Aparna Venkateshwaran
PhD Student

Prof Stephen Eales
Supervisor

A direct estimation of star formation efficiency at high redshift

OVERVIEW

Star formation efficiency (SFE) is defined as SFE = $\Sigma_{SFR}/\Sigma_{Mgas}$, where SFR is the star formation rate, and M_{gas} is the total star forming gas mass. SDP81 is an ideal candidate for this study because the magnification from gravitational lensing allows us to probe the galaxy at a physical scale of approximately 500 parsecs. Applying existing lens models to new ALMA Band 10 data, we will produce a source reconstruction map of the 0.38 mm dust continuum. Then, using archival multi-wavelength ALMA observations, we will first probe dust temperature variation across the galaxy, and fit an SED. Dust mass will serve as a tracer for M_{gas}, while the total infrared luminosity computed using the SED is used to estimate the SFR.

MOTIVATION

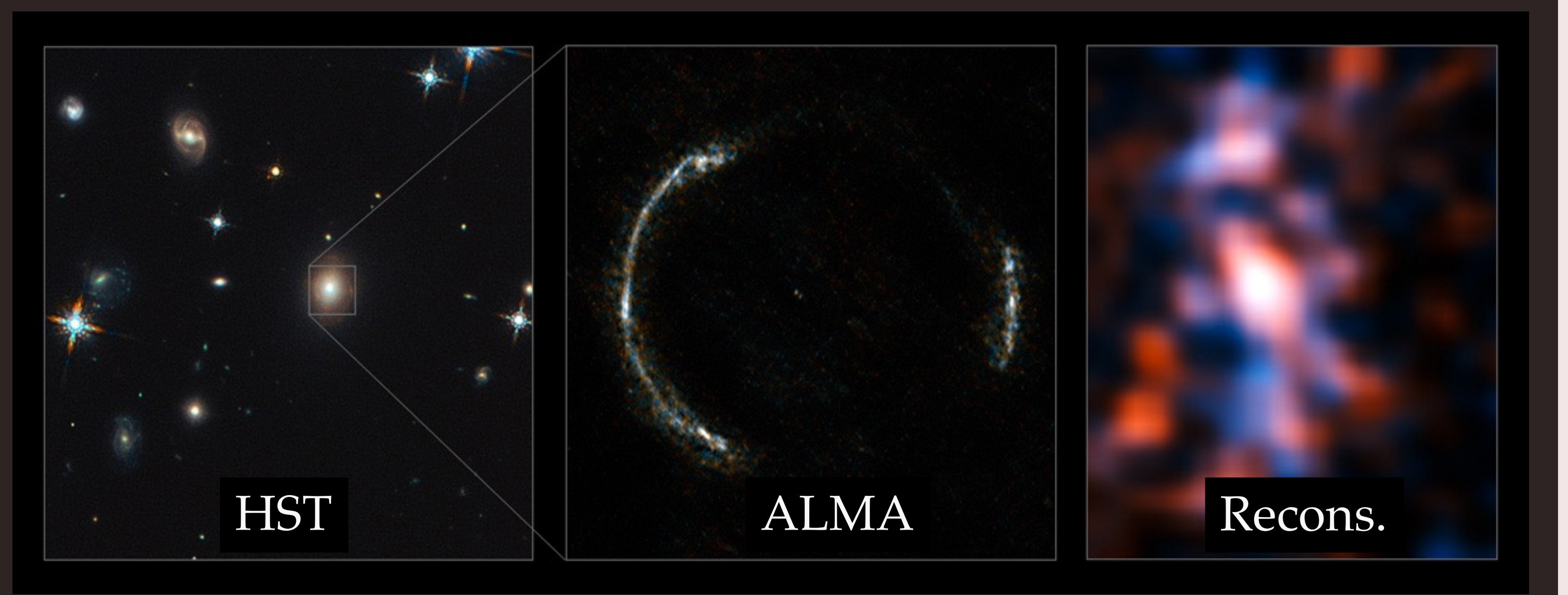
Star formation exclusively occurs in molecular gas clouds comprised of cold, dense molecular hydrogen (H_2). n ~ $10^2 - 10^5$ cm^{-3}, T ~ 10 – 50 K,. Tracing rotational transitions in H_2 requires $T_{EX} > 50$ K, therefore making it invisible at lower temperatures.

CO (1–0) is the second most abundant molecule with ($[CO/H_2] \sim 10^{-4}$) and low T_{EX}. However, this line is the strongest to observe and therefore is frequently used as a tracer, giving $M(H_2) = \alpha_{CO\,(1\text{-}0)} \times L_{CO\,(1\text{-}0)}$.

A major caveat in using CO (1-0) is its strong, unpredictable dependence on metallicity. At high-redshifts, only higher transitions are observed and therefore additional conversion factors are required to determine $L_{CO\,(1\text{-}0)}$.

SDP81 (H-ATLAS J090311.6+00390) is a lensed galaxy discovered in the H-ATLAS survey. At z = 3.042, it is lensed by a foreground early-type elliptical galaxy at $z_{lens} = 0.2999$.

Typical magnification (μ): 11 – 20, with an Einstein radius (θ_r): 1.6”.



Credit: ALMA (NRAO/ESO/NAOJ), Y. Tamura, M. Swinbank

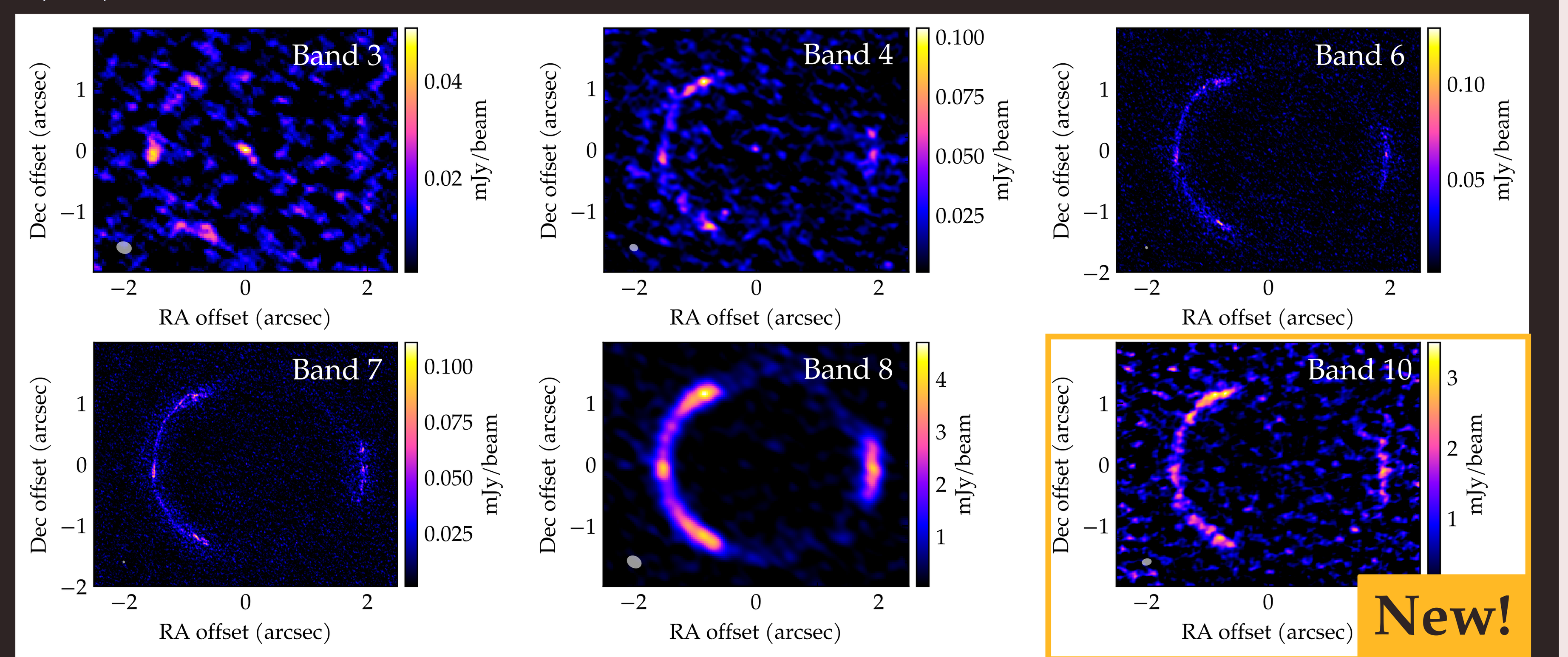
DUST AND MULTI-WAVELENGTH OBSERVATIONS

Dust is ubiquitous. While it is a hindrance in some cases, it becomes a powerful tool to probe the high-redshift Universe. Dust continuum observations take a significantly less time to obtain compared to line emission data.

Spectral energy distribution (SED) fitting for a galaxy in the infrared part of the spectrum allows for tracing its recent (~100 Myr) star-formation history.

The use of dust as a tracer for molecular gas mass has been studied since 1983. By comparison, it has a predictable dependence on metallicity. The only caveat is usually unavailability of multi-wavelength data required to constrain dust temperature variation.

What we need is $\boxed{SFE = \frac{\eta_{IMF} \times L_{IR}}{\alpha_{850} \times L_{850}}}$ and for SDP81, we have (all) the tools to find it.

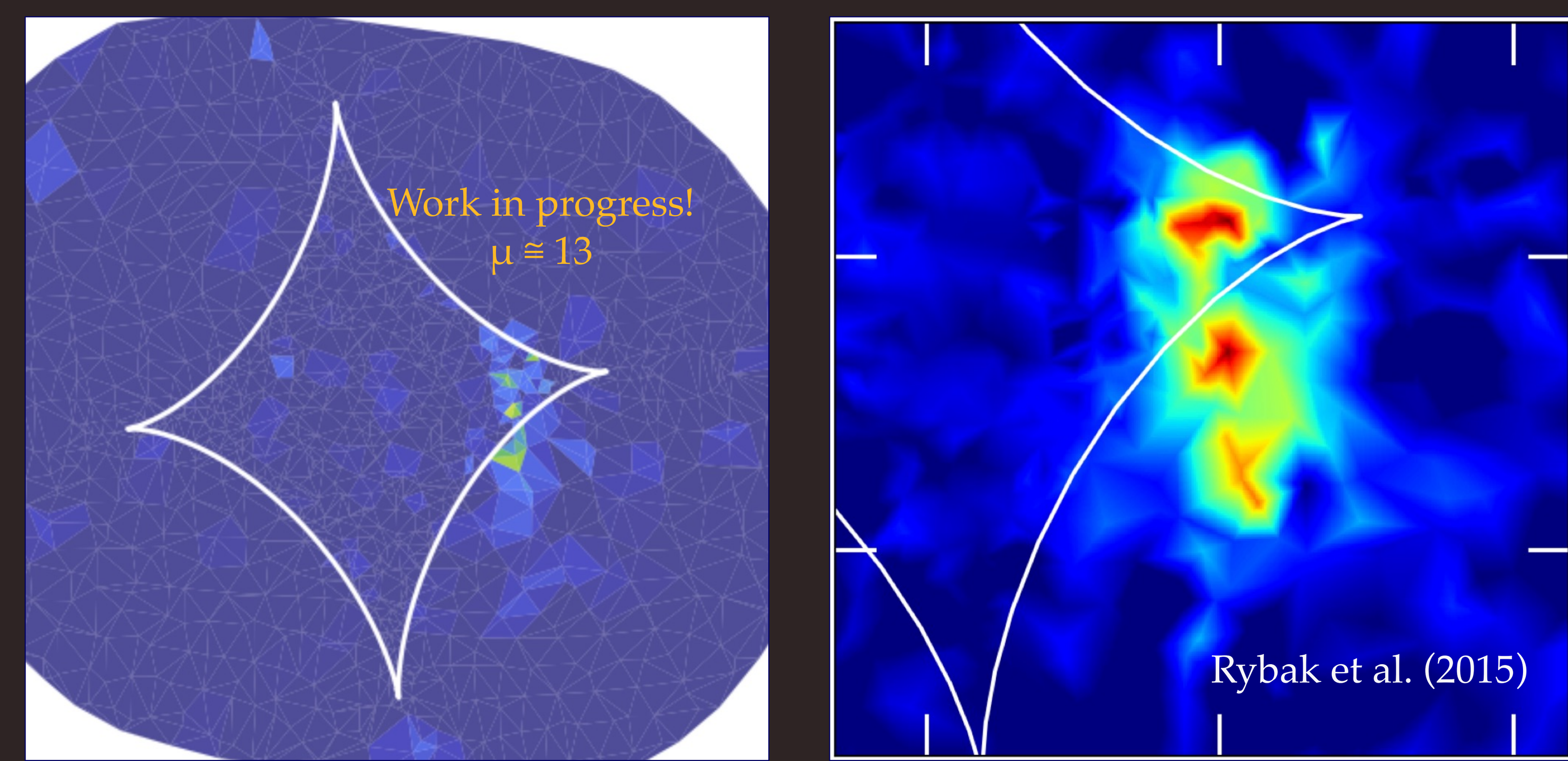


Dust continuum observations in ALMA Bands 3, 4, 6, 7, 8 and 10.

SOURCE RECONSTRUCTION

Gravitational lensing is an especially useful probe at high redshift. Depending on magnification factors, one can study spatial scales in the order of parsecs.

In this work, we use PyAutoLens to perform source reconstruction (de-lensing) for all the available ALMA images. Below (left) is the first reconstruction of ALMA Band 10 image!



Left: This work.
Right: Band 6 reconstruction as presented in Rybak et al. (2015).

NEXT STEPS

- Probe dust temperature variation using reconstructed multi-wavelength data and fit an SED for SDP81.
- Extract the Infrared Luminosity (L_{IR}) from the SED. Then, apply an IMF proportionality factor (η_{IMF}) to convert L_{IR} to SFR via SFR = $\eta_{IMF} \times L_{IR}$
- Find the molecular gas mass using ~ 850 μm dust as tracer in $M(H_2) = \alpha_{850} L_{850}$, following Dunne et al. (2022). $\alpha_{850} = 6.9\times10^{12}$ W Hz^{-1} $M_\odot^{-1}$