The PTF Orion Planet-Search Project

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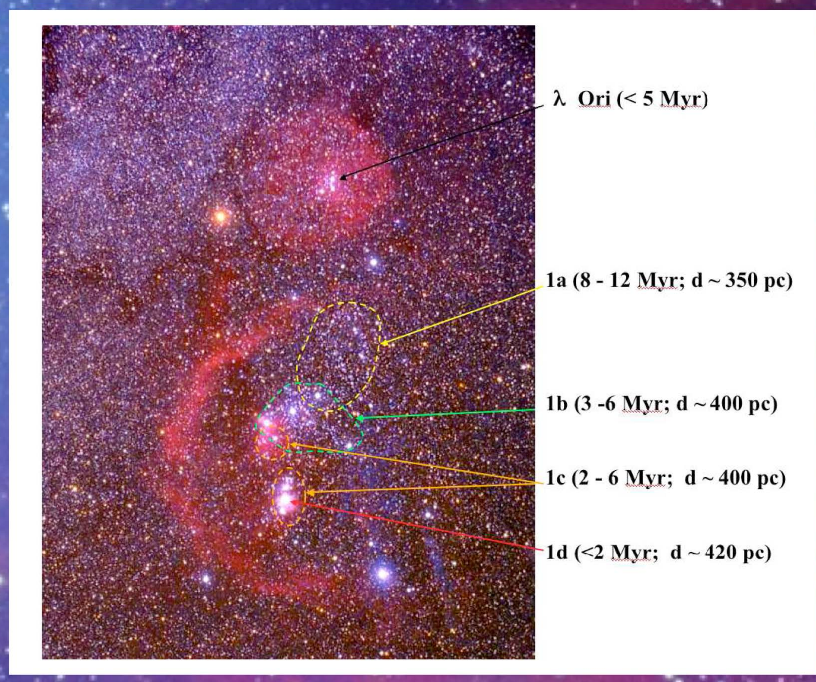
Abstract

The Palomar Transient Factory (PTF) is a new survey for astronomical transients to be undertaken with the wide-field CCD array recently installed on the Palomar 48" telescope. The camera consists of a 12-CCD array, each 2048 by 4096 pixels, giving a total nominal 7.8 square degree array with 1" pixels. The Orion project is an experiment that during its first year will focus on a single pointing in the Orion star-forming region as part of the PTF survey. The project has been assigned 40 consecutive nights per year for three years to perform intensive time-series observations with the aim of detecting close-in, Jupiter-sized planets transiting young stars. Little is known about the distribution and frequency of planets around stars that are 1-100 Myr old - the time frame in which the giant planets are expected to form. Our principal goal is to investigate the frequency of planets around stars at young ages. In addition, the observations will provide a unique dataset to study a variety of stellar astrophysics, including eclipsing binary systems for testing star formation and evolution models; characterising stellar activity and rotational periods; and characterising previously unknown young stars in the Orion region. Here we present the current status of the project and some of the findings from the preliminary test data.

Observations



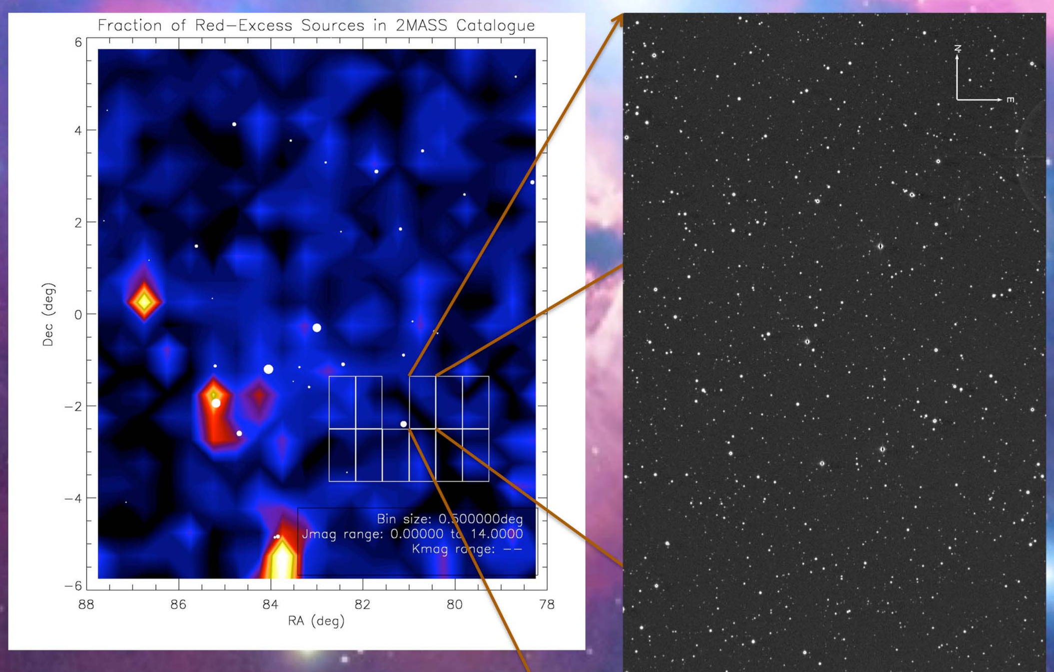
Approximate ages of the Orion OB1 association subgroups (reproduced from Bally, 2008)

Preliminary test data were taken during instrument commissioning time in Feb/March '09, with the purpose of using them to build a differential photometry pipeline. Two data sets were taken:

- An overlapped tiling of the entire Orion region, R band, 60s exposures.
- A single-field time-series data set, R band, 30s exposures, ~1min cadence, over three nights.

The results presented here represent a preliminary first-cut reduction of two nights from the time-series data to begin to assess performance.

The aim is to observe a field where the disks of young stars are on the point of dissipation (~5—10Myr old), leaving behind any new born planets. The field just south of Orion's belt, chosen for the time-series test, satisfies this goal (see figures above and below).



Above: *location of time-series field south-west of Orion's belt. Chip 2 (**right**) was used for the data reduction here. Note the adjacent dead CCD chip, where the bright star η Ori was deliberately placed. (See 'Selecting a Field' for explanation of the contours).*

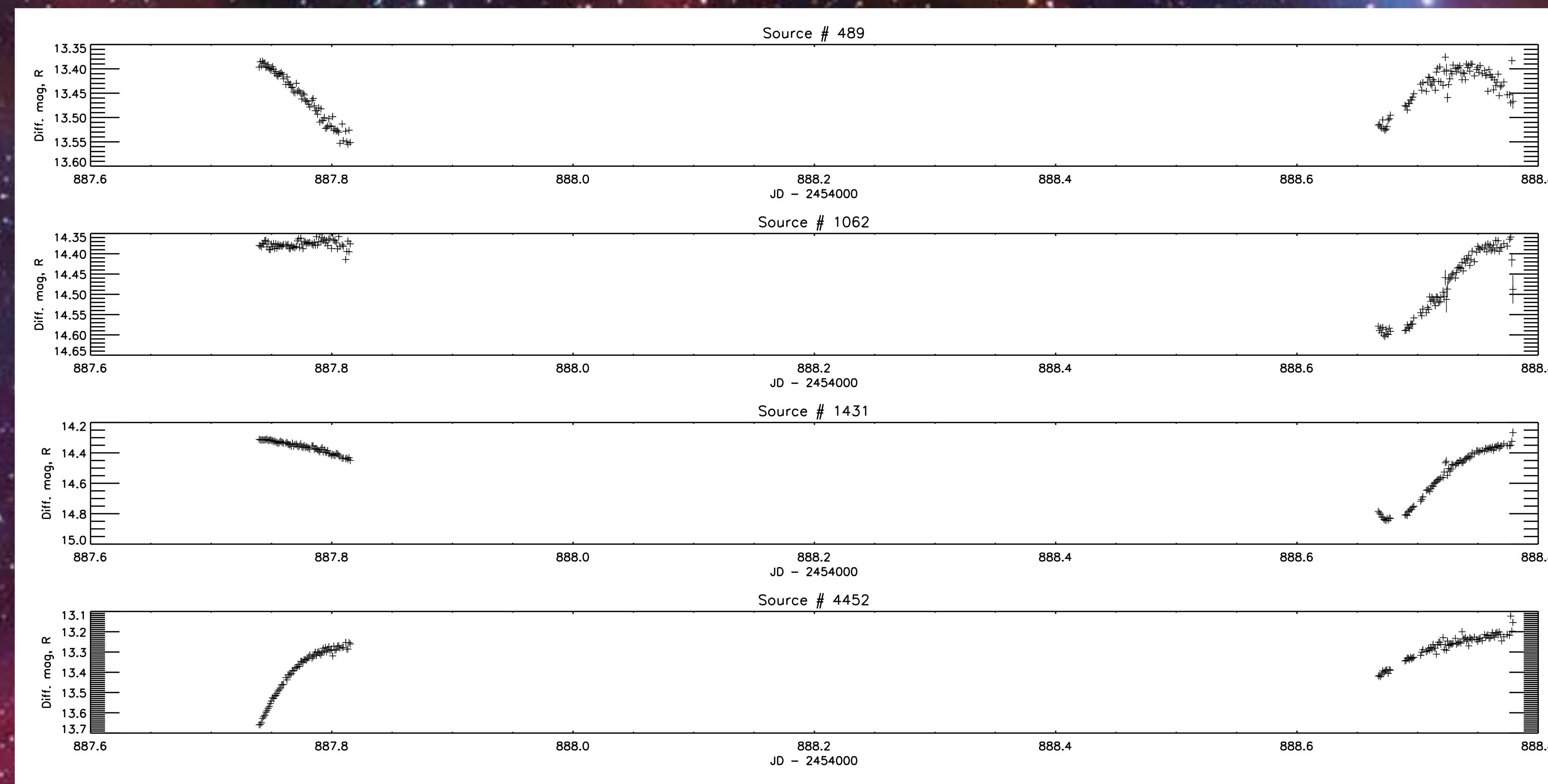
Differential Photometry

Where the standard PTF pipeline is designed to produce absolute photometry, the Orion project requires high precision differential photometry. Data reduction steps are broken down as follows:

- Image pre-processing/astrometry using standard IPAC PTF pipeline.
- Standard aperture photometry – DAOPHOT.
- Zero point correction in IDL referenced to USNO-B1.0 catalogue.
- Source matching – IDL.
- Differential photometry – IDL: Each frame corrected by modal magnitude difference between itself and mean reference frame.

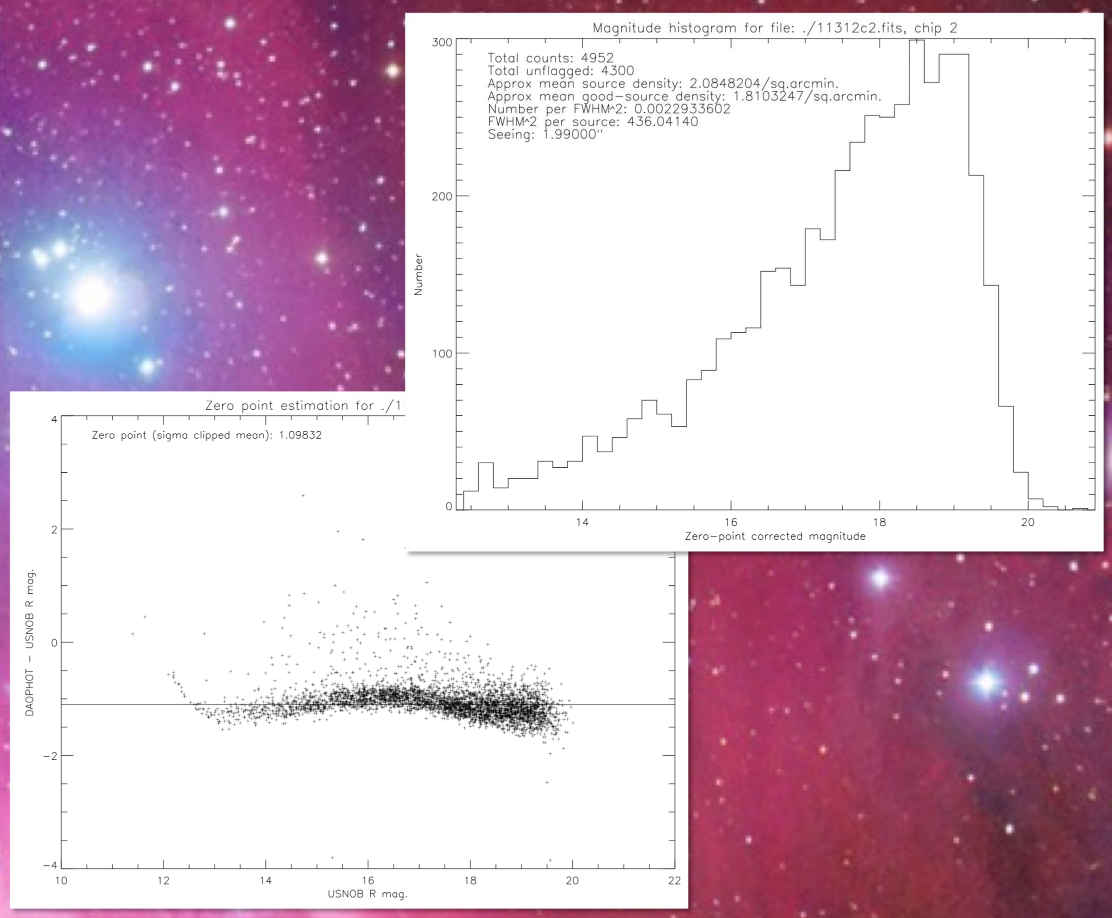
In order to obtain a quick first reduction:

- No iteration of differential photometry.
- Entire chip reduced as a single ensemble.
- Single aperture size used – no adaptation to match variable seeing.
- Only crude checking against USNO-B for confused sources.



Example variable sources obtained from differential photometry. 2MASS colours suggest these ones are probably main sequence F – K stars, with little reddening, and not embedded in any optically thick IR disk. Data with sec z>4.0 and seeing FWHM>5.0 are omitted from the plot. From top to bottom, std. dev.'s after removing polynomial fits to the trends are 0.0125, 0.0122, 0.0123, and 0.0132 mag, with median DAOPHOT raw photmetry error bars of 0.003, 0.006, 0.006, and 0.003 mag respectively.

Photometric calibration



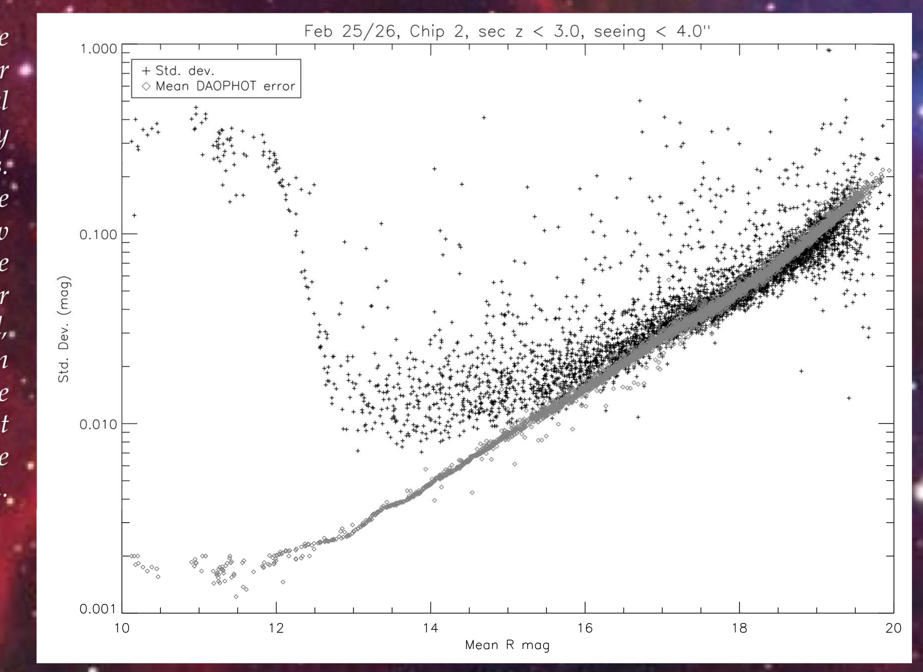
Top: *R-magnitude histogram, showing completeness and saturation limit.* ***Bottom***: *Zero-point determination -- difference between DAOPHOT aperture photometry and USNO-B1.0 R magnitude, vs. R. Saturation sets in at around R~12.5.*

DAOPHOT output photometry is zero-point corrected with a calibration against the USNO-B1.0 catalogue to obtain a rough absolute R magnitude estimate for each source detection. From the figures above:

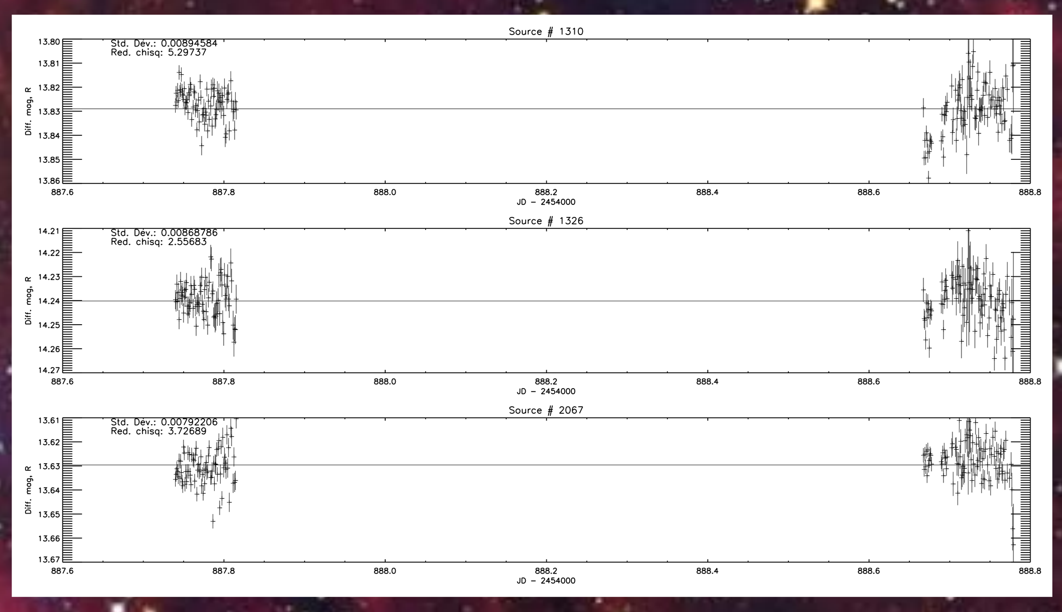
- 4300 unflagged sources detected on chip 2 (~0.6 deg^2 FOV)
- R-mag. histogram implies:
  - completeness limit at R~19.3 in 30s.
  - saturation at R~12.5
- Curvature in zero-point plot may be due to non-linearity in USNO-B catalogue, and/or to mismatch between USNO-B and PTF R-filters.
- USNO-B precision is ~0.25mag, so curvature is not unreasonable.

Preliminary Results

RMS magnitude variation after differential photometry correction vs. abs. magnitude. The mean raw aperture photometry error bar is overplotted, giving an estimate of the theoretical best achievable precision.



Example stable stars from the ensemble



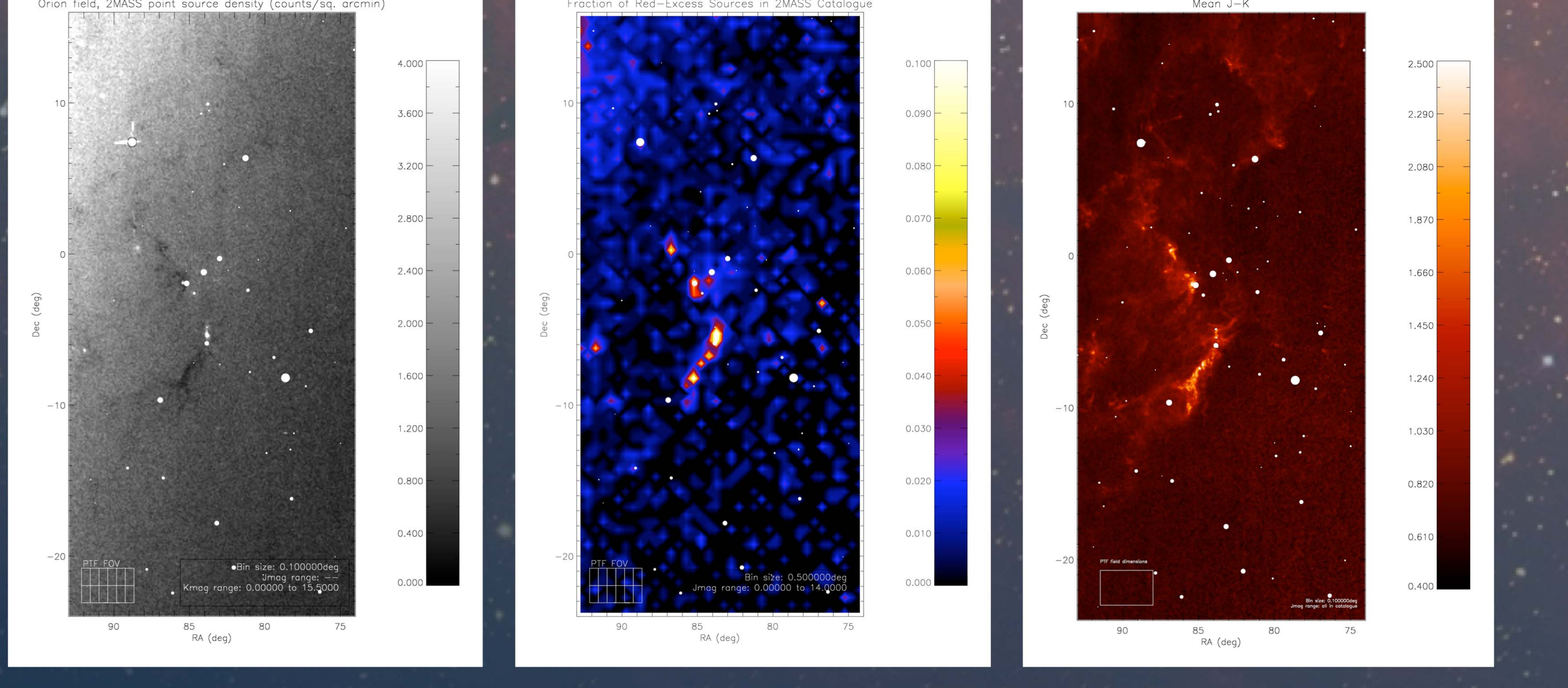
Across the top are shown some apparently variable stars after differential photometry correction. Their nature has yet to be determined, though their 2MASS colours put them near the late main sequence. For comparison the top figure above shows examples of the most stable stars from the ensemble. The noise is above the standard statistical error bars, but there is no obvious correlation between stars, suggesting that the differential photometry algorithm is performing adequately, while not over-correcting bright stable stars.

As shown in the bottom figure, the noise floor starts to set in at around the 9mmag level. *Rejecting data at sec z > 2.0 and seeing > 3.0" reduces this noise floor to ~4 – 5mmag,* adequate for detecting Jupiter-sized planets, particularly if consecutive data points can be binned together. Fine tuning and more sophisticated data reduction should yield further improvement.

Selecting a Field

Choosing the final Orion project field requires balancing a number of requirements. These plots of the entire Orion area derived from the 2MASS point source catalogue provide an initial handle on some of these, as well as showing interesting tracers of dust and star formation in the Orion complex.

- ***Left:*** Source count density – need uncrowded field, but sufficient source counts to detect planets.
- ***Center:*** Fraction of red-excess (presumably young, variable) sources – high stellar variability incidence may impede differential photometry.
- ***Right:*** Mean J-K colours – traces extinction. Dust may limit source counts and also point to regions of high variability.



Reference – Bally, J., 2008, Handbook of Star Forming Regions, Volume I: The Northern Sky ASP Monograph Publications, Vol. 4. Edited by Bo Reipurth, p.45.