

初期宇宙におけるクエーサーの探索

松岡良樹 (愛媛大学)

遠くへ

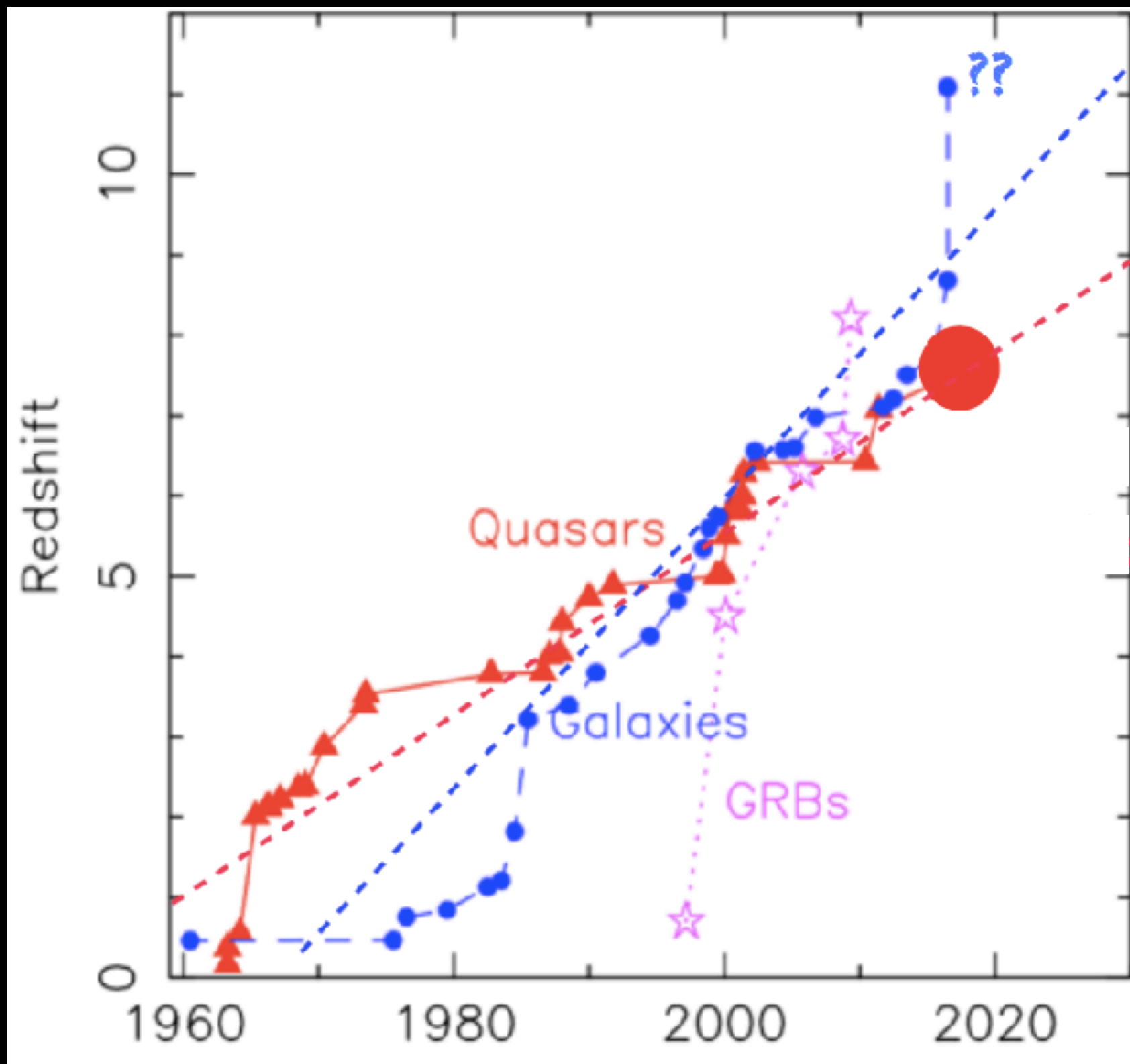
★ $z = 0.158$ (1963年)



★ $z = 7.54$ (2017年)



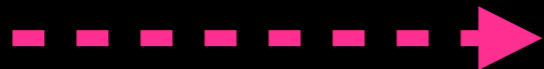
Banados+17



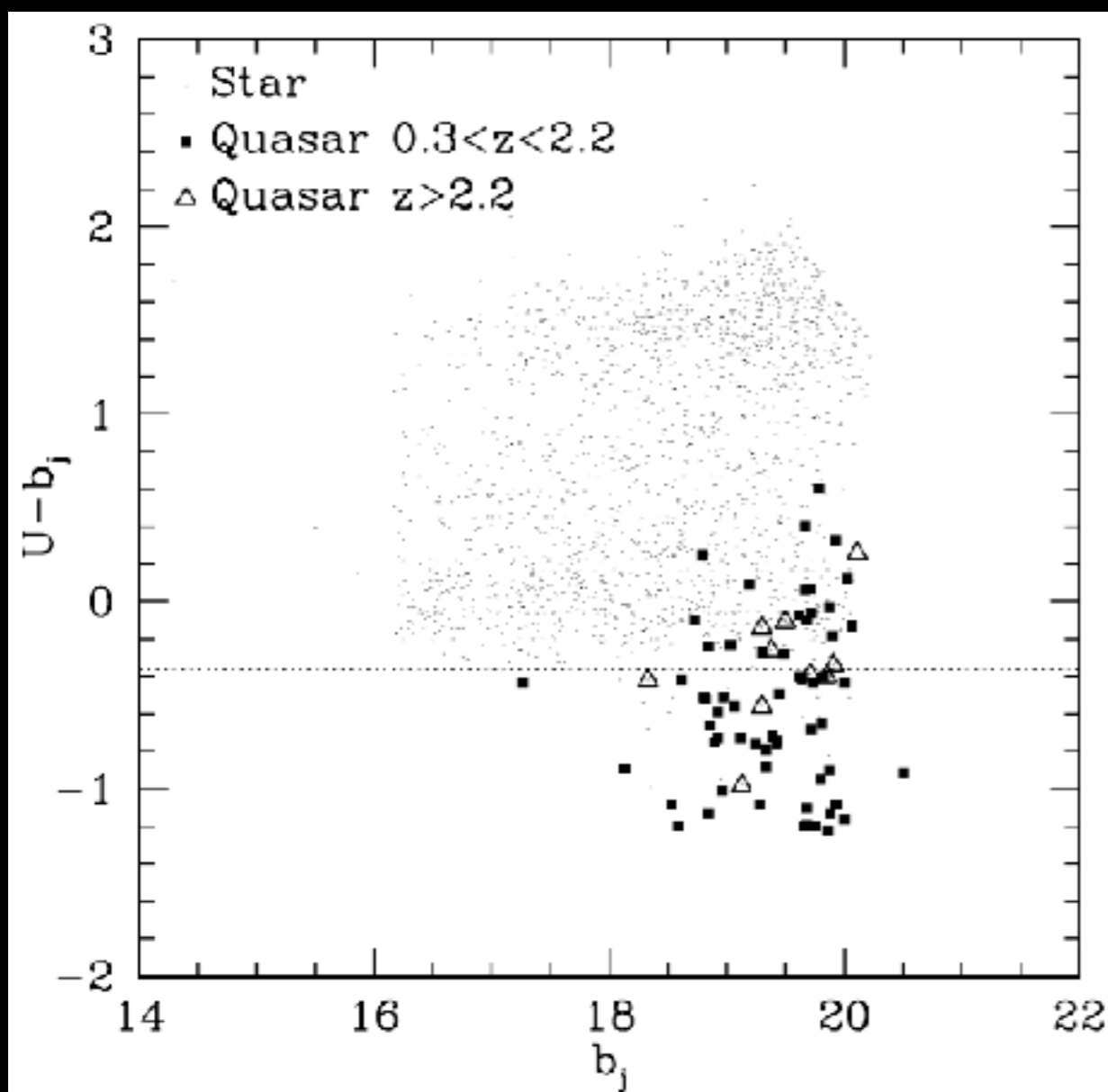
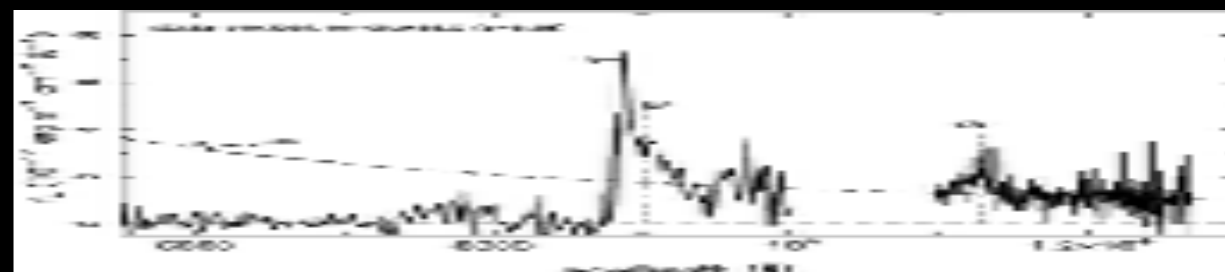
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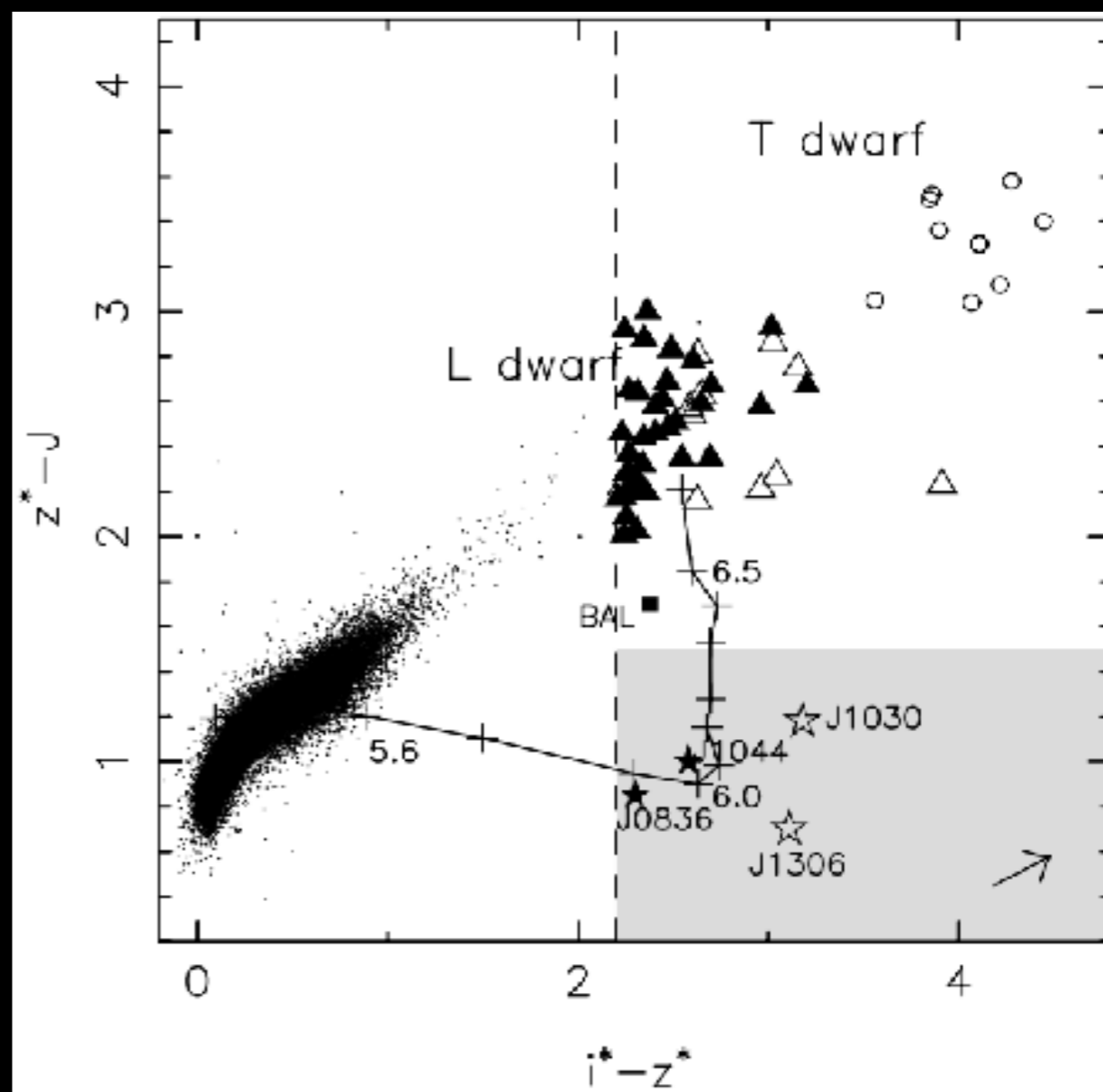
★ UV-excess selection



★ Dropout selection



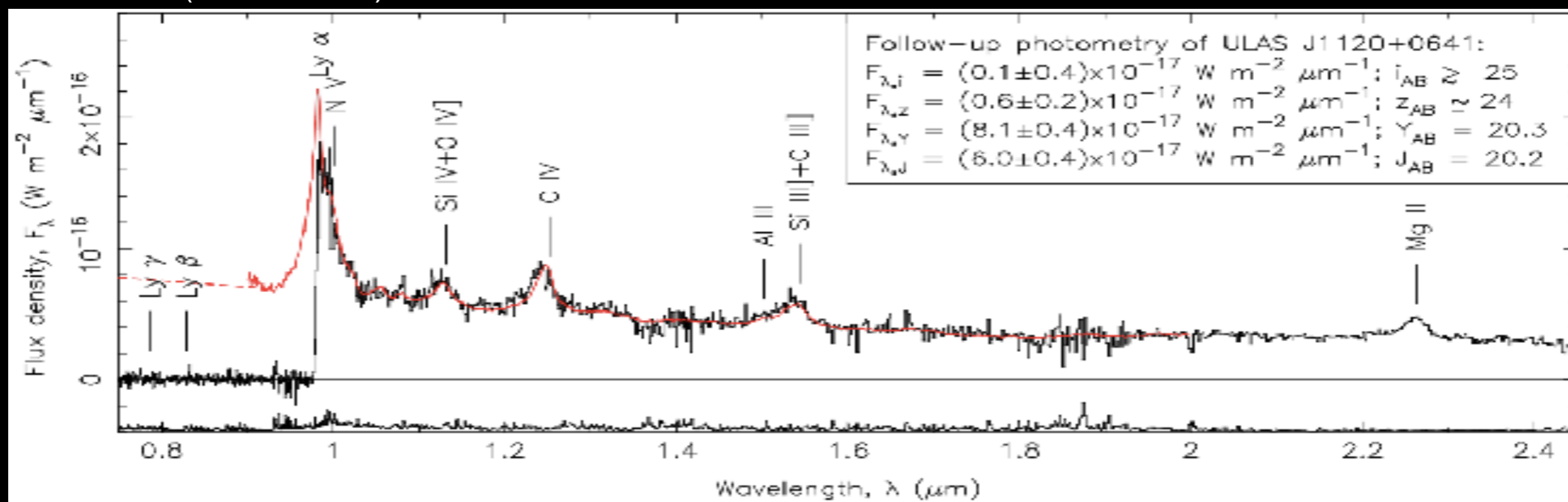
Meyer+01



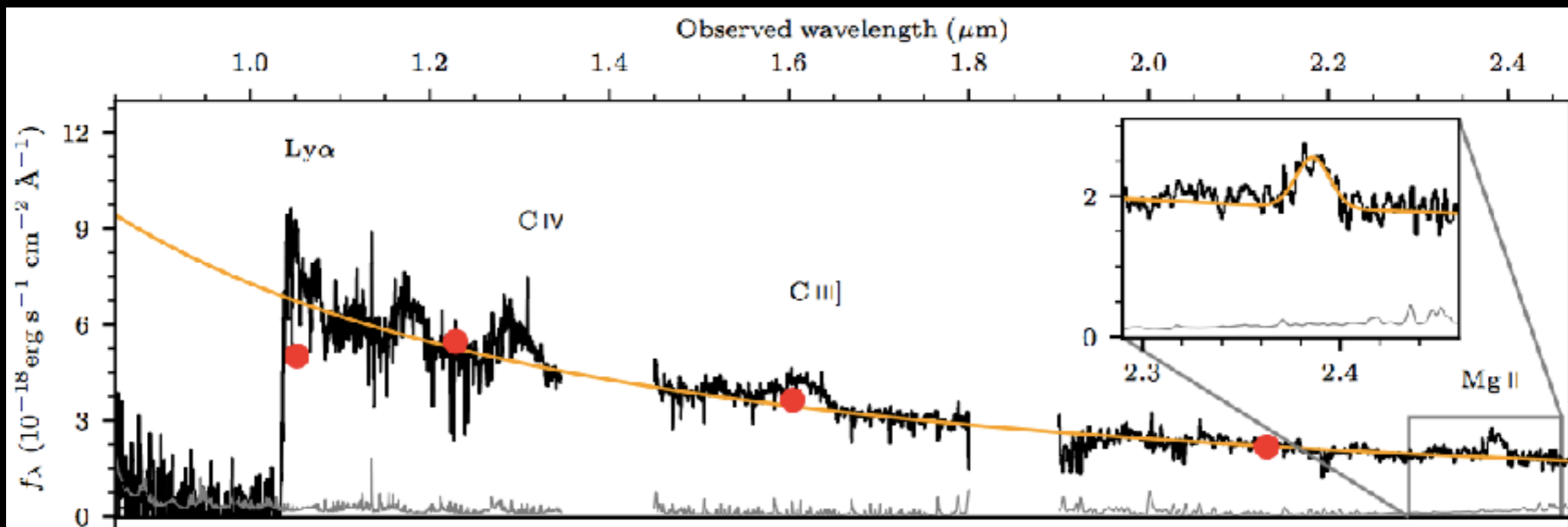
Fan+01

遠くへ

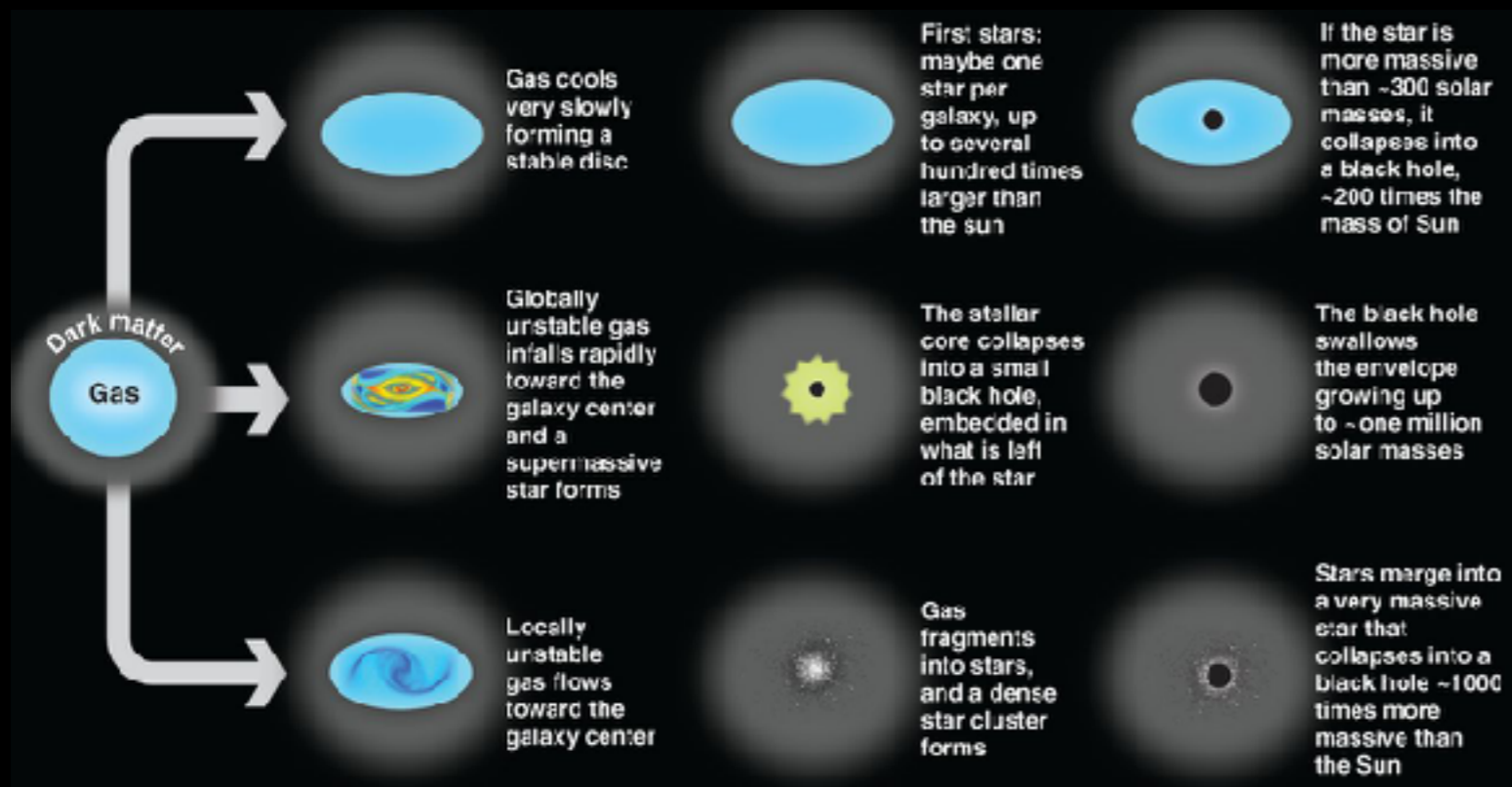
★ $z = 7.085$ (Mortlock+11)



★ $z = 7.54$ (Banados+17)



遠いクエーサーは、何を教えてくれるのか？



Formation of SMBHs

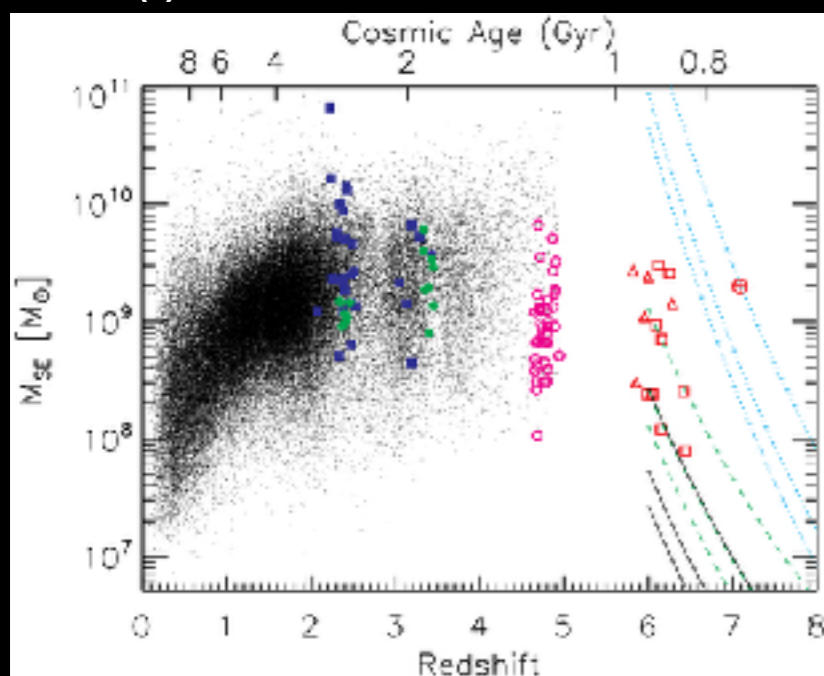
- ★ What were the seeds?
- ★ When were they born?
- ★ How did they grow?

Maximum M_{BH}

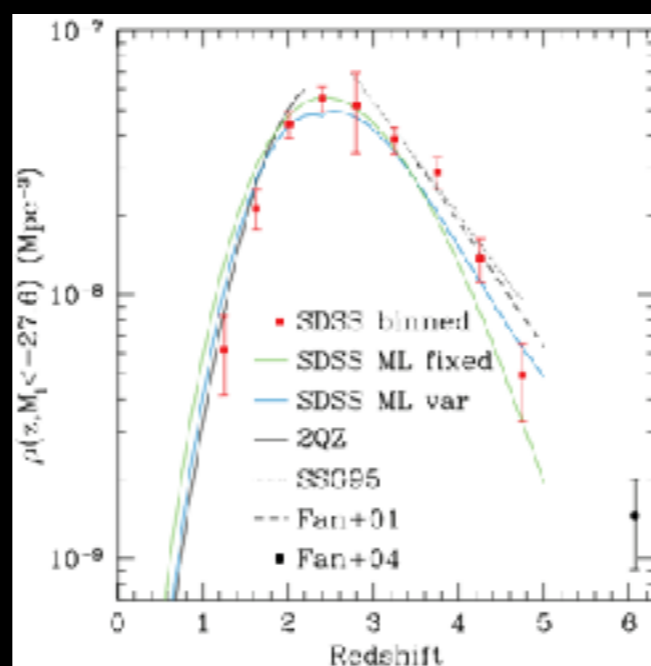
$$M(t) = M_0 e^{[\lambda(1-\epsilon)/\epsilon](t/0.45 \text{ Gyr})}$$

Number density

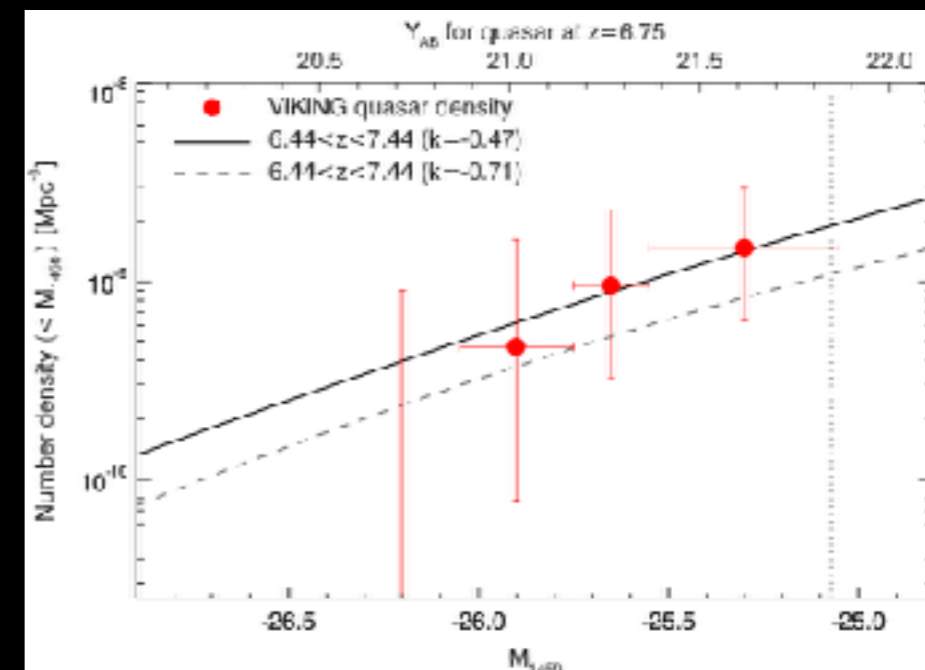
$L/M_{BH}/R_{Edd}$ functions



Shen11

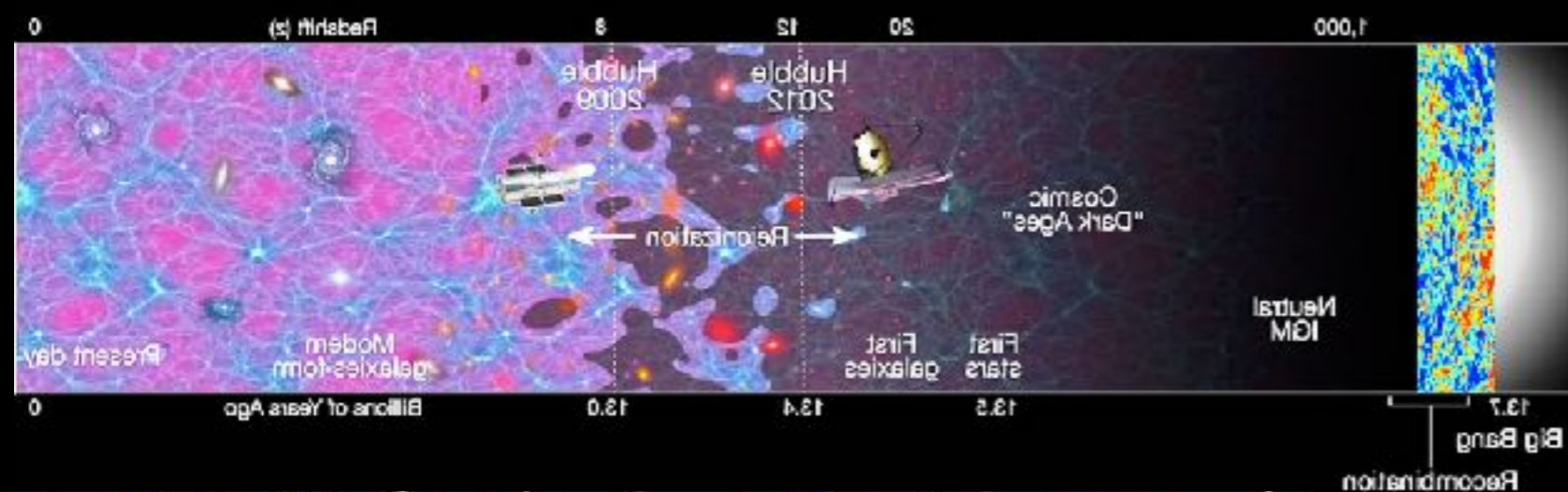


Richards+06



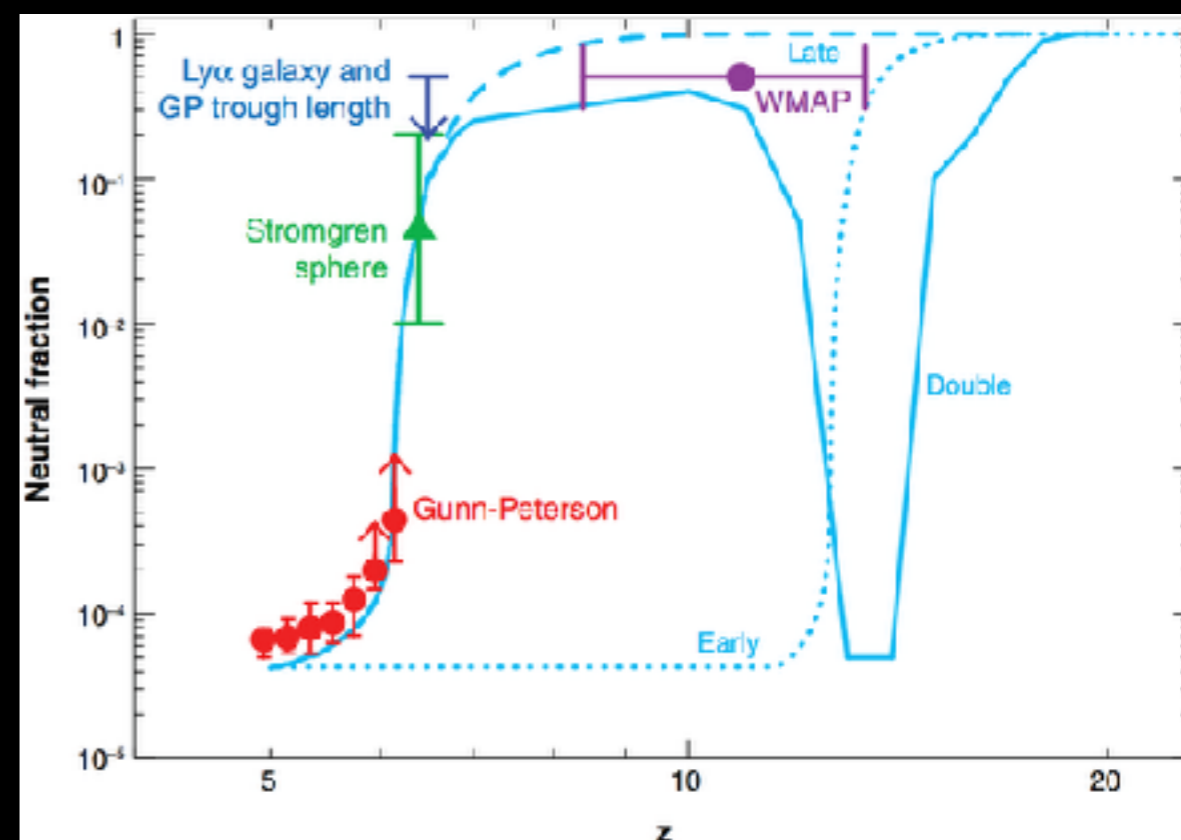
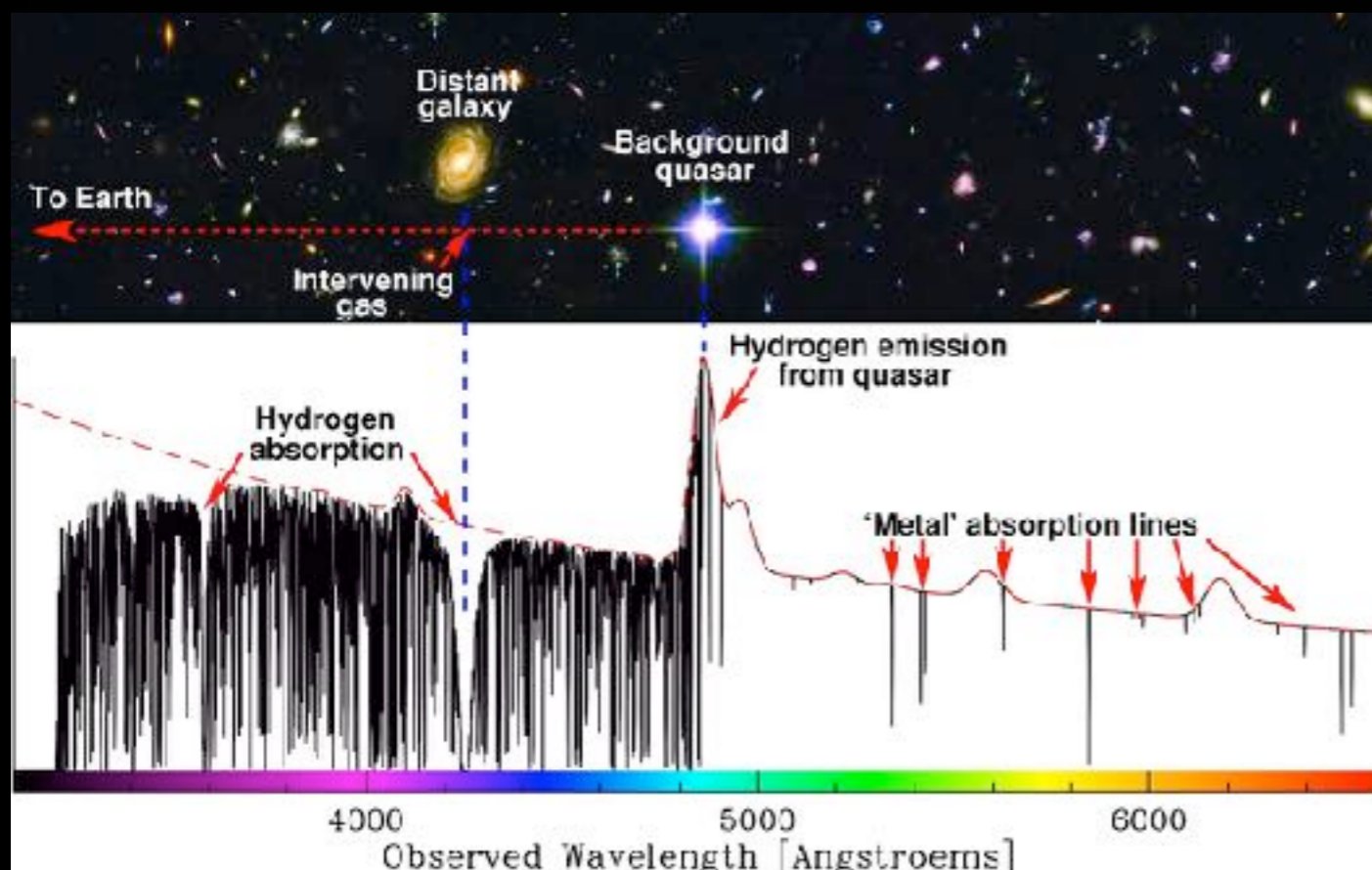
Venemans+13

遠いクエーサーは、何を教えてくれるのか？



Cosmic Reionization

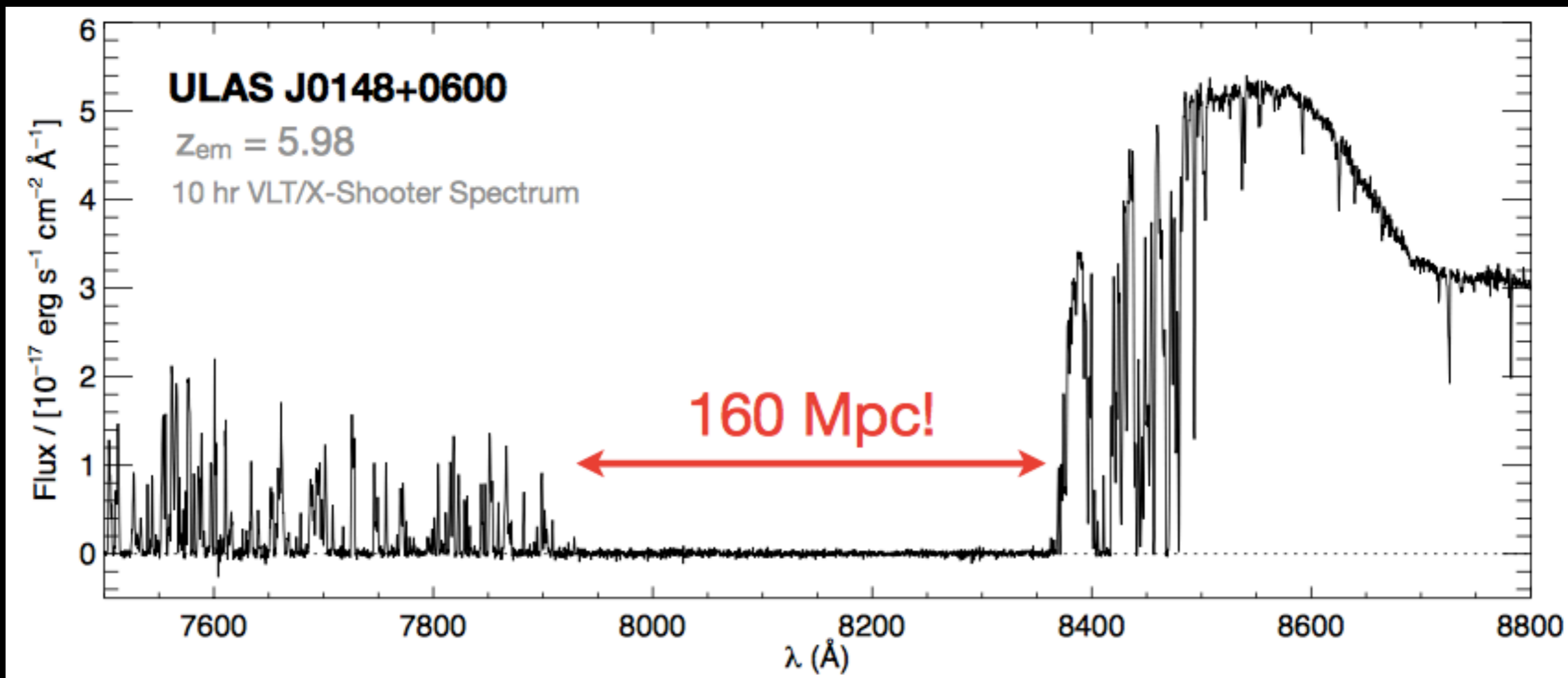
- ★ When and where?
- ★ How did it proceed?
- ★ Ionizing sources?



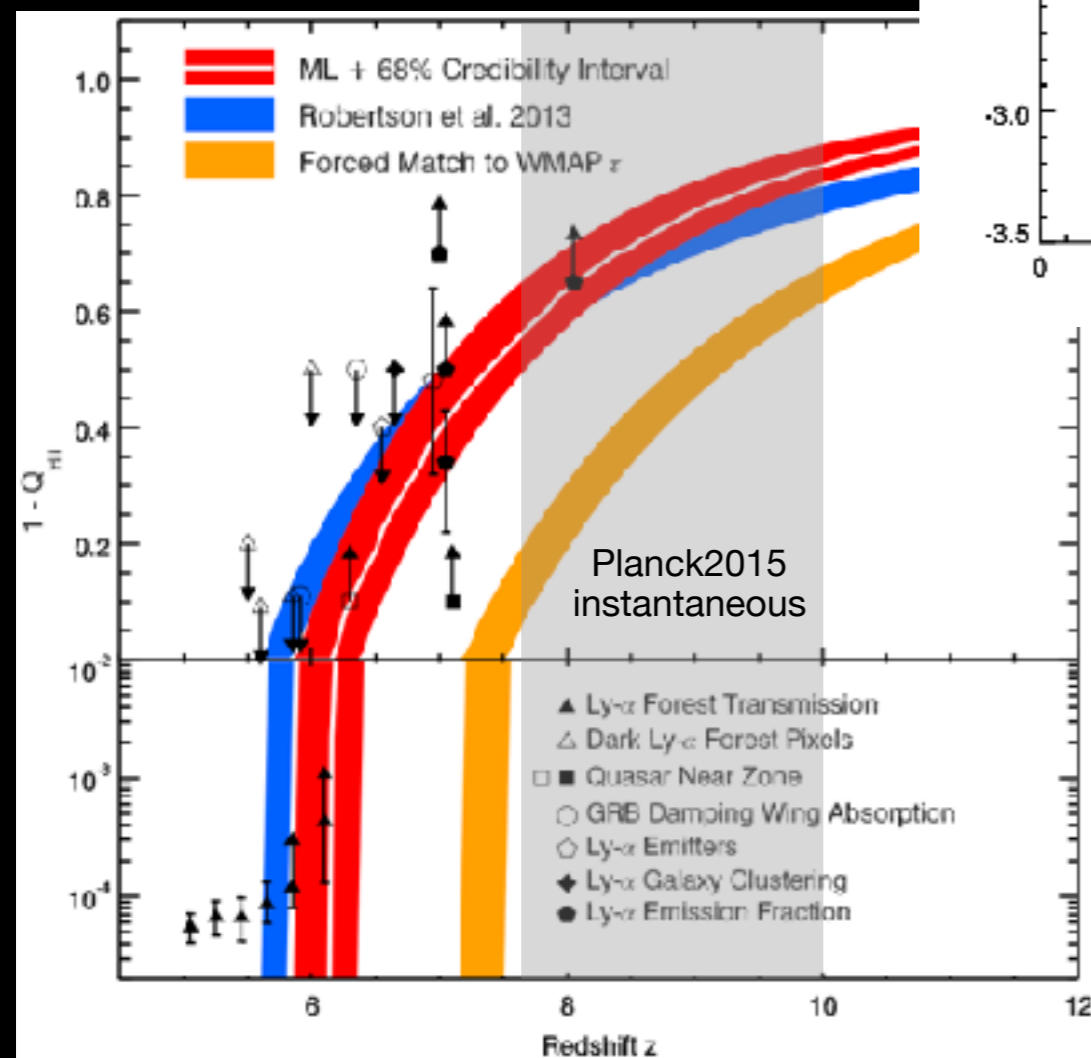
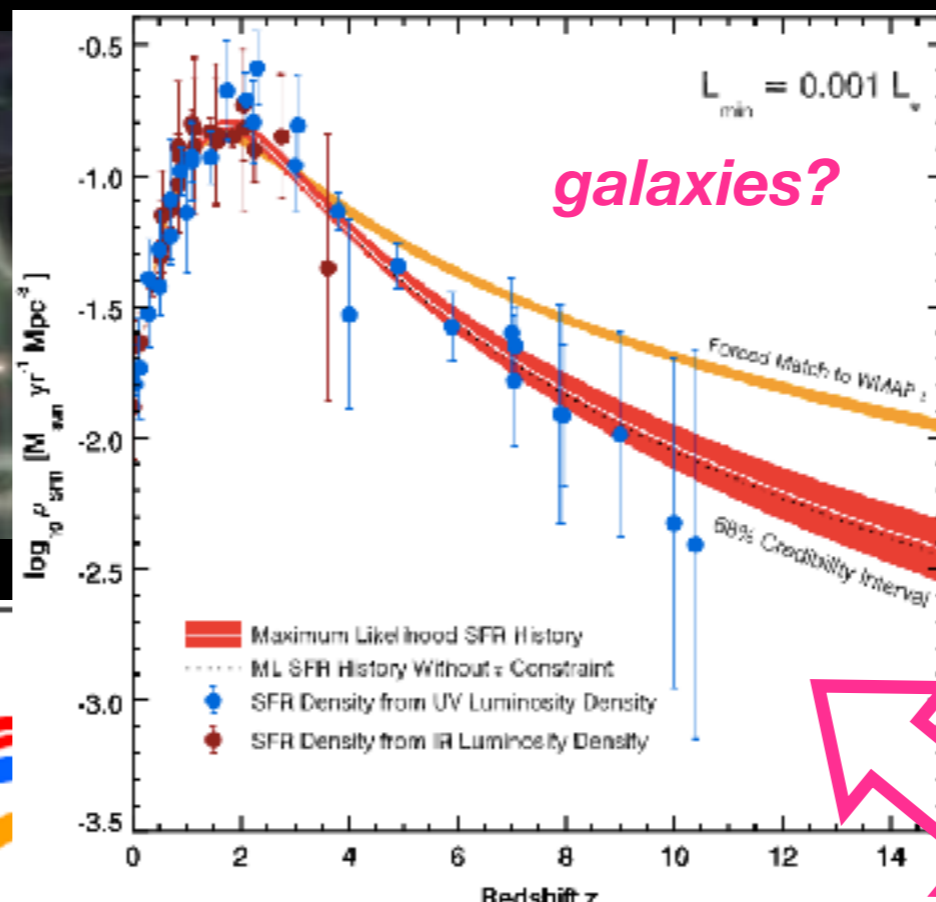
Fan+06

遠いクエーサーは、何を教えてくれるのか？

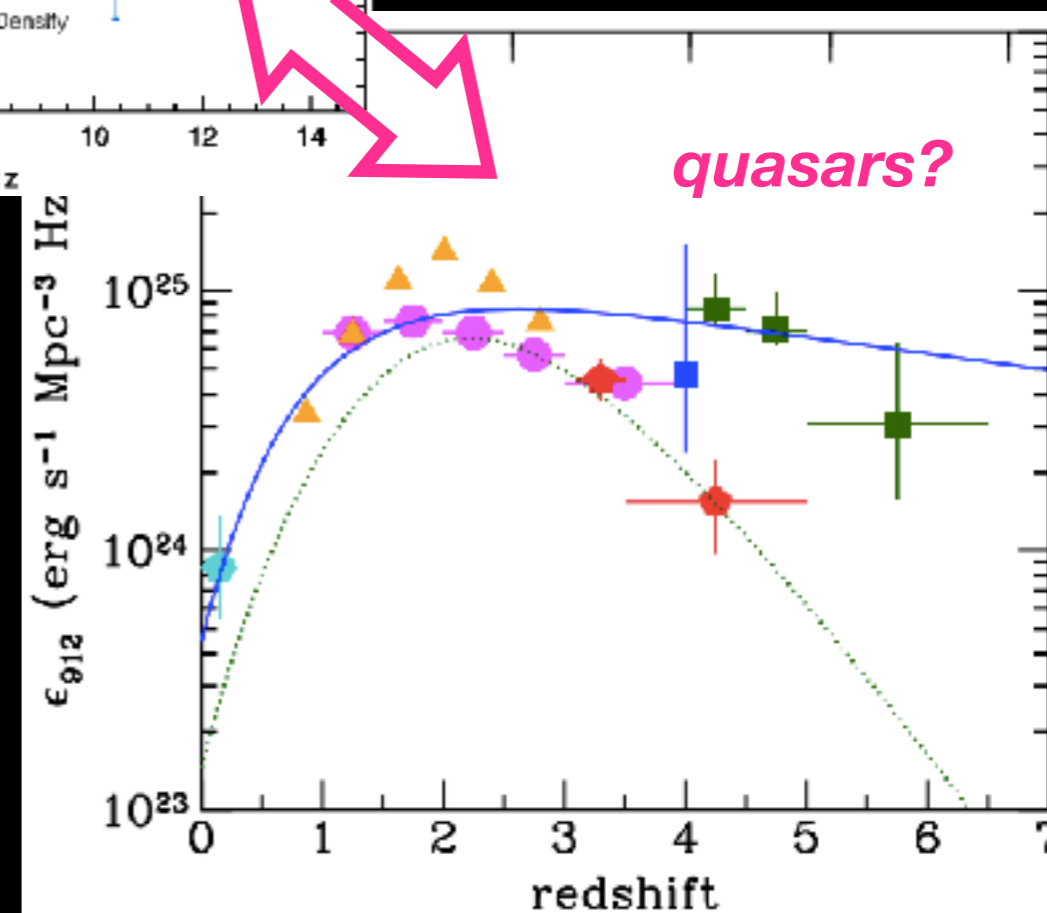
The biggest “thing” in the universe (George Becker)



遠いクエーサーは、何を教えてくれるのか？

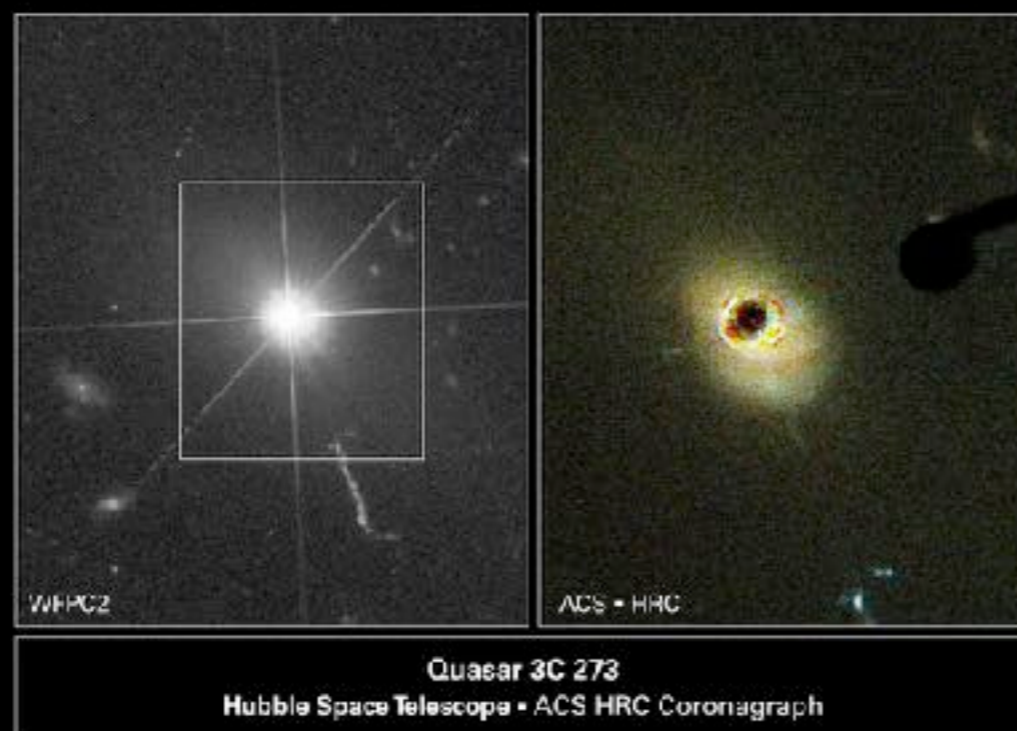


(Robertson+15)

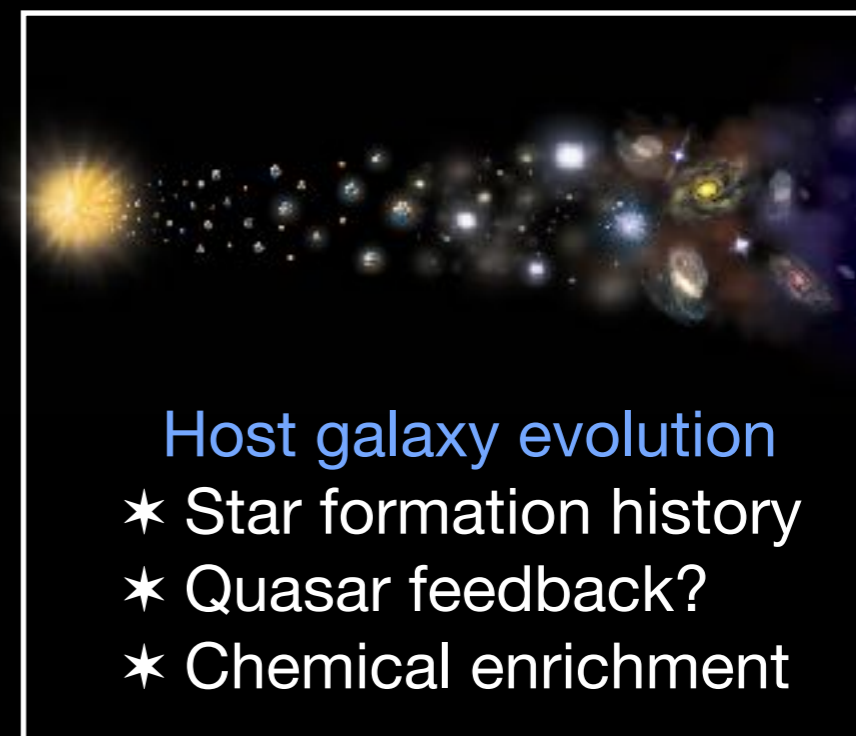


(Madau+15)

遠いクエーサーは、何を教えてくれるのか？

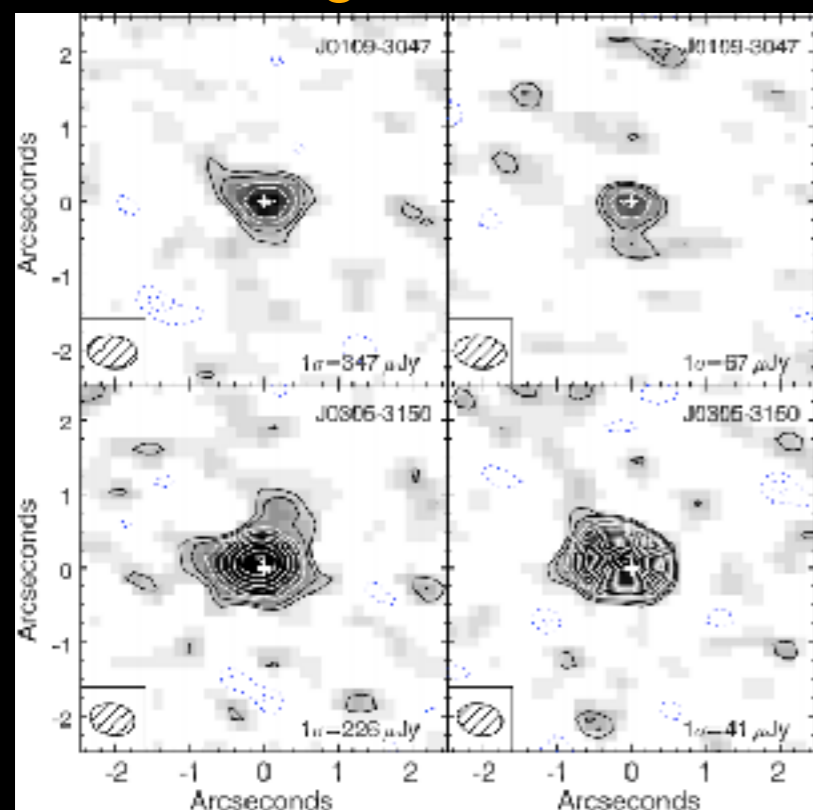


NASA, & Mami (JHU), the ACS Science Team, J. Banfill (JMS) and ESA + STScI-PRC03403



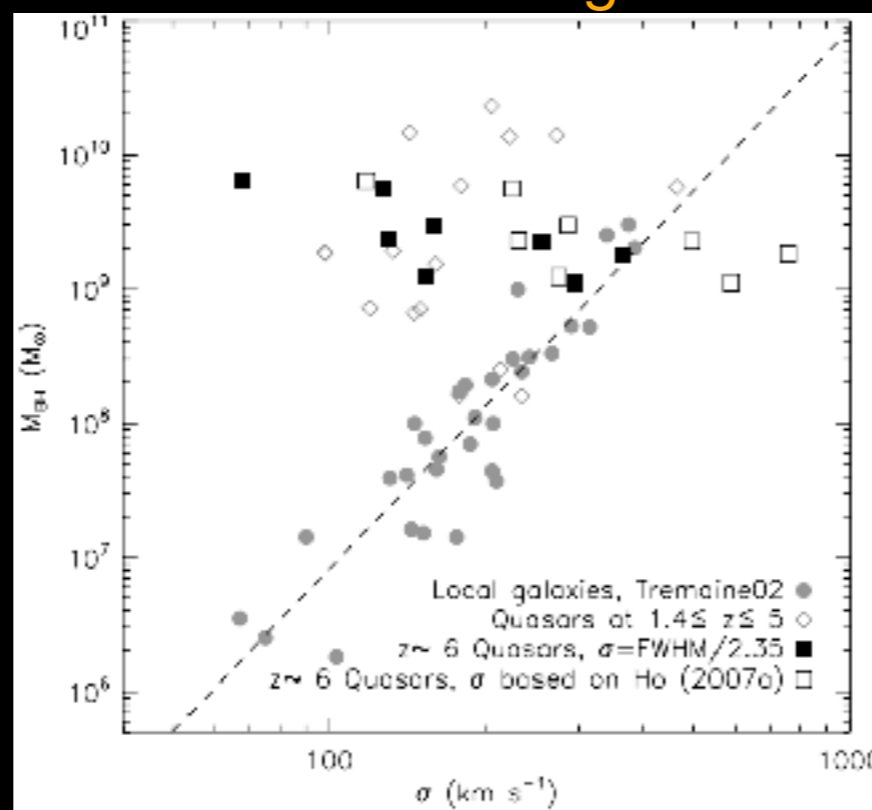
- Host galaxy evolution
- ★ Star formation history
- ★ Quasar feedback?
- ★ Chemical enrichment

Stars and gas in the hosts



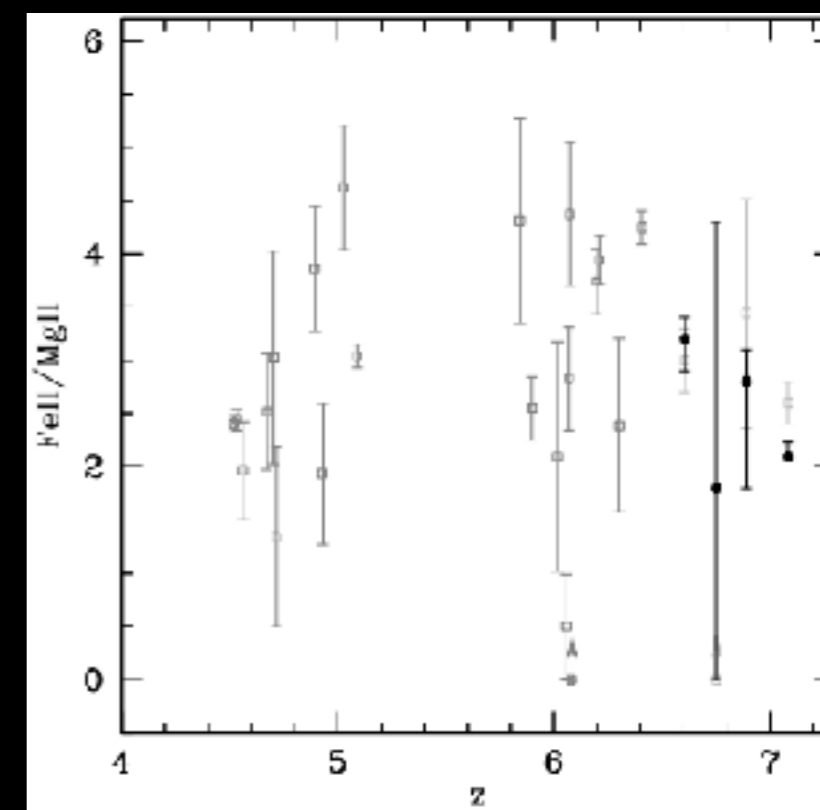
Venemans+16

Scaling relations



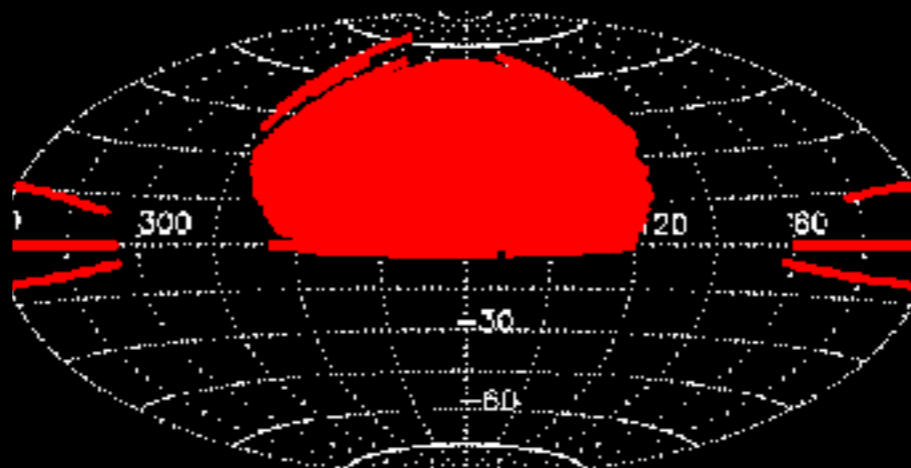
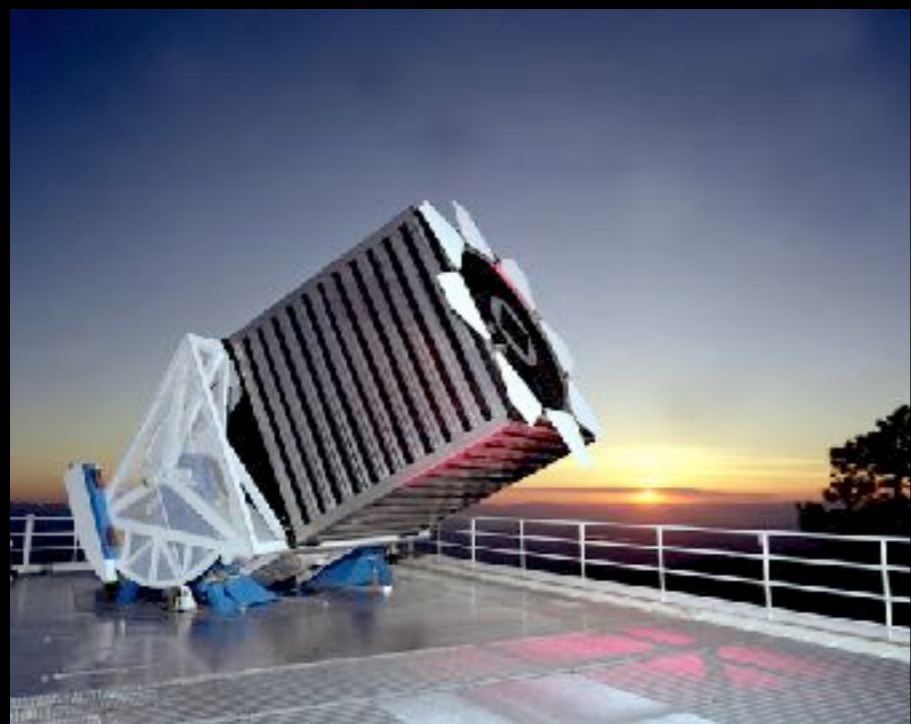
Wang+10

Chemical evolution



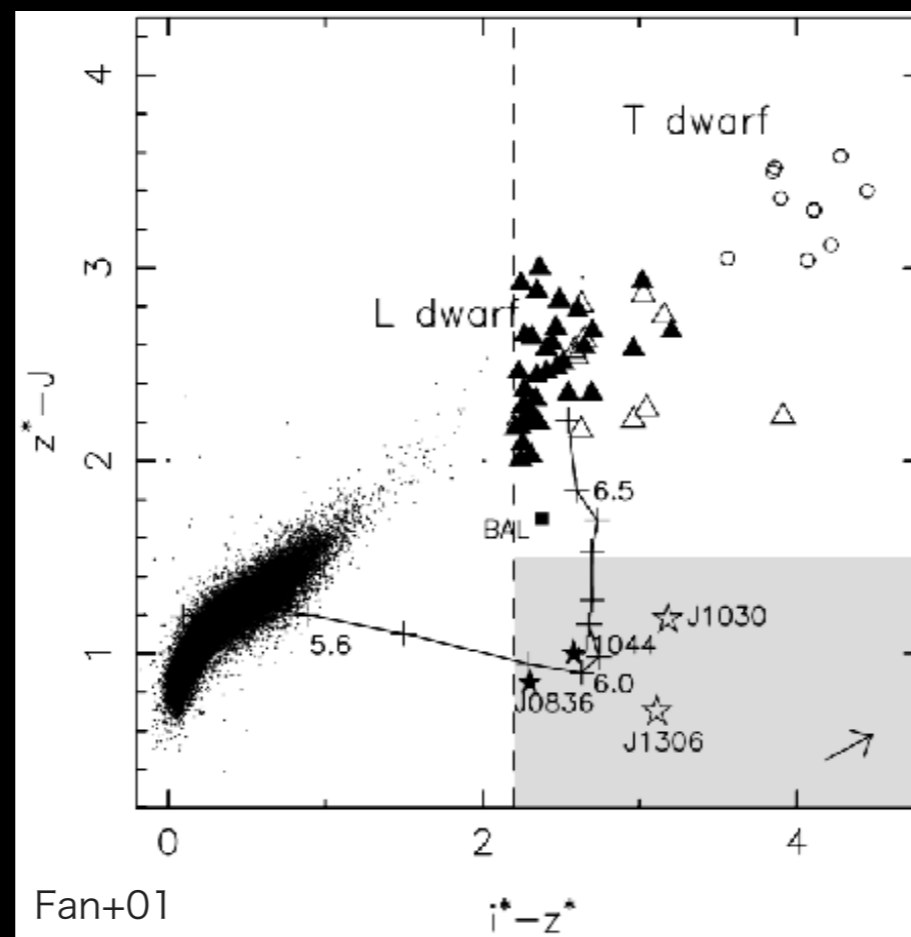
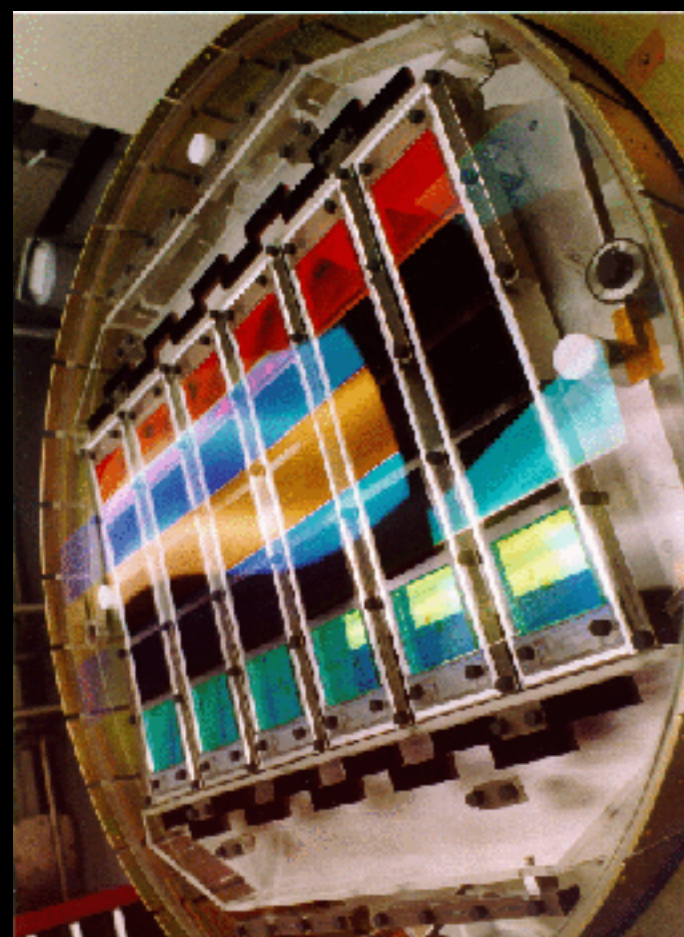
De Rosa+14

Success of Sloan Digital Sky Survey

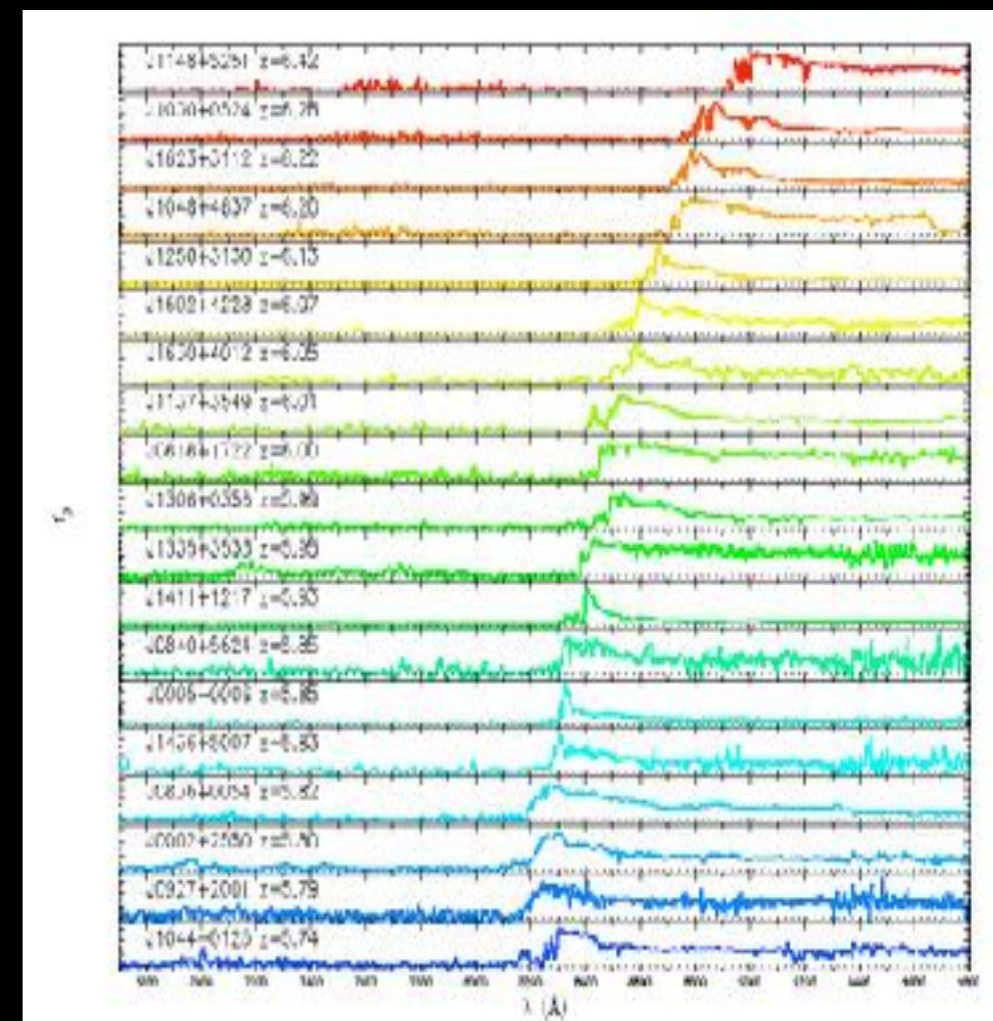


52 high-z quasars in $\sim 10,000 \text{ deg}^2$
 $\rightarrow \sim 1 \text{ per } 200 \text{ deg}^2$

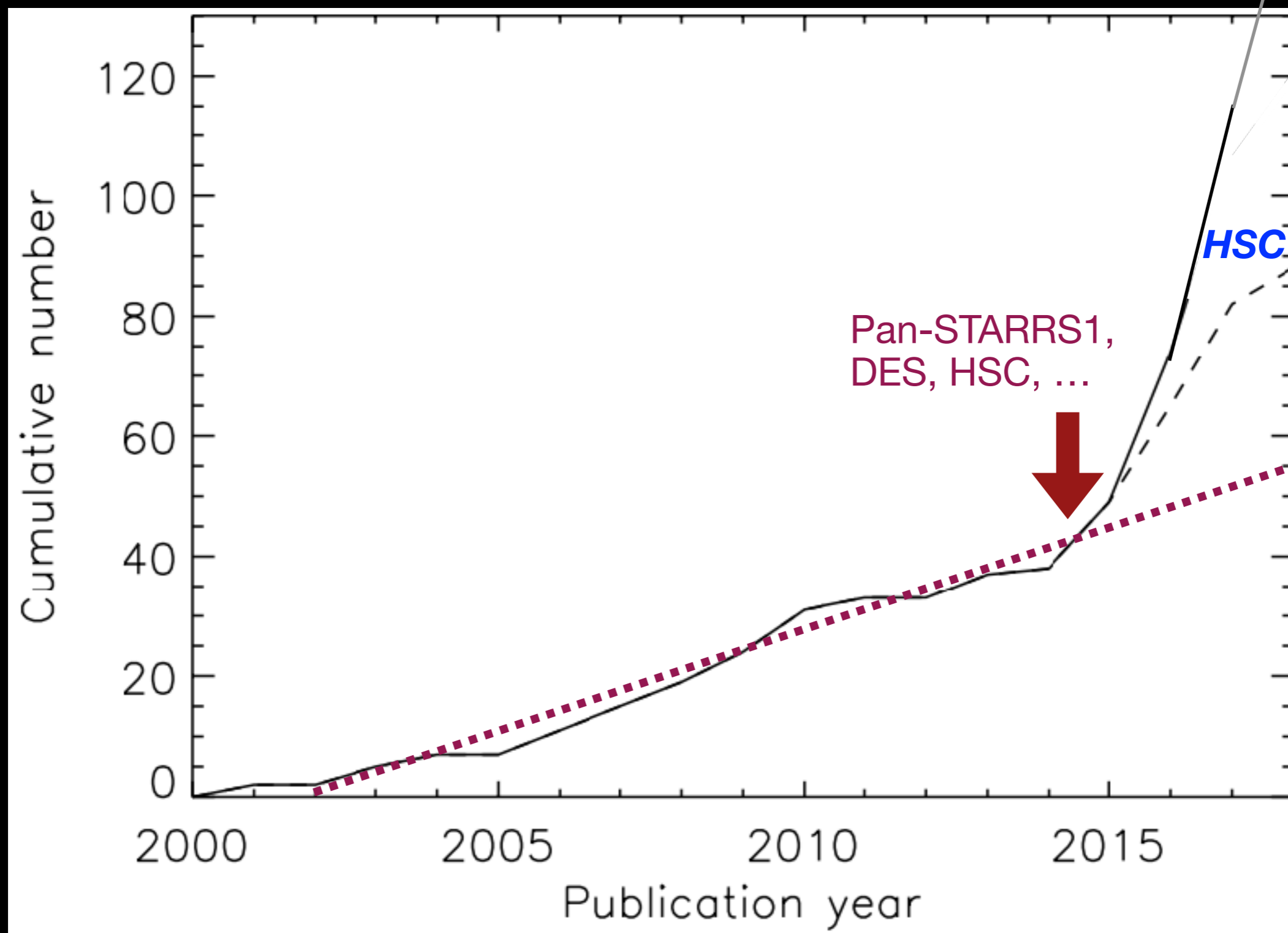
Fan+06



Fan+01

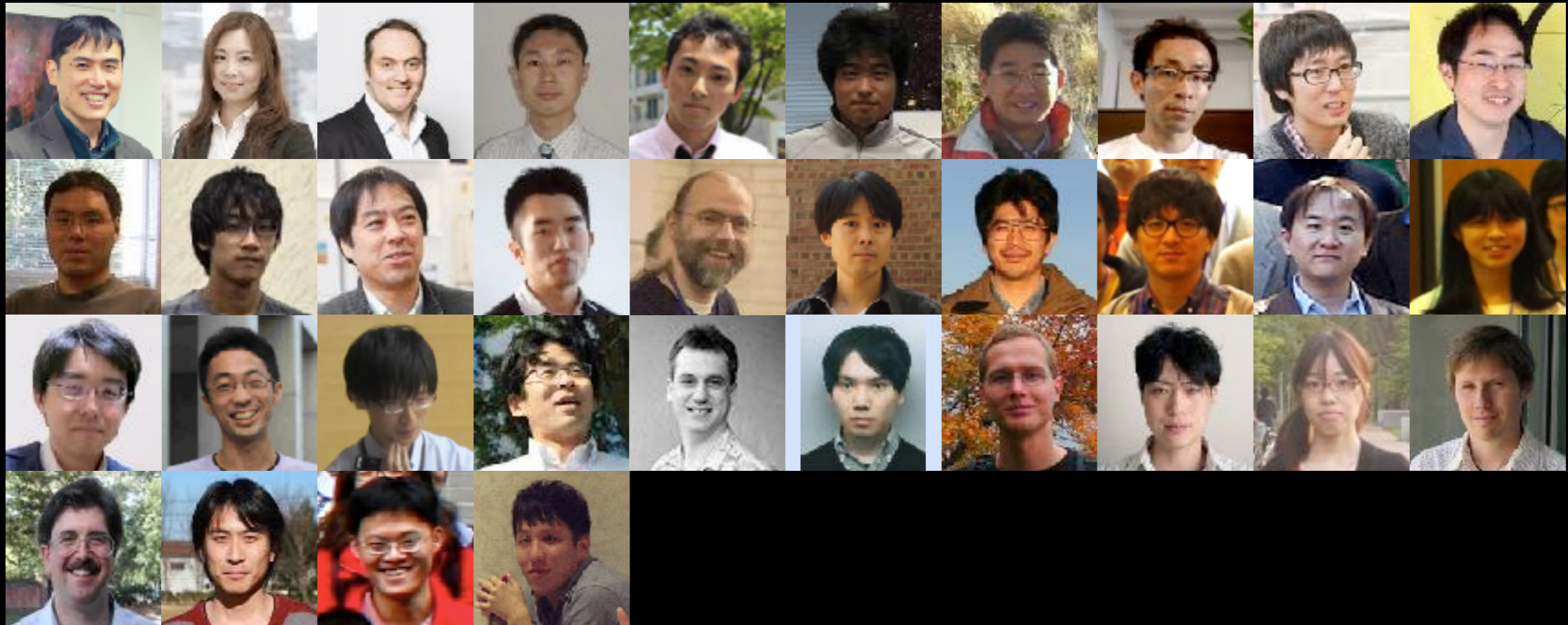
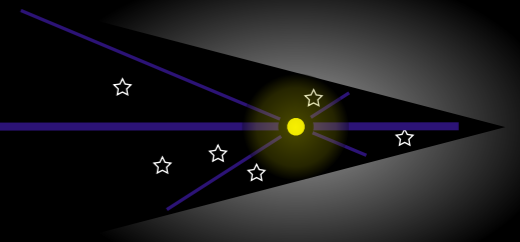


$z > 6$ クエーサーの積算発見数



SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars

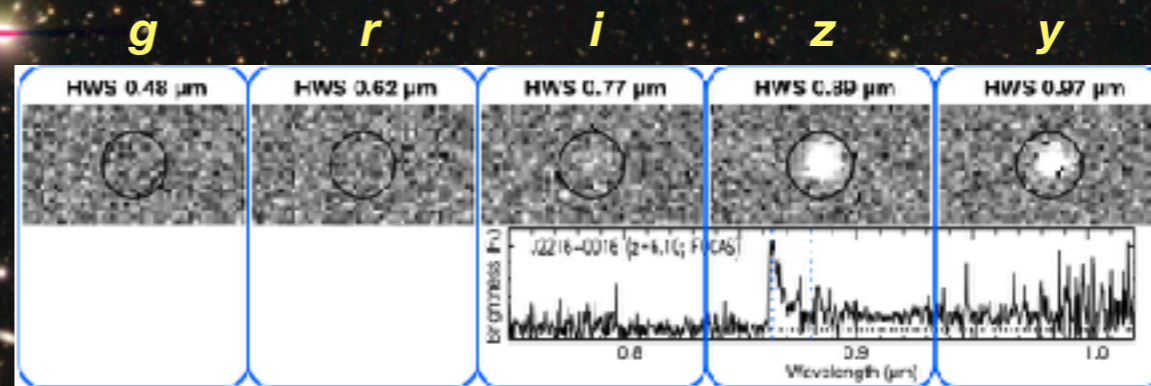


Members

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¹NAOJ, ²Tohoku, ³JPSE, ⁴Tsinghua, ⁵Tokyo, ⁶Barcelona, ⁷Sapporo Medical, ⁸Ehime, ⁹Princeton, ¹⁰Kyoto Sangyo, ¹¹Hokkaido, ¹²ASIAA



HSC SSP survey

Bayesian probabilistic selection

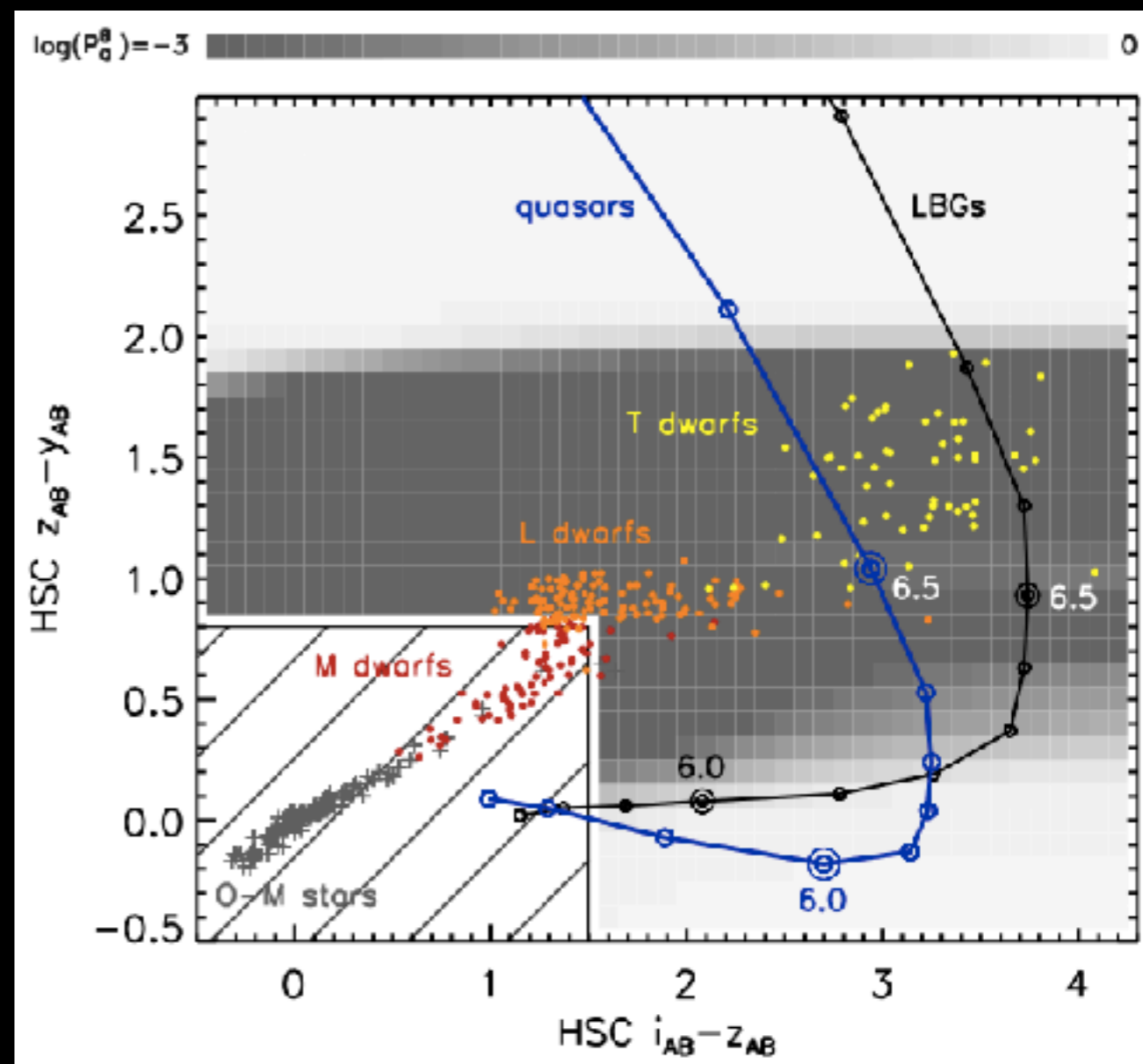
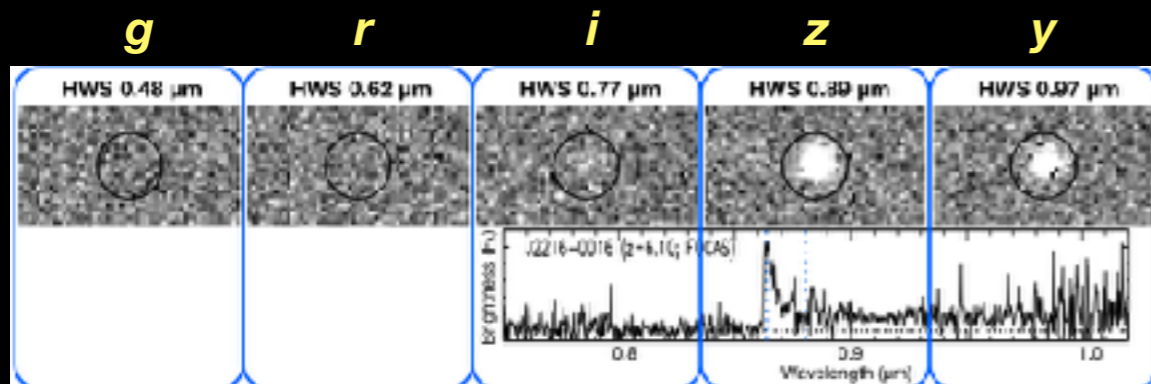
Quasar probability: $P_Q = W_Q / (W_Q + W_D)$

$$W_Q(\mathbf{m}, \text{det}) = \int \int \rho_Q(m_{\text{int}}, z) \Pr(\text{det} | m_{\text{int}}, z) \Pr(\mathbf{m} | m_{\text{int}}, z) dm_{\text{int}} dz$$

$$W_D(\mathbf{m}, \text{det}) = \int \int \rho_D(m_{\text{int}}, t_{\text{sp}}) \Pr(\text{det} | m_{\text{int}}, t_{\text{sp}}) \Pr(\mathbf{m} | m_{\text{int}}, t_{\text{sp}}) dm_{\text{int}} dt_{\text{sp}}$$

observed magnitudes
in HSC + NIR bands

source detection



→ Spectroscopic follow-up of all the photometric candidates with $P_Q > 0.1$

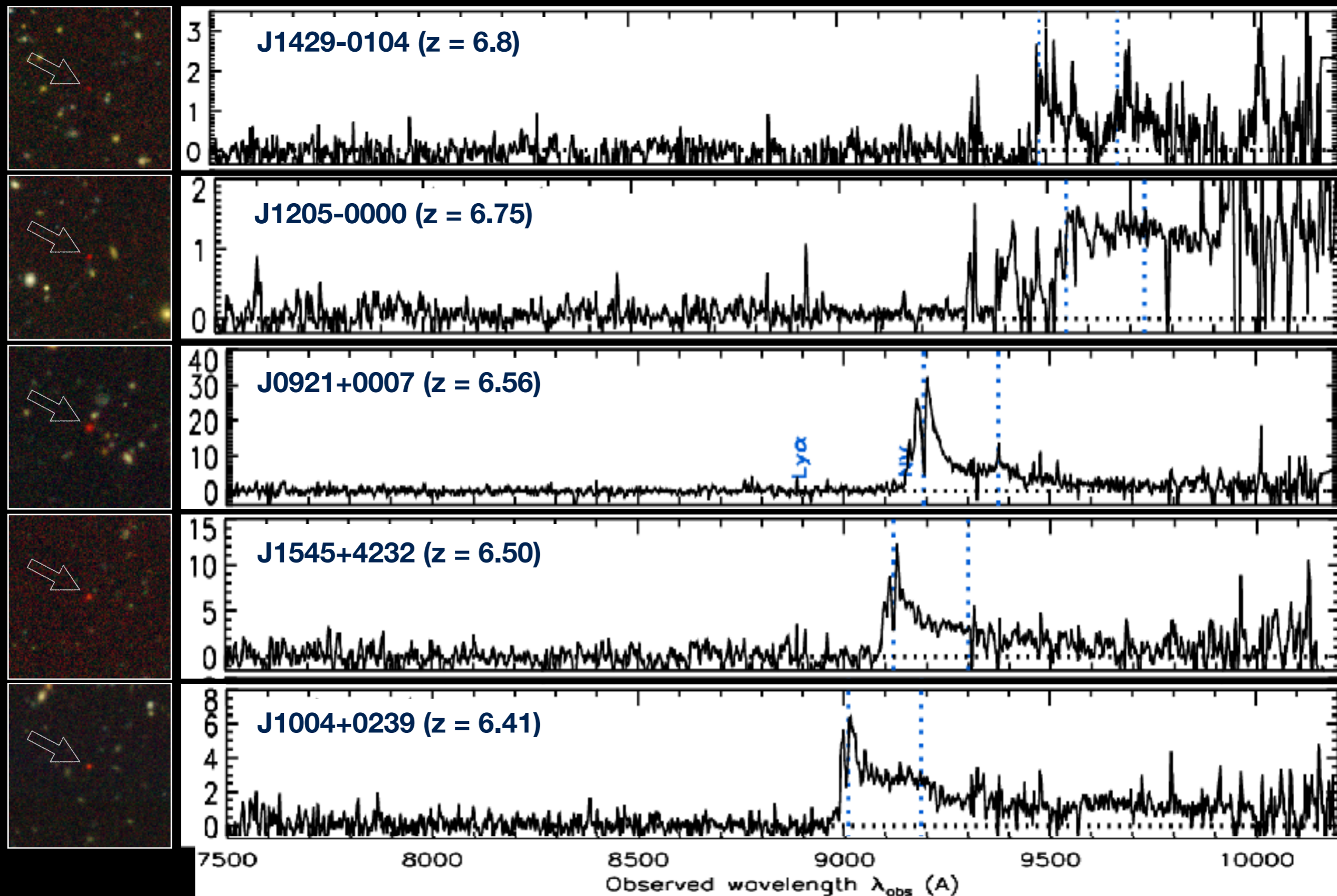
SHELLQs progress to date

- ★ HSC-SSP survey: the latest, S17A data release contains $\sim 650 \text{ deg}^2$ of the Wide fields, with more than a single exposures in the i , z , and y bands.
- ★ Candidate selection: ~ 300 candidates with ($z_{AB} < 24.5$ or $y_{AB} < 24.0$) & $P_Q > 0.1$.
- ★ Spectroscopic follow-up is underway, with Subaru, Gemini, and GTC. In particular, we are carrying out a two-year “Subaru intensive program” with 20 nights.

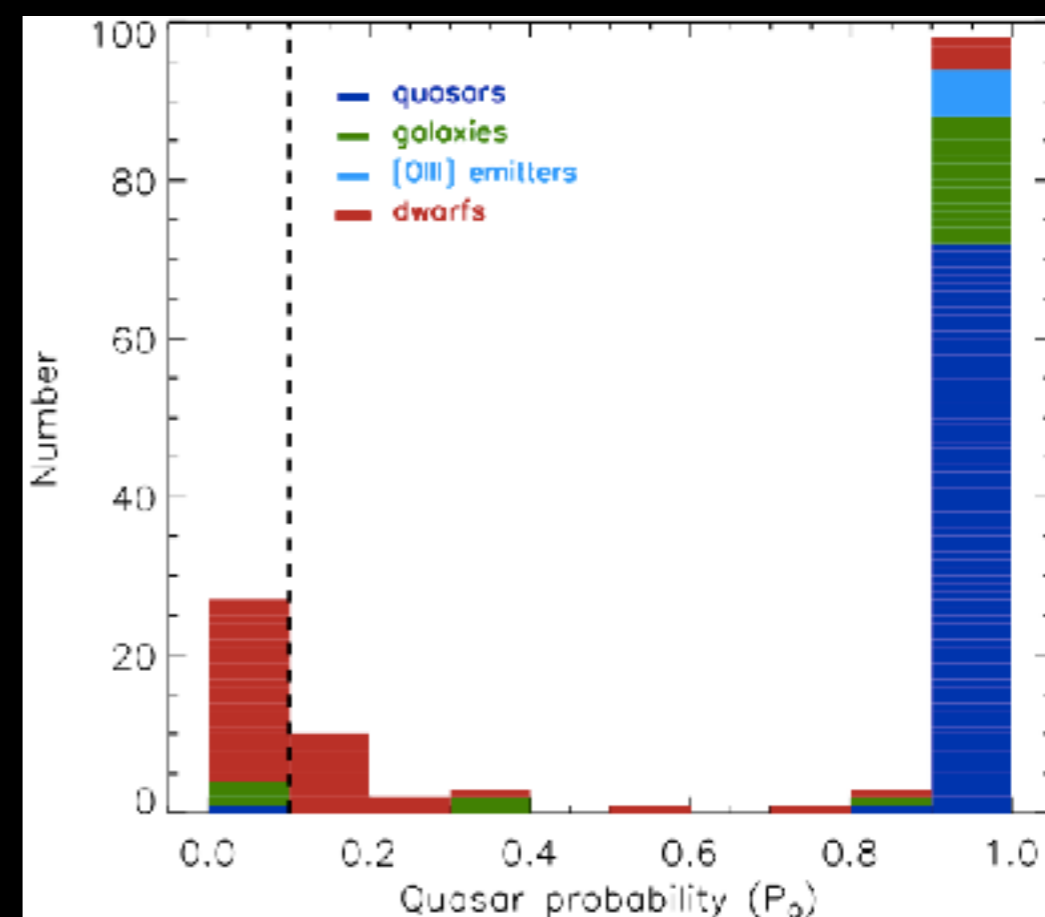
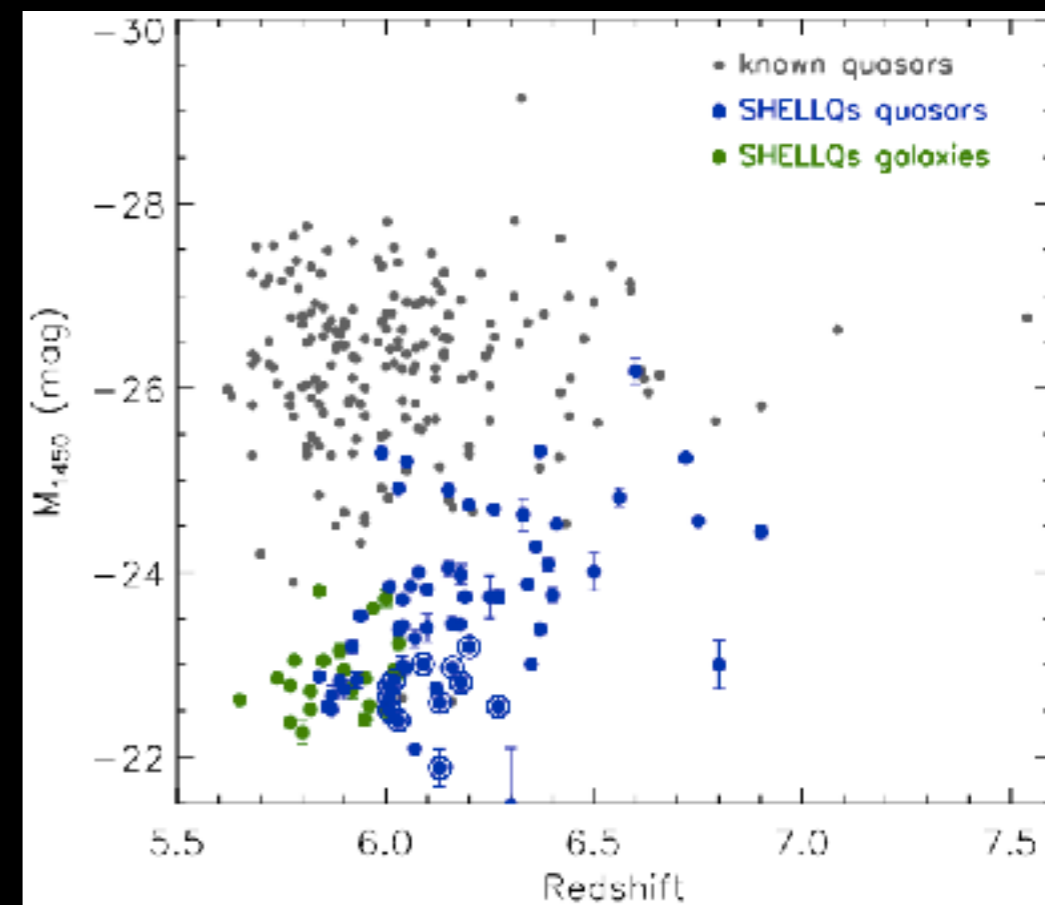
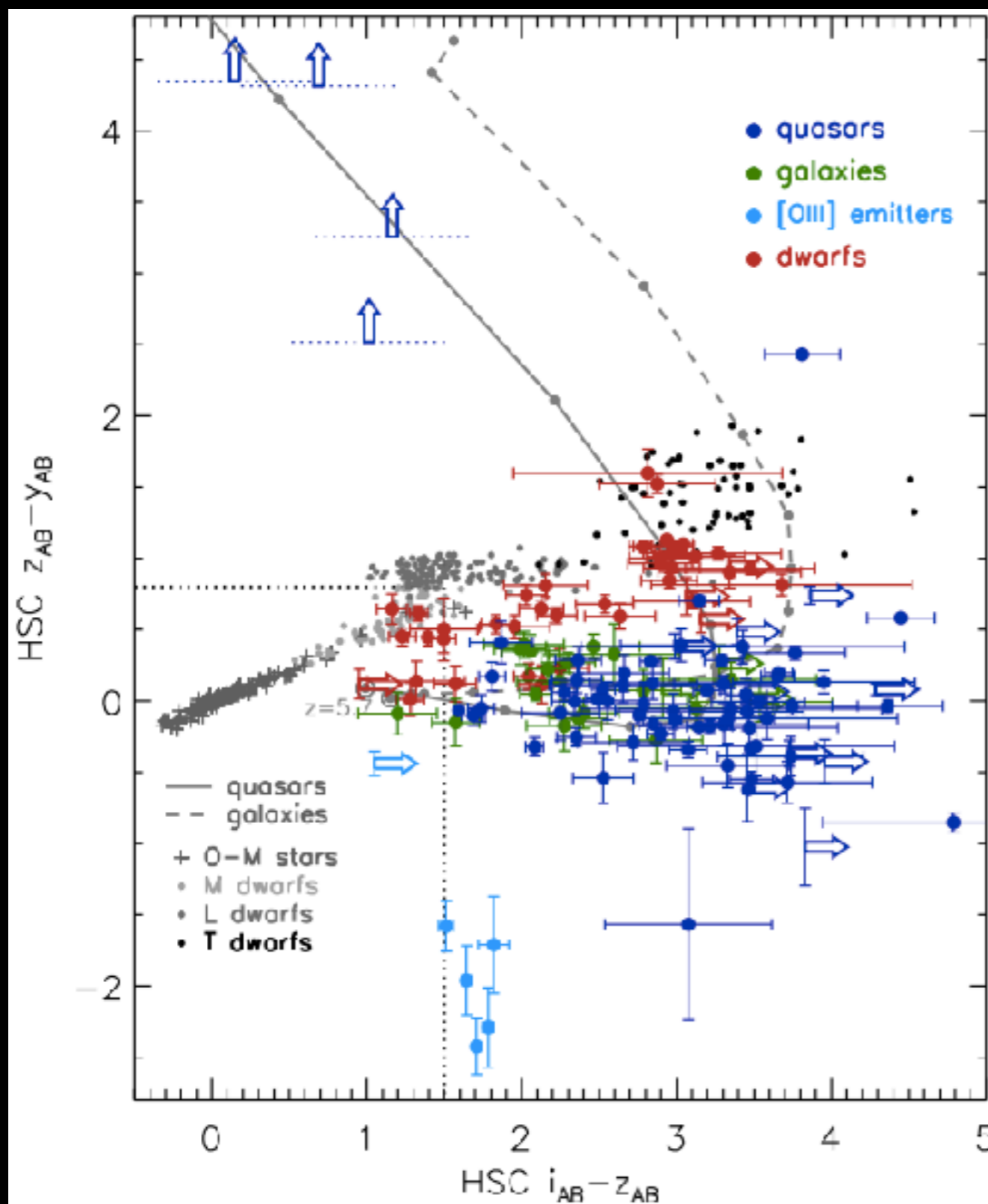


- ★ We have identified **136 extremely-red HSC sources** so far, which include **65 high- z quasars**, 22 high- z galaxies, 6 [O III] emitters at $z \sim 0.8$, and 43 brown dwarfs.
- ★ A series of publication:
 - Paper I (Matsuoka+16): initial discovery of 9 quasars
 - Paper II (Matsuoka+18): more discovery of 24 quasars
 - Paper III (Izumi+18): ALMA follow-up
 - Paper IV (Matsuoka+18, in prep): more discovery of 32 quasars

発見天体の例



発見天体の統計

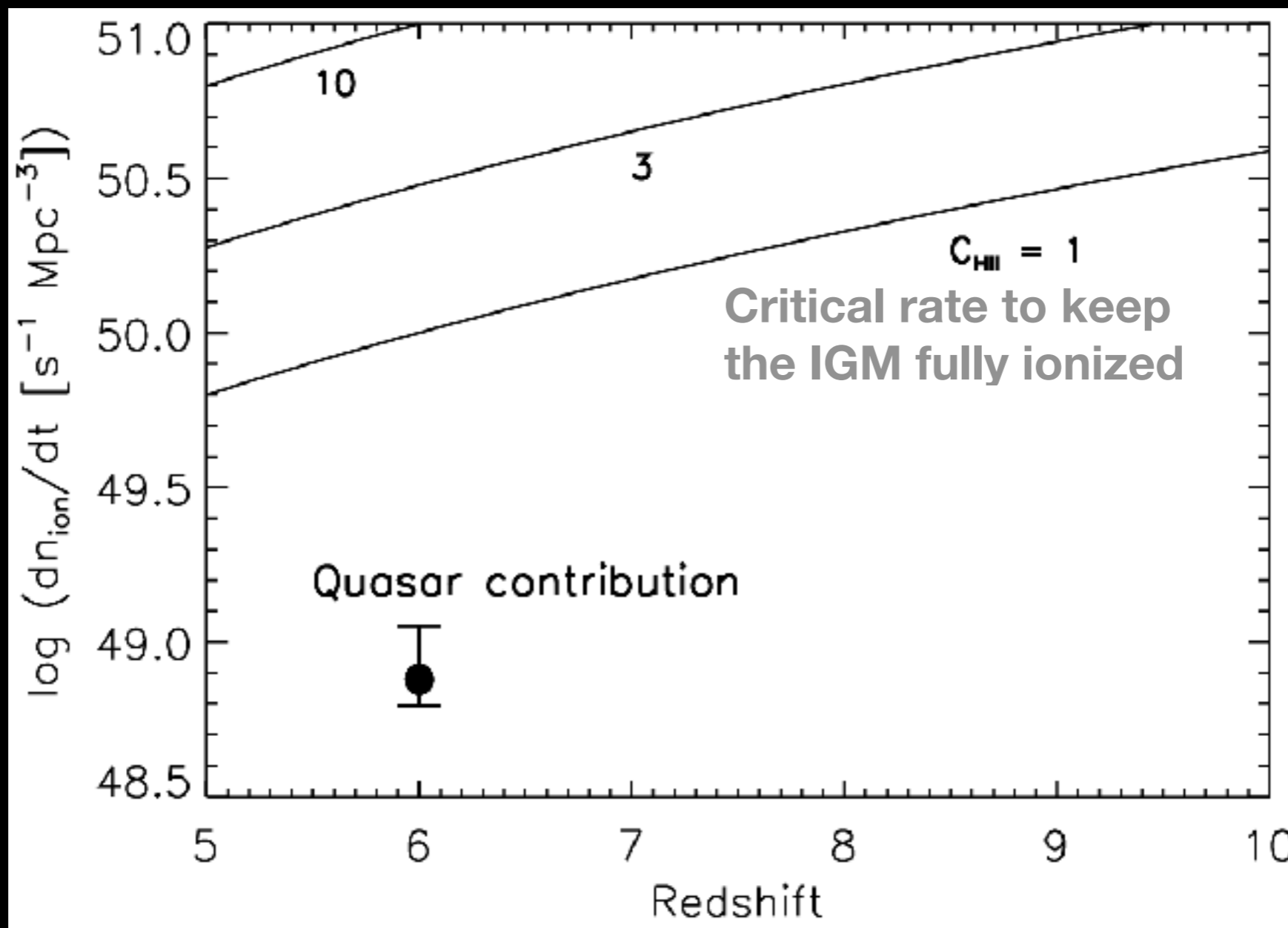


宇宙再電離への寄与

★ Our QLF indicates:

$$\dot{n}_{\text{ion}} = 10^{48.9 \pm 0.2} [\text{s}^{-1} \text{Mpc}^{-3}] \text{ at } z \sim 6$$

Preliminary!

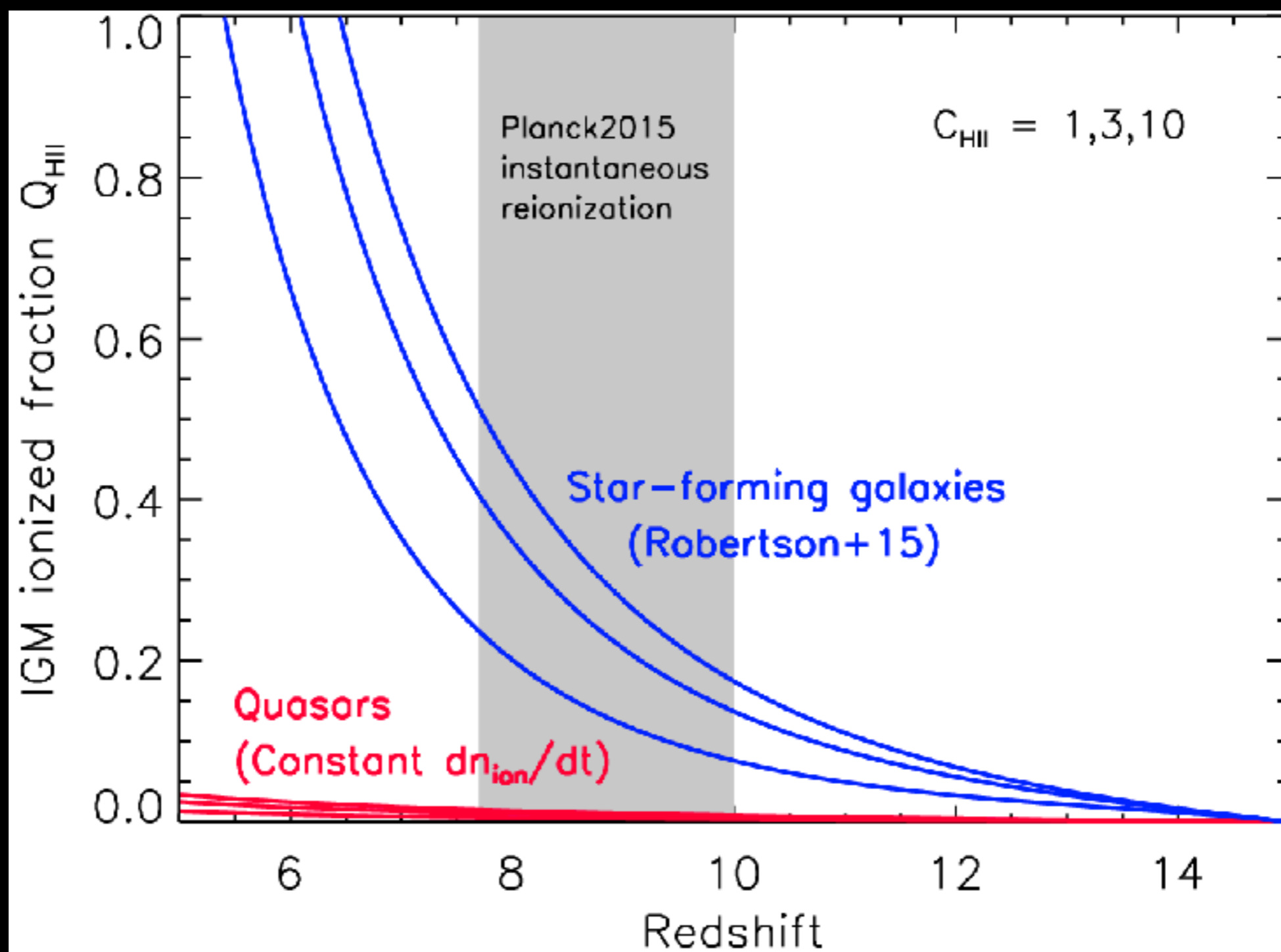


→ Quasars alone cannot reionize the Universe.

宇宙再電離への寄与

Evolution of Q_{HII} , for constant
quasar \dot{n}_{ion} at $5 < z < 15$ (which is unlikely)

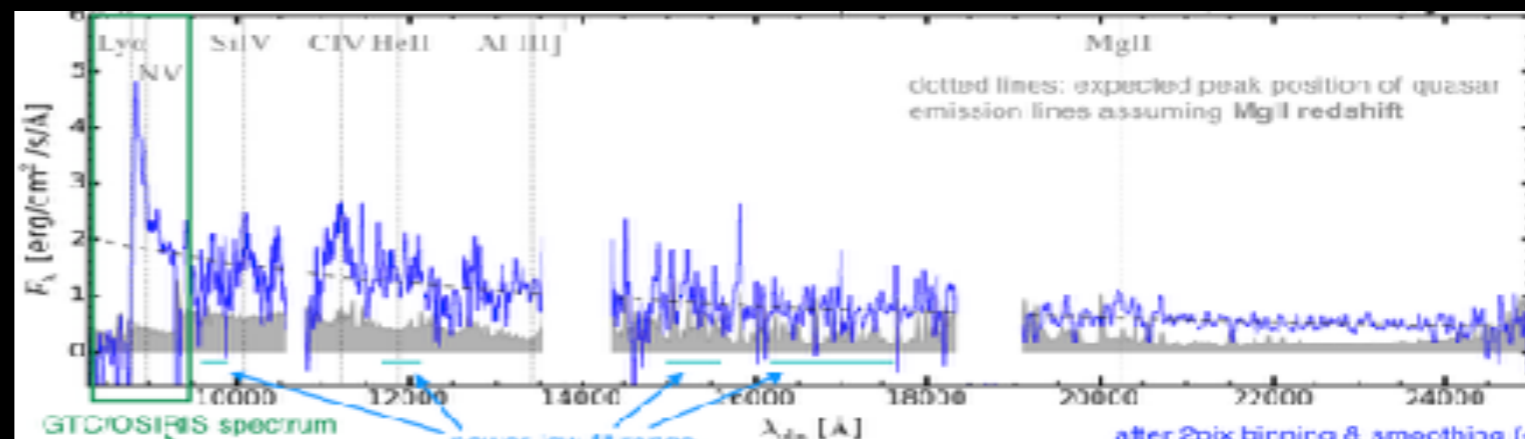
Preliminary!



多波長フォローアップ観測

★ BH mass measurements (led by M. Onoue)

- ✓ VLT/X-shooter (16B)
- ✓ Gemini/GNIRS (FT + 17A)
- ✓ Subaru/MOIRCS (18A)



★ Extremely-luminous Ly α objects (led by M. Onoue & N. Kashikawa)

- ✓ VLT/X-shooter (18A)

★ Star formation, dust, and mass of the host galaxies (led by T. Izumi)

- ✓ ALMA Band 6 (Cycles 4 & 5)

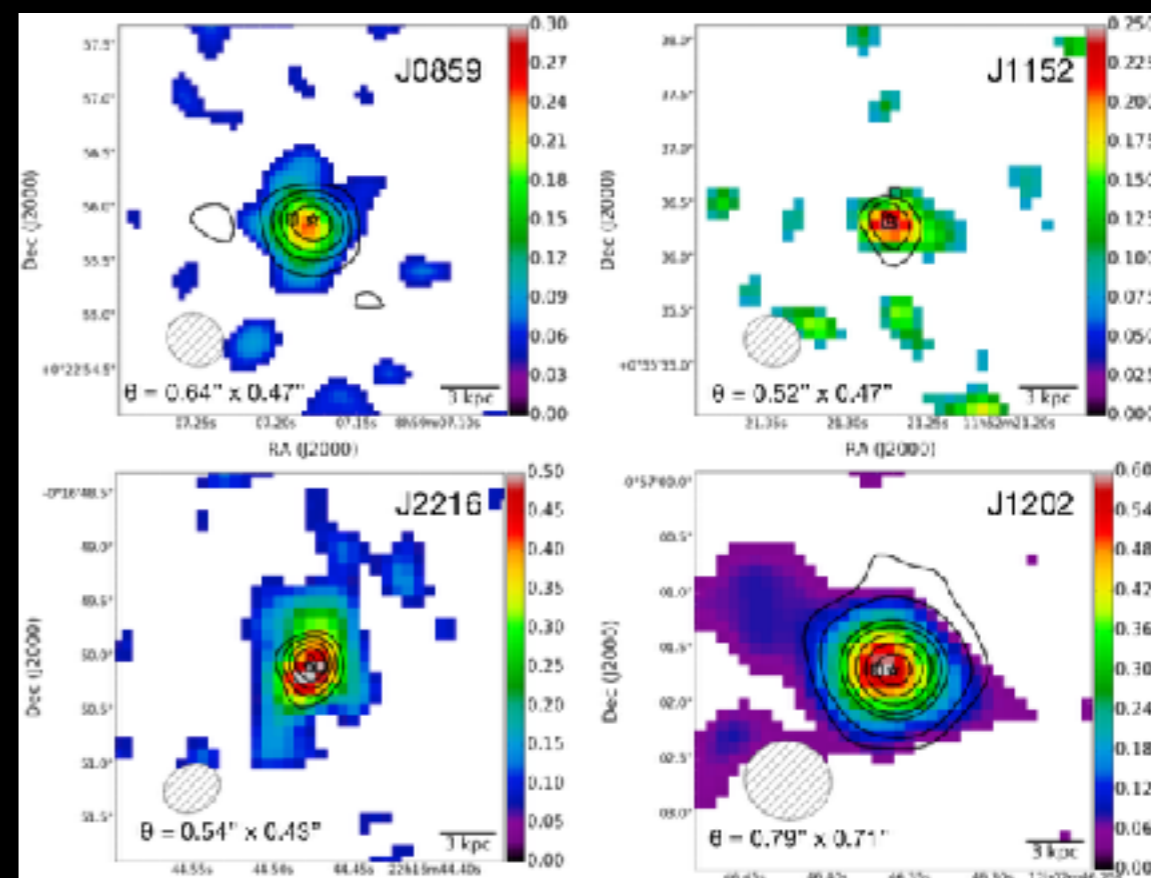
★ Proposals being considered

- ✓ JVLA ... radio properties (led by C.-F. Lee)
- ✓ JWST ... host galaxies (led by YM & T. Izumi)

BH mass (led by M. Onoue)

nature of extremely-luminous Ly α objects (led by T. Nagao)

dust torus (led by Y. Toba)

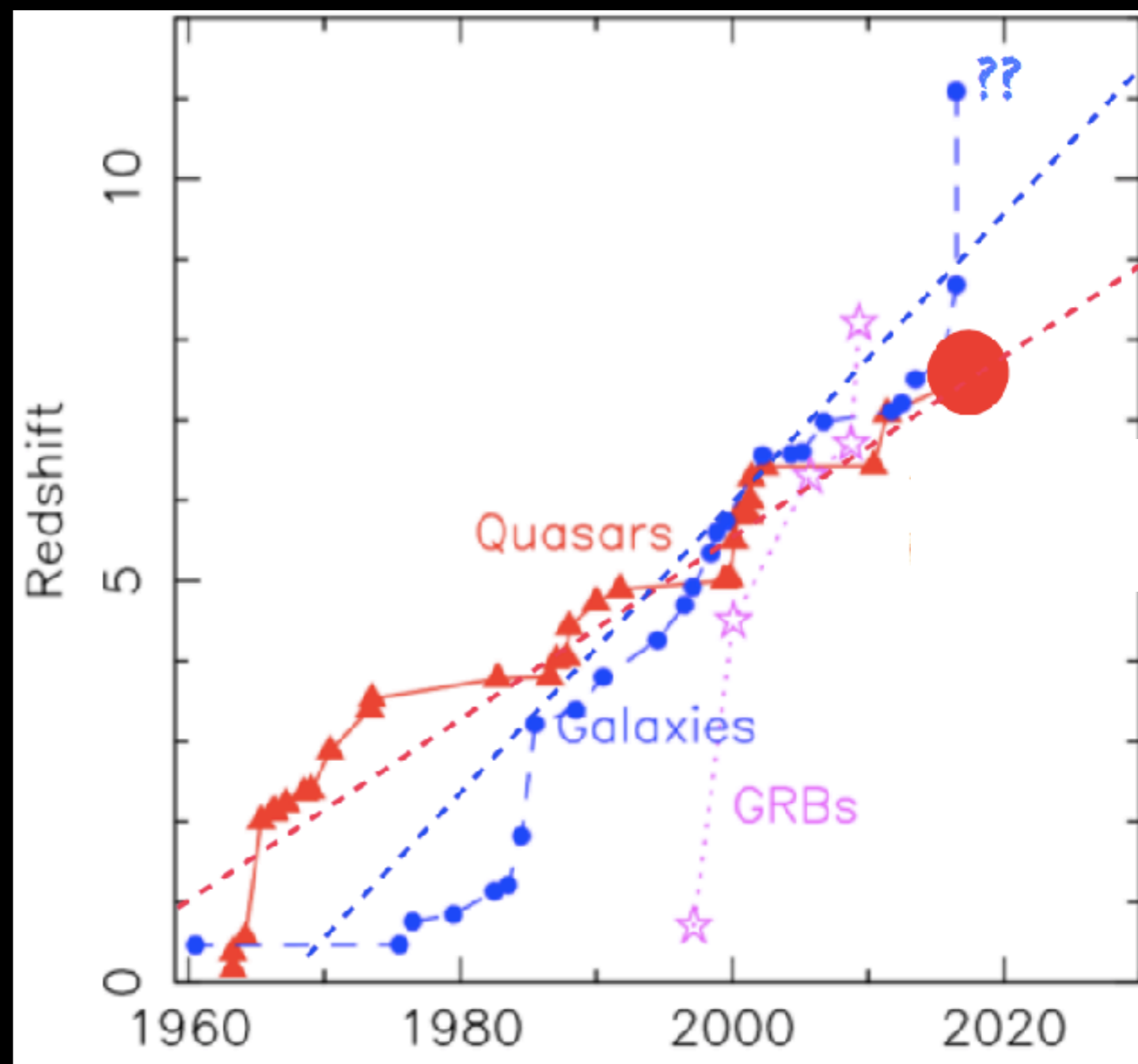


さらに遠くへ

★ WFIRST



★ TAO



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