N75 12736

PAPER 1.1

BALLOON-BORNE INFRARED CORONAGRAPH

John Strong
Astronomy Research Facility
University of Massachusetts
Amherst, Massachusetts 01002

ABSTRACT

The use of balloon vehicles to observe the solar corona with an infrared coronagraph is reviewed: both the scientific results and the instruments employed. A parallel is drawn between the required functions of a coronagraph and of a far-infrared cold telescope.

Scientific ballooning has been attractive for providing observation stations for astronomical observations by virtue of two features: 1) the altitude lies above substantially all infrared absorption by the polyatomic atmospheric constituents (H_2O and CO_2); and 2) above substantially all of the sky scattering of the infrared solar radiation.

A third feature of observations at balloon altitudes, perfect "seeing," we have never required.

The reliability of the scientific balloons themselves, and the management of their flights, have both improved substantially over the 20 years that we have been involved. During the past 10 years our experience has been excellent. Now that the art has matured I am gratified to be here to see how scientific programs have developed, and to see if our attempts to adapt to the changed climate of funding may be typical.

I shall describe our program and its projections: the scientific results and the instruments involved. Finally, I shall point out similarities of function between a coronagraph and a far-infrared helium-cooled telescope.

My remarks on the scientific side will be largely restricted to an infrared ($\lambda\lambda \sim 2.2\mu$) emission feature in the corona at $4R_\odot$ elongation (first observed at the 1966 Bolivian eclipse) and to an aura of infrared emission around the sun of substantially constant strength out to $6R_\odot$ (observed on our October 1971 balloon coronagraph flight).

MacQueen used, for his dissertation, the eclipse results and a subsequent 1967 balloon coronagraph flight that confirmed the $4R_\odot$ feature and added other subsidiary emission features (MacQueen, 1968). The 1967 balloon observations showed, significantly, that the $4R_\odot$ feature was strongest at the azimuth angle corresponding to the solar system's invariable plane (approximately the plane of Jupiter's orbit).

Our observations have been equivocal regarding the $4R_\odot$ feature: On our March 1971 flight, the increment of insolation on the servo-sensors, due to altitude, was less than we were led to expect, so that the solar tracking was sluggish. As a result, we had frequent sunlight leaks which made the data uncertain. However, correcting for this, on our two subsequent flights the servo-mechanism has tracked our equipment on the center of the sun to within ±10 arc sec angle--and that uninterrupted throughout both of the two data-taking periods.

Five hours of data on the October 1971 flight showed the $4R_\odot$ feature weak and more diffuse than formerly. It was at $\sim 4.3R_\odot$ (rather than $4.1R_\odot$, after MacQueen); and it varied uniformly with azimuth across the invariable plane.

Also, the aura or shelf out to $6R_\odot$, first observed on this flight, was more than an order of magnitude "too strong." I say "too strong" because it disagreed with MacQueen. Since we did not participate in the reduction of the 1967 data, we, perhaps, gave his data more respect than justified. Nevertheless, we suspected that we may have been measuring the coronagraph, rather than the corona with it. I shall confront this possibility later. For now, let it suffice to say that we "believe" these 1971 results.

Last summer we observed the infrared corona in Africa at the eclipse. These measurements with S-1 photomultipliers were filtered at $\lambda\lambda \sim 1\mu$ (as contrasted, $\lambda\lambda$ 2 to 3.5μ with the balloons). The eclipse results (Smartt *et al*, 1974) must be believed implicitly. They show neither a $4R_\odot$ feature nor a shelf.

Since the African eclipse, another balloon flight in October 1973 shows, in preliminary data reductions, no shelf; but, perhaps, a weak feature near $5R_\odot$ elongation.

In the context of these variable results, we plan one more flight with the present coronagraph, adding polarization analysis to the instrumental functions. If the infrared corona continues to behave transiently, as is now indicated, then regular studies will be indicated. But since regular studies with our present heavy equipment would be very expensive, we have been planning, in anticipation, a program with an order of magnitude lighter package. With such, several flights a year would be supportable--leading eventually, perhaps, to continuous monitoring observations from a space lab.

Since 1971 we have used a mirror coronagraph; the tracking has been described (Li, 1973). Below we describe the optical system:

Our program depends primarily on the twilight-bright sky, in the visible, at altitude--a sky that is midnight-dark in the infrared. But one must cope with the sun--even brighter at altitude than at the earth. The conventional means of coping is to create an artificial eclipse by means of an exterior occulting disk--a moon surrogate.

I broke convention by substituting exterior occulting paddles. This new procedure was invented primarily to cope with a tracking error we had at the time--annoying vertical nodding. Characteristics of the new system are: (1) the paddle obscuration effectiveness is immune to nodding; (2) since one is scanning horizontally, over-occultation at other azimuths was inconsequential; (3) Fresnel diffraction of the paddle edge is much weaker than the Lummel diffraction of a disk.

The use of primary mirrors, rather than a fused silica lens, constituted another innovation (since 1971). With mirrors we obtained an order of magnitude improvement in the signal-to-noise quality of the recorded read-out. The use of mirrors was cued by Zirin and Newkirk (1963). They showed that mirrors supplied by the Liberty Mirror Division of Libbey-Owens-Ford Glass Company scattered incident light close to coronagraph quality. Accordingly, primary mirrors that had been super-polished were procured from Frank Cooke Inc. Smartt and Dalton (1971) coated them with gold by thermal evaporation, and investigated their scattering. Smartt has recoated these mirrors by thermal evaporation several times, and re-measured relative scattering. Each time the mirrors exhibited the same hierarchy of quality, showing that it is the polished glass surface which is limiting. This is not to imply that of these mirrors those that scatter most do not have a superb finish. It only means the testing method is very sensitive. I do not think Frank Cooke regards his procedures as proprietary; but I do think that the people who accomplish such extraordinarily excellent work in his shop may often neglect to tell all the nuances of technique that they practice.

There are a pair of occulting paddles in tandem. The front occulting paddle shades the rear one, while the rear paddle obscures the front paddle edge so that its diffracted radiation cannot irradiate its primary mirror. The rear of this pair of paddles lies 215 inches in front of its primary mirror. Thus, it must extend out, laterally, by at least one inch farther than the outer edge of its primary mirror, if all of that mirror is to be in full shade. As a result, the paddles begin to occult their mirror's view of the corona at <5$R_\odot$--and fully occult it at the inner limit of the scan. This arrangement avoids excessive dynamic range; but it requires that corrections be applied to the data (based on laboratory calibrations).

There are two primary mirrors. They are scanned by swinging their common mounting arm--one scans out on the right side of the sun as the other scans in on the left, and *vice versa*. There are two identical optical trains which bring the corona views to a single aspheric silicon lens which closes the opening in an LN-2 cooled chamber containing six detectors (5 PbS and 1 InAs). The optical trains are each comprised of two off-axis ellipsoidal mirrors; a 400 cps Bulova chopper (reflecting a view of the N-sky to detectors in the off-phase of each chop cycle); an image dissector that divides a 1$R_\odot$ by 1$R_\odot$ corona image into three samples, and separates them so they are focused by the silicon lens on three filtered detectors ($\lambda\lambda$ 2.2μ, 2.5μ, and 3.4μ).

We tested the efficiency of the light baffling of the coronagraph--to restrict the detector irradiation to its corona view--as follows: A black box with a 2.8 x 6 inch "mouth" in one end, enclosing in it two black pitch polished mirrors (6 x 16 inch rectangles) to form a wedge of 10° included angle, was prepared. With the coronagraph just outside our laboratory, in Amherst, and tracking the sun, we separately mounted this box parallel to the boom that supports the paddles, and in their shade. Then we scanned the primary mirrors so that the detector view fell entirely within the mouth of the rectangular black hole that the box provided. Thus, we found that the detector response was less than the smallest in-flight responses, at the greatest elongation angles ($\sim 12R_\odot$). Even so, the primary mirrors used in this instance were not subject to in-flight scrupulosity: they had been used for the calibration above mentioned. And certainly the Amherst ambient light was at a higher level than in-flight.

Let us return now to the October 1971 flight data. Adney (1973) has made an ardent analysis for us, motivated to impugn the October 1971 data. He tried out every possibility we could imagine of instrumental artifacts--especially emitted or reflected paddle radiation.

Our confidence that the shelf was coronal, not instrumental, is based on the following (with no contrarywise evidence):

1) The three views of the corona are separated 3/10$R_\odot$ in elongation. We asked if the features as seen by the three detectors on one side collated as to coronal position, or with time. They were found to collate in coronal position--both the 4.3$R_\odot$ feature and the 6$R_\odot$ fall-off of the shelf.

2) The shelf is established by the detector view fields lying outside of the point where the field of view first intrudes on the paddle.

3) On the October 1973 flight the in-flight paddle temperature was $\sim 0°$C. This confirms a conclusion that Adney had come to: that thermal emission of the paddles is negligible, particularly for the two $\lambda\lambda$ 2.2μ detectors.

4) Reflected telluric light is estimated as negligible.

Scientifically, we can draw a very tentative conclusion and indulge a fantasy:

It is currently supposed that the 4$R_\odot$ feature is comprised of interplanetary particles coming into the sun by loss of angular momentum through the Poynting-Robertson effect. As they get close to the sun, they get hot enough to evaporate--near the sun, at 4$R_\odot$, irradiation is like that at the focus of an f/2 solar furnace. This evaporation reduces particle diameters until radiation pressure turns their inward drift outward, to provide the 4$R_\odot$ maximum. If this process were correct, then the infrared corona should have a very long characteristic time; a much longer period than we have observed--seven years.

If, contrarywise, the features are of solar origin, how are they to be explained? Here we have indulged the fantasy that they are clouds constituted of the "metallic" elements of the sun--particles grown and concentrated by fractional distillation, the residue as the solar wind is evaporated away. We suppose that clouds of such particles may be dispersed from time to time.

We have also fantasized that the individual particles may be whiskers. Whiskers are a strange form of matter, too little known to be modeled into the harsh environment of the corona, but particles that could have a larger infrared than visual "antenna cross section."

Now, finally, we shall consider applications of coronagraph procedures to helium-cooled far-infrared astronomical telescopes. A requirement for them is protection of the detector from saturation by emitted or scattered infrared radiation. In my design, a large helium-cooled primary mirror is fed by a tessellated system of parallel optical trains. In each optical train there is a pair of confocal infrared achromatic lenses (Strong, 1971 and 1972). The forward lens of the pair focuses the far field on a plate that is perforated by a small sampling hole. The rear achromat collimates the radiation passed by this hole. A single chopper next to this plate, with slots for each optical train, modulates the radiation transmitted by the plate. All parallel beams are brought to the detector with a single mirror system.

Each optical train is comprised of two parts: one lies before, and the other aft of the lens pair. The forward parts are enclosed in LN-2 cooled tubes; the latter in helium-cooled tubes.

The prime advantage of this system is that diffraction at the forward opening and LN-2 wall radiations are occulted. The prime disadvantage is that the angular resolution of the system is limited to that of the diameter of the achromatic lenses.

Rather than apologize for this complicated gadget, I shall quote Goethe:

"Ein Mann, der recht zu wirken denkt,
Muss auf das beste Werkzeug halten.
Bedenkt, Ihr habet weiches Holz zu spalten."

REFERENCES

Adney, K.J., "Reduction of Data, Balloon-Borne Infrared Coronagraph Flight of October 24, 1971," NASA Report, October 1973; UMASS-ARF-73-284.

Li, T.C., Appl. Opt. 12, 2828 (1973).

MacQueen, R.M., Astrophys. J. 154, 1059 (1968).

Smartt, R.N. and W.S. Dalton, J. Opt. Soc. Am. 61, 665 (1971).

Smartt, R.N., J. Strong, W.S. Dalton, and T.C. Li, "1973 Africa Eclipse Observations," NASA Report, January 1974.

Strong, J., Appl. Opt. 10, 1439 (1971).

Strong, J., Appl. Opt. 11, 2331 (1972).

Zirin, H. and G. Newkirk, Appl. Opt. 2, 977 (1963).

DISCUSSION SUMMARY — PAPER 1.1

Paper 1.1 submitted but not presented.