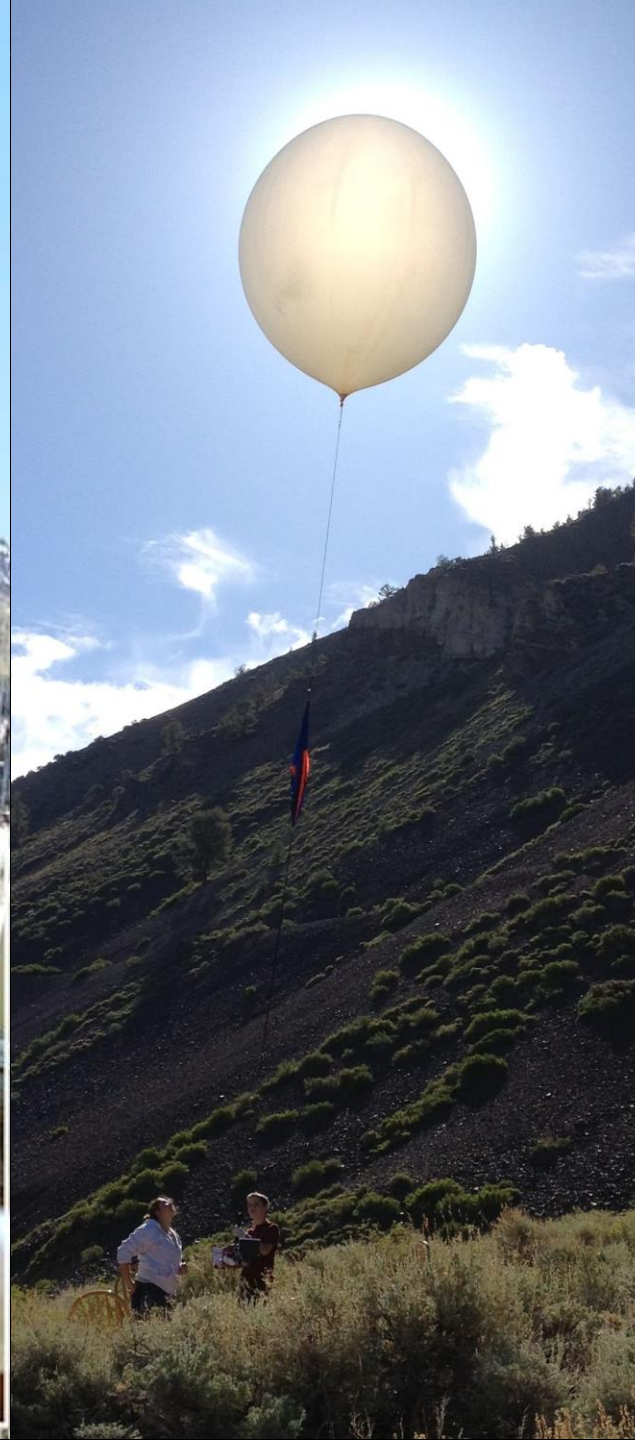
SPACE WEATHER BALLOONING

Space is not as far away as you think….

Earth to Sky Calculus



The launch crew

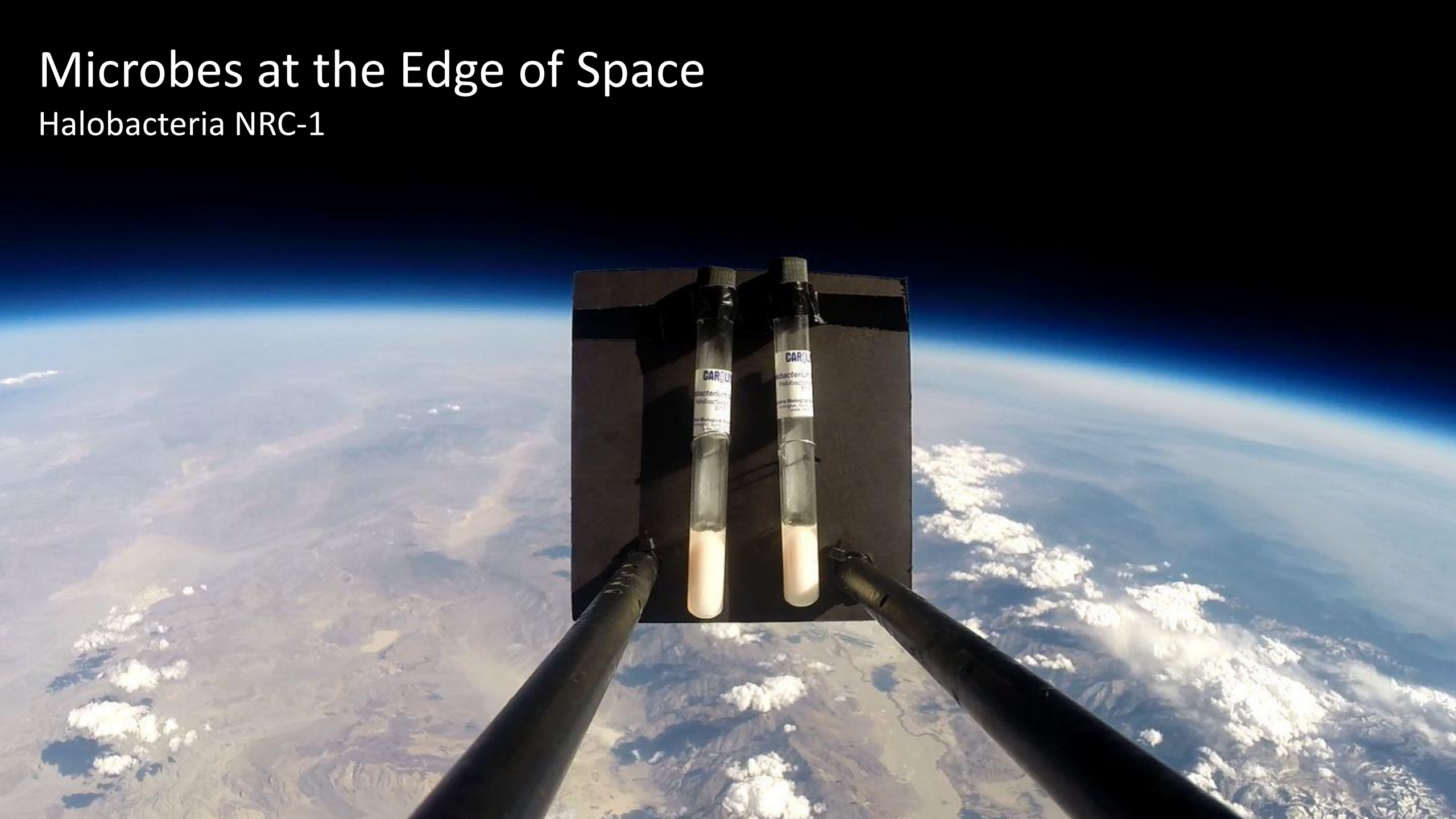
Space Weather Buoy

Our hometown

Bishop, California

Microbes at the Edge of Space

Halobacteria NRC-1



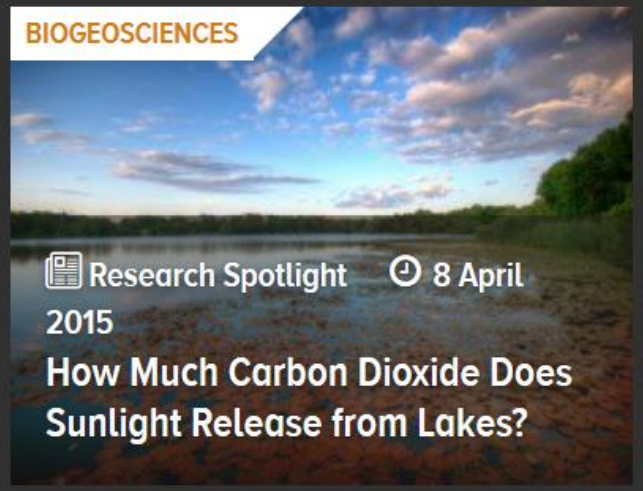
BIOGEOSCIENCES

News 9 hours ago

Can Microbes Survive Multiple Trips into the Stratosphere?

READ MORE »

BIOGEOSCIENCES



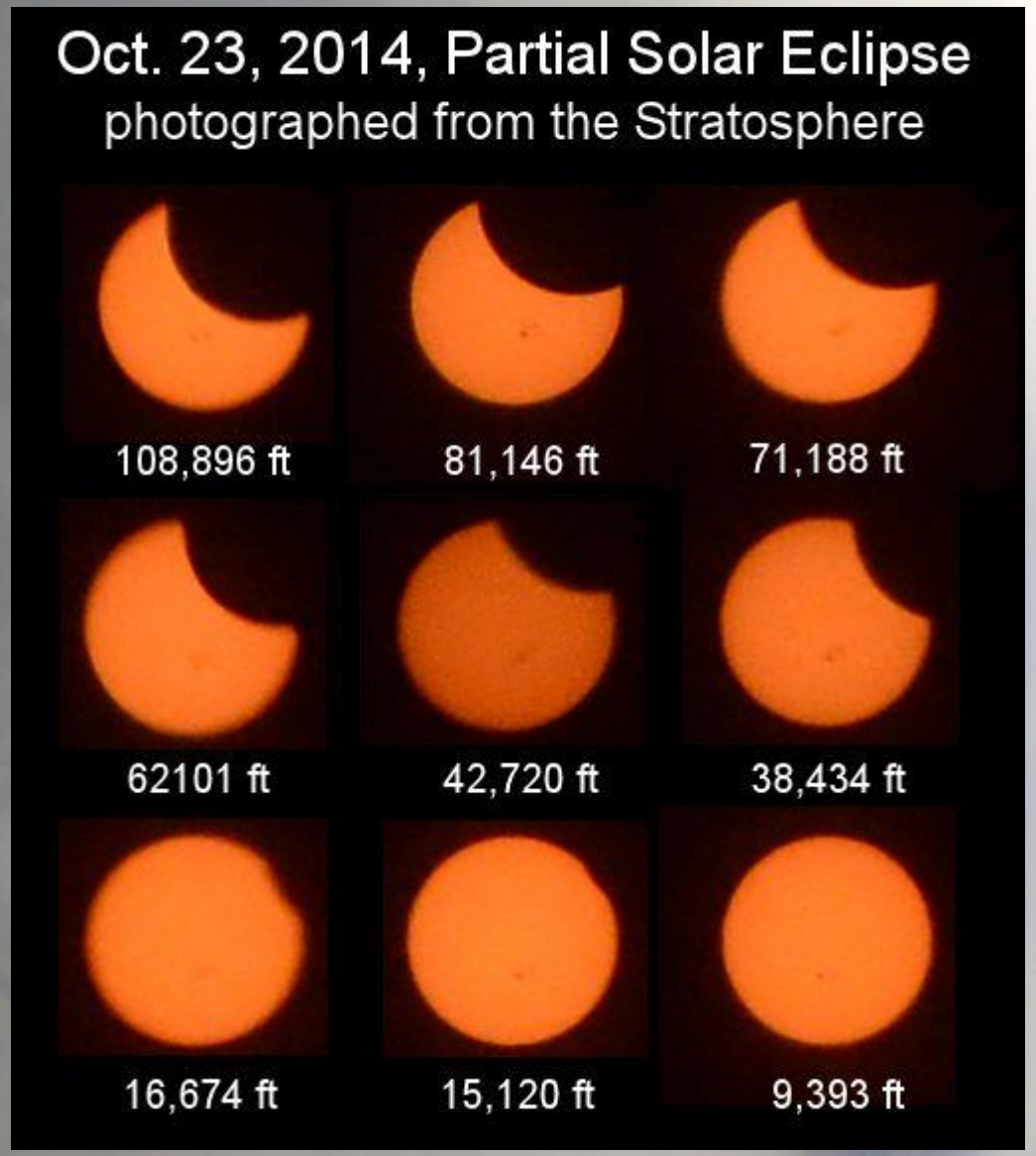
Research Spotlight 8 April 2015

How Much Carbon Dioxide Does Sunlight Release from Lakes?

NATURAL HAZARDS

Project Update 7 April 2015

Fire in the Hole: Recreating Volcanic Eruptions with Cannon Blasts

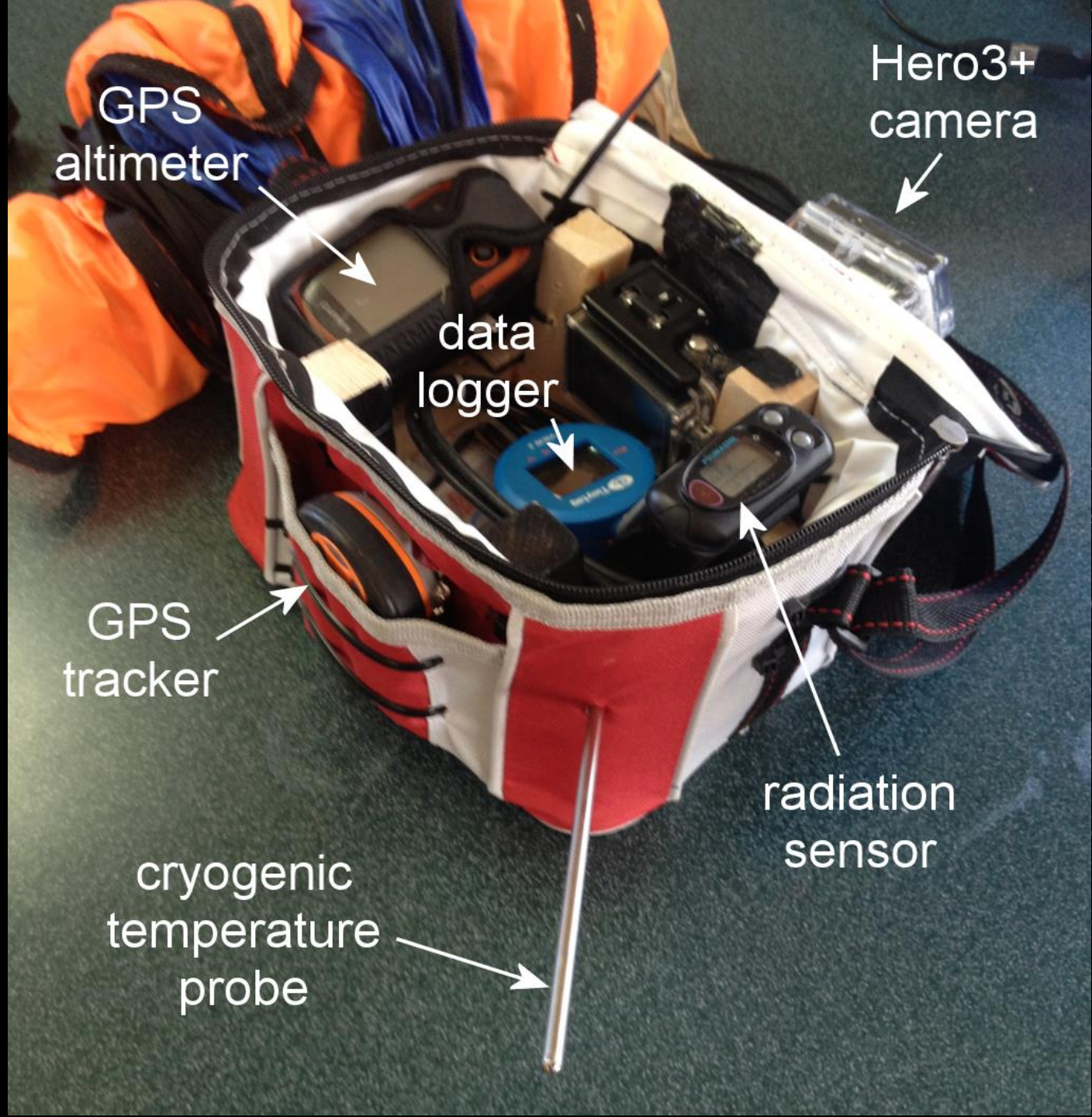


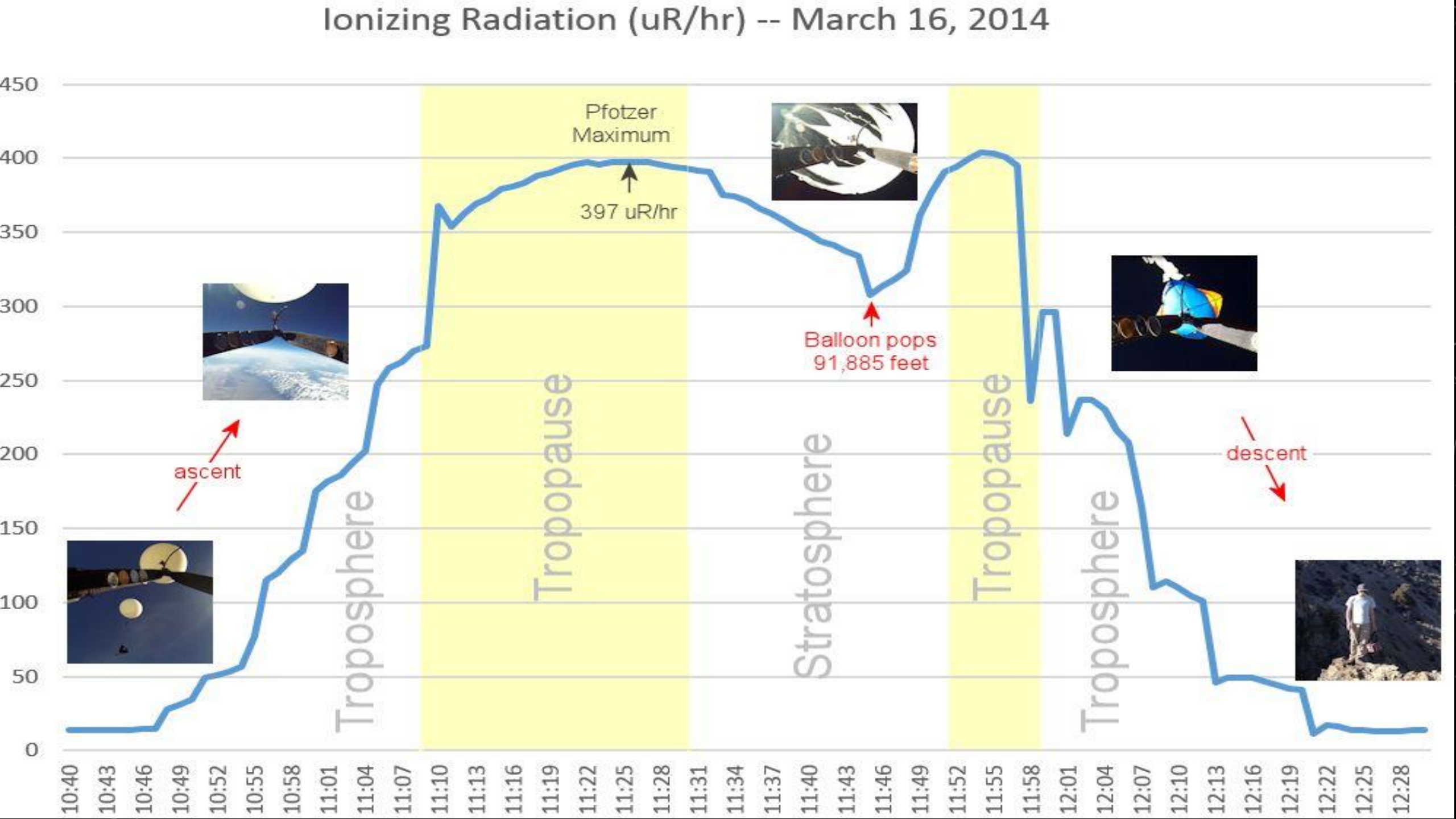
Who needs a tripod?

Astrophotography from a rapidly spinning, rocking platform hurtling upward at 15 mph

SPACE WEATHER BUOY

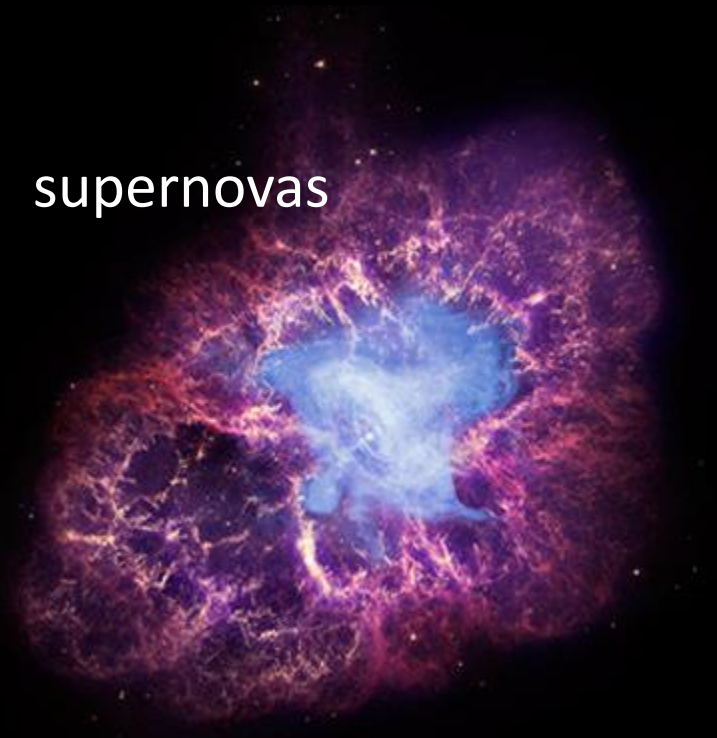
- K-mart lunchbox
- Berkeley Nucleonics Radiation Sensor (10 keV – 20 MeV, X-rays and gamma rays)
- Two SPOT Trackers (for recovery)
- Two Hero3+ cameras
- Cryogenic Temperature Probe
- Garmin GPS altimeter
- Lots of hand warmers
- Hardware cost = $2300
- Launch cost = $400



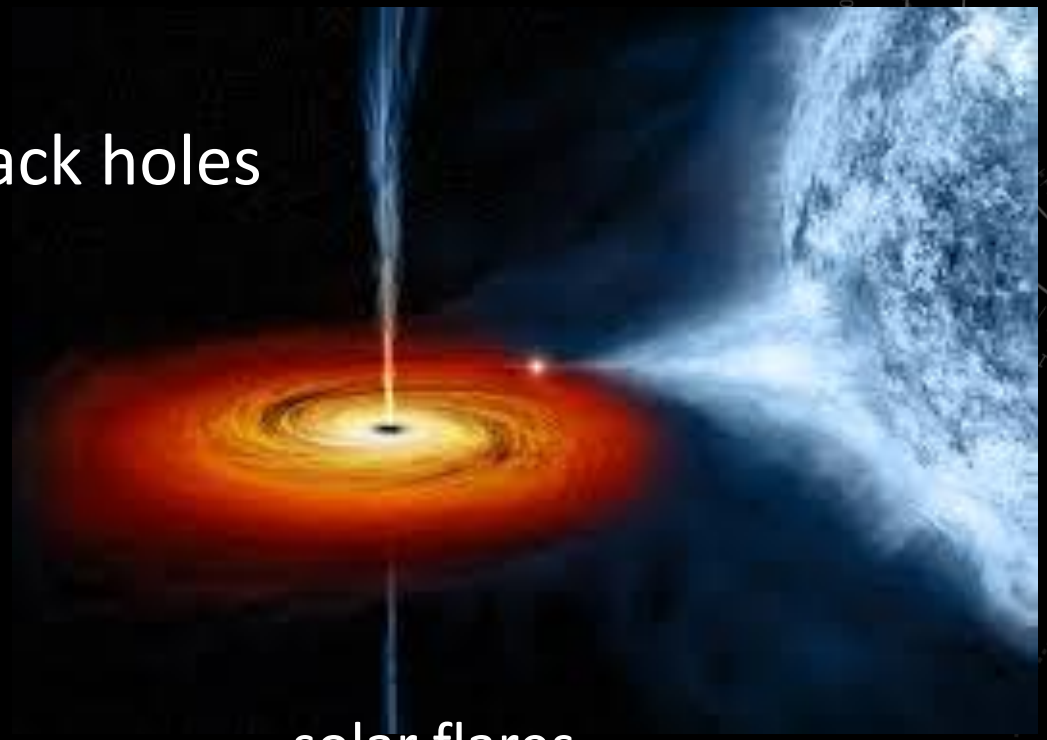

Ionizing Radiation (uR/hr) -- March 16, 2014
450
400
350
300
250
200
150
100
50
0
Pfotzer Maximum
397 uR/hr
Balloon pops 91,885 feet
ascent
descent
Troposphere
Tropopause
Stratosphere
Tropopause
Troposphere
10:40
10:43
10:46
10:49
10:52
10:55
10:58
11:01
11:04
11:07
11:10
11:13
11:16
11:19
11:22
11:25
11:28
11:31
11:34
11:37
11:40
11:43
11:46
11:49
11:52
11:55
11:58
12:01
12:04
12:07
12:10
12:13
12:16
12:19
12:22
12:25
12:28

WHERE DOES THIS RADIATION COME FROM?

supernovas



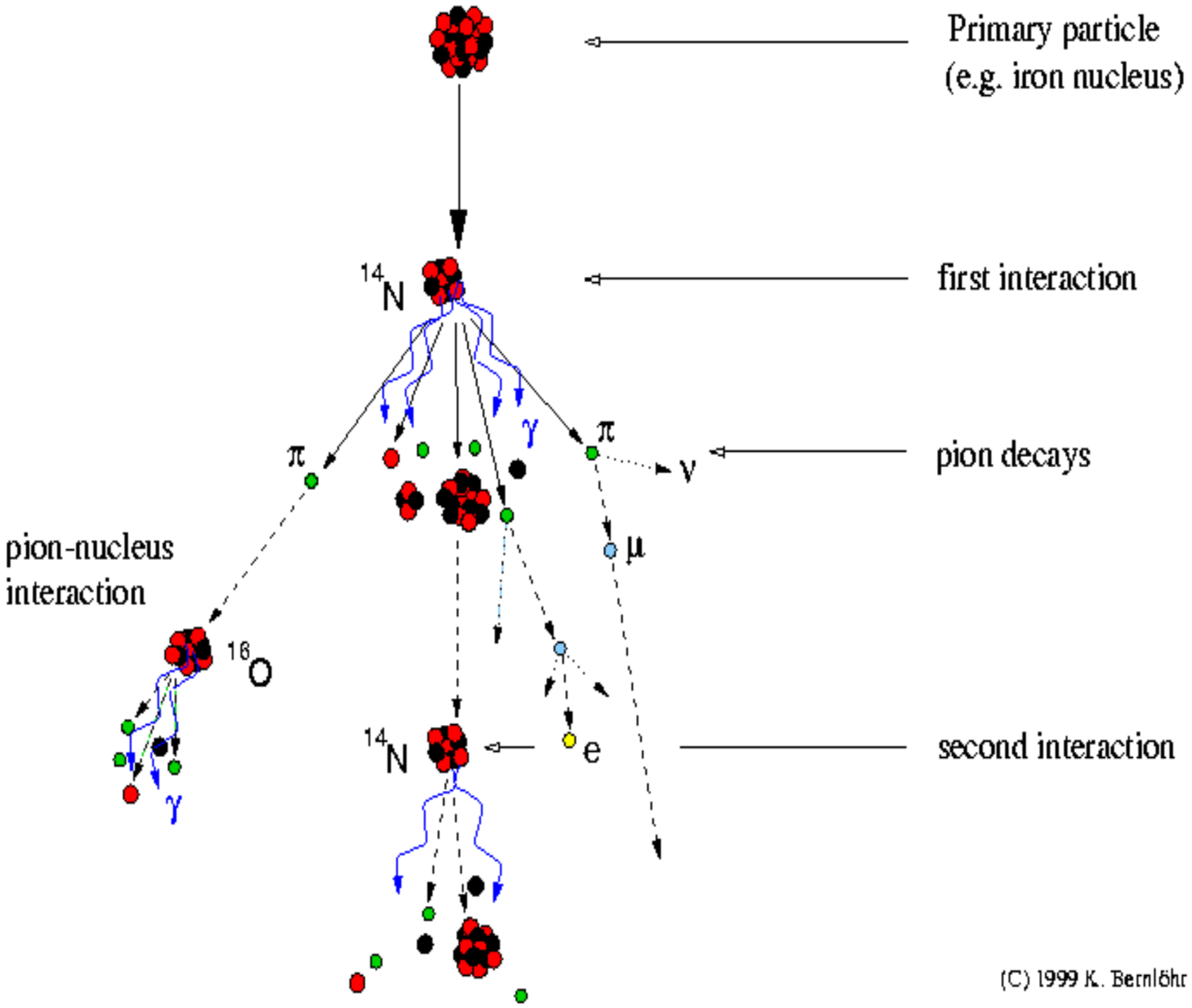
black holes



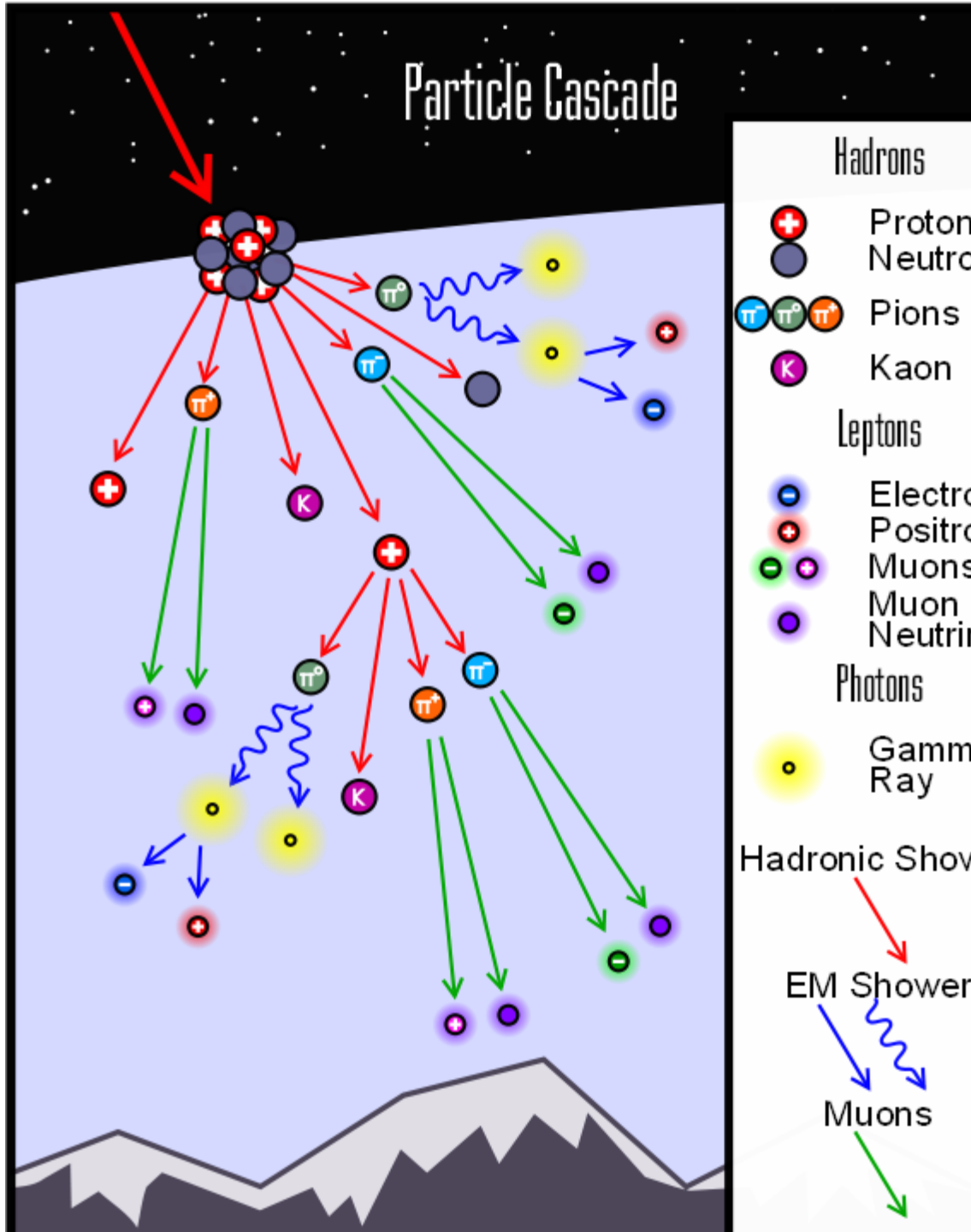
solar flares

COSMIC RAYS

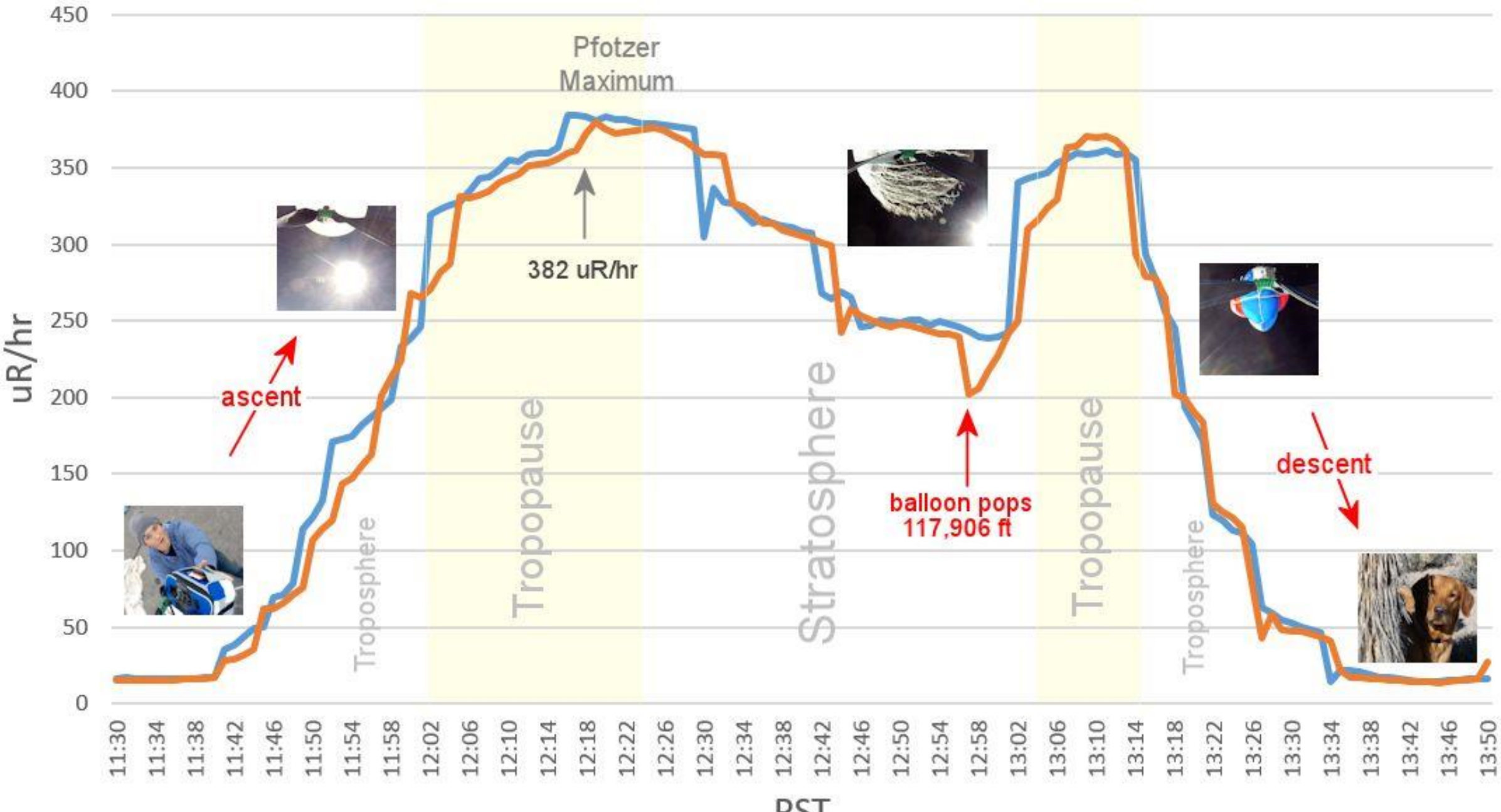
Development of cosmic-ray air showers

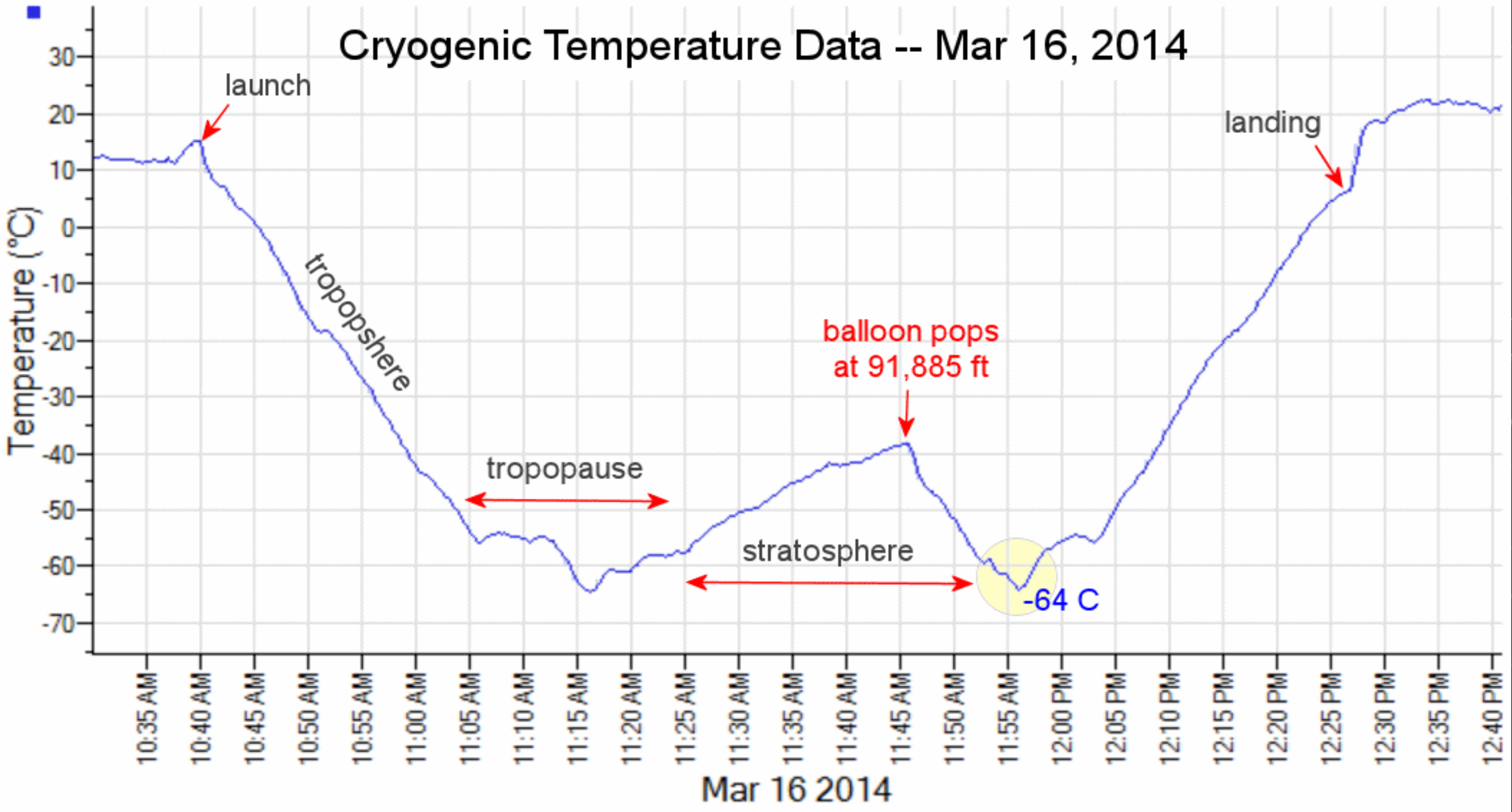


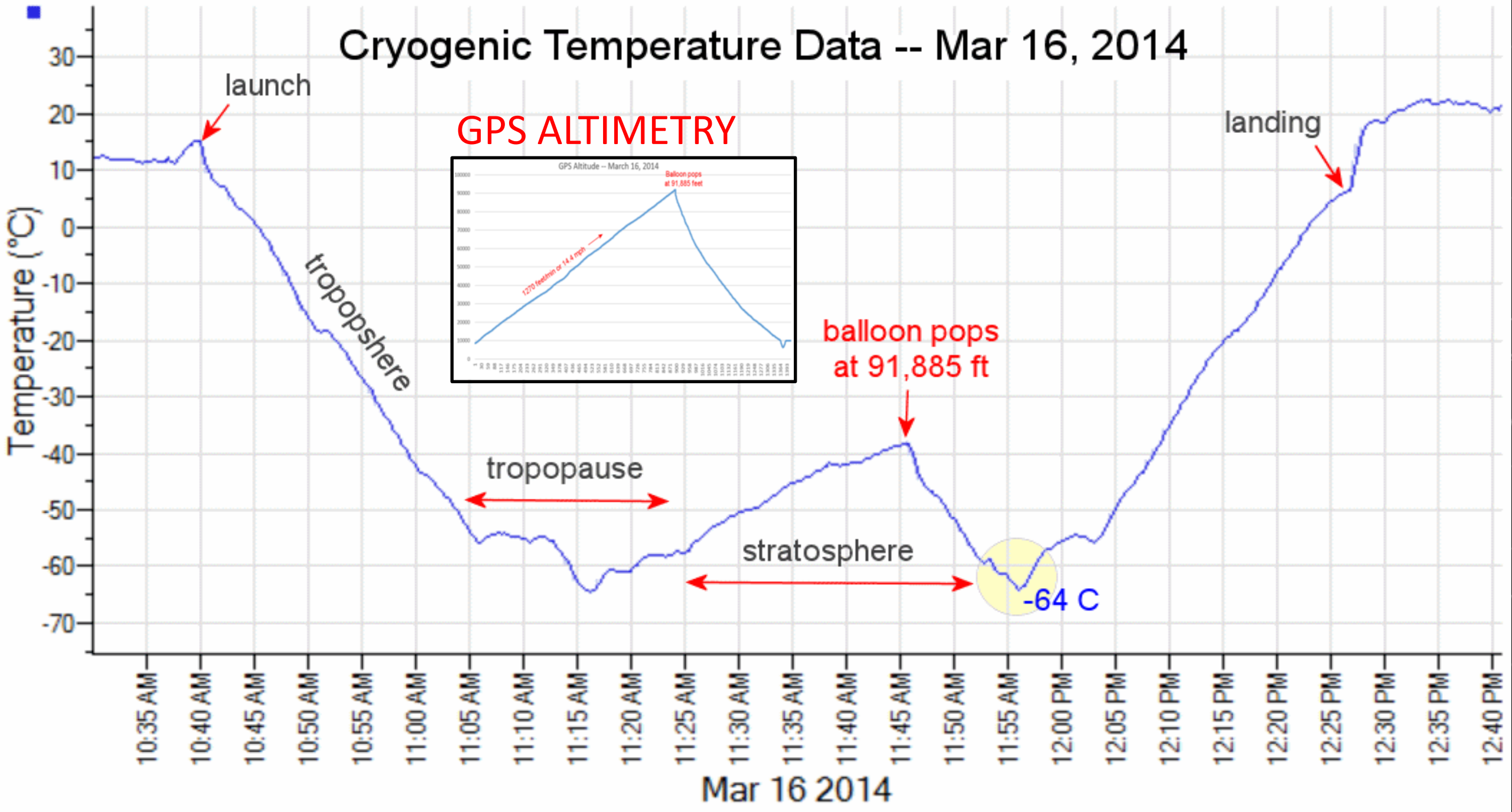
(C) 1999 K. Bernlöhr

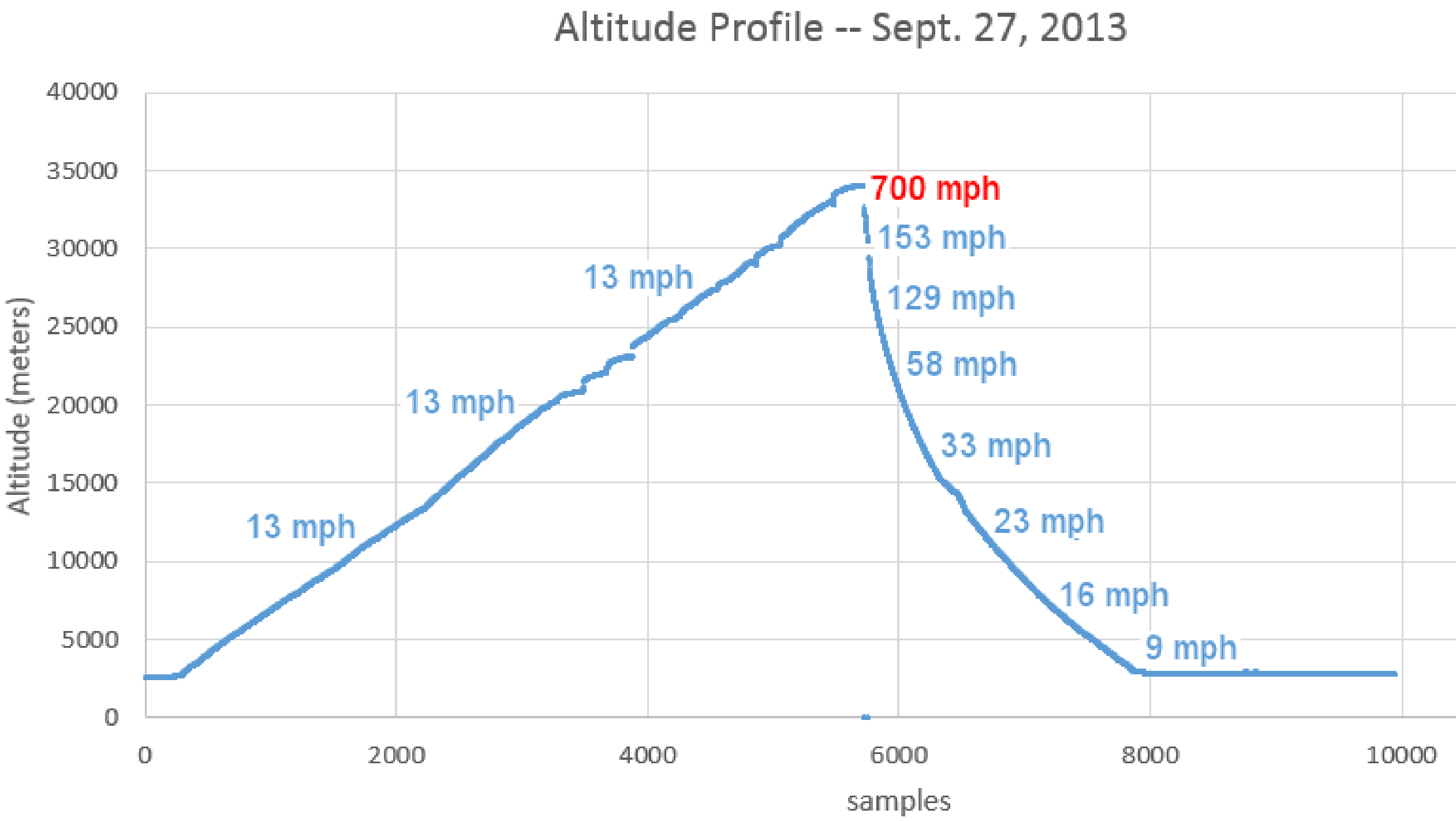


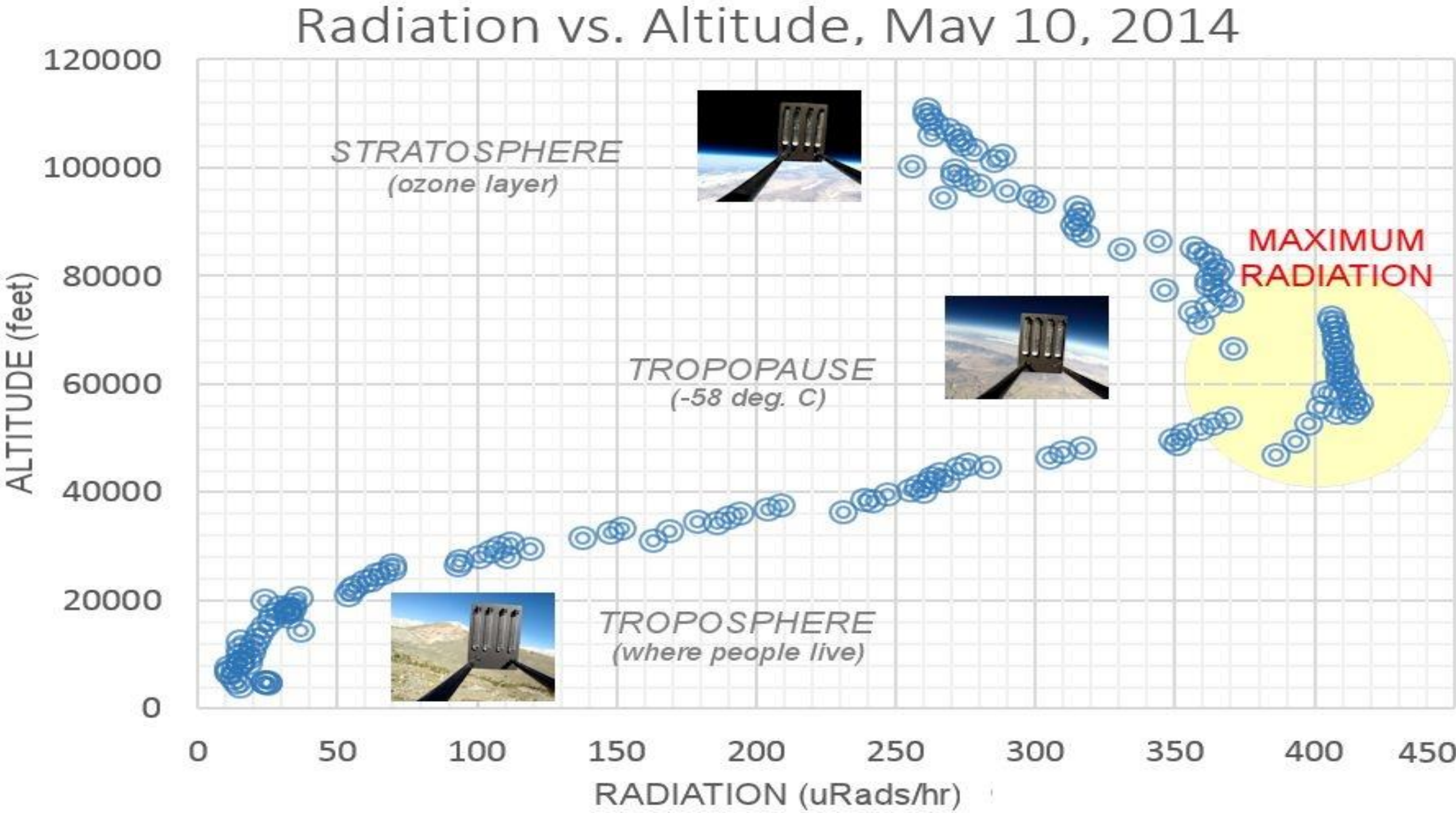
Radiation Profile -- Dec. 24, 2014




Cryogenic Temperature Data -- Mar 16, 2014
launch
landing
tropopshere
balloon pops
at 91,885 ft
tropopause
stratosphere
-64 C
Temperature (°C)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
10:35 AM
10:40 AM
10:45 AM
10:50 AM
10:55 AM
11:00 AM
11:05 AM
11:10 AM
11:15 AM
11:20 AM
11:25 AM
11:30 AM
11:35 AM
11:40 AM
11:45 AM
11:50 AM
11:55 AM
12:00 PM
12:05 PM
12:10 PM
12:15 PM
12:20 PM
12:25 PM
12:30 PM
12:35 PM
12:40 PM
Mar 16 2014


Cryogenic Temperature Data -- Mar 16, 2014
launch
GPS ALTIMETRY
GPS Altitude -- March 16, 2014
Balloon pops at 91,885 feet
1270 feet/min or 14.4 mph
tropopshere
tropopause
balloon pops at 91,885 ft
stratosphere
-64 C
landing
Temperature (°C)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
10:35 AM
10:40 AM
10:45 AM
10:50 AM
10:55 AM
11:00 AM
11:05 AM
11:10 AM
11:15 AM
11:20 AM
11:25 AM
11:30 AM
11:35 AM
11:40 AM
11:45 AM
11:50 AM
11:55 AM
12:00 PM
12:05 PM
12:10 PM
12:15 PM
12:20 PM
12:25 PM
12:30 PM
12:35 PM
12:40 PM
Mar 16 2014

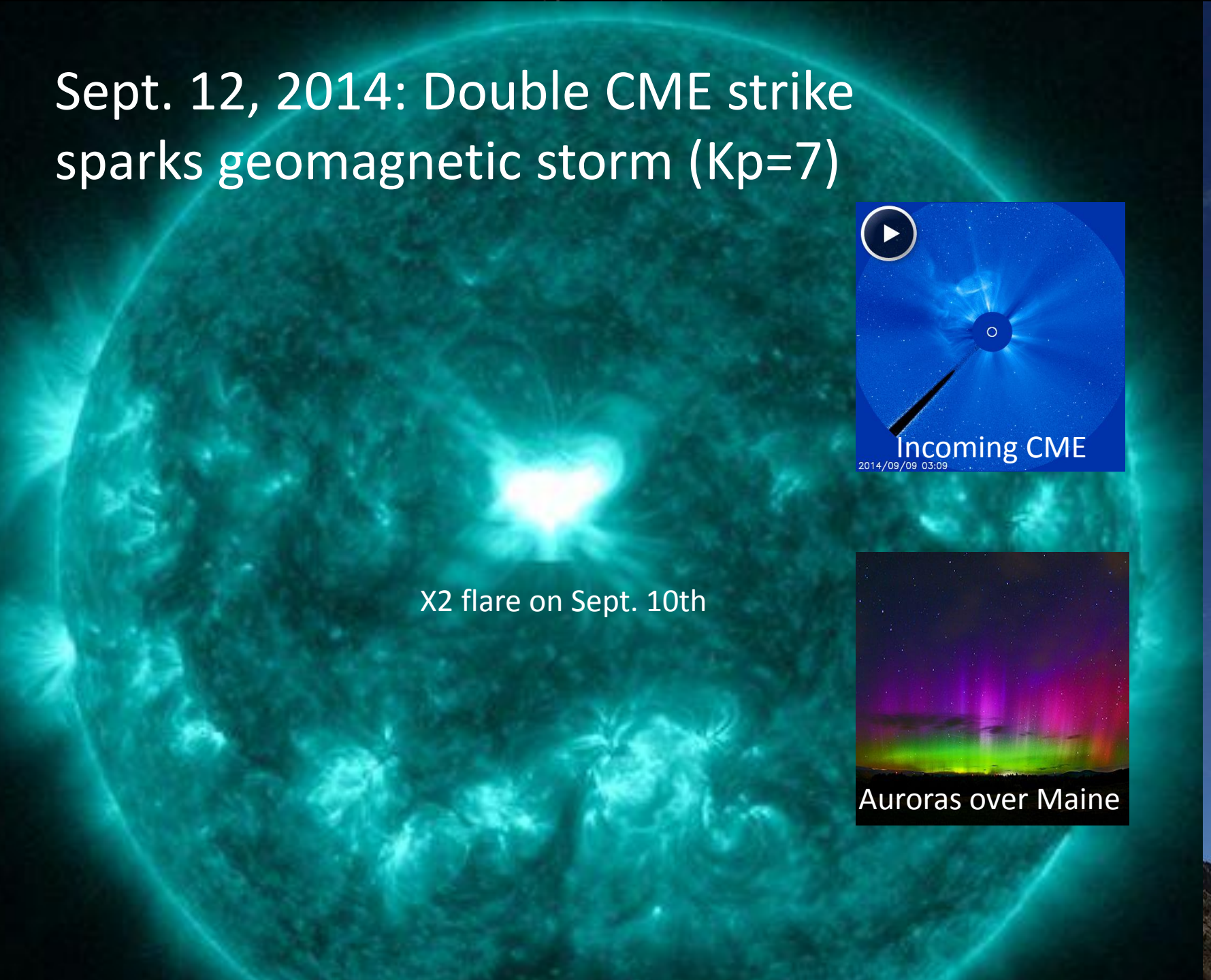

Altitude Profile -- Sept. 27, 2013
Altitude (meters)
40000
35000
30000
25000
20000
15000
10000
5000
0
0
2000
4000
6000
8000
10000
samples
13 mph
13 mph
13 mph
700 mph
153 mph
129 mph
58 mph
33 mph
23 mph
16 mph
9 mph


Radiation vs. Altitude, May 10, 2014
ALTITUDE (feet)
120000
100000
80000
60000
40000
20000
0
0
50
100
150
200
250
300
350
400
450
RADIATION (uRads/hr)
STRATOSPHERE
(ozone layer)
TROPOPAUSE
(-58 deg. C)
TROPOSPHERE
(where people live)
MAXIMUM
RADIATION

RADIATION BUOY FLIGHTS 2013-2015

- Oct. 27, 2013
- Dec. 14, 2013
- Dec. 21, 2013
- Jan. 1, 2014
- Jan. 8, 2014
- Mar. 16, 2014
- Apr. 20, 2014
- May 4, 2014
- May 10, 2014
- June 7, 2014
- June 19, 2014
- Aug. 8, 2014
- Aug. 22, 2014
- Sep. 12, 2014
- Sep. 28, 2014
- Oct. 8, 2014
- Oct. 23, 2014
- Nov. 23, 2014
- Dec. 8, 2014
- Dec. 24, 2014
- Jan 10, 2015
- Jan 14, 2015
- Jan 28, 2015
- Feb 1, 2015
- Feb. 19, 2015
- Mar 13, 2015
- Mar 17, 2015
- Mar 21, 2015
- Mar 24, 2015
- April 1, 2015

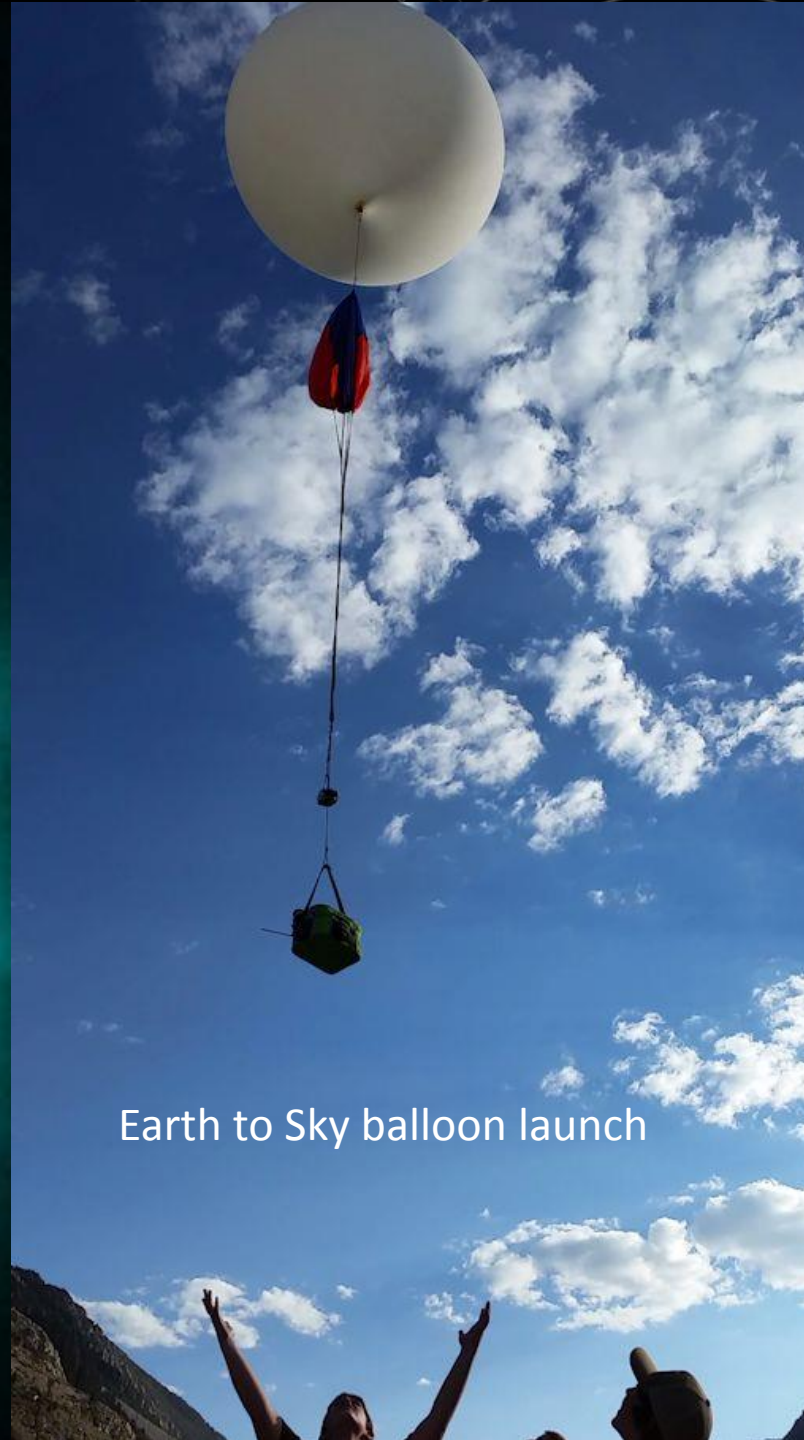
Sept. 12, 2014: Double CME strike sparks geomagnetic storm (Kp=7)



X2 flare on Sept. 10th

Incoming CME

Auroras over Maine



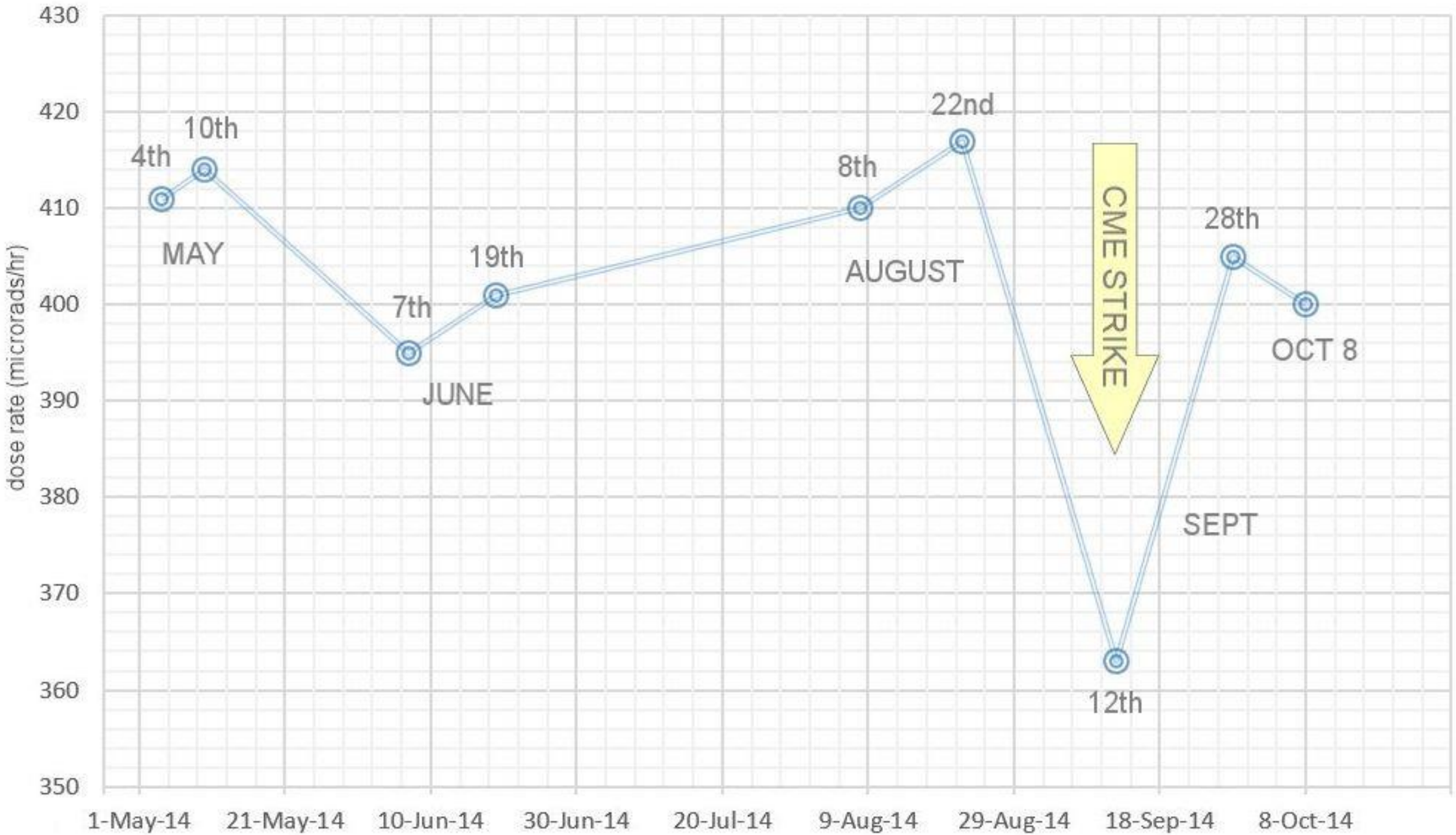
Earth to Sky balloon launch

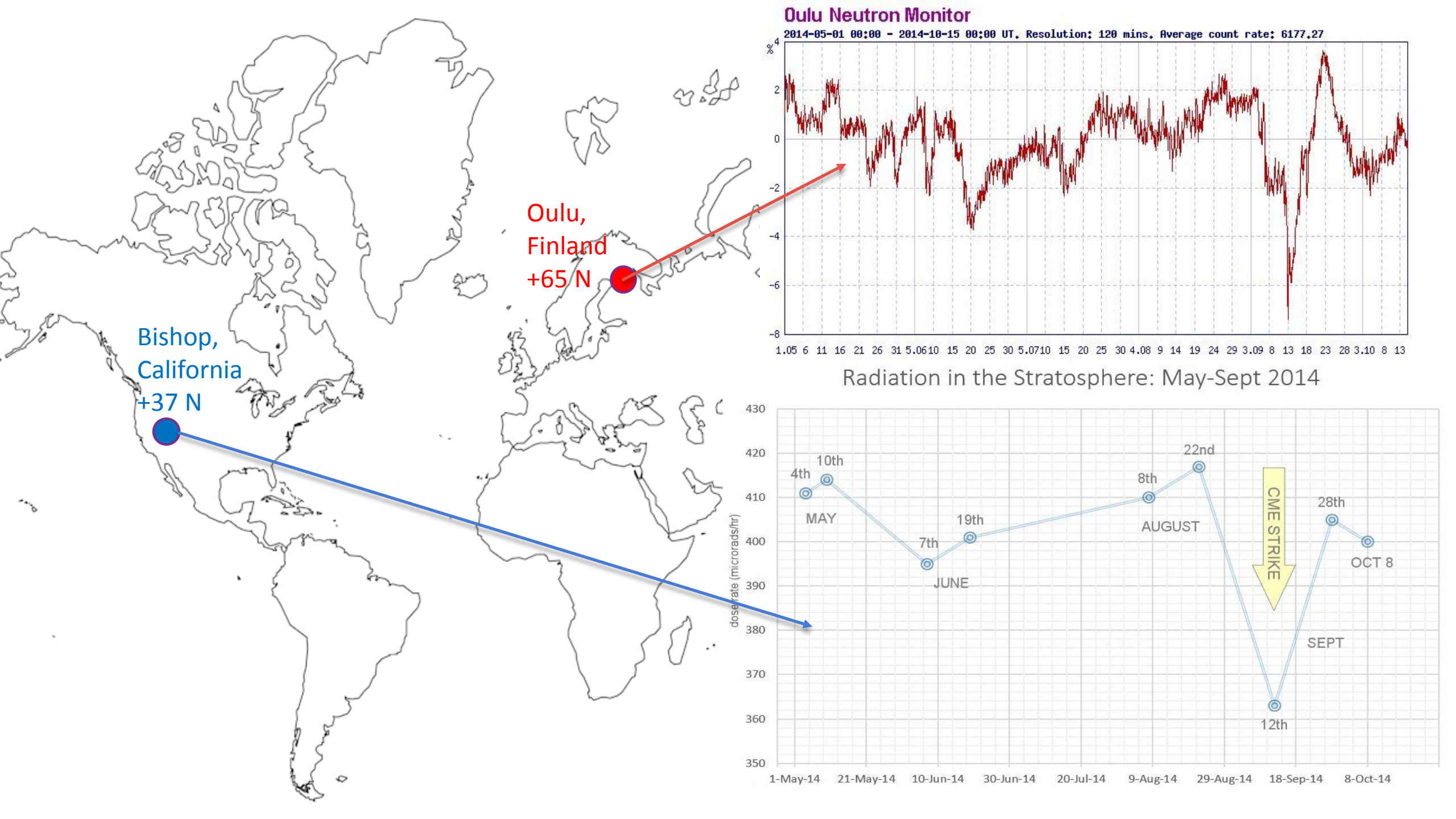
In the stratosphere on Sept. 12, 2014

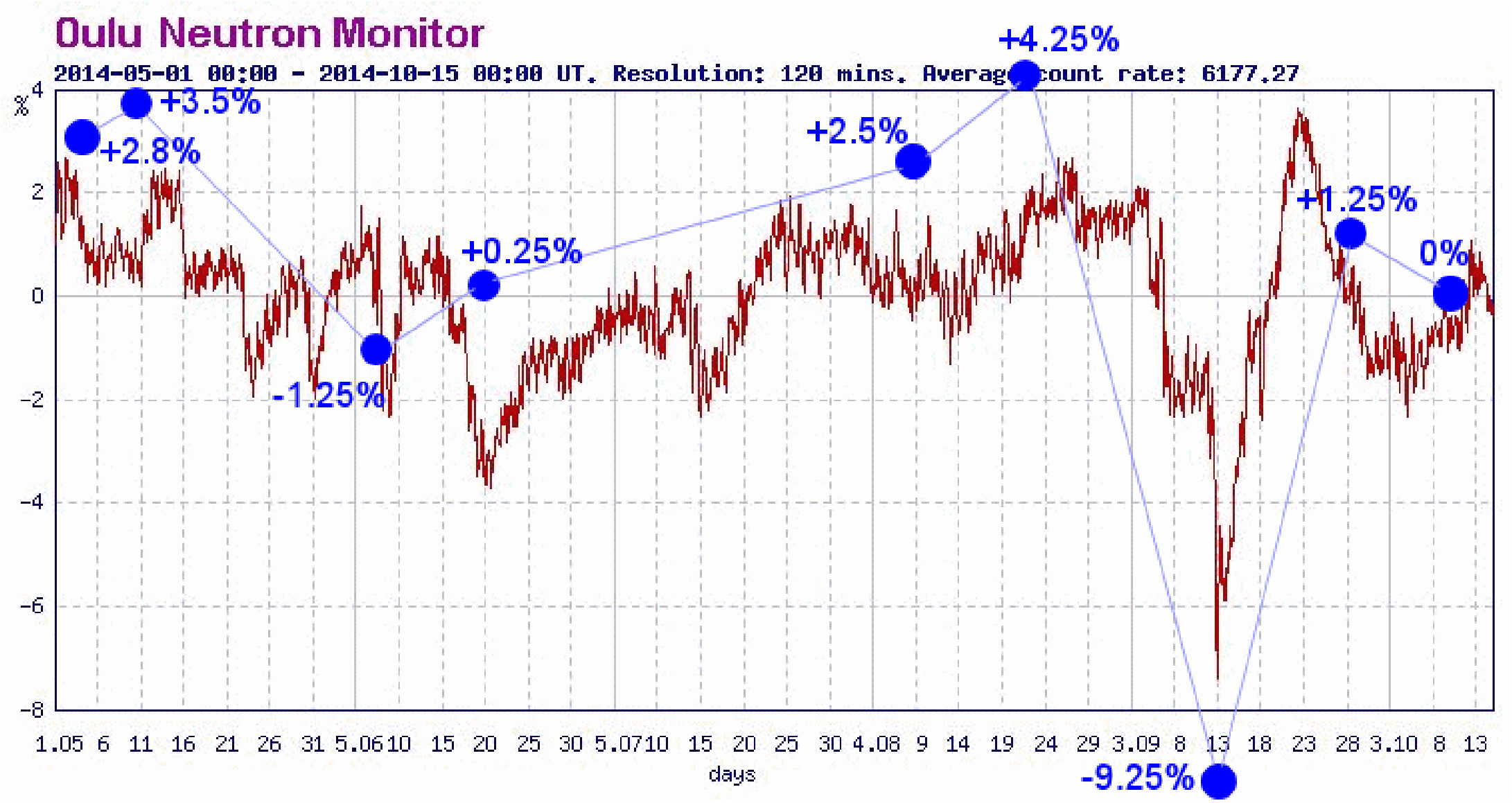
geomagnetic storm in progress….

We expected to see an **increase** in radiation……

Radiation in the Stratosphere: May-Sept 2014

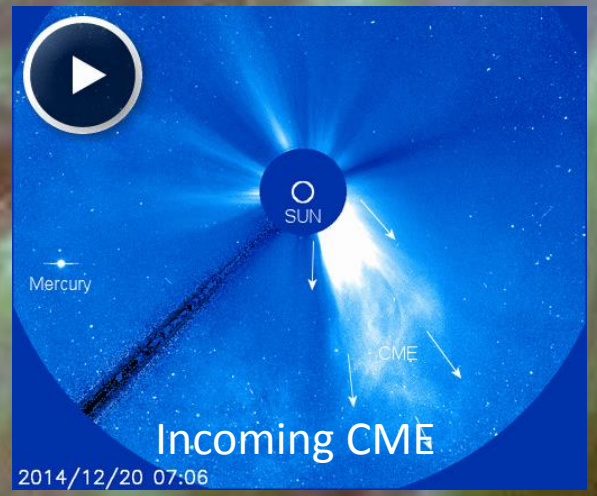


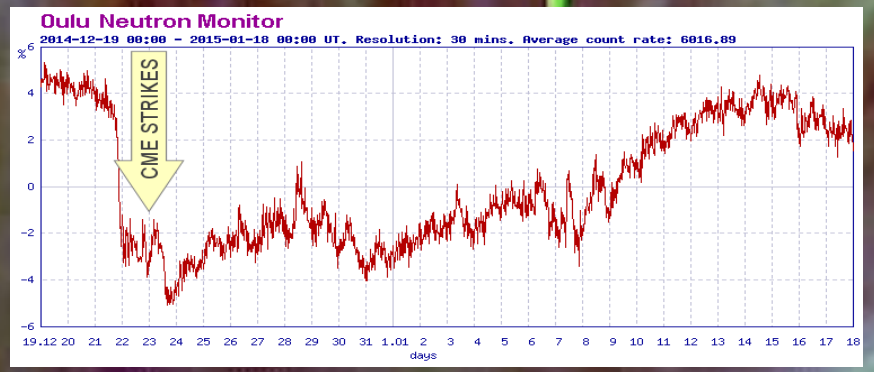

Oulu Neutron Monitor
2014-05-01 00:00 - 2014-10-15 00:00 UT. Resolution: 120 mins. Average count rate: 6177.27
%
4
2
0
-2
-4
-6
-8
1.05 6 11 16 21 26 31 5.06 10 15 20 25 30 5.07 10 15 20 25 30 4.08 9 14 19 24 29 3.09 8 13 18 23 28 3.10 8 13
Oulu,
Finland
+65 N
Bishop,
California
+37 N
Radiation in the Stratosphere: May-Sept 2014
dose rate (microrads/hr)
430
420
410
400
390
380
370
360
350
4th
10th
MAY
7th
19th
JUNE
8th
22nd
AUGUST
CME STRIKE
12th
28th
SEPT
OCT 8
1-May-14
21-May-14
10-Jun-14
30-Jun-14
20-Jul-14
9-Aug-14
29-Aug-14
18-Sep-14
8-Oct-14


Oulu Neutron Monitor
2014-05-01 00:00 - 2014-10-15 00:00 UT, Resolution: 120 mins, Average count rate: 6177.27
%
4
2
0
-2
-4
-6
-8
+2.8%
+3.5%
-1.25%
+0.25%
+2.5%
+4.25%
-9.25%
+1.25%
0%
1.05 6 11 16 21 26 31 5.06 10 15 20 25 30 5.07 10 15 20 25 30 4.08 9 14 19 24 29 3.09 8 13 18 23 28 3.10 8 13
days

Dec 21-22: Double CME impact sparks minor geomagnetic storm (Kp=5)

X2-class flare on Dec. 20th



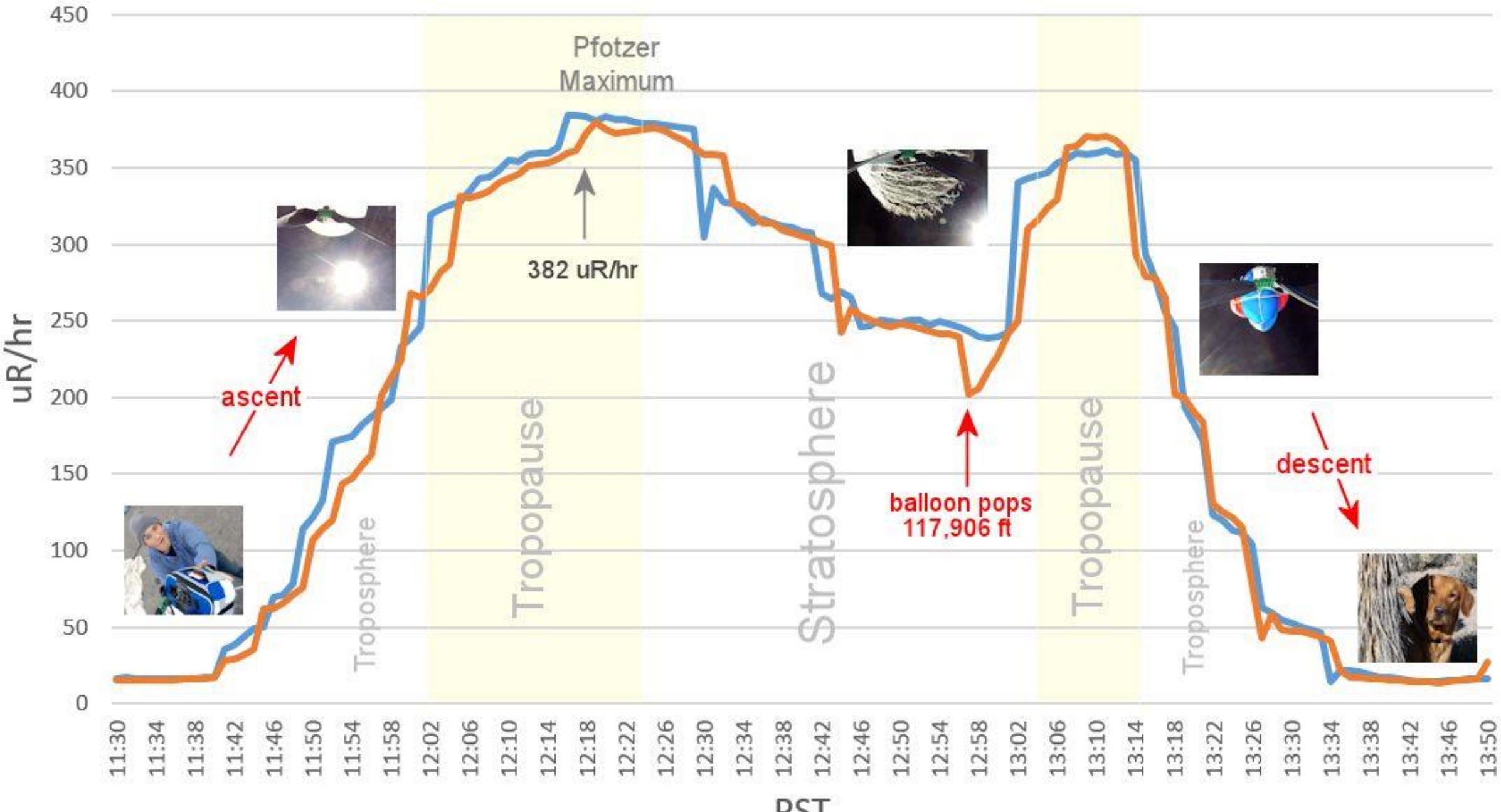


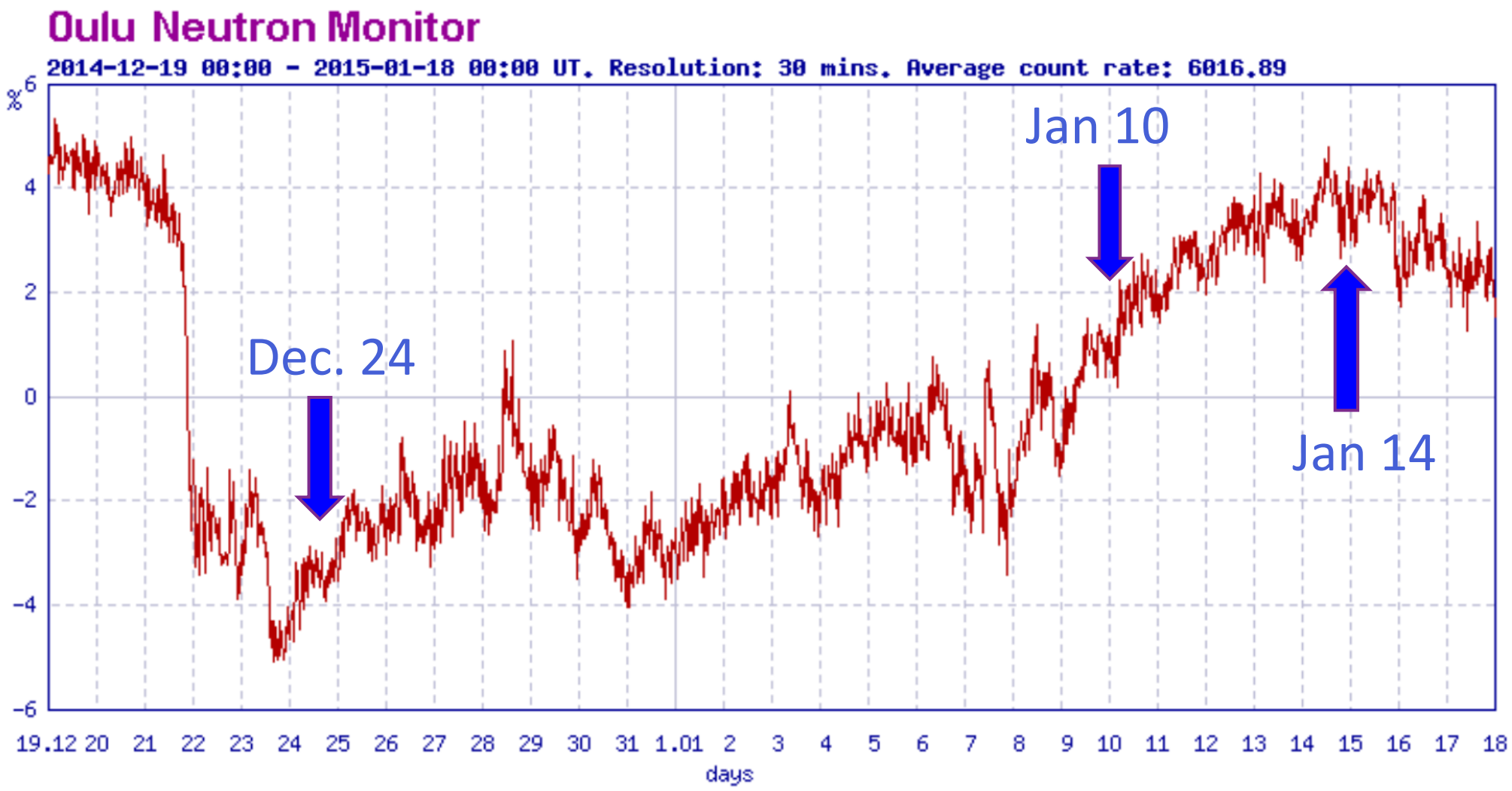
Dec. 24: Earth to Sky Balloon Launch

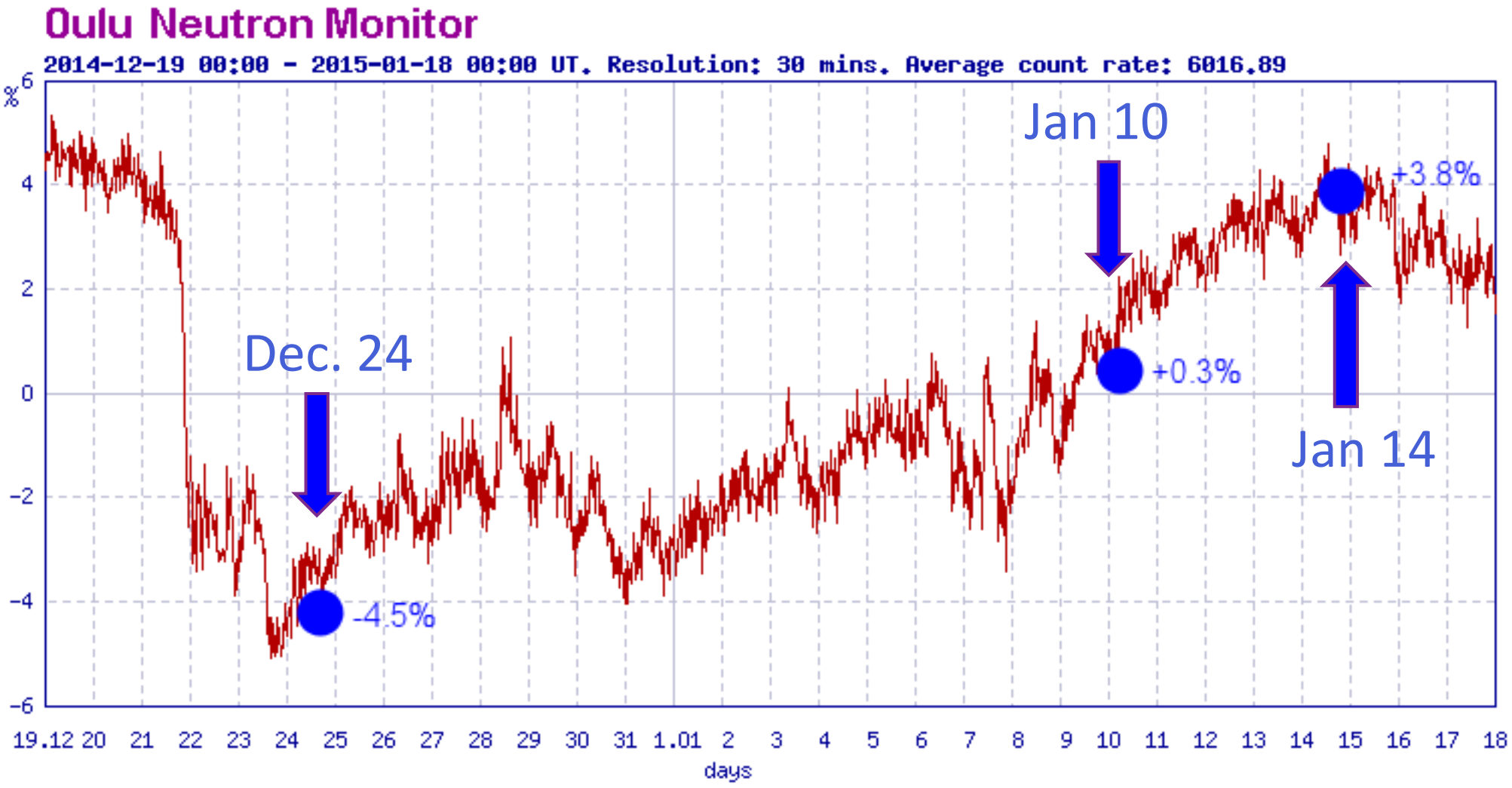
In the stratosphere on Dec. 24, 2014

Forbush Decrease in progress…..

Radiation Profile -- Dec. 24, 2014

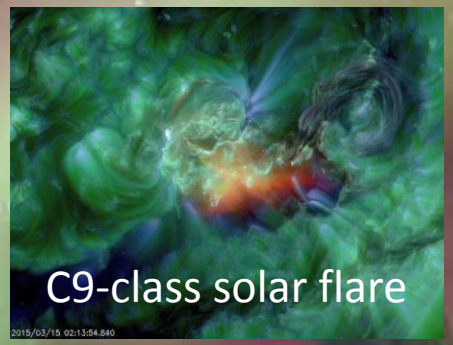



Oulu Neutron Monitor
2014-12-19 00:00 - 2015-01-18 00:00 UT. Resolution: 30 mins. Average count rate: 6016.89
%
6
4
2
0
-2
-4
-6
Dec. 24
Jan 10
Jan 14
19.12 20 21 22 23 24 25 26 27 28 29 30 31 1.01 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
days


Oulu Neutron Monitor
2014-12-19 00:00 - 2015-01-18 00:00 UT. Resolution: 30 mins. Average count rate: 6016.89
%
6
4
2
0
-2
-4
-6
Jan 10
Dec. 24
Jan 14
+3.8%
+0.3%
-4.5%
19.12 20 21 22 23 24 25 26 27 28 29 30 31 1.01 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
days

March 17, 2015

A glancing blow from a CME sparks the strongest geomagnetic storm of the current solar cycle (Kp=8)

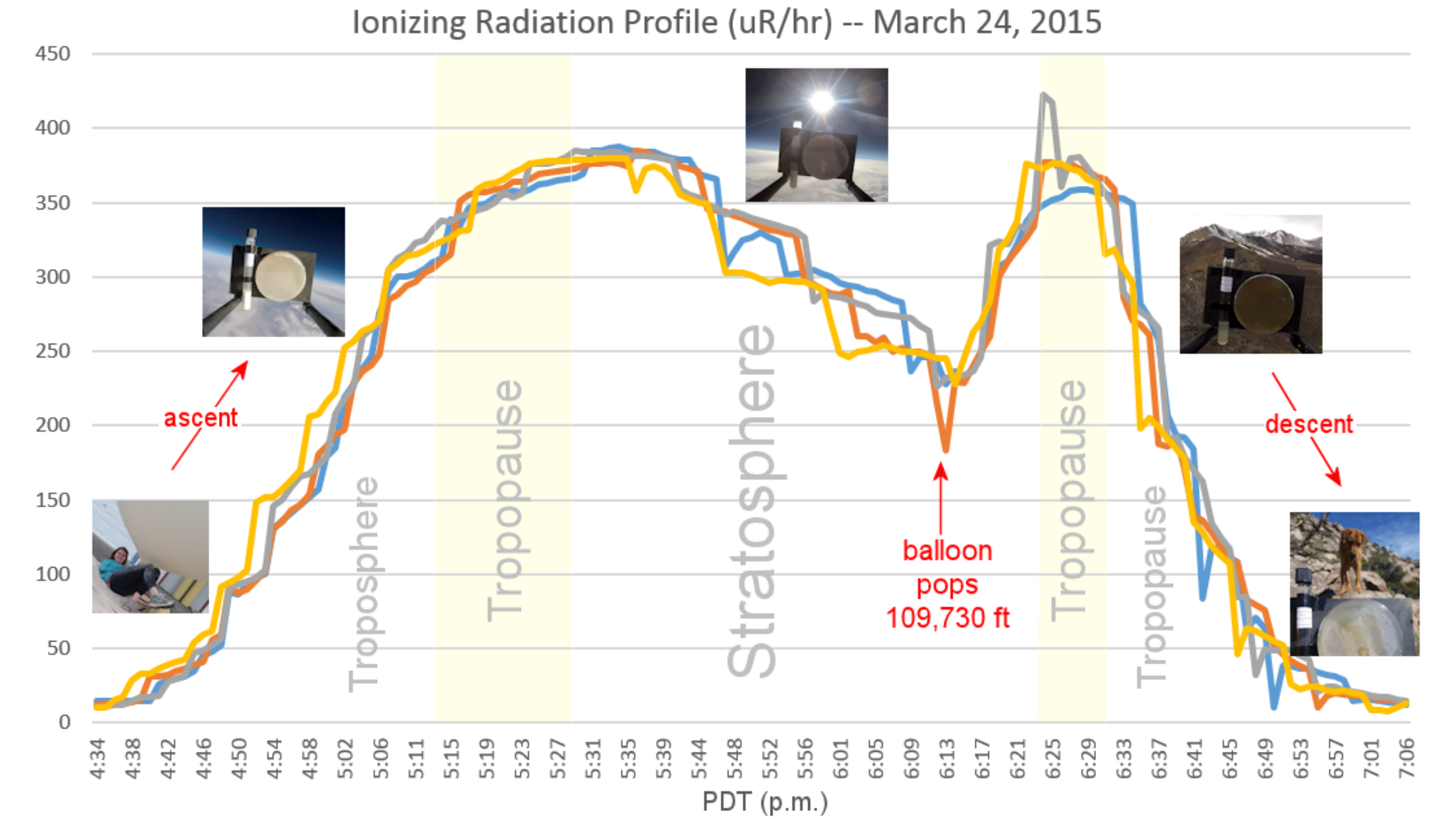


Auroras over Alaska

Earth to Sky balloon launch

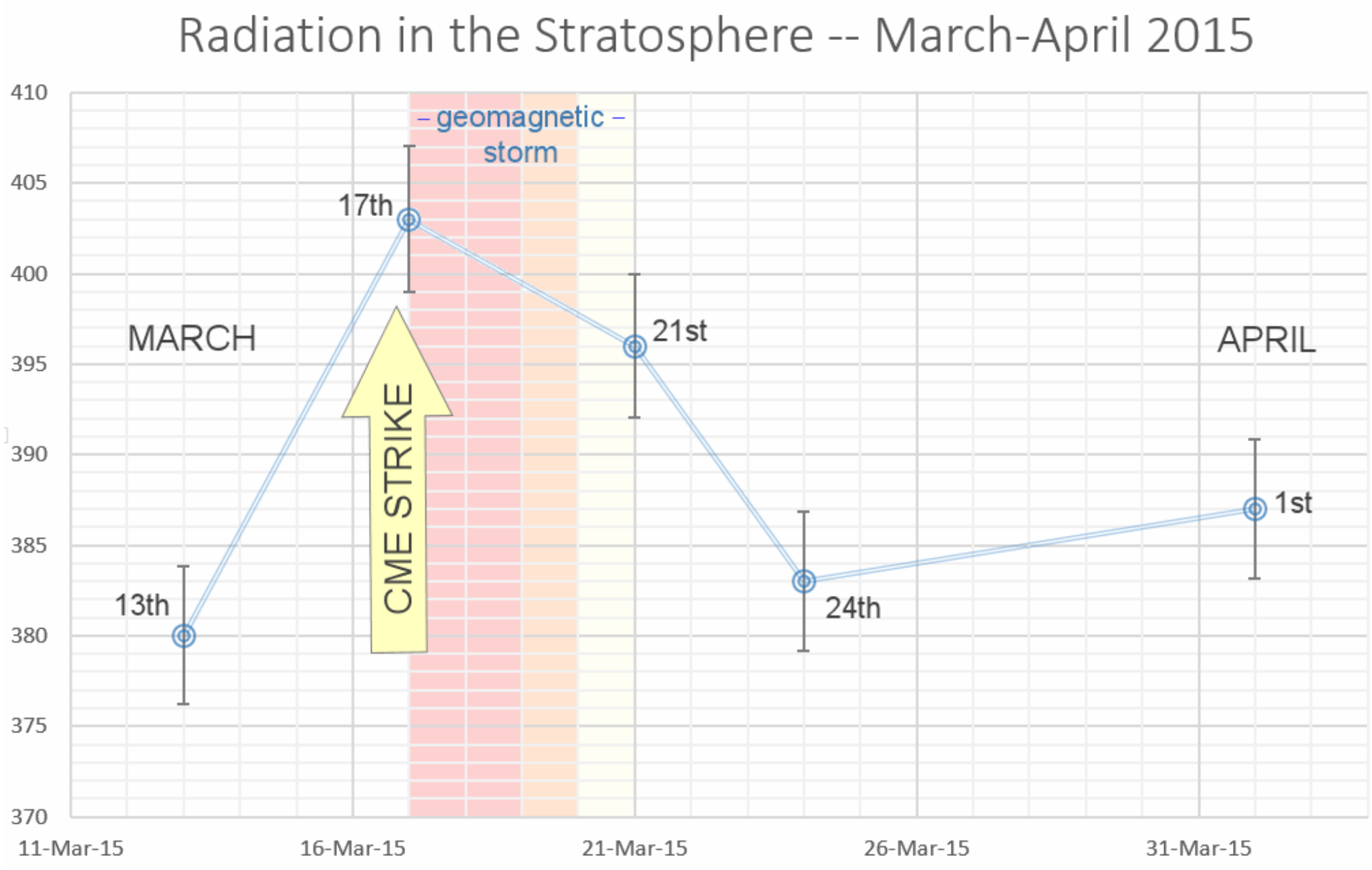
In the stratosphere on March 17, 2015

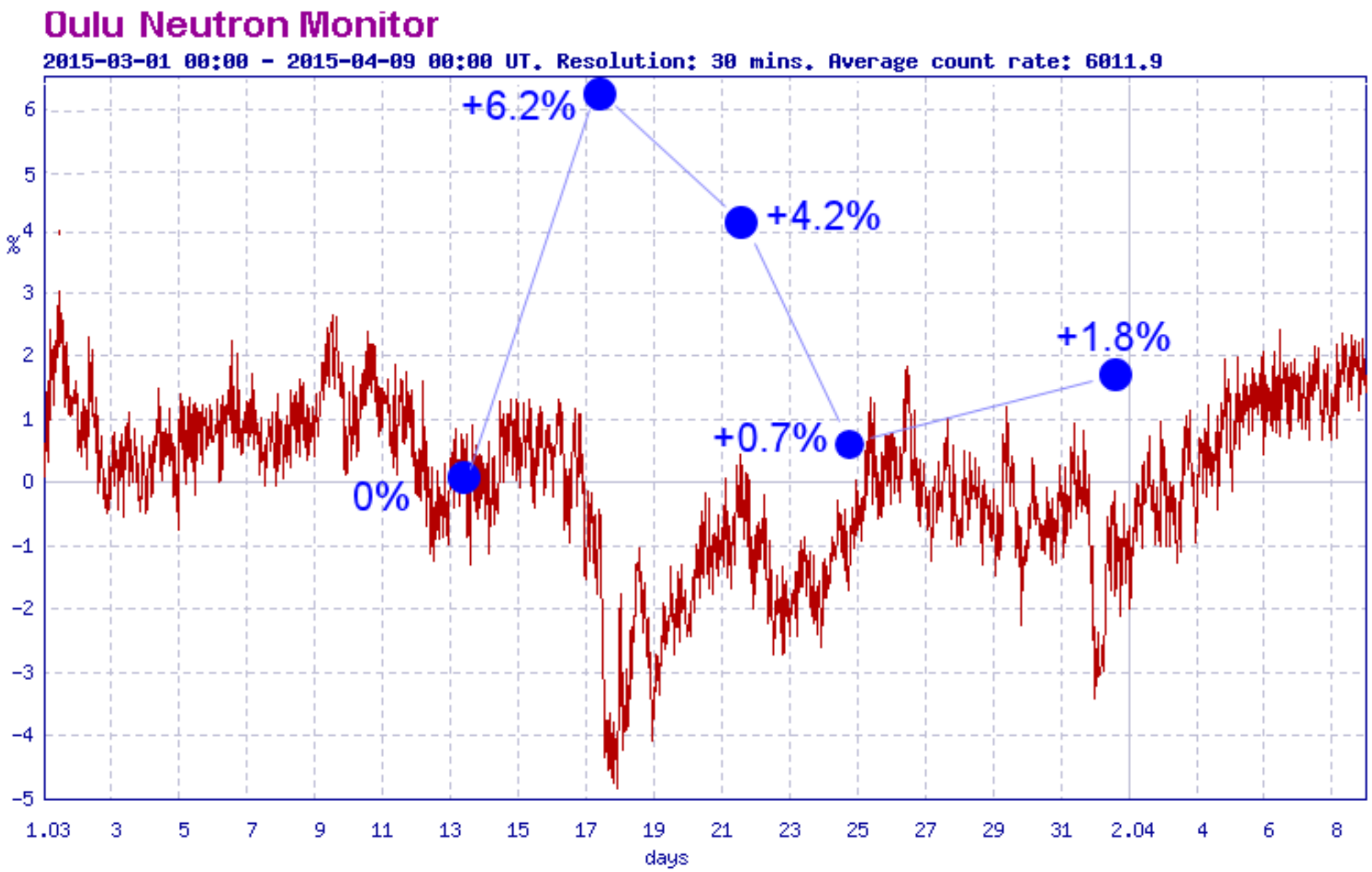
Geomagnetic storm in progress……

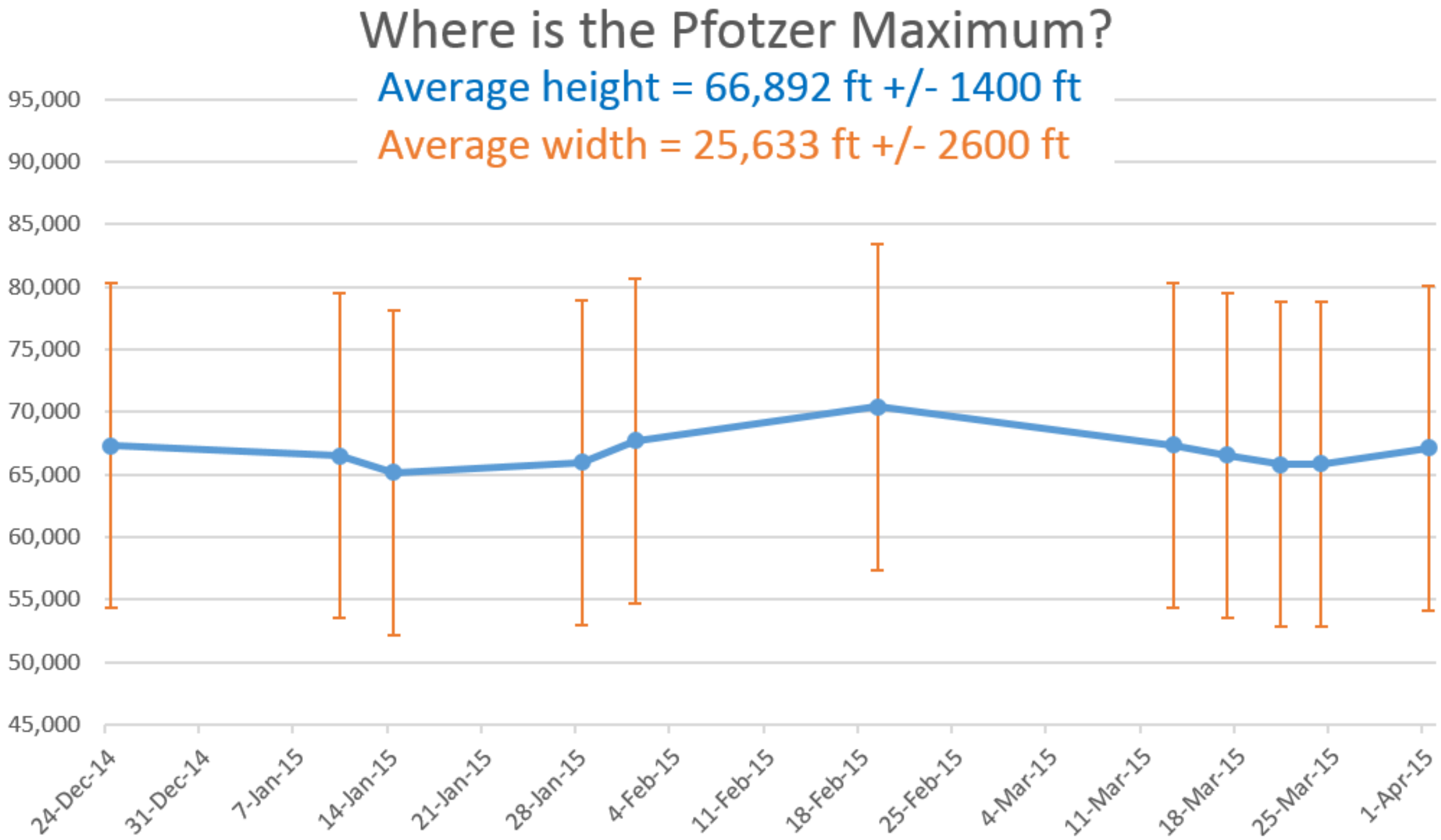

Ionizing Radiation Profile (uR/hr) -- March 24, 2015
450
400
350
300
250
200
150
100
50
0
ascent
Troposphere
Tropopause
Stratosphere
balloon
pops
109,730 ft
Tropopause
Tropopause
descent
4:34
4:38
4:42
4:46
4:50
4:54
4:58
5:02
5:06
5:11
5:15
5:19
5:23
5:27
5:31
5:35
5:39
5:44
5:48
5:52
5:56
6:01
6:05
6:09
6:13
6:17
6:21
6:25
6:29
6:33
6:37
6:41
6:45
6:49
6:53
6:57
7:01
7:06
PDT (p.m.)

(6 months wiser….)

We expected to see a ~~increase~~ **decrease** in radiation……


Radiation in the Stratosphere -- March-April 2015
410
405
400
395
390
385
380
375
370
– geomagnetic –
storm
17th
21st
MARCH
APRIL
CME STRIKE
1st
13th
24th
11-Mar-15
16-Mar-15
21-Mar-15
26-Mar-15
31-Mar-15


Oulu Neutron Monitor
2015-03-01 00:00 - 2015-04-09 00:00 UT. Resolution: 30 mins. Average count rate: 6011.9
+6.2%
+4.2%
+1.8%
+0.7%
0%
%
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
1.03
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
2.04
4
6
8
days

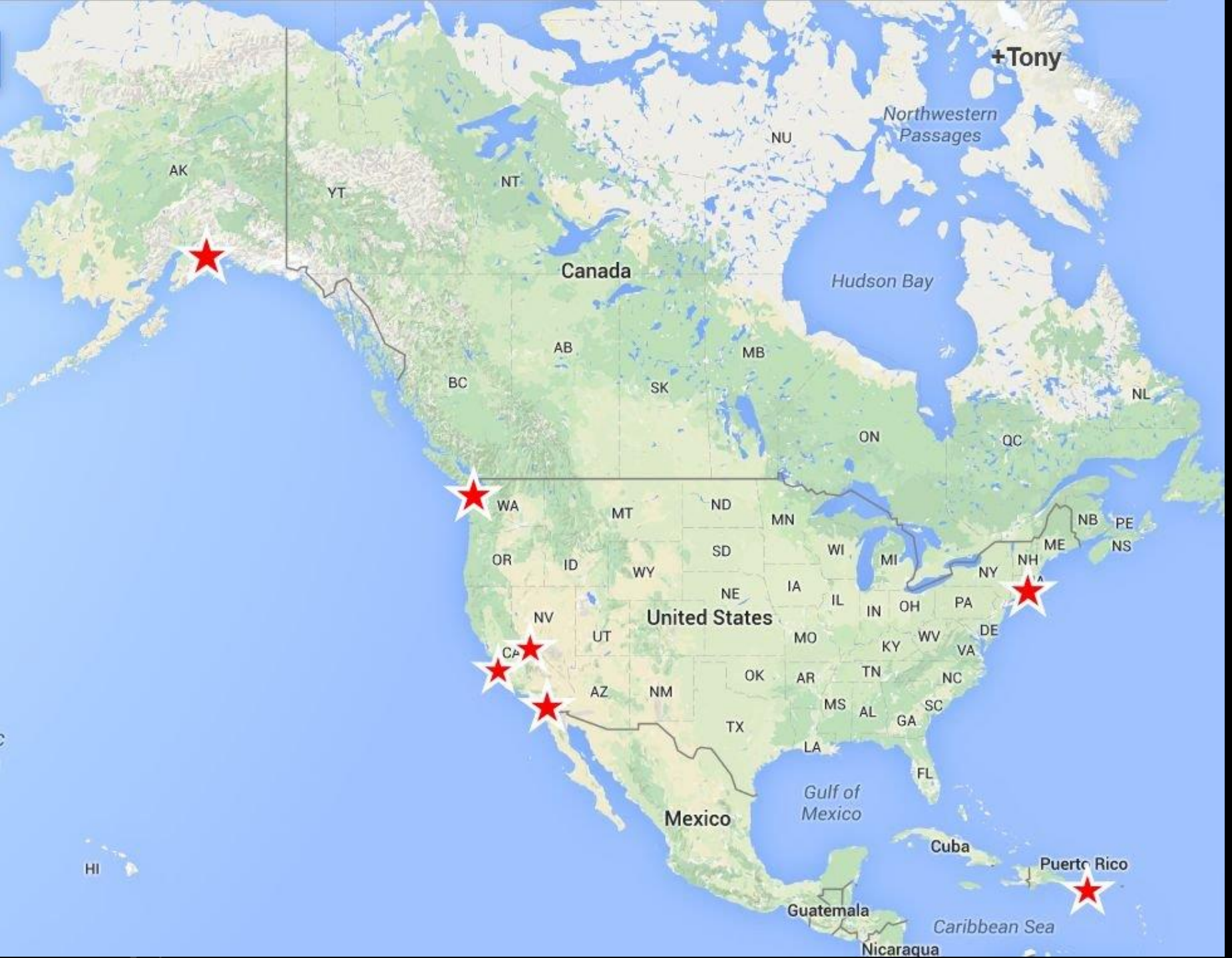

Where is the Pfotzer Maximum?
Average height = 66,892 ft +/- 1400 ft
Average width = 25,633 ft +/- 2600 ft
95,000
90,000
85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
24-Dec-14
31-Dec-14
7-Jan-15
14-Jan-15
21-Jan-15
28-Jan-15
4-Feb-15
11-Feb-15
18-Feb-15
25-Feb-15
4-Mar-15
11-Mar-15
18-Mar-15
25-Mar-15
1-Apr-15

What’s Next?

1. **Cross calibrate our sensors** with more sophisticated instruments and particle beams

2. **Summer in Brazil!** In June we will conduct a simultaneous balloon launch from California and Brazil—right into the South Atlantic Anomaly.

3. **Add Neutron Detectors** to our payload



North American Space Weather Balloon Network

Anchorage, AK
Palo Alto, CA
Berkeley, CA
San Diego, CA
Bishop, CA
Wellesley, MA
Seattle, WA
Arecibo PR

RADS ON A PLANE

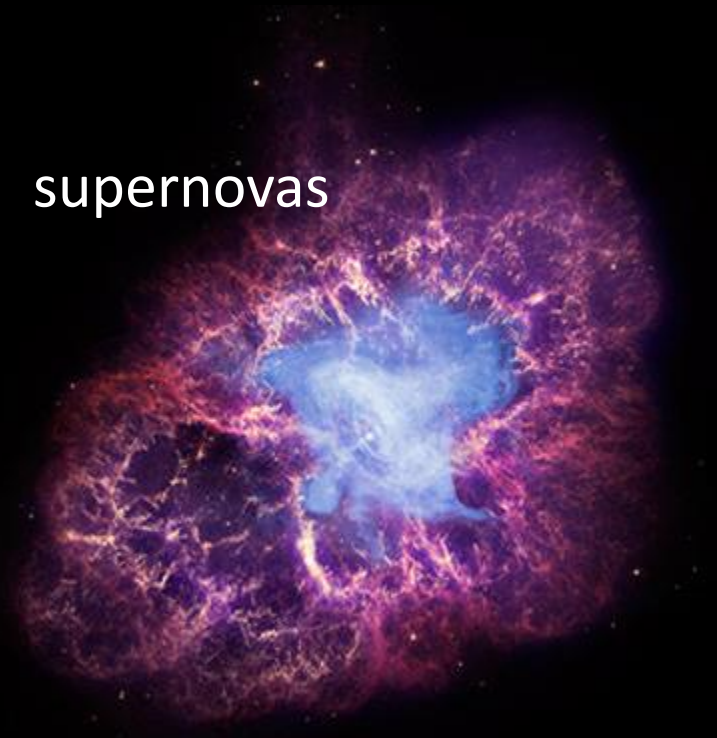
PILOTS ARE “OCCUPATIONAL RADIATION WORKERS”

(passengers are exposed too – 100,000 miles = 20 chest X-rays)

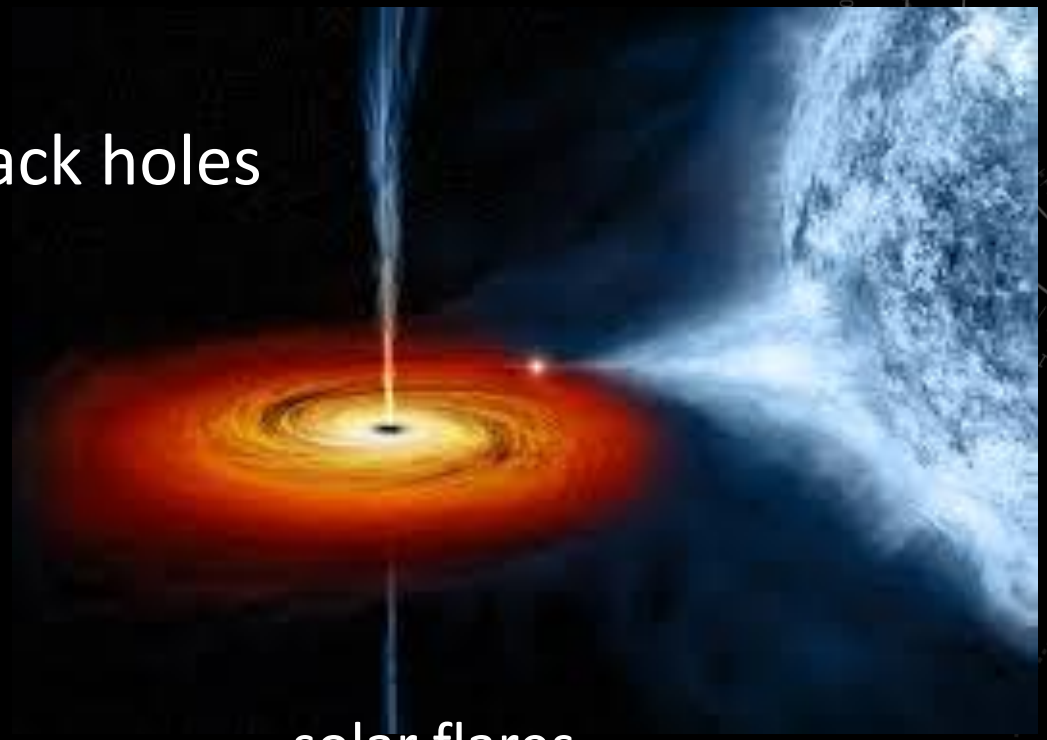
High-altitude radiation measurements are also important for space tourism

WHERE DOES THIS RADIATION COME FROM?

supernovas

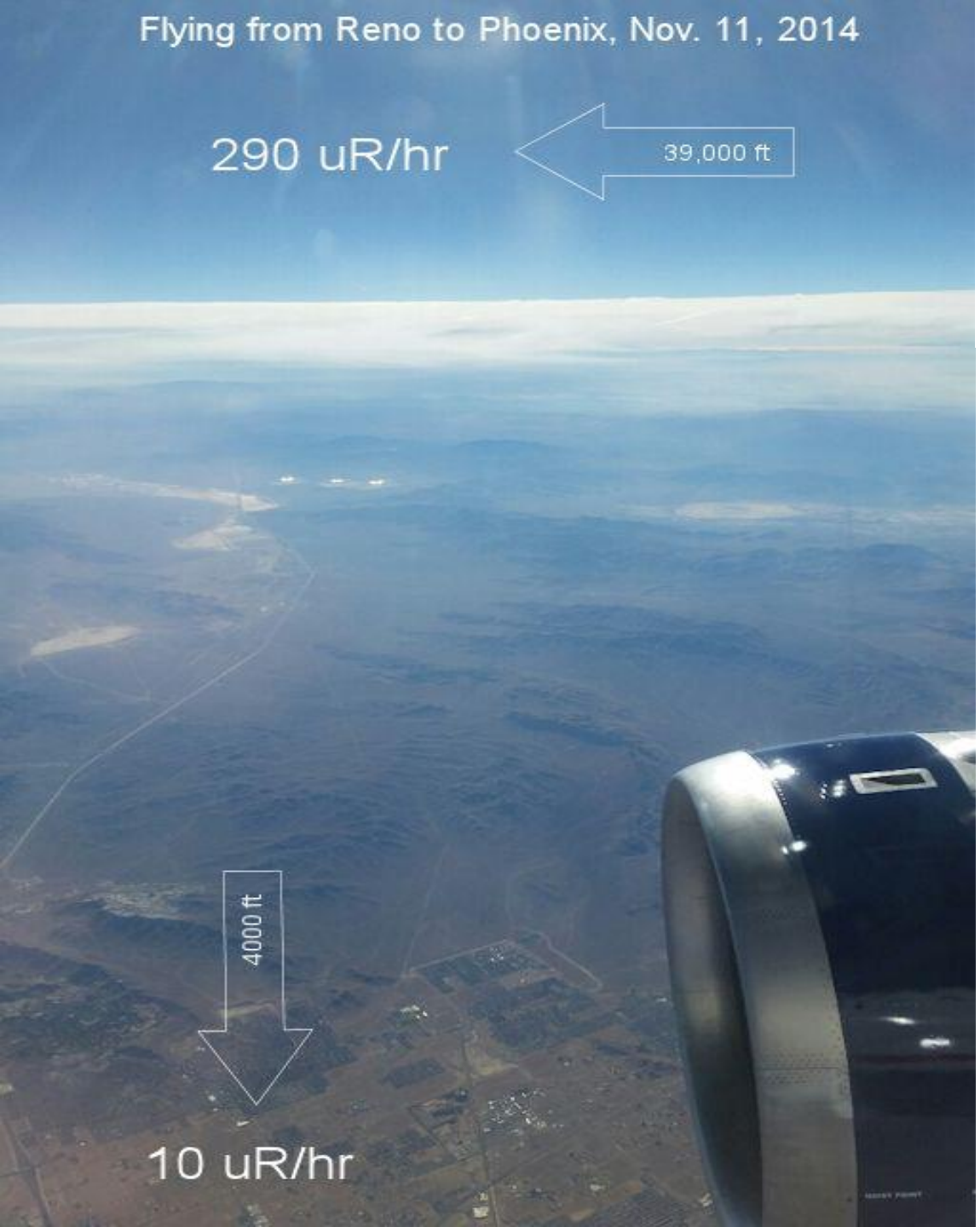


black holes

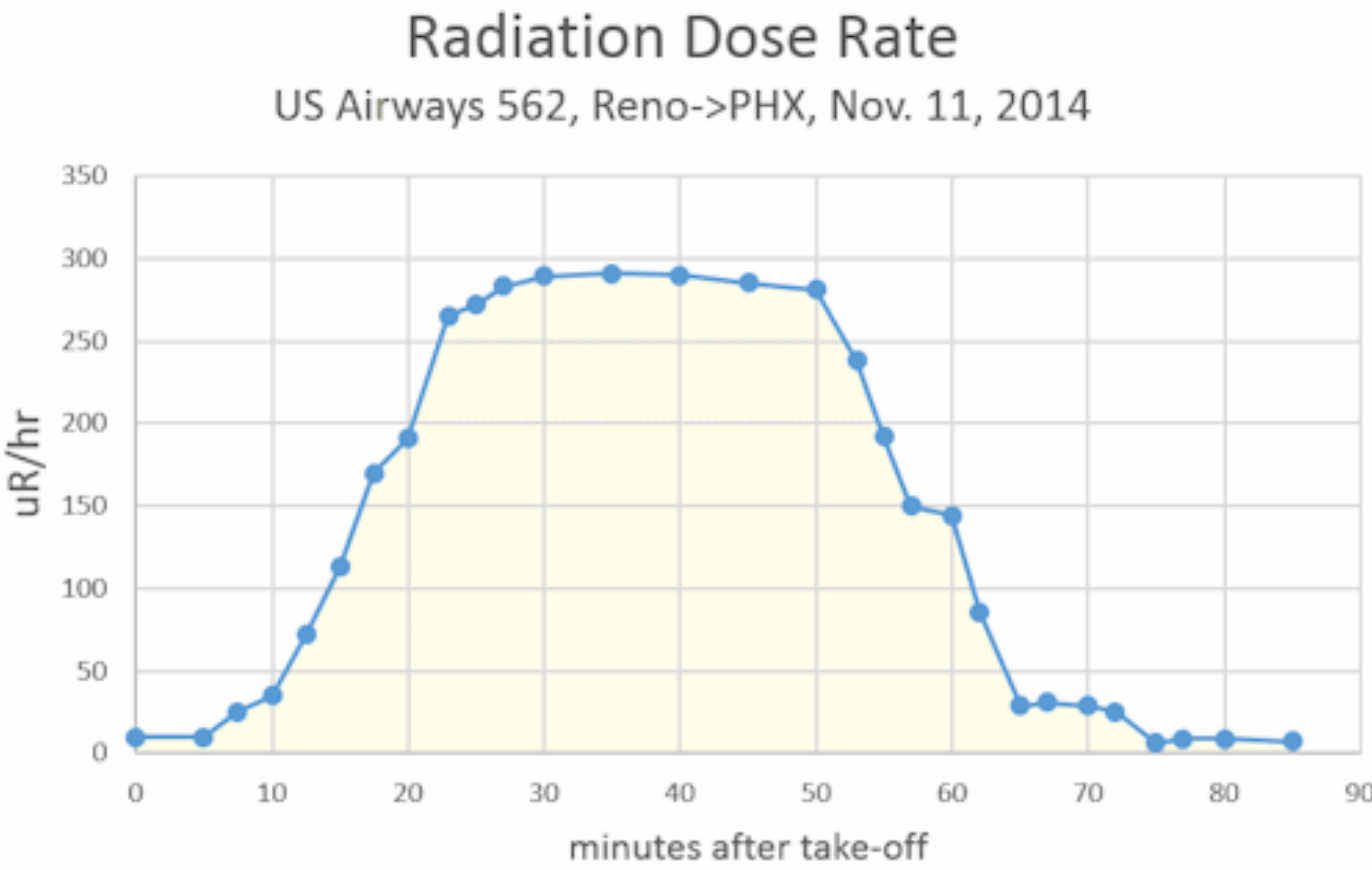


solar flares

COSMIC RAYS

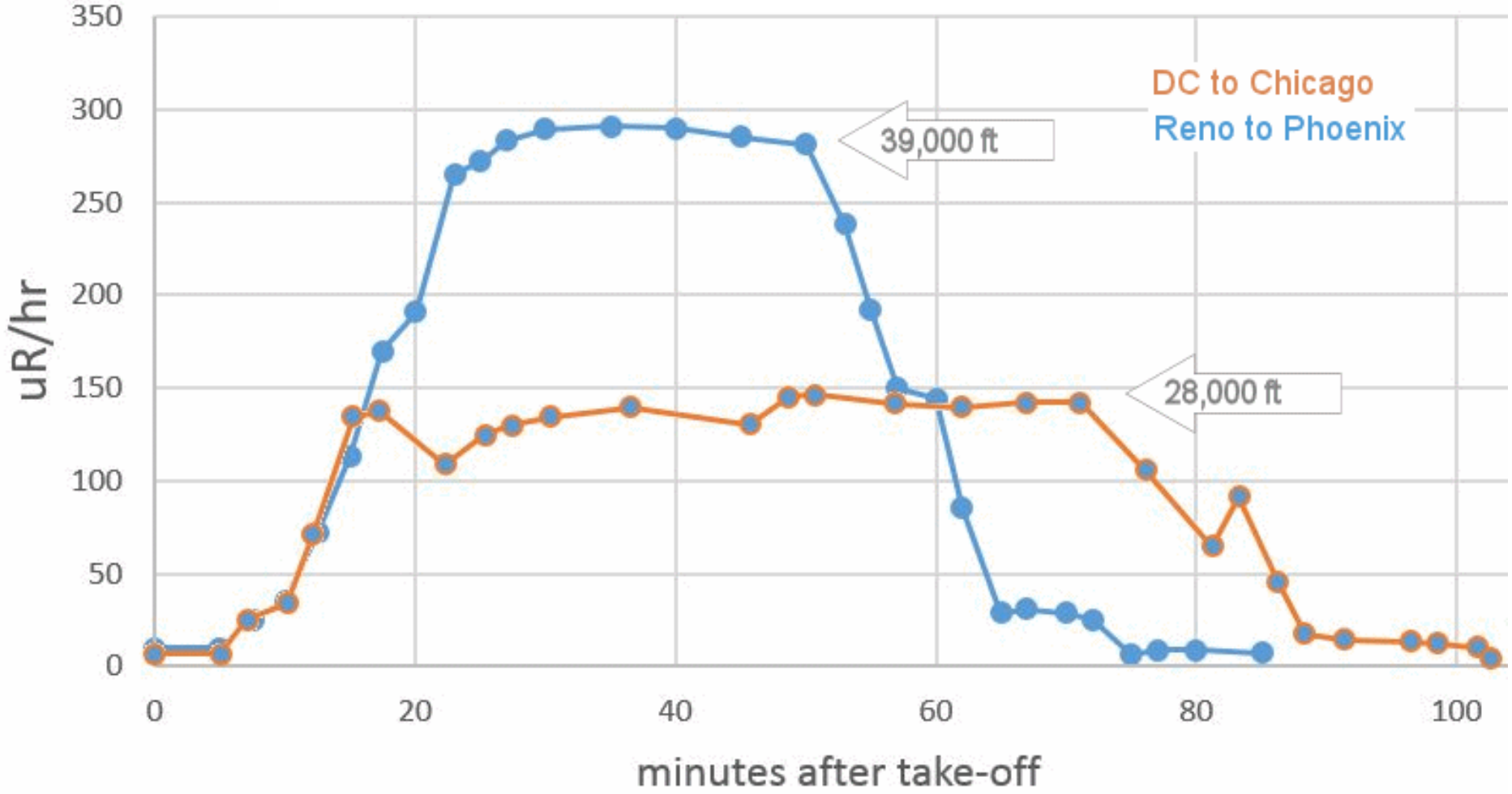


RADS ON A PLANE: On Nov. 11th, we flew from California to Washington DC. We took a radiation sensor onboard the plane—the same one we fly on our balloons. During the apex of the flight to DC, cruising 39,000 feet above the desert between Reno and Phoenix, we recorded a dose rate almost **30 times higher** than on the ground below:



What a difference 11,000 feet makes

November 2014 NSF trip

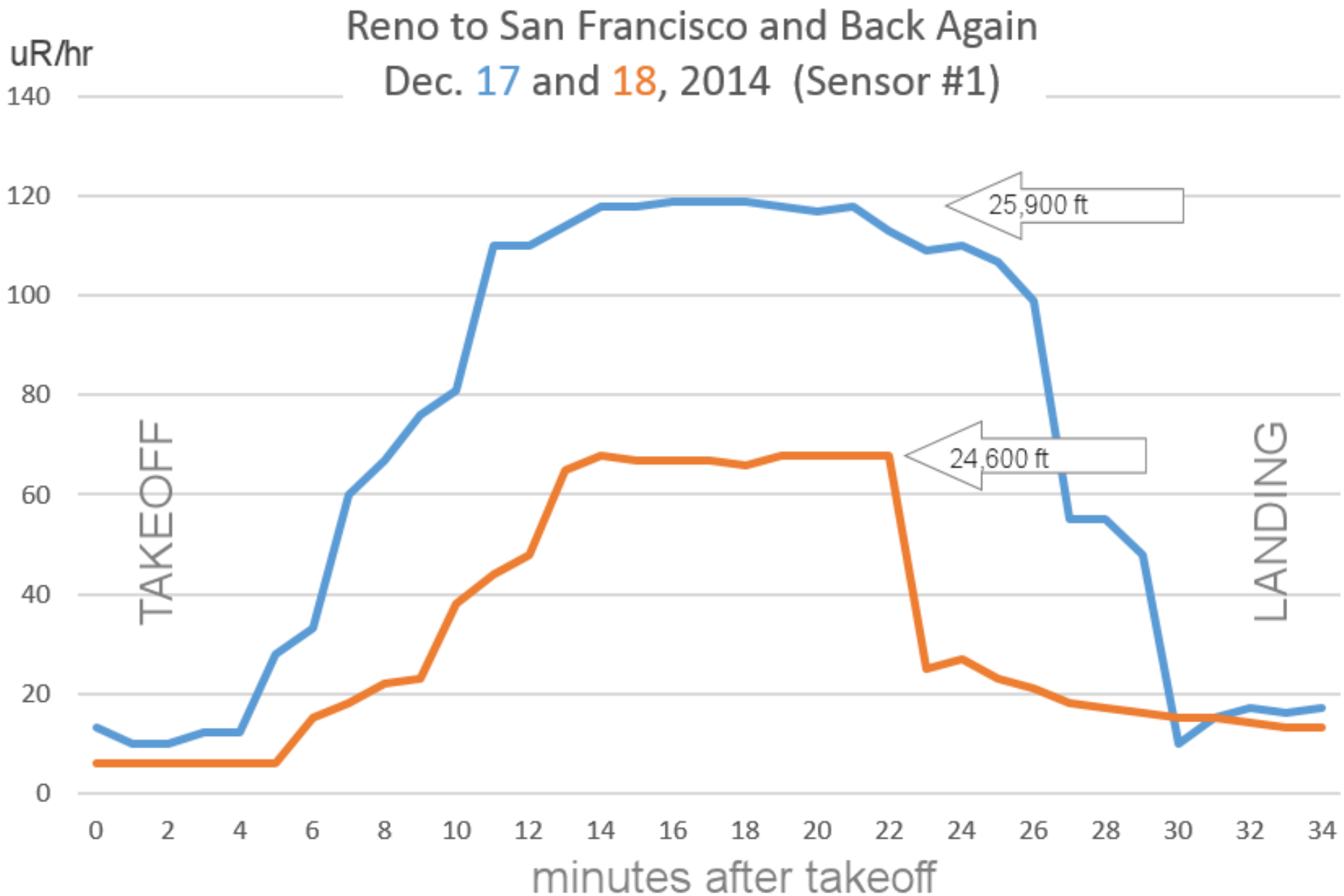


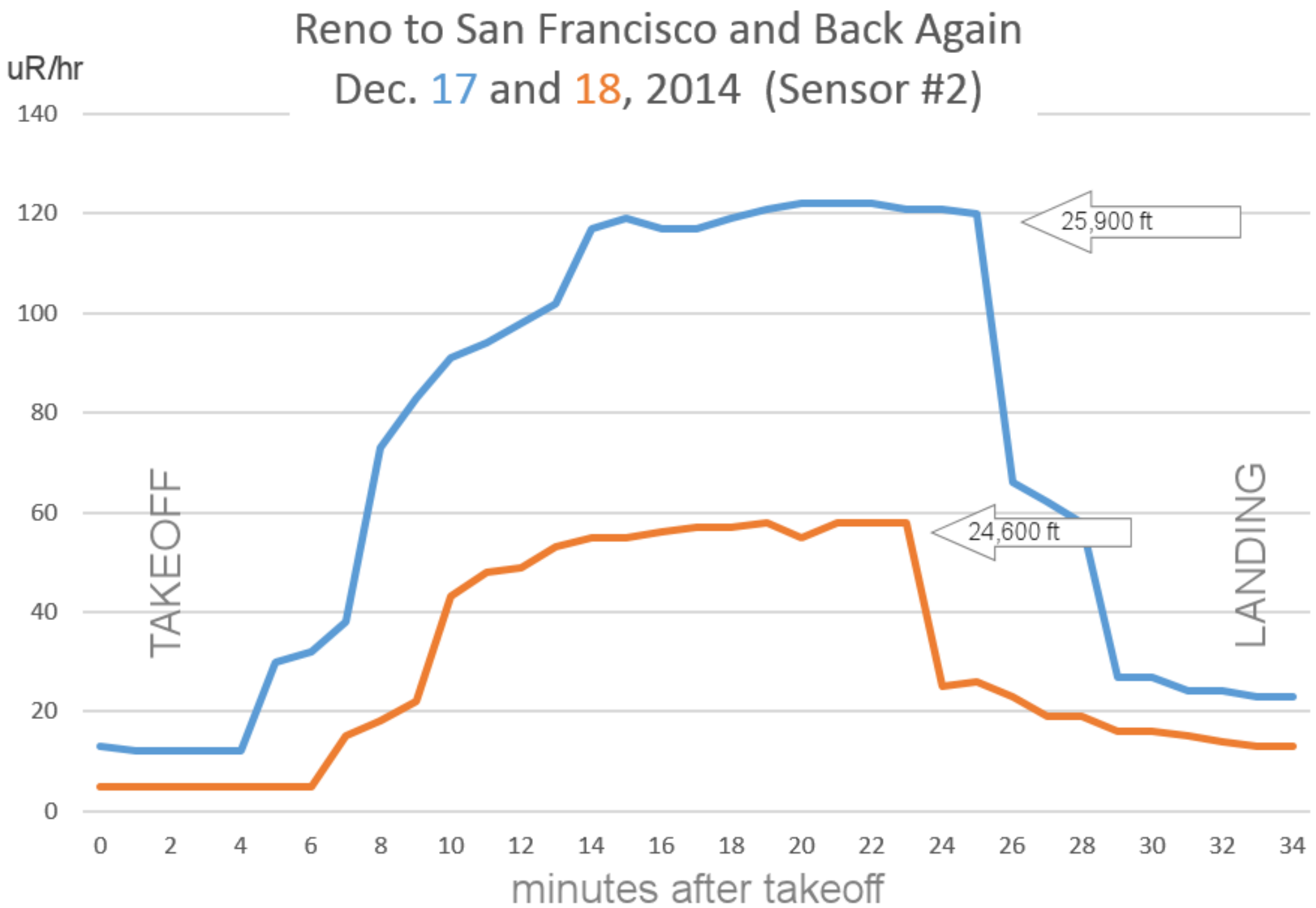
The radiation inside these planes comes from space--that is, cosmic rays that penetrate Earth's atmosphere and reach down to aviation altitudes. In the plot we can see what a difference altitude makes: Cruising at 39,000 feet, the Reno to Phoenix flight was closer to space and thus experienced double the radiation of the DC to Chicago flight cruising at 28,000 feet. Altitudes in this plot are as reported by the pilots.

Passenger Safety
Information
CRJ900
M
POLIMASTER
POLIMASTER

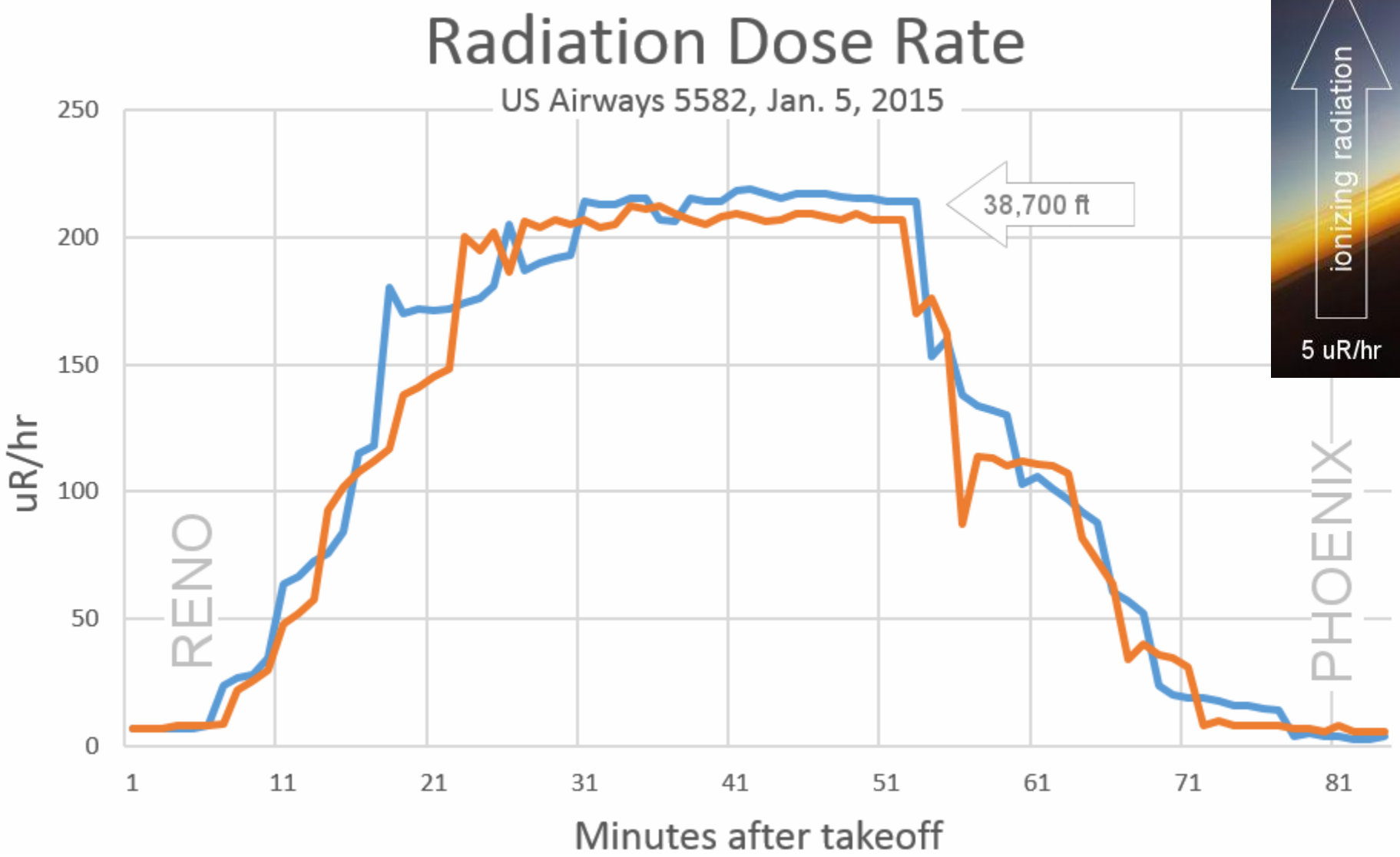
What a difference 1,100 feet makes

December 2014 AGU trip




Reno to San Francisco and Back Again
Dec. 17 and 18, 2014 (Sensor #2)
uR/hr
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
minutes after takeoff
TAKEOFF
LANDING
25,900 ft
24,600 ft

Reno to Phoenix again -- Jan. 5, 2015



At the same altitude, dose rates were 40% lower than in Nov. 2014

WHY?

In the stratosphere on Sept. 12, 2014

geomagnetic storm in progress….

Sunset in the Stratosphere

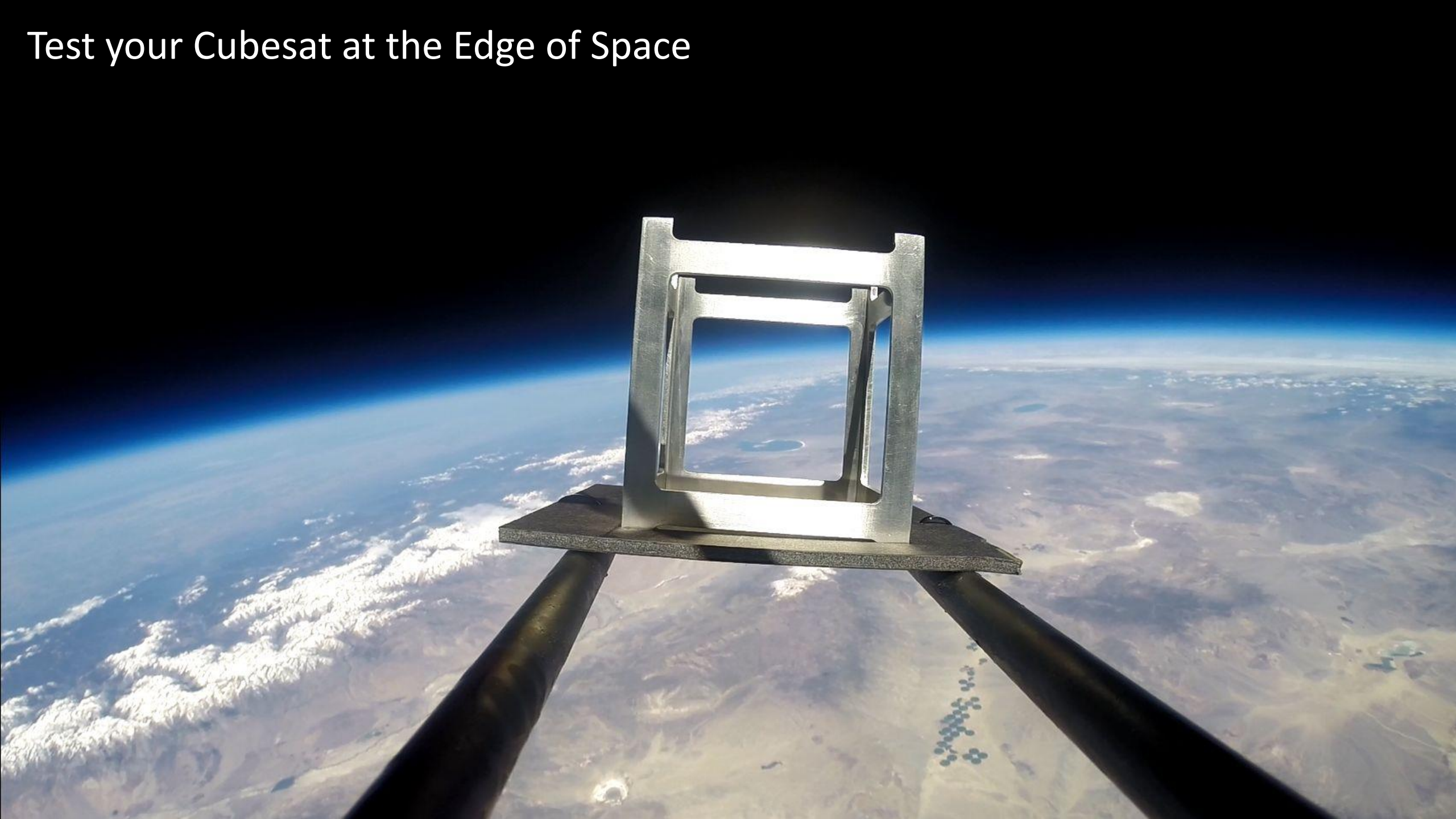
HOW DO WE PAY FOR ALL THIS?

EARTH TO SKY CALCULUS LLC

GP020621

14:41

Test your Cubesat at the Edge of Space

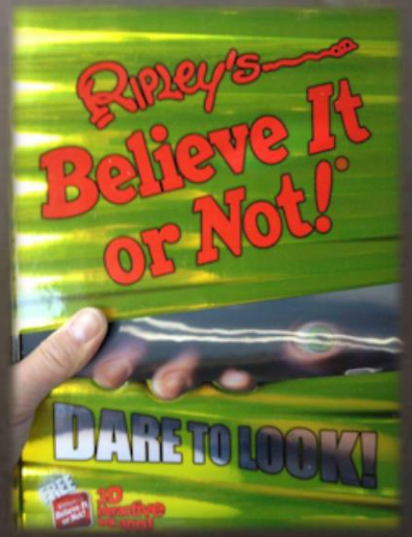


Earth to Sky Calculus LLC

Amelia Koske-Phillips, Michael White, Sam Johnson, Justin Gilpin, Carson Reid, Olivia Grah, Rachel Molina, Ginger Perez, Aaron Lamb

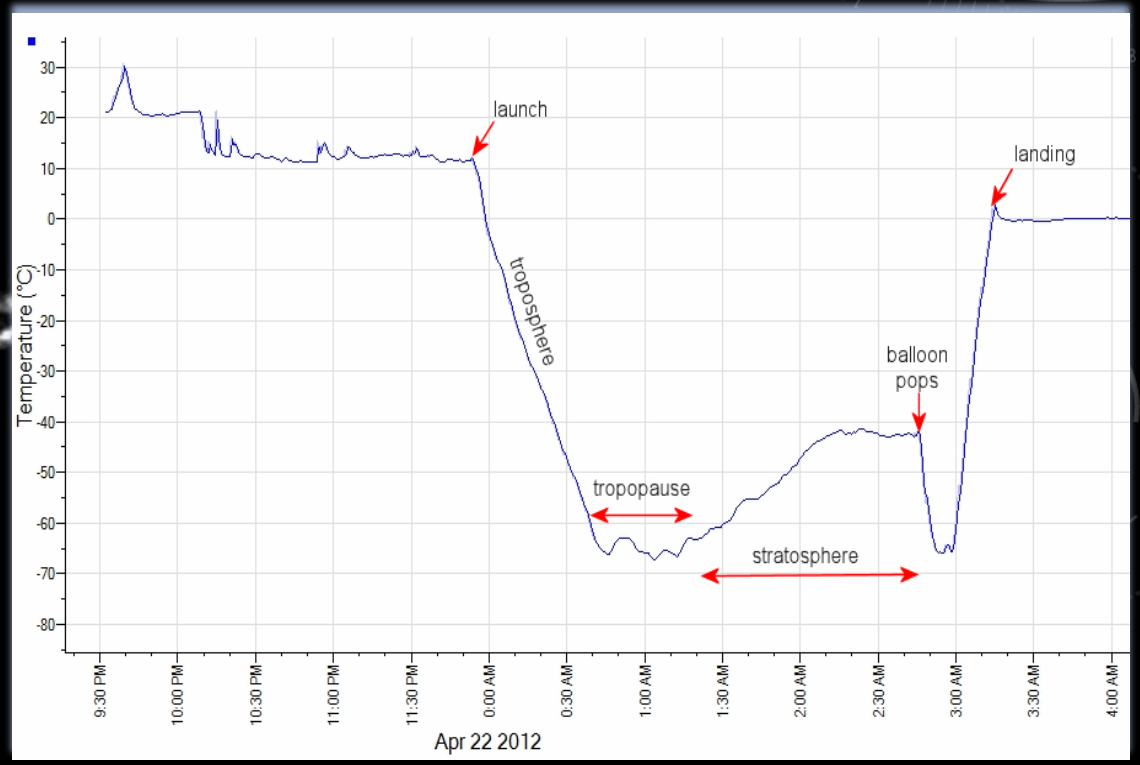
Time Magazine

Top 100 Pictures of 2012

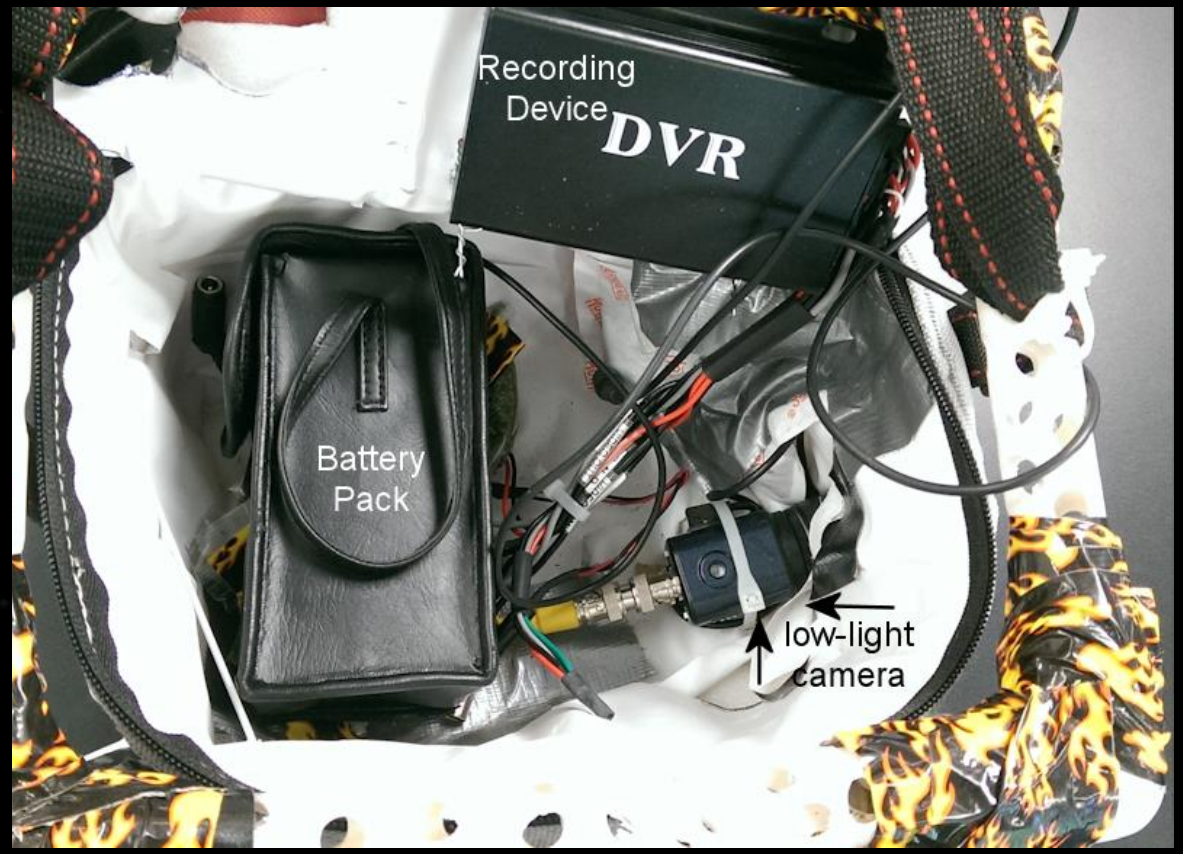


PHOTOGRAPHING METEOR SHOWERS (LYRIDS AND ORIONIDS)

Balloon payloads floating in the calm stratosphere make an excellent platform for astrophotography

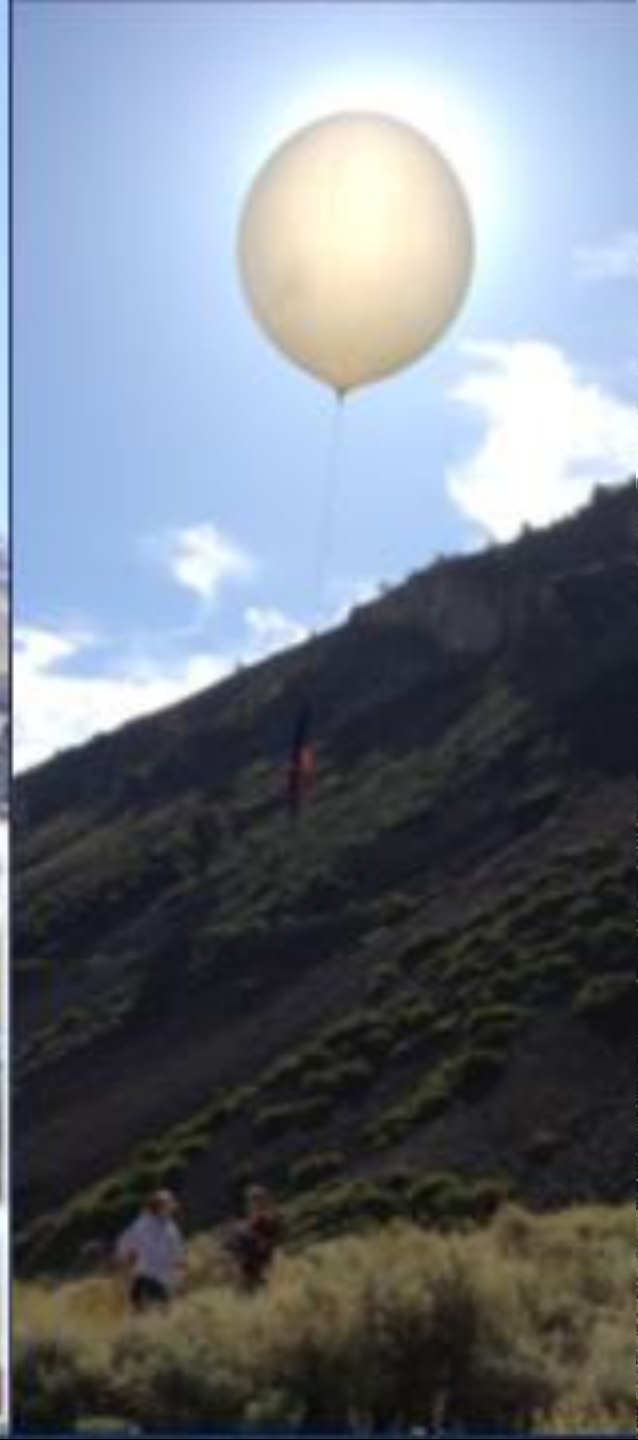


NASA LOW LIGHT CAMERA



MONITORING THE CALIFORNIA DROUGHT

Stanford
Berkeley
UCSB
Stanford
Babson
U. Washington
Earth to Sky Calculus
UC San Diego
BACON
MAKES IT
BETTER!



EXTRA SLIDES

Stratospheric Microbe Catcher

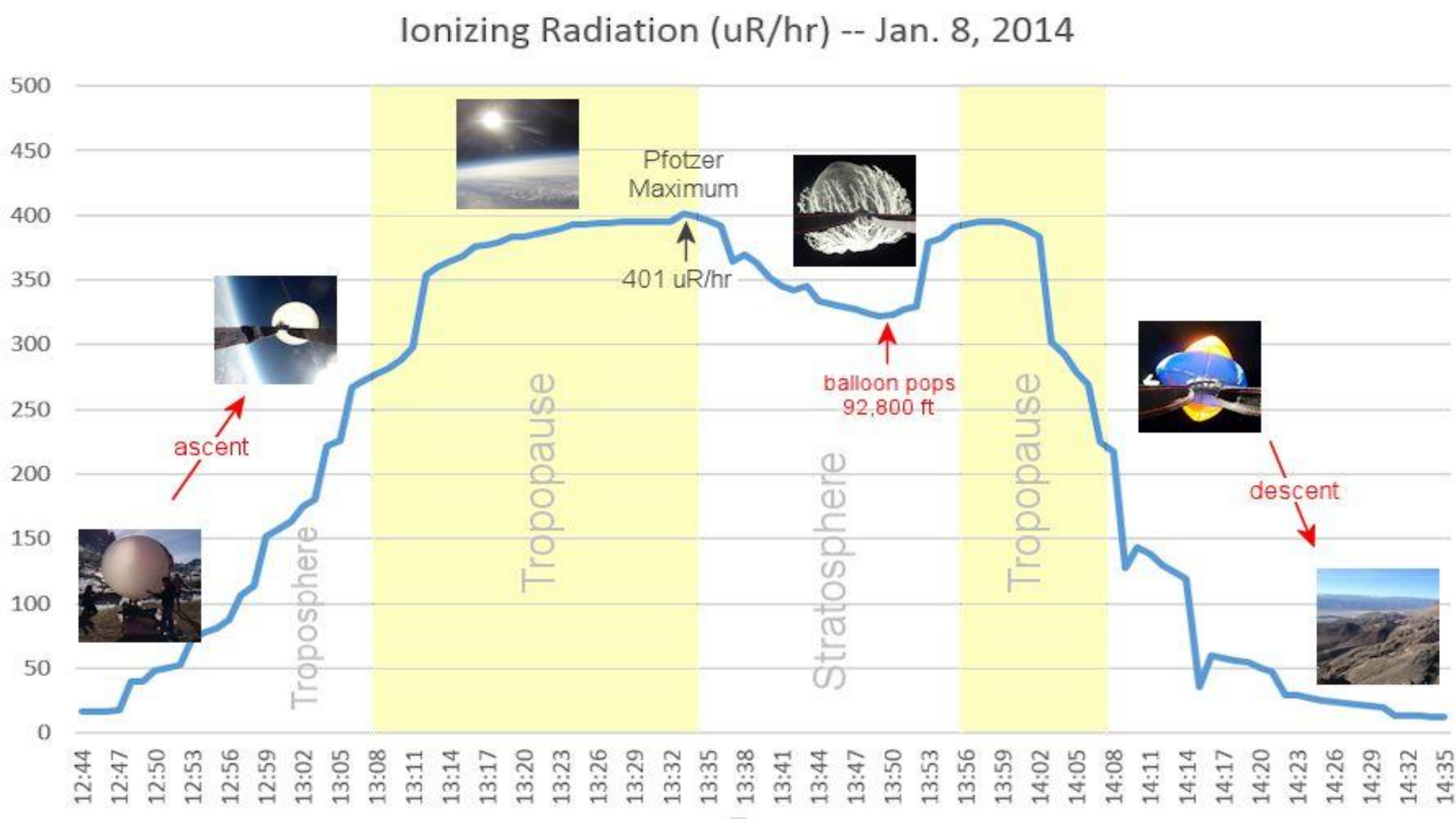
June 30, 2012

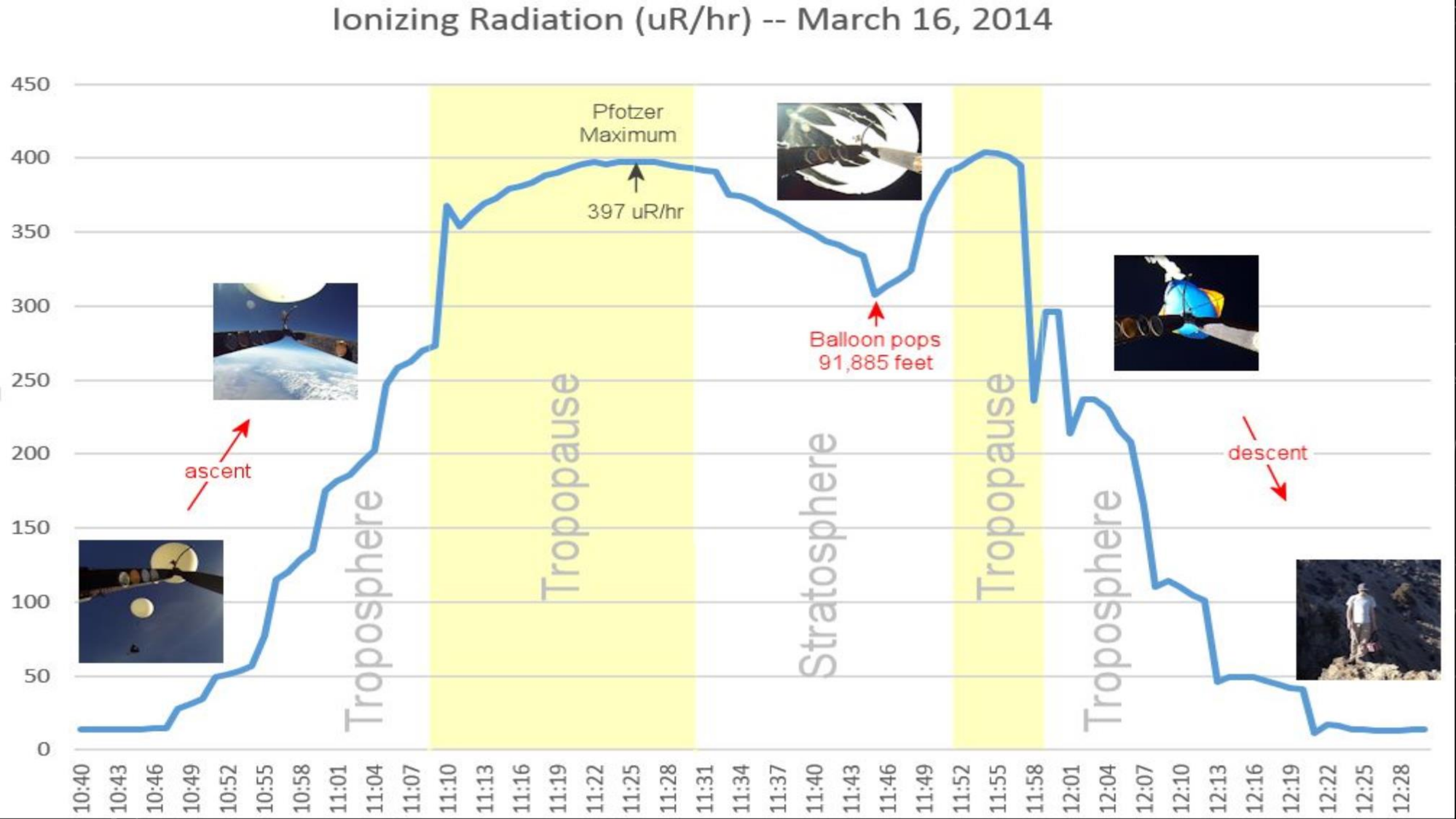
MICROBES AT THE EDGE OF SPACE

Halobacteria exposed to a solar radiation storm – May 22, 2013

PETUNIAS IN SPACE

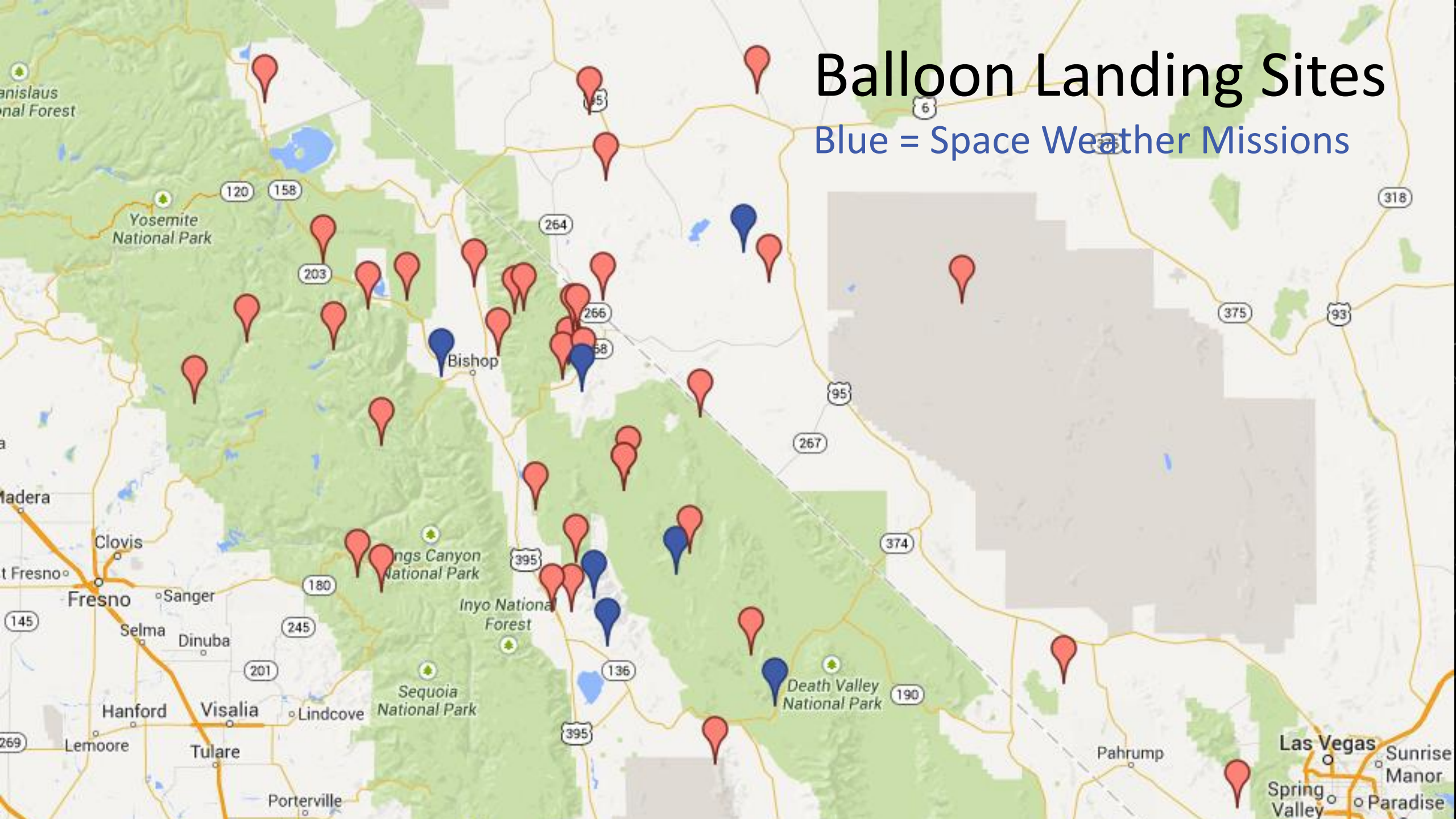
ON THE WAY UP WE PASS
THROUGH AVIATION ALTITUDES


Ionizing Radiation (uR/hr) -- Jan. 8, 2014
500
450
400
350
300
250
200
150
100
50
0
Pfotzer Maximum
401 uR/hr
ascent
Troposphere
Tropopause
Stratosphere
Tropopause
balloon pops
92,800 ft
descent
12:44
12:47
12:50
12:53
12:56
12:59
13:02
13:05
13:08
13:11
13:14
13:17
13:20
13:23
13:26
13:29
13:32
13:35
13:38
13:41
13:44
13:47
13:50
13:53
13:56
13:59
14:02
14:05
14:08
14:11
14:14
14:17
14:20
14:23
14:26
14:29
14:32
14:35

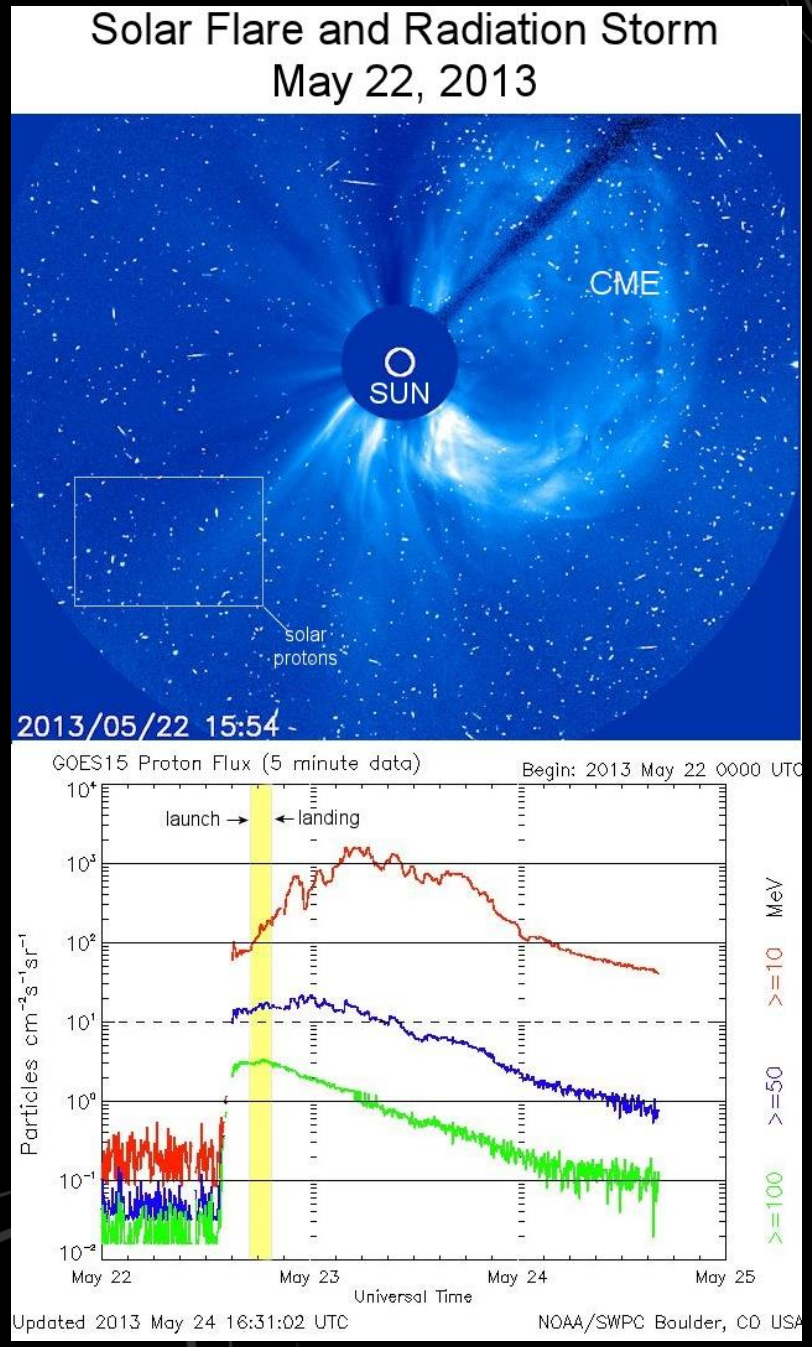

Ionizing Radiation (uR/hr) -- March 16, 2014
450
400
350
300
250
200
150
100
50
0
Pfotzer Maximum
397 uR/hr
Balloon pops
91,885 feet
ascent
descent
Troposphere
Tropopause
Stratosphere
Tropopause
Troposphere
10:40
10:43
10:46
10:49
10:52
10:55
10:58
11:01
11:04
11:07
11:10
11:13
11:16
11:19
11:22
11:25
11:28
11:31
11:34
11:37
11:40
11:43
11:46
11:49
11:52
11:55
11:58
12:01
12:04
12:07
12:10
12:13
12:16
12:19
12:22
12:25
12:28

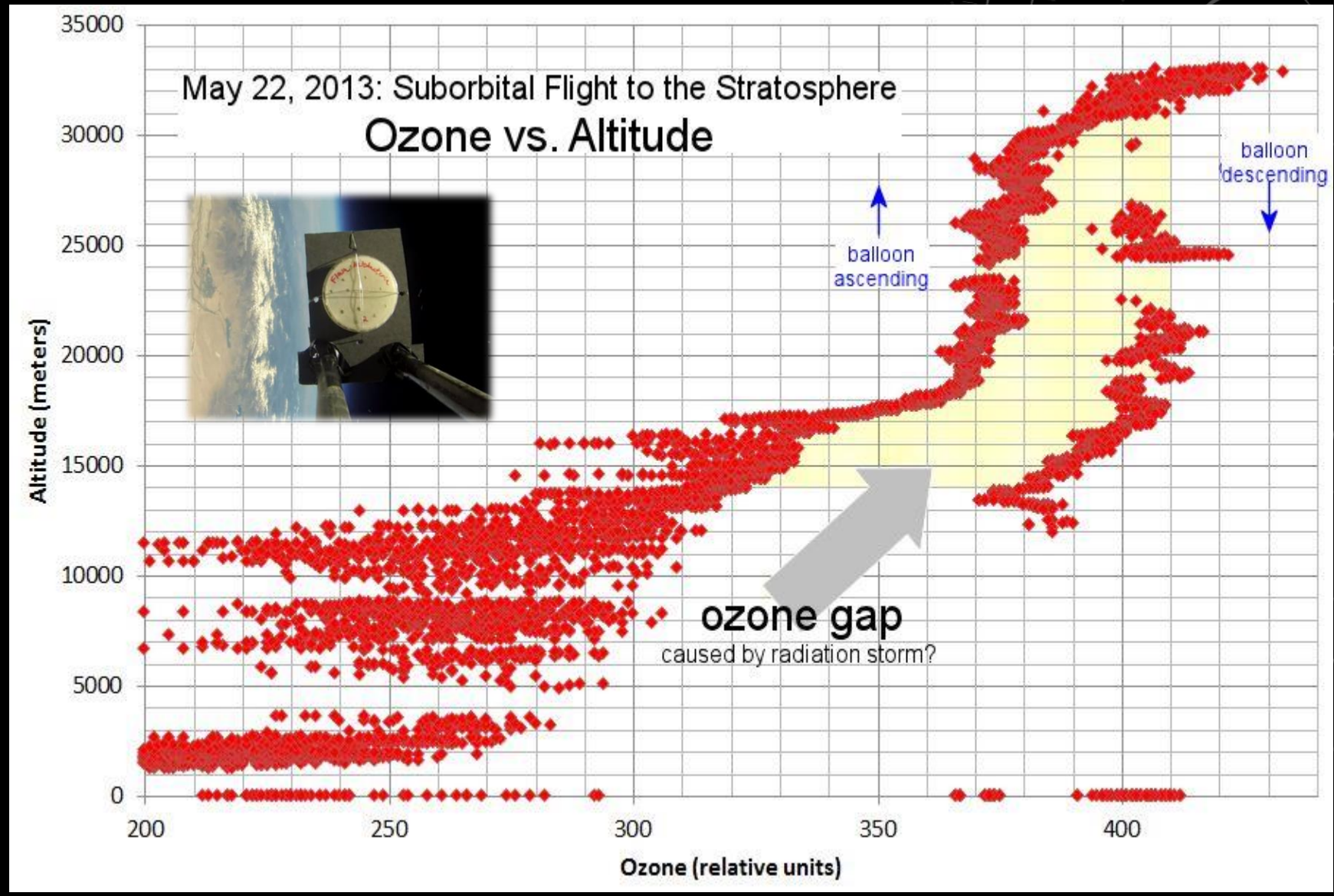
Balloon Landing Sites

Blue = Space Weather Missions



OZONE MEASUREMENTS





Space Environment Technologies

NAIRAS

Nowcast of Atmospheric Ionizing Radiation System

Northern Hemisphere Dose | Global Dose | Selected Flight Path Dose | Geomagnetic Cutoff Rigidity

Effective Dose Rate[1](E) for 2014-04-06 17:00-18:00 GMT

5km (16,000 feet) Radiative Dose Rate (uSv/hr)

lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	2.95	2.29	1.40	0.70	0.64	1.11	2.26	2.80
max	3.23	3.10	2.39	1.27	1.52	2.41	2.89	3.00

11km (35,000 feet) Radiative Dose Rate (uSv/hr)

lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	10.53	8.15	4.09	1.59	1.41	2.99	7.85	10.49
max	10.99	10.61	9.09	3.43	4.43	9.00	10.65	10.91

15km (49,000 feet) Radiative Dose Rate (uSv/hr)

lat	90S-60S	60S-40S	40S-20S	20S-0	0-20N	20N-40N	40N-60N	60-90N
avg	14.71	11.27	5.12	1.81	1.60	3.60	10.56	14.88
max	15.37	14.91	13.03	4.14	5.50	12.54	15.03	15.40

Representative High-Latitude Flights

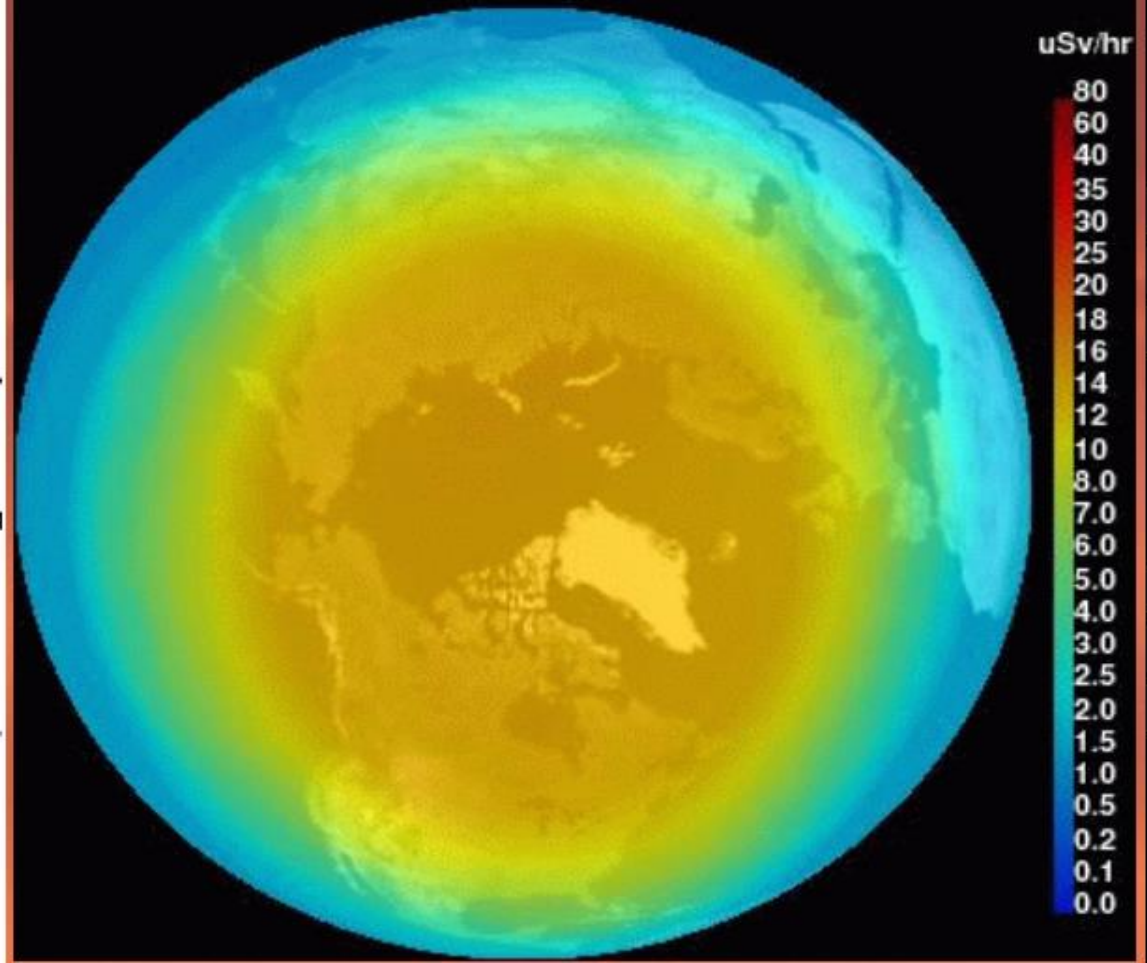
2014-04-06 17:00-18:00 GMT

Flight Name	Time	Rate[1]	Dose[1]	Safety Signal		
	hours	uSv/hr	mSv	Aircrew[2]	Public[3]	Prenatal[4]
London,GBR - New York,USA	5.50	9.54	0.052			
Chicago,USA - Stockholm,SWE	8.50	10.09	0.086			
Chicago,USA - Munich,DEU	8.50	9.67	0.082			
Chicago,USA - Beijing,CHN	13.50	9.75	0.132			

Signal	Aircrew[5] Max_Annual(800hrs)	Public[6] one_trip	Prenatal[6] one_trip
	0-6.0mSv	0-0.330mSv	0-0.167mSv
	6.0-12.0mSv	0.330-0.670mSv	0.167-0.333mSv
	>12.0mSv	>0.670mSv	>0.333mSv

Global view at selected altitudes and viewing perspective

Effective Dose Rate(E) at 15km for 2014-04-06 17:00-18:00 GMT



Static View

5km

11km

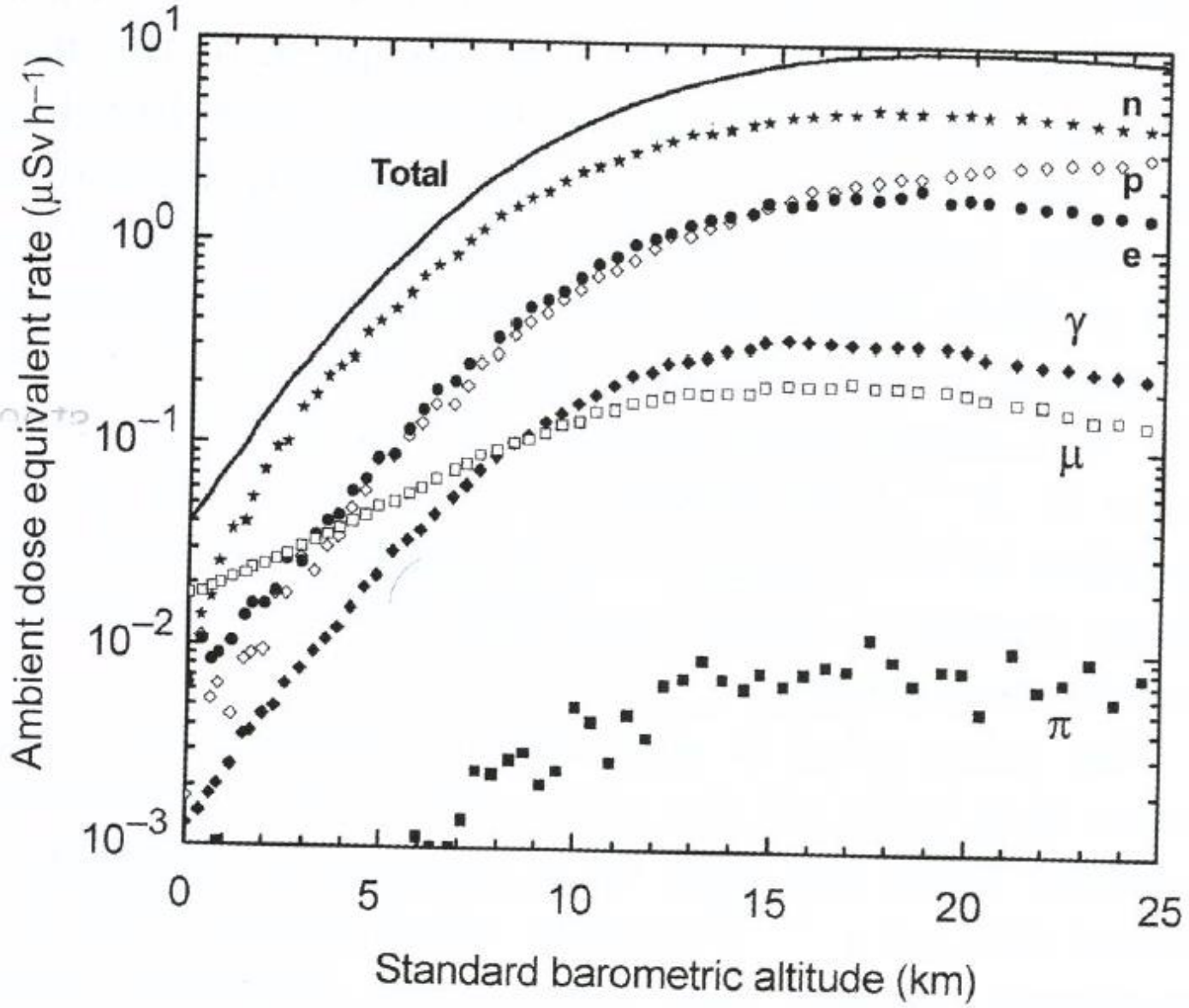
15km

Dynamic View

5km

11km

15km


Ambient dose equivalent rate (μSv h⁻¹)
10¹
10⁰
10⁻¹
10⁻²
10⁻³
Total
n
p
e
γ
μ
π
0
5
10
15
20
25
Standard barometric altitude (km)