Impact Hazard Assessment for 2011 AG5

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http://neo.jpl.nasa.gov/risk/

2011 AG5
Earth Impact Risk Summary

Torino Scale (maximum)	1
Palermo Scale (maximum)	-1.01
Palermo Scale (cumulative)	-1.00
Impact Probability (cumulative)	2.0e-03
Number of Potential Impacts	4

Analysis based on
210 observations spanning 316.77 days
(2010-Nov-08.629742 to 2011-Sep-21.398727)

V_{impact}	14.67 km/s
$V_{infinity}$	9.55 km/s
H	21.8
Diameter	0.140 km
Mass	4.1e+09 kg
Energy	1.1e+02 MT

all above are mean values weighted by impact probability

Orbit diagram and elements available here.

These results were computed on Mar 31, 2012

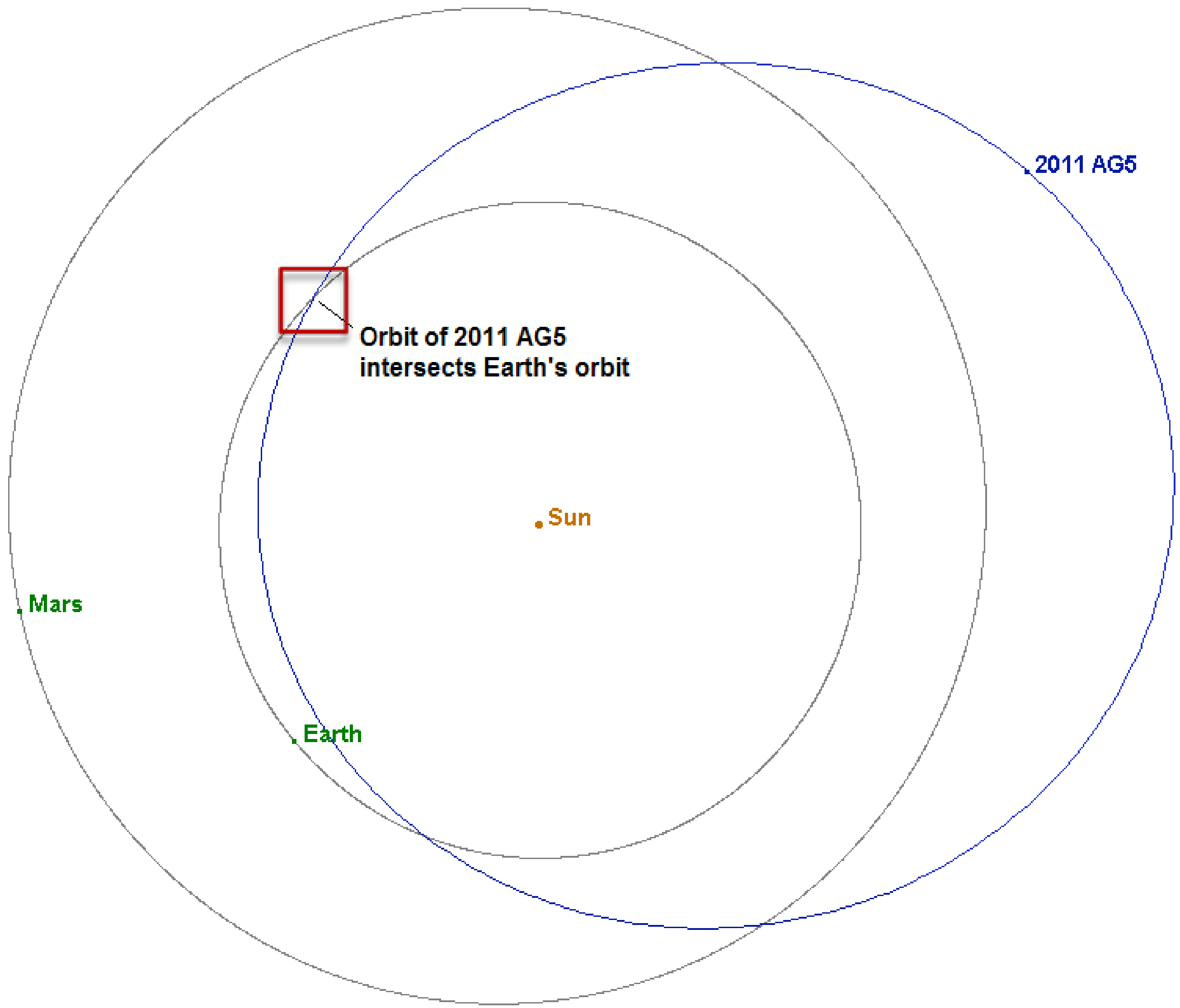
2011 AG5
Earth Impact Table

Date	Distance	Width	Sigma Impact	Sigma LOV	Stretch LOV	Impact Probability	Impact Energy	Palermo Scale	Torino Scale
YYYY-MM-DD.DD	(r_{Earth})	(r_{Earth})			(r_{Earth})		(MT)		
2040-02-05.16	0.31	1.04e-03	0.000	0.26494	3.70e+02	2.0e-03	1.05e+02	-1.01	1
2043-02-04.90	0.56	< 1.e-04	0.000	0.24025	1.39e+06	4.6e-07	1.05e+02	-4.68	0
2045-02-04.43	0.52	1.01e-03	0.000	0.09607	5.53e+04	1.2e-05	1.05e+02	-3.29	0
2047-02-04.92	0.57	9.82e-04	0.000	0.37496	1.69e+05	3.6e-06	1.05e+02	-3.84	0

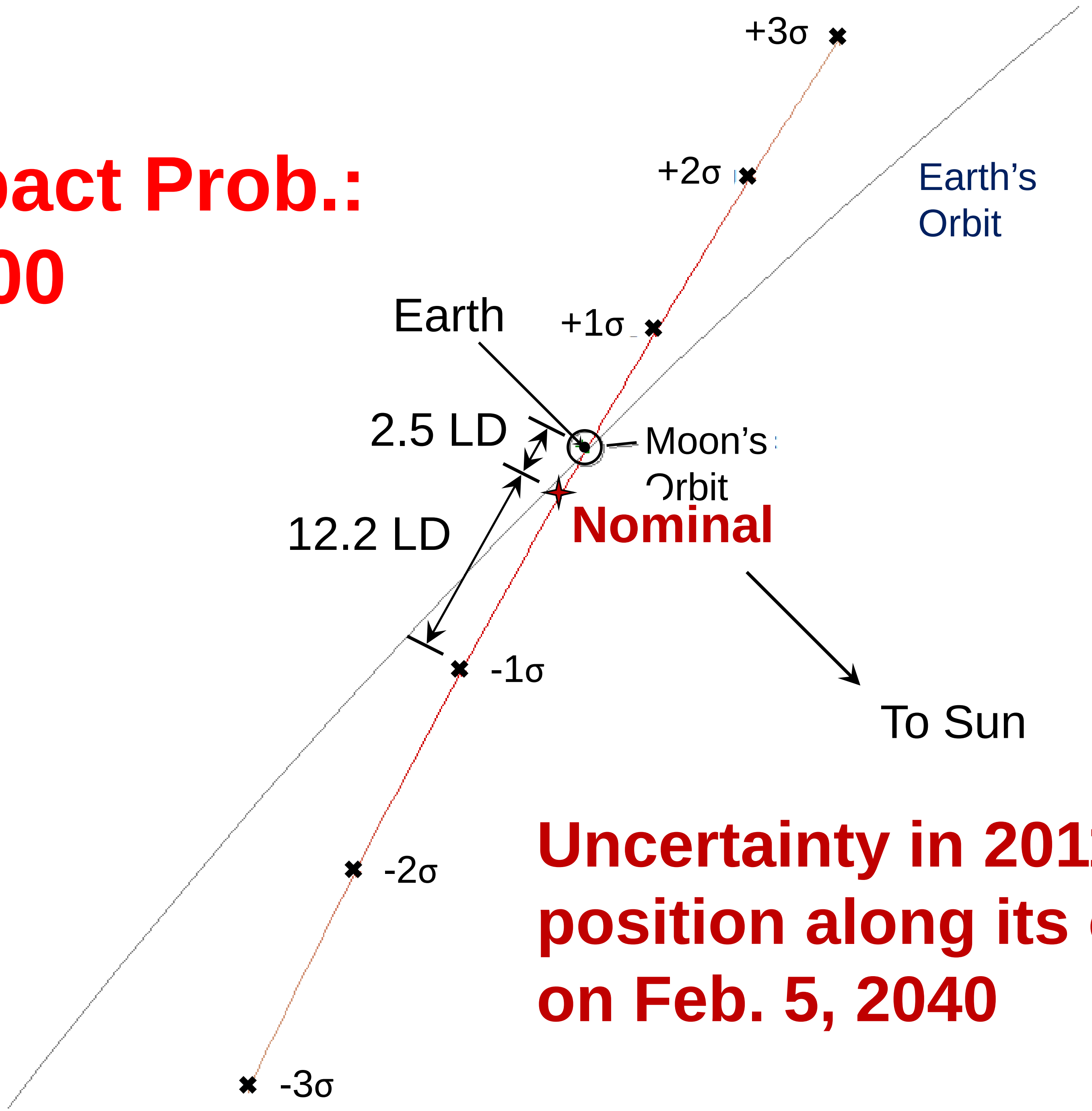
Background - 2011 AG5 in late 2011

- Discovered Jan. 2011 by Catalina Sky Survey
  - Pre-discovery obs. by Pan-STARRS dated Nov. 2010
  - Observations still covered only ~half of 625 day orbit
  - Asteroid was unobservable for a long period of time
- Earth impact probability: 1-in-500 for Feb. 5, 2040
  - Impact requires passage through 365 km keyhole on Feb. 3, 2023
  - Post-keyhole deflection is ~50x harder than before 2023
- In 2012, JPL did a full study to answer the key question:
  - If we wait until AG5 is observable again, and it turns out to be on a collision course, is there enough time to design, build, launch and execute a deflection mission before it passes through the keyhole in 2023, a time span of possibly

Heliocentric Orbit of 2011 AG5

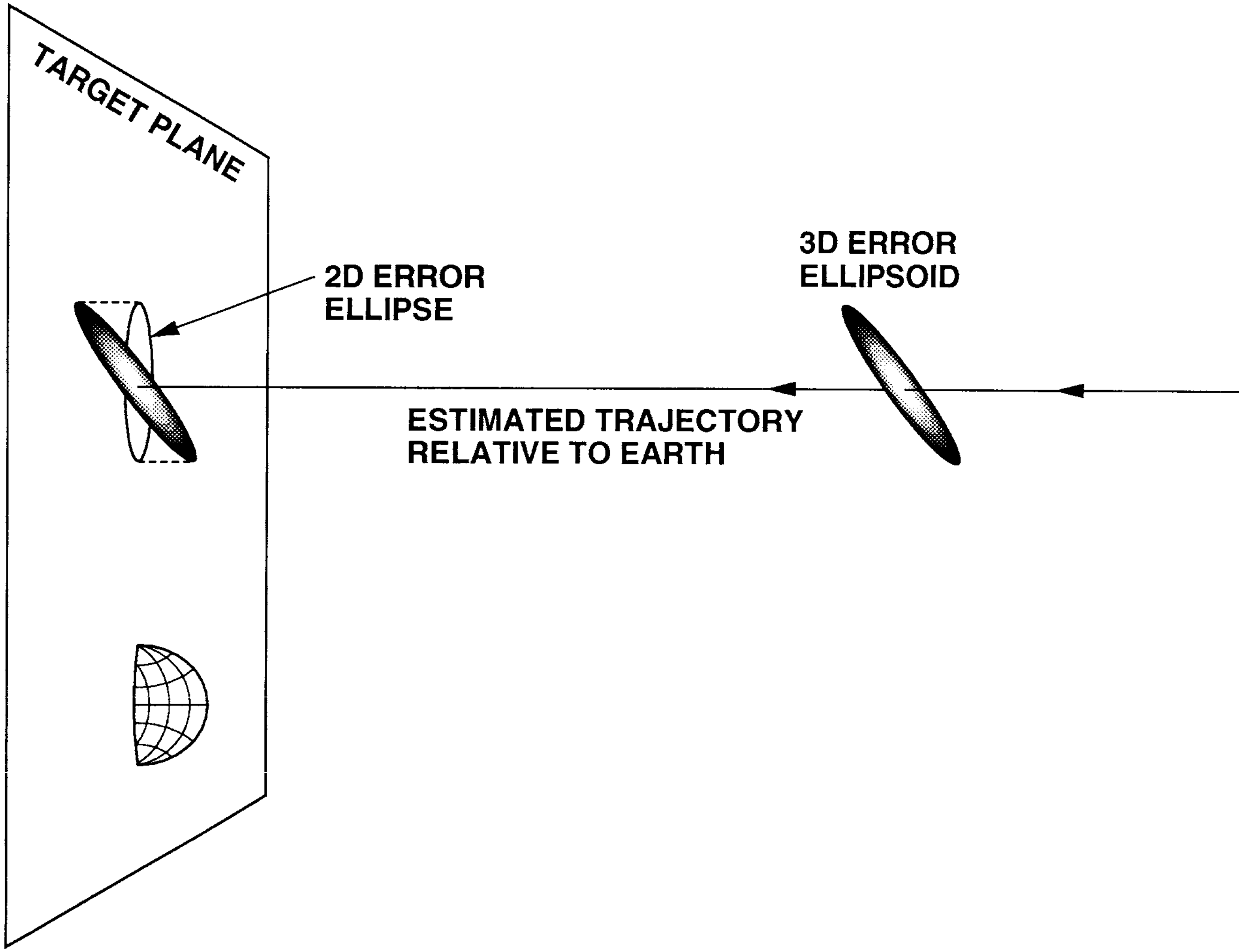


Impact Prob.: 1/500

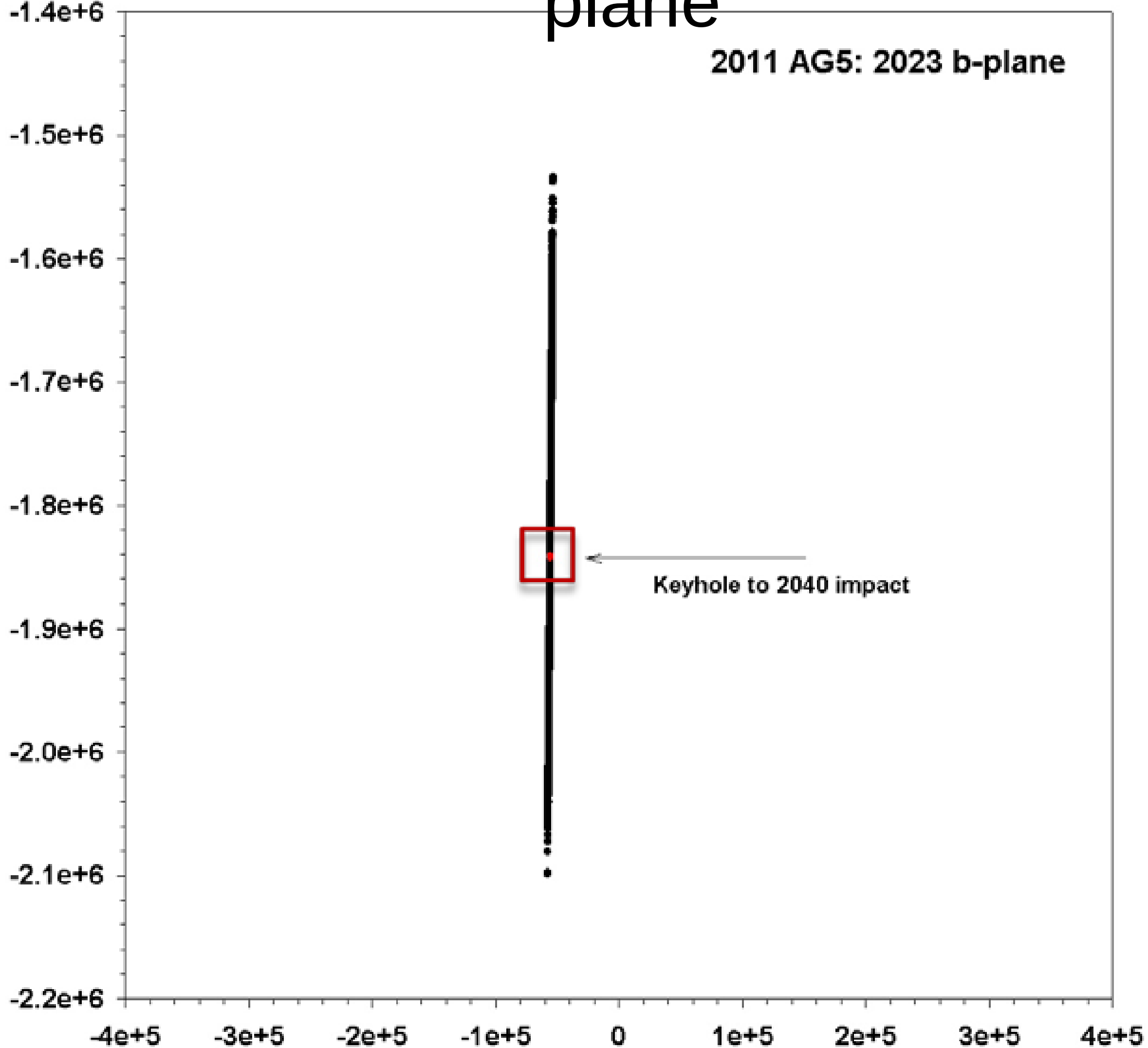


Uncertainty in 2011 AG5's position along its orbit on Feb. 5, 2040

Uncertainty Region at a Close Approach



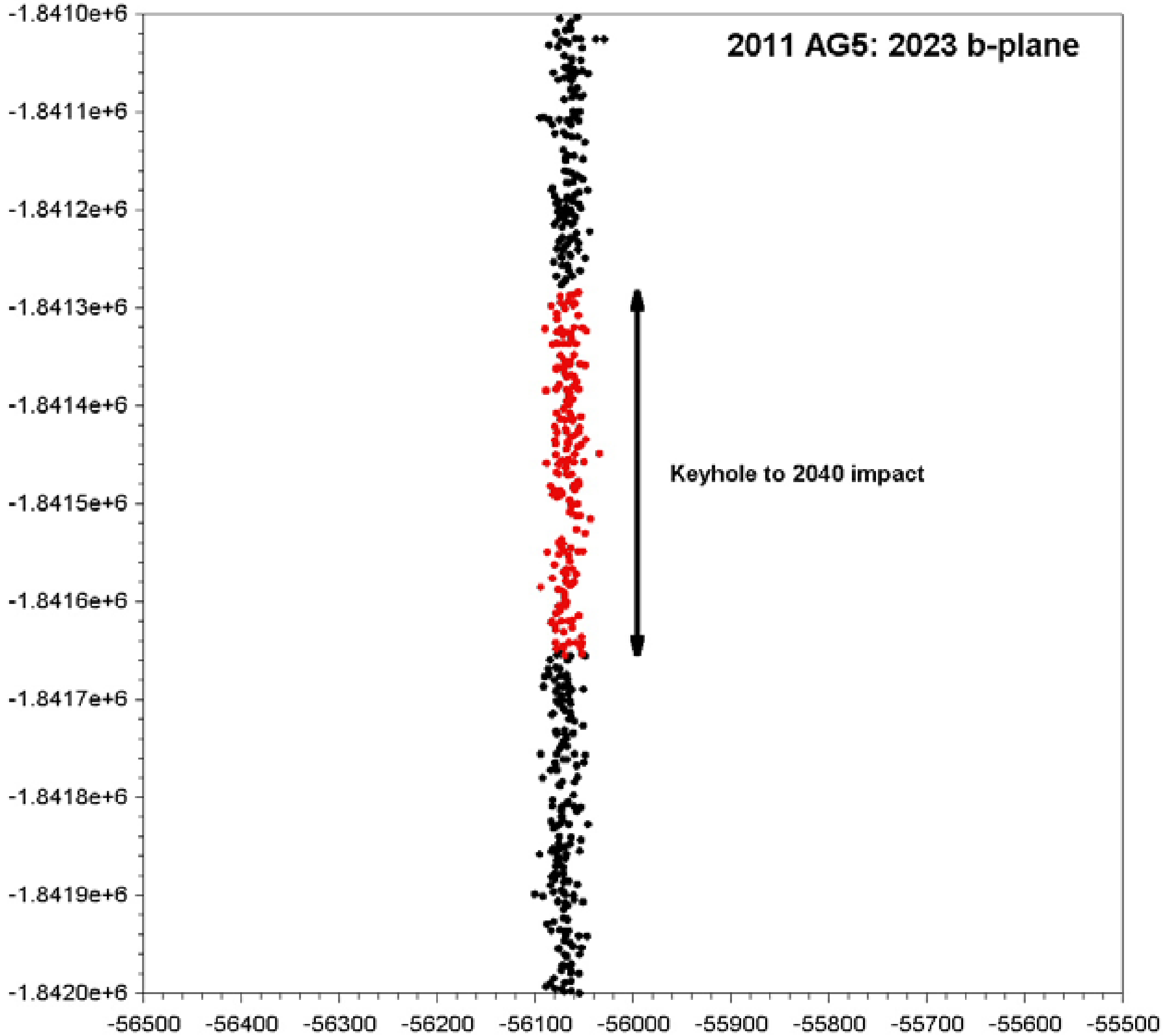
2011 AG5 Uncertainty Region in 2023 b-plane



10,000 Monte Carlo points trace the uncertainty region

Keyhole size: ~365 km

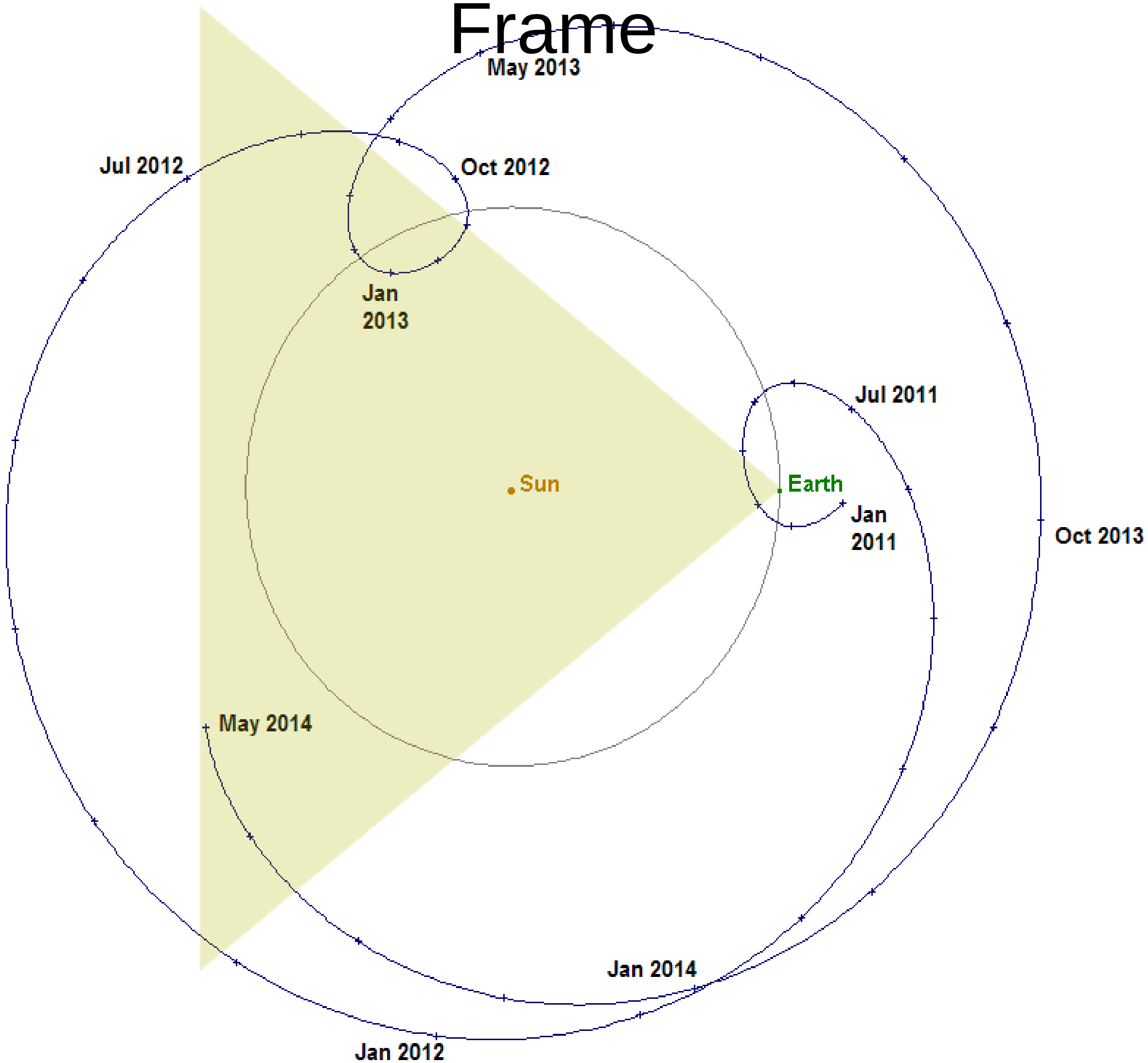
2011 AG5 Keyhole in 2023 b-plane



10,000 Monte Carlo points trace the uncertainty region

Keyhole size: ~365 km

Position of 2011 AG5 in a Rotating Reference Frame

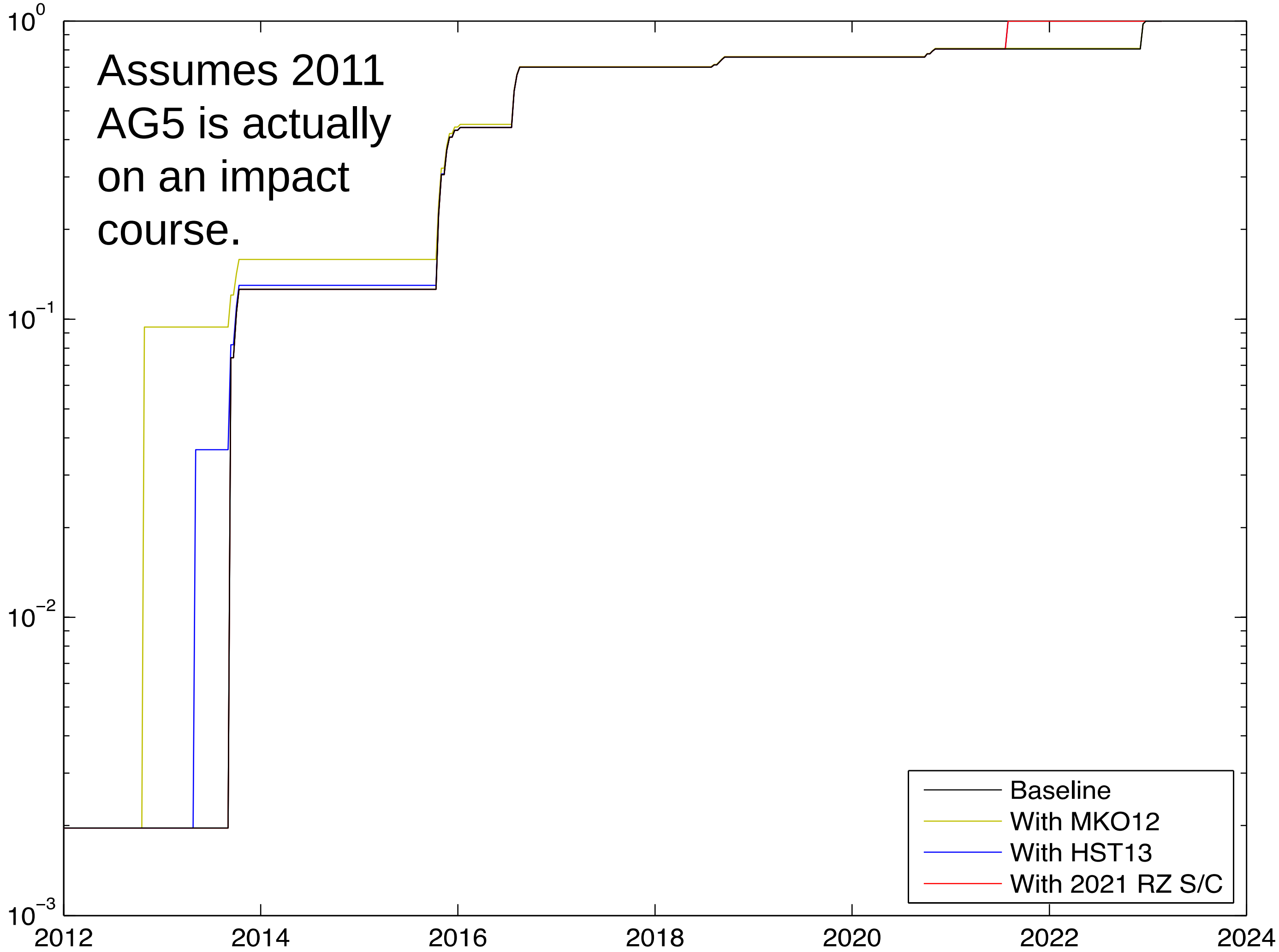


“Future” Observing Opportunities

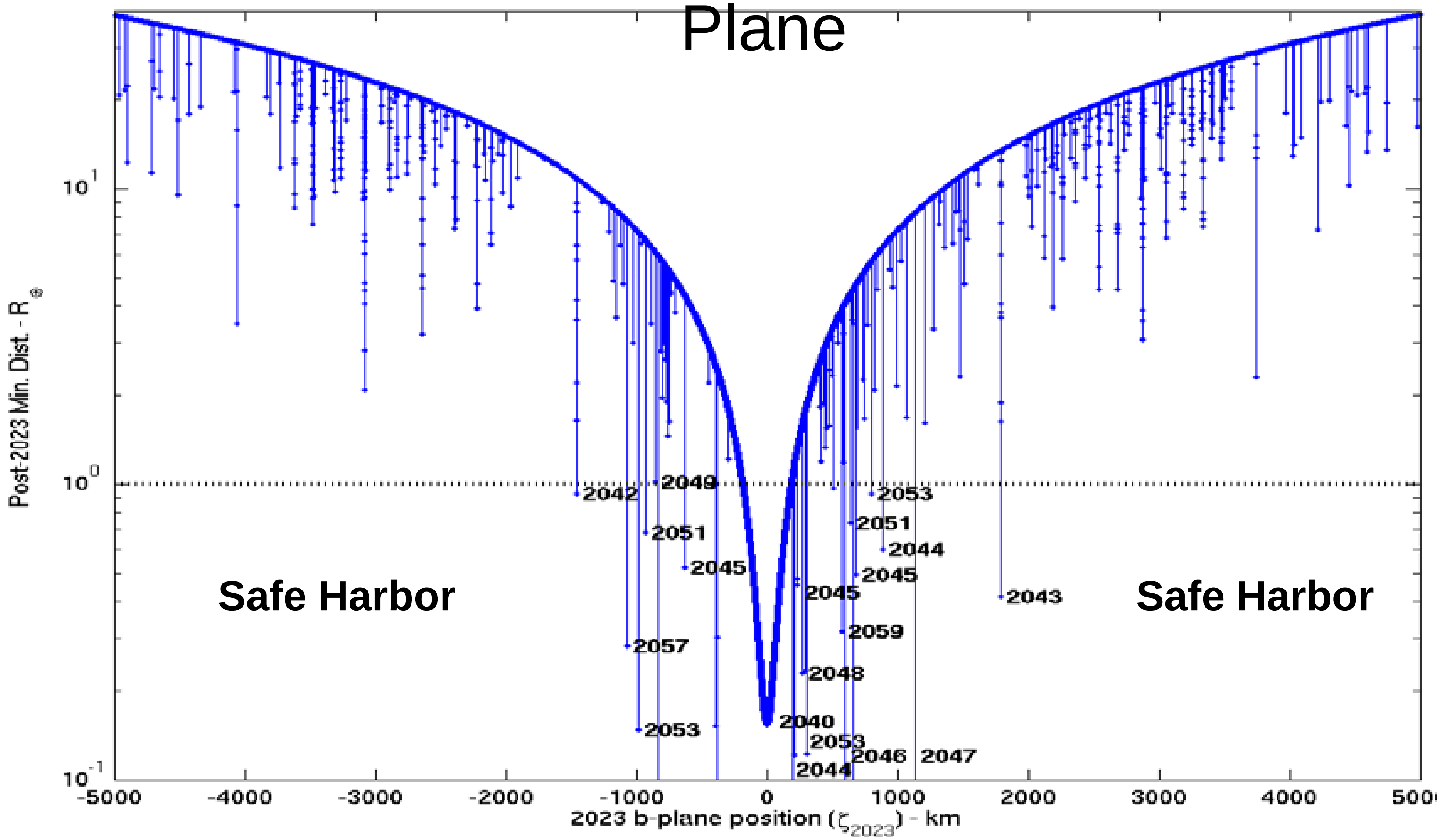
Date	Brightness (mag)	Solar Elong. (deg)	Remarks
Oct. 2012	24.5	42	Requires Keck. ‘MKO12’
Apr. 2013	25.5	50	Requires HST. ‘HST13’
Sep. 2013	23.6	175	Requires 2-4m aperture
Nov. 2015	22.9	170	Requires 2-4m aperture
June 2016	22.9	85	Requires 2-4m aperture
Sep. 2018	23.1	175	Requires 2-4m aperture
Oct. 2020	23.5	172	Requires 2-4m aperture
Feb. 2023	14.3	135	Radar Opportunity

- Oct. 2012 obs. require large aperture & favorable conditions
  - (In fact obtained by Tholen et al. using Gemini 8m and UH 2.2m)
- April 2013 HST observations
  - Would require advance characterization of star field
- “Normal” observations begin in Sept 2013
  - First observations likely in early August

Maximum Impact Probability vs. Time



Keyhole Map for 2011 AG5 in the 2023 B-Plane

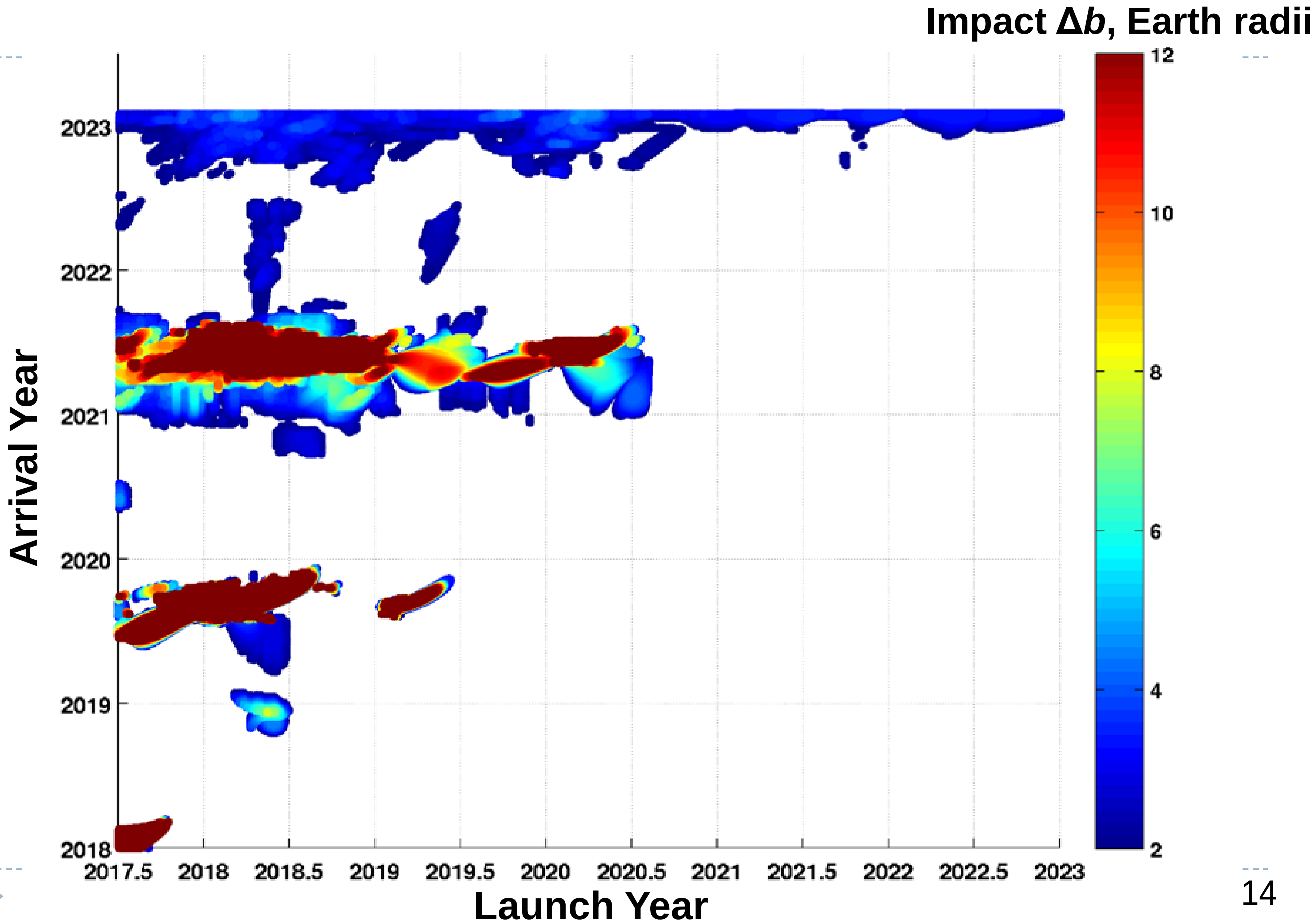


- Secondary keyholes exist but are < 100 m down to a few meters wide.
- Safe harbor zones: -8,000 km to -1,500 km on left & +2,00 km to +12,00 on right
- Left safe harbor is preferred because it corresponds to front side impact by S/C

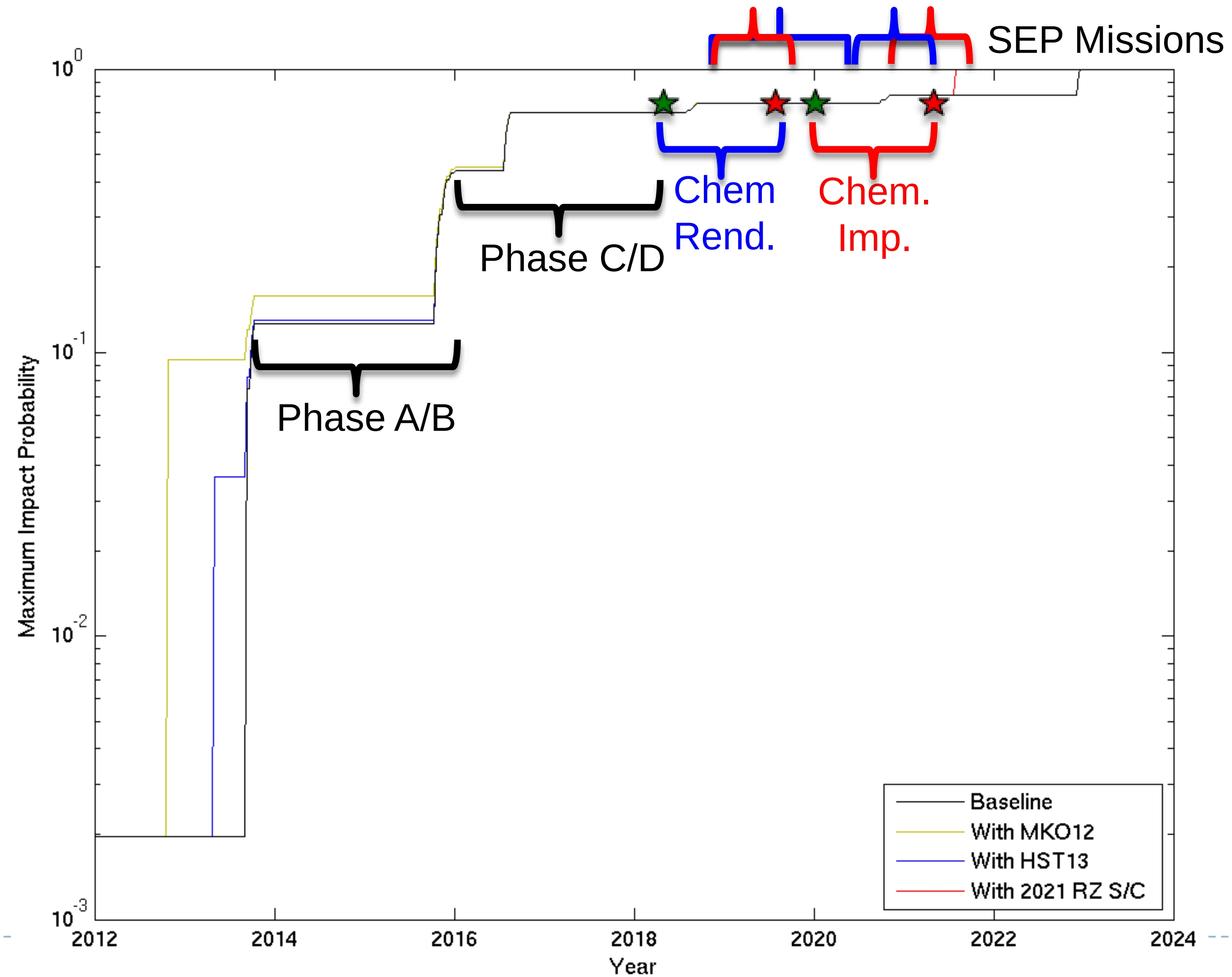
Deflection Campaign (see poster by Damon Landau)

- Kinetic impactor deflection with observer spacecraft
  - Examine both chemical & solar electric propulsion (SEP) missions
  - Require precursor rendezvous spacecraft arriving >2 months before impactor to aid targeting and confirm successful deflection
- Tune spacecraft mass to obtain the desired deflection
  - $\Delta V = \beta/M \times V_\infty \times m$
    - Β is the momentum enhancement due to impact ejecta (likely range: 1 to 4)
    - M is the mass of the asteroid
  - Take safety factor of 10 on β/M, and so strive for >10 R_E deflection
  - But if β/M is much higher than expected could lead to a deflection approaching 100 R_E
- Without early reconnaissance it may be impossible to ensure that deflection moves asteroid to a “safe harbor” (8-

Pre-Keyhole Deflection Options Atlas V (401)



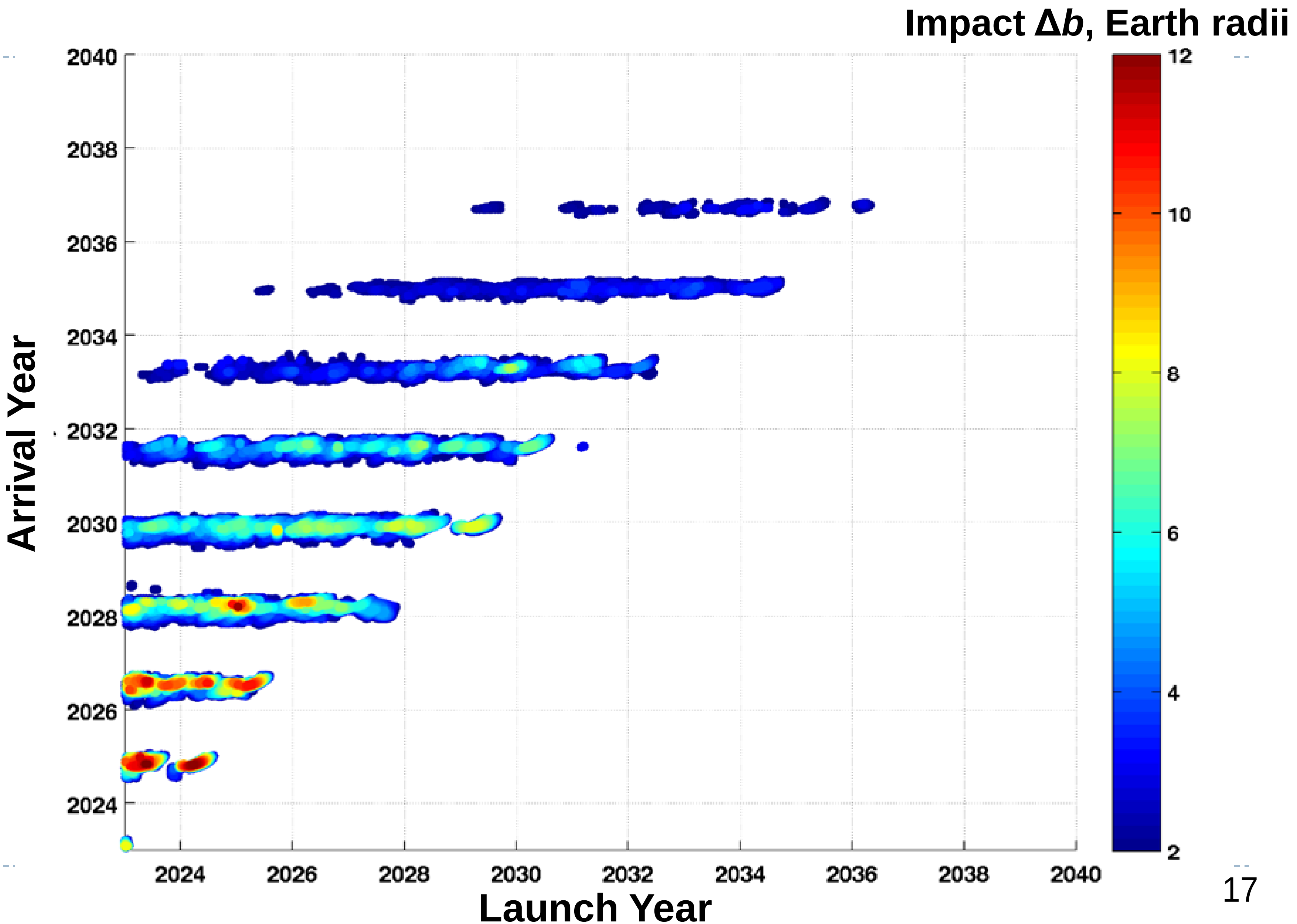
Mission Timelines



Post Keyhole Mission Designs

- Post keyhole missions are ~50 more challenging but there are viable rendezvous/deflection options after 2023 that could be carried out with existing launch vehicles
  - Backup in case pre-keyhole missions unsuccessful
  - Both chemical and SEP propulsion options are available

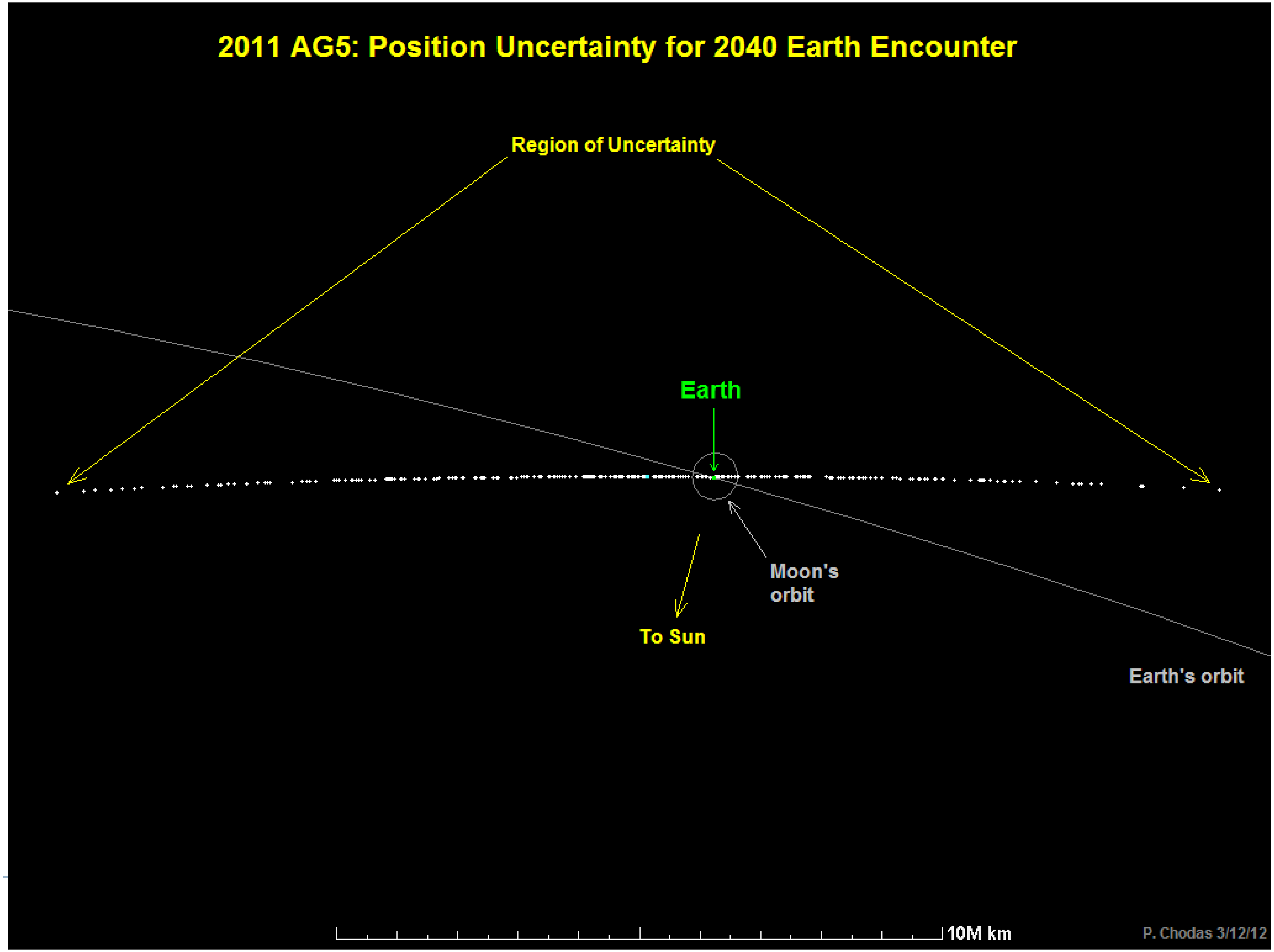
Post-Keyhole Deflection Options (Delta IV Heavy)



Key Conclusions from the 2012 Report:

- If 2011 AG5 really is on an collision trajectory, the next observations will cause the impact probability to jump to ~10% or more
- In the unlikely case where the 2012/2013 observations do not eliminate the potential hazard, there is time to plan and carry out a pre-keyhole rendezvous and deflection mission from that point.
- There exist numerous viable rendezvous/deflection mission options both **before** and **after** keyhole in 2023
- The full report is available online:
  - http://neo.jpl.nasa.gov

Postscript: Uncertainty Region Before 2012 Obs.



Postscript: Uncertainty Region After 2012 Obs.