The Sleeping Behemoth: Star Formation in the Faintest Disks

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A key proponent to galaxy evolution is the multiphase gas that surrounds and permeates the galactic disk. Studying this complex gas network allows us to better understand how it regulates the metallicity, structure, and star formation within a galaxy. Within the disk there are small dust grains called polycyclic aromatic hydrocarbons (PAHs). These grains are effective tracers of cold molecular gas and H II regions, as well as production sites for molecular hydrogen which make PAHs excellent probes for studying star formation in galaxies. We use the James Webb Space Telescope (JWST) to study the infrared emission from PAHs throughout the disk of the giant low surface brightness galaxy Malin 1. Compared to high surface brightness galaxies, Malin 1 exhibits less structure and overall dust content. This is potentially hinting at a deficit of cold molecular gas, which is a necessary ingredient for star formation. By mapping out where the dust exists throughout the disk, we can trace areas of stellar formation and gain insight into the properties of this extreme galaxy.

Background

Characteristics of Malin 1:

Malin 1 is a giant low surface brightness galaxy (6.5× bigger than our MW) 366 Mpc away with a surface brightness less than the night sky (~28 mag arcsec^{-2}). It has an estimated virial mass of $2.6\times10^{12} M_{\odot}$ [3] and an HI mass of $6.8\times10^{10} M_{\odot}$ [4]. The current estimated H_2 gas SD is $< 0.3\ M_{\odot}pc^{-2}$ [5]; this puts it at the extreme end of the Kennicutt Schmit law (see Figure 1).

Kennicutt-Schmidt Star Forming Law:

The Kennicutt-Schmidt (KS) law describes the relationship between SFR and gas surface densities [1,2]. The power law described by KS is different for each galaxy subset (Figure 1) with the low end of the law containing LSBGs. The interstellar medium (ISM) conditions in galaxies in the low-density regime of the KS Law are poorly understood. Below an SD of 10 $M_{\odot}pc^{-2}$ neutral HI turns into molecular H_2. The dramatic change in slope could be due to low H_2 filling factors in an ISM dominated by HI or just low star formation efficiency in these H_2 regions.

Role of Polycyclic Aromatic Hydrocarbons (PAHs) in Star Formation:

PAHs are small dust structures that exist in the interstellar medium of galaxies. These compounds are heated by nearby stars and glow in the infrared. PAHs make excellent tracers for dust and star forming regions (also known as HII regions) as they are a major production site for H_2 [6]. In the mid-infrared the largest PAH complex is at 7.7μm (MIRI/F770W) and another smaller complex at 12.86μm (see Figure 2). Malin 1 has an estimated number of 200 HII regions throughout the disk that are capable of heating PAH to a detectable level [7]. In some galaxies, HII regions can be strong enough to destroy PAH grains in the ISM. However, in the case of Malin 1 we do not think that the HII regions are able to completely destroy PAH, instead the intensity of the emission might just be diminished.

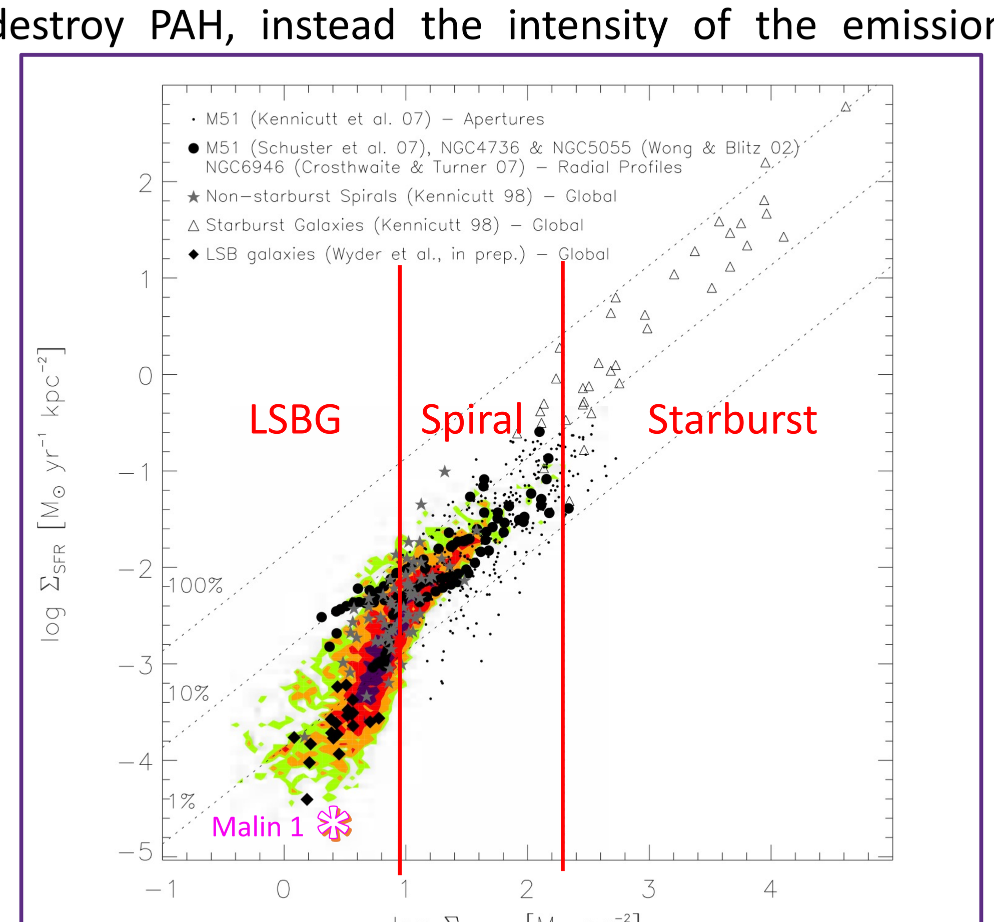

Figure 1: The Kennicutt-Schmidt Law for star forming galaxies [8]. Breaks in the law are shown by the vertical red lines. There are LSBG (*left*), normal spiral galaxies (*middle*), and starburst galaxies (*right*) each galaxy class has different star formation efficiencies. The approximate location of Malin 1 is represented by the pink star at the very bottom of the LSBG class which makes it perfect to study this low-density regime of star formation.

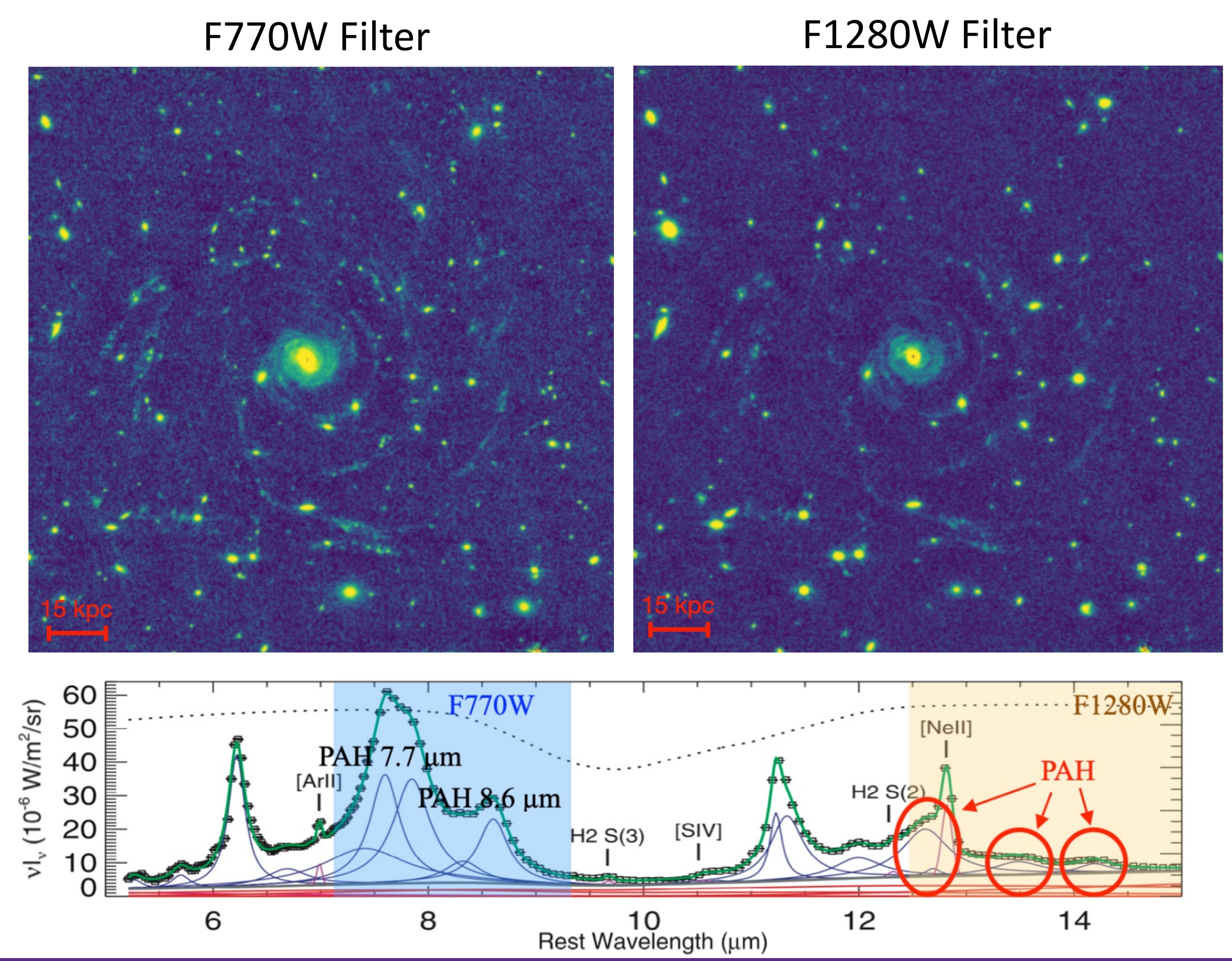

Figure 2: Left: F770W image of Malin 1 that shows emission features from PAH heating. The bottom panel shows and example spectral energy distribution (SED) including the features covered by the MIRI/F770W band and the PAH complex we measure. *Right:* F1280W image that includes warm dust continuum as well as contamination from another PAH complex and a strong NII emission feature. Both images were reduced using PjPipe and PSF corrected.

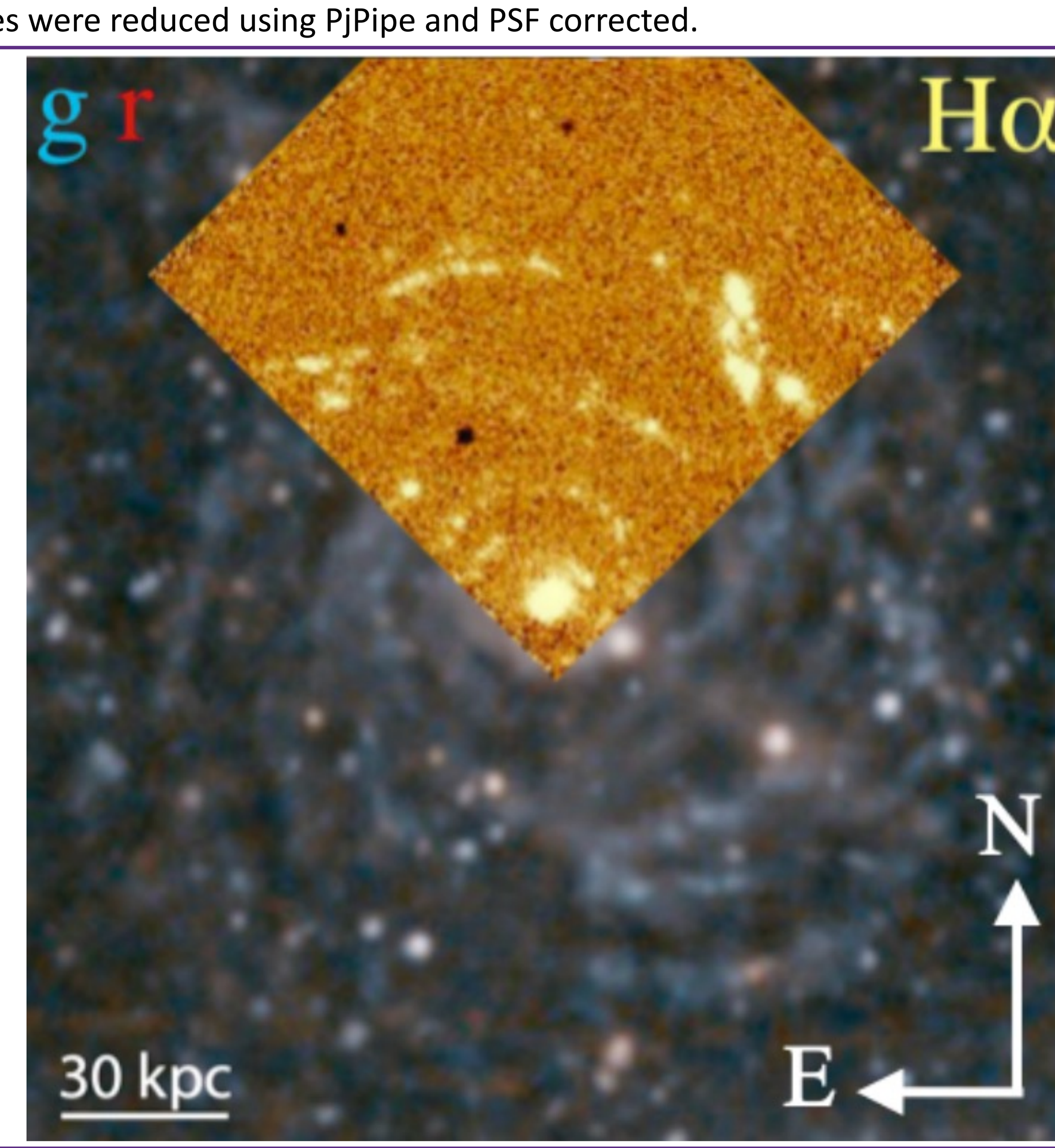

Figure 3: Colored (g- and r-band) image of Malin 1 [12] with an VLT/MUSE Hα image of the northern quadrant overlaid showing detectable HII regions which are also detected in our images (see Fig. 1).

Star Forming Law of Malin 1

The star formation law of Malin 1 will be calculated using combined JWST and MUSE observations. The PAH emission map will be used to calculate the total gas surface density across star forming regions of the disk using the relation [16]:

$$\frac{I_{\nu}^{7.7}}{MJy\ sr^{-1}} \approx 0.020 R_{24}^{7.7}\left(\frac{\Sigma_{gas}}{1\ M_{\odot}pc^{-2}}\right)\left(\frac{D/G}{0.01}\right)\left(\frac{U}{U_0}\right)\left(\frac{q_{PAH}}{0.046}\right)$$

The star formation rate surface density will be determined from the Hα emission map from MUSE observations. The relationship between star formation rate and Hα luminosity is given as [7]:

$$SFR_{H\alpha}(M_{\odot}yr^{-1}) = 5.1\times10^{-42} L_{H\alpha}(erg\ s^{-1})$$

The star formation rate surface density can be calculated by dividing by the area of the region containing the Hα emission.

Previous studies have estimated the KS Law for Malin 1. However, only a few recorded HI column densities have been measured across the disk of the galaxy so the full star forming law cannot be reliably fit yet. Figure 4 shows the KS Law for Malin 1 across multiple gas surface density values. One important thing to note is that Malin 1 has little to no molecular gas so it cannot be put on the full KS Law plot [7]. Additionally, there may be a secondary break in the star forming law at very low gas surface densities. The values that will be calculated from the PAH emission map will provide more insight into if this break exist and where is it located.

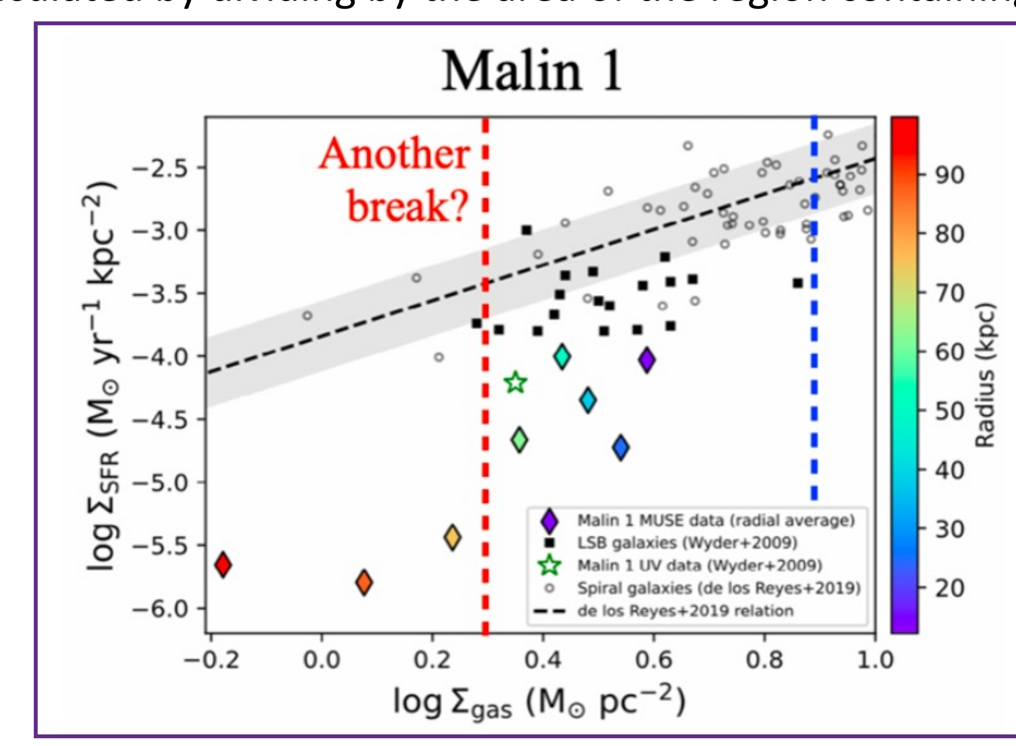

Figure 4: The star forming law as calculated using SFR density values at eight H I column densities from [7]. A possible break in the Malin 1 KS Law is shown at the dashed red line. More data points across the disk from the PAH map of Malin 1 will be used to determine the validity of this break.

Conclusion and Future Plans

While the images of Malin 1 have not yet be corrected for warm dust continuum, an estimate could still be made for its structure and dust content. Malin 1 has very low dust content and overall structure as compared to a more normal high surface brightness galaxy. This hints at the potential deficit of cold molecular gas in the galaxy which is a necessary aspect of star formation. Future plans for Malin 1 are: to refine the reduction pipeline to get better background subtracted images, to correct the contamination from the dust continuum image to get a complete map of PAH in the disk, and to examine the topological structure of the disk and compare it to the PHANGS-JWST Project [16]. Finally, we will be able to define the KS Law for Malin 1 to the most extreme value probed; constraining the low-density end of the KS Law.

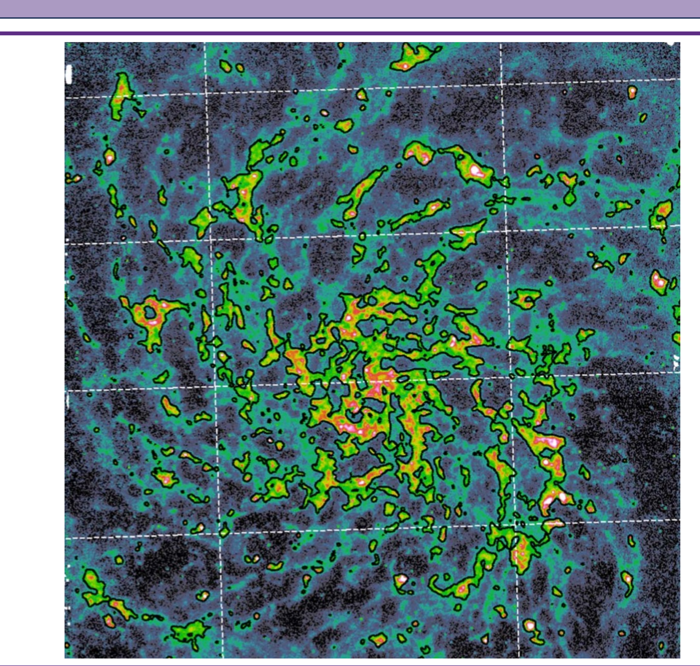

Figure 5: Gas density plot of IC 5332 from scaled F1130W filter emission [16] as part of the PHANGS-JWST Project. This galaxy shows strong structure and high dust content.

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