Search for the optical counterparts of *Fermi* gamma-ray pulsars

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Abstract: **The observation of pulsars at optical wavelengths provides an opportunity derive a number of important pulsar characteristics, including the energy spectrum of the emitting electrons and the geometry of the emission zone. These parameters will be vital for a comprehensive model of pulsar emission mechanisms. However, only seven pulsars have been observed to pulsate at optical wavelengths, and new ones are intrinsically faint and difficult to locate. Lacking a dedicated survey to date, optical pulsar studies have been limited a few favoured objects.**
A targeted search is underway using data available at other wavelengths to provide coordinates for possible optical pulsars. Since 2008 the Fermi satellite has detected over 50 gamma-ray pulsars, and it is probable that some of these new pulsars will have detectable pulsed optical emission. A comprehensive CCD survey of the optical emission from Fermi pulsars is currently being performed using the WHT, TNG and INT telescopes. Candidate targets have been identified for follow-up time-resolved observations with instruments such as GASP, ULTRACAM and OPTIMA.

(1) Introduction

Optically-emitting pulsars are rare; currently, only 5 "normal" pulsars and 2 anomalous X-ray pulsars (AXPs) are known to pulsate at optical wavelengths. These low numbers result in a scarcity of optical pulsar data, and this, combined with the intrinsic faintness of optical observations, makes finding new optical pulsars an important, albeit difficult, task.
Optical wavelengths, however, provide valuable data: here it is possible to measure all the Stokes parameters of polarisation of the emitted light, relating to both the spectral index of the emitting electrons and potentially the geometry of the emission region.
Through optical studies it should be possible to restrict pulsar emission models, but this will require an increase in the number of known optical emitters. This programme, allocated time by the CCI International Time Programme, surveyed the brightest northern hemisphere *Fermi*-identified pulsars with no known optical counterpart.

(2) New optical pulsars: following *Fermi*

An approach that is proving promising is to use the data available at other wavelengths to provide coordinates for possible optical pulsar targets. The *Fermi* gamma-ray satellite detected its first pulsar within a month of launch, and since then many more pulsars have been detected by *Fermi* (and AGILE), increasing the number of known gamma-ray pulsars to over 60, including 10 millisecond pulsars (Abdo et al., 2010).

It is probable that some of these new gamma-ray pulsars will have detectable pulsed optical emission (Shearer & Golden, 2001). As seen in figure **??** below, the *Fermi* pulsars have similar characteristics to pulsars with known optical counterparts.

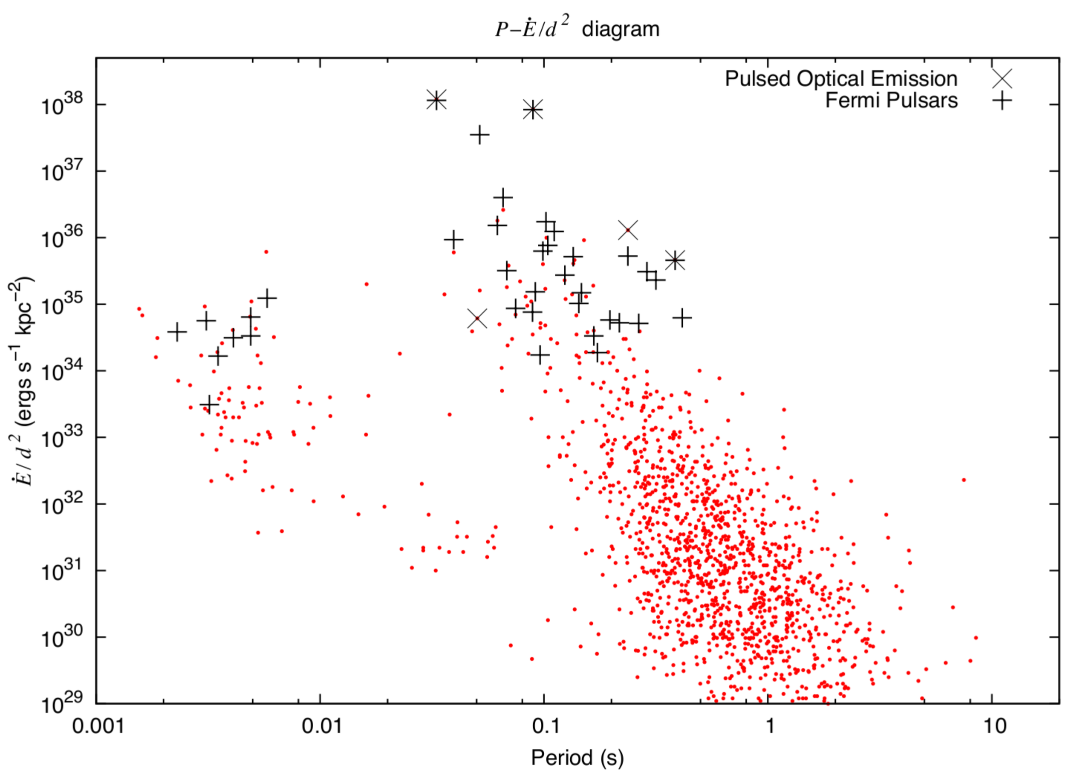

Figure 1: *The Period-Spindown Energy diagram for radio (red),* Fermi *and optical pulsars. The spindown energy has been scaled for pulsar distance.*

We are currently conducting an International Time Programme survey to observe and identify the potential optical emission from *Fermi* pulsars, using integrated CCD exposures with the INT, TNG, and NOT telescopes. The wide field-of-view of the INT/WFC makes it ideal to search for optical counterparts, given the FERMI source location accuracy of 10′ (Abdo et al. 2010.) For targets with good radio positions, we observe with TNG/Dolores or NOT/StandCam.
Further to this, we are analysing archival observations of *Fermi* coordinates made using the HST and Gemini telescopes.

(3) Survey results

We are nearing the end of our initial survey and analysis. The limiting magnitudes of our images are in the range 23.5 (INT bright time) to 26.5 (TNG dark time), with the majority in excess of 25 (figure **??**) These images give a good starting point for pulsar identification using timing.

	5-σ limiting magnitude						Upper flux density limit
Target	B	V	R	I	g′	r′	(μJy) (as Bessel et. al, 1998)
PSR J0007+7303		26.3					0.110
			25.9				0.134
PSR J0205+6449		25.1					0.332
			25.4				0.212
PSR J0357+32	26.1						0.148
			25.2				0.255
				24.1			0.554
PSR B0355+54			24.7				0.404
PSR J0613-0200	25.4						0.281
				22.9			1.67
PSR J0631+1036		23.6					1.32
			22.2				4.04
				20.6			13.9
PSR J0633+0632	26.2						0.135
		26.8					0.069
				23.7			0.800
PSR J0751+1807	26.0						0.162
		26.2					0.120
				23.1			1.39
PSR J1231.5-1410	24.9						0.445
		25.7					0.191
				19.3			46.0
PSR J1836+5925		25.5					0.230
			25.4				0.212
PSR B1952+32					24.8		0.437
						22.8	2.76
PSR J2021+4026	23.2						2.13
		23.5					1.45
			23.5				1.22

Figure 2: *Provisional 5-σ limiting magnitudes, and corresponding upper flux density limits, calculated for selected images from this survey*

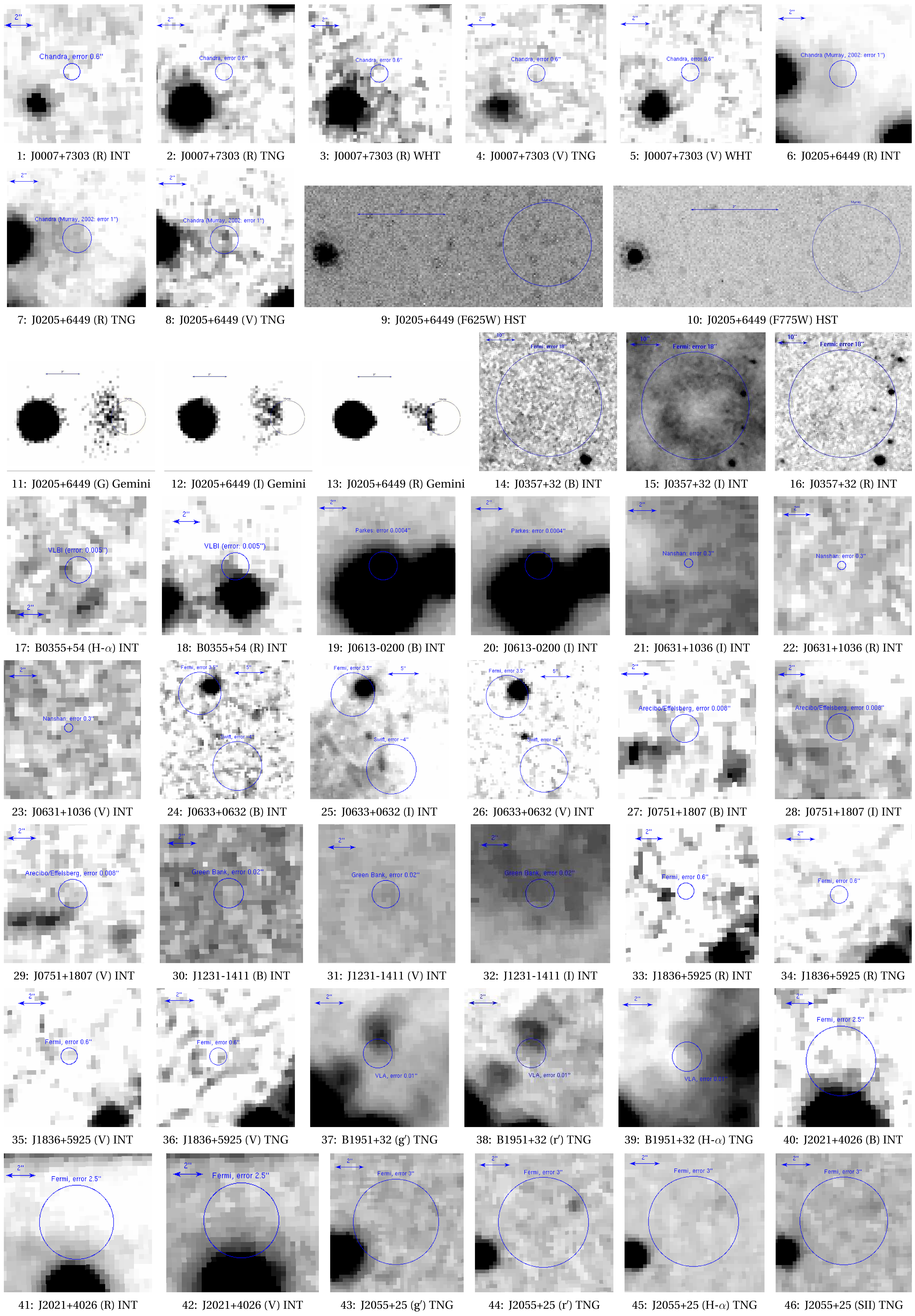

Figure 3: *Selected survey images, median-filtered. Target positions are marked, with errors if known*

(4) What's Next

The next stage will be to compare with existing X- and gamma-ray fluxes to determine F_γ/F_{opt}, either for identification or in the case of upper limits, to give limits to emission mechanism parameters (thermal, beaming angle etc.) for the particular pulsar.
Follow-up observations are planned using one of three high time resolution cameras, Optima (Kanbach et al., 2003), UltraCam (Dhillon, 2008) and GASP. We are particularly interested in polarisation measurements as these can give a unique insight into the geometry of the pulsar emission region.
FERMI targets have increasingly improved locations, through longer timing solutions and observations at other wavelengths (Ray et al., 2011.) Consequently, optical identification will be increasingly easier in the future based on these improved positions and timing observations.

References

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