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Fermi-LAT Observations of fast rotating, magnetic white dwarfs J191213.72-441045.1 and EUVE J0317-85.5

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We report the possible detection of pulsed γ-ray emission from one confirmed white dwarf pulsar J191213.72-441045.1 and a candidate white dwarf pulsar EUVE J0317-85.5 using ~15 years of data from the *Fermi*-LAT observatory. Pulsed γ-ray emission in the 0.5-10 GeV energy range from J191213.72-441045.1 were detected at a period of P=319.99±0.35s with a -log(Pr)=6.76 which corresponds to a significance of ~4.37σ using the H-test Test Statistic. This H-test Test Statistic avoids the application of statistical penalties to the periodogram. The phase-folded γ-ray light curve on this period is remarkably in phase with the recent optical observations of J191213.72-441045.1 suggesting that the pulsed γ-rays and optical photons might be emanating from the same region in J191213.72-441045.1. Pulsed γ-ray emission in the 0.5-10 GeV energy range were also found from the isolated, highly magnetic white dwarf EUVE J0317-85.5 at the period of P=724.65±0.54s with a -log(Pr)=5.02 which corresponds to significance of ~3.72σ using the H-test Test Statistic. The phase-folded γ-ray light curve on this period is also in phase with recent optical observations of EUVE J0317-85.5 using the BOOTES-6 robotic telescope. We propose that the pulsed γ-ray emission in the 0.5-10 GeV energy range from both of these fast spinning, magnetic white dwarfs is likely produced by the curvature radiation mechanism based on recent studies suggesting that fast spinning, magnetic white dwarfs to be possible low-level γ-ray emitters.

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1. Introduction

1.1 J191213.72-441045.1 (J1912)

J1912 is a white dwarf binary system that was discovered by [1] and [2] to emit pulsed emission from radio up to X-rays at a period of ~5.3 minutes. J1912 is in a tight binary orbit with orbital period of ~4.03 hours with a secondary companion of spectral type M4.5±0.5 [1]. The white dwarf in J1912 has a mass of M=1.2±0.2 $M_\odot$ and the secondary a mass of M=0.25±0.05 $M_\odot$. This M-dwarf fills ~90% of its Roche lobe and [1] detected a flare in the X-ray and optical light curves for which they proposed to be an accretion-induced flare as a result of early onset mass transfer from the M-dwarf to the white dwarf. [3] further refined the white dwarf mass to M=0.59±0.02 $M_\odot$ with radius R=0.0131±0.004 $R_\odot$ and determined an orbital inclination of i=59±6° and also estimated an upper limit of the white dwarf magnetic field of ≤50 MG. A white dwarf spin period of P=319.34903(8)s and a relatively high magnetic field strength of ≤50 MG, J1912 might indeed possess the required properties to accelerate charged particles like electrons to high energies resulting in pulsar-like γ-ray emission through processes like perhaps curvature radiation [4] although we do not exclude other mechanisms like perhaps inverse Compton scattering of the seed photons from the M-dwarf.

1.2 EUVE J0317-85.5 (J0317)

J0317 was discovered by [5] to emit optical pulsations at a period of P=725.4±0.9s and these authors estimated a magnetic field strength of B~340 MG. [5] found that J0317 was accompanied by a non-magnetic white dwarf LB 9802 but they could not detect any accretion occurring in this system mainly because LB 9802 was 7.2″ away from J0317 which corresponds to a projected separation of ~200 AU ([6]) making J0317 effectively an isolated white dwarf. [7] did ultraviolet observations of J0317 and found pulsations at a period of P=725.5±0.8s and the first harmonic P=362.9s. These authors refined the magnetic field strength to B=450 MG using spectropolarimetric studies. Given this high magnetic field and relatively fast spin period, J0317 could indeed be a white dwarf pulsar candidate.

2. Data Processing and Analysis

2.1 *Fermi*-LAT Observations of J1912

The new Pass 8 [8] γ-ray data from the *Fermi*-LAT spacecraft [9] were retrieved from the *Fermi* Science Support Center (FSSC[1]) from 01 January 2009, 00:00:00 to 05 November 2024, 00:00:00 in the energy range 0.5-10 GeV. The standard unbinned likelihood analysis was carried out on γ-ray events in a region of interest (ROI) of 1° centered around J1912 (right ascension (RA)=288.057166°, declination (DEC)=-44.17919007°, J2000). SOURCE class events (evclass=128 and evtype=3) were selected and γ-ray photons originating from Earth's limb were excluded by choosing the zenith angle to be less than 90°. The command `gtmktime` was used with expression "(DATA_QUAL>0)&&(LAT_CONFIG==1)" to only include the good time intervals (GTIs, times where *Fermi*-LAT collected good quality data) and the background emission was modelled using "iso_P8R3_SOURCE_V3_v1.txt" for extra-galactic diffuse emission and the

[1] https://fermi.gsfc.nasa.gov/ssc/

"gll_iem_v07.fits[2]" file for galactic diffuse emission. The ROI was further reduced to 0.6° to exclude spurious background emission and the command `gtsrcprob` was used to only include γ-ray photons having a probability of >80% originating from J1912. These γ-ray photons have recorded RA and DEC coordinates and we further restrict the DEC of these γ-ray photons to -45°≤DEC≤-44° followed by a RA restriction of 288°≤RA≤289°. The final γ-ray event file was then used to run a periodic analysis using the Rayleigh test [10] that is part of the `gtpsearch` tool which performs on-the-fly barycentric corrections. Using the `Tempo2` [11] tool with the *Fermi*-plugin [12] γ-ray events were then phase-folded (see Rayleigh periodogram in Figure 1) on this predominant period using the spin ephemeris BJD(TDB) = 2459772.142522(24) + 0.0036961693(10)E provided by [1]. To create a spectral energy distribution (SED) of J1912, we used the TS gating method (see [13]). This method involves dividing the whole ~15 years of data into 5-day sections, running the likelihood analysis on those sections and then only considering sections having TS>0. The SED (see Figure 2) across the whole 0.1-500 GeV energy range with a ROI=10° was used to account for *Fermi*-LAT's broad point-spread function at lower energies ([9], [14]) was created using the TS gated event files together with *FermiPy* [15].

2.2 *Fermi*-LAT Observations of J0317

Some of the same *Fermi*-LAT data selection criteria described in section 2.1 were also followed for J0317 i.e., 01 January 2009, 00:00:00 to 05 November 2024, 00:00:00, energy range 0.5-10 GeV, size of the ROI=1° centered on J0317's coordinates (RA=49.31602858°, DEC=-85.54043285°, J2000). A standard unbinned likelihood analysis was then performed considering these criteria. The ROI was also reduced to 0.6° and `gtsrcprob` was used to only include γ-ray photons that have probability >80% originating from J0317[3]. A periodic analysis was performed on this event file using the Rayleigh Test and the events were phase-folded (see Figure 3) on this predominant period and an SED of J0317 is shown in Figure 4.

3. Results and Discussion

3.1 J1912

From Figure 1, there is a predominant pulsation close to the spin period of the white dwarf in J1912 at P=319.99±0.34s where the error on the period was calculated using the bootstrap resampling method [18]. This period is about $\sim 5.74\sigma$ with a false-alarm probability (FAP) of $\sim 1.74\times 10^{-7}$(99.99998%) compared to the background periodogram noise. A more robust approach is using the *H-test test statistic* ([17] and references therein) in Figure 1 to estimate the probability of uniformity which scales as Prob(>H)$\approx e^{-0.4H}$ ([17]) where H is the maximum *H-test test statistic* and Figure 1 reveals a maximum TS~30 corresponding to a probability of uniformity of $\sim 6.14\times 10^{-6}$ or $\sim 4.37\sigma$ in the Gaussian distribution. We quote $\sim 4.37\sigma$ as the more robust significance because it avoids the application of statistical penalties to the periodogram. The phase-folded light curve on this predominant period is phase-aligned with the optical phase-folded light curves using the same spin ephemeris.

[2] https://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html

[3] An RA and DEC restriction on J0317 resulted in an insufficient amount of γ-ray photon for a reliable periodic analysis.

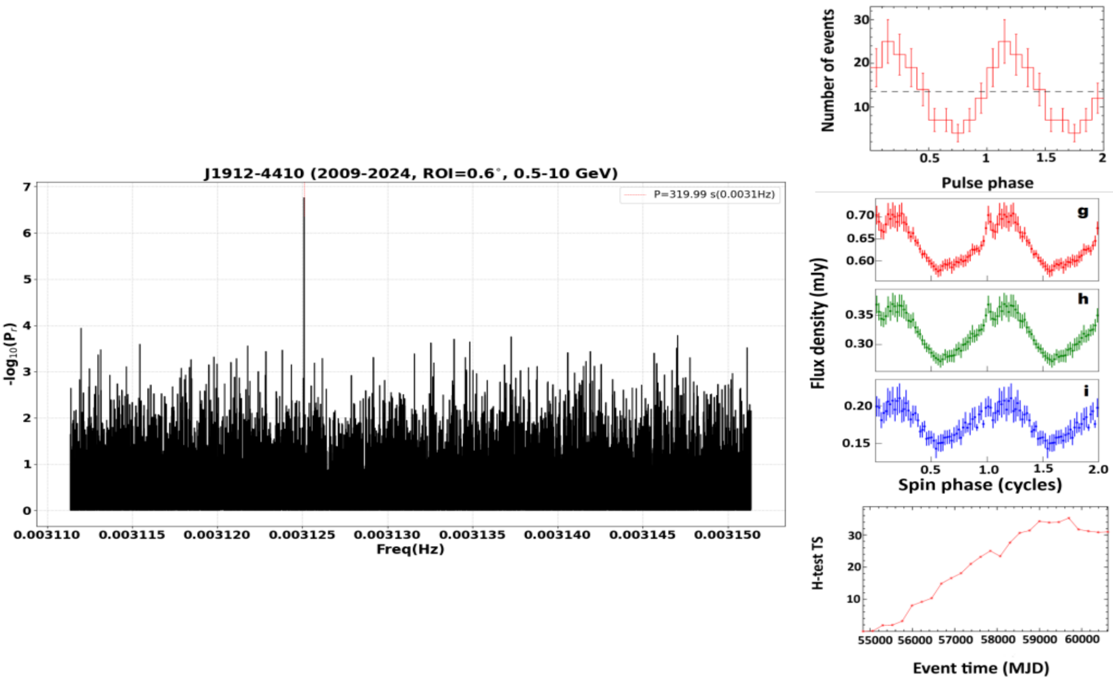

Figure 1: Rayleigh periodogram (left) showing pulsations at P=319.99±0.35s at -log(P_r)= 6.76 with ~4.37σ. Right showing the phase-folded γ-ray (0.5-10 GeV) light curve (top right) on predominant period using spin ephemeris by [1]. Optical observations from [1] are also shown in **g, h** and **i** (i_s, g_s and u_s ULTRACAM [16] filters respectively). The *H-test test statistic* [17] is shown in the bottom panel.

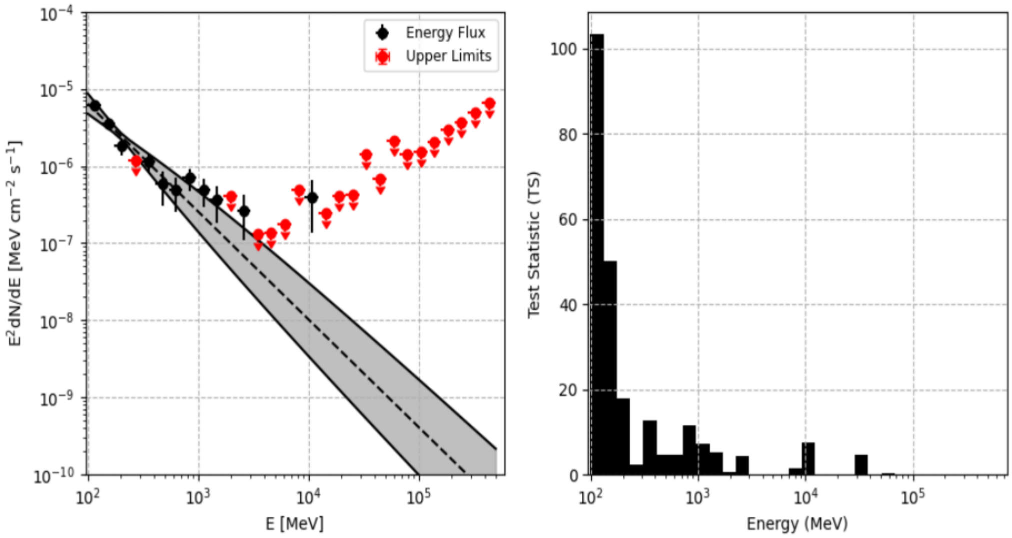

Figure 2: SED of J1912 in the energy 0.1-500 GeV range. Histogram shows the TS distribution with energy.

This might suggest that the optical and γ-ray photons originate from the same regions on the white dwarf in J1912. We propose that this pulsed γ-ray photons in the 0.5-10 GeV range could be due to the curvature radiation mechanism ([4] and references therein) since a recent study by [19] suggested that these highly magnetic and fast rotating white dwarfs might indeed emit low-level pulsed γ-ray emission at energies <50 GeV. The SED and TS histogram is shown in Figure 2 indicates that the γ-ray emission from J1912 is well-described by a power law with index Γ=3.34±0.18 at energies below ~10 GeV.

3.2 J0317

The predominant period in Figure 3 is at P=724.65±0.54s with ~4.01σ with FAP=9.55×10^{-6} (99.99905%) compared to the periodogram noise. The *H-test TS* reaches a maximum value of TS~23 which corresponds a probability of uniformity of ~1.0×10^{-4} or a ~3.72σ using the Gaussian distribution. Phase-folding the γ-ray photons on this period with the spin ephemeris T_0= HJD 2450237.72019 provided by [7] reveals that it is double-peaked per rotation with a second faint peak at spin phase ~1. This could possibly be the first harmonic of the spin period of J0317. This γ-ray phase-folded light curve is phase-aligned with recent optical phase-folded light curves using the BOOTES-6 ([20], [21]) robotic telescope at the Boyden Observatory. This might also suggest that the pulsed γ-ray photons and optical photons originate from the same region in the isolated white dwarf.

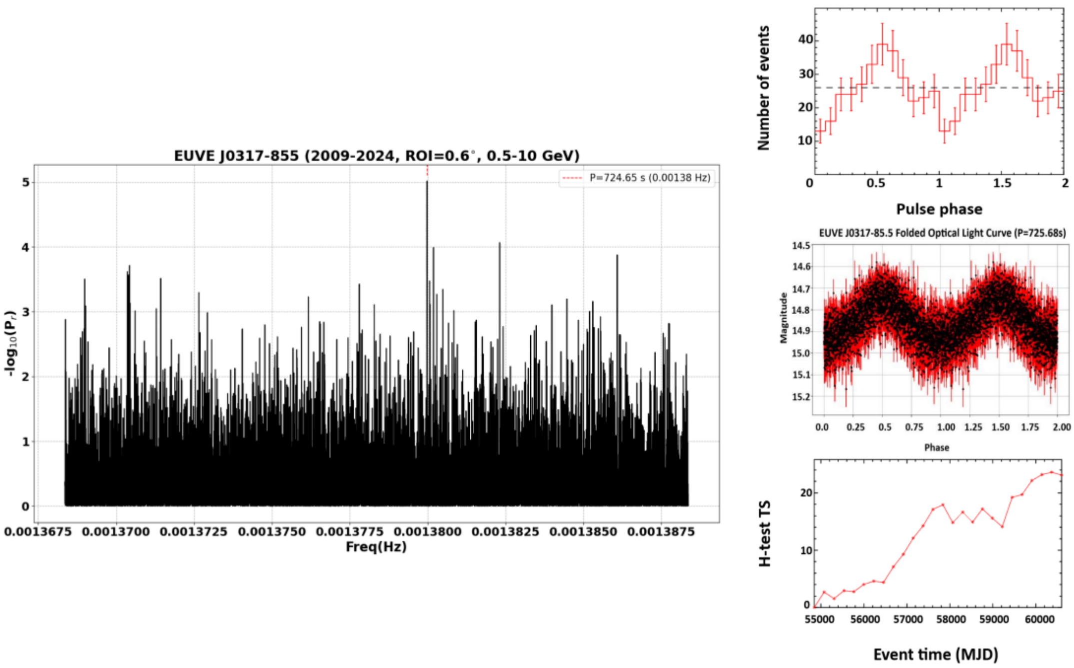

Figure 3: Rayleigh periodogram (left) showing pulsations at P=724.64±0.54s at -log(P_r)= 5.02 with ~3.72σ. Right showing the phase-folded γ-ray (0.5-10 GeV) light curve (top) on predominant period using ephemeris by [7]. BOOTES-6 optical observations is also shown in the middle panel. The *H-test test statistic* [17] is shown in the bottom panel.

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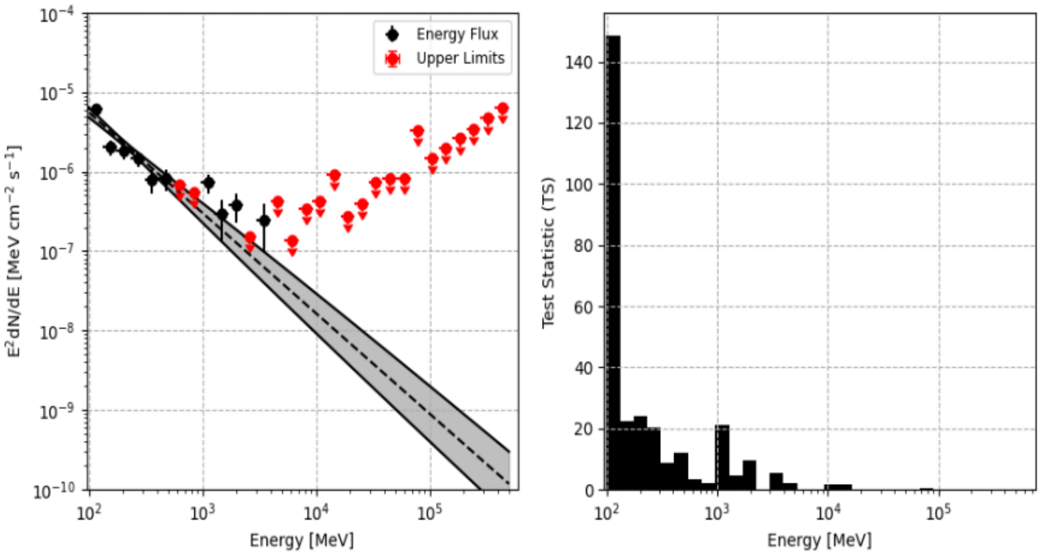

Figure 4: SED of J0317 in the energy 0.1-500 GeV range. Histogram shows the TS distribution with energy

Figure 4 shows the SED that is also well described by a power-law model with spectral index Γ=3.26±0.20 with most of the γ-ray emission at energies below ~10 GeV. For both J1912 and J0317, an order of magnitude within parameter estimates reveal that both sources could possibly accelerate electrons to higher energies with electric potentials ranging from $\Delta V_{max} \approx 10^{12}$-$7\times10^{12}$ V (see [19] and references therein). The scale height above the polar caps where these electrons could be accelerated is $h_{max}\approx 10^8$ cm with maximum Lorentz factors of $\gamma_{max}\leq 10^8$ with a radius of curvature $R_c\approx 10^{10}$ cm. Given that the energy of curvature photons scale as $\epsilon_c \propto \gamma^3 R_c^{-1}$ reveals an upper limit of $\epsilon_c \leq$10 GeV for both sources and this is seen in the SED for both sources showing similar power-law behaviour where the γ-ray emission is located below $\leq$10 GeV.

4. Conclusions

We detect possible pulsed γ-ray emission from both the white dwarf binary system J1912 and the isolated white dwarf J0317 in the energy range 0.5-10 GeV. In J1912, we detect a period of P=319.99±0.34s at a ~4.37σ using the *H-test test statistic*. The phase-folded γ-ray light curve is phase-aligned with the optical observations from [1] using the same spin ephemeris. Using the TS gating method and *FermiPy* ([15]), we produced an SED which revealed that most of the emission is emitted below an energy range <10 GeV with a power-law model with a spectral index of Γ=3.34±0.18. For J0317, we detect a period of P=724.64±0.54s at ~3.72σ. The phase-folded γ-ray light curve is also phase-aligned with the phase-folded optical light curve from the BOOTES-6 robotic telescope using the same spin ephemeris. This might also suggest that the pulsed optical photons and γ-ray photons originate from the same regions from J0317. The SED of J0317 is well-described by a power-law model with a spectral index of Γ=3.26±0.20 in energies below <10 GeV. We propose the curvature radiation mechanism for the possible pulsed emission close to the spin periods of both J1912 and J0317 since a recent study by [19] did suggest the at these fast rotating and high magnetised white dwarfs might emit pulsed low-level γ-ray emission at energies below <50 GeV.

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References

[1] I. Pelisoli, T. Marsh, D. A. Buckley, I. Heywood, S. B. Potter, A. Schwope et al., *Nat. Astron.* **7** (2023) 931.

[2] Schwope, A., Marsh, T. R., Standke, A., Pelisoli, I., Potter, S., Buckley, D. et al., *A&A* **674** (2023) L9.

[3] I. Pelisoli, S. Sahu, M. Lyutikov, M. Barkov, B. T. Gänsicke, J. Brink et al., *MNRAS* **527** (2023) 3826.

[4] V. V. Usov, *Soviet Astronomy Letters* **14** (1988) 258.

[5] M. A. Barstow, S. Jordan, D. O'Donoghue, M. R. Burleigh, R. Napiwotzki and M. K. Harrop-Allin, *MNRAS* **277** (1995) 971.

[6] S. Vennes, G. D. Schmidt, L. Ferrario, D. J. Christian, D. T. Wickramasinghe and A. Kawka, *ApJ* **593** (2003) 1040.

[7] L. Ferrario, S. Vennes, D. T. Wickramasinghe, J. A. Bailey and D. J. Christian, *MNRAS* **292** (1997) 205.

[8] W. Atwood, A. Albert, L. Baldini, M. Tinivella, J. Bregeon, M. Pesce-Rollins et al., *arXiv e-prints* (2013) arXiv:1303.3514 [1303.3514].

[9] M. Ackermann, M. Ajello, A. Albert, A. Allafort, W. B. Atwood, M. Axelsson et al., *ApJ Suppl. Ser.* **203** (2012) 4.

[10] K. V. Mardia, *Statistics of directional data*, Probability and mathematical statistics. Academic Press, London, 1972, https://doi.org/10.1111/j.2517-6161.1975.tb01550.x.

[11] G. B. Hobbs, R. T. Edwards and R. N. Manchester, *MNRAS* **369** (2006) 655.

[12] P. S. Ray, M. Kerr, D. Parent, A. A. Abdo, L. Guillemot, S. M. Ransom et al., *ApJ Suppl. Ser.* **194** (2011) 17.

[13] S. T. Madzime and P. Meintjes, *PoS* **HEASA2022** (2023) 055.

[14] W. B. Atwood, A. A. Abdo, M. Ackermann, W. Althouse, B. Anderson, M. Axelsson et al., *ApJ* **697** (2009) 1071.

[15] M. Wood, R. Caputo, E. Charles, M. Di Mauro, J. Magill, J. S. Perkins et al. in *35th International Cosmic Ray Conference (ICRC2017)*, vol. 301 of *International Cosmic Ray Conference*, p. 824, July, 2017, 1707.09551, DOI.

[16] V. S. Dhillon, T. R. Marsh, M. J. Stevenson, D. C. Atkinson, P. Kerry, P. T. Peacocke et al., *MNRAS* **378** (2007) 825.

[17] de Jager, O. C. and Büsching, I., *A&A* **517** (2010) L9.

[18] B. Efron and R. J. Tibshirani, *An Introduction to the Bootstrap*. Chapman and Hall/CRC, 1 ed., 1994, 10.1201/9780429246593.

[19] P. J. Meintjes, S. T. Madzime, Q. Kaplan and H. J. van Heerden, *Galaxies* **11** (2023) .

[20] H. van Heerden, E. J. Fernández-García, A. J. Castro-Tirado, A. Martin-Carrillo, A. Castellon, P. del Pulgar et al., *PoS* **HEASA2023** (2024) 015.

[21] A. J. Castro-Tirado, *Acta Polytech.* **51** (2011) .