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CFH

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Annex 1
Scientific Capabilities of the Canada-France-Hawai'i Telescope

For more information about the current suite of instrumentation at CFHT, please contact
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1 An Exceptional Observatory on an Exceptional Site

Located on Hawai'i Island near the 4,200-meter summit of Maunakea, the Canada-France-Hawai'i Telescope (CFHT, Figure 1) hosts a world-class, 3.6-meter optical and infrared telescope, one of the most scientifically productive 4-meter-class optical telescopes in the world. From proposal preparation to easily accessible, science-ready data, CFHT's science operations are tailored to help our partners achieve their science goals. Annex 1 details the synergistic combination of instrumentation, observing processes, and unique features that make CFHT so exceptional.

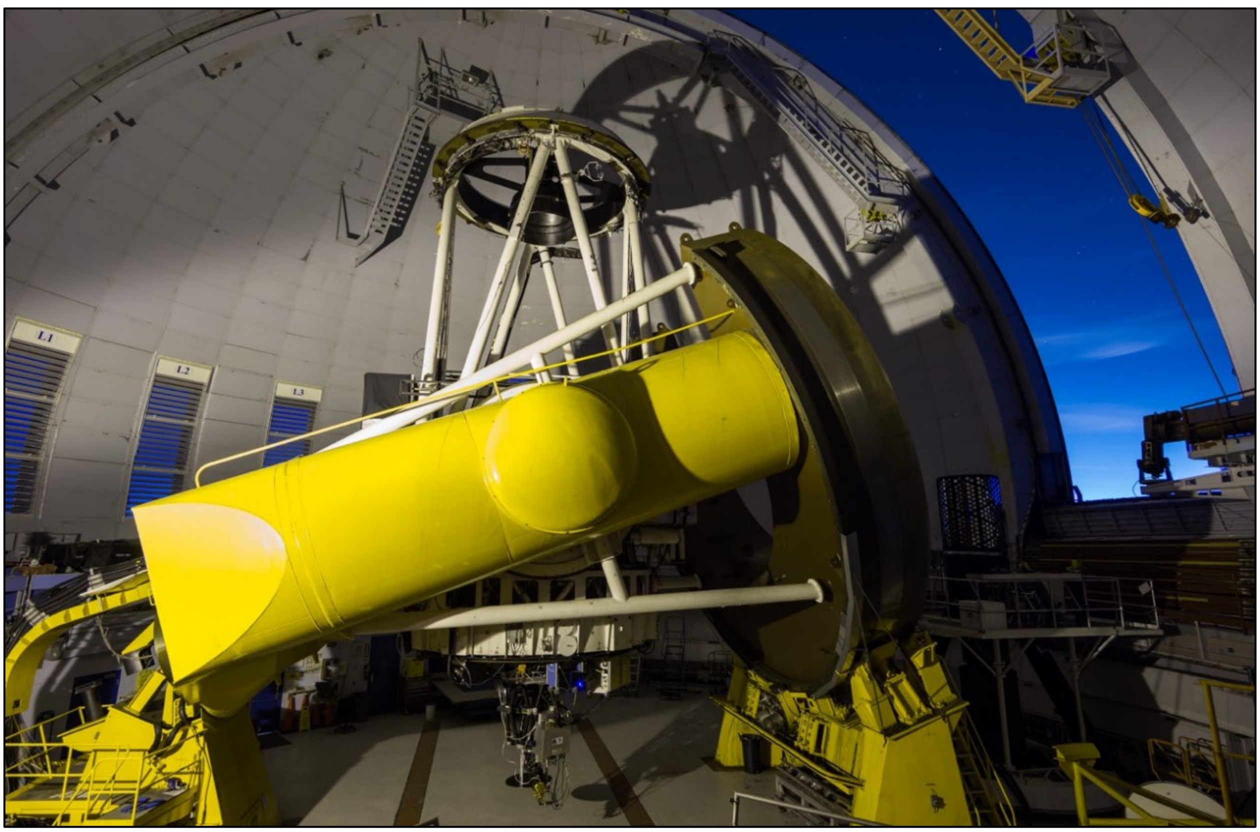

Figure 1: The Canada-France-Hawai'i Telescope [Credit: CFHT]

2 CFHT Instrument Characteristics

Five instruments are currently available at CFHT: MegaCam, a wide field of view (FOV) optical imager; WIRCam, a wide FOV infrared imager; ESPaDOnS, a high-resolution (R=68,000) optical spectrograph and spectropolarimeter; SITELLE, an optical imaging Fourier transform spectrometer (IFTS); and SPIRou, a near-infrared spectrograph and spectropolarimeter with high radial-velocity precision that can reach 1 m/s. All instruments benefit from exquisite sub-arcsec seeing conditions frequently observed from Maunakea.

Instrument	Type	FOV/Spectral Resolution	Wavelength Range	Pixel Scale
MegaCam	Imaging	1° x 1°	311 – 1002 nm (50% transmission)	0.19" pix^{-1}
WIRCam	Imaging	21.5' x 21.5'	1076 – 1987 nm (50% transmission)	0.31" pix^{-1}
ESPaDOnS	Spectropolarimeter	1.6" aperture hole R= 68,000 – 81,000	369 – 1048 nm	1.8 km s^{-1}
SITELLE	IFU/Imaging Fourier Transform Spectrometer	11' x 11' R= 1 – 10,000	350 – 900 nm	0.32" pix^{-1}
SPIRou	Spectropolarimeter	1.3" aperture hole R= 75,000	967 – 2493 nm	2.3 km s^{-1}

Table 1: Attributes of CFHT's current suite of instrumentation

3 Queued Service Observing

CFHT provides full user support for the data collection process from proposal submission to observations and data reduction. CFHT partners rank the programs submitted by their agency, identifying and prioritizing the observations.

CFHT executes all observations under a Queued Service Observing (QSO) mode, planning and performing observations within the specifications given by the science investigators. CFHT observes more than 80% of high-priority programs within their science requirements.

CFHT accommodates programs spanning anywhere from a few minutes to several semesters. Targets can be monitored at any cadence, from multiple times per night to a few times per semester. CFHT also observes time-sensitive events such as exoplanet transits and allows for Target of Opportunity observations, e.g., gravitational waves. For further information, please visit the QSO website.

Figure 2: Stephen's Quintet in LSB mode [Credit: CFHT, Duc, and Cuillandre]

4 Data Processing and Archiving Services

CFHT removes instrumental signatures from all raw data and delivers reduced, calibrated data products. The Canadian Astronomy Data Centre (CADC) archives CFHT's raw, processed, and calibrated observations and datasets. Additionally, CADC offers a unique suite of state-of-the-art computing infrastructures and data mining, processing, and distribution expertise. All CFHT data are publicly available after a one-year proprietary period. With MegaCam, a Low Surface Brightness (LSB) mode is available down to 28.5 mag arcsec^{-2} (AB) in the *g*-band, as demonstrated in Figure 2.

5 CFHT Publications

CFHT's scientific productivity regularly exceeds 200 peer-reviewed publications annually (Figure 3), a reflection of Maunakea's extraordinary seeing (a median of 0.65'' at 600 nm) combined with CFHT's QSO, powerful instrumentation, data reduction pipelines, and staff expertise. In conjunction with other observatories, CFHT's datasets have enabled breakthrough discoveries and precursor science for flagship space missions.

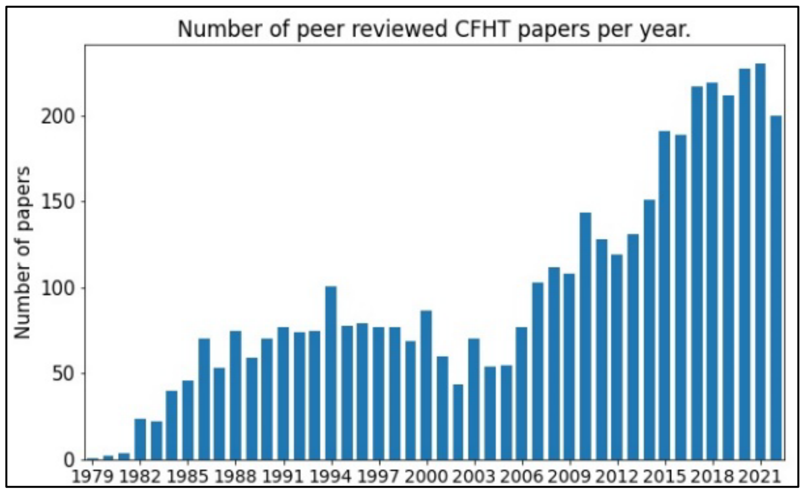

Figure 3: CFHT publication rate since first light

6 Science with CFHT's Suite of Instrumentation

MegaCam

MegaCam is a wide-field, optical imager mounted on the telescope during 10-to-18 nights of dark time per month. Executing a wide variety of science programs ranging from moving targets to *u*-band wide-field surveys, MegaCam is CFHT's workhorse instrument, accounting for approximately half of the refereed papers per year. As a critical part of the preparation for the EUCLID mission, members of the UNIONS collaboration recently used MegaCam data to compile one of the largest catalogs of gravitationally-lensed galaxies. Figure 4 is typical of the UNIONS data set, representing 1/10,000 of the survey area.

The current set of MegaCam filters includes broadband (*u, g, r, i, z*), narrowband (Hα, Hα-OFF, OIII, OIII-OFF, Ca-HK), and an ultrawide *gri* filter. MegaCam reaches a limiting magnitude of 25.3 (AB) at 10σ in the *u*-band on a point-source for a one-hour exposure under dark sky conditions and 0.8'' seeing.

Figure 4: A $1^0 \times 0.5^0$ *image of the sky representing a subset of the UNIONS large program at CFHT using MegaCam [Credit: CFIS-UNIONS / CFHT / J.-C. Cuillandre]*

WIRCam

WIRCam is CFHT's near-infrared mosaic imager, equipped with four 2k x 2k pixel H2RG detectors. The combination of WIRCam and MegaCam on a world-class site enables CFHT's unparalleled ultraviolet-to-infrared wide-field imaging capability. WIRCam can perform milli-magnitude photometry and high-precision astrometry, enabling science programs ranging from high-quality nebulae imaging to searches for faint brown dwarfs. WIRCam's high astrometric accuracy and sensitivity were essential in directly imaging exoplanet 2MASSJ0249-0557c (Figure 5), located 2,000 AU from its host binary brown dwarfs. The planet is a virtual twin to Beta Pictoris b.

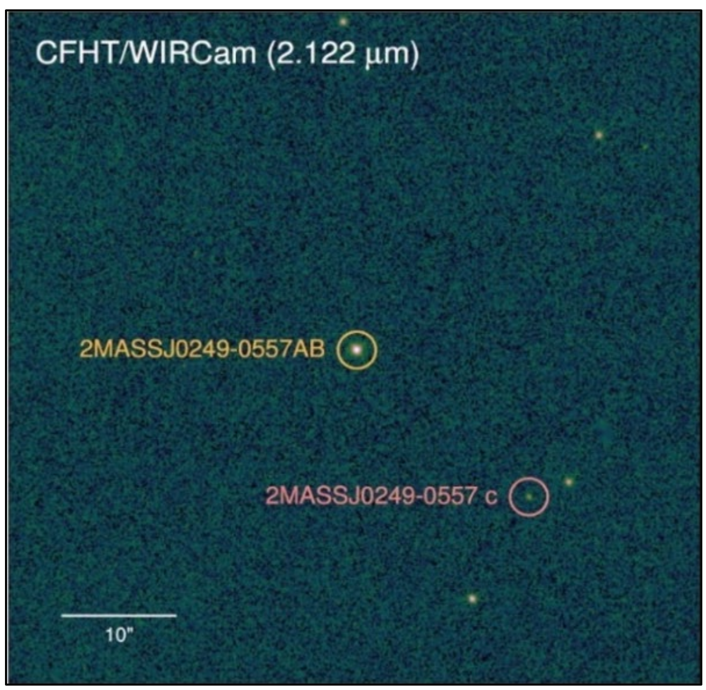

Figure 5: Image of 2MASS 0249 system [Credit: CFHT]

The current suite of WIRcam filters includes broadband (Y, J, H, Ks) and narrowband (LowOH-2, LowOH-1, W, CH4On, CH4Off, K continuum, H2, Brγ, CO) filters. WIRCAM reaches a limiting magnitude of 23.3 (Vega) at 5σ in the *H*-band on a point-source for an exposure time of 1-hour and 0.7'' seeing.

SITELLE

SITELLE produces 3D data cubes consisting of one spectrum for each of its 4.2 million pixels. Each pixel (the x, y dimensions of the cube) has an associated interferogram generated by a Michelson scanning interferometer. Each interferogram, once reduced, produces a spectrum in the z dimension of the reduced cube. In addition to the measurements of the dynamics and chemical abundances of extended nebulae, SITELLE also enables measurements of the dynamics and star formation rate of galaxies. SITELLE's unique capabilities led to the creation of a realistic three-dimensional reconstruction of the Crab Nebula from high-resolution (9,600) spectra of every single point of the nebula (Figure 6).

The current suite of filters covers wavelengths relevant to numerous emission lines studies. The spectral resolution is user-selectable and reaches R=10,000. The Hα line sensitivity in the SN3 filter at a resolution of 5,000 is 4 10^{-17} erg s^{-1} cm^{-2} $arcsec^{-2}$ in 4-hours under dark sky conditions and 0.8'' seeing.

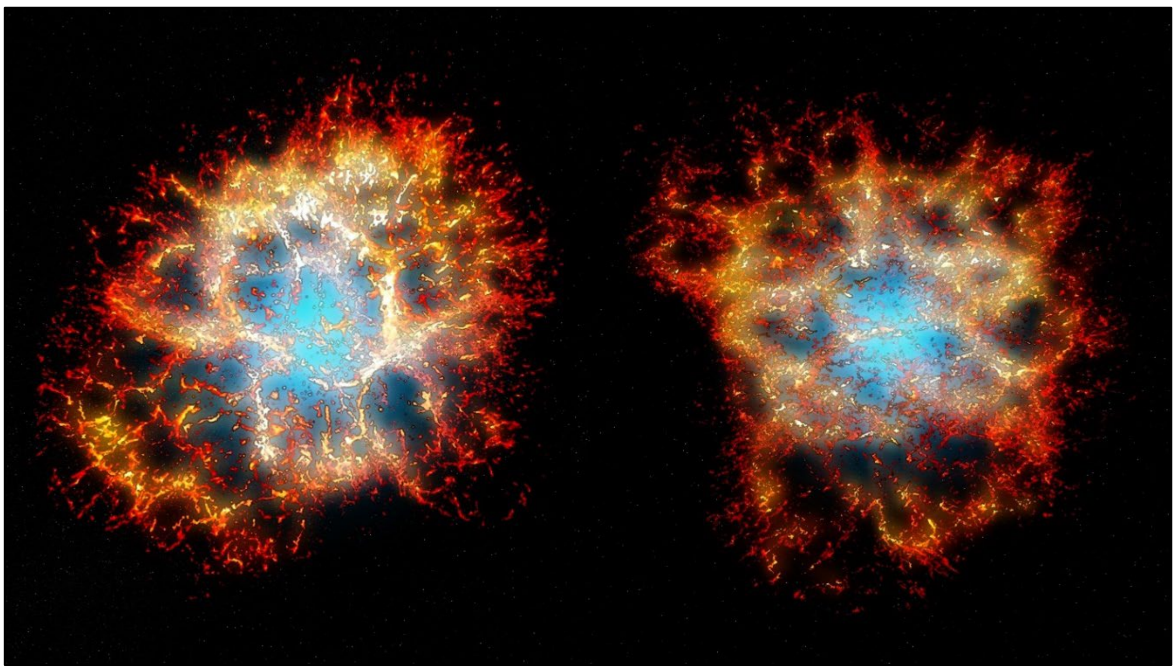

Figure 6: 3D reconstruction of the Crab Nebula remnant as seen from Earth (left) and another point of view showing its heart-shaped morphology (right) [Credit: Martin, Milisavljevic, and Drissen]

SPIRou

SPIRou is a state-of-the-art, fiber-fed, infrared spectropolarimeter and high-precision velocimeter specifically designed to detect potentially habitable earth-like exoplanets around low-mass stars.
SPIRou provides excellent follow-up of space-based missions like TESS, enabling the measurement of mass, density, and orbital tilt of transit-detected planets. Its unique combination of velocimetric and spectropolarimetric capabilities enables the detection of the host star's magnetic field, unveiling planets otherwise hidden in the noise. For example, SPIRou was instrumental in characterizing the properties of the Neptune-like planet AuMic b. The curves in Figure 7 depict the probability of a periodic oscillation present in the AuMic SPIRou radial velocity (RV) data. Once the periodic RV signal caused by the activity of the rotating star (at a

period of 4.86 days) is removed, the signal induced by the planet (at a period of 8.46 days) clearly appears at a confidence level higher than 99.9%.
Equipped with a 16.8-million-pixel H4RG detector, SPIRou produces near-IR spectra ranging

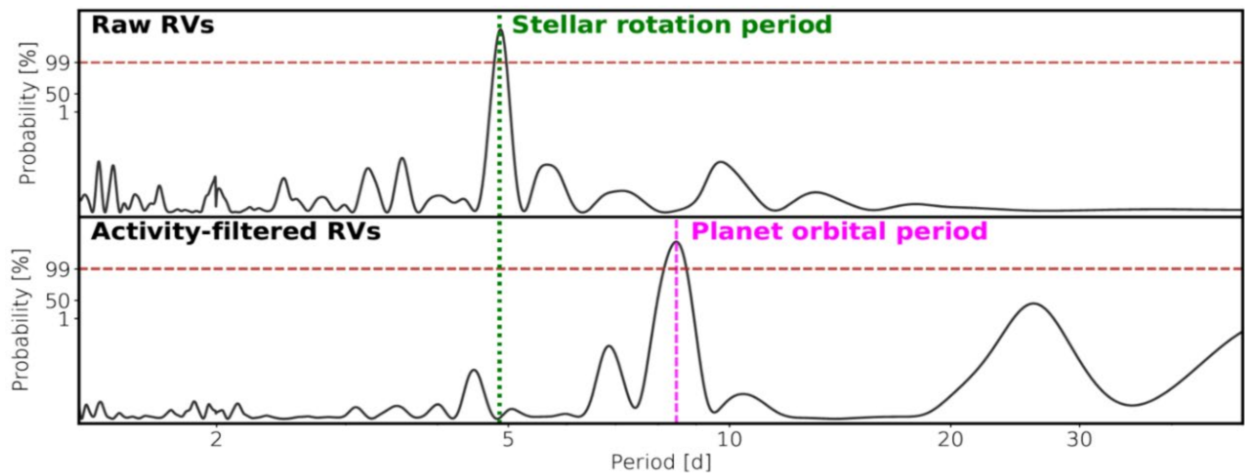

Figure 7: Probability curves of the AUMic radial velocity measurements from SPIRou [Graph Credit: B. Klein]

from 0.95 to 2.35 microns at a spectral resolution of up to 75,000. SPIRou measures spectra of stars with an *H*-band magnitude (Vega) of ~3 at a signal-to-noise ratio (SNR) of 300 in 30 s, or with an *H*-band magnitude of ~15 at an SNR of 5 in 1 h. The radial velocity precision is 1 m s^{-1} with adequate data processing.

ESPaDOnS

ESPaDOnS is a fiber-fed, high-resolution échelle spectrograph and spectropolarimeter. Compared to spectroscopy alone, ESPaDOnS' spectropolarimetric capabilities increase the sensitivity to and detection of magnetic fields by over two orders of magnitude, facilitating the characterization of magnetic fields in white dwarfs (Figure 8).

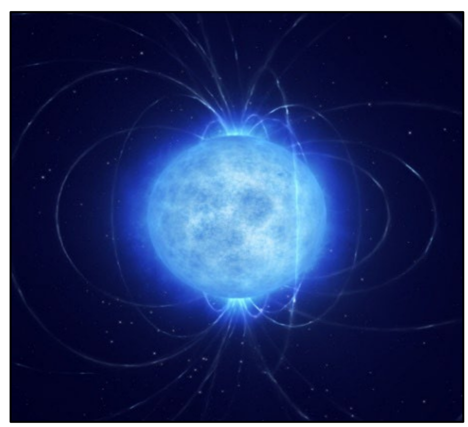

Figure 8: Artist's rendering of the magnetic field of a white dwarf [Credit: ESO/L Calçada]

ESPaDOnS produces optical spectra with a resolving power between 68,000 and 81,000. The instrument measures spectra of stars with a *V*-band magnitude (Vega) of`~ 16 at an SNR of 10 in 25 min. The radial velocity precision can reach ~ 20 m s^{-1} using telluric lines imprinted in the spectra.

VISION

CFHT is developing VISION, a powerful NUV to NIR high-resolution spectrograph that will enhance CFHT's spectroscopic and spectropolarimetric capabilities. The instrument will allow the simultaneous use of ESPaDOnS and SPIRou, offering unique data coverage from 0.37 µm to 2.44 µm and resolutions above 70,000. VISION is expected to be fully implemented in 2025.