Progress with the Whole Earth Telescope

D. O'Donoghue[1] and J. Provencal[2]

[1] *Department of Astronomy, University of Cape Town, South Africa,* [2] *Department of Astronomy, University of Texas at Austin, USA*

Abstract

A summary of the results from seven global runs using the Whole Earth Telescope is presented, together with an evaluation of the scientific results obtained to date. Factors such as the distance of the target star from the equator, the nature and timescales of its intrinsic variability, etc. are shown to affect the value and quality of the results, as well as the traditional factors such as brightness and long-term coherent behaviour. Experience with the network shows that, taken as a whole, it enjoys far better weather than any one of its sites, and provides unprecedented 'uncluttered' resolution of time-series power spectra.

1. Introduction

The Whole Earth Telescope (WET) is a collaboration between astronomers from about a dozen nations who obtain, twice yearly on average, observing time on 1-2m class telescopes at about a dozen observatories in both hemispheres. The longitude distribution of these sites enables the observation of variable stars continuously, without any gaps in the data, for intervals of ~1-2 weeks. The scientific motivation for this capability is the elimination of the aliasing problem inherent in data collected at a single site. Aliasing confuses the interpretation of amplitude spectra of variable stars: instead of a single peak in the amplitude spectrum for each real frequency at which the star is varying, there is a retinue of peaks, as illustrated in Fig. 1 of Nather et al. (1990) (hereafter NWCHH). The amplitude spectra of multi-periodic pulsating stars often exhibit many overlapping 'aliasing patterns', and the disentanglement of the real signals from the aliases can be a hopeless task. The only way to overcome this difficulty is to obtain essentially continuous data and for this, a network of observing stations, well-spaced in longitude, is required. This paper describes progress with the WET; other descriptions appear in Nather (1989), NWCHH and Nather (1992).

2. Operating the Whole Earth Telescope

A world map showing WET sites as at 1989 March appears in Fig. 2 of NWCHH. More recent campaigns have added Kitt Peak, ESO, Poland, the Wise Observatory in Israel and Mt. John Observatory in New Zealand, although not all sites operate for every campaign. The minimum observing equipment required is a 2-channel high-speed photometer with offset guiding, and the ability to measure the guide star

https://doi.org/10.1017/S0252921100007636 Published online by Cambridge University Press

using the photomultiplier tube on the second channel. The preferred instrumental configuration is a 3-channel, portable photometer constructed by Prof. Ed Nather and collaborators at the University of Texas. The additional channel is used as a continuous monitor of the brightness of the sky background, measurement of which can only be done occasionally with a 2-channel instrument. Portability of the instrument, and its associated data acquisition laptop computer, is essential to allow observers to travel to distant sites without complicated instrumental handling procedures.

Each campaign concentrates on ~2 targets, each of which has an associated 'Principal Investigator' (PI), who has proposed the target for observation and who is expected to lead the analysis of the data. The PI's are present in the WET operations centre in Austin, Texas during the campaign. Observers are either attached to 'home observatories', such as McDonald, or travel to common user facilities, such as Kitt Peak or CTIO. The network is controlled by daily telephonic contact from the WET operations centre in Austin: each observer reports the weather conditions at the site and receives instructions about which target to observe. This 'real-time' operation is particularly needed at longitudes where there is more than one observatory: it ensures that the highest priority target is always observed (if possible), and that the most efficient use of telescope time is made. At the end of each observing session, the observer is expected to send the data just acquired back to Austin, either via email or telephone line using the Kermit data transfer protocol.

Table 1. Whole-Earth Telescope Observing Log

WET Run No.	Targets	Type	Date	Principal Investigator	Status
1	PG1346+082	Int. Bin.	1988 Mar	Winget/ Provencal	In prep. (Thesis)
	V803 Cen	White Dwarfs		O'Donoghue	Published
2	V471 Tau	DA + K2V	1988 Nov	Clemens	Published
	G29-38	DAV		Winget	Published
3	PG1159-035	DOV	1989 Mar	Winget	Published
4	AM CVn	IBWD	1990 Mar	Solheim/ Provencal	In prep. (Thesis)
	G117-B15A	DAV		Kepler	Published
5	GD358	DBV	1990 May	Winget	Submitted
	GD165	DAV		Bergeron	In Prep.
	HD166473	Rap.Osc.Ap		Kurtz	Failure
6	GD154	DAV	1991 May	Vauclair	In analysis
	PG1707+427	DOV		Grauer	In analysis
7	1H0857-242	CV	1992 Mar	Buckley	In analysis
	PG1115+158	DBV		Barstow/ Clemens	In analysis
	G226-29	DAV		Kepler	In analysis
	WET-0856	Del.Sct.		Breger	In analysis
Forthcoming attraction:					
8	PG2131+066	DOV	1992 Sep	Kawaler	In anticipation
	G185-32	DAV		Moskalik	

https://doi.org/10.1017/S0252921100007636 Published online by Cambridge University Press

The data are reduced as soon as they are received in Austin and a 'quick-look' analysis is performed, usually involving the calculation of Fourier Transforms. The PI's use the 'quick-look' analysis to evaluate the scientific return and debate the ongoing prioritization for each target. After the campaign is over, each PI receives a complete set of raw data to be rereduced and analyzed at a more leisurely pace. The PI is also expected to write the paper describing the scientific results obtained. All participants in the campaign are included as co-authors resulting in papers with 30 authors or more (e.g. Winget et al. 1991). Such a large list of co-authors is less than satisfactory from the point of view of many of the co-authors: authorities in their home institutions/countries evaluating their research productivity regard their contribution to such publications as far less significant than they were. From the point of view of the collaborators, the contribution of each member of the WET is vital for the success of the collaboration.

3. Results

3.1 WET History

Table 1 gives an observing record for the WET: most of the objects observed so far are white dwarf or pre-white dwarf pulsators (DAV, DBV, DOV). A few binaries showing oscillations have been observed and the Delta Scuti star observed in 1992 Feb was a serendipitous discovery: it was the 2nd channel/guide star chosen for 1H0857 and was not known to be variable prior to the campaign. However, it quickly revealed its pulsations soon after being observed for the first time. It is apparent that usually an interval of ~12-18 months elapses between the WET run and the production of the paper reporting the results.

3.2 Highlights

Undoubtedly the most spectacular success from the results obtained so far came from the observations of the pre-white dwarf PG1159-035 in 1990 March. These have been fully discussed in Winget et al. 1991 (hereafter W91), but it is worth emphasizing some features of the results which illustrate the power of WET to obtain new science. 264 hr of data were obtained during 12 nights giving over 90% coverage (Fig. 4 of NWCHH). This virtual elimination of aliasing from the power spectrum (Fig. 5 of NWCHH) enabled the number of reliably determined frequencies to increase from ~10, as found in previous studies, to more than 100 (see W91 and references therein). As pointed out by Nather (private communication), an improvement in measurement by a factor of 10 is not merely an improvement in precision, it enables a new 'kind' of science to be done. This potential was fully realized in the study of PG1159-035. Of the 125 frequencies obtained from the power spectrum, 121 were identified with l=1 or 2, non-radial g-modes. As described in W91, this identification could be verified using several independent checks, and enabled: (i) the mass to be determined to 3 significant digits; (ii) the rotation period of the star to be measured to similar accuracy; (iii) an upper limit to the magnetic field of 6 kG to be established; (iv) the pulsation and rotation axes to be determined to be collinear. Perhaps the most exciting seismological result from the study was the detection of a chemically-stratified envelope surrounding the stellar core, as expected from theory. This insight was gleaned from the slight departure of the frequencies in the power spectrum of PG1159-035 from the equal-period spacing expected from asymptotic theory applied to chemically- homogeneous envelopes. Clearly, impressive results can be expected from the analysis of WET data for other compact pulsators. Indeed, the analysis of the DBV star GD358 just being completed at the time of writing (September 1992) is bearing out this expectation (Winget et al., in preparation).

4. Factors affecting data quality

As expected for almost all astronomical targets, brightness is a major consideration in determining WET data quality. Fig. 7 of NWCHH provides a vivid illustration of the difference in signal-to-noise provided by a ~4-m compared to a ~1-m telescope for signals at the limit of detection. The inclusion of 4-m telescopes in the WET network is rare. Nevertheless, one of the less obvious advantages of WET is that it typically collects a very large number of photons on high priority targets resulting in much improved signal-to-noise ratios compared to data sets obtained by 1-2 m class telescopes at a single site.

Essential to the goal of ensuring no gaps in the data is a degree of overlap in coverage between sites at different longitudes. This overlap often occurs for large airmasses at both sites. Fig. 6 of NWCHH shows an example of the light curve of PG1159-035 observed by 3 sites simultaneously. The excellent agreement is apparent.

For the study of multi-periodic variable stars, the most important consideration for data quality is the elimination of all gaps in the data set. A number of factors have an important bearing on the viability of this goal, of which the completeness and redundancy of the longitude coverage is perhaps the most important. In the first WET run in 1988 March, there was no site in the network between Siding Spring, Australia and Sutherland, South Africa which resulted in significant 1 cycle per day aliases in the spectral window of even the highest priority target, PG1346+082. Even though the analysis of this star is still in progress, these aliases, combined with the complexity of its power spectrum (as apparent in Fig. 7 of Nather 1989) may defeat the attempt to decipher the frequency structure of this star.

As can be seen from the WET site map in NWCHH (Fig. 2), as updated above, there is significant redundancy for longitudes of Europe/Africa, and N. and S. America. But the longitudes from 60°E to 120°W include only 3 sites: Kavalur (India), Siding Spring (Australia) and Mauna Kea (Hawaii). This necessarily means that complete coverage is possible at any one time for only 1 target. Limited coverage of lower priority targets can, however, be useful: just three 2-hr light curves from Australia were sufficient to resolve the aliasing ambiguity in the 90-min photometric period of CP Pup during the first WET run (O'Donoghue et al. 1989). Nevertheless, such limited coverage is unlikely to produce 'ground-breaking' science of the kind demonstrated in the study of PG1159-035.

Another important consideration is the declination of the target. Obtaining complete coverage for objects far from the celestial equator is difficult because they are accessible only from sites in the corresponding hemisphere. This is especially true for southern objects because of the more restricted spread in longitude of southern hemisphere sites.

Finally, experience from the 7 WET runs to date has shown that the redundancy in longitude in the network has prevented bad weather from spoiling the coverage obtained for the highest priority target. WET weather is better than weather at any one site!

5. Resources required to run the WET

5.1 Manpower

There is a large administrative overhead in running the WET. Plans for each campaign have to be made well over a year before the campaign. Once the targets proposed by the PI's have been accepted, the PI's are expected to provide a 'generic' observing proposal to be supplied to each member of the WET collaboration who is going to apply for observing time. Members of the Texas group co-ordinate proposals for most of the common user observatories (e.g. La Palma, CTIO, Kitt Peak); other collaborators apply for time to their 'home' observatories. These applications have to be sent in before a very wide variety of deadlines. For example, observing time for the WET campaign of 1992 September had to be requested by 1991 Oct 15 for ESO and 1992 July 24 at Siding Spring, a difference of 9 months.

During the WET campaign, in addition to the PI's, the WET control centre in Austin is manned by at least 6 people (usually more) who work 8-hr shifts. These 'workers' phone each site daily to receive weather reports and assign targets, reduce the data that are sent back from each site, and perform the 'quick-look' analysis.

Each observing site is manned by at least one, and often two observers. Again, members of the Texas group usually travel to the common-user observatories accompanied by the 3-channel portable photometers mentioned above. The remaining observers are provided by members of the WET collaboration resident near the other observatories, using either 3-channel or 2-channel photometers obtained from the Texas group, or equivalent devices constructed at their home institutions. An important task at the end of each observing session is to communicate the data back to Austin for the 'quick-look' analysis. Not all sites enjoy this capability.

5.2 Money

The cost of running WET is very modest, both when considered against the scientific return, and when compared with other comparable networks (e.g. GONG). Perhaps the simplest way of reporting costs is to list the impact on the Texas NSF WET grant of each WET run. The cost of travel and maintenance for the two PI's to be present in Austin ($3500), 1 observer at Siding Spring ($3000), 2 observers at La Palma ($5500), 1 observer in Hawaii ($2300), 1 observer at CTIO ($2500) and 2 observers on two telescopes at McDonald ($2200) totals $19000. This accounting does not include the costs to collaborators at their 'home' observatories: no estimates of these costs are available but they are likely to be significantly less than the above. Finally, it the goal of WET to equip each site with identical instrumentation. The cost of a 3-channel, portable photometer from Texas is $20000. Funding is being sought to provide such an instrument to those currently lacking it.

6. Conclusion

The WET is a working global network of telescopes of modest aperture which operates twice per year on average. From the 7 campaigns that have been conducted, 5 papers in refereed journals have been published along with some progress reports in conference proceedings. Analyses of other data sets are at an advanced stage and should soon be in preprint form. Although administratively onerous and manpower intensive, the WET network requires very modest financing. The study of PG1159-035 has demonstrated that WET is capable of increasing the number of frequencies measurable in the power spectra of compact pulsators from ~10 to more than 100. With the exception of the Sun, this improvement in high-resolution power spectroscopy of variable stars is unprecedented. The resulting asteroseismological capability has opened up new horizons in the exploration of the interiors of pulsating stars.

Acknowledgements

We gratefully acknowledge the contributions of all members of the WET collaboration, especially Prof. R.E. Nather who provided useful ideas and information for this paper.

References:

Nather, R.E., 1989, in Int. Astr. Un. Coll. 114: White Dwarfs, ed. G. Wegner, Springer Verlag, Berlin, Heidelberg and New York, p109.

Nather, R.E., 1992, in Proceedings of the 8th Europoean Workshop on White Dwarfs, ed. M. Barstow, Kluwer, Dordrecht, in press.

Nather, R.E., Winget, D.E., Clemens, J.C., Hansen, C.J., Hine, B.P., 1990, Astrophys. J., 361, 309 (NWCHH).

O'Donoghue, D., Warner, B., Wargau, W., Grauer, A.D., 1989, Mon. Not. R. astr. Soc., 240, 41.

Winget, D.E., Nather, R.E., Clemens, J.C., Provencal, J., Kleinman, S.J., Bradley, P.A., Wood, M.A., Claver, C.F., Frueh, M.L., Grauer, A.D., Hine, B.P., Hansen, C.J., Fontaine, G., Achilleos, N., Wickramasinghe, D.T., Marar, T.M.K., Seetha, S., Ashoka, B.N., O'Donoghue, D., Warner, B., Kurtz, D.W., Buckley, D.A., Brickhill, J., Vauclair, G., Dolez, N., Chevreton, M., Barstow, M.A., Solheim, J.E., Kanaan, A., Kepler, S.O., Henry G.W., Kawaler, S.D., 1991, Astrophys. J., 378, 326 (W91).

Discussion

C.L. Sterken: *You analyse the data, and publish the scientific results of your analysis, but what do you do with the data? Do you publish these data* in extenso *or do you submit to the data archives?*

O'Donoghue: The data enter the public domain after 1-2 years. Manpower shortage prevents the data from being sent to an archive like Strasbourg.

J. Baruch: *The World Telescope is a trivial result of the GNAT programme. Many continuous observing programmes will be viable. GNAT will also be suitable for observing the active galactic nuclei and searching for chaotic behaviour.*

O'Donoghue: When do you expect to get data?

M. Breger: *The problem is that some observers need publications in which they are first authors. In the Delta Scuti Network the problem was addressed by observers publishing their own data in their national publications. An example can be found in China. The main paper with the astrophysical analyses is still published in the major journal with everybody as co-author.*

R.M. Genet: *A long list of co-authors that are observers can be a problem. In the main, robotic telescopes do not require robotic co-authorship. Presumably this would change if robots took over the world.*

W. Tobin: *Does WET have enough redundancy? Doesn't having a second priority target complicate administration by requiring global real-time decisions as to which star to observe, and also degrade the window function you finally obtain?*

O'Donoghue: No a compromise on achieving maximum coverage on the highest priority target is made. The first WET campaigns have gaps in longitude coverage.

D.L. Crawford: *Those interested in these issues should also be aware of the excellent work done by the Global Oscillation Network Group (GONG) for solar research and its potential relative to networked astronomy.*