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2024 AAPC
Anomalous Aerospace Phenomena Conference
Bridging the Gap: Bringing Scientists, Government and Academia together to better understand UAP
Huntsville Alabama - May 31 to June 2, 2024

Aviation Safety and Steps Toward Eliminating Space-Object Caused UAP Reports

Doug Buettner, PhD, Richard Griffiths, PhD, Nick Snell, John Stilley
Presented by: Doug and Nick

Agenda

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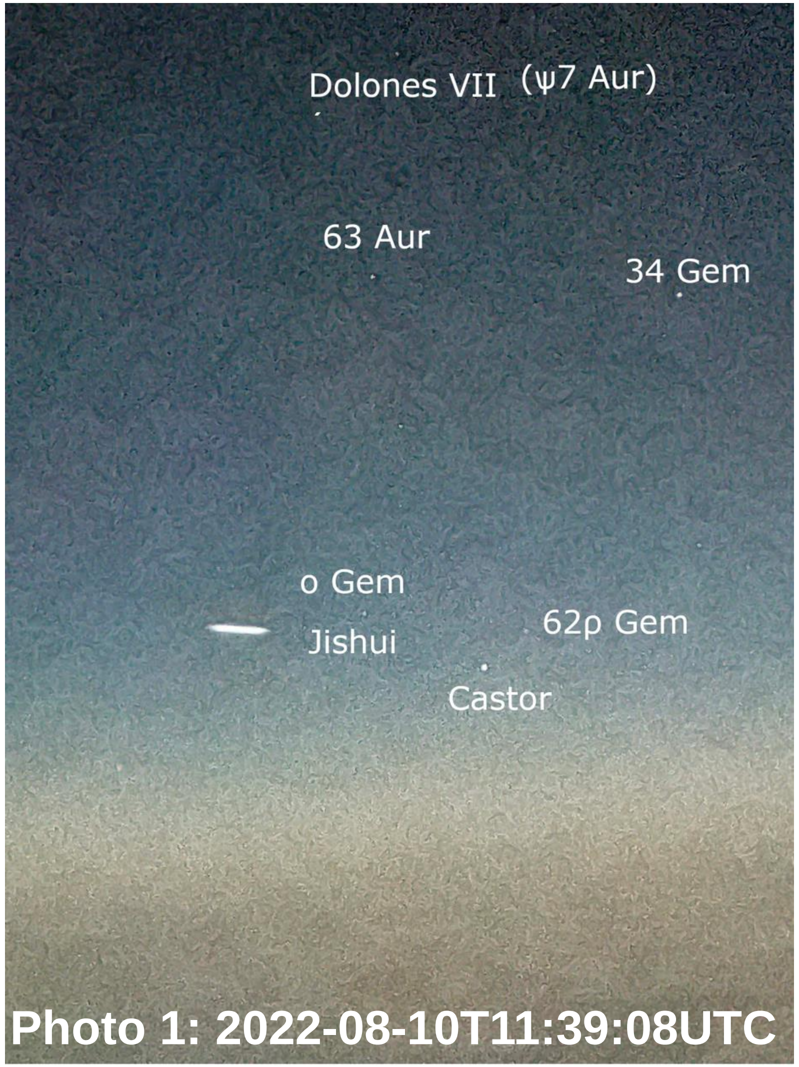
- **Astrometry:** photographic evidence of MUFON Case #124190 an Unidentified Aerospace Phenomena (UAP*) report from two commercial flights
- **Aircraft & Orbital Modeling:** how we did the initial flight and orbit modeling used to confirm that this was deploying Starlinks
- **Student Orbit & Rendering:** modeling done in a University of Utah Space Mission Engineering course
- **Geometric Analysis:** of the sighting
- **Discussion & Conclusions:** making a standard approach easily available to pilots and ground controllers in support aviation safety

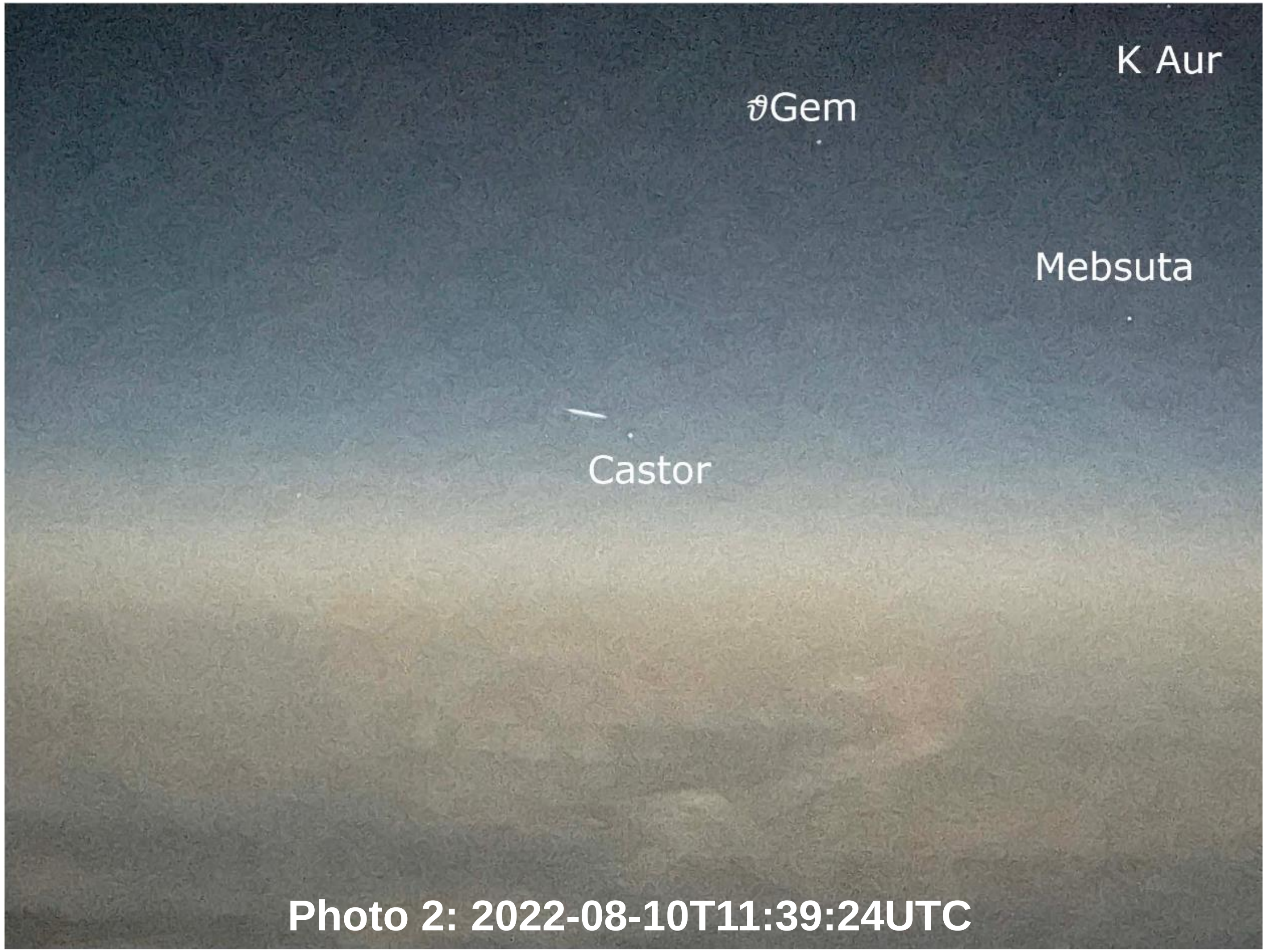
* We have adopted the SCU's acronym for UAP, vice using the "Anomalous" or "Aerial" forms.

MUFON case #124190

- What makes this case study compelling?
  - Multiple eyewitnesses:
    > 3 pilots on one flight and 2 pilots on the other flight
  - Aircraft flight data provides latitude, longitude & altitude with time:
    > AC536 flying from Maui, Hawaii to Vancouver B.C.
    > AC34 flying from Sydney, Australia to Vancouver B.C.
  - Photographic evidence (iPhone 12) from one of the AC536 pilots:
    > Photo 1: 2022-08-10T11:39:08UTC
    > Photo 2: 2022-08-10T11:39:24UTC
      - UTC is Coordinated Universal Time
    > An approximately 16 sec movie taken between the first and second photos

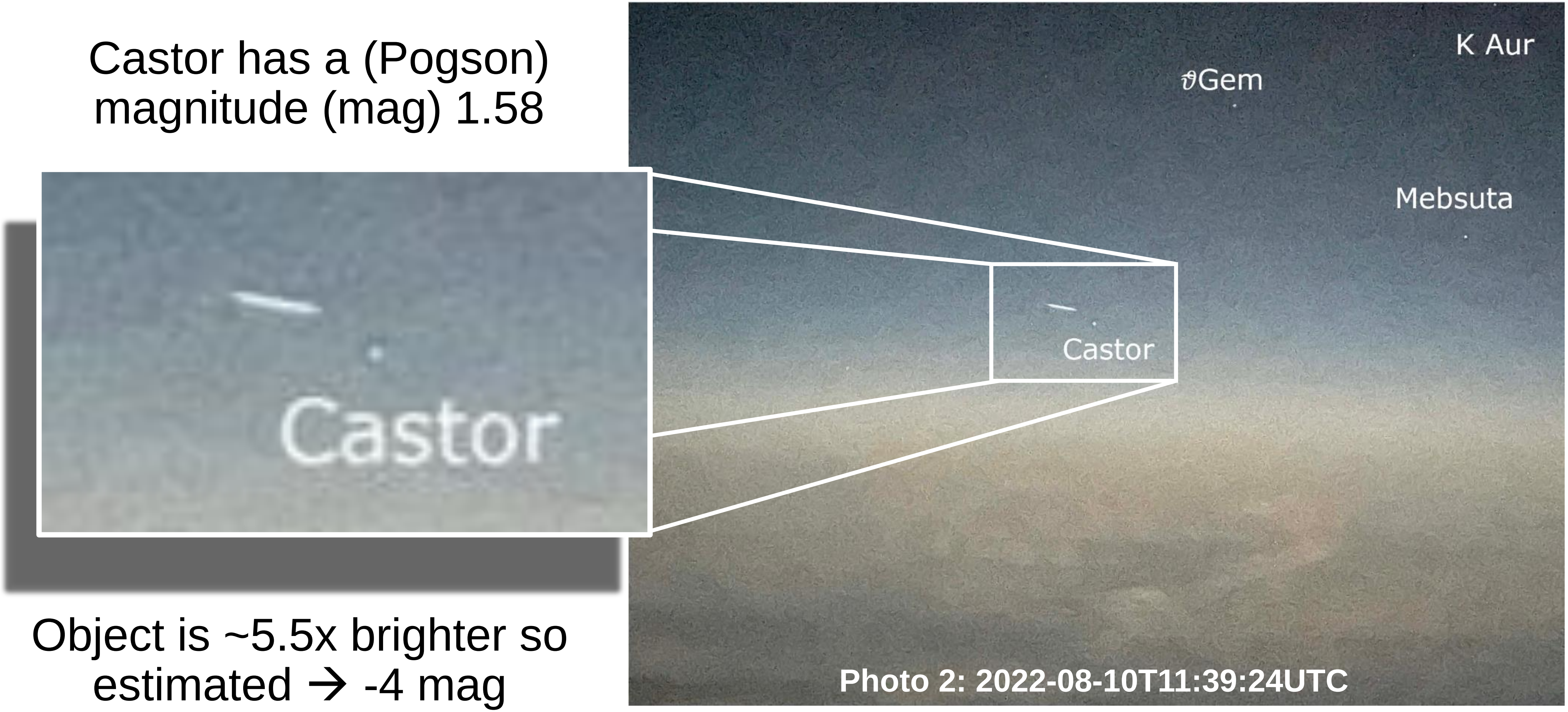
Astrometry: MUFON case #124190





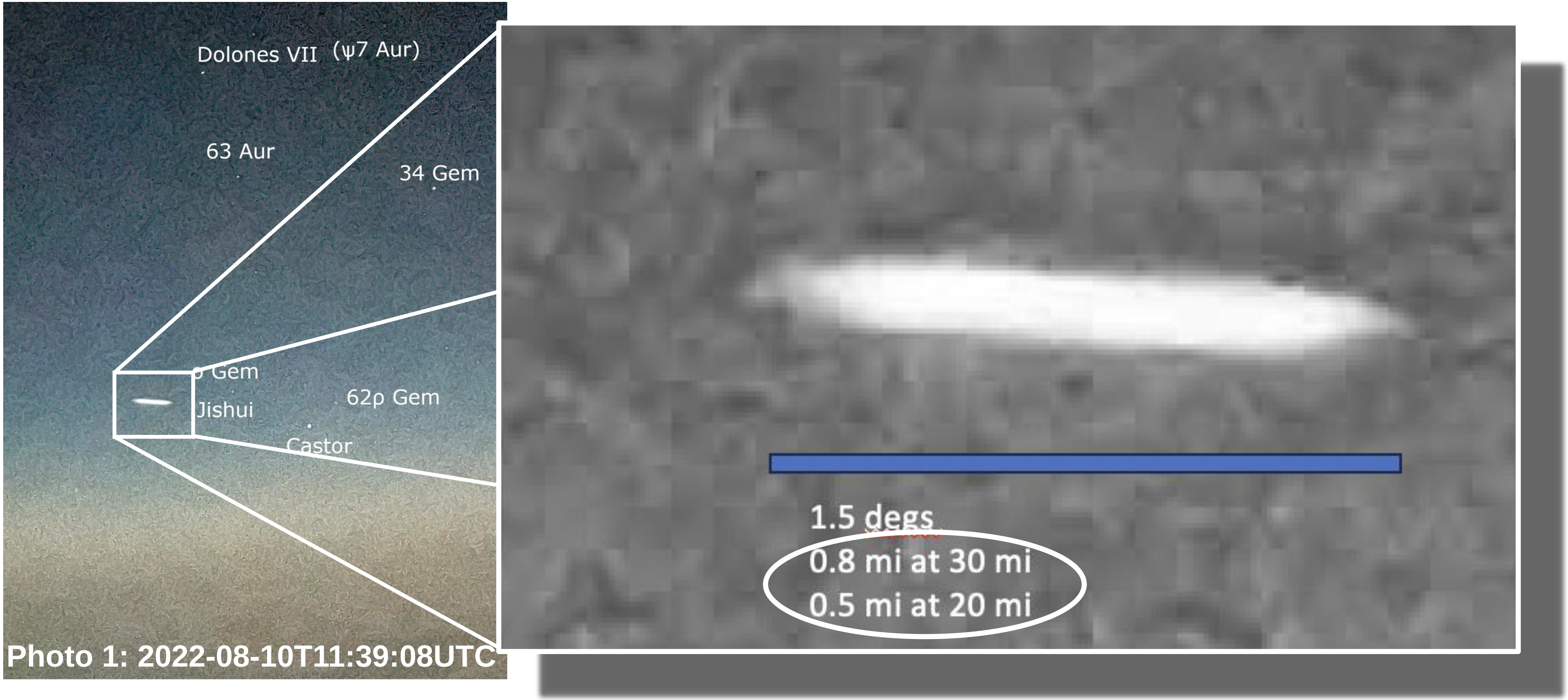
Astrometry: MUFON case #124190

Castor has a (Pogson) magnitude (mag) 1.58



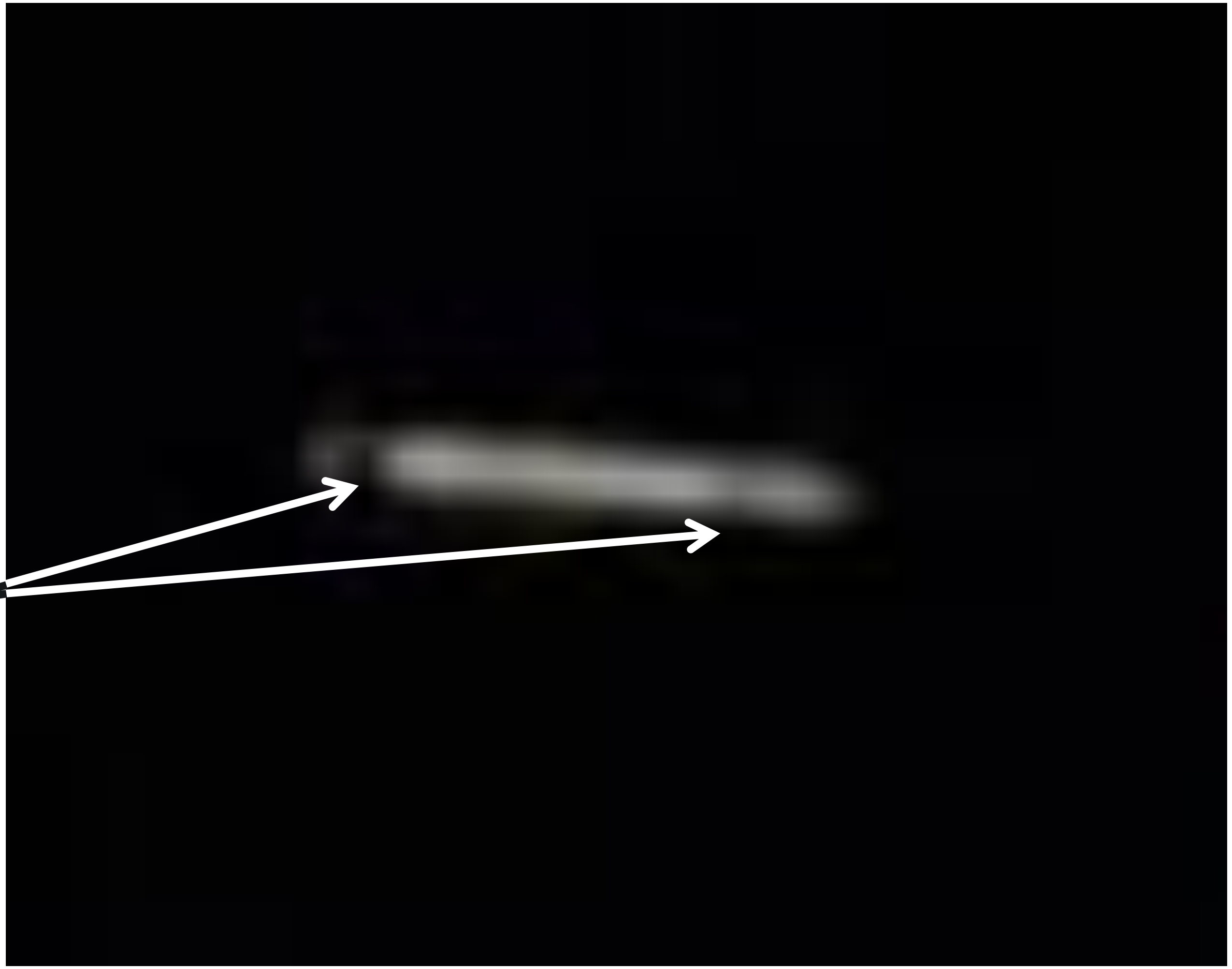
Object is ~5.5x brighter so estimated → -4 mag

Astrometry: MUFON case #124190



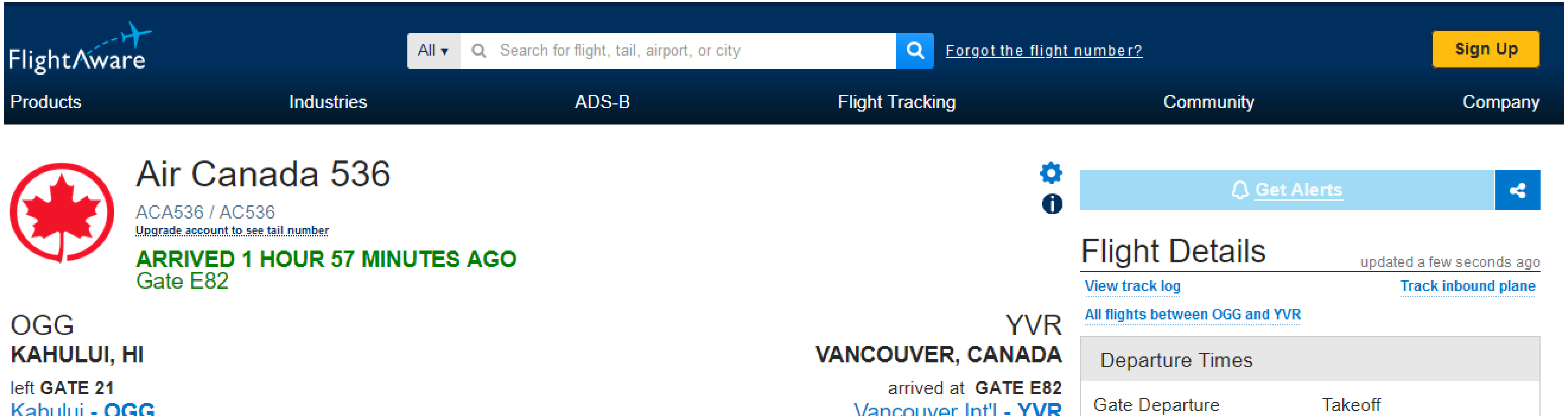
Astrometry: MUFON case #124190

- Frame #26-04 from the video
- At about 8 seconds after the first photo
- Gap structure is clearly visible



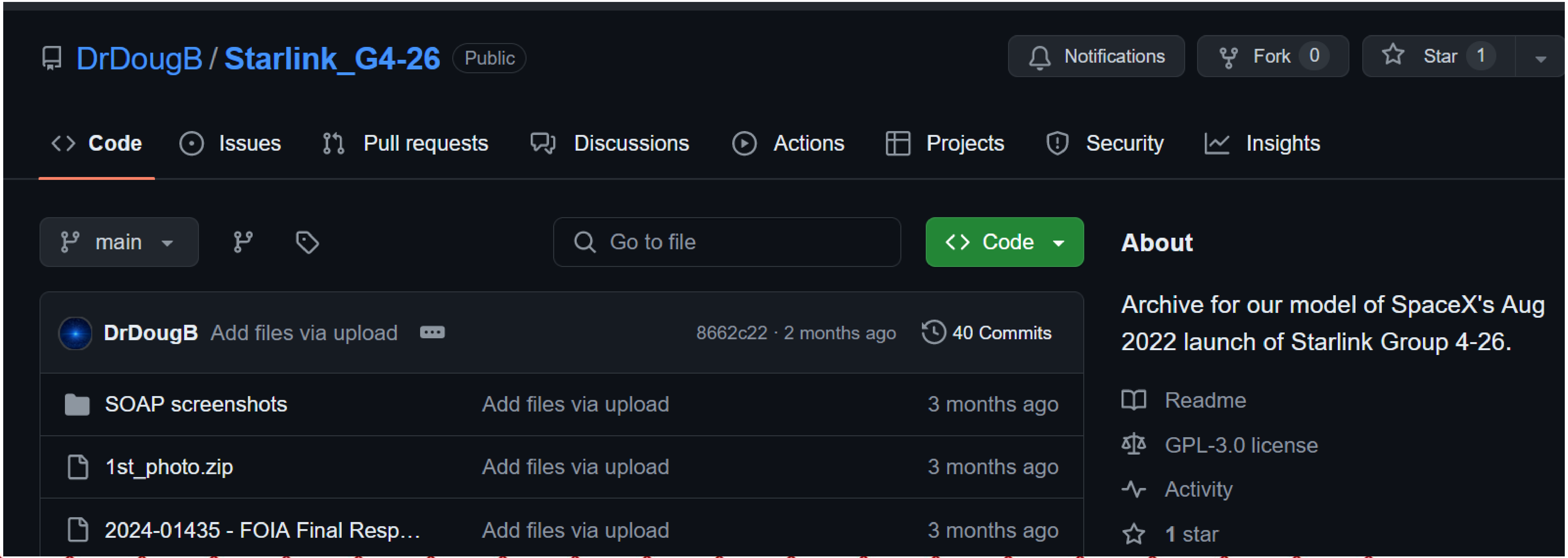
Aircraft

- Obtaining ADS-B data for the location of these photographs AC536 in our case: (https://www.flightaware.com/live/flight/ADSB/history)
  - Just ensure you are aware of the time basis (i.e., UTC or local) provided by the website used



Our Data

- Can all be found on our GitHub site
  - https://github.com/DrDougB/Starlink_G4-26/



Aircraft: ADS-B Data

- ADS-B data in our spreadsheet
  - https://github.com/DrDougB/Starlink_G4-26/blob/main/AC536.xlsx
  - Note that our data is in UTC

	A	B	C	D	E	F	G	H	I	J	K
1	Timestamp	UTC	Callsign	Position	Altitude (ft)	Altitude (km)	Speed (knots)	Speed (km/s)	Direction		
2	1.66E+09	2022-08-10T08:11:38Z	ACA536	20.893669	0	0	0	0	306		
3	1.66E+09	2022-08-10T08:20:55Z	ACA536	20.893541	0	0	3	0.001543332	295		
4	1.66E+09	2022-08-10T08:21:15Z	ACA536	20.893456	0	0	3	0.001543332	261		
5	1.66E+09	2022-08-10T08:21:34Z	ACA536	20.89349,-	0	0	2	0.001028888	210		
6	1.66E+09	2022-08-10T08:28:54Z	ACA536	20.893272	0	0	4	0.002057776	168		
7	1.66E+09	2022-08-10T08:29:05Z	ACA536	20.893055	0	0	5	0.00257222	160		
8	1.66E+09	2022-08-10T08:29:13Z	ACA536	20.892841	0	0	6	0.003086664	174		
9	1.66E+09	2022-08-10T08:29:20Z	ACA536	20.892632	0	0	7	0.003601108	191		
10	1.66E+09	2022-08-10T08:29:27Z	ACA536	20.892426	0	0	7	0.003601108	208		
11	1.66E+09	2022-08-10T08:29:34Z	ACA536	20.892214	0	0	7	0.003601108	213		

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

Aircraft: ADS-B Data

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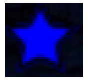
- ADS-B data in our spreadsheet
  - https://github.com/DrDougB/Starlink_G4-26/blob/main/AC536.xlsx
  - Note that our data is in UTC
  - Scrolling down, you'll find our highlighted data around the time of the photos

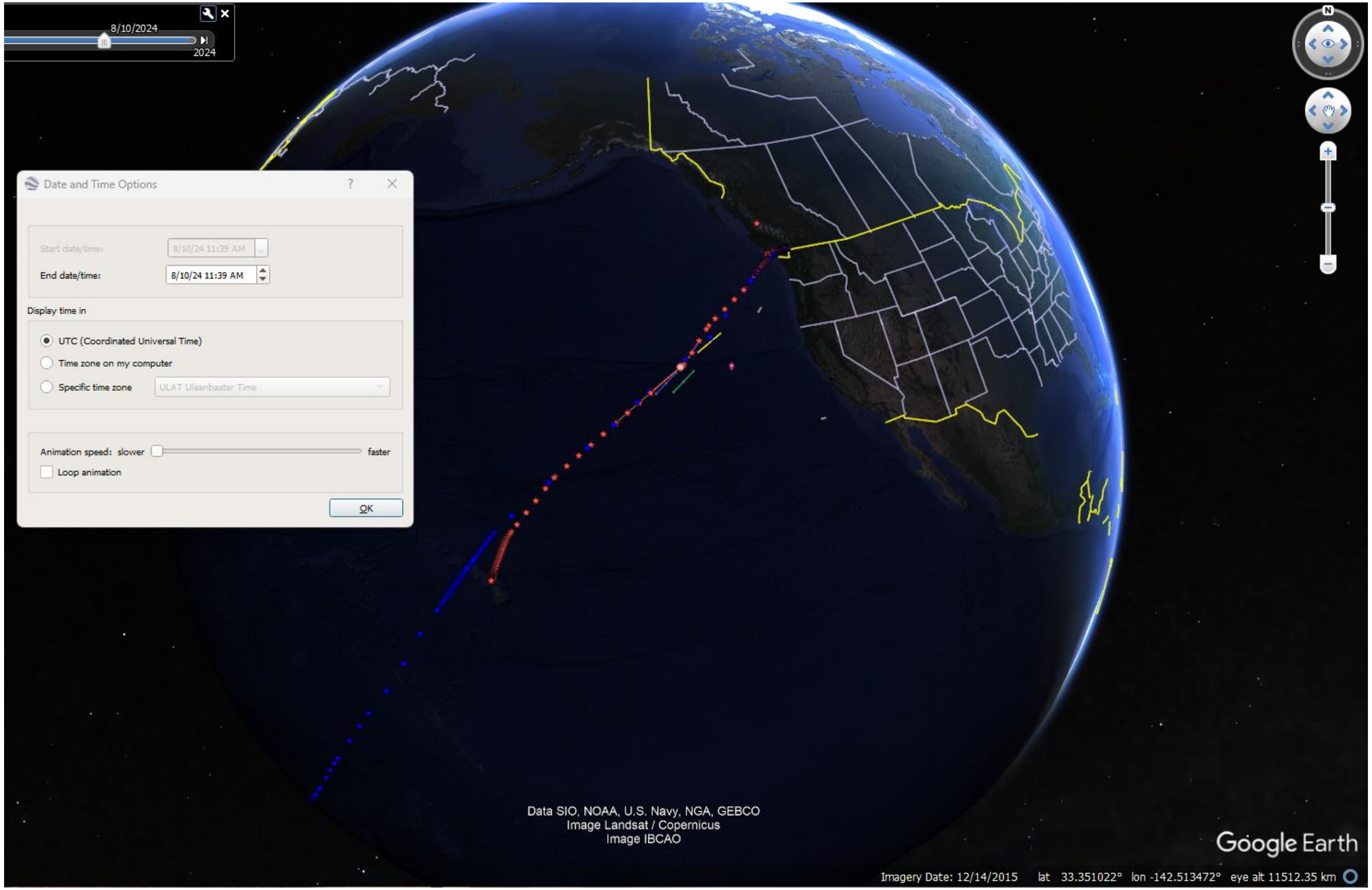
	A	B	C	D	E	F	G	H	I
136	1.66E+09	2022-08-10T10:35:02Z	ACA536	34.03508,-146.503952	37000	11.2776	499	0.256707556	46
137	**1.66E+09**	**2022-08-10T10:44:22Z**	**ACA536**	**34.94759,-145.31012**	**37000**	**11.2776**	**511**	**0.262880884**	**46**
138	1.66E+09	2022-08-10T10:44:59Z	ACA536	35.004589,-145.240067	37000	11.2776	476	0.244875344	39
139	1.66E+09	2022-08-10T10:54:07Z	ACA536	35.824635,-144.129379	37000	11.2776	468	0.240759792	47
140	1.66E+09	2022-08-10T11:03:40Z	ACA536	36.655186,-142.951508	37000	11.2776	467	0.240245348	48
141	1.66E+09	2022-08-10T11:13:16Z	ACA536	37.485031,-141.738785	37000	11.2776	466	0.239730904	48
142	1.66E+09	2022-08-10T11:41:53Z	ACA536	39.803783,-138.11734	37000	11.2776	449	0.230985356	49
143	1.66E+09	2022-08-10T11:42:13Z	ACA536	39.825115,-138.085541	37000	11.2776	449	0.230985356	37
144	1.66E+09	2022-08-10T11:51:39Z	ACA536	40.77491,-137.149582	37000	11.2776	450	0.2314998	35
145	1.66E+09	2022-08-10T12:01:04Z	ACA536	41.758778,-136.242462	37000	11.2776	447	0.229956468	35
146	1.66E+09	2022-08-10T12:10:48Z	ACA536	42.73772,-135.283798	37000	11.2776	448	0.230470912	36

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

Aircraft: Google Earth Trajectory

Import as CSV data to create KML/KMZ files… Google Earth Pro

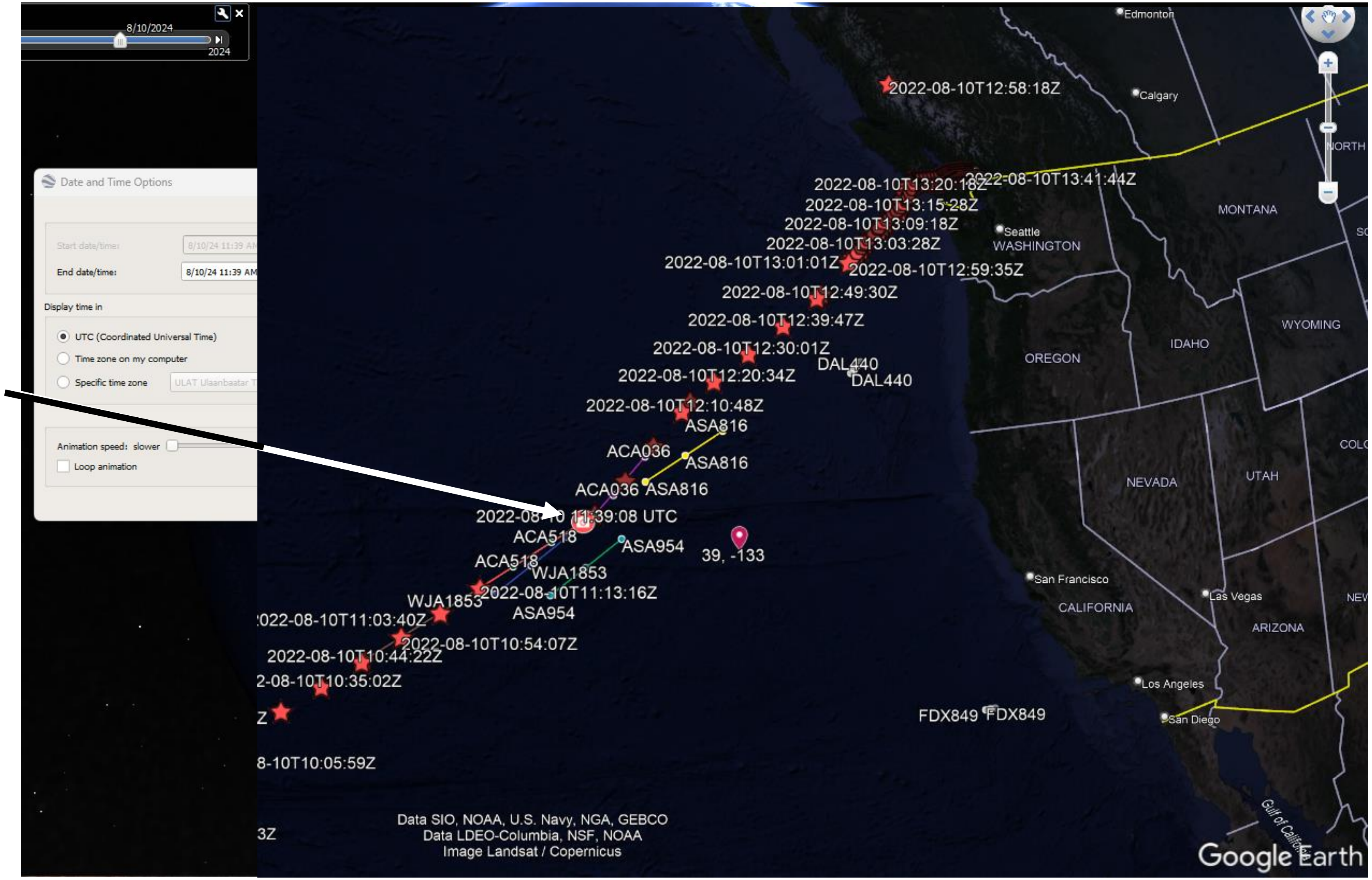
- We provide an AC536 kmz file for you in our GitHub repository
- Automatic Dependent Surveillance-Broadcast (ADS-B) data
- Unable to display 8/10/22 UTC time had to use 8/10/24
- Shows sunlit part of the Earth
- AC34  Icon
- AC536  Icon



Aircraft: Trajectory Location of Photos

Google Earth Pro

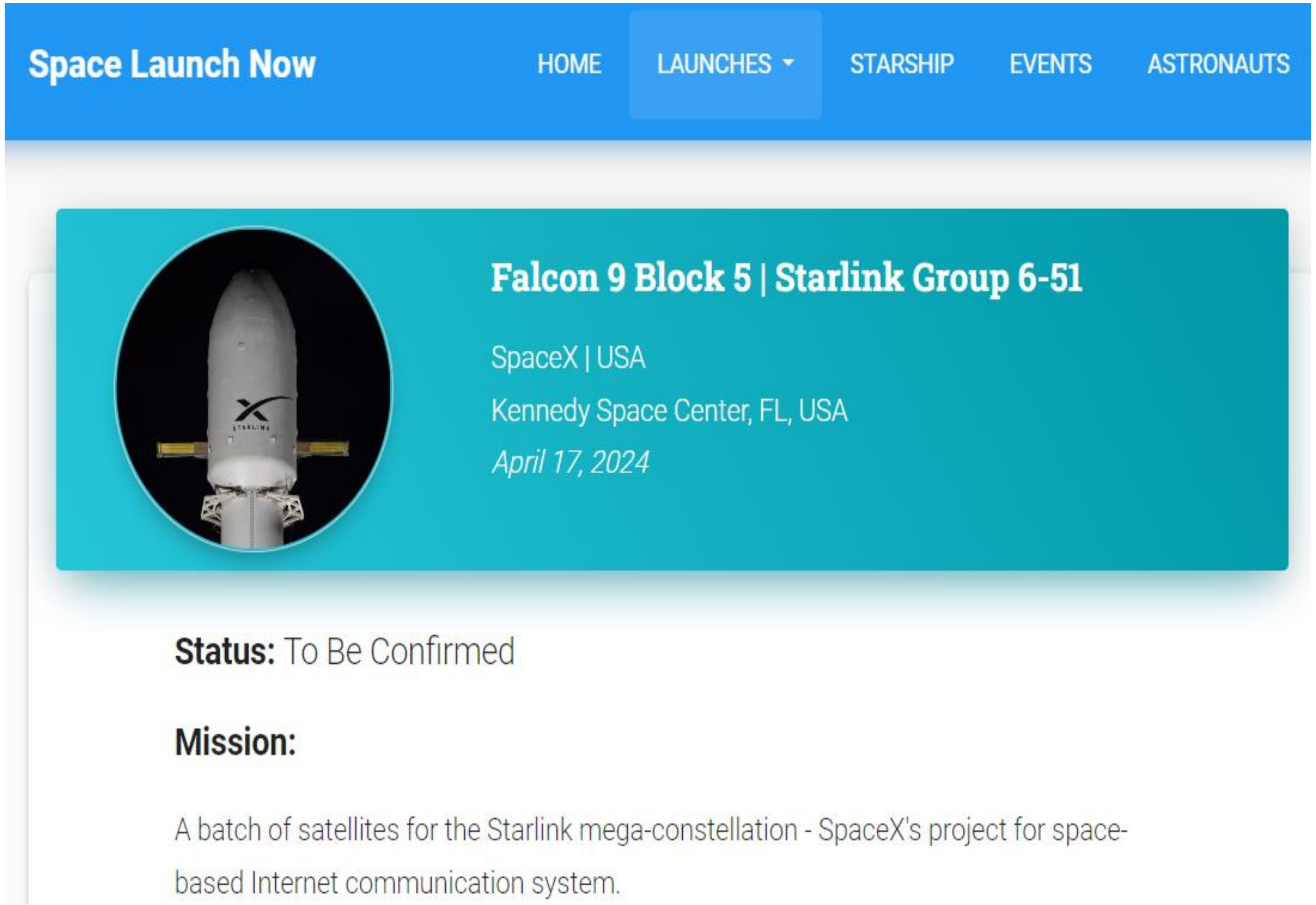
- Zooming in…
- Location of AC 536 at the time of the photos



Orbit modeling: Upcoming Launches

Proactive mode:

- 1st, need to get info about the upcoming launches
  - Space Launch Now used here
  - NASA Space Flight is another potential site
  - And there are others…
  - After bringing up the page, we can scroll down and find the next scheduled Starlink launch



Orbit modeling: Starlink Group 6-51

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- Use Celestrak to download Two-Line Elements (TLEs) for the Starlinks to plot using Orbit Modeling & Analysis Software
- We'll see if this one is in Celestrak yet (as of April 14th, 2024), to do this you use the following query:

CELESTRAK® SINCE 1985

Guess not, and hence the,

Status: To Be Confirmed

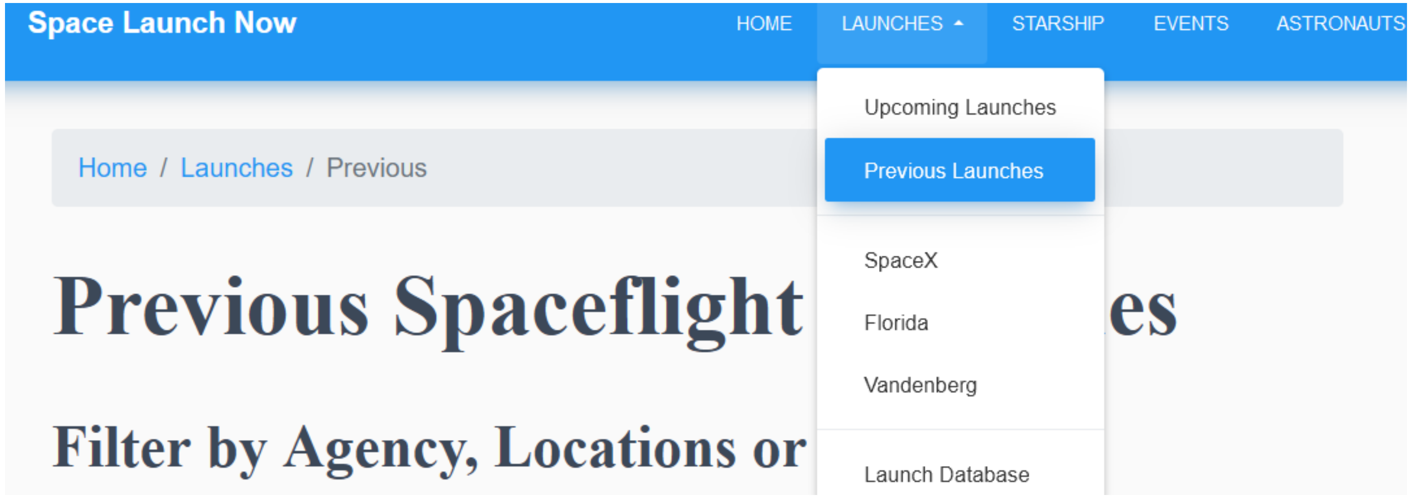
https://celestrak.org/NORAD/elements/supplemental/sup-gp.php?FILE=starlink-g6-51&FORMAT=TLE

```
Invalid query: "FILE=starlink-g6-51&FORMAT=TLE" (FILE=starlink-g6-51 not found)
```

Orbit modeling: Historic launches

Reactive mode:

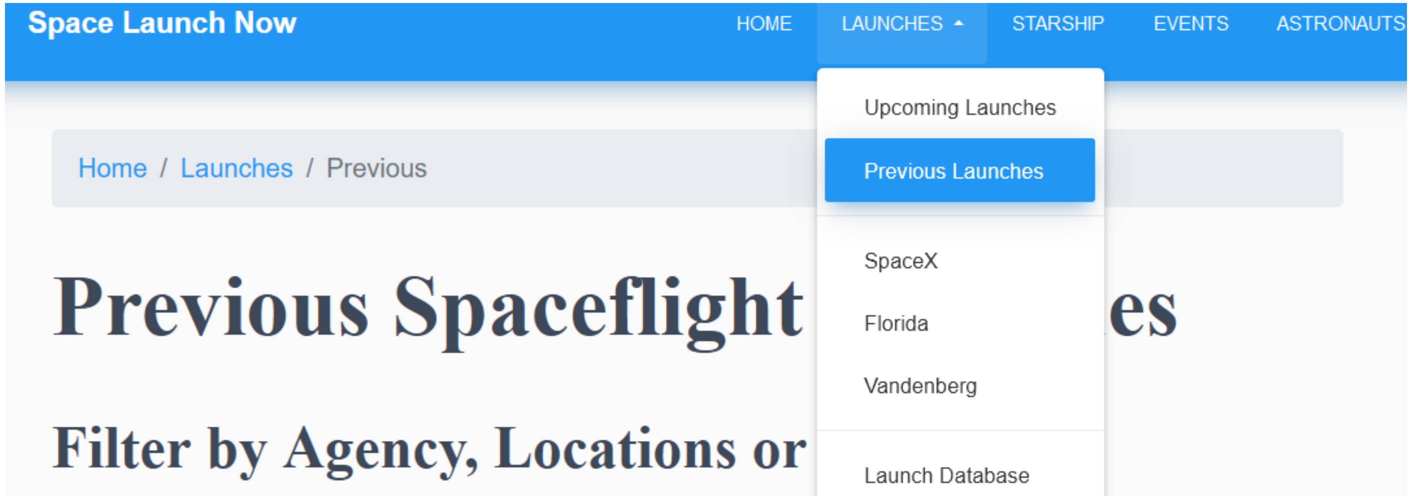
- 1^{st}, need to get info about the launch
  - Space Launch Now used here
  - NASA Space Flight is another potential site
  - And there are others…



Orbit modeling: Historic launches

Reactive mode:

- 1st, need to get info about the launch
  - Space Launch Now used here
  - NASA Space Flight is another potent
  - And th



Orbit modeling: Starlink Group 4-26

- Use Celestrak to download Two-Line Elements (TLEs) for the Starlinks to plot using Orbit Modeling & Analysis Software
- Dr T.S. Kelso provided significant support to make these queries easier

You can change this URL for your queries, but this is what gave us the original “high level” TLEs that were provided for launch

https://celestrak.org/NORAD/elements/supplemental/sup-gp.php?FILE=starlink-g4-26&FORMAT=TLE

```
STARLINK-G4-26 STACK
1 72000C 22097A   22222.10427778  .00079168  00000+0  13040-3 0    09
2 72000  53.2190 249.4977 0077526  44.7868  32.1202 15.96675264    19
STARLINK-G4-26 SINGLE
1 72001C 22097B   22222.10427778  .01041707  00000+0  16879-2 0    01
2 72001  53.2189 249.4977 0077464  44.9070  32.0000 15.96664287    14
```

Orbit modeling: Starlink Group 4-26

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- Use Celestrak to download Two-Line Elements (TLEs) for the Starlinks to plot using Orbit M
Analysis Soft
- Dr T.S. Kelso
significant support to make these queries easier

CELESTRAK® SINCE 1985

Celestrak is dependent on SpaceX to provide the data in advance, and they do provide it, when they can…

You can change this URL for your queries, but this is what gave us the original "high level" TLEs that were provided for launch

https://celestrak.org/NORAD/elements/supplemental/sup-gp.php?FILE=starlink-g4-26&FORMAT=TLE

```
STARLINK-G4-26 STACK
1 72000C 22097A   22222.10427778  .00079168  00000+0  13040-3 0    09
2 72000  53.2190 249.4977 0077526  44.7868  32.1202 15.96675264    19
STARLINK-G4-26 SINGLE
1 72001C 22097B   22222.10427778  .01041707  00000+0  16879-2 0    01
2 72001  53.2189 249.4977 0077464  44.9070  32.0000 15.96664287    14
```

Orbit modeling: What is a TLE???

- A Two-Line Element or (TLE) is an orbit info format created by NORAD to catalog & track space objects
- Technically, this is a "3LE", where the first line is the name of the 'object' in orbit
  - Orbit modeling software can usually import an entire list of 3LEs in a single file
- This object is the "STARLINK-G4-26 STACK"
  - "STACK" indicates it's the payload
  - If you pull this same group days later, this object is replaced by the individual satellite names
  - "SINGLE" on the previous page, indicates the 2nd stage rocket body which SpaceX now deorbits
  - How to read TLEs →

```
STARLINK-G4-26 STACK
1 72000C 22097A   22222.10427778  .00079168  00000+0  13040-3 0    09
2 72000  53.2190 249.4977 0077526  44.7868  32.1202 15.96675264    19
```

And this is the Two-Line Element Portion

Orbit modeling: How to read TLEs

```
STARLINK-G4-26 STACK
1 72000C 22097A  22222.10427778  .00079168  00000+0  13040-3 0    09
```

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1		2	5	5	4	4	U		9	8	0	6	7	A				0	8	2	6	4
1		2					3		4		5			6				7		8		

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
.	5	1	7	8	2	5	2	8		-	.	0	0	0	0	2	1	8	2			0
										9											10	

47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
0	0	0	0	-	0		-	1	1	6	0	6	-	4		0			2	9	2	7
							11									12		13				14

Field	Columns	Content	Example
1	01	Line number	1
2	03–07	Satellite catalog number	25544
3	08	Classification (U: unclassified, C: classified, S: secret) [12]	U
4	10–11	International Designator (last two digits of launch year)	98
5	12–14	International Designator (launch number of the year)	067
6	15–17	International Designator (piece of the launch)	A
7	19–20	Epoch year (last two digits of year)	08
8	21–32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34–43	First derivative of mean motion; the ballistic coefficient [13]	-.00002182
10	45–52	Second derivative of mean motion (decimal point assumed) [13]	00000-0
11	54–61	*B**, the drag term, or radiation pressure coefficient (decimal point assumed) [13]	-11606-4
12	63–63	Ephemeris type (always zero; only used in undistributed TLE data) [14]	0
13	65–68	Element set number. Incremented when a new TLE is generated for this object.[13]	292
14	69	Checksum (modulo 10)	7

Prior to launch, this is the anticipated launch year and UTC day number fraction. If the launch is scrubbed… (yah, this happens… A LOT!) Then this will be updated!

https://en.wikipedia.org/wiki/Two-line_element_set

Wonderfully described by Wikipedia!

Orbit modeling: How to read TLEs

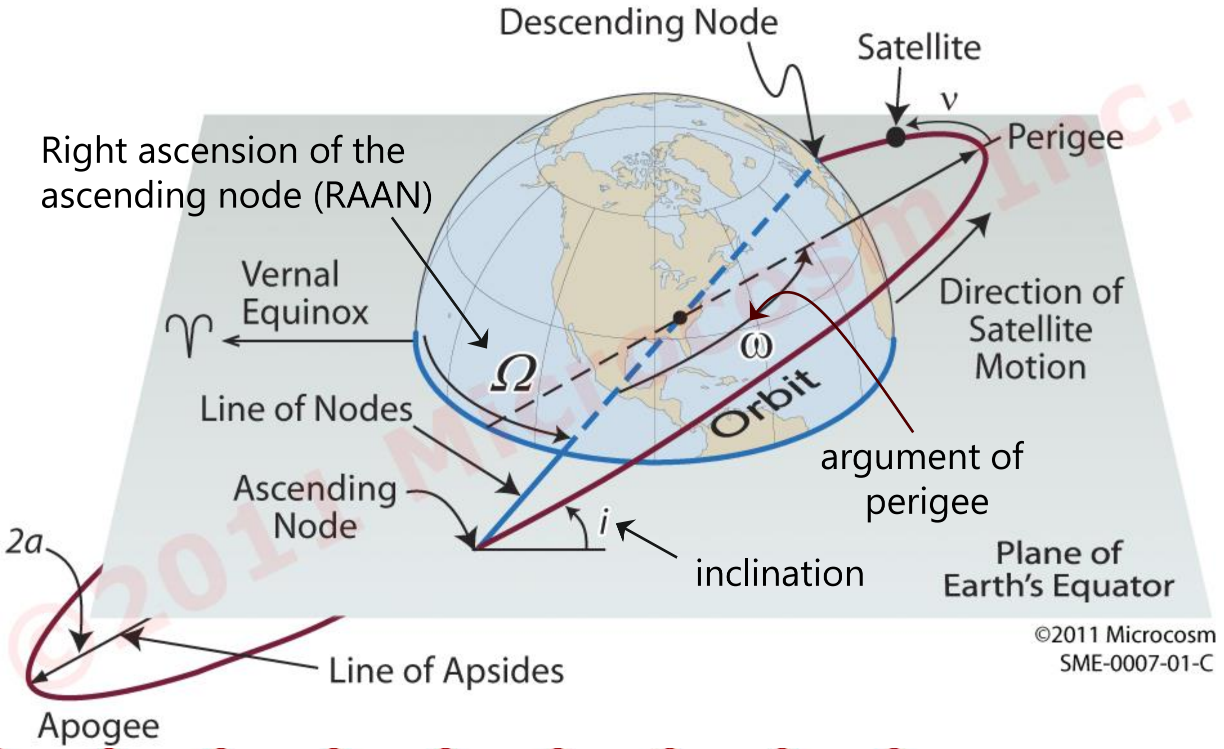
```
1 72000C 22097A   22222.10427778  .00079168  00000+0  13040-3 0    09
2 72000  53.2190 249.4977 0077526  44.7868  32.1202 15.96675264    19
```

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
2		2	5	5	4	4			5	1	.	6	4	1	6		2	4	7	.	4	6	2	7		0	0	0	6	7	0	3		1
1		2						3									4									5								6

36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
3	0	.	5	3	6	0		3	2	5	.	0	2	8	8		1	5	.	7	2	1	2	5	3	9	1	5	6	3	5	3	7
								7									8											9					10

Field	Columns	Content	Example
1	01	Line number	2
2	03–07	Satellite Catalog number	72000
3	09–16	Inclination (degrees)	53.2190
4	18–25	Right ascension of the ascending node (degrees)	249.4977
5	27–33	Eccentricity (decimal point assumed)	0077526
6	35–42	Argument of perigee (degrees)	44.7868
7	44–51	Mean anomaly (degrees)	32.1202
8	53–63	Mean motion (revolutions per day)	15.96675264
9	64–68	Revolution number at epoch (revolutions)	1
10	69	Checksum (modulo 10)	9

These are the "orbital elements" also called the "Keplerian Elements"



Eccentricity = e = $\frac{\sqrt{a^2-b^2}}{a}$; a = semi-major axis; b = semi-minor axis

Mean anomaly = E – e SIN(E); where E is called the Eccentric anomaly

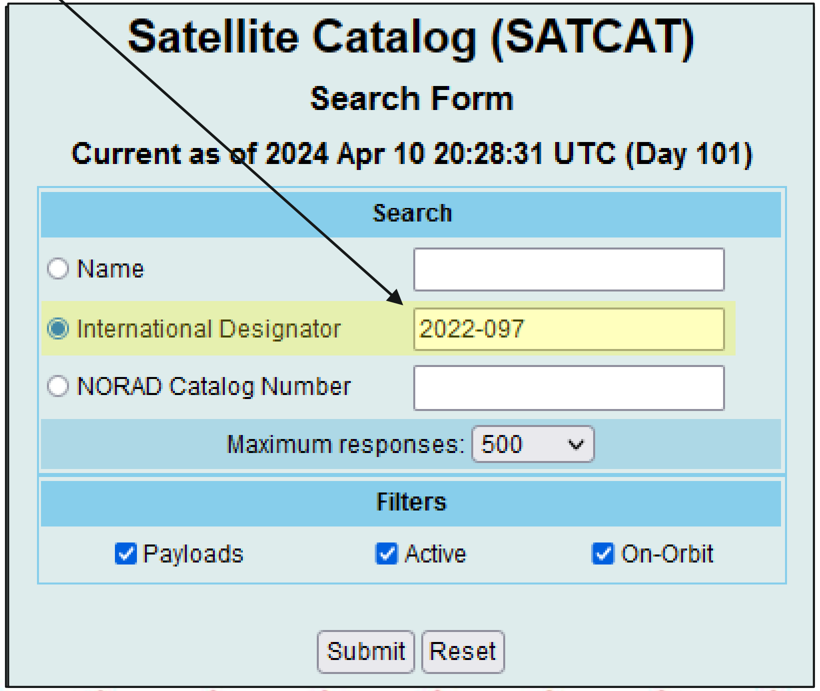
Mean motion = $n = \frac{2\pi}{P}$; where P is the period

https://en.wikipedia.org/wiki/Two-line_element_set

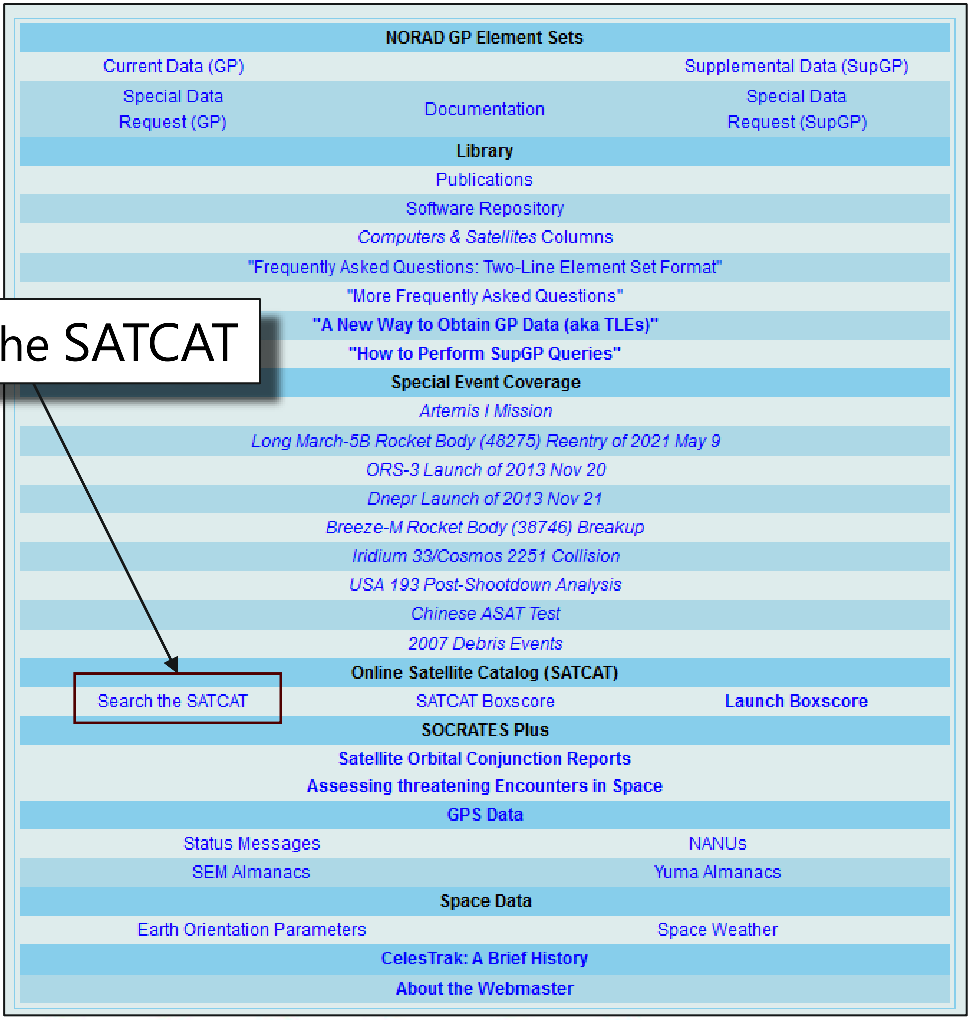
Orbit modeling: Back to Group 4-26

- Dr T.S. Kelso provided significant support to make full queries easier: 2 ways to pull… **<u>1st Approach</u>**:
- 2 ways to pull … for the first:
- Scroll down on http://www.celestrak.org/ website to find →

```
STARLINK-G4-26 STACK
1 72000C 22097A   22222.10
```



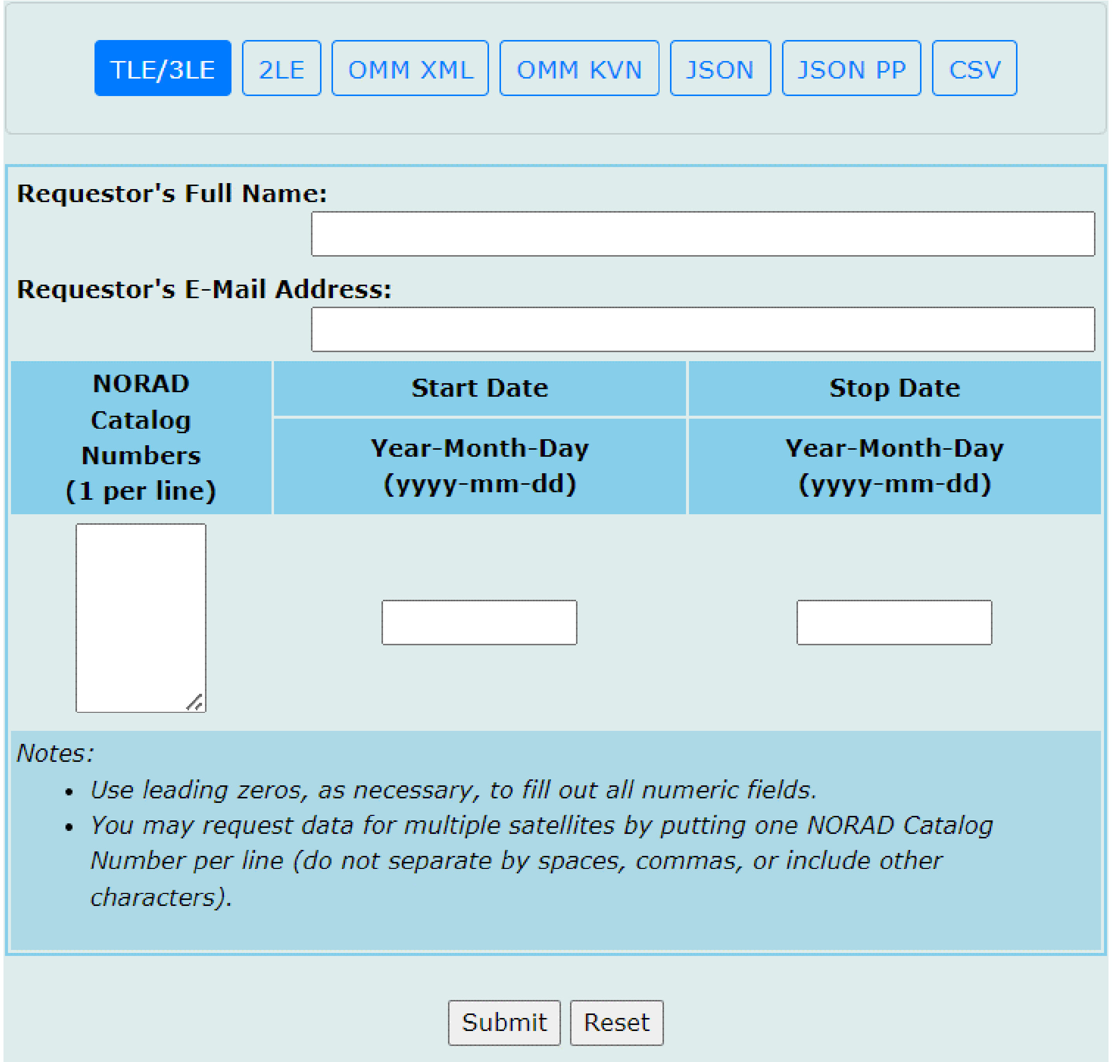
Search the SATCAT



Orbit modeling: Back to Group 4-26

- We then use Celestrak's Supplemental GP's (SupGP) selecting the TLE button

  https://celestrak.org/NORAD/archives/sup-request.php



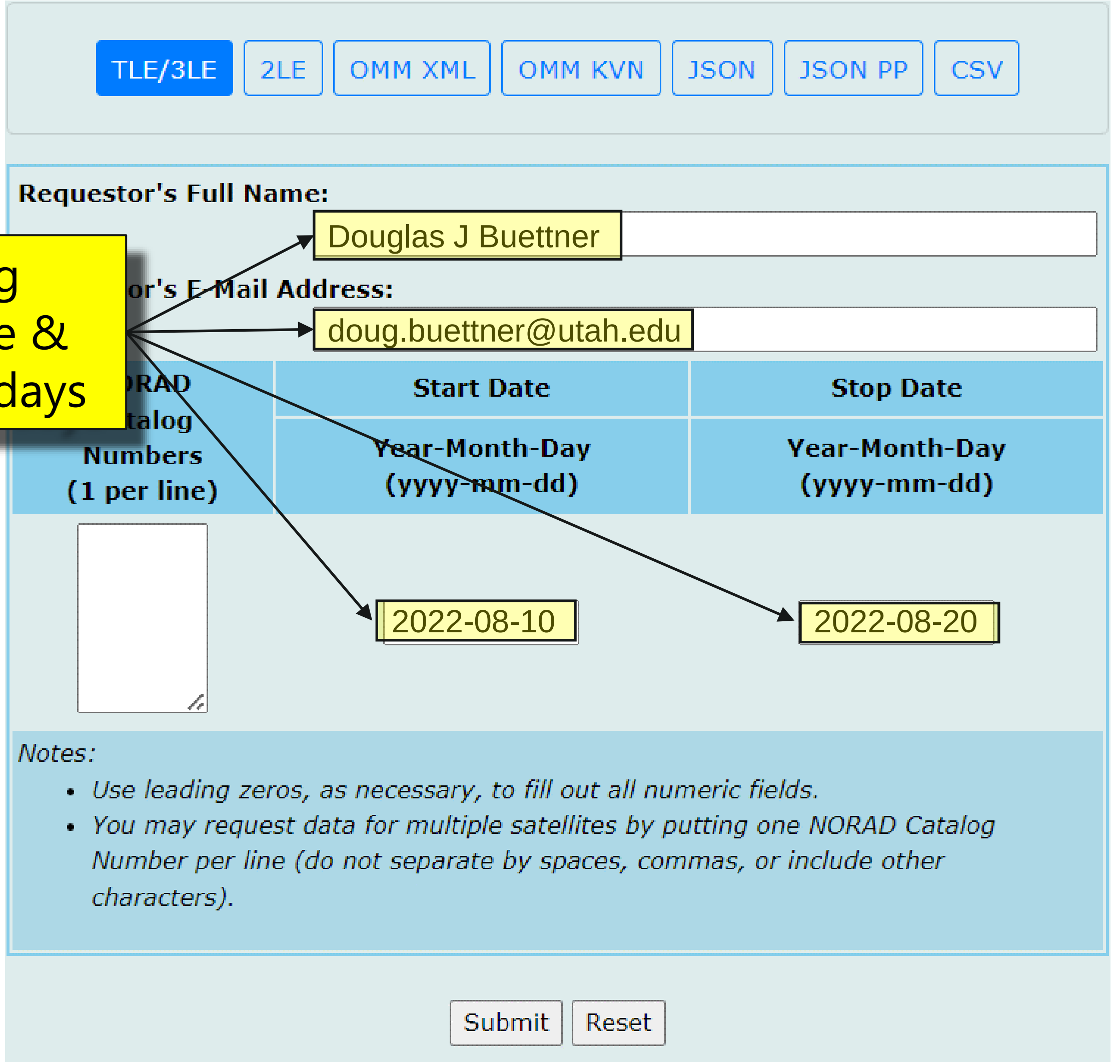
Orbit modeling: Back to Group 4-26

- We then use Celestrak's Supplemental GP's (SupGP) selecting the TLE button

  https://celestrak.org/NORAD/archives/sup-request.php

- Email will contain all the individual .txt files.
- These need to be concatenated into a single TLE file by selecting the TLE with the time closest to the sighting.

Fill in the Form using
Start is the launch date &
Stop date launch + 10 days



Orbit modeling: Back to Group 4-26

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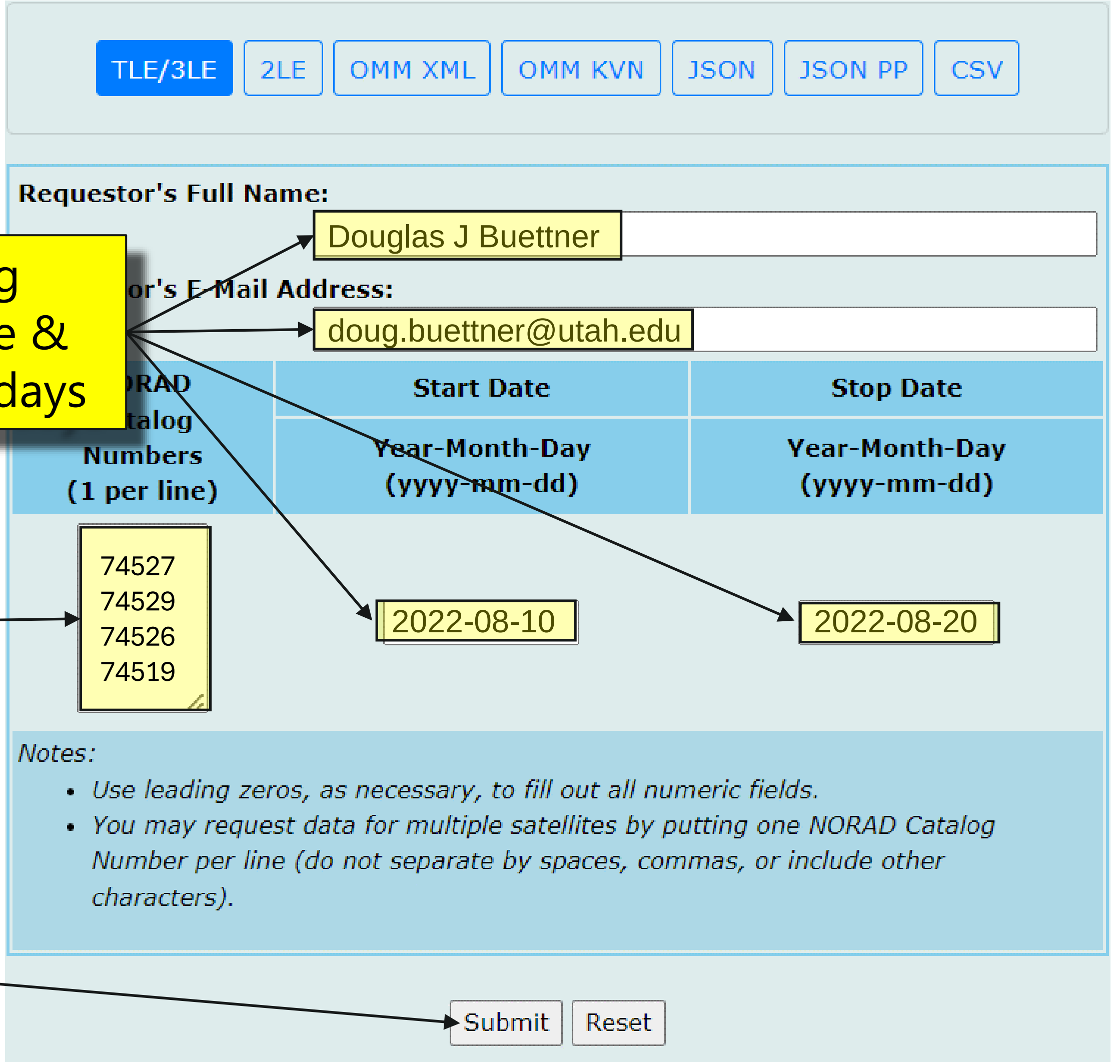
- These need to be concatenated into a single TLE file by selecting the TLE with the time closest to the si

Fill in the Form using
Start is the launch date &
Stop date launch + 10 days

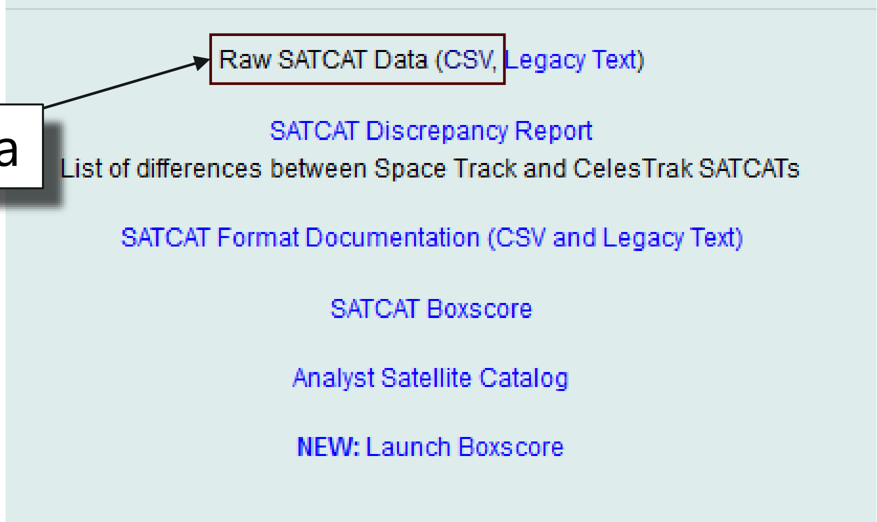
Paste in ALL the
7XXXX numbers



Select Submit!
Results will be emailed to you

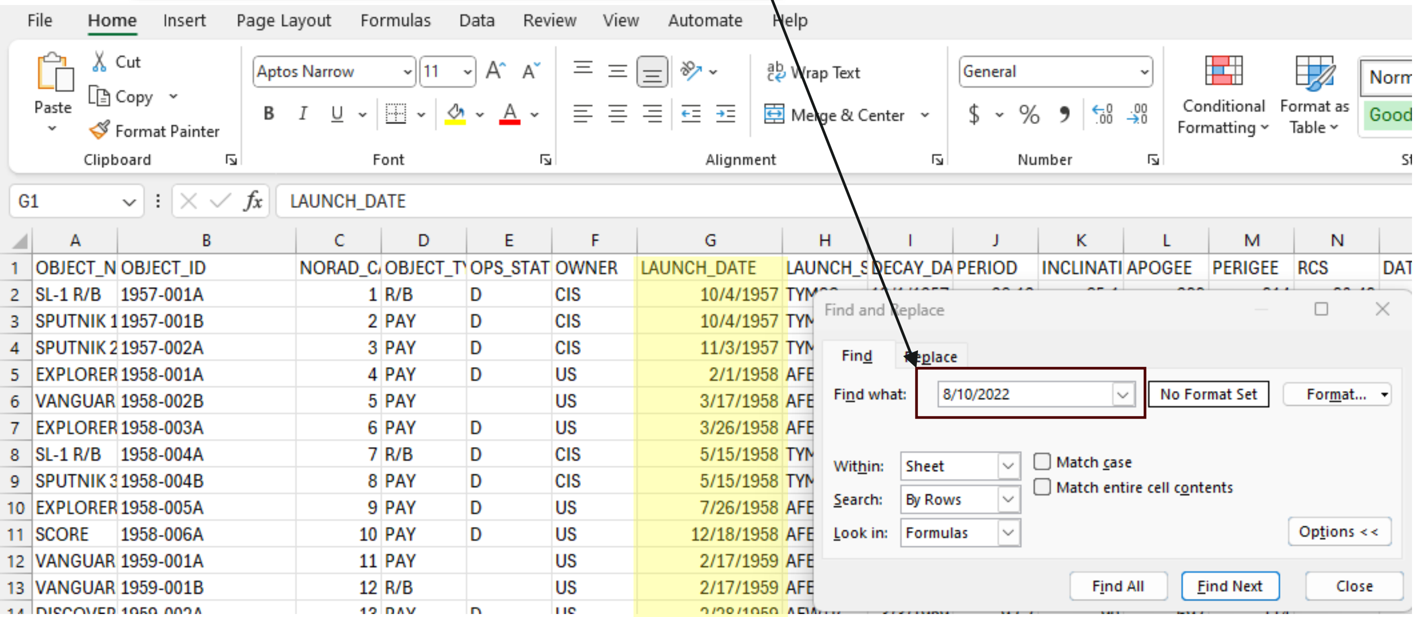
Orbit modeling: Back to Group 4-26

- Dr T.S. Kelso provided significant support to make full queries easier: 2 ways to pull… **<u>2nd Approach</u>**:
- Scroll down on http://www.celestrak.org/ website to find →



Download the Raw SATCAT Data

Open in Excel and search



Orbit modeling: Back to Group 4-26

Show All entries Search:

Change to All

It's very important to track the changes to Celestrak…

We used these had to use these numbers!

International Designator	NORAD Catalog Number	Name	Source ⓘ	Launch Date	Launch Site ⓘ	Decay Date	Ops Status ⓘ	Latest Data ⓘ
2022-097A	53388	STARLINK-4522	US	2022-08-10	AFETR		+	
2022-097B	53389	STARLINK-4523	US	2022-08-10	AFETR		+	
2022-097C	53390	STARLINK-4517	US	2022-08-10	AFETR		+	
2022-097D	53391	STARLINK-4521	US	2022-08-10	AFETR		+	
2022-097E	53392	STARLINK-4535	US	2022-08-10	AFETR		+	
2022-097F	53393	STARLINK-4530	US	2022-08-10	AFETR		+	
2022-097G	53394	STARLINK-4544	US	2022-08-10	AFETR		+	
2022-097H	53395	STARLINK-4534	US	2022-08-10	AFETR		+	
2022-097J	53396	STARLINK-4524	US	2022-08-10	AFETR		+	
2022-097BA	53436	STARLINK-4527	US	2022-08-10	AFETR		+	
2022-097BC	53438	STARLINK-4526	US	2022-08-10	AFETR		+	
2022-097BD	53439	STARLINK-4519	US	2022-08-10	AFETR		+	

Notes:

ⓘ Link to additional information

Link to custom search query for related news, information, and images

Link to raw GP data

ⓘ and in the International Designator column are for all objects associated with that launch

*DL Link to plot of apogee, perigee, and eccentricity for actual or potential decays (apogee < 350 km)

*GL Link to plot of longitude of the ascending node (LAN) and mean semi-major axis (SMA) for GEO altitude ± 250 km

Link to plot of orbit data: right ascension of the ascending node (RAAN), mean semi-major axis (SMA) altitude, eccentricity, inclination, and argument of perigee.

Orbit modeling: Back to Group 4-26

Show All entries

Search:

Change to All

It's very important to track the changes to Celestrak…

But now you need these numbers!

International Designator	NORAD Catalog Number	Name	Source	Launch Date	Launch Site	Decay Date	Ops Status	Latest Data
2022-097A	53388	STARLINK-4522	US	2022-08-10	AFETR		+	
2022-097B	53389	STARLINK-4523	US	2022-08-10	AFETR		+	
2022-097C	53390	STARLINK-4517	US	2022-08-10	AFETR		+	
2022-097D	53391	STARLINK-4521	US	2022-08-10	AFETR		+	
2022-097E	53392	STARLINK-4535	US	2022-08-10	AFETR		+	
2022-097F	53393	STARLINK-4530	US	2022-08-10	AFETR		+	
2022-097G	53394	STARLINK-4544	US	2022-08-10	AFETR		+	
2022-097H	53395	STARLINK-4534	US	2022-08-10	AFETR		+	
2022-097J	53396	STARLINK-4524	US	2022-08-10	AFETR		+	
2022-097BA	53436	STARLINK-4527	US	2022-08-10	AFETR		+	
2022-097BC	53438	STARLINK-4526	US	2022-08-10	AFETR		+	
2022-097BD	53439	STARLINK-4519	US	2022-08-10	AFETR		+	

Notes:

- Link to additional information
- Link to custom search query for related news, information, and images
- Link to raw GP data
- and in the International Designator column are for all objects associated with that launch
- *D Link to plot of apogee, perigee, and eccentricity for actual or potential decays (apogee < 350 km)
- *G Link to plot of longitude of the ascending node (LAN) and mean semi-major axis (SMA) for GEO altitude ± 250 km
- Link to plot of orbit data: right ascension of the ascending node (RAAN), mean semi-major axis (SMA) altitude, eccentricity, inclination, and argument of perigee.

Orbit modeling: Back to Group 4-26

- Use Celestrak to download SupGP (TLEs) for these Starlinks

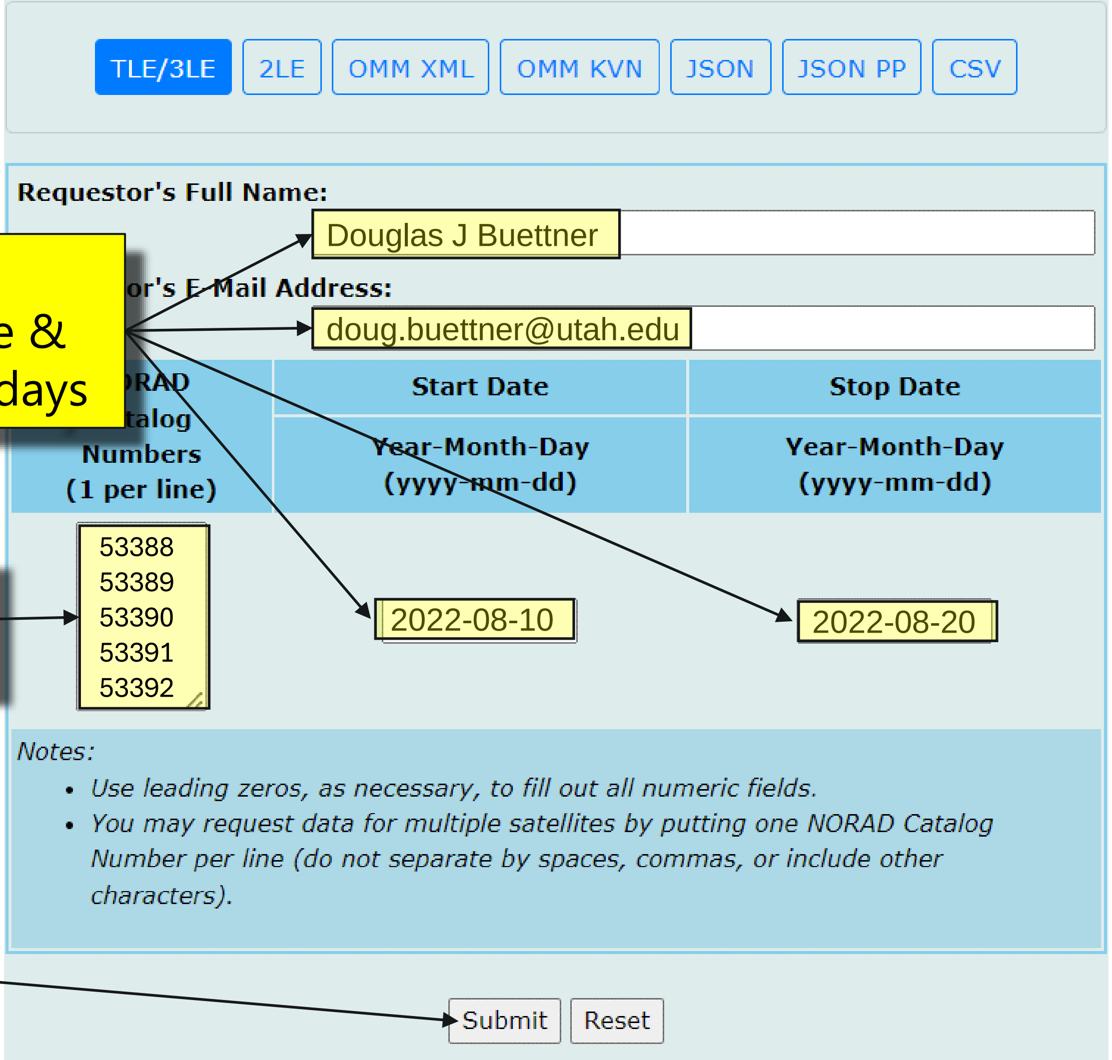
  https://celestrak.org/NORAD/archives/sup-request.php

- Celestrak will provide a c… change and then will se… confirmation email to the email address you specify
- Typically, within about … receive an email that w… Starlinks in individual .txt files
- We describe next how to select the TLE with a time closest to the sighting, from the individual .tx… the email response from Celestrak →

Fill in the form
Start is the launch date &
Stop date is Start + 10 days

Paste in ALL the NORAD catalog numbers

Select Submit…
Results will be emailed to you



Orbit modeling: Celestrak Email Result

THE UNIVERSITY OF UTAH

UNIVERSITY of HAWAI'I HILO

Re: Special Data Request

DK Dr. T.S. Kelso <ts.kelso@celestrak.org>

To: Douglas Buettner

Cc: T.S. Kelso <ts.kelso@celestrak.org>

Reply | Reply all | Forward

Sat 4/13/2024 12:45 PM

sat000053388.txt 5 KB | sat000053389.txt 5 KB | sat000053390.txt 5 KB

Show all 12 attachments (57 KB) | Save all to OneDrive - University of Utah | Download all

Selecting this file as an example...

```
Fulfillment of your request sent Saturday, ... UTC:

> The following special data request for historical SupGP element sets
> has been sent by:
>
>     Full Name:  Douglas J Buettner
>     E-Mail:     doug.buettner@utah.edu
>
> For NORAD Catalog Numbers:
```

Orbit modeling: Celestrak TLE Data

```
STARLINK-4522
1 71167C 22097A   22222.23937500  .00296751  00000+0  47900-3 0  2222
2 71167  53.2211 248.8138 0077023  44.7781  89.0212 15.96826481    15
STARLINK-4522
1 71167C 22097A   22222.55395833  .00284329  00000+0  45584-3 0  2228
2 71167  53.2207 247.2019 0076680  45.8686  97.4990 15.96989304    15
STARLINK-4522
1 71167C 22097A   22222.91368056 -.01179439  00000+0 -20598-2 0  2220
2 71167  53.2179 245.3604 0071048  44.8543   7.8661 15.97652517    10
STARLINK-4522
1 71167C 22097A   22223.23173611 -.01321948  00000+0 -25157-2 0  2238
2 71167  53.2182 243.7296 0065967  46.0021  36.5908 15.97011681    15
STARLINK-452
1 71167C 220
2 71167  53.
STARLINK-452
1 71167C 220
2 71167  53.
STARLINK-452
```

```
STARLINK-4522
1 71167C 22097A   22222.55395833  .00284329  00000+0  45584-3 0  2228
2 71167  53.2207 247.2019 0076680  45.8686  97.4990 15.96989304    15
```

This is the TLE closest to the times of the photographs...

- After selecting this satellite's TLE, we start concatenating the satellites into a single .tle file
- Our concatenated TLE file can be found on our GitHub site by looking for the file "STARLINK-8-10.tle"

Orbit Modeling: UTC to TLE time

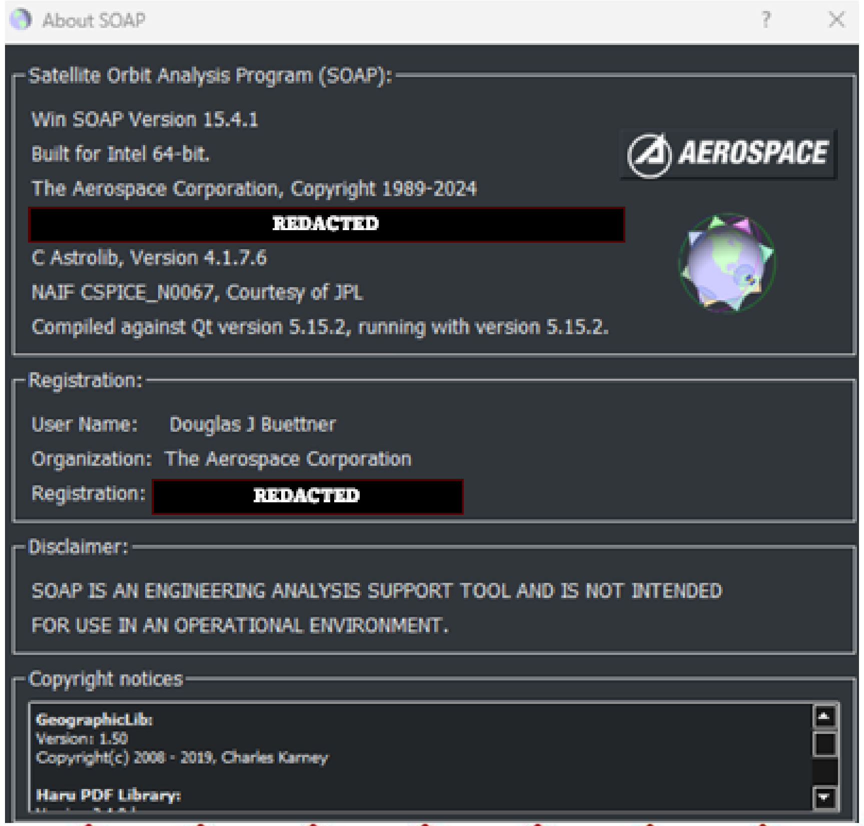
- The "Photo UTCs" tab in our spreadsheet (on GitHub), you see how we convert the photo's UTC into "TLE equiv. Day of Year Fractions"

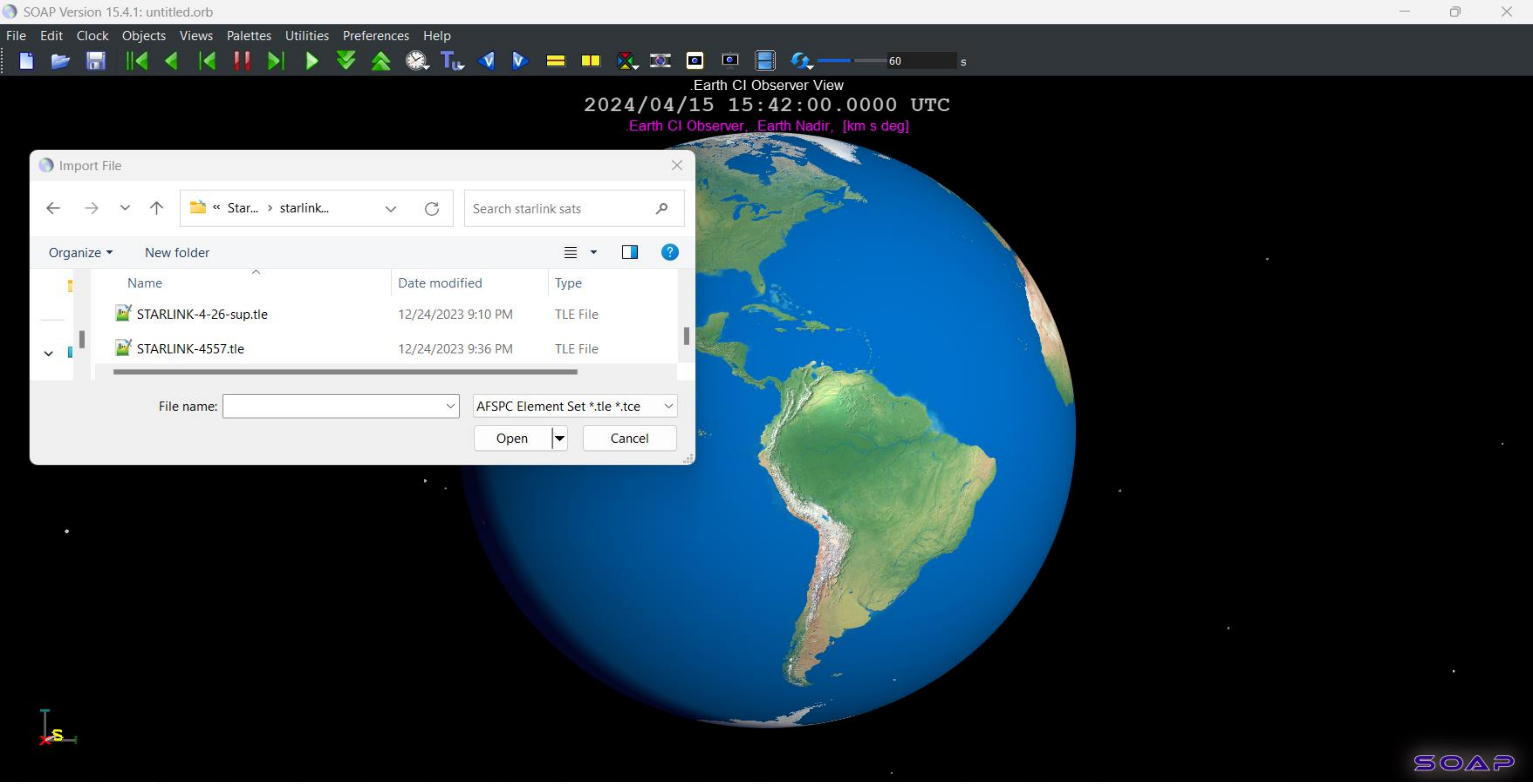
	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Photo Time in UTC	"T"	C (hr:min:s	UTC Date	UTC YR	UTC Mnth	UTC Day	UTC (hr)	UTC (min)	UTC (sec)	Time (S)	TLE equiv. Day of Year Fraction
2	1st Photo	**2022-08-10T11:39:08**	11	11:39:08	2022-08-10	2022	08	10	11	39	08	41948	**222.4855093**
3	2nd Photo	**2022-08-10T11:39:24**	11	11:39:24	2022-08-10	2022	08	10	11	39	24	41964	**222.4856944**
4													
5													
6													
7													
8													
9													
10													

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs | +

Orbit modeling: SOAP

- For orbit modeling, I initially used The Aerospace Corporation's Satellite Orbital Analysis Program (SOAP)
  - TLE's can be directly imported into SOAP and then can be propagated to the correct UTC time…




SOAP Version 15.4.1: untitled.orb
File Edit Clock Objects Views Palettes Utilities Preferences Help
60
s
.Earth CI Observer View
2024/04/15 15:42:00.0000 UTC
.Earth CI Observer, .Earth Nadir, [km s deg]
Import File
« Star... › starlink...
Search starlink sats
Organize
New folder
Name
Date modified
Type
STARLINK-4-26-sup.tle
12/24/2023 9:10 PM
TLE File
STARLINK-4557.tle
12/24/2023 9:36 PM
TLE File
File name:
AFSPC Element Set *.tle *.tce
Open
Cancel
SOAP

Orbit modeling: AC536 into SOAP

- Importing ADS-B data, however, is not as easy!
  - SOAP requires altitudes in kilometers above the Mean Sea Level. ADS-B altitude is not supplied by the Global Positioning System (GPS) and is pulled from the aircraft's altimeter which is from the measured barometric pressure in feet
  - Now let's go back and look at our spreadsheet…

This is altitude in barometric feet

This is altitude in barometric km

	A	B	C	D	E	F	G	H	I
136	1.66E+09	2022-08-10T10:35:02Z	ACA536	34.03508,-146.503952	37000	11.2776	499	0.256707556	46
137	**1.66E+09**	**2022-08-10T10:44:22Z**	**ACA536**	**34.94759,-145.31012**	**37000**	**11.2776**	**511**	**0.262880884**	**46**
138	1.66E+09	2022-08-10T10:44:59Z	ACA536	35.004589,-145.240067	37000	11.2776	476	0.244875344	39
139	1.66E+09	2022-08-10T10:54:07Z	ACA536	35.824635,-144.129379	37000	11.2776	468	0.240759792	47
140	1.66E+09	2022-08-10T11:03:40Z	ACA536	36.655186,-142.951508	37000	11.2776	467	0.240245348	48
141	1.66E+09	2022-08-10T11:13:16Z	ACA536	37.485031,-141.738785	37000	11.2776	466	0.239730904	48
142	1.66E+09	2022-08-10T11:41:53Z	ACA536	39.803783,-138.11734	37000	11.2776	449	0.230985356	49
143	1.66E+09	2022-08-10T11:42:13Z	ACA536	39.825115,-138.085541	37000	11.2776	449	0.230985356	37
144	1.66E+09	2022-08-10T11:51:39Z	ACA536	40.77491,-137.149582	37000	11.2776	450	0.2314998	35
145	1.66E+09	2022-08-10T12:01:04Z	ACA536	41.758778,-136.242462	37000	11.2776	447	0.229956468	35
146	1.66E+09	2022-08-10T12:10:48Z	ACA536	42.73772,-135.283798	37000	11.2776	448	0.230470912	36

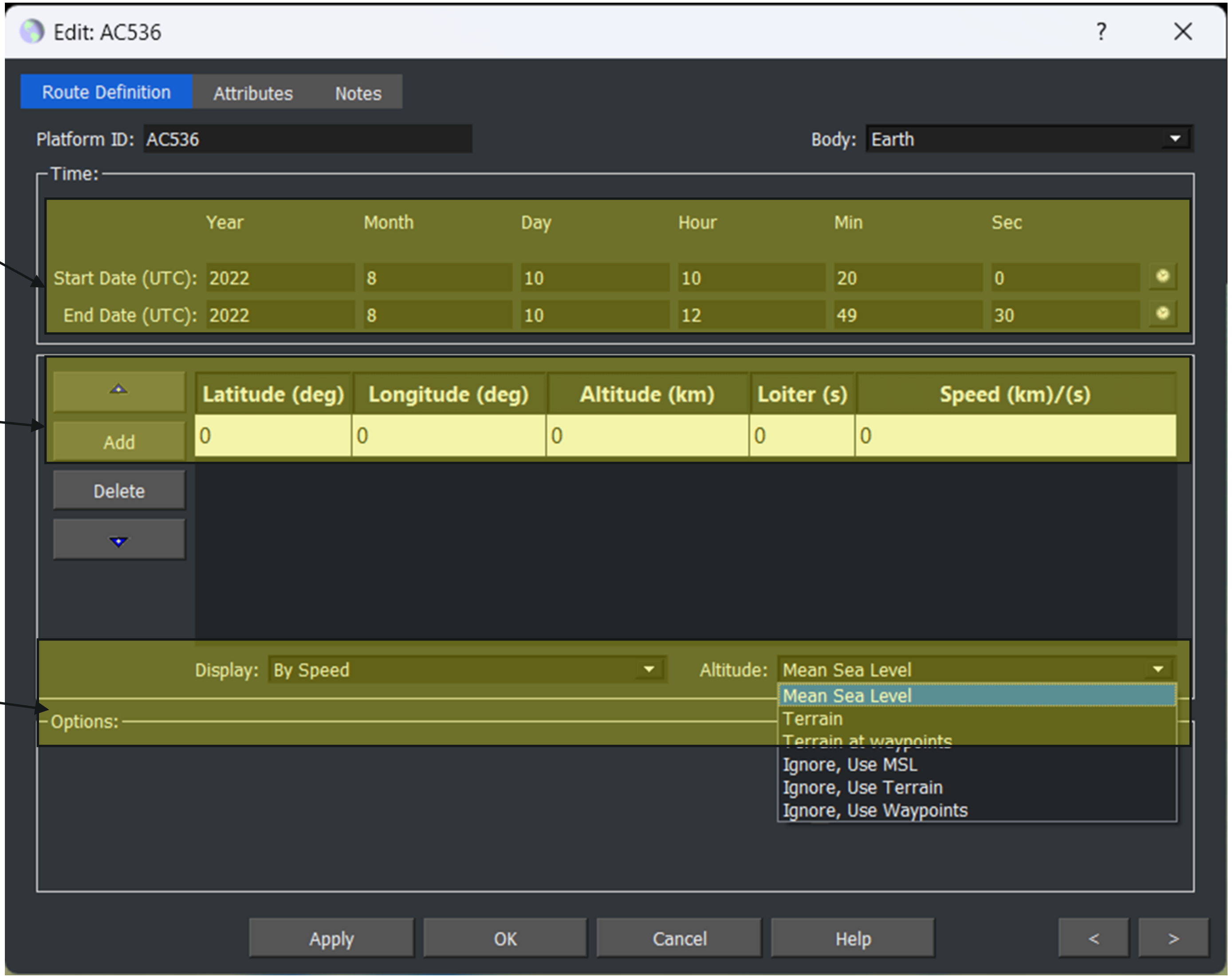
AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

Orbit modeling: AC536 into SOAP

UTC times for each ADS-B point

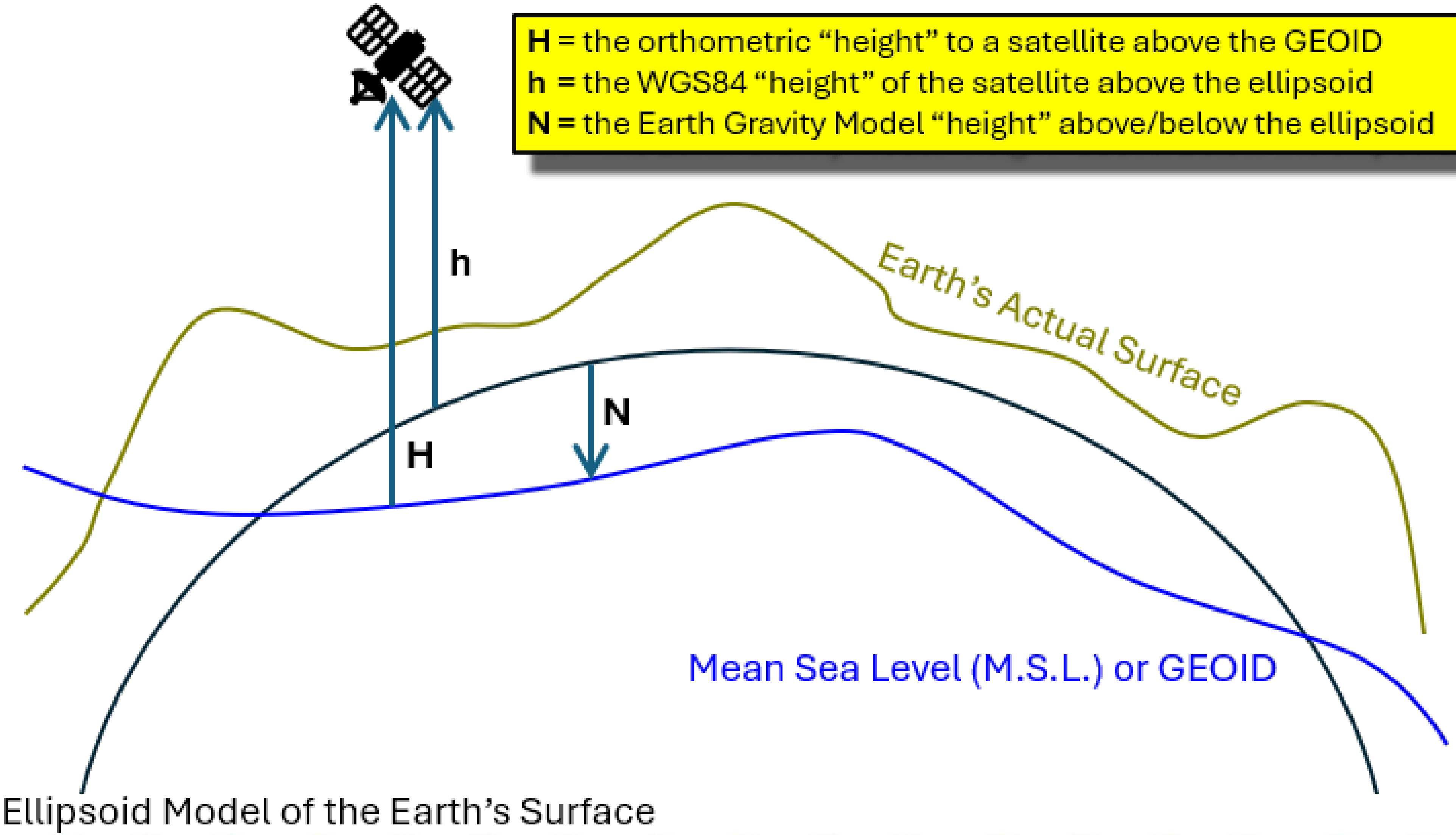
Latitude, Longitude and Altitude for each ADS-B point

HOWEVER …
SOAP requires Altitude in Mean Sea Level (M.S.L)



Gravity Model of the Earth: Satellite’s View

H = the orthometric “height” to a satellite above the GEOID
h = the WGS84 “height” of the satellite above the ellipsoid
N = the Earth Gravity Model “height” above/below the ellipsoid



Aircraft: Converting Altitude for SOAP

- In our paper we described steps used to convert into the local GEOID…
  - Using the paper's described online conversion utility, we get the 2nd tab's values
  - Selecting the "AC536" tab and scrolling to the right…
  - We also modeled an approximate maximum error from barometric pressure (~2500 feet or ~0.8 km), showing that there was negligible affect on the apparent location of the satellites

	A	B	C	D	E	F	G	H	I
136	1.66E+09	2022-08-10T10:35:02Z	ACA536	34.03508,-146.503952	37000	11.2776	499	0.256707556	46
137	**1.66E+09**	**2022-08-10T10:44:22Z**	**ACA536**	**34.94759,-145.31012**	**37000**	**11.2776**	**511**	**0.262880884**	**46**
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141	1.66E+09	2022-08-10T11:13:16Z	ACA536	37.485031,-141.738785	37000	11.2776	466	0.239730904	48
142	1.66E+09	2022-08-10T11:41:53Z	ACA536	39.803783,-138.11734	37000	11.2776	449	0.230985356	49
143	1.66E+09	2022-08-10T11:42:13Z	ACA536	39.825115,-138.085541	37000	11.2776	449	0.230985356	37
144	1.66E+09	2022-08-10T11:51:39Z	ACA536	40.77491,-137.149582	37000	11.2776	450	0.2314998	35
145	1.66E+09	2022-08-10T12:01:04Z	ACA536	41.758778,-136.242462	37000	11.2776	447	0.229956468	35
146	1.66E+09	2022-08-10T12:10:48Z	ACA536	42.73772,-135.283798	37000	11.2776	448	0.230470912	36

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

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	L	M	N	O	P	Q	R	S	T	U	V
1	Time (S)	TLE equiv. Day of Year Fraction	Lat	Lon	Calculated Alt (km)	Numeric Alt (km)	Calculated Alt + 1 km error	Numeric Alt + 1 km error	Calc from SOF Time Offset (s)	Num from SOF Time Offset (s)	Time Offset for 1 Hr before S.O.E.
140	39820	222.4608796	36.65519	-142.952	11.30798	11.30798	12.10798	12.10798	10322	10322	1158
141	40396	222.4675463	37.48503	-141.739	11.30911	11.30911	12.10911	12.10911	10898	10898	1734
142	42113	222.4874190	39.80378	-138.117	11.31142	11.31142	12.11142	12.11142	12615	12615	3451
143	42133	222.4876505	39.82512	-138.086	11.31135	11.31135	12.11135	12.11135	12635	12635	3471
144	42699	222.4942014	40.77491	-137.15	11.30904	11.30904	12.10904	12.10904	13201	13201	4037
145	43264	222.5007407	41.75878	-136.242	11.3083	11.3083	12.1083	12.1083	13766	13766	4602
146	43848	222.5075000	42.73772	-135.284	11.30783	11.30783	12.10783	12.10783	14350	14350	5186

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

SOAP: Photo 1-Starlinks from flight AC536

- After getting all the ADS-B data into SOAP, and changing the SOAP view so we can display the constellations with respect to what the aircraft would see
- We then propagate the Starlinks and the aircraft to the 1st Photo's UTC time, we get the following →

SOAP: Photo 1-Starlinks from flight AC536

- After getting all the ADS-B data into SOAP, and changing the SOAP view so we can display

In the paper we have a zoomed in view of Photo-1's modeled UTC time

- We then propagate the Starlinks and the aircraft to the 1st Photo's UTC time, we get the following →

SOAP: Photo 2-Starlinks from flight AC536

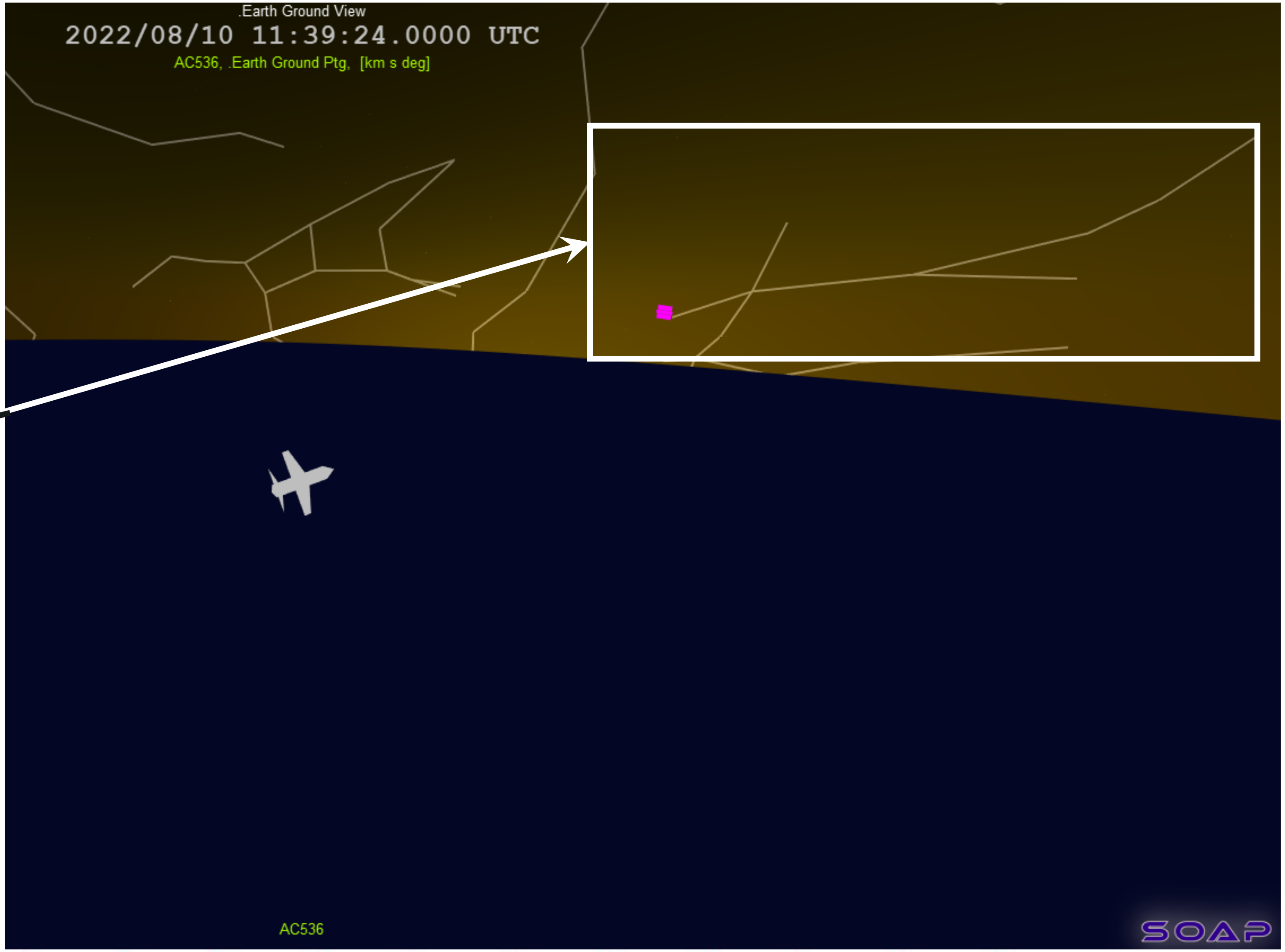
- After getting all the ADS-B data into SOAP, and changing the SOAP view so we can display the constellations with respect to what the aircraft would see
- And then propagating the Starlinks and the aircraft to the 2nd Photo's UTC time, we get the following →

SOAP: Photo 2-Starlinks from flight AC536

- After getting all the ADS-B data into SOAP, and changing the SOAP view so we can display

In the paper we have a zoomed in view of Photo-2's modeled UTC time

- And then propagating the Starlinks and the aircraft to the 2nd Photo's UTC time, we get the following →



SOAP: Photo 2-Starlinks from flight AC536

- After getting all the ADS-B data into SOAP, and changing the SOAP view so we can display the constellations with

And with an even better zoomed in view of Photo-2's modeled UTC time

- And then propagating the Starlinks and the aircraft to the 2nd Photo's UTC time, we get the following →

Student Project: Orbit & Rendering

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- As SOAP is only available to government customers and employees of The Aerospace Corporation, we also did this modeling in Ansys/AGI's System Toolkit (STK) in our University of Utah Space Mission En course

Over to Nick Snell

- We also wanted to attempt physics-based rendering of the scene in an attempt to replicate what the pilots saw from their cockpit

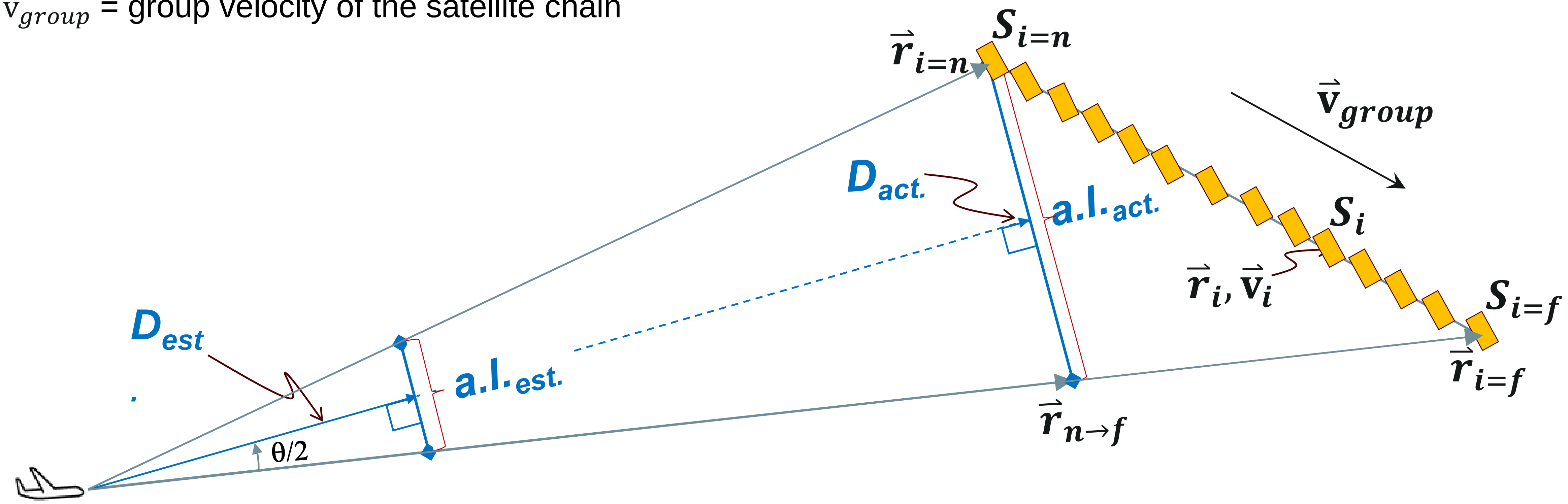
blender

OpenSpace

Geometric Model: Aircraft to Satellite Train

θ = angle subtended by the satellites from the aircraft's point of view
$\vec{r}_{i=n}$ = distance to nearest satellite ($S_{i=n}$)
$\vec{r}_{i=f}$ = distance to furthest satellite ($S_{i=f}$)
$\vec{r}_i, \vec{v}_i$ = state vector for the i[th] satellite
$\vec{v}_{group}$ = group velocity of the satellite chain

$D_{est.}$ = estimated distance
$D_{act.}$ = actual distance
$a.l._{est.}$ = apparent length estimate (if getting the distance incorrect)
$a.l._{act.}$ = apparent length actual



Geometric Model: Aircraft to Satellite Train

- Quiz … how do you determine the angle between two vectors in 3D space, no matter which coordinate system is being used?
  - Answer … That's right! You use the dot product of the vectors

$$\cos\theta = \frac{\vec{r}_n \cdot \vec{r}_f}{|r_n||r_f|} \Rightarrow \theta = \cos^{-1}\left(\frac{\vec{r}_n \cdot \vec{r}_f}{|r_n||r_f|}\right)\frac{180^o}{\pi}$$

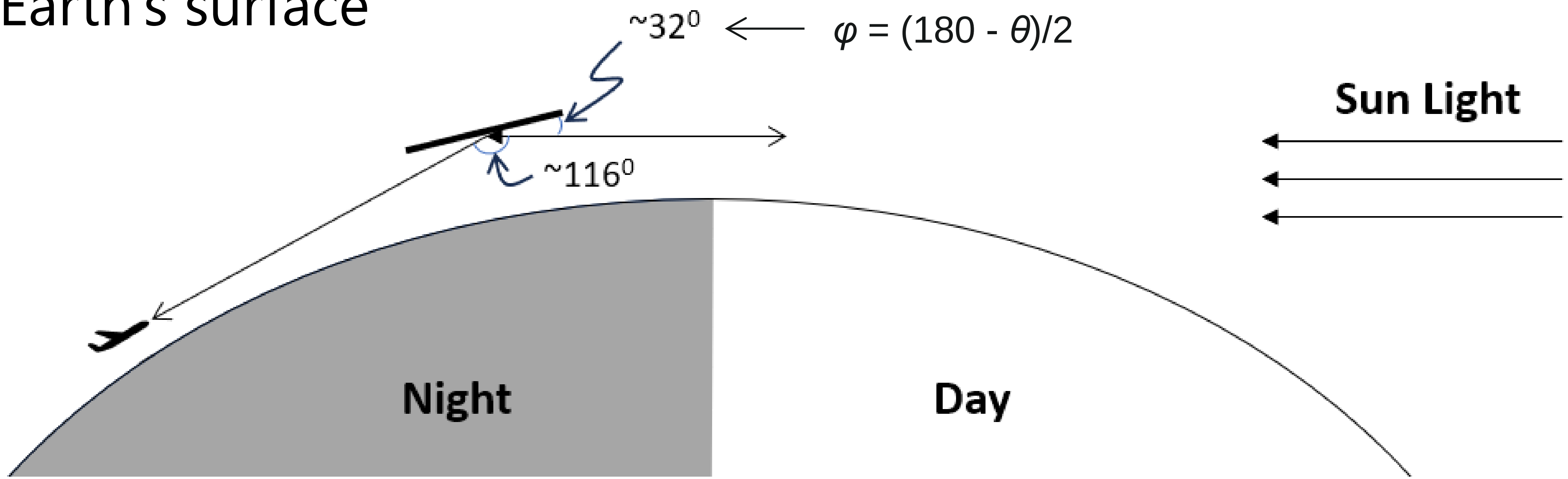
  - Using state vectors relative to the aircraft (AC536)

$$\vec{r}_{i\ rel\ to\ ac.} = \vec{r}_{i\ in\ ECEF} - \vec{r}_{ac.in\ ECEF}$$
$$\vec{v}_{i\ rel\ to\ ac.} = \vec{v}_{i\ in\ ECEF} - \vec{v}_{ac.in\ ECEF}$$

  - And the vector's magnitude is $|r| = \sqrt{{r_x}^2 + {r_y}^2 + {r_z}^2}$

Geometric Model: Aircraft to Satellite Train

- For the sun's grazing angle, and sometimes the term "glint" angle is used… we do the same thing, but now from the perspective of the satellite, so using satellite local coordinates.
- In our case, we've had to assume the satellite's surface is parallel to the Earth's surface



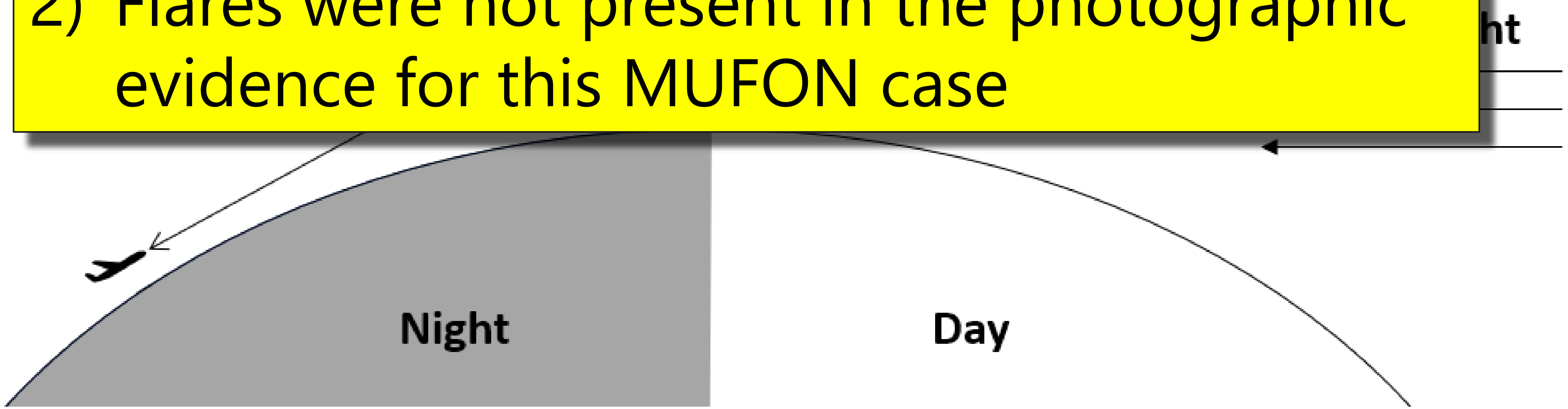
Using the geometry from the wonderful paper, Fankhauser, F., J. A. Tyson, and J. Askari. 2023. "Satellite Optical Brightness."

Geometric Model: Aircraft to Satellite Train

- For the sun's grazing angle, and sometimes the term "glint" angle is used… we do the same thing, but now from the perspective of the satellite, so using satellite local coordinates
- In ou llel to the E

<u>Satellite "flares"</u>

1) Caused by the same basic geometry
2) Flares were not present in the photographic evidence for this MUFON case



Using the geometry from the wonderful paper, Fankhauser, F., J. A. Tyson, and J. Askari. 2023. "Satellite Optical Brightness."

Geometric Model: Aircraft's Point of View

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- To transform the Earth Centered Earth Fixed (ECEF) from the orbital modeling software, and into the local coordinates for AC536, or a satellite (pick a Starlink)
  - We need two coordinate rotations into East-North-Up (ENU) coordinates used for the aircraft

$$R_{ECEF \to ENU} = R_\phi R_\lambda = \begin{bmatrix} -\sin\lambda & -\sin\phi\cos\lambda & \cos\phi\cos\lambda \\ \cos\lambda & -\sin\phi\sin\lambda & \cos\phi\sin\lambda \\ 0 & \cos\phi & \sin\phi \end{bmatrix}$$

  - AC536's latitude (ϕ), and longitude (λ), which were propagated to the time of the photographs from an interpolation of the ADS-B data points

Geometric Model: Pilot's Point of View

- Now once in ENU, we needed to account for the aircraft's heading, and we wanted to define the coordinates to be positive clockwise and negative counterclockwise from the nose of the aircraft
- This is accomplished using a rotation of the heading angle, <u>but with a negative angle</u>

$$R_{heading} = \begin{bmatrix} \cos(-\theta_{heading}) & \sin(-\theta_{heading}) & 0 \\ -\sin(-\theta_{heading}) & \cos(-\theta_{heading}) & 0 \\ 0 & 0 & 1 \end{bmatrix} \Rightarrow$$

$$\begin{bmatrix} \cos(\theta_{heading}) & -\sin(\theta_{heading}) & 0 \\ \sin(\theta_{heading}) & \cos(\theta_{heading}) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Geometric Model: Pilot's Point of View

- Finally … the look and elevation angles from the pilot's perspective are given by the following:

$$\alpha_{look} = ArcTan2\left(E_{ECEF\rightarrow ENU\rightarrow heading}, N_{ECEF\rightarrow ENU\rightarrow heading}\right)\frac{180}{\pi}$$

$$el = ArcTan2\left(U_{ECEF\rightarrow ENU\rightarrow heading}, D_{horizontal}\right)\frac{180}{\pi}$$

$$D_{horizontal} = \sqrt{E_{ECEF\rightarrow ENU\rightarrow heading}{}^{2} + N_{ECEF\rightarrow ENU\rightarrow heading}{}^{2}}$$

Geometric Projection: Photo 1's Time

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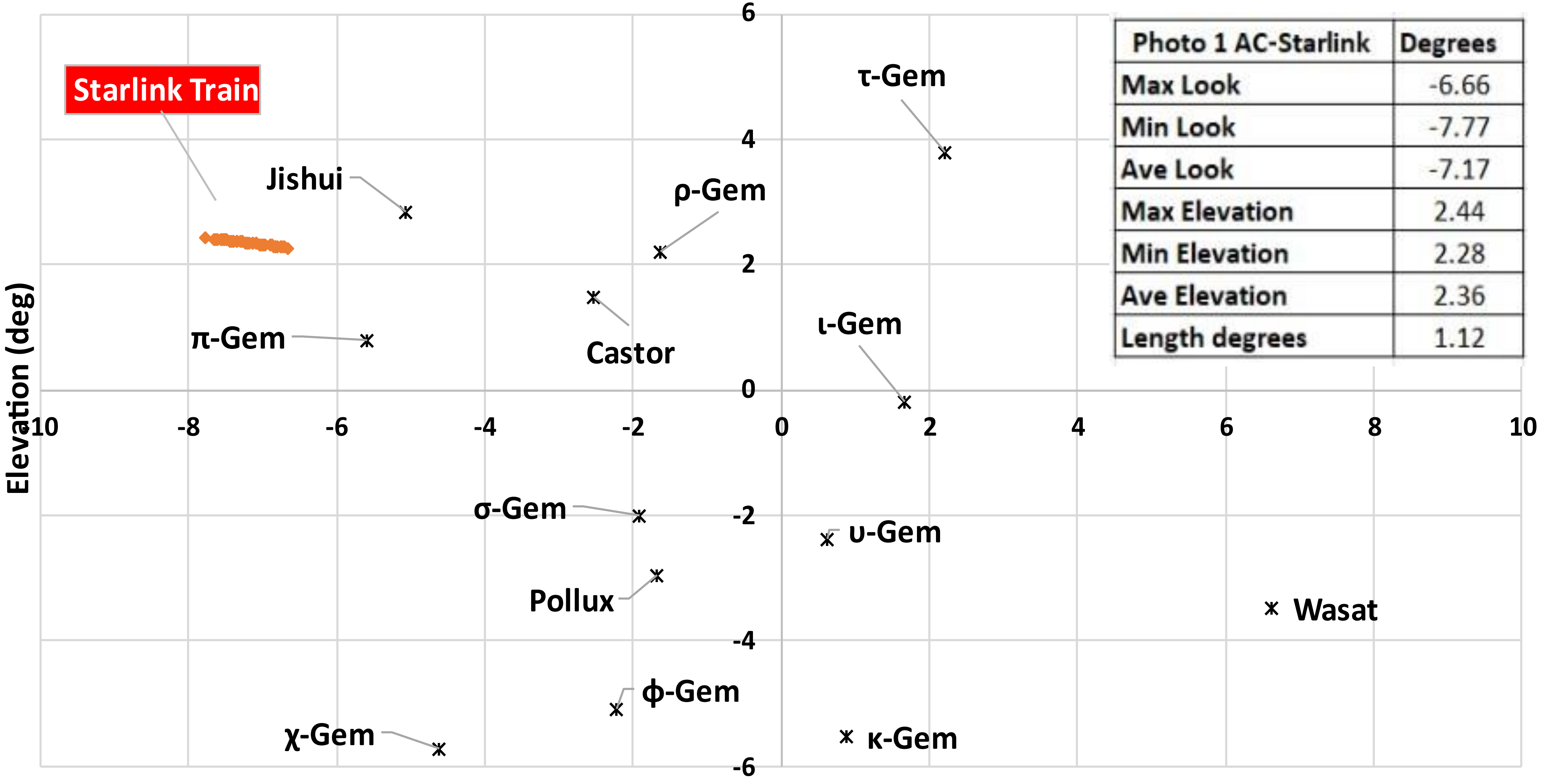


Photo 1 AC-Starlink	Degrees
Max Look	-6.66
Min Look	-7.77
Ave Look	-7.17
Max Elevation	2.44
Min Elevation	2.28
Ave Elevation	2.36
Length degrees	1.12

Geometric Projection: Photo 2's Time

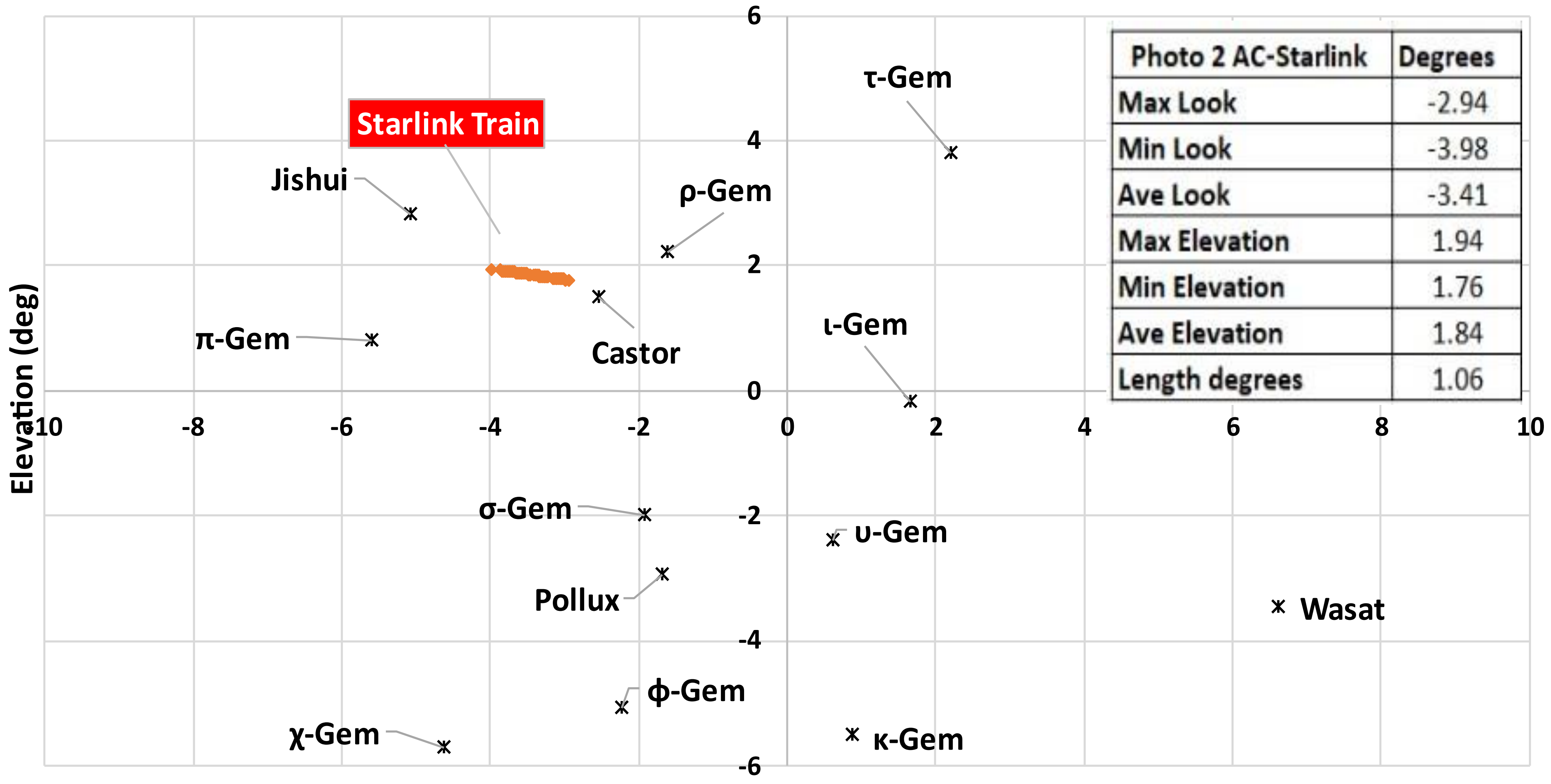


Photo 2 AC-Starlink	Degrees
Max Look	-2.94
Min Look	-3.98
Ave Look	-3.41
Max Elevation	1.94
Min Elevation	1.76
Ave Elevation	1.84
Length degrees	1.06

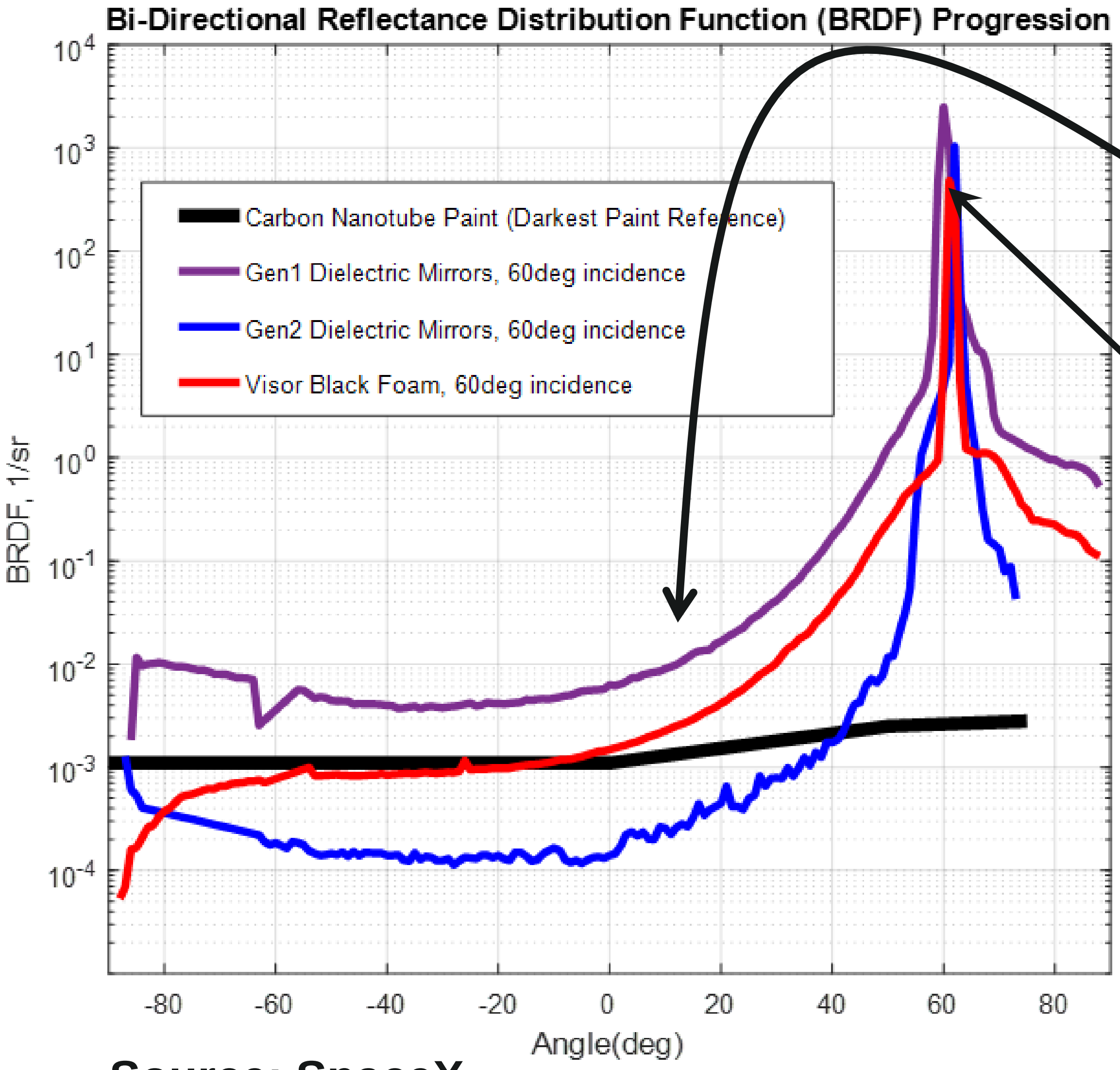
Results: How Close Were We?

- Comparison of the Astrometry and Geometric Models

Name (units)	Astrometry	Geometric Model
Apparent Length (deg)	~1.5^{o}	~1.1^{o}
Apparent Speed (deg/s)	0.26	0.23
Apparent magnitude	-4	Incomplete

Discrepancy likely due to JPEG compression artifacts, atmospheric scattering effects, and the photos were also taken from a handheld camera out a cockpit window – none of which were modeled

Discussion: Starlink Reflectance



Source: SpaceX

After three* redesigns, only thing they have drastically improved is the diffuse reflections

Specular reflections have not changed significantly in these design iterations

SpaceX implements reorientations across the day/night terminator regions but only at a higher orbit

* three, because I consider their temporary use of a solar shade as a design iteration

Discussion: What about Aviation Safety?

- What is the FAA doing…
  - There are the Unmanned Aircraft Systems (UAS) sightings reports, but apparently there is not a systematic approach for gathering all sightings
  - A recent case where a passenger was unable to provide a UAS report near an aircraft…
    - *For example, the "UFO over NYC" video is not included in the FAA UAS reports*
  - Congress has prepared language to protect pilots for reporting UAPs
- How about the Pentagon?
  - Reportedly working on multi-wavelength sensors for aircraft that can routinely provide a wide range of additional information about UAPs
  - Less clear if the FAA will adopt requiring these sensors on aircraft

- No phone calls or emails from the FAA after we pushed our paper out onto the arXiv…

Conclusions

- We accurately modeled the SpaceX/Starlink satellite train using both Aerospace's SOAP and Ansys' STK to demonstrate that this was the source of MUFON case #124190 report
  - Starlink train was in the right place at the right time, had the correct orientation, and we were able to replicate the gap structure that was seen in the frame from the movie
- Documented an approach in our paper that provides a viable method to provide *a priori* information to pilots and ground controllers about the visibility of Starlink satellites
  - Information provided to us during multiple reviews indicate that some pilots consider this as a safety risk
  - Numerous recommendations were made regarding what would be needed to adopt this approach
  - Approach can also support identifying and reporting the visibility of satellite "flares"

Acknowledgements

- This work would not have been possible without the excellent support from the following individuals and organizations:
  - SCU's Board, for the funding to present our work here
  - The anonymous pilot of ACA536, for taking the photographs and the movie required to do this case study analysis
  - Dr. Todd Easton, Univ of Utah Dept of Mech. Eng.'s Systems Eng. Program lead for funding Nick's trip to 4th IAA SSA Conf.
  - Mr. Mick West and his associates at metabunk.org, for identifying the correct culprit behind the sighting
  - Dr. Sarah Little, SCU's Science Advisor for ADS-B data and thorough reviews for readability have been beyond extraordinary
  - Robert Powell, SCU's Executive Director for providing the FAA FOIA data used in our revised paper and the invite and funding to present this work here
  - Rich Hoffman, for handling all the logistics for our presentation, and for picking me up at the airport
  - Micah Hanks, our moderator for the kind introductions
  - Dr. T.S. Kelso, Celestrak.org, for adding changes to his website that facilitate pulling supplemental TLEs
  - Dr. Jonathan McDowell for providing relevant supplemental TLEs
  - Dr. Philip Antón, SERC/AIRC Chief Scientist for his support with my "hobby"
  - Dr. Dinesh Verna, SERC/AIRC Executive Director for his support with my "hobby"
  - Ben Hansen, for his insights into flight safety issues facing the aviation community and their lack of official feedback about their sightings
  - Tony Mallama and Richard Cole, for discussions about their unpublished/corroborating data and insights that suggested additional clarifications that we should include
  - AND FINALLY, the anonymous reviewers that were highly critical of our initial paper, that resulted in our adding several clarifications to our revision which greatly improved it

Finally…

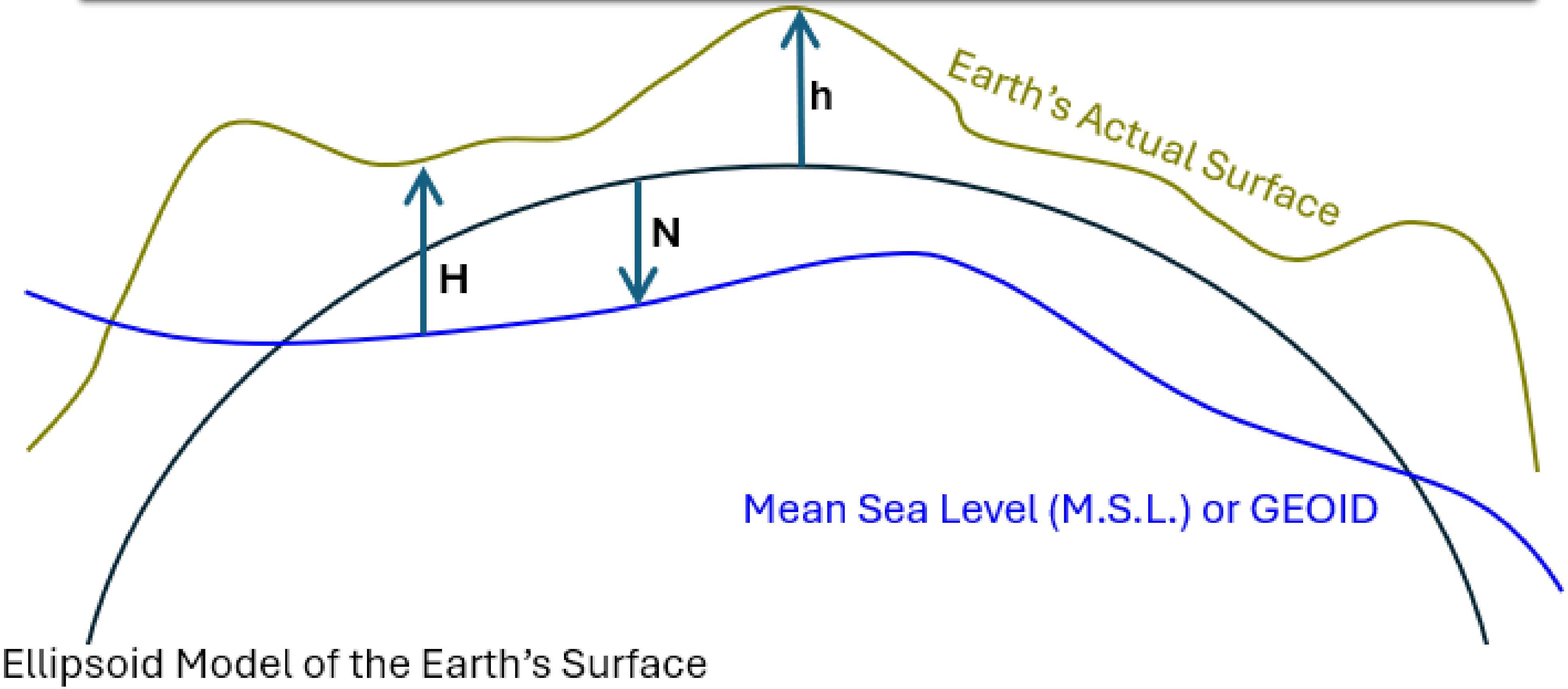
To characterize the unknown, we must first develop methods to characterize the known.

SCU's Science Advisor Dr. Sarah Little

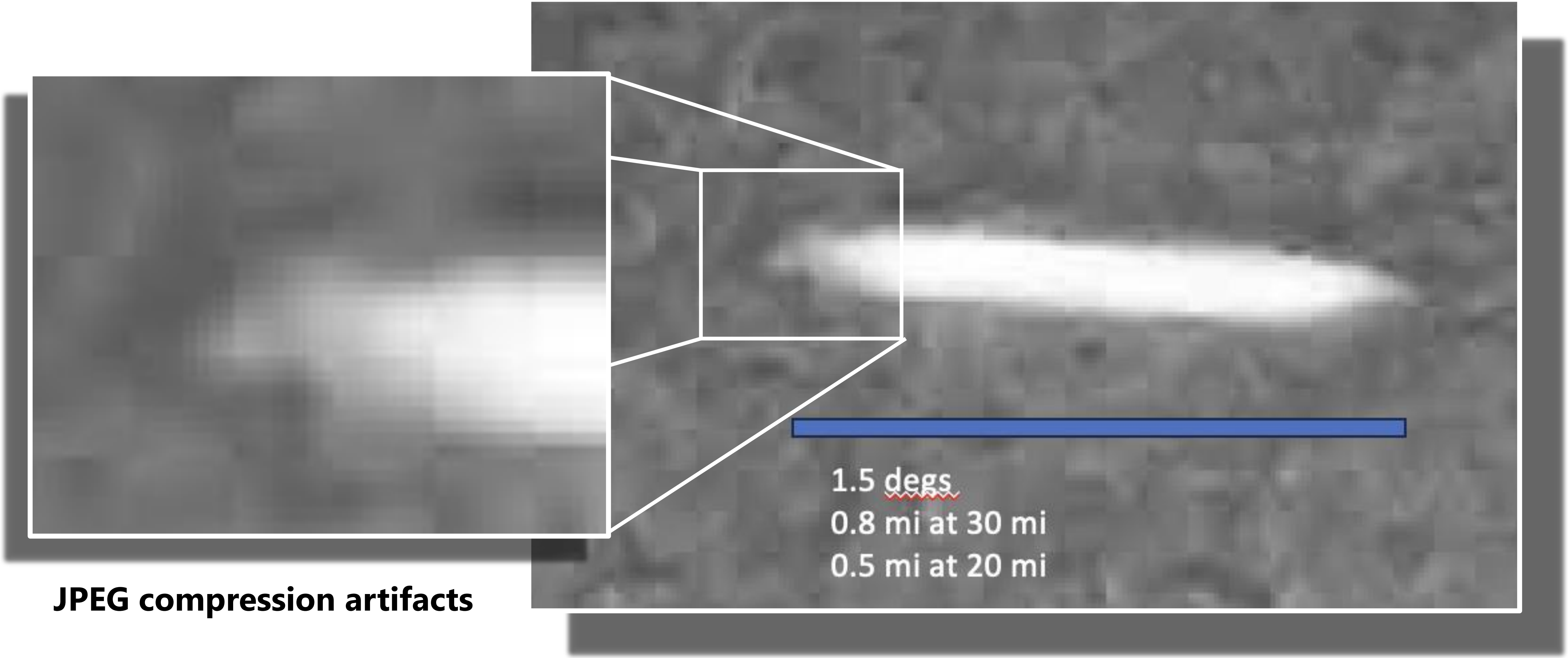
BACKUP

Gravitational Model of the Earth

H = the orthometric (or M.S.L.) "height" to an observer on the Earth's surface
h = the World Geodetic Survey 1984 (WGS84) "height" above the reference ellipsoid
N = the Earth Gravity Model or GEOID "height" above/below the reference ellipsoid



Case Study: MUFON case #124190



JPEG compression artifacts

Simulation Results for this Geometry

SOAP Simulation Option: Name (units)	**Photo 1 at 11:39:08UTC**	**Photo 2 at 11:39:24UTC**
SOAP route smoothing off		
Apparent Length (deg)	1.12	1.05
Actual Apparent Length (km)	30.78	29.8
Actual Apparent Length (mi)	19.13	18.52
*Estimated Apparent Length @ 30 miles (mi)**	*0.59*	*0.55*
Average Grazing Angle (deg)	31.92	31.95
Nearest Satellite Distance (km)	1574.4	1626.2
Nearest Satellite Distance (mi)	978.5	1010.69
Furthest Satellite Distance (km)	1590.5	1644.1
Furthest Satellite Distance (mi)	988.5	1021.81
Max Look Angle (deg)	-7.42	-3.75
Min Look Angle (deg)	-8.53	-4.79
Average Look Angle (deg)	-7.93	-4.23
Max Elevation Angle (deg)	2.41	1.9
Min Elevation Angle (deg)	2.24	1.72
Average Elevation Angle (deg)	2.32	1.8
Distance Traveled from Photo 1 to 2 (deg)	3.74	
Tangential Speed Photo 1 to 2 (deg/s)	0.23	
* The values in this row are estimated lengths based on the pilot's perceived distances.		

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Simulation Results for this Geometry

SOAP Simulation Option: Name (units)	**Photo 1 at 11:39:08UTC**	**% Diff.**	**Photo 2 at 11:39:24UTC**	**% Diff.**
Apparent Length (deg)	1.12	0.00	1.05	0.00
Actual Apparent Length (km)	30.7	0.26	29.74	0.20
Actual Apparent Length (mi)	19.08	0.26	18.48	0.22
Estimated Apparent Length @ 30 miles (mi)	*0.59*	*NA*	*0.55*	*NA*
Average Grazing Angle (deg)	31.93	-0.03	31.97	-0.06
Nearest Satellite Distance (km)	1570.6	0.24	1622.6	0.22
Nearest Satellite Distance (mi)	976.13	0.24	1008.45	0.22
Furthest Satellite Distance (km)	1586.7	0.24	1640.6	0.21
Furthest Satellite Distance (mi)	986.14	0.24	1019.64	0.21
Max Look Angle (deg)	-6.66	10.24	-2.94	21.60
Min Look Angle (deg)	-7.77	8.91	-3.98	16.91
Average Look Angle (deg)	-7.17	9.58	-3.41	19.39
Max Elevation Angle (deg)	2.42	-0.41	1.91	-0.53
Min Elevation Angle (deg)	2.25	-0.45	1.73	-0.58
Average Elevation Angle (deg)	2.33	-0.43	1.81	-0.56
Distance Traveled from Photo 1 to 2 (deg)			3.8	-1.60
Tangential Speed Photo 1 to 2 (deg/s)			0.24	-4.35