TEN YEARS OF SCIENCE: LESSONS ON TARGET SELECTION FOR THE WHOLE EARTH TELESCOPE

D. E. Winget

Department of Astronomy and McDonald Observatory, University of Texas, Austin, TX 78712, U.S.A.

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Abstract. The Whole Earth Telescope is an extremely powerful scientific tool. It involves a large group of people and telescopes comprising a significant fraction of the total astronomical resources of our planet. It must therefore be used sparingly and wisely. Our best guide to the use of the WET comes from a critical examination of the results of our first decade: we must consider what worked, what did not, and why. Building on Nather's assessments in the last workshop, we can derive some general principles for selection of WET targets and operation. Armed with this knowledge we can proceed confidently into the next decade of WET science.

Key words: stars: white dwarfs, interiors, oscillations – telescopes – methods: observational

1. CHARACTERIZATION OF THE WHOLE EARTH TELESCOPE AS AN INSTRUMENT

The operation and instrumental characteristics of the Whole Earth Telescope (hereafter WET) have been summarized by Nather et al. (1990), Nather (1993, 1995), O'Donoghue (1993) and Solheim (1993); consequently I will give only the briefest description of the points immediately relevant to our discussion here and refer the reader to those beautifully written papers for more detail.

The ideal of a Whole Earth Telescope (hereafter WET) run is to obtain a record of the intensity of light from an astronomical source as a function of time *without interruption*. The maximum length of this run is set by the phase of the moon for faint targets, and by

politics of time allocation committees. These considerations combine to give 10–12 days for the maximum extent of a run.

WET data is most useful when the scientific information we are seeking is in the form of relatively coherent periodic variations in intensity. After reducing the data and combining as described by Nather et al. (1990) and Nather (1993, 1995), we produce a light curve. For the vast majority of WET data sets, the existing gaps are small in comparison with the actual chunks of data between. In practice gaps occur in the data due to the vagaries of weather, or surprisingly rarely, due to instrumentation or equipment problems. The WET scientists at the telescope have gone to heroic measures to eliminate human considerations as a cause for gaps – witness Edmund Meištas dramatic story. Most important is that the gaps do not occur periodically in the data. Unfortunately, this does occur sometimes in practice when a particular longitude is not covered, or is wiped-out by weather for an entire run.

For the next step in analysis of the data we construct the Fourier transform of the combined light curve. R. E. Nather, WET founder and Director Emeritus, coined the term high-resolution power spectroscopy to describe the Fourier transform of the light curves obtained with the WET. This analysis tool is most useful when the target is periodic and relatively coherent. The periods observable in this way are set at the high-end by the Nyquist frequency resulting from our integration times which are typically seconds, and at the low-end by sky transparency variations which are the order of thousands of seconds. The latter limit is the result of our current observing technique and may be considerably lengthened when we begin to do CCD time-resolved photometry. For now, we are relatively blind to variations on time-scales longer than about half an hour. In addition, the signal-to-noise we obtain with present equipment limits us to the study of variations with modulation amplitudes in excess of 10^{-4} ; we are blind to variations with lower amplitudes.

2. PHOTOMETRIC PROPERTIES OF AN IDEAL WET TARGET

The above more-or-less instrumental characteristics allow us to state the properties of an ideal WET target. It is an object with multiple-periods in the range from a few seconds to a few thousand seconds, and modulation amplitudes well in excess of 10^{-4} . Although rich in periods, individual periodicities must be spaced no closer

together than about $1\ \mu\text{Hz}$, in order to be resolved. Further, the periods must be coherent over at least several days, or failing that at least repeatable (see discussions by Clemens 1995 and Kleinman 1995).

Fortunately, there are a number of known classes of objects which exhibit all or most of these properties: the DOV, DBV, and DAV stars; sdB pulsators, δ Scuti stars, roAp stars and cataclysmic variables. With the exception of the newly discovered sdB pulsators, stars from all of these classes have been observed with the WET. Nather (1993, 1995, see also Clemens 1995 and Kawaler 1995) has reviewed the relative success of past targets. Individually, we might make some changes in the sense that some of the objects we have described as failures in the past, such as AM CVn and PG 1346+082, we might now term successes. Likewise, some of our successes seem more like failures, for example the distance to PG 2131 and the rate-of-period-change of PG 1159. For the most part, however, I think most of us would not quibble with the assessments he provides. It is clear that with a very few exceptions the closer an object has come to exhibiting our above described ideal photometric properties, the more scientifically successful we have been with the WET data.

Given that a potential target possesses most, if not all, of the above attributes, let us consider other factors that lead to a successful WET run, again basing our comments on past experience.

The above discussions treat the WET as if it were *only* a mechanical and electrical instrument. It is much more. It is built not of glass and steel, but of flesh and bone. It exists as a loose collaboration of scientists with common scientific goals and uncommon scientific standards. This is our most important resource and one we must spend sparingly and wisely if the WET is to continue into the future.

The problems of coordination and operation of the WET have largely been solved, within the limitations of the current instrumentation, and it is possible to operate the WET in a way that has been largely described as routine. This has lulled most of us, me too I confess, into forgetting the magnitude of the cost to plan and carry out a WET run. O'Donoghue (1993) estimated the funds required to operate WET. They are substantial, yet they are not the major cost. The major cost must be measured in a different way.

Many of the groups participating in the WET (succinctly termed nodes by Solheim 1993) give a substantial fraction of their available telescope time to the WET project. The amount ranges from about

30% to 100% of their available telescope time. In addition, we must consider the contribution each person in the field observing makes in terms of their research and personal time. Each observer contributes about 3 weeks per run, and sometimes more, observing, preparing and testing equipment, packing and unpacking. This represents a major commitment of time and personal resources on the part of each individual involved. Particularly, as pointed out by O'Donoghue (1993), to be buried as one of 30 plus authors on an eventual paper.

Getting telescope time allocation committees to continue to give us time and getting individuals to continue to make the personal sacrifices they each make, puts a significant pressure on each run to be a scientific success. Of course we cannot guarantee this, but we must do everything we can to give ourselves the best chance. We can accomplish this by applying the following strict criteria to a proposed primary target.

In order for an object to become a primary target, we must show that the WET is essential to its understanding. More importantly, the understanding achieved should deliver, or hold the potential to deliver, a significant scientific advance. The scientific yield must be in proportion to the investment of the time, money and resources of the astronomers involved.

3. MULTIPLE TARGETS

The above proposed rather strict criteria lead us to consider the past practice of accepting multiple targets for a run. We did this to optimize the scientific return; when the scientific objectives of the primary target were met, the secondary was promoted. Also, overlapping sites with clear weather could provide data on more than one object. In this sense, the idea was a spectacular failure, and a great disappointment to the PI on the (initially) secondary target. We do not, typically, solve a star in the first half of the run, or in the few cases where we have either solved the star or given up on it, not enough time has remained in the run to do justice to a secondary target.

Interestingly, the multiple target concept has also been very successful. This has been when the secondary target was selected with different objectives than for the primary target. These fall into two categories: science goals can be accomplished without need for extensive coverage and scouting an object to see if it will be a productive WET primary target. An example of the first category is

the many observations of G 117-B15A where phase measurements of the largest amplitude mode were the goal, and only total photons counted mattered, not the temporal distribution of the data. An example of the second category is the observations of RXJ 2117 in XCOV9 which established the validity of its selection as the primary target for XCOV11.

Thus secondary targets should be used in the future, to optimize the use of the time at each site and provide supplementary data on objects. We should not consider secondary targets that will require a significant fraction of the run to obtain useful results. So while No Fishing Allowed is the rule for the primary targets, potential future primary targets should be encouraged for secondary targets. This gives us a practical way to take a chance on relatively under-observed, but potentially interesting, objects without risking the integrity of the WET.

4. SINGLE-SITE SUPPORT

This is an area where we have often failed miserably in the past. Single site observations are needed in order to make a convincing case for an object to be a primary target candidate. Without this data it is impossible to establish the suitability of the photometric properties of an object. In addition, single-site data in months immediately preceding and following a WET run should be done by the PI and other interested nodes as well. This will allow us to maximize the return of the WET run itself. An example of when we needed it, but did not do it was the PG 1159 runs when a bit of data before and after would have greatly helped us in determining the phases of the pulsations and therefore the rates of period change. Another instance was GD 358, where we had the data, and therefore established the need for a second run on the object since the instabilities in the frequencies and amplitudes called into question the interpretations from the first run.

This also raises the question of the value of re-observing targets. Based on our experience re-observing both GD 358 and PG 1159 we can draw some conclusions. Both objects clearly meet the photometric requirements extremely well, and as a result the first runs were extremely productive. Yet the stringent scientific productivity criteria have not been met for the second run. The data will ultimately be useful for both stars. We did succeed in making a correct re-determination of the rate of period change in the 516 s mode

of PG 1159 (Kepler et al., these proceedings). The observations of GD 358 did reveal changes in amplitude during the WET run and changing multiplet structure as well, the WET run was too short to establish if these changes are themselves strictly periodic.

These last observations establish the need for data on time-scales intermediate between the two weeks covered by a WET run and the year between observing seasons. There are clearly significant changes occurring on these time-scales that must be investigated if we are to understand the nature of the variations we observe. This is the province of single-site observations. These must push the phase of the moon and the observing season as far as instrumentation allows.

5. A SUMMARY OF GENERAL GUIDELINES FOR FUTURE TARGET SELECTION

Based on the above considerations, WET runs should be planned only based on pressing scientific need, not at a pre-established rate (i.e. one or two per year). This need should be established by the proposal of a candidate object which meets the following conditions.

- Extensively observed from a single site before proposing (necessary to establish the following criteria in any case) before the WET run, and after the WET run, in support of the run itself.

- Multiple-periods in the range from a few seconds to a few thousand seconds and modulation amplitudes well in excess of 10^{-4} . Periods must be coherent over at least several days, or at least repeatable.

- WET is essential to understanding the object. The understanding achieved should deliver, or hold the potential to deliver, a significant scientific break-through.

- If all of the above criteria are well met, then preference should be given to objects which coordinate well with secondary targets.

- Secondary targets should be included in the plans for every run. They should be selected based on the utility of small and sporadic chunks of data, or to be scouted for potential primary target status on a subsequent run.

Application of these principles (with due apologies for unwanted militaristic connotations but in keeping with the proud tradition of our Polish hosts and colleagues), leads us to consider the WET as a sort of Science Cavalry: mobilized when needed, incapable of a sustained engagement and acting swiftly and decisively. Holding fast to these guiding principles will ensure the future of the WET.

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