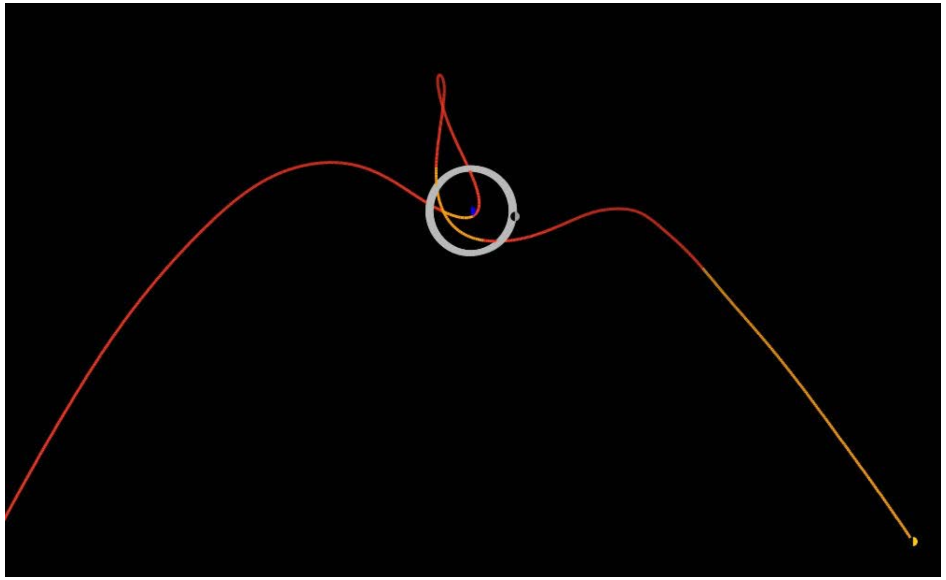
Challenges in Differentiating NEOs and Rocket Bodies: 2020 SO Study



Presented by Prof. Vishnu Reddy, University of Arizona

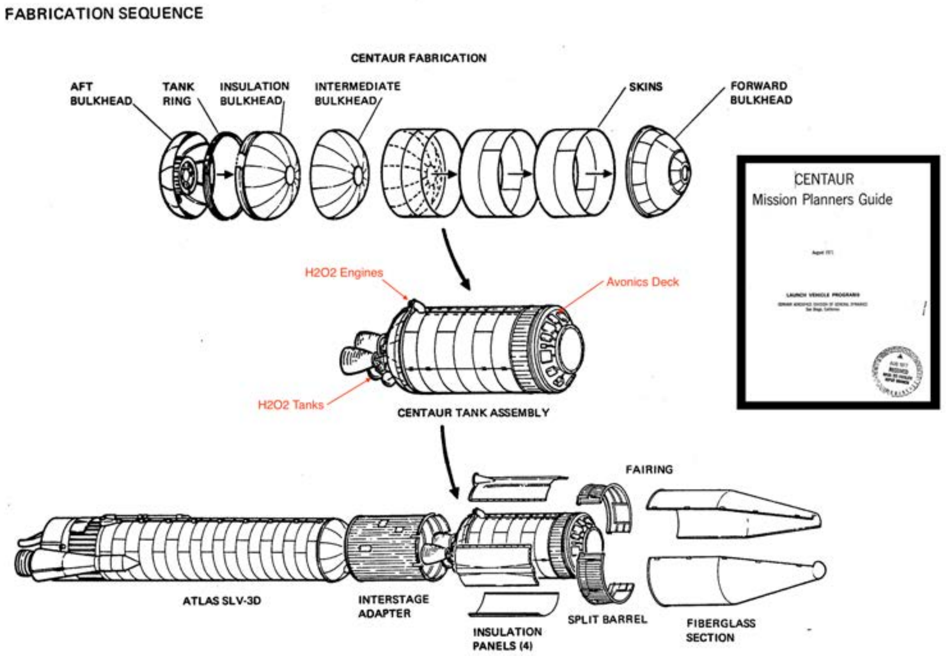
Team: Adam Battle, Peter Birtwhistle, Tanner Campbell, Paul Chodas, Al Conrad, Dan Engelhart, James Frith, Roberto Furfaro, Davide Farnocchia, Ryan Hoffmann, Olga Kuhn, David Monet, Neil Pearson, Jacqueline Reyes, Barry Rothberg, Benjamin Sharkey, Juan Sanchez, Christian Veillet, Richard Wainscoat

2020 SO: Background

- Discovered by PanSTARRS 1 telescope in Hawaii on September 17, 2020
- Temporarily captured on Nov. 8, 2020

Two close approaches:
- Inbound approach on December 1, 2020 at a distance of 0.13 LD (50,414 km)
- Outbound approach on February 2, 2021 at a distance of 0.58 LD (225,144 km)
- Low orbital velocity and Earth like orbit Paul Chodas suggested this could be artificial object (Surveyor 2 Centaur rocket booster)

Atlas-Centaur



- Launched September 20, 1966 from KSC, Florida
- Centaur upper stage went into heliocentric orbit similar to the Earth

Centaur D 2nd Stage Dimensions:
Length: 9.6 meters
Diameter: 3.05 meters
Unfueled Mass: 2631 kgs

Goals and Challenges

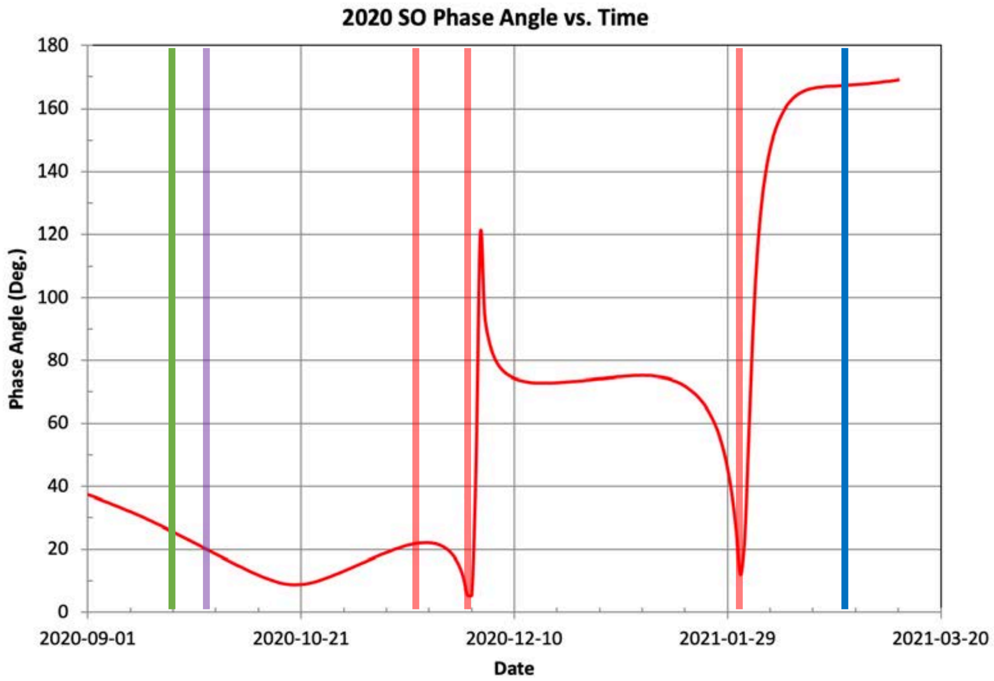
Study Goals:

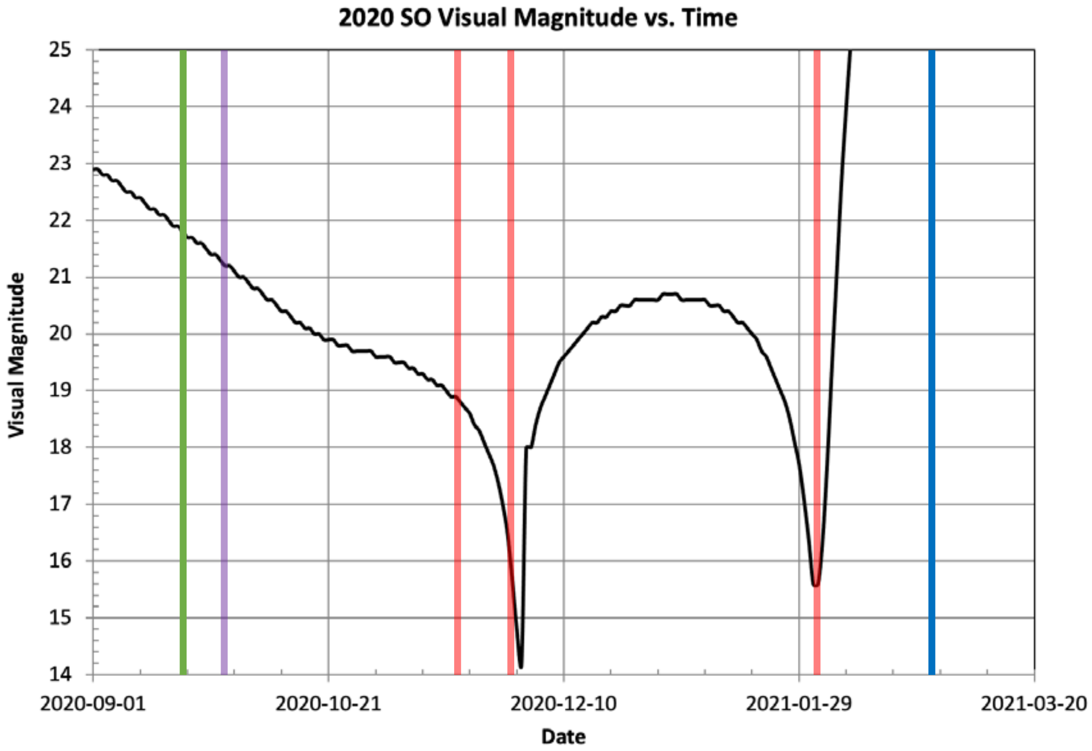
- Is 2020 SO an asteroid or rocket body?
- If it is a rocket body, is it a Centaur upper stage from Surveyor 2?

Challenges:

- Observability: 2020 SO was too faint for traditional near-IR characterization till mid-Nov. Late Sept. 2020 it was at V. Mag. 21.5, which limited us to broadband colors.
- Can you tell the difference between an asteroid and rocket body with colors?
- Spectral Interpretation: Do we have relevant spectral libraries of analog materials to verify if 2020 SO is a Centaur R/B? Especially something that had been in space for 54 years?

Observability Plot and Table





Date (UTC)	Target	V. Mag.	Phase Angle	Range (km)	Range (LD)	Telescope	Aperture	Instrument	Type of Observations	Wavelength Range	Spec. Res.
28-Sep-20	2020 SO	21.5	20.5	3420234	8.898	LBT	8.2-m	LBC	Sloan griz colors	0.464-0.90 µm	R=4
10-Oct-20	NORAD ID: 3598	~6-8	76.8	745	0.002	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
22-Oct-20	NORAD ID: 6155	~6-8	15.5	1300	0.003	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
17-Nov-20	NORAD ID: 4882	~6-8	80.6	4900	0.013	RAPTORS I	0.6-m	FLI 4220	Visible spectroscopy	0.438-0.950 µm	R~30
17-Nov-20	2020 SO	19.3	21.9	1160736	3.020	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
29-Nov-20	2020 SO	15.7	5.4	300896	0.783	NASA IRTF	3.0-m	SpeX	Near-IR spectroscopy	0.69-2.54 µm	R~100
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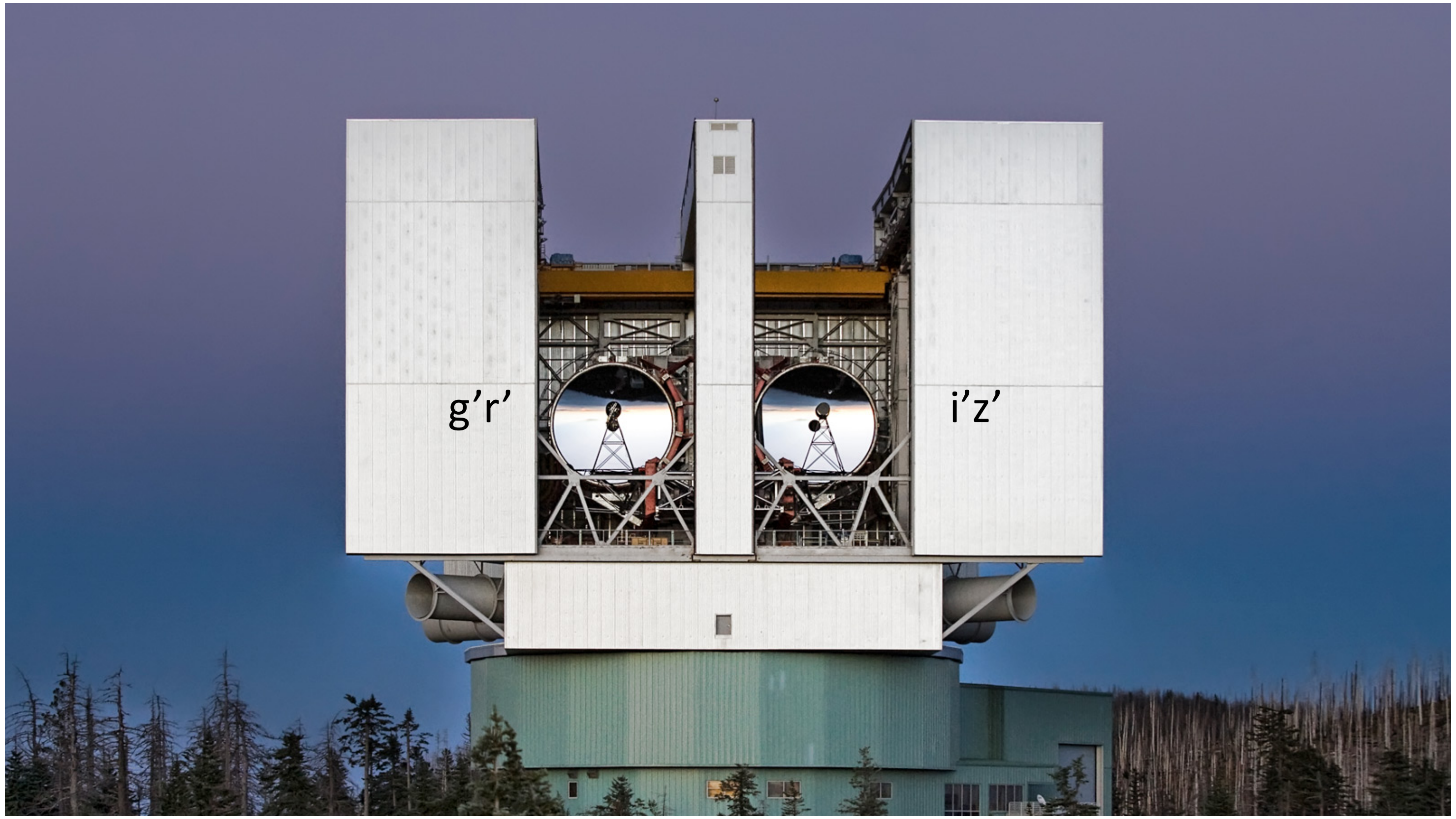
Color Observations

Study Lead: Ben Sharkey (grad student)

- Large Binocular Telescope: Two 8.2 meter optical/IR telescopes
- Instrument: Large Binocular Camera (red) and (blue) for color photometry (Sloan) and astrometry
- Exposure times: 60 seconds
- Visual Magnitude: 21.5
- Images: 10 per filter
- Filters: Sloan g'r'I'z'
- SNR: ~15 for g'r'i'; 10 for z'



Mt. Graham, AZ

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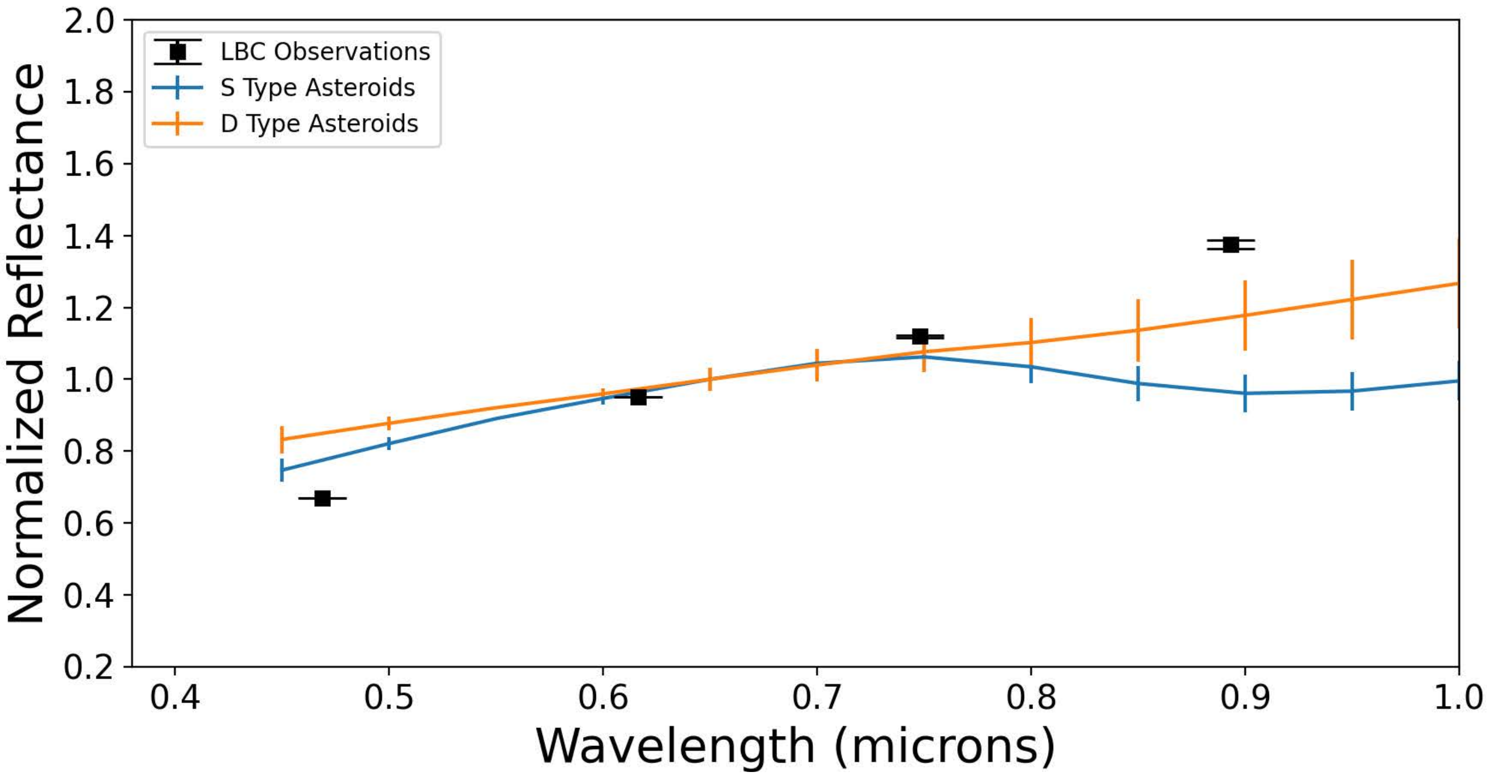
Comparison with S-type and D-type asteroids



Visible Spectral Observations

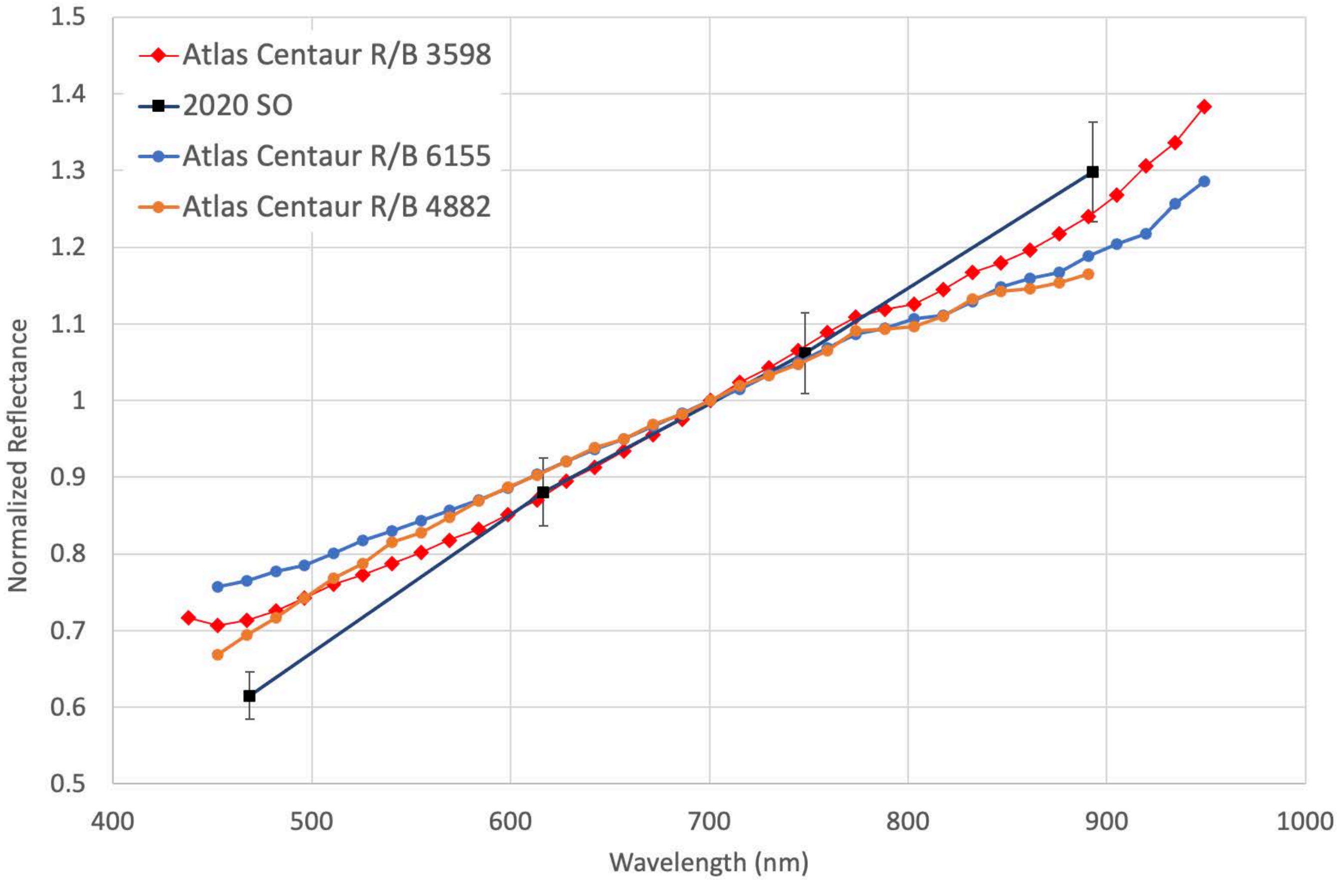
Study Lead: Adam Battle (grad student)

- Goal: Observe another Centaur in Earth orbit from the same period and compare with LBT color spectrum of 2020 SO
- RAPTORS: Robotic Automated Pointing Telescope for Optical Reflectance Spectroscopy
- Telescope: 0.6-meter F/4.6 Newtonian optical/NIR telescopes (RAPTORS I and II)
- Instrument: FLI4210 CCD and Richardson Grating 30L transmission grating giving a spectral resolution R~30
- Exposure times: 0.01-1.0 seconds (Object kept in the center to make sure there are no shutter effects)

Tucson, AZ

Comparison with Centaur R/Bs

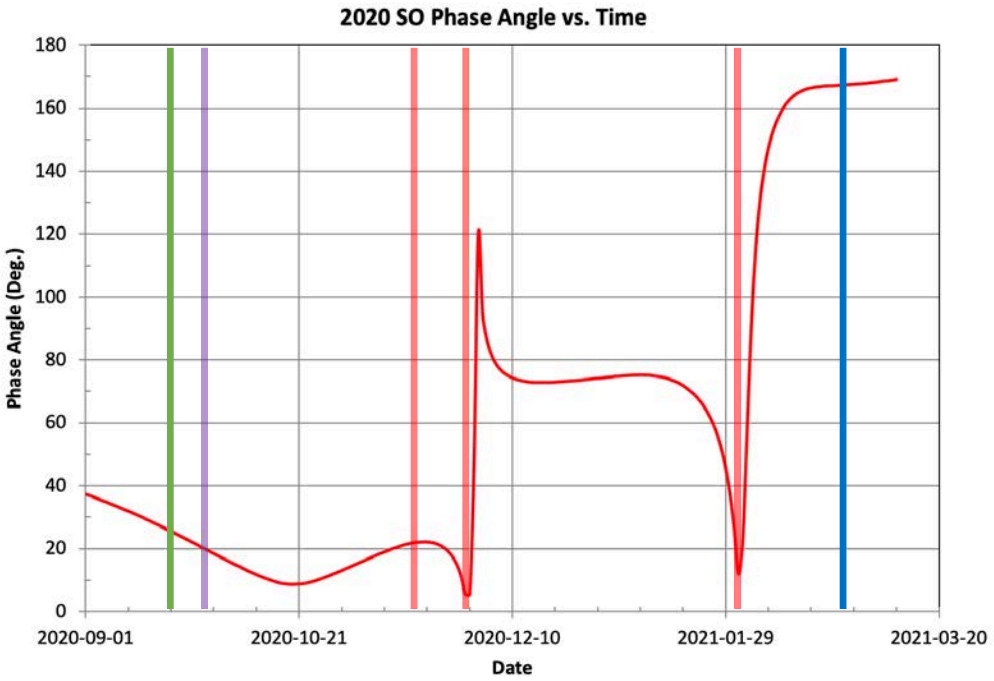
Here are the visible wavelength spectra of the three Centaur bodies NORAD ID 3598, 4882 and 6155. 3598 was launched in 1968, 4882 in 1971 and 6155 in 1972. All Centaur spectra are consistent with each other. Differences at the shortest and longest wavelengths could be due to phase angle.

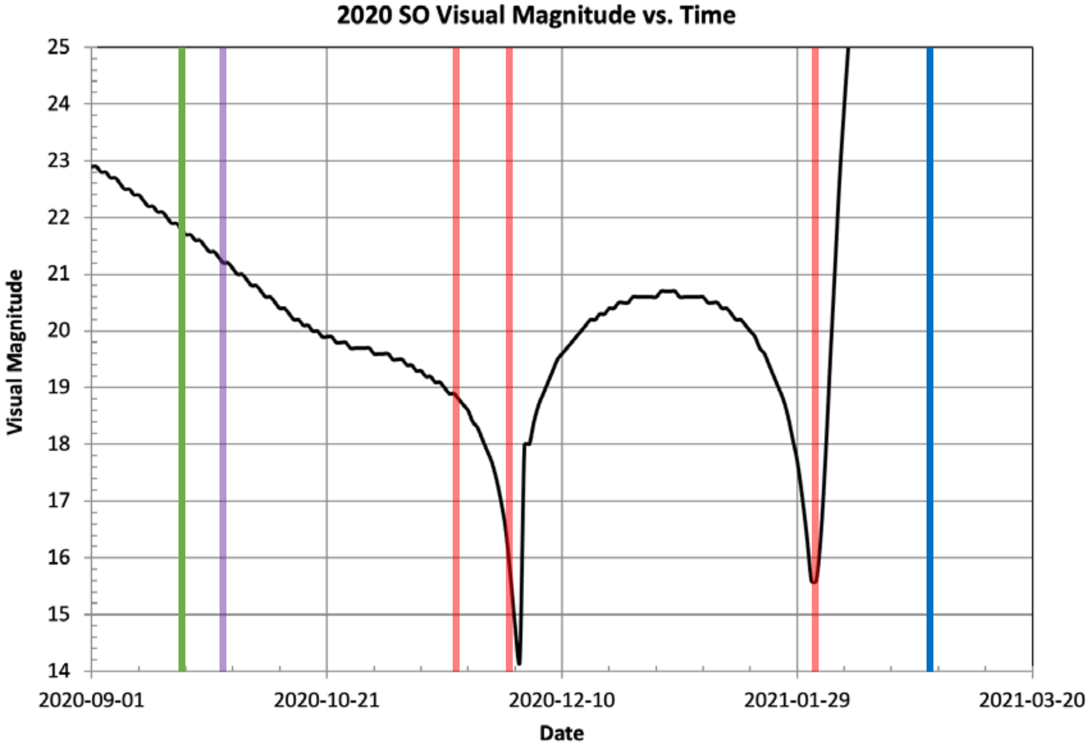


Near-IR Observations

- NASA IRTF: 3-meter IR telescope
- Instrument: SpeX spectrometer
- Exposure times: 200 seconds
- Visual Magnitude: 19.3, 15.7, 14.9 and 15.8

Mauna Kea, HI

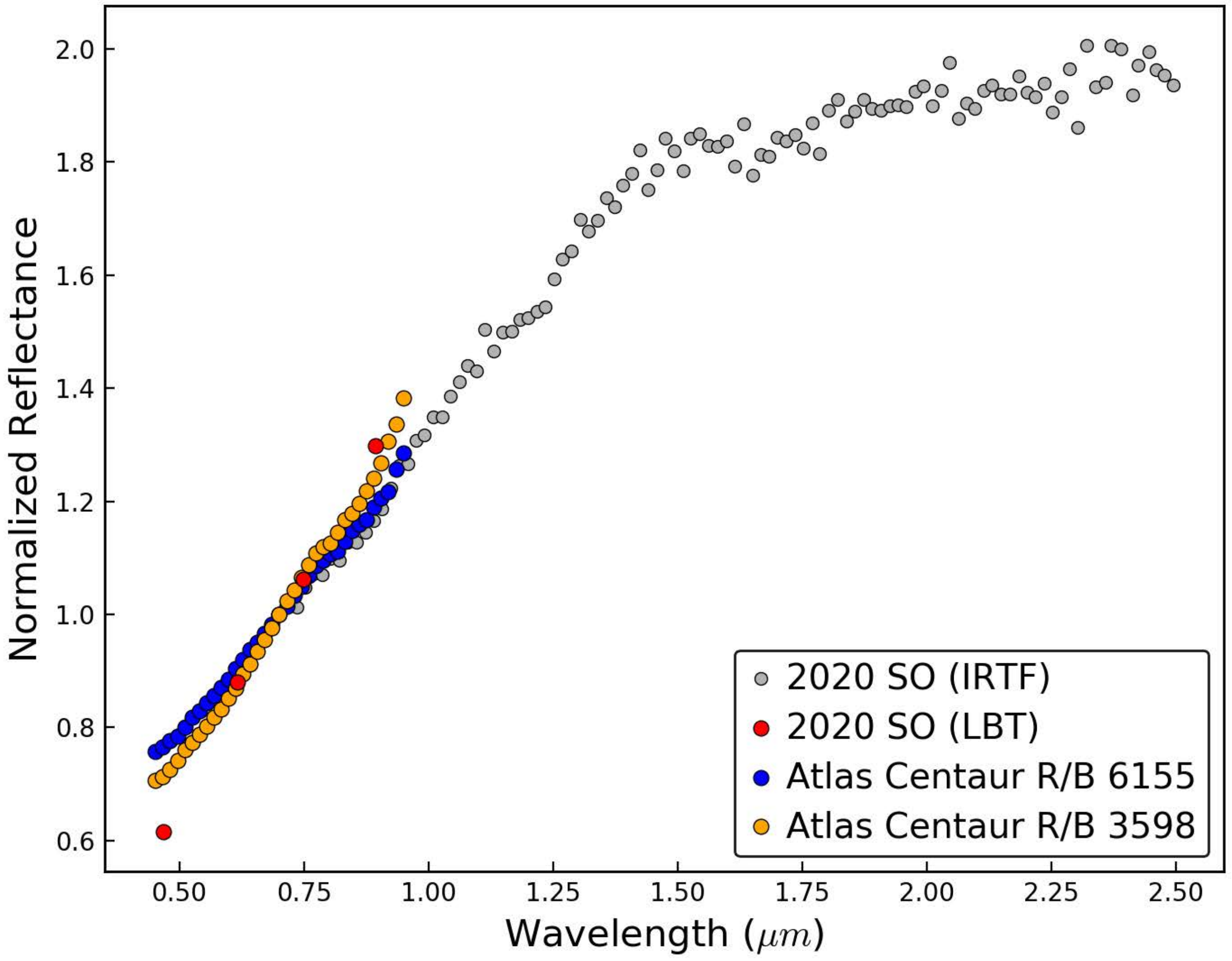




Near-IR Observations

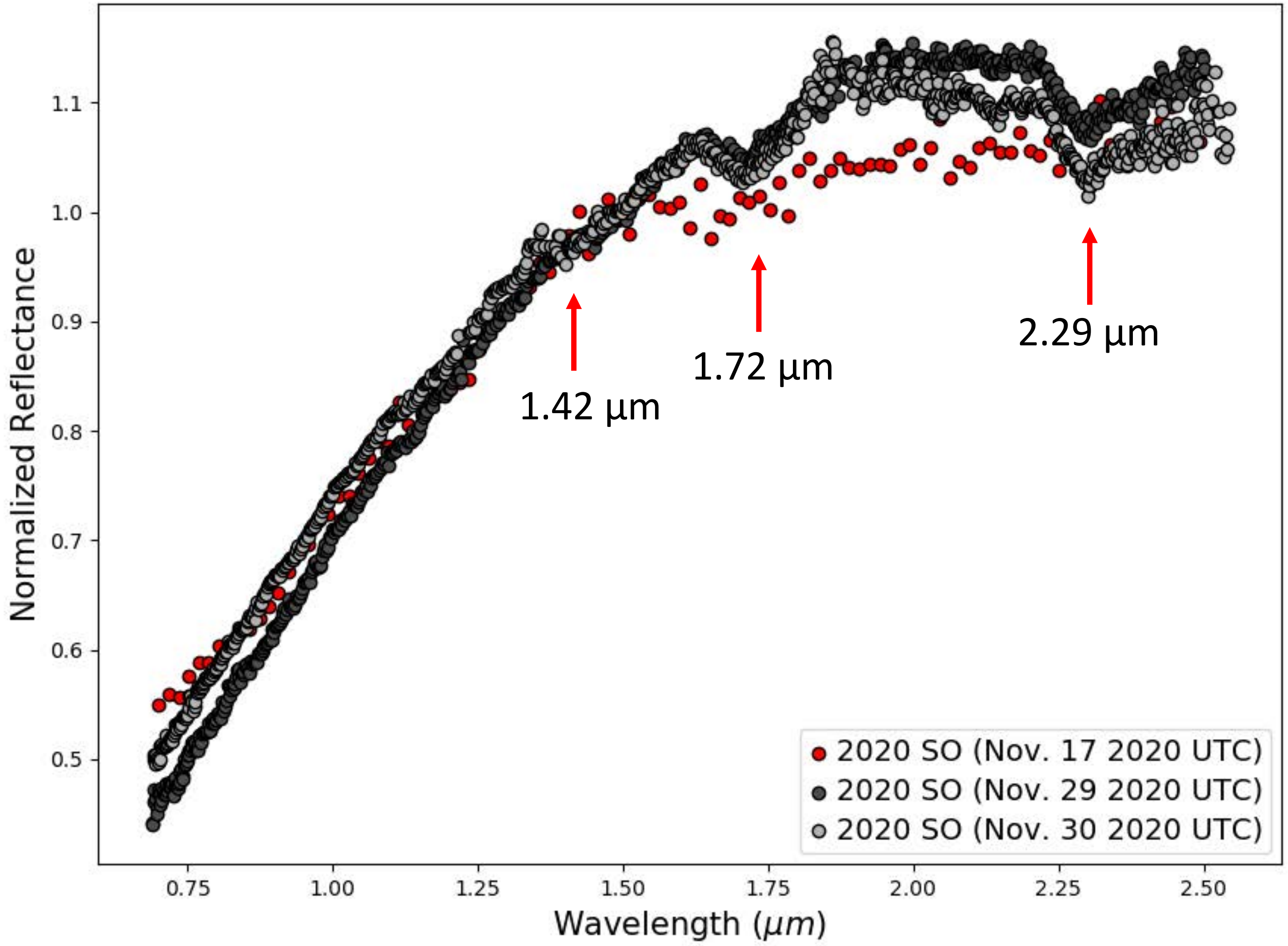
Study Lead: Juan Sanchez (post doc)

- First spectrum of 2020 SO (V. Mag. 19.3) obtained at the limit of IRTF's capabilities (V. Mag. 19.5)
- Steep red slope till 1.5 µm
- No major absorption features detected, possible weak ones
- Diagnostic absorption bands key to constraining composition
- Compared LBT 2020 SO data and RAPTORS spectra of Centaur R/Bs
- Consistent with NASA IRTF data



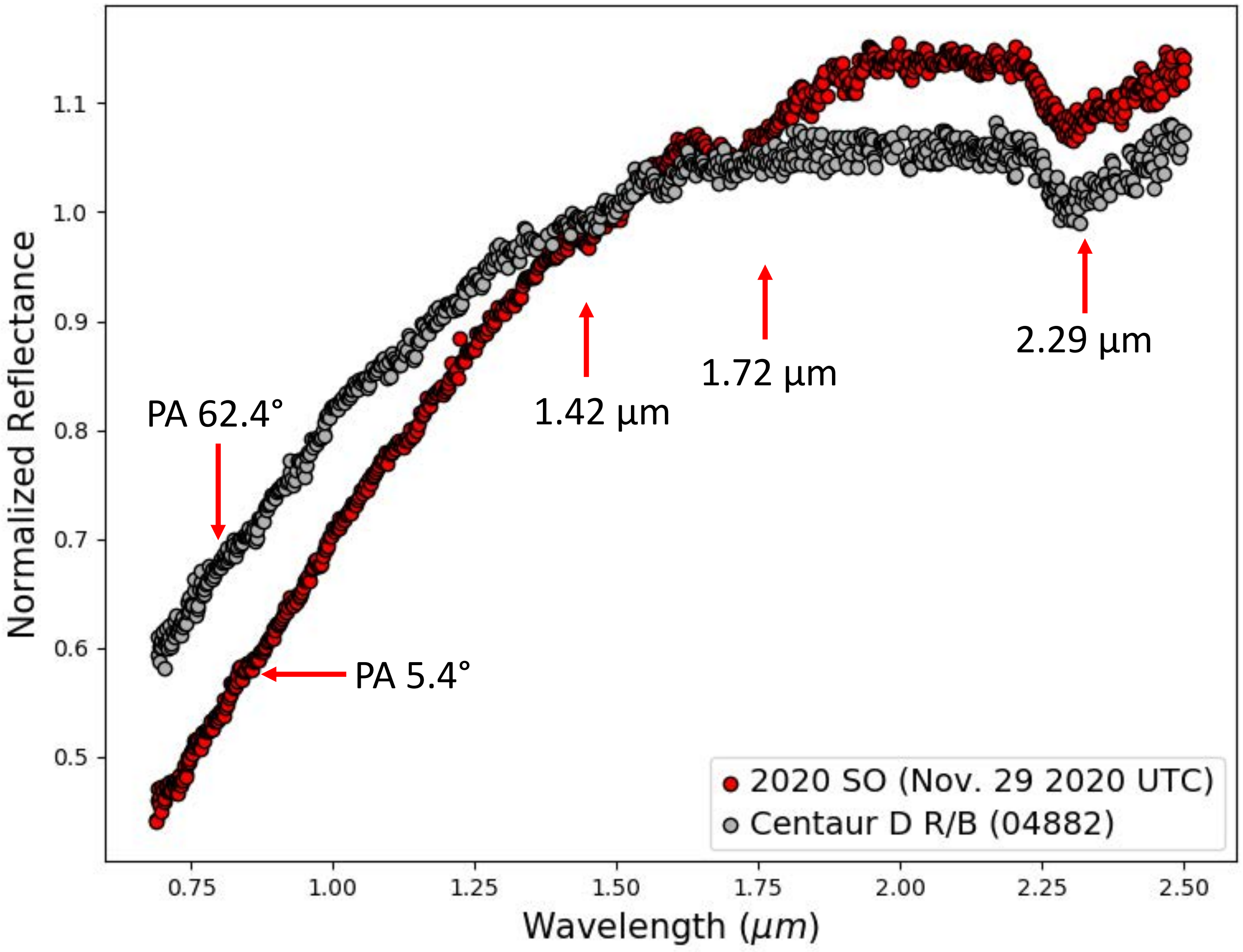
Near-IR Observations

- Next two spectra of 2020 SO were obtained days before close approach (Dec. 1, 2020)
- Spectral slope consistent with Nov. 17 data
- Major absorption bands are seen in spectra from Nov. 29, 30.
- Diagnostic absorption bands key to constraining composition
- Bands are located at 1.42±0.02, 1.72±0.01 and 2.29±0.01 µm
- But we did not have good lab spectral of analog materials



Near-IR Observations

- Spectrum of Centaur R/B (4882) consistent with 2020 SO
- Red spectral slope with absorption bands
- Absorption features at 1.42±0.02, 1.72±0.01 are weaker in the Centaur than 2020 SO.
- Spectral slope and absorption band depth difference could be due to phase angle differences or space ageing
- What materials on 2020 SO is causing these absorption bands?

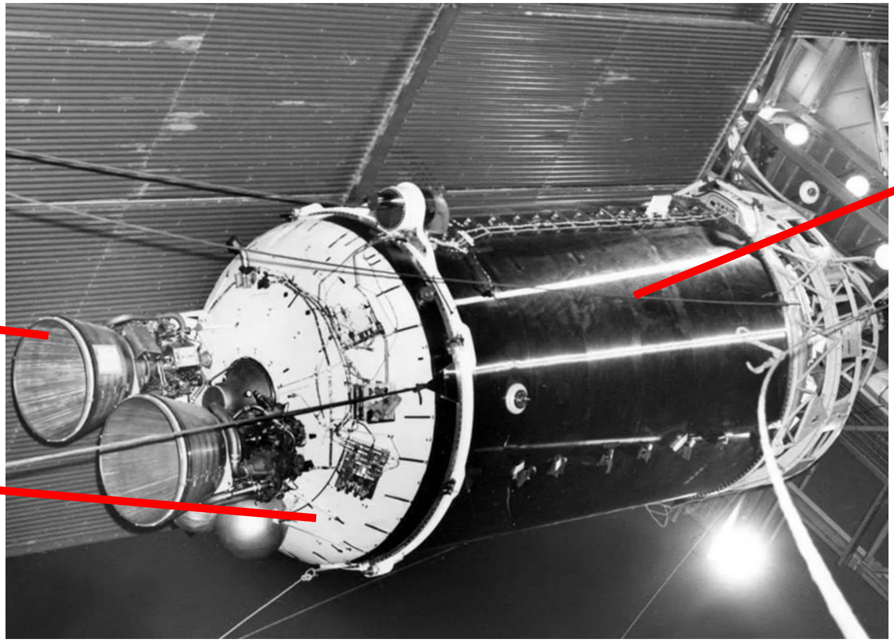


Interpretation

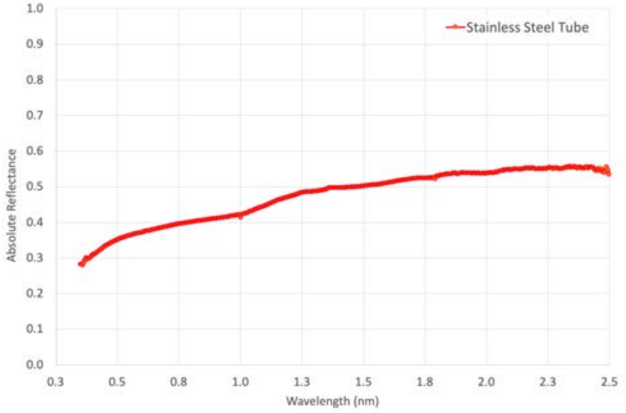
Spectrally-significant components

301 Stainless Steel

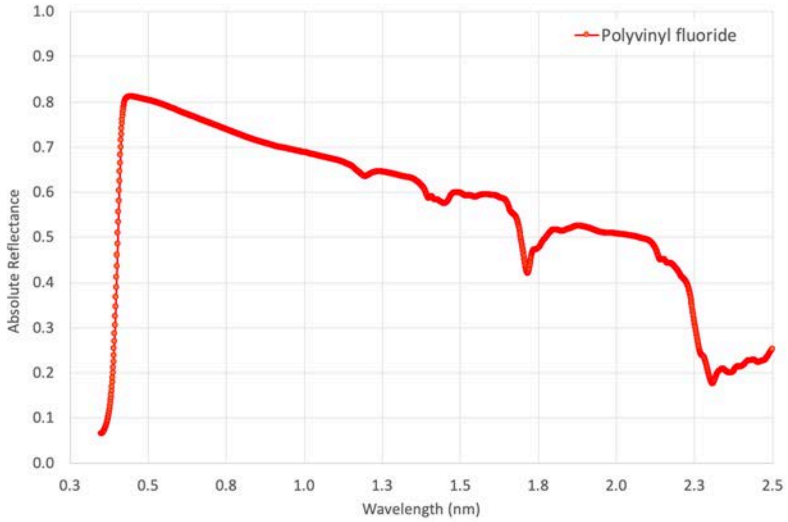
White polyvinyl fluoride



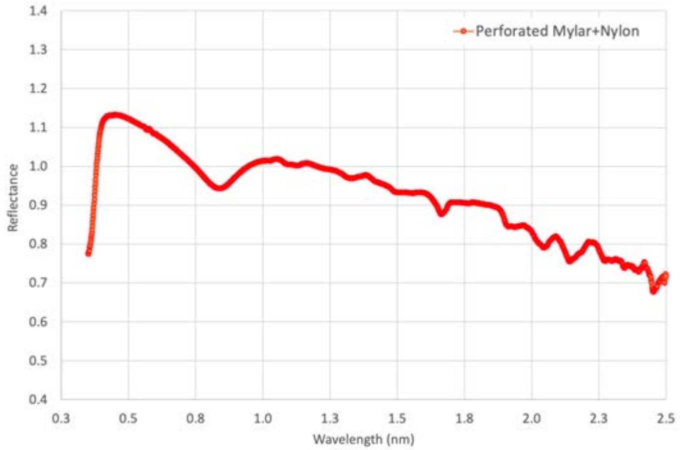
301 Stainless Steel



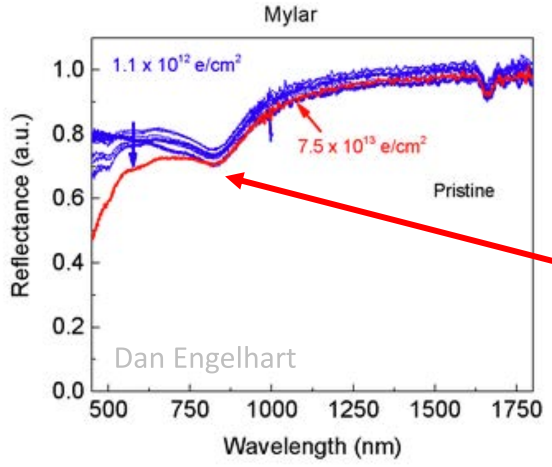
3.2.4 AFT BULKHEAD RADIATION SHIELD AND MEMBRANE. (Figures 3-19 and 3-20) The radiation shield is a rigid assembly made of laminated nylon fabric with aluminized Mylar on its inner surface and white polyvinyl fluoride on its outer surface. It is made up of 12 gores forming a complete ellipsoidal half covering the aft tank bulkhead. The shield is supported on brackets which hold it one inch from the tank bulkhead surface. Cutouts are provided for the LO_2 sump and the various equipment mounting brackets.



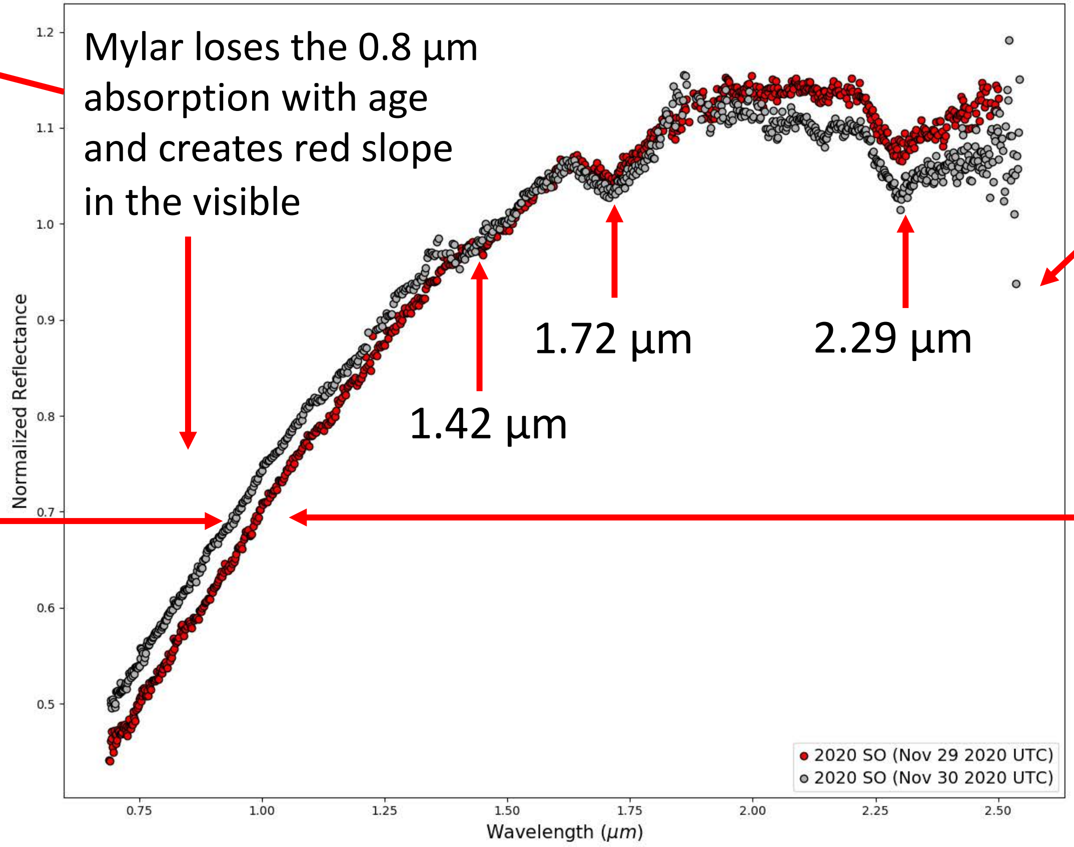
Aluminized Mylar

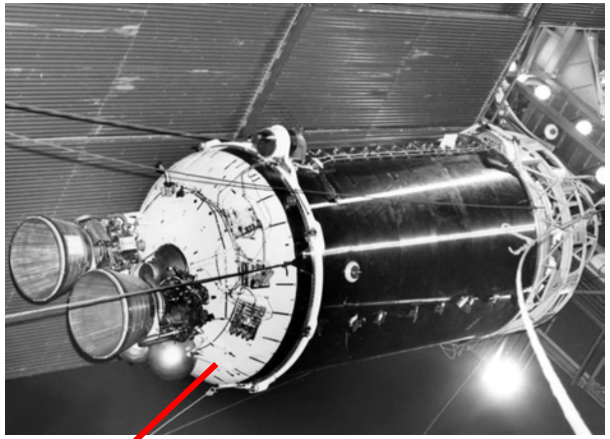


Interpretation



Object/ Material	Band I Center (µm)	Band II Center (µm)	Band III Center (µm)
PVF (Lab)	1.432±0.001	1.716±0.001	2.307±0.001
2020 SO	1.430±0.02	1.720±0.01	2.290±0.01





Stainless Steel also has red spectral slope similar to aged Mylar

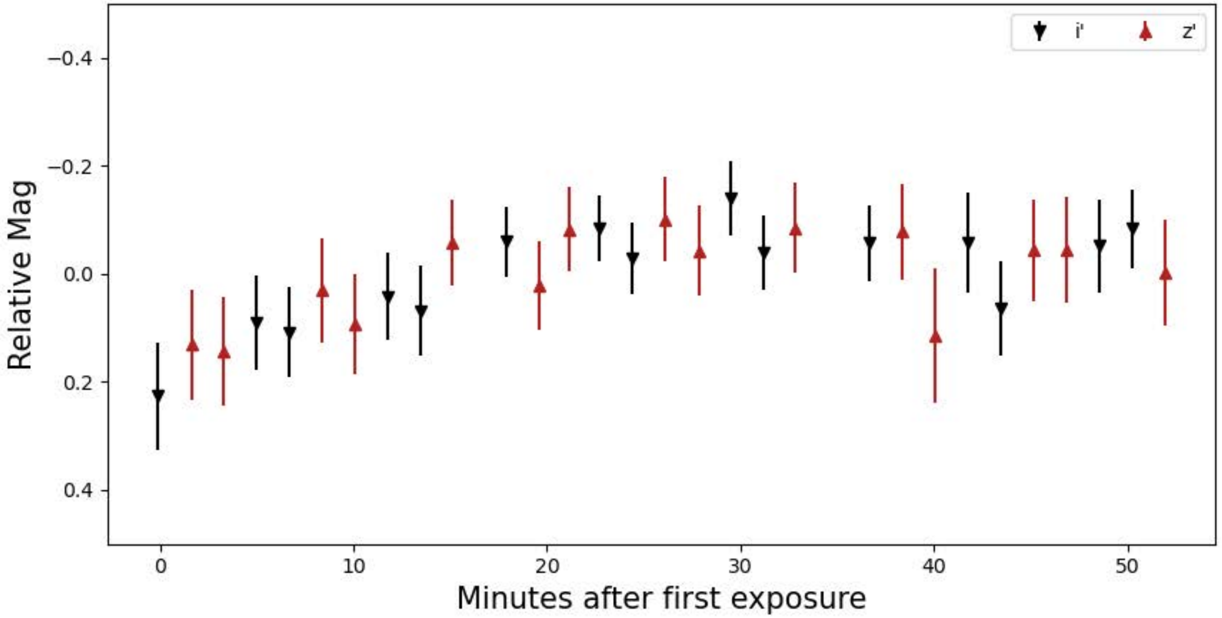
Summary

- We have demonstrated the power of spectroscopy in differentiating natural vs. artificial objects in near-Earth space.
- Fast turn around (2 weeks) for 2020 SO characterization (Asteroid Yes/No) after discovery (LBT color observations).
- Space ageing/weathering remains a major challenge in our ability to interpret 2020 SO spectra.
- We will attempt spectral mixing models once we have better end member lab spectra.

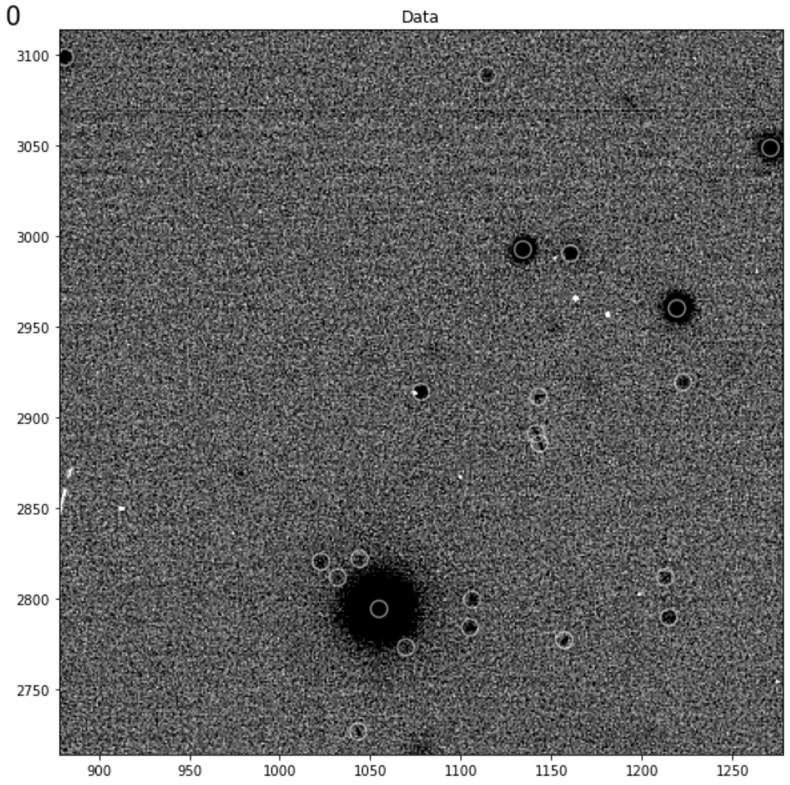
Acknowledgment: This work was funded by NASA Near-Earth Object Observations Grant NNX17AJ19G (PI: Reddy).

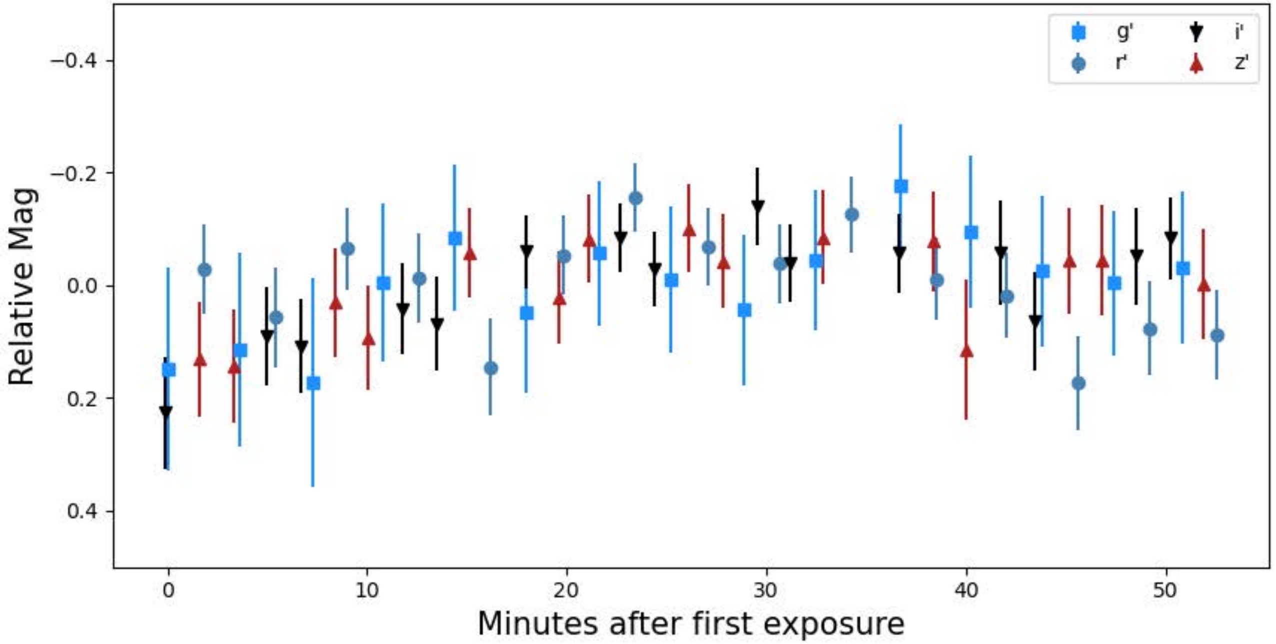
Backup Slides

Lightcurve Observations

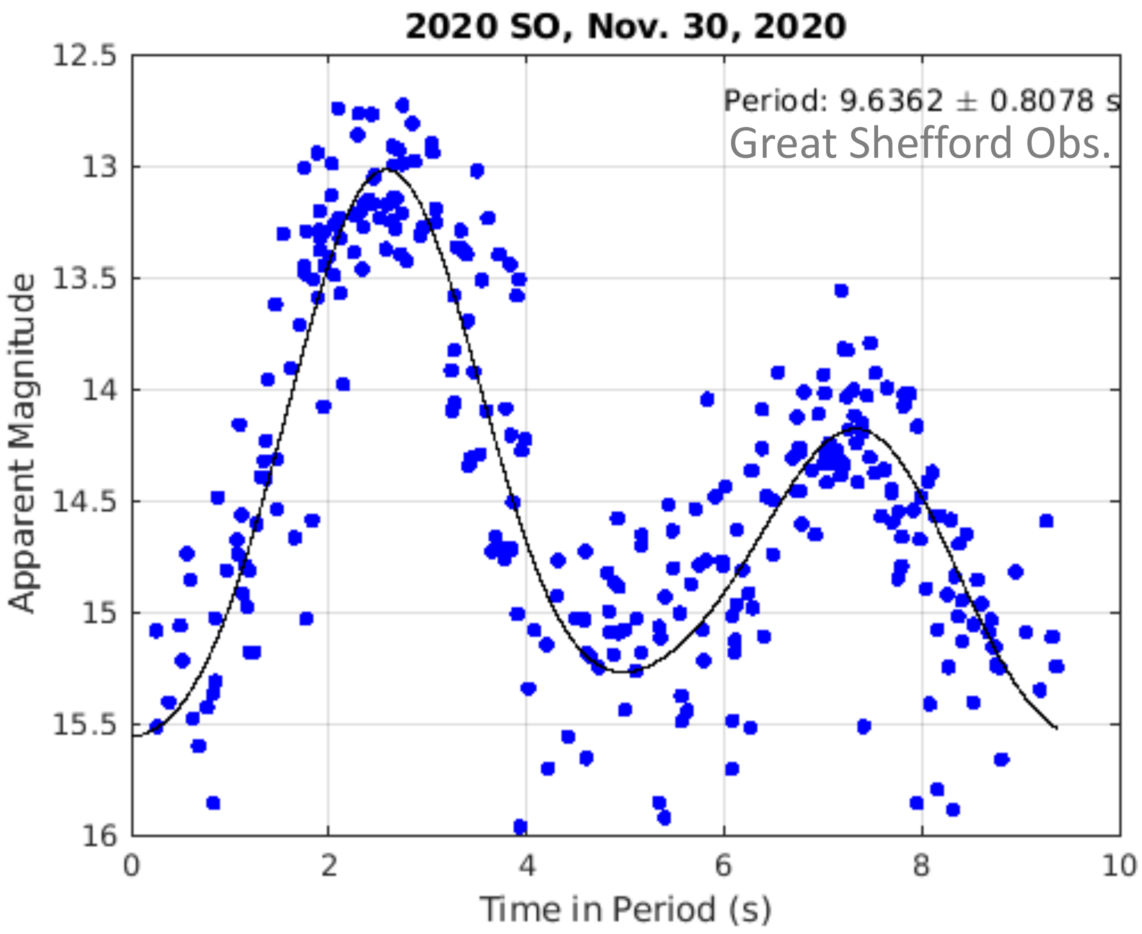


No clear evidence for a rotational period
Maybe a fast rotator or tumbling?

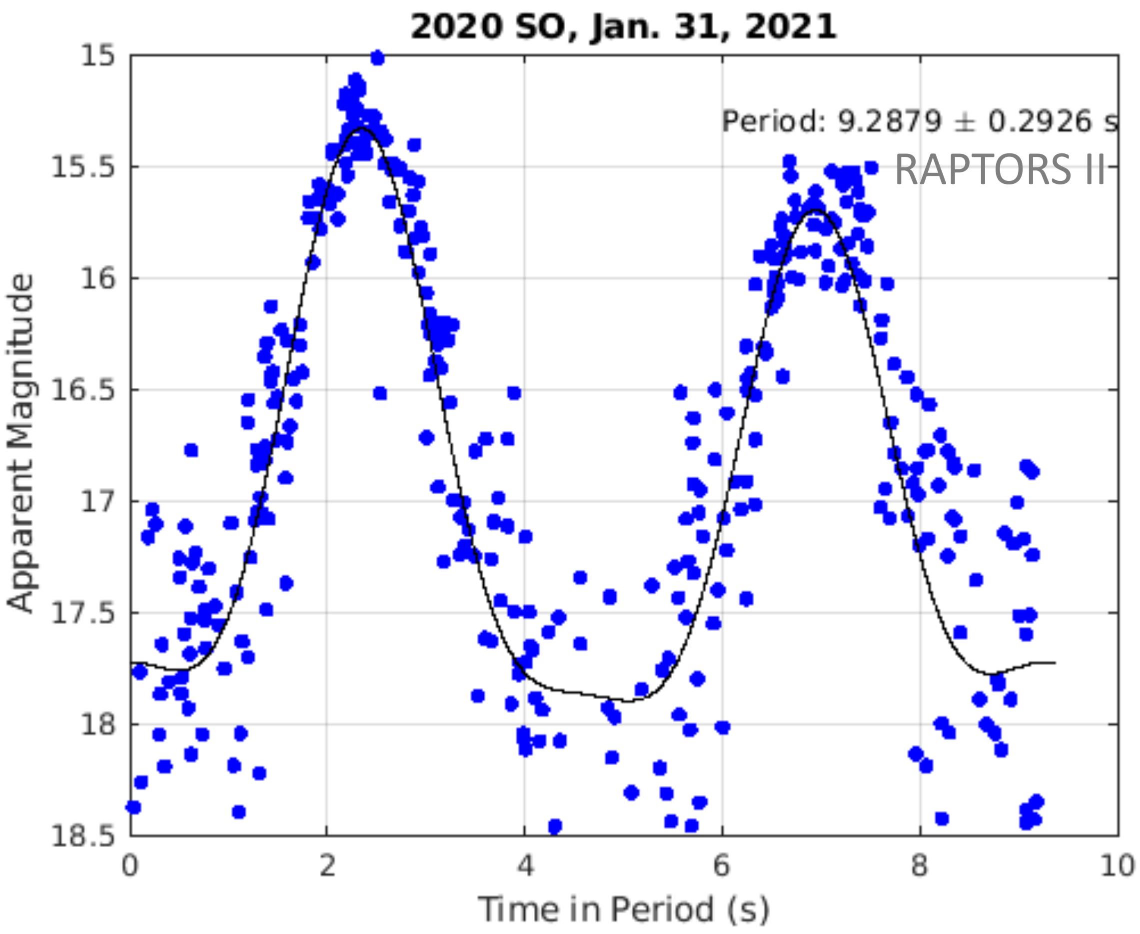




Lightcurve Observations



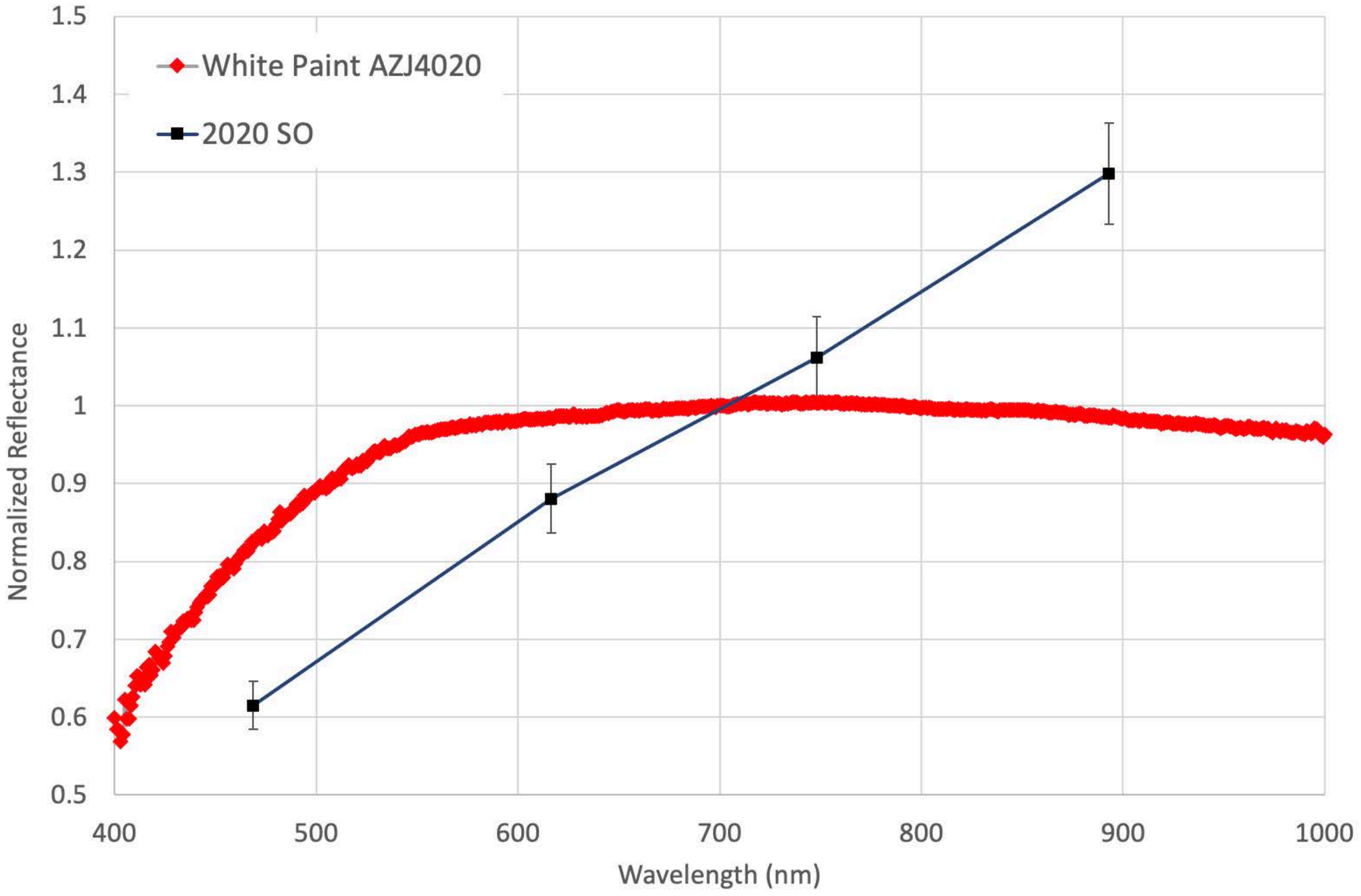
Close Approach 1, Range 94,000 km

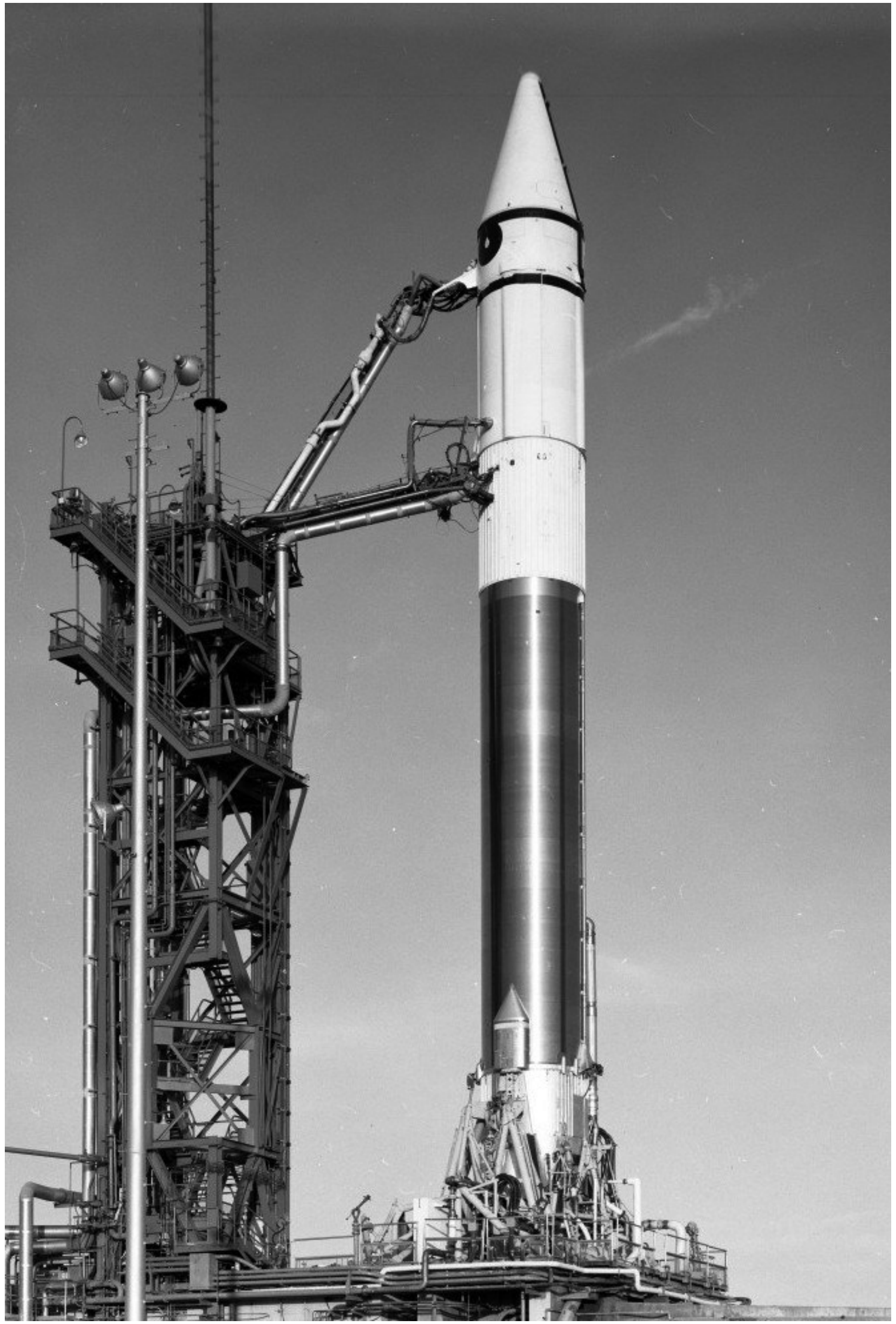


Close Approach 2, Range 360,000 km

Color Observations

- Is the Centaur D Stage really painted white?





Color Observations

- If it is not white paint what is it?
- Phillip Anz-Meador (Jacobs, at NASA JSC)
- "Centaur D (operational) models jettisoned the foam insulation panels revealing the SS underneath"
- 2020 SO should be made of Stainless Steel 301.

FABRICATION SEQUENCE

Visible Spectral Observations

<u>Centaur D History:</u> 24 Centaur D upper stages were launched between Aug. 1965 and Aug. 1972. Eight of which remain in Earth orbit. The three we picked were based on their visibility from Tucson. Two in LEO orbits were extremely challenging for spectroscopy, third was in GTO and easier to track at apogee.

Launch Vehicle	Seq. Name	Launch Date			Primary Payload	NORAD ID	Period (Min)	Inclination (Deg)	Apogee Altitude (km)	Perigee Altitude (km)
Atlas-LV3C	AC-11	14	JUL	1967	Surveyor 4	2883	113.38	64.66	2499	265
Atlas-SLV3C	AC-16	07	DEC	1968	OAO 2	3598	99.00	34.99	746	676
Atlas-SLV3C	AC-18	12	AUG	1969	ATS 5	4069	703.13	17.88	37299	2331
Atlas-SLV3C	AC-25	26	JAN	1971	Intelsat-4 2	4882	652.52	27.33	36499	585
Atlas-SLV3C	AC-26	20	DEC	1971	Intelsat-4 3	6779	655.72	28.31	36599	648
Atlas-SLV3C	AC-28	23	JAN	1972	Intelsat-4 4	5816	651.92	27.78	36449	605
Atlas-SLV3C	AC-29	13	JUN	1972	Intelsat-4 5	6058	647.68	26.27	36294	543
Atlas-SLV3C	AC-22	21	AUG	1972	OAO 3	6155	97.85	35.01	682	630

GD/C-BTD65-017
1 May 1965

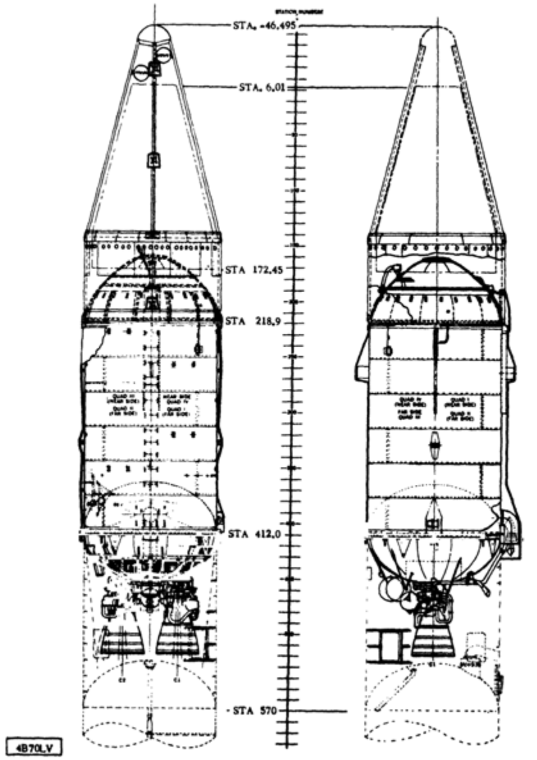


Figure 1.3-5. Centaur Operational Vehicle Configuration (Reference Only)

1-9

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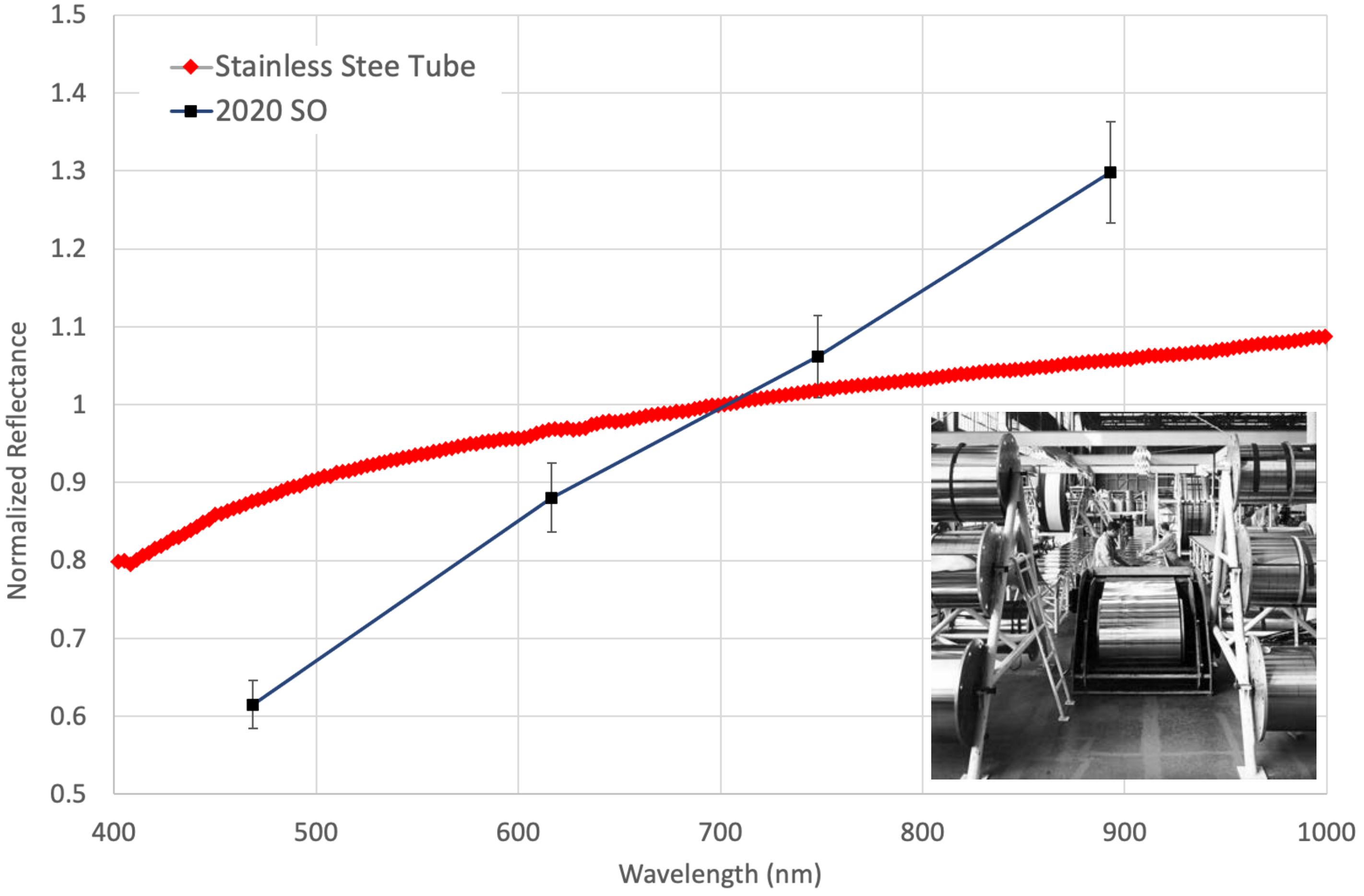
Color Observations

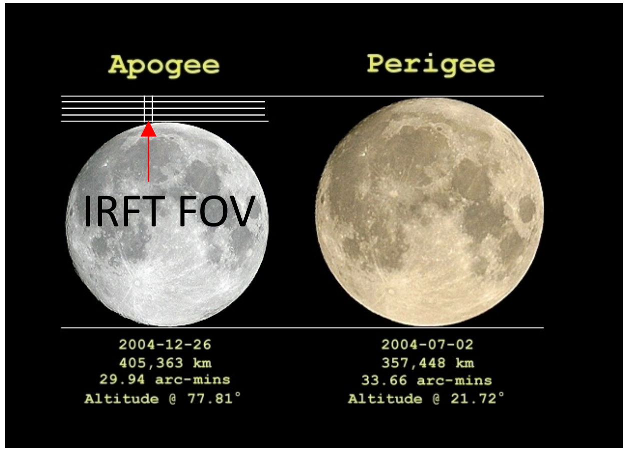
- Spectra of SS 301 obtained from AFRL (Dan Engelhart)
- These spectra were not aged under the assumption that Stainless Steel won’t oxidize like Aluminum would.
- Plot on the right compares 2020 SO griz colors with Stainless Steel Tube.
- Both have red spectral slopes, but 2020 SO is redder than lab spectrum of Stainless Steel.



Chasing Centaur

Challenges

- Identifying specific materials requires extensive lab spectroscopy if we can get the material samples
- How do spectra of materials change with space ageing?
- Logical solution was to observe another Centaur with the IRTF, preferably one of three we observed with RAPTORS I (visible spectra)



IRTF Tracking Limit: 40”/sec
Centaur Rates: RA Rate: 13 "/sec

TLE for 4882 was 2.5 days old

Centaur position off by 8.15’ (8X IRTF FOV)

We tried to observe 4882 from my backyard a few hours before IRTF observations but was too low in the sky.

Tucson, AZ

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