18th International Workshop on Laser Ranging

FujiYoshida
10-15 November 2013

Lunar Laser Ranging: Recent activities of POLAC

Sébastien Bouquillon et al.

Service Polac / SYRTE / Observatoire de Paris
In collaboration with the INPOP Group and the MéO laser Station
(IMCCE Observatoire de Paris /GeoAzur, Observatoire de la Côte d'Azur)

Presentation Number: 13-0403

Lunar Laser Ranging: Recent activities of POLAC

Contents

Overview of POLAC history and activities.

POLAC recent activities:

- Support for LLR observers:
  - Improvements of “Prediction and Validation” tools
  - Validation of LLR Observations by e-mail
- Support for LLR DATA users:
  - Critical analyse of an extended LLR data gathering.

POLAC projects.

Overview of POLAC history activities.

Paris **O**bservatory **L**unar **A**nalysis **C**enter *(since 1996)*

In SyRTE division of Paris Observatory

- Current members: *S. Bouquillon & C. Le Poncin-Lafitte*
- Founding members: *J. Chapront, M. Chapront-Touzé & G. Francou*
- Main collaborators: *H. Manche(IMCCE), J-M Torre(OCA), D. Feraudy(OCA)*
  C. Lhotka(Roma University)

Specificities of this service:

- LLR data reduction based on two semi-analytical Lunar theories:
  - ELP(Ephéméride Lunaire Parisienne) *J.Chapront & M.Chapront-Touzé*
  - The Lunar Libration Theory *developed by M.Moons*
- Implications with EOP-PC and ICRS-PC (products centers of IERS)
- Close Cooperation with the Grasse Station(MeO).
- Collaboration (since 2006) with the group in charge of the development of INPOP (Intégration Numérique Planétaire de l'Observatoire de Paris)
- Recent interactions with the Team “Theory & Metrology” of SyRTE divison of Paris Observatory

POLAC recent activities:
Support for LLR observers.

Improvement of “Prediction & Validation” Tools

http://polac.obspm.fr/PaV/

Improvement of “Prediction & Validation” Tools


Applications Raccourcis Système
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http://polac.obspm.fr/PaV/
la mediterranee paris
Courriel Meteo Dico Astro Reservations PagesJaunes Cinema Cartes Les Roches - La Ma... MissionCNRS Transport Nara
http://polac.obspm.fr/PaV/
apercu - Dictionnaire Franç...
http://polac.o...dexValid.html
Lunar Laser Ranging Service
Paris Observatory Lunar Analysis Center
Version 1.1 : 11th September 2013
Prediction for future LLR Observations
Validation of past LLR Observations
HELP
HOME
Developed by : C. Barache, S. Bouquillon, T. Carlucci, F. Deleflie, D. Feraudy, G. Francou, H. Manche, E. Samain, J-M. Torre & W. Zerhouni
Acknowledgments to Randall Ricklefs & to Pierre Tessandier for their helps.
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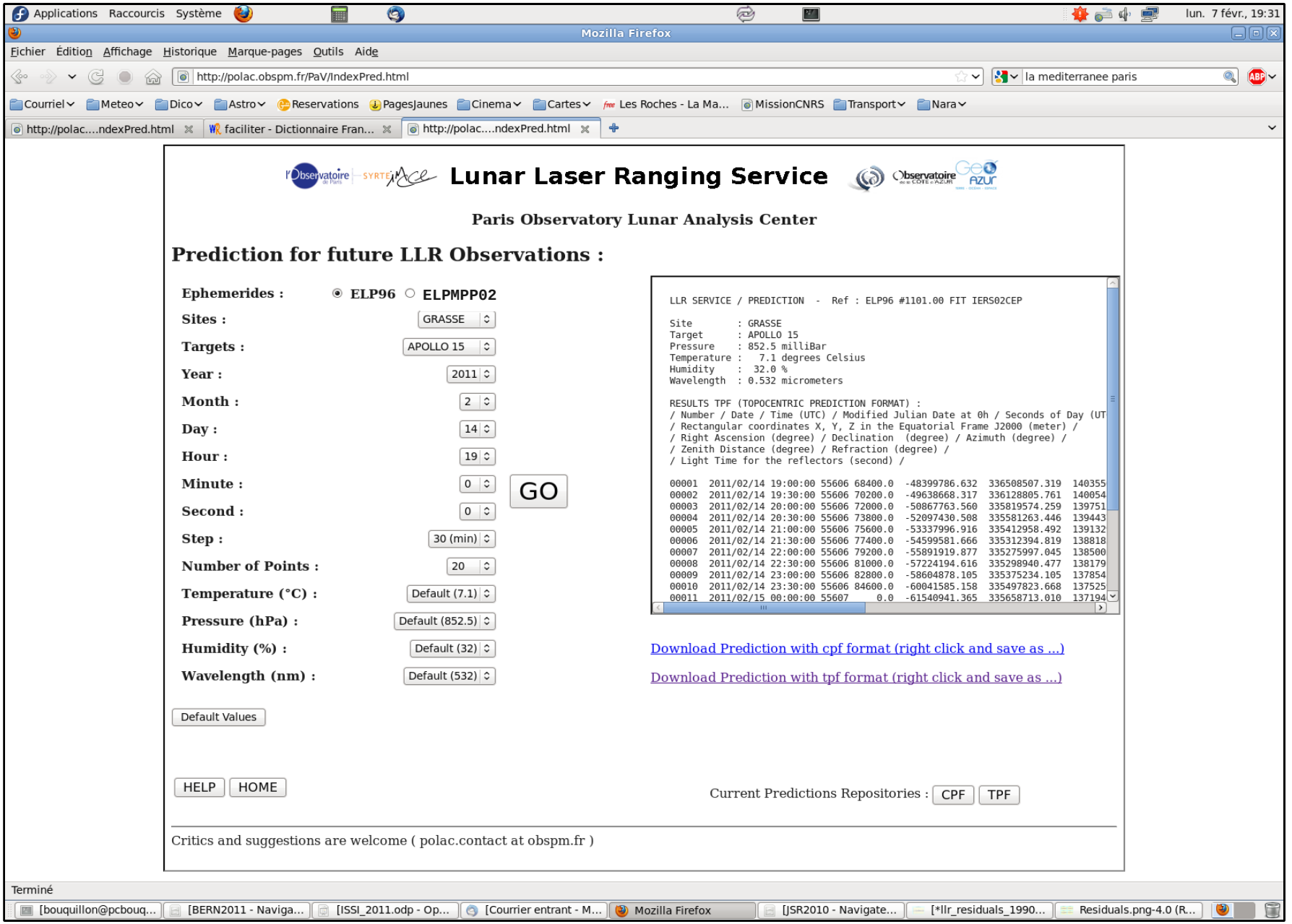
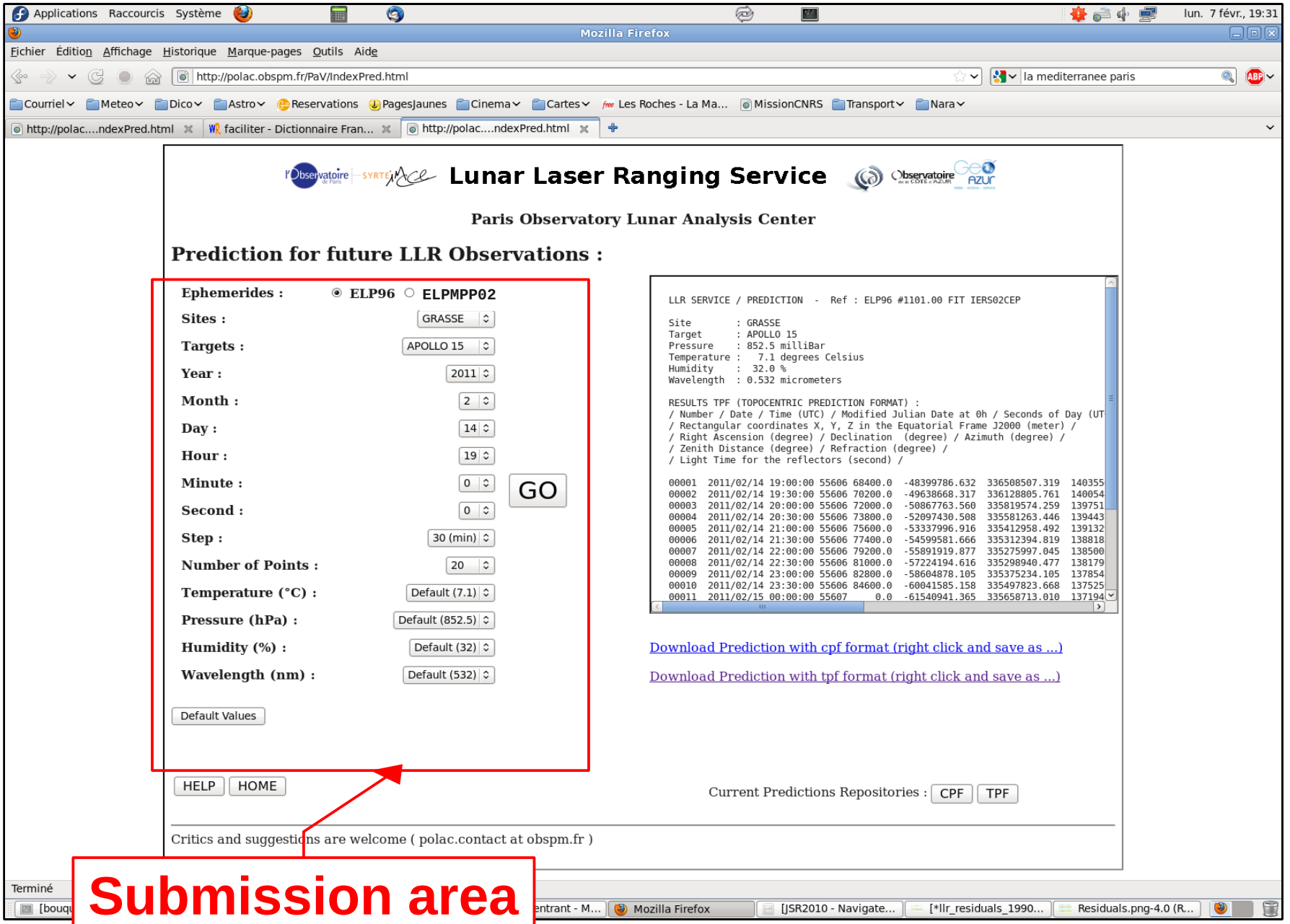
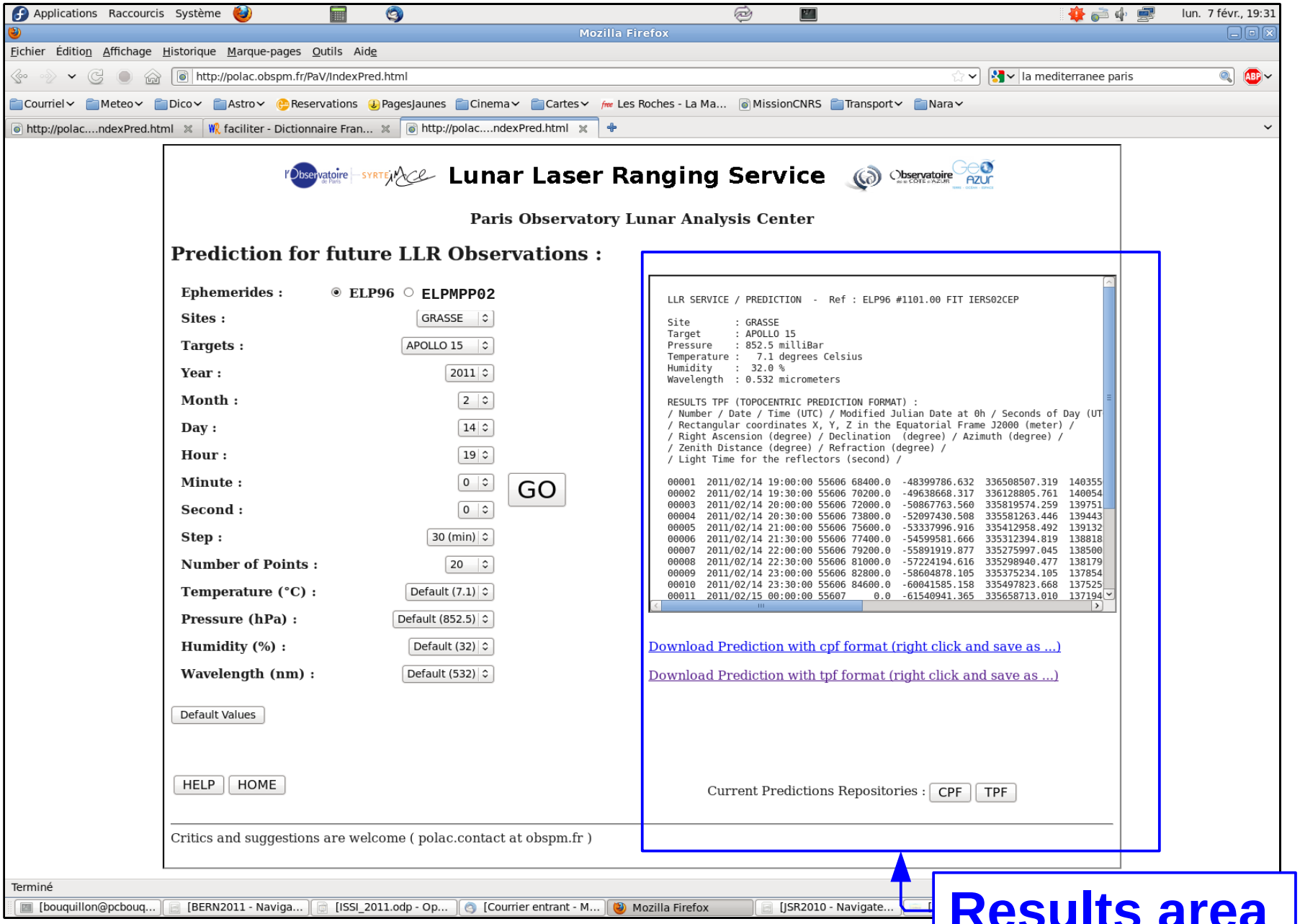
Pointing towards the Moon.



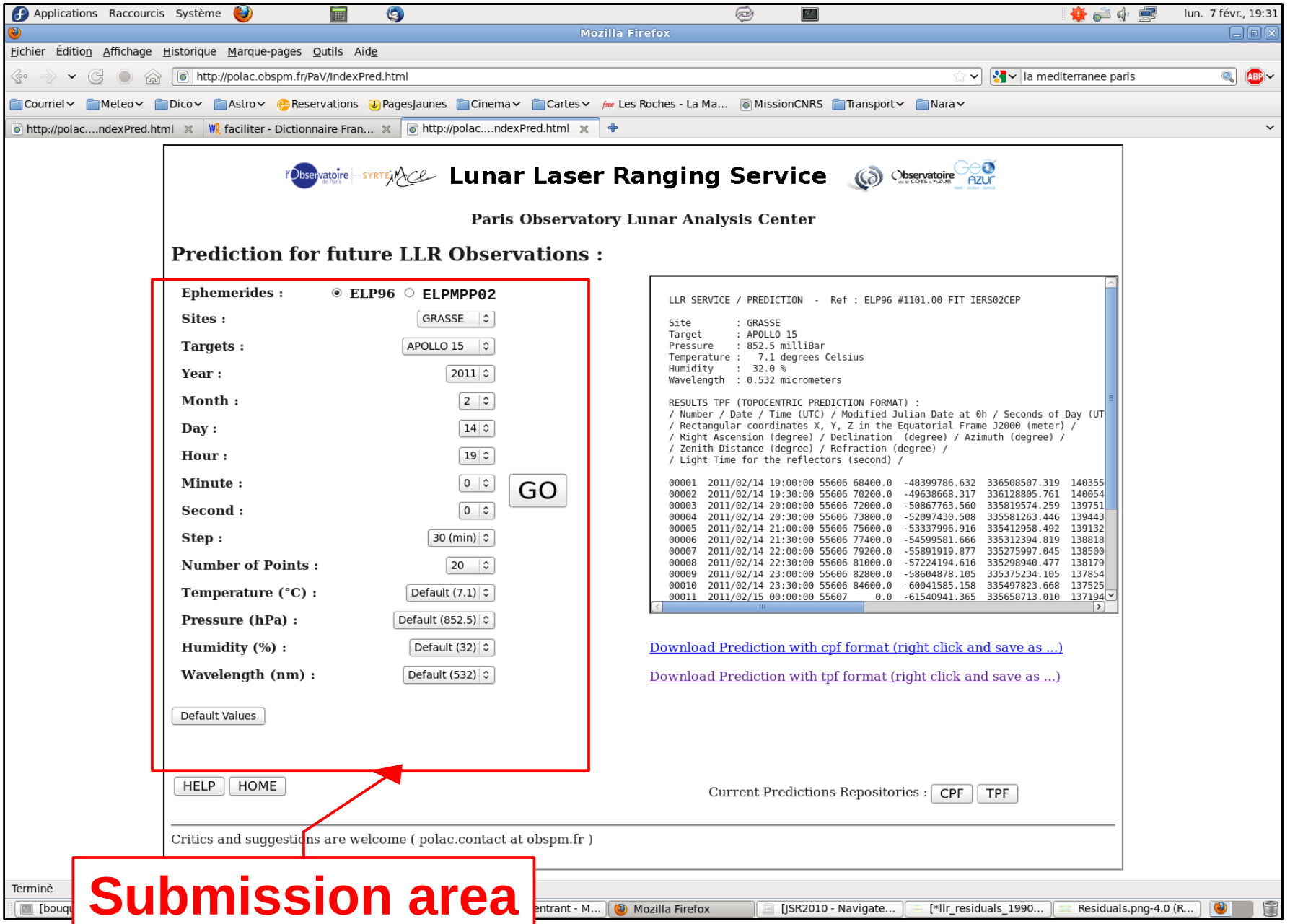
Pointing towards the Moon.



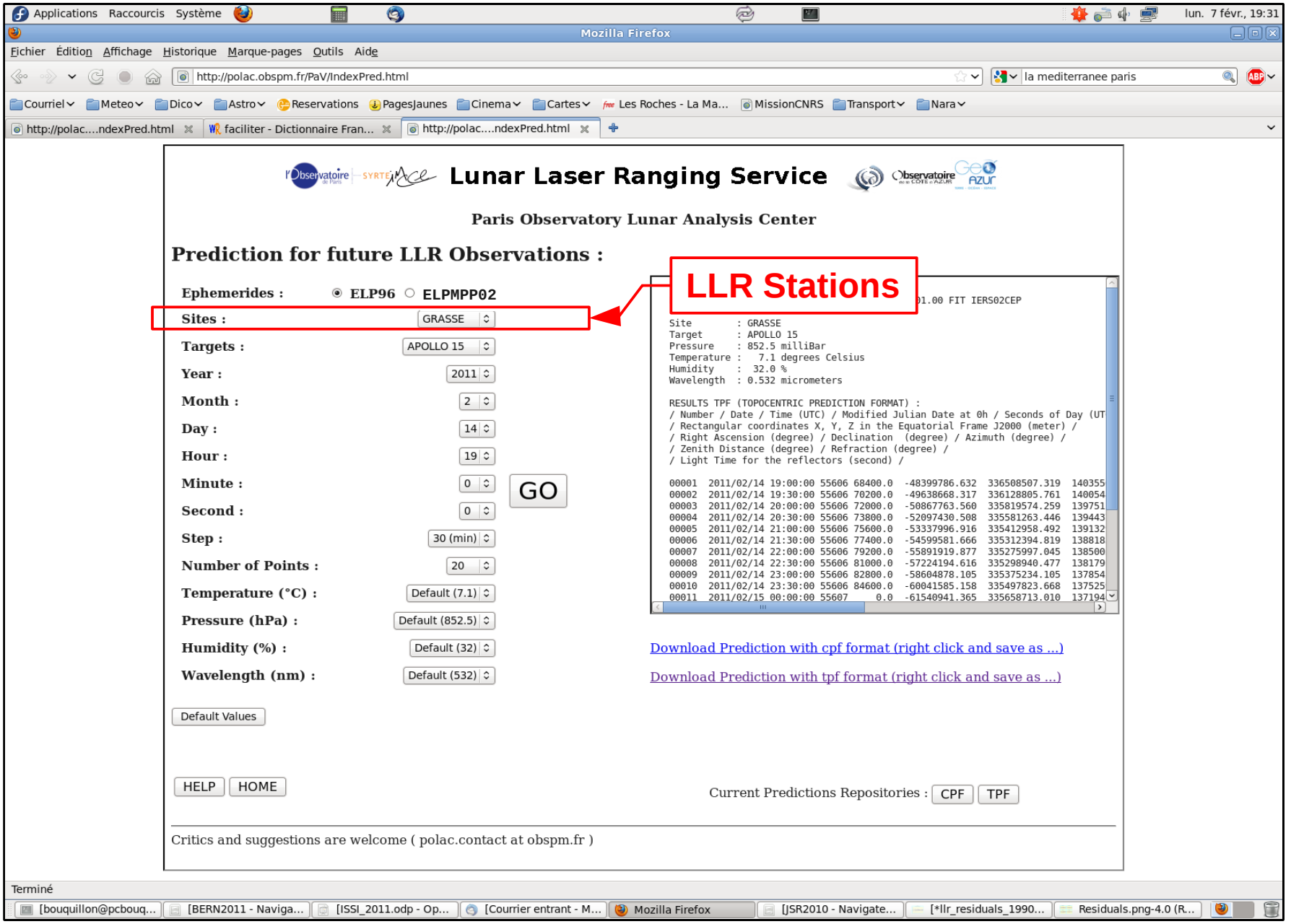
Pointing towards the Moon.



Pointing towards the Moon.

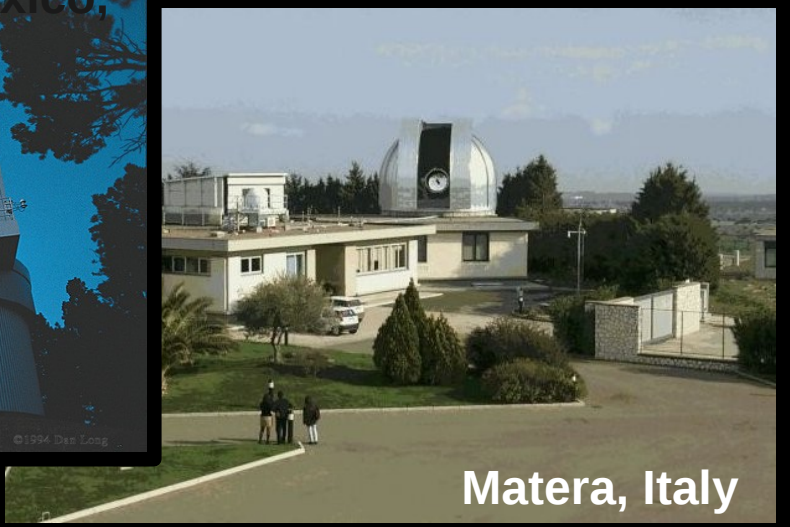


Pointing towards the Moon.



Pointing towards the Moon.

- sites currently available in the web interface

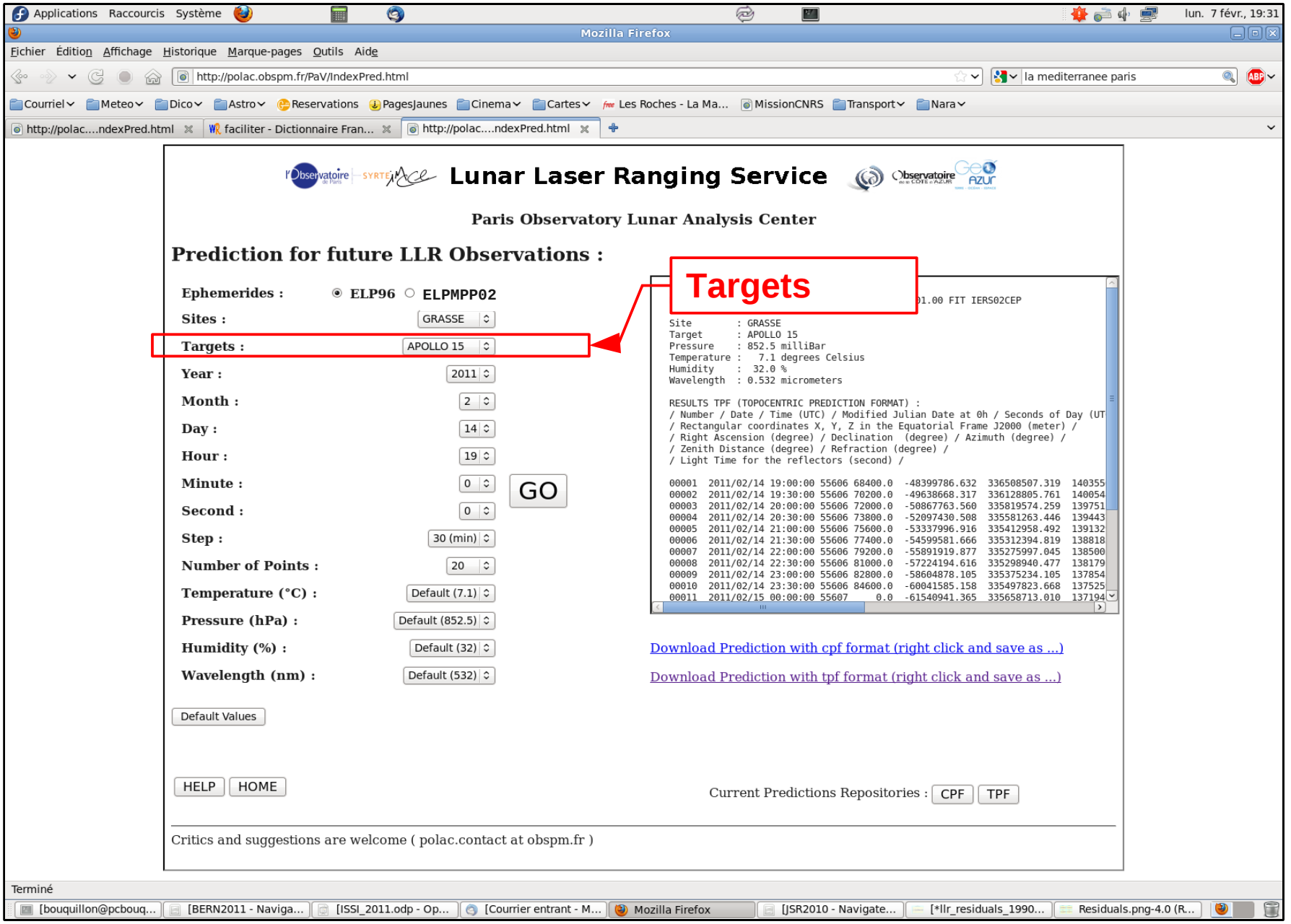


Pointing towards the Moon.

- sites currently available in the web interface

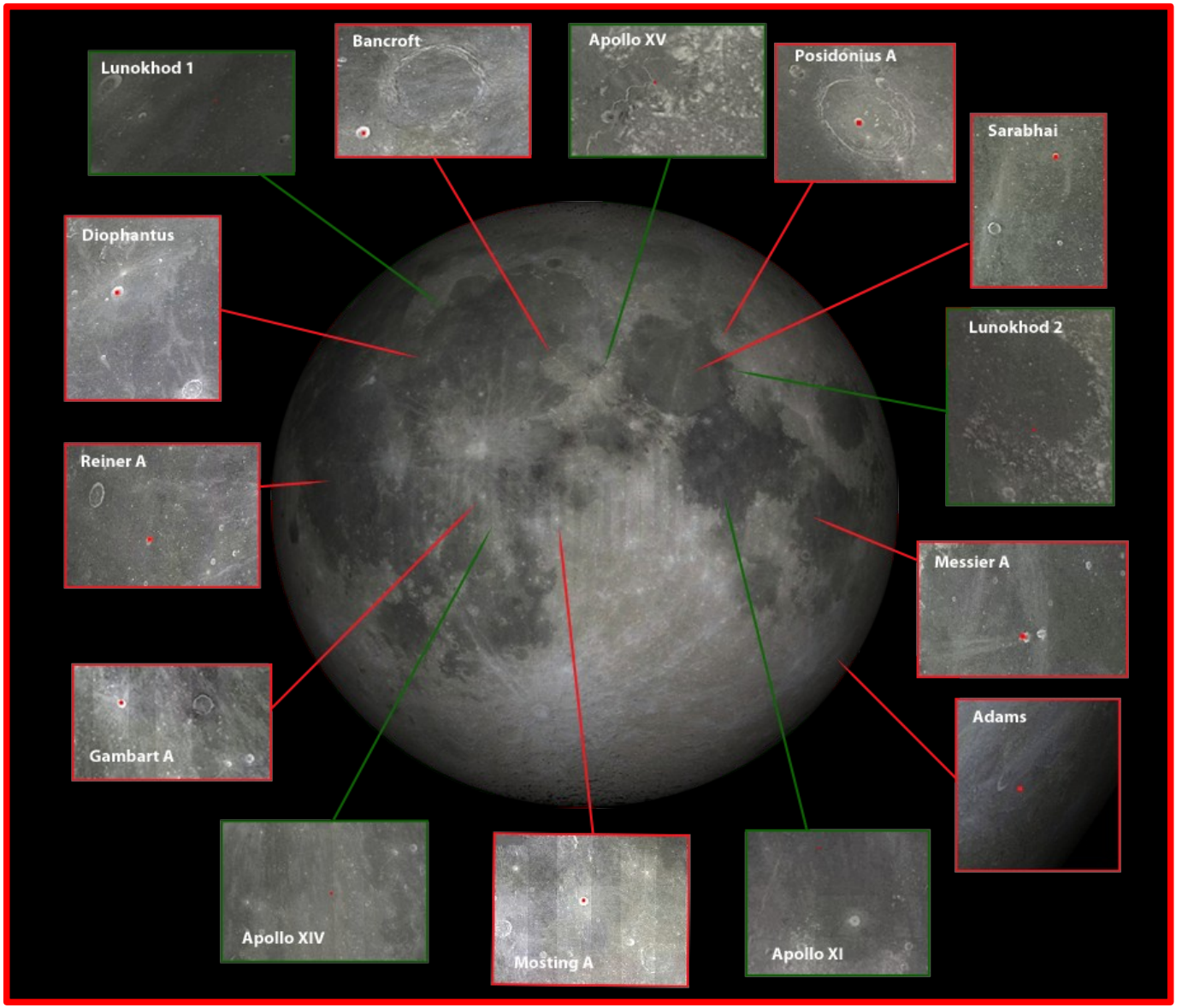
- **New site added last year : Shanghai SLR station (07821)**

Pointing towards the Moon.

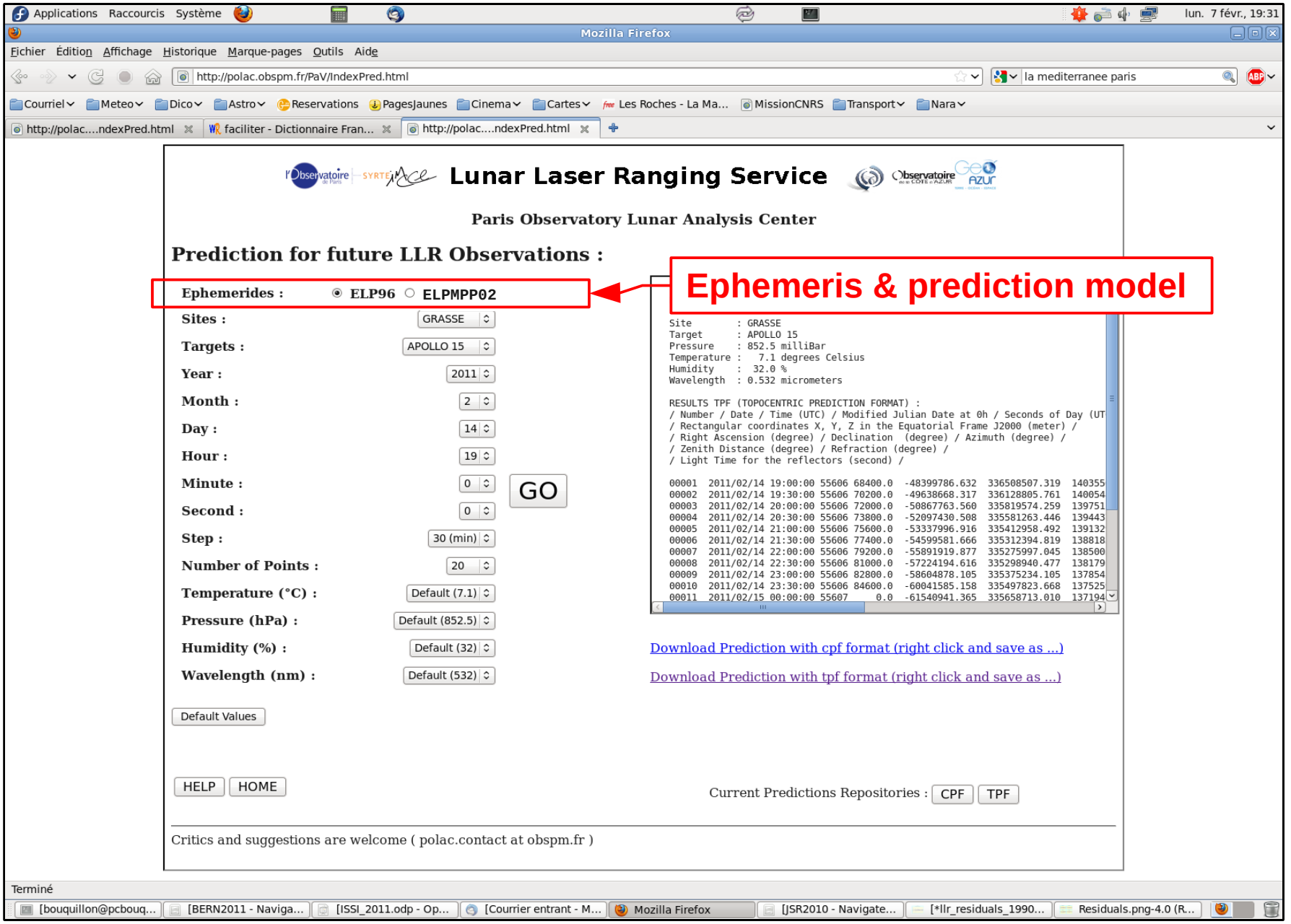


Pointing towards the Moon.

- Reflectors and Craters currently available in the web interface



Pointing towards the Moon.



Pointing towards the Moon.

- Lunar solutions & reduction models available to compute predictions:

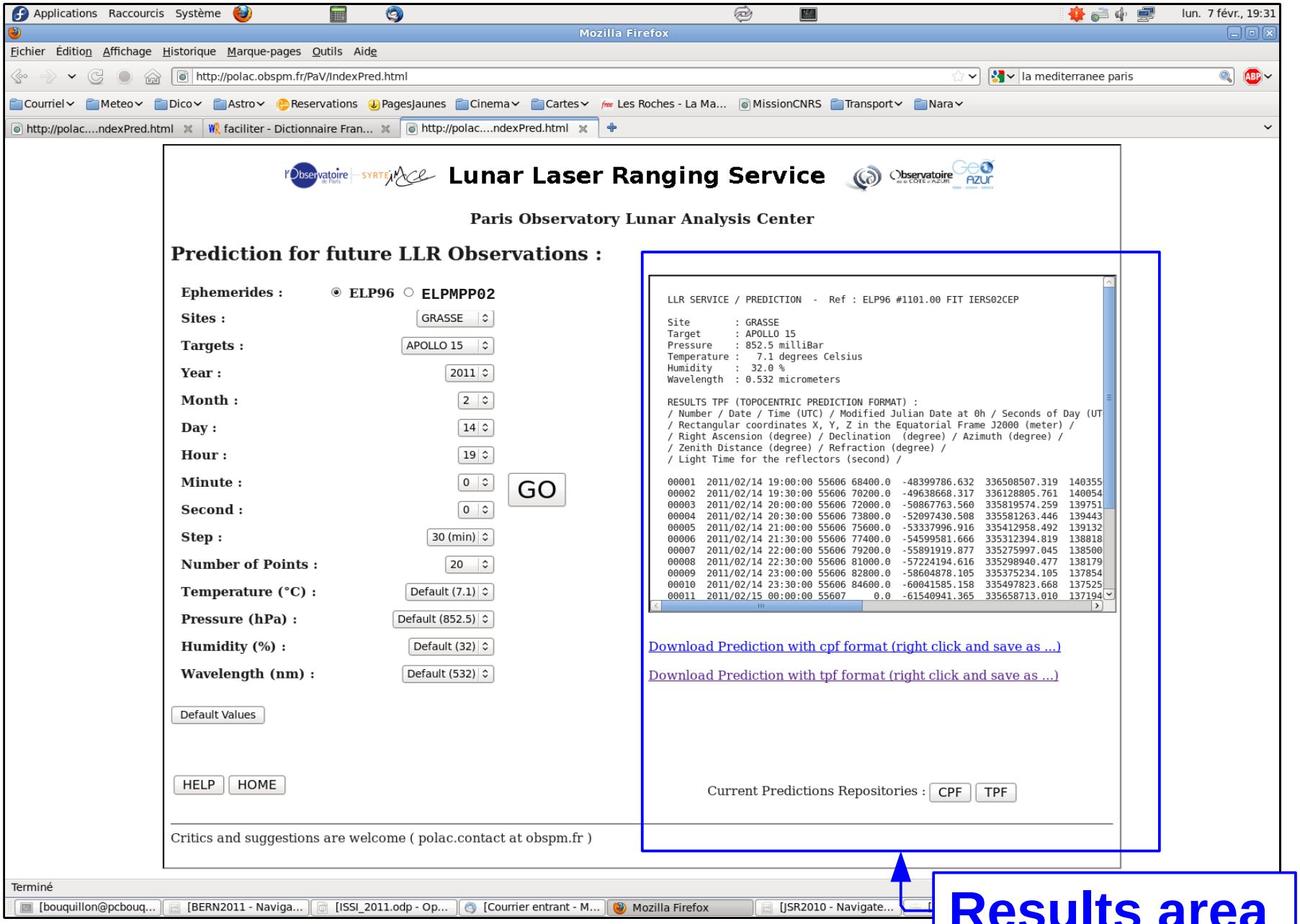
ELP96: It is an improved version of the analytical solution of the Moon ELP2000-82B (Chapront-Touzé M. & Chapront J., 1988, 1997). The numerical ephemeris DE245 (JPL) is used for the motion of the Earth-Moon barycenter and for numerical complements to the lunar librations and orbital motion. Initially, the lunar coordinates given by this solution are referred to the dynamical mean ecliptic of the date. The change to the equatorial frame of the Celestial Ephemeris Pole (J2000) is carried out by analytical expressions of the precession-nutation. This solution is fitted to the Lunar Laser Ranging observations made from 1972 until 2010 (Chapront J. & Francou G., 2002)

ELPMPP02: The main differences from the previous solution 'ELP96' is the use of the new planetary perturbations MPP01 (Bidart, 2001). The numerical ephemeris DE405 is used for the motion of the Earth-Moon barycenter and for numerical complements to the lunar librations and orbital motion. This solution is fitted to the Lunar Laser Ranging observations made from 20/08/1969 until 30/05/2013. The initial positions of station are given in ITRF 2008 and the transformation between terrestrial reference frame and celestial reference frame is done with the help of SOFA routines (consistent with IERS Conventions 2003)

New Ephemeris and New Reduction Model

Bidart,P., 2001, A&A,366,351B.
Chapront-Touzé, M., Chapront, J., 1988, A&A, 190, 342.
Chapront-Touzé, M., Chapront, J., 1996, Celest.Mech., 66, 31.
Chapront-Touzé, M., Chapront, J., Francou, G., 1997, Celest.Mech., 66, 31.
Chapront, J., Chapront-Tousé, M., Francou G., 2002, A&A, 387, 700.

Pointing towards the Moon.



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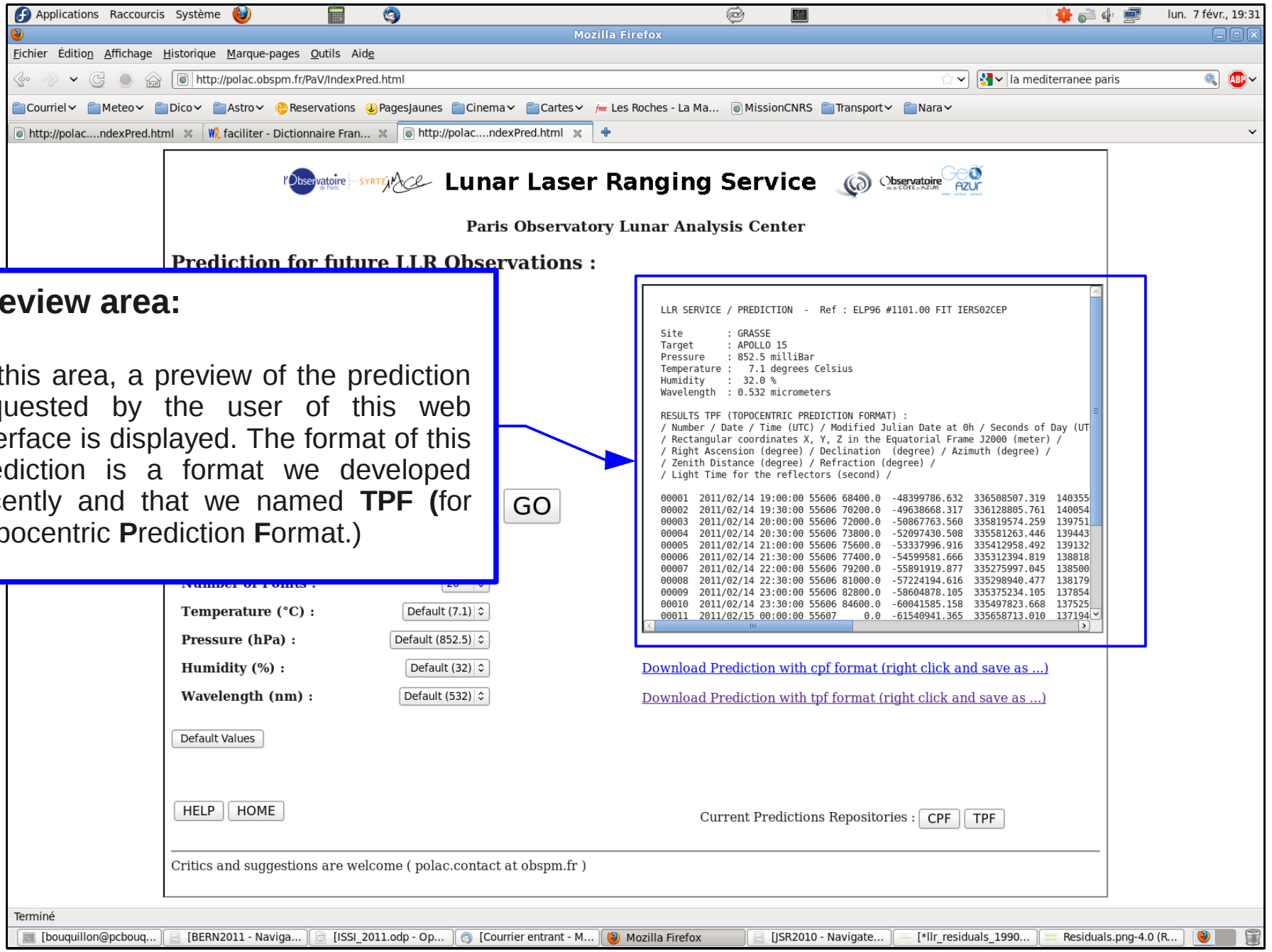

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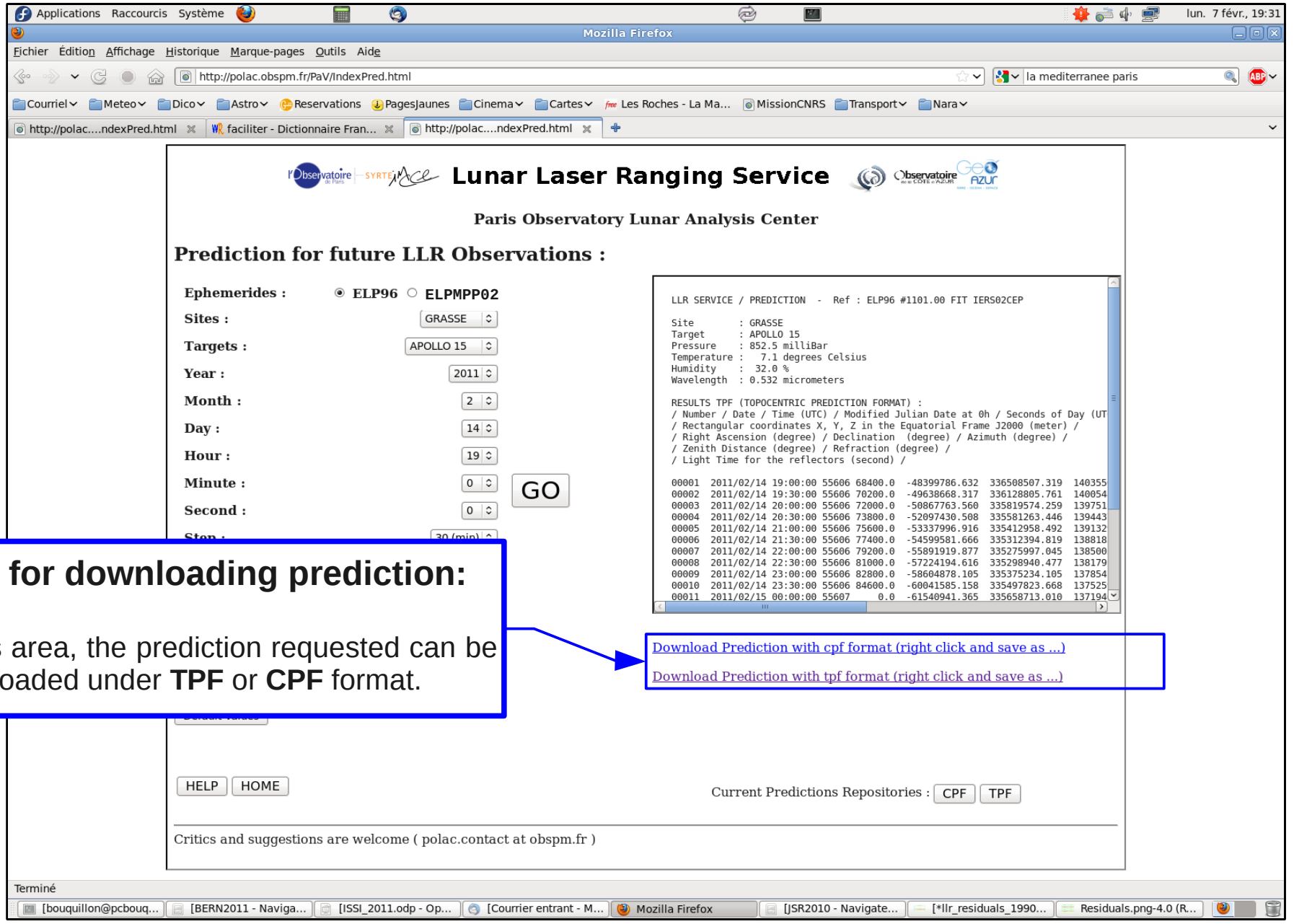
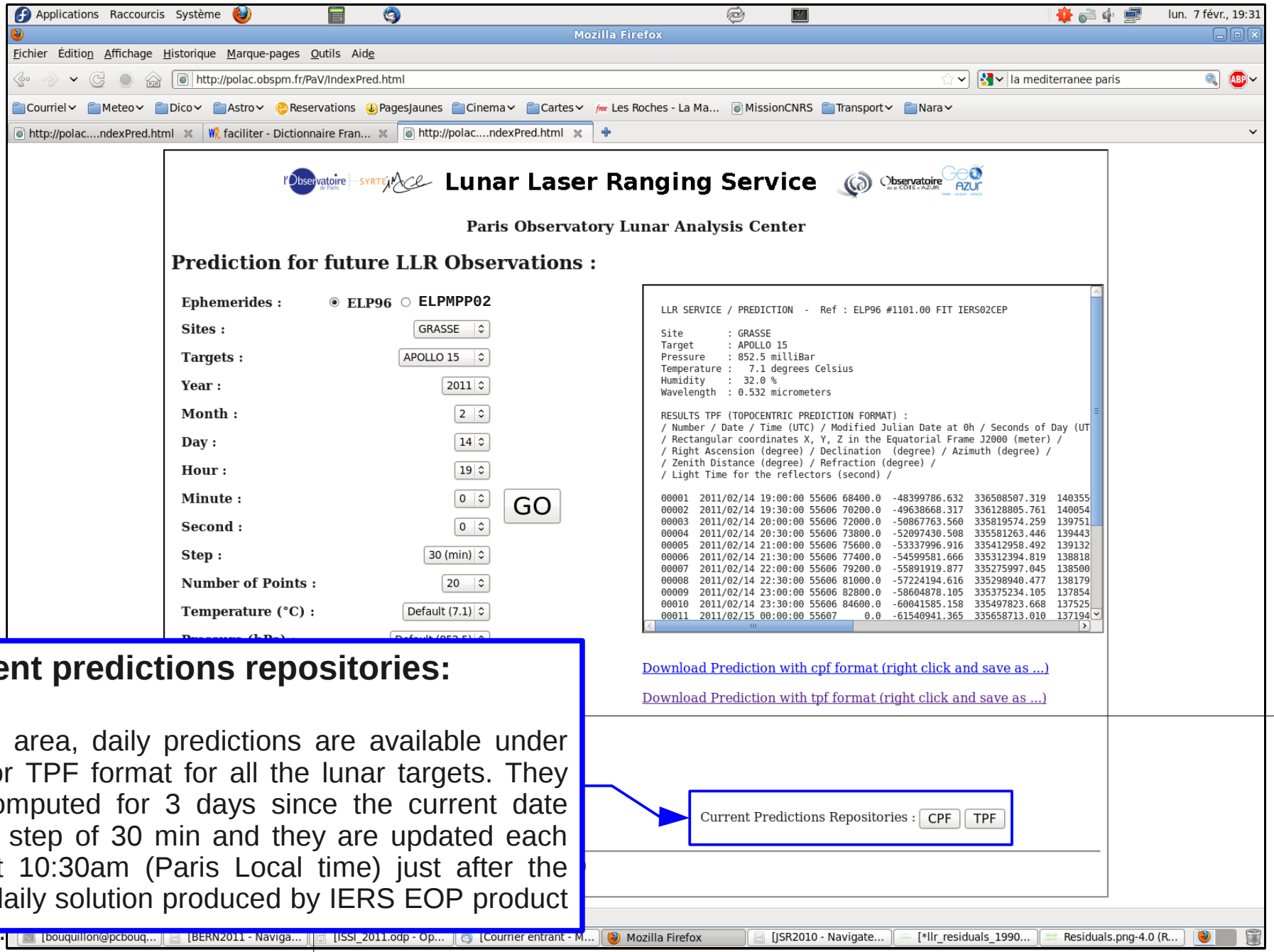


Area for downloading prediction:

In this area, the prediction requested can be downloaded under **TPF** or **CPF** format.

Pointing towards the Moon.



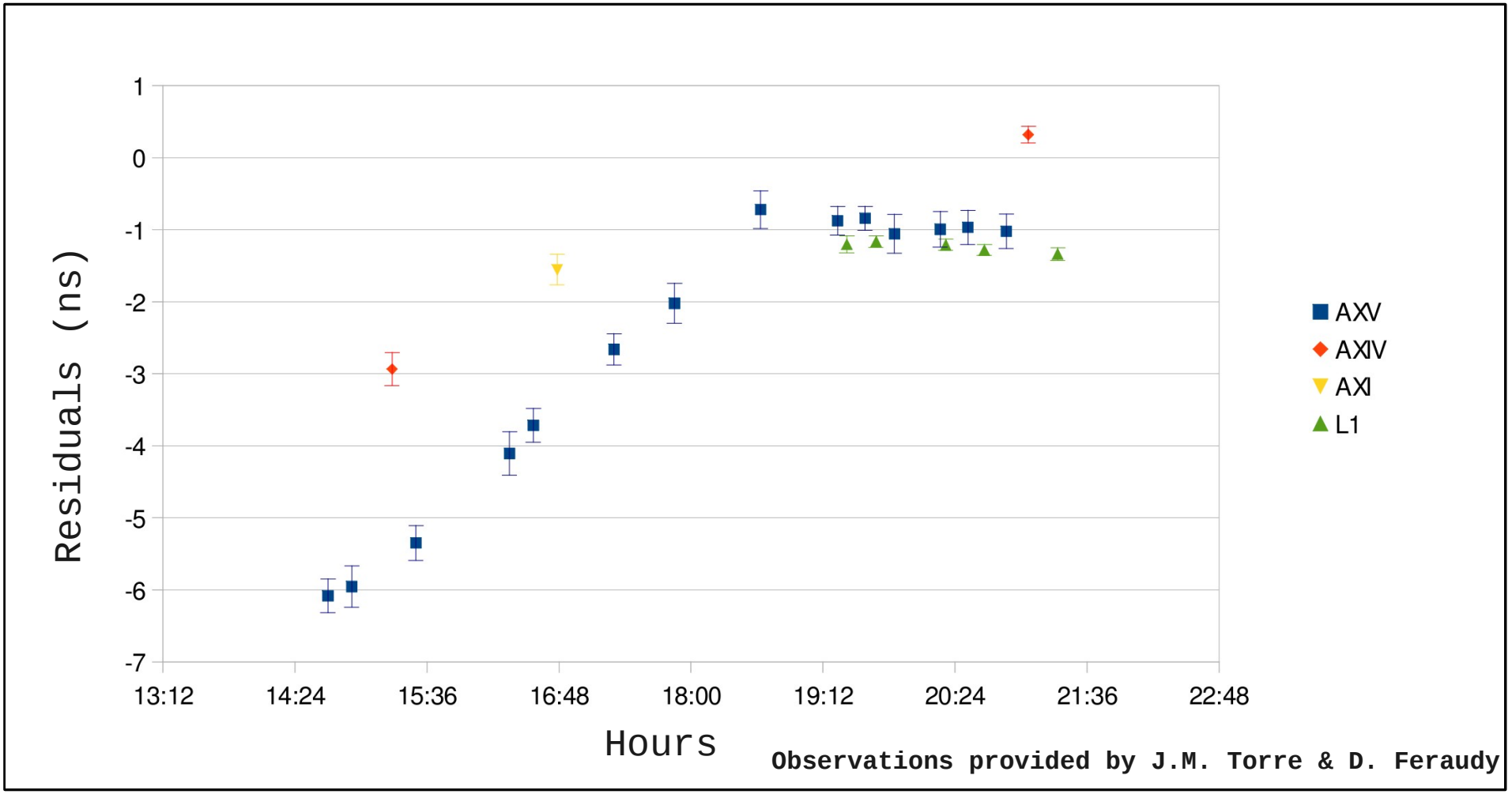
Current predictions repositories:

In this area, daily predictions are available under CPF or TPF format for all the lunar targets. They are computed for 3 days since the current date with a step of 30 min and they are updated each day at 10:30am (Paris Local time) just after the **EOP** daily solution produced by IERS EOP product center.

Example of Prediction done with this tool: First Detection of Lunokhod 1 with MeO

Night 19th/20th of March 2013

- LLR NP Residuals obtained during the night



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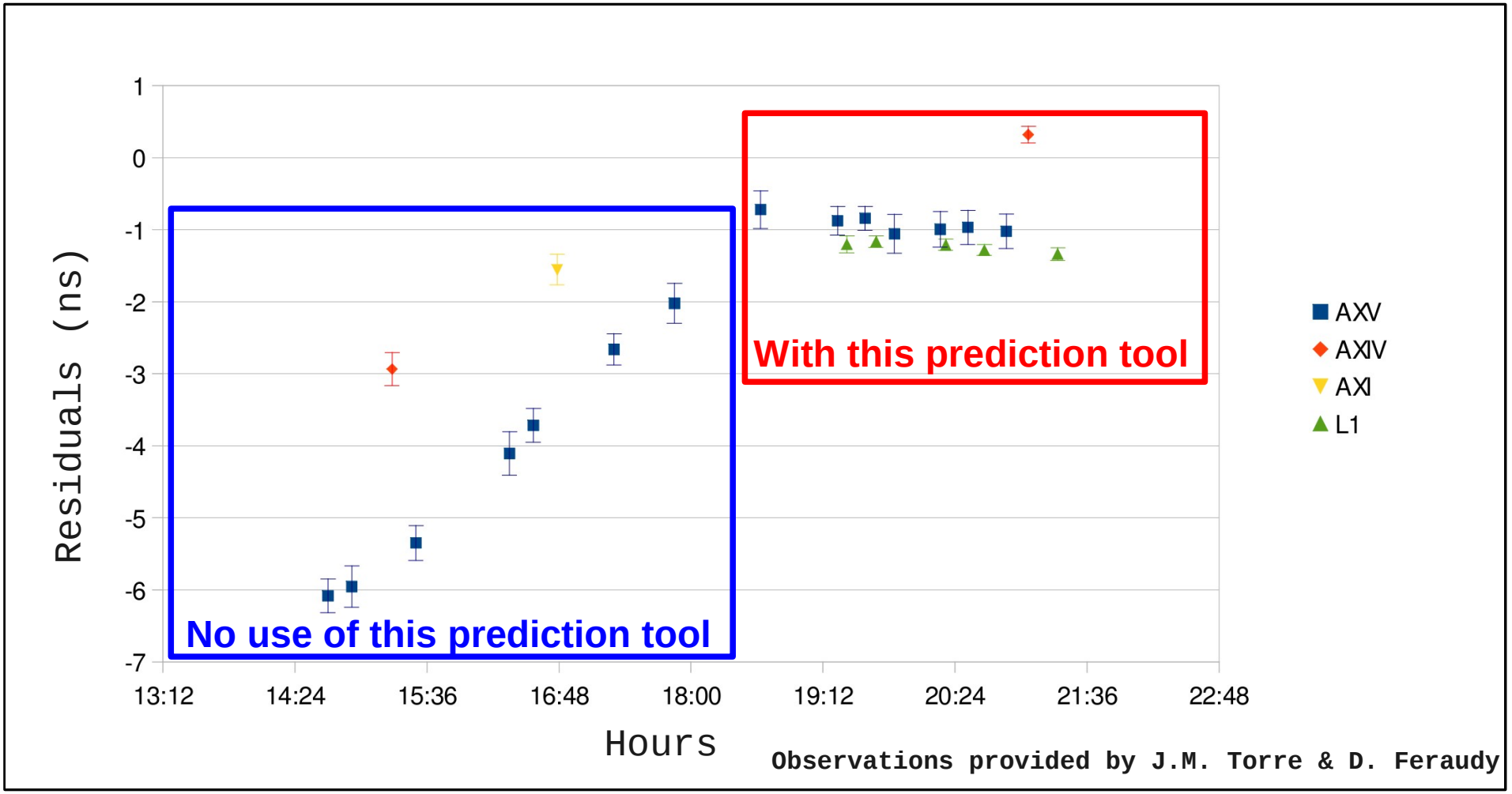

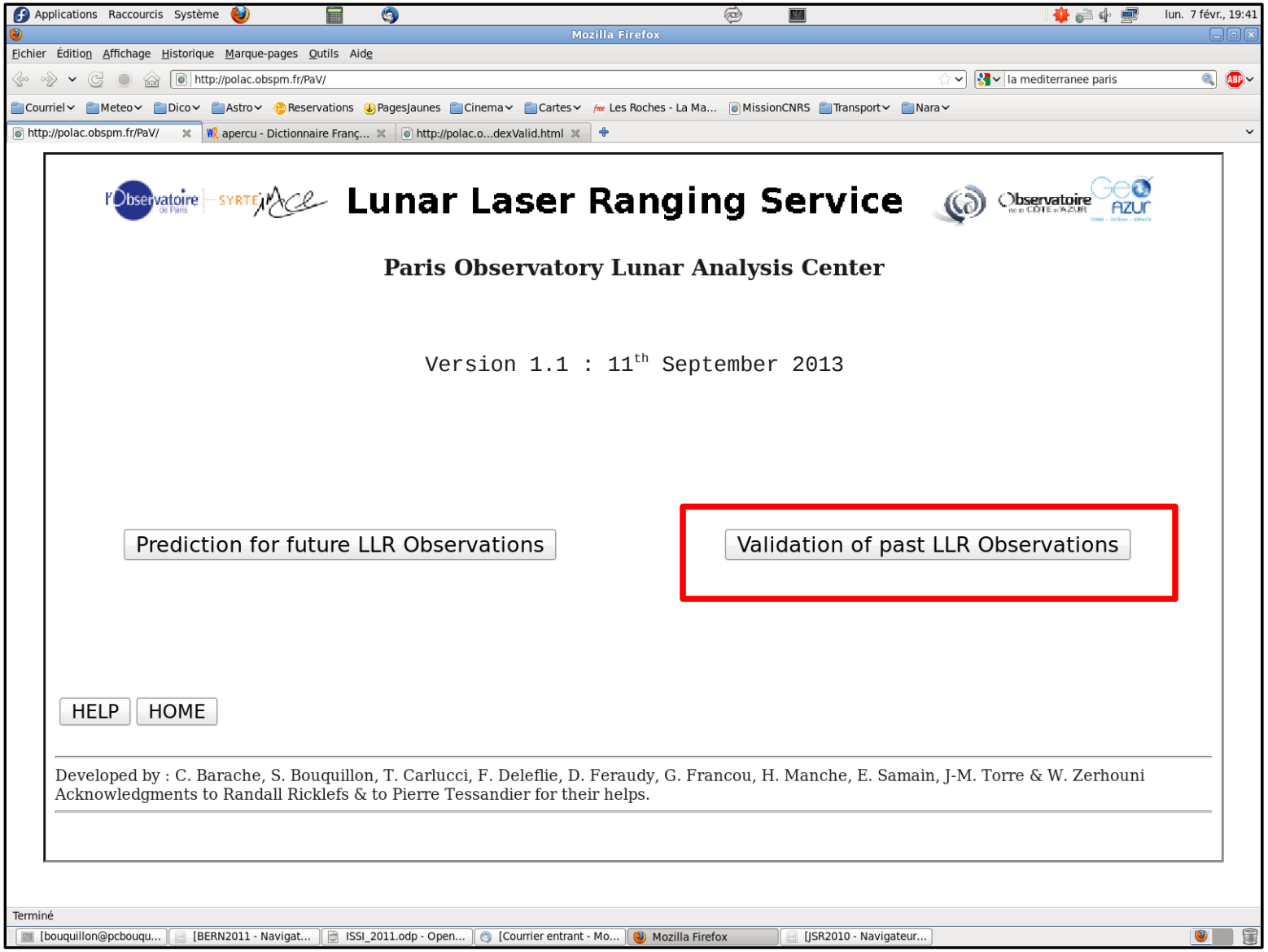
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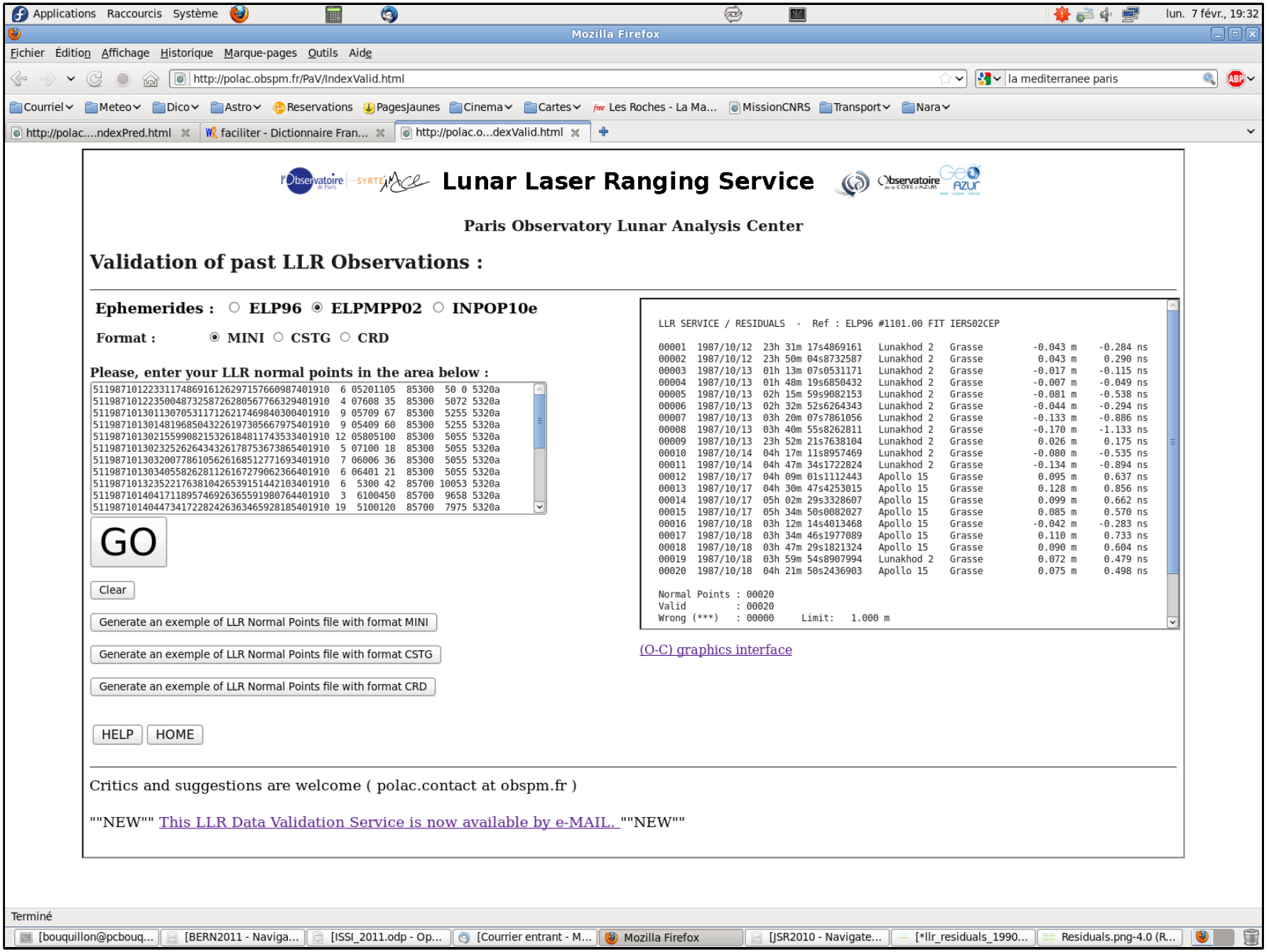
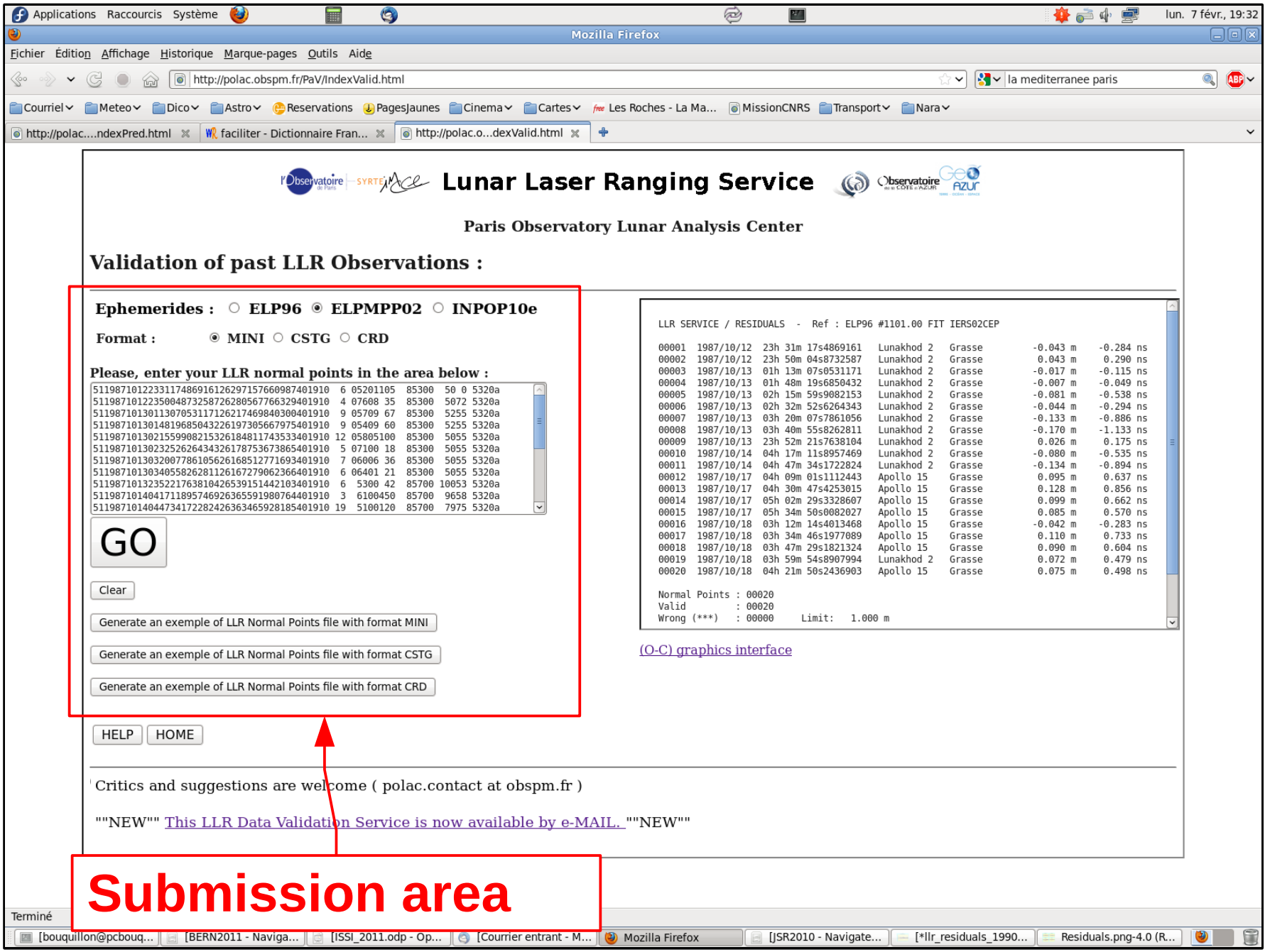
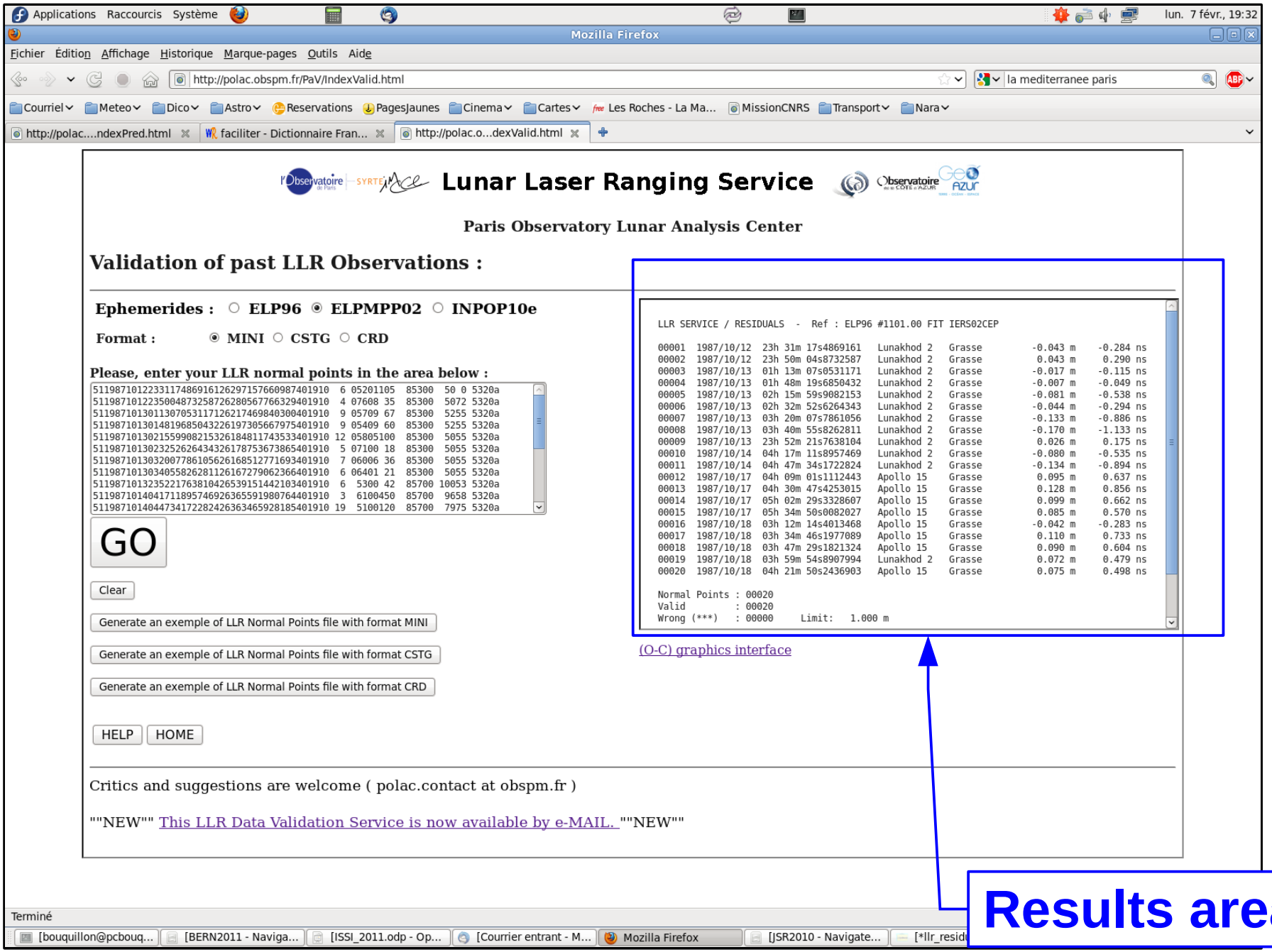
Validation of LLR normal Points.



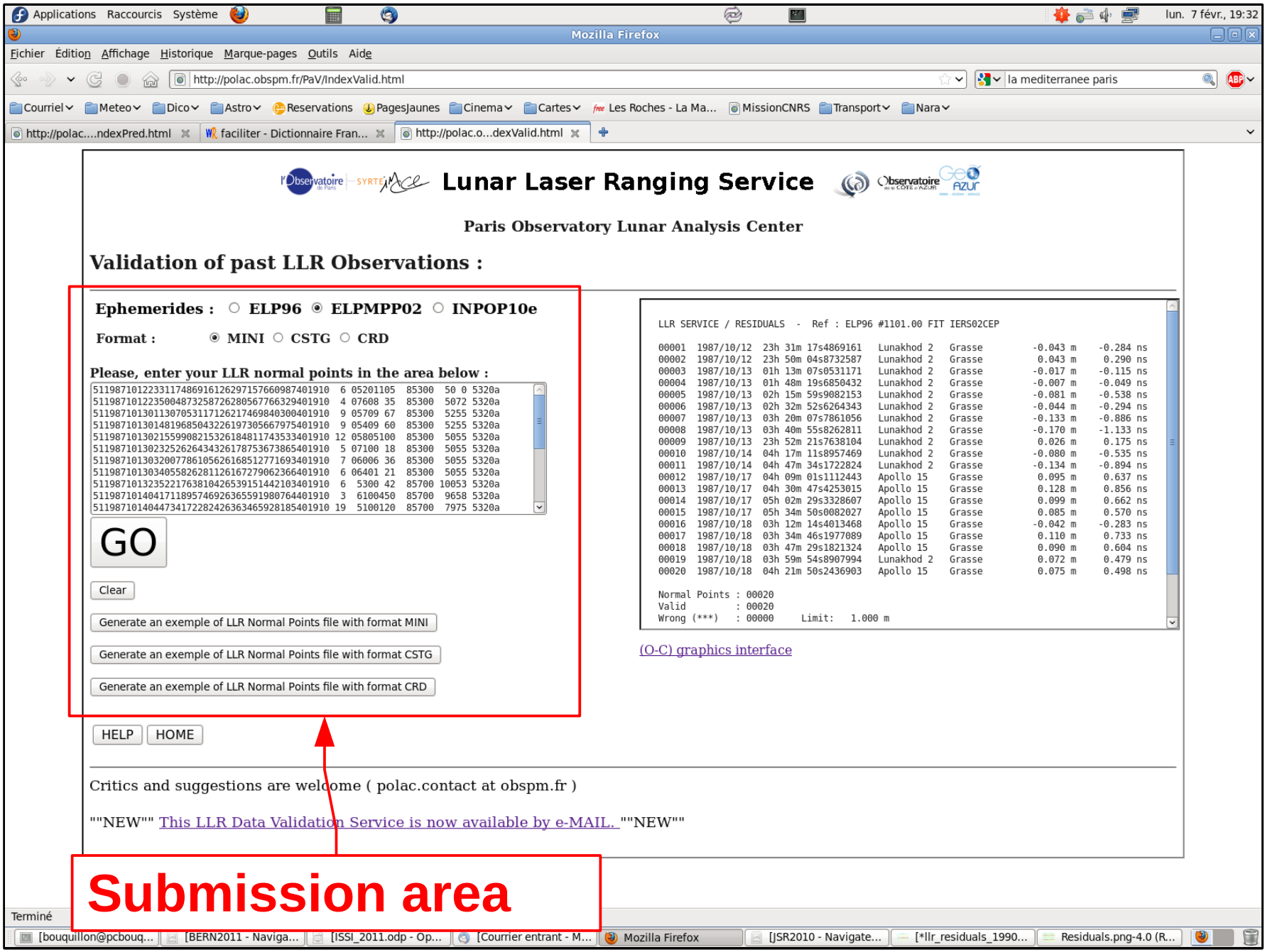
Validation of LLR normal Points.



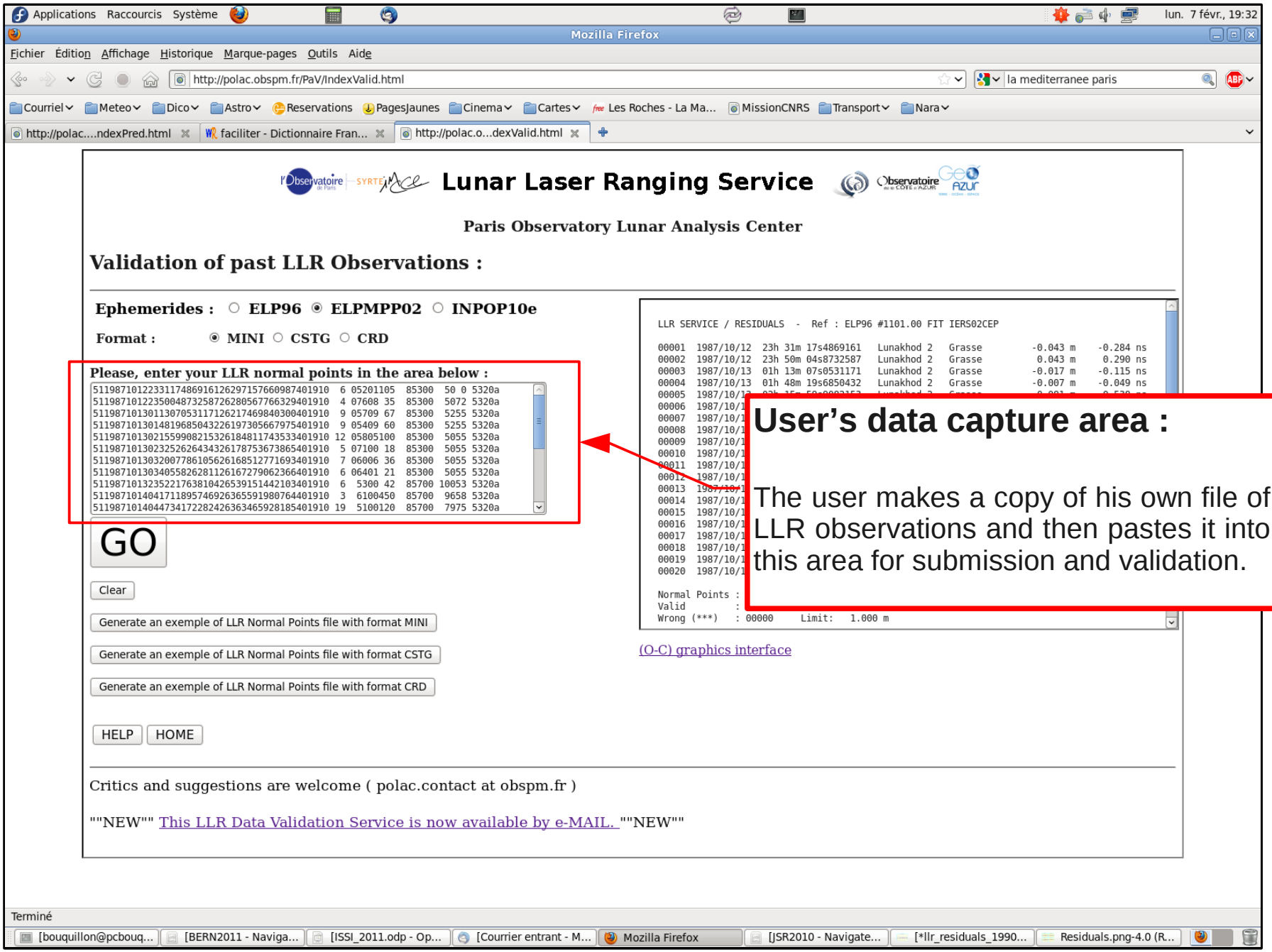
Validation of LLR normal Points.



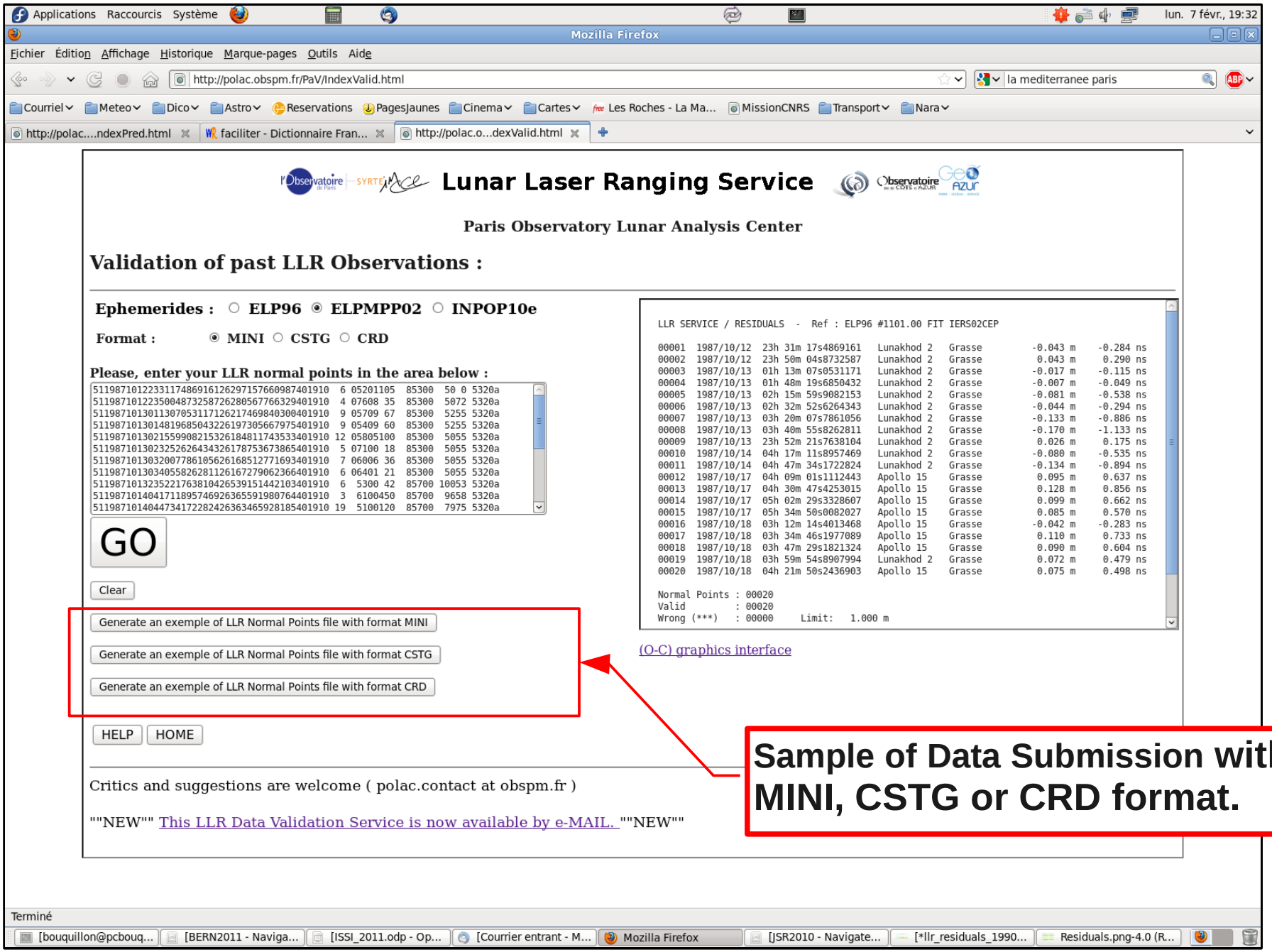
Validation of LLR normal Points.



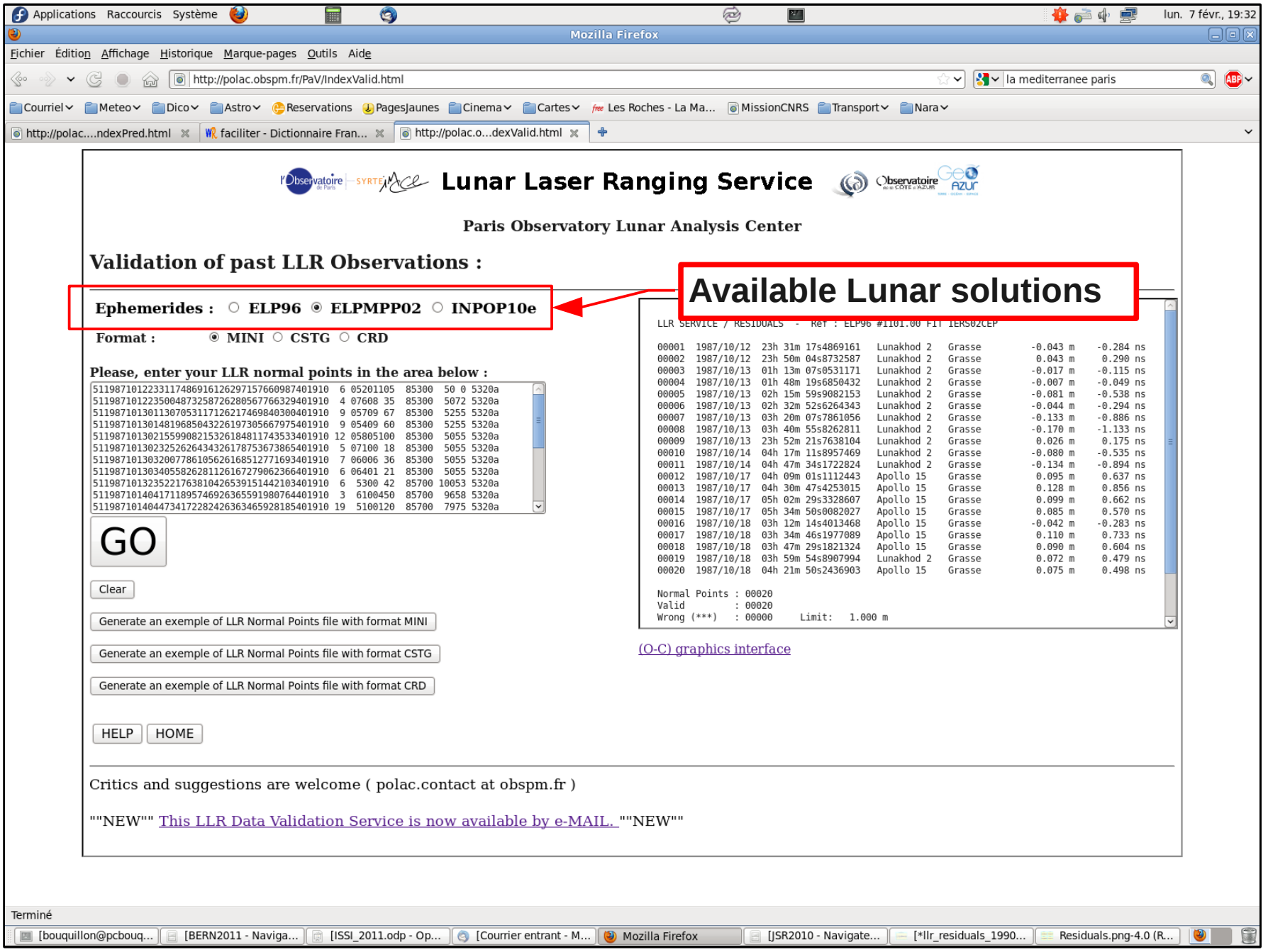
Validation of LLR normal Points.



Validation of LLR normal Points.



Validation of LLR normal Points.



Validation of LLR normal Points.

- Lunar solutions & reduction models available to compute Validation :

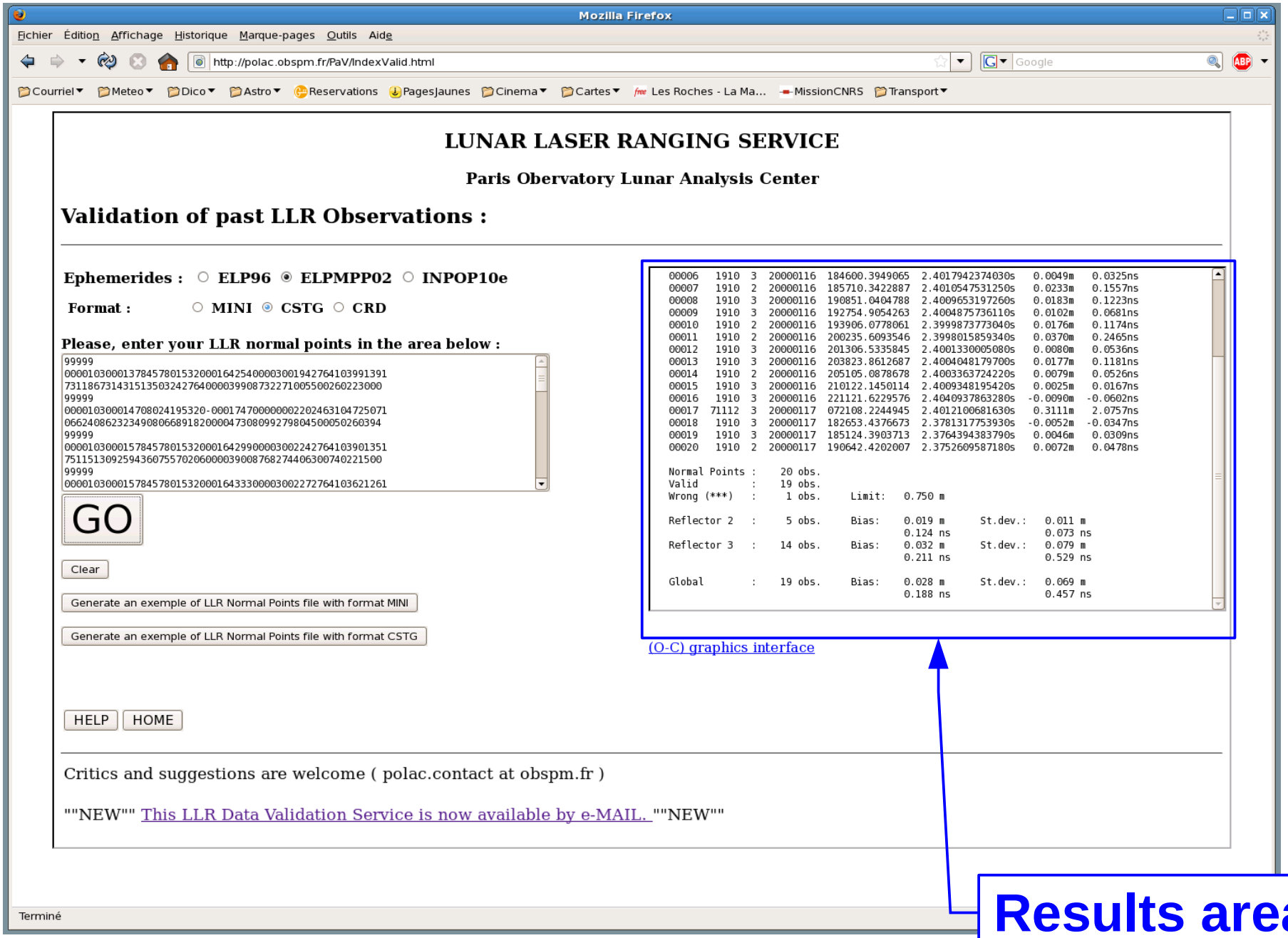
ELP96 & ELPMPP02: Same Ephemeris and Reduction Model than the ones used in the prediction tool.

INPOP10e:It is the latest version of the planetary and lunar ephemeris INPOP, developed at the Observatory of Paris (IMCCE). This numerical solution is fitted on both planetary and LLR observations. It is available at http://www.imcce.fr/inpop, and is used to estimate new initial conditions and librations parameters as well as tests for inner Moon (Fienga et al., 2008, 2009,2011).
The LLR observations are reduced with a model consistent with IERS Conventions 2003, including tectonic plate motion, solid tides effects, ocean and atmospheric loading, polar tide, relativistic light deviation and tropospheric time delay.

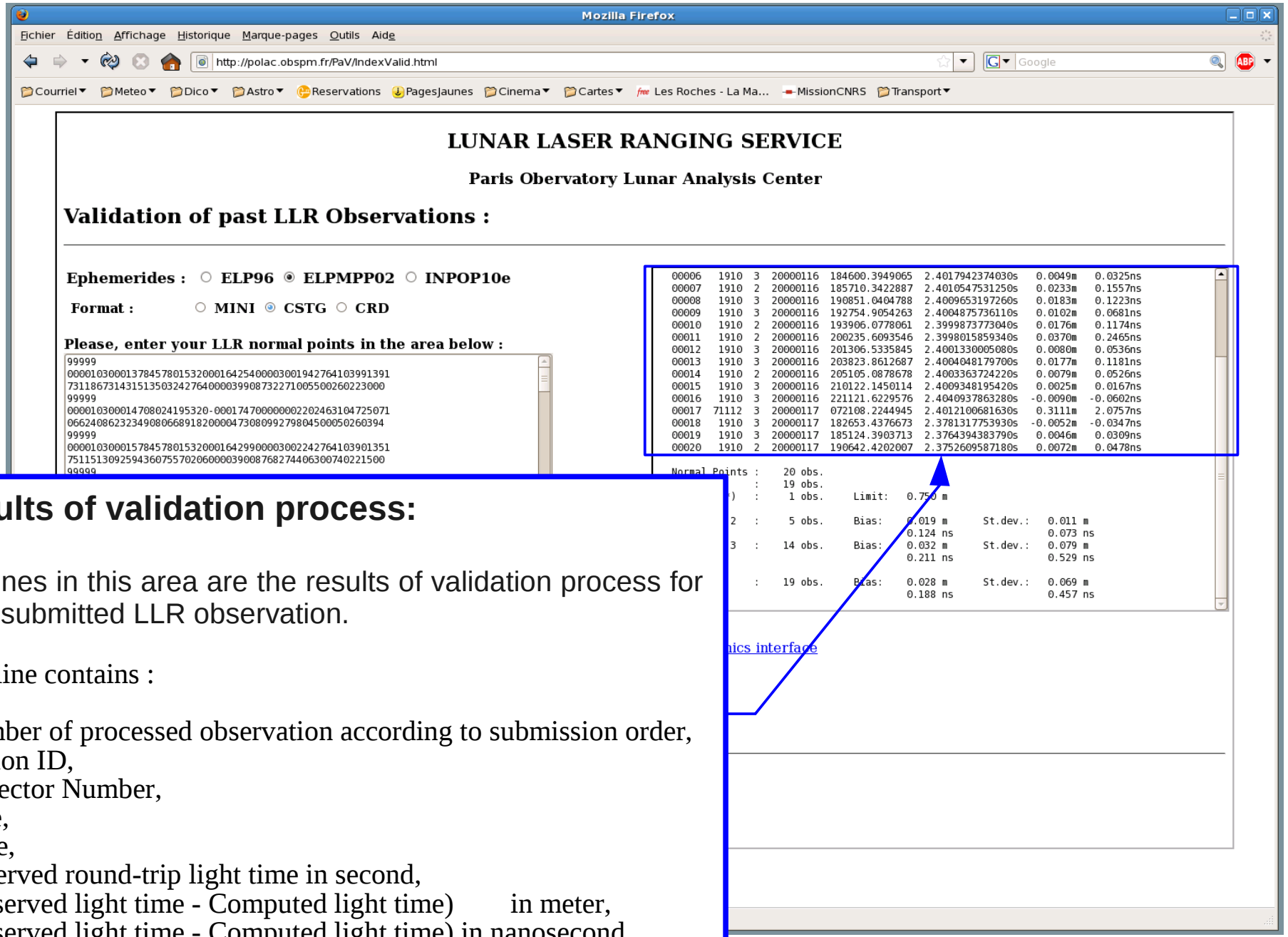
Fienga, A., et al., 2008, A&A, 477, 315.
Fienga, A., et al., 2009, A&A, 507, 1675.
Fienga, A., et al., 2011, Celest.Mech., 111, 363.

New Ephemeris and New Reduction Model

Validation of LLR normal Points.



Validation of LLR normal Points.



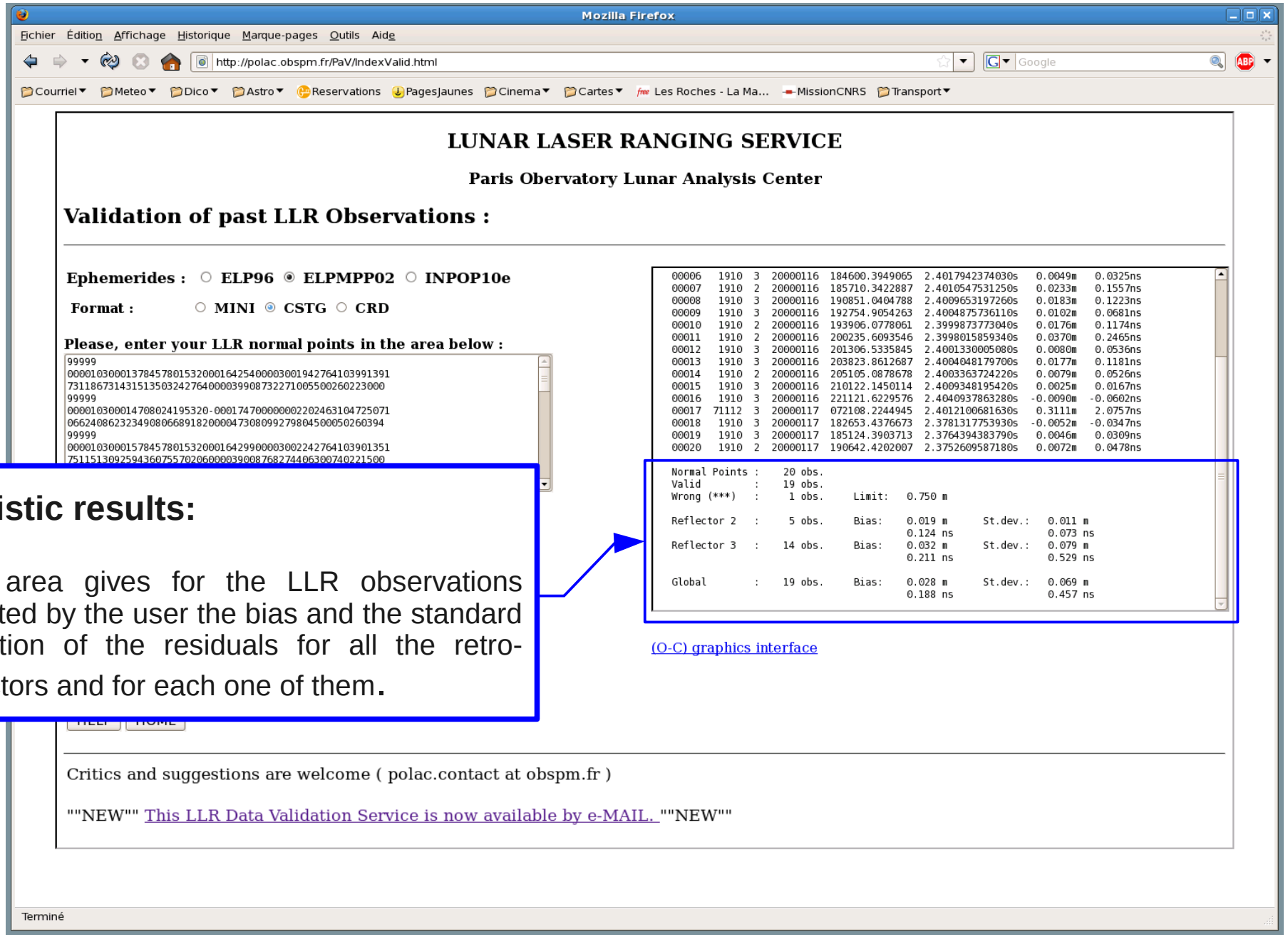
Results of validation process:

The lines in this area are the results of validation process for each submitted LLR observation.

Each line contains :

- Number of processed observation according to submission order,
- Station ID,
- Reflector Number,
- Date,
- Time,
- Observed round-trip light time in second,
- (Observed light time - Computed light time) in meter,
- (Observed light time - Computed light time) in nanosecond.

Validation of LLR normal Points.



Statistic results:

This area gives for the LLR observations selected by the user the bias and the standard deviation of the residuals for all the retro-reflectors and for each one of them.

Validation of LLR normal Points.

Mozilla Firefox

Fichier Édition Affichage Historique Marque-pages Outils Aide

http://gbot/fov/llrObs/IndexValid.html

Courriel Meteo Dico Astro Reservations PagesJaunes Cinema Cartes Les Roches - La Ma... MissionCNRS Transport

LUNAR LASER RANGING SERVICE

Paris Obervatory Lunar Analysis Center

Validation of past LLR Observations :

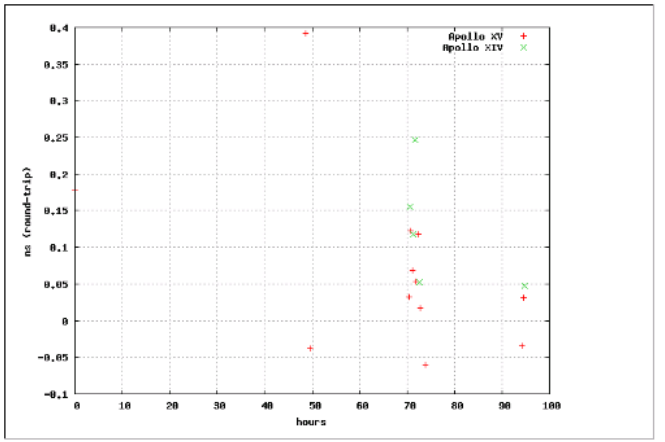
Ephemerides : ELP96 **ELPMPP02** INPOP10e

Format : MINI **CSTG** CRD

Please, enter your LLR normal points in the area below :

```
99999
000010300013784578015320001642540000300194276410399139 1
731186731431513503242764000039908732271005500260223000
99999
000010300014708024195320-000174700000002202463104725071
066240862323490806689182000047308099279804500050260394
99999
000010300015784578015320001642990000300224276410390135 1
751151309259436075570206000039008768274406300740221500
99999
000010300015784578015320001643330000300227276410362126 1
```

GO



Sites : GRASSE | Reflectors : All REFLECTORS | X-axis unit : HOURS | Y-axis unit : NS (round-trip)

Date of First Observations : 2000/01/13_20:18

(O-C) numerical results

Graphs of residuals:

Residuals are displayed according to the sites, the reflectors, the time and residuals units.

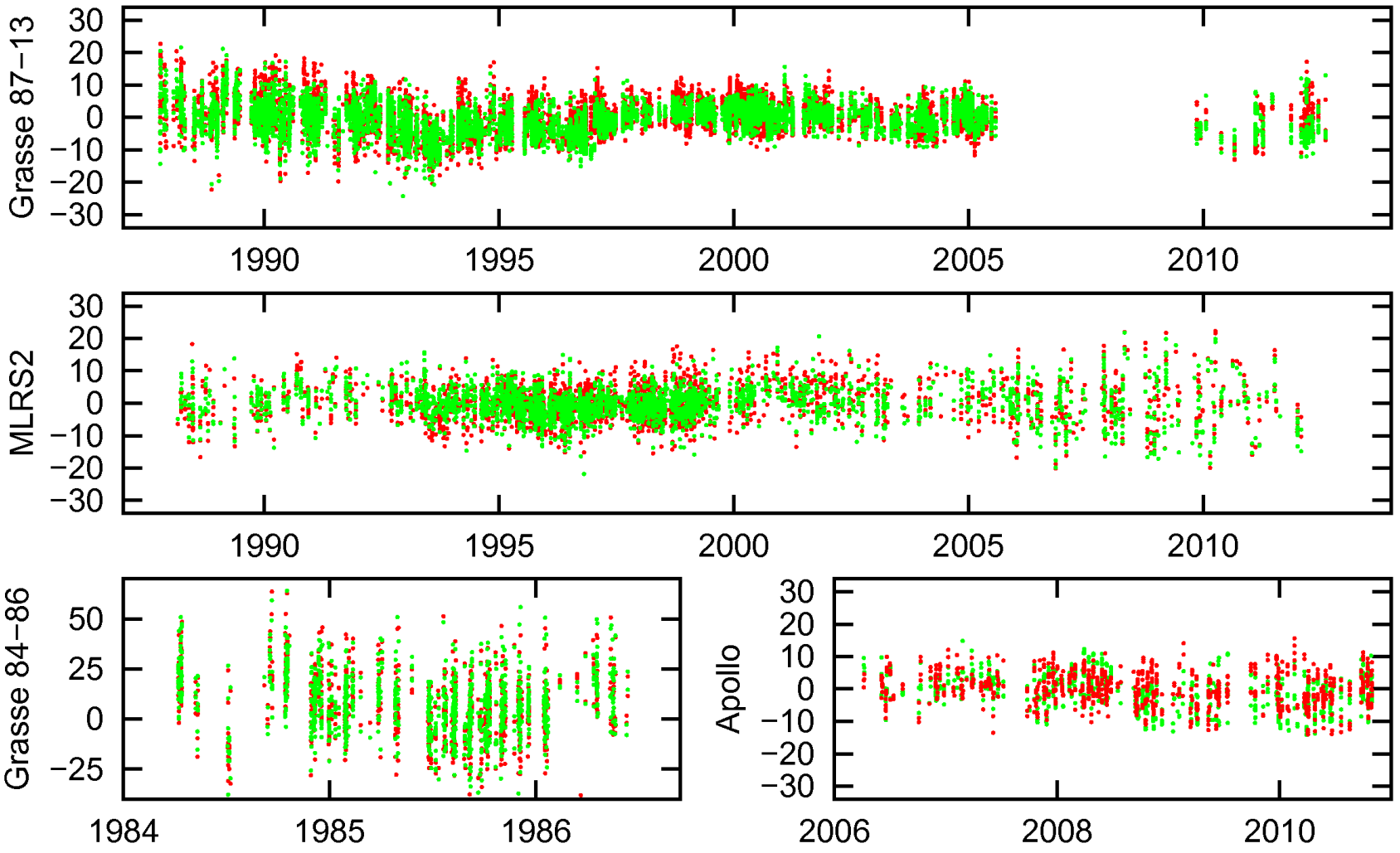
Critics and suggestions are welcome (polac.contact at obspm.fr)

""NEW"" This LLR Data Validation Service is now available by e-MAIL. ""NEW""

Reduction of All LLR normal Points since 1984 carry out with this interface:

O-C plots for two different models: ***INPOP10e*** *and* ***ELPMPP02***

INPOP10e and ELPMPP02: residuals in cm



Reduction of All LLR normal Points since 1984 carry out with this interface:

*O-C Statistics for **INPOP10e** & **ELPMPP02** models*

INPOP10e and ELPMPP02: RMS of residuals in cm

Stations *(periods)*	**INPOP10e**	**ELPMPP02**
GRASSE *(1984-1986)*	15,89	15,41
GRASSE *(1987-1995)*	6,35	5,48
GRASSE *(1995-2012)*	4,01	3,82
MLRS2 *(1985-1996)*	4,71	4,29
MLRS2 *(1996-2012)*	5,59	5,08
Apollo *(2006-2012)*	5,22	5,34

POLAC recent activities:
Support for LLR observers.

Validation of LLR Observations by e-mail

polac.processing at obspm.fr

Validation of LLR Observations by e-mail

E-mail Format Example for the Submission of LLR Observations to Validate:

```
TO : polac.processing at obspm.fr
Subject : ##LLR-VALIDATION##

DISPLAYOMC=1
DISPLAYOBS=1
DISPLAYPLOT=1
DISPLAYSTAT=1
EPHEM=1
FORMAT=1
IDOBS=MINI_01_17Nov1987
STARTOBS
5119871017053450008202726457869244256301910  9  6000 56  86100 10591 5320a
5119871018031214401346826524391650493301910 18  4800160  87700 12020 5320a
5119871018033446197708926495002457698301910  7  6900140  86400  7684 5320a
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5119871018042150243690326437079172454301910 51  3700320  86400  6970 5320a
ENDOBS
```
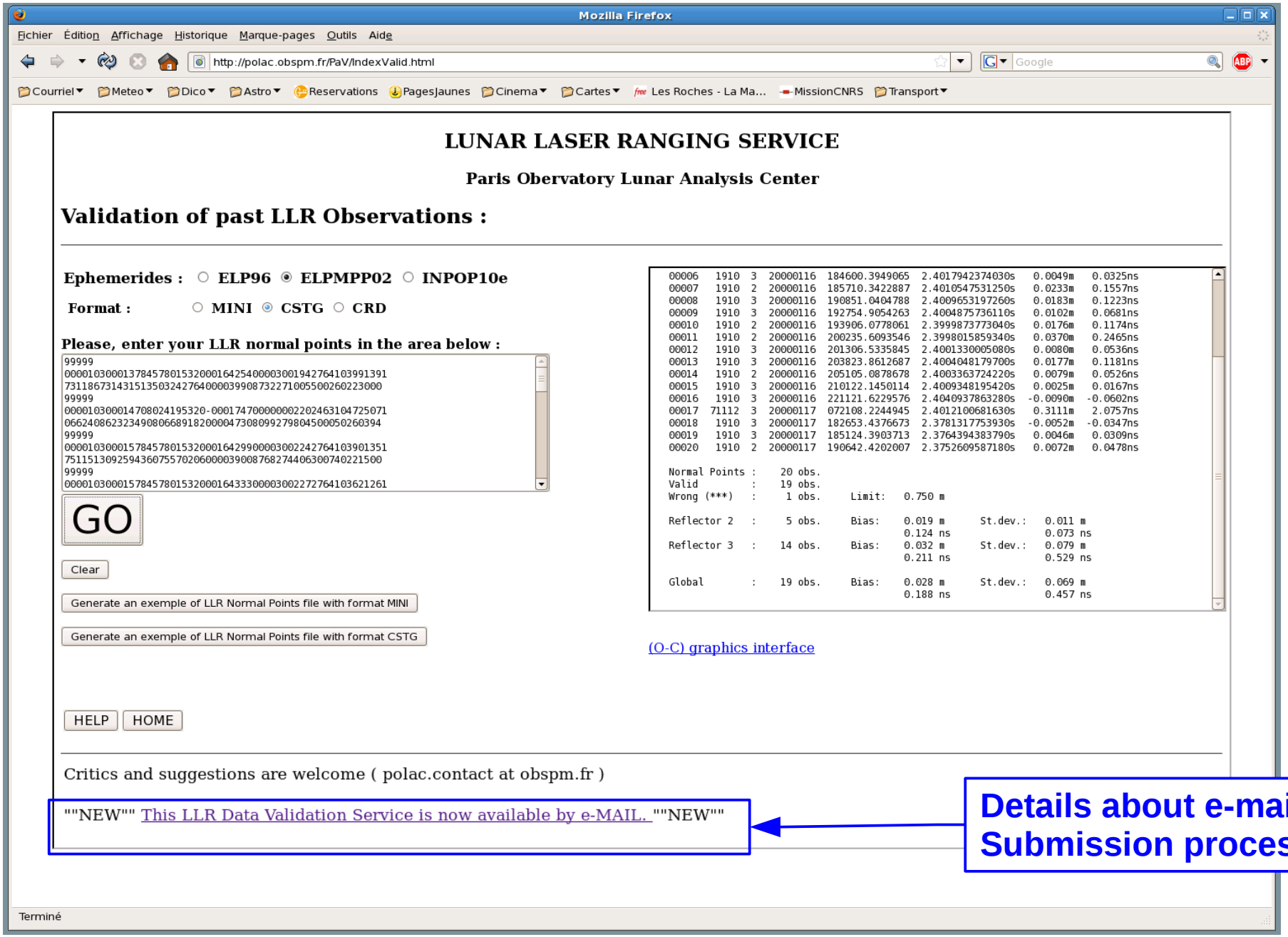

Mandatory keywords in red

Validation of LLR Observations by e-mail



POLAC recent activities:
Support for LLR data users.

critical analysis of an extended LLR data gathering

ftp://polac.obspm.fr/pub/LLR_Observations/

critical analysis of an extended LLR data gathering

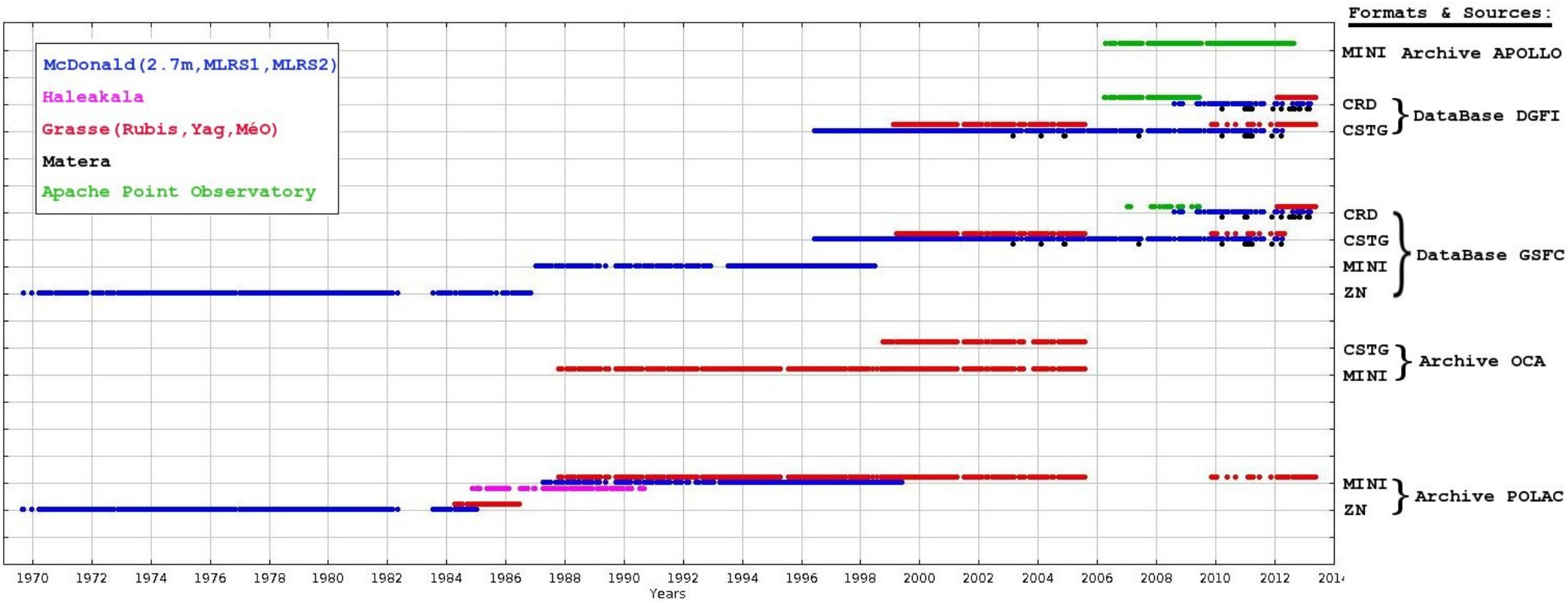
LLR Data Sources:

- Archive POLAC
- Archive of Grasse laser station (Observatoire de la Côte d'Azur, MéO)
- Archive of APOLLO laser station (Apache Point Observatory Lunar Laser-ranging Operation)
- ILRS DataBase :
  - GSFC (Goddard Space Flight Center)
  - DGFI (Deutsches Geodätisches Forshung Institut)

LLR Data Formats:

- ZN Original Format, COSPAR Working Group 1, (Mulholland, 1971)
- MINI Mini Normal Point Record, NASA Management/Operations Working Group on LLR, (COSPAR Information Bulletin No. 108, April, 1987.)
- CSTG Coordination of Space Techniques for Geodesy and Geodynamics, ILRS Normal Point Format since March 1997
- CRD Consolidated Laser Ranging Data Format,ILRS Normal Point Format since 2009, (R.L. Ricklefs, C.J. Moore, October 2009).

critical analysis of an extended LLR data gathering



Distribution of All LLR Observations per Archive Center & per Format

critical analysis of an extended LLR data gathering

Main Steps of LLR Data gathering and Critical analysis Method:

First Step: DATA NORMALIZATION

FOR EACH DATABASE:

- Split LLR data by LLR station and by format
- Check the consistency of each data (values, format nomenclature, etc.)

  Example:

  Original data: *13467749292847034696532300001050879228262**50**00560222200*

  Error for format of Humidity => correction 250 -> 025 :

  Modified data: *13467749292847034696532300001050879228262**025**00560222200*
- Erase redundant data (only strictly identical Normal Points)
- Change the data format in the LLR standard Format "MINI"
- Check this new file consistency
- Sort Chronologically
- For each Normal Point keep a trace of Original Archive and Format

Example:

5 20130513163307152933326651640619930 1910 42 1949 16 87344 13556 5321 0673 | *DGFI-CRD*

Normal Point in “MINI” format

Archive and Format Name

critical analysis of an extended LLR data gathering

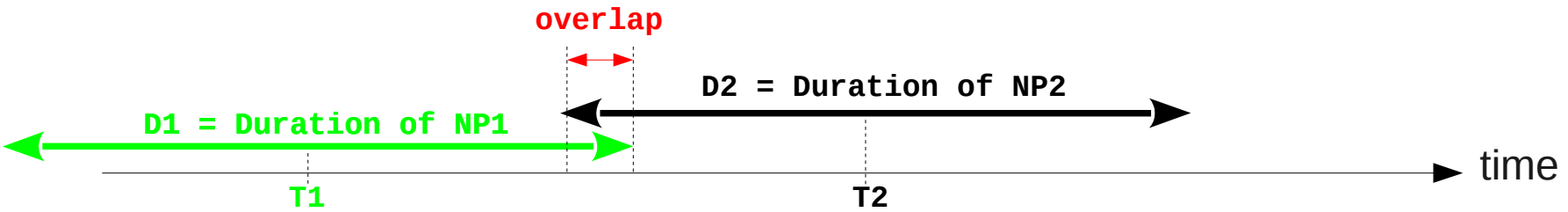
Main Steps of LLR Data gathering and Critical analysis Method:

Second Step: ERASE DATA WITH RESIDUALS LARGER THAN 100 METERS

Third Step: IDENTIFICATION OF DATA DUPLICATIONS AND SELECTION

METHOD FOR IDENTIFICATION OF DATA DUPLICATIONS:

- 2 Normal Points are considered as data duplications if there is a temporal overlap Larger than 20% of the sum of their half-duration.



Test : sign of [(T2−T1) - (D1/2 +D2/2)*0.8]

- If LLR Normal point duration is not given, we fix it to 3 minutes.

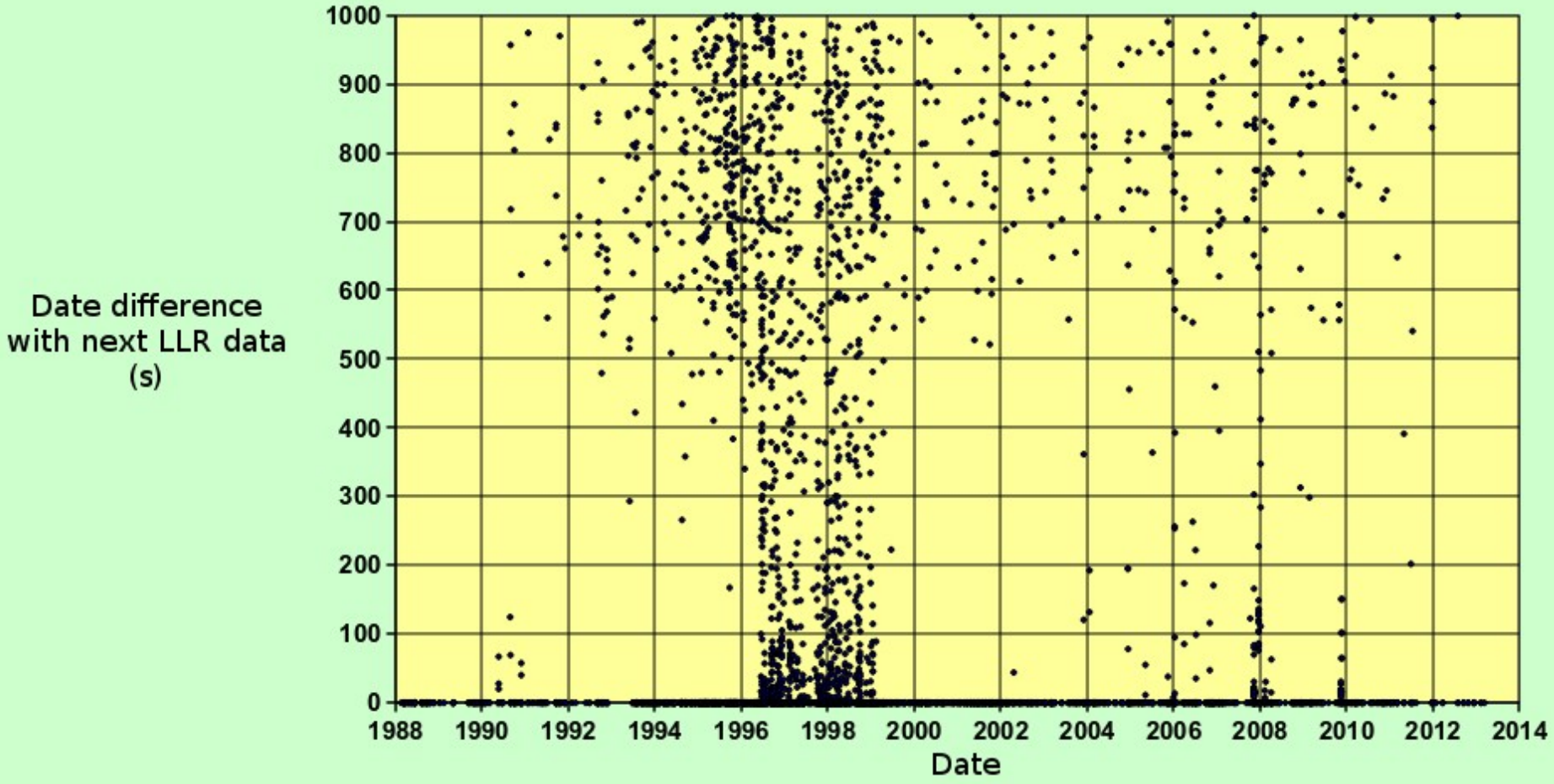
METHOD OF DATA SELECTION IN CASE OF DUPLICATION:

- The selection of one observation in case of duplication is based on the criteria listed below:
  - The Residual [O-C] (weight = 2)
  - The Echoes Number (weight = 1)
  - The Uncertainty (weight = 1)
  - The Signal to Noise Ratio (weight = 1)
  - The duration (weight = 1).

critical analysis of an extended LLR data gathering

Main Steps of LLR Data gathering and Critical analysis Method:

Third Step : IDENTIFICATION OF DATA DUPLICATIONS AND SELECTION

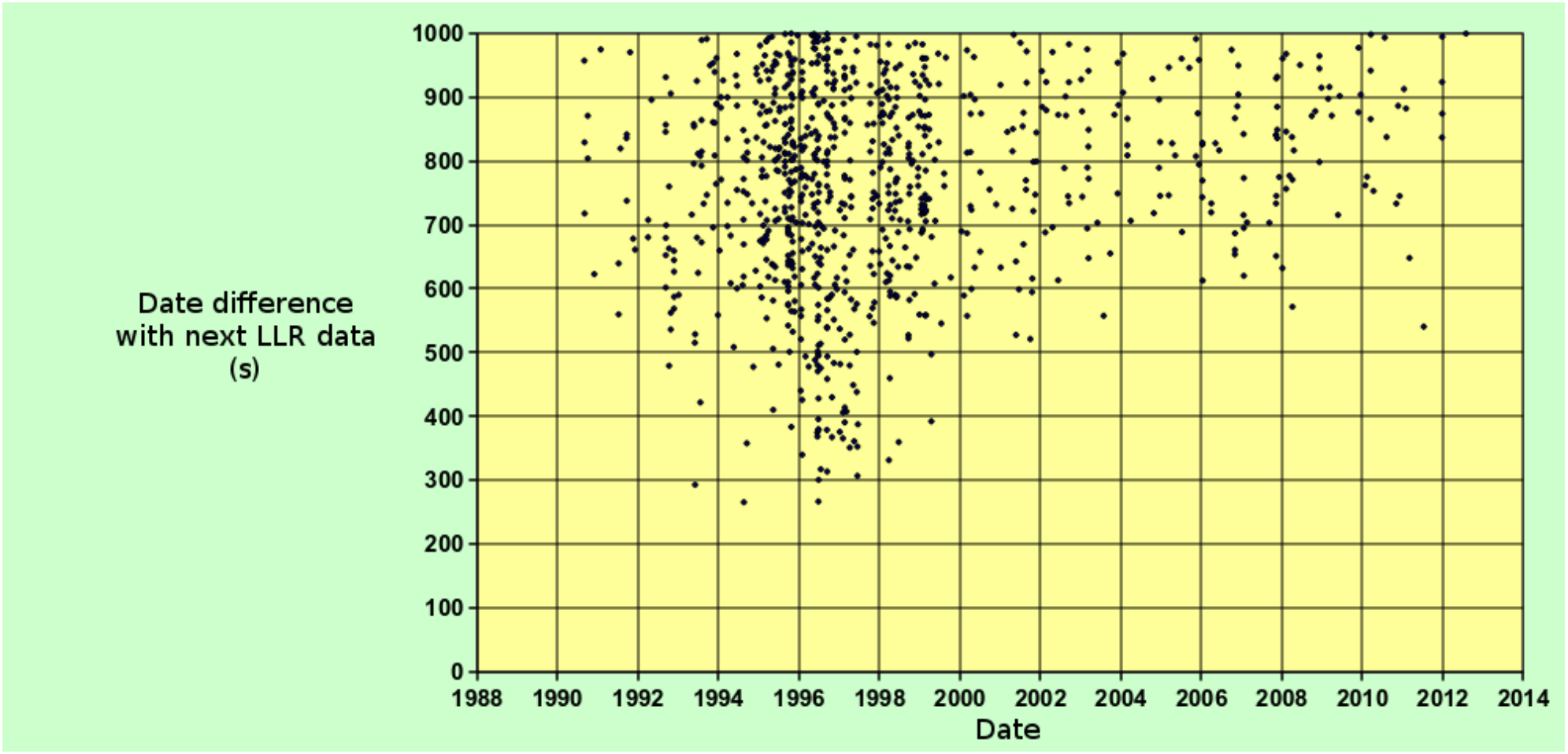


This plot shows for each LLR data gathering for the MLRS2 station, the observation date in X axis and the date difference with the next data in second in Y axis **with data duplications.**

critical analysis of an extended LLR data gathering

Main Steps of LLR Data gathering and Critical analysis Method:

Second Step : IDENTIFICATION OF DATA DUPLICATIONS AND SELECTION



This plot shows for each LLR data gathering for the MLRS2 station, the observation date in X axis and the date difference with the next data in second in Y axis **with no data duplications.**

critical analysis of an extended LLR data gathering

LLR Resulting Data Set:

ftp://polac.obspm.fr/pub/1_llr_analysis/2_llr_residuals/observationsUpdate/

- DATA SETS OF LLR OBSERVATIONS BY STATION AND PERIOD
  - **OMCD6985.DAT :** 3604 Observations (20/08/1969 – 30/06/1985)
  - **OMCD8388.DAT :** 631 observations (02/08/1983 – 27/01/1988)
  - **OMCD8813.DAT :** 3653 observations (29/02/1988 – 20/03/2013)
  - **OGRA8486.DAT :** 1188 observations (07/04/1984 – 12/06/1986)
  - **OGRA8705.DAT :** 8324 observations (22/01/1987 – 30/07/2005)
  - **OGRA0913.DAT :** 654 observations (11/11/2009 – 20/05/2013)
  - **OHAL8490.DAT :** 770 observations (13/11/1984 – 30/08/1990)
  - **OMAT0313.DAT :** 83 observations (22/02/2003 – 05/03/2013)
  - **OAPO0612.DAT :** 1564 observations (07/04/2006 - 28/08/2012)

- DATA SETS FOR ALL THE LLR OBSERVATIONS FROM 1969 AUGUST 20 TO 2013 MAY 30
  - **TOTALOBS6913.DAT :** Valid Observations (20471) (Format MINI)
  - **TOTALOBS6913.xml :** Valid Observations (20471) (Format VOTABLE)
  - **TOTALSUP6913.DAT :** Observations with residuals > 100m

Grasse	103
McDonald	305
Matera	3
Haleakala	0
Apollo	0
Total	411

  - **TOTALDBL6913.DAT :** DUPLIACATED DATA (28615)

Planed improvements.

For Prediction Tool

- add some helpful information for reflectors (as their libration angle, their sun illumination, etc.)

For Validation Tool

- Implementation of other lunar solutions or other reduction processes:
  - JPL lunar solution (DE421)
  - FESG/IFE Lunar solution
  - ?

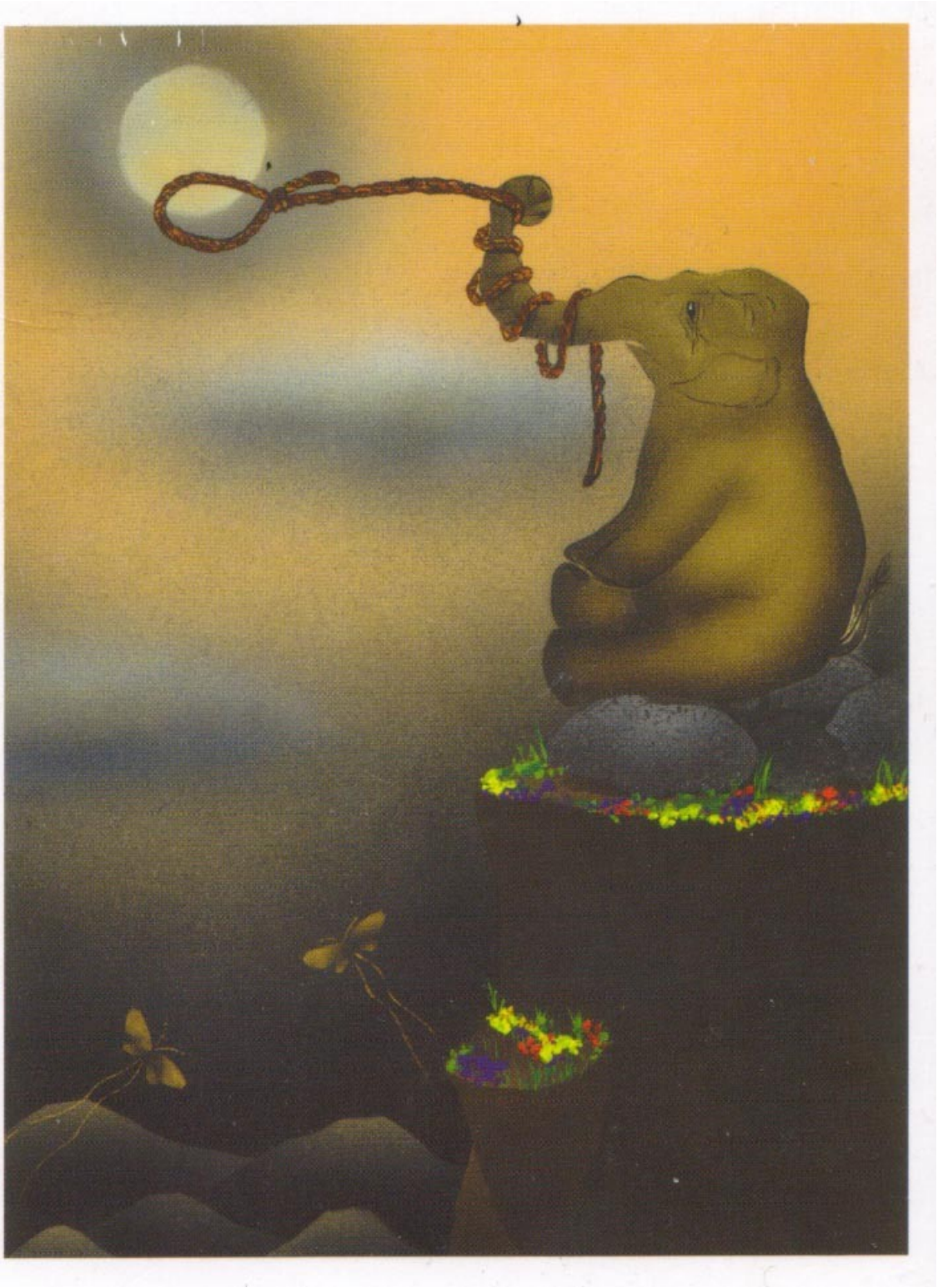
  => Useful for unification of LLR observation reduction process
  => Useful for comparison of different lunar solutions

- Improvement of speed of PaV Tools when using ELP
  (by using a tabulated version of ELP Ephemeris instead of Poissons Series) **DONE**

- Separate for the interface user the choice of Reduction Model to the choice of the Moon Ephemeris

For LLR Data Set

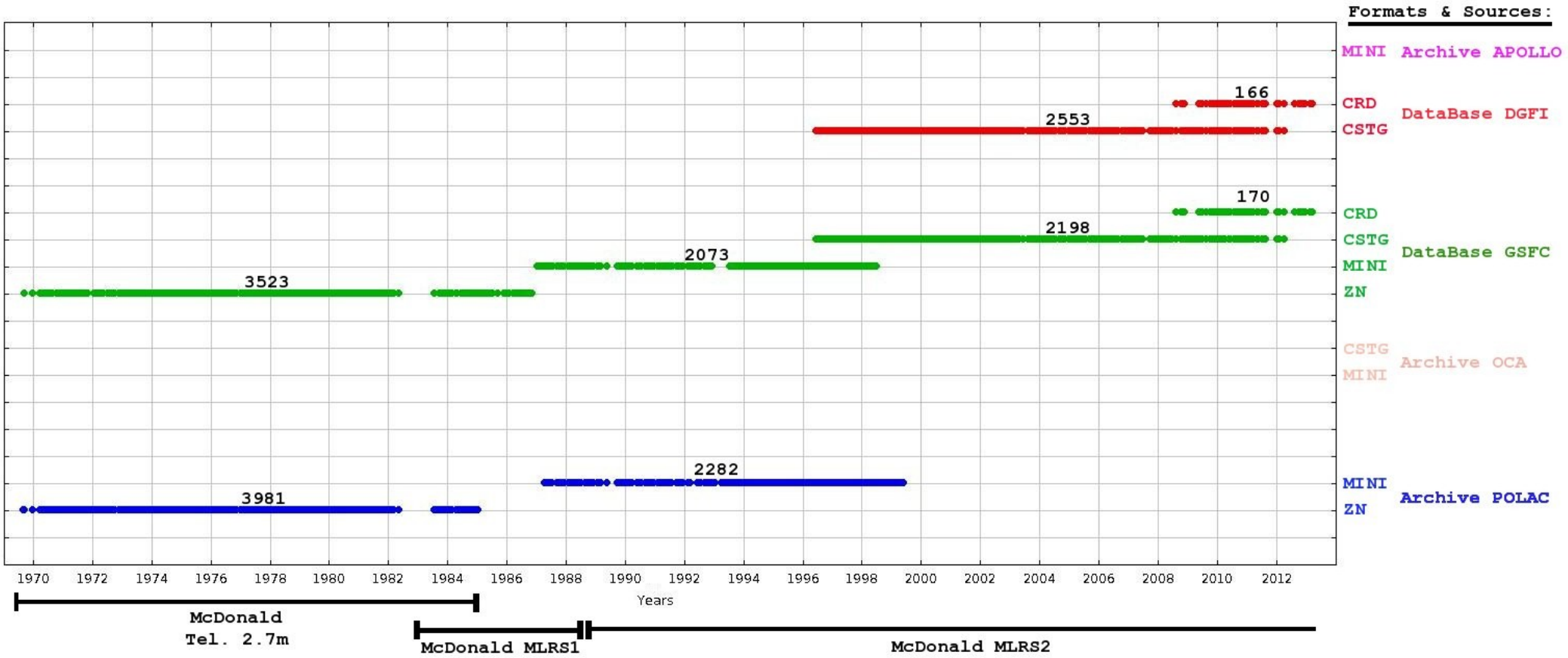
- Regularly update this data set
- Method Improvement for the Identification of LLR Data duplications



ありがとうございます。

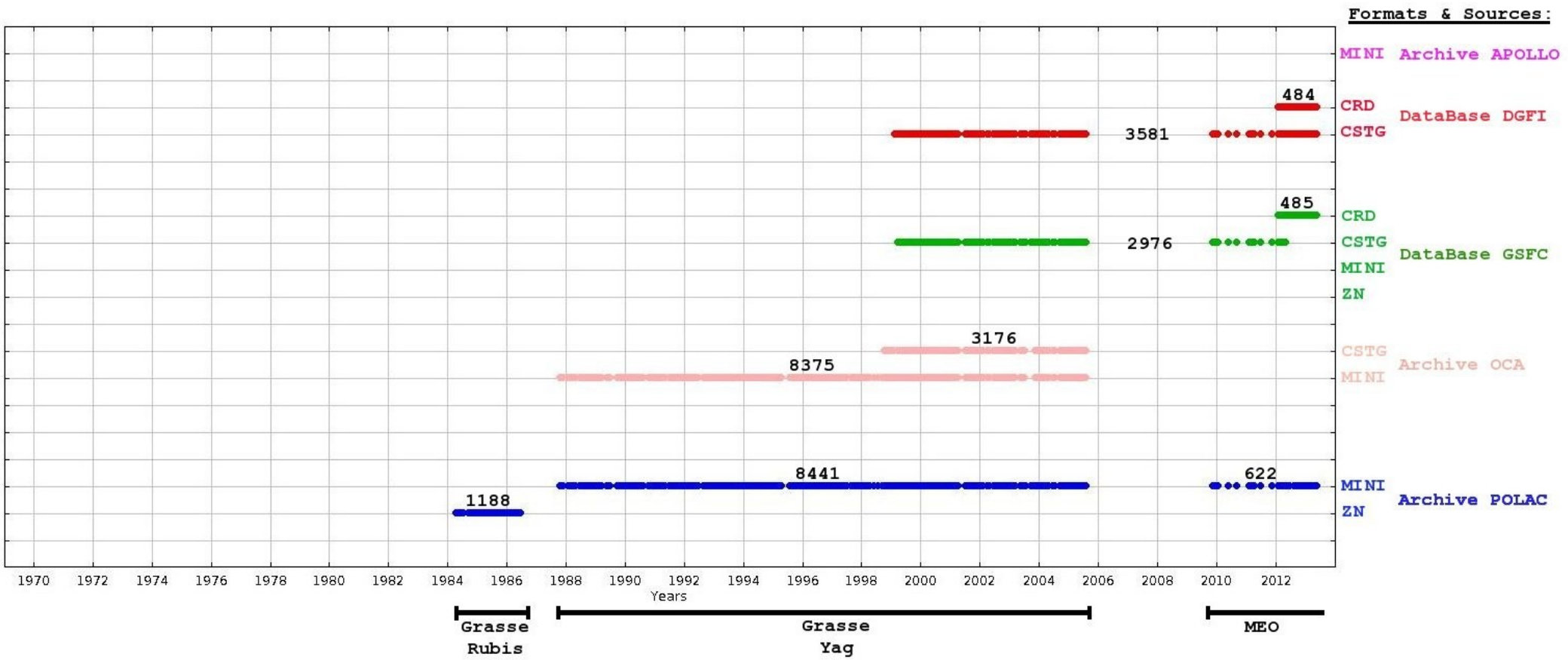
Extra slides

critical analysis of an extended LLR data gathering



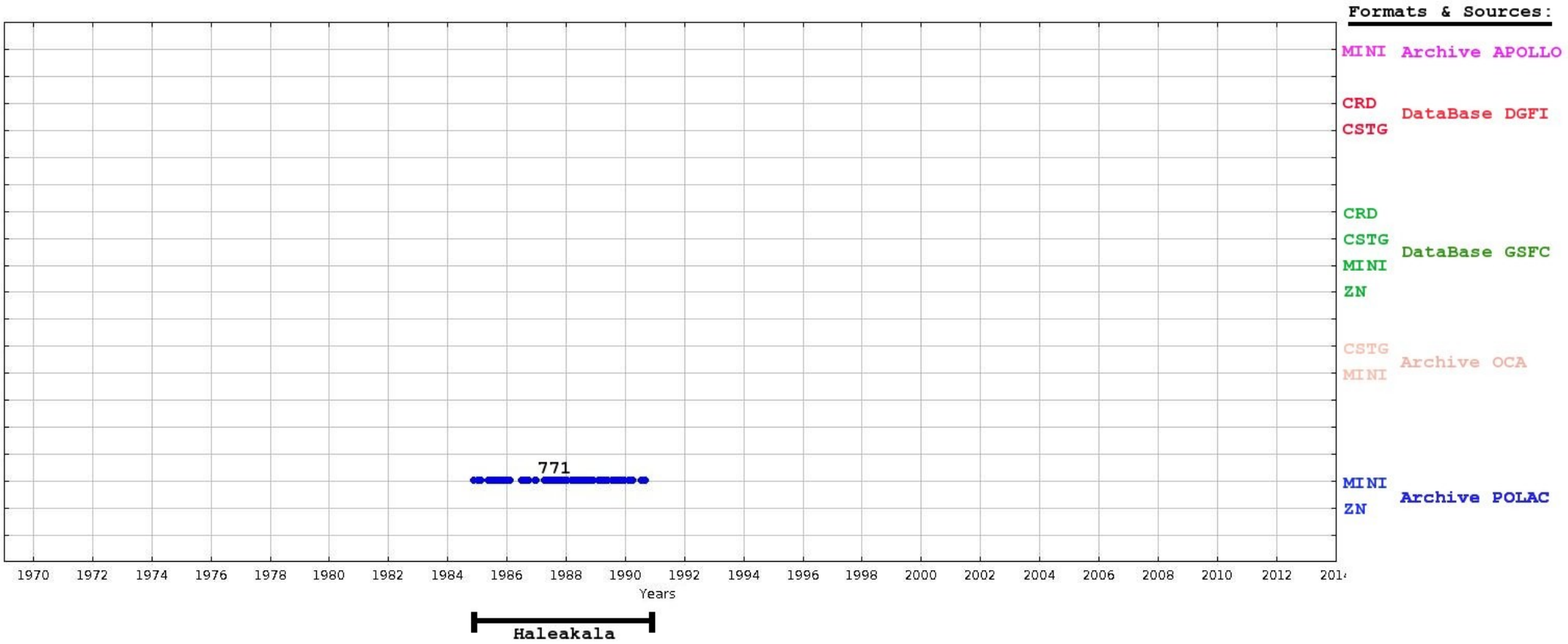
Distribution of **McDonald** LLR Observations per Archive Center & per Format

critical analysis of an extended LLR data gathering



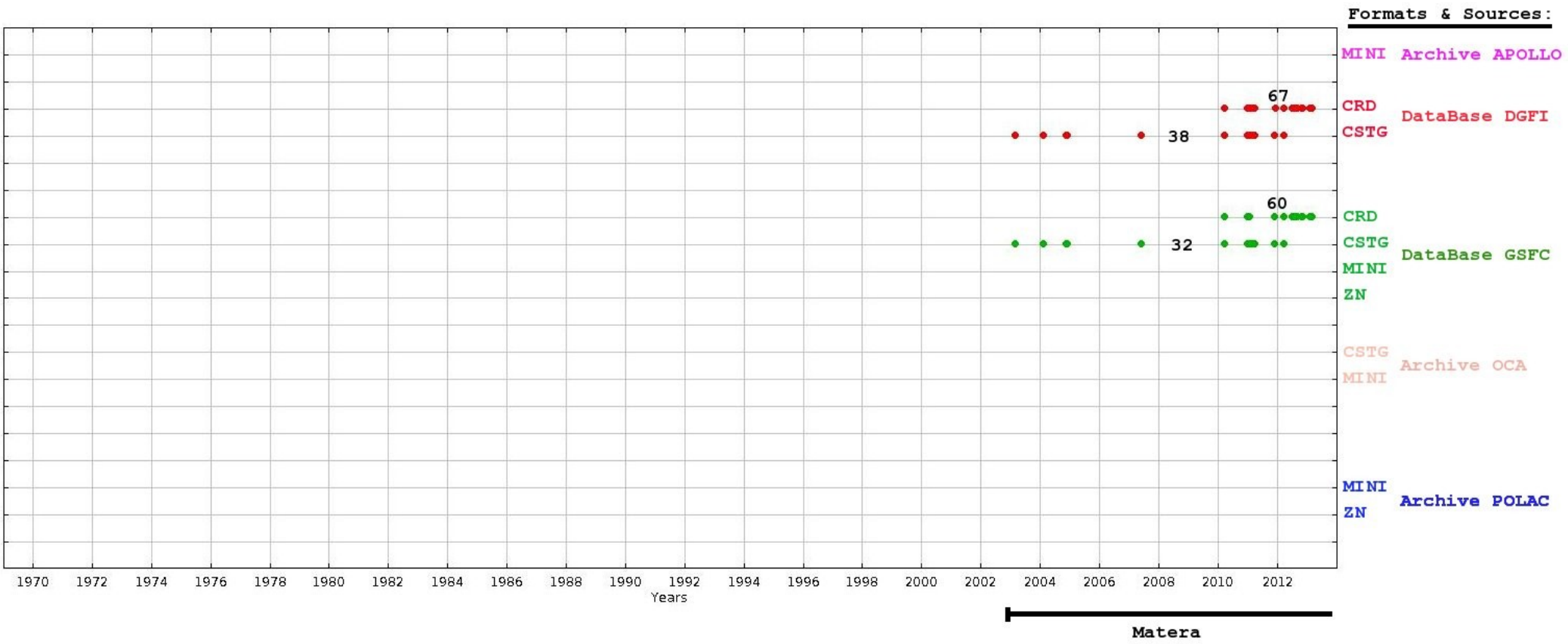
Distribution of **Grasse** LLR Observations per Archive Center & per Format

critical analysis of an extended LLR data gathering



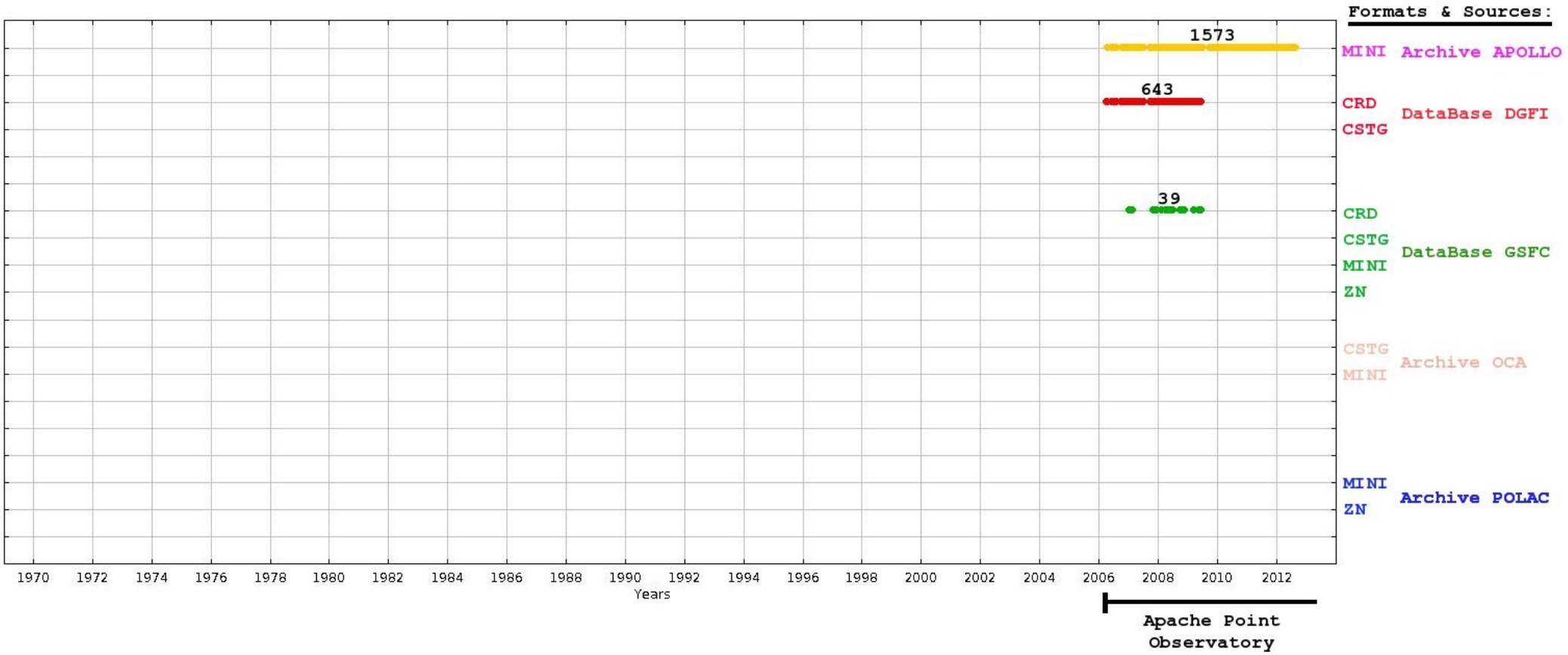
Distribution of **Haleakala** LLR Observations per Archive Center & per Format

critical analysis of an extended LLR data gathering

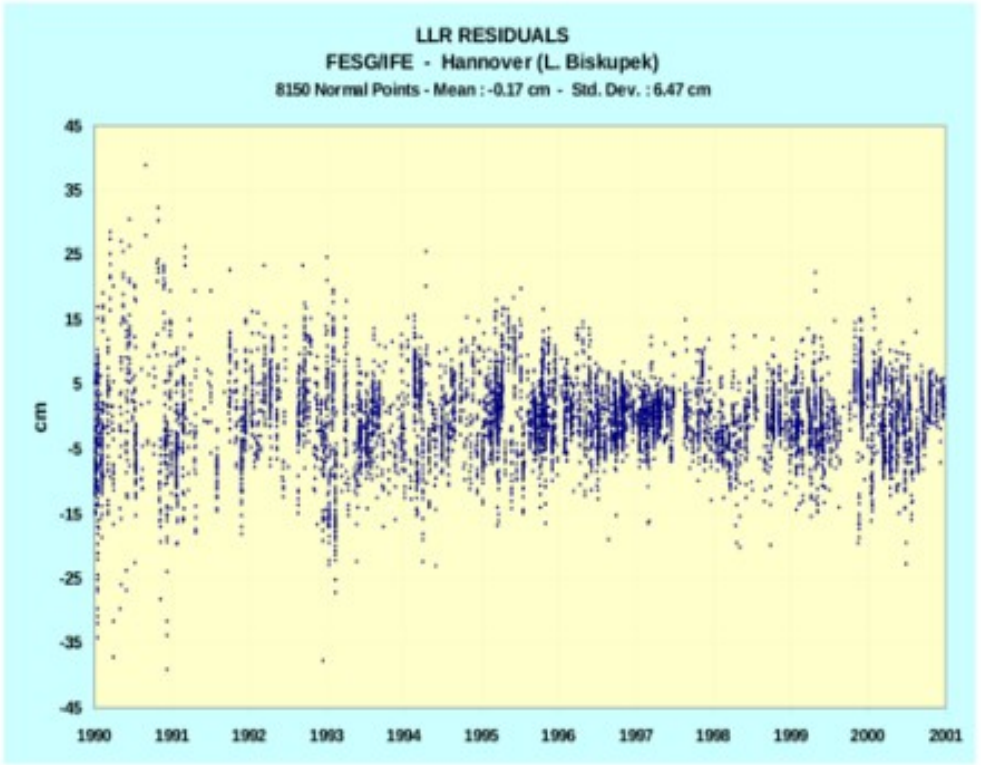


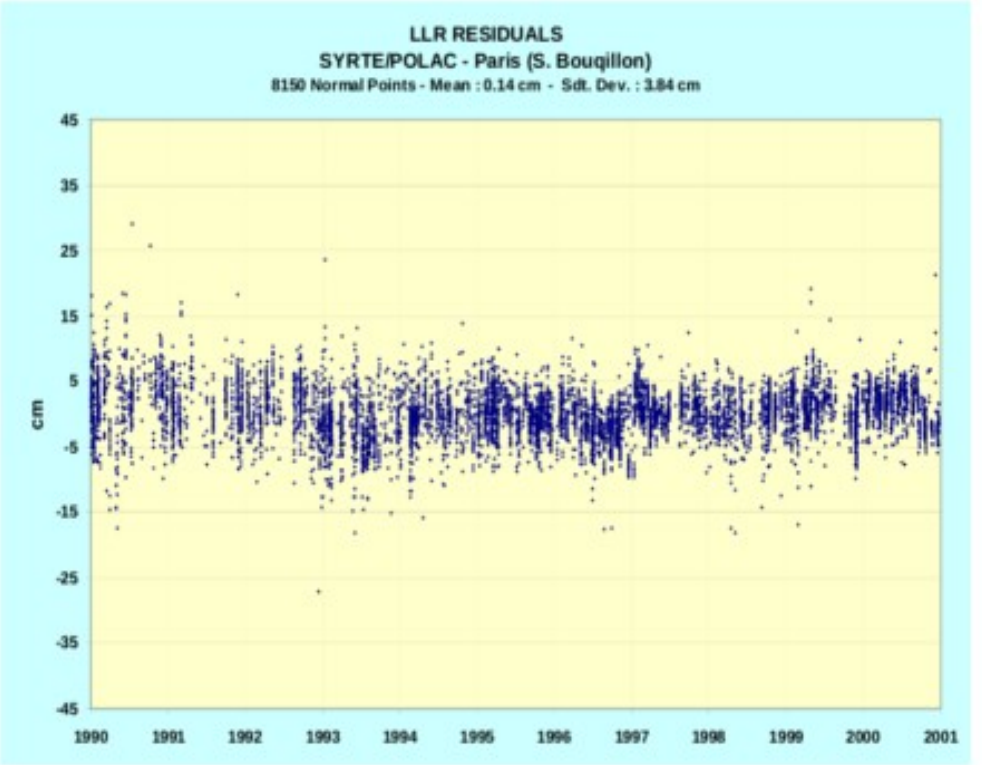
Distribution of **Matera** LLR Observations per Archive Center & per Format

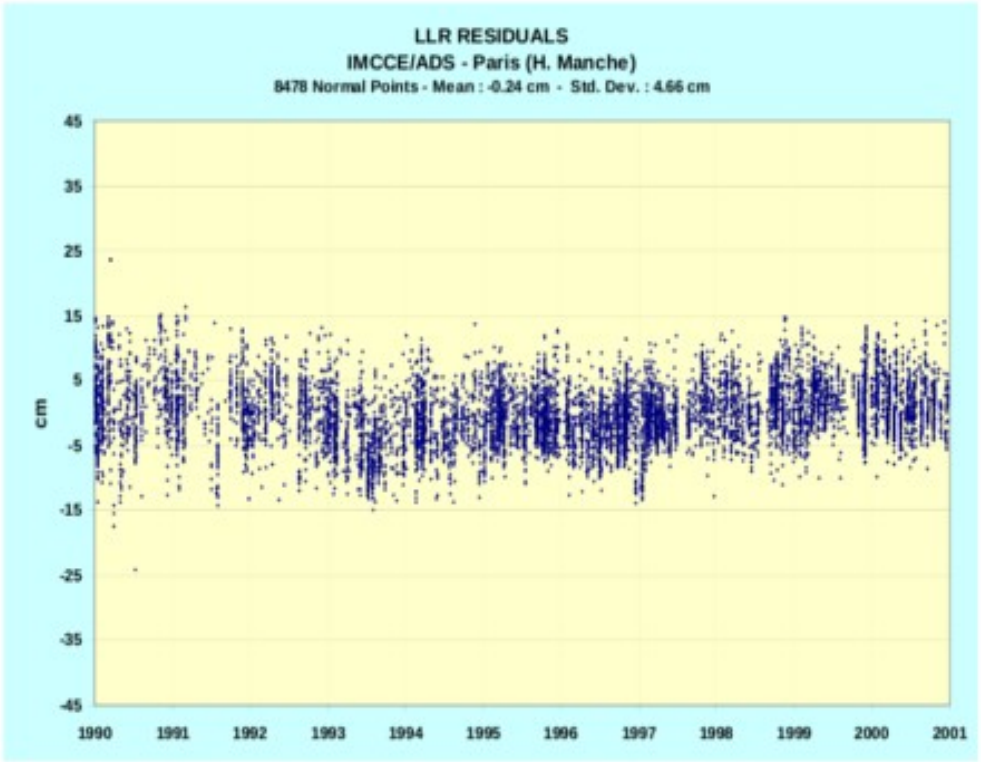
critical analysis of an extended LLR data gathering

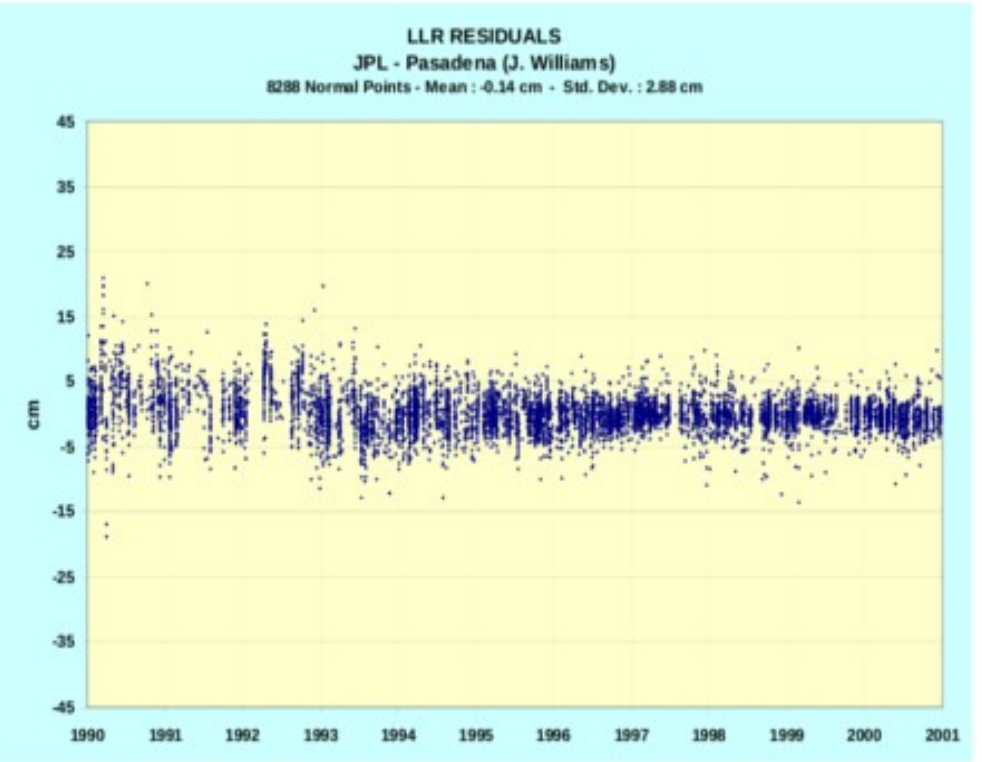


Distribution of **APOLLO** LLR Observations per Archive Center & per Format


LLR RESIDUALS
FESG/IFE - Hannover (L. Biskupek)
8150 Normal Points - Mean : -0.17 cm - Std. Dev. : 6.47 cm
cm
45
35
25
15
5
-5
-15
-25
-35
-45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001


LLR RESIDUALS
SYRTE/POLAC - Paris (S. Bouqillon)
8150 Normal Points - Mean : 0.14 cm - Sdt. Dev. : 3.84 cm
cm
45
35
25
15
5
-5
-15
-25
-35
-45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001


LLR RESIDUALS
IMCCE/ADS - Paris (H. Manche)
8478 Normal Points - Mean : -0.24 cm - Std. Dev. : 4.66 cm
cm
45
35
25
15
5
-5
-15
-25
-35
-45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001


LLR RESIDUALS
JPL - Pasadena (J. Williams)
8288 Normal Points - Mean : -0.14 cm - Std. Dev. : 2.88 cm
cm
45
35
25
15
5
-5
-15
-25
-35
-45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001