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MUSINGS ON THE WHOLE EARTH TELESCOPE

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Abstract. The paper describes the Whole Earth Telescope project history, present policies and future prospects. A list of all observing campaigns to date is given.

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1. WET origins

The Whole Earth Telescope (WET) observing network had its origin in frustration: our inability to resolve, from a single site, the complex pulsations we were able to observe in the variable white dwarf stars. For over a decade we tried to merge single-site observations, taken on successive nights, into a stream of data long enough to resolve them; the gaps in the data ultimately defeated any attempt at detailed analysis by introducing aliases - spectral leakage - into the power spectra of the objects. Observations from two different longitudes helped in a few cases, but it became clear that all of the longitudes on the planet had to be represented, if we were to make any real progress. The potential scientific rewards were very great: if we could resolve the individual pulsation frequencies and identify them according to their quantized index values, we could begin to construct, for the first time, detailed models of their interiors that matched the real stars.

This is old stuff to those present at this meeting, but I want to remind us all that the WET organization was formed with a basic scientific goal in mind, and its successes (or failures) as an organization should not be allowed to divert us from that goal. We could have taken quite a different approach to this problem, as others have in the past and are doing now.

Table 1. The Whole Earth Telescope campaigns

Run	Target	Type	PI	Status
XCOV1 Mar 88	PG 1346+082	IBWD	Winget/ Provencal	In Prep. (Thesis)
	V803 Cen	IBWD	O'Donoghue	Published
XCOV2	G 29-38	DAV	Winget	Published
Nov 88	V471 Tau	ICBS	Clemens	Published
XCOV3 Mar 89	PG 1159-035	DOV	Winget	Published
XCOV4 Mar 90	AM CVn	IBWD	Solheim/ Provencal	In Prep. (Thesis)
	G 117-B15A	DAV	Kepler	Published
XCOV5	GD 358	DBV	Winget	In Press
May 90	GD 165	DAV	Bergeron	In Press
	HD 166473	ROAp*	Kurtz	Failure
XCOV6	PG 1707+427	DOV	Grauer	In analysis
May 91	GD 154	DAV	Vauclair	In analysis
XCOV7	1H 0857	CV	Buckley	In analysis
Feb 92	PG 1115	DBV	Barstow/ Clemens	In analysis
	G 226-29	DAV	Kepler	In analysis
	WET 0856	δ Scuti	Breger/ Handler	In analysis
XCOV8	PG 2131+066	DOV	Kawaler	In analysis
Sep 92	G 185-32	DAV	Moskalik	In analysis
XCOV9	PG 1159-035	DOV	Winget	In analysis
Mar 93	FG Vir	δ Scuti	Breger	In analysis
	RXJ 2117+066	DOV	Vauclair	In analysis

* Rapidly oscillating Ap star.

We could, for example, have organized ourselves along the lines of the GONG project, whose goal is to make similar kinds of observations of the sun. They have garnered considerable funding from the U.S. National Science Foundation, and are now busily engaged in designing specialized telescopes and instruments for global observations, along with extensive computer simulations of their expected results. They have been at work for several years and will be for several more, before their network is installed and the first helioseismological data obtained. In contrast, the WET, started at about the same time, has been gathering, analyzing and publishing asteroseismological results since 1988 (Table 1). We have the same basic goal as the GONG, but we have approached it very differently. I am prepared to defend our approach, warts and all, based on our scientific returns.

Rather than approaching governments, or even observatory directors, to solicit cooperative observations, we approached individual astronomers and tried to interest them in the science we could do if we worked together. This yielded quick results compared with other possible strategies, and has largely shaped the way WET works – or fails to work – today. We depend on our colleagues at the different longitudes around the planet to approach their own local organizations to get the necessary telescope time, based on the scientific descriptions provided by the Principal Investigator (P.I.) for a particular target. We send Texas observers to those sites where we do not have interested colleagues, and which allow telescope access to visitors, and these travel costs are a large part of our budget. We basically use what is already in place: working telescopes around the planet at existing observatories, instead of trying to build our own.

This approach is a mixed blessing. All of our collaborators have experienced the shortcomings: lack of communication, missed deadlines, late (or no) responses to urgent messages, etc. Guilty as charged. Unfortunately we at Texas tend to concentrate primarily on the science, rather than on the smooth operation of an organization. The alternative, in which the WET director spends full time running the show and has no time for the science, is not one I am willing to embrace. Perhaps someone else could do the job better, and I would be happy to have them do so, providing the basic scientific returns are not compromised.

On the positive side, of course, is the science that has already come out of our enterprise, and which will come out in the future. We have established that the asteroseismology of white dwarf stars is both practical and fruitful. As we explore the interior structure of white dwarfs, we examine the remnants of the nuclear fusion that took place when they were main sequence stars, and we can begin to address basic questions about the evolution of stars and of our galaxy that we can approach in no other way. The science we do is unique and valuable. I am all in favor of organizational improvements, so long as the science we produce is not weakened or diluted. I am probably the wrong person to initiate them, however.

2. WET policies

We have so far operated in a very open way, promoting the complete and unrestricted sharing of what is now called "intellectual property" – computer programs, equipment designs, algorithms, techniques and data. We have adopted this policy at a time when there seems to be a strong trend toward a much more proprietary view of these things, particularly among those involved in space-based astronomy and its astonishing cost per photon, and I hope our success demonstrates that restrictive and secretive policies are not needed. I consider them harmful.

As a recent example, the optical spectrum of a ROSAT source was described at the Leicester conference on white dwarf stars, which suggested it was a PG 1159 star, and, therefore, might be variable. We were able to identify it on the POSS plates by its color, given the rough coordinates embedded in its name, and one of our students observed it and found that it showed coherent pulsations in its light curve. We immediately sent out an IAU telegram to call it to the attention of any other observers who might be interested in it, and offered to provide finding charts on request. We were immediately criticized for this action by Christian Motch, who felt that we should have first consulted him, since he was involved in the original ROSAT identification, and should have obtained his permission to observe it – he also hinted that an offer of collaboration would have been appropriate.

I rejected his position then and I reject it now. If scientific exploration is to be conducted on a proprietary basis, then it will become barren and ultimately useless to our society, in my view. I strongly urge that the WET collaboration continues to be completely open in sharing whatever we have, not only among ourselves but with the astronomical community at large, Christian Motch included. We have a policy of limited access only to WET data that are actively under analysis by the P.I., and we have placed a time limit even on that (18 months originally, extended to 2 years as a response to experience). After that time the data become public domain information, and we are working toward making them readily available, in usable form, to anyone interested. To this end I have established access to our computer workstation via anonymous FTP on the Internet, so anyone can access our public area, and can download anything they find there. It is not very well organized yet (surprise!) but it presently contains manuscripts (in postscript format) and the latest versions of our data acquisition program (Quilt 9) and our new data reduction program, QED. The scientific justification for our next WET run, in the first semester 1994, is also in residence. Suggestions and contributions are welcome.

Is such a policy dangerous to us? I don't think so, but we may want to think about how we deal with non-reciprocity - people who take everything we offer but offer nothing in return. I think that would be a suitable topic for discussion at this meeting. We might also want to address the possibility of abuse - someone with access to a P.I.'s data that publishes it without his knowledge or permission before the 2 years have elapsed, but this strikes me as borrowing trouble. Perhaps we should wait to deal with such a problem should it ever arise; it never has.

The only written policy we now have is one I wrote several years ago, and I attach a copy of it as an appendix. We can discuss whether it needs to be expanded, if it does, but I strongly urge that whatever policies we adopt for the WET be short, simple and easy to implement and understand. Bureaucratic rules and procedures will kill us if we let them.

3. WET today

Our joint work has been noticed: our paper on the DOV PG 1159–035 was summarized in Science magazine as "...a stunning series of observations..." and news articles have appeared in Nature, Scientific American, Equinox, and others. While we don't spend any time soliciting such recognition, it can only help us when it appears, since we depend on granting agencies for the funds we need to keep the WET in operation. In any event, I have always felt that astronomers owe the public an understandable explanation of what we find out, since they are footing the bill, either directly or indirectly. Members of time allocation committees may also look more kindly on our proposals, if they know we are putting the telescope time to good use.

The experience we have gained in operating the WET for a total of nine global runs to date has been rewarding, if not always painless. We have learned where the scientific returns are great and where they are not, and all of our runs have not been an unqualified success. I hope we can learn from our mistakes. As an example, the WET spent time observing the ROAp star HD 166473 which was not successful, and that failure taught us some lessons:

1. The P.I. should always be present in the WET control center during a run; if this is not possible, a local substitute should take on the responsibility of targeting decisions, and should oversee the quick-look data analysis to be sure the data are of adequate quality, at least.
2. Observing procedures must be laid out in detail so each observer can follow them, and the quick-look data reductions must confirm they are being followed, with corrective calls to any observer who deviates.
3. We cannot expect to cover more than two targets during any WET run well enough to overcome aliases from data gaps, and we do better with one than with two. We should discuss the relative merits of overlapping data on a single target, vs. observing two targets, when we have longitude redundancy.

In the case of HD 166473, we violated all three of these principles.

On the positive side, we have learned how important it is to have a continuous measurement of sky brightness in a separate channel, and we have designed and built two units that replace the channel one (target star) detector with a pair of photomultipliers (PMT) so one of them can monitor the sky. This design has the advantage that older two-channel photometers can be upgraded to three channels fairly simply and cheaply, just by changing the Channel 1 detector assembly. Three channel data improve our measurement accuracy for pulsation amplitudes by about 5 times, and improve the overall signal-to-noise ratio in the power spectrum by a similar factor for low frequencies.

We have also improved our data reduction and analysis techniques: the data reduction program QED, successor to DRED, was designed as a better match to the reduction procedures we developed as a result of doing a lot of them, and has the reduction sequence built into its logic. A user can add or remove particular operations, but for most of the data the standard sequence is quite adequate and does the job more easily. Any sequence of operations can be reversed, so one can try out a few changes to the standard sequence to see if they work better, without the need to start over if they do not. A crude but effective procedure for removing the effects of atmospheric extinction lets us work to much lower frequencies than polynomial fitting allowed, although a better extinction model might help even more.

Most important of all, though, is the improvement in our scientific insight into the pulsation processes that actually take place in real stars. As we examine more of them we can identify their common behavior with more assurance, so their differences can begin to tell us about them as individuals. The physics is tractable, if sometimes initially obscure. A good example is GD 358, which I will describe in more detail in another presentation. The presence of triplets suggested $\ell = 1$ as the pulsation degree, yet the frequency (m) splitting was not constant from one triplet to the next, as it had been in PG 1159, and there were more complex patterns evident at high frequencies. These effects baffled us for some time, but we now have a consistent and convincing explanation for all of them – an explanation which leads us in a new direction concerning the origin of the DB variables. Later.

Finally, I would like to suggest we introduce a new term to describe the kind of measurements we make. Time-series photometry is the method, but that term does not suggest the rich and varied kinds of information we now routinely extract from the power spectrum of the variability we measure. We could describe our process better, I think, if we call it "temporal spectroscopy." There are several reasons for this suggestion: if we call our measurements "time-series photometry" most people think they know what we do, and what information we get from it. Most of them are wrong. Many are startled to hear we can measure the mass of a (single, variable) white dwarf star to an accuracy of about 1%, that we can determine its rotation properties (including differential rotation, if present), that we can detect the presence of magnetic fields of a few hundred Gauss only, that we can explore the layers below the stellar photosphere and measure their thicknesses, and that we can determine the star's absolute luminosity, and hence its distance, much farther away than parallax measurements allow, but with comparable or greater precision. This is photometry??

We might also avoid a wide-spread prejudice that relegates photometrists to the smaller telescopes because "...they can just integrate a little longer." Not so if the star sets the time-scale, as ours do. As "temporal spectroscopists" we might find the playing field a bit more level. At the very least, by introducing a new term, we signal that we are not making conventional measurements, and we might have some hope that we would not be pre-judged incorrectly. I think this happens a lot now, and we may be able to minimize it.

4. WET tomorrow

One of our strengths is that we can do important science with modest-sized telescopes, but as we exhaust the brightest white dwarfs, we will need larger telescopes to explore fainter ones. We have had occasional access to telescopes larger than 3 meters, and frequent access to those larger than 2 meters, but most of our network is made up of telescopes of 1 meter aperture or smaller. We can still make good use of them to study the changes we observe in our targets with timescales of a few weeks, months or years, and there is much unexplored physics there. But eventually we will need bigger glass, and I know of no way to get it that works better than being rated first in Time Allocation Committee's rankings. I think we'll get to use the larger telescopes on the planet, if we do our jobs well, and show that what we do is really worth doing. It may not be cosmology, but it's good stuff.

I keep looking into the possibility of better detectors (CCDs, mostly) in the hopes that we can improve our instrumental sensitivity, and in effect turn our 1 meter telescopes onto 2 or 3 meter telescope equivalents. My most recent explorations of available detector characteristics suggest there is still little to be gained, but they are getting better. Right now I would rate PMT and CCD detectors about equal: the CCDs have better quantum efficiencies in the red, but not in the UV, where most of our photons are; PMTs still count single photons while CCDs do not, so their noise properties are somewhat better (this is where CCDs are rapidly catching up) and a PMT instrument is still far simpler to build, maintain and transport than any CCD system I can envision. Smaller CCDs (with faster readout) are in the works, so things could change quickly. We must be prepared to change with them.

I believe the WET network is approaching maturity: we now have access to all of the longitudes on the planet, lacking only a northern-hemisphere equivalent of Australia and New Zealand, so I don't see a need to add yet more sites. Membership is voluntary, of course, and we may lose a few collaborators in the future and need to replace them, but I don't think we should try to get any bigger. More sites make the administration tougher without adding very much to the science. Perhaps our greatest need for the future is a stable source of funding, one we can count on to keep the network in productive operation, without the need to drop everything periodically and write proposals to funding agencies. And maybe the horse will talk.

Appendix 1: Whole Earth Telescope policies (July 18, 1989)

1.1. Author qualification

In general, we feel that anyone who contributes to the science presented in a paper should be a co-author. We would normally expect to include anyone directly involved in gathering the data, coordinating the observations, analyzing the data or writing the final paper. There is one special case we feel must be addressed: what happens, if someone applies and receives telescope time, agrees to observe a designated WET target, but fails to get data because of cloud, or other uncontrollable circumstance? By our current policy they would be included in the author list; otherwise, we would be in the awkward position of trying to assess how much data would constitute a "contribution" and we'd like to avoid that kind of decision.

1.2. Author order

There is probably no universally acceptable process for choosing the order in which names appear on a many-author paper. We expect the P.I. on an object to either be first author or designate who will be; beyond that, the matter becomes fairly arbitrary, and we can only hope to be fair over time by encouraging different people to accept P.I. responsibility. Our current policy, described by one colleague as "...no worse than any other" is to group the authors according to their affiliation (with an observatory, university or research organization), starting with the P.I. and his group, and proceeding around the globe from there in the direction of advancing astronomical twilight. We expect the senior member of each group to suggest the ordering within a group. We plan to inform readers, in a footnote, how the order of authors was chosen. If you have an alternative you feel is better, please tell us about it.

1.3. Access to the data

The data sent by electronic mail or computer disk is subjected to reduction in real time at the Texas command center, so the P.I. can make the necessary scientific decisions about coordinating further observations. Our "quick-look" facilities are limited, so we currently re-reduce all of the data a second time to weed out any discrepancies in timing or other details of the data gathering process. At this point the data are in shape to begin the scientific analysis. We solicit help in this re-reduction and in the analytical process; we will provide copies of the raw data, and of the reduction programs we use, to any collaborator requesting them. The programs are continually evolving as we learn the process, and are not of "production quality," but they are usable and we'll try to keep the current versions available and documented.

1.4. Data sharing

Any data gathered as part of a WET run remains the property of all members of the cooperative for a period of 18 months* after which time it should be placed in the public domain. During the 18 month period any cooperating member can work on it, but should not provide it to others, or publish work based on it, without first getting permission from the P.I. The time limit might be extended as a special case, proving the data are under diligent analysis, but in general the policy will be to make them public after a reasonable amount of time.

1.5. Publications

The first author on any paper should select the journal of publication. While a greater long-term benefit might derive from publishing in a single journal, we are aware that other considerations may well be more important. To encourage some small measure of uniformity, we will offer to absorb the cost of publication in the Astrophysical Journal, should the first author request it.

1.6. Becoming a P.I.

We hope to keep the P.I. assignment process informal, based primarily on a genuine scientific interest, and perhaps prior work, on a particular object. The P.I., in addition to designating the target, must provide written scientific justification for its choice, so the various members of the cooperative can justify their requests for telescope time to their local Time Allocation Committee. The P.I.

* Changed to two years at this workshop.

should also provide a technical package for each site, including finding charts, designated comparison stars, and written details of the observing procedure. For the time being we ask the P.I. to be present at the Texas command center during the run, to direct the quick-look reduction and analysis, and to assume responsibility for the complete reduction, analysis and publication of the resulting data.