Design concepts of the "Fly's Eye" all-sky camera system

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Abstract

In this document we briefly summarize the design concepts of the "Fly's Eye" camera system, a proposed high resolution all-sky monitoring device which intends to perform high cadence time domain astronomy in multiple optical passbands while still accomplish a high étendue. Fundings have already been accepted by the Hungarian Academy of Sciences (`http://mta.hu`) in order to design and build a "Fly's Eye" device unit. Beyond the technical details and the actual scientific goals, this document also discusses the possibilities and yields of a network operation involving ~ 10 sites distributed geographically in a nearly homogeneous manner. As of this writing (early summer in 2012), we expect to finalize the mount assembly – that performs the sidereal tracking during the exposures – until the end of 2012 and to have a working prototype with a reduced number of individual cameras sometimes in the spring or summer of 2013.

1 Introduction

Astrophysical phenomena take place on a wide range of timescales. From the shortest millisecond signals of pulsars up to the lifecycle of stars, that can be comparable to the age of the Universe, there is an astonishing span of ~ 20 magnitudes. The key to unveil the physical processes beyond these phenomena is to monitor the alterations of observable quantities, such as flux. Although some of the processes have their own characteristic timescales, most of the complex systems exhibit variations on a broader temporal spectrum. These complex systems show signs of periodic, quasi-periodic and sudden transient, eruptive processes. The observed timescales imply not only the possible durations of matter rearrangement whatever is the reason behind, but constrain the physical backgrounds of the variabilities of the observed systems. Hence, persistent monitoring of such "astrophysical laboratories" helps us to understand how stars evolve, and from a wider perspective, how planetary systems and even our Solar System develop from their early stages of life until its end.

Astronomical surveys require a complex optical and detector system to cover a large field of view, which often pairs with large light collecting area. The cumulative light collecting power, know as the *étendue* defines how effective a certain instrument is for survey purposes. By following the astronomical scientific discovery orientations, as one of these is the time-domain astronomy (Blandford et al., 2010), recent initiatives for survey projects highly focus on the most extensive ways of implementing instrumentation with high optical acceptance (see the left panel of Fig. 1).

The aim of our proposal is to develop and build an instrument coined as "Fly's Eye Camera System" that allows the continuous monitoring of optical sky variability. The timescale window in which the instrument will operate covers ~ 6 order of magnitudes: from the data acquisition cadence in the range of minutes up to the expected range of several years of operation.

This proposed design yields an étendue that is comparable to the currently operating survey programs, such as the highly successful *Kepler* space telescope (Borucki et al., 2007) and the ambitious *Pan-STARRS* project (Kaiser et al., 2002). The *Fly's Eye Camera System* is a "high cadence + low imaging resolution + large solid angle coverage" instrument. Unlikely to e.g. *Kepler* that uses a "high cadence + high imaging resolution + small solid angle coverage" setup and *Pan-STARRS* that provides a "small cadence + high imaging resolution + large solid angle coverage" combination, the "Fly's Eye" allows the monitoring of a presently unexplored range of the domain of astronomical events (see also Fig. 1).

Persistent monitoring of several thousand bright, scientifically relevant systems can only be implemented by the means of smaller multiplexed instruments exploiting smaller imaging resolutions. In addition, transient detection in various known or undiscovered systems and statistical analysis is also feasible in this domain. Thus, such an instrument will provide a backbone of high resolution photometric, polarimetric, interferometric, infrared, spectroscopic and space-borne follow-up measurements as well. An extended, nearly uniform geographical distribution of $8-10$ "Fly's Eye" units would results in a light-grasp power comparable to the *Large Synoptic Survey Telescope* (LSST, see e.g. Ivezić et al., 2008). The *LSST* is the highest ranked ground based facility in the strategic roadmap of American astronomy

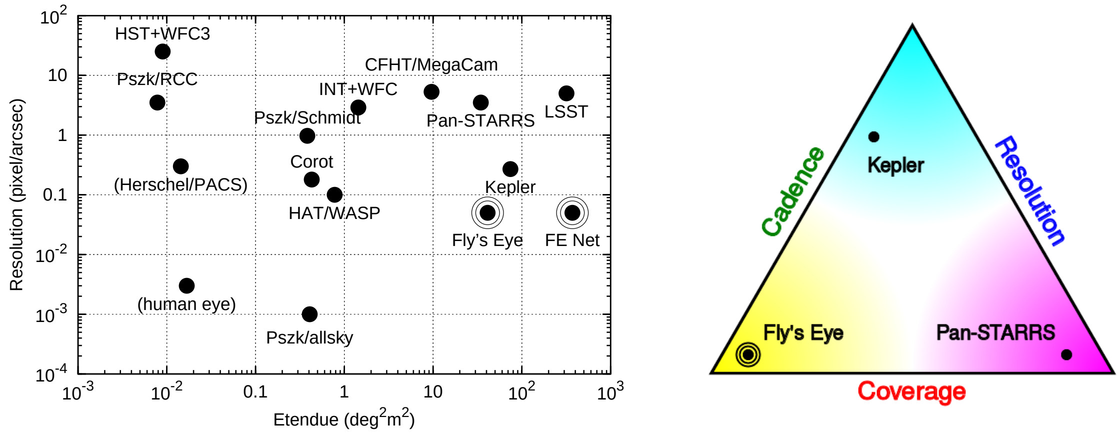

Figure 1: *Left panel:* the optical light-collecting phase volume, or étendue and effective resolution for various known, mostly optical telescope systems. The instruments denoted as Pszk/RCC, Pszk/Schmidt, and Pszk/allsky are installed at the Piszkéstető Mountain Station of the Konkoly Observatory and refers to the 1 m-class Ritchey-Chrétien-Coudé, the 60/90 cm Schmidt telescope and the allsky-camera, respectively. As it can be seen from the plot, the proposed design of a single "Fly's Eye Camera" unit yields a value that is comparable to the available instruments which have the largest étendue: a single unit of the *Pan-STARRS* telescope(s) and the *Kepler* space telescope. A network of nine "Fly's Eye" devices (see labelled as "FE Net") yields an étendue comparable to the proposed design of *LSST*. *Right panel:* the sampling cadence, solid angle coverage and resolution for some optical systems having an étendue of $30-70\,\mathrm{deg}^2\,\mathrm{m}^2$. The planned design of *LSST* has an étendue that is larger by nearly an order of magnitude than the instruments shown here but it will be located close to the point of *Pan-STARRS*.

for the next decade (Blandford et al., 2010). Furthermore, as it is discussed in more details later on, the "Fly's Eye" design will provide a continuous transition to the brighter targets from the fainter ones aimed to be observed by *LSST*.

As we will explain here, the design is also simple and robust (Sec. 2) to build a geographically extended network of this camera system, providing a more dense phase coverage of the observed events and a wider perspective to the sky (Sec. 3). The proposed scientific applications cover disciplines from within the nearby Solar System (including even the atmosphere of the Earth) up to extragalactic investigations (Sec. 4).

2 Timeline and instrument design

We foresee to execute the five-year work plan in three stages:

- First, the instrument platform will be designed and deployed.
- In the second step, we develop and commission a simplified camera system (with five cameras in total, covering the declination strip $30° \lesssim \delta \lesssim 65°$), including the specialized hardware and data reduction software components, while using the test data to refine the instrument platform.
- Finally, we deploy a full-scale version of the "Fly's Eye" device with all of the planned functionalities.

The steps of image processing are based on existing software solutions designed for batched, automatic and easily parallelizable utilities (Pál, 2009, 2011). We note here that surveys with large field-of-view optics have been initiated by Pepper et al. (2007) and there were attempts to implement permanent all-sky monitoring using completely fixed set of cameras (i.e., without any implementation for sidereal tracking) by Deeg et al. (2004).

The advance in consumer and computer electronics in recent years allows us to build this "Fly's Eye" device from commercially available and well-tested components with parameters that would not have been possible even a few years ago. Hence, by exploiting these hardware and optics, it is possible to design cost-effective instrumentation for scientific purposes. In the following, we detail the properties of specific cameras and lenses available in the marked from which the proposed design can easily be built and deployed.

The 19 cameras are mounted on a fixed assembly, i.e., the relative positions and field rotation angles are also kept fixed throughout the observations. We intend to employ the very recent and compact model ML-16803 of the FLI company and standard, commercially available Canon lenses with the focal length of $f = 85\,\mathrm{mm}$ with a rather fast focal ratio of $f/1.2$. This field of view will cover the sky all above the $30° \leq h$ horizontal altitude (i.e. half of the whole visible celestial sphere, up to

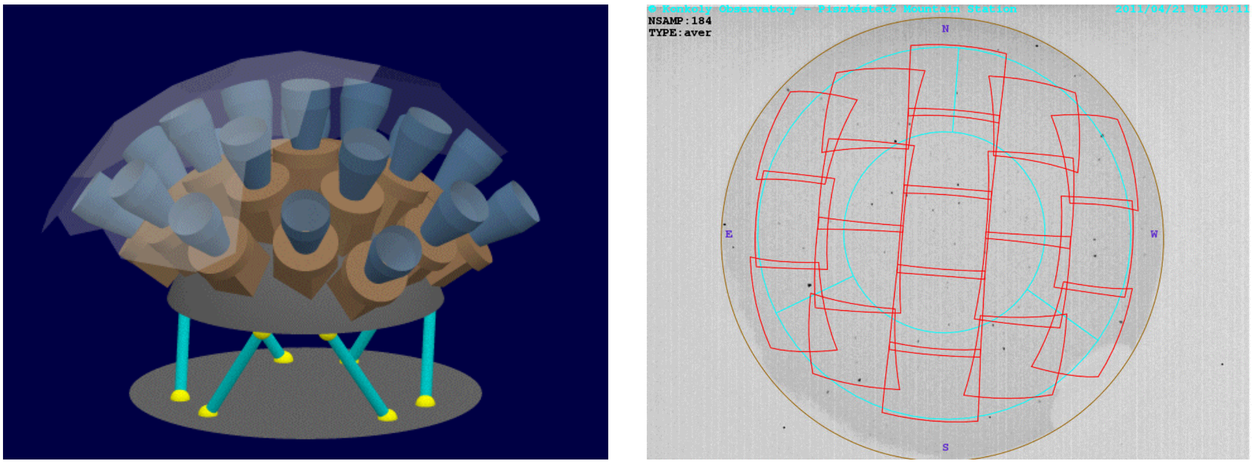

Figure 2: *Left panel:* a simple visualization of the camera mount. The payload platform – on which the 19 FLI Microline cameras have been mounted – are shown to scale. Hence, the diameter of the platform is approximately 55 cm while the effective diameter including the cameras and lenses is nearly 1 m. The lower, fixed platform and the hexapod strut drawings are merely figurative, but the expected distance between the two platforms are roughly $25 - 30$ cm (as it is implied by the figure scale). The mosaic dome is partly shown also to scale, as a transparent set of hexagonal elements. The size of the hexagonal elements are roughly $23 - 25$ cm. See also the movie found at `http://szofi.elte.hu/~apal/work/flyseye.avi` for a full view of the mount. *Right panel:* the field-of-view of the 19 cameras shown on an (inverted) all-sky image. Assuming a focal distance of 85 mm for the lenses and ML-16803 cameras as detectors, the field-of-view of each camera-lens pair will be roughly 26°. The placement and field orientation of the cameras are exactly the same as it is shown in the left panel. The two concentric circles mark the 30° and 60° horizontal altitudes.

airmasses $A \leq 2$), allowing the persistent survey of the sky with moderate imaging resolution. According to the specifications of the KAF-16803 detectors that are used by the ML-16803 cameras, this setup yields a resolution of $22''$/pixel. The resulting cumulative optical light collecting power (i.e. the étendue) of the system will be nearly $35 - 40\,\mathrm{deg}^2\,\mathrm{m}^2$, depending on the vignetting of the lenses. This large value places the whole device among the group of the instruments with the highest optical attendance, see also Fig. 1 for a comparison with known optical instruments. A visualization of the mount design concept is displayed in Fig. 2 along with the resulting sky coverage and the field of view of each camera-lens pair.

The main concept of the camera design are a) to minimize the number of moving parts and b) not to use specialized, uniquely designed and/or manufactured mechanical, optical or electric components in the device. This second "rule of thumb" allows us to have spare parts of all of the necessary components that can be replaced instantly upon a failure and hence, does not add a significant investment and maintenance cost. Therefore, one can expect a smooth and continuous operation of the camera system, since the simple design concepts allows a fast replacement of broken parts.

2.1 Camera mount and lenses

The camera platform will minimize the unique types of moving parts. In the history of automated telescope surveys we clearly identified this to be the main problem of reliable operation. The mount planned to be based on a hexapod-design (also known as Steward-platform[1]), that requires only identical mechanical elements and allows the desired motion independently of the placement of the mount support base. See also the left panel of Fig. 2 of a schematic drawing of the hexapod mount. By implementing only a "local sidereal tracking" using this hexapod mechanism, our design allows the tracking for only shorter periods of time and this limit is equivalent to the rotational domain of the camera platform.

In addition, the planned lenses feature built-in focuser motors, and these mechanisms can be controlled via standardized protocols that have documentations in the public domain. Hence, focusing can be implemented directly, without any additional components and only a board of custom electronics should be built to control the lenses via a computer interface.

2.1.1 Sidereal tracking

According to the current plans, sidereal tracking of the camera platform is performed during the exposures while

[1] See e.g. `http://en.wikipedia.org/wiki/Stewart_platform`

the local first equatorial coordinates of the platform would exactly be the same throughout the subsequent exposures. Therefore, during the image readout, the whole platform is slewed back to its initial position and performs the same apparent path in the next exposure and so on.

Currently, the expected exposure times are not longer than a few minutes, however, the placement calibration procedure requires images to be acquired in the same (expected) celestial frame. Thus, if we limit the maximum allowed span for sidereal tracking for ≈ 25 minutes (e.g. 5×5 minutes of exposition) it requires rotations of 6°, equivalently of a travel range of $\pm3^\circ$, cumulatively in all of the three axes (pitch, roll and yaw). Assuming a characteristic size for the camera platform of $55-60$ cm (see above), the total travel range of each hexapod actuators is in the range of ±30 mm.

Using the pixel size of $9\,\mu$m and a focal length of $f = 85$ mm, the resolution of the camera system is $22''$/pixel, that is equivalent to $\approx 100\,\mu$rad/pixel. Therefore, the expected *precision* of the positioning throughout the sidereal tracking is some tenths of a pixel, i.e. $\approx 15-25\,\mu$rad. Since the angular speed of the apparent celestial rotation is the same as it is computed from the rotation period of Earth, i.e. 2π rad/day, which is equivalent to $72.9\,\mu$rad/sec[2], regular updates in the hexapod platform position is needed $3-4$ times in a second.

In order to avoid the undersampling of the sharp stellar profiles, an additional vibration is also added in the pitch and roll axes accordingly during the exposures (in a nearly Gaussian pattern, with a standard deviation of $\approx 50-100\,\mu$rad in both pitch and roll directions). Since this update period of the hexapod position is definitely smaller than the period of few seconds that is needed by this vibration, this type of motion can well be separated from the primary sidereal tracking due to its lower frequency.

Since parameterization of the rotation via the pitch, roll and yaw axes does not imply any singularity (like a gimbal lock) for *arbitrary* small rotations (i.e. when the total rotation is $\rho \ll 90^\circ$), this mount can be employed for sidereal tracking on arbitrary geographical latitudes. Indeed, installing the mount to the poles of the Earth yields a pure yaw rotation while installing the mount on the equator yields a pure roll rotation (expecting the $x\pm$ axis pointing to north-south). On "temperate" latitudes, the sidereal rotation will be a combination of yaw and roll, while the pitch rotation is required only for correcting the polar alignment and perform the vibration blur (see above).

We should emphasize here that the calibration of the motion (sidereal tracking) can be done directly, using images from the sky. Since the astrometric precision of a single bright but not saturated star is some hundredths (or even less) in the units of pixel size, i.e. a few microradians, the whole image (with several tens of thousands of reference star) yields a calibration precision of some tens of nanoradians. The sky field centroid tells us the pitch and roll offset while from the sky field rotation, we can compute the yaw offset. In addition, using the fact that linear travel is not performed by the hexapod mount, the actuator lengths can also be calibrated directly based on the astrometric results. For instance, the roll, pitch and yaw rotations are implied by the variations of the actuator length ℓ_k $(1\le k\le 6)$ combinations of

$$\ell_2+\ell_3-\ell_4-\ell_5, \tag{1}$$

$$\ell_1+\ell_6-\ell_2/2-\ell_3/2-\ell_4/2-\ell_5/2, \tag{2}$$

and

$$\ell_1+\ell_3+\ell_5-\ell_2-\ell_4-\ell_6 \tag{3}$$

while the other three orthogonal combinations are kept constant. This is a similar procedure that can be applied for the "classic" bi-axial telescope mounts, where the polar alignments, motion axis deviations and zero-points are fitted via linearized transformations. Here, the joint position offsets and actuator length zero-points are fitted from a small series of sky images.

2.1.2 Hexapod parameters

Based on the calculations and estimations described in the previous sections above, the following list summarizes the criteria that are needed for the design of the hexapod platform.

- Payload: mass: $50-55$ kg, moment of inertia: $3.5-4\,\mathrm{kg\,m^2}$ (yaw), $1.5-2\,\mathrm{kg\,m^2}$ (pitch and roll), see also Fig. 2.
- Payload barycenter offset: $(0,0,0)$, it can be arbitrary and it is irrelevant for the problem.
- Platform travel length: $(0,0,0)$ (irrelevant).
- Rotation: $\pm3^\circ$, cumulative in the yaw and roll direction, $\pm1^\circ$ in pitch direction.
- Motion speed: $\approx 75\,\mu$rad/sec (during sidereal tracking), $\approx 2-3$ millirad/sec (at least, during repositioning).
- Precision (resolution): $\le 20\,\mu$rad. Accuracy (repeatability): $\le 200\,\mu$rad.
- Position update period : at least 250 msec with the precision of $20\,\mu$rad (it yields the $\approx 75\,\mu$rad/sec motion speed during sidereal tracking).

[2]Here, one day should be considered as a *sidereal* day, that is nearly $23^\mathrm{h}\,56^\mathrm{m}\,04^\mathrm{s} = 86164$ sec.

- Implied precision (resolution) for the hexapod actuators: $\leq 5-10\,\mu$m, implied accuracy (repeatability) for the hexapod actuators: $\leq 50-100\,\mu$m (assuming a characteristic platform size of ≈ 50 cm, however, it strongly depends on the actual arrangements of the joints).

The calibration is to be performed on-site at the precision level of tens of nanoradians: the hexapod platform can be calibrated to the celestial reference frame using real sky images. This calibration can be done directly (converting to pitch, roll and yaw offsets) or indirectly, i.e. applying to the actuator lengths.

2.2 Onboard computing

Due to the advance of low-cost embedded-level computer hardware (also known as "single board computers", SBCs), it is possible to integrate both the full data acquisition control and the preliminary image processing within the whole "observatory dome". In addition, the output (imaging data) are going to be available via higher level protocols such as TCP/IP and can be easily transmitted via non-copper based media that not only helps the full galvanic isolation of the complete hardware but such protocols and media are definitely more fault tolerant and versatile than the primary data acquisition media (e.g. USB). The relevance for the consideration of minimizing the moving components is the fact that SBCs do utilize neither cooling fans nor hard drives, i.e. these are fully functioning "personal computer"-class devices with no moving parts at all.

Wherever it is possible, we plan to employ off-the-shelf components. These include the optics, filter wheels, cameras, parts of the mount and motion control devices. We plan to build the "observatory dome" itself, including the glass-mosaic dome, insulation and other inner components (fixed and non-moving assemblies, control computer racks and enclosures), using the machining facilities of the Konkoly Observatory and/or optionally involving independent contractor(s). The dome will only have a chord for power supply and a pair of fiber optics connection for controlling and downloading the data. Optionally, some other communication protocols (wireless: Wi-Fi or GSM) can also be available as a fallback – such network devices are also available for SBCs.

One of our preferred SBC model is the ALIX board series of PCEngines[3], which provides models where all of the high level peripherals that allow the communication using various media (RS232, USB, Ethernet) but lacks functionality that otherwise not essential in an embedded system (such as a graphics card). The background storage is supported by CompactFlash (CF) cards: a slot for a single CF card is integrated on the board from which the operating system boots up.

The power consumption of such devices are a few watts, thus even a small "cluster" of boards can be embedded in the camera and motion control system and linked together via ethernet/internet. The ALIX system board model 6E2/6F2[4] provides two Ethernet, two USB, a single serial port (RS232) and an onboard I^2C bus host. Therefore, one board can control two cameras (out of the 19) without any external USB hubs (and therefore without losing the image download bandwidth). All in all, a dozen of such boards can be able to safely control both the image acquisition, the hexapod motion and the auxiliary devices (pressure, thermal and humidity sensors, via the I^2C bus).

3 Further network developments

Since the "Fly's Eye" camera observes the sky above the $h = 30^\circ$ horizontal altitude, it monitors simultaneously almost exactly the one fourth of the whole celestial sphere. From a temperate geographical latitude (e.g. from Hungary, at $\varphi \approx 47^\circ$), the Sun is below the horizon more than 12° within a time fraction of close to 0.4 on average throughout a year[5]. Hence, from this location, the proposed camera system observes approximately the $(1/4)\cdot 0.4 = 10\%$ of the events that are above its precision level and/or detection threshold. A natural way of increase this ratio is to install similar devices at other locations on Earth. The smaller the geographical distance between two such devices, the larger the overlap both in spatial coverage and in time. In addition, monitoring the sky simultaneously from distinct (and far) locations significantly decreases the one-day aliases in the phase domains of periodic events. Moreover, synchronization in image acquistion also aids the accurate data reduction since the overlapping regions observed by distinct devices have to be exactly the same. This approach makes the characterization of systematic noise sources much more easier. For instance, such a synchronization can be accomplished by starting the exposures at every three minutes in Greenwich (i.e. some sort of "universal") sidereal time, or, in other words, without the need of any preferred site or unit.

Hence, we will initiate further collaborations and seek for another types of grants that will cover the costs of building a network of these devices all around the world. Negotiations have also been started with the

[3] `http://pcengines.ch/`

[4] `http://www.pcengines.ch/alix6e2.htm`

[5] This is the limit coined as the beginning of the astronomical twilight, when the sky background is low enough to observations from point sources become feasible but it is not completely dark. The ratio of 0.4 slightly increases to southern latitudes and decreases as one goes to north.

staff of Teide Observatory, Tenerife, Canary Islands. An example configuration of 9 devices located on various places on Earth with well-known infrastructure suitable for installing astronomical instrumentation is displayed in Fig. 3.

4 Scientific goals

The "Fly's Eye Camera System" will consist of 19 wide-field camera-lens pairs, with built-in filter selector holding three Sloan filters of g, r and i passbands. This filter setup is a subset of the filter used by current or proposed surveys (Sloan Digital Sky Survey, Large Synoptic Survey Telescope, etc.) and optimizes the observations by acquiring in the spectral bands where the CCD detectors are the most sensitive. Based on the known characteristics and our former experiences related to the planned detector and the optical properties of the $f = 85\,\mathrm{mm}$, $f/1.2$ lenses, the "Fly's Eye" camera system will provide an effective resolution of $22''$/pixel and a photometric precision of 4-500 ppm on a cadence of 3 minutes for point sources of $r = 10$ magnitude in apparent brightness, and deliver this for 1/4 of the entire sky at any given moment (see Sec. 2 for the description of the proposed instrument). Covering an intensity range of nearly $8-9$ magnitudes, our faintest targets will be at the level where other synoptic sky surveys (*LSST*, *Pan-STARRS*) have their saturation limit. Hence, the "Fly's Eye" design yields complementary data, with a much more frequent sampling cadence. There are many kind of transient events as well as moving targets that both requires different kind of detection and characterization methods and the uncertainties of the respective measurements are also estimated differently. In the following, we detail the list of goals and proposed key projects in which the "Fly's Eye Camera System" provides significant scientific yield. Moreover, the proposed instrument and its unique location on the cadence – coverage – resolution diagram (Fig. 1) implies the same paradigm what is quoted related to LSST, namely "ask not what data you need to do sour science, ask what science you can do with your data" (by Ž. Ivezić). In the following, we detail relevant scientific applications in which the "Fly's Eye" project will have a significant contribution. These topics are split into three parts, by focusing on the Solar System, on our Galaxy and on extragalactic sources.

4.1 In the Solar System

Meteors. Even with its moderate resolution, the "Fly's Eye" device is capable to detect meteors and map these with an effective resolution of $\sim 10\,\mathrm{m/pixel}$. This resolution allows not only the characterization the fine structure of meteoroid paths but yields very precise constraints on the orbit of the infalling object. Because of its large light collecting power and an unbiased sampling of sky images, from these "Fly's Eye" data, a more accurate distribution of Solar System dust distribution can be derived. This would be valuable information to restrain the theories of planet system formation, one of the key questions in today's astronomical research.

Rotation and shape of asteroid family members. Due to their irregular shapes and other surface structures, most of the asteroids in the Solar System exhibit observable variations in their brightness. Since both the asteroids and the observing location (Earth) orbits the Sun, the apparent direction relative to the given asteroid also changes. Hence, it is obvious that the detected flux changes will encode information about the direction of the rotational axis as well as the shape irregularities of the object. Databases and models exist where such reflected light variation measurements are collected and the shape and rotation parameters of the objects are characterized (Ďurech, Sidorin & Kaasalainen, 2010). However, the "Fly's Eye Camera System" will provide a continuous monitoring of the brightest asteroids, namely assuming a detection limit converted into absolute magnitudes of $H_{\mathrm{V}} \lesssim 12$, the number of these asteroids (for which precise models are predicted) might increase by an order of magnitude or even more. Hence, an almost unbiased statistics of rotation and shape parameters of asteroid family members will be available, that constrains several aspects of Solar System dynamics and evolution.

Near-Earth objects. Near-Earth objects represent a potentially hazardous subset of small bodies in the Solar System due to the proximity of their orbits to that of Earth. Objects passing the orbit of Moon and have a diameter larger than a few tens of meters will be detected and monitored by our instrument. For instance, prominent objects like 2005 YU_{55} and 2012 BX_{34} recently had a flyby at 0.85 and 0.15 lunar distances, and had a respective peak brightness of $V = 11.2$ and $V = 13.9$ magnitudes: well above the detection threshold.

"Fly's Eye" images can be used not just to monitor identified but also to search for unknown NEOs. Since S/N ratio on individual images are not sufficient to detect fainter objects we will implement highly specialized image processing techniques, such as the Hough transformation. Once the track parameters (direction, speed, curvature, etc.) are known such digital "tricks" are easy to perform. On the other hand to search for the best-fit track parameters in an appropriate parameter domain requires exhaustive computing power. In other words, due to its large étendue, "Fly's Eye" image series contain large amount of information about such objects, and it is merely a technical problem to extract these.

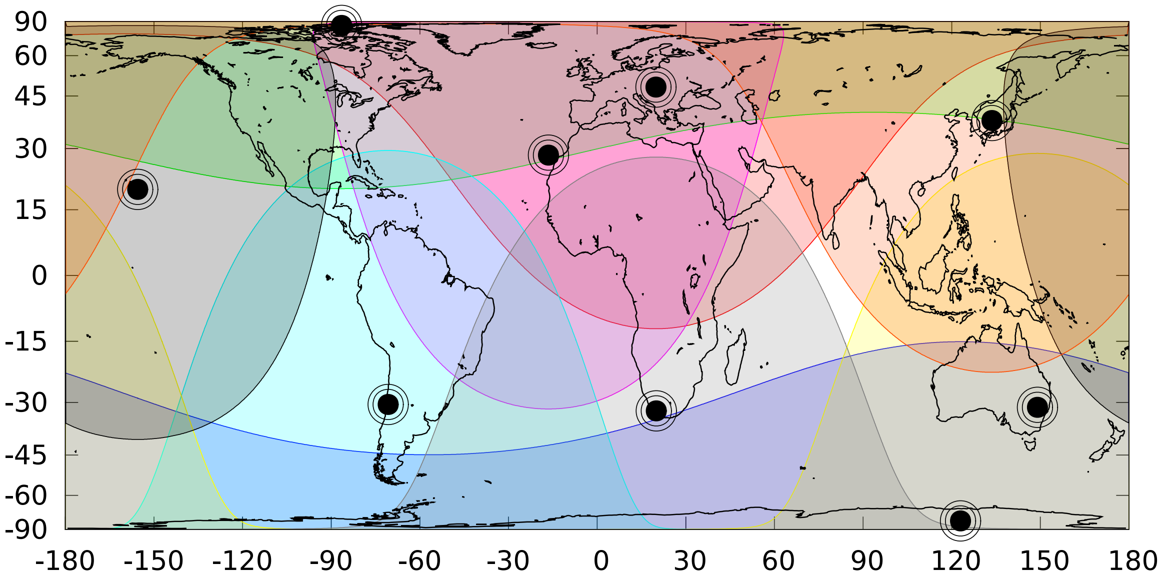

Figure 3: An example configuration and the yielded visibility coverage of 9 "Fly's Eye" devices, distributed nearly homogeneously on the Earth (using Lambert cylindrical equal-area projection). See text for further details.

4.2 Stellar and planetary astrophysics

Young stellar objects. Young stellar objects are complex astrophysical systems and show signs of both quasi-periodic and sudden transient, eruptive processes. By monitoring their intrinsic variability, one is able to obtain several constraints regarding to the ongoing processes. These transients or nearly periodic observed changes in the visible flux are connected to the presence of gas as dust which form a circumstellar disk around the young star. This disk also has a complex dynamics that can lead either to obscuration of light coming from the central star or to sudden brightening in the observed flux when the accretion rate significantly increases (Hartmann & Kenyon, 1996).

Outbursts in the inner parts of a circumstellar disk attract the attention of many high-end instruments, both space-borne (e.g. *Spitzer*, *Herschel*) and ground-based. Such outbursts are almost always detected in visible wavelengths and by combining these optical data with subsequent infrared photometric or spectroscopic information, it leads to spectacular results that help us to understand the formation of not only the stars but the planets or planetary disks around these stars (Herbig, 2007; Ábrahám et al., 2009).

Persistent monitoring of numerous young stellar objects or candidates for young stellar objects will reveal the nature of the currently unexplored domains of stellar birth. Since observing campaigns are organized mostly on daily or yearly basis, the behaviour of such systems is practically unknown on other timescales. However, a more frequent and homogeneous sampling of such young systems will aid to have a more complete view for these, being either in eruption or in quiescent state (Kóspál et al., 2011).

The "Fly's Eye" device allows a rather homogeneous sampling of these systems, being either known objects, candidates or currently unidentified ones. Moreover, shorter timescale behaviour constraints currently rarely studied phenomena of these systems. For instance, flares or other stellar surface transients are related to processes on a smaller spatial scals and also correlates with the magnetic activity.

Stellar activity. Stars with magnetic activity show photometric variability on all the time-domains of the planned instrument, from minutes through hours to years, just like the Sun does (Strassmeier, 2009). Continuous monitoring of the sky opens up a new research area for active stars: the instrument makes possible to obtain good flare statistics since flares occur on minutes-hours timescale (see e.g. Hartmann et al., 2011; Walkowicz et al., 2011), starspot evolution and differential rotation (the timescale is from hours to weeks, Oláh et al., 1997) and activity cycles (years timescale, Oláh et al., 2009) of the same star. One example of the very few active stars studied in all timescales is EY Dra (Vida et al., 2010), which, beside a spot evolution study and the determination of the shortest known activity cycle, presents data and models of flares observed only by blind luck. If active stars, like EY Dra, are monitored continuously, the measurements will give us data in the broad time range of the magnetic phenomena. By now, the Sun is the only active star, on which we have full picture of the manifestation of the magnetic field. In the solar active nests spots, faculae, plages and flares are observed and their spatial correlation studied. The proposed instrument allows similar research on different kinds of active stars individually, which is unprecedented. The results give us a broader view of the magnetic activity of stars of different ages. Through this, we will be able to reconstruct the past of the Sun and foresee its future.

Eclipsing binary stars. The observation of wide eclipsing stellar binaries provide an independent, direct and rather accurate estimation for the masses and radii of the stars (see, for example, Latham et al., 2009). Therefore, these astrophysical systems play key role in the verification of stellar evolution theories and models. The wider the binary system, the smaller the gravitational interaction and hence the tidal distortion between the components. Although it is relatively easy to discover close binaries, wider and *known* ones are definitely less frequent due to both the geometric probability (i.e. the line of sight falls close to the orbital plane of the system) and the longer period that makes the discovery more sensitive to observational biases. Due to the continuous monitoring of the sky, the "Fly's Eye" device will provide numerous candidates for wide eclipsing stellar binaries.

Transiting extrasolar planets. Similarly to the eclipsing systems, our proposed instrument is expected to yield numerous candidates of transiting extrasolar planets. Since this telescope system monitors the whole sky simultaneously, it can provide candidates with longer periods as well as on a longer timebase, shallower detections might also be found (and hence, the radius of the given planet can also be smaller). Projects like SuperWASP (Pollacco et al., 2004) or HATNet (Bakos et al., 2004) yielded several dozens of discoveries, hence this type of search effort turned to be a rather effective way of planet hunting.

Furthermore, measurements of *known* transiting extrasolar planetary systems characterize how precise the whole instrument setup is, including the qualification of the data processing steps (Pál et al., 2008). Moreover, a "Fly's Eye" device located on northern temperate latitudes will monitor the *Kepler Field* (Borucki et al., 2007). This field is also a rich source of hundreds of transiting systems for which such auxiliary series of photometric measurements are valuable in further studies.

Cepheids. By their well-known period – luminosity relation, the Cepheid types of variable stars provide the "standard candles" in the calibration between galactic and extragalactic distance scales. Therefore, their importance in the scaling of the Universe is undoubted. Various types of Cepheids also exhibit several unsolved features (see e.g. Szabados, 2009), thus these are important candidates for the space mission Gaia (Eyer et al., 2009, 2011), which will offer a direct calibration of the distances via astrometric measurements. However, Gaia provides approximately less than a hundred of photometric data on individual stars, therefore additional photometric support is required to reveal other intrinsic properties (colors and color variations, period changes, etc.) of these stars. Due to its homogeneous data acquisition scheme, the "Fly's Eye" project will be an ideal instrument to provide such ground-based follow-up and confirmation data, even for stars that are detected by Gaia after the initiation of this project (thus, for these targets, *a priori* data will also be available).

4.3 In the extragalactic environment

Supernovae are transient events occurring mostly in another galaxies and widely used as standards for distance determination. Continuous monitoring of brighter supernovae in nearby galaxies yield valuable data that can be exploited by combining other kind of measurements. The "Fly's Eye" camera is capable to observe the brightest supernovae directly even up to a month during their peak brightness (see e.g. Vinkó et al., 2012) and by combining images, it is possible to go even deeper in brightness using more sophisticated ways of photometric techniques. Study of supernovae light curves is undoubtedly essential to understand the large scale structure and evolution of the Universe. Although cosmologically relevant supernovae are faint transients, observing nearby events yield an accurate calibration for this method of distance determination. In addition, the "Fly's Eye" device can provide *a posteriori* photometric data series of bright supernovae that are discovered after their peak brightness has been passed.

References

Ábrahám, P. et al., 2009, Nature, 459, 224

Bakos, G. Á. et al., 2004, PASP, 116, 266

Blandford, R. D. et al. (Committee for a Decadal Survey of Astronomy and Astrophysics): *New Worlds, New Horizons in Astronomy and Astrophysics* The National Academic Press, Washington DC, USA (available from `http://www.nap.edu/catalog.php?record_id=12951`)

Borucki, W. J. et al., 2007, ASP Conf. Ser., 366, 309

Deeg, H. J.; Alonso, R.; Belmonte, J. A.; Alsubai, K.; Horne, K.; Doyle, L., 2004 PASP, 116, 985

Ďurech, J.; Sidorin, V. & Kaasalainen, M. 2010, A&A, 513, 46

Eyer, L. et al. 2009, Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics, p.45

Eyer, L. et al. 2011, EAS Publications Series, Volume 45, pp.161-166

Hartman, J. D. et al. 2011, AJ, 141, 166

Hartmann, L. & Kenyon, S. J., 1996, ARA&A, 34, 207

Herbig, G. H., 2007, AJ, 133, 2679

Ivezić, Ž. et al: *LSST: from Science Drivers to Reference Design and Anticipated Data Products*, available from `http://lsst.org/lsst/overview/`

Kaiser, N. et al, 2002, in the proceedings of "Survey and Other Telescope Technologies and Discoveries", edited by Tyson, J. Anthony; Wolff, Sidney. Proceedings of the SPIE, Volume 4836, pp. 154-164

Kóspál, Á. et al., 2011, A&A, 527, 133

Latham, D. W. et al. 2009, ApJ, 704, 1107

Oláh, K. et al. 1997, A&A, 321, 811

Oláh, K. et al. 2009, A&A, 501, 703

Pál, A. et al. 2008, ApJ, 680, 1450

Pál, A. 2009, PhD thesis, Eötvös Loránd University, Budapest, Hungary (arXiv:0906.3486)

Pál, A. 2012, MNRAS, 421, 1825

Pepper, J. et al. 2007, PASP, 119, 923

Pollacco, D. et al., 2006, Ap&SS, 304, 253

Strassmeier, K. G. 2009, A&ARv, 17, 251

Szabados, L. 2009, EAS Publications Series, Volume 38, pp. 65-72

Vida, K. et al 2010, AN, 331, 250

Vinkó, J. et al. 2012, A&A, accepted (arXiv:1111.0596)

Walkowicz, L. M. et al. 2011, AJ, 141, 50