3D VISUALISATION OF NOVA REMNANTS

MARTÍN A GUERRERO & EDGAR I SANTAMARÍA

GERARDO RAMOS-LARIOS, JESÚS A TOALÁ, LAURENCE SABIN,
SARA CAZZOLI, ALESSANDRO EDEROCLITE, LARISSA TAKEDA

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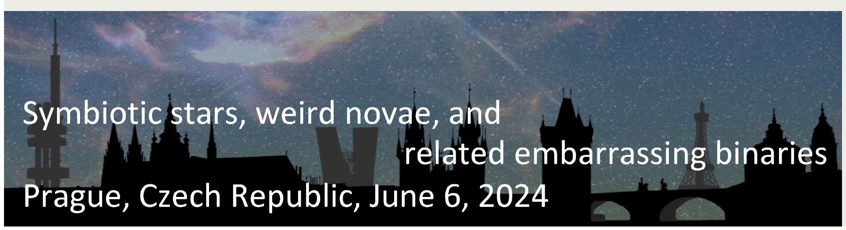

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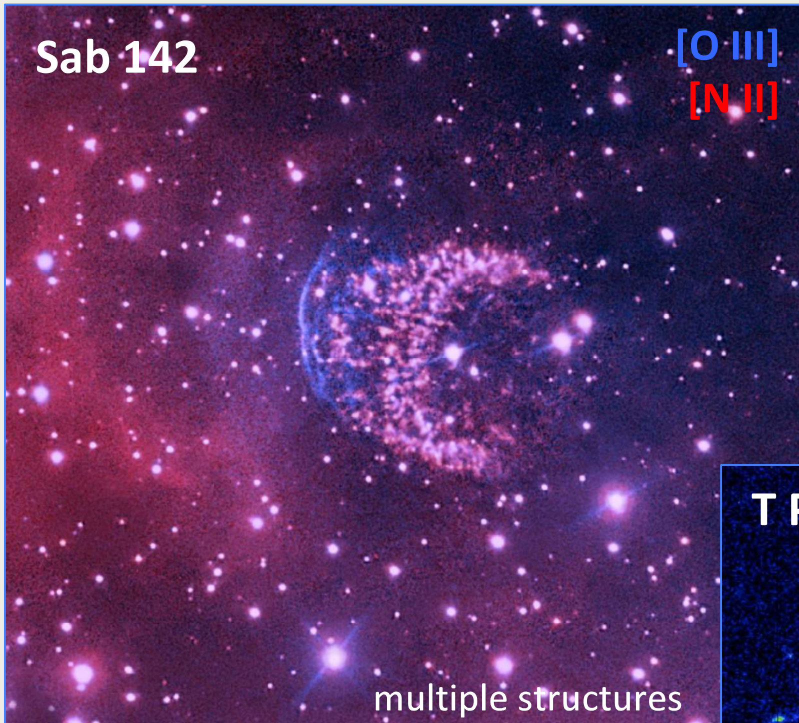
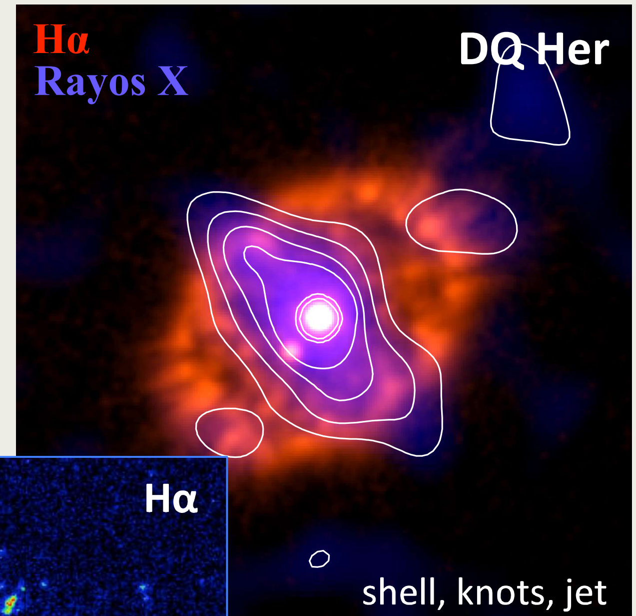
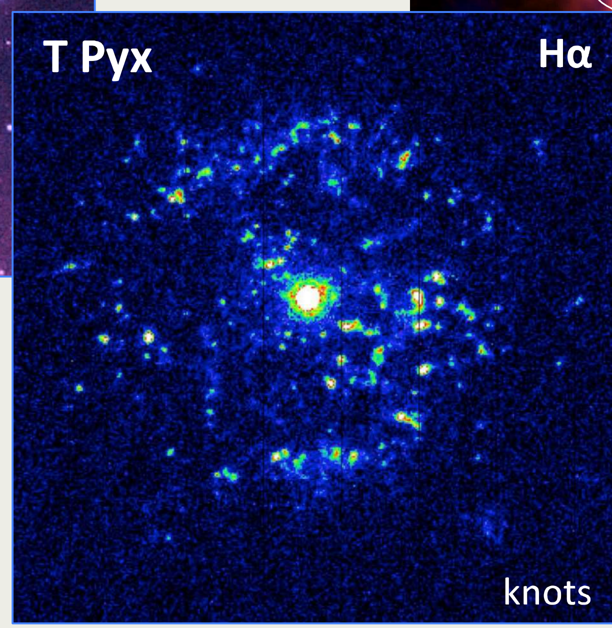
NOVA REMNANTS MORPHOLOGIES (OR PROJECTED 3D STRUCTURES)







Guerrero+2018; Shara+1997; Toalá+2020

NOVA REMNANTS MORPHOLOGIES (OR PROJECTED 3D STRUCTURES)

Imaging catalog of nova remnants

Compilation of available archival ground-based/HST and targeted narrow-band Hα, Hα+[N II], [N II], [O III] images of ≈50 nova remnants

Ages from 15 up to 600 yr

Large morphology variety

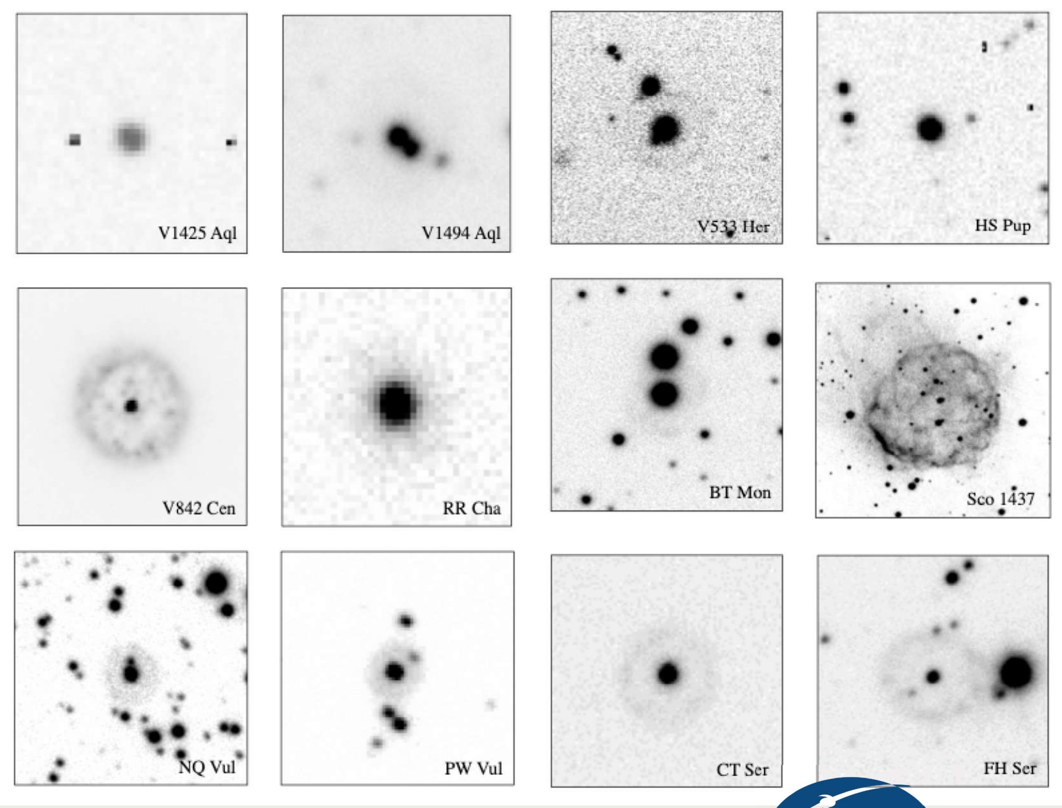
Single/multiple shell
Smooth/clumpy
Mostly elliptical/few bipolar

Study in progress

Morphology statistics
Time-evolution: age effects
Distance: resolution effects

FITS/JPG available in a dedicated webpage soon hopefully this year

Contributions welcome!



Santamaría+2024, in prep.; Poster #18

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SHAPING OF NOVA REMNANTS

Wind-wind interaction

Impulsive ejection at TNR ... short-lived wind **few hours**

Prompt ejection (minutes to hours) of just a fraction of the WD envelope

Rather a wind with mass-loss rate rapidly declining by ≈10 (in few hours)

M_{ej} and V_{ej} depending on WD and envelope mixing during TNR

Prolonged optically thick wind **days to months**

Radiation-pressure driven wind

Mass-loss rate decreases (nuclear burning, envelope mass loss), while V_{ej} increases up to $V_{ej} \geq 1000$ km/s as photosphere recedes and moves in

Geometry of the pre-nova outburst circumstellar environment

Classical novae: accretion disk, low density CSM

Embedded novae: wind accretion, WD within red giant companion wind

Starrfield+1978; Prialnik & Kovetz 1992; Kato & Hachisu 1994; Lloyd+1995; Chomiuk+2021

SHAPING OF NOVA REMNANTS

Geometry of the ejecta

<u>Early phase</u>: Fast <u>WD rotation</u>

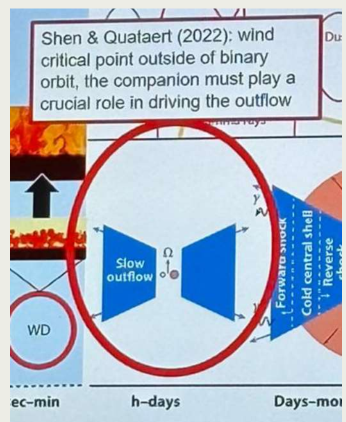
Latitude-dependent peak P_{TNR} and T_{TNR}

Envelope corotation with WD surface by B coupling

<u>Common envelope phase</u>: Binary effects

At light peak, the photosphere may engulf the binary system

Mass loss focused towards <u>orbital plane</u> preferentially through outer L2 Lagrange point by frictional drag, binary orbital motion (centrifugal forces), companion's gravity, ...



remember
Ondrej Pejcha's talk

Binary influence greater for slower ejecta: $V_{ej} \leq 1000$ km/s

Livio+1990; Scott 2000; Zhao & Fuller 2020; Chomiuk+2021

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EARLY SHAPING
(UNRESOLVED NOVA REMNANTS)

<u>Multi-peaked line profiles at nebular stage</u>

Ejecta asymmetry:

bipolar ejecta + equatorial torus or disk

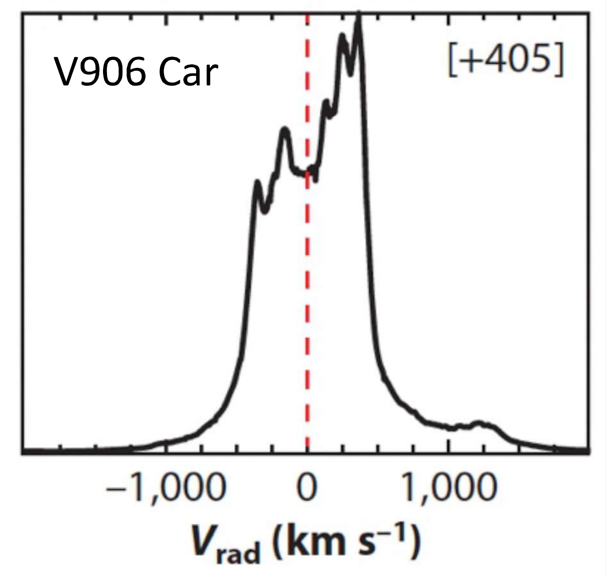
<u>Velocity persistent structures in spectral lines</u>

Discrete clumps

<u>Low and high ionization species spectral features</u>

N_e and T_e broad range within ejecta:

self-shielding clumps



Saizar & Ferland 1994; Shore+2013; Williams 2013; Mason+2018; Aydi+2020

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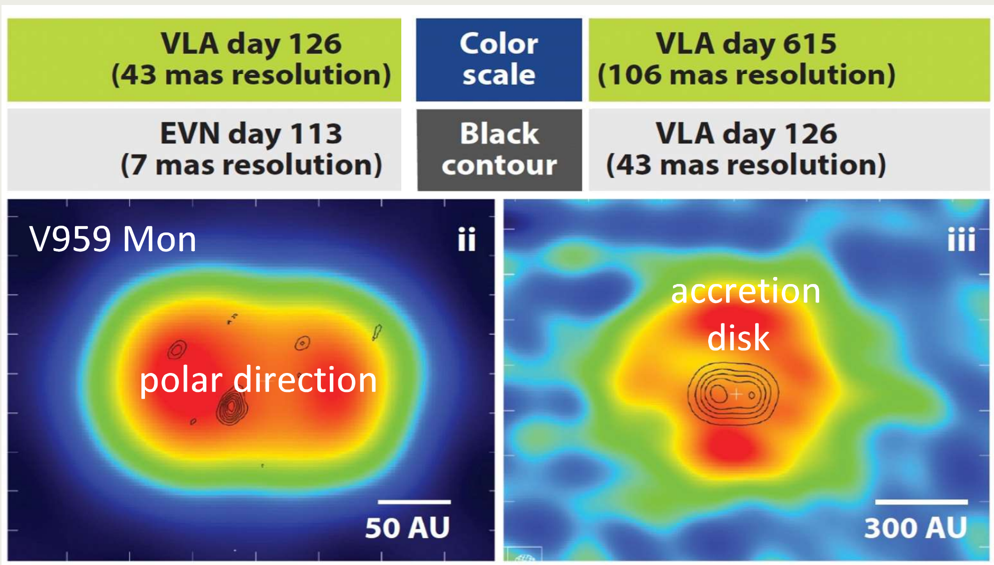
EARLY SHAPING
(JUST RESOLVED NOVA REMNANTS)

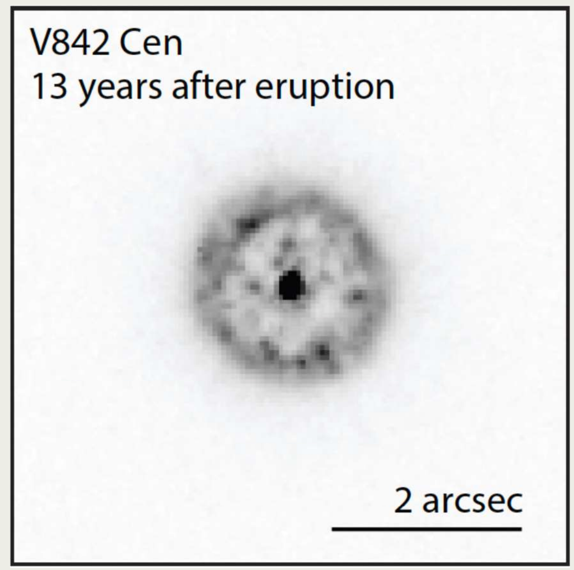
Early images of nova ejecta: Nova angular size expansion rate

$$\theta = 0.115\,\mathrm{arcsec}\left(\frac{d}{1\,\mathrm{kpc}}\right)^{-1}\left(\frac{v_{\mathrm{ej}}}{1{,}000\,\mathrm{k\,s^{-1}}}\right)\left(\frac{t}{100\,\mathrm{days}}\right)$$

High-resolution facilities like HST, near-IR adaptive-optics and radio/mm interferometers can **resolve nova ejecta ~months to ~years** after eruption



Ellipticity/orientation evolution in time: interaction of winds with different symmetry



Clumpy structure

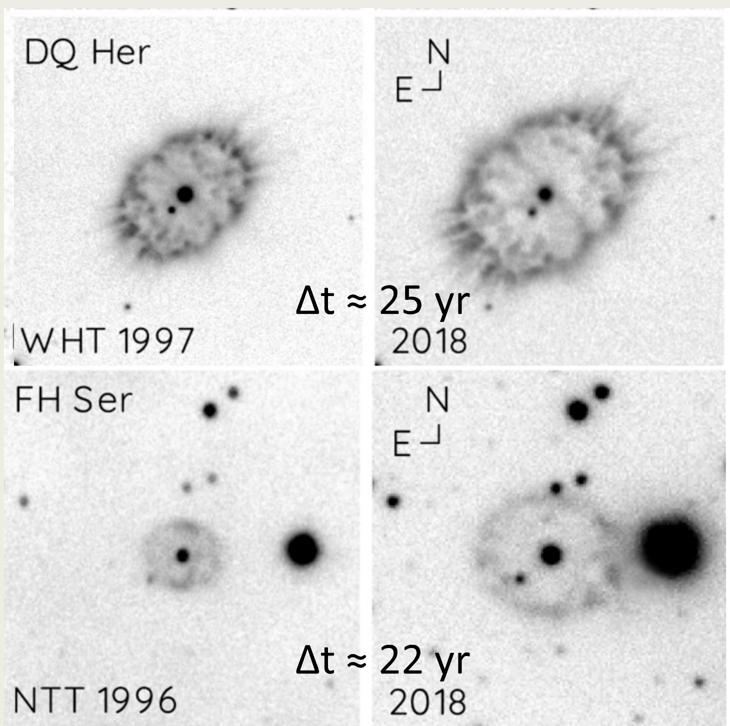
Healy+2017; Chochol+1997; Chomiuk+2021

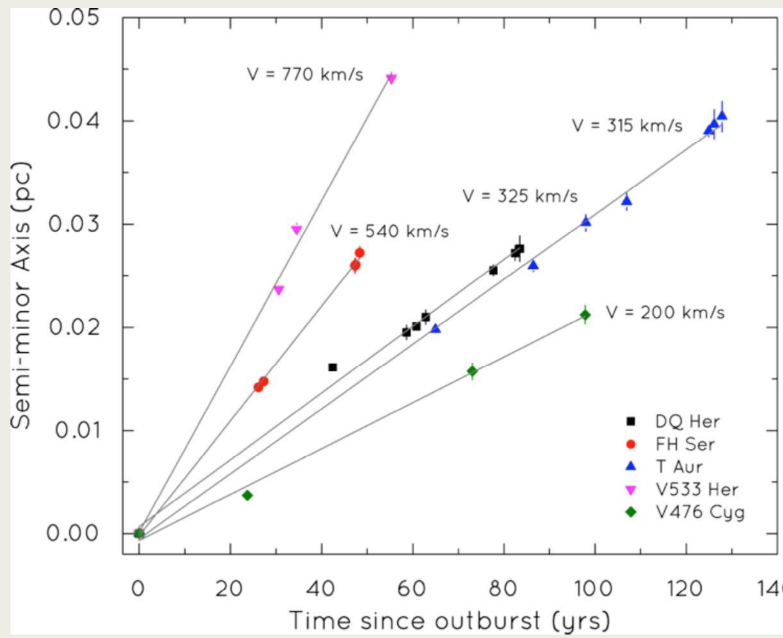
LATE NOVA SHAPING AND EXPANSION

(RESOLVED NOVA REMNANTS)

<u>Late images of nova ejecta</u>

Ground-based optical imaging **resolve novae ~years to ~decades** after eruption and trace their **<u>free</u>** angular expansion − linking early shaping to present nova shape (but note that individual features may fade/brighten as in T Pyx)





Santamaría+2020

Slavin+1995; Shara+1997; Gill & O'Brien 1998; Downes & Duerbeck 2000; Schaefer+2012

NOVA 3D STRUCTURE

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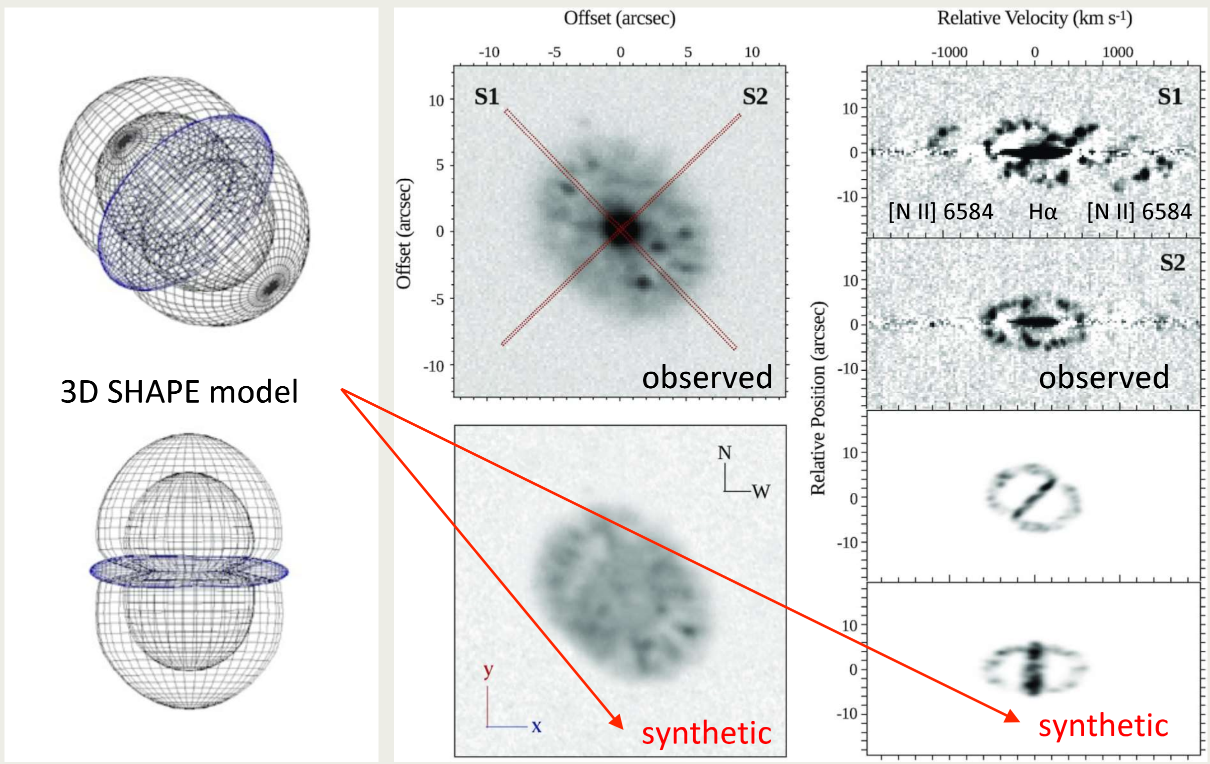
Imaging & Long-slit Spectroscopy + 3D SHAPE Model

HR Del

Hα mild bipolar / peanut morphology; [N II] ring-like structure



Image/spectra at different epochs, observing setups and conditions, ...

Limited spatial sampling, thus only simplified 3D model

Santamaría+2022; Gill & O'Brien 2000

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NOVA 3D STRUCTURE

<u>Integral Field Spectroscopy (IFS)</u>

Spectra obtained at each position of the field of view

If "high spectral dispersion" ($R \geq 3{,}000$ − $\Delta v \leq 100$ km/s), then kinematics

Image and spectra at same epoch, with equal observing setups and conditions

Full spatial coverage

Linda Schmidtobreick and Lientur Celedon talks; Celedon+2024; Izzo+2024

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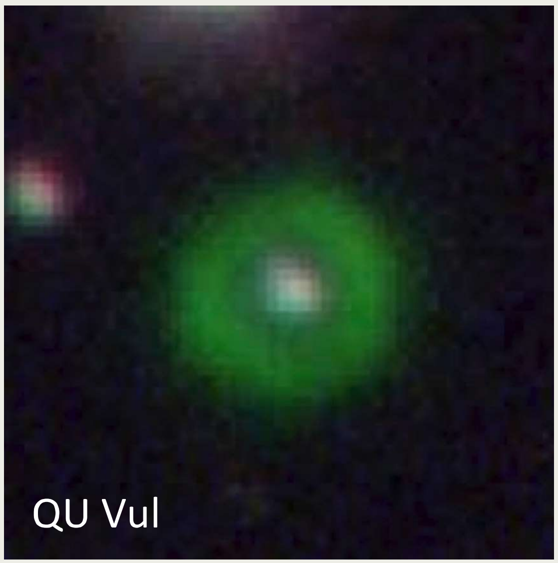
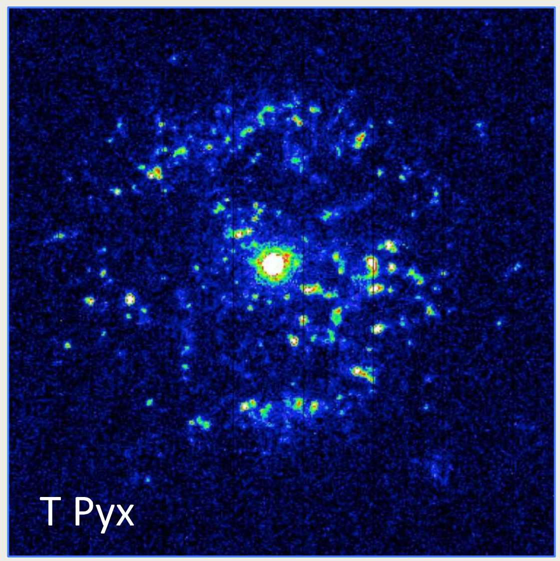
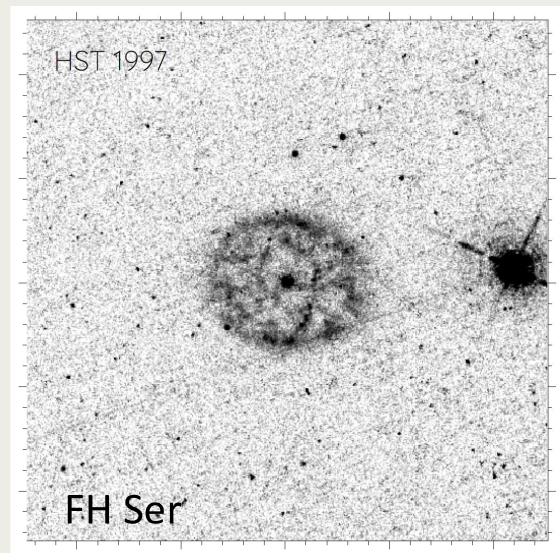
HD-IFS STUDIES OF NOVA REMNANTS

QU Vul:	GTC 10.4m MEGARA	R @ Hα ≈ 18,700	or Δv ≈ 16 km s^{-1}
T Pyx:	VLT 8m MUSE	R @ Hα ≈ 2,500	or Δv ≈ 120 km s^{-1}
FH Ser:	VLT 8m VIMOS	R @ Hα ≈ 3,100	or Δv ≈ 100 km s^{-1}







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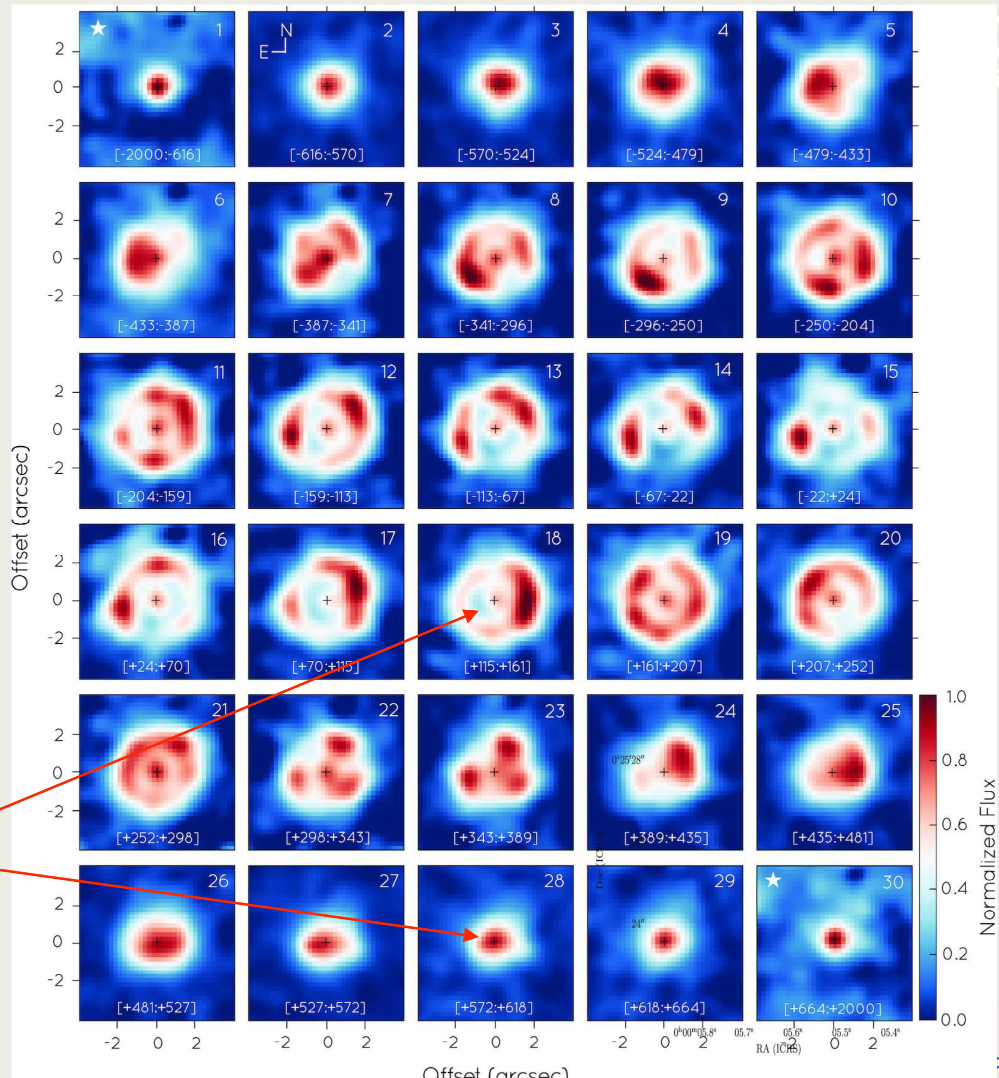
HD-IFS STUDY OF QU VUL

Classical tomographic view

Nebular emission

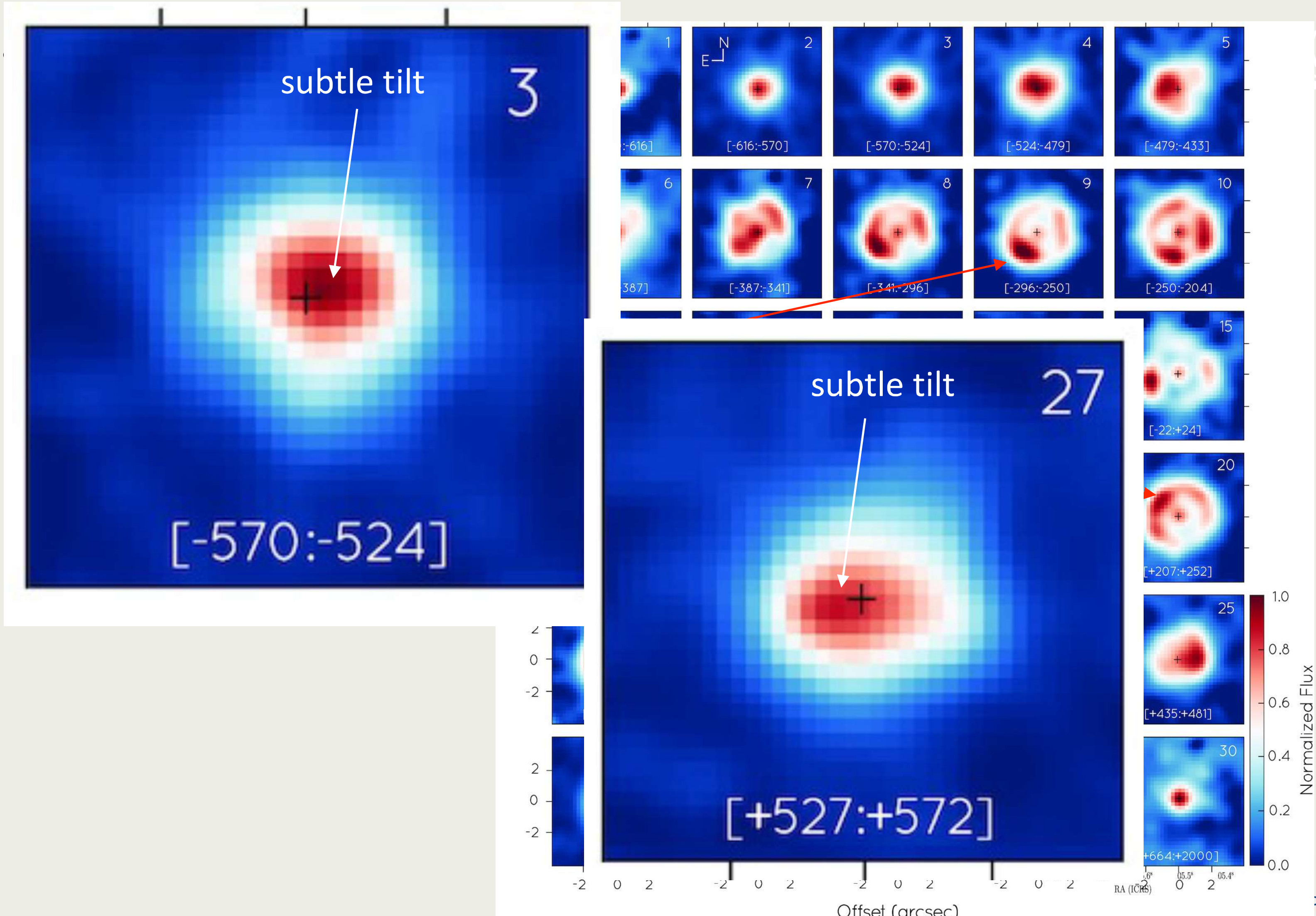
$-616\ km\ s^{-1} < Vr < +664\ km\ s^{-1}$
$\Delta V \approx 45\ km\ s^{-1}$

expanding shell



Santamaría+2022b

HD-IFS STUDY OF QU VUL



Santamaría+2022b

HD-IFS STUDY OF QU VUL

Classical tomographic view

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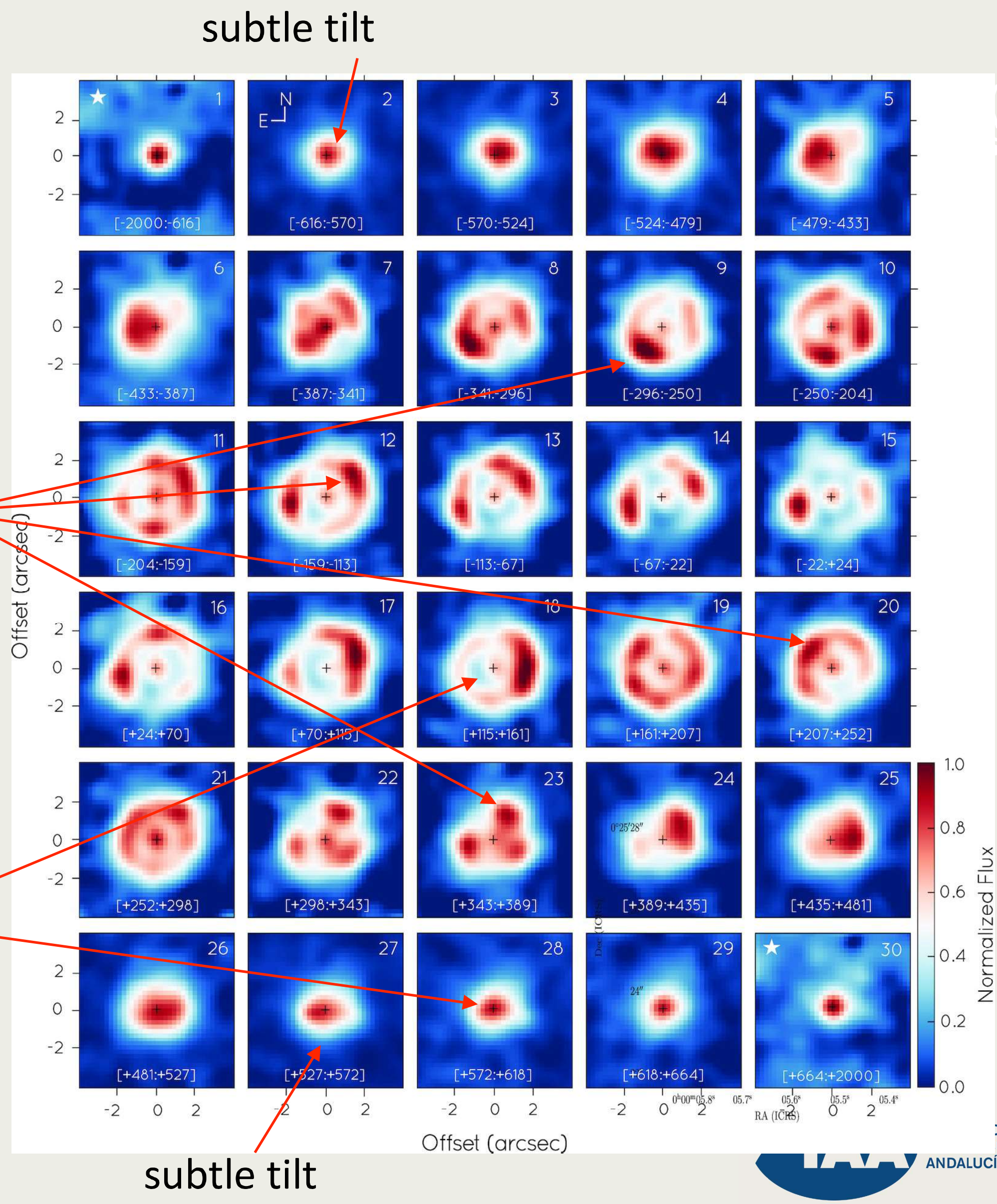
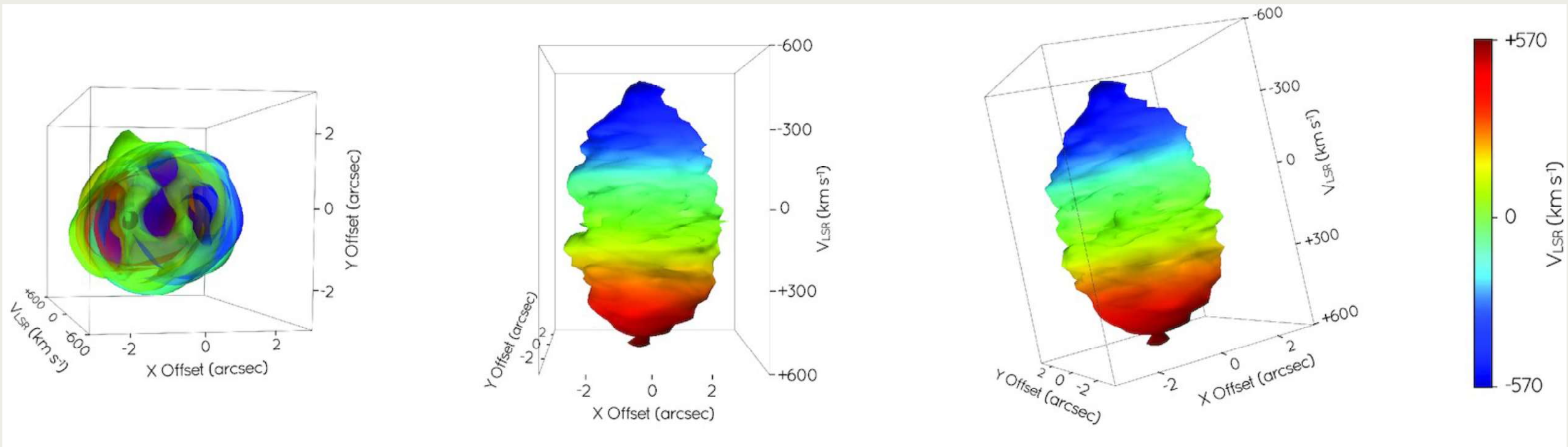


Too much information!!!

Santamaría+2022b

HD-IFS STUDY OF QU VUL

Single iso-intensity velocity colour-coded surface



Santamaría+2022b

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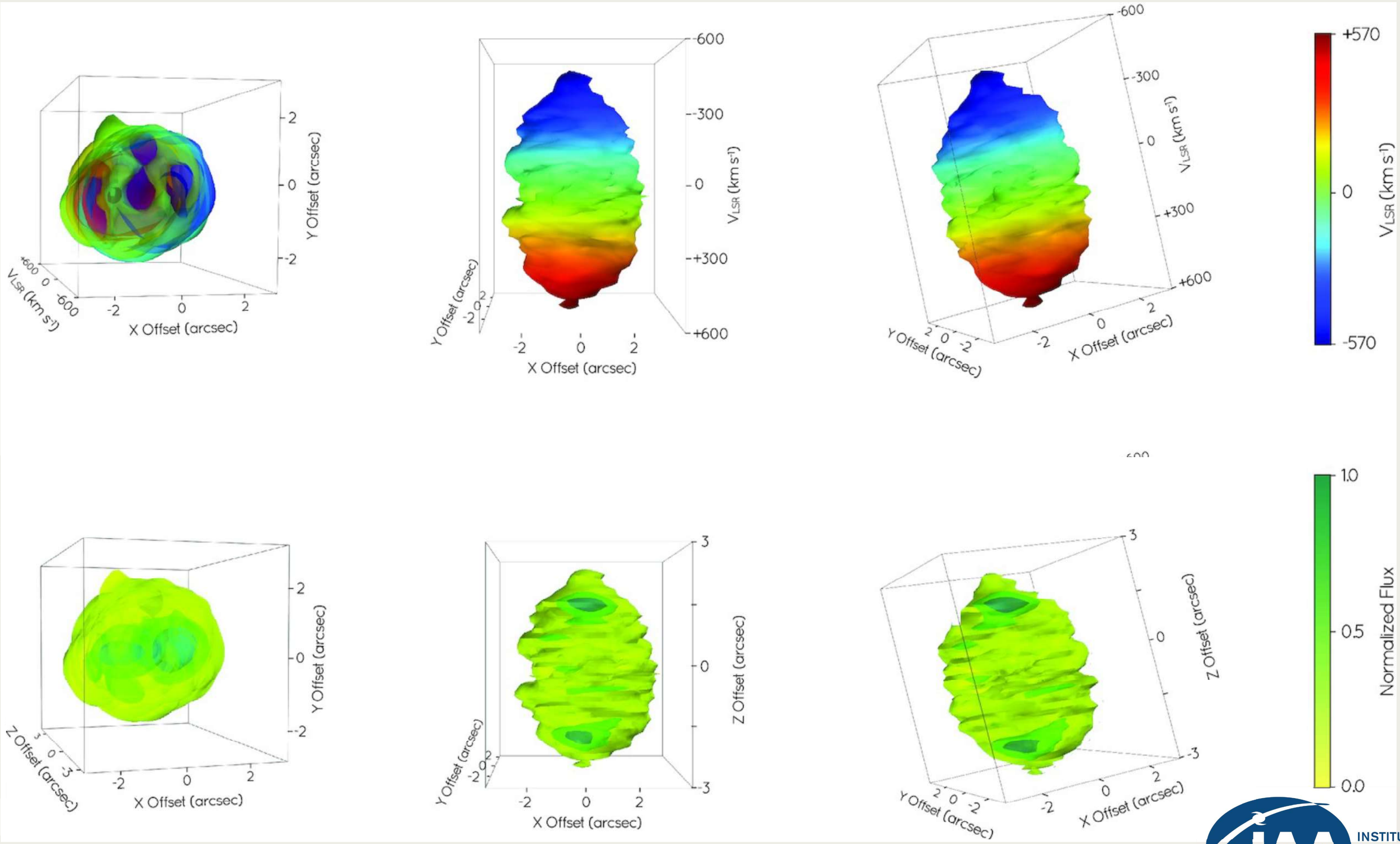
HD-IFS STUDY OF QU VUL

Single iso-intensity velocity colour-coded surface



Multiple iso-intensity surfaces for knots enhancement

Santamaría+2022b

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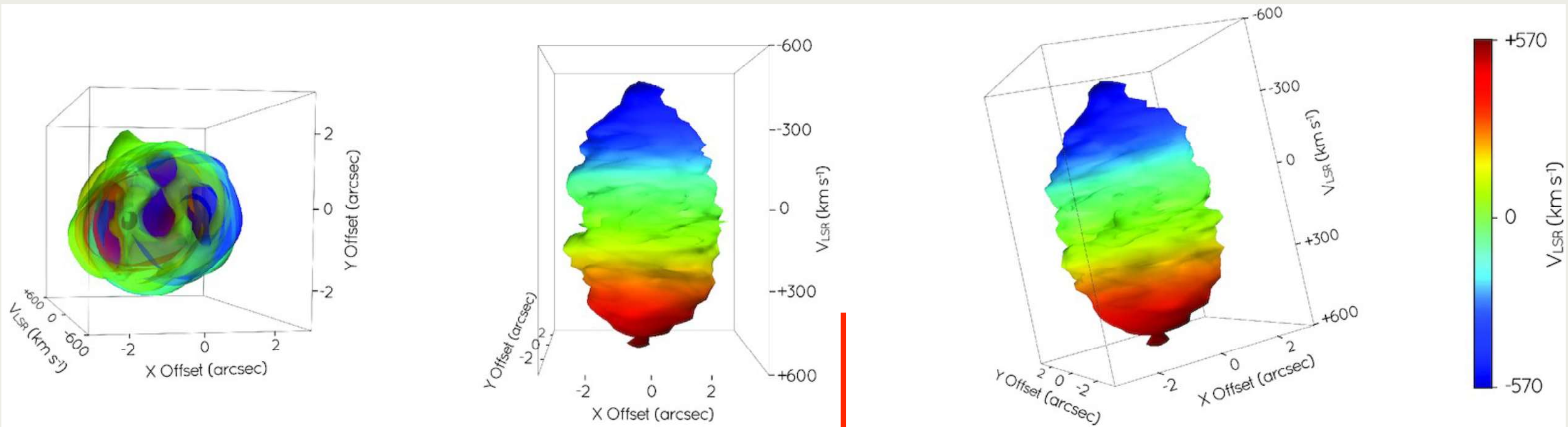
HD-IFS STUDY OF QU VUL

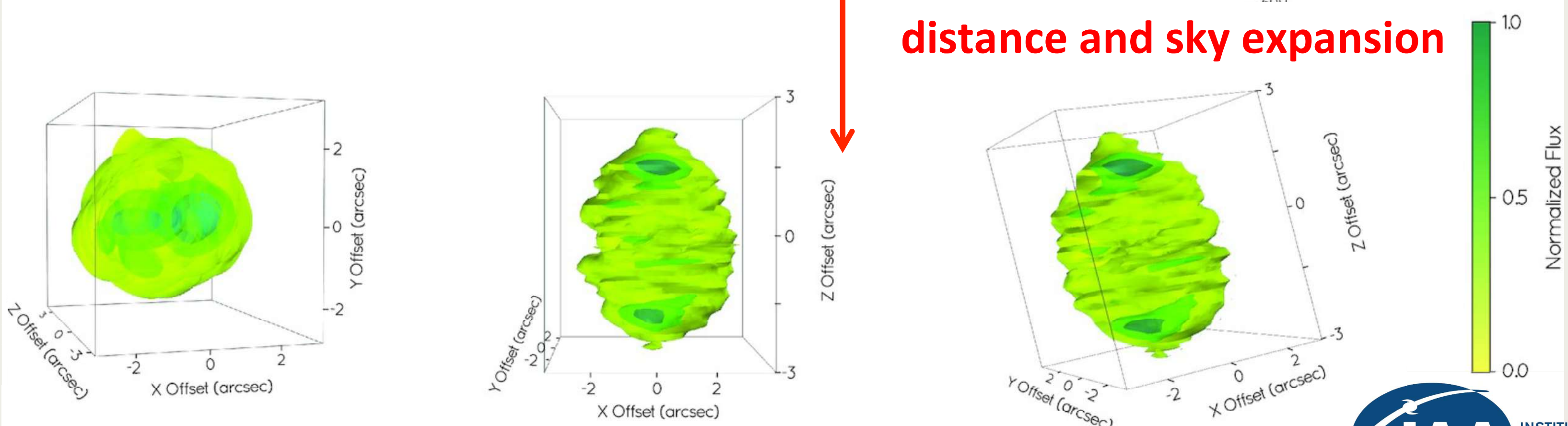
Single iso-intensity velocity colour-coded surface



Basic assumptions: V_z proportional z

simple geometry (ellipsoid)

distance and sky expansion



Santamaría+2022b

Multiple iso-intensity surfaces for knots enhancement

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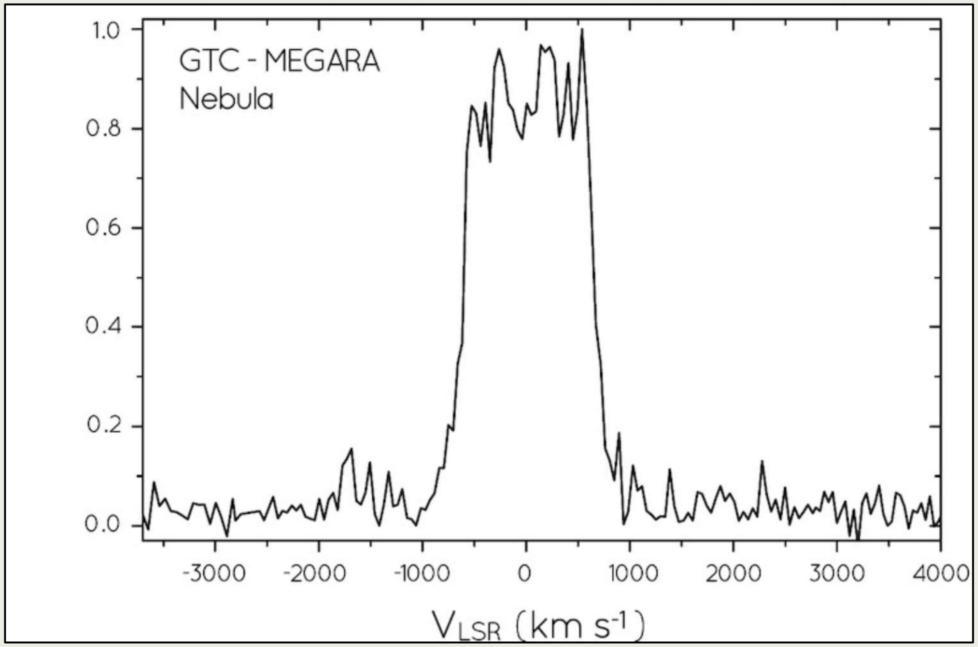
HD-IFS STUDY OF QU VUL

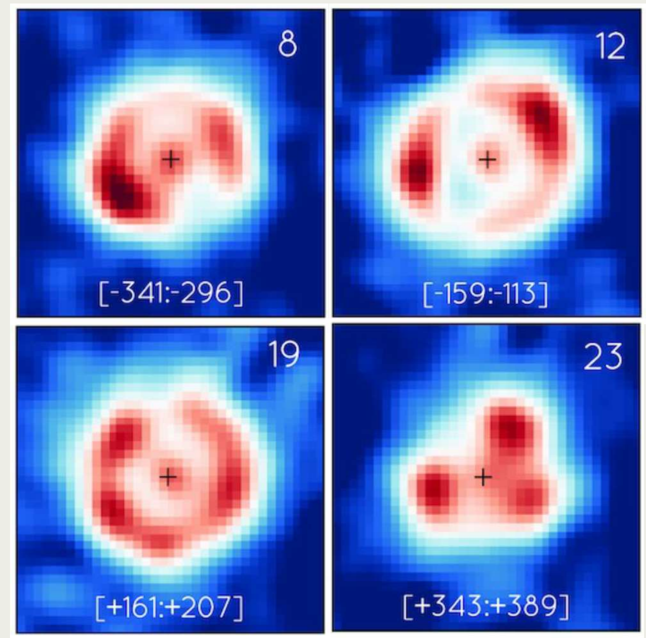
Prolate ellipsoid: axial ratio 1.4±0.2 inclination LOS 12°±6°

$V_{pol} \approx 560$ km s^{-1} // $V_{eq} \approx 400 \pm 60$ km s^{-1}

$M_i \approx 2\times10^{-4}\ M_\odot$ $E_{kin} \approx 3\times10^{44}$ erg (reduced uncertainty on filling factor)



Integrated nebular Hα line profile
"Castellated" line profile



Clumpy 3D structure
Line peaks at different V_r

Usual early $V_{exp} \approx$ FWHM ... overestimates true

$\mathbf{V_{exp} \geq (V_{red} - V_{blue})/2}$

Santamaría+2022b

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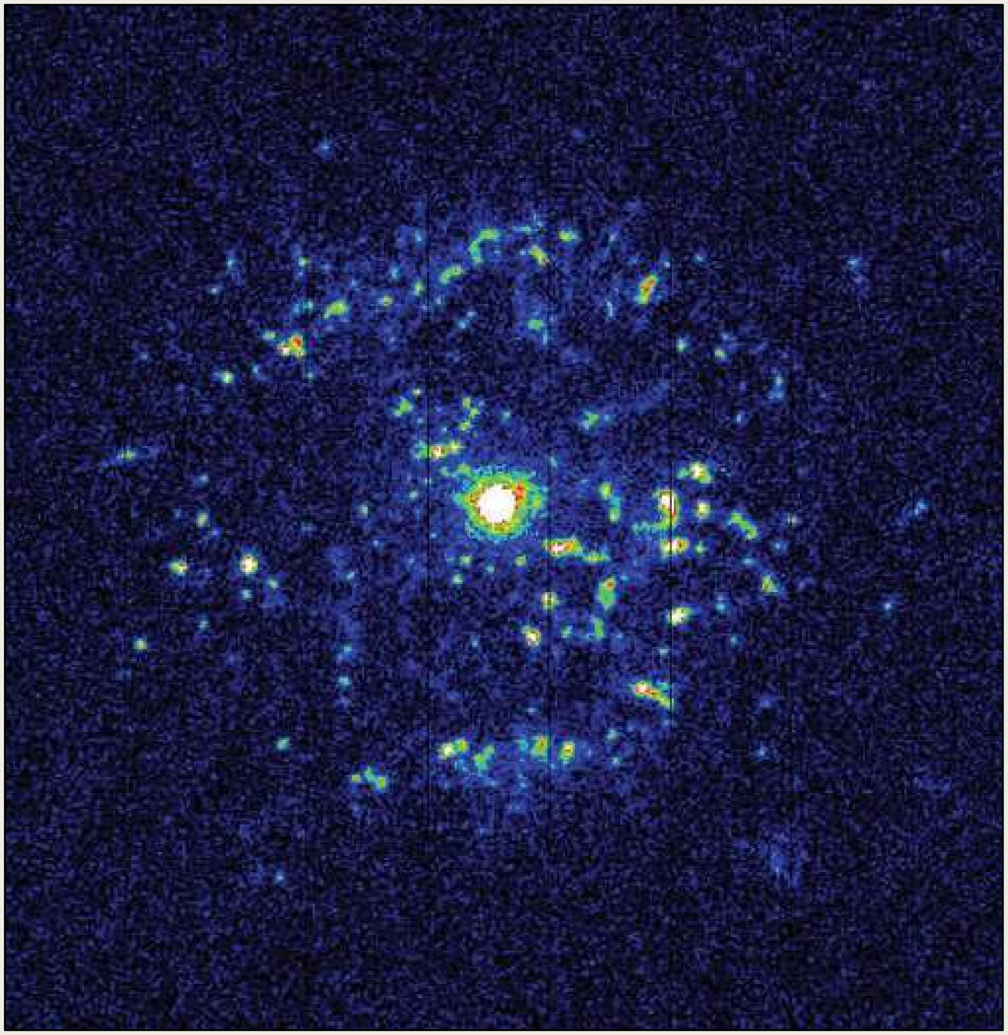
HD-IFS STUDY OF T PYX



Archetype of clumpy nova shell

Detected both in Balmer emission lines of Hα and Hβ and forbidden emission lines of [O III] and [N II]

Santamaría+2024; see also Izzo+2024

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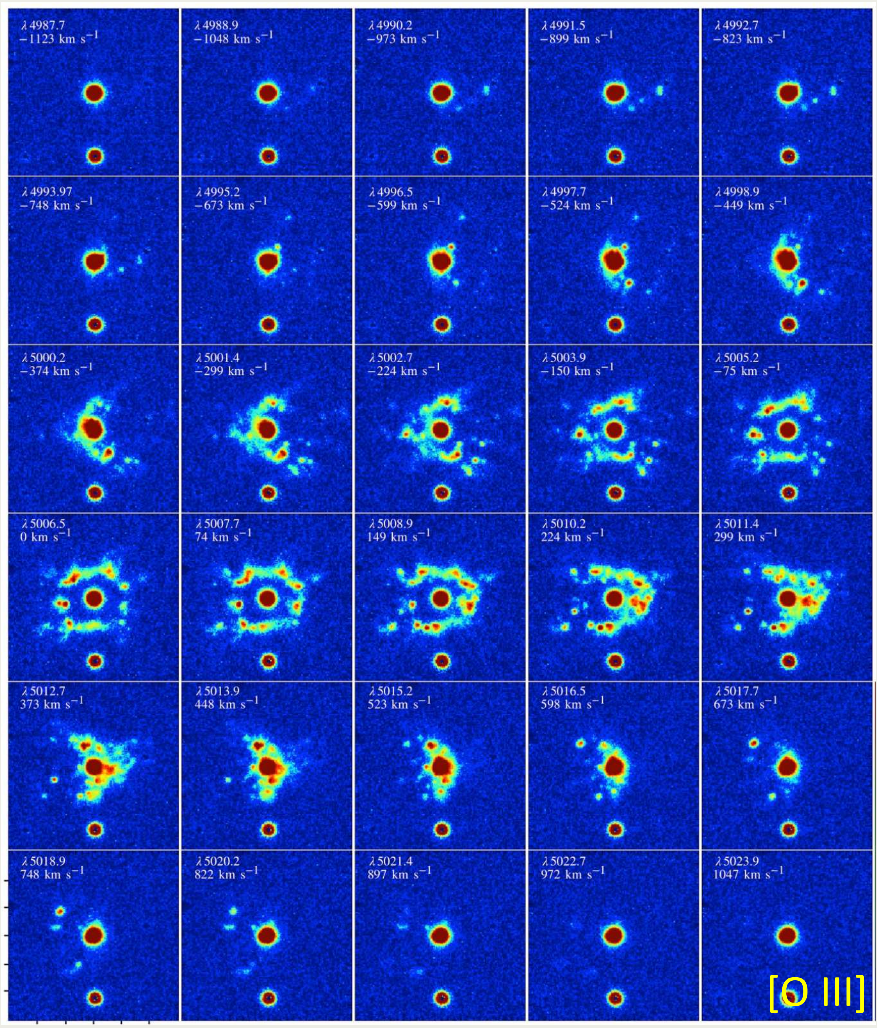
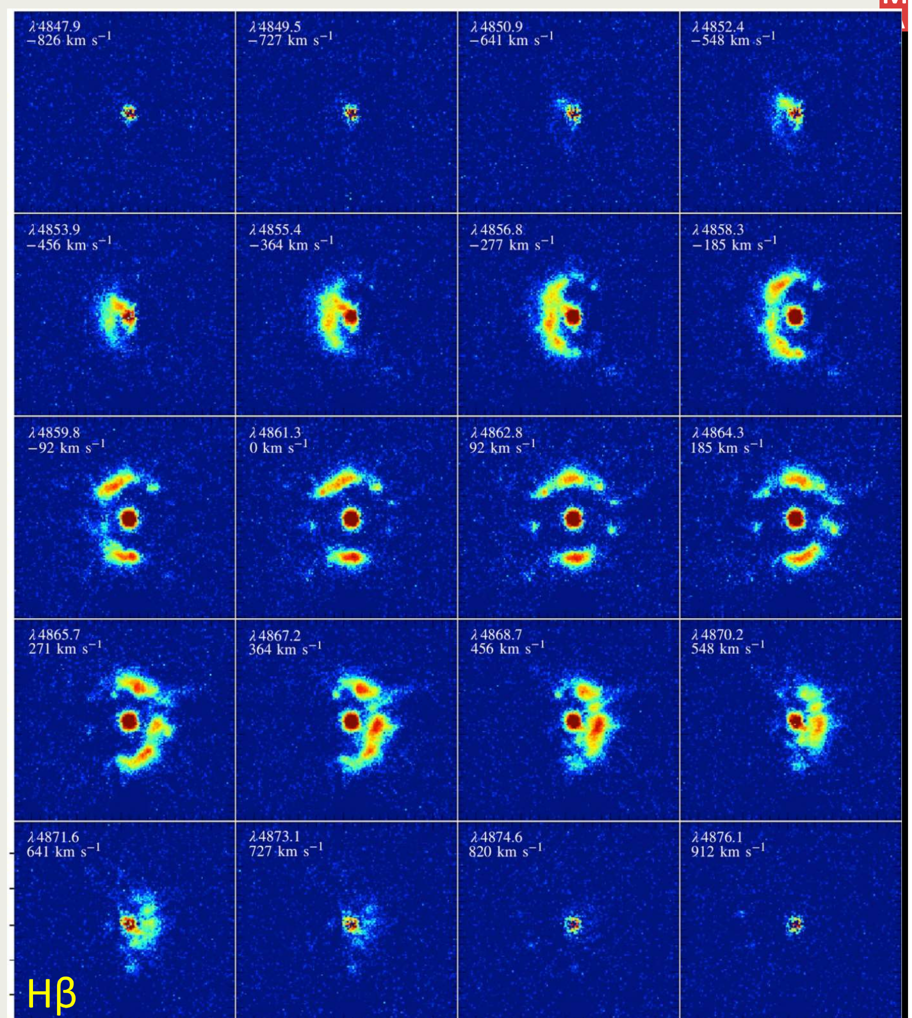
HD-IFS STUDY OF T PYX

Classical tomography in the [O III] 5007 Å and Hβ emission lines ±1050 km s^{-1}





Santamaría+2024; see also Izzo+2024

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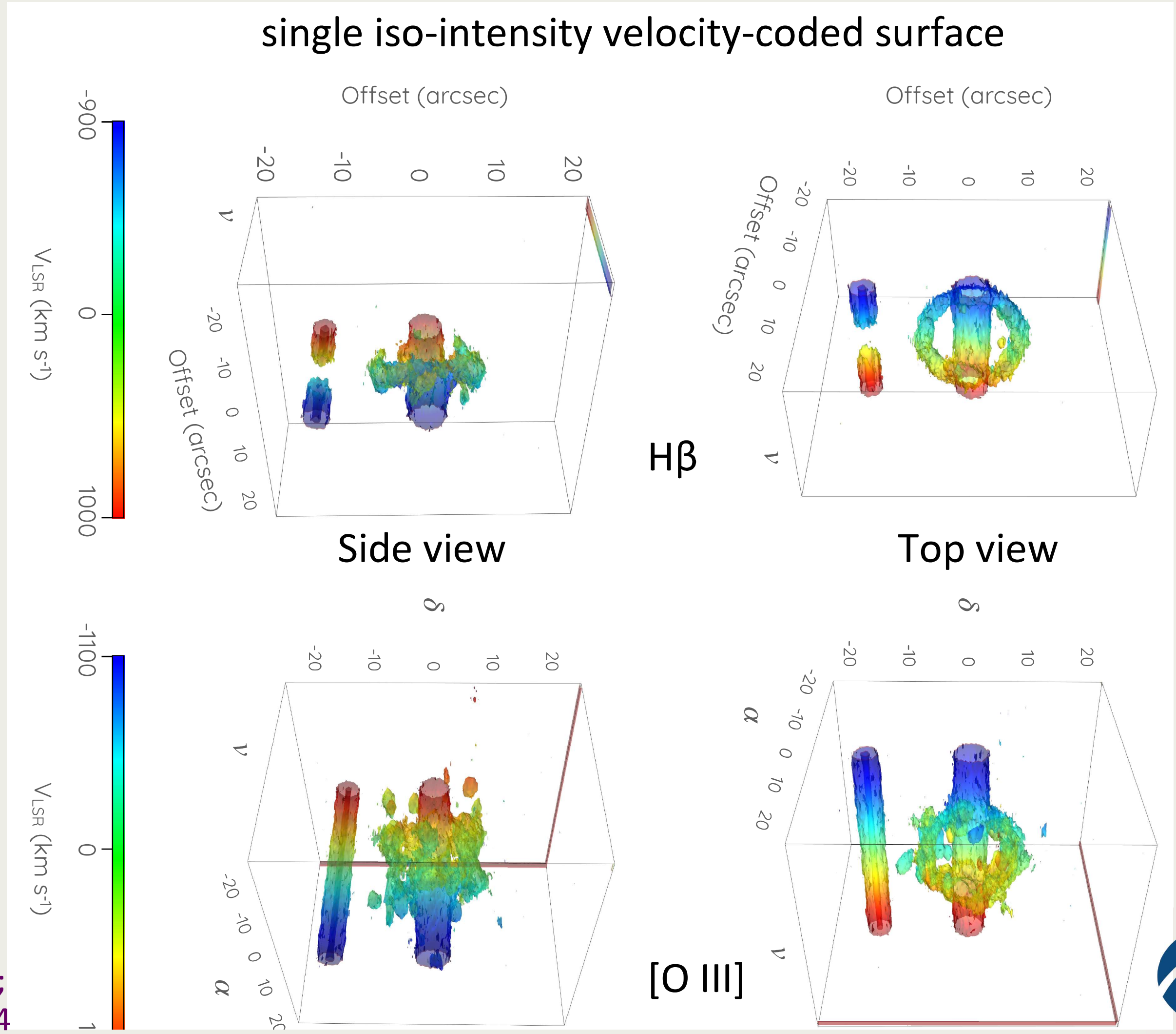
HD-IFS STUDY OF T PYX

Very different spatio-kinematic structure in H Balmer and forbidden emission lines

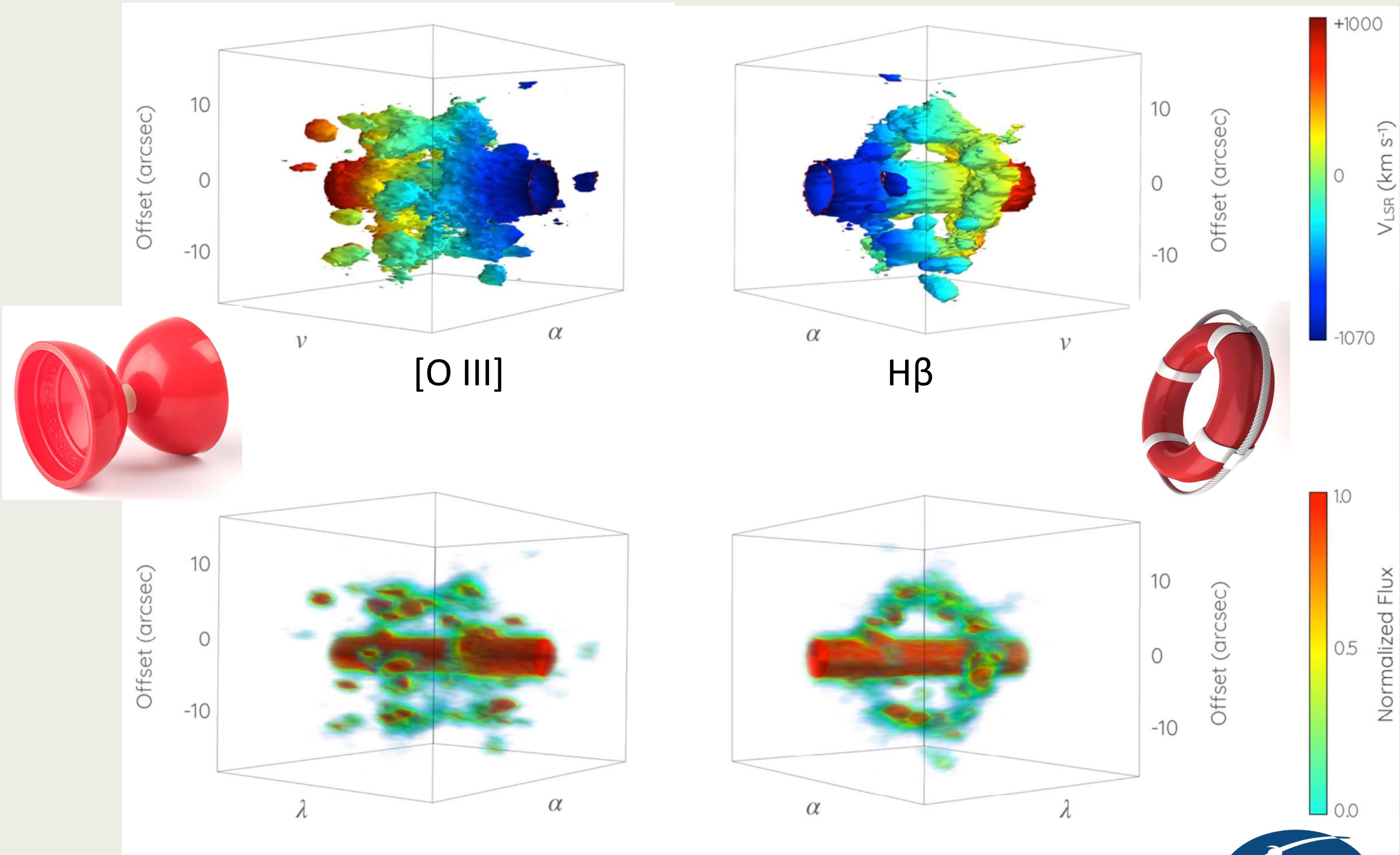


Santamaría+2024;
see also Izzo+2024

HD-IFS STUDY OF T PYX

Exact inclination and 3D model:

[O III] diabolo (truncated hourglass) H I Balmer ring



Similar to RR Pic

Santamaría+2024;
see also Izzo+2024; Celedon+2023

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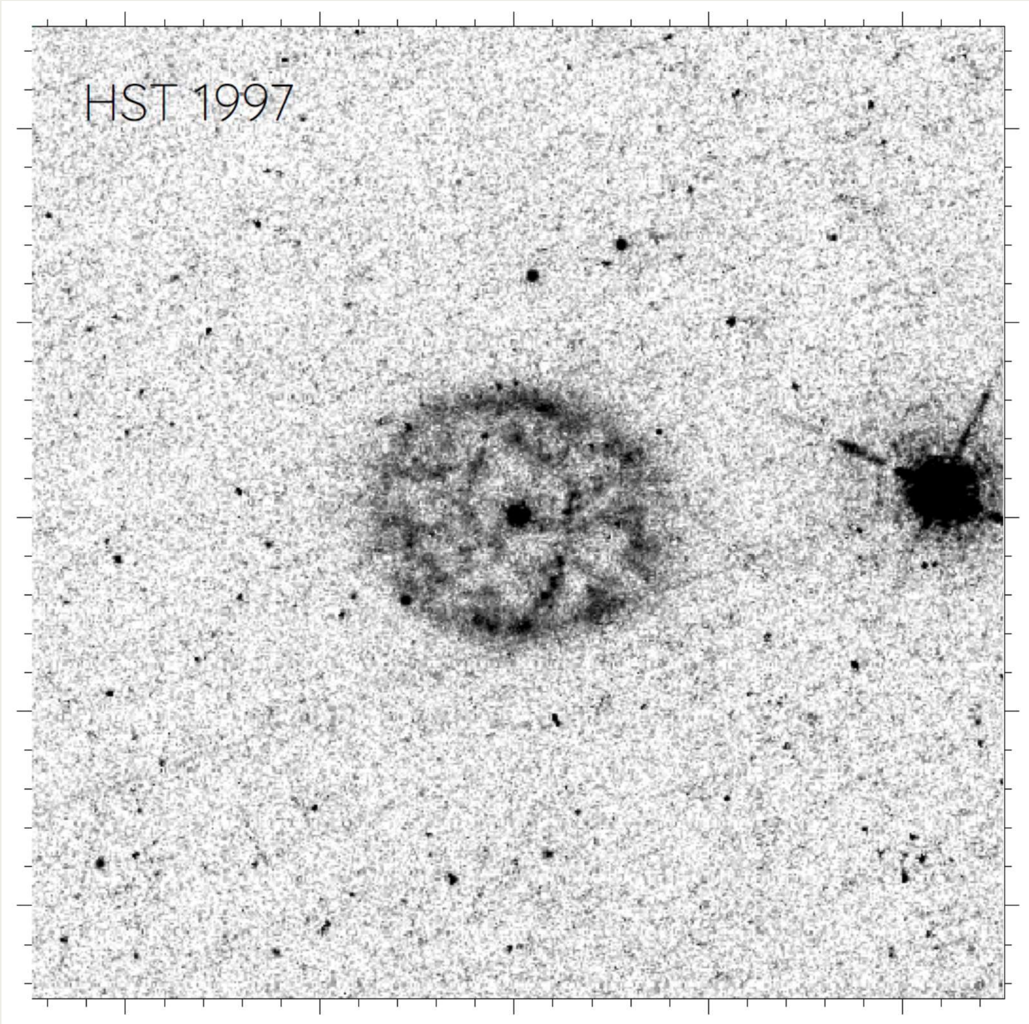
HD-IFS STUDY OF FH SER

Hα elliptical morphology with “equatorial” ring-like structure



Guerrero+2024, in prep

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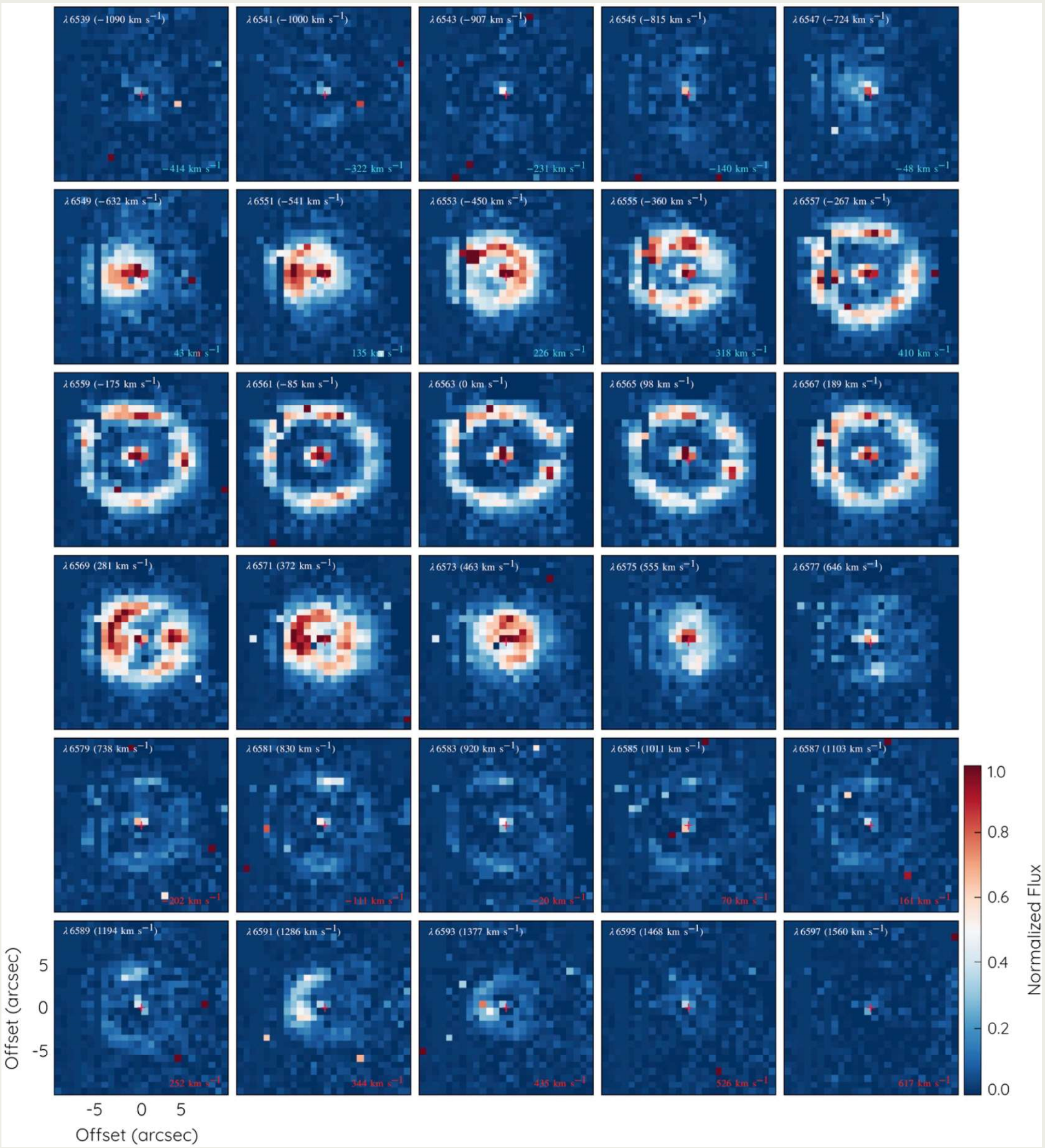
HD-IFS STUDY OF FH SER



Classical Hα and [N II] tomography ...

± 800 km s^{-1}

... too much information:

- expanding shell
- knots/filaments
- Hα and [N II] blended

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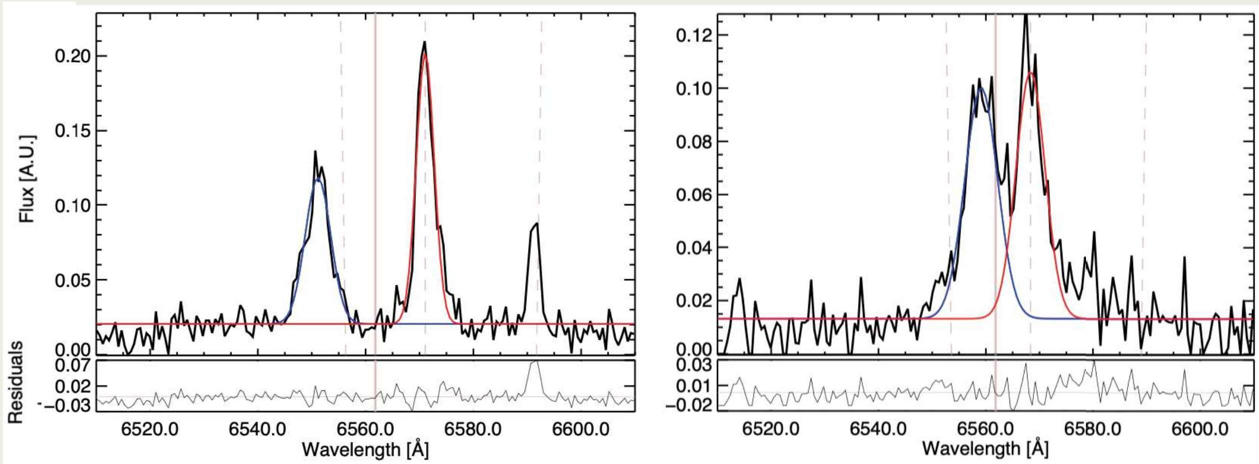
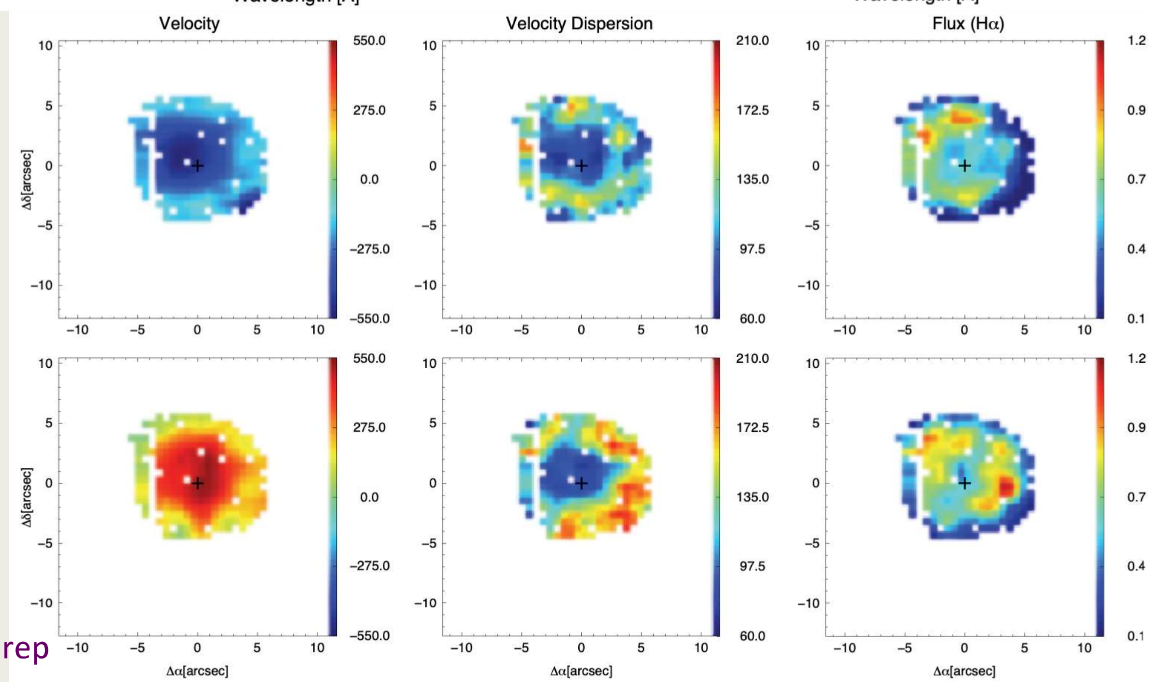
HD-IFS STUDY OF FH SER

Multi-Gaussian 2D fit (velocity, dispersion, flux) for subsequent 3D ellipsoid fit





Guerrero+2024, in prep

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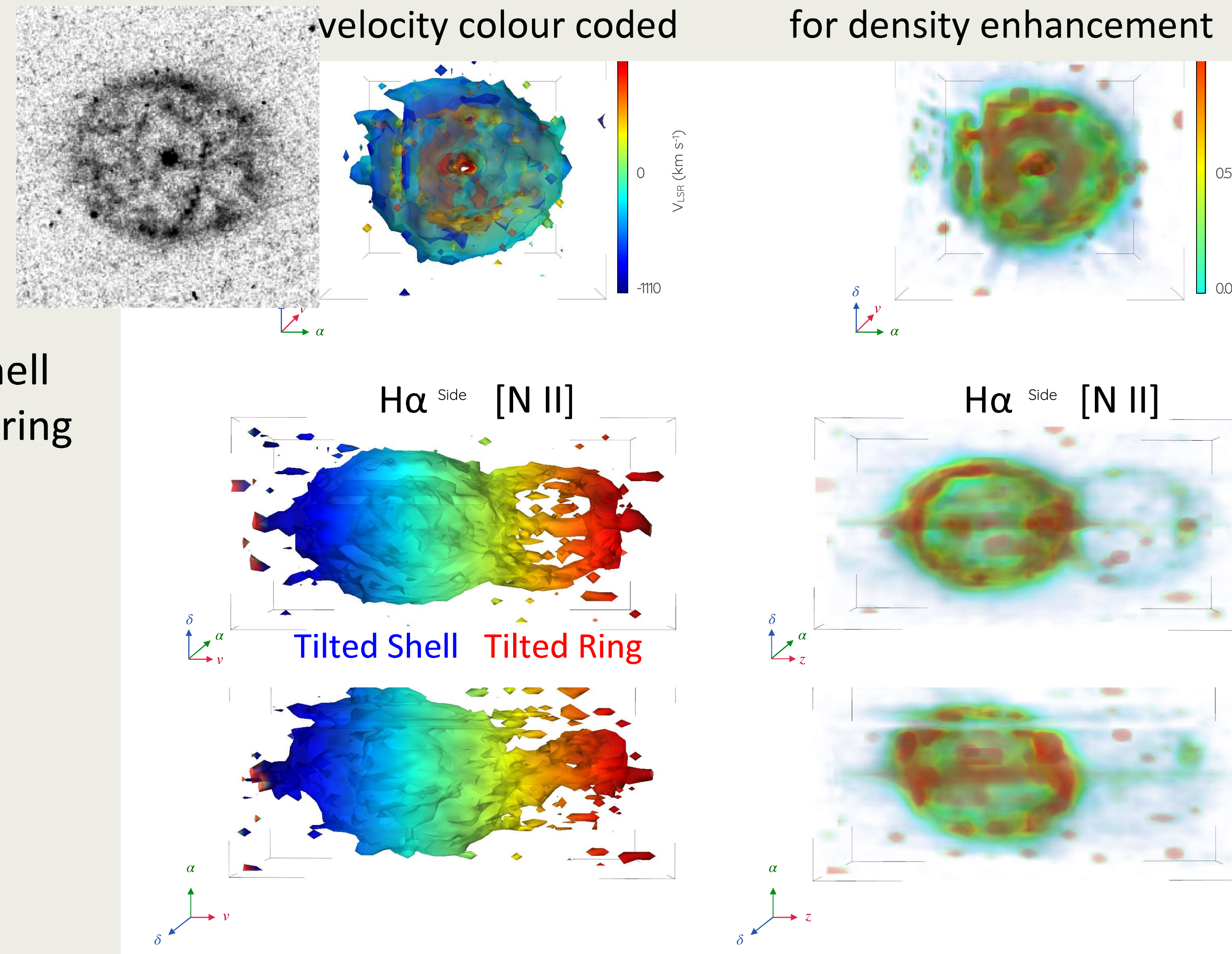
HD-IFS STUDY OF FH SER

Single iso-intensity surface
velocity colour coded

Multiple iso-intensity surfaces
for density enhancement



Direct image

Top view

Side view

Hα shell
[N II] ring

Guerrero+2024, in prep

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TAKE HOME MESSAGE

- "HD"-IFS studies of nova shells are essential to assess their shape, but also M_i, E_{kin}, ...
- IFS datasets provide humongous amounts of information requiring a simplified "natural" visualisation
- H I Balmer and forbidden lines trace different structural components:
  shocks, wind-CSM interactions, non-isotropic ejecta
- Narrow-band Hα imaging may be misleading
- Clumps may dominate nova remnants (even decades after nova event), trapping with in nova yields
- Present day 3D nova remnant structure can trace down the nova event to understand wind-wind and wind-CSM interactions and help interpreting early observations

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