N82 17023

SCLERA SOLAR DIAMETER OBSERVATIONS[1]

Henry A. Hill, Thomas P. Caudell and Randall J. Bos
Department of Physics
University of Arizona
Tucson, Arizona 85721

ABSTRACT

The accurate measurement of the solar shape and diameter has proven to be a very difficult endeavor, as evidenced by the large scatter in the data record. Although observer bias, changing environment and atmospheric seeing have been identified as the major sources of this scatter, attempts to correct for these still leave disagreement regarding the constancy of the solar diameter. Most data have been derived from solar meridian and Mercury transit timings, with total solar eclipse observations adding some additional information. Interest in the time dependence of the mean solar diameter has been revived lately as a means to infer indirectly variability in the solar luminosity. However, theoretical results regarding the relationship between these two properties are strongly model-dependent, demonstrating the need for independent measures of diameter and luminosity variations before inferences about the latter can be made. The recent use of computer-controlled photoelectric devices has led to the systematic removal of observer bias and atmospheric seeing from measurements of the solar diameter, but a new set of problems has surfaced due to variations in the sun itself. Careful attention must be given to the definition of an edge on the solar disk in order to distinguish between observed diameter variations due to physical shape changes and those due to variability in other solar properties which affect the edge definition. For example, the discovery at SCLERA[2] of differences in the solar limb darkening function between equator and pole required that special precautions be taken to extract a visual oblateness determination with minimal interference from such effects. Therefore, programs which propose to accurately measure intrinsic solar diameters must not only guard against the classical systematics mentioned earlier, but must be prepared to detect changes in other properties of the sun at the extreme limb.

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[1]The work was supported in part by the National Aeronautics and Space Administration and the Department of Energy.

[2]SCLERA is an acronym for the Santa Catalina Laboratory for Experimental Relativity by Astrometry, a facility jointly operated by Wesleyan University and the University of Arizona.

INTRODUCTION

With regard to man's apparent desire for stability, i.e., constancy, in the structure of the universe, the sun has been a considerable disappointment. Variability seems to occur in each observed solar property when it is examined with sufficient care. The advent of the telescope brought about the discovery of the sunspot cycle; later the magnetic cycle was found and recently, with the addition of new observing techniques, variation has been detected in the apparent solar shape. Focus is now being given to possible variations in solar luminosity and accurate methods of monitoring it. Aside from direct bolometry, one methodology for this type of research makes use of measurements of the solar diameter and limb darkening function as indirect indicators of the solar luminosity. This approach, which is currently being used at SCLERA, will be reviewed here.

DIAMETER VS. LUMINOSITY VARIATION

A change in the solar diameter will occur when a change in energy output or a redistribution of energy within the sun occurs. Some recent theoretical work has been directed toward attempting to identify the fundamental physical processes affecting the relationship between a change in radius and a change in luminosity. Reference 1 and, in more detail, reference 2 describe work to derive such a relationship by varying the convective efficiency used in local mixing length theory. Reference 3 uses changes in magnetic flux tube buoyancy to alter the radius while holding the luminosity constant. The argument is put forth in reference 4 that variations in lower convection zone magnetic fields with the solar cycle could alter the difference between the actual and adiabatic temperature gradients, thus affecting the convective flux. The results of these models vary considerably in the predicted magnitude of the relationship between radius and luminosity variation, even predicting different signs in some cases. Comparisons between the various models can be found in references 5 and 6. It appears at this time that independent observations of solar diameter and luminosity will be necessary to resolve these differences.

Another problem, and one which is commonly overlooked, relates to the observational definition of a solar diameter and its relationship to the theoretically modeled perturbations. A discussion of the use of the solar diameter as an indirect measure of luminosity makes little sense without careful consideration of this matter. We will deal with this in a later section. Nonetheless, historical records of diameter have been analyzed for variation and these analyses are reviewed in the following section.

HISTORICAL RECORD OF THE SOLAR DIAMETER

Attempts have been made for over three centuries to measure the diameter of the sun. These observations, which consist of meridional transits, Mercury transits, and solar eclipse timings, have been reviewed recently in an effort to determine the long-term character of the solar diameter. Reference 7, in an analysis of the Greenwich meridian circle data, initially reported a decrease in the solar diameter of nearly 2" per century; this figure has recently been revised downward to about 0".1 per century (reference 6). An analysis of the record of Mercury transit timings from the late 1700's to the present has resulted in the conclusion, at the 90% confidence level, that the solar diameter has decreased by less than 0".3 per century and, within the stated error, probably not at all (reference 8). References 9 and 10 employed a large sample of published solar semidiameter determinations taken between 1660 and 1978 and found no indication of a substantial secular variation, although a variation with solar cycle may exist. Finally, timings of eclipses made near the limits of totality in 1715 and 1925 show that the sun was larger than it is currently by 0".3 and 0".7, respectively (references 11 and 12).

It is clear from the above summary that the historical record provides no clear interpretation. Changing environmental conditions, observer bias, and errors in correcting systematics like irradiance, lunar limb shape, and seasonal changes in refraction partially contribute to the "scatter" in the observations. The salient point, however, is this: the weight of these studies indicates that the solar diameter is variable at the 0.1% level over time scales of 10-100 years. Modern observations and techniques will be necessary for more detailed conclusions.

MODERN OBSERVATIONS

The use of photoelectric devices to determine the shape and diameter of the sun allows greatly increased precision. The usual observer biases are immediately removed and the systematics can be controlled for. Even so, controversy has arisen from the intercomparison of modern measurements of the solar shape (references 13 and 14), primarily because of differing definitions of the solar edge used in the diameter determinations. In fact, this intercomparison led to the discovery of changes in the solar limb darkening function on time scales of several months (reference 13). These changes are manifested as an excess equatorial brightening and were detected through the use of an edge definition which distinguishes between physical changes in radius (i.e., a rigid translation of the limb) and changes in the shape of the intensity pattern used to define the edge. This definition, which also demonstrates a markedly reduced sensitivity to seeing effects, is referred to as the finite Fourier transform definition or FFTD (see reference 15 for a more complete description). When the FFTD was applied in an observing program to measure solar oblateness at the SCLERA telescope during the early 1970's, the oblateness was found to contain a time-varying component. The properties of the FFTD allowed the differentiation of those periods of time when the excess equatorial brightness was minimal, i.e., when the equatorial and polar limb darkening functions were most similar, resulting in a determination of the intrinsic visual solar oblateness.

These measurements have far-reaching implications. Changes in the solar limb darkening function must be accompanied by changes in, for example, the temperature and density profiles throughout the photosphere and chromosphere. Alteration in these properties will change the energy flux associated with various energy transport mechanisms. The existence of a time-varying excess equatorial brightness implies, then, an anisotropy in the solar flux. The accuracy to be expected for direct bolometric measurements of the solar constant will be strongly affected by this anisotropy, since any observation of that type works in a very narrow solid angle.

Variability of the limb darkening function may well pose the ultimate limitation on the precision to which a solar diameter can be determined, and progress must be made in understanding its effects on measurements of the solar diameter. On the other hand, changes in the limb darkening function, rather than in the absolute solar diameter, may turn out to be the dominant source of information on the solar driving function for the earth's climate.

SCLERA'S OBSERVING PROGRAM

At SCLERA, an active program is planned for 1980-81 (reference 8) to study long-term solar variability and its effect on solar energy output. For the first time the full astrometric capabilities of the SCLERA facilities will be utilized. A review of the various aspects of this program follows.

To accurately measure changes in the shape and diameter of the sun, a Michelson interferometer with a He-Ne laser source is used. This device continuously monitors the separation between the detectors which gather the limb intensity profiles used in the FFTD definition of the edge. To study long-term solar variability, extreme stability of this interferometer and its supporting hardware must be maintained throughout the planned observing period. To meet this goal for the short term, approximately the first year, the observing instrument will perform in a "frozen" configuration. This implies that no modifications or improvements will be made to the hardware during this initial period. To allow the comparison of diameter observations taken from day to day, a white light interferometer has been implemented which coexists with the Michelson interferometer. The measurement of the white light fringe with respect to the laser fringe provides the necessary day-to-day fiducial for the short term.

The balance between freezing an astrometric instrument to insure consistency of results and the necessity to respond to new technological developments, thus staying at the frontier of the field, represents a major dilemma in astrometry. A calibration scheme is currently being developed at SCLERA to avoid this predicament. The new device uses grating optics and laser light to produce reference fiducials in the telescope's focal plane at a standard angle of separation. This calibration system will allow absolute diameter measurements to be made with high precision in a historically repeatable manner. In addition, its incorporation into the observing program will remove the necessity to maintain the detectors in a frozen state and permit technological upgrading when appropriate.

Another feature of SCLERA's observing program is the continuous record of the limb darkening function which is made simultaneously with the diameter measurements. The FFTD edge definition is then applied to these intensity profiles off-line to generate a sensitive "barometer" of changes in the limb darkening. This will provide the necessary information to separate physical diameter changes from those due to changes in the shape of the limb, thus avoiding the possible misinterpretations mentioned earlier.

The 1980-81 observing program calls for daily operation of the telescope, weather and equipment permitting. The analysis of these new observations should provide, among other things, an improved value for solar oblateness and a new measure of the long-term variability of the sun. It is anticipated that this program at SCLERA should launch a new era in the study of the global properties of the sun.

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