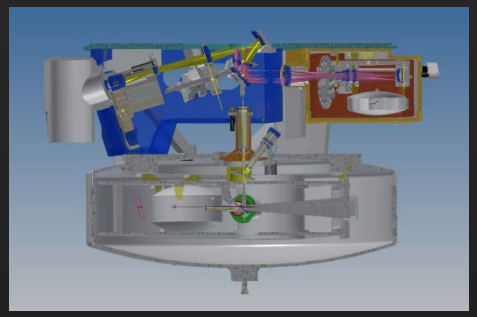
(1) Introduction of project NTE



(2) CARMENES finds Super-Earth at Barnard's Star – after all

(1) Introduction of project NTE (MPIA project #1901)

- A new instrument for the Nordic Optical Telescope (NOT) on La Palma, NOT Transient Explorer (NTE)
- Medium resolution optical/NIR spectroscopy and imaging in rapid response mode to catch transient astronomical phenomena fast
- Instrument consortium led by the Niels Bohr Institute (NBI), Copenhagen
- PI: Johan Fynbo (NBI), PM: Jacob Clasen (NOT)
  - *Thanks go to them for providing much of the material of this talk*

- MPIA will provide NTE with our in-house read-out electronics (ROE) for the NIR cameras of NTE, i.e. two systems for the imaging and spectroscopic channels plus one spare unit
- A unique opportunity to bring our ROE to a new facility and continue contributing our expertise

CANARY ISLANDS

La Palma

Roque De Los Muchachos 2423

Santa Cruz de la Palma

Los Llanos de Aridane

Tenerife

Tacoronte

Santa Cruz de Tenerife

Puerto de la Cruz

La Orotava

Icod de los Vinos

Candelaria

Güimar

Pico Del Teide 3718

Guía de Isora

Adeje

Granadilla de Abona

Arona

Isla de la Gomera

Gáldar

Arucas

Las Palmas

Teror

Santa Brígida

Telde

Pico De Las Nieves 1949

San Bartolomé de Tirajana

Ingenio

Agüimes

Gran Canaria

Pico Malpaso 1501

Hierro

Isla de Alegranza

Montaña Clara

La Graciosa

Lanzarote

Teguise

San Bartolomé

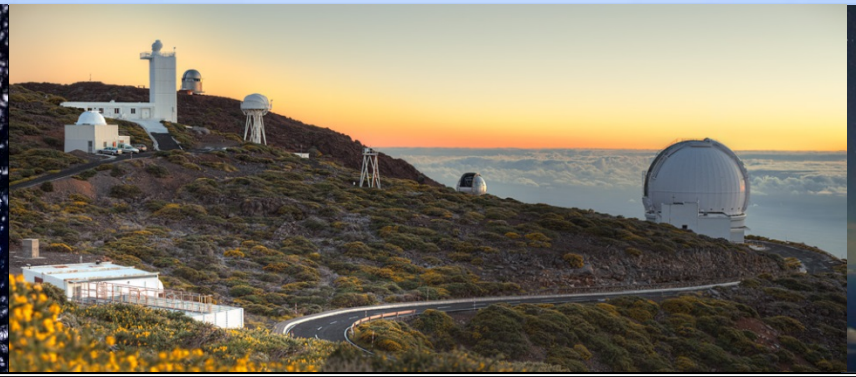
Arrecife

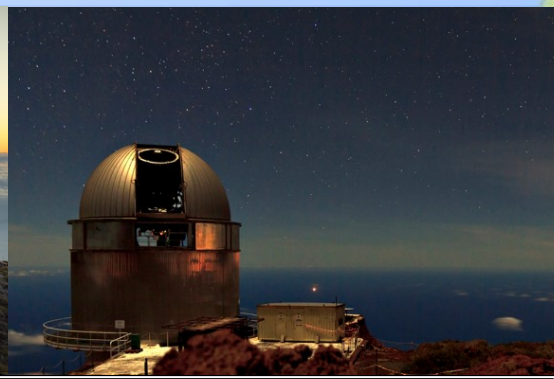
Tías

Isla de Lobos

Puerto del Rosario

Fuerteventura





Institutes participating in NTE

- Denmark:
  - Niels Bohr Institute, Copenhagen University
  - Institute for Astronomy, University of Aarhus
  - IDA (Instrument Center for Danish Astronomy)

- Finland:
  - FINCA (Finnish Center for Astronomy with ESO)
  - University of Helsinki

- Iceland:
  - University of Iceland, Faculty of Physical Sciences

- China:
  - NAOC (National Astronomical Observatories, Chinese Academy of Sciences)

- Germany:
  - MPIA (Max-Planck-Institut für Astronomie) Heidelberg

- France:
  - LAM (Laboratoire d'Astrophysique de Marseille)
  - OHP (Observatoire de Haute-Provence)

- Israel:
  - Weizmann Institute of Science

- And:
  - The Nordic Optical Telescope, La Palma

Nordic Optical Telescope

- *"Nordic:"* Denmark, Sweden, Iceland, Norway, Finland
- 2.56 m effective *f*/11 Ritchey-Chrétien telescope
  - Cassegrain variant with hyperbolic primary and secondary mirrors
  - Roque de los Muchachos Observatory, La Palma
  - NOT inaugurated in 1989

Project milestones

- Contract on spectrograph alone signed — Feb 2014

- MoU NBI – MPIA signed — Dec 2018
- Start of manufacture ROE system #1 at MPIA — Dec 2018

- Project approaching FDR
- Several elements are being build (calibration unit, tel. simulator, ADC)

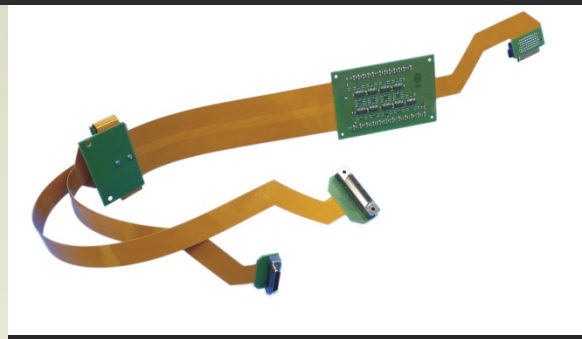
- Start of manufacture ROE system #2 at MPIA — Apr 2019
- End of manufacture ROE system #1 and delivery to NBI — Sep 2019
- AIV ROE system #1 at NBI — Nov 2019
- Start of manufature of ROE system spare at MPIA — Jan 2020
- End of manufacture ROE system #2 and delivery to NBI — Feb 2020
- AIV of ROE system #2 at NBI — Apr 2020
- Shipment of NTE and start of installation at NOT — Nov 2020
- Start of commissioning NTE at NOT — Dec 2020

- First light

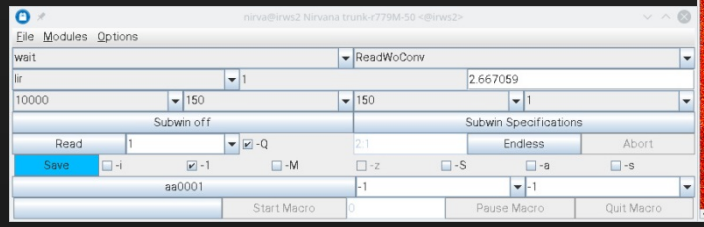
- End of commissioning NTE at NOT — Feb 2021
- Preliminary acceptance La Palma — Mar 2021

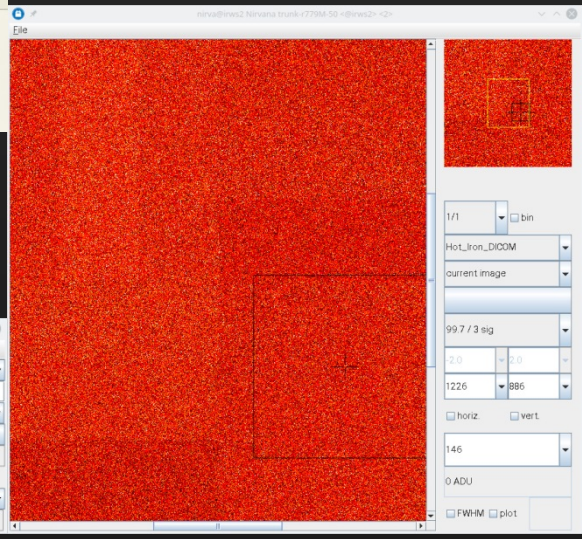
MPIA contribution

- Labor: 20.9 PM = 2.15 FTE
- HW: € 42,000. –
- Travel: € 5,000. –

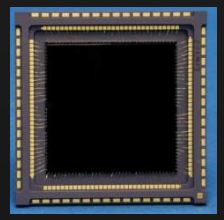


- Three read-out electronics systems (incl. cabling)
  - for the NIR imager
  - for the NIR spectrograph
  - plus a spare unit
    - ➢ *10.5 PM*
- Includes the read-out SW
  - with currently available functionality
    - ➢ *4.0 PM*





- Assist with the integration (“AIV“) of the two HAWAII-II-RG detectors with the ROE
  - Includes basic detector characterization & optimization
    - Gain, dark, RON, full-well capacity, and linearity
      - ➢ *6.4 PM*
- Five-year maintenance
  - Can be extended



Compensation

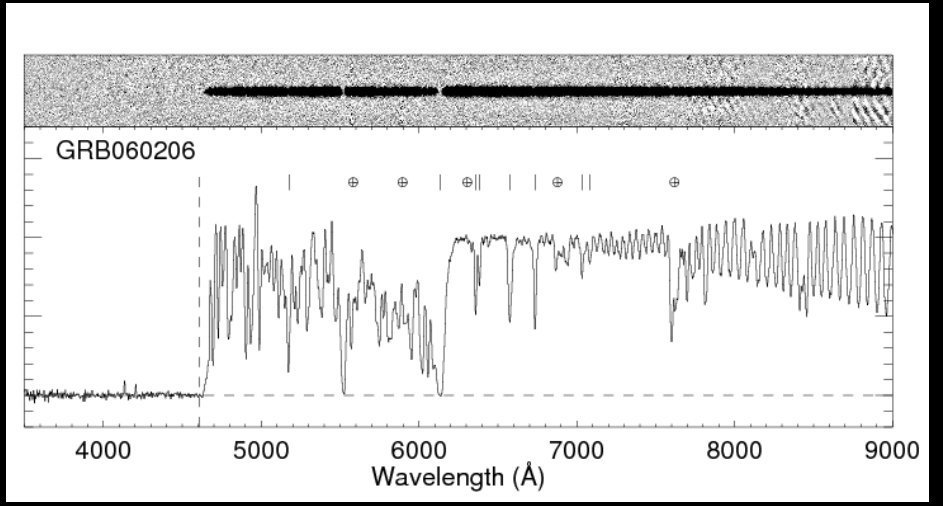
- 65 visitor mode nights at the NOT – 2021 onwards ...
  - Free choice of instrument
    - NTE or FIES (a FEROS-like spectrograph)
  - Nights distributed over the first six years of operation
    - (If ToO mode is used, one ToO night = 1.25 visitor mode nights)
- Plus one night per year as compensation for maintenance

NOT instrumentation in 2021

- FIES
  - Fibre-fed Echelle Spectrograph
  - High-resolution spectroscopy
  - New fiber-scrambler that will improve the radial velocity stability
- NTE
  - NOT Transient Explorer
  - Medium-resolution NUV/optical/NIR spectroscopy and imaging
  - Rapid Response Mode for fast (<2 min) transient reaction is being developed

Science cases for NTE

- Transient phenomena
  - GRBs, kilonovae, GWs
  - Supernovae Ia
  - Core-collapse supernovae
  - New transients
- Other programs with time variability
  - Masses of black holes at galaxy centers
    - "Reverberation/echo mapping"
  - Exoplanet atmospheres
- Non-transient programs
  - AGN hosts
  - Spectroscopic follow-up of sources from wide-field surveys
  - QSOs from GAIA
  - Solar System objects



Gamma ray burst at redshift z=4.05,
i.e. ~1.5 billion years after the big bang.

Follow-up started 48 min after burst trigger
(Fynbo et al. 2006)

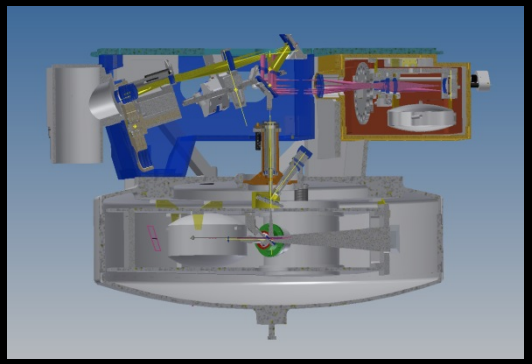
Important drivers: wide wavelength coverage, resolution, simultaneous optical and near-IR imaging, versatility

NTE – a new work-horse for the NOT

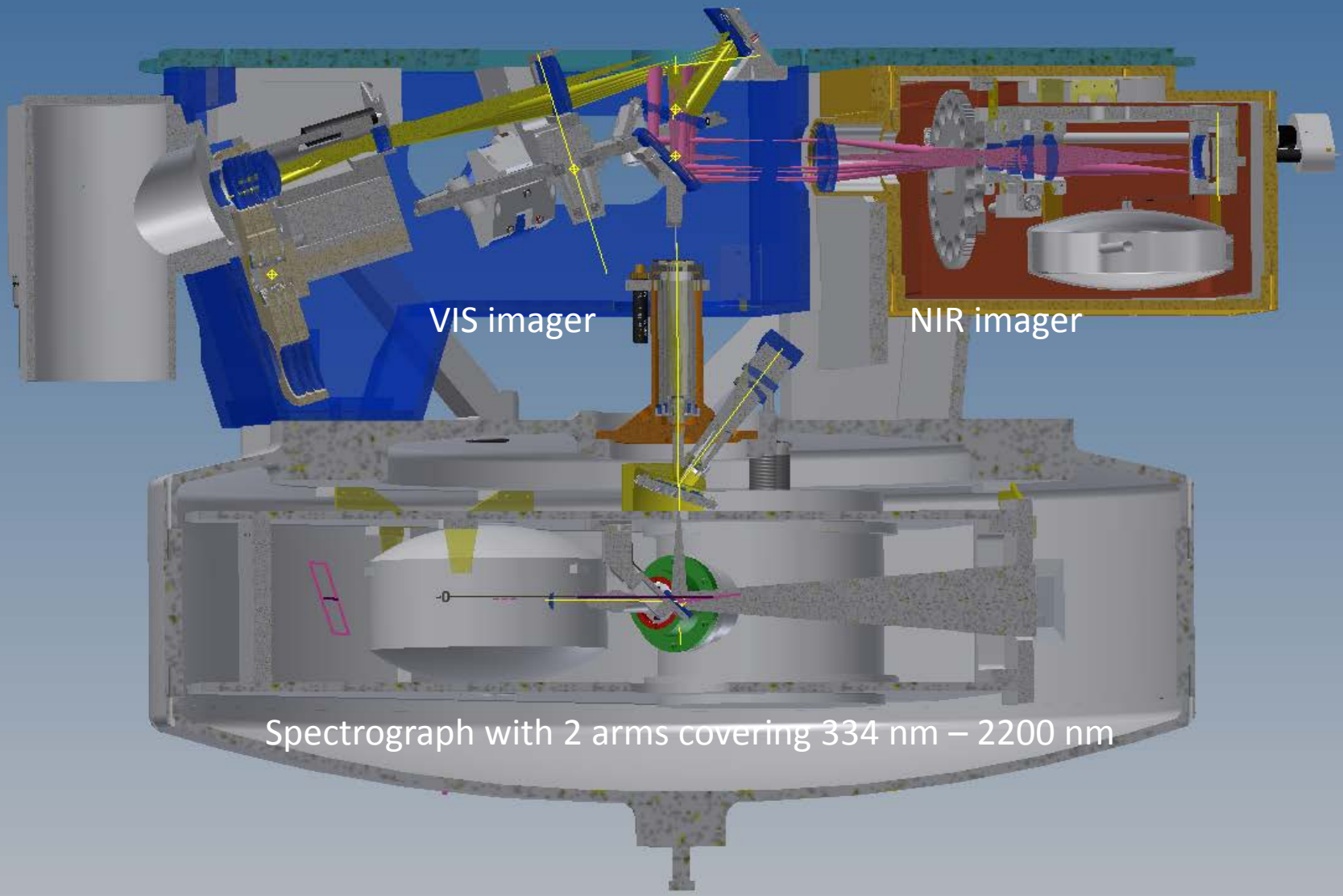
- A cross-dispersed spectrograph
  - similar to X-Shooter at the ESO VLT, but with extras
  - covering 334-2200 nm
  - resolution ~5000
  - single 20” slit (with different choices for the slit width)
  - including atmospheric dispersion corrector (ADC)
  - efficient enough to be sky-limited in 30 min integration
  - detectors contain one 2k x 2k HAWAII-II-RG

- Visible imager
  - ~6 arcmin FOV
  - 2k x 2k detector
  - sampling 0.18 arcsec per pixel

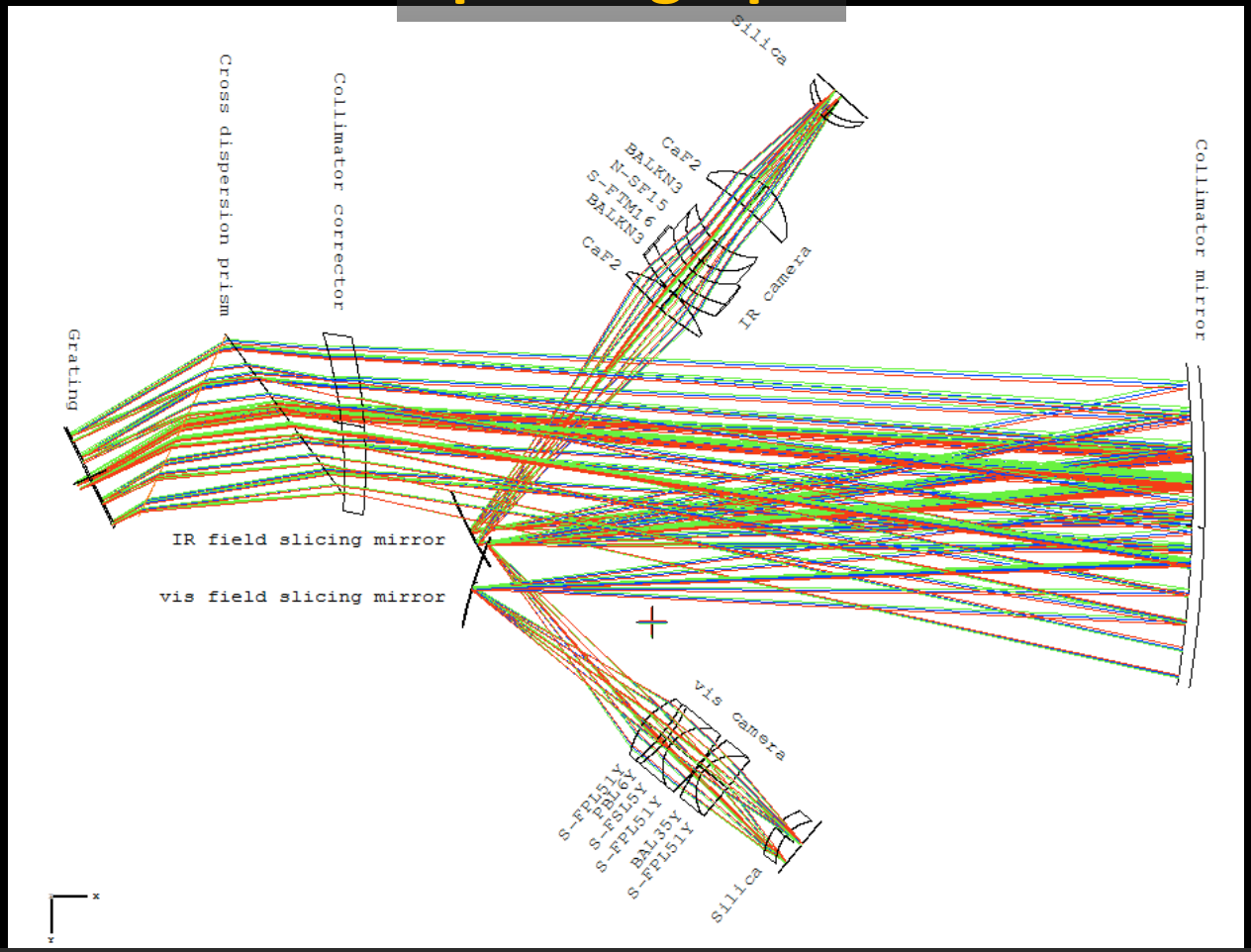
- Near-IR imager
  - J, H & K bands
  - 2k x 2k HAWAII-II-RG detector
  - same FOV and sampling as in the visible



Instrument design

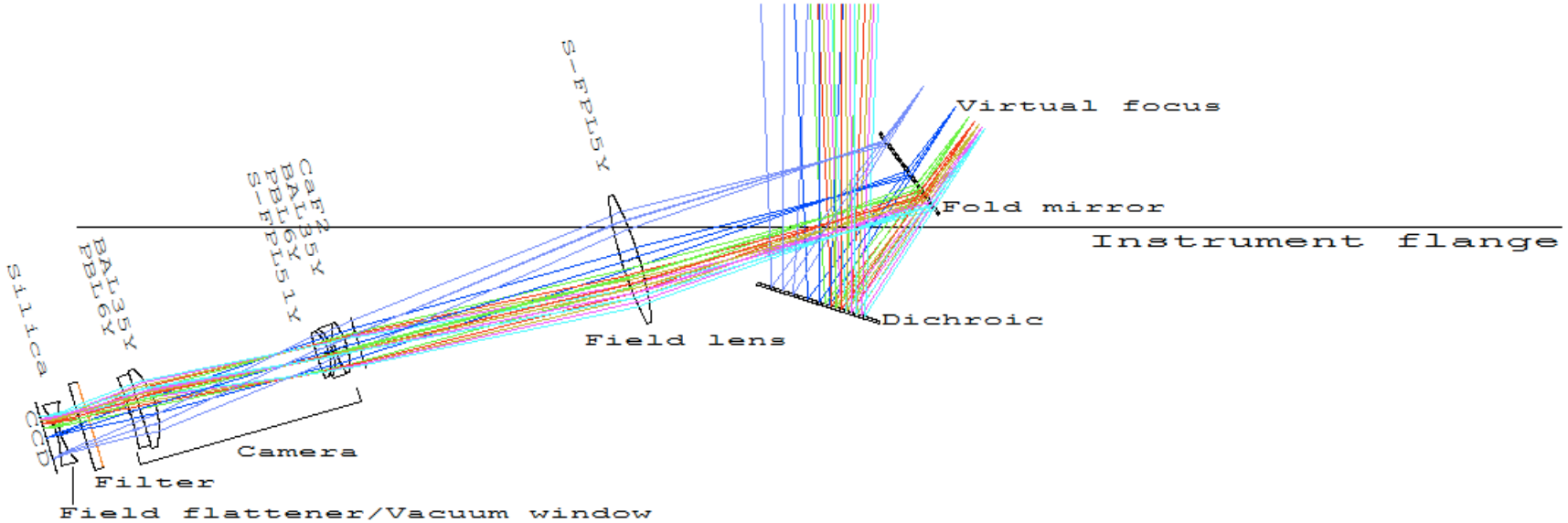


Spectrograph



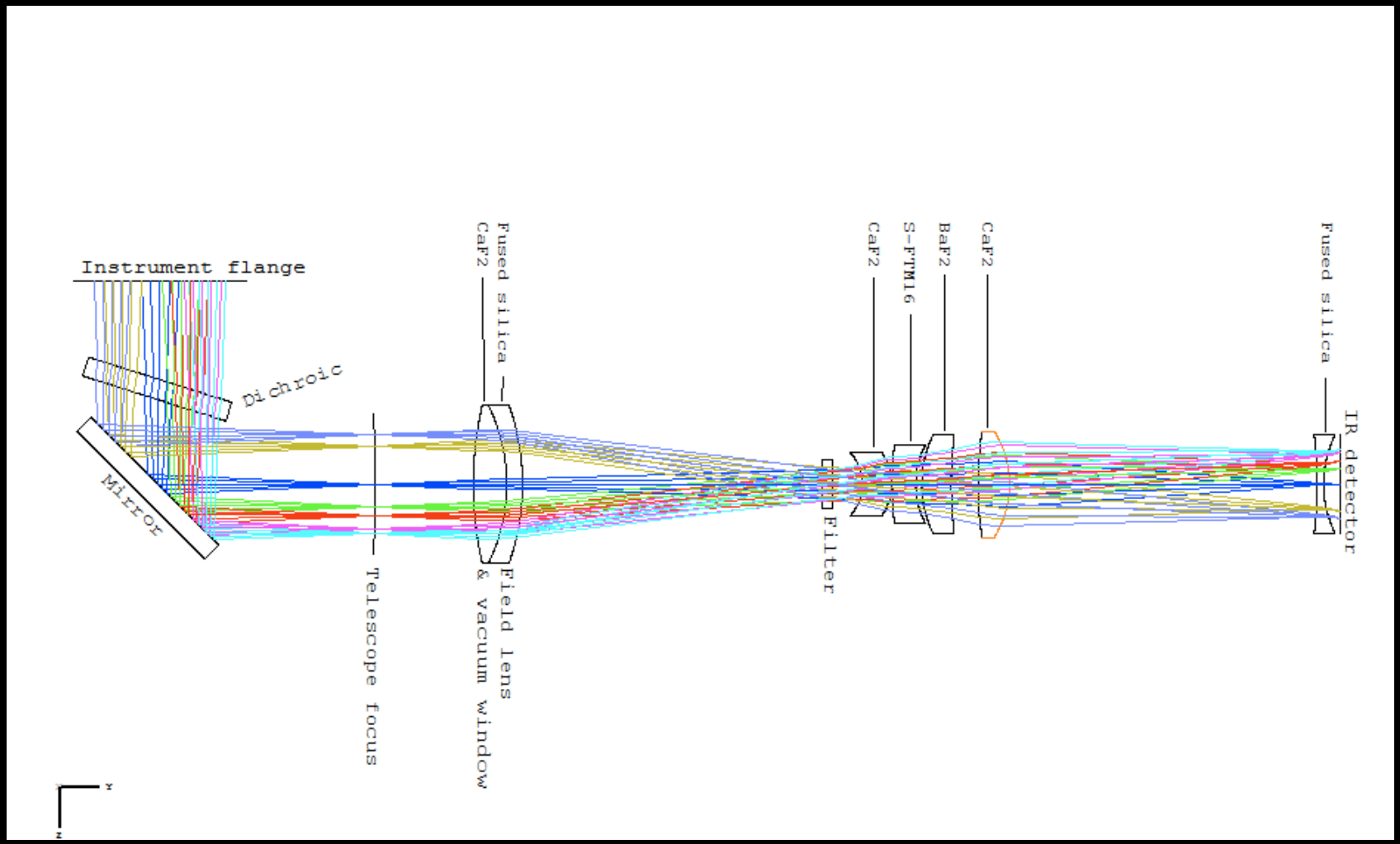
- Spectrograph optical layout
- An unusual feature are the field slicing mirrors, which split the visible and IR light without the need for dichroic mirrors
- The slit is above the cross in the middle, coincident with the telescope optical axis
- A fold mirror is located below the slit

VIS imager



- Optical layout of the visible imager
- Glass materials are indicated
- Due to packaging constraints, part of the light path is inside the instrument adaptor
- The shutter will be placed in front of the camera

VIS imager

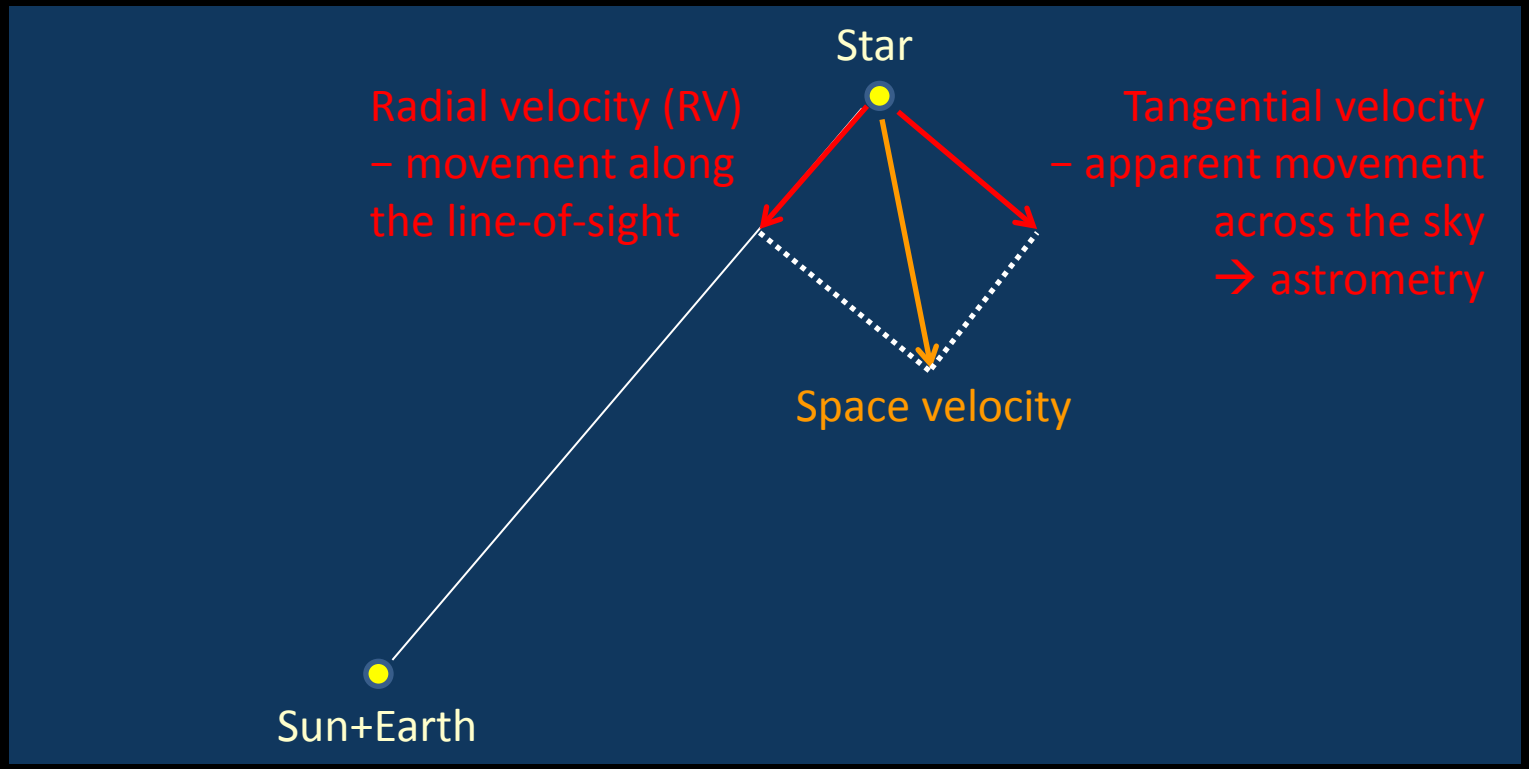


- Optical layout of the near-IR imager
- Glass materials are indicated

(2) CARMENES finds Super-Earth at Barnard's Star – after all

- Up until the 1990s astronomical textbooks claimed that two Jupiter-like planets were orbiting Barnard's star, the closest single star to the Sun
- This claim was based on astrometric measurements, which determine the reflex motion of a star caused by the gravitational pull of its planets
- More precise observations demonstrated later that these planets do not exist and that the apparent motion of the star had been caused by uncorrected instrumental effects. Actually, until today, the astrometric technique has not found a single exoplanet
- Recently though, the well-established radial velocity method has led to a new exoplanet claim around Barnard's star, a cold Super-Earth, the first of its type near the snow line of its system
- This difficult discovery was made possible by combining data from seven instruments among which CARMENES was a key player
- It will require independent confirmation, expected to come after 2021 from the most precise astrometric measurements ever to be provided by the final release of data from the GAIA satellite

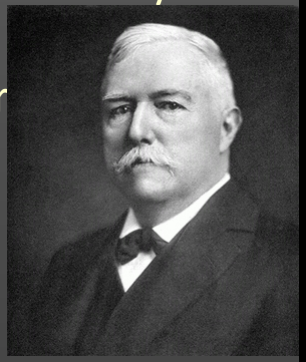
Stellar space motion



Stars move through space!

Barnard's Star

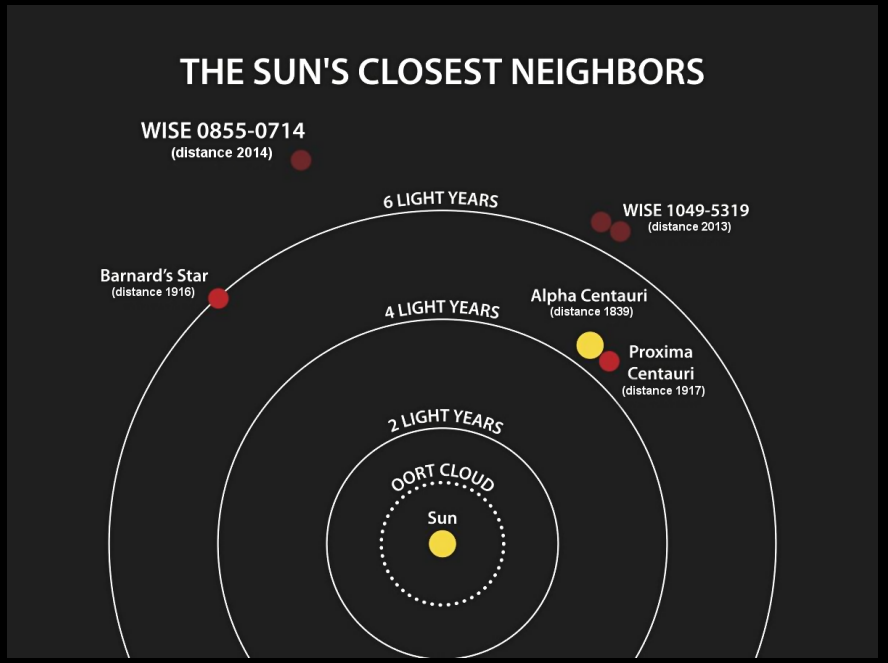
- Identified by E.E. Barnard in 1916 as the fastest moving star on the sky
  - 10.3"/year
  - it covers the angular diameter of the Moon in ~180 years

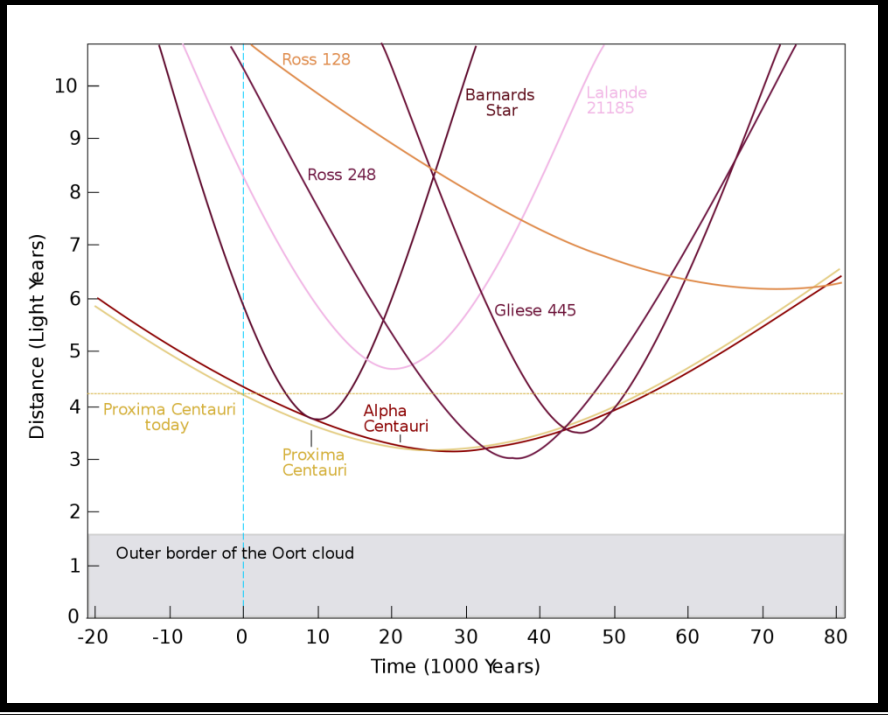


- It also has a large radial velocity
  - -111 km/s

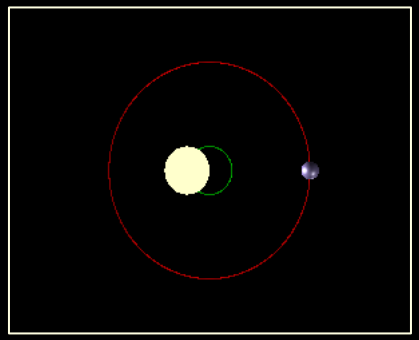
- Spectral type M4V → faint red star
- V = 9.54 mag
  - 16.5 x too faint for the human eye
- Mass = 0.16 solar masses
- Radius = 0.18 solar radii
- Effective temperature = 3280 K

- Distance 6.0 light years
  - nearest single star
  - only α Cen A+B + Proxima closer





Astrometry

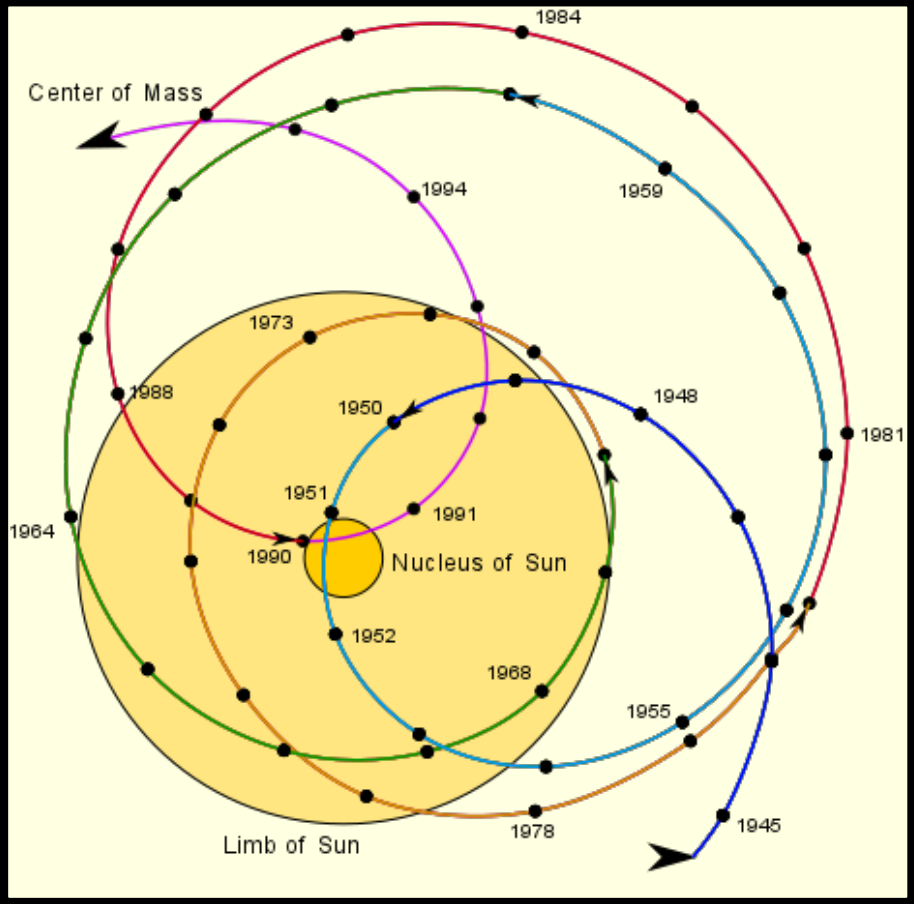


A star and its planet revolve around their common center-of-mass.

Astrometry means measuring the positional changes of a nearby star with respect to distant reference stars

So far no exoplanets have been found by the astrometric method.

But it has provided a few confirmations of planets found by other methods



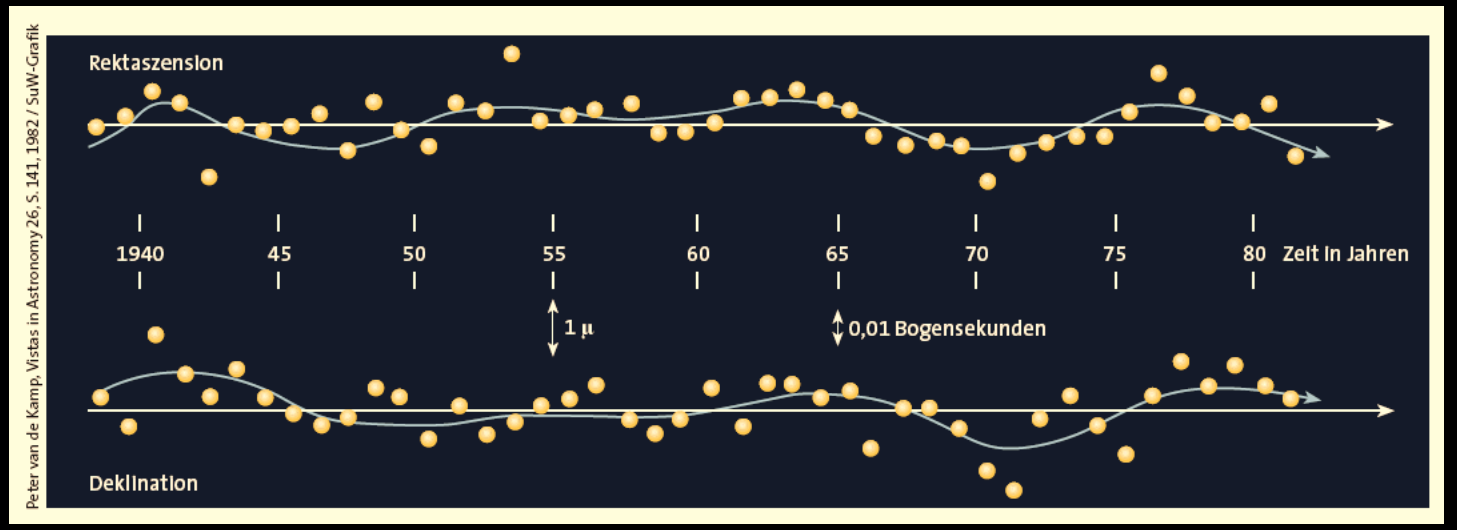
Movement of the Sun around the center-of-mass of the solar system

Astrometry of Barnard's Star

The notion that this star has two Jupiter-like planets was widespread in the 1960's – 80's ...
... but an error, as it turned out.

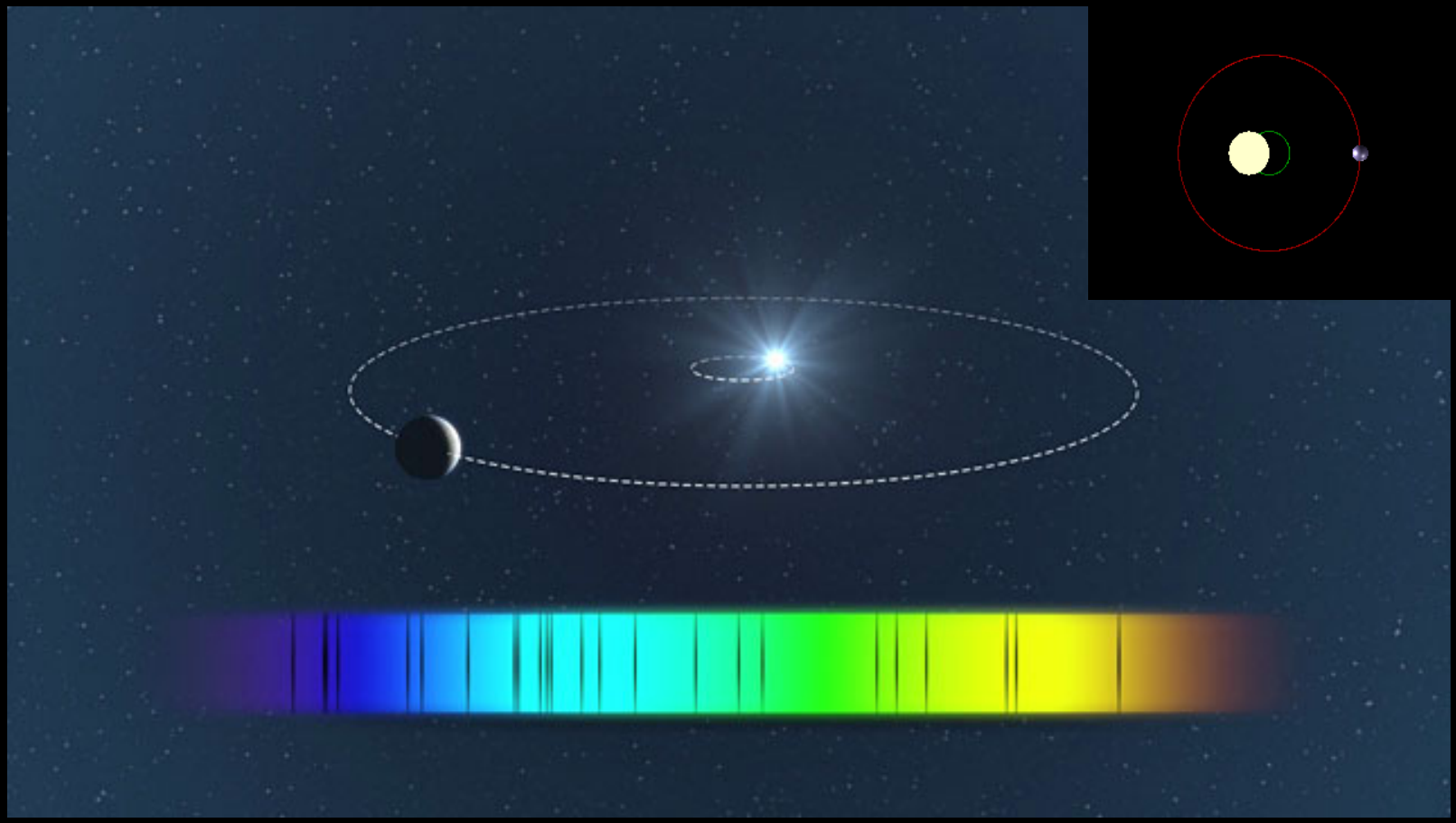
Position measurements with photographic plates with Sproul Observatory's 61 cm refractor showed signals at periods of 12 years and 20 years

Peter van de Kamp
(1901 – 1995)



More recent measurements cannot confirm these signals
→ Most likely instrumental effects

Planet search with the RV method



Top: Star and planet orbit the common center-of-mass
Bottom: Stellar spectrum with Fraunhofer lines

Stellar movement leads to measurable Doppler effect

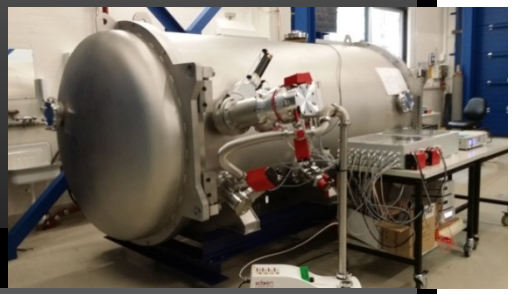
The new planet around Barnard's Star:

Found with the radial velocity method by Ignasi Ribas (ICE Barcelona) together with the CARMENES consortium & other colleagues (63 authors)

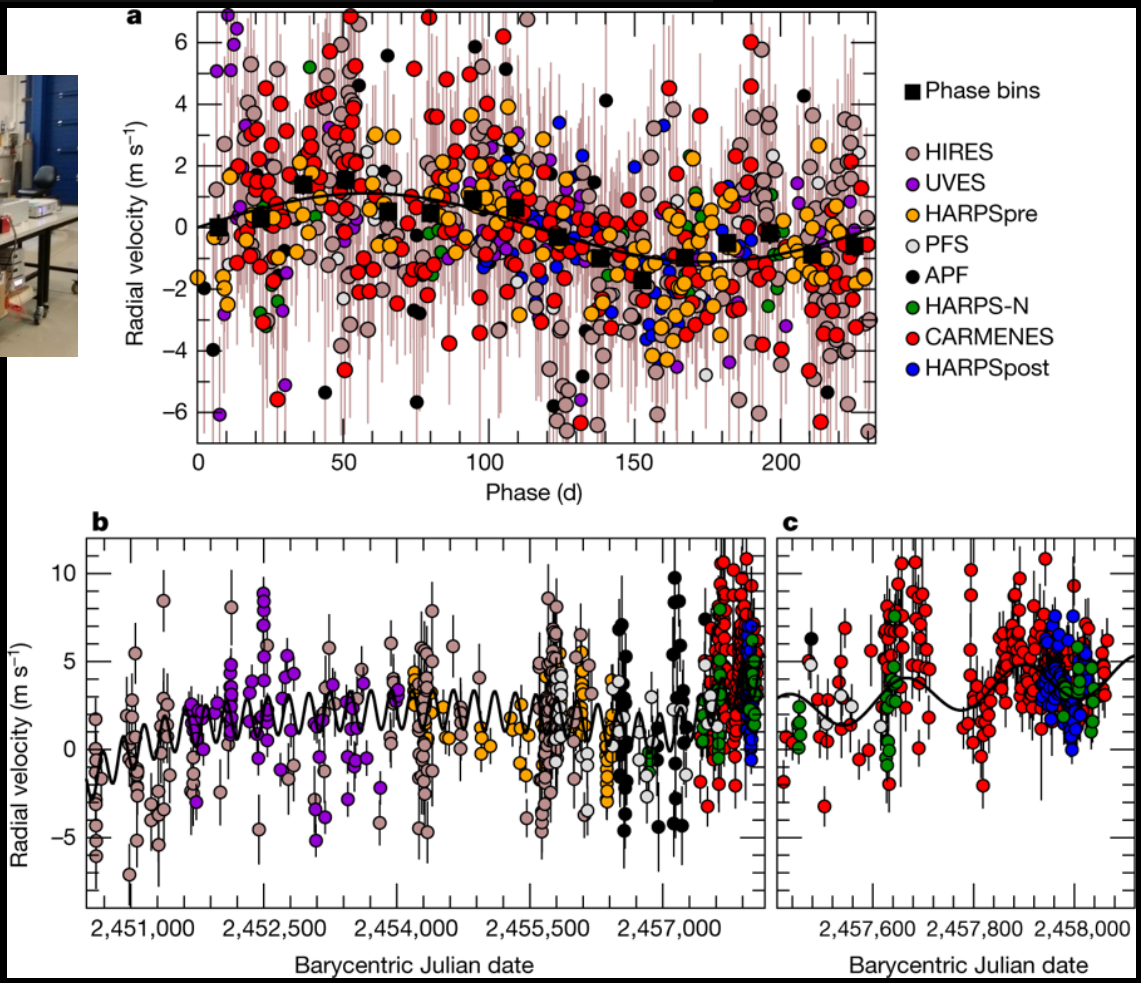
(Ribas et al. 2018, Nature 563, 365)

RV data from eight different instrument configurations were combined

Largest data set from CARMENES (visual channel)

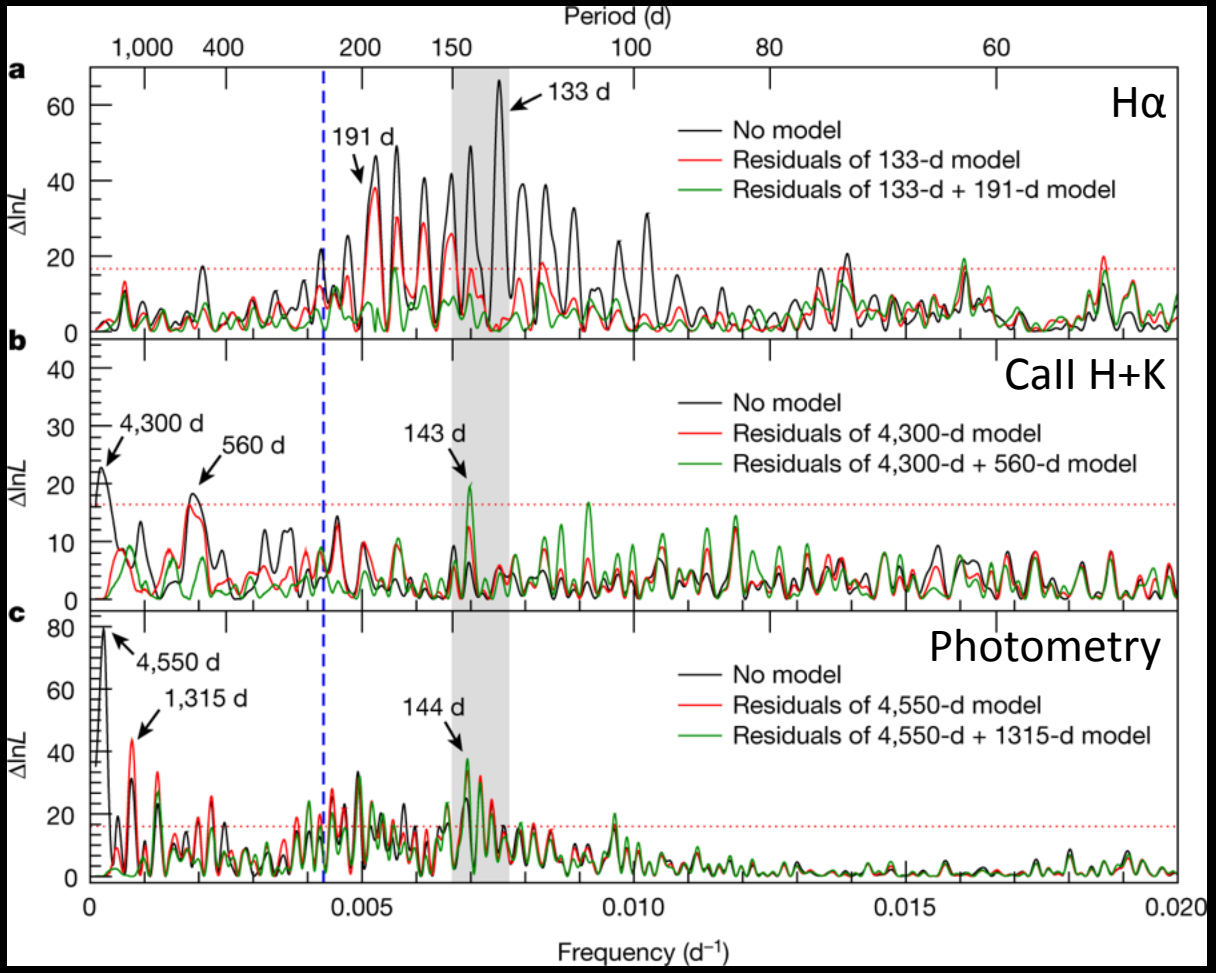


RV semi-amplitude	1.2 m/s
Period	233 day
Mass	≥ 3.23 Earth masses
	→ *a Super-Earth*
Semi-major axis	0.40 AU
Irradiance	0.020 Earth units
Equilibrium temp.	≤ 105 K
	→ *near the snow line!*
Astrom. semi-ampl.	>0.0133 mas
	→ *GAIA confirmation!*
Amgular separation	221 mas
	→ *SPHERE, MATISSE confirmation?*



The new planet around Barnard‘s Star:

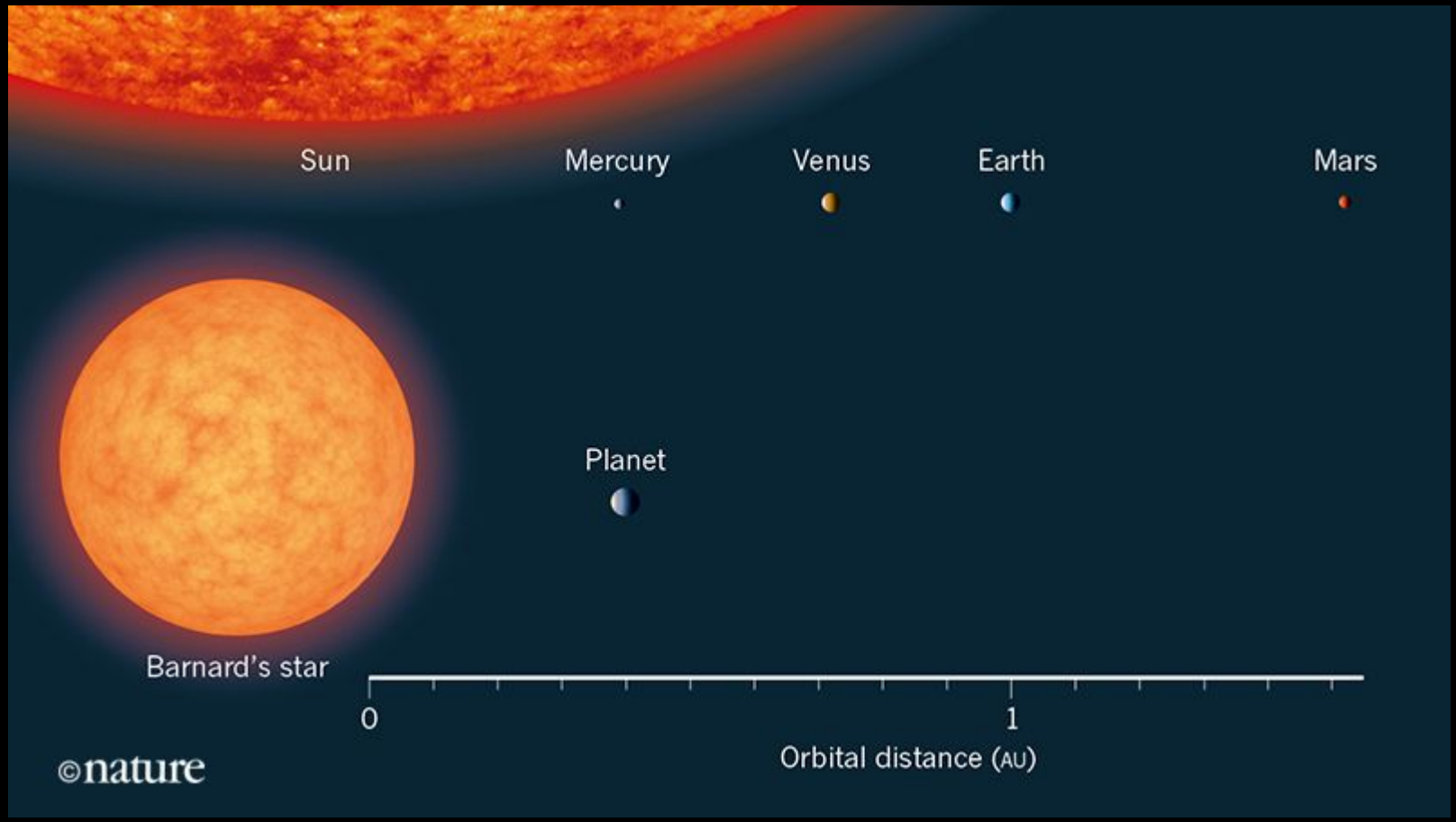
Found with the radial velocity method by Ribas et al. (2018), Nature 563, 365



Excluding stellar activity as the source of the signal

The new planet around Barnard‘s Star:

Found with the radial velocity method by Ribas et al. (2018), Nature 563, 365



Comparing Barnard‘s Star‘s system with the solar system

What is special about Barnard‘s Star b ?

- It orbits near the snow-line of its star
  - i.e. the location cold enough for volatile compounds to condense into solid ice grains
    - (water, ammonia, methane, carbon dioxide, carbon monoxide)
- Barnard‘s Star b is the first low-mass, rocky planet found at this location in any star
  - This finding is at the limit of what is technically feasible
- Giant planet formation is thought to occur beyond the snow line from smaller rocky planets
  - But they must get there in the first place
  - Very important finding for the theory of planet formation


Thank you very much
for your interest