Photometric ground follow-up: When is it needed and which instruments are required

Hans J. Deeg (IAC) + PLATO WP 143x

I. Capacity of PhotFU for detection of false alarms from EBs (in comparation to centroiding), from estimations in report by Klagyivik & Deeg (2019)

II. Quantitative estimates on target distribution for PhotFU based on expected transit counts

-> determine types of telescope we need , and to what amounts

2019 Report by Klagyivik & Deeg (PLATO-IAC-PSM-TN-0001)

'Identification of false positives from PLATO PSF position measures and from ground-based photometry'

- Describes capacity of target centroid information for detection of false positives
- Outlines capacity of ground-PhotFU
- … and compares the two methods

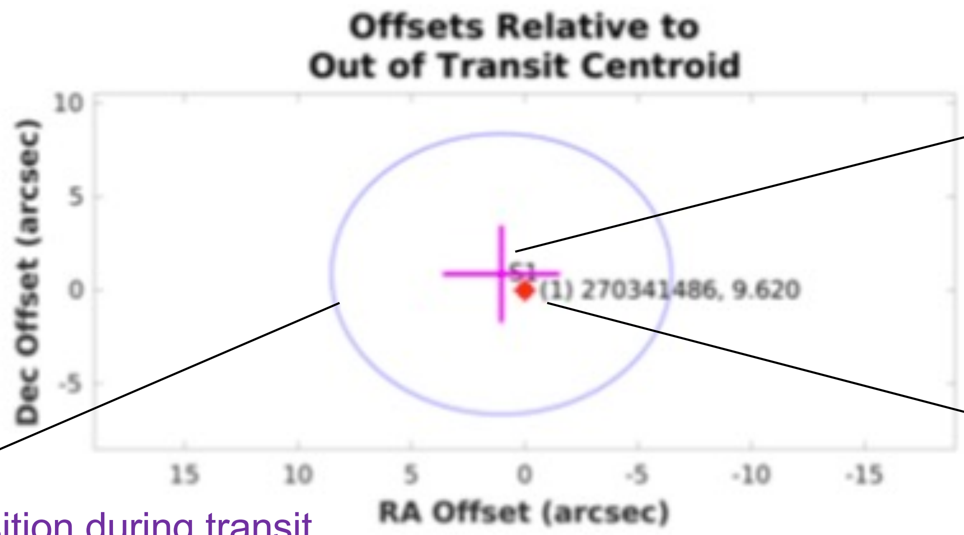
Parameterization used:

- Position of target on CCD (close / far from PLATO-CAM opt. axis)
- Target brightness
- PLATO-detected transit depth,
- angular distance to contaminating star

Detecting false positives from target centroid info

'Centroiding': Measuring the center of the target's *psf* during transit and off-transit.

Example from Kepler / Tess data validation report:



Position during transits

Off-transit target positon

3σ confidence of position during transit

Centroiding test: Is a significant centroid motion detected during transit?

Yes: 'transit' arises from laterally separated source whose *psf* merges with target *psf*

No: 'transit' is either from target's planet or from source with very small lateral separation

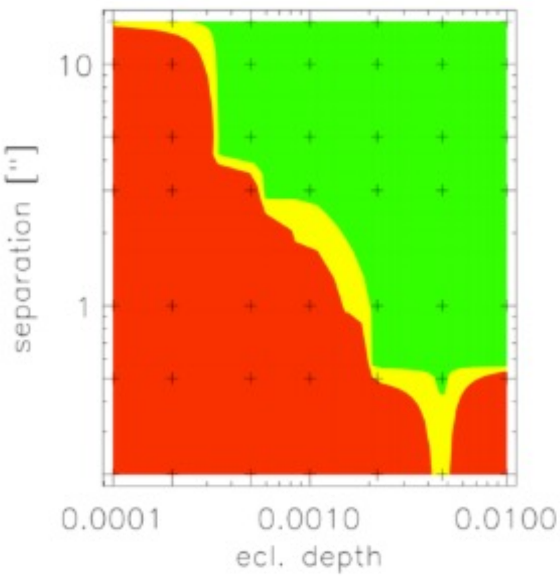
PLATO Centroiding simulations

Klagyivik & Deeg 2019 report, centroiding evaluation of blended psf's made with PLATO-SIM

Assuming a group of 6 PLATO cameras:
FOR different positions on CCD (PLATO optical axis + 18 further positions on CCD)
FOR a target of given magnitude (V=8.5 to 15)
FOR given observed eclipse depth (from 0.01% to 1%): brightness of contaminating star is calculated, assuming it to be an EB with 50% deep eclipses.
FOR separations of 0.2" to 15" of contaminator from target

300 on and 300 off-transit centroids of the merged psf are calculated and the significance of the on-off shift in centroid position is evaluated

10.0 mag near opt. axis



On-off centroid shift is:
significant
marginal
insignifcant

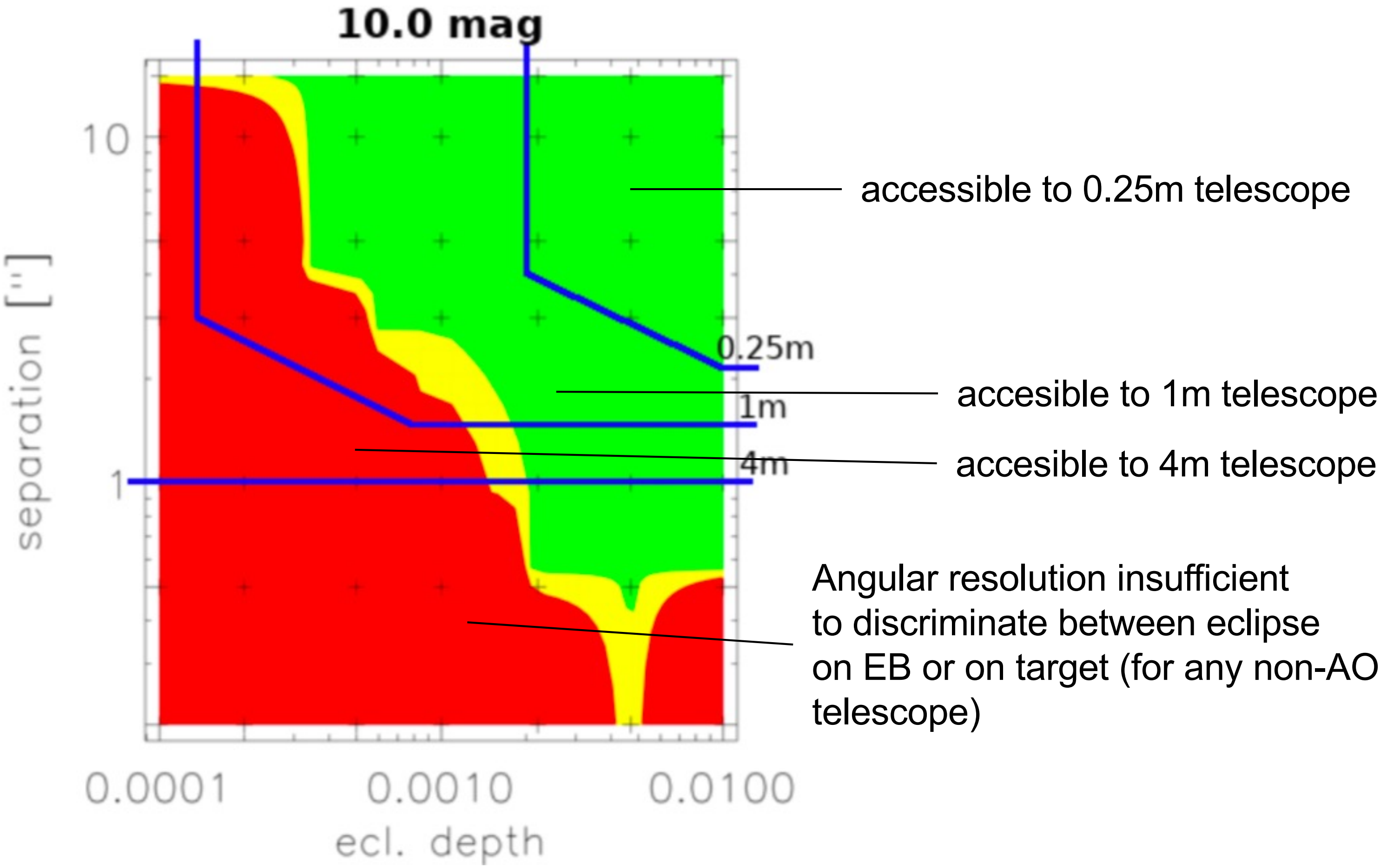
Centroiding versus PhotFU capacity

Capacity of photFU for detection of eclipses on contaminating nearby stars:

for given telescope-size, target-mag, transit-depth, and contaminant separation :

estimations based on time-series precision from two telescopes (0.8m and 1.5m); use of scaling relations . Also, angular resolution versus telescopes size.

-> photFU capacities are rough estimates.



PLATO centroiding, current status

Juan Cabrera, Oct 2021, priv. comm:

P1 (15 000 dwarfs and subgiants F5 to K7, V≤11): centroids from imagettes

P2 (1000 dwarfs and subgiants V ≤ 8.2): centroids from imagettes

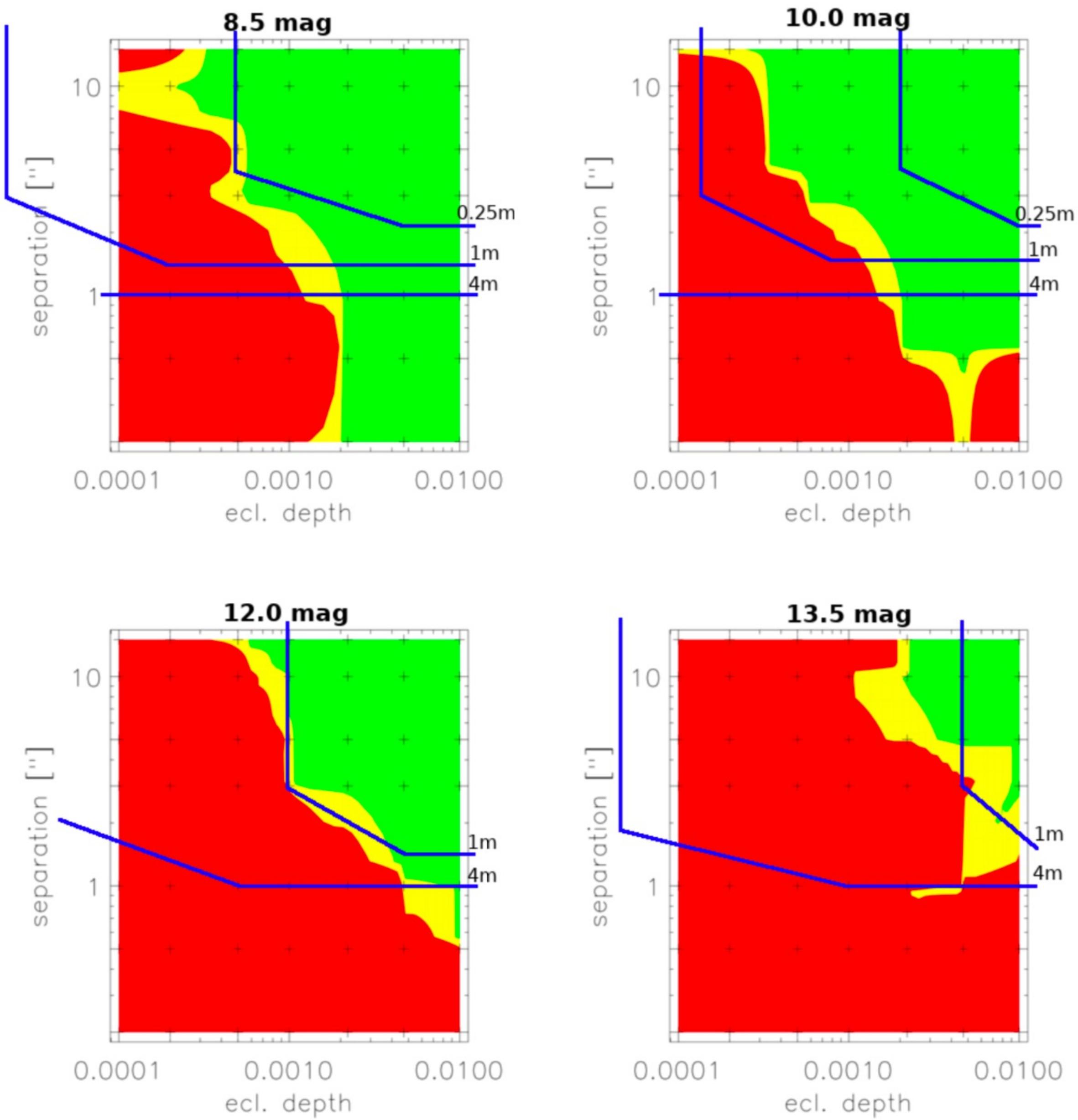
P4 (5000 M dwarfs V ≤ 16) : centroids from imagettes

P5 (245 000 dwarfs and subgiants V≤13): 5000 centroids from imagettes
~12500 (5 % of P5) centroids determined on-board

Uncertainty of factor 2 in number of centroids.

Summary:
V<11 : most with centroids,
V>11 : most without centroids

Photfu telescope capacities for different target mags:

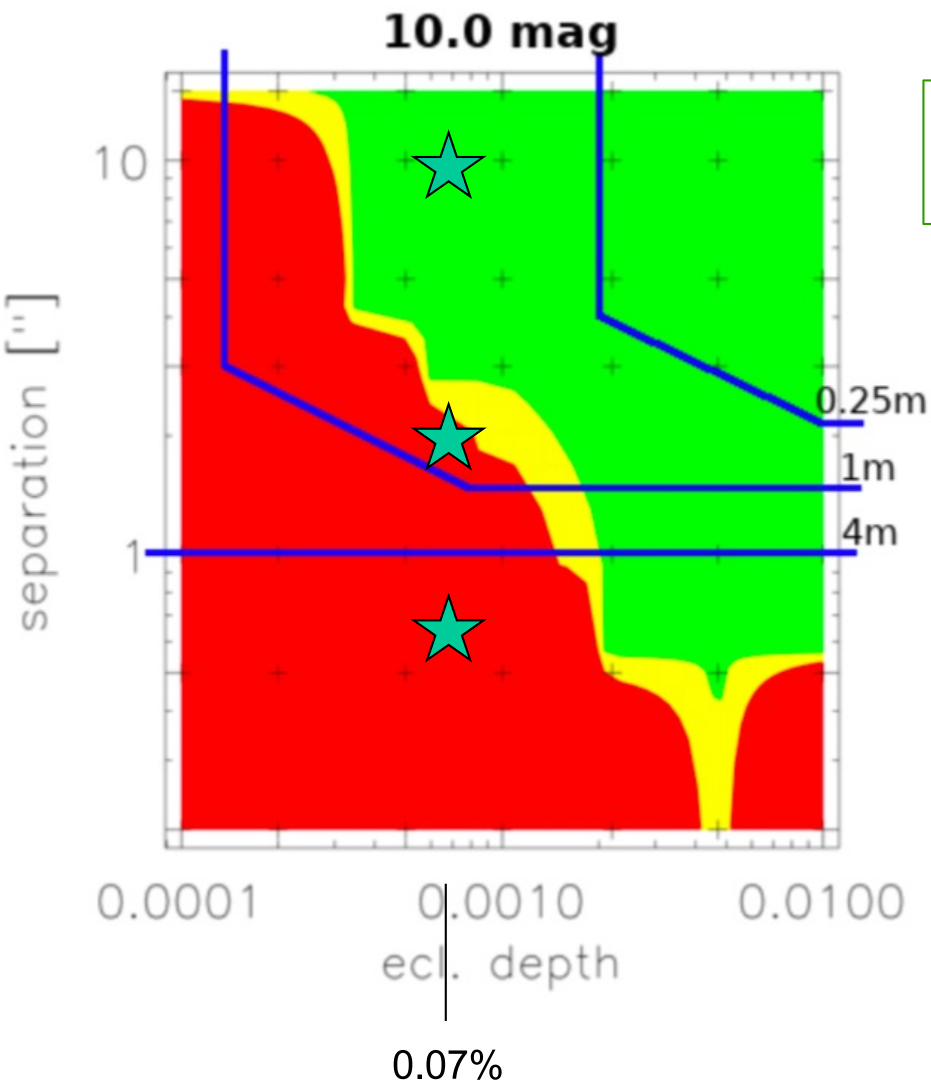


IF centroiding has been done, false alarms from EBs in green zone should be known before doing FU work!

For targets up to V $\lesssim$ 11,
2m telescopes should suffice

(and 1m telescopes for V $\lesssim$ 10)

photFU: choosing the right telescope



Example: candidate w transit depth of 0.07%, with 3 contaminators at different distances (0.6", 22, 10") known from imaging (archival or dedicated obs.)

Contaminator at 10":

IF centroiding unkown, good target for small telescope

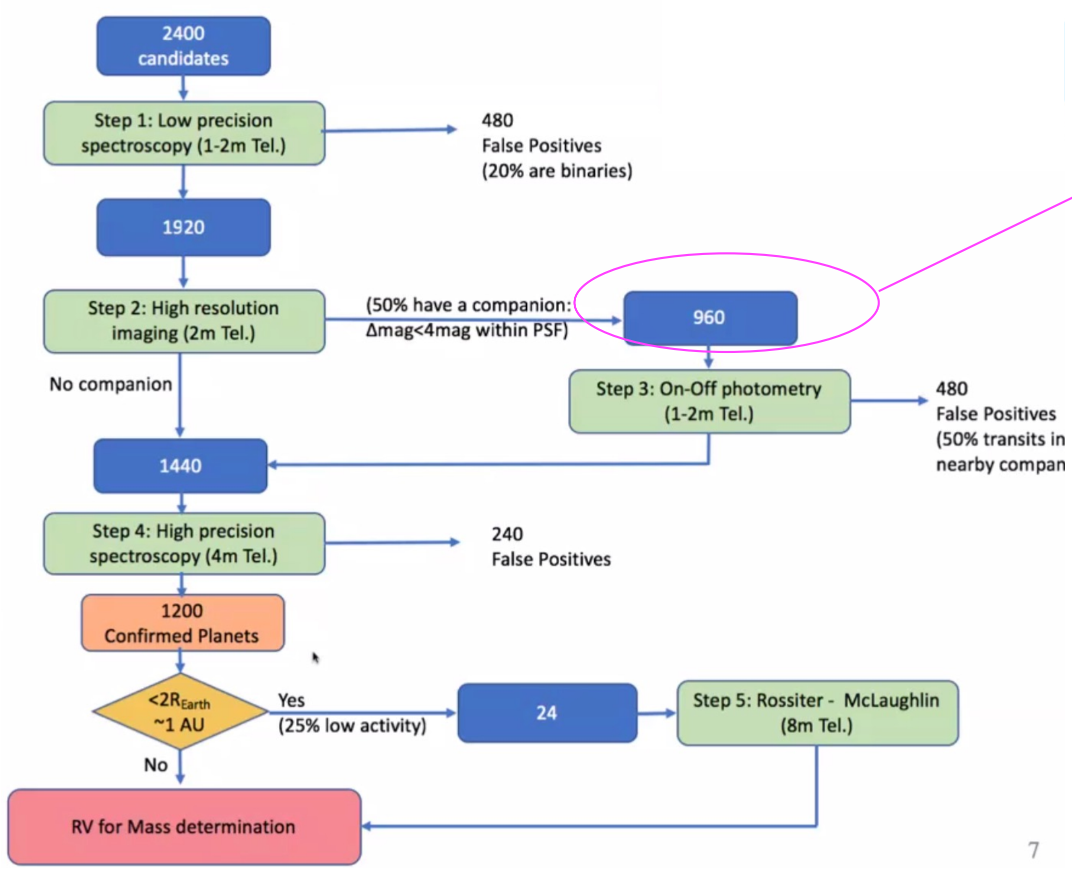
IF centroiding is known, unlikely to be EB, but this could be verified (Citizen Science)

Contaminator at 2": 1m telescope

Contaminator at 0.6" too close for photFU with conventional telescope (maybe doable at excellent seeing)

Towards quantitative estimates

Estimate of GOP target numbers (Udry, Nov. 2021)



For very rough estimate;
assume ~1000 for PhotFU (easy to scale!)

Mag-distribution of 1000 targets in V = 8 to 13:

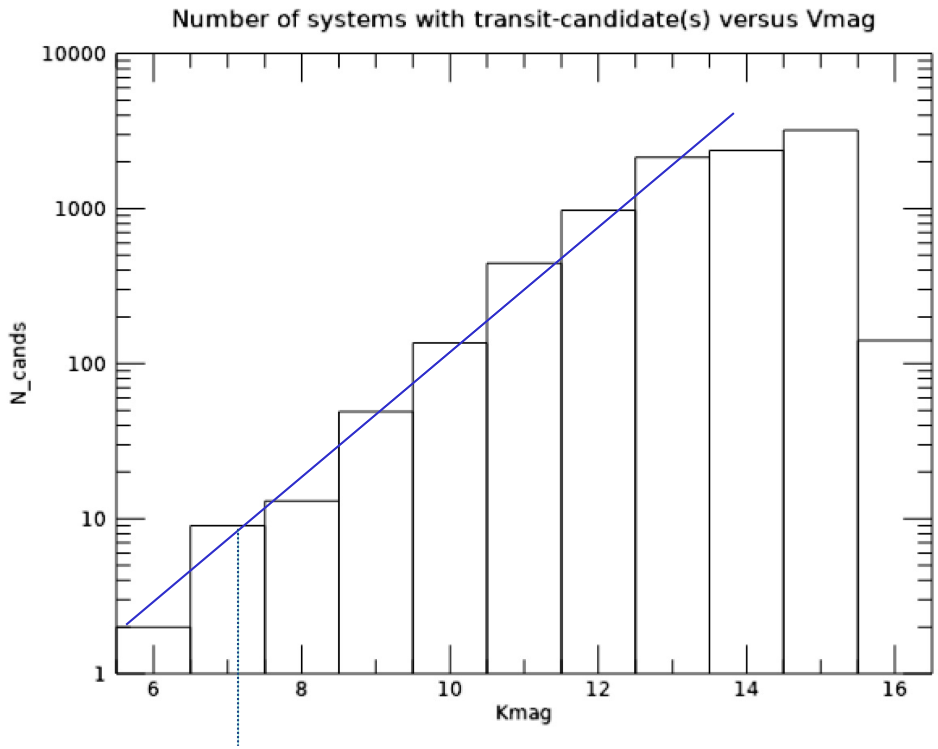
V	Nstar
8	4
9	12
10	33
11	91
12	260
13	599

Due to P1, P2 target preselection, potentially more targets relative to fainter ones. Maybe 2x more

Assuming the 2x enhancement:
25% bright targets V = 8 to 11
75% faint targets V ≳ 12

How will the PLATO transit sample look like:

Brightness distribution of Kepler KOI's with one or more candidates



Slope Δlog N/Δmag ~0.42
(very similar to slope of counts, Δlog N/Δmag ~0.45)

Kepler sample: less complete for V < 13.5

PLATO will be:
~1 mag shallower in 24 camera coverage
~2.5 mag shallower in 6 camera coverage

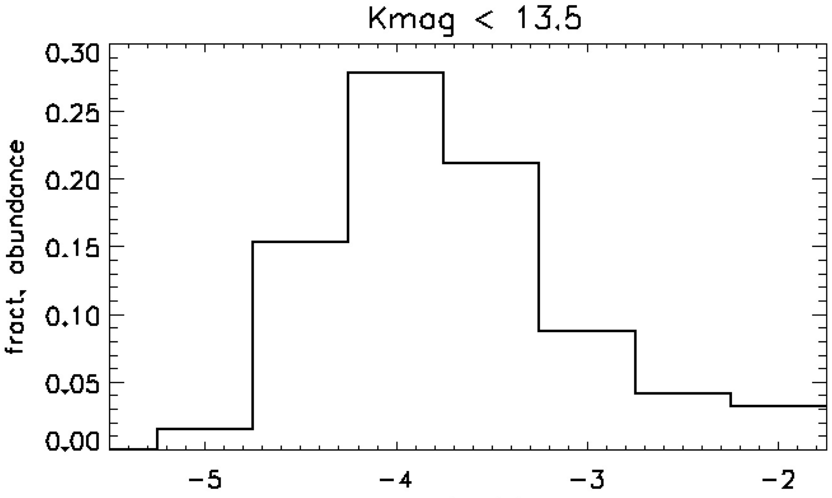
->Assume that PLATO transit sample is 2 mag shallower

What depths will the transits have:

KOI transit-depths, based on 9565 Kepler KOI's

Kepler
'bright sample'
Kmag<13.5

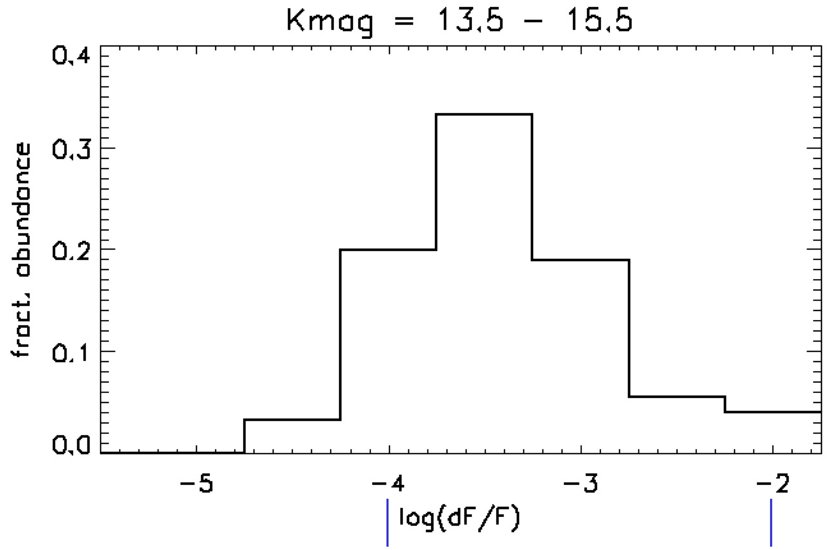
For PLATO: V ≲ 11.5
P1 sample



in bright sample, distribution of transit-depths nearly independent of target mag

Kepler
'faint sample'
Kmag=13.5 to 15.5

For PLATO: V = 12, 13
P5 sample



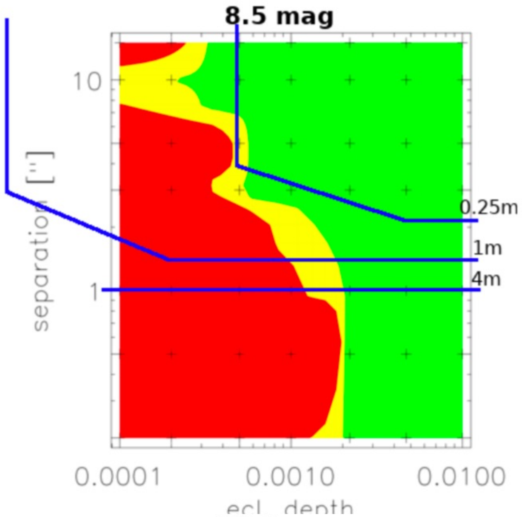
In faint sample, incompleteness on shallower transits ($\Delta F/F \lesssim 0.03\%$)

$\Delta F = 0.01\%$
Terrestrial

$\Delta F = 1\%$
Giants

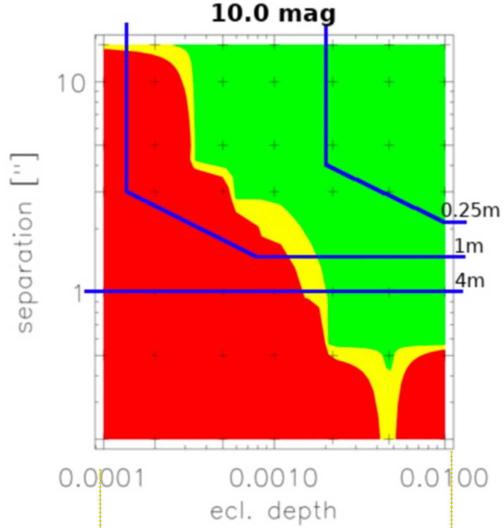
Bright sample: P1 sample, bright P5 cases:

Candidates will mostly have passed centroiding



V ≲ 9; esp. if centroiding absent of interest for small telescopes

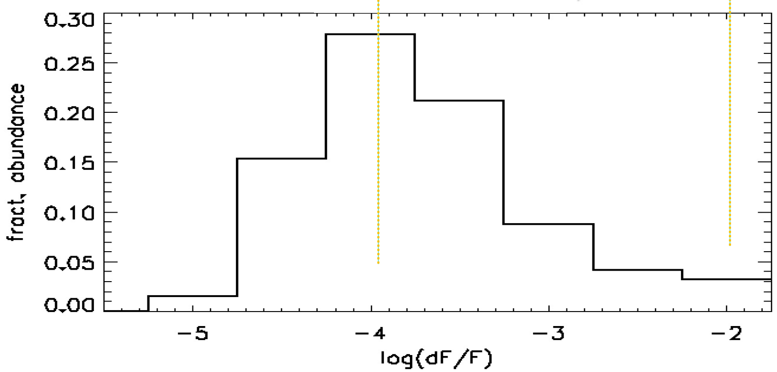
N_{photfu} ~ 30



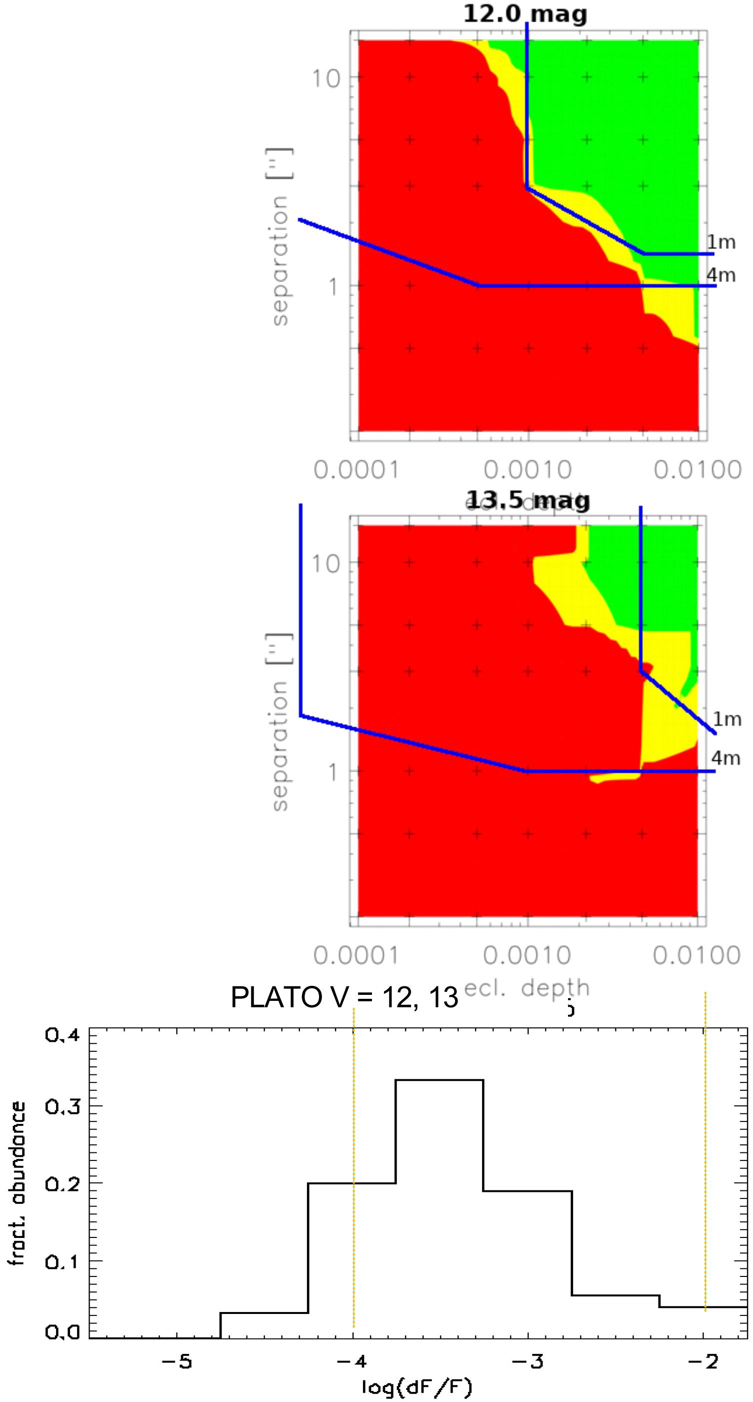
V=10,11: telescopes with 1- 2m
(2m able to cover most cases to V ~11)

Many (30-50%) candidates too shallow for photFU

N_{photfu} ~ 150



Faint sample



Most of P5 candidates:
Centroiding mostly absent,
fewer very shallow transit-candidates

30 – 50% of V=12 cases accessible to
1 – 2m telescopes

N_{photfu} ~ 400

Faint (V ≳ 13) and shallow targets:
larger telescopes IF special interest;
usually RV is easier

N_{photfu} ~ 50 ?

Exception? (TBD): M-star sample with deep eclipses

Conclusions

- Centroiding will catch many false alarms in P1 sample. Cases w/o centroiding of main interest for small-telescope photFU.

- Telescopes in the 1 - 2m range (better 1.5 -2.5m) will be able to do most work

- Bigger ones $\gtrsim$3 m are better, but are realistic only for cases of special interest

- Only false-alarm detection covered here;
  needs for follow-up of *known* planets TBD

Anciliary slides follow

KOI transit depths, versus target Kmag