SEARCHING FOR LONG DURATION RADIO TRANSIENTS WITH OVSA

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Abstract. There have been persistent claims for long duration radio transients (duration greater than 0.1 day and as long as a week). The claim arose from archival analysis of VLA blank field data by G. Bowers and colleagues. By far the most unique aspect of this class of sources is the absence of any quiescent optical counterpart. This rules out an extra-galactic origin. Ofek and colleagues suggest that these are burps from old neutron stars (sort of stellar flares but from dead neutron stars).

Here I propose night time searches with the Owens Valley Solar Array (OVSA). This system is unique for its wide band response, 1–18 GHz. I show devoting 25% of night time observations (especially during the months of May through October when the Galaxy is up) can decisively confirm or reject the existence of this new class of transients.

To realize the proposed experiment requires cooled wide band receivers (in the range 2–18 GHz), wide band feed and wide band (single baseline) cross-correlator.

Finally the symmetry of the proposed program: flares from a living star during daytime and flares from dead stars during night time would allow us to make poetic (but vacuous as usually most poetic matters tend to be) claims.

1. Owens Valley Solar Array

At the north end of the Owens Valley lies the town of Big Pine, California. It is wedged by the Sierra Nevada to the West and by the Inyo Mountains on the West. Mammoth mountain terminates the Valley to the North. The Owens River is fed by the melting snow of the Sierra Nevada. Today the River is a but a pale imitation following the plunder of water in 1913 by the LA Department of Water and Power. On the other hand, I have water in my pool.

The Owens Valley Radio Observatory was founded by the nonpareil radio astronomer John Bolton and Gordon Stanley in the late fifties. The first major facility was an East-West interferometer formed by a pair of 27.4-m telescopes. For its time it was a very powerful facility and certainly pushed the frontiers of decimeter astronomy and espcially interferometric spectroscopy of the 21-cm line (whilst Ryle and colleagues were advancing the field of meter wave astronomy). A large number of now luminaries cut their teeth on this system: B. Clark, K. Kellerman, E. Greisen and S. Shostak (PhD students) and V. Radhakrishnan, E. Fomalont and R. Ekers (young researchers).

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Let us now skip to the nineties. The Owens Valley Solar Array (OVSA) is dedicated to the sun of the Sun. OVSA consists of seven antennas: the original pair of 27-m antennas and five 1.8-m antennas that were added about a decade ago. The speciality of OVSA is the frequency agility: the array can obtain observations from 1 to 18 GHz.

2. The performance of the interferometer

We now focus only on the pair of 27-m telescopes. The separation between the telescopes is $B = 300$-m (East-West orientation). Let us assume that we can replace the existing receivers with wide-band 1–18 GHz, cooled receiver. I will make the optimistic assumption that the aperture efficiency (including the coupling of the primary to the feed horn) is $\eta = 0.5$ in the entire range. Again for lack of any specific knowledge, I will set the system temperature, $T_{\rm sys}$, to be 30 K for the entire range.

I will assume that we can process an instantaneous bandwidth, $\mathcal{B} = 1\,\text{GHz}$, anywhere in this frequency range (phase I). For phase II we will assume that we can operate the interferometer over the *entire* 1–18 GHz range.

In Table 1 I summarize the performance of this interferometer using the following formulations:

$$S_{\rm sys} = \frac{2k_BT}{\eta A_g} \tag{1}$$

$$\theta_{\rm HPBW} = 1.2\frac{\lambda}{D} \tag{2}$$

$$\sigma_S = \frac{S_{\rm sys}}{\sqrt{\mathcal{B}\tau}} \tag{3}$$

$$\theta_I = \frac{1}{2\pi}\frac{\lambda}{B}. \tag{4}$$

Here, $S_{\rm sys}$ is the system noise for a primary antenna, D is the diameter of each telescope, $A_g = \pi/4D^2$ is the geometric collecting area, $\theta_{\rm HPBW}$ is the full width at half maximum, σ_S is the rms noise (ignoring pre-factor of order unity for polarization, the use of only the cross-correlation and simplified post-fringe detection), τ is the integration time and θ_I is the position accuracy (but with lobe ambiguities) assuming SNR of fringe of only unity. The localization of any source is $\theta_{\rm HPBW}$/SNR (RA and Dec). The localization is nominally better in RA but suffer from lobe ambiguities.

3. Searches for Long Duration Transients

The areal reach is defined to be

$$\Omega_t = \frac{\pi}{4}\theta^2_{\rm HPBW}\tau \tag{5}$$

ν GHz	$T_{\rm sys}$ K	η	$S_{\rm sys}$ Jy	σ_S mJy	$\theta_{\rm HPBW}$ arcmin	θ_I arcsec	Ω_t deg^2 hr	Disk deg^2 hr	Euclidean deg^2 hr
1.0	30	0.50	289.2	0.91	45.8	32.8	1.7×10^{1}	2.0×10^{-2}	6.9×10^{-4}
3.0	30	0.50	289.2	0.91	15.3	10.9	1.8×10^{0}	3.4×10^{-2}	4.7×10^{-3}
5.0	30	0.50	289.2	0.91	9.2	6.6	6.6×10^{-1}	4.5×10^{-2}	1.2×10^{-2}
7.0	30	0.50	289.2	0.91	6.5	4.7	3.4×10^{-1}	5.3×10^{-2}	2.1×10^{-2}
9.0	30	0.50	289.2	0.91	5.1	3.6	2.0×10^{-1}	6.0×10^{-2}	3.2×10^{-2}
11.0	30	0.50	289.2	0.91	4.2	3.0	1.4×10^{-1}	6.6×10^{-2}	4.6×10^{-2}
13.0	30	0.50	289.2	0.91	3.5	2.5	9.8×10^{-2}	7.2×10^{-2}	6.2×10^{-2}
15.0	30	0.50	289.2	0.91	3.1	2.2	7.3×10^{-2}	7.7×10^{-2}	7.9×10^{-2}
17.0	30	0.50	289.2	0.91	2.7	1.9	5.7×10^{-2}	8.2×10^{-2}	9.8×10^{-2}

TABLE 1. OVRO Solar Interferometer.

where τ, the integration time, is set to 100 s. The preferred units for this quantity is degrees hour.

Ofek et al. (2009) quote the following rate of long duration transients at $b \approx 30^\circ$:

(6) $$R[S(5\text{GHz}) > 0.37\,\text{mJy}] \sim 2700\ \text{deg}^{-2}\,\text{yr}^{-1}\ \text{or}\ \mathcal{R} \sim 0.3\,\text{deg}^{-2}\,\text{hr}^{-1}.$$

We need to know something about the behavior of the source counts,

(7) $$dR/dS \propto S^n$$

where dR/dS is the number of sources in the range $[S, S + dS]$ and $n \sim -1$ (for disk distribution) and $n \sim -3/2$ (for spherical Euclidean distribution). The rate of events which are ten (or more) brighter relative to the $S_0 \sim 0.37$ mJy normalization of Equation 6 is thus reduced by

(8) $$\mathcal{F} = \left(\frac{S}{S_0}\right)^{-n}$$

or $\mathcal{F} \sim 10$ to 30.

Consider the 5-GHz band. Let us assume an allocation of 10 hours per night and 100 such nights. Then the duration of the experiment is $T_{\rm hr} = 10 \times 100$ hr. However, our 6-σ detection corresponds to 5.5 mJy. The corresponding reduction from the luminosity function is $\mathcal{F} \sim 0.17$ to 0.07. The expected number of LRTs over the duration of this experiment is

(9) $$N = \mathcal{R}T_{\rm hr}\Omega_t\mathcal{F} \sim 45\mathcal{R}\ \text{to}\ 12\mathcal{R}$$

where we have parametrized the clearly poorly determined rate as $\mathcal{R} \sim 0.3\,\text{deg}^2\,\text{hr}$. The expected trove is thus 1.2 to 4.5 even if $\mathcal{R} \sim 0.1\,\text{deg}^2\,\text{hr}$.

Ofek et al. (*ibid*) provide plausible justification for the LRTs being absorbed in the decimeter band. If so, $S(\nu) \propto \nu^\alpha$ where $\alpha = 5/2$. In Table 1 I summarize $\mathcal{F}\Omega_t$ as a function of frequency (last two columns). One can see that the discovery rate rises towards high frequency in this framework. For example, at 15 GHz, the nominal expected numbers approach two dozen.

A larger trove is expected if low latitude fields are targeted.

4. A Proposed LRT Program

OVSA equipped with cooled wide band receivers and processing capacity in the range 2–18 GHz can make great progress in the area of radio transients. The observing time requirements are about a thousand night time hours per year. The search should focus on the inner Galaxy and so the preferred observing allocations are May through October.

There are several operational issues (search standard fields versus drift scan; reference field provided by previous observations or by eVLA catalog undertaken in advance of the proposed program). In any case, this memo outlines a juicy case for OVSA doing some interesting stellar astronomy when the Sun goes to sleep. Even in the eVLA era the wide band of OVSA will make the instrument unique.

The poor localization of OVSA can be compensated by immediate observations of suspect candidates by eVLA. After all the analysis of a simple single baseline interferometer is not all that arduous nor time consuming.

Finally this will be an excellent thesis topic. Indeed, if I were young all over again I would do this project. The student will learn everything about interferometry and will have to write her or his own analysis code. Finally, the student may make a great discovery – a simple way to identify the almost dead stars in our Galaxy.