

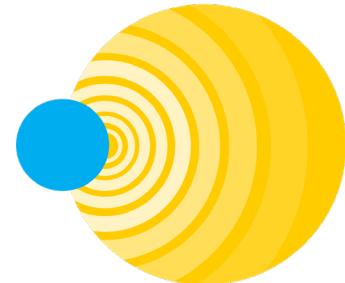
Signal Synchronization Strategies and Time Domain SETI

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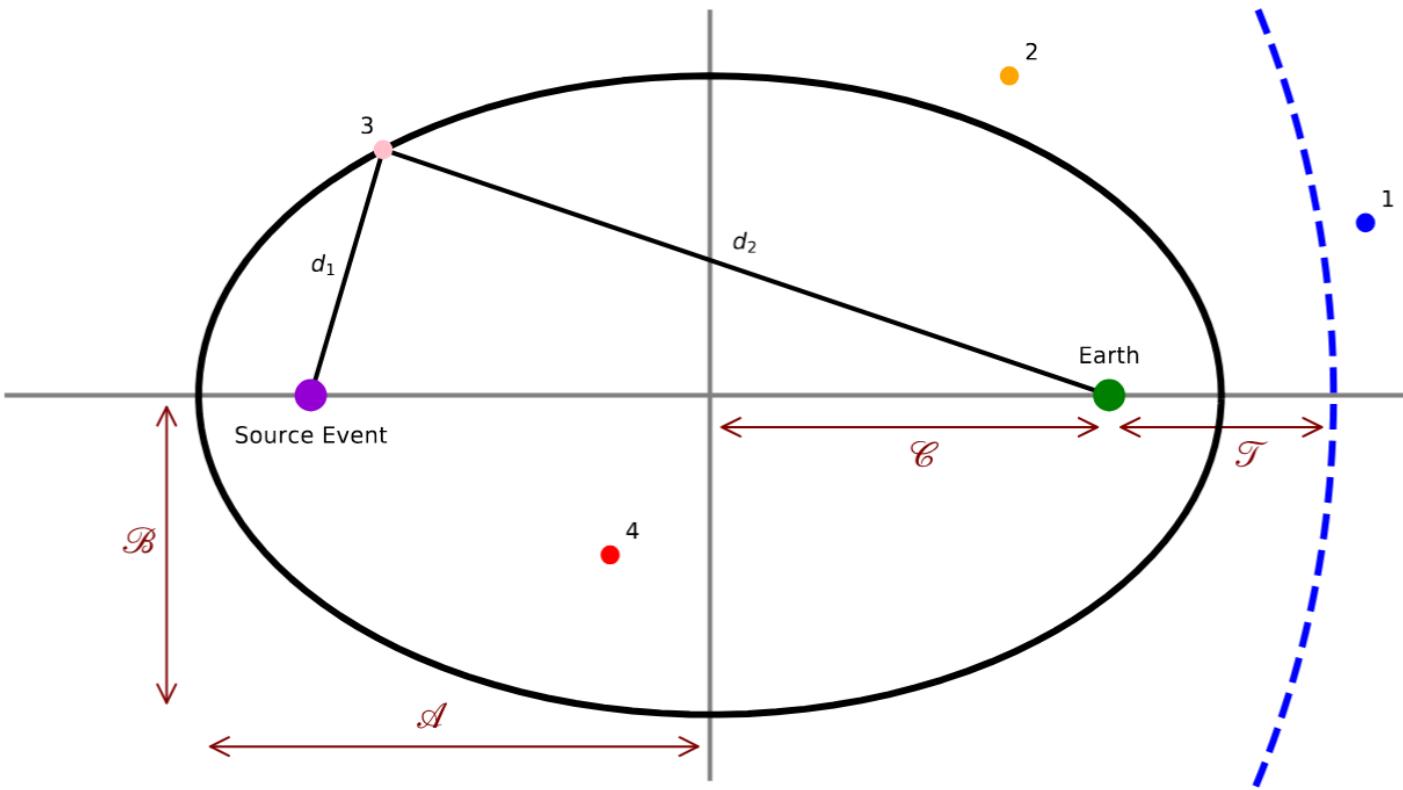


BERKELEY SETI
RESEARCH CENTER

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



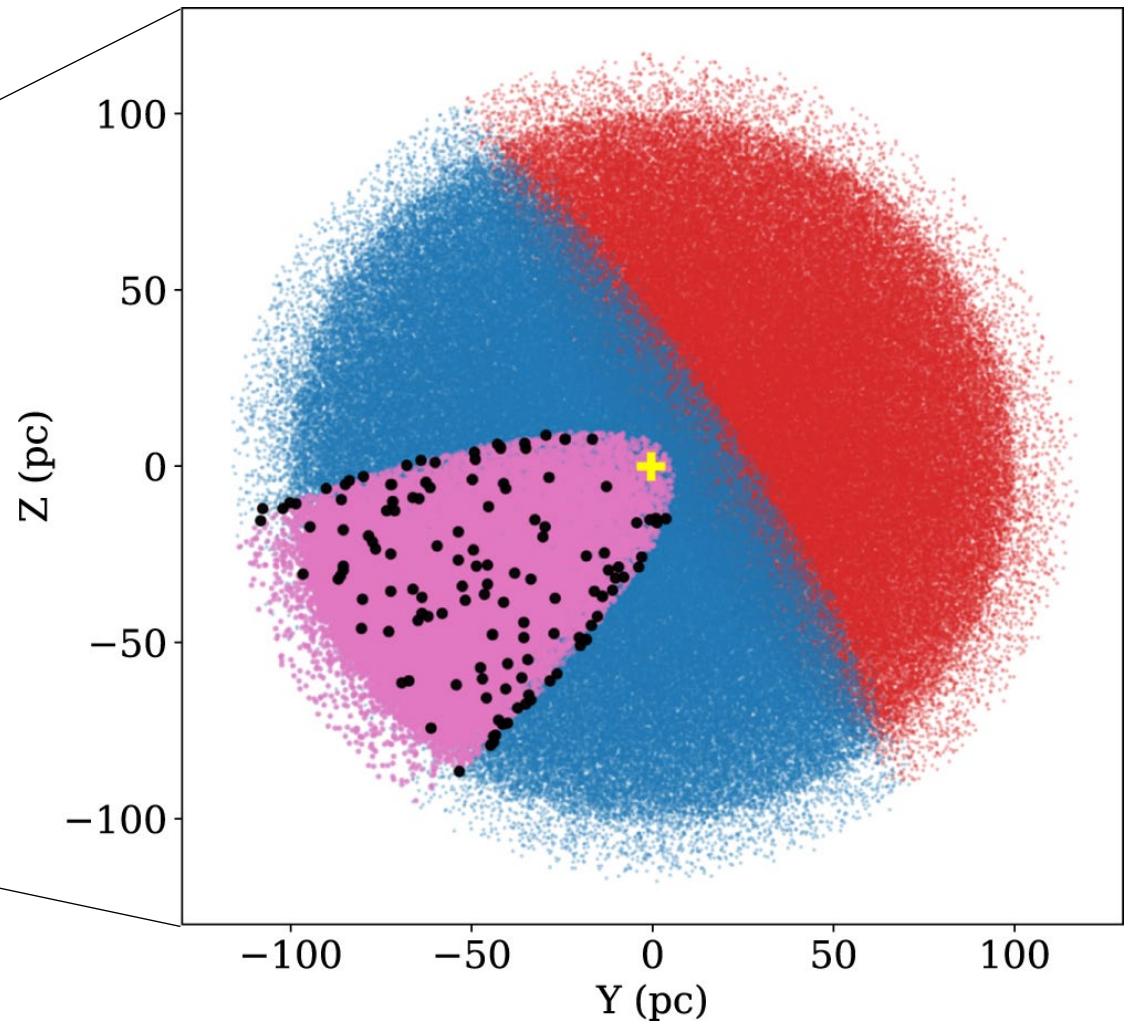
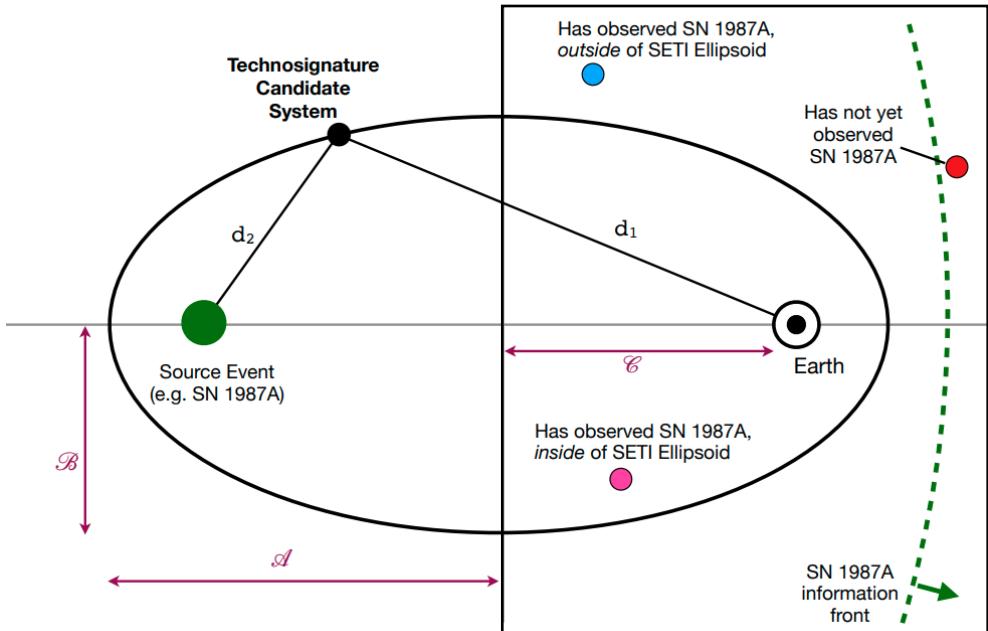
SETI Ellipsoid:
$$d_1 + d_2 = D + \mathcal{T} = D + cT$$

Star Classes

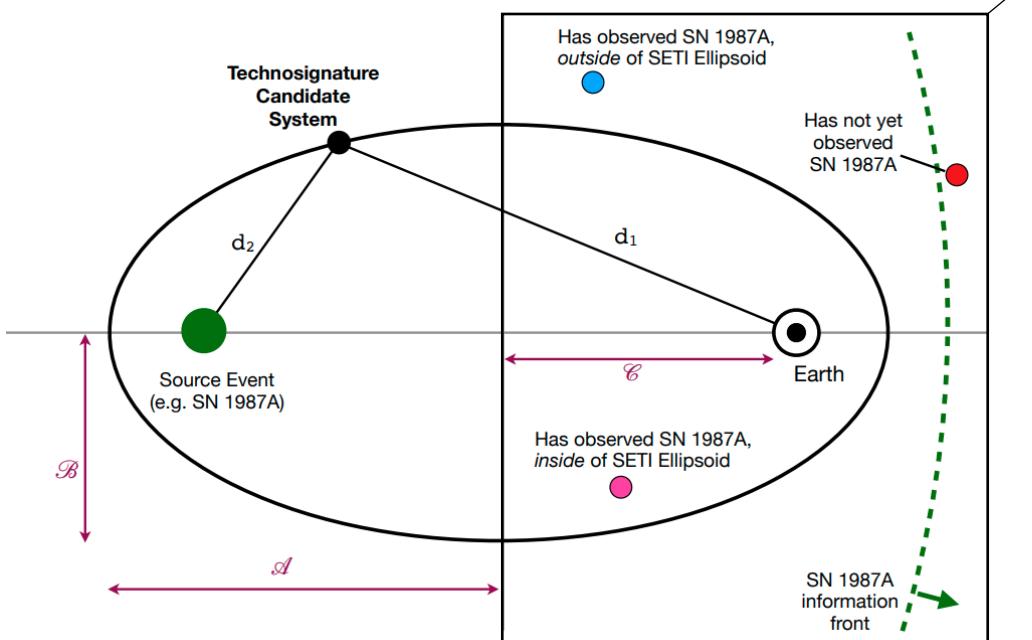
- 1: $d_1 > D + cT$
- 2: $d_1 < D + cT, d_1 + d_2 > D + cT$
- 3: $d_1 + d_2 = D + cT$
- 4: $d_1 + d_2 < D + cT$

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

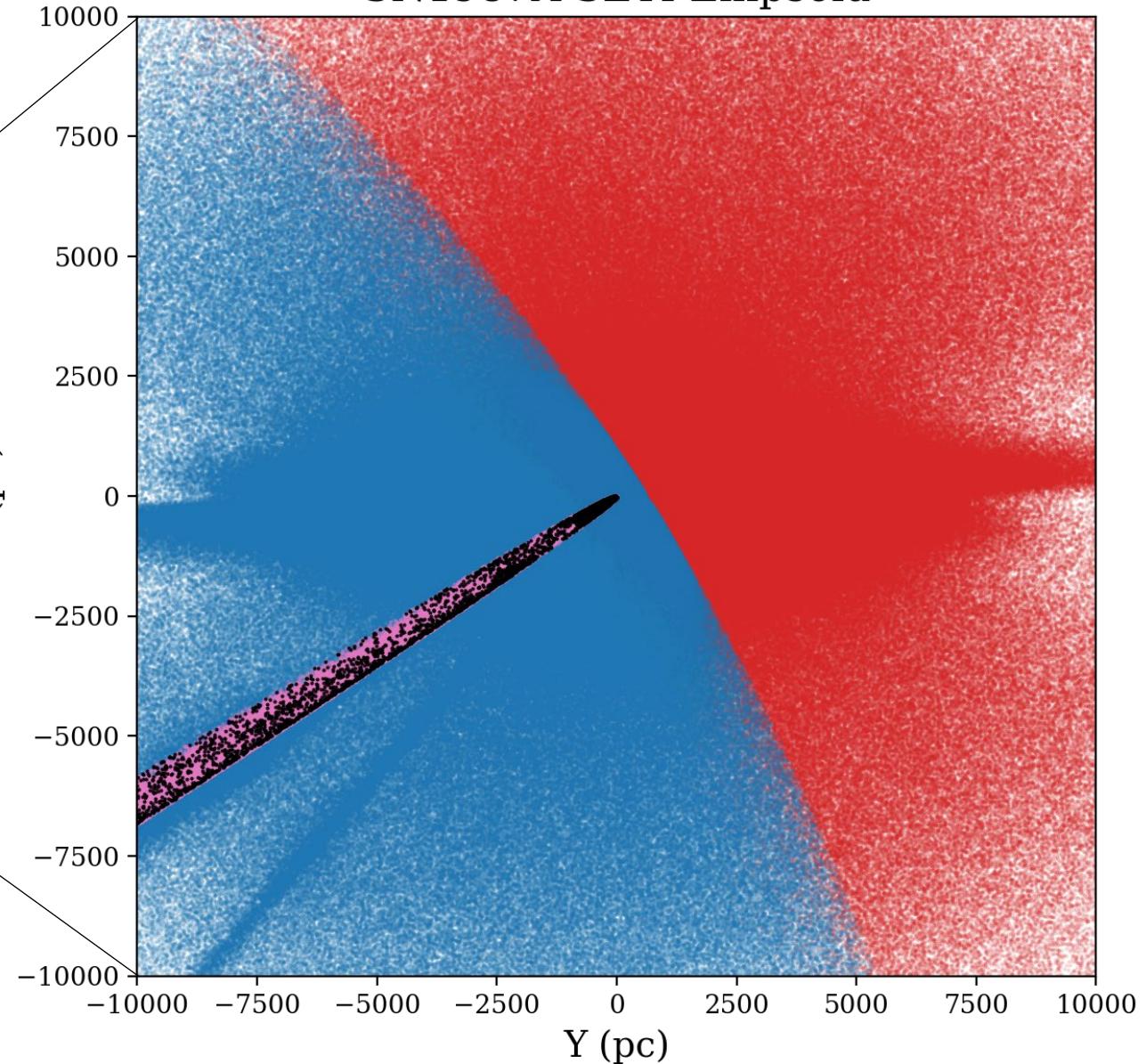
SETI Ellipsoid with Gaia



SETI Ellipsoid with Gaia DR3

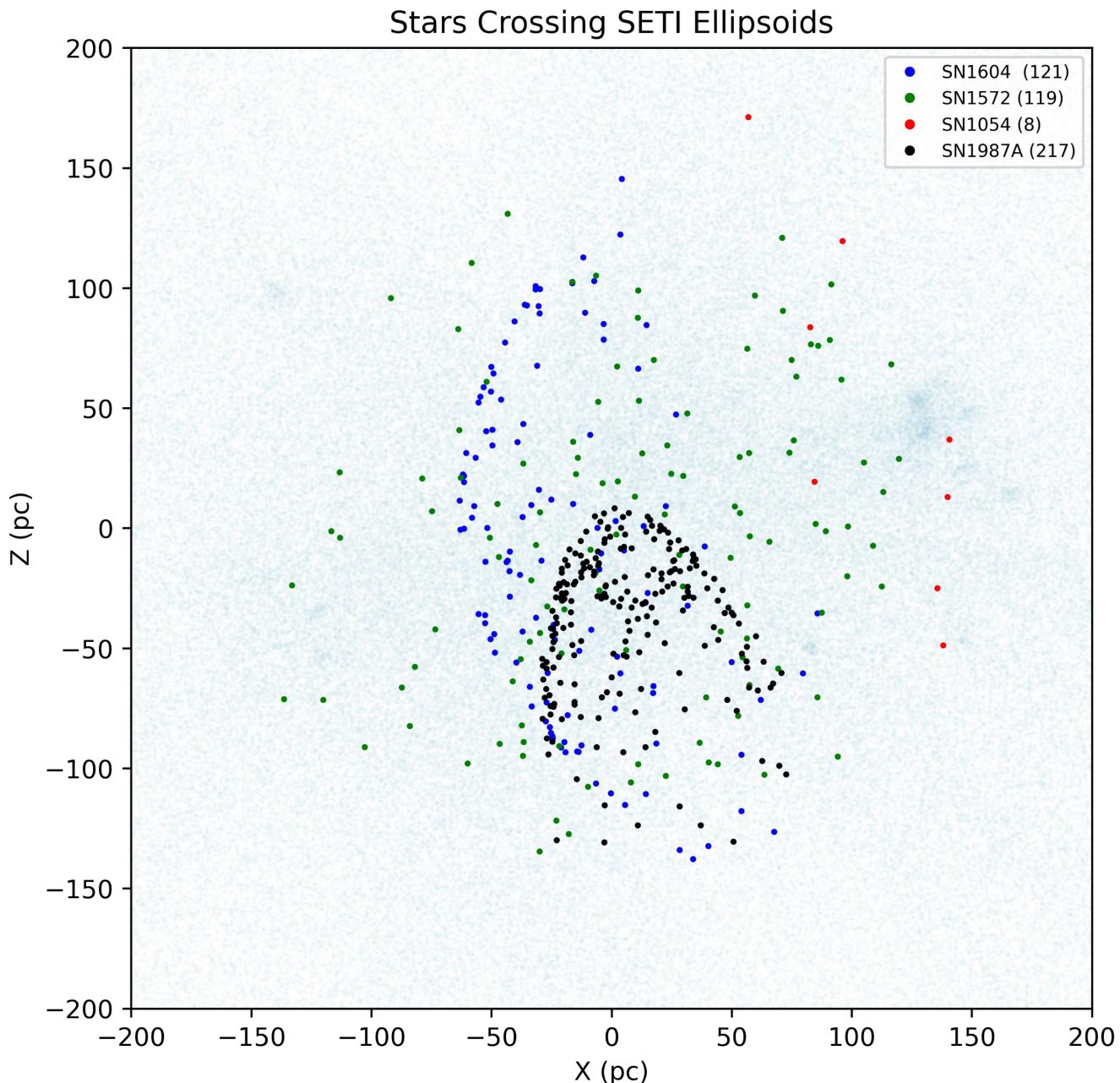


SN1987A SETI Ellipsoid

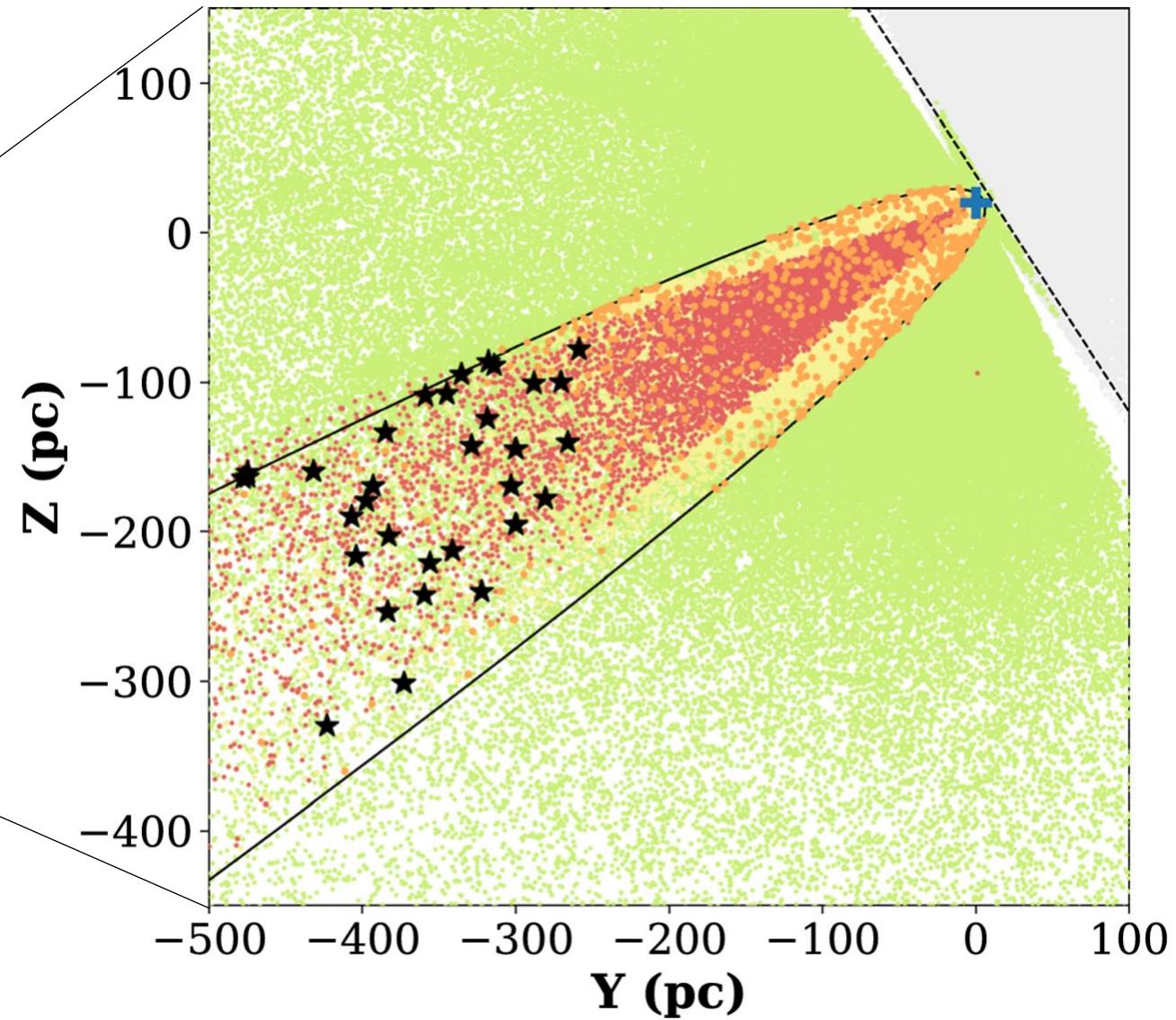
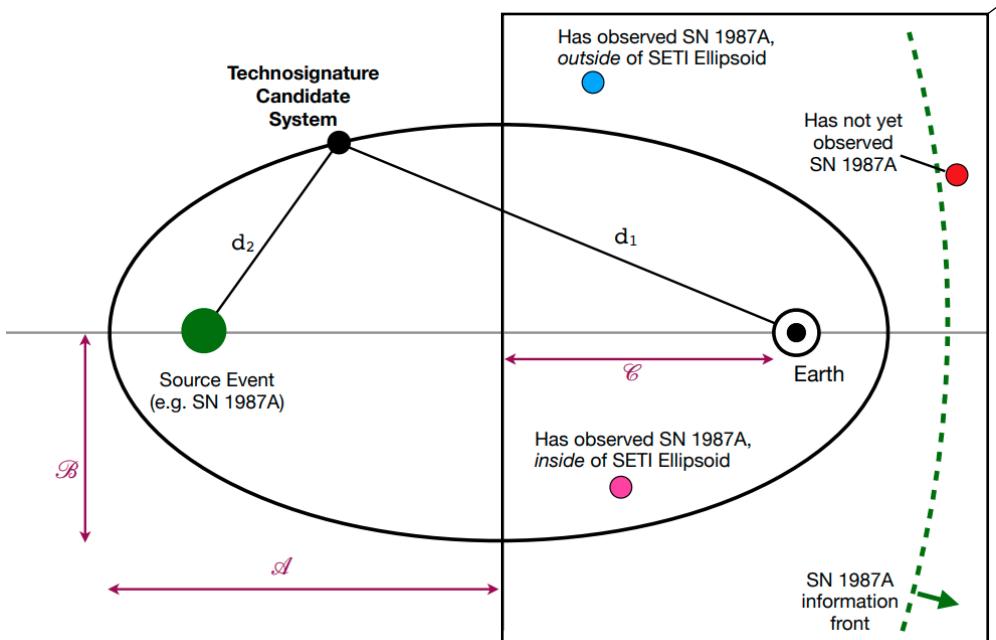


SETI Ellipsoid with Gaia DR3

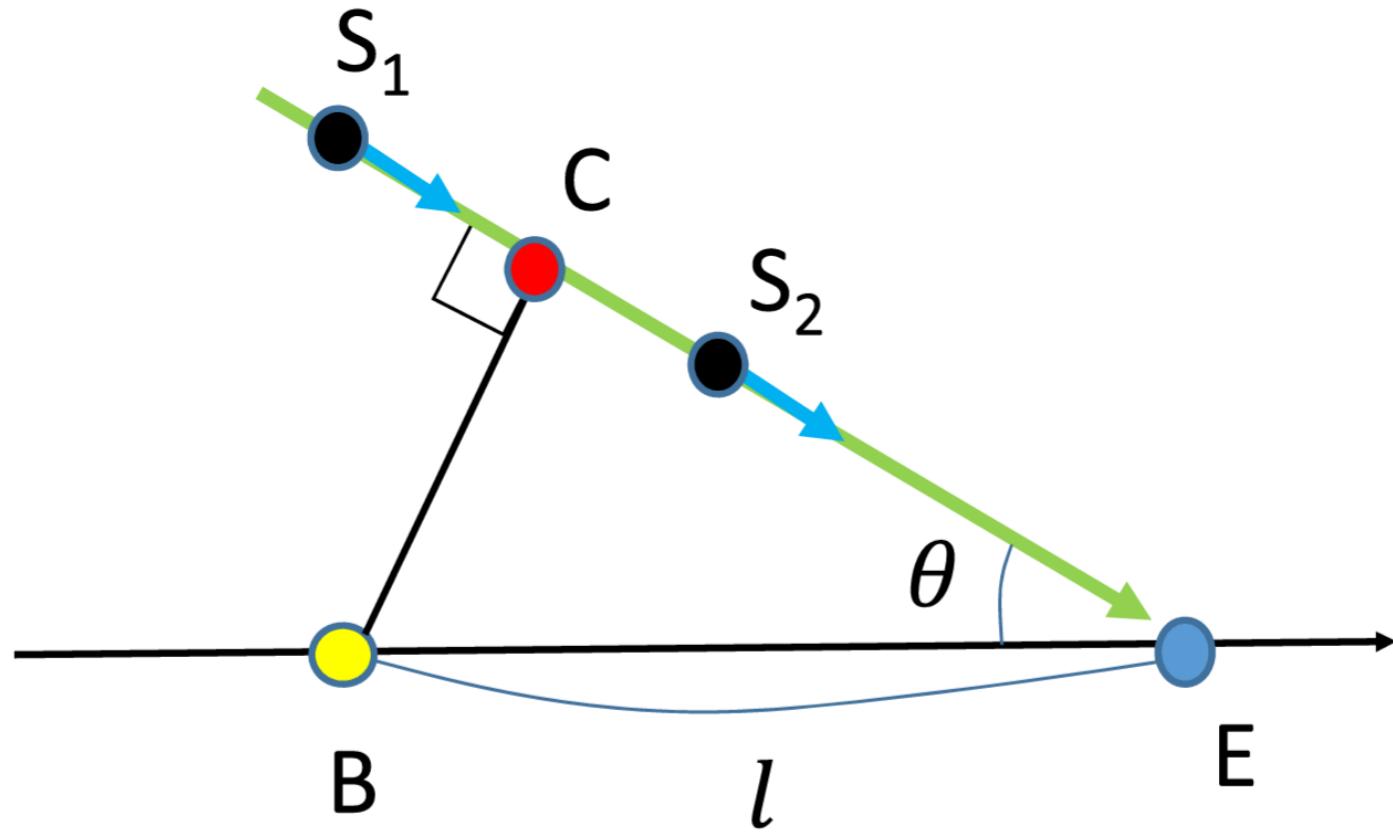
465 stars crossed the SETI Ellipsoids for SNe 1987A, 1604, 1572, or 1054 between 2014 and 2017



SETI Ellipsoid with TESS



Seto (2021) Signaling Scheme



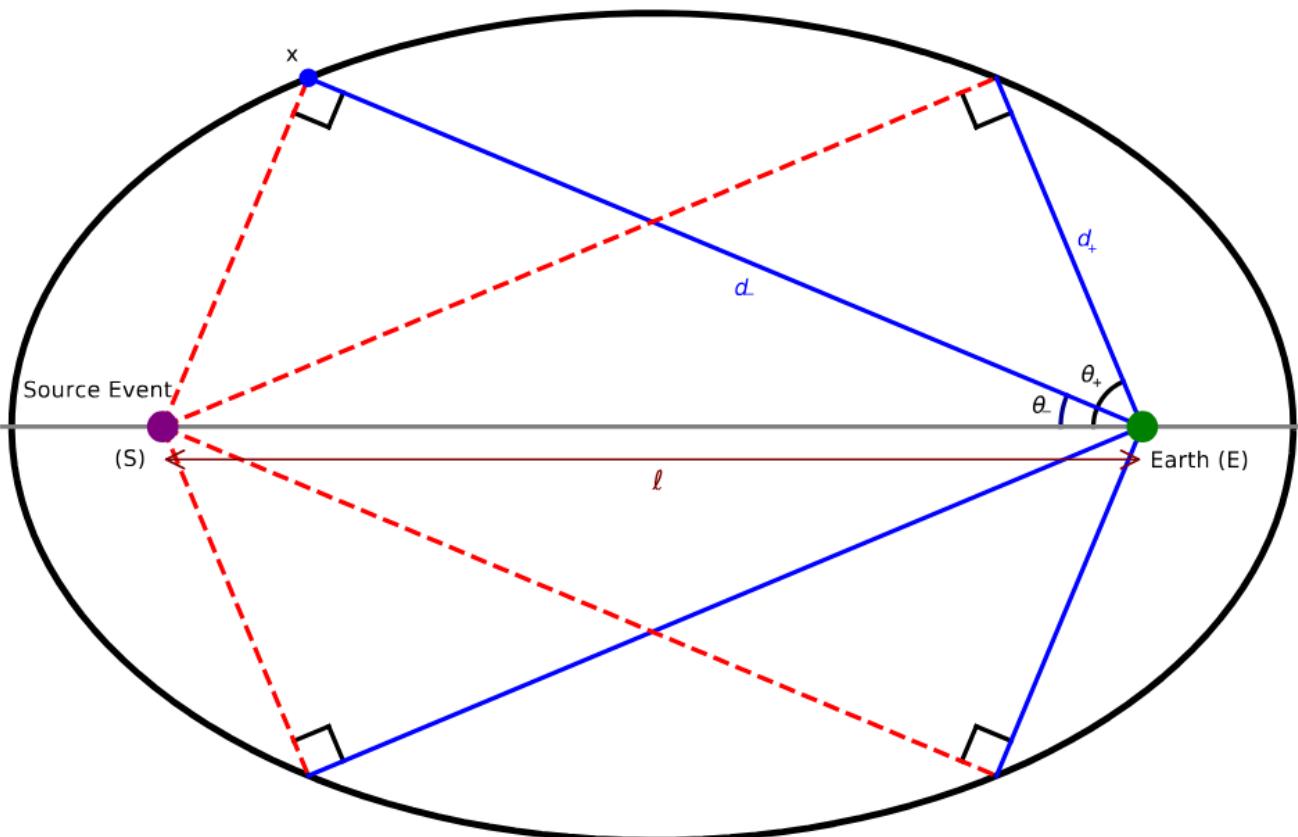
Unique Reference Point for Each Angle:

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

Seto Crossing Time:

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

Seto (2021) Signaling Scheme



Seto Normalized Crossing Time:

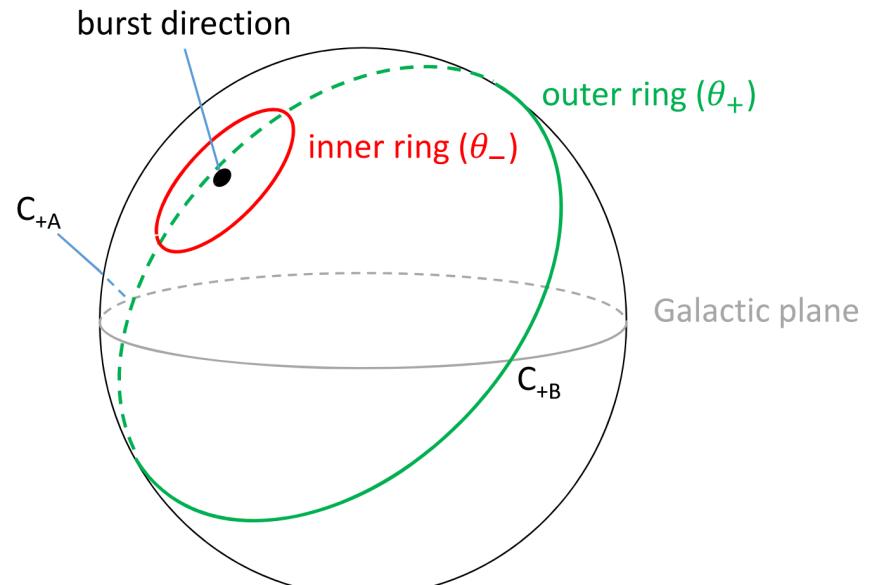
$$\tau_E(\theta) = \sin\theta + \cos\theta - 1$$

Seto Search Angles:

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

Seto Closing Time:

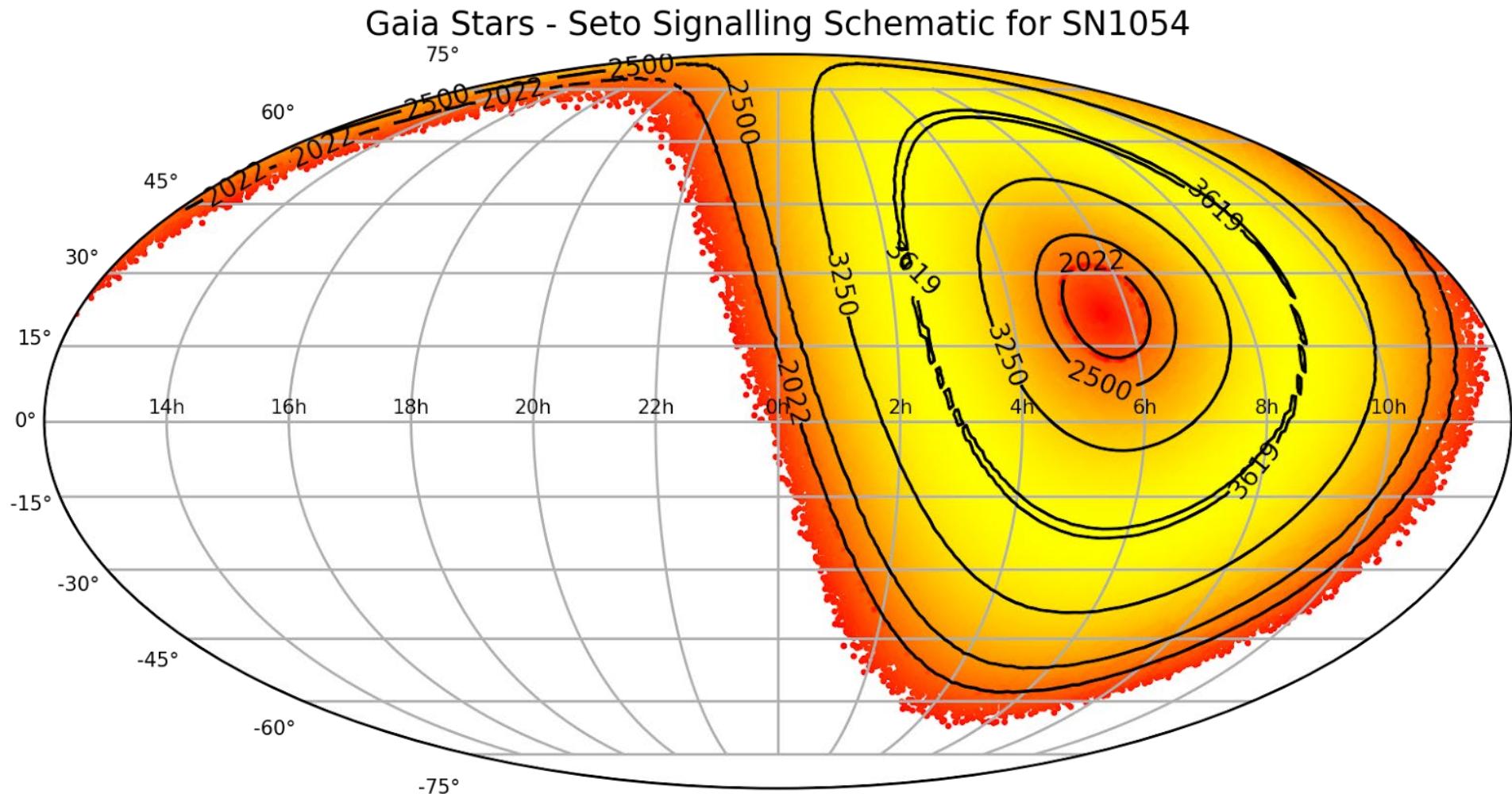
$$\tau_E = \sqrt{2} - 1$$



Seto (2021) Signaling Scheme

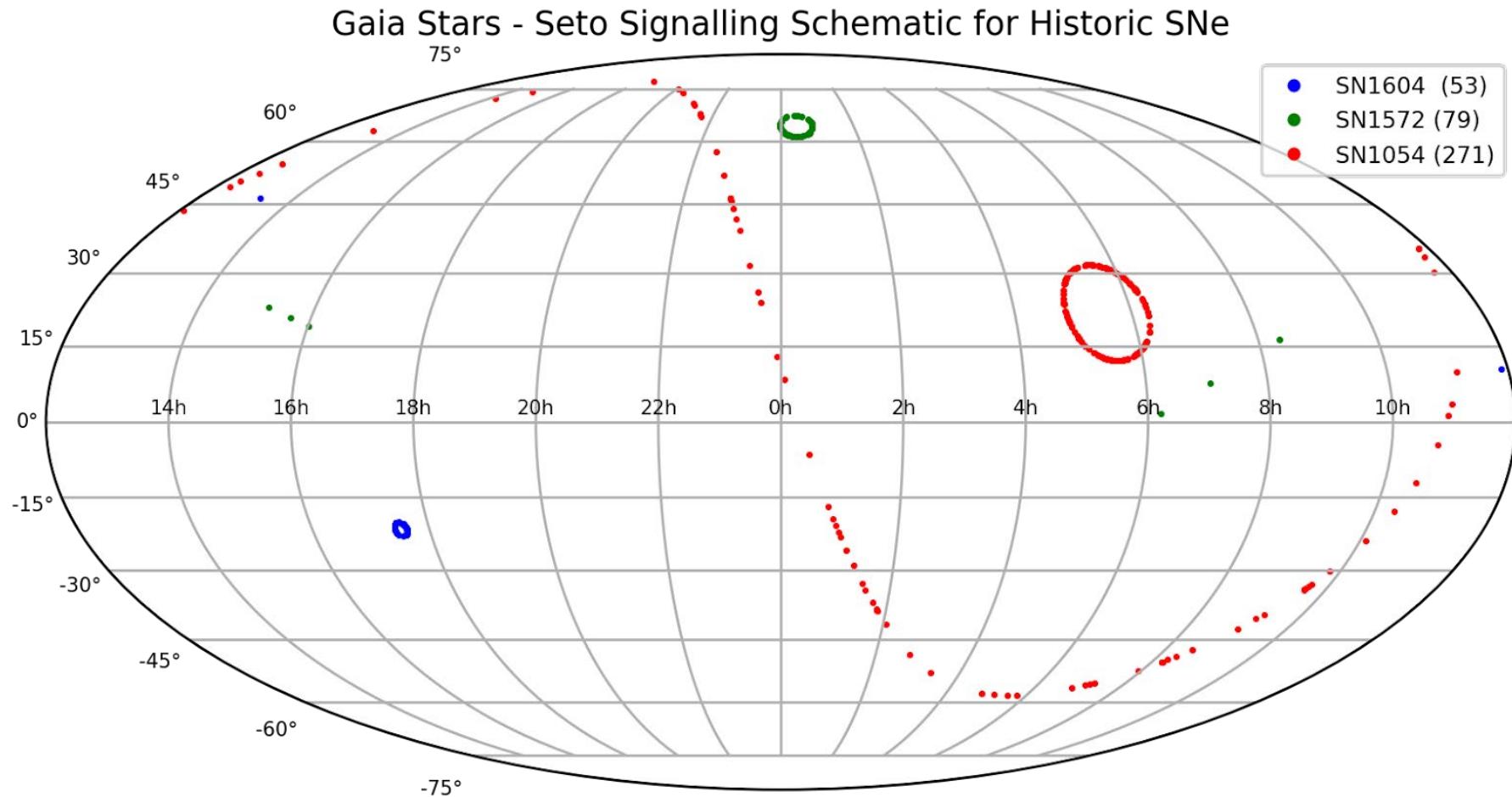


Seto (2021) Scheme with Gaia DR3



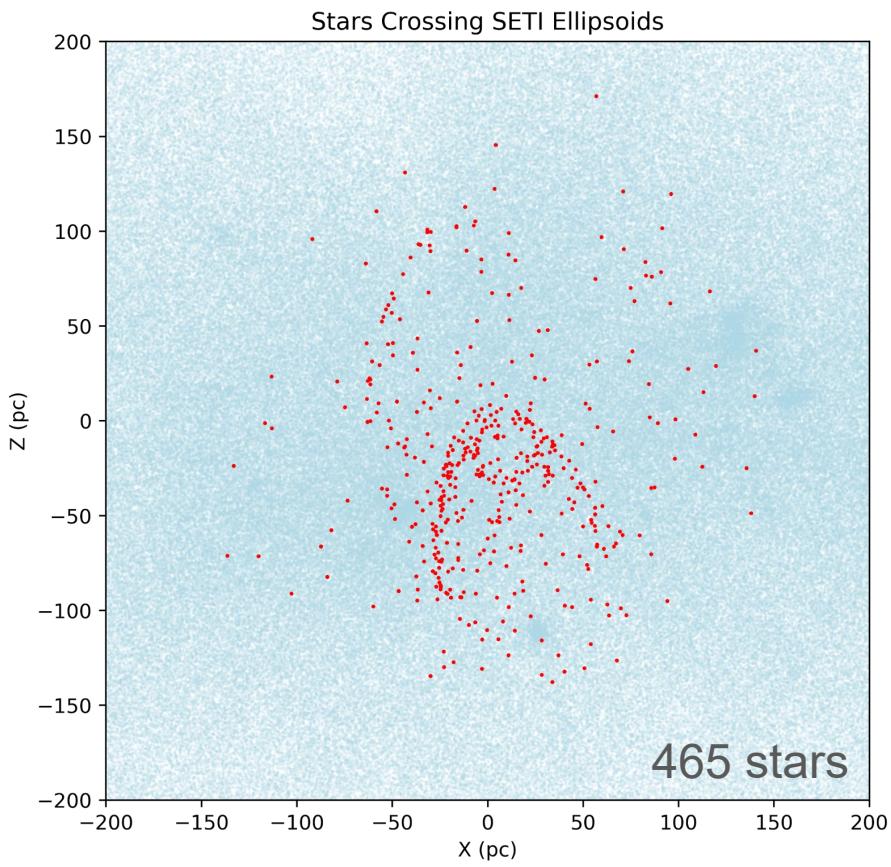
Seto (2021) Scheme with Gaia DR3

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

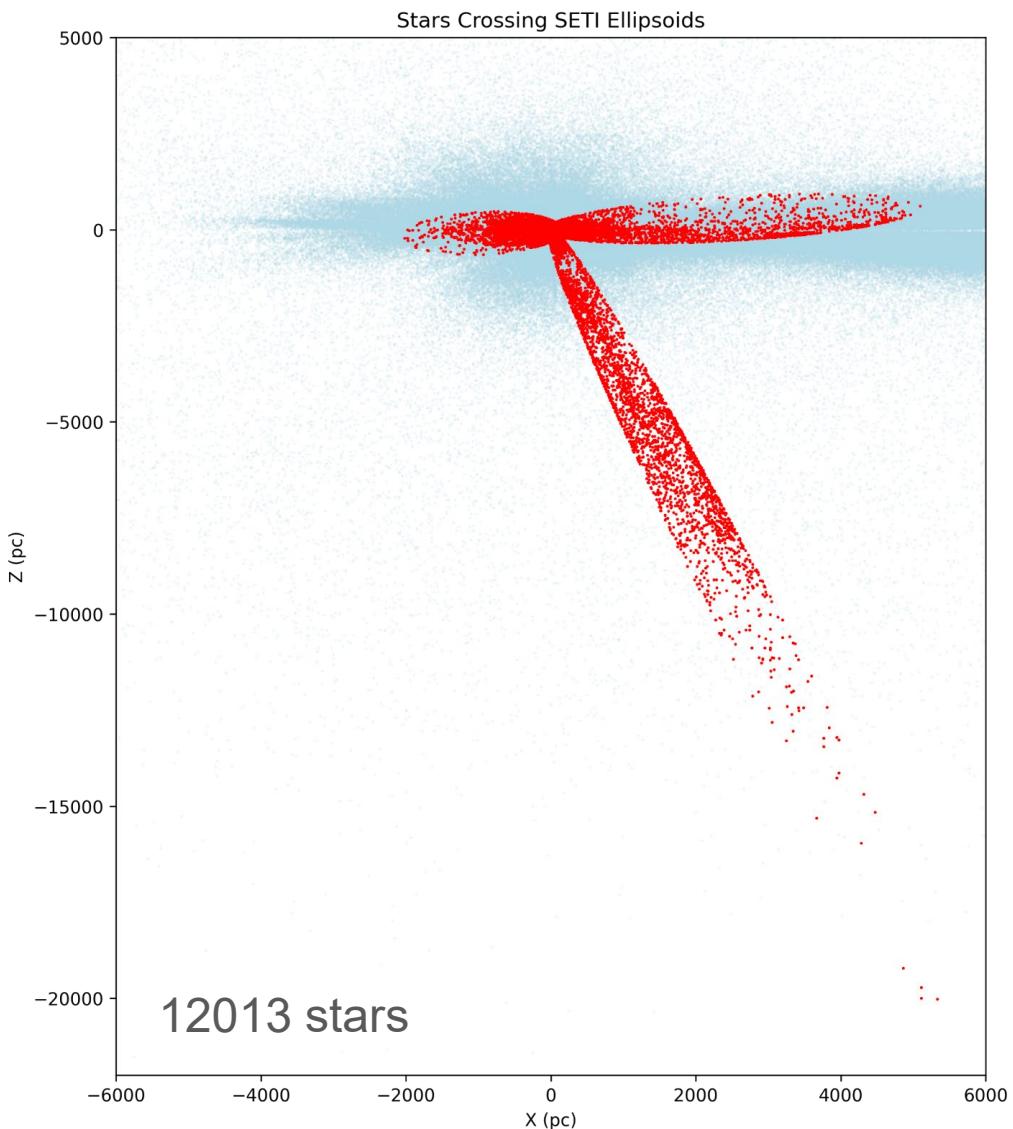


Limitations of the SETI Ellipsoid and Seto (2021) Methods

Stellar distance errors

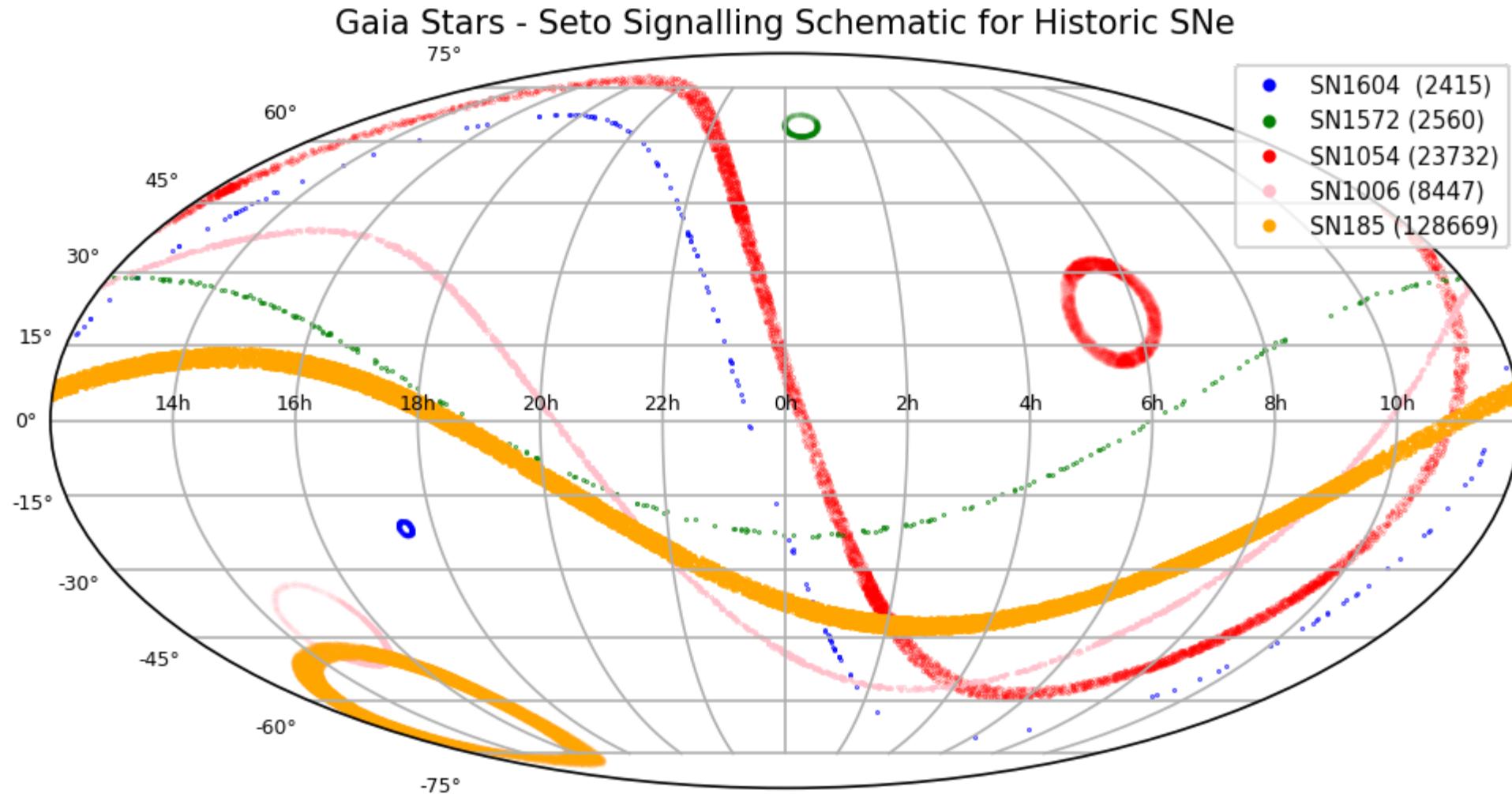


vs.

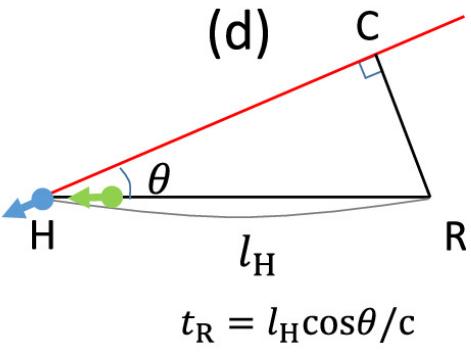
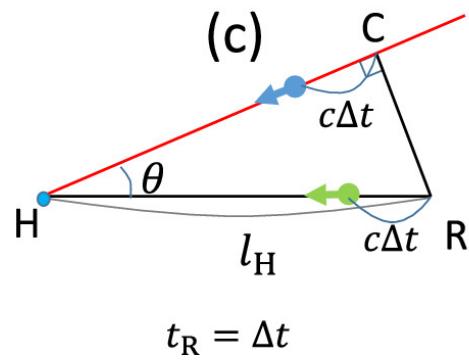
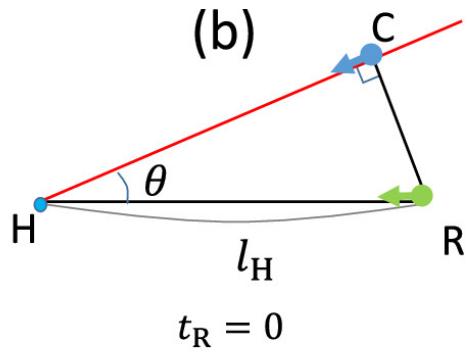
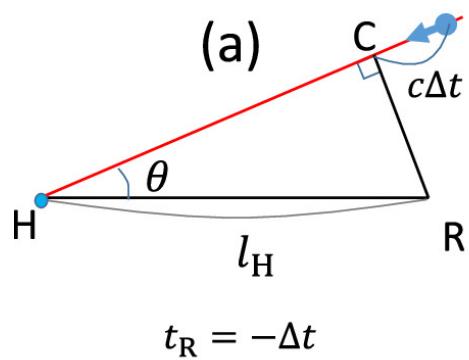


Limitations of the SETI Ellipsoid and Seto (2021) Methods

SN distance errors



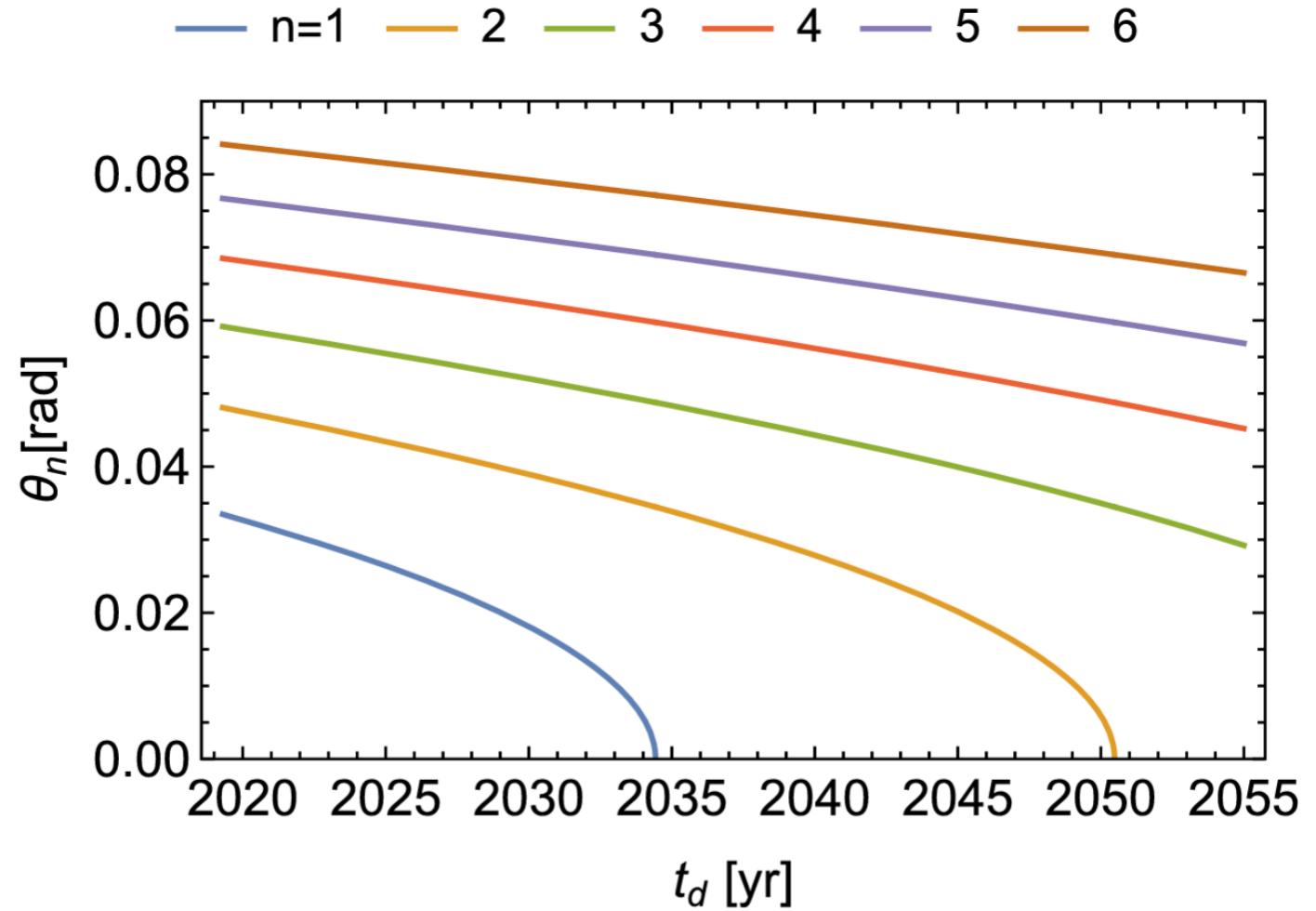
Seto (2024) Signaling Scheme



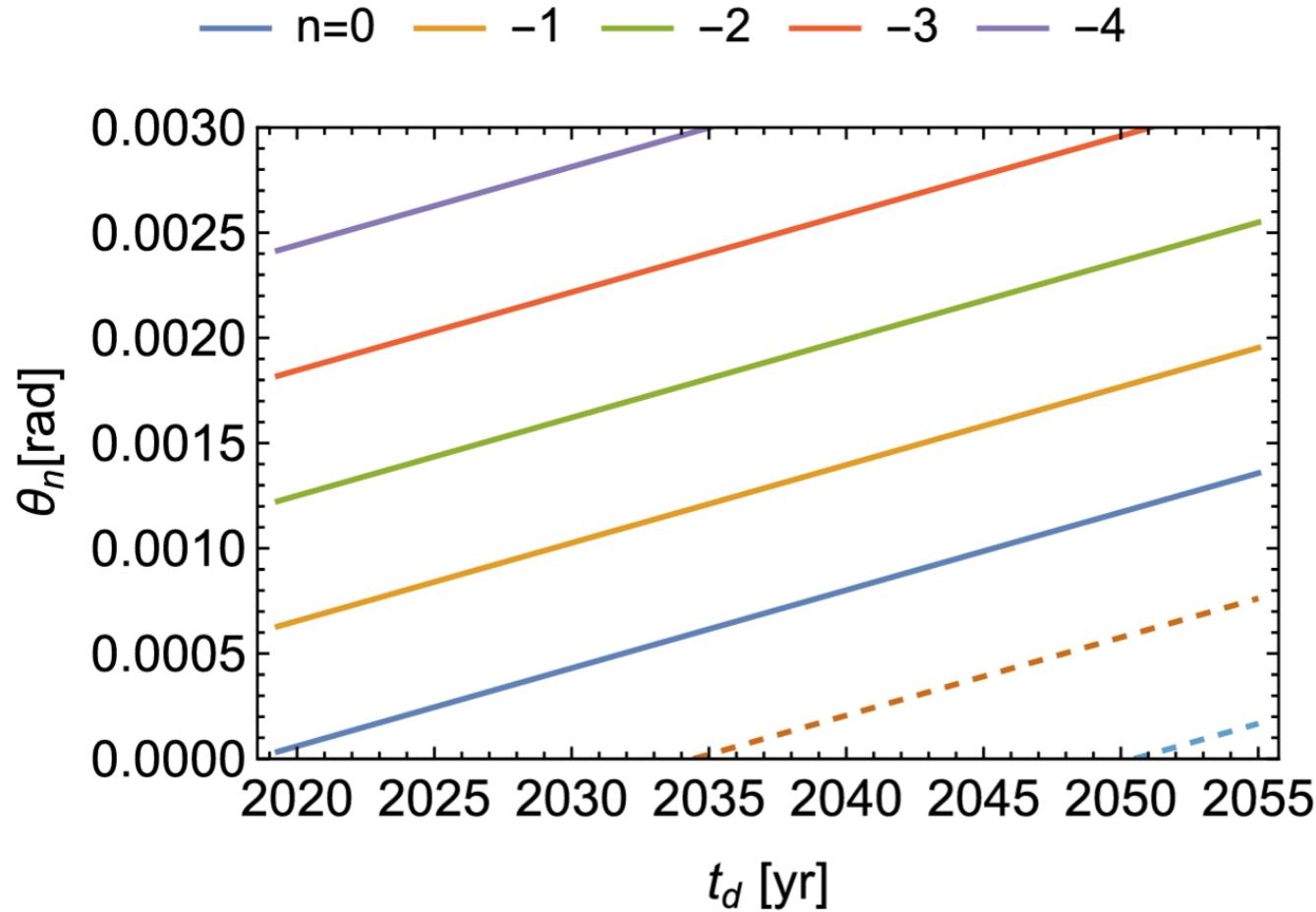
Unique Reference Point for Each Angle:

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

Seto (2024) Signaling Scheme



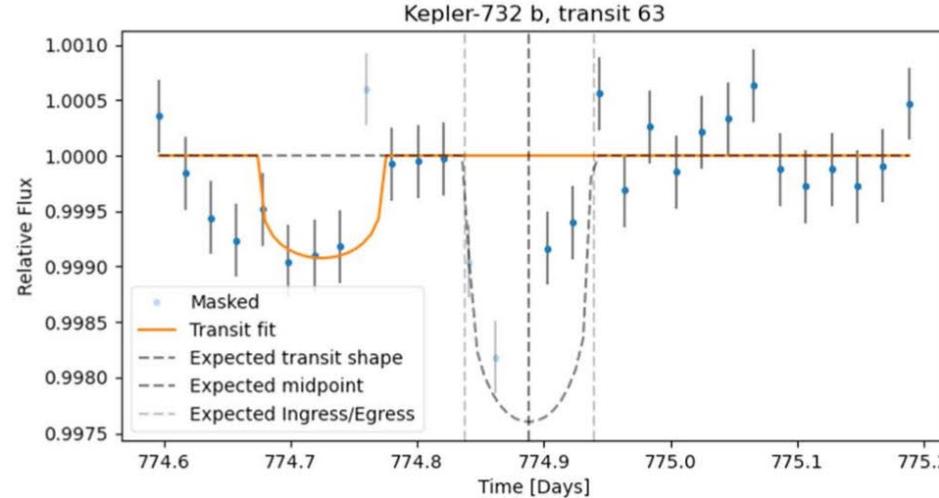
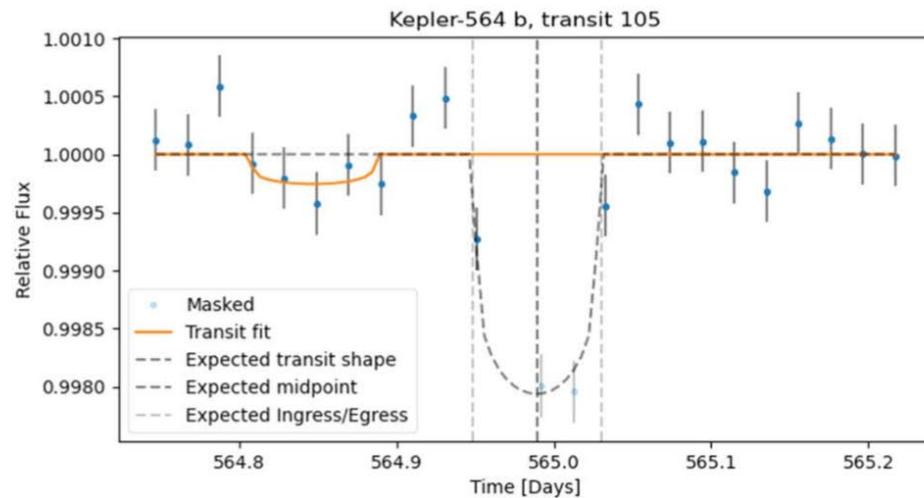
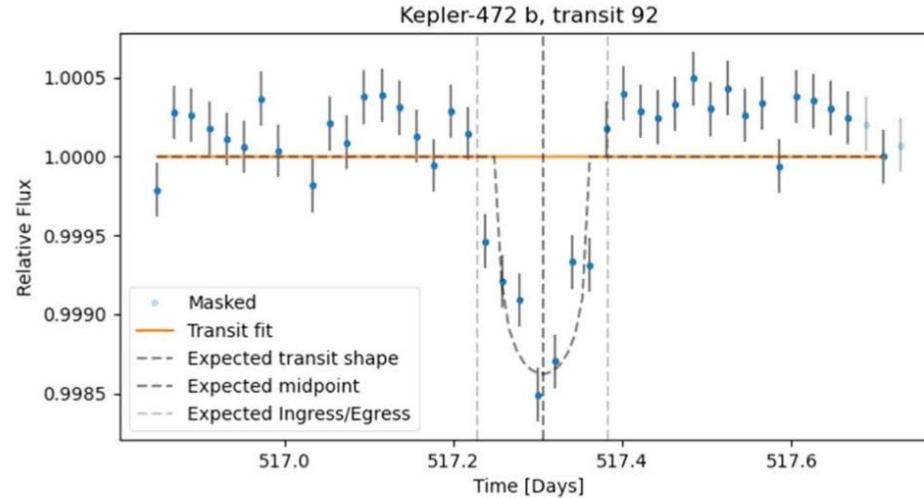
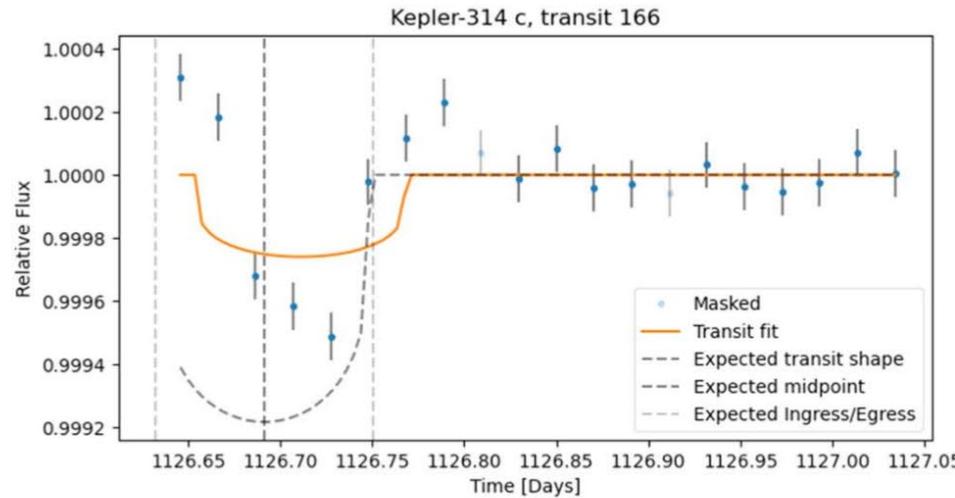
Seto (2024) Signaling Scheme



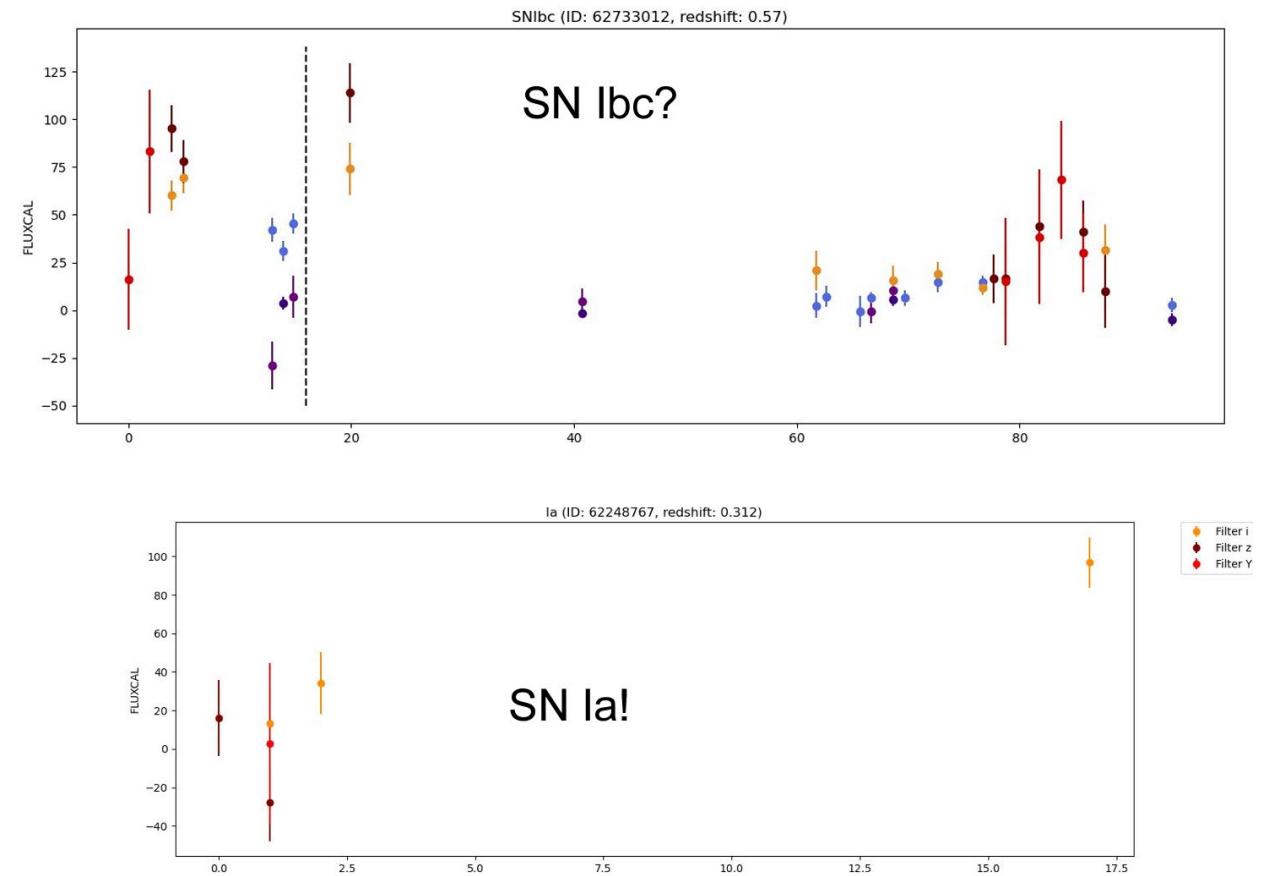
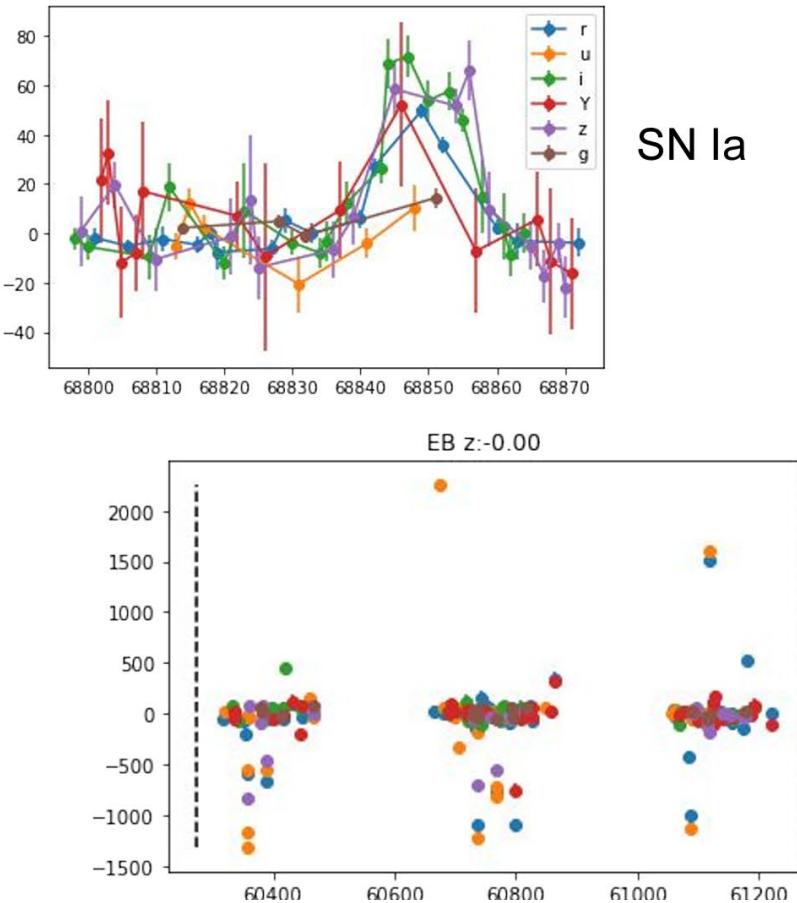
Time Domain SETI

- 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

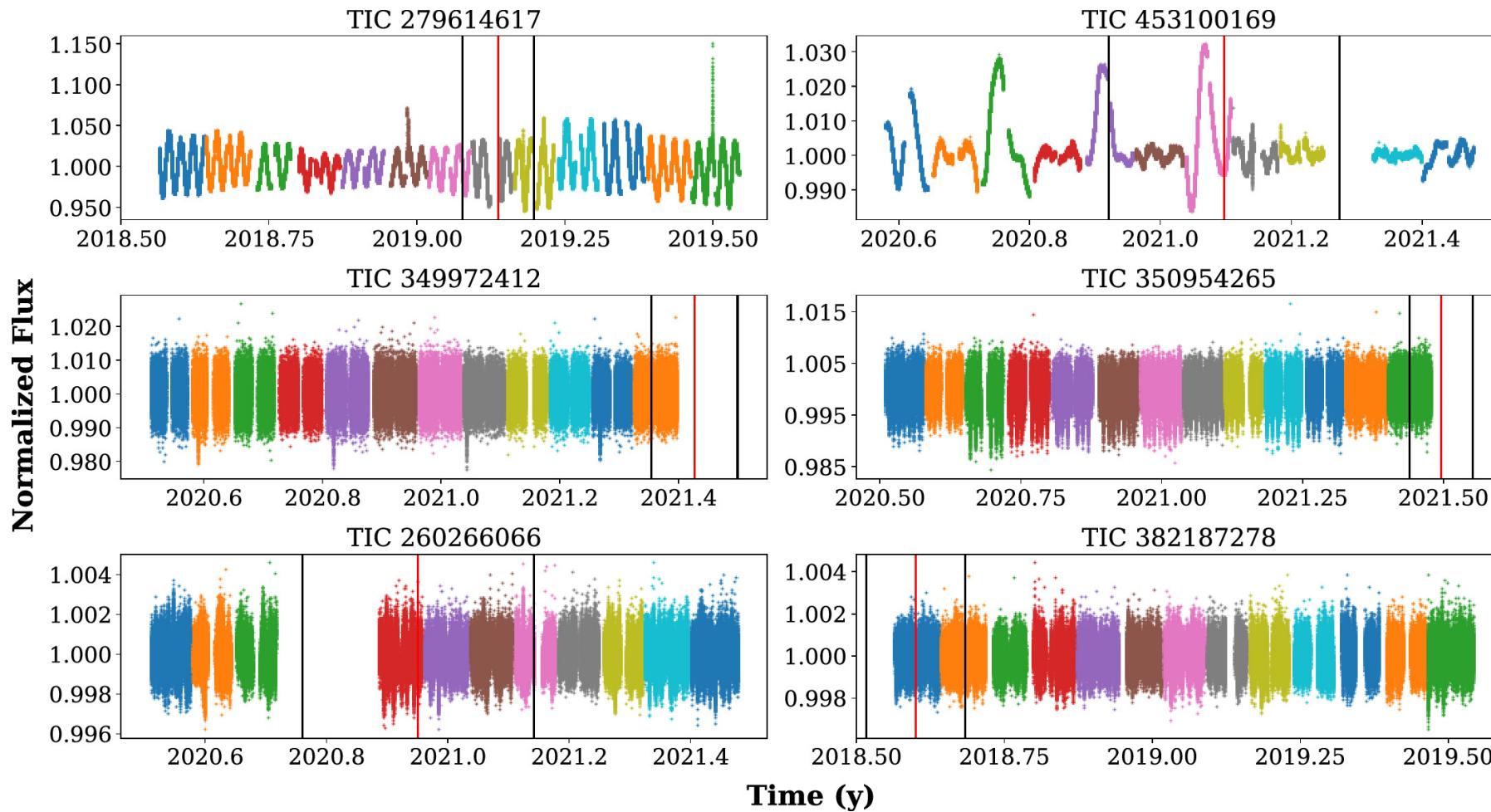
Anomalous Transits with Kepler



Variability Classification with LSST

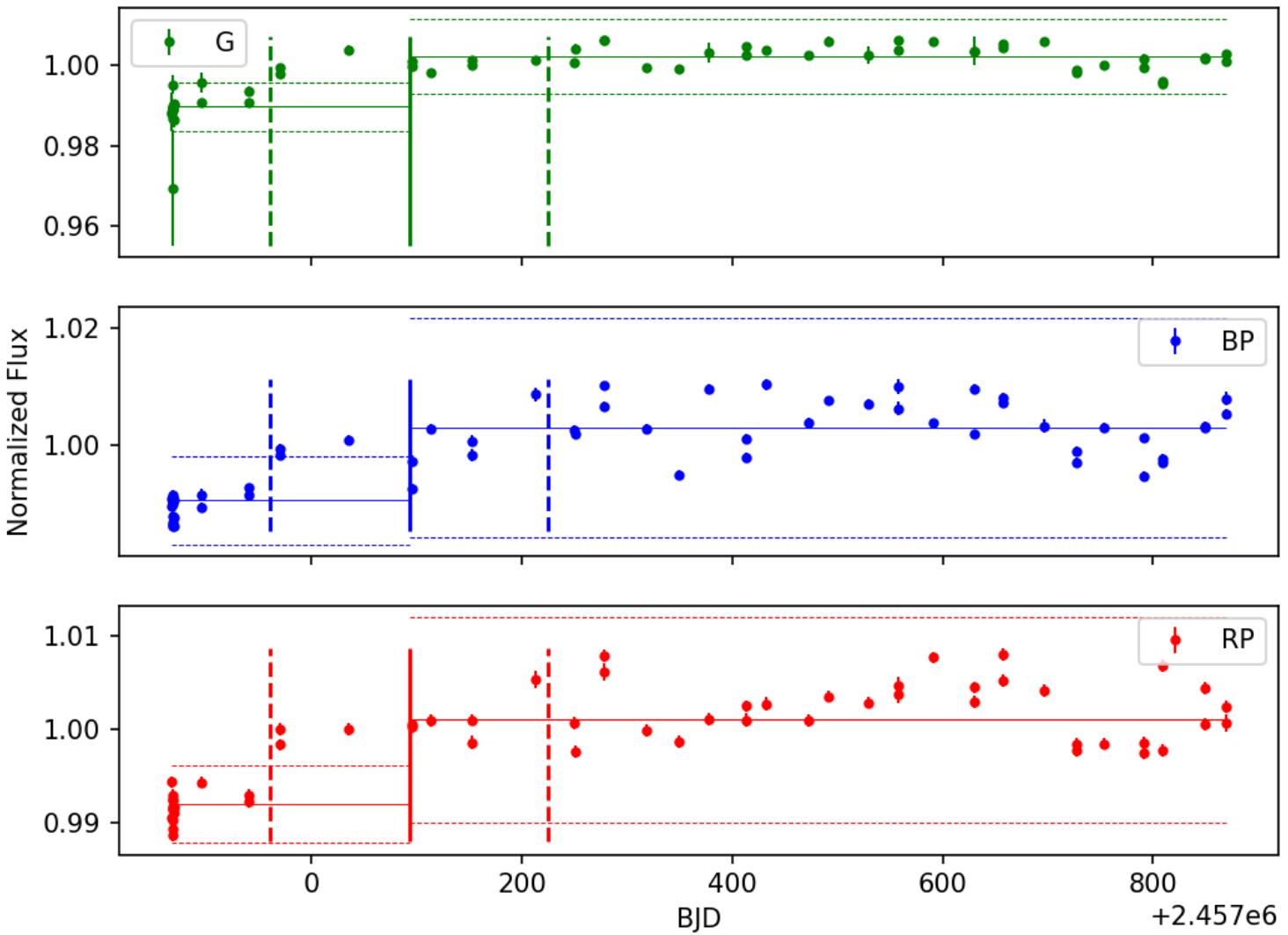


Time Domain SETI + Signal Synchronization Strategies with TESS



Time Domain SETI + Signal Synchronization Strategies with Gaia

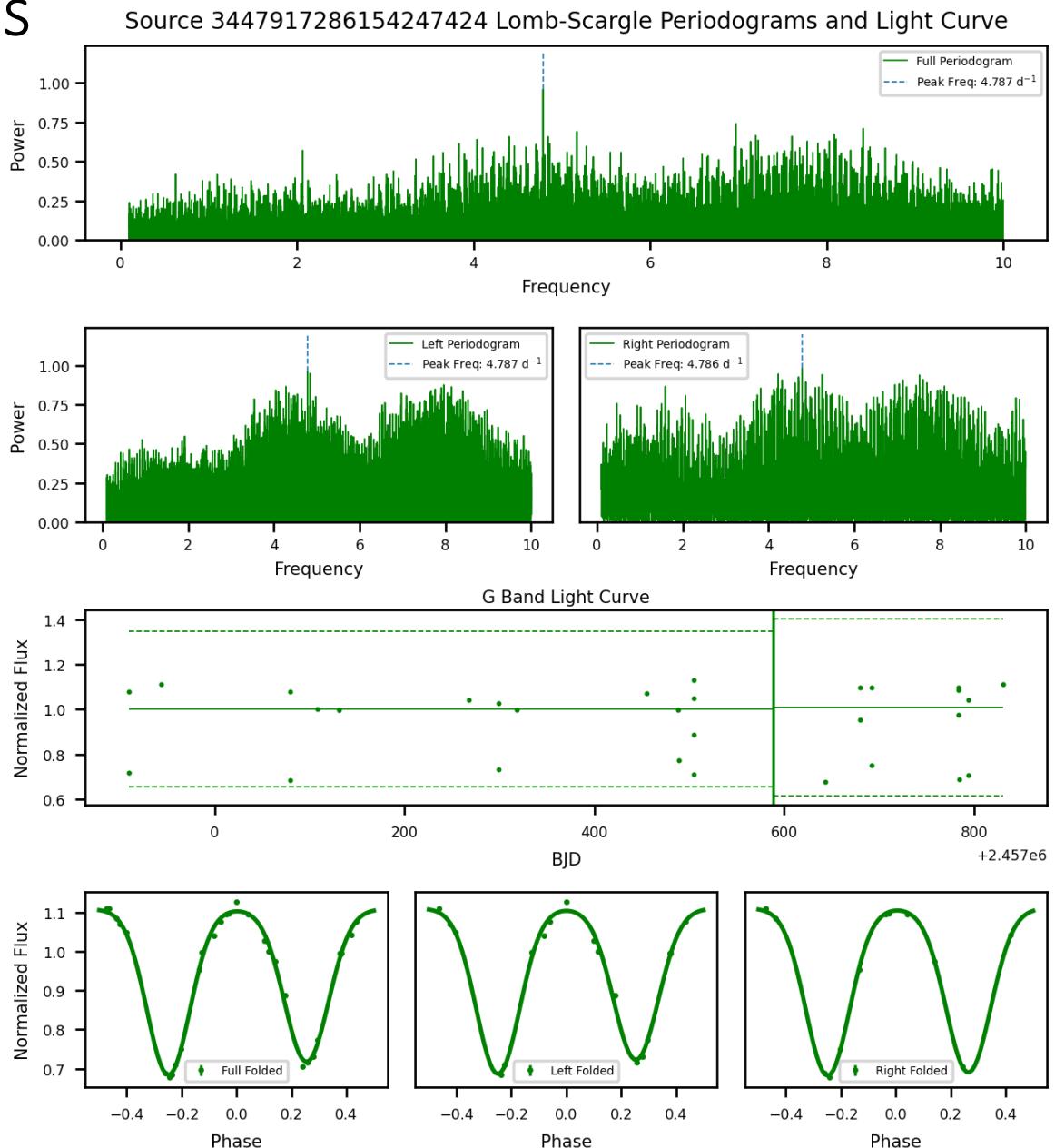
Source 4738129894277454336



Noticeably sparse and incomplete, but has long-term stability

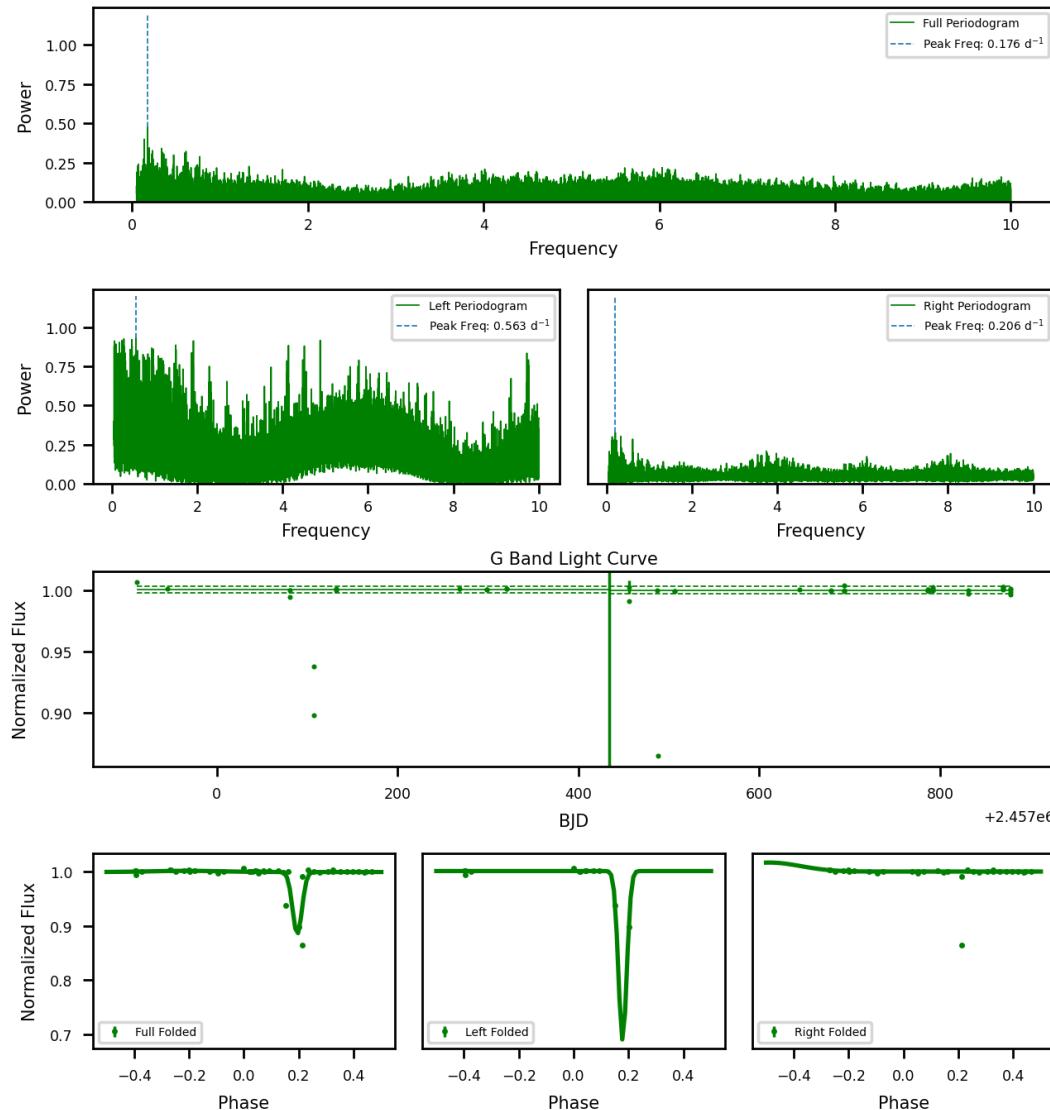
Eclipsing Binary Variability Analysis

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



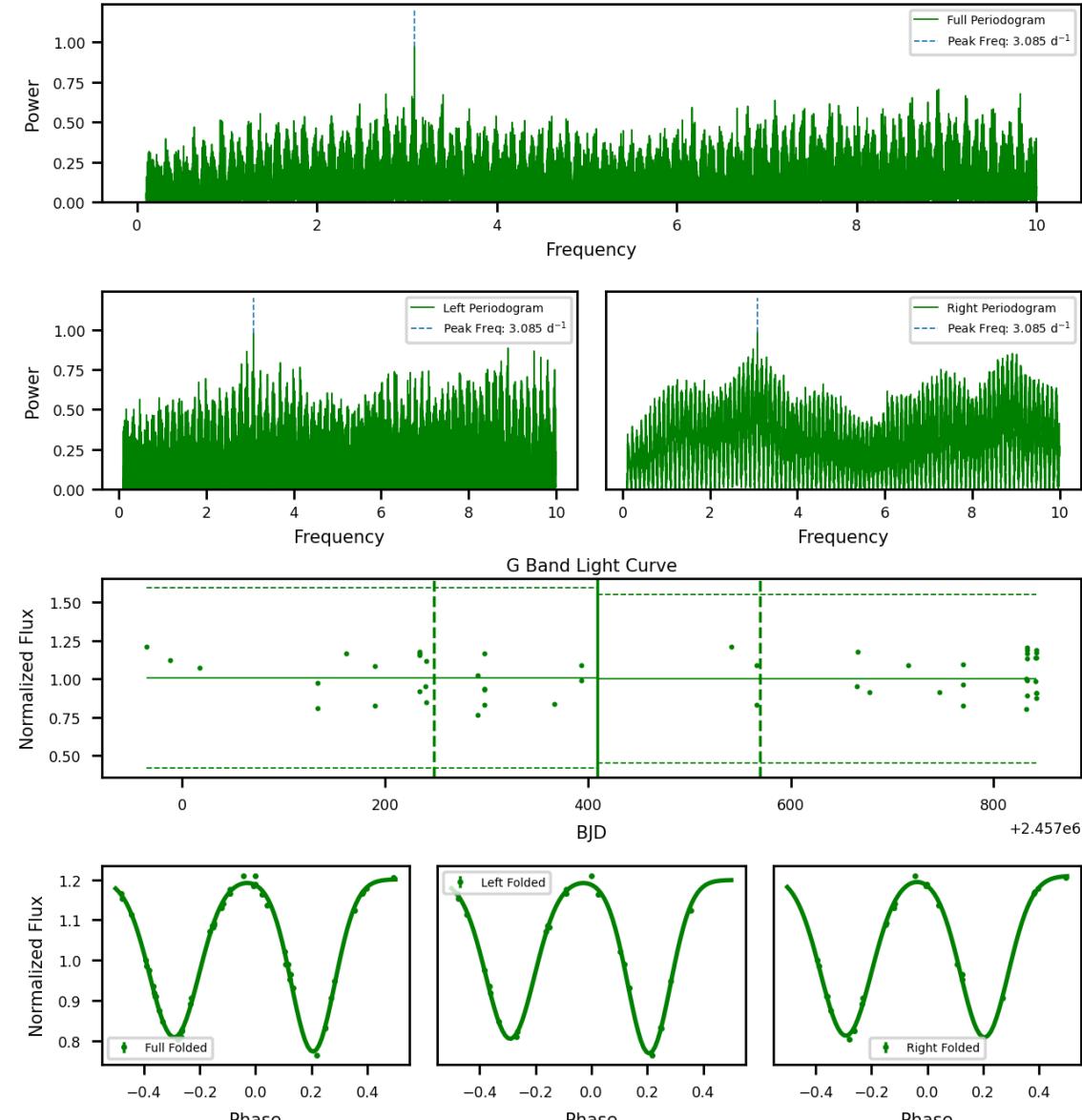
Lowest Ranking ECL

Source 3444070610365980928 Lomb-Scargle Periodograms and Light Curve



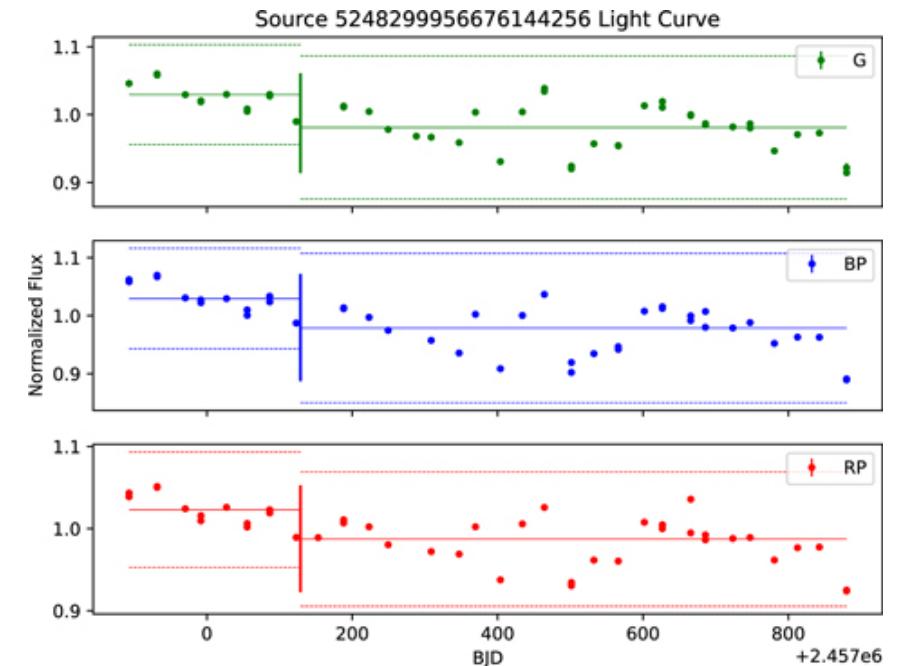
Highest Ranking ECL

Source 5633777360297734016 Lomb-Scargle Periodograms and Light Curve



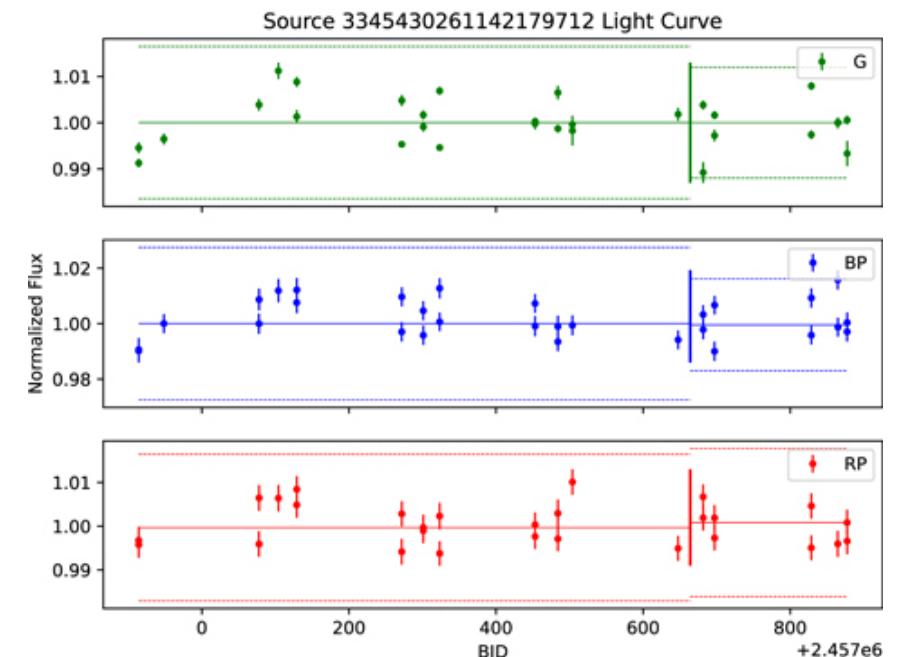
Non-periodic Variability Analysis

Highest Ranking Variable

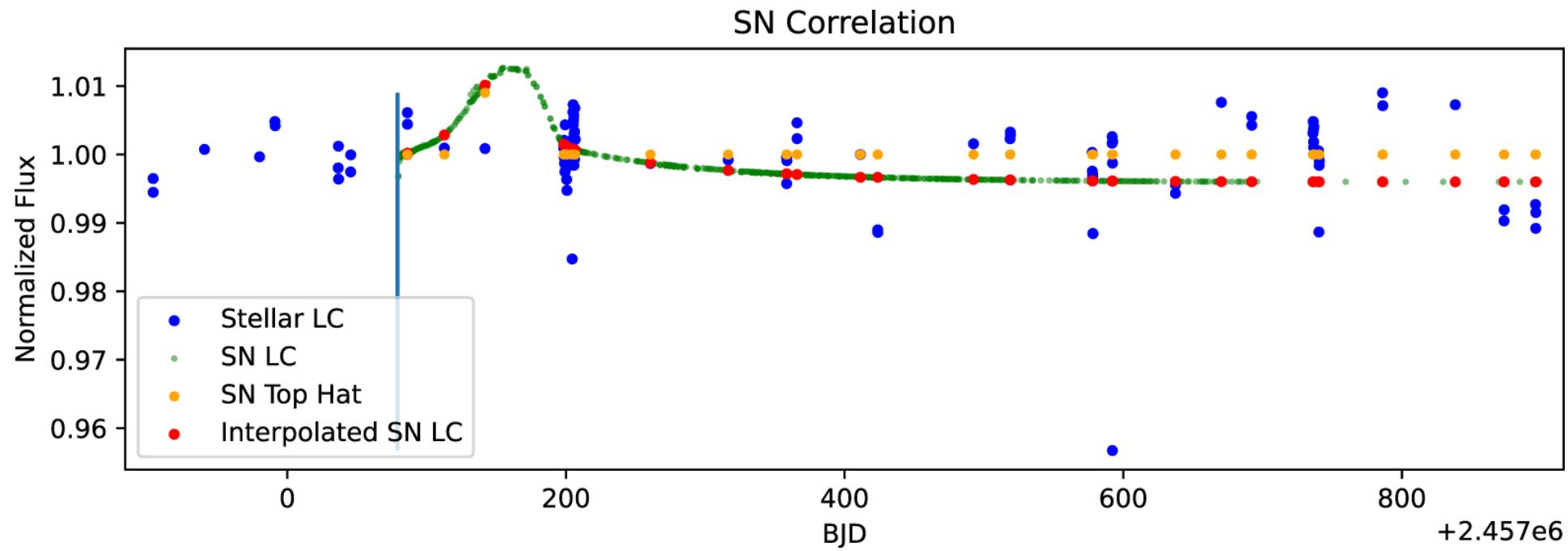


We ranked the remaining 734 candidate systems with sufficient light curve data using the error weighted distance between left and right light curves for nine parameters

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.