RENU2 Mission Overview

Marc Lessard, UNH

6 Jan 2016

Rev 1.0 (current as of 2 Feb 2016)

This paper is intended to be a repository to summarize the RENU2 mission, including information about the launch conditions, trajectory, data and instrumentation (including both ground and onboard instruments). *At this point, the information contained in this document is considered proprietary.*

1 Launch overview

Launch took place on Dec 13, 2015 at 07:34:00 UT. Conditions leading up to launch consisted of the development of a series of PMAFs. These were observed without a strong sign of cusp aurora, presumably because the positive B_y kept the cusp further to the east of us and the PMAFs were propagating to the northwest, which is consistent with what we were seeing. Magnetic noon occurs at approximately 09:00 UT, so this seems to make sense. During the minutes before launch, Cutlass Radar signatures were intermittent but seemed to show hints of us being in the cusp, with stronger cusp-like signatures a bit to the east of us. Not long after launch, these signatures became quite a bit stronger (so I am told, but I wasn't watching that data).

During the fourth stage, the payload took a right turn and went 2.8 sigma to the right. This, it turns out, was very good for us. The planned trajectory would have been fine, but the drift to the east 1) brought us over brighter 630 nm emissions and 2) meant that the payload cut through the arc obliquely as it dropped in altitude, providing LOTS of interesting data. The unexpected trajectory did result in an apogee of only 447 km, as opposed to the planned 500 km. Remember, the idea was that apogee occurs to the south of EISCAT, so the plan was to descend as parallel to the EISCAT magnetic field as possible.

The payload reached apogee at T+409, which was very close to nominal so it does seem like we descended down along the arc in some sense (or maybe along a set of adjoining arcs). Preliminary quick-looks show electron precipitation beginning near T+442 and lasting until T+655 (200+ seconds of data within an arc!?). It may be the case that we hit re-entry while still inside the arc. Finally, there is also an electron heating event around T+335 to T+370, though with no obvious precipitation at that time.

We have excellent allsky camera data, EISCAT and Cutlass data, in addition to other ground instruments from KHO.

2 Payload instrumentation

Here are the descriptions of the various instruments (grabbed from the proposal, so maybe not quite "as flown"). This is included here for general information, but descriptions of instrument problems will be added as we move forward. All instruments seemed to have worked as intended, though the onboard imager was swamped by sunlight.

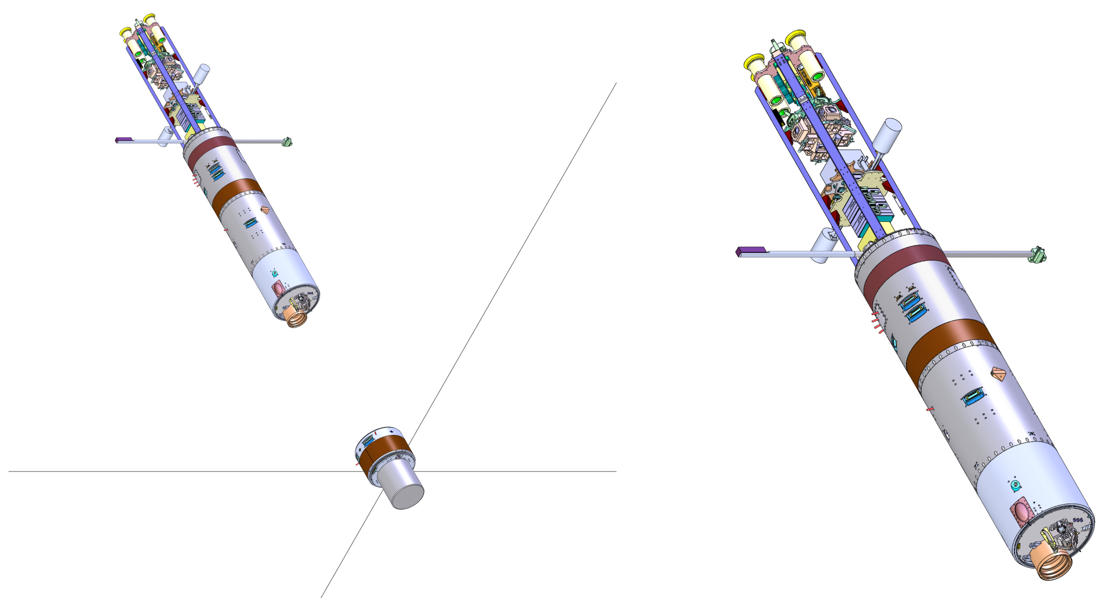

Figure 1: This figure shows SolidWorks drawing of the payload. I can add labels to show instrument locations, if needed.

Instrument	Institution	Measurement	Range
Ion Gauges	Aerospace	Neutral density and temp	$\geq 10^{-10}$ T
PMTs	Aerospace	N_2^+ (391.4 nm), O (630.0, 844.6 nm)	30 cts/s/R
EPLAS	UNH	3D distributions, precip. electrons	6 eV - 15 keV
HT - Thermal ions	Dartmouth	3D distributions, ambient ions	0.06-3 eV
HM - SuperT Ions	Dartmouth	3D, upflowing ions	6-800 eV
BEEPS - Ion mass	Dartmouth	3D, upflowing O^+, H^+	6-800 eV
Ion Mag Spec	Aerospace	???	??
ERPA (2)	UNH	Cold electron temps (and density?)	0.06 - 3 eV
COWBOY E-Fields	Cornell	Onboard electric fields	0-20 kHz, 0-1000 Hz
Billingsley mag	Cornell	3-axis fluxgate	$\pm 60,000$ nT
Racetrack Mag	UNH	3-axis fluxgate, 24-bit (30 pT)	$\pm 60,000$ nT
Imager	UNH	630 nm images, below the payload	
UV-PMT	UNH	O (130.4 nm), 12° FOV, above	TBD

Table 1: RENU2 instruments and quantities measured.

3 Trajectory

Figure 2 shows the actual payload trajectory. The near-vertical dotted lines are IGRF magnetic field lines; the gold line is the sunlight terminator, calculated step-by-step throught the flight. The payload reached sunlight at T+88 and returned to darkness near T+650. The location of the PMAF is based on the in-situ electron data (and confirmed by the allsky camera data). All of these numbers are quite close to planned trajectory, except that the

Instrument	Contact	Measurement
EISCAT	Kjellmar Oksavik	Ion T, v; Electron T, n; along **B**, to ~400+ km
KHO	Fred Sigernes, et al.	Auroral cameras, MSP and high-res spectrometers
Oslo Allsky Cameras	Jøran Moen	630.0 & 557.7 nm, at both LYR and NAL
Cutlass (SuperDARN)	Tim Yeoman	Ionospheric flows (convection) and irregularities
Fluxgate Mag	??	Ground-based fluxgates at LYR, NAL and HOR
Induction Coil Mags	Marc Lessard	0-1 Hz dB/dt; EMIC waves, etc., from Hornsund

Table 2: Groundbased sources of data that directly supported this mission.

Satellite	Transit	Measurement
ePOP	East of Svalbard, at 0928 UT	Ions, electrons, waves?
NOAA	Larry Paxton?	SSUSI, particles

Table 3: Satellite sources of data that coincide with this mission.

eastward drift of the payload placed it approximately 158 km from the EISCAT beam, at its closest approach which occurred near T+482.5.

The image on the right (of Figure 2) is from the Univ of Oslo allsky camera in Longyearbyen, with the track of the payload superimposed. The track shown is the expected trajectory, but just from mapping latitudes and longitudes (no magnetic mapping in this case). See Section 5 for more information regarding allsky data and the payload trajectory.

4 Moving forward...

Figure 3 shows electron precipitation from the EPLAS instrument. Time after launch is on the horizontal axis, energies are plotted along the vertical axis and color represents fluxes (counts). The plot shows a good summary of the flight, except that EPLAS missed the heating event at around T+335 to T+370. This plot is now from the Svalsat TM and contains the entire flight. In addition to the additional data, this plot also includes time stamp and dead-time corrections. **IMPORTANT:** we are taking the launch time to be 7:34:00.000 UT and are using the data from the Svalsat TM for consistency.

In any case, it's easy to see that we caught a beautiful event, dropping down the field line as planned. The time of interest starts near T+442, lasting until T+655. In order to make good progress on the data analysis, we plan to do a few things.

1. Post summary plots at http://mirl.sr.unh.edu/projects_renu2/FlightData/FlightData.html. Login is RENU2, password is Upwelling. Bruce has already posted plots from 3 of our instruments. Please send similar summary plots to Bruce Fritz (bav66@wildcats.unh.edu), with comments about what is being shown as seen in the examples on the website). Please make these PDF or PNG files so that we can see good quality plots. Also PLEASE INCLUDE REASONABLE LABLES ON THE PLOTS!! POINTS WILL BE DEDUCTED FOR POOR AXIS LABELING!

2. It would be very helpful to be able to stack plots of data from any or all of the various

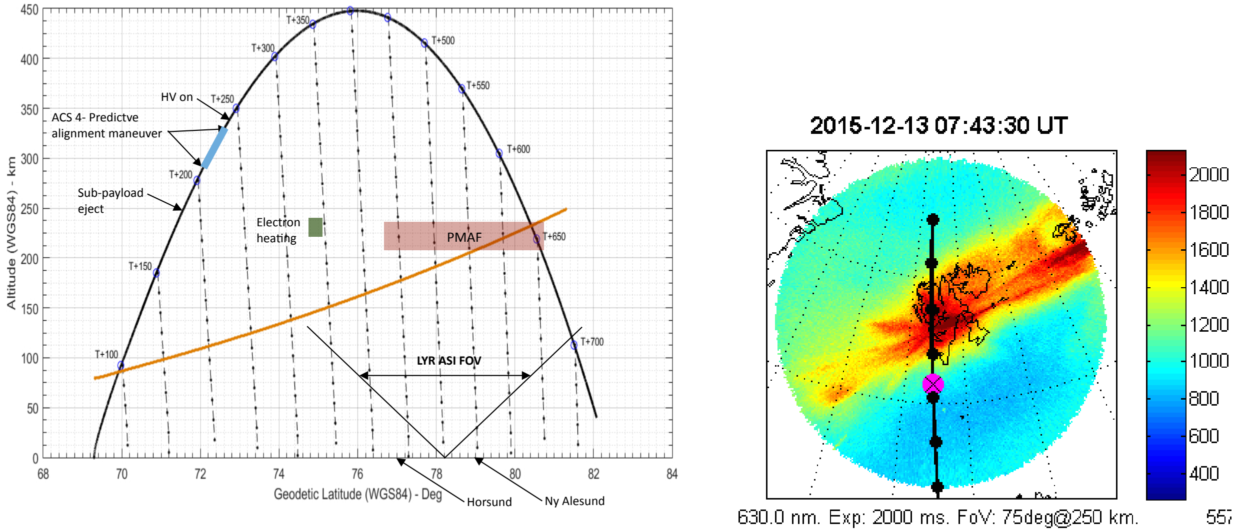

Figure 2: This figure shows the trajectory. On the right, the Oslo allsky camera that coincides with T+570, the the payload was near 340 km altitude, on its downleg, just to the north of Ny Alesund (needs to be confirmed and made more precise).

instruments. Probably the easiest way to do this is for us to provide an IDL save file (if you are using IDL) or a .mat file if you are using MATLAB that can be easily read in and plotted. I am hoping that we can do this for all of the instruments. Send the files to Bruce and he will post them to the website but will also compile a "big picture" plot showing data from all of the instruments on a single page.

3. Finally, about publications... as we make progress on the data analysis, I think it will be very important to talk to each other to make sure we are not competing amongst ourselves. Also, it looks like there will be several papers coming out of this launch and I wonder if we should consider (after we have a deeper understanding of what the data really can tell us) the possibility of a GRL special issue, as was done with the SCIFER mission. Finally, I realize that people make have concerns about data ownership and am sure that we can make this all work out.

5 Optical observations.

Lasse Clausen has provided detailed (and calibrated) plots of allsky camera data. Figure 4 shows keograms extracted from the 630 nm allsky camera. The panel on the left includes data from an hour before launch to show the development of PMAFs and temporal aspects of auroral heating. Note that there was snow on the camera dome, initially. The KHO crew scrambled to clear the dome as things developed and data before about 06:42 are not reliable. The panel on the right shows details of the PMAf transited by the payload.

From Lasse: "Our imager has a resolution of 20-30 seconds; I can prepare plots of all the images we have during the flight. Note that these images are already available at http://tid.uio.no/plasma/aurora (click your way to the right date, and chose the appro-

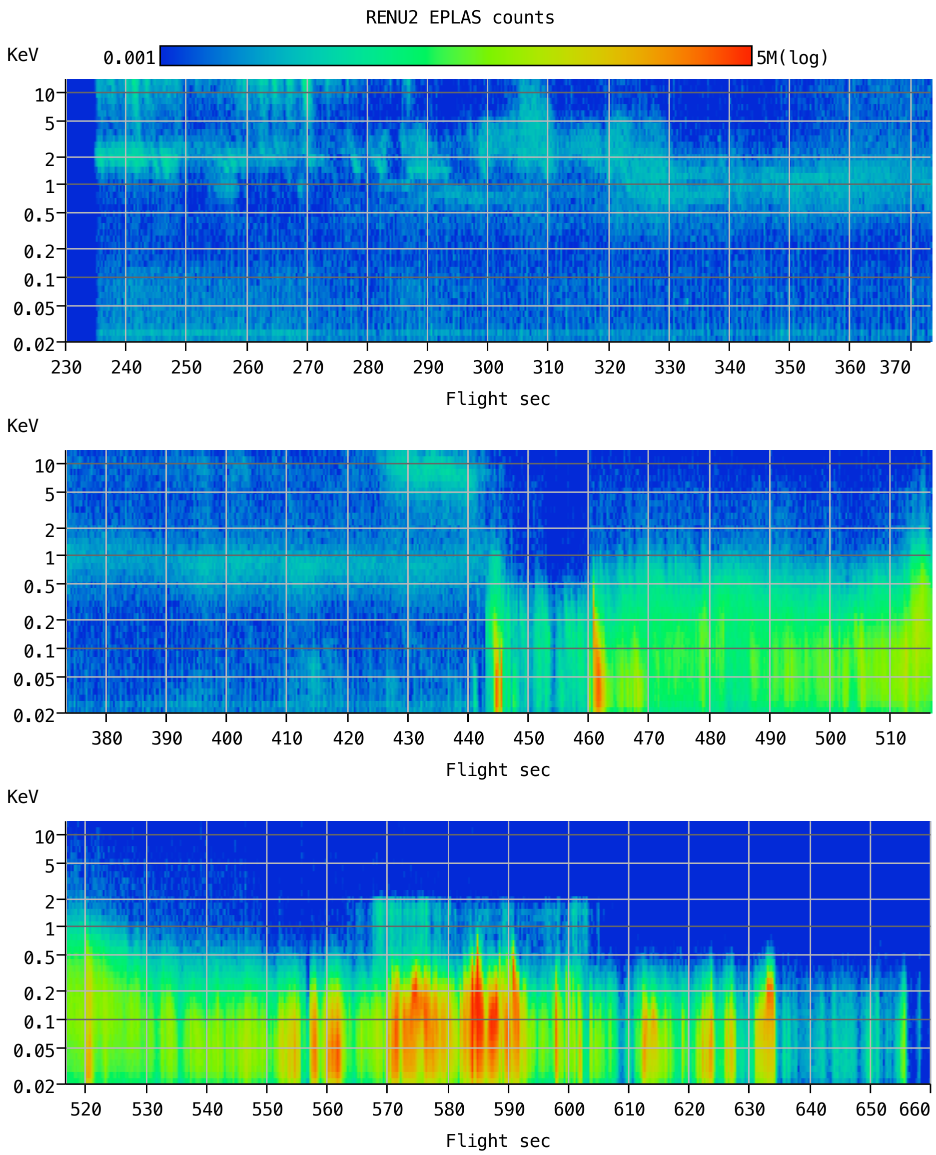

Figure 3: This figure shows the EPLAS data (electron precipitation).

priate hour of the Longyearbyen keogram - below it is a link “show individual images” which does just that). However, these images are individually scaled so it is difficult to compare between them - like I said, I will prepare all images on a common scale for you. You can also download the PNGs from the website and do your own analysis (click “open raw image folder” instead of “show individual images”).”

5.1 DMSP SSUSI data.

Bruce has been following up on a suggestion from Kjellmar to look at DMSP UV data. There are excellent data available from the UV imagers on F16 , F17 and F18. The imagers use a

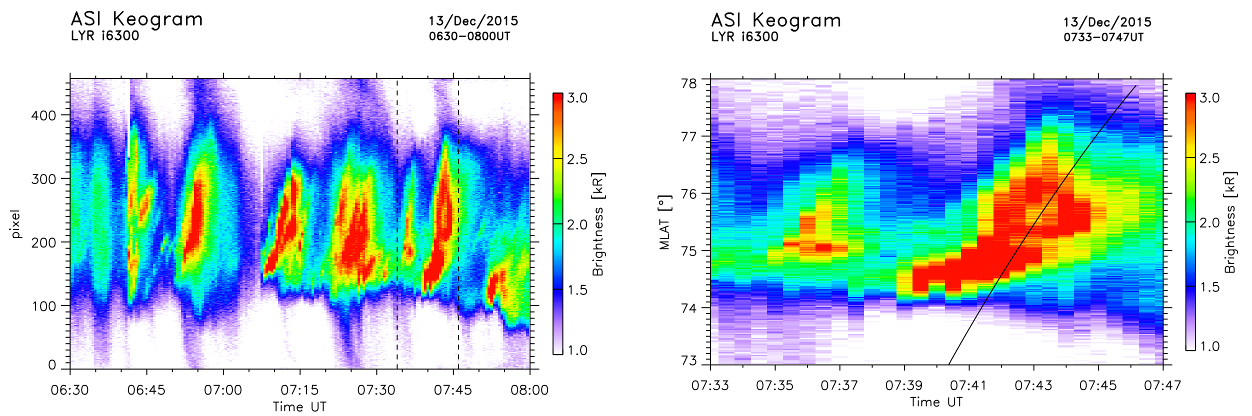

Figure 4: On the left is a keogram from the 630 nm allsky camera showing the PMAF development of the event over time (i.e., a measure of the auroral heating that took place). On the right is a zoomed-in image showing the trajectory of the rocket through the PMAF.

"pushbroom" technique, so we get one image per orbit (altitudes are near 830 km).

The imaged wavelengths include 130.4 nm (nominally from solar UV fluorescence) and 135.6 nm (nominally from electron bombardment), both from neutral atomic oxygen. The onboard UNH UV PMT instrument used a narrow bandpass filter that included both of these lines. The onboard PMT was aimed UP the field line.

Figure 5 shows an image from F18 that corresponds (we think) to the RENU2 overflight. This is just an initial effort, but you can easily see Greenland, as well as a faint white spot (Svalbard) with atomic oxygen roughly in the same vicinity as the PMAF. On the right side of that figure is the data from the UNH PMT, where you can see these same emission lines as the payload passed over the PMAF.

There is still a lot of work still to do with these data, but it seems clear that the satellite observed atomic (neutral) oxygen below the spacecraft, while RENU2 saw similar emissions as it looked UPWARDS, so observed atomic oxygen ABOVE the rocket payload. Obviously, it will be important to compare the relative brightnesses of these observations in order to estimate the density but it looks like we have a very good measurement of upwelling atomic oxygen.

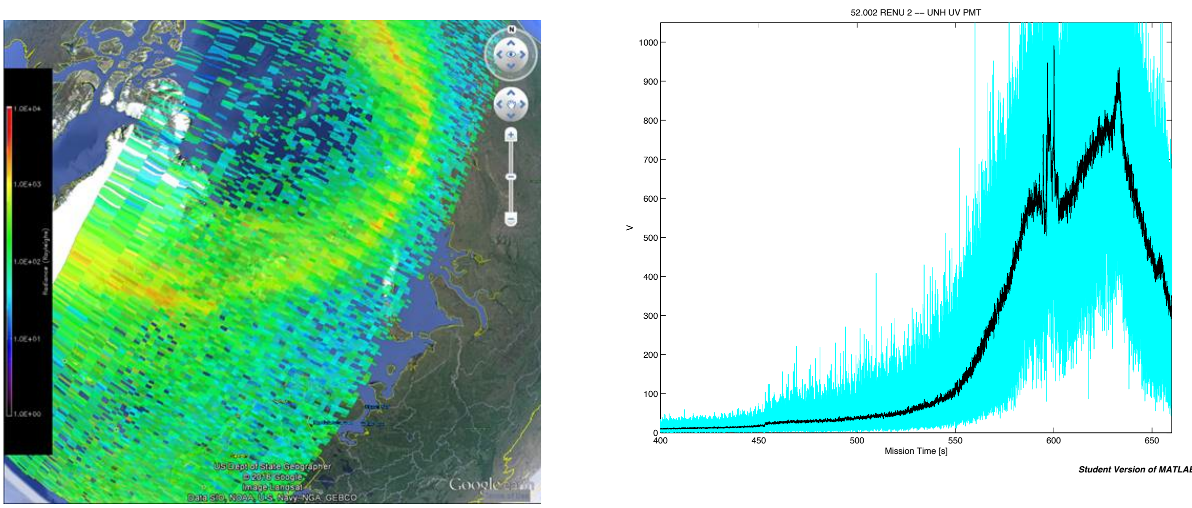

Figure 5: Left: SSUSI UV image. Svalbard is the faint white spot in the center of the image. Right: UV PMT data from onboard RENU2, now looking UP the field line, as the payload passed over the PMAF. It appears that we can show the presence of neutral atomic oxygen at altitudes roughly between 400 and 800 km altitude. Realistically, these emissions are likely at the lower altitudes - otherwise the 2D image would not map correctly, as it seems to do.