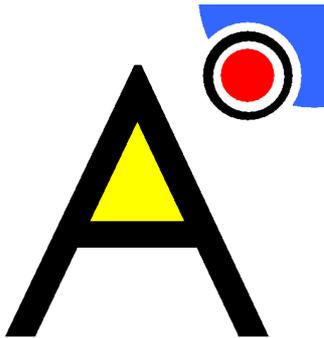




carmenes

What is it?

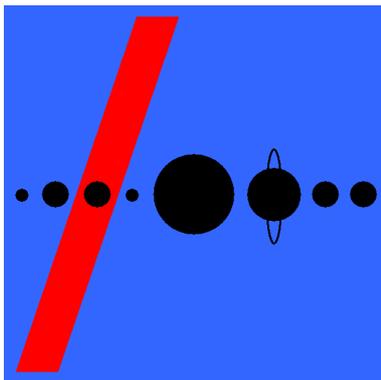
Exoplanets and exoearths



Our Solar System has eight **planets**. Four of them are “terrestrial” planets: Mercury (with its Moon-like surface), Venus (with its greenhouse atmosphere), the Earth (with its living creatures) and Mars (with its volcanoes and canyons), while the other four are “gas giant” planets: Jupiter (with its Red Spot), Saturn (with its rings) and the icy twins Uranus and Neptune (with their almost featureless atmospheres).

Other planets (or, better, **exoplanets**) also orbit other suns. Over 500 exoplanets have been discovered since the annus mirabilis of 1995 (see the *Extrasolar Planets Encyclopaedia* for an updated catalogue). However, most of them are inhospitable giant gaseous planets with high temperatures that resemble those of the coolest stars and orbit very close to their suns (and their years last only a few days).

With the improvement of the technology for the detection of exoplanets, especially through highly-stabilised spectroscopy for measuring the radial velocity reflex motion of the host star induced by unseen companions, the minimum mass of the newly discovered exoplanets is getting lower and lower. However, in spite of the efforts of astronomers, we have not been able to detect yet the first **exoearth**: an exoplanet with roughly the same mass as the Earth ($M \sim 0.5\text{-}2.0 M_{\text{earth}}$).



A **habitable planet** is understood as one that sustains liquid water (and, possibly, life) on its surface, and the search for them is at the forefront of Astrophysics research. Exoearths in habitable zones around solar-like stars are to be discovered (maybe with NASA's *Kepler* and ESA's *PLATO* missions or ESPRESSO at the VLT). By contrast, according to the equation of radiative equilibrium, exoearths in the habitable zones of very cool low-mass stars must be located much closer and produce a larger radial velocity reflex motion that could be measured with current technology.

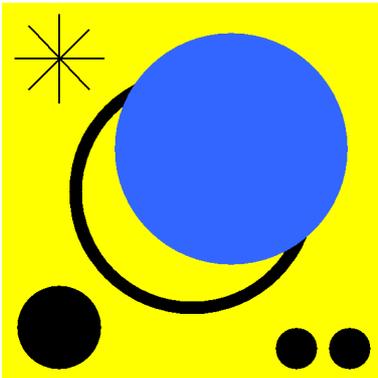
M dwarfs and near-infrared spectrographs

Low-mass stars are the most common ones in the Universe. They are relatively cool (between ~ 4000 and ~ 2200 K) and faint at visible wavelengths, and have M spectral types and masses of less than $0.6 M_{\text{sol}}$. Habitable exoearths around **M dwarfs** should produce a radial velocity wobble of the same amplitude as those caused by exojupiters around warmer solar-like stars, which are much brighter in the visible. Unfortunately, visible

spectrographs like HARPS or HIRES are not optimised for observing low-mass stars. Because of their low effective temperatures, the luminosity of M dwarfs is low, but they also have red colours: while the Sun emits the peak of its energy in the yellow-green, at 550 nm, M dwarfs peak do it in the near infrared, at $\lambda > 900$ nm. Therefore, a highly stabilised spectrograph operating in the near infrared would be one of the most suitable tools for discovering the first habitable exoearth.

The ExoPlanet Task Force recommended developing near-infrared spectrographs for investigating the characteristics of planets in the habitable zones around bright, nearby M stars before 2013: *"Near-IR spectrographs are potentially the best way to find terrestrial mass planets in the habitable zones of main sequence stars later than M4 (a relatively warm or "early" M dwarf); optical spectroscopy is competitive and already available for earlier spectral types. Develop IR spectrographs with a target precision of 1 m/s for radial velocity surveys of late M dwarfs. A near-term demonstration of 10 m/s is critical to validate this technique."*

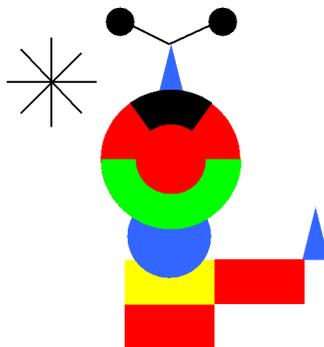
Calar Alto observatory and the 3.5 m telescope



The German-Spanish Calar Alto Astronomical Observatory (2168 m) is located in the Andalusian Sierra de Los Filabres, north of Almería, Spain. It is operated jointly by the Max-Planck-Institut für Astronomie (MPIA-MPG) in Heidelberg, Germany, and the Instituto de Astrofísica de Andalucía (IAA-CSIC) in Granada, Spain. Calar Alto provides three reflector telescopes with apertures of 1.23 m, 2.2 m and 3.5 m to the general community.

The 3.5 m telescope (1984) is to date the largest telescope in Western Europe (not counting the Canary Islands). There are six instruments available, including wide-field visible and near-infrared cameras, an intermediate-resolution spectrograph, and an integral field unit.

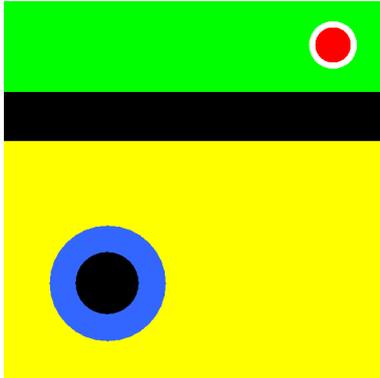
CARMENES: the consortium



In 2008, there was a competition after a call for letters of intent, issued by the Centro Astronómico Hispano-Alemán, for the construction of the next generation instrument for the Calar Alto 3.5 m telescope. CARMENES was one of the two instruments that were selected for a conceptual design study (Phase A) funded by the German Max-Planck-Gesellschaft and the Spanish Consejo Superior de Investigaciones Científicas. The other one was an extreme multiplex spectrograph that was ultimately not pursued.

The CARMENES consortium was officially created in early 2009 with the aim of designing, building, integrating and operating the homonymous instrument. The consortium is currently made up of ten centres and universities in Germany and Spain, in close collaboration with the Calar Alto Astronomical Observatory. To date, there are over 80 researchers and engineers in the consortium.

CARMENES: the instrument



CARMENES will be optimised for searches of planets around stars with very low masses. With **1 m/s**-class stability in the near infrared and simultaneous monitoring of activity indicators in the visible, exoearths can be detected in the habitable zones of several of the targeted M dwarfs, some of which may also be transiting. The instrument is well-suited for operation at Calar Alto in a "large experiment mode". Smaller dedicated campaigns can also be performed to use asteroseismology to refine the parameters of planet host stars.

The target radial velocities will be monitored with a two-channel fibre-fed cross-dispersed échelle spectrograph that will provide almost full coverage of their respective wavelength ranges in one shot (see the table below). The near infrared channel will cover the *Y*, *J* and *H* bands from 950 to 1700 nm (we will focus on optimising the range 950-1350 nm) and have a spectral resolution $R \sim 85,000$. With an overall efficiency of $> 5\%$, we expect to reach a signal-to-noise ratio of 150 in 900 s of exposure time on a target with $J = 9$ mag. The visible channel, covering the spectral range from about 530 to 1050 nm, will provide the necessary simultaneous monitoring of activity indicators (e.g., $H\alpha$, $Ca II$). The two spectrograph channels have bench-mounted white-pupil designs.

	VIS	NIR
$\Delta\lambda$	530-1050 nm	950-1700 nm
$R=\lambda/\Delta\lambda$	80,000	85,000
Fibre size	1.50 arcsec	1.65 arcsec
Grating	2 x R4 (31.6 mm ⁻¹)	2 x R4 (31.6 mm ⁻¹)
Cross disperser	grism	grism
Detector	e2v 231-84 (4k x 4k)	2 x Hawaii-2RG (4k x 2k)

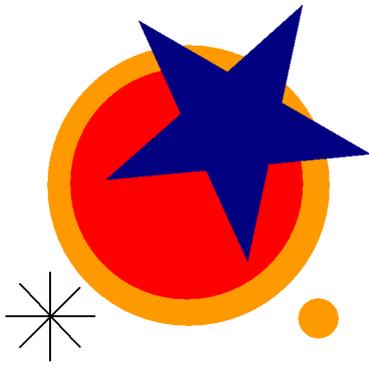
Other CARMENES main components comprise a new front-end at the Cassegrain focus compatible with the current instrument PMAS, fibre feeding and image scramblers, a calibration unit able to inject light from halogen and ThAr-like lamps or Fabry-Pérot wavemeters, stabilised cooling systems and vacuum tanks for the two spectrograph channels ($\Delta T \approx 0.01$ K), and an advanced instrument control system.

There is a number of comparable spectrographs, either in operation or in development. However, CARMENES has some advantages that make it a unique instrument.

- Simultaneous near-infrared and visible observations (to discriminate between exoplanets and stellar activity).
- Both high resolution and wide spectral coverage.
- Dedication to stable high-precision radial-velocity survey of exoplanets around M dwarfs.
- Long guaranteed time for the completion of the project (>600 useful nights for five

- years).
- Avoid the complications of cryogenics (focus on red optical YJ bands).
 - Early first light (late 2013-early 2014).

Name and logo



CARMENES [kár-meh-nes] stands for **Calar Alto high-Resolution search for M dwarfs with Exo-earhts with Near-infrared and optical Échelle Spectrographs**. Cármenes (with acute a) is also the plural of Carmen, which is a typical woman name in Spain that can also be found in Germany. Carmen is also the traditional house with gardens and orchards from Granada, an asteroid discovered from Heidelberg by M. F. Wolf (558 Carmen, 1905 QB), and a French opera by Georges Bizet based on a novela by Prosper Mérimée. Cármenes, in plural, is a small (397 inhabitants) municipality in the Spanish province of León.

The name of CARMENES was democratically chosen by the consortium members. Other considered names were, for example, HRS (High-Resolution Spectrograph), ICARVS (International Calar Alto Radial Velocity Spectrograph), CAIROS (Calar Alto Infra-Red and Optical Spectrograph) or CAPERUSITA.

The CARMENES logo (at the beginning of this document) is a minimalist version of the famous logo 'Turismo español' by Joan Miró with the word *carmenes* written in Bauhaus typeface (Herbert Bayer 1925). One may see a black planet around a red star. The pictures that illustrate this document are also Bauhaus-like minimalist versions of famous Miró's drawings.

José A. Caballero and the
CARMENES Consortium
carmenes.caha.es