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Author
Middleditch, J.

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J. Middleditch, D. Cudaback, B. Oliver,
C. Pennypacker, M.J. Lebofsky, G.H. Rieke,
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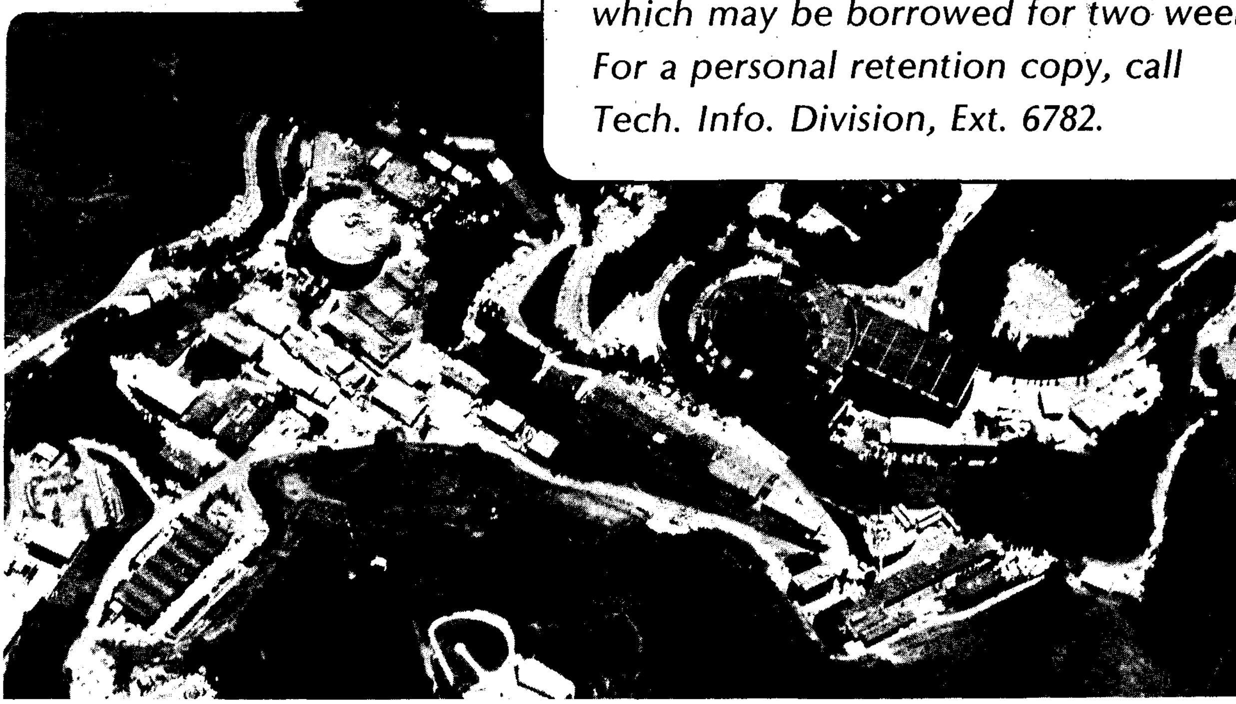

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A Search for Pulsed IR and Near-IR Emission from PSR1937+214

J. Middleditch[1], D. Cudaback[2,3], B. Oliver[3], C. Pennypacker[4]
Lawrence Berkeley Laboratory, University of California,
Berkeley, California 94720

M.J. Lebofsky, G.H. Rieke, J.T. McGraw, D. Dearborn, W. Wisniewski
Steward Observatory
University of Arizona
Tucson, Arizona 85721

R. Chini
Lunar and Planetary Laboratory
Max-Planck-Institut fur Radioastronomie
5300 Bonn 1
Auf dem Hügel 69
Federal Republic of Germany

[1]Earth and Space Sciences Division, Los Alamos National Laboratory, University of California, Los Angeles.
[2]Radio Astronomy Laboratory, University of California, Berkeley.
[3]Department of Astronomy, University of California, Berkeley.
[4]Space Sciences Laboratory, University of California, Berkeley.

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Backer et al[1,2] discovered PSR 1937+214 at radio wavelengths. Djorgovski[3] identified a candidate optical counterpart with a red sensitive CCD on a 1 meter telescope, although he found nothing on the paper prints of the Palomar Sky Survey. Manchester, Peterson and Wallace[4] at the Anglo Australian Telescope reported optical pulses from a field including Djorgovski's red candidate, although they have not confirmed this. Their 3.5" field barely included the pulsar position. Two of us (M.J.L. and G.H.R.) find a bright infrared flux of 12.3 magnitudes at 2.2 μm, an image at the plate limit on the red sensitive glass print of the Sky Survey, and CO absorption bands, all for the red candidate[5]. It is probably an ordinary red giant. We do not find statistically significant pulsations at the pulsar frequency or any harmonic up to the fourth in 6 to 8" fields including both the red candidate and the radio pulsar positions.

Table 1 gives all positions known to us. We now conclude that the position difference between the red candidate and the pulsar is real with 2.1" nominal separation, although we did not believe that at the time of the observations. For the red candidate the estimated red magnitude on the Sky Survey glass print is 20±0.5. Conventional time averaged photometry with the MMT and the 2.3-m Steward telescope give J = 14.2, H = 13.0, K = 12.3. Narrowband measurements at 2.2 and 2.33 μm give a CO index[7] of +0.19 discussed below. Independent evidence of the stellar nature of the red candidate agreeing with our results will be reported by Djorgovski and Spinrad (in preparation).

We searched for pulsations with sufficiently large diaphragms to include all positions in Table 1. Our sensitivity to pulsed light was greater than most measurements of time averaged light, so we could have detected pulsations in directions where an image is not visible. The telescopes, diaphragm apertures, wavelength bands and detectors used for pulsed light searches are: (a) Catalina 1.5-m, 6.5", unfiltered, Varian III-V; (b) Steward 2.4-m, 7.8", 1.4-2.3 μm, Hecooled InSb; (c) Mt. Hopkins MMT, 6", unfiltered, RCA 31034 GaAs. For all observations a well understood system[8] recorded the number of photomultiplier pulses or voltage to frequency converter pulses (following infrared detectors) in every 100 microsecond interval. The frequency response of the detector system used at the Steward 2.3-m was improved by reducing its preamplifier feedback until its 3db rolloff was near 1 kHz. The 2.3-m and MMT observations also used a multiscaler display synchronized by a stable frequency synthesizer at the expected apparent pulsar rate.

No significant peaks were seen in the multiscaler display as the data were collected. The recorded time series data were Fourier transformed in groups of 2^{24} or 2^{25} points and the regions of the resulting power spectra bracketing the first four harmonics of the pulsar's apparent frequency were examined to determine the significance of any peaks. Table 2 gives relative spectral power levels and limiting stellar magnitudes for 100% modulation concisely at the expected pulse frequencies. The resolution of the power spectra is 0.3 or 0.6 mHz; higher power levels are in other bins but are not considered as candidates for pulsation. The power levels are relative to noise power at nearby frequencies. The red magnitude estimates come from scaling similar measurements made on other telescopes and are uncertain by 0.5 magnitudes. The infrared data were calibrated from the measured frequency response of the detector system and by using the chopping secondary of the 2.3-m to modulate the signal from a standard star at 30 Hz. This signal was analyzed in the identical way as the pulsar observations. Magnitude limits are 90% confidence upper limits (lower limits on the magnitude scale).

The radio pulses have more power at the second harmonic than at the fundamental frequency, so it is notable that there are peaks at the second harmonic in most of the data. Nevertheless even the highest has 3% probability of being noise and the next highest has 7% probability[9]. There are not even noise peaks at the fundamental frequency.

We have no compelling evidence of pulsations from the source. Conservative upper limits for 100% sinusoidal modulation are 24 magnitudes in the band of 0.7 to 0.9 μm and 16.4 magnitudes in the band of 1.4 to 2.3 μm. These limits correspond to about a 3% modulation of the total light from the red candidate or a variability of less than 0.03 magnitudes.

We suspect that the red candidate is a reddened ordinary star falling near the position of the pulsar by chance. The commonest stars visible at great distances are K giants; their intrinsic J-K color is 0.7 magnitudes and their R-K color is 1.8 magnitudes[10]. If the red candidate is a K giant, A_v = 8 from comparison of observed and intrinsic colors. The K magnitude of the star is 11.5 after correction for extinction with A_K=0.8. A typical M_K for K giants is -2.5, which at 6.3kpc gives the observed m_K. The density of K giants[11] in the direction of the pulsar is 0.6 to 2.5 x $10^{-4}/pc^3$. If all objects within 4" of the radio position are studied for connection with the pulsar, there is a cumulative probability of 1 to 3% that a K giant of at least the required flux would be found by chance.

The two-filter CO photometric index between 2.2 and 2.33 μm is defined as follows. It is zero magnitude for unreddened AO stars with a Rayleigh-Jeans spectrum, and the index increases as the spectrum becomes steeper than that of an AO star. For a source as red as the proposed counterpart to PSR1937+214, a negative index would be expected, whereas our measured value was +0.19 $\pm$ 0.03. This value is a strong indication for the presence of CO absorption bands of a strength typical for K giants[7]. We conclude that the red candidate is probably a red giant.

We thank Jerry Hudson for calculating the pulsar ephemeris used for real time averaging and S. Djorgovski for prepublication results and many discussions. These observations were supported by the National Science Foundation under grant AST 81-14717 and performed in part under the auspices of the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics, Department of Energy under Contract Number DE-AC03-76SF00098.

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Table 1 Positions of PSR 1937+214 and red candidate (1950)

Observer	RA-19h37m28s	Dec-21°28'00"
PSR 1937+214	sec	"
Backer et al[2], VLA	.72	1.3
Becker and Helfand[6], VLA	.74	1.8
Mean radio pulsar	.73	1.5
Red candidate		
This paper, Sky Survey	.90	2.2
This paper, Steward 2.3-m	.85	3.2
Manchester et al[4], AAT 4-m	.78	3.3
Mean red candidate	.84	2.9

Table 2 Results of searches for pulsation

Date, 1982	Nov 15	Dec 03	Dec 04	Dec 08
Telescope	1.5-m	2.3-m	2.3-m	MMT
Wavelength	Red	IR	IR	Red
Int. time	50 min	42 min	30 min	52 min
	Relative power Limiting magnitude			
1st Harm.	0.2 22.	0.2 16.9	0.3 16.7	0.3 24.2
2nd Harm.	0.4 21.7	3.7 15.6	1.8 15.9	2.7 23.3
3rd Harm.	0.8 21.3	0.2 16.9	0.7 16.2	1.9 23.4
4th Harm.	0.2 22	0.3 16.7	1.6 16.	0.3 24.2

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720