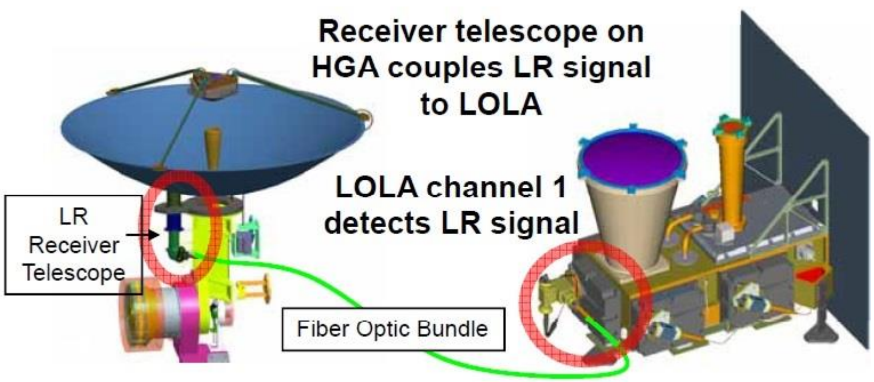
TWO WAY RANGING ON LUNAR RECONNAISSANCE ORBITER AT GRASSE MÉO STATION

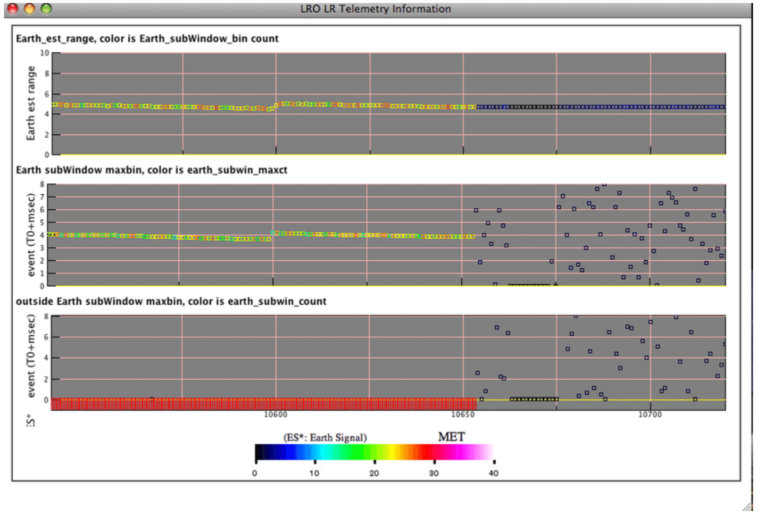
NASA GFSC

One way laser ranging on LRO

Mission Parameters:

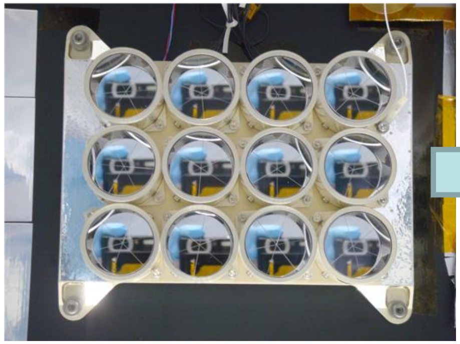
Sponsor:	NASA
Expected Life:	1 year
Primary Applications:	Conduct lunar investigations to support future human exploration of the moon
Primary SLR Applications:	Precision orbit determination
COSPAR ID:	0903101
SIC Code:	0059
Satellite Catalog (NORAD) Number:	35315
Launch Date:	June 17 2009
NP Bin Size:	5 seconds
Reflectors:	One-way transponder experiment; no return light from spacecraft
RRA Diameter:	N/A
RRA Shape:	N/A
Orbit:	Polar (lunar)
Orbital Period:	~2 hours
Inclination:	~90 deg, with respect to the lunar equator
Eccentricity:	Near-circular; eccentricity is bounded and controlled by station-keeping
Altitude:	Near-circular, ~50 km (lunar)
Weight:	100 kg





TWO-WAY LASER RANGING ON LRO

- 12 solid corner cubes, 31.7mm diameter
- Materials Suprasil cubes, Al frame
- Mass 650.25g
- Volume: 15 x 18 x 5 cm^3
- Operating temperature range : -150 to +30°C
  Thermally isolated from spacecraft
- Tested for 14-g vibration
- Optical characteristics:
  - 90° dihedral angle (unspoiled)
  - Total internal reflection (bk uncoated)
  - AR coating on top surface



MOTIVATIONS FOR RANGING LRO IN TWO WAY:

- Compare corner cubes of Apollo XI mission to thus of LRO
  - no dust on retroreflectors on lro
  - younger corner cubes (10 years to 50 years)
  - main difference is their number, 100 for AXI to 12 for LRO
  - so if AXI is as good as new we can expect a difference of a factor 10 between number of echos from AXI to LRO

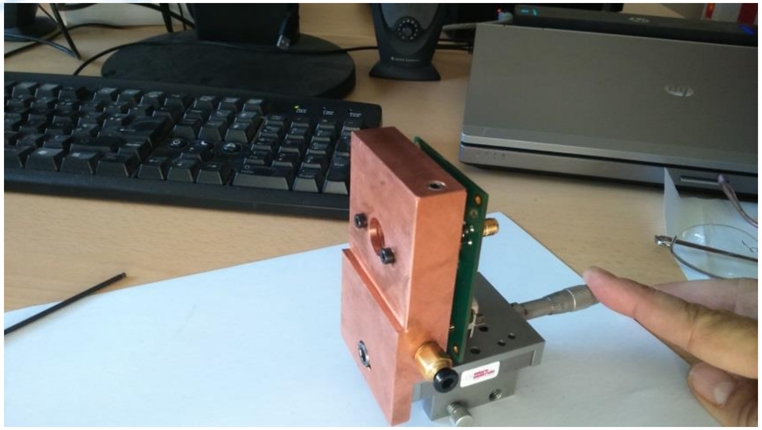
- Time transfer (one way in green / two way in infrared) between ground station using the LRO transponder & clock

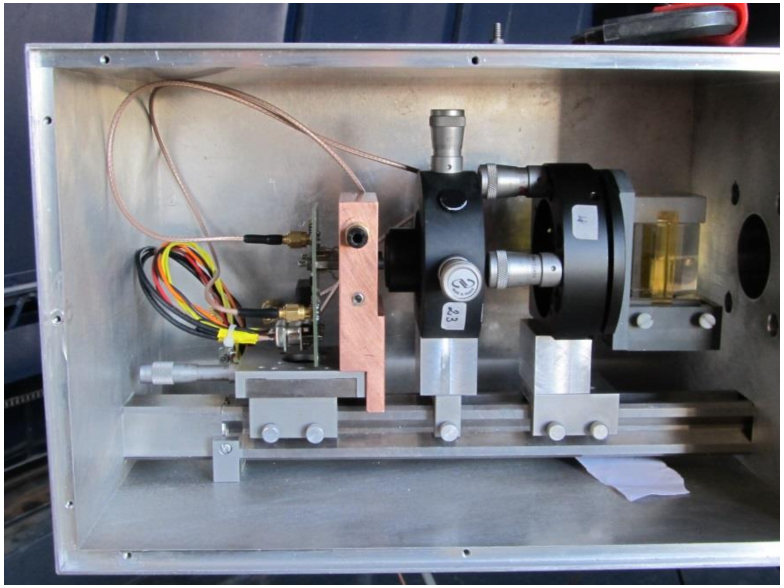
- Since 2014 the MéO station range the five lunar retro-reflectors in infrared which lead to much more data and they are easier to acquire.So our station was a good candidat to attempt this experiment

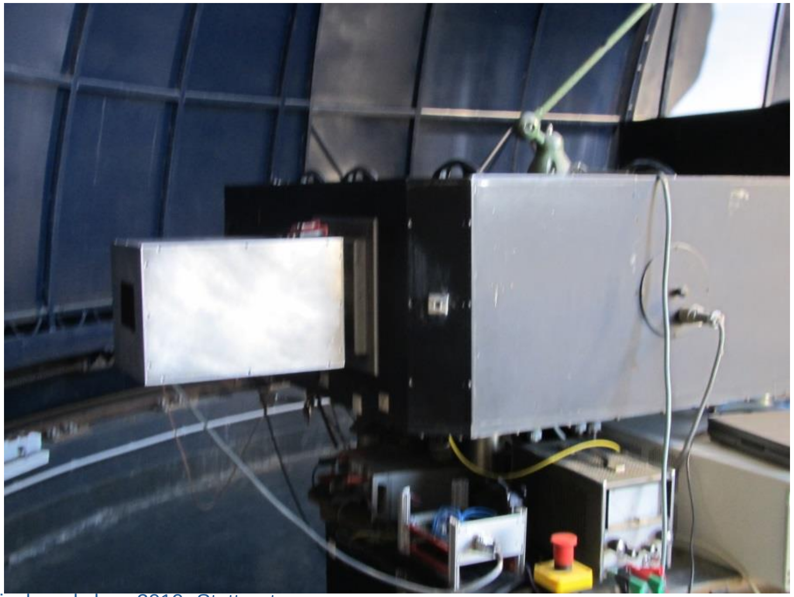
IR SPAD for LLR

- Princeton ligthwave PGA-284 in TO-8 header.
  - Quantum efficiency 20% in Geiger mode
  - DCR < 30 kHz @ +10V over the breakdown @ -40°C
  - 80 µm active area
  - Timing jitter with pulse widths of 20 ps:
    - 46,2 ps rms (109 ps FWHM) with a trigger at -100 mV on the event timer (Dassault)
    - 28 ps rms (66ps FWHM) with a trig at -10 mV on the event-timer (STX)
  - Time walk of 100 ps/decade
  - Station calibration precision of 101 ps rms (compared to the 74 ps rms in green)
  - Special asks
    - TO-8 => three stage peltier for cooling

IR SPAD for LLR







Events leading to our first succes in 2 way ranging

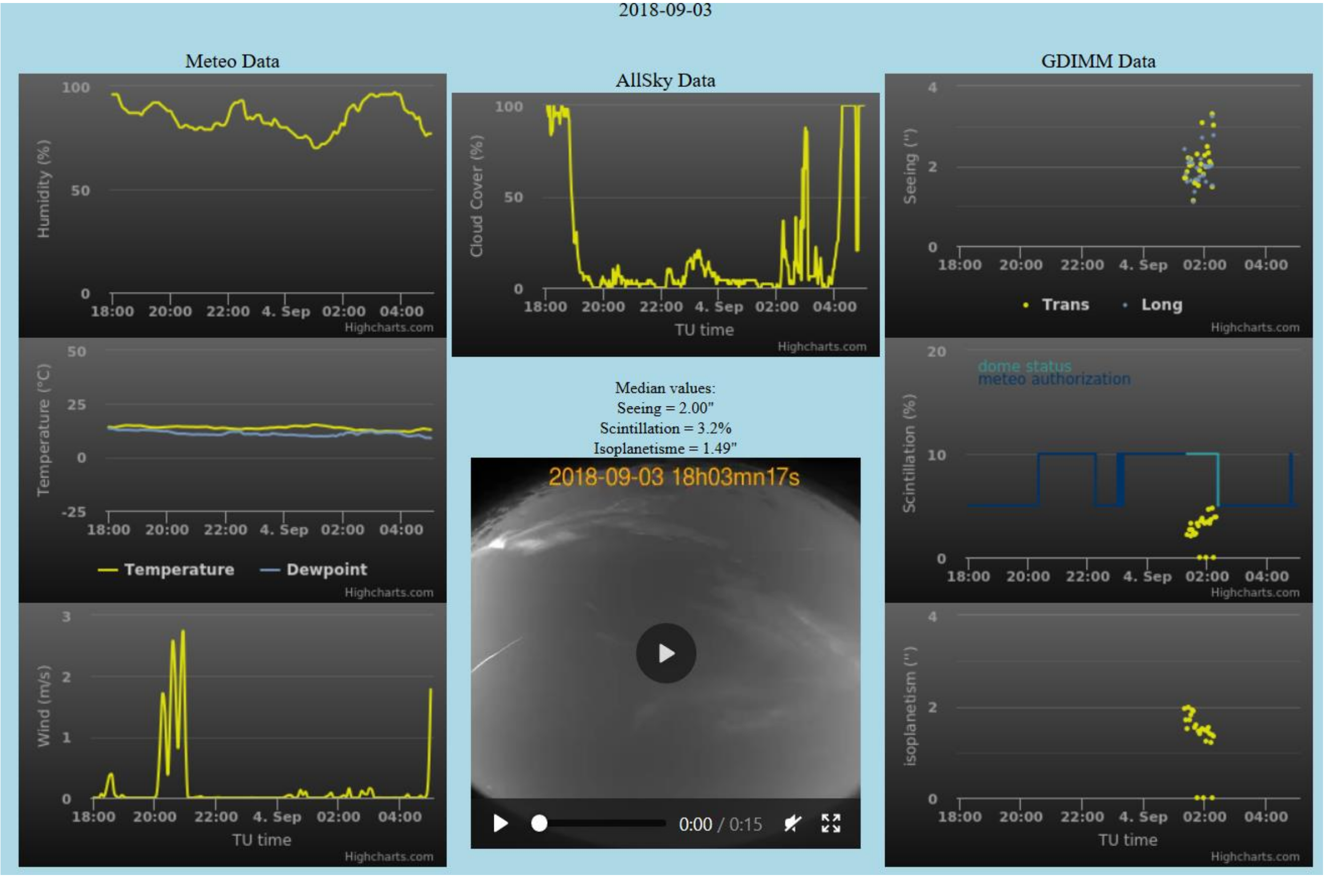
- June 2009 : launching of LRO
- 18 may 2010 : first one way tracking at MéO Grasse station
- September 2014 : ending of one way tracking on LRO
- In early 2017 first discussion to attempt to range LRO in two way with MéO
- In mid 2017 one way tracking opportunities were made available again by GSFC, and the realtime website was reactivate. Our first attempt was made in june, with active orientation of LRO toward MéO, the one way was an immediate success.

Events leading to our first succes in 2 way ranging

- But our firsts two way attempts were unsuccessfull
- We adjust our targeting precision and the divergence of our laser by ranging LRO in one way with as little energie as possible and by ranging alternativly the lunar retroreflectors and LRO
- In the end of 2017 we find that the prediction files we used for LRO had a error of 1,5µs. The prediction files we used were dedicated to one way laser ranging and were biased for two way ranging. This problem was solve by completing the header file
- The rare opportunities and other hazards (bad weather, moon too low on the sky …) lead to further delay until our first success
- First success in september 2018:

Observation condition on 4 september 2018

- Bad seeing condition: 2’’ (median value)
- Sky cloudiness ~ 30%

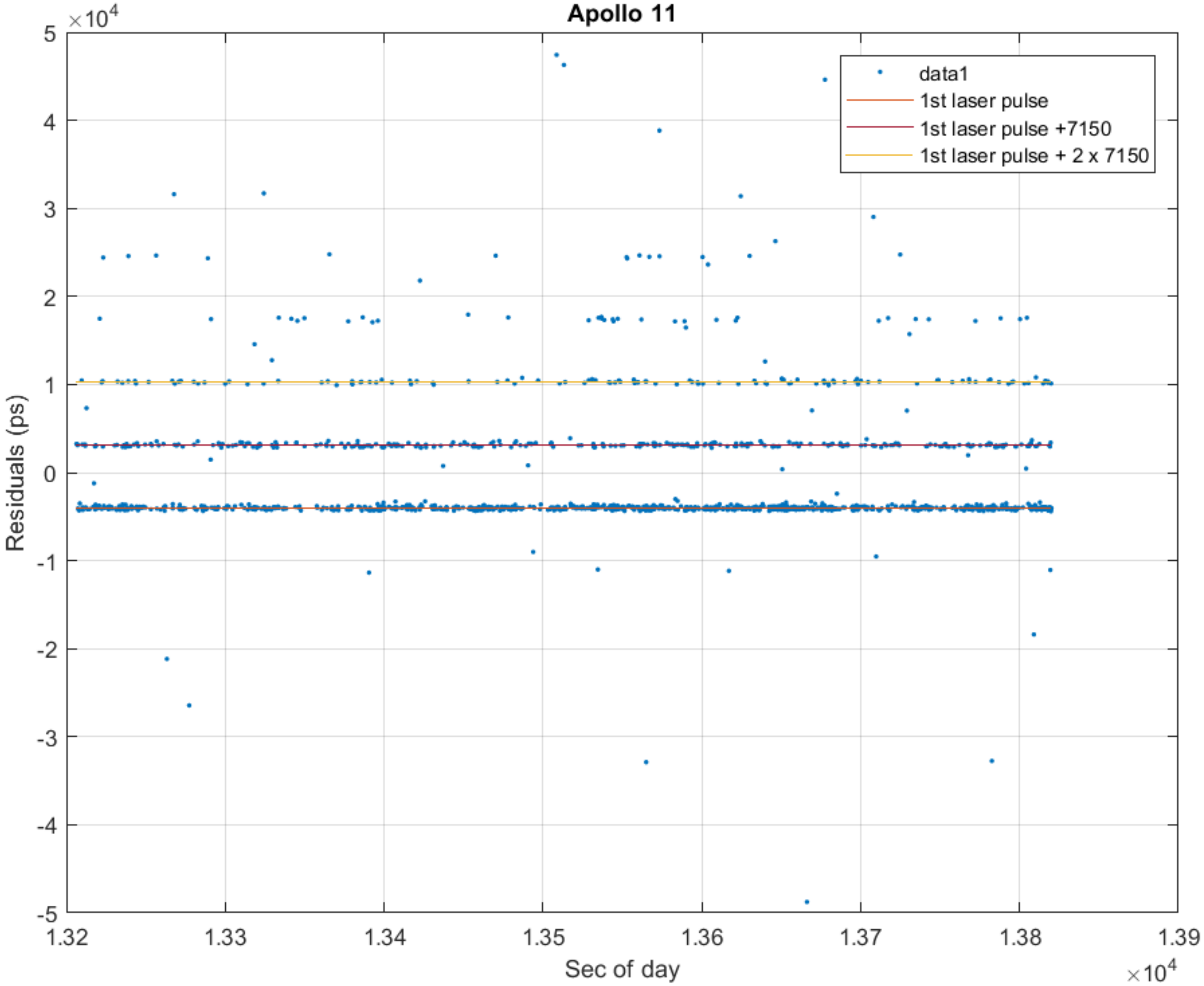


MéO's laser configuration

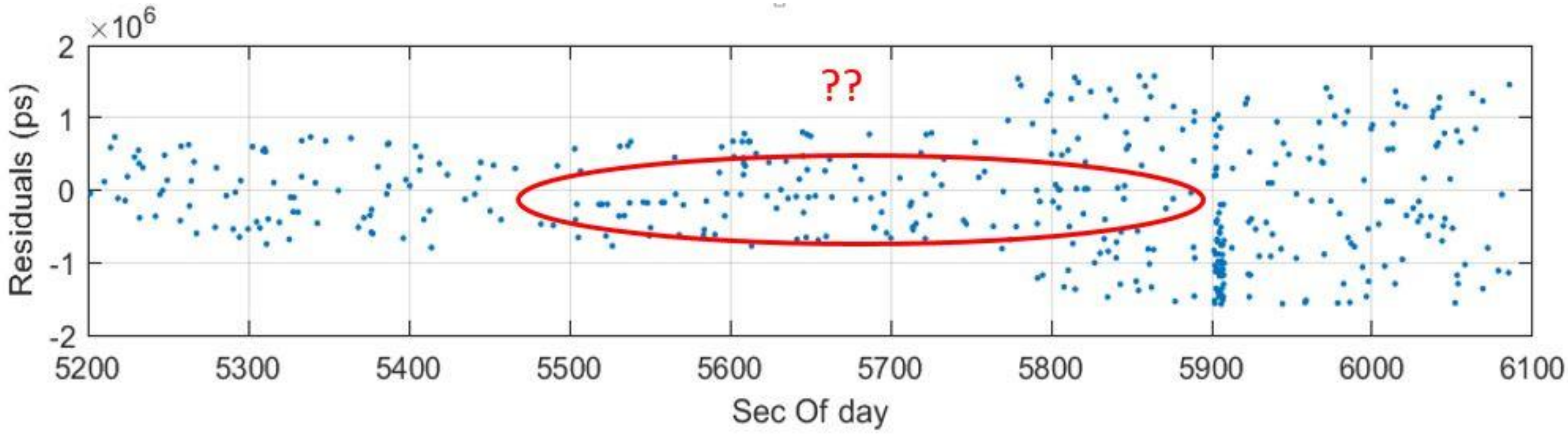
- We did not range in single laser pulse as usual, but we used the MéO's laser in half-train mode :

  - 3 pulses separated by 7.150 ns
  - Green link for 1-way ranging (few mJ pulses)
  - Infra-red link for 2-way ranging (500mJ in 3 pulses)

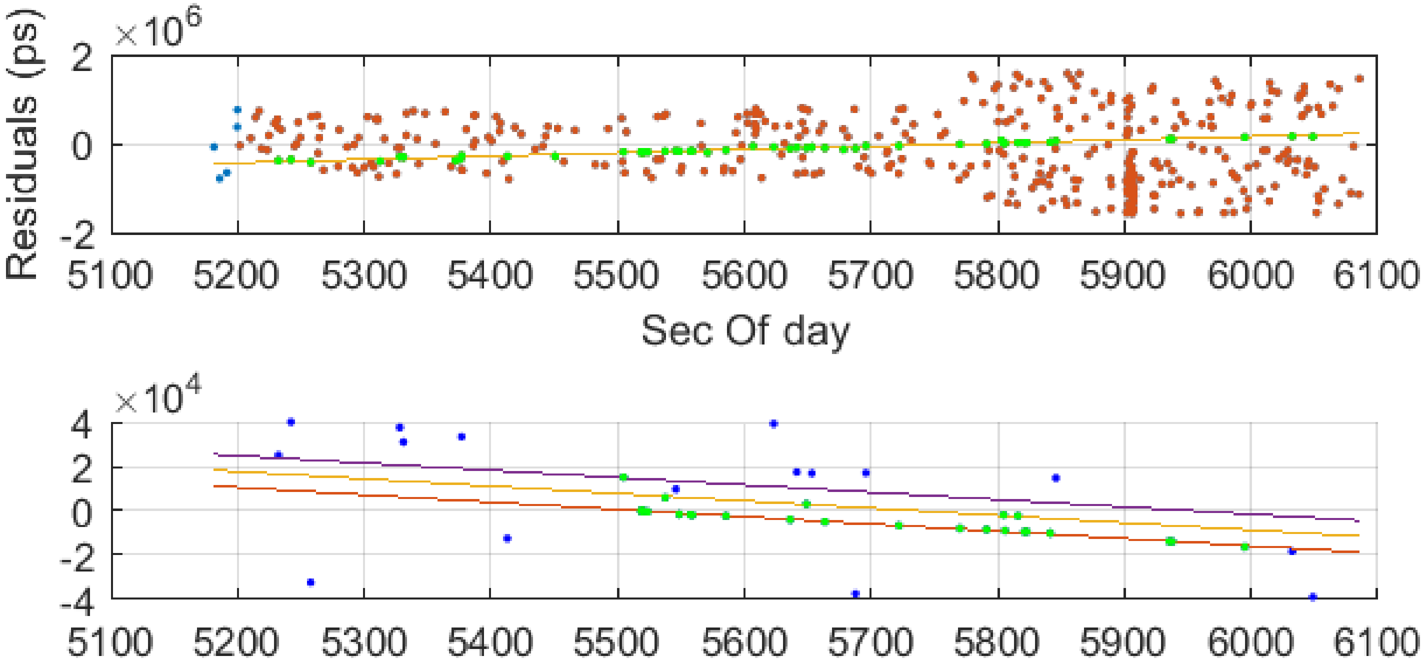
Example on Apollo 11 between two LRO passes



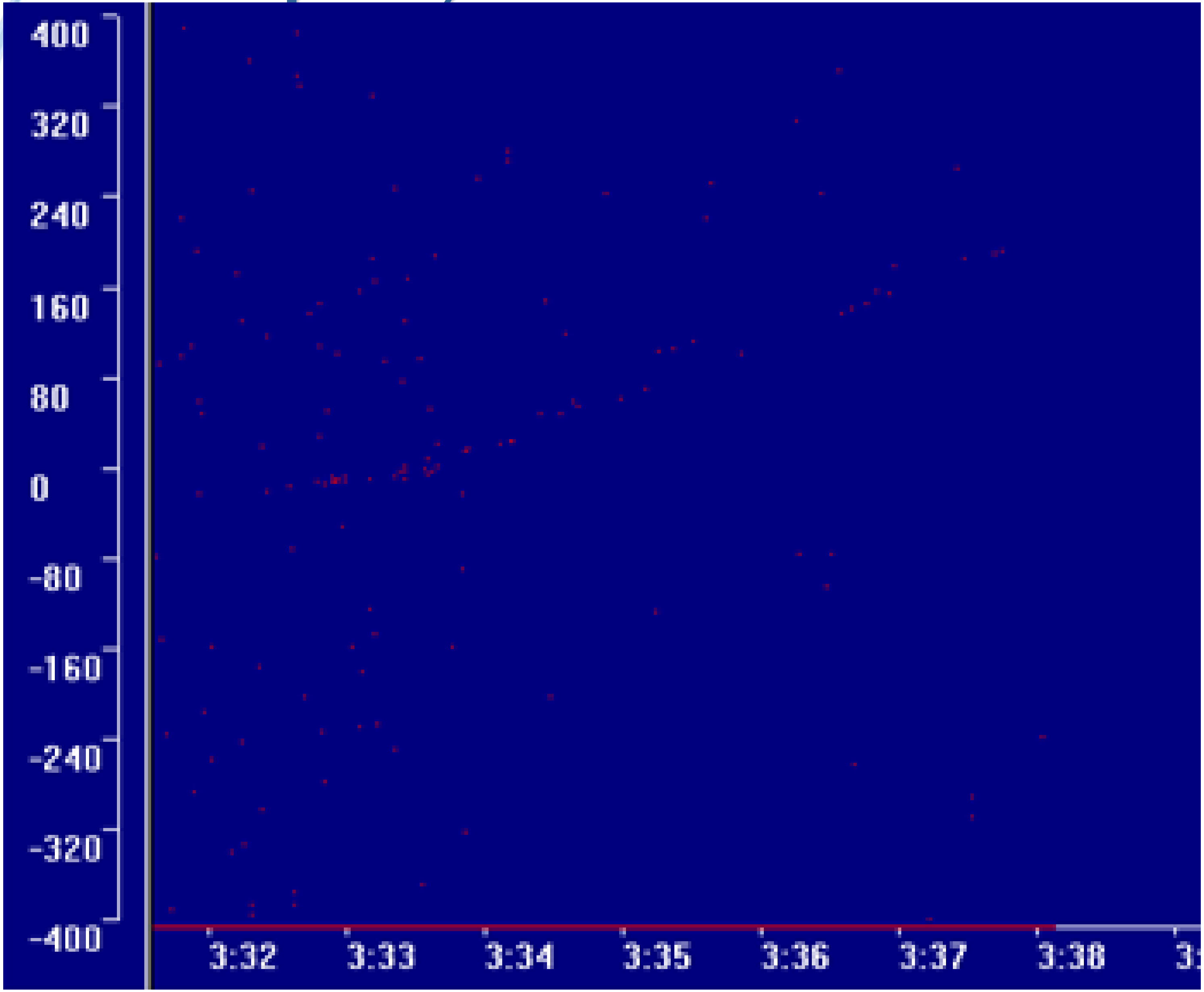
First pass : raw data



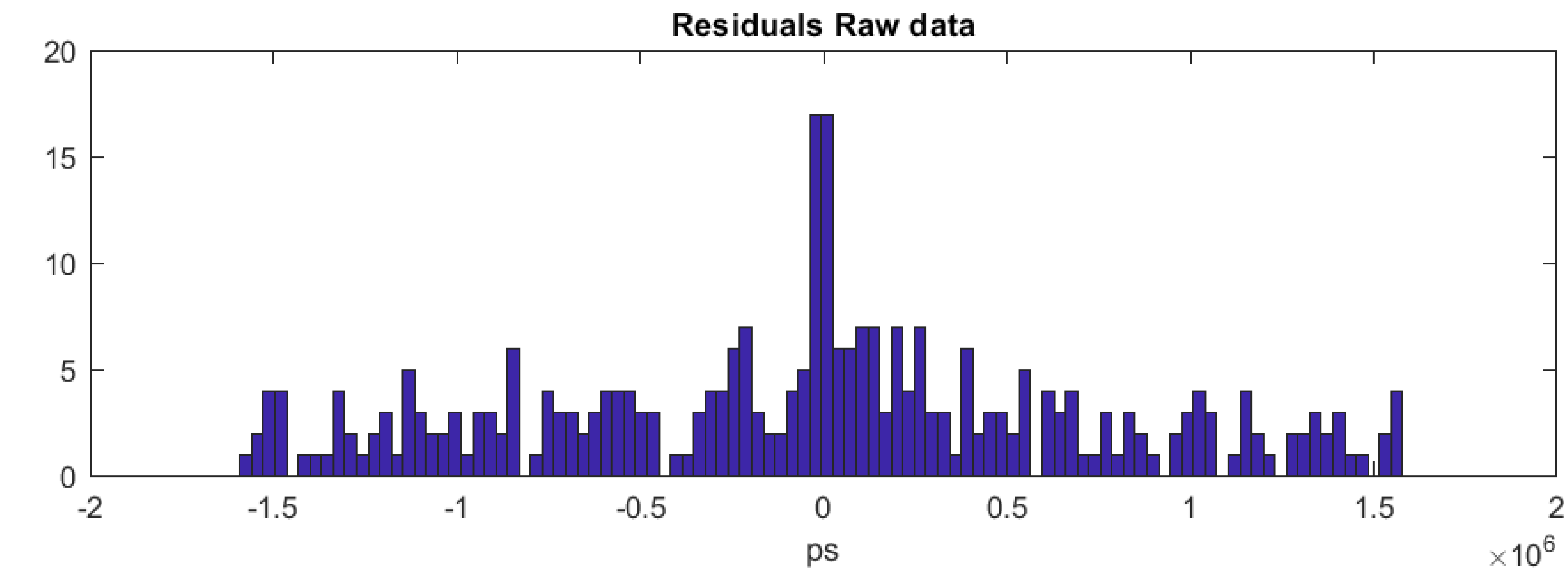
First pass : filtering by eyes of faith

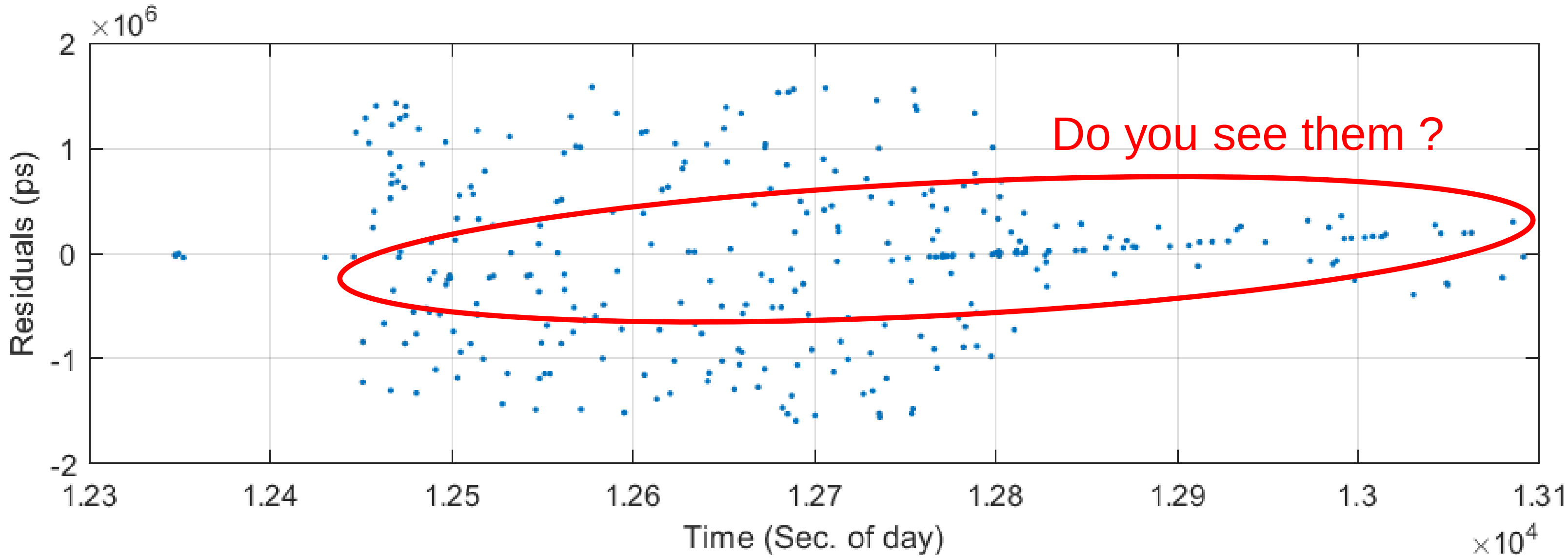


Second pass, screenshot

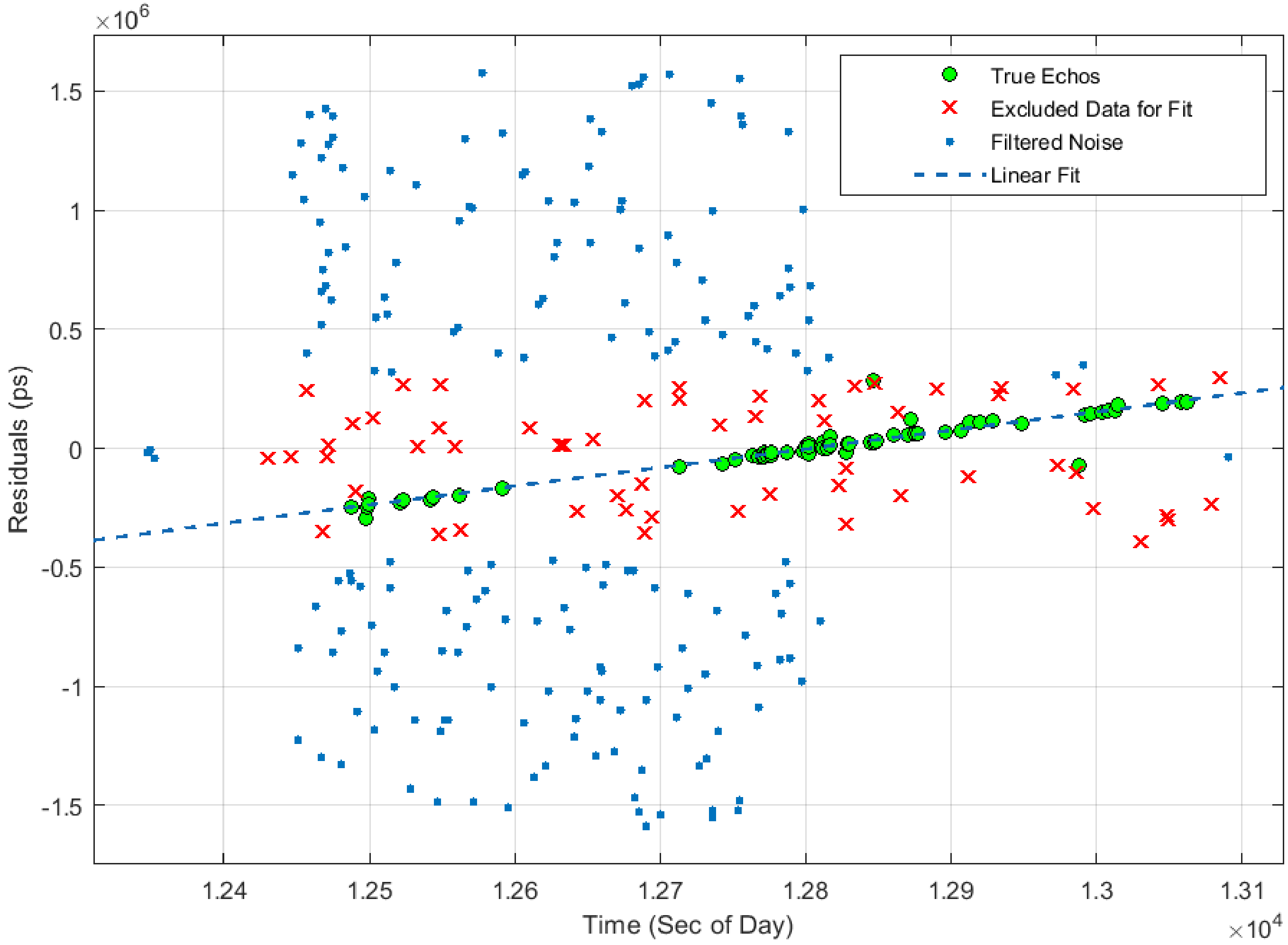


SECOND PASS


Residuals Raw data
20
15
10
5
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
ps
$\times 10^6$


$\times 10^6$
2
1
0
-1
-2
Residuals (ps)
Do you see them ?
1.23
1.24
1.25
1.26
1.27
1.28
1.29
1.3
1.31
Time (Sec. of day)
$\times 10^4$

Second pass linear fit



Events leadind to our third and fourth successfull two way ranging

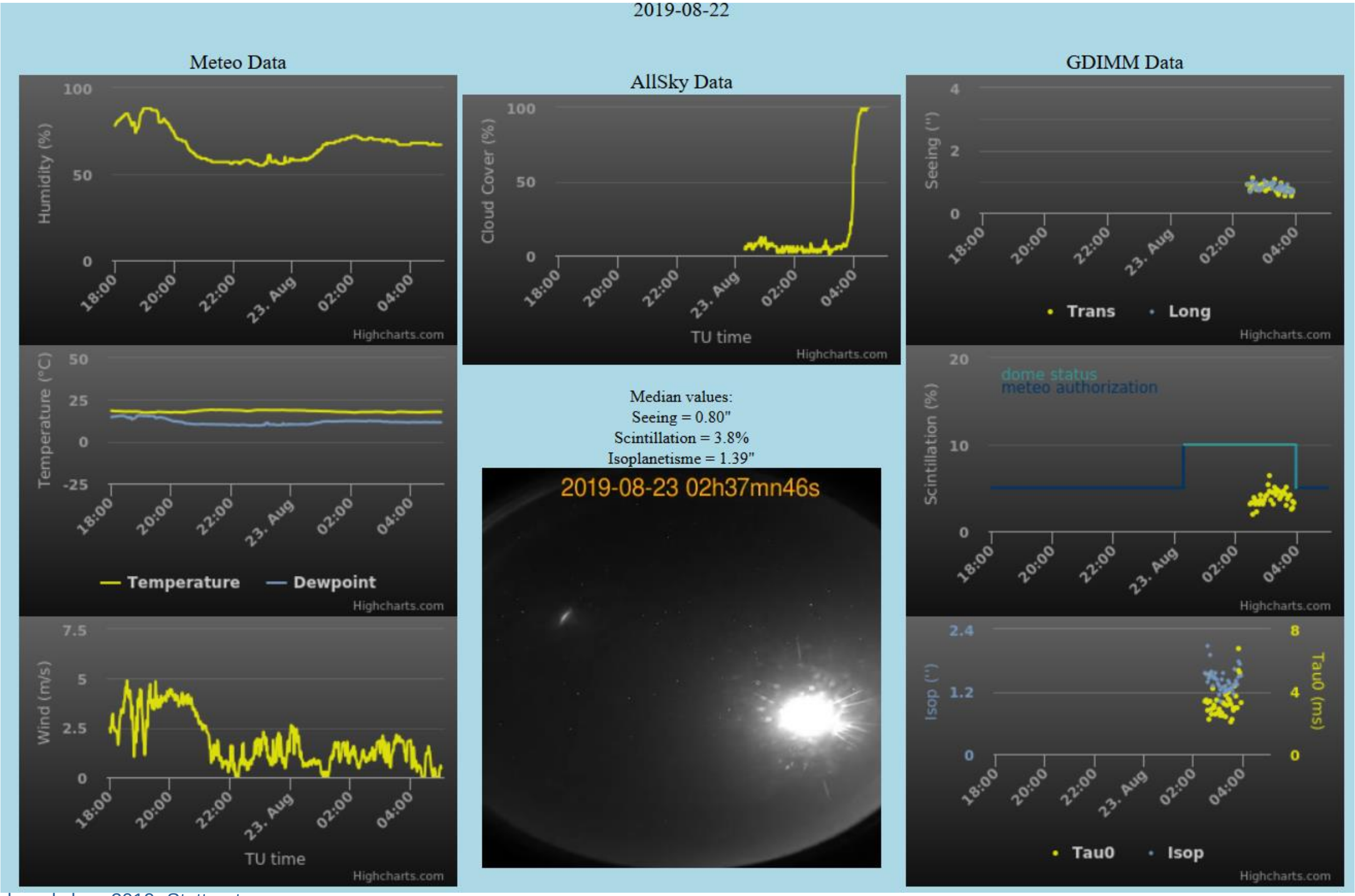
Very shortly after theses two measurements our photodiode broke and the manufacturer doesn’t make them anymore

New IR photodiode (manufactured by RMY) arrive in february 2019, same as Princeton ligthwave PGA-284

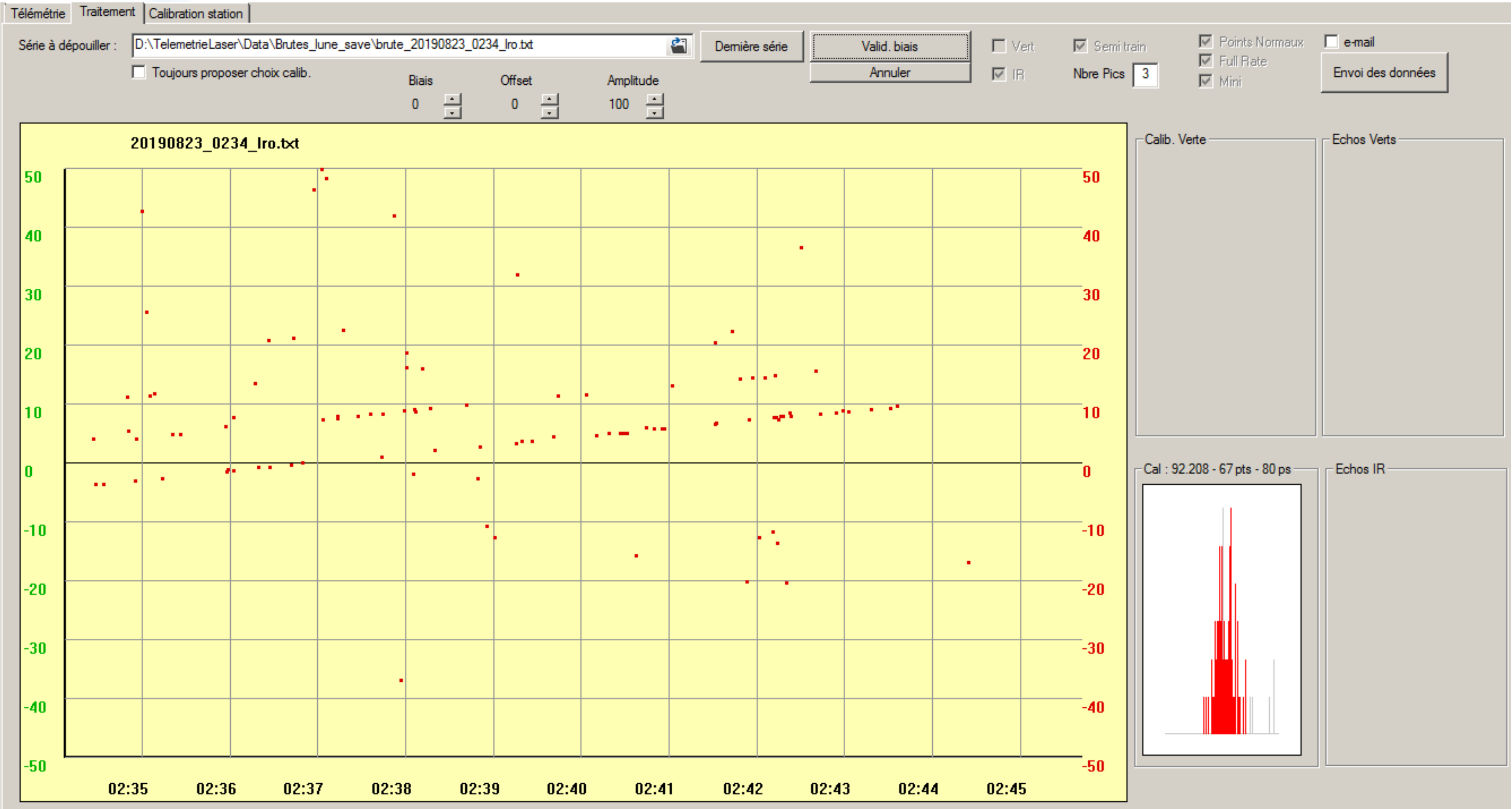
Du to weather condition and the rarity of 2way ranging opportunities the next 2 successfull measurement happens in the 23th and the 24th of august 2019

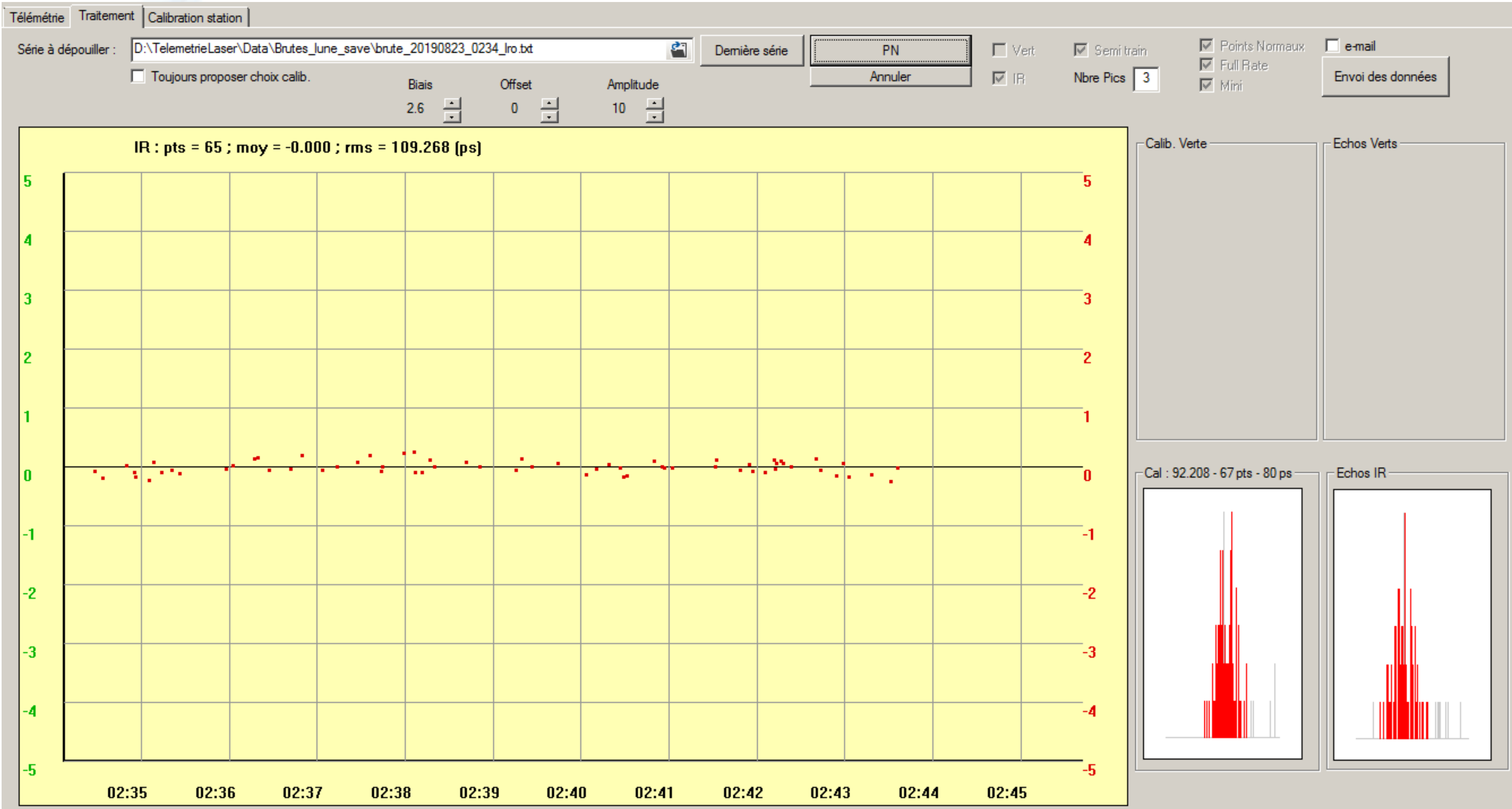
Observation condition on 23 august 2019

- Very good seeing condition: < 1'' (median value)
- Some clouds near the moon

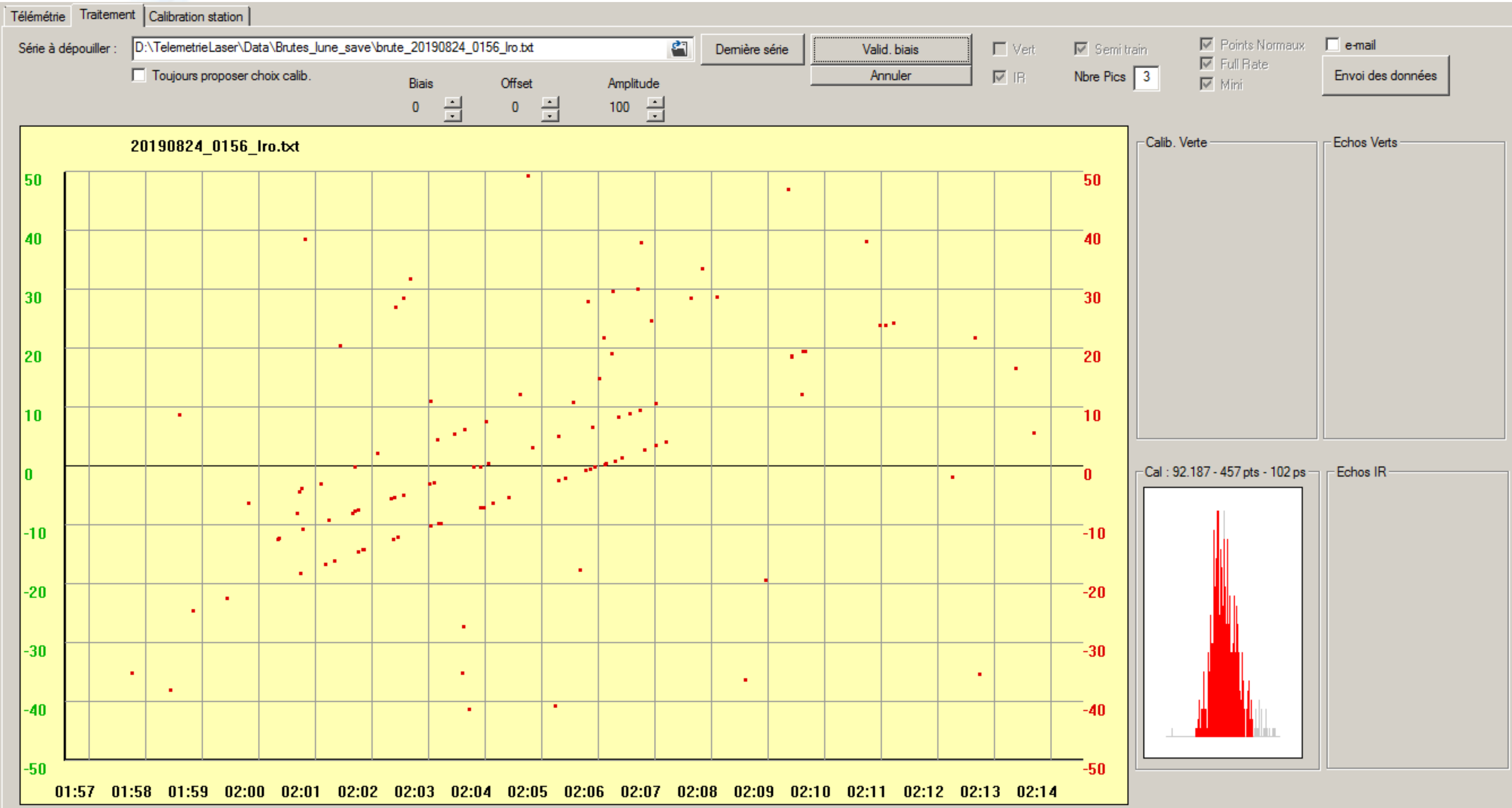


23/08/2019 echos on LRO




Télémétrie
Traitement
Calibration station
Série à dépouiller :
D:\TelemetrieLaser\Data\Brutes_lune_save\brute_20190823_0234_lro.txt
Dernière série
PN
Annuler
Vert
IR
Semi train
Nbre Pics 3
Points Normaux
Full Rate
Mini
e-mail
Envoi des données
Toujours proposer choix calib.
Biais
2.6
Offset
0
Amplitude
10
IR : pts = 65 ; moy = -0.000 ; rms = 109.268 (ps)
5
4
3
2
1
0
-1
-2
-3
-4
-5
02:35
02:36
02:37
02:38
02:39
02:40
02:41
02:42
02:43
02:44
02:45
Calib. Verte
Echos Verts
Cal : 92.208 - 67 pts - 80 ps
Echos IR

24/08/2019 echos on LRO



Télémétrie
Traitement
Calibration station
Série à dépouiller :
D:\TelemetrieLaser\Data\Brutes_lune_save\brute_20190824_0156_lro.txt
Dernière série
PN
Annuler
Vert
IR
Semi train
Nbre Pics
3
Points Normaux
Full Rate
Mini
e-mail
Envoi des données
Toujours proposer choix calib.
Biais
5.8
Offset
0
Amplitude
10
IR : pts = 65 ; moy = -0.000 ; rms = 106.486 (ps)
01:57
01:58
01:59
02:00
02:01
02:02
02:03
02:04
02:05
02:06
02:07
02:08
02:09
02:10
02:11
02:12
02:13
02:14
Calib. Verte
Echos Verts
Cal : 92.187 - 457 pts - 102 ps
Echos IR

Comparison between return rate of LRO and Apollo XI

For these two instance of two way ranging on LRO we were able to range Apollo XI before and after the passage although the weather condition was not identical

For the first one we have

248 echos during 608 seconds for AXI before LRO (0,4 photon / second)
65 echos during 600 seconds for LRO (0,11 photon / second)
112 echos during 653 seconds for AXI after LRO (0,17 photon / second)

For the second one we have

46 echos during 231 seconds for AXI before LRO (0,19 photon / second)
65 echos during 780 seconds for LRO (0,08 photon / second)
35 echos during 591 seconds for AXI after LRO (0,06 photon / second)

So it seems that we have less return on Apollo XI than expected if the retroreflectors are not degraded in some way, but we have very few data and many factors can explain this. So we'll need more successfull 2 way ranging to have more confidence in these results

Thank you for your attention!

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