The CARMENES radial velocity instrument: performance and results

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Calar **A**lto
High-**R**esolution Search for
M Dwarfs with
Exo-Earths
With **N**ear-Infrared and Optical
Echelle **S**pectrographs

MAX-PLANCK-GESELLSCHAFT
Calar Alto
CSIC

The CARMENES instrument

- Single-purpose, high-stability instrument
- Wide wavelength coverage for discrimination against intrinsic variability

Visible channel

- Precision ~1 m/s
- 520-970 nm, R = 93,500, 2.5-pix sampling
- In vacuum, stabilized at ambient temperature
- 4kx4k CCD E2V
- U-Ne & U-Ar & Th-Ar lamps (+F-P etalon)

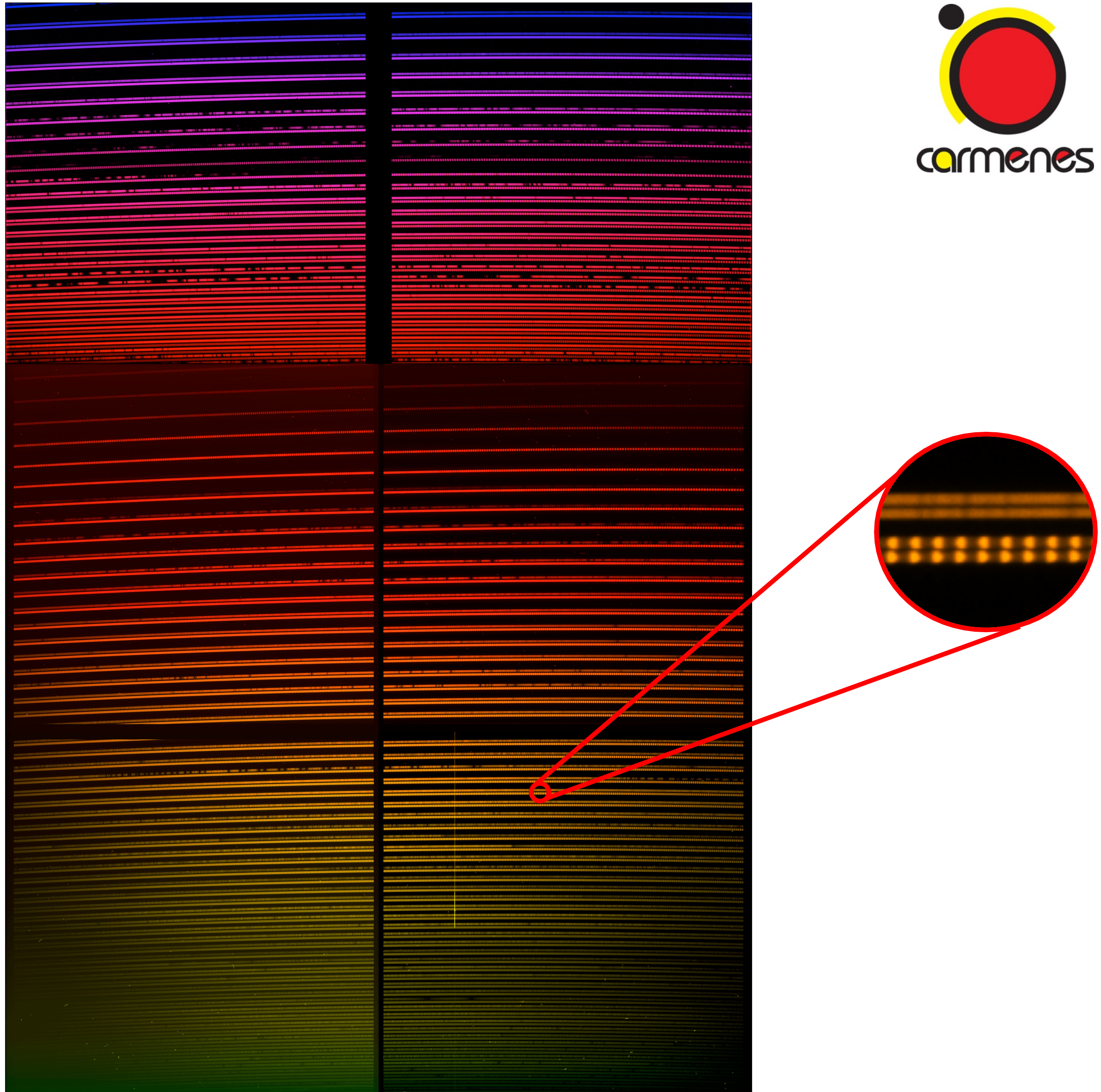
Near-Infrared channel

- Precision ~1 m/s
- 970-1710 nm, R = 80,400, 2.8-pix sampling
- In vacuum, stabilized at 140 K
- Mosaic 2 2kx2k Hawaii2RG 2.5 μm
- U-Ne lamp (+F-P etalon)

½ of λ coverage in far-red/NIR…

The CARMENES instrument

NIR 28 orders
0.97-1.71 µm



VIS 55 orders
0.52-0.97 µm

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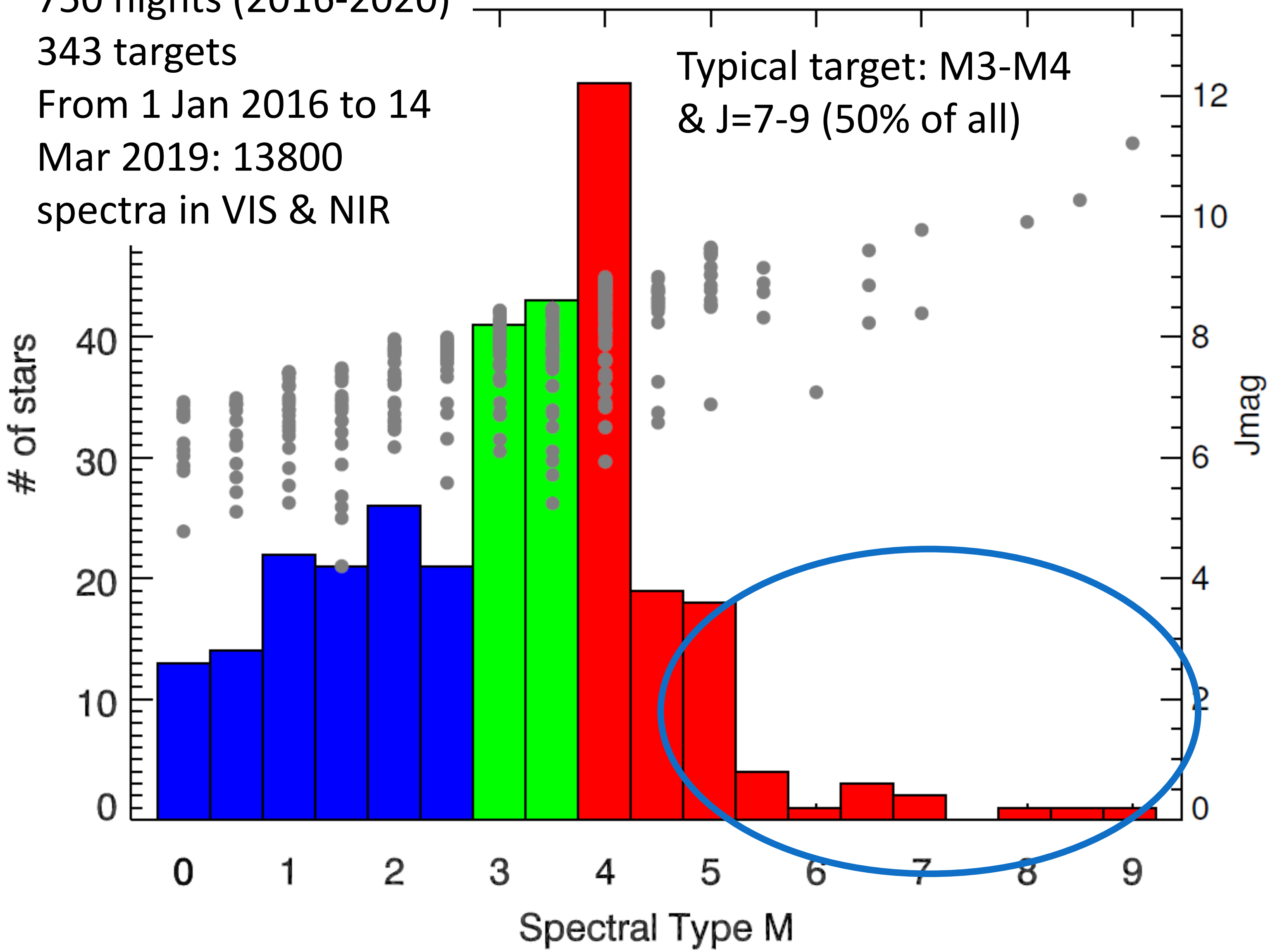
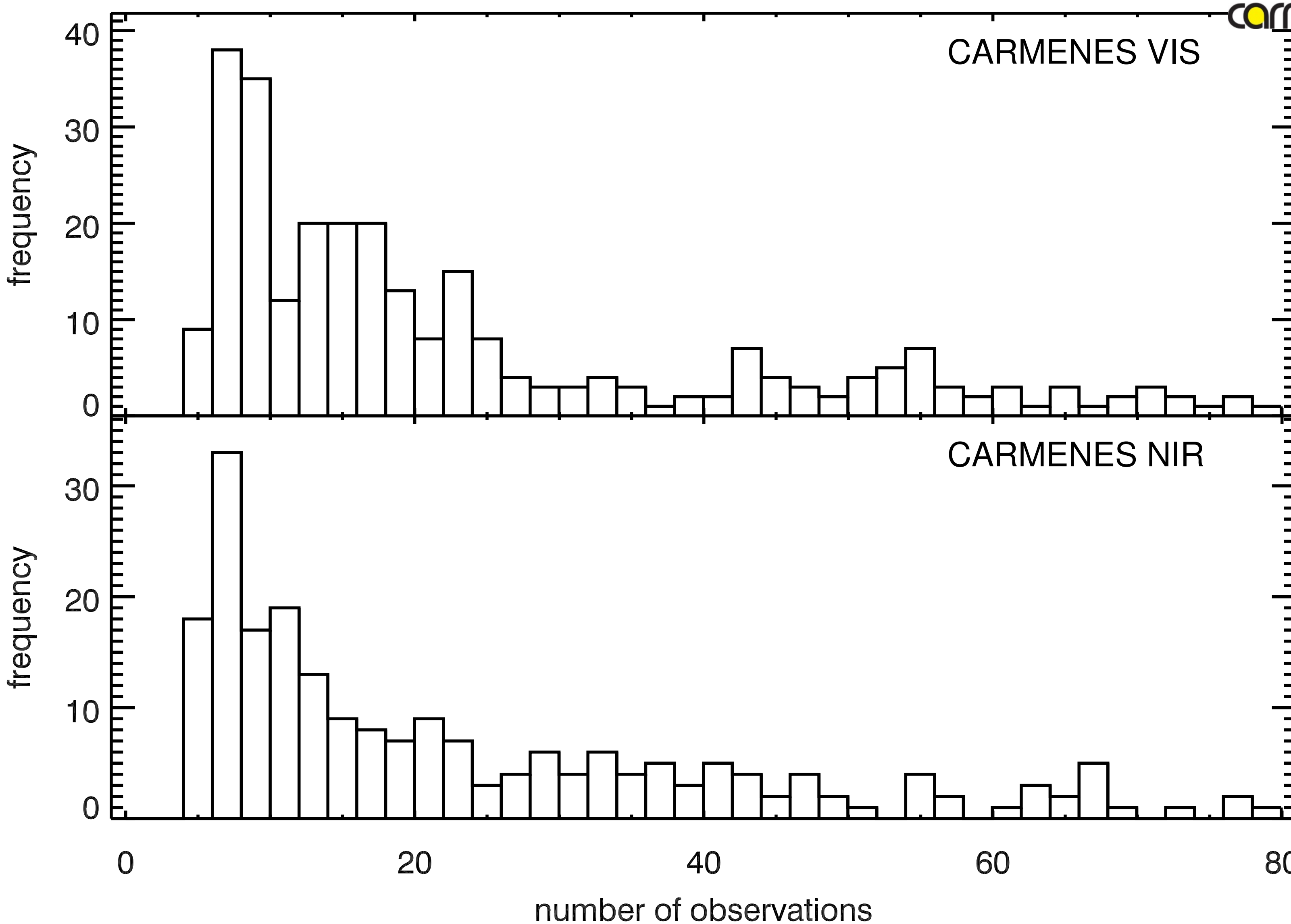
The CARMENES survey

- 750 nights (2016-2020)
- 343 targets
- From 1 Jan 2016 to 14 Mar 2019: 13800 spectra in VIS & NIR

<d> = 13 pc



The CARMENES survey

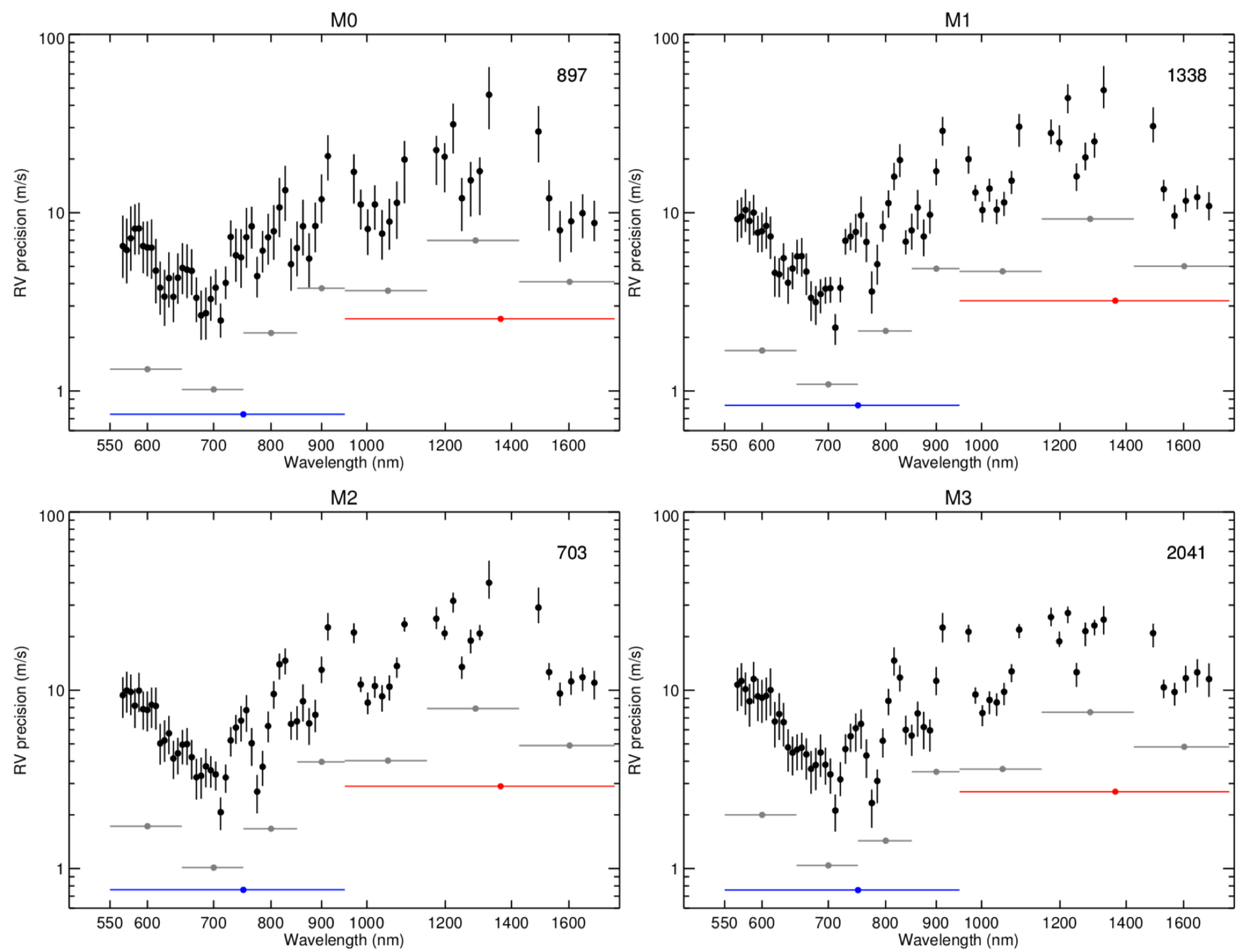


The CARMENES search for exoplanets around M dwarfs

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

A. Reiners[1,★], M. Zechmeister[1], J. A. Caballero[2,3], I. Ribas[4], J. C. Morales[4], S. V. Jeffers[1], P. Schöfer[1], L. Tal-Or[1], A. Quirrenbach[3], P. J. Amado[5], A. Kaminski[3], W. Seifert[3], M. Abril[5], J. Aceituno[6], F. J. Alonso-Floriano[8,12], …

Normalized to SNR150 @J



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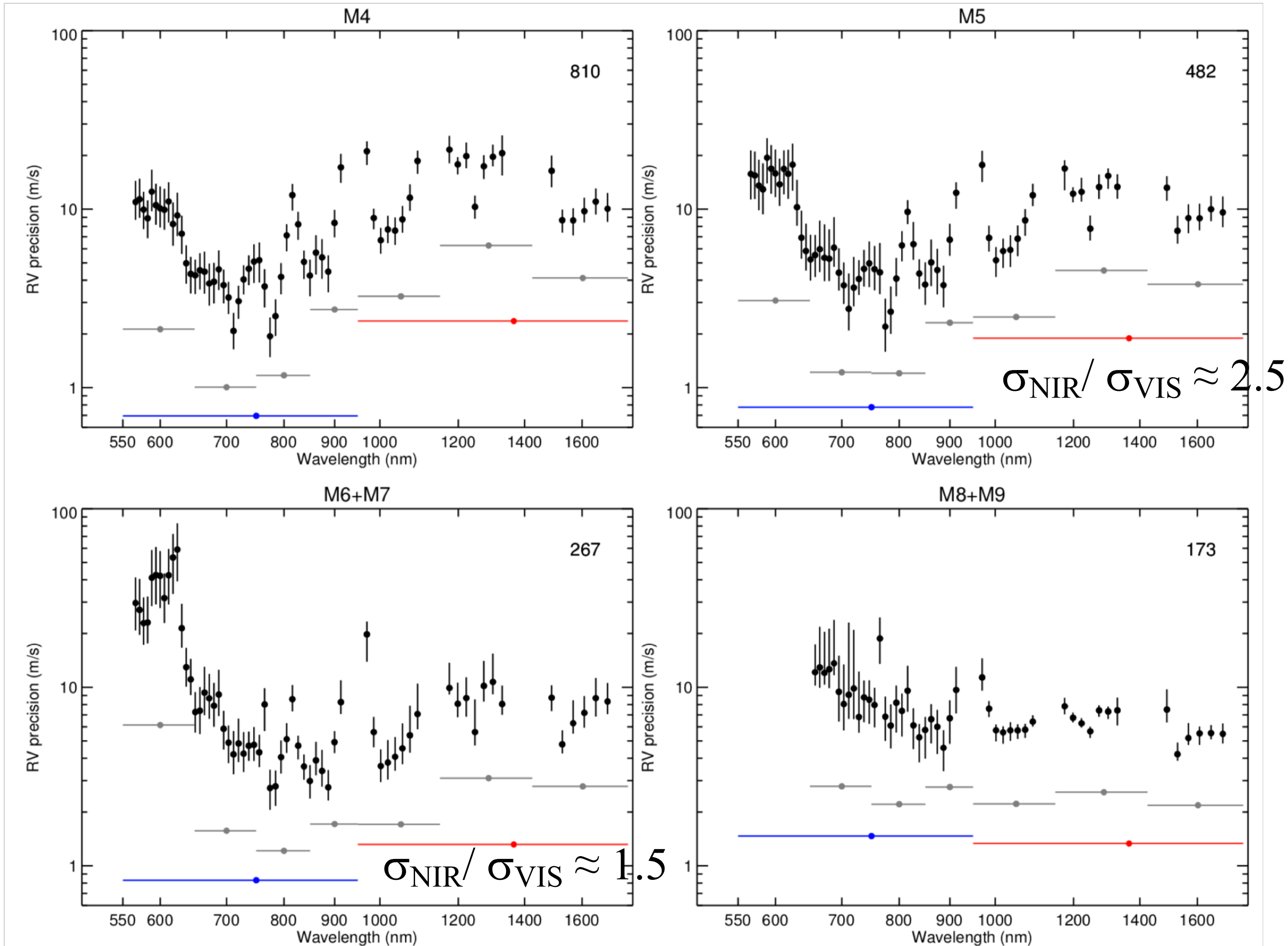
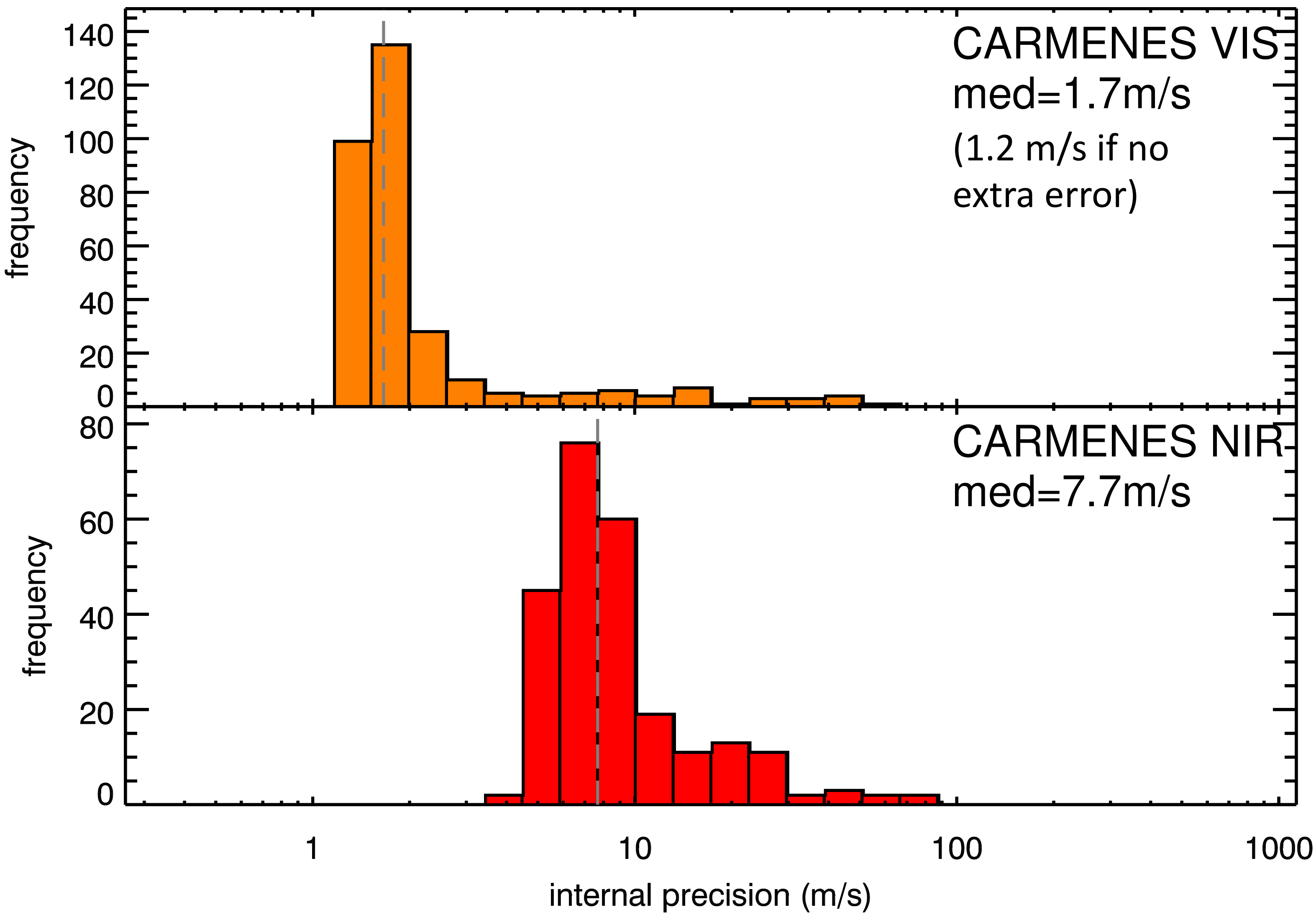
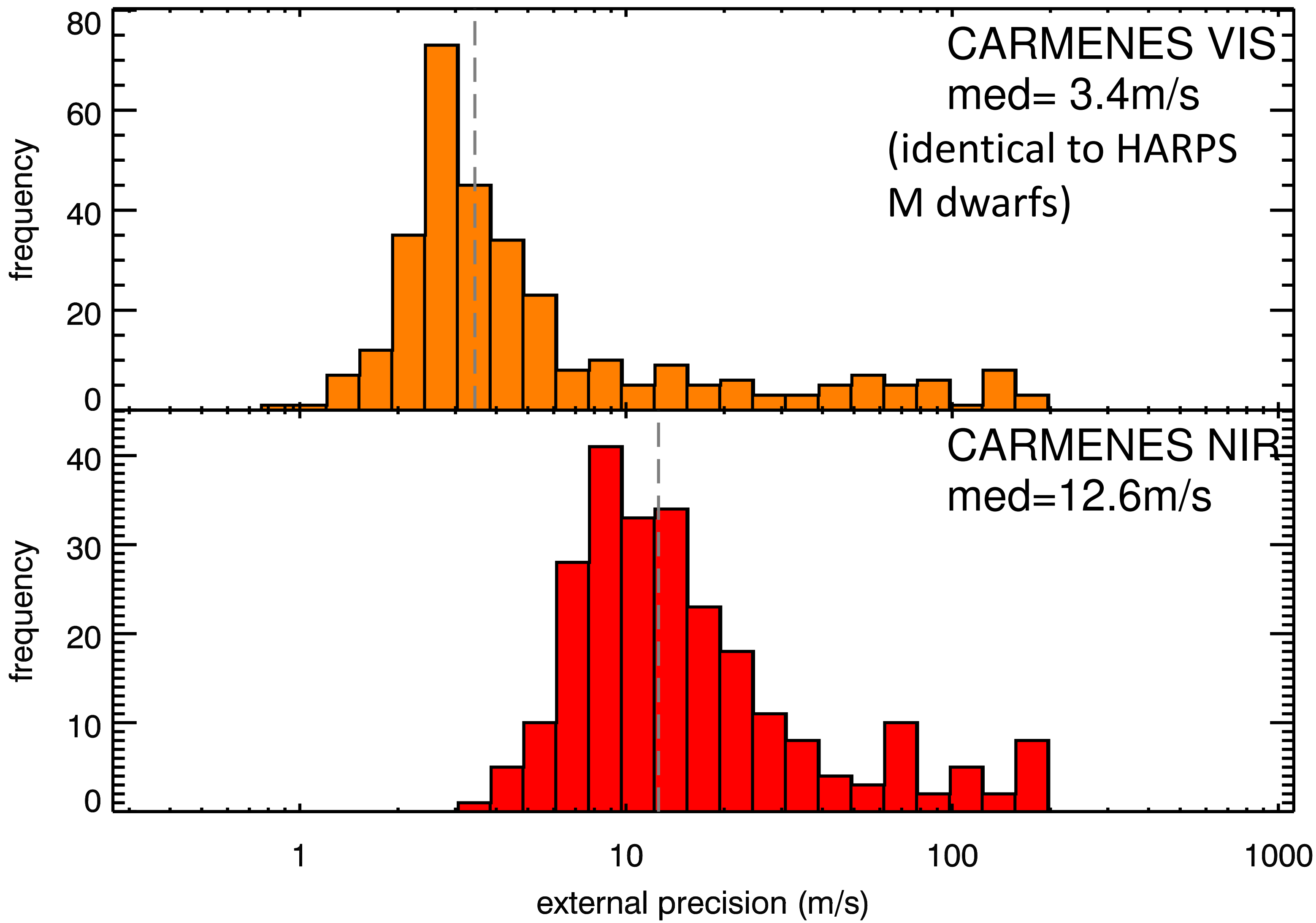


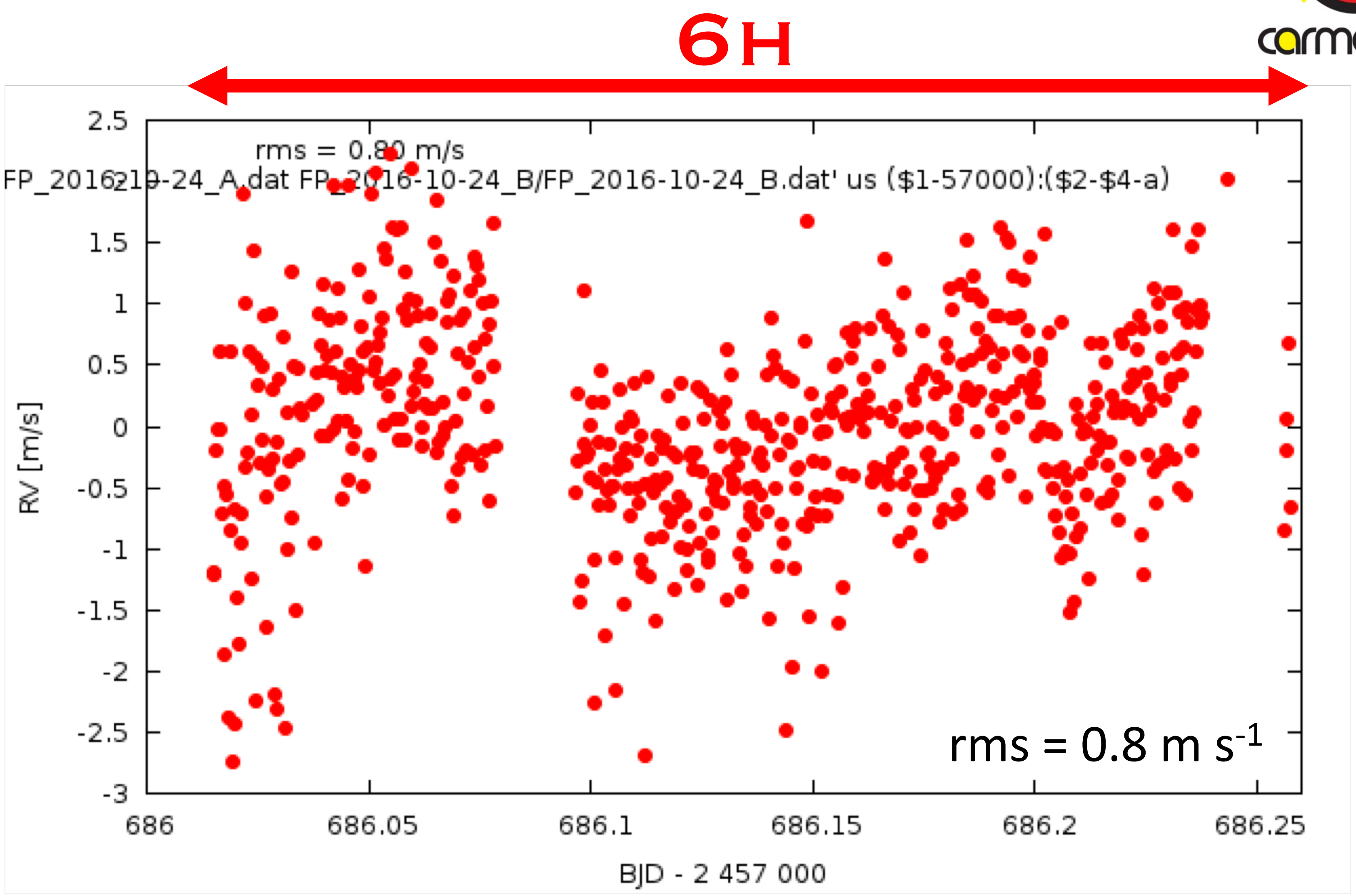
Internal precision



Measurement dispersion



CARMENES-NIR performance



Stability of ~m s^{-1} over short timescale demonstrated with FP light

FP light: fiber A – fiber B

CARMENES-NIR performance

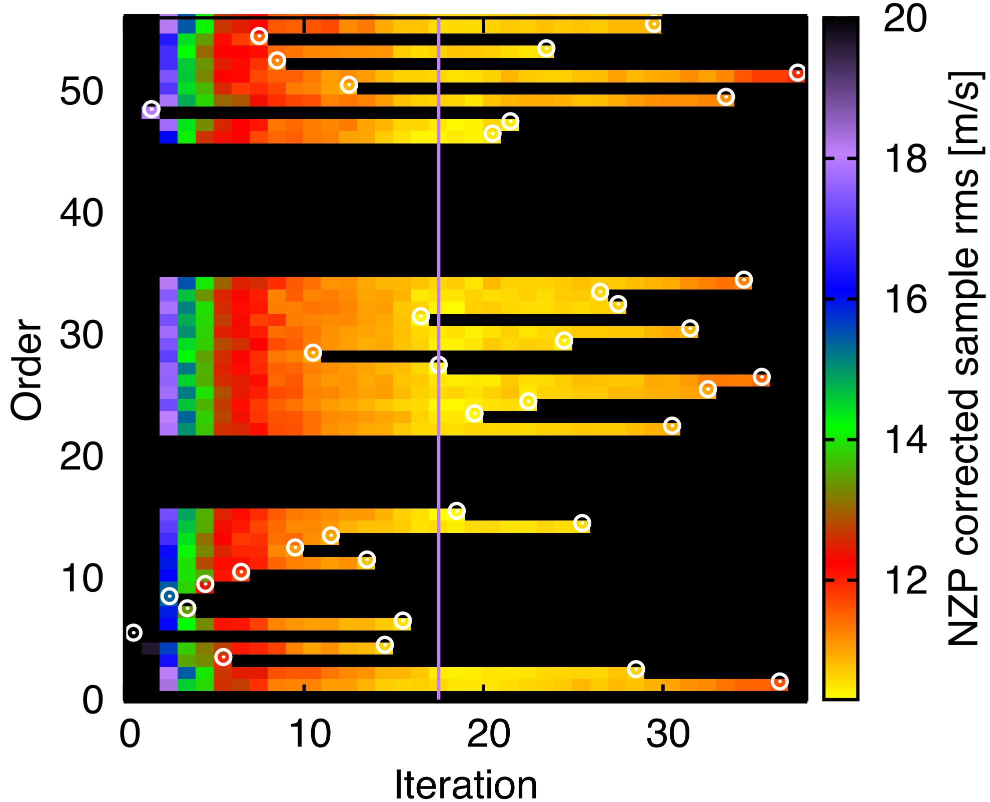
- The net amount of RV information is lower in the NIR for nearly all spectral types (this assumes a flat instrument response)
- Over long timescales (months, years), the thermo-mechanical stability of the instrument is not sufficient to yield a dispersion comparable to the internal error (+ stellar jitter). However:
  - ➢ There is room for improvement in the telluric correction
    - Right now, masking: Y & H ➞ $D_{telluric}$ > 4%; J ➞ $D_{telluric}$ > 2%; + emission
    - Masked pixels Y: 25.8%, J: 44.7% (!), H: 18.9% (+ gaps!)
  - ➢ Much less manpower from the CARMENES team has gone into the NIR channel instrument characterization compared with the VIS

Accurate RVs in the NIR

H

J

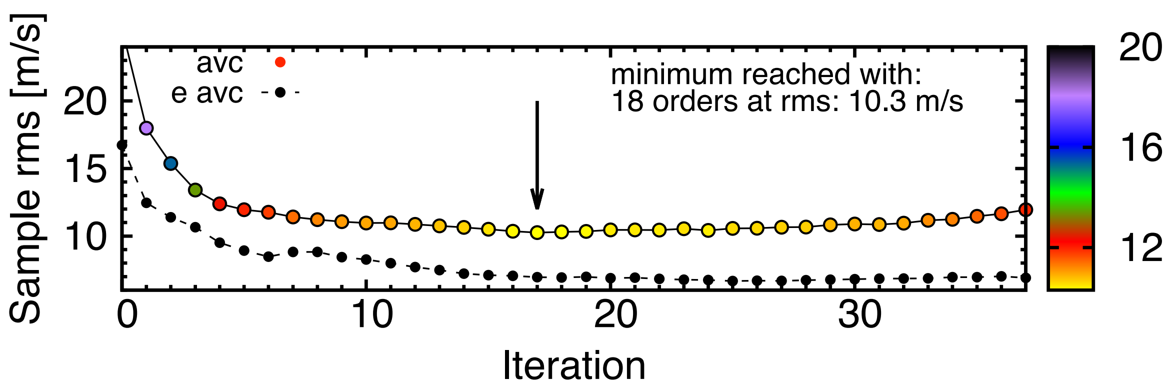
Y



H: Has RV content. One detector has many bad pixels & odd-even effect

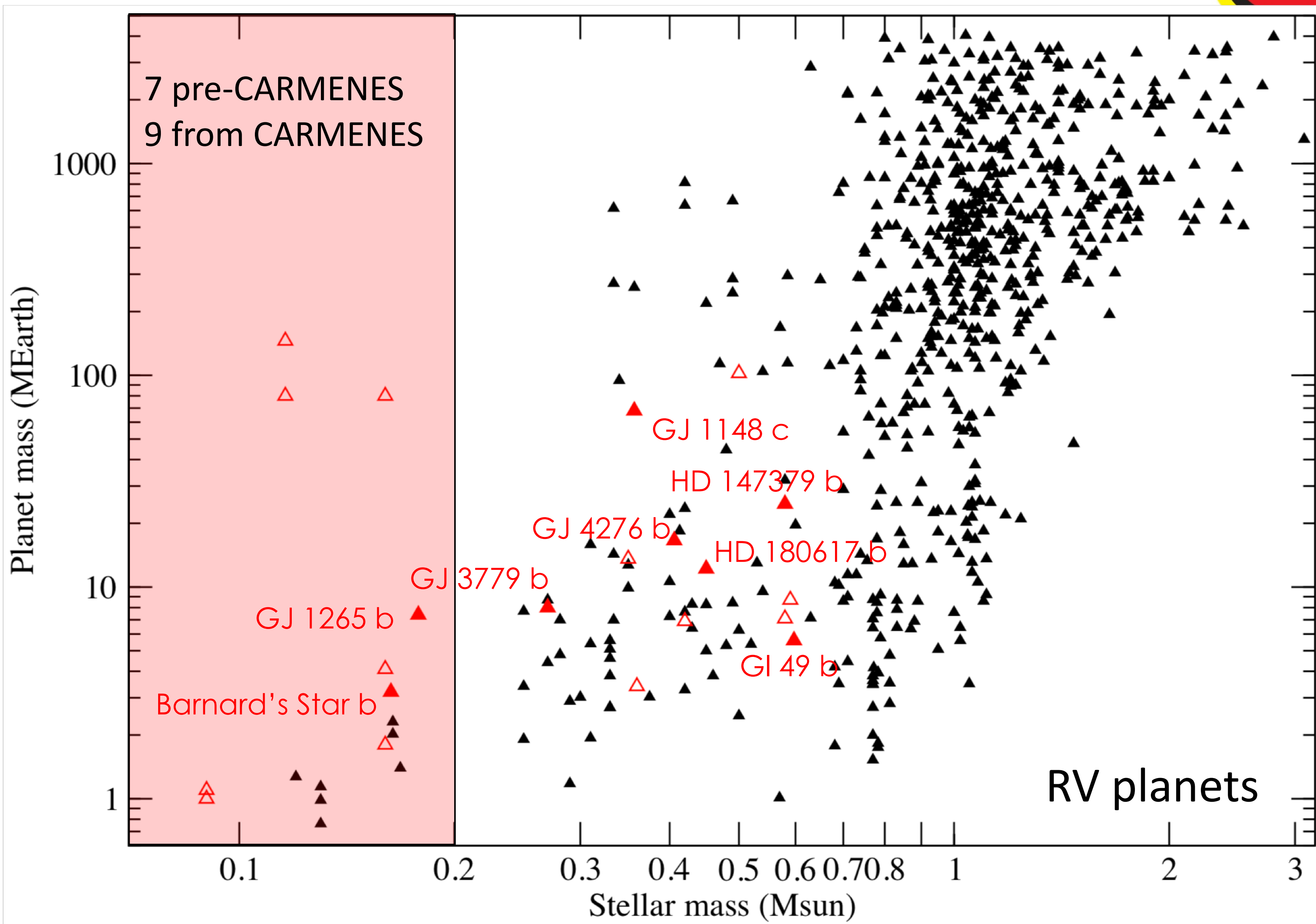
J: Low RV content & lots of tellurics

Y: Most RV content



19 of the half-orders used

CARMENES discoveries



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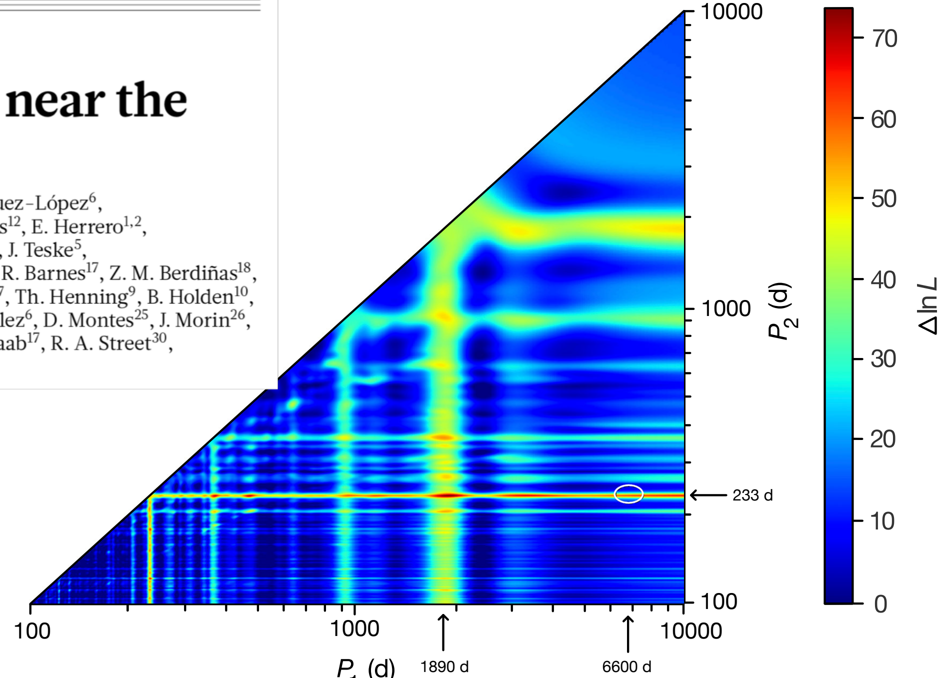
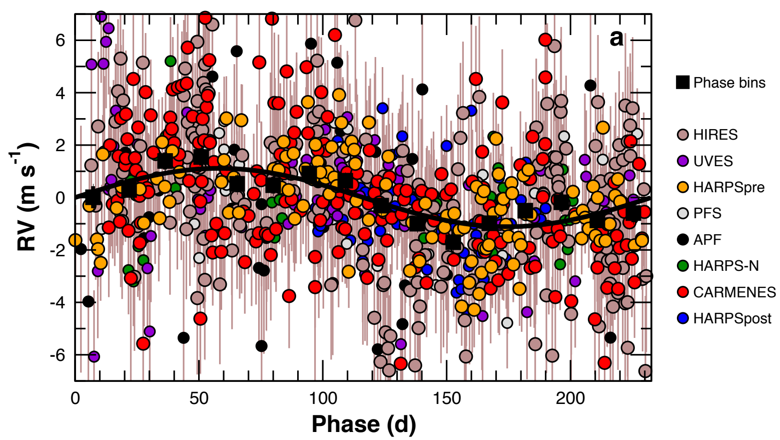
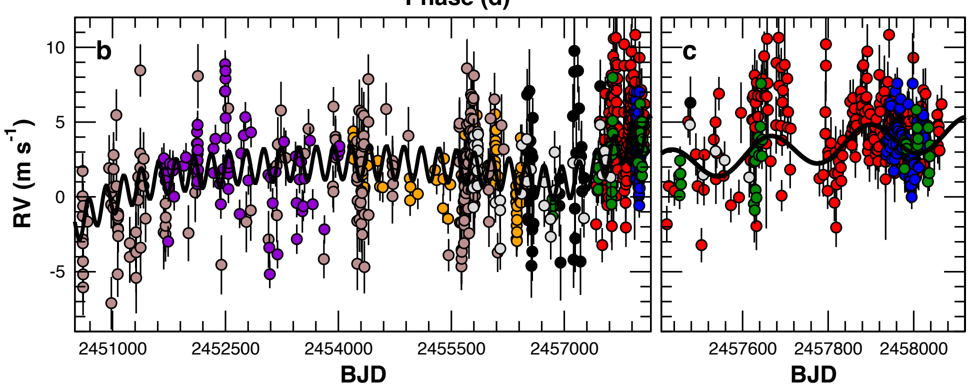
A candidate super-Earth planet orbiting near the snow line of Barnard's star

I. Ribas[1,2]*, M. Tuomi[3], A. Reiners[4], R. P. Butler[5], J. C. Morales[1,2], M. Perger[1,2], S. Dreizler[4], C. Rodríguez-López[6], J. I. González Hernández[7,8], A. Rosich[1,2], F. Feng[3], T. Trifonov[9], S. S. Vogt[10], J. A. Caballero[11], A. Hatzes[12], E. Herrero[1,2], S. V. Jeffers[4], M. Lafarga[1,2], F. Murgas[7,8], R. P. Nelson[13], E. Rodríguez[6], J. B. P. Strachan[13], L. Tal-Or[4,14], J. Teske[5], B. Toledo-Padrón[7,8], M. Zechmeister[4], A. Quirrenbach[15], P. J. Amado[6], M. Azzaro[16], V. J. S. Béjar[7,8], J. R. Barnes[17], Z. M. Berdiñas[18], J. Burt[19], G. Coleman[20], M. Cortés-Contreras[11], J. Crane[21], S. G. Engle[22], E. F. Guinan[22], C. A. Haswell[17], Th. Henning[9], B. Holden[10], J. Jenkins[18], H. R. A. Jones[3], A. Kaminski[15], M. Kiraga[23], M. Kürster[9], M. H. Lee[24], M. J. López-González[6], D. Montes[25], J. Morin[26], A. Ofir[27], E. Pallé[7,8], R. Rebolo[7,8,28], S. Reffert[15], A. Schweitzer[29], W. Seifert[15], S. A. Shectman[21], D. Staab[17], R. A. Street[30], A. Suárez Mascareño[7,31], Y. Tsapras[32], S. X. Wang[5] & G. Anglada-Escudé[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, $M\sin i$ ($M_\oplus$)	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, $\alpha\sin i$ (mas)	0.0133 ± 0.0013
Angular separation (mas)	221 ± 10

First cold super-Earth with a measured mass

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