
00 00 00
100,000 ASTEROIDS
DOWN THE BACK OF THE COUCH
1 COIN 1 PLAY
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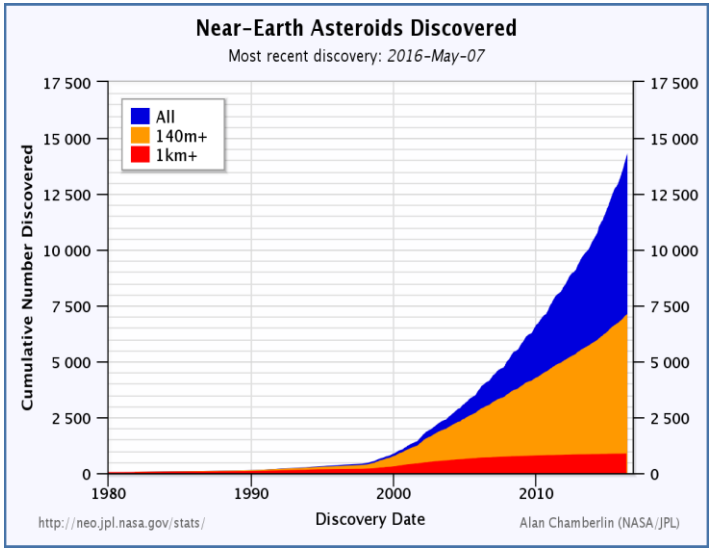
CS182 ARTIFICIAL INTELLIGENCE

CS182 ARTIFICIAL INTELLIGENCE 30 NOVEMBER 2017

MISSING ASTEROIDS!

CONNECTING ASTEROID TRACKLETS

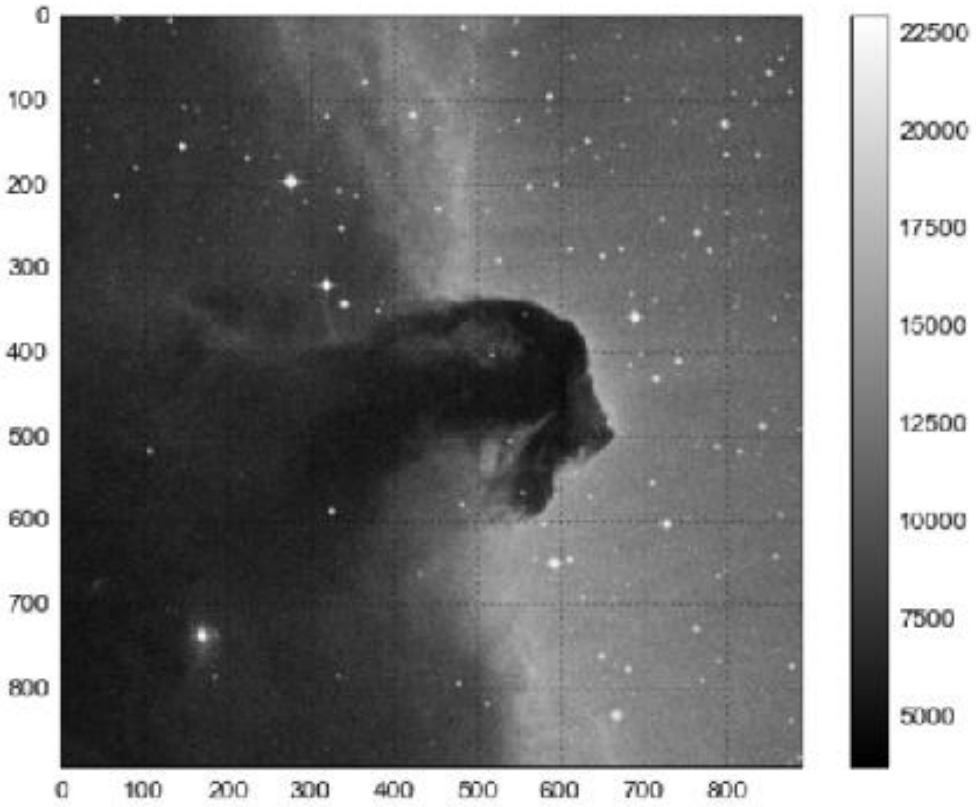
Mandate from Congress:
Discover >90% of potentially hazardous asteroids with diameters >140 meters



Currently, we have 170m asteroid observations

MISSING ASTEROIDS!

CONNECTING ASTEROID TRACKLETS



Asteroids ‘tracklets’ are found by matching 3+ detections in digital exposures

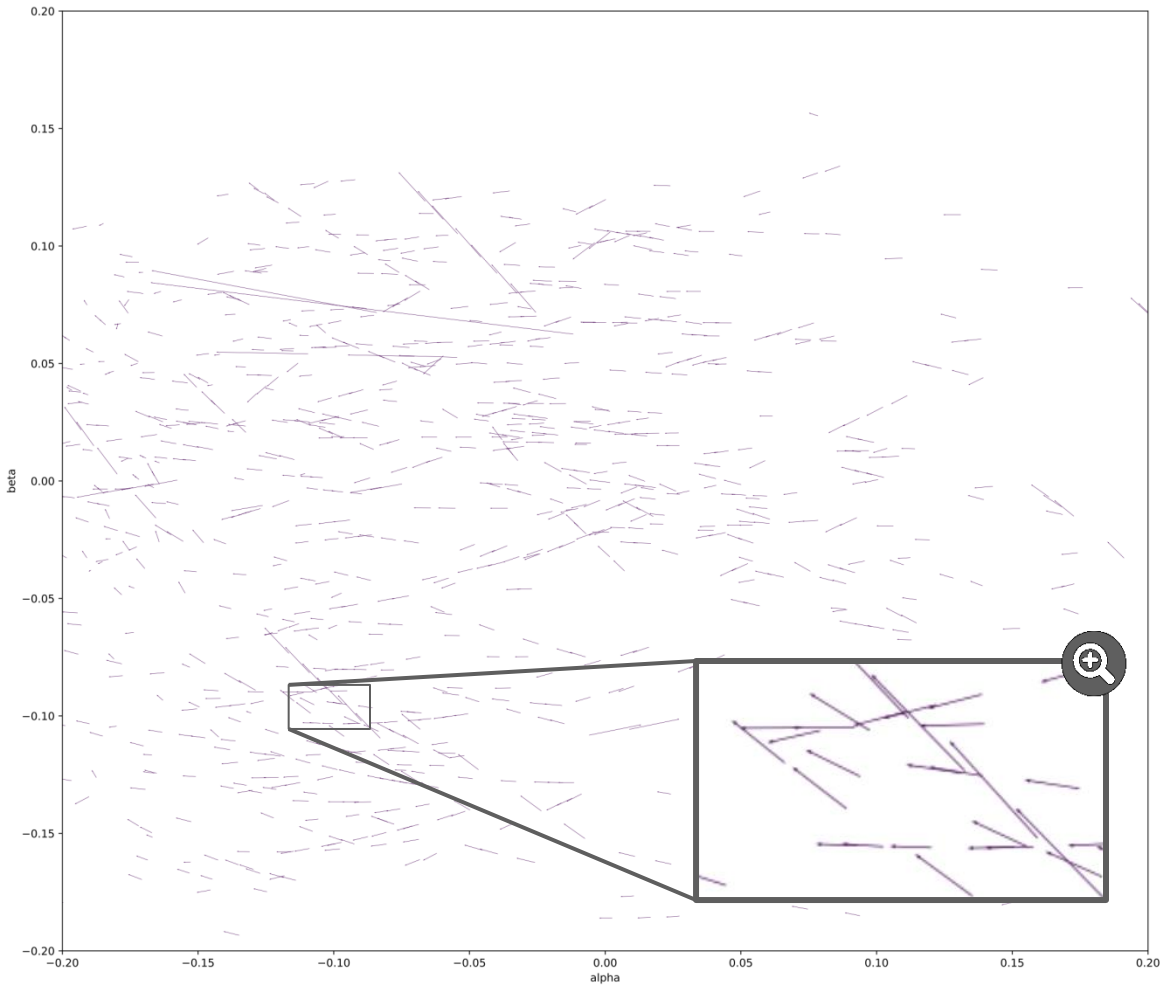
90% can be identified immediately. But there are **14 million** unmatched tracklets

Growing quickly as telescope aperture increases

A HARD PROBLEM...

- Observed from Earth, asteroid trajectories are highly nonlinear
- This, with the high density of asteroids makes naïve linking difficult
- Missing data (cannot tell asteroid pos'n/velocity in the radial direction)
- Sparse observations can be separated by weeks, months, or years
- Brute force is impractical with 14m observations (Current soln = $O(n^3)$!

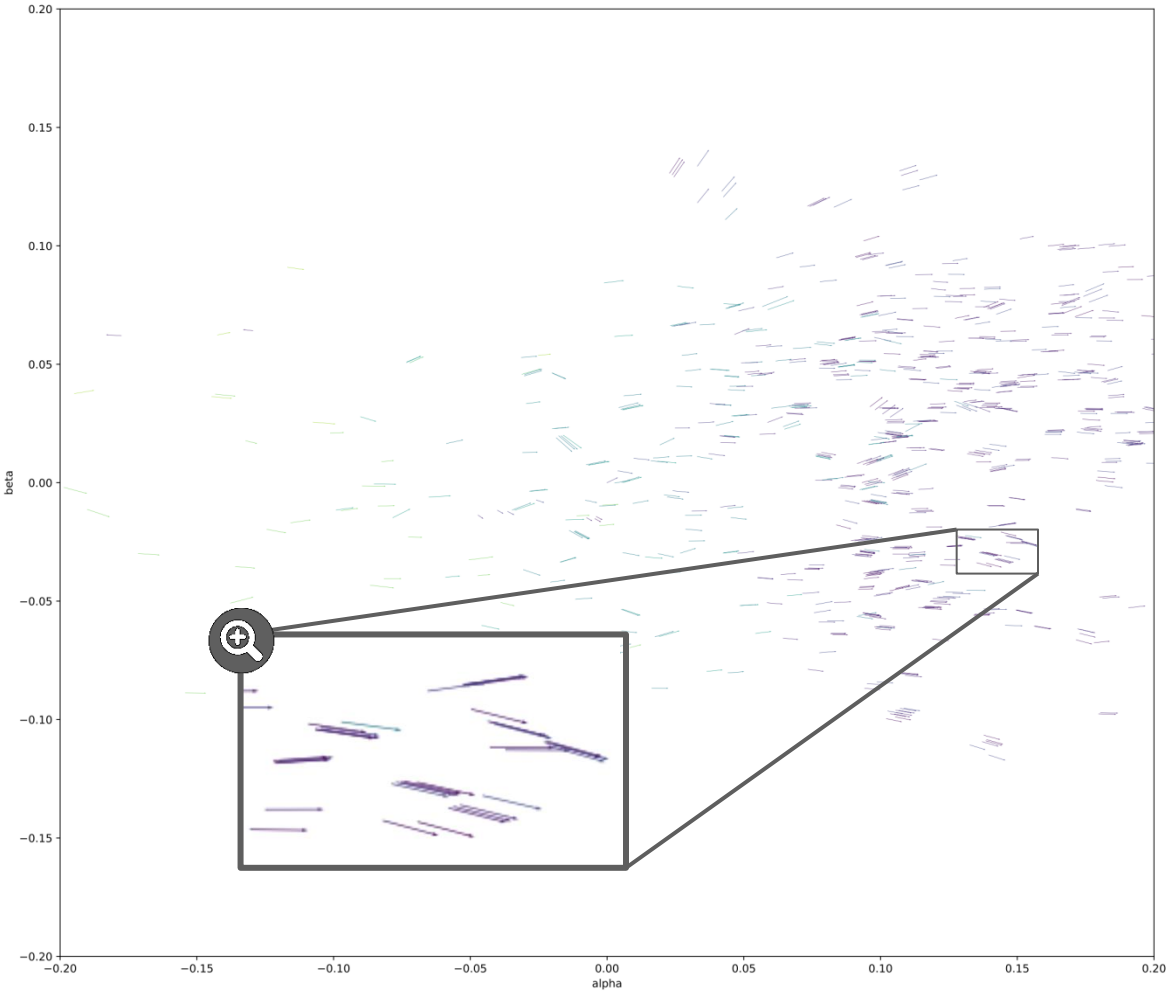
Asteroid tracklets (from Earth's perspective)



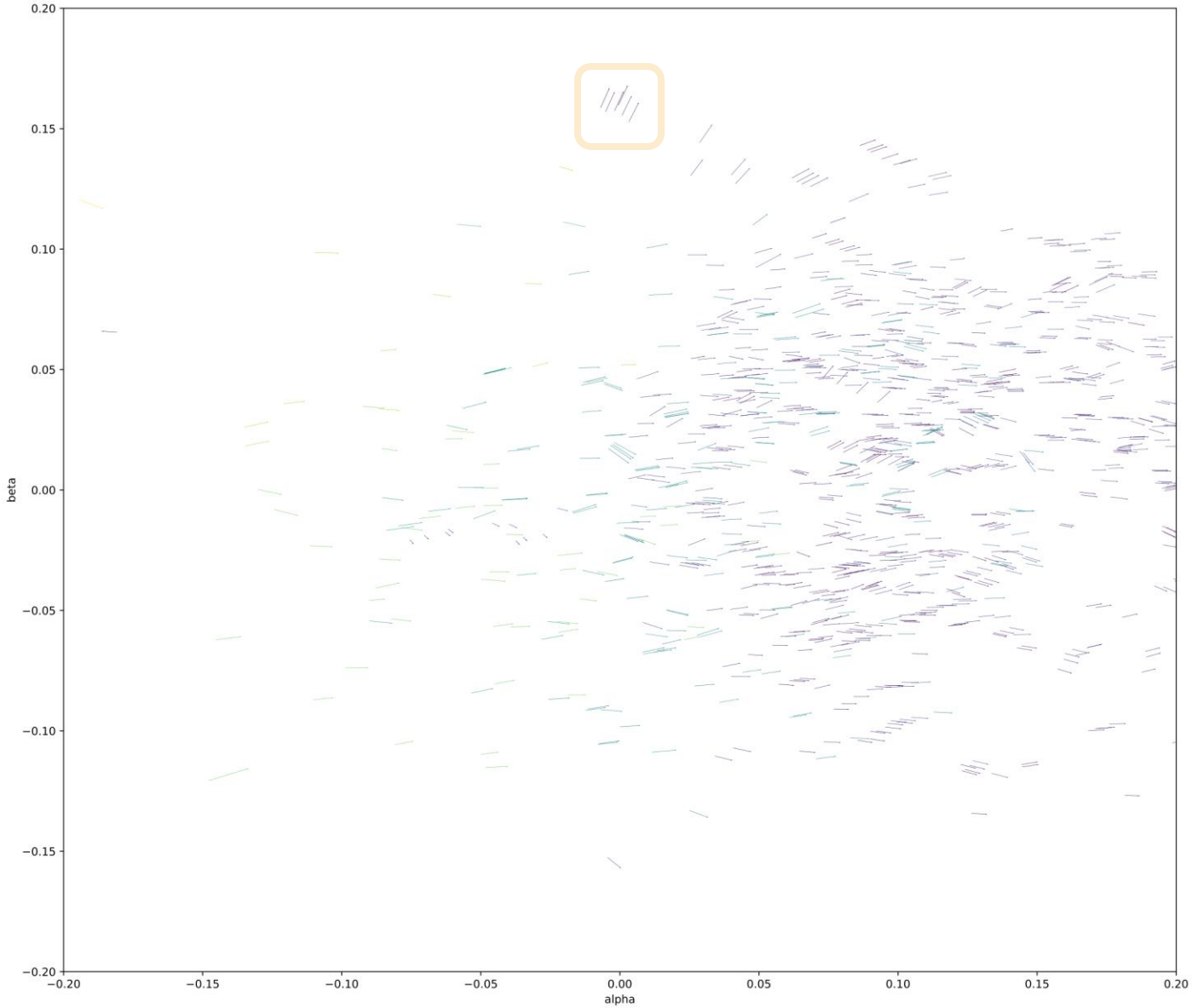
PROPOSED SOLUTION

- When we apply a heliocentric transformation, the trajectories become clear!
- Similar to applying the kernel trick from 2d to 3d space
- Can then set a ‘focal distance’ by scanning radial distances/velocities

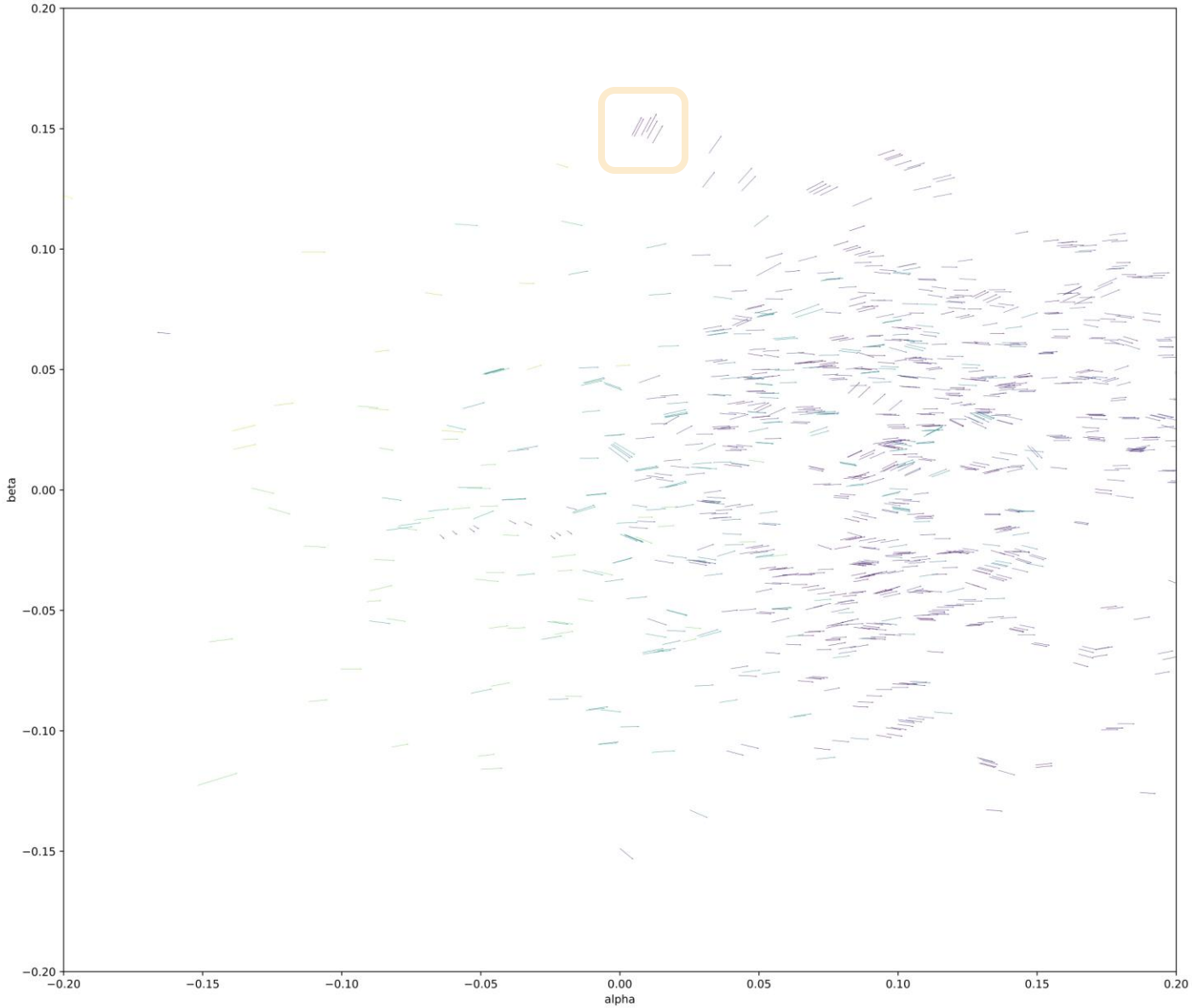
Asteroid tracklets (from the Sun’s perspective)



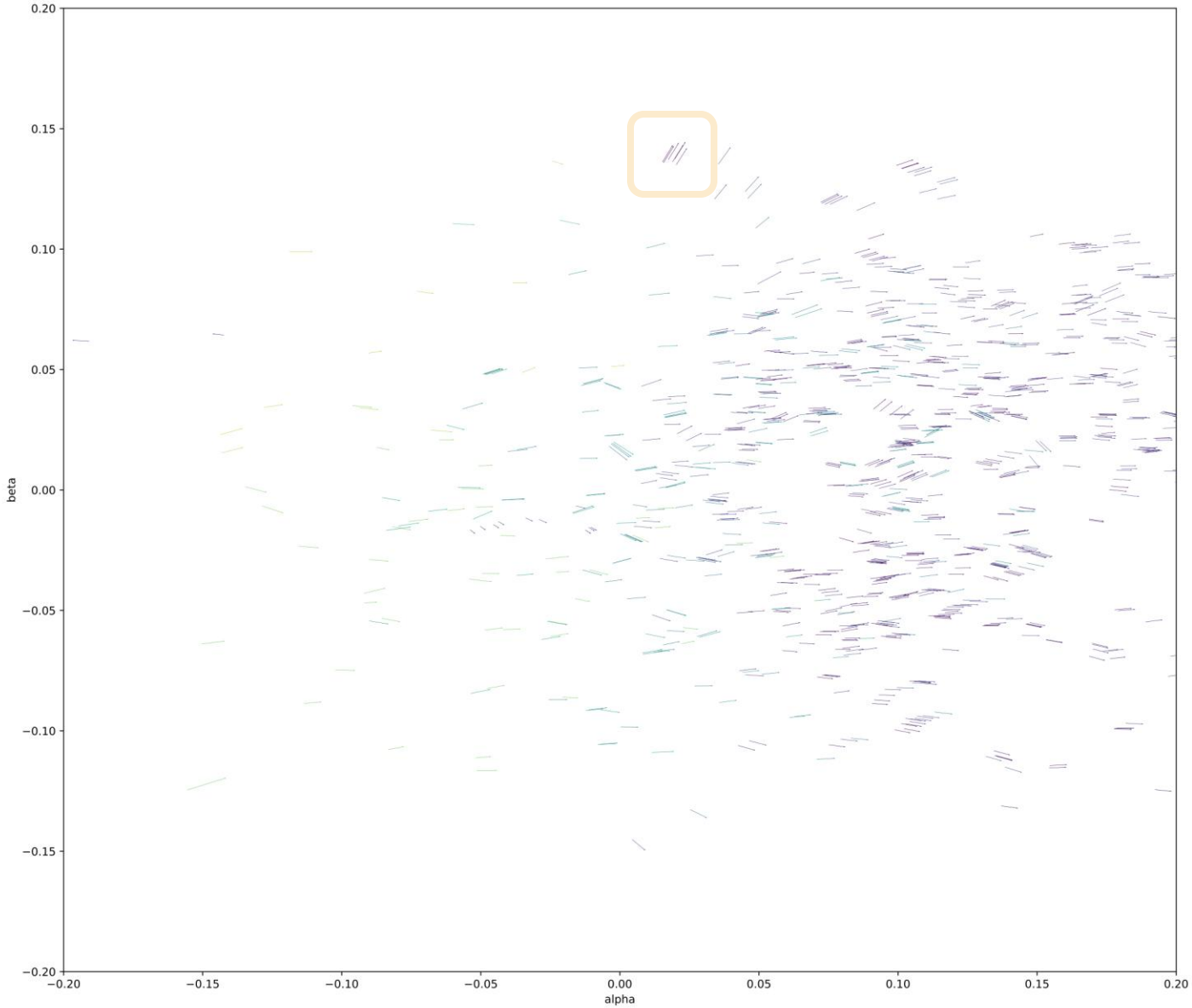
THE VIEW FROM THE SUN



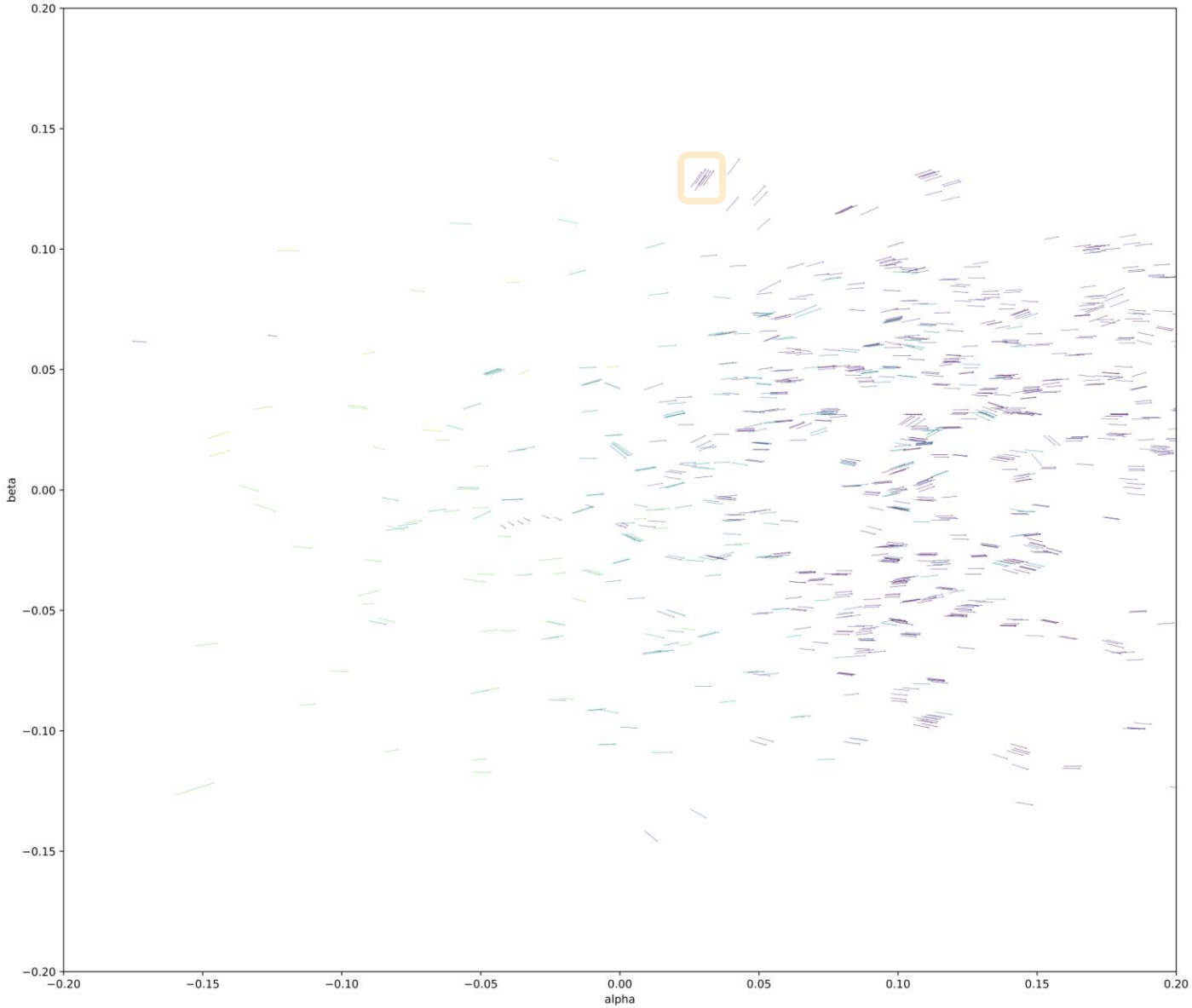
THE VIEW FROM THE SUN



THE VIEW FROM THE SUN



THE VIEW FROM THE SUN



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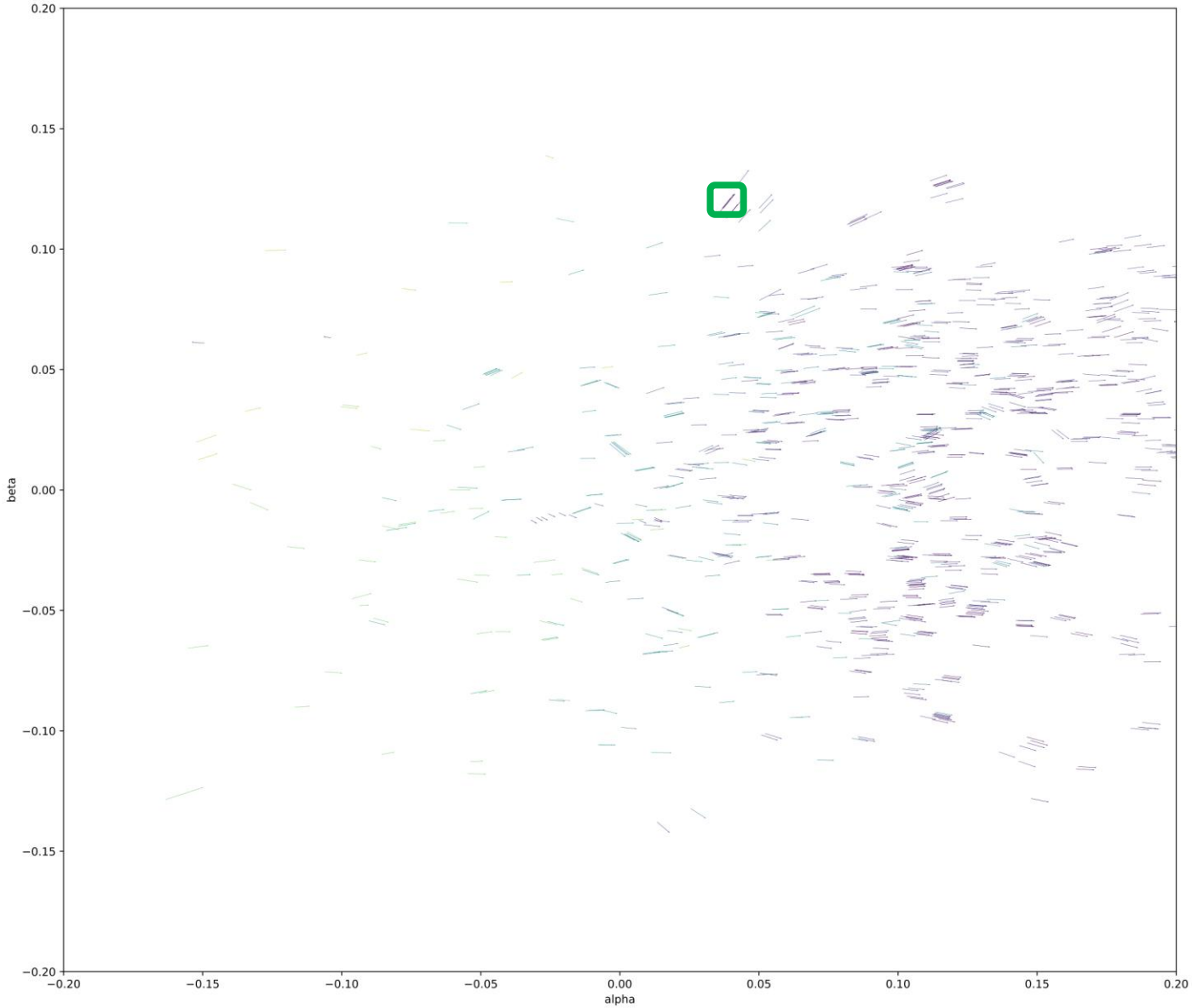

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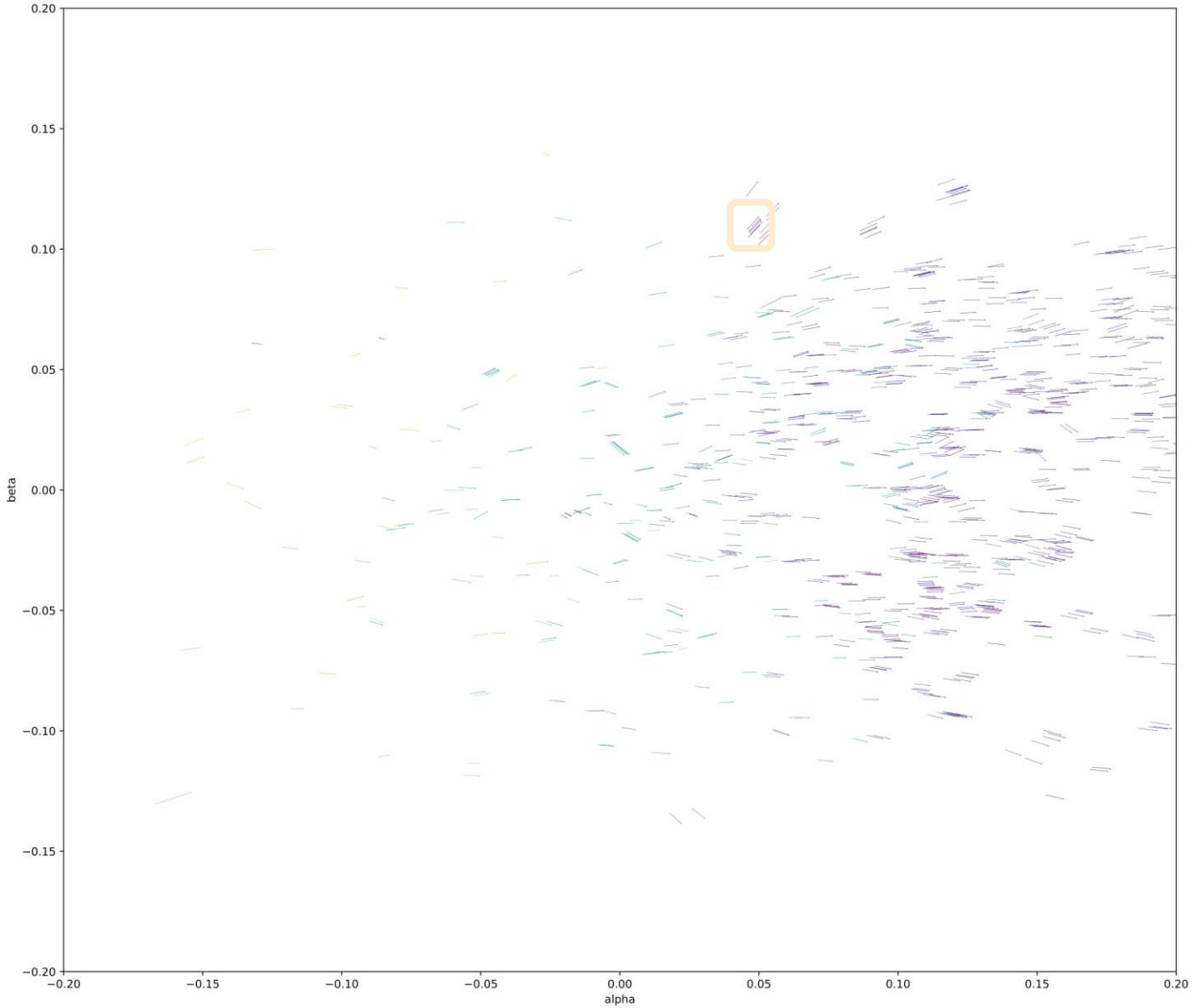
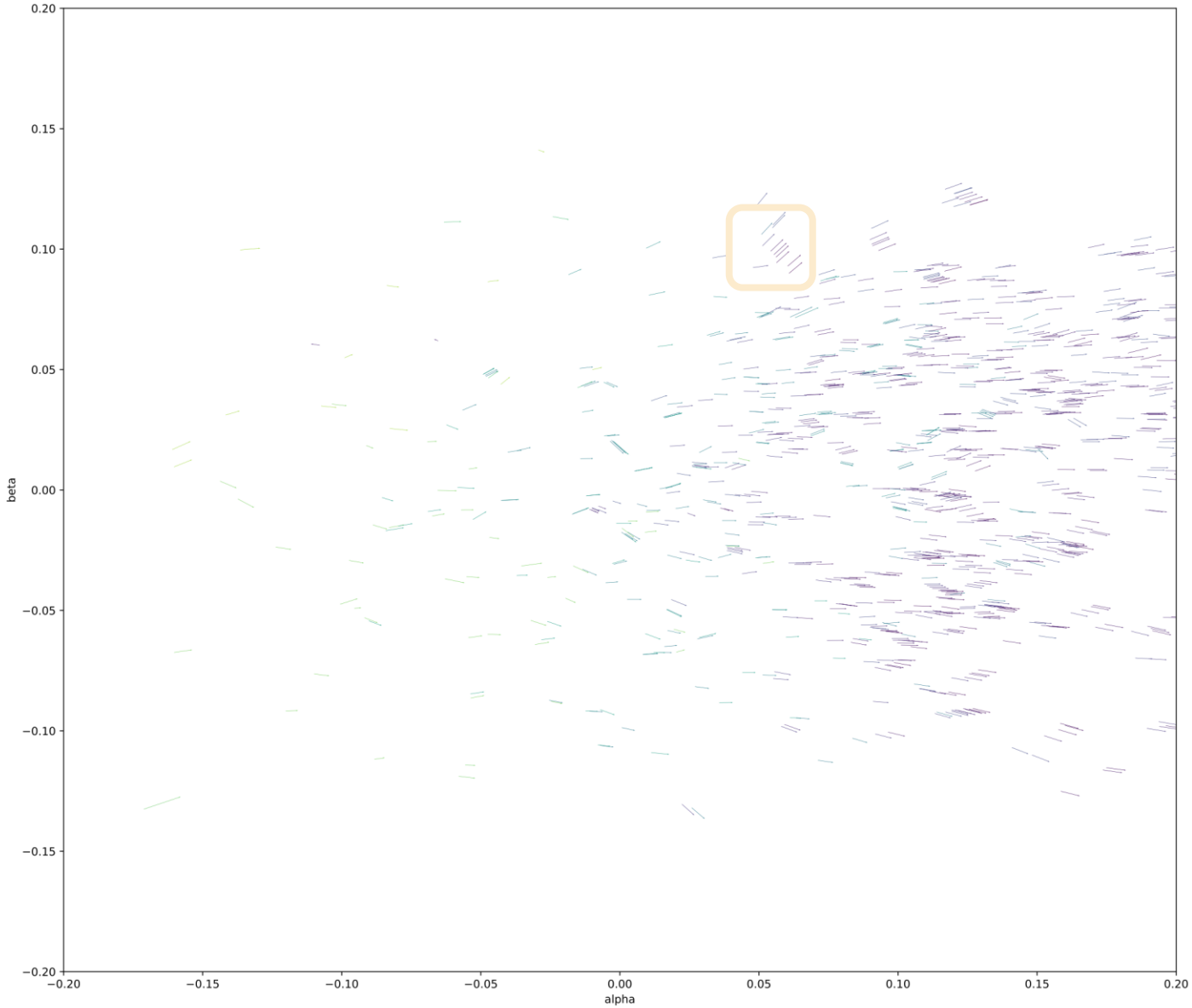


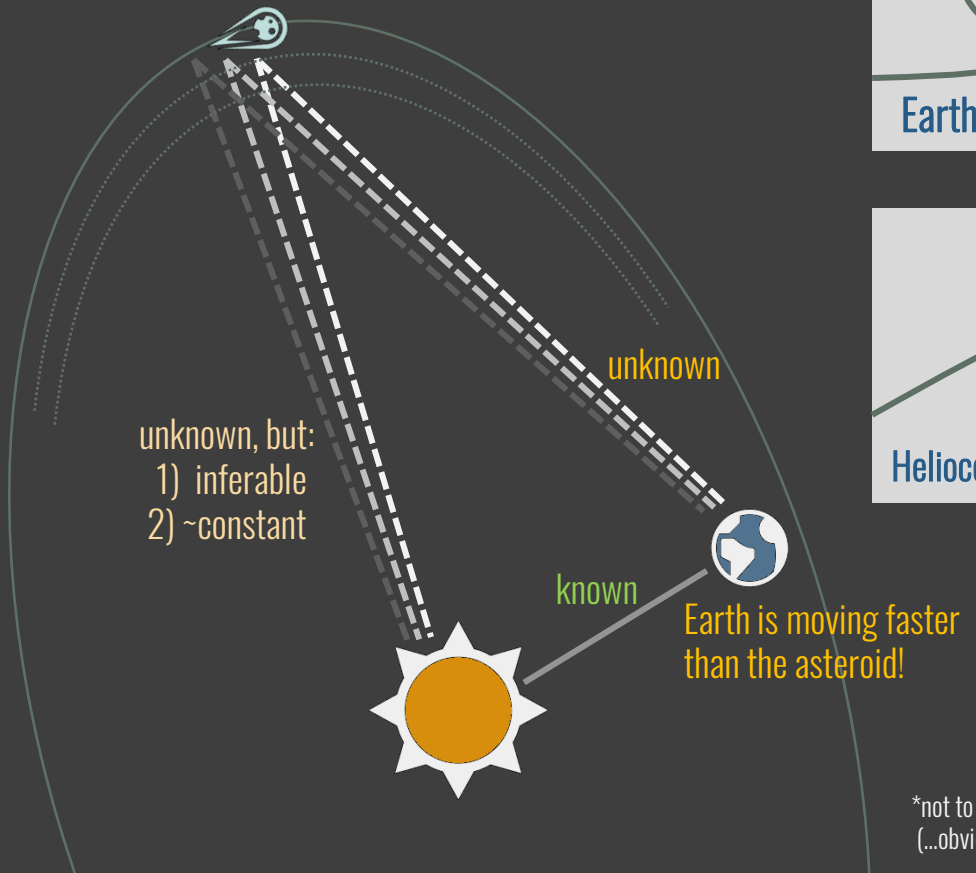
THE VIEW FROM THE SUN

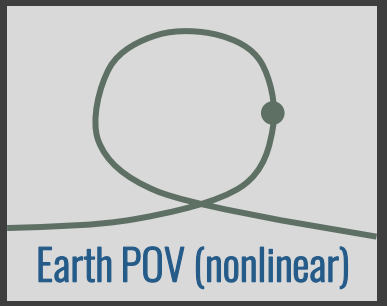


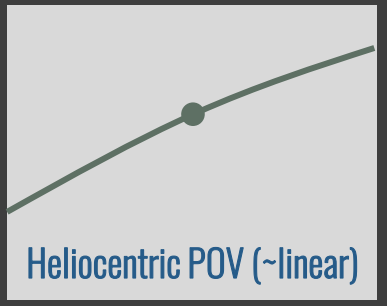
CORE INTUITION

WHY DOES HELIOCENTRIC LINKING WORK?

- Heliocentric transformation allows us to infer a near-constant distance from the sun (we have a strong prior)
- Also helps us compare asteroid tracklets in a linear space, at a common time
- Enables clustering to identify observations as one object







*not to scale
(...obviously)

OUR METHODOLOGY

1. DIVIDE SKY INTO 300 MONTHLY TIME SLICES, 800 SKY REGIONS

2. ASSERT THE (UNKNOWN) RADIAL DISTANCE FROM THE SUN

Dividing into sky regions allows for a more precise clustering

OUR METHODOLOGY

1. DIVIDE SKY INTO 300 MONTHLY TIME SLICES, 800 SKY REGIONS
2. ASSERT THE (UNKNOWN) RADIAL DISTANCE FROM THE SUN
3. ITERATE OVER RADIAL VELOCITIES, FIT FOR OTHER MOTION PARAMS
4. CLUSTER BASED ON RESULTING PARAMS: X/Y/Z POSITION, VELOCITY

4 of our 6 motion parameters are known, and 1 is relatively constant

Model is linear in the parameters (least squares fit)

OUR METHODOLOGY

TUNE CLUSTERING HYPERPARAMETERS OVER KNOWN TRAINING SET (THANKS TO MATT PAYNE, MINOR PLANET CENTER!)

TRAIN CLUSTER RADIUS/WEIGHTING

1. DIVIDE SKY INTO 300 MONTHLY TIME SLICES, 800 SKY REGIONS
2. ASSERT THE (UNKNOWN) RADIAL DISTANCE FROM THE SUN
3. ITERATE OVER RADIAL VELOCITIES, FIT FOR OTHER MOTION PARAMS
4. CLUSTER BASED ON RESULTING PARAMS: X/Y/Z POSITION, VELOCITY

We tune two hyper-parameters:

1) OPTIMAL **CLUSTER RADIUS**

2) **WEIGHTING** OF VELOCITY VS. POSITION

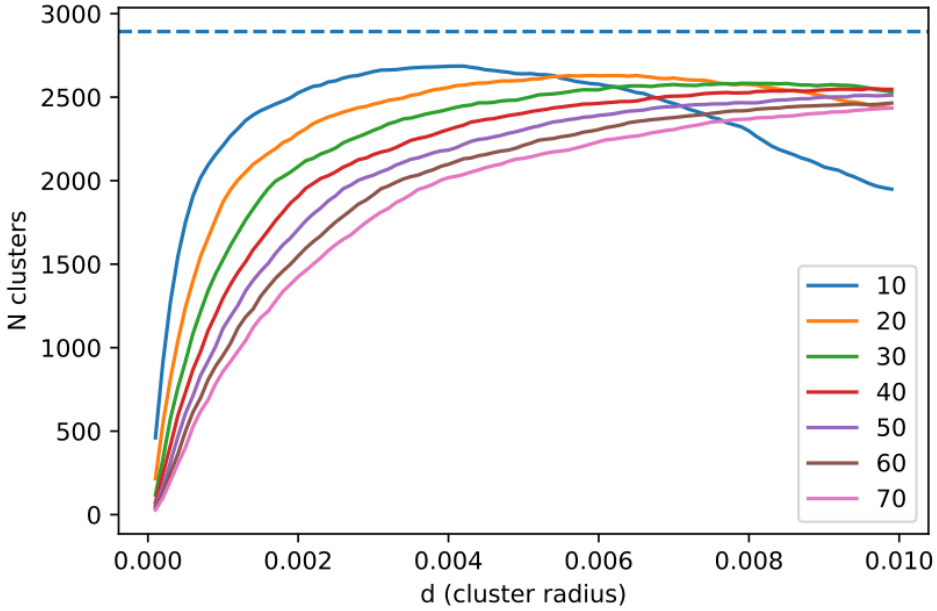
TUNING PERFORMANCE

OPTIMAL RADIUS:
0.0005-0.0010rad

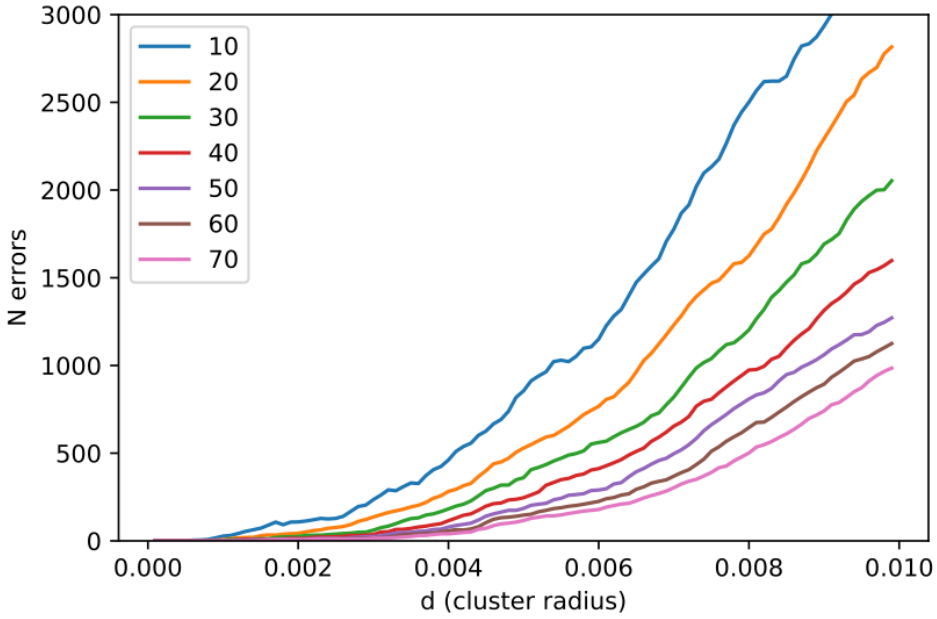
Selected KD-tree clustering for speed (average case log(n))

Also had good results with agglomerative clustering

Total clusters detected vs. KD-tree cluster radius (training set)



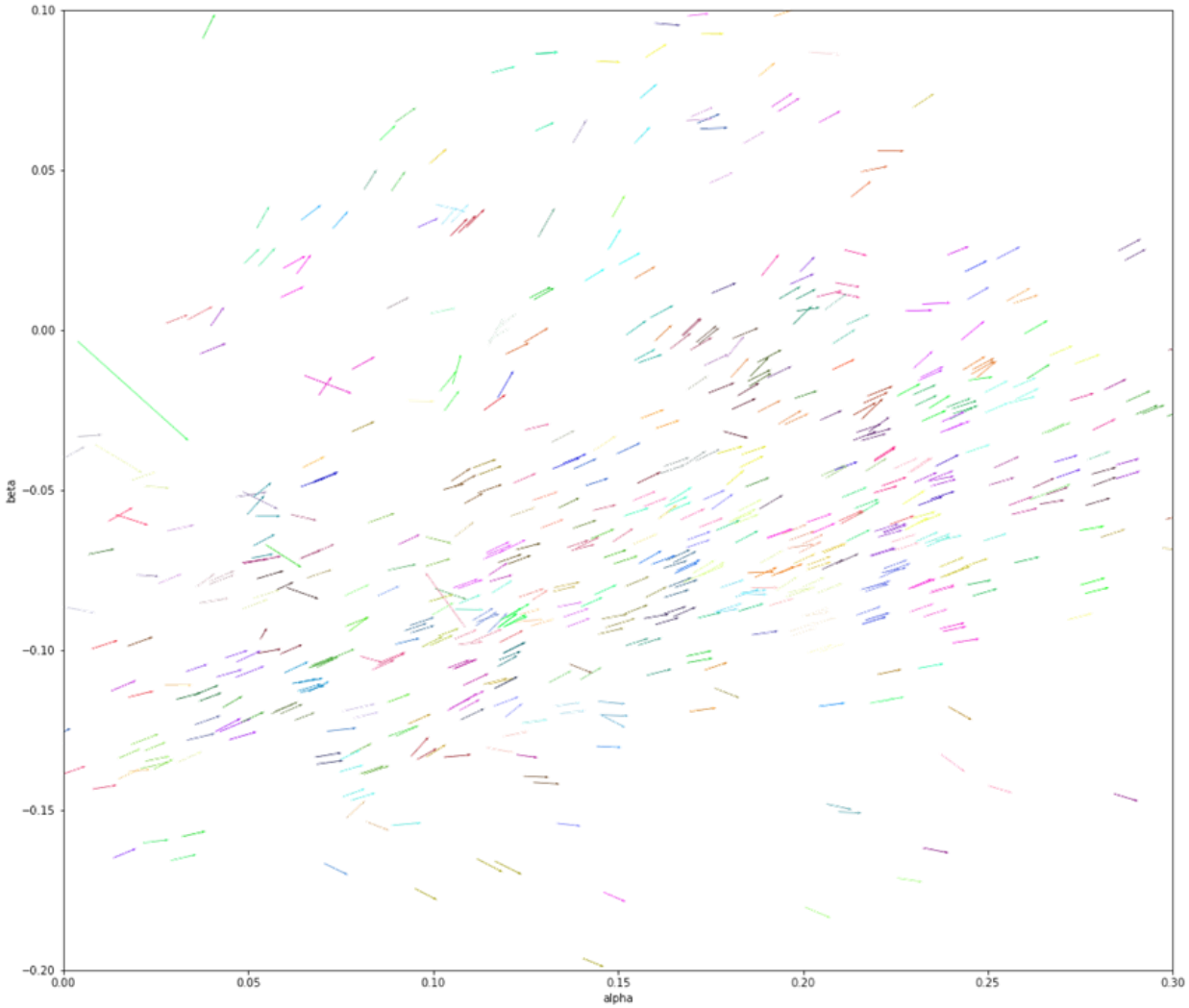
Error rate vs. KD-tree cluster radius (training set)



CLUSTERING RESULTS

90% OF ASTEROIDS DETECTED WITH NEAR-ZERO ERROR!

Identified Asteroids (common colors = a single asteroid)



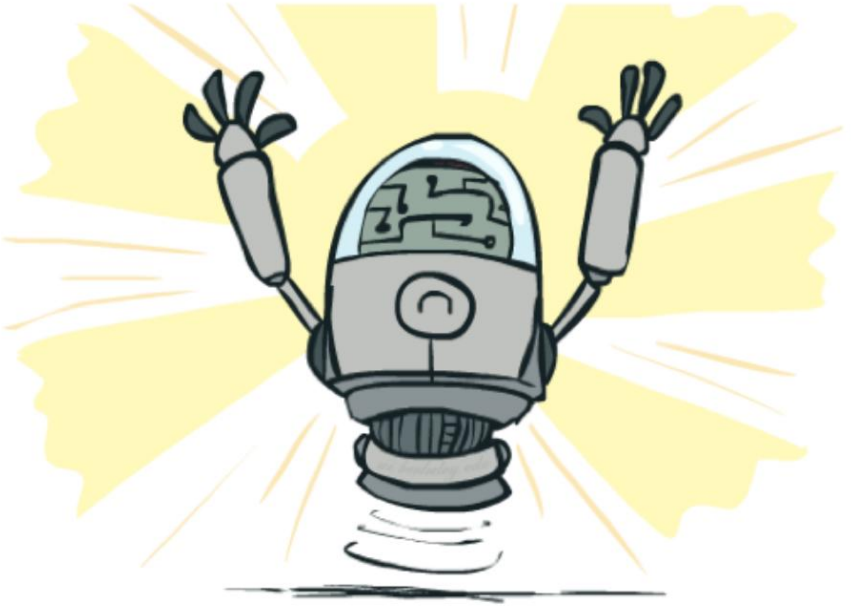
CONCLUSIONS

Conclusion: Strong tracklet linking with heliocentric transformation & KD-tree clustering

Also able to do so in just **O(n log n)** time, a scalable solution!!

Limitations: currently restricted to small (monthly) observation time window

Next Steps: Run the algorithm over all 14m tracklet observations!



Thanks To: The Minor Planet Center for training data, Scott and Brian for project support!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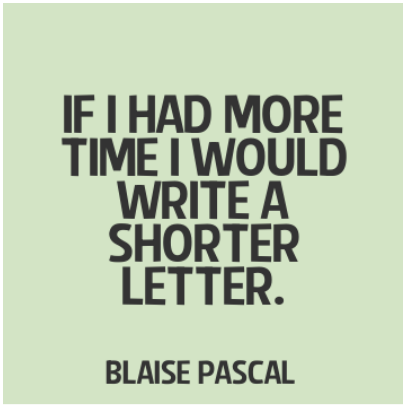
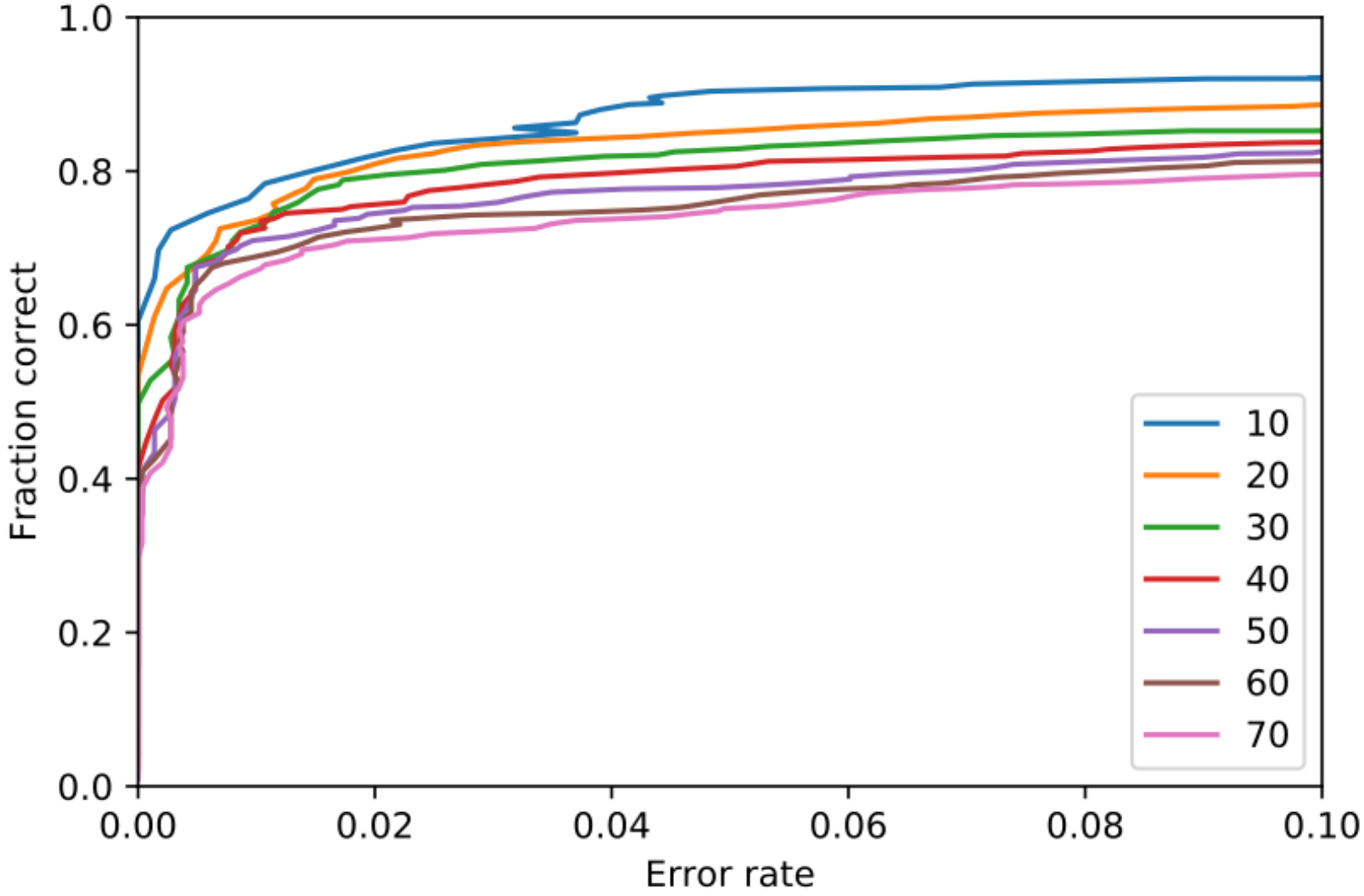
APPENDIX/SUPPORTING SLIDES



Training AUC



Agglomerative Clustering Dendogram (Truncated)