ER-2 High Altitude Solar Cell Calibration Flights

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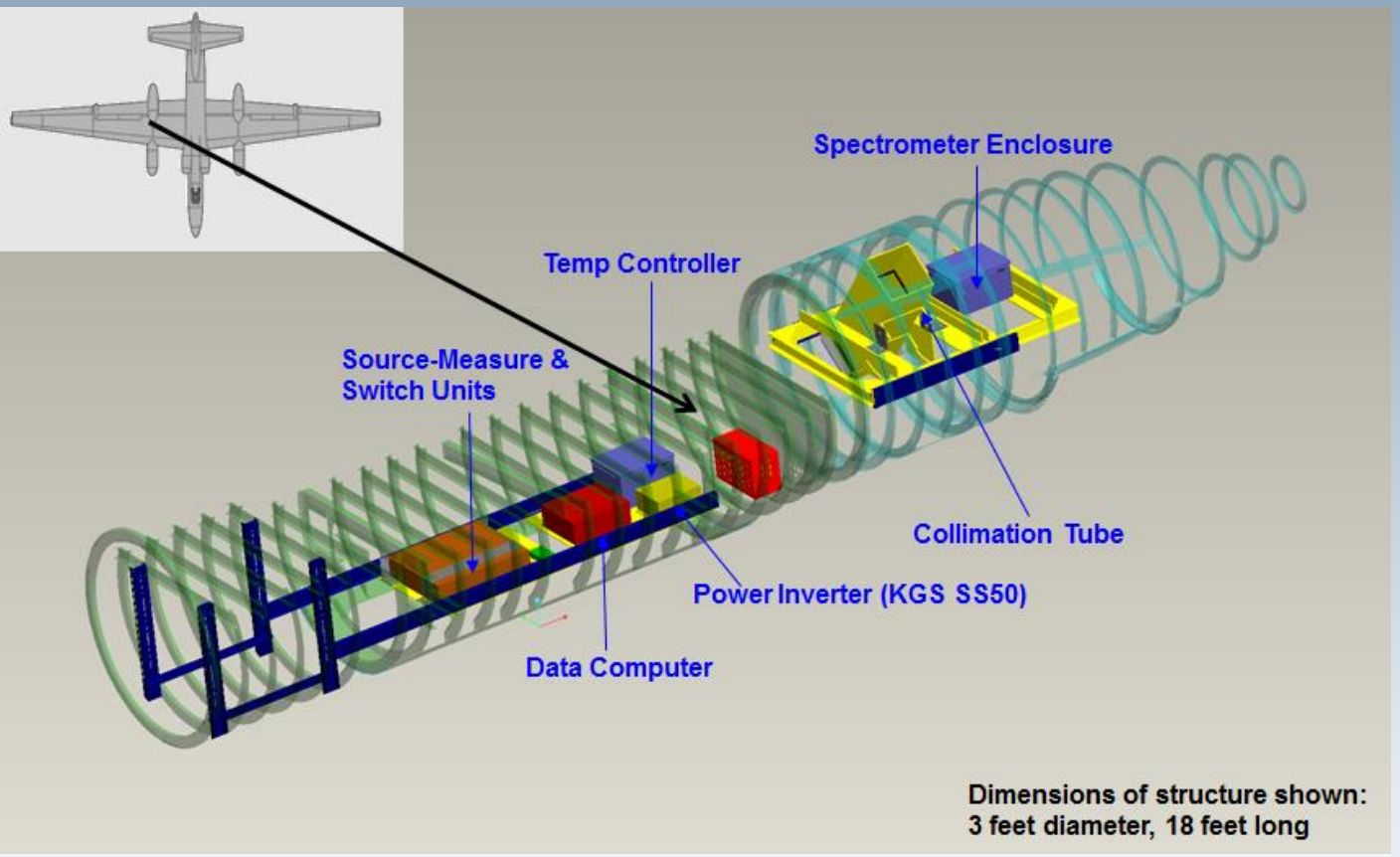
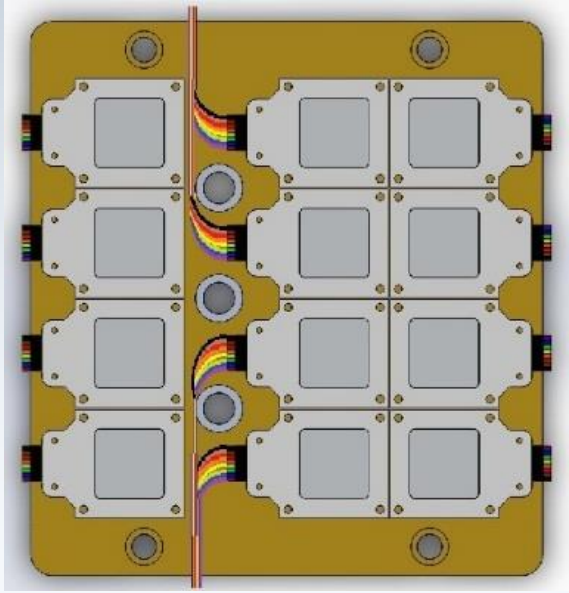
Test Platform Overview



Demonstrated Capabilities

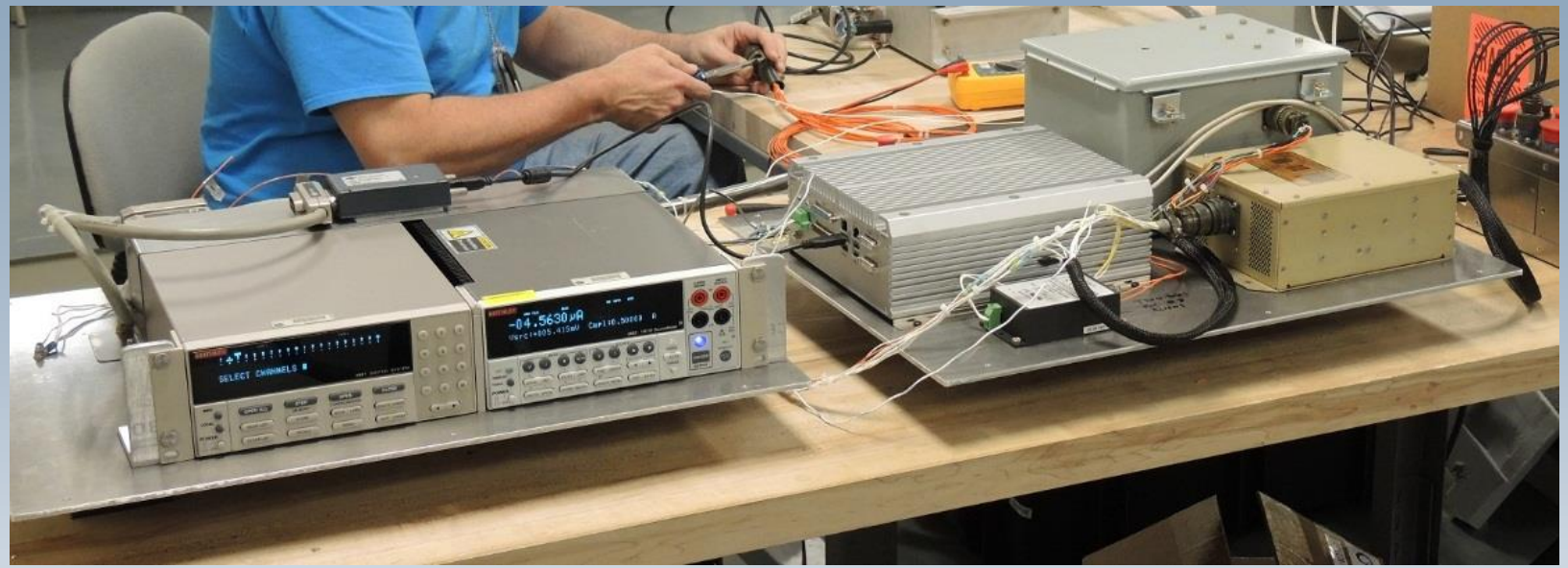
Altitude: 70,000ft+
Illuminated Area: 5.6 x 5.6 inches
Pointing Accuracy: <2° deviation
Temperature Control: (+/-) 0.5°C
Number of devices per flight: 12 Maximum
Cell Measurements: Isc, Voc, IV Curve
Fiber-optic Port for spectrometer or other sensor
Flight Season: April through September



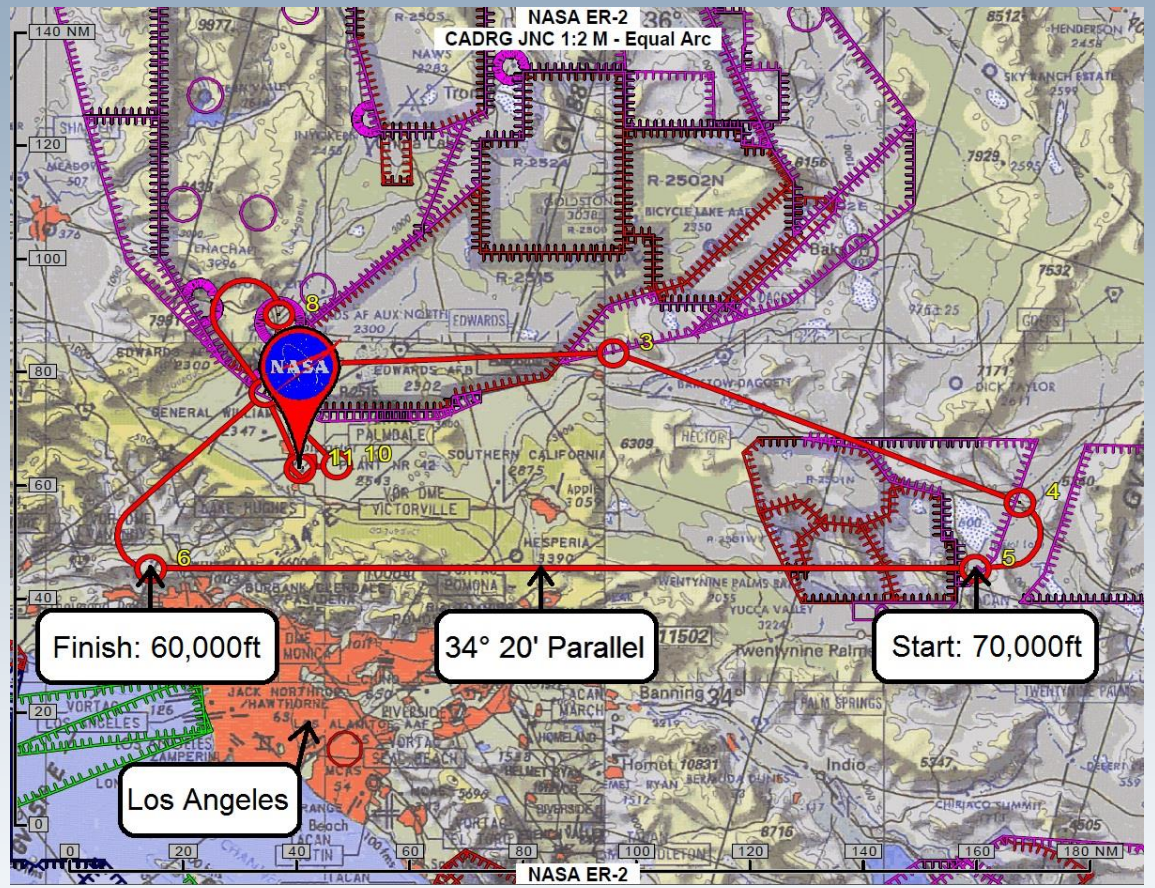
Instruments Flown

Keithley 2425 Source/Measure Unit
Ocean Optics HR2000+ Spectrometer
Ocean Optics NIRQuest NQ512-1.9 Spectrometer

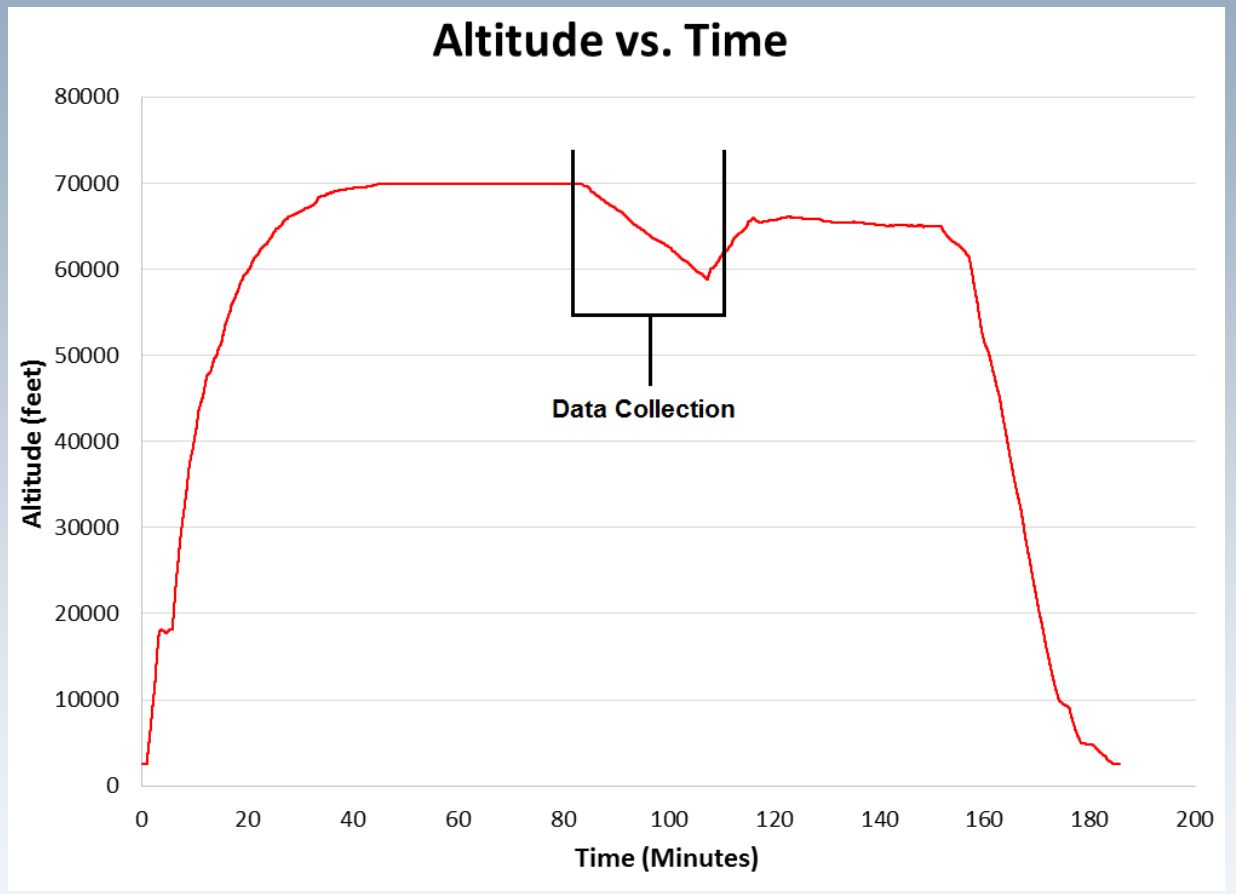
Equipment



Flight Profile



Ideal Regular Season Flight Path



Actual Altitude Profile

Langley plot method

1. Estimate ozone above cell using tables from appendix A in publication:

   “Earth Probe Total Ozone Mapping Spectrometer (TOMS) Data Products User's Guide”

Table A.1. TOMS Version 7 Standard Ozone Profiles

	Umkehr Layer Number										
Profile	0	1	2	3	4	5	6	7	8	9	>9
225L	15.0	9.0	5.0	7.0	25.0	62.2	57.0	29.4	10.9	3.2	1.3
275L	15.0	9.0	6.0	12.0	52.0	79.2	57.0	29.4	10.9	3.2	1.3
325L	15.0	9.0	10.0	31.0	71.0	87.2	57.0	29.4	10.9	3.2	1.3
375L	15.0	9.0	21.0	53.0	88.0	87.2	57.0	29.4	10.9	3.2	1.3
425L	15.0	9.0	37.0	81.0	94.0	87.2	57.0	29.4	10.9	3.2	1.3
475L	15.0	9.0	54.0	108.0	100.0	87.2	57.0	29.4	10.9	3.2	1.3
125M	6.0	5.0	4.0	6.0	8.0	31.8	28.0	20.0	11.1	3.7	1.4
175M	8.0	7.0	8.0	12.0	26.0	41.9	33.6	22.3	11.1	3.7	1.4
225M	10.0	9.0	12.0	18.0	44.0	52.1	39.2	24.5	11.1	3.7	1.4
275M	16.0	12.0	15.0	29.0	58.0	63.7	40.6	24.5	11.1	3.7	1.4
325M	16.0	14.0	26.0	45.0	74.7	66.9	41.7	24.5	11.1	3.7	1.4
375M	16.0	16.0	39.0	64.0	85.7	71.1	42.5	24.5	11.1	3.7	1.4
425M	16.0	18.0	54.0	84.0	97.7	71.7	42.9	24.5	11.1	3.7	1.4
475M	16.0	22.0	72.0	107.7	101.0	72.6	43.0	24.5	11.1	3.7	1.4
525M	16.0	26.0	91.0	127.7	108.0	72.6	43.0	24.5	11.1	3.7	1.4
575M	16.0	30.0	110.0	147.7	115.0	72.6	43.0	24.5	11.1	3.7	1.4
125H	9.5	7.0	18.3	7.6	8.2	28.6	22.0	12.4	7.7	2.5	1.2
175H	9.5	8.0	22.8	22.0	26.9	32.3	26.8	15.0	8.0	2.5	1.2
225H	10.0	9.0	27.6	45.7	41.0	35.0	28.8	15.4	8.3	2.9	1.3
275H	14.0	12.0	34.0	66.9	54.2	36.0	28.8				
325H	14.0	15.0	46.8	82.6	65.2	41.7	28.8				
375H	14.0	20.0	61.2	93.8	75.2	45.9	32.5				
425H	14.0	25.0	76.2	104.9	84.2	51.4	35.6				
475H	14.0	32.0	91.0	117.1	93.0	55.8	37.5				
525H	14.0	41.0	107.1	128.1	101.0	60.2	38.2				
575H	14.0	49.0	123.2	142.2	111.0	60.6	38.8				

Umkehr Level	Ozone above top of level (DU) for specified total column
	290
Ground	290.00
0	275.53
1	264.86
2	251.72
3	224.65
4	163.79
5	90.39

a.) Linearly Interpolate ozone distribution data to flight latitude

b.) Find polynomial fits of ozone in given levels as a function of total ozone column

c.) Use data from the Ozone Monitoring Instrument (OMI) on board the Aura spacecraft to determine total ozone column at the time and location of the flight

d.) Use ozone layer distribution model to interpolate and estimate of the ozone above the cell for each data point taken as the aircraft descends

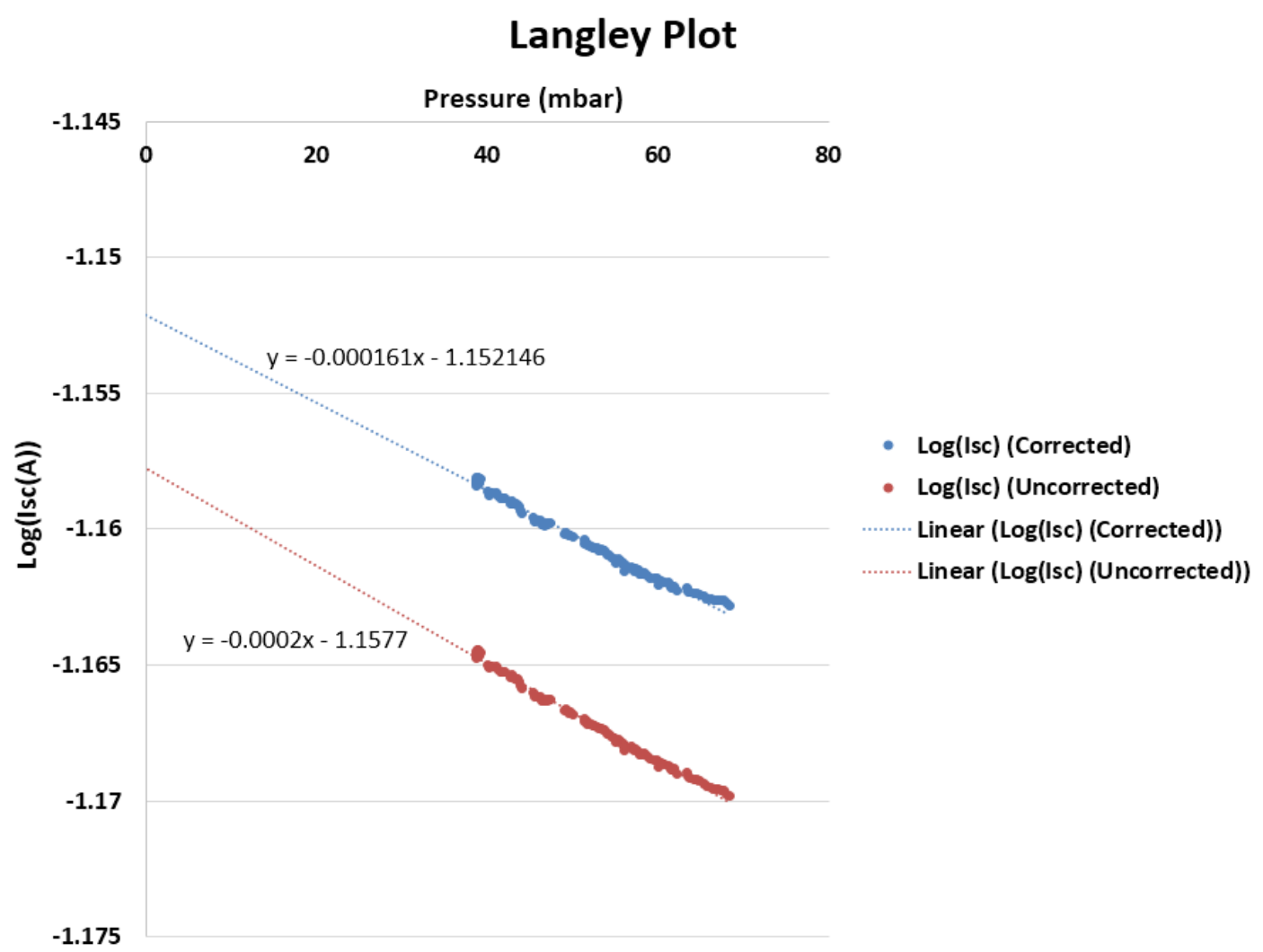
Langley plot method

2. Generate Langley Plot

a.) Correct each Isc data point for overhead ozone, ozone sensitivity coefficient, and sun elevation angle

b.) Plot log of ozone-corrected Isc vs airmass (pressure over sine of elevation angle

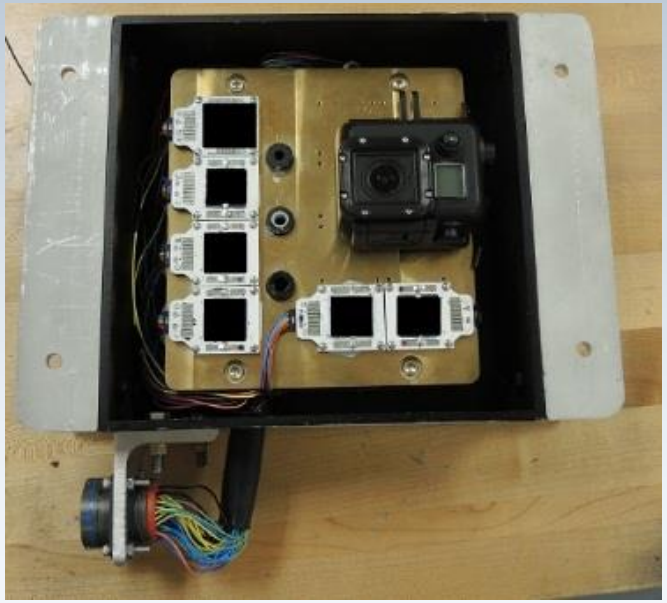
c.) Extrapolate linear fit of plot to zero airmass and estimate AM0 Isc



Langley Plot shown for GRC ZTJ 2x2cm top cell flown October 10th 2014

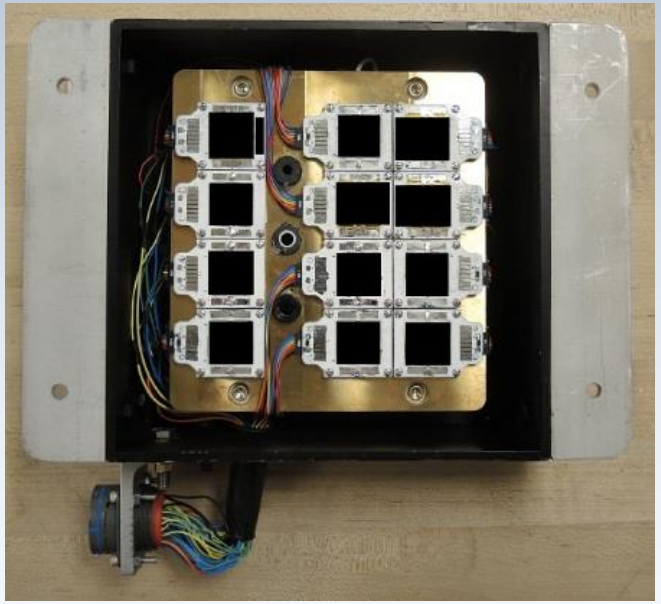
Summary of First ER-2 Campaign

- Three flights were flown between October 8th and October 14th, 2014
- Data was taken between 55,000 and 70,000 feet
- The first flight consisted of six 2x2cm cells and a camera to observe plate illumination conditions
- The second and third flights consisted of twelve 2x2cm cells
- All flights carried two sun sensors and two Ocean Optics spectrometers
- A ZTJ top and middle 2x2cm sub cell which were previously flown on the Learjet were flown all three flights
- Thirteen other cells were flown at least once



First flight stage plate configuration

View of sun from stage plate



Second and Third flight stage plate configuration

ER-2 Takeoff and Landing

Corrected Isc Results

Full Data Set

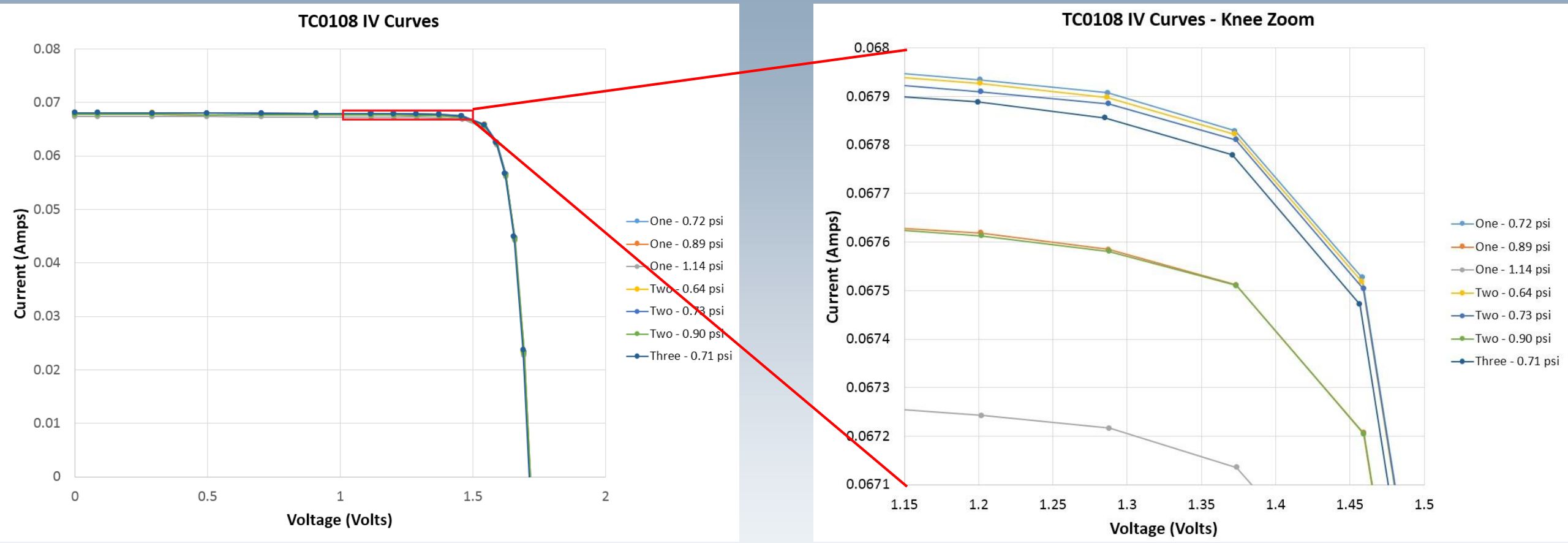
Cell	TC0108	MC0907	TC0109
Flight One	69.925	66.004	70.096
Flight Two	70.232	66.063	
Flight Three	70.289	65.990	
Average	70.149	66.019	70.096
Std Dev	0.196	0.039	
Covar %	0.279	0.059	
Learjet Value	70.510	66.230	70.51
Lear Variance (%)	0.512	0.319	0.587

<60mb Data Only

Cell	TC0108	MC0907	TC0109
Flight One	70.339	65.995	70.576
Flight Two	70.325	66.069	
Flight Three	70.289	65.990	
Average	70.318	66.018	70.576
Std Dev	0.026	0.044	
Covar %	0.037	0.067	
Learjet Value	70.51	66.23	70.51
Lear Variance (%)	0.27	0.32	-0.09

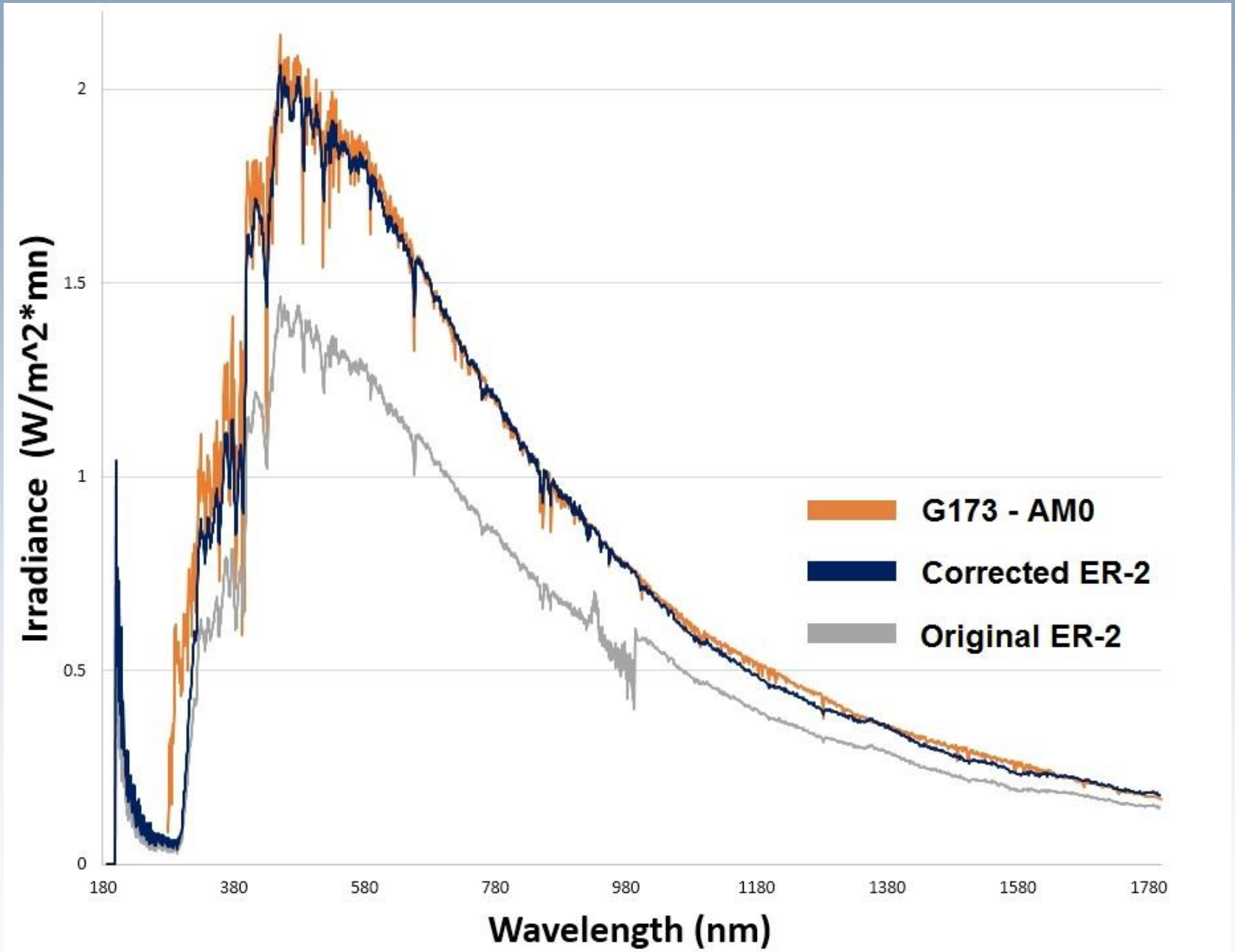
- Data shown for GRC 2x2cm ZTJ sub cells (two top cells and one middle)
- Ozone corrections based on established Learjet methods
- Further atmospheric correction methods are being investigated
  - SMARTS or other ozone models
  - Using only higher altitude data
  - Ozone correction coefficients using cell EQE data

IV Curve Examples



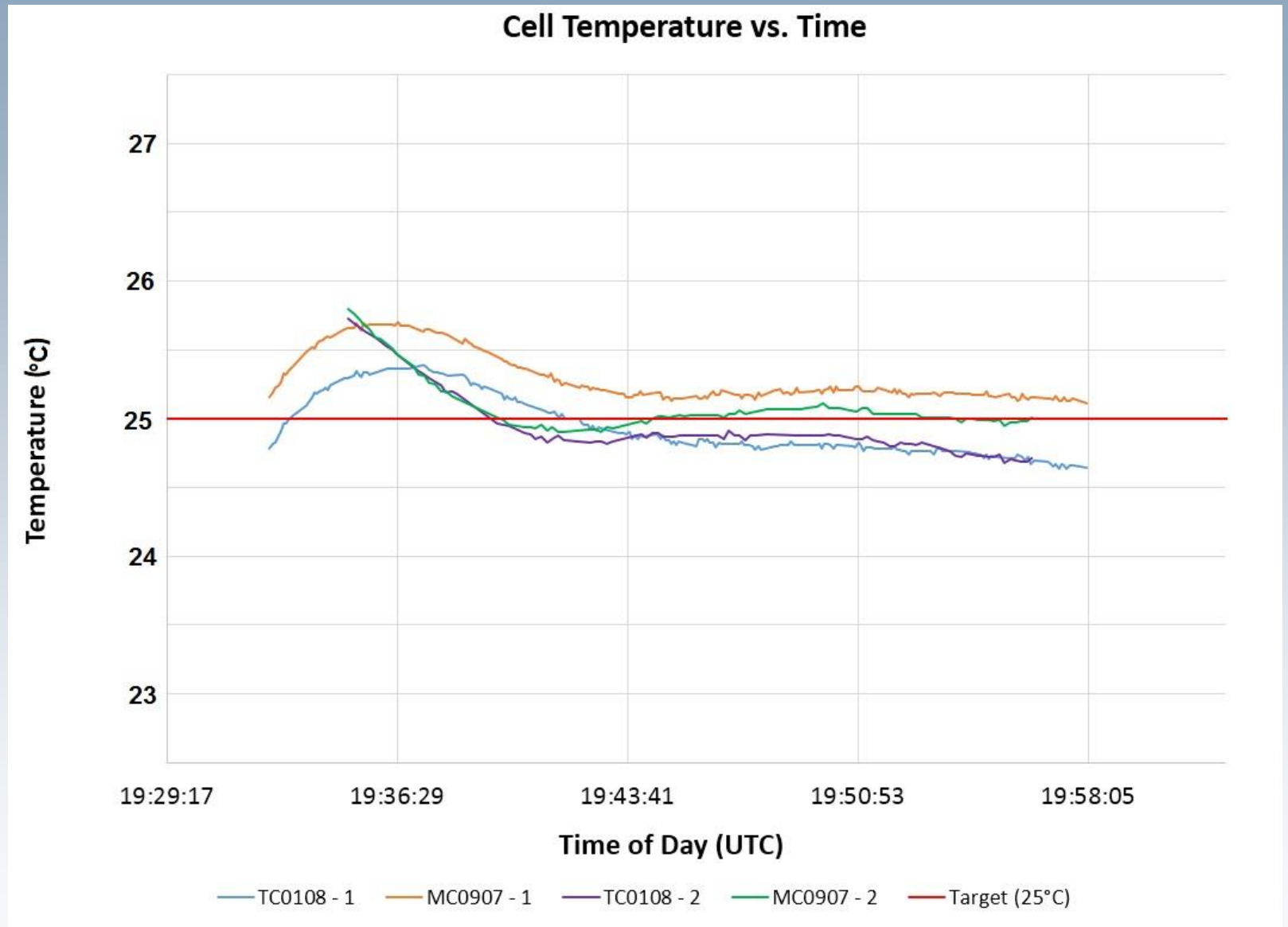
IV Curves show good repeatability over multiple flights and a predictable change with pressure

Solar Spectra



Device Temperature Control

- Mounting Plate temperature is used for heater feedback control
- All cell temperatures are monitored independently using AD590 IC temperature transducers
- After a slight bump caused by initial solar illumination, all cell temperatures were maintained within approximately 0.25°C from the target of 25°C
- Variation of temperature for any individual cell was on the order of 0.1°C after the initial on-sun disturbance

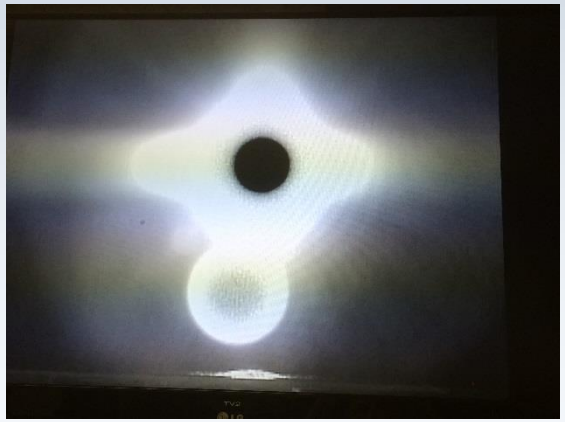


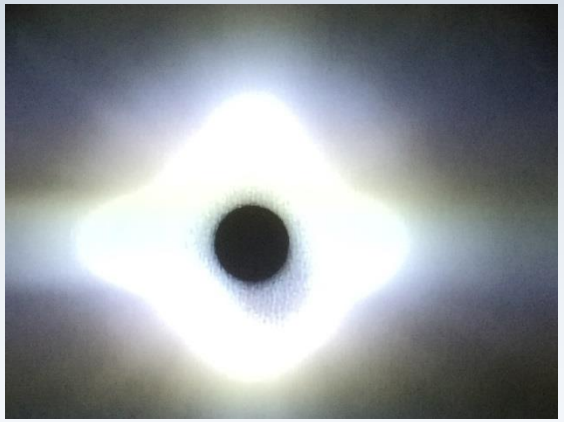
Sun Pointing

Summary of ER-2 Capability

- Flights can be conducted once every one to two days during a campaign
- Flight season runs from April through September
- Twelve 2x2cm cells can be flown per flight, or any other configuration that fits inside of the 14.2x14.2cm illuminated area
- This capacity could be doubled if the second ER-2 pod is used
- Data supplied includes Isc, Voc, IV curve, and cell temperature
- Other optical or atmospheric sensors can be flown as able

Recent Results on Solar Cell Experiment on ISS





2015 GRC/AFRC ER-2 Flight Campaign for Creating Air Mass Zero (AM0) Primary Calibration Standards

- GRC announcement sent out the week of May 4, 2015
- New platform supplements the Learjet AM0 calibration capability
  - GRC Learjet flight season January– March
  - DFRC ER-2 flight season April - September
- Current 2015 ER-2 Flight Campaign:
  - July 6th – 20th, 2015