

The CARMENES GTO survey

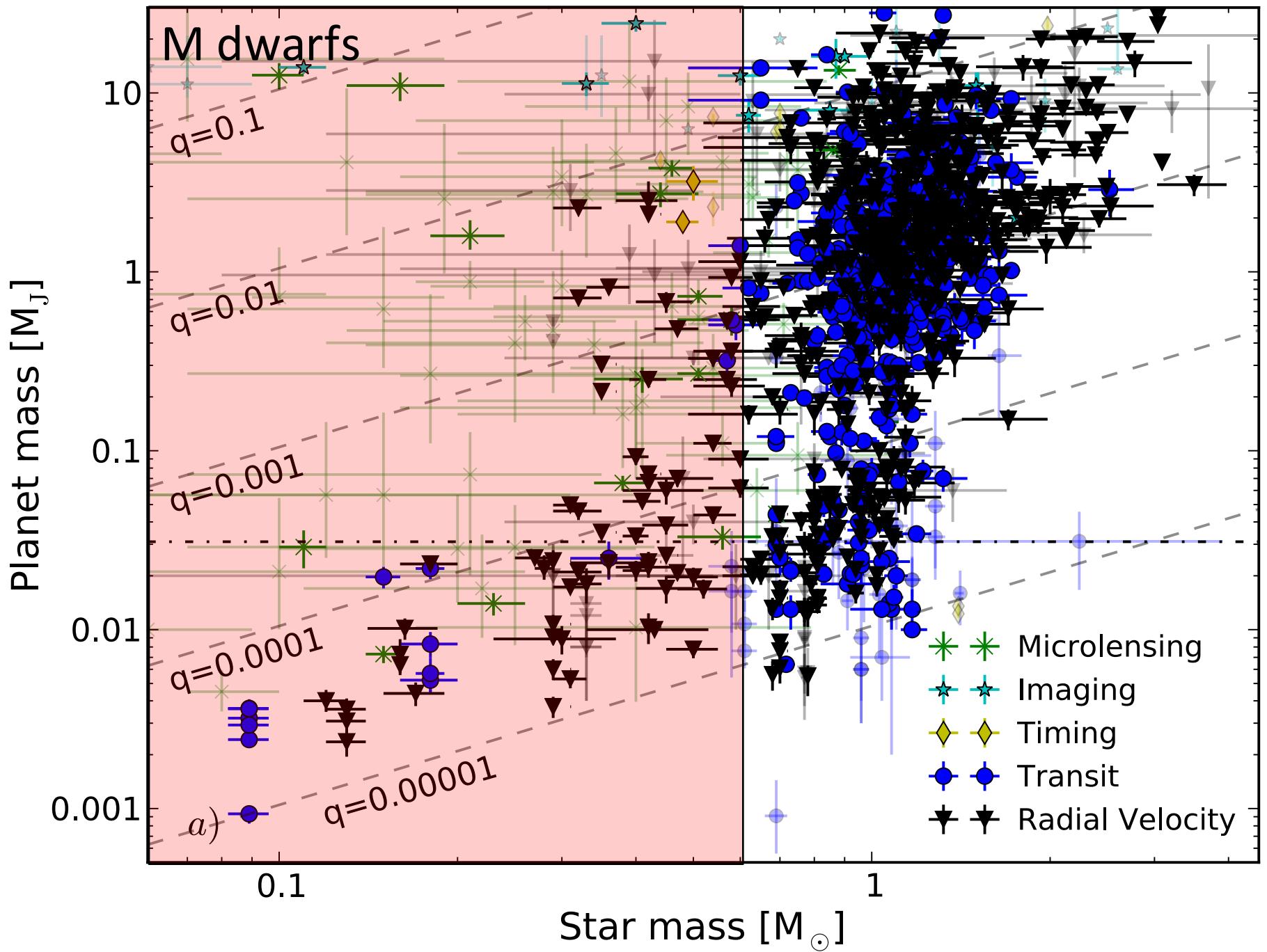
Ignasi Ribas

Institut de Ciències de l'Espai (ICE, CSIC)

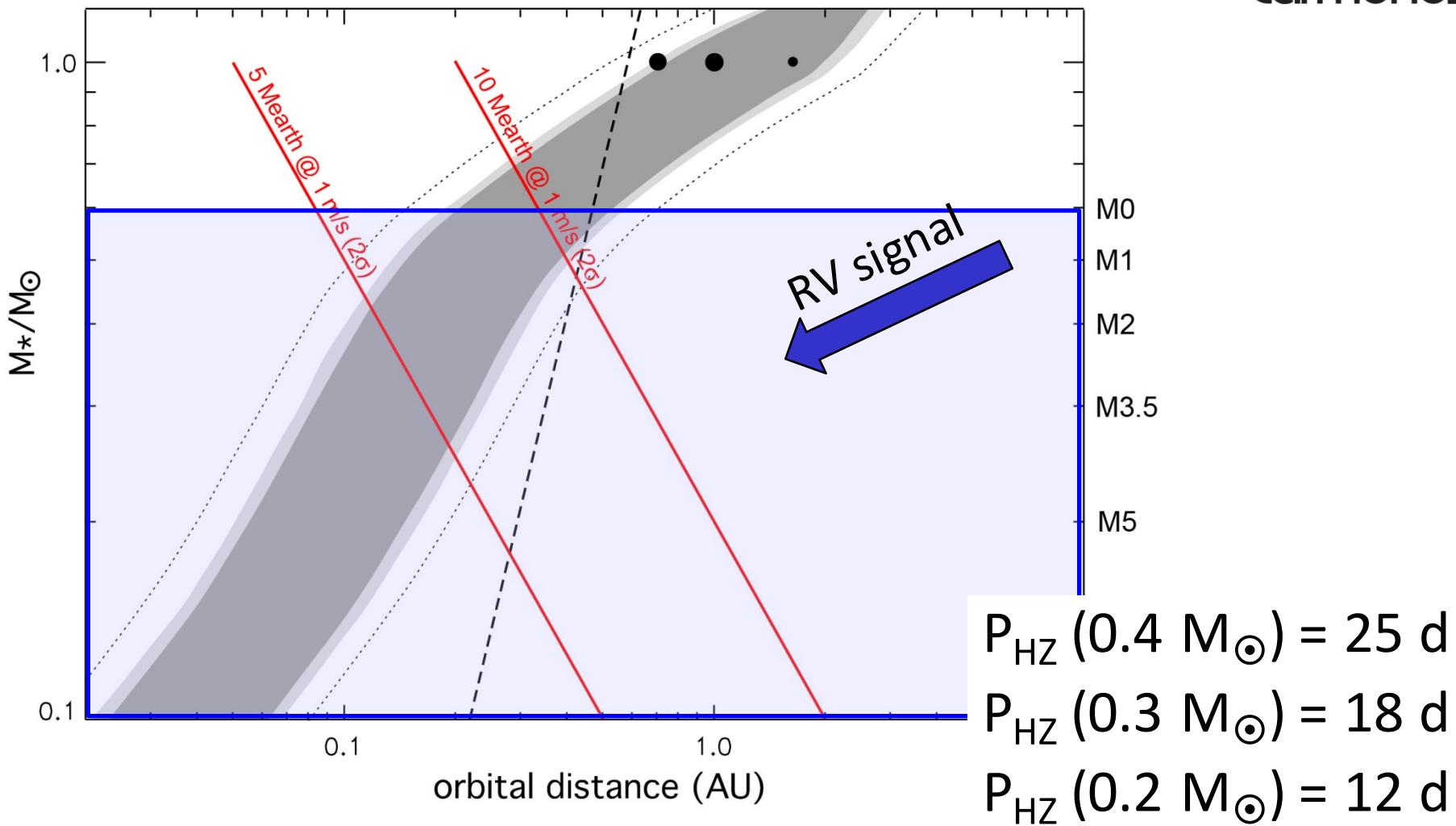
Institut d'Estudis Espacials de Catalunya (IEEC)

Ciencia presente y futura con CARMENES, February 2019





Detecting M-type planets



Global science questions: M-dwarf planets

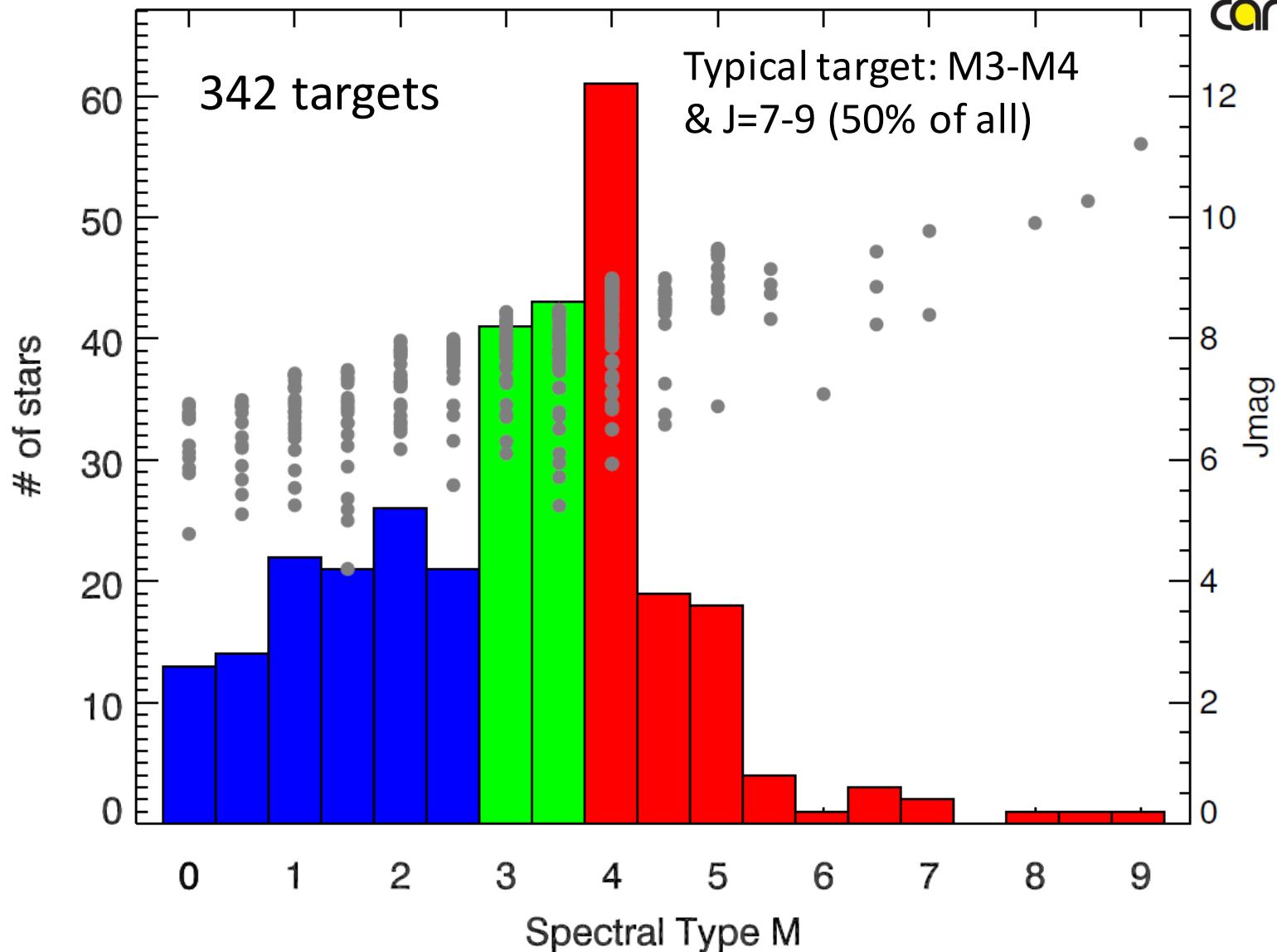
- How many planets are there?
- What are they like?
- How do planets form and evolve?
- What are the architectures of planetary systems?

CARMENES:
**Find and measure a significant
number of planets**

The CARMENES survey



$\langle d \rangle = 13$ pc

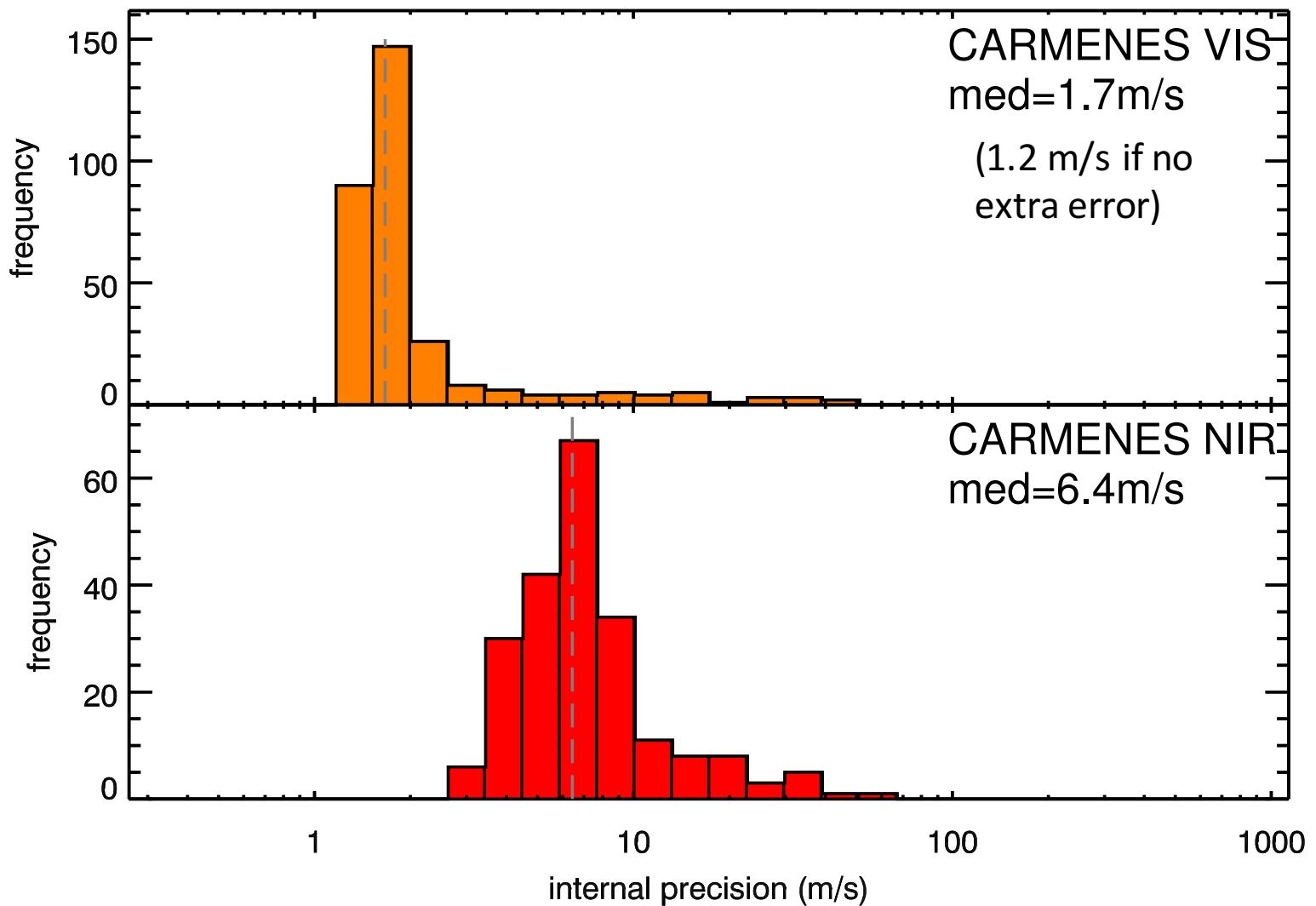


CARMENES

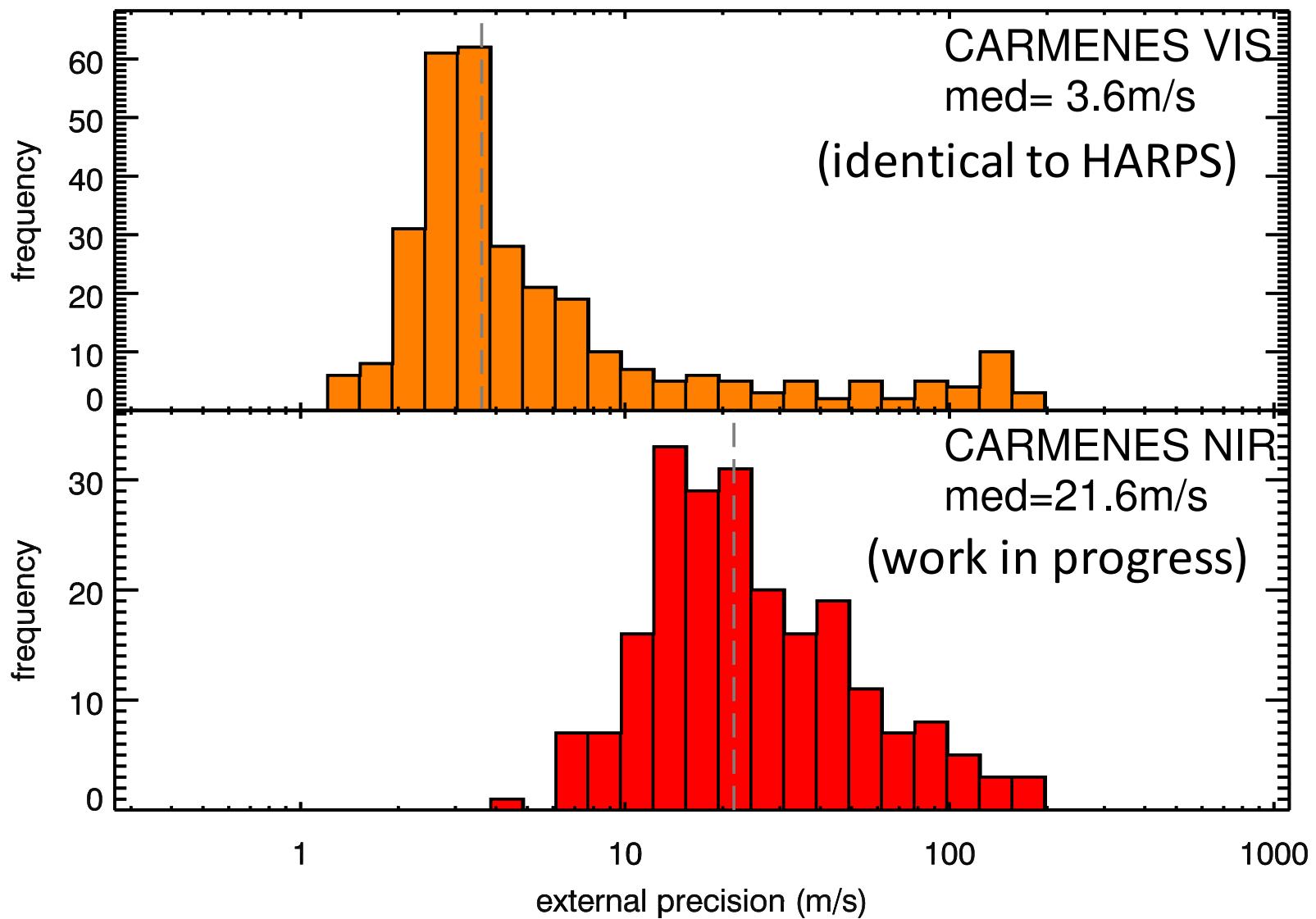


- CARMENES Survey since January 1, 2016
- ~3 years along the survey:
 - 342 targets with (>5) observations
 - 13294 VIS RVs & 12703 NIR RVs
 - ~3500h integration, 440 nights (60% of 750)
 - CARMENES papers: 26 (published, in press, submitted)
 - CARMENES discoveries:
 - New planets: 7 (published)
 - Firm planet candidates: 14

Internal precision



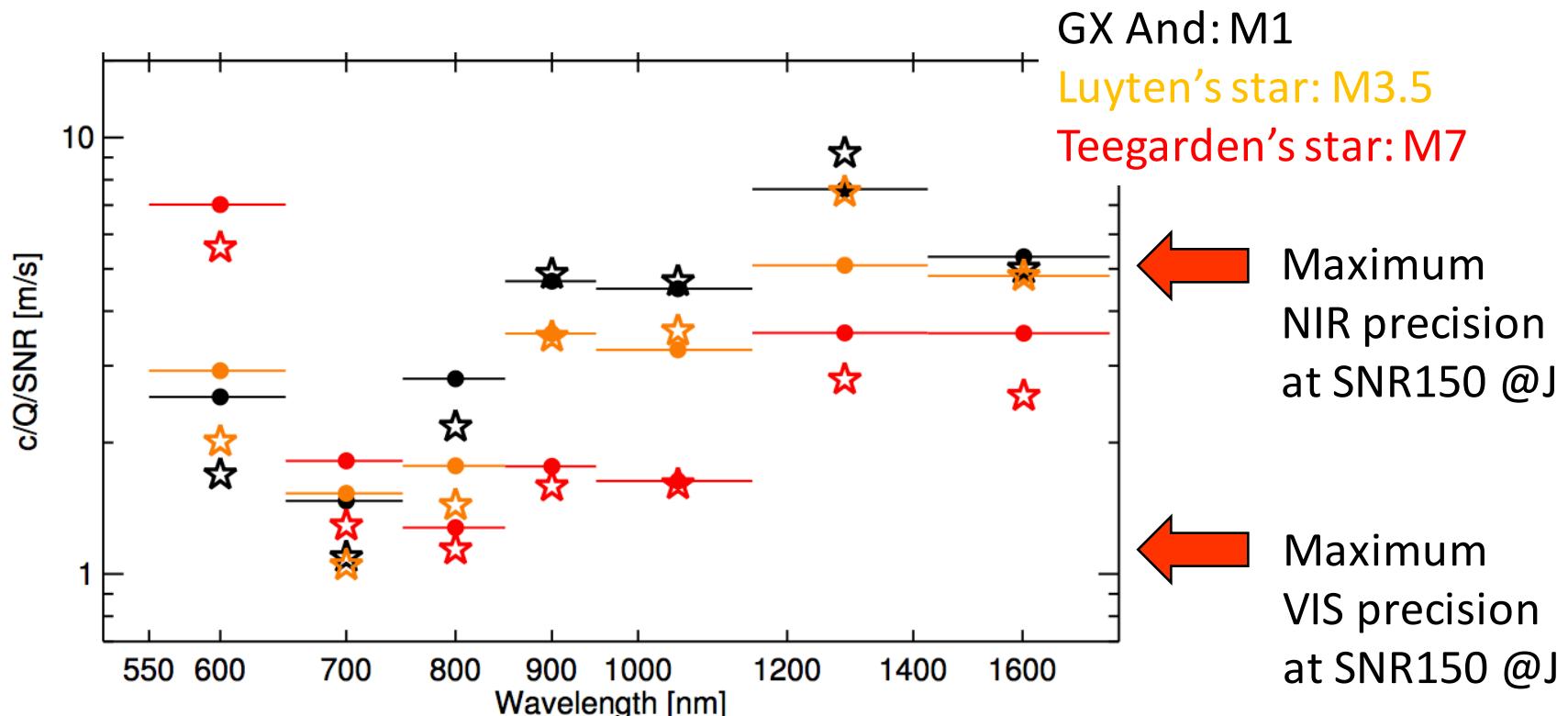
External precision



The CARMENES search for exoplanets around M dwarfs

High-resolution optical and near-infrared spectroscopy of 324 survey stars

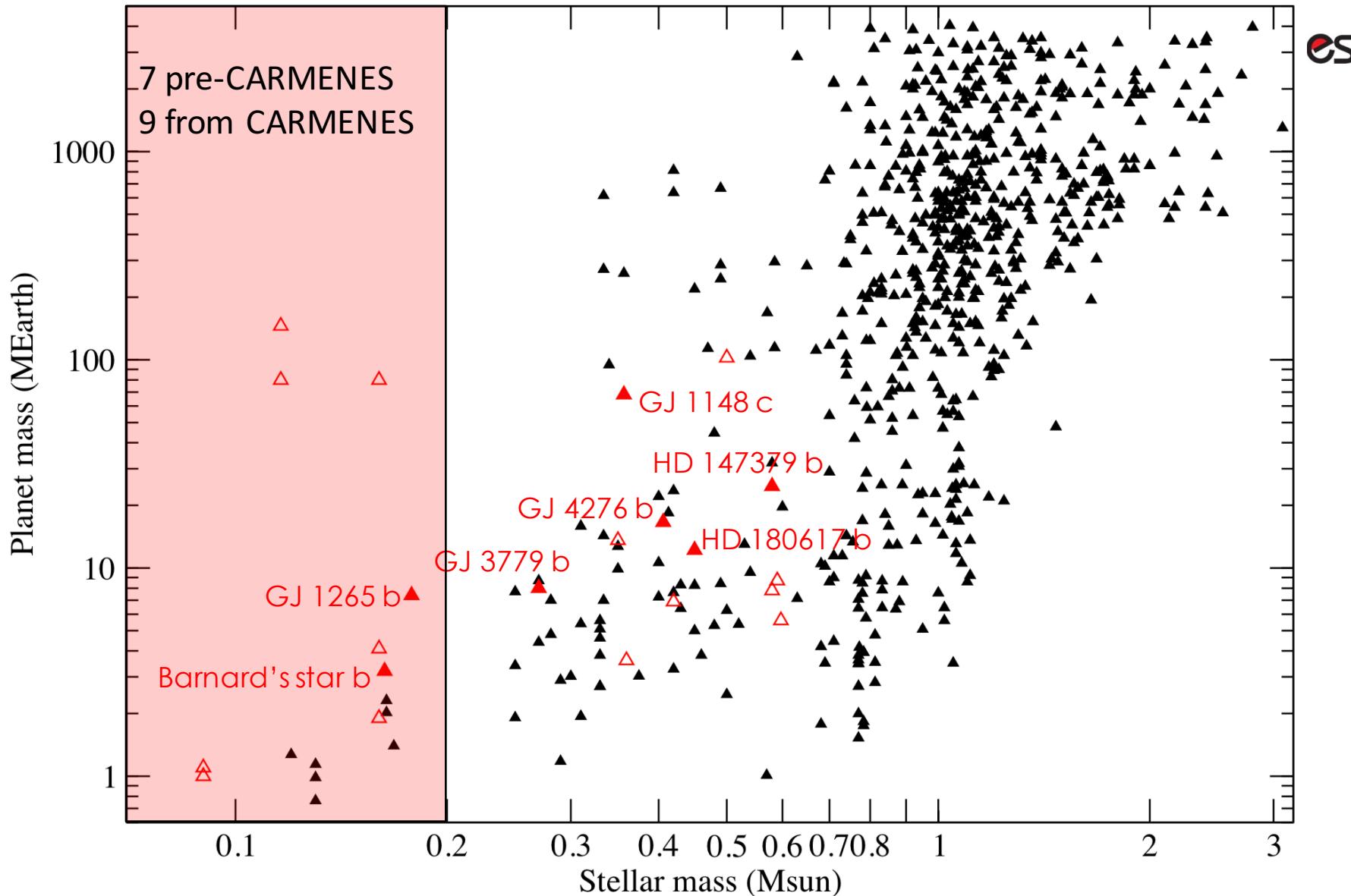
A. Reiners^{1,*}, M. Zechmeister¹, J. A. Caballero^{2,3}, I. Ribas⁴, J. C. Morales⁴, S. V. Jeffers¹, P. Schöfer¹, L. Tal-Or¹,
 A. Quirrenbach³, P. J. Amado⁵, A. Kaminski³, W. Seifert³, M. Abril⁵, J. Aceituno⁶, F. J. Alonso-Floriano^{8,12},
 ...



CARMENES discoveries



es



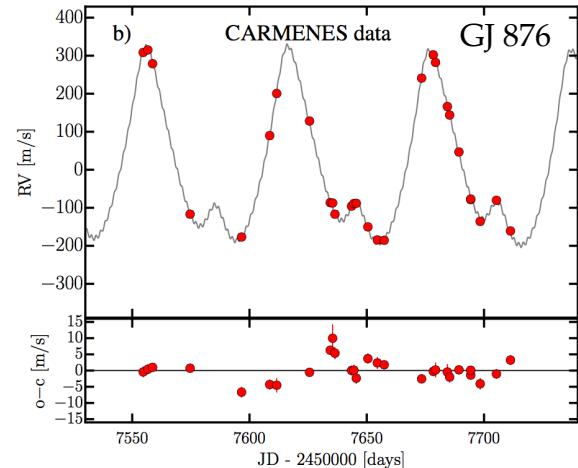
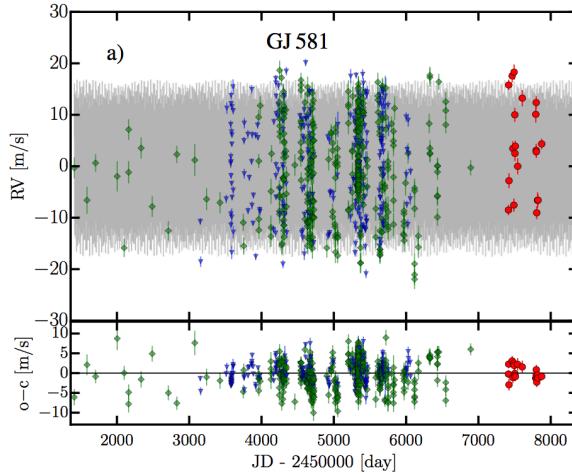
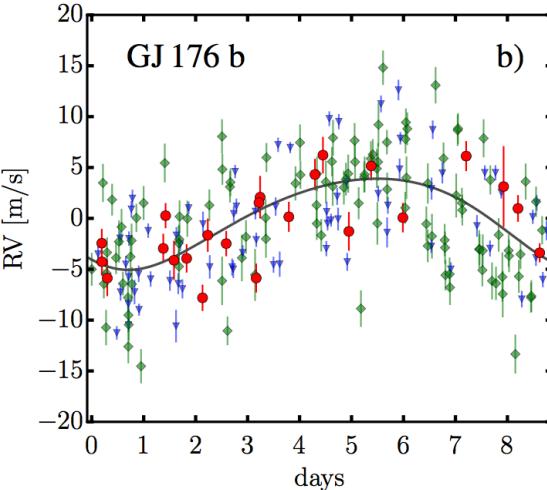
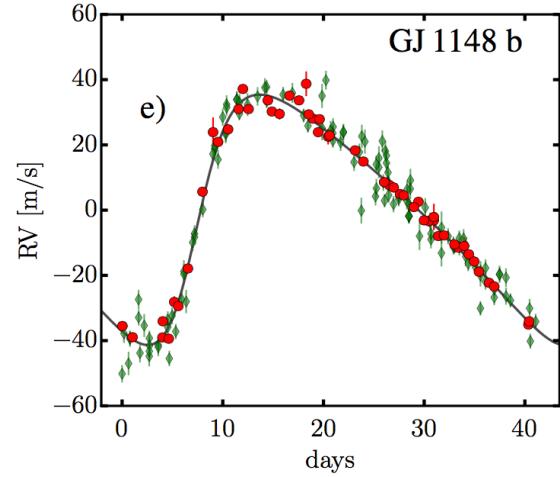
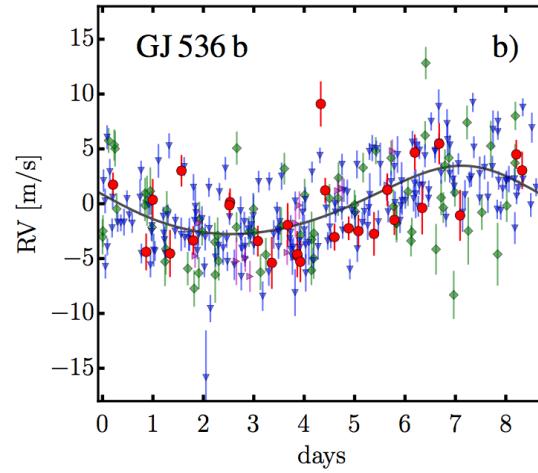
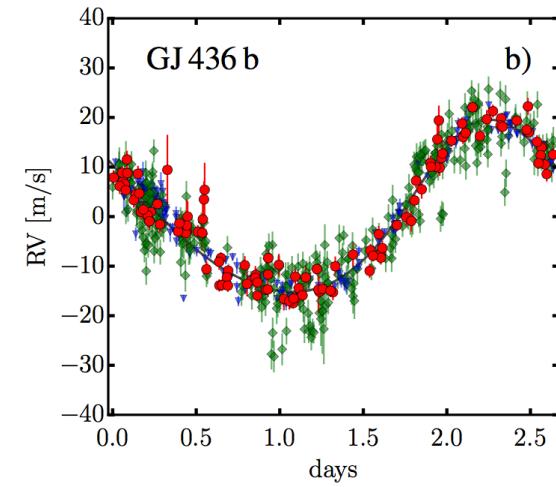
The CARMENES search for exoplanets around M dwarfs

First visual-channel radial-velocity measurements and orbital parameter updates
of seven M-dwarf planetary systems*

T. Trifonov¹, M. Kürster¹, M. Zechmeister², L. Tal-Or², J.A. Caballero^{3,5}, A. Quirrenbach⁵, I. Ribas⁷, A. Reiners², S. ...



2018, A&A

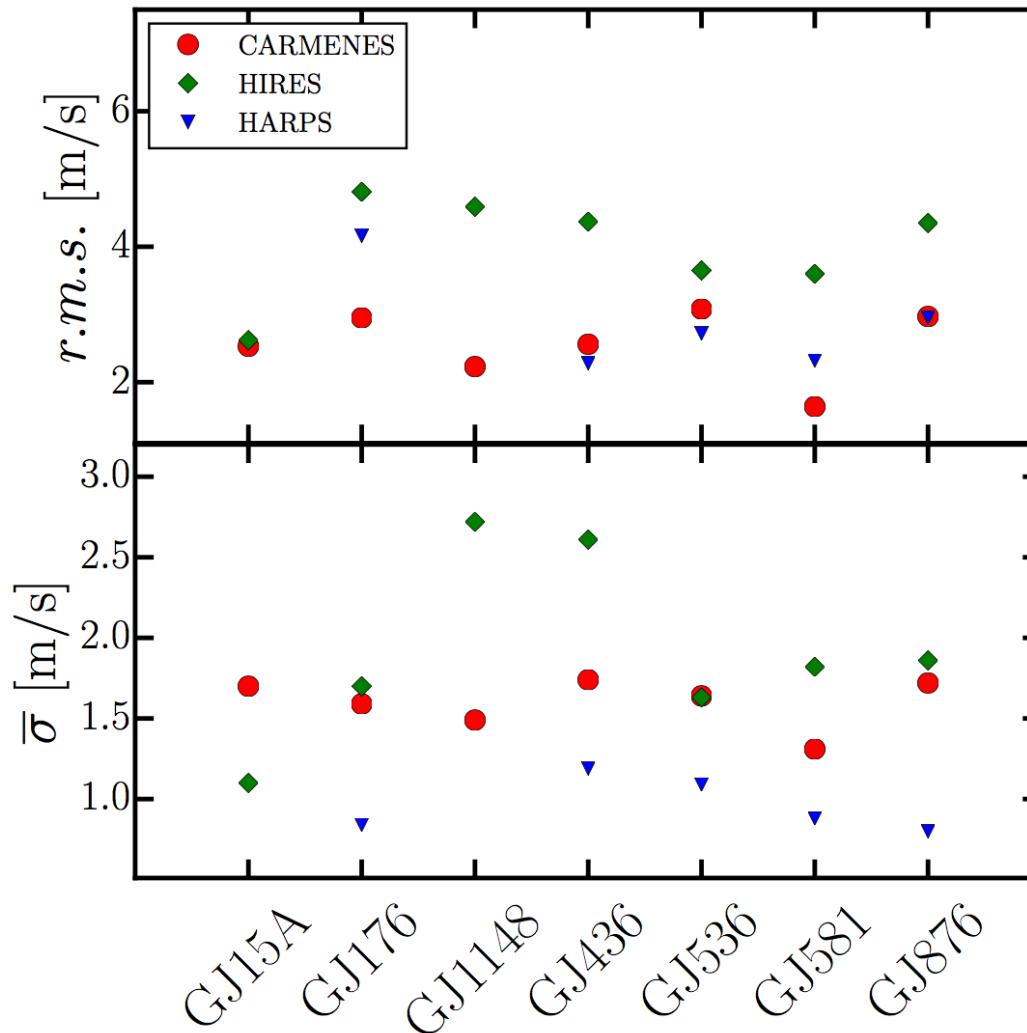


The CARMENES search for exoplanets around M dwarfs



First visual-channel radial-velocity measurements and orbital parameter updates
of seven M-dwarf planetary systems*

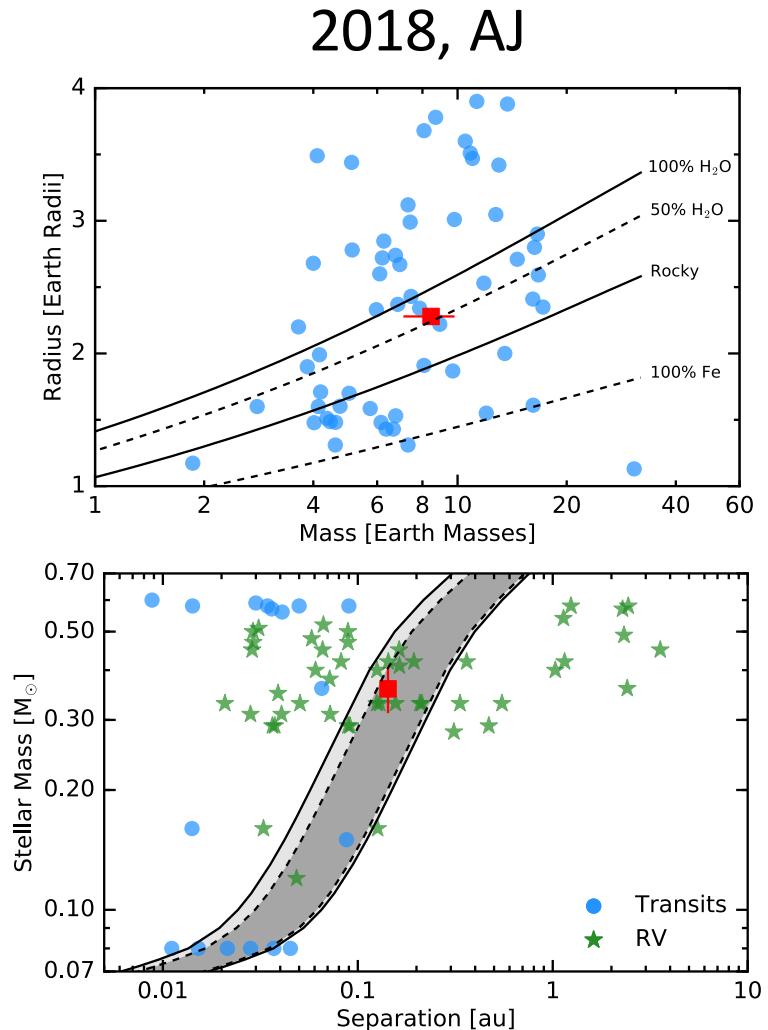
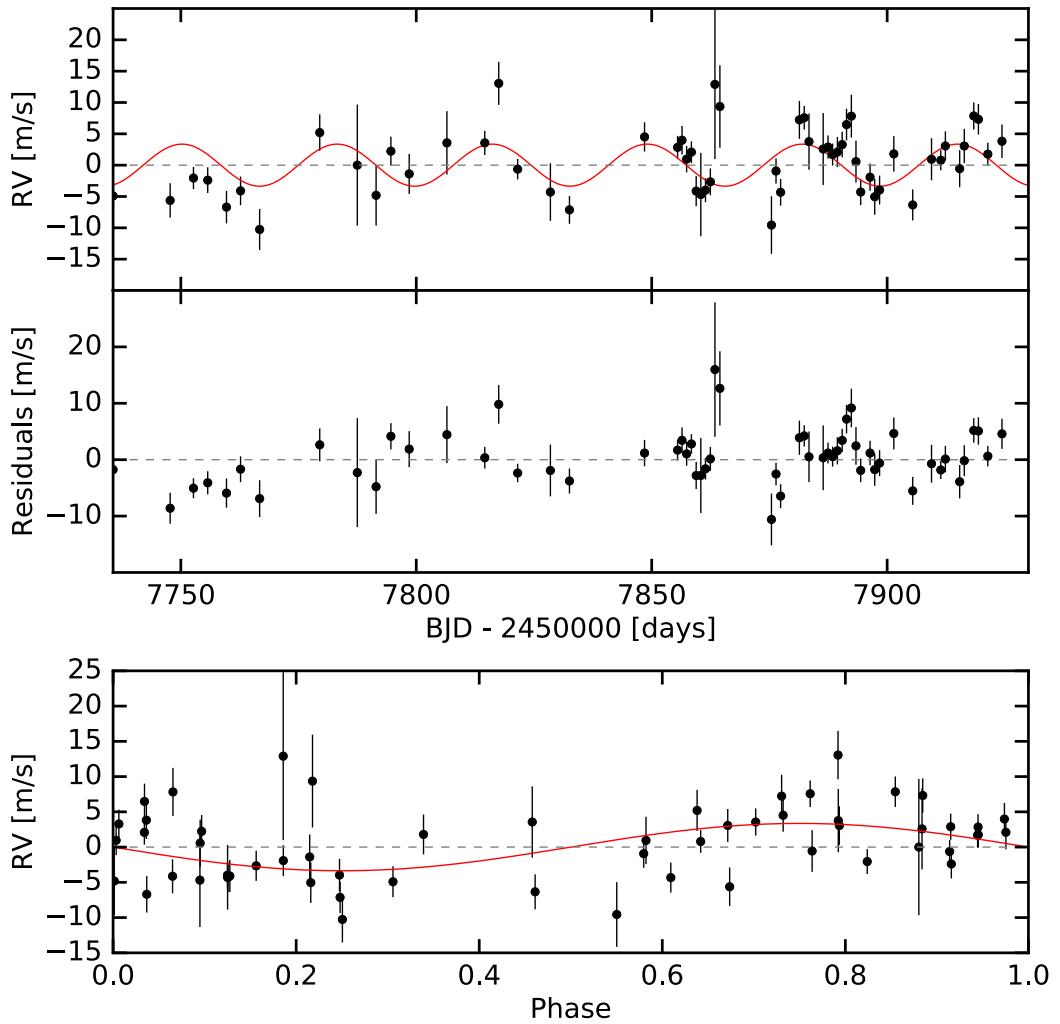
T. Trifonov¹, M. Kürster¹, M. Zechmeister², L. Tal-Or², J.A. Caballero^{3,5}, A. Quirrenbach⁵, I. Ribas⁷, A. Reiners², S. ...



THE CARMENES SEARCH FOR EXOPLANETS AROUND M DWARFS:
A LOW-MASS PLANET IN THE TEMPERATE ZONE OF THE NEARBY K2-18



PAULA SARKIS,¹ THOMAS HENNING,¹ MARTIN KÜRSTER,¹ TRIFON TRIFONOV,¹ MATHIAS ZECHMEISTER,² LEV TAL-OR,²
GUILLEM ANGLADA-ESCUDÉ,³ ARTIE P. HATZES,⁴ MARINA LAFARGA,⁵ IGNASI RIBAS,⁵ JOSÉ A. CABALLERO,^{6,7}
ANSGAR REINERS,² MATTHIAS MALLONN,⁸ JUAN C. MORALES,⁵ ADRIAN KAMINSKI,⁷ JESÚS ACEITUNO,⁹
PEDRO J. AMADO,¹⁰ VICTOR J. S. BÉJAR,¹¹ STEFAN DREIZLER,² HANS-JÜRGEN HAGEN,¹² SANDRA JEFFERS,²
ANDREAS QUIRRENBACH,⁷ RALF LAUNHARDT,¹ AND DAVID MONTES¹³



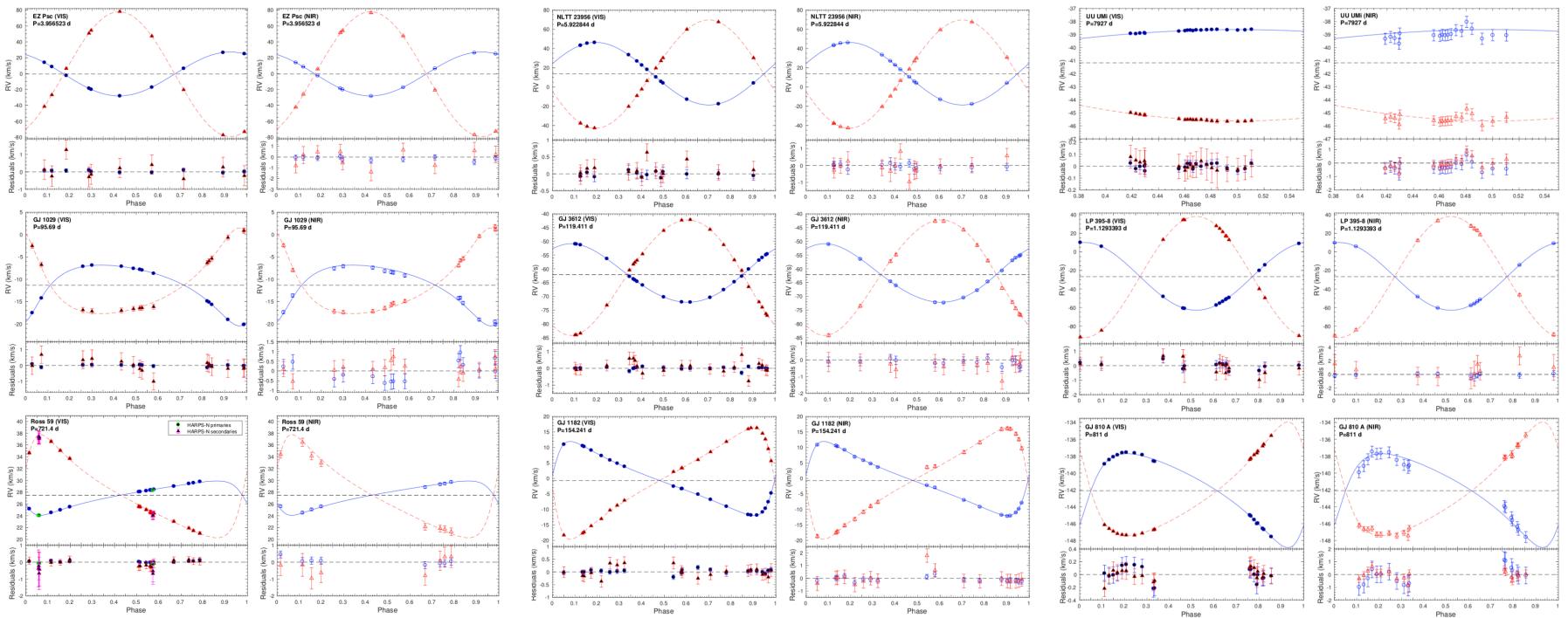


The CARMENES search for exoplanets around M dwarfs

Nine new double-line spectroscopic binary stars

D. Baroch^{1,2}, J. C. Morales^{1,2}, I. Ribas^{1,2}, L. Tal-Or^{3,4}, M. Zechmeister³, A. Reiners³, J. A. Caballero⁵, A. Quirrenbach⁶, P. J. Amado⁷, S. Dreizler³, S. Lalitha³, S. V. Jeffers³, M. Lafarga^{1,2}, V. J. S. Béjar^{8,9}, J. Colomé^{1,2}, M. Cortés-Contreras^{7,5}, E. Díez-Alonso⁵, D. Galadí-Enríquez¹⁰, E. W. Guenther¹¹, H.-J. Hagen¹², T. Henning¹³, E. Herrero^{1,2}, M. Kürster¹³, D. Montes¹⁴, E. Nagel¹², V. M. Passegger¹², M. Perger^{1,2}, A. Rosich^{1,2}, A. Schweitzer¹², W. Seifert⁶.

2018, A&A



The CARMENES search for exoplanets around M dwarfs

HD 147379 b: A nearby Neptune in an early-M dwarf's temperate zone

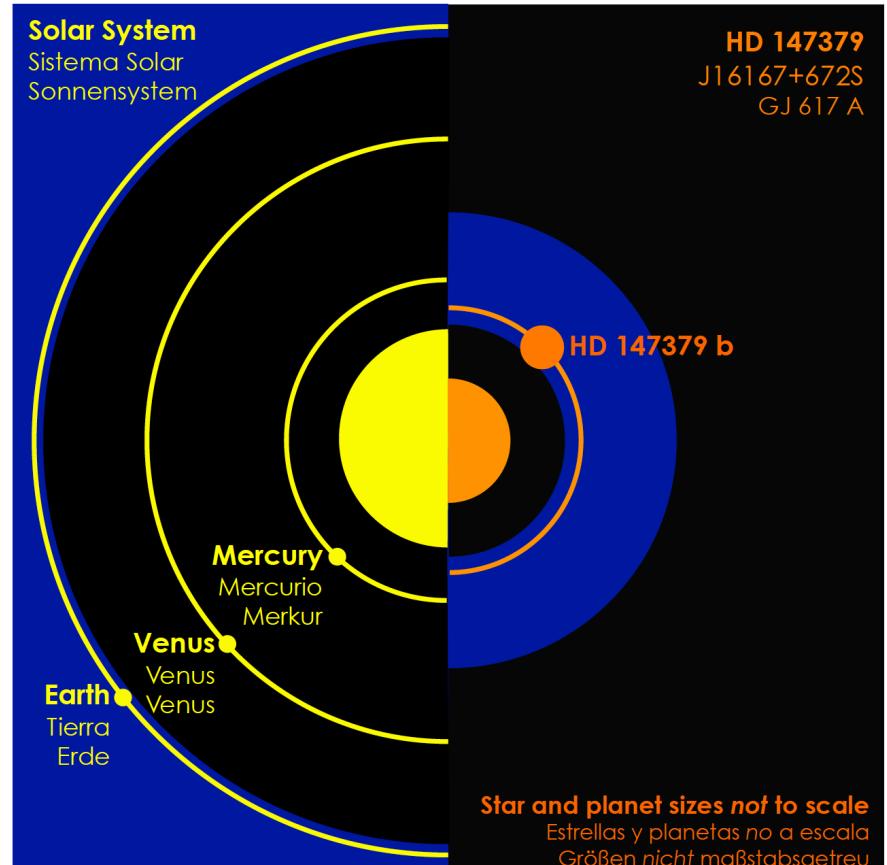
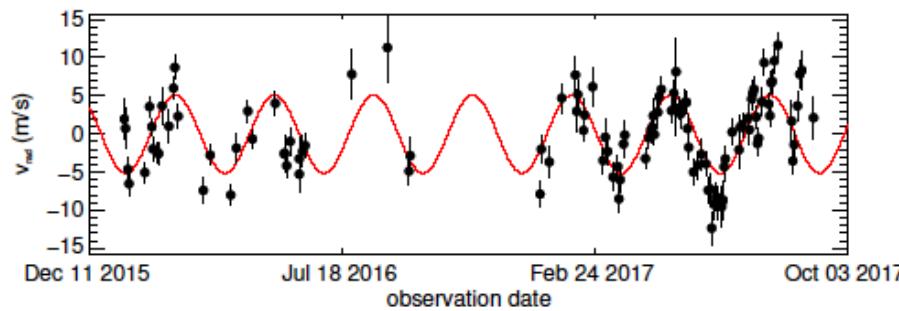


A. Reiners¹, I. Ribas², M. Zechmeister¹, J.A. Caballero^{3,4}, T. Trifonov⁵, S. Dreizler¹, J.C. Morales², L. Tal-Or¹, M. Lafarga², A. Quirrenbach⁴, P.J. Amado⁶, A. Kaminski⁴, M. Abril⁶, J. Aceituno⁷, F.J. Alonso-Floriano, M. Ammler-von

...

2018, A&A

| Orbital Parameter | HD 147479 b |
|---|------------------------------|
| K (m s^{-1}) | $5.49^{+0.36}_{-0.43}$ |
| P (d) | $86.48^{+0.07}_{-0.05}$ |
| e | $0.07^{+0.06}_{-0.05}$ |
| ϖ (deg) | $45.3^{+116.4}_{-64.7}$ |
| M (deg) | $99.2^{+75.7}_{-110.6}$ |
| γ_{HIRES} (m s^{-1}) | $-1.90^{+0.80}_{-0.74}$ |
| γ_{CARMENES} (m s^{-1}) | $0.60^{+0.33}_{-0.30}$ |
| $\sigma_{\text{jitter,HIRES}}$ (m s^{-1}) | $3.82^{+0.93}_{-0.30}$ |
| $\sigma_{\text{jitter,CARMENES}}$ (m s^{-1}) | $2.50^{+0.41}_{-0.14}$ |
| a (au) | $0.3400^{+0.0002}_{-0.0001}$ |
| $m_p \sin i$ (M_\oplus) | $29.87^{+1.91}_{-2.39}$ |



HD 147379 b
CARMENES • Reiners et al. • 2017





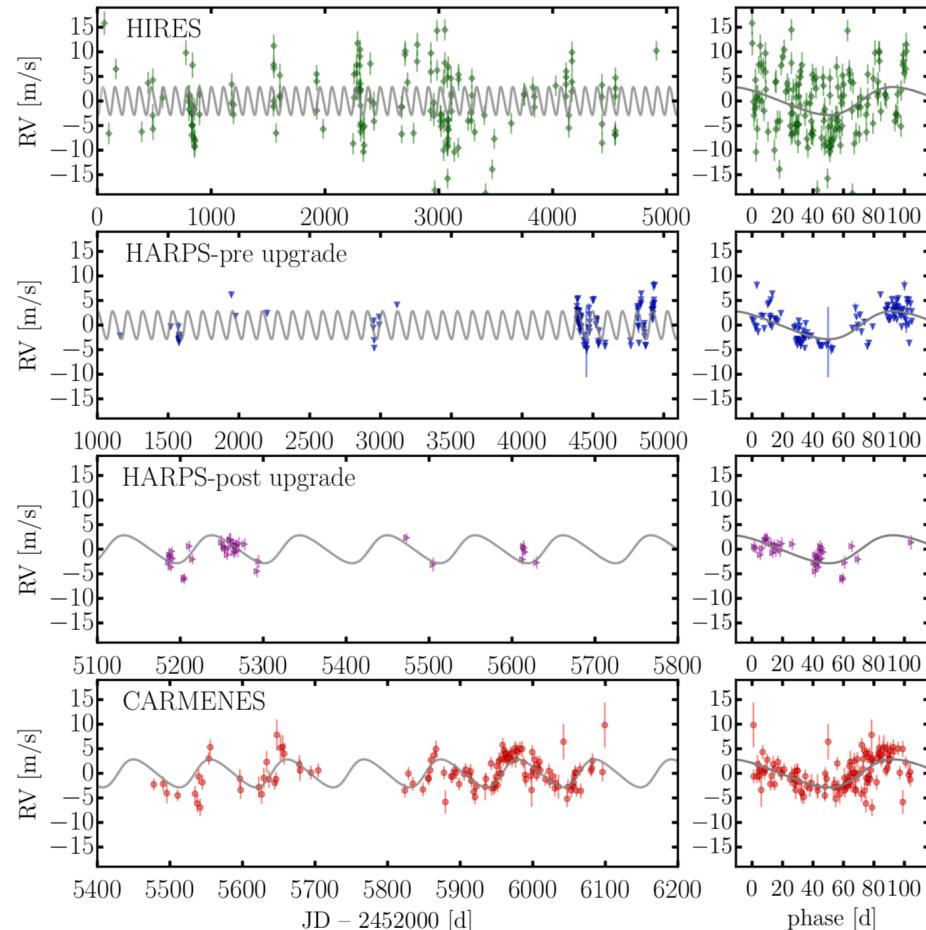
The CARMENES search for exoplanets around M dwarfs

A Neptune-mass planet traversing the habitable zone around HD 180617

A. Kaminski¹, T. Trifonov², J. A. Caballero³, A. Quirrenbach¹, I. Ribas^{4,5}, A. Reiners⁶, P. J. Amado⁷, M. Zechmeister⁶, S. Dreizler⁶, M. Perger^{4,5}, L. Tal-Or^{8,6}, X. Bonfils⁹, M. Mayor¹⁰, N. Astudillo-Defru¹¹, F. Bauer^{7,6}, V. J. S. Béjar^{12,13}, C. Cifuentes¹⁴, J. Colomé^{4,5}, M. Cortés-Contreras³, X. Delfosse⁹, E. Díez-Alonso¹⁴, T. Forveille⁹, E. W. Guenther¹⁵, A. P. Hatzes¹⁵, T. Henning², S. V. Jeffers⁶, M. Kürster², M. Lafarga^{4,5}, R. Luque^{12,13,1}, H. Mandel¹, D. Montes¹⁴, J. C. Morales^{4,5}, V. M. Passegger¹⁶, S. Pedraz¹⁷, S. Reffert¹, S. Sadegi¹, A. Schweitzer¹⁶, W. Seifert¹, O. Stahl¹, and S. Udry¹⁰

2018, A&A

| Orbital Parameters | | HD 180617 b |
|---|--|-------------------------------|
| K_b [m/s] | | 2.85 $^{+0.16}_{-0.25}$ |
| P_b [day] | | 105.90 $^{+0.09}_{-0.10}$ |
| e_b | | 0.16 $^{+0.05}_{-0.10}$ |
| ϖ_b [deg] | | 269 $^{+30}_{-45}$ |
| M_b [deg] ^a | | 118 $^{+49}_{-37}$ |
| l_b [deg] ^b | | 27 $^{+14}_{-15}$ |
| $t_{\text{trans.}}$ [BJD] | | 2451974.5 $^{+4.5}_{-4.1}$ |
| γ_{HIRES} [m/s] | | 0.43 $^{+0.47}_{-0.48}$ |
| $\gamma_{\text{HARPS-pre}}$ [m/s] | | -0.44 $^{+0.24}_{-0.21}$ |
| $\gamma_{\text{HARPS-post}}$ [m/s] | | -4.67 $^{+0.30}_{-0.37}$ |
| $\gamma_{\text{CARM.}}$ [m/s] | | -0.41 $^{+0.21}_{-0.22}$ |
| $\sigma_{\text{jitt,HIRES}}$ [m/s] | | 5.62 $^{+0.49}_{-0.29}$ |
| $\sigma_{\text{jitt,HARPS-pre}}$ [m/s] | | 2.03 $^{+0.21}_{-0.11}$ |
| $\sigma_{\text{jitt,HARPS-post}}$ [m/s] | | 1.41 $^{+0.49}_{-0.13}$ |
| $\sigma_{\text{jitt,CARM.}}$ [m/s] | | 1.69 $^{+0.27}_{-0.16}$ |
| $m_b \sin i$ [M_\oplus] | | 12.2 $^{+1.0}_{-1.4}$ |
| a_b [au] | | 0.3357 $^{+0.0099}_{-0.0100}$ |

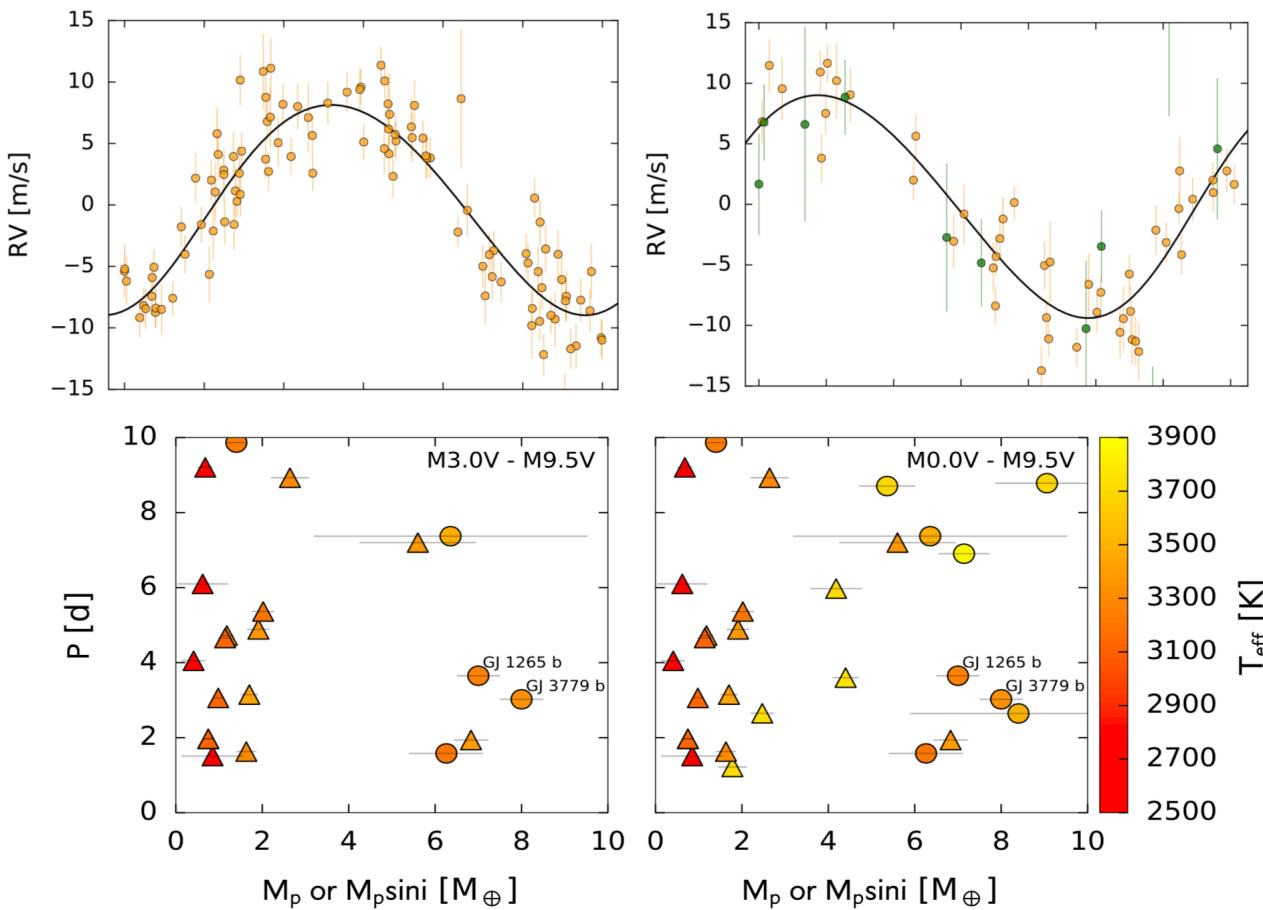




The CARMENES search for exoplanets around M dwarfs

The warm super-Earths in twin orbits around the mid-type M dwarfs Ross 1020 (GJ 3779) and LP 819-052 (GJ 1265)

R. Luque^{1,2}, G. Nowak^{1,2}, E. Pallé^{1,2}, D. Kossakowski³, T. Trifonov³, M. Zechmeister⁴, V. J. S. Béjar^{1,2}, C. Cardona Guillén^{1,2}, L. Tal-Or^{4,14}, D. Hidalgo^{1,2}, I. Ribas^{5,6}, A. Reiners⁴, J. A. Caballero⁷, P. J. Amado⁸, A. Quirrenbach⁹, J. Aceituno¹⁰, M. Cortés-Contreras⁷, E. Díez-Alonso¹¹, S. Dreizler⁴, E. W. Guenther¹², T. Henning³, S. V. Jeffers⁴, A. Kaminski⁹, M. Kürster³, M. Lafarga^{5,6}, D. Montes⁷, J. C. Morales^{5,6}, V. M. Passegger¹³, J. H. M. M. Schmitt¹³, and A. Schweitzer¹³



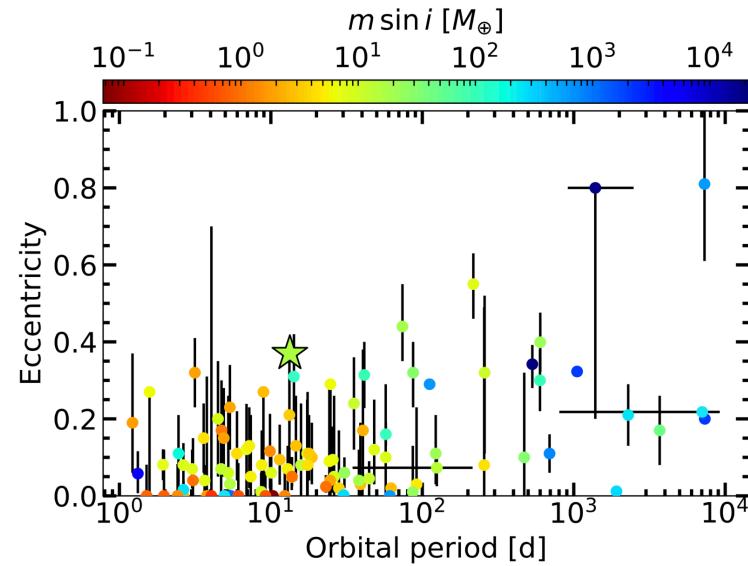
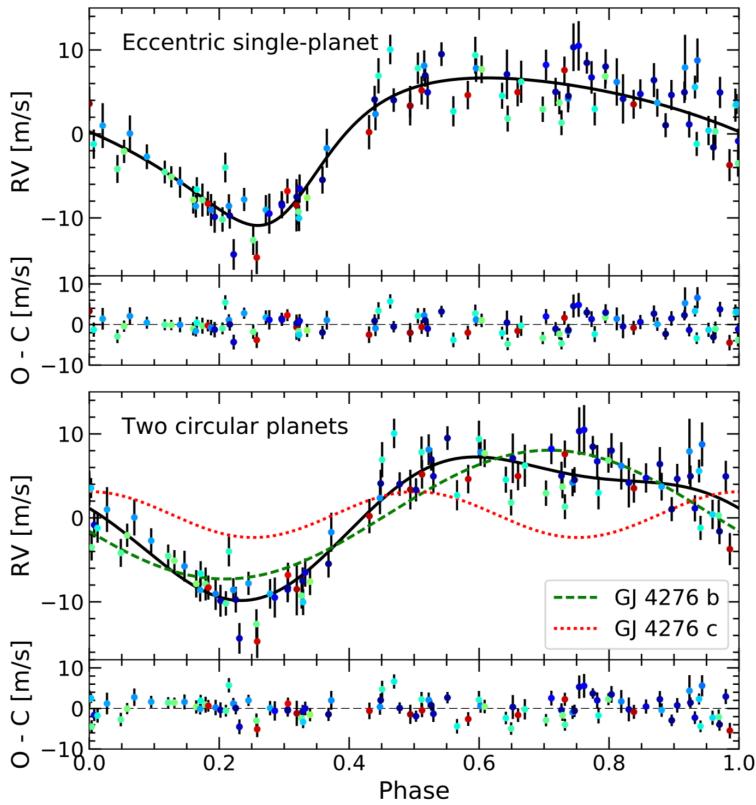
2018, A&A

| Parameter | Best-fit | MCMC |
|---|-------------------|------------------------------|
| GJ 3779 b | | |
| K [m s ⁻¹] | 8.61 ± 0.40 | $8.62^{+0.39}_{-0.39}$ |
| P [days] | 3.023 ± 0.001 | $3.0232^{+0.0004}_{-0.0004}$ |
| e | 0.07 ± 0.05 | $0.06^{+0.05}_{-0.06}$ |
| ω [deg] | 225 ± 42 | 231^{+42}_{-54} |
| M [deg] | 339 ± 41 | 333^{+52}_{-41} |
| γ_{VIS} [m s ⁻¹] | 0.85 ± 0.52 | $0.86^{+0.30}_{-0.29}$ |
| $\sigma_{\text{jitt,VIS}}$ [m s ⁻¹] | 2.2 (fixed) | $2.19^{+0.29}_{-0.29}$ |
| $m_p \sin i$ [M_\oplus] | 8.0 ± 0.5 | |
| a [au] | 0.026 ± 0.001 | |
| GJ 1265 b | | |
| K [m s ⁻¹] | 9.28 ± 0.63 | $9.24^{+0.66}_{-0.66}$ |
| P [days] | 3.651 ± 0.001 | $3.6511^{+0.0001}_{-0.0001}$ |
| e | 0.09 ± 0.07 | $0.10^{+0.07}_{-0.10}$ |
| ω [deg] | 259 ± 43 | 266^{+19}_{-22} |
| M [deg] | 49 ± 49 | 44^{+29}_{-25} |
| γ_{VIS} [m s ⁻¹] | 2.18 ± 0.76 | $2.13^{+0.49}_{-0.49}$ |
| γ_{HARPS} [m s ⁻¹] | 4.61 ± 1.76 | $4.80^{+1.76}_{-1.62}$ |
| $\sigma_{\text{jitt,VIS}}$ [m s ⁻¹] | 2.3 (fixed) | $2.33^{+0.46}_{-0.48}$ |
| $\sigma_{\text{jitt,HARPS}}$ [m s ⁻¹] | 3.0 (fixed) | $3.07^{+2.23}_{-2.20}$ |
| $m_p \sin i$ [M_\oplus] | 7.0 ± 0.5 | |
| a [au] | 0.026 ± 0.001 | |

The CARMENES search for exoplanets around M dwarfs

The enigmatic planetary system of GJ 4276: one eccentric planet or two planets in a 2:1 resonance?

E. Nagel¹, S. Czesla¹, J. H. M. M. Schmitt¹, S. Dreizler², G. Anglada-Escudé^{3,4}, E. Rodríguez³, I. Ribas^{5,6}, A. Reiners², A. Quirrenbach⁷, P. J. Amado³, J. A. Caballero⁸, J. Aceituno⁹, V. J. S. Béjar^{10,11}, M. Cortés-Contreras⁸, L. González-Cuesta^{10,11}, E. W. Guenther¹², T. Henning¹³, S. V. Jeffers², A. Kaminski⁷, M. Kürster¹³, M. Lafarga^{5,6}, M. J. López-González³, D. Montes¹⁴, J. C. Morales^{5,6}, V. M. Passegger¹, C. Rodríguez-López³, A. Schweitzer¹, and M. Zechmeister²



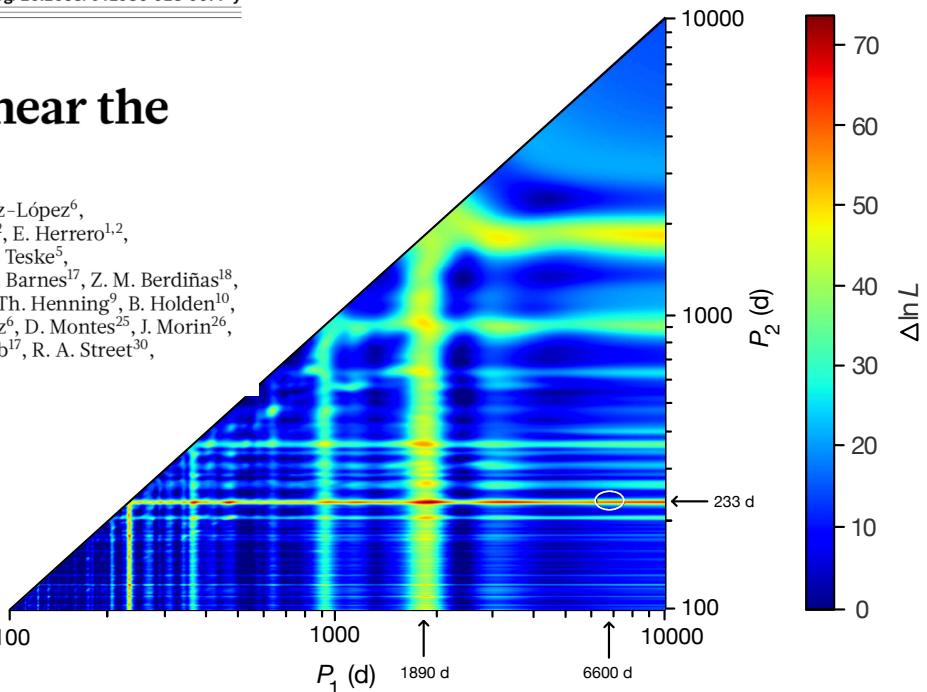
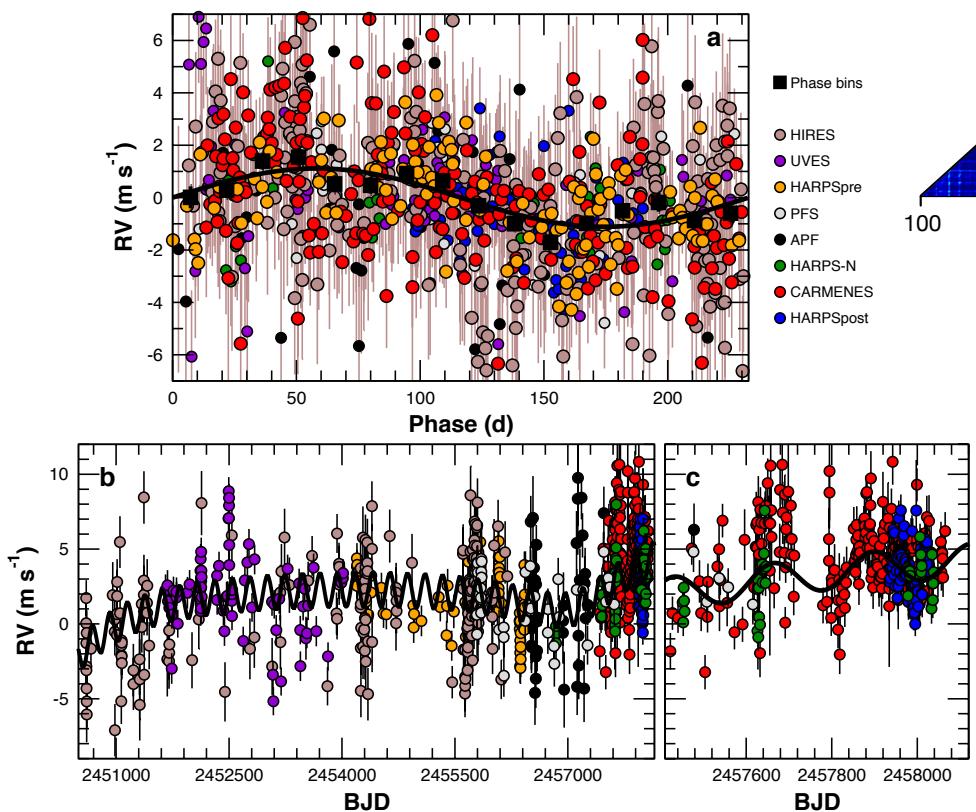
| Orbital parameters | GJ 4276 b ⁽¹⁾ | GJ 4276 b ⁽²⁾ | GJ 4276 b ⁽³⁾ | GJ 4276 c ⁽³⁾ |
|---|----------------------------|----------------------------|----------------------------|---------------------------|
| K [m s ⁻¹] | $7.93^{+0.32}_{-0.32}$ | $8.79^{+0.27}_{-0.27}$ | $7.67^{+0.25}_{-0.25}$ | $2.73^{+0.23}_{-0.24}$ |
| P [d] | $13.348^{+0.005}_{-0.005}$ | $13.352^{+0.003}_{-0.003}$ | $13.350^{+0.004}_{-0.004}$ | $6.675^{+0.002}_{-0.003}$ |
| e | 0 (fixed) | $0.37^{+0.03}_{-0.03}$ | 0 (fixed) | 0 (fixed) |
| ω [deg] | 90 (fixed) | $216.83^{+4.74}_{-4.56}$ | 90 (fixed) | 90 (fixed) |
| τ [BJD – 2457572] | $0.28^{+0.23}_{-0.22}$ | $4.72^{+0.19}_{-0.17}$ | $0.10^{+0.17}_{-0.17}$ | $2.35^{+0.18}_{-0.18}$ |
| γ [m s ⁻¹] | $0.31^{+0.24}_{-0.23}$ | $0.52^{+0.18}_{-0.18}$ | $0.39^{+0.18}_{-0.17}$ | $1.89^{+0.18}_{-0.17}$ |
| σ_{jitter} [m s ⁻¹] | $2.83^{+0.22}_{-0.20}$ | $1.74^{+0.18}_{-0.17}$ | $0.082^{+0.002}_{-0.002}$ | $0.051^{+0.001}_{-0.001}$ |
| a [au] | $0.082^{+0.002}_{-0.002}$ | $0.082^{+0.002}_{-0.002}$ | $0.082^{+0.002}_{-0.002}$ | $15.58^{+0.93}_{-0.90}$ |
| $m_p \sin i$ [M_\oplus] | $16.11^{+1.03}_{-1.01}$ | $16.57^{+0.94}_{-0.95}$ | 179.77 | $4.40^{+0.44}_{-0.44}$ |
| σ_{O-C} [m s ⁻¹] | 3.29 | 2.46 | 2.57 | |
| $-2 \ln \mathcal{L}$ | 229.71 | 170.48 | | |

2019, A&A

Eccentric
Neptune or 2:1
resonant pair?

A candidate super-Earth planet orbiting near the snow line of Barnard's star

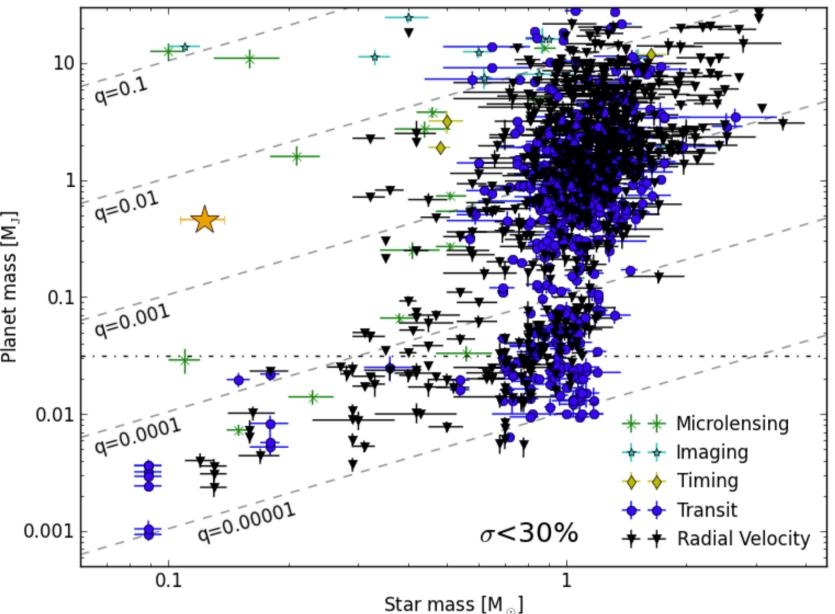
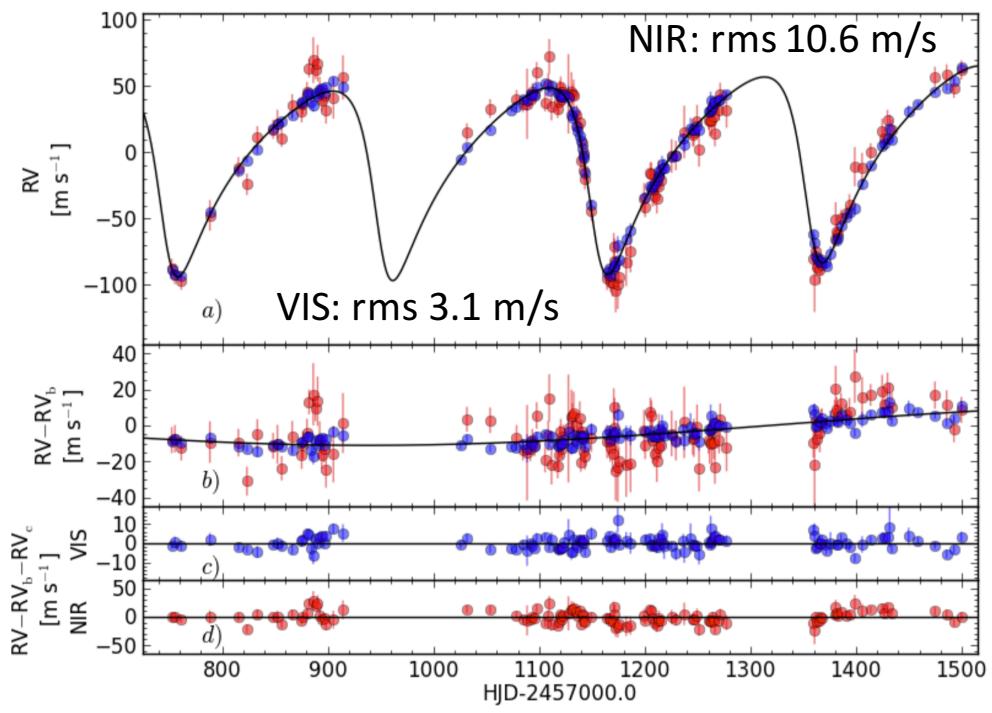
I. Ribas^{1,2*}, M. Tuomi³, A. Reiners⁴, R. P. Butler⁵, J. C. Morales^{1,2}, M. Perger^{1,2}, S. Dreizler⁴, C. Rodríguez-López⁶, J. I. González Hernández^{7,8}, A. Rosich^{1,2}, F. Feng³, T. Trifonov⁹, S. S. Vogt¹⁰, J. A. Caballero¹¹, A. Hatzes¹², E. Herrero^{1,2}, S. V. Jeffers⁴, M. Lafarga^{1,2}, F. Murgas^{7,8}, R. P. Nelson¹³, E. Rodríguez⁶, J. B. P. Strachan¹³, L. Tal-Or^{4,14}, J. Teske⁵, B. Toledo-Padrón^{7,8}, M. Zechmeister⁴, A. Quirrenbach¹⁵, P. J. Amado⁶, M. Azzaro¹⁶, V. J. S. Béjar^{7,8}, J. R. Barnes¹⁷, Z. M. Berdiñas¹⁸, J. Burt¹⁹, G. Coleman²⁰, M. Cortés-Conterras¹¹, J. Crane²¹, S. G. Engle²², E. F. Guinan²², C. A. Haswell¹⁷, Th. Henning⁹, B. Holden¹⁰, J. Jenkins¹⁸, H. R. A. Jones³, A. Kaminski¹⁵, M. Kiraga²³, M. Kürster⁹, M. H. Lee²⁴, M. J. López-González⁶, D. Montes²⁵, J. Morin²⁶, A. Ofir²⁷, E. Pallé^{7,8}, R. Rebolo^{7,8,28}, S. Reffert¹⁵, A. Schweitzer²⁹, W. Seifert¹⁵, S. A. Shectman²¹, D. Staab¹⁷, R. A. Street³⁰, A. Suárez Mascareño^{7,31}, Y. Tsapras³², S. X. Wang⁵ & G. Anglada-Escude^{6,13}



| Planetary parameter | Value |
|---|--------------------------|
| Orbital period (d) | $232.80^{+0.38}_{-0.41}$ |
| Radial-velocity semi-amplitude (m s ⁻¹) | 1.20 ± 0.12 |
| Eccentricity | $0.32^{+0.10}_{-0.15}$ |
| Argument of periastron (°) | 107^{+19}_{-22} |
| Mean longitude at BJD 2,455,000.0 (°) | 203 ± 7 |
| Minimum mass, $M_{\text{sin} i}$ (M_{\oplus}) | 3.23 ± 0.44 |
| Orbital semi-major axis (AU) | 0.404 ± 0.018 |
| Irradiance (Earth units) | 0.0203 ± 0.0023 |
| Maximum equilibrium temperature (K) | 105 ± 3 |
| Minimum astrometric semi-amplitude, $\alpha_{\text{sin} i}$ (mas) | 0.0133 ± 0.0013 |
| Angular separation (mas) | 221 ± 10 |

First cold super-Earth with a measured mass

- Jupiter-mass planet around a very low-mass star
- Eccentric
- Possibly with a further companion
- First of its class
- First planet discovered with NIR

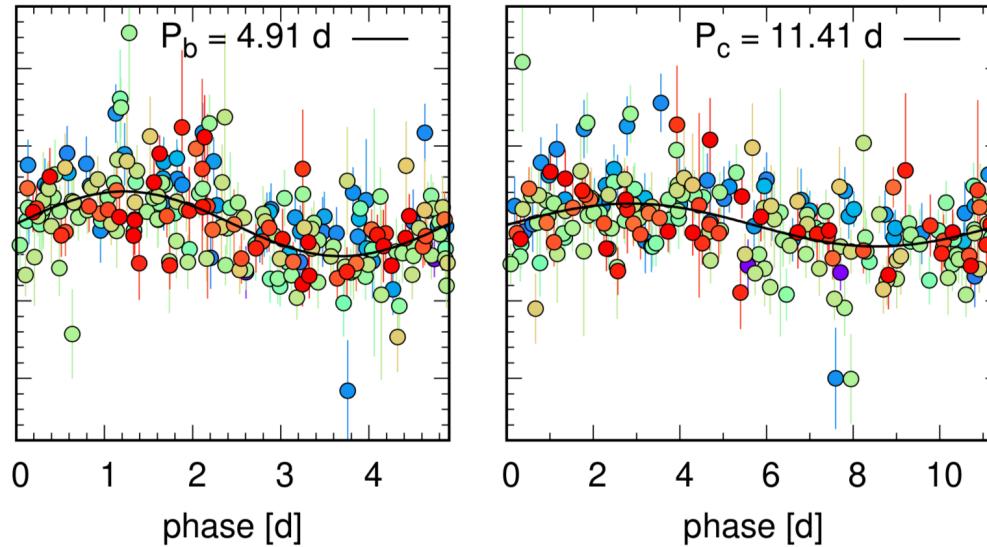


| Planet parameter | Value |
|---|---------------------------------|
| Orbital period (d) | $203.30^{+0.25}_{-0.23}$ >950 |
| Radial velocity semi-amplitude (m s ⁻¹) | $71.25^{+0.46}_{-0.46}$ >8.5 |
| Eccentricity | $0.4318^{+0.0050}_{-0.0054}$ - |
| Argument of periastron (deg) | $126.95^{+0.91}_{-0.86}$ - |
| Time of periastron - BJD2450000.0 (d) | $7746.62^{+0.66}_{-0.74}$ - |
| Minimum mass ($M \sin i$; M_J) | $0.459^{+0.037}_{-0.038}$ >0.1 |
| Orbital semi-major axis (au) | $0.338^{+0.013}_{-0.014}$ >0.95 |
| Minimum astrometric semi-amplitude ($\alpha \sin i$; mas) | $0.127^{+0.001}_{-0.001}$ >0.08 |
| Planet angular separation (mas) | $35.2^{+2.4}_{-2.8}$ >100 |

Morales et al., in prep.

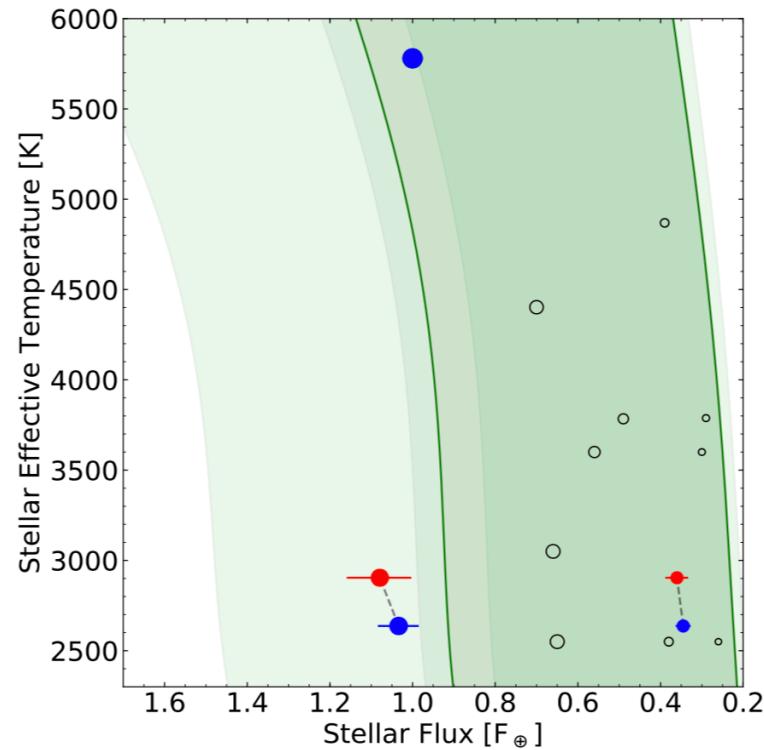


Two habitable 1-Earth mass planets



| Keplerian parameters | Planet b | Planet c |
|-------------------------|------------------------------|----------------------------|
| P [d] | $4.9099^{+0.0014}_{-0.0014}$ | $11.408^{+0.010}_{-0.010}$ |
| K [m/s] | $2.02^{+0.20}_{-0.19}$ | $1.44^{+0.20}_{-0.20}$ |
| e | $0.09^{+0.10}_{-0.06}$ | $0.12^{+0.13}_{-0.08}$ |
| ω [deg] | 52^{+63}_{-87} | 278^{+86}_{-87} |
| $t_p - 2\,457\,000$ [d] | $418.6^{+0.9}_{-1.1}$ | $414.0^{+2.6}_{-2.9}$ |

| Derived parameters | Planet b | Planet c |
|-----------------------------|------------------------|------------------------|
| a [au] | 0.026 ± 0.002 | 0.045 ± 0.003 |
| $m \sin i$ [M_{\oplus}] | $1.09^{+0.20}_{-0.19}$ | $1.01^{+0.22}_{-0.20}$ |
| m [M_{\oplus}] | $1.32^{+0.70}_{-0.29}$ | $1.24^{+0.67}_{-0.30}$ |
| $\sin i$ | $0.87^{+0.12}_{-0.31}$ | |
| M [M_{\odot}] | | $0.09^{+0.02}_{-0.02}$ |



Efficient scheduling of astronomical observations



Application to the CARMENES radial-velocity survey

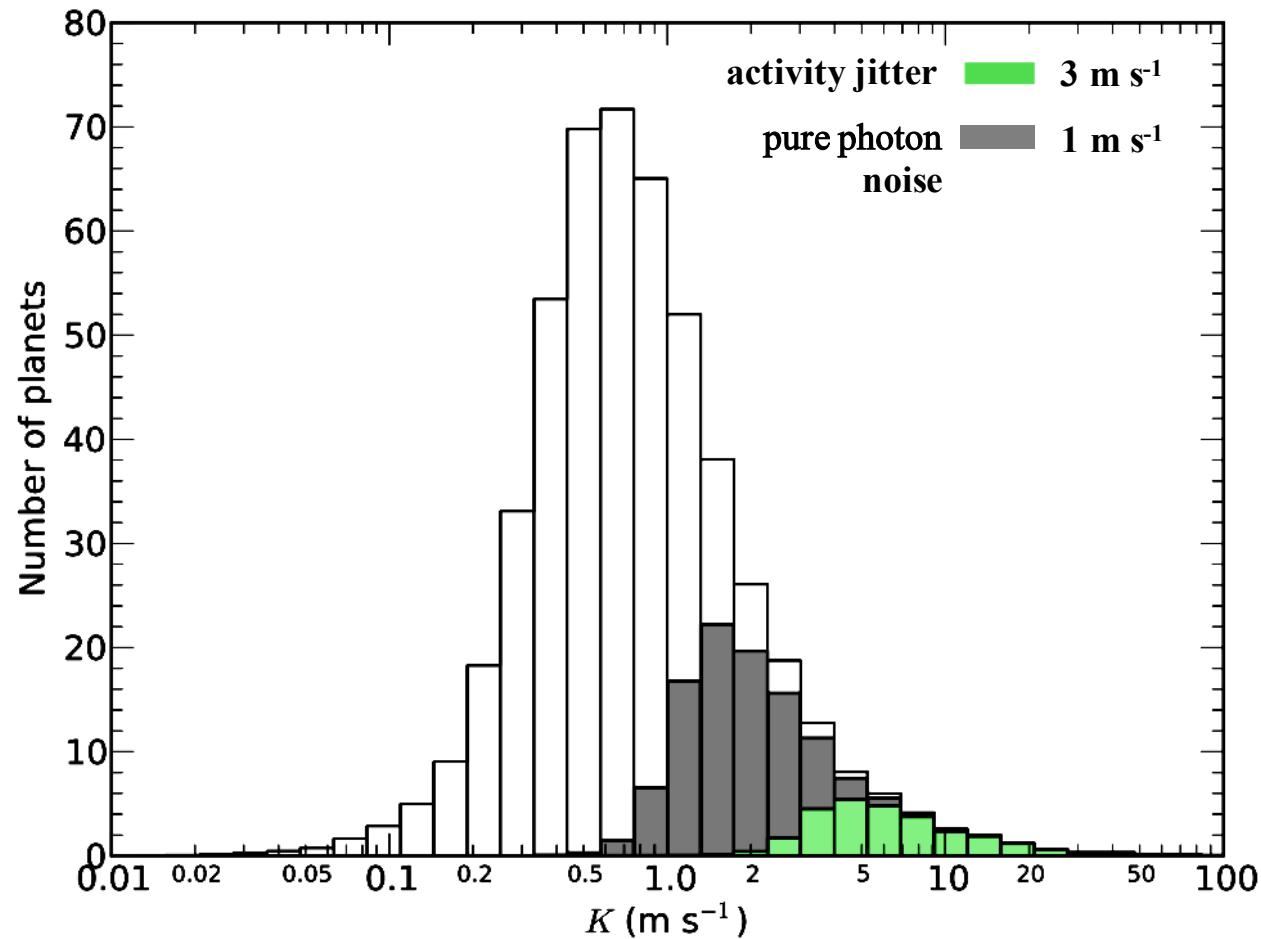
A. Garcia-Piquer¹, J. C. Morales^{1,2}, I. Ribas¹, J. Colomé¹, J. Guàrdia¹, M. Perger¹, J. A. Caballero^{3,4}, M. Cortés-Contreras⁵, S. V. Jeffers⁶, A. Reiners⁶, P. J. Amado⁷, A. Quirrenbach³, and W. Seifert³

2017, A&A

750 nights
60-70 obs. / star

| σ_{activity} [m s ⁻¹] | Generated planets | Detected planets |
|--|----------------------|---------------------|
| <hr/> | | |
| All planets | | |
| 0 | 505^{+16}_{-17} | 118^{+9}_{-9} |
| 3 | 505^{+16}_{-17} | 28^{+5}_{-6} |

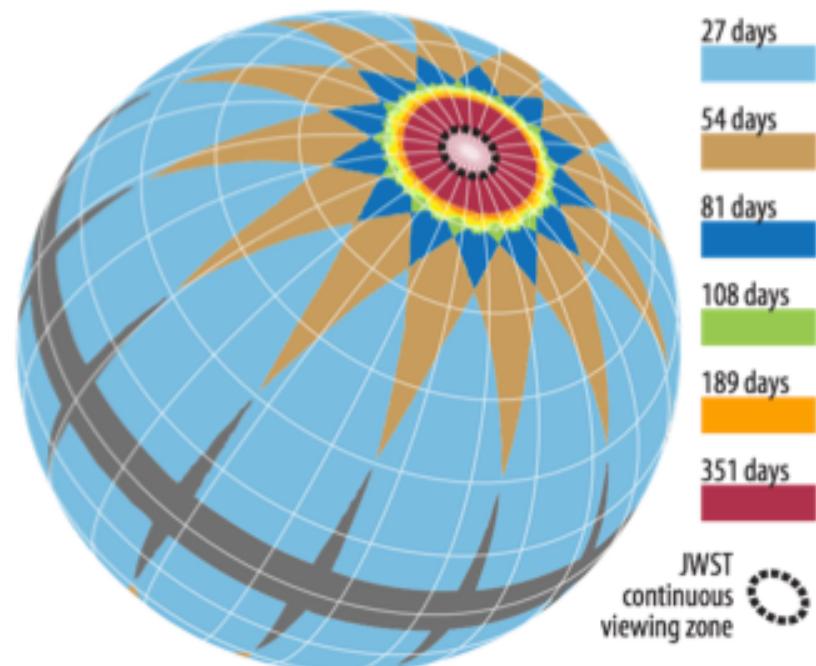
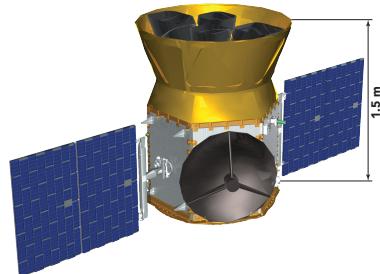
From real
survey, ½ along
the way: 21
planets as sure
detections





TESS follow-up

- The CARMENES survey will invest 50 nights in the follow-up of TESS M dwarf candidates
- This should allow the confirmation of some 30-40 transiting planet candidates
- It is an optimization of the sample → from a blind to a guided search
- Most targets will appear during the second year of the TESS survey (starting mid 2019)



Summary



- CARMENES regular operations since Jan 1, 2016 for a 5-year survey (750 n., 2016-2020)
- Both channels are online and acquiring data
- The CARMENES survey is revealing a treasure trove of extremely interesting planets
- Will discover a statistically-significant sample
- Besides planets, the CARMENES survey data is enabling the study of many other science cases (stellar properties, stellar activity, binarity, etc)