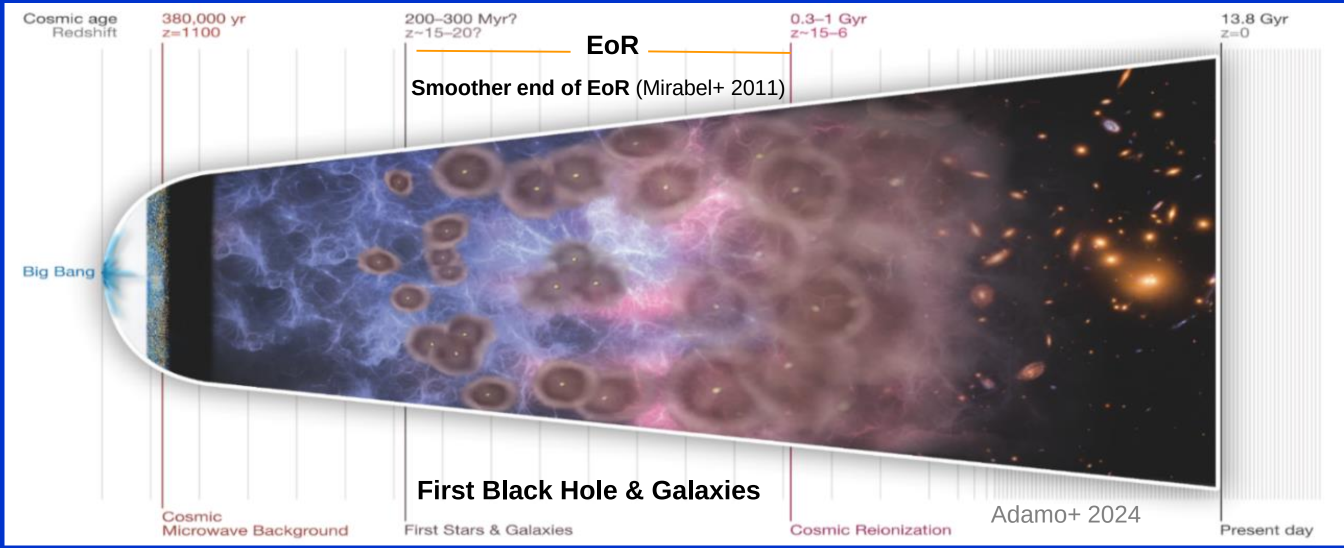
SMBHs & MASSIVE GALAXIES IN THE EARLY UNIVERSE

Félix Mirabel[1,2]
[1]CEA-Univ. Paris-Saclay-France & [2]IAFE-Univ. Buenos Aires-Argentina

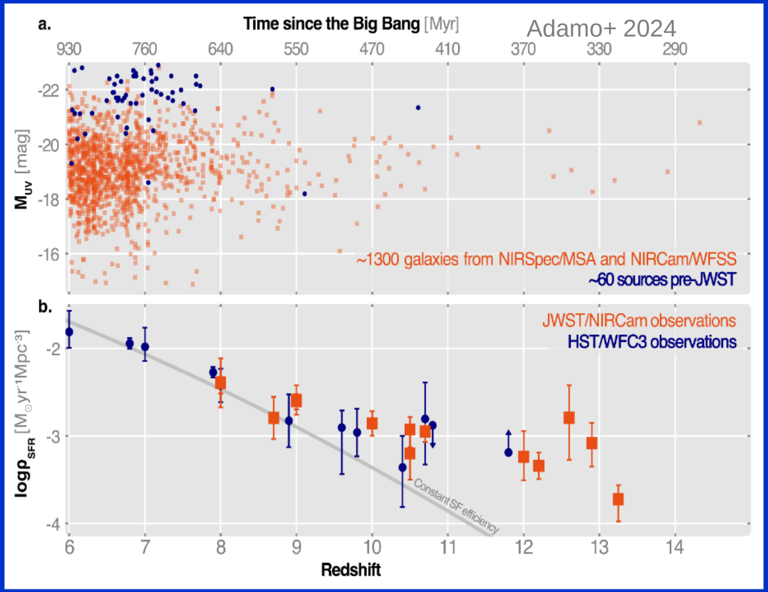


The first JWST observations of early bright galaxies suggest that the formation, assembly, and quench rates of bright galaxies at z > 10 are higher than predicted

by DM Cosmologies alone, which produced great surprise!

The First Billion Years, According to JWST

Following an ISSI Breakthrough Workshop (Bern, March 2024)



Two highlights

~1300 massive galaxies at z > 6, 20 spectroscopically confirmed at z > 10, with the current high mark galaxy at z = 14.32 (Carniani+ 2024)

Blue dots are absolute magnitudes and redshifts of spectroscopically confirmed galaxies from pre-JWST. Orange squares are candidates from public JWST data.

A slower decrease of the UV Luminosity Function at z > 8 than expected. That would imply more early production of UV photons, due to an unexpectedly larger number of luminous galaxies.

Cosmic SFR density in the first billion years as seen from HST/WFC3 samples (dark circles) compared to JWST/NIRCam (orange squares).

To explain the flattening of the UV LF, several baryonic scenarios were proposed: (a) decreasing dust obscuration beyond z ~ 10, (b) SF variability resulting in a flattening LF, (c) a top-heavy IMF, (d) magnification biases of the UV…

However, in that review is not mention **BH-JET POSITIVE FEEDBACK**

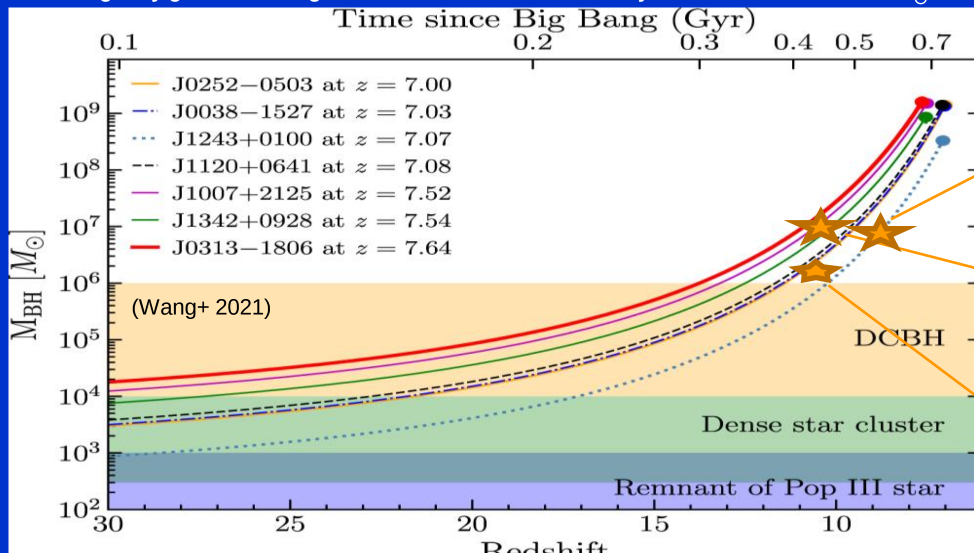
BH-jets and associated molecular outflows interacting with cold gas clouds of large column densities trigger Star Formation (SF)

and also it is not mention that

Before JWST: SMBHs of ~10^9 $M_\odot$ in z > 5 quasars (Fan+ 2023)

How SMBHs can grow up to ~10^9 $M_\odot$ when the Universe was less than 700 Myr old?

Assuming they grow at Eddington limit with radiative efficiency of 10% from seeds >10^3 $M_\odot$ at z = 30



JWST high-z MBHs

BH at z = 8.679
M_{BH} = 8.9 x 10^6 $M_\odot$
Larson+ (2023)

BH at z = 10.3
M_{BH} 4 × $10^7 M_\odot$
Bogdan+ (2023)

AGN at z = 10.6
Bunker+ (2023)
M_{BH} = 1.6 × 10^6 $M_\odot$
Maiolino+ (2023)

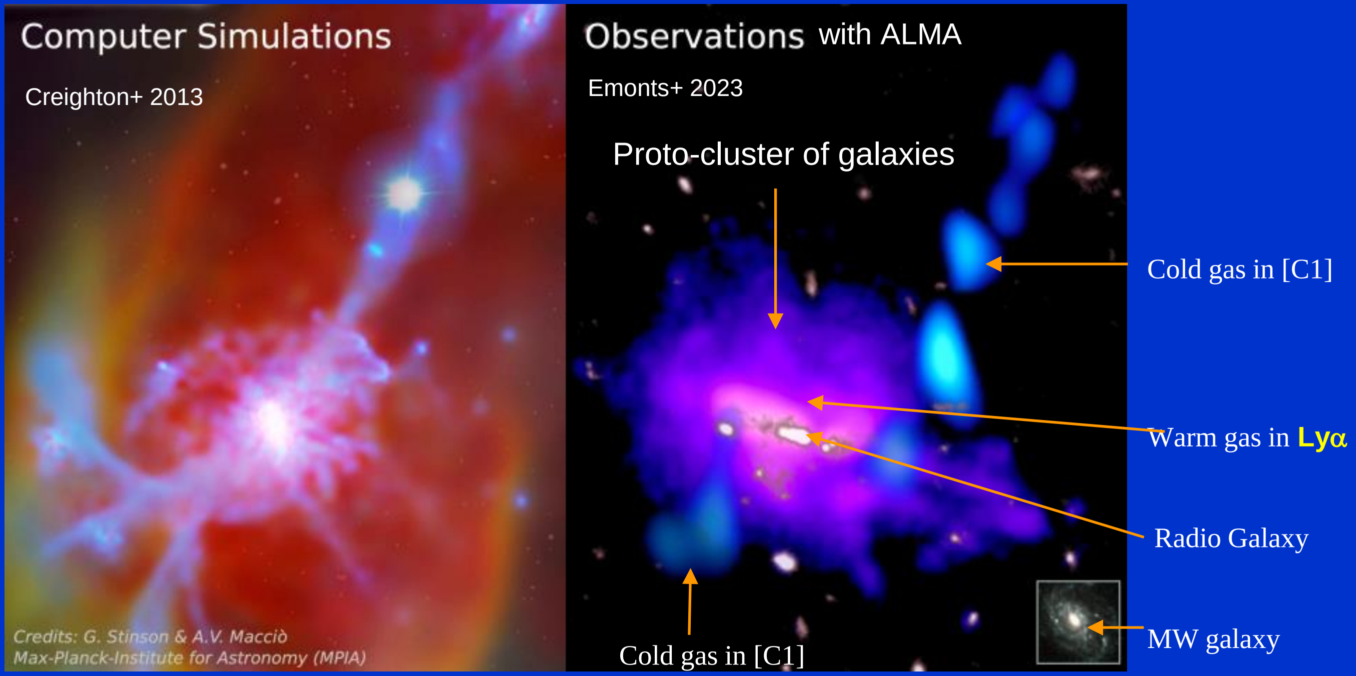
(1) The seeds of SMBHs could be of primordial origin (Zeldovich & Novikov 1966), stellar, or **form at z > 25 by direct collapse of converging streams of cold gas in DM haloes of ~few x 10^5 $M_\odot$ of DM cosmologies** (Latif+ 2022)

(2) High accretion rates of MBHs must imply high gas densities at z > 6

Are there observational evidences of: (1) converging streams & (2) high gas column densities N(H) at z > 6?

(1) Cosmic streams of cold gas

Converging in a dark matter halo that hosts the powerful radio galaxy 4C 41.17 at z = 3.8 in the center of a Proto-cluster of galaxies



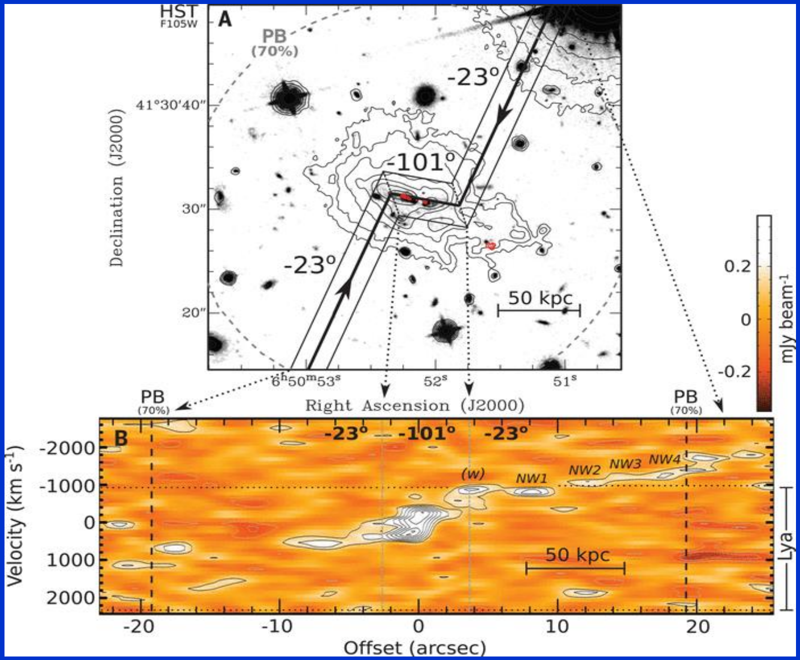
ALMA observes in the [C I] λ609 μm transition, turbulent cold gas accreted by the SMBH in 4C 41.17 at z = 3.8

ALMA observations of **[C I]** in the rest-frame λ609 μm (492 GHz). [C I] has an upper energy level of 23.6 K, & a critical density of n_{crit}~ 500 cm^{-3} … **traces H_2**

Stream M_{H2} ~ 7 × 10^{10} $M_\odot$
Central M_{H2} ~1.4 × 10^{11} $M_\odot$
Macc-rate ~ 450 ± 180 $M_\odot$/yr
SFR ≳ 250 $M_\odot$/yr in the last 10^9 yrs

The NW & SE streams converge at a relative velocity of ~1500 km/s

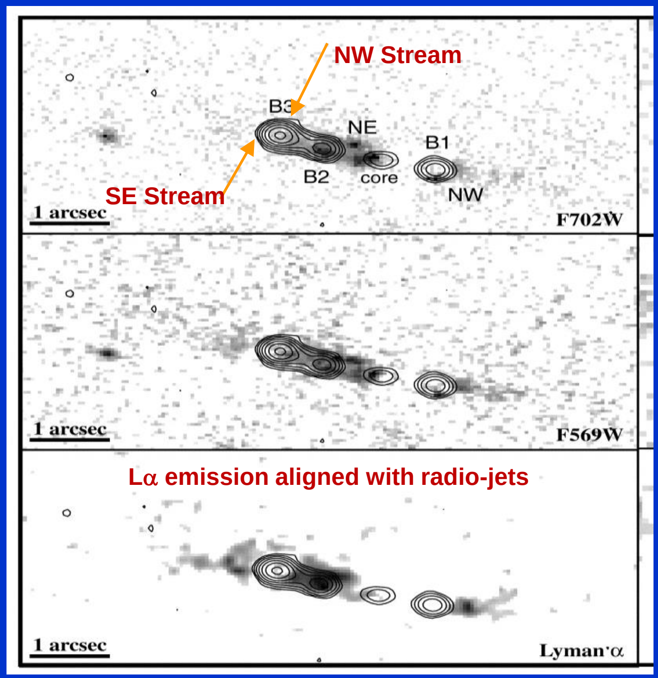
Emonts+ (Science 2023)

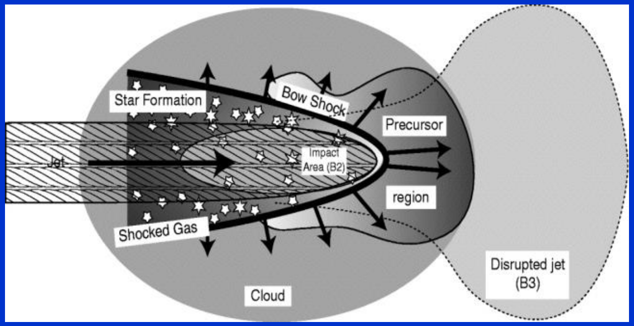


Therefore

The SMBH in 4C 41.17 accretes gas at high rates, producing jets that trigger star formation (SF)

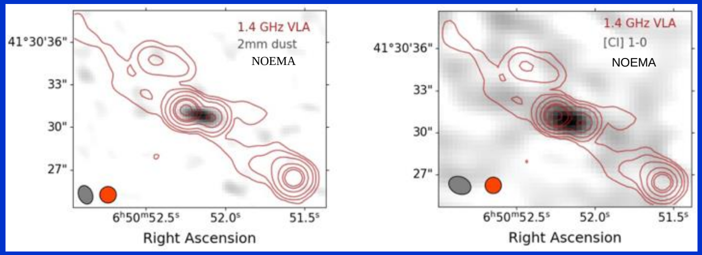
Bicknel+ 2000





Suggested morphology of a jet-cloud interaction

Nesvadba+ 2020

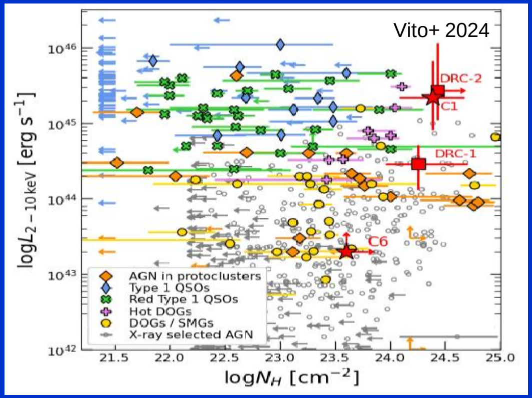


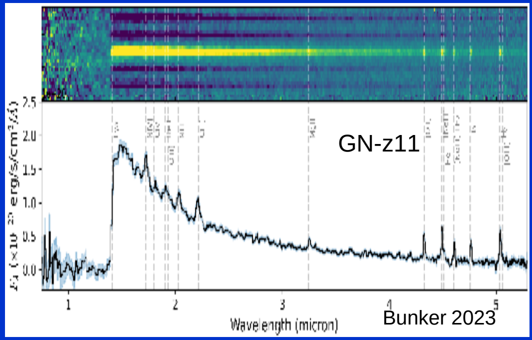
HST images with F702W (λrest ~ 1430 Å), F569W & Lyα filters. Contours are 8 - 12 GHz radio images.

The AGN is surrounded by dust & high N(H)s of cold gas
SFR = 650 M⊙/yr

What are the evidences that SMBHs at higher redshifts grow enshrouded in higher N(H)s?

(2) SMBHs in Proto-clusters of galaxies at z > 6 grow immersed in high N(H)s





The observational evidences

JWST AGN at z > 6 in the GOODS Fields are more numerous than X-ray selected due to Compton-thick X-ray absorption by dense clouds of BLR type (Maiolino+ 2024)

The high hard to soft X-ray fluxes of z > 6 AGN imply N(H)s > 10^{24} cm^{-2} (Vito+ 2024)

Lyα drops in galaxies at z = 9-13 suggest N(HI)s > 10^{22} cm^{-2}

2 orders of magnitude above of IGM origin, implying gas mass fractions > 0.1-0.5

(D'Eugenio+2023; Heintz+ 2023; Hainline+ 2024; Juodžbalis+ 2024)

N(HI) > 10^{22} cm^{-2} are more than one order of magnitude the typical N(HI) in the inner MW disk

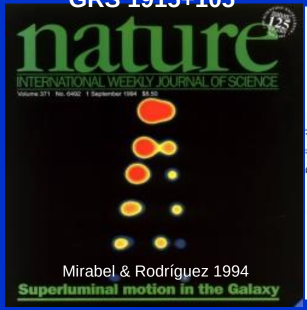
(Downes+ 1980)

BH-jets/outflows interacting with high N(H)s of cool gas induce SF (Fragile+ 2017)

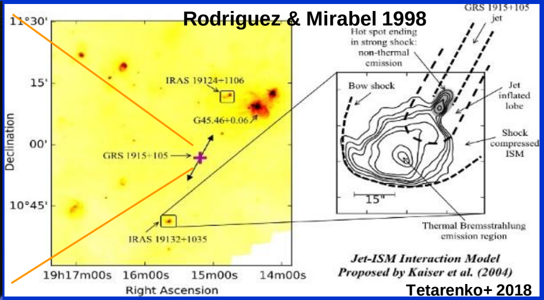
Positive feedback by BH-jets in the Local & Distant Universe

In the MW:
The microquasar
BH-XRB:
M_{BH} ~10 $M_{\odot}$ & 1$M_{\odot}$ RG
Récemment :
D = 8.6 ± 1.6 kpc
Jet = 0.81±0.04c
Reid+ (2014)

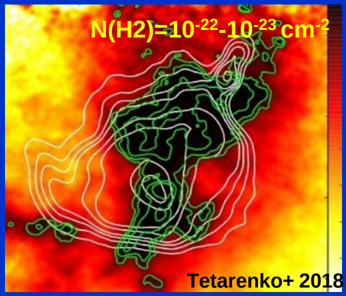
GRS 1915+105



IRAS 19132+1035:

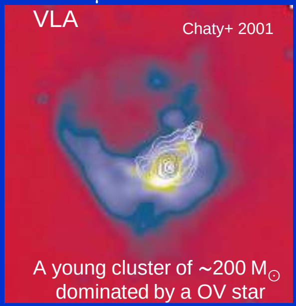


ALMA $C^{18}O$ column denity



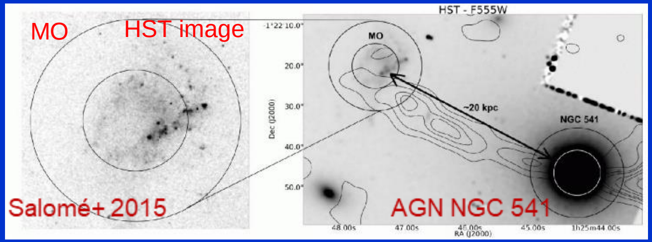
Kaiser+2004

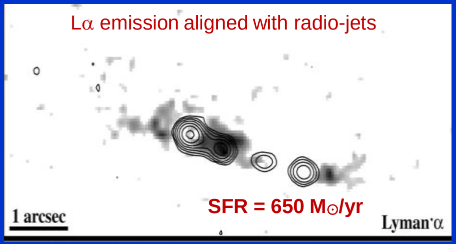
ISO 7μm & radio VLA

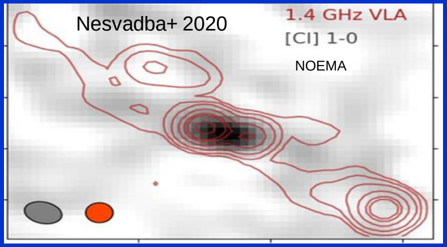


Positive feedback

In the Local & distant Universe







Positive feedback is rare in the Local Universe, but should be common in the Early Universe

However

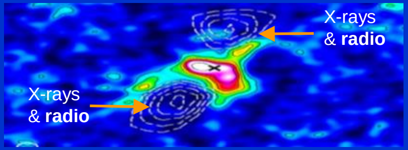
Positive Feedback is difficult to observe because at z > 6 is hidden by N(H), and at z < 6 by dust

BH Negative feedback in the Local and Distant Universe

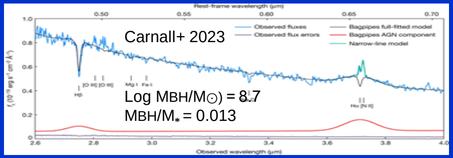
Negative Feedback

From the Local Universe to JWST galaxies at z > 4

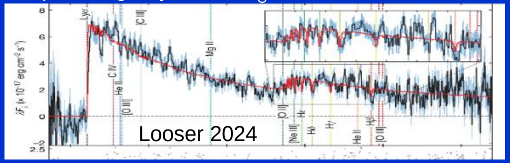
ALMA CO(3-2) in the Phoenix cluster at **z = 0.6**



Galaxy at z = 4.7 quenched at z = 6. 5



Mini-quenched galaxy of 5×10^{8} $M_{\odot}$ at z=7.3 wth Balmer break SB



Feedback from AGN regulate in stochastic way the evolution of galaxies in the Early Universe.

Gas-rich mergers generate the conditions for AGN positive feedback

- Gas-rich mergers enhance the BH environmental N(H), the BH accretion rate & jet power

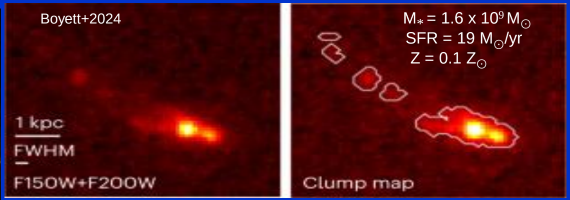
The diameter of the Universe evolves as 1/(1+z)…and it is expected that

- Gas-rich mergers are frequent in the Early Universe but rare in the Local Universe

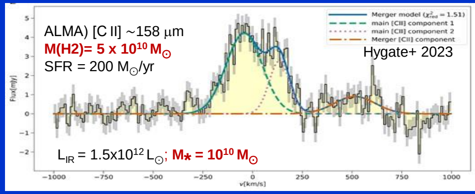
ULIRGs in the Local Universe (Sanders & Mirabel ARAA 1996) and Early Universe (Boyett+ 2024; Hygate+2023)

ULIRG in the Local Univers

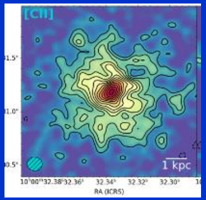
ULIRG at z = 9.3



REBELS-25 at z=7.31: Most baryons are in H2 & HI



with spiral structure



CONCLUSION

If the mechanisms of AGN feedback and massive gas-rich mergers are taken into account, the JWST observation of a very early appearance, fast growth and rapid quench of luminous galaxies in the Early Universe may be consistent with DM cosmologies…and not surprising.