What can the Dispersed Matter Planet Project do for ARIEL?

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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 $R_{HK}$


Ca II H&K line cores
Activity: characterised by $R_{HK}$

Line core emission quenched by diffuse gas

Dan Staab PhD work
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

Absorbing gas constrained to orbital plane?

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?

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

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??

The Dispersed Matter Planet Project: Targets

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

39 targets, all d < ~100pc

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

The Dispersed Matter Planet Project: Characterisation

Transit surveys like SuperWASP are sensitive to more distant host stars than SuperWASP planets. RV discoveries are restricted to nearby stars, while microlensing planets in the Galactic bulge are DMPP systems with distances typical of RV discoveries.
The Dispersed Matter Planet Project: Targets

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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⊕ - ~24 M⊕

DMPP-1 148 observations over 3 years
c.f. 373 observations over 13 years for 4 planets orbiting HD 215152


Delisle et al arXiv:1802.04631
DMPP-1 bisectors show parallel shifts

DMPP-1 nearby compact multiplanet system

If dispersed gas in orbital plane, transits likely


Image credit: Mark Garlick
DMPP-1 nearby compact multiplanet system

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

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

Image credit: Mark Garlick
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DMPP-1 TESS analysis: Jones, Haswell, Barnes, Staab 2019, in prep

Need to search with CHEOPS

Larger aperture, should detect really shallow transits
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

DMPP-2b:
fold on ~5.2d, K~40 m/s, Saturn mass

DMPP-2b: 

- Bisector Span
- Periodgram
- FWHM
- Periodogram

Line profile variability does not show RV period
Genuine reflex RV detected

DMPP-2b:
Highly significant FAP \(<\) 0.1% detection of \(~5.2\)d or \(~6\)d 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

DMPP-2b:
Highly significant FAP $\ll 0.1\%$ detection of $\sim 5.2\text{d}$ or $\sim 6\text{d}$ period
$K \sim 40 \text{ m/s}$
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Interior planet(s) w/
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Image credit:
Mark Garlick
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 \( M_\odot \)
\( (80 \text{M}_{\text{Jup}} - \text{i.e. close to lowest possible mass of a hydrogen burning star}) \)

DMPP-3 eccentric binary system

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DMPP3-B: 0.077 M☉
(80M_Jup - i.e. close to lowest possible mass of a hydrogen burning star)

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

DMPP-3Ab
- circumprimary super-Earth
  - $2.58 \, M_{\oplus}$
  - 6.67 d
  - $a = 0.066 \, \text{AU}$
  - $e = 0.14$
- orbit stable $> 10^6$ years
- $a / e$ cycle over 800 yrs
  - $0.0 < e < 0.18$
  - $\Delta a = 0.1 \%$

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DMPP3-B : 0.077 M ⊕
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DMPP-3: S-type planet in tightest known binary system

DMPP-3Ab
- circumprimary super-Earth
- DMPP-3B drives eccentricity

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

DMPP-3A: 0.87 M☉ (K0V)

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

# The Dispersed Matter Planet Project: Targets

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

39 targets d <100pc

DMPP systems in context

DMPP planets found around not within Neptunian desert

DMPP systems in context

DMPP planets so far

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

DMPP systems in context

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

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

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,
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. $\text{M}_P$, $\text{R}_P$ & composition directly?

Zeng, Sasselov & Jacobsen
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

- 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
talks yesterday

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

• DMPP  Anomally 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