Insights from the Earliest Galaxies on the Growth of Magnetic Fields, and the Fine Structure Constant

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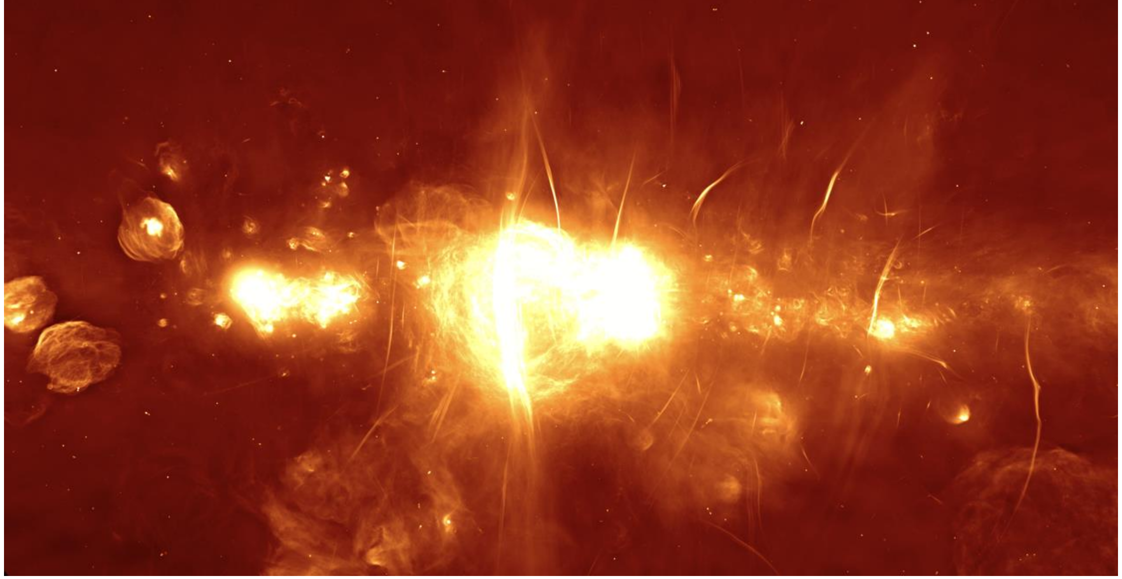
Motivation

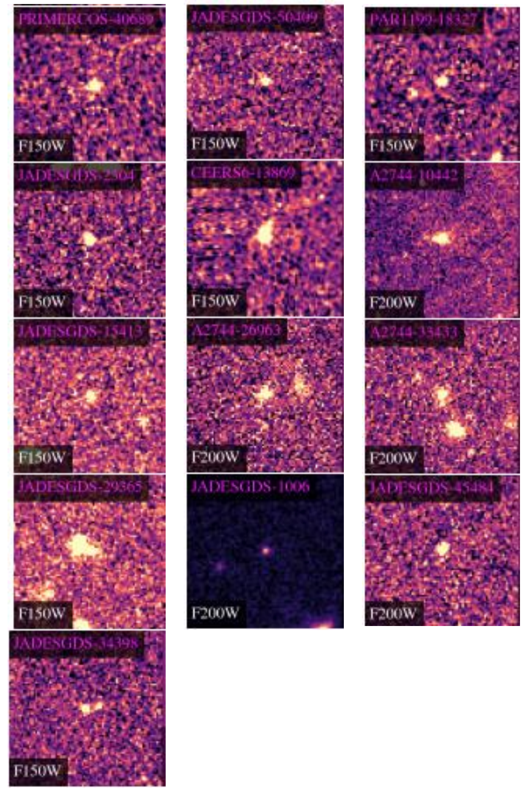


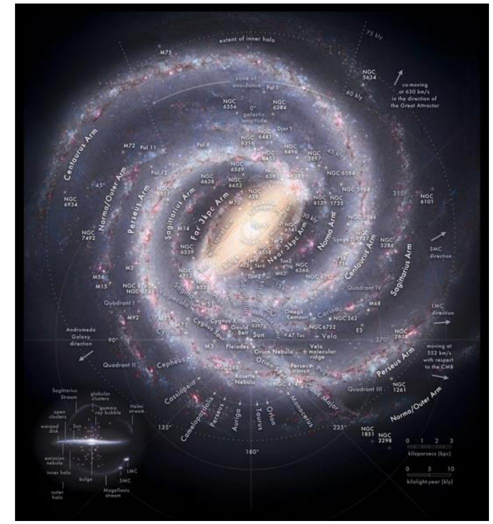
MeerKAT image of Galactic center

HST Image of 1Zw18

- Massive stars and magnetic fields (~μG) drive the evolution of galaxies
  - Massive stars drive feedback, remnants are the seeds of supermassive black holes
  - Magnetic fields drive cosmic rays, seeds for relativistic particles
- The distant Universe probes lower metallicity environments, fewer dynamical timescales.

z>5 Lyman-Break Galaxy Morphologies

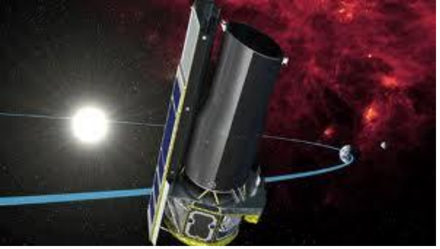




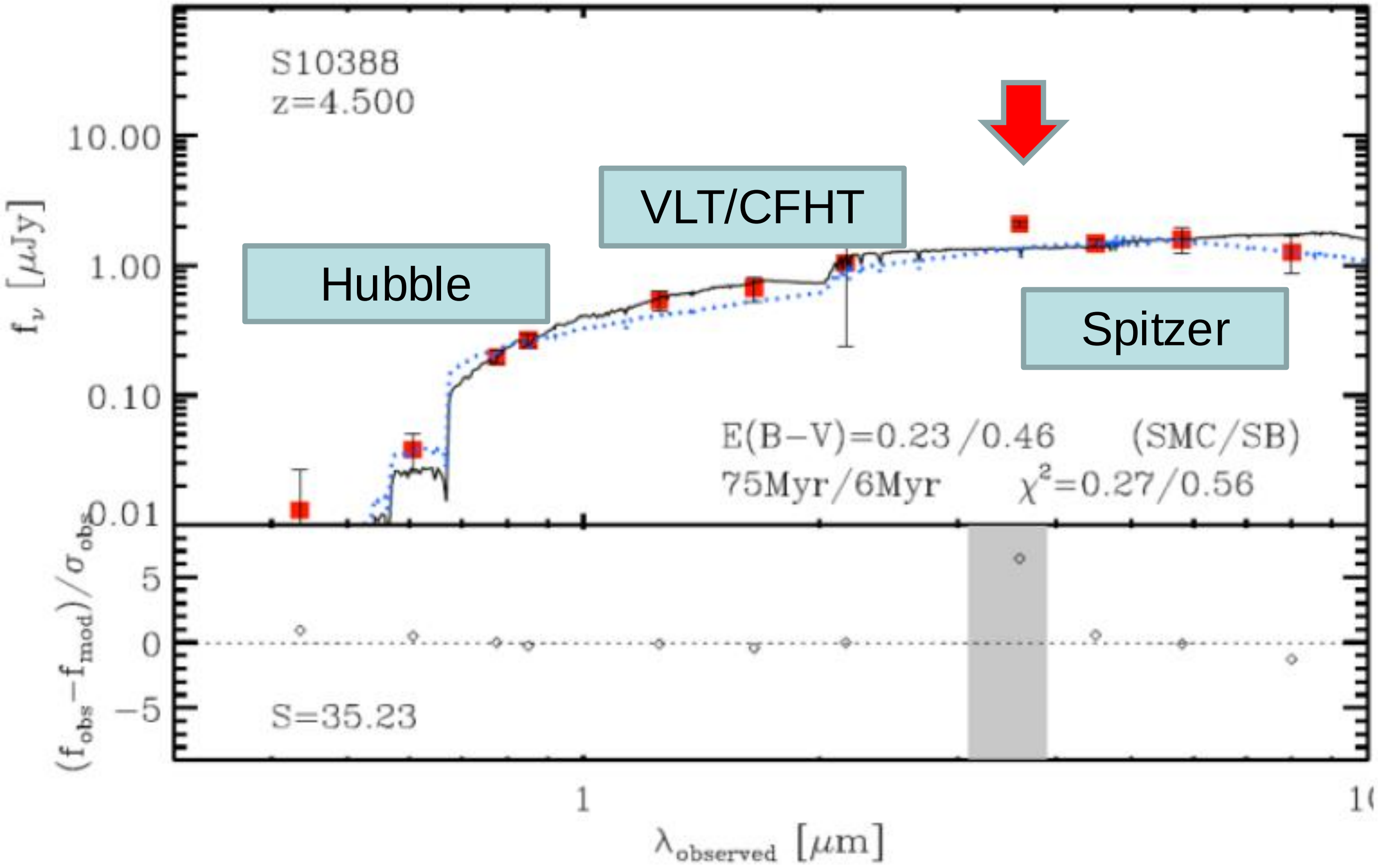
Our Galaxy is:
x10 bigger
x30 less luminous

z~7-12 from JWST/NIRCAM, ~350 Myr after Big Bang
Morishita, RC et al. 2023

Un-remarkably blobby and small (<1 kpc) with some evidence of interactions in ~half the cases.
We did not build a $12B telescope just to do blob-ology ☺



The real science is in the multiwavelength characterization

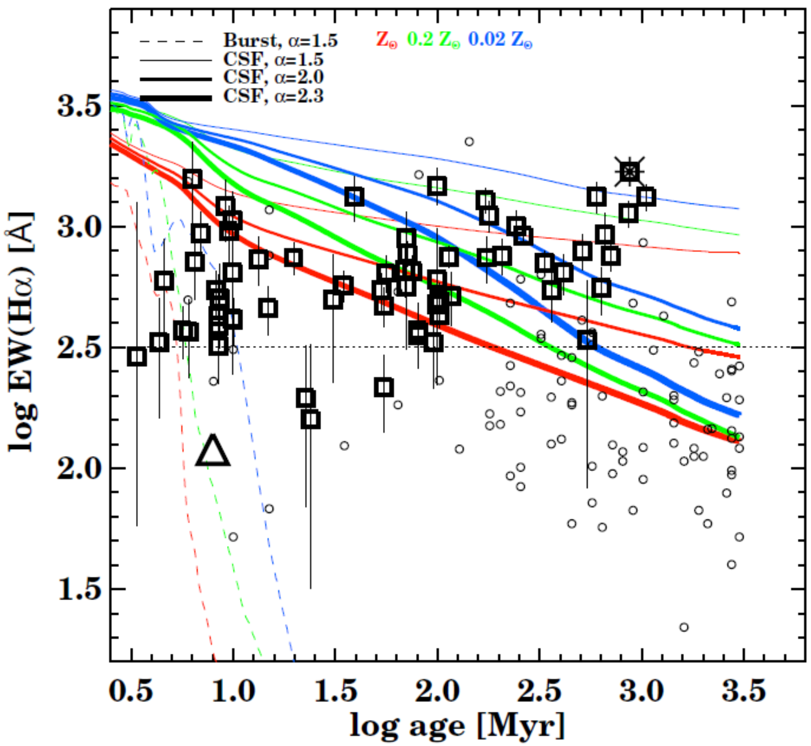


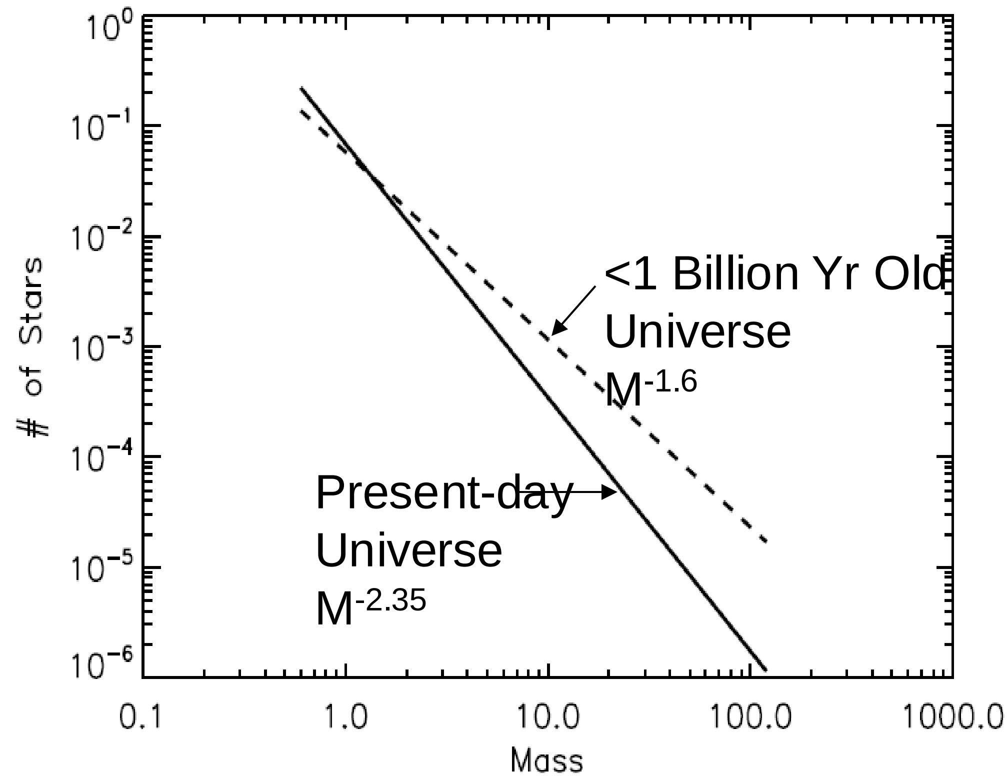
Halpha nebular emission: seen in 70% of 3.8<z<5 galaxies in Spitzer data

Chary et al. 2005

Shim, RC, et al. 2011

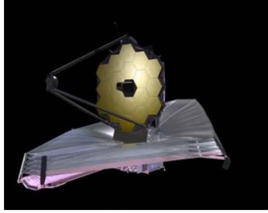
The data favor near continuous production of massive stars for ~100s Myr with a top-heavy IMF

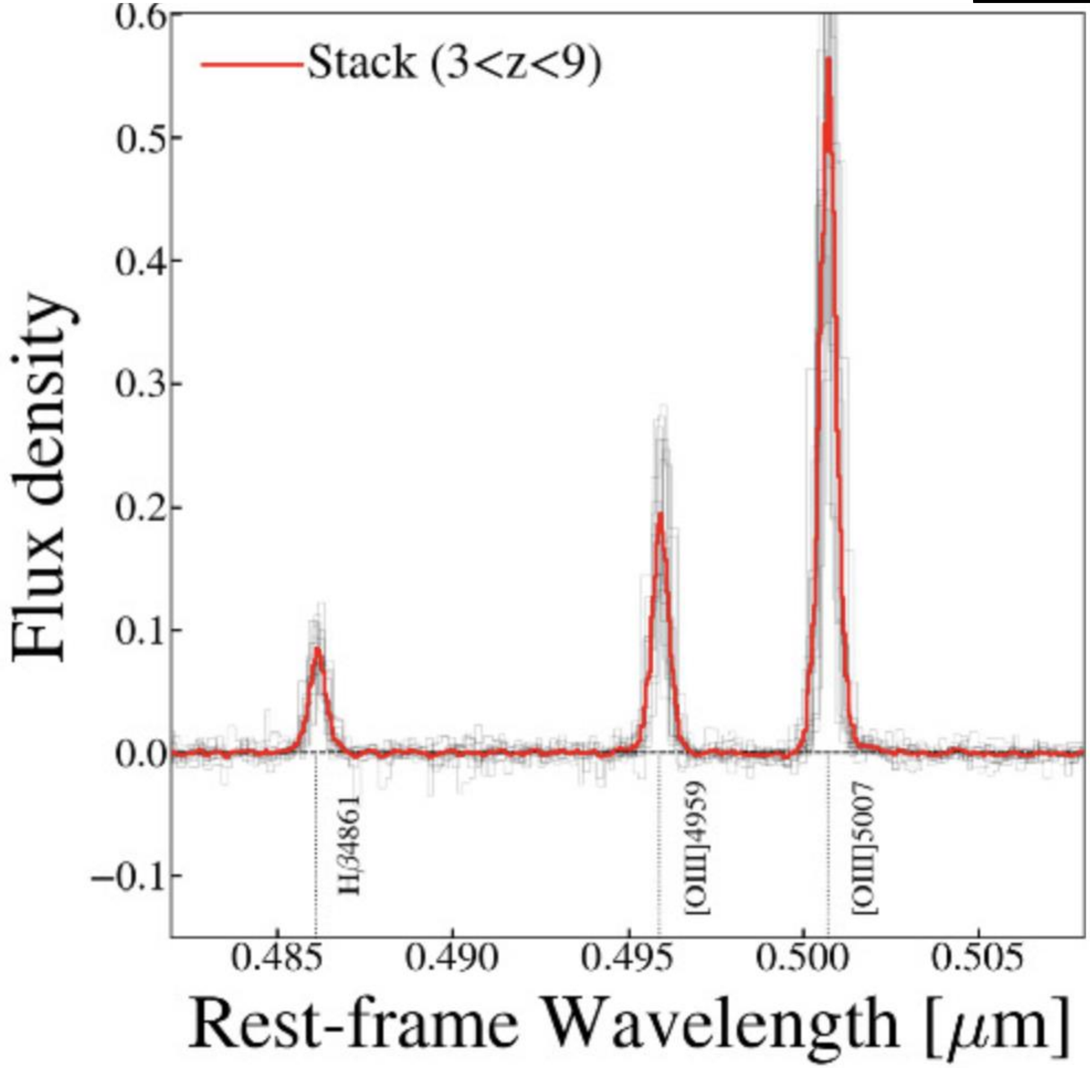




Shim, RC et al. 2011, RC 2008

A Spectrum is Worth a 100(0) Images
- F. Shu

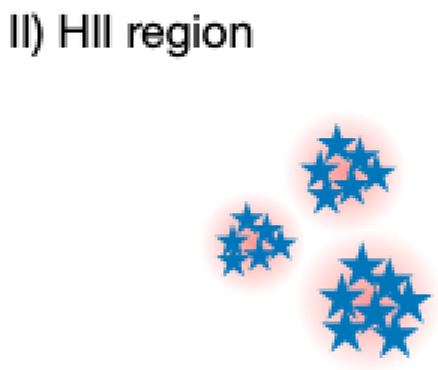


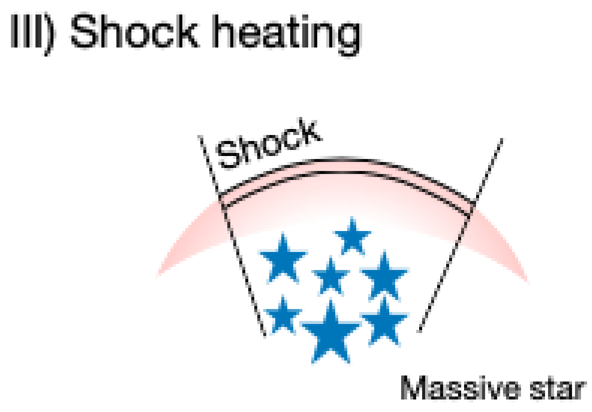


Morishita et al.+RC 2023

Insights into the Origin of Magnetic Fields in Galaxies

Concentrated radiation fields produce high-velocity shocks

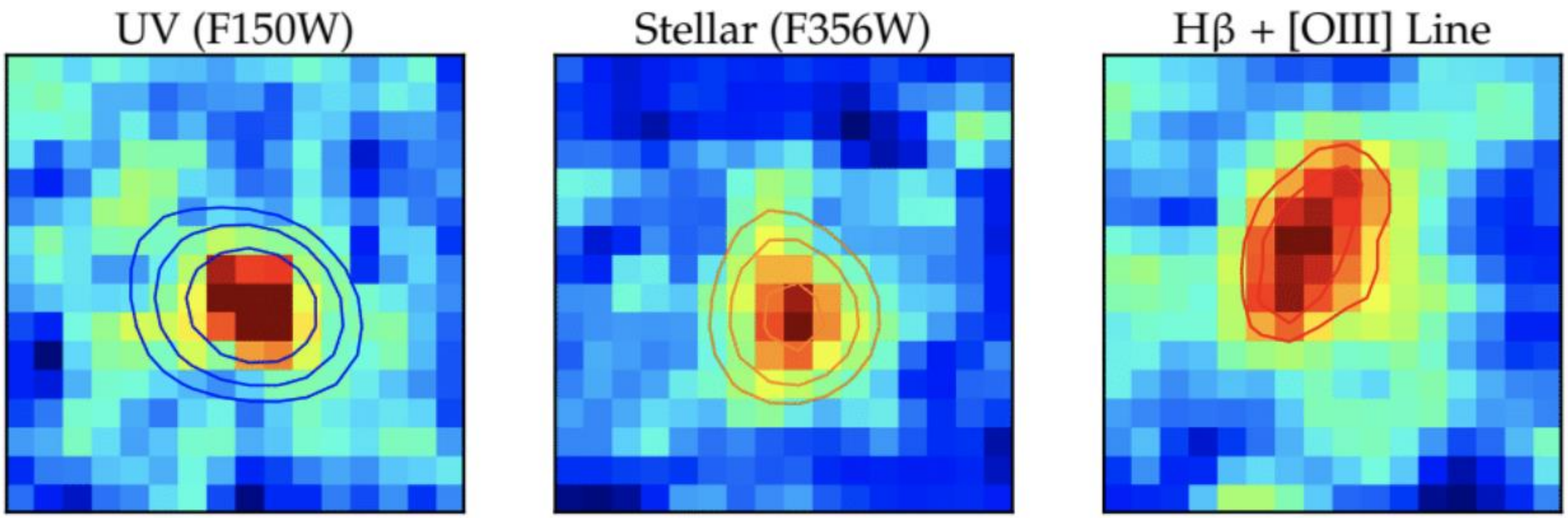




- Lines can be excited in photoionization regions from radiation
- But radiation pressure on the gas drives shocks which also produce line emission
- Only JWST medium/narrow-band imaging is sensitive to probing this efficiently…

Daikuhara et al.+ RC 2024

Spatial distribution of ionized gas separates shocks from photoionization



Daikuhara et al.+ RC 2024

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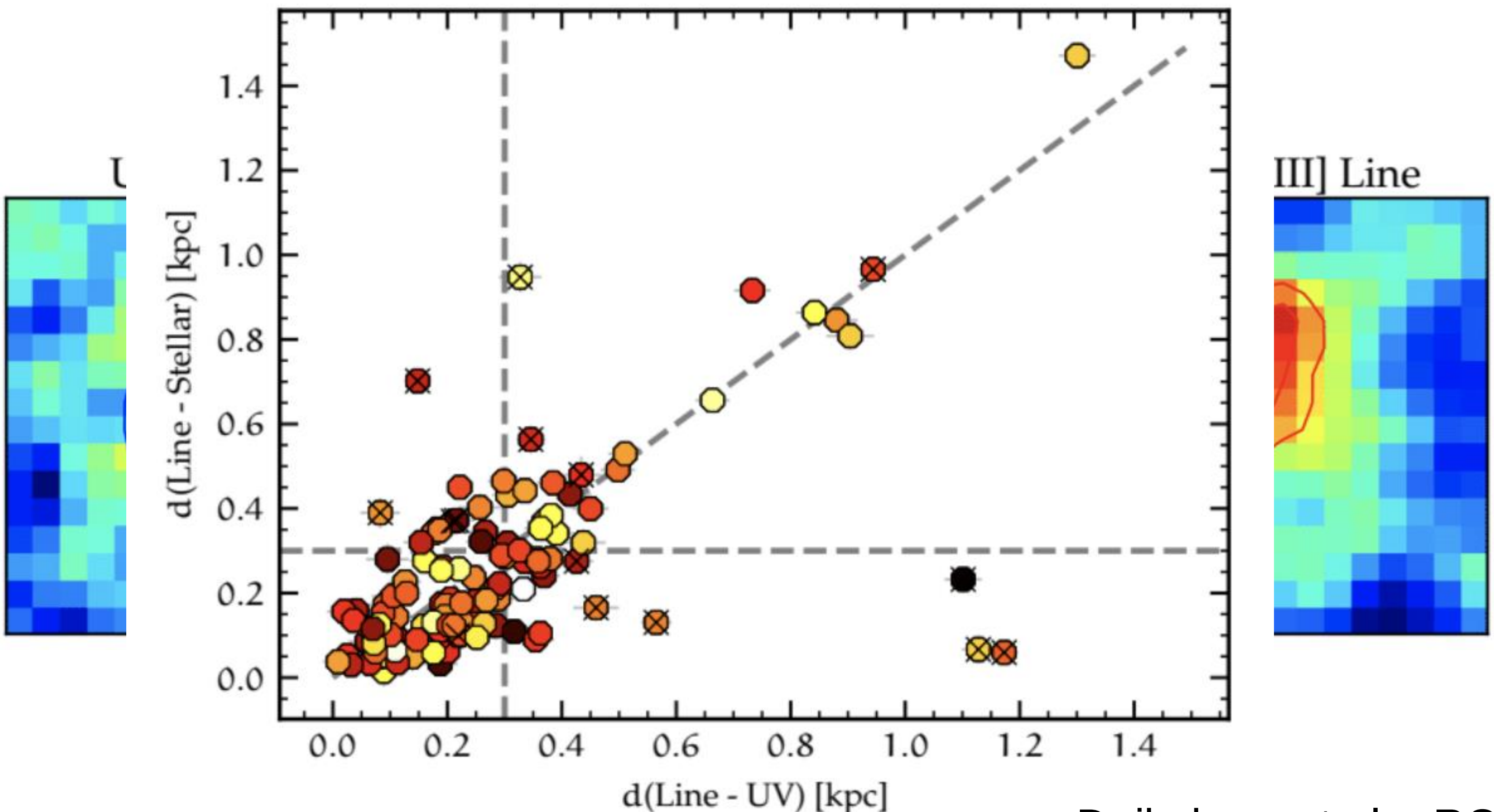
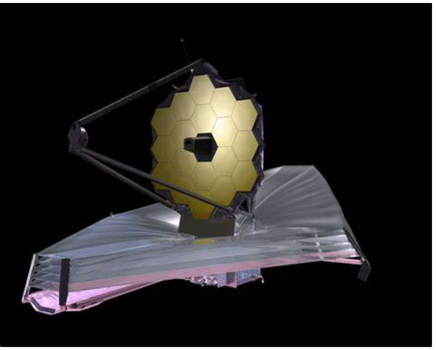
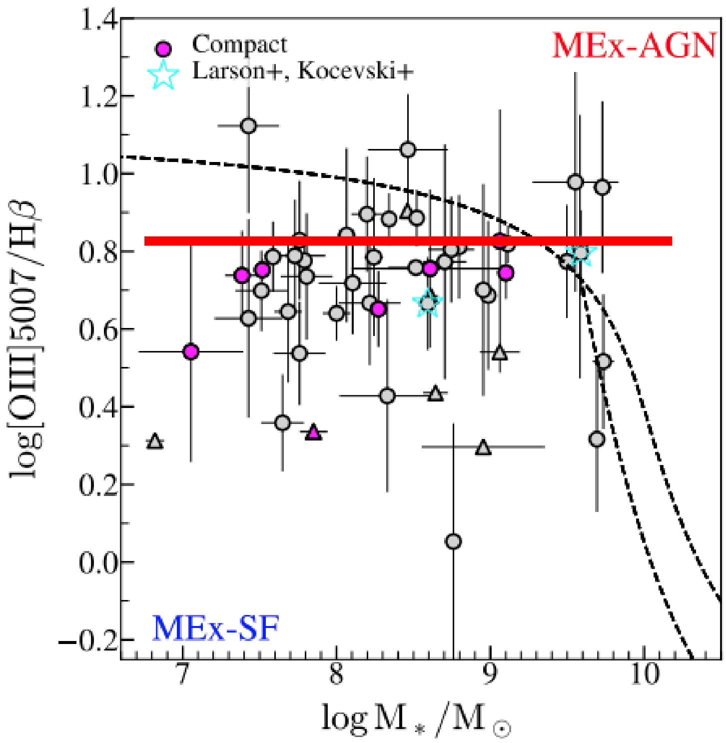
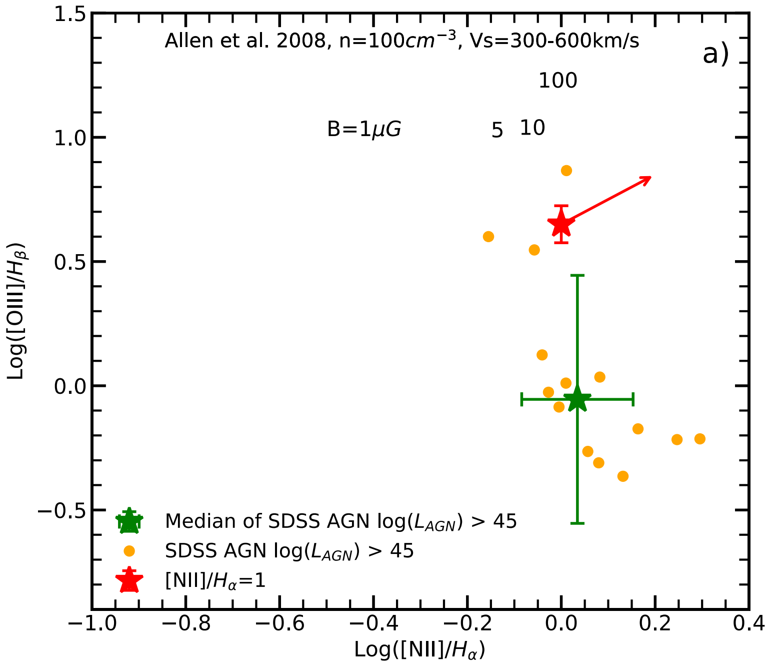


Daikuhara et al.+ RC 2024



[OIII]/Hbeta ratios are high in some galaxies, indicating shocks

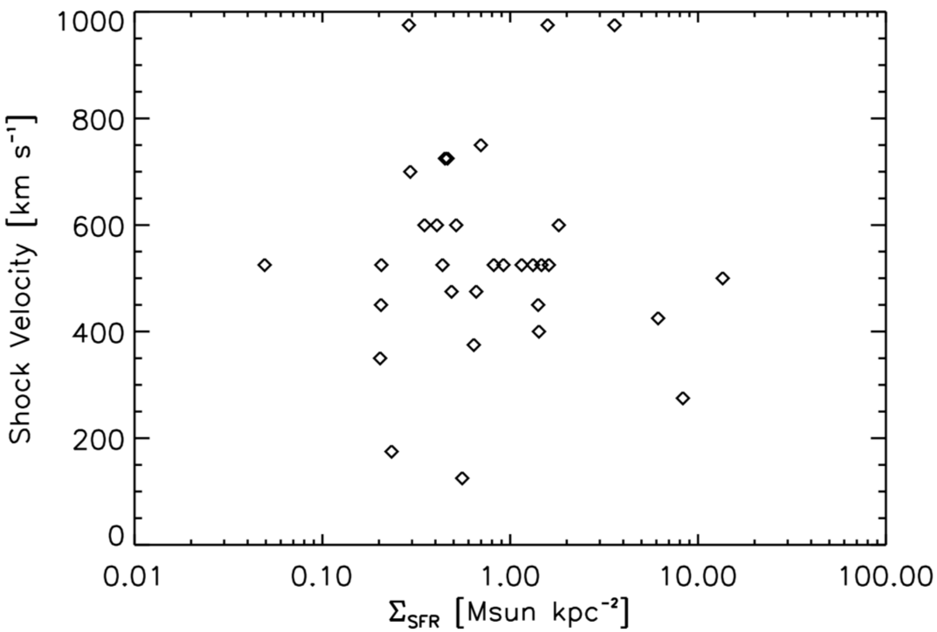




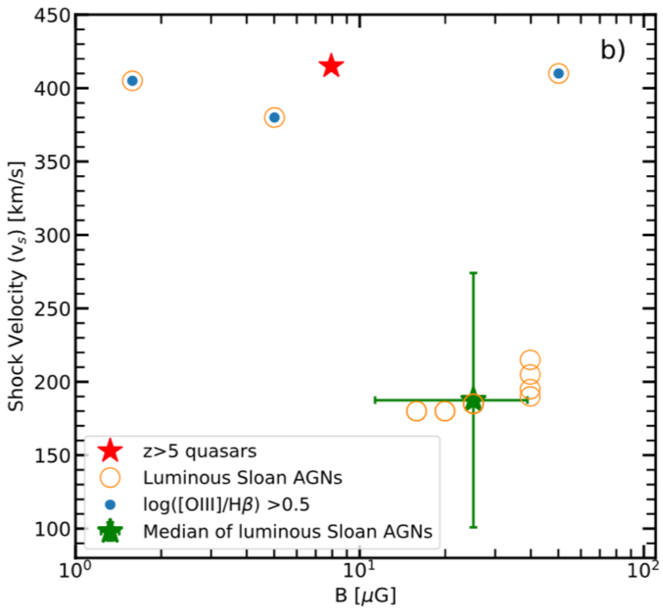
Star-forming galaxies 5<z<9.5
Morishita et al. 2023, Shim & RC 2013

Spitzer+WISE, quasar NLR z~6.4
Lee & Chary 2022

Magnetic Fields of few microGauss and Shock Velocities of 400km/s at t<1 Gyr

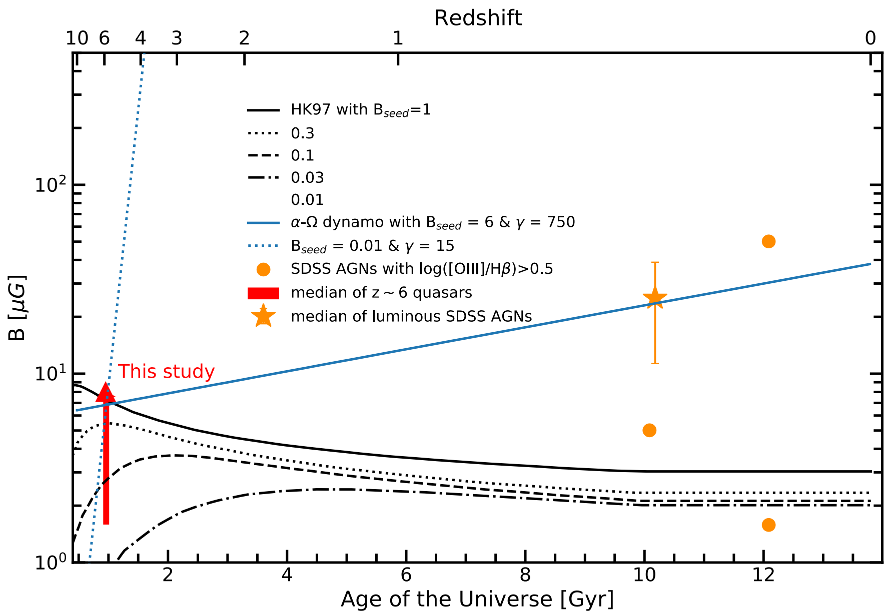


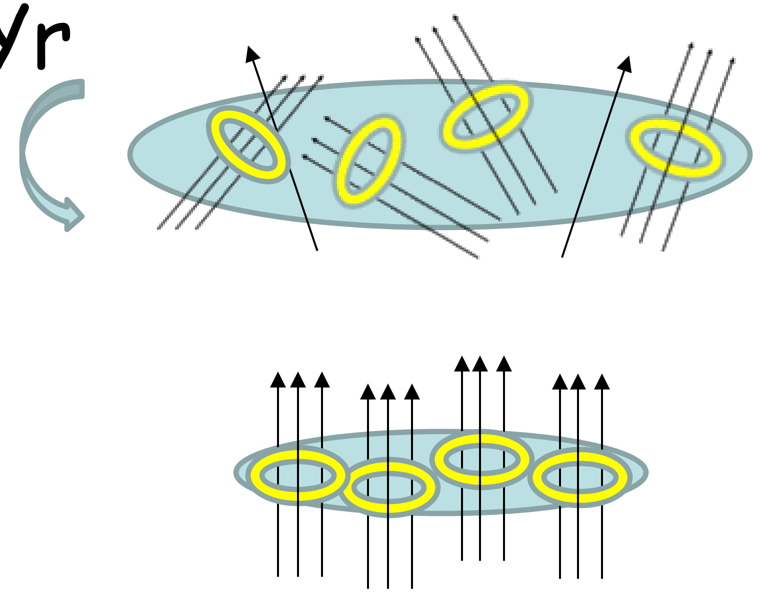
Star-forming galaxies 5<z<9.5
Morishita et al. +RC, 2023
RC et al. 2024 in prep.



Spitzer+WISE, quasars z~6.4
Lee & Chary 2022

[OIII] is very strong and B field is >1μG at t=1 GYr

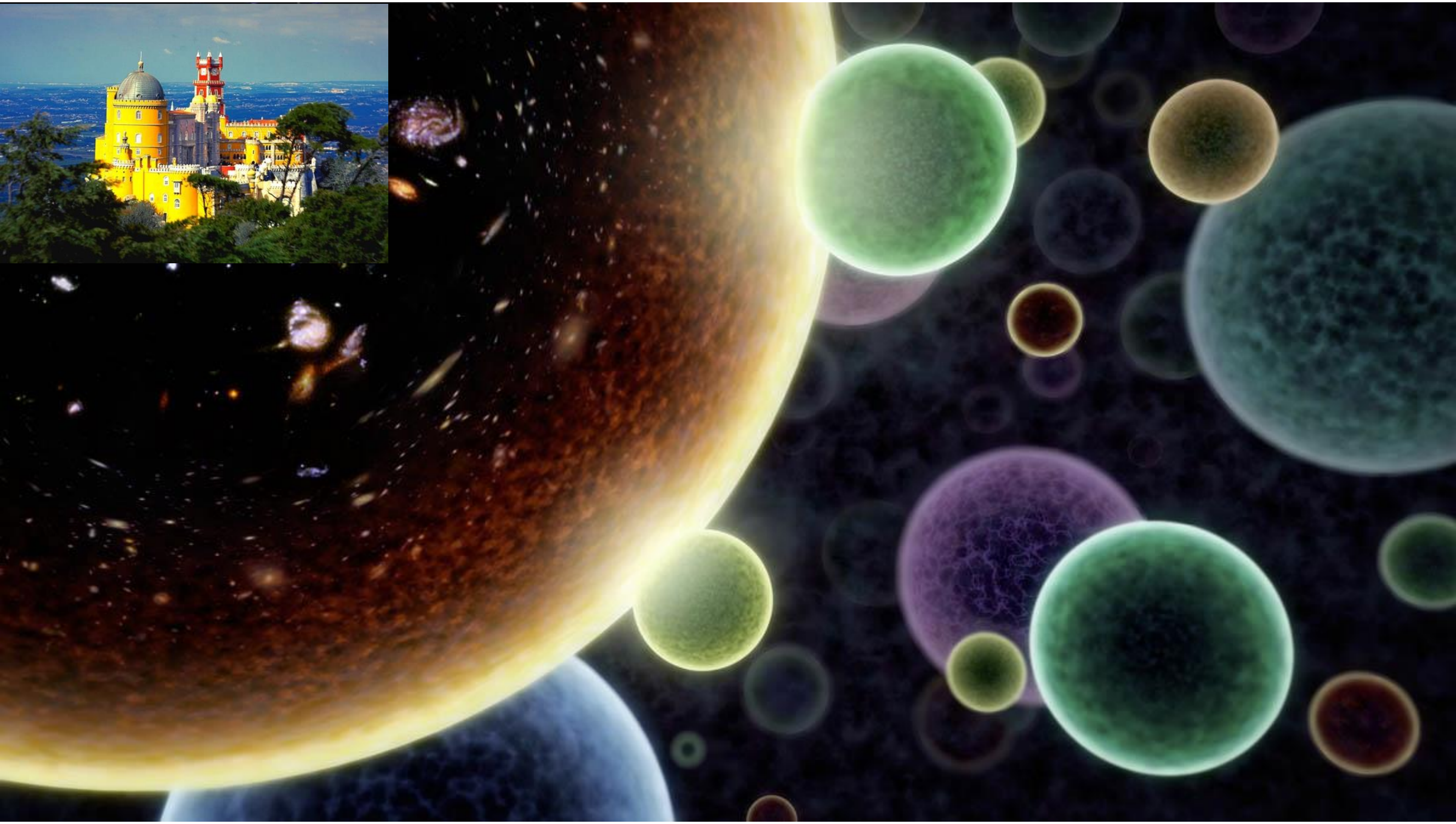




Conclusion

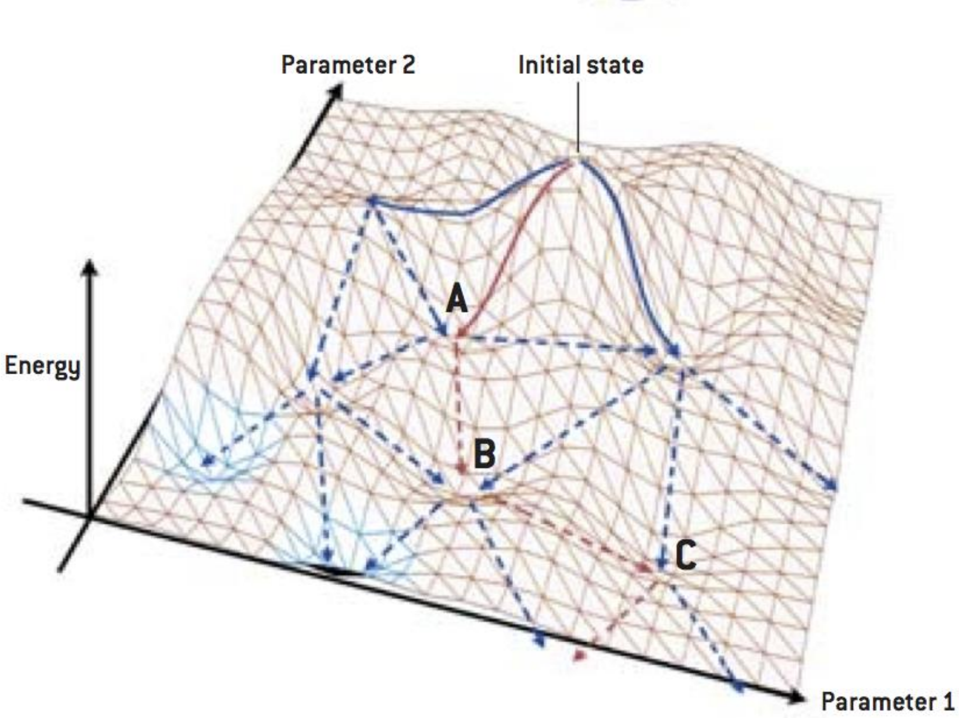
- Magnetic fields were in place within t=1 billion years
- The seed field must have been >0.1 microGauss amplified to 1-10 microGauss in galaxies

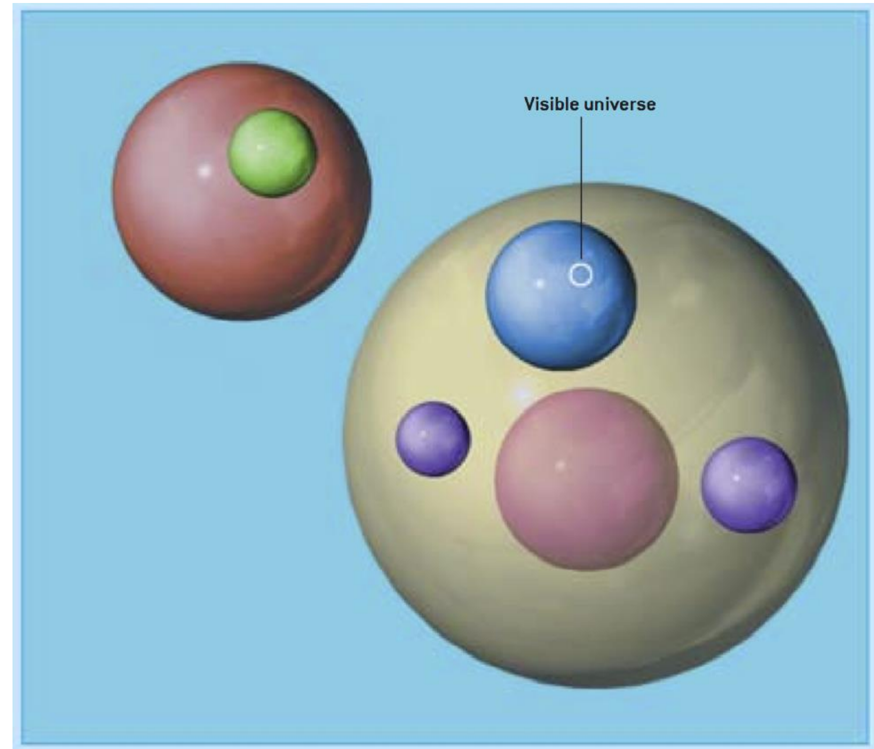
Beyond the Edge of the Universe…..



RC, 2016, ApJ

What causes the Big Bang and Inflation?
From String Theory....





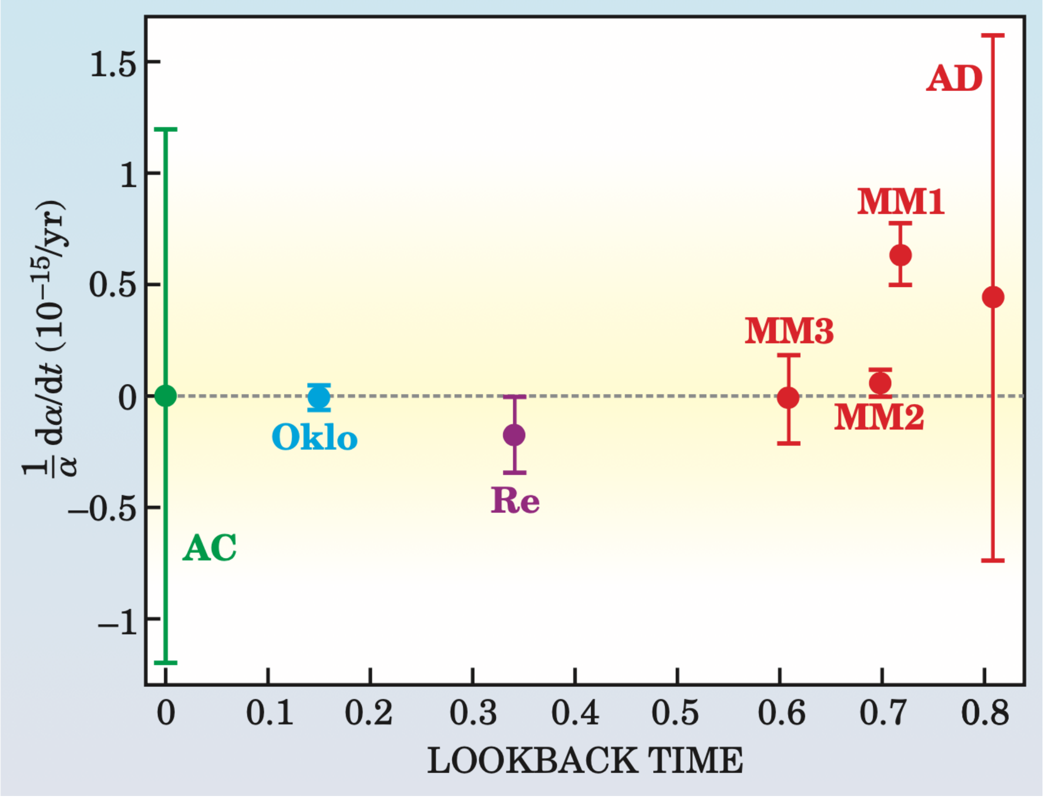
Phase transitions from multi-dimensional strings

If you don't want God, you'd better have a multiverse – Bernard Carr

Kallosh, Kachru, Linde, Trivedi (KKLT) 2003
Bousso & Pochinski

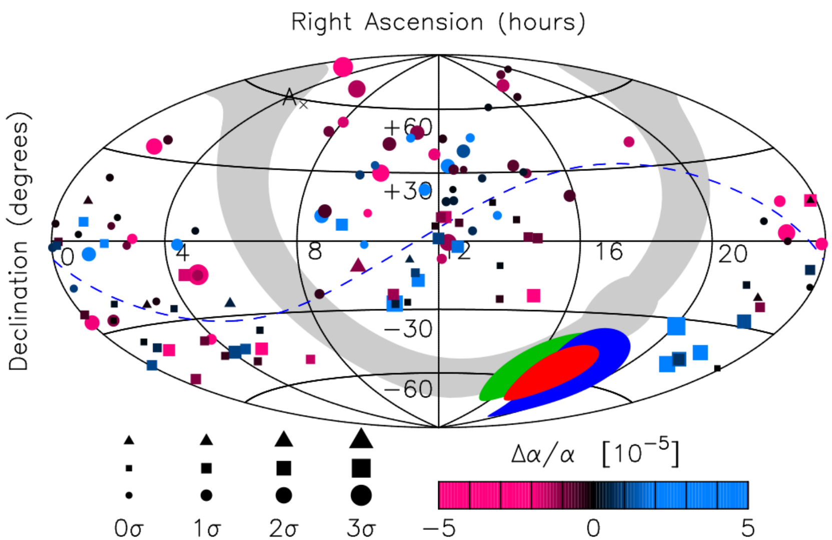
Time-varying dark energy can be well probed by looking at dimensionless quantities: fine structure constant

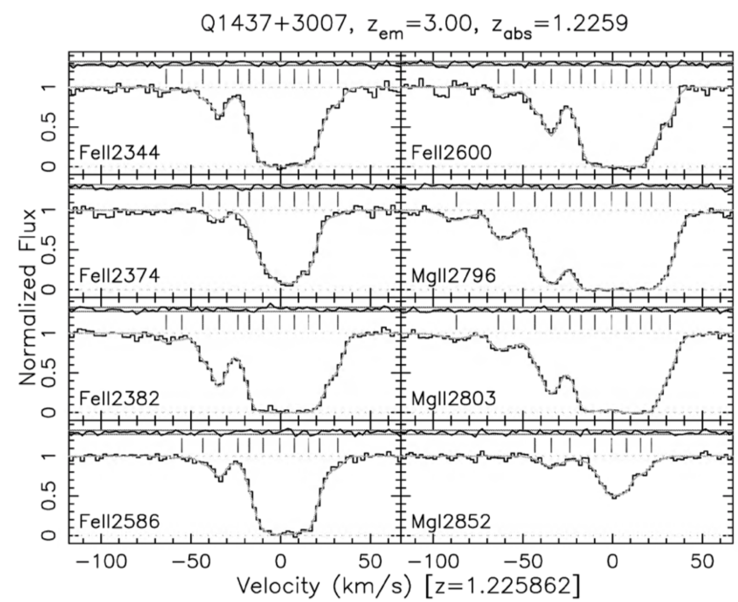
To assess if the Universe is homogeneous and isotropic,
need to study the variation of dimensionless quantities.
$\boldsymbol{\alpha}$~1/137~$e^2/\hbar c$ (in CGS)



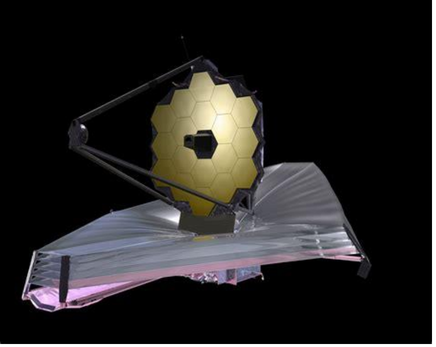
K. Olive et al. 2004

QSO absorption lines study suggest some variation at the ~4 sigma level

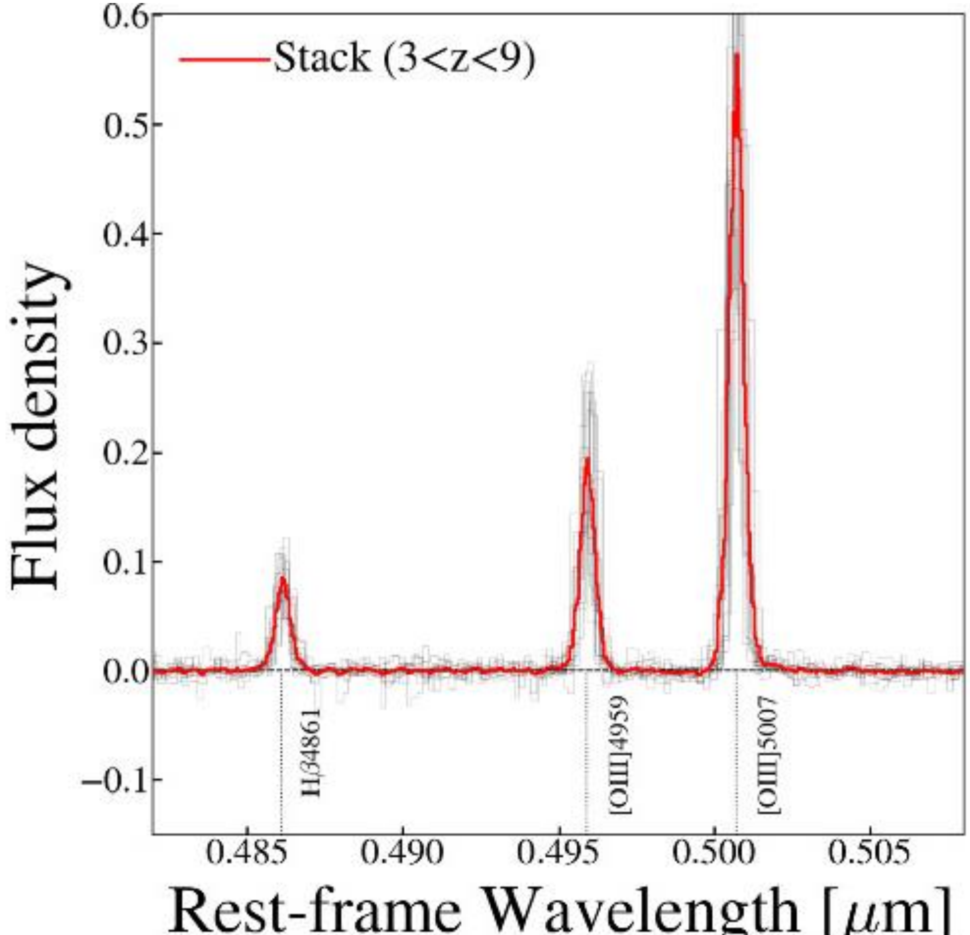




Webb et al., 2011, claim a dipole at 4.2 sigma with lower alpha in the past



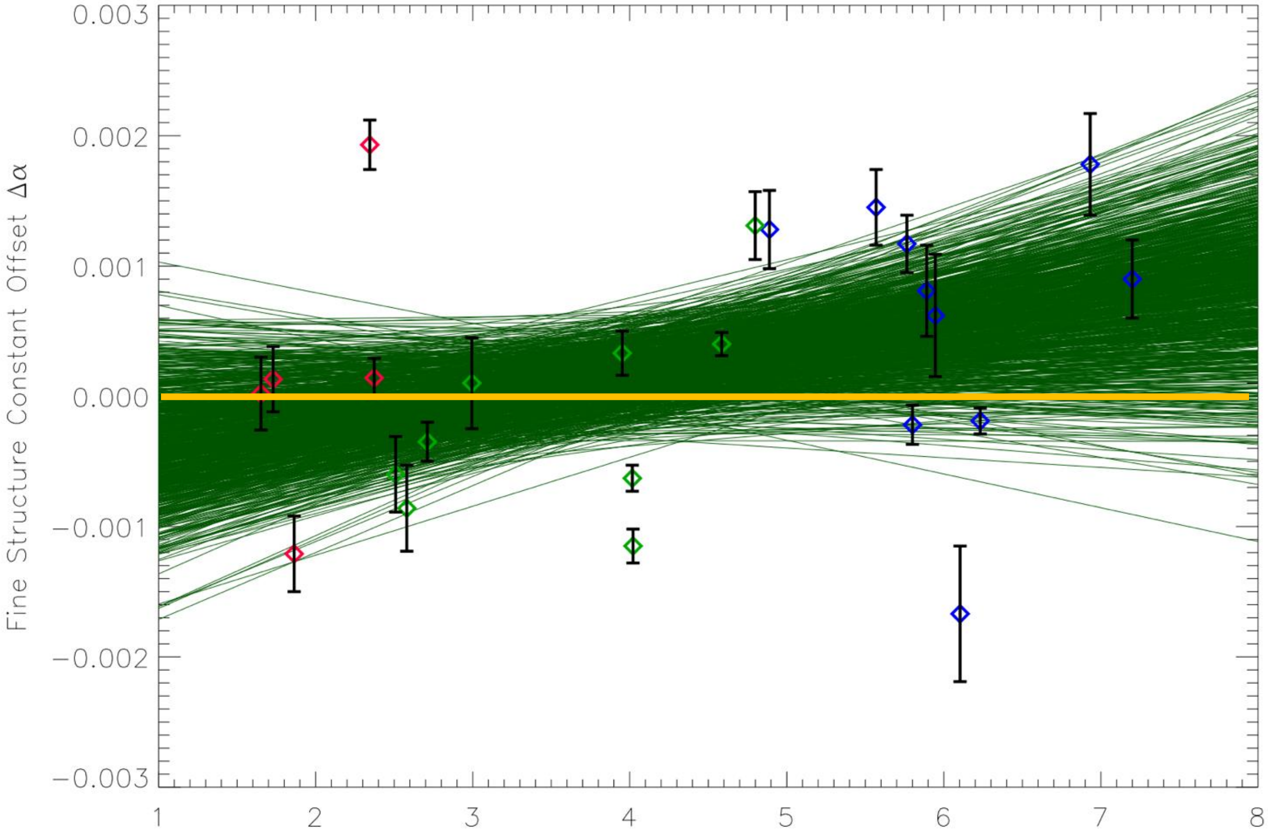
With JWST, the [OIII] doublet is easily detected



We can also see [SII]
Morishita et al. + RC 2024
See also Jiang et al. 2024

Constraints from JWST on α

Offset of Alpha from 1/137



RC, Morishita, in prep.

Redshift

- Consistent with no variation
- With samples of ~100,000 through archival multi-object spectroscopic samples, in 5 years time, we'll get into an interesting regime of $\sim 10^{-6}$

Summary

A penny for each properly calibrated
JWST High Resolution Spectrum of [OIII] or [SII] emitter…..

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  - likely due to a top-heavy IMF in some cases.

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- Strong evidence for high shock velocities (>400 km/s) and magnetic field (~1-10 microG) strengths
  - First evidence that magnetic fields arise from currents in the turbulent ISM and get amplified by a dynamo process.

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- Strong evidence for high shock velocities (>400 km/s) and magnetic field (~1-10 microG) strengths
  - First evidence that magnetic fields arise from currents in the turbulent ISM and get amplified by a dynamo process.
- No evidence for variation in the fine structure constant at 10^{-3} level but needs 3-5 years of galaxy samples to get into an interesting regime…

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