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The Cosmic Dawn Center (DAWN), Niels Bohr Institutet, Københavns Universitet

Oplæg, Niels Bohr Institutets temadag for fysiklærere, 30.01.2026

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Billede credit: NASA / STSci & Heintz et al. 2024, *Science*

Kort om mig

… og min baggrund

Student i 2020

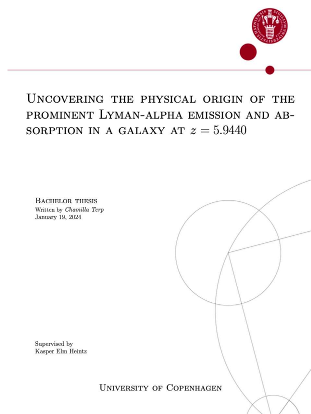
Corona…

September 2020: Starter på fysik på KU

Januar 2024: Forsvarer bachelorprojekt

September 2024: Starter på kandidaten i astrofysik på KU

Juni 2026: (efter planen) færdiguddannet astrofysiker



UNCOVERING THE PHYSICAL ORIGIN OF THE PROMINENT LYMAN-ALPHA EMISSION AND ABSORPTION IN A GALAXY AT $z = 5.9440$

BACHELOR THESIS
Written by *Chamilla Terp*
January 19, 2024

Supervised by
Kasper Elm Heintz

UNIVERSITY OF COPENHAGEN

Bachelor i fysik, 2024

Student, 2020

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Kort om mig

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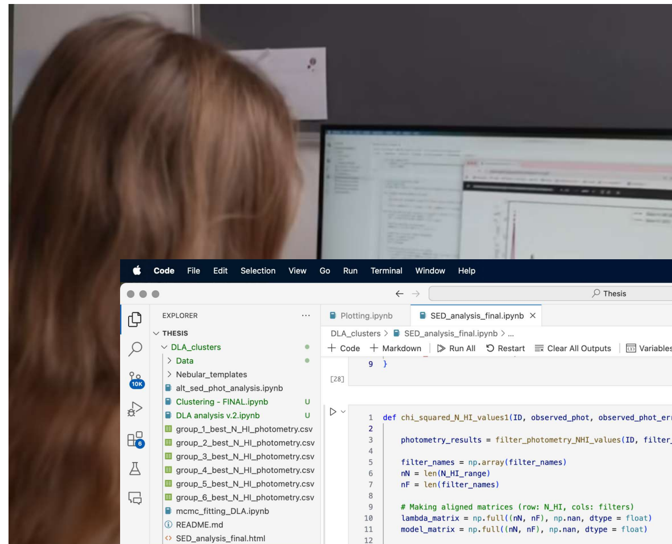
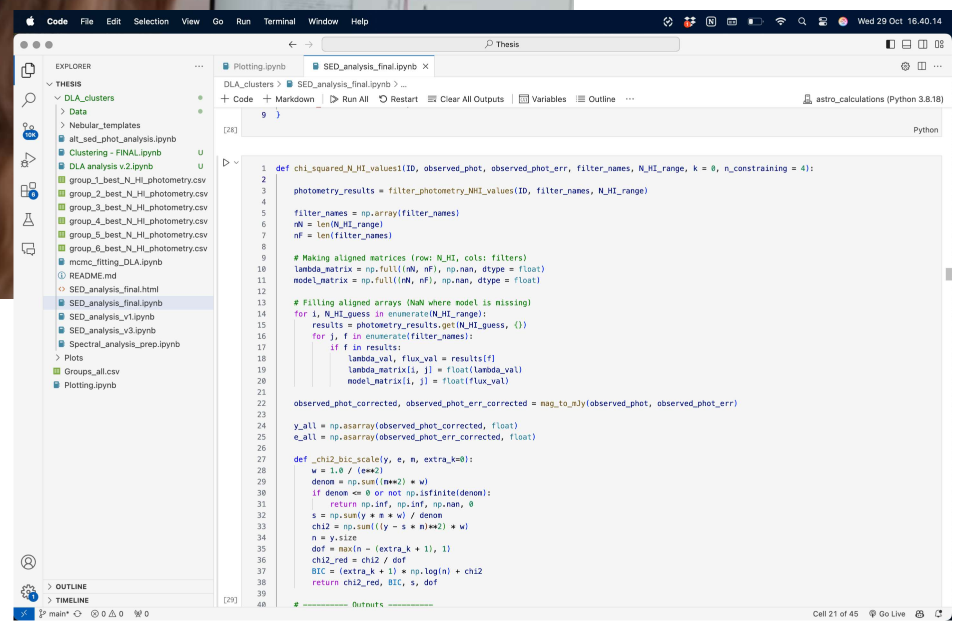
Astrofysiker?

Forventning vs. realitet





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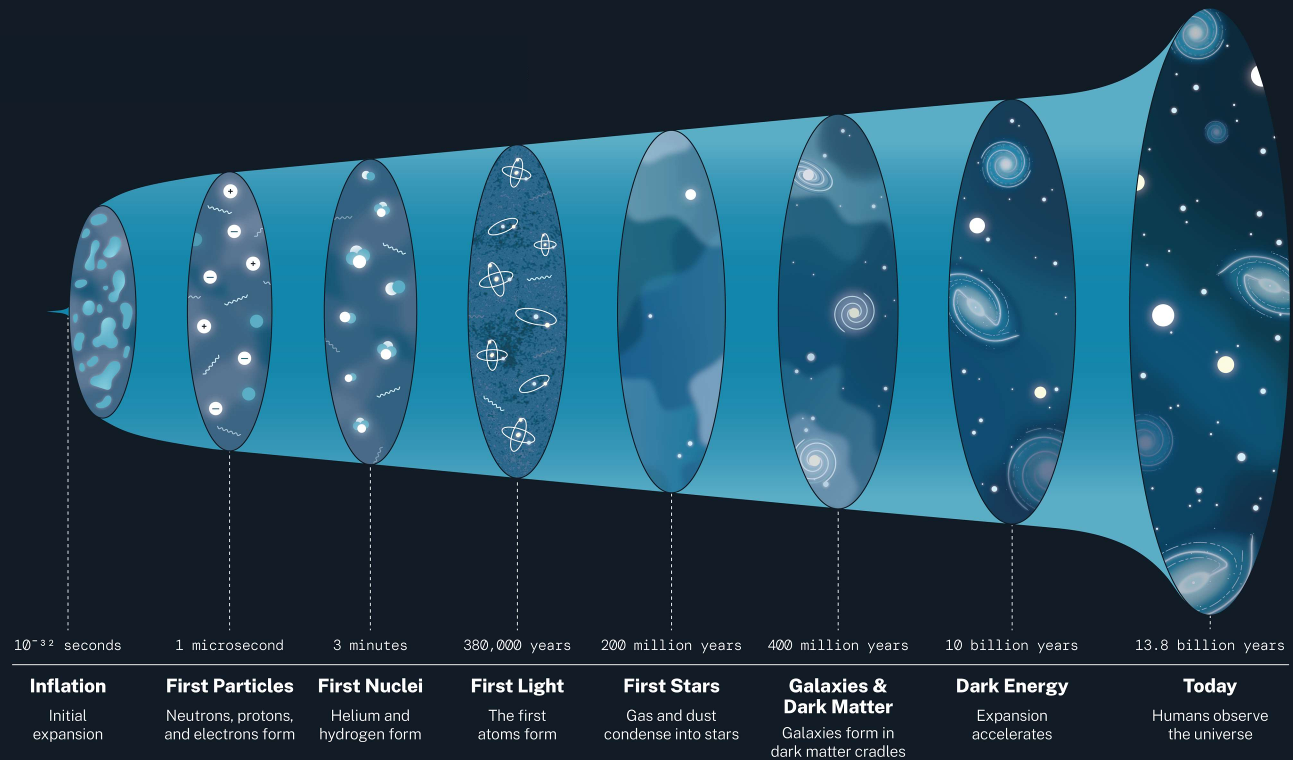
Hvad ved vi om universet i dag?
Moderne kosmologi



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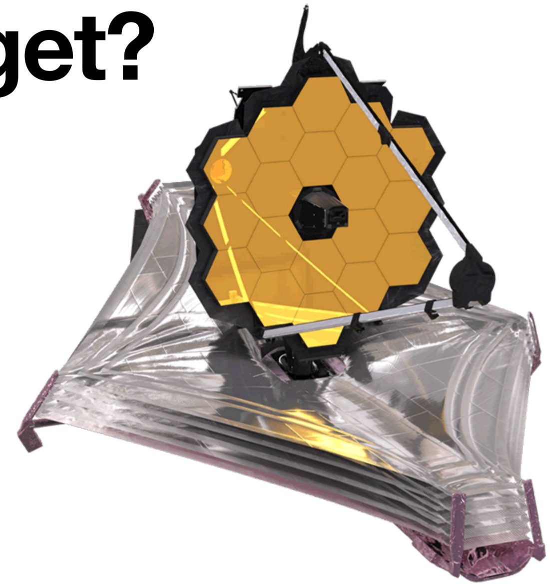
Hvordan ved vi overhovedet noget?

Astrofysikerens bedste venner



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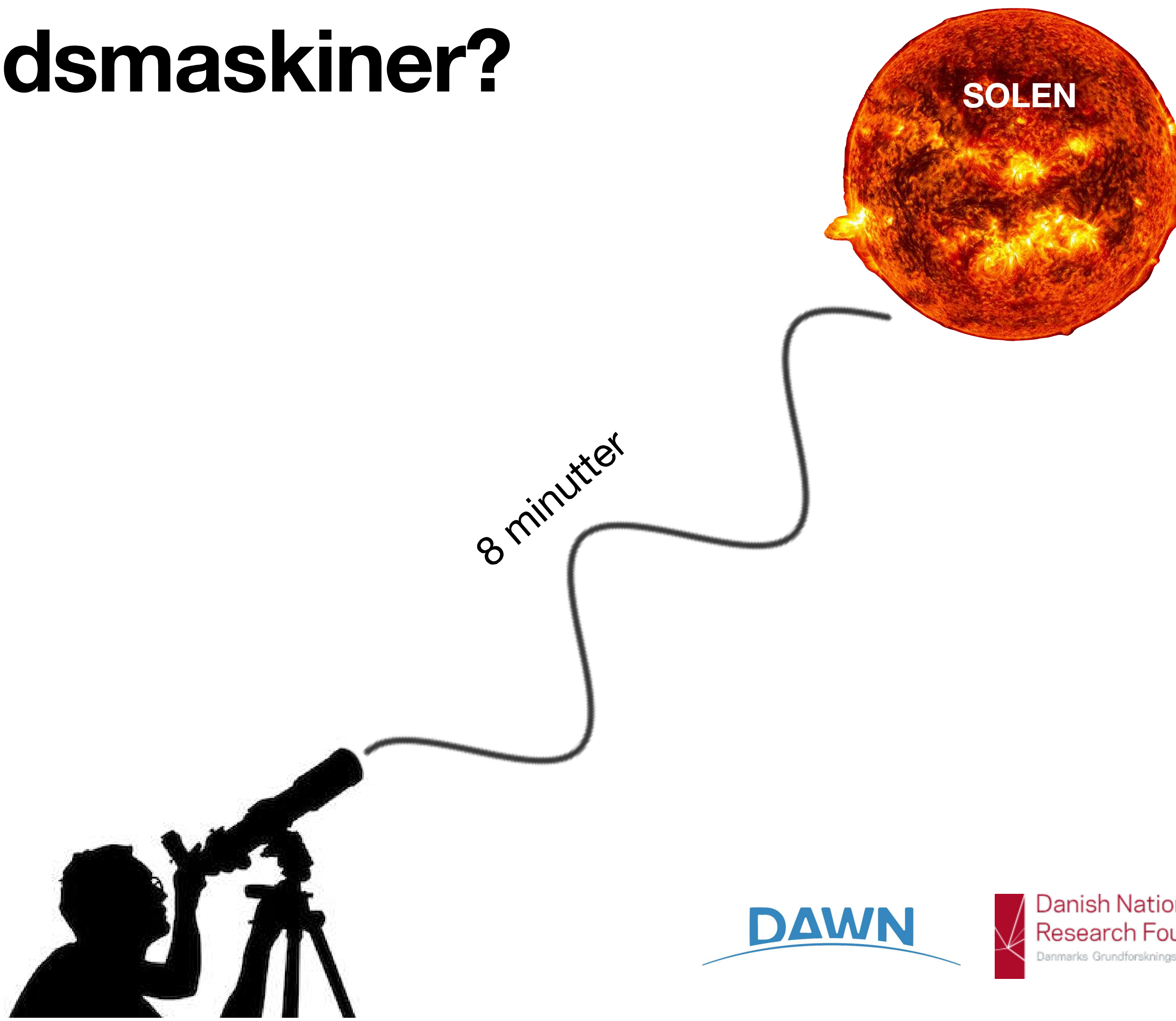
Teleskoper = tidsmaskiner?

Et kig tilbage i tiden



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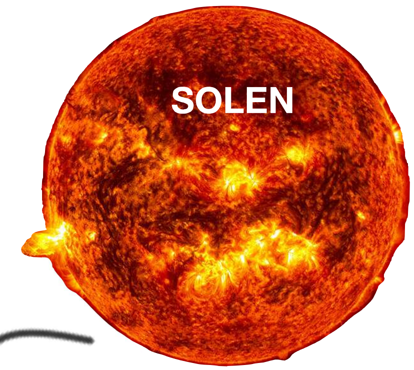
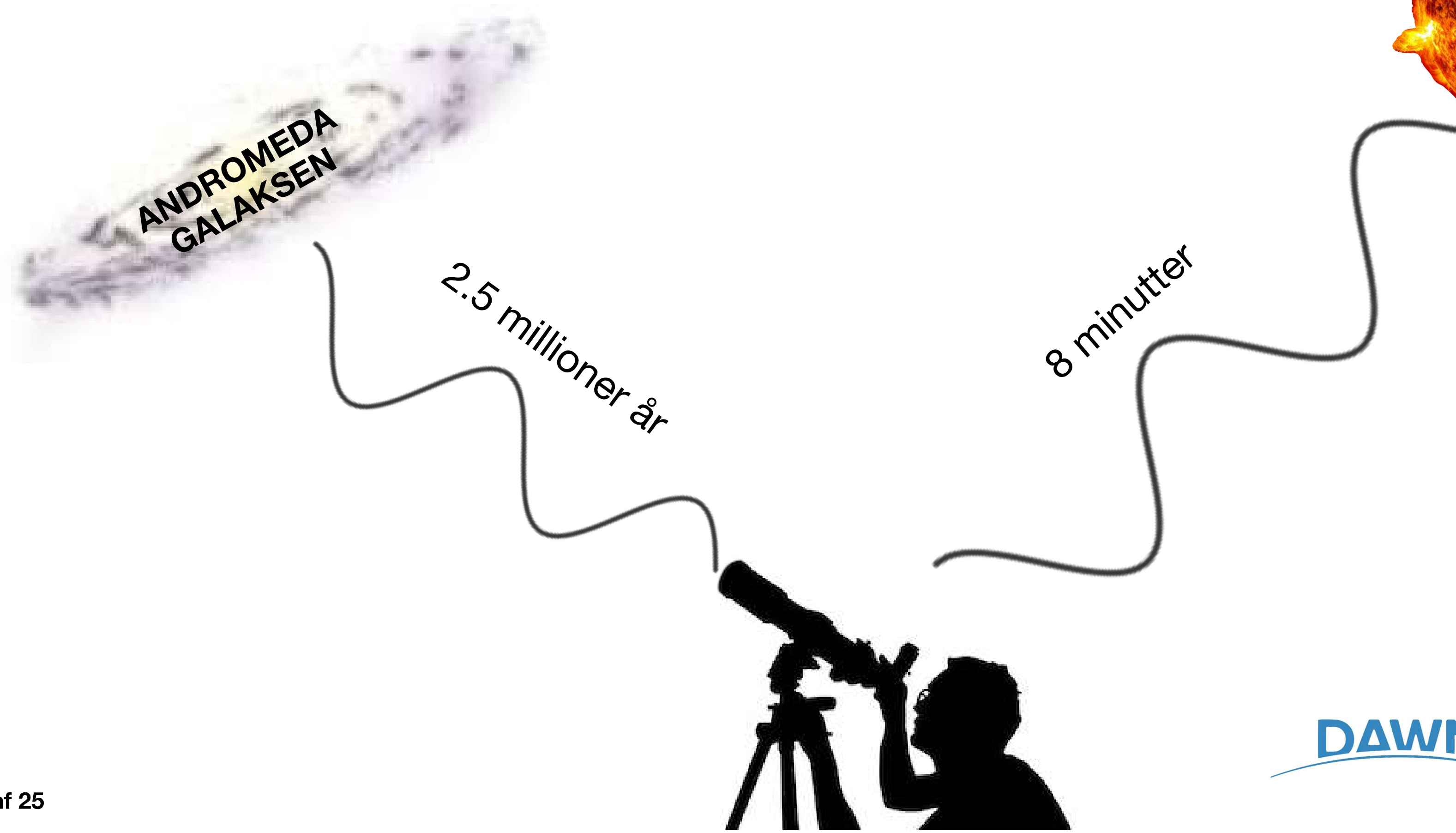
Teleskoper = tidsmaskiner?

Et kig tilbage i tiden





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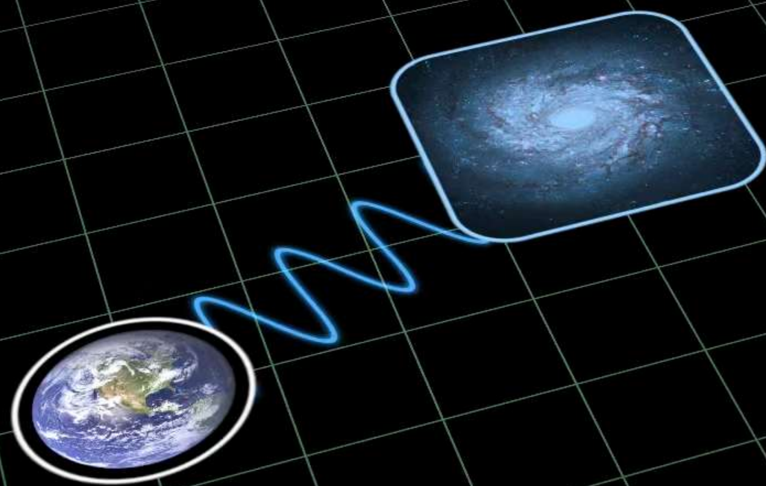
Universets udvidelse

Kort introduktion til rødforskydning



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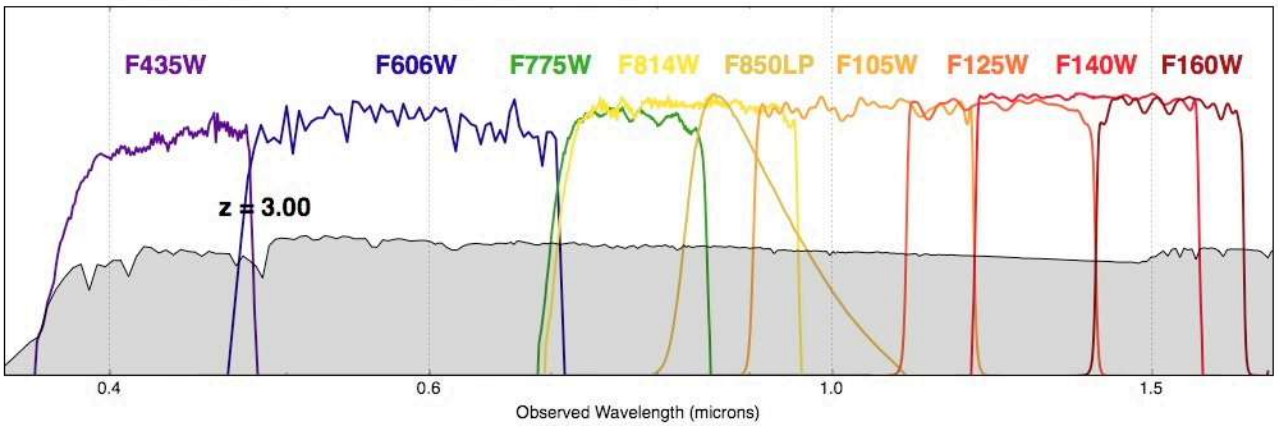
Universets udvidelse

Kort introduktion til rødforskydning

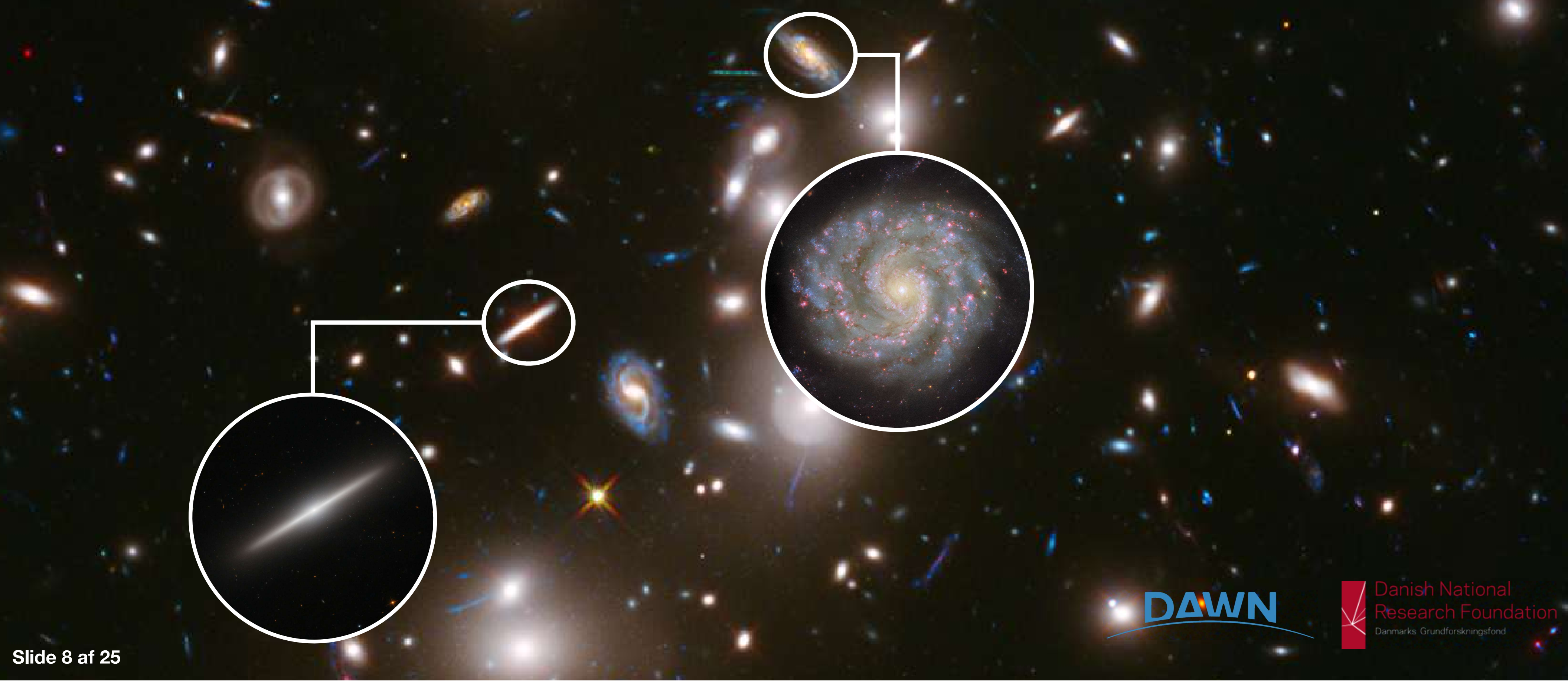


Hvordan bliver vi klogere på det tidlige univers?

Galakser!

Hvordan bliver vi klogere på det tidlige univers?

Galakser!



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Galakser består af mange ting…
Supermassive sorte huller
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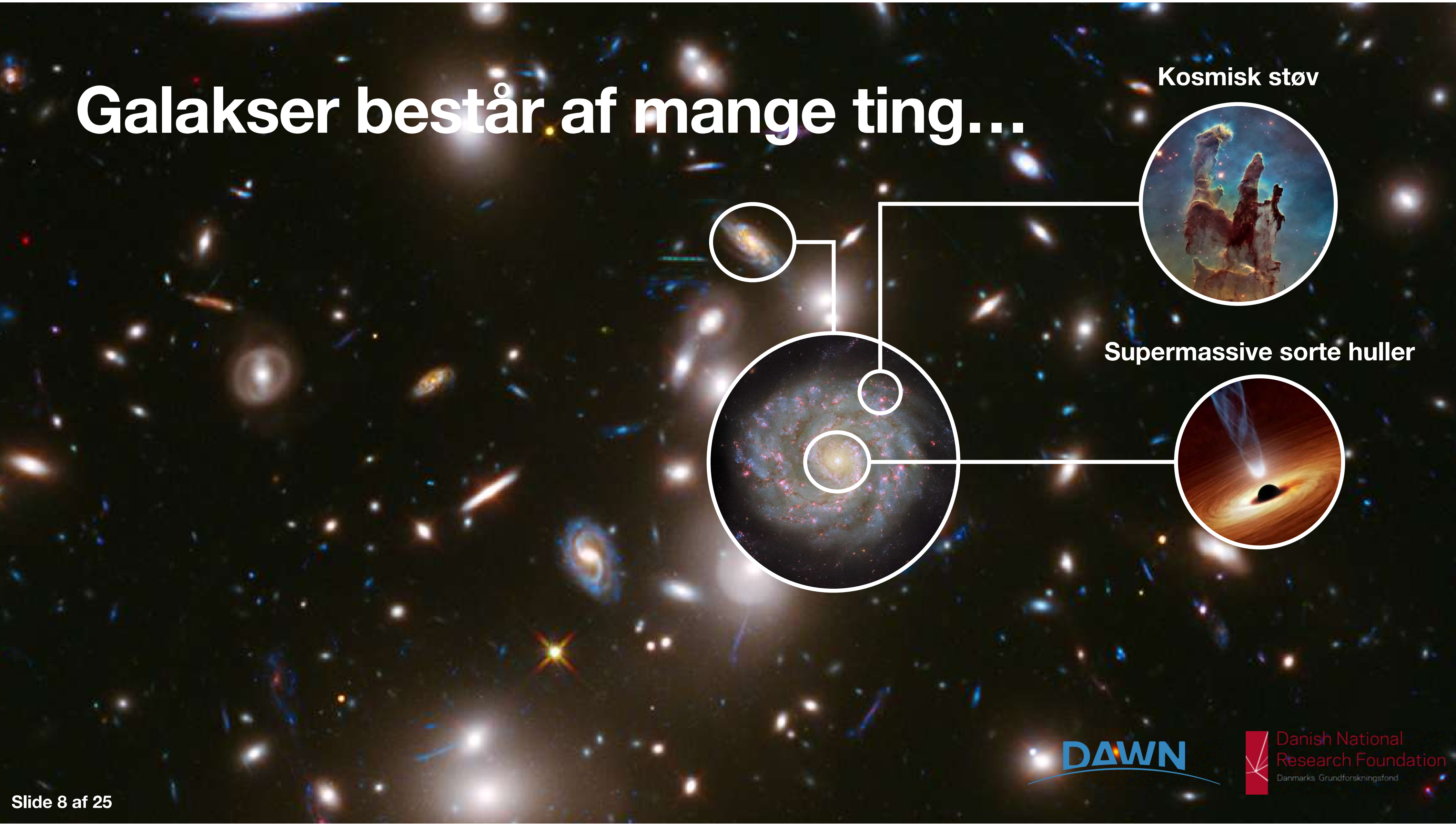
Galakser består af mange ting…
Kosmisk støv
Supermassive sorte huller
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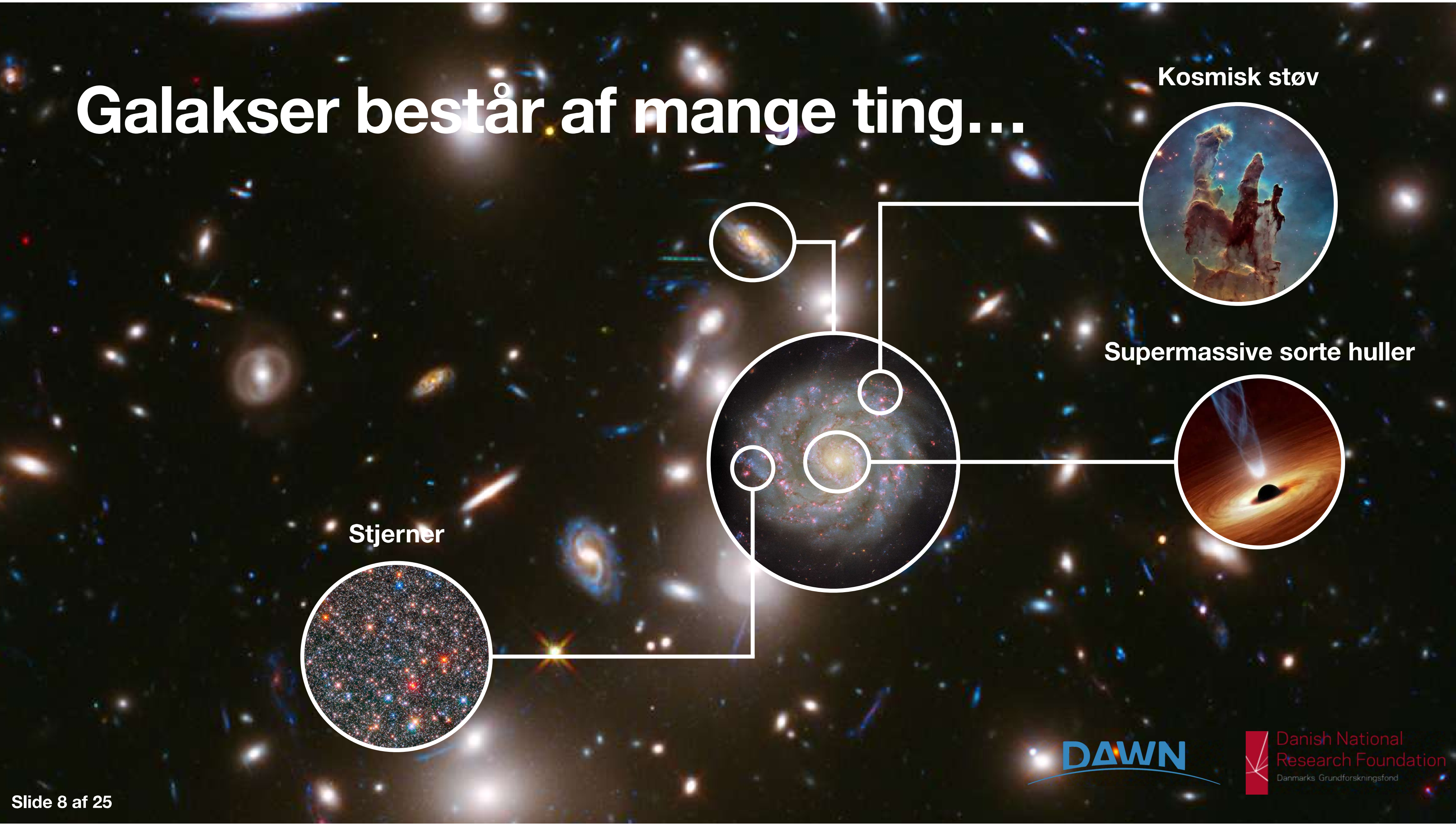
Slide 8 af 25


Galakser består af mange ting…
Kosmisk støv
Supermassive sorte huller
Stjerner
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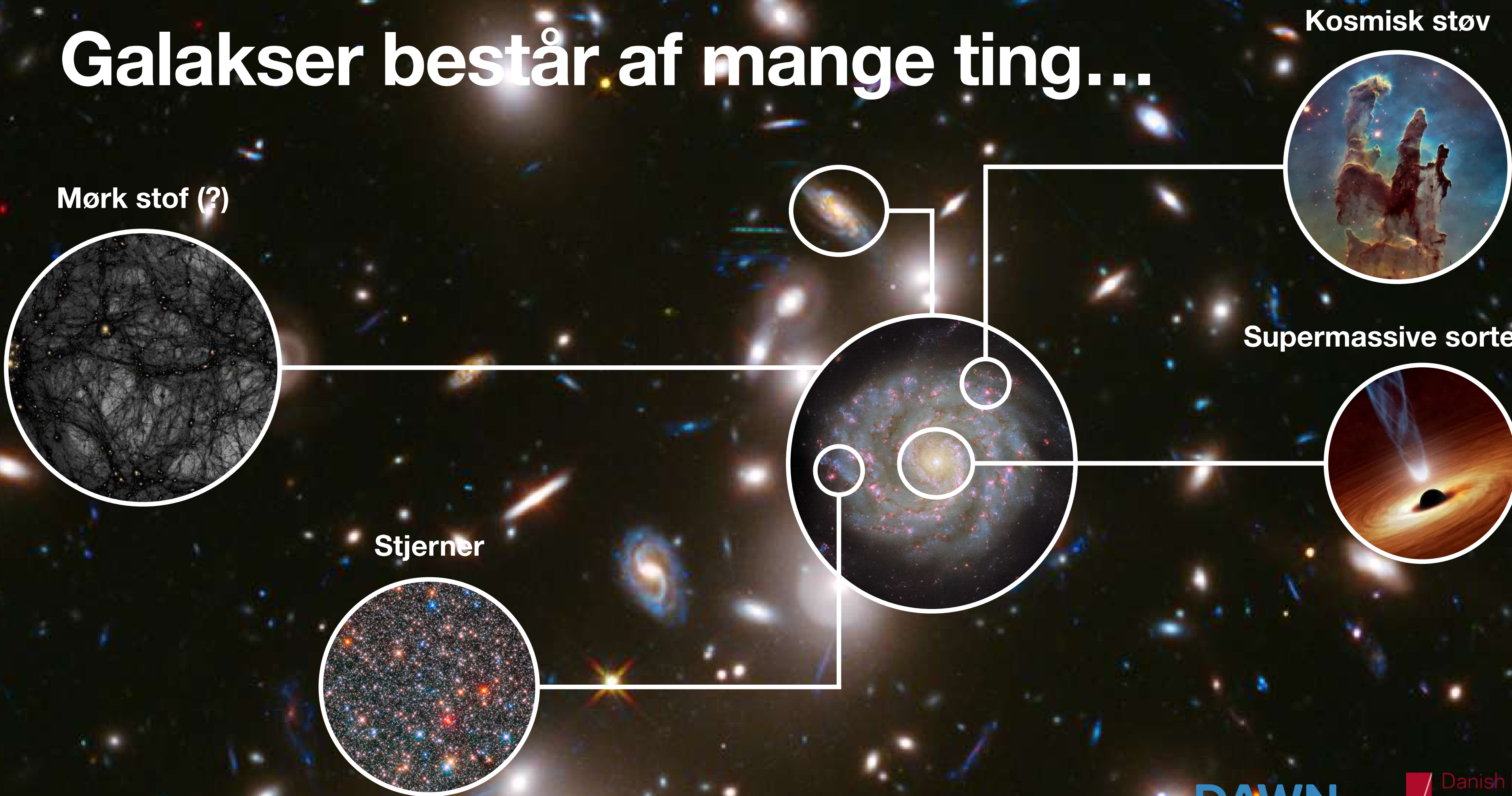
Slide 8 af 25

Galakser består af mange ting…



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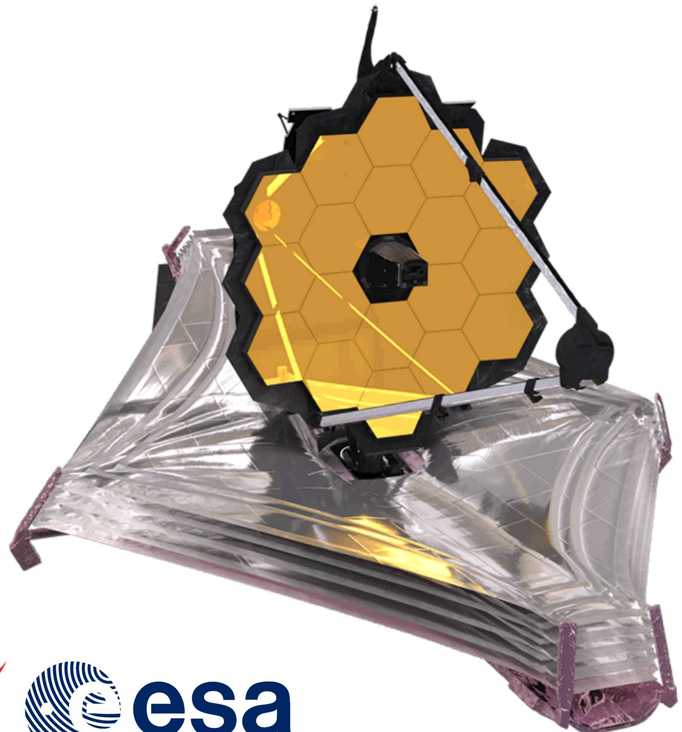
Universets barndom

… kræver et helt specielt teleskop!



James Webb Space Telescope

Opsendt 25. december 2021

Fremme ved sin destination i januar 2022

Pris: ca. 70 mia. kr.

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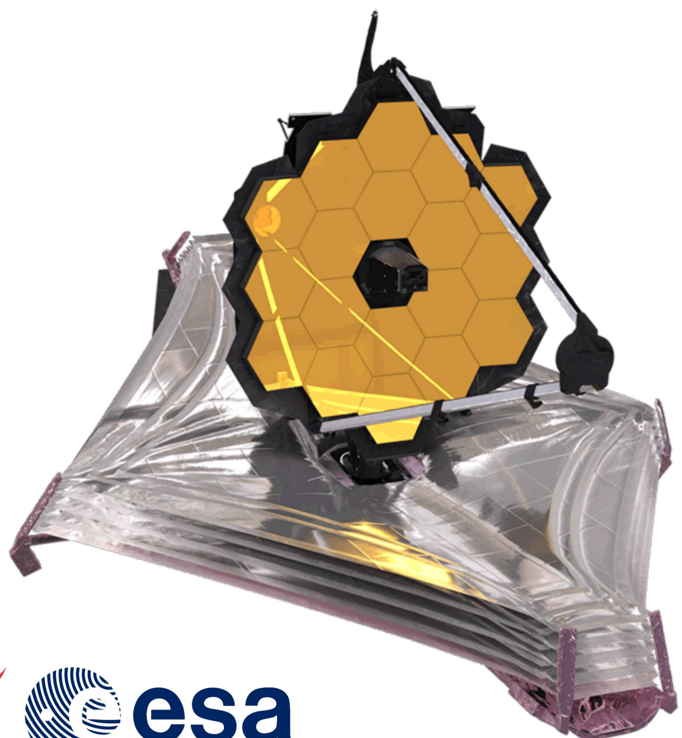
Universets barndom

… kræver et helt specielt teleskop!



James Webb Space Telescope

Verdens største rumteleskop

Observerer **infrarødt** lys

Spejl: 6.5 meter i diameter, lavet af guld
(reflekterer infrarødt lys med 99% effektivitet)

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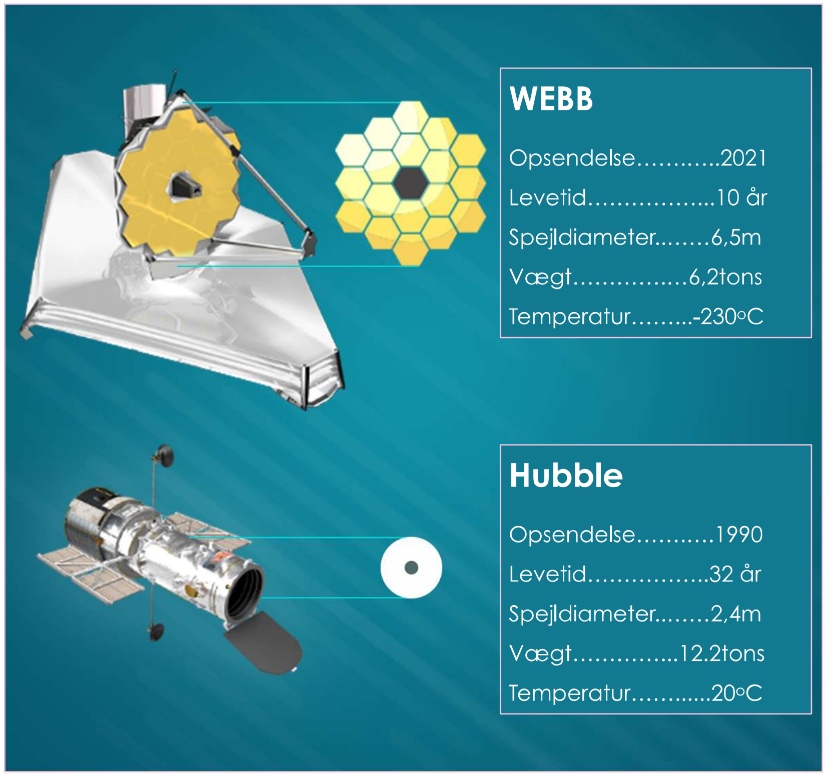
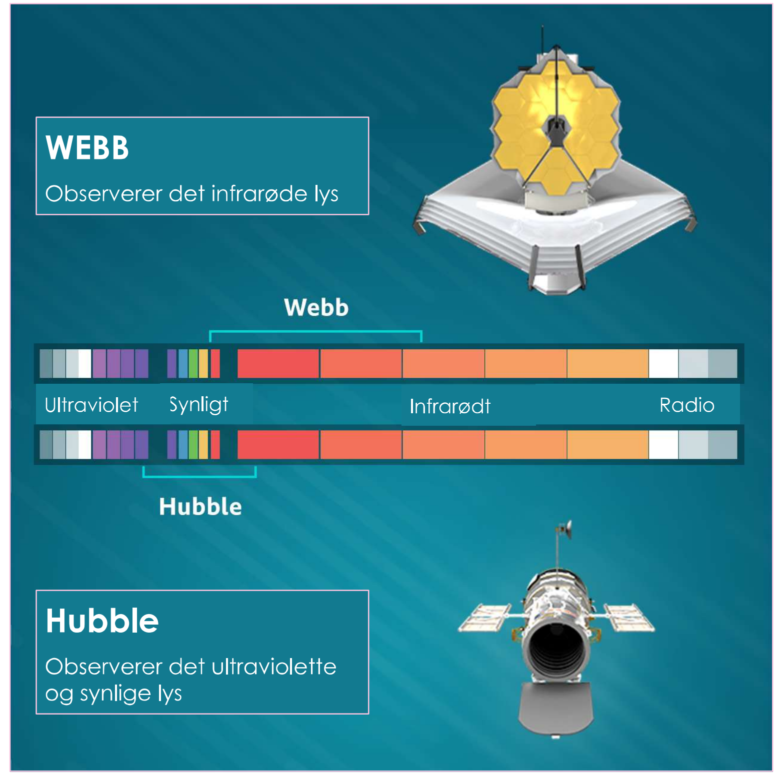
Hubble Space Telescope vs. James Webb Space Telescope





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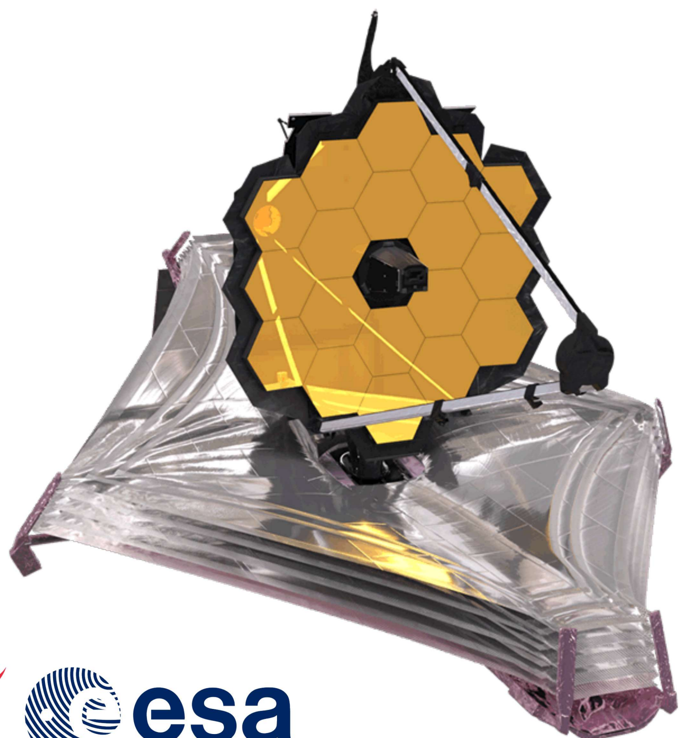
Hubble Space Telescope vs. James Webb Space Telescope



NASA esa

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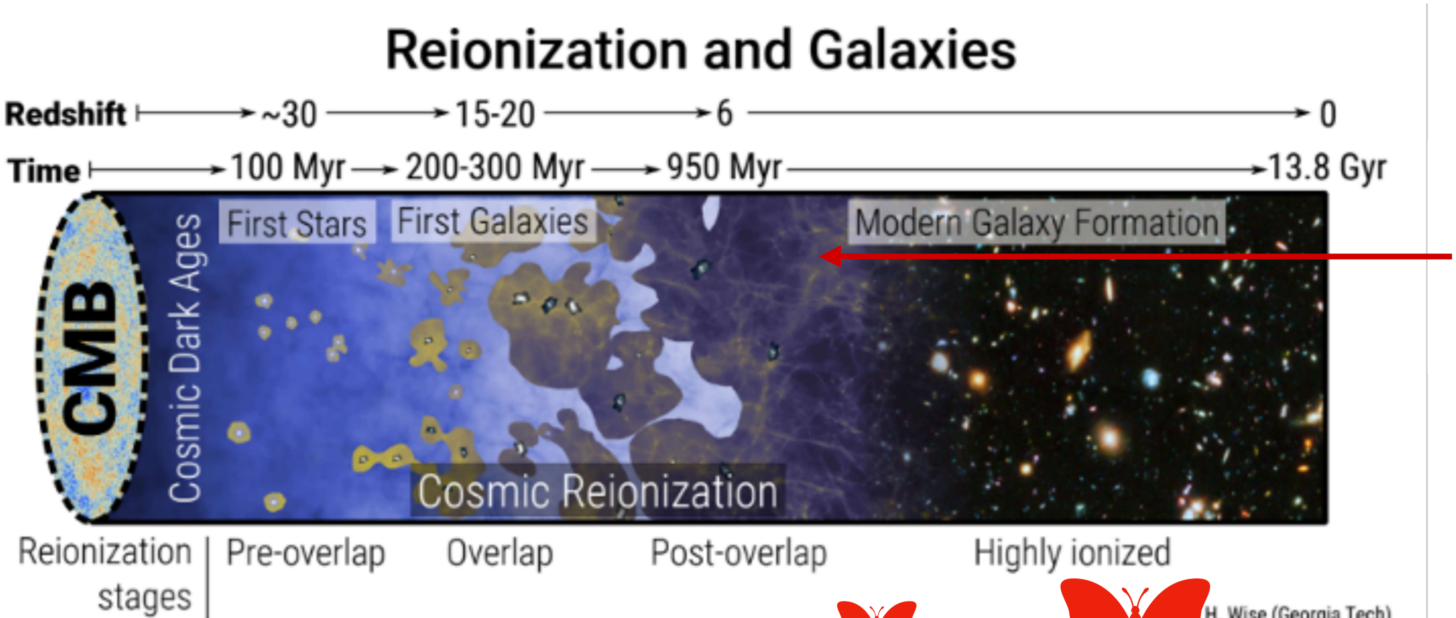
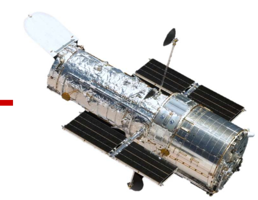
Første billede fra JWST, 2022

Galaksehoben SMACS0723 5 milliarder lysår væk

Dannelsen af de første galakser





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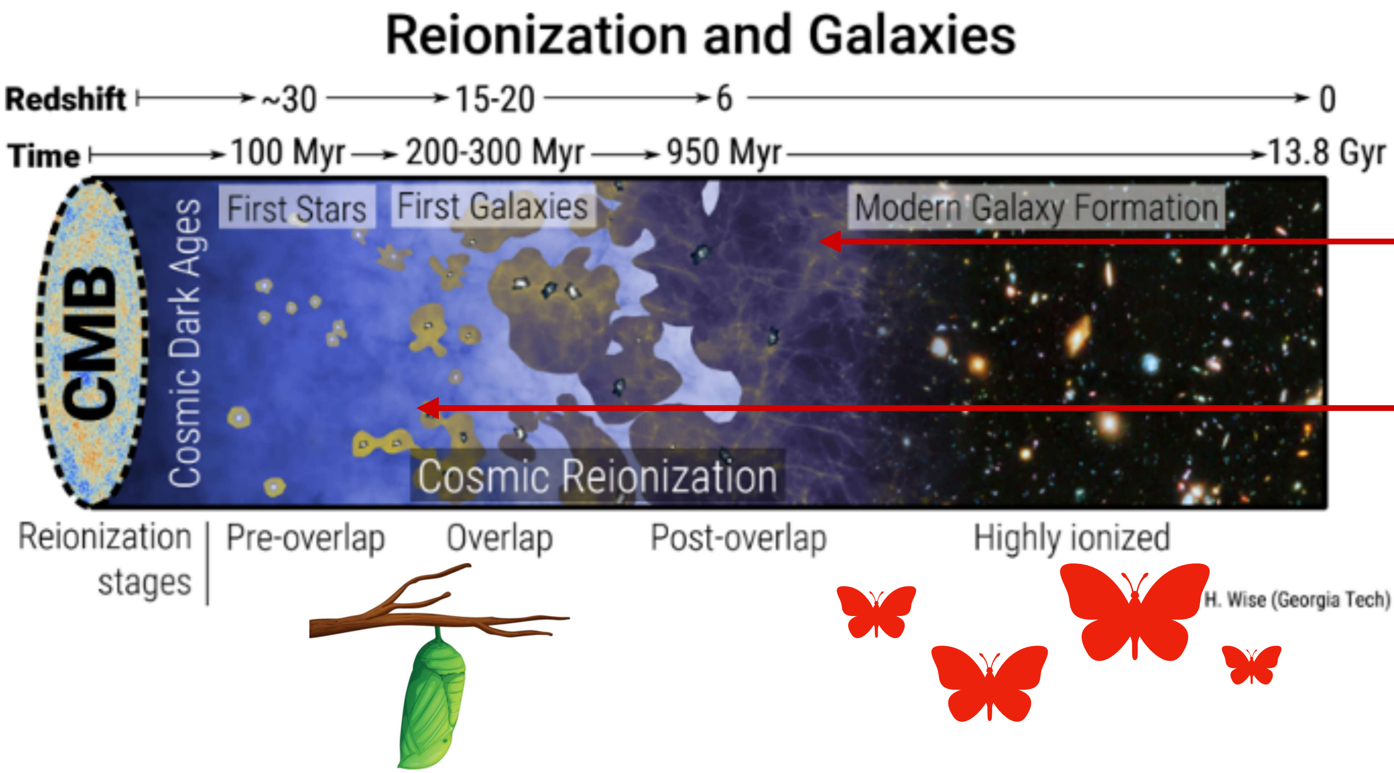
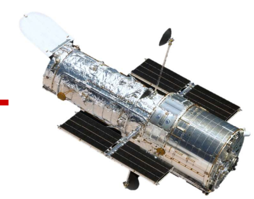
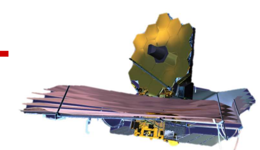
Dannelsen af de første galakser







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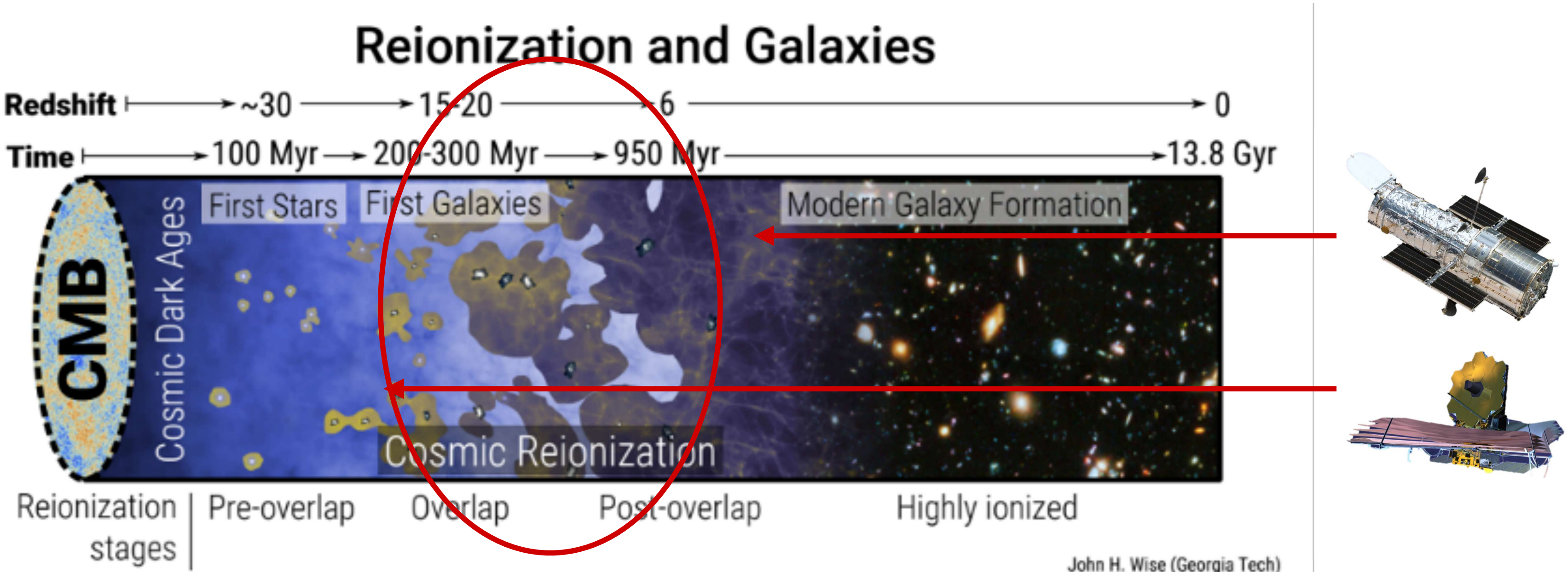
Spændende periode i universets historie…



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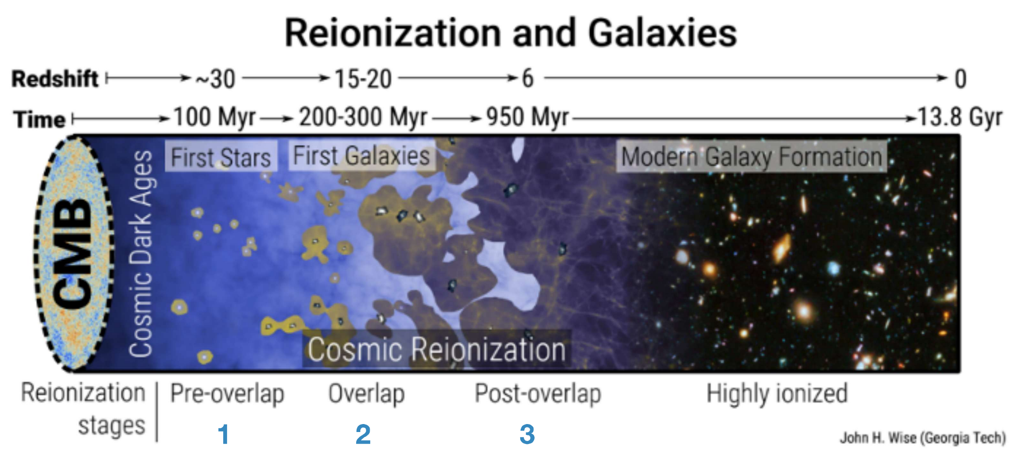
Galakse formation og reionisering
The Epoch of Reionization (EoR)

Galakse formation

1. Mørk stof haloer sætter gang i stjerne- og galaksedannelse —> H II regioner
2. H II regioner begynder at vokse sammen
3. Stjerner forventes at have reioniseret universet ($z \sim 6$)

HI regioner; giver indsigt i, hvordan galakser samles og udvikler sig

Lyman-alpha emission; siger noget om ioniseringstilstanden af en galakse



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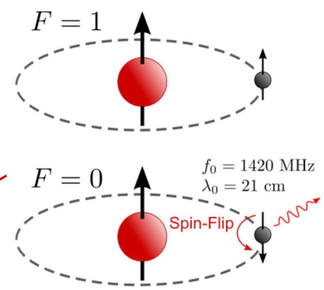
Hvordan undersøger vi HI?

Begrænsningerne ved høje rødforskydninger

Hvordan opdager vi HI?

1. 21-cm hyperfine overgang



En anden løsning?

JA!

Nuværende rekordholder for 21-cm linjen, $z \sim 1.3$

(Chowdhury+23, Chakraborty&Roy23)

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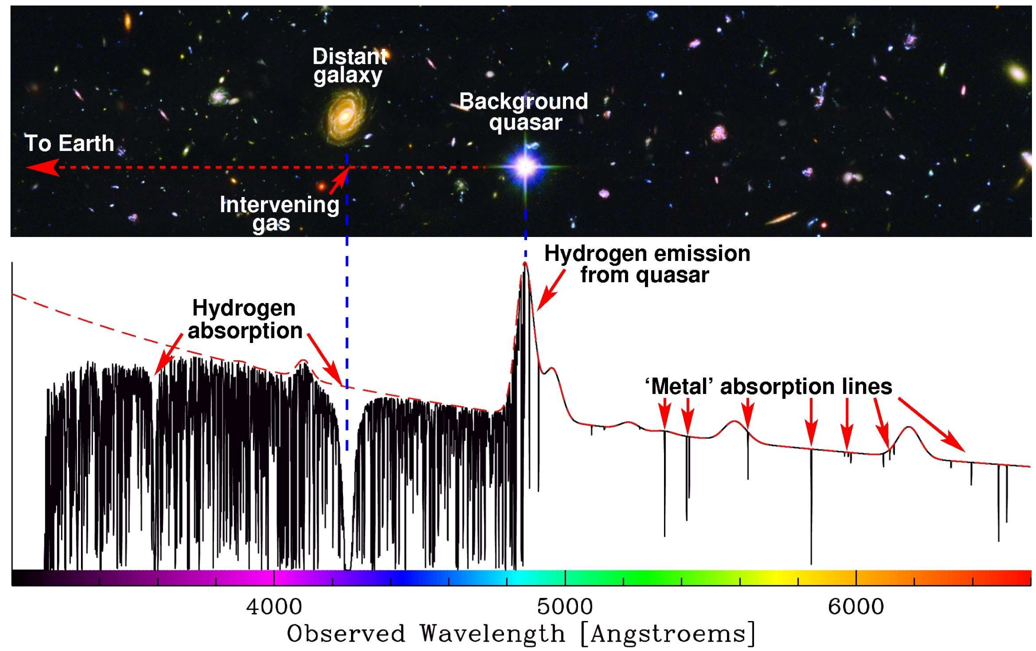
Hvordan undersøger vi HI?
Lyman-alpha absorption

Kan måles op til $z \sim 6.5$ i kvasarer og gammaglimt

Begrænsningerne er at

1. Vi kigger på tilfældige sigtelinjer
2. Kvasarer og gammaglimt er sjældne
3. Vi kan ikke se dem ved meget høje rødforskydninger



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Damped Lyman-alpha Absorption

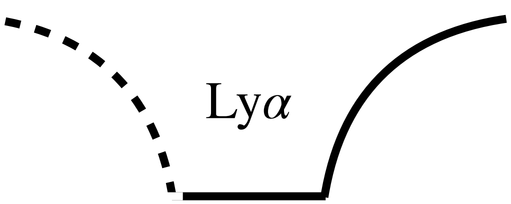
Galakser ved $z \gtrsim 9$

Damped Lyman-alpha Absorption (DLA)

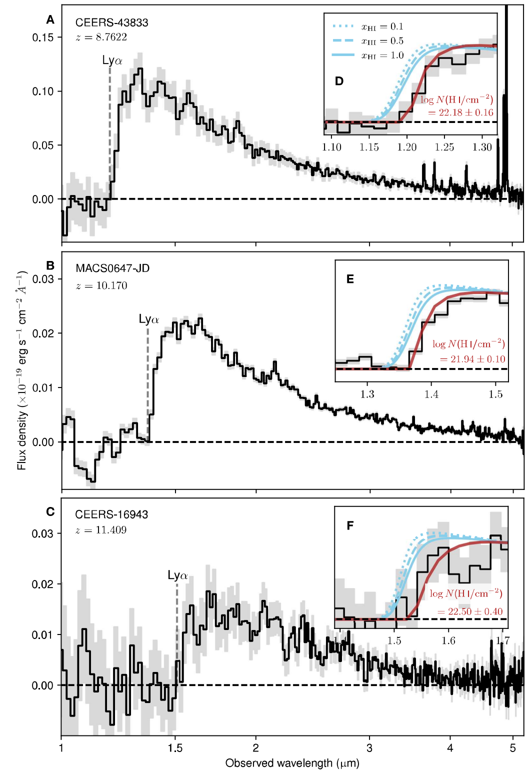
$$N_{HI} \geq 2 \times 10^{22}\ cm^{-2}$$

DLA'er afslører tætte, fuldstændigt self-shielded HI gas

Muligt at observere ved høje rødforskydninger - især med JWST



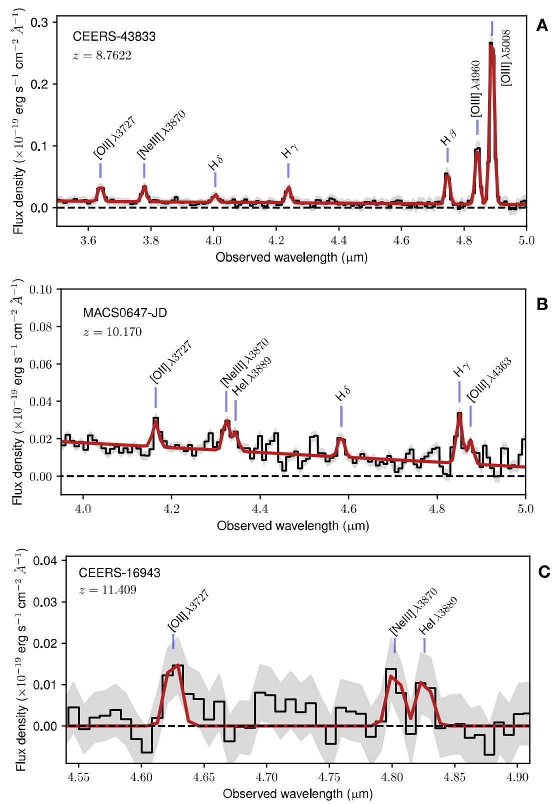
Heintz et al. 2024, *Science*

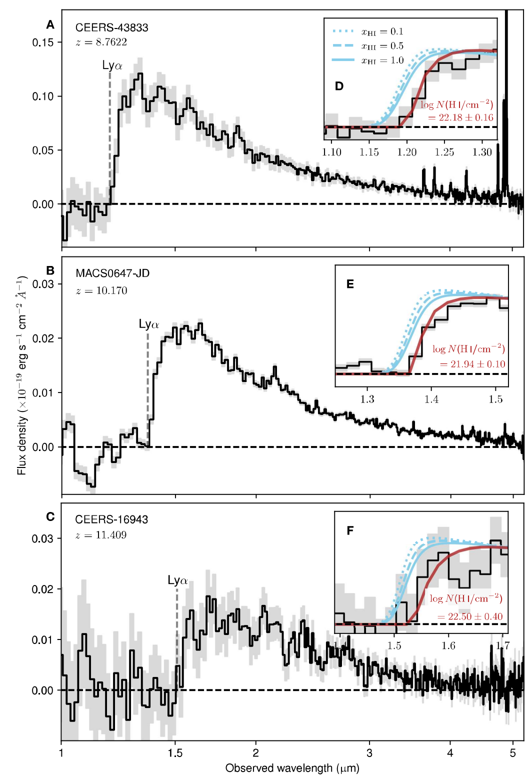


Damped Lyman-alpha Absorption

Galakser ved $z \gtrsim 9$

Heintz et al. 2024, *Science*





Nøglen til at måle en DLA:

Præcis emissionslinje rødforskydning!

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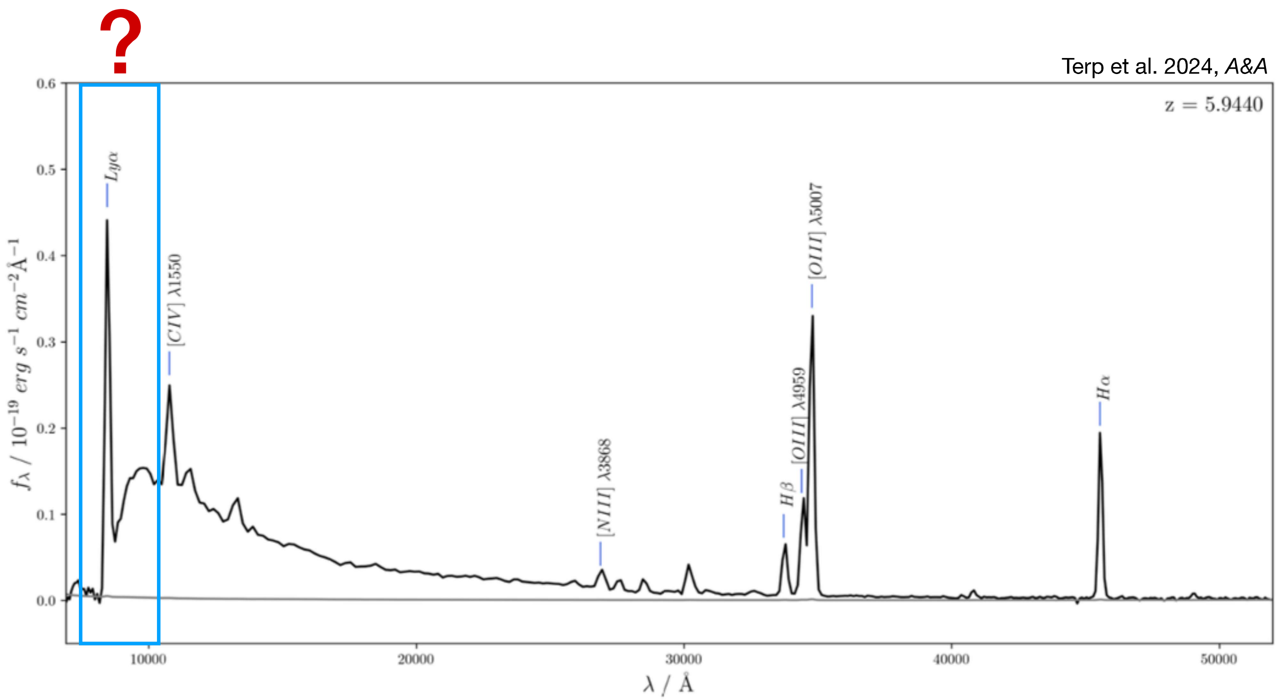
Galaksen GS9422

Stærk Lyman-alpha emission *og* absorption

Et interessant tilfælde…

Identificeret i PRIMAL-surveyet (Heintz et al. 2024)

Note: Også undersøgt af Cameron et al. (2023)



Terp et al. 2024, *A&A*

Kilde observeret med JWST som en del af JADES - source ID: 13176

Galaksen GS9422

Karakterisering af GS9422

- Lav metallicitet
- Aktiv stjernedannelse
- Forhøjet ionisationstilstand
  (Lyman-alpha emission)
- Ekstrem DLA
  (Lyman-alpha absorption)

Hvordan kan vi forklarer det her?

z_{gal}	5.942 ± 0.001
R_e [kpc]	0.59
A_e [kpc^2]	1.85
$SFR_{H\alpha}$ [$M_\odot$ yr^{-1}]	8.20 ± 0.15
$12 + \log(O/H)$	7.56 ± 0.05
$\log(Z/Z_\odot)$	-1.13 ± 0.05
$f_{esc,Ly\alpha}$	0.3 ± 0.2
$^a\log(N_{HI})$ [cm^{-2}]	23.85 ± 0.10
$\log\Sigma_{SFR}$ [$M_\odot$ yr^{-1} pc^{-2}]	0.64 ± 0.01
$\log\Sigma_{gas}$ [$M_\odot$ pc^{-2}]	3.01 ± 0.01
$^b\log(N_{HI})$ [cm^{-2}]	23.11 ± 0.01
$^bM_{HI}$ [$M_\odot$]	$(1.89 \pm 0.04) \times 10^9$
$t_{depl.}$ [Gyr]	0.23 ± 0.01

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Galaksen GS9422
Mulige løsninger

Hvordan takler man problemet?

Eksotisk fysik? Eller en mere simpel tilgang?

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Galaksen GS9422

Mulige løsninger

Hvordan takler man problemet?

Eksotisk fysik? Eller en mere simpel tilgang?

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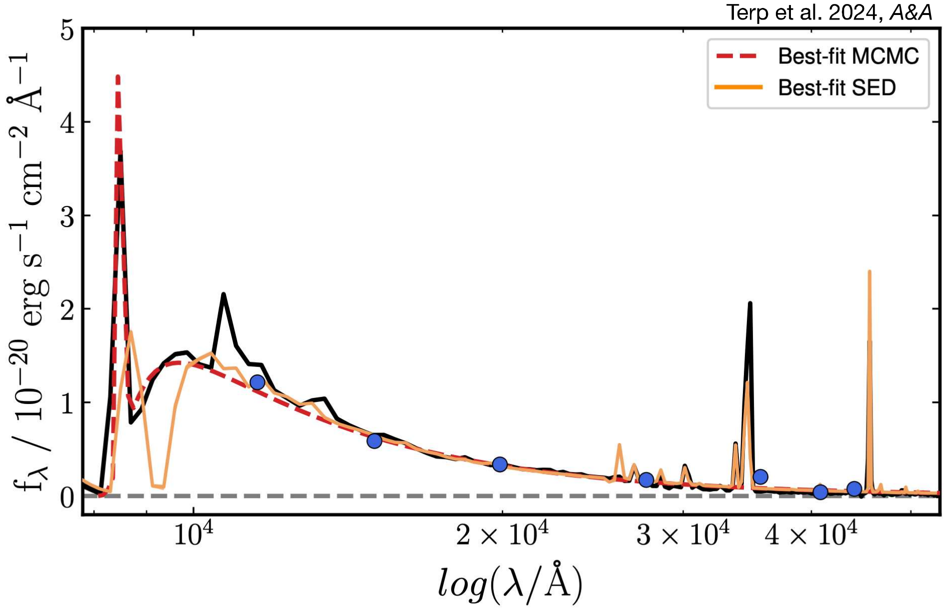
Galaksen GS9422

Resultaterne



DLA'en er ikke forbundet med selve galaksen!

z_{gal}	5.942 ± 0.001
R_e [kpc]	0.59
A_e [kpc^2]	1.85
$SFR_{H\alpha}$ [$M_\odot$ yr^{-1}]	8.20 ± 0.15
$12 + \log(O/H)$	7.56 ± 0.05
$\log(Z/Z_\odot)$	-1.13 ± 0.05
$f_{esc,Ly\alpha}$	0.3 ± 0.2
$^a z_{abs}$	5.349 ± 0.101
$^a\log(N_{HI})$ [cm^{-2}]	23.85 ± 0.10
$\log\Sigma_{SFR}$ [$M_\odot$ yr^{-1} pc^{-2}]	0.64 ± 0.01
$\log\Sigma_{gas}$ [$M_\odot$ pc^{-2}]	3.01 ± 0.01
$^b\log(N_{HI})$ [cm^{-2}]	23.11 ± 0.01
$^b M_{HI}$ [$M_\odot$]	$(1.89 \pm 0.04) \times 10^9$
$t_{depl.}$ [Gyr]	0.23 ± 0.01

Alternativ: Two-photon emission
(Cameron+23,Katz+24)
See also: Tacchella+23, Li+23

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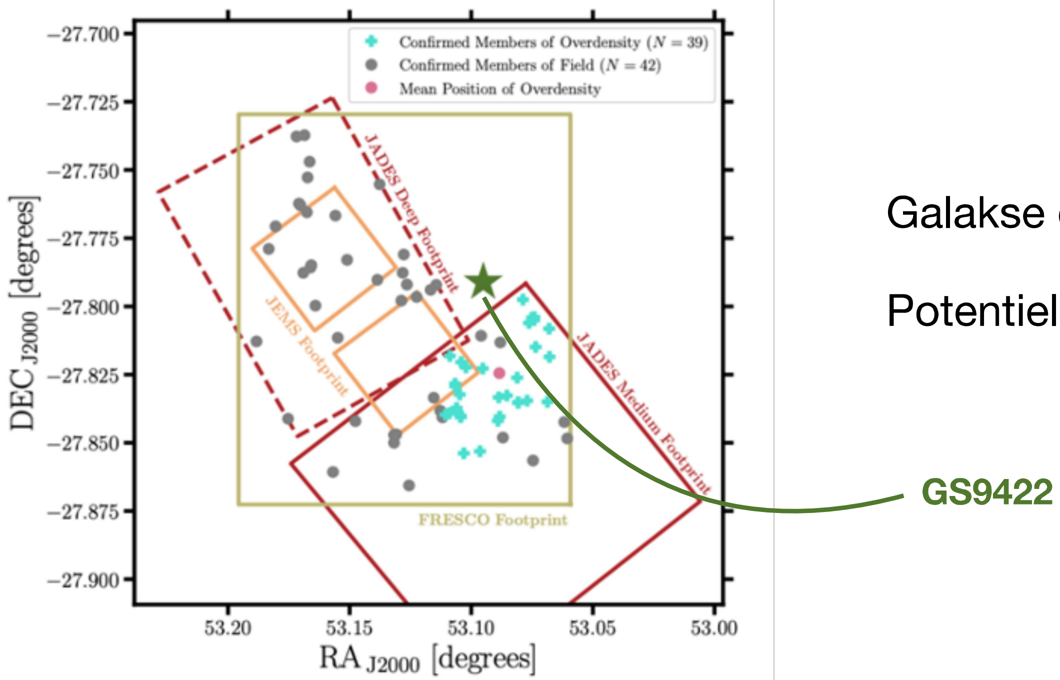
Galaksen GS9422

En sjov ekstra opdagelse



Helton et al. 2024

Galakse overdensitet ved $z = 5.4$ (Helton et al. 2024)

Potentiel proto-galaksehob?

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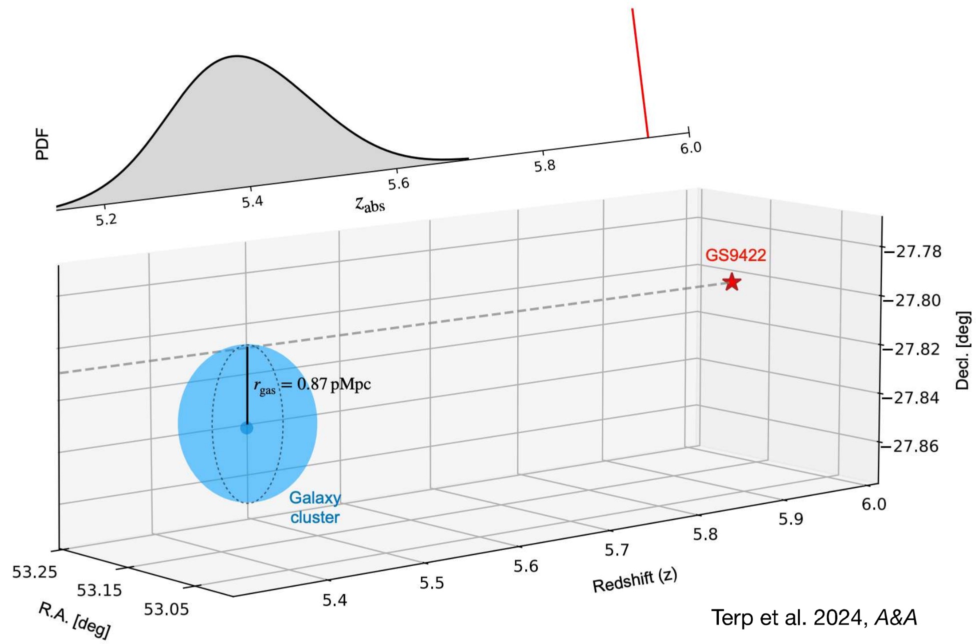
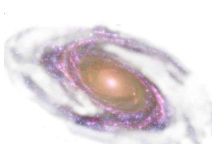
Galaksen GS9422

En sjov ekstra opdagelse

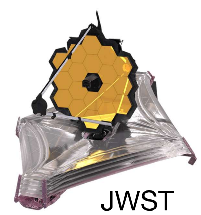


Terp et al. 2024, *A&A*

GS9422 som udsender
Lyman-alpha lys ved $z = 5.943$



Potentiel proto-galaksehob
ved $z = 5.4$



JWST

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Galaksen GS9422

Paper i Astronomy & Astrophysics

A&A, 690, A70 (2024)
https://doi.org/10.1051/0004-6361/202450375

Astronomy & Astrophysics

Uncovering the physical origin of the prominent Lyman-α emission and absorption in GS9422 at $z = 5.943$

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[5] Kavli Institute for Cosmology, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
[6] Cavendish Laboratory, University of Cambridge, 19 JJ Thomson Avenue, Cambridge CB3 0HE, UK
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Received 15 April 2024 / Accepted 2 August 2024

ABSTRACT

We present a comprehensive spectrophotometric analysis of galaxy GS9422 from the JADES GTO survey located at $z = 5.943$, anomalously showing a simultaneous strong Lyα emission feature and damped Lyα absorption (DLA), based on JWST NIRSpec and NIRCam observations. The best-fit modeling of the spectral energy distribution (SED) reveals a young, low-mass ($\log(M_\star/M_\odot) = 7.80 \pm 0.01$) galaxy, with a mass-weighted mean age of the stellar population of $(10.90^{+0.07}_{-0.12})$ Myr. The identified strong nebular emission lines suggest a highly ionized ($O_{32} = 59$), low-metallicity ($12 + \log(O/H) = 7.78 \pm 0.10$) star-forming galaxy with a star-formation rate (SFR) of $(8.2 \pm 2.8)\,M_\odot\,yr^{-1}$ over a compact surface area $A_e = 1.85\,kpc^2$, typical for galaxies at this epoch. This corresponds to an intense SFR surface density of $\log(\Sigma_{SFR}/M_\odot\,yr^{-1}\,kpc^{-2}) = 1.14 \pm 0.30$. We carefully modeled the rest-frame UV NIRSpec Prism spectrum around the Lyα edge, finding that the Lyα emission-line redshift is consistent with the longer-wavelength recombination lines and an escape fraction of $f_{esc,Ly\alpha} = 30\%$ but that the broad DLA feature is not able to converge on the same redshift. Instead, our modeling suggests $z_{abs} = 5.40 \pm 0.10$, the exact redshift of a newly identified protocluster in nearby projection to the target galaxy. We argue that most of the H I gas producing the strong Lyα damping wing must be unassociated with the galaxy itself, and thus may indicate that we are probing the cold, dense circumcluster medium of this massive galaxy overdensity. These results provide an alternative solution to the recent claims of continuum nebular emission or an obscured active galactic nucleus dominating the rest-frame UV parts of the spectrum, and provide further indications that strong DLAs might preferentially be associated with galaxy overdensities.

Key words. galaxies: clusters: general – galaxies: clusters: intracluster medium – galaxies: evolution – galaxies: formation – galaxies: high-redshift

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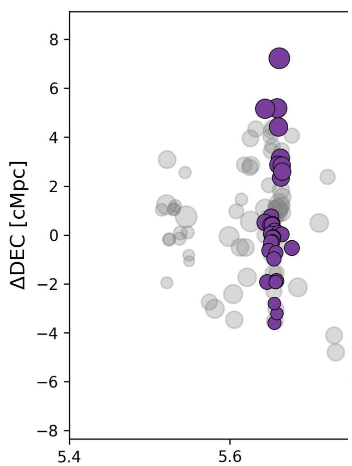
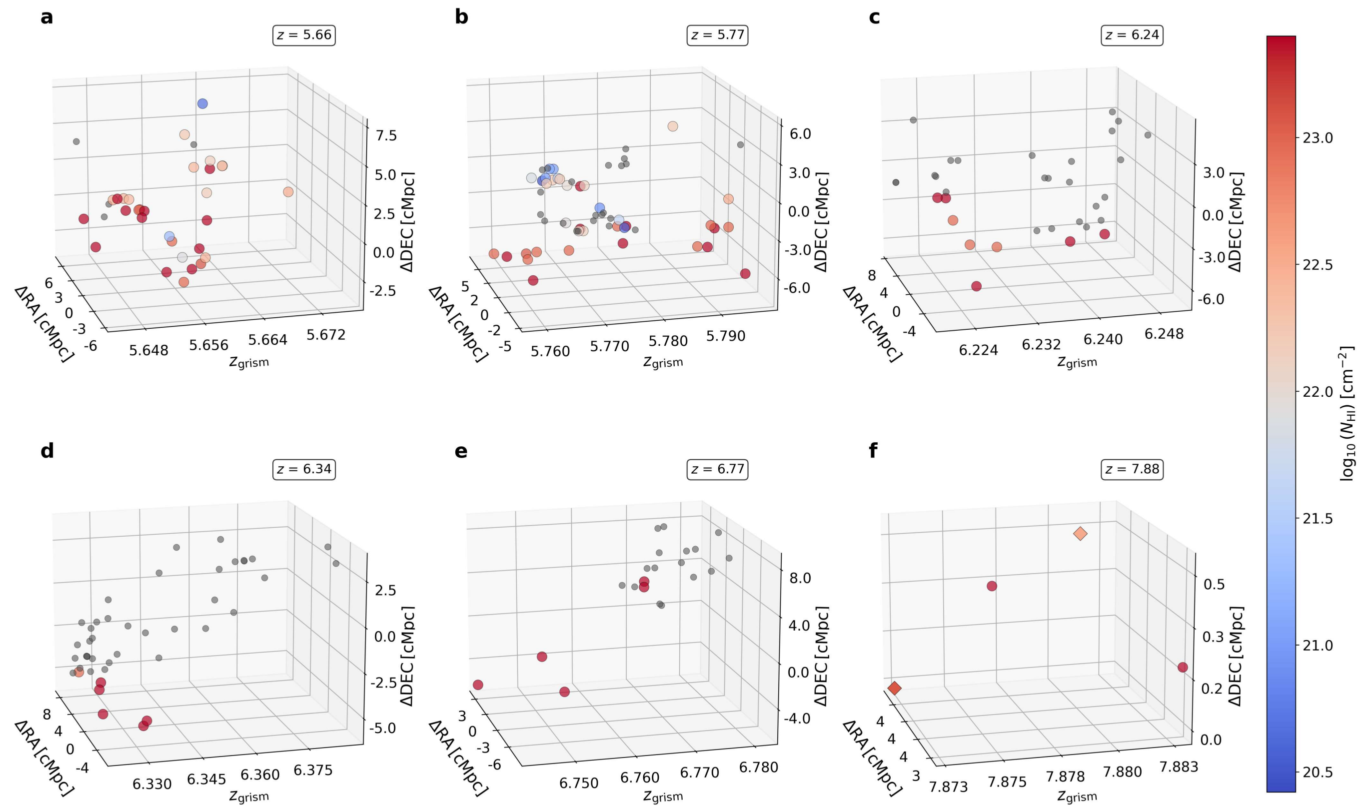
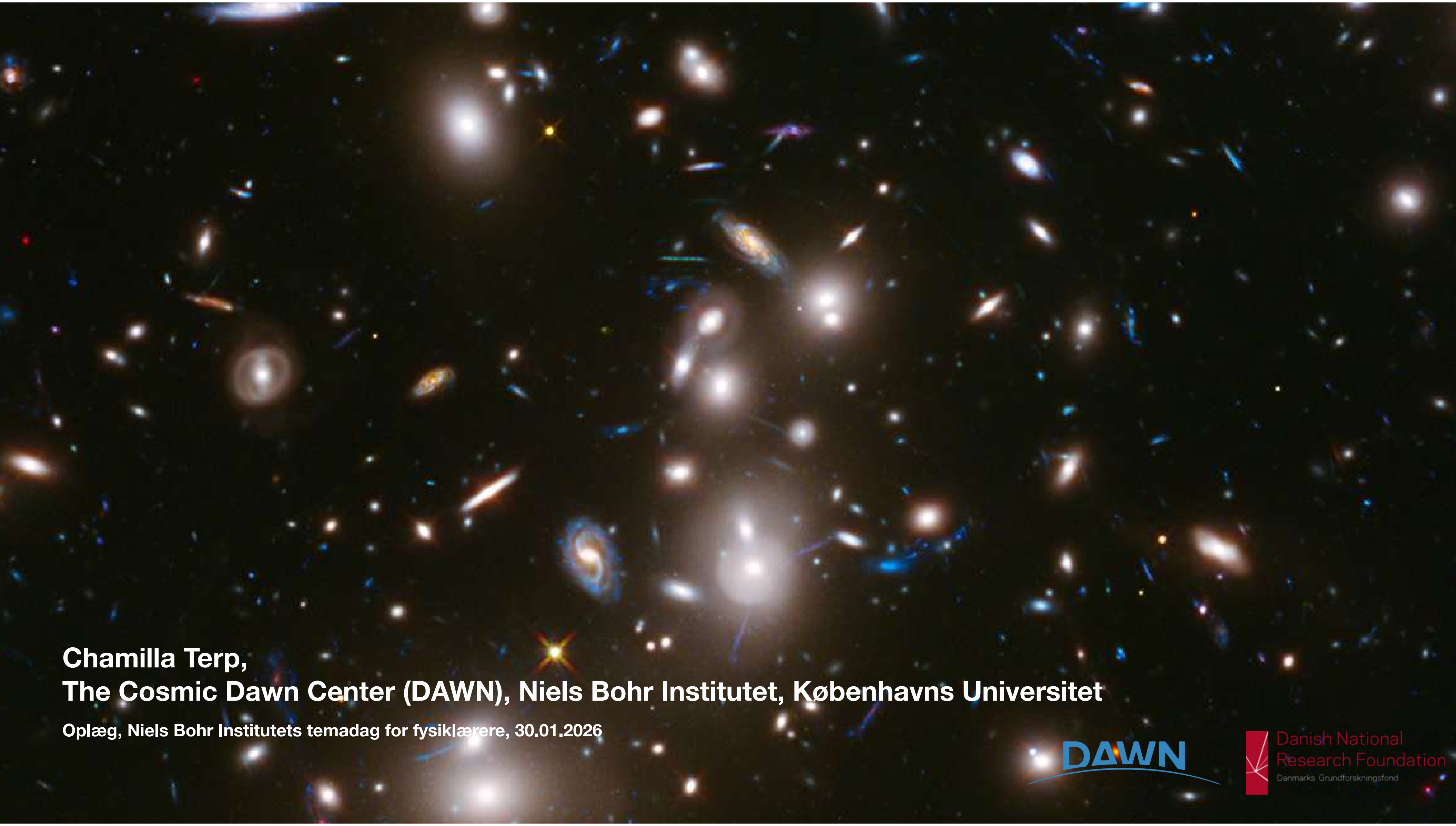
Hvad nu?

Flere galaksehobe!



Terp et al. in prep.





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Oplæg, Niels Bohr Institutets temadag for fysiklærere, 30.01.2026

DAWN
Danish National Research Foundation
Danmarks Grundforskningsfond