Figures of Merit for the High-cadence survey

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Scientifc justification for cadence and area

We propose a high-cadence survey in the Galactic Plane ($|b| < 7°$) covering the full inner Plane visible from the northern hemisphere (Galactic longitude $10° < l < 230°$) as part of the ZTF partnership time. This results in a total coverage of 3080 deg^2 which is more then 10 times larger then the current coverage of OmegaWhite (see Tab. 1 for an overview of high-cadence surveys). We propose to obtain 3 hr continuous lightcurves of each field with a cadence of 40 sec resulting in a total of ≈200 hrs of observing time to complete the survey.

Cataclysmic variables (CVs) should be the most numerous of the ultracompact binaries found in the survey, as they are 100 times more numerous than double white dwarf (DWD) binaries. We expect to find a few thousand with the majority being close to the period minimum of ≈ 80 min. Currently, merger rates for DWD mergers are purely based on binary population studies. With the merger rate and the observable volume, we expect to find about 110 new DWD systems with $P_{\text{orb}} < 60$ min in the high-cadence survey (8 systems with $P_{\text{orb}} < 20$ min and even 700 with $P_{\text{orb}} < 2$ hr). Additionally, we expect to find about 10-15 new (ultra)compact low-mass helium star (sdB/sdO) binaries with white dwarf companions and orbital periods $P_{\text{orb}} \leq 60$ min (≈30 systems with $P_{\text{orb}} < 2$ hr). The merger rate of NS binaries with white dwarf companions is about a factor of 100 lower than for DWD systems. Therefore, we expect to find probably 1-2 ultracompact NS+WD binaries and 1 ultracompact NS+sdB/sdO binary.

In the following we will discuss comments from the review and some figures of merit to show why we chose this survey strategy.

FoM: Decreasing the survey area to the Strawman survey

Ultracompact binaries represent the final stage of stellar binary evolution and therefore have moved away from their origin as they are at least hundreds of Myr old. Consequently, the density of systems is expected to correlate with the stellar density across the Galactic Plane. In the Strawman survey a Galactic block of 2 months (mid-Nov to mid-Jan) was proposed. Fig. 1 shows the density of PSF-fit extractions from PTF CCDs. Clearly visible is the smaller stellar density towards the Galactic anti-center where the number of objects is decreased by a factor of 4-5. The red box shows the region which is not accessible during the winter months and shows that without observations earlier in the year we miss the smaller Galactic longitude fields where the stellar density is significantly higher and therefore where most objects are expected to be found.

Hence, a factor of two decreased survey area does not result in a factor of two decreased number of systems. Leaving out the regions towards the Galactic center results in an expected decrease of number of systems by a factor of about 10 (factor of two in area and factor of 4-5 in stellar density). Therefore, we would expect to find only $\approx 1-2$ (ultra)compact low-mass helium star (sdB/sdO) binaries with white dwarf companions and orbital periods $P_{\text{orb}} \leq 60$ min as well as a maximum of ≈ 10 new double white dwarf (DWD) systems with $P_{\text{orb}} < 60$ min and at most 1 DWDs with $P_{\text{orb}} \leq 20$ min. The latter are the systems which are predicted to be the strongest sources of gravitational wave radiation in the eLISA regime. Such a small sample will not allow for

Table 1: Overview of recent high-cadence synoptic surveys

Survey	Field location (deg)	Total sky coverage (deg^2)	Depth (V mag)	Variability sensitivity (min)
ZTF High-cadence	$\|b\| \leq 7$	3080	≈20.5	$> 2-3$
OmegaWhite	$\|b\| \leq 10$	400	21.5	> 6
RATS	$\|b\| \leq 30$	46	22.5	> 5
RATS-Kepler	$6 \leq \|b\| \leq 21$	49	22.5	> 5
FSVS	$\|b\| \geq 20$	23	24.0	> 24
DLS	$\|b\| < 10$	21	25.5	> 15
Kepler	$15 \leq \|b\| \leq 25$	116	20.0	> 1 or > 30
SuperWASP	All sky	All sky	15.0	> 10

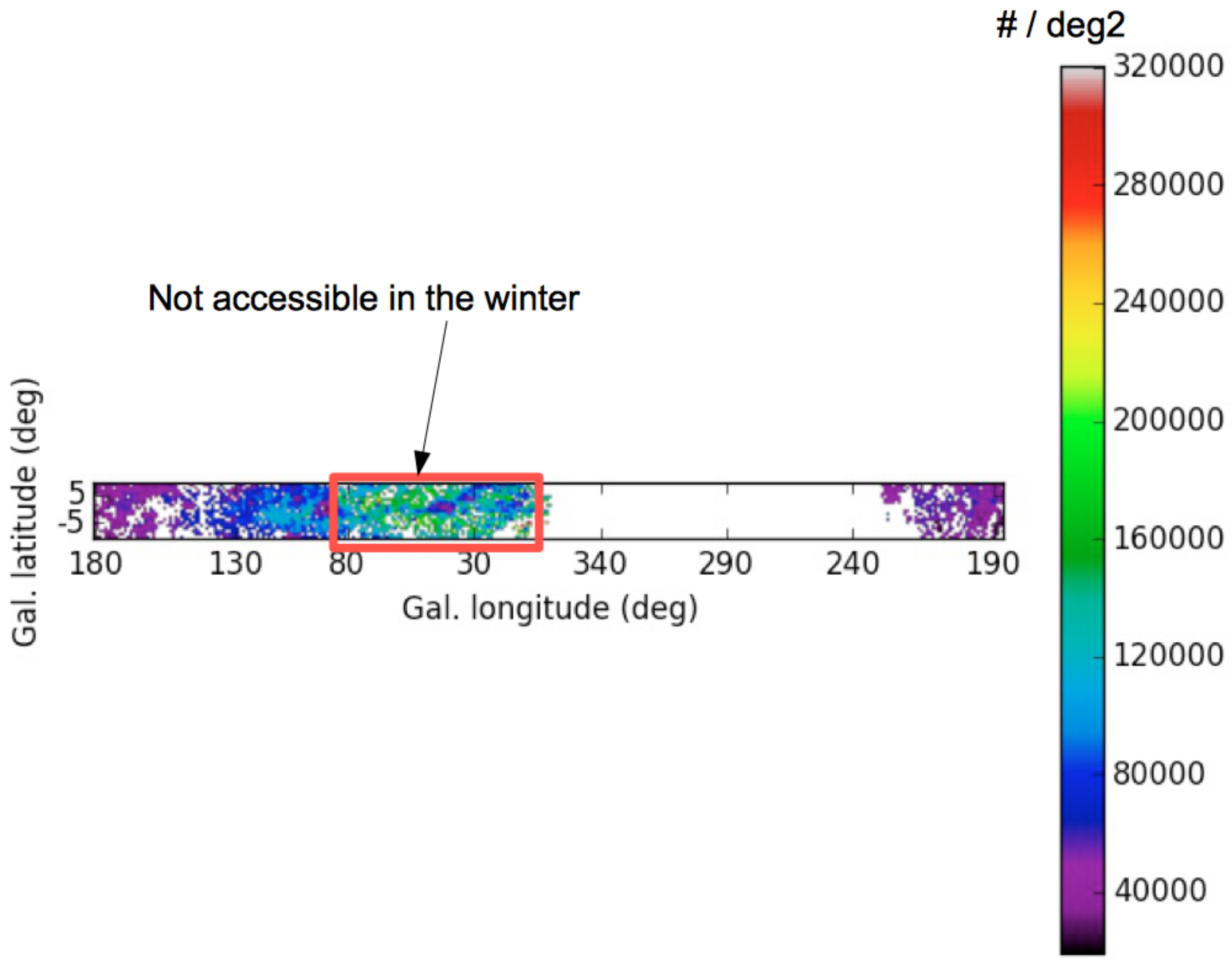

Figure 1: Density of PSF-fit extractions (number of stars per deg^2) from PTF CCDs. Clearly visible is the smaller stellar density towards the Galactic anti-center. The red box shows the region which are not accessible during the winter months

a detailed population study. Additionally, covering only a fraction of the full Plane would require additional completeness calculations which introduces additional systematic errors in population studies.

FoM: Slower cadence

PTF was very successful identifying longer period (≈several hours) systems but previous experience from PTF and OmegaWhite has shown, that a fast cadence is needed to identify ultracompact binaries. To illustrate this, we have conducted three simulations. A model lightcurve of the detached 12 min eclipsing double white dwarf (DWD) binary SDSS J065133.338+284423.37 (Hermes at al. 2012) was constructed using LCURVE. We added 10% noise to account for real photometry and used three different survey setups to obtain the lightcurve. For all lightcurves we assumed a 30 sec exposure time:

1. 270 observation with a 40 sec cadence (to simulate a continuous 3 hr lightcurve)
2. Lightcurve over 6 days with observations on 4 days [0,1,3,6]. Each night has 6 observations separated by 30 min with slightly randomized cadence (to simulate a 30min cadence spread over a few days with gaps in the days to account for weather loss)
3. 60 days of observations with a 75% chance of good weather, again with 6 observations and 30 min cadence resulting in 270 total epochs (to simulate a lower cadence over a long period of time resulting in the same number of epochs compared to the high-cadence survey)

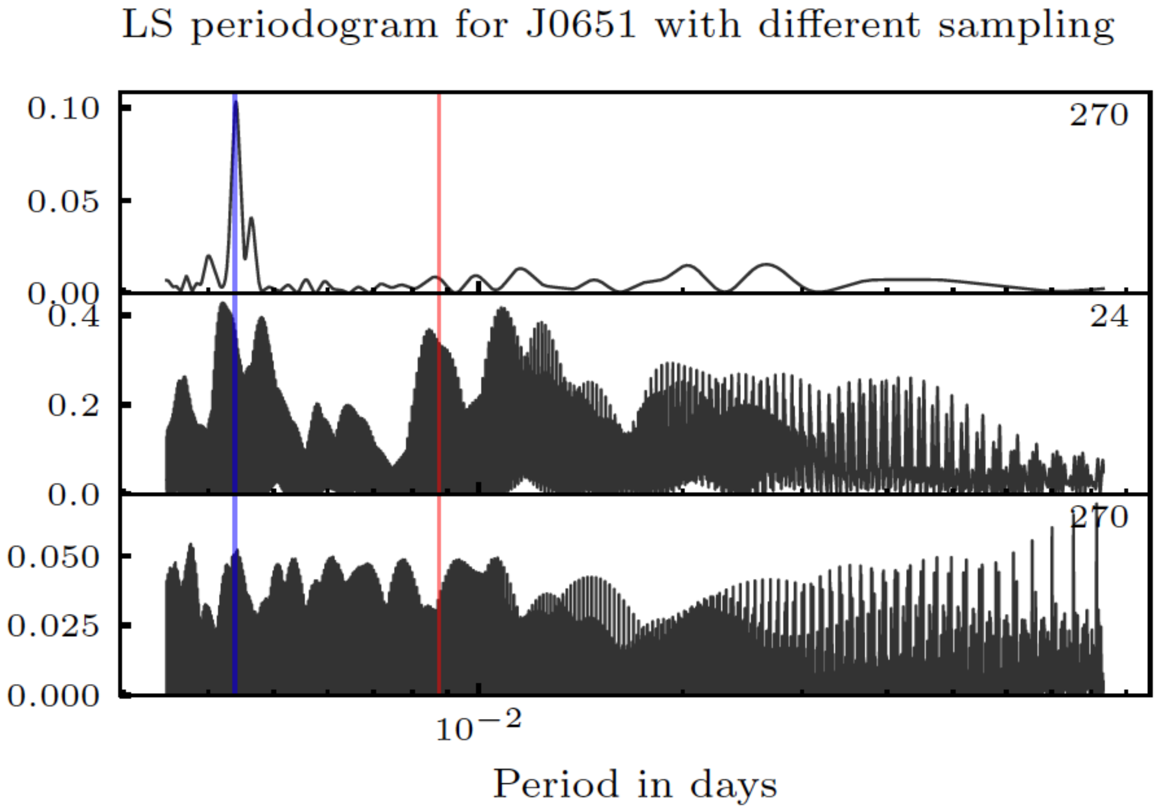

Figure 2: Lombscargle periodograms of the three tested survey setups. Red marks the orbital period of the system and blue half the orbital period **Upper panel:** High-cadence survey with 3 hr continuous lightcurves. **Middle panel:** Lower cadence over 6 nights **Lower panel:** Lower cadence with 75% chance of good weather and a total of 270 epochs.

Fig. 2 shows the lombscargle periodogram for all three survey strategies. We would like to stress that only the fast cadence survey was able to recover the period of the binary with sufficient sensitivity which shows clearly that the fast cadence is needed to identify ultracompact binaries with very short periods.

FoM: Decreasing the lightcurve length from 3 to 2 hr

Cataclysmic variables are expected to be the most numerous of the compact binaries found in the survey, as they are 100 times more numerous than DWD binaries. Population models as a function of orbital period predict the majority of systems should be near orbital periods of about 80 min. However, observational evidence is still lacking as the number of discovered systems close to the period minimum are still lacking. An orbital period of 80 min corresponds to the period minimum for hydrogen rich cataclysmic variables because the smallest main sequence dwarf will not fit in its Roche Lobe for periods shorter than 80 min.
From previous experience we know that two full cycles are needed to clearly identify the orbital period, e.g. capture two eclipses. With only 2 hr continuous lightcurves we would not cover two full orbits and therefore we expect to miss a significant fraction of hydrogen rich cataclysmic variables close to the orbital period minimum which would not allow us to do a population study of the short period end of cataclysmic variable stars.

Galactic reddening and filter choice

We propose to use the g-band filter for the high-cadence survey because most of our objects are predicted to be intrinsically blue and hence show the largest variability in the bluer bands. Galactic reddening is only expected for source several kpc away and for regions close to the Galactic center. Fig. 3 shows extinction maps obtain from IPHAS for 1,2 and 3 kpc distance to the sun. Clearly visible is that only the innermost parts close to the Galactic center are affected by reddening.

Additionally, DWD binaries and cataclysmic variables close to the period minimum are intrinsically faint

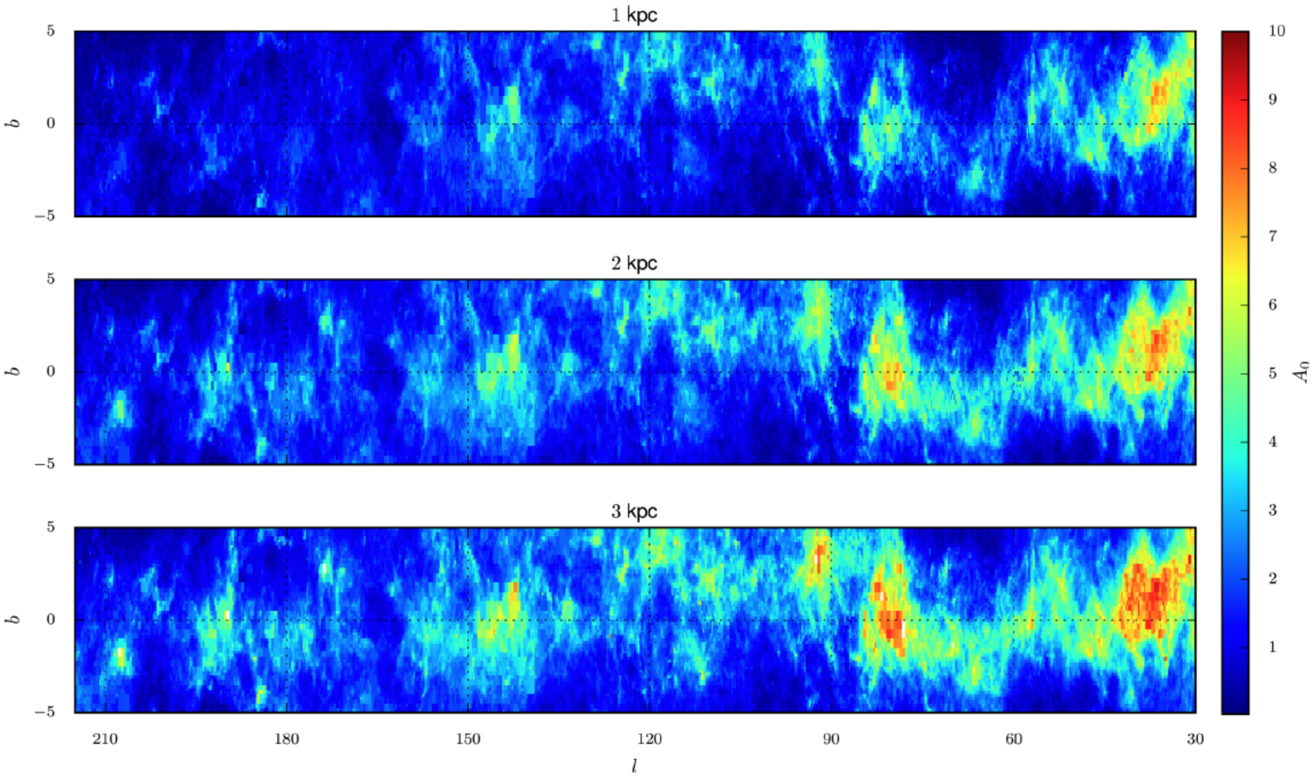

Figure 3: Slices through the 3D cumulative extinction map at heliocentric distances of 1, 2 and 3 kpc. The extinctions plotted are from the Sun to the distance of the plane.

and we expect to detect them up to a distance of about 2 kpc where extinction is not very strong. Only the low-mass helium stars which can be detected up to 8-10 kpc are expected to be affected by reddening but again only in the innermost region of the Galaxy.

We expect that the gain of higher sensitivity in the g-band is more valuable than some reddening for low mass helium stars towards the Galactic center.

Proposed separation of the fields

We tried to concentrate most of the fields in the winter month between December 1st and March 1st and propose to do half the survey in the winter because of the following reason:

In the winter months the weather is pretty unstable. Therefore, a regular relatively high-cadence survey over several days is pretty much impossible. However, for this proposal we only need three hours of stable weather. Unfortunately Galactic longitudes close to the Galactic center are only visible in the summer/fall. Therefore, we cannot fully exclude the summer/fall. See Fig. 4 for a visibility plot of the Galactic Plane over the year. Here is the proposal:

- Between End of May and End of August we propose to do Galactic longitude 10 - 60 degrees. This results in 50*14 = 700 square degrees which corresponds to about 15 ZTF fields. 15 ZTF fields spread over 3 months result in 5 fields per month or about 1 field per week.
- Between End of August and End of November we propose to do Galactic longitude 60 - 120 degrees. This results in 60*14 = 840 square degrees which corresponds to about 18 ZTF fields. 18 ZTF fields spread over 3 months result in 6 fields per month or about 1-2 fields per week.
- Between End of November and End of February we propose to do Galactic longitude 120 - 230 degrees. This results in 110*14 = 1540 square degrees which corresponds to about 33 ZTF fields. 33 ZTF fields spread over 3 months result in 11 fields per month or about 2-3 fields per week.

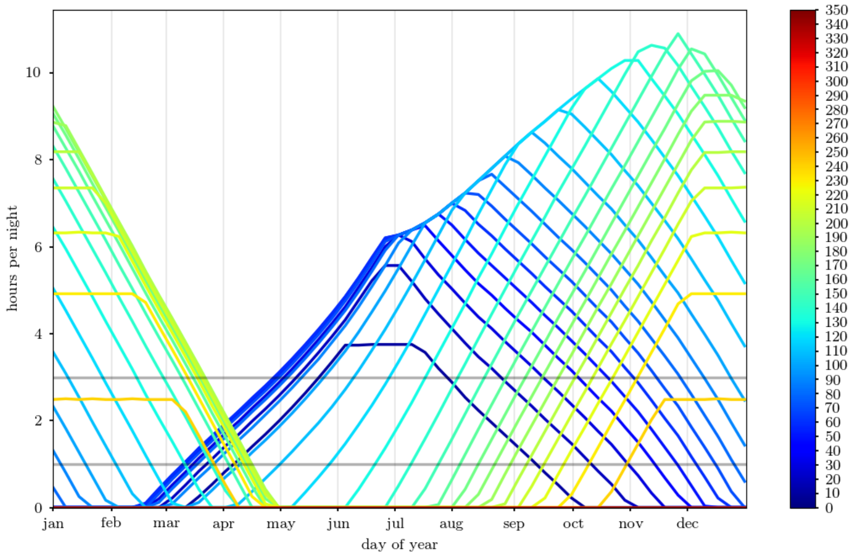

Figure 4: Visibility plot for the Galactic Plane over the full year. Each line shows the time above airmass 2 for a given Galactic longitude. Color-scaling is set with Galactic longitudes. Small Galactic longitudes are only visible for at least 3 hours in summer/fall. Whereas the Galactic anticenter is visible in winter.

- We leave March, April and May out to not interfere with any other survey which requires constant monitoring over several nights. We propose to observe a few fields in the beginning of ZTF operations (during winter) and take the gap between March, April and May to analyze and understand pipeline performance and systematics in the data.