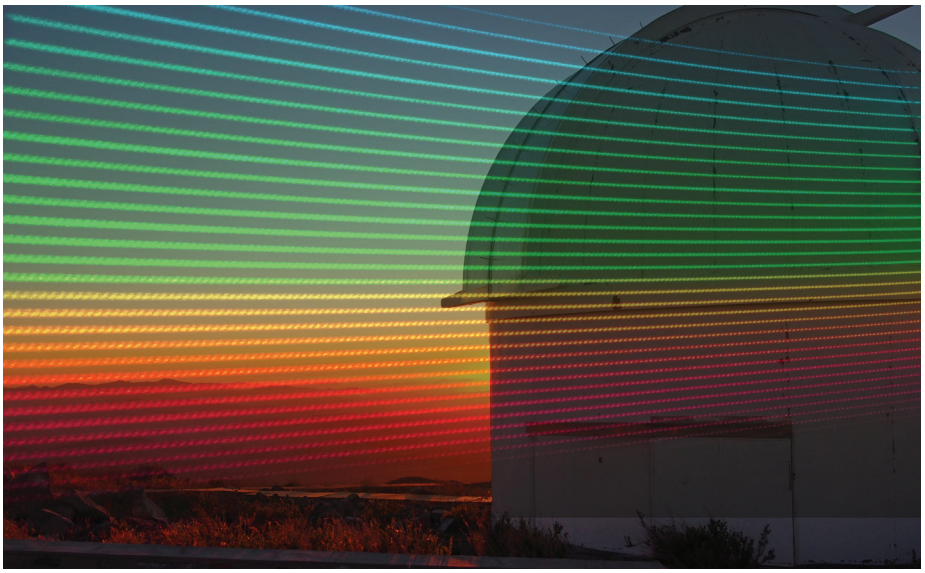
AstroComb

The Most Precise Calibration System for Astronomical Spectrographs

MenloSystems

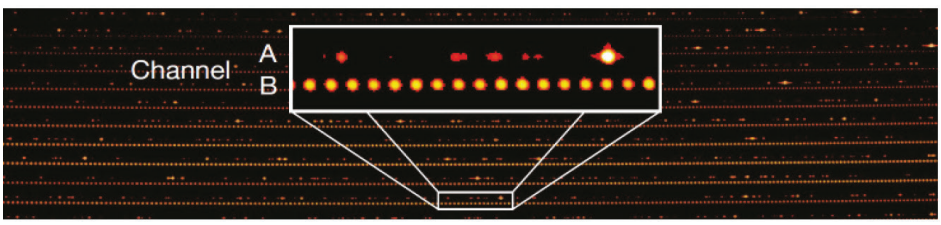


Artist view of the AstroComb spectrum superimposed over the La Silla Observatory (ESO)

SPECTROGRAPH CALIBRATION WITH THE ASTROCOMB

Accurate analysis of the light emitted or absorbed by celestial objects requires spectrographs, which must be precisely calibrated. AstroCombs provide a stable and known set of evenly spaced sharp spectral lines that act as reference points, enabling precise calibration of the spectrograph's wavelength scale. The comb-like pattern spreads across a wide wavelength range in the visible and near-infrared, and illuminates individual pixels of the spectrograph. The resulting high resolution provided by the AstroComb in any part of the spectrum cannot be achieved with traditional Thorium-Argon (ThAr) calibration lamps.

Calibration by AstroCombs is stable and repeatable, and reduces systematic errors, all of which is important for long-term observations and for comparing data taken at different times or by different instruments. E.g., the detection of exoplanets requires a precision of 5 cm/s over years, and the direct observation of the accelerated cosmic expansion requires 1 cm/s over decades. A high level of automation makes calibration by AstroCombs efficient and particulary benefits large-scale astronomical studies.



Echelle spectrum of a thorium-argon (ThAr) lamp (channel A) above the evenly-spaced modes of an AstroComb (channel B) at HARPS, ESO

RESEARCH OBJECTIVES

- Spectroscopy of the solar atmosphere
- Search for Earth-sized exoplanets
- Observation of variable stars and galaxies
- Cosmological redshift measurements
- Measurement of the cosmic expansion
- Search for variations of the universal constants

APPLICATIONS

- High-resolution spectroscopy
- High-precision radial velocity measurements
- Near-infrared spectroscopy

KEY FEATURES

- Collaborative system integration with subsequent turn-key operation
- Regular line spacing
- Radial velocity resolution <2.5 cm/s
- Tunable line positions to illuminate each CCD pixel
- Uniform output spectrum, adaptable to spectrograph sensitivity
- Reference frequency given by atomic clock
- High long-term stability, state-of-the-art short-term stability

SYSTEMS IN OPERATION

- LARS, VTT, Teneriffe, ES
- FOCES, Wendelstein Observatory, DE
- Xinglong National Astronomical Observatory, CN
- HARPS, La Silla Observatory, CL
- ESPRESSO, Paranal Observatory, CL
- EXPRES, Lowell Observatory, US
- VELOCE, Anglo-Australian Telescope, AU
- NEID, Kitt Peak Observatory, US
- SPIRou, CFHT, Hawaii, US
- KPF, Keck Observatory, Hawaii, US
- MAROON-X, Gemini Observatory, Hawaii, US

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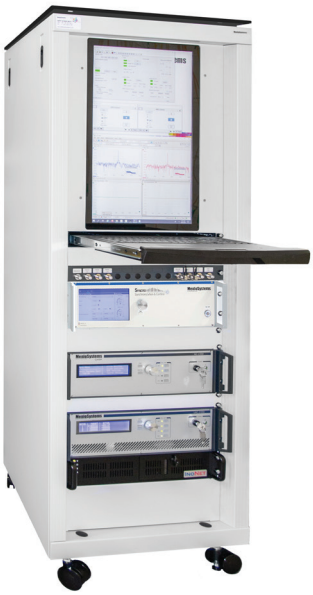
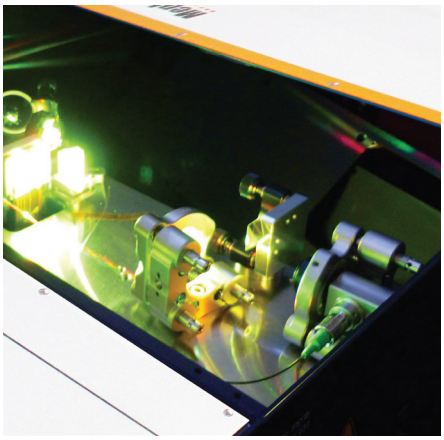
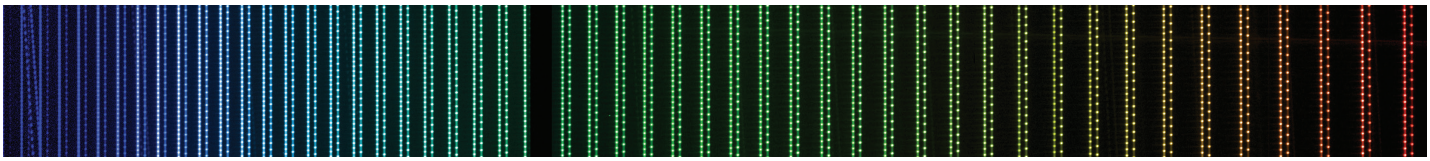
SYSTEM COMPONENTS





Oscillator with CEO stabilization above and filtering cavities below (left), AstroComb system control rack (center), and the spectral flattening unit (right)

The AstroComb is a complete solution for spectrograph calibration in the visible and near-infrared spectral range. The system contains an optical frequency comb, a filter unit to adjust the comb mode spacing to the resolution of the spectrograph, an amplifier and spectral broadening unit, spectral flattening units for unstructured spectral characteristics, and system operation electronics with software for full automation and remote control. An atomic clock serves as a reference to transfer its accuracy and stability to all frequency comb modes.



Example of an echelle spectrum measured at the HARPS spectrograph at the ESO 3.6-metre telescope at the La Silla Observatory in Chile. The outputs from two independent laser frequency combs were coupled to the two channels of the high-resolution spectrograph. Image credit: ESO

ASTROCOMB - FROM PLANNING TO ROUTINE OPERATION

Due to its high flexibility of configuration, the AstroComb's unrivaled performance is available for both newly-commissioned high-resolution spectrographs and as an upgrade for calibration sources of existing spectrographs. A sophisticated design process, characterized by close collaboration between the user facility and Menlo Systems, precedes each system installation and is key to successful system operation. The system features and specifications are tailored to address an observatory's specific instrumentation and research interests, providing the spectral range, comb mode spacing, and optical power required. A requisite service contract ensures continuous support by Menlo Systems' experts, including on-site visits. With maturing user experience the AstroComb system operation becomes truly turn-key.

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MENLO SYSTEMS CONTINUING EXPERTISE

Menlo Systems' expertise and continuing research interests in the field of astronomy are reflected in numerous co-authorships of its customers' scientific publications. The company's technological competence is demonstrated by proprietary patents.

CO-AUTHORSHIP IN SCIENTIFIC PUBLICATIONS

The solar gravitational redshift from HARPS-LFC Moon spectra - A test of the general theory of relativity
J. I. González Hernández et al., *Astronomy & Astrophysics* Vol. 643, A146 (2020)

A crucial test for astronomical spectrograph calibration with frequency combs
R. A. Probst et al., *Nature Astronomy* Vol. 4, p. 603 (2020)

LARS: An Absolute Reference Spectrograph for solar observations - Upgrade from a prototype to a turn-key system
J. Löhner-Böttcher et al., *Astronomy & Astrophysics* Vol. 607, A12 (2017)

A compact echelle spectrograph for characterization of astro-combs
R. A. Probst et al., *Appl. Phys. B* 123, p. 76 (2017)

State of the Field: Extreme Precision Radial Velocities
D. A. Fischer et al., *Publications of the Astronomical Society of the Pacific* Vol. 128, p. 066001 (2016)

Comb-calibrated solar spectroscopy through a multiplexed single-mode fiber channel
R. A. Probst et al., *New Journal of Physics* Vol. 17, p. 023048 (2015)

A frequency comb calibrated solar atlas
P. Molaro et al., *Astronomy & Astrophysics* Vol. 560, A61 (2013)

A Laser Frequency Comb System for Absolute Calibration of the VTT Echelle Spectrograph
H.-P. Doerr et al., *Solar Physics* Vol. 280, p. 663 (2012)

Astronomical Spectrograph Calibration at the Exo-Earth Detection Limit
G. Lo Curto et al., *ESO The Messenger* Vol. 149, p. 2 (2012)

A spectrograph for exoplanet observations calibrated at the centimetre-per-second level
T. Wilken et al., *Nature* Vol. 485, p. 611 (2012)

Laser Frequency Combs for Astronomical Observations
T. Steinmetz et al., *Science* Vol. 321, p. 1335 (2008)

"High-precision calibration of high-resolution spectrographs is essential for the search for exoplanets. The AstroComb was a significant breakthrough in the field of astronomical instrumentation and has revolutionized the precision and accuracy of spectroscopic measurements in astronomy."

Dr. Tilo Steinmetz,
Product Manager AstroCombs

TECHNOLOGY PROTECTED BY PATENTS

US6785303, US6724788, US7026594, DE10044404, US7804863, US8995796, US8873601, JP4668423, JP5615397, CN103311780

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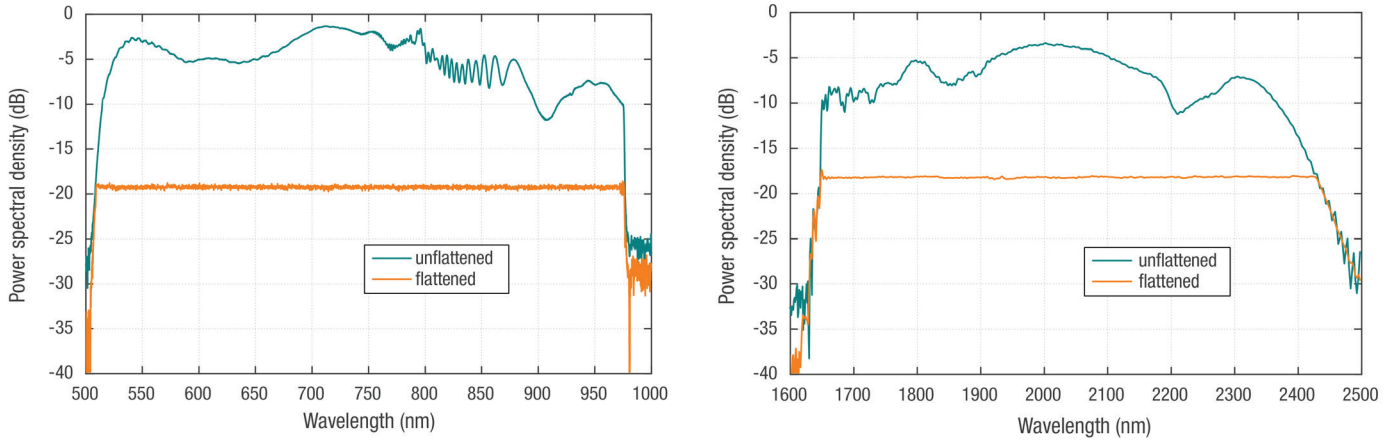
RANGE OF SPECIFICATIONS



Output spectrum of a visible (left) and an infrared (right) AstroComb, before and after spectral flattening.

PARAMETER	CONFIGURATION RANGE
Optical output spectrum	VIS: 450 – 1000 nm* NIR: 1.0 – 2.3 µm*
Mode Spacing	10 - 25 GHz*
Accuracy	3 x 10^{-14} in 100 s**
Stability	1 x 10^{-12} in 1 s**
Optical power per spectral line	>10 nW after spectral flattening (at 18 GHz mode spacing)

** others available on request*

*** or same as reference, whichever applies first*

ORDERING INFORMATION

Product Code	AstroComb

Please call for pricing. Specifications are subject to change without notice. Custom modifications are available, please inquire.

Invisible laser radiation
avoid exposure to beam
Class 4 laser

Menlo Systems GmbH
T+49 89 189 166 0
sales@menlosystems.com

Menlo Systems US
T+1 303 635 6406
ussales@menlosystems.com

Menlo Systems Japan
T+81 907 409 20 21
jpsales@menlosystems.com

Menlo Systems China
T+86 21 6071 1678
chinasales@menlosystems.com