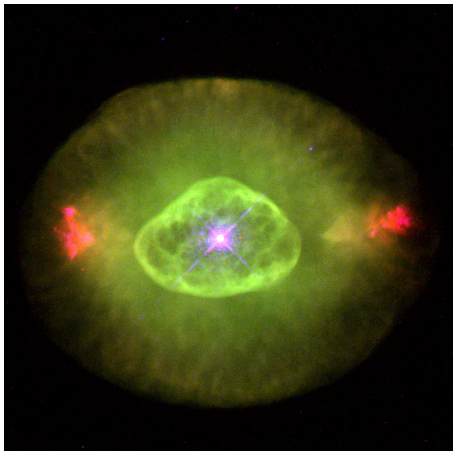
# astro-ph ゼミ 2018.01.23 (担当: 大澤)

# $H_2$ in low-ionization structures of planetary nebulae

Stavros Akras, et al., MNRAS, 465, 1289 (2017)

We report the detection of near-IR $H_2$ emission from the low-ionization structures (knots) in two planetary nebulae. The deepest ever high-angular-resolution $H_2$ (1–0) S(1) at 2.122 μm, $H_2$ (2–1) S(1) at 2.248 μm and Br$\gamma$ images of K 4-47 and NGC 7662, obtained using the Near InfraRed Imager and Spectrometer (NIRI) at Gemini-North, are analysed here. K 4-47 reveals a remarkable highly collimated bipolar structure not only in the optical but also in the molecular hydrogen emission. The $H_2$ emission emanates from the walls of the bipolar outflows and also from the pair of knots at the tip of the outflows. The $H_2$ (1–0) S(1)/(2–1) S(1) line ratio ranges from ∼7 to ∼10, suggesting the presence of shock interactions. Our findings can be explained by the interaction of a jet/bullet ejected from the central star with the surrounding asymptotic giant branch material. The strongest $H_2$ line, (1–0) S(1), is also detected in several low-ionization knots located at the periphery of the elliptical planetary nebula NGC 7662, but only four of these knots are detected in the $H_2$ (2–1) S(1) line. These four knots exhibit an $H_2$ line ratio between 2 and 3.5, which suggests that the emission is caused by the UV ionizing flux of the central star. Our data confirm the presence of $H_2$ gas in both fast- and slow-moving low-ionization knots, which has only been confirmed before in the nearby Helix nebula and Hu 1-2. Overall, the low-ionization structures of planetary nebulae are found to have similar traits to photodissociation regions.



NGC 6826 の HST 画像
赤色は [SII] & [NII] で低電離領域を示す

- 惑星状星雲は [OIII] などの高電離輝線が特徴的 ⇆ 低電離領域を微小構造として持つことがある (↑参照)
- 低電離構造の成因・物理を理解するためには neutral & molecular gas の分布を調べることが必要
- 低電離構造が高速で動いている天体 (**K 4-47**) とさほどでもない天体 (**NGC 7662**) をそれぞれ選択
- Gemini-N/NIRI の narrow-band imaging で $H_2$ (1-0), $H_2$ (2-1), Brγ の強度マップを作成
- 輝線強度比から K 4-47 では shock が NGC 7662 では中心星からの UV が $H_2$ の主な励起源であると推定
- 内部に密度の高いガスがあり局所的に PDR に似た構造を形成しているという説明と矛盾がない

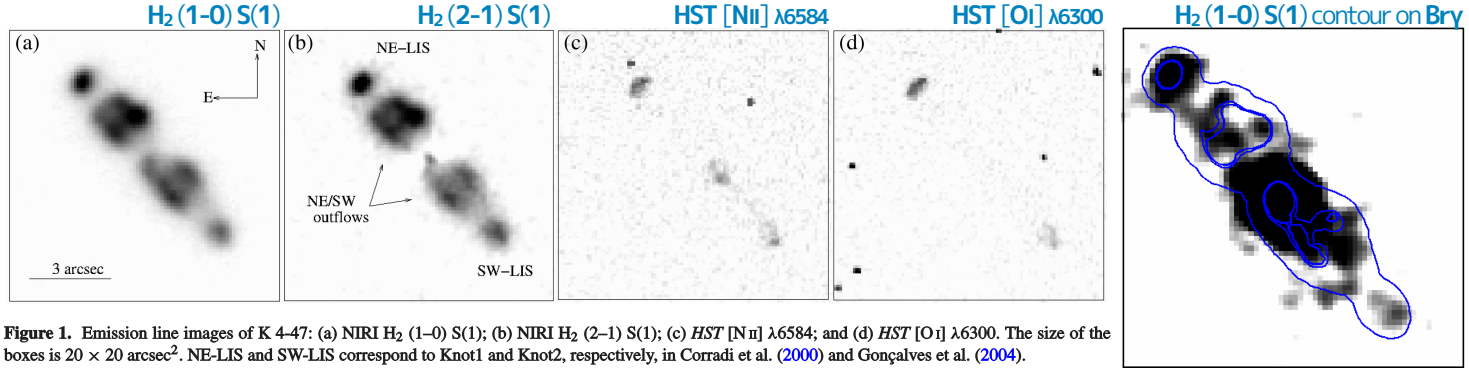



**Figure 1.** Emission line images of K 4-47: (a) NIRI $H_2$ (1–0) S(1); (b) NIRI $H_2$ (2–1) S(1); (c) *HST* [N II] λ6584; and (d) *HST* [O I] λ6300. The size of the boxes is 20 × 20 arcsec$^2$. NE-LIS and SW-LIS correspond to Knot1 and Knot2, respectively, in Corradi et al. (2000) and Gonçalves et al. (2004).

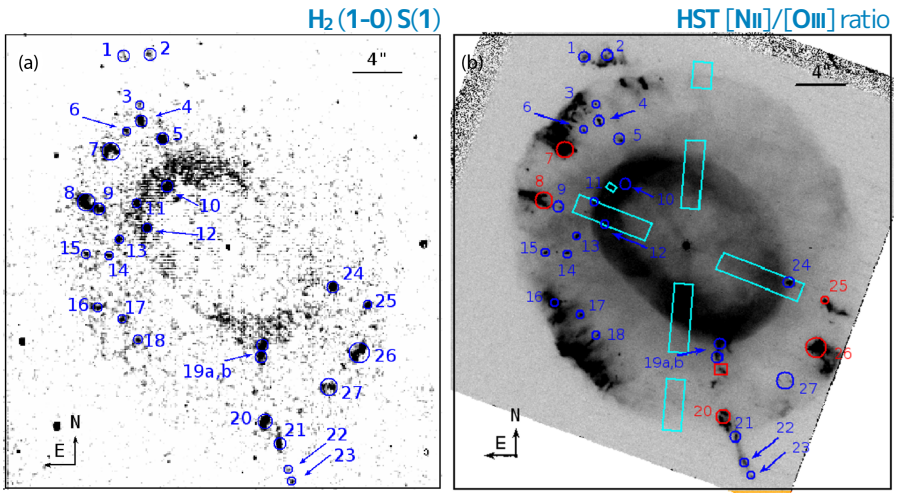



**Figure 3.** Emission line images of NGC 7662: (a) NIRI $H_2$ (1–0) S(1) continuum-subtracted; and (b) *HST* [N II]/ [O III] line ratio image. The circles (in both panels) correspond to the low-ionization emission lines (LISs) detected in $H_2$. The red circles and cyan boxes in panel (b) indicate LISs and nebular regions with available optical spectra (Perinotto et al. 2004; Gonçalves et al. 2009). Both structures have been used in the optical diagnostic diagram (Fig. 5). The red box indicates an LIS with an available optical spectrum that is not detected in $H_2$ emission. The box size is 35 × 37 arcsec$^2$.

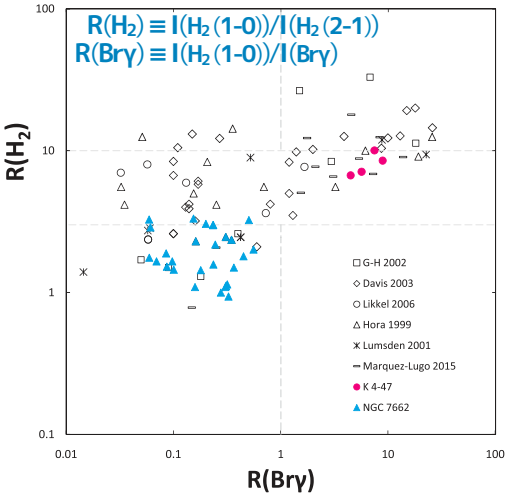



**Figure 4.** $R(H_2)$ versus $R(Br\gamma)$ line ratio diagram from Marquez-Lugo et al. (2015), including the values of K 4-47 (filled circles) and NGC 7662 (filled triangles).