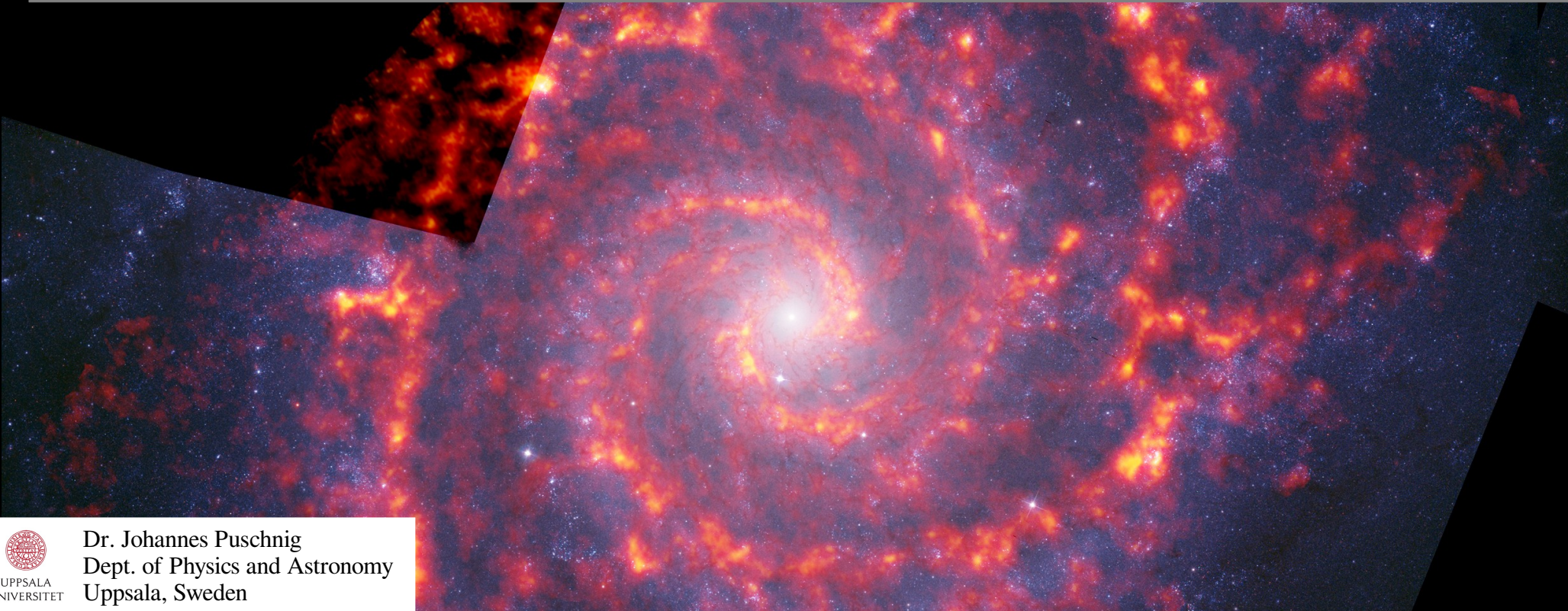


Galaxienentwicklung

(unter anderem mit Hilfe von Radio/mm-Beobachtungen)



Dr. Johannes Puschig
Dept. of Physics and Astronomy
Uppsala, Sweden

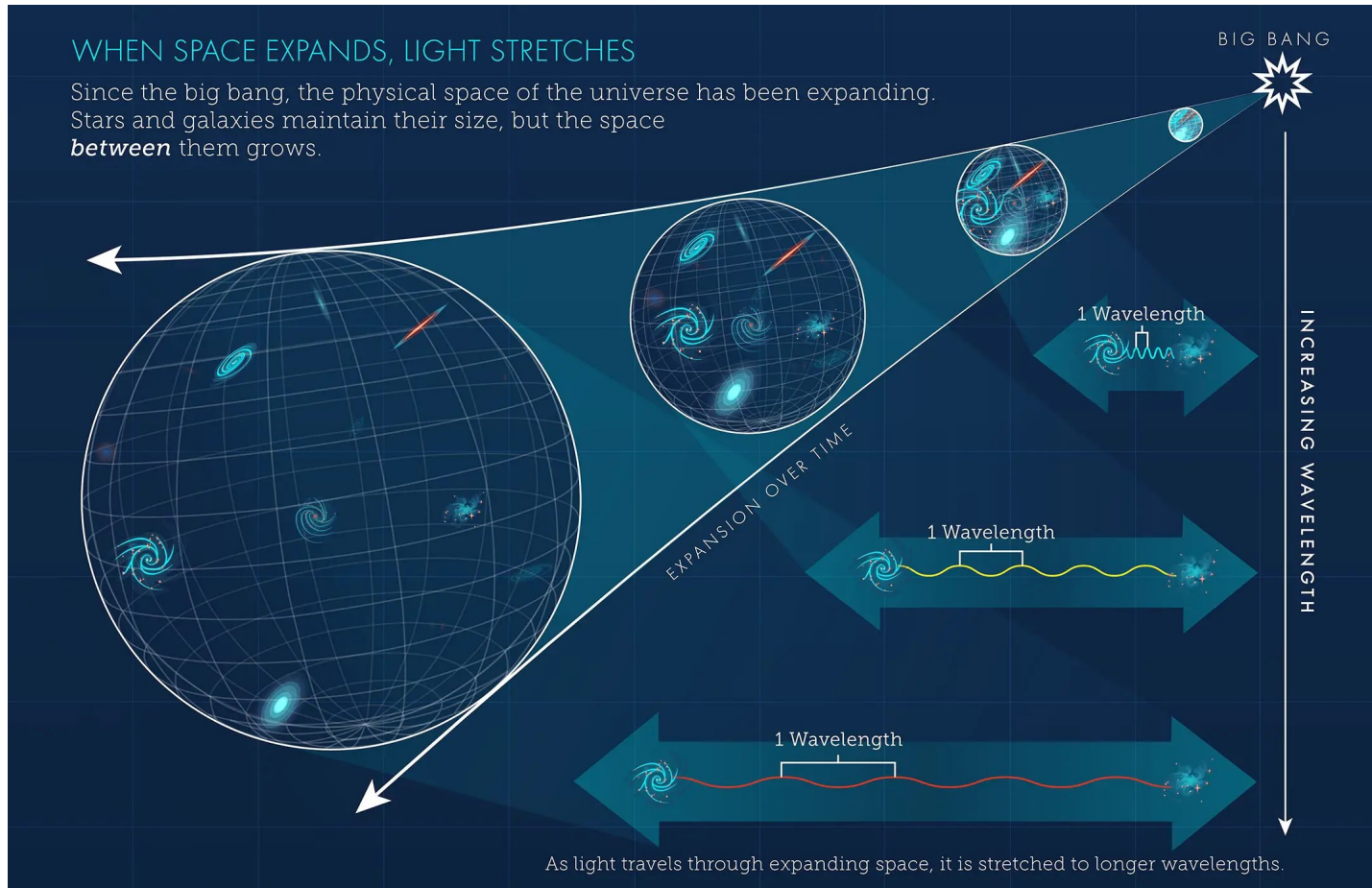
Inhalt

- Urknall und Expansion des Universums (“Hubble Tension”)
(JWST: unser kosmologisches Modell am Prüfstand)
- Galaxienentwicklung:
 - Allgemeines zu Galaxien u. Sternentstehung
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 - Sternentstehung, Moleküle und Radioastronomie
 - Galaxien am Höhepunkt der Sternentstehung

Was ist Rotverschiebung

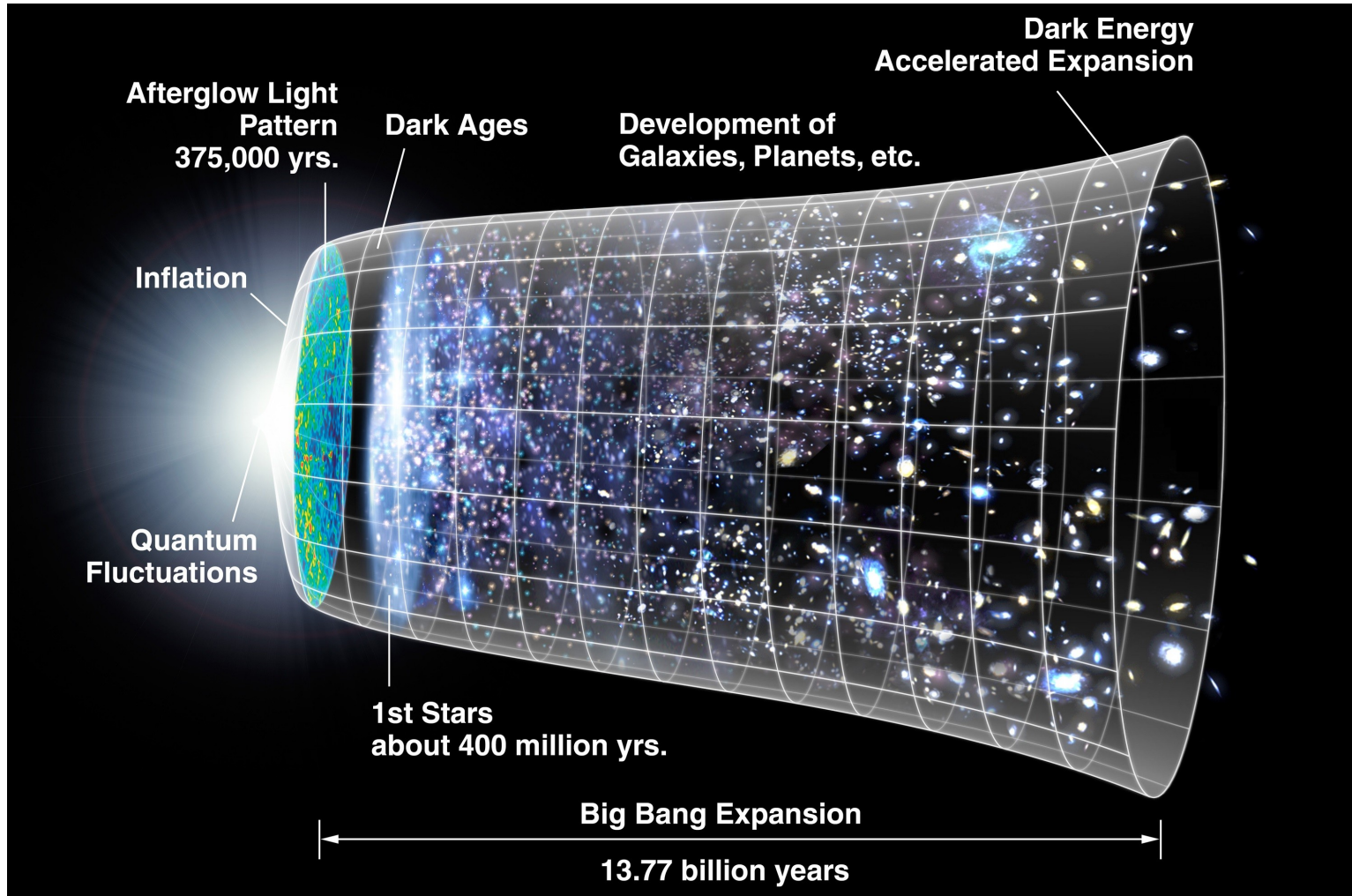
WHEN SPACE EXPANDS, LIGHT STRETCHES

Since the big bang, the physical space of the universe has been expanding. Stars and galaxies maintain their size, but the space **between** them grows.

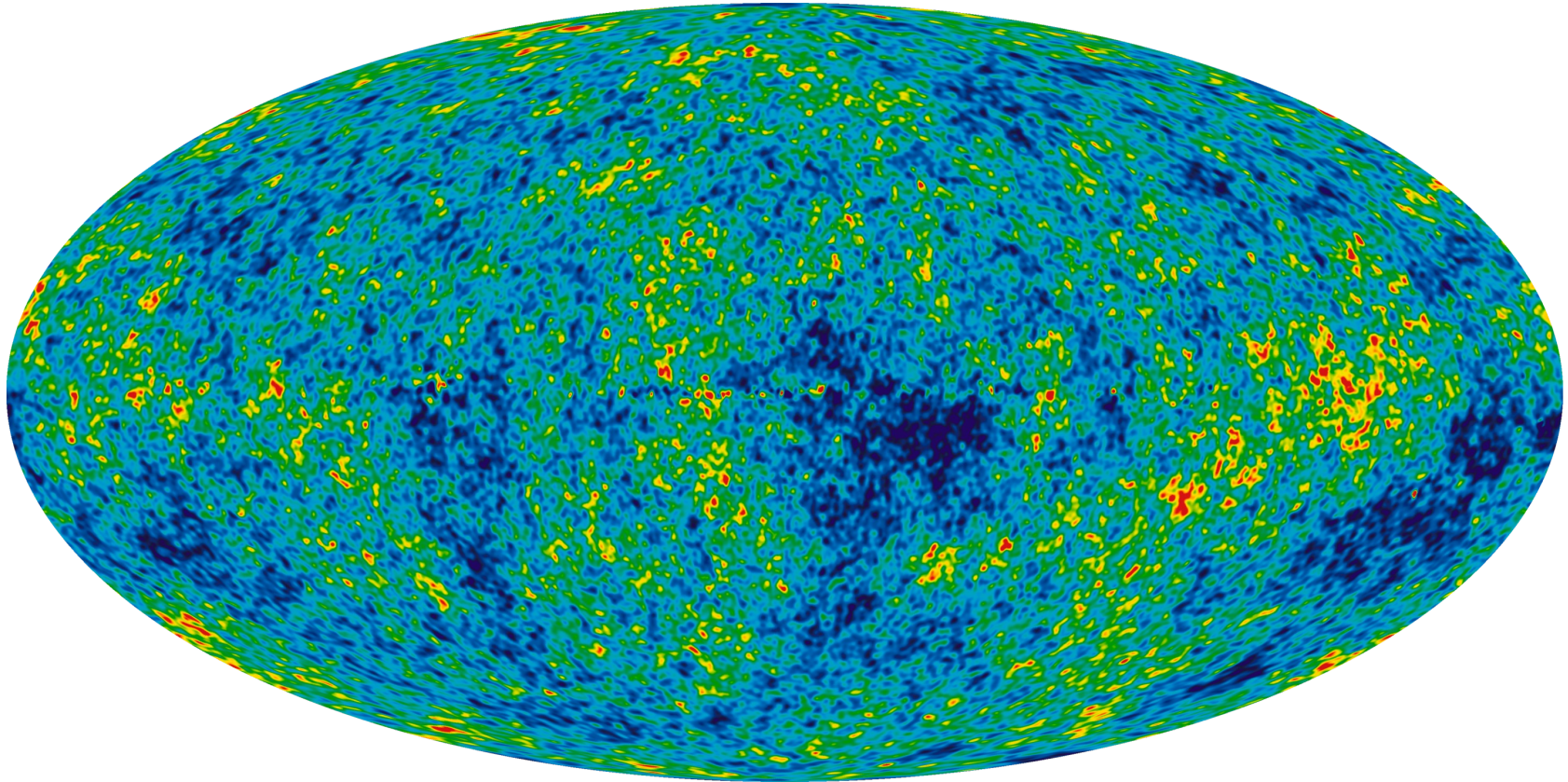


As light travels through expanding space, it is stretched to longer wavelengths.

Urknall und Expansion des Universums (“Hubble Tension”)



Urknall und Expansion des Universums (“Hubble Tension”)



CMB → Alter und Expansion des Universums (Hubble Konstante)

Urknall und Expansion des Universums (“Hubble Tension”)

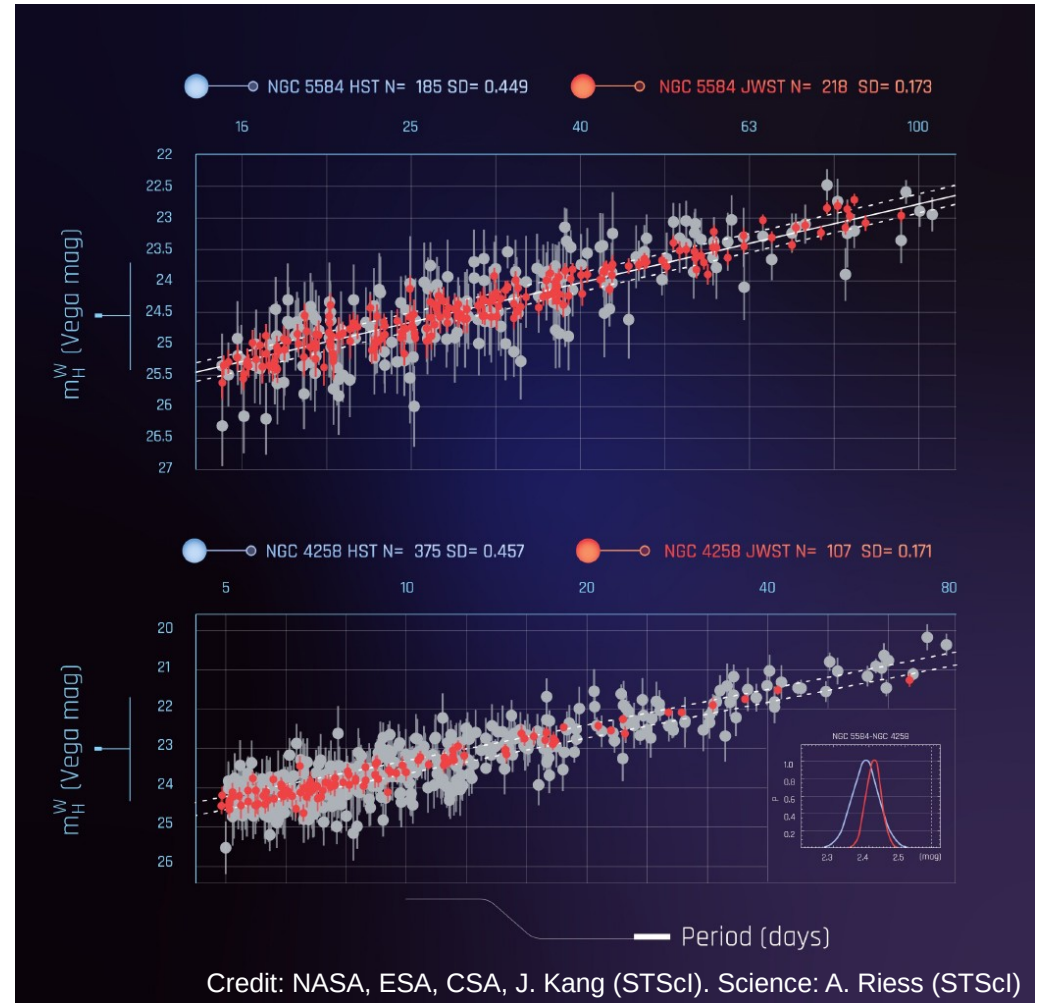


Urknall und Expansion des Universums (“Hubble Tension”)



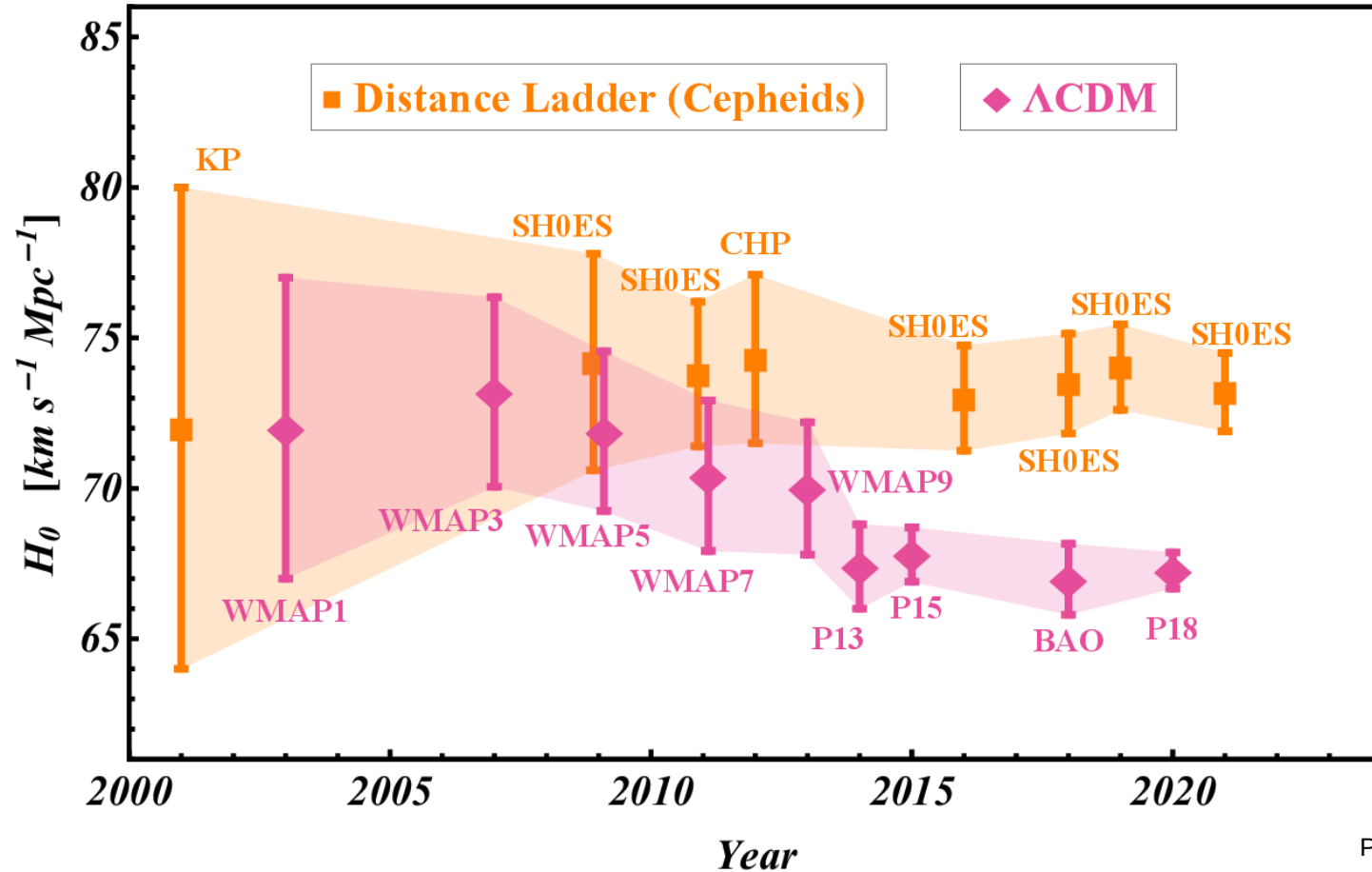
Henrietta Swan Leavitt

Perioden-Leuchtkraft-Beziehung
→ **Entfernungsbestimmung**
→ **Expansion des Universums**

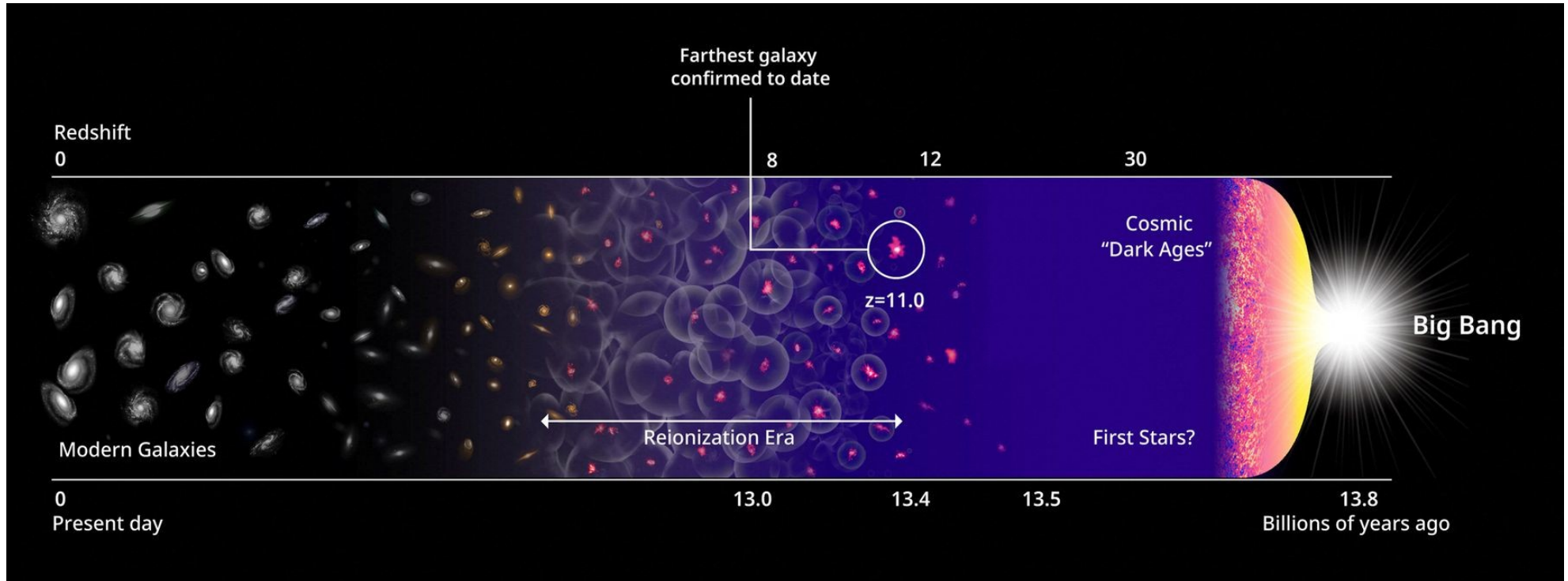


Urknall und Expansion des Universums (“Hubble Tension”)

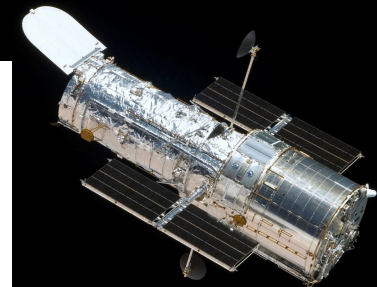
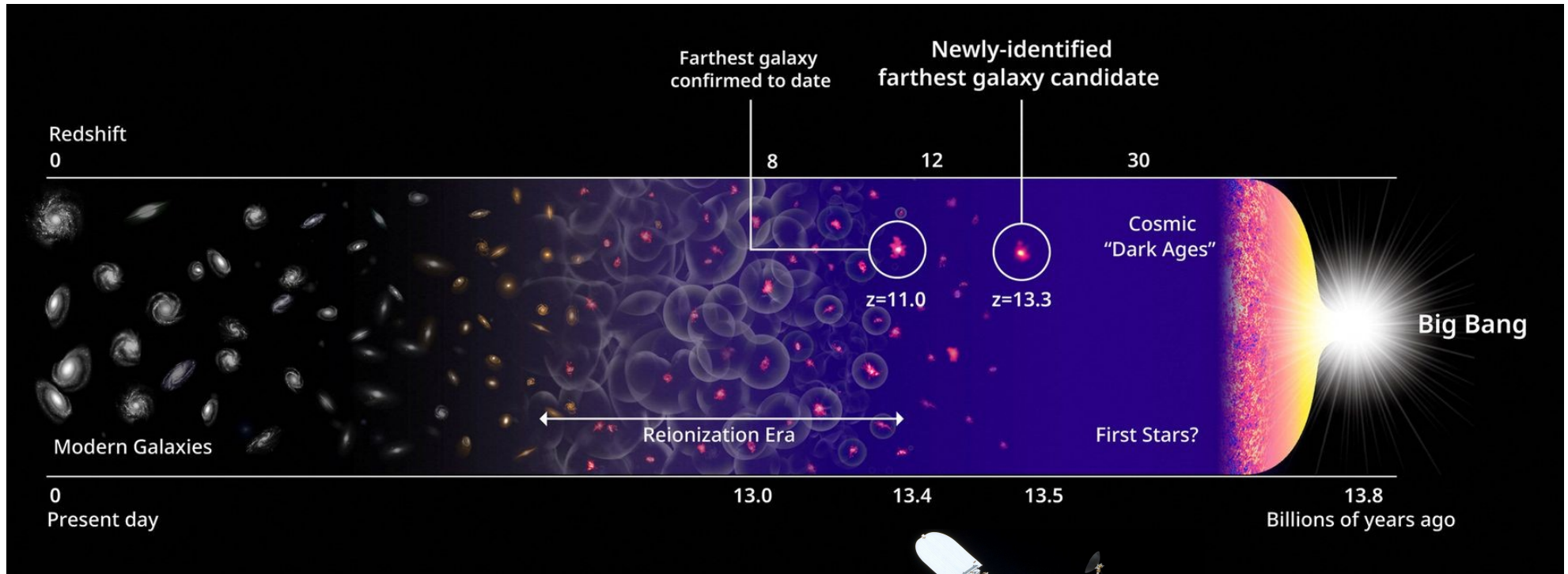
Hubble Tension



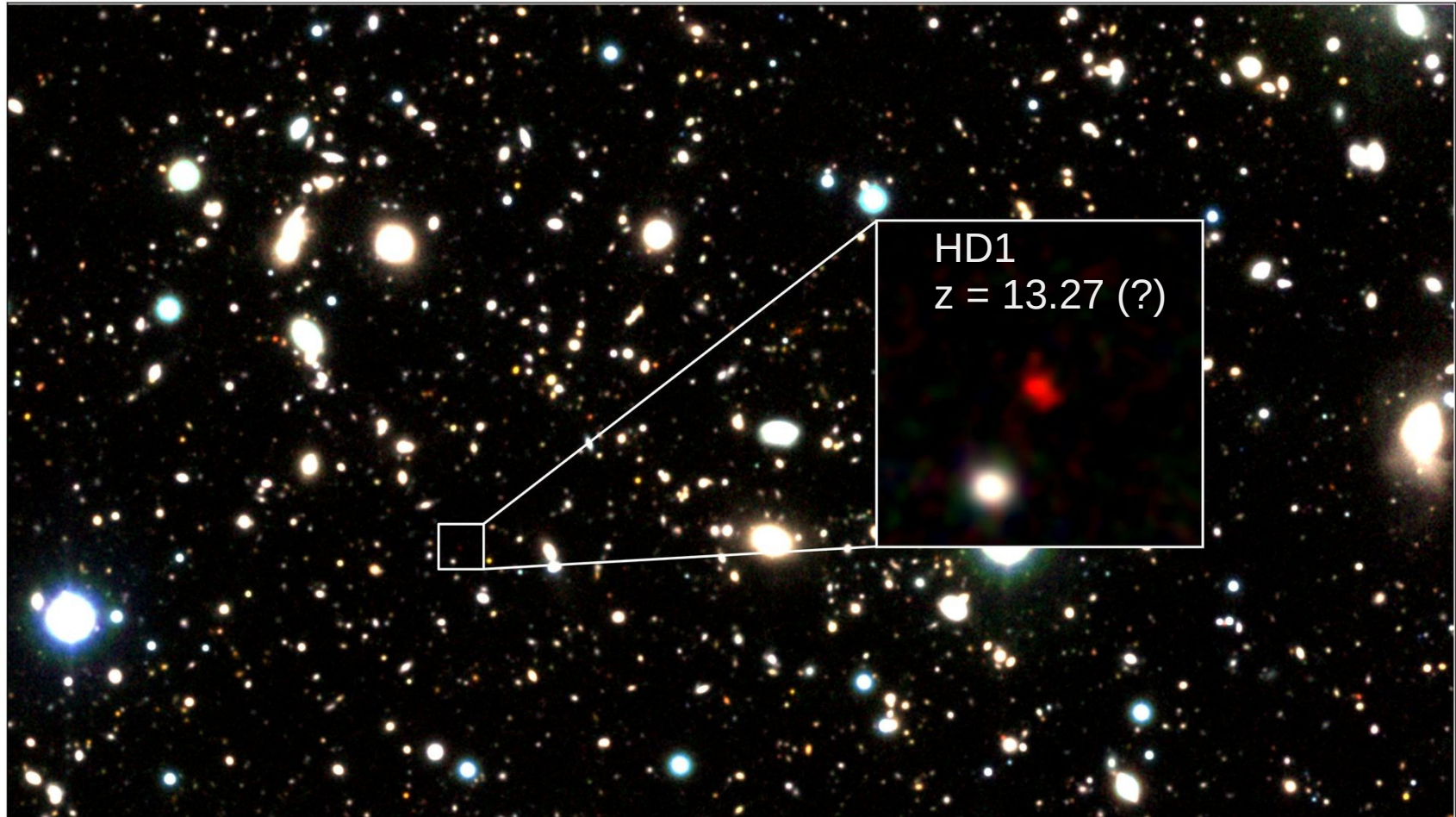
Urknall und Expansion des Universums – Massive Galaxien bei $z \sim 11$?



Urknall und Expansion des Universums – Massive Galaxien bei $z \sim 13$?

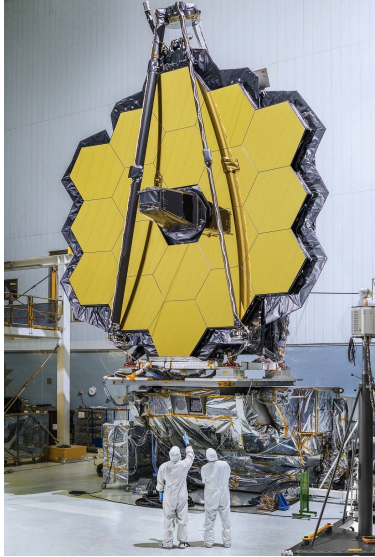


Urknall und Expansion des Universums – Massive Galaxien bei $z \sim 13$?



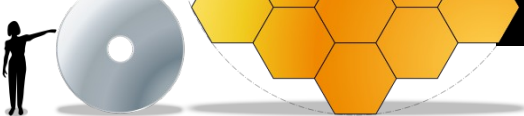
Urknall und Expansion des Universums – Massive Galaxien bei $z \sim 13$?

JWST Advanced Deep Extragalactic Survey (JADES)

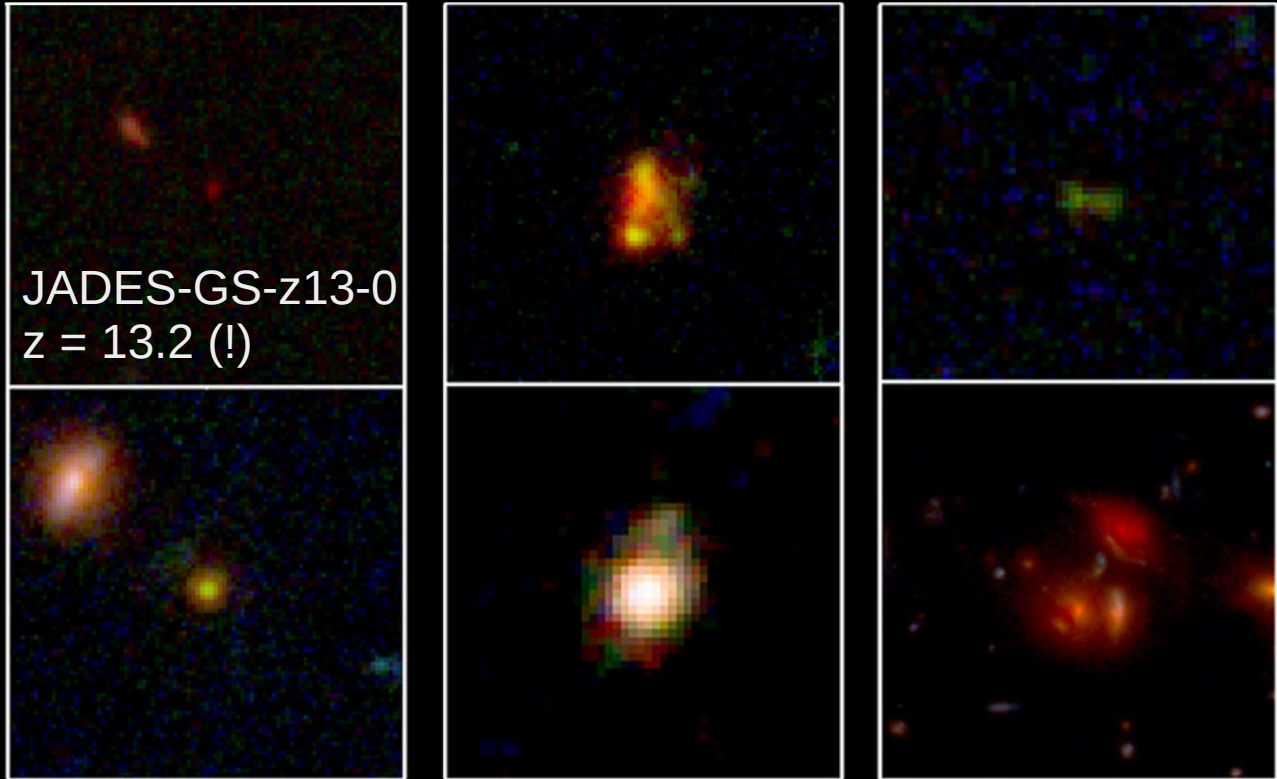


JWST primary mirror

Hubble primary mirror



JADES-GS-z13-0
 $z = 13.2$ (!)



Urknall und Expansion des Universums – eine Alternative

Monthly Notices

of the

ROYAL ASTRONOMICAL SOCIETY



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JWST early Universe observations and Λ CDM cosmology

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Urknall und Expansion des Universums – eine Alternative

ABSTRACT

Deep space observations of the *JWST* have revealed that the structure and masses of very early Universe galaxies at high redshifts ($z \sim 15$), existing at ~ 0.3 Gyr after the Big Bang, may be as evolved as the galaxies in existence for ~ 10 Gyr. The *JWST* findings are thus in strong tension with the Λ CDM cosmological model. While tired light (TL) models have been shown to comply with the *JWST* angular galaxy size data, they cannot satisfactorily explain isotropy of the cosmic microwave background (CMB) observations or fit the supernovae distance modulus versus redshift data well. We have developed hybrid models that include the tired light concept in the expanding universe. The hybrid Λ CDM model fits the supernovae type 1a data well but not the *JWST* observations. We present a model with covarying coupling constants (CCC), starting from the modified FLRW metric and resulting Einstein and Friedmann equations, and a CCC + TL hybrid model. They fit the Pantheon + data admirably, and the CCC + TL model is compliant with the *JWST* observations. It stretches the age of the Universe to 26.7 Gyr with 5.8 Gyr at $z = 10$ and 3.5 Gyr at $z = 20$, giving enough time to form massive galaxies. It thus resolves the ‘impossible early galaxy’ problem without requiring the existence of primordial black hole seeds or modified power spectrum, rapid formation of massive population III stars, and super Eddington accretion rates. One could infer the CCC model as an extension of the Λ CDM model with a dynamic cosmological constant.

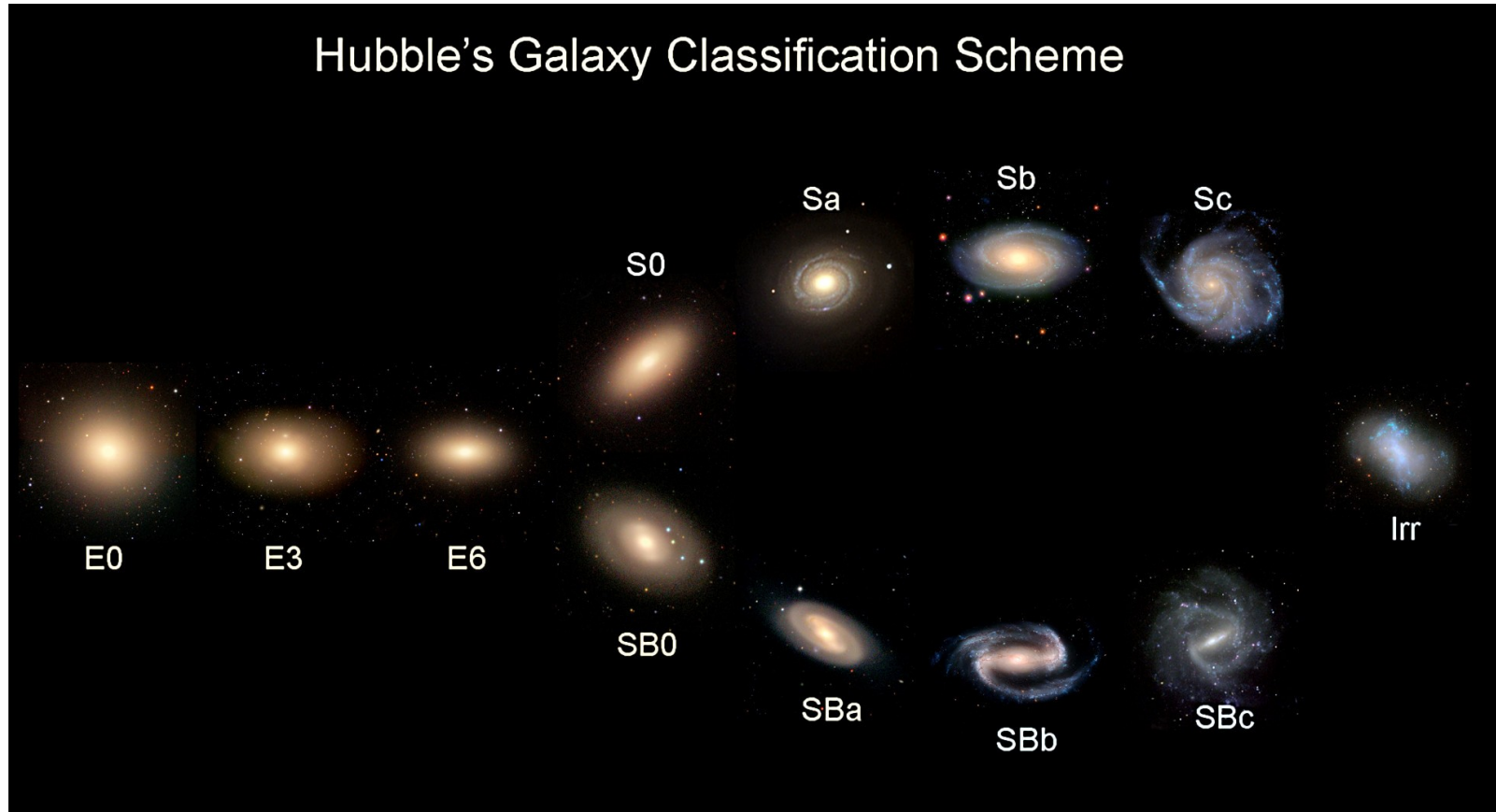
Urknall und Expansion des Universums

Die Beobachtung von Galaxien (und Sternen) ist letztlich unser Maßstab für die Entwicklung des Universums und des Lebens.

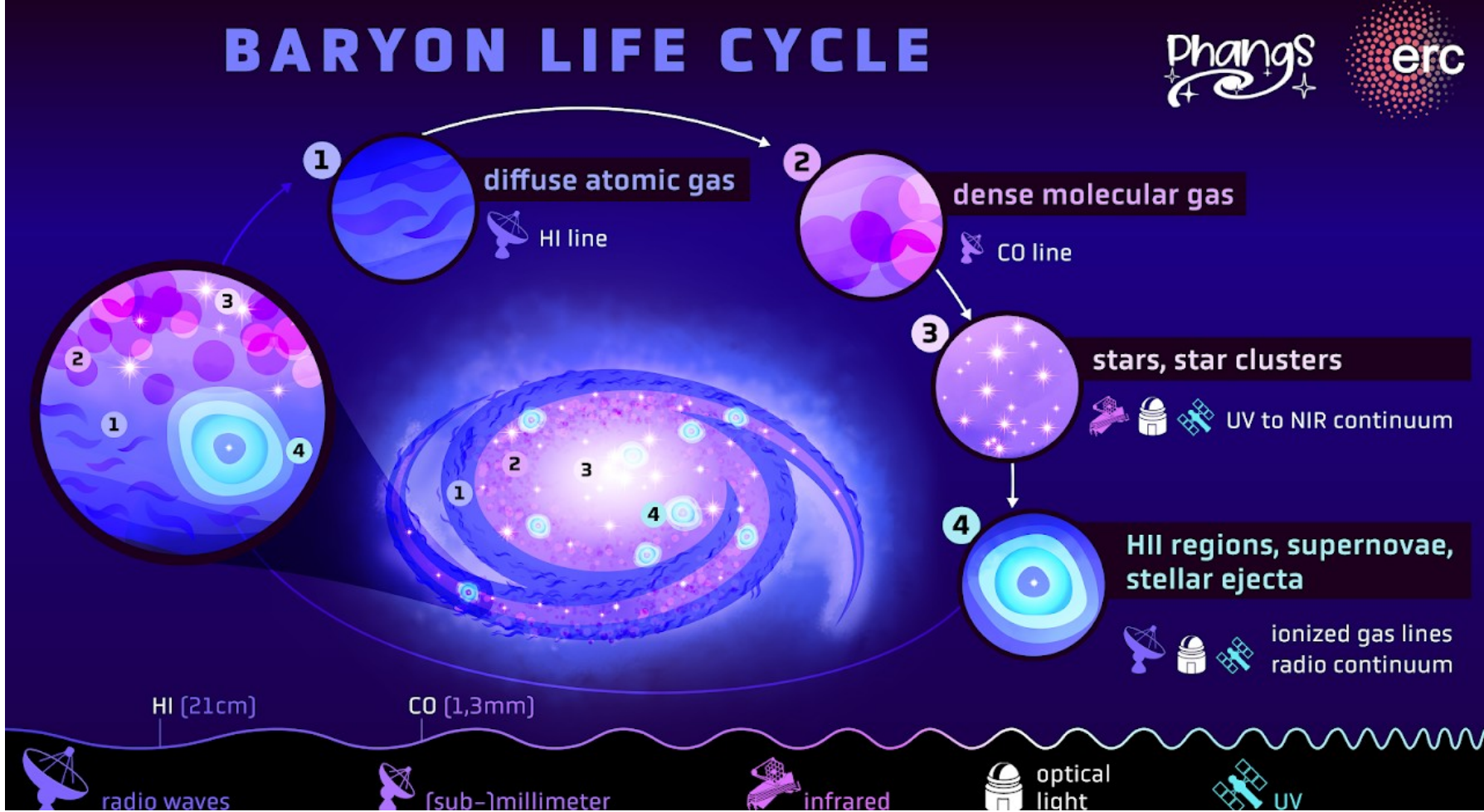
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Galaxienentwicklung – Allgemeines zu Galaxien

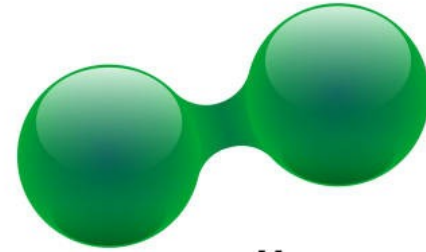


Galaxienentwicklung – Allgemeines zu Galaxien



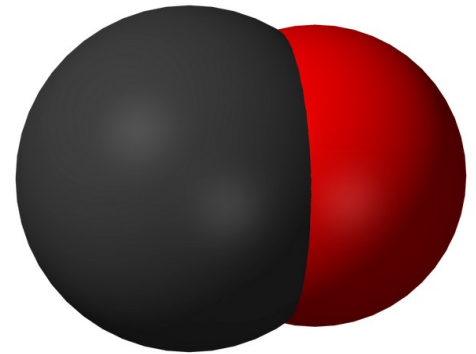
Galaxienentwicklung – Warum CO statt H₂

H₂ kein Dipolmoment



H₂

CO zeithäufigstes Molekül mit Dipol



Anregung von Rotationsübergängen ab ca. 5K

Ein paar meiner Lieblingsteleskope

IRAM 30m
Teleskop



Ein paar meiner Lieblingsteleskope

Nordic
Optical
Telescope



Ein paar meiner Lieblingsteleskope

**Nobeyama
45m Telekop**

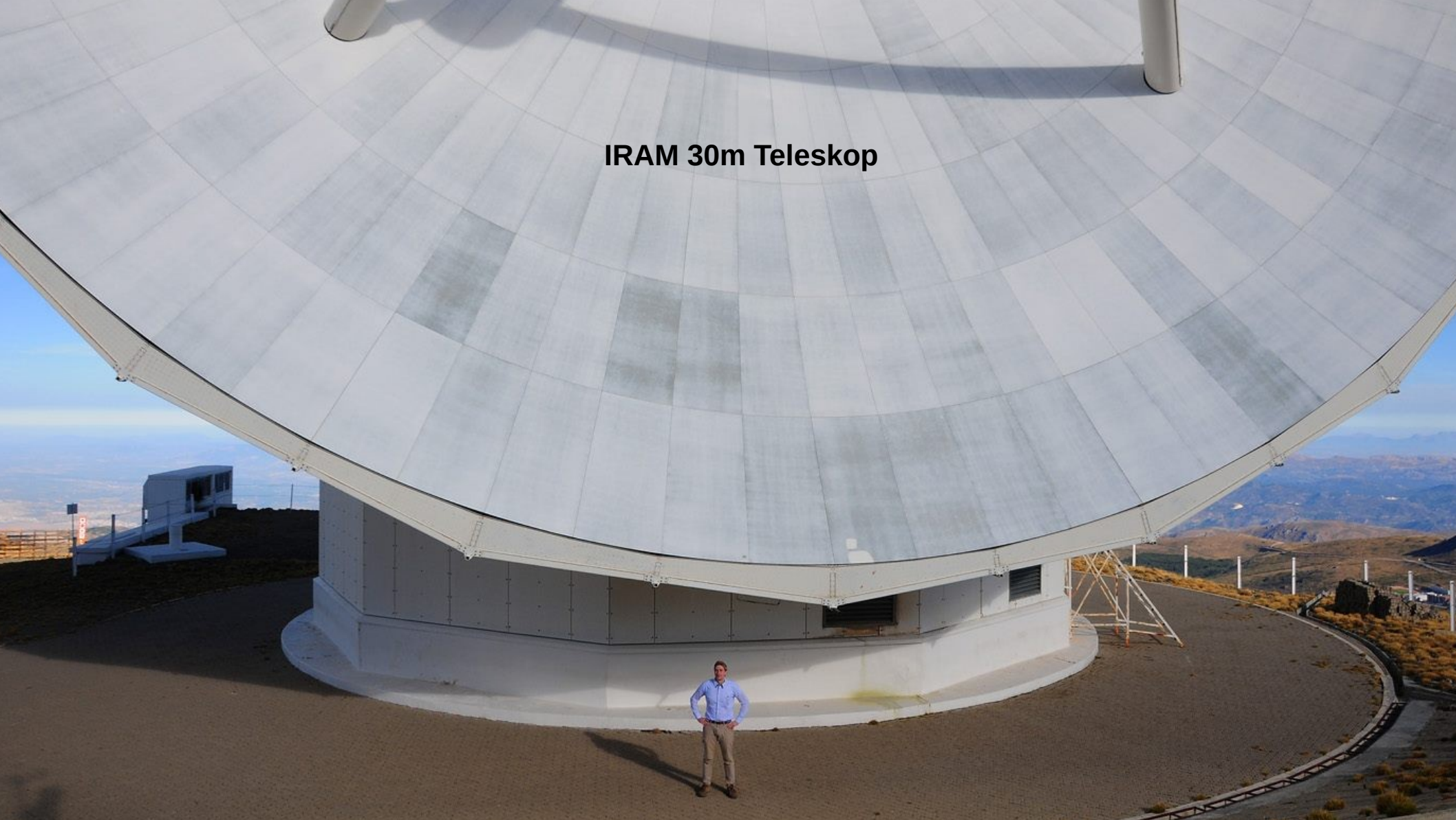


Ein paar meiner Lieblingsteleskope

Nobeyama 45m Telekop



IRAM 30m Teleskop



IRAM 30m Teleskop Control Room



Atacama Pathfinder Experiment (APEX)



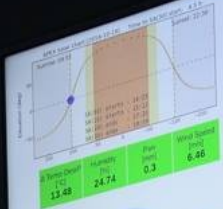
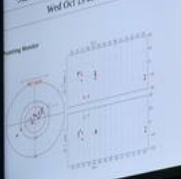
APEX Control Room



APEX WOBBLER MONITORING

	Commanded	Calculated
Thrust(")	49.8	50.8
Freq(Hz)	6.58	6.58
Offset(")		-0.18
Status	Enabled (Wobbling)	

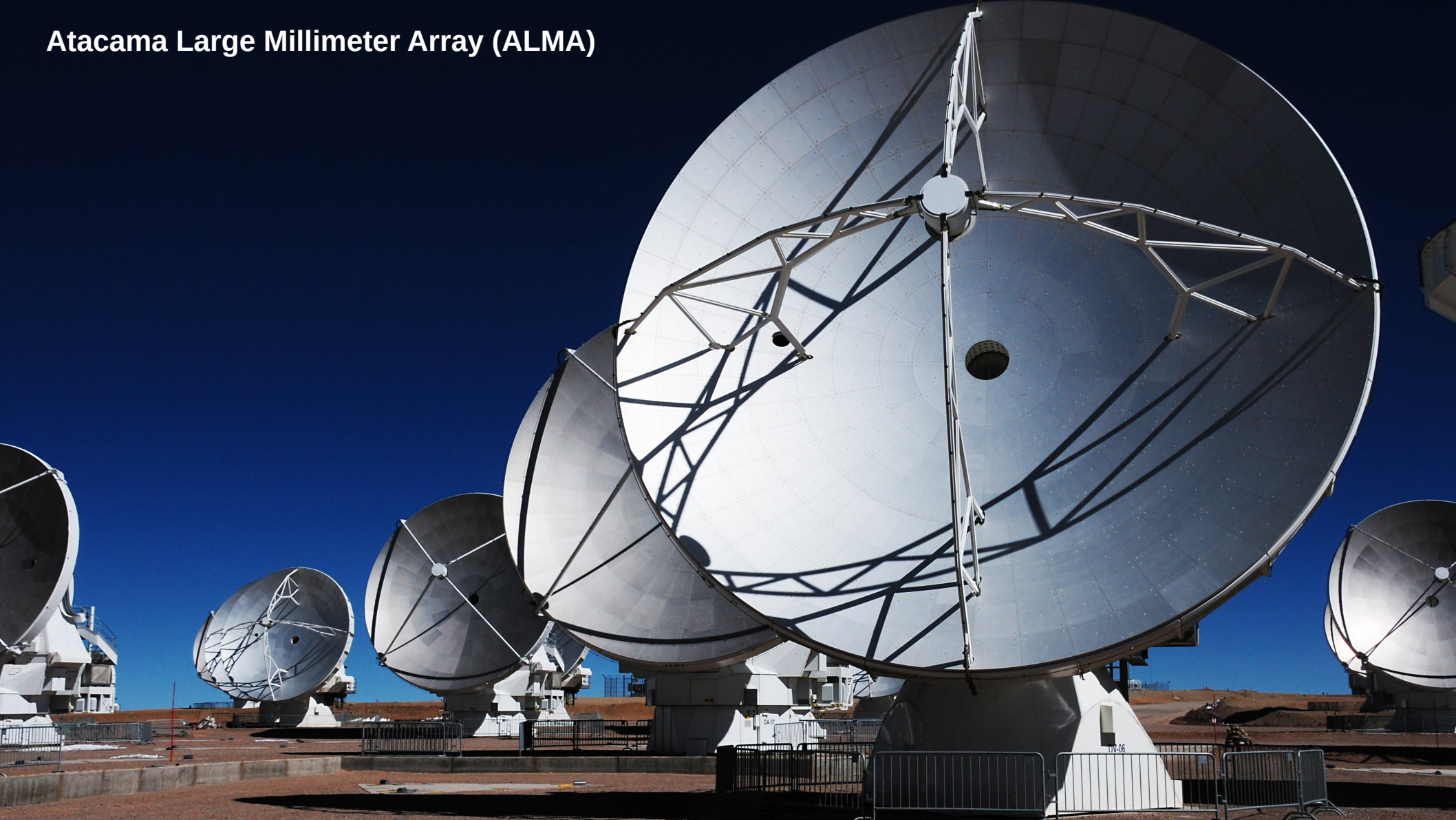
Wed Oct 19 09:13:21 2016



Time	Value	Unit
00:00	10.0	Hz
00:05	10.5	Hz
00:10	11.0	Hz
00:15	11.5	Hz
00:20	12.0	Hz
00:25	12.5	Hz
00:30	13.0	Hz
00:35	13.5	Hz
00:40	14.0	Hz
00:45	14.5	Hz
00:50	15.0	Hz
00:55	15.5	Hz
01:00	16.0	Hz
01:05	16.5	Hz
01:10	17.0	Hz
01:15	17.5	Hz
01:20	18.0	Hz
01:25	18.5	Hz
01:30	19.0	Hz
01:35	19.5	Hz
01:40	20.0	Hz
01:45	20.5	Hz
01:50	21.0	Hz
01:55	21.5	Hz
02:00	22.0	Hz
02:05	22.5	Hz
02:10	23.0	Hz
02:15	23.5	Hz
02:20	24.0	Hz
02:25	24.5	Hz
02:30	25.0	Hz
02:35	25.5	Hz
02:40	26.0	Hz
02:45	26.5	Hz
02:50	27.0	Hz
02:55	27.5	Hz
03:00	28.0	Hz
03:05	28.5	Hz
03:10	29.0	Hz
03:15	29.5	Hz
03:20	30.0	Hz
03:25	30.5	Hz
03:30	31.0	Hz
03:35	31.5	Hz
03:40	32.0	Hz
03:45	32.5	Hz
03:50	33.0	Hz
03:55	33.5	Hz
04:00	34.0	Hz
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04:15	35.5	Hz
04:20	36.0	Hz
04:25	36.5	Hz
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04:35	37.5	Hz
04:40	38.0	Hz
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04:50	39.0	Hz
04:55	39.5	Hz
05:00	40.0	Hz
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05:10	41.0	Hz
05:15	41.5	Hz
05:20	42.0	Hz
05:25	42.5	Hz
05:30	43.0	Hz
05:35	43.5	Hz
05:40	44.0	Hz
05:45	44.5	Hz
05:50	45.0	Hz
05:55	45.5	Hz
06:00	46.0	Hz
06:05	46.5	Hz
06:10	47.0	Hz
06:15	47.5	Hz
06:20	48.0	Hz
06:25	48.5	Hz
06:30	49.0	Hz
06:35	49.5	Hz
06:40	50.0	Hz
06:45	50.5	Hz
06:50	51.0	Hz
06:55	51.5	Hz
07:00	52.0	Hz
07:05	52.5	Hz
07:10	53.0	Hz
07:15	53.5	Hz
07:20	54.0	Hz
07:25	54.5	Hz
07:30	55.0	Hz
07:35	55.5	Hz
07:40	56.0	Hz
07:45	56.5	Hz
07:50	57.0	Hz
07:55	57.5	Hz
08:00	58.0	Hz
08:05	58.5	Hz
08:10	59.0	Hz
08:15	59.5	Hz
08:20	60.0	Hz
08:25	60.5	Hz
08:30	61.0	Hz
08:35	61.5	Hz
08:40	62.0	Hz
08:45	62.5	Hz
08:50	63.0	Hz
08:55	63.5	Hz
09:00	64.0	Hz
09:05	64.5	Hz
09:10	65.0	Hz
09:15	65.5	Hz
09:20	66.0	Hz
09:25	66.5	Hz
09:30	67.0	Hz
09:35	67.5	Hz
09:40	68.0	Hz
09:45	68.5	Hz
09:50	69.0	Hz
09:55	69.5	Hz
10:00	70.0	Hz
10:05	70.5	Hz
10:10	71.0	Hz
10:15	71.5	Hz
10:20	72.0	Hz
10:25	72.5	Hz
10:30	73.0	Hz
10:35	73.5	Hz
10:40	74.0	Hz
10:45	74.5	Hz
10:50	75.0	Hz
10:55	75.5	Hz
11:00	76.0	Hz
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11:10	77.0	Hz
11:15	77.5	Hz
11:20	78.0	Hz
11:25	78.5	Hz
11:30	79.0	Hz
11:35	79.5	Hz
11:40	80.0	Hz
11:45	80.5	Hz
11:50	81.0	Hz
11:55	81.5	Hz
12:00	82.0	Hz



Atacama Large Millimeter Array (ALMA)

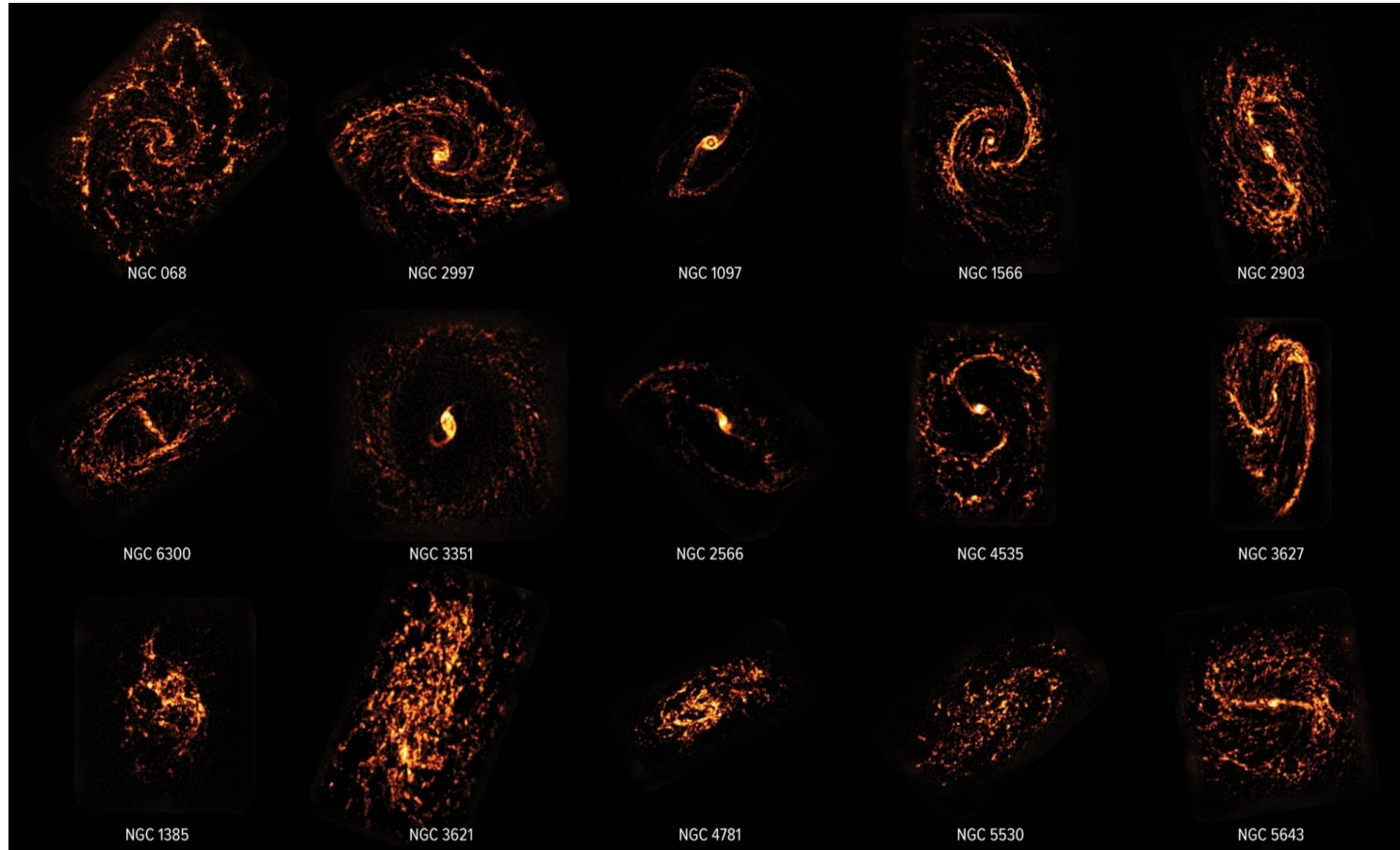


Atacama Large Millimeter Array (ALMA)



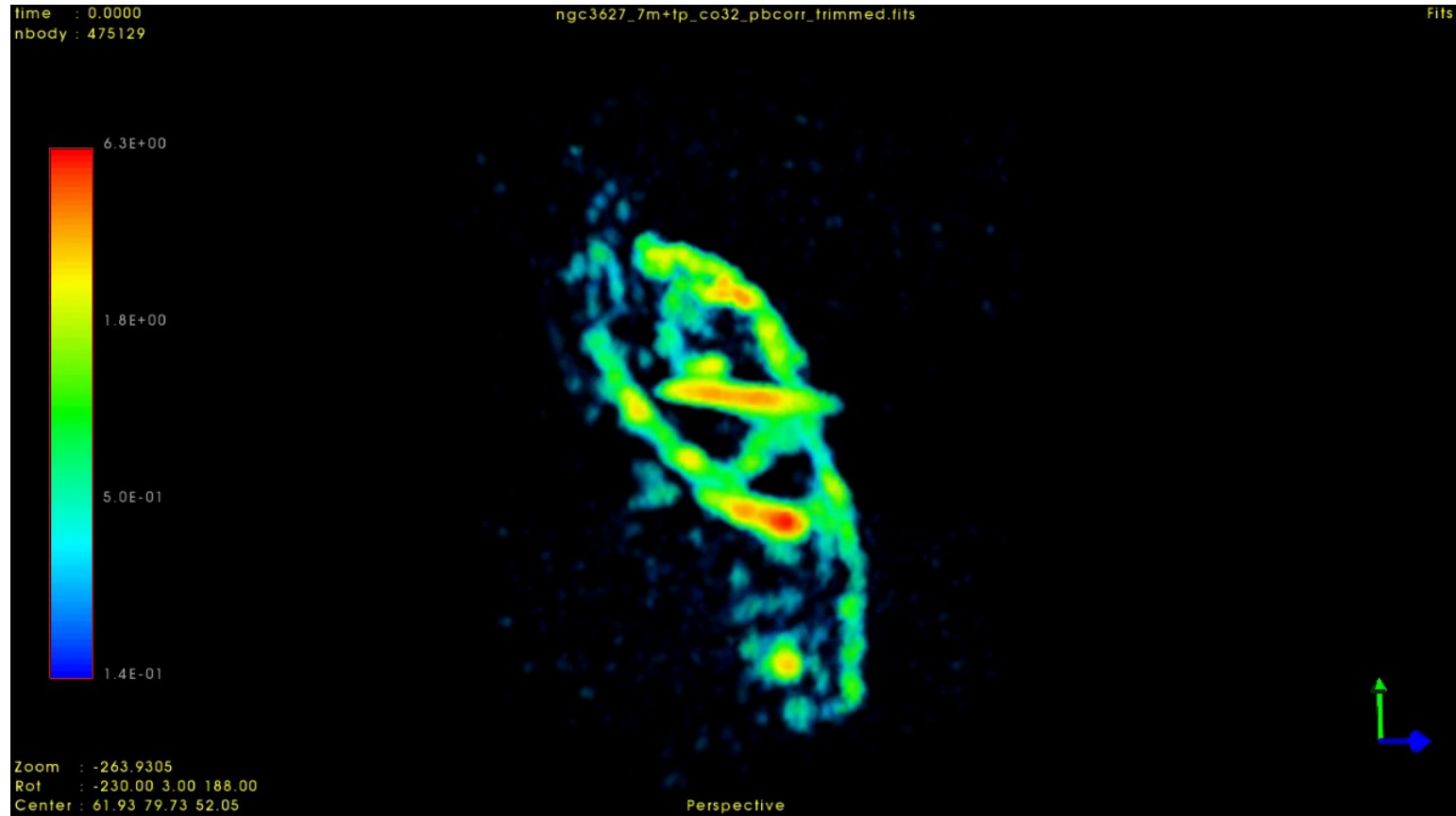
Galaxienentwicklung – ALMA Daten

Molekulares Gas: CO (2-1)

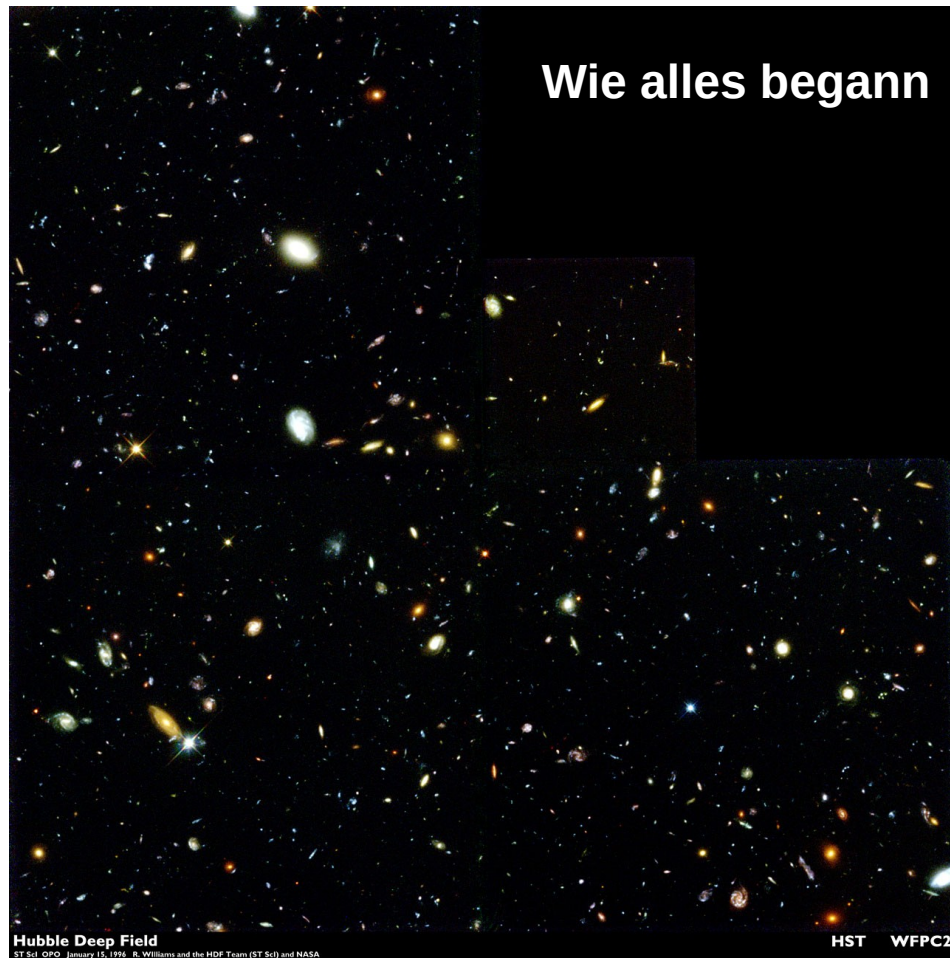


Galaxienentwicklung – ALMA Daten

Molekulares Gas: CO (3-2)



Galaxienentwicklung – Hubble Deep Field

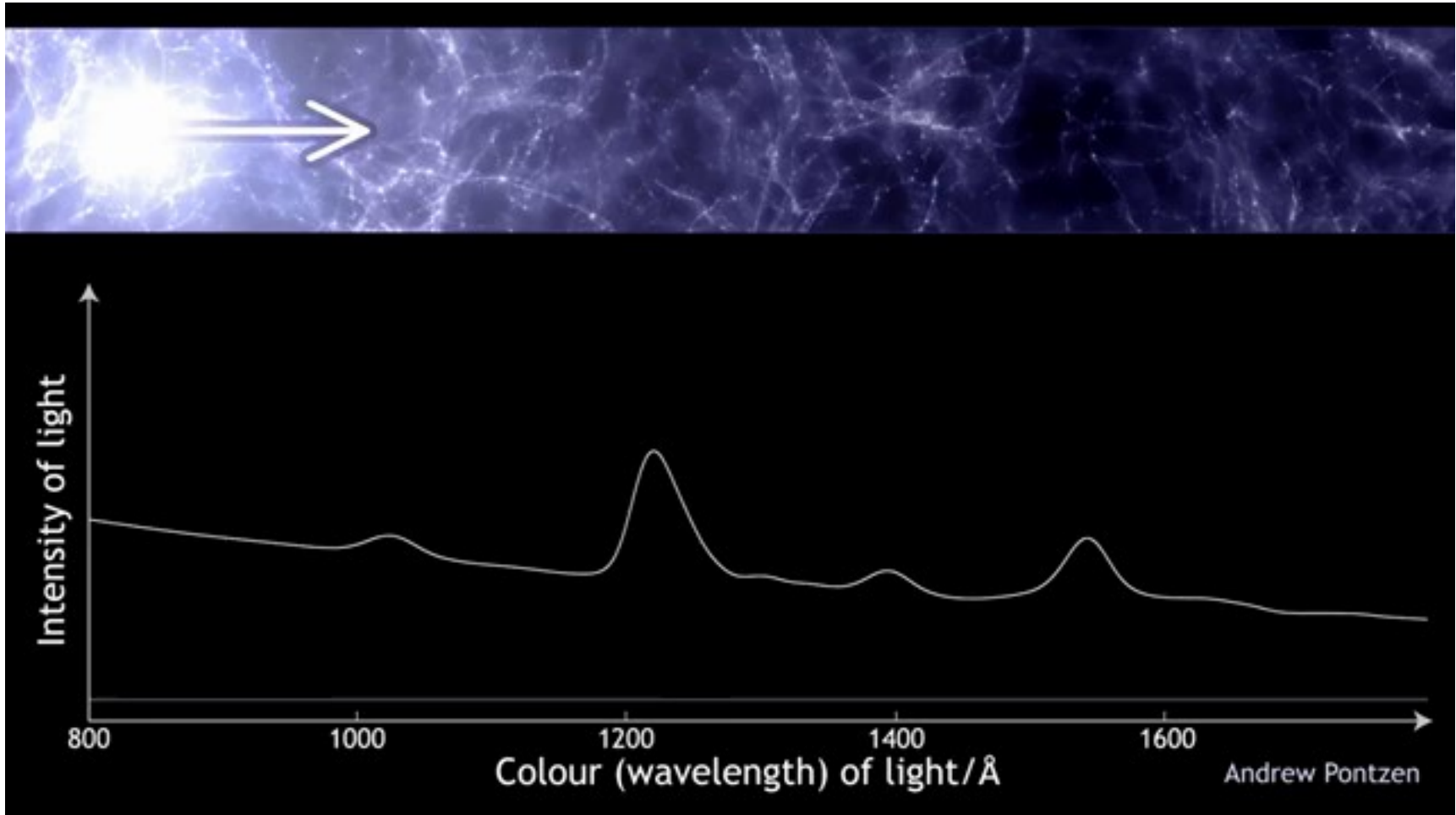


Credit: Robert Williams and the Hubble Deep Field Team (STScI) and NASA/ESA

Galaxienentwicklung – Hubble Deep Field

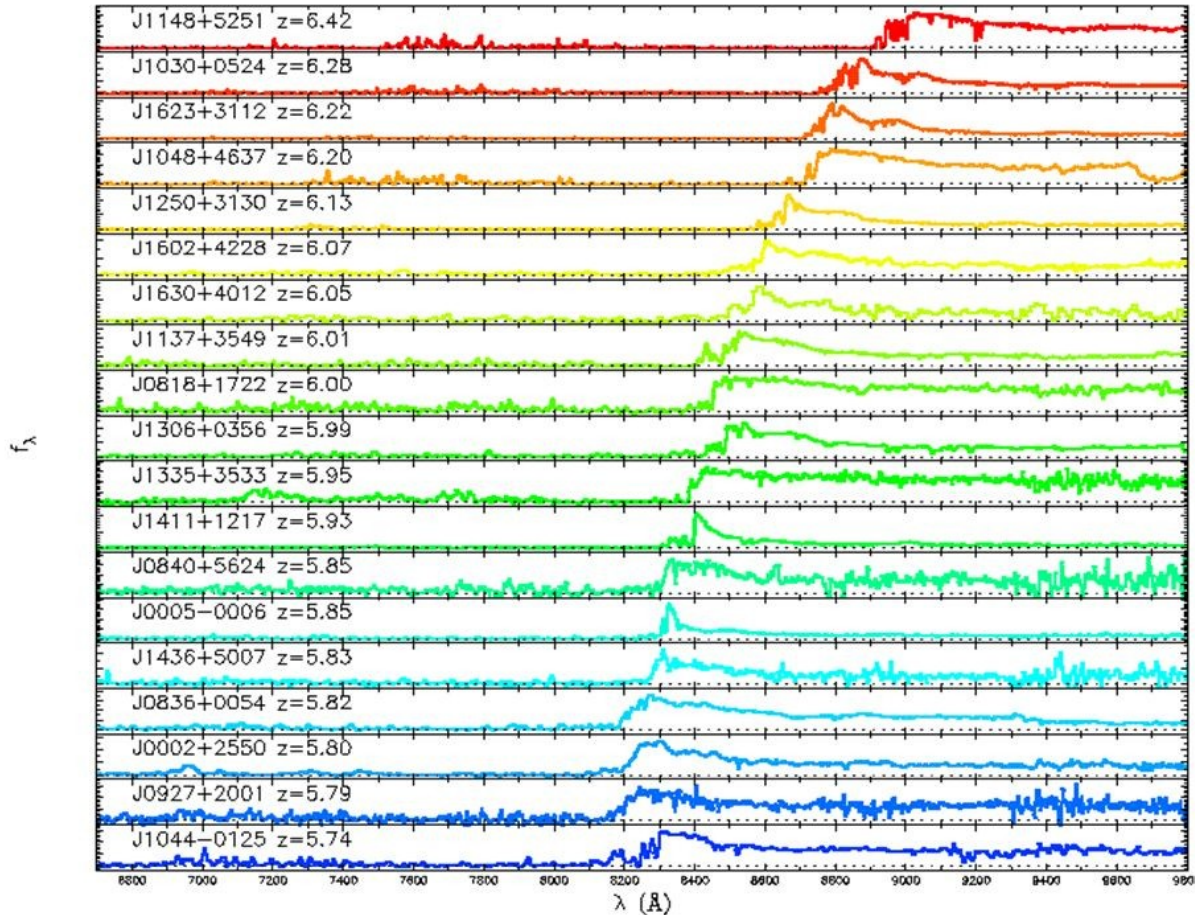


Galaxienentwicklung – Lyman Alpha Wald

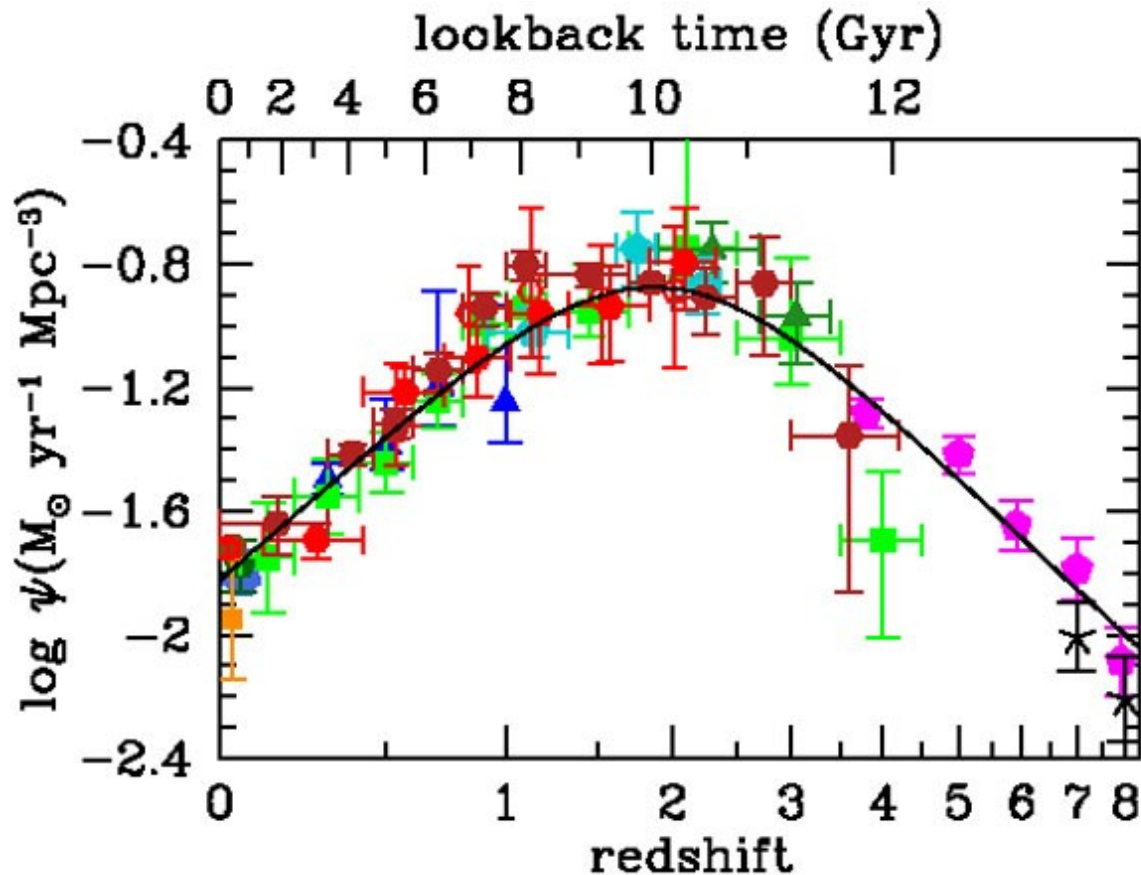


Galaxienentwicklung – Zeitpunkt der kosmischen Reionisation

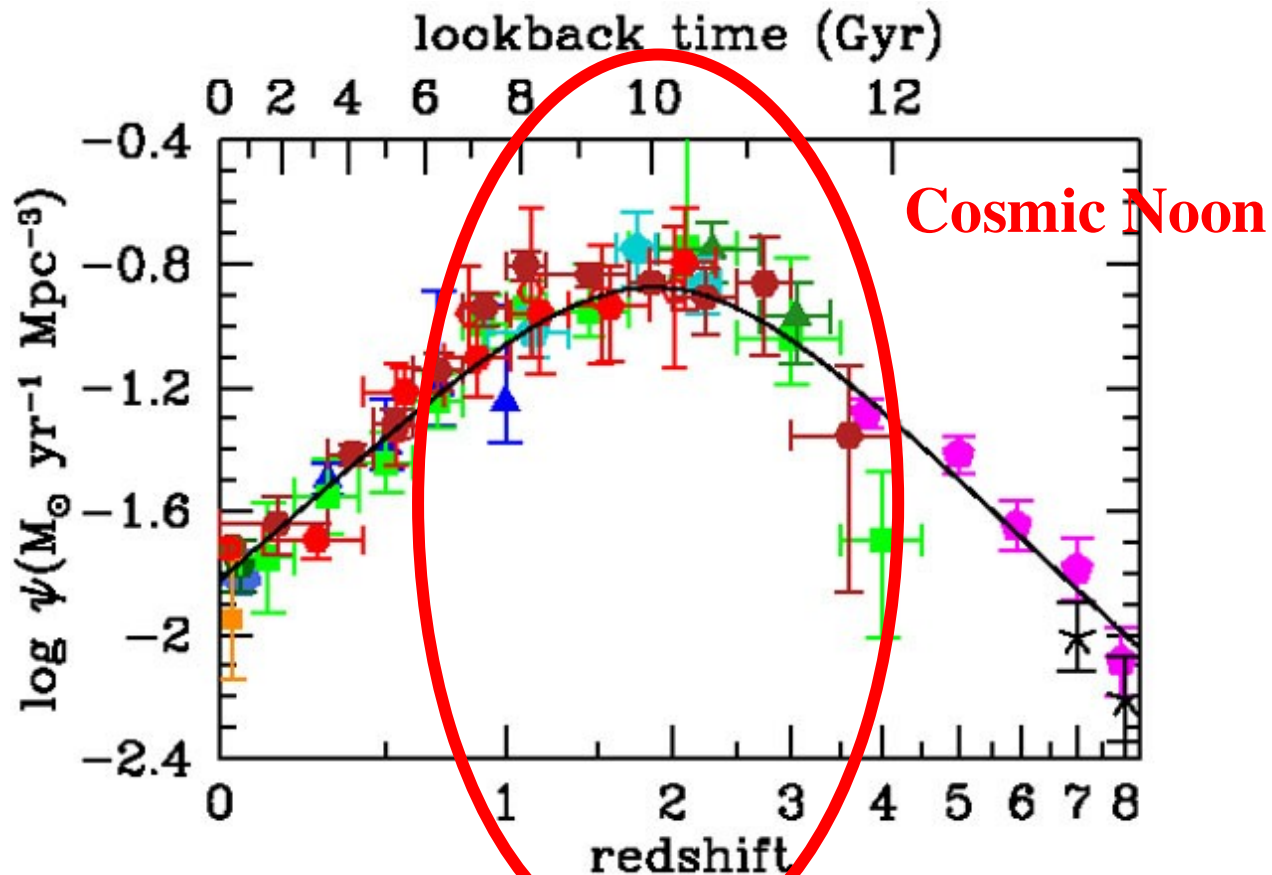
Wann alles begann:
 $z \sim 6$



Galaxienentwicklung – kosmische Sternentstehungsrate



Galaxienentwicklung – kosmische Sternentstehungsrate

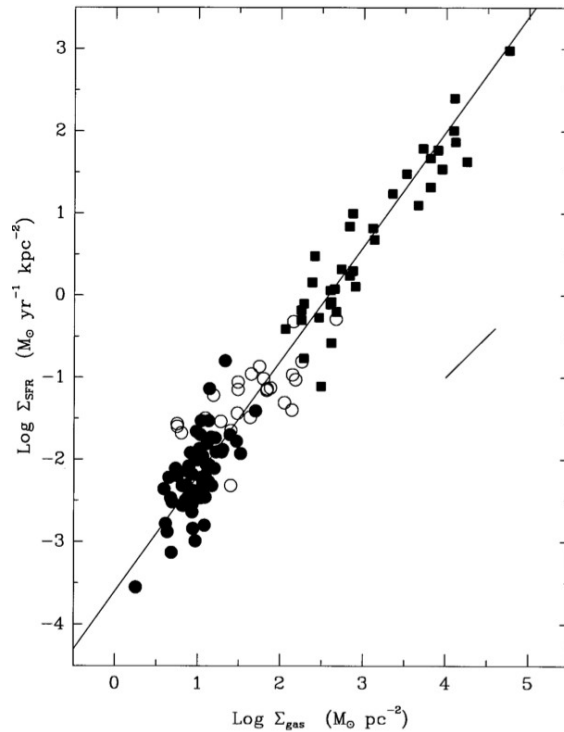


Galaxienentwicklung

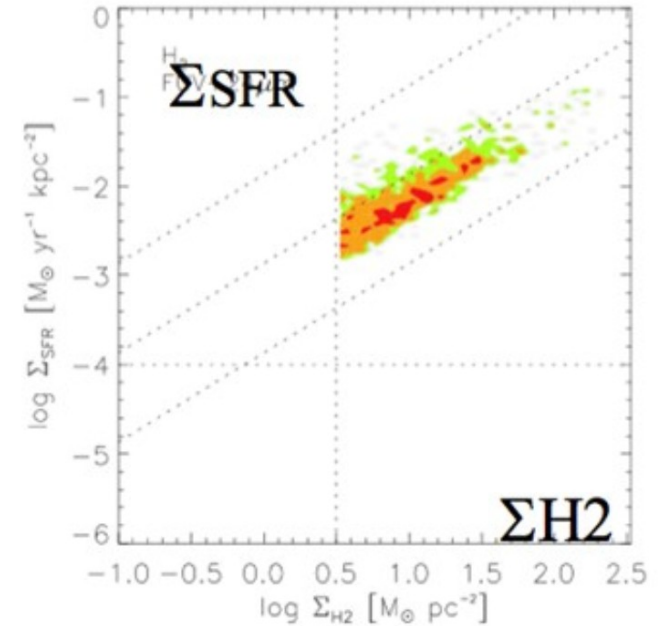
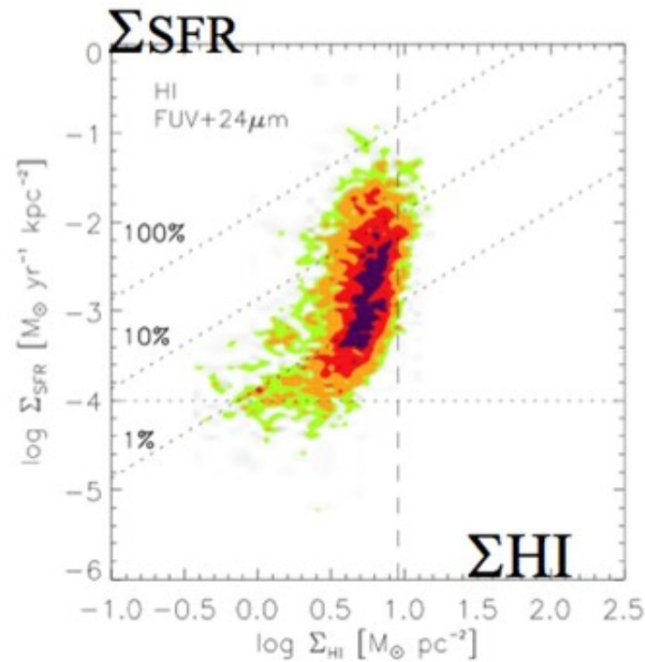
Die Hälfte der heute existierenden
Sterne entstand vor ca. 10
Milliarden Jahren bei $z \sim 1-3$.

Galaxienentwicklung

Sternentstehungsrate vs. molekulares Gas



Kennicutt et al. (1998)



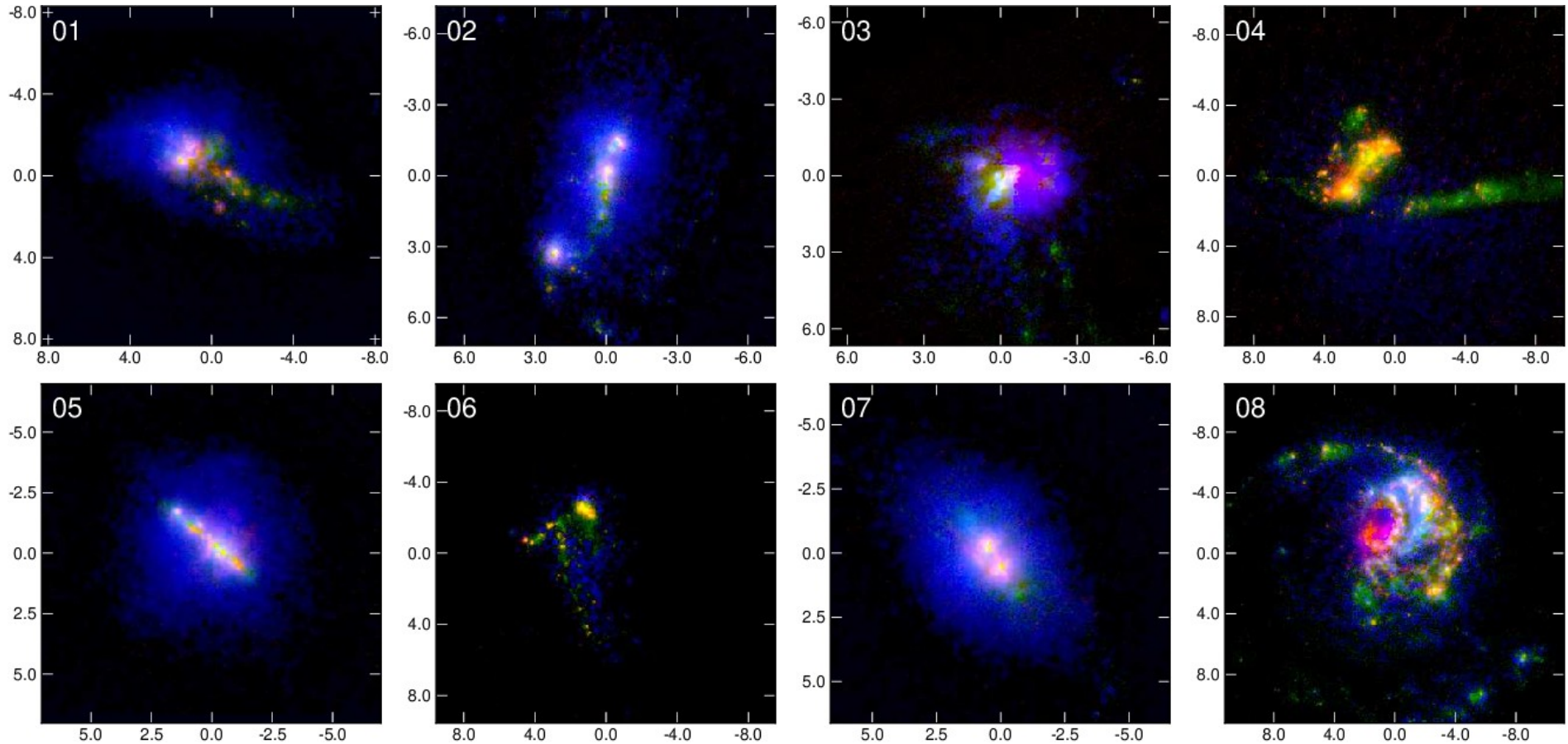
Bigiel et al. (2008)

Eigenschaften von Galaxien bei $z \sim 1-3$

- Massereiche Scheibengalaxien (MW)
- Rotationsgestützt
- Sehr massereiche Super-Sternhaufen (clumpy)
- Sehr grosser Gasanteil
- Sehr hohe Sternentstehungsraten

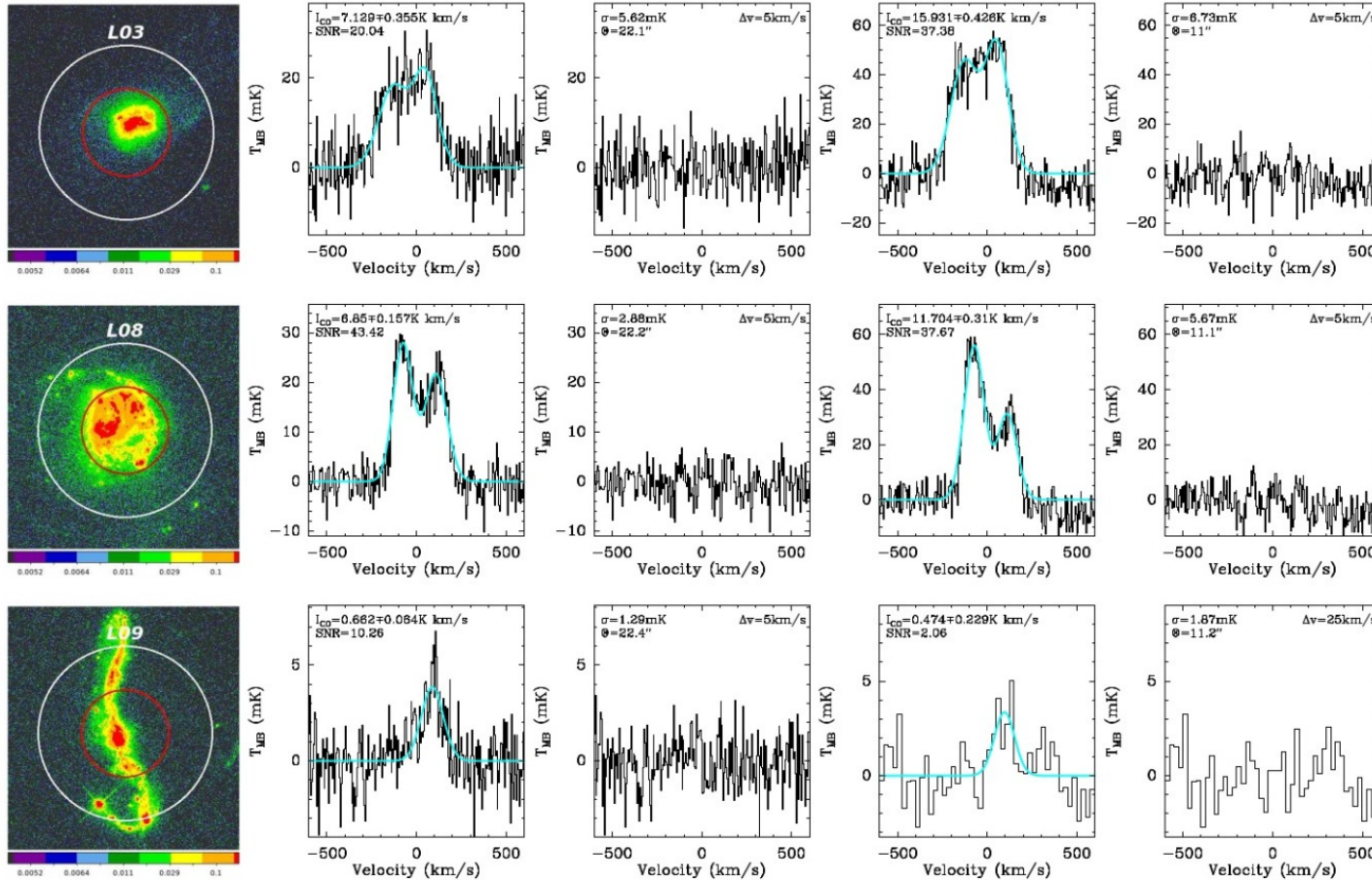
Galaxienentwicklung – Lokale Galaxien als Laboratorien

Lyman Alpha Reference Sample



Galaxienentwicklung – Lokale Galaxien als Laboratorien

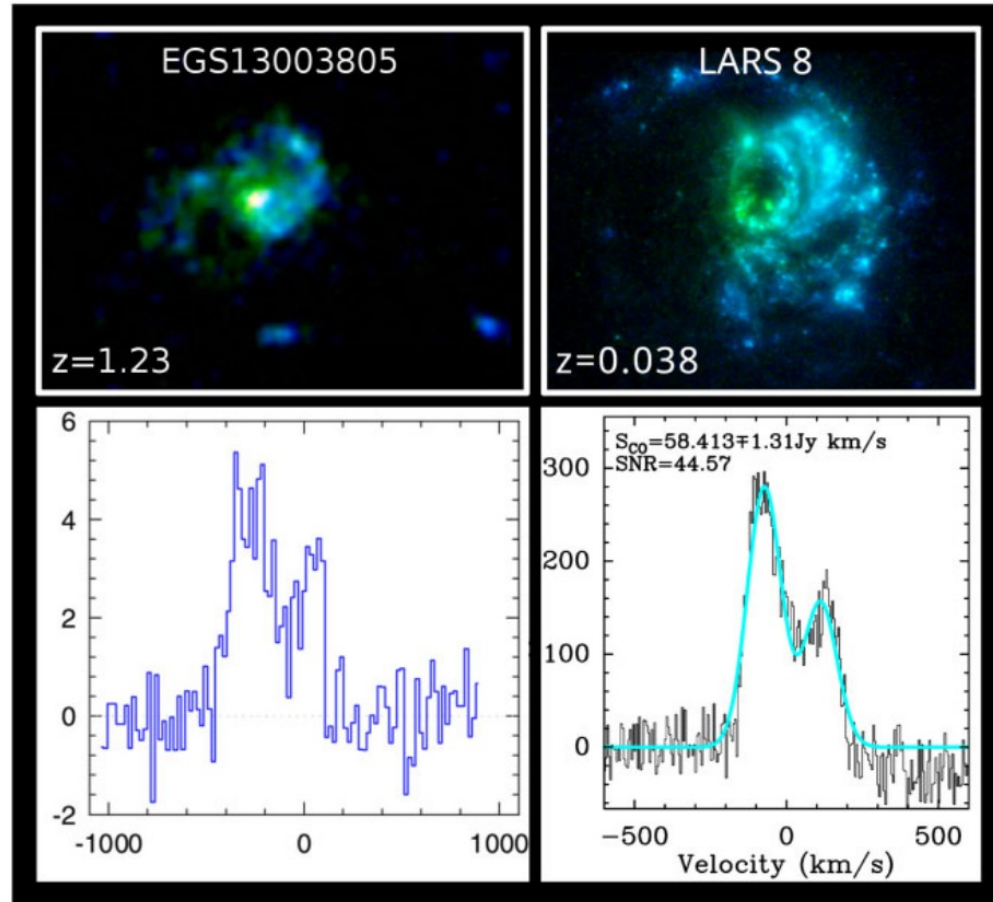
Lyman Alpha Reference Sample



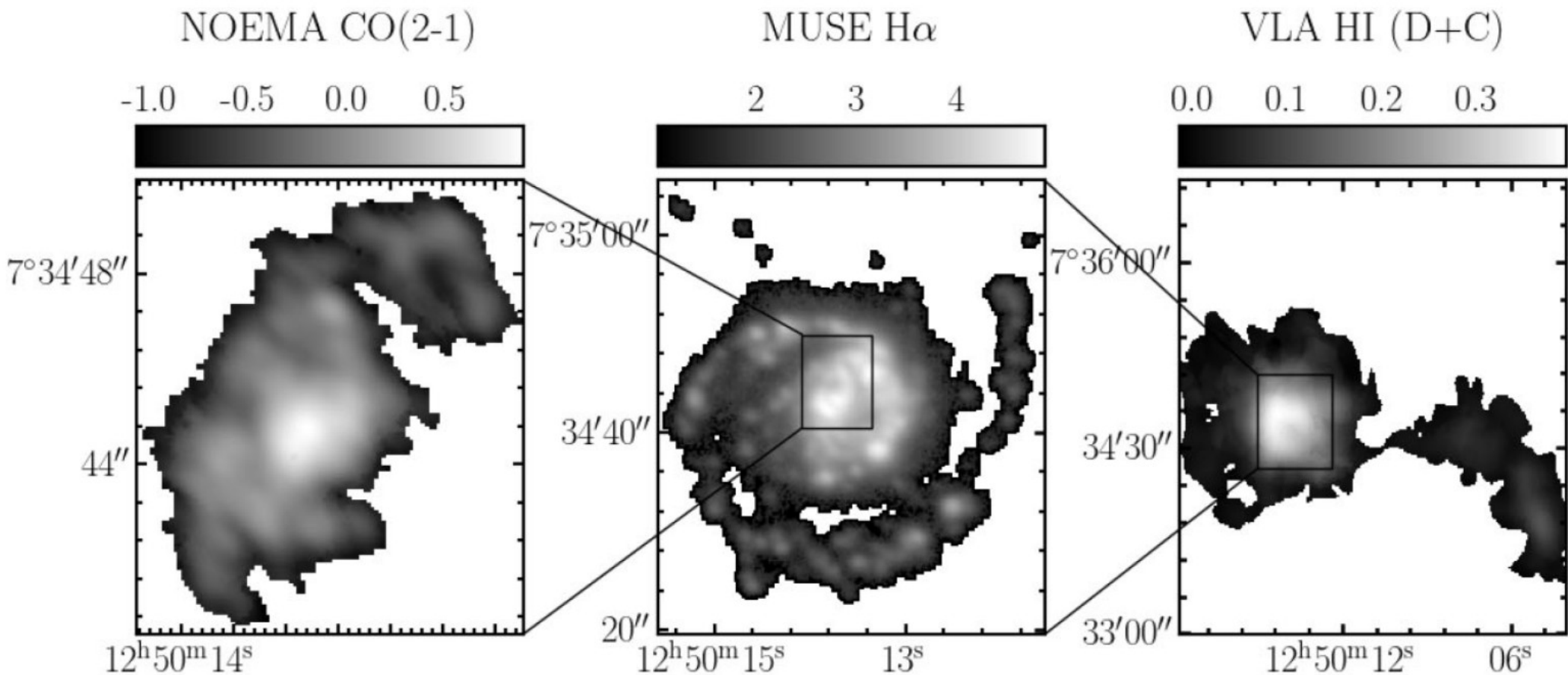
Galaxienentwicklung – Entstehung von Super-Sternhaufen

Eigenschaften von
Galaxien bei $z \sim 1-3$:

Fallstudie zur Entstehung
massereicher Super-
Sternhaufen



Galaxienentwicklung – Entstehung von Super-Sternhaufen



Galaxienentwicklung – Entstehung von Super-Sternhaufen

NOEMA CO(2-1)

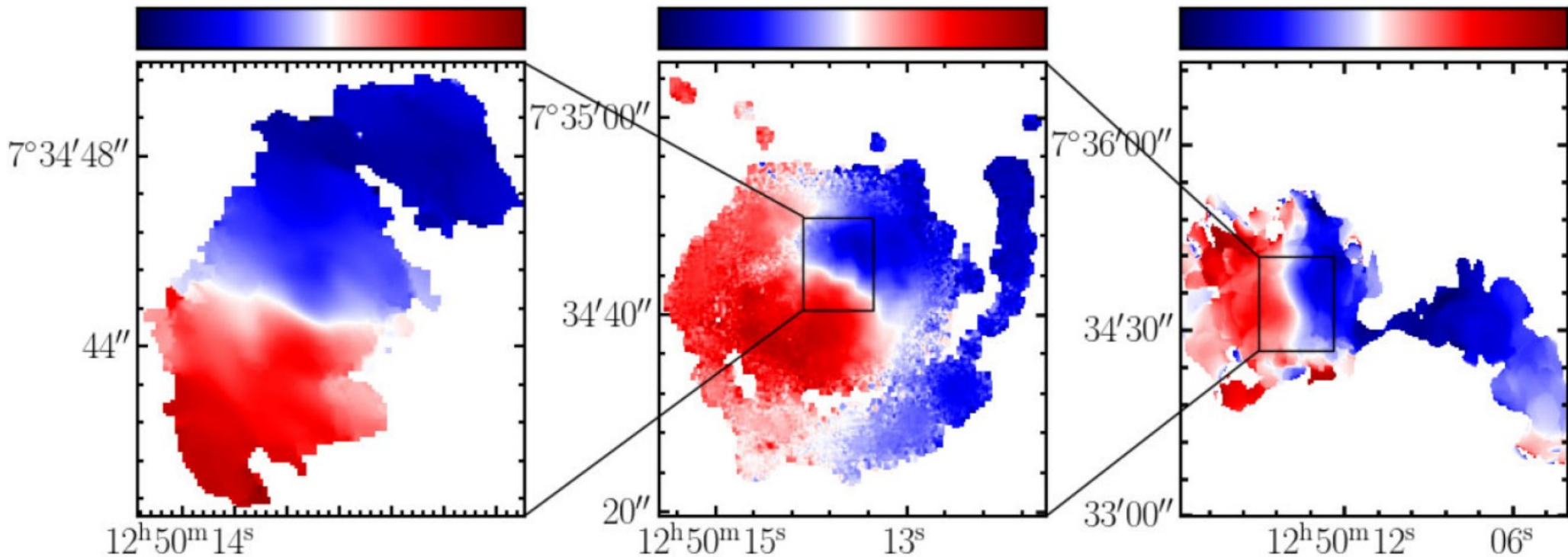
-100 0 100 200

MUSE H α

-100 0 100 200

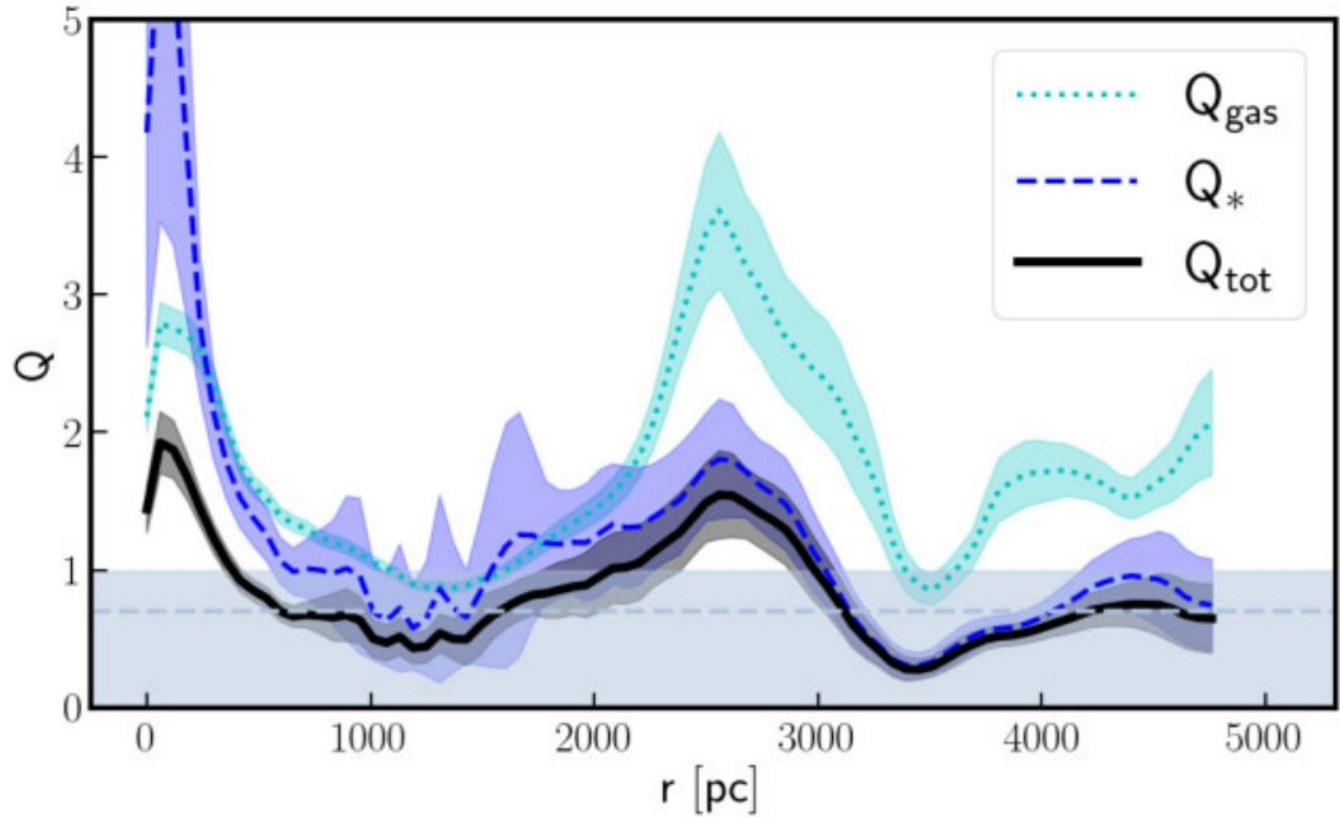
VLA HI (D+C)

-100 0 100



Galaxienentwicklung – Entstehung von Super-Sternhaufen

$$Q_g = \frac{\kappa \sigma_g}{\pi G \Sigma_g} > 1$$



Instabil auf großer Skala → Sternentstehung

Zusammenfassung

- Unser kosmologisches Modell steht durch neue Beobachtungen derzeit unter Druck (Hubble Tension, JADES)
- Limit der kosmischen Reionisation aus Quasarsichtlinien sehr gut bestimmt zu: $z \sim 6$
- Kosmische Sternentstehungsrate hatte Peak bei $z \sim 1-3$ (die meisten Sterne heute entstanden zu diesem Zeitpunkt)
- Sterne entstehen aus molekularem Gas: Zusammenhang CO vs. Sternentstehungsrate
- Wir können einige ausgesuchte lokale Galaxien als Laboratorien für das frühe Universum verwenden (z.B. LARS → Entstehung supermassereicher Sternhaufen)





Danke

