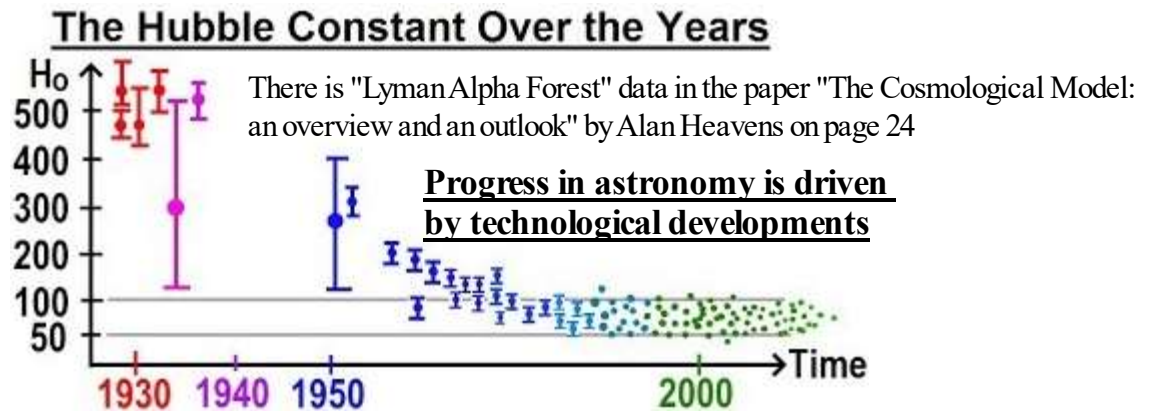


## XXIV. Advances in Measurement and Technology for Measuring Hubble Constant

Hubble's original value in 1923 was  $500 \text{ kms s}^{-1} \text{ Mpc}^{-1}$ . The high value was that he overestimated the distance. Unknown to him there are two classes of Cepheids: Type I Cepheids ( $\delta$  Cepheus is a classical Cepheid) are population I stars with high metallicities, and pulsation periods generally less than 10 days. Type II Cepheids (W Virginis stars), are low-metallicity, population II stars, that are older, cooler, and redder, with pulsation periods between 10 and 100 days. Hubble had used Population I Cepheid variable stars to determine distances to spiral nebulae. Hubble had made the assumption that these Pop I Cepheid stars in distant spiral nebulae were similar to those observed in our galaxy. In fact, the stars Hubble was using to estimate distances were systematically brighter than the nearer comparison stars. When this was realized in the **1950s**, thanks to Baade's work, Hubble's distances were doubled and  $H_0$  halved from 500 to 250.

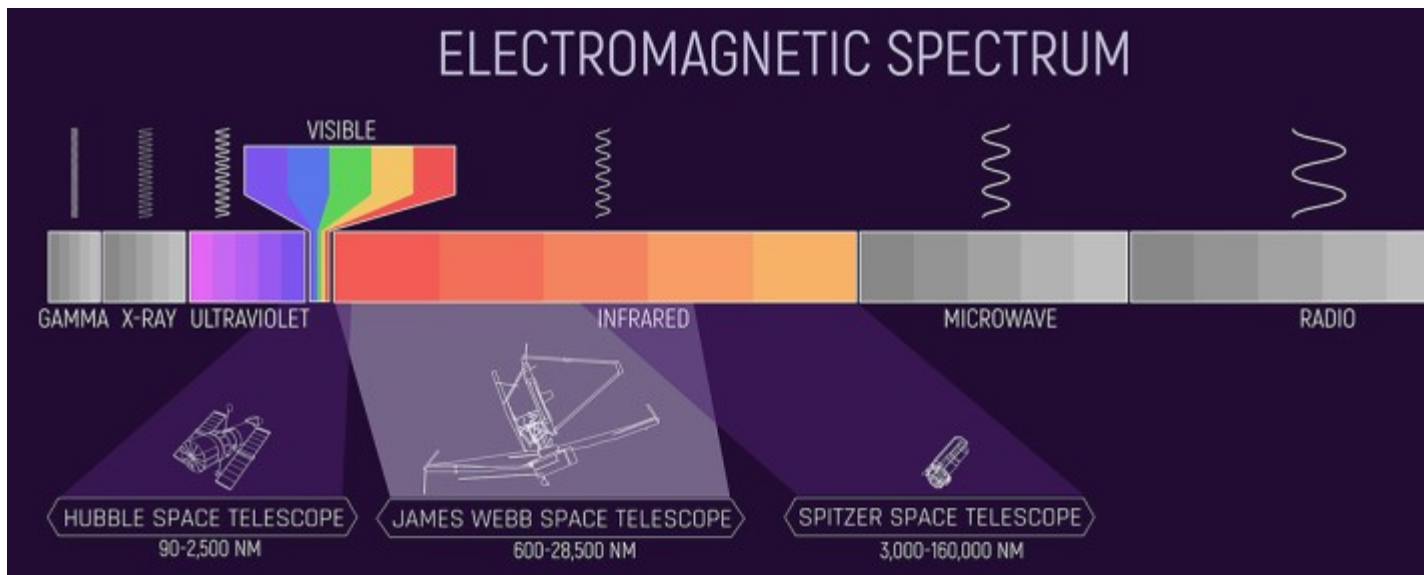


Charge-coupled devices (CCDs) were first used in astronomy in **1976** by Jim Janesick and Brad Smith. Compared to photographic plates, they have better low-light performance, a wider (red) spectral range, and the ability to quickly convert photons into electrons. Photographic plates saturate and cannot discriminate brightness like CCDs. GigaPixel CCDs also improved the light gathering power of telescopes by nearly two orders of magnitude. These advances revolutionized astronomy by facilitating immediate data analysis and enabling practical space-based observations.

The Hubble Space Telescope was launched in **1990**, taken to space in the cargo bay of the space shuttle Discovery. Its main purpose was to figure out a distance scale of the Universe (how big it is) and where the elements present in space came from. **HST was optimized for 0.1 to 2.5  $\mu\text{m}$  region.**

The Planck Space Telescope 2009, was designed to study the Cosmic Microwave Background (CMB) at **3-160  $\mu\text{m}$ .**

The Goal of the JWST (Launched in 2021) is to see high redshift galaxies to observe farther into the universe than ever before. To observe the Cosmic Dawn. JWST Instruments capable of studying **0.6 to 28 $\mu\text{m}$  Infrared Region.**



# James Webb Space Telescope (JWST) - Infrared Deep Field Survey

The James Webb Space Telescope (JWST) is the scientific successor to both the Hubble Space Telescope (HST) and the Spitzer Space Telescope. It is envisioned as a facility-class mission. JWST aims to achieve science goals that can never be reached from even the largest envisioned groundbased telescopes. **HST Optimized for 0.1 to 2.5 μm region.**

It will be equipped with four instruments capable of studying the **0.6 to 28μm region** using both imaging and spectroscopic techniques. The instrument suite provides broad wavelength coverage and capabilities aimed at four key science themes:

$$z = (\lambda_{\text{obs}} - \lambda_{\text{rest}}) / \lambda_{\text{rest}} \quad \text{Lyman-alpha break} = 121 \text{ nm}$$

**1) The End of the Dark Ages:** First Light and Reionization; finding the light from the first objects to coalesce after the Universe has cooled after the Big Bang

**2) The Assembly of Galaxies;** how do galaxies change from first light objects to the suite of morphologies and galaxy types that we see today. To unravel the birth and early evolution of star, from the earliest epochs  $\approx 300$  Myr after the Big Bang, through the Epoch of Reionization.

**3) The Birth of Stars and Protoplanetary Systems;**

**4) Planetary Systems and the Origins of Life.** NIRCam is the 0.6 to 5 micron imager for JWST, and it is also the facility wavefront sensor used to keep the primary mirror in alignment. JWST will work to unravel the birth and early evolution of stars, from infall onto dust-enshrouded protostars to the genesis of planetary systems. The Hubble Space Telescope (HST) has a highest resolution of about 0.03 arcseconds, while the Very Long Baseline Array (VLBA) makes images with a resolution smaller than 0.001 arcsec. The JWST at located at Lagrange 2, has 6.5 m mirror, and a resolution of 0.1 arcsec.

## JWST Mid Infrared Instrument

## JWST Instruments

The JWST Mid-Infrared Instrument (MIRI) provides imaging and spectroscopic observing modes from  $\approx 5$  to 28μm.

## JWST Near Infrared Camera

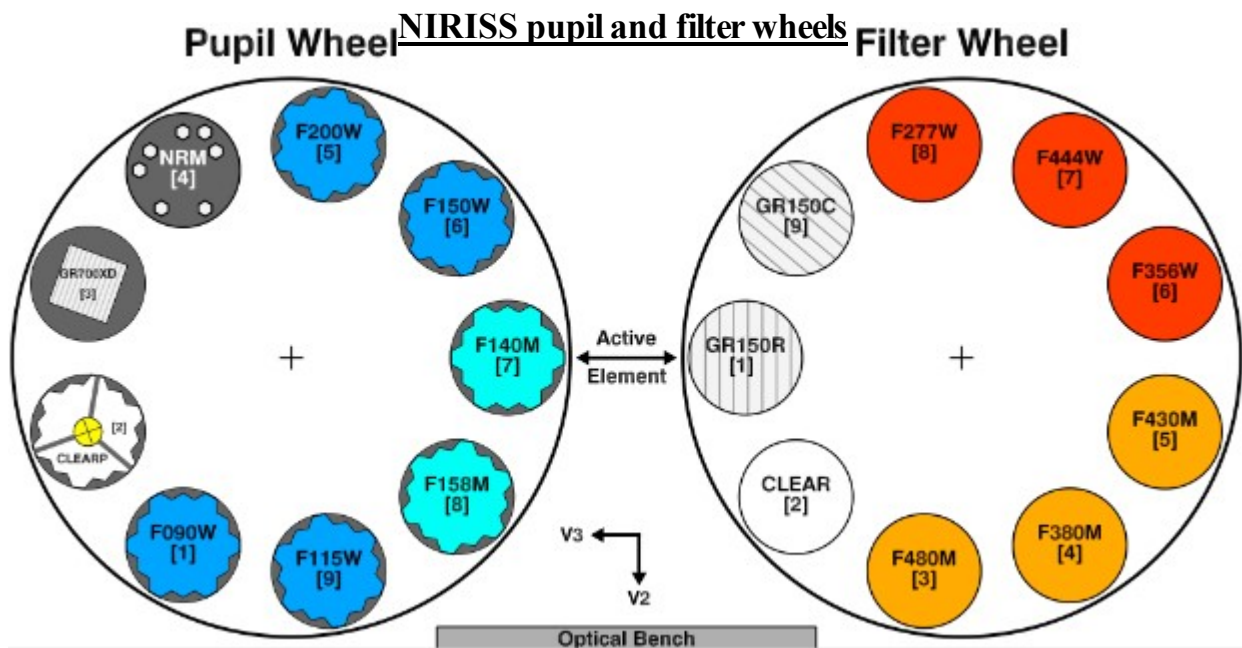
The JWST Near Infrared Camera (NIRCam) offers imaging, coronagraphy, wide field slitless spectroscopy, and time-series monitoring both in imaging and spectroscopy, as well as wavefront sensing measurements for JWST mirror alignment. The JWST provides near-IR spectroscopy from 0.65.3 μm within a 3.4 x 3.6 arcmin field of view using a micro-shutter assembly (MSA), an integral field unit (IFU), and fixed slits (FSs).

## JWST Near Infrared Imager and Slitless Spectrograph

The JWST Near Infrared Imager and Slitless Spectrograph (NIRISS) provides observing modes for slitless spectroscopy, high-contrast interferometric imaging, and imaging, at wavelengths between 0.6 and 5.0 μm over a 2.2' x 2.2' FOV.

## JWST Near Infrared Spectrograph

The JWST Near Infrared Spectrograph (NIRSpec) provides near-IR spectroscopy from 0.6–5.3 μm within a 3.4 x 3.6 arcmin field of view using a micro-shutter assembly (MSA), an integral field unit (IFU), and fixed slits (FSs).



# JADES: JWST Advanced Deep Extragalactic Survey Near-IR Spectroscopy Optics

# JADES: Lookback Time versus Red Shift and Age of Univ z = 14.3 Gyr

Look-Back Time & Age of Univ vs. z. 2024 Metal-Poor JADES-GS-z14-0 galaxy @z=14.3, Age: 290 million years

## The Value of the Cosmological Constant, John D. Barrow, 2018

"If you neglect the energy density of radiation and consider that the universe is currently flat, the following formula is derived from the Friedmann equation:"

$$H_0 := 71 \frac{\text{km}}{\text{s} \cdot \text{Mpc}}$$

$$\Omega_{\Lambda 0} := 0.73$$

$$dt = \frac{da}{H_0 \left( \frac{\Omega_{m,0}}{a} + a^2 \Omega_{\Lambda,0} \right)^{\frac{1}{2}}}$$

$$H^2 = \frac{8\pi G}{3} \rho + \frac{\Lambda}{3} - \frac{K}{a^2},$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} (\rho + 3P) + \frac{\Lambda}{3}$$

$$\dot{\rho} + 3H(P + \rho) = 0,$$

The subindices mean current values for the Hubble parameter (=71 Km /s Mpc), Omega matter (=0.27), Omega cosmological constant (=0.73). To get the age at a given redshift z, you have to integrate from a = 0, to a = 1/(1+z).

The fraction of the effective mass of the universe attributed to "dark energy" or the cosmological constant is  $\Omega_{\Lambda 0}$  With 73% of the influence on the expansion of the universe in this era, the dark energy is viewed as the dominant influence on that expansion.

We assume that the matter source of the FLRW universe is a perfect fluid with energy density  $\rho$  and pressure P related by the barotropic, linear, and constant equation of state  $P = w\rho$ ,  $w = \text{const}$ .

$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{expected}}}{\lambda_{\text{expected}}}$$

## Values of Some Constants

$$L_{\text{yr}} := 1 \text{ yr} \cdot c \quad L_{\text{yr}} = 9.461 \times 10^{15} \text{ m} \quad M_{\text{pc}} := 3.086 \cdot 10^6 L_{\text{yr}} \quad G_{\text{yr}} := 10^9 \text{ yr} \quad w := 0.1 \dots 1$$

### w: Ratio P/ρ for a fluid

Note:  $t_L(z)$  factor should be 3/2. Used 1.45 to get a better match.

$$t_L(z) := \frac{3}{2H_0 \cdot 1.45} \cdot \left[ 1 - (1+z)^{-\frac{3}{2}} \right]$$

$$t_0(w) := \frac{2 \cdot H_0^{-1}}{3(w+1) \cdot \sqrt{\Omega_{\Lambda 0}}} \cdot \ln \left( \frac{1 + \Omega_{\Lambda 0}}{\sqrt{1 - \Omega_{\Lambda 0}}} \right)$$

## Some Results of JWST Advanced Deep Extragalactic Survey - Lookback Time

### Age of Universe (tBB) from from 2021 Lambda-CDM concordance Model (Billion Years)

$$t_{\text{BB}} := 13.737 \quad \text{BigBang} := t_{\text{BB}}$$

### Furthest Observations of 2023 Metal-Poor JADES-GS-z14-0 galaxy @z=14.2, 290 Million Years Old

(Refer to Section VIII for Derivation of Lookback Time)

$$t_{\text{lb}}(z) := t_{\text{BB}} \cdot t_{L\_tH0}(z, 0.3, 0.7, 10^{-10}) \quad t_{\text{age}}(z) := t_{\text{BB}} \cdot t_{tH0}(z, 0.3, 0.7, 10^{-10}) \cdot 1000$$

$$\text{Furthest}_z := 14.3 \quad \frac{1}{H_0} = 13.765 \cdot \text{Gyr} \quad j := 0, 0.01 \dots 20 \quad z_j := j$$

# Initial Galaxy Census from JWST 2023 (See Section X - IMF)

The study of galaxies at the highest redshifts is crucial to unveiling the earliest stages of galaxy formation and evolution

**References:** *The abundance of z ~ 10 galaxy candidates in the HUDF using deep JWST NIRCcam medium-band imaging*, Donnan et al 2023, Perez-Gonzalez et al. 2023

## Read Data from JWST Observations:

Donnan et al 2023, Harikane et al 2022, McLeod et al 2016, Oesch et al 2018, Perez-Gonzalez et al. 2023  
Bouwens et al. 2022

Similar Graph,  $\rho_{UV}$  *The Dearth of z ~ 10 Galaxies in All HST Legacy Fields — The Rapid Evolution of the Galaxy Population in the First 500 Myr*, Oesch, The Astrophysical Journal, 855:105 ( 12pp ), 2018 March

$Dat\rho_{UV} := READPRN("Luminosity density Galaxies per Volume vs z.txt")$     Model Curve to UV Luminosity  $\rho$   
 $\rho_{UV} := Dat\rho_{UV}^{\langle 1 \rangle}$      $z_{fit} := Dat\rho_{UV}^{\langle 0 \rangle} \cdot \frac{17}{16.5}$      $fit(z) := \log\left[(1+z)^{-4.2}\right] + 29.5$

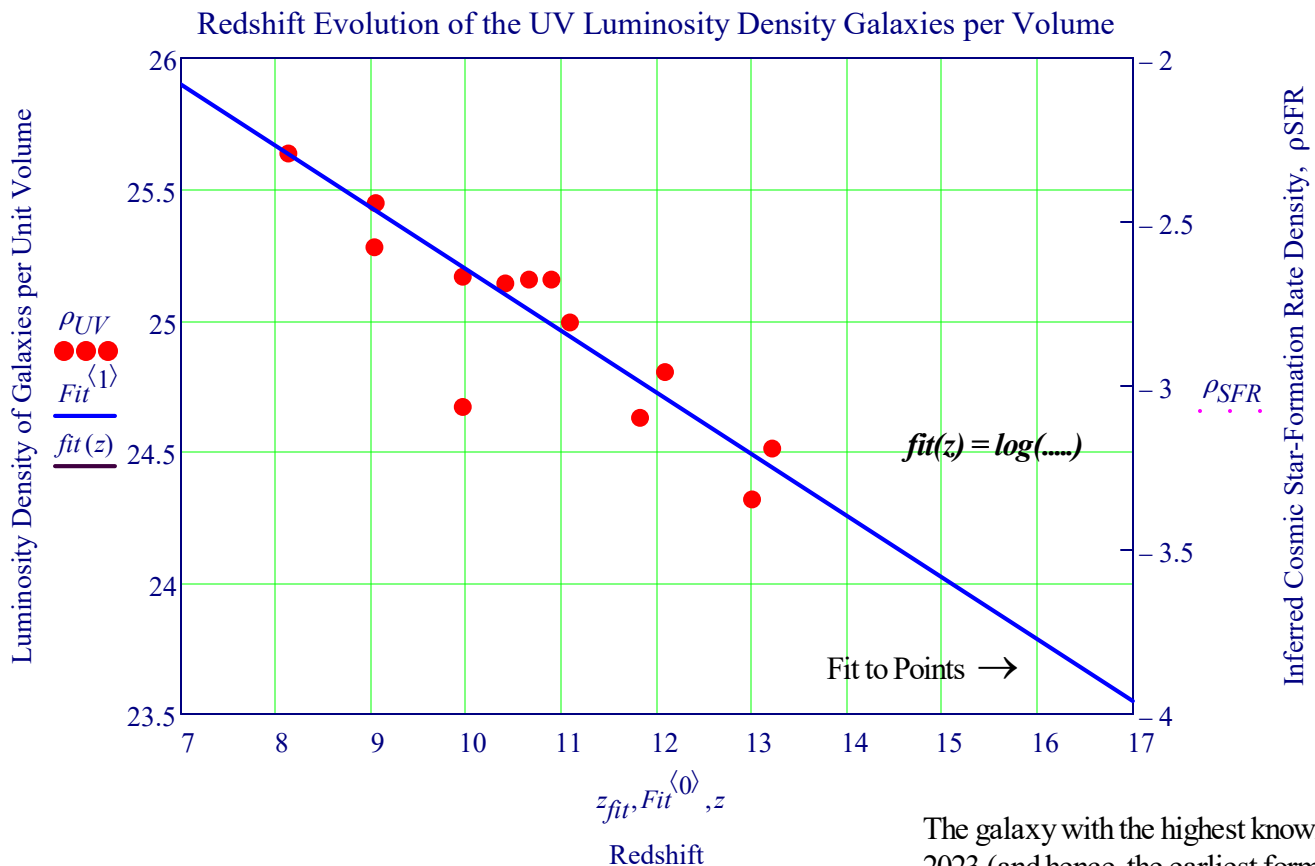
## Redshift Evolution of the UV Luminosity density, $\rho_{uv}$ and Inferred Cosmic Star-Formation Rate Density, $\rho_{SFR}$

$\log_{10}(\rho_{uv}/\text{ergs s}^{-1} \text{ Hz}^{-1} \text{ Mpc}^{-3})$  vs. Redshift, z

### Initialize Second Unit Scale

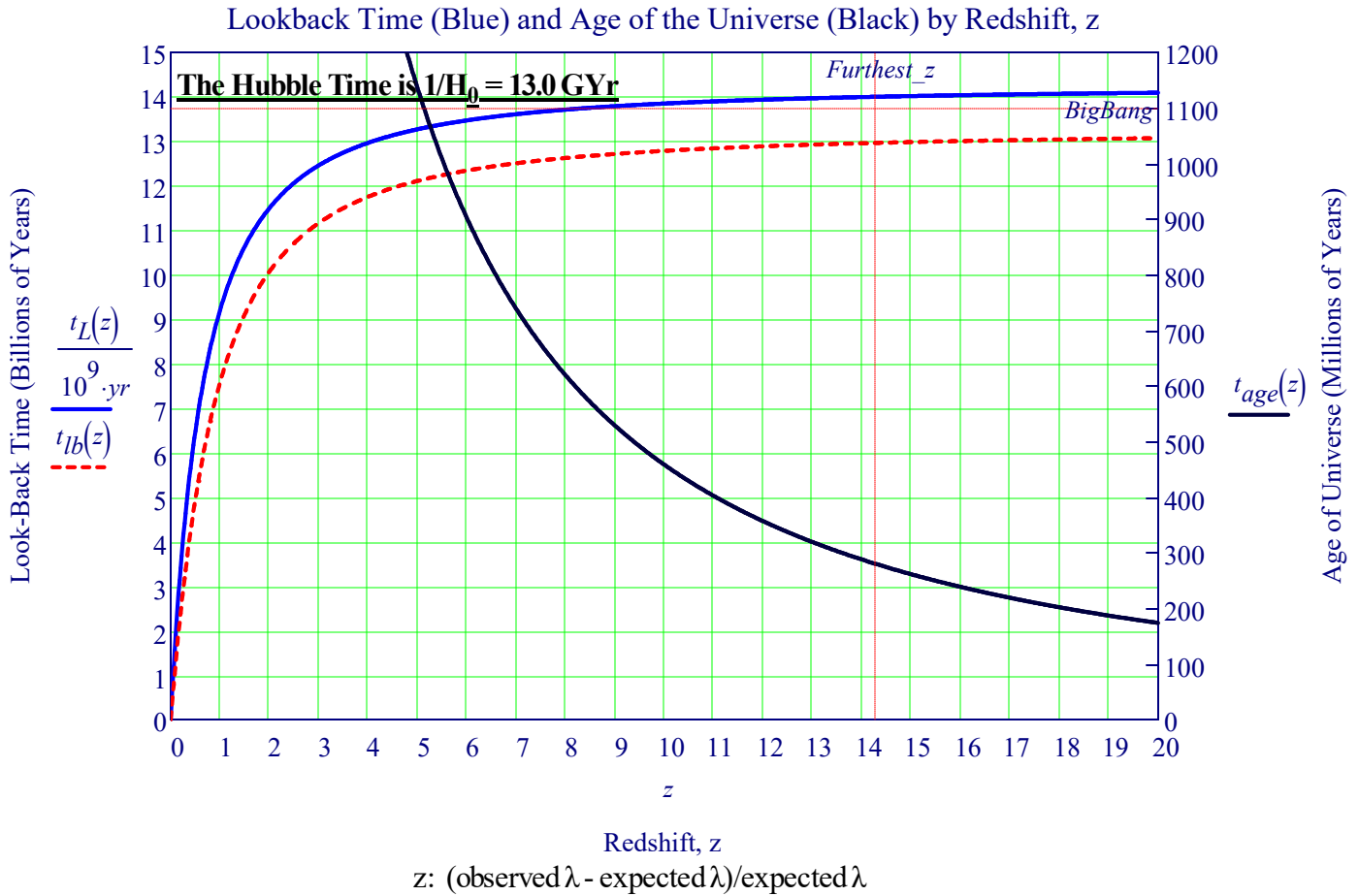
$$\rho_{SFR} := 1$$

### UV Luminosity Density, $\rho_{UV}$

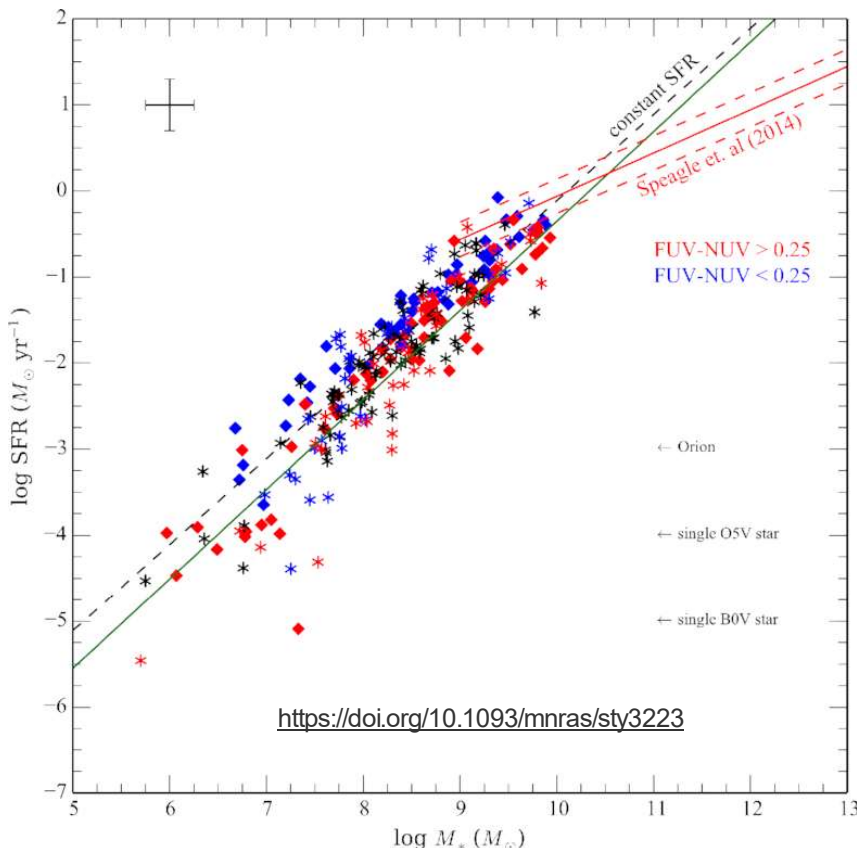


The galaxy with the highest known redshift 2023 (and hence, the earliest formed) is now JADES-GS-z13-0 at redshift 13.20, 400 million years after the Big Bang

# Look-back Time by Redshift and Age of Universe



## The mass-to-light ratios and the star formation histories of Disc Galaxies



### The main sequence for high- and low-mass star-forming galaxies.

**Star Formation Rate, SFR**, is the rate at which gas and dust is turned into stars. It is the total mass of stars formed per year. The term can be used in describing a galaxy or globular cluster. **Data: 2017**

The data sets from Cook et al. (the solid symbols) and LSB + SPARC (the starred symbols) are shown, colour coded by FUV–NUV color.

The **green line** is a fit to the LSB + SPARC sample (McGaugh, Schombert & Lelli 2017).

The **dashed line** is the line of constant star formation for a 13 Gyr Universe.

There is a clear trend for **blue FUV –NUV colors** to lie **above** the constant SFR line (rising SFR in the last 100 Myr) versus **red FUV –NUV color's below the line** (declining SFH).

The  $S_{\text{FUV}} = 0$  relationship from Speagle et al. is shown for the high-mass spirals, along with  $3\sigma$  boundaries.

Also shown are the values for SFR that correspond to an Orion-sized complex, a single O star and a single B star.

SFR estimates below  $-4.5$  are highly inaccurate.

A representative error is shown in the upper left, errors in SFR and stellar mass are from McGaugh, Schombert(2017).