaia Stars - Seto Signalling Schematic for Historic SNe



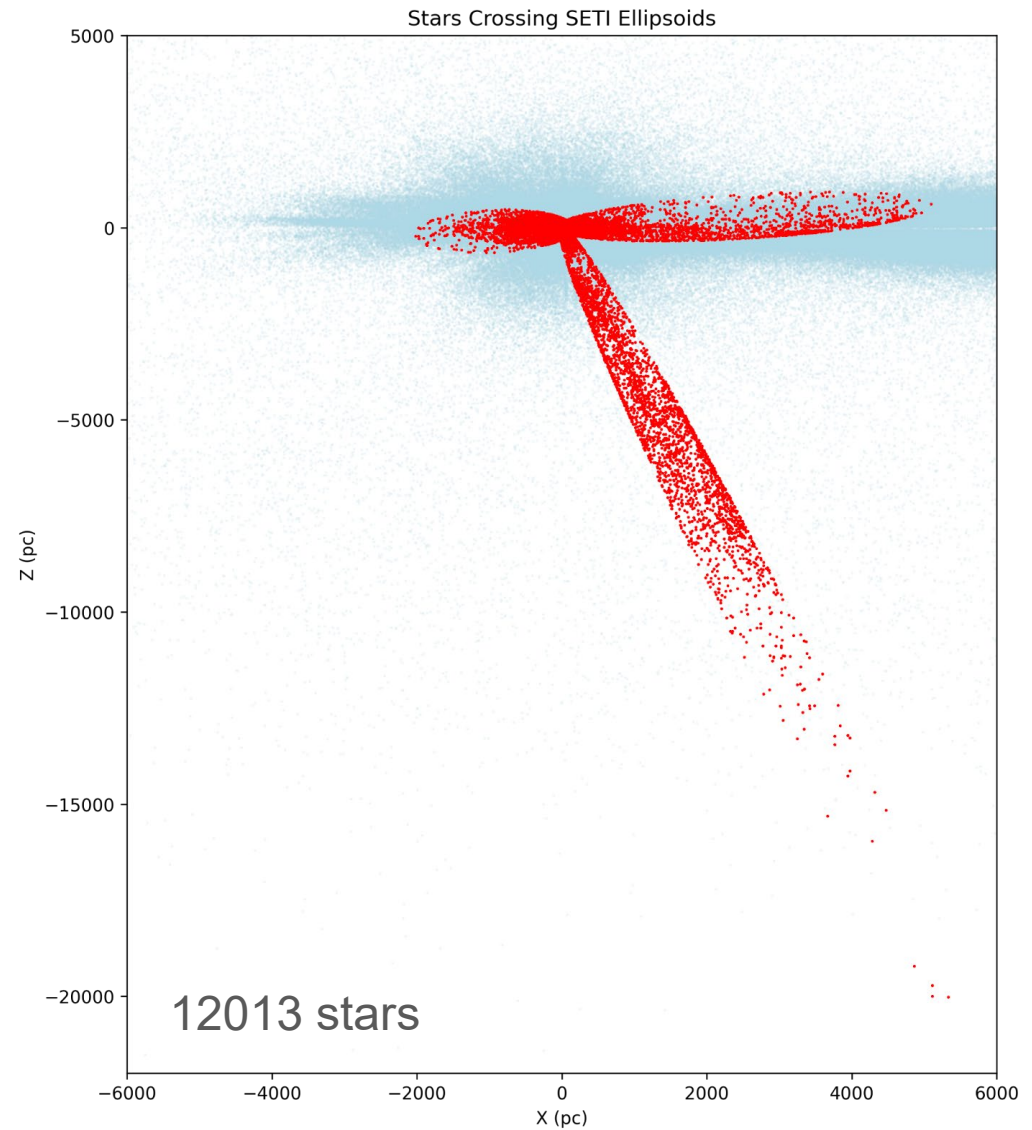
403 stars following this signaling scheme would be observation candidates between 2014 and 2017

# Limitations of the SETI Ellipsoid and Seto (2021) Methods

## Stellar distance errors

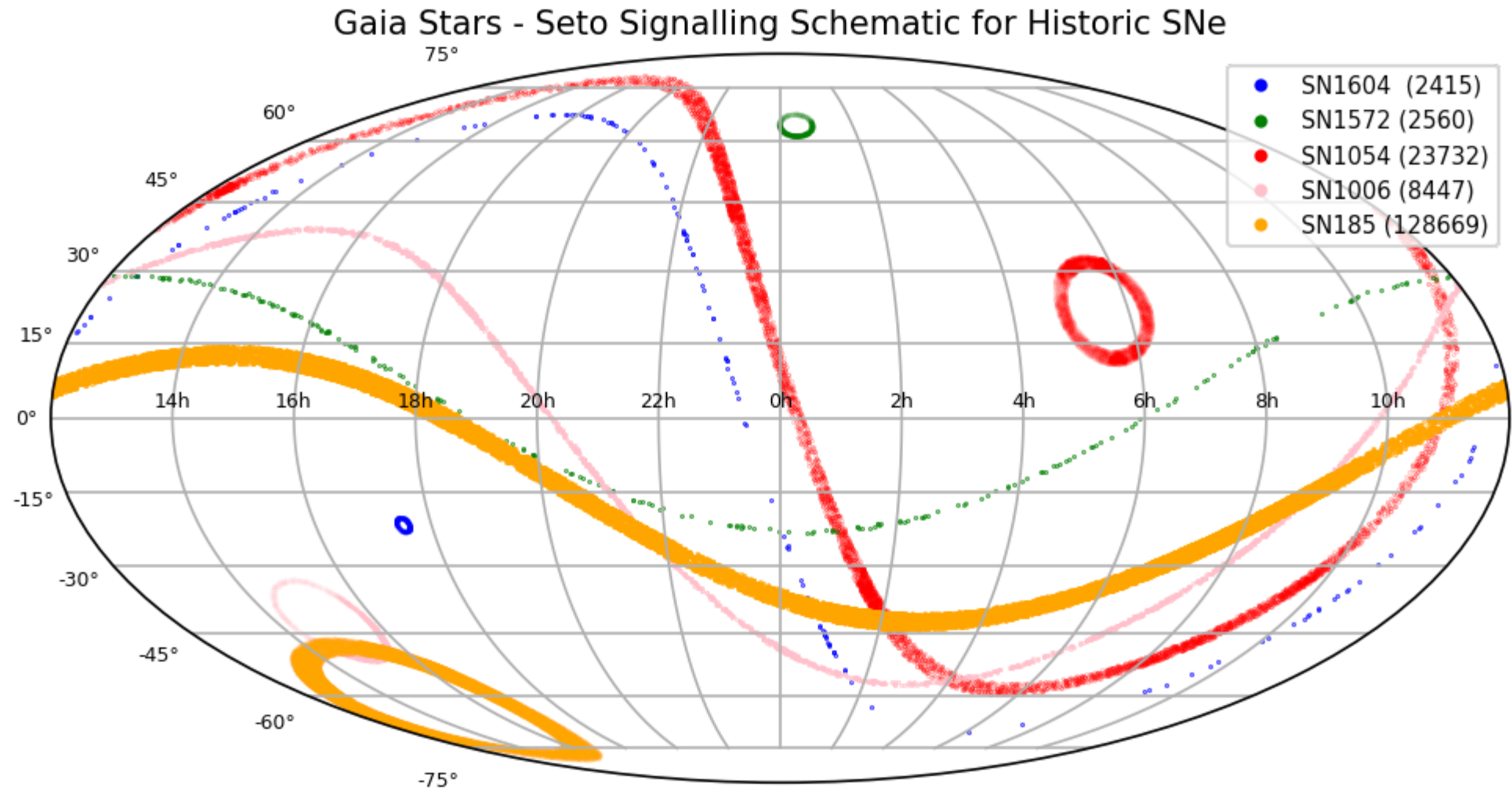


VS.

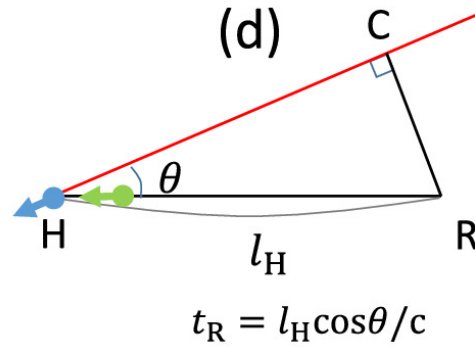
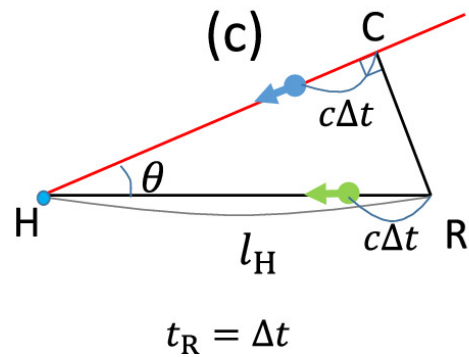
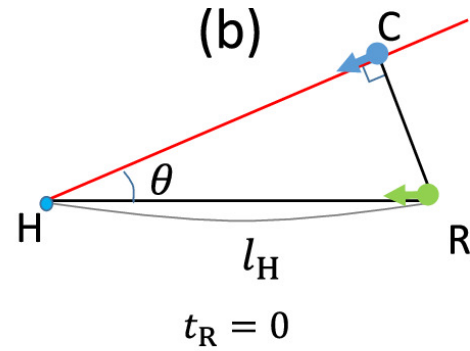
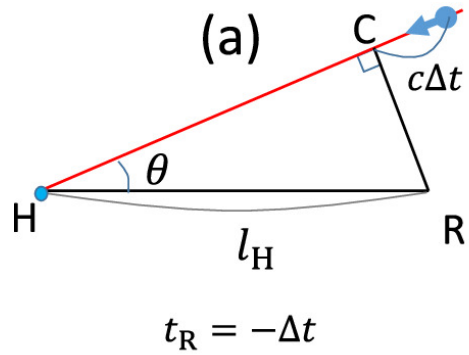


# Limitations of the SETI Ellipsoid and Seto (2021) Methods

SN distance errors



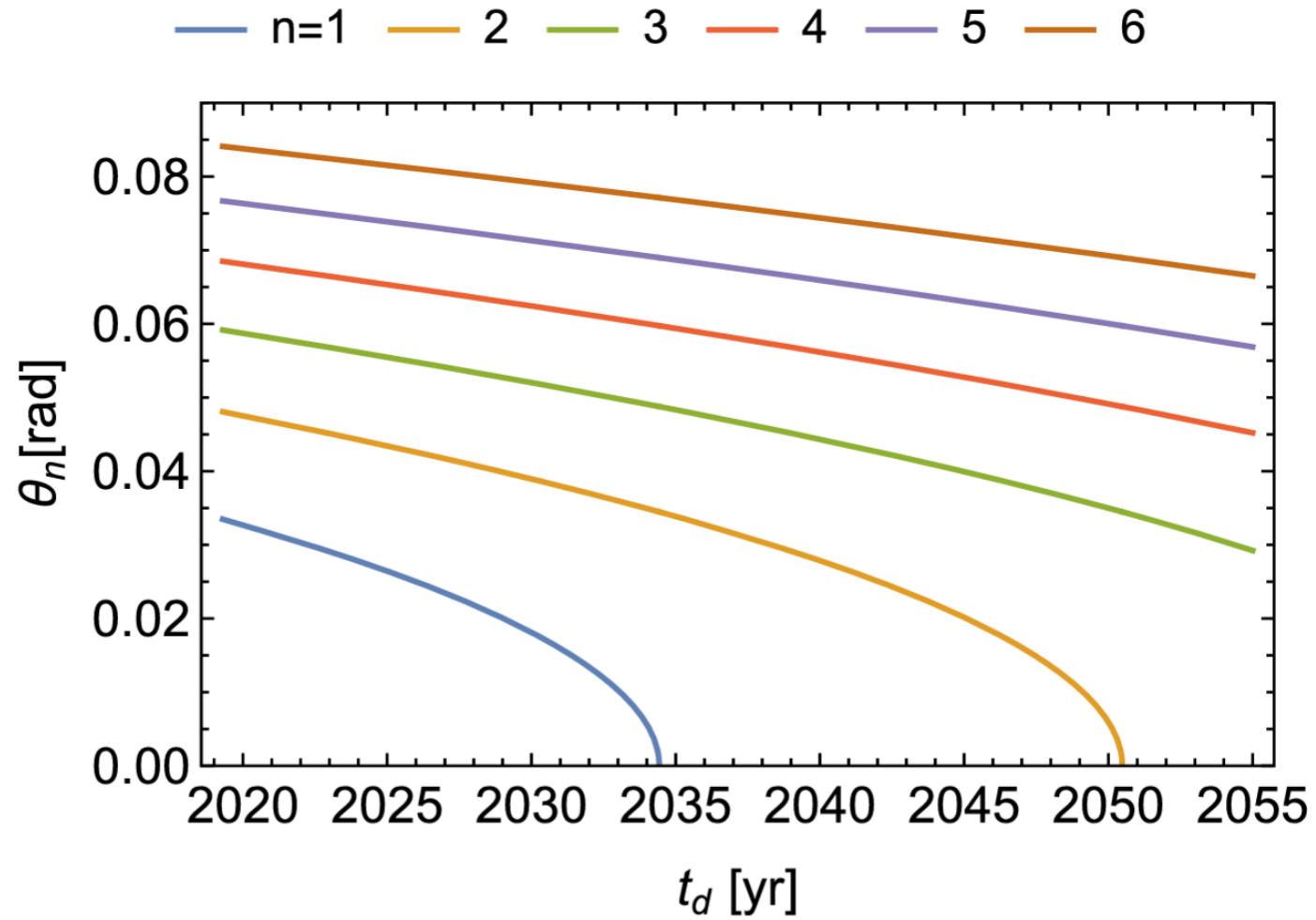
# Seto (2024) Signaling Scheme



Unique Reference Point for Each Angle:

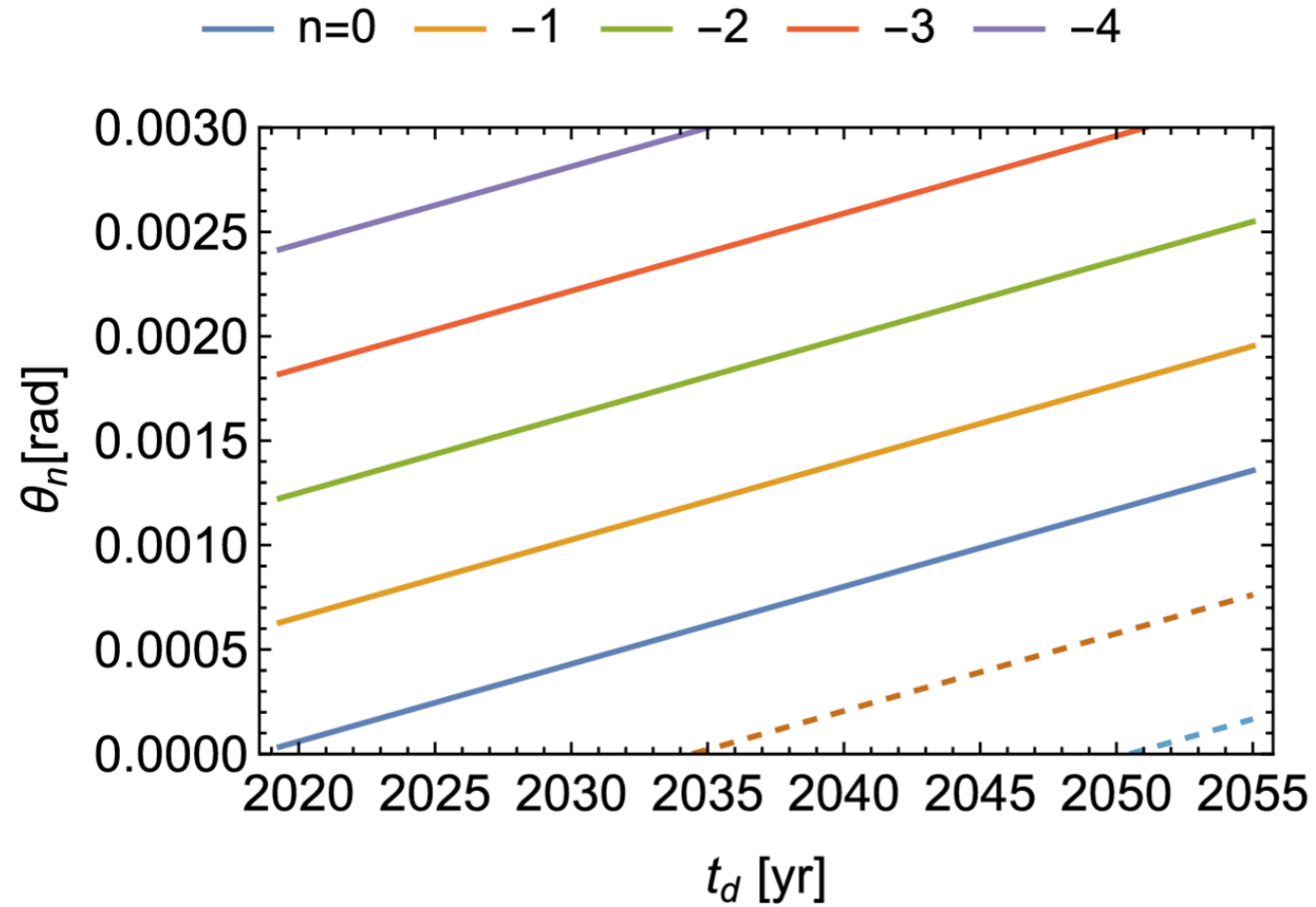
$$\left( C, t_0 + \frac{l \sin \theta}{c} \right) \rightarrow (C, t_0)$$

# Seto (2024) Signaling Scheme





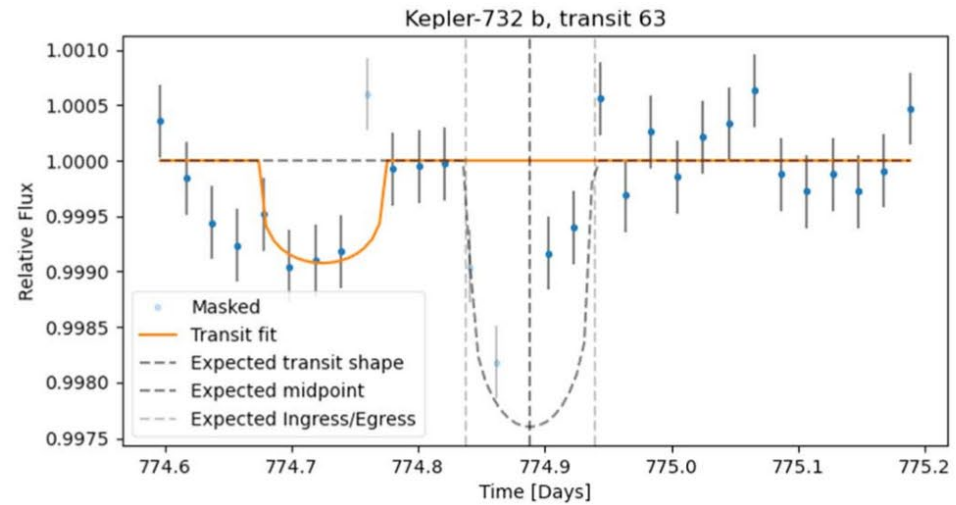
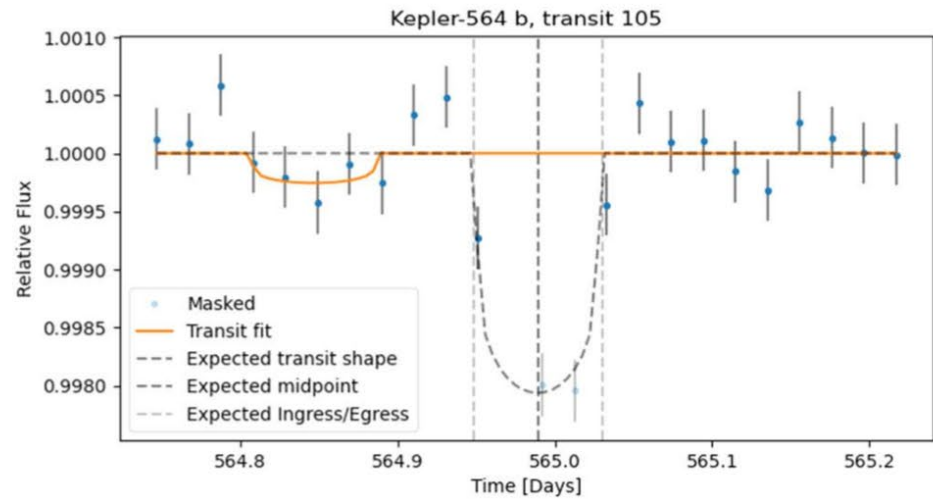
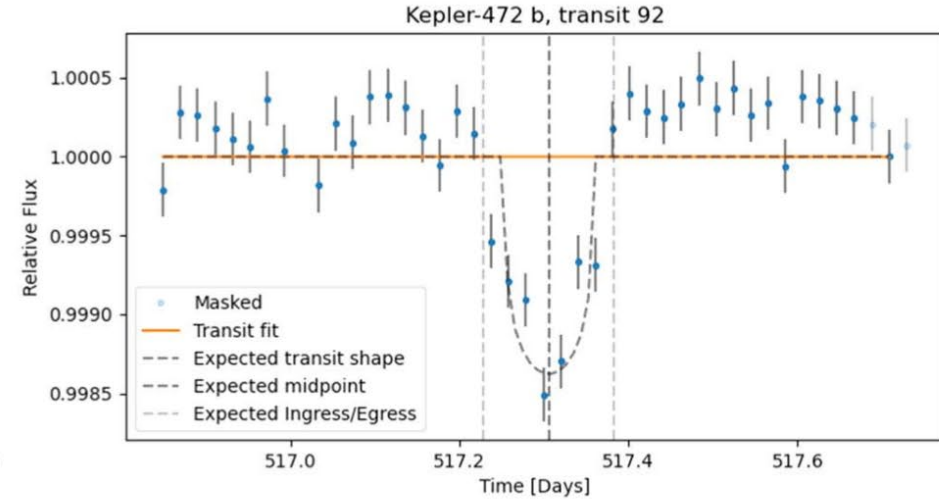
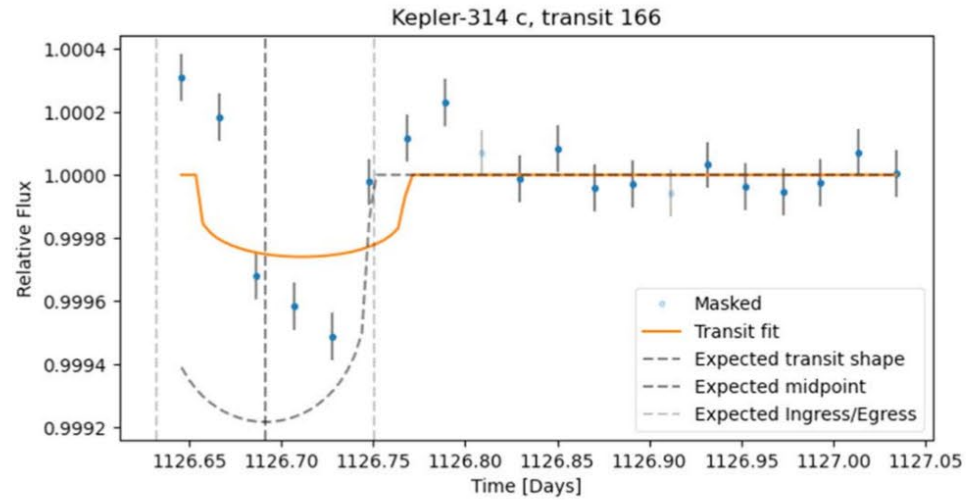
# Seto (2024) Signaling Scheme



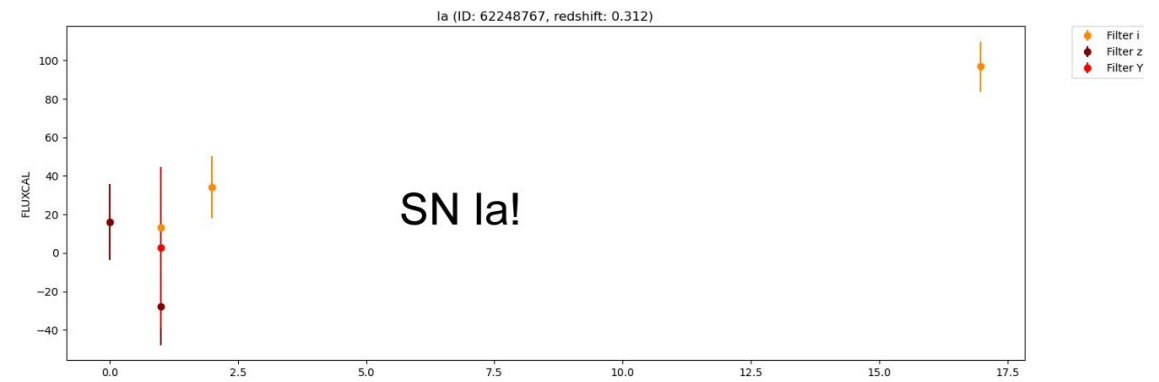
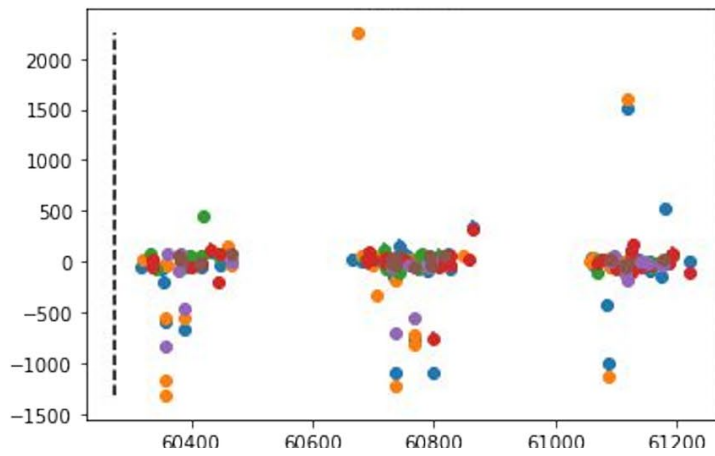
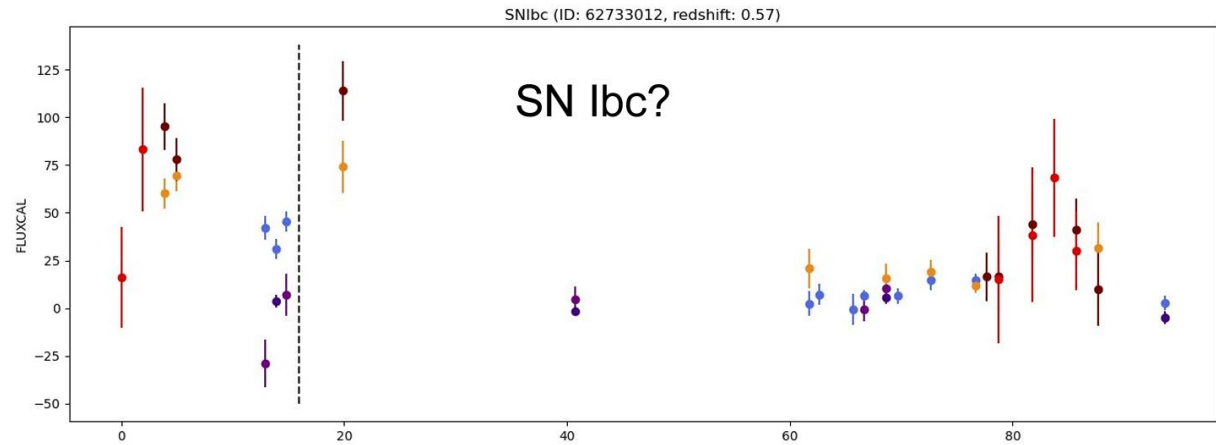
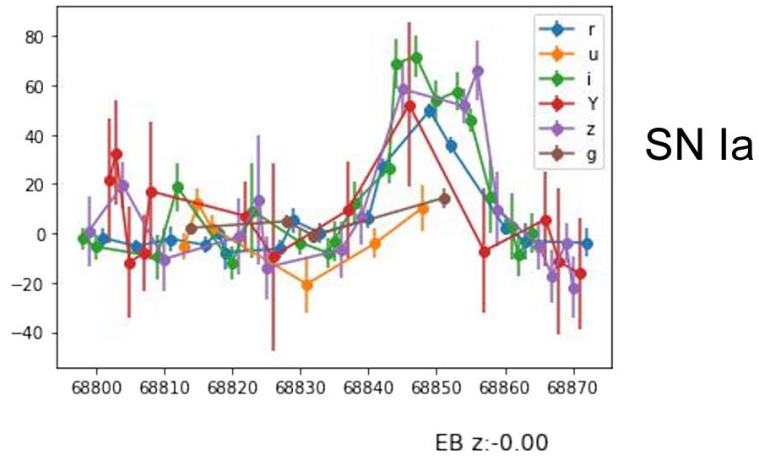
# Time Domain SETI

- Unusual variability
  - Boyajian's star, disappearing stars, missing transits
- Unnatural patterns
  - Broadcasting primes or Fibonacci numbers with transits, flares, etc.
- Outliers
  - Classify everything in a time domain survey into known classes, and consider the rest to be technosignature candidates

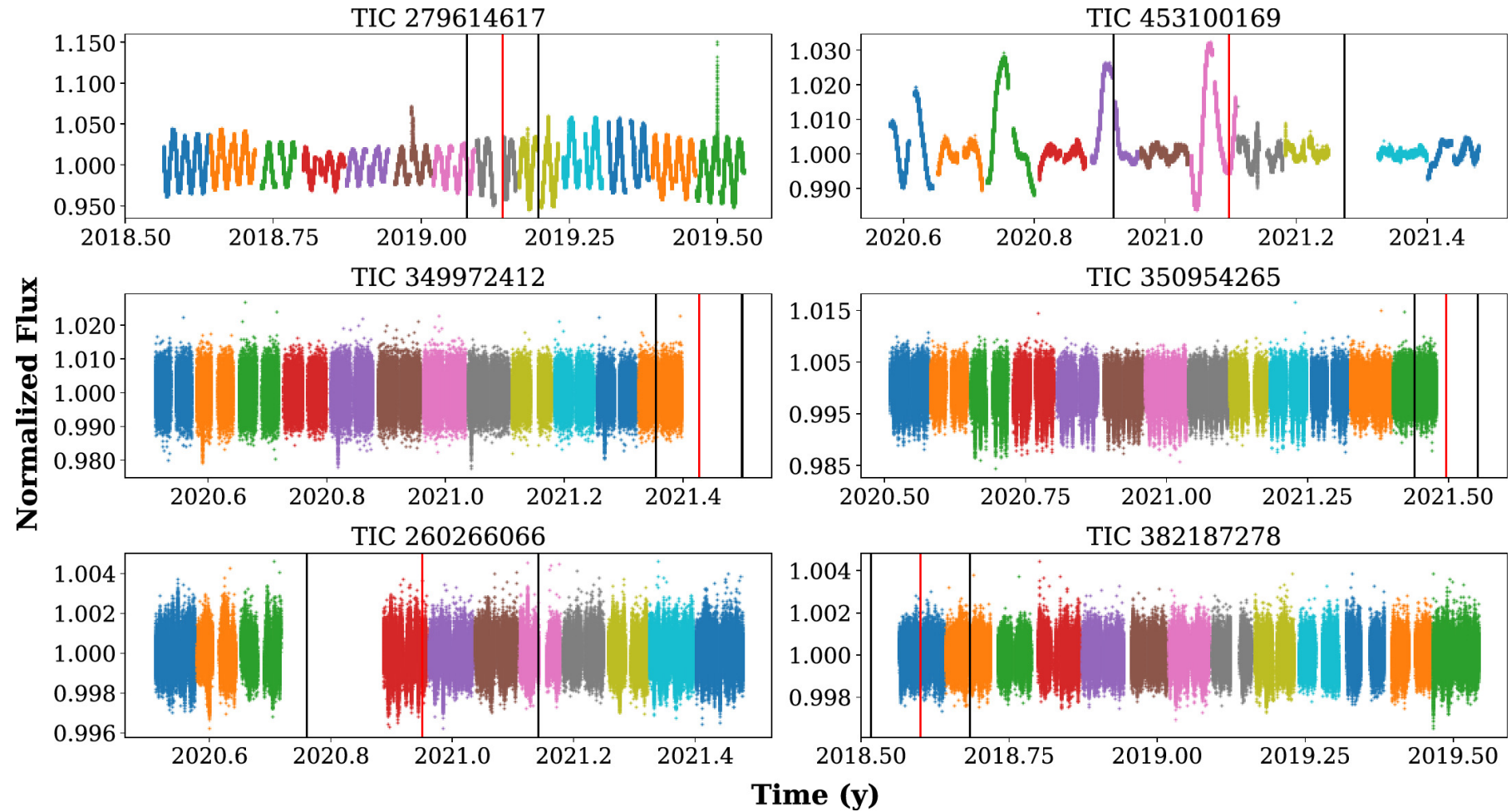
# Anomalous Transits with Kepler



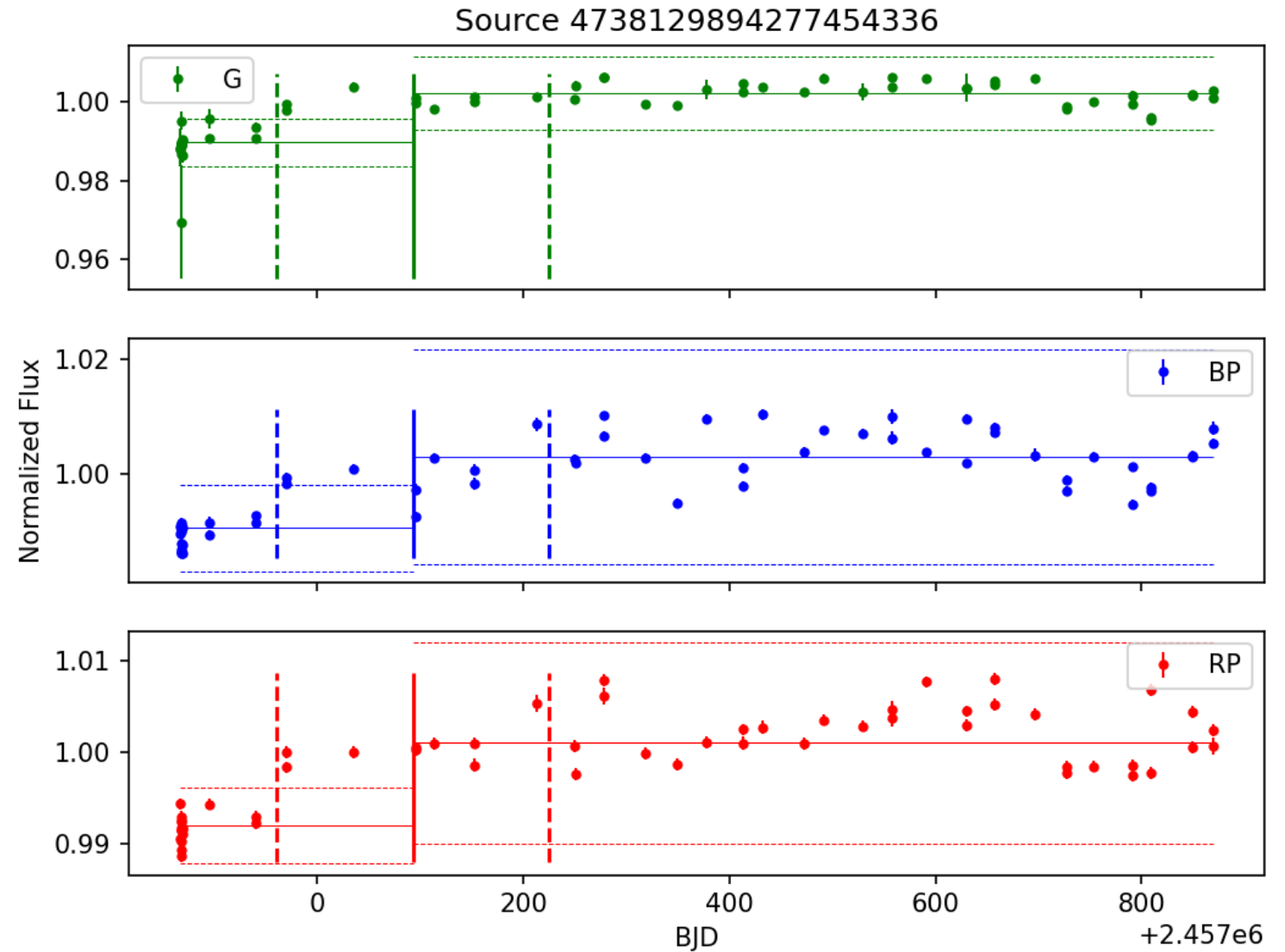
# Variability Classification with LSST



# Time Domain SETI + Signal Synchronization Strategies with TESS



# Time Domain SETI + Signal Synchronization Strategies with Gaia

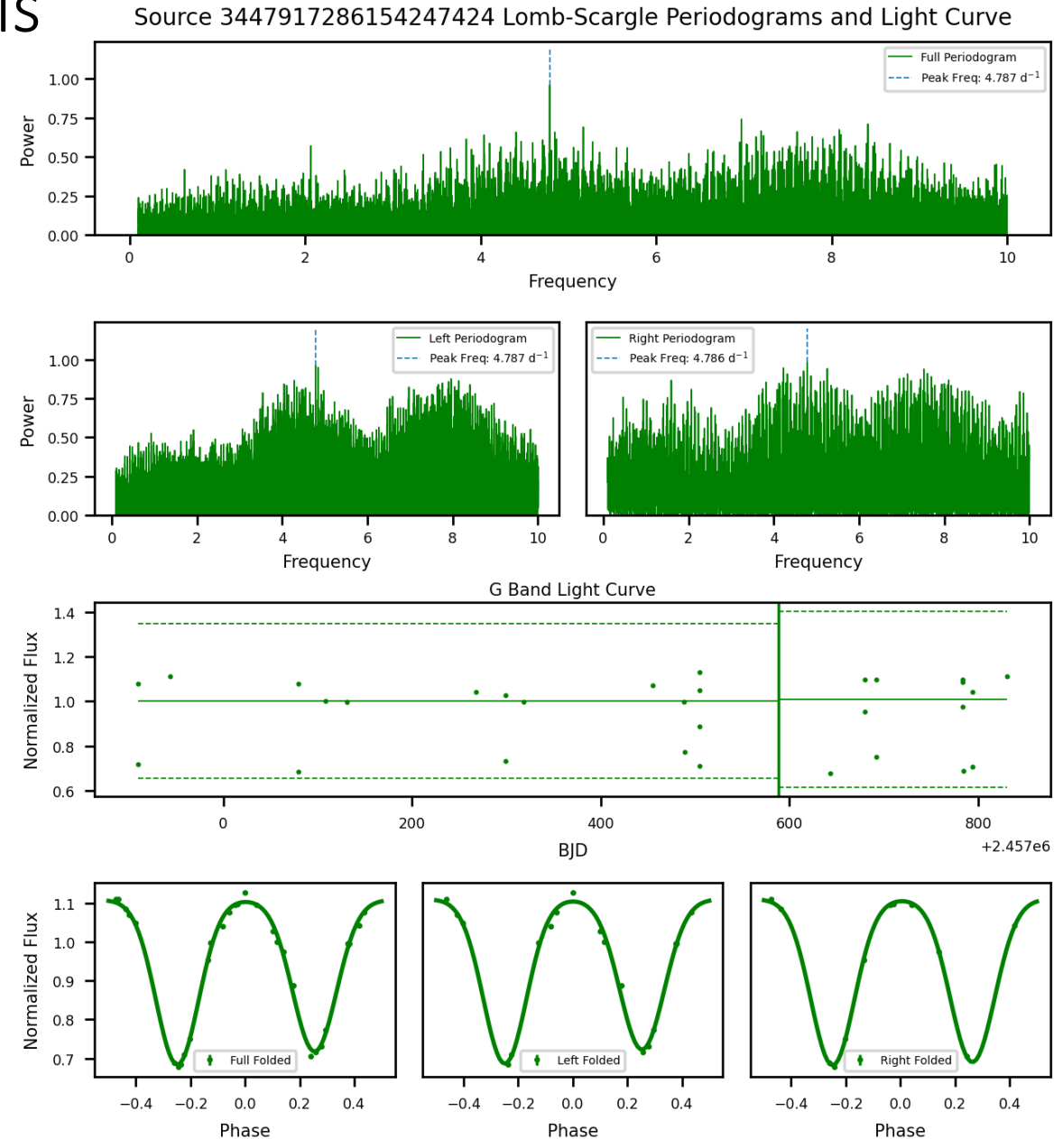


Noticeably sparse and incomplete, but has long-term stability

# Eclipsing Binary Variability Analysis

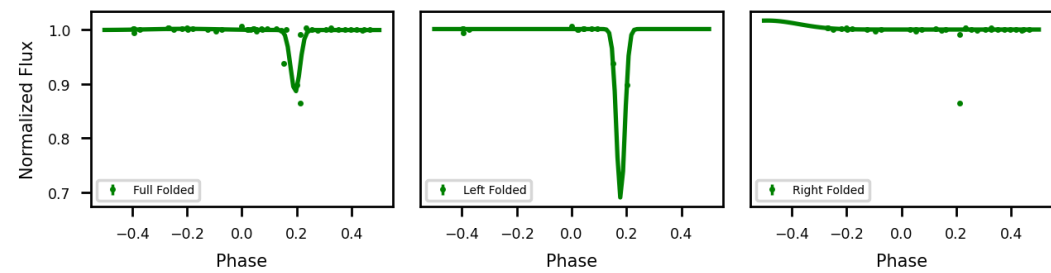
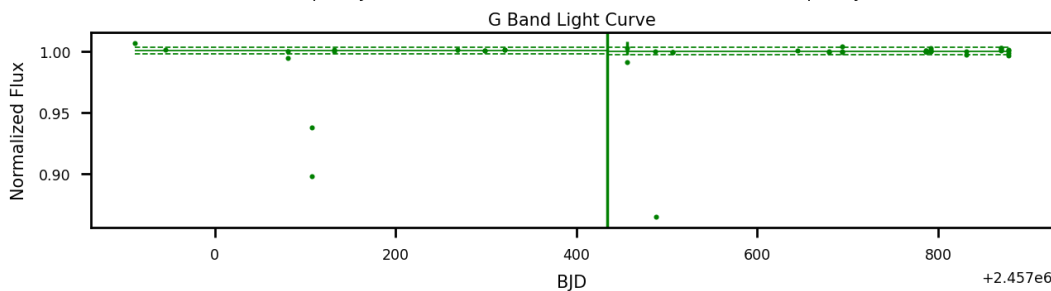
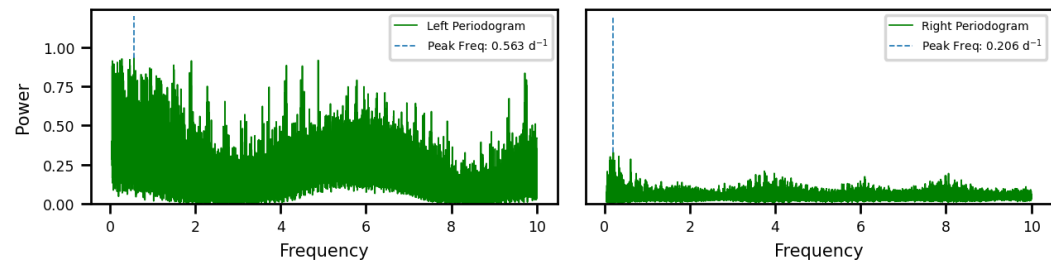
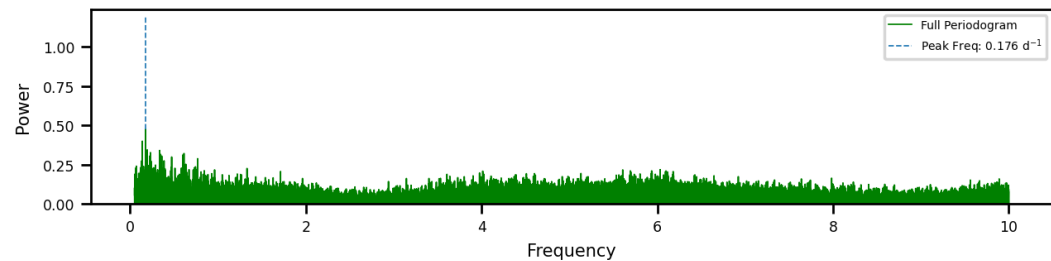
We ranked all 45 eclipsing binary candidate systems with sufficient light curve data using the error weighted distance between left and right light curves for nine variability parameters

(Nilipour et al. 2023)



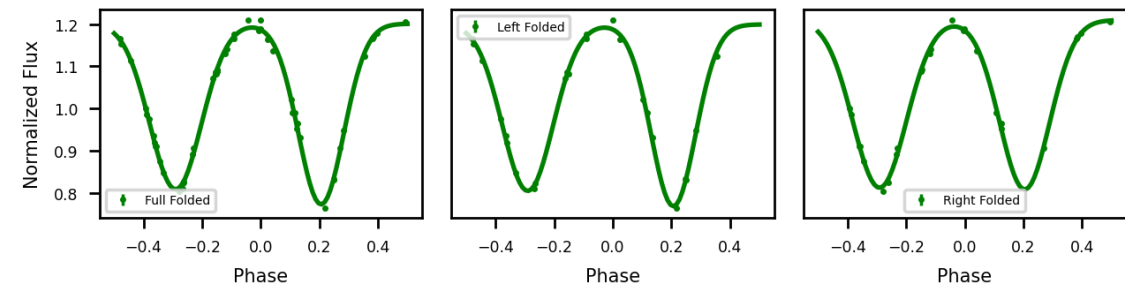
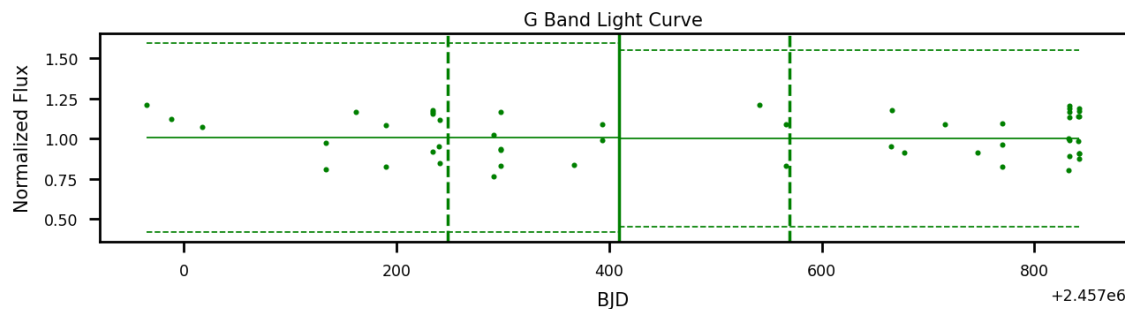
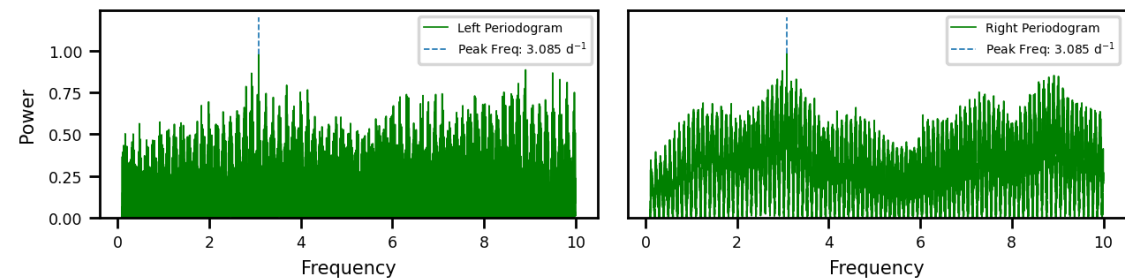
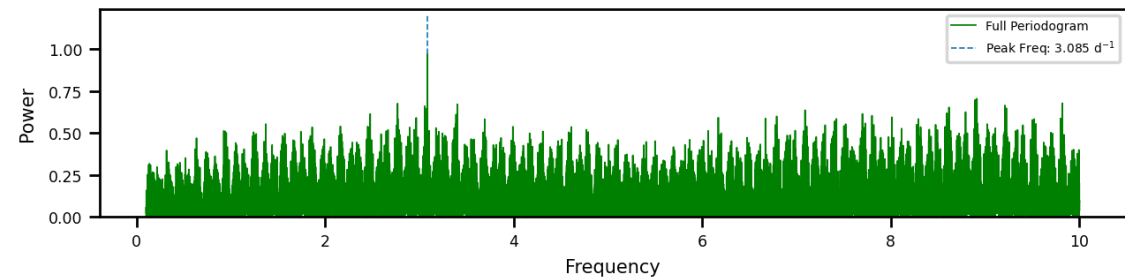
# Lowest Ranking ECL

Source 3444070610365980928 Lomb-Scargle Periodograms and Light Curve



# Highest Ranking ECL

Source 5633777360297734016 Lomb-Scargle Periodograms and Light Curve



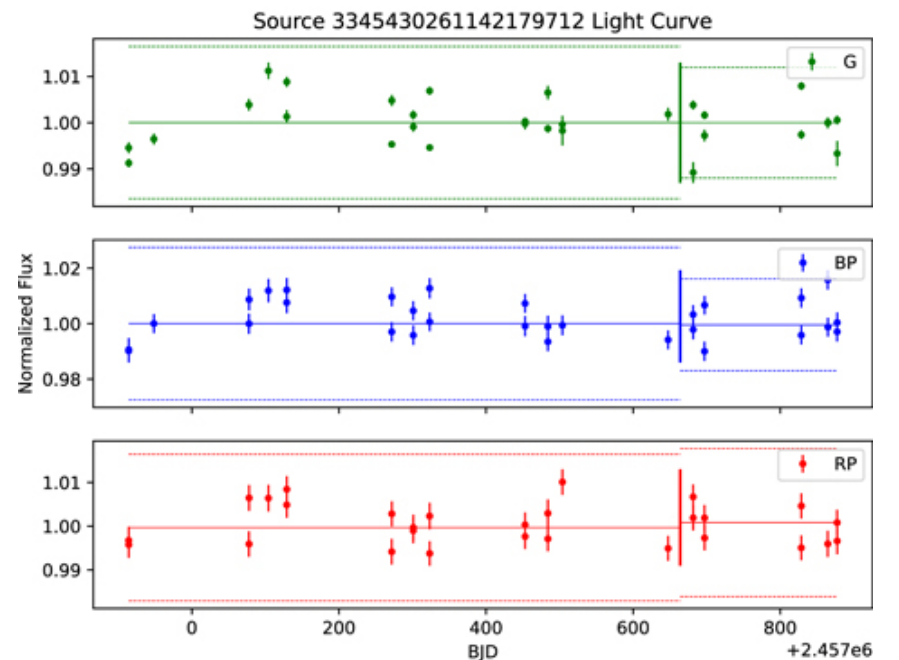
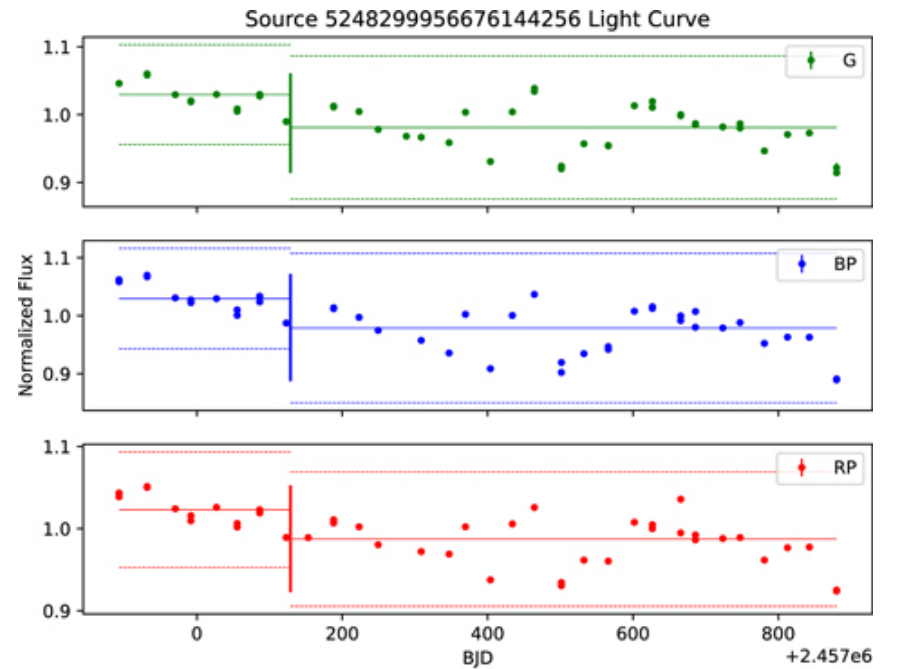


# Non-periodic Variability Analysis

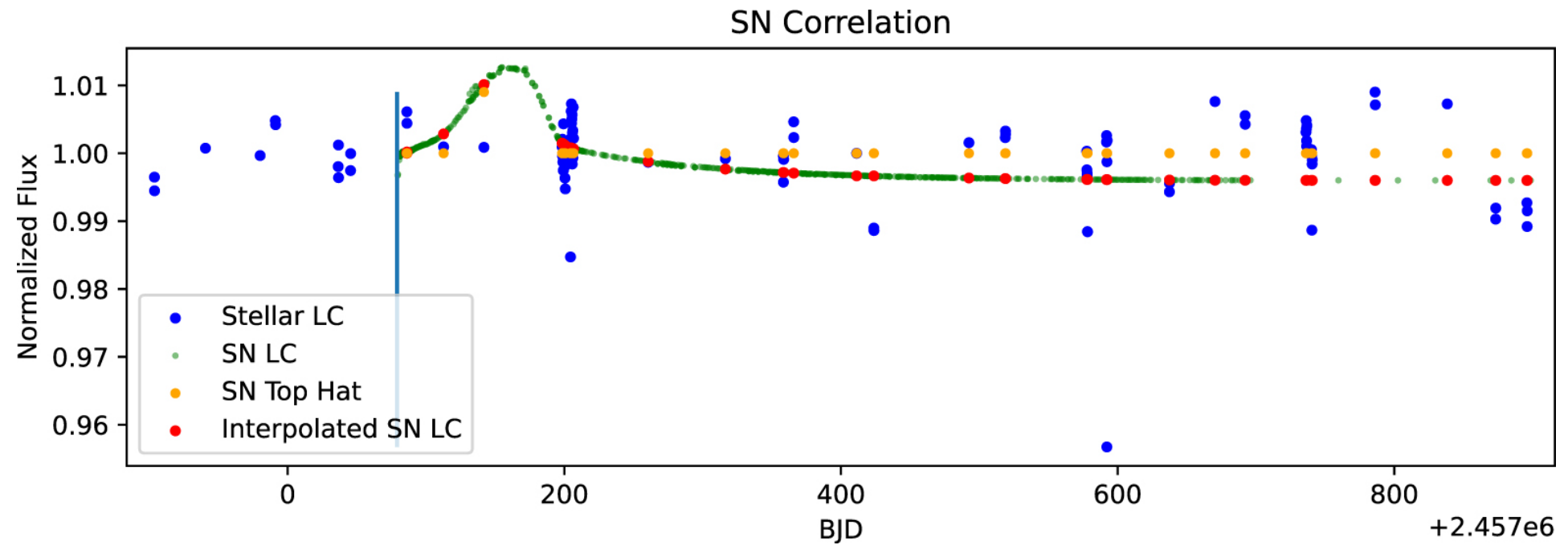
Highest Ranking Variable

We ranked the remaining 734 candidate systems with sufficient light curve data using the error weighted distance between left and right light curves for nine parameters

Lowest Ranking Variable



# Other Signal Searches



# Summary + Future Prospects

- Signal synchronization strategies
  - SETI Ellipsoid with Gaia and TESS
  - Seto (2021) method with Gaia
  - Seto (2024) method to be explored
- Time domain SETI
  - Anomalous transits with Kepler
  - Lots of possibility with Rubin Observatory
- Signal synchronization strategies + Time domain SETI
  - Looking at SETI Ellipsoid crossing times in TESS light curves
  - Splitting light curves at the Ellipsoid/Seto crossing time and comparing phase-folded parameters
  - Other (time domain) signal searches at the crossing time – Gaia, TESS, Kepler, Rubin, ZTF, etc.