



# Discovery of Low-ionization Envelopes in the Planetary Nebula NGC 5189

## Spatially-resolved Diagnostics from HST Observations



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The planetary nebula NGC 5189 shows one of the most spectacular morphology among planetary nebulae. Using high-resolution *HST*/WFC3 imaging, we discovered the low-ionization structures within  $0.3\text{pc} \times 0.2\text{pc}$  around the central binary system. We used  $\text{H}\alpha$ ,  $[\text{O III}]$ , and  $[\text{S II}]$  emission line images to construct line-ratio diagnostic maps, which allowed us to spatially resolve two distinct *low-ionization envelopes* within the inner regions. Our diagnostic maps show that *highly-ionized gas surrounds these low-ionization envelopes*. These envelopes could be a result of a powerful outburst from the central interacting binary, when one of the companions (now a [WO] star) was in its AGB evolutionary stage. Dense material ejected from the progenitor AGB star is likely heated up as propagating along a symmetric axis into the previously expelled material. Our diagnostic mapping using high-resolution imaging can provide a novel approach to detection of low-ionization regions in other planetary nebulae and in other objects including symbiotic systems and expanding envelopes of novae.

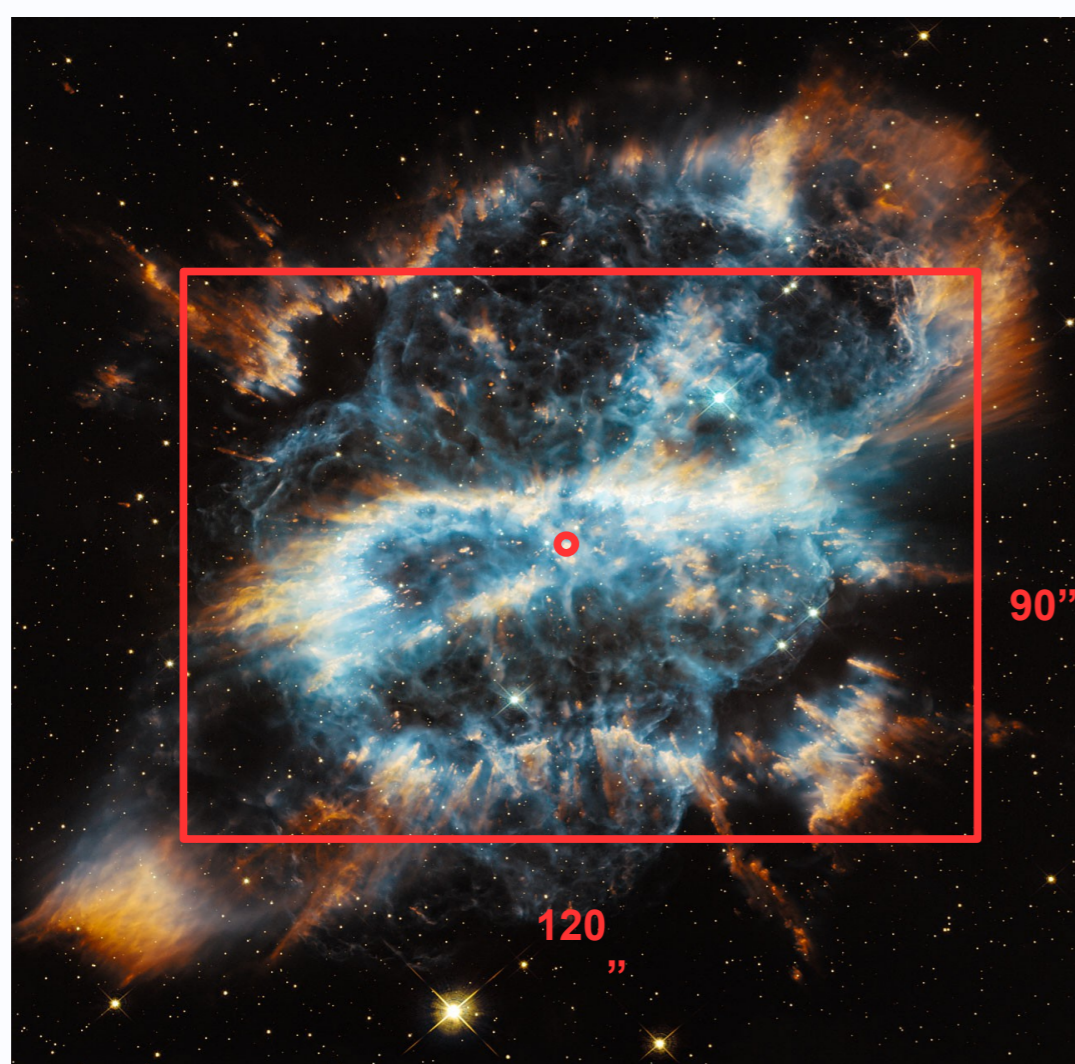


FIG 1. Image with specific colors of fluorescing sulfur, hydrogen, and oxygen. Credit: NASA/ESA Hubble Space Telescope (Dec 18, 2012).

### Spatially-resolved Flux Ratio Maps

- $[\text{S II}]/\text{H}\alpha$  flux ratio: high in *low-excitation* regions
- $[\text{O III}]/\text{H}\alpha$  flux ratio: high in *high-excitation* regions

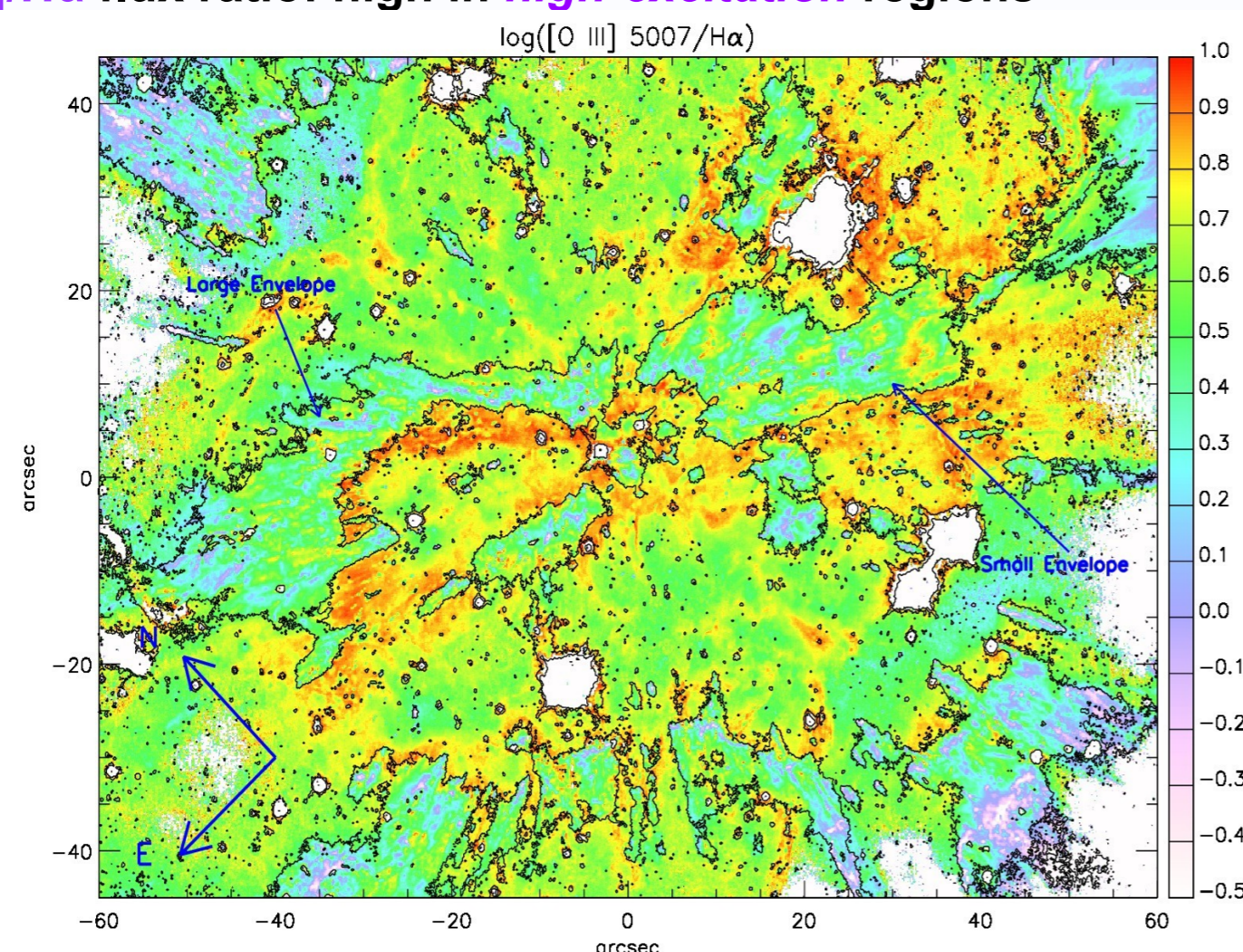


FIG 2. Logarithmic flux  $[\text{O III}]/\text{H}\alpha$  ratio map of the  $120'' \times 90''$  region chosen from the *HST* observations. The contour lines show the boundaries of photo-ionized and low-ionization regions. Two main morphological structures are labelled.

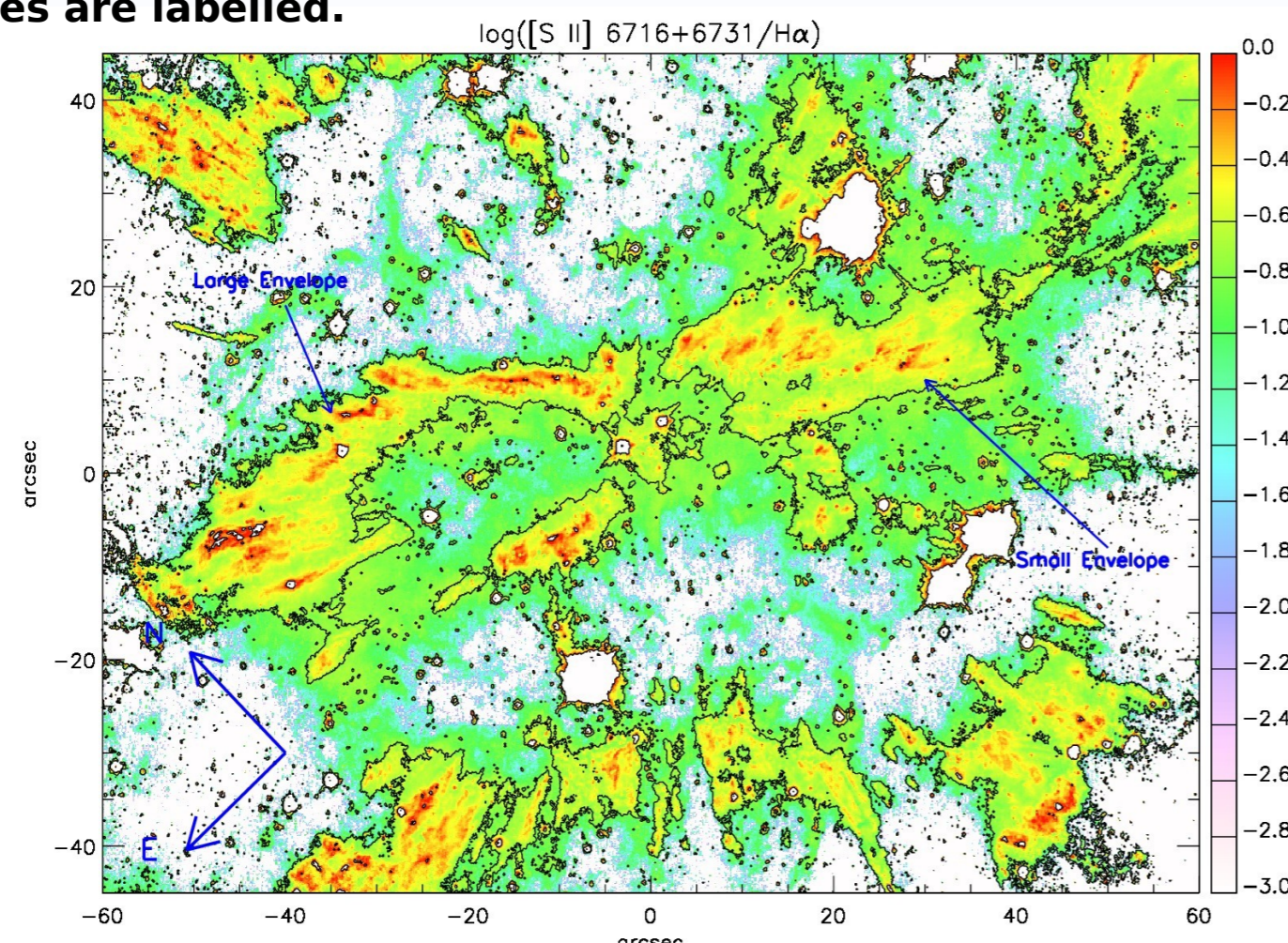
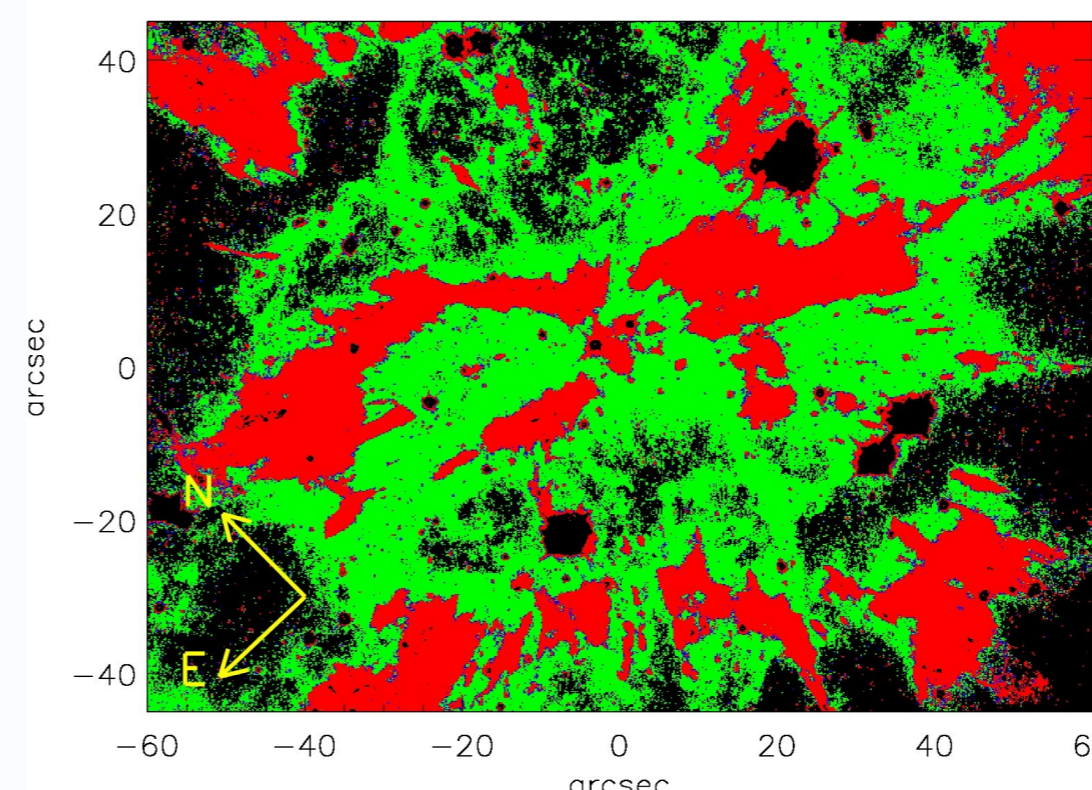


FIG 3. Logarithmic flux  $[\text{S II}]/\text{H}\alpha$  ratio map of the  $120'' \times 90''$  region chosen from the *HST* observations. Two main morphological structures are labelled

### Resolved Diagnostic Mapping

#### Shock-ionized Structures within Photoionized Nebula



Diagnostic diagrams based on  $[\text{O III}]/\text{H}\alpha$  vs.  $[\text{S II}]/\text{H}\alpha$  ratios

- Dividing *Shock-ionized* and *Photoionized* regions (Raga + 2008)
- Similar to LINER and Seyfert regions (e.g. Maksym + 2016) in BPT diagrams (Baldwin, Phillips & Terlevich 1981; Kewley + 2006)

FIG 4. Spatially-resolved diagnostic map of the inner region of NGC 5189. Red and green pixels correspond to low-ionization and photo-ionized regions, respectively.

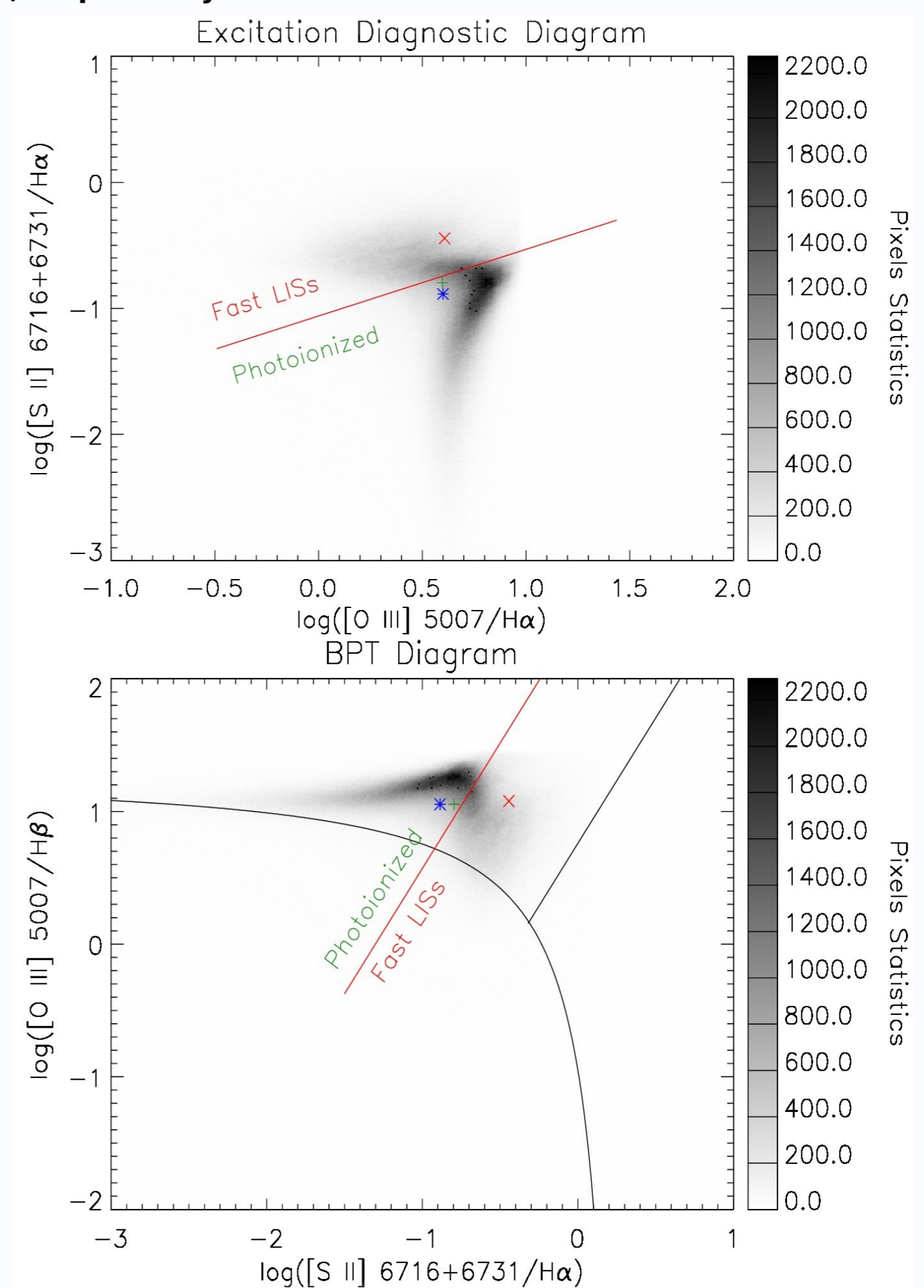


FIG 5. Excitation diagnostic diagram and BPT diagram produced from the  $120'' \times 90''$  region of NGC 5189 to disentangle fast LISs from photoionized regions. Solid black lines: LINER-like and Seyfert-like boundaries (Kewley+2006), solid red line: nebular photon-shock dividing line (Raga + 2008), star (\*): the mean flux ratios, cross (x): Garcia-Rojas+2012, and plus (+): Kingsburgh & Barlow (1994).

### Main Findings and Future Prospects

- Two *low-ionization* envelopes within the inner, ionized gaseous environment, extending over  $0.15\text{pc}$  from the central star.
- Both appear to be expanding along a NE to SW axis.
- The SW envelope appears smaller than its NE counterpart.
- These low-ionization envelopes are surrounded by the *highly ionized, low-density* gas.
- *Our diagnostic methodology is a powerful tool for identifying low-ionization structures in other objects, e.g. complex planetary nebulae, expanding nebulae around symbiotic systems and expanding shells of novae (e.g. V445 Puppis).*

### References

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