An Overview of the C-REX Sounding Rocket Mission Into Earth's Geomagnetic Cusp Near Svalbard[1]

Cusp

Region

EXperiment

NASA, NSROC-2, University of Alaska, Clemson University, Andoya Space Center, University College London, Unis, Kochi-Tech

[1] Background image by Jason Ahrns; C-REX logo by Miguel Larsen

Scientific Problem: A Thermospheric Density Anomaly

This mission is a collaborative project led by the University of Alaska Fairbanks.
Science Question: Why is there always a region of enhanced neutral mass density at 400 km altitude, associated with Earth's geomagnetic cusp?

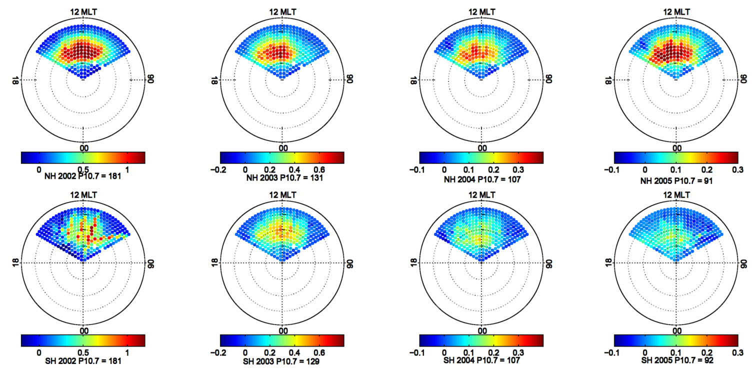
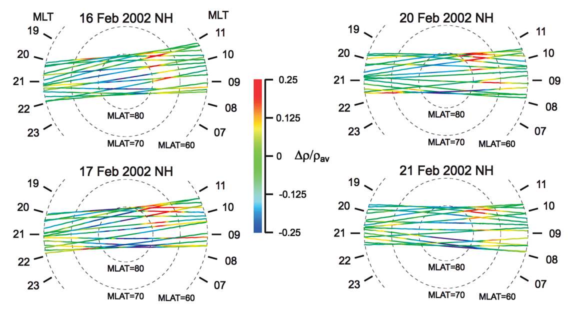


Figure: Neutral mass density measurements from the CHAMP satellite for years 2002 to 2005. The top row is for the northern hemisphere, whereas the bottom row is for the southern hemisphere. **The density anomaly corresponds to the red regions.**

The Density Anomaly is Always Present



- Most observations of the density anomaly come from CHAMP, which saw mass density enhancements as large as 100%, although the typical factor was more like 30%.

- Enhancements were observed when CHAMP passed through latitudes similar to or slightly equatorward of the geomagnetic cusp at magnetic local times near noon.

- *The anomaly was seen on almost all cusp passes, regardless of geophysical conditions*.

Fluid Configurations That Could Maintain the Anomaly

Could the following fluid configurations sustain the observed anomaly:

Static: Local heating could increase the scale height and so locally elevate the density contours. But, for a given height, this would also increase the pressure locally. *A static configuration would not balance the resulting horizontal pressure gradient.*

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- With this experiment, we hope to observe this vertical wind and divergence in action.

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- Ground based instrumentation will support the mission. This includes the EISCAT Svalbard Radar, the University College London all-sky Fabry-Perot spectrometer at Longyearbyen, and various instruments run by UNIS.

Mass Density Affects Orbital Decay

Reentry Prediction

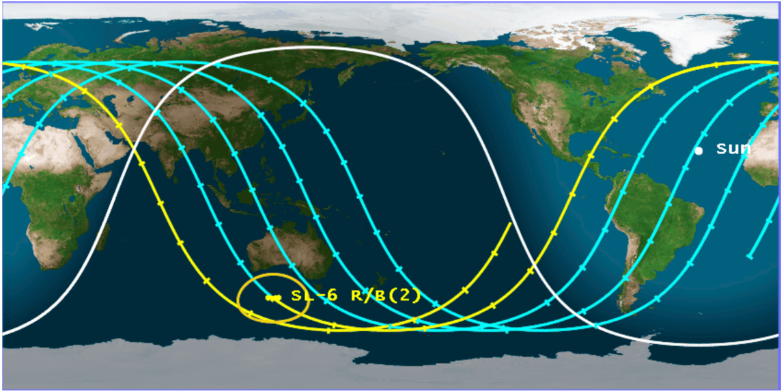
Predicting 3 days out...

Predicted Reentry Time: 17 JUL 2013 14:36 UTC ± 21 hours

Prediction Epoch: 14 JUL 2013 02:40:19.853 UTC

Prediction Ground Track:

Reentry could be... Anywhere!



For clarity, ground track plot is limited to ± 6 hours

Screen Capture from:
http://www.aerospace.org/cords/reentry-predictions/upcoming-reentries/1996-045d/

Satellite Collisions

- Events where two satellites approach within several kilometers of each other occur numerous times each day. Even in 2007, operators of the Iridium constellation were receiving 400 notifications per week for predicted approaches within 5 km of their satellites.[2]

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- Following loss of Iridium 33's signal, the US Space Surveillance tracked 382 pieces of debris from it, and 893 pieces from Cosmos 2251.

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Simulation of the Collision Between Iridium-33 and Kosmos-2251

http://www.youtube.com/watch?v=ISmggU0UOYY

Measuring Winds Using Vapor Tracers

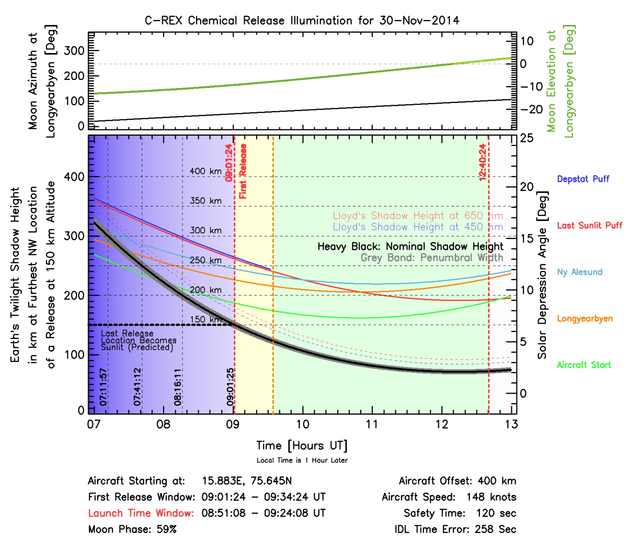
We can measure winds in the thermosphere from the drift of "vapor tracer" clouds released at high altitude by a rocket.

- But this only measures wind variations along the trajectory.
- *To determine divergence we need wind measurements resolved over three spatial dimensions.*

Visualization of the Planned Mission

- A Black-Brant 12 rocket launched from Andoya will <u>eject</u> 24 vapor tracer cannisters during its upward flight.
- They cannisters will hen separate and, on the way down, they will *deploy tracer clouds throughout a three-dimensional volume* spanning altitudes between 150 km and 400 km over the Greenland Sea west of Svalbard.

Observing Geometry



- To be visible at all, *the vapor tracers must be sunlit* at their altitudes of 150 km and above.

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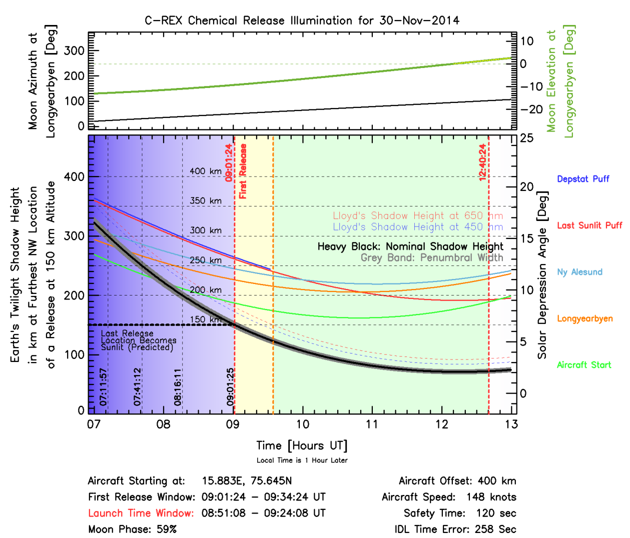

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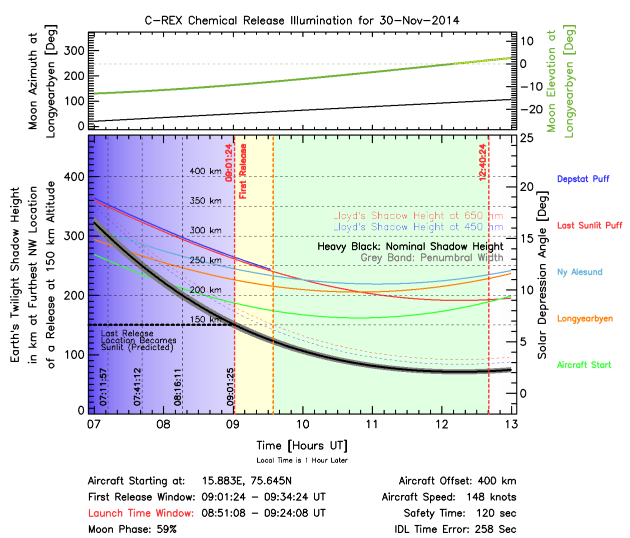

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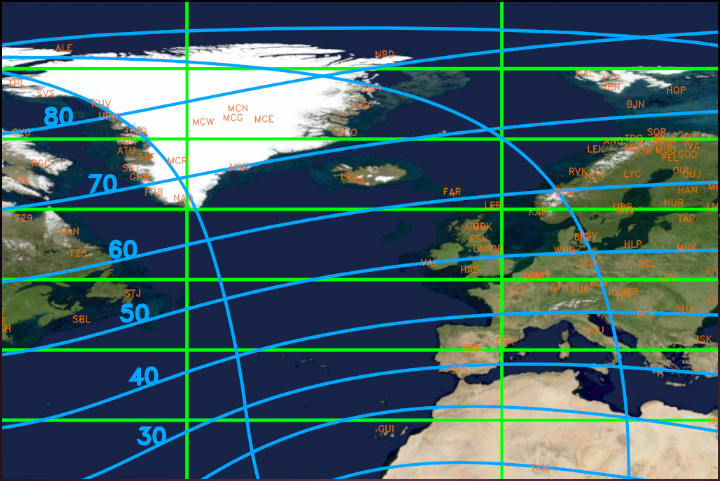
- But skies on the ground must be dark.
- So the experiment is only possible during a small range solar elevation angles, corresponding to very specific times.

Why Andoya and Svalbard?



- Andoya is the only range that can currently launch a Black Brant 12 safely into the cusp region.
- Svalbard is the only corresponding ground site far enough north to have dark skies at local noon.

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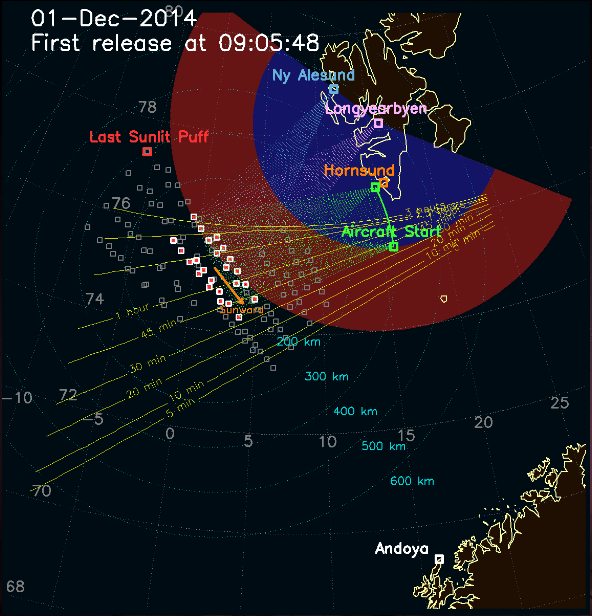
- But our advice was that getting two sites on Svalbard with simultaneously clear skies would be tough in November.
- So we convinced NASA to send us an aircraft – which <u>guarantees</u> that we'll have at least one site clear.
- It also allows us to increase our triangulation baseline somewhat.

Experiment Overview Maps



- This map shows the nominal tracer release locations, plus observing sites at Longyearbyen, Ny Alesund, and on the aircraft.

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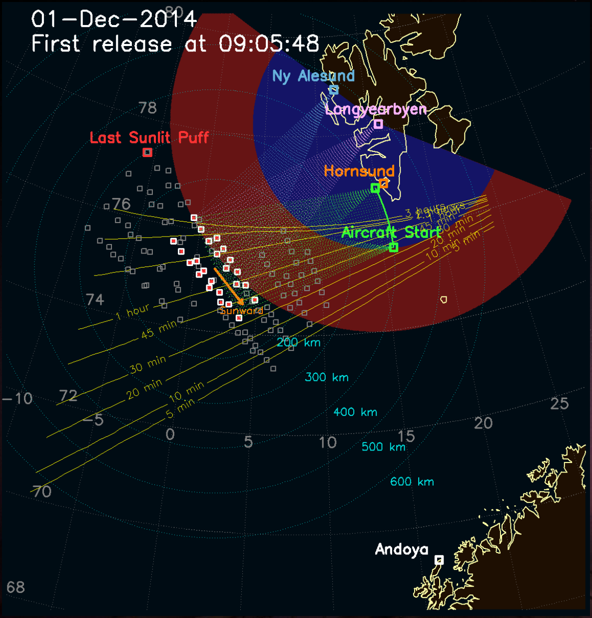

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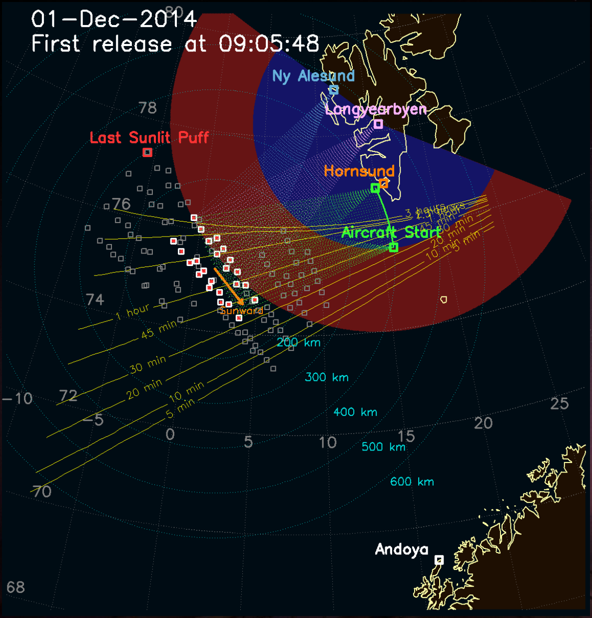

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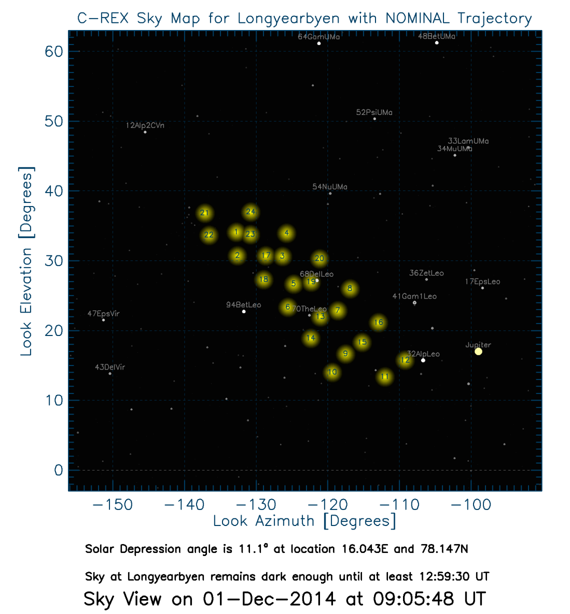
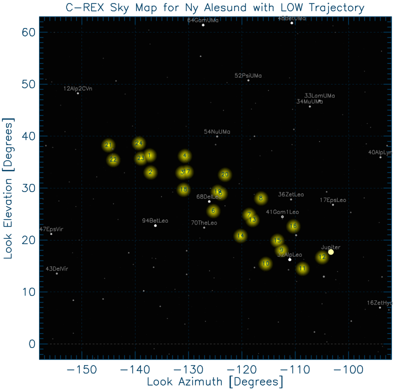
- The blue (partial) circle shows the region within which we could currently observe from the aircraft.

Predicted Appearance of the Puff Constellation



- We now have software that can predict how the chemical puffs will appear from any ground or aircraft based observing location.
- The software also predicts the appearance of the background star field, which should help our observers orient their cameras.
- Here is an example showing the predicted puff constellation for a nominal rocket trajectory, as seen from Longyearbyen on December 1.

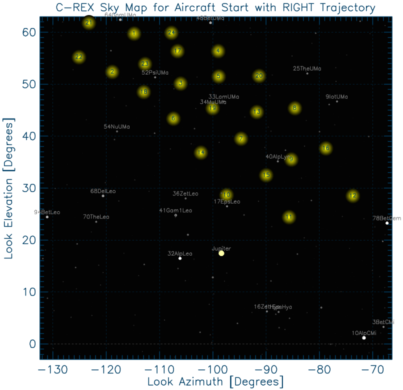
More Examples of the Puff Constellation Appearance



Solar Depression angle is 12.1° at location 11.928E and 78.925N

Sky at Ny Alesund remains dark enough until at least 12:59:30 UT

Sky View on 01−Dec−2014 at 09:05:48 UT



Solar Depression angle is 8.8° at location 15.883E and 75.645N

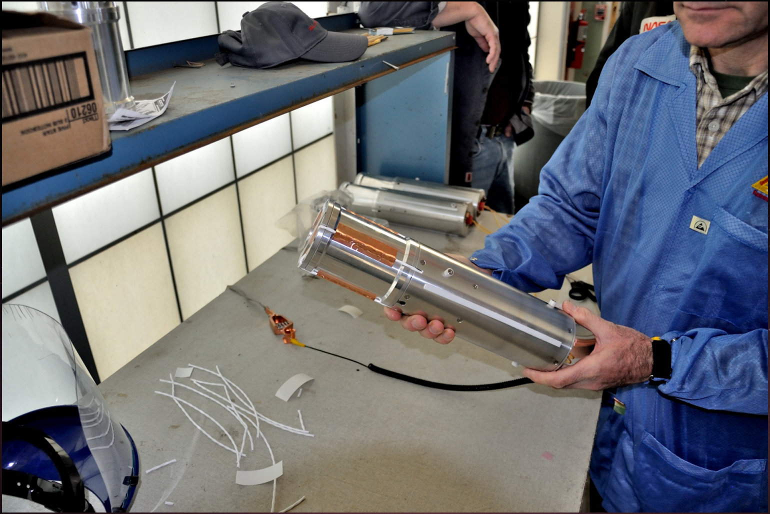
Sky becomes too bright here on 01−Dec−2014 at 09:44:00 UT

Sky View on 01−Dec−2014 at 09:05:48 UT

Rocket-Propelled Sub-Payloads

- To measure wind gradients with the required accuracy ($\sim 0.0002\,\mathrm{s}^{-1}$) demands wind measurements separated over baselines that are 80 to 100 km long.
- The only way to eject sub-payloads fast enough to achieve this separation is to propel them out with small rocket motors.
- This shows a test of the deployment system that we conducted earlier this year.
- Note the "rifled" launch tube. This is to spin-stabilize the sub-payload, because it is launched exo-atmospherically, where fins are not useful.

An Example Sub-Payload



- This shows one of the ejectable sub-payloads.
- Material to produce the vapor cloud is the front section. The rear section contains electronics, batteries, and a small rocket motor.

Sub-Payload Electronics Section

This photo shows how the batteries and electronics are packaged around the sub-payload rocket motor.

Test Burn of the Small Rocket Motor Under Vacuum Conditions

We built a special “rough service” vacuum tank for testing the small motors.

Releasing the Vapor

- The vapor clouds are released by detonating a small explosive.
- This shows a test of the system, conducted on the ground.

First Test Flight from Poker Flat – Feb 2010

This is an ultra slow-motion video showing the launch of first test of the ejectable sub-payloads, conducted in Alaska in February 2010.

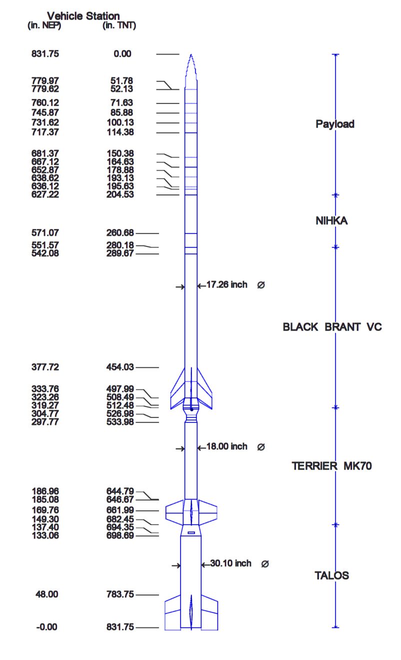
Visual Appearance

- This time-lapse was taken with a simple DLSR camera; it gives a good idea of how the clouds look by eye.
- Note how the neutral and ion clouds separate – ions stay fixed to the $\overrightarrow{\mathbf{B}}$ field, whereas neutral drift with the wind.

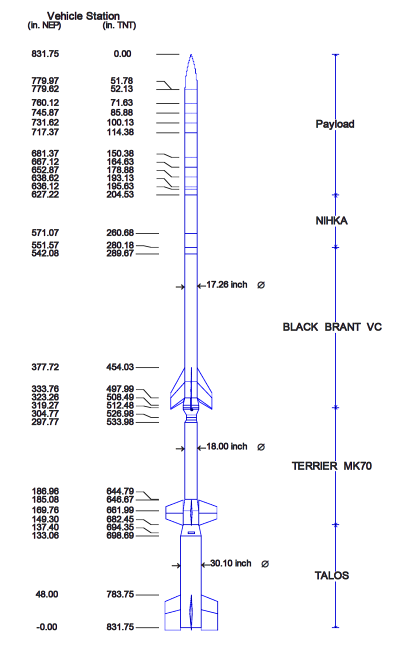
Low Light Camera View

- Tracer clouds released above 200 km altitude disperse quickly, because the atmosphere is so tenuous at high altitude.
- Tracking the tracer clouds for long periods requires expensive low-light cameras, which give results like these.
- While the resolution is lower, this camera is far more sensitive than a DSLR.

Vehicle Layout



- The launch vehicle will be a four-stage Black Brant-12 sounding rocket, with a total length at launch of 21.1 m.



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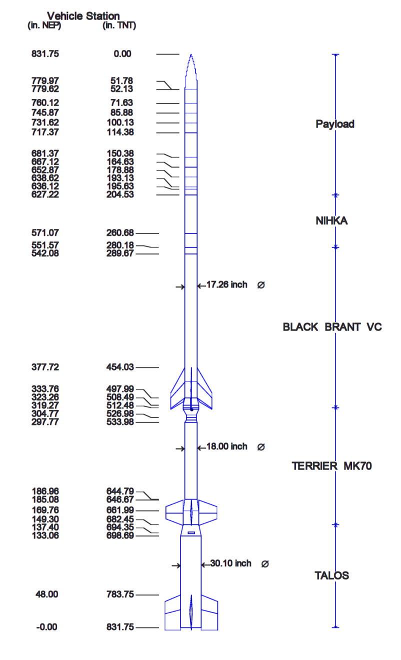

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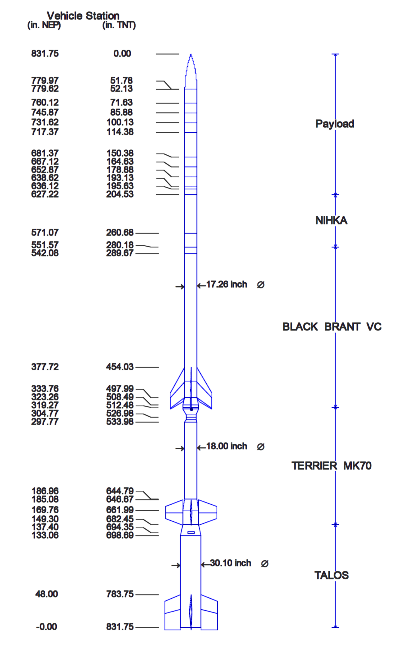

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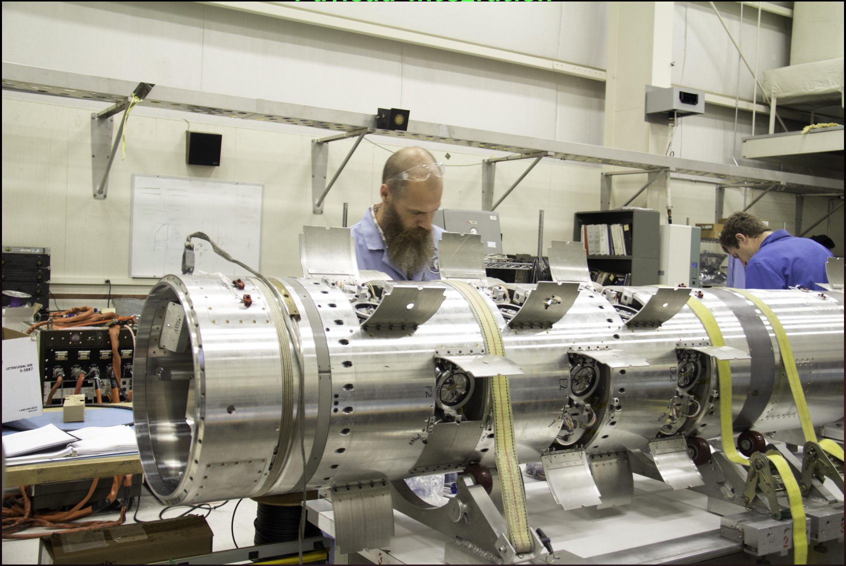
- A real-time onboard trajectory calculation will update each sub-payload's release time prior to ejecting it. This is required to ensure the releases occur at the science altitudes we want.

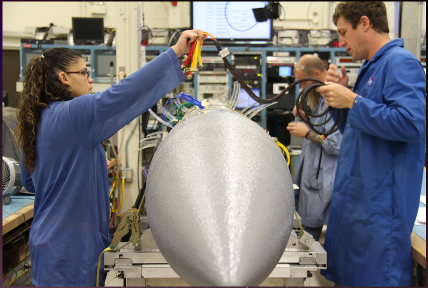
Payload Integration



This photo shows one half of the "stack" of ejectables, seen during payload integration at NASA's Wallops Flight Facility.

More Payload Photos

deployment bay.jpg



These are two more views of the C-REX payload, seen during integration and testing at Wallops Flight Facility.

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- Since we need good weather, you can probably guess for yourself how like a launch is – but to make it worth setting up cameras it will be nice to have some “official” status information.

Launch Window

Date	Launch Window UT	First Release Time UT	Moon Phase
Nov-18	07:52:39 - 07:56:09	08:02:56 - 08:06:26	17%
Nov-19	07:57:50 - 08:02:50	08:08:06 - 08:13:06	11%
Nov-20	08:02:57 - 08:09:27	08:13:14 - 08:19:44	5%
Nov-21	08:08:02 - 08:16:02	08:18:19 - 08:26:19	1%
Nov-22	08:13:05 - 08:23:05	08:23:21 - 08:33:21	0%
Nov-23	08:18:04 - 08:29:34	08:28:20 - 08:39:50	0%
Nov-24	08:22:59 - 08:36:59	08:33:16 - 08:47:16	3%
Nov-25	08:27:51 - 08:43:51	08:38:08 - 08:54:08	9%
Nov-26	08:32:40 - 08:51:40	08:42:56 - 09:01:56	17%
Nov-27	08:37:24 - 08:59:24	08:47:40 - 09:09:40	26%
Nov-28	08:42:03 - 09:07:03	08:52:20 - 09:17:20	37%
Nov-29	08:46:38 - 09:15:38	08:56:55 - 09:25:55	48%
Nov-30	08:51:08 - 09:24:08	09:01:24 - 09:34:24	59%
Dec-01	08:55:32 - 09:33:32	09:05:48 - 09:43:48	70%
Dec-02	08:59:50 - 09:43:50	09:10:06 - 09:54:06	80%
Dec-03	09:04:01 - 09:56:01	09:14:18 - 10:06:18	88%
Dec-04	09:08:06 - 10:11:36	09:18:23 - 10:21:53	94%
Dec-05	09:12:03 - 14:12:03	09:22:20 - 14:22:20	98%

This table shows our current time windows during which the rocket launch and the first tracer releases would occur.

Please – Take Lots of Pretty Photos!

These releases seen above the gorgeous mountains of Svalbard should make for a once-in-a-lifetime photo opportunity!