A sophisticated Bayesian spectral energy distribution synthesis and analysis tool for multiband study of galaxies

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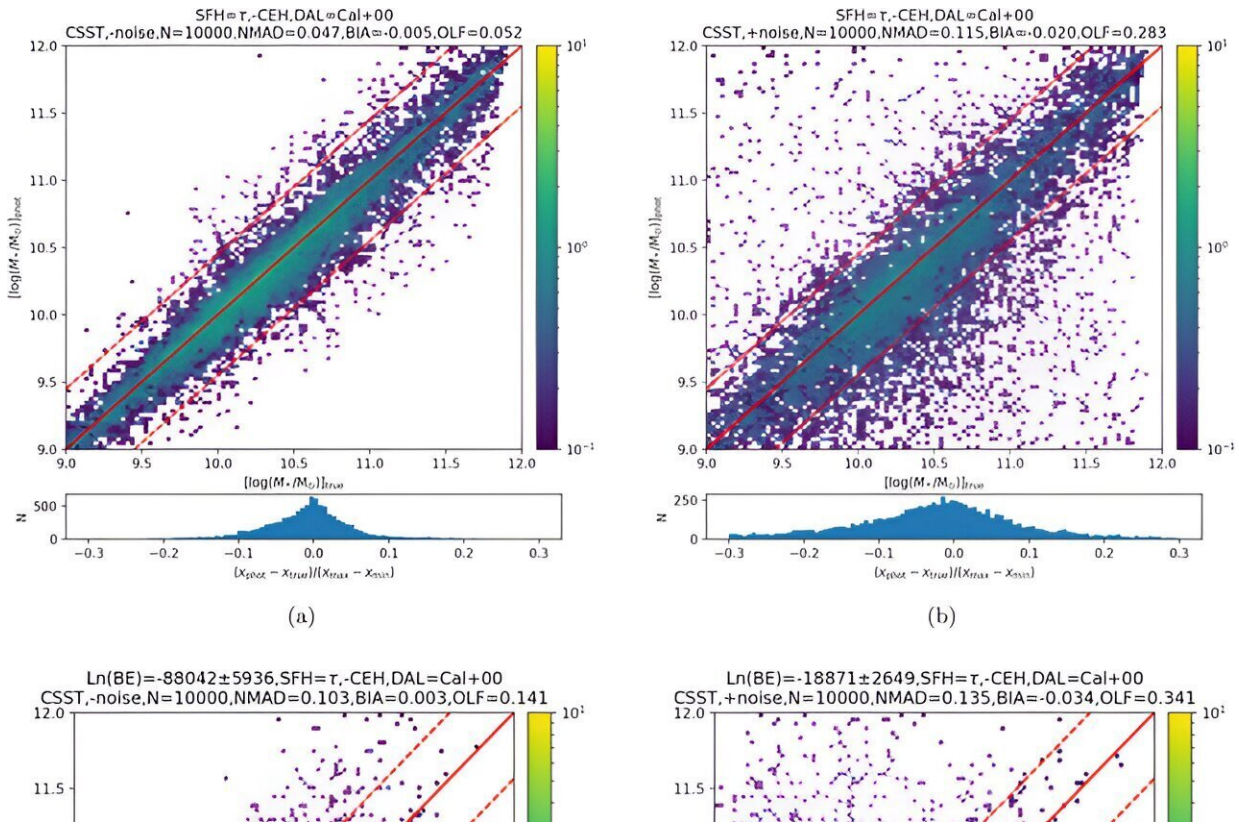

In general, the observational noise is the more important source of error for the photometric stellar mass estimation of galaxies, and the contribution from imperfect SED modeling is almost comparable. Credit: *The Astrophysical Journal Supplement Series* (2023). DOI: 10.3847/1538-4365/acfc3a

A study, published in *The Astrophysical Journal Supplement Series*, reports new findings in the performance test for simultaneous photometric redshift and stellar population parameter estimation of galaxies in the China Space Station Telescope (CSST) wide-field multiband imaging survey.

The research was conducted by Han Yunkun from Yunnan Observatories of the Chinese Academy of Sciences (CAS), Prof. Fan Lulu from the University of Science and Technology of China of CAS and Zheng Xianzhong from Purple Mountain Observatory of CAS, among others.

Galaxies are the fundamental units that constitute the universe. Studying the formation and evolution of galaxies helps unravel the nature of dark matter and dark energy. The multi-band spectral energy distribution (SED) analysis of galaxies can be utilized to measure fundamental physical parameters of galaxies such as their redshift, stellar mass, and star formation rate. This approach serves as a crucial foundation for understanding the myriad complex physical processes associated with stars, interstellar medium, and supermassive black holes within galaxies.

State-of-the-art telescopes such as James Webb Space Telescope (JWST), the Euclid space telescope, the forthcoming CSST, and Roman Space Telescope, will provide a massive amount of multi-wavelength data, which not only presents a tremendous opportunity for a deeper understanding of the formation and evolution of galaxies, but also poses significant challenges for the development of SED synthesis and analysis methods and tools.

Many teams worldwide have been actively developing methods and tools for multi-band SED synthesis and analysis of galaxies. Since 2012, Han Yunkun and the colleagues at Yunnan Observatory have been focused on this field. They systematically developed the BayeSED code, which has

undergone three major iterations and upgrades. BayeSED, and other internationally recognized tools such as CIGALE (France), PROSPECTOR (U.S.), and BAGPIPES (UK), have been widely used in the field of international astronomy.

In the latest version of BayeSED, the researchers have incorporated a galaxy population synthesis method based on some empirical statistical properties of galaxies and the nested sampling algorithms. This version also includes an observational error modeling based on the limiting magnitudes in different bands, as well as various new stellar formation history and dust absorption models.

The algorithm for composite stellar population synthesis realizes a substantial increase in the speed of detailed SED modeling: Synergy between rapid SED modeling based on machine learning, and slow but more flexible detailed SED modeling, has been achieved.

The MPI-based parallel algorithm has been enhanced to support checkpointing for resuming calculations and has substantially reduced memory resource consumption for parallel analysis of massive data. Data input and output have been optimized, adopting new data formats to meet the storage and analysis requirements of big data.

After improvements, BayeSED has achieved an average of around two seconds for detailed Bayesian analysis of the multi-band photometric SED of a galaxy using a single-core 2.2GHz CPU.

This analysis provides a self-consistent estimation of a series of fundamental physical parameters, including redshift, stellar mass, and star formation rate, along with their associated uncertainties. Meanwhile, it offers the Bayesian evidence for the SED model, a quantitative implementation of the principle of Occam's Razor—"do not multiply entities beyond necessity."

The Bayesian evidence can be employed for an objective and quantitative comparison of various physical assumptions in galaxy SED modeling. The overall performance of the BayeSED has surpassed similar tools, which supports the scientific output of CSST.

Based on the design parameters of the CSST wide-field multi-band imaging survey, the researchers have employed the empirical statistics–based and hydrodynamical simulation-based approaches to generate two mock samples of galaxies. A systematic performance test has been conducted for galaxy photometric redshift and stellar population parameter estimation.

The results indicate that the largest contributions to parameter estimation errors come from observational errors and SED modeling errors, followed by contributions from parameter degeneracy, while the contributions from the BayeSED code is minimal. The findings of this study will serve as a valuable reference for the further research.

More information: Yunkun Han et al, BayeSED-GALAXIES. I. Performance Test for Simultaneous Photometric Redshift and Stellar Population Parameter Estimation of Galaxies in the CSST Wide-field Multiband Imaging Survey, *The Astrophysical Journal Supplement Series* (2023). DOI: 10.3847/1538-4365/acfc3a

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