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ALMA imaging of the complex, dynamical atmosphere of the AGB star W Hya at 20-milliarcsecond resolution

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We present 20-milliarcsecond resolution ALMA imaging of the well-studied AGB star W Hya at 250–269 GHz. The high resolution of our ALMA observations allowed us to spatially resolve the detailed structures of the mass loss within ~100 mas (5 stellar radii).

The mass-loss mechanism in asymptotic giant branch (AGB) stars is not yet fully understood. It is often argued that the combination of the levitation of the atmosphere by stellar pulsation, dust formation, and radiation pressure on dust grains can drive the mass loss (Höfner & Olofsson, 2018 and references therein). The recent high spatial resolution imaging reveals inhomogeneous structures over the surface and atmosphere of AGB stars seen in infrared molecular lines (Ohnaka et al., 2019) as well as clumpy dust formation within ~2 stellar radii (Khouri et al., 2016; Ohnaka et al., 2016, 2017; Adam & Ohnaka, 2019), as predicted by the 3D dynamical models (Höfner & Freytag, 2019; Freytag & Höfner, 2023). Also, the shocked atmosphere leads to non-equilibrium chemistry, which is important for dust formation (e.g., Gobrecht et al. 2016). Therefore, it is crucial to spatially resolve the region within several stellar radii, where the stellar wind accelerates, in order to better understand the mass-loss mechanism.

W Hya is one of the best-studied, nearby AGB stars. Thanks to its high brightness and proximity (98 pc, Vlemmings et al. 2003), it has been observed with different techniques from the ultraviolet to the radio. We observed W Hya with ALMA in Band 6 at 250–269 GHz, using a maximum baseline of 16 km, which resulted in a beam size of ~16×20 mas (Ohnaka et al., in prep). The millimeter continuum emission has an angular diameter of ~60 mas, which is ~1.5 times larger than the stellar angular diameter measured in the near-infrared (Woodruff et al., 2009). We identified nearly 60 molecular lines, which include ^{29}SiO, ^{30}SiO, Si^{17}O, H_2O, SO_2, SO, HCN, AlO, AlOH, TiO, and OH. The asymmetric molecular emission extends to ~100 mas (~5 stellar radii) with a plume extending in the NNW, a tail extending in the SSE, an extended atmosphere elongated in the ENE-WSW direction, and many clumpy structures.

The beam size of ~16×20 mas allowed us to see the spectral lines in absorption over the stellar disk as we expect. The absorption is not uniform over the stellar disk, indicating inhomogeneities in the density and/or temperature. However, surprisingly, approximately a third of the identified lines show emission over the stellar disk. The lines of ^{29}SiO $\upsilon = 2\ J = 6 - 5$ at 253.703 GHz and the vibrationally excited H_2O $\upsilon_2 = 2$, $6_{5,2} - 7_{4,3}$ at 268.149 GHz show particularly strong emission over the stellar disk, which we interpret as maser actions. The emission from certain lines of ^{30}SiO, Si^{17}O, SO_2, and AlO is less prominent, which can be interpreted as weak maser actions and/or masers attenuated by absorption due to overlying layers.

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