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Post-Mitigation Impact Risk Assessment for Near-Earth Asteroid Deflection Demonstration Mission Concepts: AIDA and NEOTωIST

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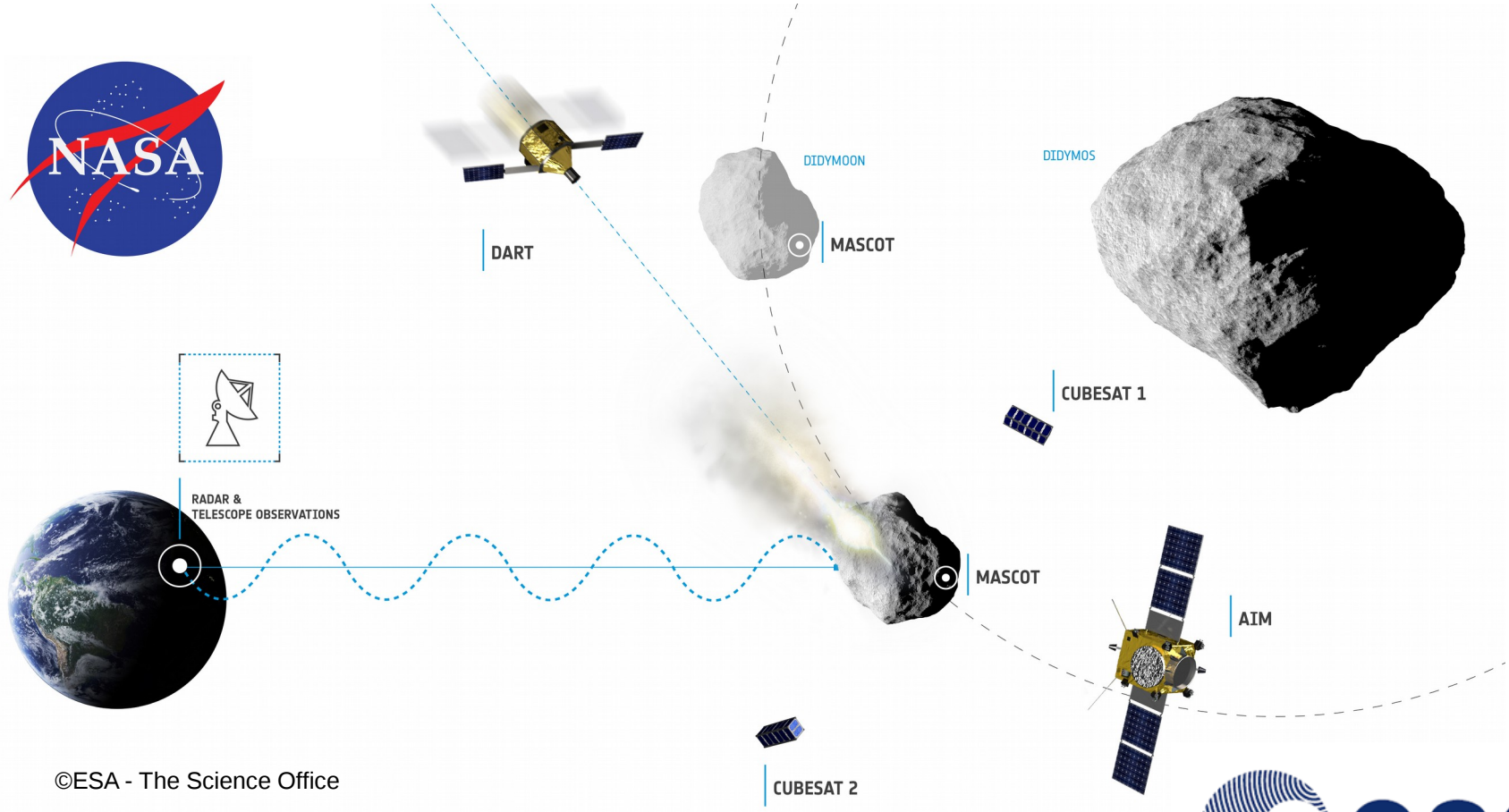
AIDA Concept : AIM + DART



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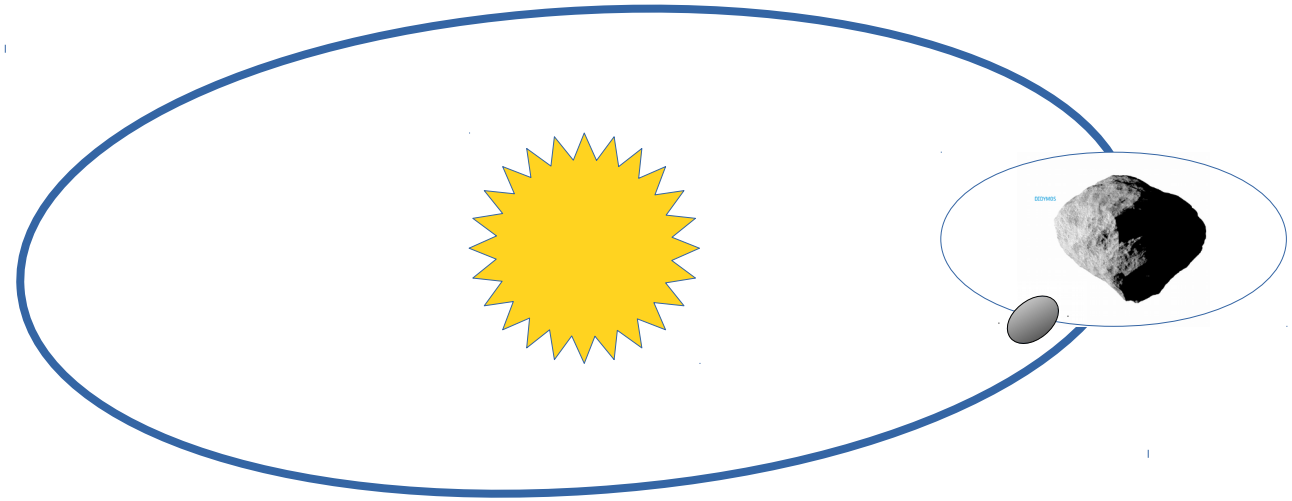
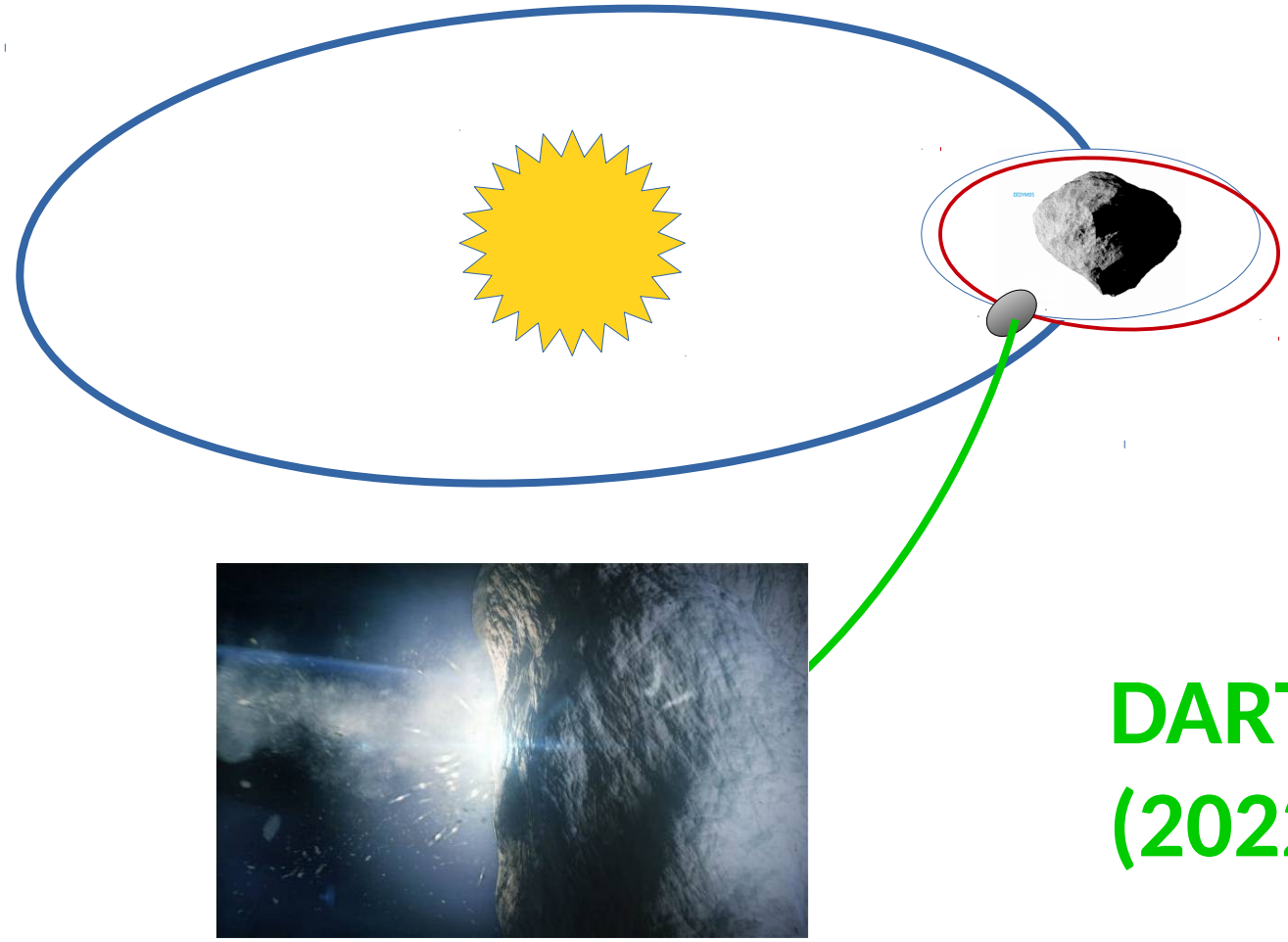
Pre-Decisional Information -- For Planning and Discussion Purposes Only

(65803) Didymos



What is Post Mitigation Impact Risk Analysis (PMIRA)?

DART changes orbits



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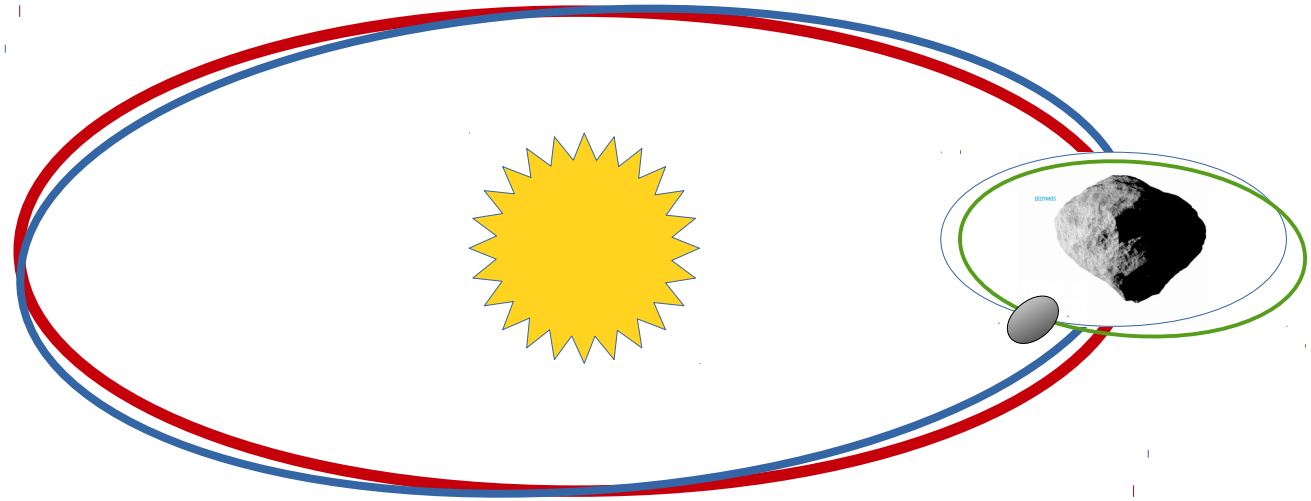
DART changes orbits

Adding momentum…



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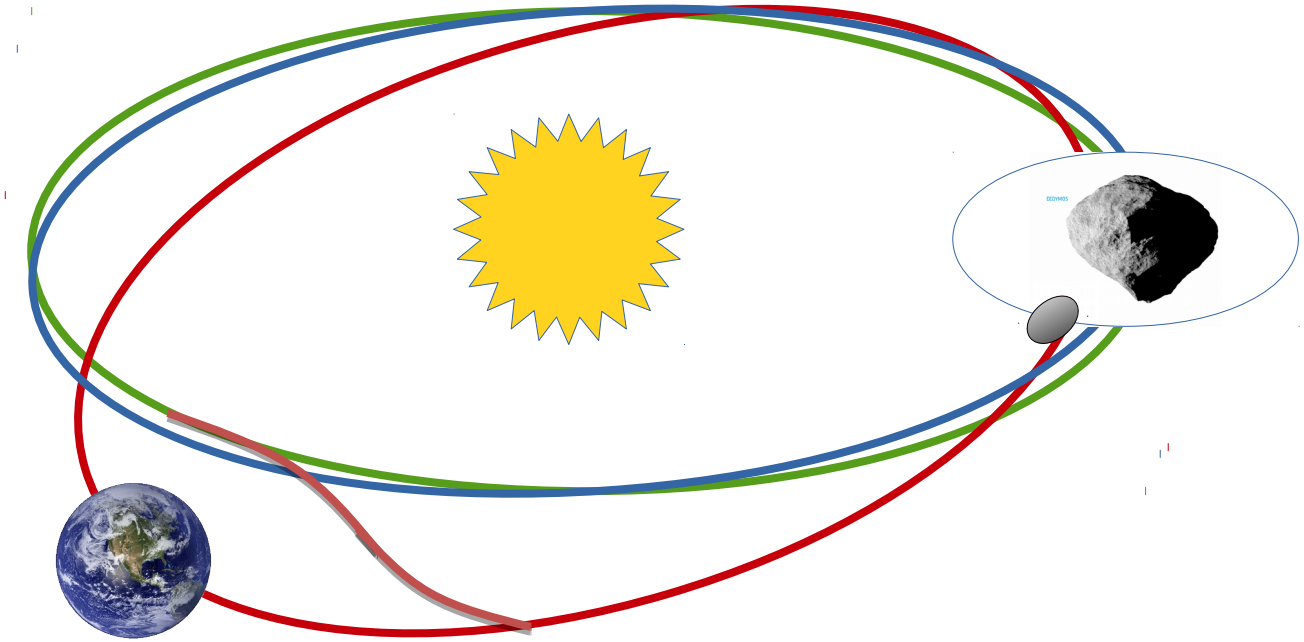
… changes HELIOCENTRIC orbit as well!

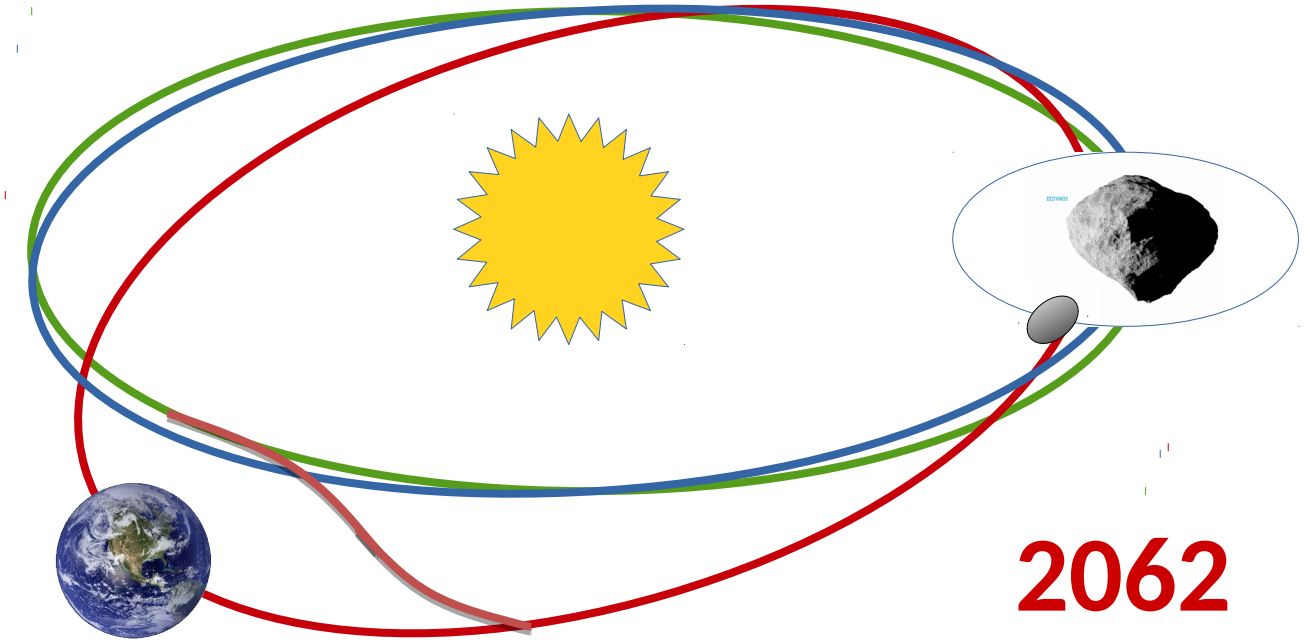
DART changes orbits



The new orbit

+ the dynamic near-Earth environment…

DART changes orbits



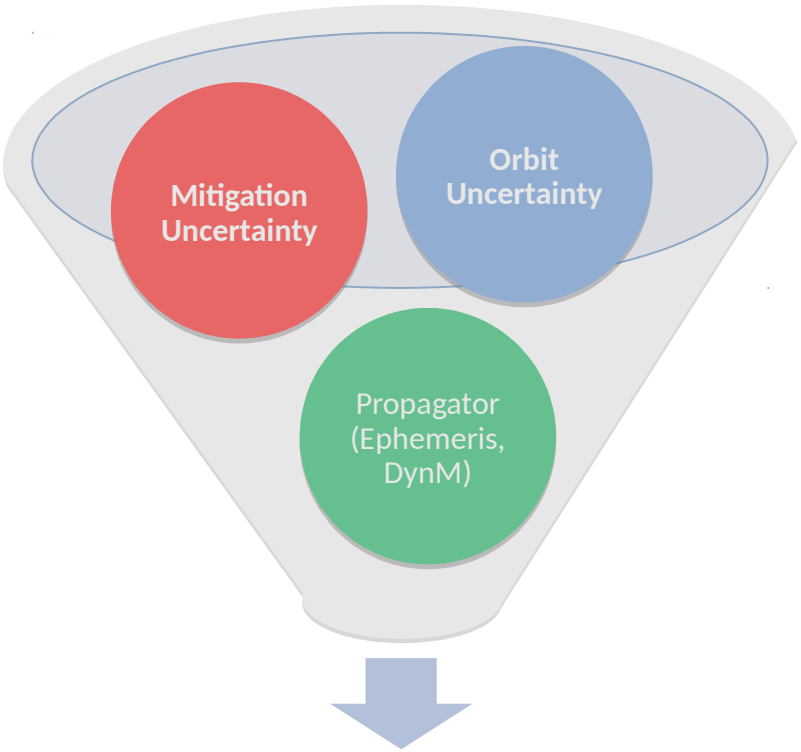
2062

… must not allow for a future collision with the Earth!

DART changes orbits

… must not allow for a future collision with the Earth!

Uncertainties



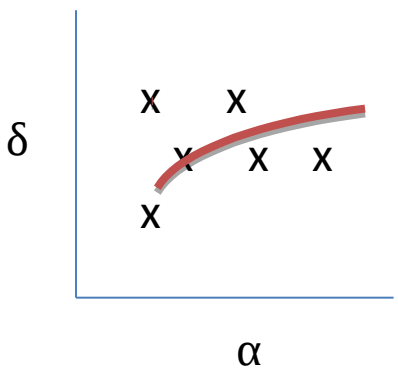
Post Mitigation Impact Probability

Relevant uncertainties:

- **NEO orbit**
- **Mitigation**
(physical properties, S/C)
- **Impact predictions**
(dynamical model, propagator, ephemeris)

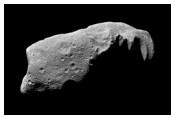
Orbit Uncertainty

Fit Orbit



Create Clone

$$a_1, e_1, \cdots$$



$$a_0, e_0, \cdots$$

Covariance matrix

$$\begin{pmatrix} \sigma_a^2 & \sigma_a \sigma_e & \cdots \\ \sigma_e \sigma_a & \sigma_e^2 & \\ \vdots & & \ddots \end{pmatrix}$$

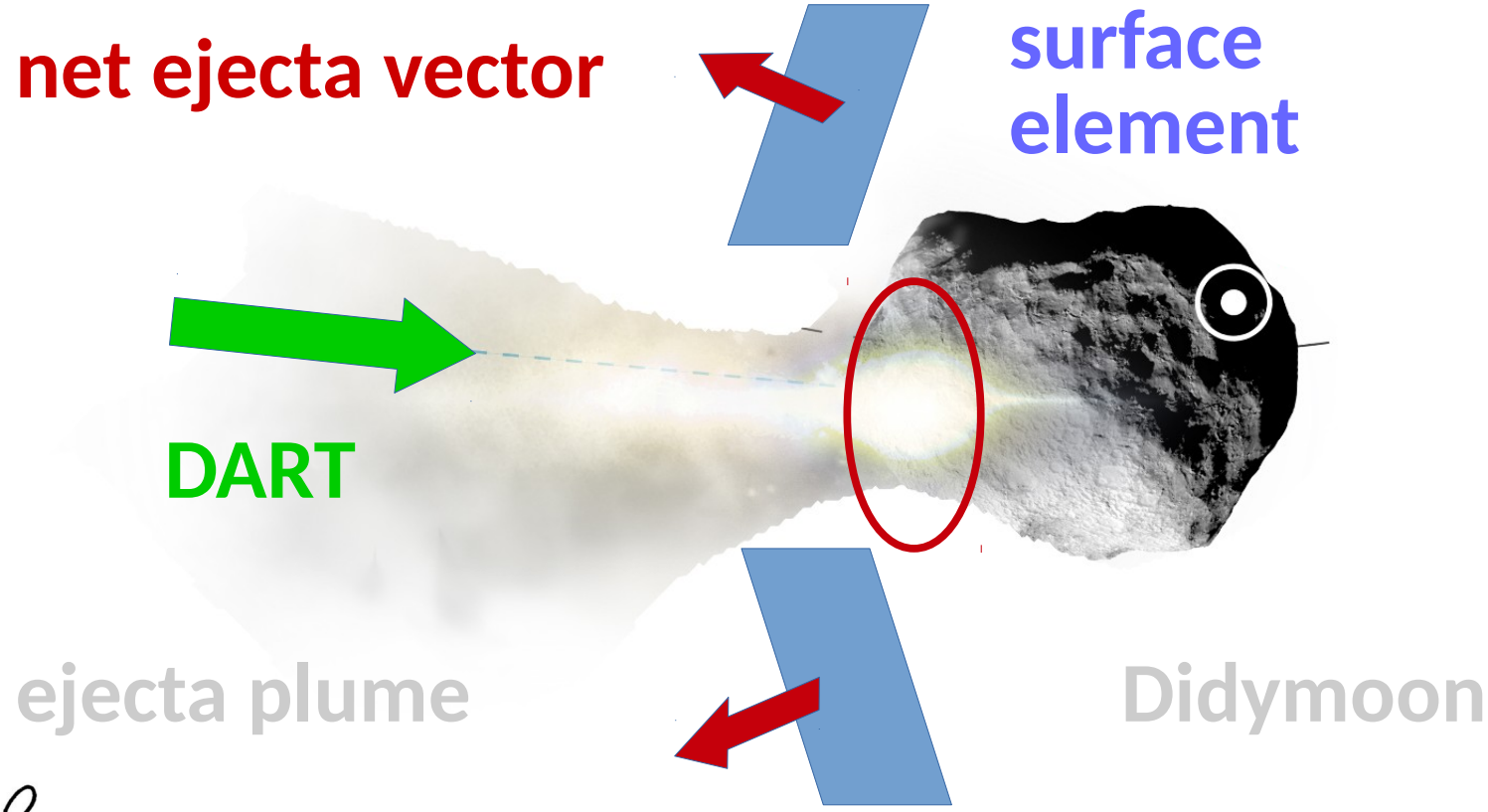
Eigenvalues (Weak Directions, Line of Variation, e.g. Milani et al. 2003)

$$\lambda_1 > \lambda_2 > \cdots$$

Momentum Transfer Uncertainties

$$\Delta\vec{V} \approx \frac{m}{M}[\mathcal{I} + (\beta - 1)\hat{n}\hat{n}]\Delta\vec{v}$$

Scheeres et al. (2015)

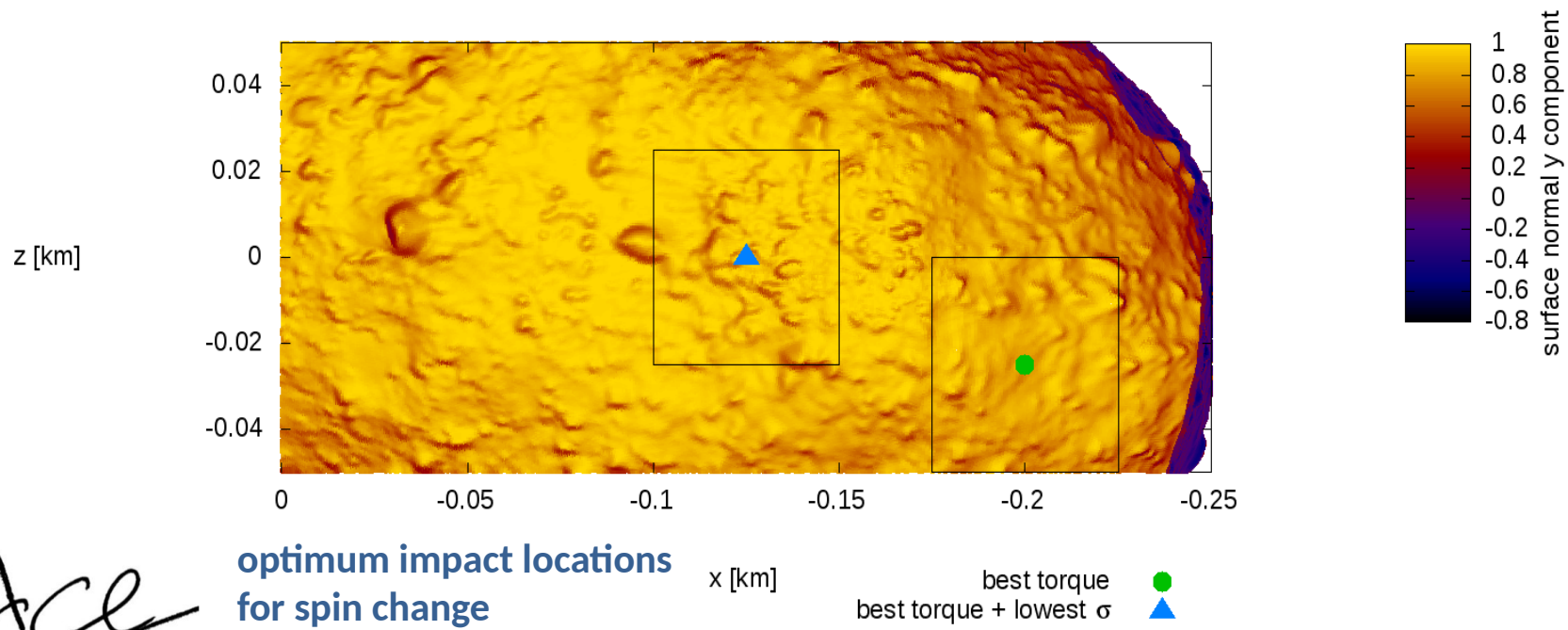


Surface Orientation Uncertainty

NEOTwIST (Drube et al. 2016, Eggl et al. 2016, Engel et al 2016)

Uncertainty in impactor GNC ~ 25 x 25m

Itokawa : uncertainty in surface normal orientation ~ 23°

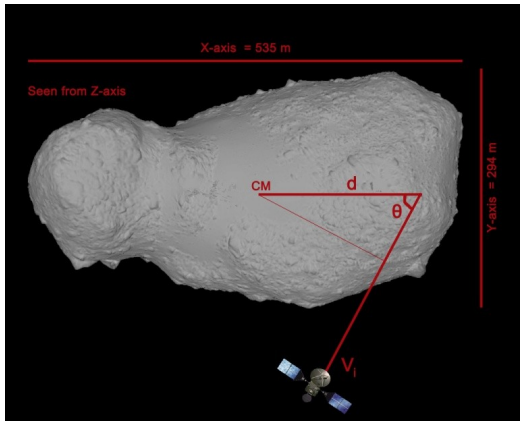


optimum impact locations for spin change

Deflection Parameter Uncertainty

$$\begin{pmatrix} \sigma_M^2 & \sigma_M \sigma_{\beta x} & \cdots \\ \sigma_{\beta x} \sigma_M & \sigma_{\beta x}^2 & \\ \vdots & & \ddots \end{pmatrix}$$

Mitigation Parameter (MP) uncertainty covariance matrices (mass, beta vector,...)



$$\begin{pmatrix} [OE] & \cdots \\ \vdots & [MP] \end{pmatrix}$$

MP + Orbital Element covariances (OE) (Spoto et al. 2014)

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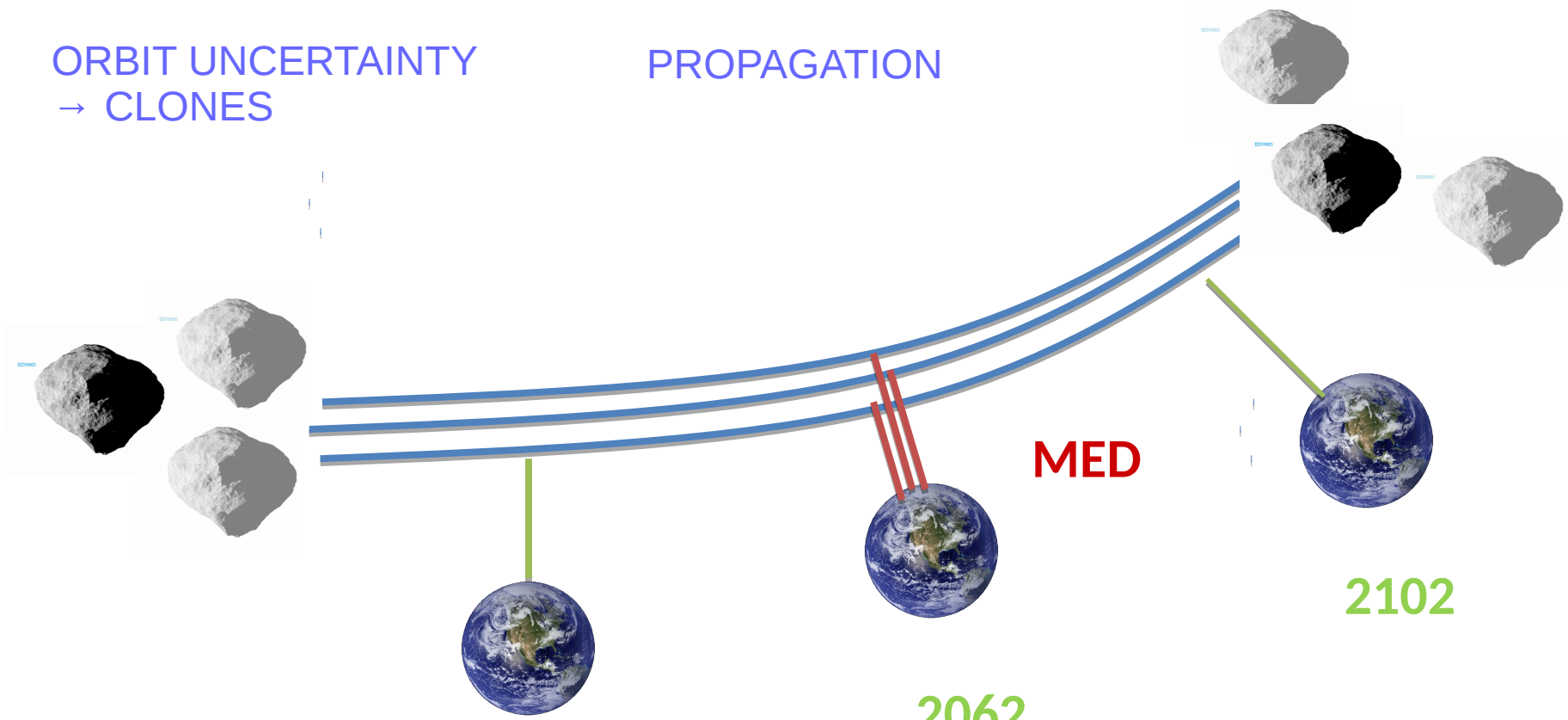
Find combined covariance (OE + MP) matrix and use LOV sampling.

Eggl et al. (2015a & b), Drube et al. (2016) NEOTwIST

Orbit Uncertainty Propagation

ORBIT UNCERTAINTY
→ CLONES

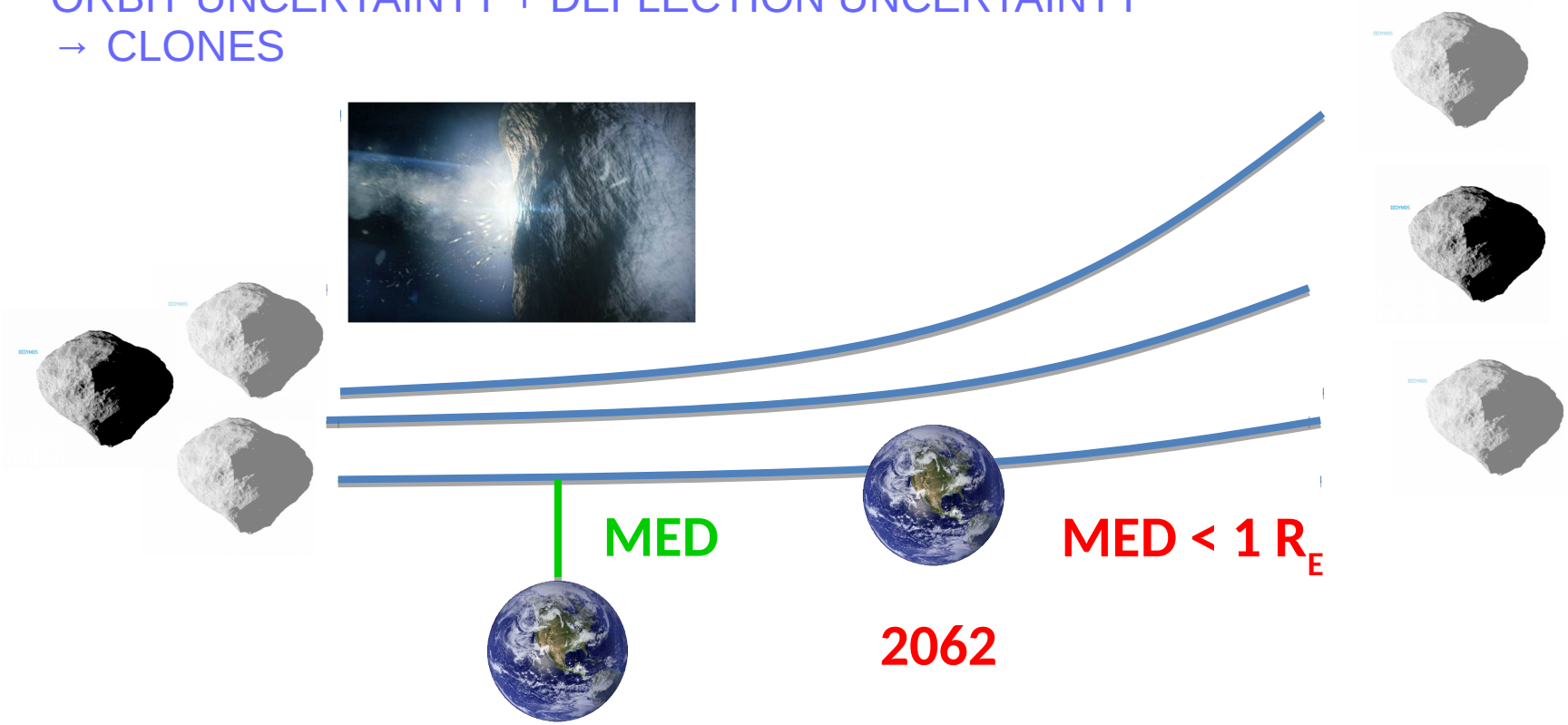
PROPAGATION



MED… Minimum Encounter Distance

Post Mitigation Impact Risk Assessment

ORBIT UNCERTAINTY + DEFLECTION UNCERTAINTY
→ CLONES



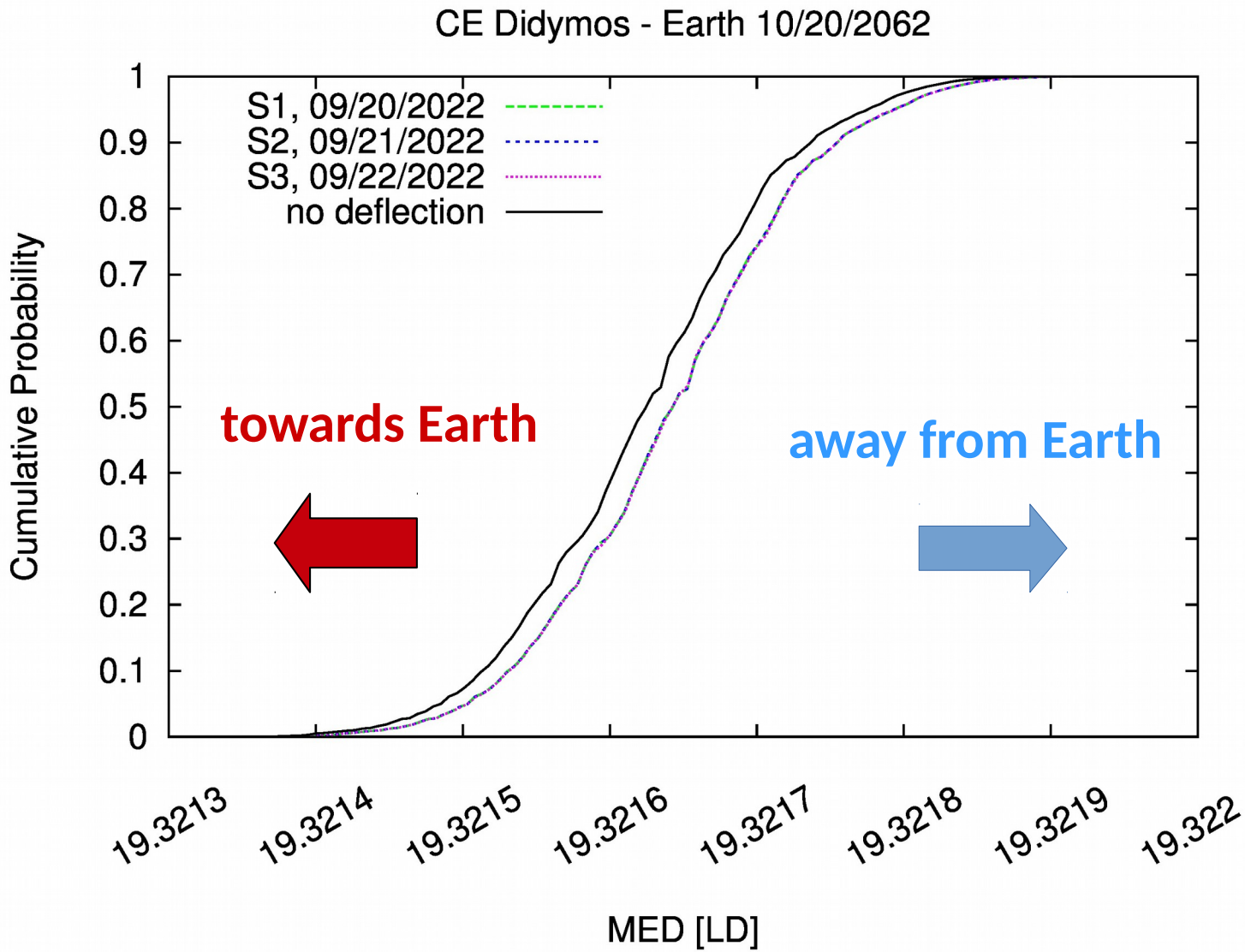
MED… Minimum Encounter Distance

Didymos System Properties

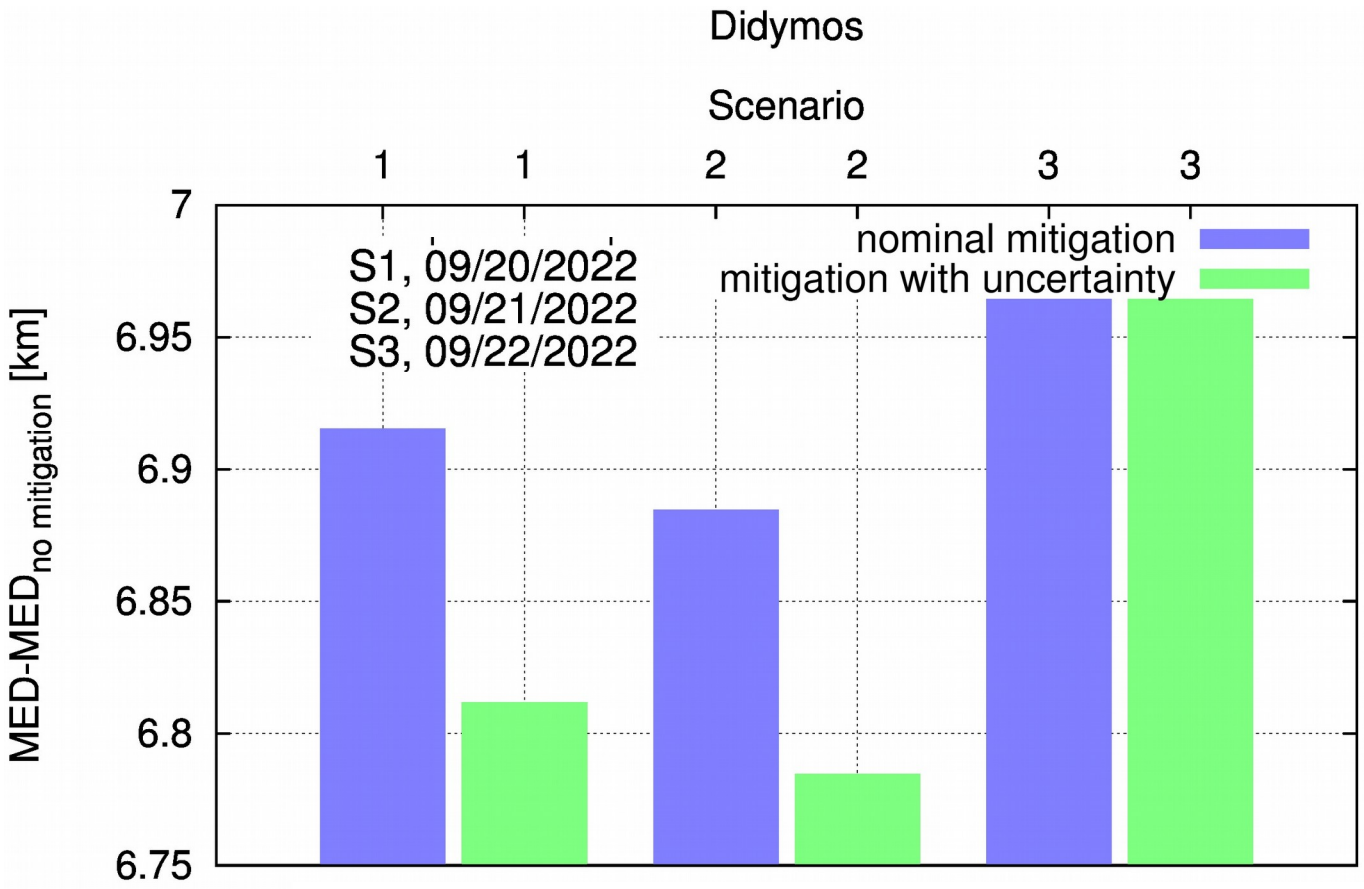
Parameter	Uncertainty / Range
Orbit	JPL SPK-ID: 2065803, 2015-Jun-04 18:20:59
Impact time	± 1s
Mass of Didymos system	3.66 – 6.89 x 10^{11} kg
Mass of impactor	200 - 400kg
BETA	**1 – 5 (?)**
Sufrace normal orientation	± 23° (Itokawa)

Minimum Encounter Distance

to Earth

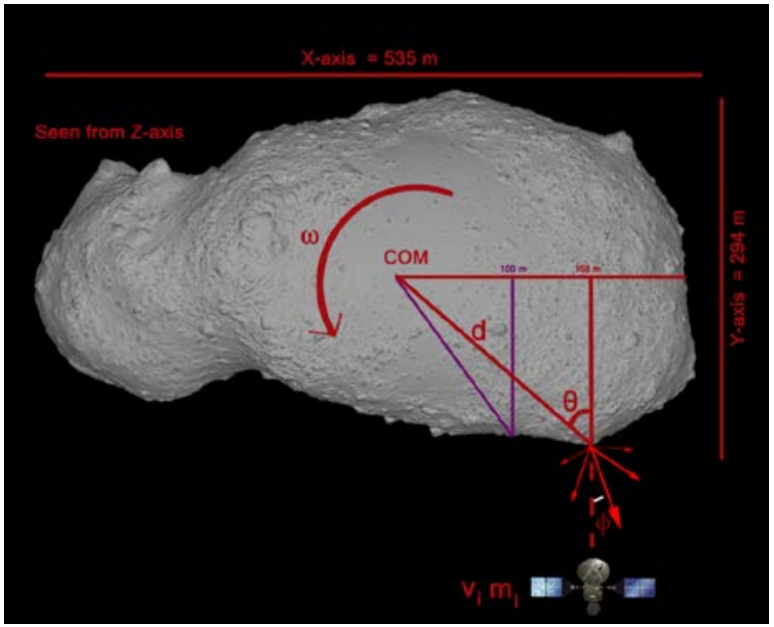


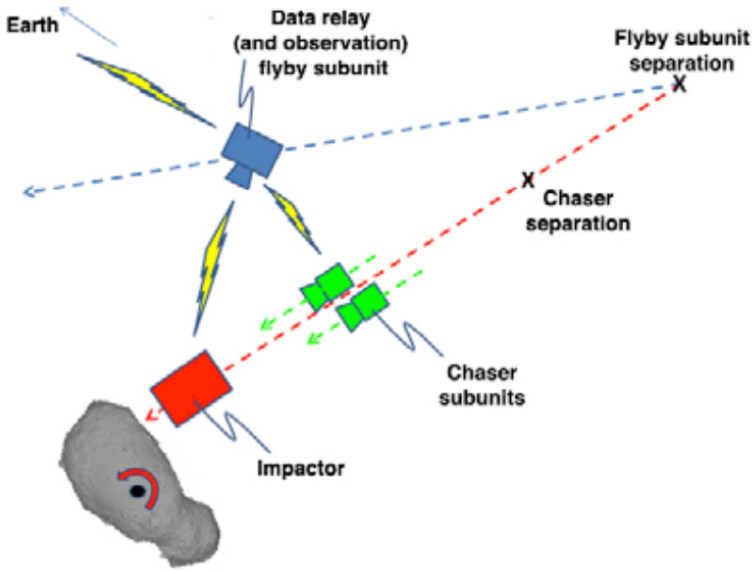
Different Impact Dates



Change the spin-state of (25143) Itokawa

(Drube et al. 2016, Eggl et al. 2016, Engel et al. 2016)



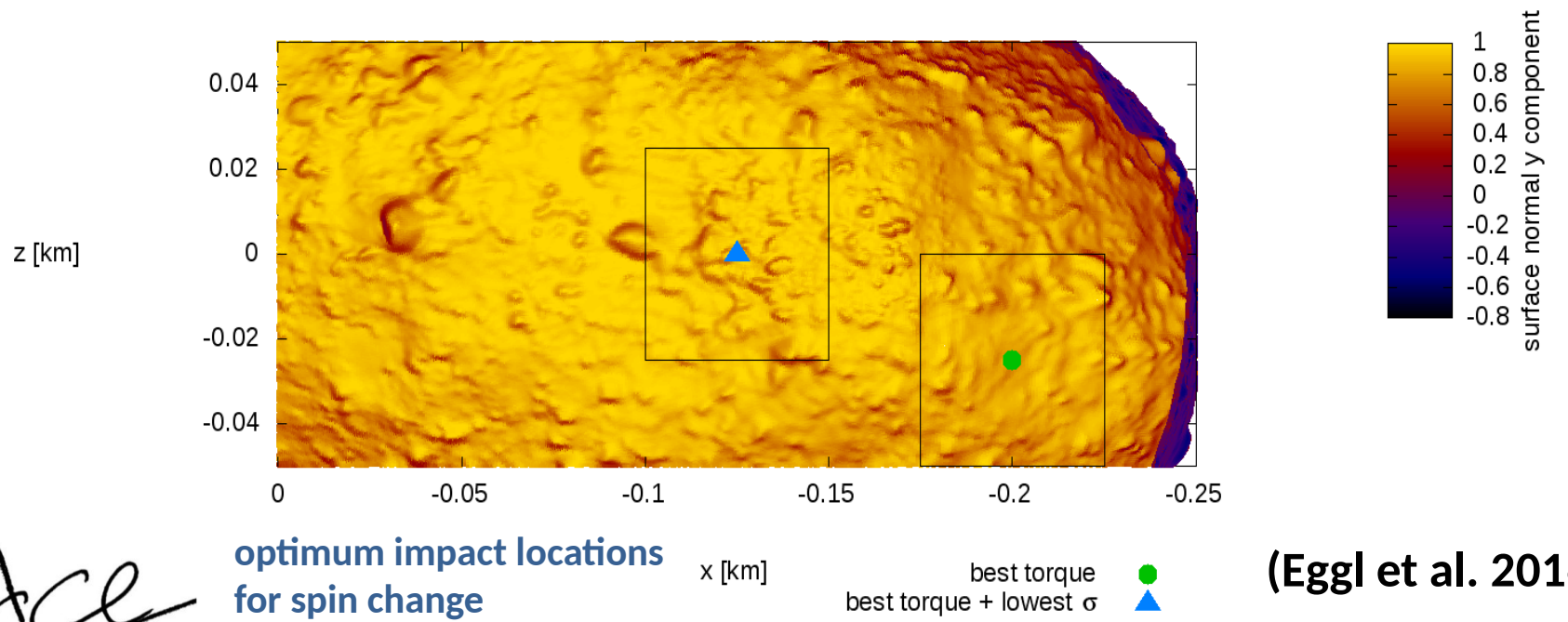


NEOTωIST

Surface properties :

Uncertainty in impactor GNC ~ 25 x 25m

Itokawa : uncertainty in surface normal orientation ~ 23°

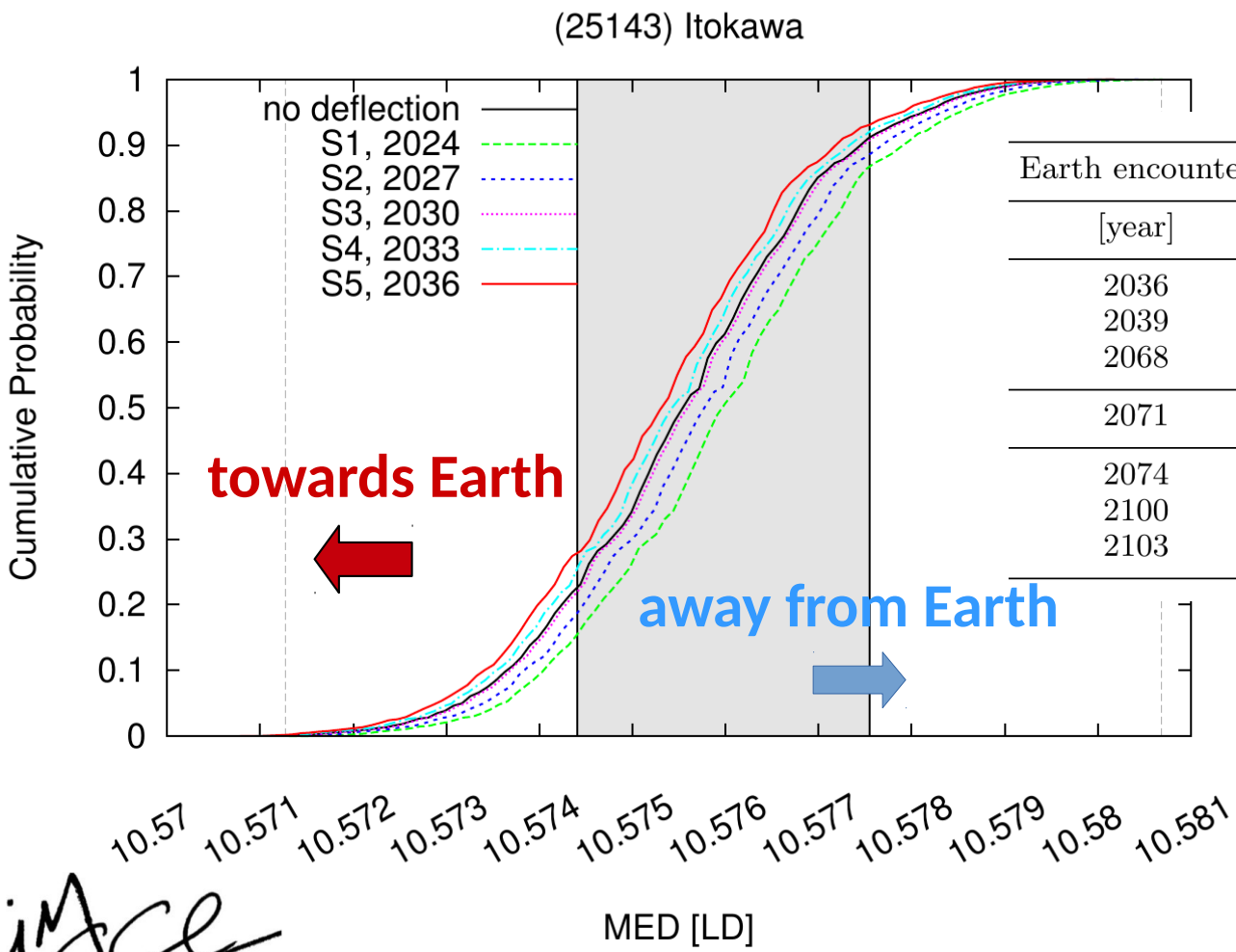


optimum impact locations for spin change

(Eggl et al. 2016)

NEOTωIST

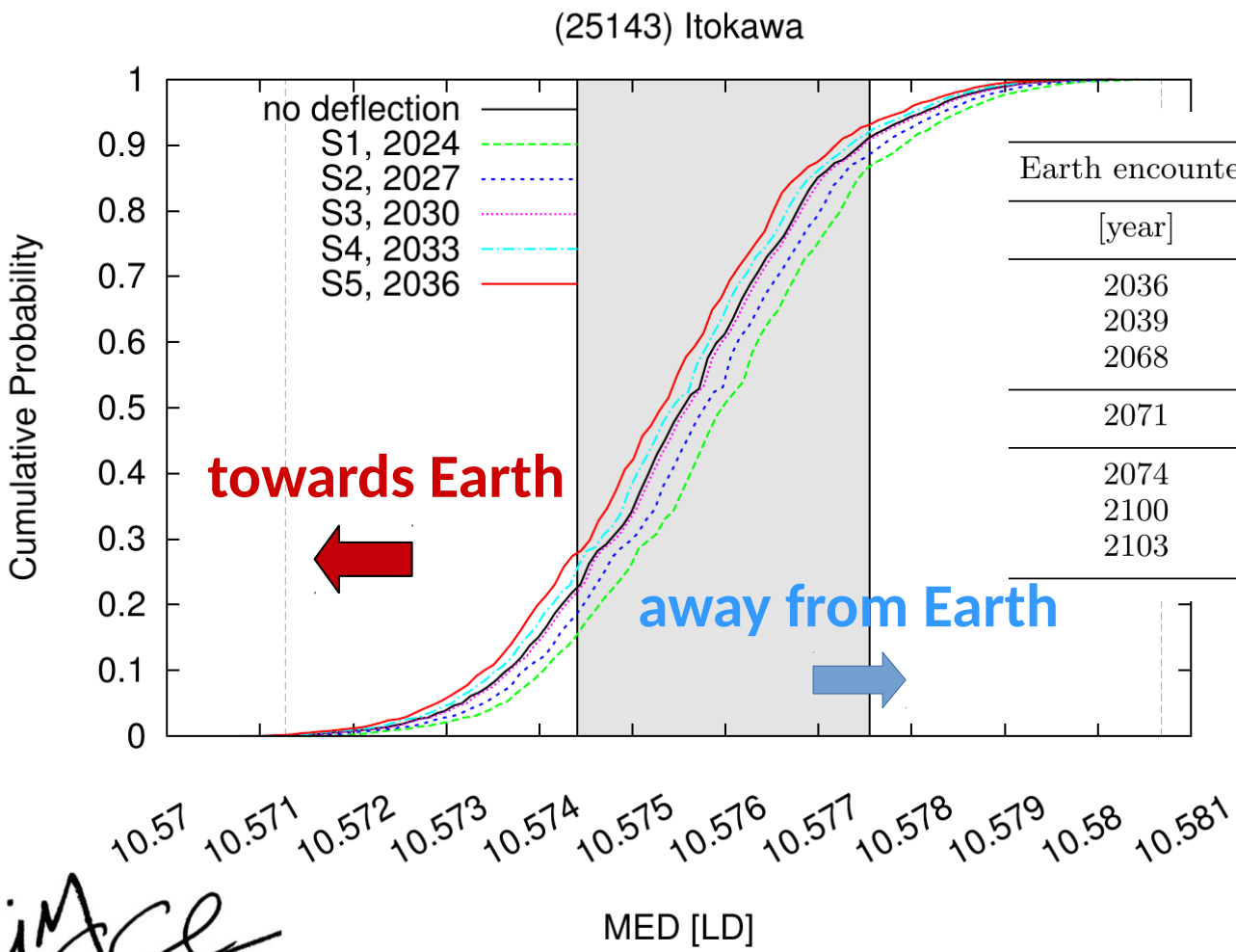
5 misson scenarios with impact dates between 2024 and 2036 (Eggl et al. 2016)



Earth encounter	d_{nom}	Δ MED [km]				
[year]	[au]	S1	S2	S3	S4	S5
2036	0.041	10	10	10	1	-/-
2039	0.185	-55	-51	-51	-37	-28
2068	0.228	-472	-241	-40	119	0
2071	0.027	70	62	29	-72	-165
2074	0.047	401	401	96	-218	-505
2100	0.128	915	915	208	-505	-1158
2103	0.045	450	450	242	-149	-522

NEOTωIST

5 misson scenarios with impact dates between 2024 and 2036 (Eggl et al. 2016)



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Discussion

- Parameter uncertainty range conservative enough (β<5)?
- Surface and net ejecta momentum VECTOR properties?
- Ejecta SYSTEM escape time (long term acceleration) ?
- Trajectory updates

Conclusions

- **Uncertainties** in Kinetic Impactor mission concepts are **acceptable**, as long as consequences can be quantified. > PMIRA

- AIDA concept > **PMIRA : Dart impact 'safe'** (trajectory updates ?)

- NEOTωIST concept **> PMIRA : selection of 'safe' mission scenarios**