CHORUS: A High Resolution Ultra-Stable Spectrograph for GTC

Kai Zhang [1], Jianrong Shi [2], Sharon X. Wang [3], Liang Wang [1], Jean-Louis Lizon [1], Xinqiqige [1], Huiqi Ye [1], Liang Tang [1], Fujia Du [1], Jian Han [1], Huatao Zhang [1], Jiajia Wu [1], Lei Wang [1], Yujuan Liu [2], and Fei Zhao [2]

1. Nanjing Institute of Astronomical Optics and Technology, National Astronomical Observatories, Chinese Academy of Sciences
2. National Astronomical Observatories, Chinese Academy of Sciences
3. Department of Astronomy, Tsinghua University

What is CHORUS?

CHORUS stands for **Canary High Optical Resolution Ultra-stable Spectrograph**. In 2016, the Chinese and Spanish astronomy communities proposed a joint program to develop a high-resolution, ultra-stable spectrograph for the 10.4m Gran Telescopio Canarias (GTC) in La Palma. It aims to conduct radial velocity measurements with extreme precision of 10~30 cm/s.

Telescope	GTC
Aperture	10.4m
Site	ORM, La Palma, Spain
Longitude	17° 53' 31''W
Latitude	28° 45' 24'' N
Altitude	2400m
Median Seeing	0.7"
Atm. Transmission	~ 20% @ 310nm

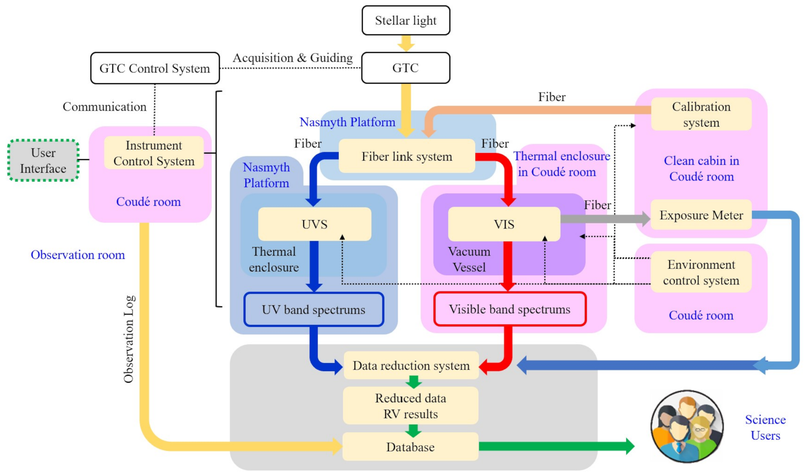
The project members include four institutes: National Astronomical Observatories, Chinese Academy of Sciences (NAOC) and Nanjing Institute of Astronomical Optics and Technologies (NIAOT) from China, and Instituto de Astrofísica de Canarias (IAC) and GRANTECAN S.A. from Spain. The feasibility study was started in 2017, and the design successfully passed the conceptual design review (CoDR) by an international committee in 2019. The instrument is expected to be installed in GTC by the year of 2026-2027.

CHORUS adopts a **dual-band** scheme to obtain a resolution of *R*~20,000 and high throughput in the UV band from 310 to 420 nm, while having a higher resolution (*R*>100,000) and a very stable environment in the visible band from 420 to 780 nm to conduct the precise RV measurement. The science cases using CHORUS include exoplanetary science, such as detecting habitable Earth-like planets around solar-like stars, confirming the transiting planets found by space missions such as TESS and PLATO, characterizing the planetary atmospheres, and measuring the star-planet obliquities. The UV band spectrograph enables a variety of studies, such as Beryllium abundance and nucleochronology.

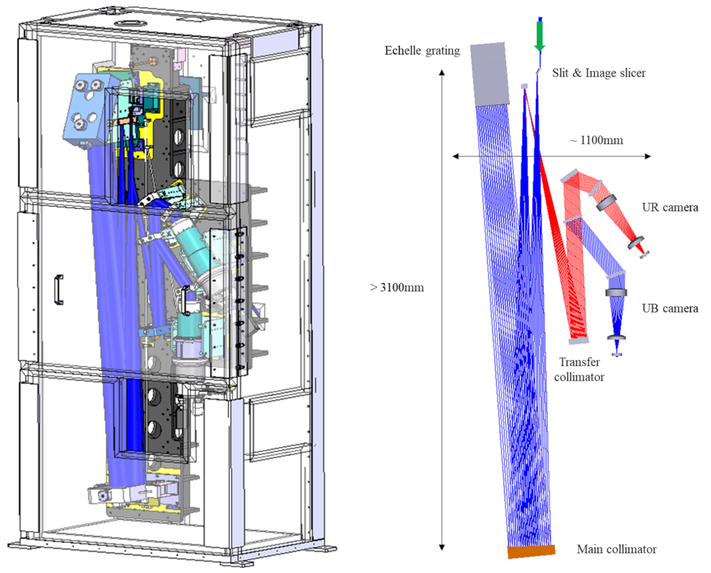
Technical Specifications

Spectrographs	UV band spectrograph	Visible band spectrograph
Spectral Resolution	*R* ≥ 20,000	*R* ≥ 100,000
Wavelength Coverage	310 – 420 nm	420 – 780 nm
Functionalities	conventional spectral observation, stellar activity monitoring with Ca II H&K in PRV measurement	Precise RV measurement (Goal: 0.1~0.3m/s)
Observation modes & Calibration Plan	Sky subtraction	Double-fiber Simultaneous Reference with ThAr/Astro-comb/FPC
Installing Location	near Nasmyth focus	Coudé room
Environment control	thermal enclosure without active control	vacuum vessel & thermal enclosure (~0.001K)
Detector	two 4K x 2K @ 15μm CCDs	two 9K x 9k @ 10μm CCDs

Instrument Overview



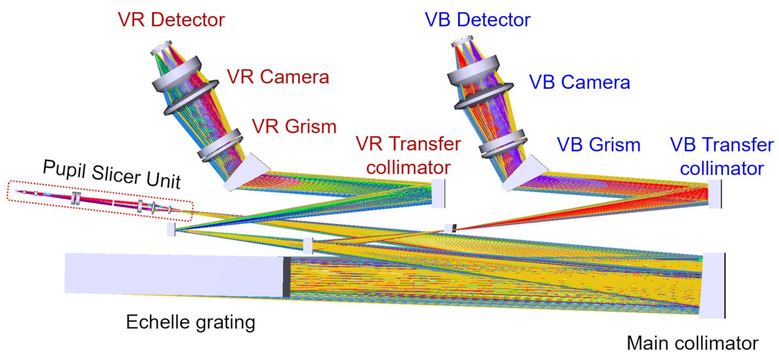
UV Band Spectrograph (UVS)



Opto-mechanical (left) and optical (right) designs of UVS

CHORUS has an independent UV band spectrograph (UVS) near the Nasmyth focus to get high throughput in the UV band. The UVS can monitor the stellar activities by Ca II H & K lines in PRV mode together with the visible band spectrograph (VIS). The short wave-length end (310 nm) enables the studies of some essential elements, such as beryllium (λ 313nm) and silver (λ 328/338nm). The UVS achieves the required spectral resolution under a reasonable sky aperture by combining an image slicer and an echelle grating. The image slicer splits the object image of Φ1.5" into 3 slices to get a spectral resolution close to 30,000.

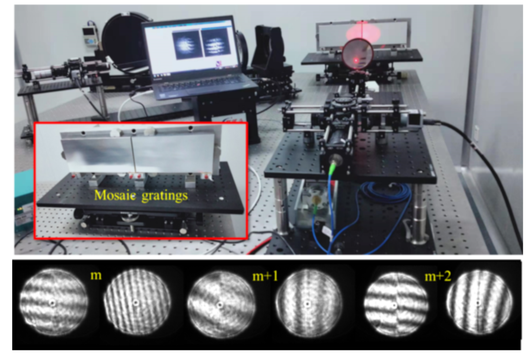
VIsible Band Spectrograph (VIS)



The optical design of the visible band spectrograph (VIS)

The visible band spectrograph (VIS) is the main component for precise RV measurements. It is a seeing-limited instrument with a spectral resolution of R≥100,000. The VIS adopts a white pupil optical design with a pupil slicer unit and two spectral channels (VB & VR) to cover the wavelength from 420 nm to 780 nm. A mosaic of three R4 echelle gratings will be used as the main disperser. Two fibers inject the stellar and calibration light into the spectrograph for simultaneous reference. To achieve a very good stability, the main part of VIS will be placed into a vacuum vessel with a thermal enclosure. The temperature stability inside the cryo-vacuum system is ~0.001K RMS, and the pressure is below 1×10E-3 mbar.

Vacuum vessel of the visible band spectrograph of CHORUS

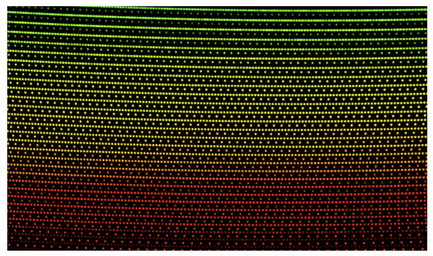


A small prototype of two mosaiced 100x200mm gratings has been successfully tested in the laboratory.

Calibration System for VIS

The calibration system for VIS contains 5 different light sources, including a broad-band laser frequency comb with a repetition rate of 18 GHz, to provide the wavelength reference. A Fabry-Perot (FP) etalon will be used in ordinary RV observations. A prototype of FP has been tested together with a Menlo astro-comb in a *R*~48,000 spectrograph (see image below).

Light Source	Usage
Astro Comb	Best RV precision < 1cm/s
ThAr - I	Daily reference
ThAr - II	Monitoring age effect
FP Etalon	Simultaneous reference
LDLS	Flat fielding correction



The science team of CHORUS includes members from the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), Nanjing Institute of Astronomical Optics and Technology (NIAOT), Department of Astronomy, Tsinghua University, Instituto de Astrofísica de Canarias (IAC), and GRANTECAN S.A. We sincerely welcome everyone who is interested in the related sciences to join us.