Southern Hemisphere Asteroid Radar Program (SHARP)

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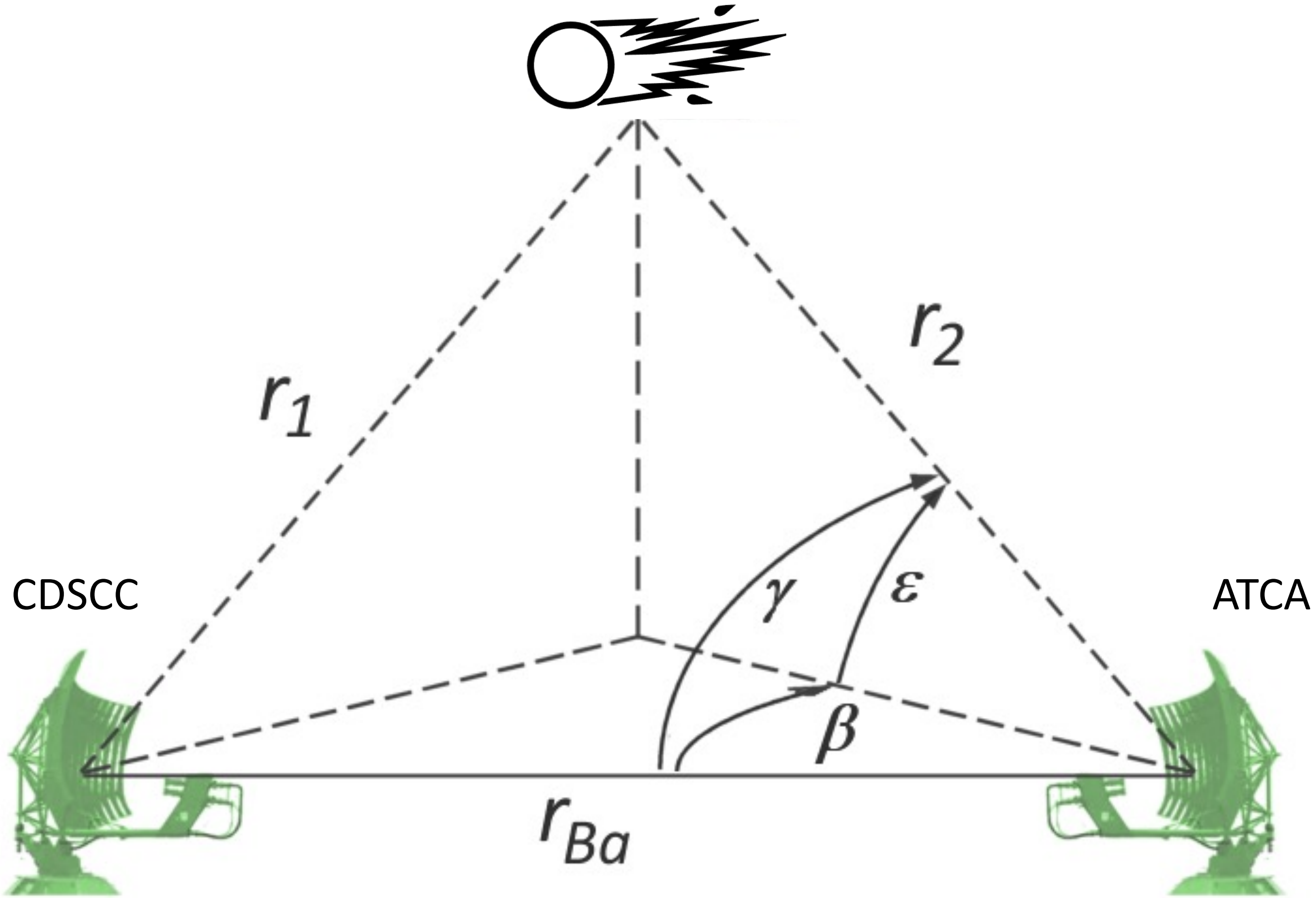
Introduction

- SHARP uses bi-static radar to observe Near Earth Asteroids
- Seeks to explore their properties
- Capable of providing information on their origins and history
- This research utilised large antennas at the Canberra Deep Space Communication Complex (CDSCC)
- Still a developing capability

Image: CDSCC showing DSS-43 (Centre) and DSS-35 and 36 (Background) Source: NASA

Bistatic Radar

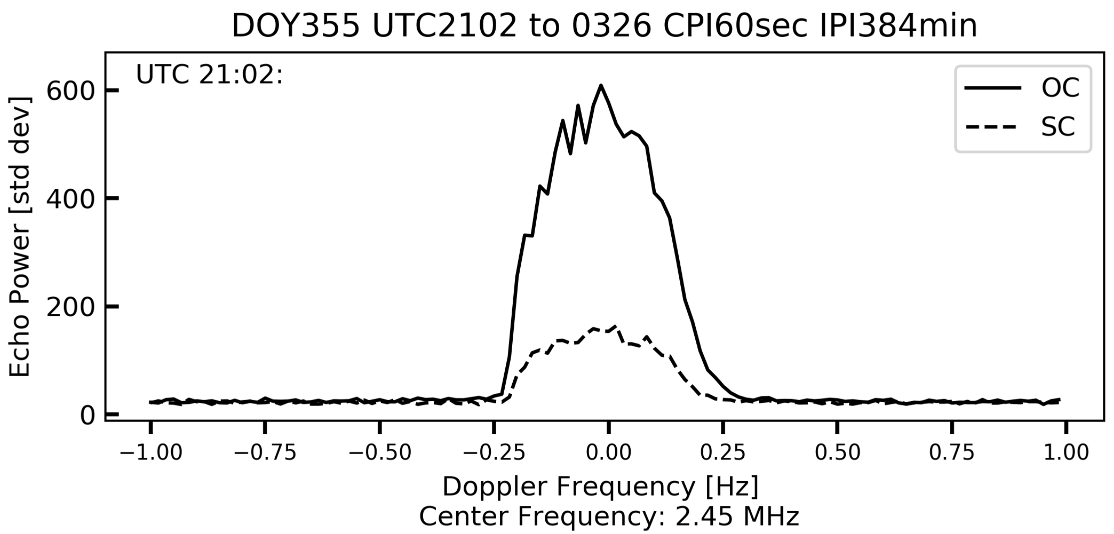


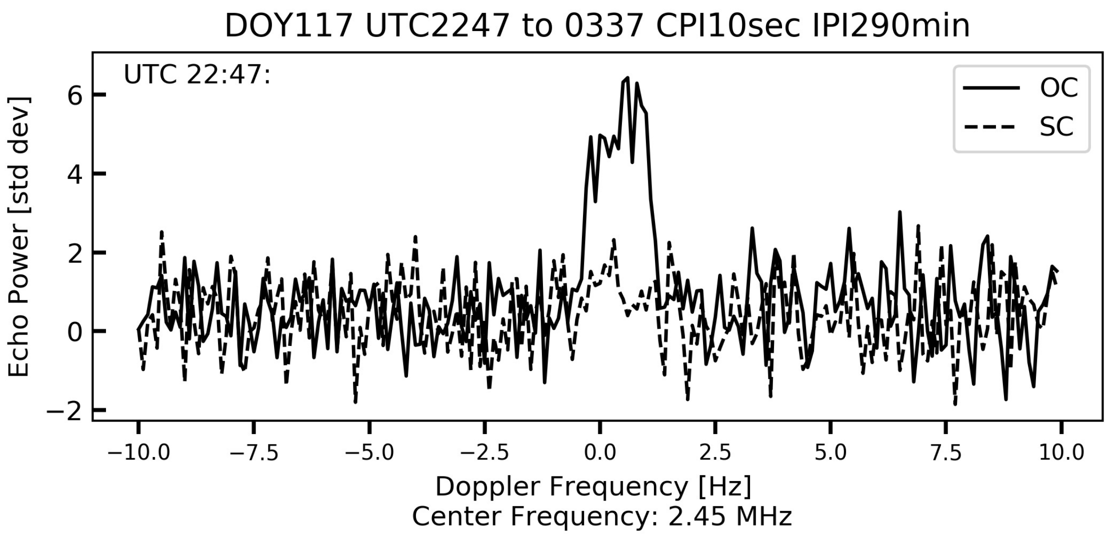
Source: C. Whisky

Image: DSS-43

Radar Echo Data

- Baseband data is transformed into the frequency domain
- Different processing intervals yield different resolutions
- Spectra is accumulated incoherently to produce a stronger SNR
- Plots contain two quantities OC and SC, related to Tx polarisation
    - OC – Opposite Sense – Left circularly polarised (LCP)
    - SC – Same Sense – Right circularly polarised (RCP)





Two plots of two separate asteroids showing the substantial difference in returns we can get based on the target

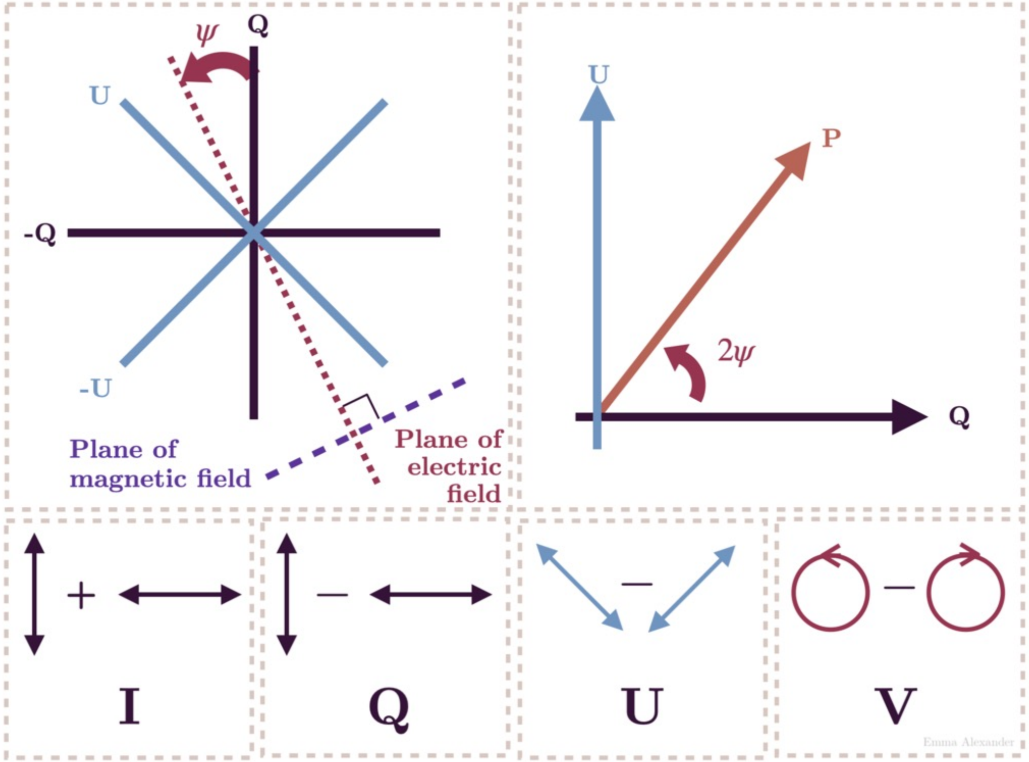
Polarimetric Decomposition

- Think of this as taking a complex system with multiple properties and describing it with four distinct values

$$\boldsymbol{S} = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$$

$$\begin{aligned} \mathbf{I} &= |E_l|^2 + |E_r|^2 \\ \mathbf{Q} &= 2Re(E_l^* E_r) \\ \mathbf{U} &= -2Im(E_l^* E_r) \\ \mathbf{V} &= |E_r|^2 - |E_l|^2 \end{aligned}$$

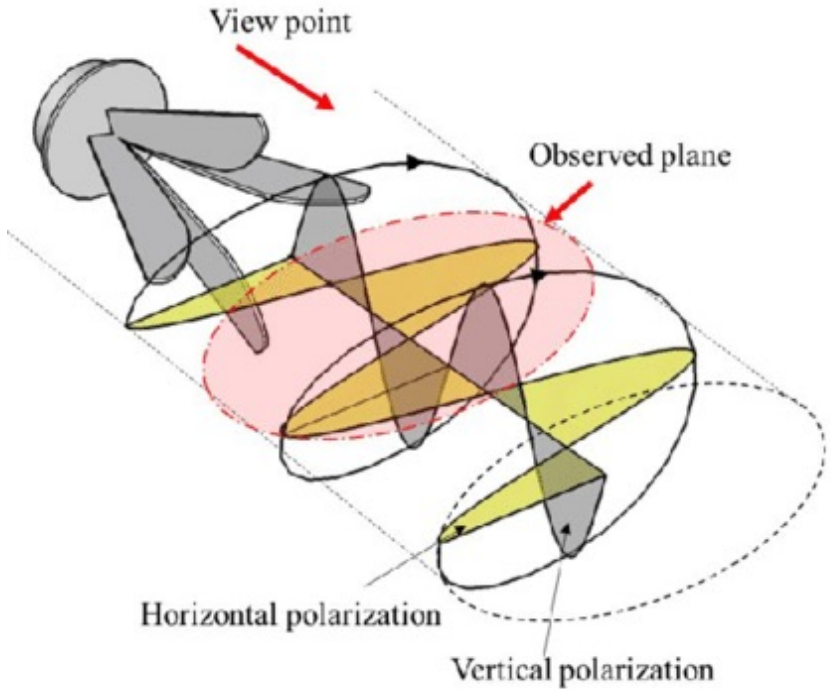
- Calculate the four-element Stokes vector (**S**) which describes the complete polarisation state of electromagnetic radiation
- Based off research in [1 – 4] but has always been applied exclusively to SAR, our system does not use SAR
- Analyzing these values provides advanced insights on asteroid properties

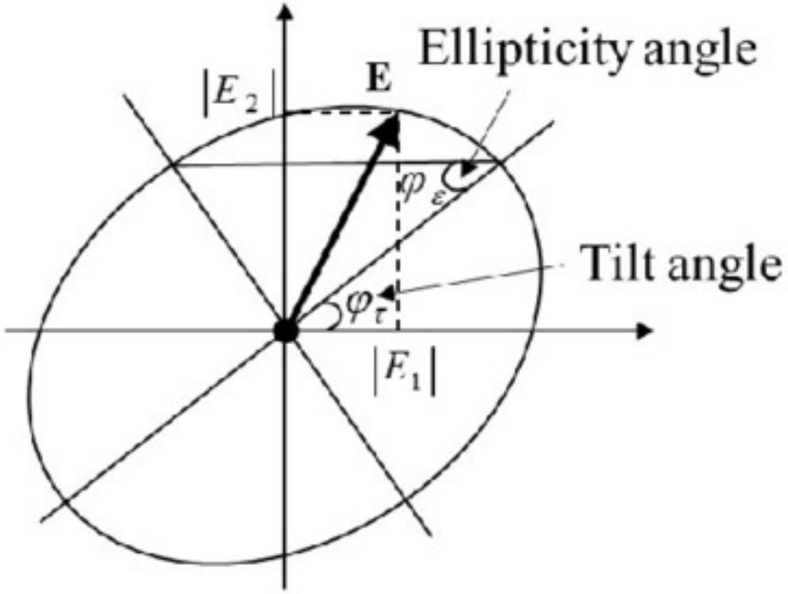


Source: Emma Alexander (Uni Manchester)

Polarimetric Decomposition

- These values allow us to calculate:
  - Degree of Polarisation (m)
    - Percentage of single, double and randomly polarised backscattering [5]
  - Ellipticity (chi) χ
  - Circular Polarisation Ratio (CPR) μ_C
    - Indicator of surface roughness
  - Degree of Linear Polarisation (DLP) m_l
    - Fraction of Rx power that is linearly polarised
- Data provides insights on surface topography and composition



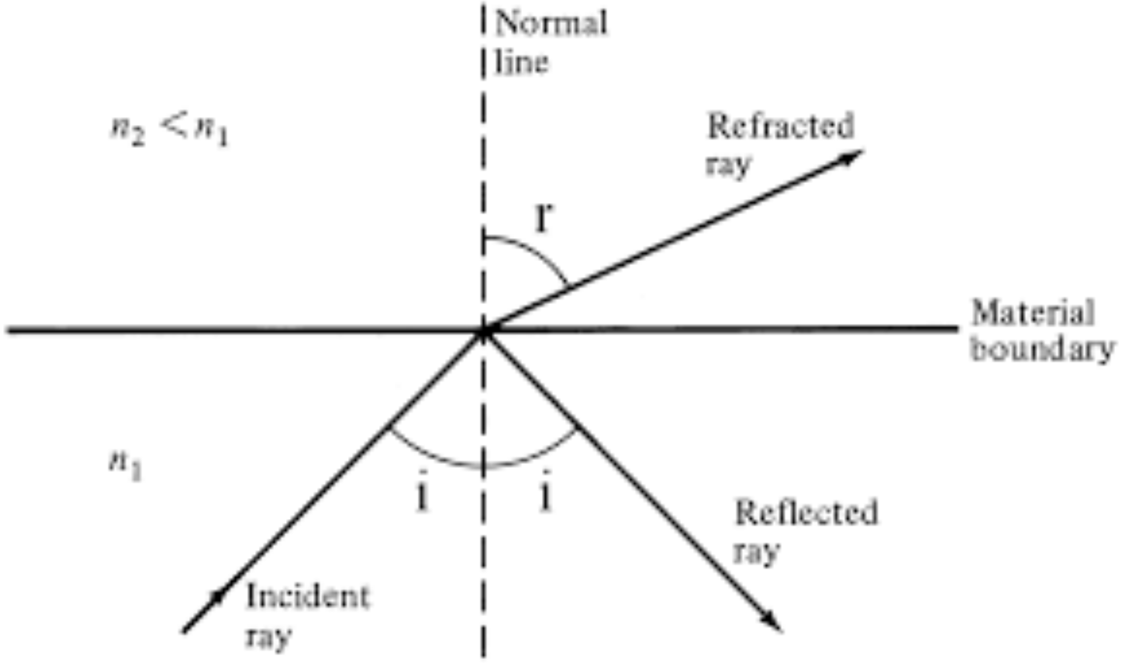


Source: Y. Izumi, *Analysis of circ pol backscattering and target decomposition using gb-sar,* 2017 [9]

So what?

- We know what we send to the asteroid and we know what we receive back
- Therefore we can figure out how these values ***change*** to learn about the asteroids composition
- Studying the effect the surface has on the radar waves
- Has turned a process which gives us four pieces of information into a process which gives us twelve pieces of information

Source: Simply Science



Source: Brookes Cole

Processing Procedure

- Data Rx at ATCA in Narribri
- Real time during measurement a program is used to plot .rdr files which give low resolution images
- Higher resolution data is loaded onto UNSW workstation for post-processing
- 1min data ≈ 1 GB
- Stokes decomposition and calculation of degrees of polarisation done in a separate script
- This is our *m, chi, CPR* and *DLP*

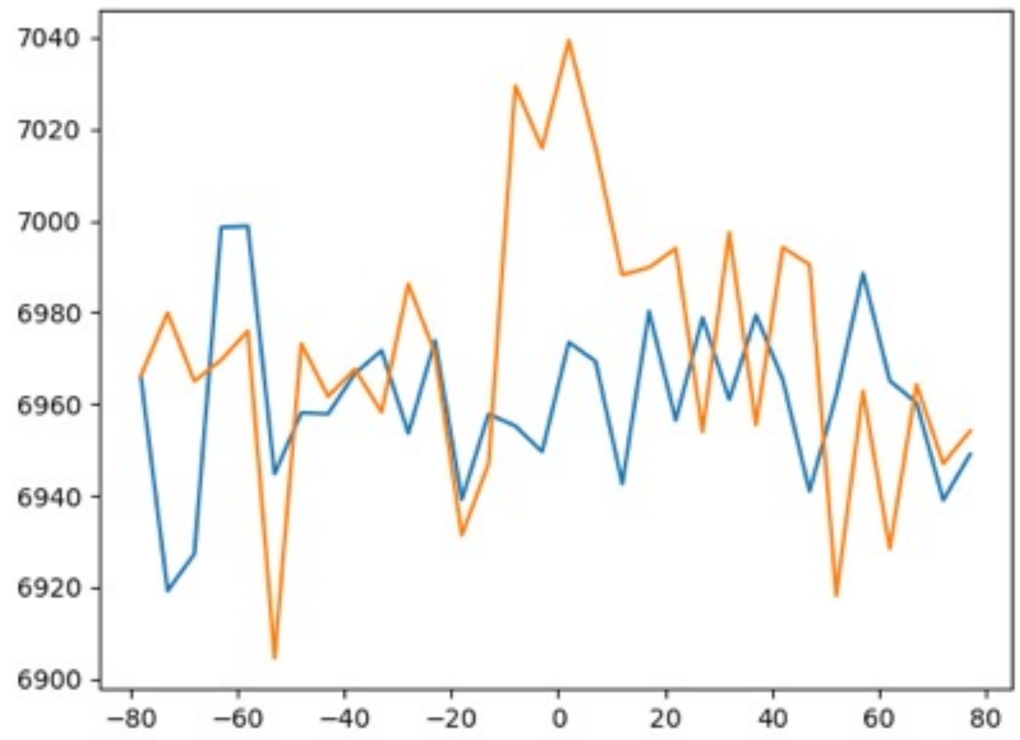


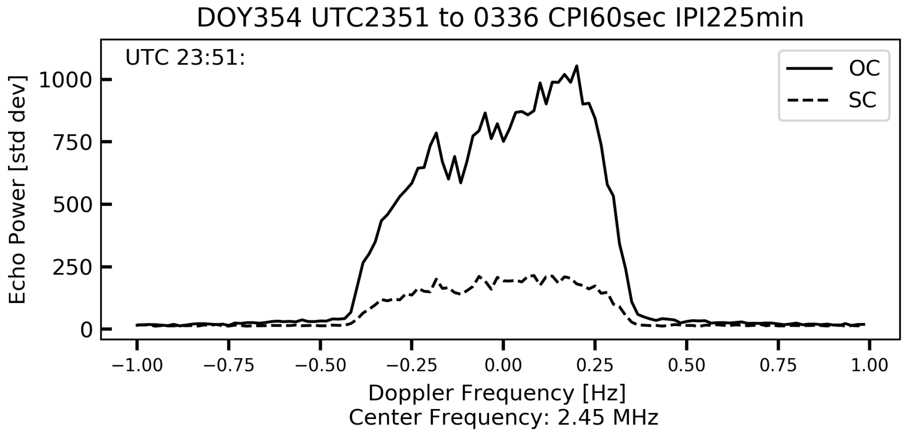
Image: Example of low-res rdr plot generated during observation for 2022 LV

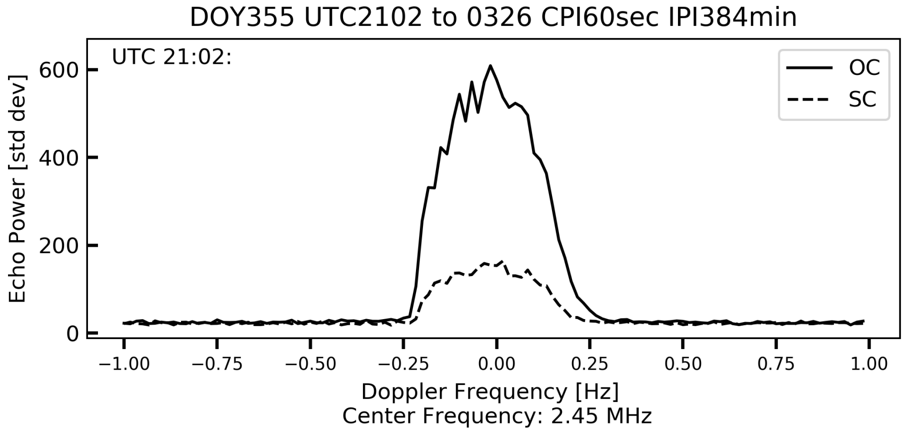
Results from a few asteroids observed this year

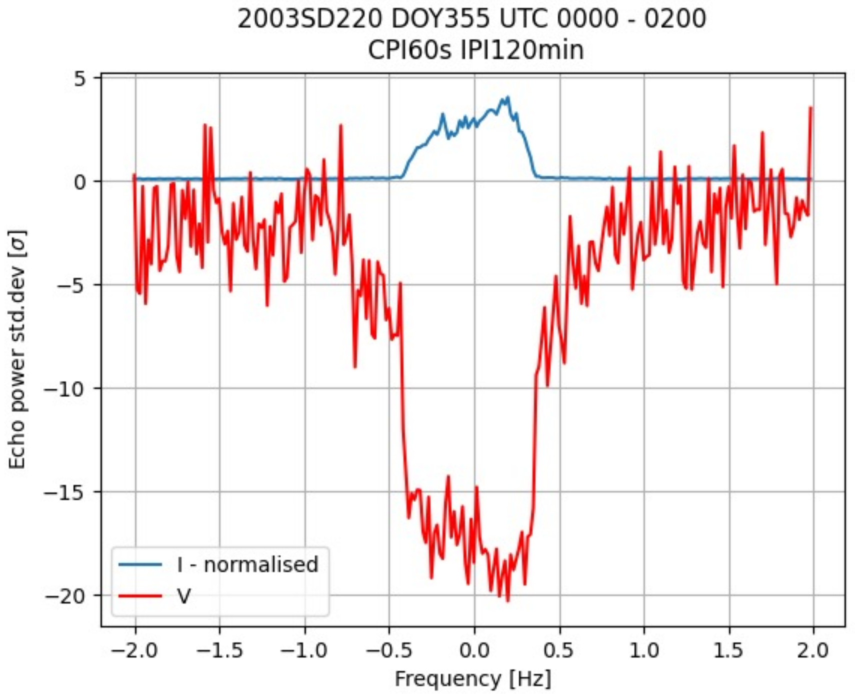
- 2003 SD220
- 2008 AG33
- 1989 JA
- 2022 LV
- Space debris

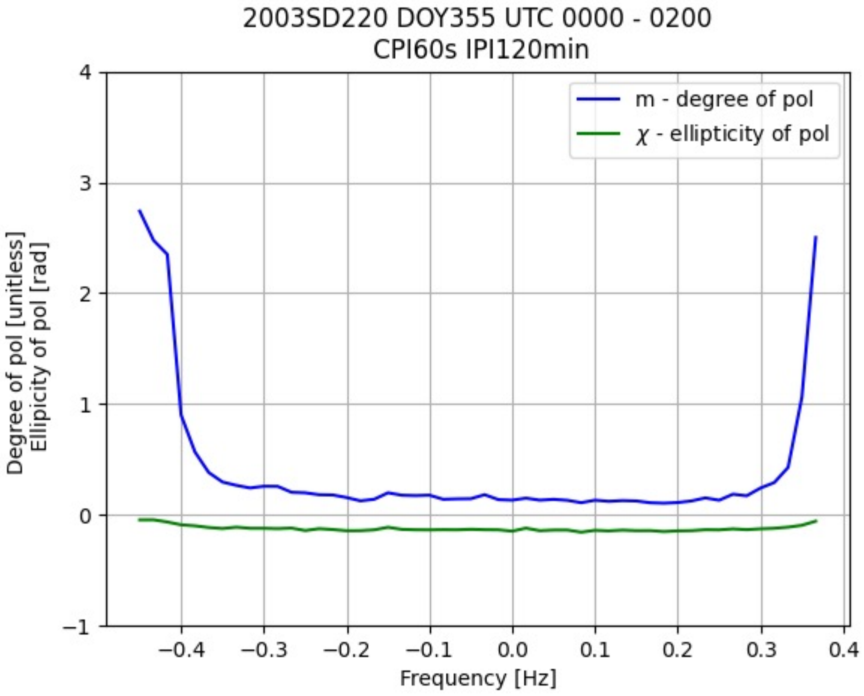
(138971) 2003 SD220

- $D = 1.53\ - 2.61$ km
- $\frac{SC}{OC} = 0.31 \pm 0.07$ nearly identical to [6] and [7]
- Change in bandwidth over two days of observation suggest an elongated shape, this analysis corresponds with images produced by NASA [8]









(138971) 2003 SD220 continued

$$S = \begin{bmatrix} I_{norm} \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} 2.13 \\ -0.567 \\ -1.17 \\ -15.9 \end{bmatrix} (\sigma)$$

$$m = 0.588$$
$$\chi = -0.118$$
$$\mu_C = -0.764$$
$$m_l = 0.00386$$

- m suggests return signal is majority polarised
  - Decent degree of diffuse scattering
- $\chi \approx -0.15$ radians
  - As $\mu_C < 1$ and χ is small depolarizing mechanisms such as double-bounces can be ruled out
- μ_C (CPR) indicates a highly left circularly polarised signal.
  - Indicates a moderate amount of surface roughness relative to the radar wavelength (deci to centimeters)
  - Deviations in OC with corresponding peaks in SC suggest the presence of larger boulders on the scale of meters
- m_l is incredibly small
  - Structural complexities which may have caused linear polarisation are minimal

- **Deductions**
  - 2003 SD220 is a siliceous asteroid with surface variation in the order of centimeters
  - Highly unlikely it contains any ice
  - Relatively smooth with the presence of few large boulders and protruding features
  - Is an elongated sausage shaped asteroid
  - 2003 SD220 is an S-type asteroid

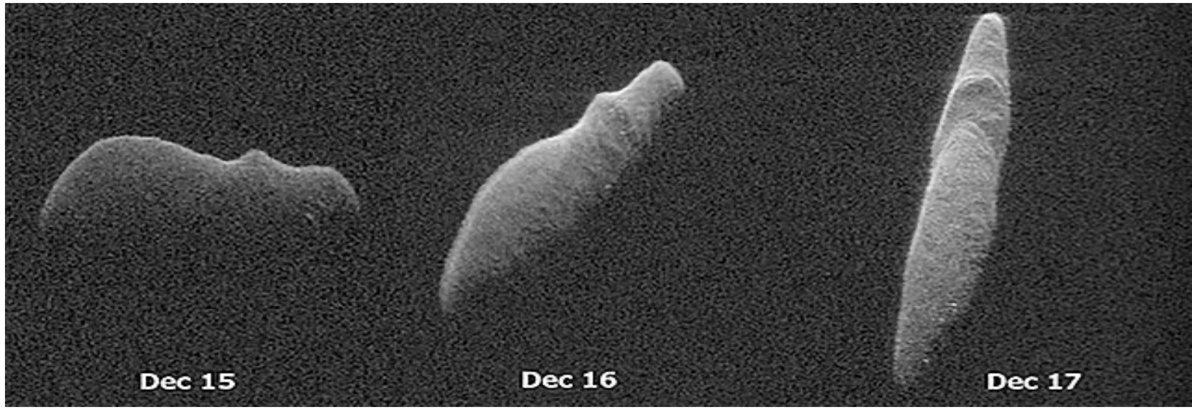
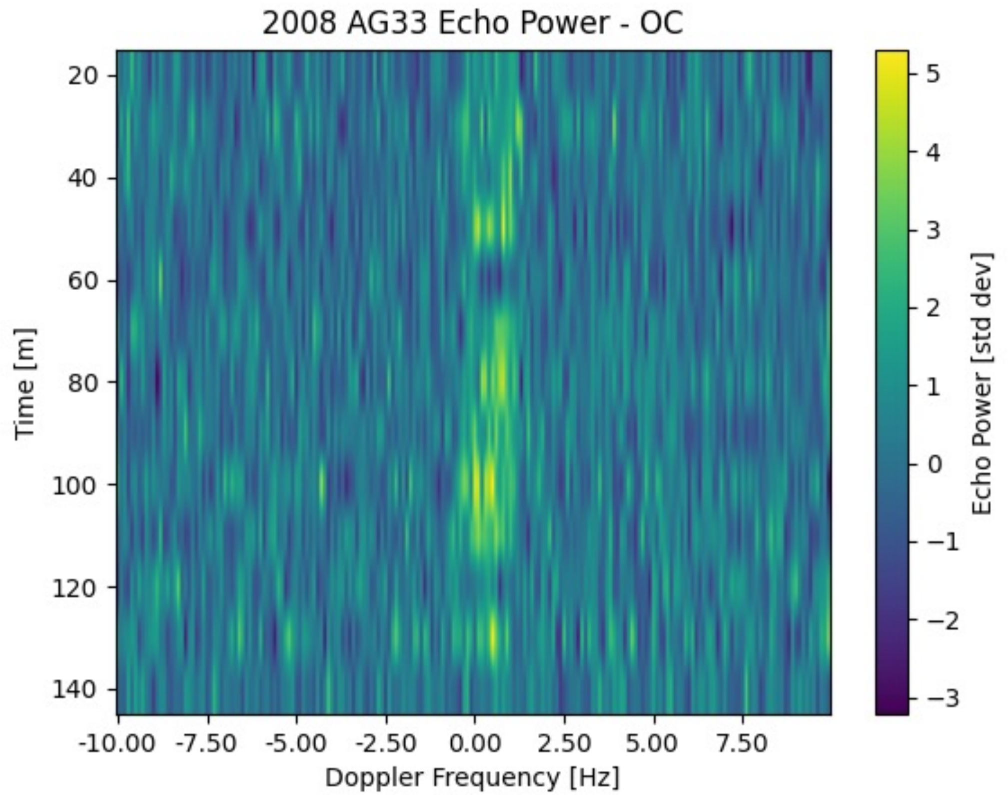


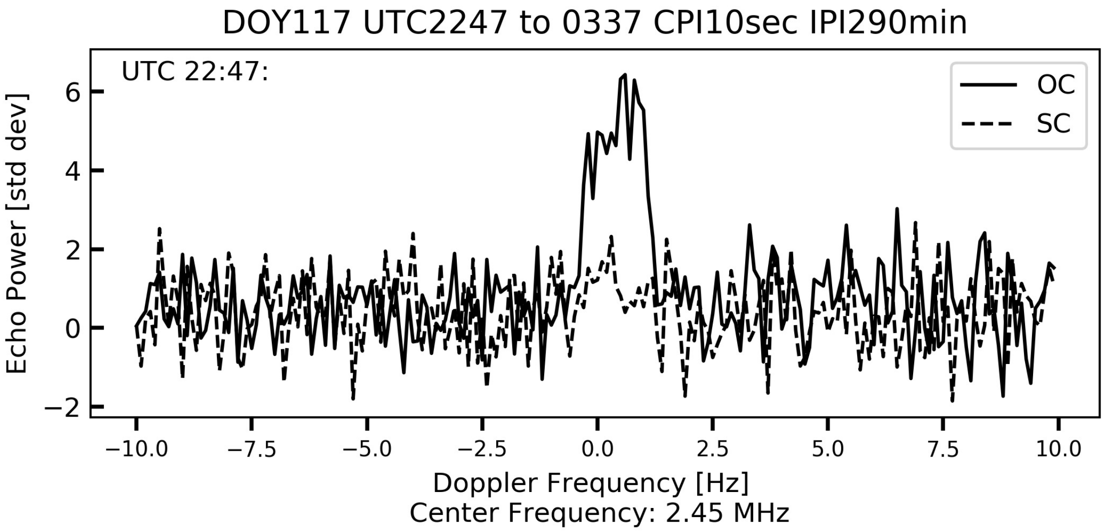
Image: Radar images of 2003 SD220 Source: Arecibo Observatory, NASA

(418135) 2008 AG33

- $D = 629 \pm 137$ m
- $\frac{SC}{OC} = 0.336 \pm 0.041$

- Presence of regolith with a moderate depth in order of meters with minimal subsurface bouldering
- Significant diffuse scattering suggests a smooth outer surface layer
- Spike in SC return attributed to two dominant features causing multiple bounces of EM signal
- 2088 AG33 is an S-type, high density and sedimentary
- Shape lends itself to the potential it was formed due to accretion
- Similar shape to asteroids Kleopatra and Itokawa, that of a dumbbell or peanut

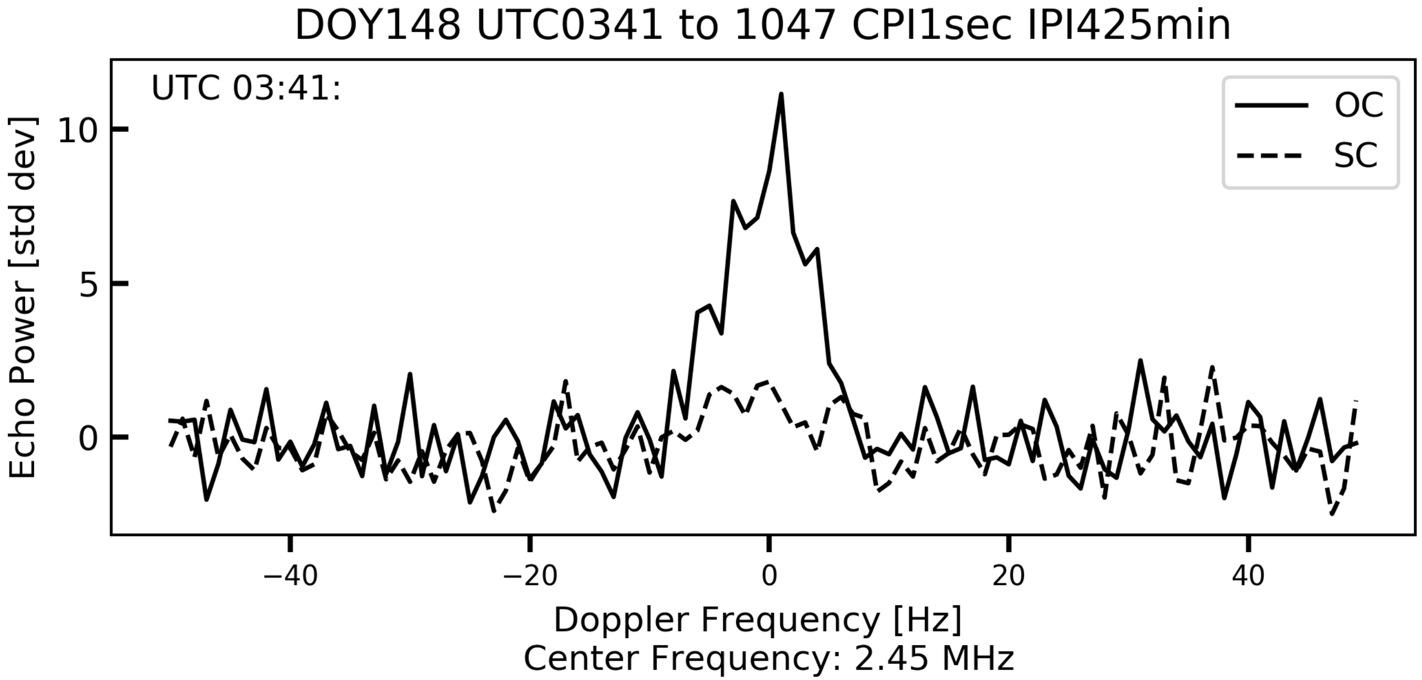




(7335) 1989 JA

- $D = 624 \pm 78$ m
- $\frac{SC}{OC} = 0.15 \pm 0.18$

- Surface is smooth on the wavelength scale
- Surface material has a lower transmission coefficient meaning it is more dense than other targets
- Lack of double bounce scattering
- Depolarization in the Rx signal is not caused by CBE
- 1989 JA is a strong reflector with a high surface bulk density
- 1989 JA is an M-type asteroid



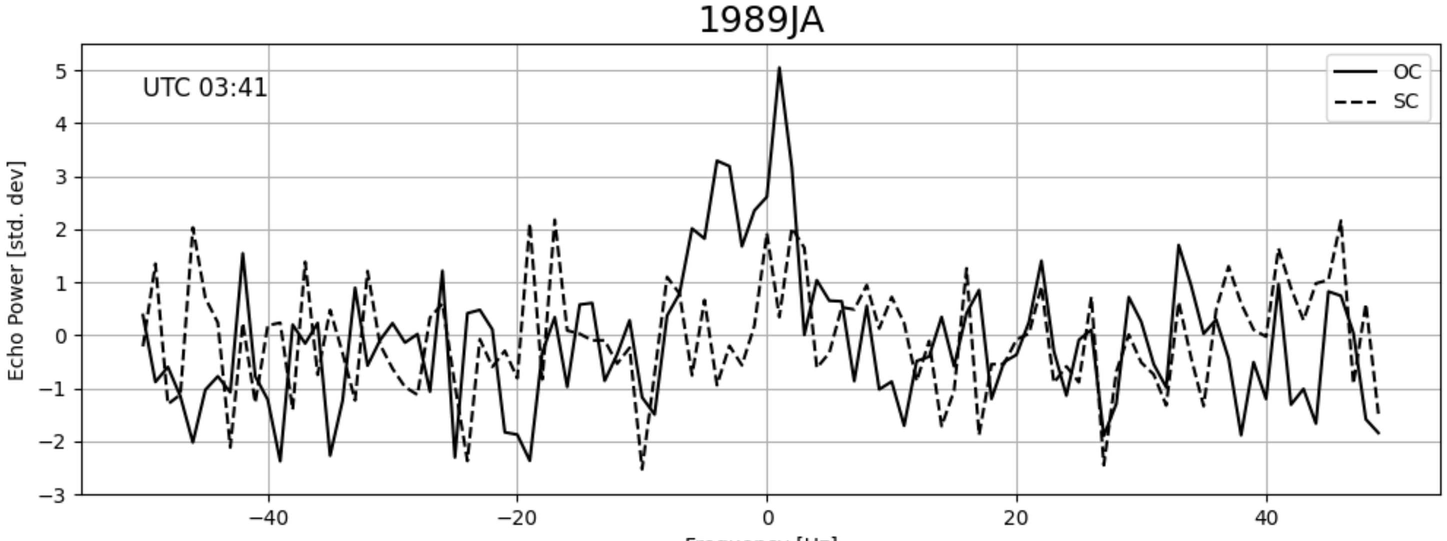
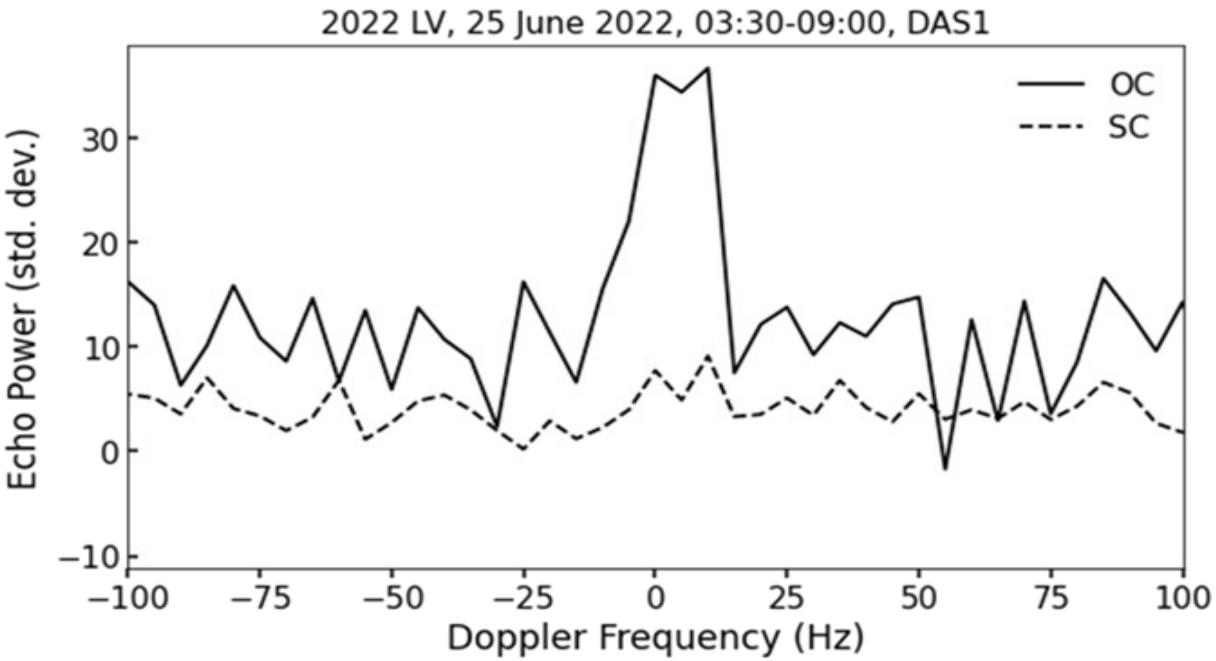


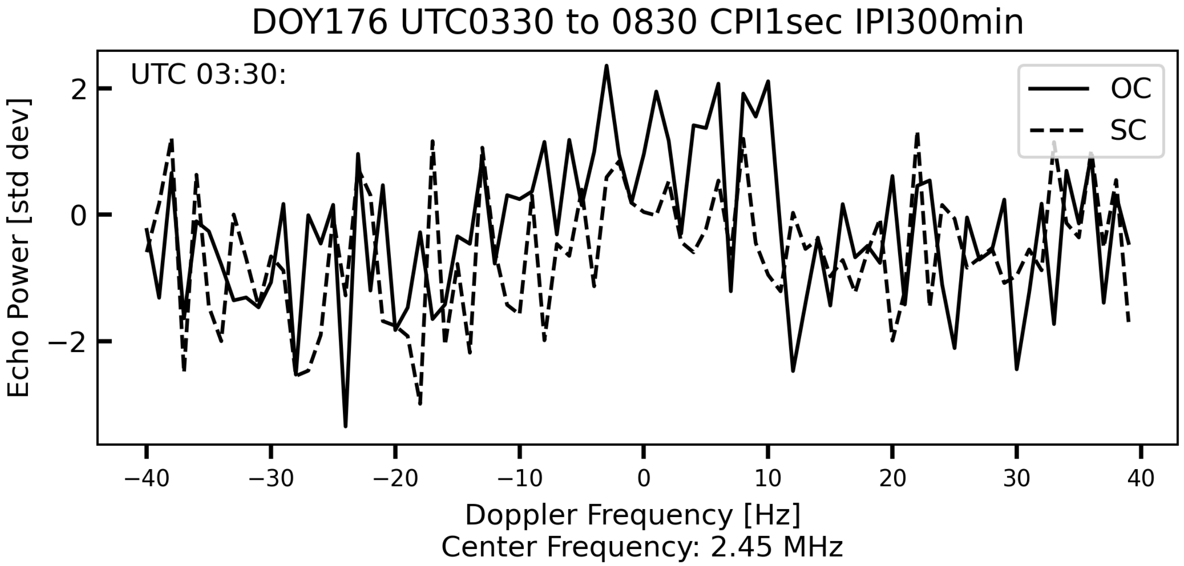
Image: Radar images of 1989 JA Source: NASA, JPL

2022 LV

- $D = 19.8 \pm 1.8m$
- $\frac{SC}{OC} = 0.125 \pm 0.043$

- 2022LV was observed on 25th and 26th June 2022 for 6hrs using the SHARP DSS-43 to ATCA configuration.
- Echo spectra were found to be relatively constant over the observing period.
- There was a substantial difference in the degree of polarisation and degree of linear polarisation in comparison to the three previous targets
- Hesitant to trust this data or make any major conclusions

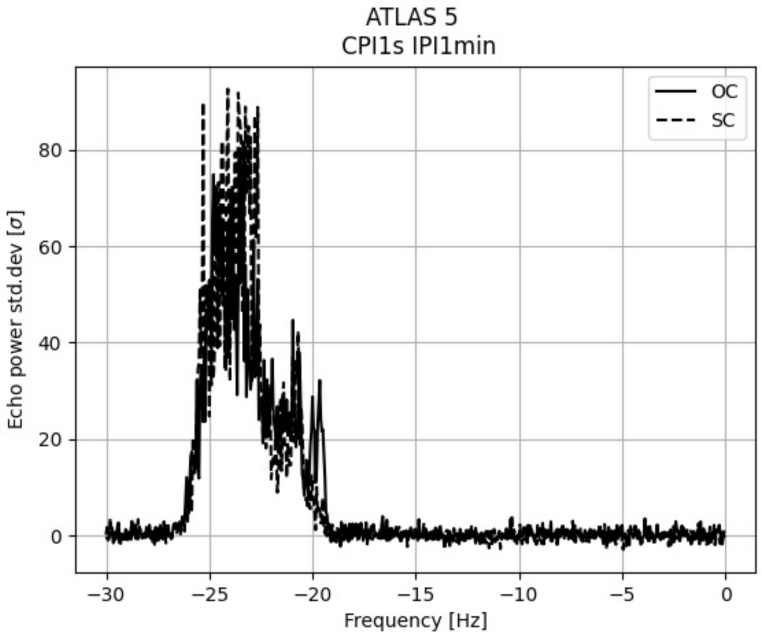


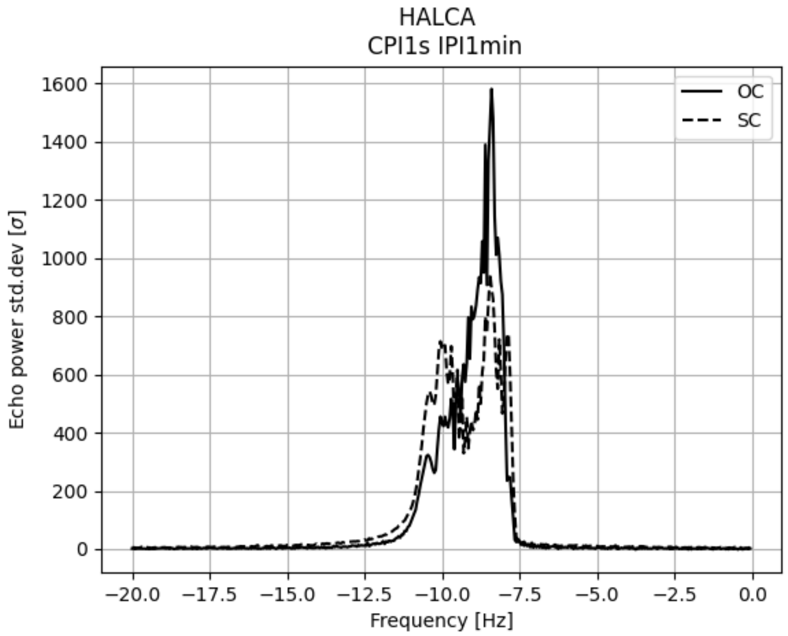


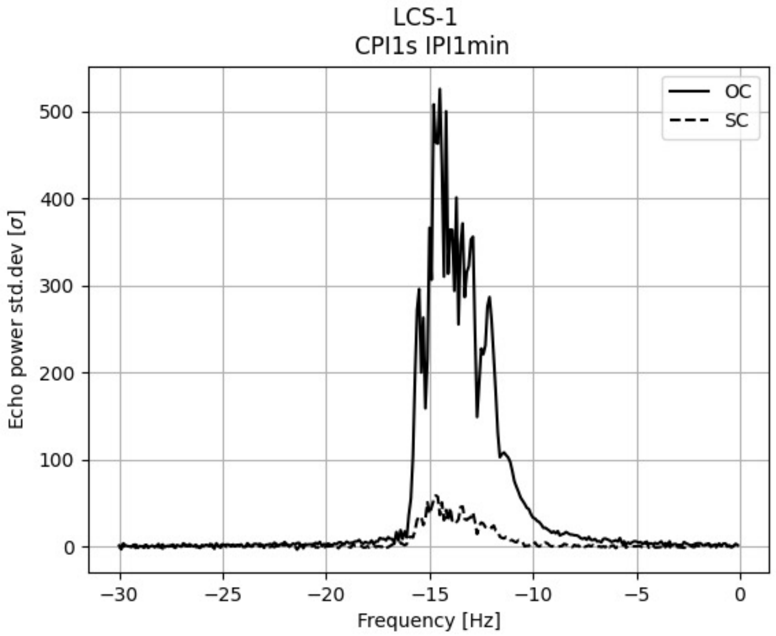
Satellites: HALCA, ATLAS 5 and LCS-1

	I_{abs}	I_{norm}	Q	U	V
ATLAS 5	3162	0.722	-0.483	-1.136	0.182
HALCA	7749	1.11	-1.589	-0.876	2.353
LCS-1	2926	0.982	-1.990	-1.570	2.861

Table: Polarimetry results for man-made space debris

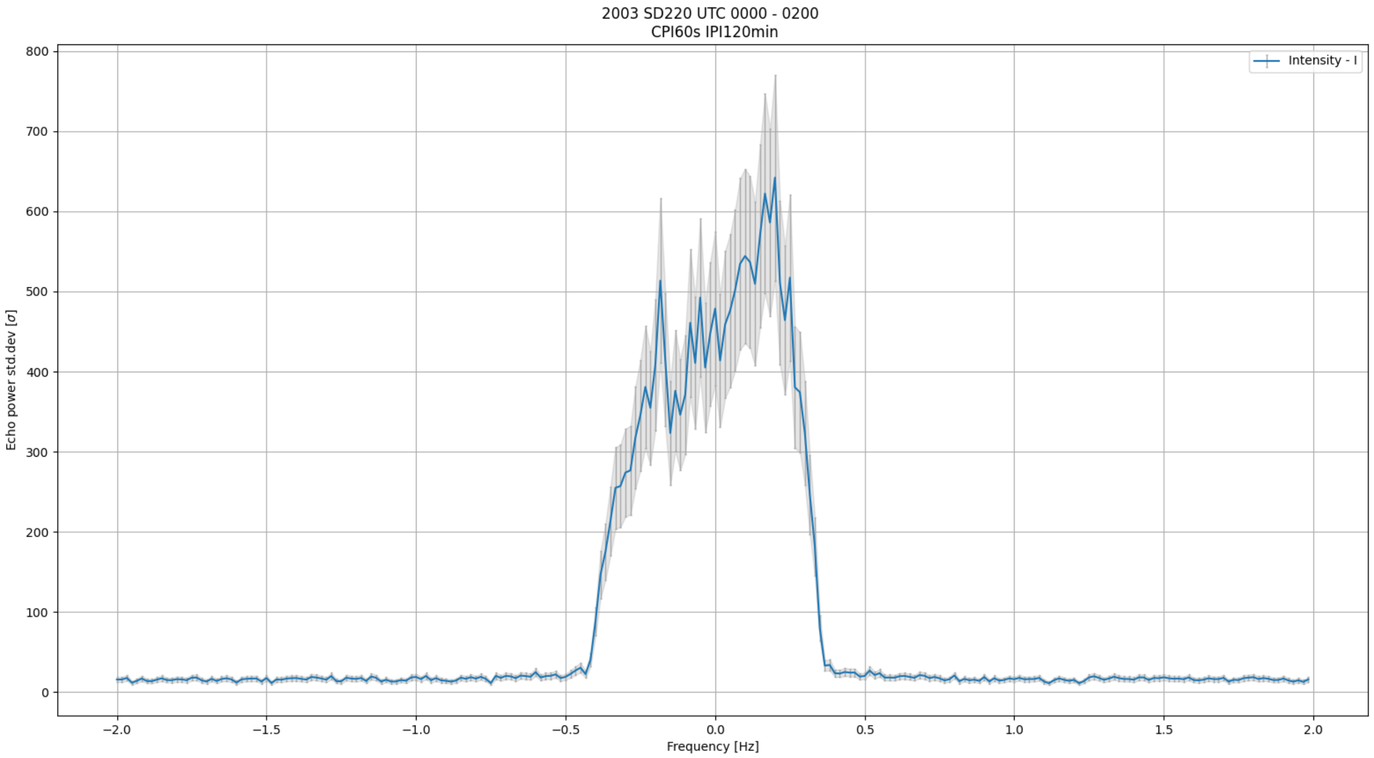


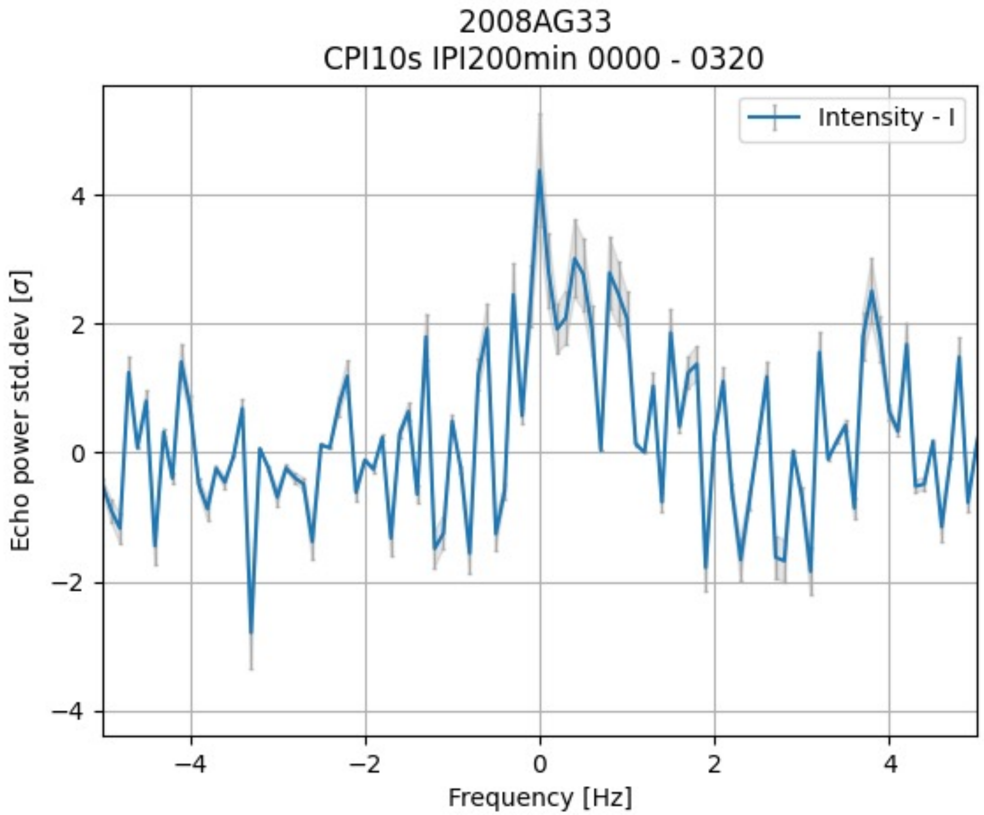




Errors

- ATCA generates a cross-coupling error in the range of $0.1 < leakage < 2\%$ which averages out to 1%
- Echoes are dominated by LCP reflections, measuring the ratio of the two polarisations gives an upper limit on the errors.
- This error is effectively directly proportional to receive power





Conclusions

- The SHARP is critical to NASA's planetary defense initiative
- Using polarimetry is new and requires more data and testing to confirm its effectiveness
- More 'antenna time' to conduct these tests will assist in advancing this field of science
- Removing the Tx power limit on DSS-43 for these experiments to assist with 'weak' targets

Acknowledgements

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- Dr Ed Kruzins
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References

- [1] D.C. Hickson et al. “Polarimetric Decomposition of Near-Earth Asteroids Using Arecibo Radar Observations”. In: The Planetary Science Journal 2 (1 Feb. 2021), p. 30. issn: 2632- 3338. doi: 10.3847/PSJ/abd846.
- [2] I. Belskaya et al. Asteroid Polarimetry. 2015. doi: 10.2458/azu_uapress_9780816532131ch008.
- [3] T. Ainsworth, J. Kelly, and J.S. Lee. “Classification Comparisons between Dual-pol, Compact Polarimetric and Quad-pol SAR Imagery”. In: ISPRS J. Photogramm. Remote Sens. 64(2009), pp. 464 471
- [4] B. A. Campbell. “Radar Backscatter from Mars: Properties of Rock-Strewn Surfaces”. In: Icarus 150.1 (2001), pp. 38–47. issn: 0019-1035. doi: https : / / doi . org / 10 . 1006 /icar . 2000 . 6566. url: https : / / www . sciencedirect . com / science / article / pii /S0019103500965667.
- [5] W. Patterson et al. m-chi decomposition of hybrid dual-polarimetric radar data with application to lunar craters. Aug. 2012.
- [6] L..M. Benner et al. “Near-Earth asteroid surface roughness depends on compositional class”. In: Icarus 198 (2 Dec. 2008), pp. 294–304. issn: 00191035. doi: 10.1016/j.icarus.2008.06.010.
- [7] S. Horiuchi et al. “Bistatic Radar Observations of Near-Earth Asteroid (163899) 2003 SD220 from the Southern Hemisphere”. In: (Dec. 2020). doi: 10.1016/j.icarus.2020.114250.
- [8] L.A.M. Benner. Goldstone Radar Observations Planning: (163899) 2003 SD220, 4660 Nereus and 2008 UZ94 url: https://echo.jpl.nasa.gov/asteroids/2003SD220/2003SD220_planning.2021.html
- [9] Y. Izumi. “Analysis of circular polarization backscattering and target decomposition using gb-sar”. Progress in Electromagnetics Research (Jan. 2017). Doi:10.2528/PIERB16081701