Gaia, PLATO and WEAVE:
Astrometry, Photometry and Spectroscopy for Exoplanet Characterisation

Nicholas Walton

Institute of Astronomy
University of Cambridge

Gavin Dalton (University of Oxford) / **Scott Trager** (University of Groningen)

WEAVE – Gaia – PLATO
characterising exo-planets systems

- **Gaia** released its first all sky data (**Gaia DR1**) Sep 2016
- The first all sky astrometric catalogues (**Gaia DR2**) April 2018
- **WEAVE** commences surveys **~mid 2020**
- Next major **Gaia** release **(E)DR3 Q3/2020 and H2/2021**
- **4MOST** commences surveys **end 2022**
- **PLATO** begins its exoplanet hunt in **2026**

- Finding and characterising extra solar planets requires a detailed knowledge of the host stars
  - And it helps to know your target stars before you observe them
  - Gaia both finds exoplanets and characterises host stars

PLATO (ESA M3)

http://sci.esa.int/plato

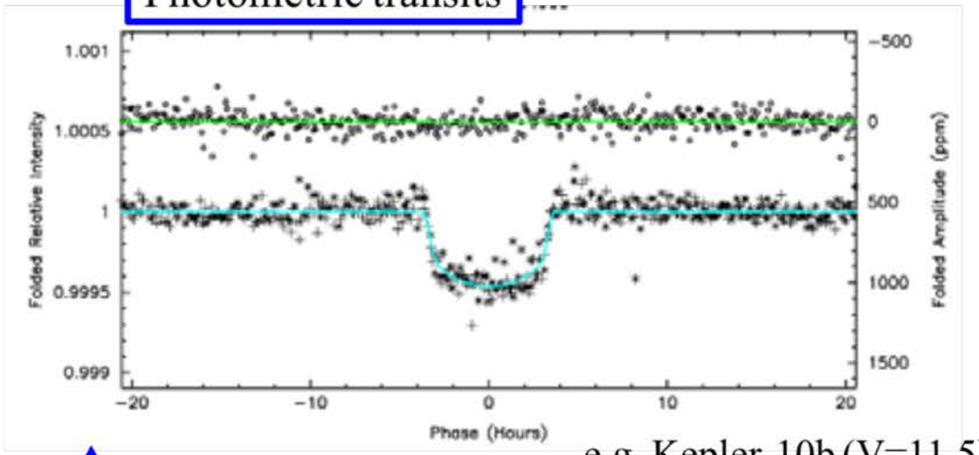
Launch end 2026.
4 to 8 years
operations plus
post operations

PLATO
PLAnetary Transits and Oscillation of stars

PLATO 2.0: Rauer et al 2013

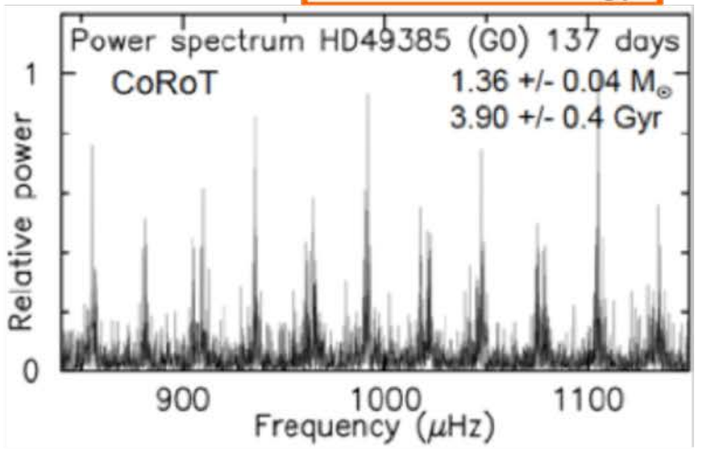
Goals: will detect and characterize planets down to Earth-size by high precision photometric transits around ~1M bright stars. Planetary masses will be determined by ground-based radial velocity measurements. Stellar parameters like age and mass will be obtained by asteroseismology

Photometric transits



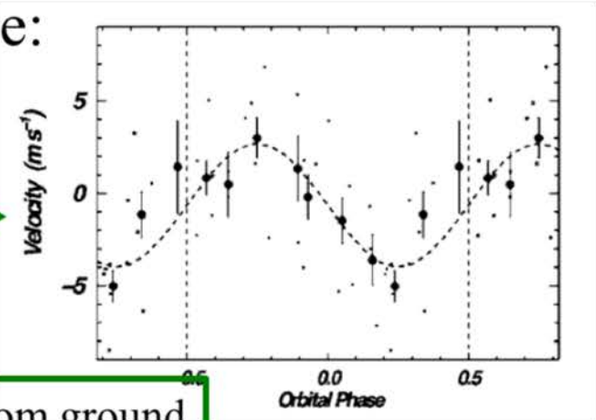
e.g. Kepler-10b (V=11.5)

Asteroseismology



For solar like stars PLATO will give:

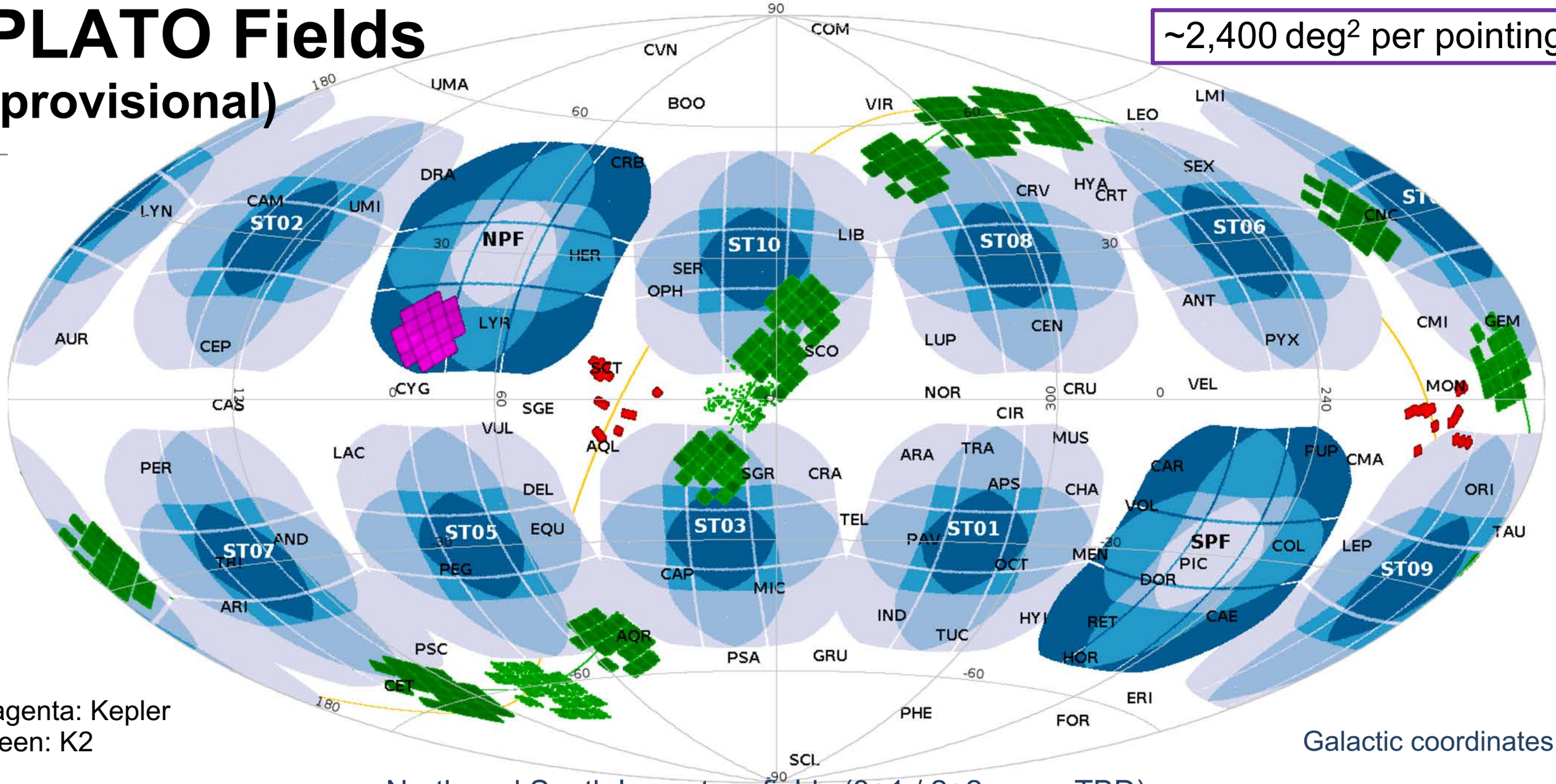
- **Radius to ~3%**
- **Mass to ~10%**
- **Age to ~10%**



RV follow-up from ground

PLATO Fields
(provisional)

~2,400 deg^2 per pointing

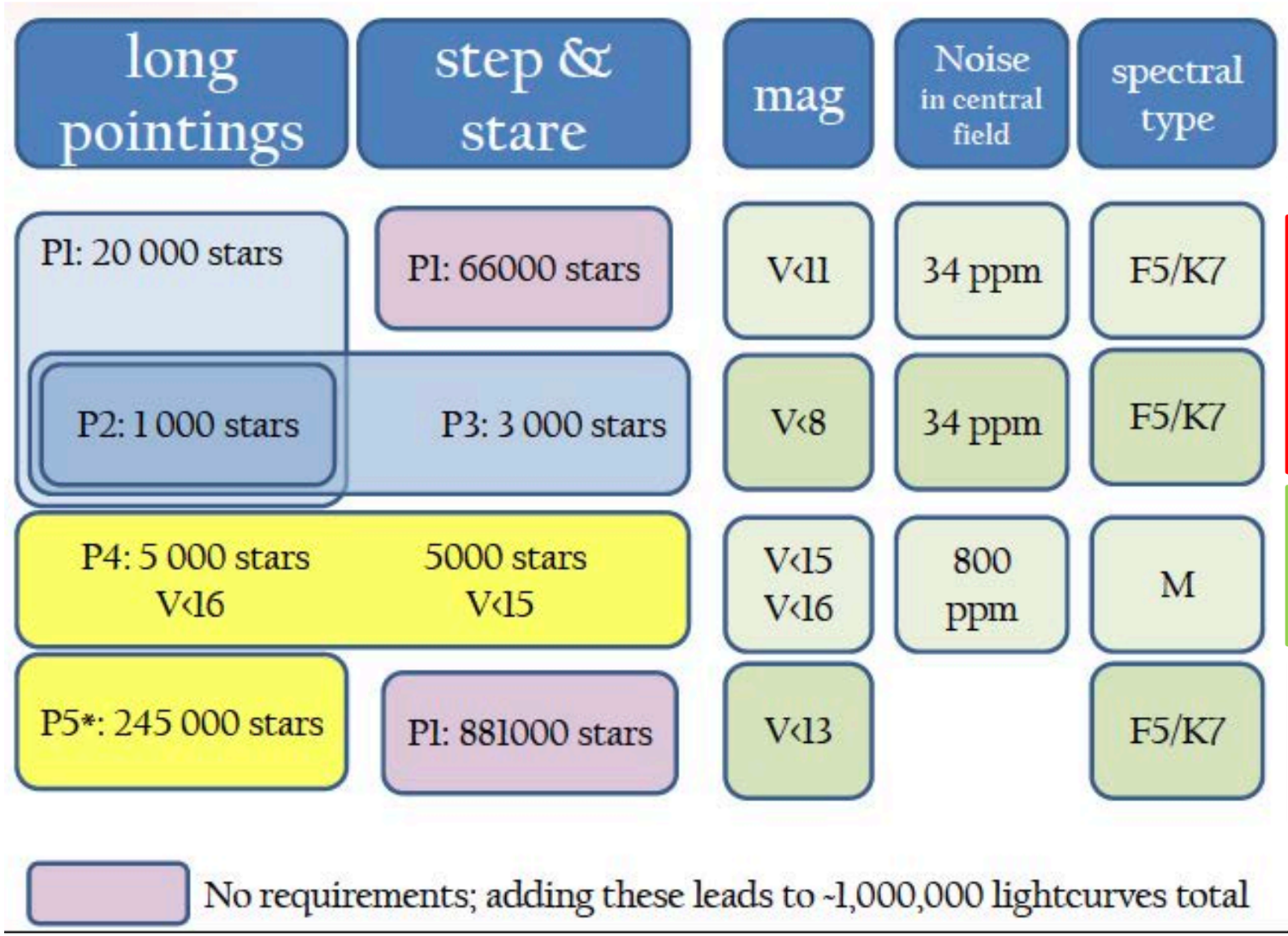


Magenta: Kepler
Green: K2

Galactic coordinates.

North and South long stare fields (3+1 / 2+2 years TBD)
Step and Stare fields (~few months each) (TBD)

PLATO Samples



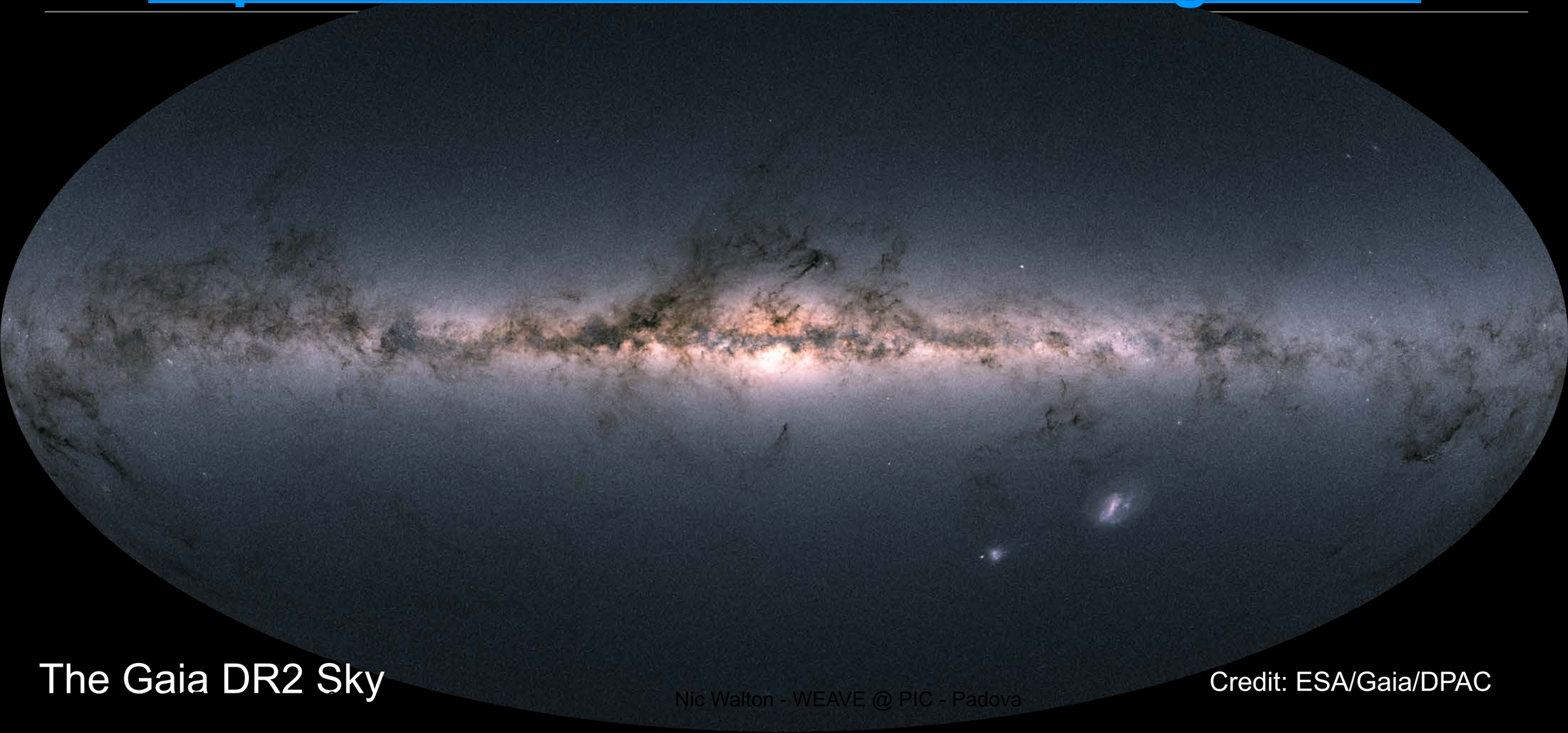
P1+P2+P3: Exoplanet characterization and asteroseismology

P4: M dwarf host star sample

P5: Exoplanet statistics and stellar science

★ P5 for long and step/stare phases:
~ 1 Million light curves at <13 mag

Gaia DR2:
https://www.cosmos.esa.int/web/gaia/dr2



The Gaia DR2 Sky

Credit: ESA/Gaia/DPAC

Gaia as a PLATO helper

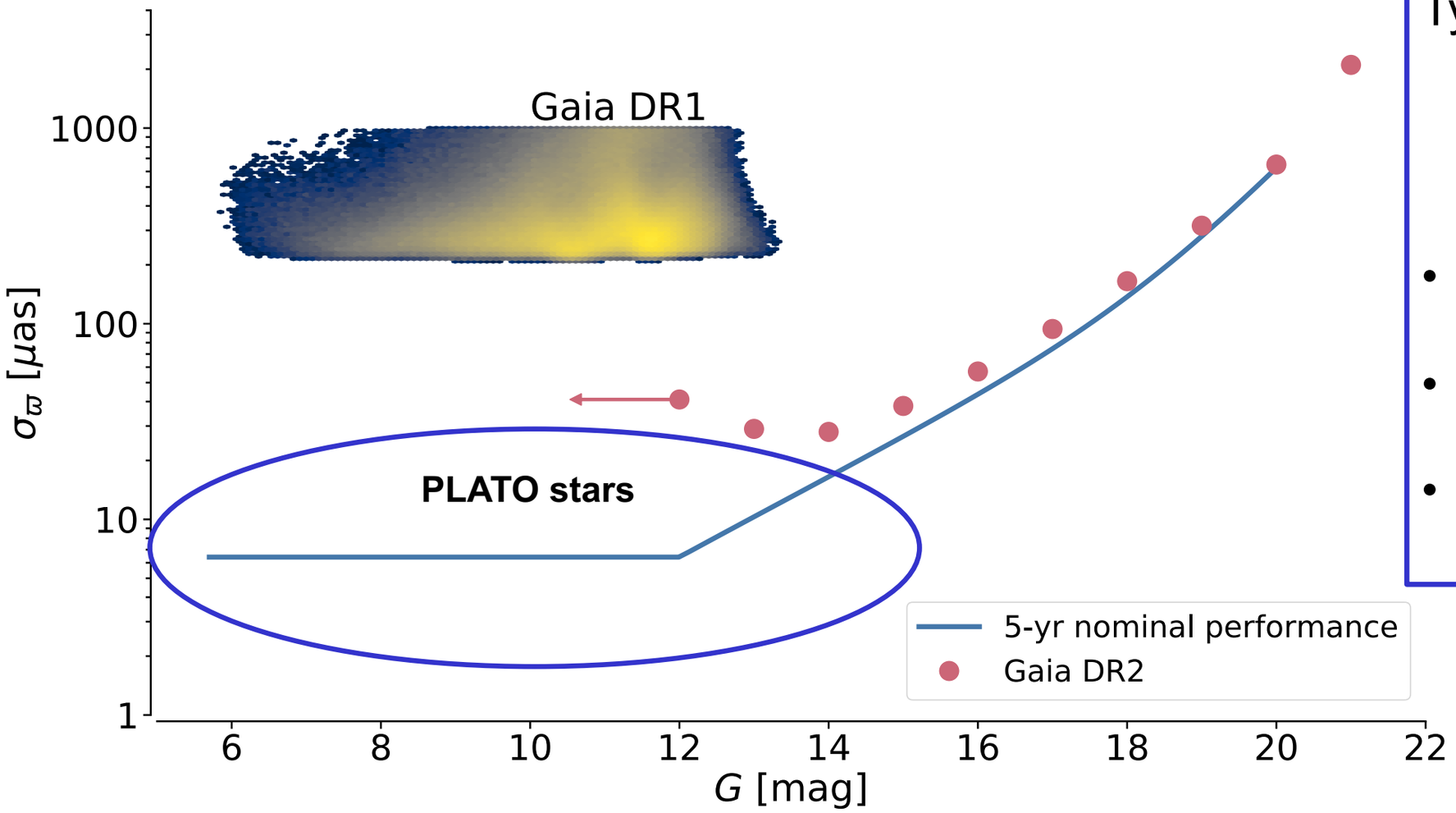
- Gaia provides detailed properties for all PLATO host stars (distances, T_{eff}, radius, log g, [Fe/H], A_v, etc)
- Gaia enables the selection of PLATO target stars – ability to type all input stars (e.g. select dwarfs, careful selection of activity type)
- Gaia astrometry will allow for detection of more massive planets in PLATO target systems
- Gaia will allow characterisation of the PLATO target fields – also at the pixel level (one PLATO pixel = over 20,000 Gaia pixels!!)

(most) Gaia data required by PIC will be public in advance of PLATO launch

Apply factors of ~ 0.7 and ~ 0.5 for positions and proper motions

Gaia DR2 Astrometric Performance

Astrometric data of unprecedented quality and quantity



Typical parallax precision

G = 15	0.02–0.04 mas
G = 17	0.1 mas
G = 20	0.7 mas
G = 21	2.0 mas

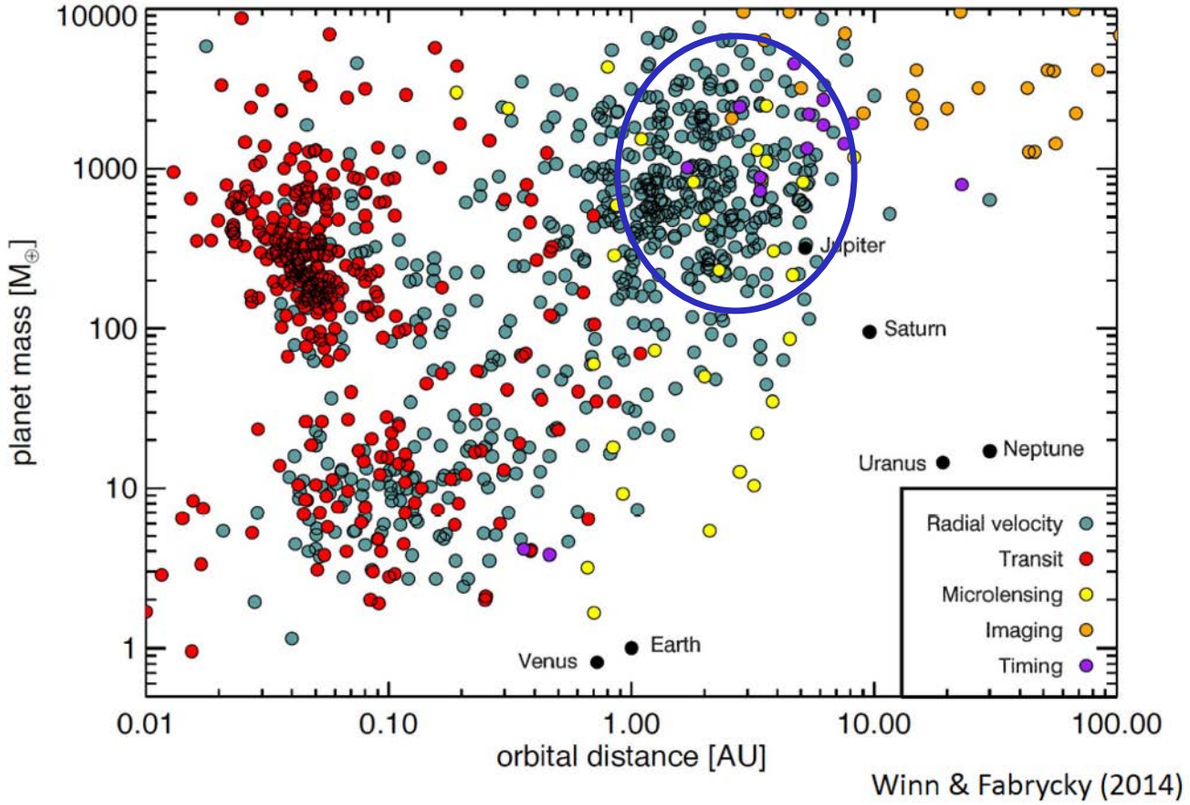
- Systematic errors below 0.1 mas
- Spatial correlations at ~1 and ~20 degree scales
- Bright star performance calibration limited

Already achieving the 5 year mission predicted uncertainties at the faint end

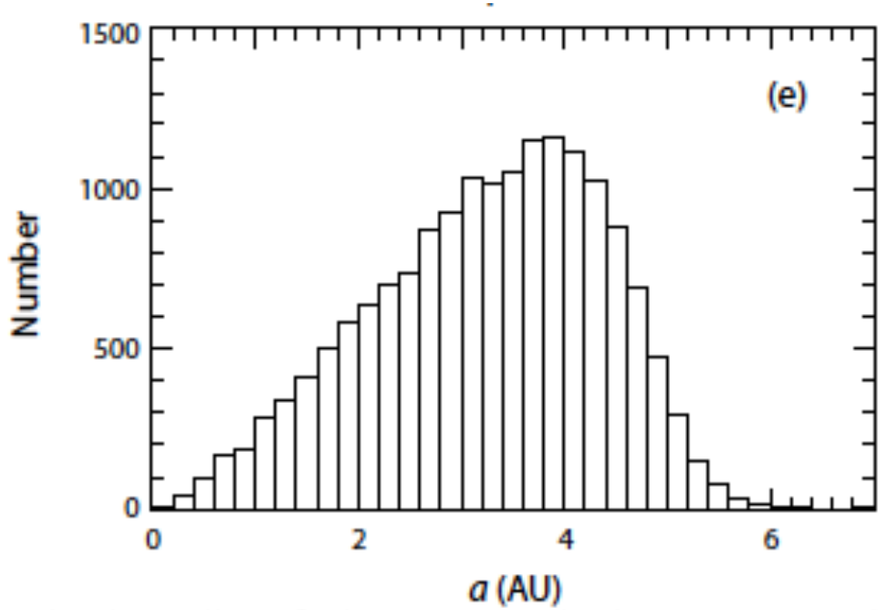
Gaia as a Planet Finder

GAIA Astrometric Planets:

typical discovery space indicated



Perryman et al, 2014, Sozzetti et al 2014
Circumbinary planets: Sahlmann et al 2015



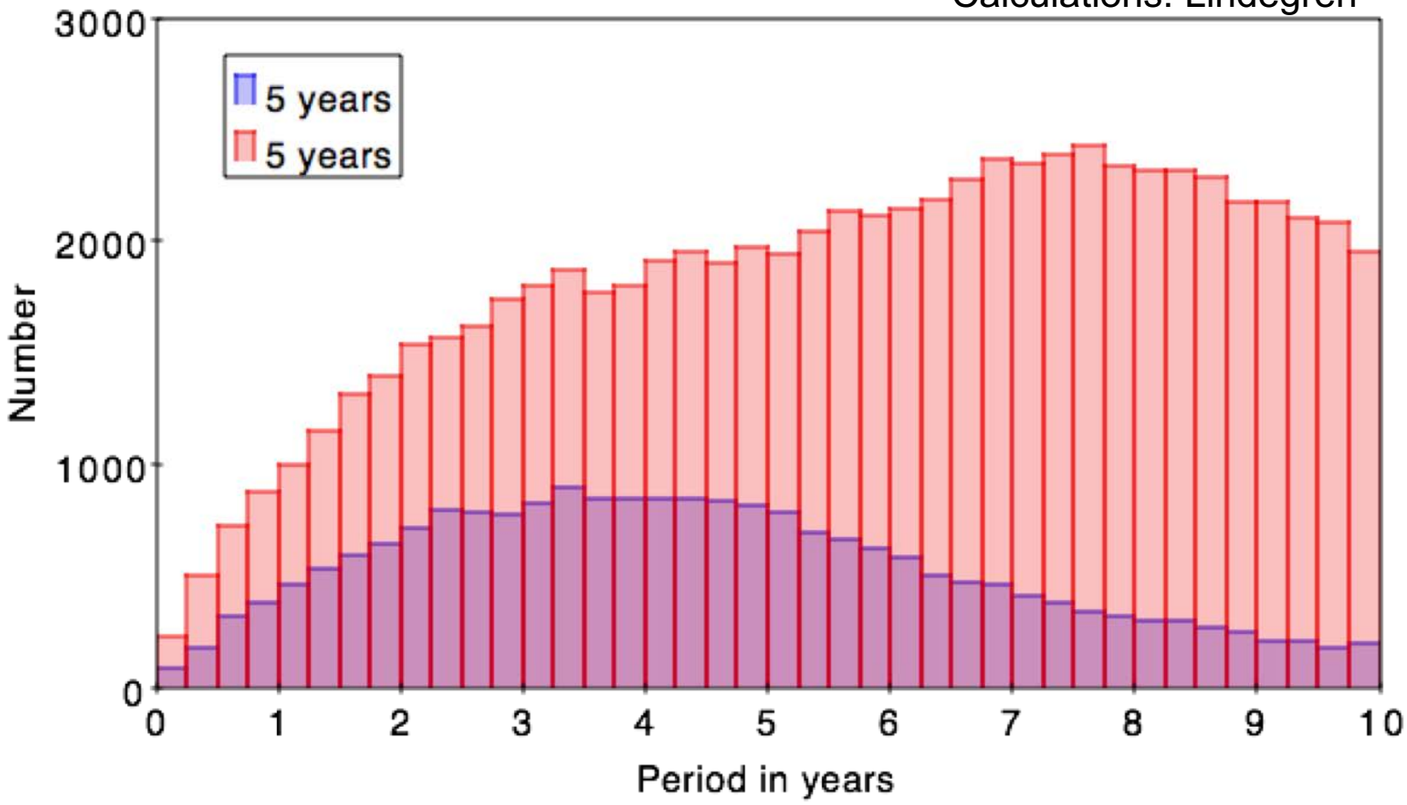
For the baseline Gaia 5 year mission expect >20,000 high mass 1-15 M_J planets out to distances of 500 pc (1000+ planets in M dwarfs to ~100pc)

Gaia will also find 100's of close in hot Jupiters via transits (Dzigan & Zucker 2012)

Gaia Mission Extension: Exoplanet
nominal mission 7/2014-6/2019 | extension 7/2019-2024

- Gaia's strength is Neptune-Jupiter mass planets around stars
- Mission extension reveals population of giant planets above several AU distances from the parent star
  - giant planets before migration, systems with giant planets 'guarding' habitable zone
- Basic mission results scale as $t^{-0.5}$
  - Proper motions scale as $t^{-1.5}$
  - High order orbital motions scale as $t^{-4.5}$

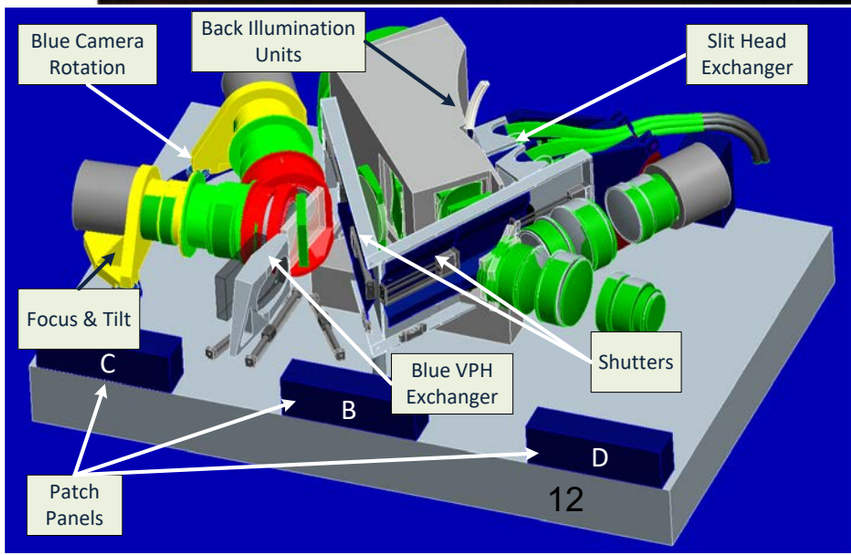
Calculations: Lindegren



WEAVE:
http://www.ing.iac.es/weave

~1000 fibres (+mIFU and IFU)
over ~π deg^2
at R up to 20,000
for λ ~366-959nm

WEAVE 5 year surveys commence
~mid 2020

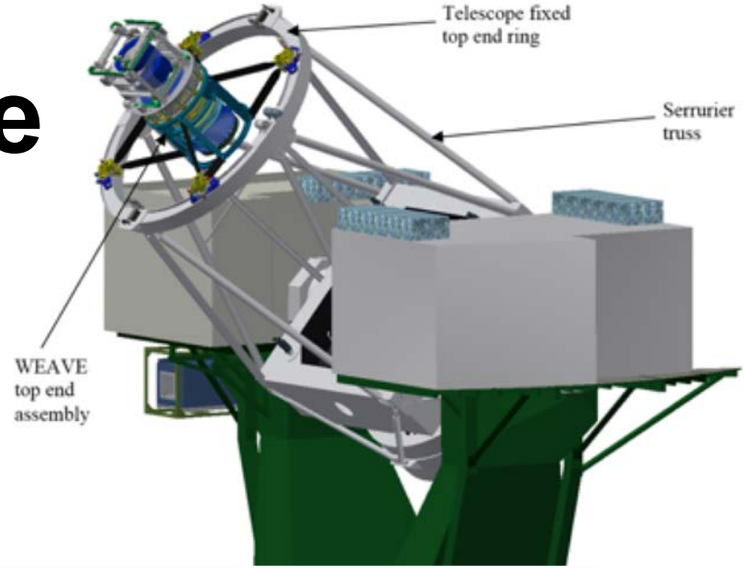


WEAVE instrument by the numbers

Telescope, diameter	WHT, 4.2m
Field of view	2º Ø
Number of fibers	960 (plate A)/940 (plate B)
Fiber size	1.3″
Number of small IFUs, size	20 x 11″x12″ (1.3″ spaxels)
LIFU size	1.3′x1.5′ (2.6″ spaxels)
Low-resolution mode resolution	5750 (3000–7500)
Low-resolution mode wavelength coverage (Å)	3660–9590
High-resolution mode resolution	21000 (13000–25000)
High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

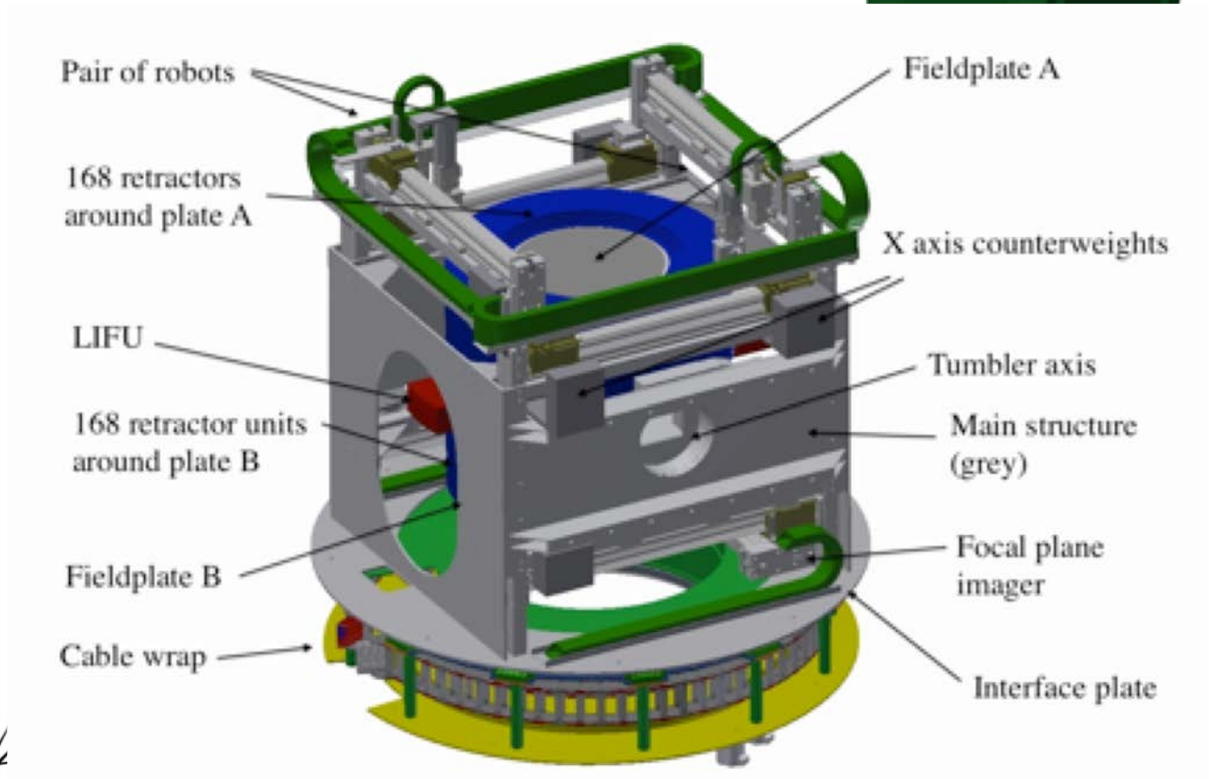
The Hardware

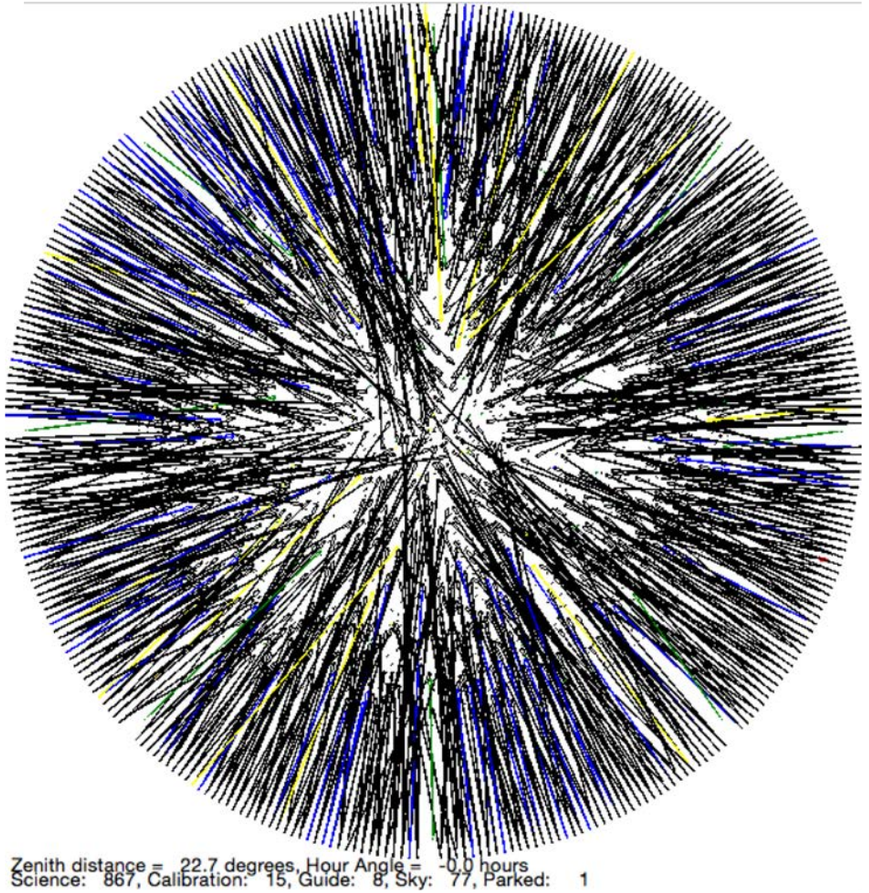
2dF-style tumbler, two robots, ~1000 fibres/plate (plus 20 miniIFUs on one plate). Large IFU in red box



- 100% of fibres placed in simulation of cluster core
- ~8500 fibre crossings
- ~1800 moves in <55 minutes with two robots
- 8 coherent guide fibre bundles (5″ø)

Configuration time ~ 55 mins: this sets limits on observational possibilities, especially for bright stars





Complementing Gaia with WEAVE

Acquire accurate V_r, stellar parameters, metallicity for 15<V<20

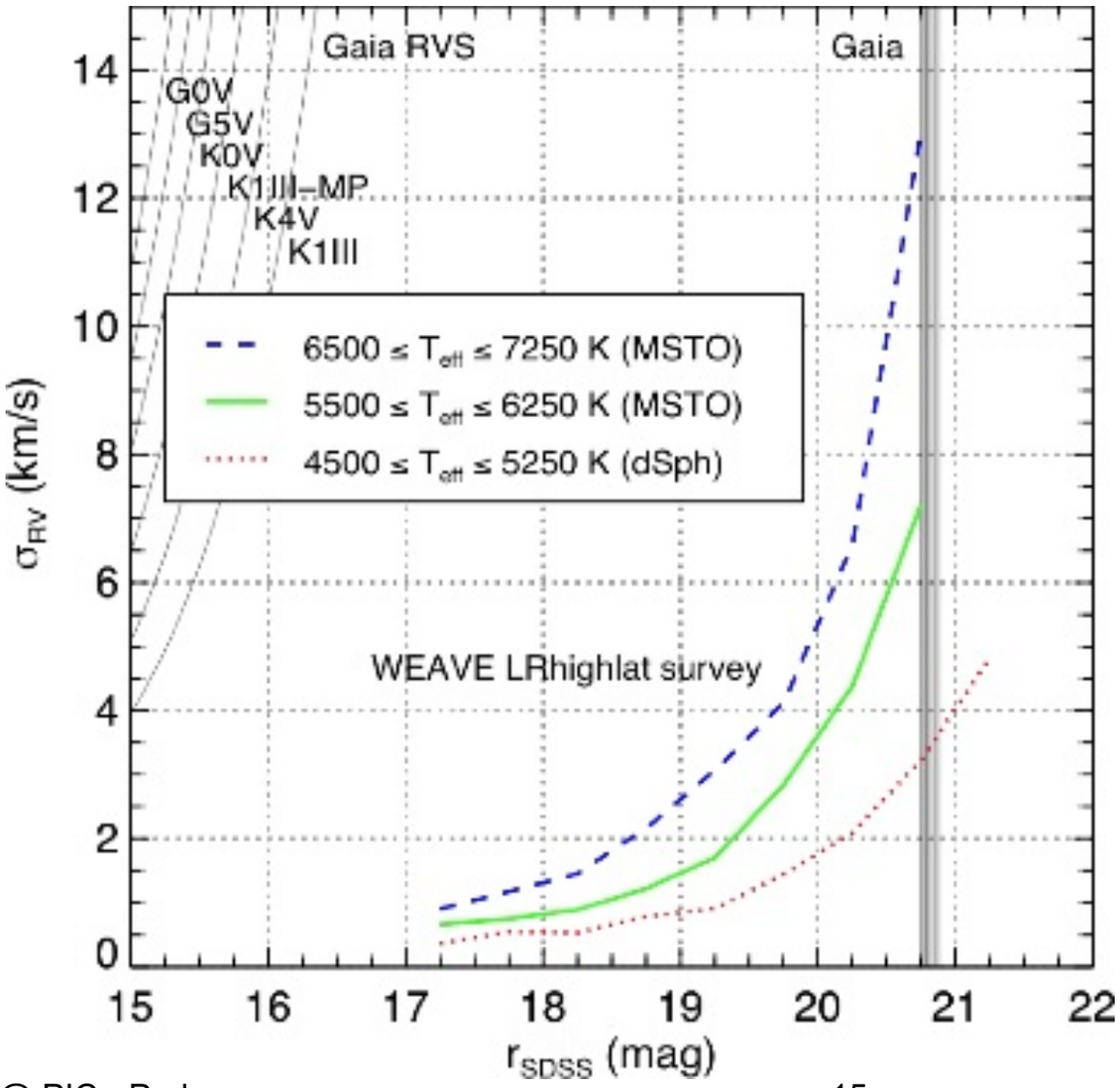
E.g. Defined the **LR mode** of WEAVE:

R = 5,000 in a wide range **[366 – 606]** nm + **[579 –959]** nm

Determine accurate stellar parameters & chemistry for V>12

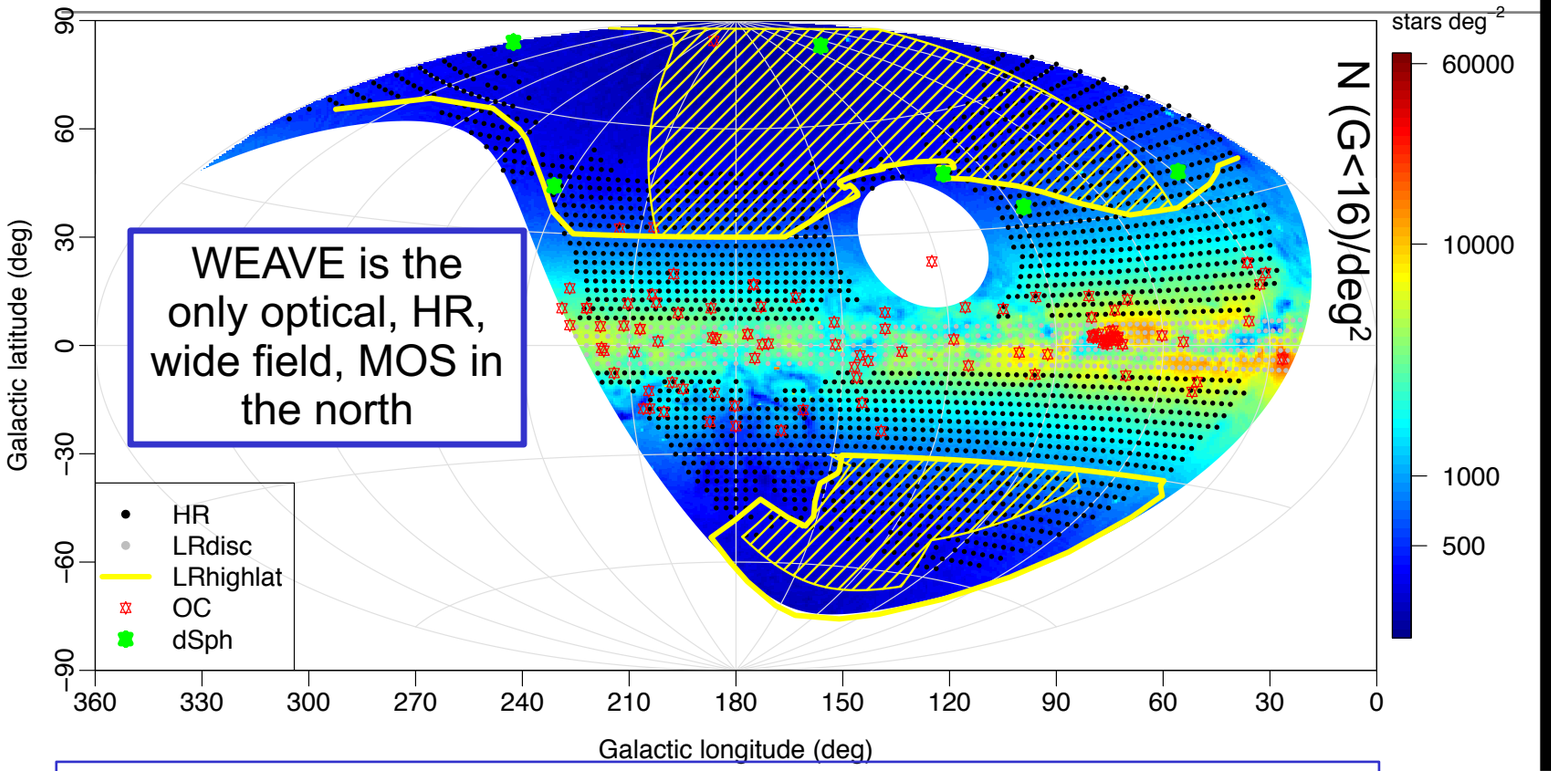
E.g. Defined the **HR mode** of WEAVE:

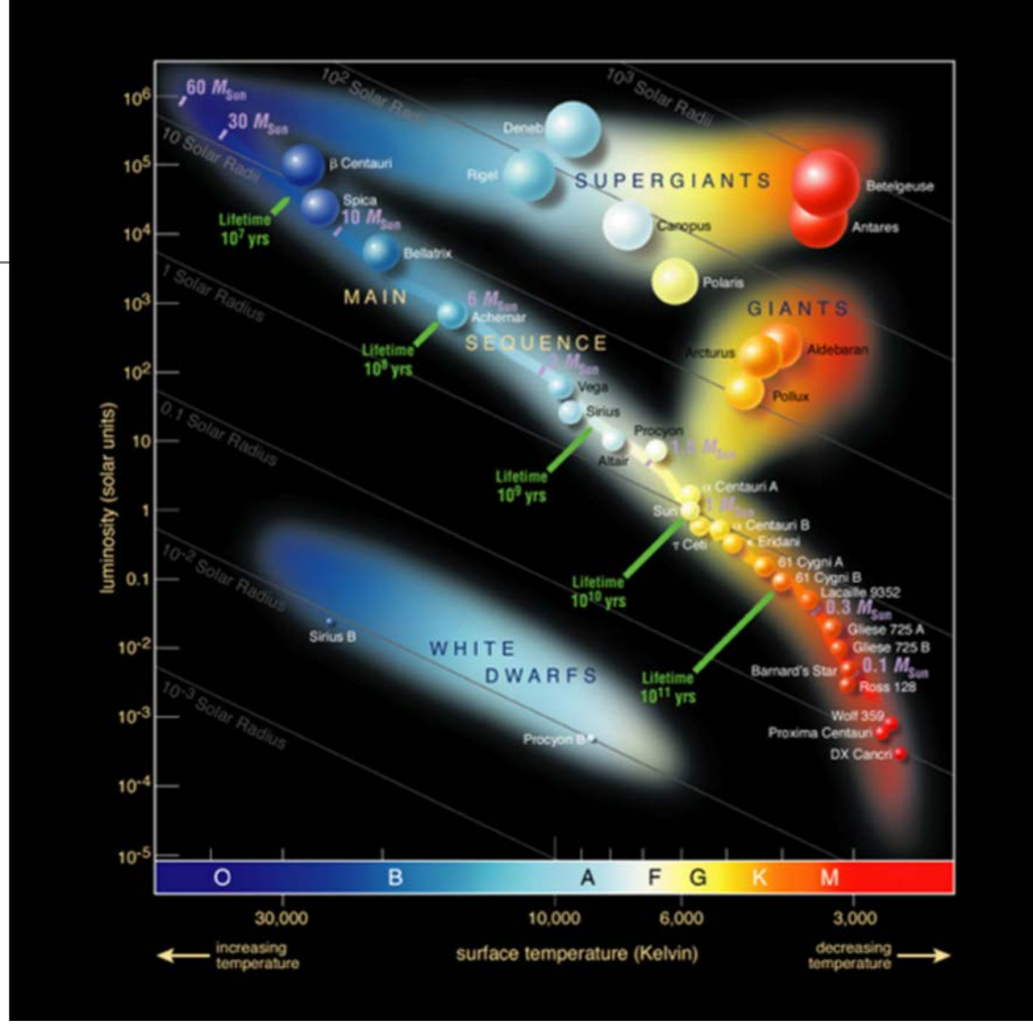
R = 20,000 in two windows: blue arm **[404 – 465]** nm or **[473 – 545]** nm and red arm **[595 – 685]** nm – these chosen to cover main nucleosynthetic channels



The Six Key WEAVE Surveys

includes > 3M stars in WEAVE-GA





- WEAVE-GA: Galactic Archaeology
- Stellar, Circumstellar, Interstellar Physics

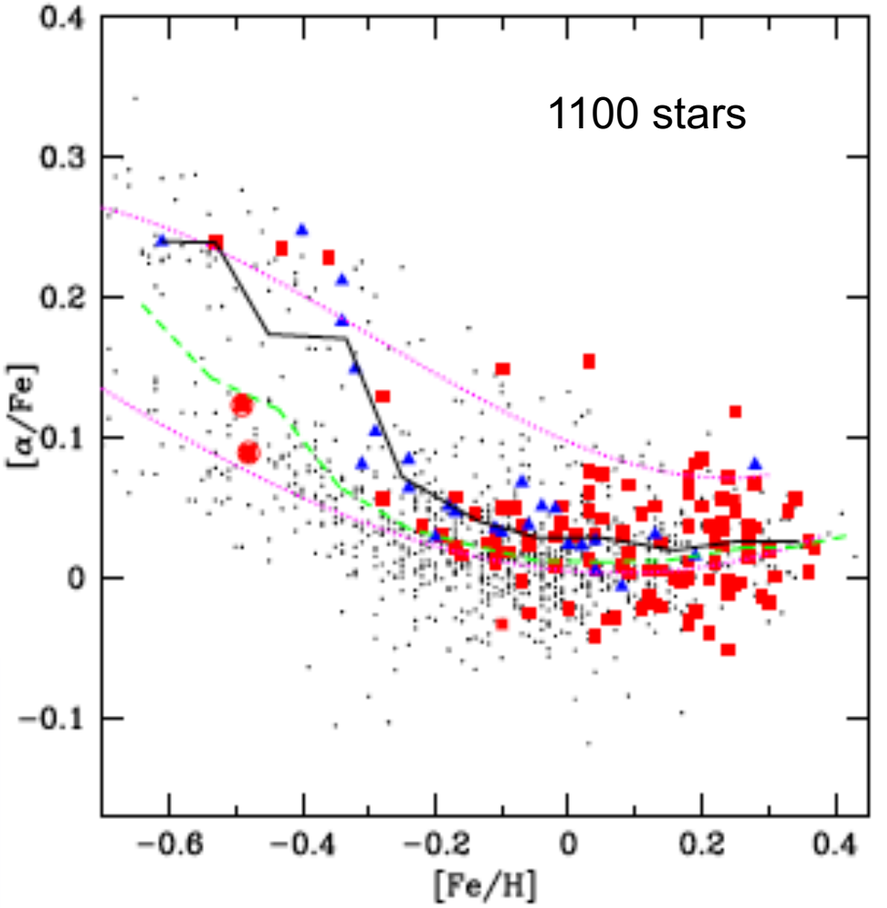
Significant numbers of 11 < V < 15 mag PLATO stars will be observed in these Surveys (depending on PLATO field selection

Galaxy Clusters
Galaxy Evolution
(WEAVE-APERTIF + StePS)
WEAVE-LOFAR/ WEAVE-QSOs

WEAVE exoEarth twilight survey (WxES)
host star chemistry at the 0.05 dex level

- Jupiters found in higher Z hosts than those with Neptunes (e.g. Sousa et al 2008). Effect ~0.2 dex
- Alpha-element overabundance for low metallicity planet hosts (e.g. Adibekyan et al 2012)
- Indication that low metallicity thick disk stars preferentially host planets
- Smaller planets found in stars with lower metallicities (Buchhave et al 2014, based on study of ~400 host stars)
- Some evidence for Si as a pointer of planets (e.g. Brugamyer et al 2011, Brewer et al, 2017)

AIM: value added survey to investigate in depth, host star metallicity/ planet relationships; monitor stellar properties with time, especially active stars
Reveal formation scenarios, investigate planet impact on stellar metallicity



Adibekyan et al, 2012

Implementing WxES

Twilight program/ potential GOP component

WxES: Walton, 2016

- R=20,000 (~1 kms^{-1}) mode spectra of the ~50,000 higher priority host stars to be observed by PLATO (visible to the WHT in the north)
  - FAST (~2-5 min exp) survey of the brighter (6 < 11th mag) PLATO stars
  - Requires new 'configuration' mode for efficiency [implement early 2021]
  - (Astronomical) Twilight observations: ~2 x 30 min slots per night
- Main PLATO northern field – ~120,000 stars at V < 13th mag (inc P5)
  - Equates to ~ 100 stars per WEAVE pointing
  - Targets available all year for PLATO Northern Hemisphere 'step' fields
- Outputs: elemental abundances to 0.05 dex
  - (alpha-elements, Fe peak) Ca, Si, Cr, Ni, Fe
  - (s-process) Ba, Sr and Na, Mg, Al, Sc, Ti, V, Mn, Co
- Identify spectroscopic binaries (rule out candidate false positives)
  - Double line in one shot, single line via multiple observations

Significant analysis by 2023/24, available for PIC pre-launch

WEAVE and 4MOST: Complete spectroscopy of Exoplanet host stars