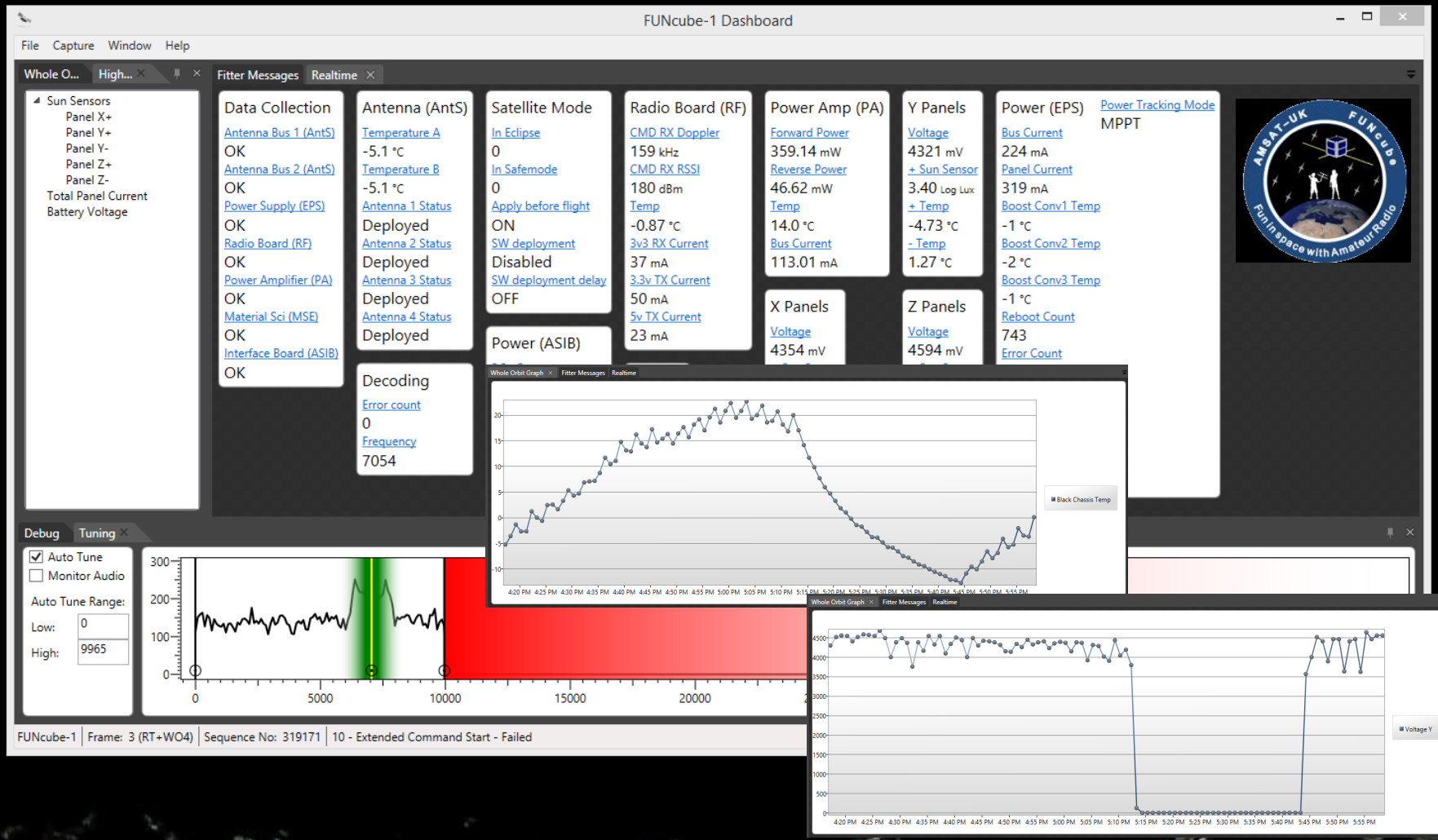
FUNcube-1 (AO-73)
2 Meter Satellite Telemetry



David Haworth
www.stargazing.net/david

CubeSat: Small Standard Size Satellites

- Standard sizes
  - 1U: 10 cm cube, mass <1.33 kilograms
  - 2U: 2x1U
  - 3U: 3x1U
- Common deployment system
  - Poly-PicoSatellite Orbital Deployer (P-POD)

Image Credit: CubeSat Design Specification Rev. 13

FUNcube-1 Satellite

- AMSAT-UK
  - http://amsat-uk.org/

- FUNcube
  - http://funcube.org.uk/
- FUNcube Warehouse
  - http://warehouse.funcube.org.uk/

- AMSAT-NL
  - http://amsat-nl.org/

1U CubSat: FUNcube-1, AO-73

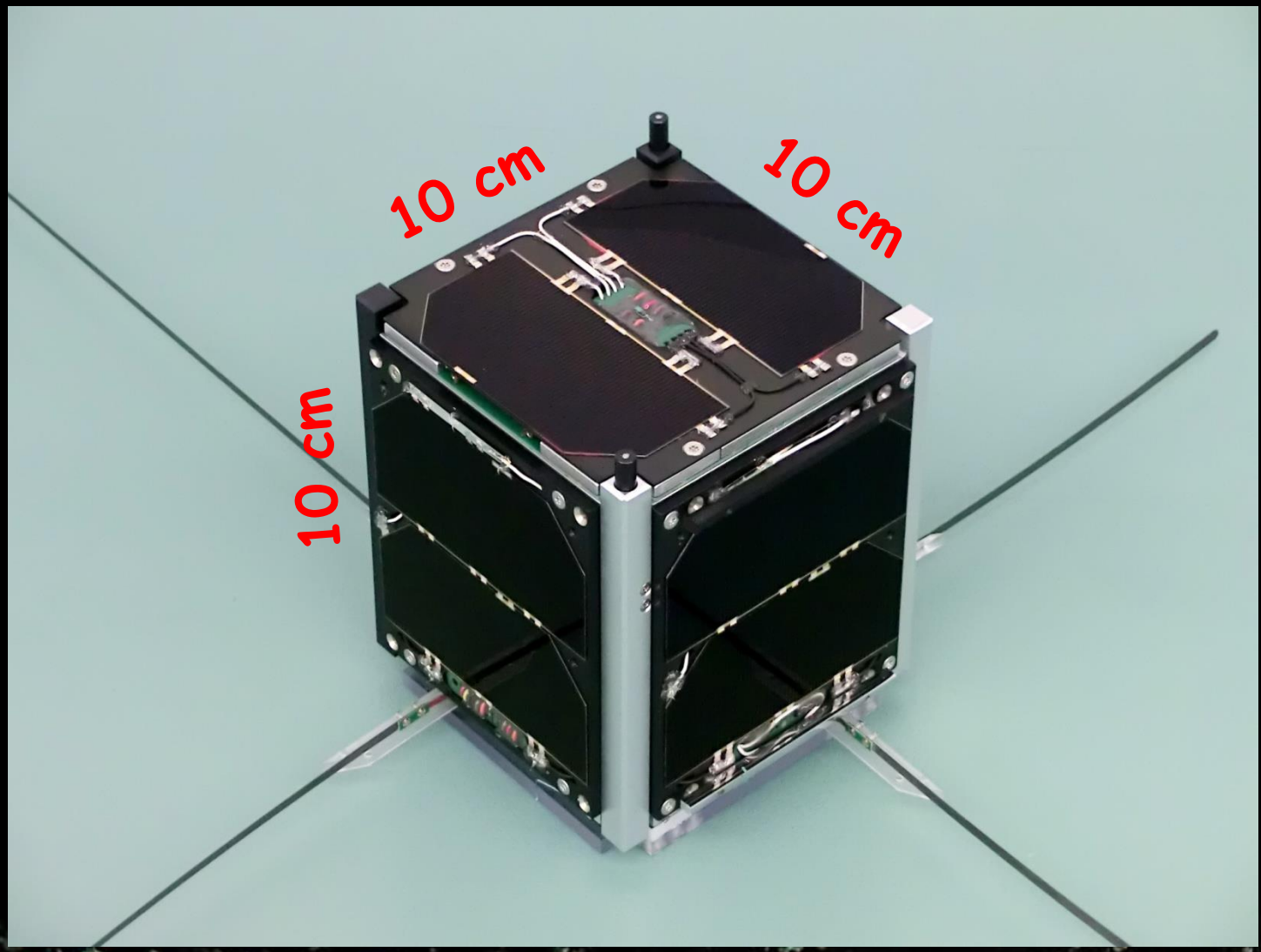


Image Credit: Wouter Weggelaar PA3WEG

1U CubSat: FUNcube-1, AO-73

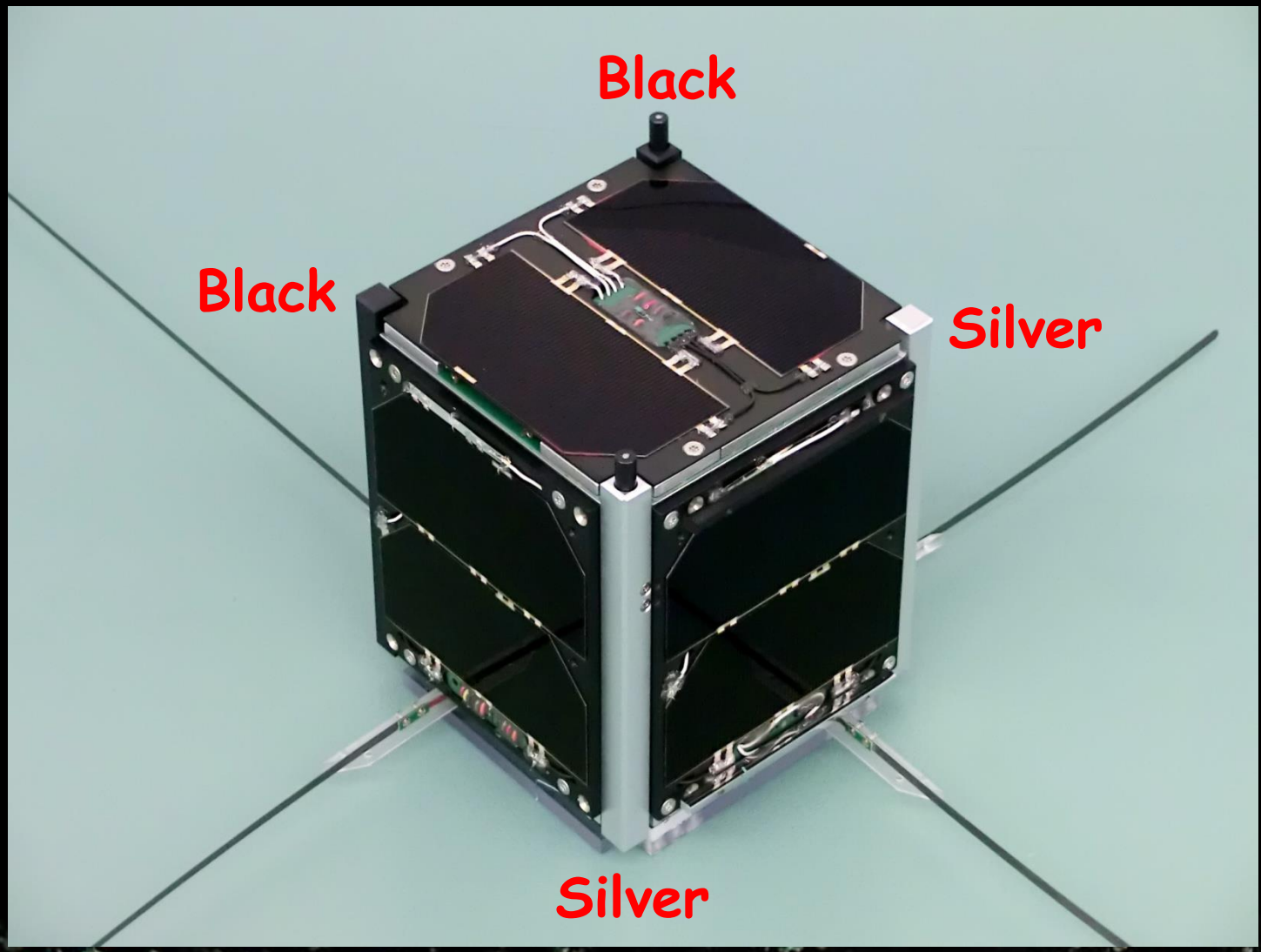


Image Credit: Wouter Weggelaar PA3WEG

1U CubSat: FUNcube-1, AO-73

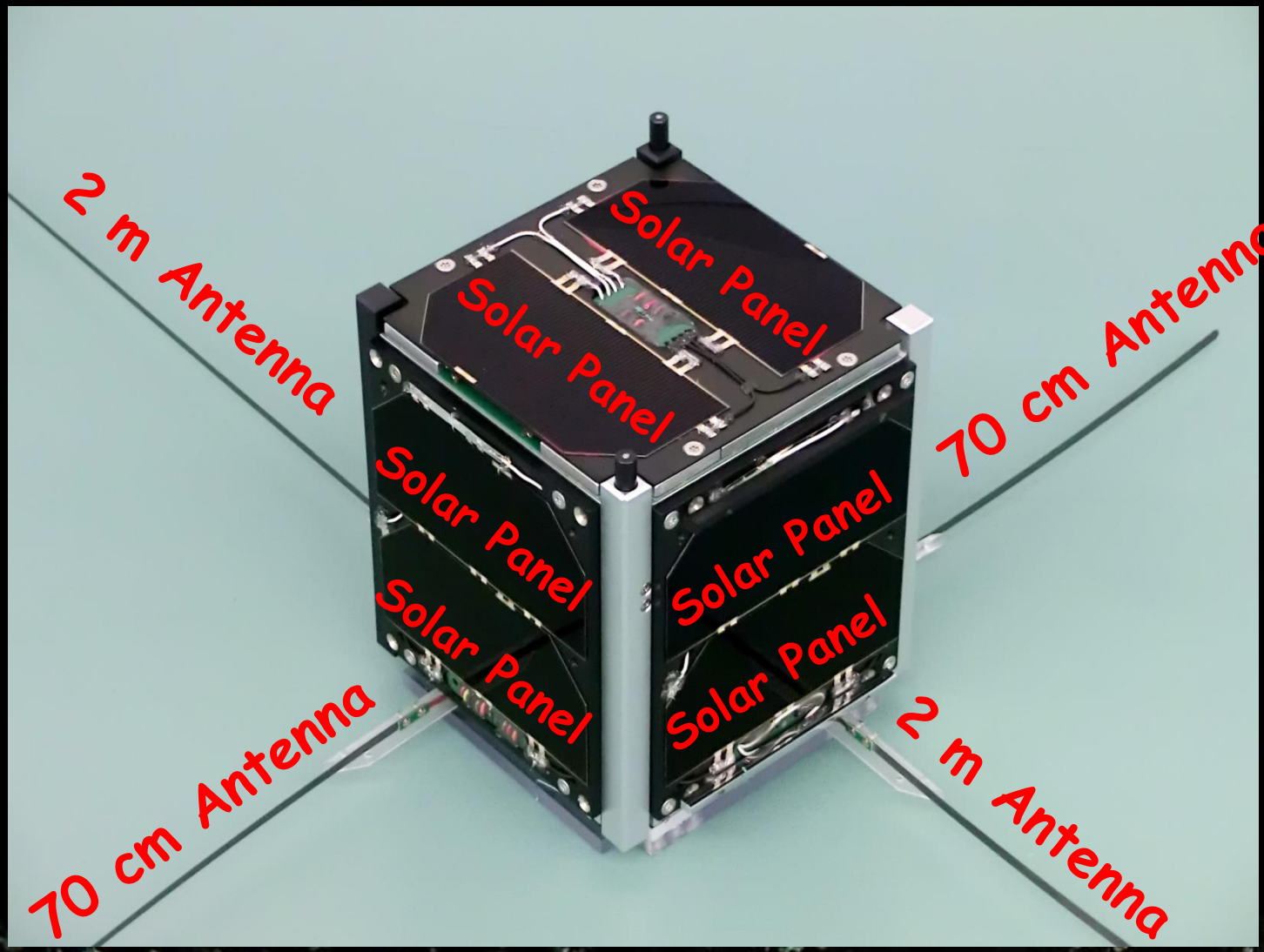


Image Credit: Wouter Weggelaar PA3WEG

FUNcube-1, AO-73

Launch Date: November 2013, Mission Goal 1 Year

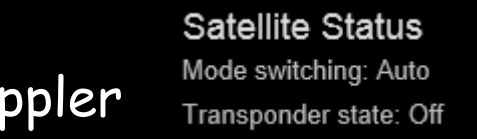
Mission type	Amateur Radio
Operator	AMSAT-NL
COSPAR ID	2013-066AE
SATCAT №	39444
Website	funcube.org.uk
Spacecraft properties	
Bus	1U CubeSat[1]
Manufacturer	ISIS-BV, AMSAT-NL, AMSAT-UK
Launch mass	0.98 kilograms (2.2 lb)
Power	2.2 watts
Start of mission	
Launch date	21 November 2013
Rocket	dnepr
Launch site	Yasny Launch Base
Contractor	ISL
Orbital parameters	
Reference system	Geocentric
Regime	Low Earth

Image Credit: funcube_oct2013fin.ppt, Table Credit: http://en.wikipedia.org/wiki/FUNcube-1

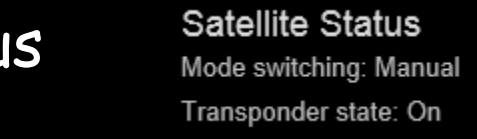
FUNcube-1 Telemetry (TLM)

2 Modes: High Power M-F Mornings, Low Power Other Times

- In sunlight full power 300 mW TLM
  - TLM down link freq 145.935 MHz +/- Doppler
  - Monday – Friday mornings Europe time
  - Transponder off



- In eclipse low power 30 mW TLM plus
  - Transponder evenings & weekends
    - Surface to satellite to surface communications
    - Uplink 435.150 - 435.130 MHz CW & LSB (Inverting)
    - Downlink 145.950 - 145.970 MHz CW & USB

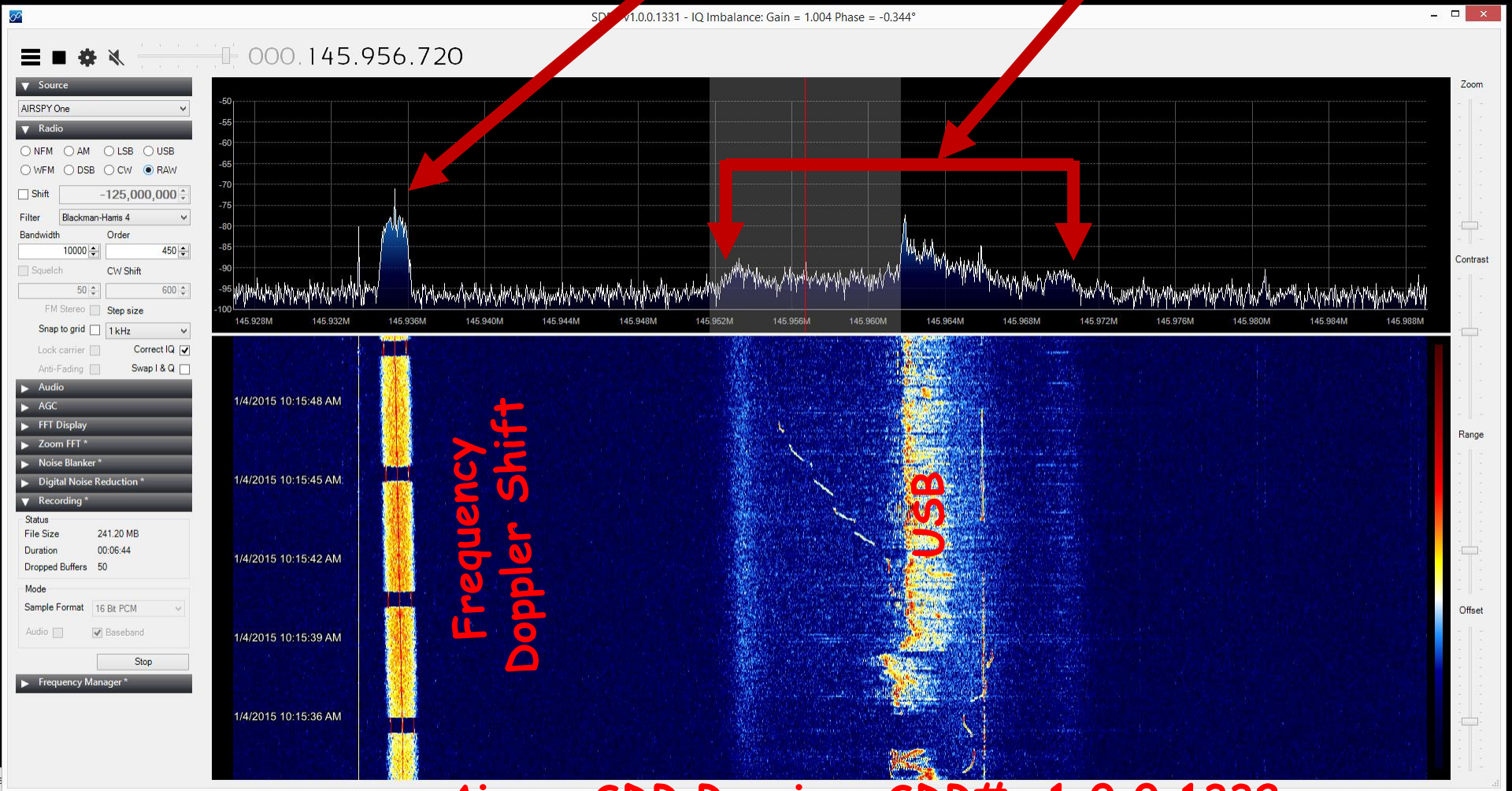


FUNcube-1 Status: http://warehouse.funcube.org.uk/

FUNcube-1 Telemetry (TLM)

Low power TLM beacon with transponder

Satellite Status
Mode switching: Manual
Transponder state: On



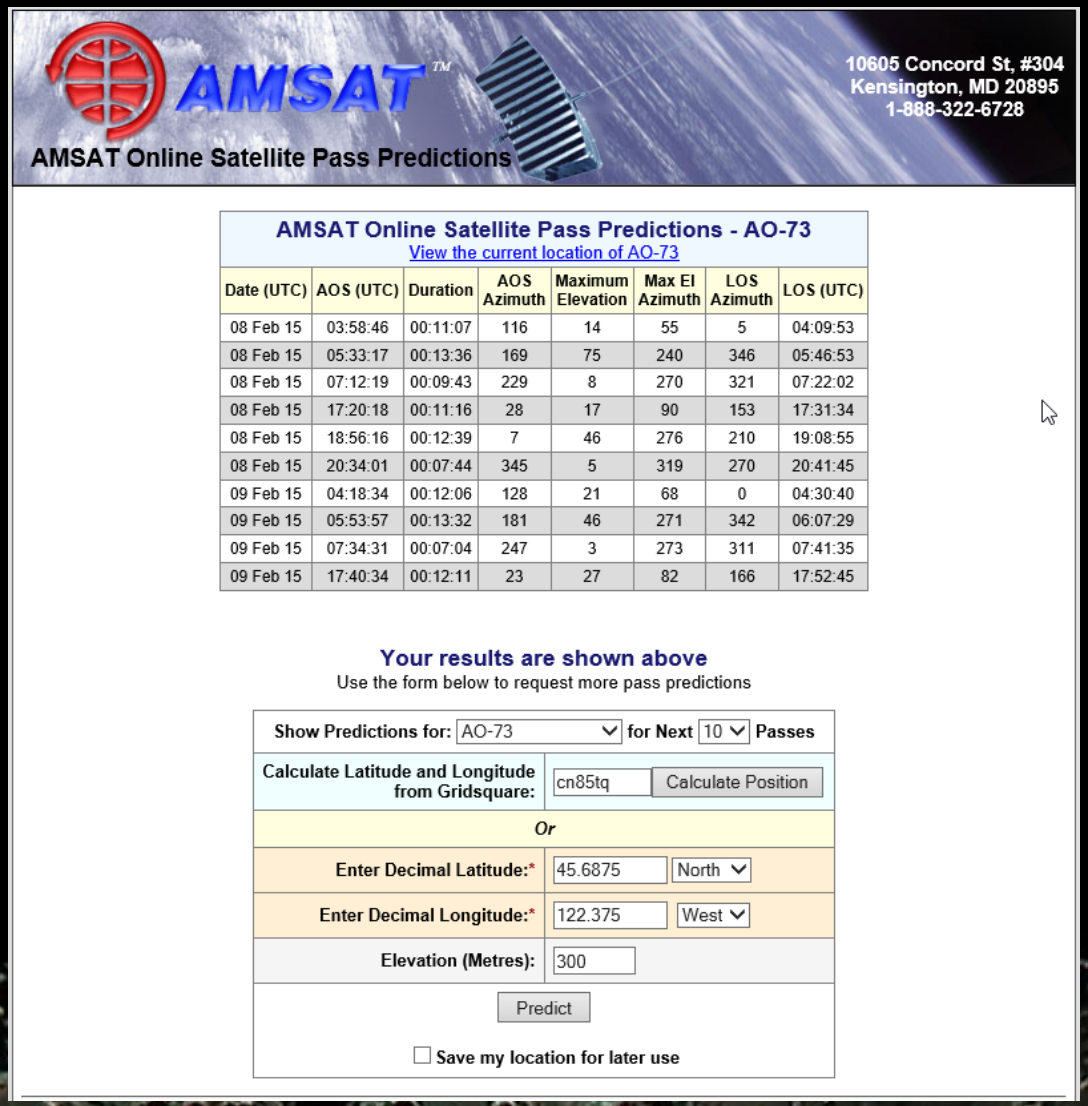
Airspy SDR Receiver SDR# v1.0.0.1332

FUNcube-1, AO-73 Position

http://warehouse.funcube.org.uk/satmap.html?satelliteId=2

FUNcube-1, AO-73 Position

http://www.amsat.org/amsat-new/tools/predict/index.php



AMSAT™

AMSAT Online Satellite Pass Predictions

10605 Concord St, #304
Kensington, MD 20895
1-888-322-6728

AMSAT Online Satellite Pass Predictions - AO-73

View the current location of AO-73

Date (UTC)	AOS (UTC)	Duration	AOS Azimuth	Maximum Elevation	Max El Azimuth	LOS Azimuth	LOS (UTC)
08 Feb 15	03:58:46	00:11:07	116	14	55	5	04:09:53
08 Feb 15	05:33:17	00:13:36	169	75	240	346	05:46:53
08 Feb 15	07:12:19	00:09:43	229	8	270	321	07:22:02
08 Feb 15	17:20:18	00:11:16	28	17	90	153	17:31:34
08 Feb 15	18:56:16	00:12:39	7	46	276	210	19:08:55
08 Feb 15	20:34:01	00:07:44	345	5	319	270	20:41:45
09 Feb 15	04:18:34	00:12:06	128	21	68	0	04:30:40
09 Feb 15	05:53:57	00:13:32	181	46	271	342	06:07:29
09 Feb 15	07:34:31	00:07:04	247	3	273	311	07:41:35
09 Feb 15	17:40:34	00:12:11	23	27	82	166	17:52:45

Your results are shown above

Use the form below to request more pass predictions

Show Predictions for: AO-73 for Next 10 Passes

Calculate Latitude and Longitude from Gridsquare: cn85tq Calculate Position

Or

Enter Decimal Latitude:* 45.6875 North

Enter Decimal Longitude:* 122.375 West

Elevation (Metres): 300

Predict

Save my location for later use

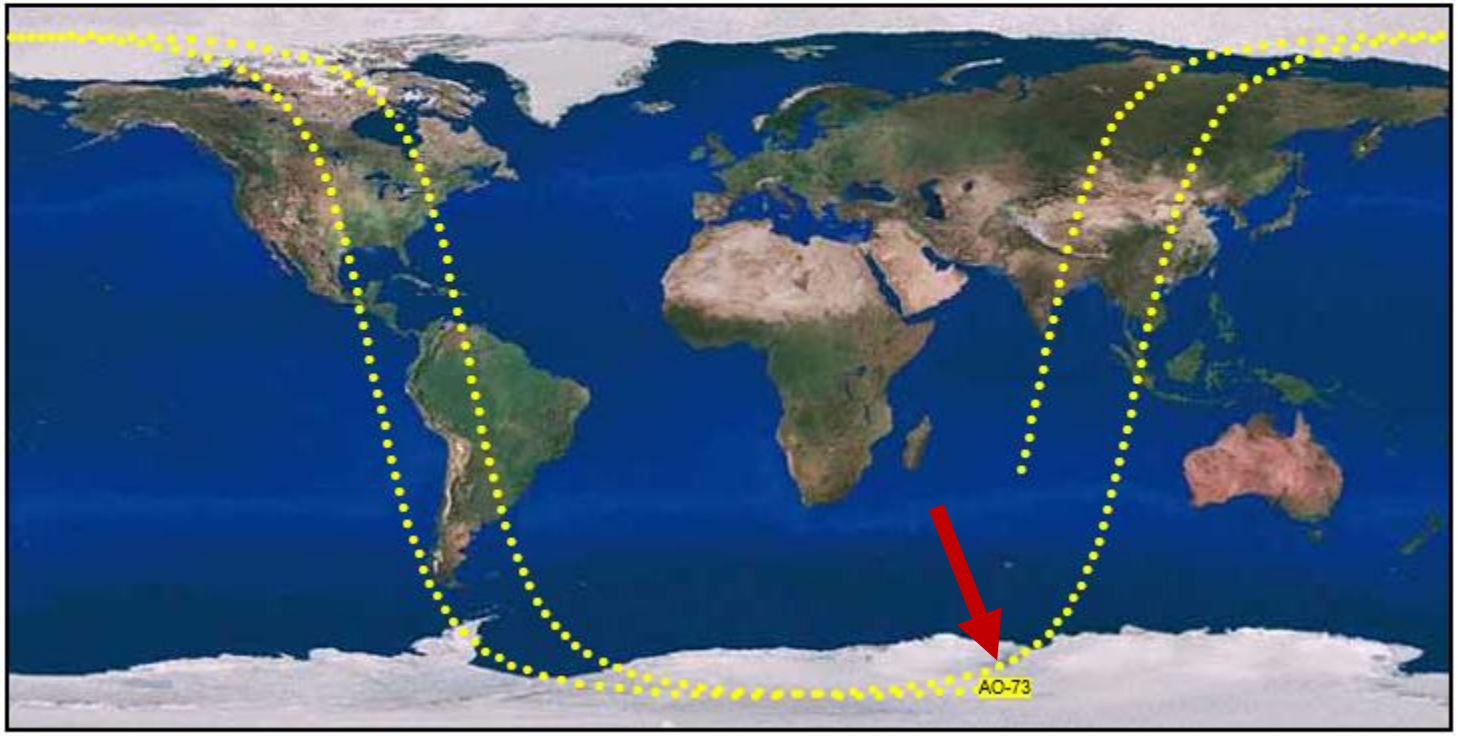
AMSAT™

10605 Concord St, #304
Kensington, MD 20895
1-888-322-6728

Satellite Tracking for AO-73

Current Position of AO-73

Sun, 08 Feb 2015 01:46:43 GMT (17:46:43 local time)
Current Location: 70E 81S



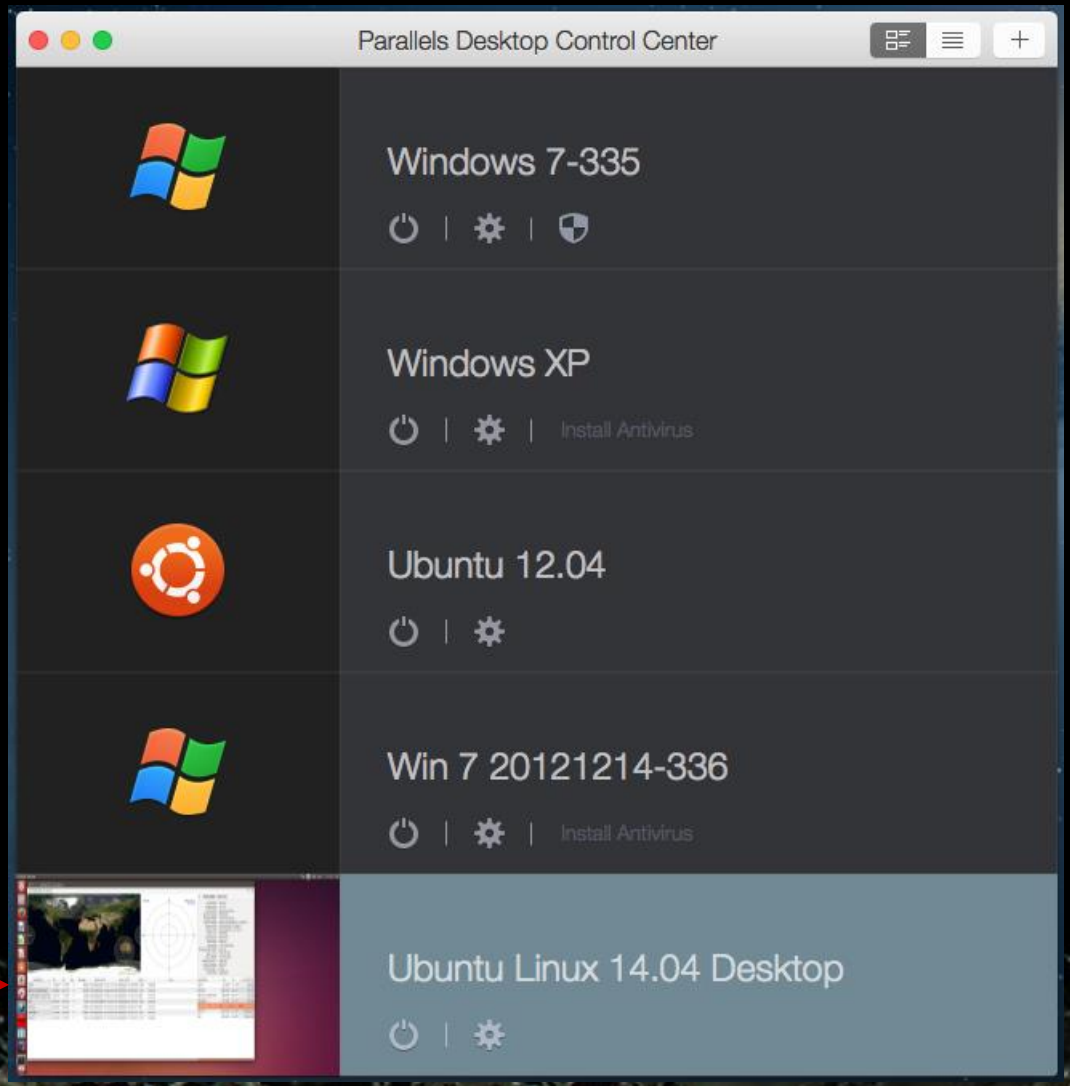
Select a Different Satellite: AO-73

Note: Position is approximate and depends on your computer's performance.

Image Credit: http://www.amsat.org/amsat-new/tools/predict/satloc.php?lang=en&satellite=AO-73

Gpredict on MacBook Pro

Ubuntu Linux 14.04 on Parallels Desktop 10



Gpredict on MacBook Pro

Ubuntu 14.04 Software Center Easy Install

Ubuntu Software Center

All Software | Installed | History | Progress

GNOME Predict

Satellite tracker

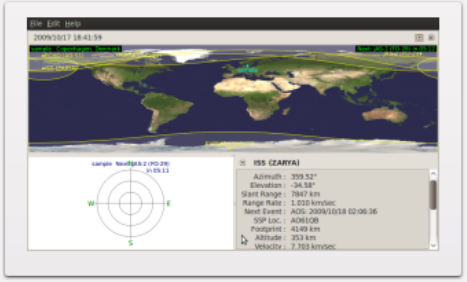
★★★★½ (8 ratings)

Installed on 2014-12-27 Remove

Gpredict is a real time satellite tracking program for GNOME, based on the tracking engine of John Magliacane's excellent satellite tracker Predict.

Gpredict includes the following features:

- Tracking an infinite number of satellites limited only by the physical memory and processing power of the computer.
- Display the tracking data in lists, maps, polar plots or any combination of these.
- You can have many modules open at the same time, either in a notebook or in their own windows. The module can also run in full-screen mode.
- You can use many ground stations. Ground station coordinates can be entered manually or you can get some approximate values from a list with more than 2000 predefined locations worldwide.
- Predict upcoming passes for satellites, including passes where a satellite may be visible and communication windows open.
- Very detailed information about both the real time data and the predicted passes.
- Gpredict can run in real-time, simulated real-time (fast forward and backward), and manual time control.
- Doppler tuning of radios via Hamlib rigctld.
- Antenna rotator control via Hamlib rotctld.



Version gpredict 1.3-2ubuntu2

About GPREDICT

GPREDICT 1.3

Copyright (C) 2001-2011 Alexandru Csete OZ9AEC

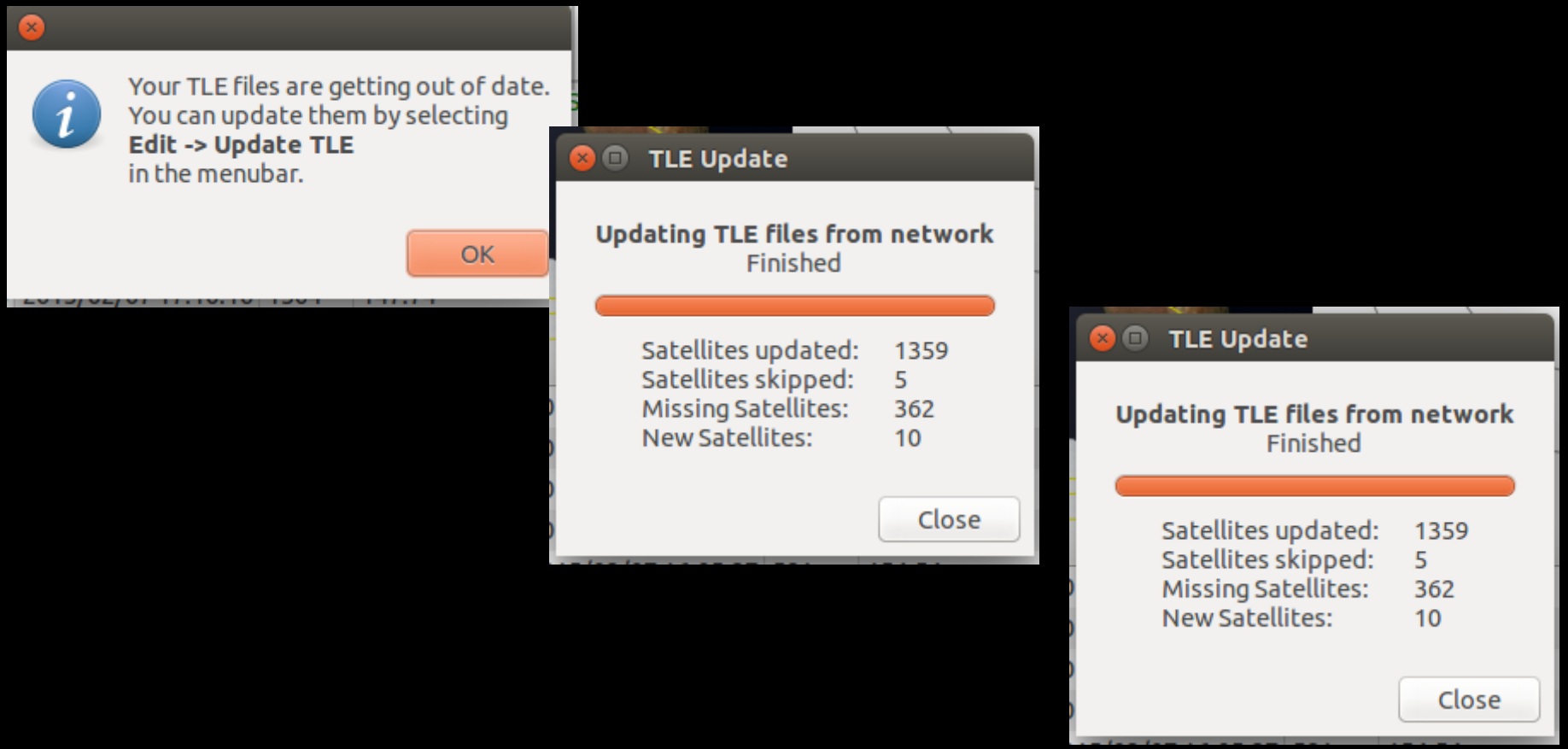
Gpredict is available free of charge from:

http://gpredict.oz9aec.net/

Credits | License | Close

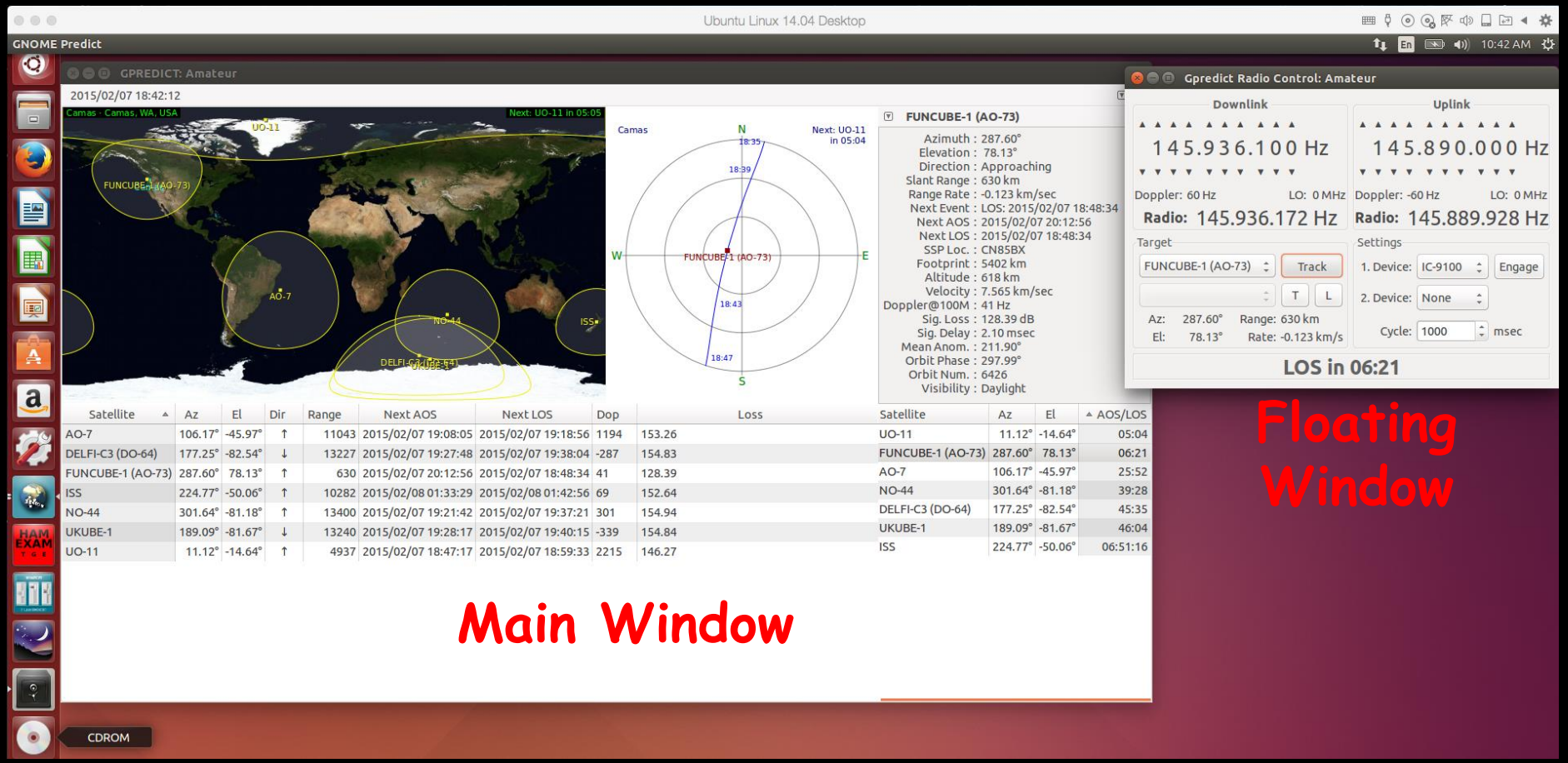
Gpredict Keplerian Elements

Elements define the satellite orbit



Gpredict Custom Layout

Main window has 5 panels

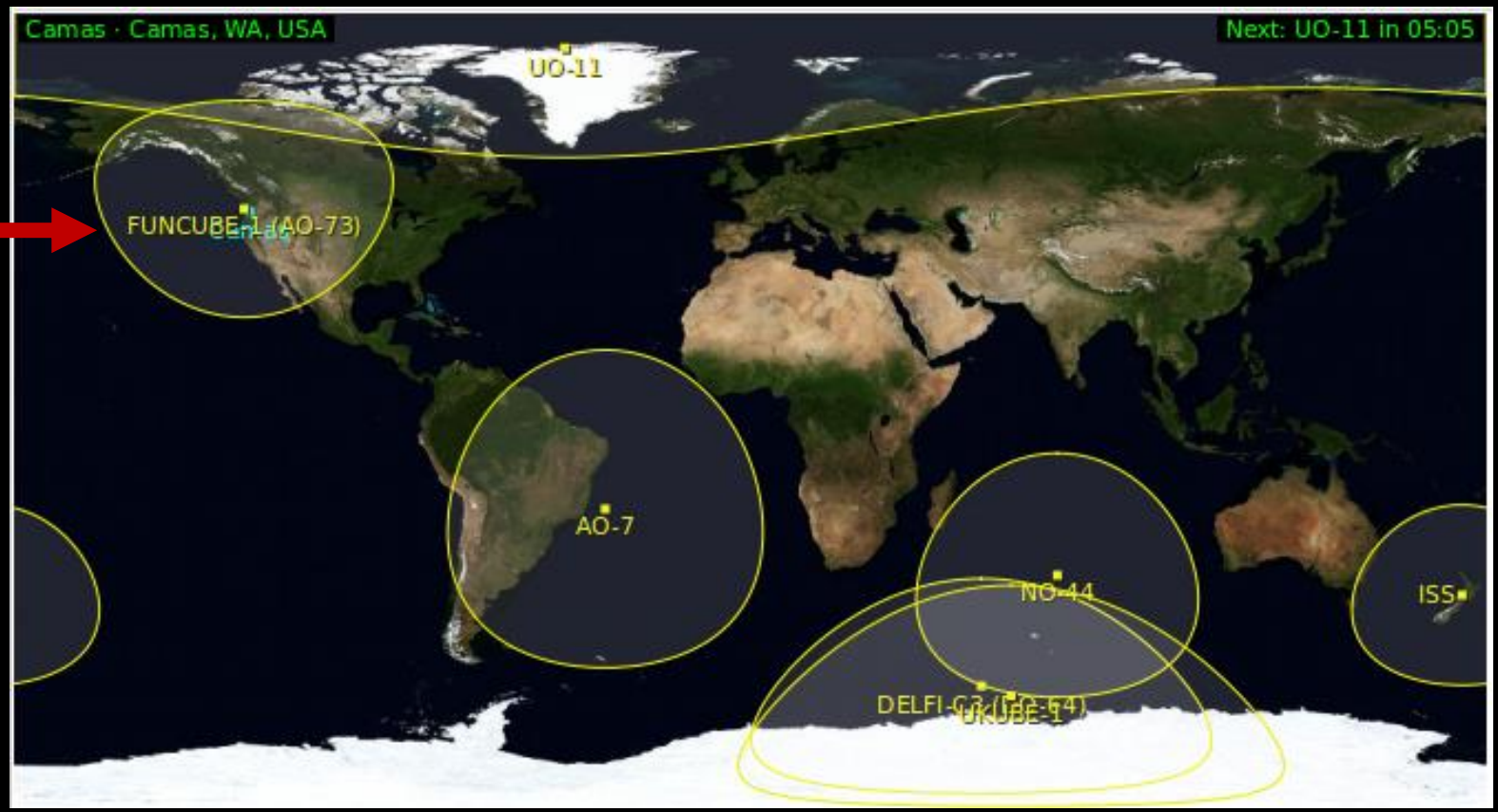


Floating Window

Main Window

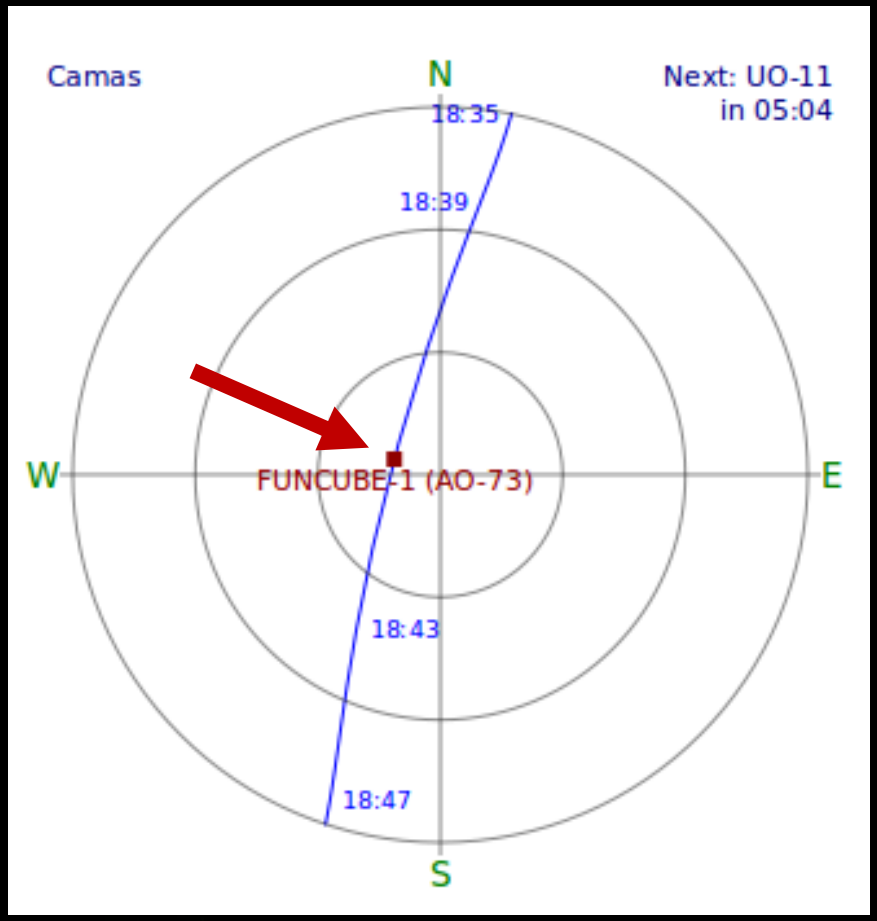
Gpredict Satellites Footprints

Can the satellite & you see each other



Gpredict Satellite Location in Sky

Altitude-Azimuth Position for pointing the antenna



Azimuth :	287.60°
Elevation :	78.13°
Direction :	Approaching
Slant Range :	630 km
Range Rate :	-0.123 km/sec
Next Event :	LOS: 2015/02/07 18:48:34
Next AOS :	2015/02/07 20:12:56
Next LOS :	2015/02/07 18:48:34
SSP Loc. :	CN85BX
Footprint :	5402 km
Altitude :	618 km
Velocity :	7.565 km/sec
Doppler@100M :	41 Hz
Sig. Loss :	128.39 dB
Sig. Delay :	2.10 msec
Mean Anom. :	211.90°
Orbit Phase :	297.99°
Orbit Num. :	6426
Visibility :	Daylight

Gpredict Satellite Prediction

Acquisition of signal (AOS) & Lost of signal (LOS)

Satellite	Az	El	▲ AOS/LOS
UO-11	11.12°	-14.64°	05:04
FUNCUBE-1 (AO-73)	287.60°	78.13°	06:21
AO-7	106.17°	-45.97°	25:52
NO-44	301.64°	-81.18°	39:28
DELFI-C3 (DO-64)	177.25°	-82.54°	45:35
UKUBE-1	189.09°	-81.67°	46:04
ISS	224.77°	-50.06°	06:51:16

Gpredict

List of satellites on 2 meters band

Satellite	Az	El	Dir	Range	Next AOS	Next LOS	Dop	Loss
AO-7	106.17°	-45.97°	↑	11043	2015/02/07 19:08:05	2015/02/07 19:18:56	1194	153.26
DELFI-C3 (DO-64)	177.25°	-82.54°	↓	13227	2015/02/07 19:27:48	2015/02/07 19:38:04	-287	154.83
FUNCUBE-1 (AO-73)	287.60°	78.13°	↑	630	2015/02/07 20:12:56	2015/02/07 18:48:34	41	128.39
ISS	224.77°	-50.06°	↑	10282	2015/02/08 01:33:29	2015/02/08 01:42:56	69	152.64
NO-44	301.64°	-81.18°	↑	13400	2015/02/07 19:21:42	2015/02/07 19:37:21	301	154.94
UKUBE-1	189.09°	-81.67°	↓	13240	2015/02/07 19:28:17	2015/02/07 19:40:15	-339	154.84
UO-11	11.12°	-14.64°	↑	4937	2015/02/07 18:47:17	2015/02/07 18:59:33	2215	146.27

2 Meters 144-148 MHz Band Plan

144.00-144.05	EME (CW)
144.05-144.10	General CW and weak signals
144.10-144.20	EME and weak-signal SSB
144.200	National calling frequency
144.200-144.275	General SSB operation
144.275-144.300	Propagation beacons
144.30-144.50	New OSCAR subband
144.50-144.60	Linear translator inputs
144.60-144.90	FM repeater inputs
144.90-145.10	Weak signal and FM simplex (145.01,03,05,07,09 are widely used for packet)
145.10-145.20	Linear translator outputs
145.20-145.50	FM repeater outputs
145.50-145.80	Miscellaneous and experimental modes
145.80-146.00	OSCAR subband
146.01-146.37	Repeater inputs
146.40-146.58	Simplex
146.52	National Simplex Calling Frequency
146.61-146.97	Repeater outputs
147.00-147.39	Repeater outputs
147.42-147.57	Simplex
147.60-147.99	Repeater inputs

Satellites

Image Credit: http://www.arrl.org/band-plan

2 Meters 145.8-146.0 MHz Satellites

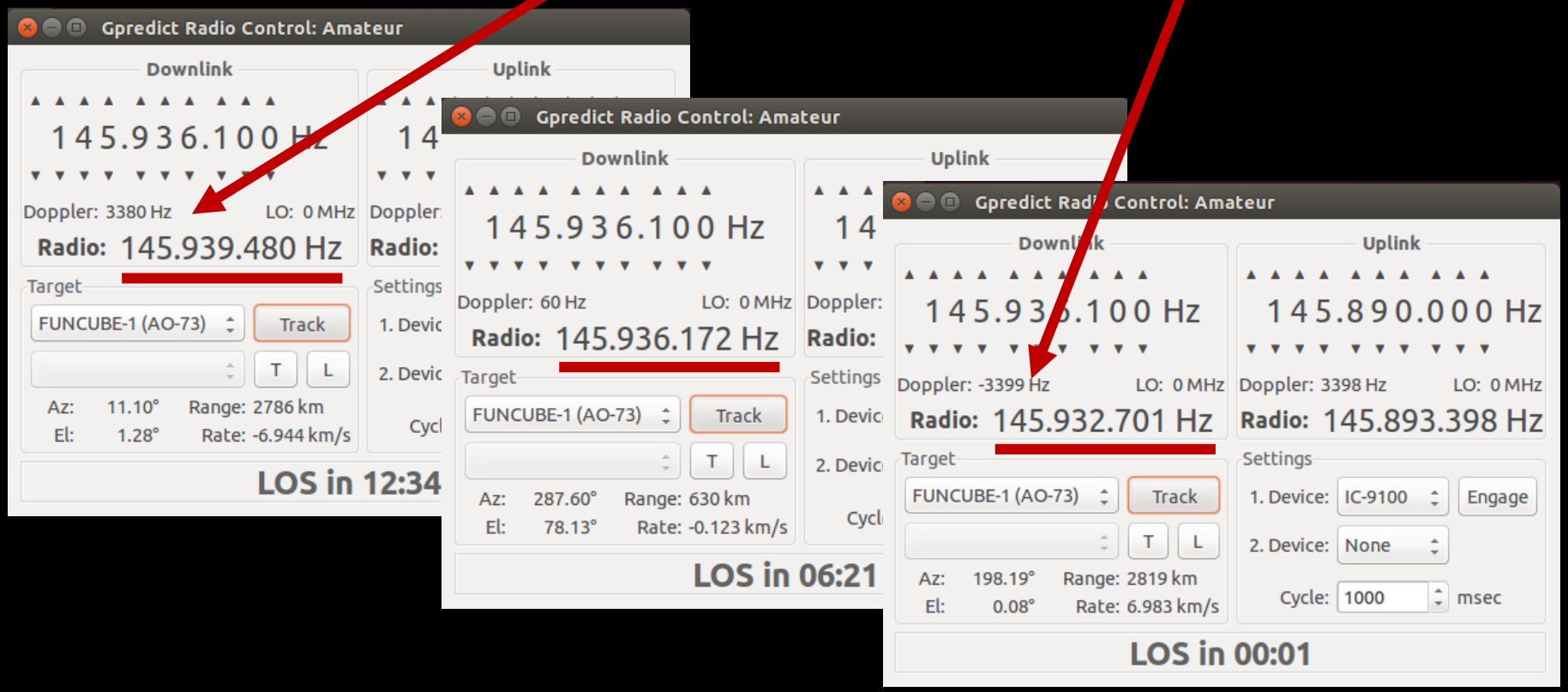
January 2015

145.800-146.000 MHz			
Frequency MHz +/- Doppler	**Satellite**	**Notes**	**Observations**
145.825	Navy-OSCAR 44, NO-44, PCsat	FM FSK, AX.25, 1k2 and 9k6 in Sun only	
145.825	ISS	FM FSK, AX.25 packet	
145.825	UoSAT OSCAR, UO-11	FM 1k2 AFSK ASCII	
145.870	DELFI-OSCAR 64, DO-64, DELFI-C3	CW and 1k2 BPSK AX.25	
145.915	FUNcube-2, UKube-1	30mW or 300 mW Telemetry Beacon 1200 bps BPSK, same as FUNcube-1 AO-73	
145.935	FUNcube-1, AO-73	30mW or 300 mW Telemetry Beacon 1200 bps BPSK	20150104 1809UT
145.925 - 145.975	AMSAT OSCAR 7, AO-7	Mode U/V (B) Linear Transponder (Inverting) alternates with Mode A USB and CW when in the Sun	
145.950 - 145.970	FUNcube-1, AO-73	Transponder Downlink USB and CW	20150104 1809UT
145.9775	AMSAT OSCAR 7, AO-7	CW Beacon when in the Sun	

http://www.stargazing.net/david/satellites/2meters.html

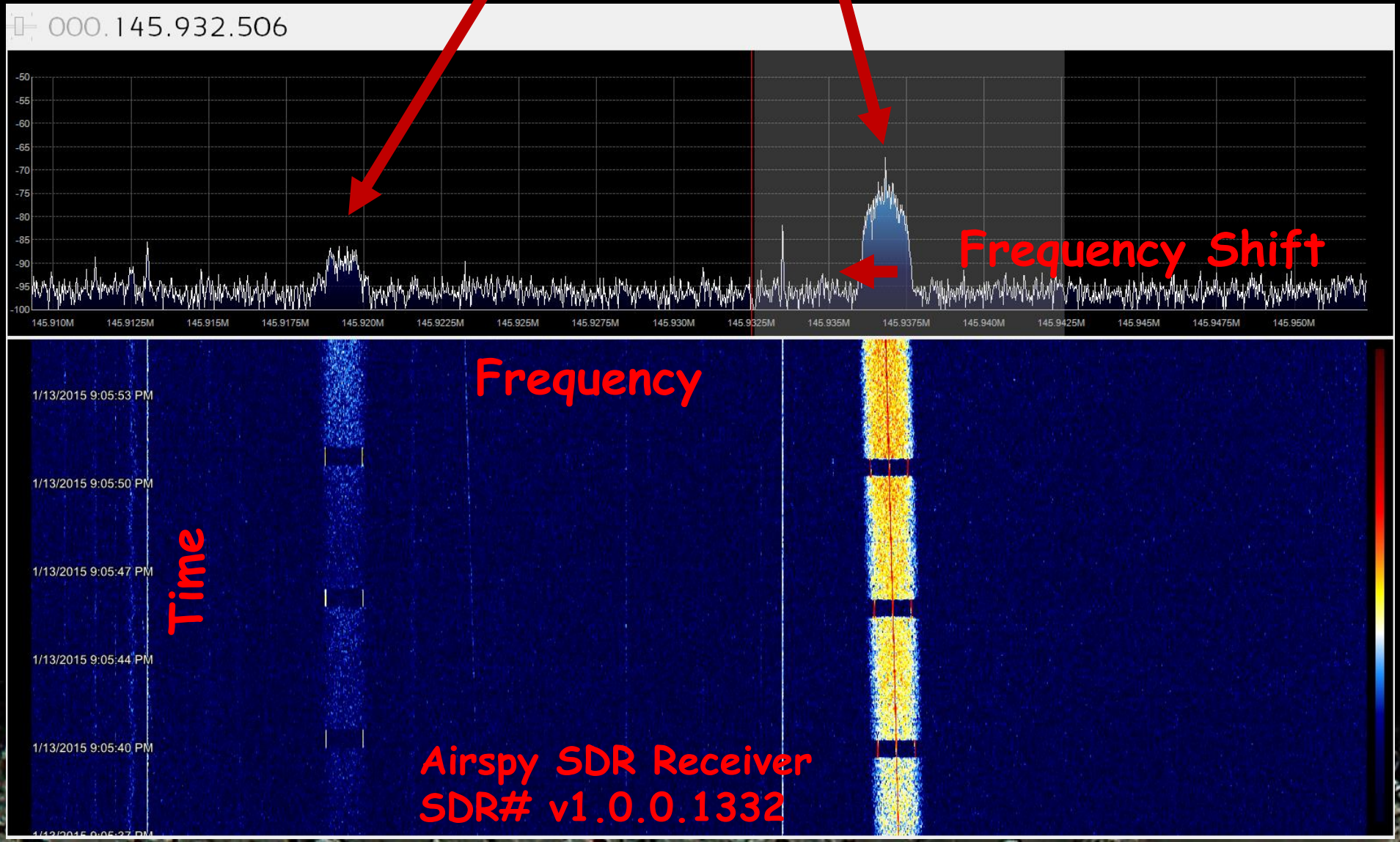
Gpredict Doppler Shift

+ Frequency Coming, - Frequency Going



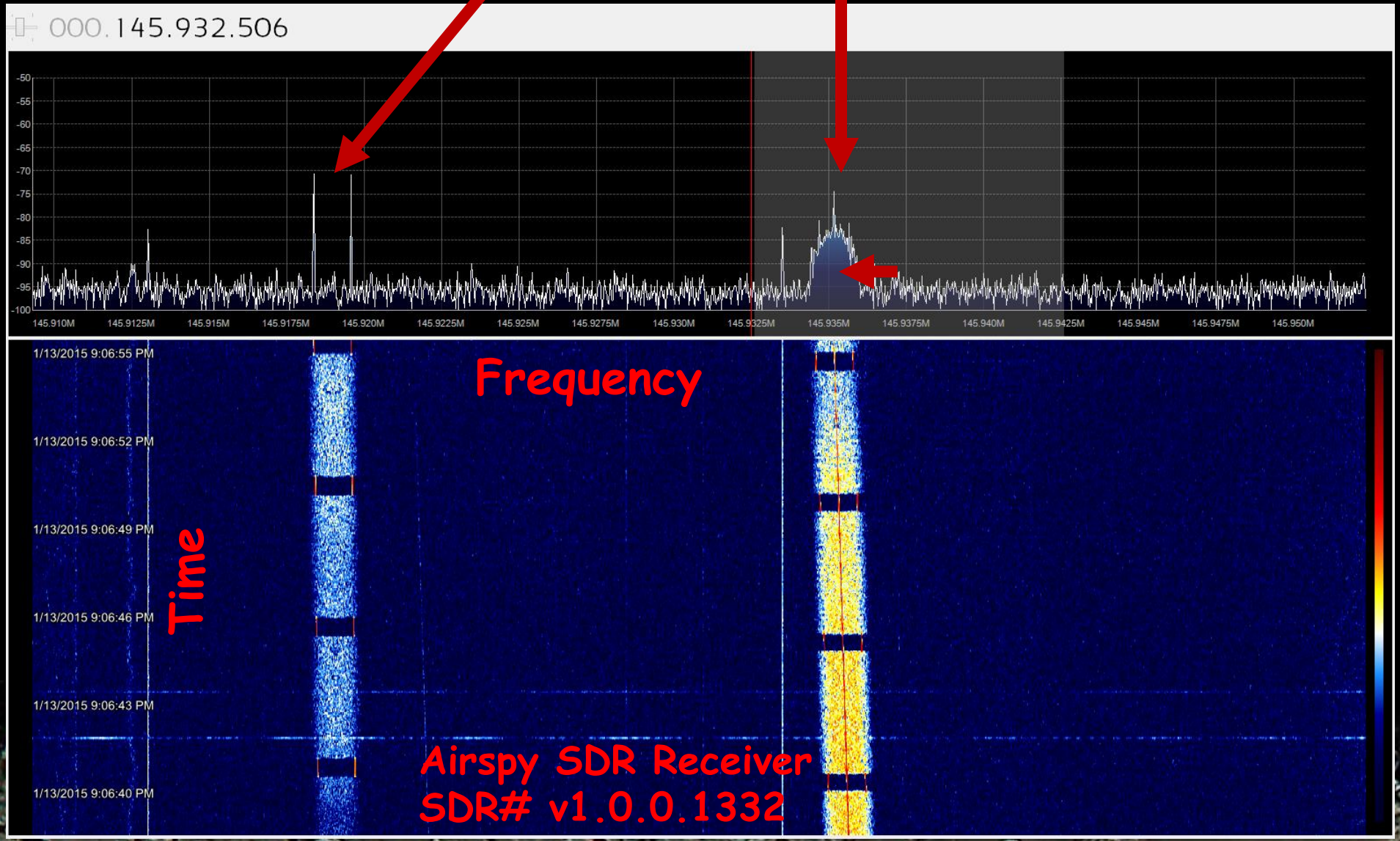
Frequency Doppler Shift

UKcube-1 TLM, FUNcube-1 TLM



Frequency Doppler Shift

UKcube-1 TLM, FUNcube-1 TLM



Saturday 2015-2-7 Passes

Camas WA, USA

3 in Morning

3 in Evening

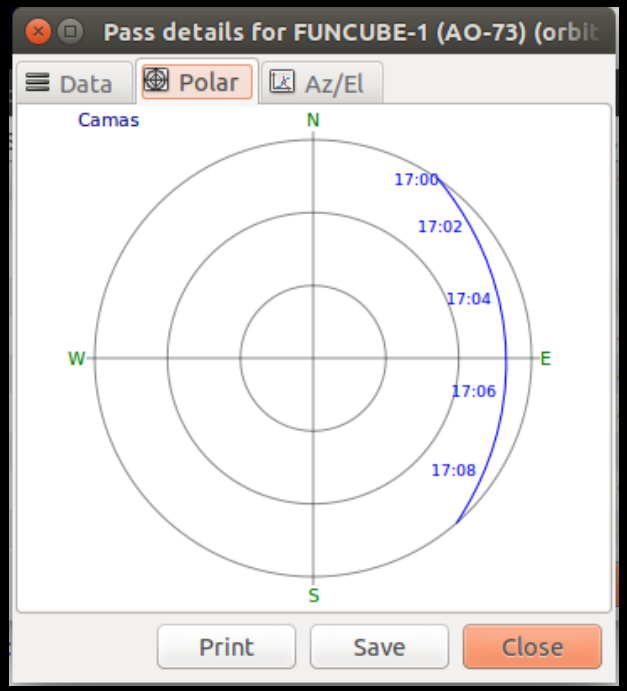
Upcoming passes for FUNCUBE-1 (AO-73)

AOS	LOS	Duration	Max El	AOS Az	LOS Az
2015/02/07 17:00:11	2015/02/07 17:10:14	00:10:03	10.46°	34.99°	138.87°
2015/02/07 18:35:39	2015/02/07 18:48:34	00:12:54	77.20°	11.16°	198.18°
2015/02/07 20:12:56	2015/02/07 20:22:27	00:09:30	9.41°	351.10°	255.42°
2015/02/08 03:58:45	2015/02/08 04:09:52	00:11:06	14.23°	115.73°	4.71°
2015/02/08 05:33:16	2015/02/08 05:46:52	00:13:36	76.21°	169.41°	346.14°
2015/02/08 07:12:17	2015/02/08 07:22:01	00:09:43	8.19°	228.45°	321.22°

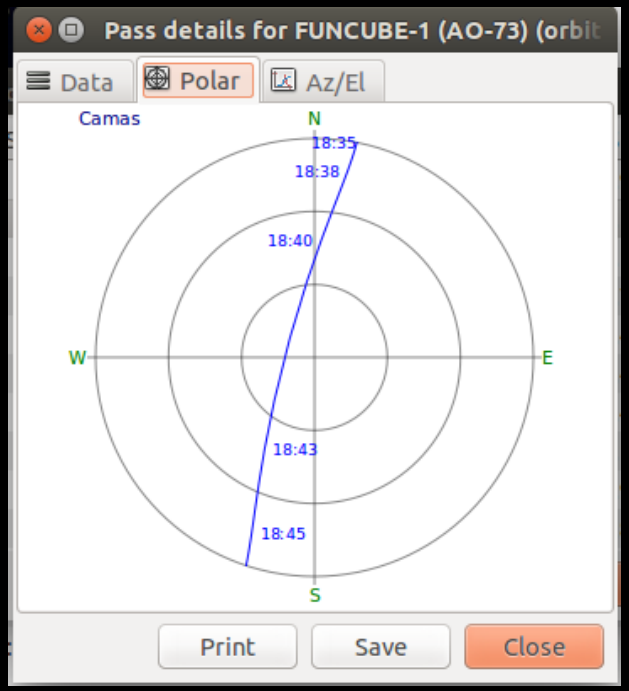
Saturday Morning 2015-2-7 Passes

Camas WA, USA

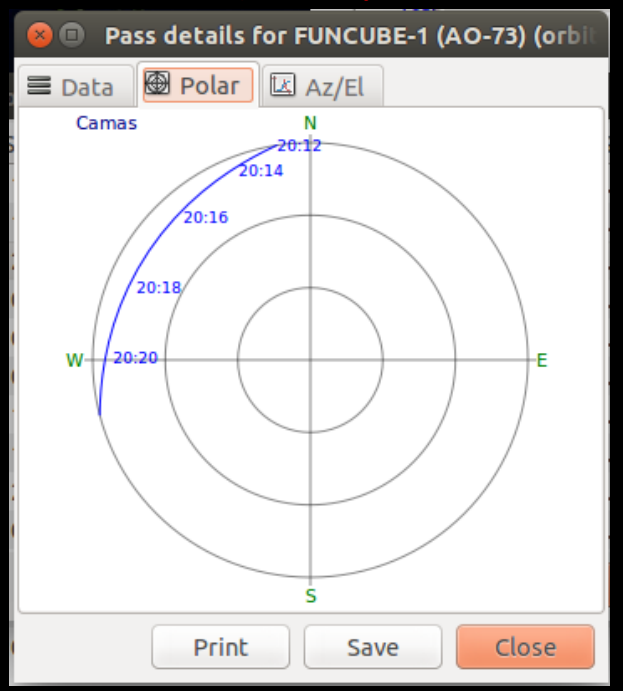
2 Frames



46 Frames



3 Frames

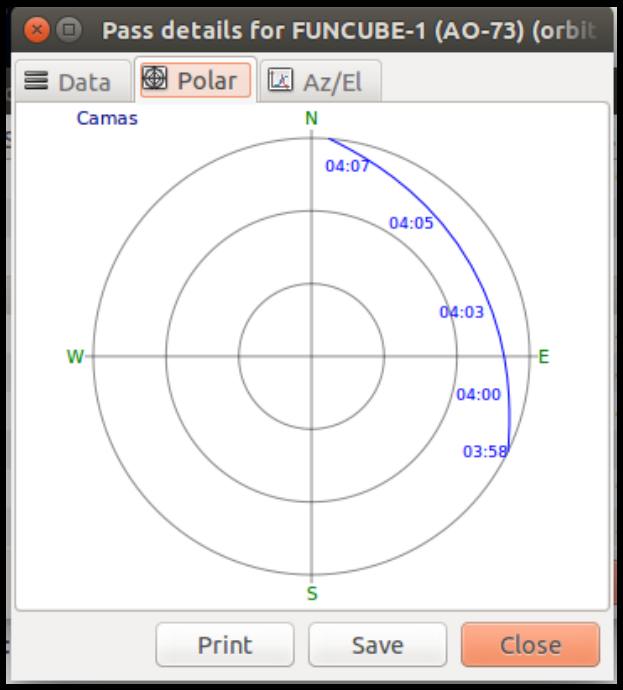


AOS	LOS	Duration	Max El	AOS Az	LOS Az
2015/02/07 17:00:11	2015/02/07 17:10:14	00:10:03	10.46°	34.99°	138.87°
2015/02/07 18:35:39	2015/02/07 18:48:34	00:12:54	77.20°	11.16°	198.18°
2015/02/07 20:12:56	2015/02/07 20:22:27	00:09:30	9.41°	351.10°	255.42°

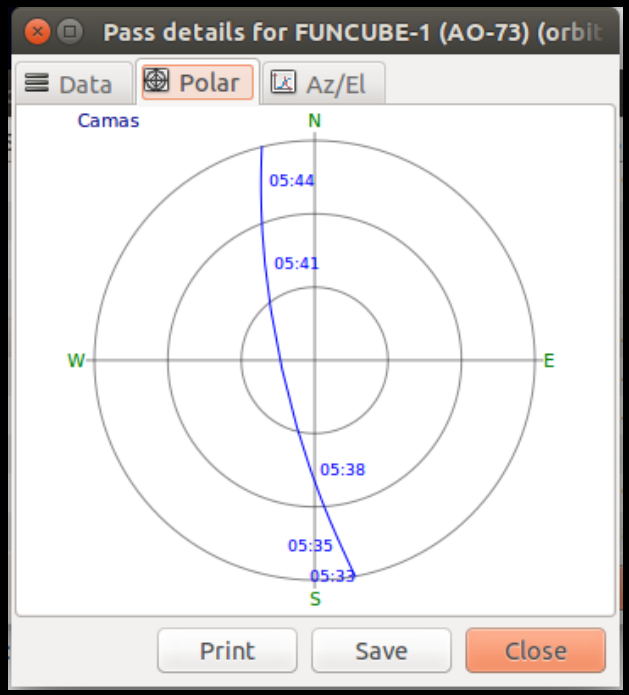
Saturday Evening 2015-2-7 Passes

Camas WA, USA

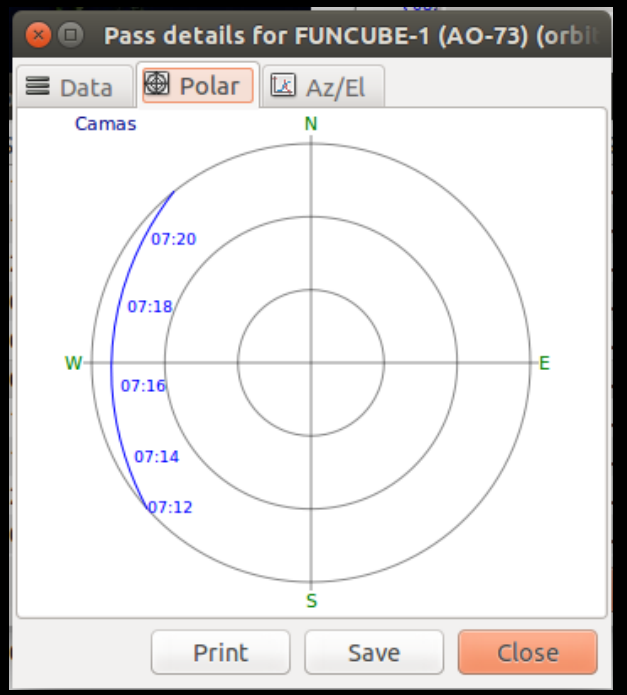
0 Frames



74 Frames



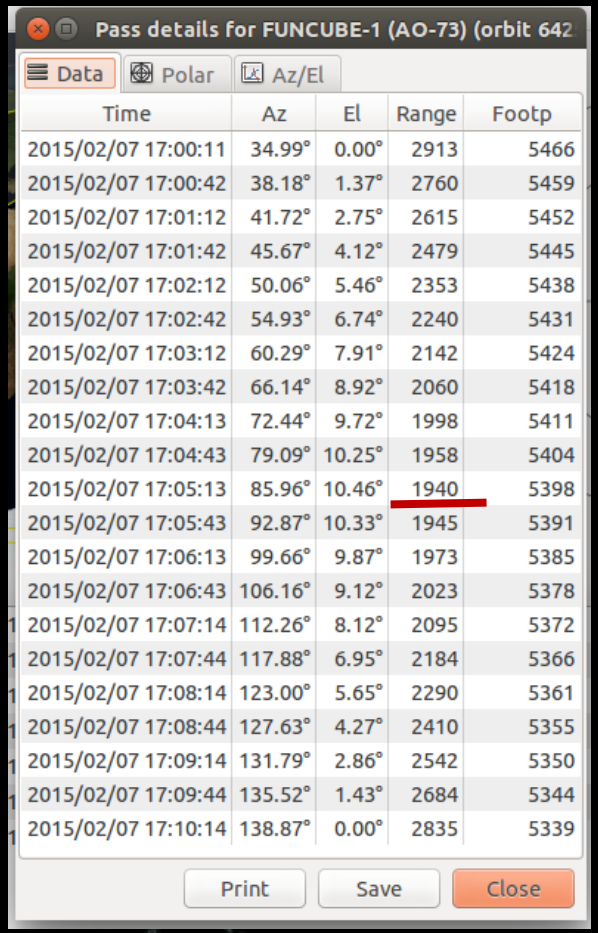
3 Frames

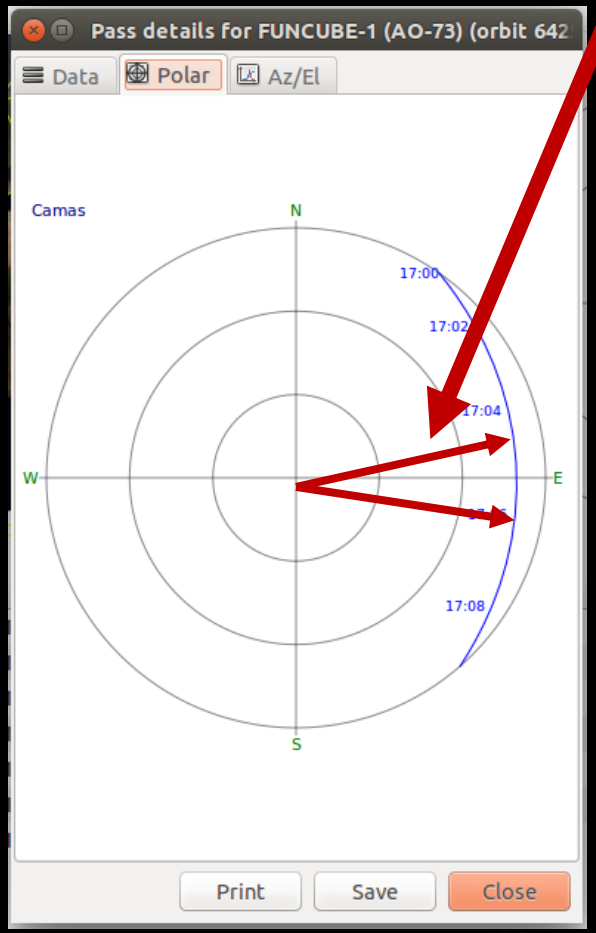


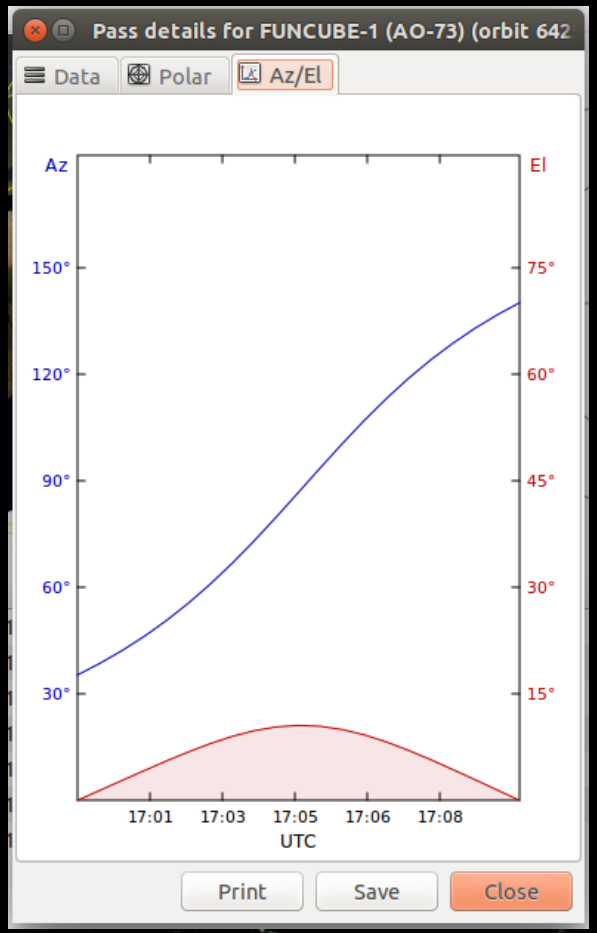
AOS	LOS	Duration	Max El	AOS Az	LOS Az
2015/02/08 03:58:45	2015/02/08 04:09:52	00:11:06	14.23°	115.73°	4.71°
2015/02/08 05:33:16	2015/02/08 05:46:52	00:13:36	76.21°	169.41°	346.14°
2015/02/08 07:12:17	2015/02/08 07:22:01	00:09:43	8.19°	228.45°	321.22°

Low Pass in the East at 30 mW

2 frames with 2 receivers 2 antennas







Two 4 Element Yagi Antennas

East at 30° alt & west at 30° alt

High Pass at 30 mW

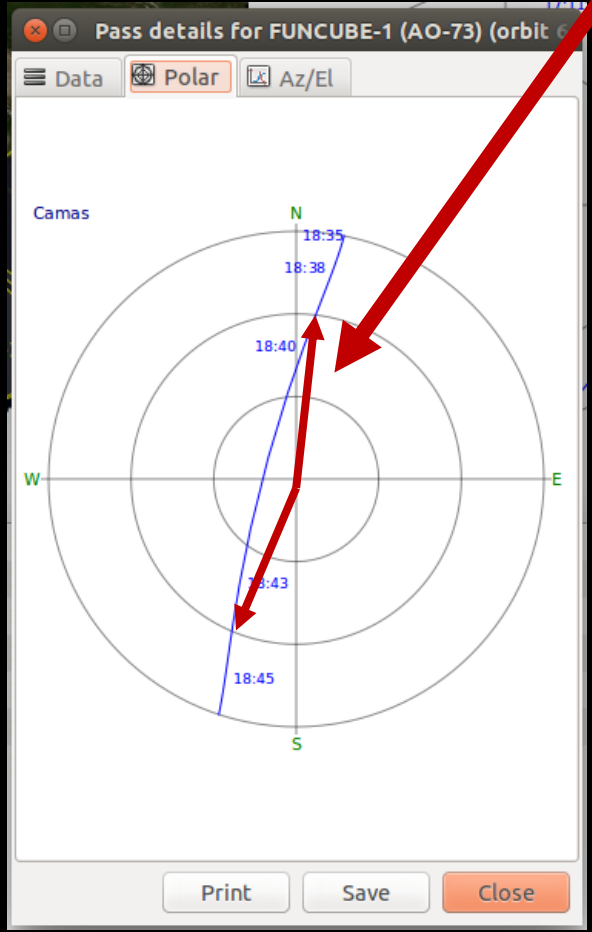
46 frames with 2 receivers 2 antennas

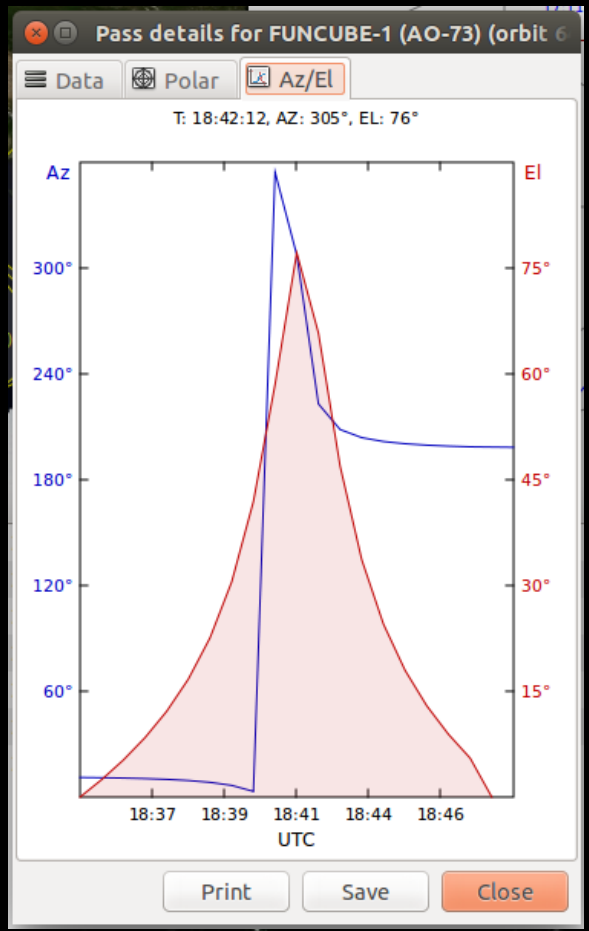
Pass details for FUNCUBE-1 (AO-73) (orbit 6

Data | Polar | Az/El

Time	Az	El	Range	Footp
2015/02/07 18:35:39	11.16°	-0.00°	2928	5491
2015/02/07 18:36:18	11.03°	2.48°	2659	5482
2015/02/07 18:36:56	10.82°	5.26°	2390	5474
2015/02/07 18:37:35	10.52°	8.43°	2123	5465
2015/02/07 18:38:14	10.08°	12.17°	1858	5456
2015/02/07 18:38:53	9.42°	16.74°	1597	5447
2015/02/07 18:39:31	8.40°	22.60°	1343	5438
2015/02/07 18:40:10	6.66°	30.53°	1102	5430
2015/02/07 18:40:49	3.27°	41.91°	885	5421
2015/02/07 18:41:28	354.42°	58.53°	715	5412
2015/02/07 18:42:06	307.53°	77.18°	632	5403
2015/02/07 18:42:45	223.01°	65.80°	669	5395
2015/02/07 18:43:24	208.49°	46.94°	810	5387
2015/02/07 18:44:03	203.88°	33.65°	1012	5379
2015/02/07 18:44:41	201.69°	24.53°	1246	5371
2015/02/07 18:45:20	200.43°	17.96°	1496	5363
2015/02/07 18:45:59	199.63°	12.94°	1756	5356
2015/02/07 18:46:38	199.08°	8.90°	2020	5349
2015/02/07 18:47:16	198.69°	5.52°	2288	5342
2015/02/07 18:47:55	198.40°	2.60°	2558	5336

Print | Save | Close





Upload Ranking of 830 Submitters

We should like to thank all the groups and individuals who have uploaded data to the FUncube data warehouse.

The following list gives the site names of those who have uploaded the most data frames:

Key: Within 1 week, within 2 weeks, greater than 2 weeks

Site Id	Count	Position
g0mjw	291648	1
OM3BC	249343	2
KC0BMF	196223	3
HB9MFL	174654	4
VK5HI	173182	5
SV2CPH	14812	142
w5sxd	14615	143
AD7MQ	14305	144
WA9ONY	14230	145
JA1GDE	14145	146
M0GBZ	13964	147
KB5WIA	13856	148
NC7V	13350	149

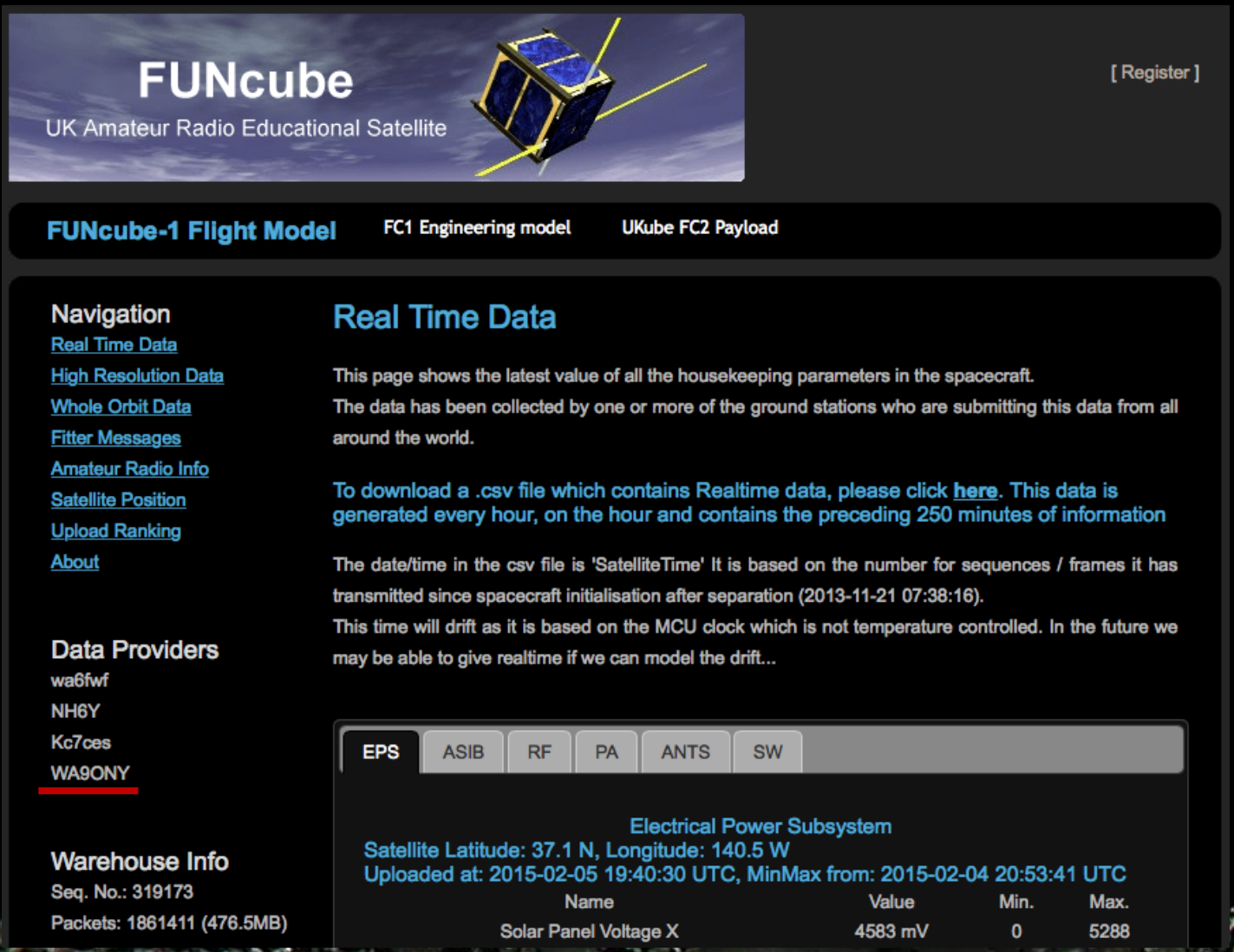
Started Jan. 2015

2015-4-5

http://warehouse.funcube.org.uk/ranking.html;jsessionid=6DA4D8E9F7793341F94C57A9F23AFE1E?satelliteId=2

Real Time Data

4 data providers for Seq. No.: 319,173



http://warehouse.funcube.org.uk/realtime.html?satelliteId=2

NH6Y 4,147.4 km Distance from WA9ONY

NH6Y Hawaii

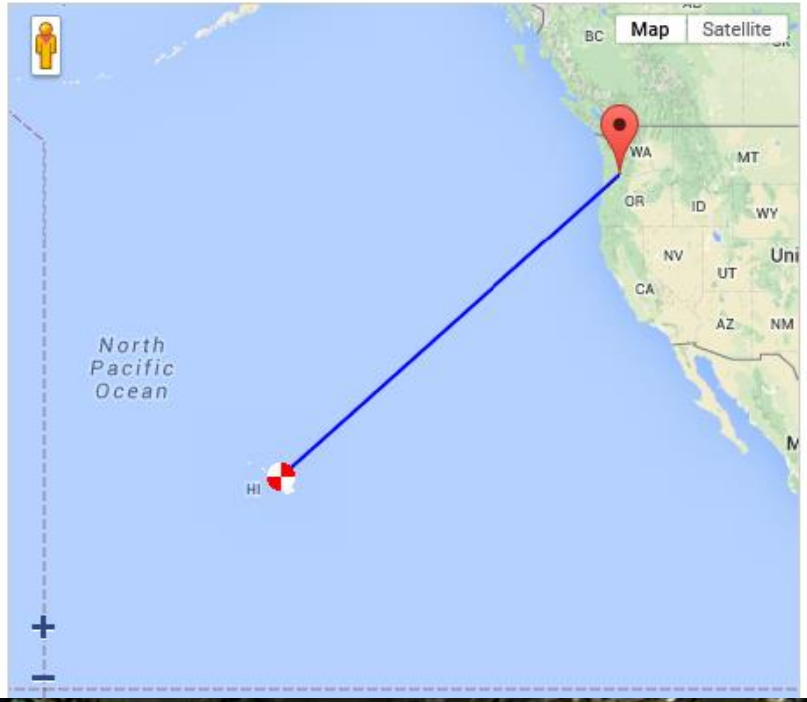
THOMAS K WORTHINGTON
1035 NAALAE RD
KULA, HI 96790
USA

Email: Use mouse to view..

Ham Member Lookups: 19997 Label

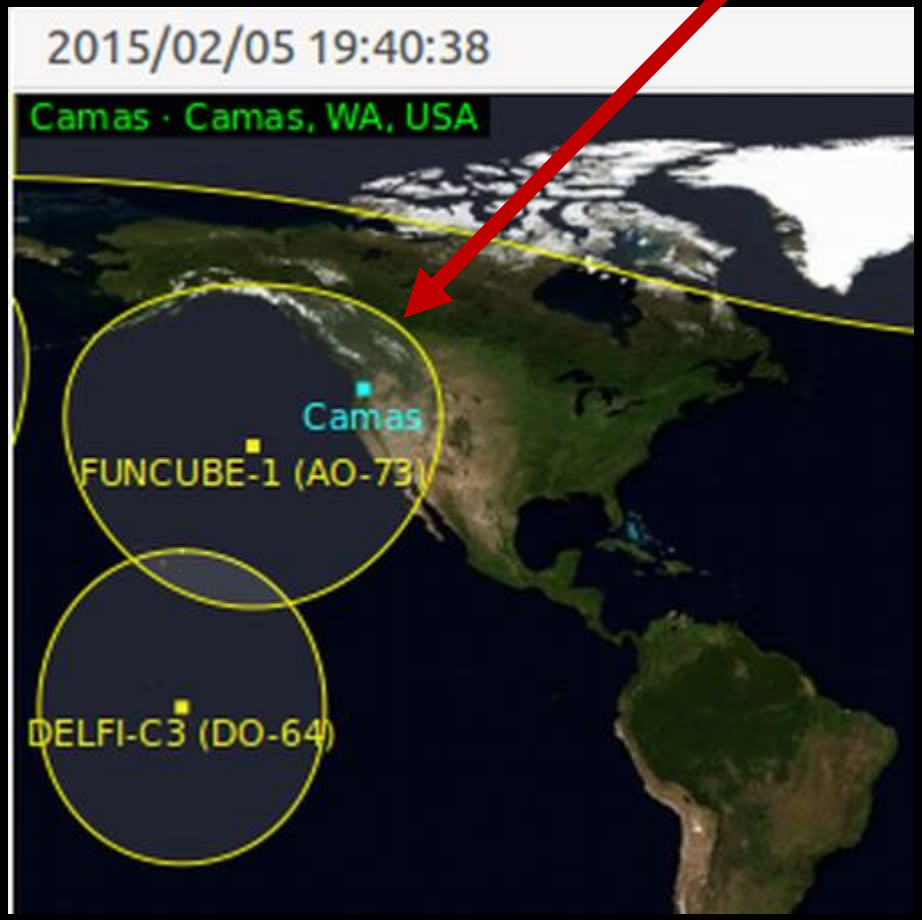
Biography | Detail | Logbook 9 | Log a NEW contact with NH6Y...

Lookups	19997 (28890)
QRZ Record#	1786998
QRZ Admin	NH6Y
Date Joined	2009-01-28 22:59:17
Last Update	2014-12-10 21:19:41
Class	E
Effective	2011-08-12
Latitude	20.756000 (20° 45' 21" N)
Longitude	-156.342000 (156° 20' 31" W)
Grid Square	BL10ts
Geo Source	User supplied
US State	Hawaii
US County	Maui
Bearing	239.6° WSW (from WA9ONY)
Distance	2577.1 mi (4147.4 km)



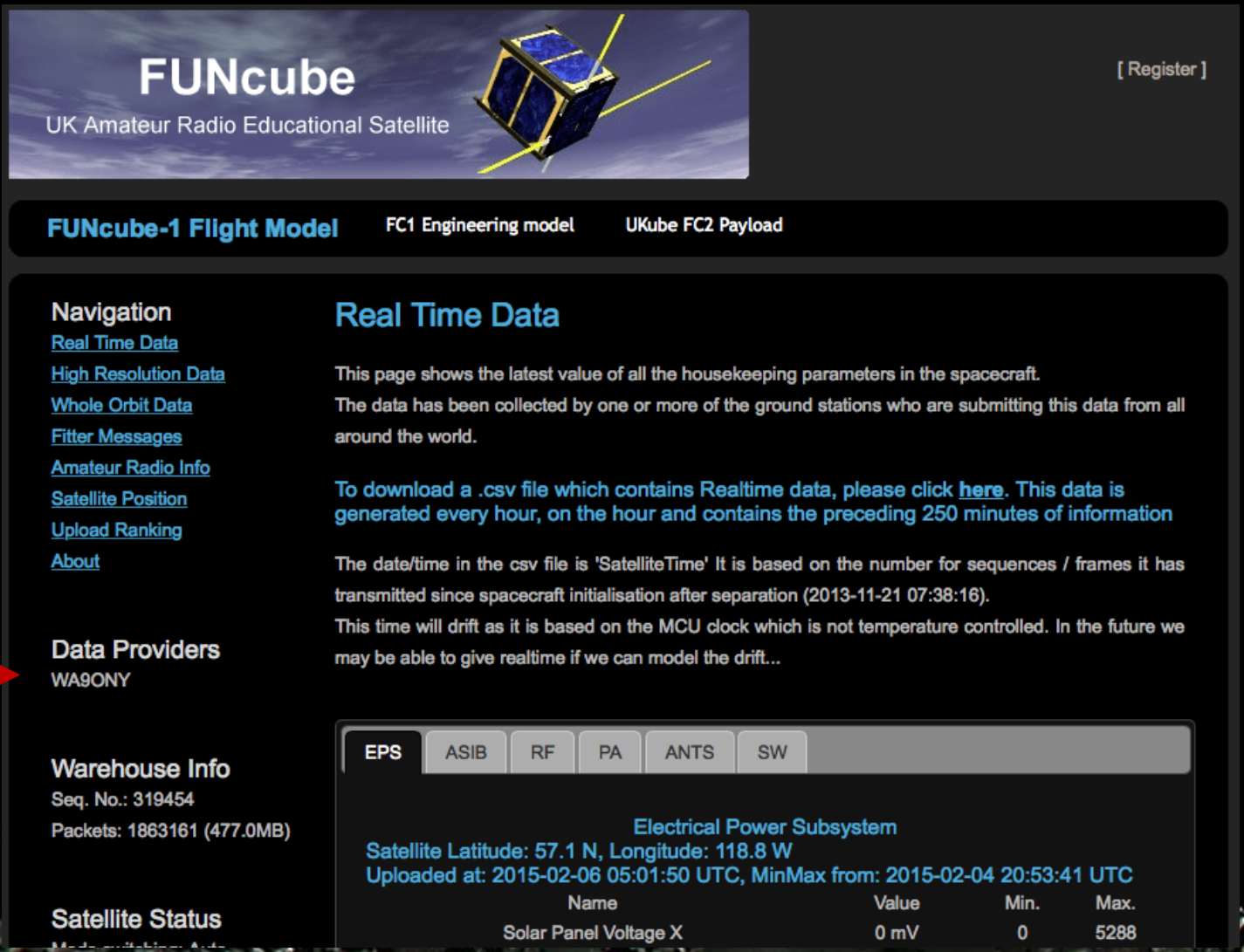
FUNcube-1 Footprint

Both WA9ONY & NH6Y see FUNcube-1 TLM at the same time



Real Time Data

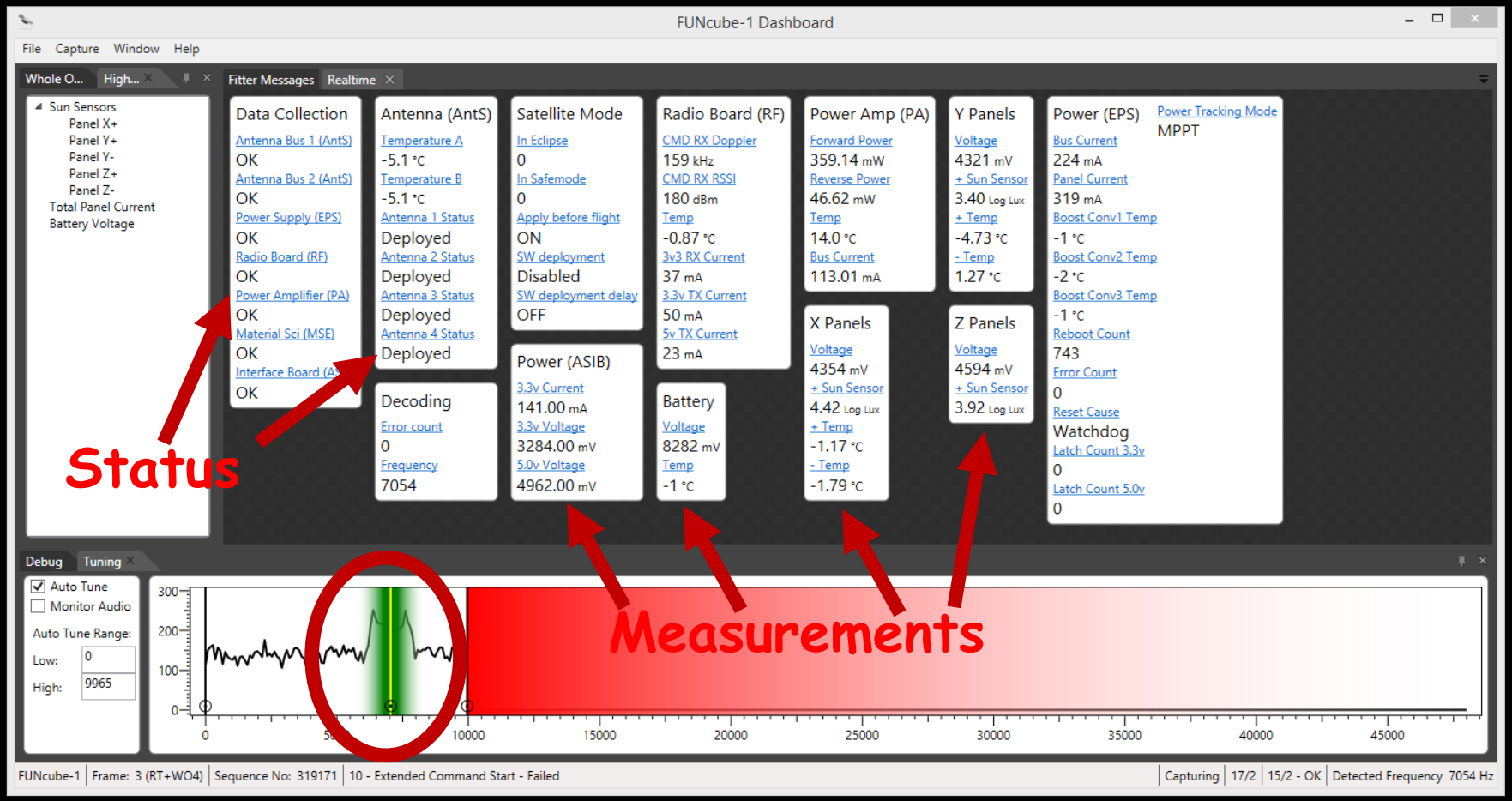
WA9ONY only data provider for Seq. No.: 319,454



http://warehouse.funcube.org.uk/realtime.html?satelliteId=2

58 Telemetry Channels

FUNcube-1 Dashboard decodes the TLM BPSK with FEC



58 Telemetry Channels

- Real-time measurements every five seconds
- High resolution data
  - Satellite stores last 60 real-time measurements
- Whole orbit data
  - Satellite stores 104 measurements
  - One measurement per minute

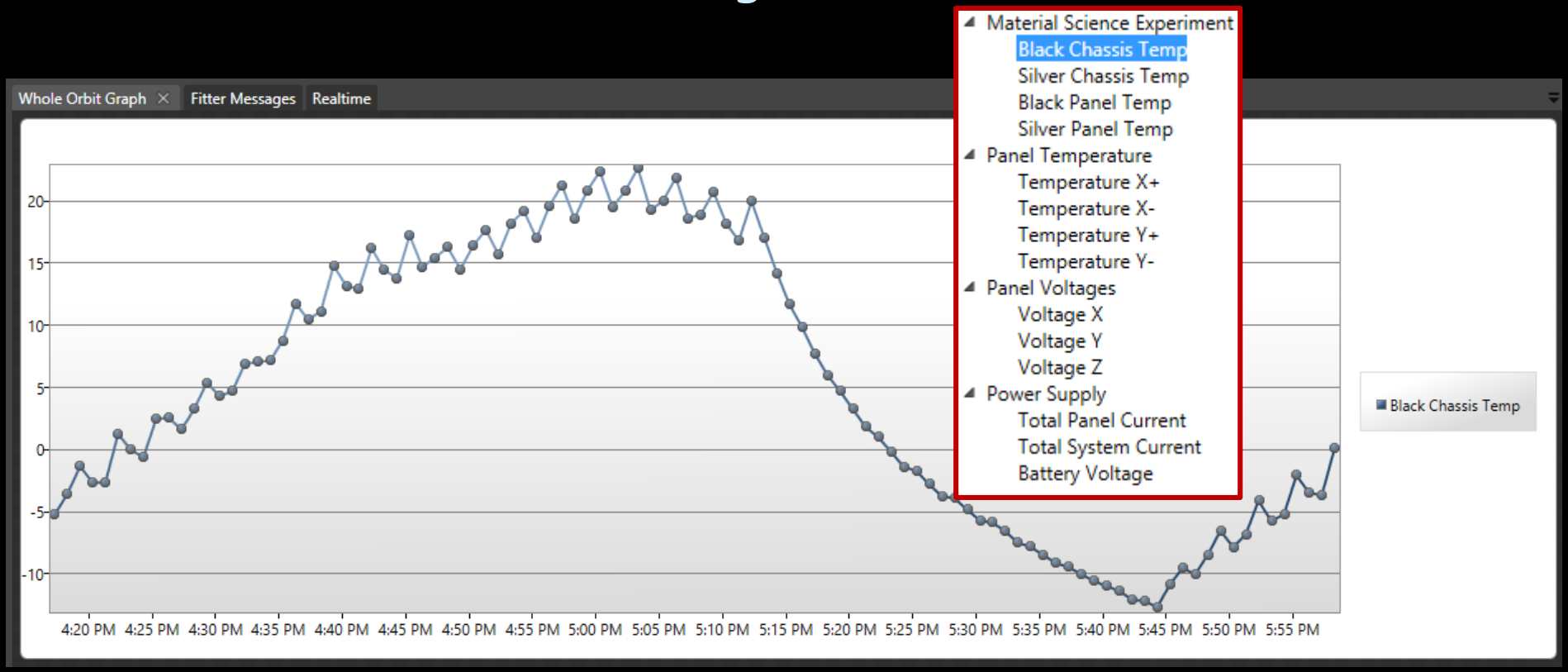
Telemetry Transmission Organization

2 minutes for sequence, 5 seconds per frame

- Sequence is composed of 24 frames
- Frame is composted of 256 bits of data after decode
  - Frame always contains real-time data
- Sequence structure
  - 12 whole orbit frames WO1 to WO12
  - 1 high resolution frame HR1
  - 3 Fitter messages FM1 to FM3
  - 1 high resolution frame HR2
  - 3 Fitter messages FM4 to FM6
  - 1 high resolution frame HR3
  - 3 Fitter messages FM7 to FM9

14 Whole Orbit Data Sets

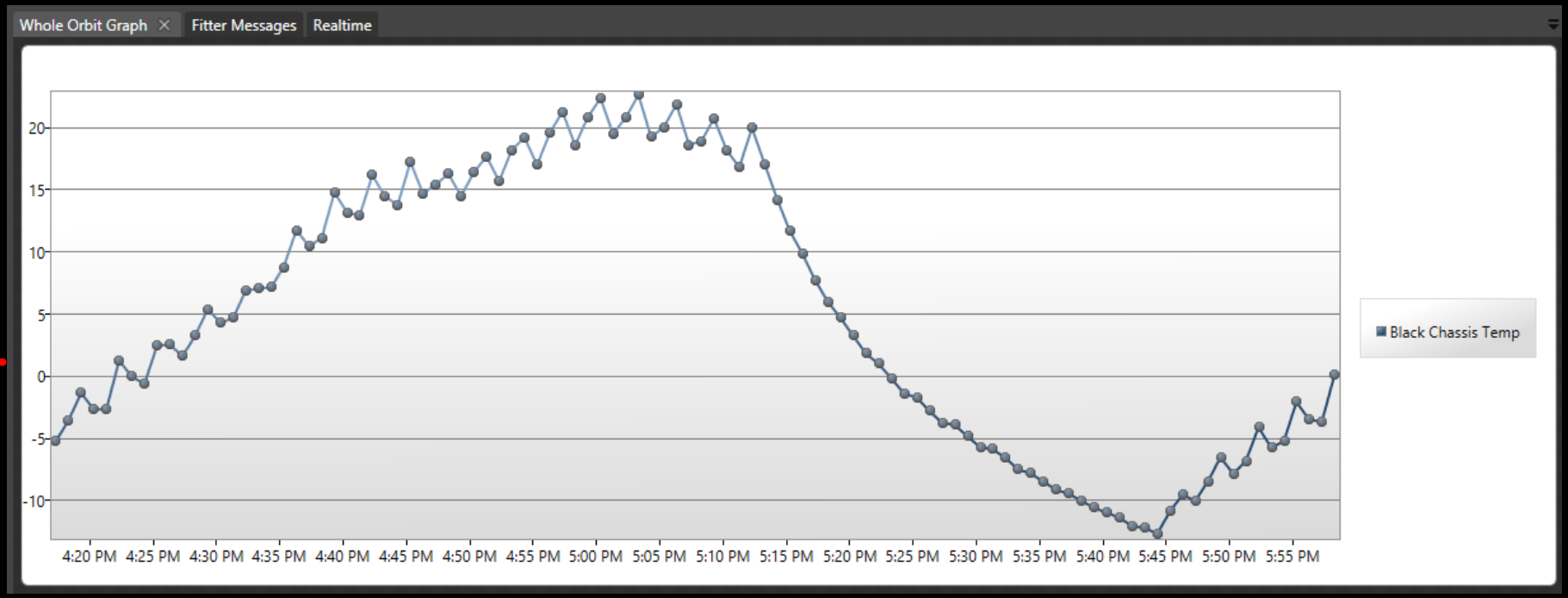
104 Measurements During 1 Orbit, 1 Minute Intervals



Satellite Saves 1 Orbit of Data Onboard

Black Chassis Temp Whole Orbit Graph

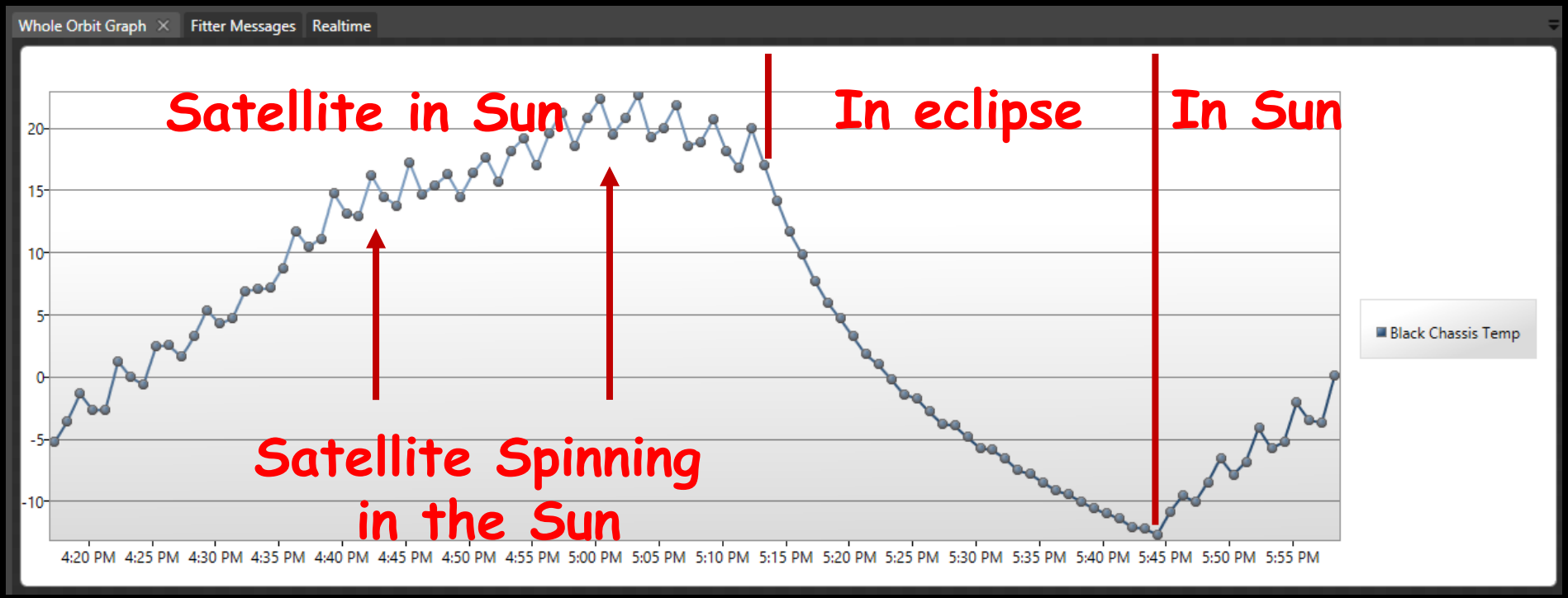
Measurements During 1 Orbit, 1 Minute Intervals



FUNcube-1 Data Received by WA9ONY 2015-2-5

Black Chassis Temp

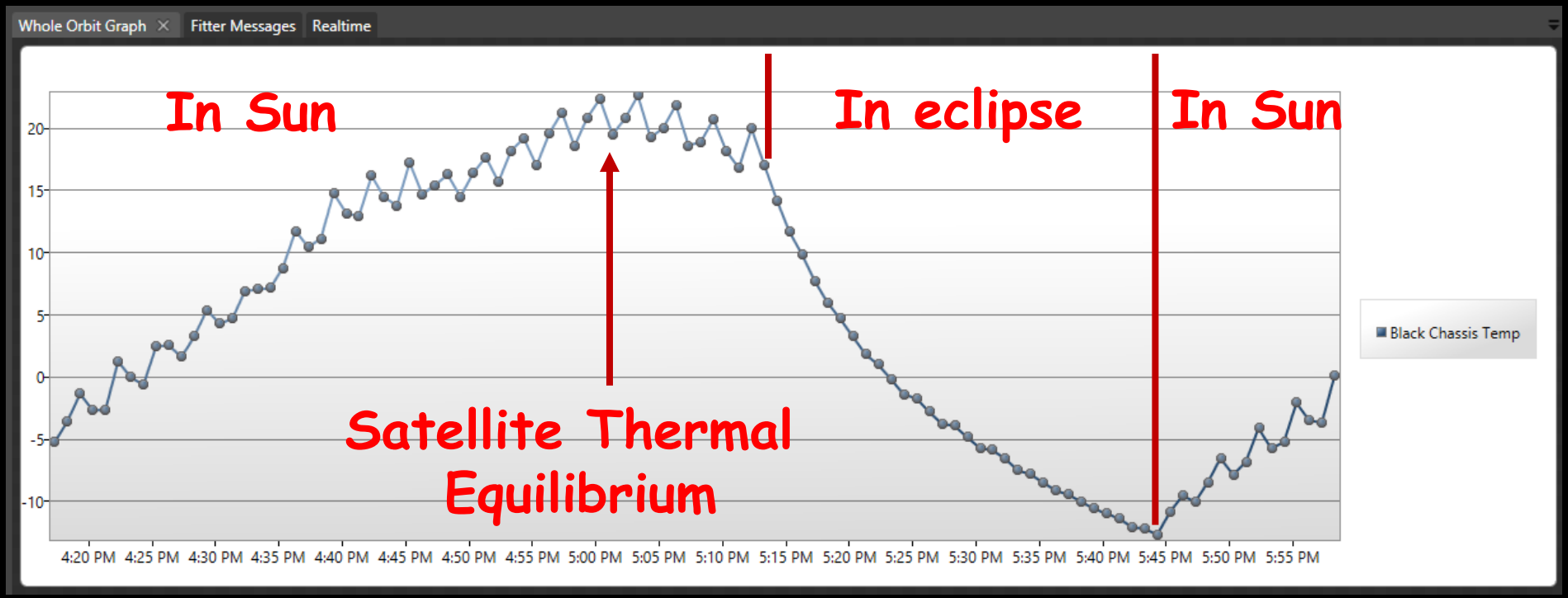
Whole Orbit Graph



FUNcube-1 Data Received by WA9ONY 2015-2-5

Black Chassis Temp

Whole Orbit Graph

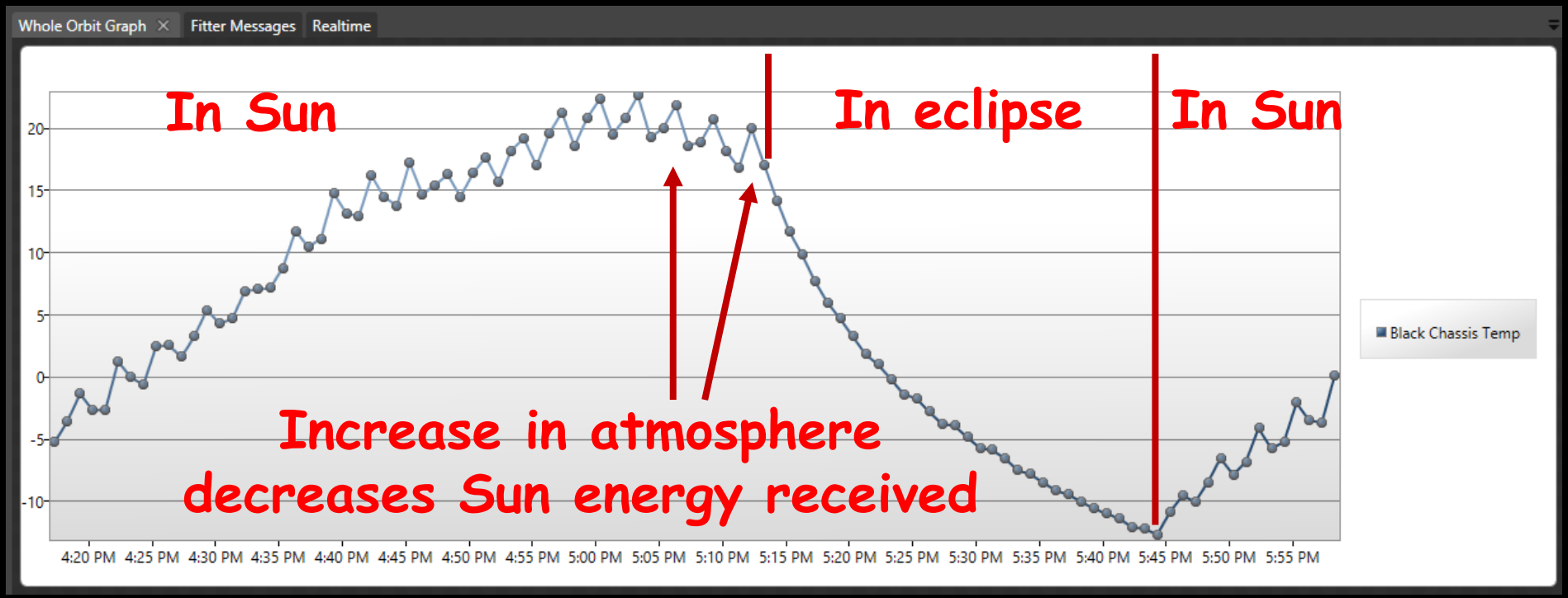


Sun Energy Received Equals Energy Radiated into Space

FUNcube-1 Data Received by WA9ONY 2015-2-5

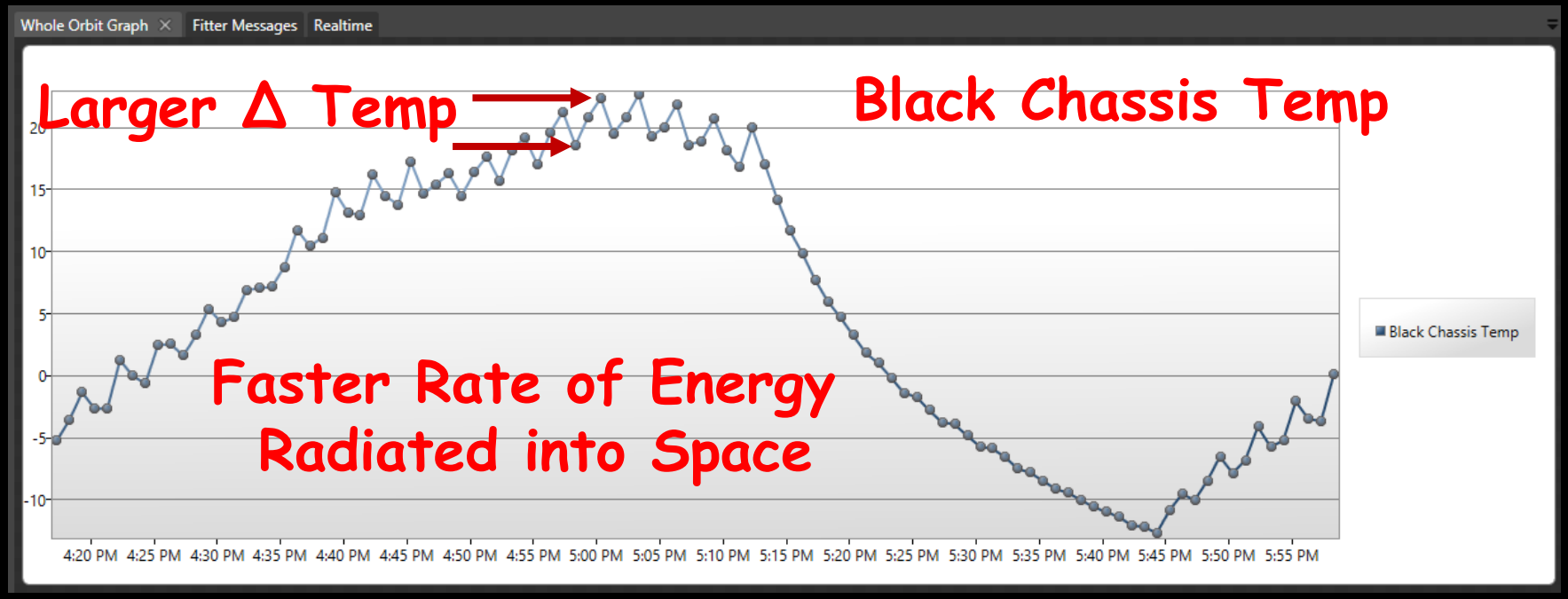
Black Chassis Temp

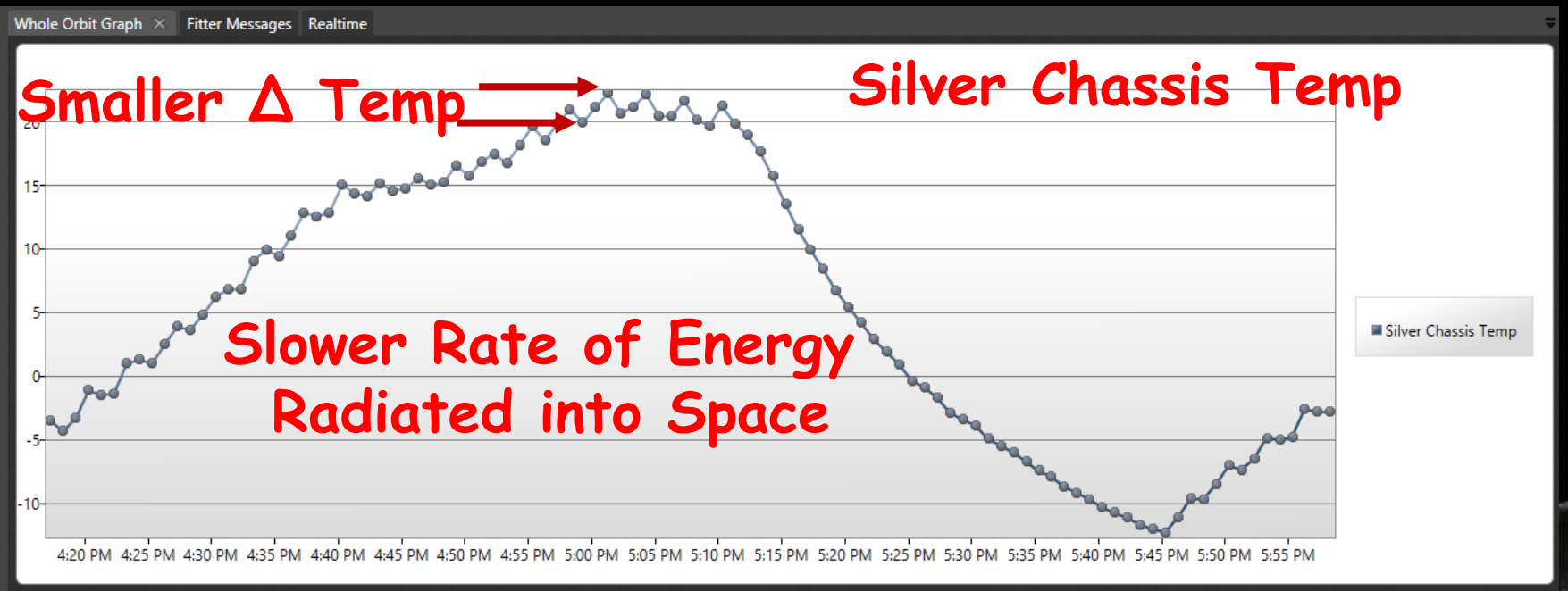
Whole Orbit Graph



FUNcube-1 Data Received by WA9ONY 2015-2-5

Temperature





Solar Panel Voltage Y

Whole Orbit Graph

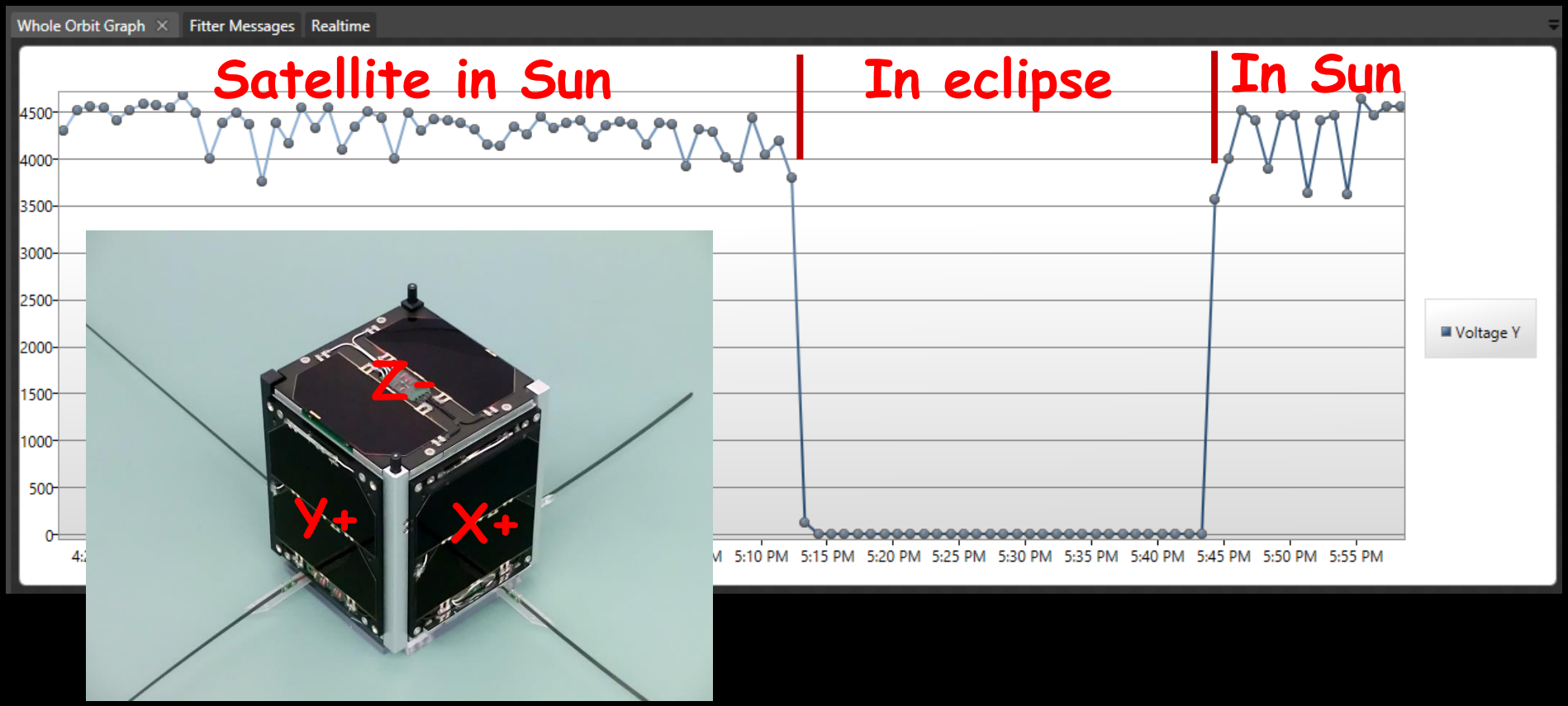


Image Credit: Wouter Weggelaar PA3WEG
FUNcube-1 Data Received by WA9ONY 2015-2-5

Fitter Messages (FM)

9 FM 200 characters each transmitted by the satellite

Receive Time	Sequence	Packet	Message
2/5/2015 6:02:01 PM	319123	FM9	2 d * V E & & " & e395m 94e73e 94e73e 94e73e 94e73e 94e73e072c541c 94e73e 94e73e 94e73e 94e73e 94e73e072c541c 94e73e 94e73e 94e73e
2/5/2015 6:01:49 PM	319123	FM7	For details of the education resources check www.funcube.org.uk/education-outreach.
2/5/2015 6:01:38 PM	319123	FM6	Hello world, this is 5JW from Central Walker primary in Newcastle upon Tyne, UK
2/5/2015 6:01:32 PM	319123	FM5	The 73 on 73 Award is organised by by Paul N8HM see http://amwat-uk.org/2014/08/18/73-on-73-award-announcement
2/5/2015 6:01:26 PM	319123	FM4	If you can read this you are receiving FUNcube fine. Please register with the FUNcube data warehouse at http://api.funcube.org.uk/
2/5/2015 6:01:15 PM	319123	FM3	AMSAT-UK Colloquium 24-26 July 2015, Guildford, UK
2/5/2015 6:01:09 PM	319123	FM2	Call all schools - if you would like a Fitter message uploaded please email operations@funcube.org.uk
2/5/2015 6:01:03 PM	319123	FM1	The main FUNcube tech team is: Dave G4DPZ, David G0MRF, Duncan M6UCK, Gerard Aalbers, Graham G3VZV, Jason G7OCD, Jim G3WGM, Howard G6LVB, Phil M6IPX, Wouter PA3WEG & Wouter Jan PE4WJ
2/5/2015 6:00:01 PM	319122	FM9	z 2 d * V E & & " & e395m 94e73e 94e73e 94e73e 94e73e 94e73e072c541c 94e73e 94e73e 94e73e 94e73e 94e73e072c541c 94e73e 94e73e 94e73e
2/5/2015 5:59:55 PM	319122	FM8	More information about this spacecraft, orbital details, etc an the telemetry decoder and dashboard can be downloaded from http://www.funcube.org.uk
2/5/2015 5:59:49 PM	319122	FM7	For details of the education resources check www.funcube.org.uk/education-outreach.
2/5/2015 5:59:38 PM	319122	FM6	Hello world, this is 5JW from Central Walker primary in Newcastle upon Tyne, UK
2/5/2015 5:59:26 PM	319122	FM4	If you can read this you are receiving FUNcube fine. Please register with the FUNcube data warehouse at http://api.funcube.org.uk/
2/5/2015 5:59:15 PM	319122	FM3	AMSAT-UK Colloquium 24-26 July 2015, Guildford, UK
2/5/2015 5:59:09 PM	319122	FM2	Call all schools - if you would like a Fitter message uploaded please email operations@funcube.org.uk
2/5/2015 5:59:03 PM	319122	FM1	The main FUNcube tech team is: Dave G4DPZ, David G0MRF, Duncan M6UCK, Gerard Aalbers, Graham G3VZV, Jason G7OCD, Jim G3WGM, Howard G6LVB, Phil M6IPX, Wouter PA3WEG & Wouter Jan PE4WJ

Send school messages to operations@funcube.org.uk

WA9ONY Receiving Equipment

SDR with a 4 element Yagi antenna

- Receiver: Airspy software defined radio (SDR)
- Preamp: Mini-Circuits ZFL-500LN+ Amplifier 24 db.
- Filters: after the preamp
  - Mini-Circuits VHF-145+ 140 to 1150 MHz high pass filter.
  - Mini-Circuits BLP-200 190 MHz low pass filter.
- Antenna: 4 elements Yagi Arrow II Portable Antenna Model 146-4 II.

WA9ONY Receiving Software

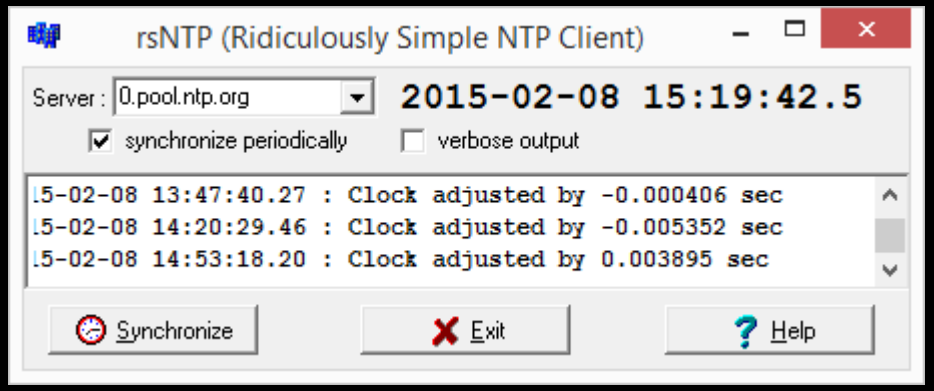
i7 core laptop with Windows 8.1

- SDR# V1.0.0.1332
- Behringer XENYX 302 USB audio mixer to USB
  - Audio line input
- FUNcube Telemetry Dashboard v848

WA9ONY Software

i7 core laptop with Windows 8.1

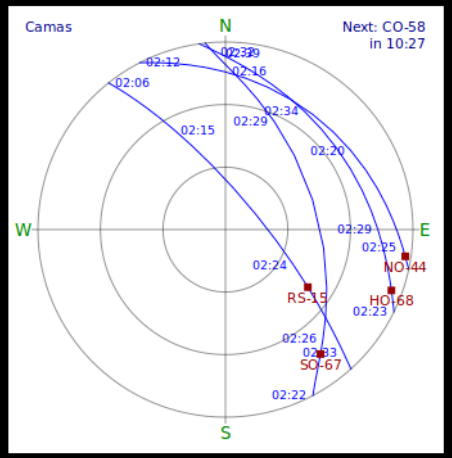
- Ridiculously Simple NTP Client by Wolfgang "Wolf" DL4YHF for time keeping



- Python 2.7.6 and Python Imaging Library (PIL V1.1.7) script taking screen captures every one second.

www.stargazing.net/david/satellites/2meters.html

ISS & Satellites on 2 Meters



Summary

Listening to the International Space Station (ISS) and satellites in orbit with a focus on radio signals in the amateur radio 2 meter band comprising frequencies from 144.000 MHz to 148.000 MHz.

The satellite radio signals are classified into two groups: voice and data tranmissions.

2 Meters Band Satellite Plan

ARRL Band Plan

- 144.300-144.500 OSCAR (satellite)
- 145.800-146.000 OSCAR (satellite)