# A Search for the optical counterpart to the radio emissions detected from the M9.5 dwarf BRI 0021-0214


**Salam Dulaimi[1], Richard P. Boyle[2],, Aaron Golden[1,3], Ray F. Butler[1]**

1 Centre For Astronomy, National University Of Ireland-Galway, Galway, Ireland
2 Vatican Observatory Research Group, Steward Observatory, University of Arizona, Tucson, USA
3 Armagh Observatory & Planetarium, College Hill, Armagh, UK



Kindly funded by the



## Abstract

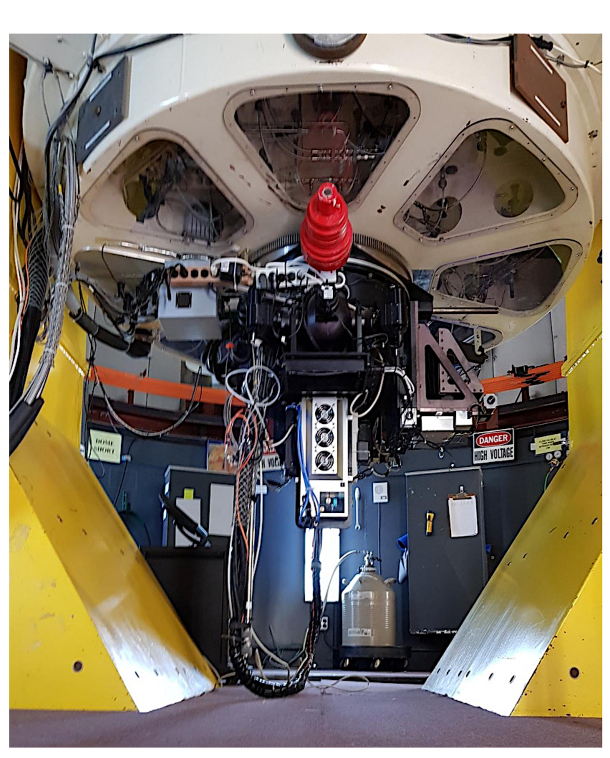
We report photometric observations of the radio-detected M9.5 dwarf BRI 0021-0214, obtained with the Galway Ultra Fast Imager (GUFI) on the 1.8m Vatican Advanced Technology Telescope (VATT) at Mt. Graham International Observatory, Arizona. In total, 19 hours of observations over a 73 day baseline were obtained. BRI 0021-0214 was shown to exhibit modulated emission with a period of 3.052 ± 0.006 hours. When combined with rotational velocity data obtained from previous work, our newly discovered rotation period gives an inclination angle of $51.6\,^{+0.3}_{-0.2}$ degrees for the rotation axis of BRI 0021-0214 relative to our line of sight. Previous studies have reported the most plausible cause for optical variability from this dwarf is a consequence of suspended co-rotating dust clouds in its atmosphere. However reports of enhanced $H_\alpha$ and intermittent coherent radio emission suggest the possibility of auroral activity in its magnetosphere. The paucity of the observed radio emission in particular is consistent with the unfavourable geometric line of sight revealed by our derived estimate of the dwarf's inclination axis.


## BRI 0021-0214

BRI 0021, an M9.5 dwarf is a rapid rotator ($v \sin i$ = 34.2 ± 1.6 km s$^{-1}$ ) (Basri and Marcy, 1995), and is located at a distance of ~11.55 pc (Basri et al., 1996; Reid et al., 1999). Many observations confirmed the presence of a magnetic field in this object by detecting extremely low levels of the Hα flare emission and radio emission. Martín et al. (2001) found I-band variability with periods of ~ 20 hrs and ~ 4.8 hrs. Harding et al. (2013) presented evidence for aperiodic variations with possible periodic variability with a period between 4 – 7 hrs, with the strongest evidence for a periodic solution of ~ 5 hours. Given both the poor quality of the previous observations of BRI 0021, we decided to implement a follow-up observation campaign for this object using GUFI/VATT over a longer baseline to definitively estimate an unambiguous rotational period for this dwarf.

## Galway Ultra-Fast Image (GUFI) mk. II

EM-CCD camera; VATT Telescope



GUFI Photometer

GUFI mk. II is a portable L3-CCD photometer which was designed specifically for variable star observations that requires second to sub-second timescales. The system uses the Andor iXon DV887 EM-CCD camera, which has a CCD97 sensor with 512 x 512 format and > 90% quantum efficiency. It offers up to 10 MHZ pixel readout rate and can operate from 32-526 frames per second, at a duty cycle approaching ~100%. It is currently stationed at the 1.8m VATT telescope in Arizona, with a FOV of 3' x 3'. We used an *I*-band (~ 7200 - 9100 Å) broadband filter for observations over the course of two separate epochs (October and December 2017), for a total of ~ 19 hours.


### References

1- Basri G., Marcy G. W., 1995, The Astronomical Journal, 109, 762.
2- Basri G., Marcy G., Oppenheimer B., Kulkari S., Nakajima T., 1996, in Cool Stars, Stellar Systems, and the Sun. p. 587.
3- Crossfield I. J., 2014, Astronomy & Astrophysics, 566, A130.
Sheehan B. J., Butler R. F., 2008, in AIP Conference Proceedings. pp 162–167.
4- Filippazzo J. C., Rice E. L., Faherty J., Cruz K. L., Van Gordon M. M.,Looper D. L., 2015, The Astrophysical Journal, 810, 158.
5- Harding L. K., Hallinan G., Boyle R. P., Golden A., Singh N., Sheehan B.,Zavala R. T., Butler R. F., 2013, The Astrophysical Journal, 779, 101.


## Results and Discussion

Fig.1

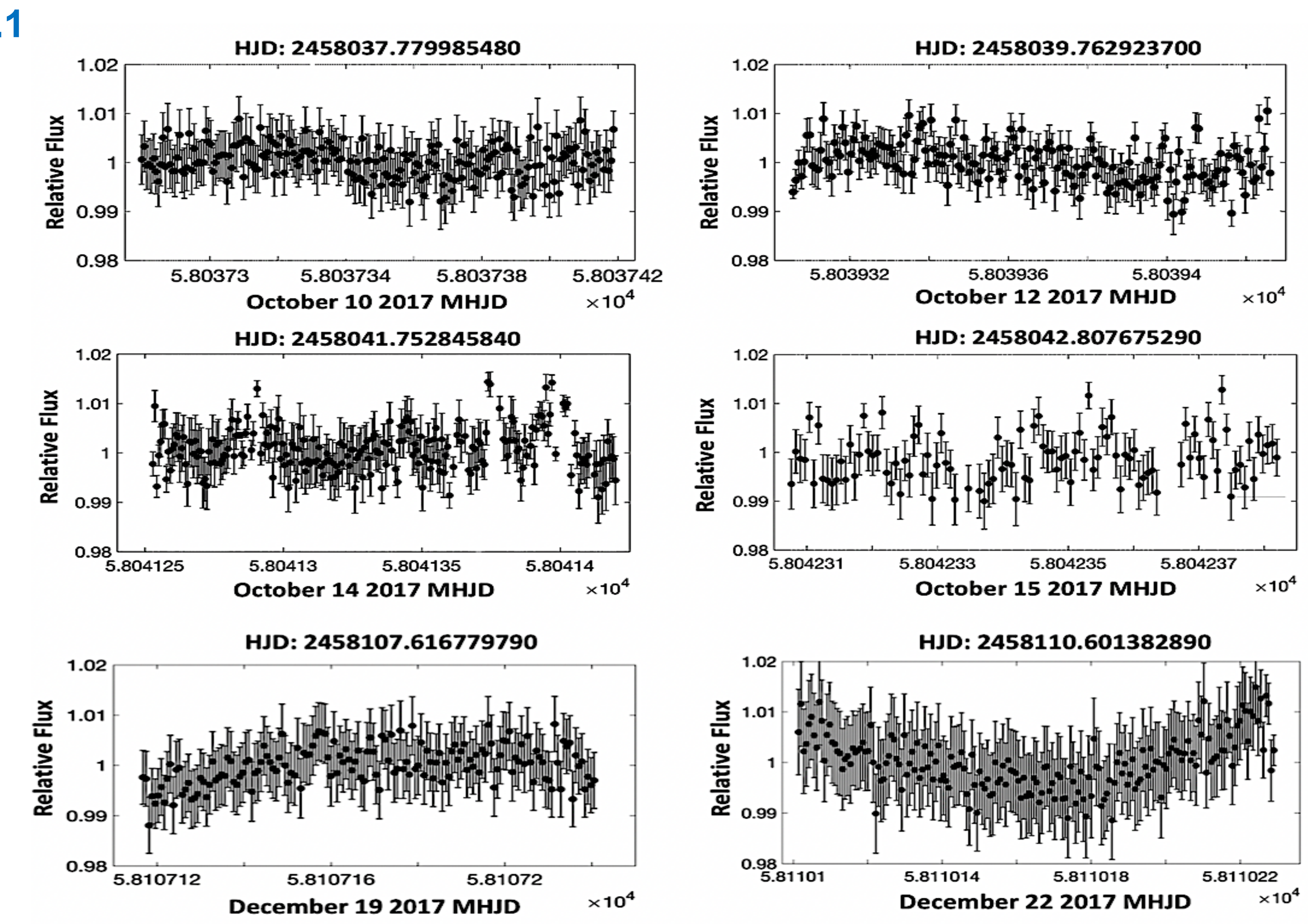



Fig.2

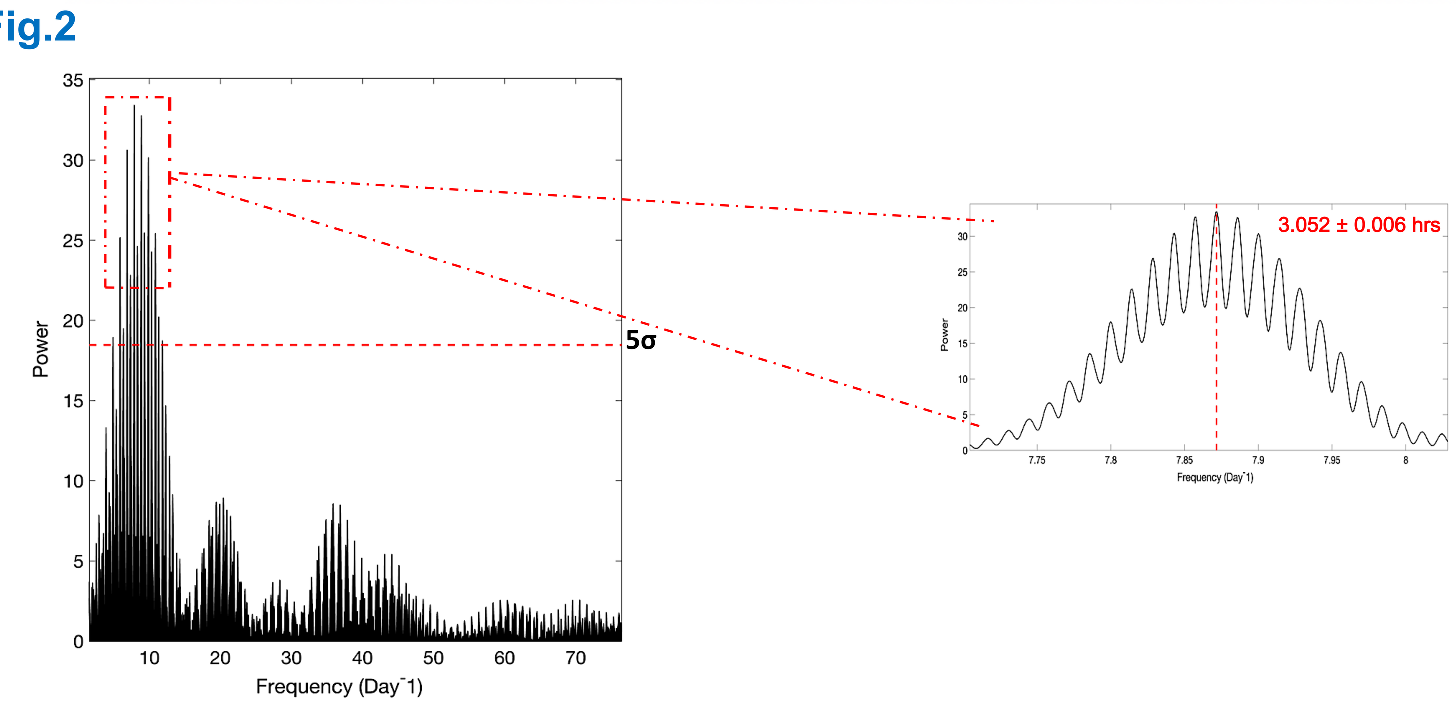



Fig.3

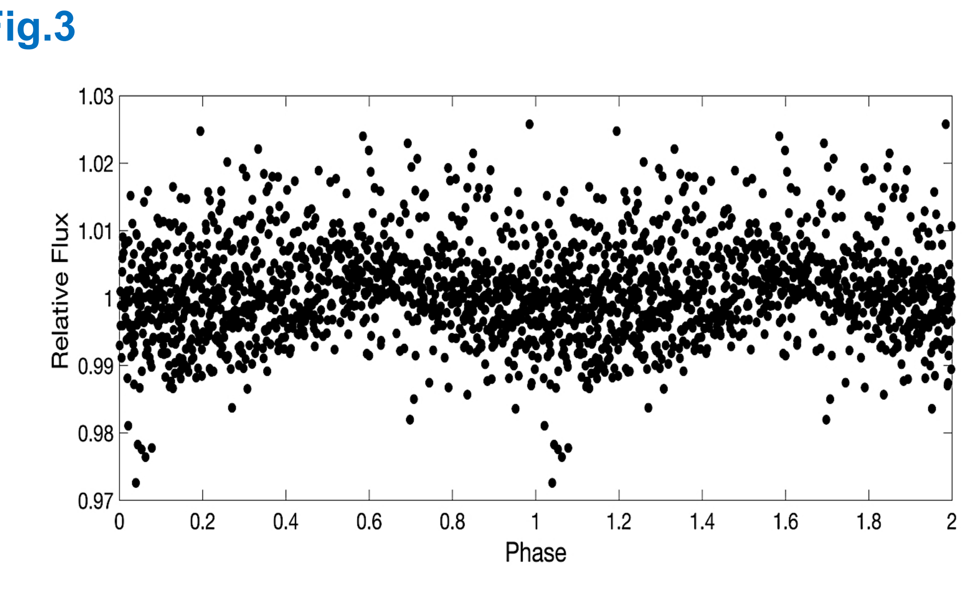



Fig.4

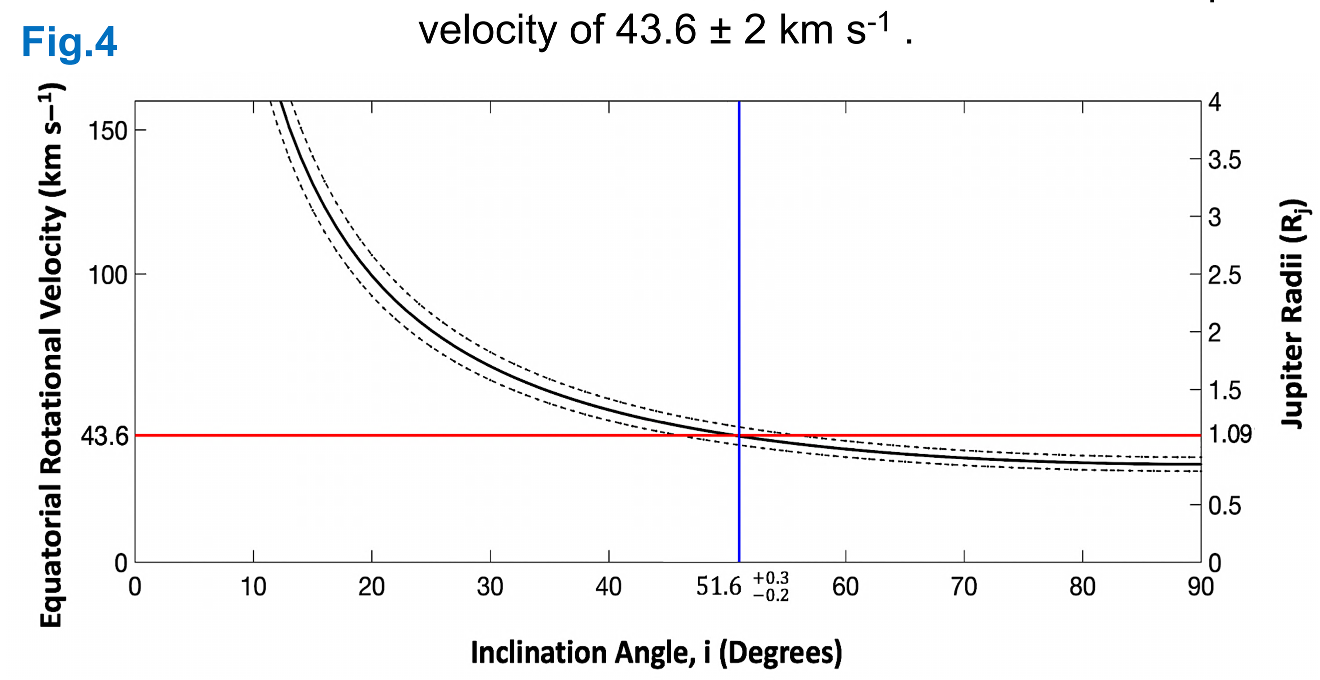



**Fig.1** BRI 0021 was monitored for a total of 6 nights, over two separate epochs. Throughout the observations, the amplitude varied from 0.0031 - 0.0056 mag, and photometric error bars were applied to each data point as calculated in Table 3. MHJD is Modified Heliocentric Julian Date (HJD - 2,400,000.5 days)..

**Fig.2** Lomb-Scargle periodogram of all BRI 0021 epochs, calculated from the combined data set in Fig 1. The red dashed and dotted horizontal line represents a 5σ false-alarm probability of the peaks, as determined by the LS periodogram algorithm. The x-axis is plotted in day$^{-1}$ because each light-curve was time-stamped in units of Heliocentric Julian Date (HJD). The vertical red dashed line at the most significant peak (shown in close-up in the inset plot) corresponds to a period of 3.052 ± 0.006 hrs at a significance of > 5σ

**Fig.3** Phase-folded light curves of BRI 0021 from all epochs combined.

**Fig.4** The $v \sin i$ of BRI 0021, 34.2 ± 1.6 km s$^{-1}$ (Crossfield, 2014), is shown by the solid black curve, with dashed lines representing the associated errors. It constrains the equatorial rotational velocity vs. the inclination angle for the rotation axis of BRI 0021 relative to our line of sight. The solid blue vertical line highlights the inclination angle. The second Y-axis, right, is the radius of the dwarf, tracking the equatorial rotational velocity. The predicted radius of 1.09 ± 0.05 $R_J$ from Filippazzo et al. (2015) is marked by a solid red line, and indicates an equatorial velocity of 43.6 ± 2 km s$^{-1}$ .

In Fig. 3, We phase-folded all lightcurves to the detected period of 3.052 ± 0.006 hrs. It is plausible that the periodicity of 3.05 hrs, as the most significant rotation period observed, is the true rotation periodicity.

In Fig. 4, We assumed our measured periodic signal of 3.052 ± 0.006 hrs corresponds to the rotational period of BRI 0021, this data allows us to break the $v \sin i$ degeneracy and so calculate the inclination angle for the rotation axis of BRI 0021 relative to our line of sight.

Taking the 3.05 hrs to be the dwarf's actual rotational period allows us to infer it's inclination angle with respect to our line of sight of $51.6\,^{+0.3}_{-0.2}$ degrees. Such a viewing angle is likely to significantly diminish the anticipated duty cycle associated with the presence of any suspended dust clouds and/or auroral ovals corotating with the dwarf, and in particular, to significantly diminish the likelihood of auroral associated beams of coherent radio emission crossing our line of sight; and it is certainly consistent with observations made to date of this rapidly rotating substellar object. Further multiwavelength observations are required to determine if BRI 0021 hosts a functioning auroral mechanism, along with the necessary stable and structured kG fields to sustain such magnetospheric processes, or whether this dwarf is the exception to the rule as regards the subset of known radio-active dwarfs spanning the substellar boundary.