# The PANOPTES project: discovering exoplanets with low-cost digital cameras

Exoplanets can be discovered by taking pictures of the sky with inexpensive digital cameras

**How ?**

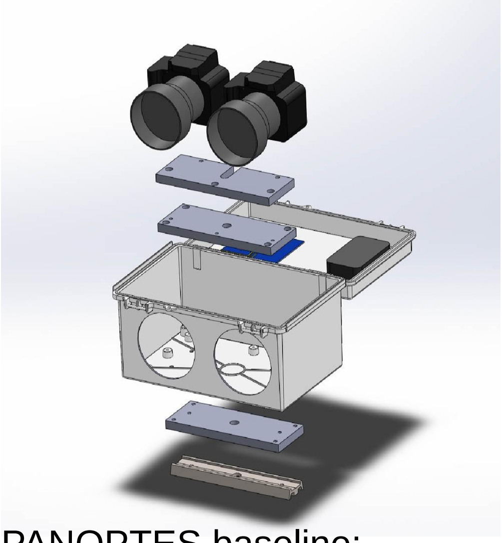
When a planet passes in front its star, it appears to dim for a few hrs (transit)
Monitoring large parts of the sky from many locations with many cameras is key
→ very well suited for citizen scientists, schools

**What is project PANOPTES ?**

After >3 yr of prototyping, we have designed a “baseline” unit, optimizing reliability, cost, simplicity and performance. We are setting up a worldwide network of units assembled by citizen scientists and professional astronomers.

**We aim at engaging public and schools in one of the most exciting current science adventure: identify planets around other stars**

Open-source, open-hardware. All data is immediately public.



PANOPTES baseline:
Designed to be assembled with drill, screwdrivers and hand saw

Check out: www.projectpanoptes.org
Software: https://github.com/panoptes
Joining request: info@projectpanoptes.org

We're also looking into using cell phones to monitor stars
This would be well-suited for the bright stars, which are too bright for our baseline unit
No hardware would be required other that a cell phone (snap pictures of the sky, or leave it outside at night, looking up)

# The PANOPTES[1] project: discovering exoplanets with low-cost digital cameras

*(1) **P**anoptic **A**stronomical **N**etworked **OP**tical* observatory for **T**ransiting **E**xtrasolar **P**lanets

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## Project Goals

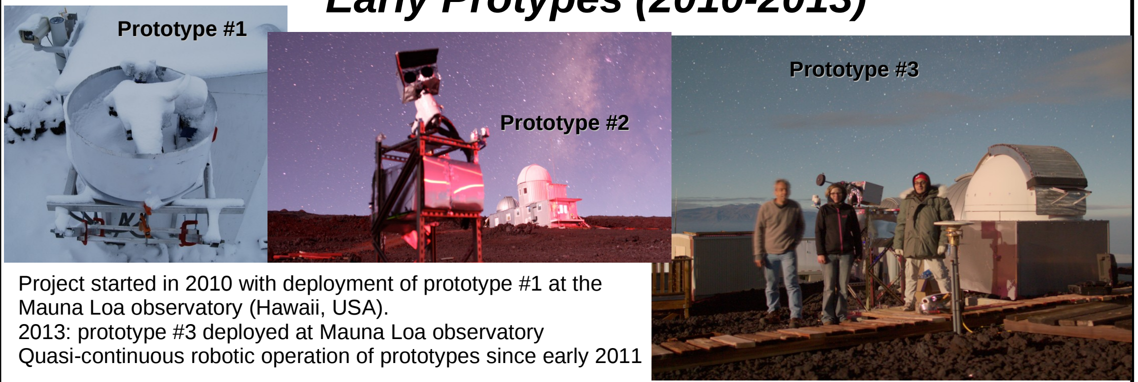
**Research**: Establish a world wide network of automated cameras to monitor a large fraction of the sky to detect exoplanet transits.
**Outreach**: Enable citizen scientists and schools to participate in all aspects of the science, from data collection to data analysis.
PANOPTES can potentially support other science (variable stars, supernovae, asteroids, etc.). We want users to come up with new projects.
→ units must be easy to duplicate, low cost and highly reliable
→ PANOPTES development (hardware and software) follows open-source software development model
→ includes both professional astronomers and citizen scientists

## Why digital cameras ?

Mass-produced digital cameras+lenses are the most affordable strategy for high etendue survey, and are widely accessible, reliable

| | Aperture Diameter | Area | Field of View | Approximate Cost | Etendue | Etendue per $ |
|---|---|---|---|---|---|---|
| | m | $m^2$ | $deg^2$ | $ | $m^2$ $deg^2$ | $m^2$ $deg^2$ / M$ |
| LSST | 8.4 | 45.8 | 9.6 | 120,000,000 | 440.6 | 3.7 |
| Pan-STARRS (PS2) | 1.8 | 1.91 | 7.1 | 8,000,000 | 13.5 | 1.7 |
| 0.6 meter CDK | 0.60 | 0.23 | 0.28 | 130,000 | 0.07 | 0.5 |
| Celestron C14 | 0.35 | 0.09 | 0.13 | 40,000 | 0.01 | 0.3 |
| Panoptes (1 camera) | 0.061 | 0.0029 | 150.0 | 4,300 | 0.43 | 101.0 |
| Panoptes (2 cameras) | 0.061 | 0.0029 | 150.0 | 5,100 | 0.87 | 170.3 |
| Panoptes (4 cameras) | 0.061 | 0.0029 | 150.0 | 6,700 | 1.74 | 259.3 |

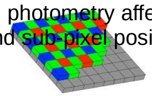
## Early Protypes (2010-2013)

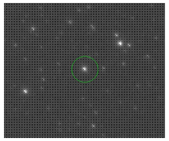



Project started in 2010 with deployment of prototype #1 at the Mauna Loa observatory (Hawaii, USA).
2013: prototype #3 deployed at Mauna Loa observatory
Quasi-continuous robotic operation of prototypes since early 2011

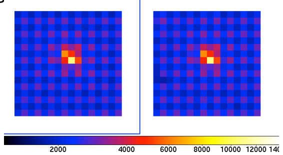

## Precision photometry with color DSLRs

**PROBLEM:**
Unknown PSF falls on grid of filtered pixels
→ photometry affected by PSF, star color, and sub-pixel position



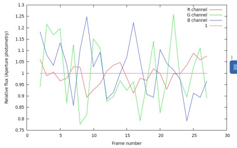


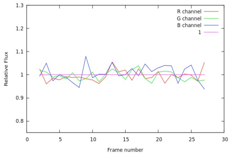
**SOLUTION:**
Use optimal PSF-matching (matching image structure, not photometry) to identify suitable references in the image, among ~100,000 PSFs available in each field



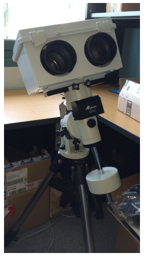

*Left: actual PANOPTES image of star HD54743, 1mn exposure*
*Right: reconstructed image from references*

Aperture photometry does not work well, with ~10% RMS error per frame for a single camera




**We have demonstrate 1.5% photometry in 1mn with a single PANOPTES camera**
**Noise shows little correlation with time, and averaging between multiple cameras at multiple sites is the safest way to ensure sqrt(N) averaging.**
**→ 2hr long 0.1% transit detectable with 100 cameras (50 units) at SNR>5**



## Preparing for wide deployment... Baseline Unit development (2014)

Cameras: Canon EOS SL1 (x2), Lenses: Rokinon 85mm F1.4 (x2)
Mount: iOptron IEQ30
Weather and cloud sensor
12V computer. All system runs on 12V battery charged by 120V AC (resilient to short power failures)
Python-based software

## More info, how to join PANOPTES

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Software: https://github.com/panoptes
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