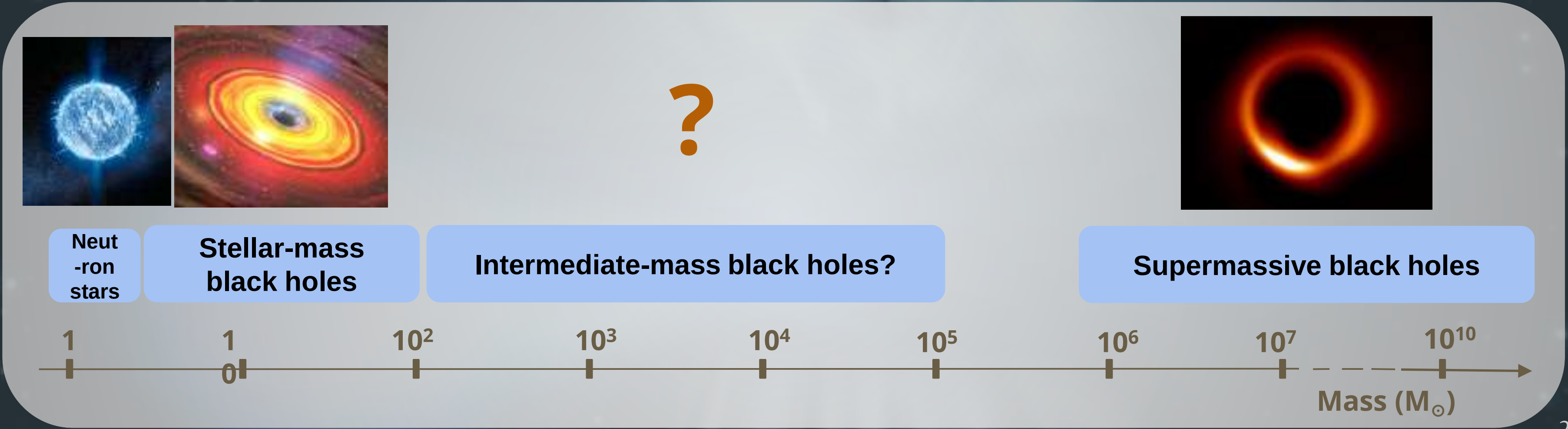
NGC 253 ULX1: Bubble of ionized gas and optical/NIR counterpart …

Anastasia Kilina, Olivier Godet
Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse

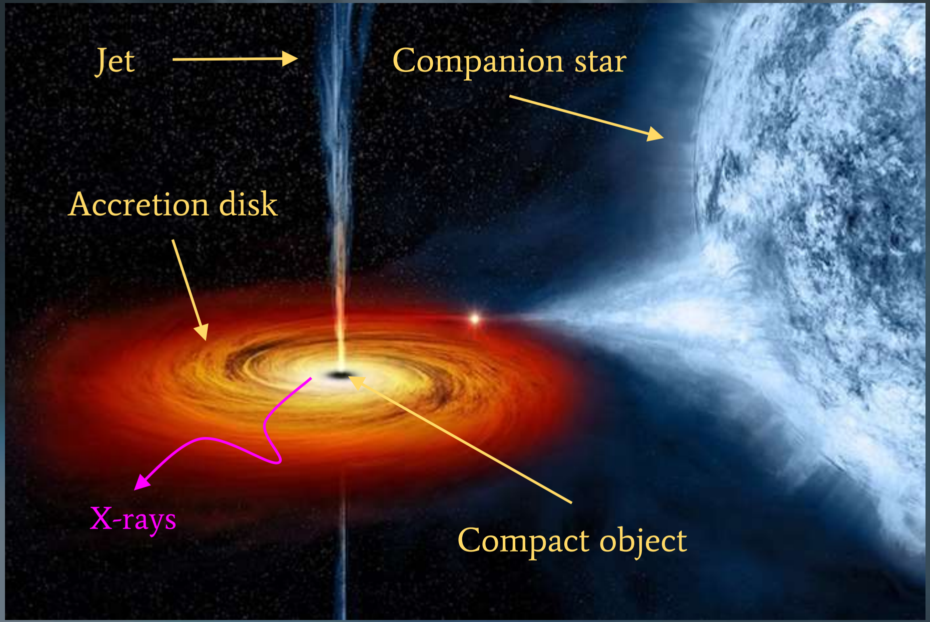
Compact objects

- **Supermassive Black Holes:** formation process and growth are not quite understood, they are found **very early after the Big Bang** (earlier than 1 Gyr after) *(Larson et al. 2023)*
- Formation scenarii:
  - ➢ Fusion of **Intermediate-mass Black Holes** (*Mezcua 2017*)
  - ➢ **Sustained high accretion rate** (super-Eddington) (*Pinto, Middleton, Fabian 2016*)
- Early = far → Difficult to observe → Need local laboratories: **ULXs**



Henning Dalhoff/Science Photo Library; NASA; NOIRLab.

Accretion



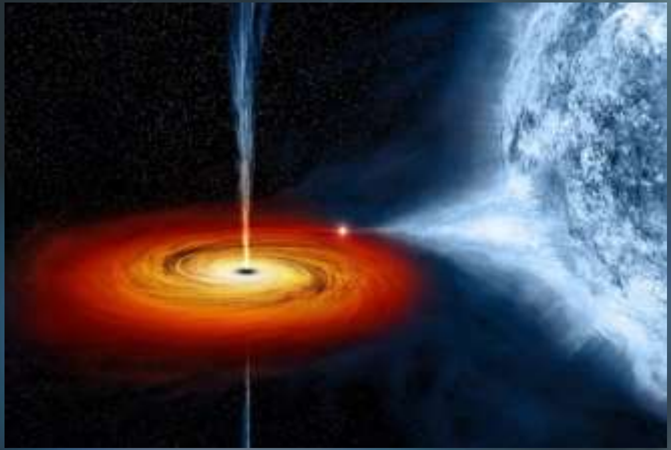
An artist's impression of an X-ray Binary.
NASA/CXC/M.Weiss.

Eddington limit

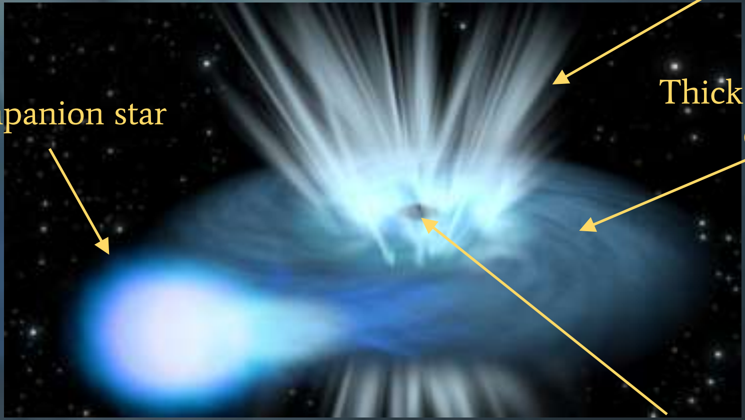
- **Eddington Luminosity:** maximum luminosity for a celestial object to be at the hydrostatic equilibrium between radiation pressure and gravity.

$$L_{Edd} = 3 \times 10^{38} \left(\frac{M}{10\,\mathrm{M}_{\odot}} \right) \mathrm{erg/s}$$

Sub-Eddington regime



Super-Eddington regime



NASA/CXC/M.Weiss. ESA–C. Carreau.

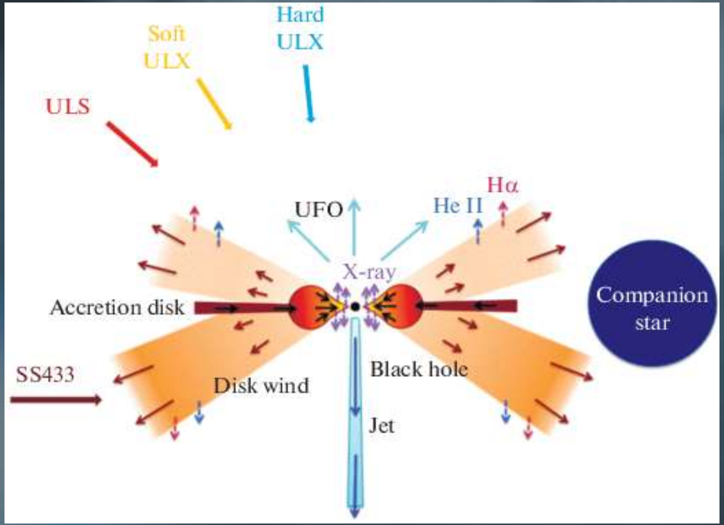
Ultraluminous X-ray sources (ULXs) (*Kaaret et al. 2017*)

- Non-nuclear extragalactic sources
- Mostly **high mass X-ray binaries**
- **X-ray luminosity:** $L_X > 10^{39}$ erg/s
- Explained by **sustained super-Eddington accretion**
  - Some ULXs pulsate → neutron stars
  - Presence of mildly relativistic (0.2-0.3c) winds

Accretion disk and winds from a ULX. *ESA–C. Carreau.*

Viewing angle

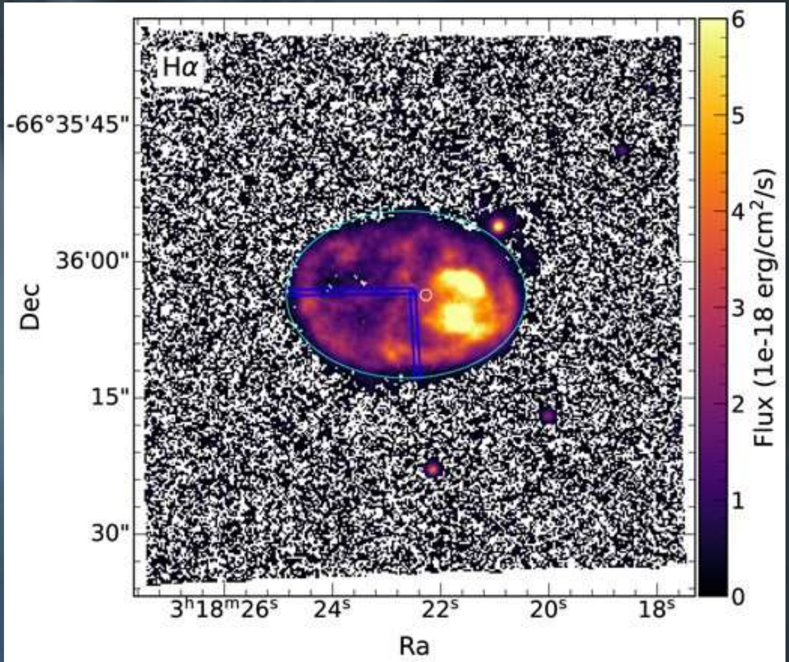
- ULX X-ray radiation may be anisotropic
- The funnel's angular size depends on the accretion rate



ULX and the emission from different points of view. (Fabrika et al. 2021)

Bubbles of ionized gas

- ULX radiation (UV/X) and/or powerful winds can ionize their environment and create bubbles of ionized gas
  - Radius up to 300 pc (*Pakull & Mirioni 2003*)
  - Characteristic ages ~ 1 Myr



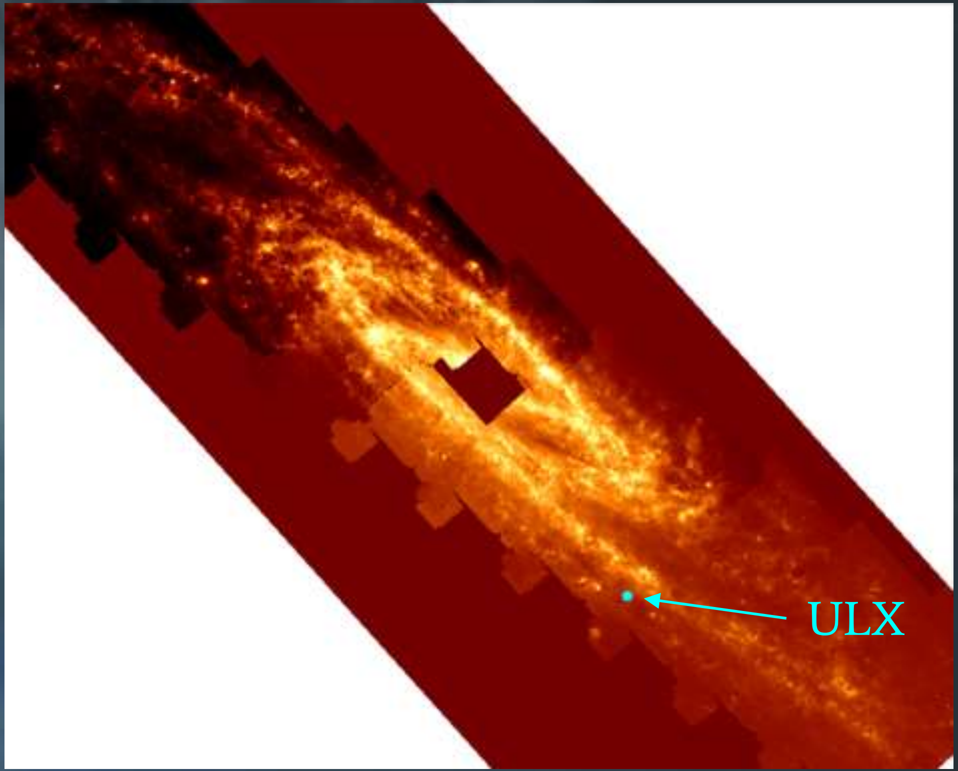
A bubble of 600 pc in diameter around the ULX NGC 1313 X-2. The white circle shows its Chandra position with 3σ uncertainty. Pixels with SNR<3 are masked. (*Gúrpide et al; 2024*)

Why do we study ULXs?

- Understand the efficiency and sustainability of super-critical accretion
  - → could help us better understand growth of supermassive black hole
- Constrain the geometries of accretion in-/out-flows
  - Role of the accretor's nature (black hole or neutron star)
  - Role of electromagnetic radiation vs winds/jets
    - → Bubbles

NGC 253 ULX1

- Host: spiral galaxy with high stellar formation
- Distance to Earth: 3.9 Mpc
- Observed ULX X-ray luminosity:
  - $L_X = 1.2 \times 10^{39}$ erg/s
  - Mean XMM (0.2-12 keV)

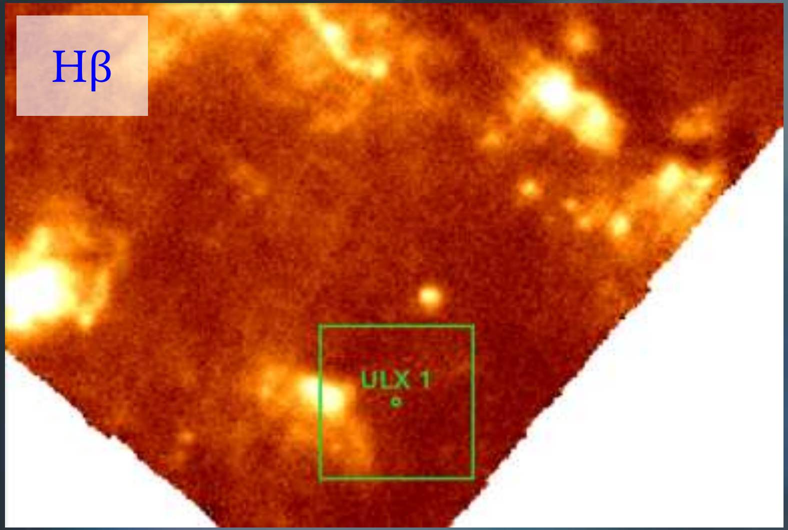


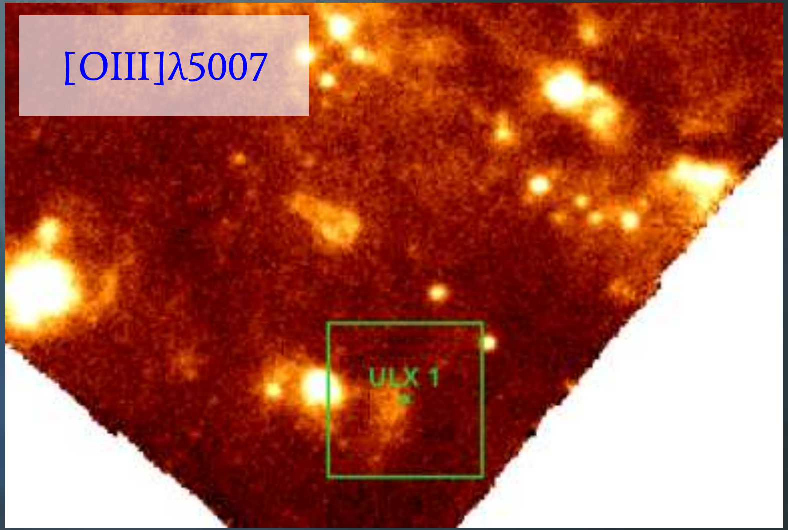
JWST/MIRI/F770W observation of the NGC 253 galaxy.

Optical spectroscopy

MUSE instrument at the Very Large Telescope *(Bacon et al. 2010)*:

- 3D spectroscopy by an integral field unit (IFU) (to every pixel corresponds a spectrum)
- 480-930 nm (optical)

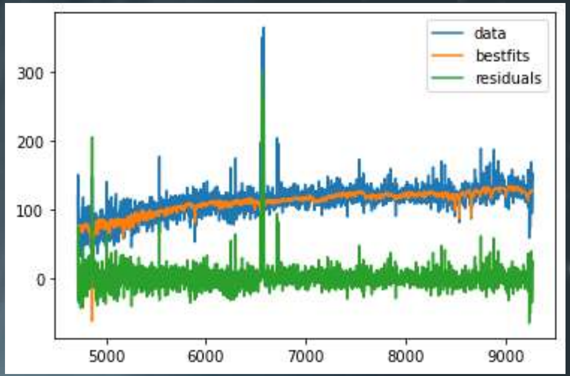


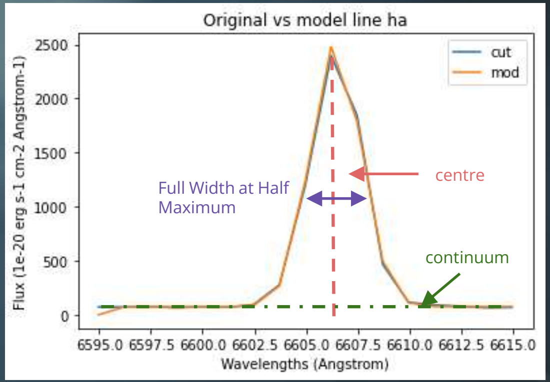


The green square corresponds to the area studied in the next slide. The Chandra position of the ULX at 95% is indicated by the green circle, which corresponds to a radius of 0.32”.

Emission line modelling

- Subtract continuum:
  - Fit continuum and absorption lines using *pPXF 9.4.1* (*Cappellari 2023*)
  - Keep only the emission lines
- Measure gas kinematics
  - Using *CAMEL* (*Epinat et al. 2009*)
  - For each emission line:
    - Area: **flux maps**
    - Line center: **line-of-sight velocity maps**
    - Line width: velocity dispersion maps

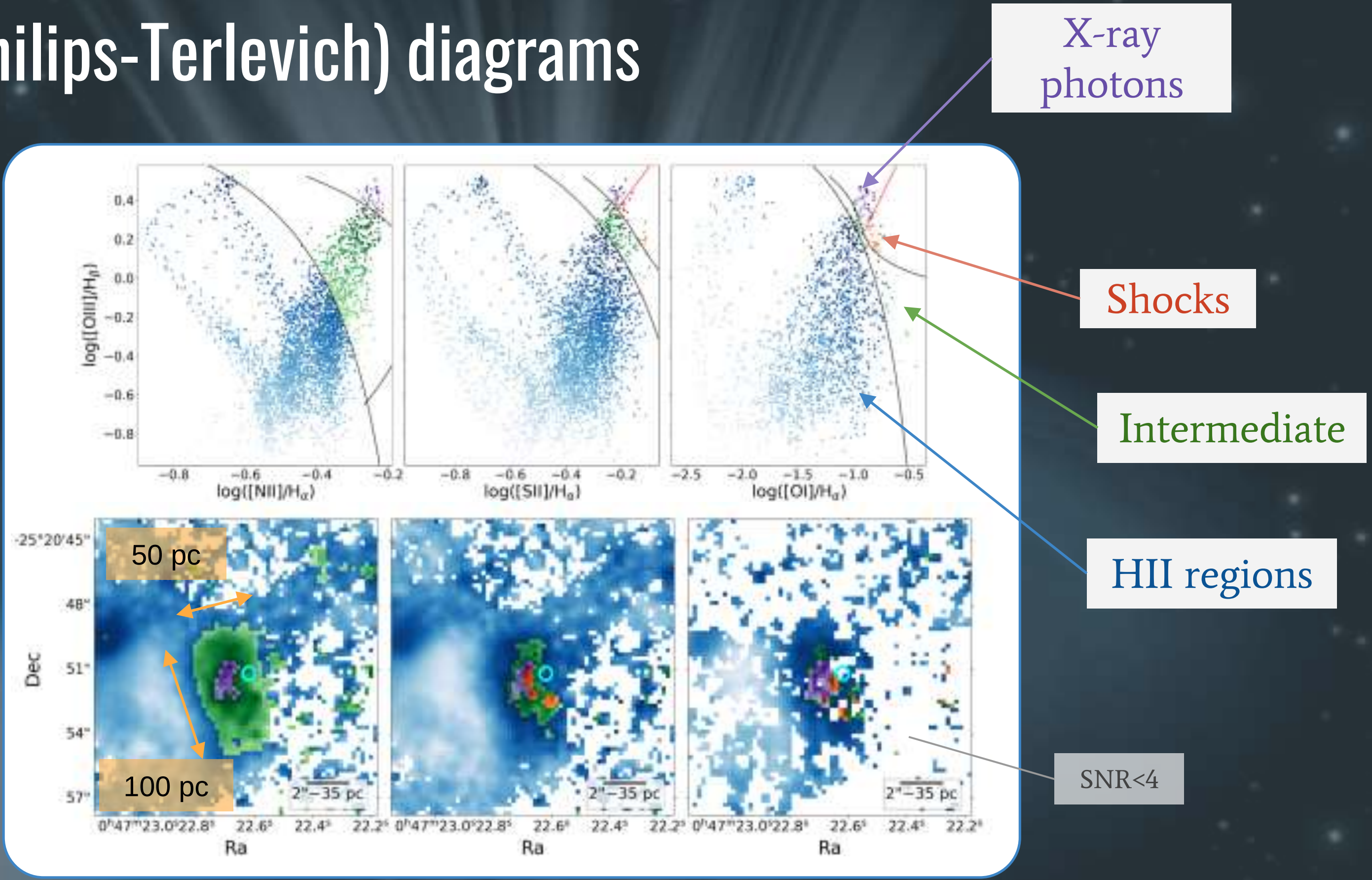




Top: Example of pPXF fitting. Bottom: Example of a spectrum around the Hα emission line (blue: observed, orange: modelled by CAMEL).

BPT (Baldwin-Philips-Terlevich) diagrams

Signs of ionization by X-ray and shocks → may indicate the presence of the winds occurring in the super-Eddington regime

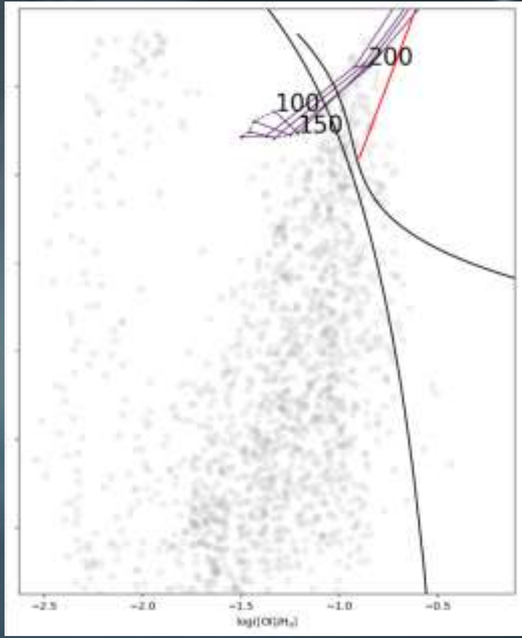


The position of the ULX is given by the green error circle at the 95% confidence level.

The bubble

Observed line flux ratios may be explained by shocks *MAPPINGS V* (*Sutherland et al. 2018*)

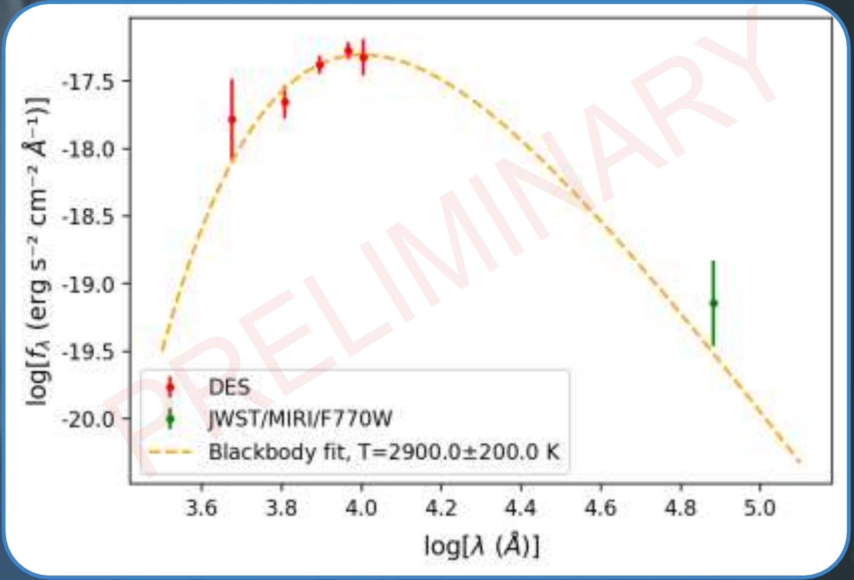
- Results:
  - v_{shock} ≈ 200 km/s
  - Age of the bubble: t ≈ 1.3e5 years
  - Mechanical power of the wind: P_{mec} ≈ 8.1e39 erg/s vs L_X ≈ 1.2e39 erg/s
- Assumptions:
  - Steady energy throughput throughout the bubble's lifetime
  - Ionization by shocks only
  - ~ Solar metallicity (from emission line fluxes, *Pilyugin & Grebel 2016*)
  - $n_{ISM} = 1\ cm^{-3}$



Values from (*Gutkin et al. 2016*) for different values of pre-shock magnetic field on the O1 BPT diagram.

Optical/NIR counterpart

- Données:
  - Dark Energy Survey (**DES**): optical to NIR wavelengths
  - **JWST**/MIRI/F770W: NIR
- Spectral energy distribution (SED):
  - The SED is well fit by a blackbody spectrum with the temperature **T_B ≈ 2900 K**
- Absolute V-band magnitude:
  - **M_V ≈ -4.4**
- The emission seems to come from the **companion star**:
  - M-type red supergiant
  - R ≈ 700 $R_\odot$
  - (as found in *Heida et al. 2015*)
- X-ray/optical flux ratio:
  - **$\log(f_X/f_V)$ ≈ 2.80**
  - Expected for a ULX



SED of the optical counterpart of ULX1. The values for flux densities (corrected for the galactic extinction and for the finite extraction aperture) and for model parameters are given with their 1σ uncertainties.

Conclusions

- ULX1 in NGC 253
- Bubble of ionized gas found around it
  - Ionized by X-rays and/or shocks
  - Mechanical power is comparable and slightly higher than the observed X-ray luminosity
- Optical/NIR counterpart:
  - Companion star: M-type red supergiant

akilina@irap.omp.eu