Jet Propulsion Laboratory
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The impact trajectory of asteroid 2008 TC_3

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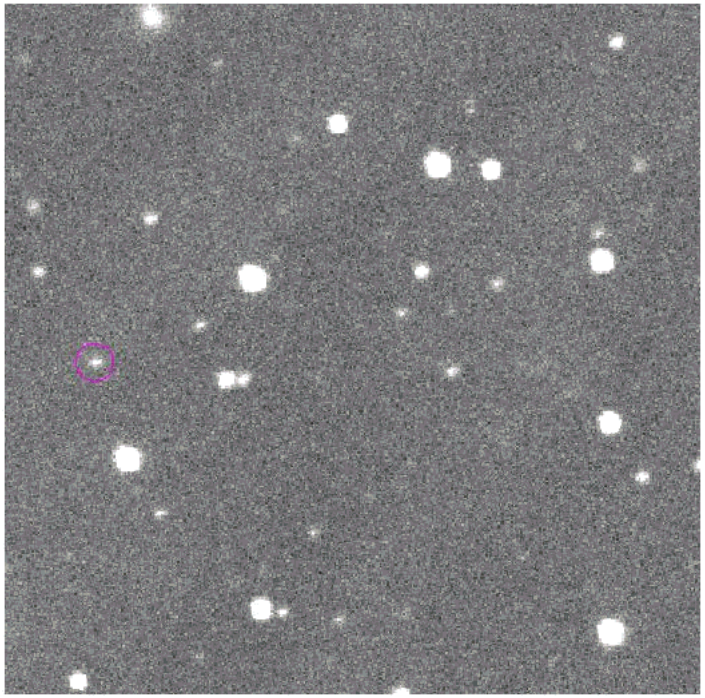
Discovery



Size 4 m

R. Kowalski, Catalina Sky Survey

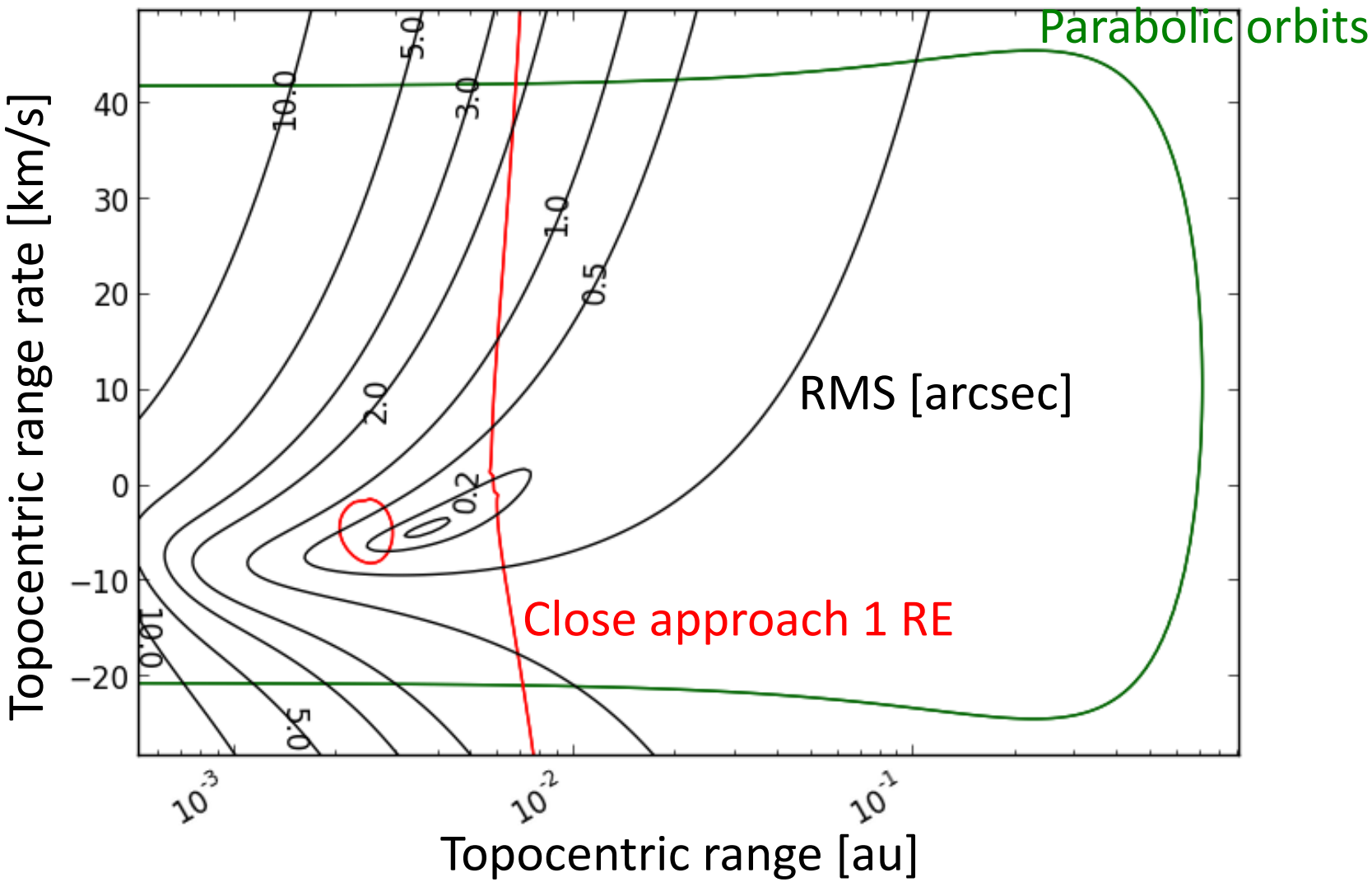
20 h before impact

4 observations over 43 min

Follow-up by Kowalski, Sabino Canyon, Moorook, Siding Spring

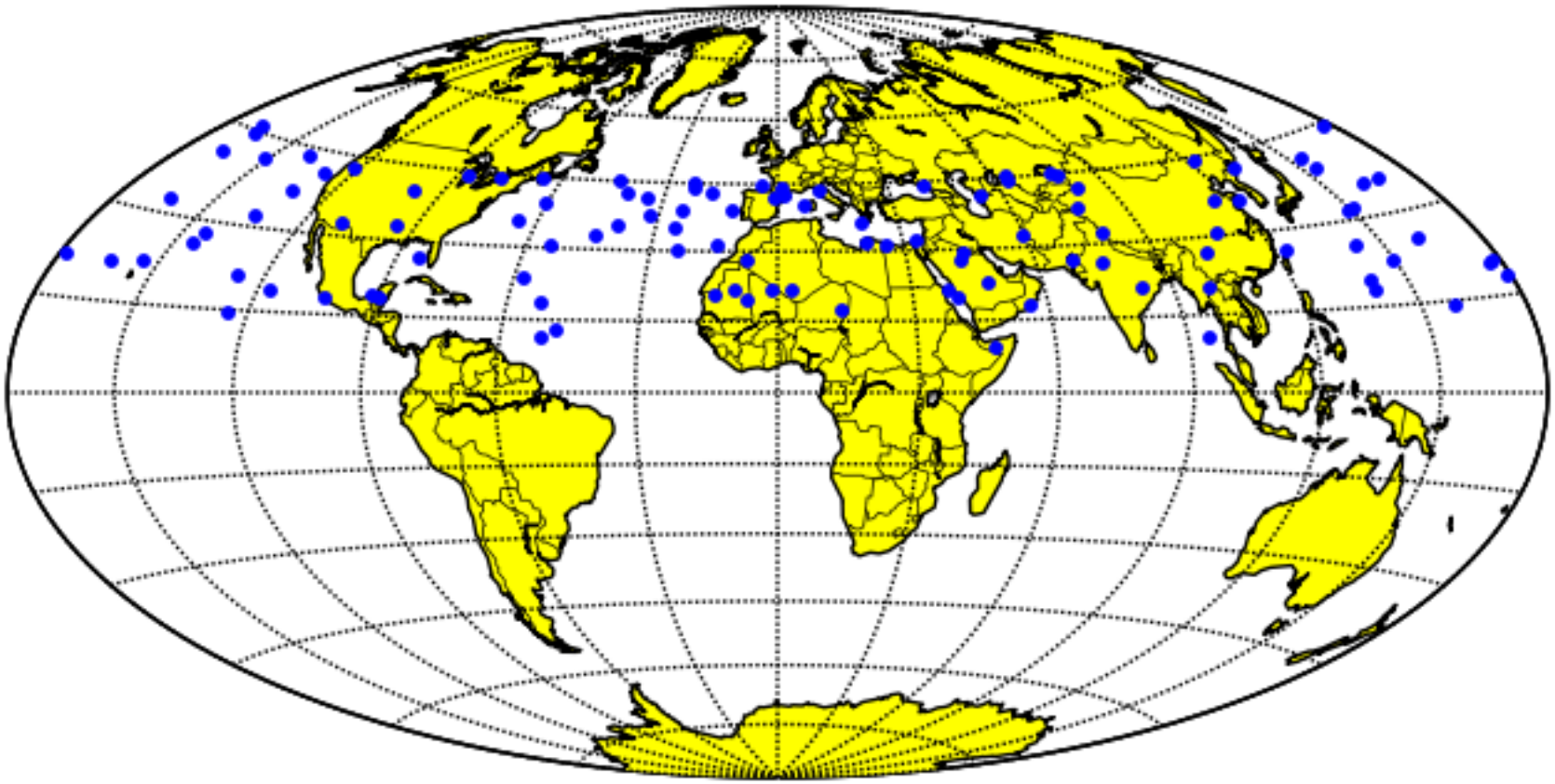
Announced by MPC 12 h before impact

First orbit assessment
4 observations over 43 minutes



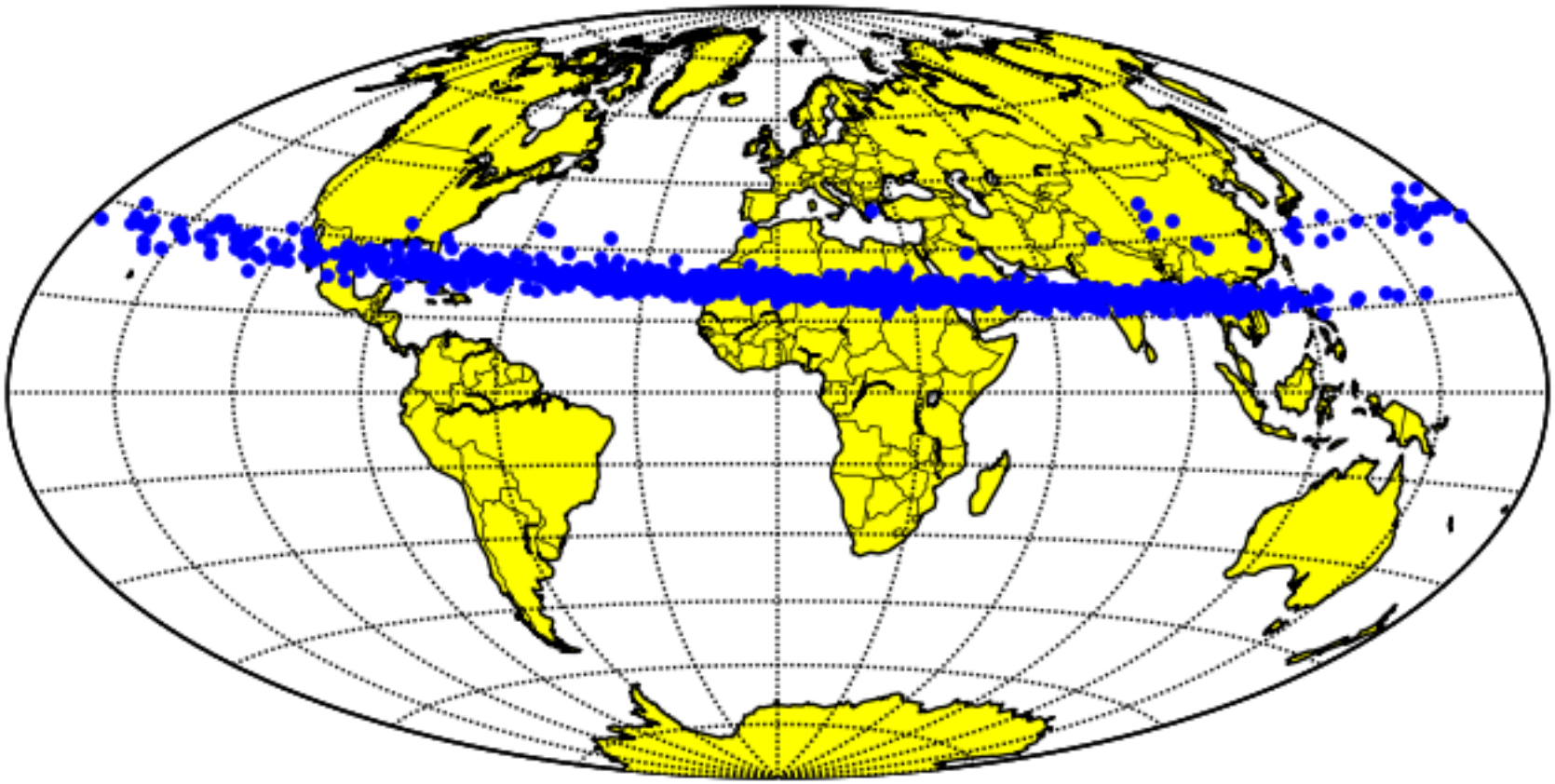
Impact prediction evolution

4 observations over 43 min
19 h 20 min to impact
Impact probability 4%



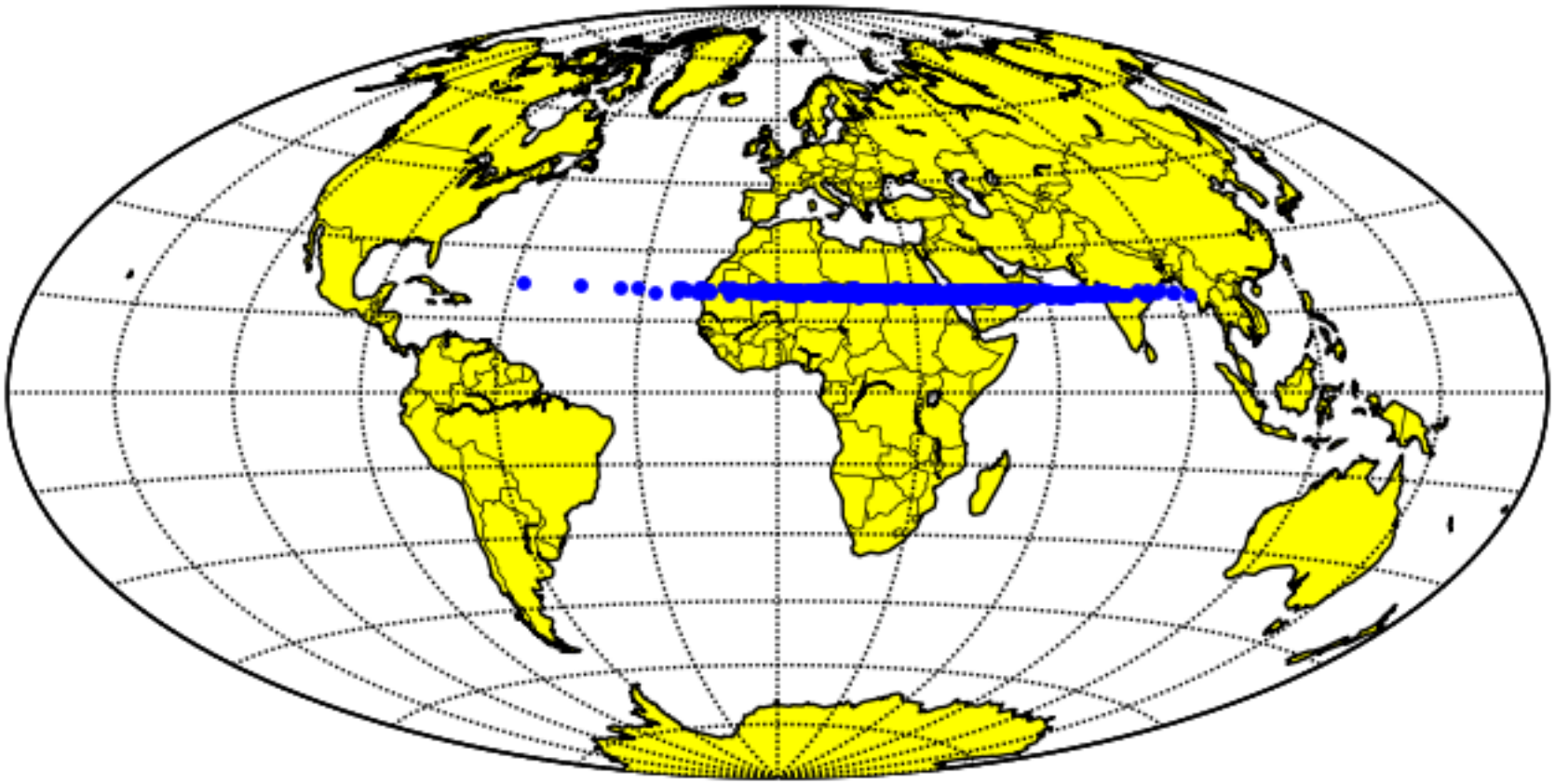
Impact prediction evolution

7 observations over 1 h 40 min
18 h 25 min to impact
Impact probability 100%



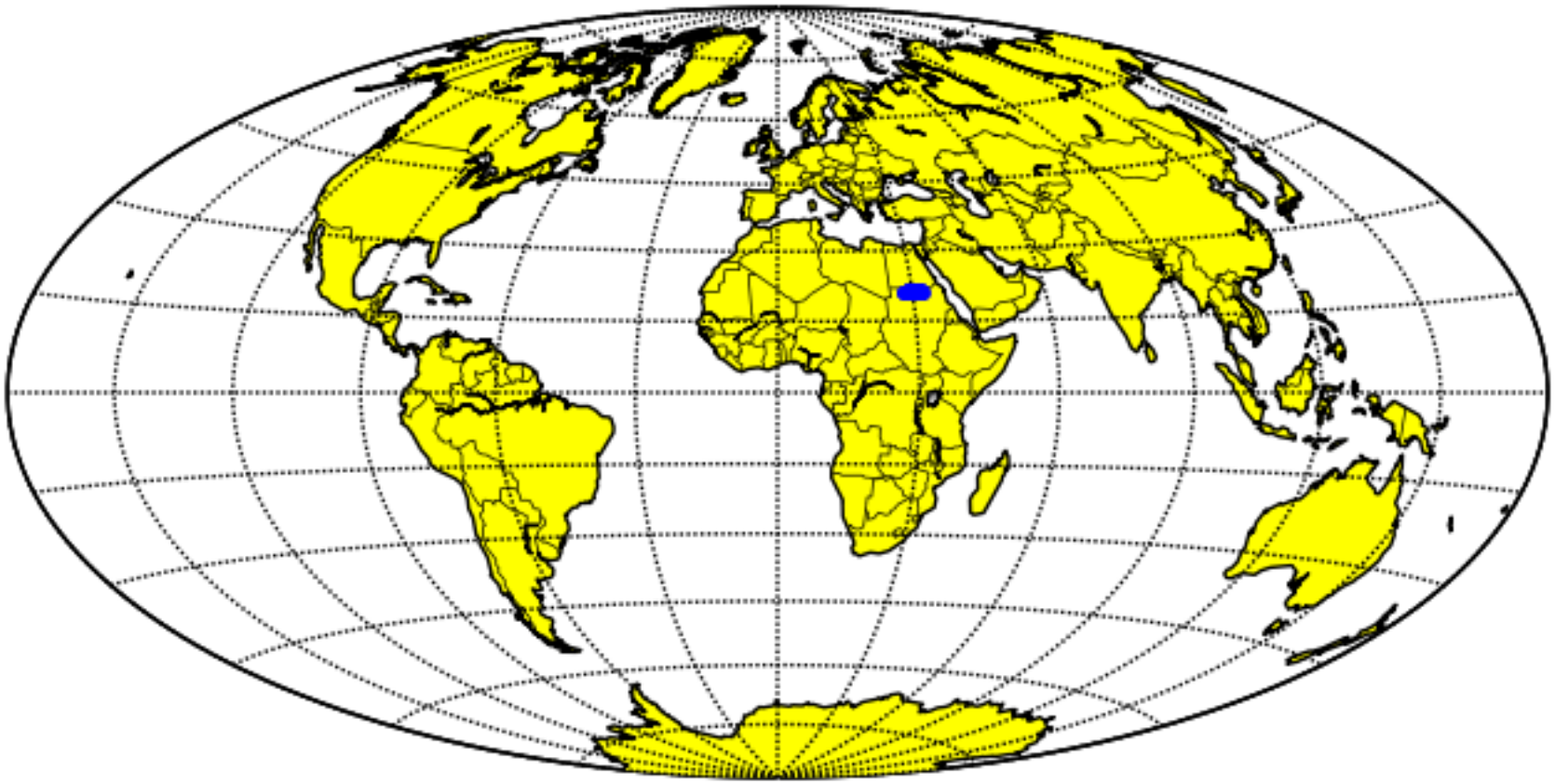
Impact prediction evolution

15 observations over 2 h 20 min
17 h 45 min to impact
Impact probability 100%



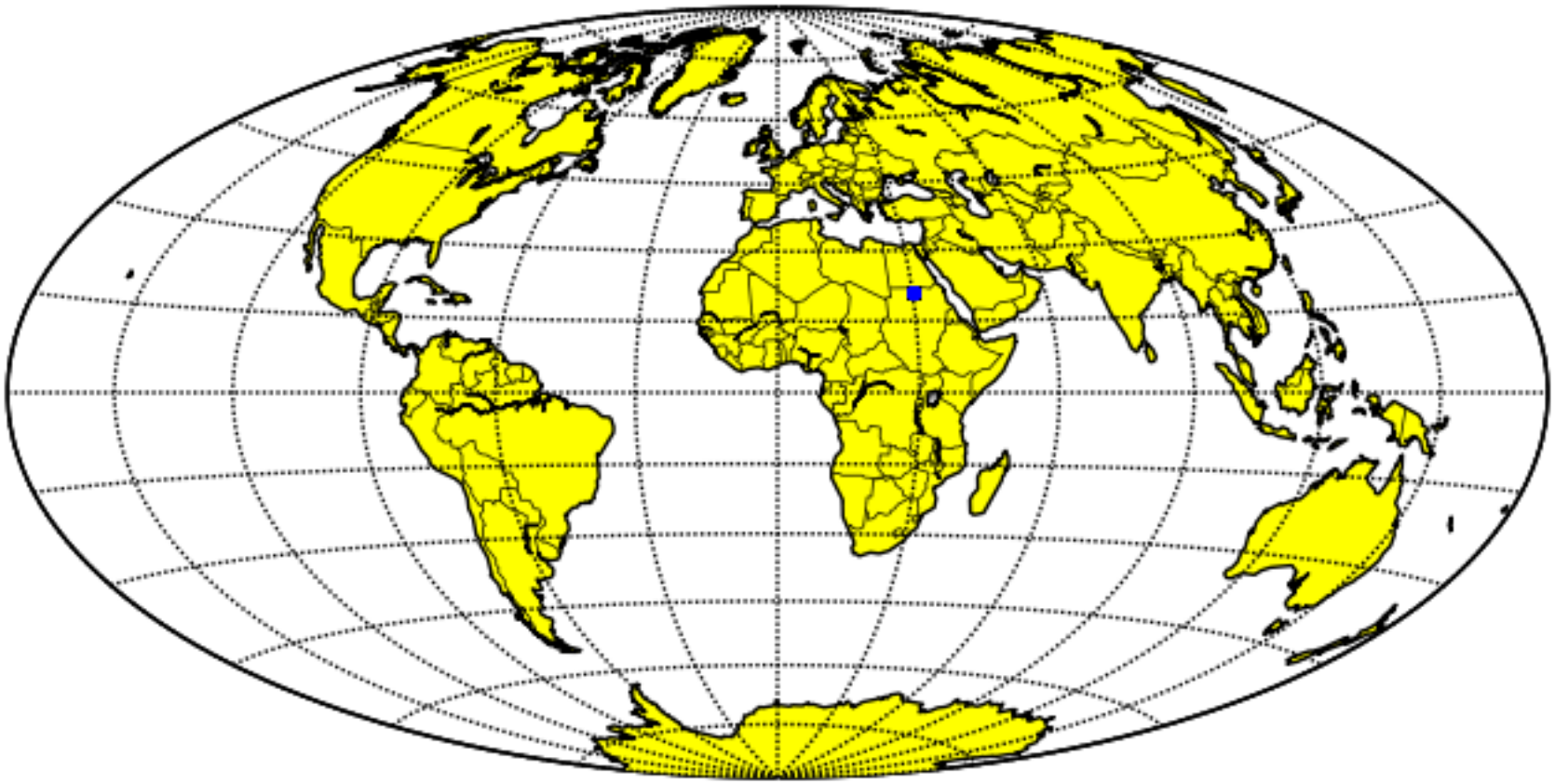
Impact prediction evolution

18 observations over 8 h 05 min
12 h to impact
Impact probability 100%



Impact prediction evolution

883 observations over 19 h 05 min
1 h to impact
Impact probability 100%



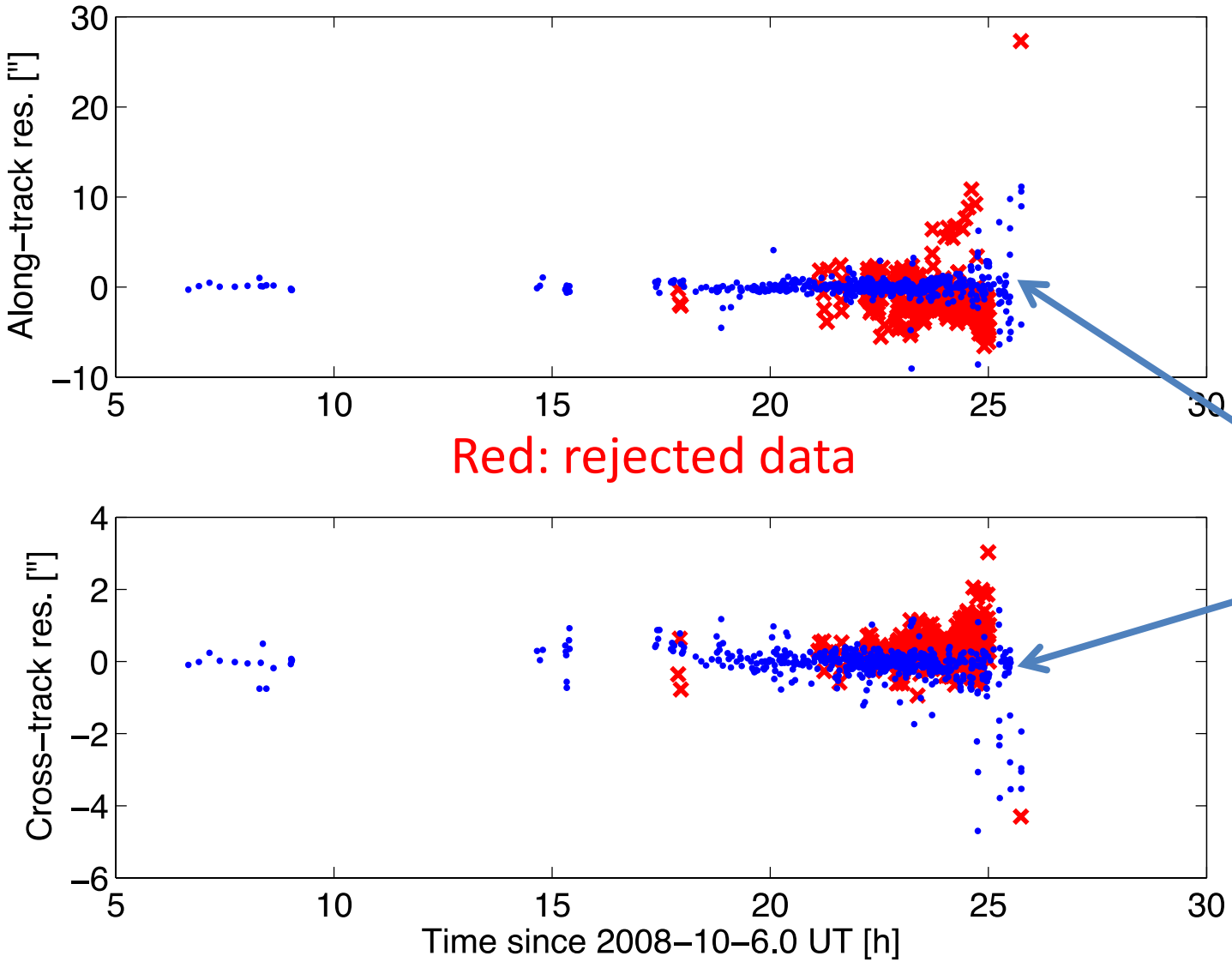
Recovery of meteorites

2008 TC_3 broke up above Nubian Desert in Sudan

Jenniskens et al. recovered 600 meteorites for a total mass 10.7 kg.

Ground truth to validate trajectory estimation and impact location predictions

Astrometric data treatment



Red: rejected data

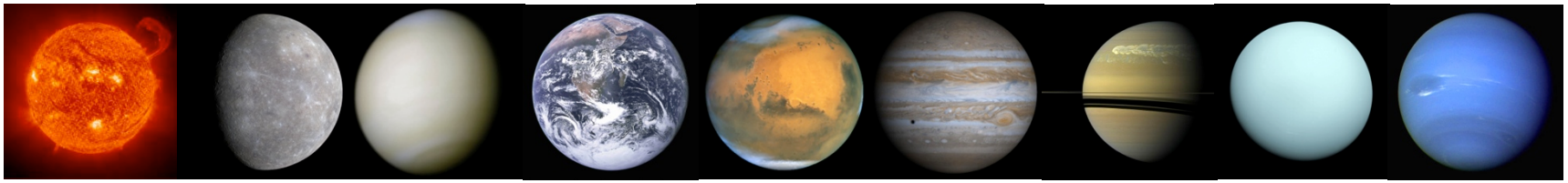
Star catalog debiasing

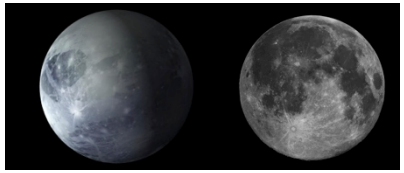
Manual weights and rejections

12 arcsec/s
Vmag ~ 13

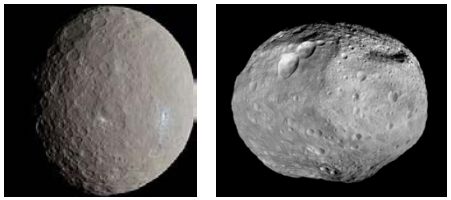
Force model

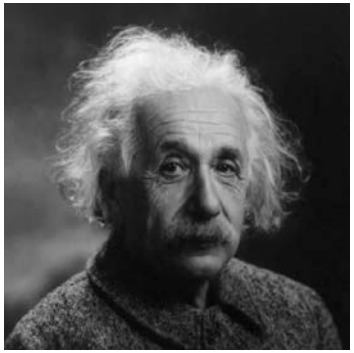
Newtonian attraction





16 main belt perturbers

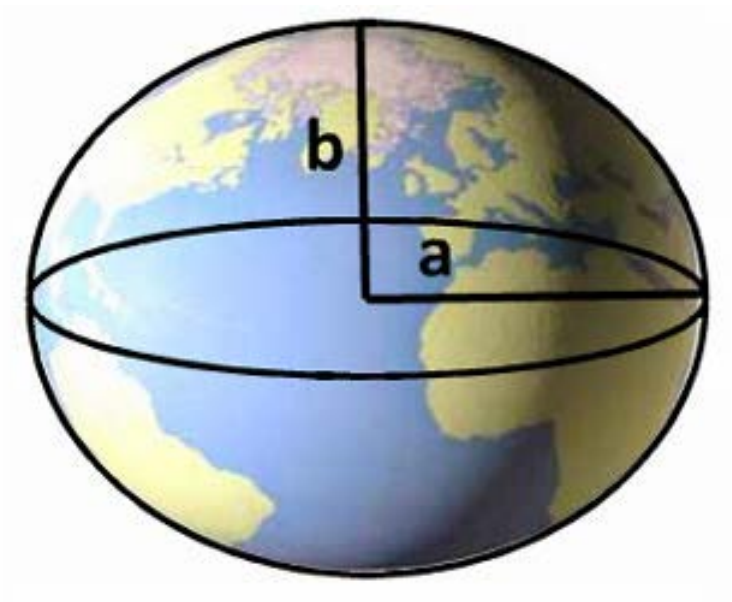




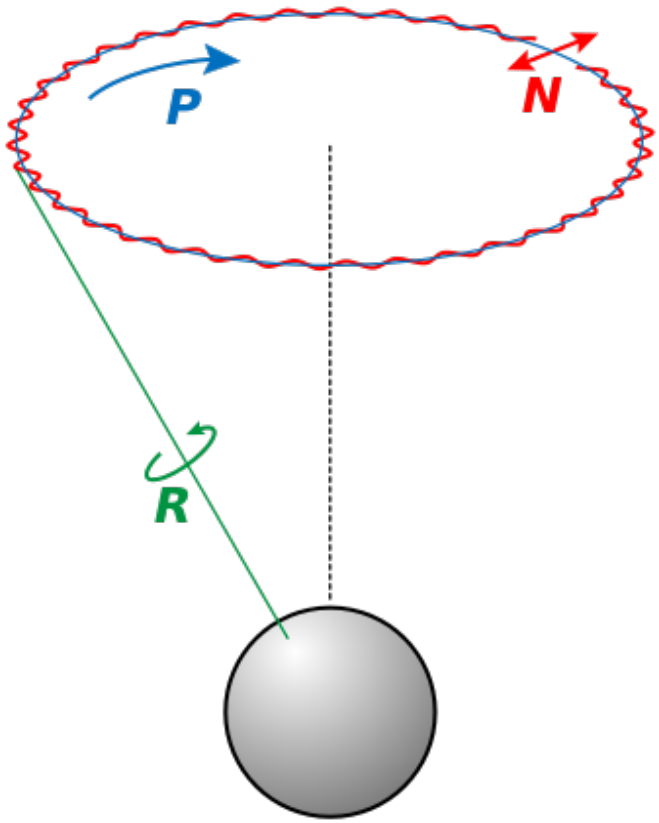
Einstein-Infeld-Hoffman formulation for relativity

Earth's J_2

Earth model



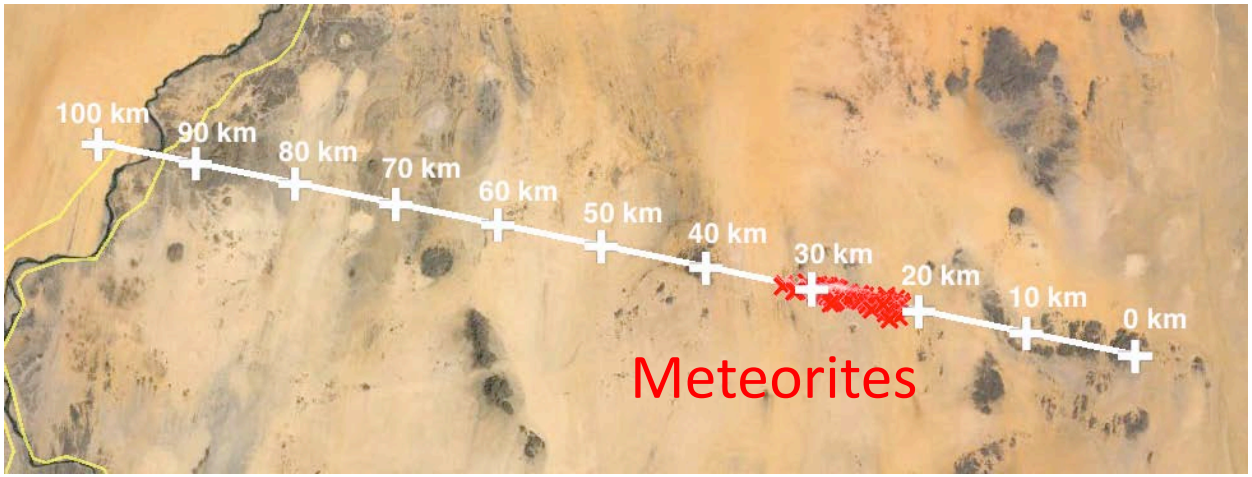
WGS-84 reference ellipsoid
Equatorial radius = 6378.137 km
Flattening = 0.003352811



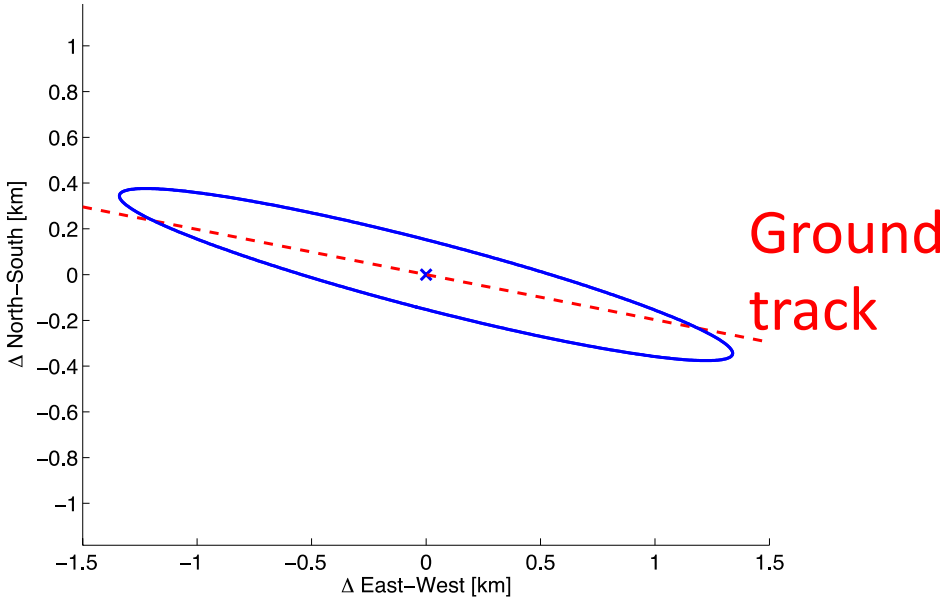
1980 IAU Theory of Nutation
+
JPL Earth Orientation Parameters

Impact location estimate

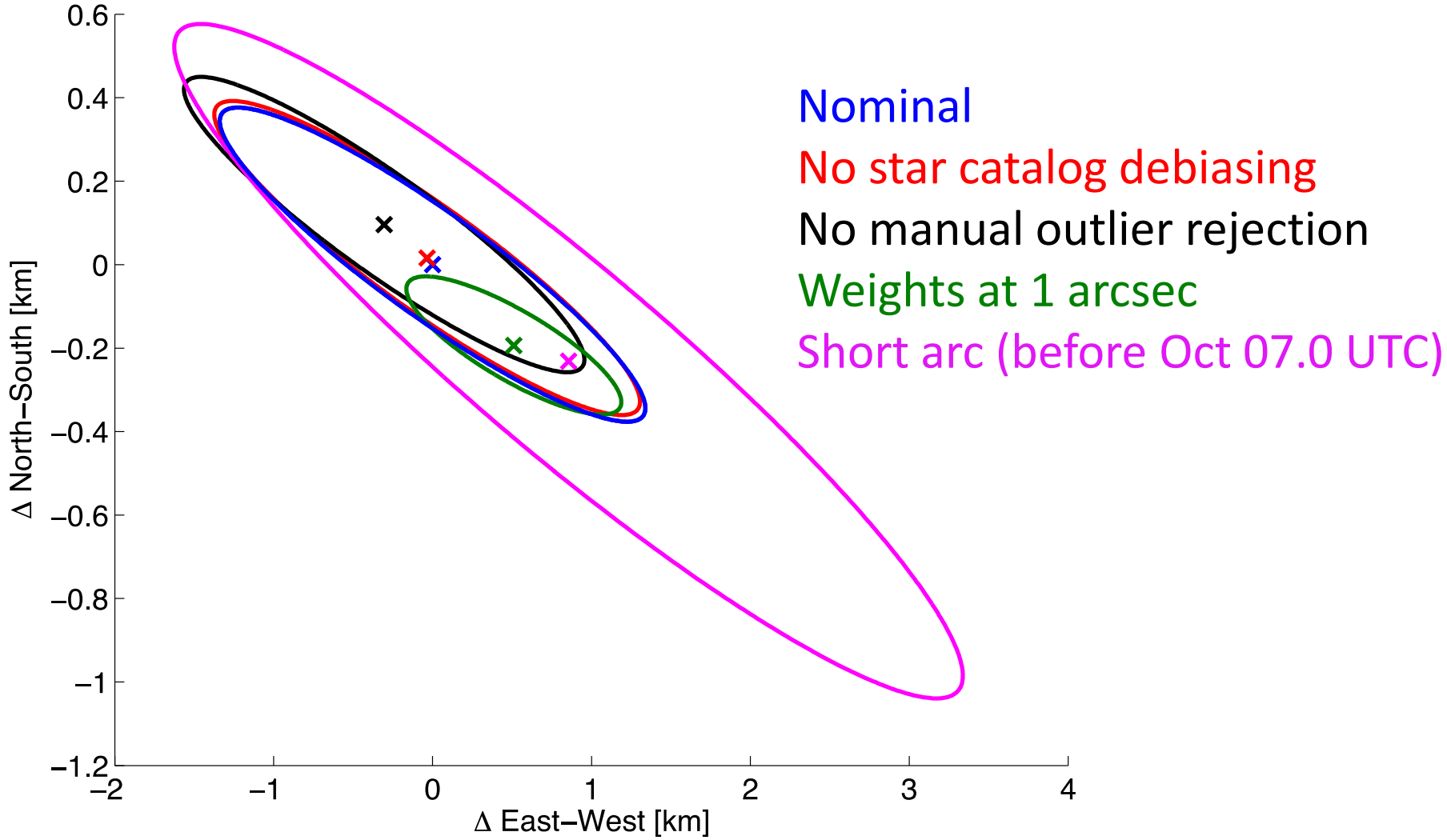
Ground track
Entry angle of 21°



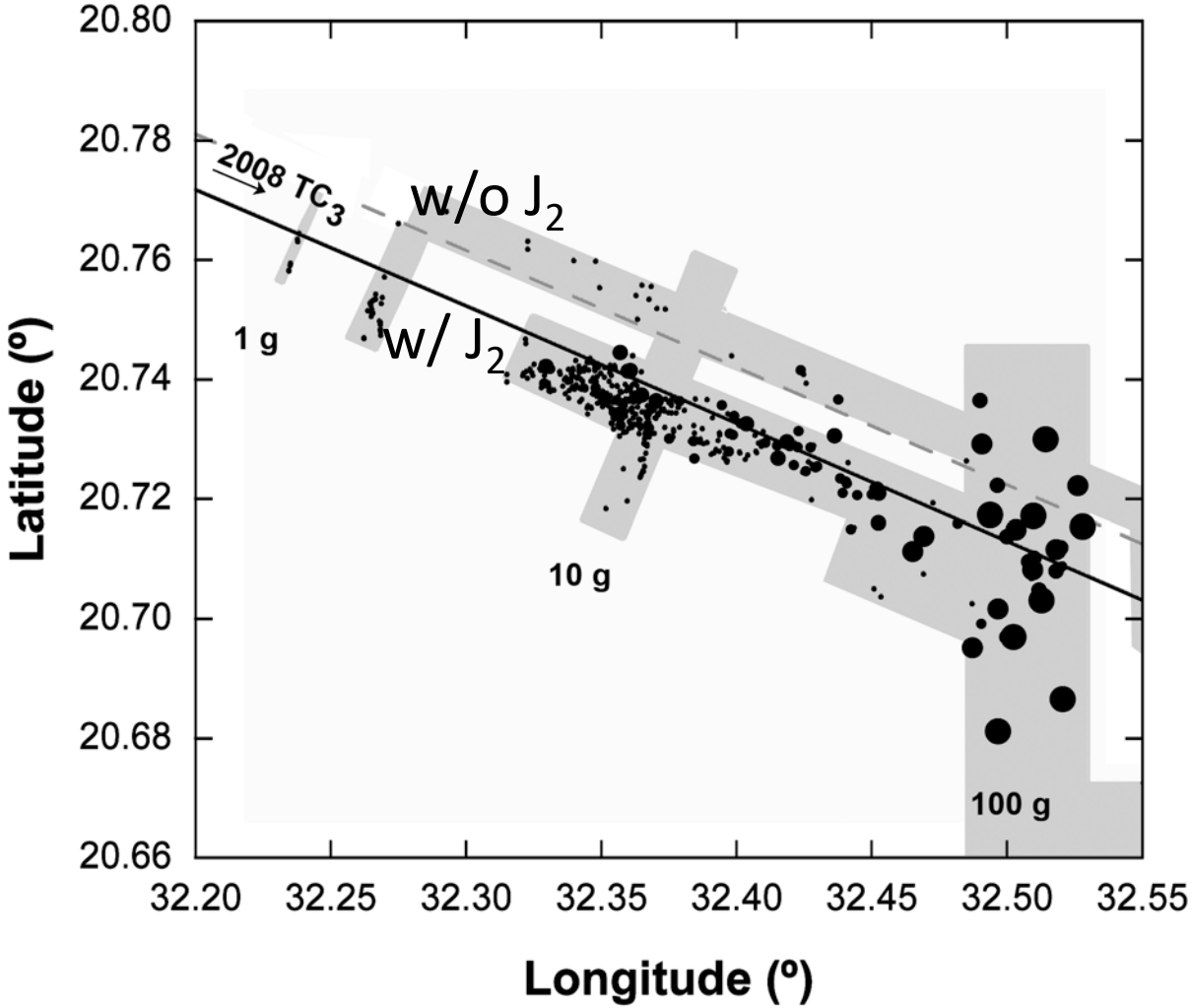
3-σ time error of 0.5 s
3-σ error ellipse of 1.4 km × 150 m



Sensitivity to treatment of the astrometry



Sensitivity to geopotential



J_2

- 2 km along-track
- 1 km cross-track

Non-zonal and higher order terms:

- 17 m along-track
- 3 m cross-track

<< uncertainties

Atmospheric drag

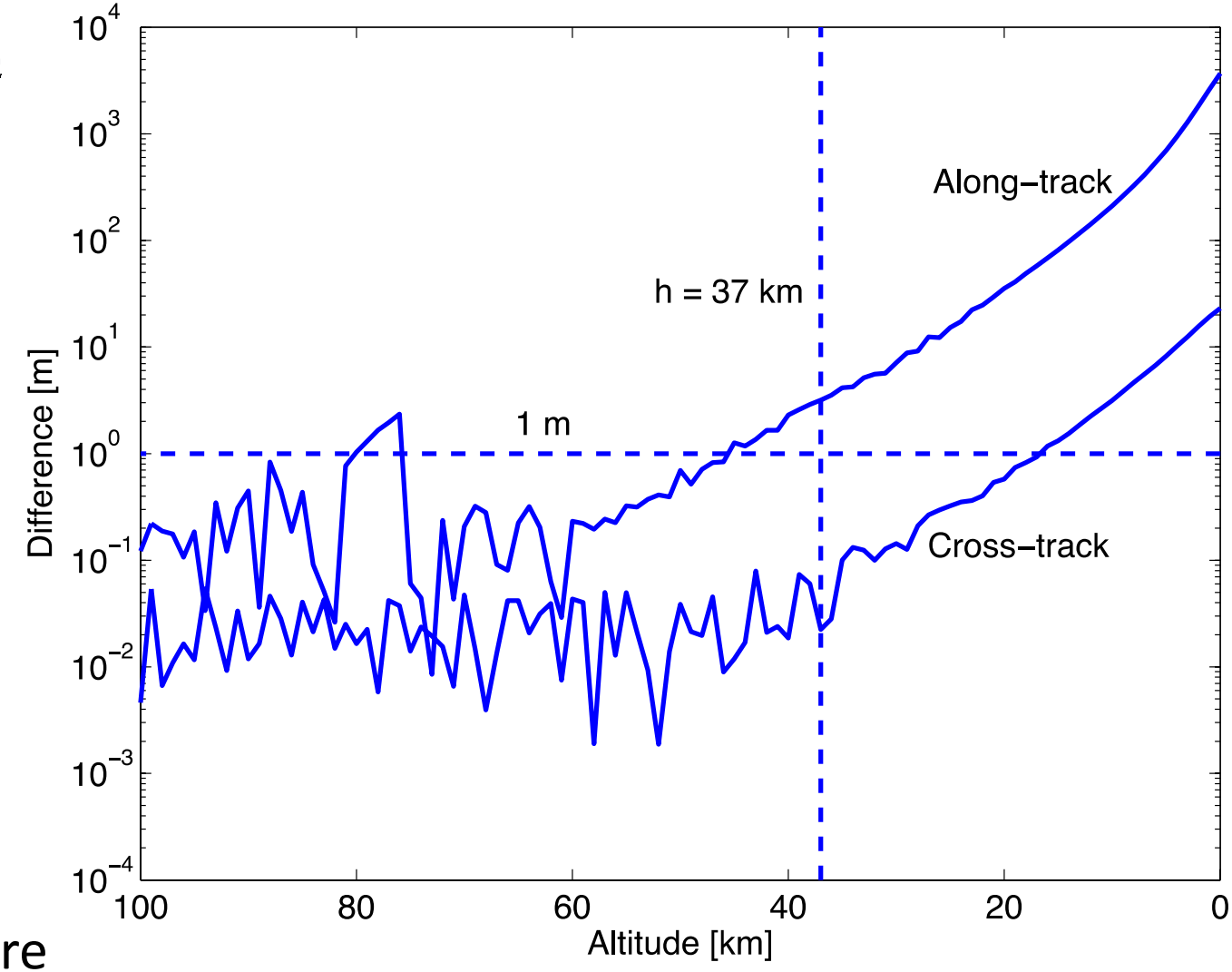
$$a_{drag} = -\frac{1}{2}\rho_{atm} C_D \frac{A}{M} v^2$$

Drag coefficient
$C_D = 1.8$

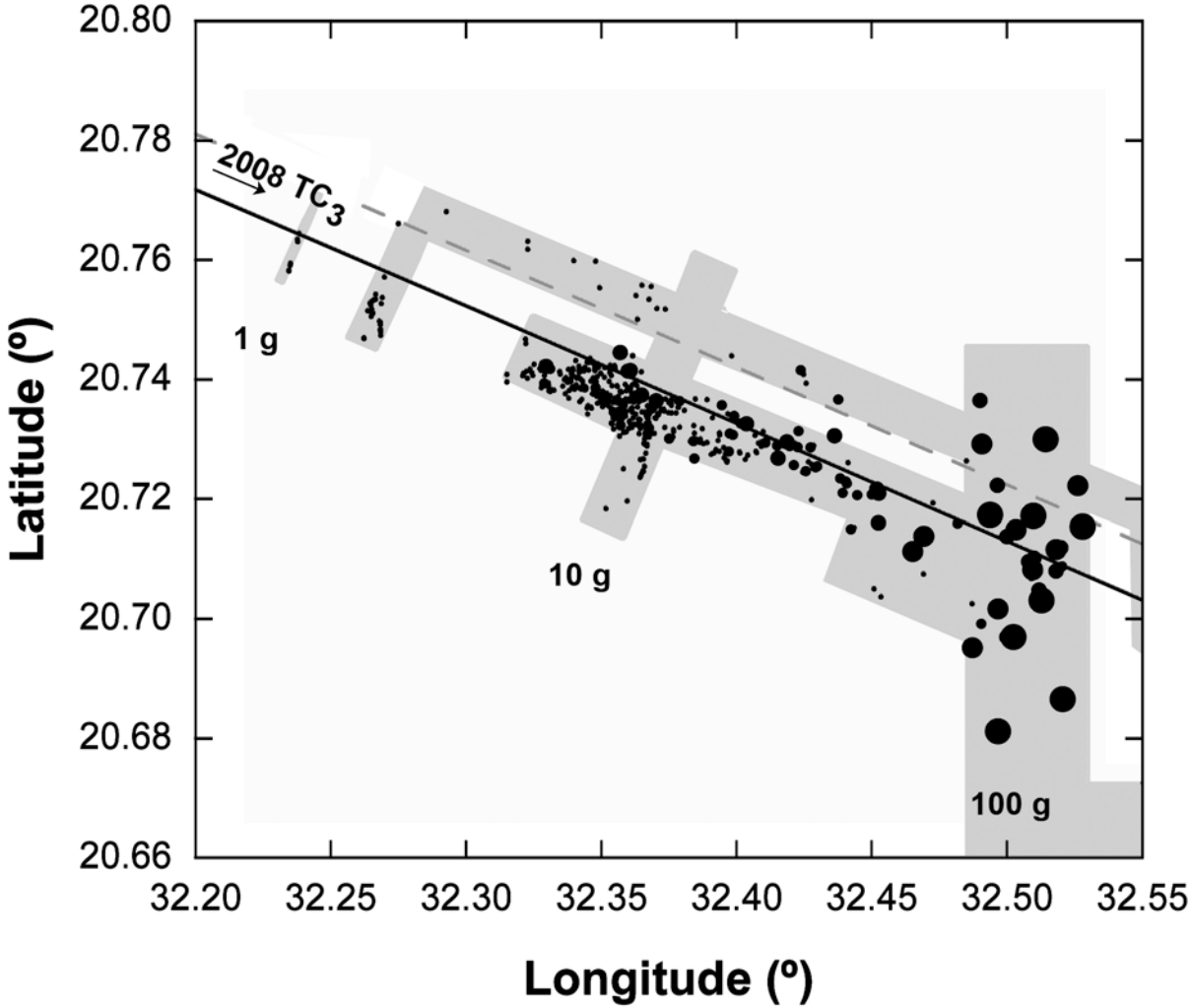
Cross section
$A = 13.2\ m^2$

Mass
$M = 83\ t$

COSPAR 2012
reference atmosphere



Winds



UK Meteorological model

Below h = 30 km
winds ~ 10 m/s.

North until h = 5 km, then South

Typical offset 100 m

Negligible effects

	Error
Numerical noise	~ 3 m
Earth rotation model	~ 30 cm
Solar radiation pressure	< 1 m
Yarkovsky effect	< 1 m
General relativity vs EIH	< 1 m
Additional perturbers	< 1 m
Planetary Ephemerides	< 1 m

Summary

- 2008 TC_3 first asteroid discovered prior to impact.
  - Abundance of observations and recovered meteorites: unique opportunity for modeling validation
- Predicted ground track agree well with meteorite locations
- Tested sensitivity of impact prediction on the adopted models
  - Degradation of the astrometric quality
  - Effect of J_2 ~ km, winds ~ 100 m
- Drag not significant above 50 km, few m at explosion altitude, few km at ground level