THE QUEST FOR PLANET NINE

A new hope?

"Why I killed Pluto and Why It Had It Coming"

DRAFT VERSION JANUARY 22, 2016
Preprint typeset using LaTeX style emulateapj v. 5/2/11

EVIDENCE FOR A DISTANT GIANT PLANET IN THE SOLAR SYSTEM

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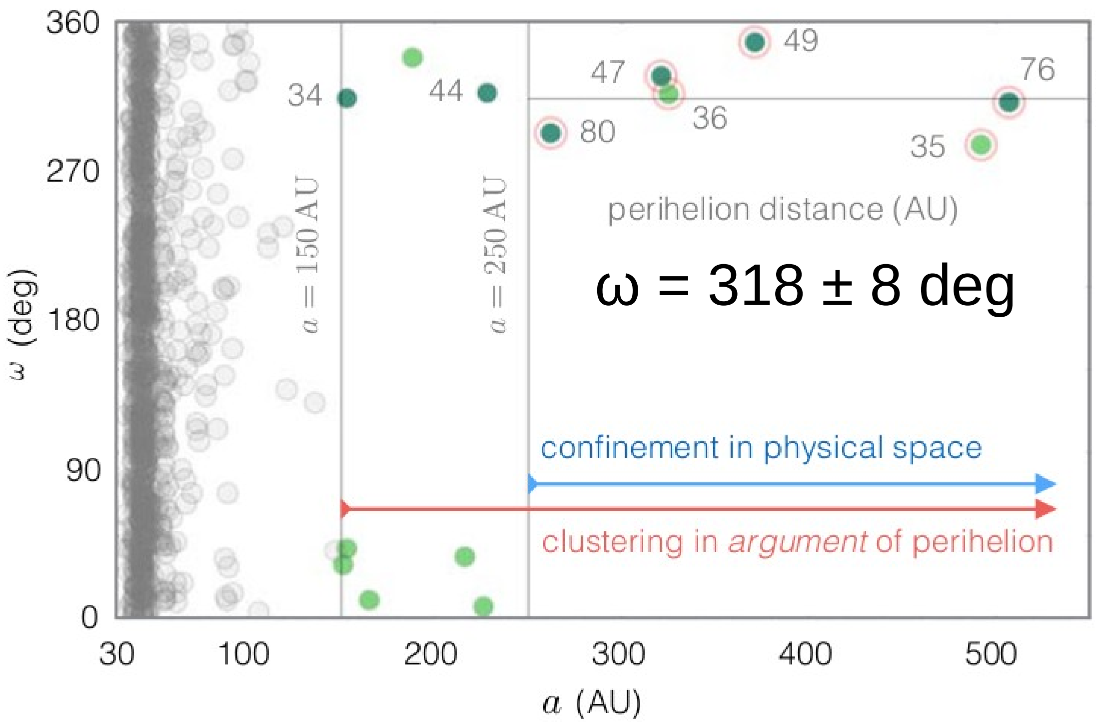
Draft version January 22, 2016

ABSTRACT

Recent analyses have shown that distant orbits within the scattered disk population of the Kuiper belt exhibit an unexpected clustering in their respective arguments of perihelion. While several hypotheses have been put forward to explain this alignment, to date, a theoretical model that can successfully account for the observations remains elusive. In this work we show that the orbits of distant Kuiper belt objects cluster not only in argument of perihelion, but also in physical space. We demonstrate that the perihelion positions and orbital planes of the objects are tightly confined and that such a clustering has only a probability of 0.007% to be due to chance, thus requiring a dynamical origin. We find that the observed orbital alignment can be maintained by a distant eccentric planet with mass $\gtrsim 10\,m_\oplus$ whose orbit lies in approximately the same plane as those of the distant Kuiper belt objects, but whose perihelion is 180 degrees away from the perihelia of the minor bodies. In addition to accounting for the observed orbital alignment, the existence of such a planet naturally explains the presence of high perihelion Sedna-like objects, as well as the known collection of high semimajor axis objects with inclinations between 60 and 150 degrees whose origin was previously unclear. Continued analysis of both distant and highly inclined outer solar system objects provides the opportunity for testing our hypothesis as well as further constraining the orbital elements and mass of the distant planet.

Batygin & Brown 2016: Let the hype begin



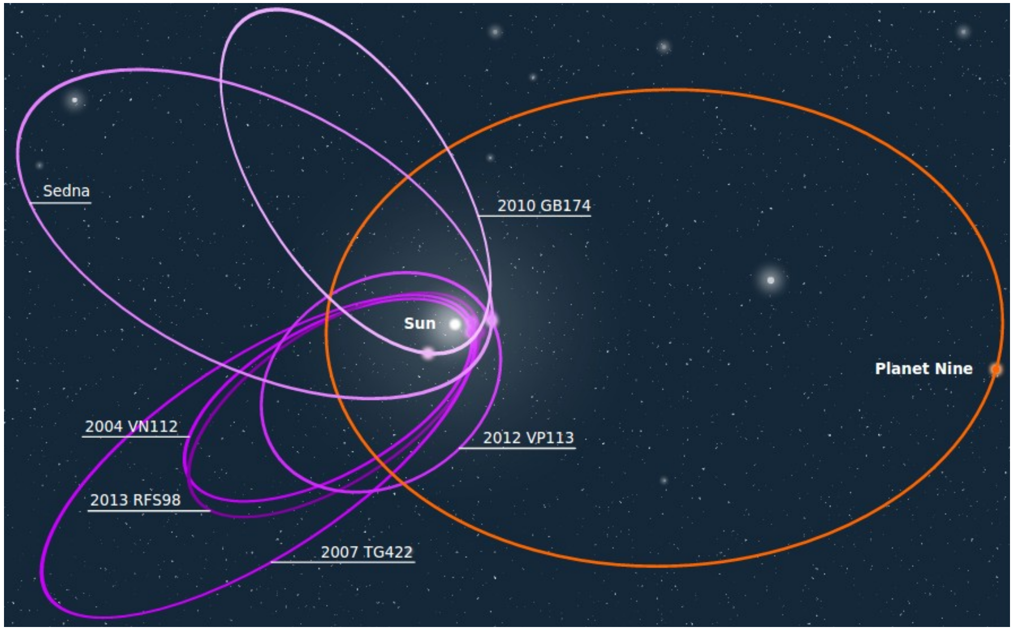
Clusterings in argument of perihelion and longitude of ascending node

=> Distant KBOs cross the ecliptic at a similar phase

Pure chance? p = 0.007%

Reproduction of clustering effects for ...

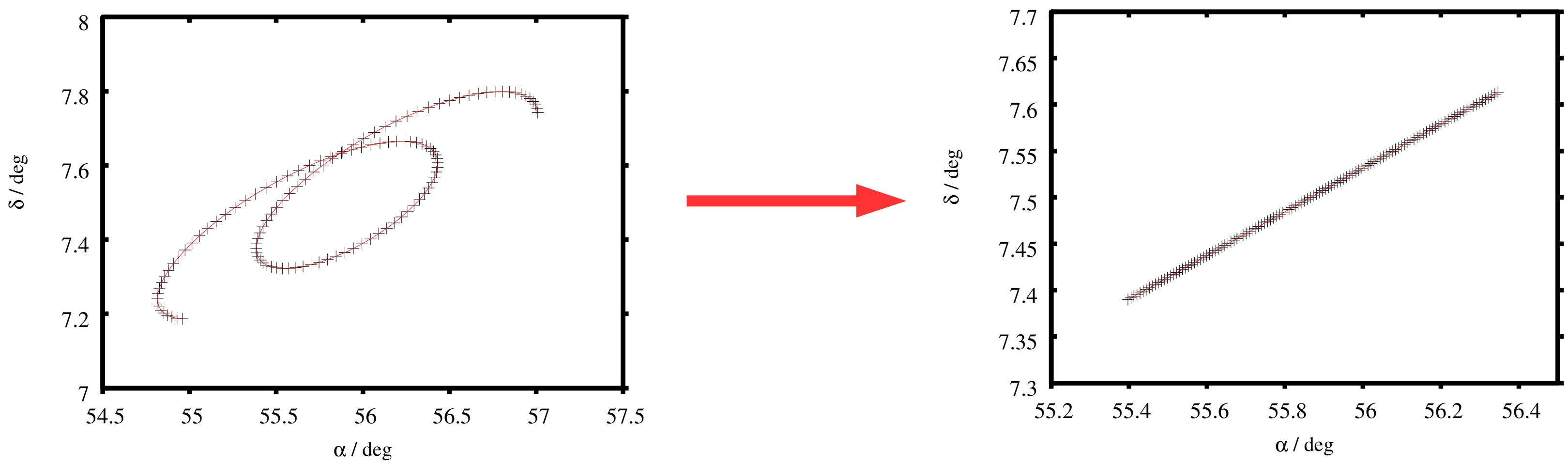
A	~ 700 au
e	~ 0.6
r	~ 280 au … 1120 au
i	~ 30°
M	~ 10-20 M_{Earth}



Any chances to find and see P9?

Wikipedia: Planet Nine

A new approach

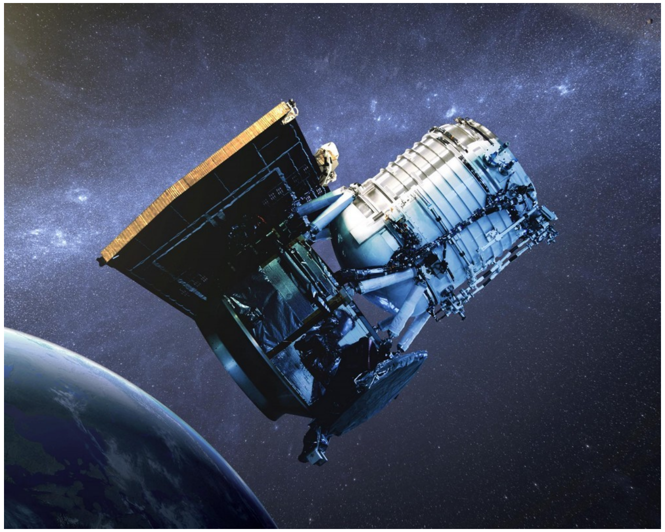


Why not WISE?

- ~10^{10} objects, multiple exposures of every sky region
  => Moving object detection (but...)

- Limits (Luhmann et al. 2014):

W1:	16.8 mag	W3: 11.3 mag
W2:	15.6 mag	W4: 8.0 mag



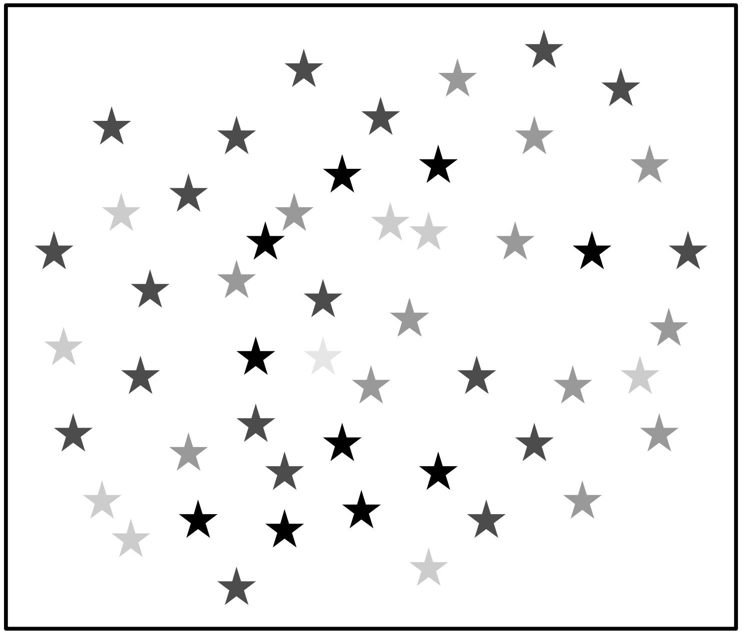
Wikipedia: Wide-Field Infrared Survey Explorer

<u>Uranus</u>:

280 AU				
	16.05	15.64	7.88	5.04
700 AU				
	18.04	17.63	9.87	7.02
1120 AU				
	19.06	18.65	10.89	8.05

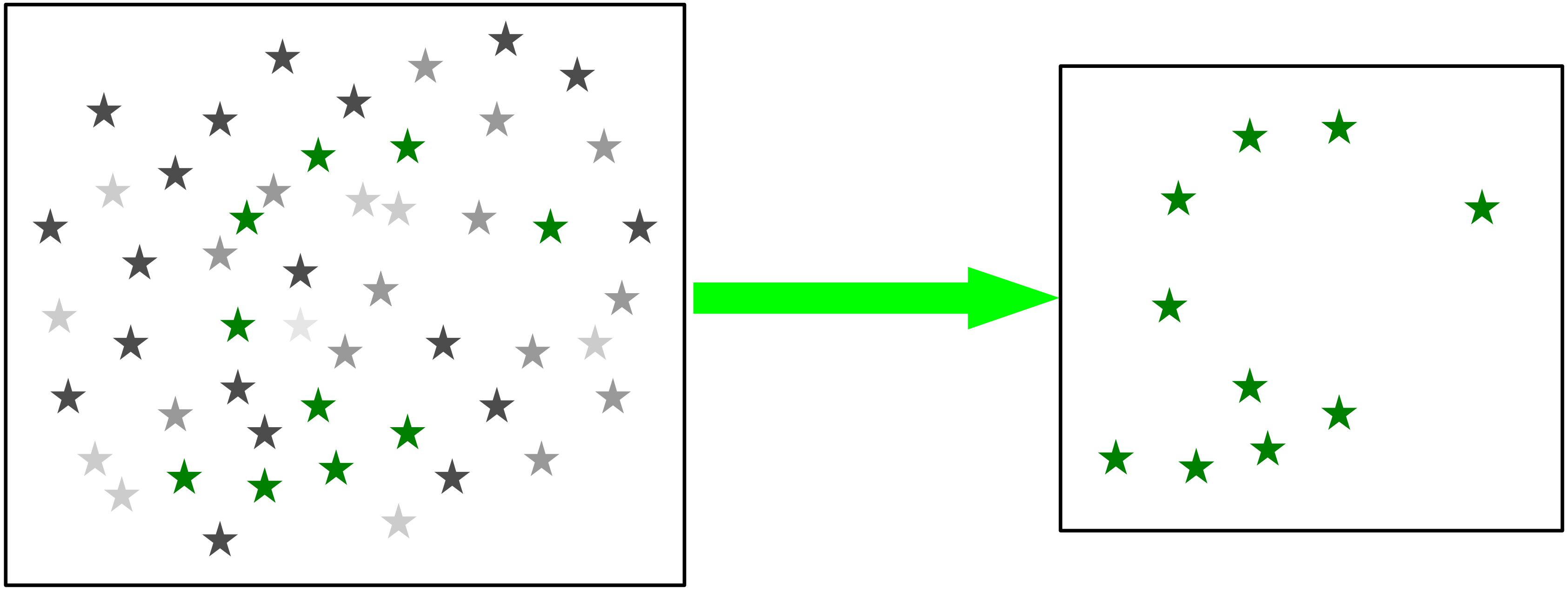
Step 1: Chunking

- (RA, DEC, W1, W2, W3, W4, MJD)
- Divide sky into chunks of 2 deg x 2 deg
- Two overlapping grids to not lose objects at grid borders

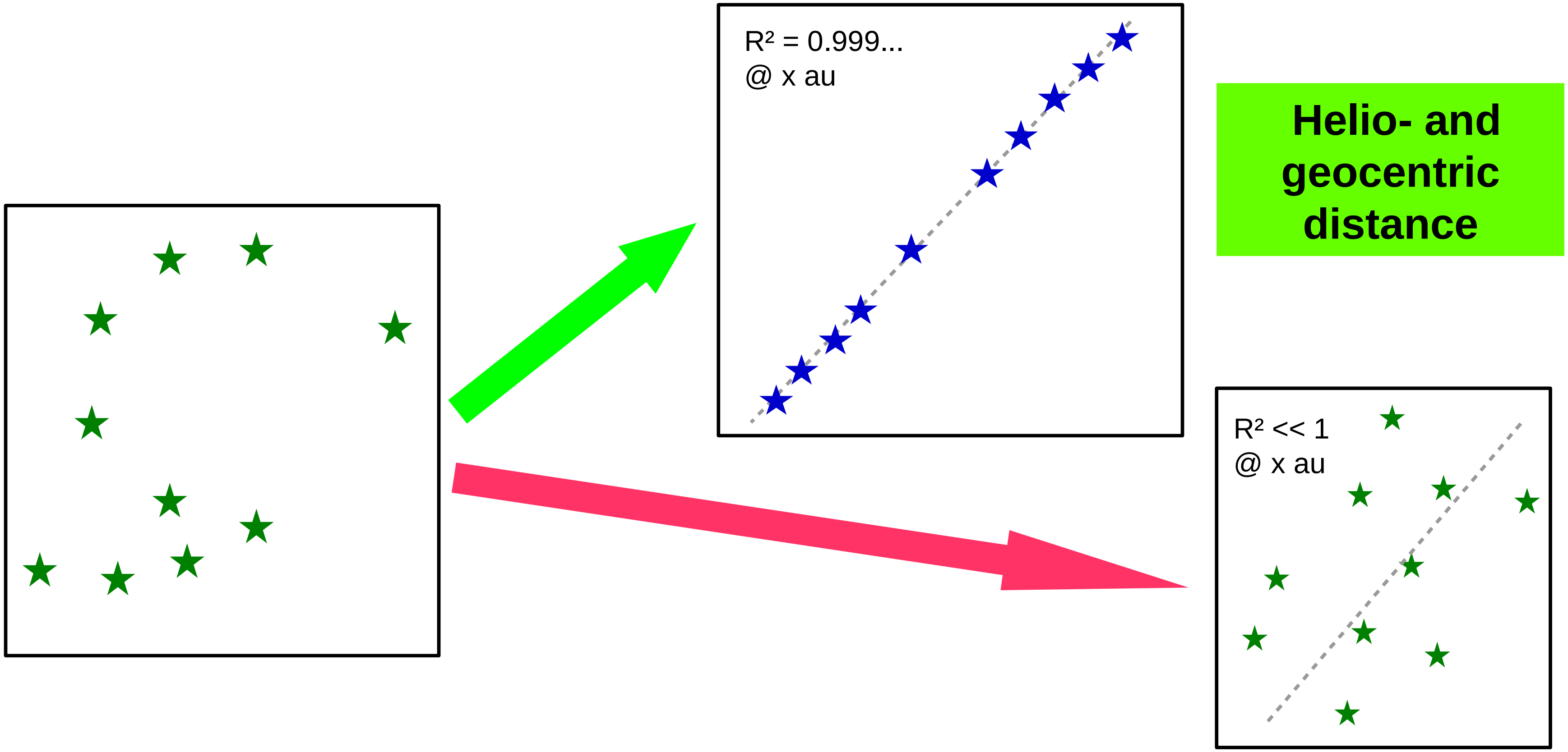


Step 2: Clustering

- Correlate objects that could be part of a SSO trajectory

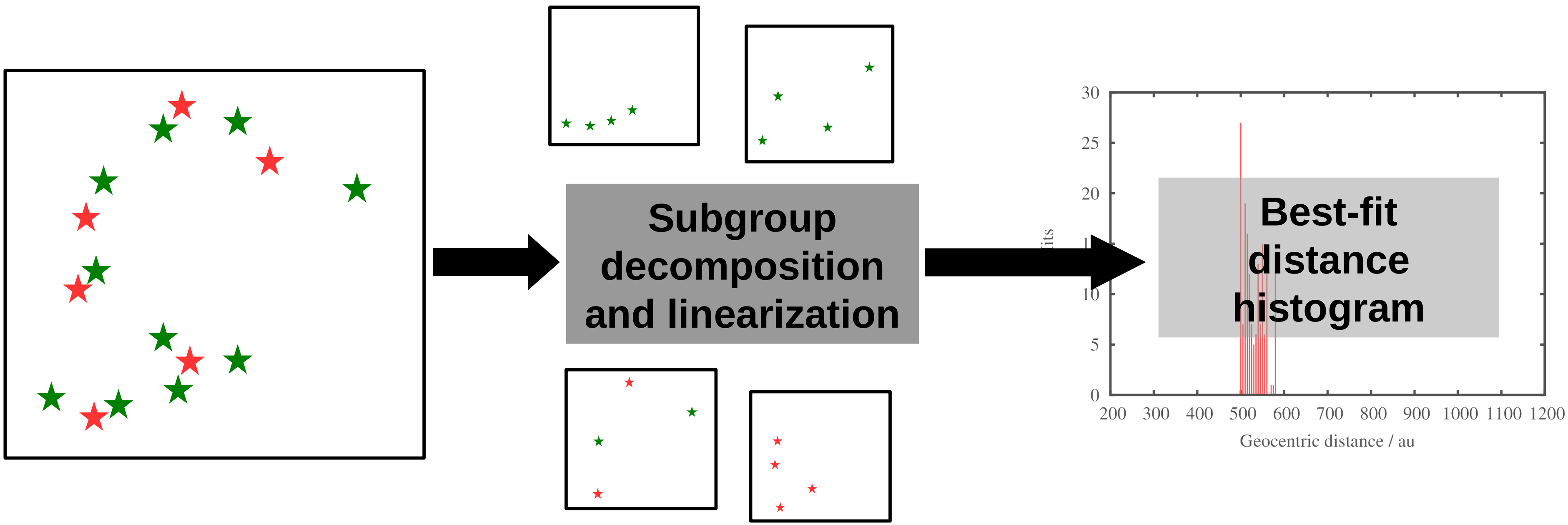


Step 3: Linearization and selection

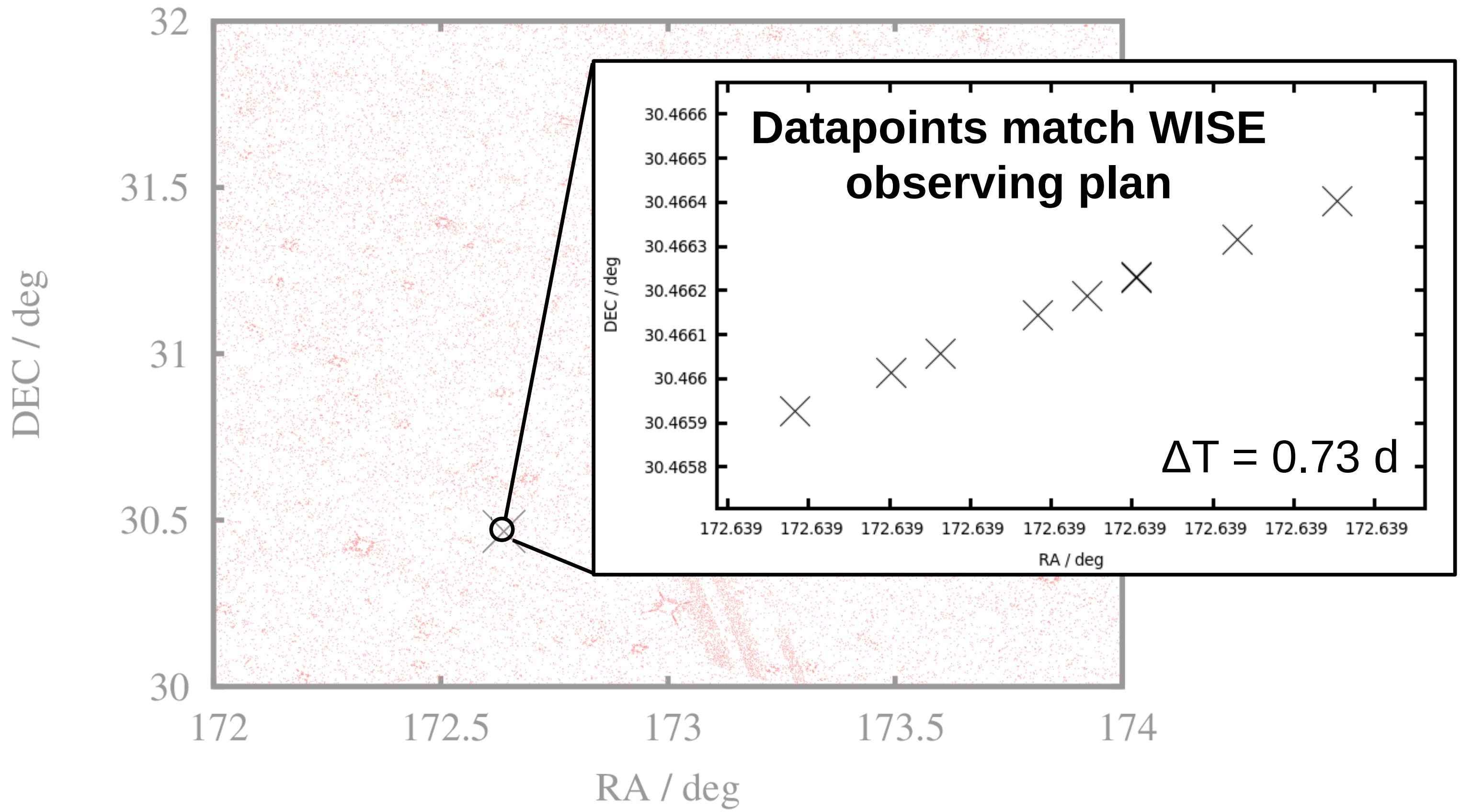


Helio- and geocentric distance

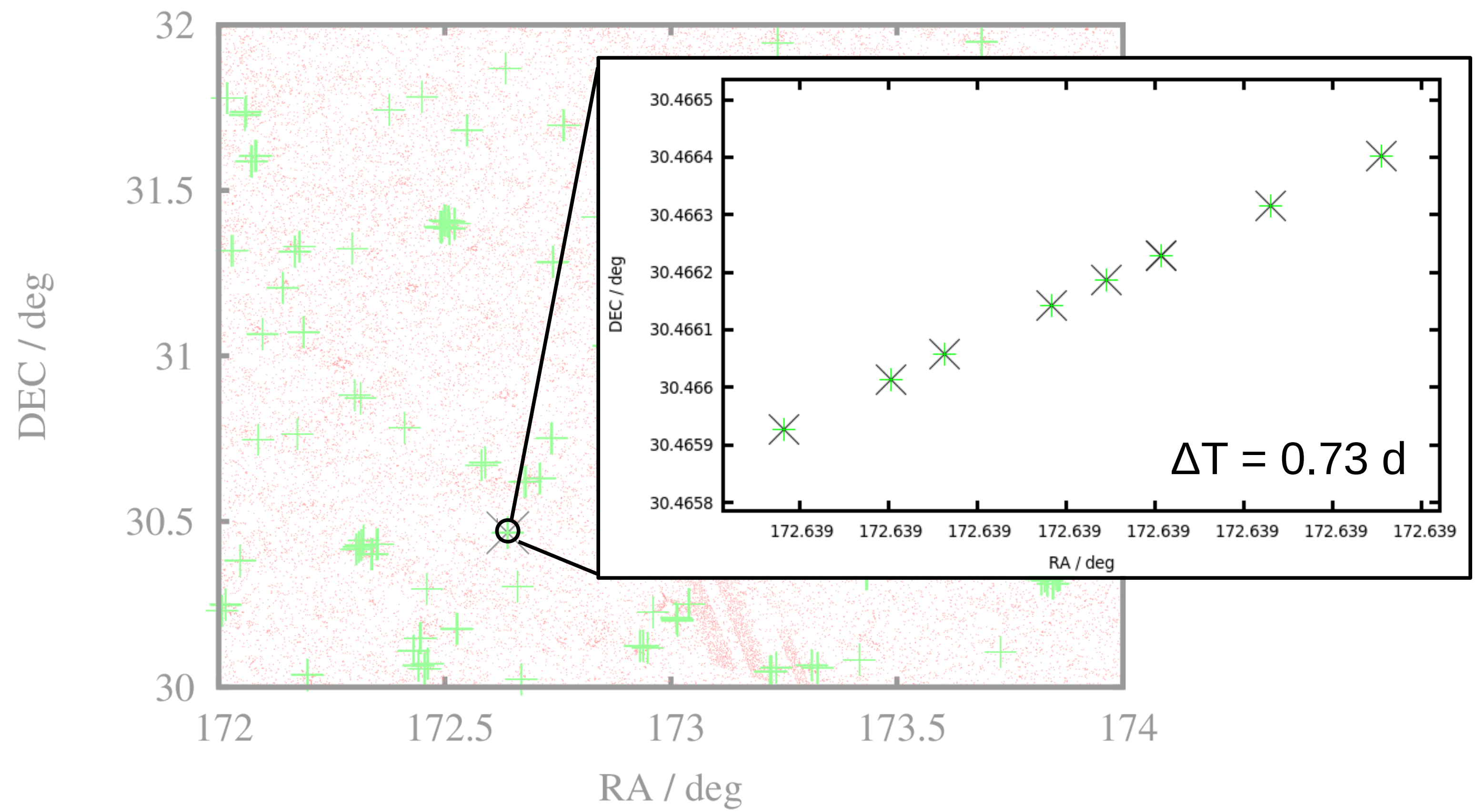
How to deal with contaminations?



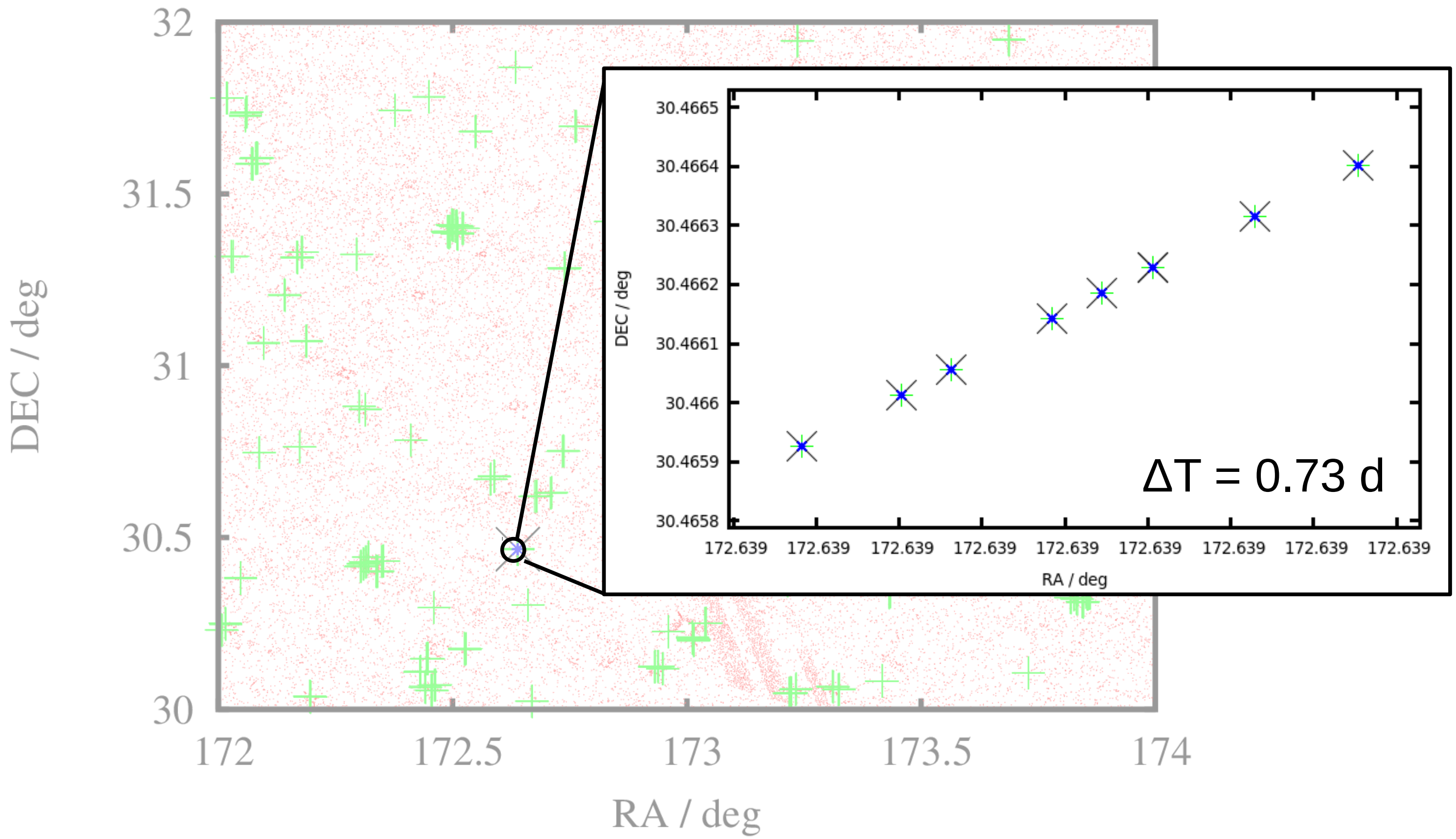
WISE data plus SSO @ 530 au



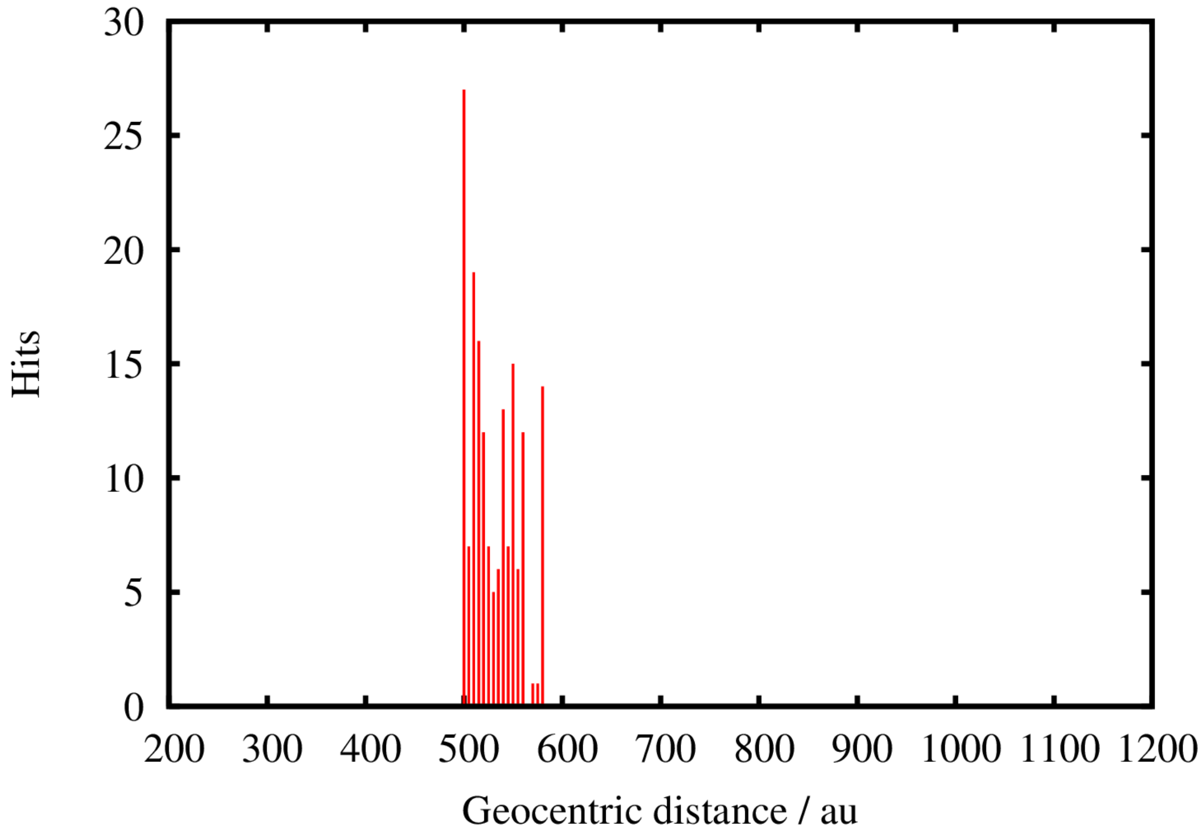
Detected clusters



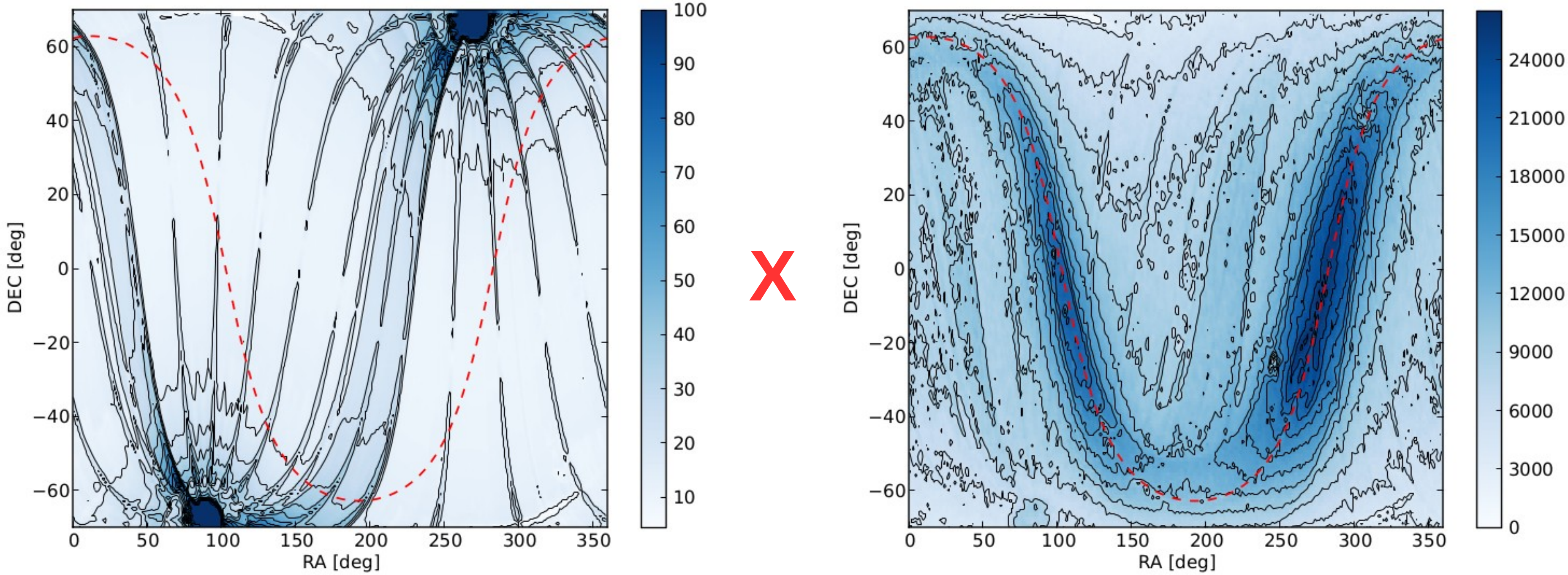
Candidate selection



Histogram of best-fit distances

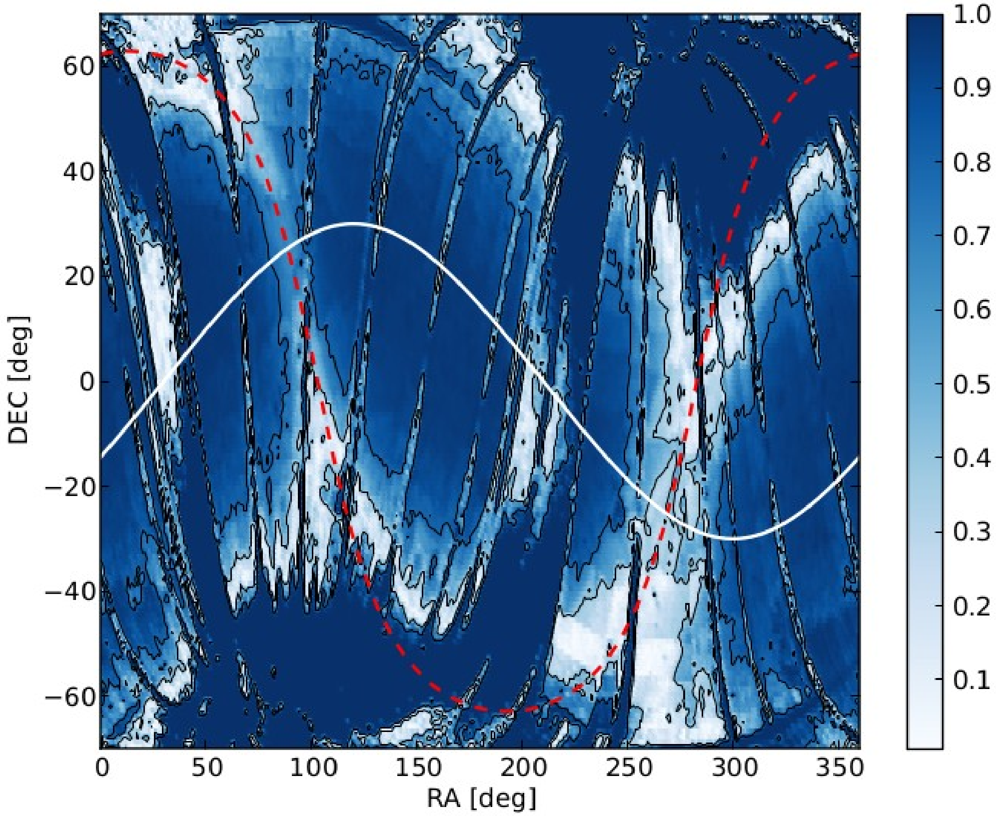


Probability of finding P9

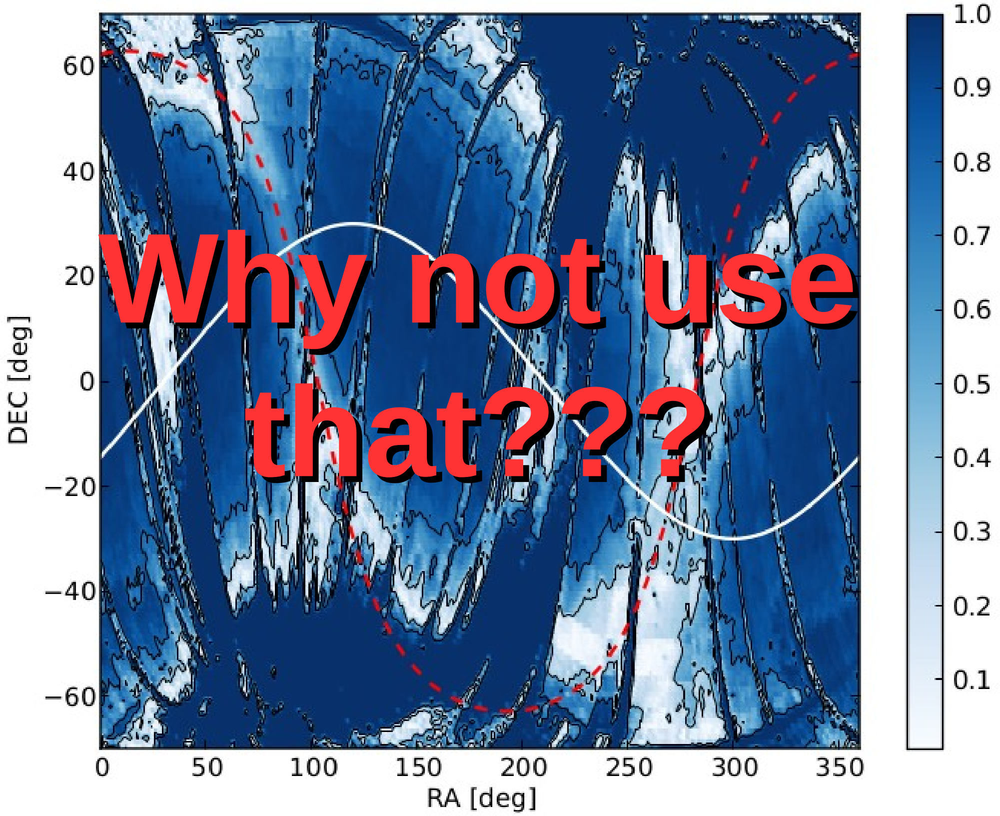


$$P^j_{det} = 1 - \sum_{j-1}^{\bar{w}} \binom{\bar{w}}{j-1} \times \left(\frac{N_\star \cdot \pi \cdot r_n^2}{A}\right)^{j-1} \times \left(1 - \frac{N_\star \cdot \pi \cdot r_n^2}{A}\right)^{\bar{w}-j+1}$$

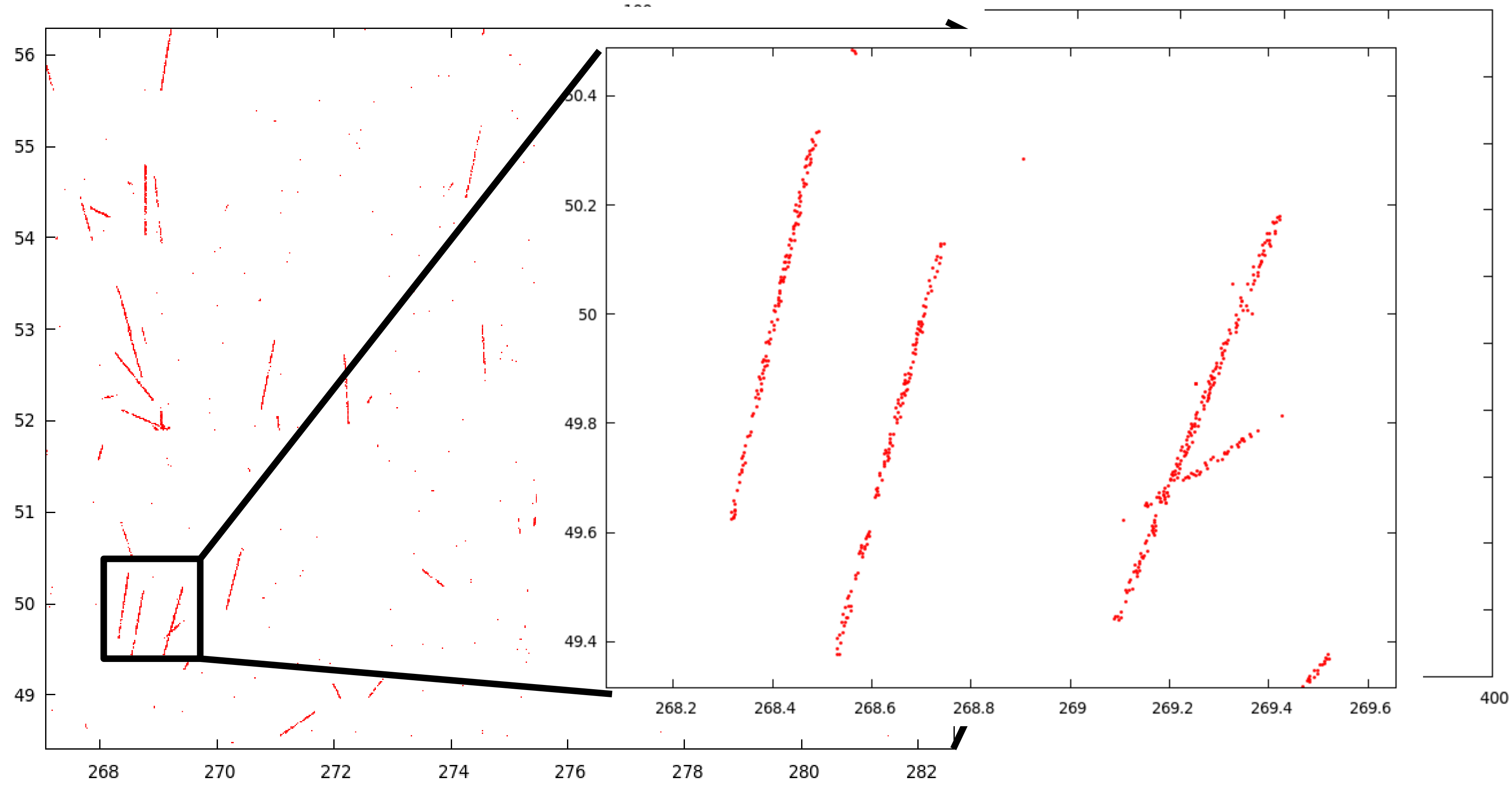
Probability of finding P9



Probability of finding P9



Why not use that???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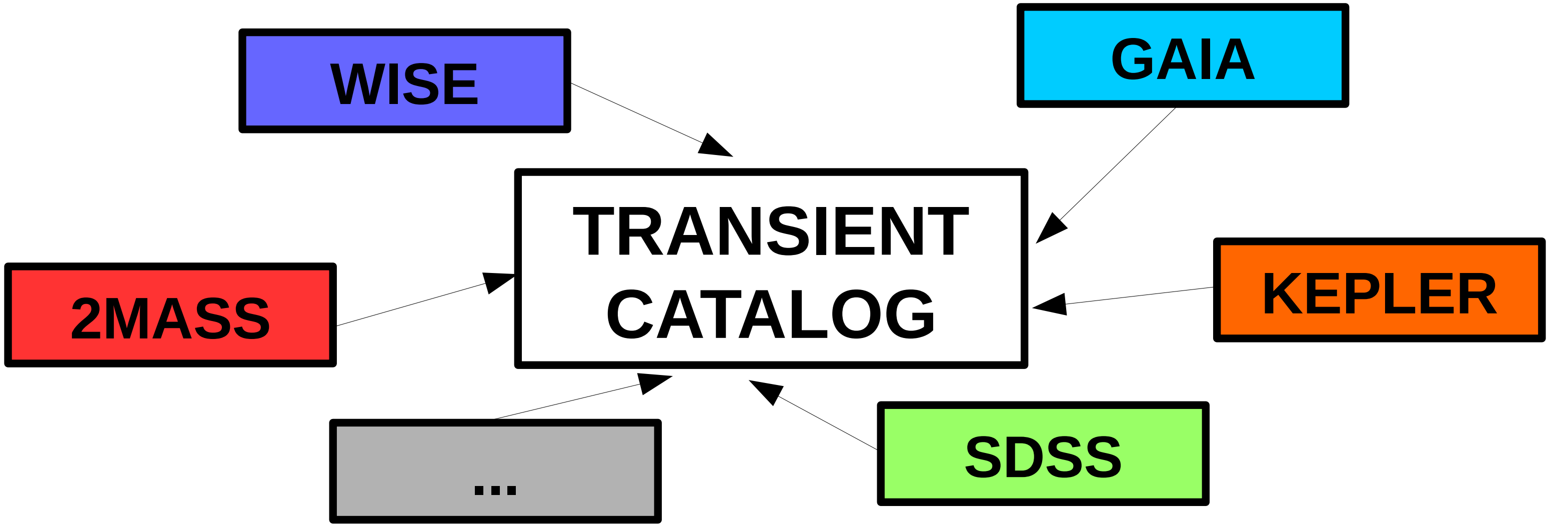
400

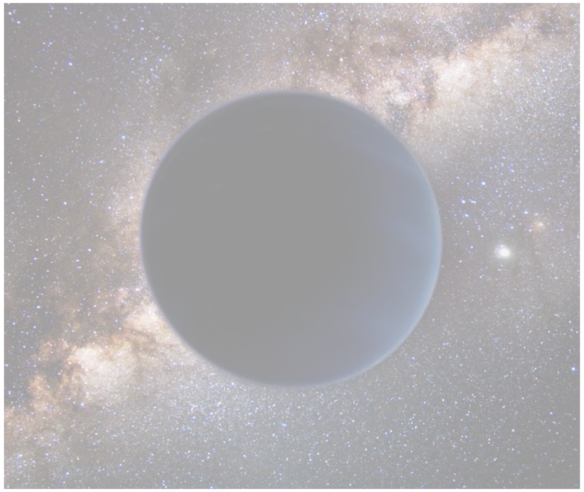
Towards a transient data monster



- Very distant and small objects detectable
- Almost now selection effects
- All wavelengths can be used

What's next?

- Final code and pipeline refinements
- Best search parameters?
- Crunch the entire catalog and other catalogs
- Perdelwitz, Völschow, Müller (in prep.)



LONG TERM:

Establishing a working pipeline to find distant KBO objects via *transients*

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Thank you for your attention!