Anomalous Cepheids: origins

Are anomalous Cepheids the result of a binary evolution channel or a single star evolution?

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Anomalous Cepheids are pulsating stars with periods from 0.3 to ~2 days which pulsate in a fundamental mode and a first overtone. They were discovered in dwarf galaxies. The number of anomalous Cepheids in the Large and Small Magellanic Clouds, as well as in the Milky Way has significantly increased. There are still no anomalous Cepheids discovered in globular clusters. They follow a period-luminosity relation that is located close to the classical Cepheids relation, but with a shorter period. They are intermediate age star, 4-5 Gyrs, with low metallicity.

How these stars came to be?

1. Single star evolution

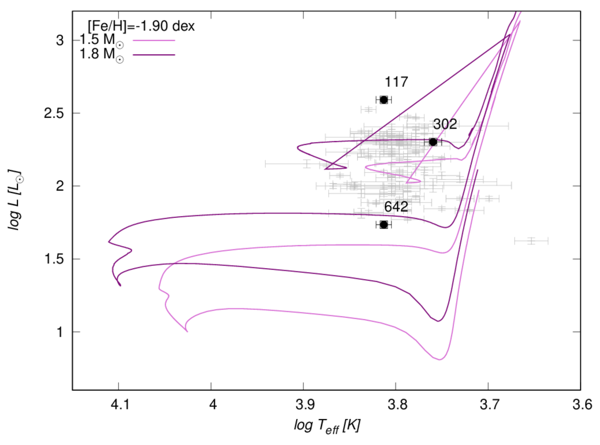

Figure 1.: HRD: BaSTI models for single evolution of the AC EPIC 202862302. The purple line is a model of mass M=1.8 Msun and the pink is for mass M=1.5Msun . The metallicity of the model is [Fe/H]=-1.90 dex, which is in good agreement of the measured metallicity of EPIC 202862302, [Fe/H]=-1.94 dex. The grey crosses are ACs from the SMC and LMC taken from the Groenewegen & Jurkovic (2017). (Jurkovic et al., 2022, MNRAS, accepted)

2. Binary star evolution

This scenario is a good explanation for anomalous Cepheids in old stellar environments (Cassisi & Salaris, 2013, Fiorentino & Monnelli, 2012). It has been proposed by Renzini et al. 1977 and Sills et al. 2009. In Gautschy & Saio, 2017 detailed binary scenarios have been modeled.

The SED fit result

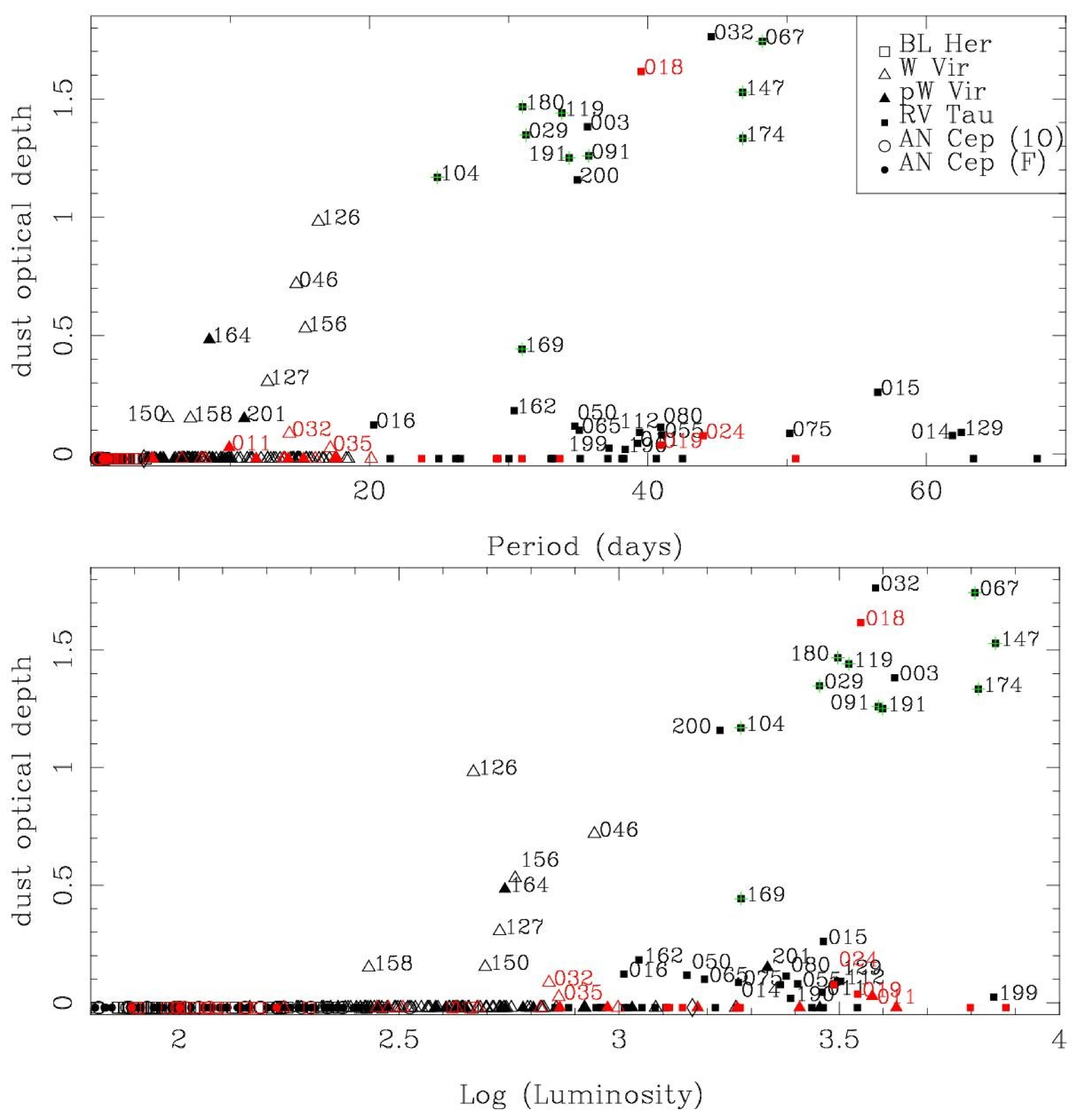

Figure 2.: Dependence of the derived dust optical depth on pulsation period and log L. Stars in the LMC are plotted in black, and in the SMC are plotted in red. Stars with an IRS spectrum are indicated by a green plus sign. Stars with a detectable IR excess are labeled by their identifier (Groenewegen & Jurkovic, 2017, A & A, 603, A70).

The Gaia RUWE parameter

From a 100 anomalous Cepheids identified in *Gaia* DR2 (Gaia et al., 2018), in EDR3 (Gaia et al., 2021) only five have any indication in the Renormalised Unit Weight Error (RUWE) parameter that they might be in a binary system. The cutoff is at 1.4.

RA	DEC	Source	RUWE	Gmag	eGmag
deg	deg			mag	mag
76.63804168541	-68.96704398403	466124097747946	4.247	17.04202	0.005616
18.3617039358	-72.87623961519	468723676522527	1.636	18.275787	0.011295
5.47215137965	-71.88622177036	468983525048087	1.747	18.978643	0.004812
5.4494173472	-72.23085384918	468960163865347	2.744	17.873724	0.004574
80.30982020921	-70.49431290052	465192347113374	1.687	18.268616	0.011786

Photometry from Kepler – K2 and spectroscopy

In the photometric data of the *Kepler – K2* (Borucki et al., 2010, Borucki, 2016) mission five anomalous Cepheids have been discovered among the sample of Type II Cepheids (Jurkovic et al., 2022, MNRAS, accepted). Since they overlap with the short period classical Cepheids maybe a few additional discoveries will be made.

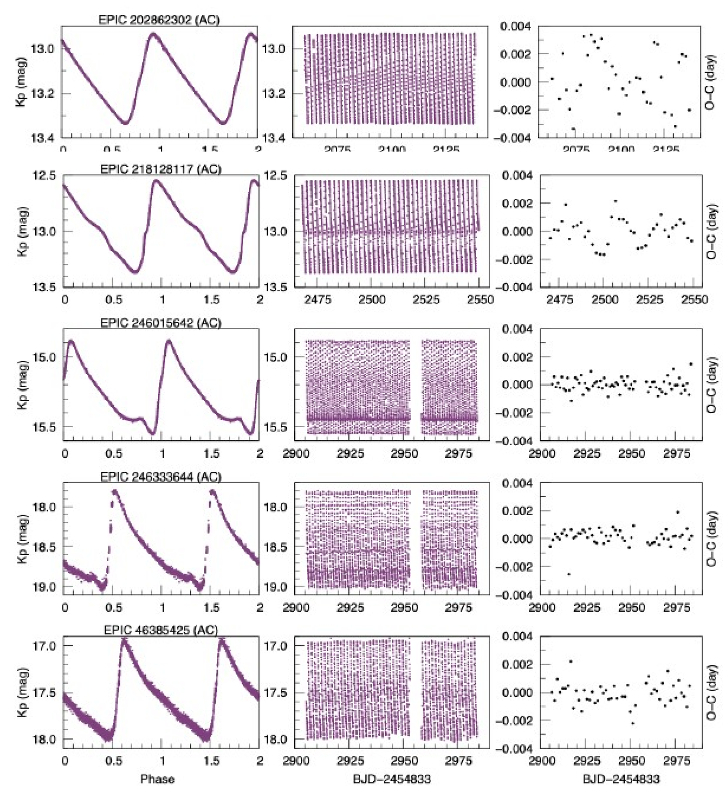

Figure 3.: Phased light curves, the time series and the Observed – Calculated plot for the anomalous Cepheids from the Kepler – K2 sample (Jurkovic et al., 2022, MNRAS, accepted).

ID	$T_{\rm eff}^{\rm literature}$ [K]	log g [cm/s^2]	[Fe/H] [dex]	M [$M_\odot$]	R [$R_\odot$]
ACs					
202862302	5428 ^{b}	3.542	-0.343	0.963	2.933
	4892.30 $^{+114.33}_{-43.40}$ ^{d}	-	-	-	-
	5950^e	2.20	-1.94	-	-
	5432.32^i	2.212	-1.17	2.528	-
	4961.94^r	1.997	-1.52	0.854	-
218128117	7158^b	4.195	-0.034	1.506	1.586
	6345.00 $^{+463.25}_{-325.69}$ ^{d}	-	-0.01	-	-
	6345^h	-	-	-	-
	6304.08^i	2.665	-1.513	1.854	-
	6742 ± 291^j	-	-	-	-
					8.959^k
	7190^n	4.019	-0.362	38.272	9.969
246015642	6353^a	-	-0.872, -0.742	-	-
	6459.00 $^{+211.00}_{-277.33}$ ^{d}	-	-	-	-
	6101.79^i	2.622	-2.00	0.794	-
	-	-	-	1.290^{k,d}	2.652
	7098^n	4.039	-0.162	2.902	2.689
	5966.6^p	3.36	-0.39, -0.76	-	-
246385425	6191^a	-	-0.579, -0.548	-	-
	-	-	0.12 $^{+0.4}_{-0.5}$ ^{d}	-	-
	6346.22^i	4.366	-0.919	0.900	-
	6060.0 ± 285^k	4.846	-	1.130	0.664
	5790.3^p	4.610	-0.14, -0.15	-	-
	6208.41^r	4.238	-1.467	0.773	-
246333644	-	-	-	-	-

Table 1. Observed spectroscopic parameters of anomalous Cepheids in the *Kepler – K2* sample. Effective temperatures (T_{eff}), surface gravity (log g), metallicities ([Fe/H]), mass (Msun) and radii (Rsun) from the literature: [a]Miller (2015), [b]Huber et al. (2016), [c]Stevens et al. (2017), [d]Gaia Collaboration et al. (2018), [e]Kovtyukh et al. (2018), [f]Luo et al. (2018), [g]Stassun et al. (2018), [h]Tonry et al. (2018), [i]Anders et al. (2019), [j]Bai et al. (2019), [k]Stassun et al. (2019), [l]Xiang et al. (2019), [m]Gaia Collaboration et al. (2021a), [n]Hardegree-Ullman et al. (2020), [o]Lucey et al. (2020), [p]Bonifacio et al. (2021), [q]Buder et al. (2021), [r]Anders et al. (2022) (Jurkovic et al., 2022, MNRAS, accepted).

Conclusion: Both evolutionary scenarios of anomalous Cepheid's is possible. In this poster we show that if mass exchange has occurred between the members of the binary systems there is no dust left in the system. On the precise light curves from the *Kepler – K2* space telescope we did not see evidence of binary systems. The *Gaia* space telescope has not seen evidence for binarity in the astrometric solution. The binary channel of the origin of anomalous Cepheids is not excluded, but the single star evolution is also very plausible.

EPIC 210990639

- The star EPIC 210990639 was discovered among the sample of Cepheid type pulsating stars in the *Kepler – K2* mission in Cycle 4. The shortness of the *K2* cycles captured only one eclipse.
- EPIC 21099369 is not a Cepheid variable, but probably a spotted rotating star, so this emphasizes the importance of correctly classifying variable stars.
- In this case blending can be a significant problem for further analysis.

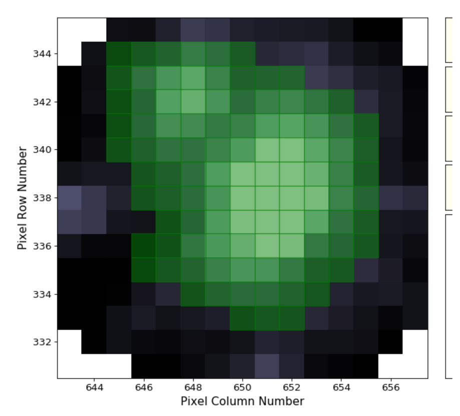

Figure 4.: The *Kepler – K2* pixels of the EPIC 210990639, which shows that two sources are very close to each other.

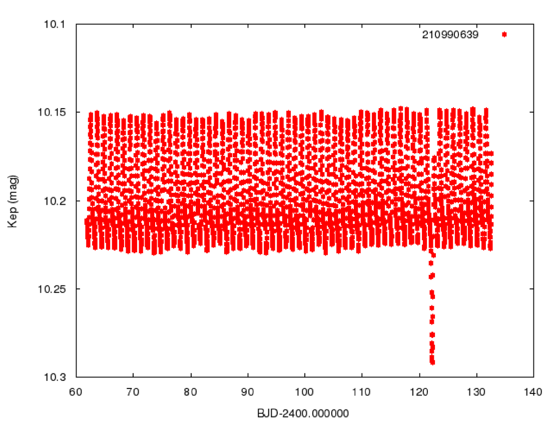

Figure 5.: The observed light curve of EPIC 210990639 with the eclipse.

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