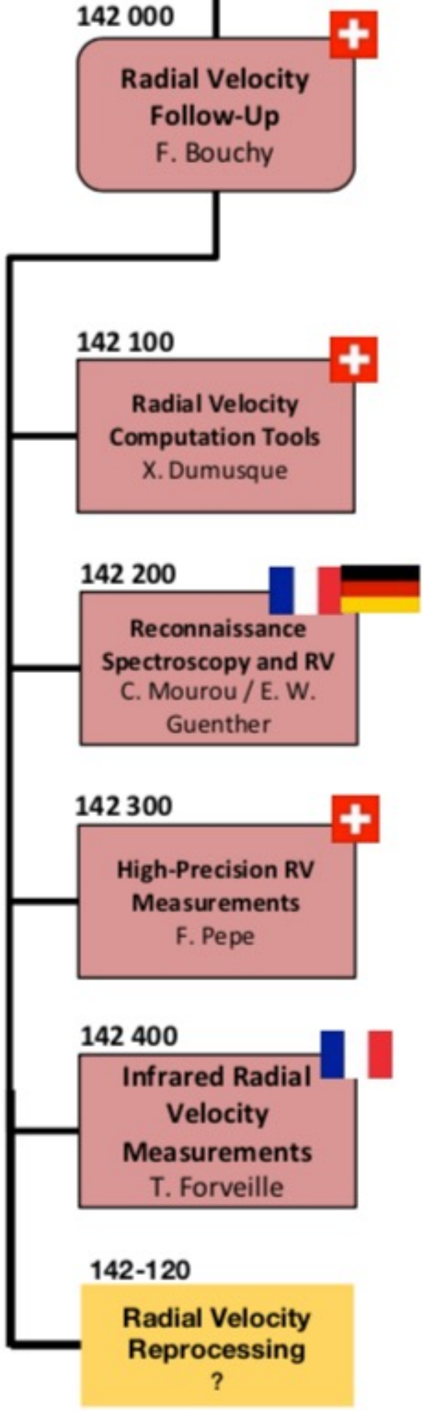
Radial Velocity requirements, benchmark and foreseen operation & coordination

F. Bouchy (Geneva) - WP142

7.11 PSM WP 142 000 DEV: Radial Velocity Follow-up



Radial Velocity Follow-up		**PSM WP 142 000**
Classification: Needed for SGS development and operations	**Development phase**	**07/2016 — 12/2026**
Leader: François Bouchy	**Institution:** Geneva University (Switzerland)	
Key Personnel: F. Bouchy; C. Moutou (LAM, France); S. Udry (Geneva); E. W. Guenther (TLS, Germany); D. Ségransan (Geneva); T. Forveille (IPAG, France); F. Pepe (Geneva)		
Objectives: Prepare and coordinate the activities of ground-based radial-velocity measurements of PLATO transit candidates to establish the nature of the transit events and to characterise the mass of the companion of the core science program from earth-like planets to brown-dwarfs.		
Tasks: 1) Identify and list all the existing and in-development RV facilities that will be in operation during the PLATO mission (2024-2030) with a significant amount of available time, competent teams, and efficient data reduction systems. Facilities will be ranked not as function of the telescope diameter but as a function of the RV uncertainties effectively obtained for a solar-type star of magnitude mv=11 in a 1h exposure. The uncertainty should include photon-noise and instrumental systematic error. 2) Prepare a list of benchmark observations to qualify the participating facilities. 3) If existing and in-development facilities are estimated to be not sufficient, define the strategy to build new facilities or/and upgrade existing ones.		

WP 142 100 - Radial Velocity Computation Tools (X. Dumusque)

Objectives:
Prepare and coordinate the activities of radial-velocity computations and global analysis tools to search for and characterise planetary systems

Tasks:
1) Definition of requirements for the deliverables of RV facilities (spectral format, SNR, resolution, RV precision)
2)Requirements for optimally computing the RV from extracted spectra (best techniques (CCF, template matching, line-by-line, PWRV, etc.) depending on type of stars (v.sin(I_{star}), spectral type, binarity, etc.)
3)Tools to mitigate at best instrumental and stellar signals in RV data and requirements for those (activity indexes, GPs, SCALPEL, YARARA)
~~4)Re-reduction of archival RV data (HARPS + HARPN + ESPRESSO)~~
5)Definition of requirements to calibrate the RV offset between different RV instruments (observation of RV standards, evaluate the effect of different resolution on planetary signal and stellar signal characterisation, to which RV precision this can be done).
6) Define tools allowing the combination of data of different nature (astrometric, photometric, spectroscopic) to optimise RV follow-up observations.

→ **Recent development in RV Extraction and analysis [Xavier Dumusque]**
→ **Modelling or mitigating stellar noise [Luca Malavolta]**

WP 142 200 – Reconnaissance spectroscopy and radial velocity (E. Guenther / C. Moutou)

Objectives:
Prepare and coordinate the activities of the first radial velocity screening at low precision and the mass determination of hot-Jupiters and brown-dwarfs for PLATO with RV facilities like ES@TLS (2m), FIES@NOT (2.5m), HERMES@Mercator (1.2m), and CAFE@CalarAlto (2.2m)

Tasks:
1) Define an efficient screening strategy using low-precision RV measurements (10-30 m/s) in order to optimise the RV-follow-up observations.
2) Define the appropriate criteria to stop, or to continue RV-measurements.
3) Define and develop tools to estimate from these first low-precision RV-measurements to the expected RV-accuracy that will be obtained with instruments of higher precision in order to optimise the follow-up strategy.
4) Define the optimum strategy in order to distinguish giant planets from brown dwarfs and binaries with the minimum number of RV-measurements.

→ **Existing facilities + Recon spectroscopy [Eike Günther]**

WP 142 300 - High-Precision RV Measurements (F. Pepe)

Objectives:
Prepare and coordinate the activities of high-precision radial-velocity measurements of PLATO candidates around quiet stars to measure the mass of Earth and super-Earth like planets with spectrographs like HARPS@ESO (3.6m), HARPS-N@TNG (3.6m), and ESPRESSO@ESO (8.2m)

Tasks:
1) Define the best strategy of very high-precision RV follow-up (≤1 m/s) to measure the mass of Earth and super-Earths out to the habitable zone of quiet stars.
2) Define the appropriate criteria to stop, or to continue very high-precision RV-measurements.
3) Specify the needs for follow-up observations with very high precision
4) Assess the status, performance and availability of telescope and instruments
5) Define and develop tools to select most appropriate quiet stars with a transiting companion in the domain of telluric planet

→ **Recent development in RV technics + new instruments [Francesco Pepe]**

WP 142 400 – Near-Infrared Radial Velocity Measurements (T. Forveille)

Objectives:

Prepare and coordinate the activities of ground-based radial-velocity measurements of PLATO transit candidates using infra-red spectrographs like SPIROU@CFHT (3.6m), CARMENES@CalarAlto (3.5m), CRIRES@ESO (8.2m), NAHUAL@GTC (10m), and GIANO@TNG (3.6m)

Tasks:

1) Establish which type of stars are best observed with IR spectrograph: M dwarfs (brighter in the IR), active stars (which systematic error are lower in the IR), etc.
2) Assess the status, performance and availability of telescope and instruments
3) Define the best use and strategy of IR spectrograph for the RV follow-up screening and mass determination

WP 142 500 ``RV reprocessing & Homogenization" L. Malavolta (TBC)

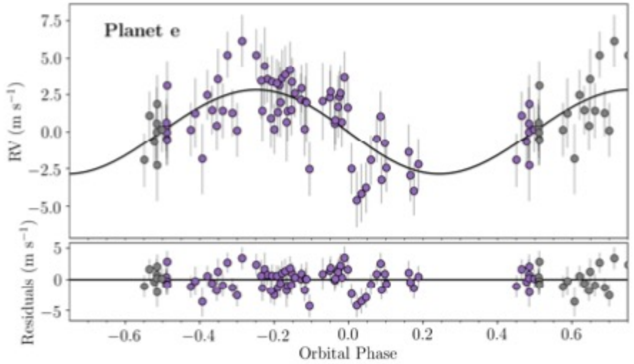
Identification of available archival data
Tests of re-processing on archival data
Homogenization of stellar activity index re-processing
Re-processed data access to PFU Data Base

Requirements for the RV facilities

- A maintained telescope and instrumentation over the mission duration,
- A significant number of available nights per years,
- High flexibility and reactivity in the scheduling
- An identified technical and scientific team in charge of the instrument, the operations and observations,
- A data reduction software providing in almost real time reduced data
- A demonstration of performances on real cases (e.g. Kepler, K2 or TESS)

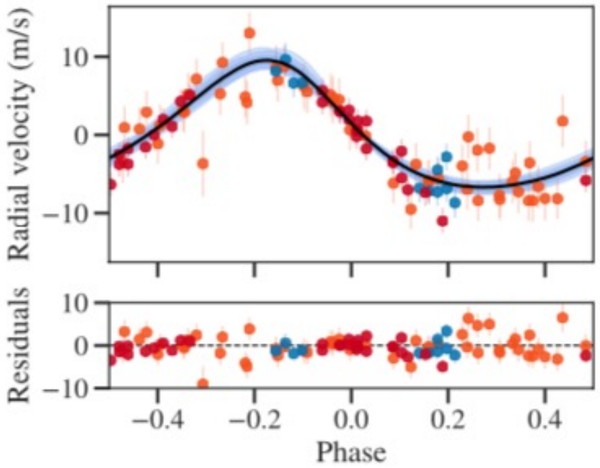
TOI-561 e - Lacedelli et al. 2020

V= 10.2 82 HARPS-N data
P= 77.2 days
Rp= 2.67 Re
K= 2.84 ± 0.41 m/s
Mp= 16.0 ± 2.3 Me



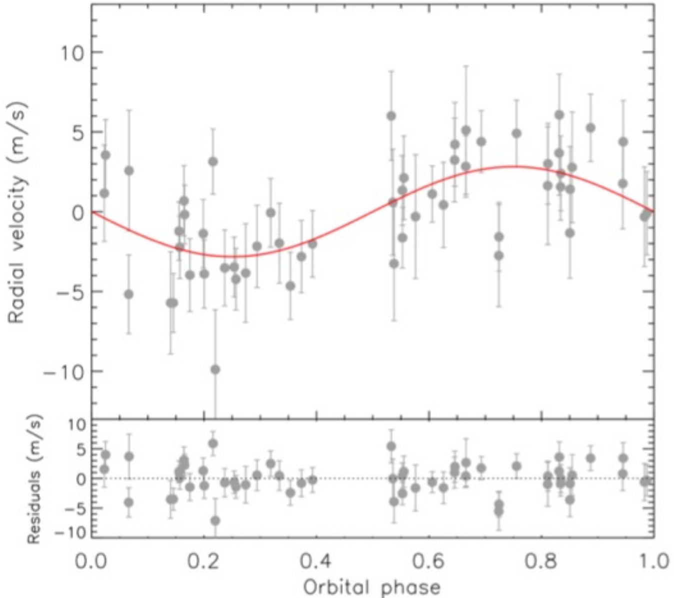
HD95338b - Diaz et al. 2020

V= 8.6 HARPS + PFS1/2
P= 55.1 days
Rp= 3.89 Re
K= 8.17 ± 0.40 m/s
Mp = 42.4 ± 2.2 Me



K2-263b - Mortier et al. 2018

V= 11.6 67 HARPS-N data
P= 50.8 days
Rp= 2.41 Re
K = 2.82 ± 0.58 m/s
Mp= 14.8 ± 3.1 Me



→ **Small-planets at long period : A test case for PLATO, HIP 41378 [Alexandre Santerne]**

→ **Lessons learned from RV FU of long-period Kepler and TESS small-size candidates [Nolan Grieves]**

Kepler-51b,c,d Masuda 2014 Hadden & Lithwick 2017

Masses from TTVs

Kepler-51c Kp= 14.7

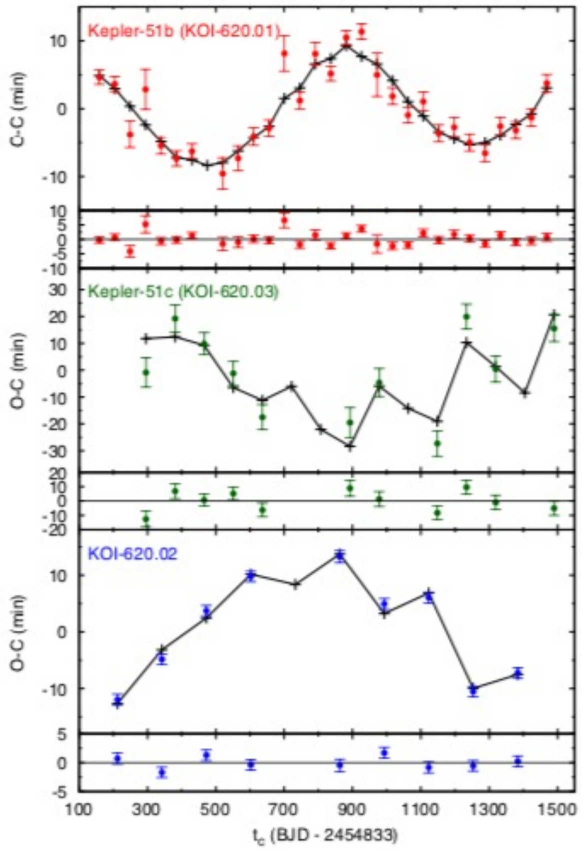
P= 85.3d

Mp= 3.9 ± 0.8 Me

Kepler-51d

P= 130.2d

Mp= 6.2 ± 1.6 Me



Kepler-87b,c Ofir et al. 2014

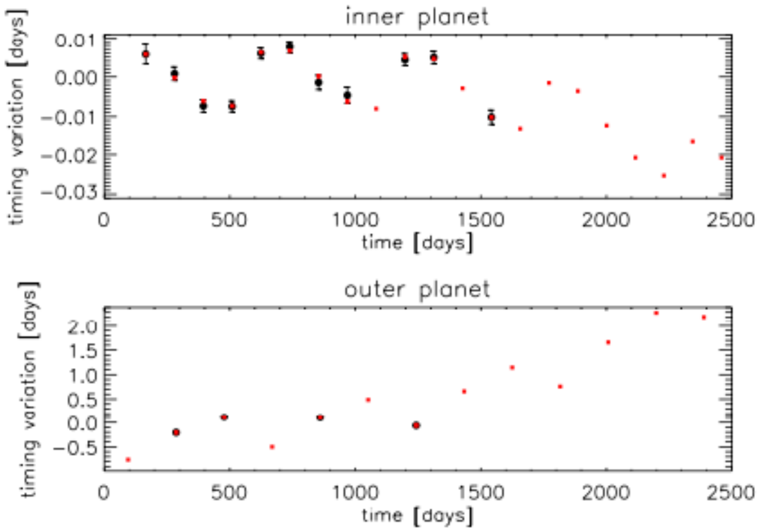
Masses from TTVs

Kepler-87c

P= 191d

Rp= 6.14 Re

Mp= 6.4 ± 0.8 Me



→ **Combining TTVs and RV for mass determination [Dan Fabrycky]**

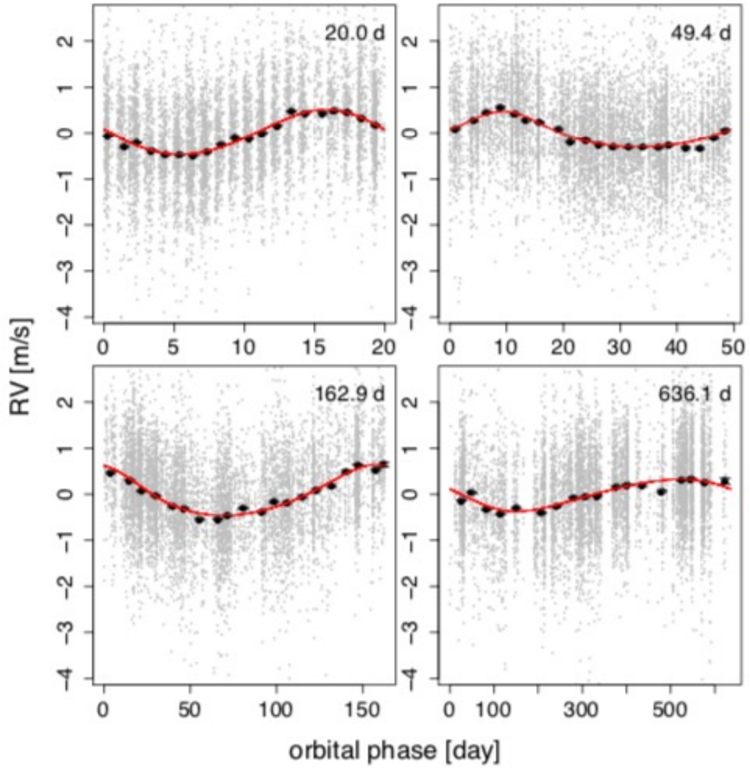
Tau Ceti - Feng et al. 2017

Not transiting

V=3.5

HARPS (x9000) + HIRES@Keck

P=	20.0	49.4	**162.9**	**636.1**	**days**
K=	0.49	0.39	0.55	0.35	m/s
Msini=	1.75	1.83	3.93	3.93	Me



GJ514b - Damasso et al. 2022

Not transiting

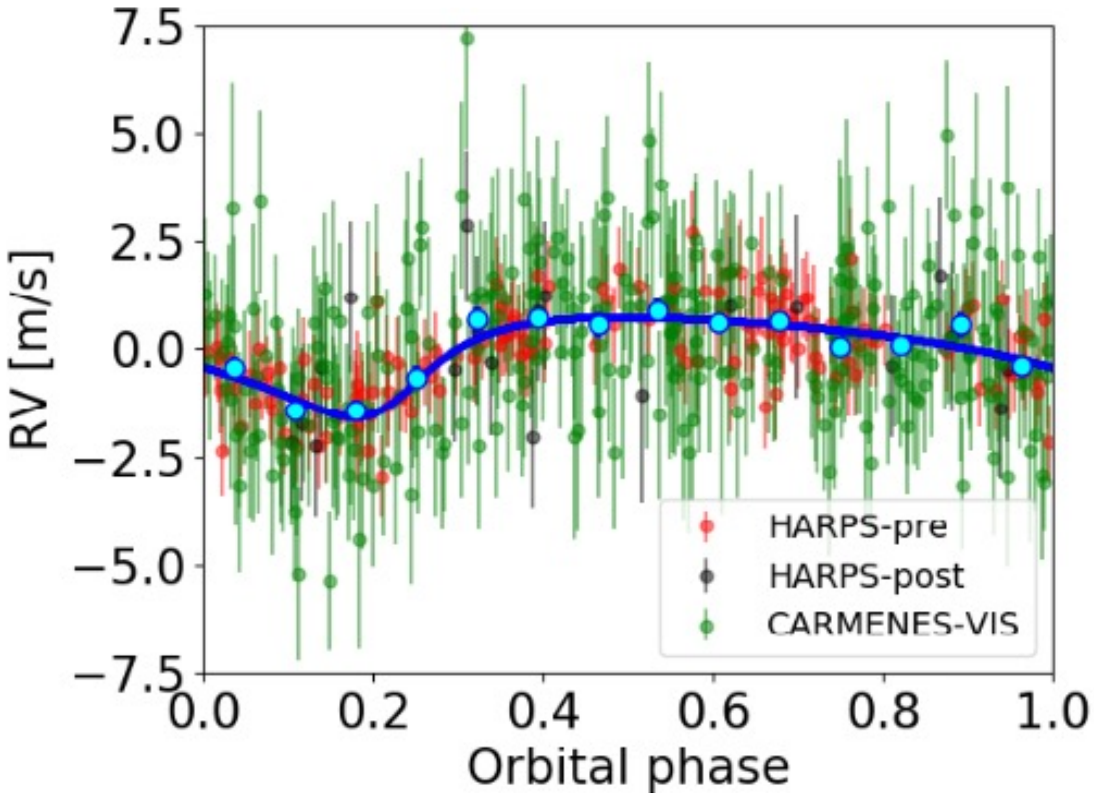
V=9.0

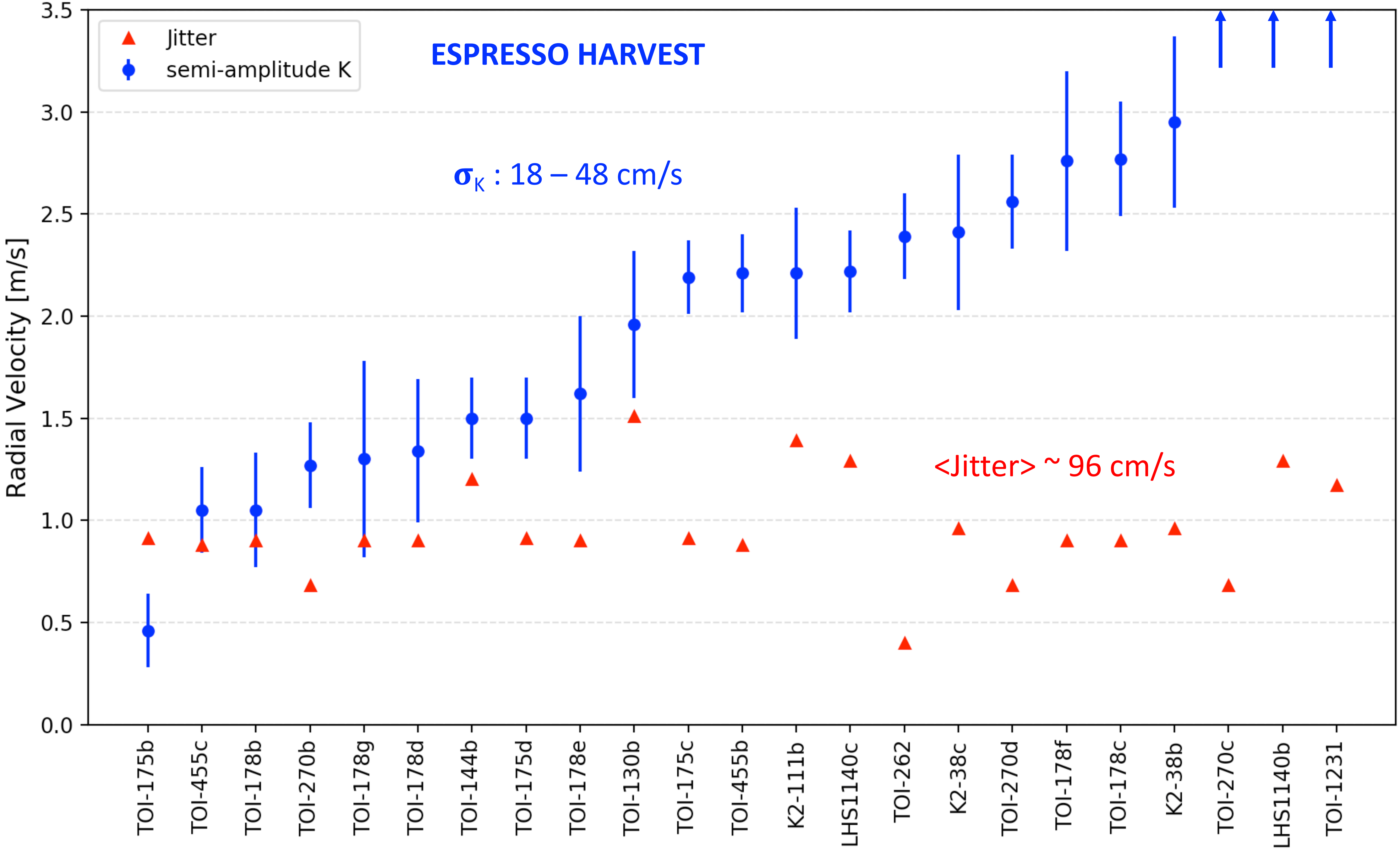
HIRES x104 HARPS x162 CARMENES-VIS x274

P= 140.4 days

K= 1.15 ± 0.20 m/s

Msini= 5.2 ± 0.9 Me





ESPRESSO HARVEST
Jitter
semi-amplitude K
σK : 18 – 48 cm/s
<Jitter> ~ 96 cm/s
Radial Velocity [m/s]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
TOI-175b
TOI-455c
TOI-178b
TOI-270b
TOI-178g
TOI-178d
TOI-144b
TOI-175d
TOI-178e
TOI-130b
TOI-175c
TOI-455b
K2-111b
LHS1140c
TOI-262
K2-38c
TOI-270d
TOI-178f
TOI-178c
K2-38b
TOI-270c
LHS1140b
TOI-1231

Main providers of precise masses

Radial Velocity Facilities

Facilities will be ranked not as function of the telescope diameter but as a function of the RV uncertainties effectively obtained for a solar-type star of magnitude mv=11 in a 1h exposure. The uncertainty should include photon-noise and instrumental systematic error.

https://docs.google.com/spreadsheets/d/1MY3GmuZhfyTFuCUCYwgCIVQQ_bQD2IHKDZkFncHGZ24/edit?usp=sharing

https://docs.google.com/spreadsheets/d/1MY3GmuZhfyTFuCUCYwgCIVQQ_bQD2IHKDZkFncHGZ24/edit#gid=0

Instrument name	Web page	Status (Existing / Project / In Dev)	Instrument PI	Starting Date of operation	Location (Observatory + Coordinates)	Telescope/Observatory Director	Telescope Diameter (m)	Median seeing (arcsec)	Expected Nb of nights/year for PLATO FU	Time Allocation (TAC / GTO)	Local contact person (support astronomer)
SOPHIE	obs-hp.fr	Existing	I. Boisse	2006	OHP/+45°	A. Le Van Suu	2	2		TAC	I. Boisse
TLS-Echelle (TC	tls-tautenburg.de	Existing	E.W.Guenther	1996	TLS/+51°	A.P. Hatzes/M. F	2	2	40	GTO	E.W.Guenther
CAFE		Existing									
CARMENES		Existing									
ESPRESSO		Existing									
CORALIE		Existing									
FEROS											
SPIROU	spirou.irap.omp.(	Existing	JF Donati	2018	MK/+20°	JG Cuby	3.6	0.65		TAC	L. Arnold
NIRPS											
Neo-Narval		in dev	T. Boehm	2020	TBL/+45°	A. Lopez	2			TAC	Ph. Mathias
SPIP		in dev	JF Donati								
CRIRES+		Existing									

Instrument name	Demonstrated RV systematic limitation (m/s)	Photon-noise uncertainties on a V=11 G2 star for 1h exposure (m/s)	Spectral resolution	Spectral Domain (nm)	Fiber/Slit acceptance (arcsec)	References for instrument description	References for RV FU	Reduction pipeline and Data products
SOPHIE			75000/40000	387-694	3			
TLS-Echelle (TC	46 m/s, 9.3 mag	60 m/s	65000	462-734 (VIS)	1.2		Kabath+ 2021	Viper
CAFE								
CARMENES								
ESPRESSO								
CORALIE								
FEROS								
SPIROU			70000	980-2450	1.3	Donati+ 2020 MNRAS		APERO
NIRPS								
Neo-Narval								
SPIP			70000	980-2450				
CRIRES+								

→ **Existing facilities**
+ Recon spectroscopy
[Eike Günther]

List of the GOP products for RVs

Name	Description	Dimension	Type	Unit
VRAD	Radial velocity value	1D	DOUBLE	[m/s]
VRAD_INF	Radial velocity inferior uncertainty	1D	DOUBLE	[m/s]
VRAD_SUP	Radial velocity superior uncertainty	1D	DOUBLE	[m/s]
BJD	Barycentric Julian Time	1D	DOUBLE	[Julian date
BISS	CCF Bissector value	1D	FLOAT	[m/s]
BISS_ERROR	CCF Bissector error	1D	FLOAT	[m/s]
FWHM	CCF FWHM value	1D	FLOAT	[m/s]
FWHM_ERROR	CCF FWHM error	1D	FLOAT	[m/s]
CCF_CONTRAST	Contrast of the CCF	1D	FLOAT	[-]
Log_RHK	Chromospheric index from CaII H&K lines	1D	FLOAT	[-]
Log_RHK_ERR	Chromospheric index from CaII H&K lines error	1D	FLOAT	[-]
HALPHA_INDEX	Equivalent width of the Hα line	1D	FLOAT	[-]
HALPHA_ERROR	Equivalent width of the Hα line uncertainty	1D	FLOAT	[-]
HELIUM_INDEX	Equivalent width of the He I λ1083 nm	1D	FLOAT	[-]
HELIUM_INDEX_ERROR	Equivalent width of the He I λ1083 nm error	1D	FLOAT	[-]
RM_FLAG	Flag whether the data were acquired during a transit	1D	INT	[-]
BERV	Barycentric Earth RV	1D	FLOAT	[m/s]
DRS_QC(*)	Data Reduction Quality Control	1D	INT	[-]

Name	Description	Dimension	Type	Unit
PLATO ID	PLATO ID of the target	0D	CHAR	
STAR NAME	Star Name from a given catalogue. Valuable in case the target is a binary	OD	CHAR	
PRODUCT_ID	ID of the PFU product	0D	UINT64	[-]
INSTRUMENT	Spectrometer used to acquire the spectrum	0D	CHAR	[-]
RESOLUTION	Spectral resolution	0D	FLOAT	[-]
REDUCTION_PIPELINE	Reduction pipeline used to issue the data (including version)	0D	CHAR	[-]
UPLOAD DATE		0D	DOUBLE	Julian date
PROCESSING DATE		0D	DOUBLE	Julian date
FIBER_ACC	Fiber/Slit acceptance	0D	DOUBLE	[arcsec]

(*) color correction, drift correction, saturation, ….

Benchmark of RV observations to qualify RV facilities

Most high-precision RV instruments already engaged on Kepler, K2 and TESS Follow-Up
→ Check published performances on mass characterization of transiting planets
→ Download/Access reduced data for End-to-End tests including Lg data

Foreseen organization / operations

- Lessons learned from TESS/TFOP → Sam Quinn

- Guided and coordinate approach → Ignasi Ribas

  Matching targets and adequate facilities + Minimize number of used facilities per targets

- Daily updated of PFU database with predefined deliverables and QC

- Telescope time-share to optimize visibility, sampling, and flexibility (like on 3.6m)

- Huge number of RV measurements is foreseen

  Main precise mass providers must be heavily engaged
  Maintain and guarantee long-term performances of existing facilities
  contribution to operation costs ?

- Precise masses may come from combination of RVs + TTVs → Dan Fabrycky

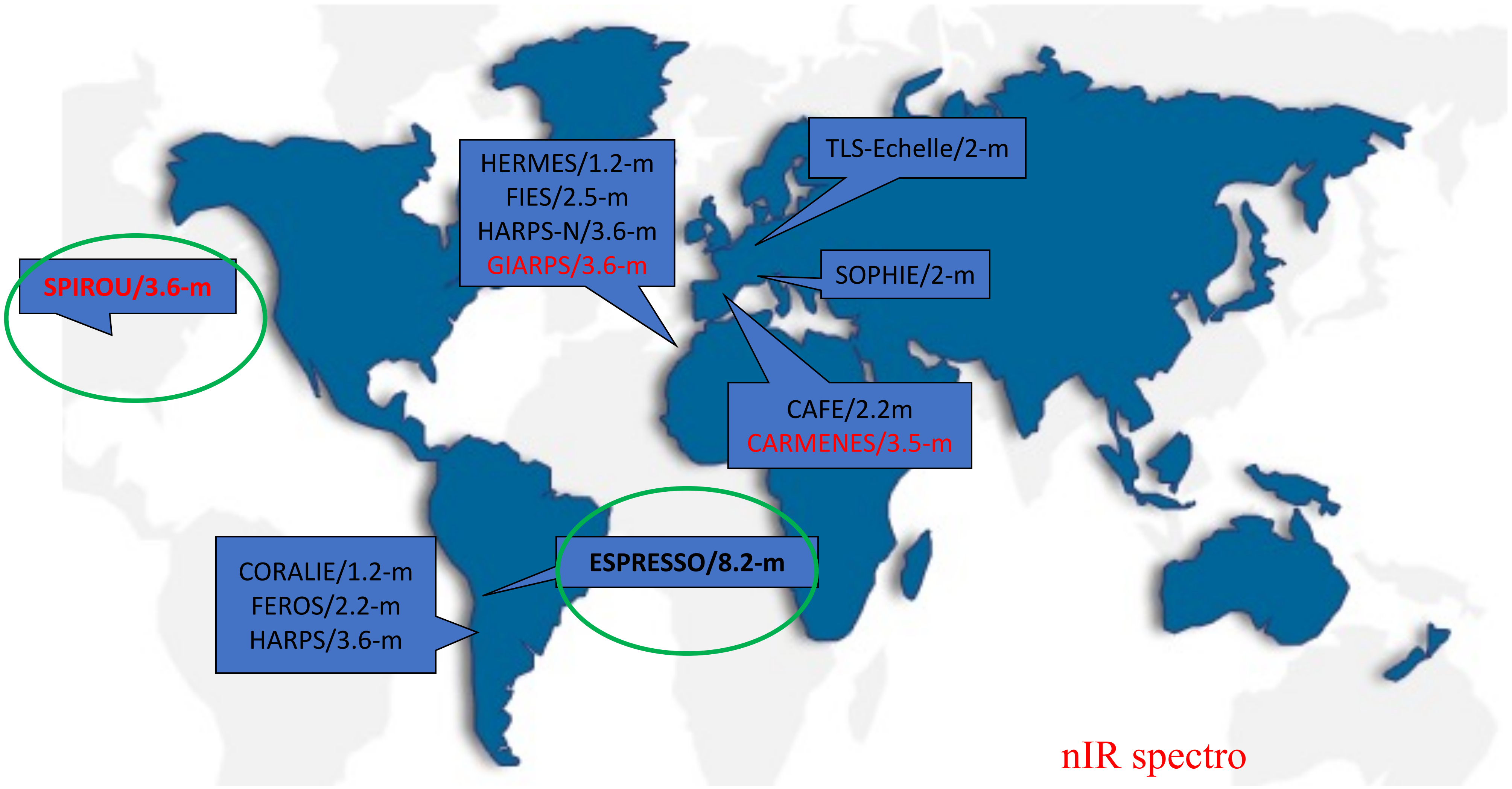
Radial Velocity instruments, requirements and operations

1. RV instrument requirements, Benchmark and foreseen operation & coordination [**François Bouchy**]
2. Recent development in RV technics + new instruments [**Francesco Pepe**]
3. Existing facilities + Recon spectroscopy [**Eike Günther**]
4. Combining TTVs and RV for mass determination [Dan Fabrycky]

Radial velocity extraction & analysis

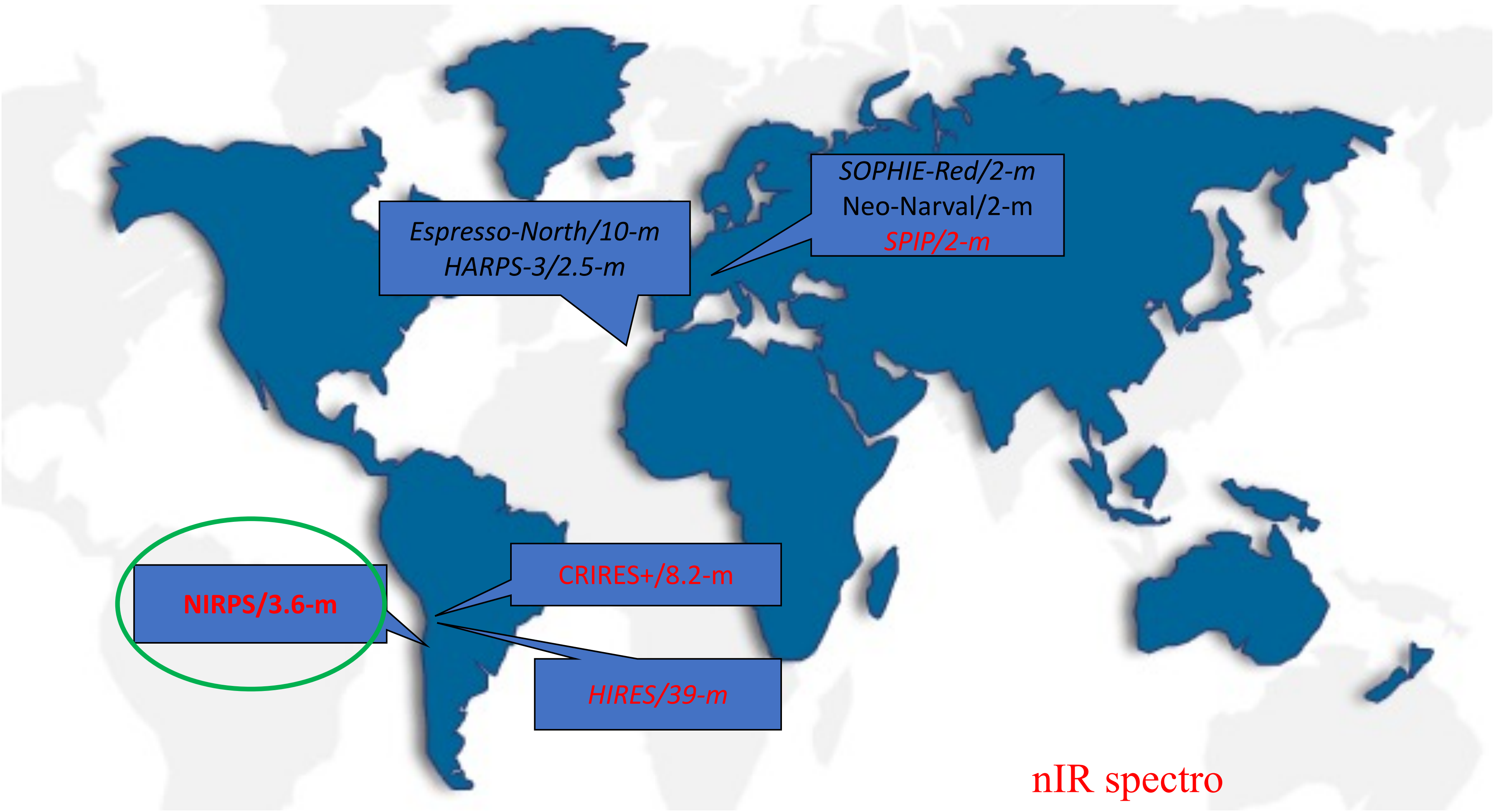
1. Small-planets at long period : A test case for PLATO, HIP 41378 [**Alexandre Santerne**]
2. Lessons learned from RV FU of long-period Kepler and TESS small-size candidates [**Nolan Grieves**]
3. Recent development in RV Extraction and analysis **[Xavier Dumusque]**
4. Modelling or mitigating stellar noise [**Luca Malavolta**]

European RV facilities in operation



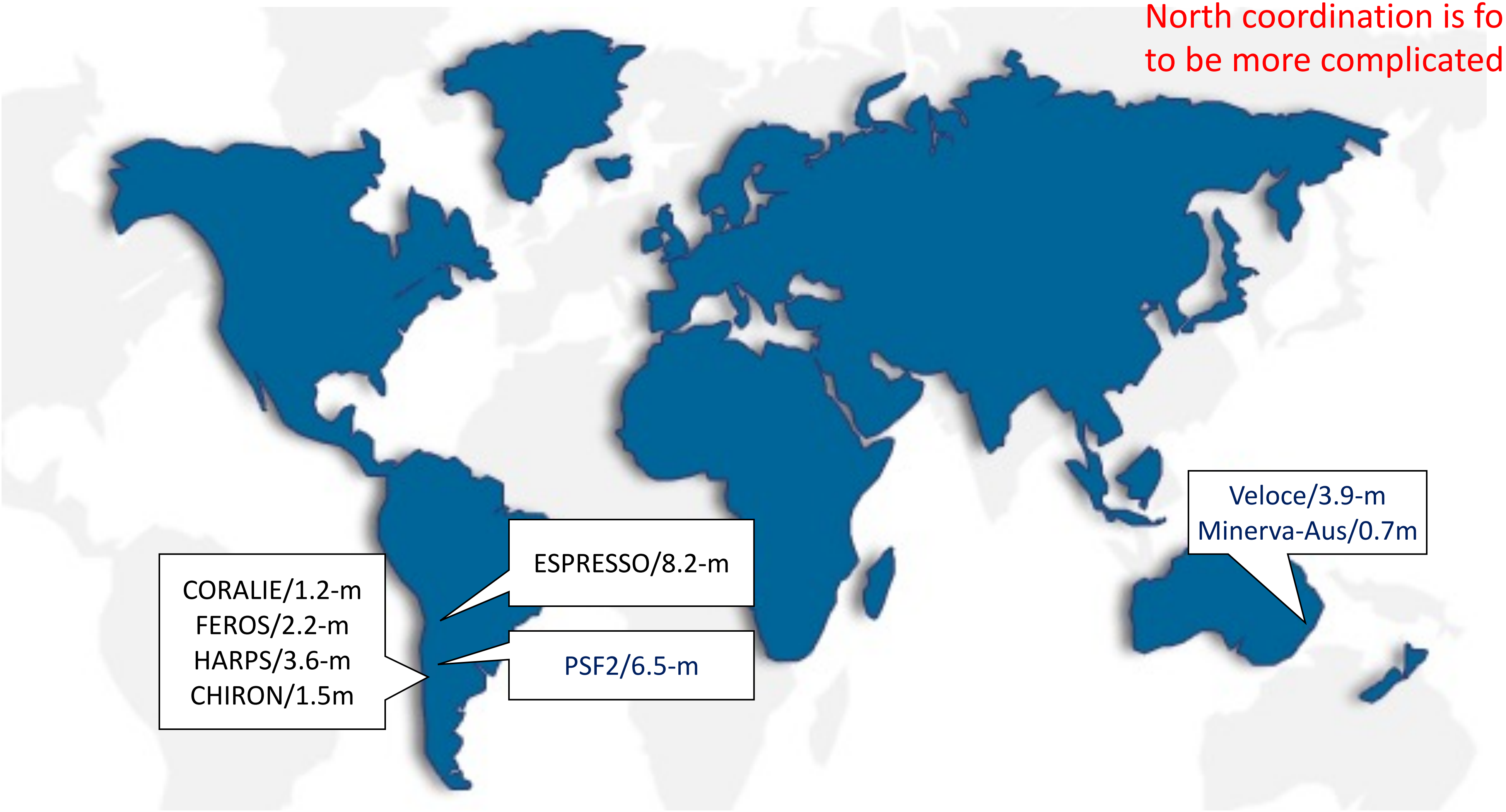
nIR spectro

European RV facilities in development or *in project*



Main south spectrograph facilities involved in TESS FU

North coordination is foreseen to be more complicated



Non-European RV facilities in operation

PFS2@Magelan (6.5m)
HRS@SALT (11m)
CHIRON@CTIO (2.5m)
HIRES@Keck (10m)
APF@Lick (2.5m)
Veloce@AAT (3.9m)
ISHELL@IRTF (3m)
PARVI@Palomar (5.1m)
HPF@HET (10m)
IRD@Subaru (8m)
EXPRES@HappyJack (4.3m)

Non-European RV facilities in development or *in project*

MAROON-X@Gemini-N (8m)
NIED@KittPeak (3.5m)
KPF@Keck (19m)
iLocater@LBT (2x8m)
GCLEF@GMT (25m)