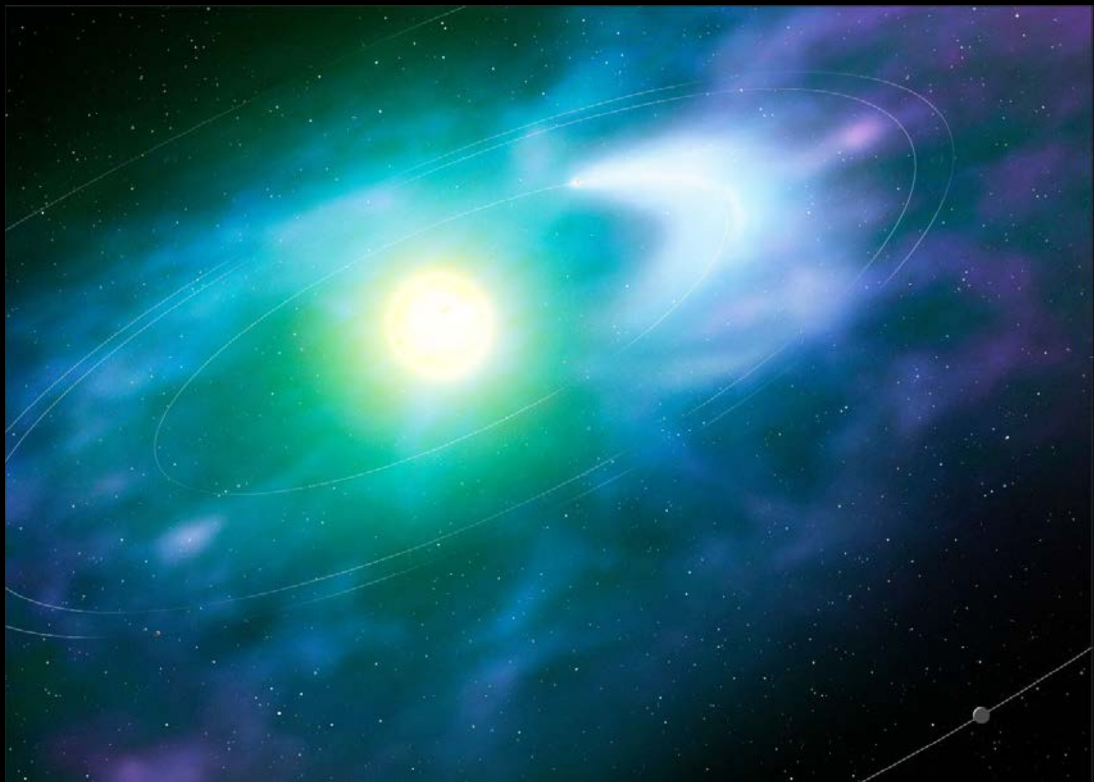
What can the Dispersed Matter Planet Project do for ARIEL?



Carole Haswell, The Open University

Principal Collaborators: Dan Staab, John Barnes, Luca Fossati, Mark Jones, Guillem Angelada-Escude, James Doherty, Joe Cooper, James Jenkins

Outline

- motivation: WASP-12:
  stellar activity masked by planetary mass loss
  → new way to select host stars of ablating planets

- Dispersed Matter Planet Project (DMPP)
  Search for Them among BRIGHT NEARBY STARS!
  Very efficient RV planet search
  39 initial targets, good success rate

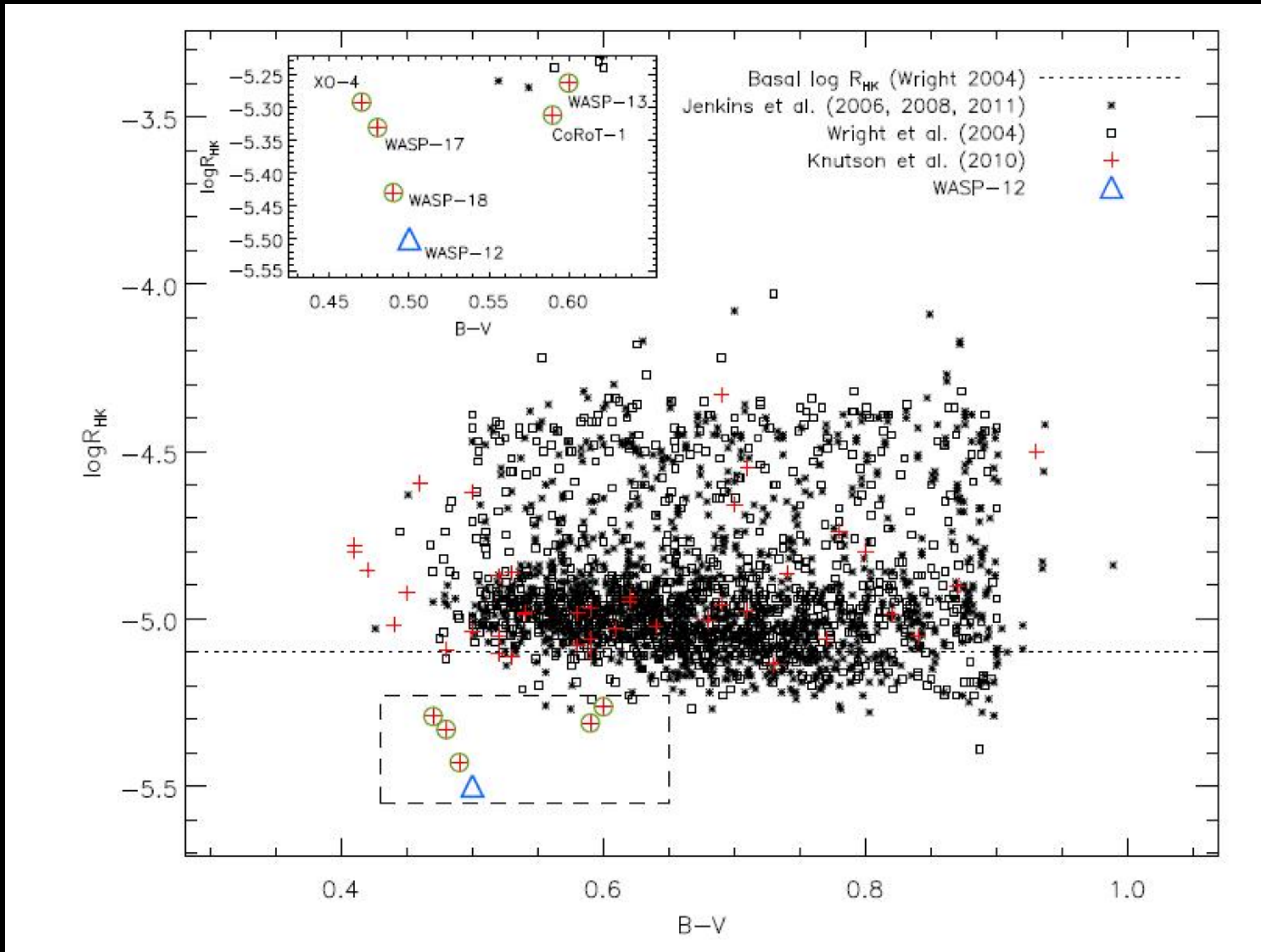
- First discoveries DMPP-1, DMPP-2, DMPP-3 …

- Characterisation of DMPP planets
  mass-radius-composition relationships, exogeology

- DMPP systems good for characterisation even if not transiting…

Activity: characterised by R_{HK}

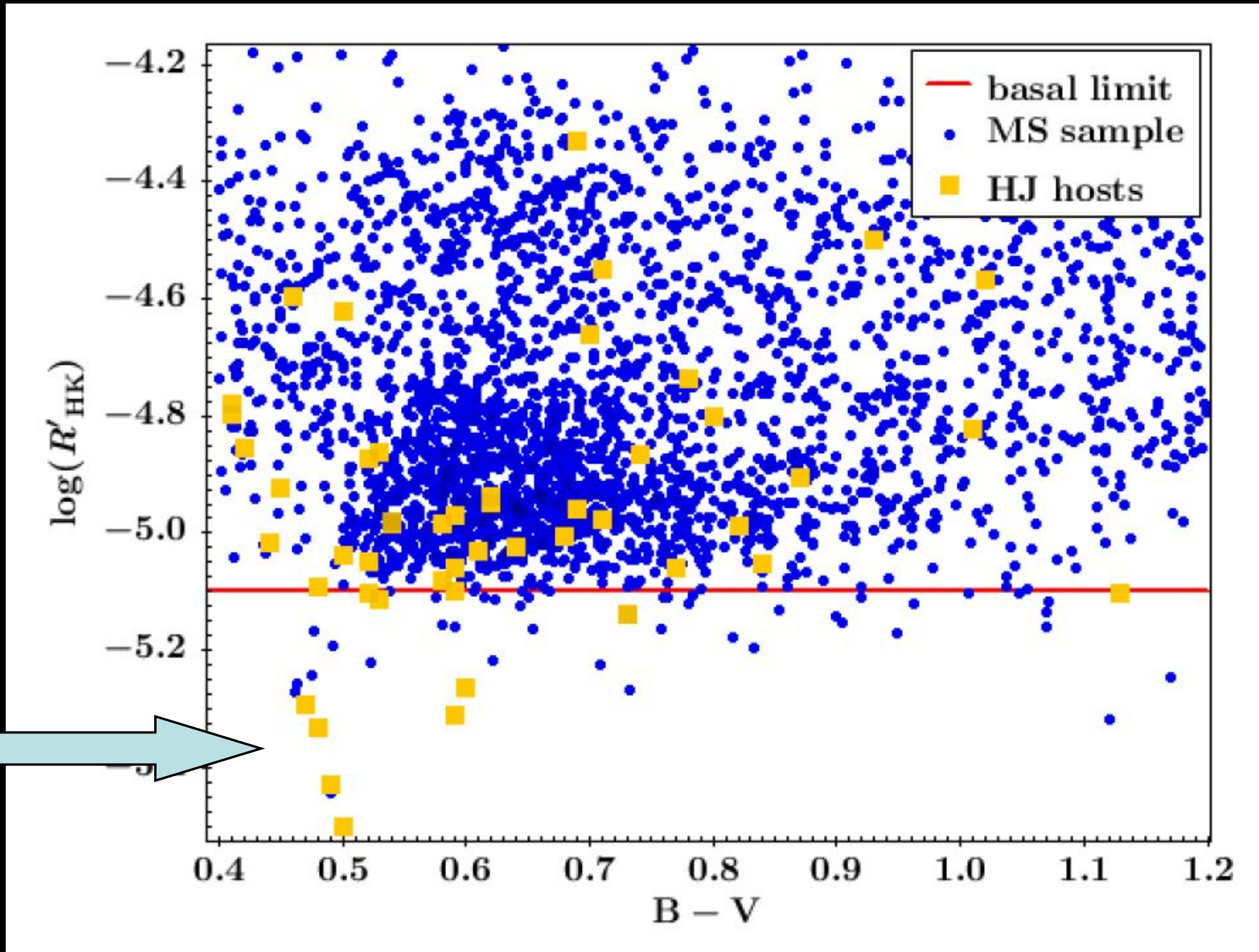
Line core Emission strength



Fossati, Ayres, Haswell, Bohlender, Kochukhov & Floer 2013, ApJLett

Ca II H& K line cores

Activity: characterised by R_{HK}



Line core emission quenched by diffuse gas

Dan Staab PhD work

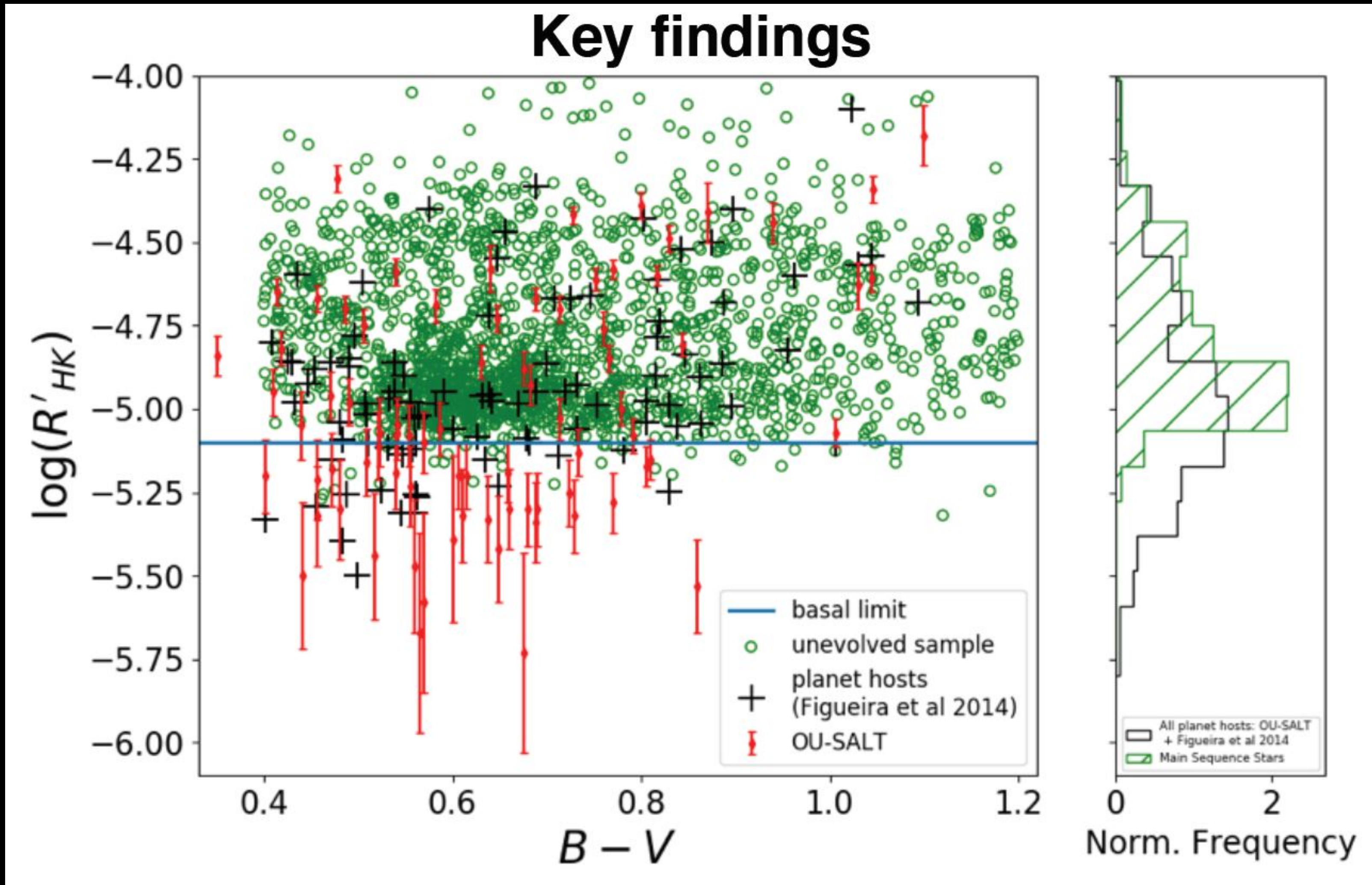
Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

Activity: characterised by R_{HK}

> 40% of close-in planet hosts:

depressed CaII H&K

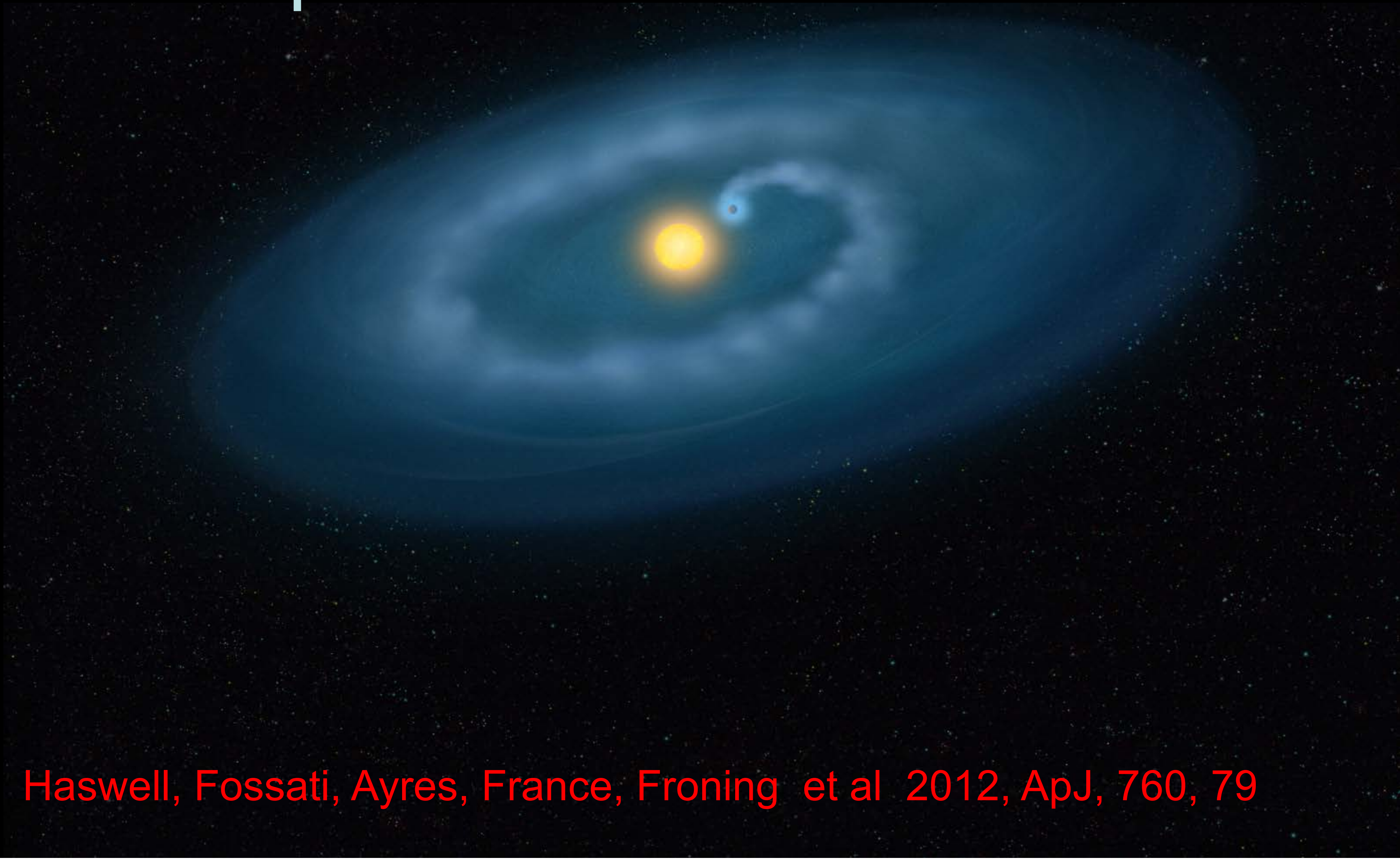
OU-SALT survey



Doherty, Haswell, Barnes, Staab, Fossati 2018, Poster Cool Stars 20; 2019 in prep

Staab, Haswell, Smith, Fossati, Barnes, Busuttil, Jenkins, MNRAS, 2017, 466, 738

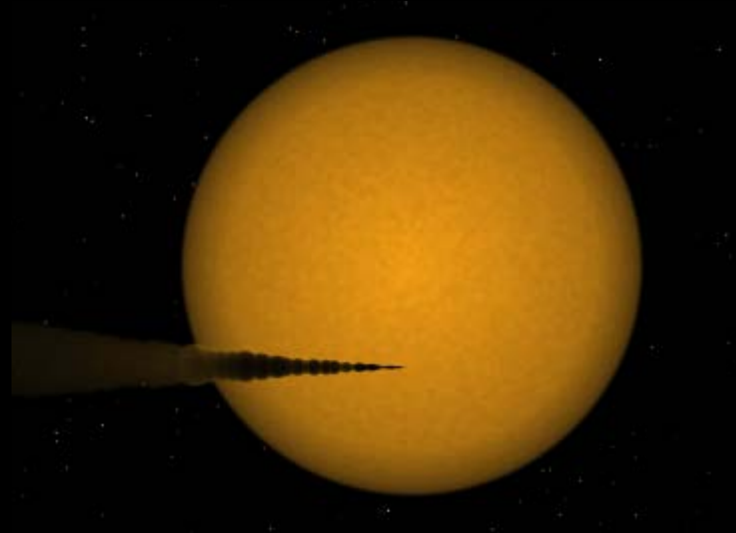
Absorbing gas constrained to orbital plane?



Haswell, Fossati, Ayres, France, Froning et al 2012, ApJ, 760, 79

Mass-losing close-in planets

e.g. Kepler 1520b have HUGE scale-heights

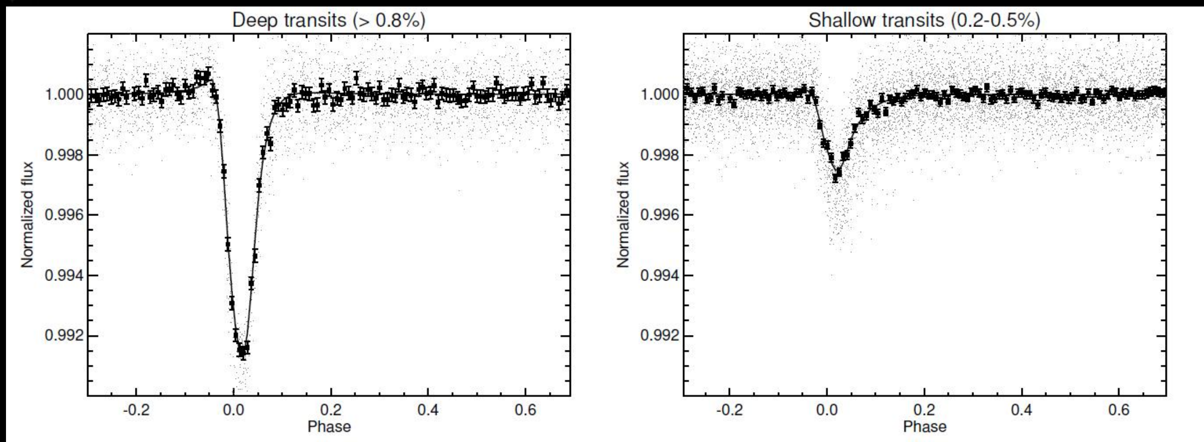


KIC 1255b aka Kepler 1520b:

- Detected by transiting dust
- Coexists with metal-rich vapour
- Subliming low mass planet
- Below our RV detection threshold

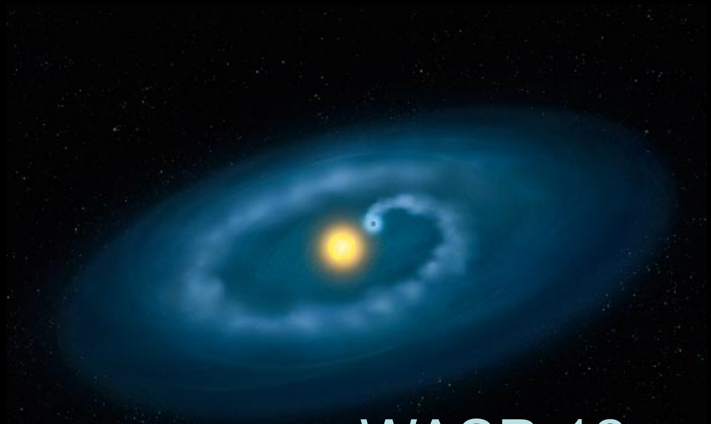
DMPP systems host analogues and progenitors of Kepler 1520b ?

Fossati, Haswell et al 2010, Haswell, Fossati et al 2012, Rappaport et al 2012, ApJ, 752, 1
Brogi et al 2012 A&A 545, L5

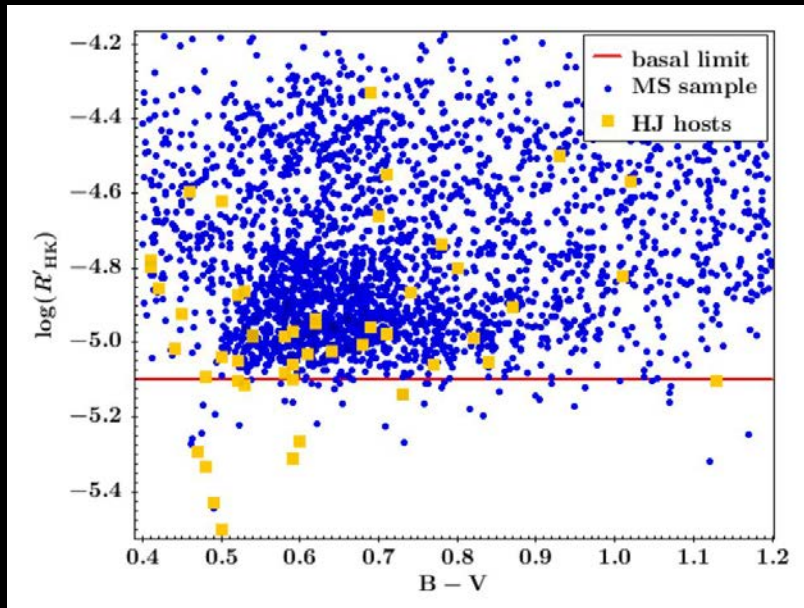


Nearby analogues and progenitors of Kepler 1520b

- WASP-12's Mg II h & k line cores have ZERO flux!
- main sequence stars all show chromospheric emission cores
- Emission cores must be absorbed
- Similar signal in the optical Ca II H&K line cores



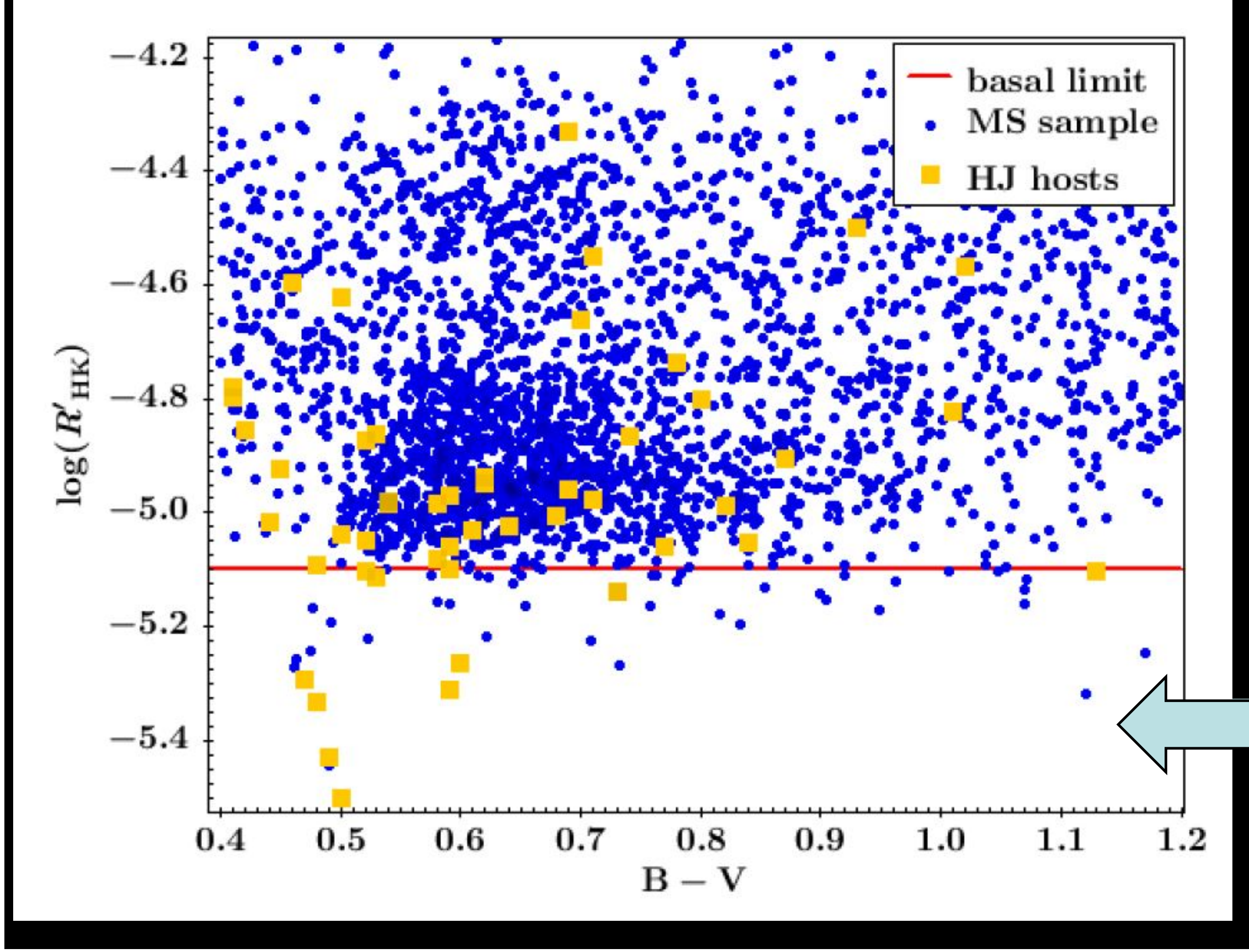
WASP-12 system shrouded in diffuse absorbing gas



Haswell et al 2012 , ApJ, 760, 79

Nearby analogues and progenitors of Kepler 1520b: find with Ca II H&K

- Examined > 6000 bright stars
- Identified ~100 prospects
- Winnowed the best dozen targets



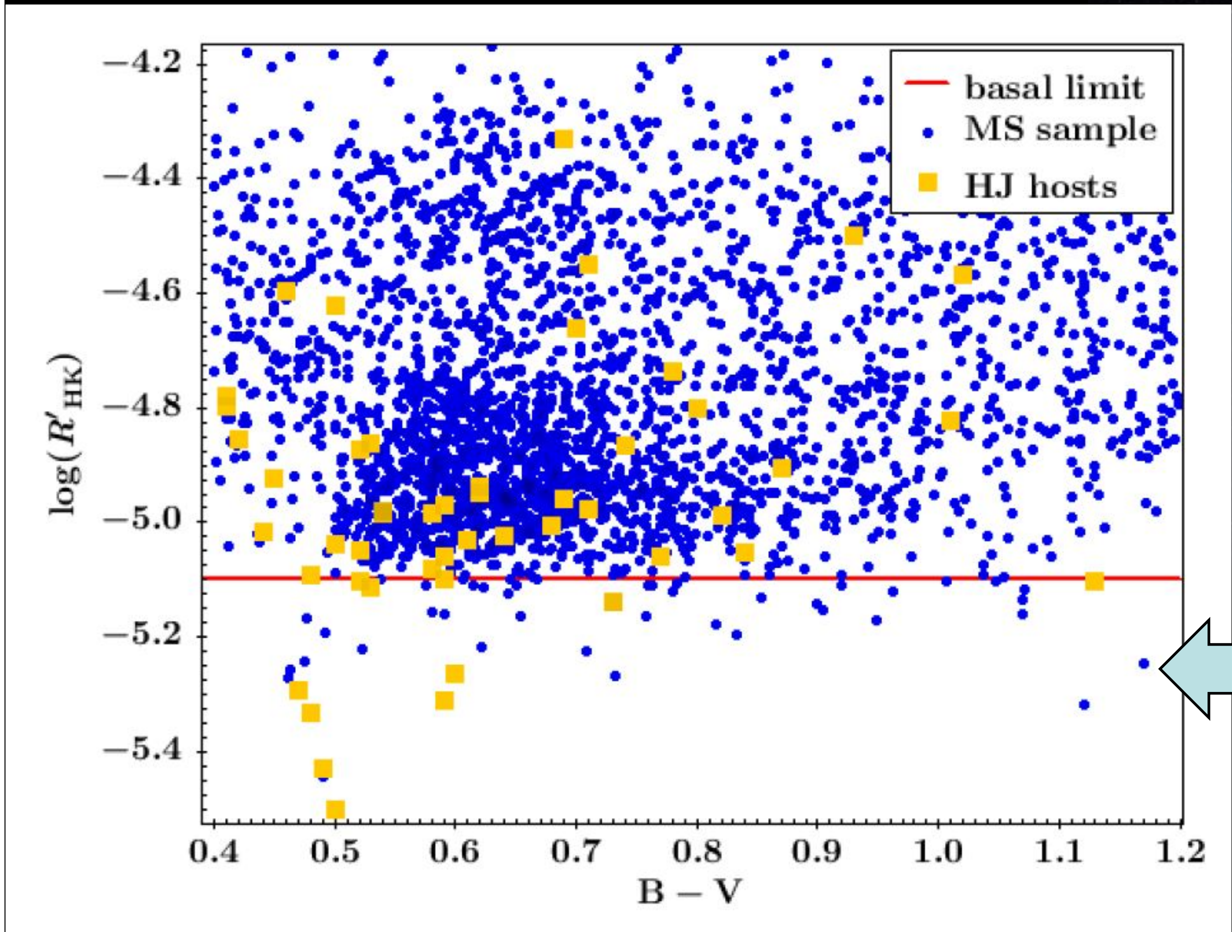
OPTICON:
5 nights OHP/SOPHIE
in 2015A (April)

ESO:
5 nights 3.6m/HARPS
Sept 2015

Search for short-period planets using RV method

BRIGHT hosts of mass-losing, low-mass, short period rocky planets?

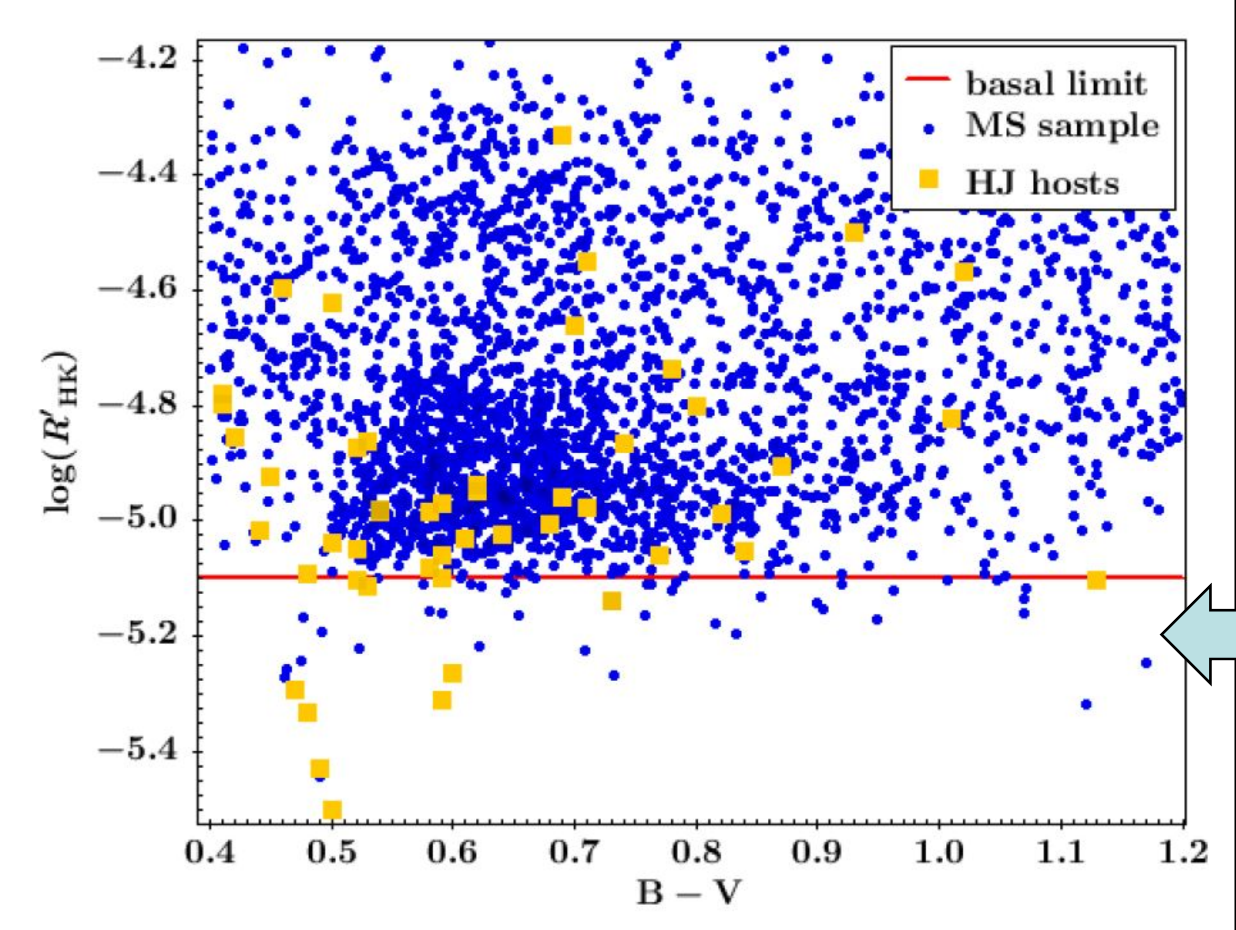
Absorbing gas constrained to orbital plane?



BRIGHT hosts of mass-losing, low-mass, short period TRANSITING rocky planets??

Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

The Dispersed Matter Planet Project: Targets



39 targets,
all d < ~100pc

BRIGHT hosts of mass-losing, low-mass, short period TRANSITING rocky planets??

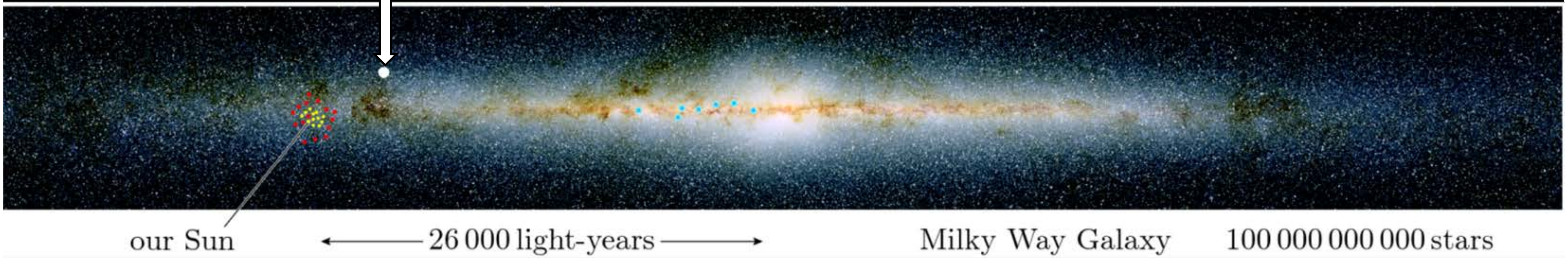
Unevolved Main Sequence population, 0.4 < B-V < 1.2 , sample of 2716 stars

Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

The Dispersed Matter Planet Project: Characterisation

transiting exoplanet candidates from Kepler ~10 times more distant than SuperWASP planets

Microlensing planets in Galactic bulge

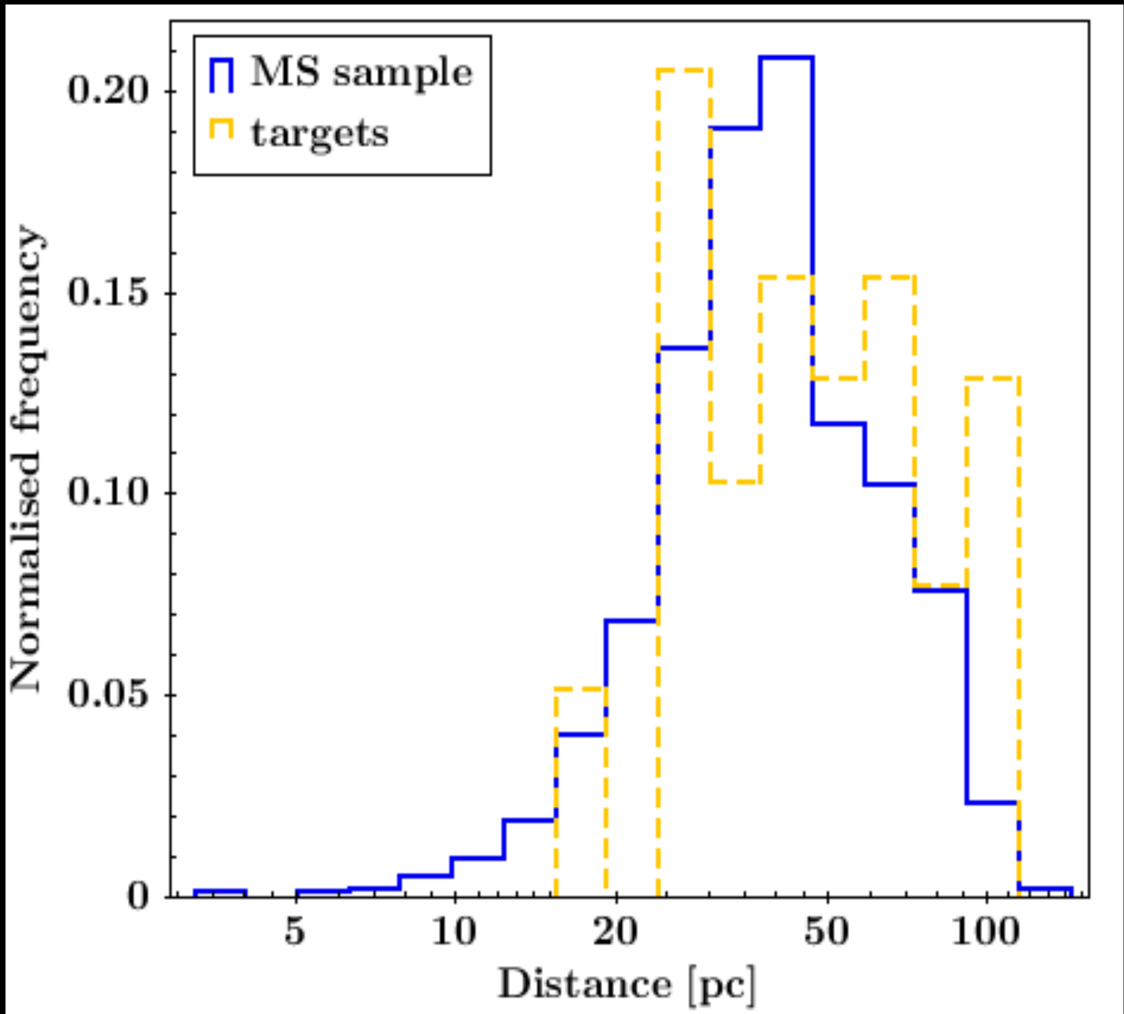


Transit surveys like SuperWASP sensitive to more distant host stars

RV discoveries restricted to nearby stars

DMPP systems have distances typical of RV discoveries

The Dispersed Matter Planet Project: Targets



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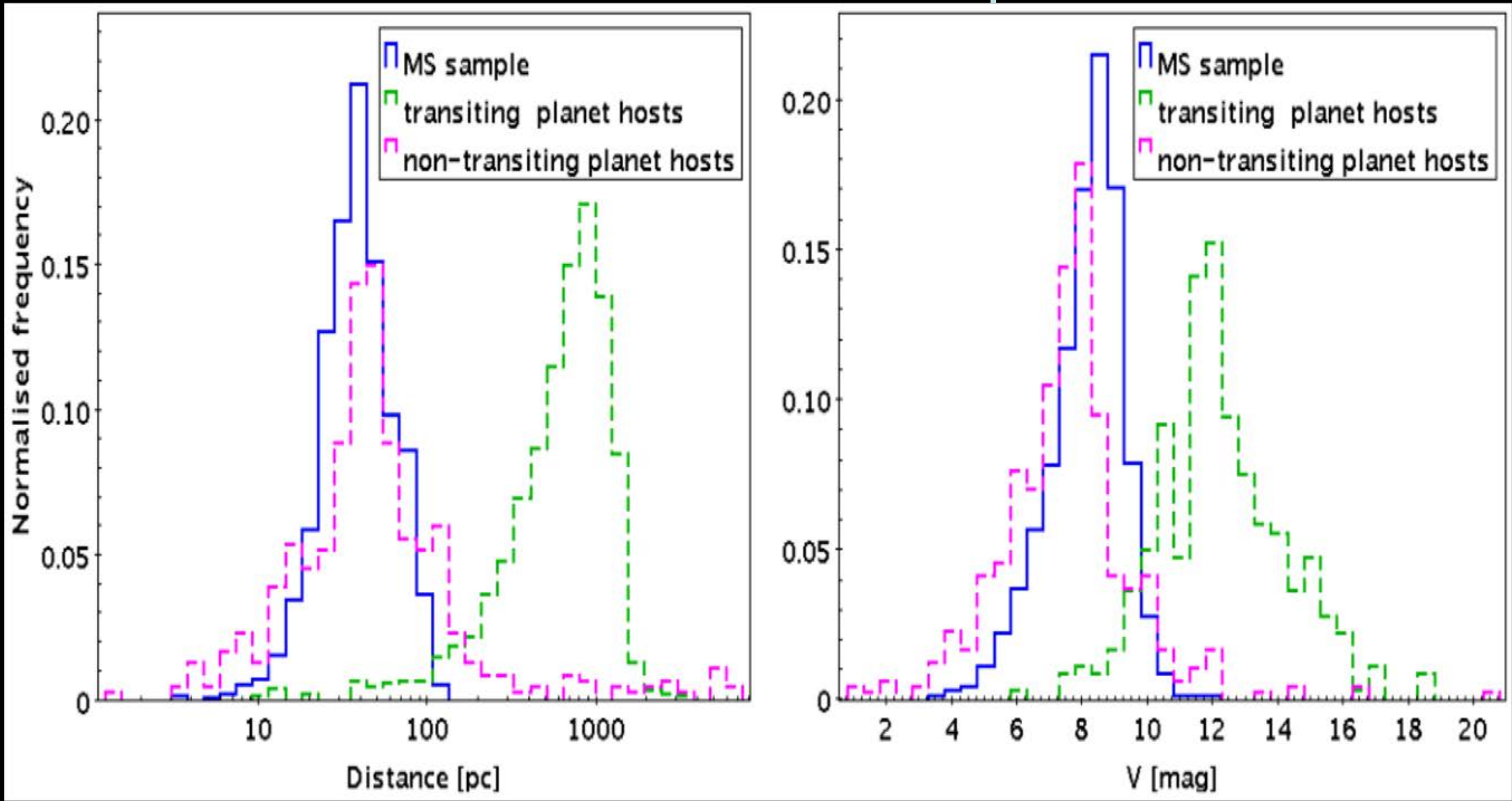

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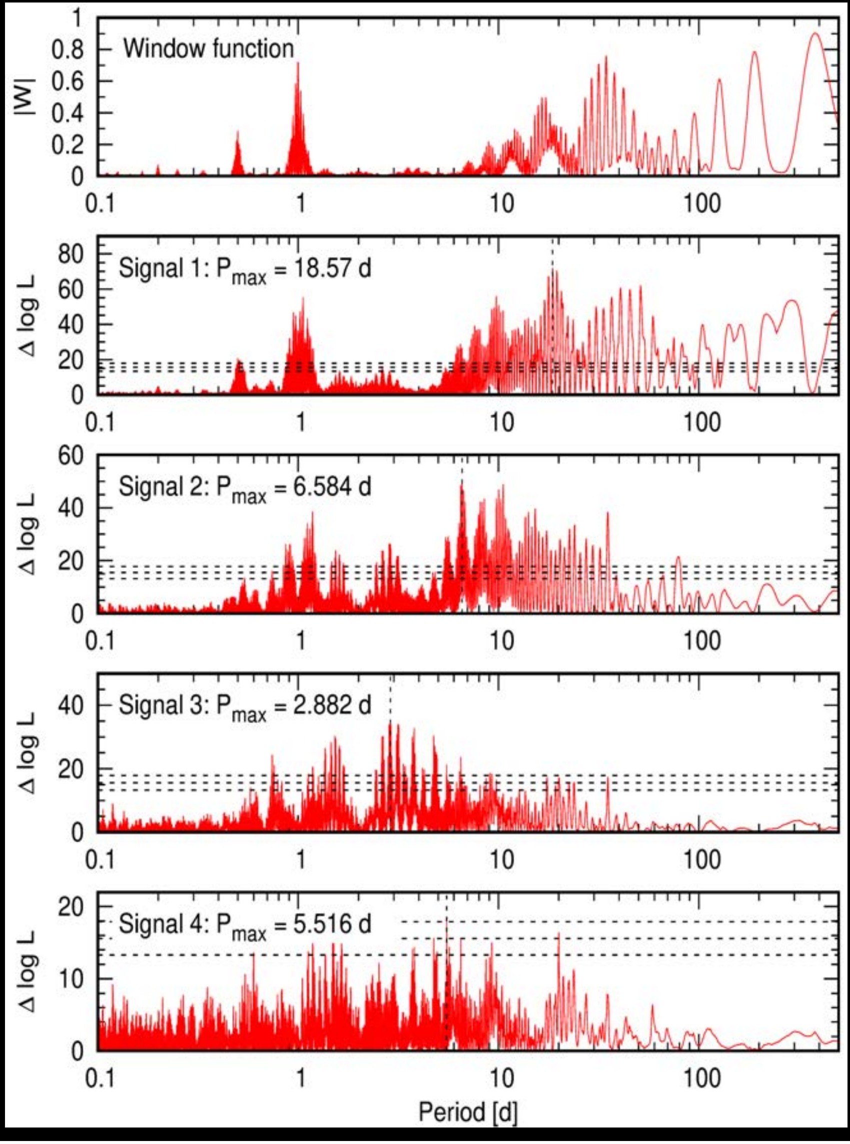
Dispersed Matter Planet Project (DMPP): RV signal detection

- short period planets detected where sufficient data (> 60 RV points)
  - Sticking-point is pinning down ephemeris: Aliasing a big problem
  - False Alarm Probability (FAP) used to assess signal
  - 1% or 0.1% FAP common in literature
  - 10%, 1% and 0.1% indicated



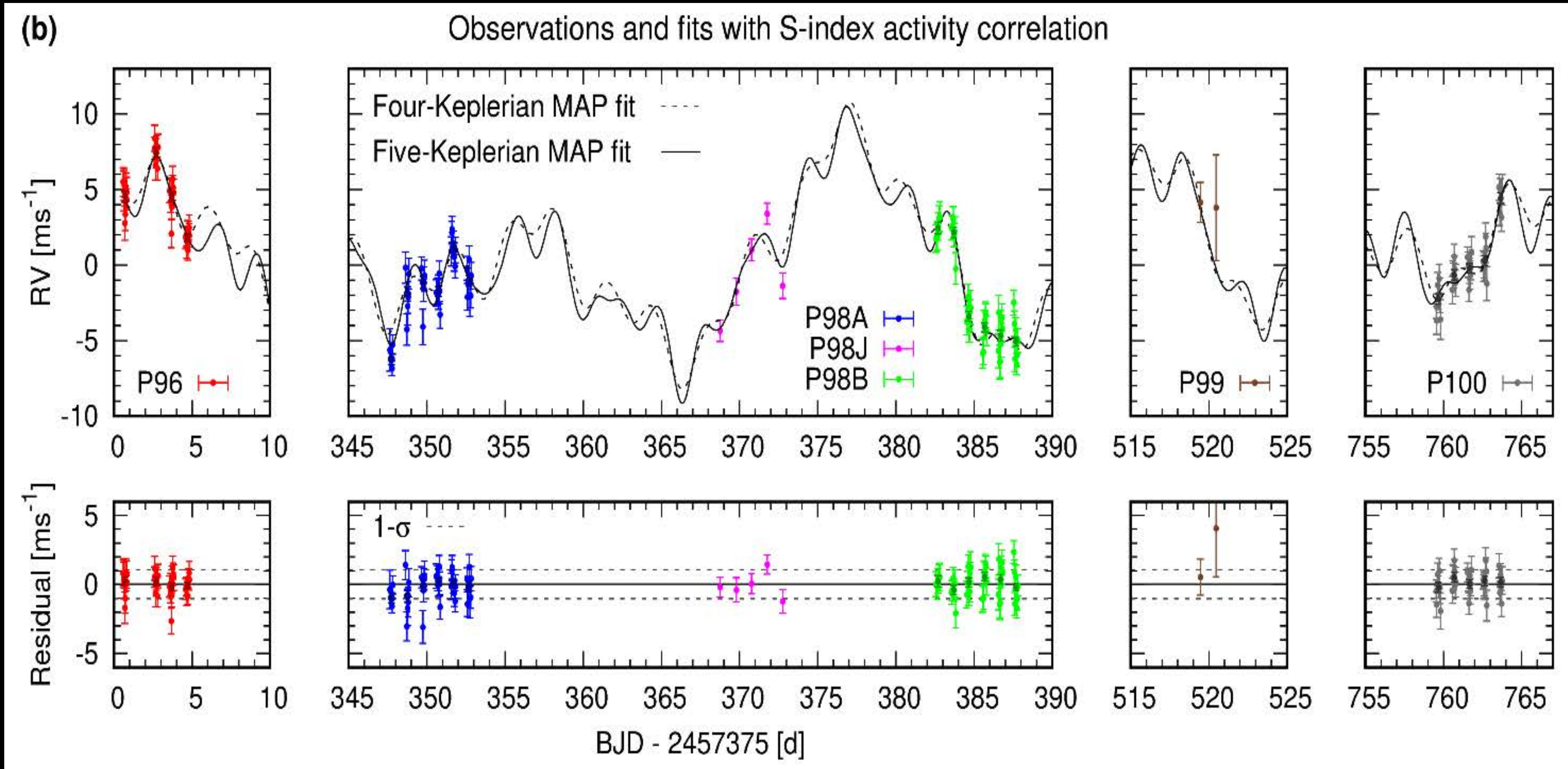
DMPP-1: 4 (or 5?) planets

Porb ~ 2.88 - 18.57 d

~3.3 $M_\oplus$ - ~24 $M_\oplus$

DMPP-1: Staab, Haswell, Barnes, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Diaz & Soto, 2019, Nature Astronomy arXiv:1912.10792

DMPP-1 HARPS observations



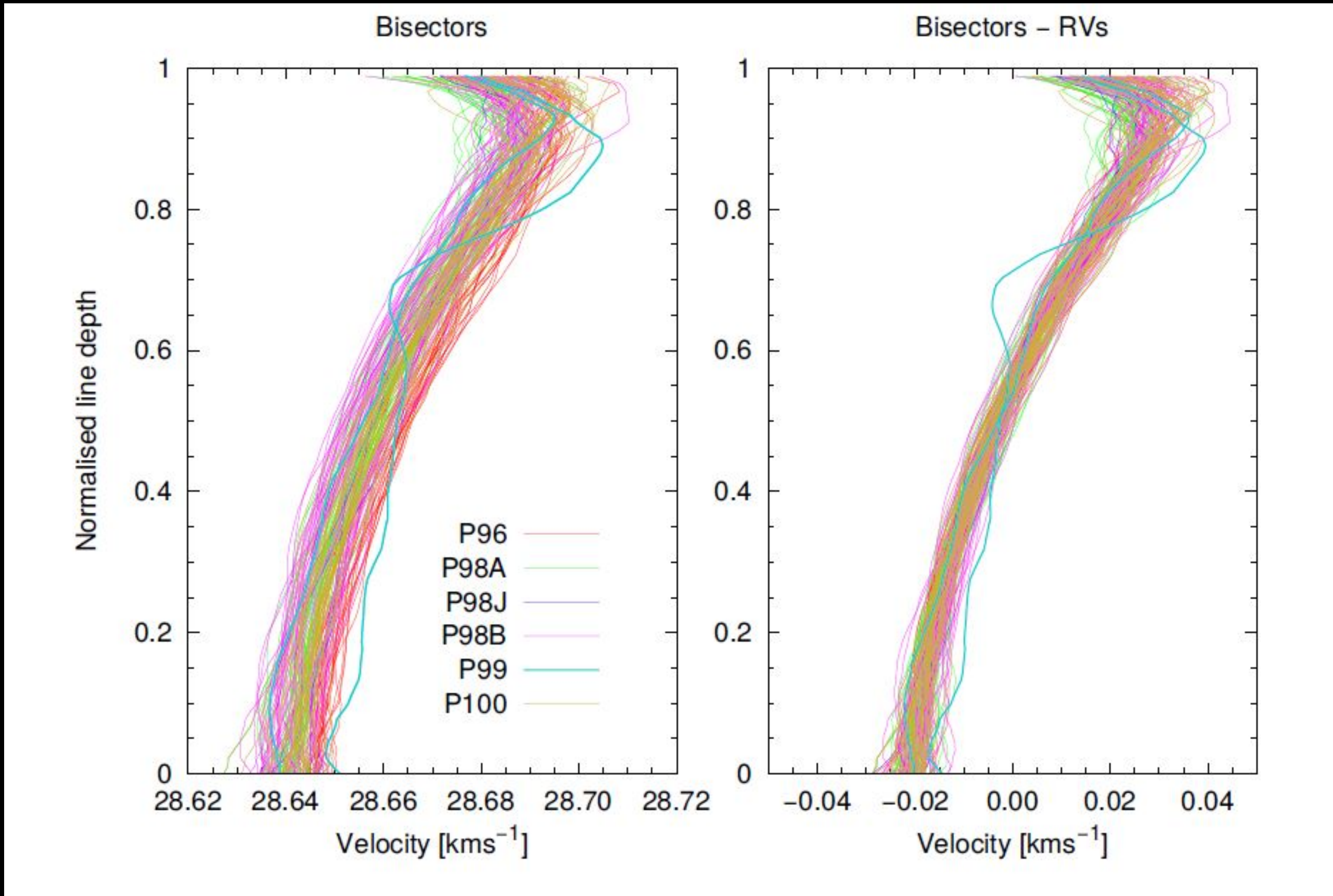
DMPP-1 148 observations over 3 years

c.f. 373 observations over 13 years for 4 planets orbiting HD 215152

DMPP-1: Staab, Haswell, Barnes, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Diaz & Soto, 2019, Nature Astronomy arXiv:1912.10792

Delisle et al arXiv:1802.04631

DMPP-1 bisectors show parallel shifts



Bisectors

Bisectors shifted by measured RV

DMPP-1: Staab, Haswell, Barnes, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Diaz & Soto, 2019, Nature Astronomy arXiv:1912.10792

DMPP-1 nearby compact multiplanet system

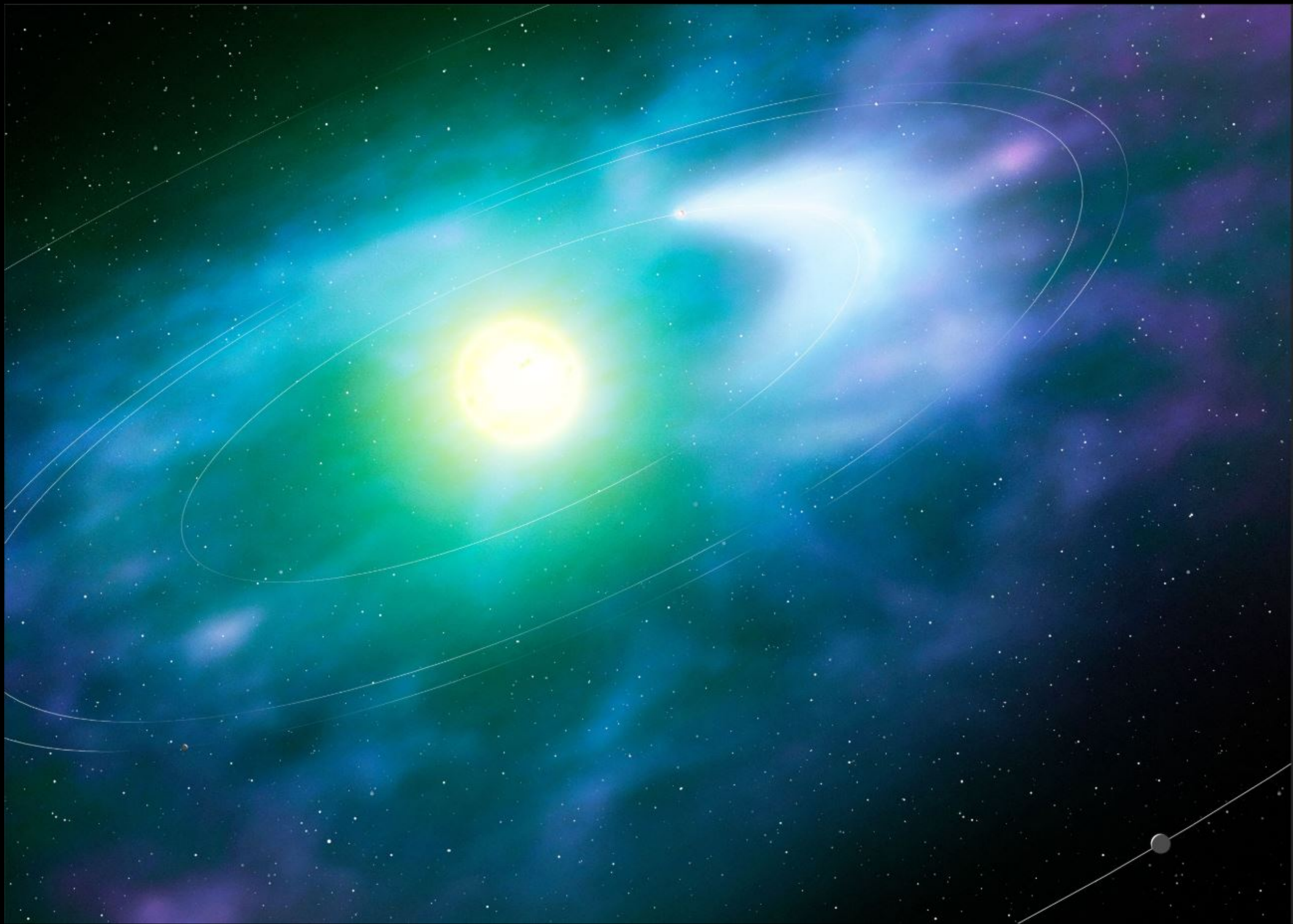


Image credit: Mark Garlick

If dispersed gas in orbital plane, transits likely

DMPP-1: Staab, Haswell, Barnes, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Diaz & Soto, 2019, Nature Astronomy arXiv:1912.10792

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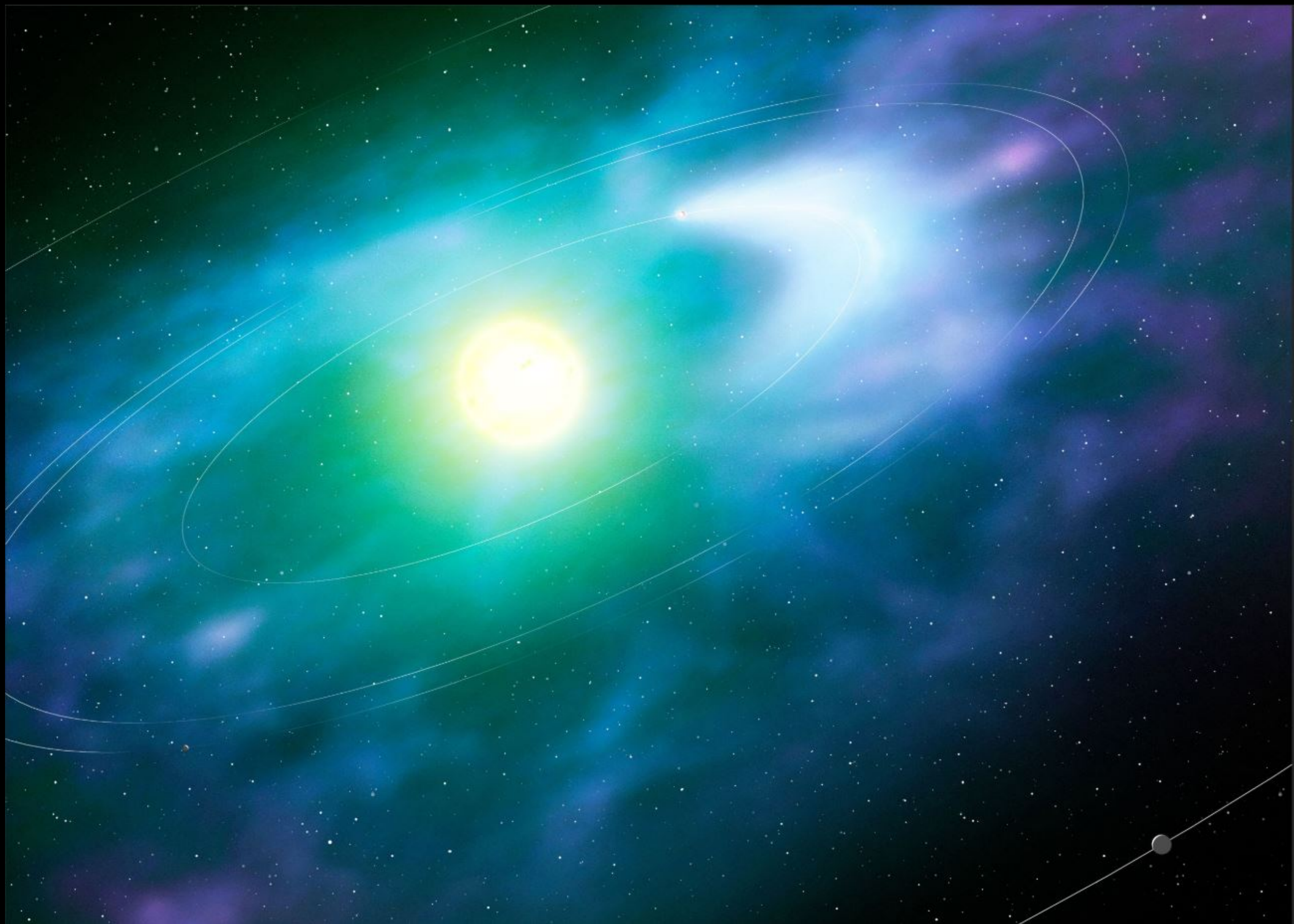

Image credit:
Mark Garlick

TESS data on DMPP-1: marginal transit detection? (<100 ppm threshold)

DMPP-1 TESS analysis: Jones, Haswell, Barnes, Staab 2019, in prep

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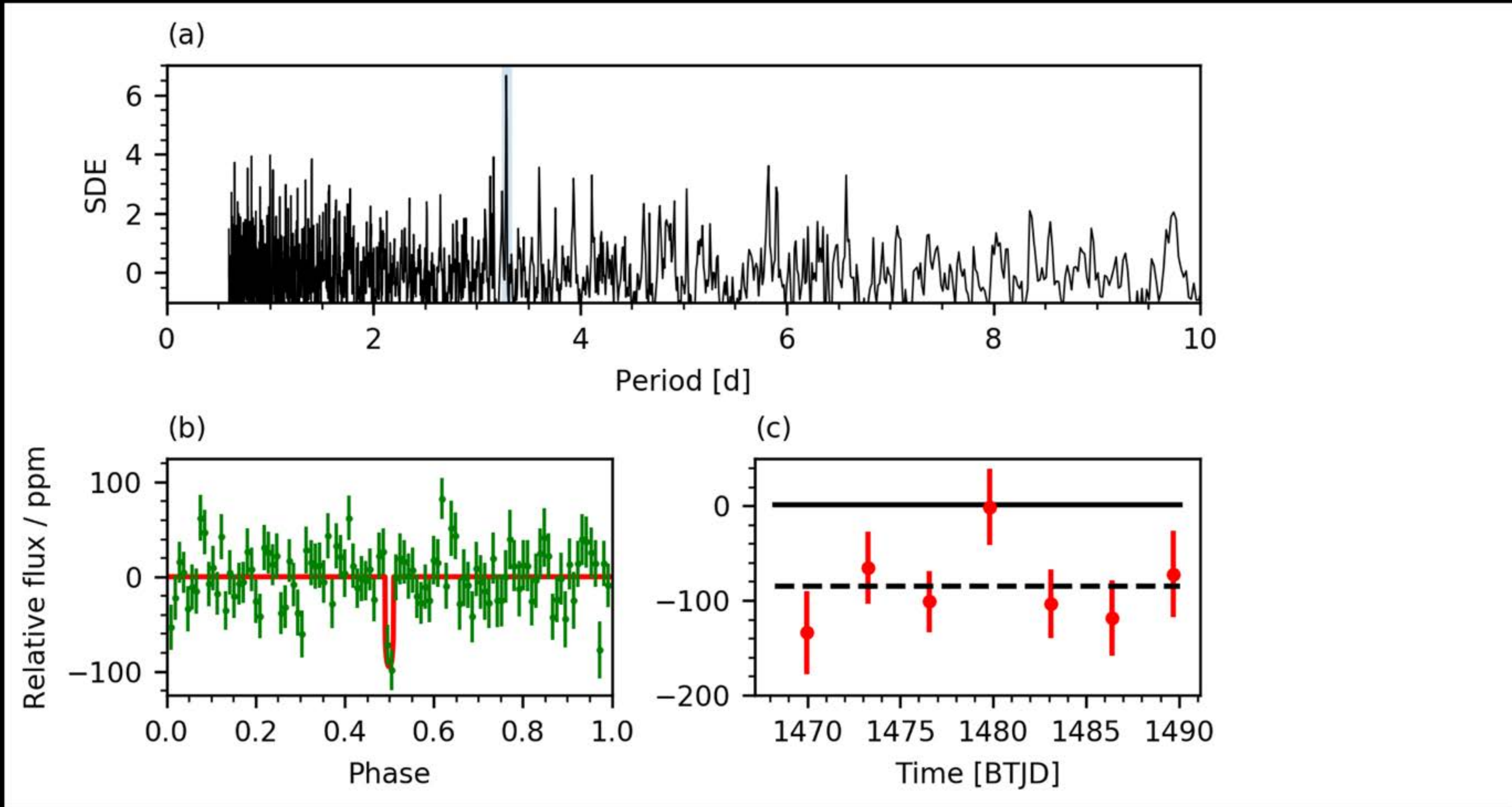

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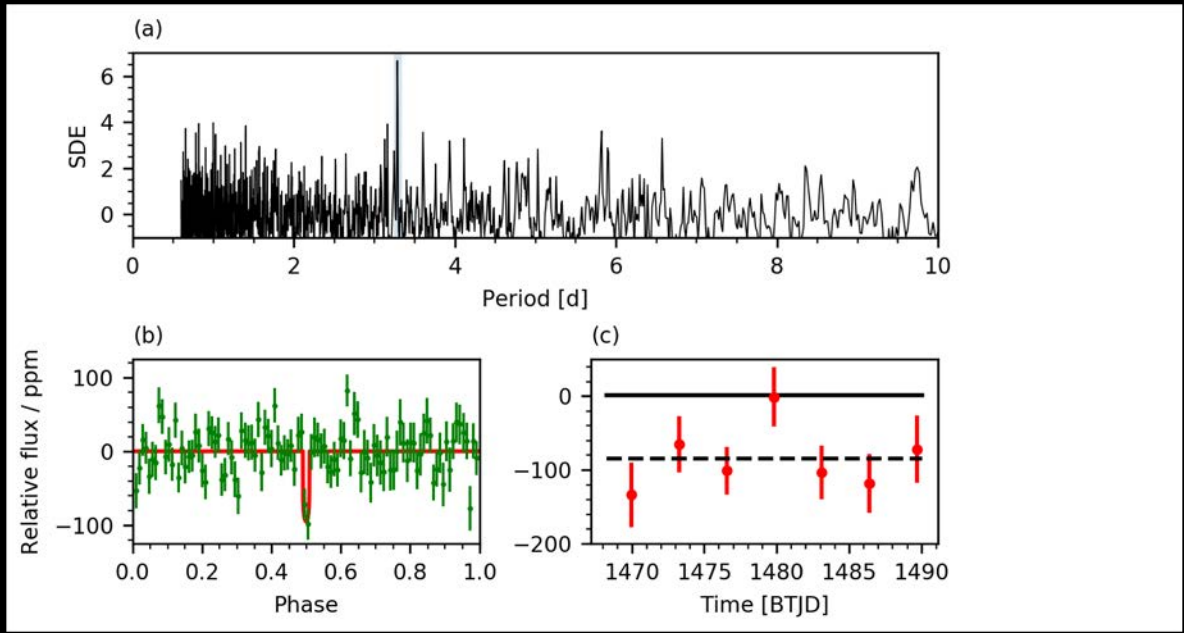
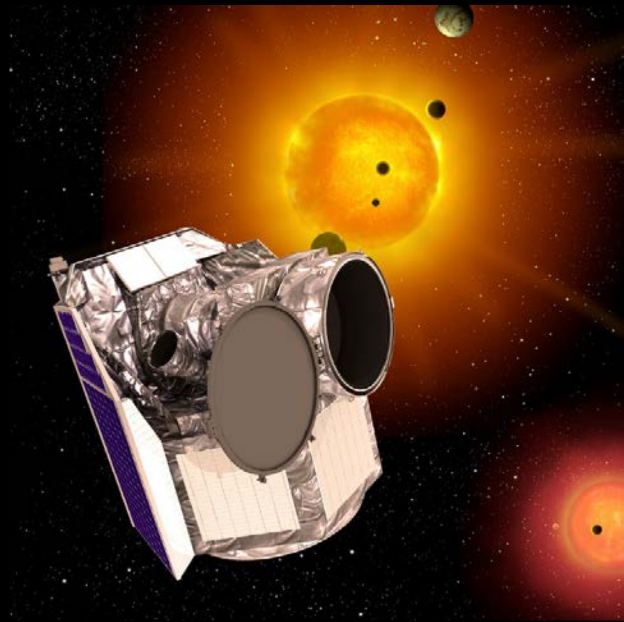




TESS data on DMPP-1: marginal transit detection? (<100 ppm threshold)

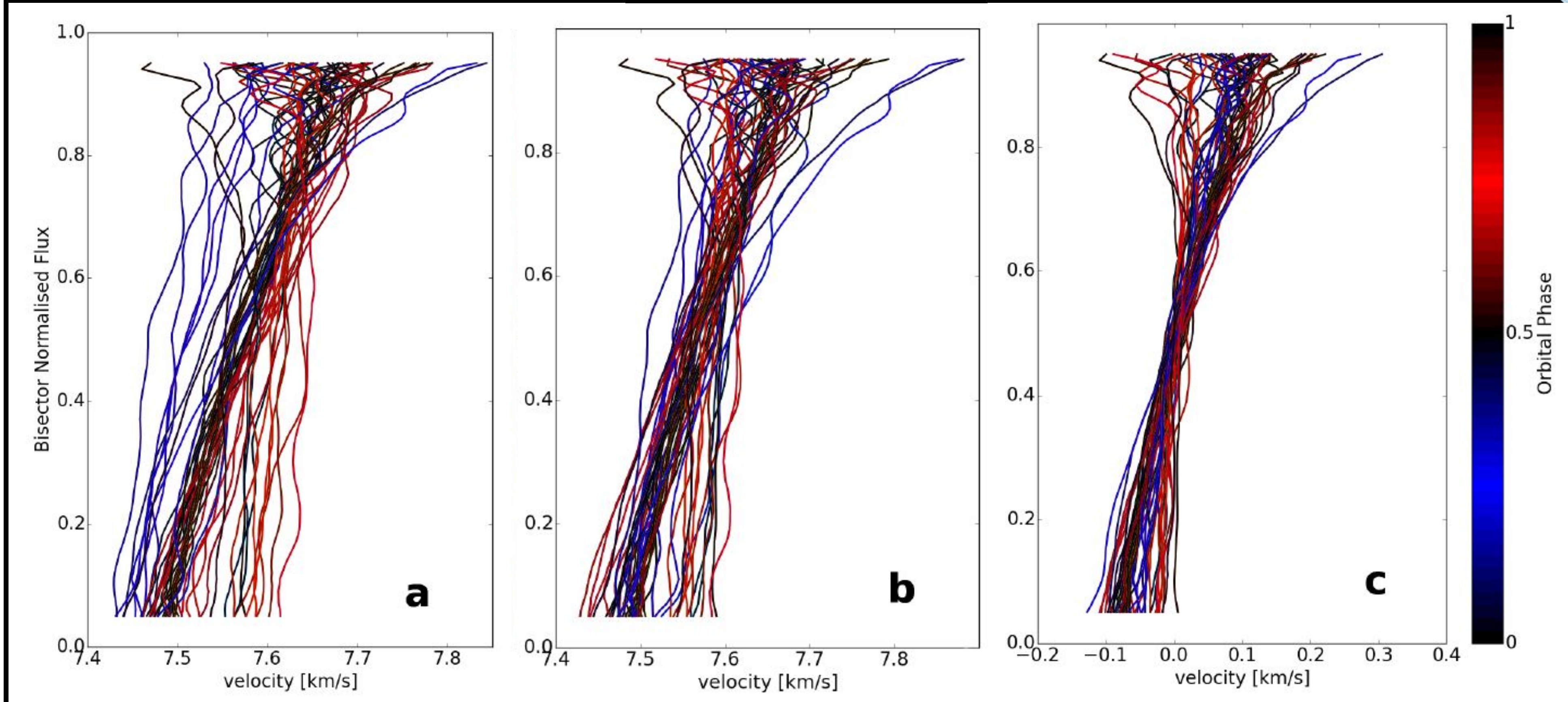
Need to search with CHEOPS

Larger aperture, should detect really shallow transits

DMPP-1 TESS analysis: Jones, Haswell, Barnes, Staab 2019, in prep

DMPP-2b:

a LOT of RV jitter – not just reflex orbital velocity



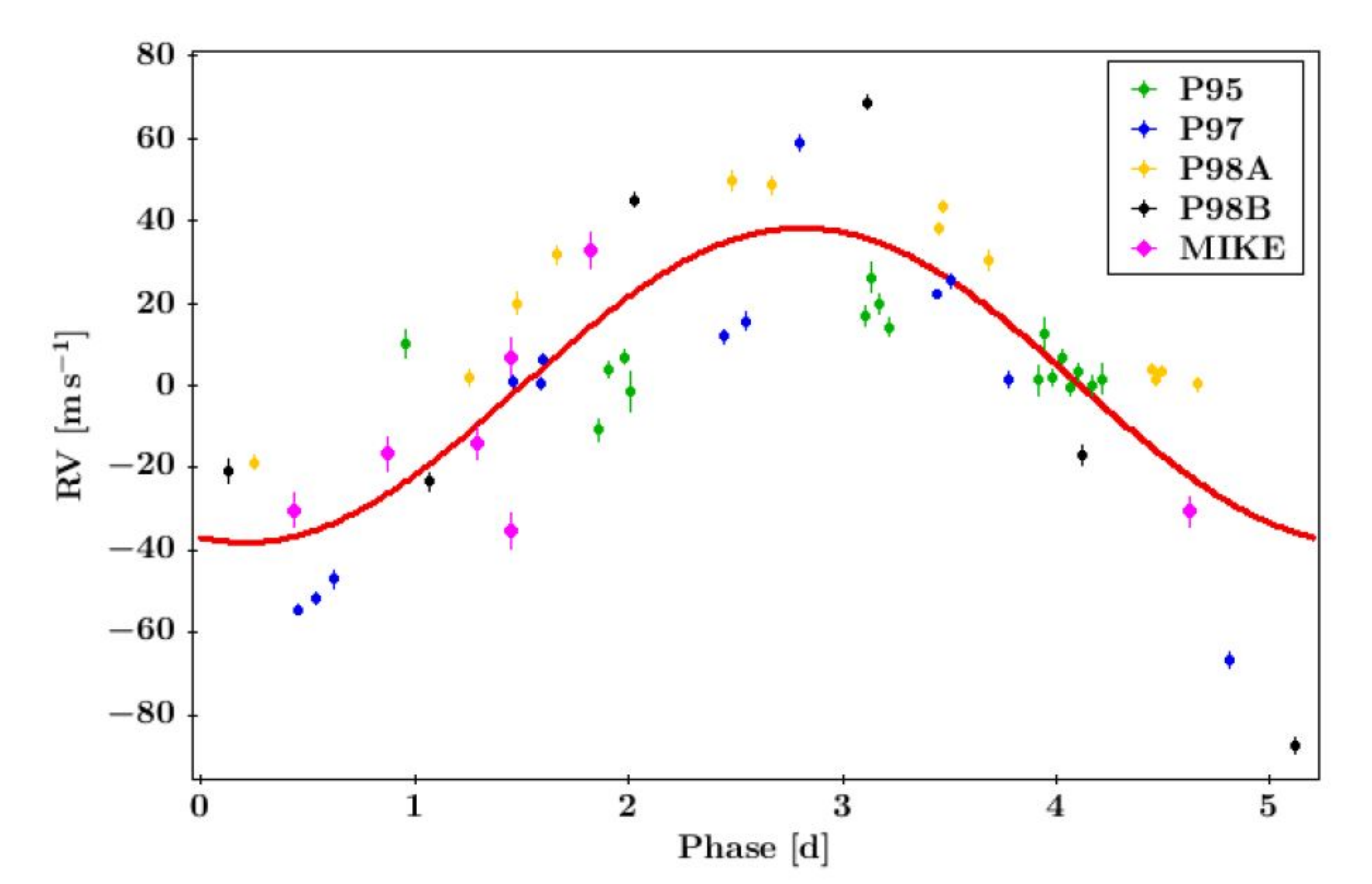
Measured | best fit orbit subtracted | measured RV subtracted

REFLEX RV orbit + line profile changes

Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP-2b:

fold on ~5.2d , K~40 m/s, Saturn mass

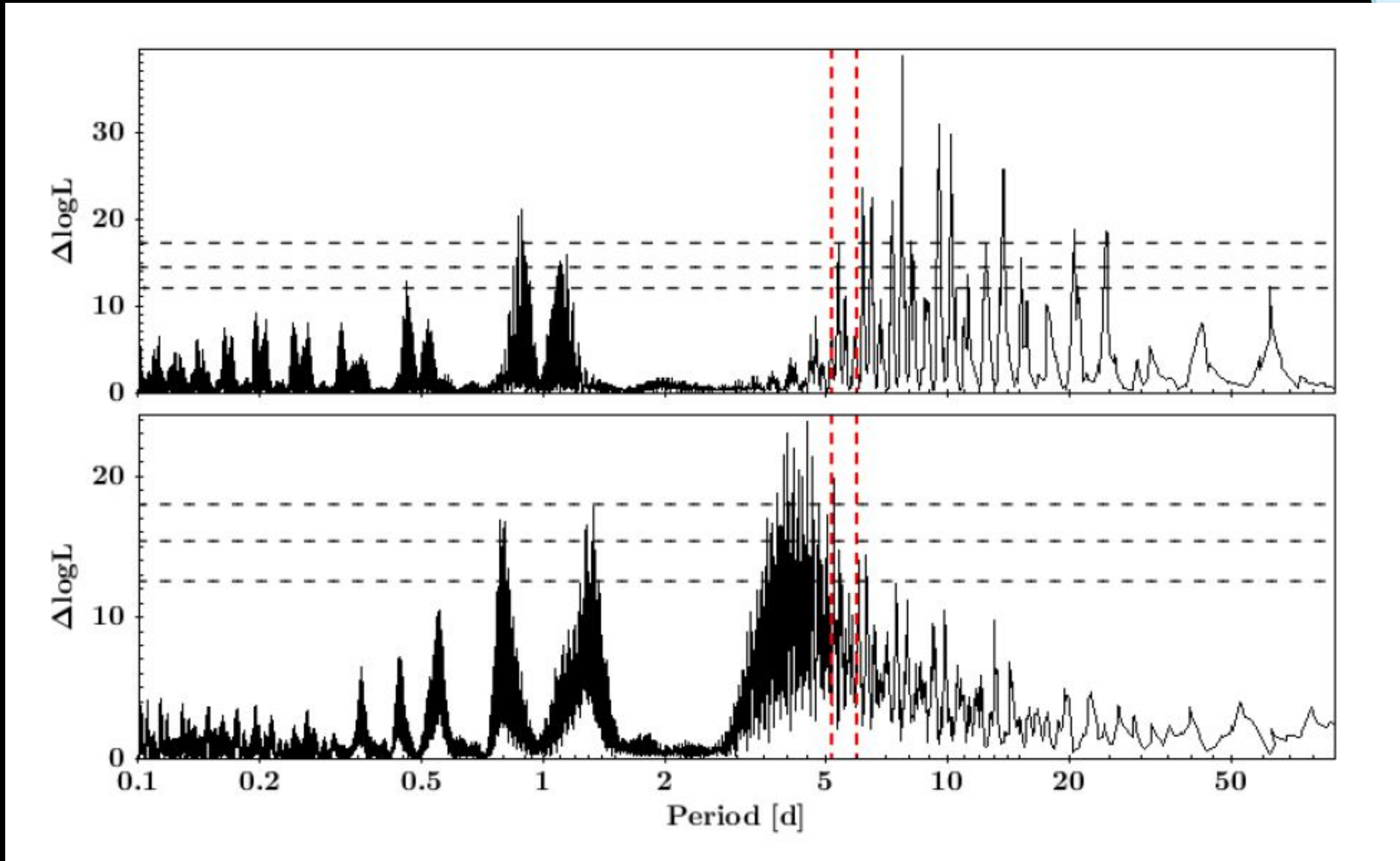


Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP-2b:

Bisector Span Periodgram

FWHM Periodogram



line profile variability does not show RV period

Genuine reflex RV detected

Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP-2b:

Highly significant FAP << 0.1% detection of ~5.2d or ~6d period

K ~40 m/s

Saturn mass planet orbiting a **bright, nearby pulsating star.**

Interior planet(s) w/
Mass below detection
threshold possible

If dispersed gas
in orbital plane,
transits likely

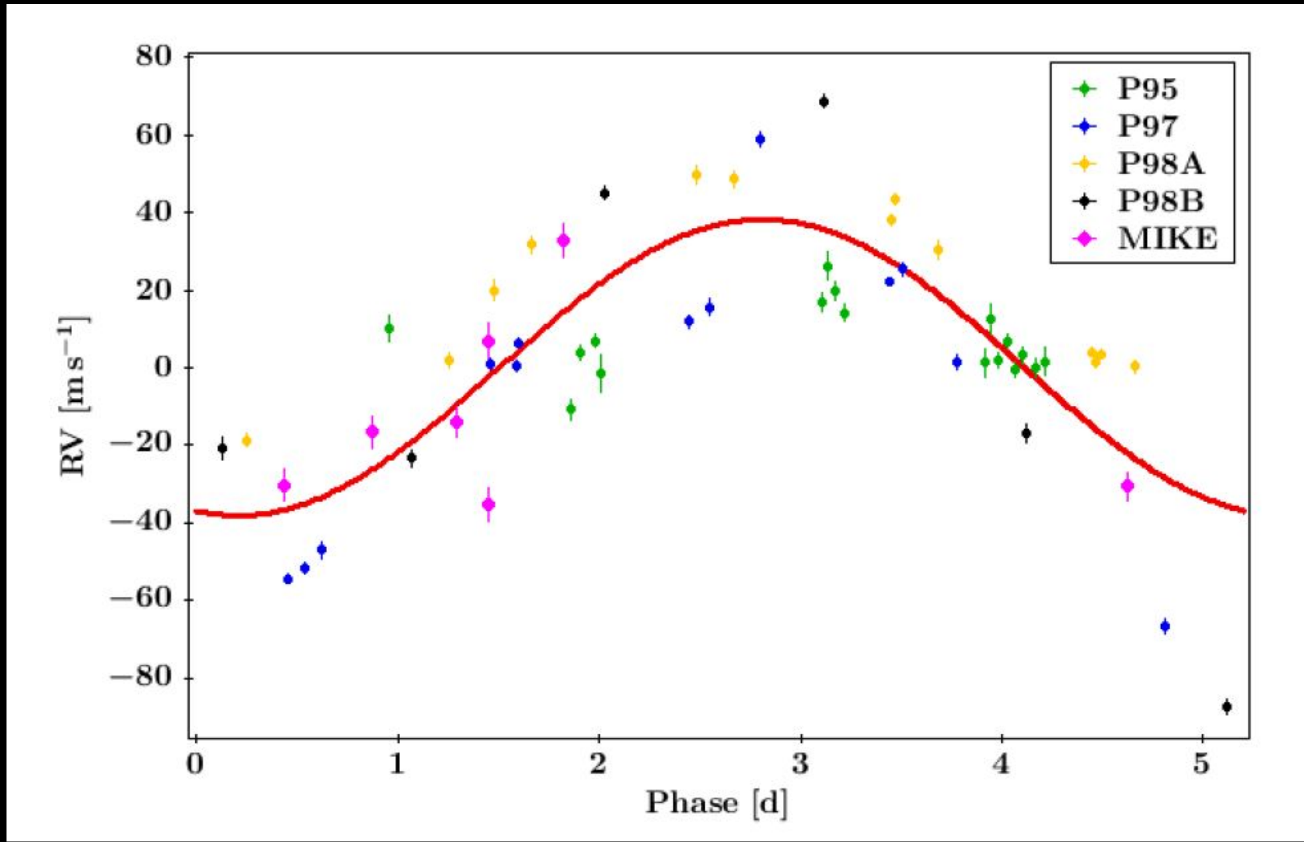


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Image credit:
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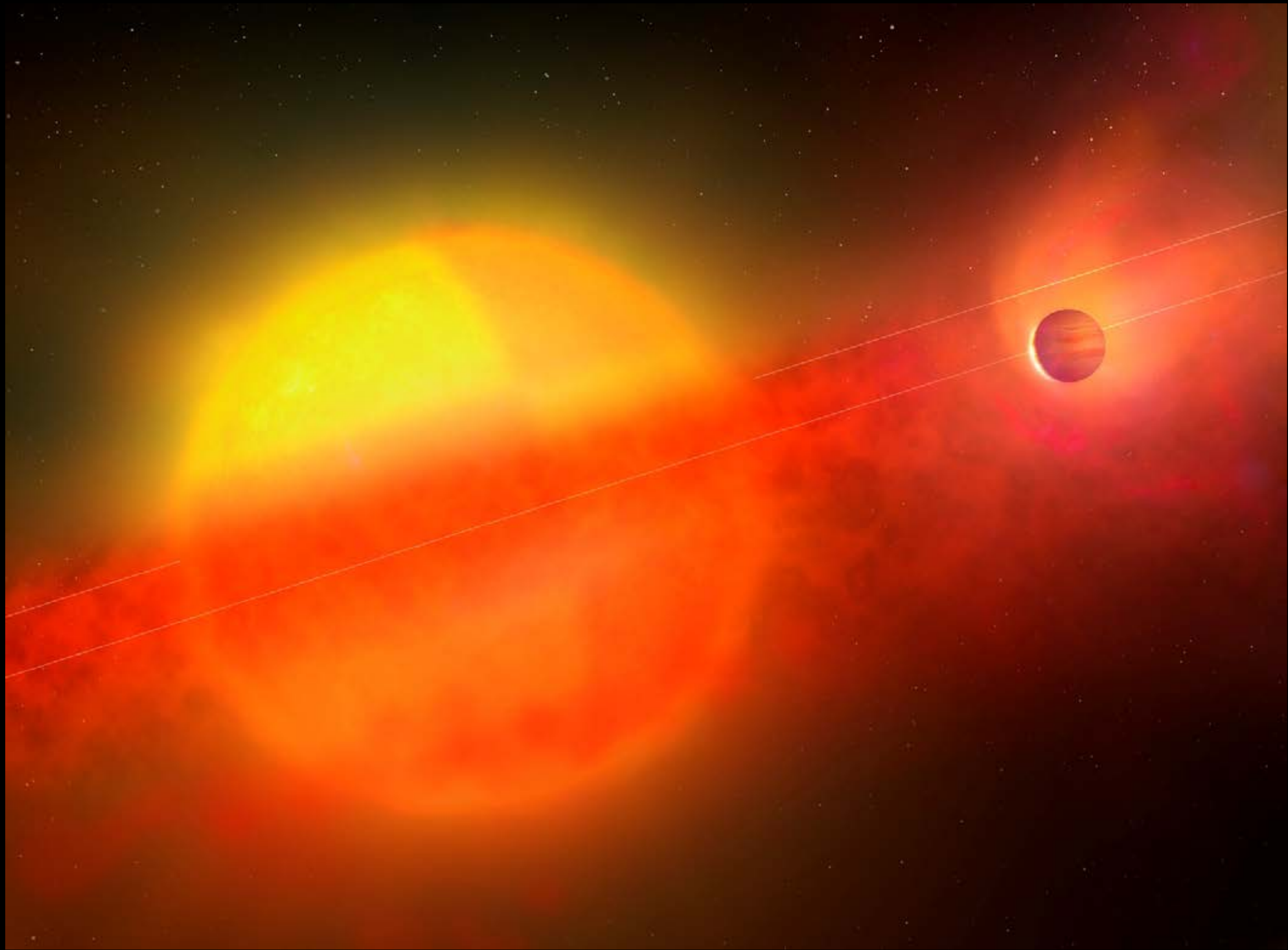
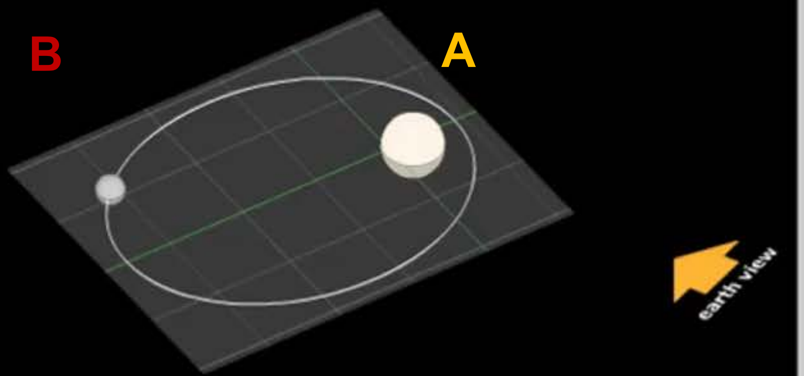
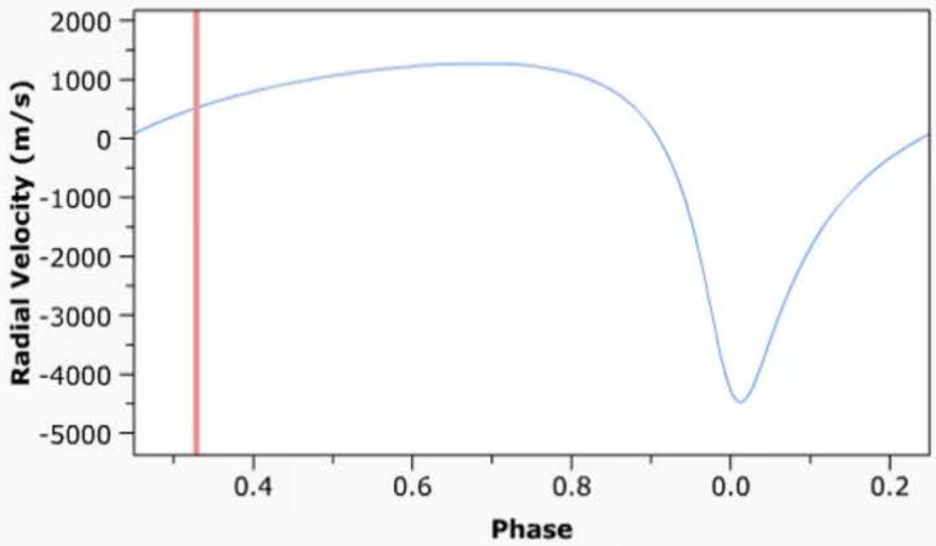


DMPP-3 eccentric binary system

DMPP-3 AB





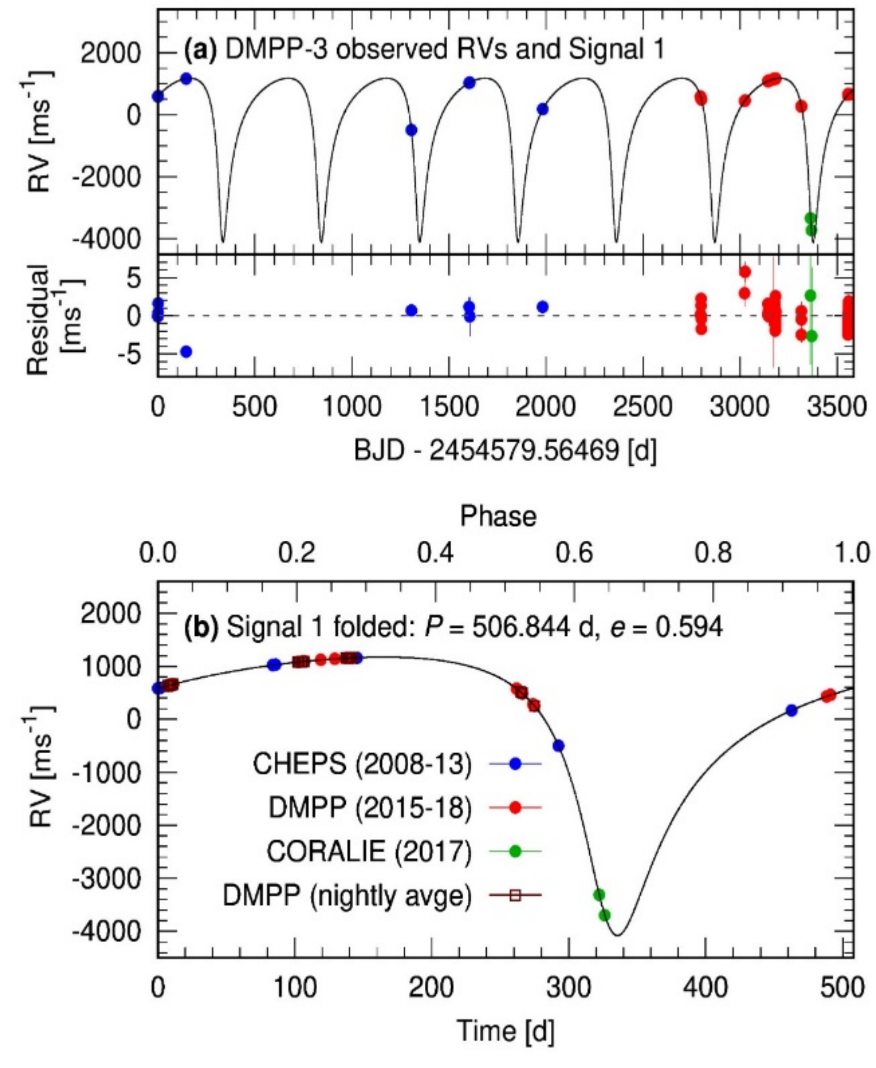
Orbital period : *P* = 506.8 days
Highly eccentric: *e* = 0.594
Separation : a = 1.22 AU

DMPP-3A : 0.87 $M_{\odot}$ (K0V)

DMPP3-B : 0.077 $M_{\odot}$
($80M_{Jup}$ - i.e. close to lowest possible mass of a hydrogen burning star)

Barnes, Haswell, Staab, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Díaz, Soto, Peña Rojas, 2019 Nature Astronomy, arXiv:1912.10793

DMPP-3 eccentric binary system



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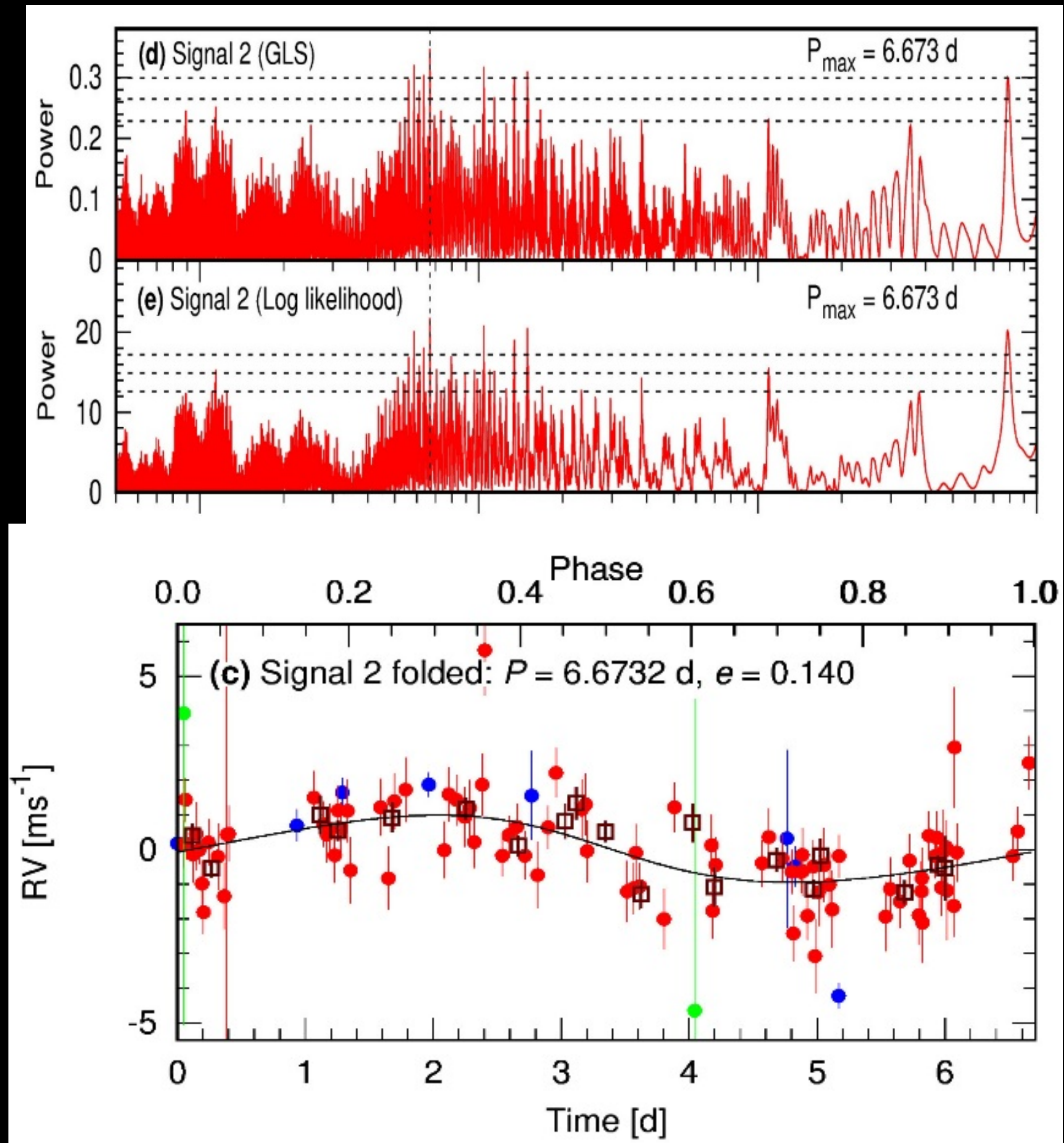
DMPP-3: S-type planet in tightest known binary system



DMPP-3Ab

- circumprimary super-Earth
  - 2.58 $M_\oplus$
  - 6.67 d
  - a = 0.066 AU
  - e = 0.14
- orbit stable > 10^6 years
- *a* / *e* cycle over 800 yrs
  - 0.0 < e < 0.18
  - Δ*a* = 0.1 %

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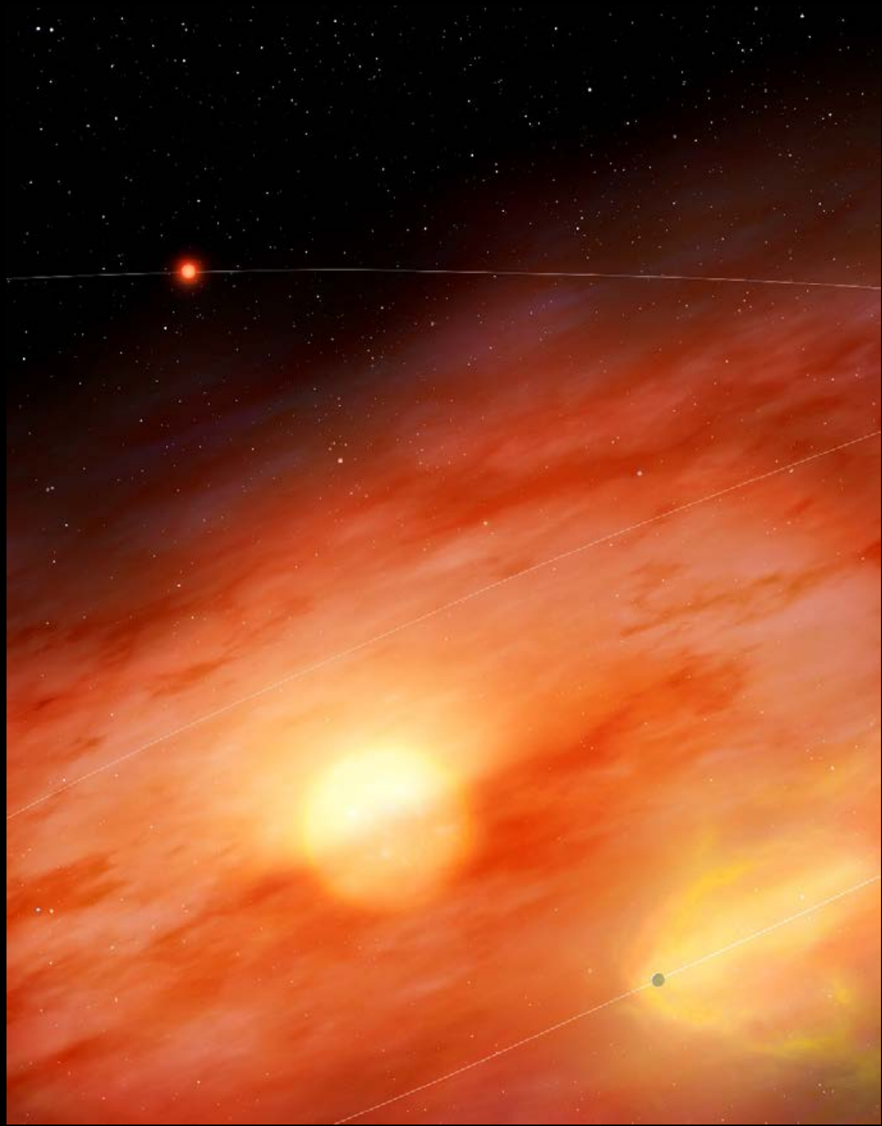

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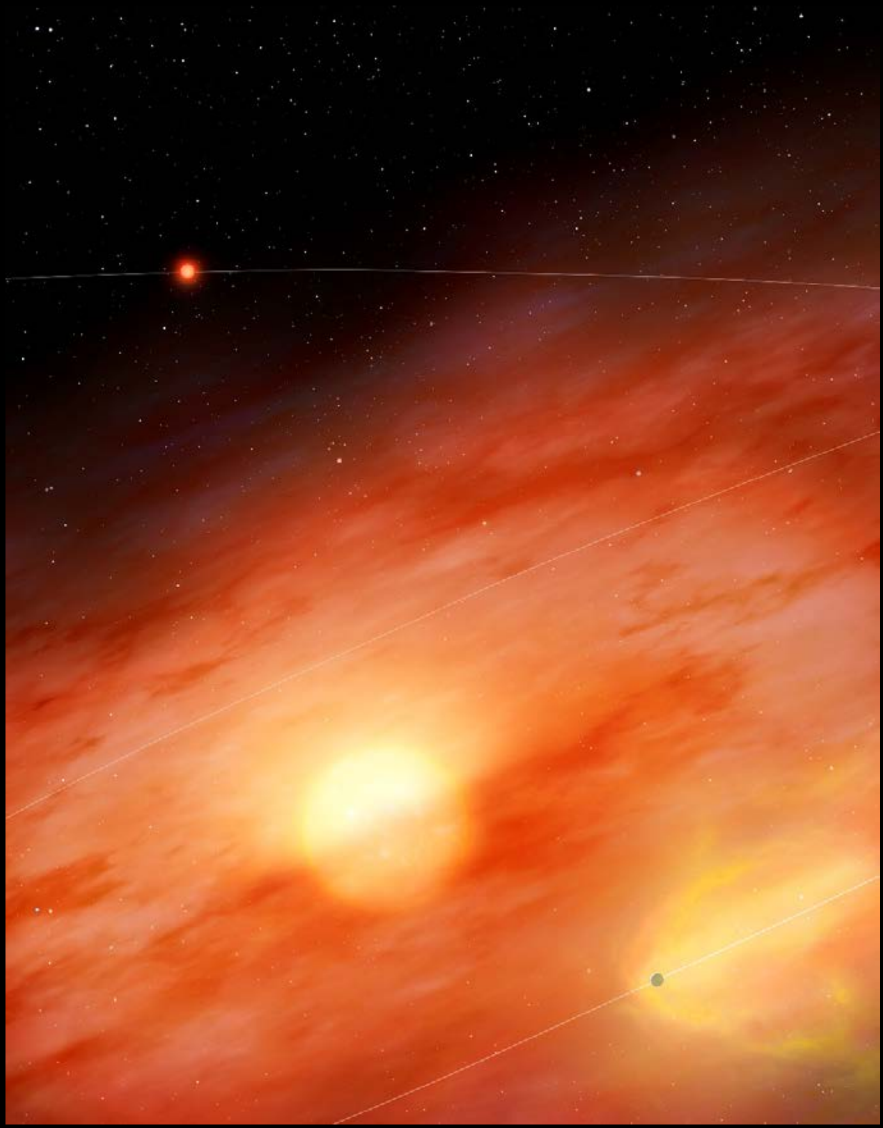
DMPP-3: S-type planet in tightest known binary system

DMPP-3Ab

- circumprimary super-Earth
- DMPP-3B drives eccenticity

- How did DMPP-3Ab get there?
  - Kozai-Lidov evolution?



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The Dispersed Matter Planet Project: Targets

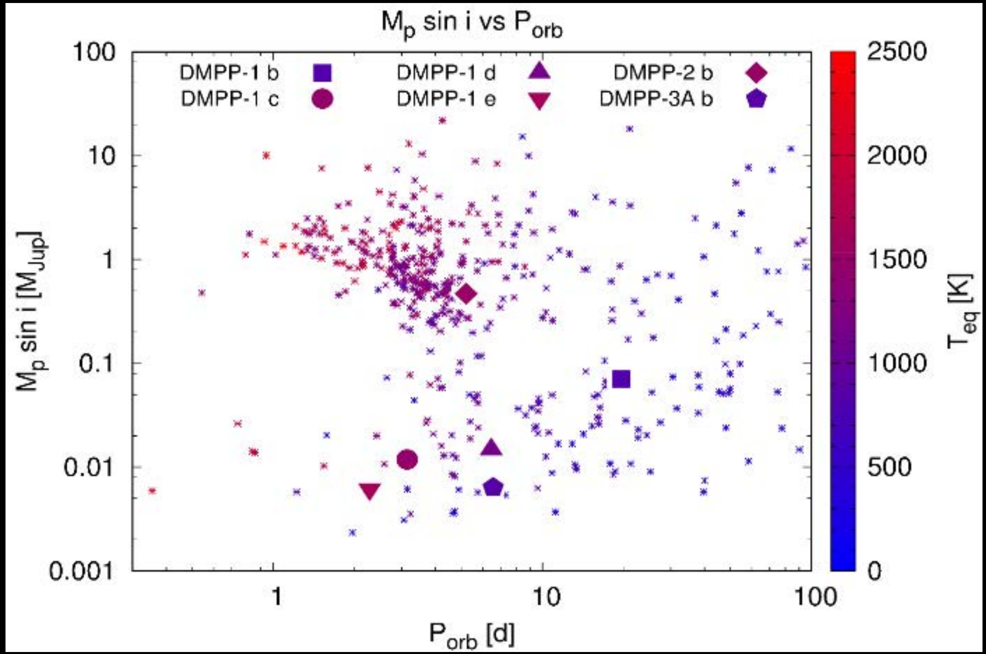
Target(s)	Nobs	Status
DMPP-1	148	Compact multi-planet system
DMPP-2	56	Planet orbiting pulsating star
DMPP-3	93 + 8 archival	Circumprimary super-Earth in binary star system.
P1-N *(DMPP-4)*	108	At least two periodic signals, GIARPS observations pending. Under analysis.
P1-S *(DMPP-5)*	81	Probable 1.6$M_\oplus$ in 2.4d orbit + firm 12 $M_\oplus$ in 19.8 d orbit (no correlations w/ activity indicators). Under analysis.
LP-S	6 +73 archival	Long period 4 M_J giant planet, more DMPP observations needed to search for short period planets.
3 targets	< 60	Encouraging short period, low amplitude periodic signals
2 targets	< 60	~2 M_{Earth} planets in sub-day orbits appear to be excluded
5 targets	< 60	Unclear RV behaviour. More observations required.
1 target	< 60	Unclear RV behaviour. Probable pulsator, with pulsation-driven RV variability.
22 targets	0	Observations required.
1 target	7	$\log R'_{HK}$> -5.1 from our spectra. Dropped.

39 targets
d <100pc

Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP systems in context

DMPP planets found *around* not *within* Neptunian desert

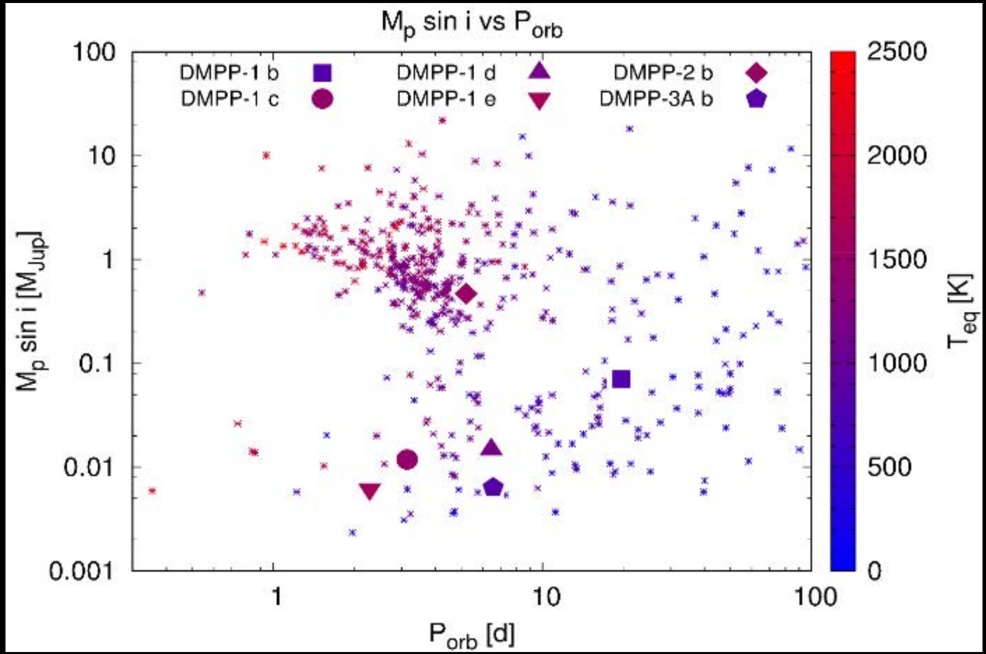


Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP systems in context

DMPP planets
so far

NOT caught in short-lived mass-losing phase crossing the desert



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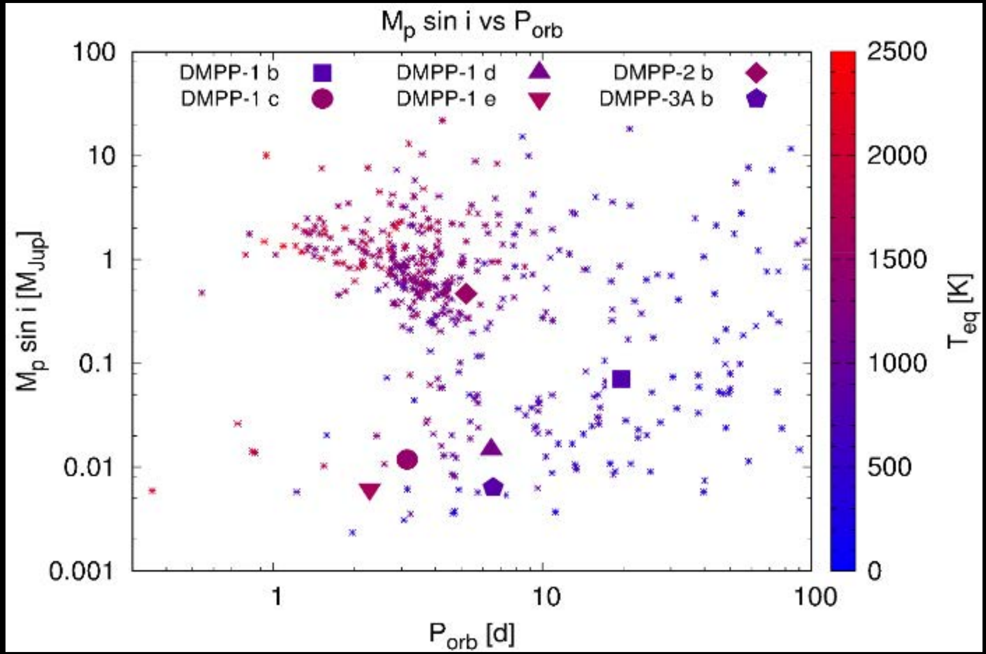
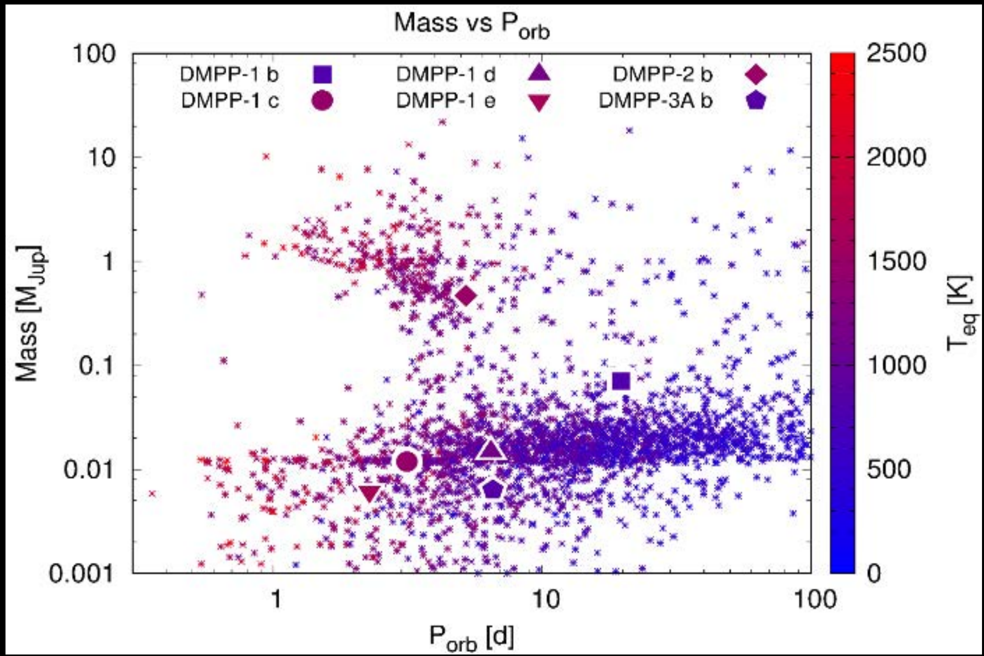
DMPP systems in context

DMPP planets
transiting subset
will add new
dimension to
radius valley /
Fulton gap

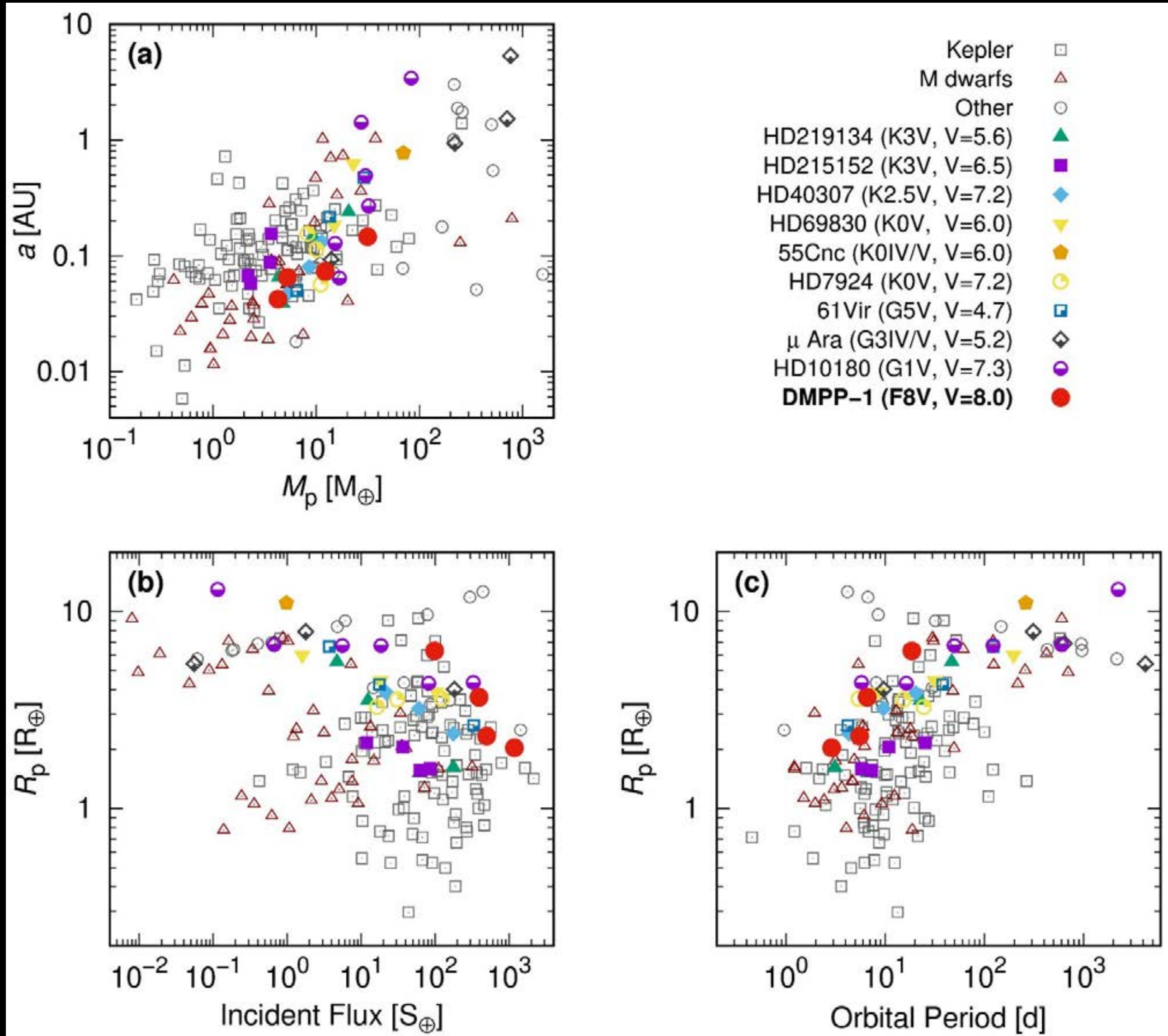




Haswell, Staab, Barnes, Anglada-Escude, Fossati, Jenkins, Norton, Doherty, Cooper 2019, Nature Astronomy arXiv:1912.10874

DMPP systems in context

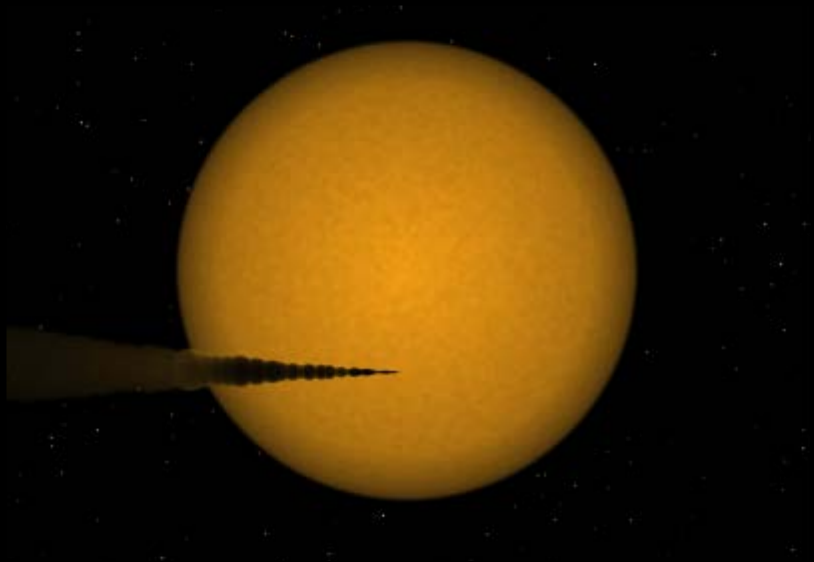
DMPP-1 planets
& DMPP-3Ab
Among the most irradiated known low mass planets

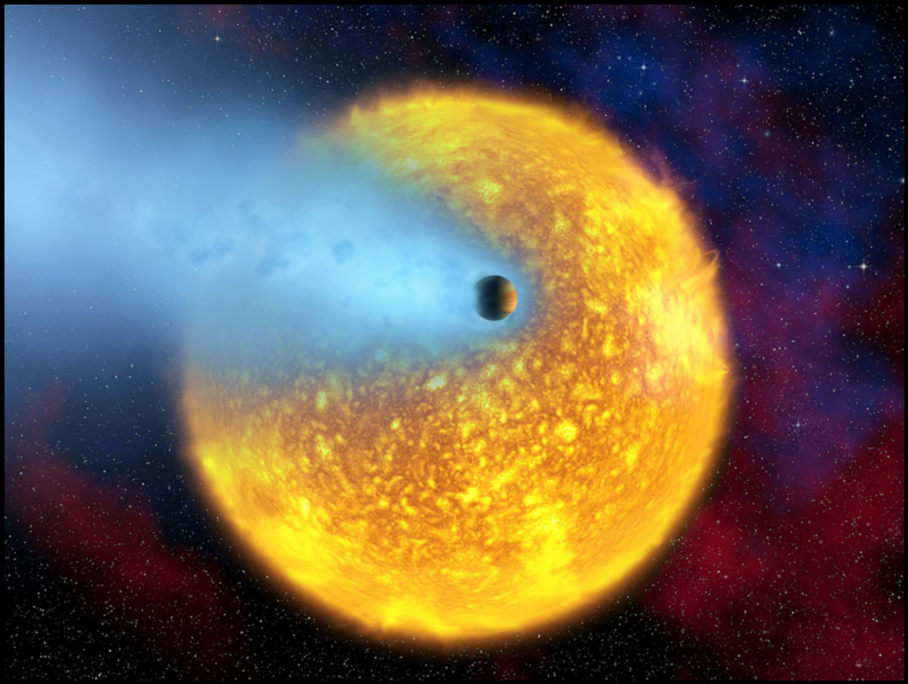


DMPP-1: Staab, Haswell, Barnes, Anglada-Escude, Fossati, Doherty, Cooper, Jenkins, Diaz & Soto, 2019, Nature Astronomy arXiv:1912.10792

Mass-losing close-in planets

e.g. Kepler 1520b, WASP-12b have HUGE scale-heights





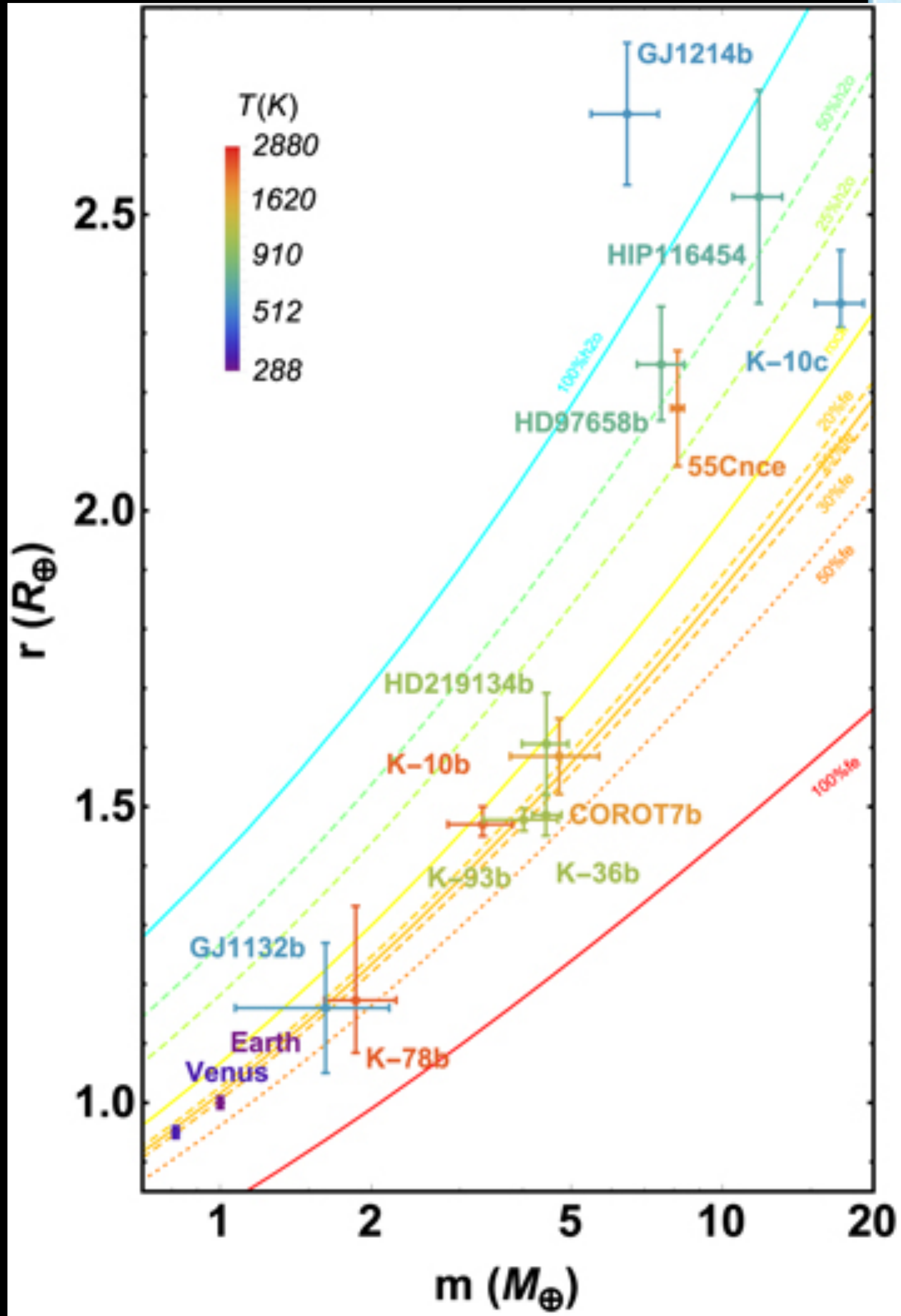
Fossati, Haswell et al 2010,
Haswell, Fossati et al 2012,
Rappaport et al 2012, ApJ, 752, 1
Brogi et al 2012 A&A 545, L5

Planet Compositions

If exclude planets w/ $\sigma(M_P) > 6\%$ diagram would contain 55 Cnc e + solar system planets

DMPP systems: provide > 12 more well-constrained planets.

M_P, R_P & composition directly?



Zeng, Sasselov & Jacobsen
2016 ApJ 819, 127

ERGO: new samples of stars

- Larger parent samples of inactive solar type stars
- intrinsically more active solar type stars
- evolved stars

DMPP planets with ARIEL:

- Kepler 1520b is detectable only by its dust cloud
- Bright analogues and progenitors amenable to gas phase transmission spectroscopy
- Transmission spectroscopy of mineral-rich atmospheres

  talks yesterday
- Transmission spectroscopy of dispersed material
- Small planets amenable to phase curve investigations

  compact multi-planet system orbiting a naked-eye star DMPP paper in prep

mass-radius-composition relation(s) for small planets

Conclusions

- DMPP Anomalously low stellar activity – efficient selection of short-period planet hosts
- diffuse circumstellar gas originating from ablating planets VERY EXTENDED ATMOSPHERES!
- Showed you
  - ❖ DMPP-1 compact multi-planet system, 4 or 5 planets, Neptune and super-Earths
  - ❖ DMPP-2 Saturn mass planet orbiting bright pulsating star
  - ❖ DMPP-3 506d eccentric brown dwarf system with circumprimary super-Earth

- If gas confined to orbital plane: TRANSITS! DMPP-1 TESS ☹
- Ablating planets allow bulk composition to be sampled with transmission spectroscopy
- Key characterisation targets

- DMPP planets will be key for exogeology