PASS, an All Sky Survey for the Detection of Transiting Extrasolar Planets and for Permanent Variable Star Tracking

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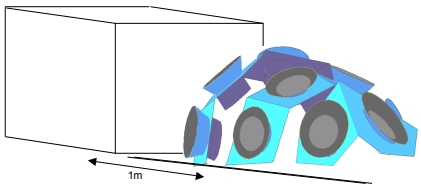


Fig.. 1 Outline of the PASS experiment, here drawn with 10 cameras. The box in the background is the removable enclosure.

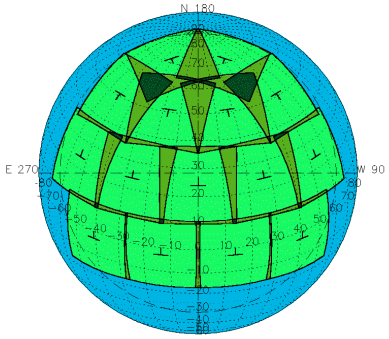


Fig. 2 Local all-sky view from a location at 28.5° N, showing camera positions for a system of 15 units (each with a field of view of 28°x28°), in orthogonal projection. Coordinate lines are declination and hour angle; also indicated is an altitude of 30° (long dashes). In this set-up, there is no coverage 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. For a location at DomeC, configurations with a few more cameras would be required, in order to take advantage of the possibility to obtain good observations at lower altitudes down to about 15°.

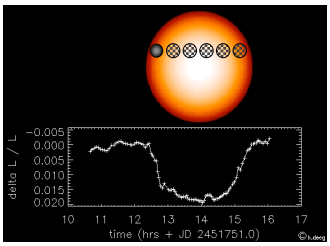


Fig. 3 Sketch of a transit of a giant planet. The corresponding lightcurve (lower panel) is from actual observations of HD209458.

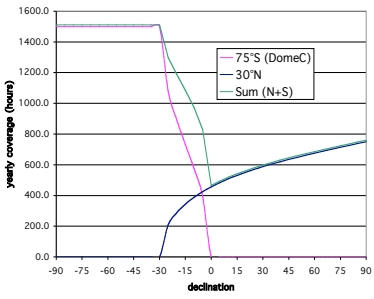


Fig. 4 The expected number of hours that a star at a given declination can be observed in one year (yearly coverage) . A yearly total of 1500 hours of good observing conditions at Dome C (violet line) and for a site at 30° North (blue line) is assumed, with altitude limits of 30° from the northern site and 15° from Dome C. Coverage for stars accessible from both sites may be summed if night-hours don't overlap (green line) . Coverage varies little with right ascension,

Overview:

The 'Permanent All Sky Survey' (PASS) will consist of arrays of wide angle CCD cameras, that will permanently survey the entire visible sky from several observing sites. Its major objectives are the detection of planetary transits and the permanent tracking of any variable or transient phenomena in the entire sky. A prototype with 2 cameras is currently being set up at Teide observatory, Tenerife. Also, the location of a prototype for wintering over at Dome C is proposed. The wide range of objectives of PASS and its easily extensible multi-site instruments may encourage further groups to join this project.

The Objectives of PASS:

i) The detection of giant planet transits (Fig. 2) of *all* stars in the sky, with a magnitude limit of V ~ 10,5. About 30 planets may be detected.

ii) 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 'optical flashes'
- •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:
Arrays of wide angle CCD cameras, with commonly available optics (F~50mm) for photographic cameras and CCD cameras available for advanced amateurs (**Fig. 1**), that would cover the entire visible sky at a given observing site (**Fig. 2**) in the search for planetary transits (**Fig. 3**). 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. An array in the northern hemisphere and one in the South would be able to cover the entire sky. For the southern location, a setting at DomeC can be expected to give better observational coverage and photometric precision than at a 'normal' good observing site like Paranal in Chile.

The Baseline Instrument:

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, 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 100", an adjustment for precession (maximum 50"/yr) may have to be undertaken every two months.

Images with exposure times of about 20 seconds will be obtained in synchronization with sidereal time. This synchronization will allow the taking of images at identical hour angles every night, which allows the direct application of difference imaging techniques between images taken at identical sidereal times, but in different nights. The expected data volume for one 15-camera array in 8 hours of observations is about 4.5 Gbytes (co-adding blocks of 10 images is assumed here).

Survey Coverage:

The sky above 30° altitude has a spatial angle of $\Omega_{>30} = 1\pi$ sterad. Thus, anytime a quarter of the entire sky will be observed by one array. The amount of time that a star can be observed during the course of a year depends primarily on its declination and on the observatory's geographical latitude **(Fig. 4).** At a mid-northern (or southern) site, coverage of stars near the celestial pole depends critically on the altitude limit (only a small zone is circumpolar, if at all); stars at the stellar equator would be visible about 1/3 of the yearly night-time, and coverage declines rapidly towards southern declinations (blue line in fig. 4). From a location at DomeC, and assuming an altitude limit for observations of 15° above the horizon, all stars south of –30° declination are circumpolar, while obtaining lower coverage for stars closer to the celestial equator (violet line). For stars in the circumpolar zone, yearly observational coverages that are 2-4 times higher than would be obtained from a mid-latitude observing site can be achieved. That is, **an instrument at DomeC obtains in one winter season for most stars coverages that are equivalent to about 3 years of observations from a mid-latitude site.** With a southern and a northern site, coverages of at least 1200 hours should be achieved in 3 years for stars at any declination, which will allow the **detection of planets with orbital periods of several weeks**. 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.

The entire sky has about 250 000 stars to magnitudes of V~10.5, on which photometry of sufficient quality may be obtained (see next section). Assuming that 25% of these are Main Sequence stars suitable for transit detection, and 1% of them have close giant planets, and that their probability for correct alignment to produce transits is 5%, **about 30 planets should be detected.**

The main motivation of PASS is however *not* the detection of huge numbers of planets but:

Due to the brightness of the sample stars, planets detected by PASS produce transits with relatively high S/N and would constitute the best sample for any detailed follow-up studies on larger telescopes.

Photometric precision

Fig. 5 shows magnitude errors that were computed for the major noise sources for 20 second integrations at a normal good high-altitude observing site and at Dome C. The expected **main advantage of a Dome C location lies in the much lower scintillation noise**. Due to the small optical aperture of the cameras, this noise is dominant with the brighter stars. At the dome C location, however, photometry for stars in the magnitude range of major interest (7-11 mag) would be dominated by photon noise, whereas at a 'normal observing location', scintillation dominates for stars as faint as 9.5mag. A second, lesser improvement from the DomeC location can be expected from a somewhat darker

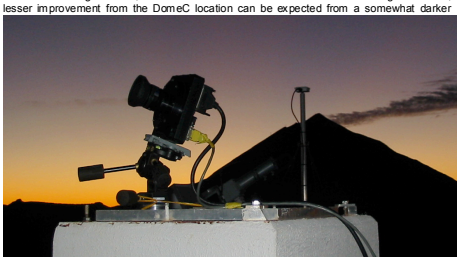


Fig. 6 'First light' of prototype at Teide observatory on 16 Jan 04 with an AP10 (2k x2k) camera (loaned by K. Horne, Univ. St.Andrews)

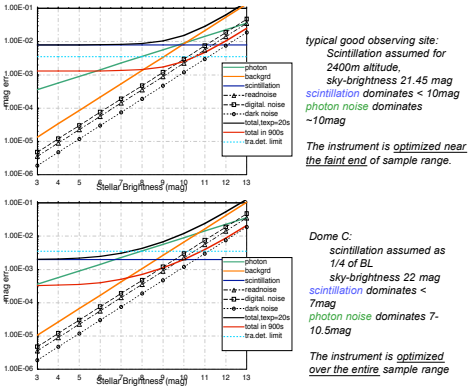


Fig. 5 Magnitude errors (Noise over Signal) from various noise sources at a typical good observing site (above) and at Dome C. All lines (except the red one) are assumed for a single 20 second exposure. The red line is the mag error in 900 sec when summing individual 20sec exposures. The blue line 'tra. det. limit.' indicates the photometric precision (about 3mmag) that is required to detect giant planet transits in 900 sec integrations. Stars brighter than 5th mag are being saturated (not shown)

The PASS prototype

Verification of the noise figures of Fig. 6 is the major objective of a 2-camera prototype of the PASS instrument. First tests have been undertaken since January 2004 at Teide Observatory, Tenerife (**Fig 6**). A small dome is currently under construction, which is required to obtain a more stable environment for more detailed and longer-duration performance tests. Individual 60 second exposures (**Fig 7**) allow straightforward visual identification of stars at 11th magnitude, and a photometric reduction chain is currently under development as part of a PhD thesis.

Prototype at Dome C

A modified prototype might be placed at Dome C. This should require only relatively few adaptations of the current prototype, since its only moving part is the camera shutter. With the recent release of very large format interline CCD chips (Kodak KAF11000), the shutter would become unnecessary as well. On the other hand, interline chips do have a lower quantum efficiency and their use for photometry requires further study. An alternative might be the enclosure of the entire prototype in a small box with an optical window and heating to the regular operating temperatures for CCD cameras, of about -10C. With the prototype being a very small instrument, easily transportable in a piece of luggage, a first placement of an astronomical instrument for over-wintering could be achieved with relatively small investments and preparations. Actual scientific data-taking may also be started already with the prototype. If it is pointed at a region at high celestial latitude (near the South pole), a 1-camera system already achieves a high temporal coverage of the stars under observation, which is suitable for the search for transits and long-term coverage of variable stars.

Future development of PASS

The principal goal of the current prototype is the undertaking of a feasibility study, for which measurements under a variety of observing conditions and pointings will be obtained. When a reduction pipeline has been put in place, further cameras may be added at this or other sites at any later date, allowing thereby a gradual start of the Permanent All Sky Survey. It should be noted that the PASS project is still in its early phase and **we expect that it provides the opportunity to cover a wide range of topics and objectives. Its initiators welcome any expression of interest that may lead to participation in this project**. We also want to stress, that the modular and extensible nature of PASS, with several camera arrays in various locations, will allow a relatively simple adding of observational equipment by collaborating teams.

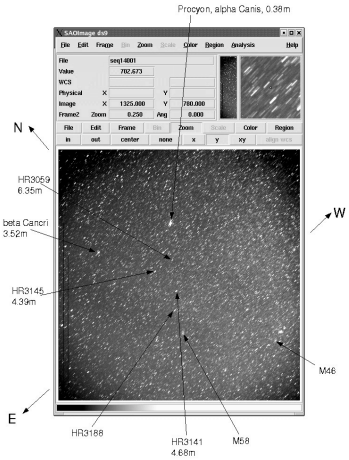


Fig. 7 PASS prototype image, taken with 60 sec exposure time and a Nikon 50mm lens set at f/2.0. The field of view is about 27° x 27°. For a few brighter stars, their V magnitudes are given. In amplified sections (upper right), stars with 11th mag may be identified visually with ease.

References:

PASS Web-site: www.iac.es/proyecto/PASS
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