SSETI Express

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Phase E

400-800 THz Downlink Report

Issue: 1.1

Date: 14-11-2015

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With special thanks to ESRANGE and the Swedish Space Corporation in recognition of their invaluable support

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Document change record

Issue	Change	By	Date
1	New Document	Neil Melville-Kenney	27/10/2015
1.1	Addition of Annex 1	Neil Melville-Kenney	14/11/2015

Table of content

1 Introduction & Objectives

This document describes the activities of a campaign to acquire downlink radiation from the SSETI Express satellite at 400-800 THz (visual light range). This campaign was executed exactly ten years after the launch of SSETI Express, at the facilities of ESRANGE, Kiruna (Sweden), by various members of the original project team.

2 Resources

2.1 Team

The Arctic Downlink Team was composed of the individuals:

Name	Affiliation	User Name	Callsign
Karl Kaas MScEE, CEO	Think Outside Space Systems ApS	OBC_Karl	OZ2KK
Neil Melville-Kenney MPhys	European Space Agency	ESA_Neil	PA9N
FH-Prof DI Dr Lars Mehnen	FH Technikum Wien	INFRA_Lars	OE3HMW
Graham Shirville FBIS FRSA	AMSAT-UK	AMSAT_Graham	G3VZV
Sascha Tietz MSc	Apple Inc.	PROP_Sascha	KJ6LIA

2.2 Facilities & Requirements

In order to maximise chances of successful signal acquisition the following considerations were accounted for regarding campaign facilities, location and timing:

- The location should experience extremely low levels of light pollution,
- High latitudes are preferred to maximise the number of satellite passes during pre-dawn and post-dusk (such that the satellite is sunlit while the ground is in eclipse),
- Facilities shall provide suitable accommodation and a modern working environment within short walking distance of the observation area,
- Facilities shall allow campaign participants to execute their campaign activities, including suitable refreshment, at any time of the day or night,
- The facility shall be accessible by all campaign participants.

After all of these considerations were taken into account, ESRANGE, Kiruna was selected as the primary campaign location.

2.3 Equipment

Campaign equipment was identified by individual participants in accordance with their specific experience, skill-sets and inventory. A non-exhaustive list is given in table 2:

Item		Rationale
Infrastructure		
Laptop Computers (x7)		For general campaign execution and data analysis
Software:	Nova	Satellite pass predictions
	Heavens Above	Satellite pass visualisation
	Gpredict	Real-time satellite position relay
	Kstars	Astronomical alignment
	Plane Finder HD	Alternative hypotheses rejection
	Celestrak	Source of satellite Two-Line Elements (TLE)
	Emerald Time app	Time-keeping
Cold weather footwear & clothing		Avoidance of premature participant termination
Portable Optical Groundstation (POG)		
* Canon EOS 6D		Main optical receiver
Canon EF 16-35mm f/4L IS USM		Low-gain variable-ultra-wide angle optical antenna
Canon EF 50mm f/1.4 USM		High-gain wide-angle optical antenna
* Canon EF 100mm f/2.0 USM		High-gain mid-angle optical antenna
Canon EF 24-105mm f/4.0L IS USM		Low-gain variable general purpose optical antenna
Canon EF 70-200mm f/2.8L IS USM II		Mid-gain variable-narrow-angle optical antenna
Canon EF 2.0x Extender III		Doubles resolvable resolution at cost of gain
* Canon BG-E13 battery grip		Power supply for main receiver
* Canon LP-E6 battery (x2)		Power supply for main receiver
* Canon RS-80N3		Wired remote control for main receiver
Canon RC-6		Wireless remote control for main receiver
* Tripod (metal, low-vibration)		Directional mount for receiver and antenna
Assorted other cameras		Backup downlink channels

** Utilised configuration for all passes Alpha – Kilo, shooting in RAW.*

Other configurations may be utilised in extended campaign (see section 9).

3 Campaign Plan

3.1 Logistics

Campaign participants travelled to Kiruna, Sweden, from their various source locations throughout Sunday 25 October 2015. Due to logistical considerations the pre-campaign planning meeting took place in the *Bishop's Arms* in Kiruna commencing at 23:42 CET upon the arrival of the final participant.

Upon completion of preparatory activities, the campaign proper commenced with the transfer of the campaign team to the ESRANGE facilities on the morning of 26 October 2015, by virtue of twin redundant automotive capabilities.

Target acquisition passes were parameterised throughout each of the ground eclipse periods from sunset on 26 October 2015 until sunrise on 28 October 2015, as per section 3.2. Working sessions were conducted in between passes for the analyses of data, preparation of subsequent passes, SSETI Express anniversary nostalgia sessions, and suitable celebratory refreshment.

Upon completion of the campaign participants returned to their respective source locations on 28 October 2015.

3.2 Target Passes

Using the latest available TLEs from JSpOC, we considered the following pass opportunities, where the maximum elevation was greater than 20 degrees and the spacecraft was potentially visible. (I.e. Sunlit but with the observers in darkness.) TCA (Time-of Closest-Approach) times and maximum elevations are shown.

26th October 2015

Alpha	16:16 UTC 42 degrees
Bravo	17:54 UTC 58 degrees
Charlie	19:31 UTC 27 degrees

27th October 2015

Delta	00:19 UTC 25 degrees
Echo	01:56 UTC 55 degrees
Foxtrot	03:34 UTC 50 degrees
Golf	16:55 UTC 68 degrees
Hotel	18:32 UTC 43 degrees
India	20:09 UTC 21 degrees

28th October 2015

Juliet	00:57 UTC 32 degrees
Kilo	02:35 UTC 82 degrees
Lima	04:13 UTC 32 degrees

Keplerian elements

Satellite name	SSETI EXPRESS
Catalog number	28894
Epoch time	15298.104168480
Element set	999
Inclination	97.82570000
RAAsc. Node	114.80040000
Eccentricity	0.00158810
Arg. of perigee	253.23400000
Mean anomaly	225.84240000
Mean motion	14.61222613
Decay rate	0.00000418
Epoch orbit #	53255

4 Execution

This shows the outcome of each of the passes

26th October 2015

Alpha 16:16 UTC 42 degrees – weather cloudy

Bravo 17:54 UTC 58 degrees – weather cloudy

Charlie 19:31 UTC 27 degrees – weather cloudy

27th October 2015 – The 10th Anniversary of the launch of SSETI Express

Delta 00:19 UTC 25 degrees
The team attended the ESRANGE balloon launch area – code name *Colin*. The ambient temperature was -6 Celsius. The sky was clear but the moon was full and approx. 25 degrees above the horizon. Optical data was acquired: exposure times 4s, f/2, ISO1000, configuration as per section 2.3.

Echo 01:56 UTC 55 degrees
The team attended *Colin*. The weather remained similar to the previous pass but the wind speed was much increased. The moon remained full and very bright. The team positioned themselves in the moon shadow of the last building on the site which, mercifully, also acted as a windbreak. Optical data was acquired: exposure times 3.2s, f/2, ISO1600, configuration as per section 2.3.

Foxtrot 03:34 UTC 50 degrees – the spacecraft track passed close to the moon
The team were not conscious during this pass.

Golf 16:55 UTC 68 degrees – weather cloudy

Hotel 18:32 UTC 43 degrees – weather cloudy

India 20:09 UTC 21 degrees – weather cloudy

28th October 2015

Juliet 00:57 UTC 32 degrees
The team attended *Colin*. There was patchy cloud, but it was well-timed for TCA and good optical data was acquired: exposure times 4s, f/2.8, ISO1600, configuration as per section 2.3.

Kilo 02:35 UTC 82 degrees
The team attended *Colin*. There was patchy cloud, which was ill-timed for TCA and poor optical data was acquired: exposure times 4s, f/2, ISO1000, configuration as per section 2.3.

Lima 04:13 UTC 32 degrees – the spacecraft track passed close to the moon and the weather was cloudy. The team were not conscious during this pass.

5 Results

5.1 Delta Pass

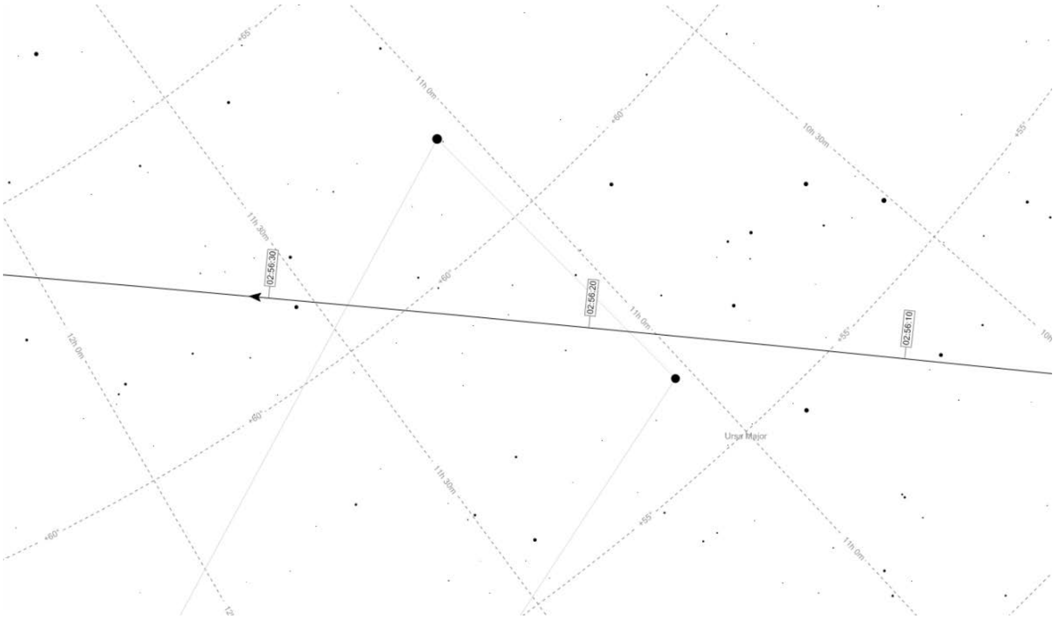
After careful analysis of the optical data set collected during *Delta* pass several satellite trails were identified, but none were comparable to the pass predictions.

5.2 Echo Pass

During *Echo* pass team member FH-Prof DI Dr Lars Mehnen reported visual acquisition of a brief satellite trail/flare comparable to the pass prediction. No other participants were privy to this, however, good optical data was collected by the POG.

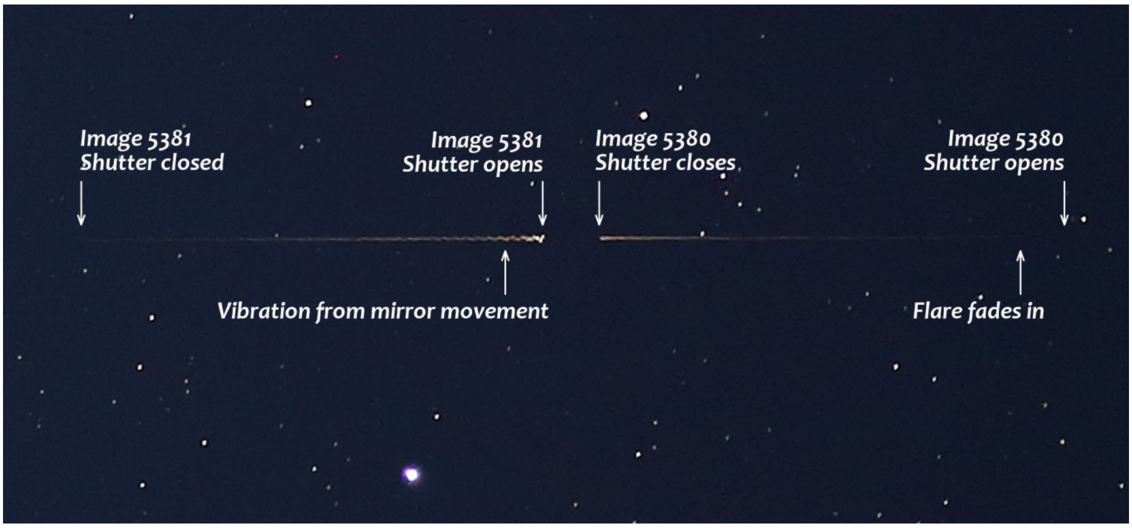
This is a Kstars representation of the sky presented to the campaign team in the direction of TCA. Data from the area outlined, in the constellation of Ursa Major, was captured by the POG:

The following shows the pass prediction from *Heavens Above*, detailing the passage of SSETI Express across Ursa Major:



The following figure is a two-image composite (IMG_5380 and IMG_5381) showing the potential satellite trail, or flare, captured by the POG during *Echo* pass, centred on 01:56:18 UTC. Canon Digital Image Optimisation (using empirical MTF lens data) has been applied at 100% to mitigate chromatic aberration and coma effects, and spherical distortion has been corrected.

The following figure is a cropped and rotated version of the above, with the flare image details explained. Note that mirror-lockup was not activated in the POG due to an incompatibility with the remote control unit that was utilised. This flare can be referred to as *Echo-01*.



5.3 Juliet Pass

After careful analysis of the optical data set collected during *Juliet* pass several satellite trails were identified, but none were comparable to the pass predictions.

5.4 Kilo Pass

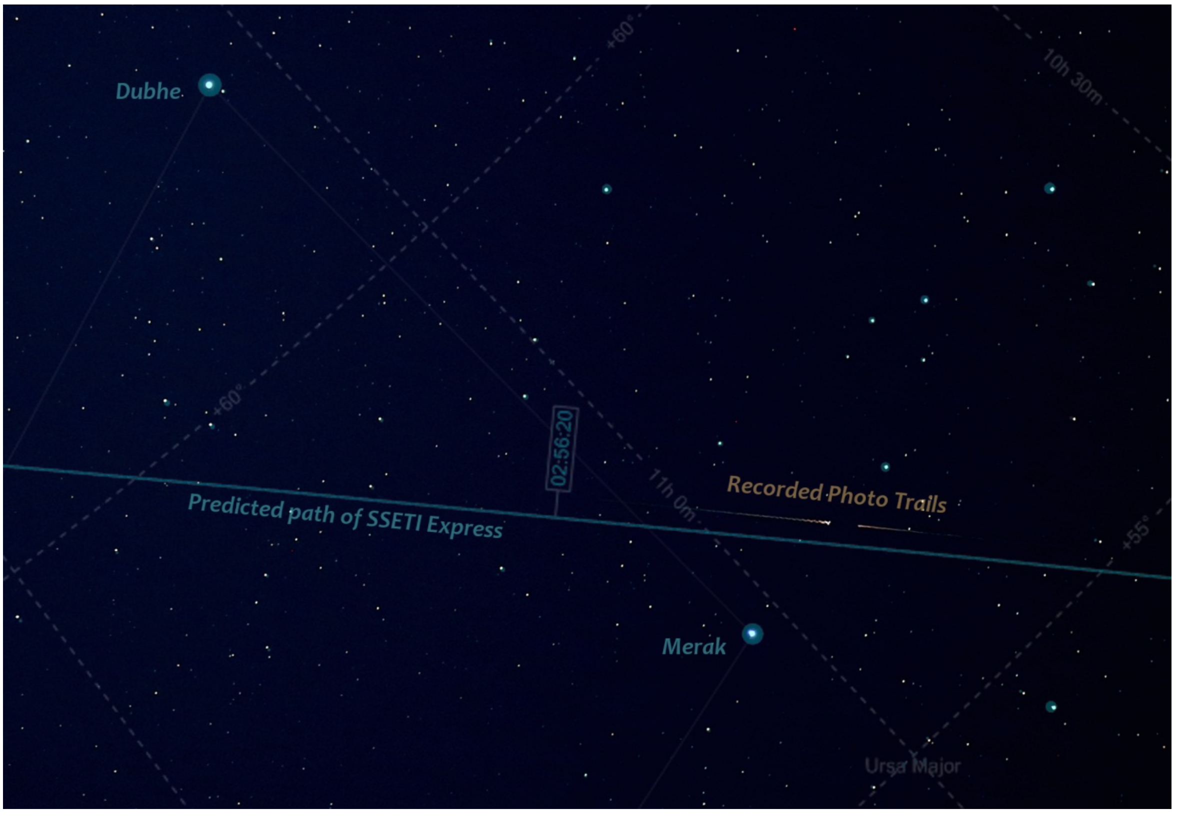
Patchy cloud was badly timed during this pass, obscuring during TCA. Optical data was still received with visible stars, but quality was poor and no satellite trails were identified.

6 Analysis

6.1 Data interpretation – Echo Pass

6.1.1 Prediction and Measurement Comparison

The following figure shows an overlay of the Heavens Above pass prediction on the composite satellite trail/flare *Echo-01*.



a) ***Direction Comparison***
The captured trails are parallel to the predicted path within detectable accuracy.

b) ***Time Comparison***
After correction of the camera clock offset to GPS time (+/- 1 second), the shutter opening timestamp on the start of image 5381 is found to be 01:56:18 UTC. The exposure time was 3.2 seconds, leading to a shutter close time of 01:56:21.2 UTC. By length comparison on the overlay image above, this corresponds to a predicted time at that azimuth of 01:56:19.7. The delta between the measurement and prediction is therefore found to be 1.5 seconds, which is well within our combined error margins.

c) Speed Comparison:

The overlay image above has aligned a polar grid over our optical data, as such direct comparison can be made between the extents of that grid and the observed data, simply by counting pixel distances. (Note: degrees of elevation should be used for baseline measurement, since they are invariant throughout the sky whether on polar coordinates or zenith coordinates.)

5 degrees of polar elevation =	$(888^2+962^2)^{0.5}$	=	1309 pixels	(1)
Trail from image 5381 =	$(442^2+44^2)^{0.5}$	=	422 pixels	(2)
Angular length of trail =	5 * (2)/(1)	=	1.612 degrees	(3)
Angular length of trail in Radians =	(3) * Pi/180	=	0.0281 radians	(4)
Range to SSETI Express at 01:56:18 UTC		=	870 km	(5)
Trail length if SSETI Express =	(4) * (5)	=	24.47 km	(6) §
Exposure time of image 5381		=	3.2 s	(7)
Apparent speed if object is SSETI Express =	(5)/(6)	=	**7.648 km/s**	

§ Correction for true arc-centre negligible

Note that the timestamp of image 5381 is extremely close to TCA, just 12 seconds early, therefore the difference between apparent speed and actual speed is negligible, since the component in the range direction is almost zero.

The predicted result for a satellite in the orbit of SSETI Express is 7.507 km/s. The difference is well within our combined error margins.

d) Position Comparison

Using length comparisons as per (c), the visible elevation delta between the measured trail/flare and the predicted path is found to be 37 pixels, which corresponds to 0.14 degrees. This is well within our combined error margins.

6.1.2 Primary Hypothesis

Given the excellent agreement between our predictions and the measured signal, in terms of timing, placement, speed and direction, our preliminary hypothesis is that observation *Echo-01* was indeed a flare from SSETI Express, caused by sunlight reflecting off one face of the satellite, in particular the quite reflective solar cells.

We consider the evidence presented above to be sufficiently convincing that, once all credible alternative hypotheses have been excluded, the burden of proof lies upon the sceptic.

6.1.3 Alternative Hypotheses #1 - Airplane

Hypothesis: The detected visible moving object could be an airborne vehicle.

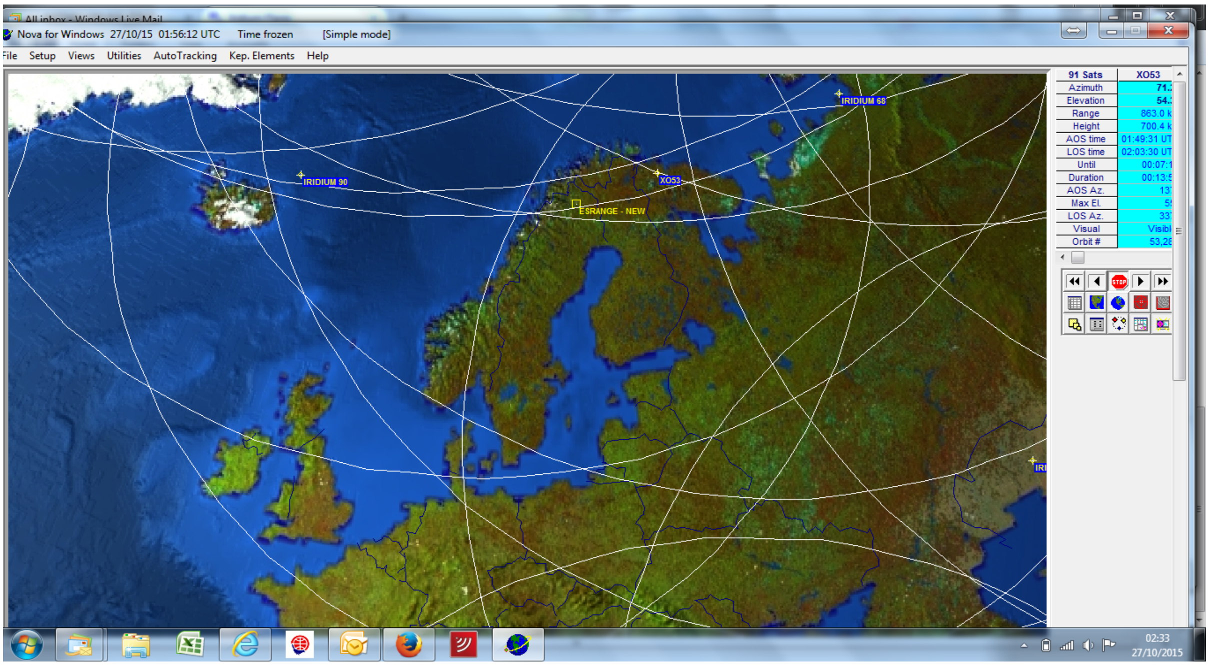
The maximum speed of airplanes is Mach 3 and the maximum altitude is 100,000 Feet (30,000m). Due to FAA regulations, and their European equivalents, airplanes have to signal red and white flashing lights. The footage of the detected object did not provide any hints of flashing lights or a longer light signature which should be seen, since the object did not change direction and therefore angle to the possible reflecting sun. The time (01:56:18 UTC) also rules out that a plane at the maximum level could reflect sunlight, since it is in the earth shadow at that time.

A further proof that it is not a registered airplane is the radar footage. As can be seen from the Plane Finder HD figure opposite, there were no planes in the area at the time. Checks undertaken the following day did show aircraft operating in the area, demonstrating that coverage exists in this location.

6.1.4 Alternative Hypotheses #2 – Iridium Satellite

Hypothesis: The observed flare, *Echo-01*, was from an Iridium satellite. Since Iridium satellites are well known to produce short flares in the optical range due to their antenna angles, shape and reflectivity, this is considered a credible hypothesis.

The actual location of all of the Iridium Satellites, at the precise moment of the detected flare, negates the possibility that the flare seen was produced by an Iridium satellite. See the following figure, which demonstrates that the nearest Iridium satellite was far out of visibility range at that moment, and nowhere near the elevation angle of the observed flare.



6.1.5 Alternative Hypotheses #3 – Meteorite

Hypothesis: The observed flare, *Echo-01*, was a meteorite burning up.

Meteorites are only visible as they enter the Earth's atmosphere and burn up due to compressive heating. For our purposes, let us consider that atmospheric interface to be at 100 km. This is a worst-case assumption, since meteorites actually tend to become visible at a significantly lower altitude.

Utilising a similar calculation as for 6.1.1 (c), but assuming a meteorite travels in a straight line:

5 degrees of polar elevation = $(888^2+962^2)^{0.5}$ = 1309 pixels (1)

Trail from image 5381 = $(442^2+44^2)^{0.5}$ = 422 pixels (2)

Angular length of trail = 5 * (2)/(1) = 1.612 degrees (3)

Range to meteorite at 55 degree elevation	= 100 / (Sin(55))	=	122 km	(4)
Trail length if meteorite	= Sin((3)/2) * (4) * 2	=	3.43 km	(5)
Exposure time of image 5381		=	3.2 s	(6)
Apparent speed if object is meteorite	= (5)/(6)	=	**1.073 km/s**	

Meteorite velocities have a lower bound of approximately 11 km/s, and are extremely rare in that range. Most are many times faster. Extreme incident angles causing such high speed to be observed as such a small apparent speed would have yielded other tell-tale effects (such as dramatic uni-directional intensity variance). The measured flare therefore cannot have been a meteorite.

7 Conclusions

Considering that

- our primary hypothesis is strongly supported by comparison of clear experimental data to demonstrably reliable theoretical prediction,
- all identified credible alternative hypotheses have been excluded,

and that

- no other credible alternative hypotheses can be identified by the Arctic Downlink Team,

we feel confident in concluding that the observed flare was a direct observation of the SSETI Express satellite, by both the Portable Optical Groundstation, and by one member of the Arctic Downlink Team.

**SSETI Express has therefore been definitively seen and recognised,
for the first time in the decade since it was launched into orbit.**

We can also conclude that SSETI Express has a non-zero tumble rate, as this is a necessary condition for the occurrence of a flare. No conclusions can be drawn about the magnitude of that tumble rate without further observation. However, given that no flares were detected during passes *Delta* and *Juliet*, despite similar conditions to *Echo*, the implication is that SSETI Express flares are relatively rare. The Arctic Downlink Team considers it rather fortuitous that a flare occurred not only during one of the highest quality passes of the campaign, but also very close to maximum elevation and in view of the portable optical groundstation.

Despite these firm conclusions, please note that, in the name of scientific rigour, the authors would welcome any additional credible alternative hypotheses worthy of consideration.

8 Recommendations

Having established the visibility of the SSETI Express satellite, both by optical ground station and the naked eye, all interested parties are encouraged to attempt their own observations. The Arctic Downlink Team would gladly offer advice and assistance to any such parties.

Our recommendations for the objectives of such activity include:

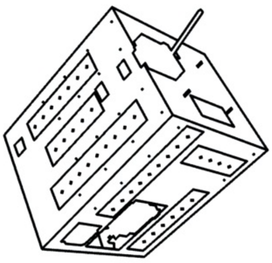
- Observation of SSETI Express when *not* flaring. This would require significantly better visibility than was available during the Arctic Downlink Campaign, due to the unfortunately timed full moon above the horizon during all viable passes.

- Observation of consecutive flares of SSETI Express, as this would yield interesting information regarding the tumble rate of the satellite. This would require observation of at least two flares, with more yielding more accurate results.

Please initiate any such discussion, or share any results, via the usual communication channels.

9 Future Actions

Fortuitously, one member of the Arctic Downlink Team, Neil Melville-Kenney, will be returning to ESRANGE for professional reasons throughout 1st– 11th November 2015. With respect to the moonlight, visibility conditions are expected to be considerably improved during that period. Therefore, weather permitting, the Arctic Downlink Campaign will be extended, albeit with reduced personnel. Any significant results shall be added as an annex to this document.



10 Annex 1 – Addendum 14/11/2015

10.1 Introduction to Extended Campaign

As mentioned in section 9, team member Neil Melville-Kenney returned to ESRANGE, Kiruna, Sweden, on 1 November 2015 for professional reasons, specifically to participate in the MASER 13 ESA microgravity research sounding rocket launch campaign. This afforded a number of additional chances to acquire visual downlink from SSETI Express.

10.2 Portable Optical Groundstation Adjustments

For several of the following passes the POG was adjusted as follows:

1. The main optical receiver firmware was replaced with third-party firmware, specifically *Magic Lantern* (build 2015 Oct 01, see http://www.magiclantern.fm/).
2. The updated firmware (1) enabled the combination of a 2-second mirror-lockup for each shot, combined with an intervalometer function.
3. The main antenna was replaced with a mid-gain narrow-angle alternative, specifically a Canon EF 70-200mm f/2.8L IS USM II, used at 200mm.
4. Due to lack of additional operators, the pass procedure was simplified thusly: one smartphone was loaded with low-light-friendly sky charts of each pass for easy reference, while a second was configured with vibration alarms at key times during each pass (e.g.: shortly before the satellite should be passing close to some easily identifiable star). This allowed a single operator to run the POG.

10.3 Execution

For the sake of brevity, the nomenclature system from section 4 shall be simplified such that only passes with findings to report shall be assigned code names.

1st November 2015 Passes from the evening of 1 November were not attempted due to recovery from extensive travel.

2nd November 2015 Passes from the evening of 2 November were unsuccessful largely due to a bright waning gibbous moon.

3rd November 2015 17:25 UTC 79 degrees pass was unsuccessful due to bewildering visibility.

Mike 19:02 UTC 31 degrees

The team member attended the far side of *Colin*. The ambient temperature was -4 Celsius. The sky was very clear and the moon had not yet risen. Optical data was acquired: exposure times 6s, f/2.2, ISO1600, configuration as per section 2.3.

4th November 2015

November 17:07 UTC 84 degrees

The team member attended the far side of *Colin*. The ambient temperature was -5 Celsius. The sky was cloud-covered to the North and overhead, but clear to the

South. The moon had not yet risen. Optical data was acquired: exposure times 10s, f/2.8, ISO3200, alternative configuration as per section 10.2.

Oscar 18:42 UTC 36 degrees

The team member attended the far side of *Colin*. The ambient temperature was -5 Celsius. The sky was clear and the moon had not yet risen, however strong aurora borealis somewhat disrupted data collection. Optical data was acquired: exposure times 8s, f/2.8, ISO6400, alternative configuration as per section 10.2.

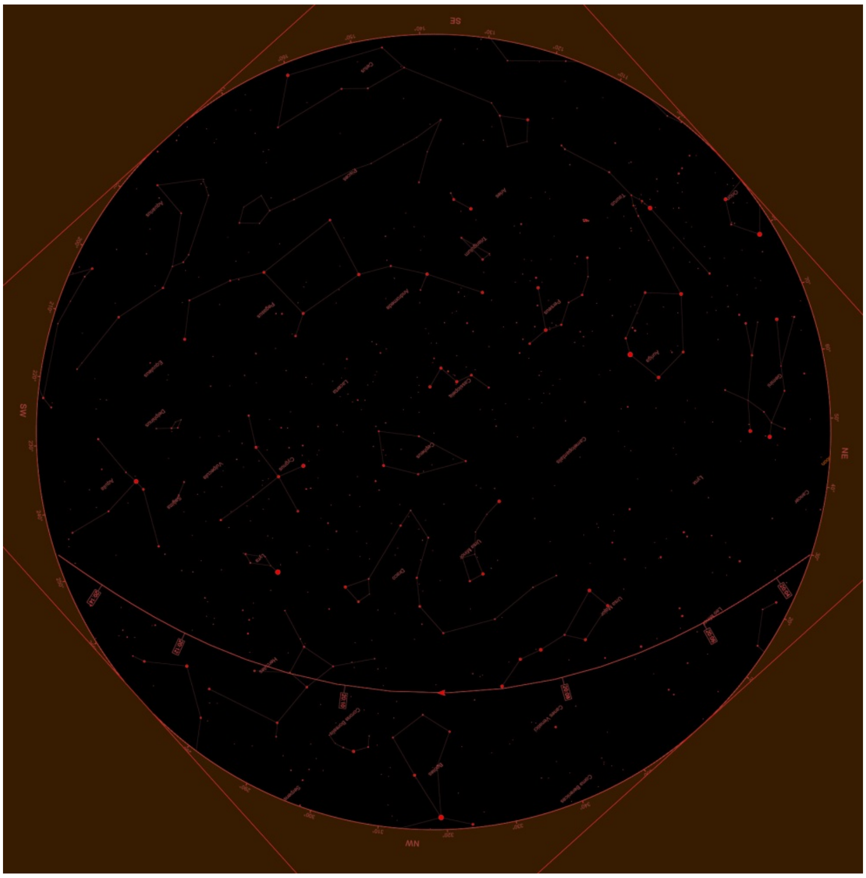
5th-15th November 2015

Persistent overcast weather, combined with professional commitments at pertinent hours, prevented collection of optical data.

10.4 Results

10.4.1 Mike Pass

Following the www.heavensabove.com prediction below, optical data was collected at the appropriate times whilst pointing the POG towards first Alkaid, the last star on the 'tail' of Ursa Major, and then towards Epsilon Herculis, on the 'waist' of the constellation Hercules.



Although the team member did not report any visual data acquisition, the POG captured three flares during the pass: two near Alkaid and a third near Epsilon Herculis.

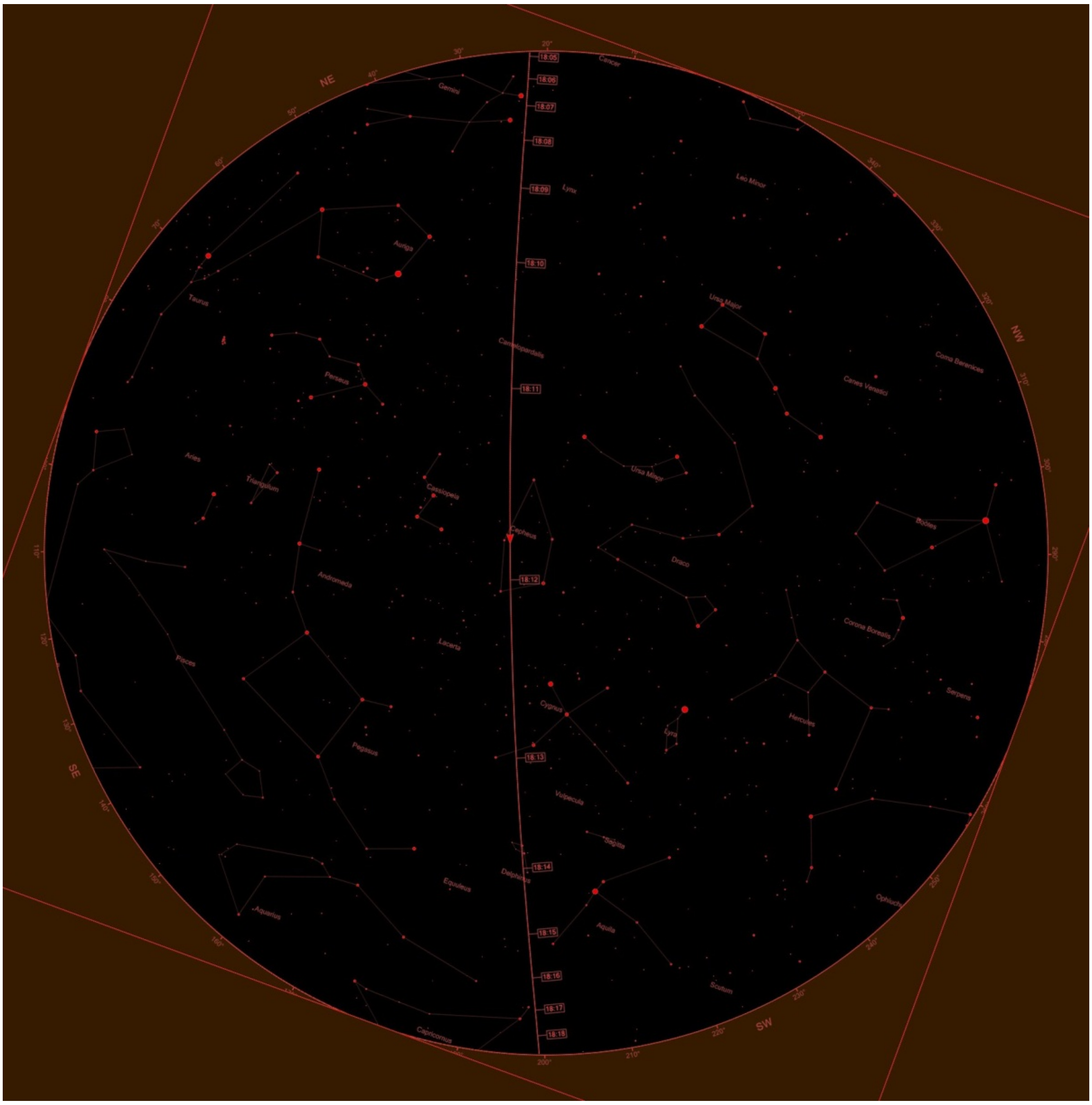
Flare Mike-01, six-second exposure IMG_5617 begins at 19:08:16 UTC

Flare Mike-02, six-second exposure IMG_5622 begins at 19:08:57 UTC
Note, the flare is variable and 'horizontal' and should not be confused with the diagonal satellite trail

Flare Mike-03, composed of two six-second exposures IMG_5630 and IMG_5631, beginning at 19:10:20 UTC and 19:10:27 UTC, from right to left, respectively

10.4.2 November Pass

Following the www.heavensabove.com prediction below, optical data was collected at the appropriate time whilst pointing the POG just below the constellation Delphinius and slightly South of the constellation Aquila.



Although the team member did not report any visual data acquisition, the POG captured one flare during the pass, immediately followed by an extremely faint contiguous non-flaring satellite trail.

It should be noted that several thousand stars are visible within the field of view, and in a section of sky with relatively few recognisable 'landmarks' at 200mm zoom. As such it has not been possible to precisely match these images with satellite pass prediction star charts from www.heavensabove.com.

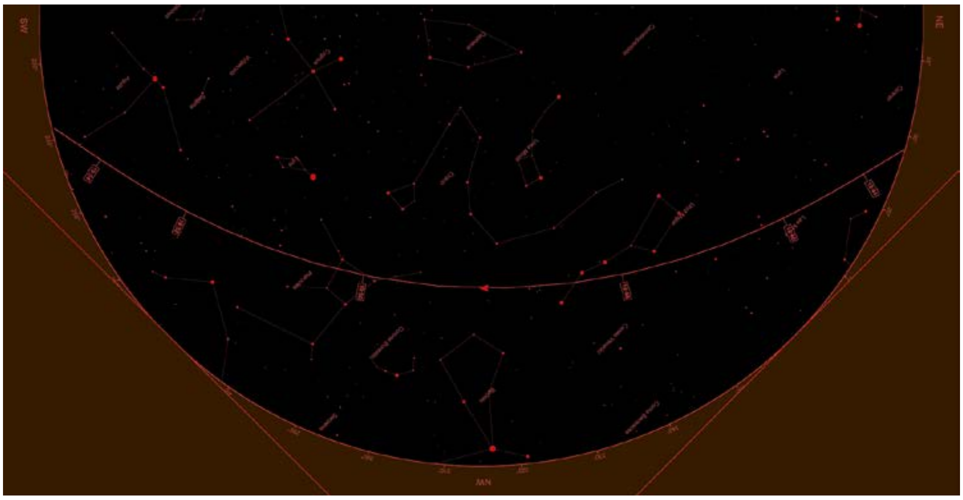
Several attempts were made to have the field of view definitively identified by uploading images to http://nova.astrometry.net/, but without success. The process is likely made more complex by the short trail each star makes at these zoom levels and exposure times.

It is believed, from memory of setting up the POG, that the brightest star in the bottom right of the figure below is either Altair or Alshain in the constellation Aquila.

Flare November-01 *and trail* November-02*, composed of two ten-second exposures IMG_6454 and IMG_6455, beginning at 17:13:42 UTC and 17:13:58 UTC, from top to bottom, respectively*

10.4.3 Oscar Pass

Following the www.heavensabove.com prediction below, optical data was collected at the appropriate time whilst pointing the POG first at Ursa Major and then at Hercules.



The team member reports *visual* acquisition of a flare at approximately 18:48:20 UTC, in between Alkaid and Mizar (the end two stars on the 'tail' of Ursa Major). It was certainly bright enough that it would have been recorded by the POG, but it unfortunately fell between IMG_6491 and IMAG_6492, each eight-seconds-long exposures beginning at 18:48:13 and 18:48:24, respectively.

The POG captured a second flare near Pi Herculis. It should be noted that strong red-coloured aurora were present in front of that part of the star field. There was also a strong North-Westerly wind, causing a significant vibration in the POG support system, hence the low image quality.

Flare Oscar-01*, eight-second exposure IMG_6500 begins at 18:50:07 UTC*

10.5 Analysis

10.5.1 Verification

For the purposes of verifying that the observed satellite flares and trails are from SSETI Express a similar process to section 6 was followed. Iridium flares and aeroplanes could be explicitly ruled out, as per sections 6.1.3 and 6.1.4, as could meteorite strikes, as per section 6.1.5 (due to optical similarity to flare *Echo-01*).

10.5.1.1 Mike Pass Flares

The figure below shows a composite image comparison between the www.heavensabove.com prediction and the observed flares *Mike-01* (right) and *Mike-02* (left), at 19:08:16 UTC and 19:08:57 UTC on 3 November, respectively.

It is clear that the flares are extremely close to the predicted path of SSETI Express, within 0.1 degrees. Flare Mike-02 appears to be closer to the prediction than *Mike-01*, but this could be due to the necessity to rotate the second image in order to align the star field, which had moved in between these two exposures. The flares were also within one second of the predicted times.

These results are well within our combined error margins, and share a great deal of similarity with the previously established results from Echo pass. As such we can confidently assert that flares *Mike-01* and *Mike-02* were indeed from SSETI Express.

The figure below shows a comparison between the satellite pass prediction from www.heavensabove.com and flare *Mike-03*, at 19:10:27 UTC on 3 November:

Again, the flare is extremely close to the predicted path and time, well within our combined error margins. The combination of three detected flares within a single pass, all well-aligned with predictions, gives further confidence in the verification. We can therefore confidently assert that all three *Mike* flares were from SSETI Express.

10.5.1.2 November Pass Flares

Flare *November-01* and trail *November-02* are somewhat more problematic to verify, given the issues specified in section 10.4.2 with identifying the star field precisely. Our ability to compare the flare optically with others is also somewhat impaired, given that the configuration of the POG for this pass differs from all previous passes (different optical antenna, with different optical properties).

However, given that the POG operator is certain that the POG field of view contained the predicted path at the predicted time, we can assume a positional accuracy at least as good as the field of view, and a temporal accuracy at least the time it would take for a satellite to completely pass through this field of view. Such considerations yield error margins for *November-01* and *November-02* of approximately +/- 6 degrees, and +/- 10 seconds. Although significantly higher than our error margins for other flares, this still provides a sufficiently small window such that there is an extremely small chance of another satellite flaring within the field of view, during the exposure time, and roughly in the right direction.

We can therefore claim with some confidence that *November-01* and *November-02* were observations of SSETI Express. We must however concede that the certainty is reduced compared to our other measurements.

10.5.1.3 *Oscar Pass Flares*

The figure below shows a comparison between the satellite pass prediction from www.heavensabove.com and flare *Oscar-01*, at 18:50:07 UTC on 4 November:

Despite the disturbance to image quality caused by wind vibration and visible red aurora, the flare is perfectly aligned with the predicted path, and perfectly aligned with the predicted time, to within the precision afforded by this method.

We can therefore very confidently assert that flare *Oscar-01* was indeed from SSETI Express.

10.5.2 Flare Repetition & Tumble

Given the reasonable assumption that flares from SSETI Express are caused by sunlight glinting off the most reflective surfaces (the solar cells), there is a possibility of inferring information regarding the tumble rate of the satellite by considering the periodicity of the flares.

Neither flare *Mike-01* nor *Mike-02* appear to have been interrupted by the start or end of an exposure, despite both being only about a second less in duration than the exposures (which were six seconds each). I.e.: they seem to 'fit' quite nicely within their exposure times. We can therefore assume the time difference between the two exposures is approximately the same as the time difference between the two flares, to within a couple of seconds. Those two exposures were 41 seconds apart (19:08:16 UTC and 19:08:57 UTC, respectively), and we can therefore claim that those two flares occurred 41 seconds apart, +/- 2 seconds (the combined uncertainty for each flare within its exposure).

Flare *Mike-03* was interrupted approximately halfway through by the end of an exposure which started at 19:10:20 UTC. We can therefore assume that the flare started approximately halfway through the exposure, at 19:10:23. This is 86 seconds after flare *Mike-02*, which is double the time between *Mike-01* and *Mike-02*, within error margins, and strongly suggesting that the reality is towards the upper end of those margins.

This set of statements is consistent with measurement:
- *Mike-01* began near the start of exposure 5617,
- then there was a 43 second gap,
- *Mike-02* began near the end of exposure 5622,
- then there was a 43 second gap,
- then a flare occurred undetected,
- then there was a 43 second gap,
- *Mike-03* began approximately halfway through exposure 5630.

Alternatively the period could be any divisor of 43 seconds, but it is reasonable to assume that more flares would have been detected by the POG were that the case.

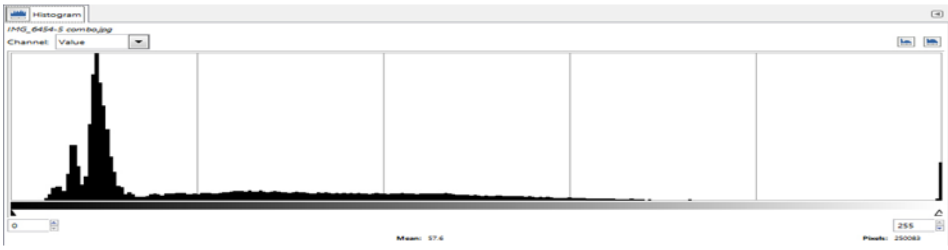
We can therefore conclude, with reasonable confidence, that the flares occur with a periodicity of 43 +/-1 seconds. Given that the flares should be caused by the four large faces of the satellite, each in turn, we can therefore conclude that the satellite tumbles a full 360 degrees in 172 +/-4 seconds. This would be a tumble around the satellite z-axis, and the axis of the passive magnet.

10.5.3 Brightness Considerations

Without proper calibration of the POG, such as characterisation of the sensor noise as a response to temperature, it is not possible to infer absolute brightness values about any of the captured phenomena. However, a relative relationship can be established.

By cropping, rotating and rearranging the images containing *Novermber-01* and *November-02* four interesting areas for comparison have been placed alongside each other, and then scaled on one axis to make the flare and trail "thicker" for the sake of clarity.

The figure below shows the results of this manipulation, along with the associated histogram of intensity levels:



The lowest peak in the histogram corresponds to the black levels found in the background, with no stars present, as found in the left panel of the upper image.

The second narrow histogram peak corresponds to the roughly constant black levels in trail *November-02*, clearly slightly brighter than, and therefore distinct from, the background blacks.

The middle of the histogram has no clear peak, but rather a range of mid-intensity pixel counts. These correspond to the flare *November-01*, which presumably faded in all the way from ‘trail’ intensity to peak ‘flare’ intensity, and back again.

The small peak to the far right of the histogram corresponds to the saturated white levels from the brightest star in the images, probably Altair.

The brightest streaks vertically across the image are from background stars behind the trail and flare, which ultimately we must eliminate for a proper comparison.

The following image and histogram simplifies the situation further: the blackest black was selected for the background, the brightest available non-star values were selected to represent the trail and flare, and the brightest white was selected to represent the star.

It can clearly be seen that the peak flare brightness is approximately 12 times further from the background black than the peak trail brightness is. This corresponds to the flare being very significantly more discernible than the non-flaring trail, as we have discovered. In fact, without the adjustments to the POG for *November* pass, the trails have not been discernible at all. Their signal-to-noise ratio even in this case was only around 1.8.

Assuming that a zero reading on the POG sensor corresponds to absolute darkness, which is not an unreasonable assumption when being compared to readings at significant portions of the response range, we can see that the flare peak is some six times brighter than the trail. This corresponds to approximately 2.5 optical f-stops.

Despite only being relative, these conclusions provide useful information for any future attempts to capture non-flaring SSETI Express trails, since either darker skies or further POG upgrades or would likely be necessary for any significant success rate.

10.6 Conclusions

This addendum somewhat bolsters the conclusions from section 7, as follows:

- The detection of multiple independent flares, which are all well-matched to pass predictions, increases our confidence beyond any credible doubt that this optical downlink is indeed from SSETI Express.
- We can conclude with significant certainty that SSETI Express was tumbling on the long axis with a period of 172 +/-4 seconds, on 3 November 2015.
- We can conclude with fair certainty that SSETI Express is visible to consumer-grade camera equipment under the right conditions, even when not flaring.
- With two independent claims, we can conclude that SSETI Express is indeed visible to the naked eye, under the right conditions, at least when flaring.

Beyond these conclusions, our recommendations given in section 8 still stand, and we would welcome any future activity by interested parties in this endeavour.