Shedding light on cosmic reionization with the James Webb Space Telescope

Jacopo Chevallard

Research Fellow at ESA-ESTEC

Outline

1) **Cosmic reionization**: what we (don't) know

2) **JWST** and its instruments

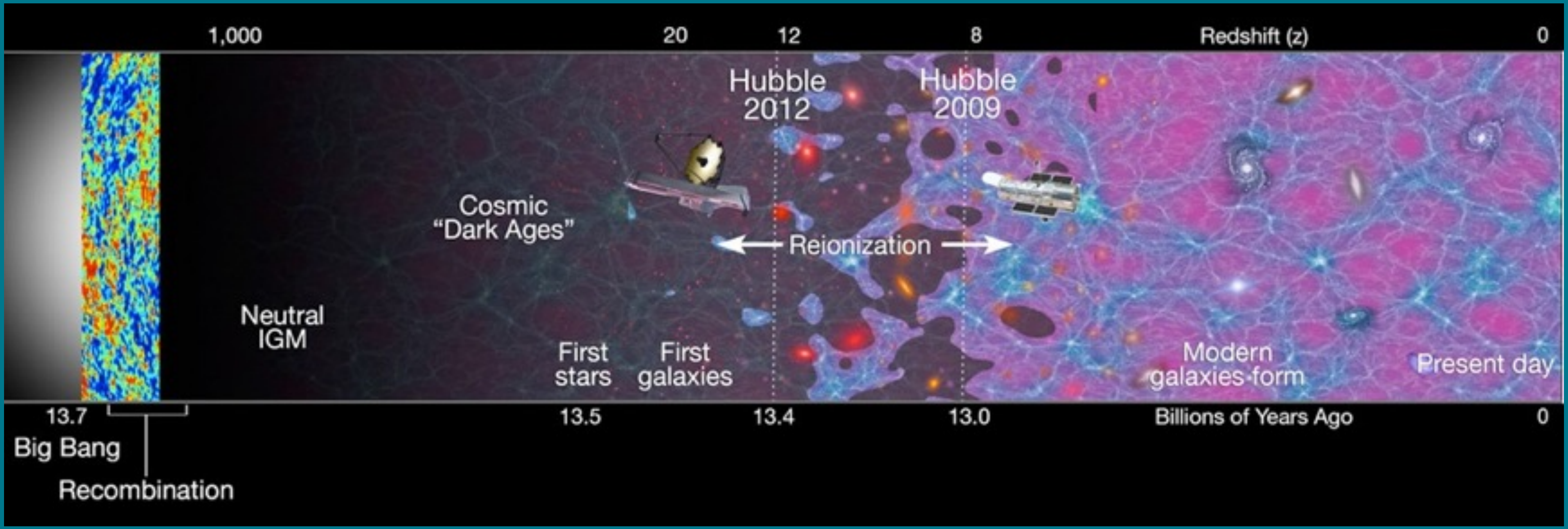
3) Current **constraints on** the cosmic **reionization history** and (some of) the future ones **with JWST**

4) **Identifying** and **characterising** the **sources** of ionising radiation with JWST

5) **Summary**

6) **Interpreting JWST** observations

Cosmic reionization



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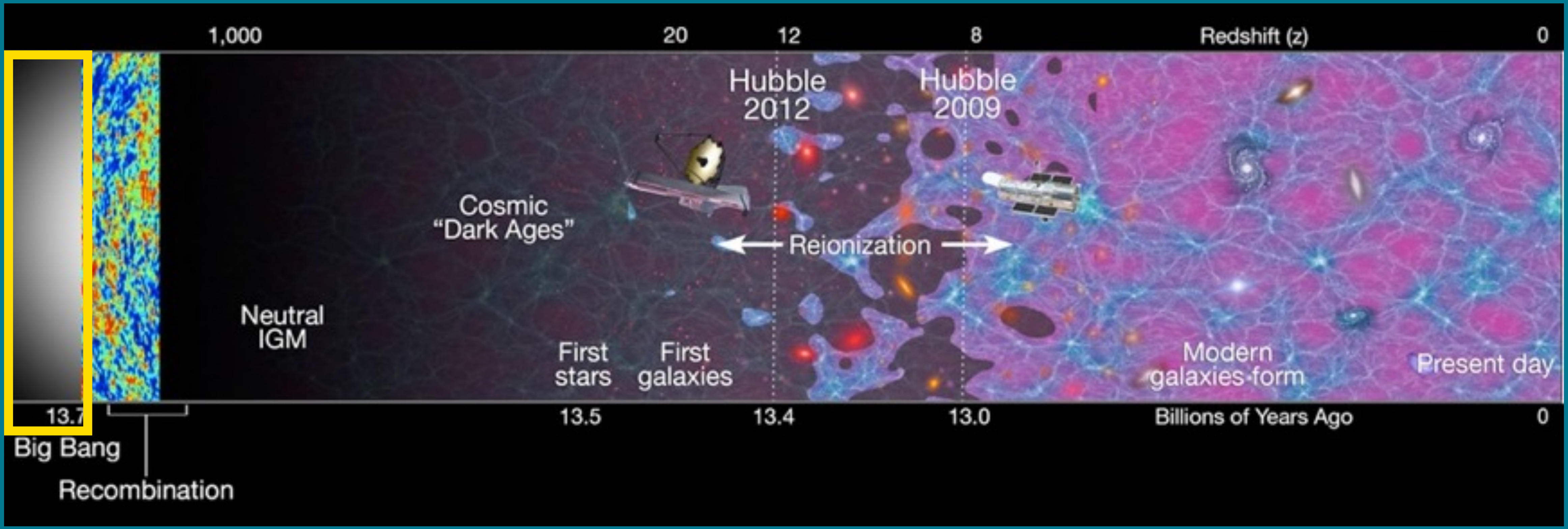

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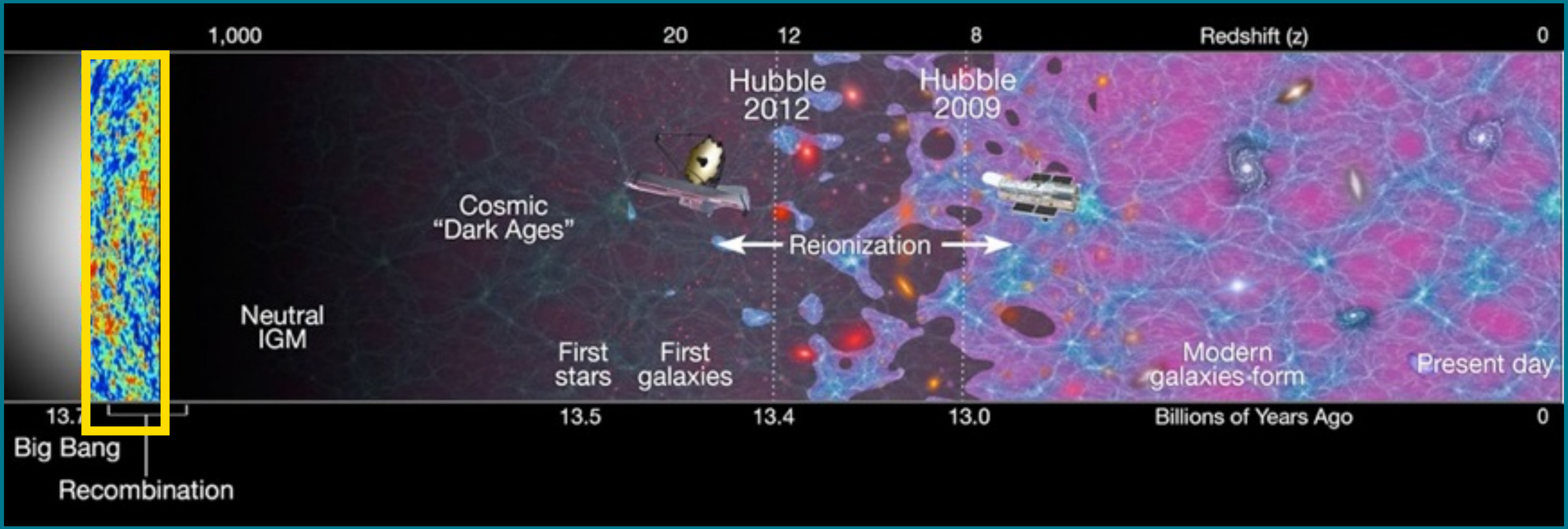

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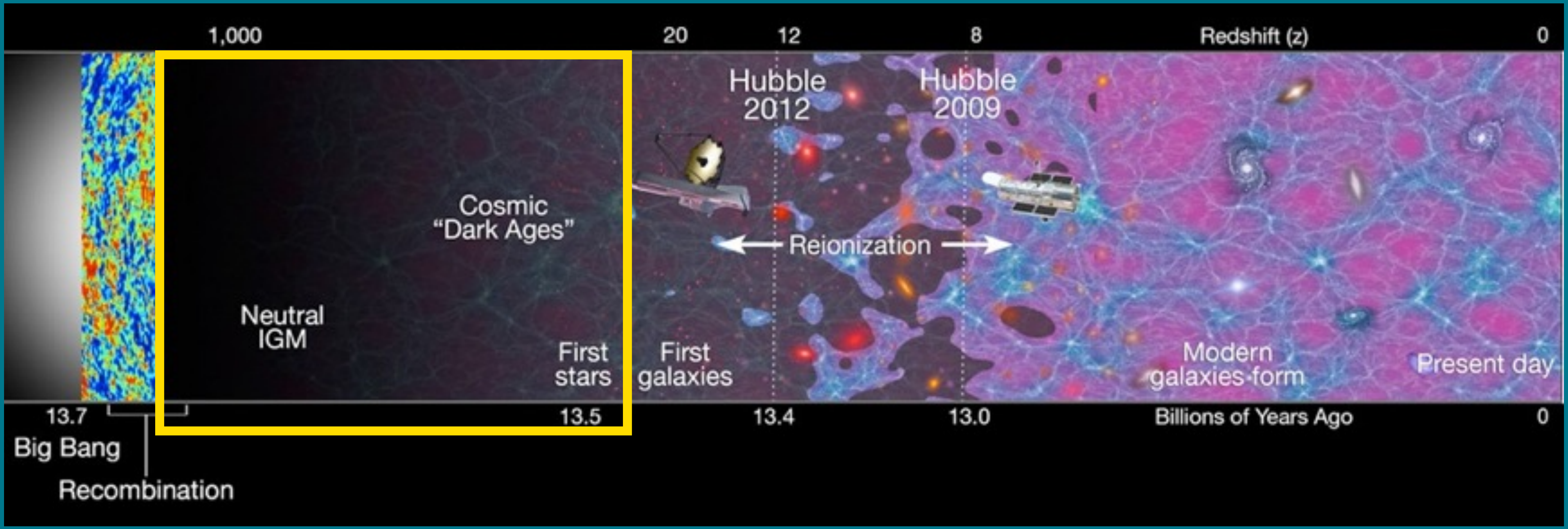

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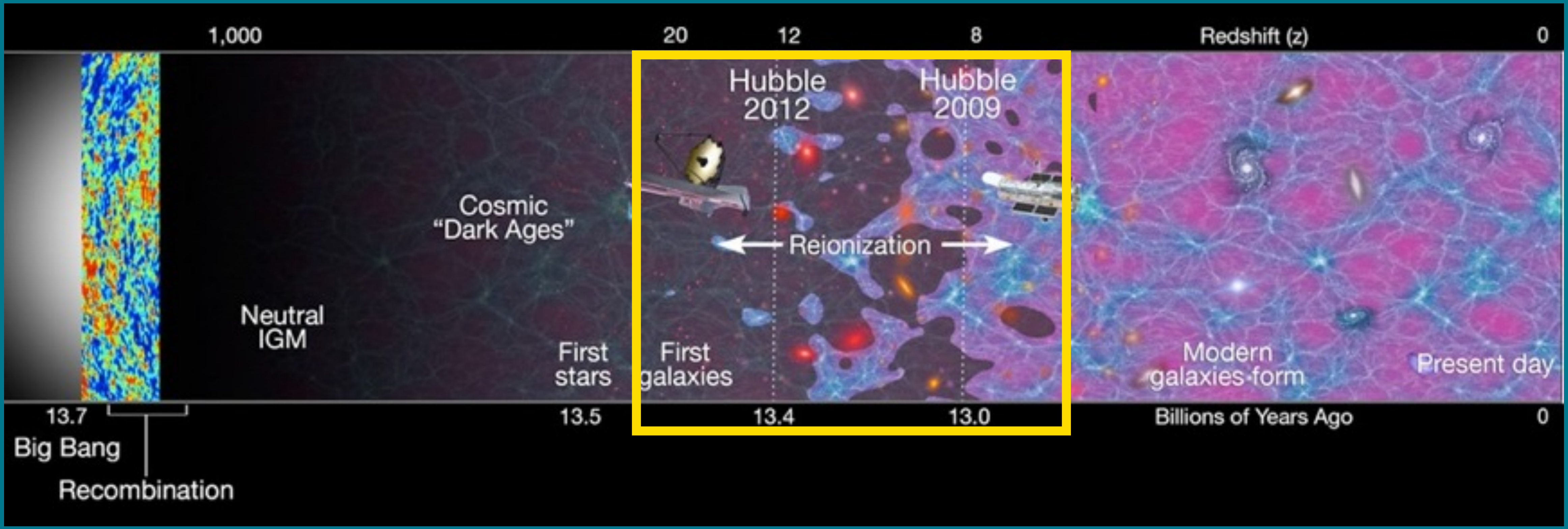

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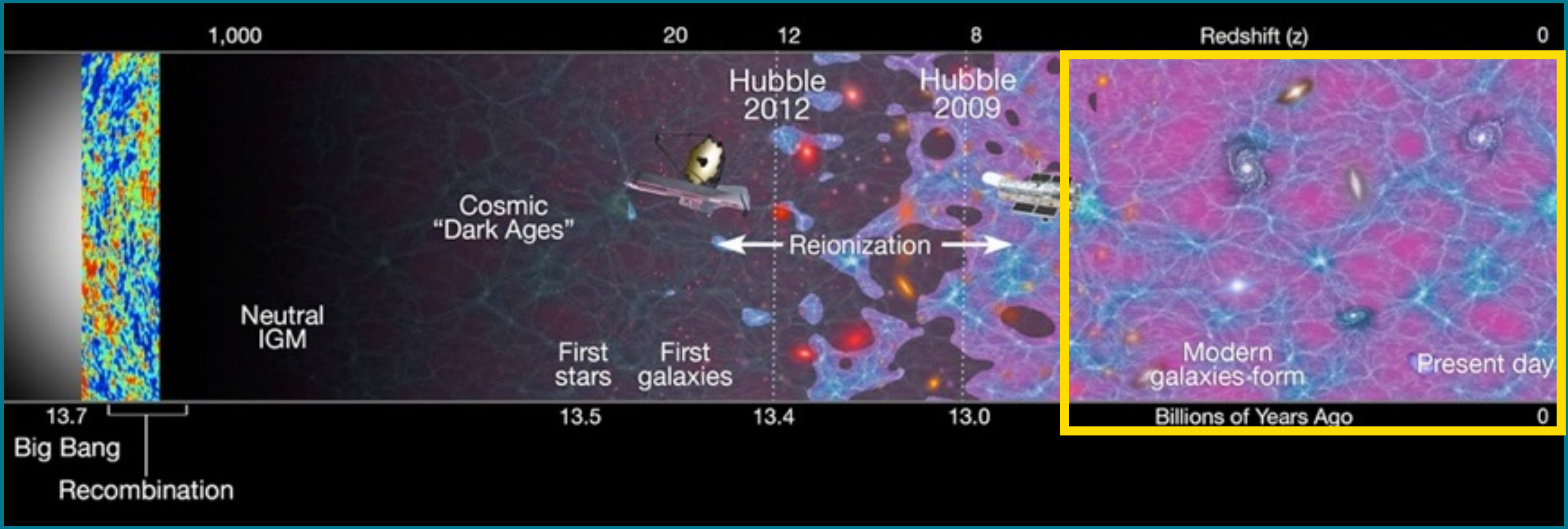

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Depends on **IGM** physical **properties**

Reionization: what we (don't) know

- **Current observations** (mainly) constrain **tail** of reionization:
  - **CMB** (Thoms. scatt. optical depth)
  - **high-z quasar** (GP trough, damping wings, "dark gaps")
  - high-z **GRB** afterglow **damping wing**

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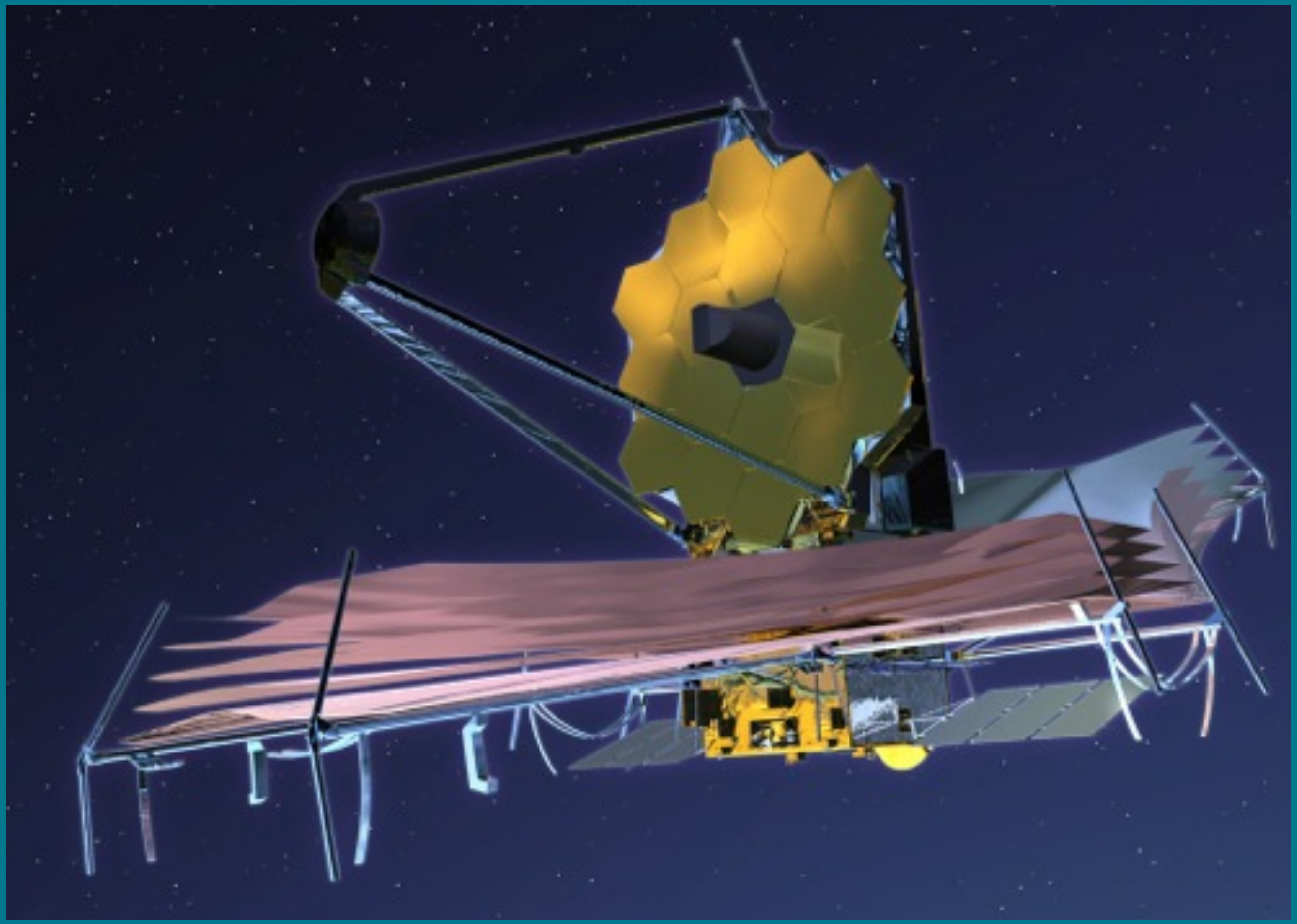
Major questions still to be answered

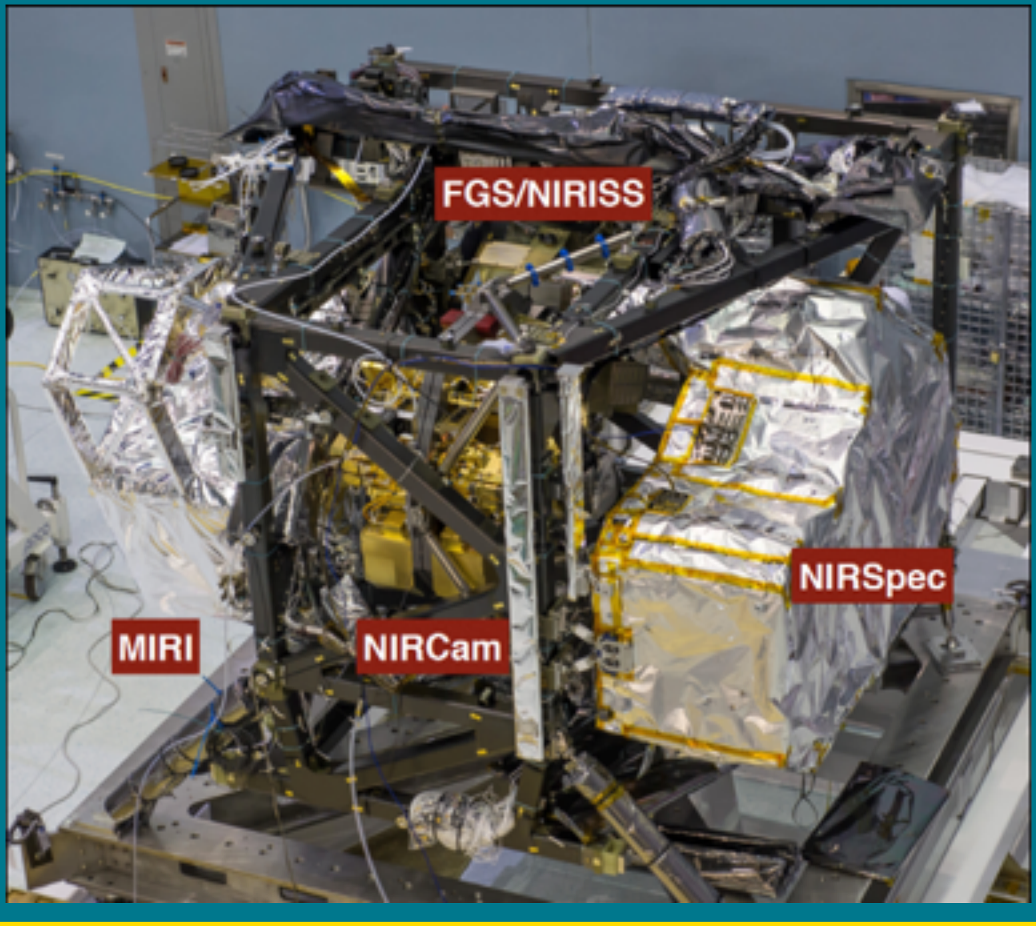
- When did **reionization start**, and how did it **proceed**? e.g. **rapid** *vs* **gradual**?
- Which **sources drove reionization**? SF **galaxies** *vs* **mini-quasars** *vs* **Pop. III** stars vs **X-ray binaries**? A (redshift-dependent) **mix** of them?
- How did **reionization affect** formation of **first galaxies** and super-massive **black holes**, and chemical **enrichment of IGM**?

The James Webb Space Telescope

JWST



- ★ 6.5 m primary mirror
- ★ **7x HST** collecting **area**
- ★ imaging + spectroscopy in **0.6-28 micron** range



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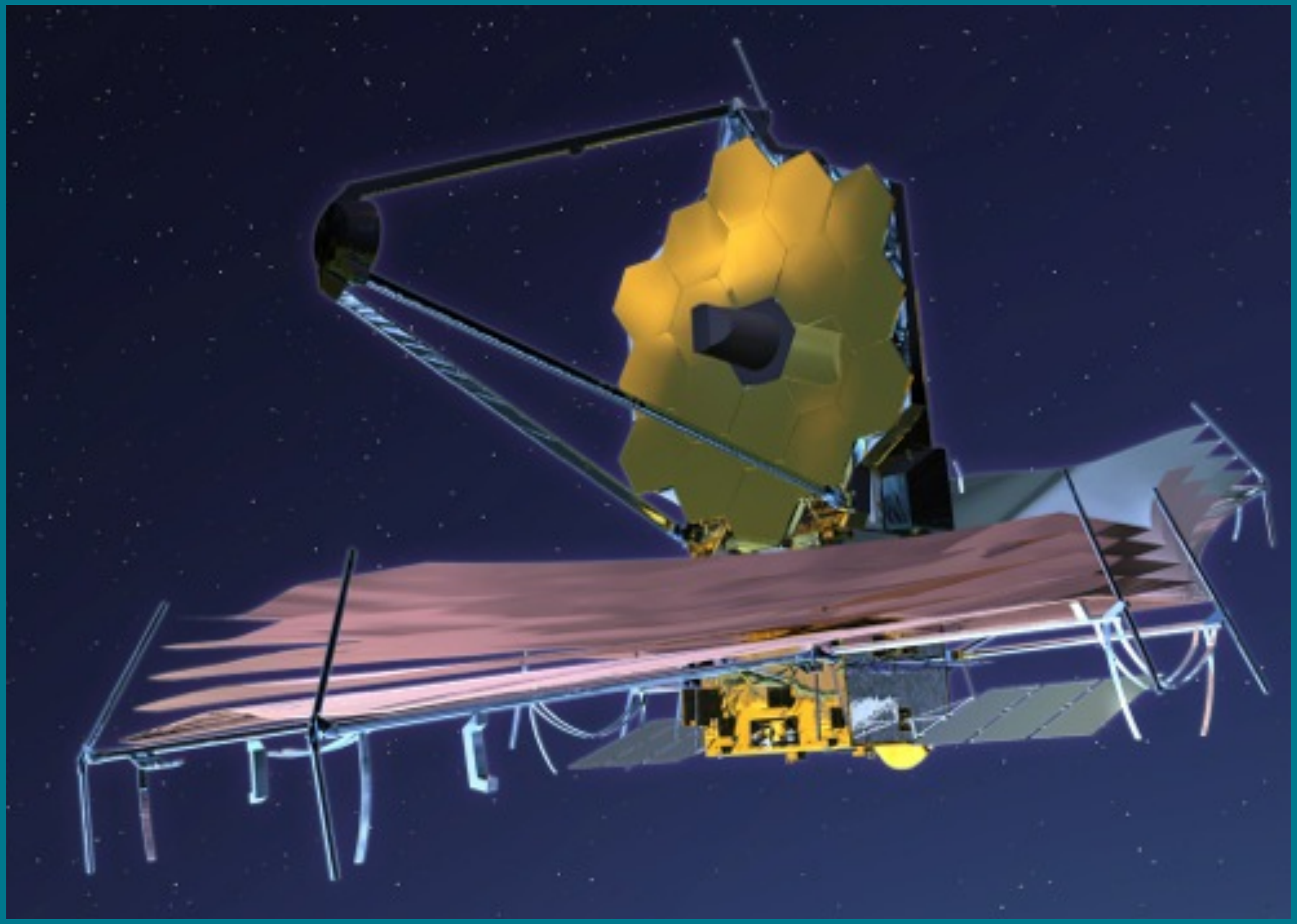
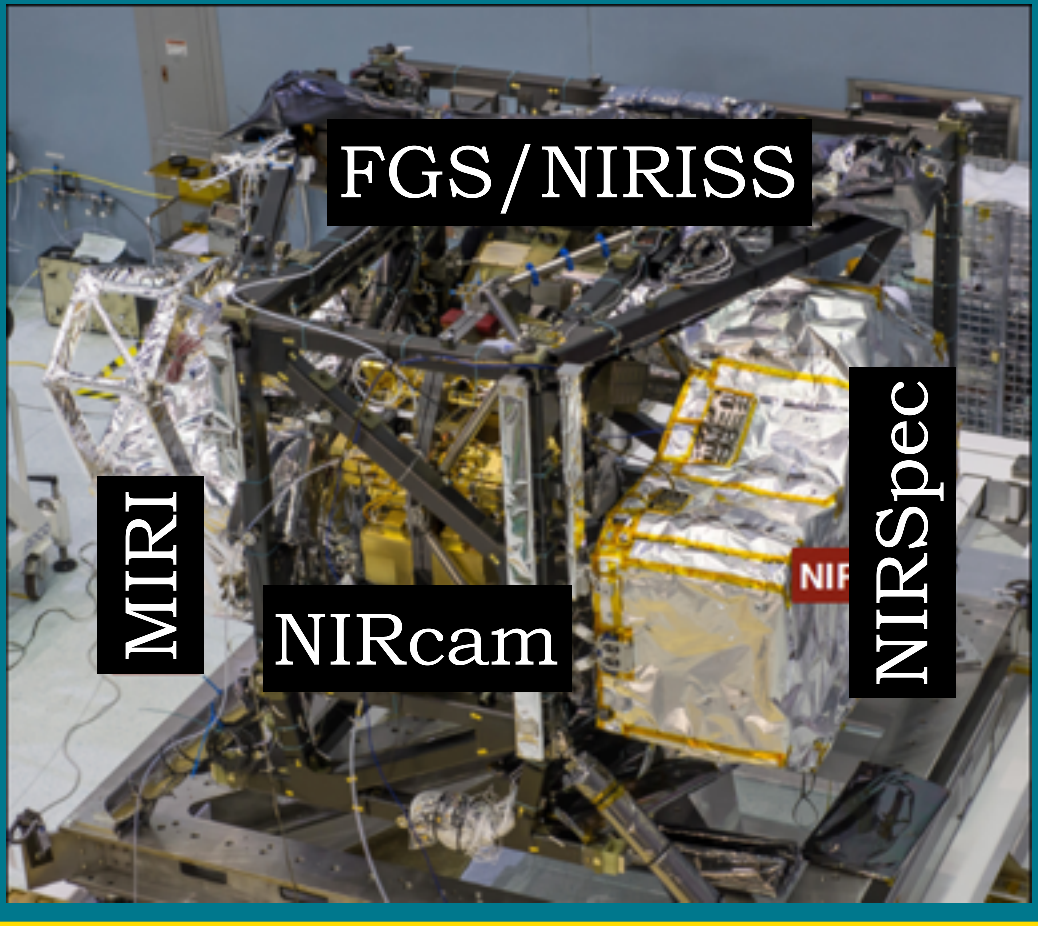


4 **instruments**:

- **N**ear **I**nfra**R**ed **Cam**era
- **N**ear **I**nfra**R**ed **Spec**trograph
- **M**id **I**nfra**R**ed **I**maging
- **F**ine **G**uidance **S**ensor + **N**ear-**I**nfra**R**ed **I**mager and **S**litless **S**pectrograph



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JWST: imaging capabilities

Instrument	Wavelength (microns)	Pixel Scale (arcsec)	Field of View
NIRCam	0.6 – 2.3	0.032	2.2 x 4.4′
NIRCam	2.4 – 5.0	0.065	2.2 x 4.4′
NIRISS	0.9 – 5.0	0.065	2.2 x 2.2′
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Credit: Jane Rigby

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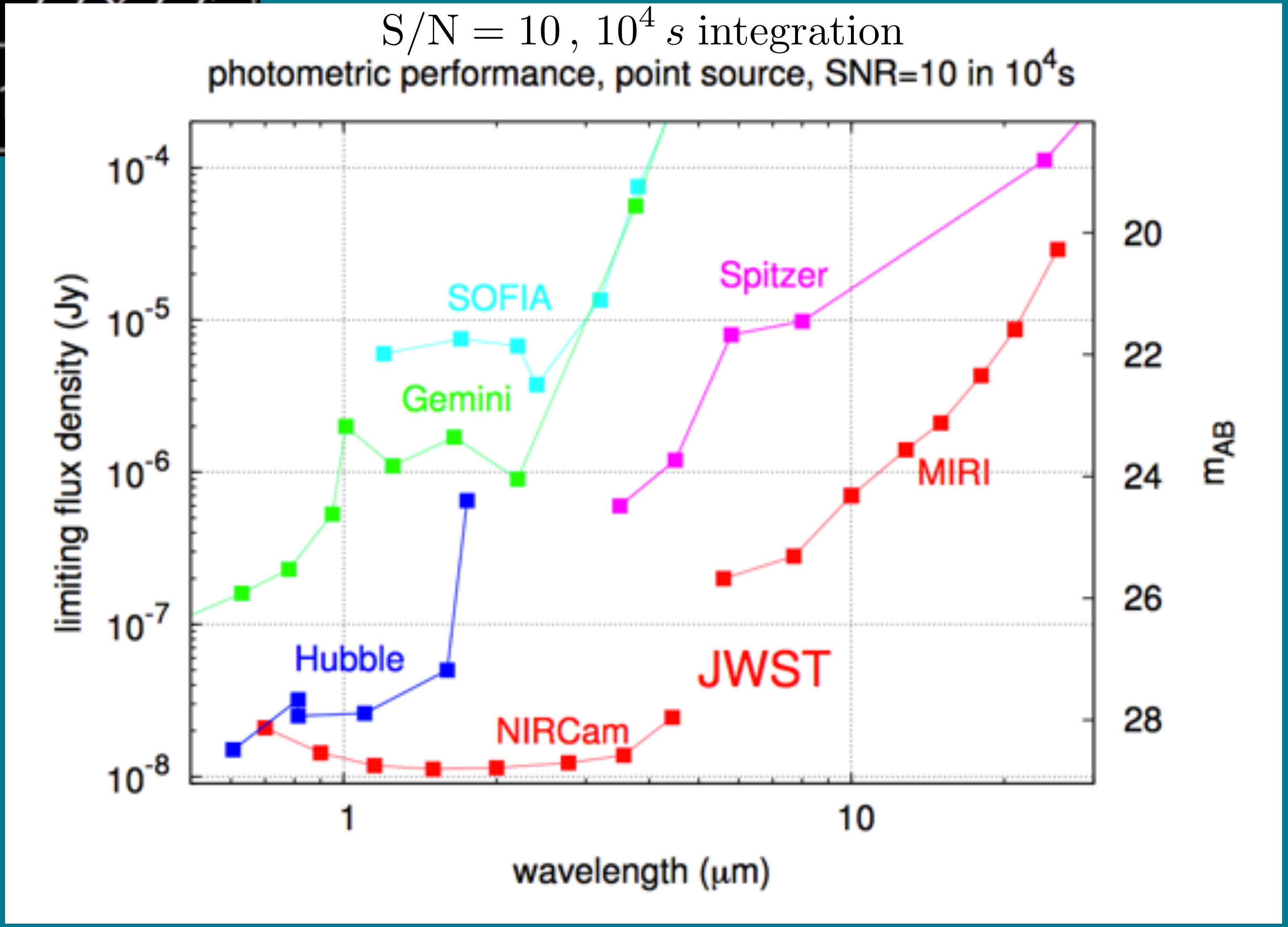

JWST: spectroscopic capabilities

Mode	Instrument	Wavelength (microns)	Resolving Power ($\lambda/\Delta\lambda$)	Field of View
Slitless Spectroscopy	NIRISS	1.0 – 2.5	150	2.2 x 2.2′
	NIRISS	0.6 – 2.5	700	single object
	NIRCam	2.4 – 5.0	2000	2.2 x 2.2′
Multi-Object Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.4 x 3.4′ with 250k 0.2 x 0.5″ microshutters
Single Slit Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	slits with 0.4 x 3.8″ 0.2 x 3.3″ 1.6 x 1.6″
	MIRI	5.0 – ~14.0	~100 at 7.5 microns	0.6 x 5.5″ slit
IFU Spectroscopy	NIRSpec	0.6 – 5.0	100, 1000, 2700	3.0 x 3.0″
	MIRI	5.0 – 7.7	3500	3.0 x 3.9″
	MIRI	7.7 – 11.9	2800	3.5 x 4.4″
	MIRI	11.9 – 18.3	2700	5.2 x 6.2″
	MIRI	18.3 – 28.8	2200	6.7 x 7.7″

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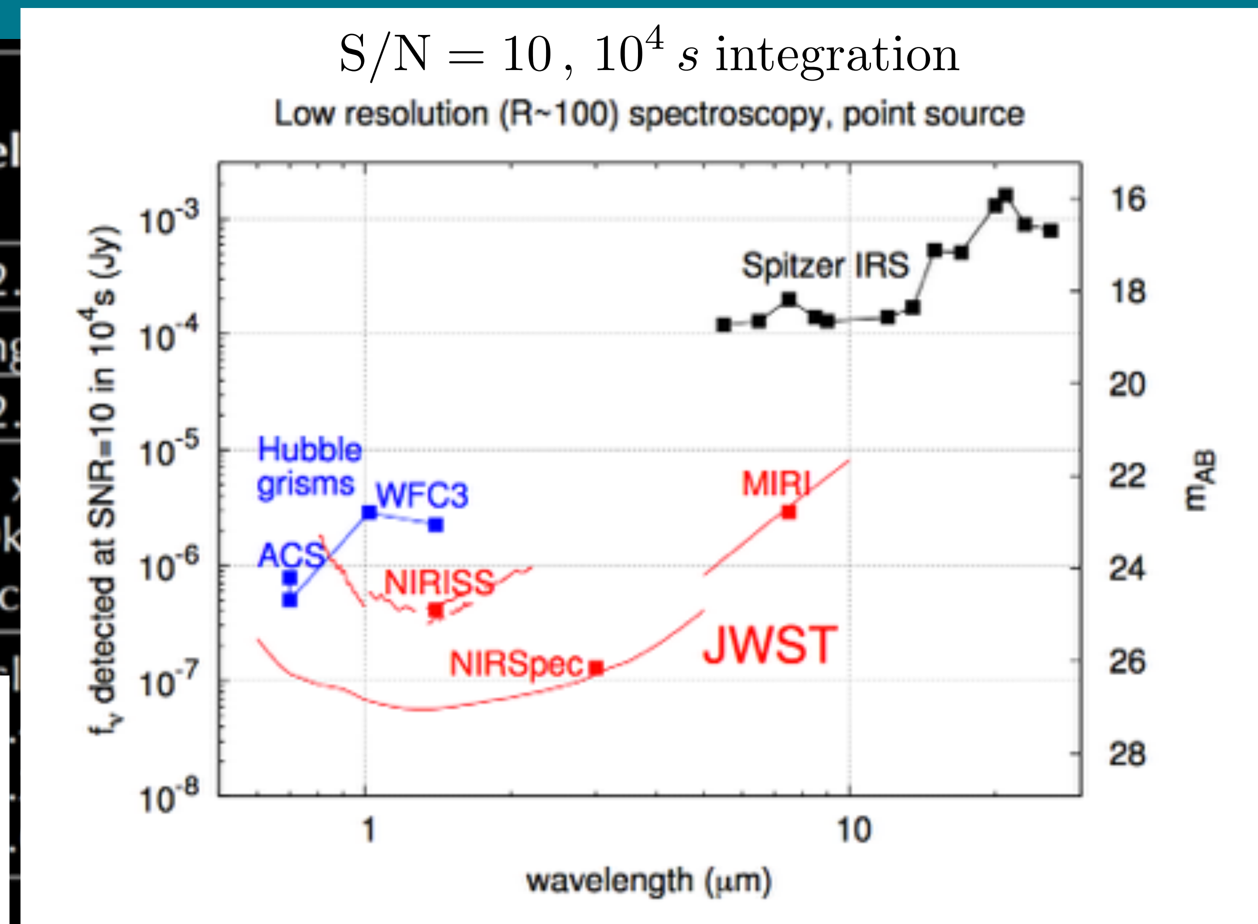

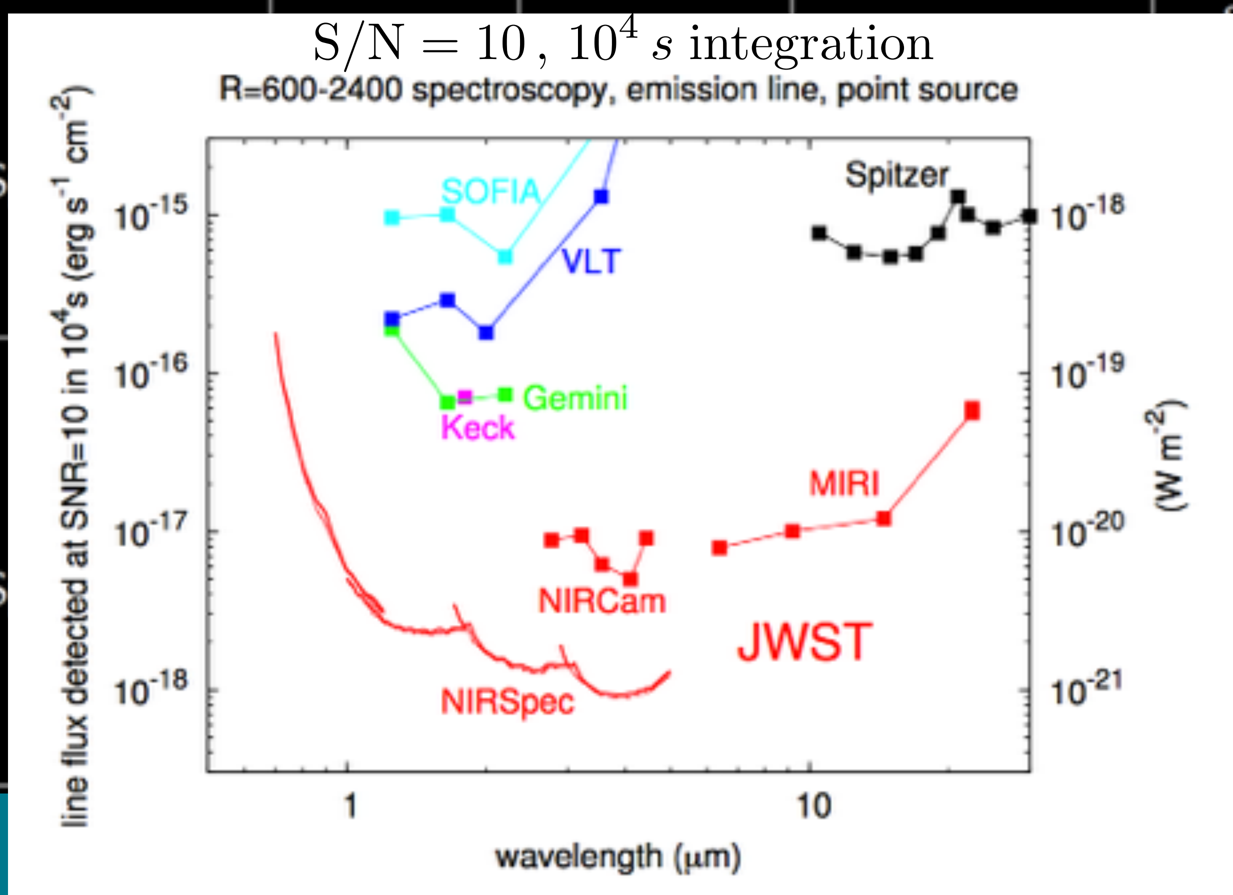

Cosmic reionization history:
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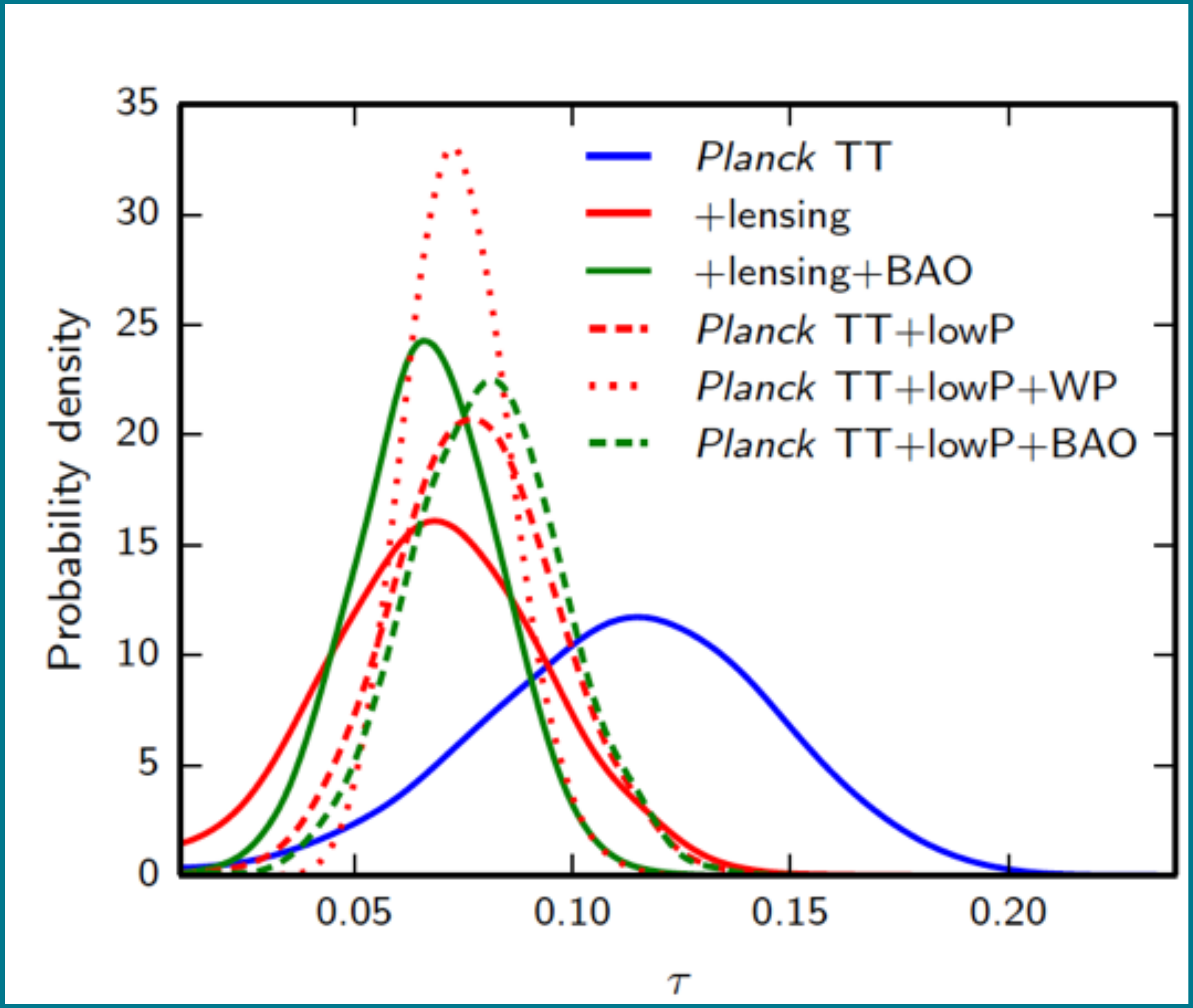
Constraints from CMB

Free e$^-$ in IGM **scatter CMB photons ➜ anisotropies** in CMB power spectra



Planck Collaboration (2015 - XIII)

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$$\tau = 0.067^{+0.016}_{-0.016}$$

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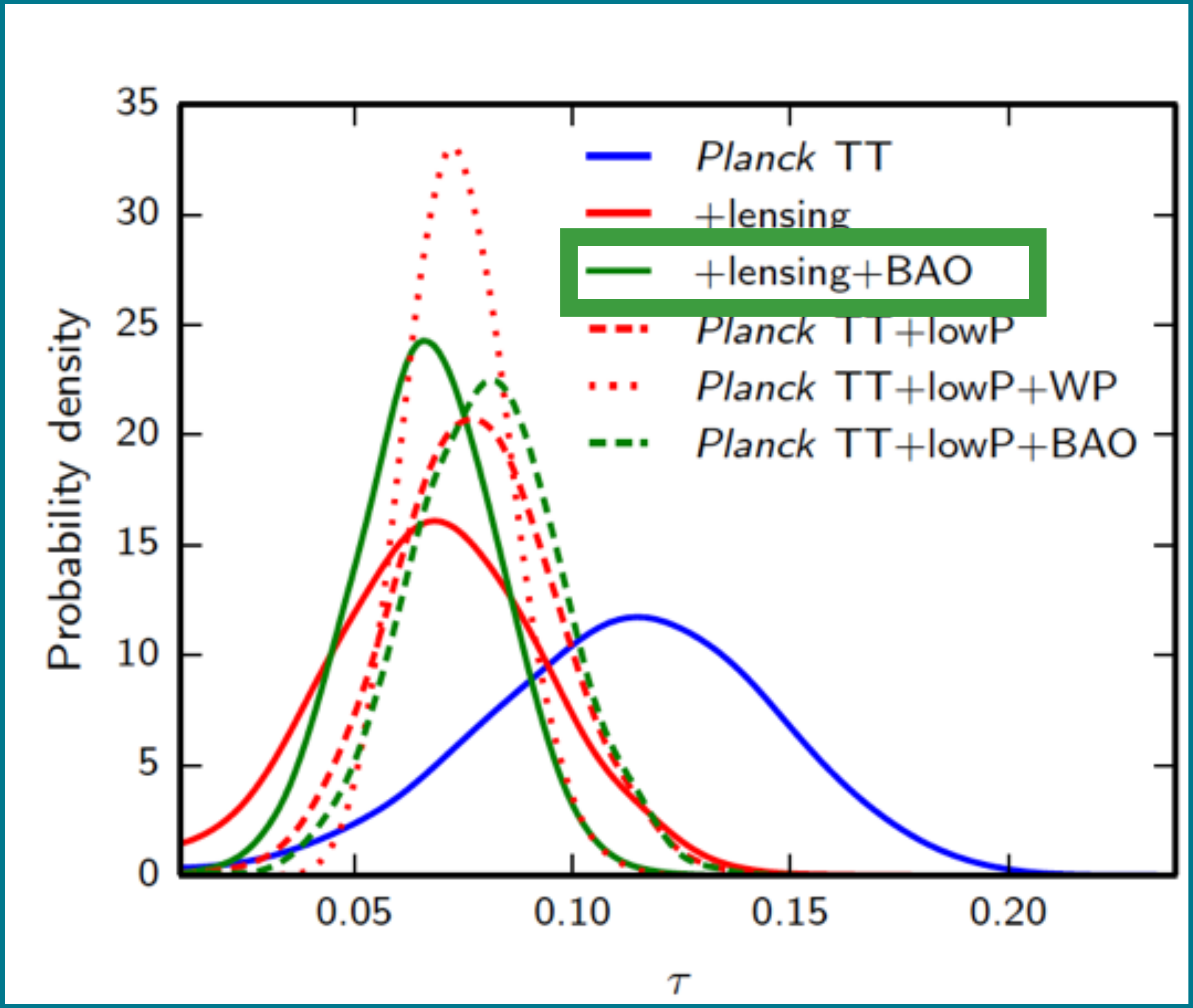

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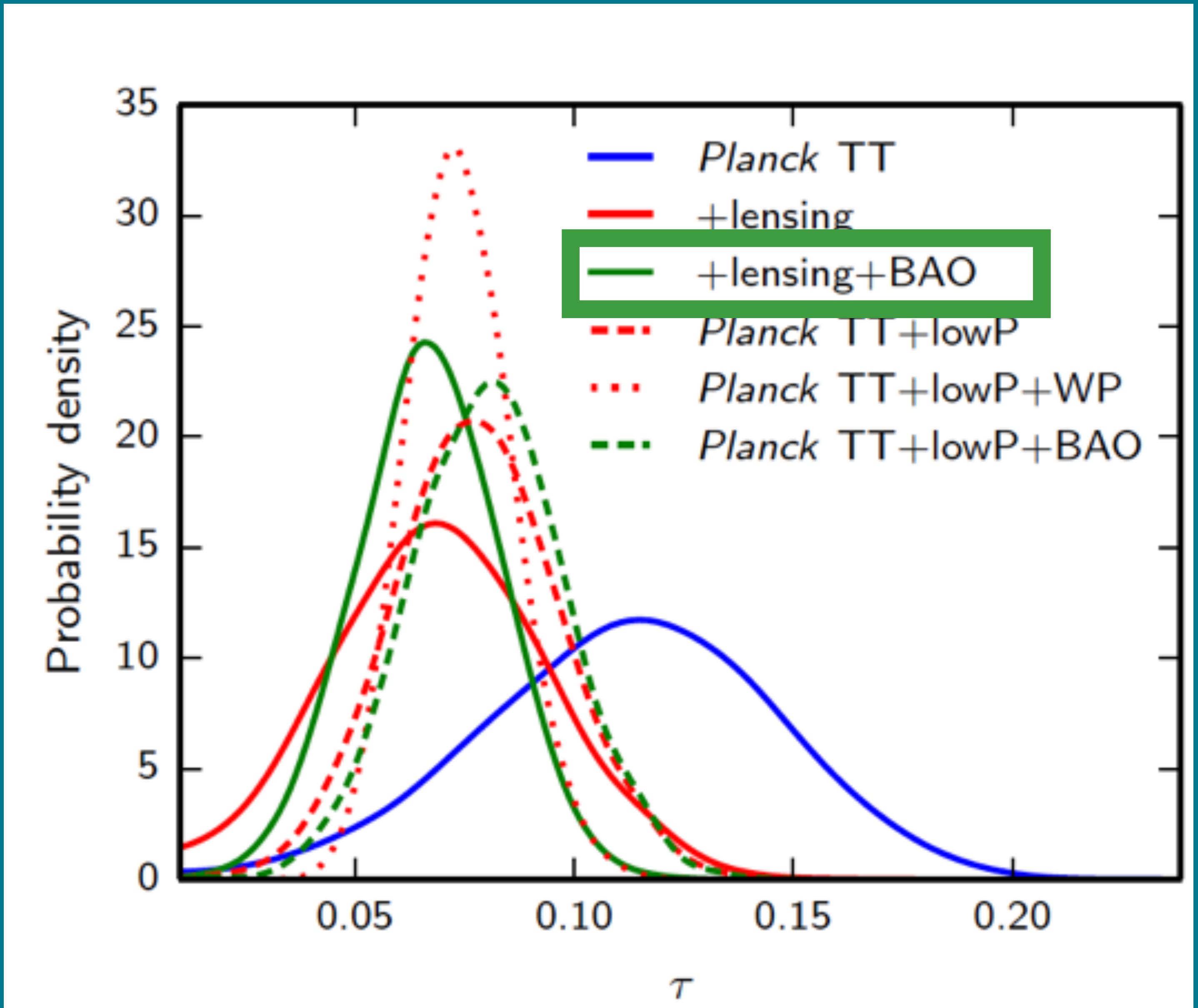

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- **Latest constraints** from **Planck**: **later** reionization than WMAP and early Planck
- **No constraint on shape** of reionization history

$$\underbrace{\tau_e}\propto \int_0^{z_{\rm dec}} dz\, \underbrace{Q_{\rm HII}(z)}$$

Optical depth of e⁻ to Thom. scatt.

Volume filling-fraction of ionized H

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- **Photons** with $\lambda_{\rm em} < 1216\,\text{Å}$ emitted by **high-*z* quasars** resonantly **scattered** by **HI clouds** at $\lambda_{\rm rest} = 1216\,\text{Å}$

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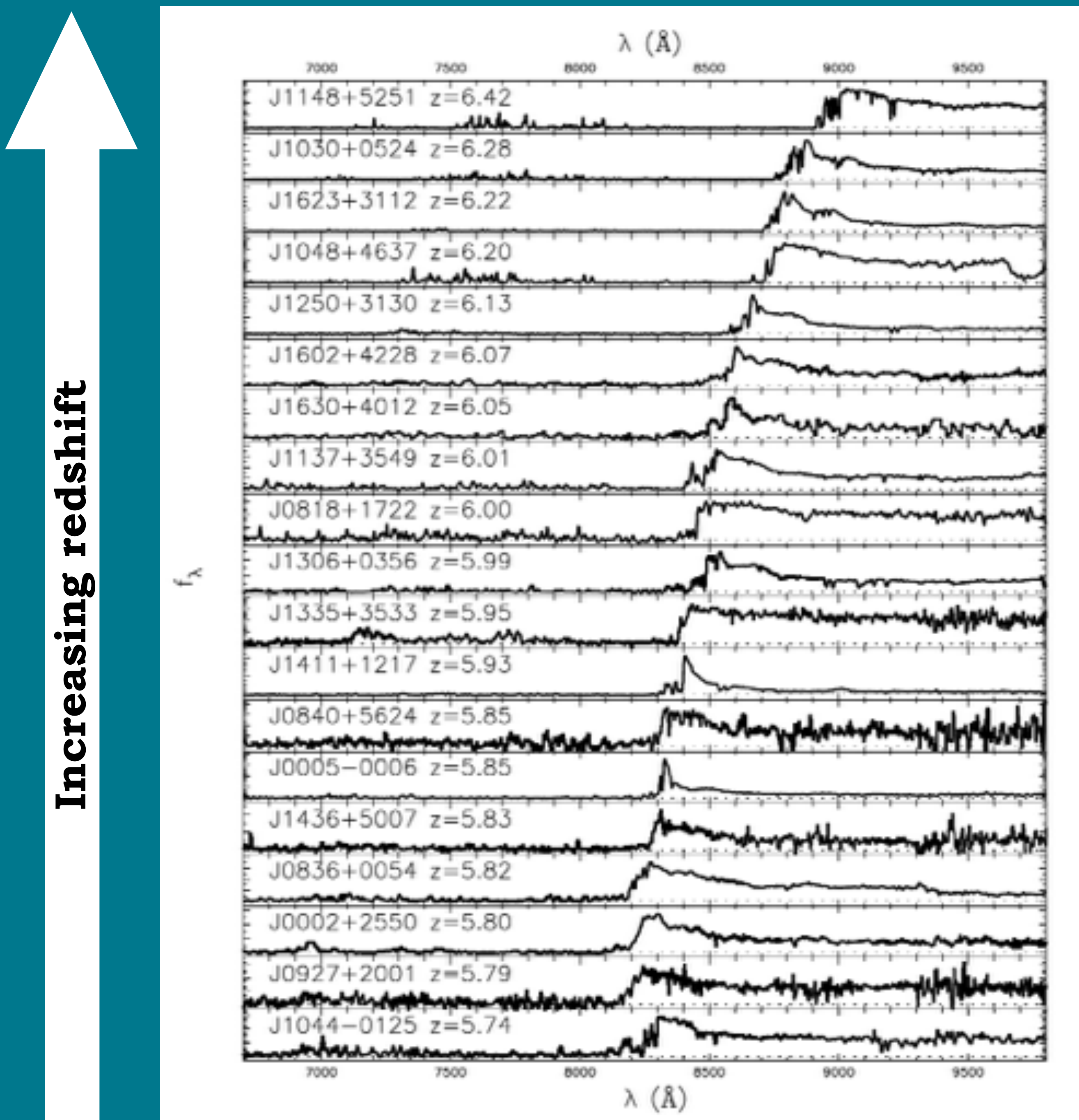
- **GP** Powerful method to **probe end of reionization**, but:
  - probes **single lines of sight** in a patchy ionized IGM
  - **saturation:** HI fraction of ~ **10^{-4}** produces $\tau_\alpha \sim 1$
  - **challenging** to take **rest-frame far-UV** spectra of $z \gtrsim 7$ quasars

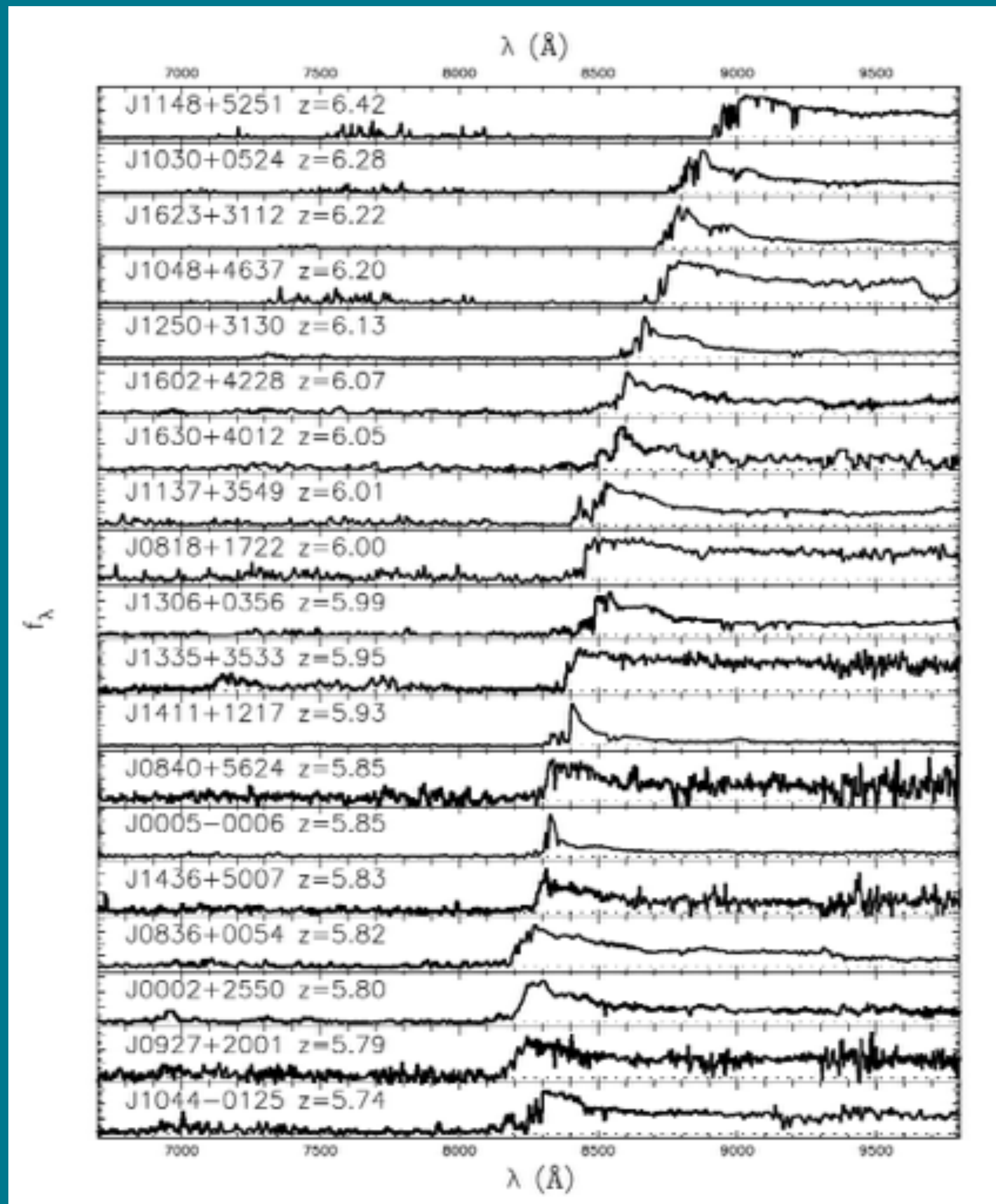
Gunn-Peterson trough



Fan et al (2006)

Gunn-Peterson trough

Increasing redshift



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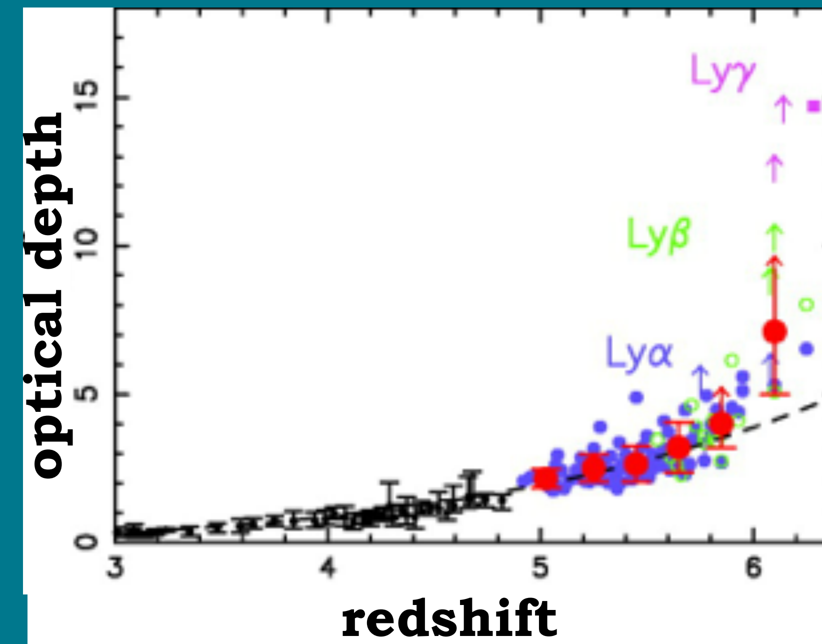

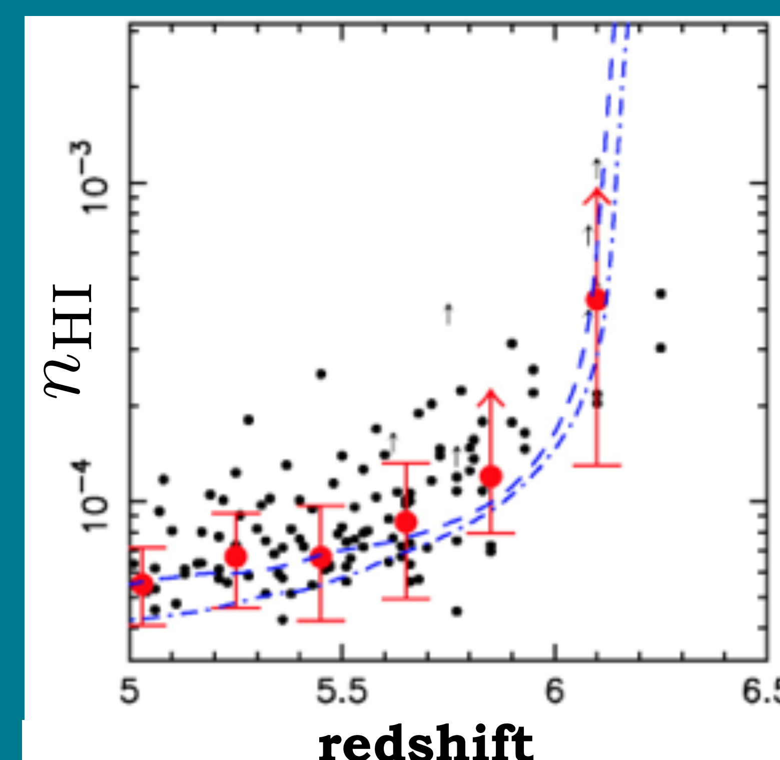

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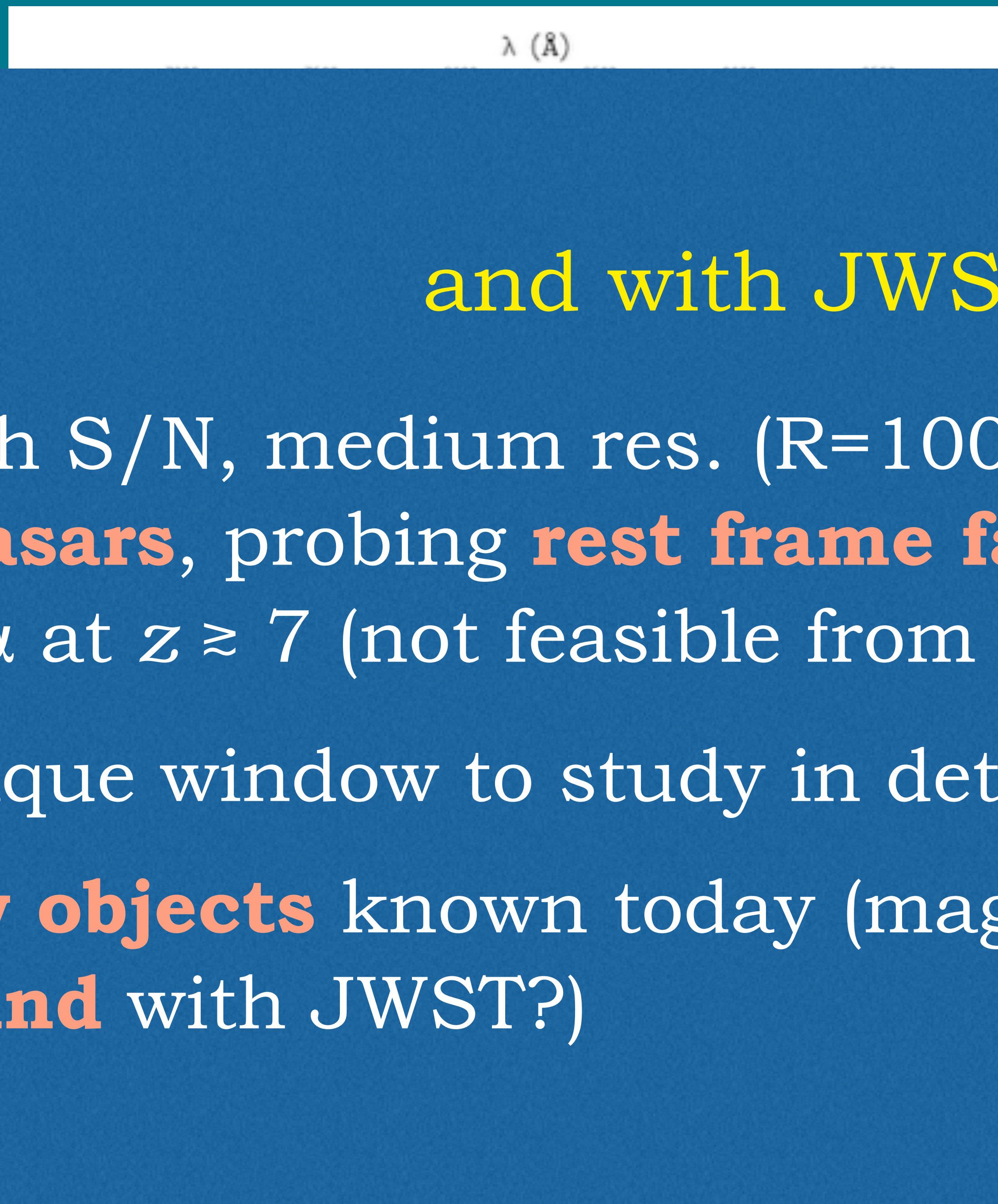

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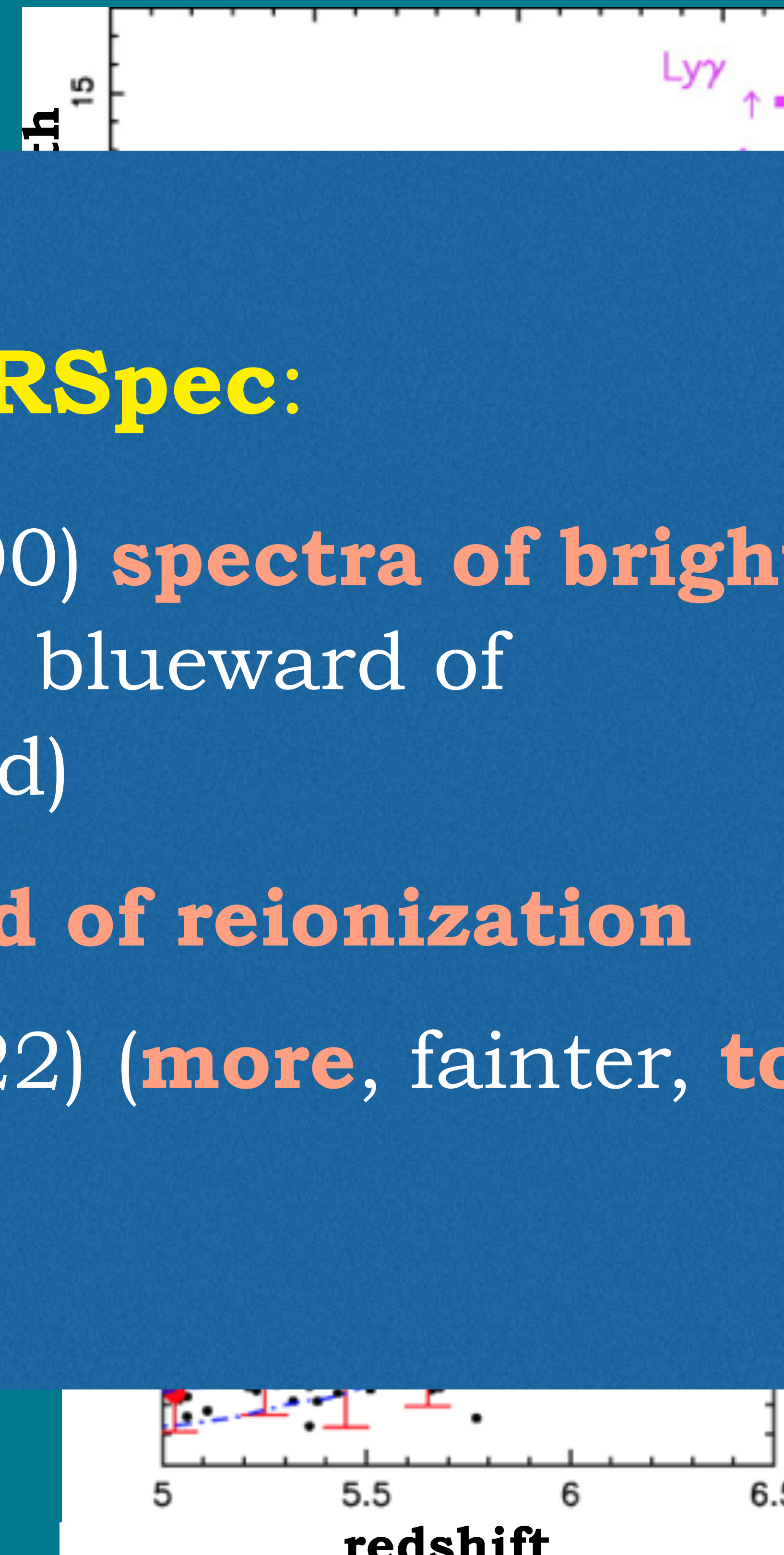

and with JWST/**NIRSpec**:

- high S/N, medium res. (R=1000-2700) **spectra of bright quasars**, probing **rest frame far-UV**, blueward of Lyα at $z \gtrsim 7$ (not feasible from ground)
- unique window to study in detail **end of reionization**
- **few objects** known today (mag~21-22) (**more**, fainter, **to be found** with JWST?)

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- **Observationally** challenging: **large areas**, **incompleteness** and **cosmic variance**

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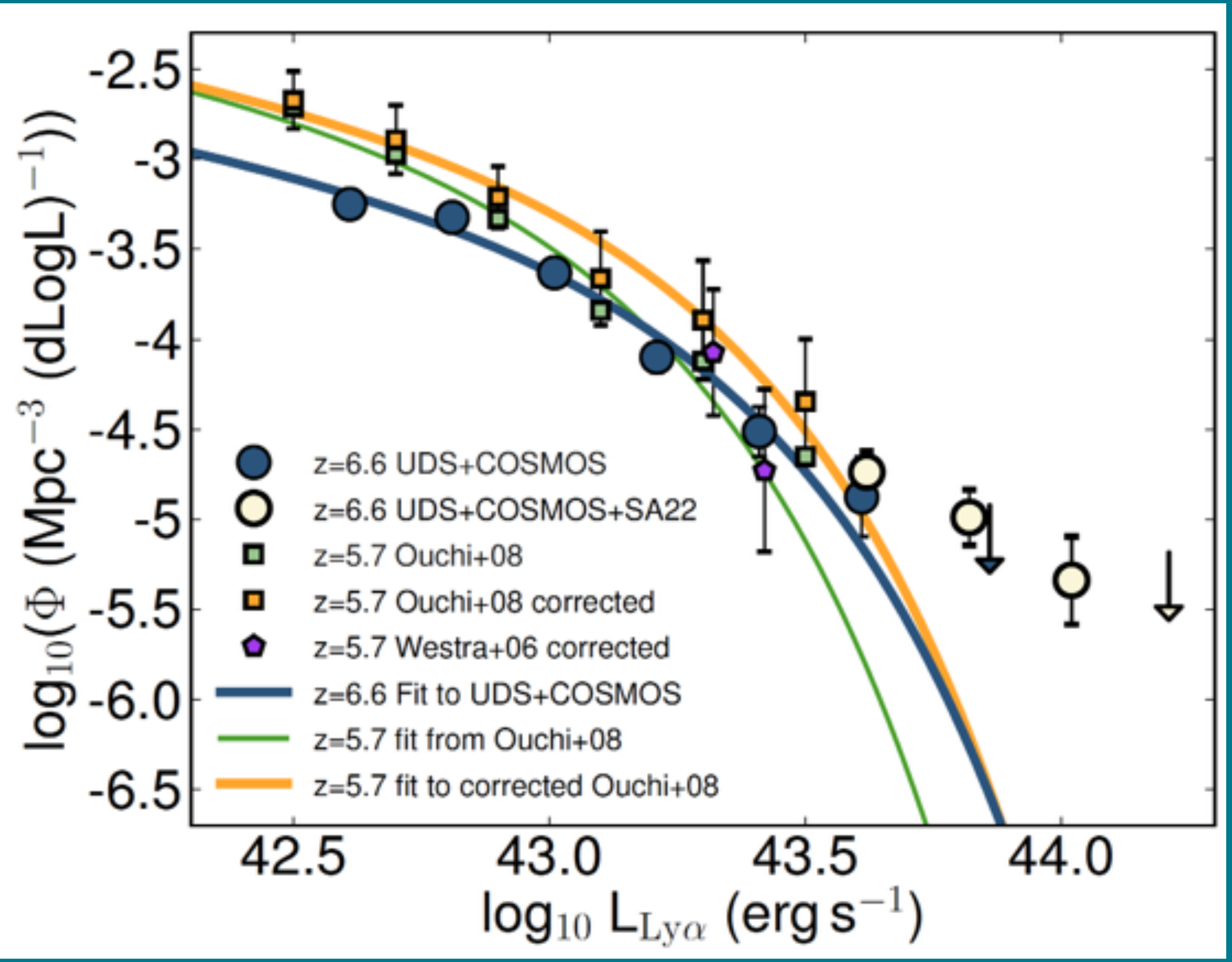

Matthee et al. (2015)

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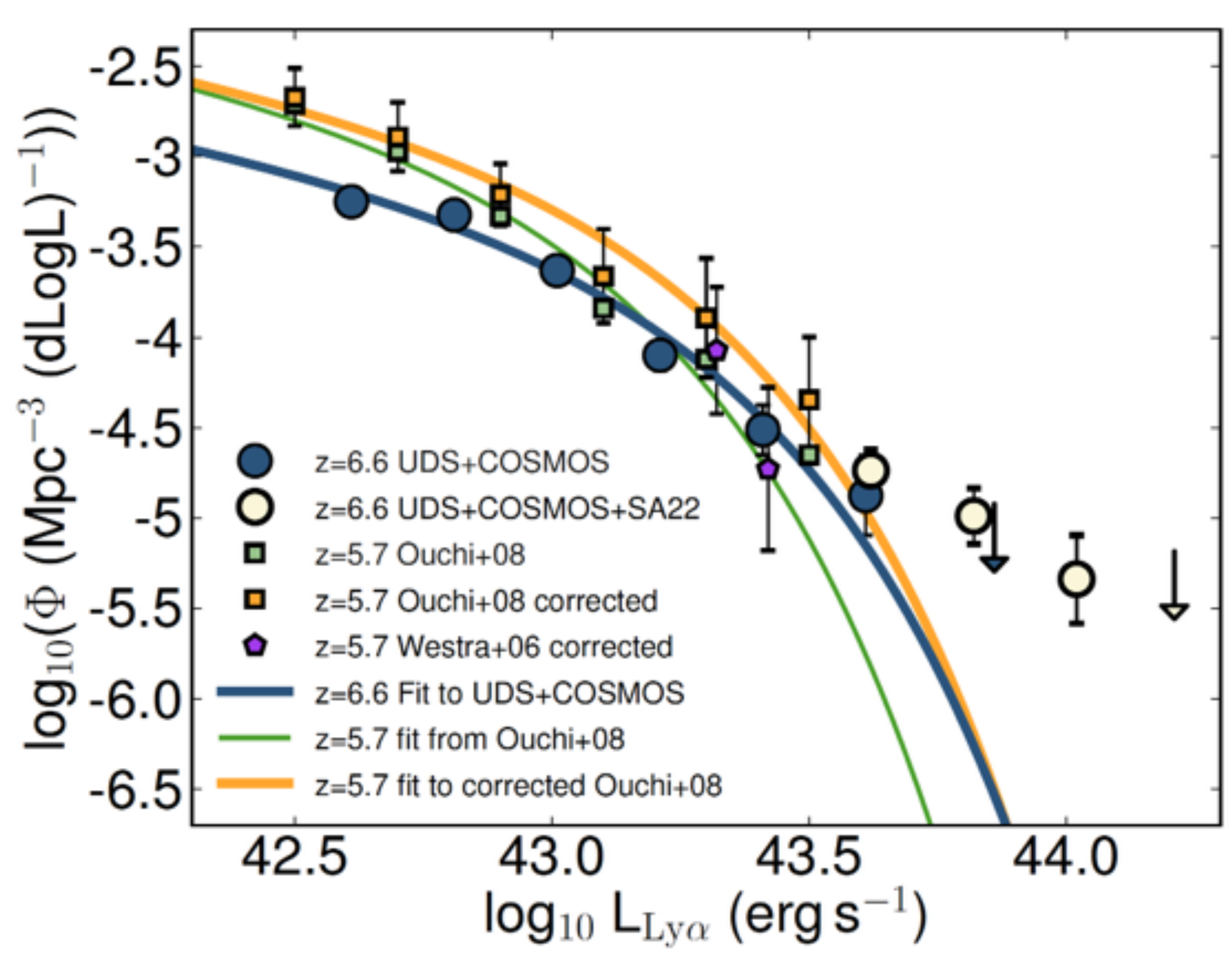

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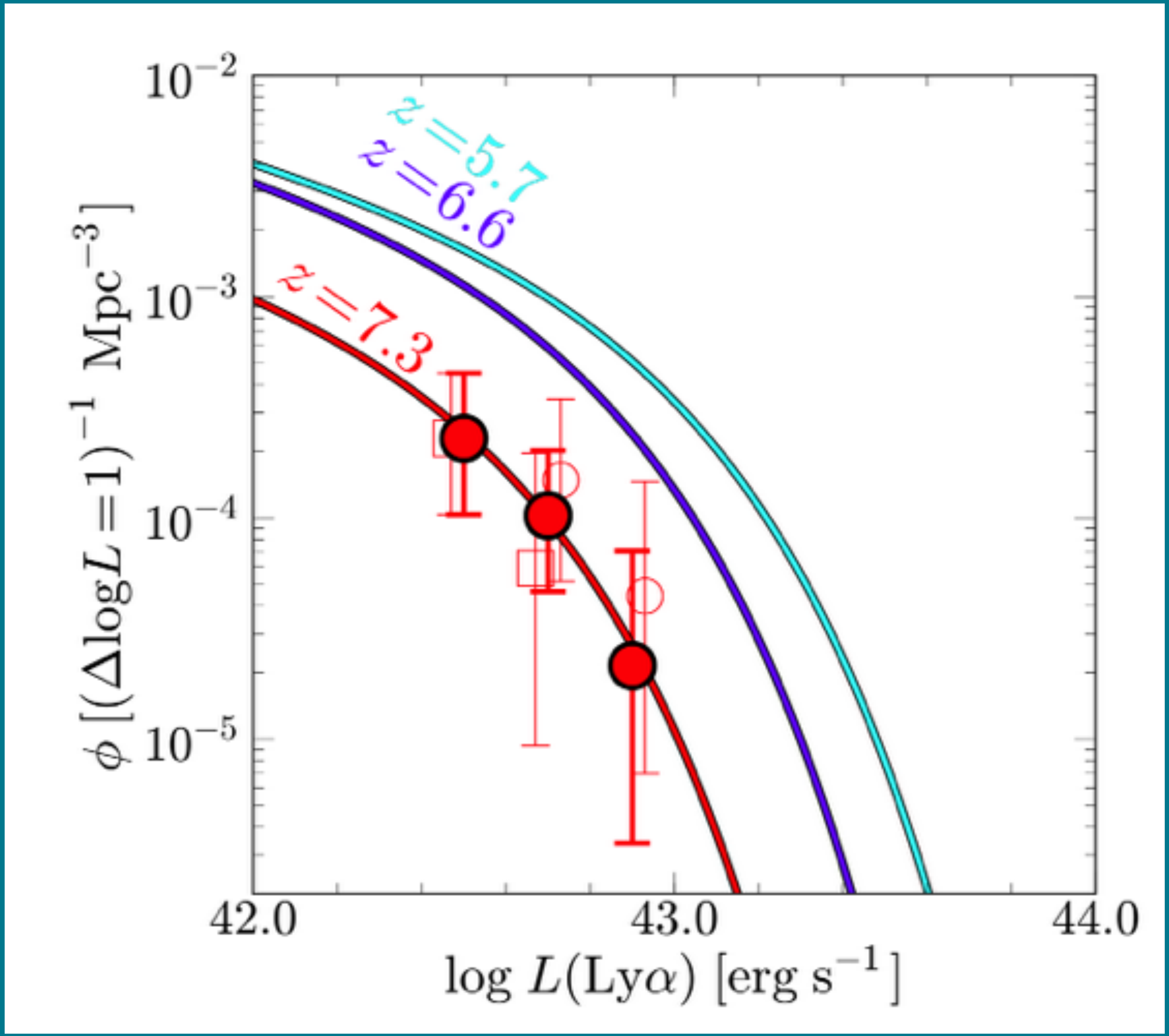

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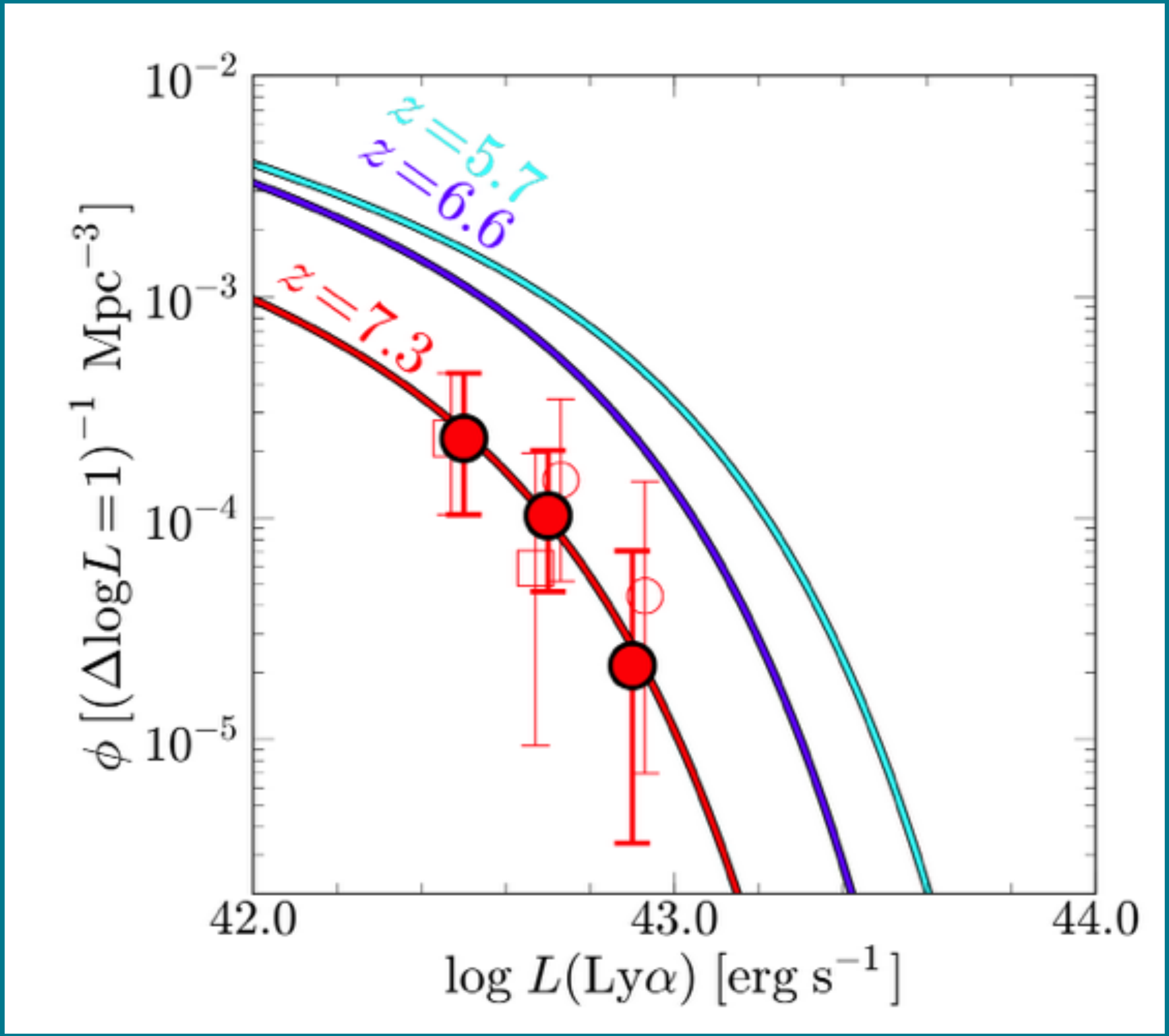

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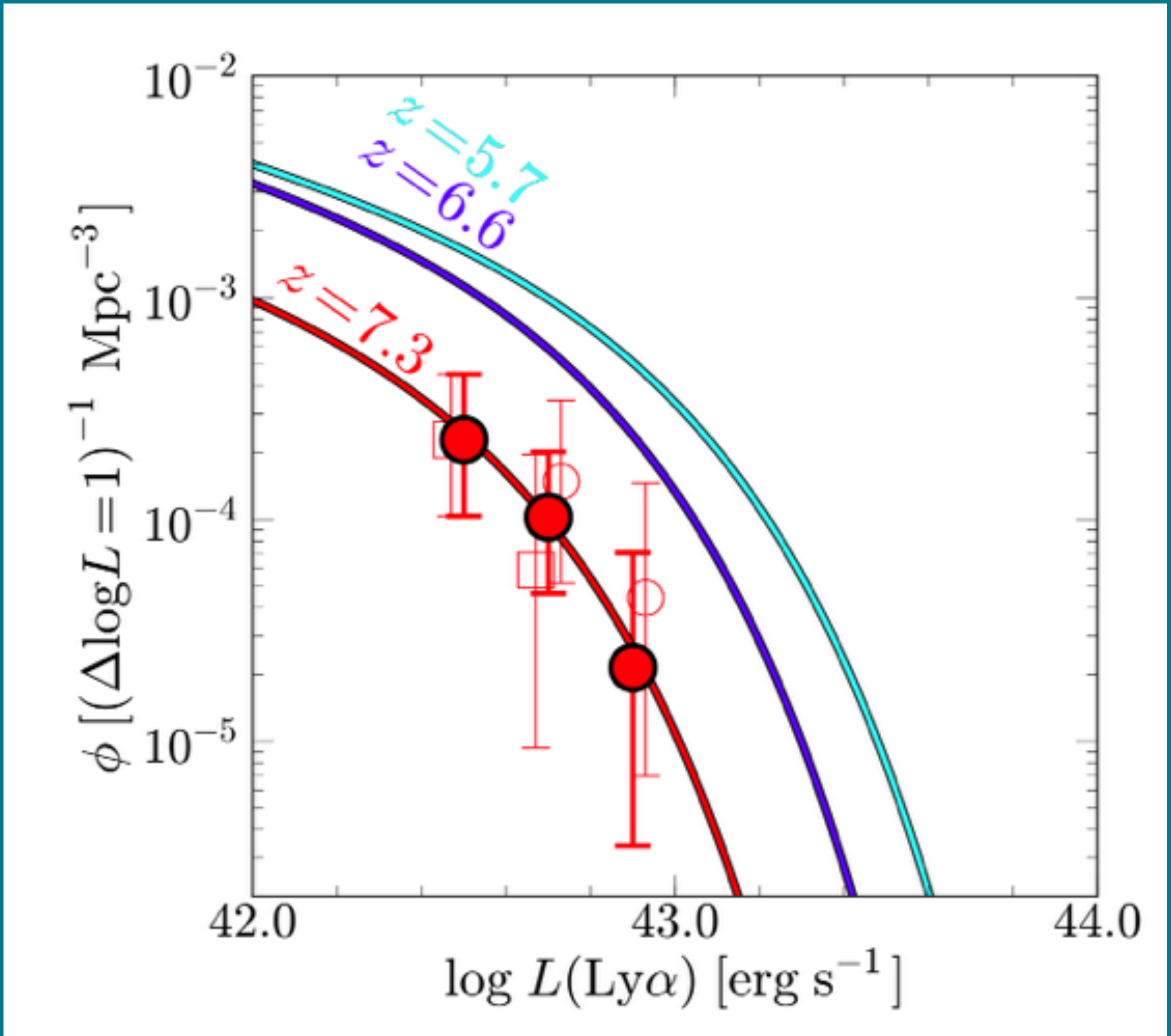

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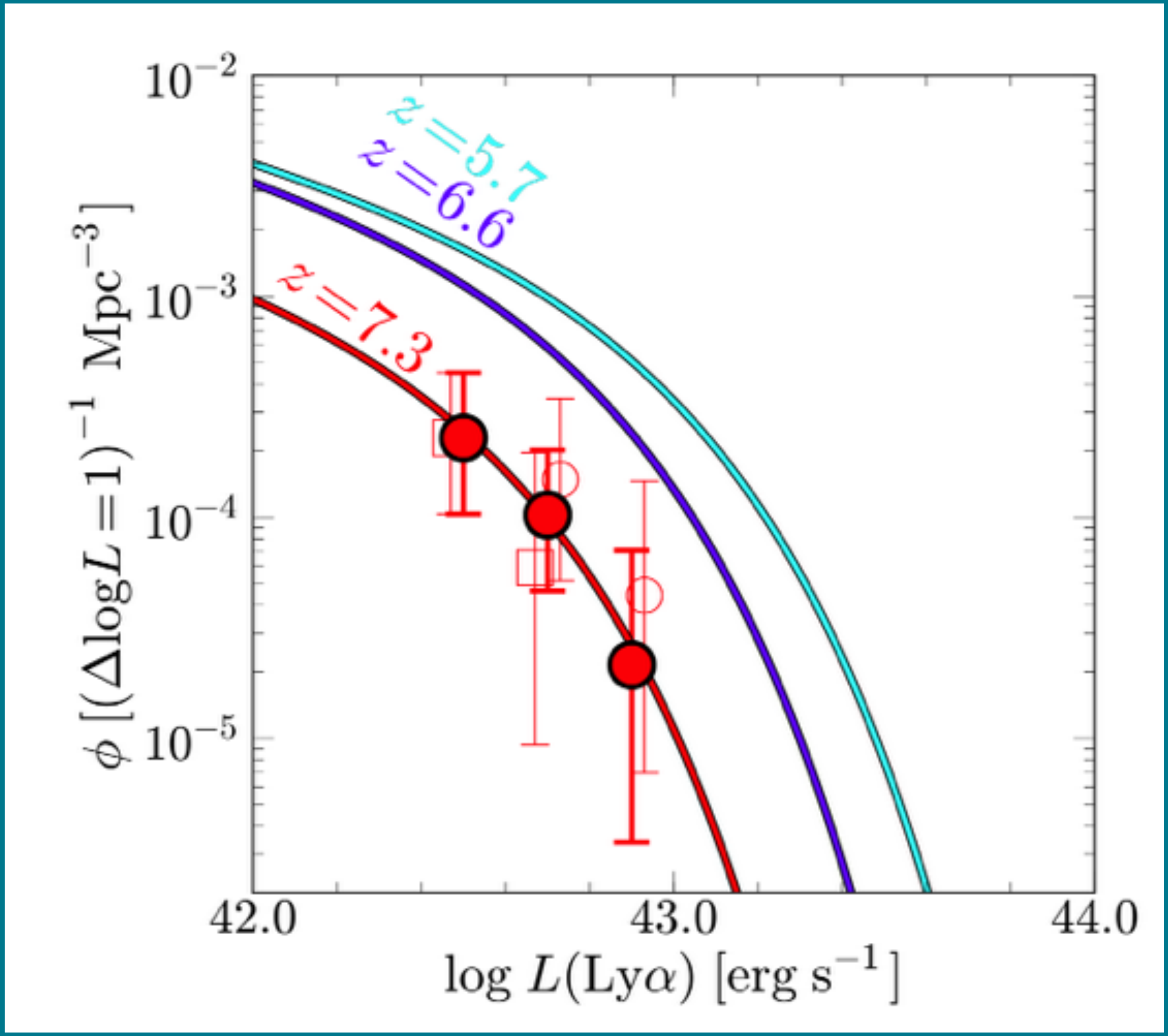

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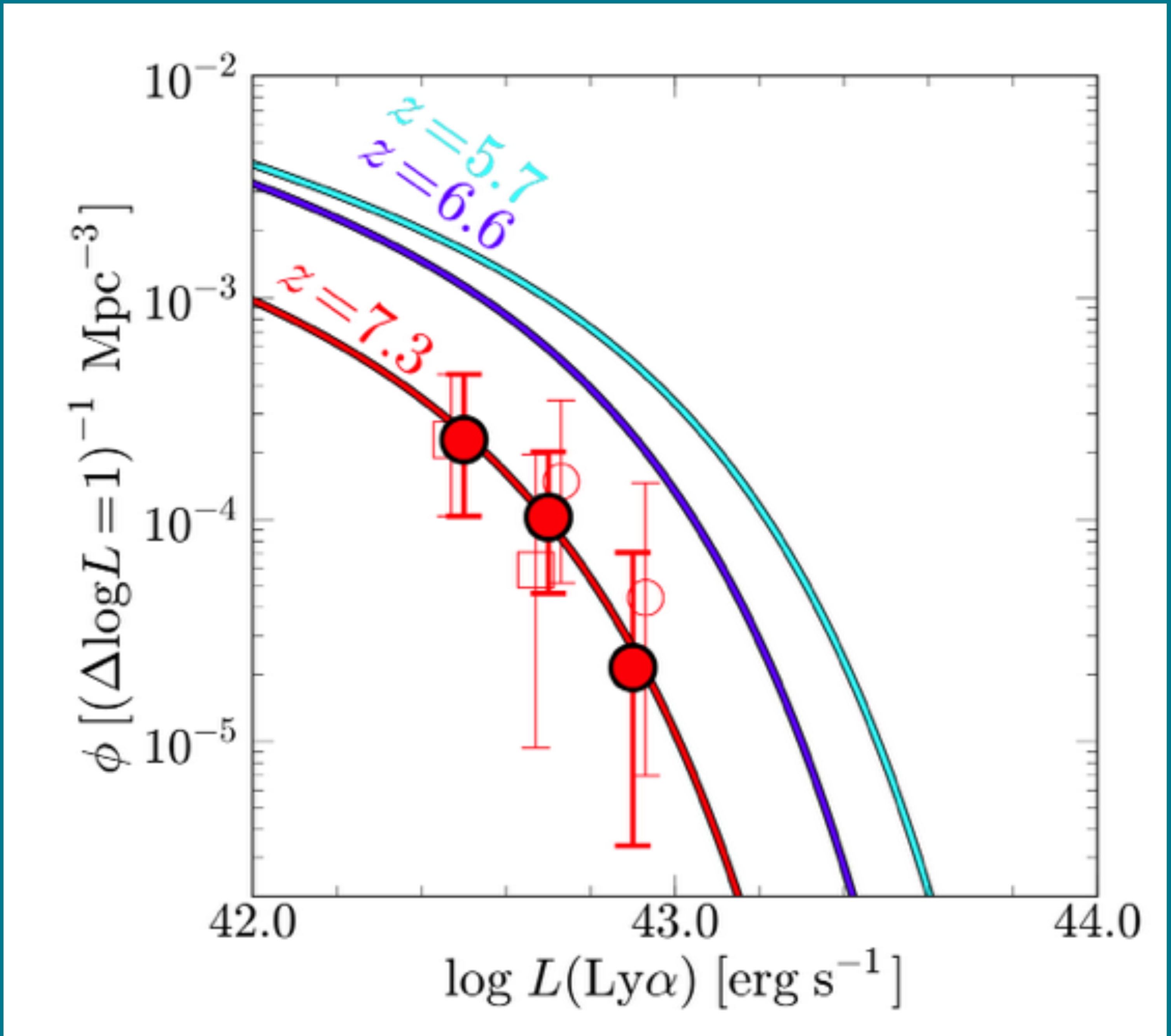

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- And **better statistics**
- Can exploit **differential evolution** of LF faint and bright ends

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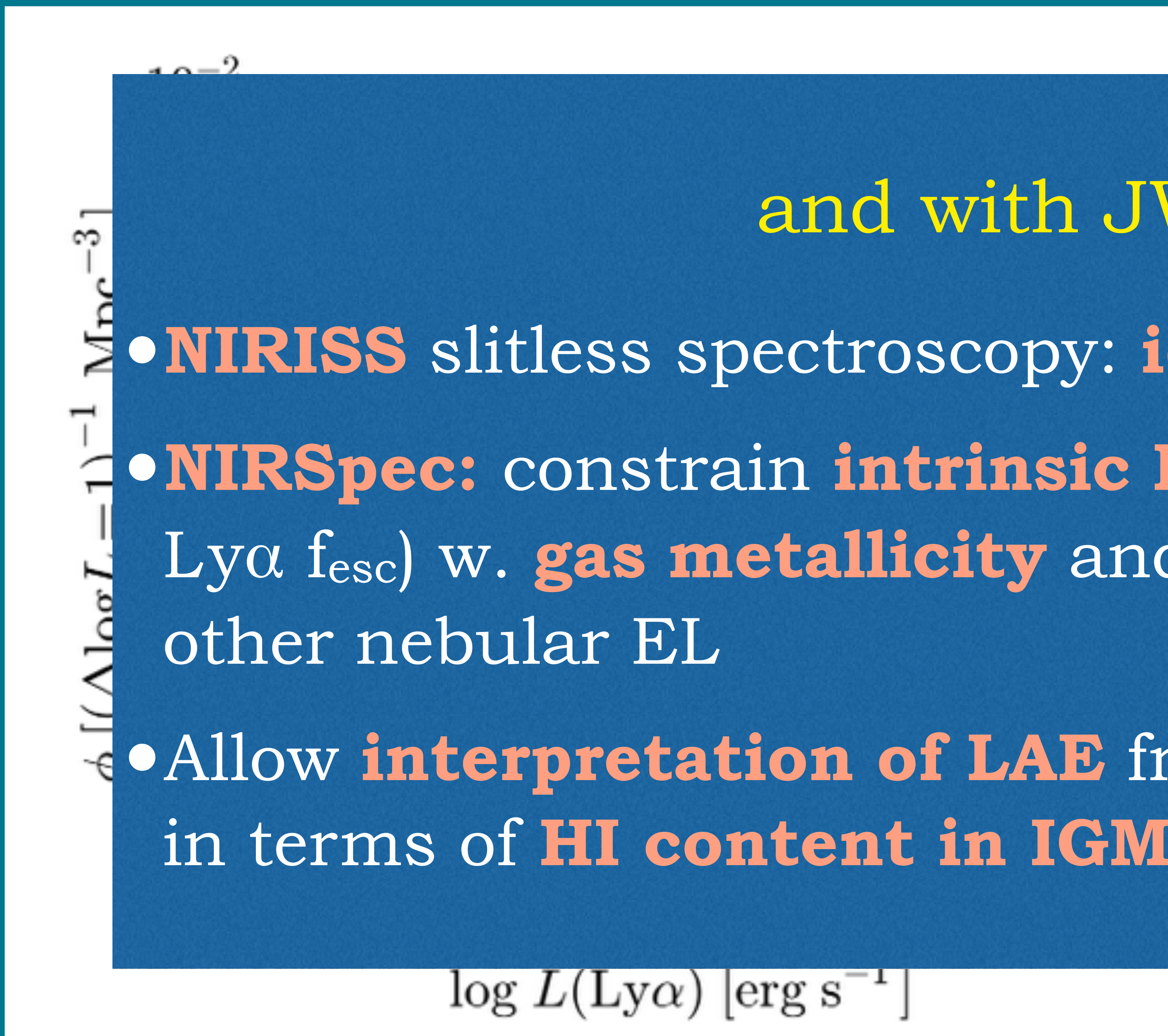

Konno et al. (2014)

and with JWST:

- **NIRISS** slitless spectroscopy: **identify LAE at $z > 6$**
- **NIRSpec:** constrain **intrinsic Lyα luminosity** (hence Lyα f_{esc}) w. **gas metallicity** and **ionisation state** from other nebular EL
- Allow **interpretation of LAE** fraction and LF evolution in terms of **HI content in IGM**

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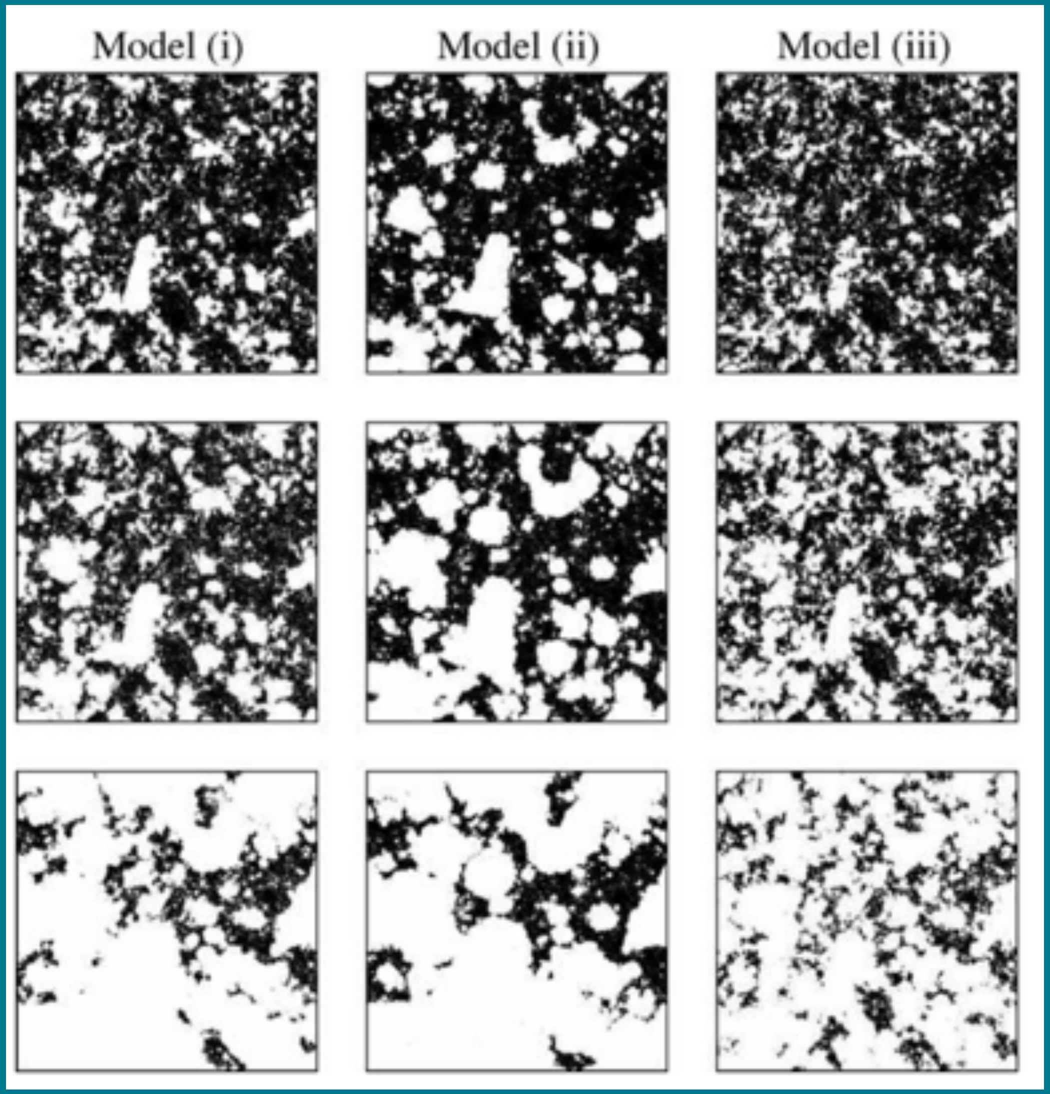

McQuinn et al. (2007)

Different reionization **models**

LAE clustering

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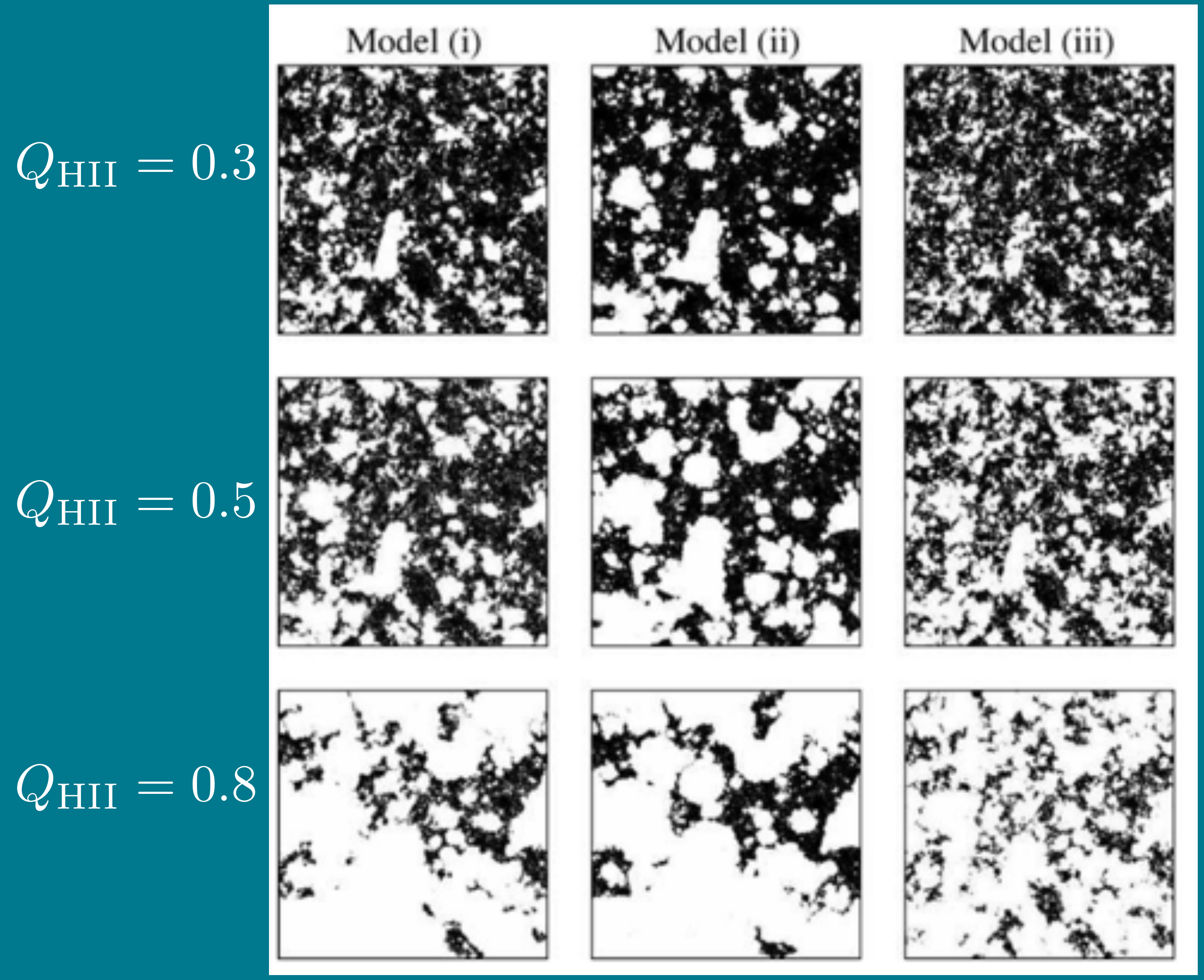

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⬇

Different degrees of "**patchiness**"

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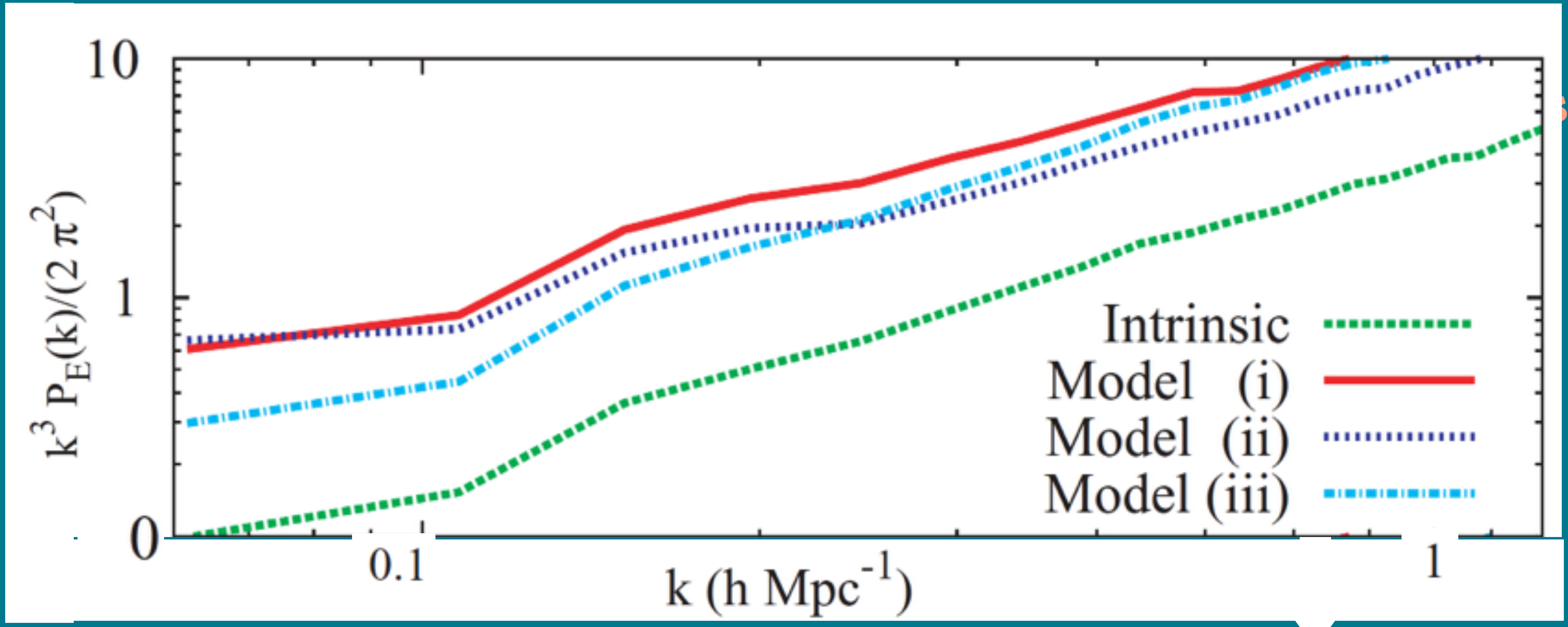

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- **JWST**: exquisite **sensitivity** (can probe faint-end, small scales), potential **limitation** is **FoV**: need 1000 arcmin^2 (~100 pointings)
- E.g.: **Subaru HSC** (ultra-) **deep survey** better suited

Different clustering signal

Sources of ionizing radiation and their physical properties

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$$\frac{dQ_{\rm HII}}{dt} = \frac{\dot{n}_{\rm ion}}{\langle n_{\rm H} \rangle} - \frac{Q_{\rm HII}}{t_{\rm rec}}$$

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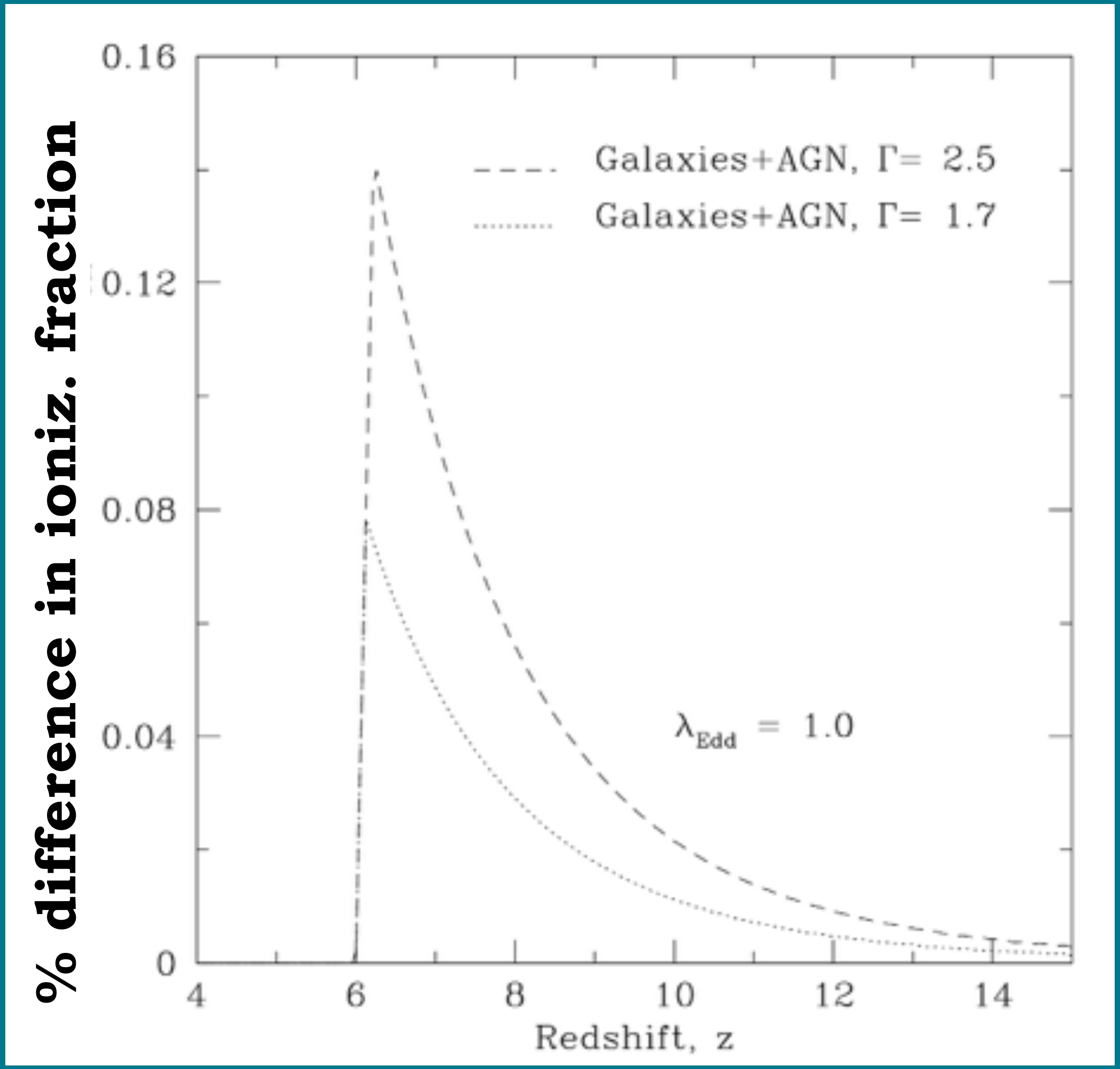

Grissom et al. (2014)

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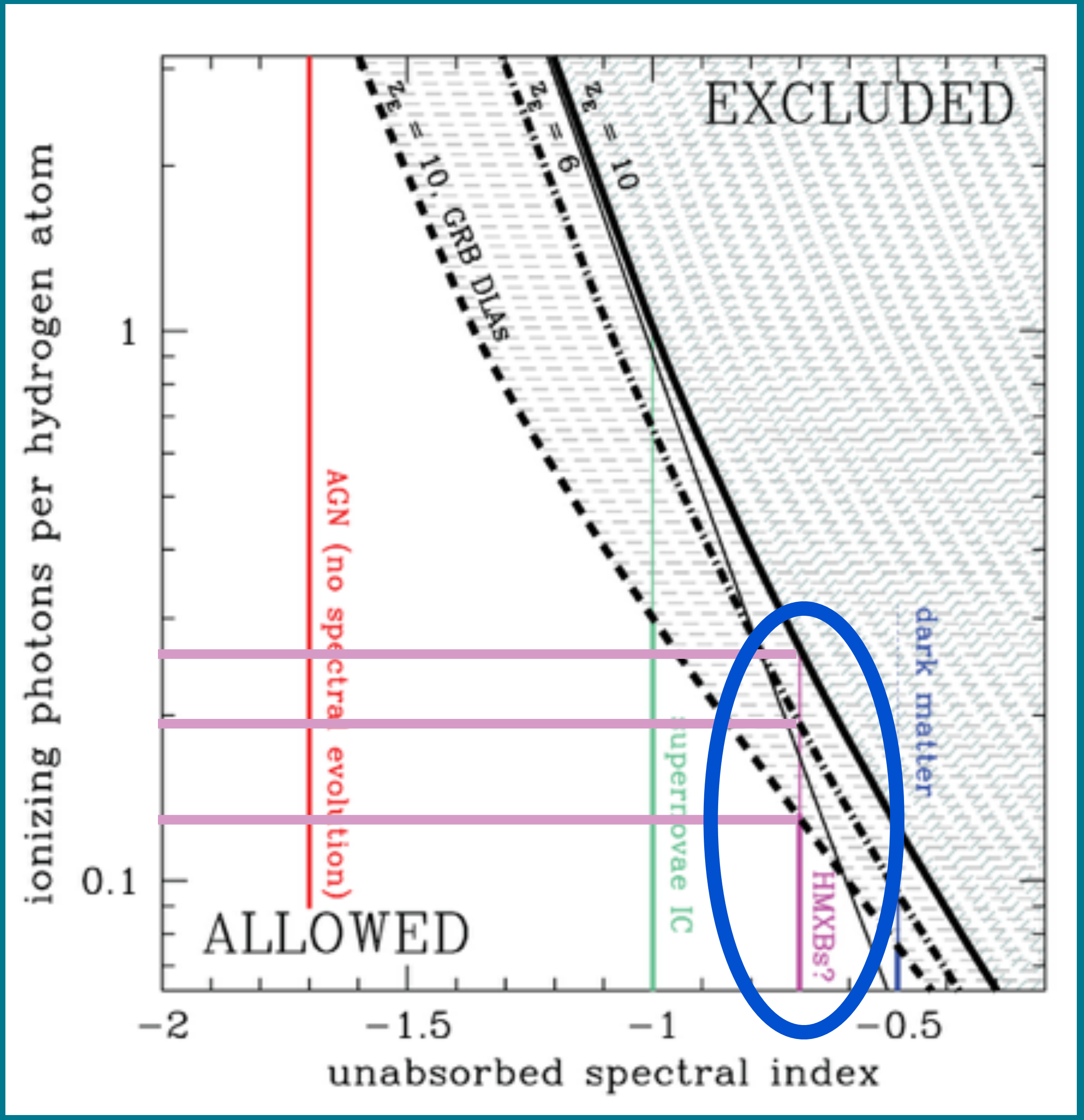

McQuinn (2012)

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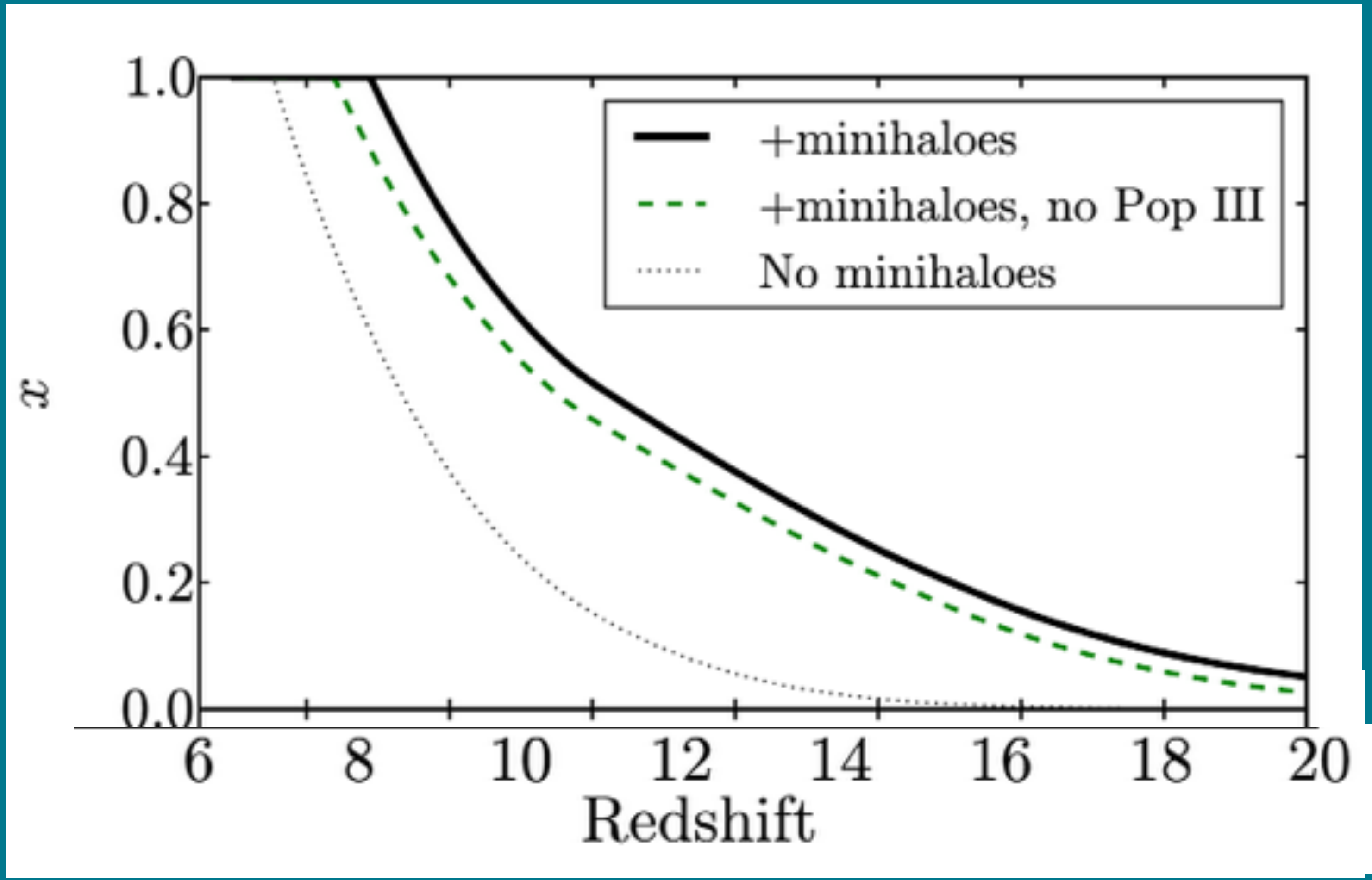

Wise et al. (2014)

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  - **Pop II stars** in SF galaxies

UV luminosity function

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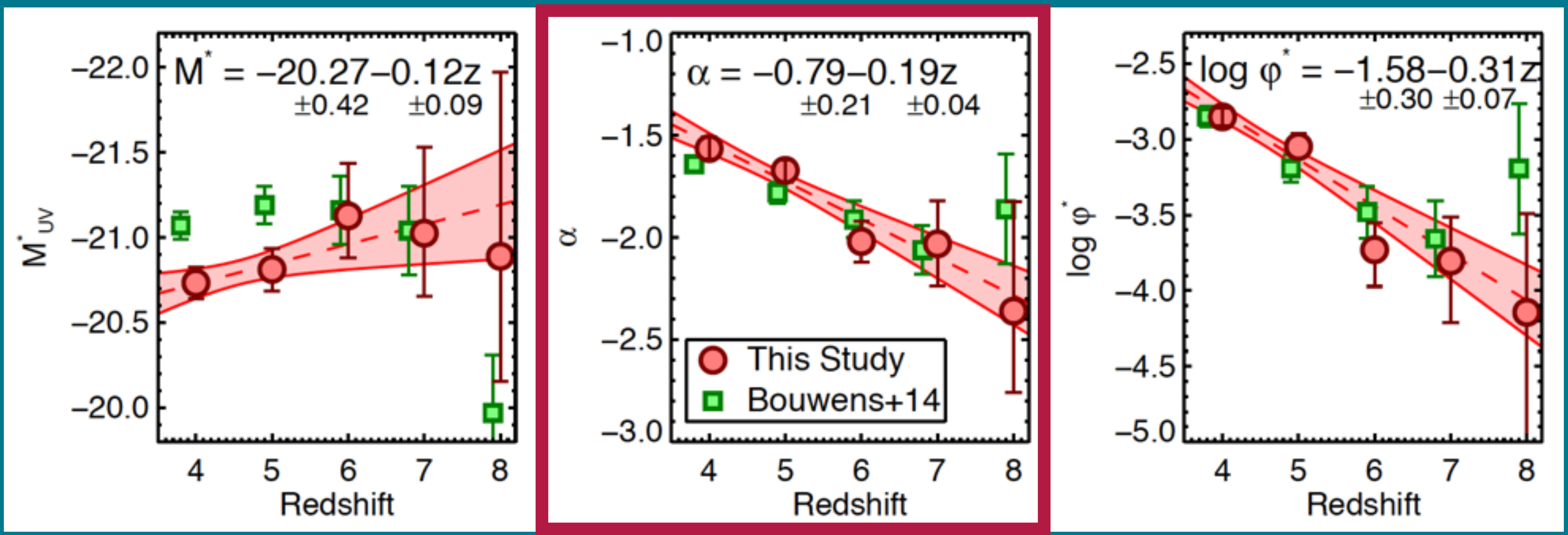
- **Bulk** of **photons** produced in galaxies **below** current **detect. lim.**
- Rapid **evolution** of **UV LF** at $z > 6$, **steepening** of **faint-end** (e.g. Atek+2014, Bouwens+2014, Robertson+2014, Oesch+2014)



Finkelstein et al. (2014)

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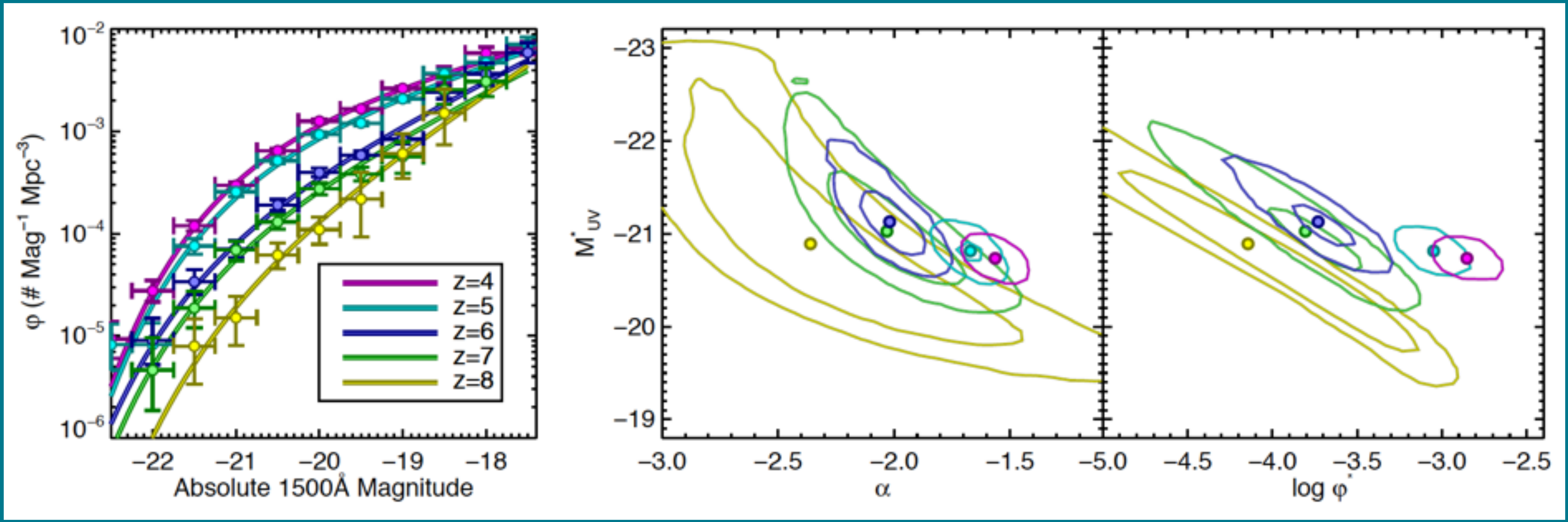

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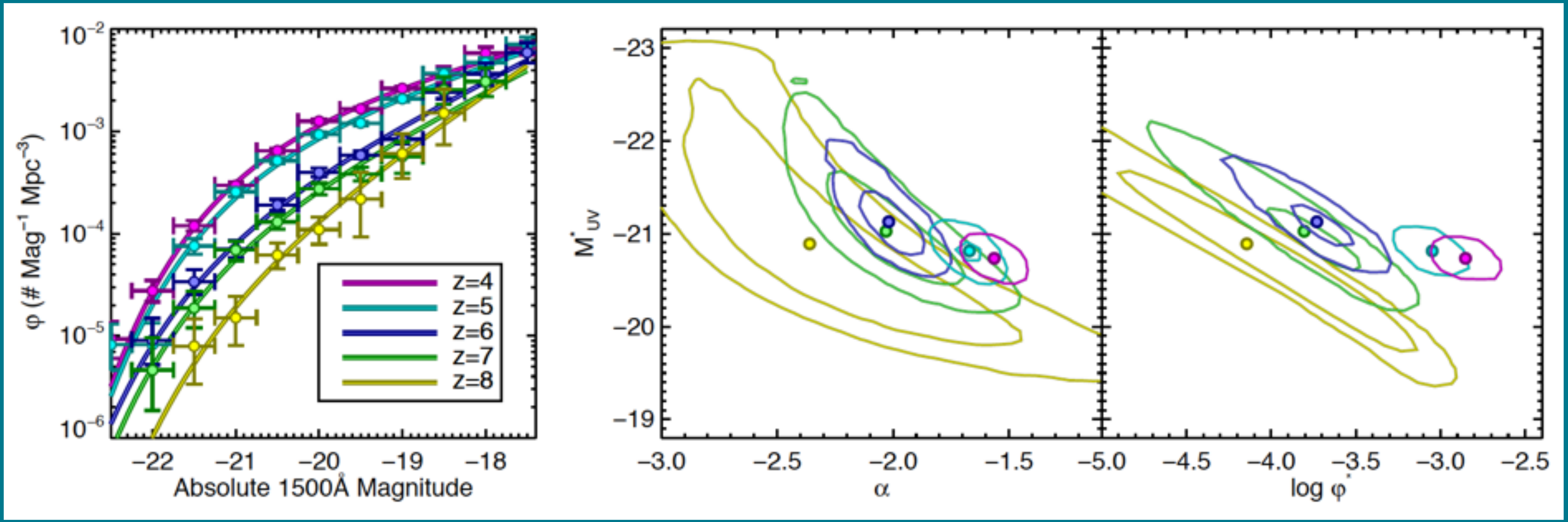

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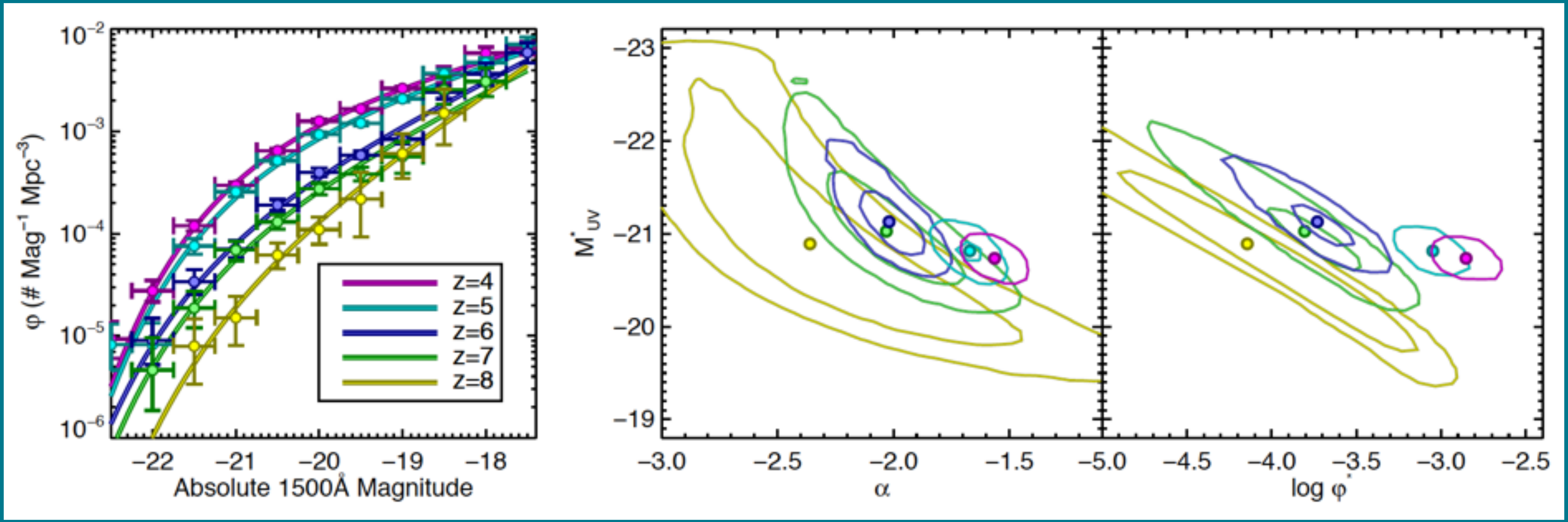

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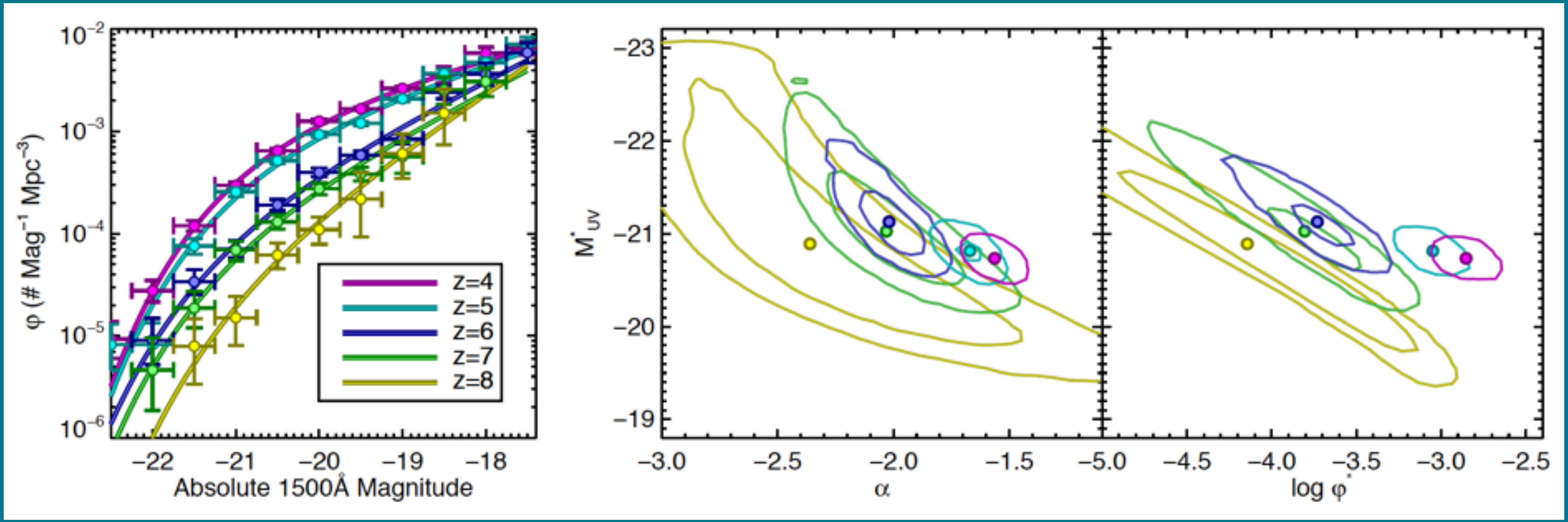

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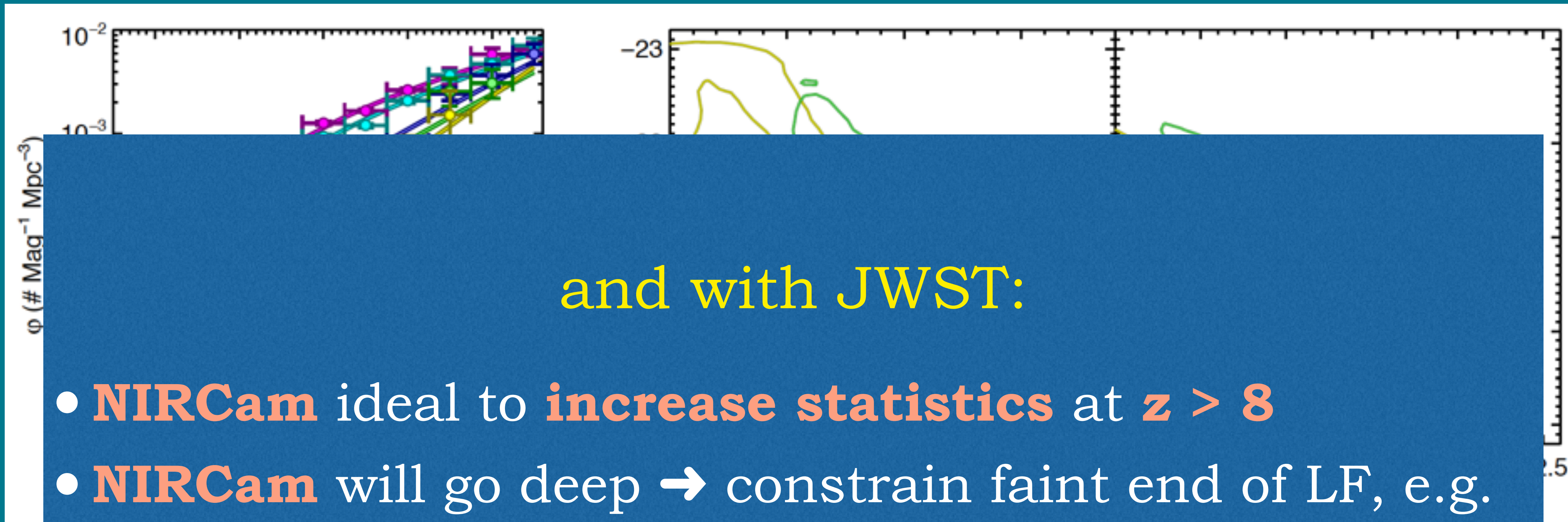

and with JWST:

- **NIRCam** ideal to **increase statistics** at ***z* > 8**
- **NIRCam** will go deep ➜ constrain faint end of LF, e.g. detect **turn-over**
- **MIRI** needed to **characterise SF galaxies**, e.g. constrain **stellar masses** at z > 9-10

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f_{esc} of LyC photons with Lyα line profiles

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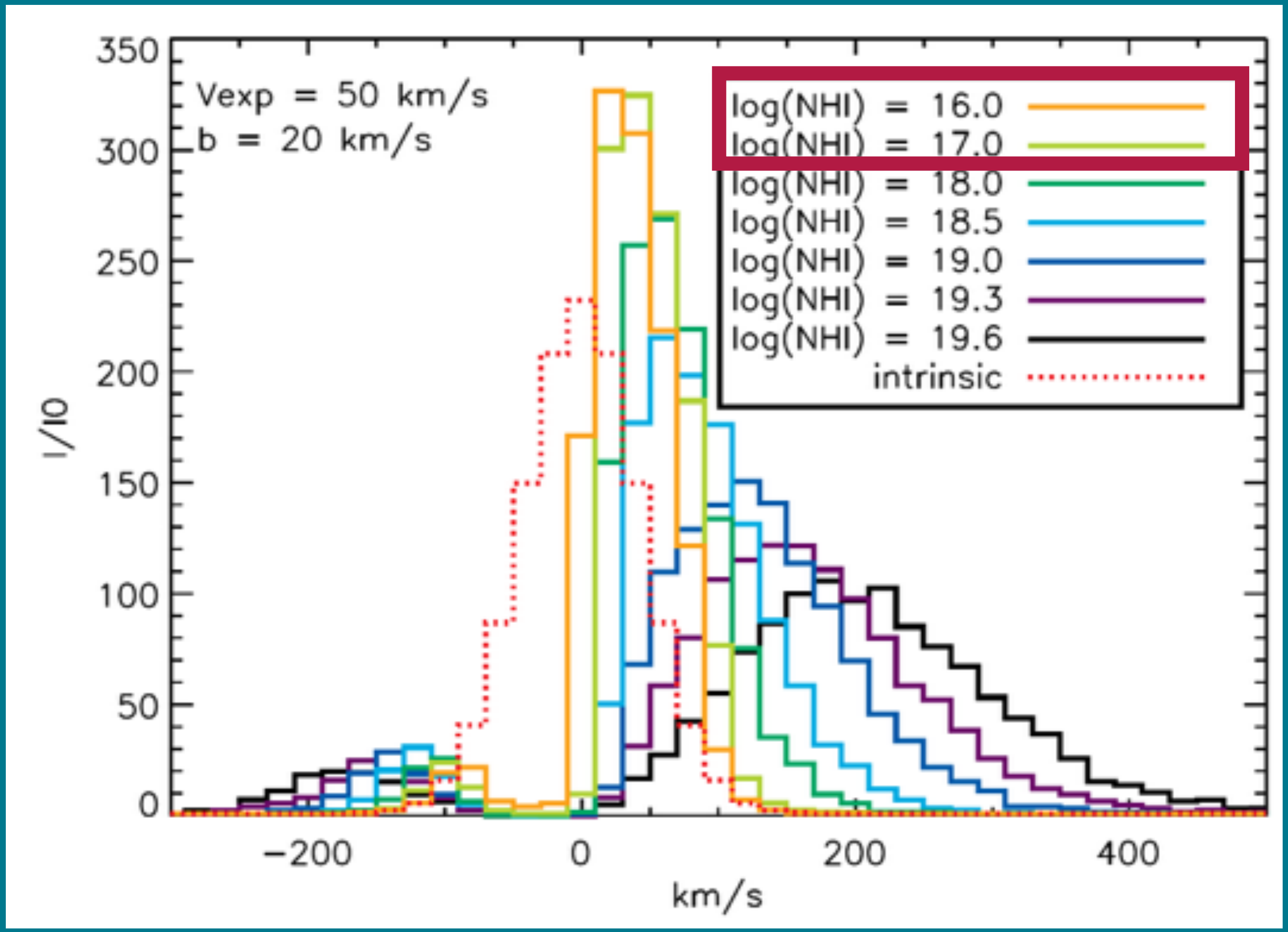

Verhamme et al. (2015)

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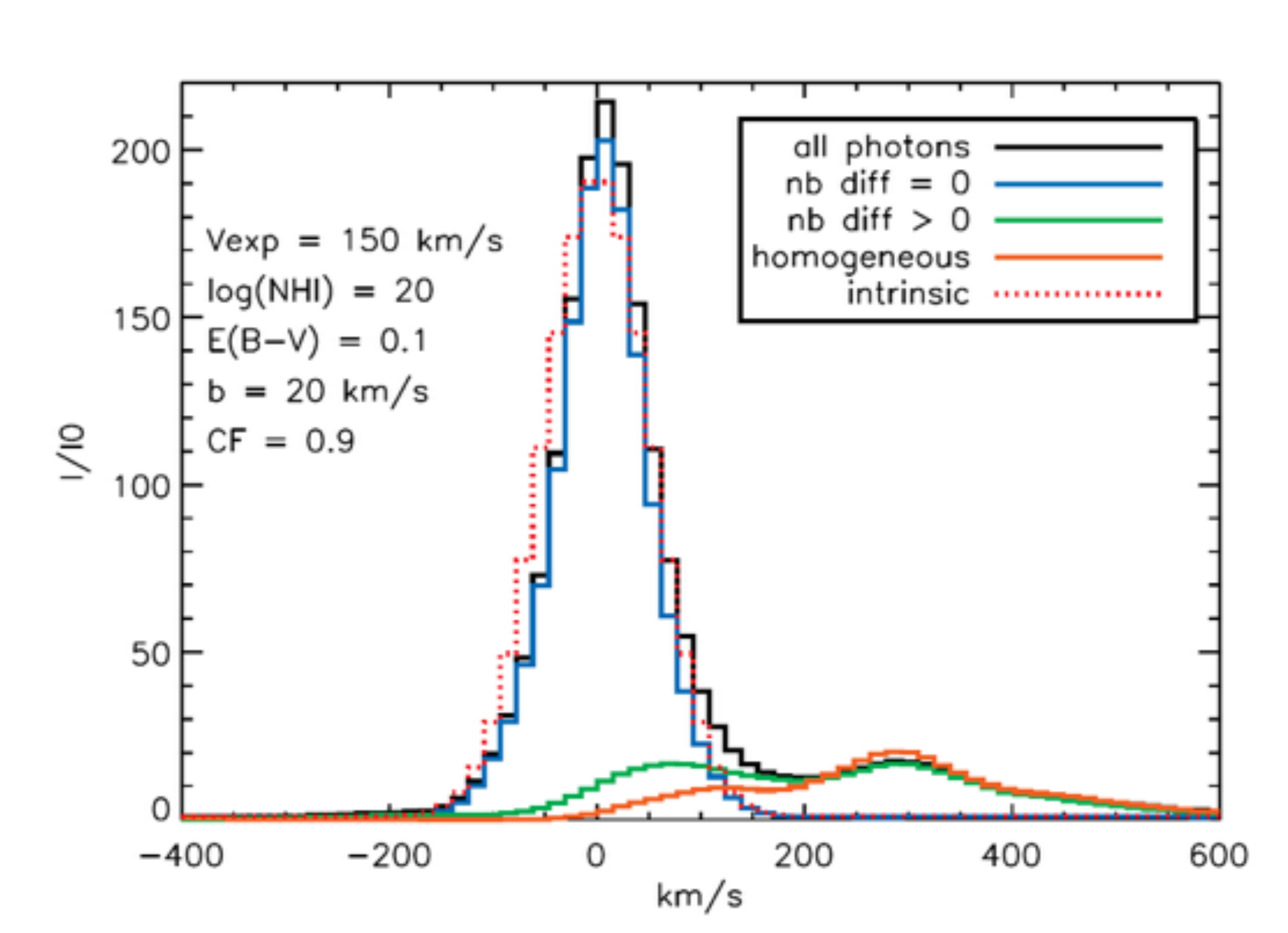

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- **Non-unit cover. fact.:**
  - no peak shift
  - non-zero flux blueward line center (does not account for IGM abs.)

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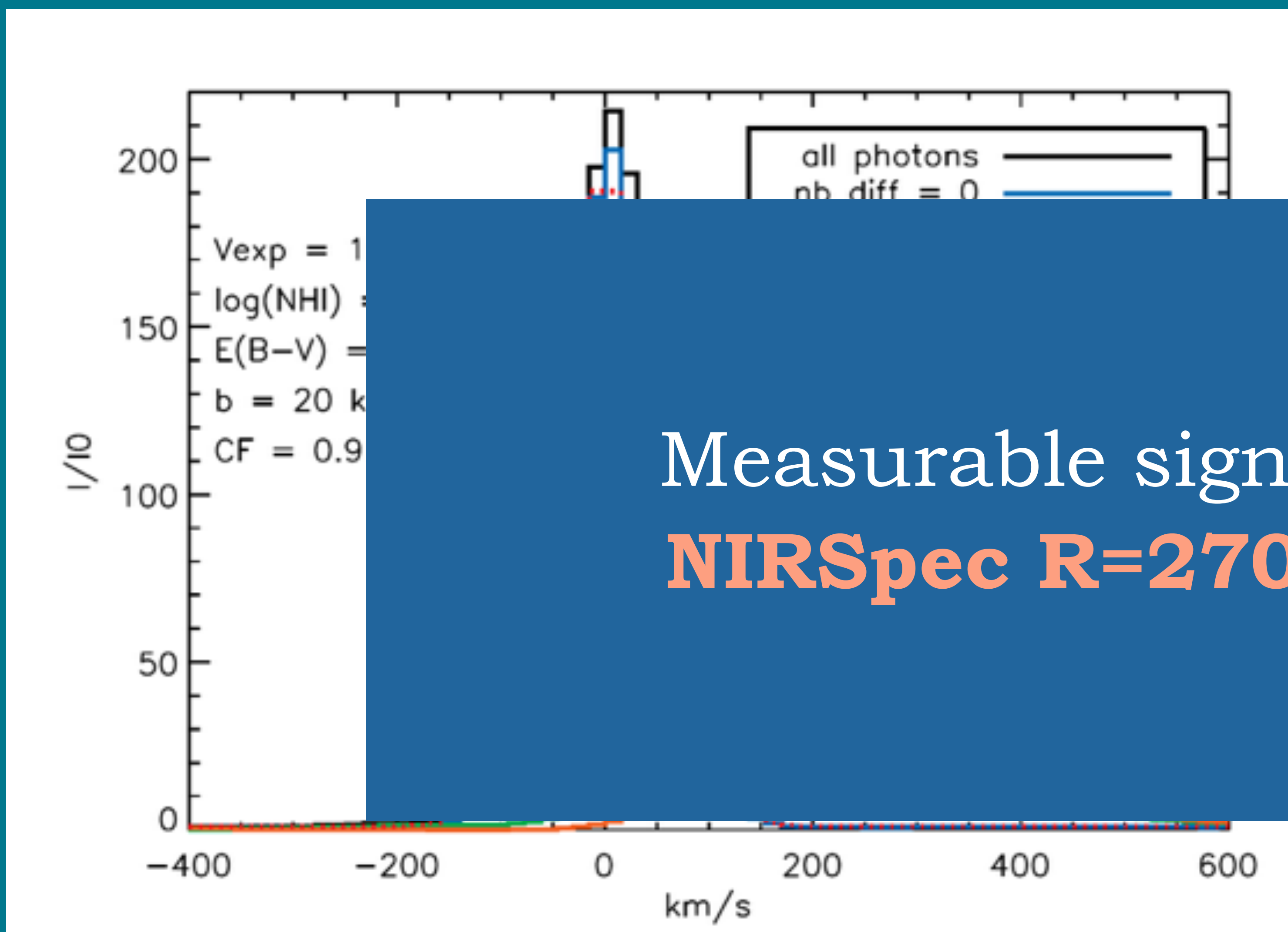

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Measurable signals with **NIRSpec R=2700** mode

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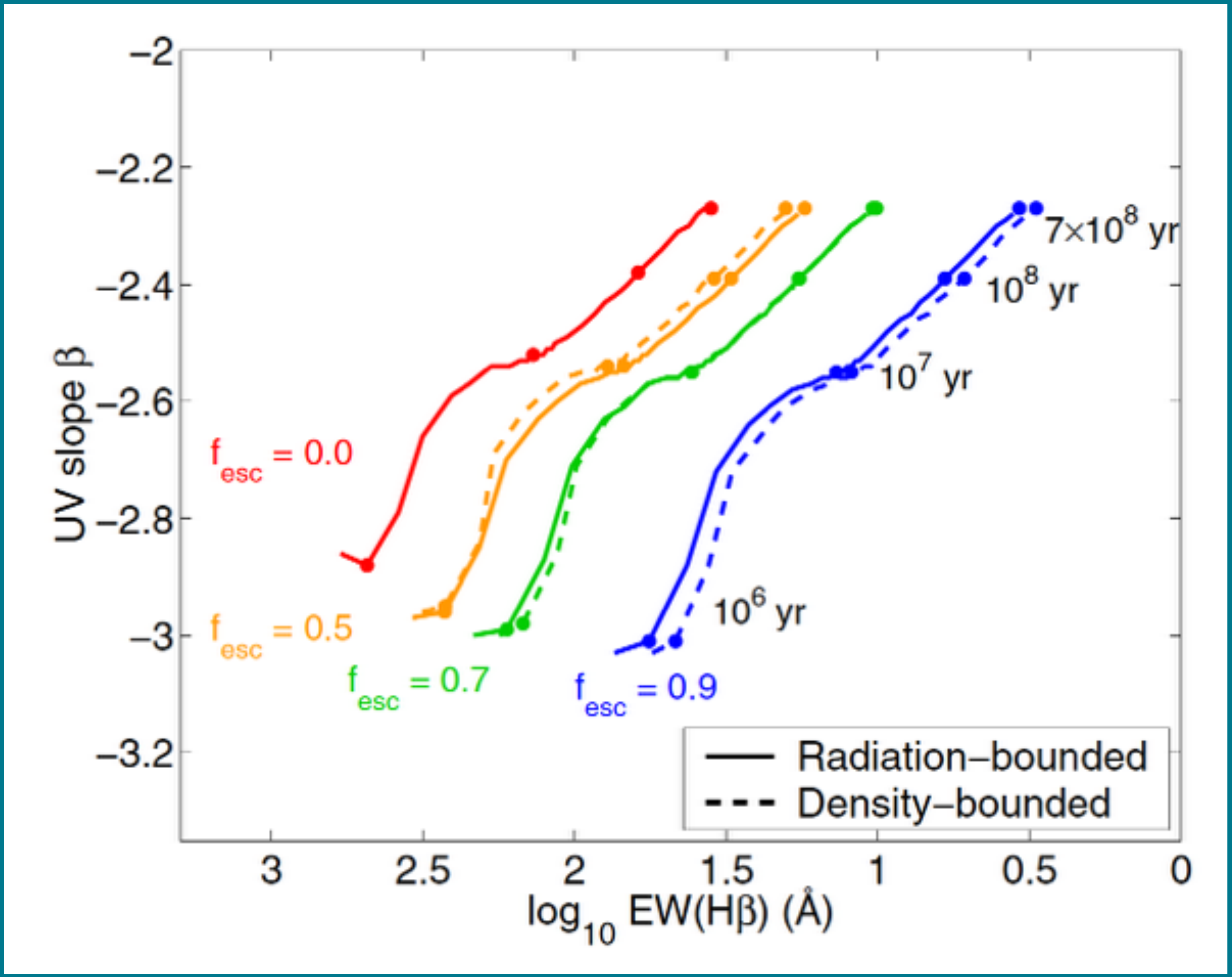

Zackrisson et al. (2013)

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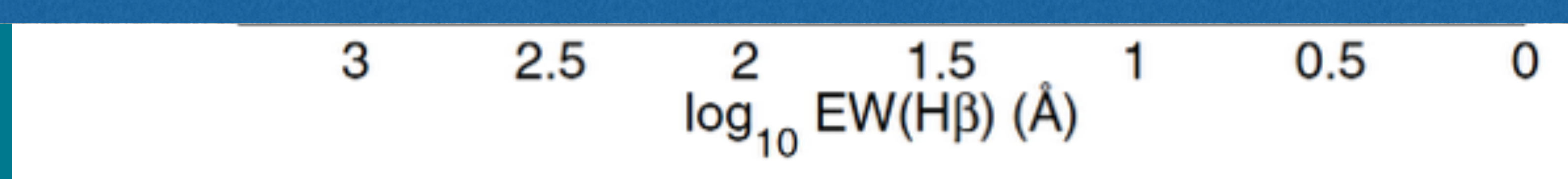
and with JWST:

- **NIRCam:** UV continuum
- **NIRSpec: gas metallicity** from metal EL
- **NIRSpec: dust attenuation** from ratio of Balmer lines
- **MIRI:** disentangle effect of **SFH** w. rest-frame optical/ near-IR



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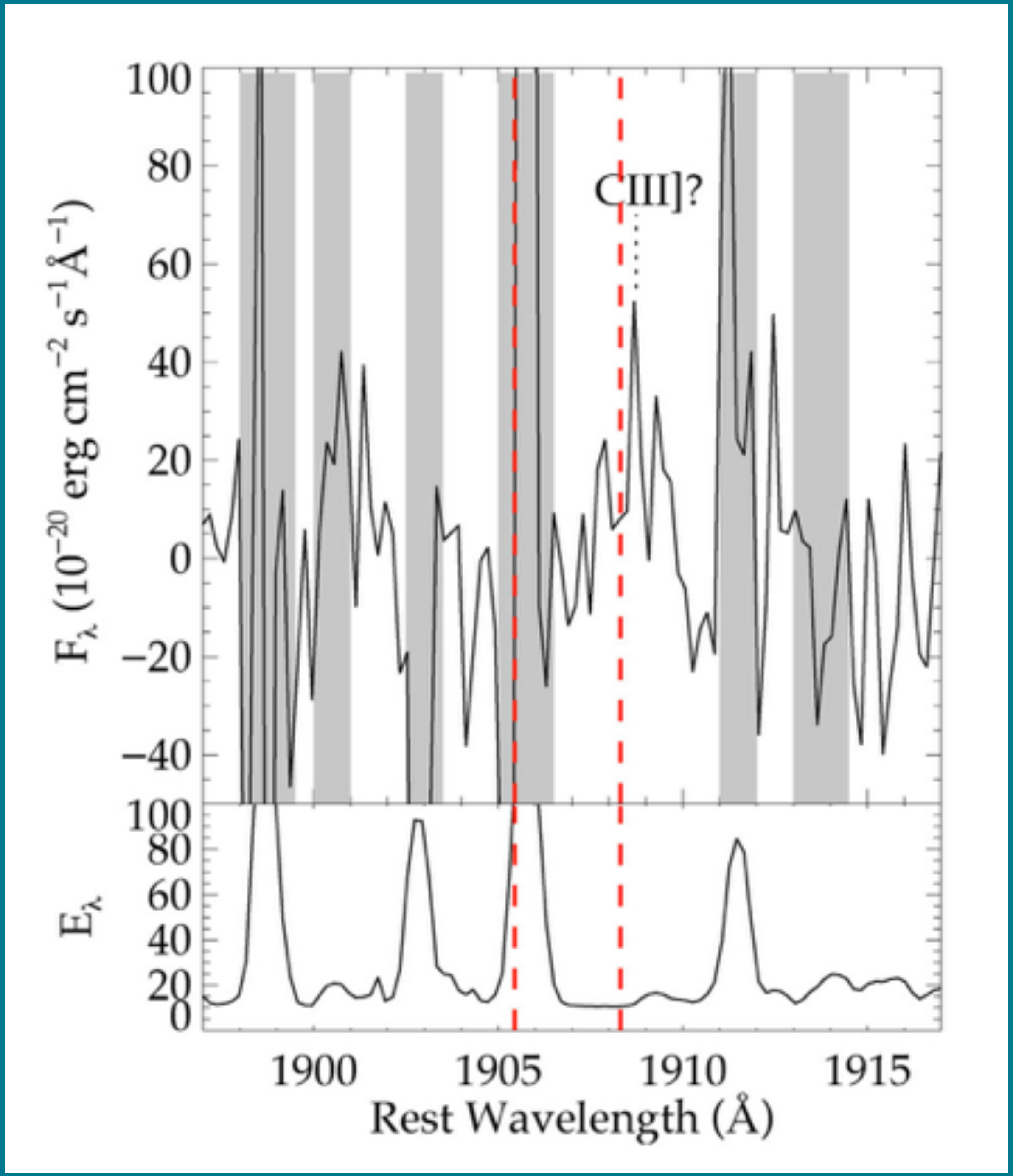

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- 3-sigma **detections** in 2 galaxies at **$z > 6$**
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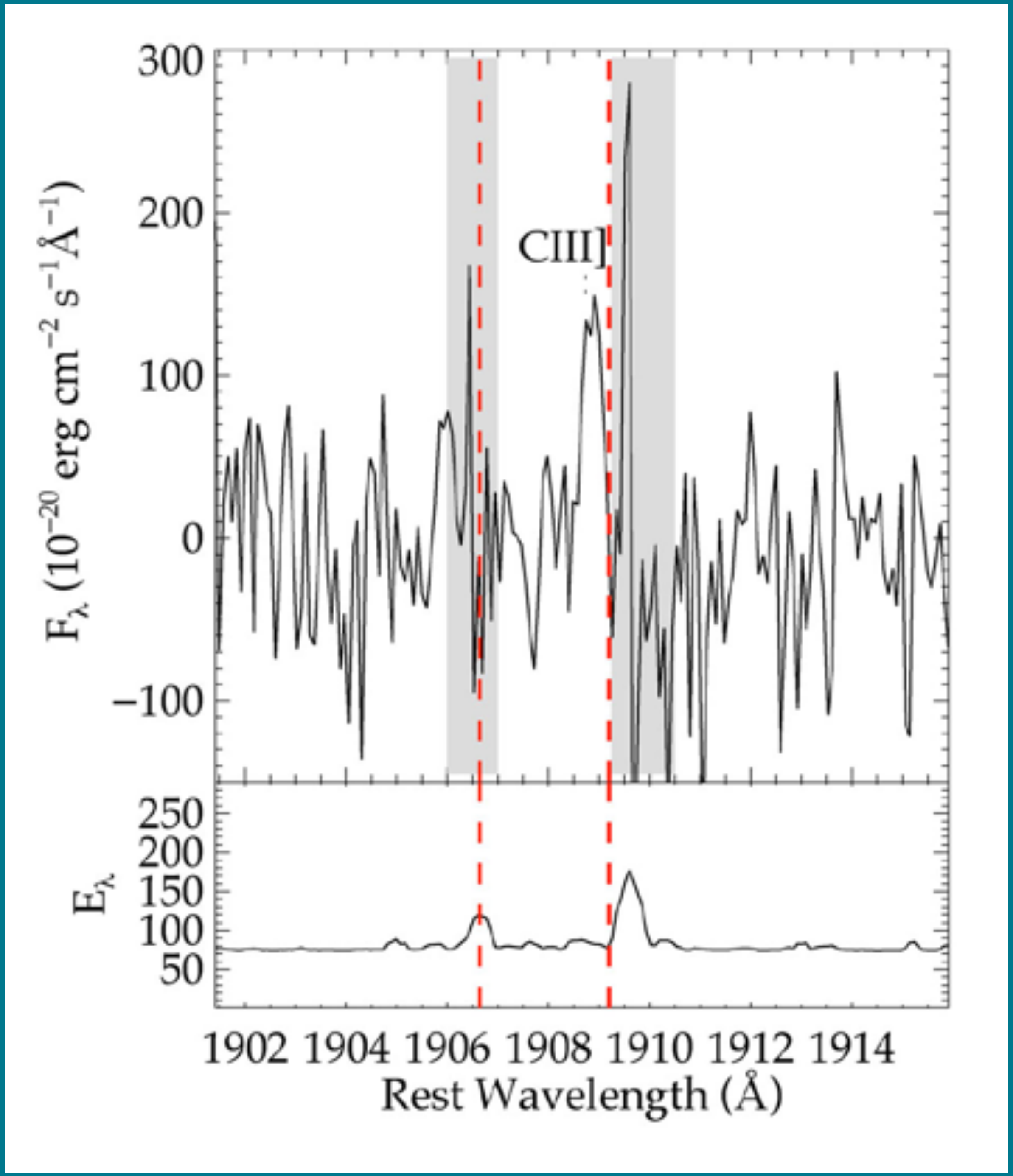

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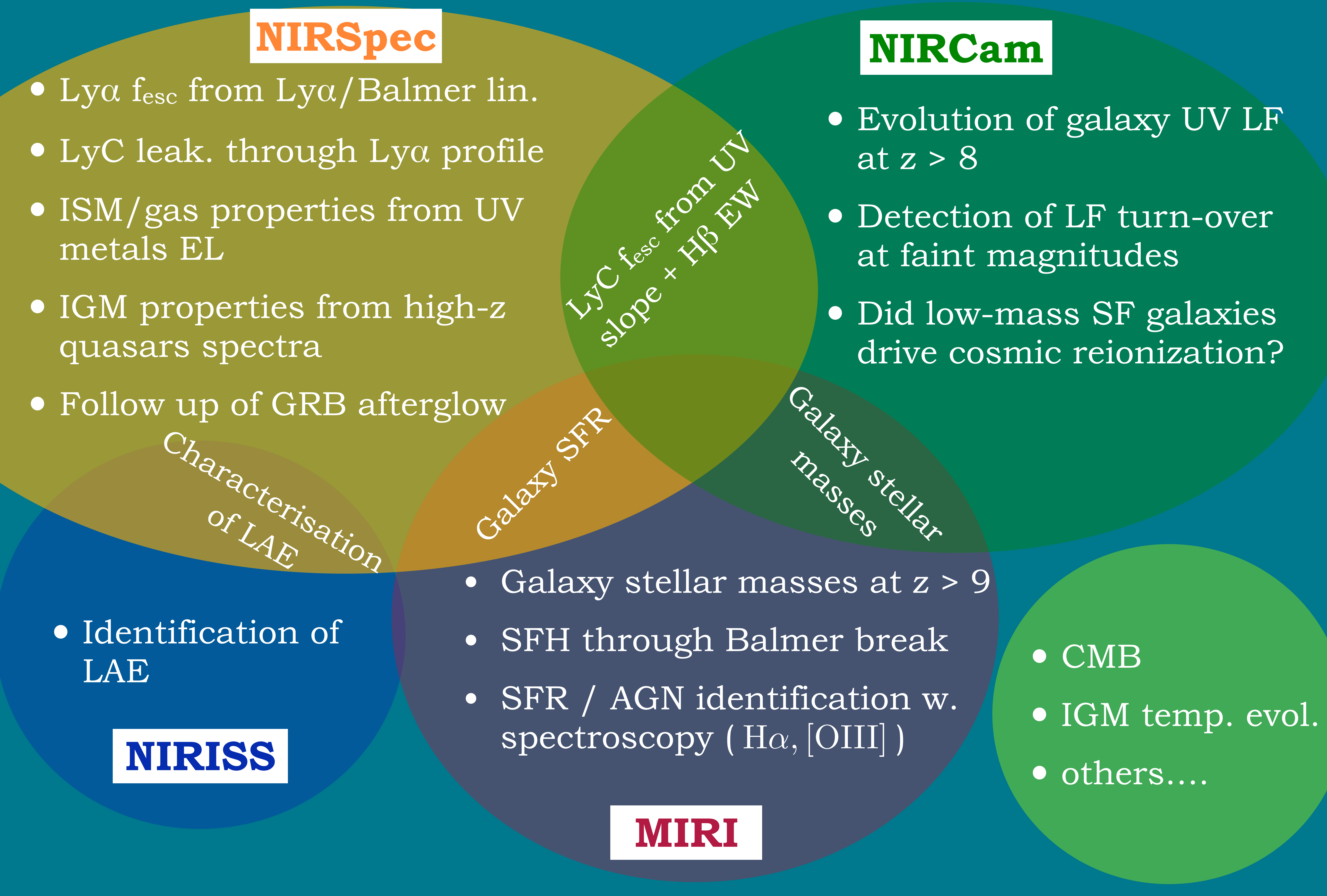
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THANKS !