Galaxies at High Redshift and Reionization

Bunker, A., Stanway, E., Ellis, R., Lacy, M., McMahon, R.,
Eyles, L., Stark D., Chiu, K.

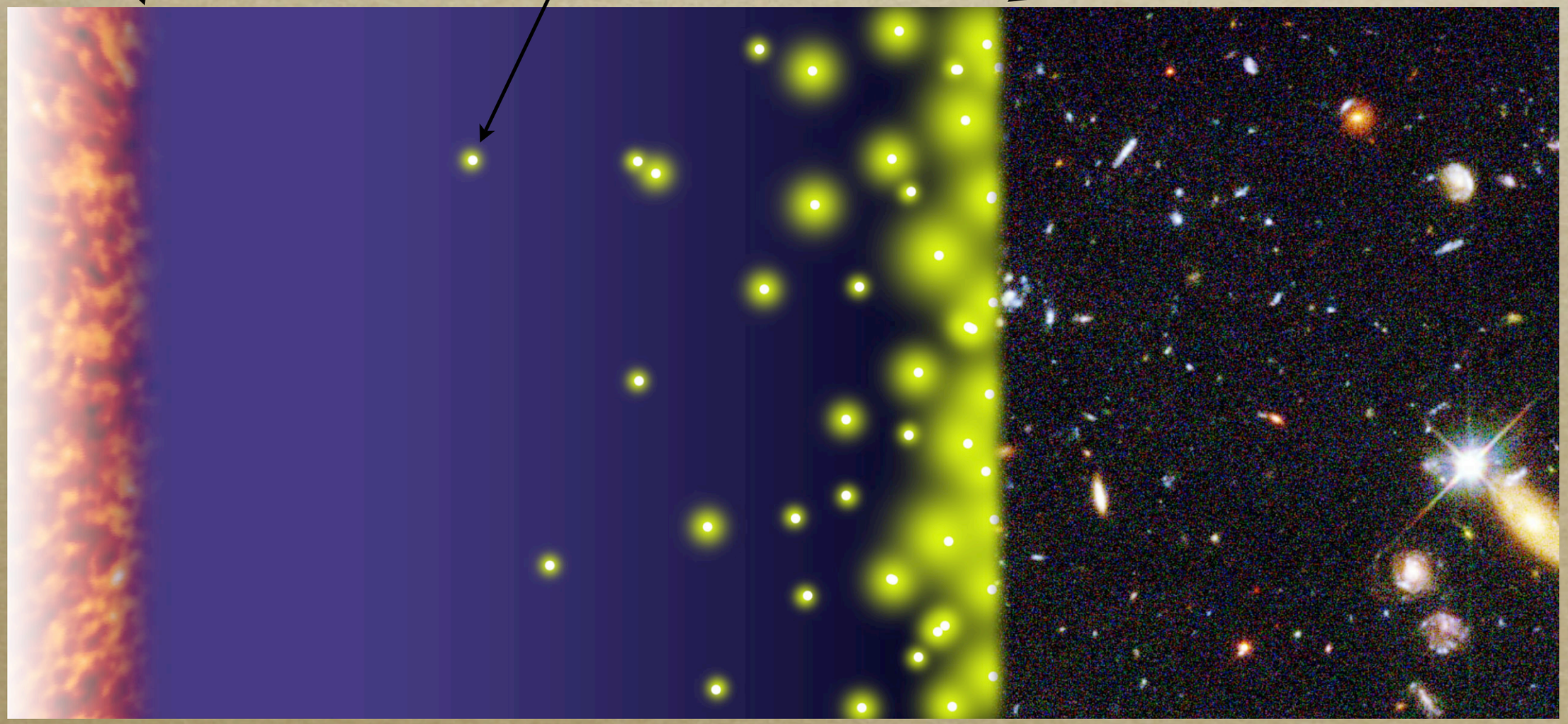
2009, ASP Conference Series, Vol. 395

$z \sim 6$ Galaxies and Reionization

Recombination

First Ionization Sources

Complete Ionization



$z \sim 1100$ $z =?$ $z \gtrsim 6$

Djorgovski et al. & Caltech Media Center

$z \sim 6$ Galaxies and Reionization

CMB

First Ionization Sources

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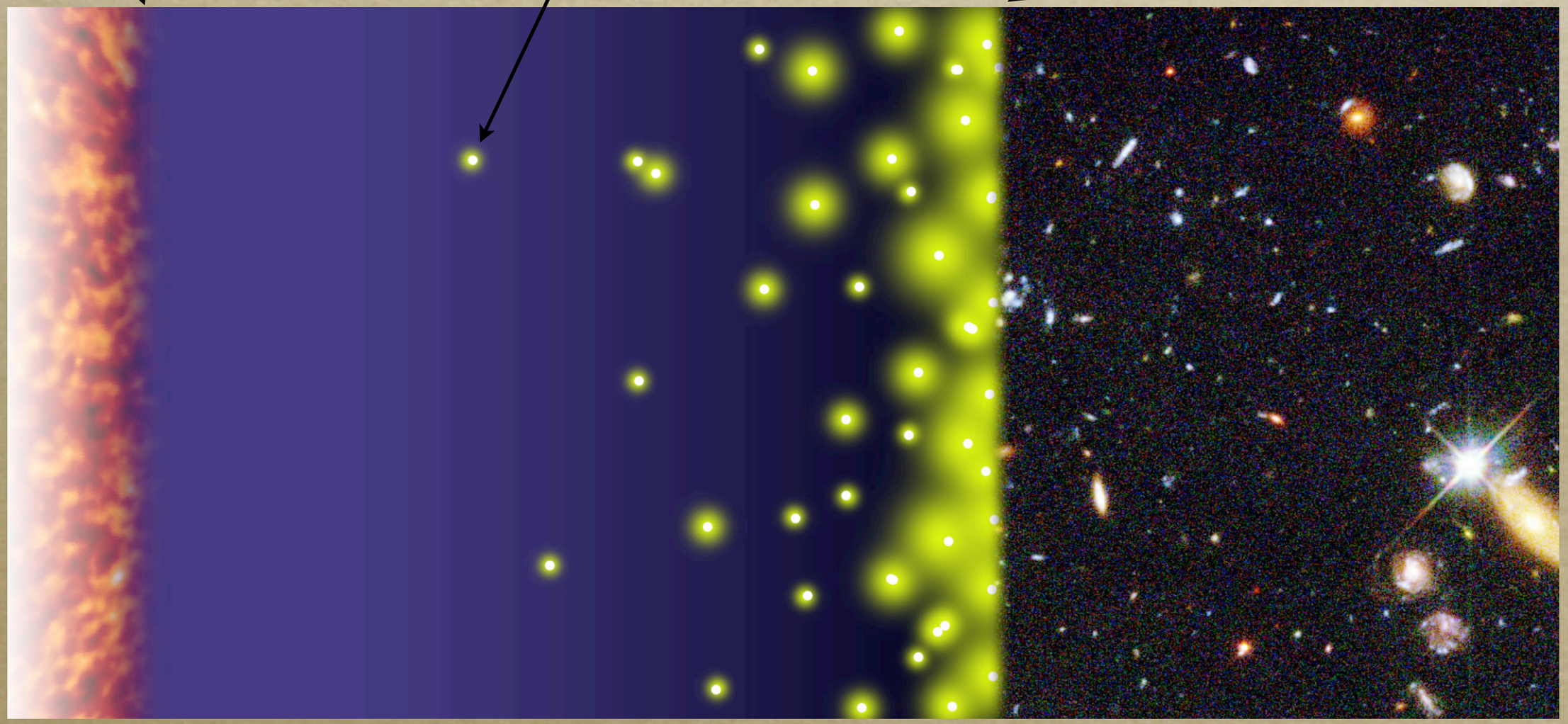

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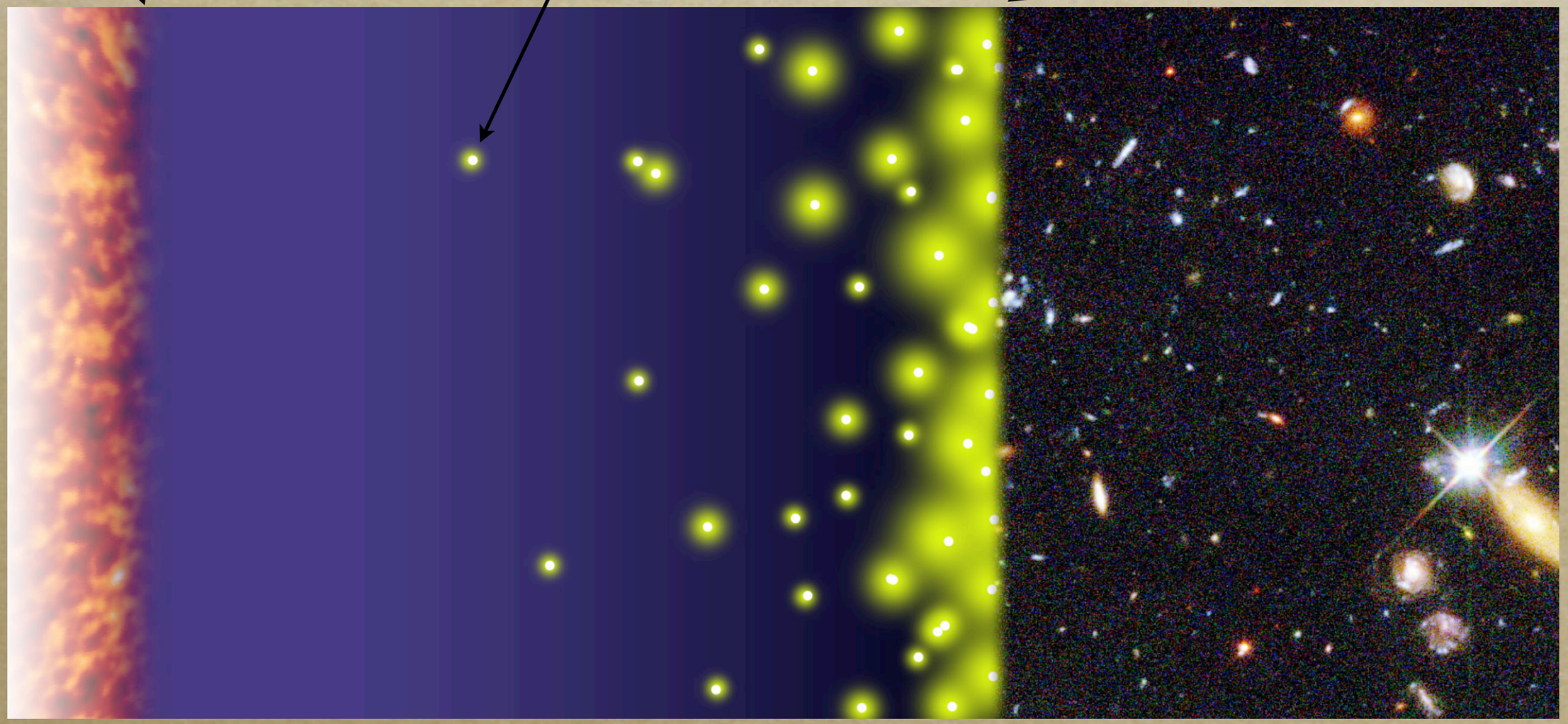
QSO Spectra, GRBs



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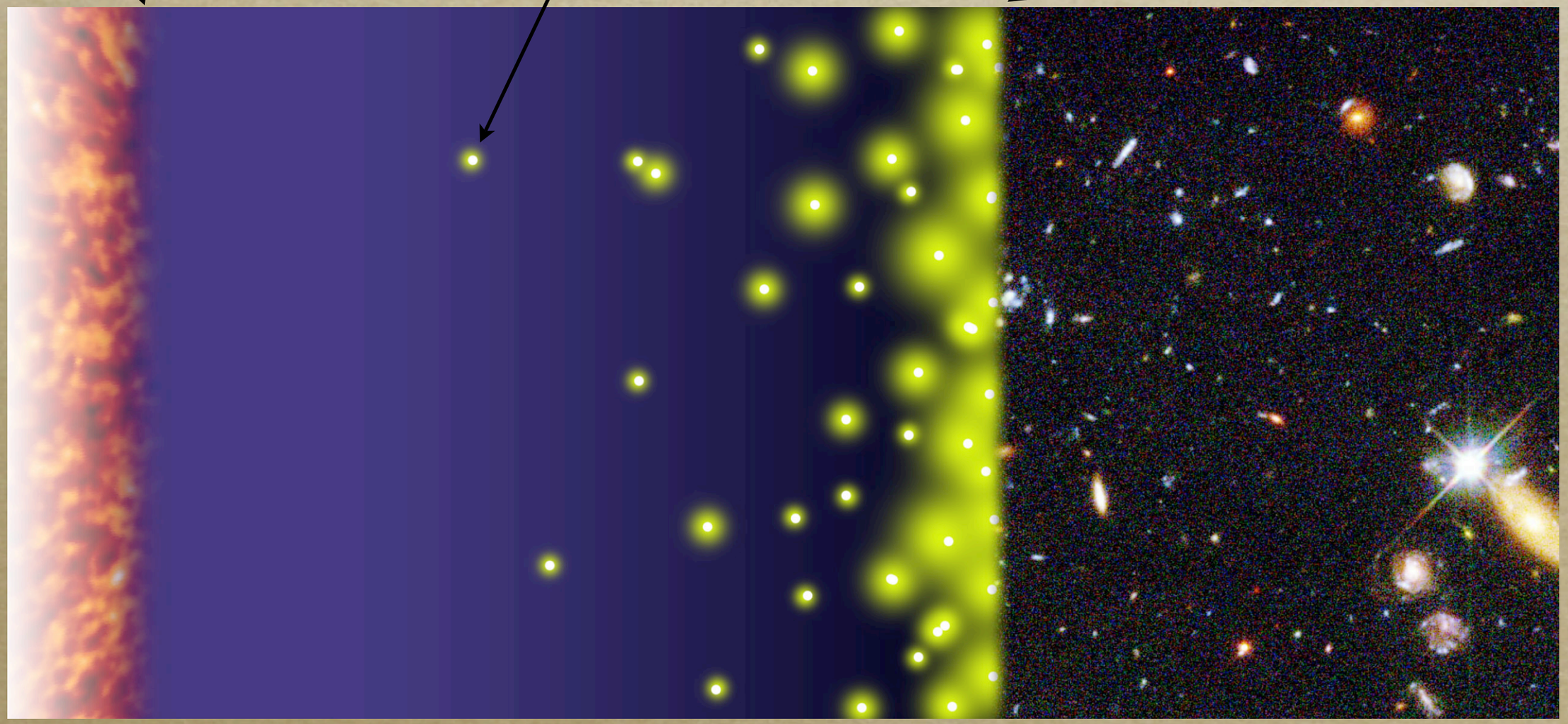
Stars? AGN?

QSO Spectra, GRBs



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$z \sim 6$ Galaxies?

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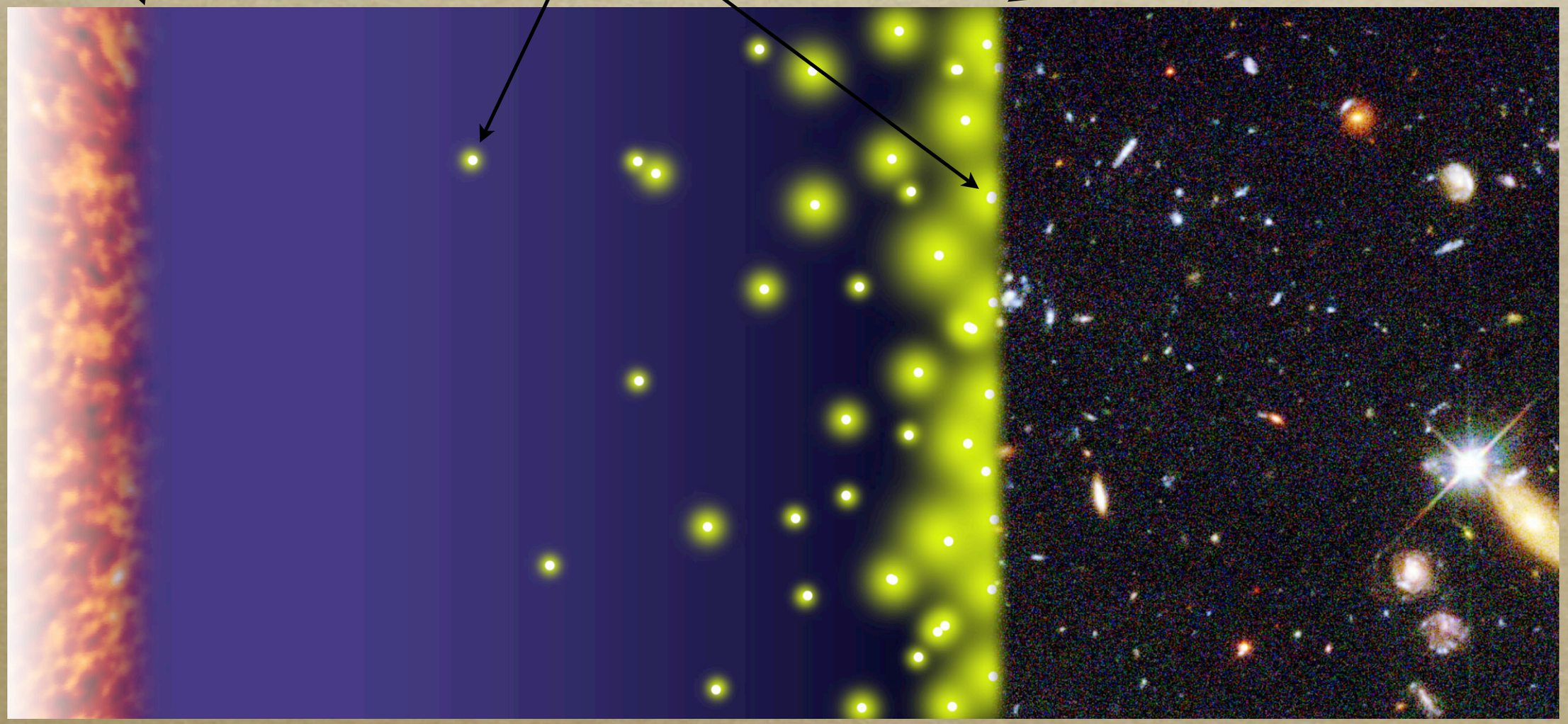

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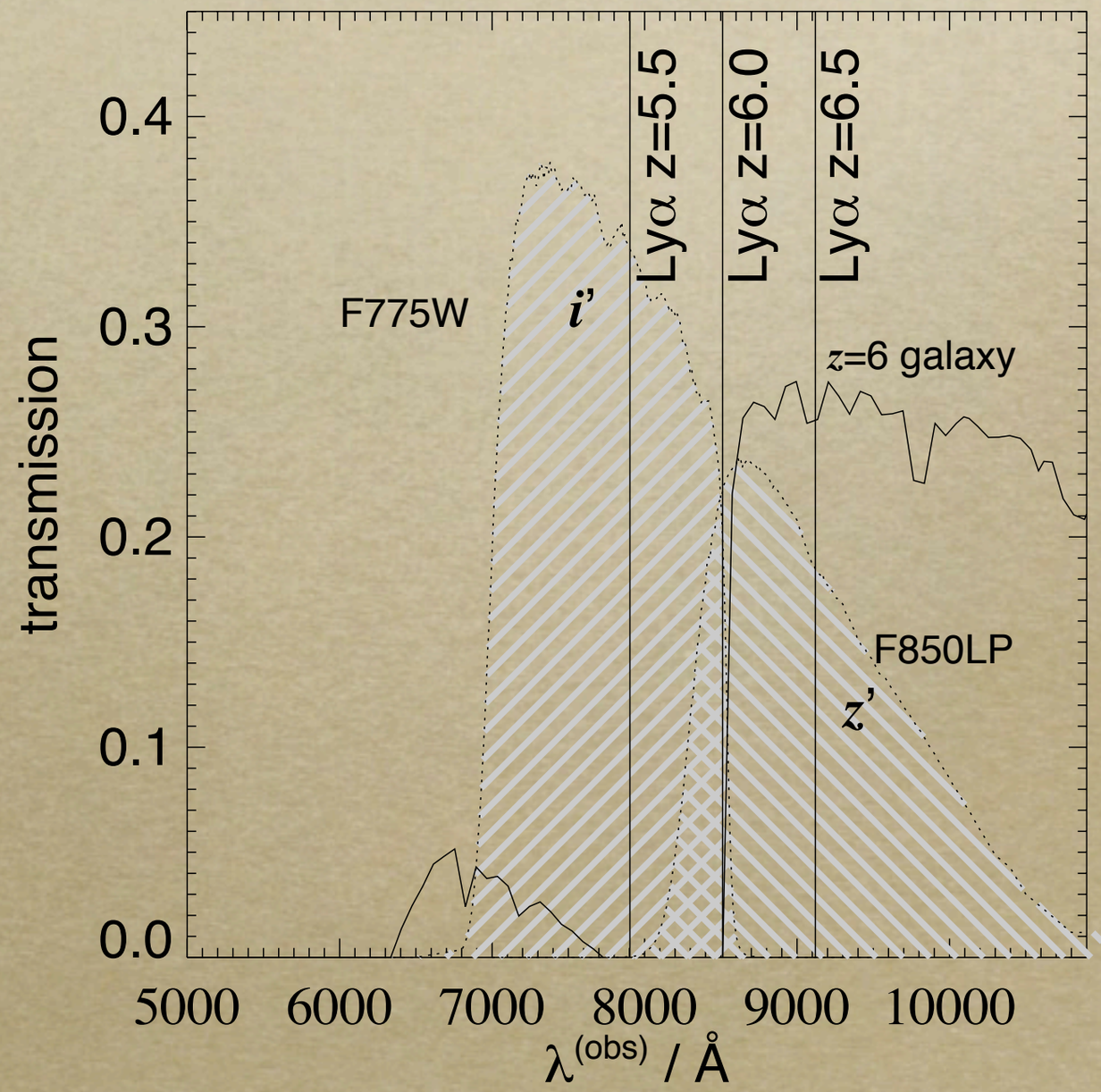
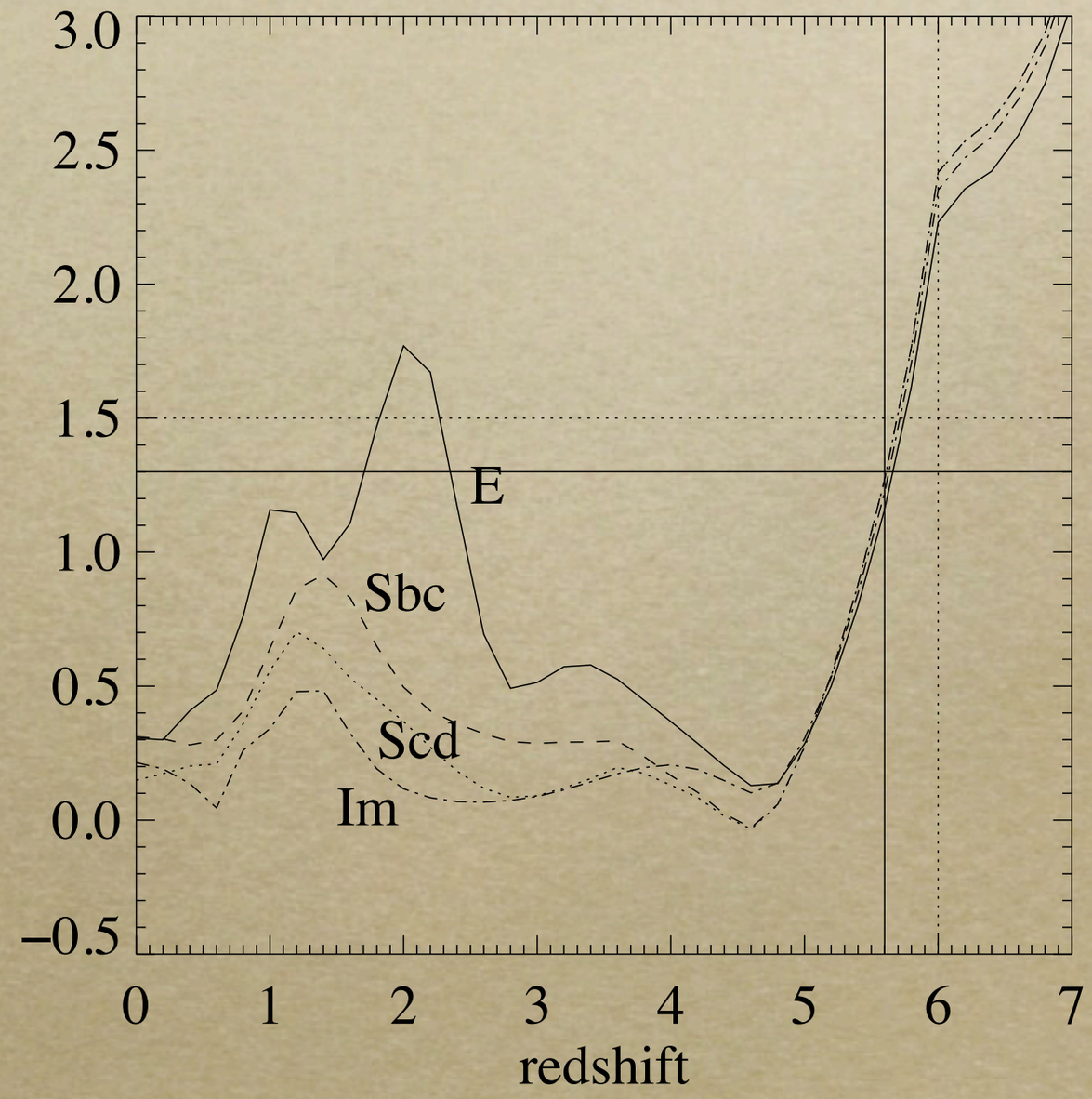
Lyman Break Technique

- $z = 6$ galaxies are hard to measure, use Lyman break technique!
- *i'* dropouts serve as candidates



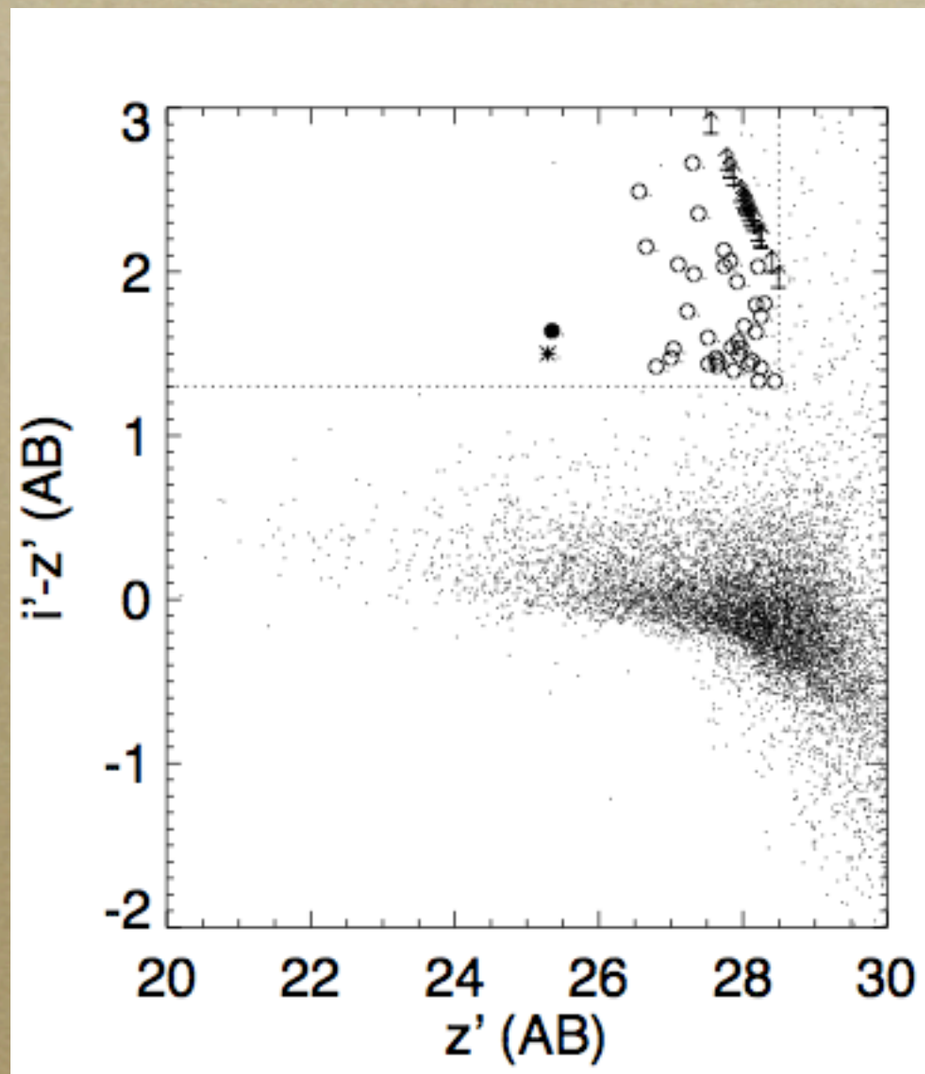
Lyman Break Technique

- $z = 6$ galaxies are hard to measure, use Lyman break technique!
- i' dropouts serve as candidates
- Cut at $(i' - z') > 1.3$
- Deep *HST* images of well known fields (e.g., GOODS, HUDF,...)
- Some contaminants from evolved galaxies, dwarf stars

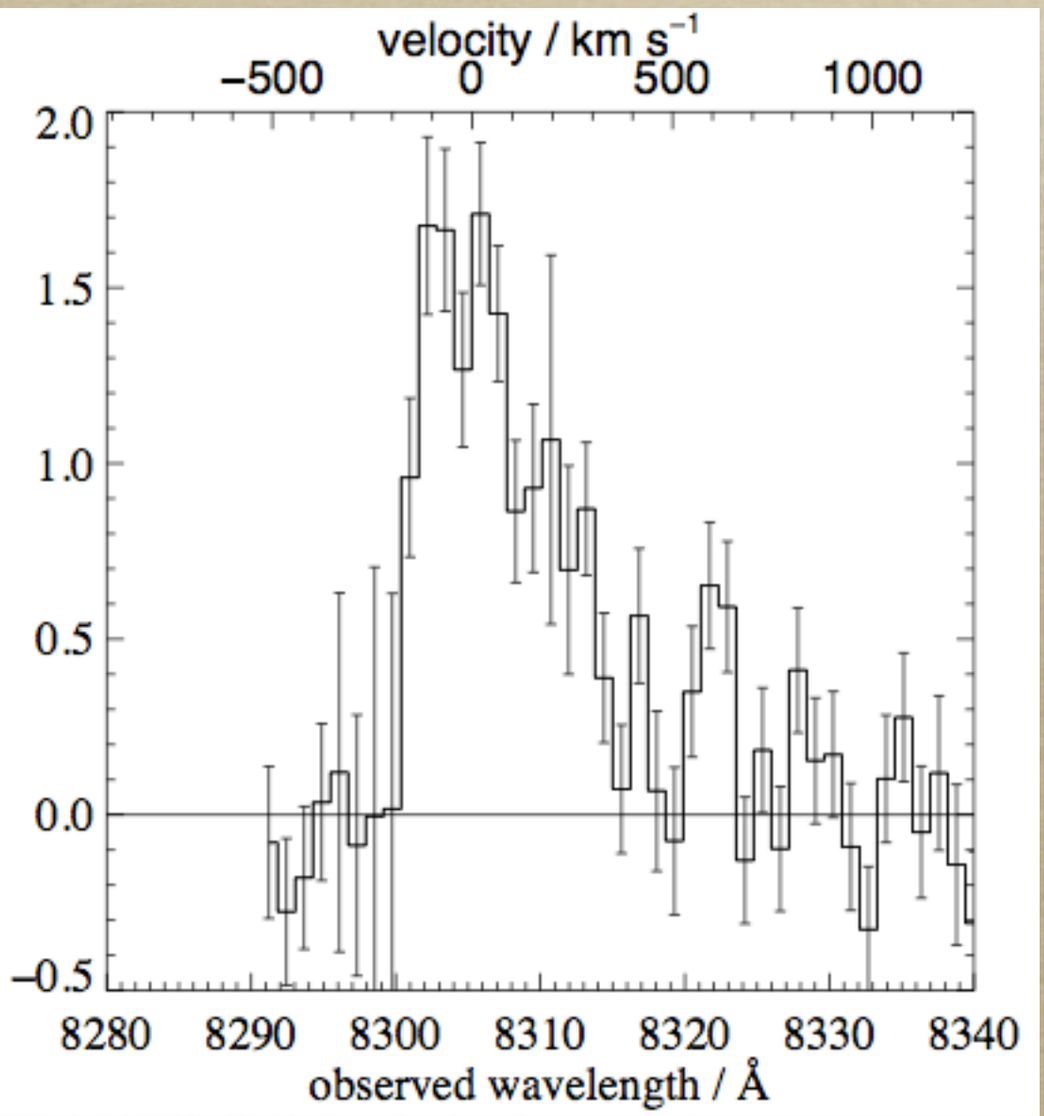


Candidates and Follow-up

HUDF



Ground Based Spectra

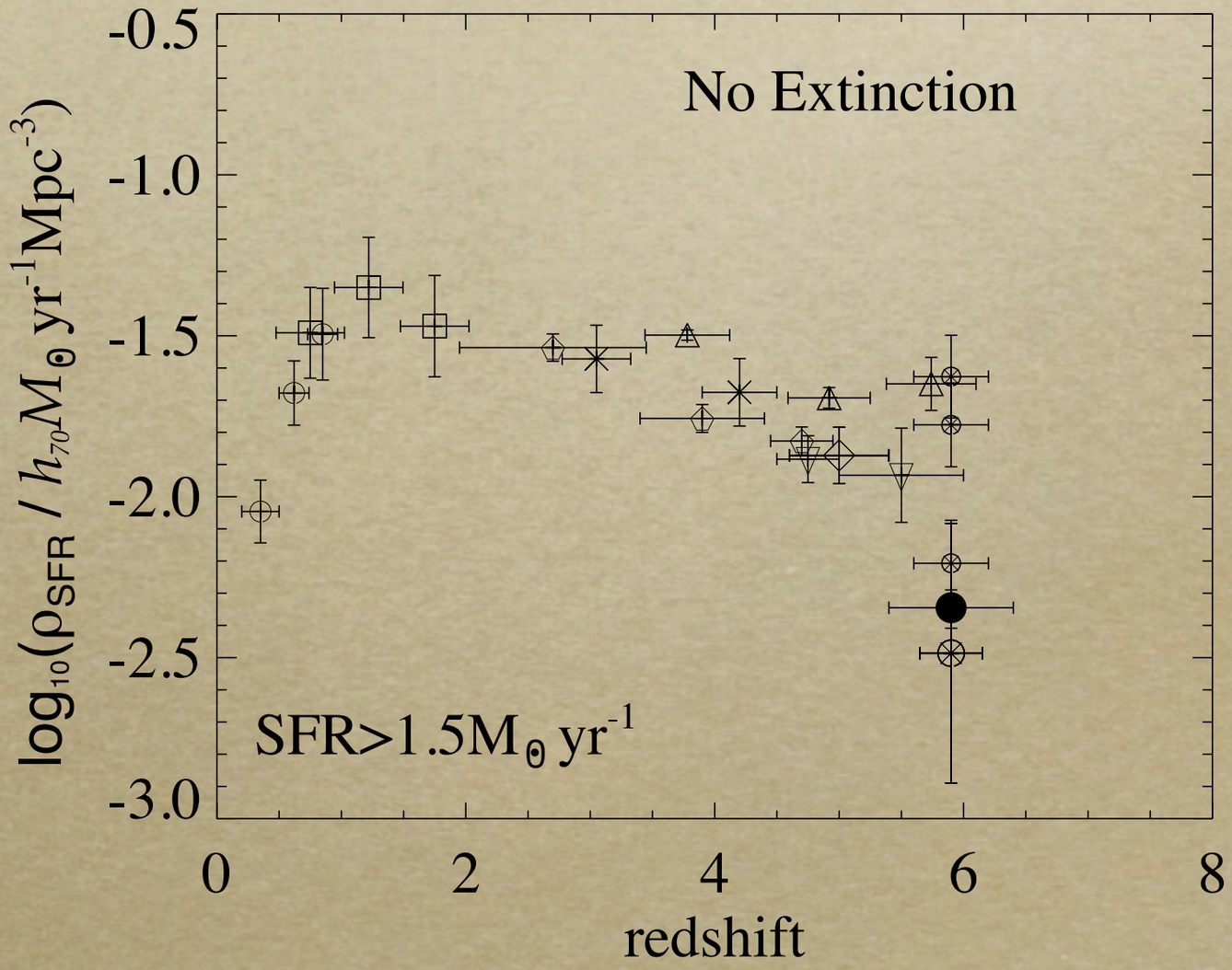


Star Formation Rate Density

- Want to know SFR and its density to constrain galaxy properties and contribution to reionization
- z' flux measures rest-frame UV, probes recent massive star formation
- Assume IMF, no extinction, and convert:

$$L_{\rm UV} = 8 \times 10^{27}\ {\rm ergs\ s^{-1}\ Hz^{-1}} = 1 M_\odot\ {\rm yr^{-1}}$$

- GOODS field: $0.005\ h_{70}^{-2} M_\odot\ {\rm yr^{-1}\ Mpc^{-3}}$
  - 6 times less than at $z = 3$
  - What about low-luminosity systems?: $z' > 25.6$
- Confirmed in HUDF
  - $z' < 28.5$ (10σ), 144 orbits



$z = 6$ Galaxies as Sources of Reionization

- Star formation rate density to reionize the universe:

$$\dot{\rho}_{\rm SFR} \sim \frac{0.026 M_\odot {\rm yr}^{-1} {\rm Mpc}^{-3}}{f_{esc}} \left(\frac{1+z}{7}\right)^3 \left(\frac{\Omega_b h_{70}^2}{0.0457}\right)^2 \left(\frac{C}{30}\right)$$ *Madau et al. (1999)*

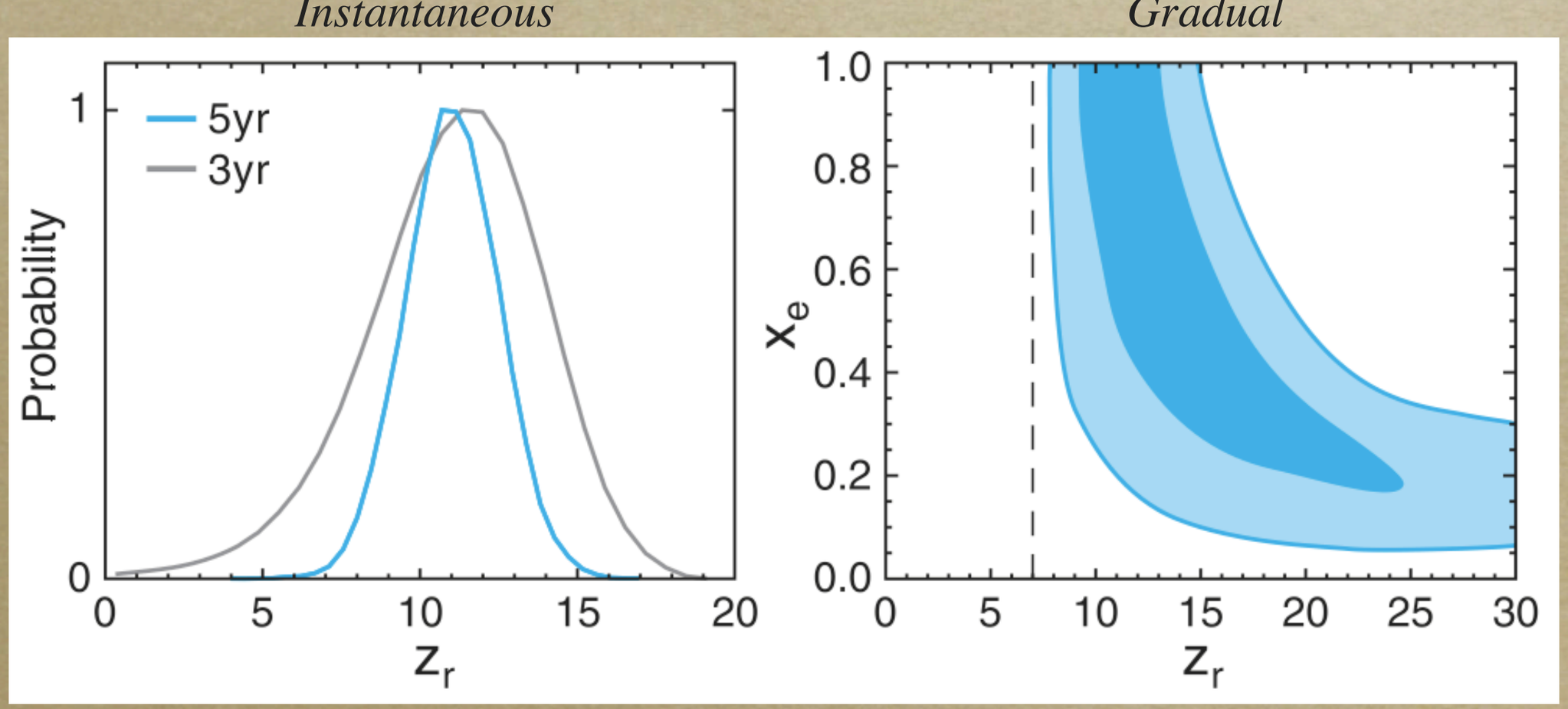
- From HUDF: $0.005\ h_{70}^{-2} M_\odot\ {\rm yr}^{-1}\ {\rm Mpc}^{-3}$
  - Even if $f_{esc} = 1$ is insufficient for reionization, except for very steep faint end slopes of luminosity function.

- For galaxies at $z = 6$ to reionize the universe, require:
  - Different IMF, neutral gas concentration, or other low luminosity sources

"Old" Stellar Populations at $z = 6$

- *WMAP* data indicates $z_{reion} > 10$
- Do $z = 6$ galaxies harbor old stellar populations?

Instantaneous *Gradual*



Dunkley, et al. (2009)

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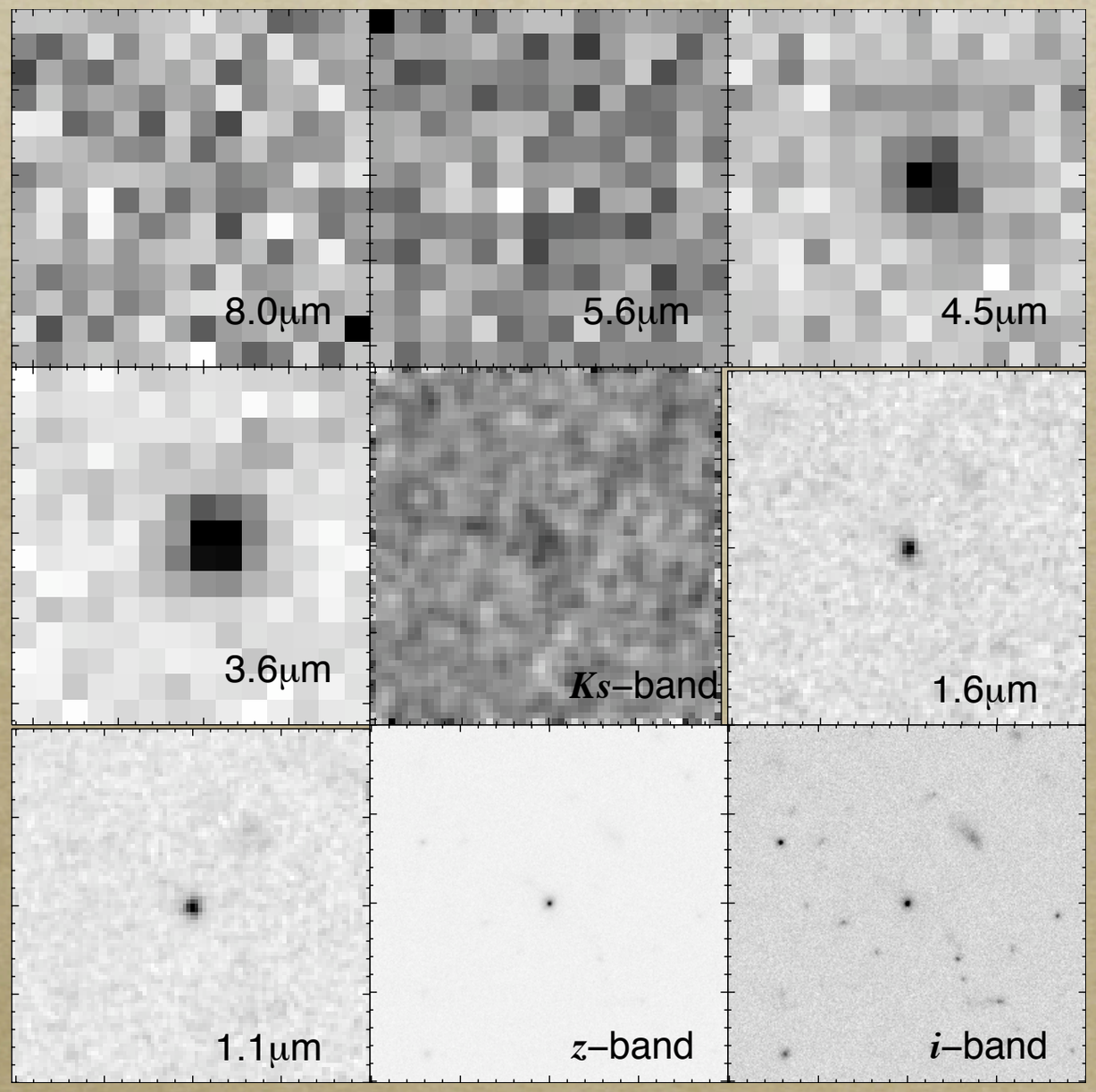

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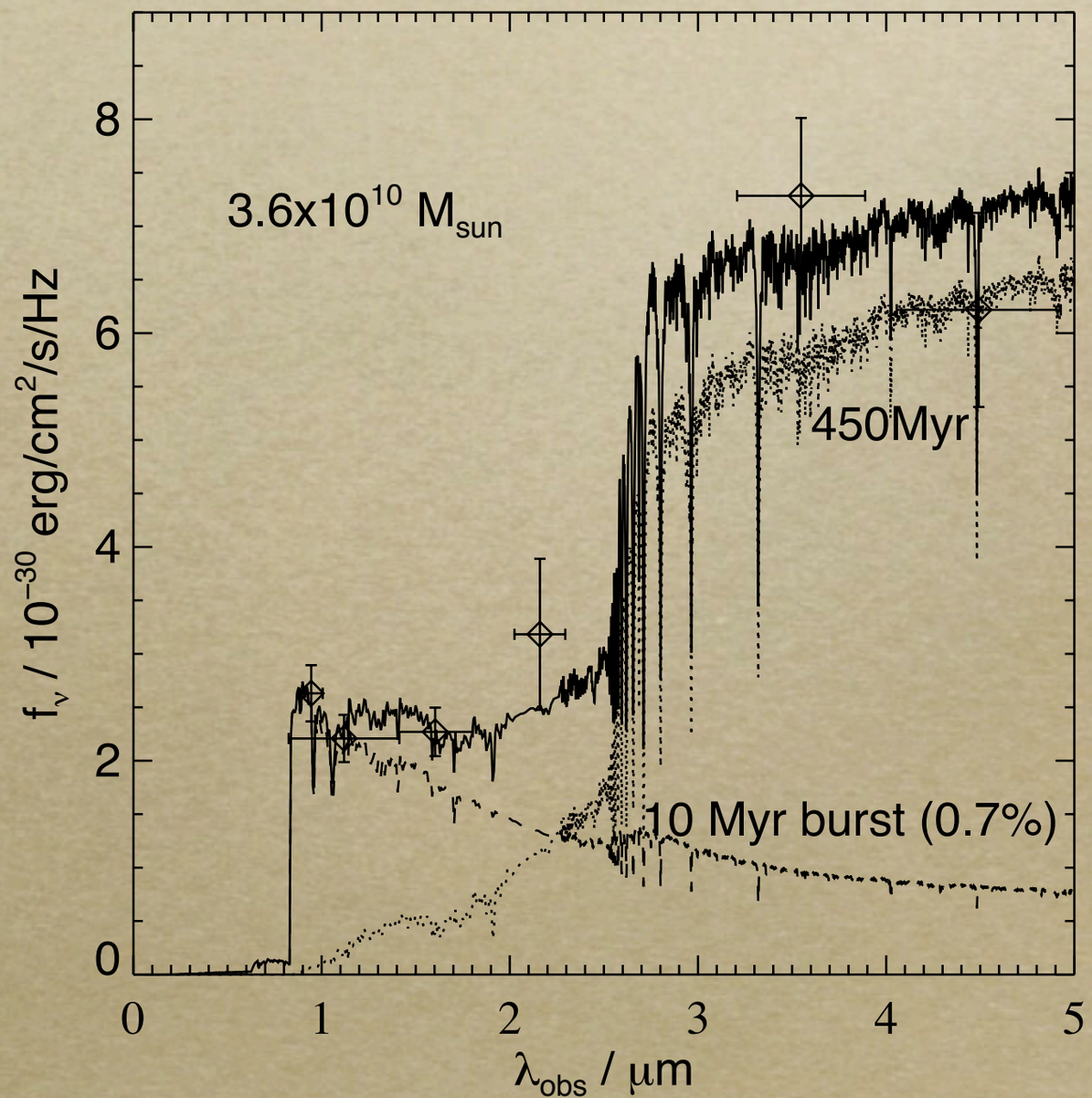
  - Few $\times 10^{10} M_{\odot}$
- In GOODS: 40% indicate old stellar pops



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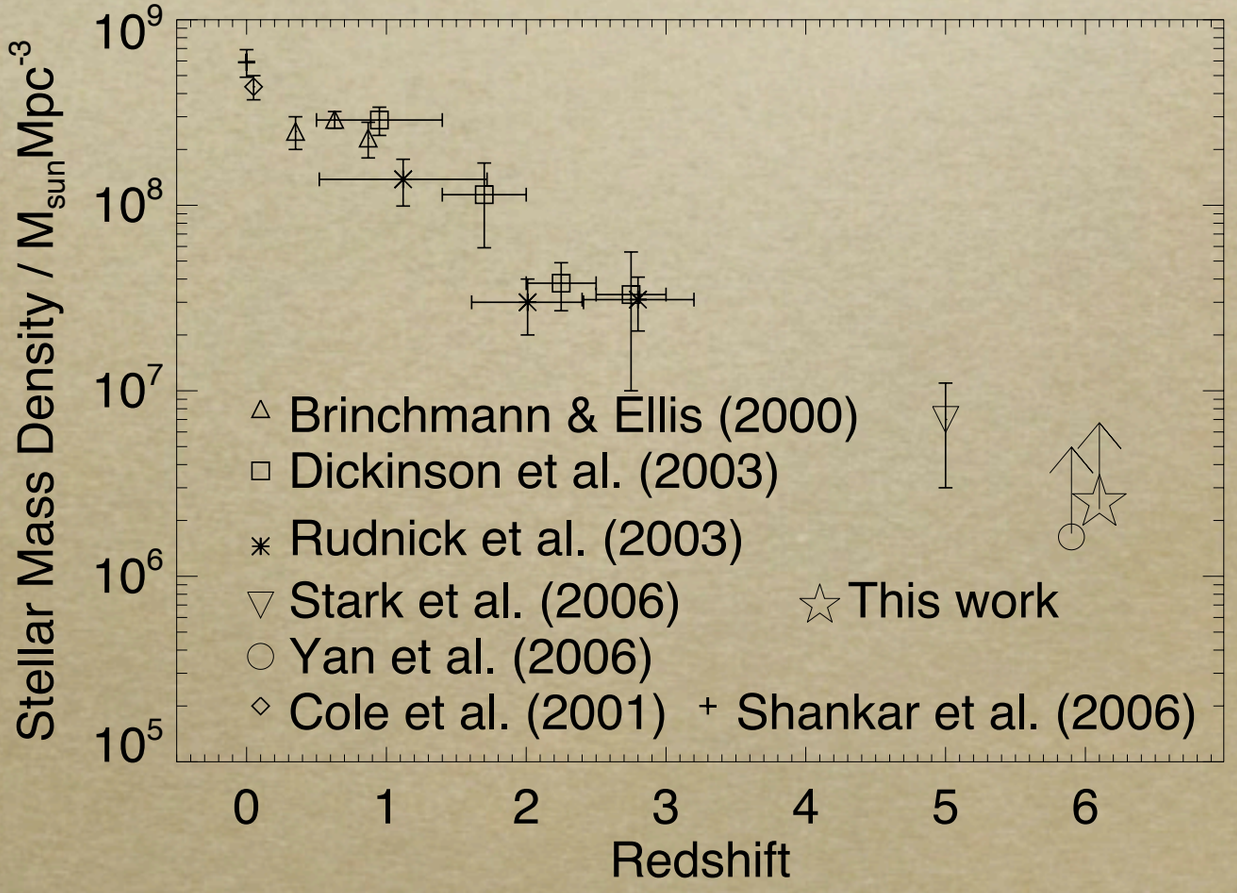

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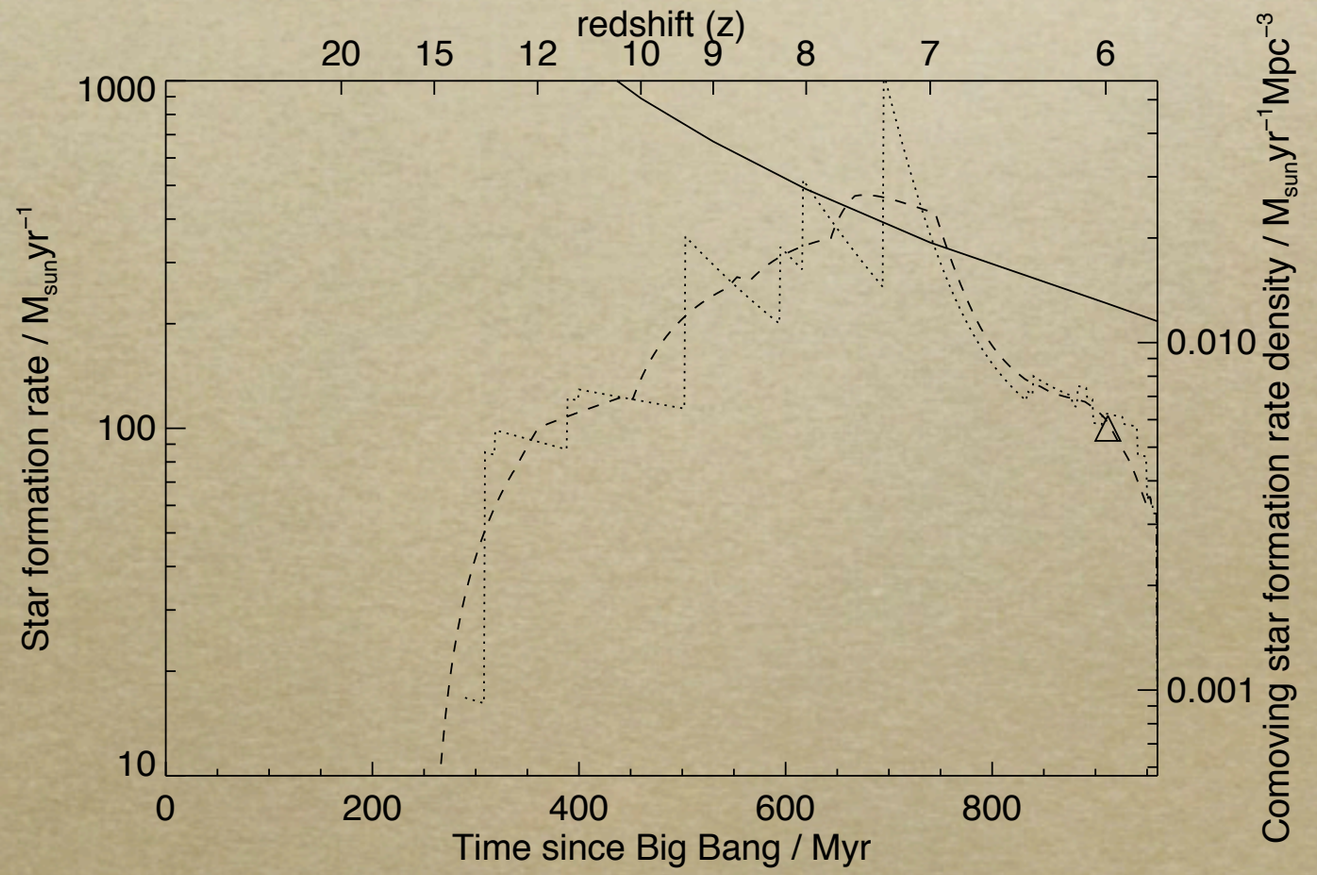
    - Stellar mass density: $2.5 \times 10^{6} M_{\odot}\ \mathrm{Mpc}^{-3}$
  - SFR at $z > 7$ may have ionized the universe



Conclusions

- $z = 6$ galaxies are not likely to be the dominant source of ionizing photons in the early universe
- SFR at $z = 6$ insufficient (and too late) to be the main epoch of reionization
- Presence of older stellar populations indicate earlier epochs of star formation may have contributed to reionization
- Better understanding of Population III stars and their IMFs may help improve understanding of reionization