Quantifying low NEO impact probabilities in the NEOShield project

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SEVENTH FRAMEWORK PROGRAMME

NEOShield Aims

Develop a Deflection Demonstration Mission!

ASTRIUM
AN EADS COMPANY

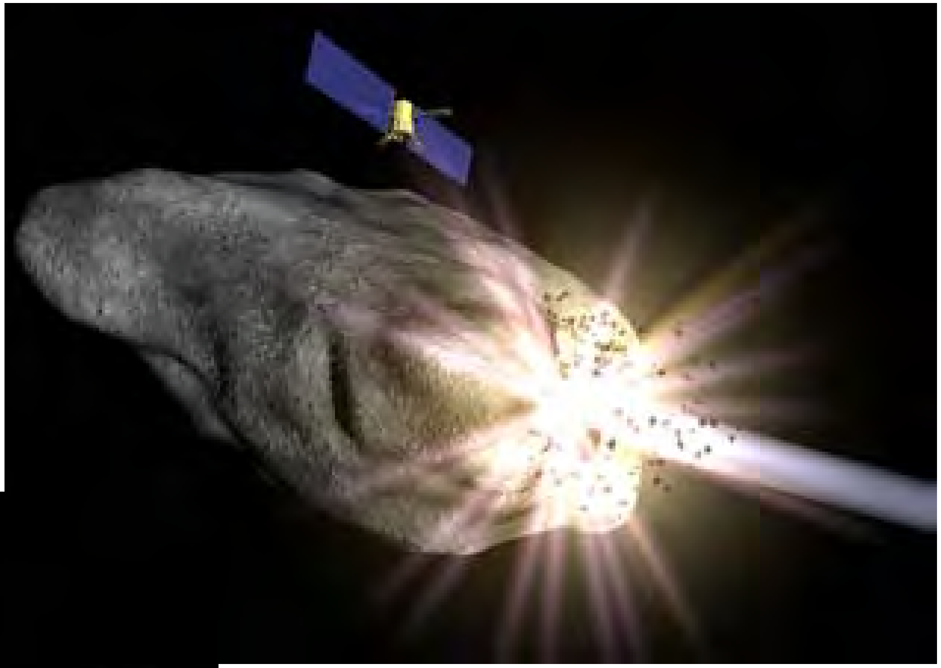
elecnor
deimos

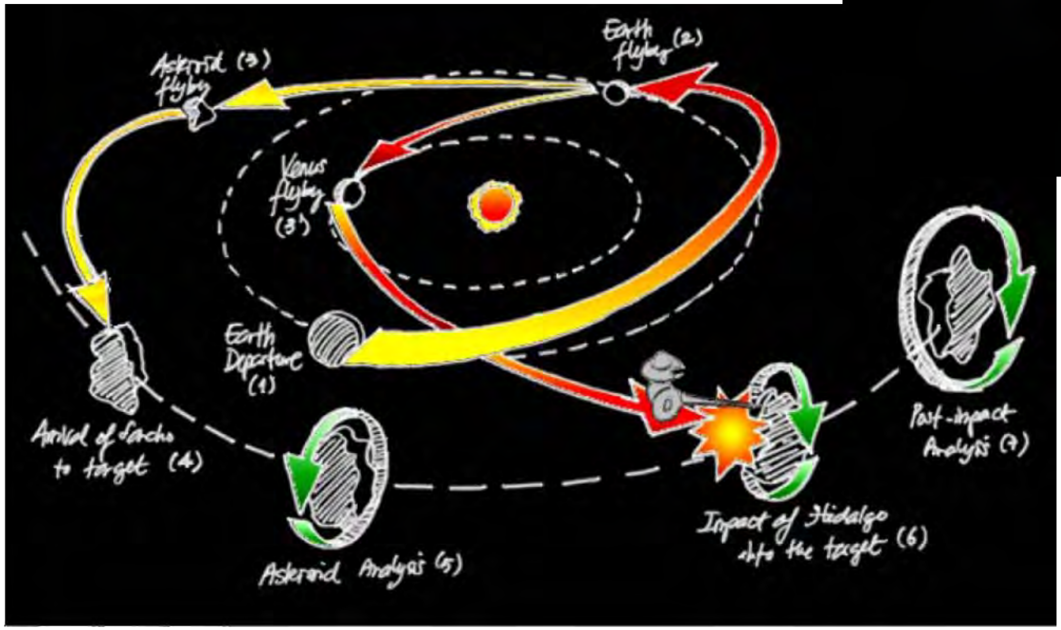
SURREY
SPACE CENTRE

Deflection Demo Mission

DON QUICHOTE

(e.g. Belló et al. 2003)
combined orbiter + KI
single asteroid
orbit deflection





Why bother?

A lot of uncertainty…

mission related (e.g. GNC)

NEO properties (β)

$$\Delta v_a = \beta \frac{m_s}{m_a} \Delta v_s$$

Physical Properties - Uncertainties

	1998 VO	2001 JV1	2001 QC34
H [mag]	20.4	21.4	20
Spectral Class	S	Sq	Q,O
D [m]	242-542	148-330	300-670
ρ [g/cm³]		1.5-3	
M [kg]	**7x10^9 – 2x10^11**	**10^9 – 5x10^10**	**10^10 - 5x10^11**
β		1-12*	
MOID [LD]	10.6	8.8	11.4

$$\Delta v_a = \beta \frac{m_s}{m_a} \Delta v_s$$

* Holsapple & Housen (2012)

KI Demonstrator

Where will the asteroid end up?

•Evaluate orbit + mitigation uncertainties at the time of KI impact.

•Propagate the uncertainties 60-100 yrs into the future.
(RA15, DE421 + relevant perturbing asteroids + GR)

•Evaluate closest encounter distances of discrete phase space samples and determine associated impact probabilities.

Orbit Uncertainties

Theory of Risk assessment given orbit uncertainties is well established (e.g. Milani et al. 2002, 2005)

→Line of Variation sampling initial uncertainty covariance matrix

→Virtual Asteroids (Clones)

→Numerical propagation of Clones

→ Risk assessment via associated probabilities of Earth impactors

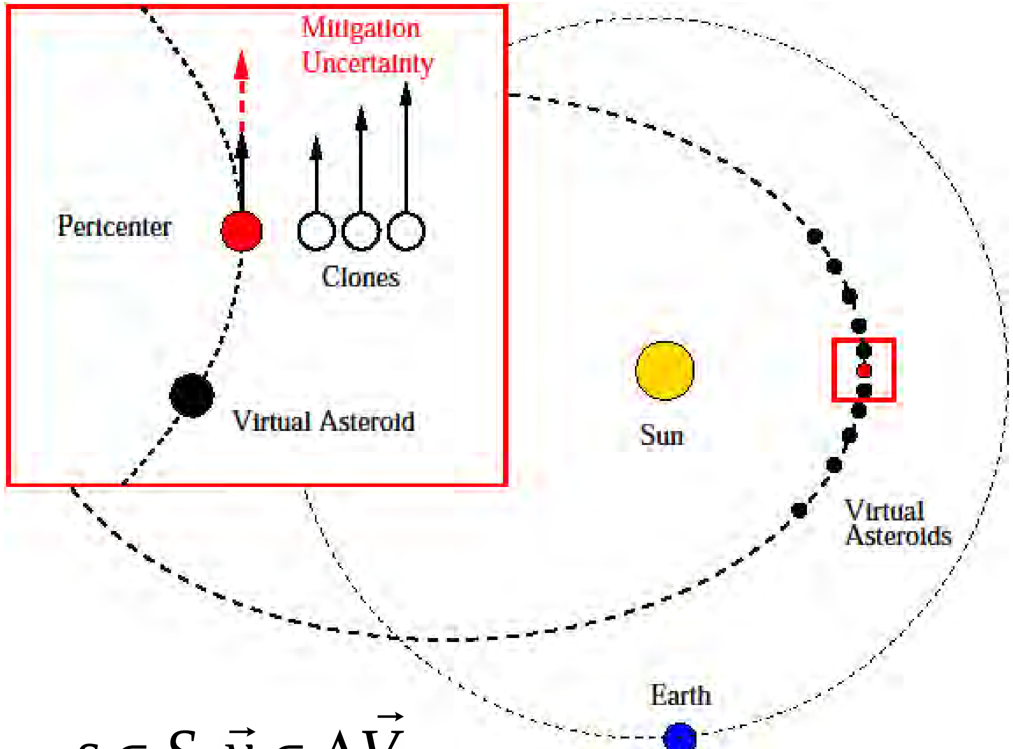
Impact probabilities for 2011 AG5 (obs data 2011)			
NINE (spline MED)	**NIRAT**	**JPL**	**CLOMON2**
1/592	1/625	1/581	1/552

Mitigation Uncertainties: Monte Carlo

Orbit + Mitigation Uncertainties:
Impulsive deflection (kinetic impact/blast)

Additional clones are produced mirroring the uncertainties during the deflection process.

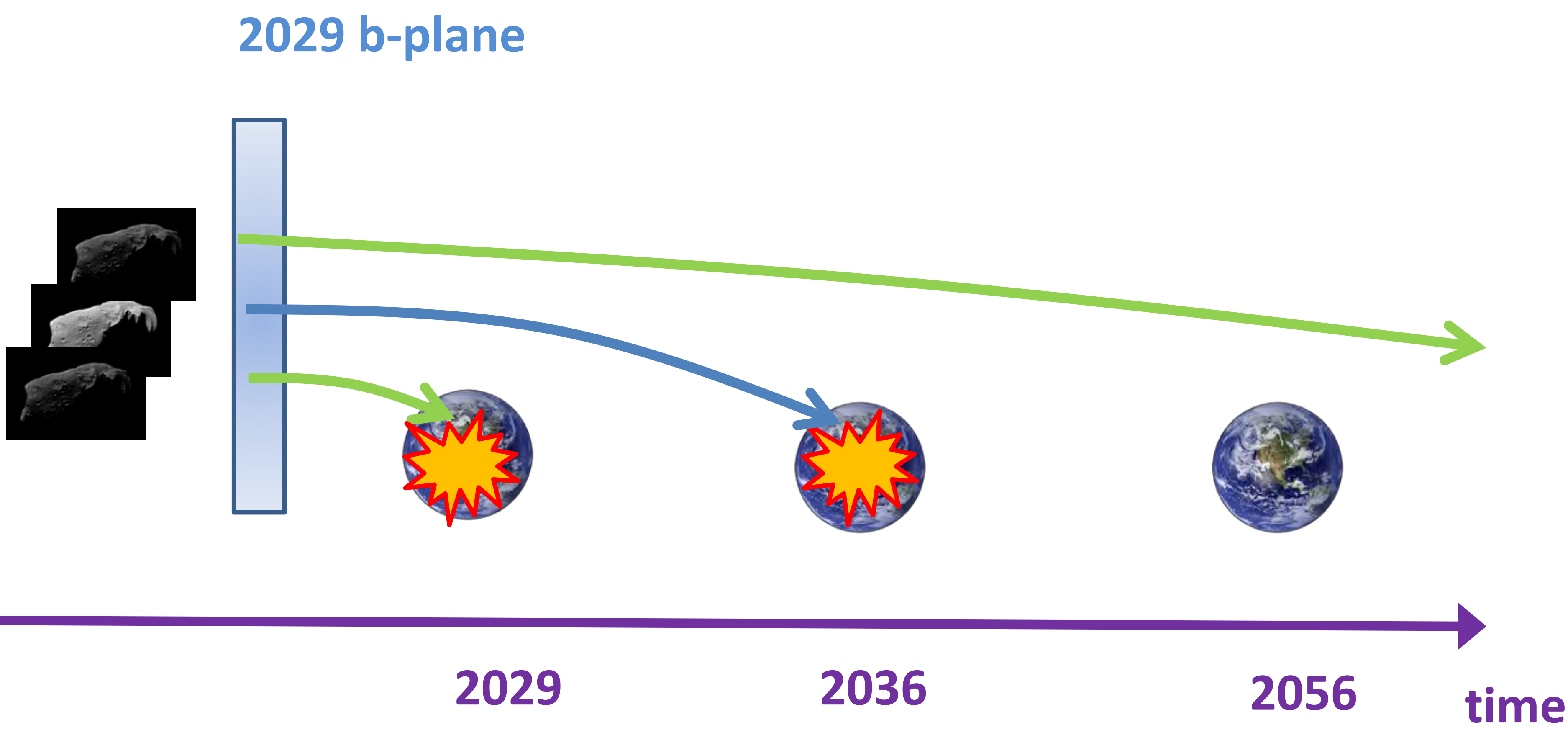
→Conditional probabilities
ΔV… mitigation, S… orbit



$$P(S|\Delta\vec{V}) \approx P(S)P(\Delta\vec{V}) \qquad s \in S, \vec{v} \in \Delta\vec{V}$$

$$P(I\,|\,S,\Delta\vec{V}) = \sum_{i=n_1,n_2,\ldots}^{N_I} \int_{\vec{v}_i}^{\vec{v}_{i+1}} \int_{\sigma_i}^{\sigma_{i+1}} \rho_S(\sigma)\rho_{\Delta\vec{V}}(\vec{v})\,d\sigma d\vec{v}$$

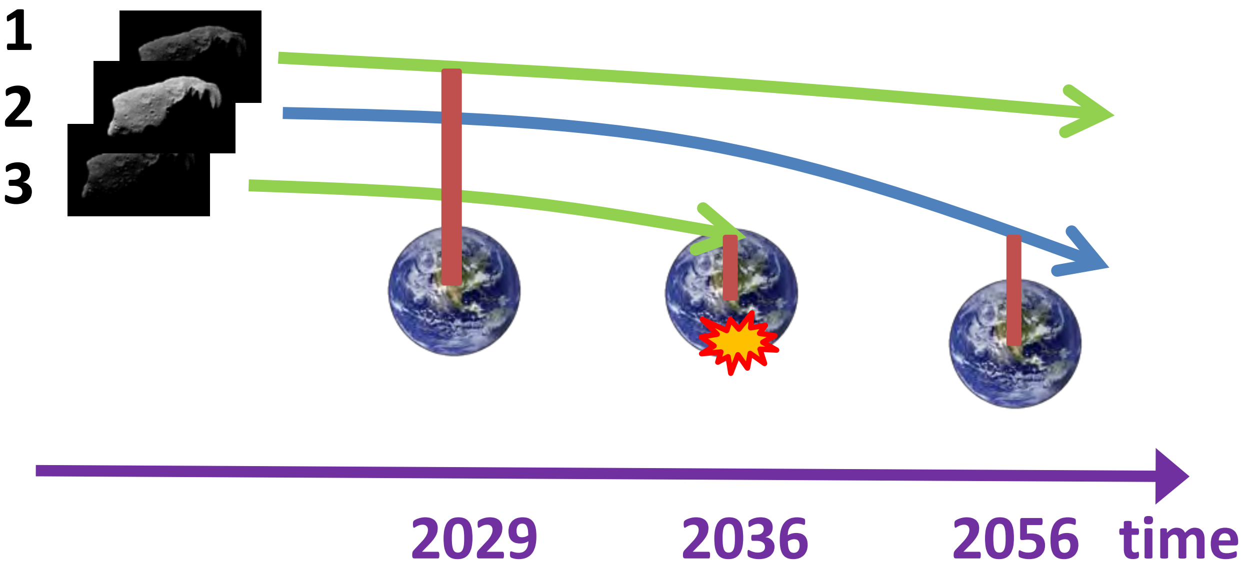
Impact Probability Estimates

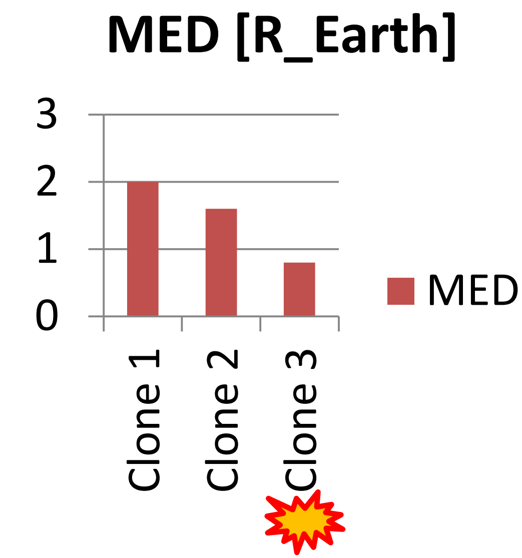


Impact probability: 2/3

Impact Probability Estimates

Minimum Encounter Distance (MED)





Impact probability: 1/3

Deterministic Mission Designs

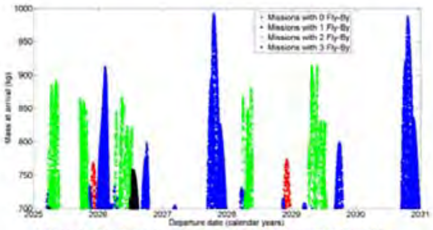


Figure 4: Arrival mass to 2000 FJ10 for the rendezvous S/C Vs departure date

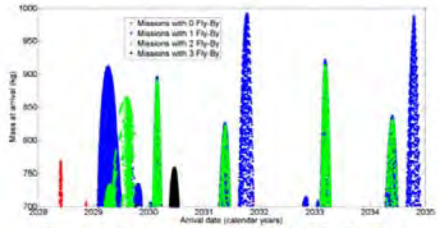


Figure 5: Arrival mass to 2000 FJ10 for the rendezvous S/C Vs arrival date

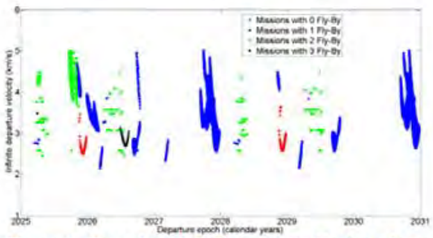


Figure 6: Departure infinite velocity Vs departure epoch for the rendezvous mission to 2000 FJ10

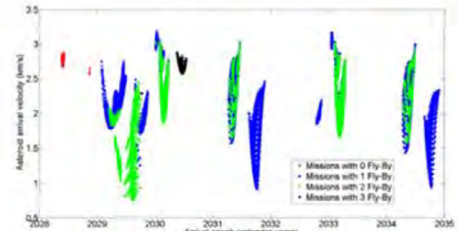


Figure 7: Rendezvous delta-V Vs arrival epoch for the rendezvous mission to 2000 FJ10

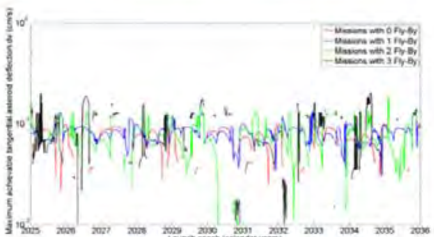


Figure 8: Maximum achievable 2000 FJ10 deflection Vs impactor departure date

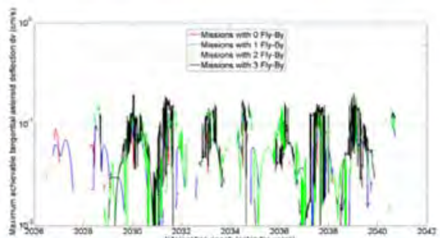


Figure 9: Maximum achievable 2000 FJ10 deflection Vs impact date

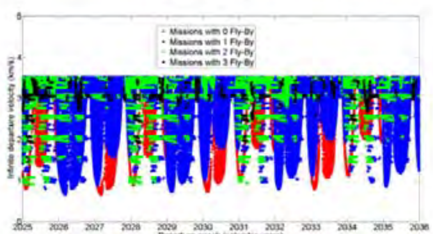


Figure 10: Departure infinite velocity Vs arrival epoch for the impactor mission to 2000 FJ10

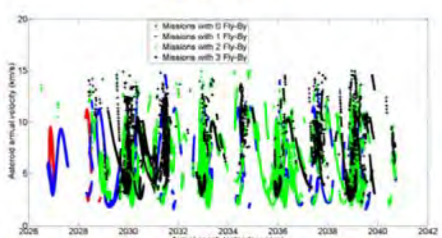
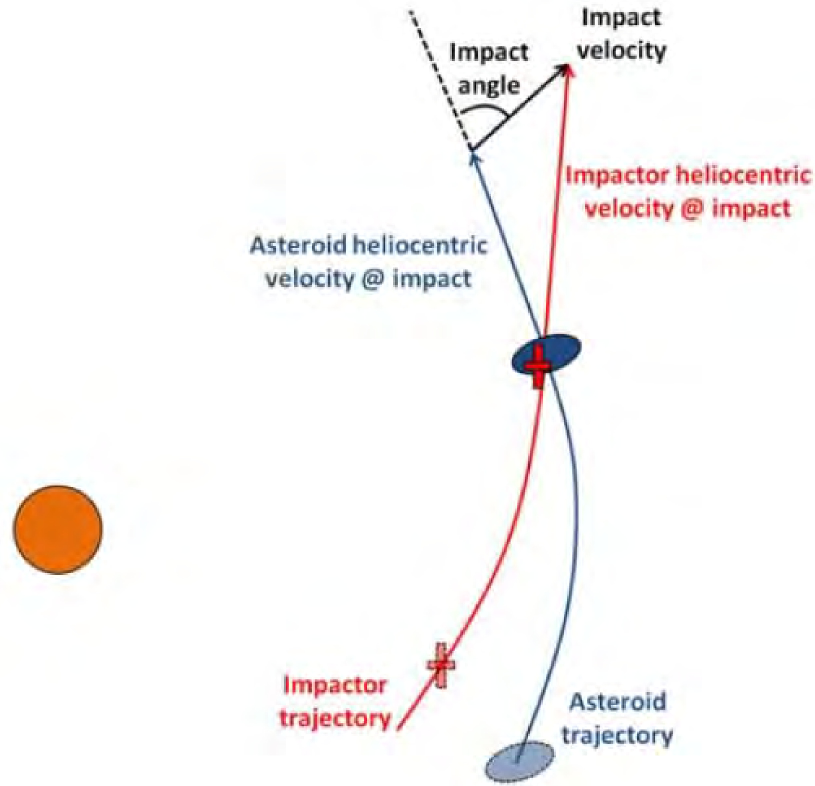
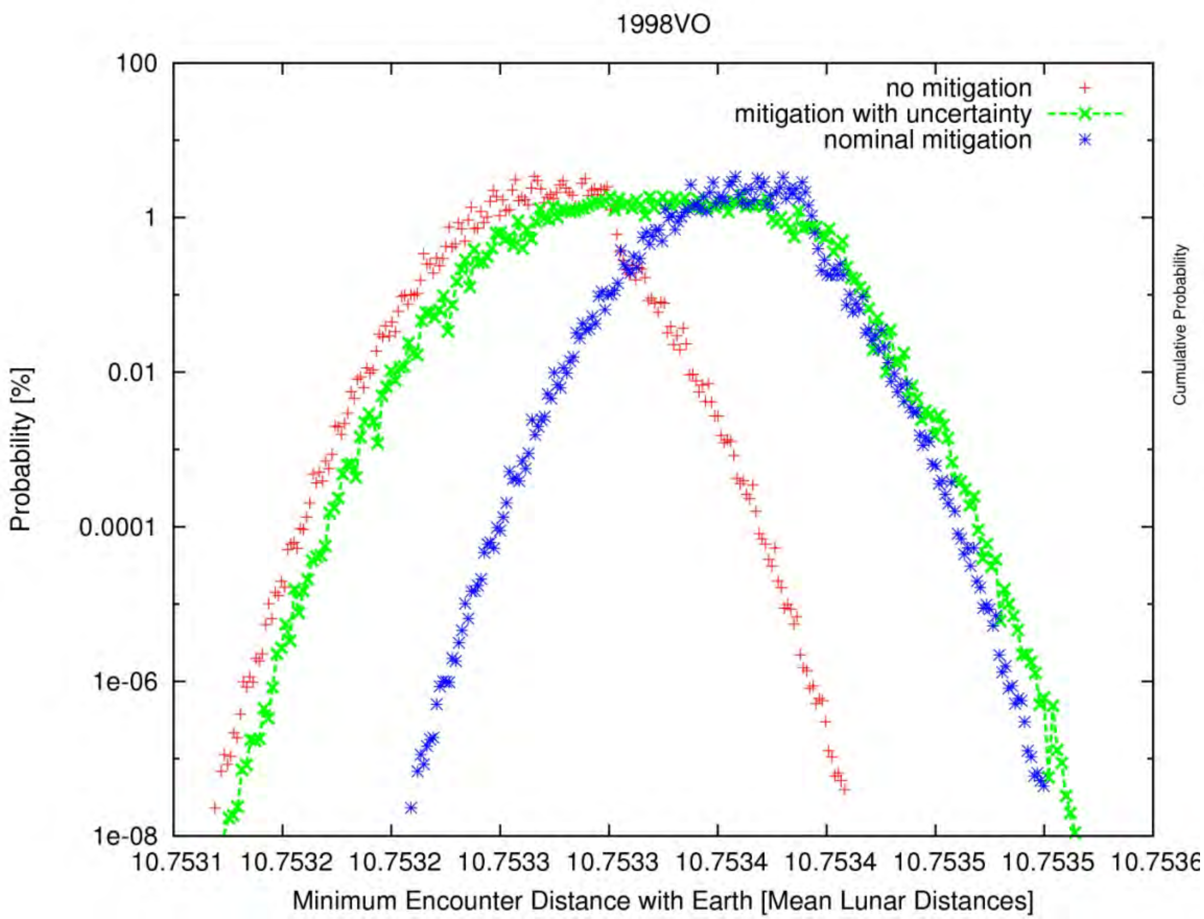


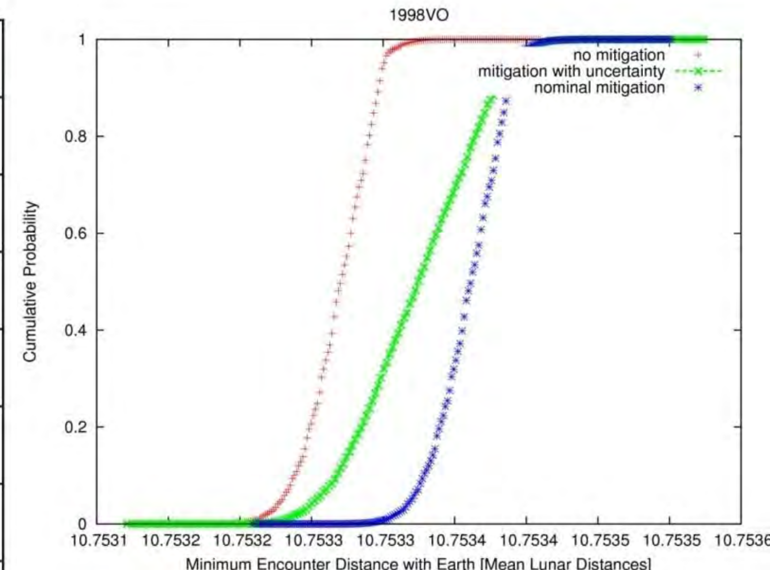
Figure 11: Impact velocity Vs impact epoch for the impactor mission to 2000 FJ10



Mitigation Uncertainty 1998 VO

Impact date	ΔV [cm/s]	S/C mass [kg]	Gravity Assists	Mission Duration [yrs]	σ a [au]	ΔMED [km]
05/02/2034	0.02 – 1	643	V,V	6	2.x10^-9	154

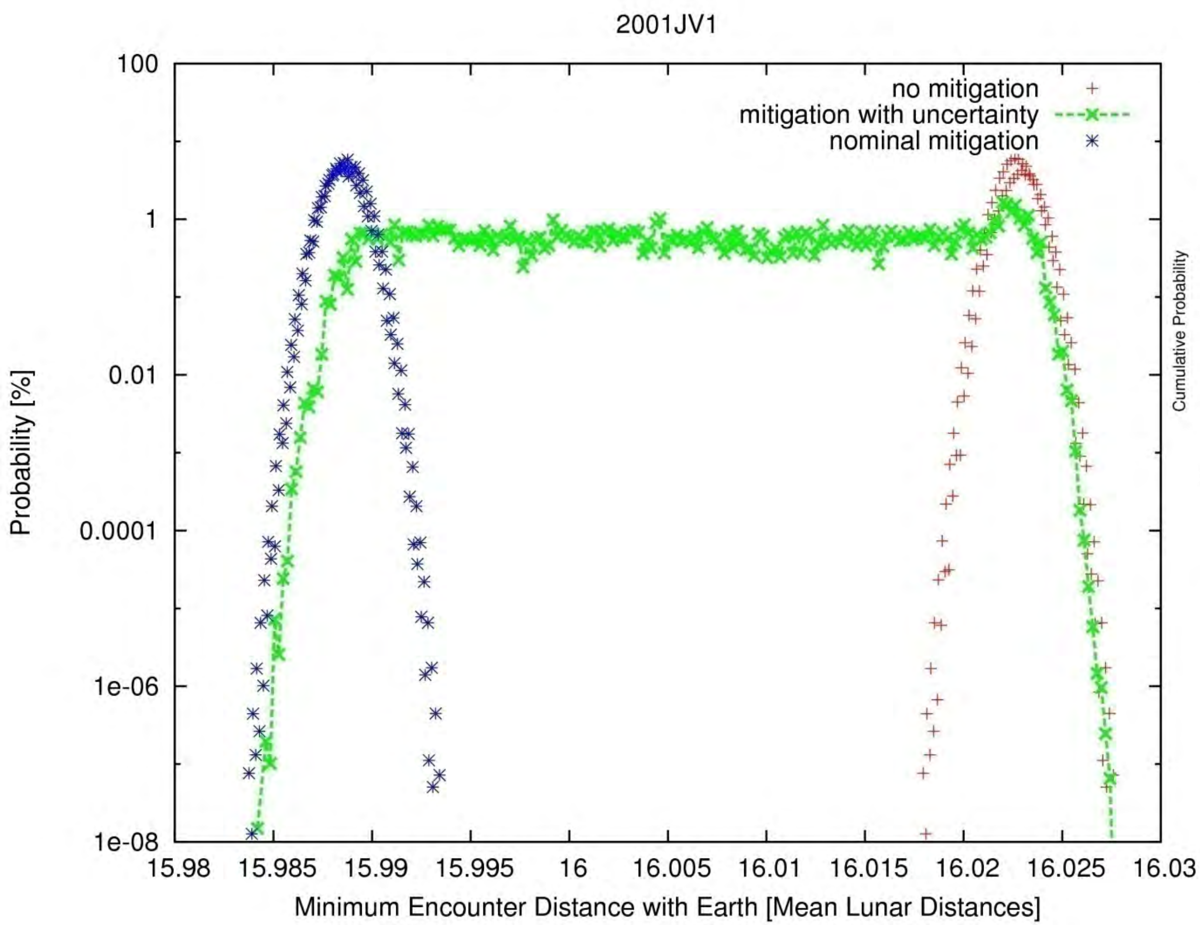


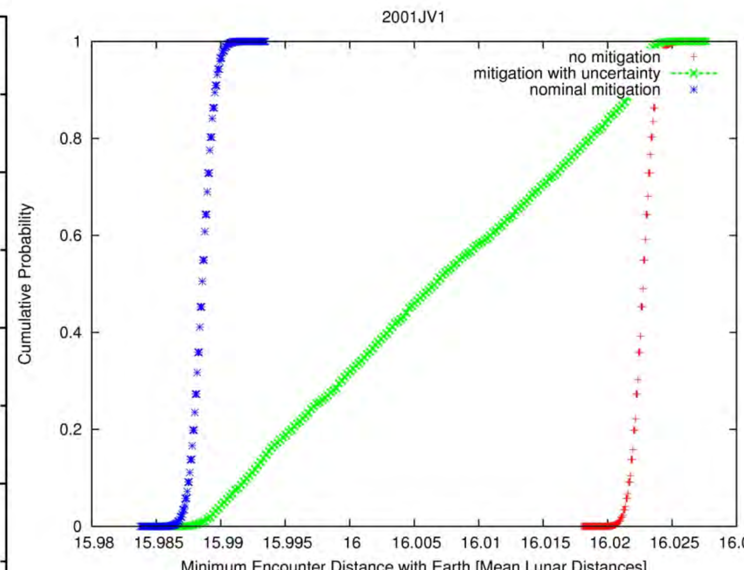


e	0.22
a[au]	1.07
i[°]	10

Mitigation Uncertainty 2001 JV1

Impact date	ΔV [cm/s]	S/C mass [kg]	Gravity Assists	Mission Duration [yrs]	σ a [au]	ΔMED [km]
16/06/2030	0.02-1.1	645	V,E	4.6	10^-7	**-16 500**

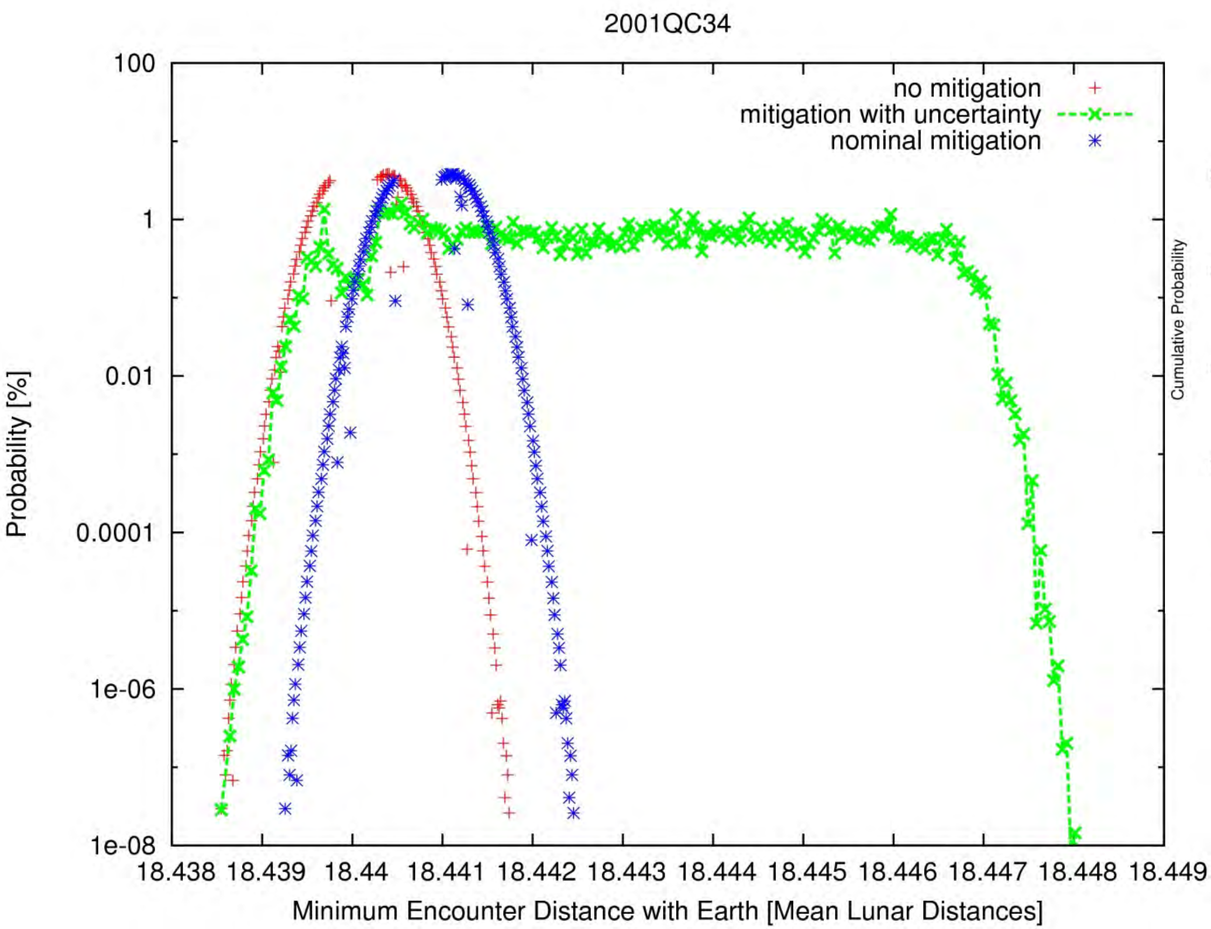


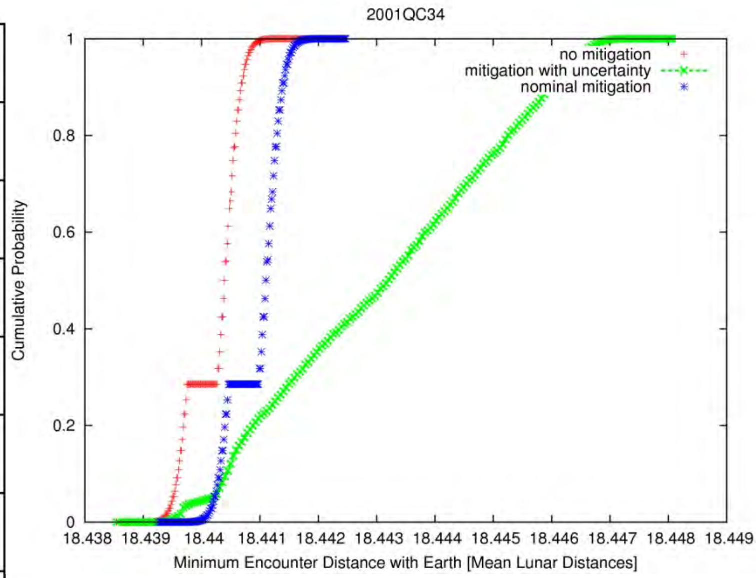


e	0.44
a[au]	1.7
i[°]	6.6

Mitigation Uncertainty 2001 QC34

Impact date	ΔV [cm/s]	S/C mass [kg]	Gravity Assists	Mission Duration [yrs]	σ a [au]	ΔMED [km]
12/10/2030	0.01 – 4	639	V,V,E	5	5x10^-9	4224

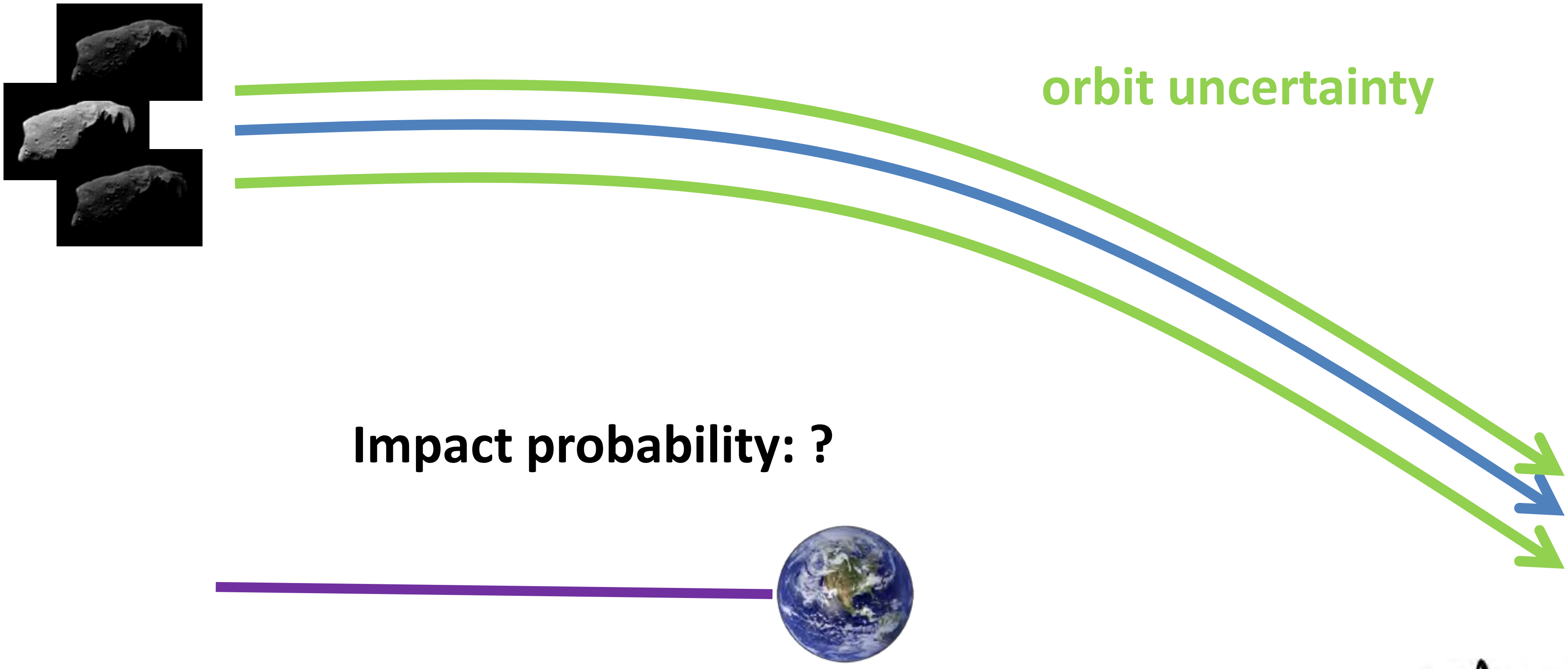




e	0.18
a[au]	1.12
i[°]	6.2

Extrapolated PSV?

Clones

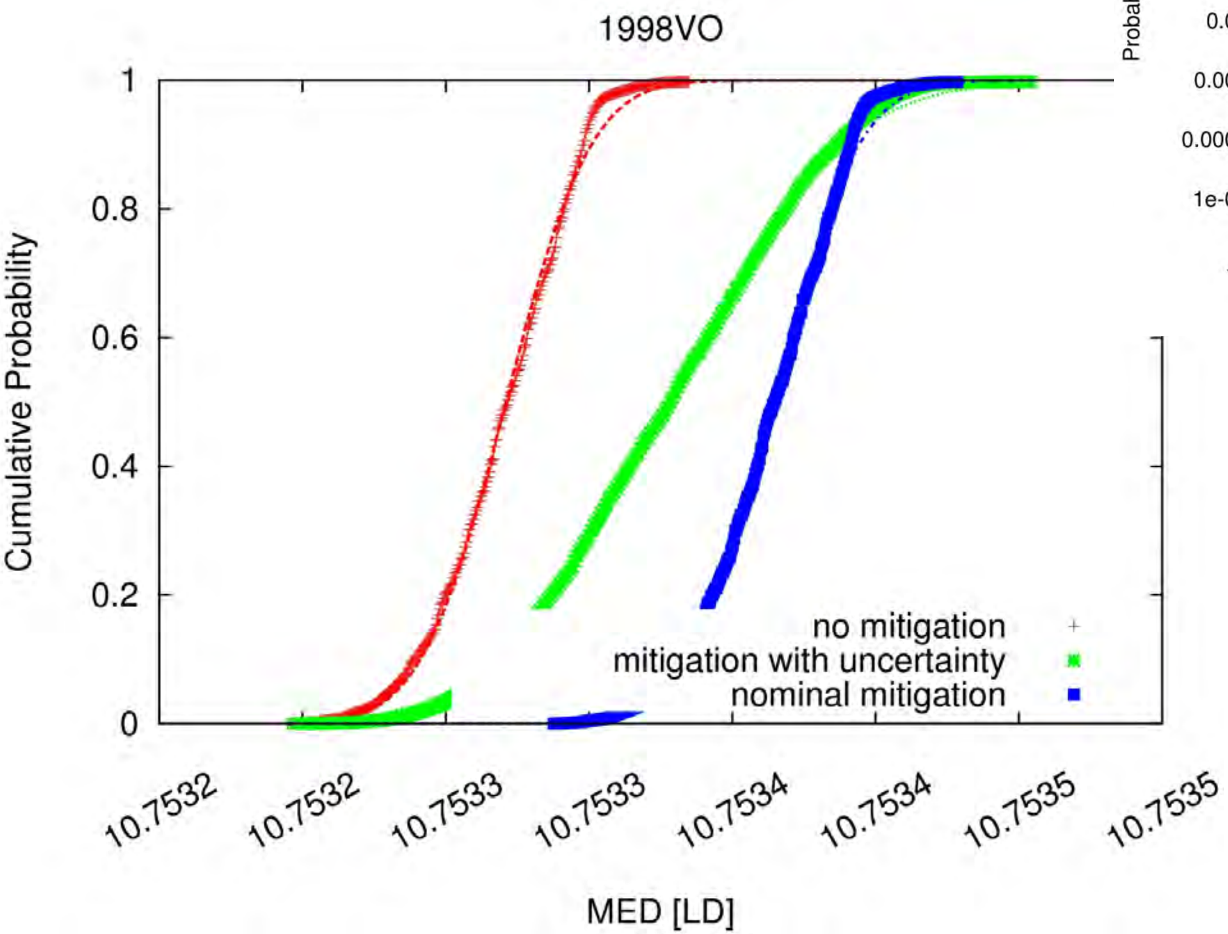


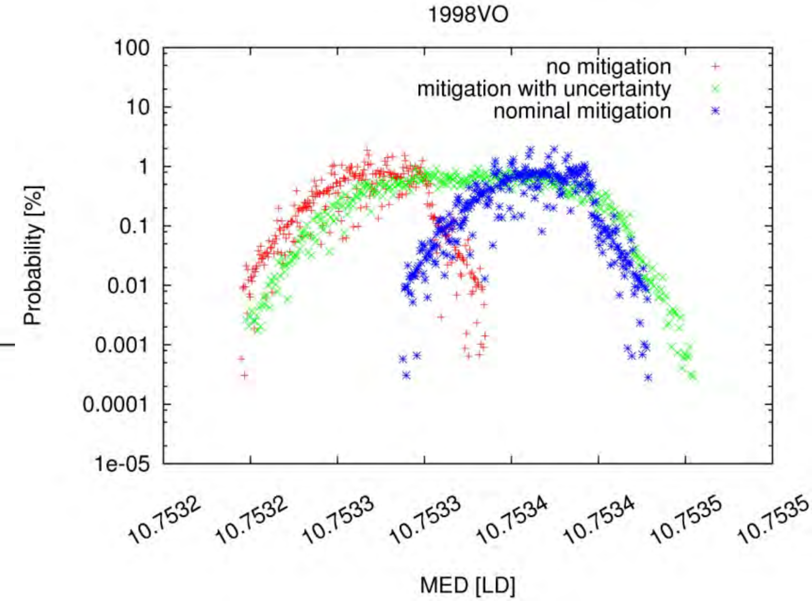
KI Demonstrator


Quantitative estimates for Palermo Scale Values?

Mixed Gaussian-Uniform PDF

$$PDF(orbit): \quad \rho_S = \frac{e^{-s/2\sigma}}{\sqrt{2\pi\sigma}}$$



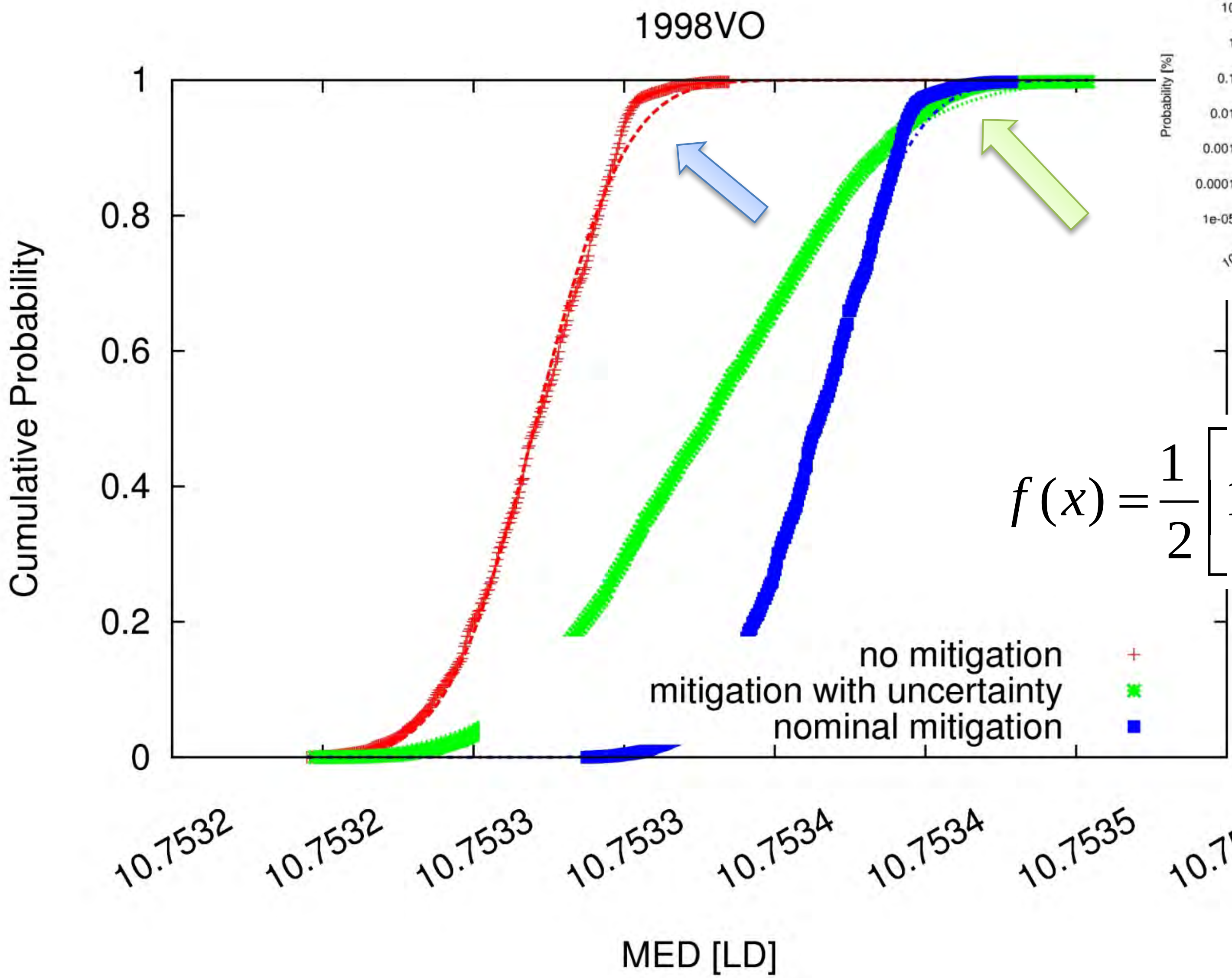


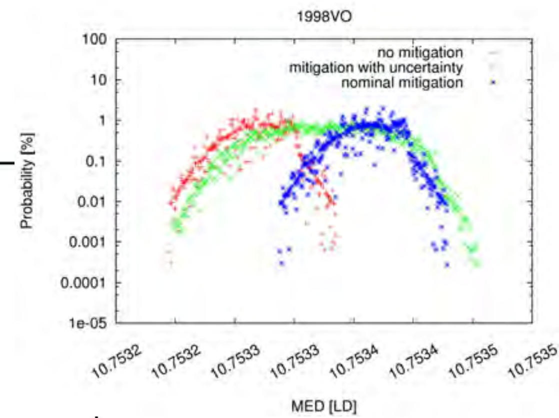
$$PDF(mitigation):$$

$$\rho_{\Delta\vec{V}}(\vec{v}) = \prod_{i=x,y,z} (v_i)^{-1}$$

$$\vec{v} = \Delta\vec{V}_n - \Delta\vec{V}_0$$

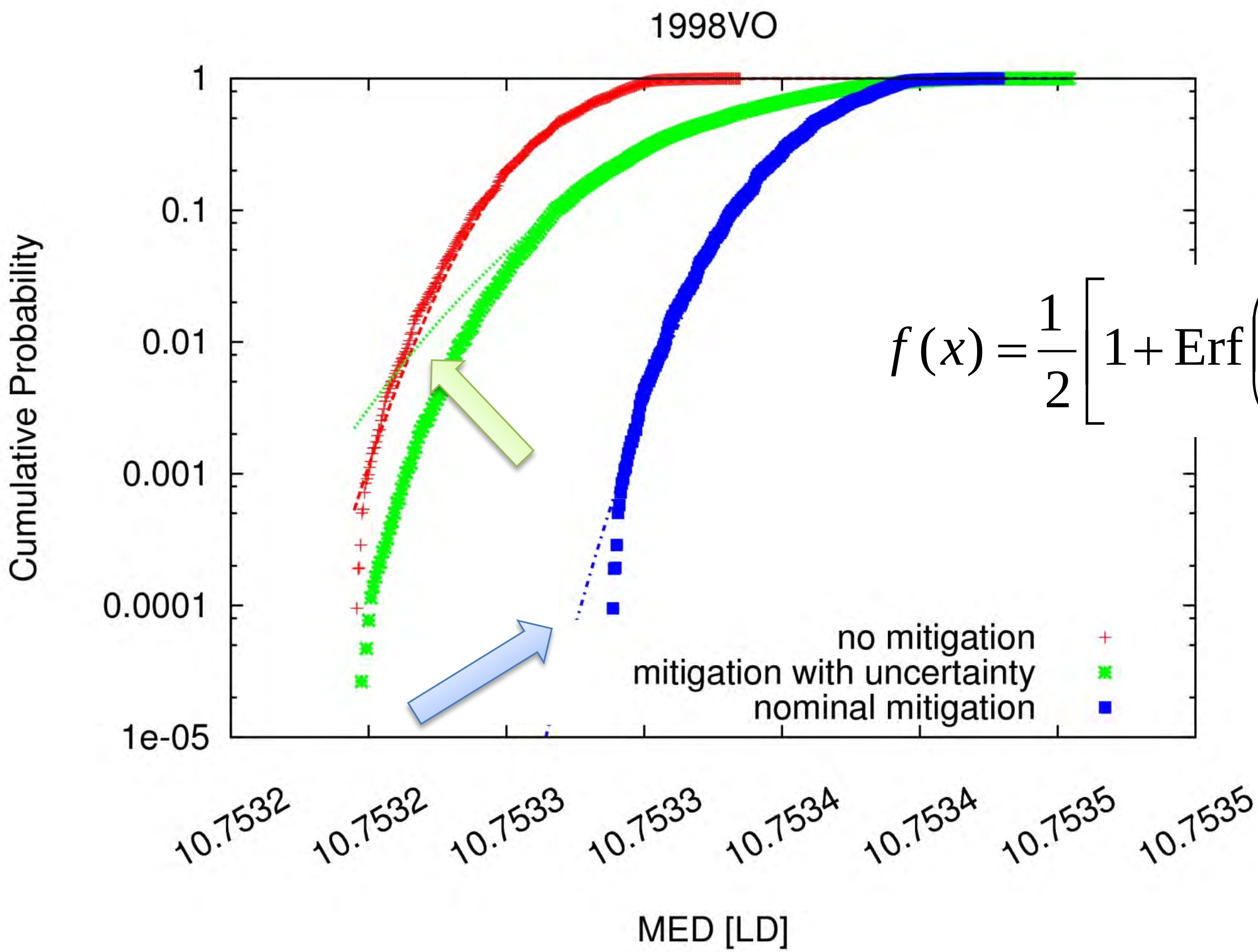
Mitigation Uncertainty 2000 FJ10





$$f(x) = \frac{1}{2}\left[1 + \mathrm{Erf}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)\right]$$

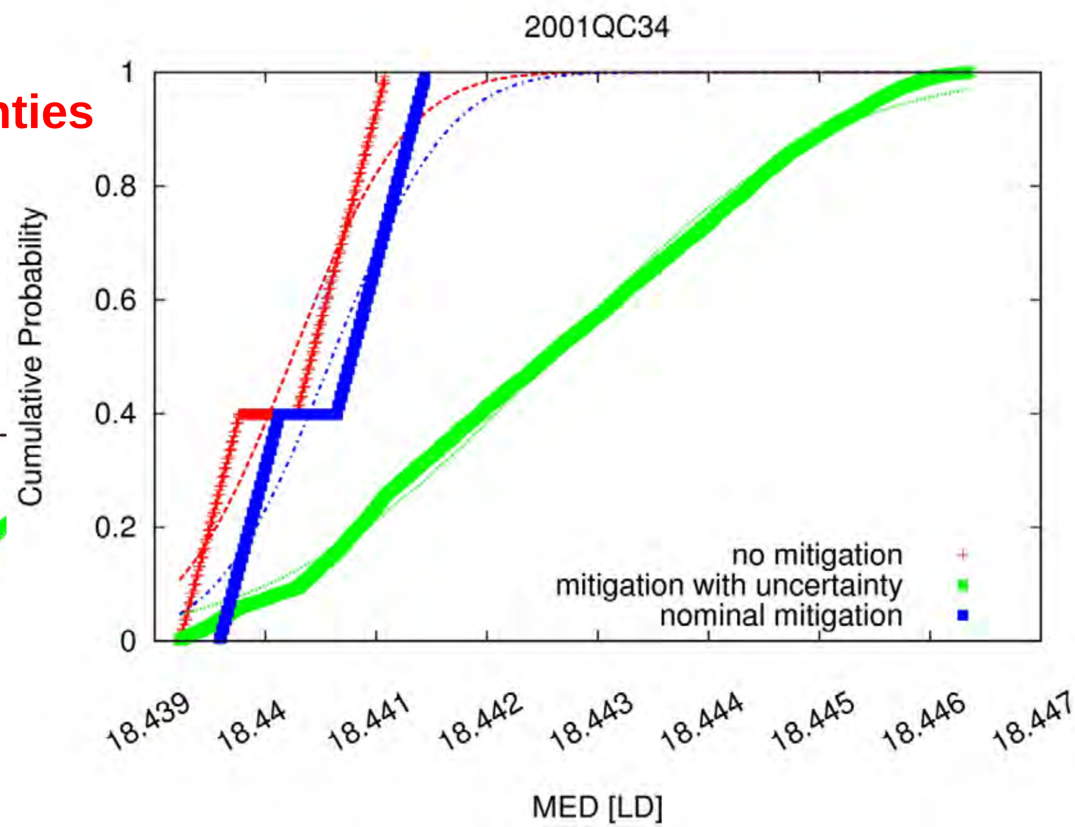
Mitigation Uncertainty 2000 FJ10

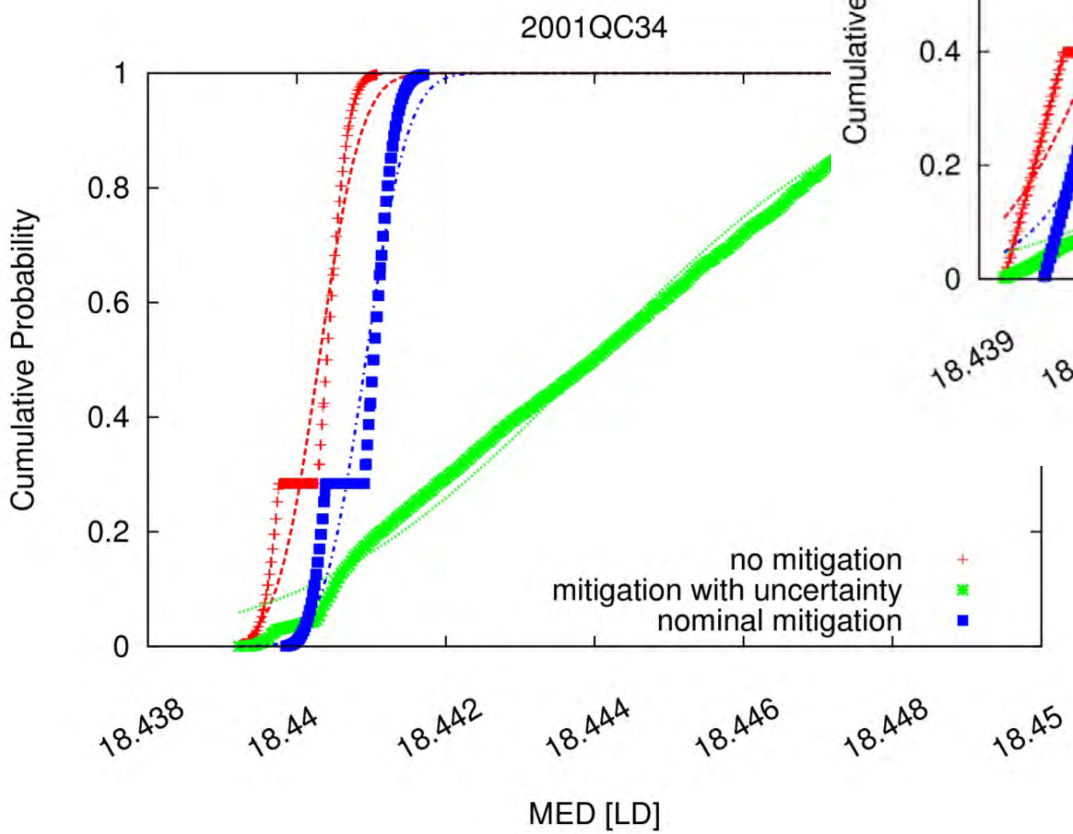


$$f(x) = \frac{1}{2}\left[1 + \mathrm{Erf}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)\right]$$

Mitigation Uncertainty 2000 FJ10

Uniform distribution of uncertainties

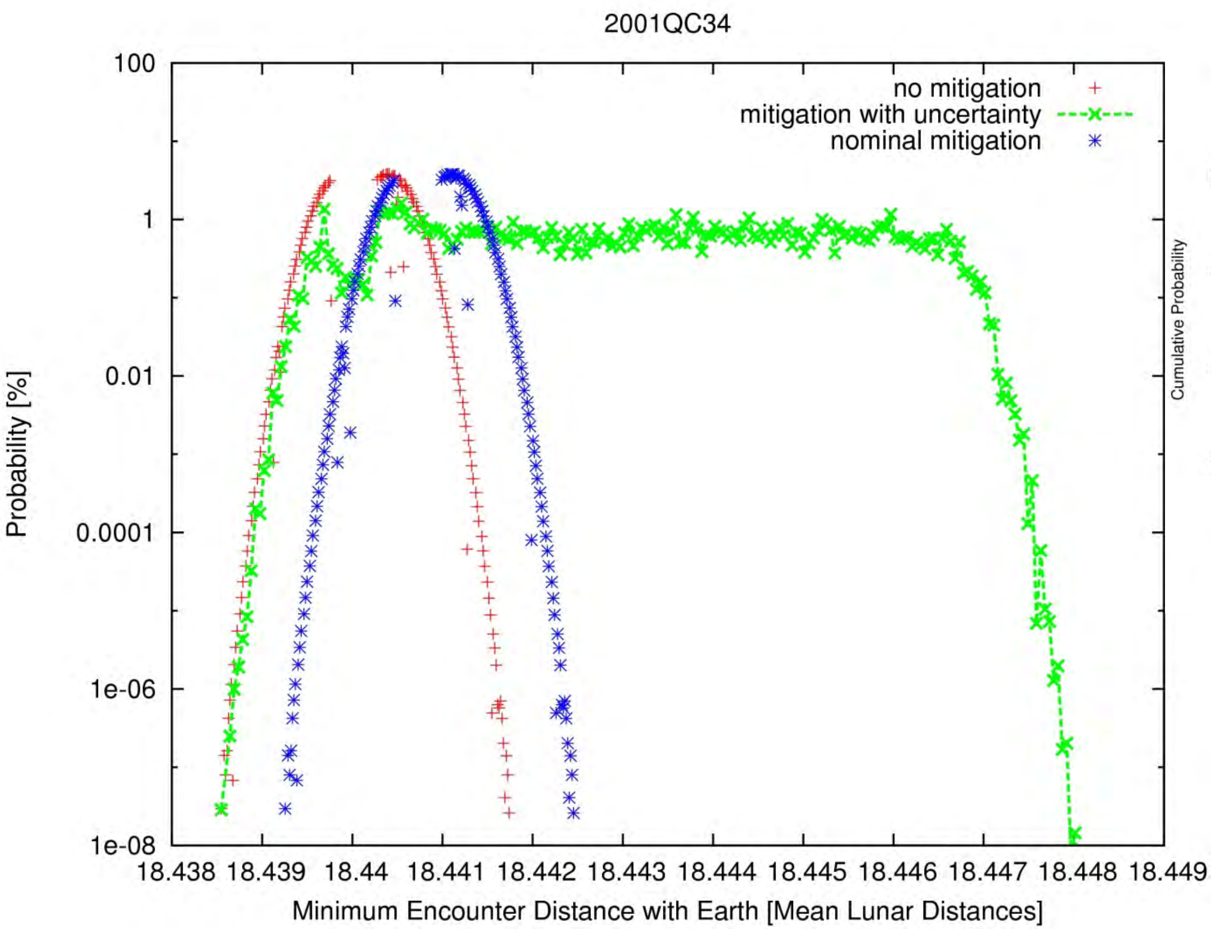


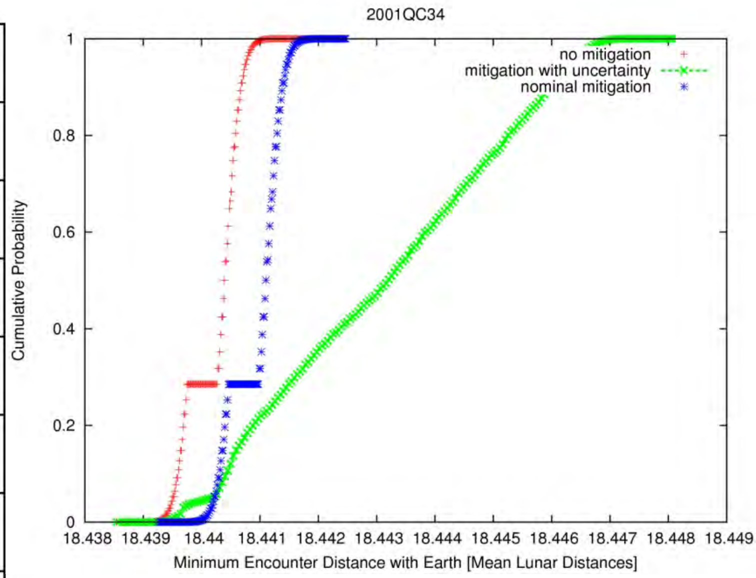


Gaussian orbit uncertainties +
Uniform mitigation uncertainties

Mitigation Uncertainty 2001 QC34

Impact date	ΔV [cm/s]	S/C mass [kg]	Gravity Assists	Mission Duration [yrs]	σ a [au]	ΔMED [km]
12/10/2030	0.01 – 4	639	V,V,E	5	5x10^-9	4224

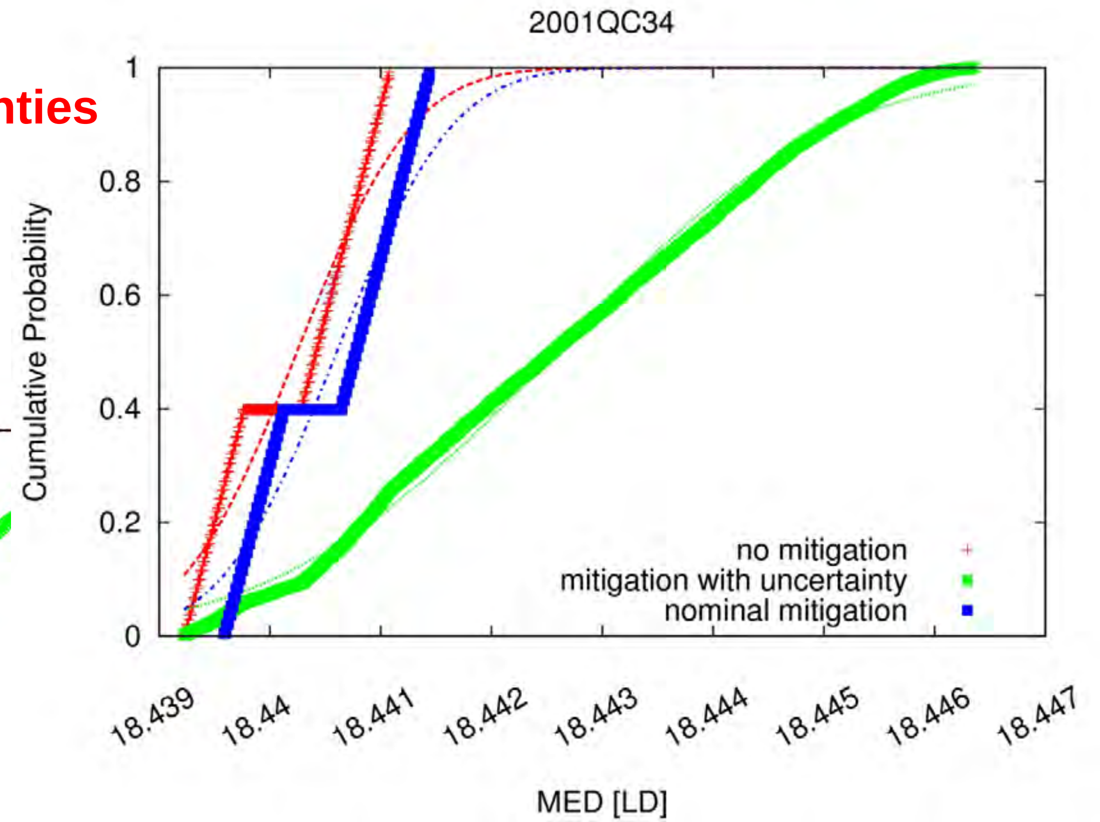


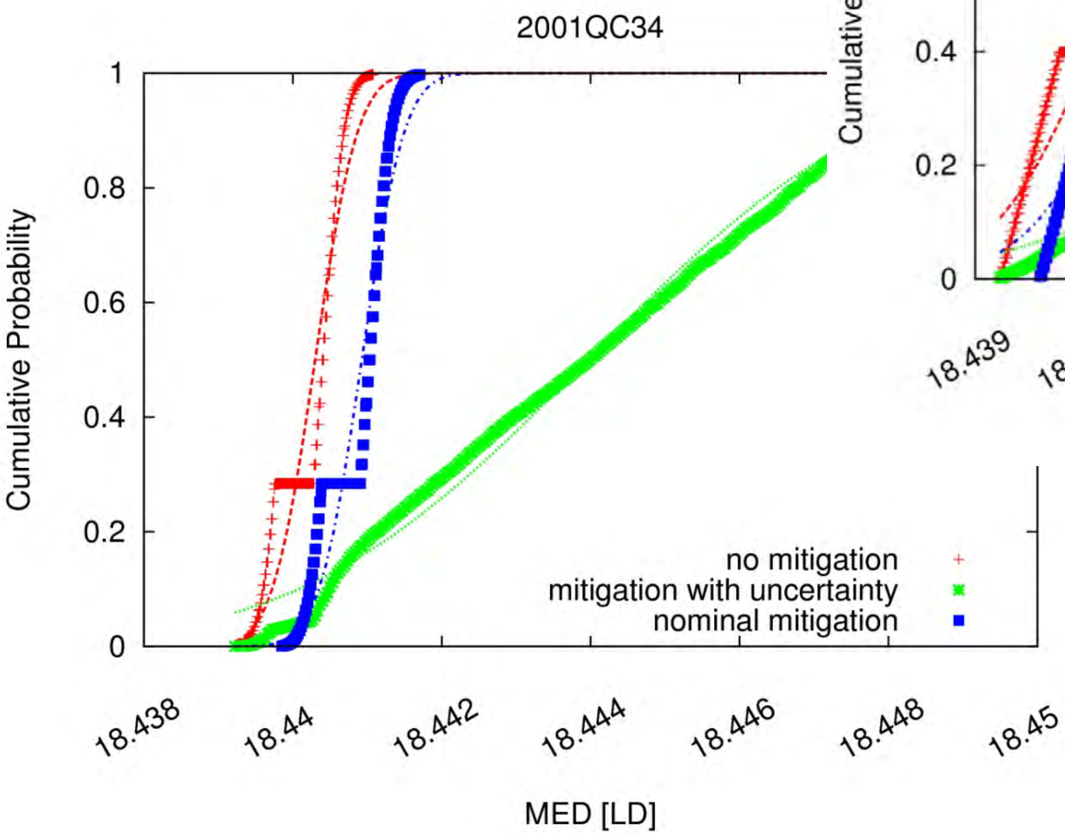


e	0.18
a[au]	1.12
i[°]	6.2

Mitigation Uncertainty 2000 FJ10

Uniform distribution of uncertainties

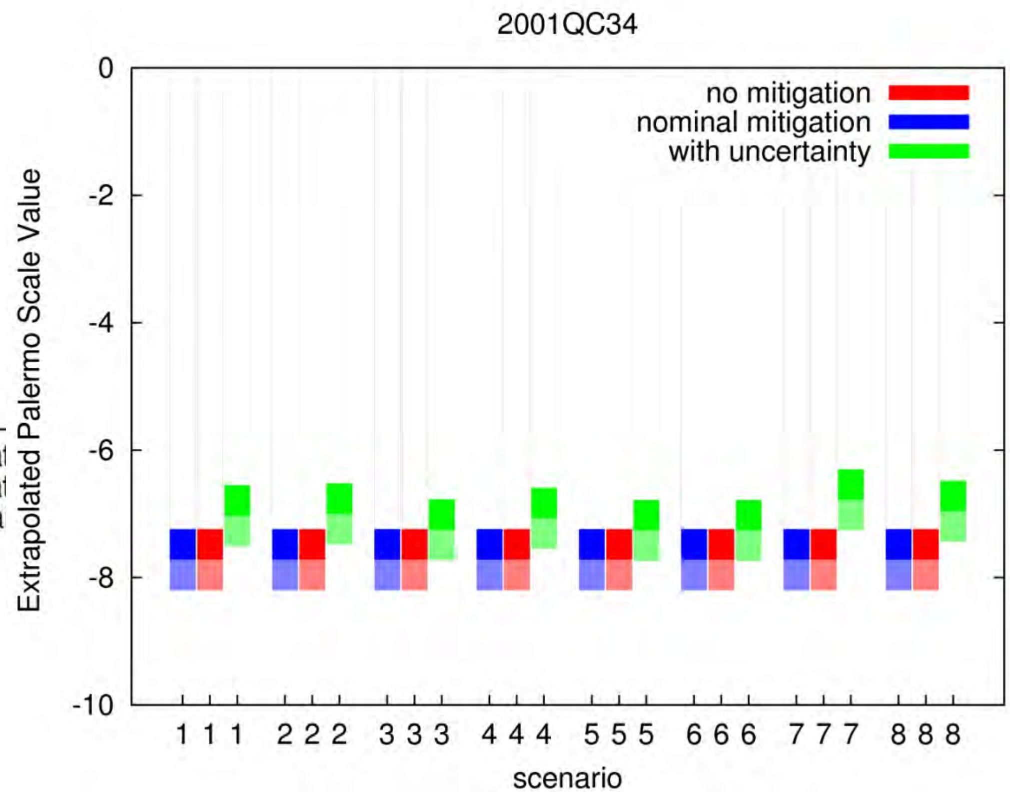


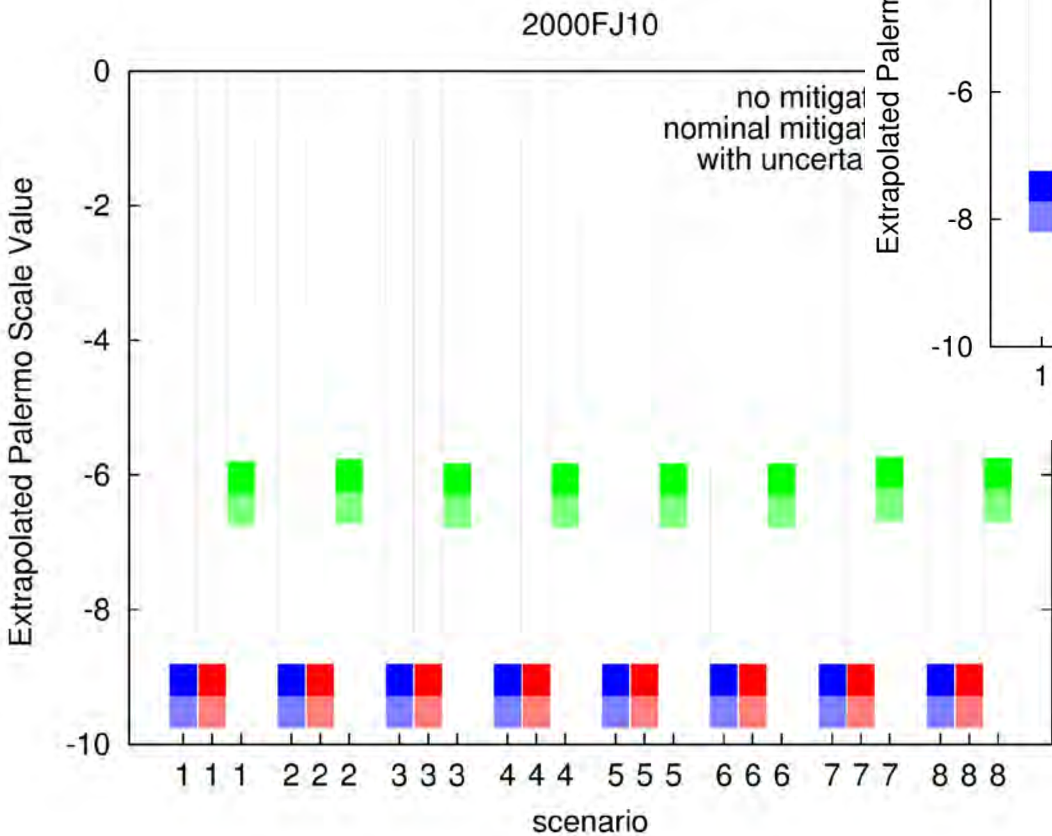


Gaussian orbit uncertainties +
Uniform mitigation uncertainties

How Cautious Shall We Be?

Will the target NEOs become more dangerous?

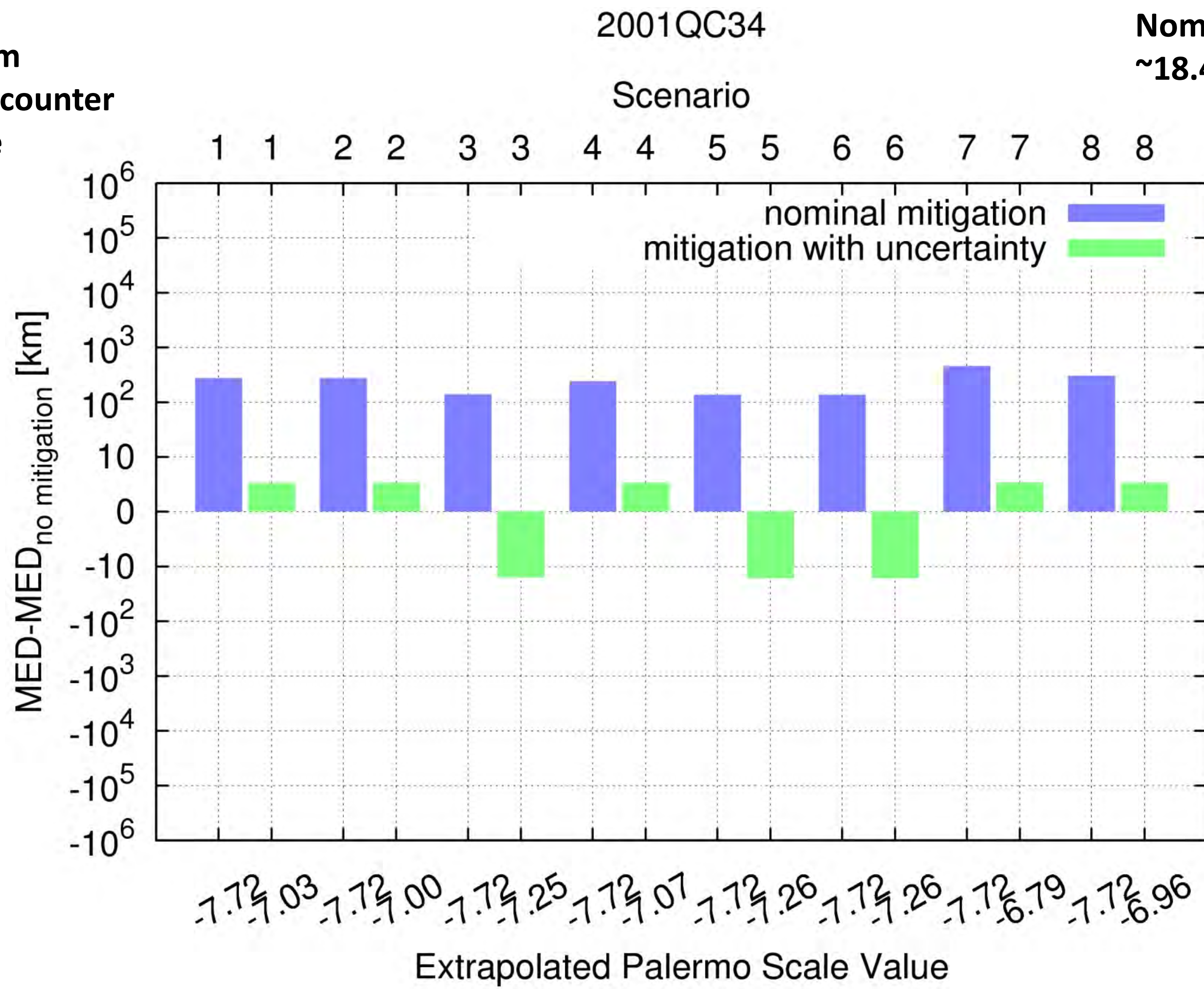




Mitigation Uncertainty 2001 QC34

MED… Minimum Earth encounter Distance

Nominal MED: ~18.4 Lunar Distances

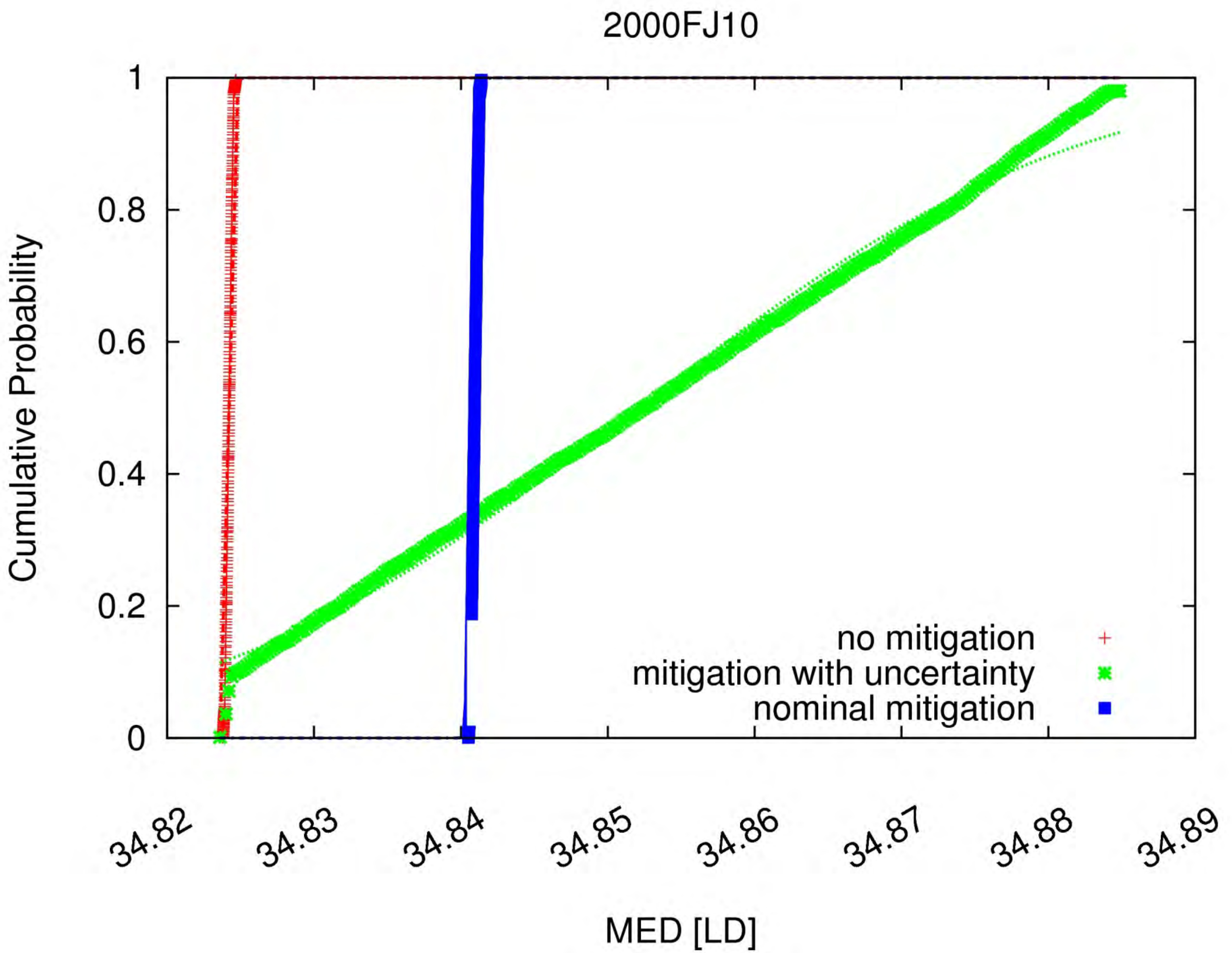


Conclusions

1. Extrapolating PSVs: heuristic but cheap!

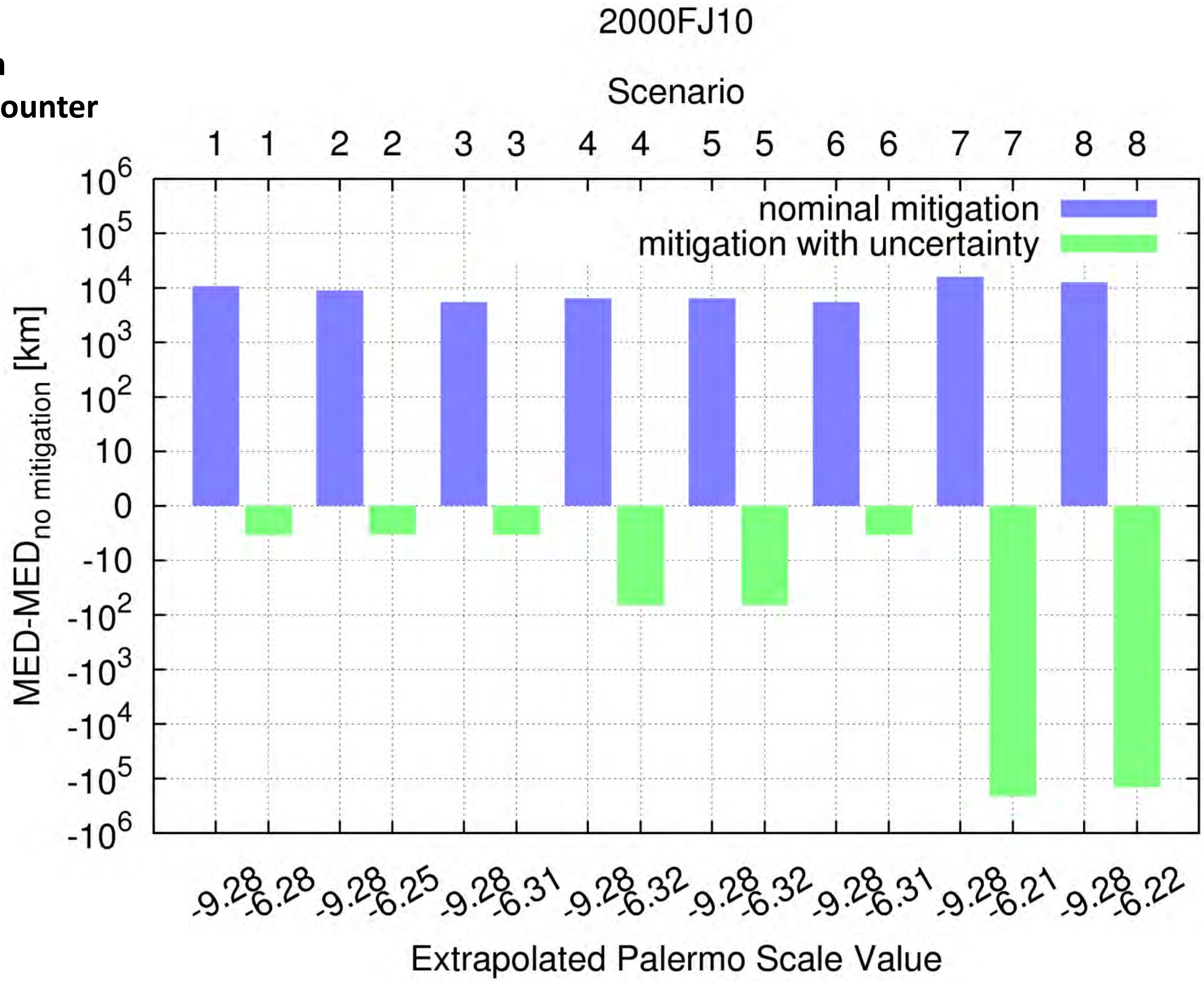
2. Take care where the asteroid ends up!

NEOShield Conclusions



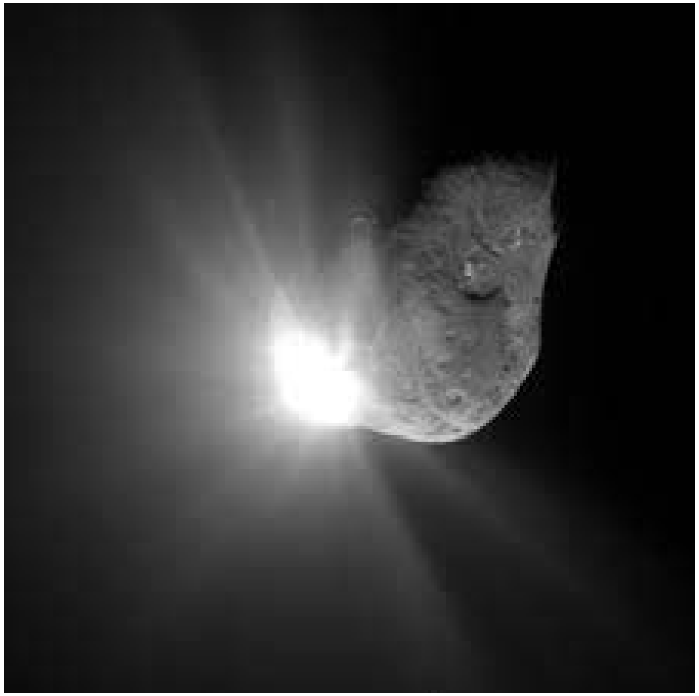
Mitigation Uncertainty 2000 FJ10

MED…
Minimum
Earth encounter
Distance



Kinetic Impactor: Been there, done that?

Deep Impact (NASA, 2005)



Target: Comet 9P/Tempel
a: 3.124 au, e: 0.517, i: 10.5°
D: **6km,** m: **7-8 10^{13}** kg

Impactor mass: **384kg**

Change in pericenter (est.): **10m**

Change in period (est.): **1s**

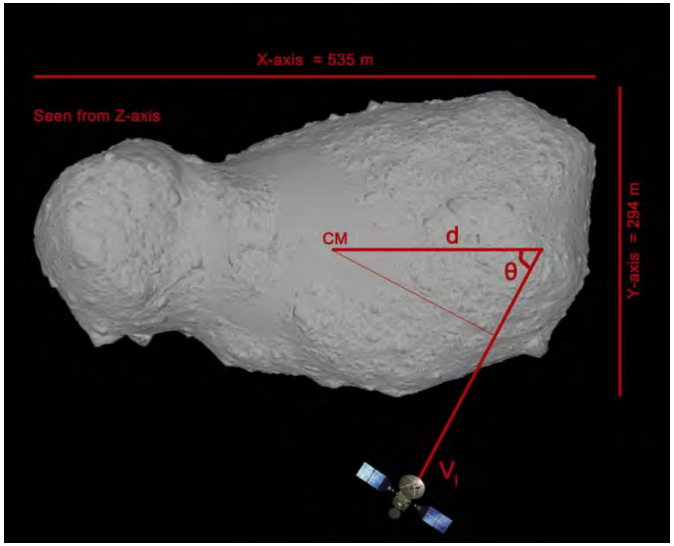
Current orbit uncertainty : **30km**

With orbiter: **~ 150m**

$$\Delta v_a = \beta \frac{m_s}{m_a} \Delta v_s$$

Demo Mission Options

Inexpensive: Spinning Itokawa



$$\Delta T = -\, m_i v_i d \sin\theta \; T^2 / \, 2\, \pi \, I_Z \approx 10 \text{ min}$$

For:
m_i = 500 kg
v_i = 15 km s^{-1}
$d\sin\theta$ = 200 m
I_Z = 7.7686 x 10^{14} m^2 kg
T = 12.132370 hr

Yet unanswered question:
How much will the impact change the shape and which effect does that have on the rotation period?
How much of the shape change can be observed from lightcurve and radar data?