PASS — a Permanent All Sky Survey for the Detection of Transits

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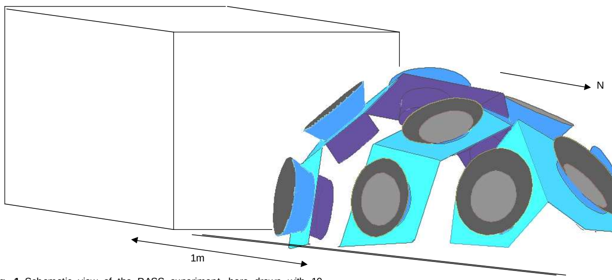

Fig. 1 Schematic view of the PASS experiment, here drawn with 10 cameras. The box in the background is the removable enclosure.

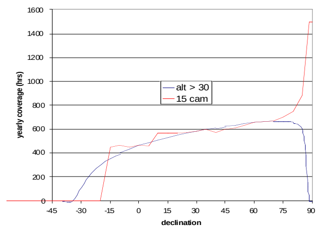

Fig. 3 (on left). Temporal coverage in dependence of declination, assuming a yearly total of 1500 hours of clear observing conditions (200 nights of 7.5 hours) for a site at 28.5¡N. Coverage varies much less with right ascension, due to variations in nightsÕ lengths and weather conditions throughout a year. The coverage shown here is the average for stars at any right ascension.

¥red line: coverage from a uniform minimum altitude of 30¡ above horizon. The North Pole, at an elevation of 28.5¡, is not covered.

¥blue line: coverage by the 15 camera system shown in Fig. 2. A small region around the celestial North Pole is now circumpolar by lowering the altitude limit to 27¡ at very high northern declinations.

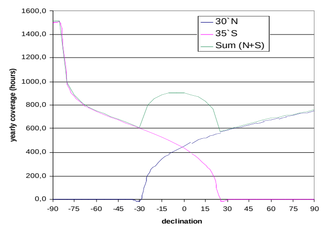

Fig. 4. As Fig. 3, showing temporal coverage from a northern (30¡N) and southern(35¡S) site, both with 30¡ altitude limits. If night-hours do *not* overlap among the sites, coverage near the celestial equator will be the sum from both sites, and a relatively uniform coverage is achieved over the *entire* sky.

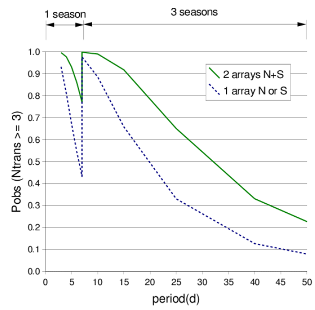

Fig. 5. Probability that transiting planets will be detected by observing at least 3 transits. The green line shows this probability for a configuration of two arrays, based on 650 hours of coverage per year (compare to Fig. 4). The blue line is for a single array, based on 400 hours per year. The left side, for periods up to 7 days, is based on observations from a *single* season, whereas for periods of 7-50 days, observations spanning 3 years were assumed.

Overview:

PASS will be an array of wide angle CCD cameras, that will permanently survey the entire visible sky from one or more locations, for the detection of planetary transits and of any other transient phenomena in the sky.

Objectives:

Detection of giant planet transits of *all* stars in the sky, with a magnitude limit of V ~ 10.5. About 120 planets may be detected.

Detection of any temporal astronomical phenomena:
- ¥detection and follow-up of stellar variabilities with low amplitudes (up to 0.1%, depending on stellar brightness and frequency)
  - -variable stars of any kind
  - -flares
- ¥Detection of supernovae
- ¥Recording of frequency and direction of meteorites
- ¥Detection of optical counterparts to gamma rays and Ôoptical flashesÕ
- ¥stellar occultations (e.g. by Kuiper-belt objects)

Sky quality and meteorological statistics:
- ¥Recording of sky brightness and extinction in all directions
- ¥Percentage of clear sky, clouds
- ¥Detection of satellites and airplanes (intrusions into protected sky area over observatory)

Concept:

An array of wide angle CCD cameras, with commonly available optics (F~50mm) for photographic cameras and CCD cameras available for advanced amateurs, that would cover the entire visible sky. The cameras would be placed on a common fixed mount, which has the advantages of mechanical simplicity and avoids any guiding errors, as stars will move over exactly the same pixels every night, which allows a very precise calibration of pixel, and inter-pixel response functions. Only the psf of the stellar images would vary, but from observations of many nights the response of the CCD below the stellar track can be characterized for all commonly appearing psf-widths. The common mount should be adjustable in a small range around the precession axis, to keep stars moving over exactly the same pixels during the course of the survey. The array should be within an enclosure that is completely removable **(Fig. 1)**.

The system:

A system based on f=50mm/f1.4 lenses for common high quality 36mm SLR cameras (Canon or Nikon for example), with a Kodak KAF-1001E CCDs of 24.6 x 24.6 mm size and 1024^2 pixels (available with cooling and electronics from several vendors) would have a field of view (fov) of 28.5¡. **Fig. 2** shows that **15 cameras** of that type give nearly complete coverage of the sky above 30¡ altitude. The experiment would need to be mounted on a sturdy platform —such as the roof of an existing building —and be covered with a completely removable enclosure with a size of about 2 x 1.5 x 1.5m. With a pixel size of about 100Ó an adjustment for precession (maximum 50Ó/yr) may have to be undertaken every two months.

Images with exposure times of about 60 seconds will be co-added and saved to disk every 500 seconds.

The experiment will thus generate about 7-800 images every night, each with a size of 2 Mbytes. The nightly total of 1.5 — 2 Gbytes of data can be saved on a single DVD disk.

Coverage:

The sky above 30¡ altitude has a spatial angle of $\Omega_{>30} = 1\pi$ rad^2. Thus, anytime a _ of the entire sky will be observed. The amount of time that a star can be observed during the course of a year depends primarily on its declination and on the observatoryÕs geographical latitude **(Fig. 3).** Coverage at high northern latitudes depends critically on the altitude limit; stars at the stellar equator would be visible about 1/3 of the yearly night-time, and coverage declines rapidly towards southern declinations.

Coverage of southern declinations could be achieved from a similar observatory located at 30-40¡S, that ideally should be located at an opposing *longitude* (Australia, for example). For stars near the celestial equator, the coverage with such an observatory in an antipodal position would then be ddoubled (as there will be no overlap; **Fig. 4**). With either one or two instruments, high detection probabilities of transiting planets up to several weeks period can be achieved within a few seasons of observations (**Fig. 5**).

Numbers of stars surveyed and expected planet detections

Within the bright stars (V < 12), about half are Main Sequence stars. From a *single* northern location with a southern declination limit of —17.5 ¡, about 65% of the entire sky would be observable with a coverage of better then 400hrs/yr. With 3 years of observations, coverages of at least 1200 hours should be achieved, which will allow the detection of planets of orbits of less then 15 days if 6 transit events are required. Longer coverages would increase the accessible orbital periods, and lower to some extent the size limit on detection due to the presence of more transits.

Such an array could survey about 250 000 stars to magnitudes of V~10.5 with sufficient precision for the detection of giant planet transits (photometry of better then 0.7%). Assuming that 1% of all MS stars have close giant planets, and that their probability for transits is 5%, on the order of 200 planets should be detected.

An ideal complement would be a similar array in the southern hemisphere, to obtain a true all-sky survey (of about 400 000 stars), with greatly improved coverage near the celestial equator. This should increase the amount of detections by 50-90%.

Due to the brightness of the sample stars, planets detected by such an array would also constitute the best sample for any detailed follow-up studies.

Simulations and photometry

Fig. 6 shows a simulated field as observed by one of PASSÕs camera and the sequence to derive the aperture masks. Simple aperture photometry through these masks was then performed. The photometric precision shown in **Fig. 7** gives the error from measuring the same simulated stars in these apertures in 10 frames (comparable to observing the same field in 10 nights at the same sidereal time). This takes into account photon noise from objects and background, and noise from scintillation.

PASS-ZERO

Funding to build a prototype with one CCD camera has recently been approved by the Spanish Science Ministry. The principal aim is a feasability study, outlining the capabilities of the instrument in all aspects. The prototype will also serve to generate real data that are needed to develop and optimize the data acquistiion strategies and the reduction pipeline. This protoype is expected to become operational this year, and will be housed at the Obsv. de Teide of the IAC.

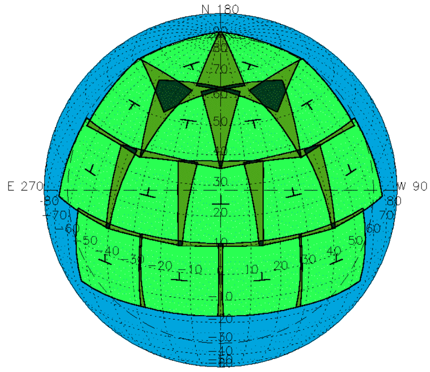

Fig. 2 Local all-sky view from a location at 28.5¡ N, showing camera positions for a system of 15 units (each with a field of view of 28¡x28¡), in orthogonal projection. Coordinate lines are declination and hour angle; also indicated is an altitude of 30¡ (long dashes). In this set-up, there is no coverage below declinations of —17.5¡,as good temporal coverage of stars further south cannot be obtained (see Fig. 3). Further north, the sky is completely covered for altitudes > 34¡, with an average limit around 30¡. Other camera positionings have been evaluated, but for a f.o.v of 28¡ this is the most efficient one.

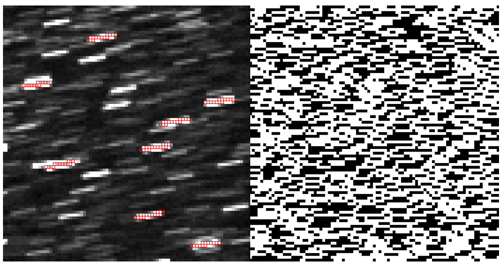

Fig. 6. **Left**: simulated PASS star field for an exposure of 60 seconds. The size of the field is about 2 x 2 degree. The brightest star is of 4th mag, several have 6-7 mag, and the faintest ones are 14-15mag. The red boxes over the brightest stars shows how the aperture mask is being build up, starting with the brightest stars. **Right**: final aperture mask, where the maximum number of non-overlapping traces have been fitted in.

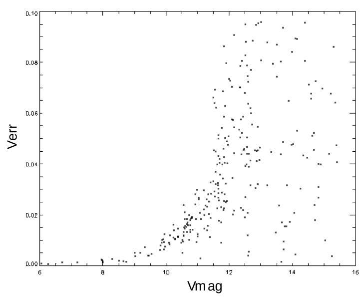

Fig. 7. Photometric error that has been achieved in 10 simulated images with the apertures of Fig. 5. Errors that are Ôtoo goodÕ result from the blending of a bright star within a faint starÕs aperture. Photometric errors suitable for transit-detection can be expected up to V~11.