# A Novel Technique of Measuring the Solar Radius from Eclipse Light Curves Results for 2010, 2012, 2013, and 2015


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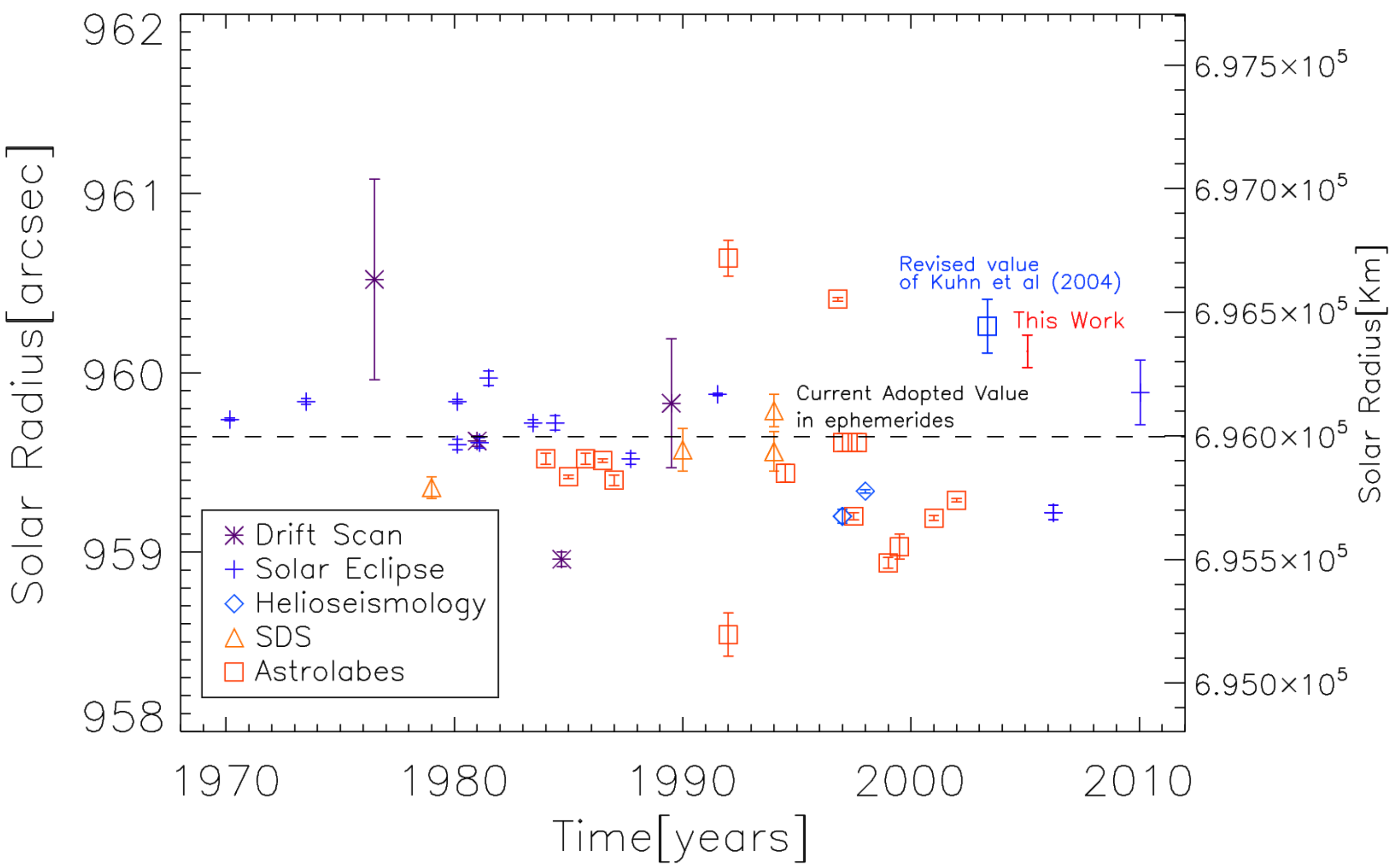
# SITUATION 1970 – 2010 (Emilio et al. 2012)




- **Large dispersion of determinations (~ 1000 km)**
- **Temporal variations still debated**

# ADVANTAGES OF ECLIPSES

►Because the occultation takes place in space, it is strictly geometrical and free of atmospheric effects.

► Because the critical observations occur near the second (C2) and third (C3) contacts, the bulk of the solar disc is occulted, resulting in very low instrumental and atmospheric levels of stray light. This is a critical point in comparison with non-eclipse measurements at the extreme limb, which are hampered by large scattered light due to the presence of the full Sun.

► The Moon itself provides an absolute geometric reference unchanging over human time scales. The technique is therefore well adapted to the detection of long-term variations of the solar diameter, with a sampling of one to three years typical of eclipses more than adequate.

# OUR APPROACH

►Implement a large number of simple, inexpensive, and autonomous devices deployed over the eclipse path and operated unattended, a strategy reminiscent of the campaign organized by Halley dispatching observers throughout England to observe the eclipse of 1715.

► A non-negligible side advantage of the multi-observation approach is obviously to increase the chance of favorable weather.

► This led us to the concept of a high-dynamic photometer coupled with a GPS driven by a micro-controller and capable of storing hours of data.

► The original idea was timing the C2 and C3 contacts but we found that a superior method was to exploit the light curves recorded just before C2 and just after C3 and compare them to rigorously calculated “synthetic" light curves, the solar diameter resulting from minimization between the two.

# ASTROMETRY

► **Latest theories implemented by IMCCE.**

► **Apparent-equatorial-topocentric coordinates of the Sun and of the Moon represented by Tchebychev polynomials of their topocentric apparent ephemerides with ten coefficients for simplicity and efficiency.**

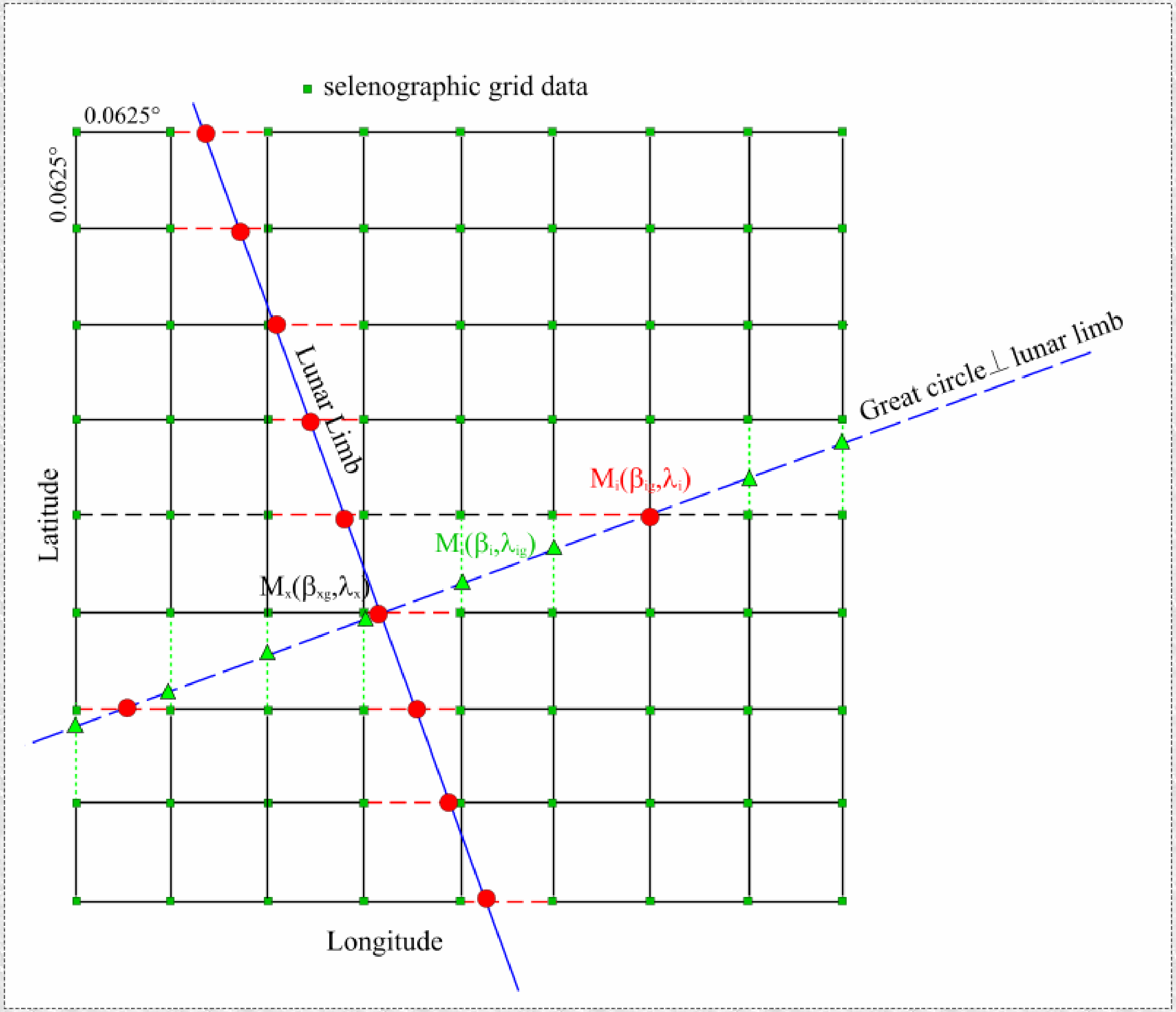
► **Lunar profiles interpolated from *Kaguya* altimetric data, a decisive breakthrough compared to the old Watts profiles.**

► **The Sun is modeled as a limb-darkened disk using a limb-darkening function (LDF) as modeled by Hestroffer and Magnan (1998)**

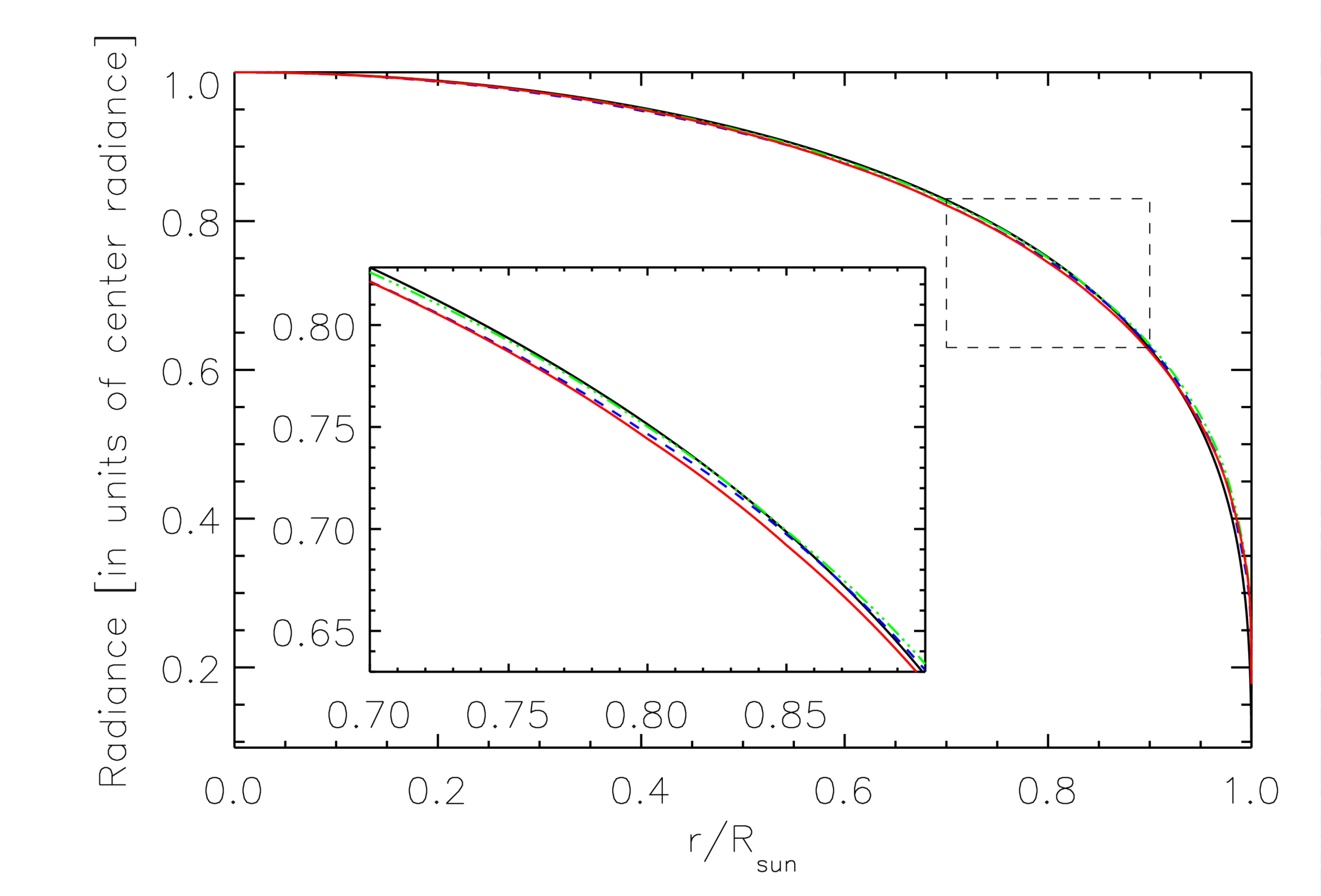
# INTERPOLATION OF THE KAGUYA DATA

**Grid of the Kaguya data (small green dots)**
**At each point where the lunar limb intersects the latitudinal grid (red dots), the lunar altitude is interpolated between the two neighboring values at the same latitude (dashed-red segments).**

**That same procedure is applied to the points where a great circle perpendicular to the lunar limb intersects the latitudinal grid (red dots). At each point where this great circle intersects the longitudinal grid, the lunar altitude is interpolated between the two neighboring values at the same longitude (dotted-green segments).**



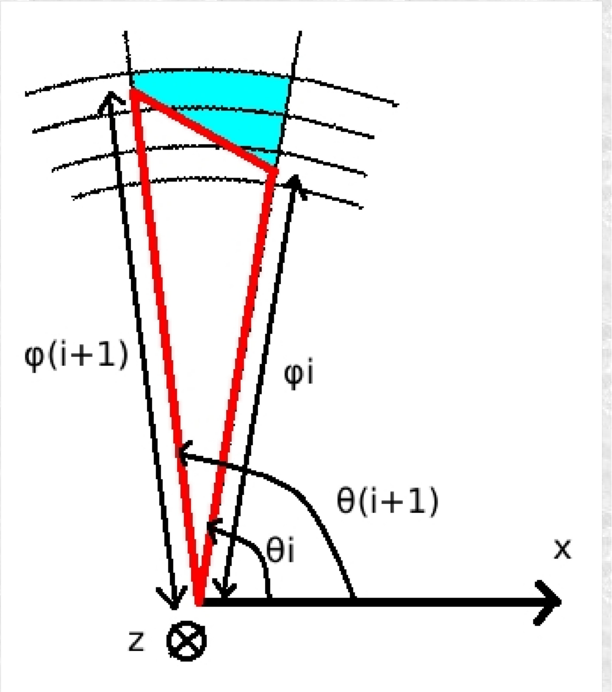
# LIMB DARKENING FUNCTION AT 500 nm

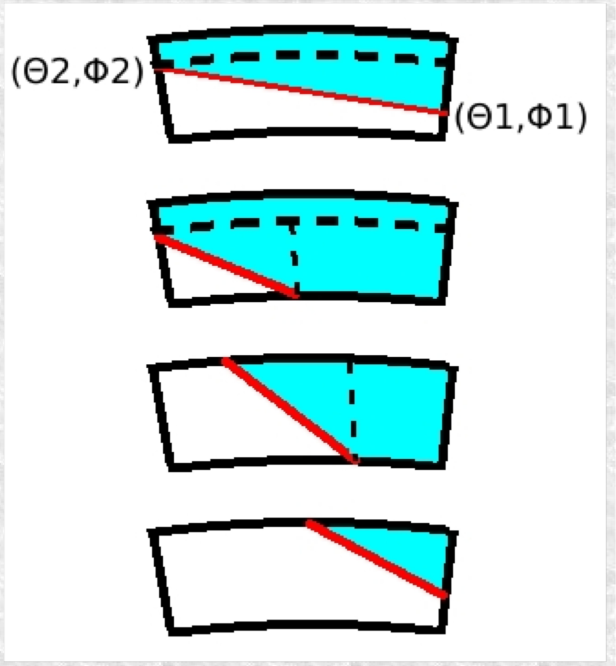



**The model of Hestroffer and Magnan (1998, black curve) and the data of Pierce and Slaughter (1977, green curve), Marakova and Kharitonov (1977 blue curve), and Wittmann (1980, red curve) are all in excellent agreement.**

# GENERATING SYNTHETIC LIGHT CURVES

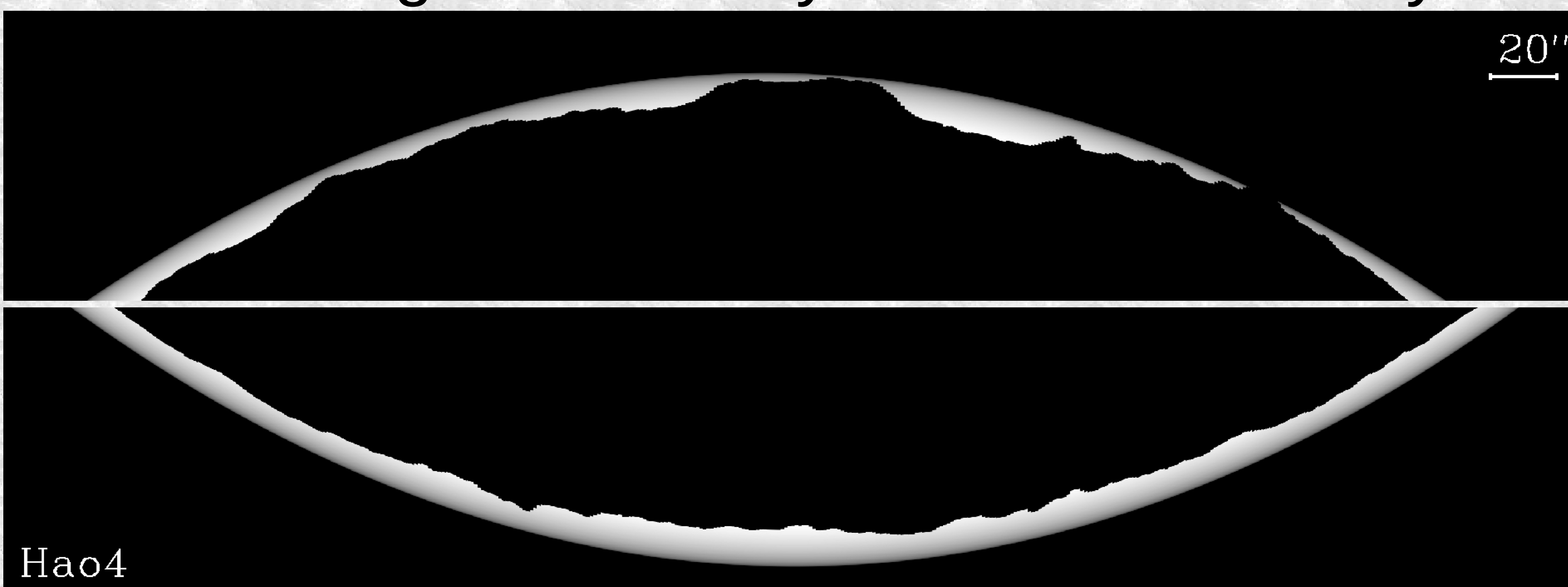
- **The lunar profile is written as a series of points of angular position (θ,φ).**
- **The solar disk, projected on the celestial sphere, is split in small areas :**
  - **Very thin in the radial direction, so we can assume an homogeneous radiance.**
  - **Bound by two successive points of the lunar profile in the tangential direction.**
- **The unobstructed area of each section can only take a few possible shapes, and is easy to compute.**
- **We iterate through each areas and sum their contribution.**
- **This process is repeated for and generates produces a light curve.**



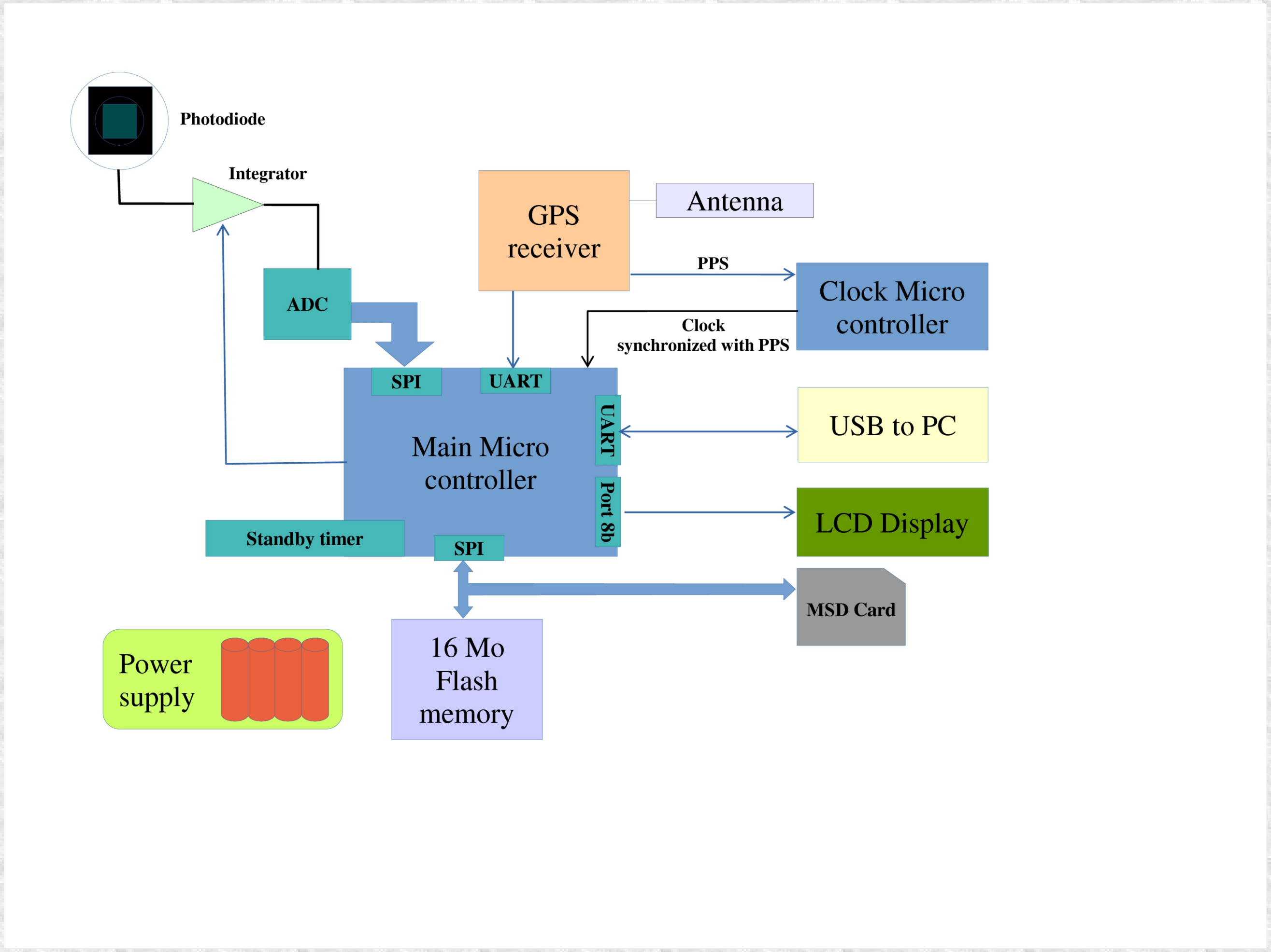



# SIMULATED IMAGES OF THE CONTACT POINTS

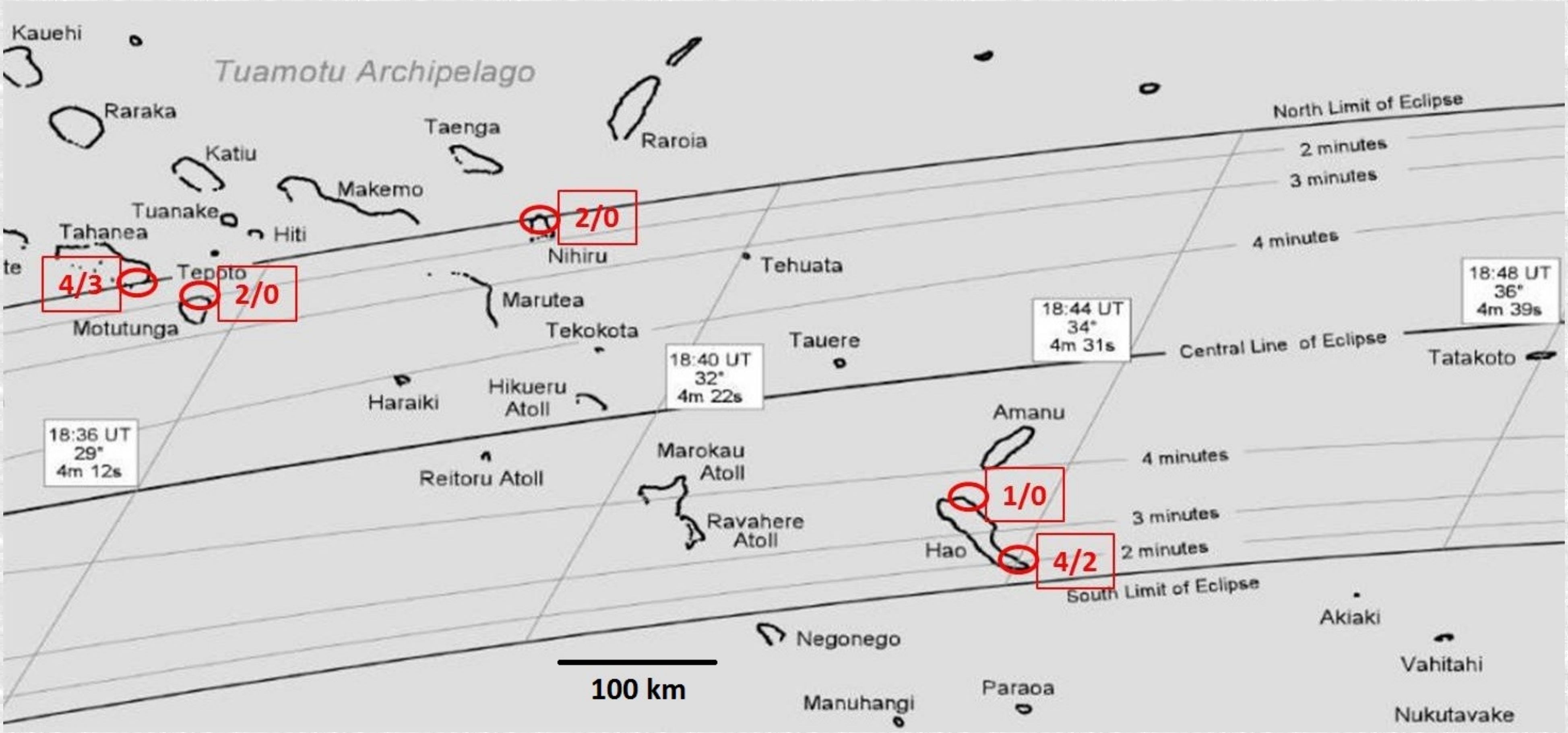

Same images dilated by a factor 3 vertically



# FUNCTIONAL DIAGRAM OF THE PHOTOMETERS

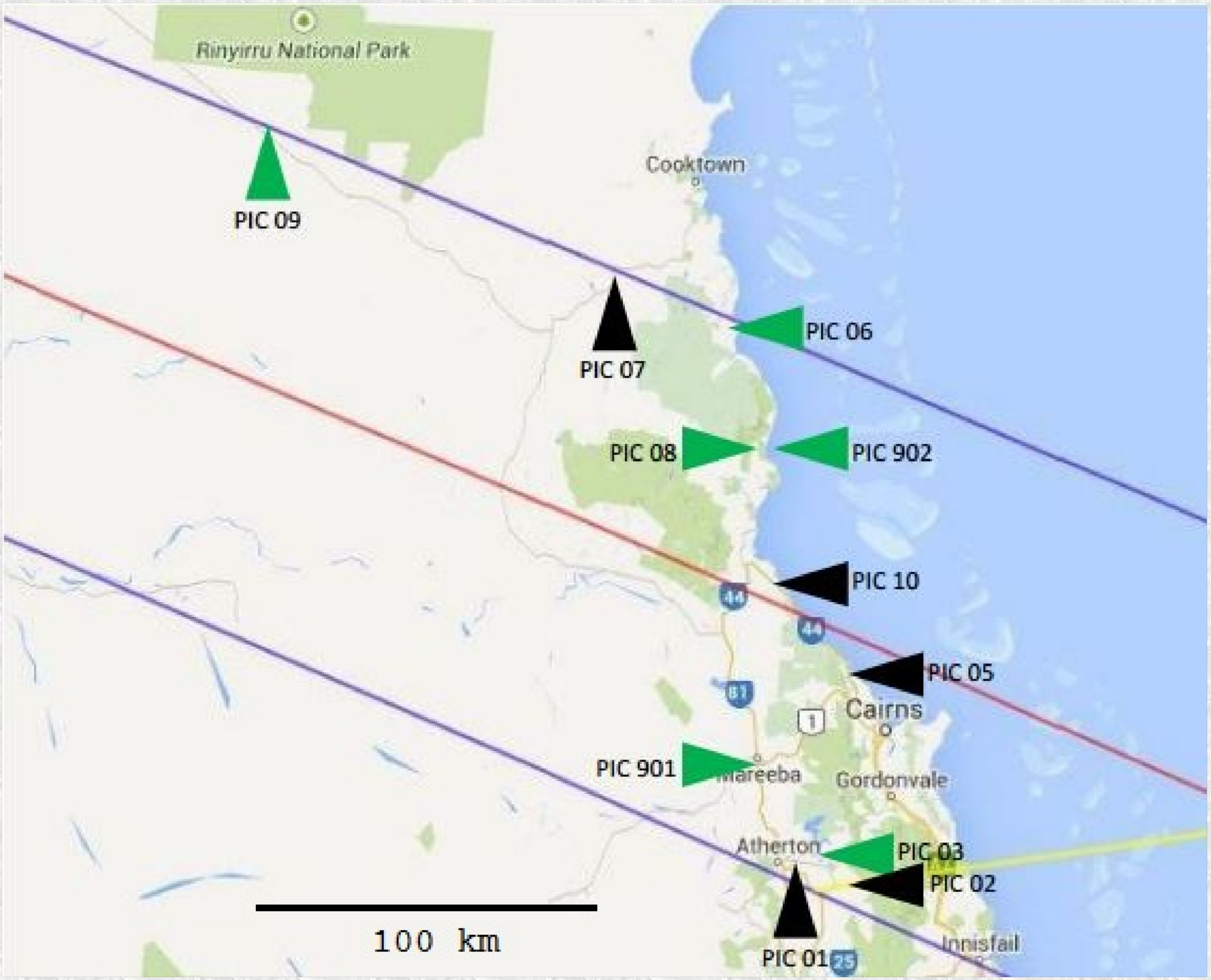



# OBSERVATION SITES ON THE 11 JULY 2010 (TUAMOTU, FRENCH POLYNESIA)



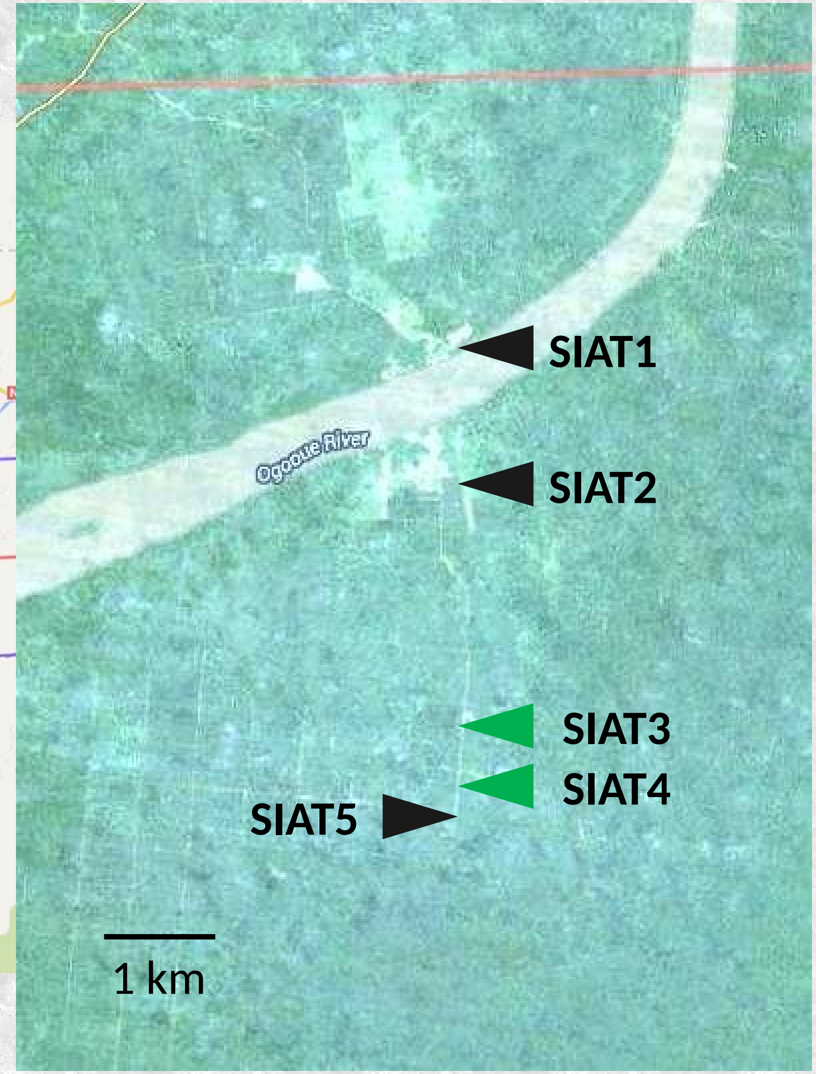

**Total number of photometers / Total number of photometers that gave useful data**

# OBSERVATION SITES ON THE 13 NOVEMBER 2012 (AUSTRALIA)



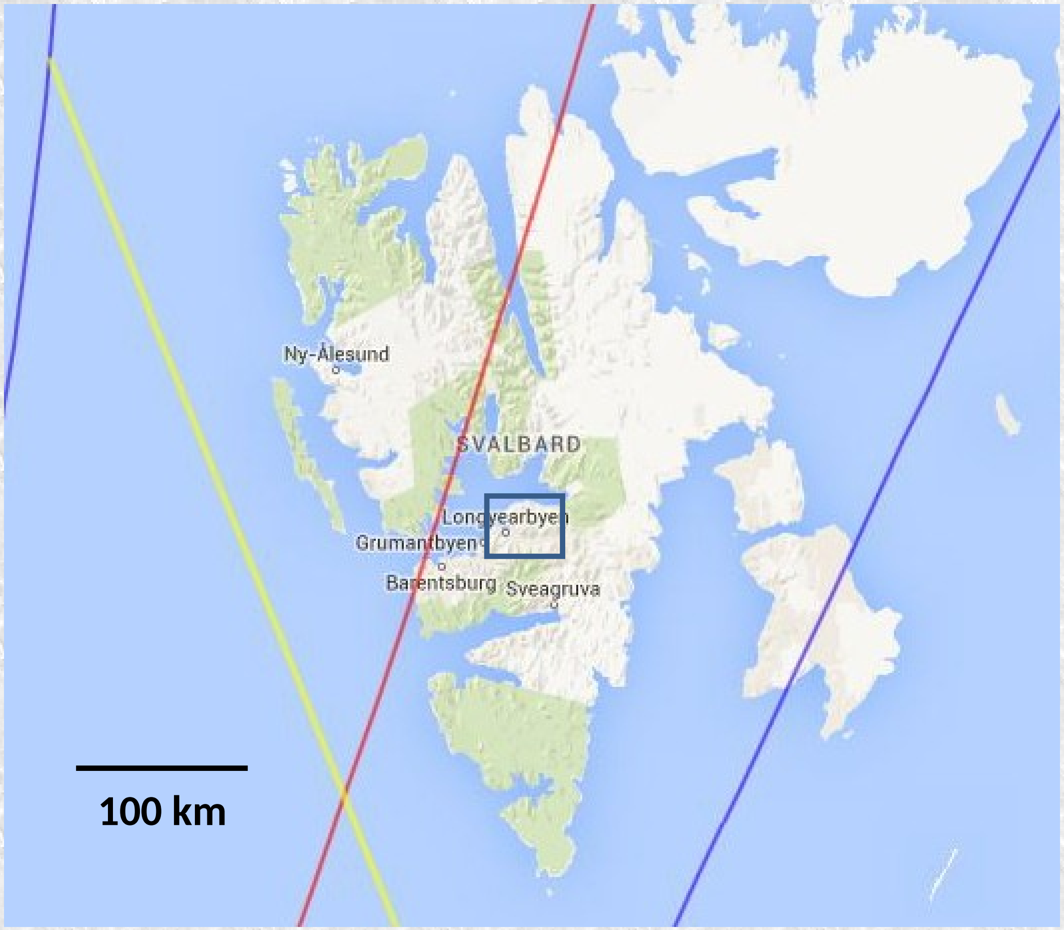

**Green triangles: photometers that gave useful data**

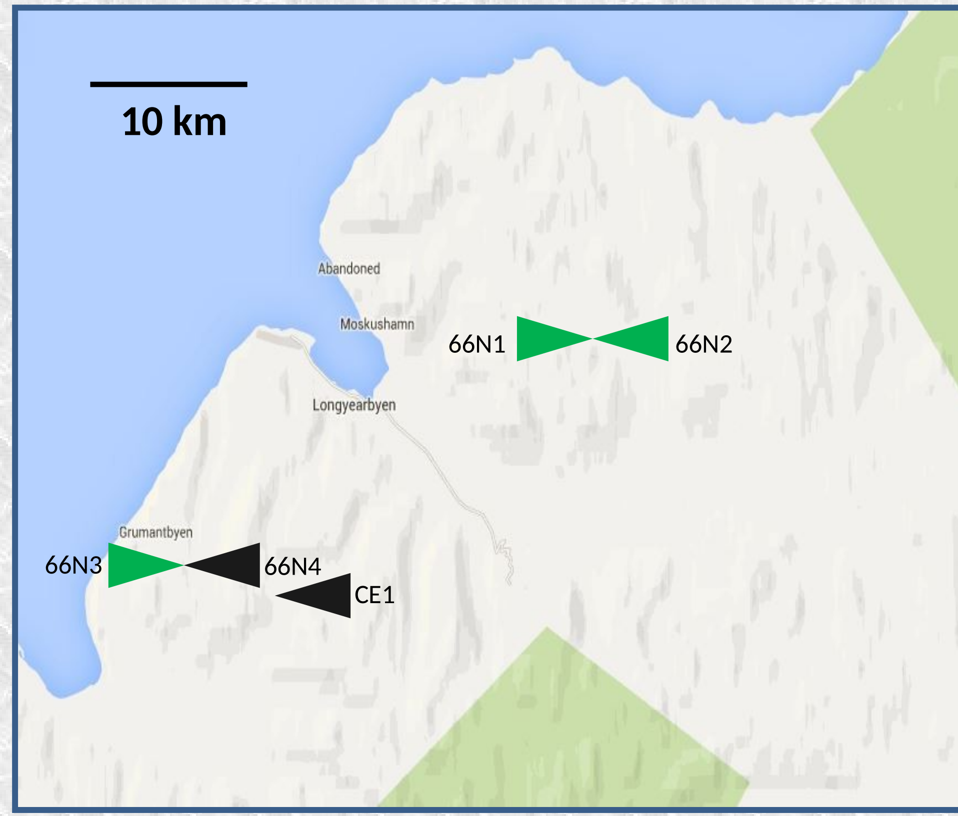
# OBSERVATION SITES ON THE 3 NOVEMBER 2013 (GABON)


**Green triangles: photometers that gave useful data**

# OBSERVATION SITES ON THE 20 MARCH 2015 (SVALBARD, NORWAY)

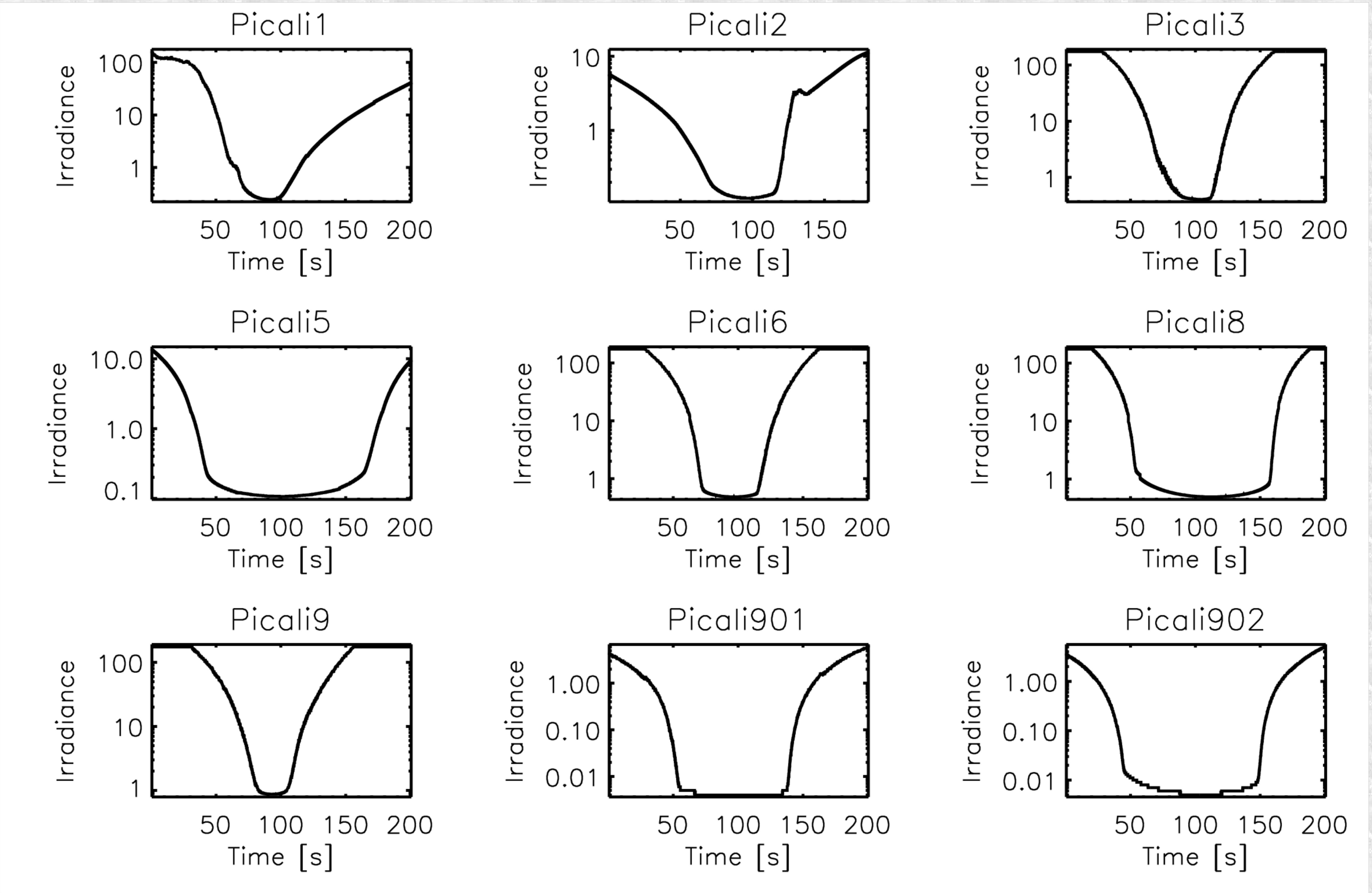



**Green triangles: photometers that gave useful data**

# PHOTOMETERS AT ECLIPSES

# MEASURED LIGHT CURVES AT THE 2012 ECLIPSE



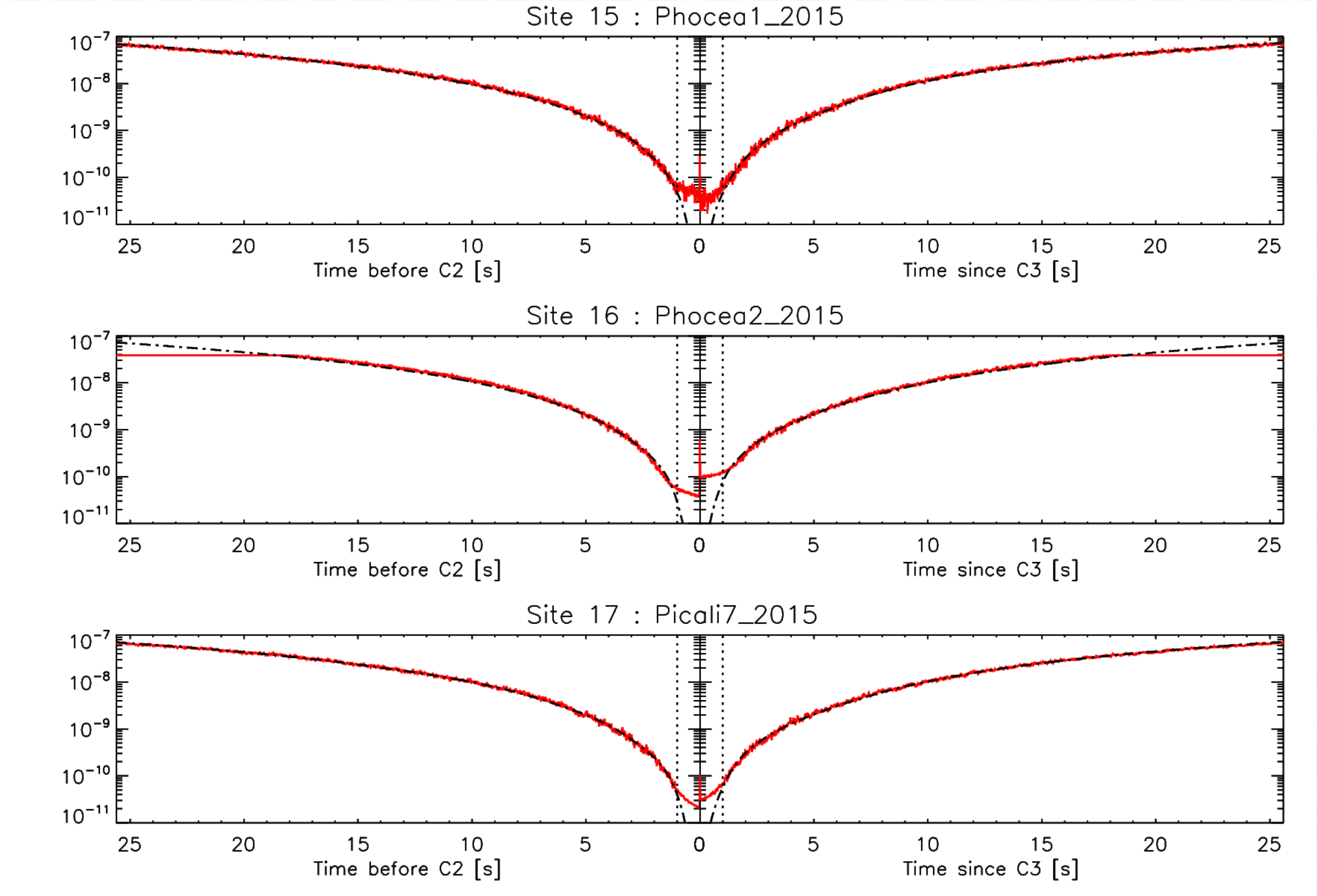
# SIMULATION / MEASUREMENT COMPARISON

► Latest Visual selection of valid data

► The synthetic light curves are computed for several values of the solar radius, and are compared to the measured light curves.

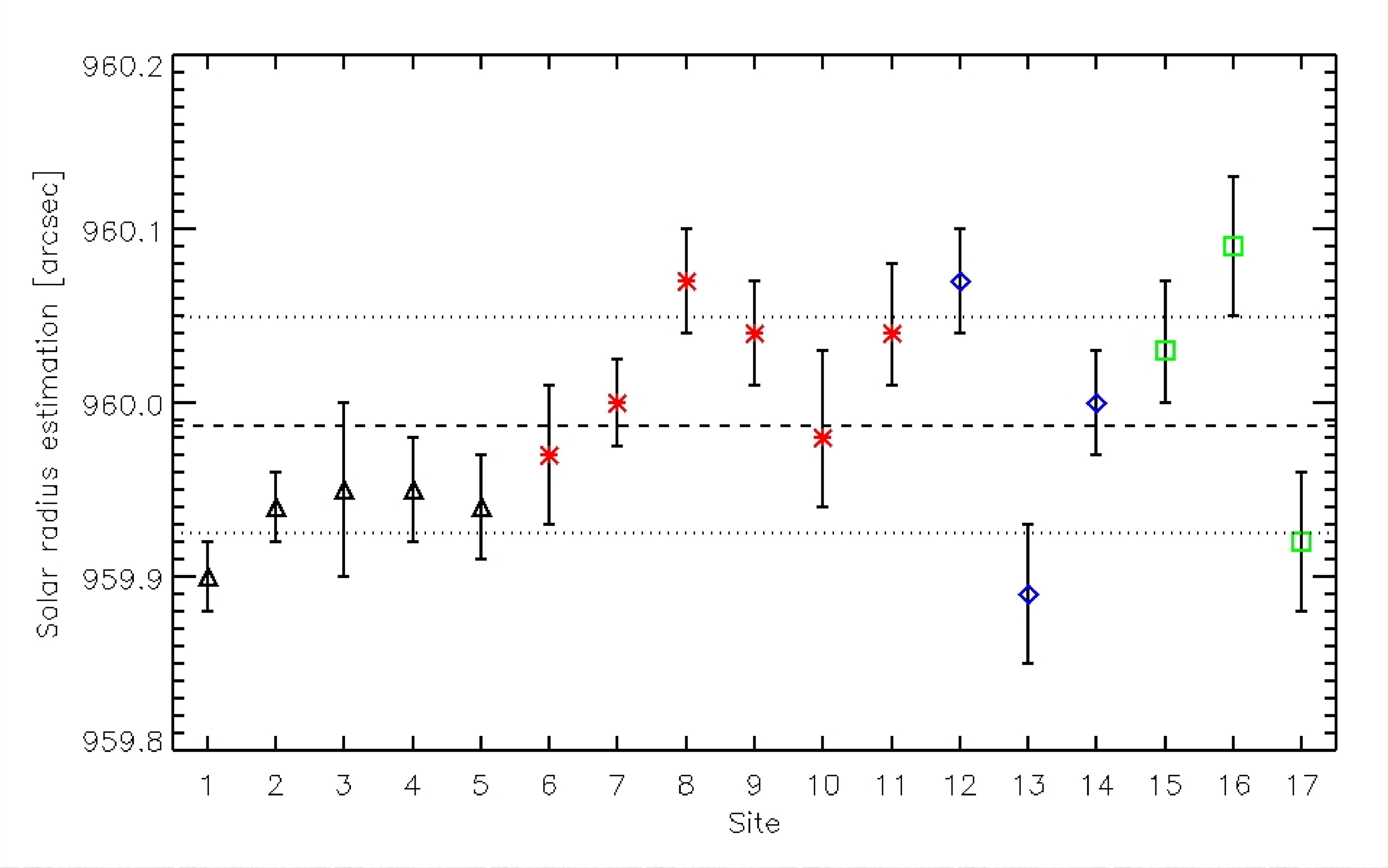
► The correct radius minimizes the mean square error between both curves, after correcting for the offsets, gain, and temporal shift of the measurements.

# SIMULATION / MEASUREMENT COMPARISON



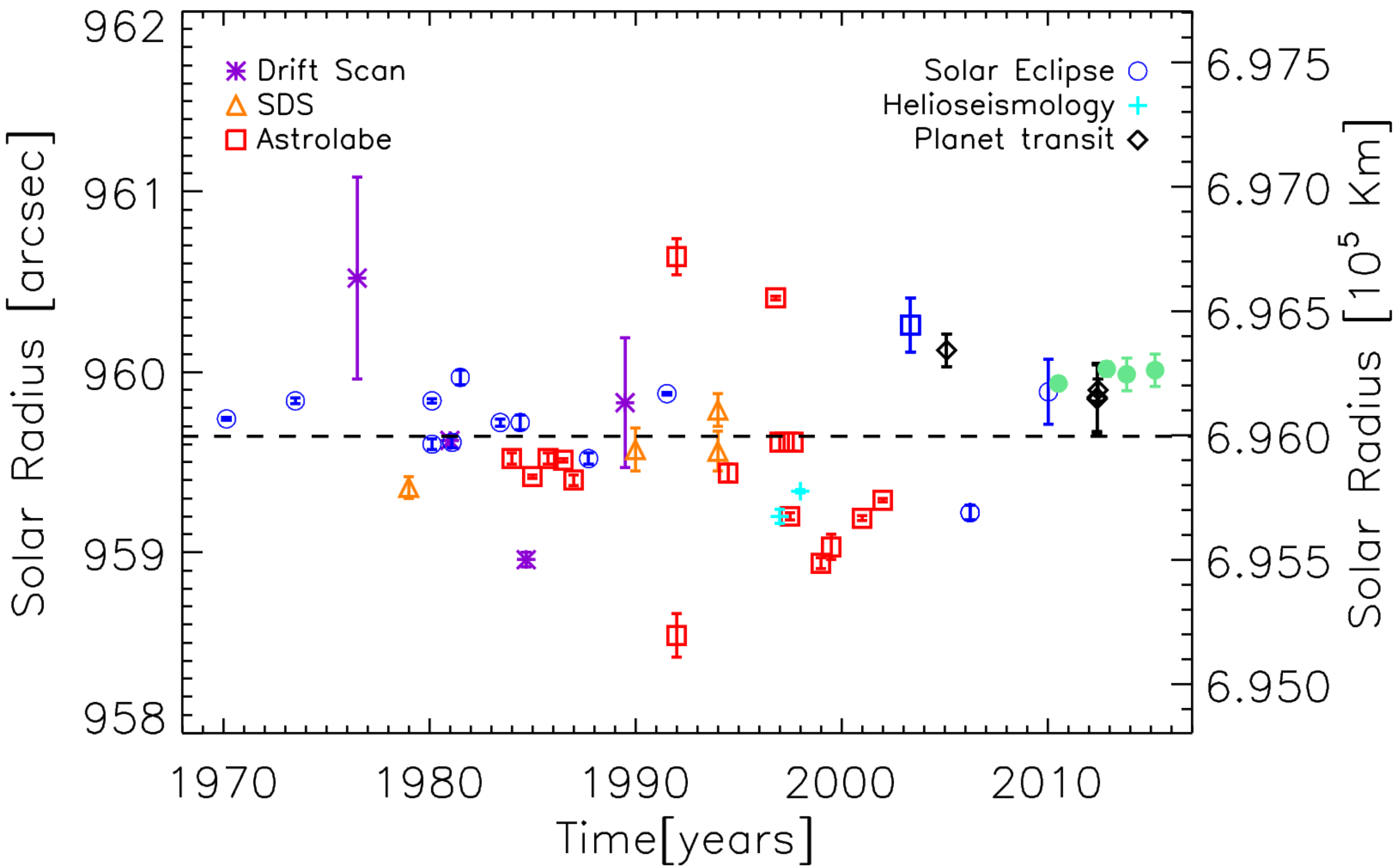

Examples of the synthetic light curves (in black) at the optimal radius for several sites, compared to the measured ones (in red).

# RESULTS FOR 2010, 2012, 2013, AND 2015 ECLIPSES




**Estimated solar radius for each data set. The same color is used for observations during the same eclipse.**

# UPDATED SOLAR RADIUS ESTIMATIONS




**Our results (average of each eclipse) green symbols) are in agreement with the recent ones of Hauchecorne et al. (2014 and Meftah et al. (2014) , and suggest a larger value of the solar radius than the IAU adopted value (dashed line)**

# CONCLUSIONS

- **Validation of a novel technique of measuring the solar radius using eclipse light curves.**
- **Using the signal over several seconds instead of the times of contact give far superior constraints with the signature of the lunar limbe.**
- **Kaguya topographic data of the Moon has been crucial for the success of our method.**
- **Simple, inexpensive photometers (16 now available) deployed over the eclipse path enhance the number of measurements and the chance of good weather.**
- **Our technique is also well adapted to the detection of temporal variations of the solar radius.**

END