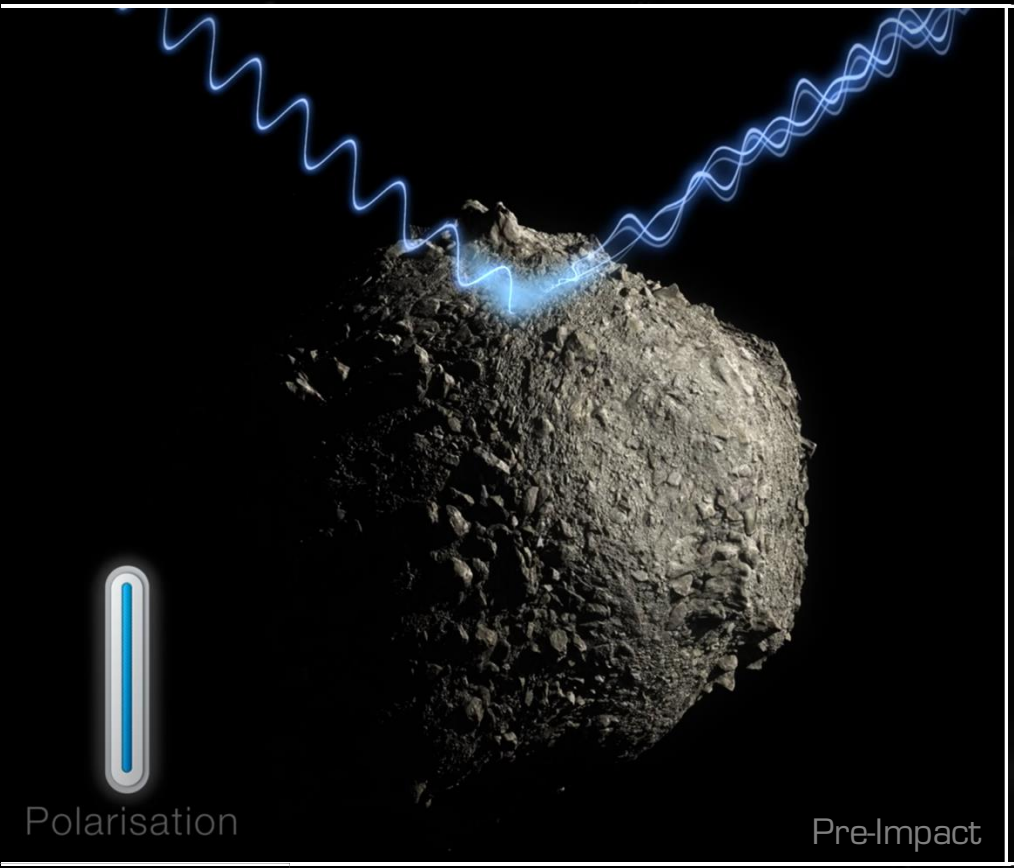
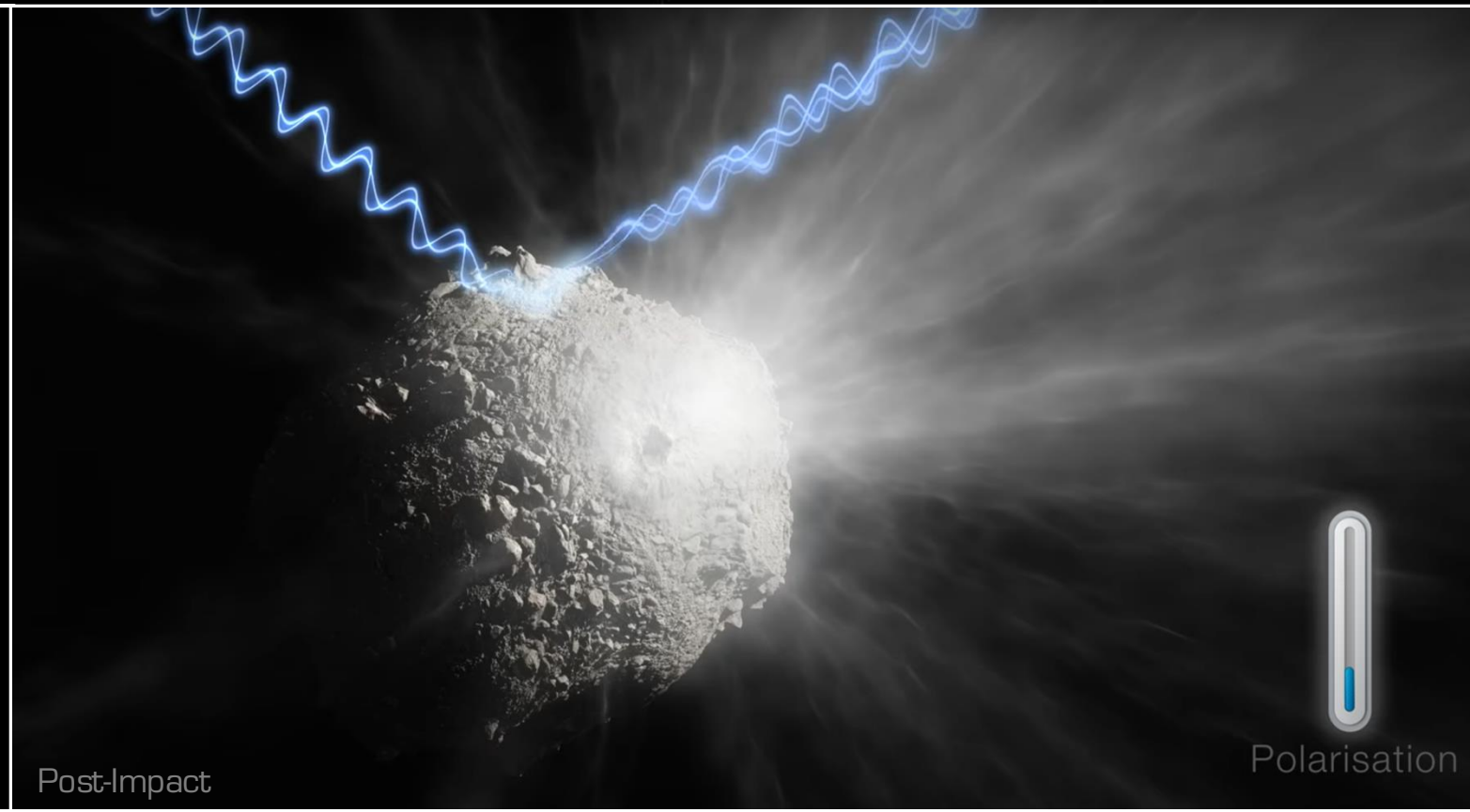
DOUBLE TROUBLE

Polarimetric Insights into the Didymos-Dimorphos post-DART Evolution

EU-ESA Workshop on Size Determination of Potentially Hazardous NEOs
11-13 November 2024

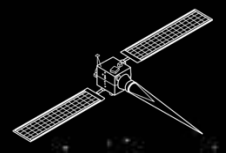
DART



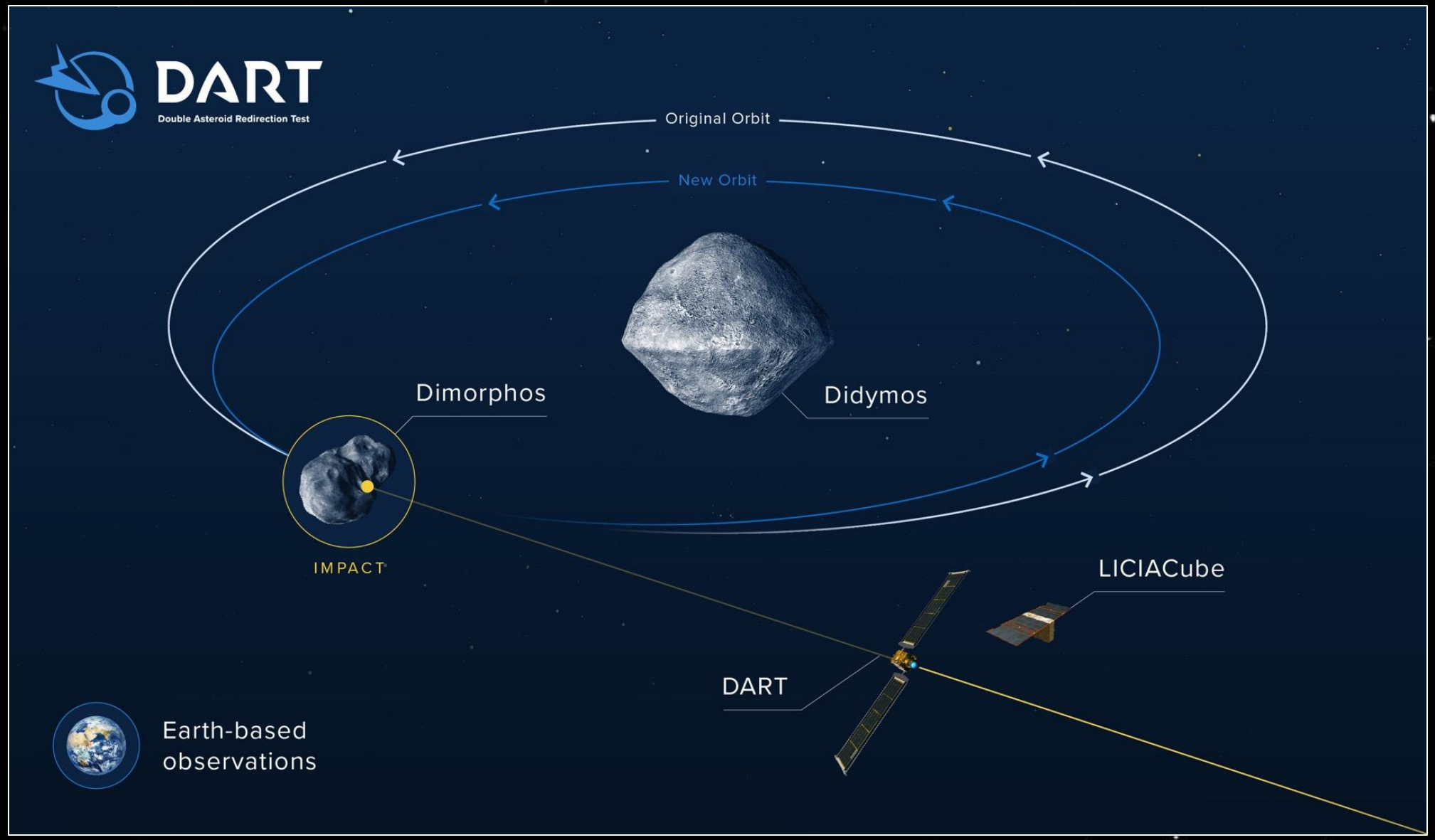


UNIVERSITY OF HELSINKI

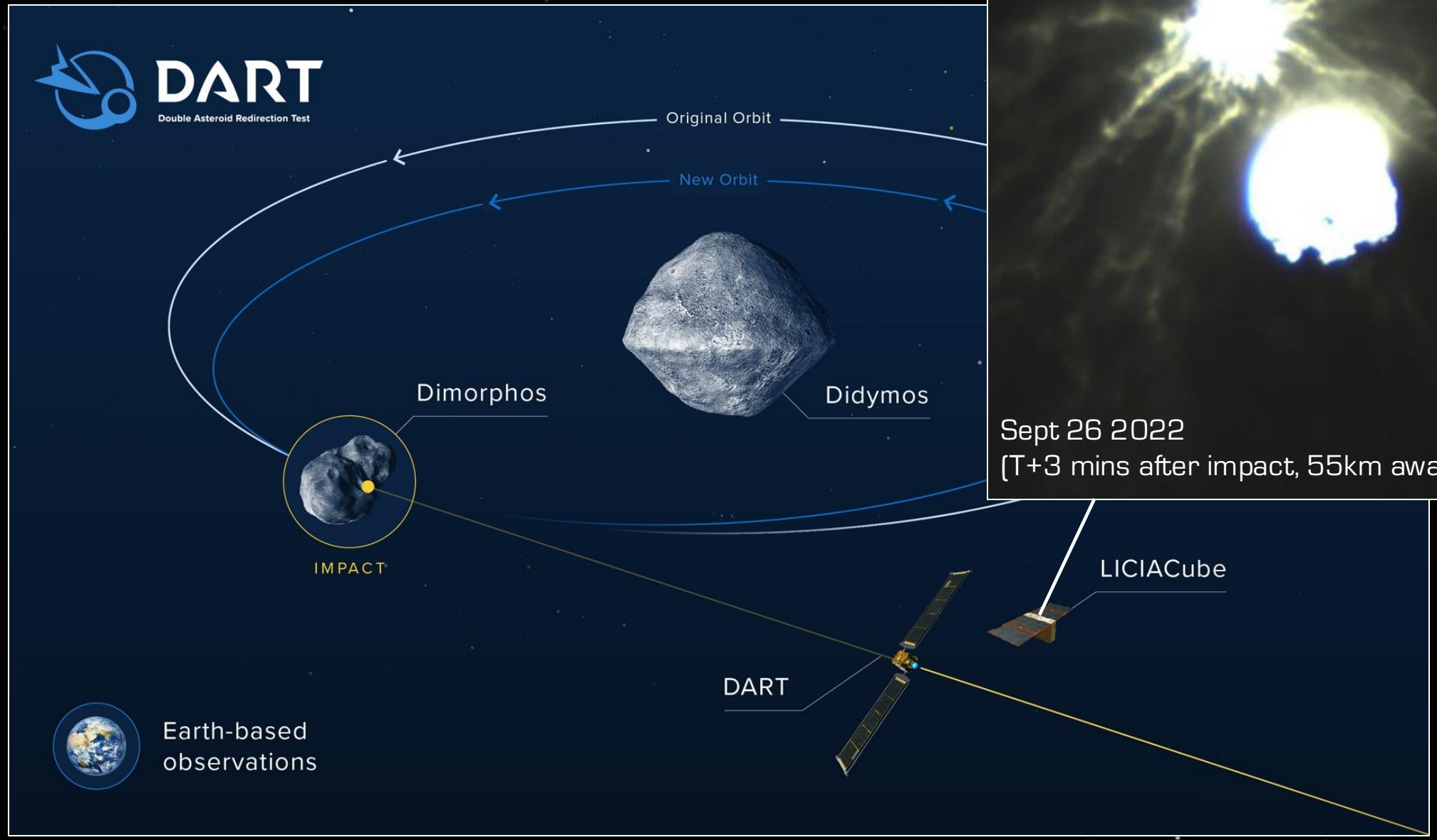
Zuri Gray (zuri.gray@helsinki.fi) Stefano Bagnulo, Mikael Granvik, Alberto Cellino, Geraint H. Jones, Ludmilla Kolokolova, Fernando Moreno, Karri Muinonen, Olga Muñoz, Cyrielle Opitom, Antti Penttilä, and Colin Snodgrass



1. Introduction



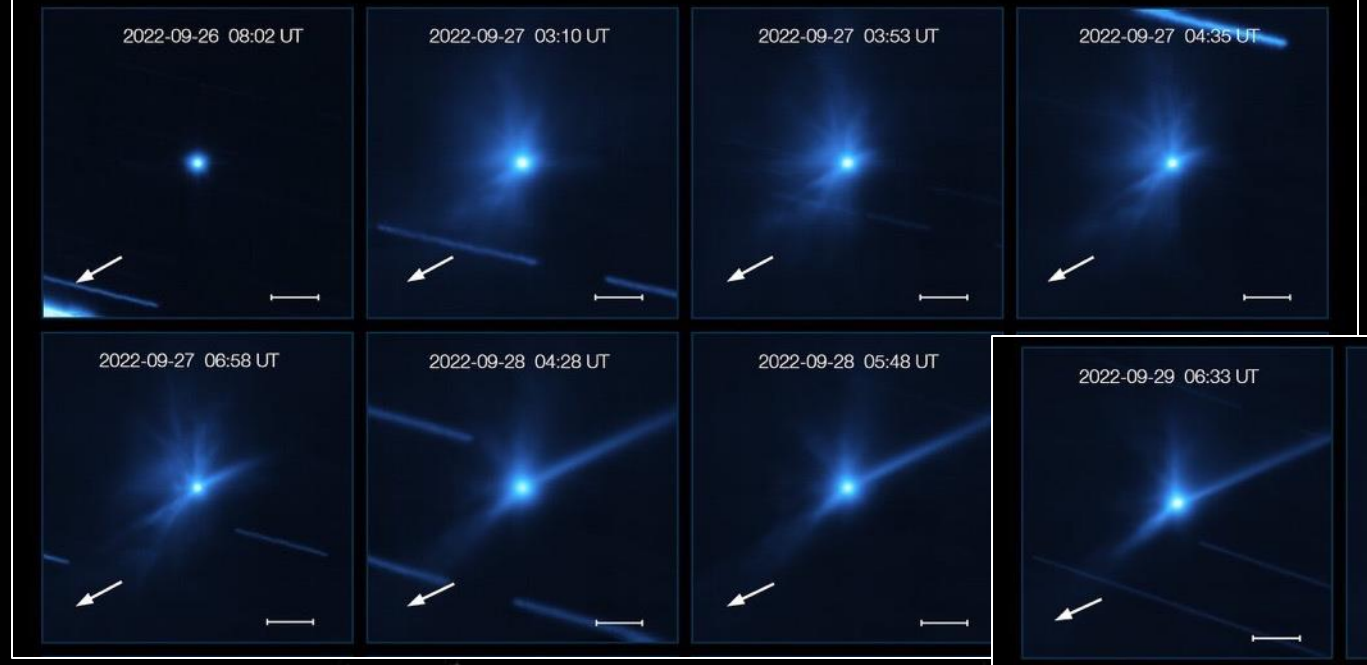
1. Introduction



Sept 26 2022
(T+3 mins after impact, 55km away)

1. Introduction

T+3--4 hrs



T+4--7 days

T+1.5 days

T+1--4 weeks

ESO / Opitom et al. 2023

1. Introduction

WORLDWIDE OBSERVING CAMPAIGN 2022 2023

DART

Arizona
LDT (4.3 m)
Hall (1.1 m)

California
Goldstone
Palomar (5 m)
TMO (1 m)

Hawaii
IRTF (3 m)
ATLAS (0.5 m x 2)

West Virginia
Green Bank

Texas
LCOGT (1 m)

New Mexico
MRO (2.4 m)

Canary Islands
TNG (3.5 m)
NOT (2.56 m)
LCOGT (1 m)

Asiago (1.8 m, 1 m)

Israel
Wise (0.71 m)

Qatar
Qatar Univ. (0.3 m)

Kenya
OPTiK (0.4 m)

Namibia
Drebach South (0.4 m)
Springbok (0.36 m)

Réunion
Les Makes (0.6 m)

Australia
LCOGT (1 m)

Chile
ALMA
VLT (8.2 m x 4)
Magellan (6.5 m)
SOAR (4.1 m)
La Silla (1.54 m)
LCOGT (1 m)
Swope (1 m)
ATLAS (0.5 m)

Argentina
Jorge Sahade (2.15 m)
EABA Bosque Alegre (1.5 m

Antarctica
ASTEP (0.4 m)

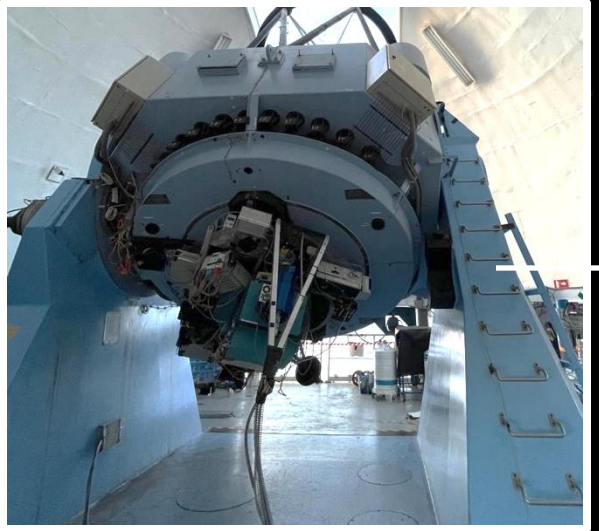
New Zealand
Mt. John (1.8 m)

HST

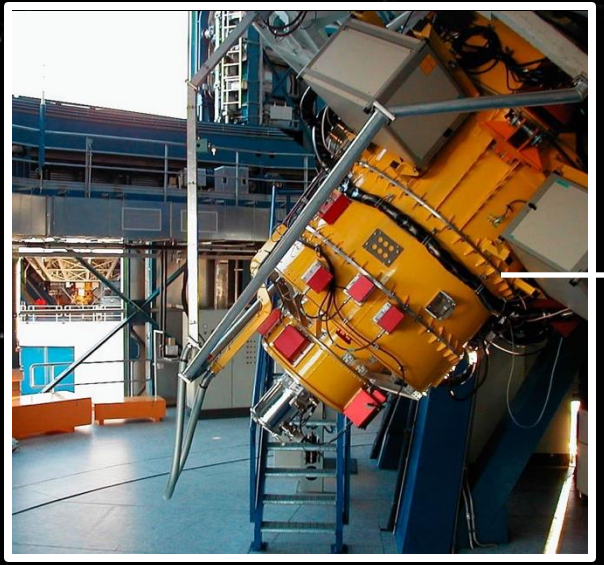
JWST

Lucy

2. Observations & Methods: Instruments & Obs. Mode

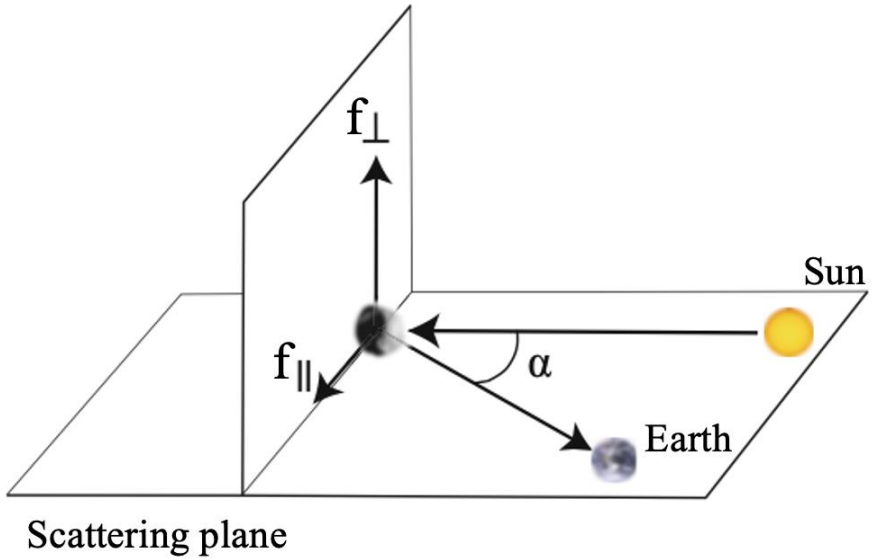


ALFOSC @ NOT:
Imaging-Polarimetry

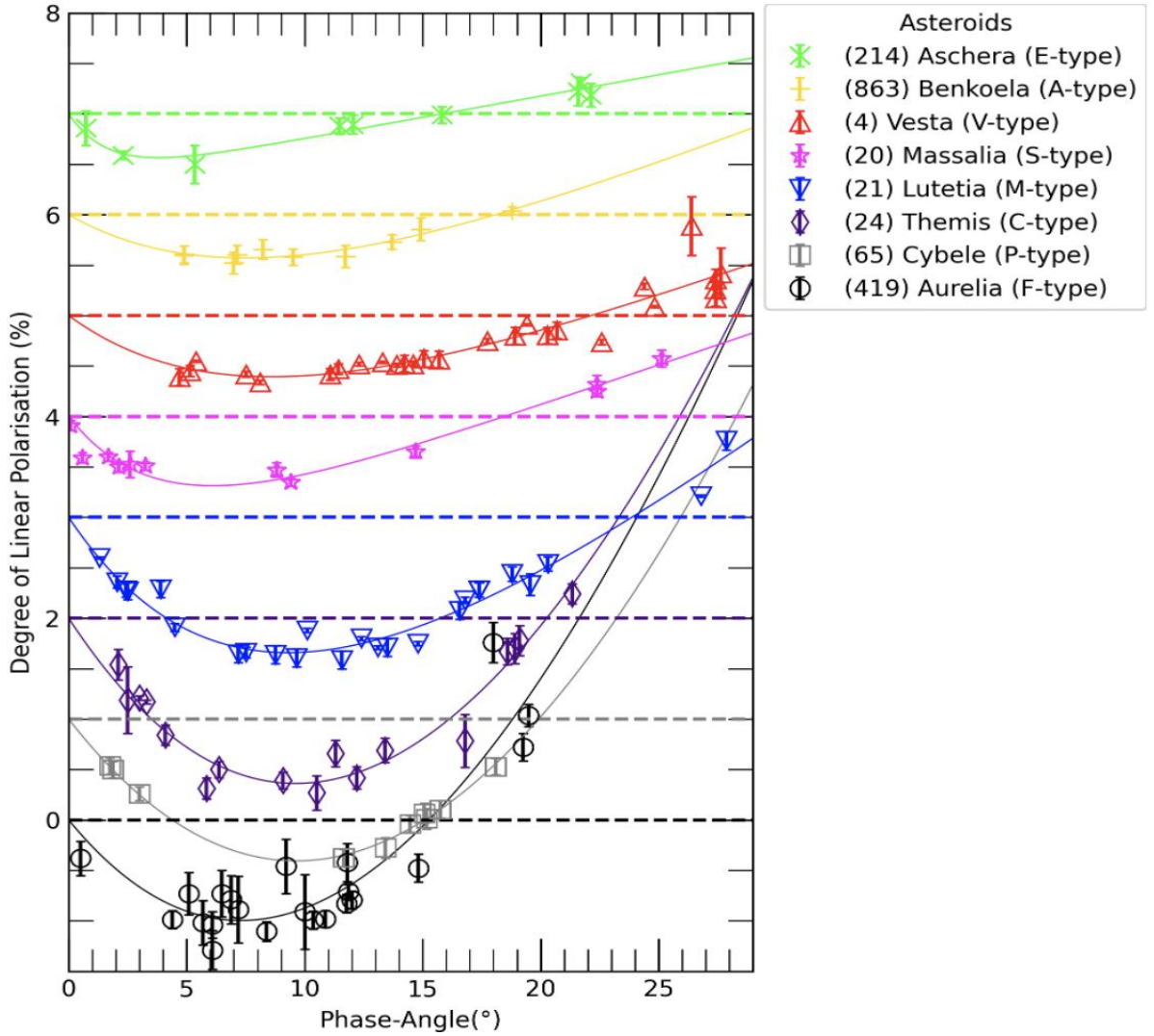


FORS2 @ VLT:
Imaging-Polarimetry &
Spectro-Polarimetry

2. Observations & Methods:

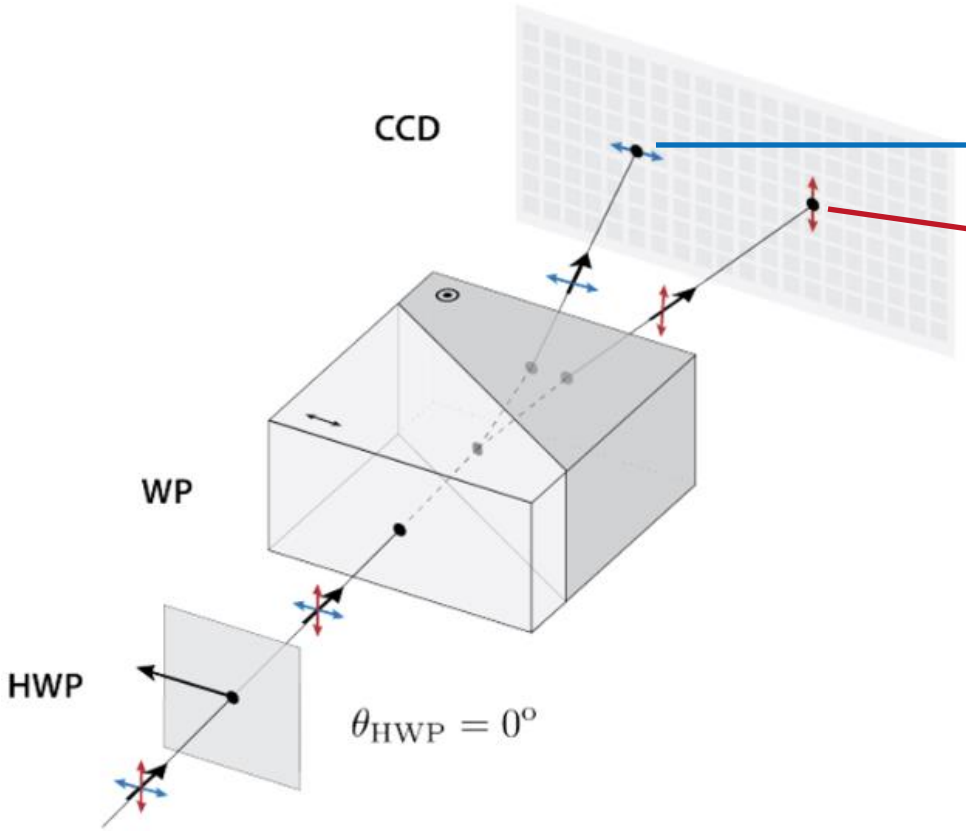


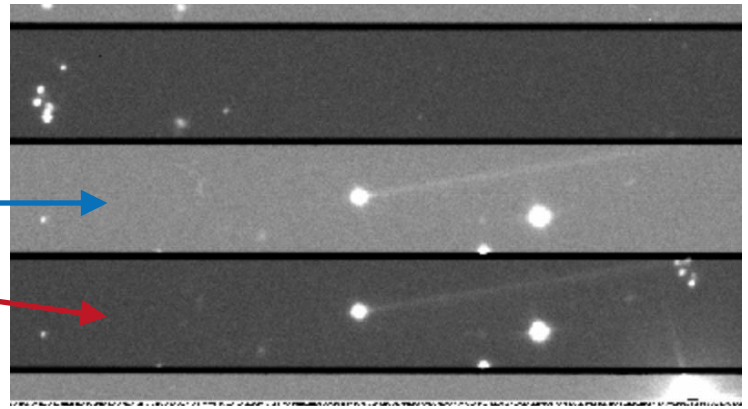
$$P_Q = \left(\frac{f^{\perp} - f^{\parallel}}{f^{\perp} + f^{\parallel}} \right)$$



2. Observations & Methods: Data Reduction

Beam swapping technique





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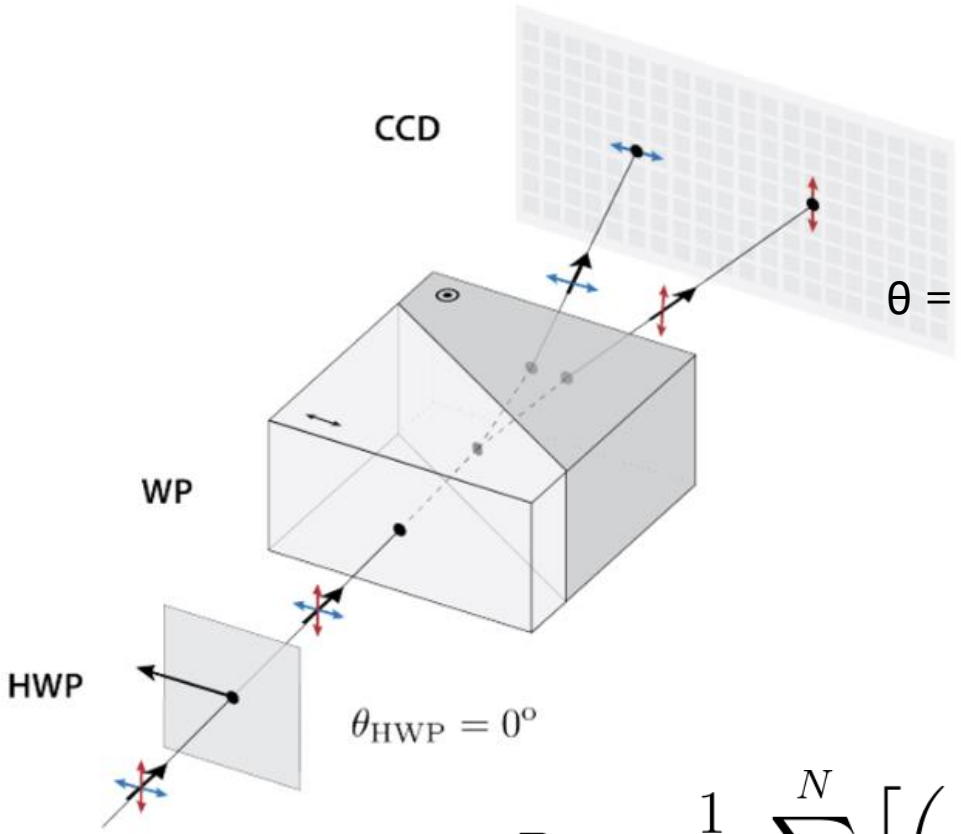
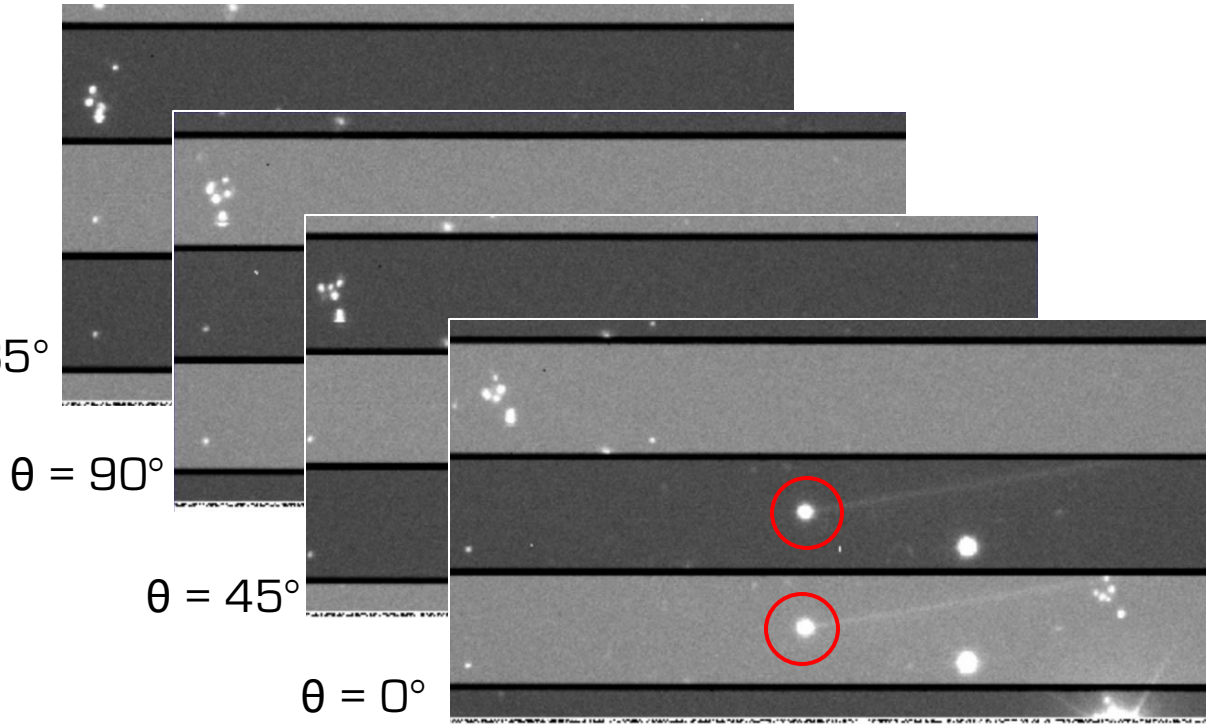
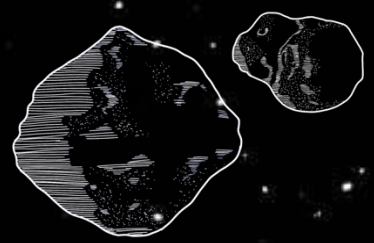




$$P_Q = \frac{1}{2N}\sum^{N}\left[\left(\frac{f^{\perp}-f^{\parallel}}{f^{\perp}+f^{\parallel}}\right)_{\theta} - \left(\frac{f^{\perp}-f^{\parallel}}{f^{\perp}+f^{\parallel}}\right)_{\theta+45°}\right] \qquad \theta = (0, 90, 180, 270)°$$



2. Observations & Methods:

Pre-Impact
(T-1.3 months to T-15 hrs)

α = 20→52°

Post-Impact
(T+4 hrs to T+3 weeks)

α = 53→76°

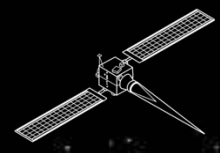
Post-Post-Impact
(T+3 weeks to T+4 months)

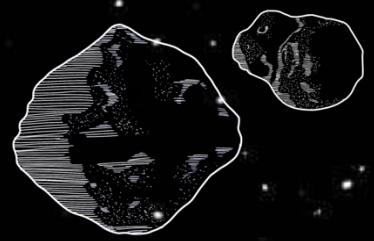
α = 76→7°

The system is unperturbed.

The system is characterised by a persistent dust cloud.

The cloud is mostly dissipated.





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Pre-Impact
(T-1.3 months to T-15 hrs)

α = 20→52°

Post-Impact
(T+4 hrs to T+3 weeks)

α = 53→76°

Post-Post-Impact
(T+3 weeks to T+4 months)

α = 76→7°

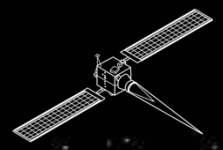
New Observations
(T+2 years)

α = 4→67°
...and more to come

The system is unperturbed.

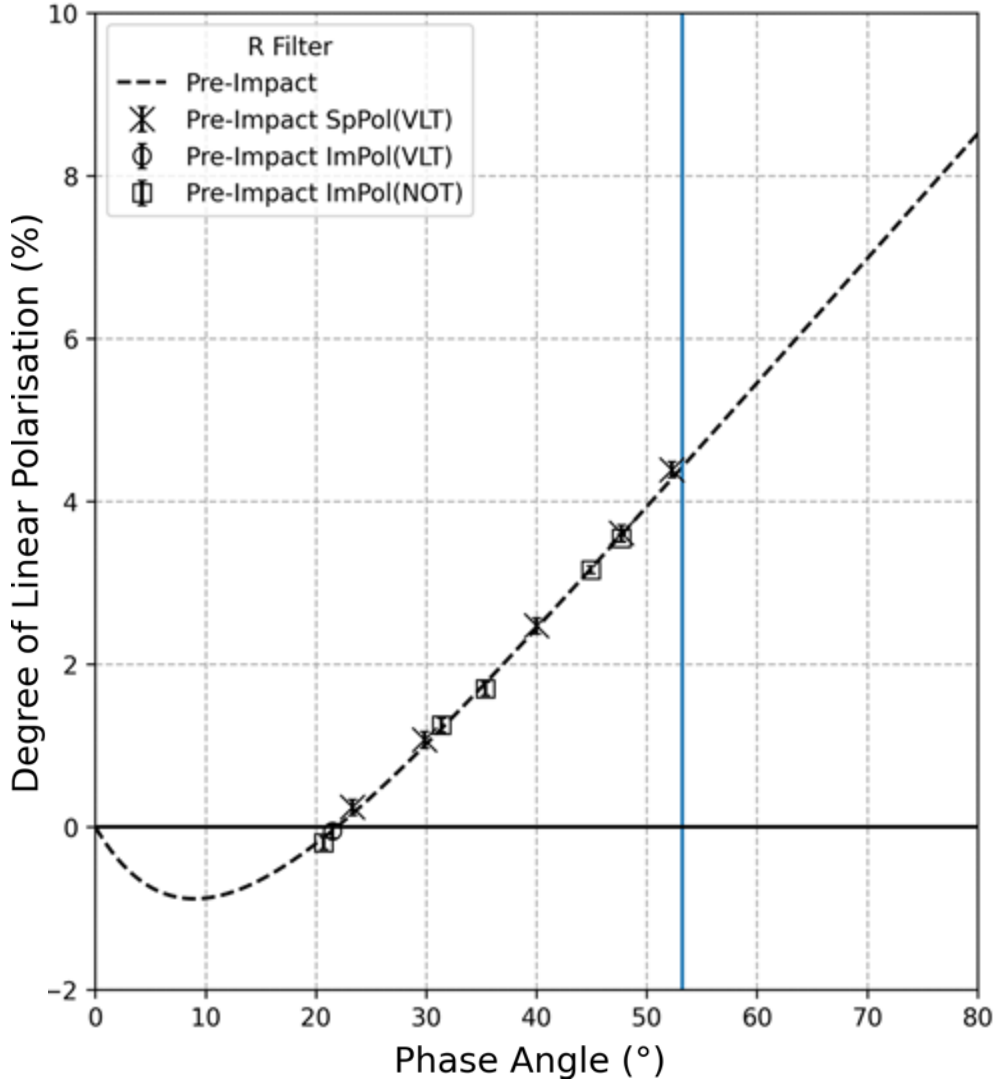
The system is characterised by a persistent dust cloud.

The cloud is mostly dissipated.

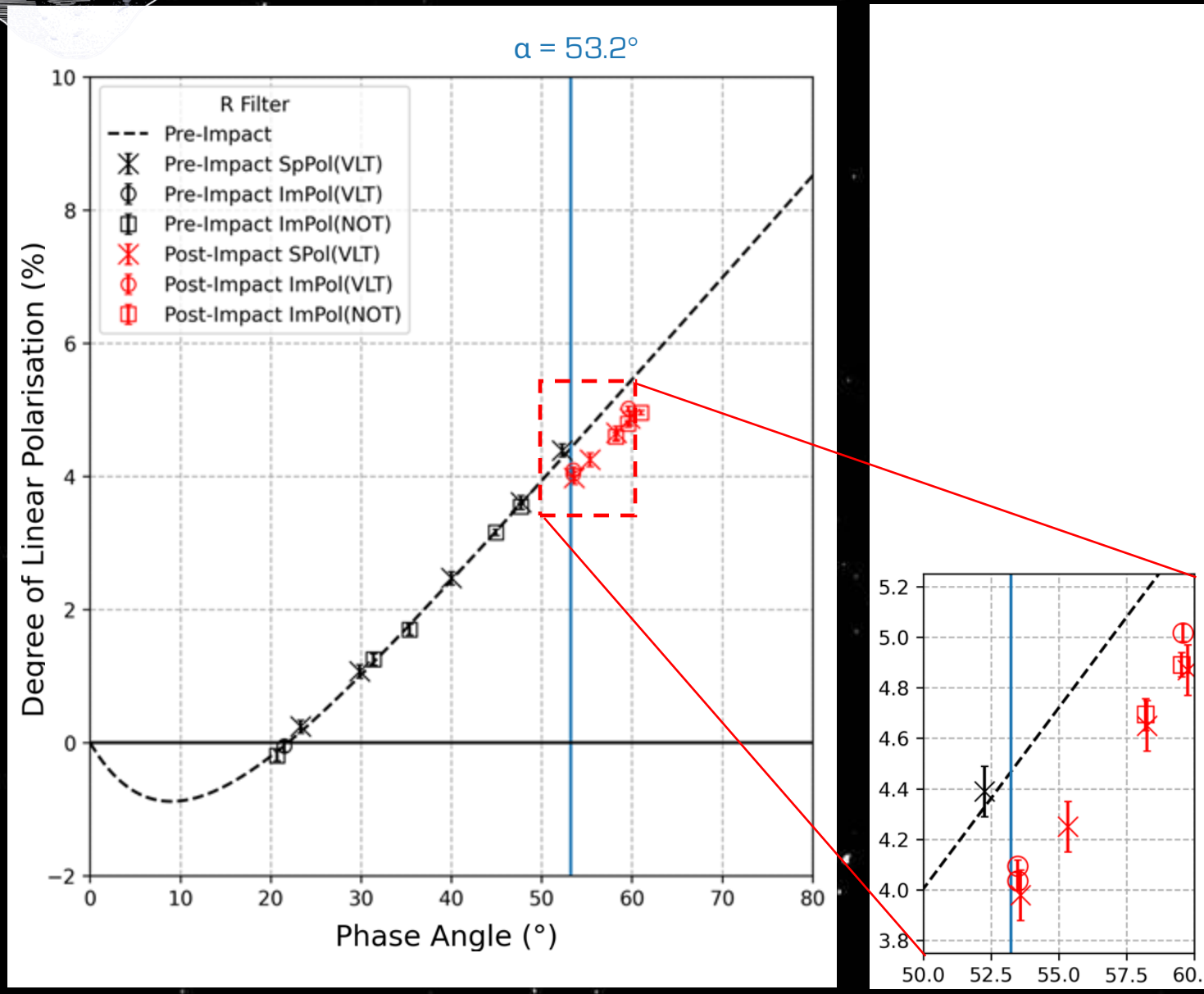


3. Results I: Pre-Impact

α = 53.2°



3. Results II: Post-Impact



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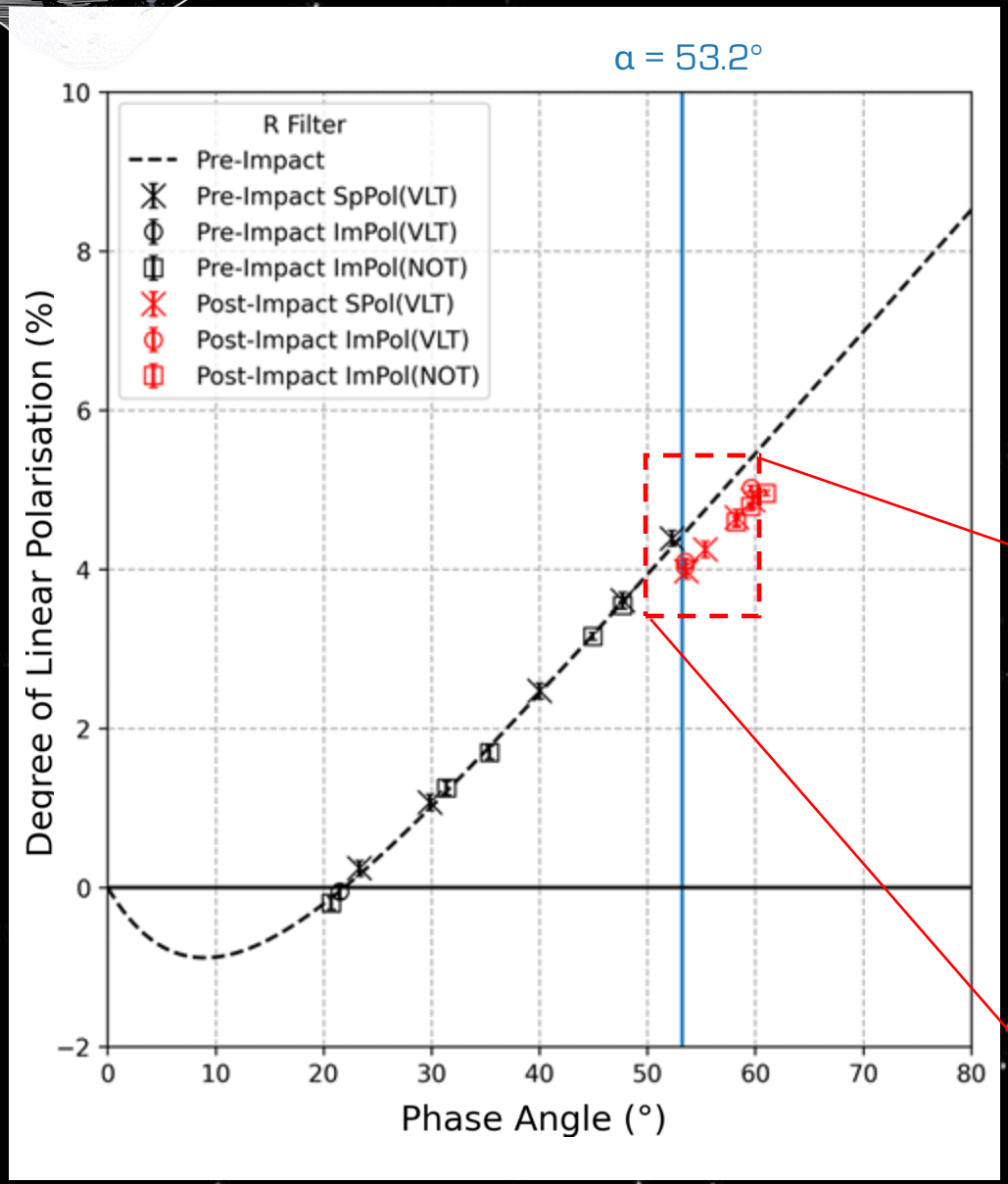
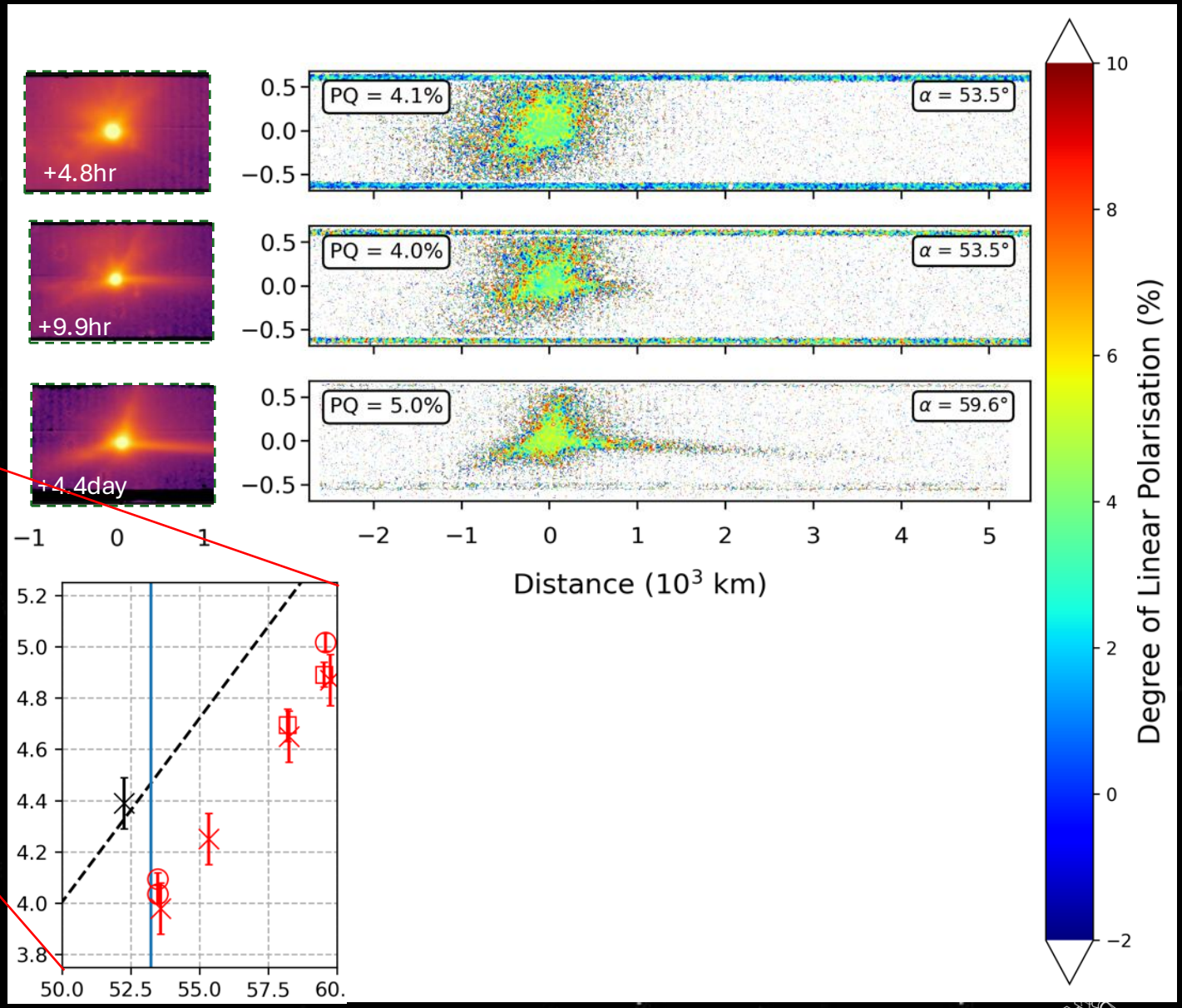


Imaging Maps

Polarimetric Maps



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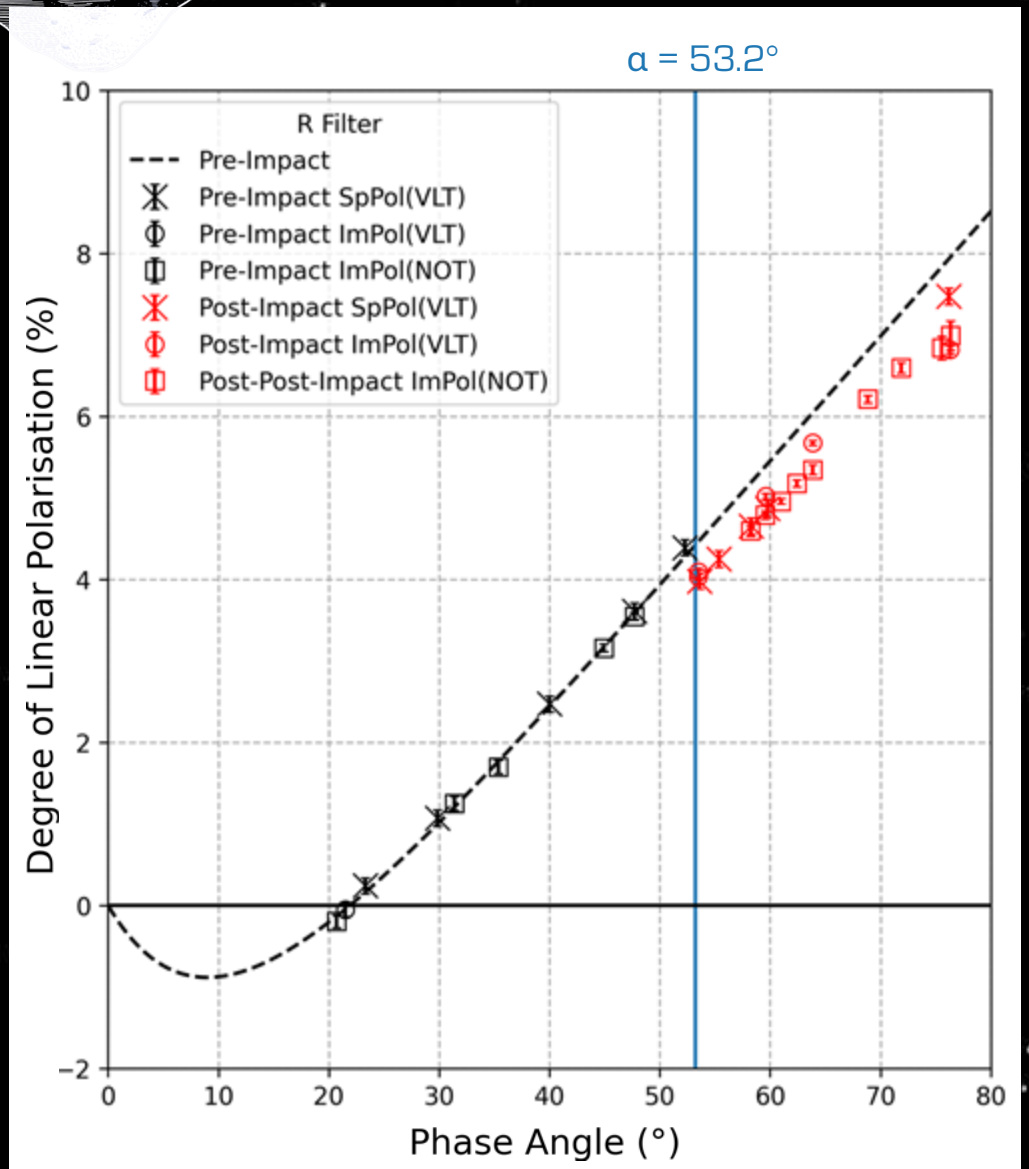

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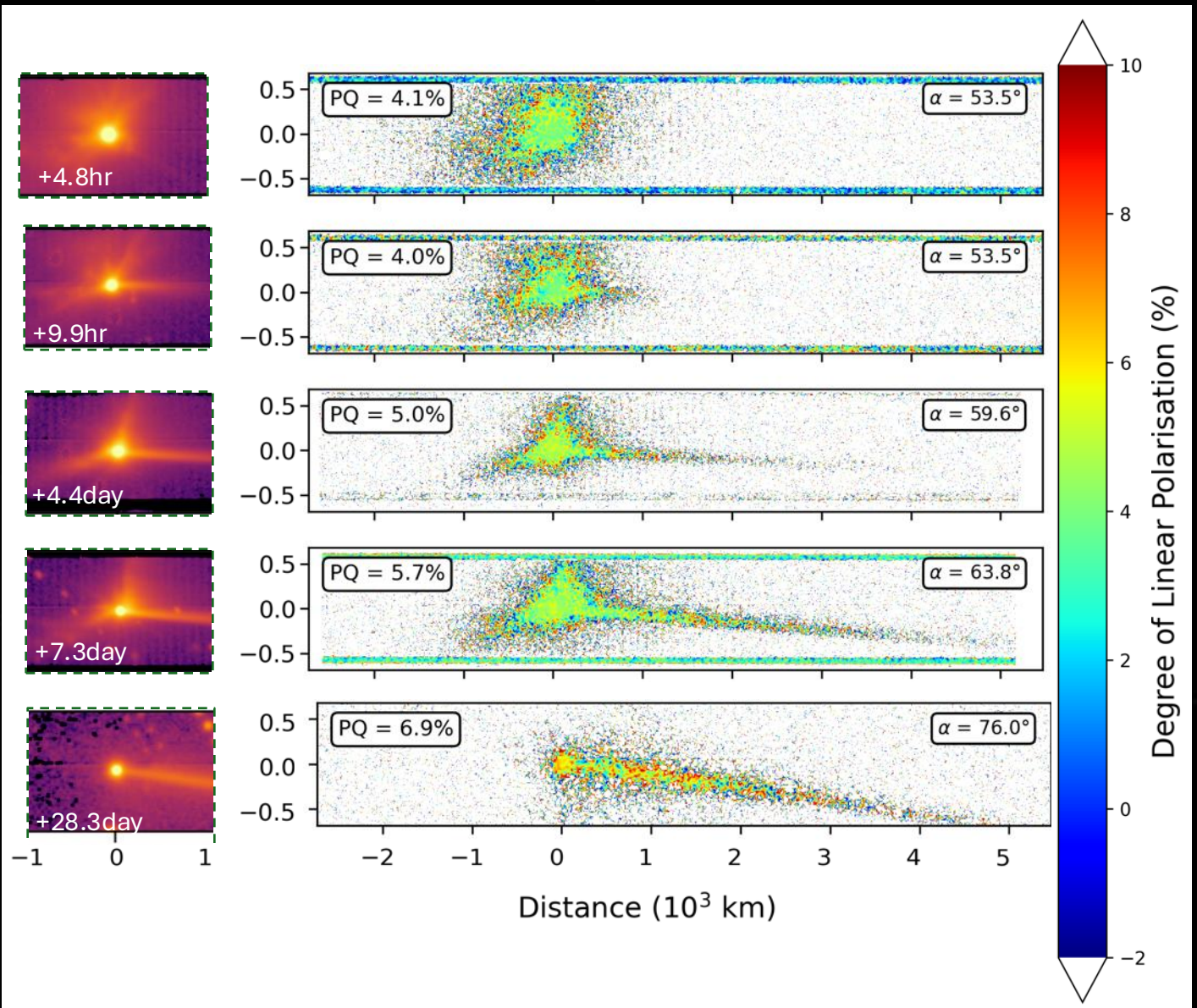

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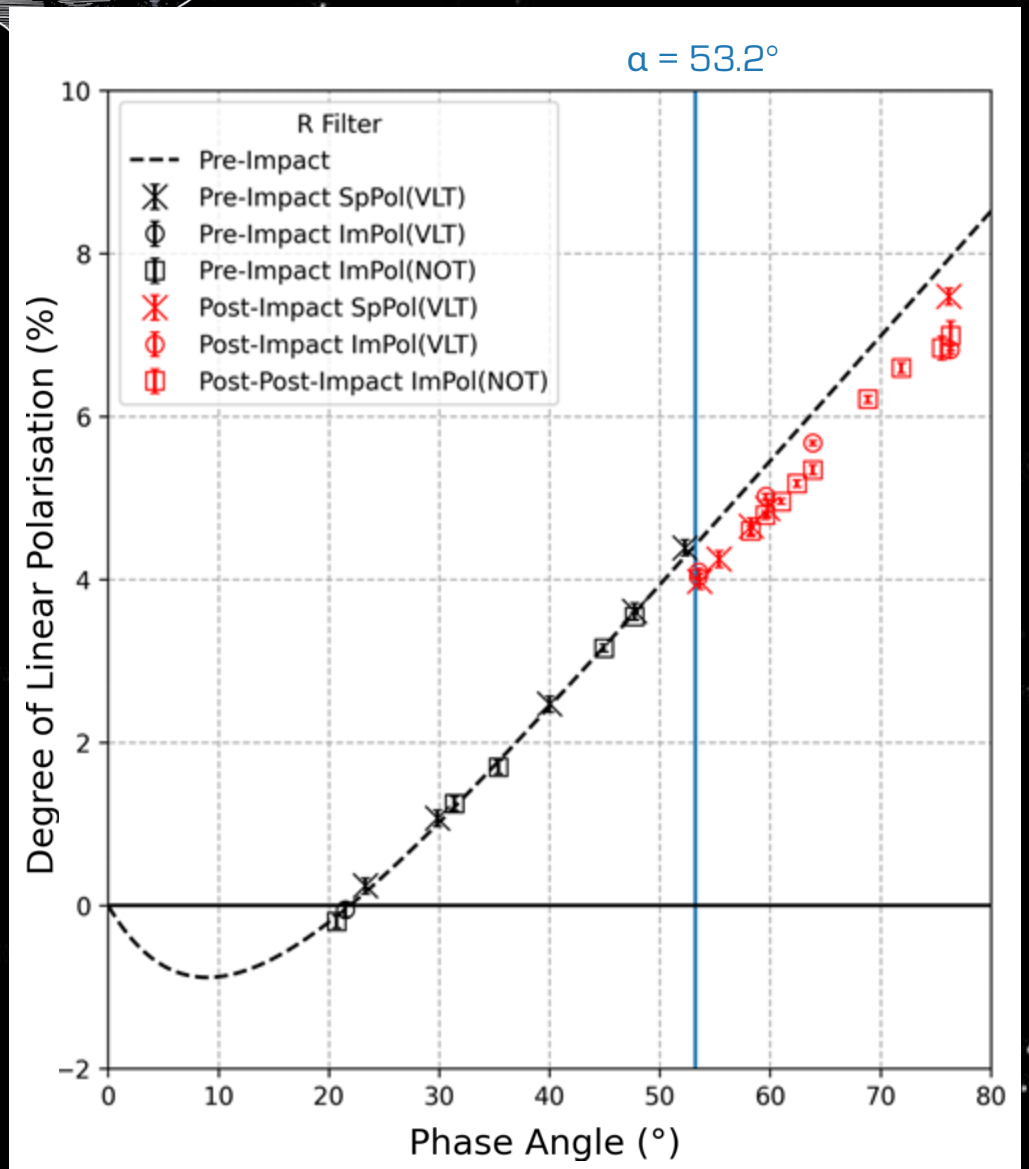

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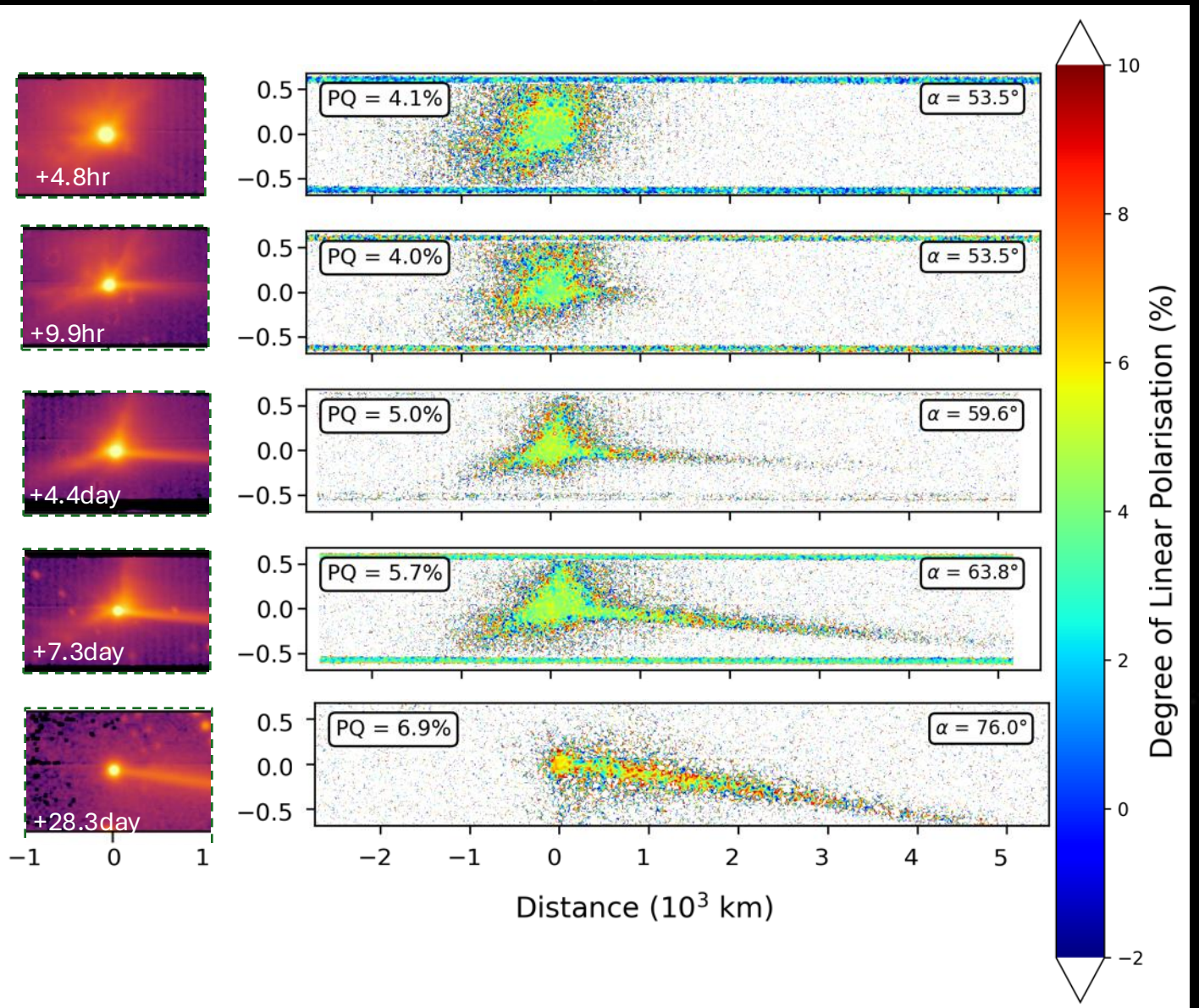
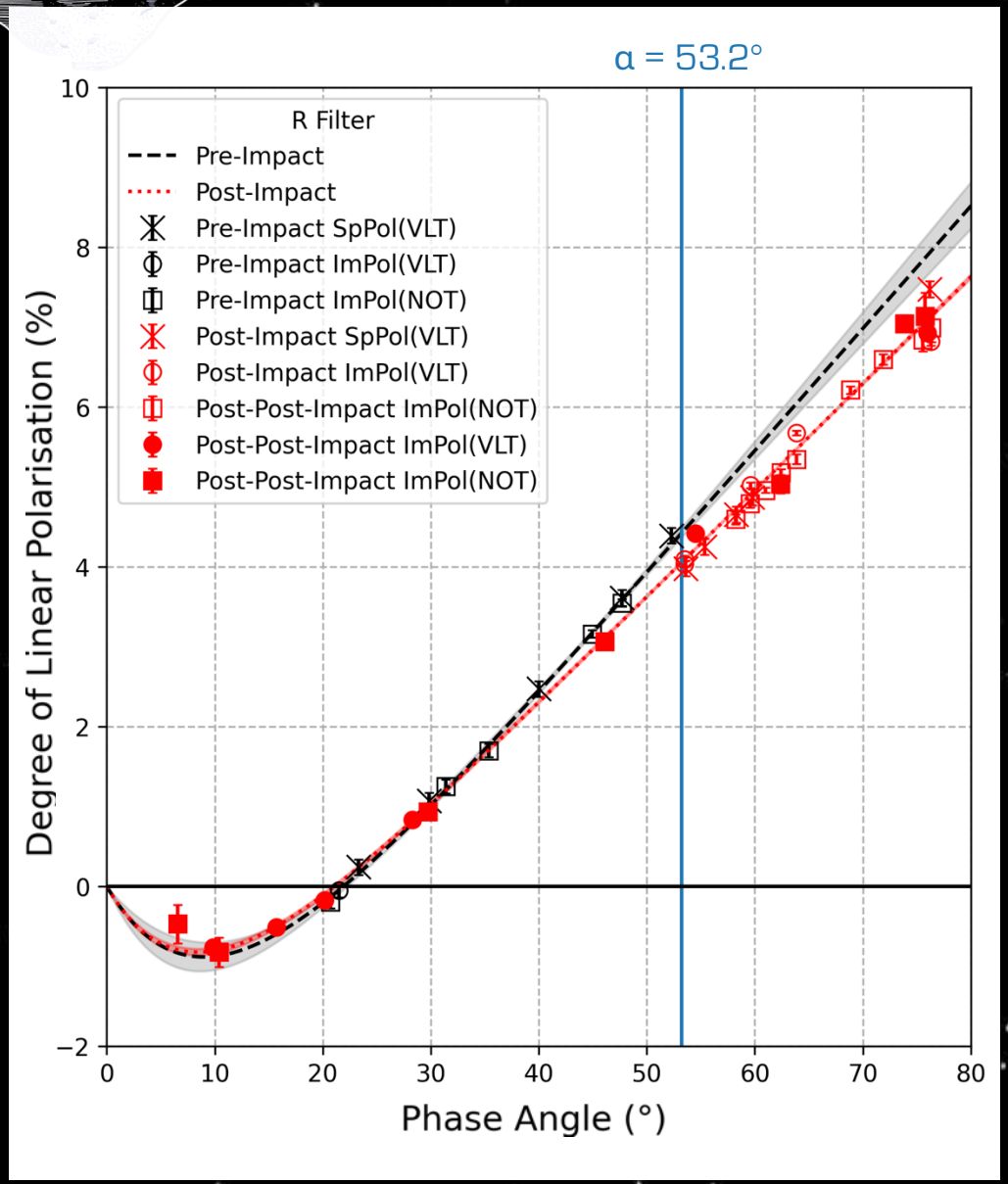
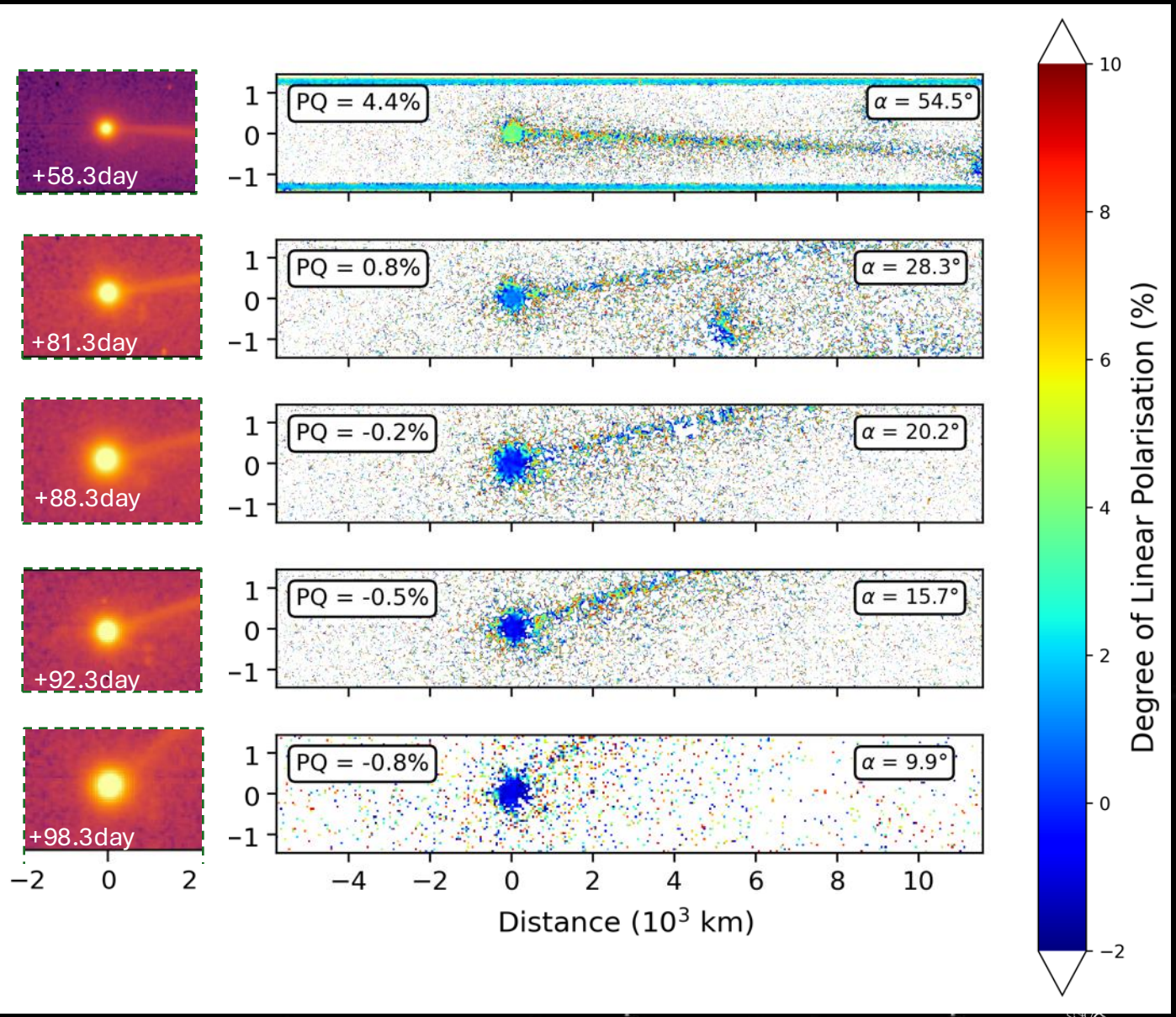


3. Results III: Post-Post-Impact

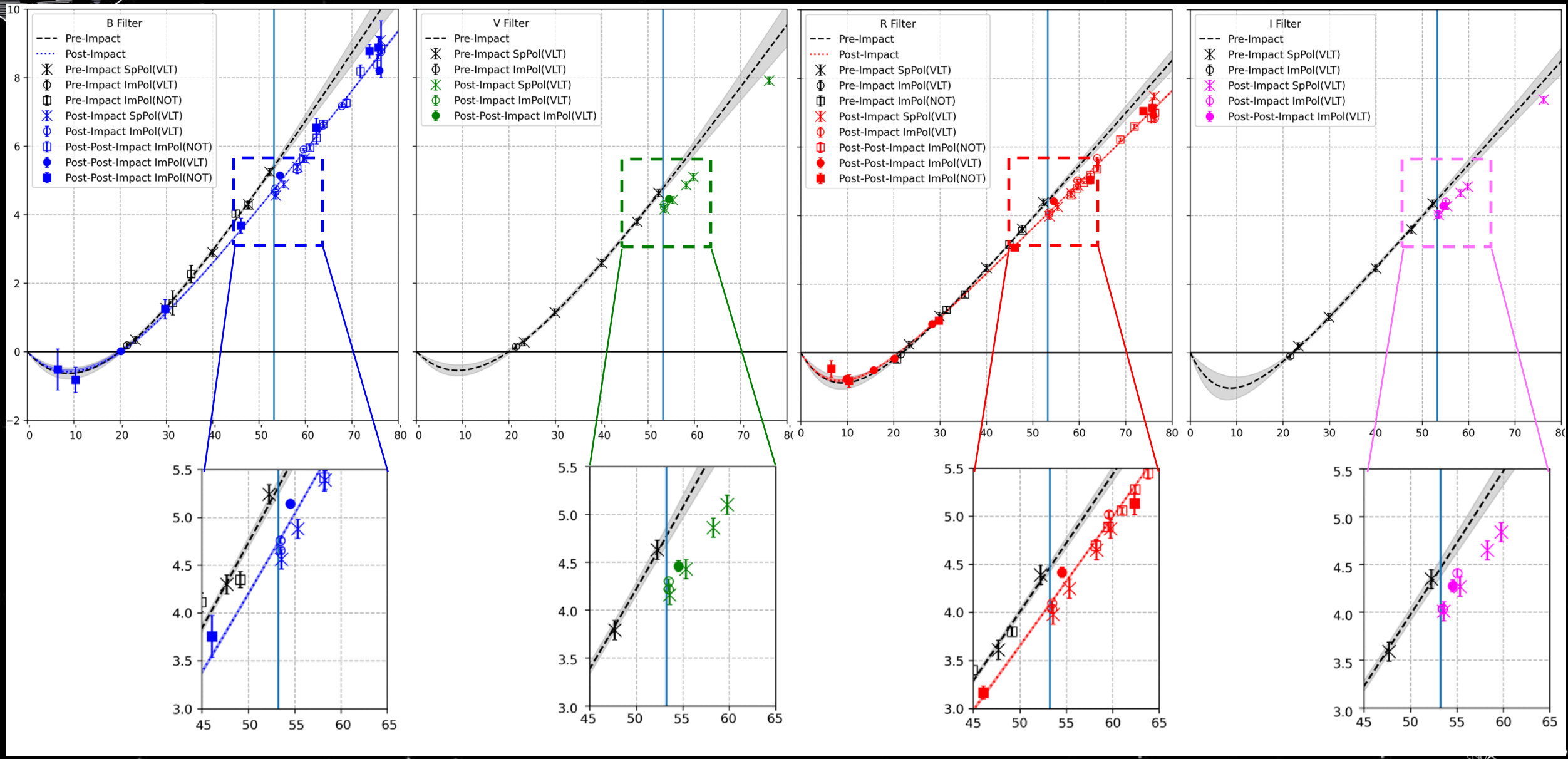


Imaging Maps

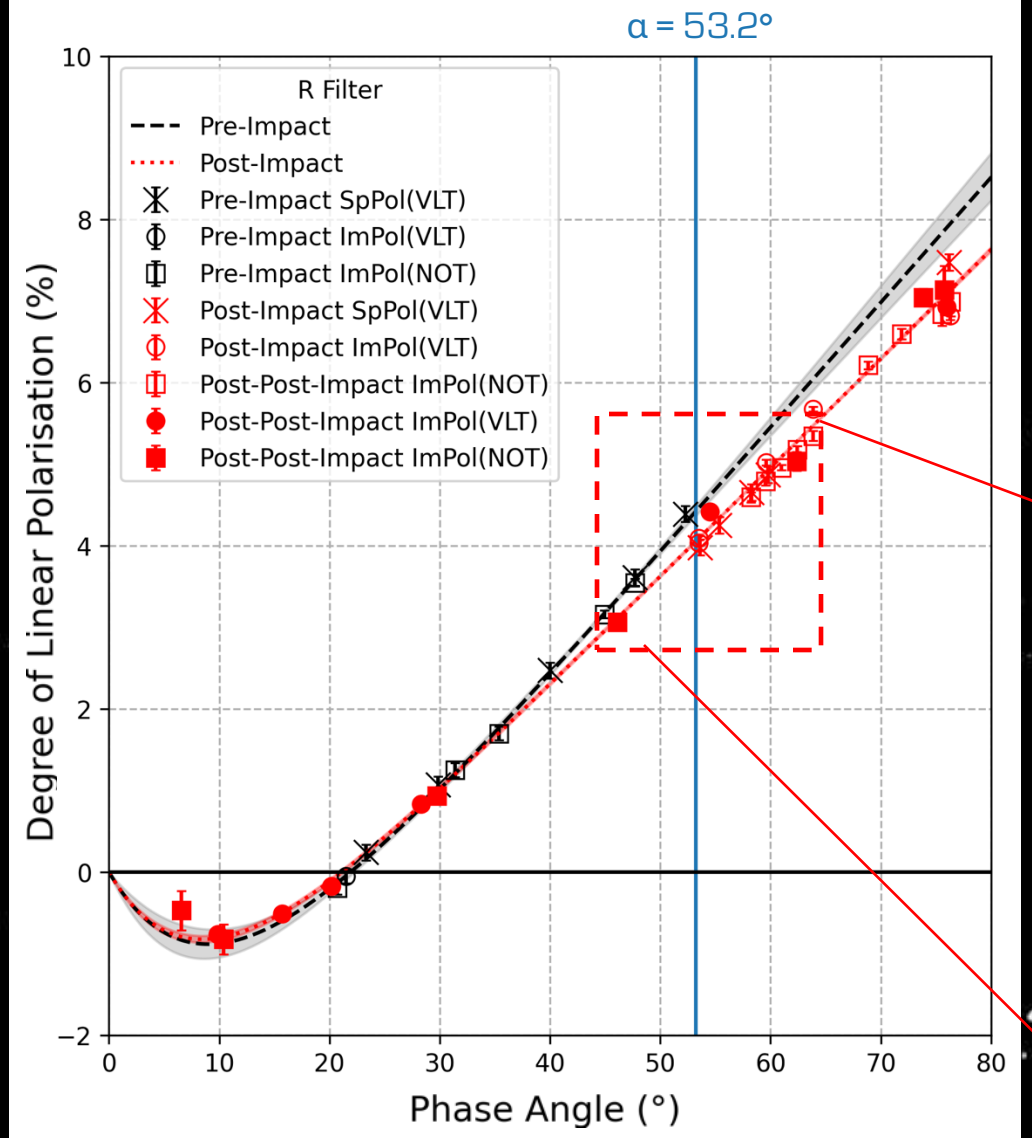
Polarimetric Maps

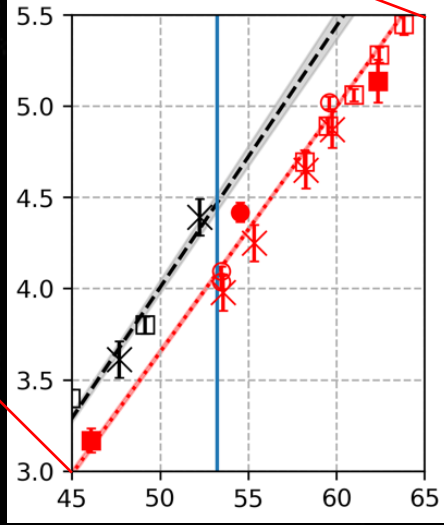


3. Results: All Filters



4. Discussion

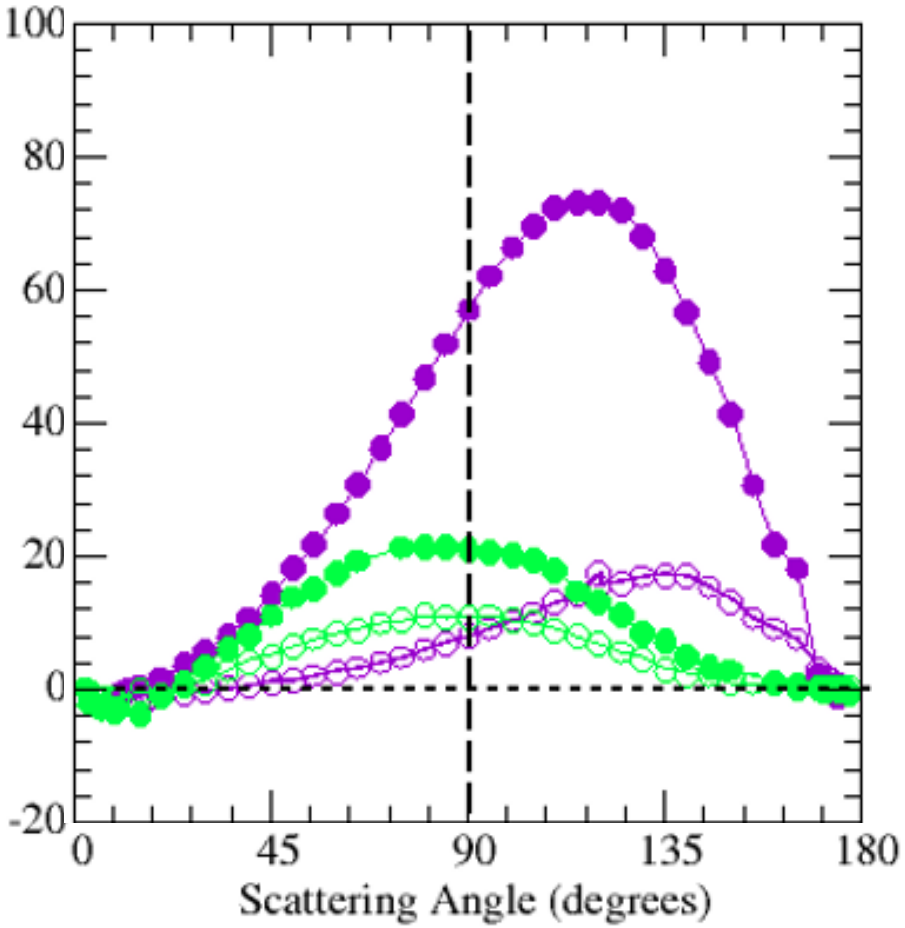


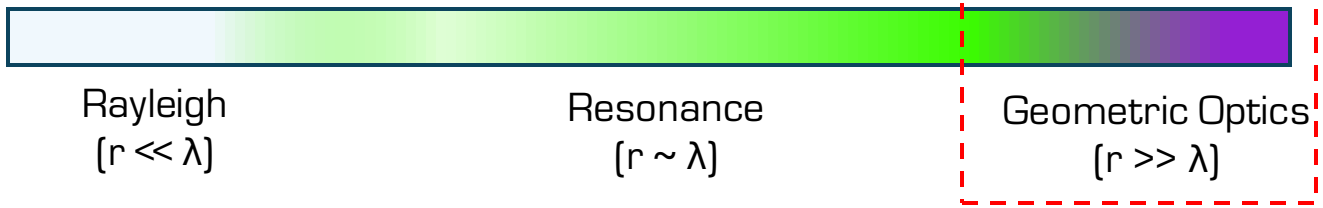


(i) Pre-Impact: typical polarisation phase angle dependence.

(ii) Post-Impact: dramatic drop in polarisation after impact.

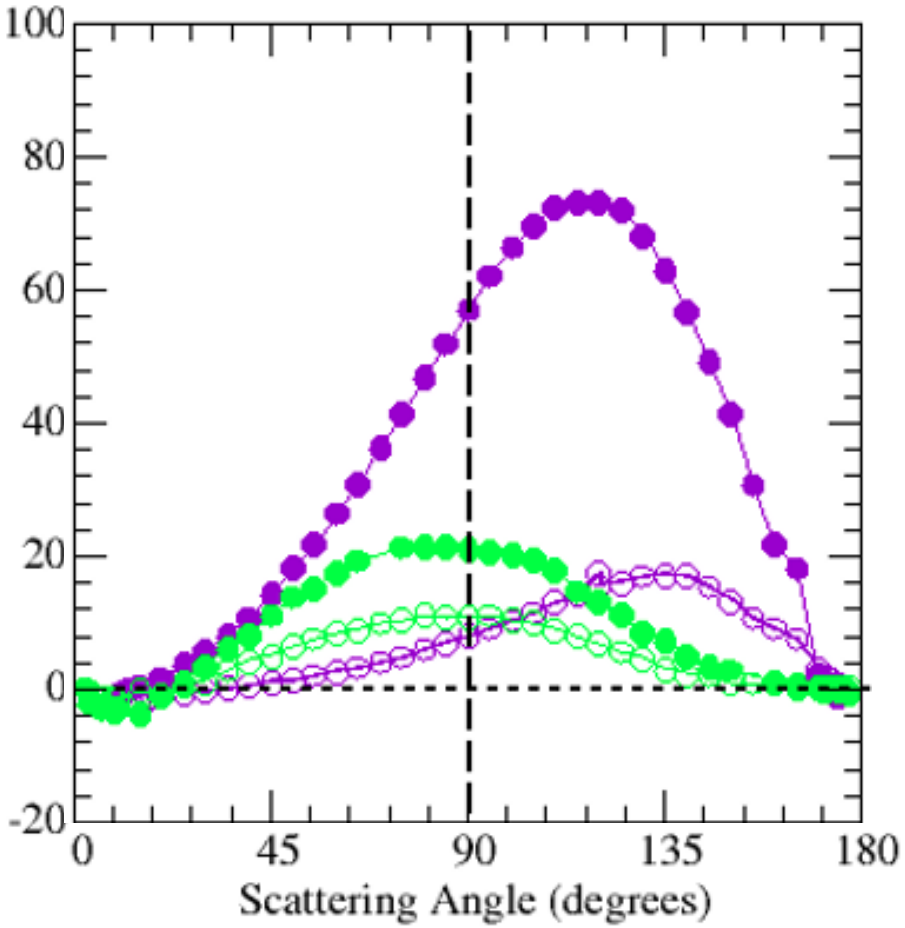
4. Discussion





Muñoz et al. (2020)

4. Discussion



Rayleigh
(r ≪ λ)

Resonance
(r ~ λ)

Geometric Optics
(r >> λ)

Dark

Bright

mm-sized

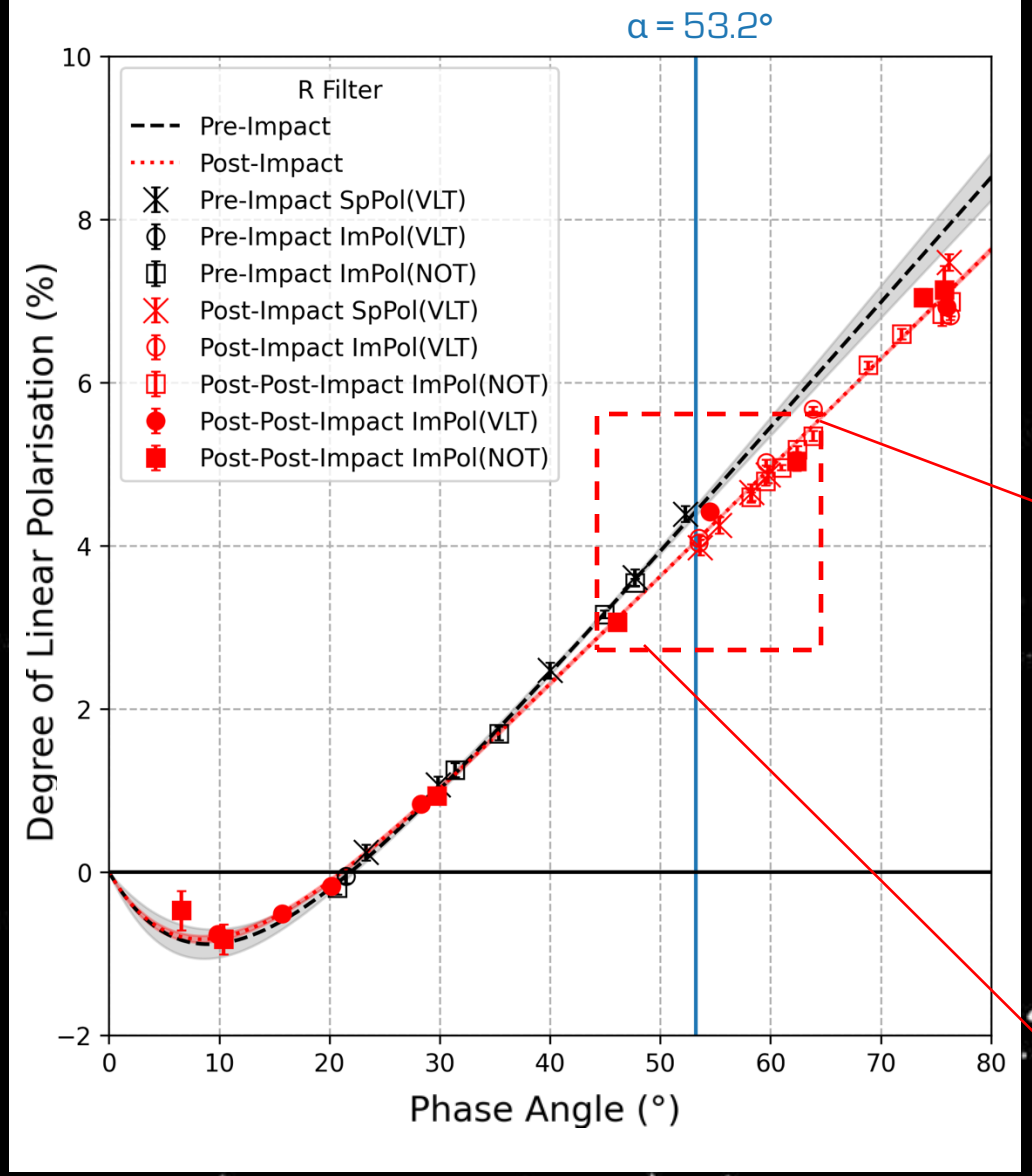
micron-sized

$P_{Dark} > P_{Bright}$

$P_{Larger} > P_{Smaller}$

Muñoz et al. (2020)

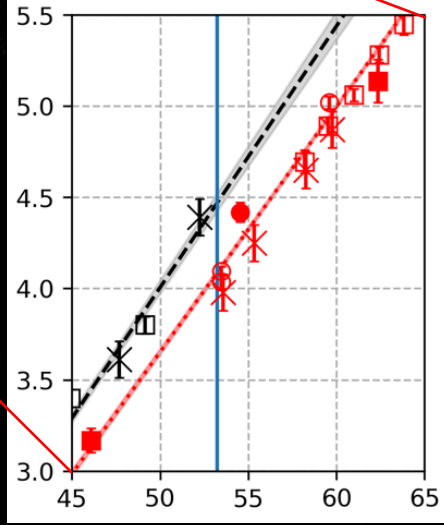
4. Discussion



(i) Pre-Impact: typical polarisation phase angle dependence.

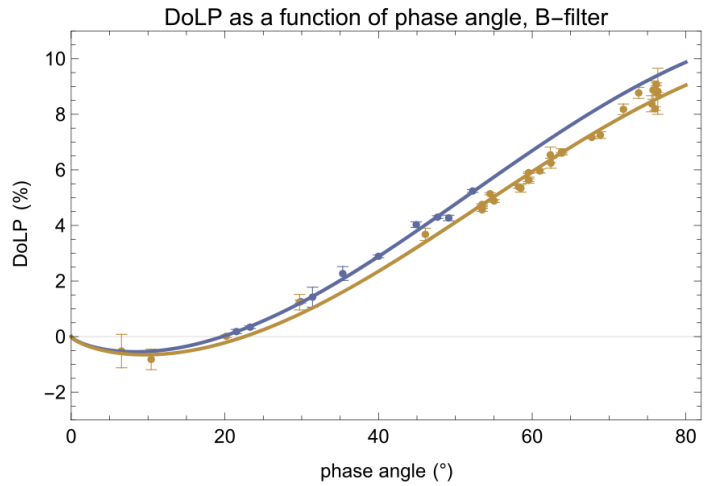
(ii) Post-Impact: dramatic drop in polarisation after impact.

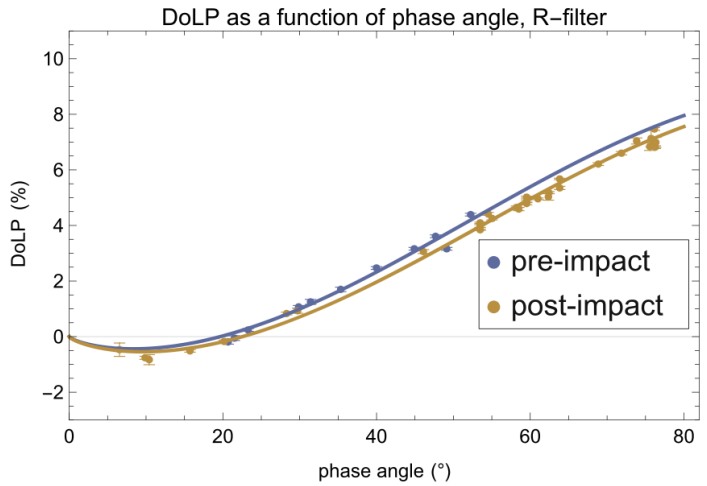
- The ejected particles are smaller and/or brighter than those on the pre-impact surface.

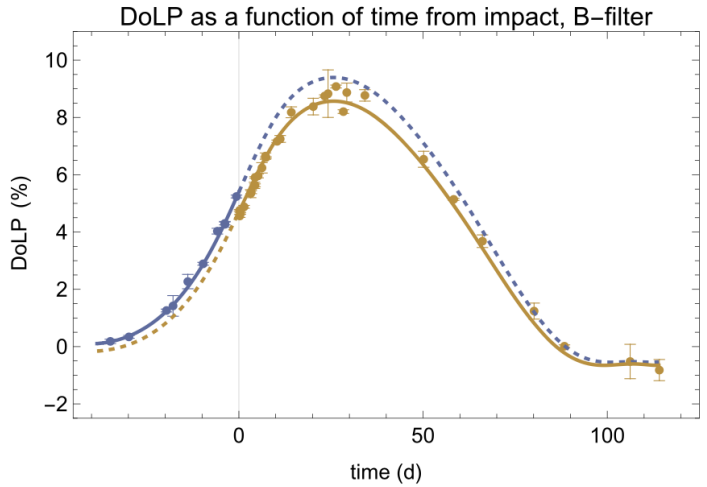


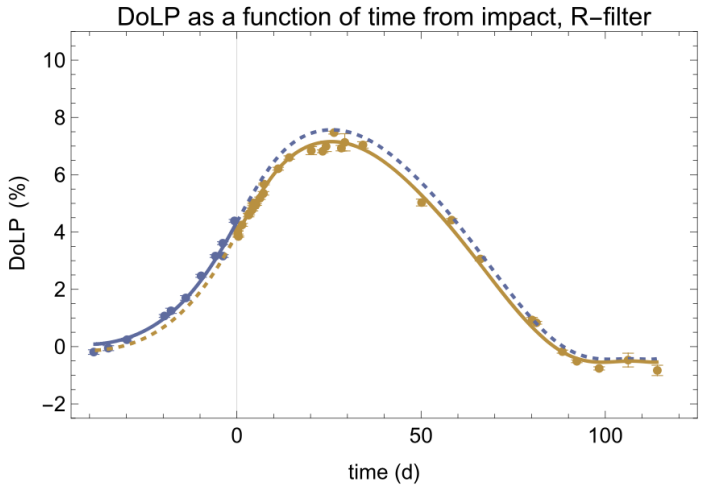
4. Discussion:

Penttilä et al. (2024), Modelling Linear Polarisation of Didymos-Dimorphos before and after the DART impact.





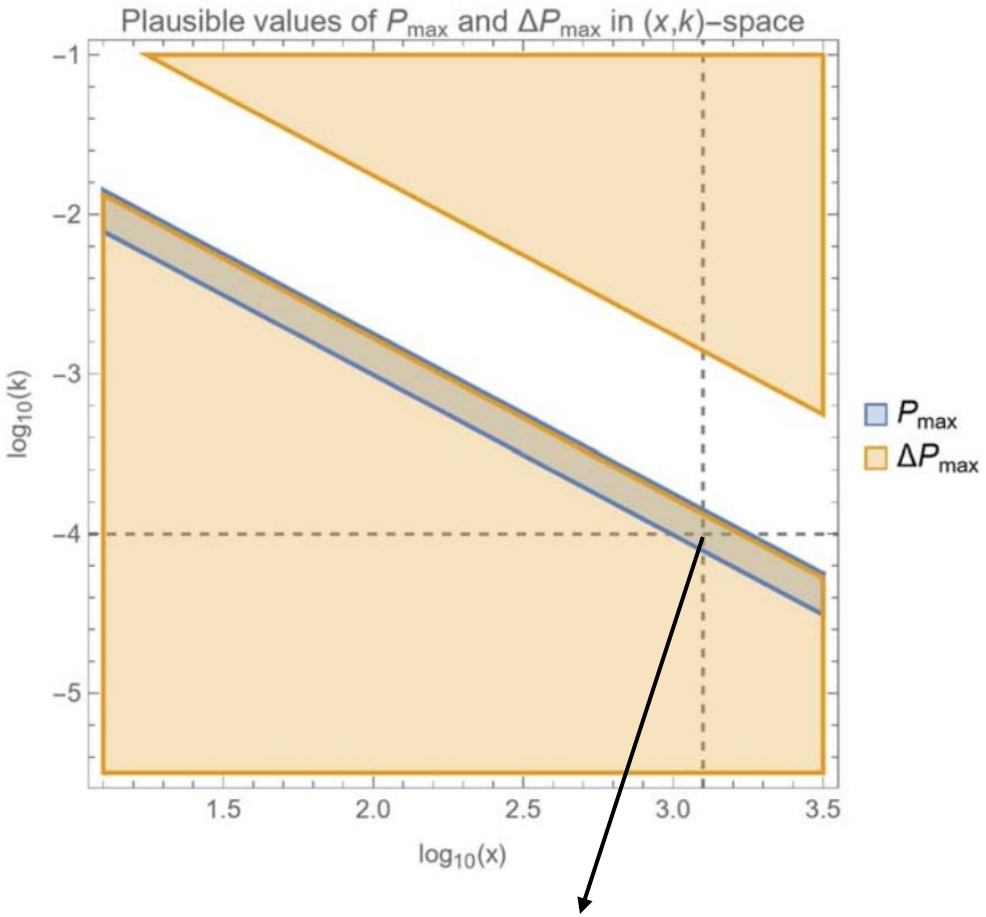




$$P_m(\alpha;\, b,\, c_1,\, c_2,\, \alpha_0) = b\, \sin^{c_1}\alpha\, \cos^{c_2}\frac{1}{2}\alpha\, \sin(\alpha - \alpha_0)$$

4. Discussion

Penttilä et al. (2024), Modeling Linear Polarisation of Didymos-Dimorphos before and after the DART impact.

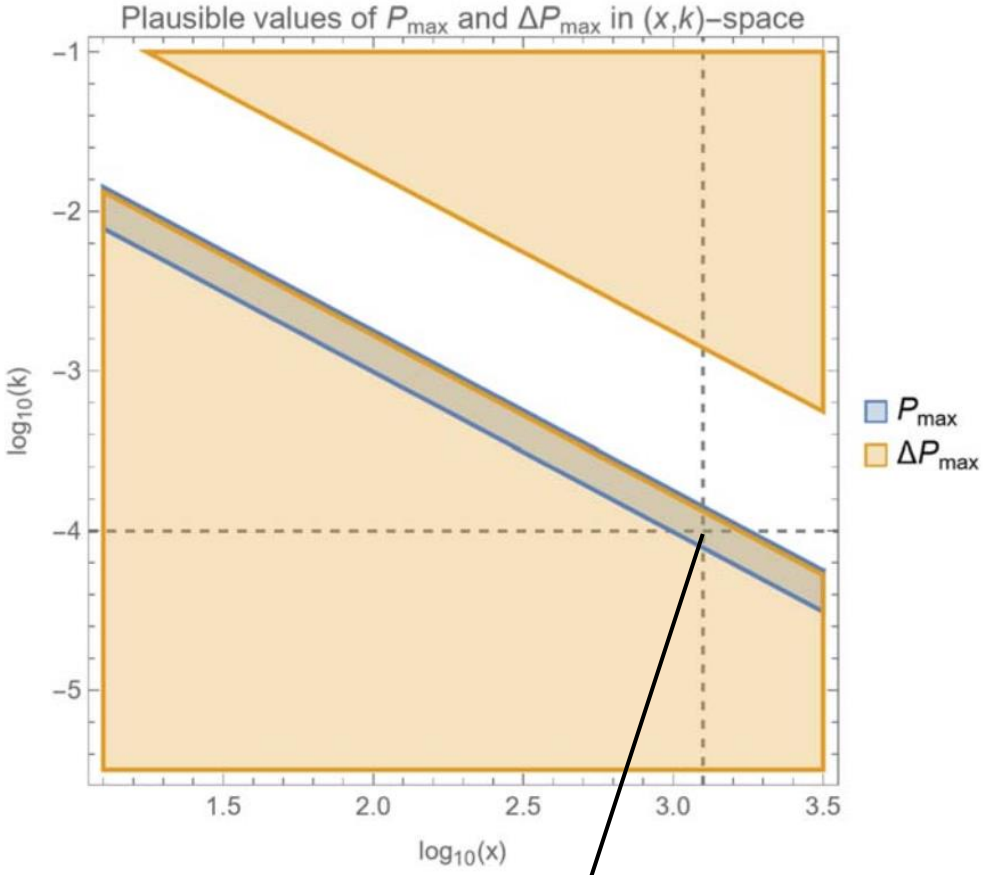


$x = 2\pi r/\lambda$
$m = n + ik$

d ~ 200 µm
k ~ 10^(-4)

4. Discussion

Penttilä et al. (2024), Modeling Linear Polarisation of Didymos-Dimorphos before and after the DART impact.



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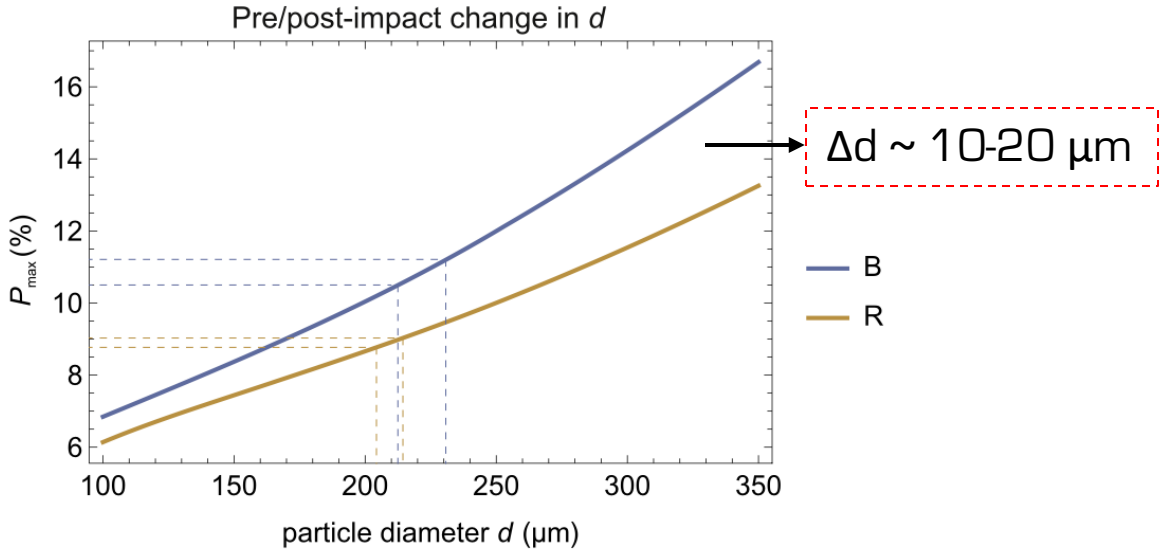
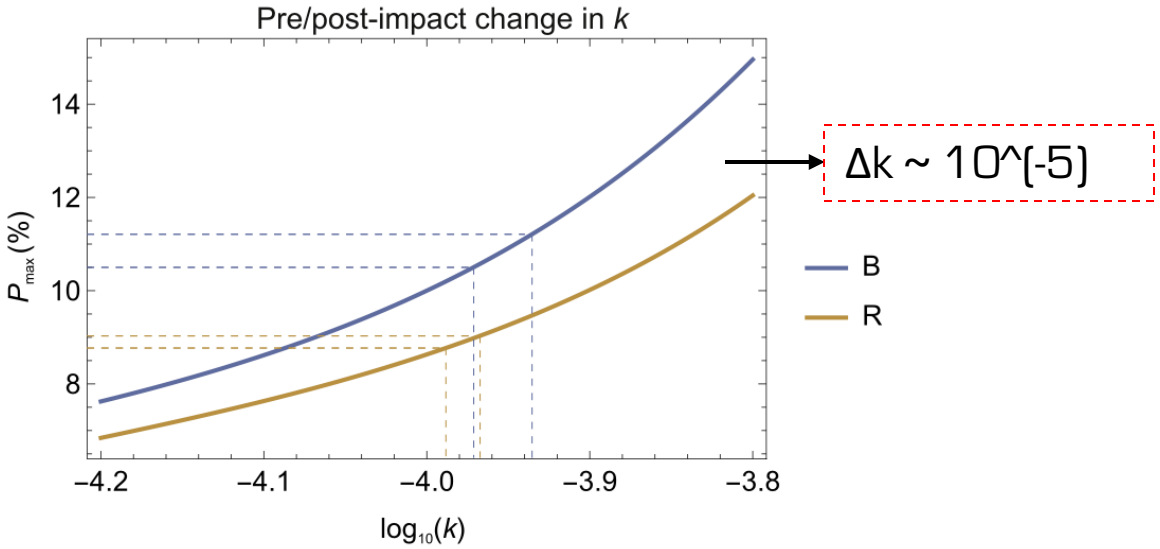


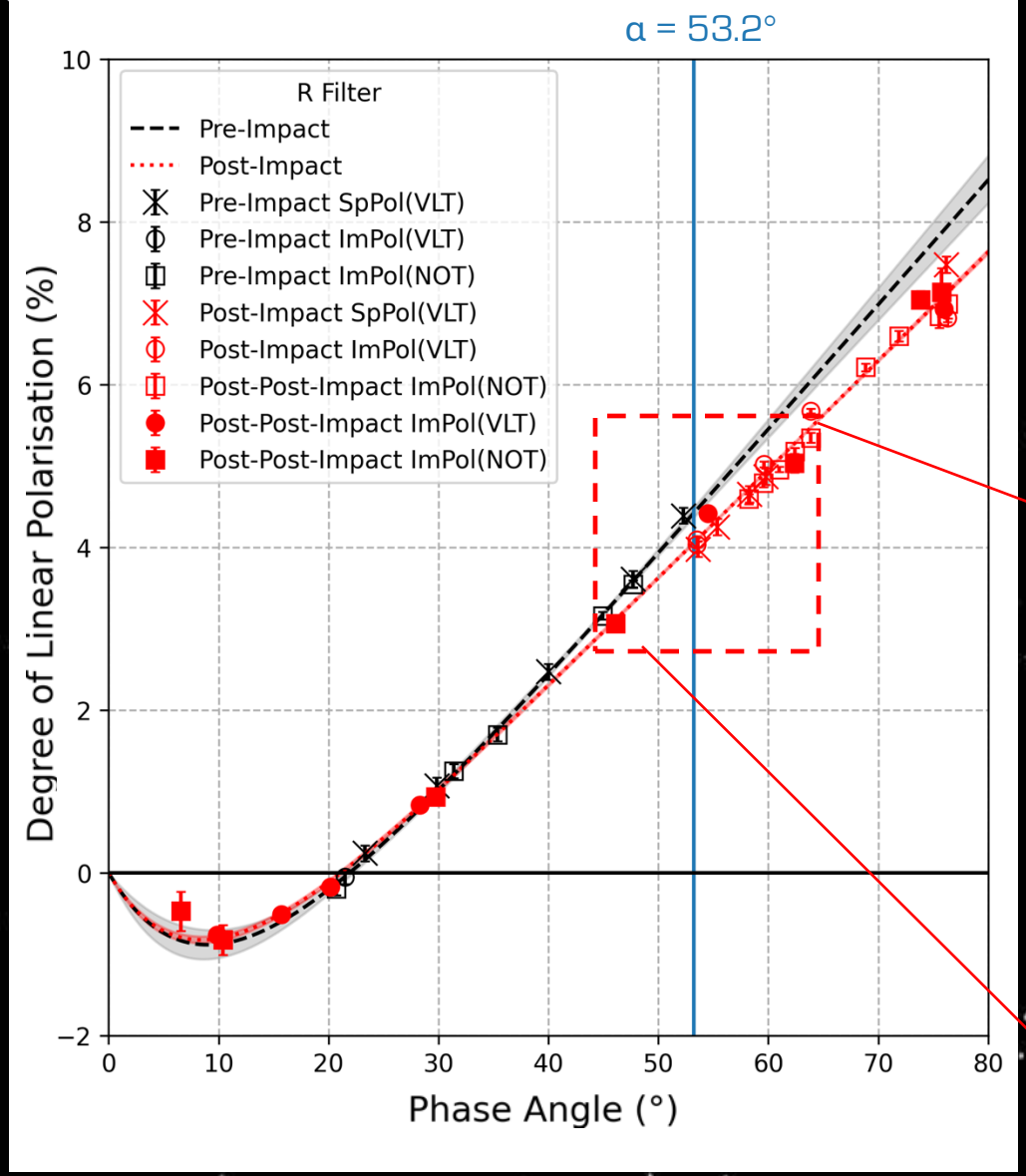
Δd ~ 10-20 µm



Δk ~ 10^(-5)

#2 Light-scattering simulations: particle properties derived from polarisation

4. Discussion

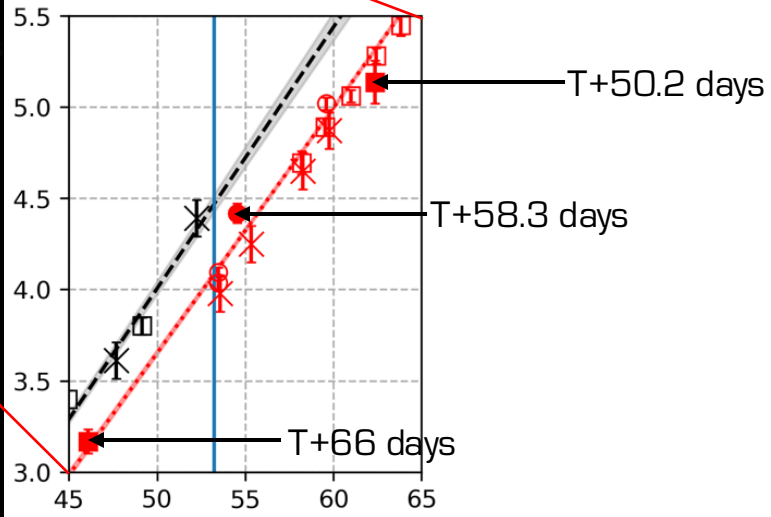


(i) Pre-Impact: typical polarisation phase angle dependence.

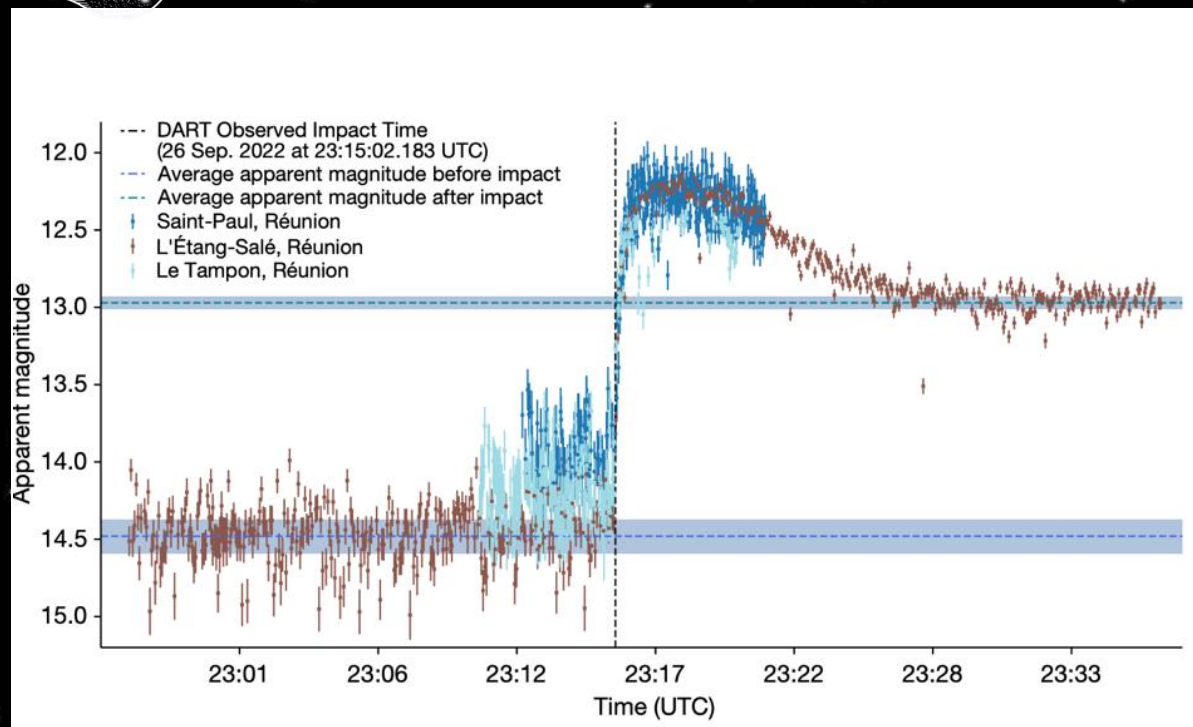
(ii) Post-Impact: dramatic drop in polarisation after impact.

- The ejected particles are smaller and/or brighter than those on the pre-impact surface.

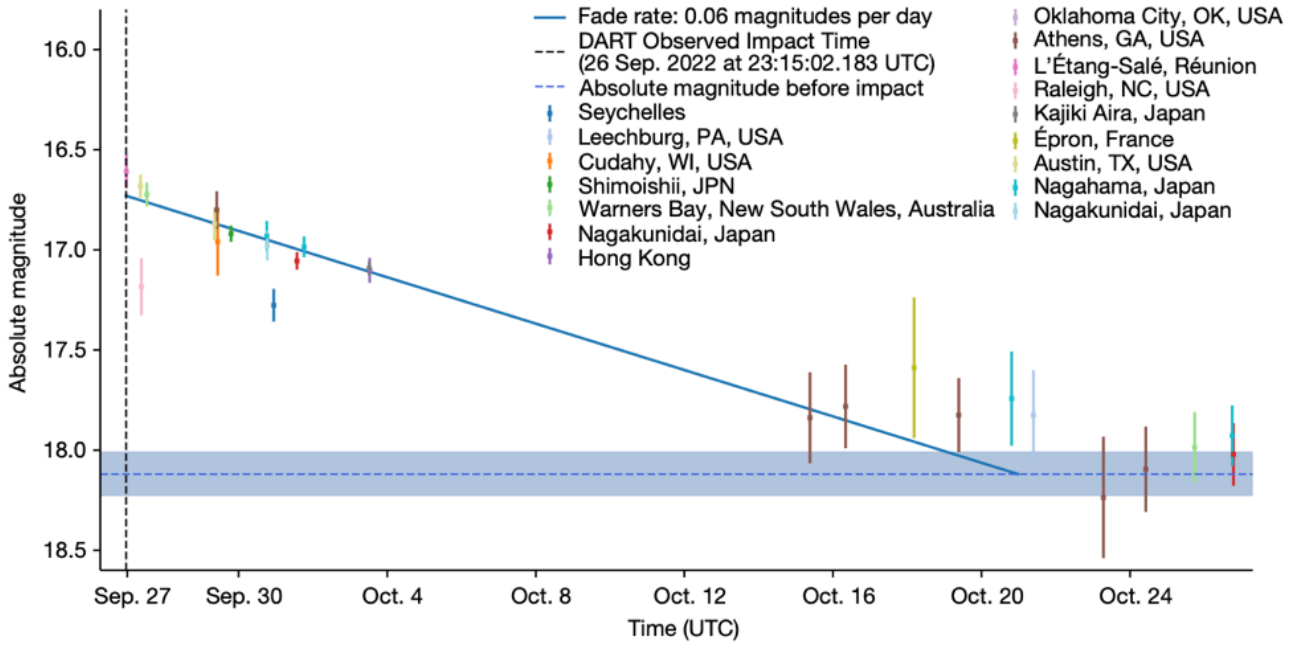
(iii) Post-Post-Impact: persistent lower level of polarisation, even months after impact.



4. Discussion



Brightening of ~ 2 magnitude

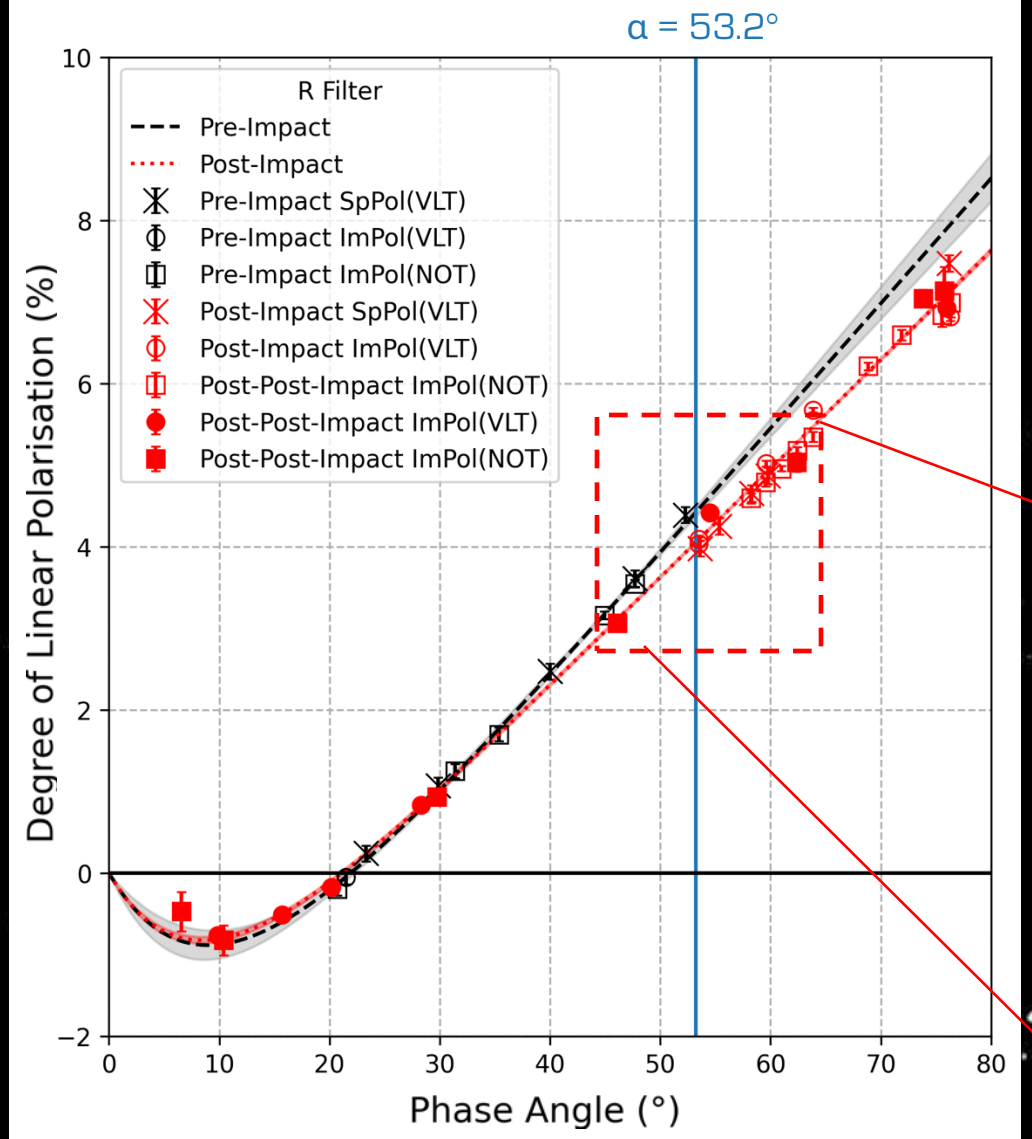


Gradually **fades** to pre-impact magnitude in **~ 24 days**

Graykowski et al. (2023)

(+ Kareta et al. (2023), Lister et al. (2024))

4. Discussion



(i) Pre-Impact: typical polarisation phase angle dependence.

(ii) Post-Impact: dramatic drop in polarisation after impact.

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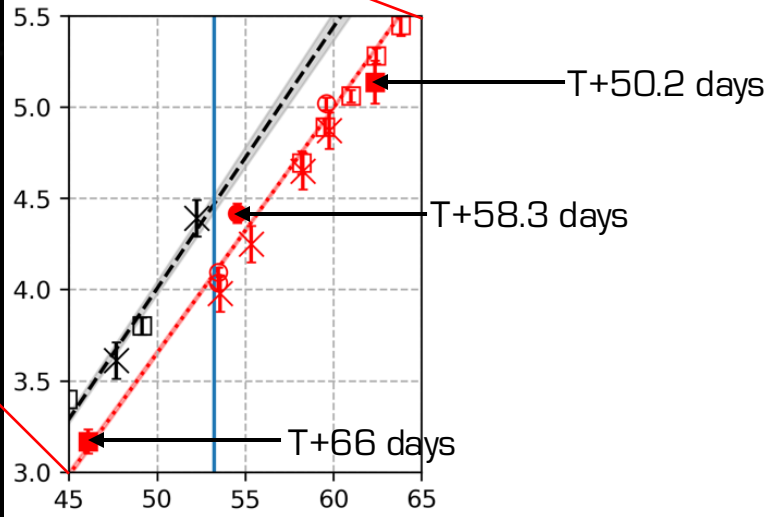
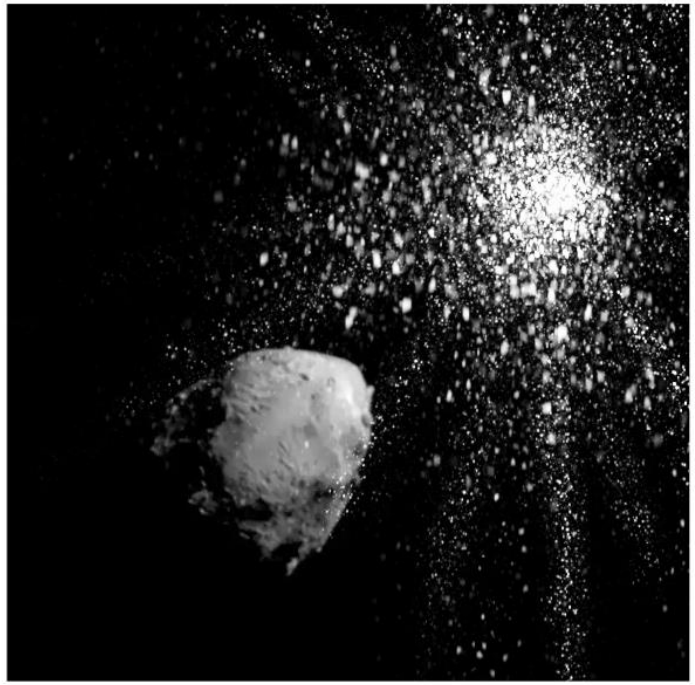
(iii) Post-Post-Impact: persistent lower level of polarisation, even months after impact.

- Residual ejecta material remaining in the system.

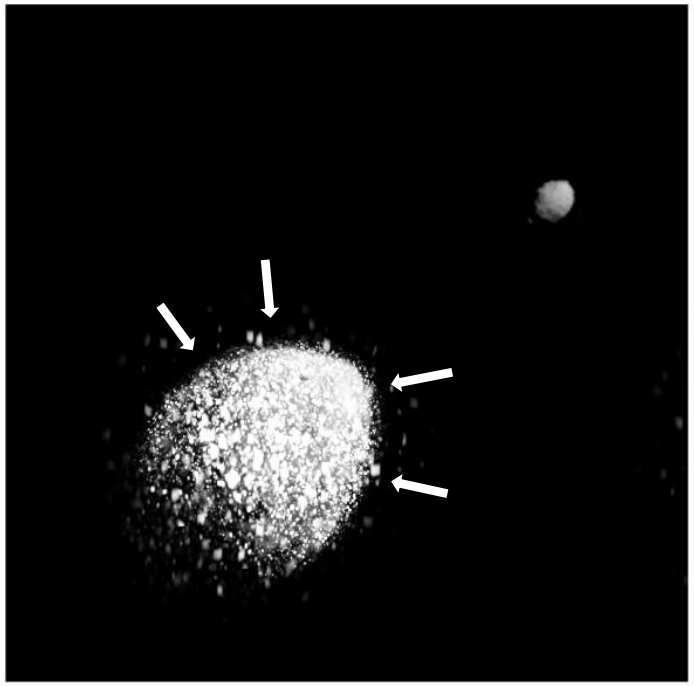


4. Discussion

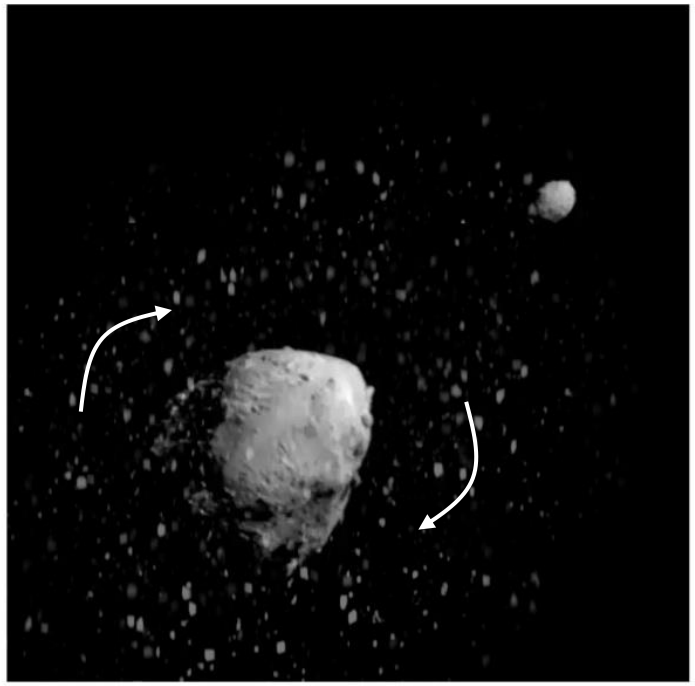
DART Impact

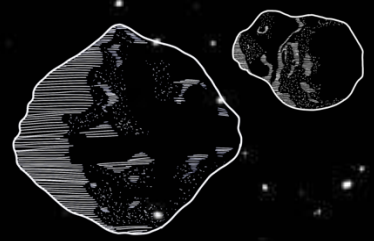


#1 Hypothesis:
Dust “blanket”



#2 Hypothesis:
Lingering dust cloud





5. New Observations

Pre-Impact
(T-1.3 months to T-15 hrs)

α = 20→52°

Post-Impact
(T+4 hrs to T+3 weeks)

α = 53→76°

The system is unperturbed.

The system is characterised by a persistent dust cloud.

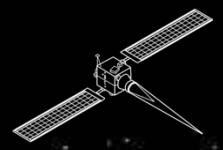
Post-Post-Impact
(T+3 weeks to T+4 months)

α = 76→7°

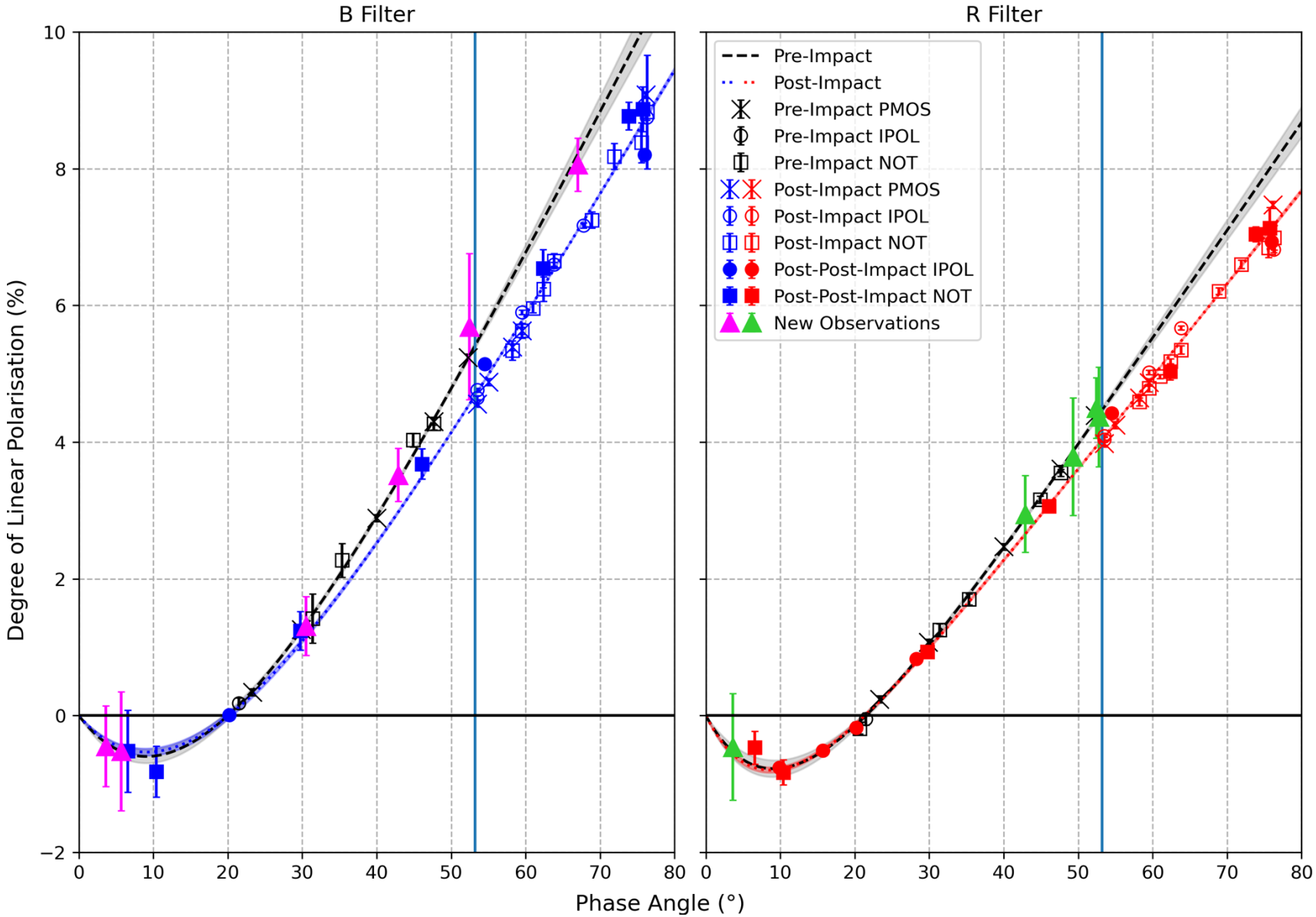
The cloud is mostly dissipated.

New Observations
(T+2 years)

α = 4→67°
...and more to come

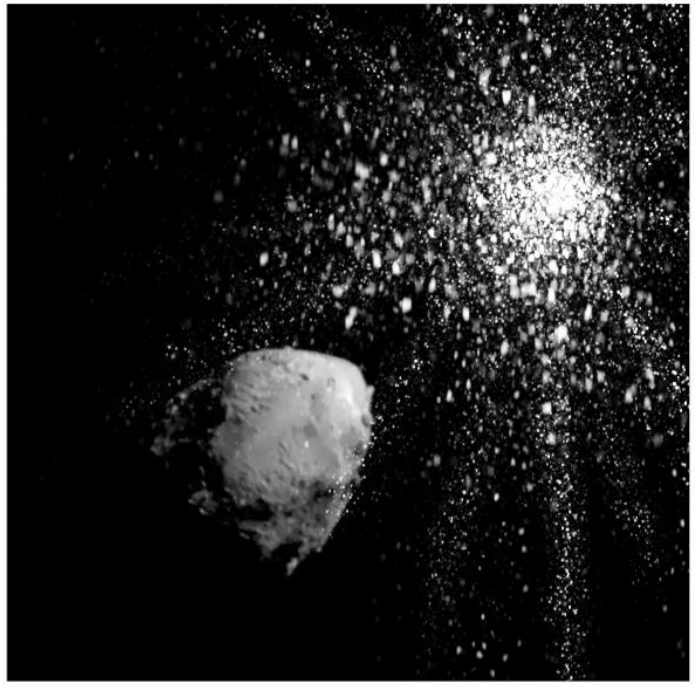


5. New Observations



5. New Observations

DART Impact



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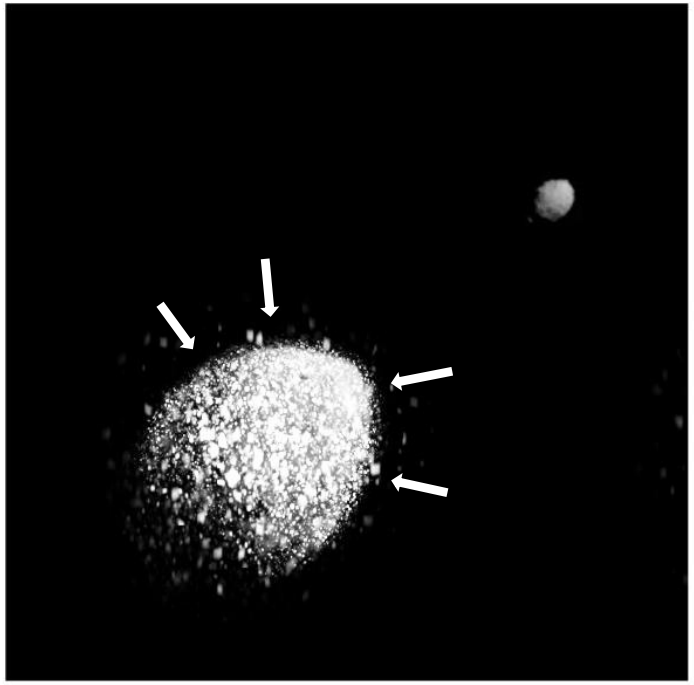

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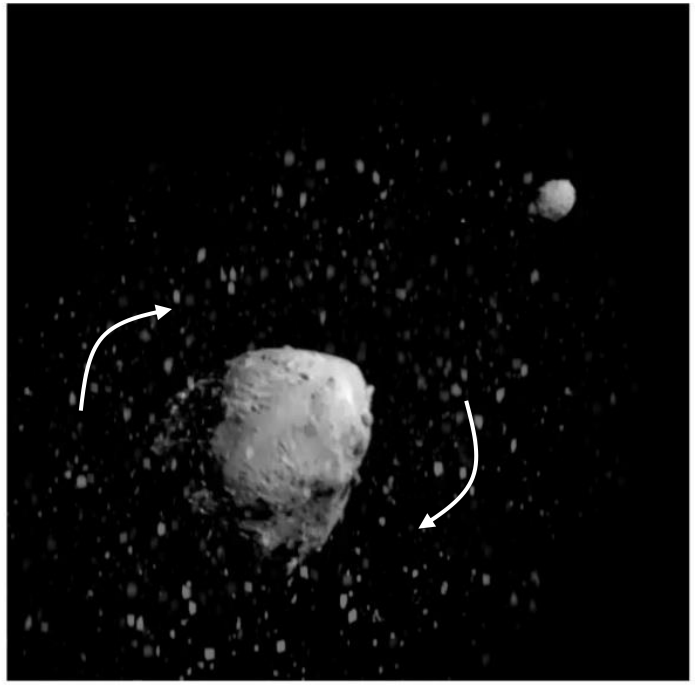
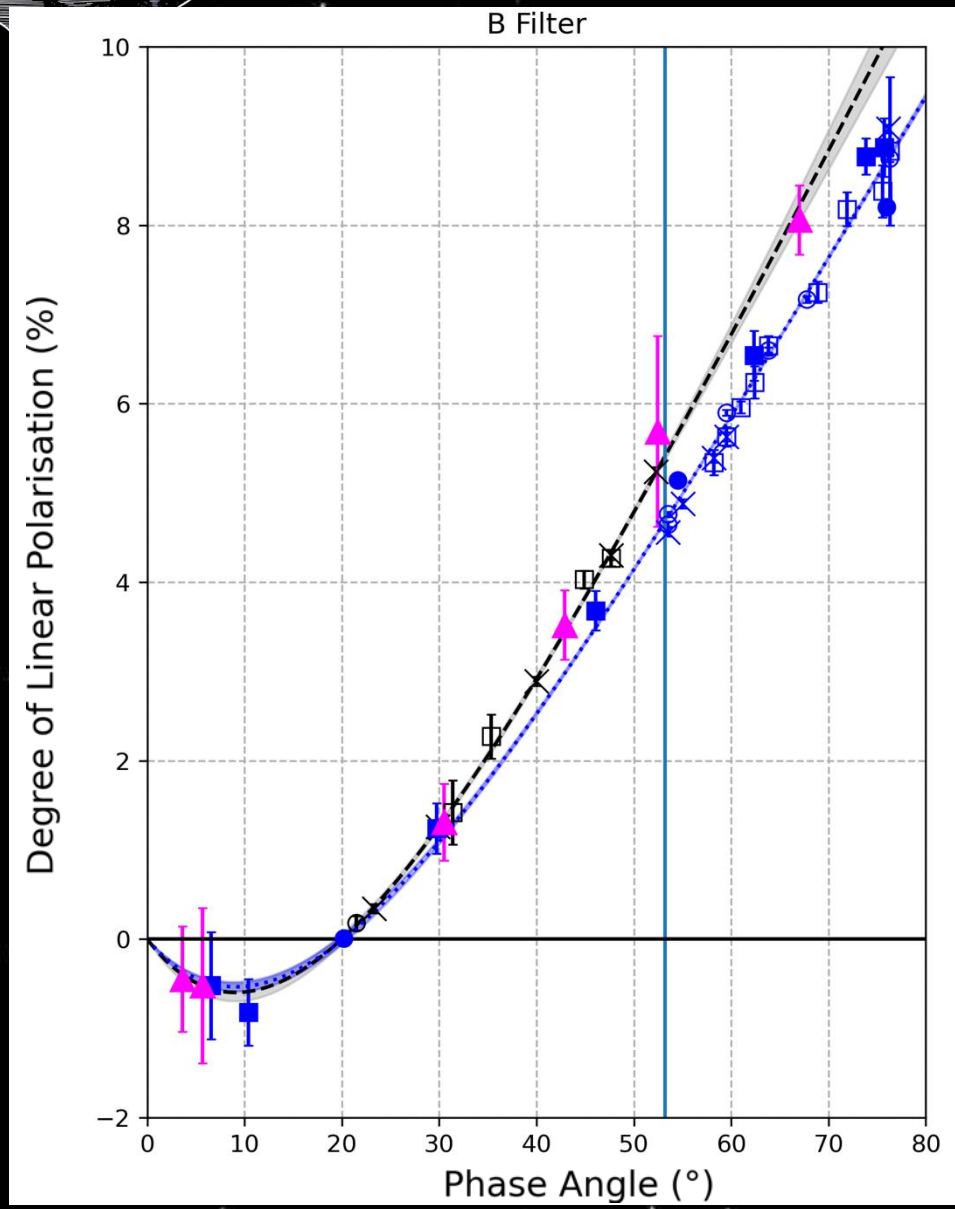
Lingering dust cloud



6. Conclusions



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Penttilä et al. (2024), Modeling Linear Polarisation of Didymos-Dimorphos before and after the DART impact.

(iv) New Observations (T+2 years): polarisation has returned to pre-impact level.

- No more/negligible residual material left in the system.
- More observations until end of Nov., up to phase angle 70°