A high time resolution transient explorer instrument for Keck

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We propose a dirt-cheap, rugged, high time resolution, optical/near-infrared (single-pulse-counting), instrument, simple enough to be run by observing staff, to be resident at a Keck focus (or mountable within a few minutes time), in order to make target-of-opportunity (TOO) observations of transients. It will split the spectrum with a dichroic, sending the reflected, shorter wavelengths (and ~10% of longer wavelengths) to a CCD acquisition camera, and will be put in use ASAP, so that Swift will still be operating during this instrument's lifetime at Keck. We expect this instrument to be eventually and permanently replaced by another with a more versatile, fully infrared-capable MKID camera, at a time when it can be similarly and routinely inserted into a focus and run by observing staff. The main type of optical/near-infrared transient to be observed with this instrument will be gamma-ray-burst afterglows, which are almost certainly 100% pulsed and likely to be the cosmology lamppost in this century, as well as a window into the heart of supernovae (SNe) and neutron star structure.

Gamma-ray-burst afterglows (AGs) *have* been observed over the last 17 years, but *never* at high time resolution, and typically about a million times too slow (~3 min – at best 0.1 s, still 100s of times to slow) to detect them as the optical/near-infrared pulsars that they likely are. One of the reasons for this is that, like their parent GRBs, AGs appear to be more luminous at distance than nearby, assuming an inverse square law.[1,2] AGs also always show polarization consistent with the phase-mean level of pulsars. GRBs themselves may show an inverted distance law due to a linear, accelerating, supraluminal excitation (the jet accelerating through the sound barrier), due to gamma-rays scattering within the volume source of polar ejecta surrounding a core-merged SN progenitor. The inverted distance law for the much more persistent AGs can only be due to the circulating, supraluminal excitation of a pulsar.[3] The ~500 pulsars in the Parkes Multibeam sample, whose pulse profiles consist of only a single sharp peak, show a perfect 1/distance law (Fig. 1), as discussed in Ref. (3).

Selected because of their 1/distance law (but only for two parallel, rotation-axis-centered circles on the sky), pulsars are likely to be the first things visible since the CMB at the time of recombination, with the underlying SN never visible. Two types of SN exist, one due to a single, massive star burning its interior into iron, and the second due to the merger of two C-O cores within a common envelope. The rotational rates at birth for these differ by an order of magnitude, the first near 50 Hz, and the second near 500 Hz, so the supraluminal, circular dynamics for these will differ by this same factor. In the present epoch, the second type (SN 1987A) is likely to be 100 times more numerous than the first (SNe 2006gy and 2007bi).

Because there is always too much angular momentum in the two-core merger SN, we expect its initial pulsar rotation frequency to be a constant near 500 Hz, and hence can determine the redshift of the pulsar, once calibrated against pulsars in closer SNe with detectable host galaxies. Figure 2 shows a large gap in population extending to just below 500 Hz, lending support to this

conjecture. The population down to 380 Hz is seeded by these pulsars spinning down, while that below this gap is seeded by pulsars slowed by high accretion rate, prior to spinning up a bit when that rate eventually drops.[3] The few above 500 Hz are likely from those born near 500 Hz spinning up. If P_0/P represent the initial (~2 ms rest frame)/measured pulse periods, then the redshift, z, is $P/P_0 - 1$. No emission lines will be observed in AGs because the recombination times will have to be shorter than a millisecond, and we can't see into such stuff. Absorption lines in the SN material will be smeared out due to mildly relativistic velocities, but the AG can backlight the Lyman α forest. Eventually, with a high-time resolution spectrograph, one can measure the difference in redshift, between the AG and the first galaxies, in one observation.

In the era since Swift was launched (2005-) there are typically eight triggers (GRBs) per month, with half of these producing afterglows. On average, though, only one afterglow occurs, with a visual magnitude (m_V or V) < 16.7, immediately accessible to your telescope in the current observing night, every 60 nights. The AG intensity typically diminishes as 1/T, where T is the time since the GRB, making a high-time-resolution observation of an afterglow with a small telescope a heroic effort (though it was tried for a while at the Crossley 0.9-m telescope at Lick Observatory in 2008-9). With Keck, even a fainter AG can be acquired (and observed) for a much longer time after the GRB, and the TOO frequency improves by a factor of 3 or more. In addition, at least one competent investigator has proposed an instrument, in the *Swift* AO cycle, which would have been 10x as productive. Should such an instrument eventually be flown, it would mean a bright, instantly accessible GRB AG every 6 nights for almost every observatory on the planet, and nearly one fainter afterglow, accessible to larger telescopes, *every night*.

A phototube with moderate red response (Hamamatsu R7400-U – chosen due to low blue response), and a washed, 36-inch mirror, will count 1/s at V=21.9, with a B-V near 0.7, typical of GRB AGs, which translates to 1/s at V=27.2 at Keck. (With the dichroic passing the V/R/I, a GaAs photocathode would do another factor of 2 better, and extend the near-IR coverage to 900 nm.) For a V=23.2, sharply-pulsed-AG count rate of 40/s, in a 3 arc-s circular aperture, with a moonlit sky background of V=(20 mag)/arc-s^2 giving about 5300/s background, a signal-to-noise ratio of 10 (55 times mean power – easy, even with spindown trials) would show up in a Fourier transform of 5.6 minutes of data. With a 5 arc-s aperture this would take 15.4 minutes.

Never in the history of Astronomy has there been such a class of objects just waiting to be exploited for such little cost and effort. The scientific payoff includes the supernova process, pulsar birth, gamma-ray bursts, pulsar-driven SN jets which may obviate any need for dark matter, and the cosmology that all of these can yield.

1. D. A. Kann, and S. Klose, 2008AIPC.1000..337P, arXiv:0804.1980
2. D. A. Kann, S. Klose, B. Zhang, et al., "The afterglows of swift-era gamma-ray bursts II. Type I GRB versus Type II GRB optical afterglows," *ApJ Lett.*, **734**, no. 2, 96, 2011.
3. J. Middleditch, "Pulsar-Driven Jets in Supernovae, Gamma-Ray Bursts, and the Universe," *Ad. Ast.*, 898907, 2012. http://www.hindawi.com/journals/aa/2012/898907

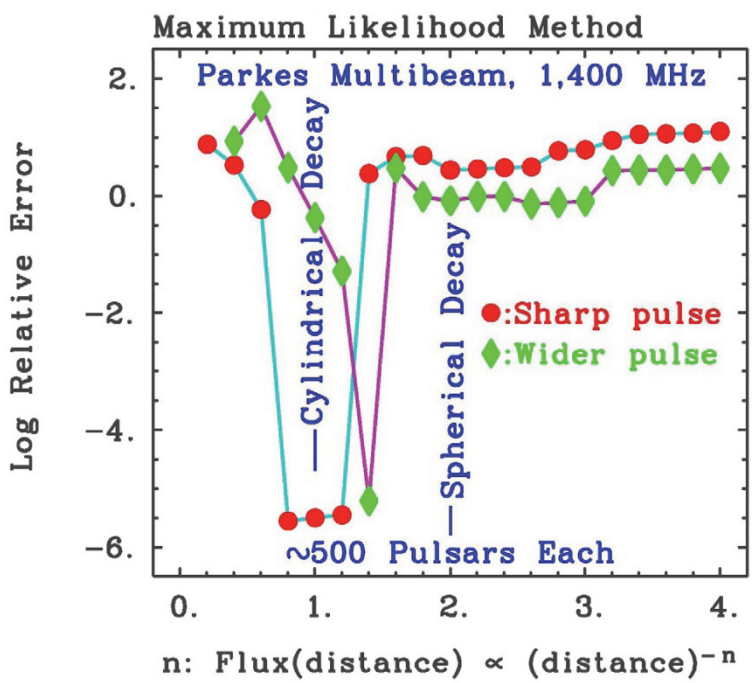

Figure 1. The distance law for ~500 pulsar samples using the method of Efstathiou, Ellis, and Peterson, 1988MNRAS.232..431E.

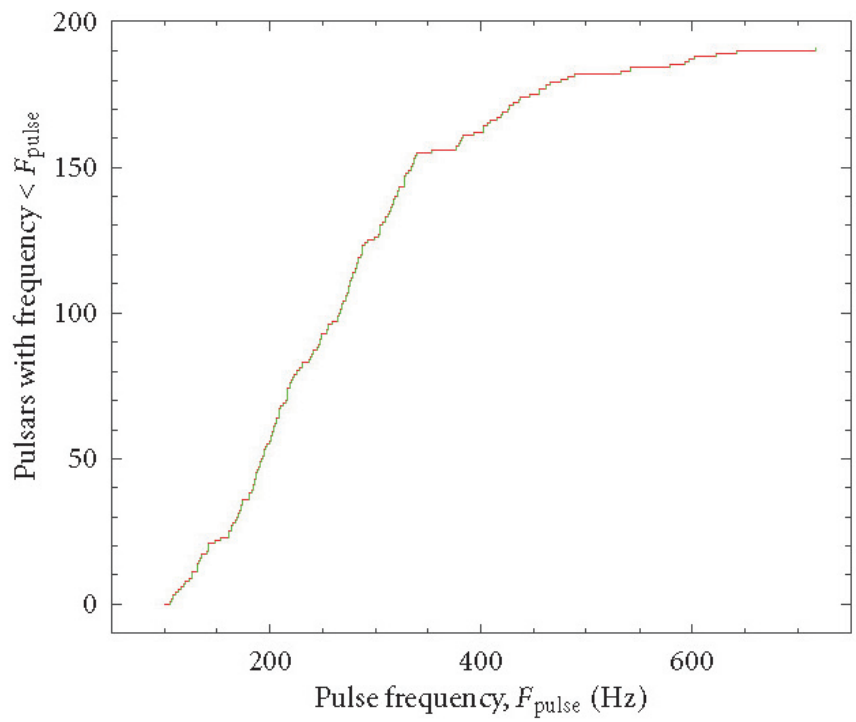

Figure 2. The cumulative distribution of pulsars from the ATNF pulsar database with spin rates greater than 100 Hz (http://www.atnf.csiro.au – R. N. Manchester, G. B. Hobbs, A. Teoh, and M. Hobbs, AJ, 129, no. 4, pp 1993-2006, 2005).