Statement of Research Interests

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My research focuses on galaxy evolution during the peak epoch of cosmic star formation ('Cosmic Noon'), with particular emphasis on the impact of active galactic nuclei (AGN) feedback and galaxy mergers on star formation, in sub-kpc (kilo parsec) scale via gravitationally lensed galaxies. The cosmic star formation rate (SFR) density increases to its peak at $z{\sim}2$, called Cosmic Noon (Franx et al. 2003; Daddi et al. 2004; Madau & Dickinson 2014), during which starburst and star-forming galaxies (SFGs) rapidly assemble most of their stellar mass and subsequently quench to become the massive quiescent galaxies observed in the local Universe (Thomas et al. 2005; Faber et al. 2007; Peng et al. 2010). AGN feedback is widely considered a key regulator of star formation and gas accretion (Ferrarese & Ford 2005; Churazov et al. 2005; Springel et al. 2005; McNamara & Nulsen 2007; Cattaneo et al. 2009; Fabian 2012; Kormendy & Ho 2013), while galaxy merger is known to trigger enhanced star formation/starbursts and contribute significantly to mass assembly, particularly around the peak epoch of galaxy growth at Cosmic Noon (Toomre & Toomre 1972; Barnes & Hernquist 1996; Mihos & Hernquist 1996; Hopkins et al. 2006; Conselice 2014).

I plan to study the AGN feedback and galaxy mergers with larger samples across the cosmic time, as well as the spatially decomposed lensing reconstruction with sub-kpc scales for lensed SFGs/starbursts in the early Universe, to expolre the understanding of the galaxy evolution.

Research Experience & Key Contributions

During my PhD at Nanjing University, I mainly investigated the impact of AGN jet feedback and galaxy merger on the evolution of the Cloverleaf quasar (H1413+117), a gravitationally lensed starburst galaxy at the redshift of 2.558, in a spatially resolved sub-kpc scale.

Discovery of a Lensed Single-Sided Jet: Utilizing the lens mass model of the Cloverleaf quasar (from synthesis ALMA observations at 300 GHz) and non-parametric source-plane reconstruction with `PyAutoLens`, I analyzed radio continuum emission from e-Merlin (L-band) and VLA (X & Ka bands). I revealed a single-sided jet located 1 kpc from the dusty disk (reconstructed from observing-frame 300 GHz continuum). SED fitting in the source plane confirmed that radio emission from the disk is dominated by star formation (Zhang et al. 2023, Zhang et al. submitted), whereas emission at the jet position is dominated by synchrotron radiation. This work suggests that AGN feedback in the Cloverleaf is driven by both AGN winds (inferred from BAL) and jets.

Jet-ISM Interaction and Quenching: Using multiple SFR tracers (H_2O $4_{22}-4_{13}$, rest-frame 120 μm, and 36 GHz continuum) and CO(3-2) as a cold interstellar-medium (ISM) tracer, I employed non-parametric modeling to investigate AGN feedback effects. I found that the star formation efficiency (SFE) on the jet-hosting side of the disk is suppressed by 30% compared to the counter side. Kinematic modeling with $^{\rm 3D}$BAROLO indicates that the jet interacts with gas along its path, actively suppressing SFE. This suggests that direct localized jet-ISM interaction serves as a potentially major quenching channel during the rapid quenching phase (Zhang et al. submitted).

Merger-Driven Multi-Phase CGM Enrichment: By combining CO(3-2) data of the Cloverleaf from various configurations, I identified two molecular tidal tails with the half of the dynamical disk mass, extending tens of kpc in the circumgalactic medium (CGM), indicative of an interaction with a neighbor galaxy. Non-parametric lens modeling revealed the root of a tidal tail stripping molecular gas from the Cloverleaf disk. Atomic gas traced by Ly-α shows no detection in the CGM, but reveals co-existence with the molecular outflow at the edge of the disk. Ionized gas traced by H-α exhibits differential spatially distribution with above gas components in the CGM. This suggests that major mergers at Cosmic Noon can remove up to half of the molecular cold ISM into the CGM, significantly enriching it in the early encounter phase, which is not expected in both simulations and observations (Zhang et al. in preparation), while different phase of gas may have different mechanisms to pollute the CGM. This work indicates that cold gas removal through tidal tails in mergers could suppress star formation in a more dramatic way than previously expected.

Future Research Interests & Plans

New rapid quenching scenario in galaxy evolution

As I have found two potentially under-estimated quenching channels (i.e. jet feedback in radio quiet quasars and cold ISM removal via tidal tails during mergers) in the unique laboratory, the Cloverleaf, at the cosmic noon. To improve our understanding of the quenching scenario and the galaxy evolution, I aim to systematically study the following projects on larger samples.

- **The AGN-jet feedback in the rapid quenching phase in larger SFG samples:** I have revealed that in the starburst galaxy, Cloverleaf, the suppression of star formation is dominated by the AGN-jet feedback, rather than massive outflow derived from AGN wind or supernovas, in the rapid quenching phase (Zhang et al. submitted). To extend our understanding of the role of AGN-jets in rapid quenching, AGN feedback, and AGN-host co-evolution scenario, more samples are necessary. I plan to study larger SFG samples which show AGN-jet feedback in the rapid quenching phase, with the high spatial/spectral resolution data from JWST/ALMA/VLA/VLBA, to analyze the AGN feedback on star formations and re-estimate the relative role of multiple feedback channels, as well as their evolution across cosmic time.

- **Multi-phase gas outflow/removal in merger events:** In merger-driven star-forming galaxies, the suppression of star formation in the rapid quenching phase could also originate from merger-related mechanism (e.g. tidal tails, merger debris), other than AGN-driven wind and jet feedback. In my work on the multi-phase CGM enrichment, molecular cold gas removal via tidal tails could decrease the SFR in the early encounter stage during a merger event, by transferring large fraction of cold ISM into the CGM (Zhang et al. in preparation). Therefore I plan to study the influence of merger-related quenching channels on star-forming galaxy pairs, with the data from JWST/ALMA/Euclid, to reveal whether these merger-related mechanisms are more important than previous thought in statistics. If there exists lensed merger samples, I can also study the merger-driven structures in both

ISM-scale and CGM-scale. Together with the multi-phase gas tracers, the complex quenching mechanisms could be explored in sub-kpc scales.

- **Spatially decomposed lensed SFGs/starbursts at the Cosmic Noon:** I have experience reducing and de-lensing multiple lines (CO, H_2O, HCN, HNC, HCO+, [CI]) in the Cloverleaf, while previous sensitivity limitations restricted reliable source plane reconstruction to only a few lines. The **PASSAGES** dataset offers the depth required to explore ambitious hypotheses regarding the cold ISM and dense gas tracers. Leveraging my experience with `myRadex` and de-lensing, I will spatially resolve emission lines morphologically and kinematically in the source plane. I plan to segment galaxies into distinct physical regions (e.g., star-forming clumps, cold gas reservoirs, feedback-impacted zones) based on their differential physical conditions (temperature, number density, column density) constrained by multiple emission lines via `myRadex`, and analyze the mechanisms driving them. I will also apply for complementary observations of the **PASSAGES** samples, for better understanding of the mechanism impacting star formation, and the differential physical conditions between the SFGs at the Cosmic Noon and local Universe. The key importance of this project is the spatially resolved decomposed source plane for starbursts and SFGs, based on multiple emission lines.

Star formation regions and jet feedback in 100-, even 10-pc scale at high-z

I have already preformed comprehensive studies in the case of Cloverleaf system—a lensed starburst quasar at $z = 2.558$—in the source plane (Zhang et al. 2023, Zhang et al. submitted). My research plan basically is to perform my previous studies as a novel method, on larger gravitationally lensed samples, with the observations by VLA, ALMA, and VLBI facilities.

- **Imaging star formation region and AGN jet in sub-kpc scale in radio wavelengthes:** Radio emission derived from free-free emission in star formation is widely believed as a tracer for SFR. By previous multi-band radio studies, I have found that **star formation region and localized AGN radio jet can be distinguished in sub-kpc scale in radio wavelengths,** (Zhang et al. 2023) and that **spatially resolved bremsstrahlung in radio wavelength can trace SFR quantitatively** (Zhang et al. submitted). With de-lensing technology, we can study the intrinsic star formation regions and AGN jet in hundreds or even tens of pc scales at high-z.

- **AGN Jet feedback:** For lensed star-forming galaxies hosting AGNs jets with high inclination angles, overlapping of skewed SFR map, enhanced velocity dispersion, and jet path can indicate AGN-jet feedback. As a 30% star formation efficiency suppression by an AGN jet was found in Cloverleaf (Zhang et al. submitted), the role of AGN-jet feedback in galaxy quenching in the early universe could be re-estimated by larger samples.

- **Resolving star formation region and jet sub-structure in tens of pc scale with VLBI facilities:** Based on the proposed observation conducted by VLBA (project ID: BZ105), with a beam size of $0''.03$, I revealed two knot-structure radio components at L-band near the caustics in the source plane with the spatial resolution of ~ 30 pc, indicating tens-pc scale jet-ISM interaction. Thus, with the observation by EAVN, VLBA, and other

VLBI facilities, 10-pc scale imaging can provide detailed star formation and jet feedback information for comparison with nearby galaxies, therefore can update our understanding of the AGN activity across cosmic time.

With the projects above, I hope to answer these questions:
Is jet-ISM interaction a popular star formation suppression channel in the early universe?
How does localized jet impact on star formation regions?
Is merger-driven gas removal a significant way to suppress the star formation in the rapid quenching phase?
How do physical conditions differ and what mechanism leads to the differences, in starbursts at the cosmic noon in sub-kpc scale?

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