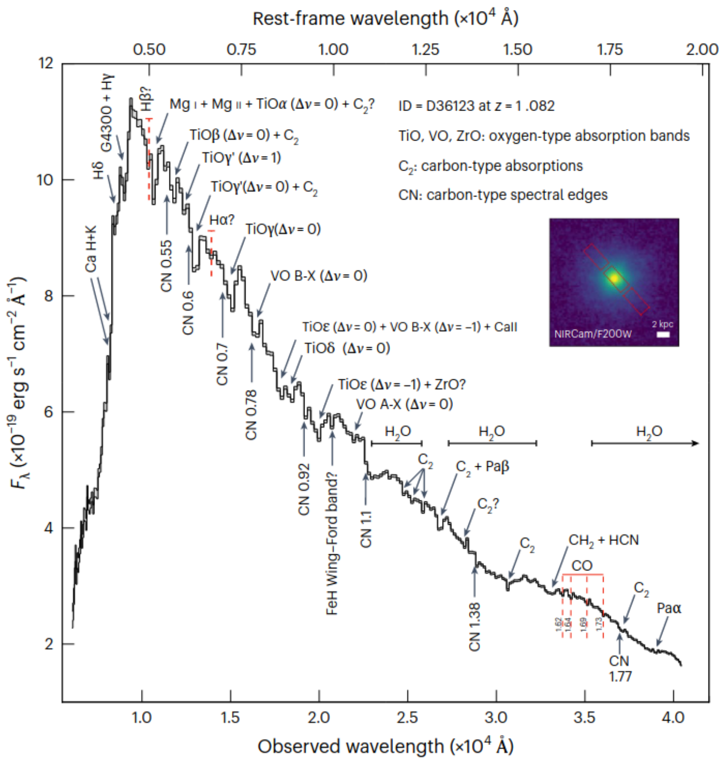
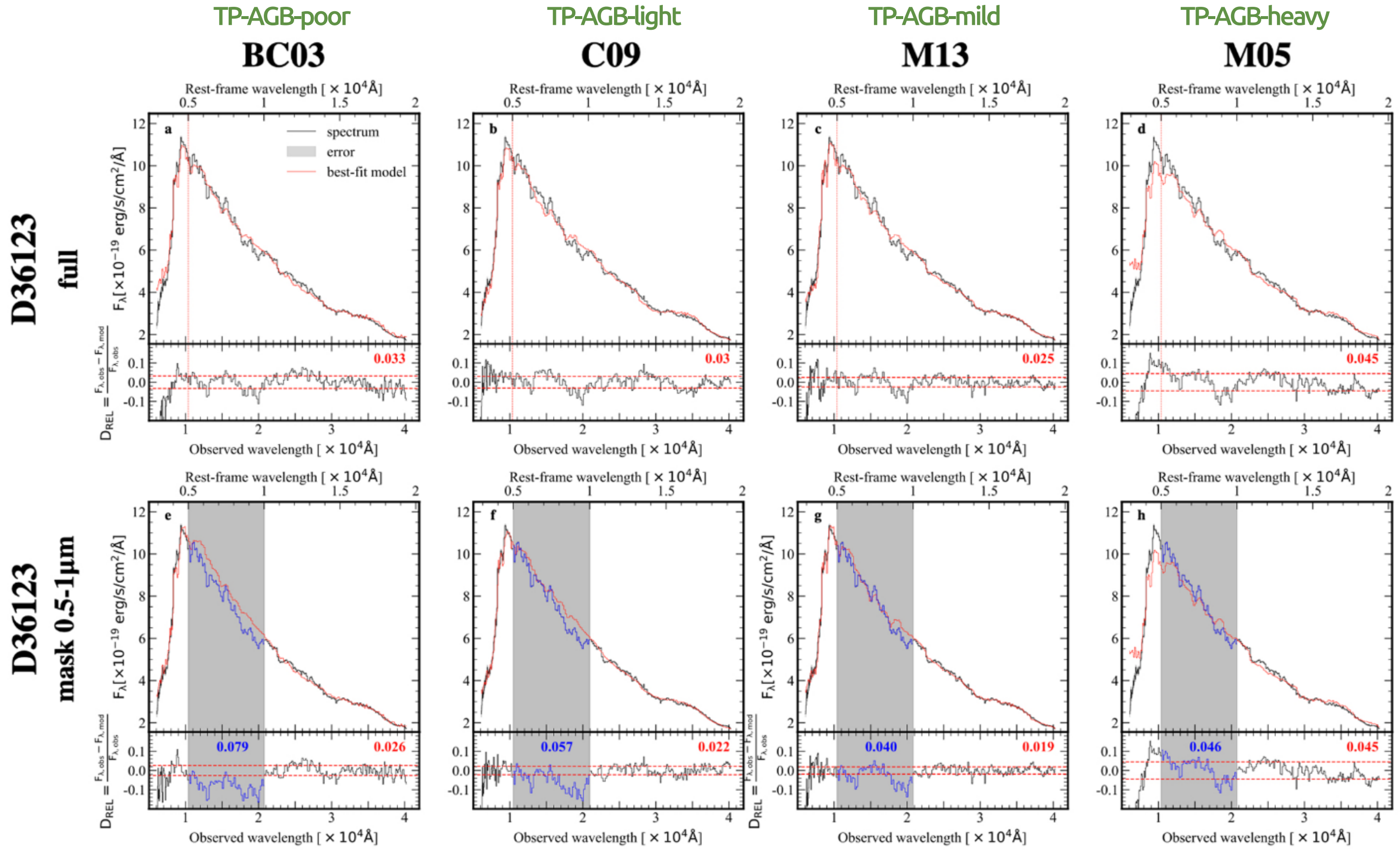
astro-ph seminar 2024.11.06 (Ryou Ohsawa)

Strong spectral features from asymptotic giant branch stars in distant quiescent galaxies

Lu et al., 2024, published in Nature Astronomy (arXiv:2403.07414)

Dating the ages and weighting the stellar populations in galaxies are essential steps when studying galaxy formation through cosmic times. Evolutionary population synthesis models with different input physics are used for this purpose. Moreover, the contribution from the thermally pulsing asymptotic giant branch (TP-AGB) stellar phase, which peaks for intermediate-age 0.6–2 Gyr systems, has been debated for decades. Here we report the detection of strong cool-star signatures in the rest-frame near-infrared spectra of three young (~1 Gyr), massive (~10^{10} $M_\odot$) quiescent galaxies at large look-back time, z = 1–2, using JWST/NIRSpec. The coexistence of oxygen- and carbon-type absorption features, spectral edges and features from rare species, such as vanadium and possibly zirconium, reveal a strong contribution from TP-AGB stars. Population synthesis models with a significant TP-AGB contribution reproduce the observations better than those with a weak TP-AGB, which are commonly used. These findings call for revisions of published stellar population fitting results, as they point to populations with lower masses and younger ages and have further implications for cosmic dust production and chemical enrichment. New generations of improved models are needed, informed by these and future observations.





Context

Evaluating the contribution of TP-AGBs to the integrated infrared SED

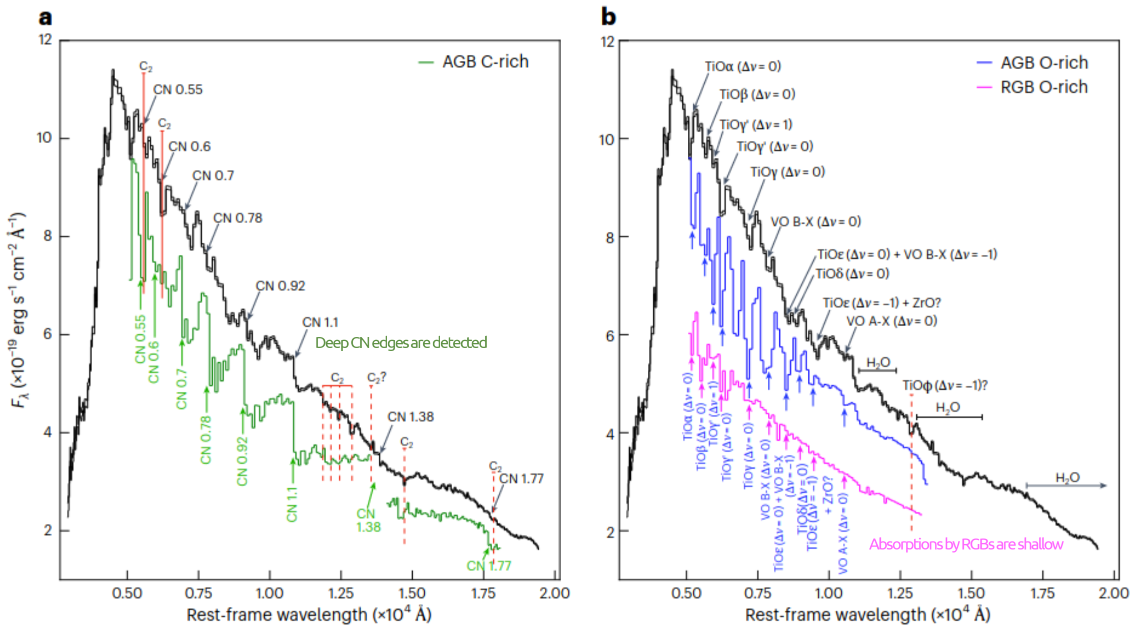
- A late stage of low- and intermediate-mass stars, that are bright, low-temperature, and short-lived (~ 3 Myr).
- The contribution of TP-AGBs can be important when a stellar population age is ~0.2–2 Gyrs.
- Understanding of pulses and mass loss is essential to predict the TP-AGB evolution.

There are several population synthesis models with different TP-AGB contributions.

- Maraston (2005): a large TP-AGB contribution in 0.2–2 Gyr, **TP-AGB-heavy** (M03) model
- Noël et al. (2013): M03 model is updated based on new observations, **TP-AGB-mild** (M13) model
- Conroy et al. (2009): a slow transition to the TP-AGB phase, **TP-AGB-light** (C09) model
- Bruzual & Charlot (2003): widely used with a negligible TP-AGB contribution, **TP-AGB-poor** (BC03) model

Quiescent high-redshift galaxies are ideal laboratory to evaluate the TP-AGB contributions.

- The spectral energy distribution is dominated by old stellar populations with ages of ~ 1 Gyrs.
- The inspectation of the TP-AGB contribution is first enabled by high-quality near-infrared spectra provided by JWST.



Observation & Instrument

Quiescent galaxy candidates (z ~ 1) were selected from CANDLES extended Groth strip catalog.

The candidate list was crossmatched with the near infrared spectra obtained with the JWST/NIRSpec in the archival data (CEER, DD-2750).

Three low-resolution spectra were available with sufficient signal-to-noise ratios (D36123, 8595, 9025).

Results & Discussion

The spectrum shows strong absorption features in 0.5–1.0 μm, suggesting the existence of TP-AGBs.

The optical spectrum suggests that the stellar population is about ~1 Gyr.

No model can reproduce the obtained spectrum, especially at the absorption features in 0.5–1.0 μm.

The TP-AGB-mild model is moderately preferred, while it also needs updated (templates & metallicity distribution).

Stellar population models have been calibrated against clusters in the Magellanic Clouds (= subsolar metallicity).

The results of the SED fitting significantly differ with the models, suggesting the importance of the TP-AGB contribution.

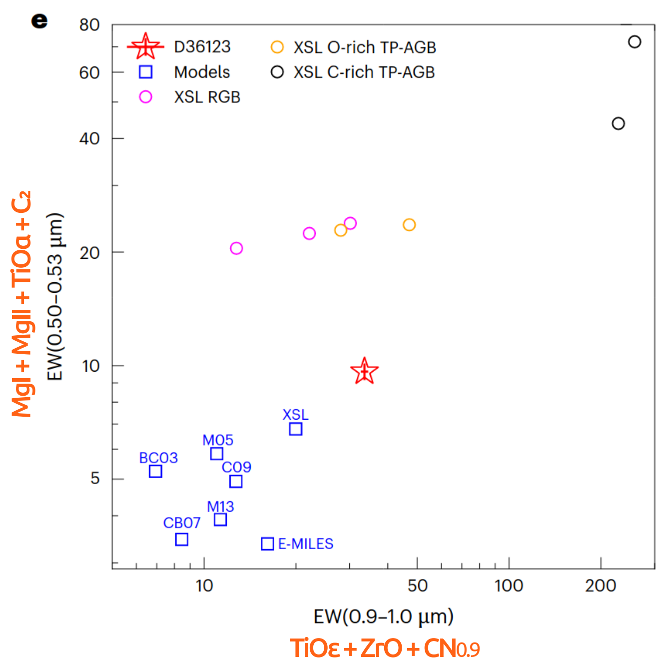


Table 1 | Stellar population properties of D36123

Rest-frame spectral range	Property	BC03 TP-AGB-poor	C09 TP-AGB-light	M13 TP-AGB-mild	M05 TP-AGB-heavy
		Right ascension (RA) 14h19m34.258s		Declination (dec.) +52°56′23.079″	
Full (0.3–2.0 μm)	Redshift	$1.074^{+0.001}_{-0.001}$	$1.075^{+0.003}_{-0.001}$	$1.082^{+0.002}_{-0.002}$	$1.075^{+0.002}_{-0.004}$
	M_* (×10^{10} $M_\odot$)	$1.493^{+0.007}_{-0.004}$	$1.489^{+0.007}_{-0.006}$	$1.167^{+0.008}_{-0.005}$	$1.552^{+0.015}_{-0.014}$
	Age (Gyr)	$1.661^{+0.024}_{-0.041}$	$0.751^{+0.025}_{-0.034}$	$0.621^{+0.029}_{-0.021}$	$2.224^{+0.016}_{-0.024}$
	$Z/Z_\odot$	$1.944^{+0.028}_{-0.034}$	$2.000^{+0.000}_{-0.008}$	$1.589^{+0.061}_{-0.039}$	$0.982^{+0.001}_{-0.001}$
	Av	$0.000^{+0.002}_{-0.000}$	$0.156^{+0.016}_{-0.022}$	$0.424^{+0.026}_{-0.026}$	$0.000^{+0.000}_{-0.000}$
	τ (Gyr)	$0.241^{+0.019}_{-0.018}$	$0.104^{+0.014}_{-0.021}$	$0.100^{+0.010}_{-0.010}$	$0.707^{+0.013}_{-0.017}$
	SFR_{best} ($M_\odot$ yr^{-1})	$0.294^{+0.036}_{-0.065}$	$0.099^{+0.001}_{-0.001}$	$0.311^{+0.003}_{-0.003}$	$1.320^{+0.006}_{-0.006}$
	SFR_{best}/SFR_{peak}	$0.019^{+0.011}_{-0.010}$	$0.014^{+0.022}_{-0.015}$	$0.024^{+0.024}_{-0.023}$	$0.368^{+0.032}_{-0.024}$
	χ^2_R	59.6	52.9	39.0	102.6
Full (excluding 0.5–1.0 μm)	Redshift	$1.076^{+0.001}_{-0.001}$	$1.093^{+0.001}_{-0.002}$	$1.081^{+0.001}_{-0.001}$	$1.075^{+0.002}_{-0.003}$
	M_* (×10^{10} $M_\odot$)	$1.581^{+0.015}_{-0.014}$	$1.750^{+0.087}_{-0.002}$	$1.076^{+0.008}_{-0.002}$	$1.535^{+0.021}_{-0.025}$
	Age (Gyr)	$1.627^{+0.021}_{-0.019}$	$1.446^{+0.095}_{-0.046}$	$0.712^{+0.018}_{-0.012}$	$2.183^{+0.038}_{-0.040}$
	$Z/Z_\odot$	$2.300^{+0.048}_{-0.036}$	$0.300^{+0.010}_{-0.009}$	$1.285^{+0.030}_{-0.023}$	$0.990^{+0.007}_{-0.007}$
	Av	$0.000^{+0.004}_{-0.000}$	$0.078^{+0.023}_{-0.017}$	$0.068^{+0.014}_{-0.013}$	$0.000^{+0.009}_{-0.000}$
	τ (Gyr)	$0.028^{+0.012}_{-0.008}$	$0.127^{+0.054}_{-0.065}$	$0.095^{+0.009}_{-0.010}$	$0.690^{+0.012}_{-0.014}$
	SFR_{best} ($M_\odot$ yr^{-1})	$0.000^{+0.008}_{-0.000}$	$0.000^{+0.045}_{-0.000}$	$0.084^{+0.013}_{-0.012}$	$1.306^{+0.022}_{-0.010}$
	SFR_{best}/SFR_{peak}	~0	~0	$0.011^{+0.009}_{-0.008}$	$0.363^{+0.027}_{-0.022}$
	χ^2_R	32.2	23.1	16.3	83.7
	$\chi_{R,msk}^2$	446.7	308.4	157.9	172.1

The first column denotes the rest-frame range of the wavelength adopted in the spectral fit. The third to sixth columns list the best-fitting physical properties derived by four models with different TP-AGB treatments. Specifically, the total stellar masses were based on the Chabrier IMF[66]. The age is the mass-weighted age, that is, the average over the look-back time weighted by the SFH. The best-fitting parameters and errors were derived from the distribution of χ^2, with the former obtained for the minimum χ^2. The errors were determined after rescaling to $\chi^2_R = 1$. SFR_{best}/SFR_{peak} is a measure of quiescence, where SFR_{best} was derived from the best fit by adopting delay-τ models, and SFR_{peak} corresponds to the SFR maximum at $t=\tau$. $\chi_{R,msk}^2$ presents the reduced χ^2 within the masked 0.5–1.0 μm region during the spectral fit.