PLATO Space Mission

Pro-am project

Originated 2020 June 11

Contents

1.0 The PLATO space mission

1.1 Introduction to PLATO

PLAnetary Transits and Oscillations of stars (PLATO) is one of three ESA missions searching for Earth-like habitable exoplanets, the other two being ARIEL and CHEOPS. Its objective is to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. PLATO has also been designed to investigate seismic activity in stars, enabling the precise characterisation of the planet's host star, including its age. Scheduled launch date is 2026, such dates always slip I am advised, so should appeal to younger members!!!

PLATO will photometrically monitor a large number of bright stars for the detection of planetary transits and the determination of the planetary radii (around 3% accuracy). PLATO measures the ratio of planetary radii to that of its host star.

Identification of bright targets for spectroscopic and photometric follow-up observations of planetary atmospheres with other ground and space facilities. Asteroseismology for the determination of stellar masses, radii, and ages (up to 10% of the main sequence lifetime).

Radial velocity follow-up observations for the determination of the planetary masses (around 10% accuracy). Radial velocity signals for different kinds of planets orbiting a solar-mass star are given in Table 1.1.

Planet	Semi-major axis (AU)	Radial velocity (m/sec)
Jupiter	0.1	89.8
Jupiter	1.0	28.4
Jupiter	5.0	12.7
Neptune	0.1	4.8
Neptune	1.0	1.5
Super-Earth (5 Earth masses)	0.1	1.4
Super-Earth (5 Earth masses)	1.0	0.45
Earth	0.1	0.28
Earth	1.0	0.09

Table 1.1. Radial velocity signals

Links;
- ESA PLATO website - https://sci.esa.int/web/plato/
- PLATO Definition Study Report - https://sci.esa.int/documents/33240/36096/1567260308850-PLATO_Definition_Study_Report_1_2.pdf
- presentation by Mark Kidger at the BAA meeting held on 2019 December 7 - https://www.youtube.com/watch?v=A8a_BsPN5uw The video shows the whole of the meeting and this presentation runs from approximately 13mins to 1hr 18 mins.

2.0 Exoplanet characterisation

2.1 Earth II

Requirements for an exoplanet to be Earth-like and capable of supporting human life (from Mark Kidger's presentation to the BAA 2019 December 7);
- gravity =< 3g
- within the Goldilocks zone where liquid water can exist on the surface. In theory this is quite broad but if the Earth were 3% closer to the Sun it would tend to a runaway greenhouse and if it were 3% further away it would tend to an iceball

To date;
- only 32 known exoplanets (4%) are < 3 Earth masses
- only 16 known exoplanets (0.9%) could support liquid water
- only 3 known exoplanets are both < 3 Earth masses and could support liquid water
- 2 of them are much hotter than Earth and are likely runaway greenhouse planets
- 1 is smaller and cooler than Earth and is more likely to be an iceball

In conclusion;
- our statistics are not good enough to say how many Earth-sized planets may exist around Sun-like stars
- only a very small number of them may be suitable candidates to be Earth !!

2.2 Mass-radius relationships

Knowing the radius and mass of an exoplanet enables its density to be determined which gives an indication of its composition – Figures 2.2.1 and 2.2.2

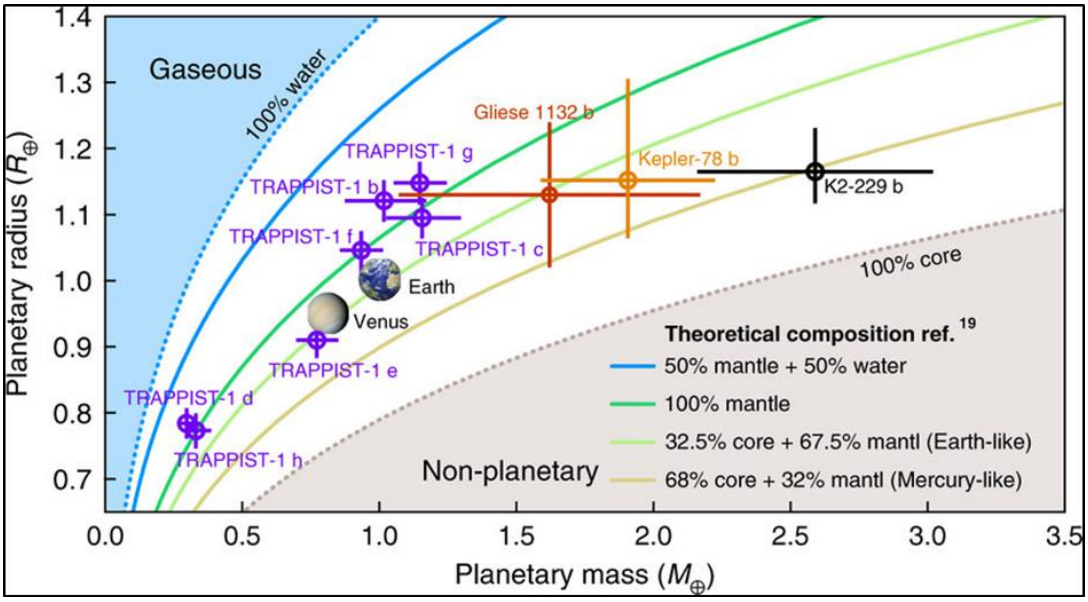

Figure 2.2.1. Mass-radius diagram of known Earth-sized planets. Credit A Santerne et al

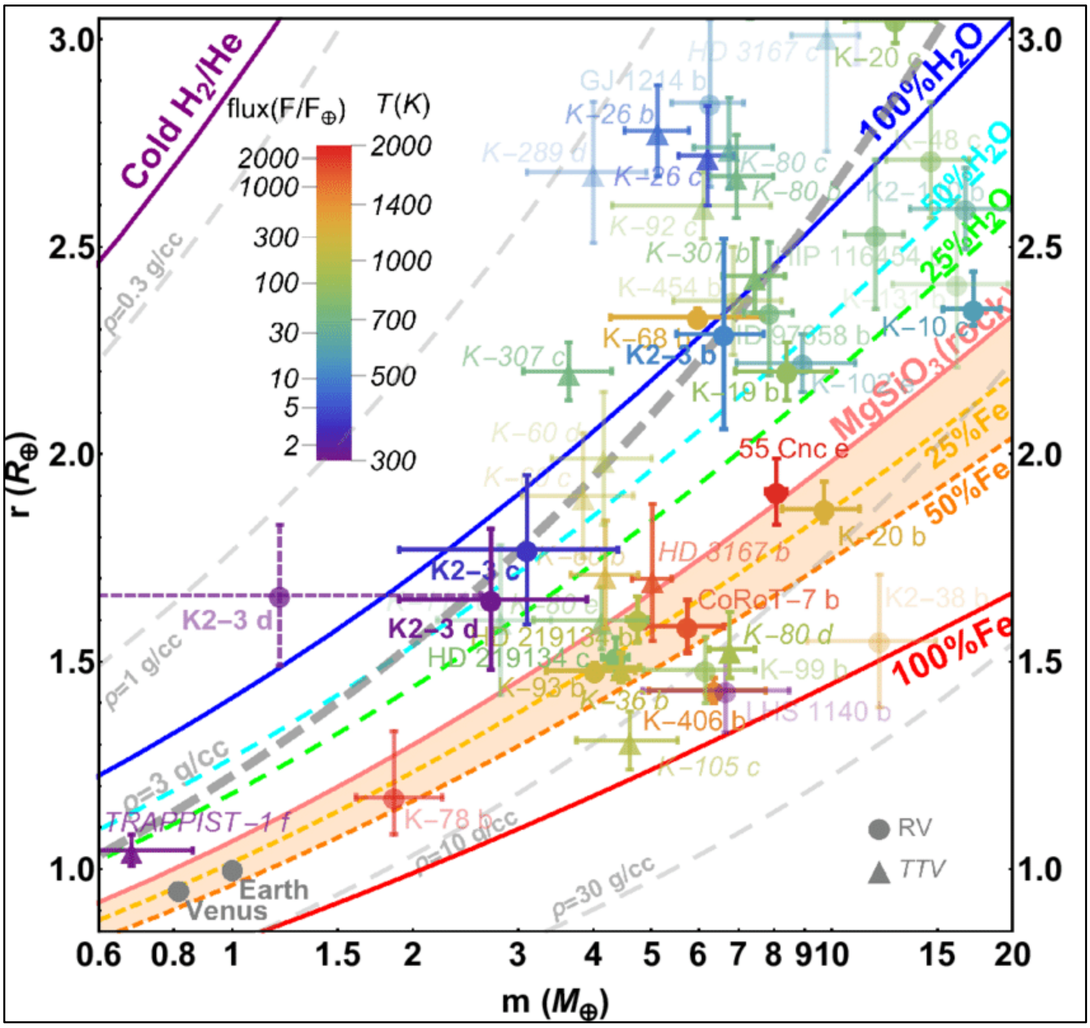

Figure 2.2.2. Mass-radius relationship indicating composition of known exoplanets. Credit Bonomo et al

2.3 Summary

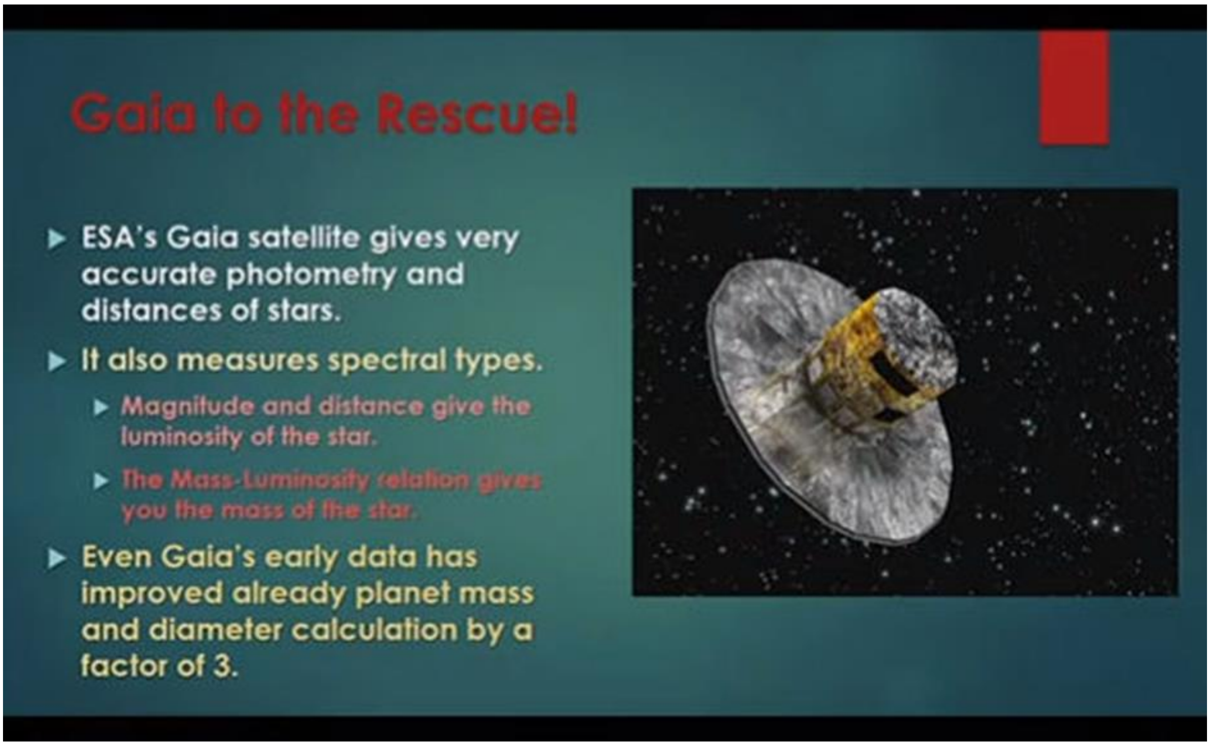

Figure 2.3.1. Gaia data Credit Mark Kidger

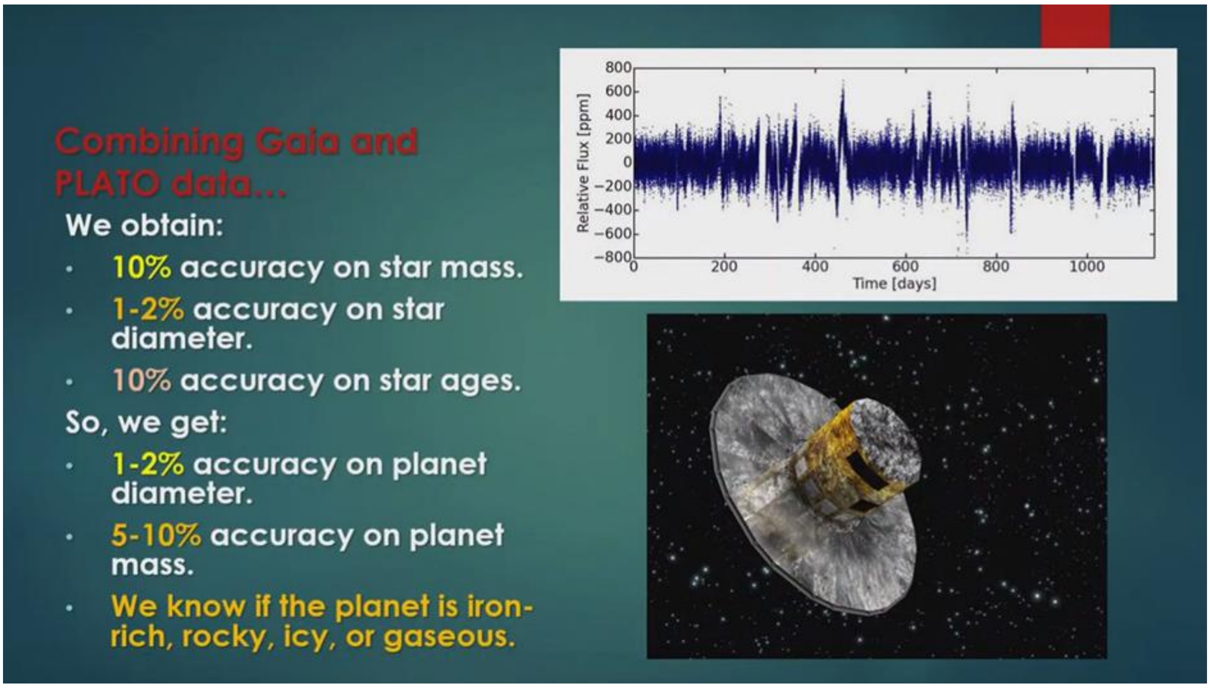

Figure 2.3.2. Exoplanet characterisation using Gaia and PLATO data. Credit Mark Kidger

3.0 Ground-based Confirmation

PLATO Ground-based Observation - https://platomission.com/2018/05/14/ground-based-observation-programme/ -

A considerable amount of help will be needed from both professional and amateur astronomers to confirm PLATO exoplanet observations. This will normally be done spectroscopically on an 8 metre telescope.

3.1 Professional collaboration

An agreement has been negotiated with the European Southern Observatory (ESO) for 50 nights per year on an 8 metre over the course of the mission for spectroscopically measuring radial velocity.

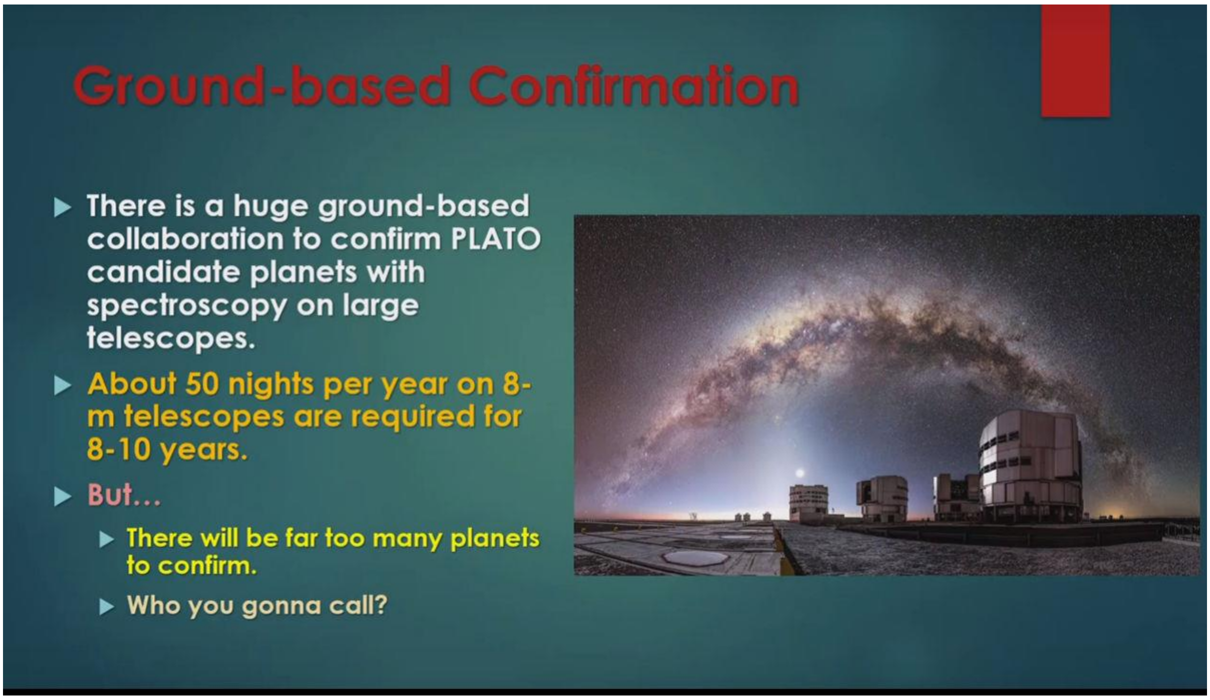

Figure 3.1.1. Ground based confirmation program Credit Mark Kidger

3.2 Amateur collaboration

Steve Futcher is the Exoplanets Division's co-ordinator for this project and the PLATO coordinator for amateur participation is Gunther Wuchtterl.

Amateur participation will, for the foreseeable future, involve transit timing. Those with very deep pockets may be able to measure radial velocities using spectroscopy but, for the majority, this aspect is beyond their horizons. However just to demonstrate what is possible see Exoplanet detection by radial velocity (in French) or Exoplanet detection by radial velocity method (translated into English) mostly by Google with a little help from Roger Dymock)

The Ground Observing Programme will probably kick-off seriously in about 2023. There may be a Splinter Session for the Amateur Observing Programme at PLATO Week 11 which, may take place in 2020 October.

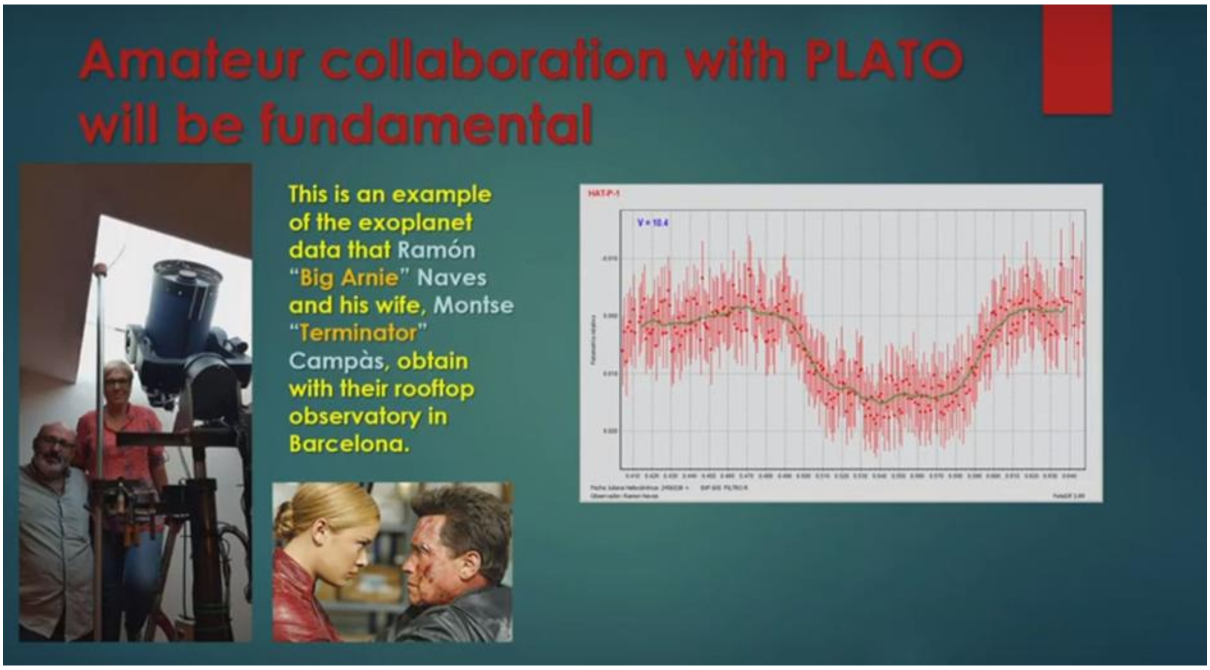

Figure 3.2.1. Example of Jupiter-size exoplanet transit light curve   Credit Mark Kidger

And now for quite a coincidence. In 2006 I attended the Meteors, Asteroids and Comets in Europe (MACE) meeting at the Kuffner Observatory in Vienna. Who am I sitting next to in Figure 3.2.1? None other than Gunther Wuchtterl!!!


Figure 3.2.2. Günther Wuchterl, Roger Dymock, Robin Lauryssen-Mitchell, Richard Miles, Petr Pravec, Korado Korlevic

There are several stellar processes which can mimic exoplanet transits, some of which are shown in Figure 3.2.2, which is why transit candidates require confirmation.

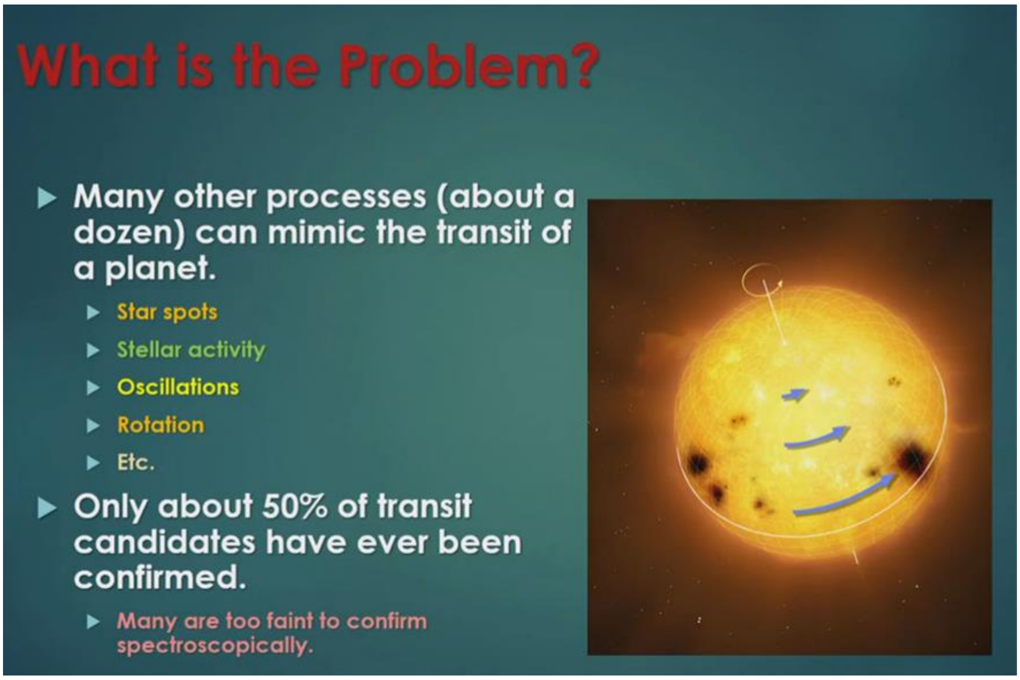

Figure 3.2.2. Transit mimics. Credit Mark Kidger

Unlike ARIEL, which will be observing known exoplanets, PLATO is a discovery mission. It is estimated that 2% of stars listed in the first version of their input catalogue which will be observed will show transits. Which 2% is as yet unknown and PLATO will give alerts for each batch of new transit candidates. Amateurs will be able to tap into these alerts and assist in confirming, by transit photometry, the presence of an exoplanet or not as the case may be and their participation will be a fundamental part of the mission. Figure 3.2.3 shows a typical transit light-curve. A 20-30 cms/8-12 ins telescope suggested

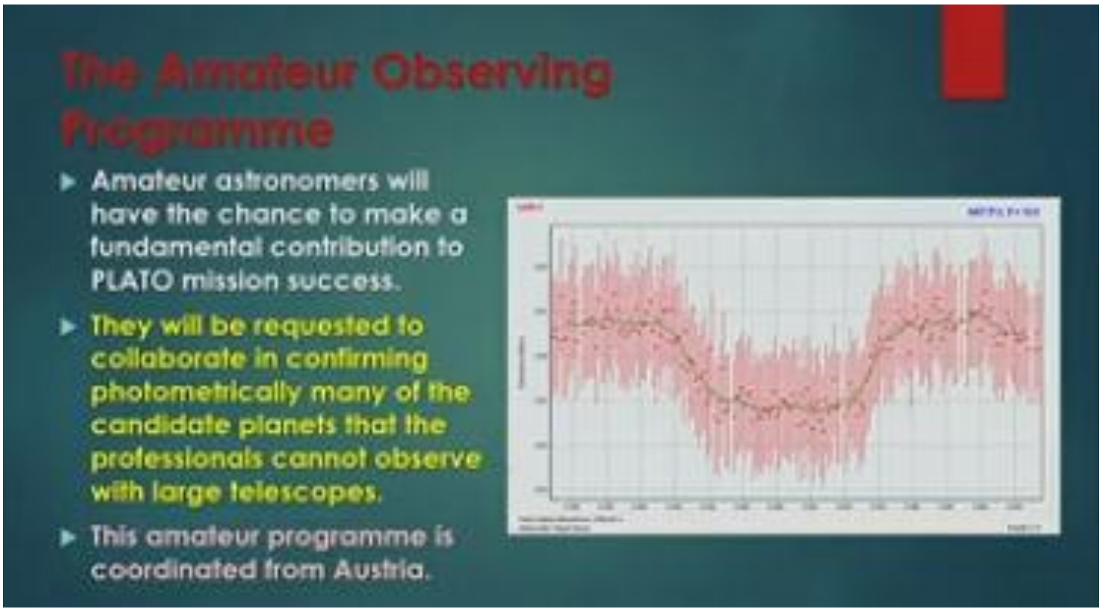

Figure 3.2.3. Amateur observing program Credit Mark Kidger

4.0 Imaging and analysis process

To be added

5.0 PLATO targets

Mark Kidger comments;

PLATO is a very different case to ARIEL as regards follow-up. ARIEL, needs a target list of 1000+, known exoplanets to characterise. Obviously, Kepler, TESS and other programmes have already supplied them with a number of targets of interest, although they are still well short of the 1000 envisaged. ARIEL's problem is the exact inverse of PLATO: while we will ask observers to go out and confirm new candidate planets that were previously unknown, ARIEL will characterise previously discovered planets that have been confirmed by observers. We cannot give a target list (yet) because we do not know which of our 270000 candidate stars will turn out to have planets. ARIEL, in contrast, cannot observe many of its target stars because the ephemeris for the planet transit is so hopelessly inaccurate and so it needs people to do the hard yards to observe a transit that may have timing that is uncertain by a number of days, in order to correct the ephemeris and tell ARIEL when to point at that star. PLATO will sit on each of its 270000 candidates for a minimum of 2 years, hoping to see something happen sometime, while, for ARIEL to be efficient, it must hop to a star, observe the transit and then hop straight to the next, without waiting around for something to happen. All this means that in terms of ground-based follow-up, it is so much easier for ARIEL to define what it needs well in advance than for PLATO to do the same.

Figure 5.1 lists potential targets in order of priority.

Figure 5.1. PLATO targets Credit Mark Kidger

Appendix A – Calculating the radius of a star

The distances to the host stars will be provided by the Gaia spacecraft measuring the parallax of stars.

Ref; Sloan Digital Sky Survey

Calculating a star's radius is a somewhat lengthy process. Even the largest star is so far away that it appears as a single point from the surface of the Earth - its radius cannot be measured directly. Fortunately, understanding a star's luminosity provides you with the tools necessary to calculate its radius from easily measured quantities.

A star's luminosity, or total power given off, is related to two of its properties: its temperature and surface area. If two stars have the same surface area, the hotter one will give off more radiation. If two stars have the same temperature, the one with more surface area will give off more radiation. The surface area of a star is directly related to the square of its radius (assuming a spherical star).

The luminosity of a star is given by the equation

$L = 4\pi R^2 s\ T^4$,

Where L is the luminosity in Watts, R is the radius in meters, s is the Stefan-Boltzmann constant (5.67×10^{-8} $Wm^{-2}K^{-4}$), and T is the star's surface temperature in Kelvin.

The temperature of a star is related to its B-V magnitude. Table A1 below can help you find the temperature of the star based on its B-V magnitude.

Robin Leadbetter advises that the temperature of a star using B-V only works in the absence of interstellar extinction. In practise stellar temperatures are determined by spectral classification using features in the spectrum. (Which underpins the HR diagram for example) Skiff's spreadsheet is a good place to start when looking for the published spectral type for a star which can then be related to temperature - http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=B/mk

You can also approximately correct for extinction using published E(B-V) values e.g. in SIMBAD (again normally derived based on the spectrum of the star)

B-V	Surface Temperature (Kelvin)
-0.31	34,000
-0.24	23,000
-0.20	18,500
-0.12	13,000
0.0	9500
0.15	8500
0.29	7300

0.42	6600
0.58	5900
0.69	5600
0.85	5100
1.16	4200
1.42	3700
1.61	3000

Table A.1 Colour surface temperature relationship

The calculation is actually somewhat easier if we try to find the ratio of another star's radius to that of our Sun. Let L_s be the luminosity of the Sun, L be the luminosity of another star, T_s be the temperature of the Sun, T be the temperature of the other star, R_s be the radius of the Sun, and R be the radius of the other star.

We can then write the ratio of their luminosities as

$L/L_s = (4\pi R^2 sT^4)/(4\pi R_s 2sT_s 4) = (R/R_s)^2(T/T_s)^4$

Solving for the ratio R/R_s yields

$R/R_s = (T_s/T)^2(L/L_s)^{1/2}$

The temperatures can be found approximately from the table above by looking at the B-V values. To find the ratio L/L_s, we can use the absolute magnitudes of the stars. The magnitude scale is a logarithmic scale. For every decrease in brightness of 1 magnitude, the star is 2.51 times as bright. Therefore, L/L_s can be found from the equation

$L/L_s = 2.51^{Dm}$,

where $Dm = m_s - m$

Let's look at the star Sirius. It has visual magnitude of -1.44, B-V of .009, and a parallax, p, of 379.21 milli arc seconds. Finding its distance from its parallax yields

One parsec is the distance, d, at which one AU subtends an angle of one second of arc therefore d = 1/p = 1/.37921 = 2.63 parsecs.

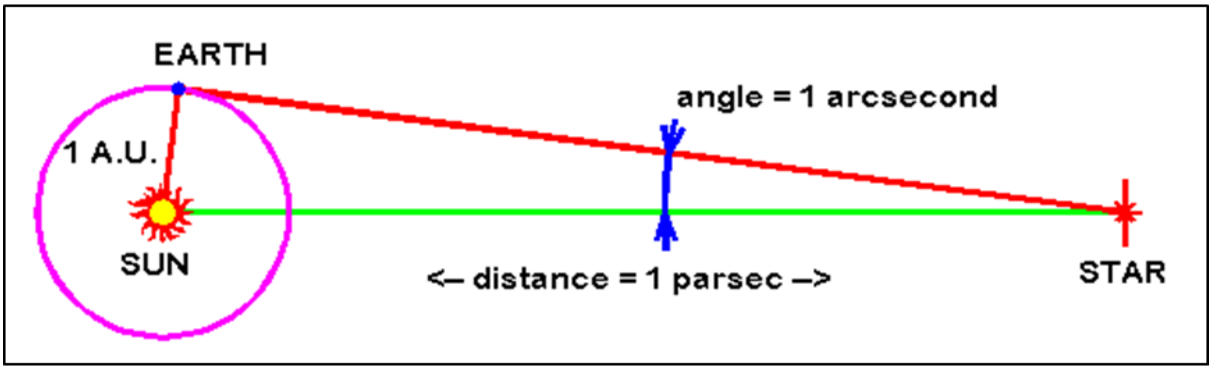

Figure A.2. Distance measurement

Knowing the distance the absolute magnitude can be calculated from the equation;
Absolute magnitude (M) = apparent magnitude (m) – 5 x log(d = distance in parsecs) + 5

$M = m - 5 \log d + 5 = -1.44 - 5 \log (2.63) + 5 = 1.46$

We know the temperature of the Sun is 5800K. From the chart, the temperature of Sirius is about 9500K. Our Sun has an absolute magnitude of 4.83. The difference in magnitude is 3.37. Putting everything together yields

$R/R_s = (5800/9500)^2(2.512^{3.37})^{1/2} = 1.76$ therefore Sirius has a radius approximately 1.76 times that of our Sun

Appendix B Measuring the surface temperature of a star by spectroscopy

Tables A2, A3 and A4 show the relationship between spectral type and surface temperature.

Spectral Type	**Temperature (K)**	**Absolute Magnitude**	**Luminosity (in solar luminosities)**
O5	54,000	-4.5	200,000
O6	45,000	-4.0	140,000
O7	43,300	-3.9	120,000
O8	40,600	-3.8	80,000
O9	37,800	-3.6	55,000
B0	29,200	-3.3	24,000
B1	23,000	-2.3	5550
B2	21,000	-1.9	3190
B3	17,600	-1.1	1060
B5	15,200	-0.4	380
B6	14,300	0	240
B7	13,500	0.3	140
B8	12,300	0.7	73
B9	11,400	1.1	42
A0	9600	1.5	24
A1	9330	1.7	20
A2	9040	1.8	17
A3	8750	2.0	14
A4	8480	2.1	12
A5	8310	2.2	11
A7	7920	2.4	8.8
F0	7350	3.0	5.1
F2	7050	3.3	3.8
F3	6850	3.5	3.2
F5	6700	3.7	2.7
F6	6550	4.0	2.0
F7	6400	4.3	1.5
F8	6300	4.4	1.4
G0	6050	4.7	1.2
G1	5930	4.9	1.1
G2	5800	5.0	1
G5	5660	5.2	0.73
G8	5440	5.6	0.51

K0	5240	6.0	0.38
K1	5110	6.2	0.32
K2	4960	6.4	0.29
K3	4800	6.7	0.24
K4	4600	7.1	0.18
K5	4400	7.4	0.15
K7	4000	8.1	0.11
M0	3750	8.7	0.080
M1	3700	9.4	0.055
M2	3600	10.1	0.035
M3	3500	10.7	0.027
M4	3400	11.2	0.022
M5	3200	12.3	0.011
M6	3100	13.4	0.0051
M7	2900	13.9	0.0032
M8	2700	14.4	0.0020
L0	2600	*	0.00029
L3	2200	*	0.00013
L8	1500	*	0.000032
T2	1400	*	0.000025
T6	1000	*	0.0000056
T8	800	*	0.0000036

Table A2. Main sequence stars

Spectral Type	**Temperature (K)**	**Absolute Magnitude**	**Luminosity (in solar luminosities)**
G5	5010	0.7	127
G8	4870	0.6	113
K0	4720	0.5	96
K1	4580	0.4	82
K2	4460	0.2	70
K3	4210	0.1	58
K4	4010	0.0	45
K5	3780	-0.2	32
M0	3660	-0.4	15
M1	3600	-0.5	13
M2	3500	-0.6	11

M3	3300	-0.7	9.5
M4	3100	-0.75	7.4
M5	2950	-0.8	5.1
M6	2800	-0.9	3.3

Table A3. Giants

spectral Type	**Temperature (K)**	**Absolute Magnitude**	**Luminosity (in solar luminosities)**
B0	21,000	-6.4	320,000
B1	16,000	-6.4	280,000
B2	14,000	-6.4	220,000
B3	12,800	-6.3	180,000
B5	11,500	-6.3	140,000
B6	11,000	-6.3	98,000
B7	10,500	-6.3	82,000
B8	10,000	-6.2	73,000
B9	9700	-6.2	61,000
A0	9400	-6.2	50,600
A1	9100	-6.2	44,000
A2	8900	-6.2	40,000
A5	8300	-6.1	36,000
F0	7500	-6	20,000
F2	7200	-6	18,000
F5	6800	-5.9	16,000
F8	6150	-5.9	12,000
G0	5800	-5.9	9600
G2	5500	-5.8	9500
G5	5100	-5.8	9800
G8	5050	-5.7	11,000
K0	4900	-5.7	12,000
K1	4700	-5.6	13,500
K2	4500	-5.6	15,200
K3	4300	-5.6	17,000
K4	4100	-5.5	18,300
K5	3750	-5.5	20,000
M0	3660	-5.3	50,600
M1	3600	-5.3	52,000

M2	3500	-5.3	53,000
M3	3300	-5.3	54,000
M4	3100	-5.2	56,000
M5	2950	-5.2	58,000

Table A4. Super giants

This paper gives an overview of more current techniques for estimating effective temperature (Teff) and surface gravity (log g) which connects mass and radius.
https://ui.adsabs.harvard.edu/abs/2005MSAIS...8..130S/abstract

Appendix C Asteroseismology

Asteroseismology can be used to determine stellar masses, radii, and ages (up to 10% of the main sequence lifetime). Papers on the subject;
- https://arxiv.org/abs/0909.0506
- https://www.aanda.org/articles/aa/pdf/2014/06/aa23408-14.pdf

Oscillations measured by Gaia can give age of stars accurate to +/- 10%. Can also determine how evolved a star is e.g. is it about to leave the main sequence (useful information if looking for a new home for mankind). Also tells us if a planet is very old or very young and therefore recently formed.

Roger Dymock
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