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Smallest Scale Clumpy Star Formation in Stephan's Quintet Revealed from UV and IR Imaging

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Abstract

The spatial distribution and physical sizes of star-forming clumps at the smallest scales provide valuable information on hierarchical star formation (SF). In this context, we report the sites of ongoing SF at ∼120 pc along the interacting galaxies in Stephan's Quintet compact group using AstroSat-UVIT and JWST data. Since ultraviolet radiation is a direct tracer of recent SF, we identified star-forming clumps in this compact group from the FUV imaging which we used to guide us to detect star-forming regions on JWST IR images. The FUV imaging reveals star-forming regions within which we detect smaller clumps from the higher spatial resolution images of JWST, likely produced by PAH molecules and dust ionized by FUV emission from young massive stars. This analysis reveals the importance of FUV imaging data in identifying star-forming regions in the highest spatial resolution IR imaging available.

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1. Detection of Smallest Star-forming Knots in the IGM

The spatial distribution of the star-forming clumps inherit the spatial properties of the gas from which they form. They can therefore be used as tracers to understand the physical processes associated with the star formation. The distribution of star-forming clumps and their physical sizes at the smallest scales provide valuable information on the hierarchical structures involved in star formation. But all these properties are strongly dependent on the properties of the host galaxy environment (Menon et al. 2021). Hence study of hierarchical nature of star formation in different galactic environments can provide valuable insights on our understanding of star formation processes. Such previous studies were restricted to very nearby galaxies due to the limited spatial resolution of the telescopes used for the detection of star-forming regions at sub kpc scales. Several studies (Peeters et al. 2004; Xie & Ho 2019; Whitcomb et al. 2020) have shown that emission features in 6.2, 7.7, 8.6, and 11.3 μ (mid-IR) from the excited PAH molecules can be used to trace the location of FUV-bright young stars (which excites the PAH molecules) and hence recent star formation. The superior spatial resolution JWST IR images of Stephan's Quintet (SQ) is the best available data to study star formation (SF) at the smallest scales in the intragroup medium (IGM). So with the superior spatial resolution IR observations from JWST, we can now trace the spatial distribution of star-forming clumps and their physical sizes in galaxies at farther distances. However, the Spitzer/IRS observations have shown that PAHs can be destroyed by intense starbursts and are also absent in low metallicity galaxies (O'Halloran et al. 2006; Li 2020). Again, PAH emission does not necessarily trace exclusively young stars as PAHs can also be excited by visible photons (Li & Draine 2002). Hence it is essential to use a direct star formation (SF) tracer and effectively use that to guide us to detect star-forming regions on JWST IR images.

Ultraviolet light produced by young OBA stars is perhaps the only direct tracer of ongoing star formation ($<10^8$ yr) with not much contamination. In this context, we study the spatial distribution and physical sizes of star-forming clumps in the IGM of a nearby compact group of galaxies, SQ, using a combined analysis of AstroSat-UVIT and JWST (Pontoppidan et al. 2022) images. We demonstrate the power of UV in showing the star-forming regions on the JWST IR images in the color composite Figures 1(a) and (b) as traced in blue color. [5] (also hosted at https://prajwel.github.io/stephans_quintet/). We detected smaller scale IR clumps from the JWST image within the FUV emitting regions in SQ, which confirms the recent SF nature of the IR clumps. F770W imaging of these clumps traces the 7.7μ emission coming from PAH molecules excited by FUV photons. This highlights the clumpy nature of dust clouds associated with the star-forming regions that we are probing. These are regions where gas is collapsing outside the galaxies forming new stars. The size distribution of these IR clumps detected inside the segments identified from UV imaging is shown in Figure 1(c). Thanks to JWST resolution, the IR clumps are detected of size as small as 120 pc within FUV clumps of larger area (due to the coarser resolution of UVIT). We note that this is similar to the typical size of OB associations (size <150 pc) detected in many nearby galaxies including the Galaxy (Mel'Nik & Efremov 1995; Ivanov 1996; Bresolin et al. 1998; Bastian et al. 2007; Mondal et al. 2018). The identified F770W IR sub-clumps within the FUV clumps basically trace the PAH molecules embedded in dust-obscured young star-forming regions. Therefore, the detection of clumps from JWST F770W image of SQ having size as small as ~120 pc signifies that the young star-forming regions in SQ have sizes similar to the OB associations (which are most efficient to excite the PAH molecules to emit in 7.7μ) detected in nearby galaxies. This further demonstrates the unique capability of JWST to probe star-forming regions up to much smaller scales in IR than what was possible earlier with Spitzer. Since UVIT has ~6 times larger PSF than the JWST/MIRI F770W, the UV segments detected in this study should be mostly composed of multiple smaller clumps. The size of UV segments therefore signifies the extent of the large hierarchical structure composed of smaller star-forming clumps (Similar values reported in nearby systems Grasha et al. 2017; Rodriguez et al. 2020; Mondal et al. 2021). Detailed follow-up studies will help to establish the connection between the FUV radiation and PAH excitation in star-forming regions within the intergalactic medium. UV imaging with a resolution similar to that of JWST will be able to probe such stellar clumps directly. We note that the future planned UV survey telescopes like INSIST with JWST like resolution when launched will be a great boost in interpreting JWST imaging data for ongoing star formation (Subramaniam 2022).

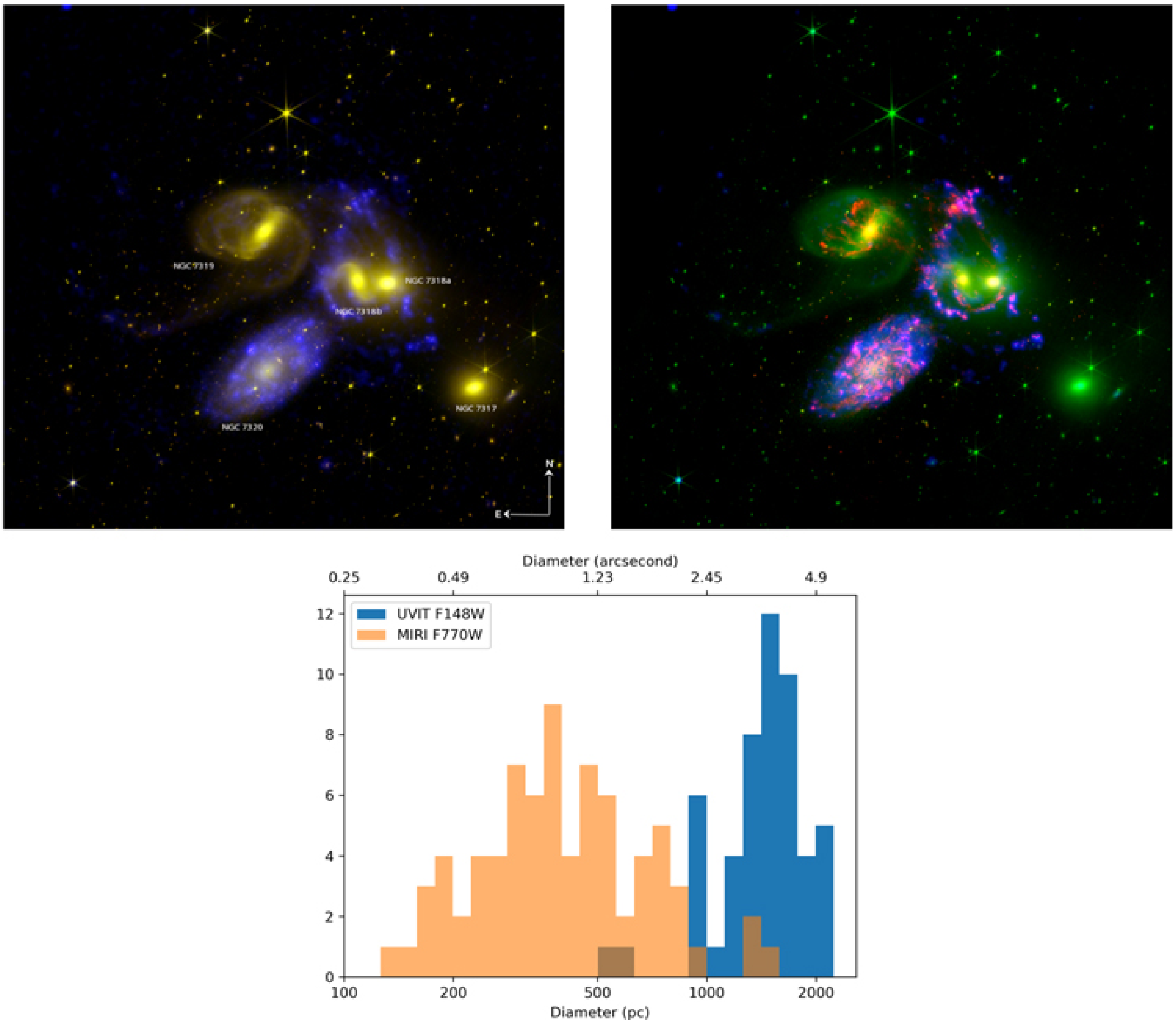

Figure 1. Clockwise from the top-left panel: (a) RGB image of SQ created by assigning red (JWST F200W band), green (JWST F150W band) and blue (UVIT F148W+F169M band) colors to the filter passband images. (b) RGB image of SQ created by assigning red (JWST F770W band), green (JWST F200W band) and blue (UVIT F148W+F169M band) colors to the filter passband images. (c) Distribution of the size of segments (diameter in arcsec and pc).

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Footnotes

5 The JWST data used in this paper can be found in MAST:https://doi.org/10.17909/qj5k-mm71.