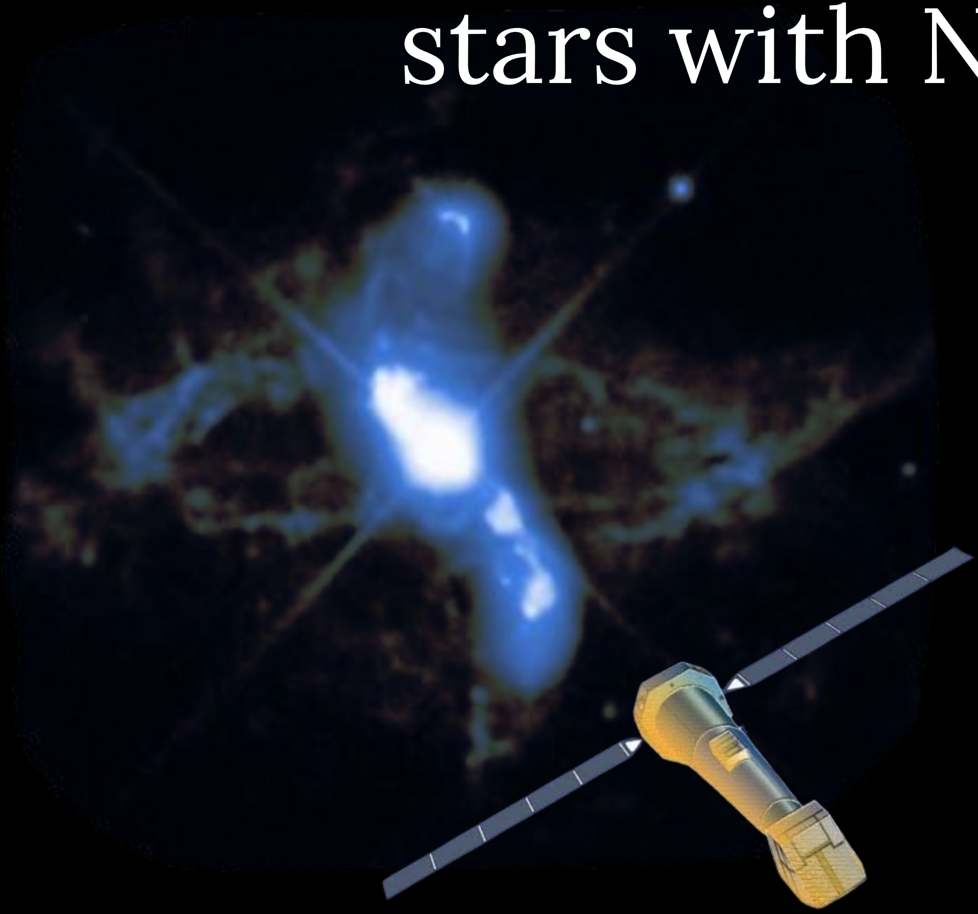
Expanding our view on symbiotic stars with NewAthena



Speaker: Jaime Alonso Hernández
Centro de Astrobiología (CAB, CSIC-INTA)
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CENTRO DE ASTROBIOLOGÍA CSIC - INTA

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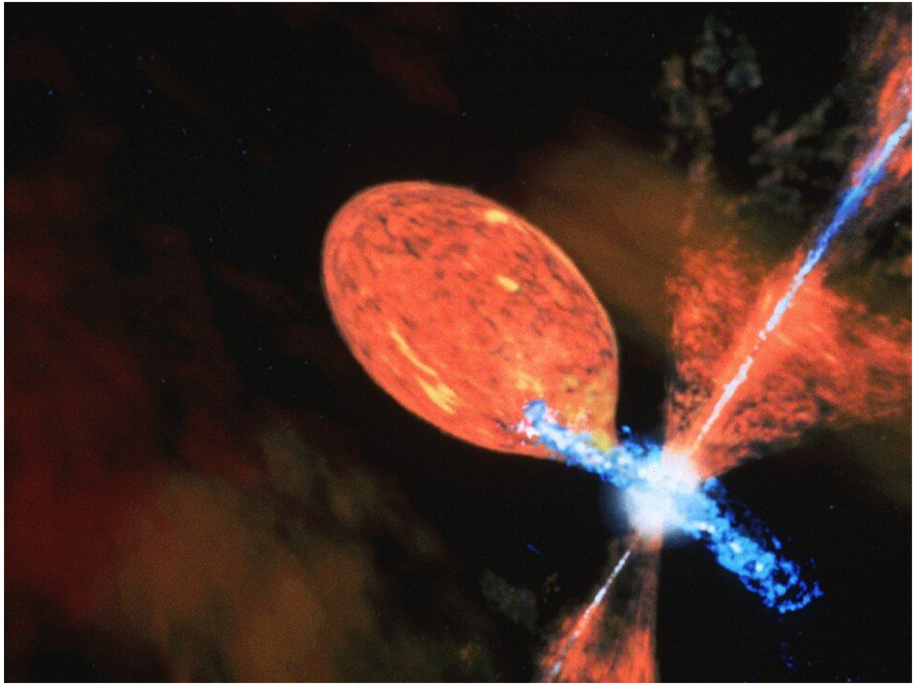
INTA

Definition of symbiotic star (or symbiotic system)

No clear definition, but binary systems composed of:

- A red giant star (RGB or AGB)
- Interacting companion (MS, WD, or NS)



Artistic impression of the symbiotic star R Aquarii (credit: Dana Berry)

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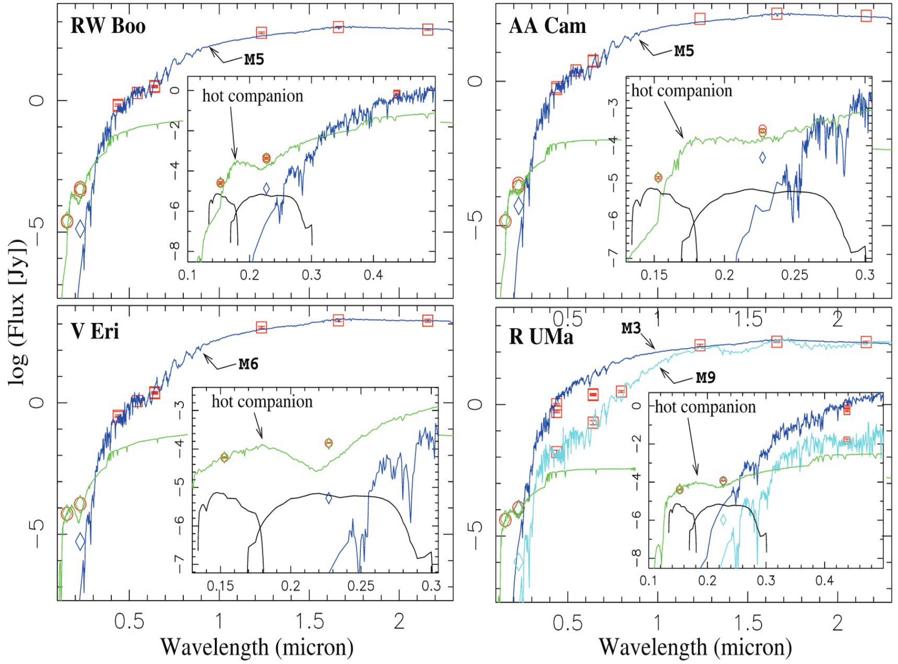
Symbiotic may display (or not) certain phenomenology:

- **Intense UV excesses**



Spectral energy distributions of symbiotic star candidates (Sahai+2008)

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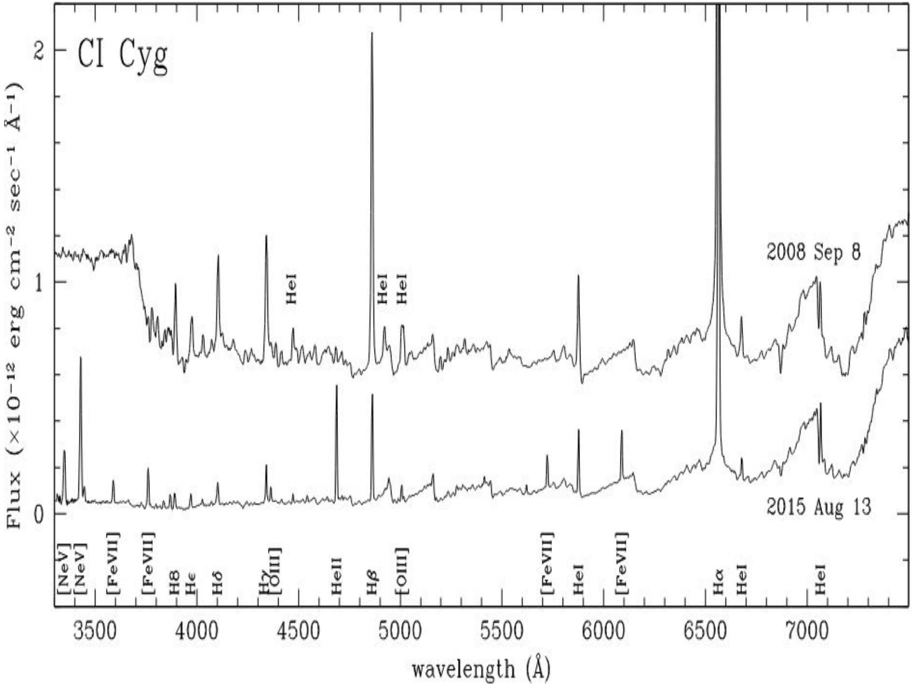

Optical spectra of CI Cyg (credit: Munari+2019)

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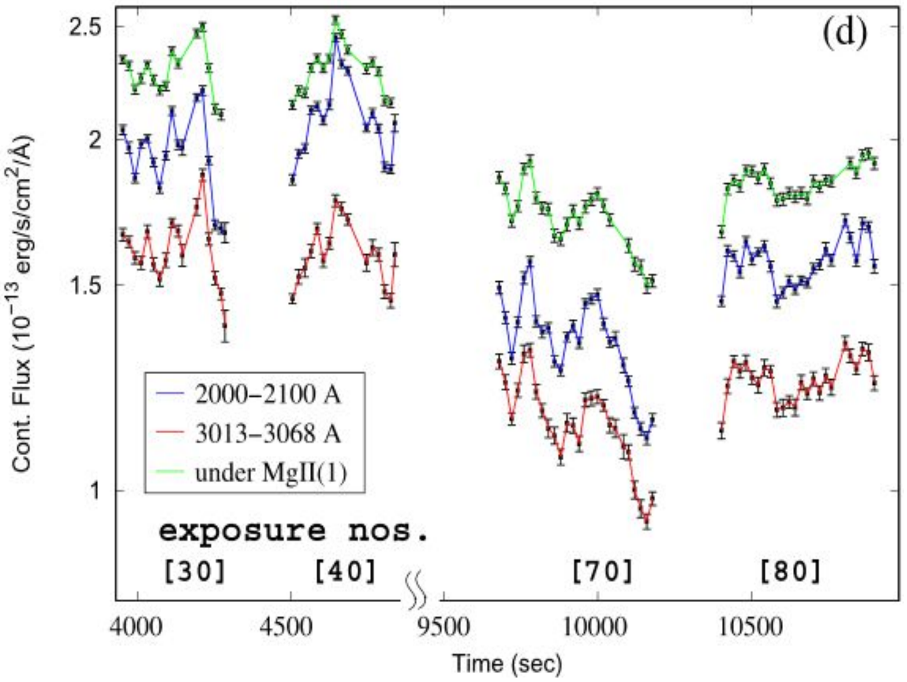

HST/STIS lightcurves of Y Gem (credit:Sahai+2018)

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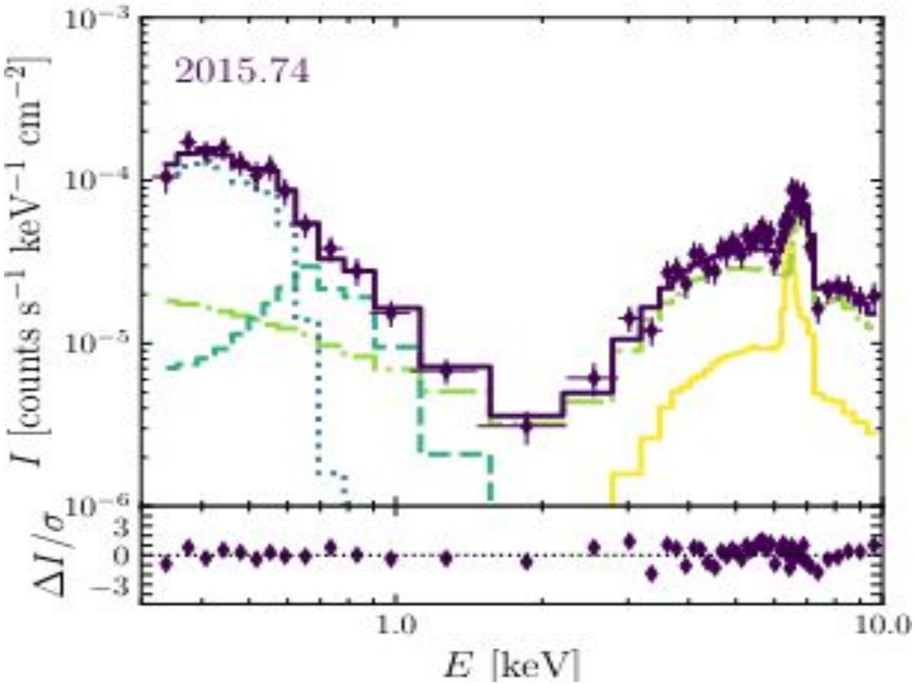
- **X-ray emission**



XMM-*Newton*/EPIC-pn spectra of Y Gem (credit: Guerrero+2024)

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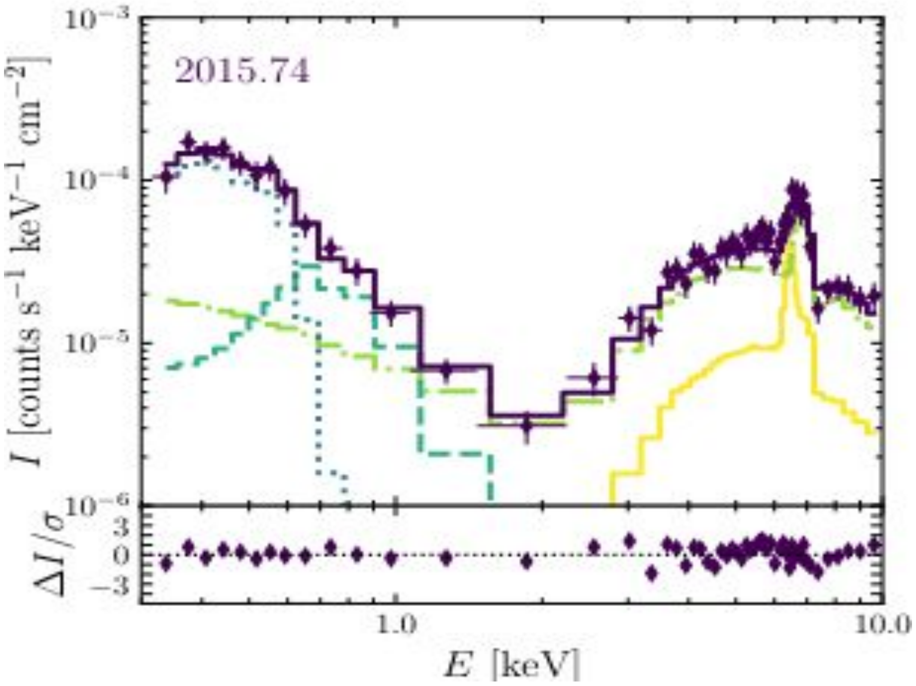
- Short-term variability
- X-ray emission

But depend on the accretion state…

20-40% of symbiotics stars detected in X-ray emission (Merc+2019, Akras+2019)

The typical symbiotic star: AGB donor + accreting WD



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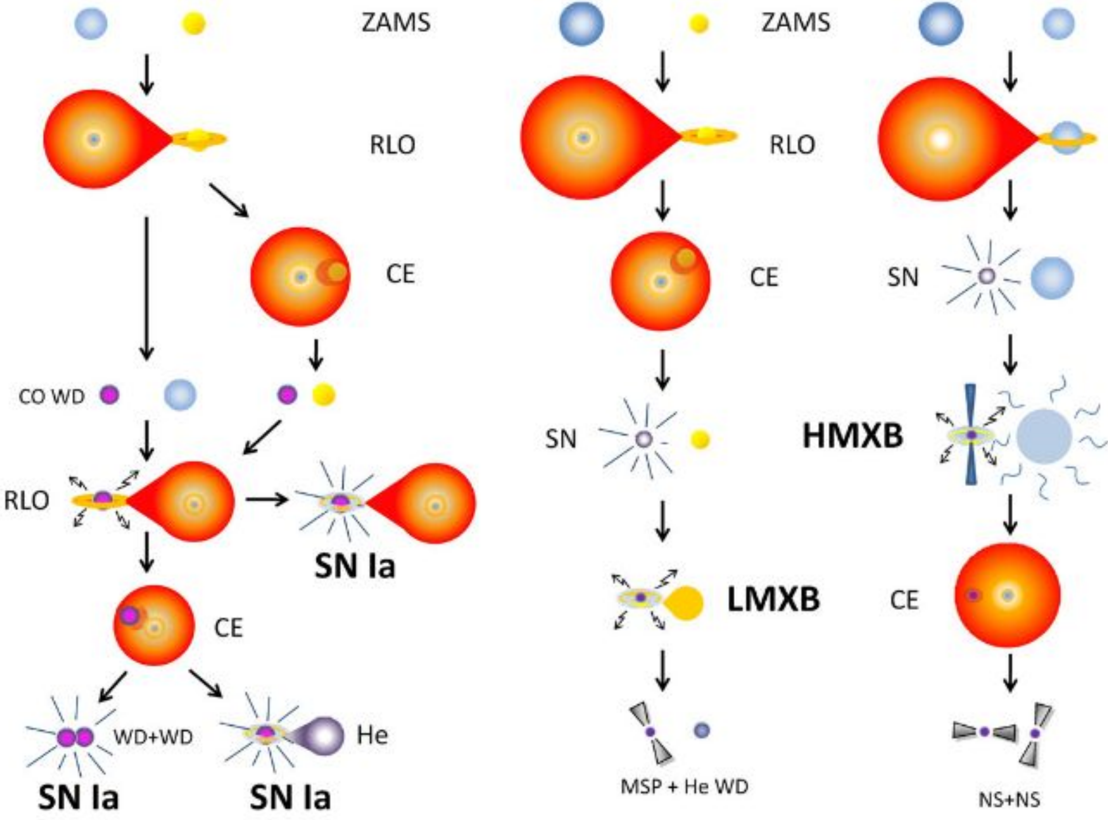
Formation of Symbiotic stars

The symbiotic phenomena occurs in close binary (or multiple) stellar systems



Schematic view of the evolution of different common envelope systems (Ivanova+2013)

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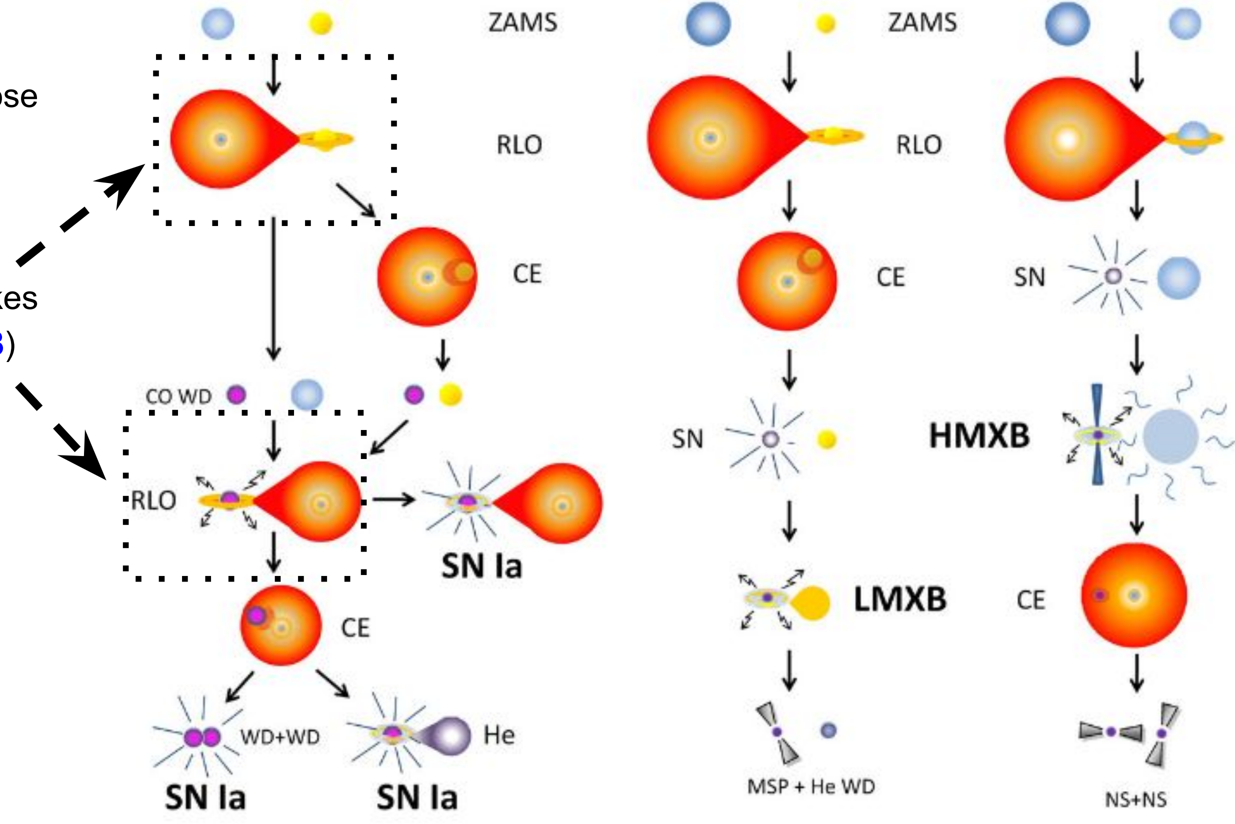
In low- and intermediate-mass binaries takes place in **two different stages** (Webbink 1988)



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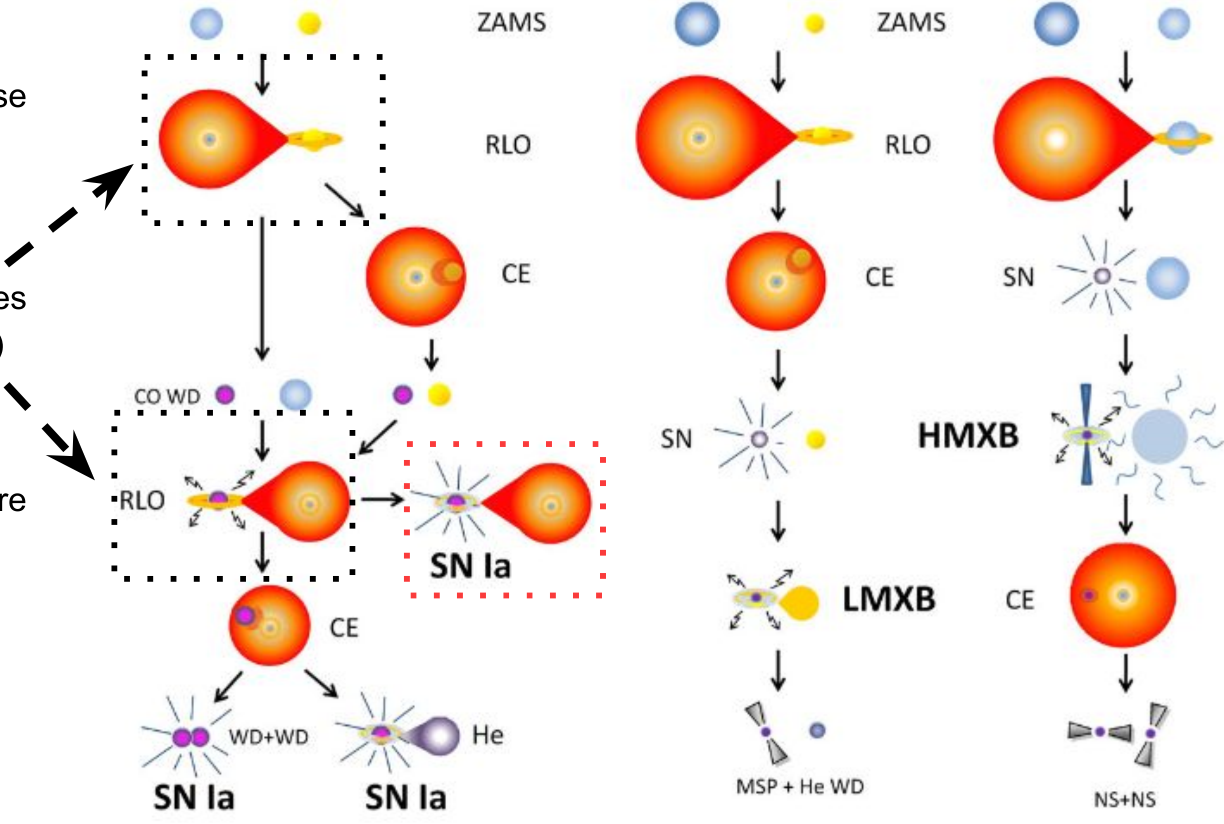

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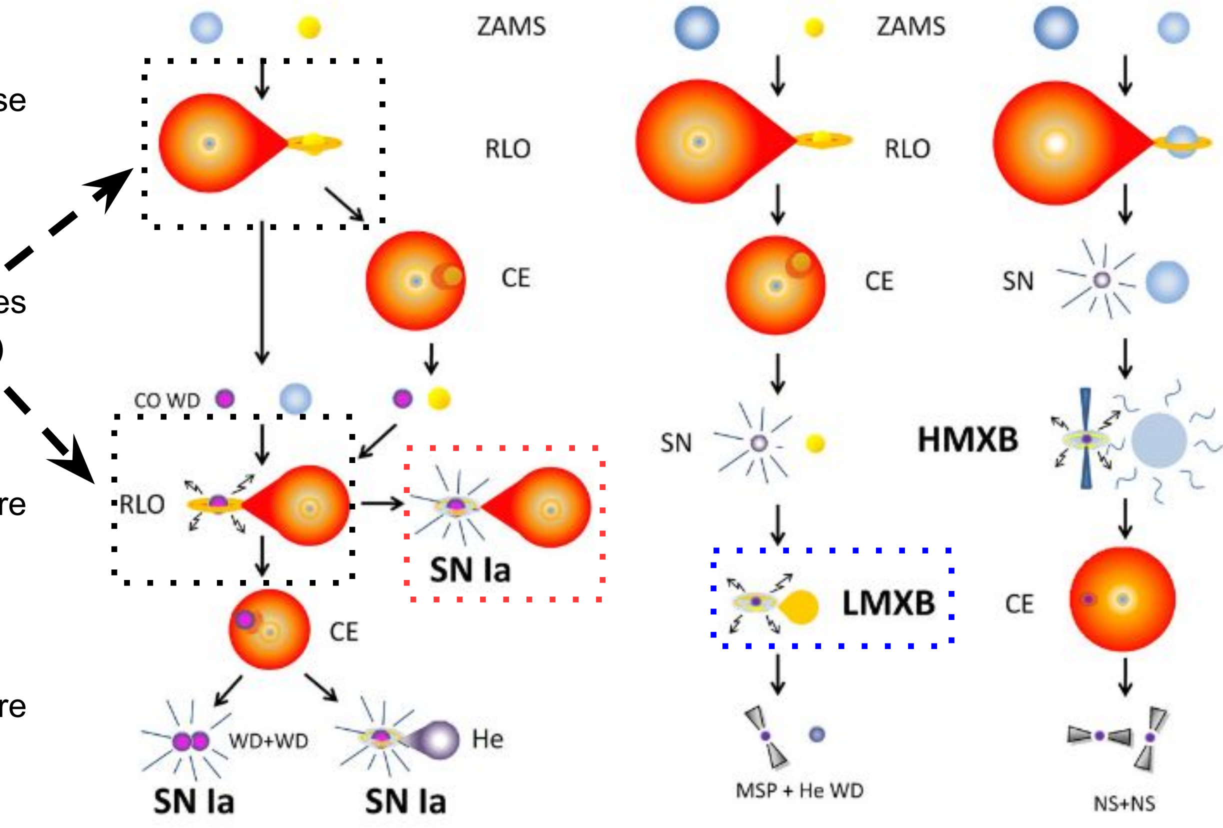
Some symbiotic stars with accreting NS are **symbiotic X-ray binaries**



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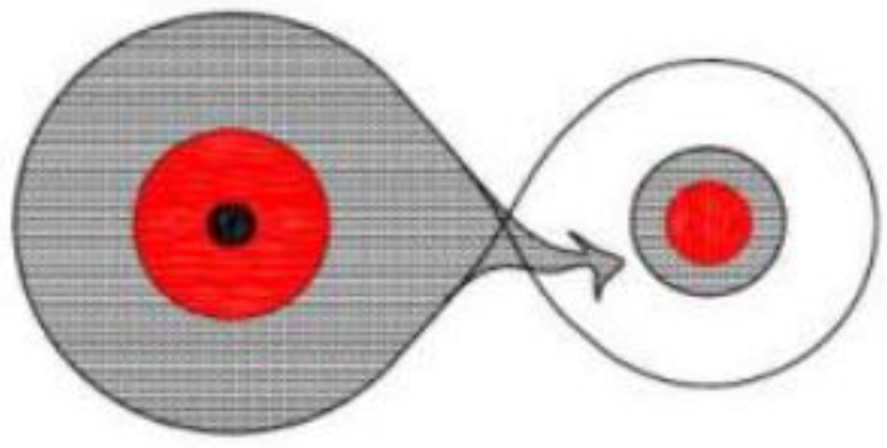
Mass transfer in symbiotic stars

Roche lobe overflow (RLOF) requires short distances ($<5\ R_*$)



Schematic view of RLOF (credit: X.Chen)

Mass transfer in symbiotic stars

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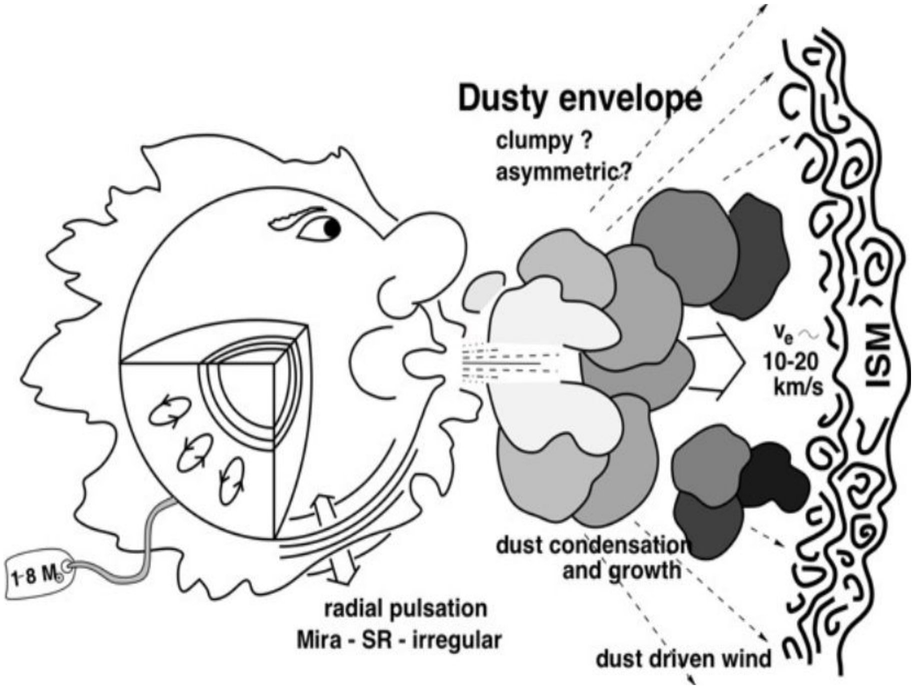
RGB and AGB stars undergo intense mass-loss:

- Cool stars -> dust formation at a few stellar radii
- High luminosities -> Radiation pressure



Cartoon of the circumstellar envelope of an AGB (credit: Harvard University)

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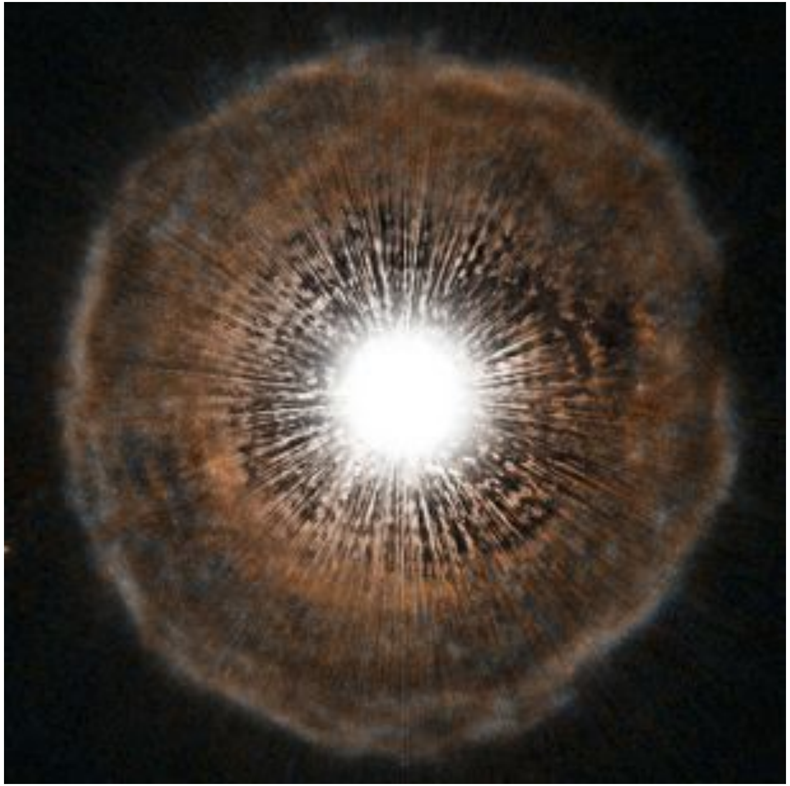
These envelopes are characterised by a rich dust and molecular chemistry (I will come back to this later!)



HST/WFC2 image of the AGB star U Cam (credit: NASA, ESA, and H. Olofsson)

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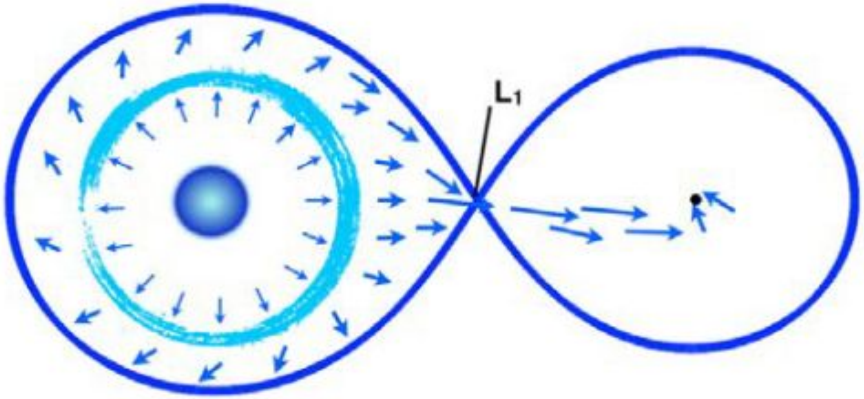
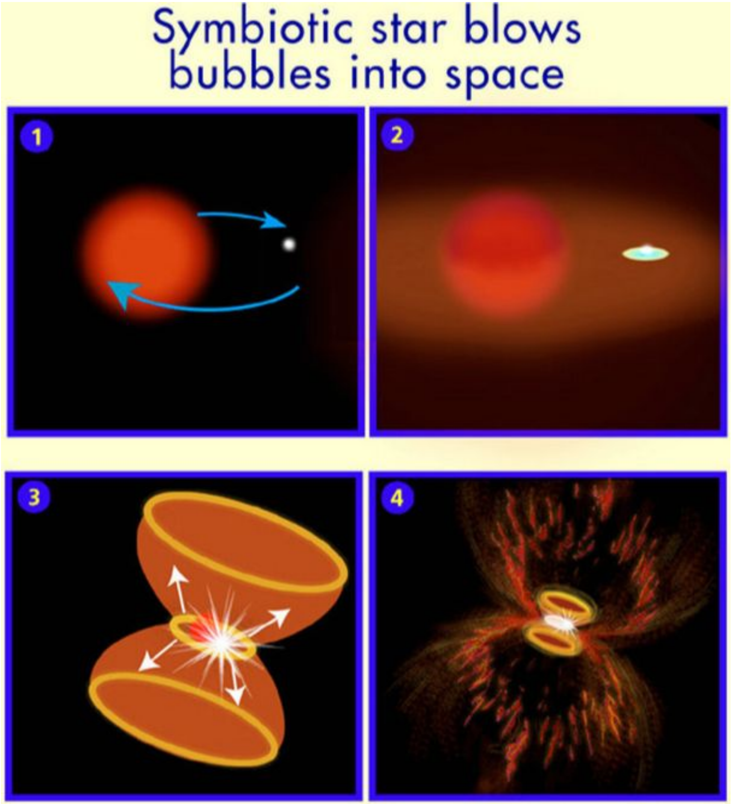
The material is bound to the star and focused towards the orbital plane (wind-RLOF, see Mohamed & Podsiadlowski 2007)

The companion may accrete and shape the circumstellar material (effective for distances <50 R_*)



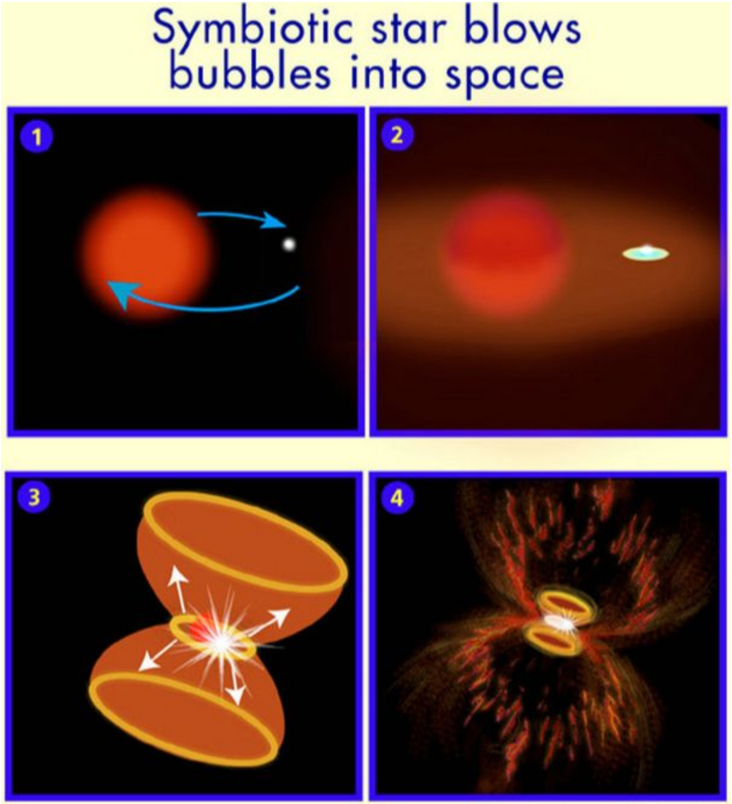
Schematic view of wind-RLOF (Mohamed+2015)

The shaping of symbiotic nebulae



Schematic view of the shaping of a symbiotic nebula (credit: NASA & ESA)

The shaping of symbiotic nebulae



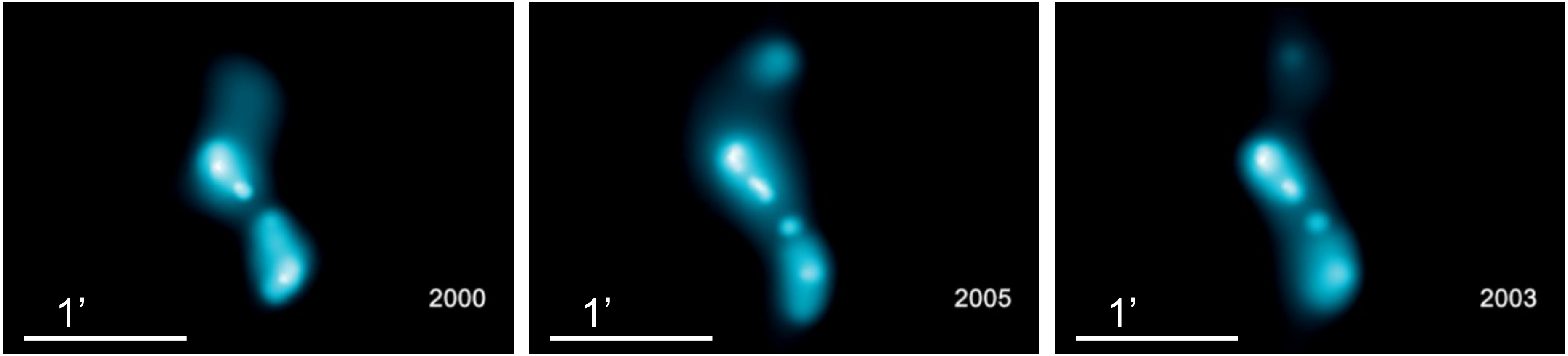
Schematic view of the shaping of a symbiotic nebula (credit: NASA & ESA)

HST/WFC2 image of the Southern Crab Nebula (credit: NASA, ESA, and STScI)

How do symbiotic stars look like in X-rays??

R Aquarii is the nearest symbiotic star with a distance of 260±27 pc (Liimets+2024)

Chandra can resolved the “S”-shaped jet of R Aqr (Montez+2017)



Chandra/ACIS images of R Aquarii at different epochs (credit: NASA)

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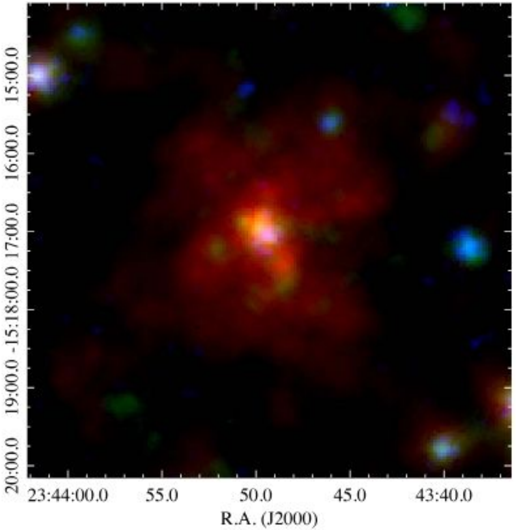
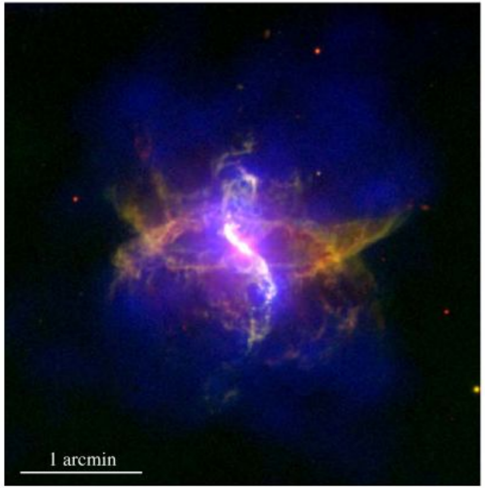
XMM-*Newton* can detect a faint and extended X-ray nebula



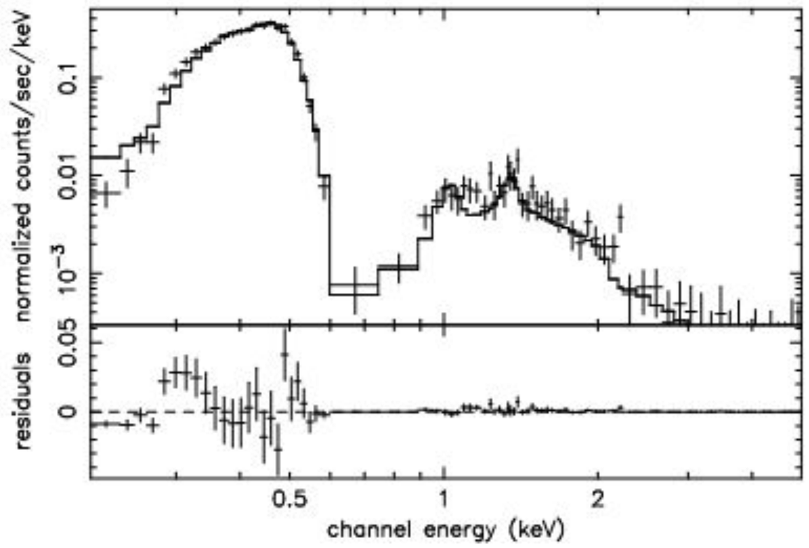


left: XMM-*Newton*/EPIC (MOS+pn) image of R Aquarii. Right: XMM-*Newton*+HST color composite (blue for X-ray, green for Hα+N II, and red for OII) of R Aquarii (Toalá+2022)

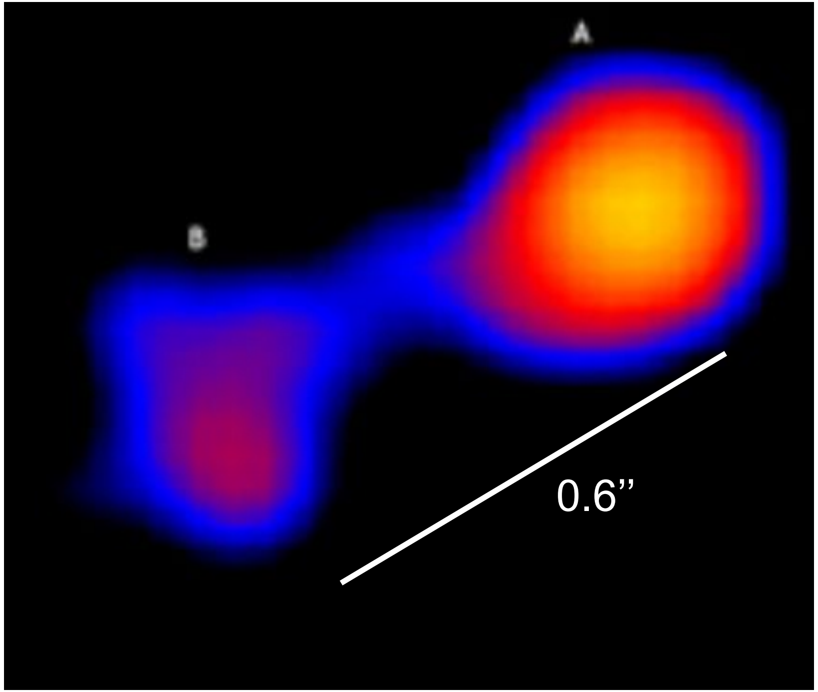
How do symbiotic stars look like in X-rays??

Mira (Omi cet) is the closest symbiotic star with a distance of ~100 pc (Van Leeuwen+2017)

Chandra/ACIS resolved both components (did the AGB have a flare??)



Chandra/ACIS spectra of Mira (Karovska+2005)



Chandra/ACIS image of Mira A and B (Karovska+2005)

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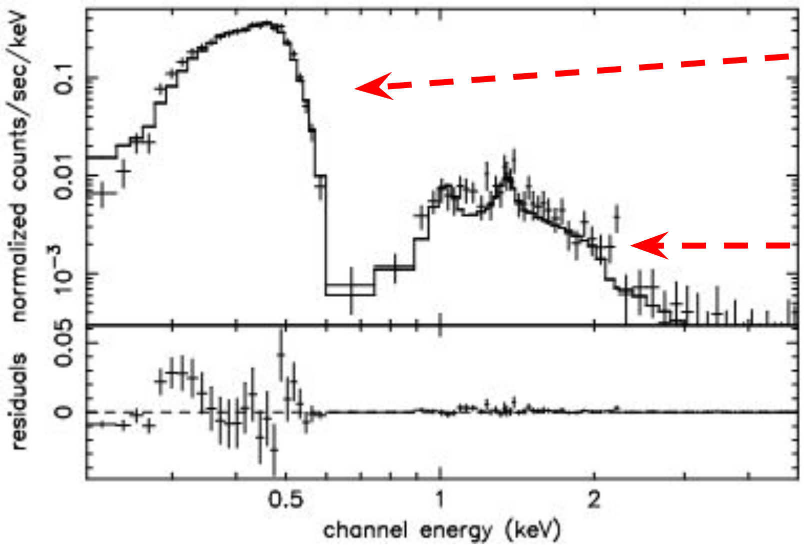

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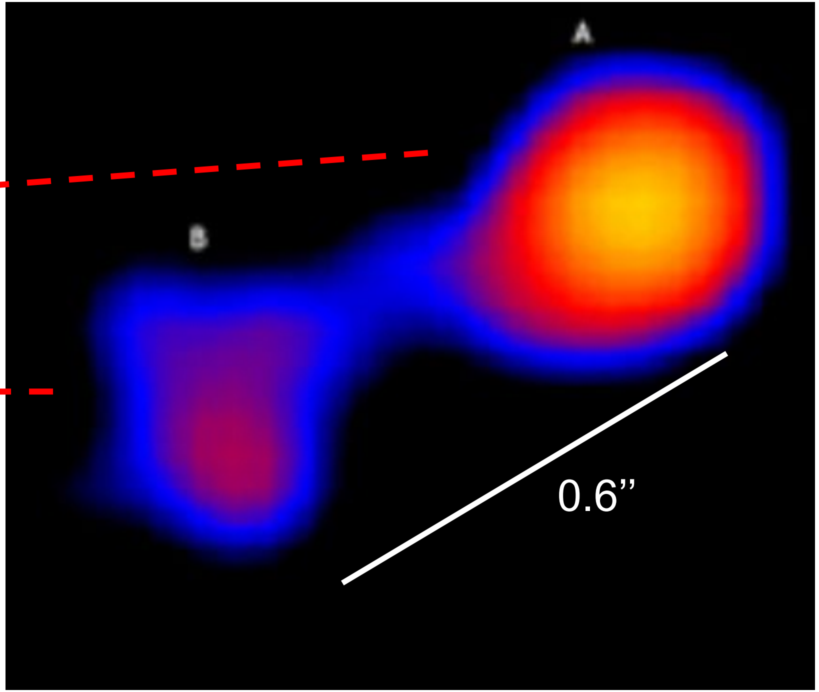

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X-ray spectral classification

First classification proposed by Mürset+1997 based on ROSAT observations:

- α soft x-ray sources
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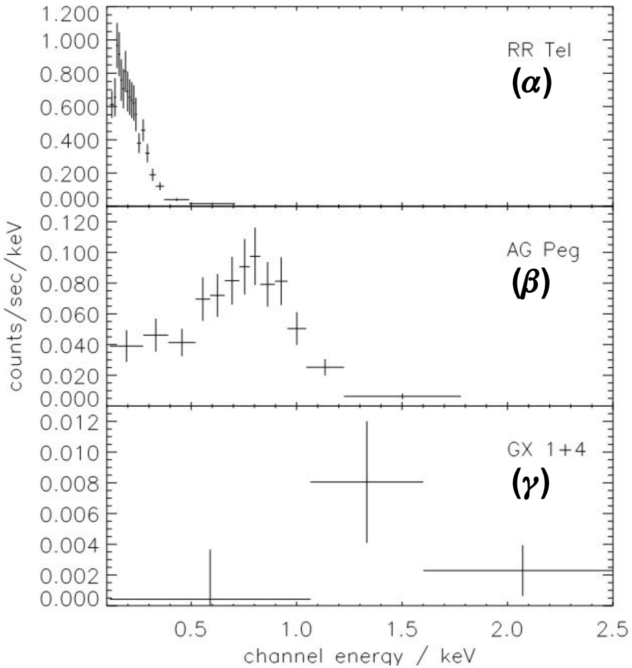
  - Shocks from colliding winds
- γ Relatively hard x-ray sources
  - Accretion onto a NS??



Examples of the three classes of X-ray spectra (Mürset+1997)

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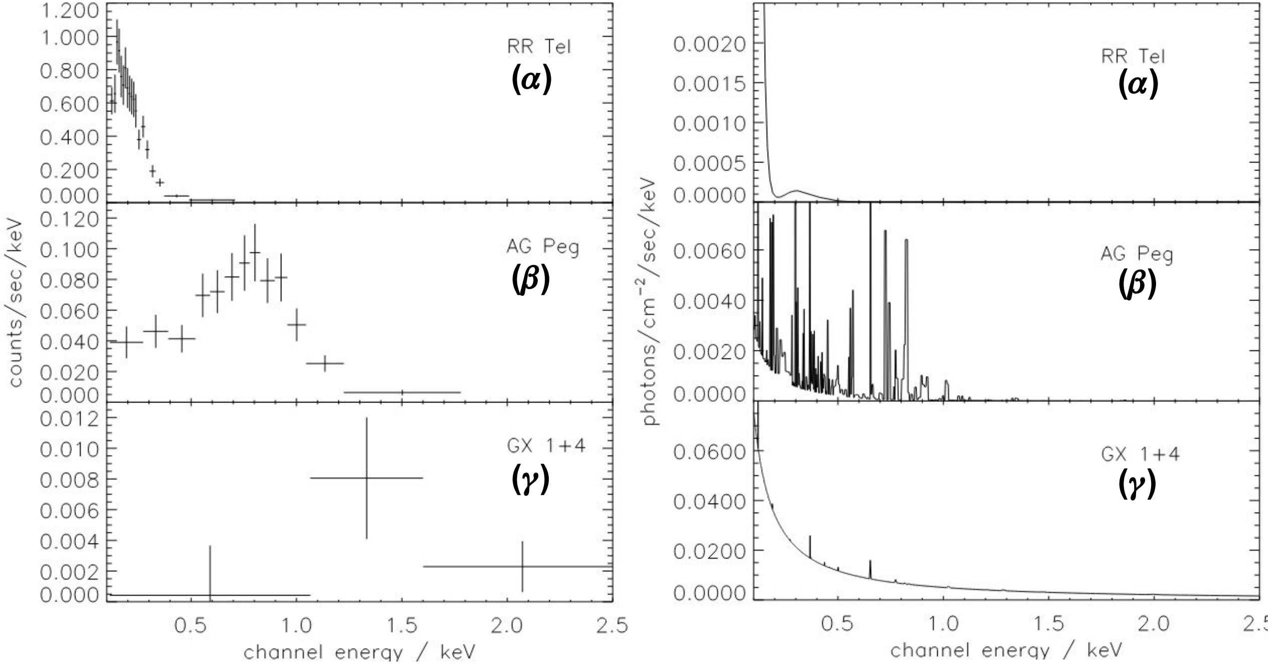

Examples of the three classes of X-ray spectra and proposed spectral models(Mürset+1997)

X-ray spectral classification

The classification was extended by Luna+2013 based on SWIFT observations:

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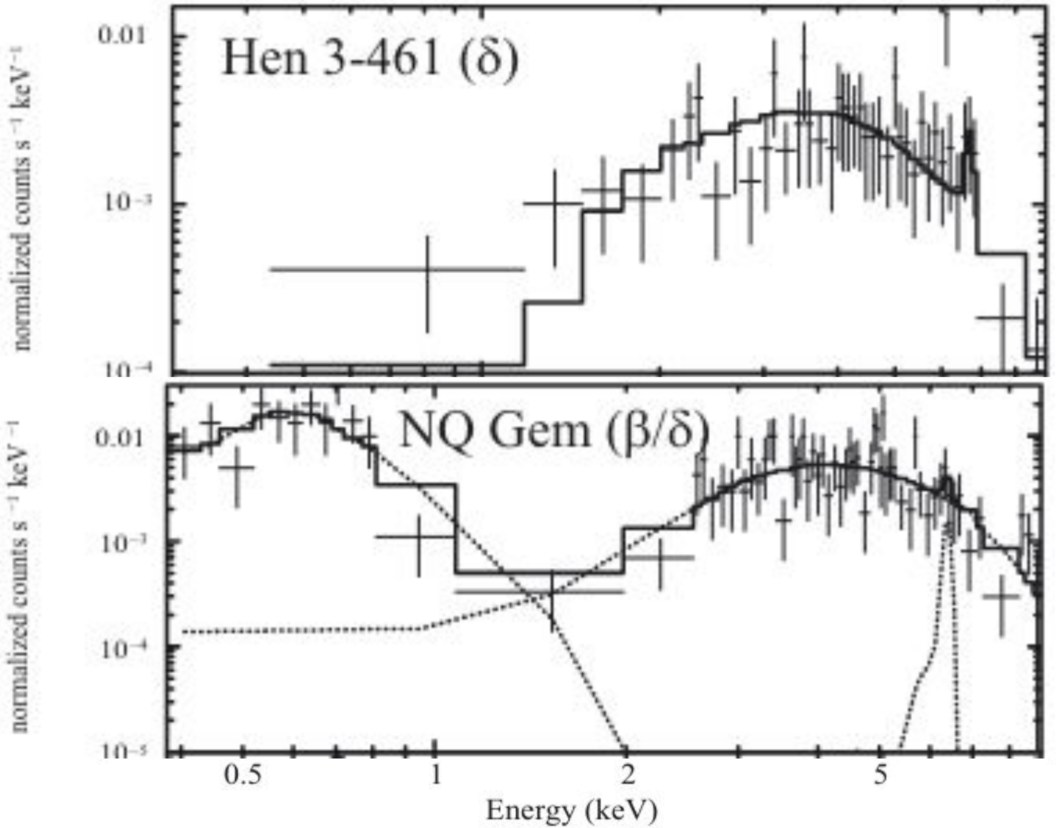
- Thermonuclear burning in a WD
- β Intermediate X-ray sources
- Shocks from colliding winds
- γ Relatively hard x-ray sources
- Optically thick Comptonized plasma
- δ Highly absorbed, hard X-ray sources
- Boundary layer between WD and the disc
- β/δ Combination of both types
- Combination of both physical processes

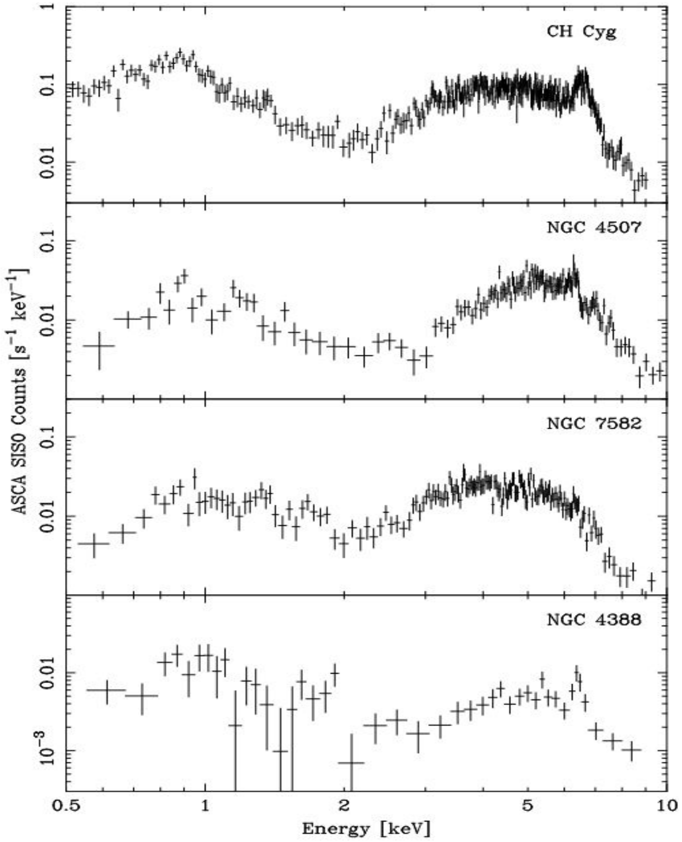


Examples of the two new classes of X-ray spectra (Luna+2013)

X-ray spectral classification

Wheatley & Kallman 2006 noted similarities with the X-ray spectra of AGNs

A reflection component should be important!



Comparison between the X-ray spectra of CH Cyg and three AGNs (Wheatley & Kallman 2006)

X-ray spectral classification

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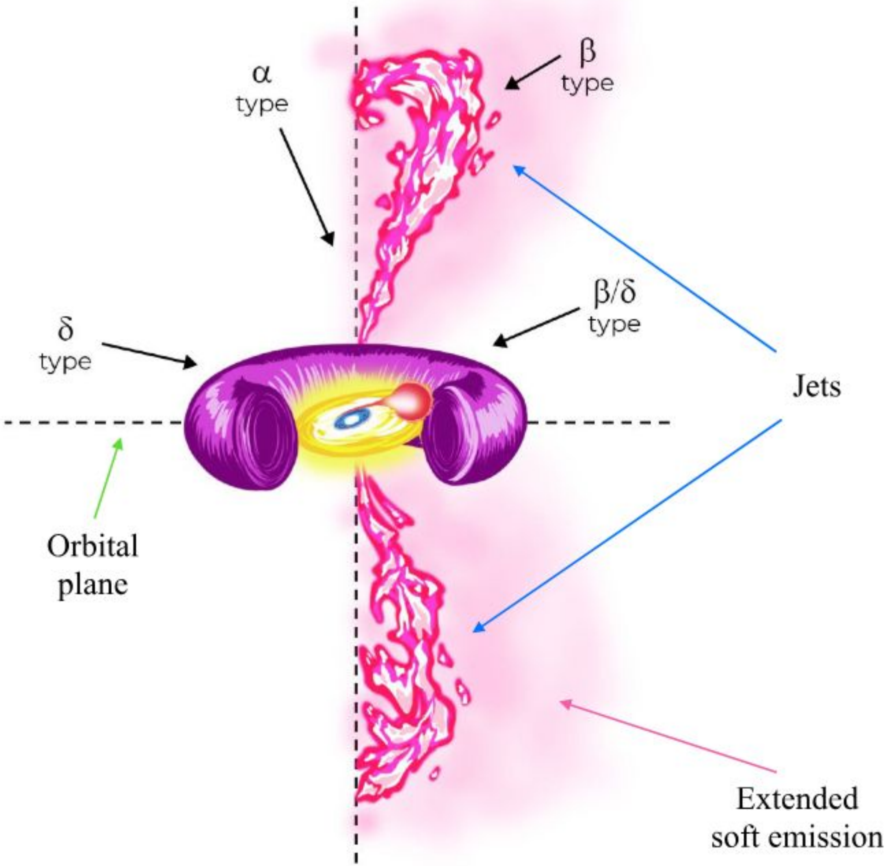
Toalá+2024,2025 presented an AGN-based model to explain the different classes of X-ray spectra:

- Plasma temperature
- Density structure of the disc
- Inclination angle



Schematic view of the different classes of X-ray spectra in symbiotic stars (Toalá+2024)

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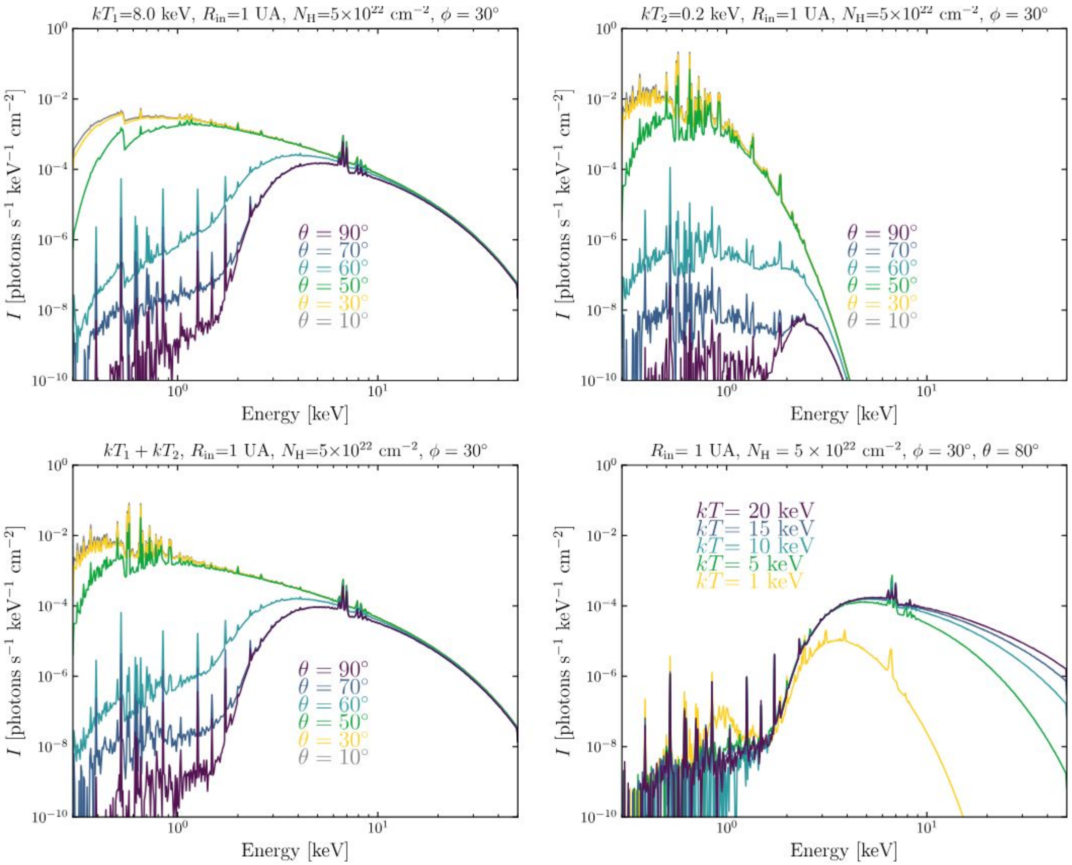

Modelled X-ray spectra for fours different classes of symbiotic stars (Toalá+2025)

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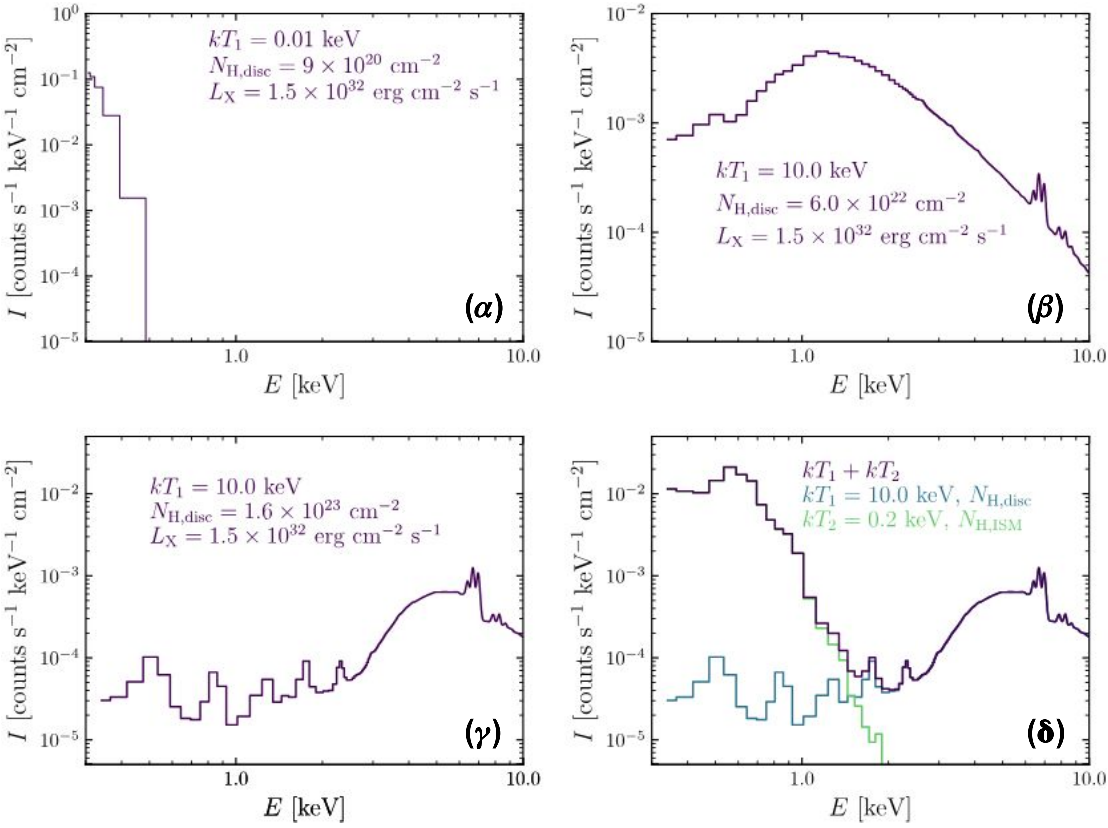
Reproduce the observed X-ray spectra!

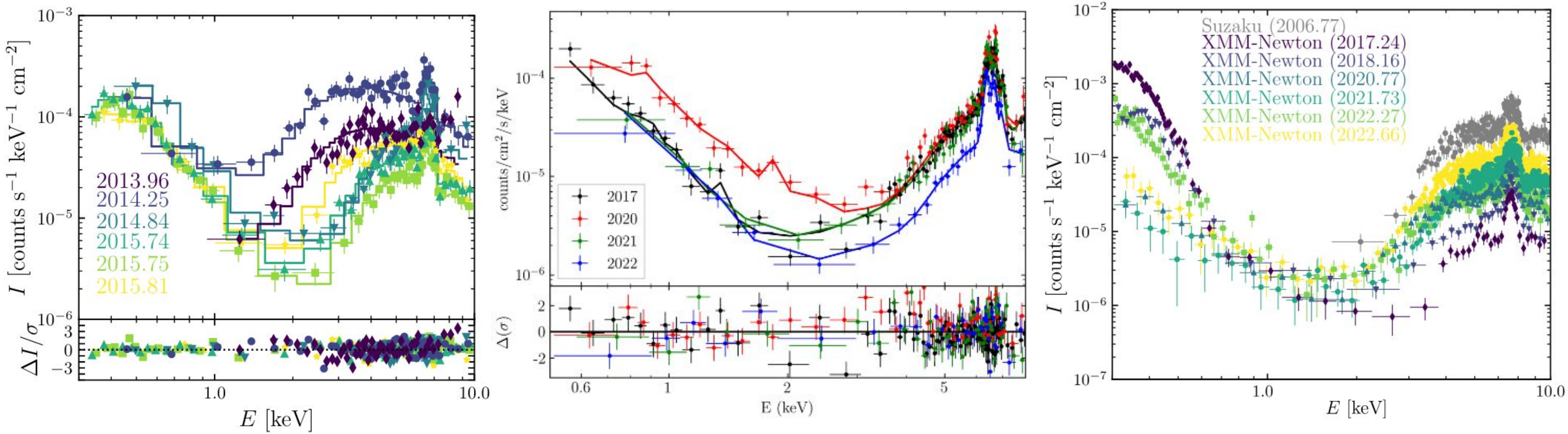


Modelled X-ray spectra for fours different classes of symbiotic stars (Toalá+2025)

X-ray spectral variability

Variability has been reported in the X-ray emission of some symbiotic stars (both L_x and spectral shape)

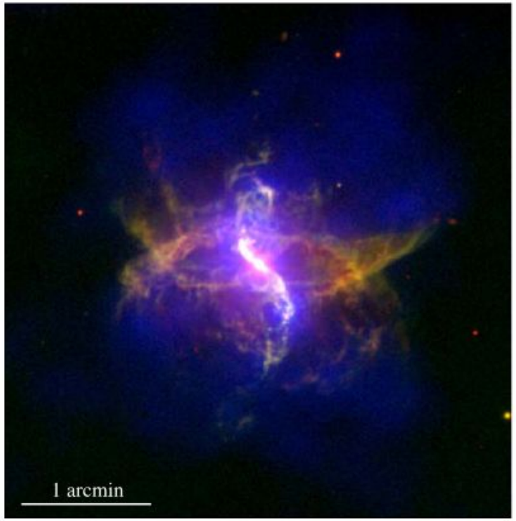
Intrinsic variability of the different physical parameters



Left: XMM-Newton/EPIC-PN spectra of Y gem (Guerrero+2025). Centre: Chandra/ACIS spectra of R Aquarii (Sacchi+2024). Right: XMM-Newton/EPIC-PN and Suzaku/XIS spectra of T CrB (Toalá+2024b)

Delving into the jet formation of R Aquarii

Synergy between sub-mm/X-ray observations



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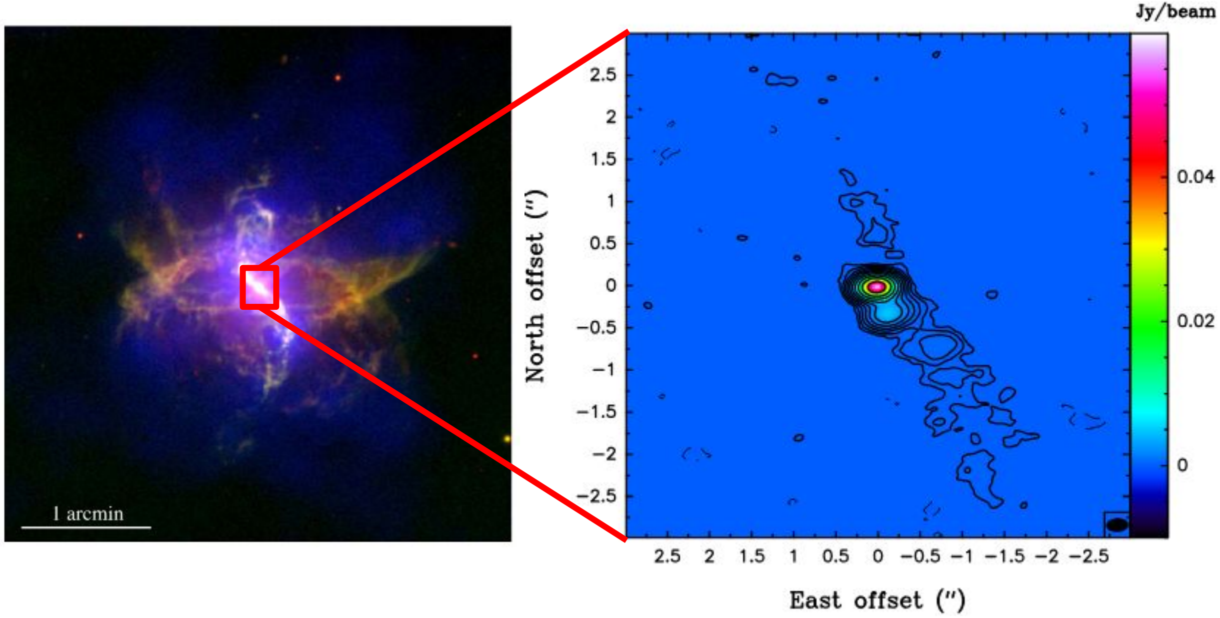
Synergy between sub-mm/X-ray observations

ALMA can trace the sub-mm continuum emission of the jet down to au-scales



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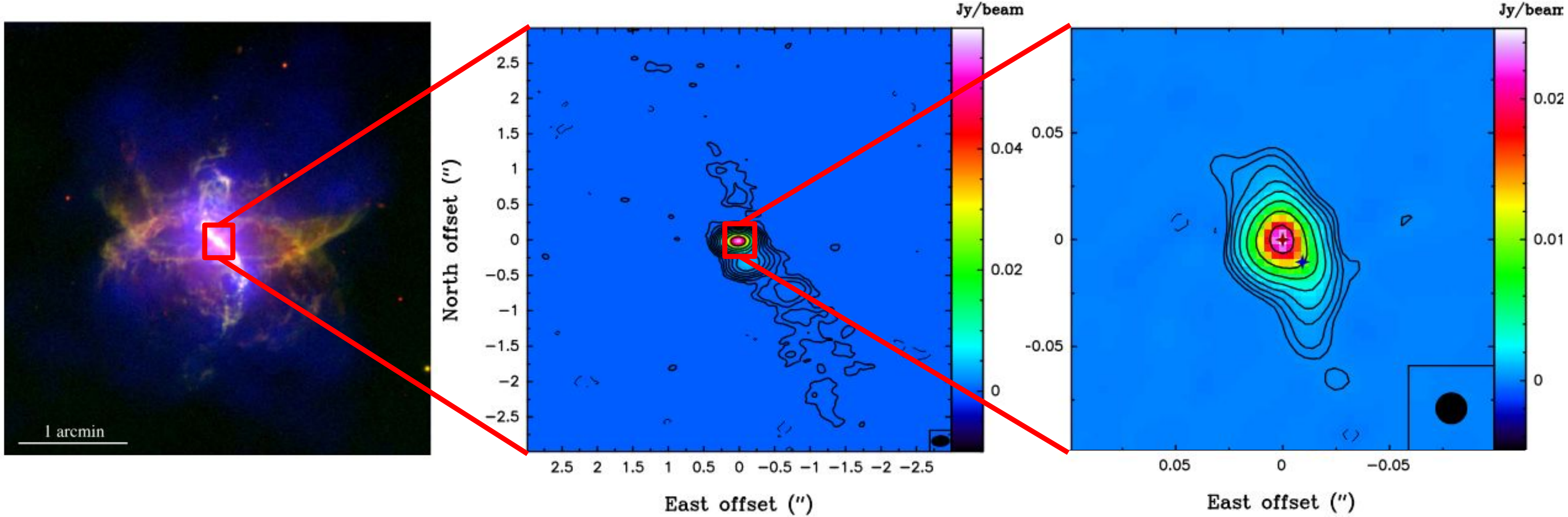


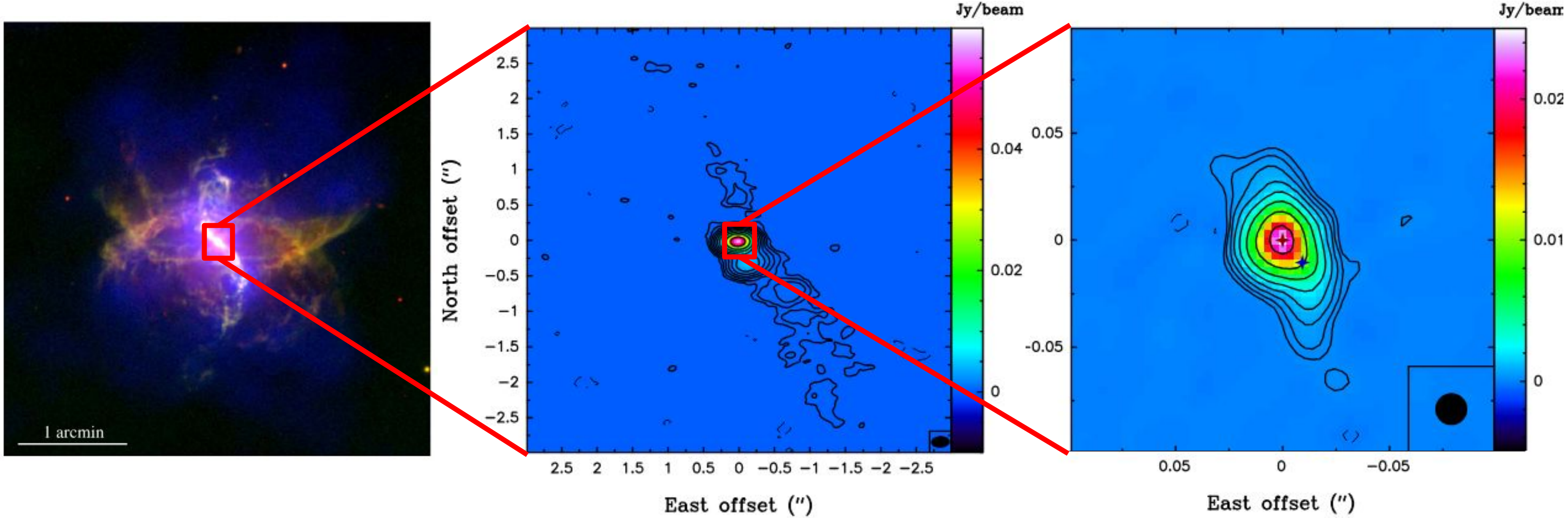
Left: XMM-*Newton*+HST color composite (blue for X-ray, green for Hα+N II, and red for OII) of R Aquarii (Toalá+2022). Centre-Right: ALMA 1.3 mm continuum images of R Aquarii at different angular scales (Gómez-Garrido+2024)

Delving into the jet formation of R Aquarii

Joint observations to monitor the physical properties of the jet at different spatial scales

Synergy between sub-mm/X-ray observations

ALMA can trace the sub-mm continuum emission of the jet down to au-scales



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X-ray impact on the circumstellar molecular chemistry of T Draconis

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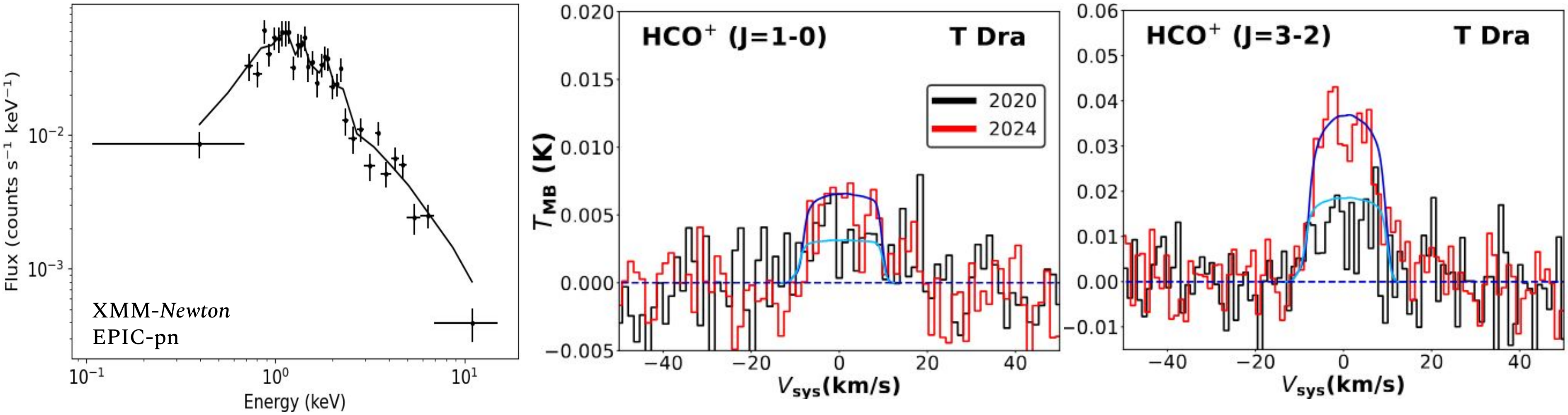


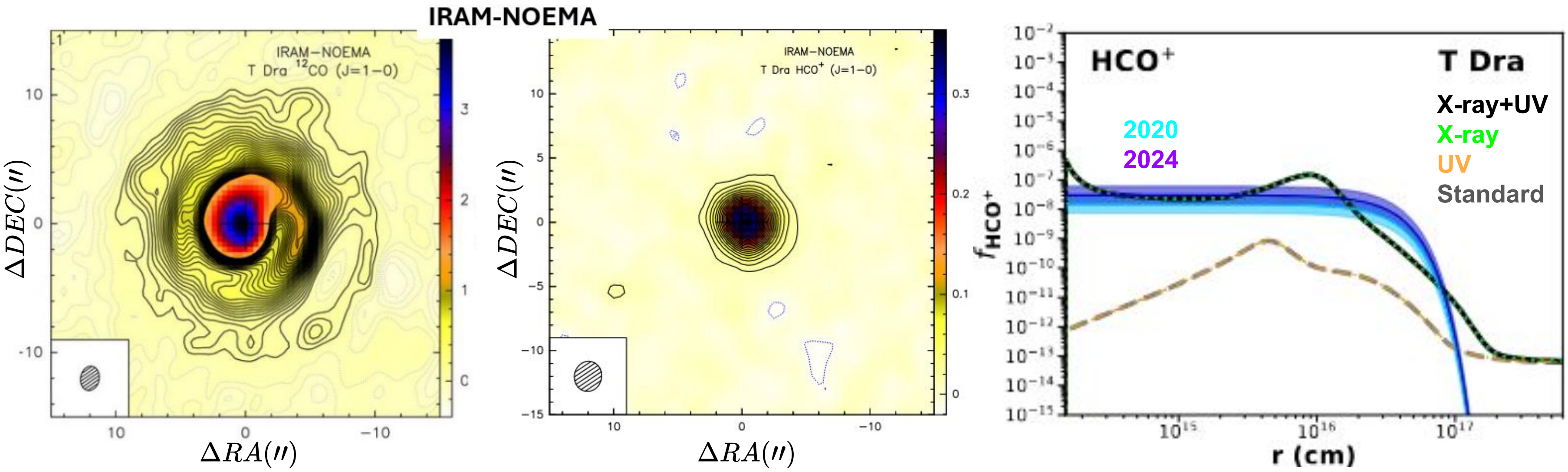
Left: XMM-*Newton*/EPIC-pn spectra of T Dra. Centre-Right: HCO$^+$ (J=1-0) and HCO$^+$ (J=3-2) emission lines (Alonso-Hernández+2025)

X-ray impact on the circumstellar molecular chemistry of T Draconis

Synergy between sub-mm/UV/X-ray observations

The analysis includes chemical kinetics modelling (with UV and X-ray spectra)

The internal X-ray emission changes the molecular composition of the circumstellar environment!



Left: NOEMA CO(1-0) emission map. Centre: NOEMA HCO^+(1-0) emission map. Right: HCO^+ radial abundance (Alonso-Hernández+2025, in prep.)

X-ray impact on the circumstellar molecular chemistry of T Draconis

Joint observations to study the effect of X-ray variability in the chemistry

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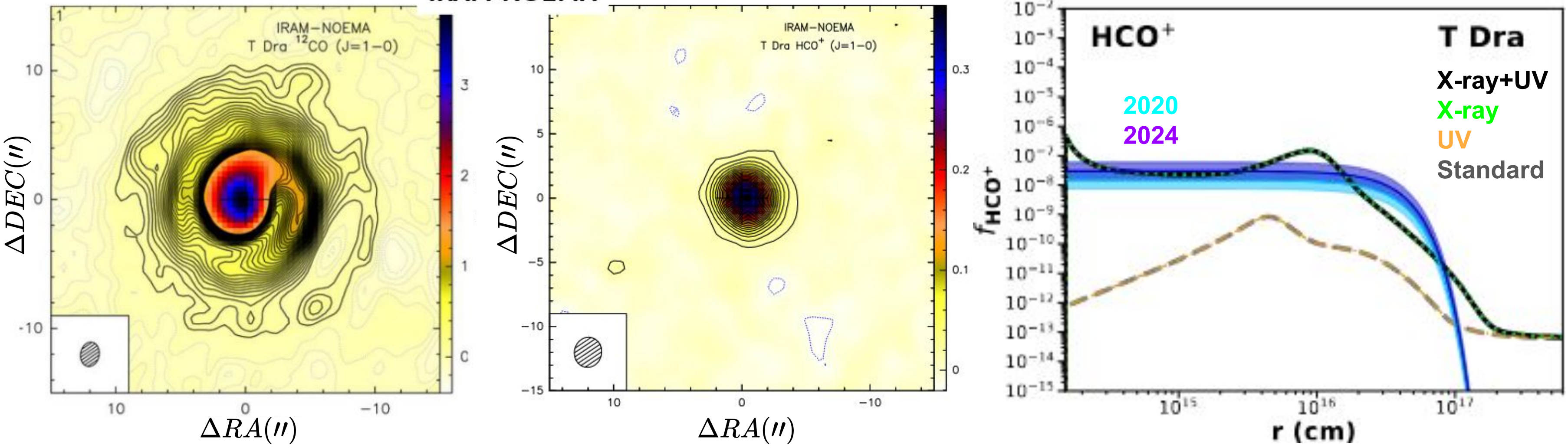
IRAM-NOEMA

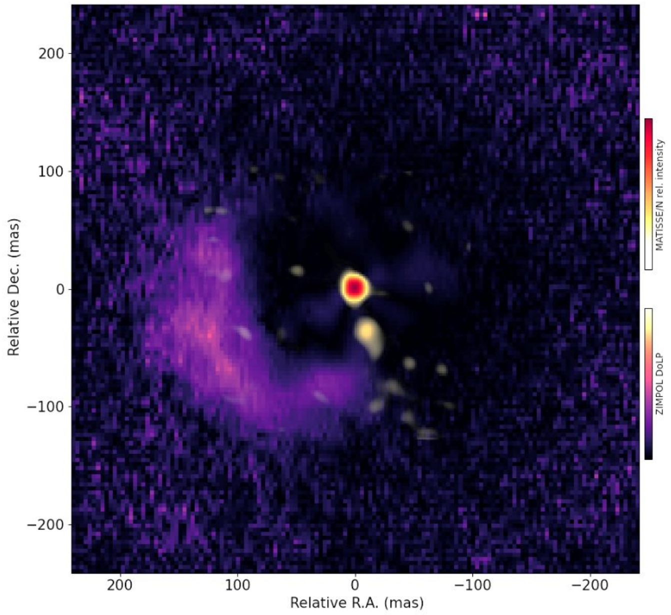


Left: NOEMA CO(1-0) emission map. Centre: NOEMA HCO$^+$(1-0) emission map. Right: HCO$^+$ radial abundance (Alonso-Hernández+2025, in prep.)

A portrait of mass transfer by VLTI/MATISSE

Synergy between infrared/X-ray observations

VLTI/MATISSE can map the gas and dust distributions around the stars and look into the mass transfer process in real time!



π^1 Gru system combining VLTI/MATISSE at 11 μm and VLT/SPHERE at 645 nm (Drevon+2026)

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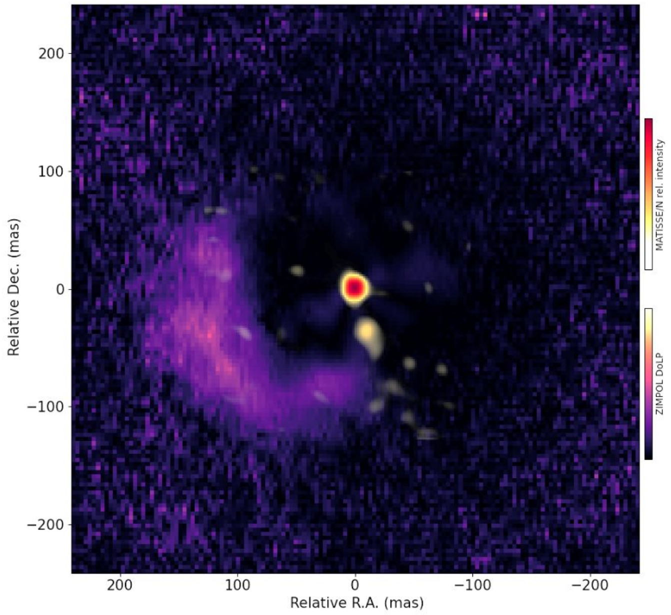
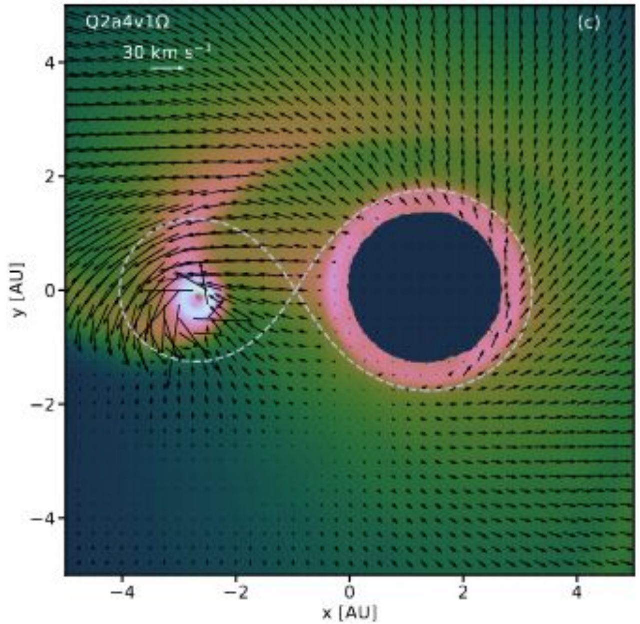


π[1] Gru system combining VLTI/MATISSE at 11 μm and VLT/SPHERE at 645 nm (Drevon+2026)



Gas density in a wind-RLOF model of a binary AGB star (Saladino+2019)

A portrait of mass transfer by VLTI/MATISSE

Joint observations to study the relationship between X-ray emission and mass transfer

Synergy between infrared/X-ray observations

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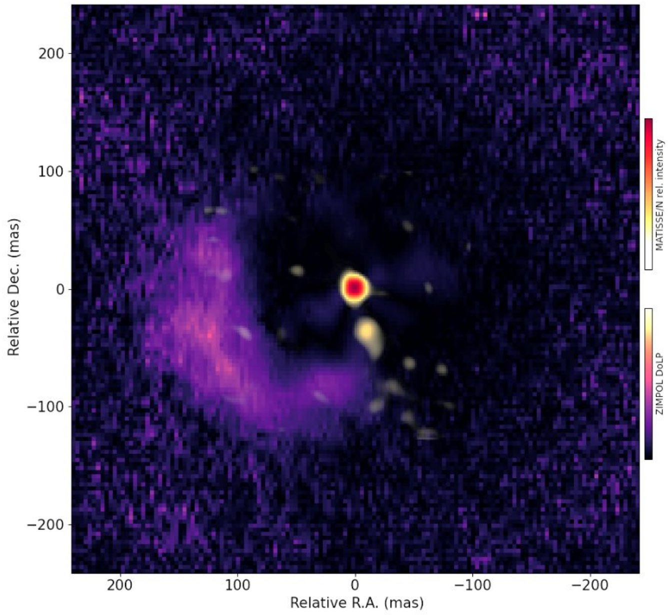

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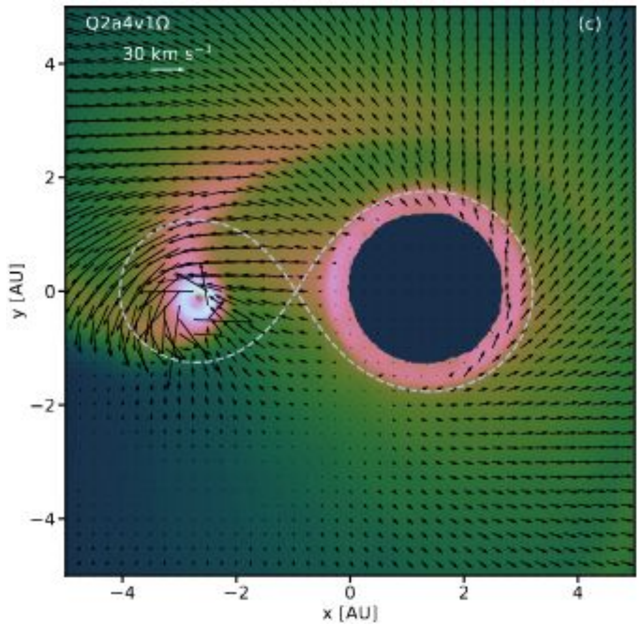


Gas density in a wind-RLOF model of a binary AGB star (Saladino+2019)

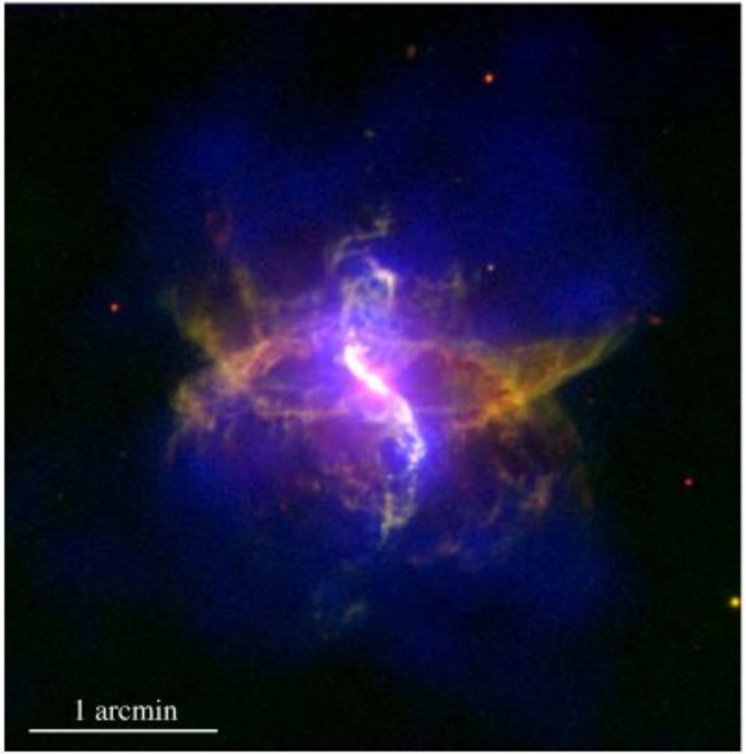
Probing the origin of the nebular X-ray emission

It is not clear whether the origin of the nebular emission is continuum or emission lines

NewAthena/X-IFU will provide:

- Sensitivity to detect the faint nebular emission
- Angular resolution to map it properly
- Spectral resolution to identify continuum and lines

NewAthena/X-IFU will probe its origin!



XMM-*Newton*+HST color composite (blue for X-ray, green for Hα+N II, and red for OII) of R Aquarii (Toalá+2022)

High-resolution X-ray spectroscopy to test current models

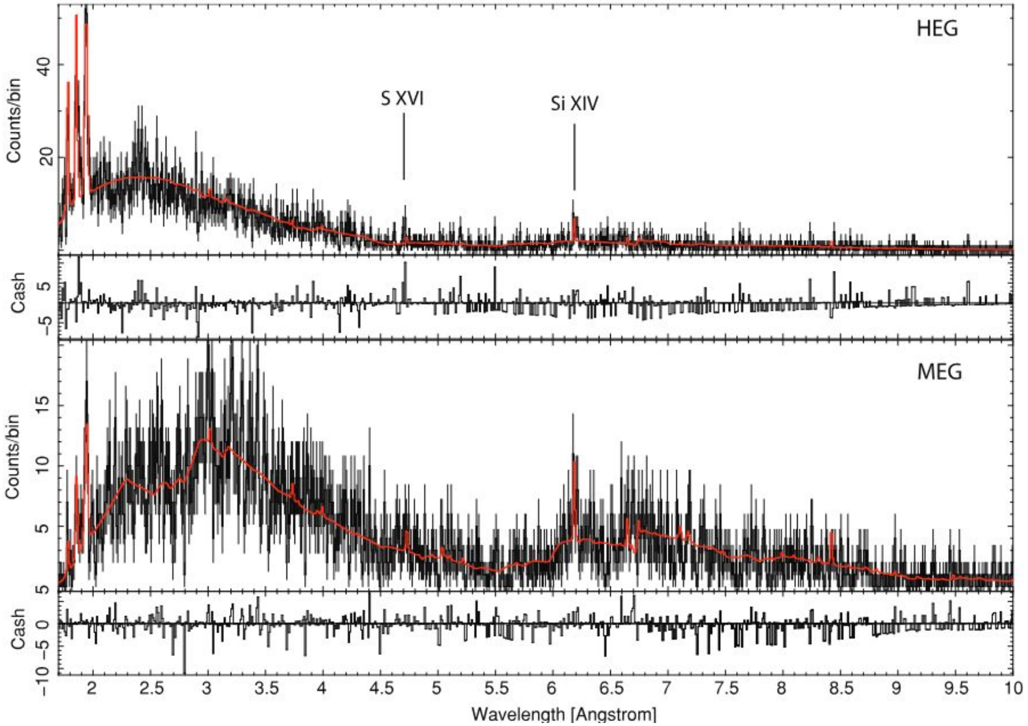
Symbiotic stars are typically weak X-ray emitters, only a few have high-resolution X-ray spectra.

However, the detection of more fluorescent lines is required to test current disc models in symbiotic stars

NewAthena/X-IFU will provide:

- Spectral resolution to identify the different lines
- Sensitivity to achieve good signal-to-noise ratio

NewAthena/X-IFU will test current models



Chandra/HETG spectra of SS73 17 indicating some detected lines (Eze+2010)

Take away messages

- **Symbiotic stars are ideal laboratories to study mass-transfer and jet formation (also nebular formation)**
- **The main properties of their X-ray spectra can be explained with an internal source and a reflection component**
- **Joint multi-wavelength observations will be key to achieve a comprehensive view of these systems**
- **NewAthena can confront the most important problems related with their X-ray emission**