Integration time adjusted completeness

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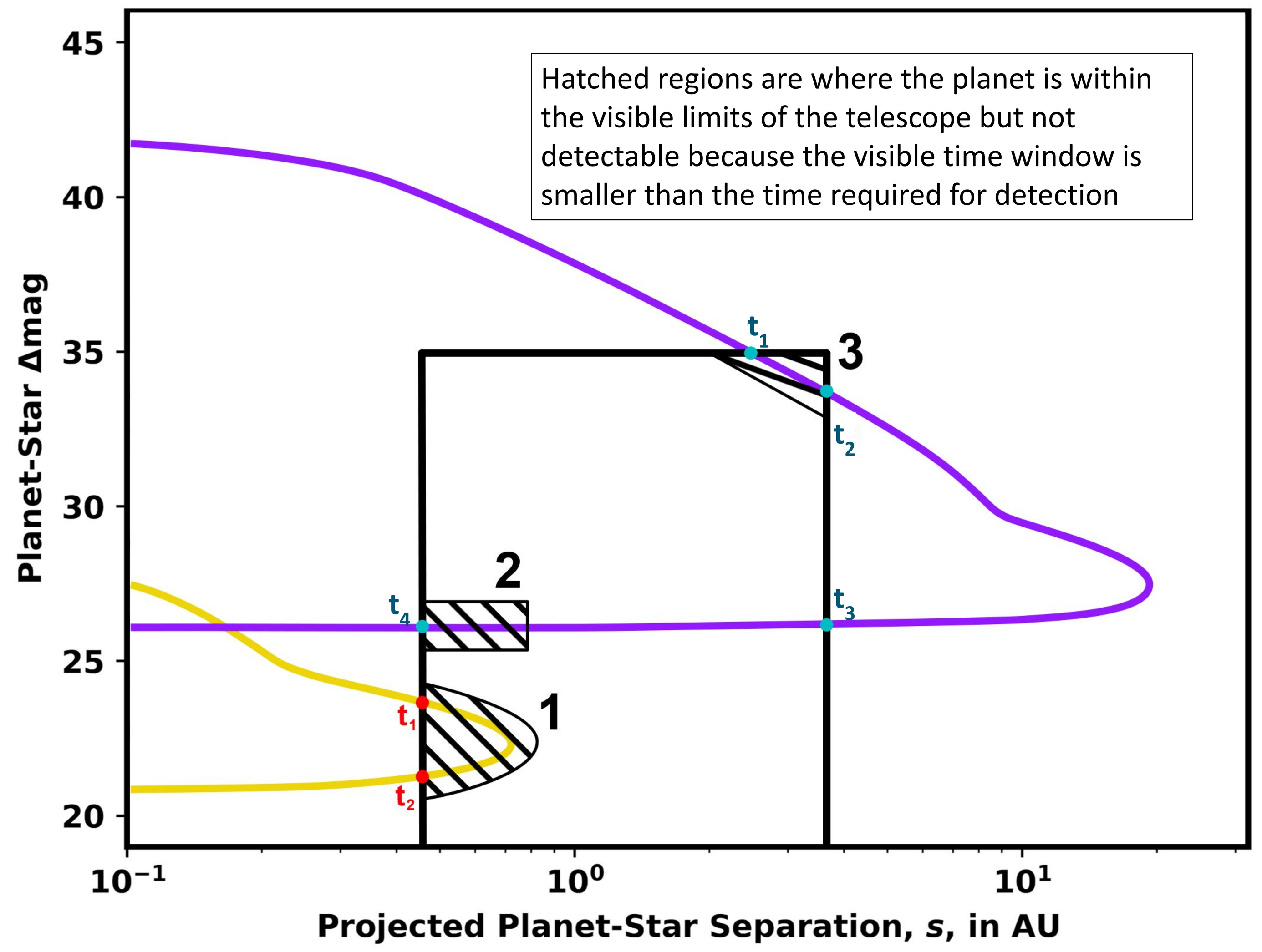
Objectives

1. Calculate completeness accounting for integration time and instrument limits
2. Demonstrate completeness sensitivity to planet integration time for varying star distances
3. Demonstrate our new, fast, and accurate methods for calculating true anomalies of a planet where that planet has an input s or Δmag

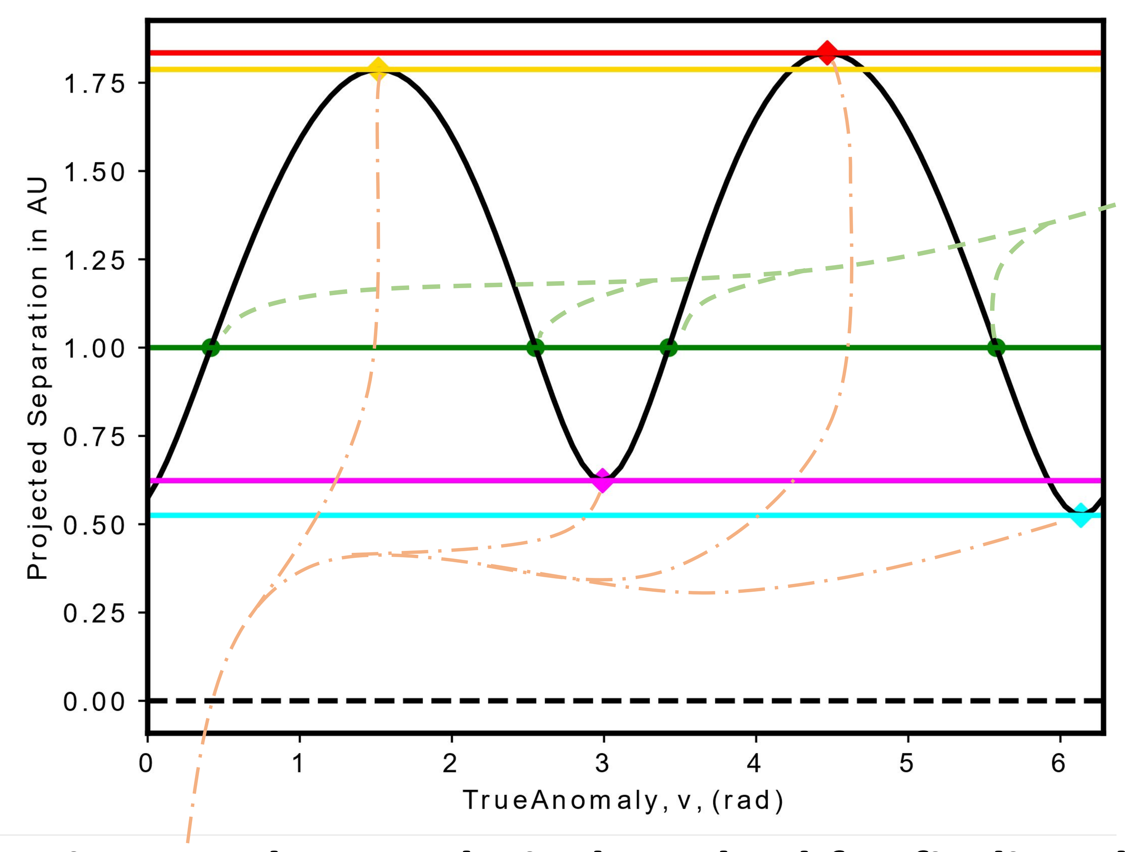
Motivation

Completeness calculations are used to evaluate telescope designs and optimize their mission simulations and only accounts for planets currently within the visibility limits of the telescope.
This old method[1] overestimates the number of planets a telescope can detect.



Takeaway: Some planets are within the visibility limits of the telescope for less time than it takes to image them (Venus, yellow)
Takeaway: Some planets enter and exit the instrument's visibility limits multiple times (Neptune, purple)
Takeaway: Only the time between t_4 - t_3 - t_{max} should be counted towards completeness

We invented an analytical method for finding the ν and s intersections for a planet.



Input: s= 1 AU and planet orbital elements
Output:

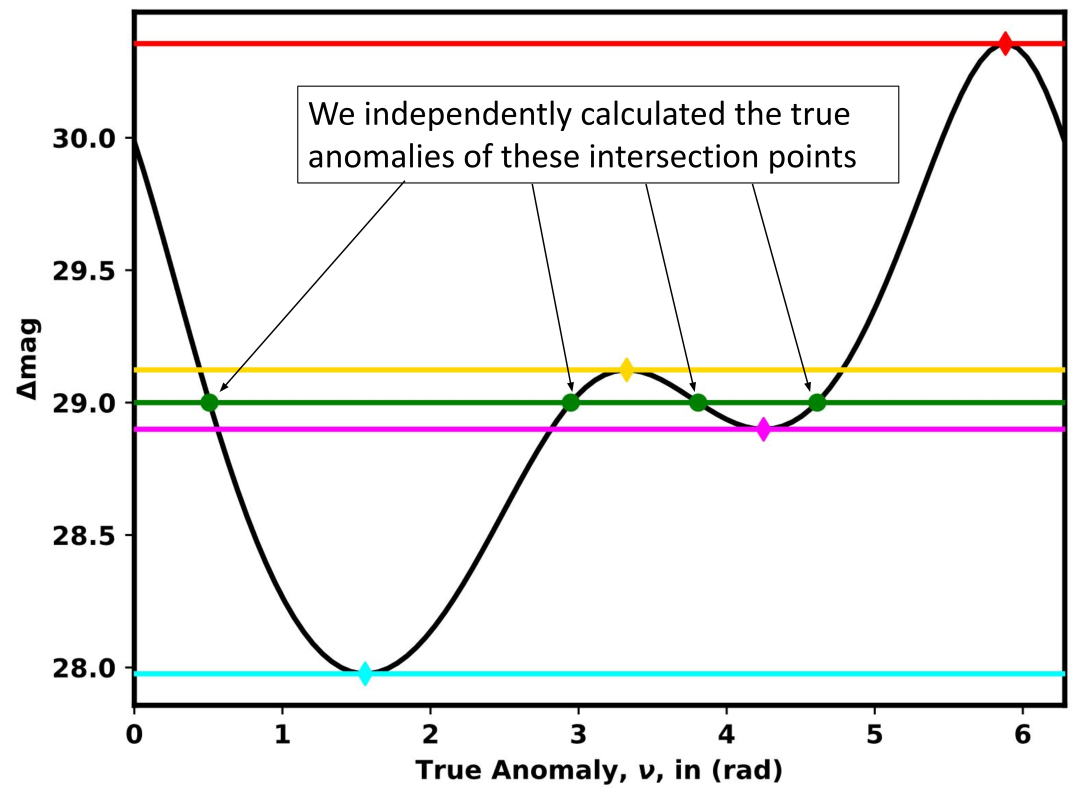
Takeaway: Errors in the true anomalies for Δmag calculated have relatively small error

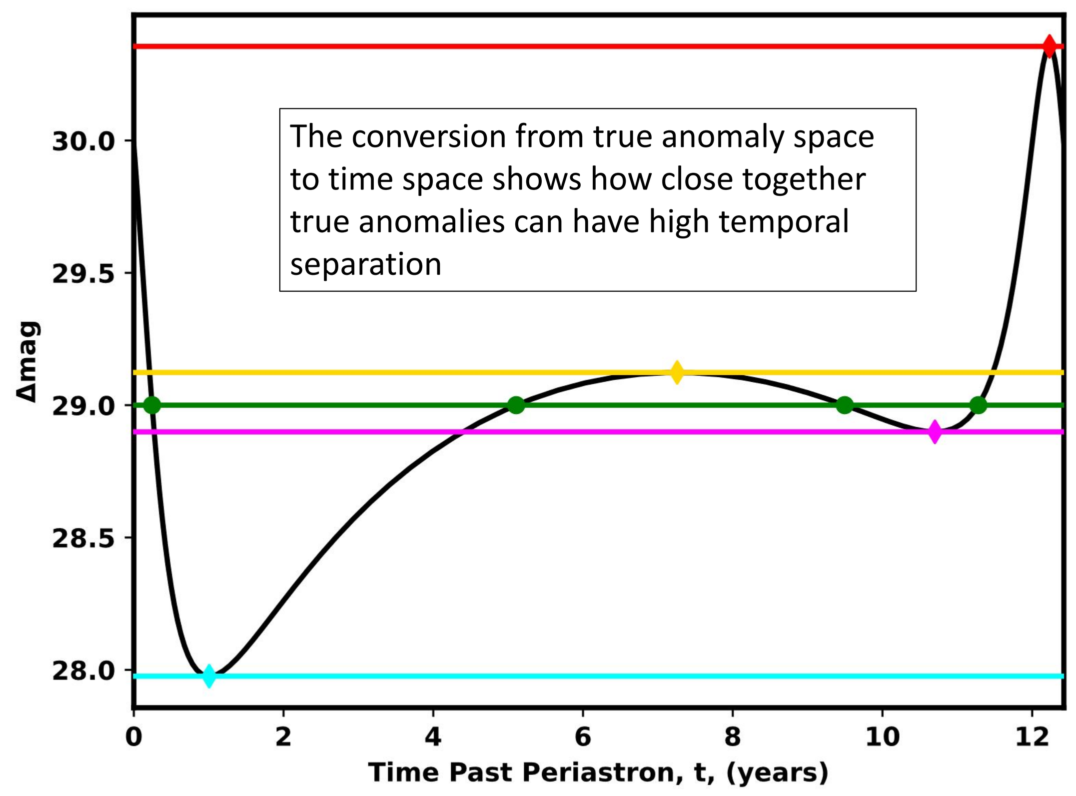
Takeaway: Errors in the separations resulting from this analytical method have relatively small error

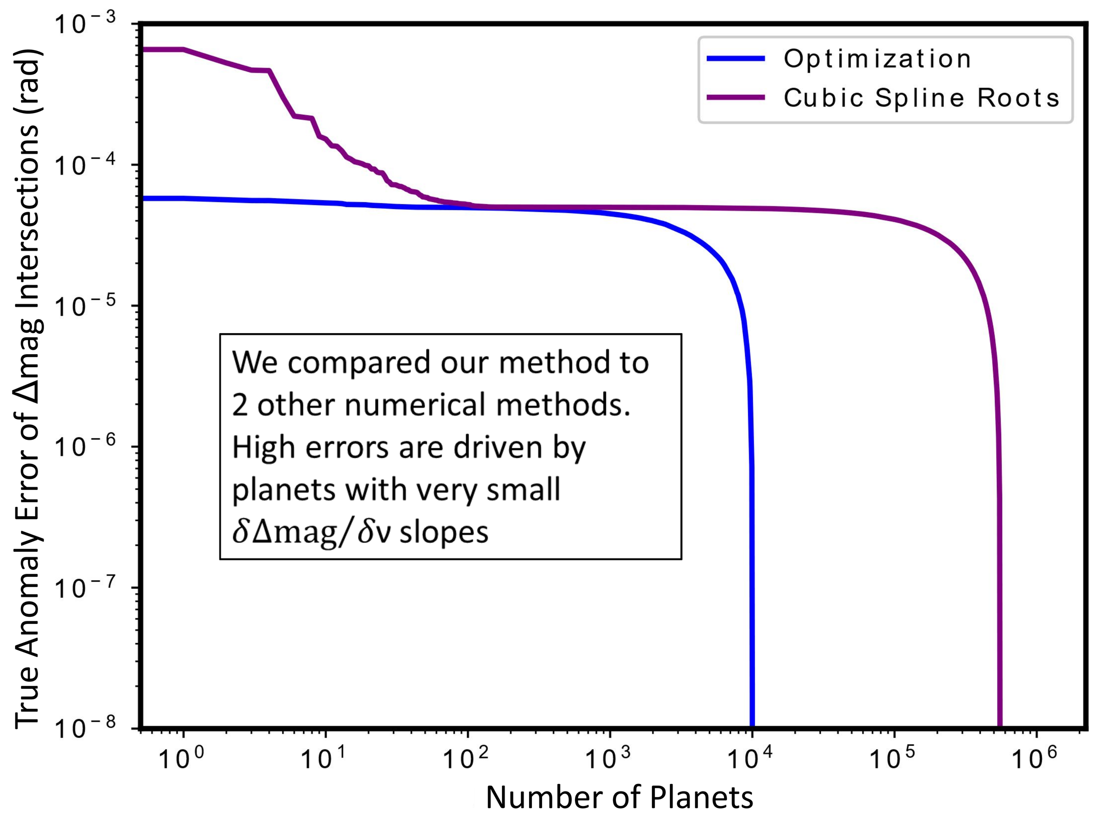
We invented an analytical method for finding the ν and s extrema for a planet.

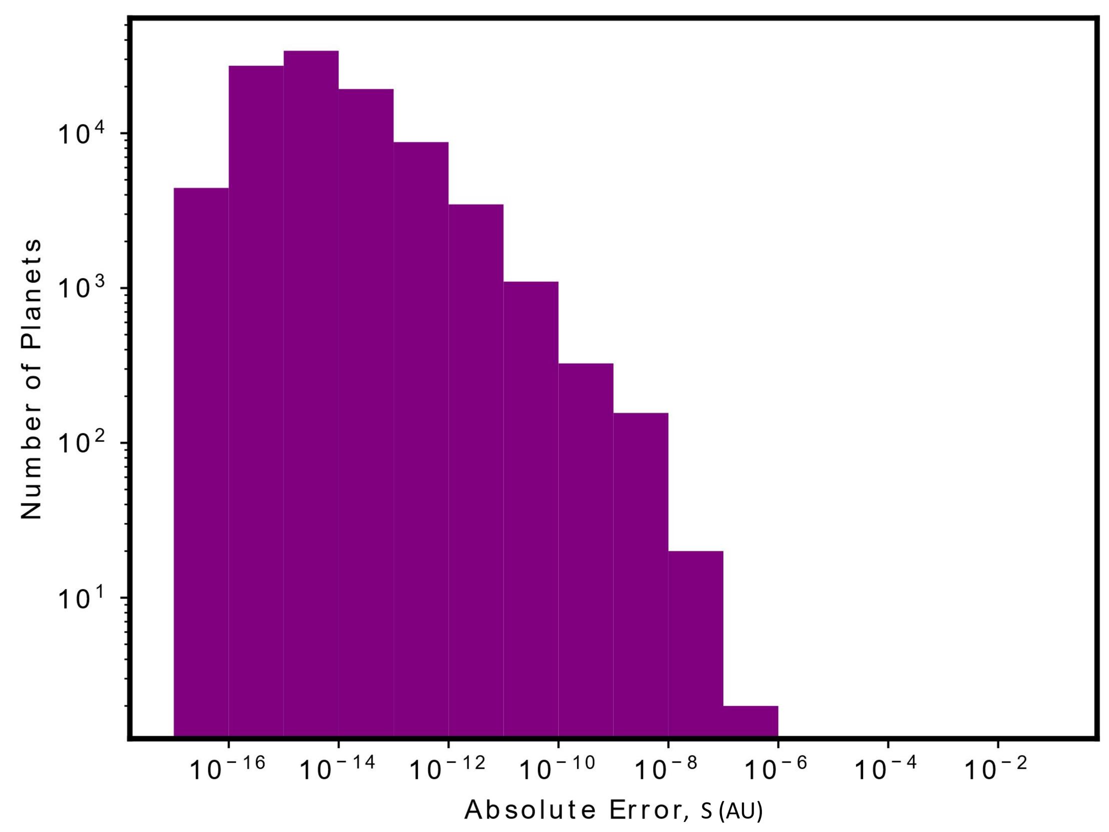
Methods

We invented a fast numerical method for finding the ν and Δmag intersections for a planet.









Completeness

To calculate completeness with these new methods, we sum each time window δt for all time windows j larger than t_{max}. We also discount each planet visibility time window by t_{max} since the planet must be in the visibility time window for t_{max} in order to be detected. We divide the total visibility by the respective planet's orbital period T_k.

$$C_{t_{max}} = \sum_{\forall k} \frac{\sum_{\forall j}(\delta t_j - t_{max})}{T_k}$$

$C_{\oplus,t_{max}}$ is the fraction of Earth-like exoplanets detectable in the whole population.
$C_{\oplus,t_{max}}$ of $\oplus$ is the fraction of Earth-like exoplanets detectable in the Earth-like sub-population.

$\oplus$ refers to Earth-Like planets

Star Distance (pc)				
5	0	0.3042	0.0106	0.5565
5	30	0.2307	0.0085	0.4472
5	60	0.1971	0.0069	0.3623
5	90	0.1739	0.0055	0.2919
10	0	0.2478	0.0101	0.5329
10	30	0.2055	0.0078	0.4094
10	60	0.1786	0.0060	0.3147
10	90	0.1612	0.0047	0.2472
15	0	0.2118	0.0092	0.4814
15	30	0.1850	0.0068	0.3595
15	60	0.1635	0.0050	0.2652
15	90	0.1474	0.0038	0.1995

Caveat: We have not reconciled $C_{t_{max}=0d}$ with Brown Completeness. For 10pc, 0d, Brown Completeness = 0.339.
We inadvertently omitted planets entirely within the telescope observability limits. We therefore expect the actual percentage drops to be smaller, but still substantial.

Takeaway: Completeness drops when increasing from t_{max} = 0 to t_{max} = 30d, the drop size appears to be between 10% and 30%
Takeaway: Completeness drops precipitously (>50% in some cases) when integration times are increased to 90d
Generally, planet integration times vary from <1d to >60d depending upon the kind of spectral characterization being done and the instrument being used.

Conclusion

- Completeness calculated with Brown Completeness overestimates the fraction of exoplanets detectable by an instrument
- Unilaterally, completeness decreases as we increase integration time
- Completeness is slightly less sensitive to integration time at further star distances (expected since close in planets move faster than planets far away and less close in planets are visible for stars far away)
- Things we invented/derived:
  - A fast and accurate analytical method of calculating (planet-star separation, true anomaly) intersections
  - A fast and accurate analytical method of calculating planet-star separation extrema
  - A fast and accurate numerical method of calculating planet (Δmag, true anomaly) intersections
  - A fast and accurate numerical method of calculating planet-star separation extrema

Acknowledgements & References

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[1] R. A. Brown, *Single-Visit Photometric and Obscurational Completeness*, ApJ, 2005
[2] R. Morgan, D. Savransky, C. Stark, E. Nielsen, *The Standard Definitions and Evaluation Team Final Report A common comparison of exoplanet yield*, Jet Propulsion Laboratory, 2019

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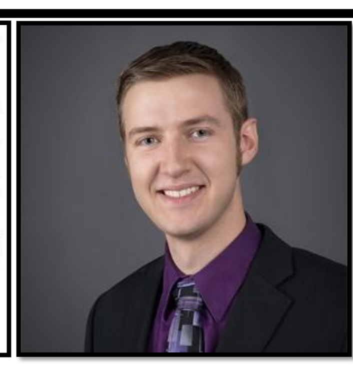

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