Mini-HaWKs

A pilot survey designed to discover new quiescent black holes

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Abstract

One of the main challenges in understanding stellar-mass black holes (BHs) is the lack of observational data, since most galactic BHs have been detected via X-ray outbursts and therefore constitute a small and biased sample. To overcome this limitation and accelerate the rate of BH discovery, the HaWKs project was designed, with Mini-HaWKs serving as its pathfinder. Mini-HaWKs is a pilot photometric survey covering 50 square degrees of the Northern Galactic Plane, with 400 hours of guaranteed time, currently being carried out with the JAST80 telescope at the Observatorio de Javalambre. It uses three interference filters centred on H-alpha, which allow the recovery of the full-width at half-maximum (FWHM) and equivalent widths (EW) of H-alpha line photometrically. This information can be used to efficiently identify quiescent BH candidates through colour–colour diagrams and light curves constructed solely from the H-alpha measurements. This method relies on the fact that very broad H-alpha emission lines (FWHM $\gtrsim$ 2200 km s^{-1}) are indicative of the strong gravitational fields surrounding compact objects. This strategy is promising not only for discovering new BHs, but also for identifying a wide range of other stellar populations, such as cataclysmic variables (CVs), Mira variables, and Wolf-Rayet stars, among others, providing valuable data for multiple lines of research. Commissioning observations have already enabled the discovery of a new CV and a Green Pea galaxy, highlighting the broad scientific potential of the Mini-HaWKs survey.

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A Hidden Population of Dormant Black Holes

In 60 years of X-ray astronomy, 72 X-ray transients (XRTs) hosting BH candidates have been discovered but only **~30% are dynamically confirmed**. This is the tip of the iceberg of a large **hidden population of ≈10^3-10^4 quiescent BHs**. **≈200 yr are required to increase number of confirmed BHs by a factor of 10.** We need more efficient methods**.**

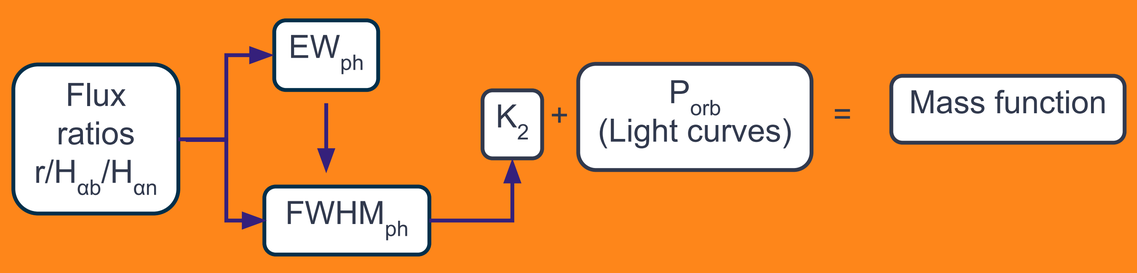
HaWKS STRATEGY

HaWKs (H-alpha Width Kilo-degree Survey)

It is a photometric survey optimized to detect broad Hα emitters in the Galactic Plane

With the flux ratios of 3 narrow filters centred on Hα (35Å / 150Å / 350Å) we can recover photometrically the EW and FWHM.

The key: **FWHM(Hα) as a proxy for deep gravitational fields around BHs**



We efficiently select BH candidates with a photometric mass function > 3, well segregated from CVs.

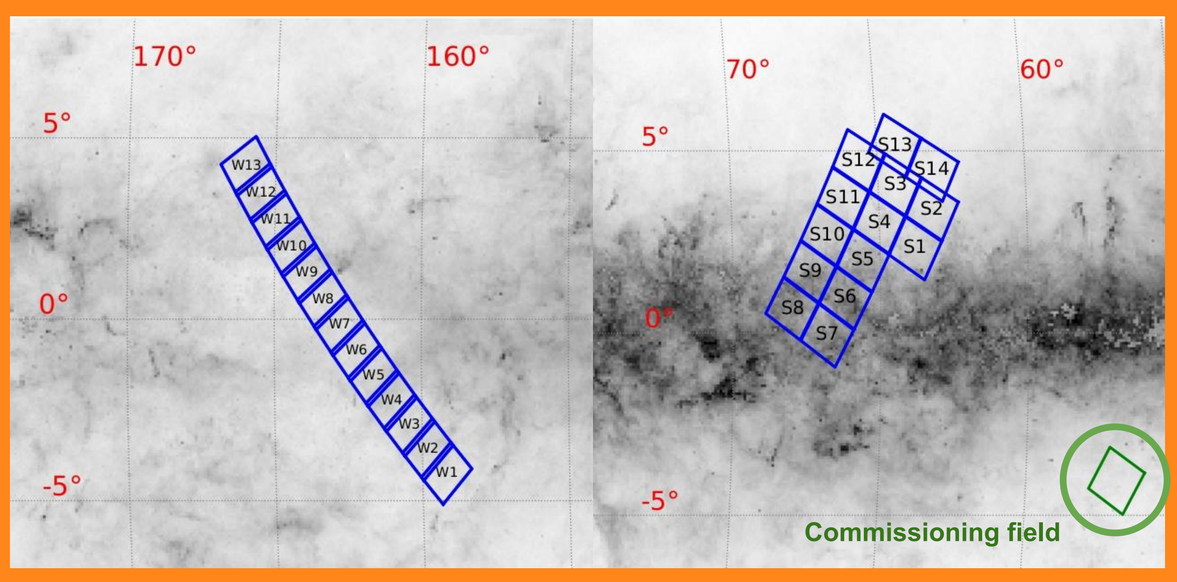
The survey will cover ~3000 sq degrees in the Galactic Plane down to R~21 and will deliver **~150 new BHs**.

We expect a 10× increase in the known quiescent BH population.

Mini-HaWKs

50 deg^2 pathfinder & Legacy Survey (400 h) **test of *HaWKs* observing strategy**

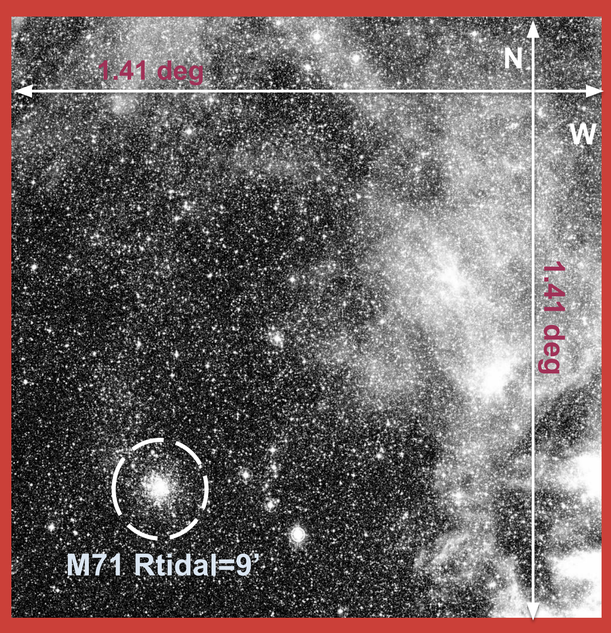
Footprint:



Hα350/Hα150/Hα35 filters: goal SNR ~ 50 at R ~ 21 in the 3 filters 40 cycles of 120/280/3x400 s to avoid bright star saturation → **20 h light curves** will detect variables (such as eclipsing CVs) and allow to obtain ***P*$_{orb}$ information.**

Will deliver ≈10^2 CVs & ≈10^3 Hα emitters (Be, T Tauri, Symbiotics, etc.)

COMMISSIONING FIELD

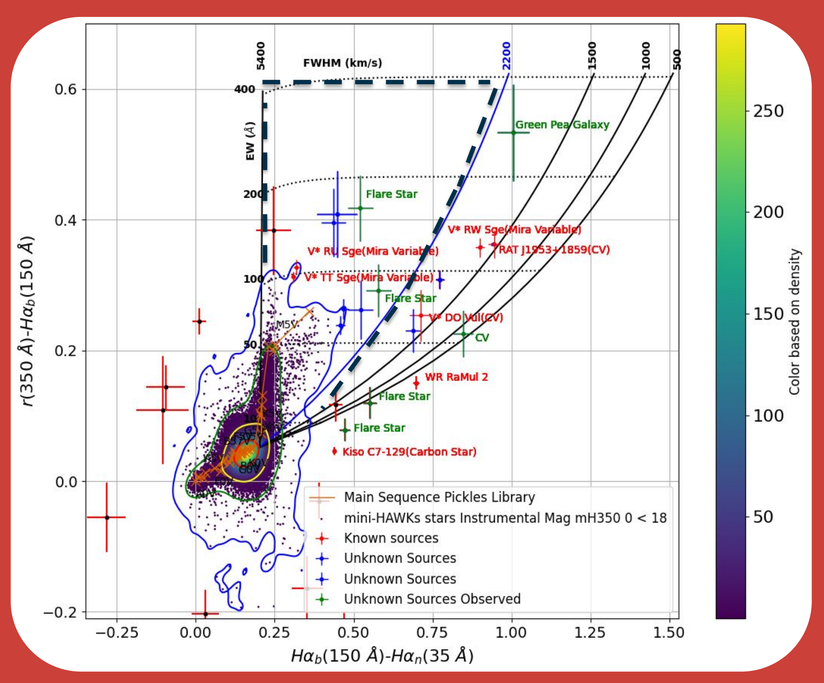


A pointing near the Galactic Plane including the globular cluster M71

Testbed of *Mini-HaWKs* observing strategy & photometric analysis (including variability) in crowded fields (b=-4.6°)

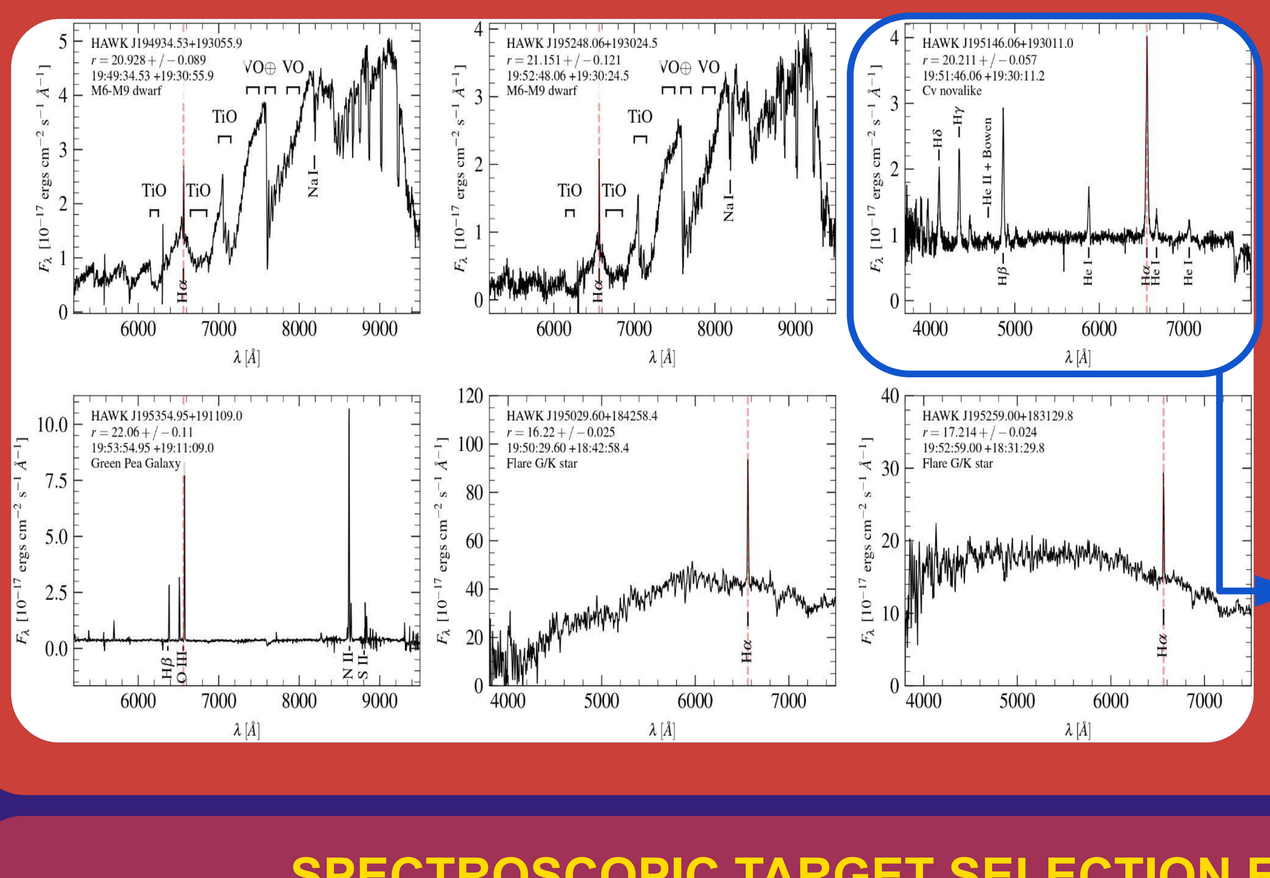
- ✔ M71 is relatively close (4 kpc).
- ✔ Hubble (UV) and Chandra (X-ray) observations.
- ✔ Overlap with the surveys IPHAS and UVEX.
- ✔ 2 known CVs in the field.

Observing strategy:
6 hr integration (S/N=50 at R=20)
40 × 400/93/40 s in Hα35/Hα150/Hα350



Hα Colour-Colour Diagram

The **main advantage** of this diagram is that the position of the targets is **independent of reddening and the stellar spectral energy distribution**. This feature represents a significant improvement over other Hα surveys, where EW is often degenerate with interstellar extinction.



Candidate selection & follow-up spectroscopy

From **~800,000 stars**, we selected **20 interesting Hα-excess sources**, including known emitters — **Mira variables, a carbon star, a Wolf-Rayet and CVs** — and new candidates such as **nova-like CVs, flare stars and a Green Pea galaxy**.

Possible Outliers in the BHs candidate region (FWHM>2200 km/s):

- CVs with ***FWHM*>2200** km/s must have $P_{orb} \lesssim$ 2.1 h and high inclinations. Detected through eclipses !!
- AGNs: we will use mid-IR **WISE** colours to distinguish them from black hole candidates.
- M-flare stars: broad absorption bands + chromospheric emission in H-alpha. Very red and nearby objects will be distinguishable through red colours and Gaia parallaxes.

Discovery of a nova-like Cataclysmic Variable

Hα photometry suggests **Porb ≈ 3.4 h**. GTC/OSIRIS spectra show broad Balmer and He I emission lines, **FWHM(Hα) = 1150 km/s**, **EW(Hα) = 91 Å**, plus weak He II 4686 and Bowen emission. The presence of eclipses, broad single-peaked emission lines and lack of outburst are typical of **SW Sex-type nova-like CVs.**

SPECTROSCOPIC TARGET SELECTION FROM THE MINI-HaWKS POINTINGS

Observations of six mini-HaWKS fields — two winter and four summer fields — have now been completed. To reduce contamination from red stellar populations, including Mira variables and active late-type stars, we excluded sources with (r − i) > 2, (i − z) > 0.6, or (r − K) > 4.

Follow-up sample: ~100 WEAVE targets · ~20 bright NOT targets · fainter candidates for GTC

These observations will classify the selected emitters, test and refine our photometric criteria, and may uncover new accreting binaries.

Could the next quiescent black hole be among them?

References: Casares, J. 2018, MNRAS, 473, 5195; Casares, J., & Torres, M.A.P. 2018, MNRAS, 481, 4372; Navarro Umpiérrez S., et al., 2025, The Astronomer's Telegram, 17442, 1