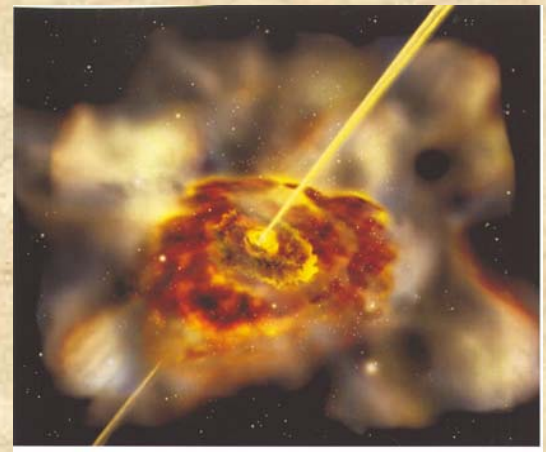

High-Redshift Quasars as Early Star Formation Probes

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Department of Astronomy

The Nuclear Region, Host Galaxy and Environment of Active Galaxies **April 19, 2007**

- **Introduction**
- **Results and Discussion**
  - **FeII / MgII Ratios at High Redshifts**
  - **UV Emission Line Diagnostics and Metallicity**
- **Summary**

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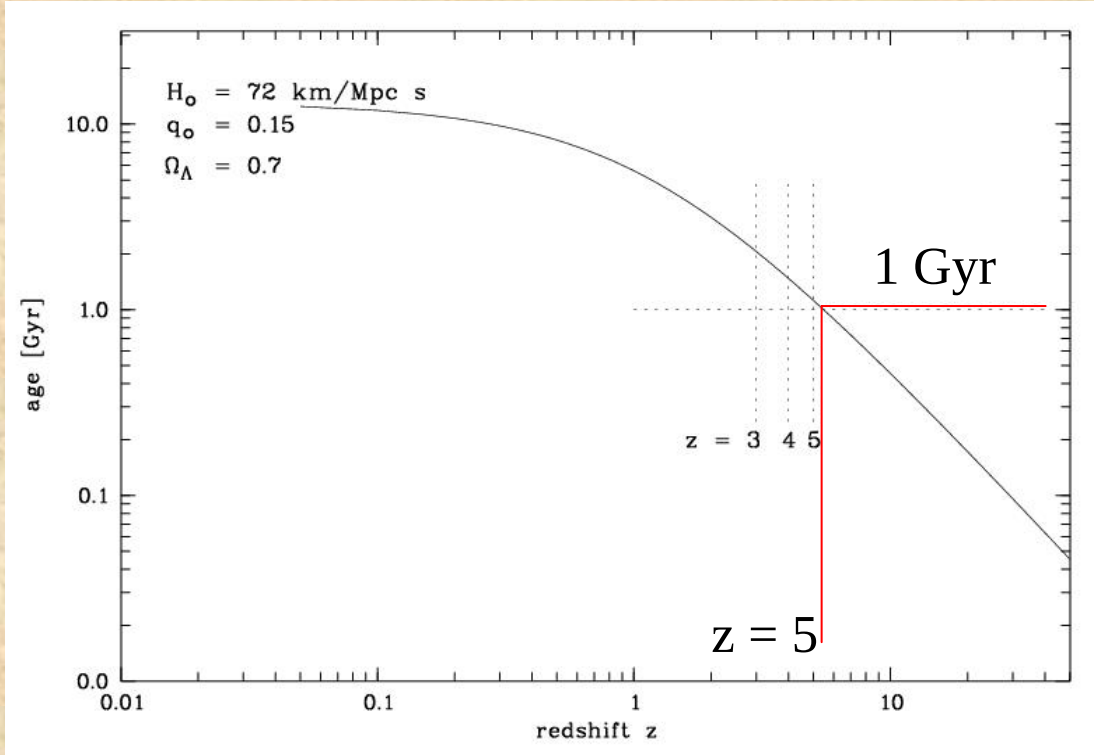
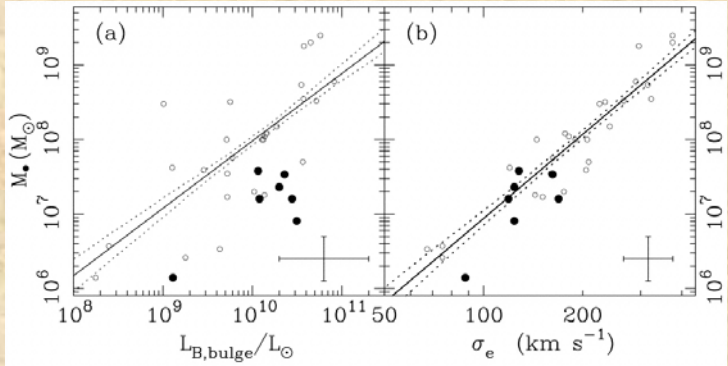
Quasars and their rich emission line spectra are powerful tools to explore (i) the early universe
(ii) first star formation episodes
(iii) the formation of their host galaxies
(iv) super-massive black hole (SMBH) growth

Quasars with redshifts of $z \gtrsim 5$ are of special interest.

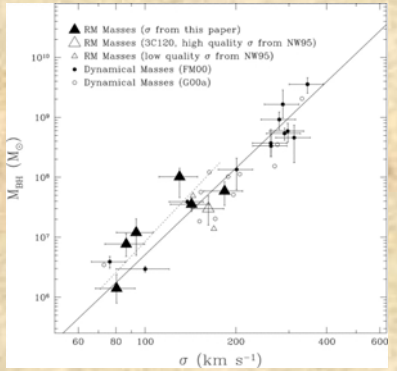


Growing evidence for a close connection of quasar activity and galaxy formation

Correlation of the black hole mass with the host galaxies mass, luminosity, and velocity dispersion

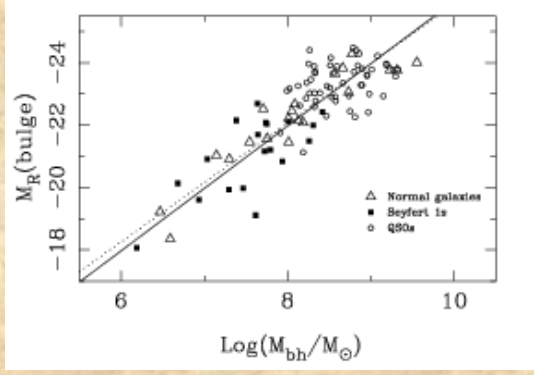


(Gebhardt et al.2000)

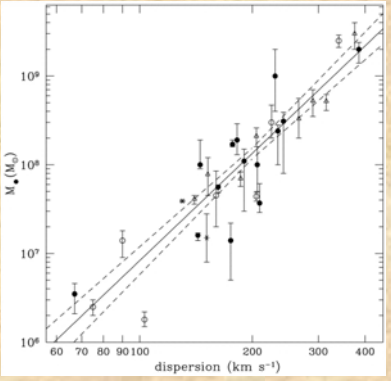


(Ferrarese et al. 2001)

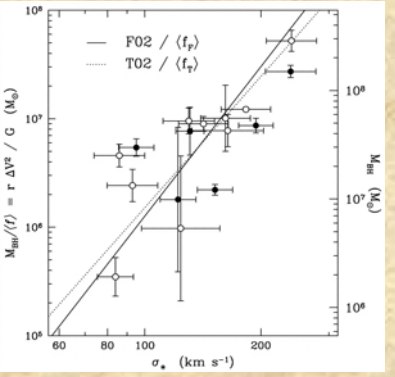
- $M_{bulge} \propto 0.0013\ M_{bh}$
- $L_{bulge} \propto M_{bh}$
- $\sigma_*^4 \propto M_{bh}$



(McLure & Dunlop 2002)



(Tremaine et al.2002)



(Onken et al.2004)

The connection of quasar activity driven by SMBHs and the formation of the juvenile hosting galaxy can be studied by

(i) BLR gas metallicity estimates

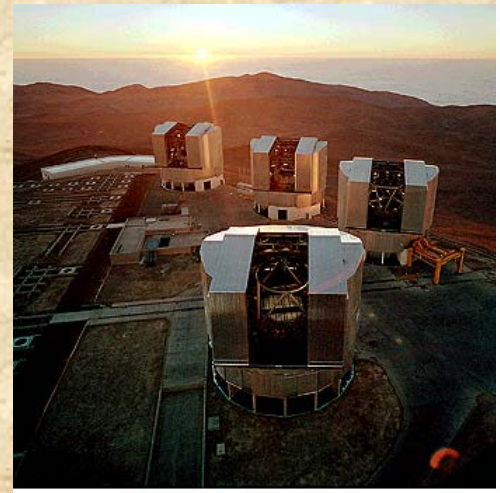
(ii) the evolution of the FeII/MgII ratio

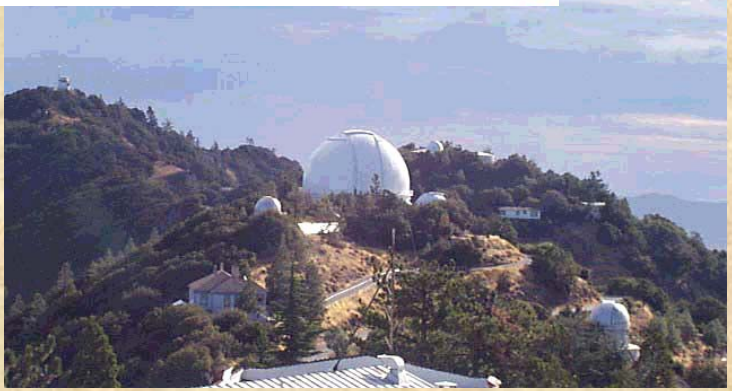
(iii) growth time of SMBHs ($M_\bullet \simeq 10^9 M_\odot$, $\tau \simeq 0.5$ Gyr)

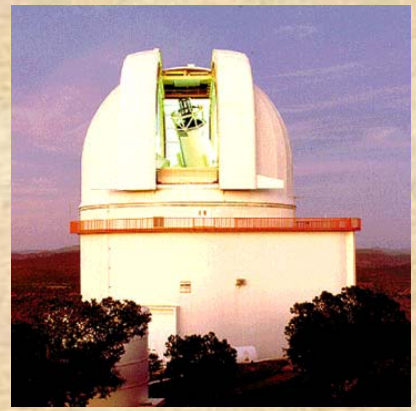
If the BLR gas is connected to the ISM of the host galaxy the enrichment process due to star formation can be traced back to redshifts $z \gtrsim 6$.

↓

Observation of high-redshift quasars in the UV, optical, and near infrared







Looking east towards the dome of the Shane 3-meter Reflector about twenty minutes after

The High Redshift Quasar Sample

Quasar	m_R	z
Q0103-260	18.82	3.36
Q0105-2634	17.30	3.48
Q0256-0000	17.50	3.37
Q0302-0019	17.60	3.29
Q2050-359	18.34	3.51
PKS2126-158	17.30	3.27
Q2227-3928	18.80	3.44
Q2348-4025	18.60	3.31
BRI0019-1522	19.00	4.52
Q0103+0032	18.60	4.44
PSSJ0248+1802	18.40	4.44
SDSS0338+0021	19.97	5.02
PC1158+4635	20.21	4.73
SDSS1204-0021	20.82	5.09
BRI2237-0607	18.30	4.57

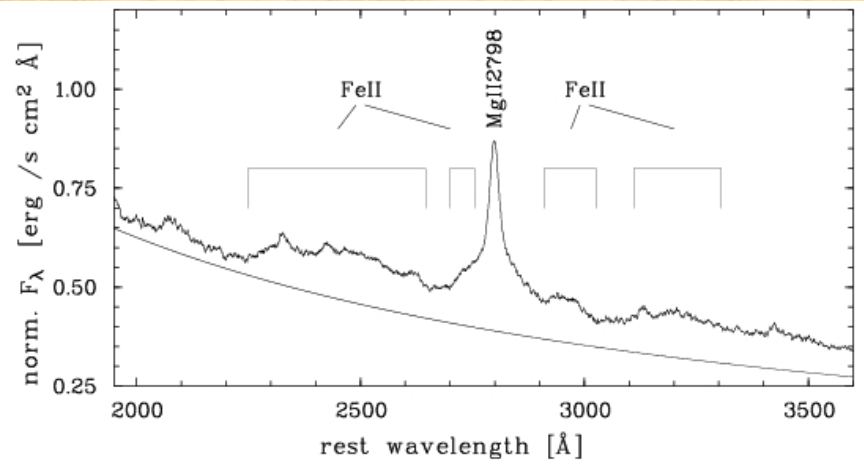
Quasar	m_R	z
BR0305-4957	18.76	4.78
SDSS0338+0021	19.97	5.02
BRI1202-0725	18.70	4.70
SDSS1605-0112	22.50	4.92
SDSS2200+0017	20.68	4.78

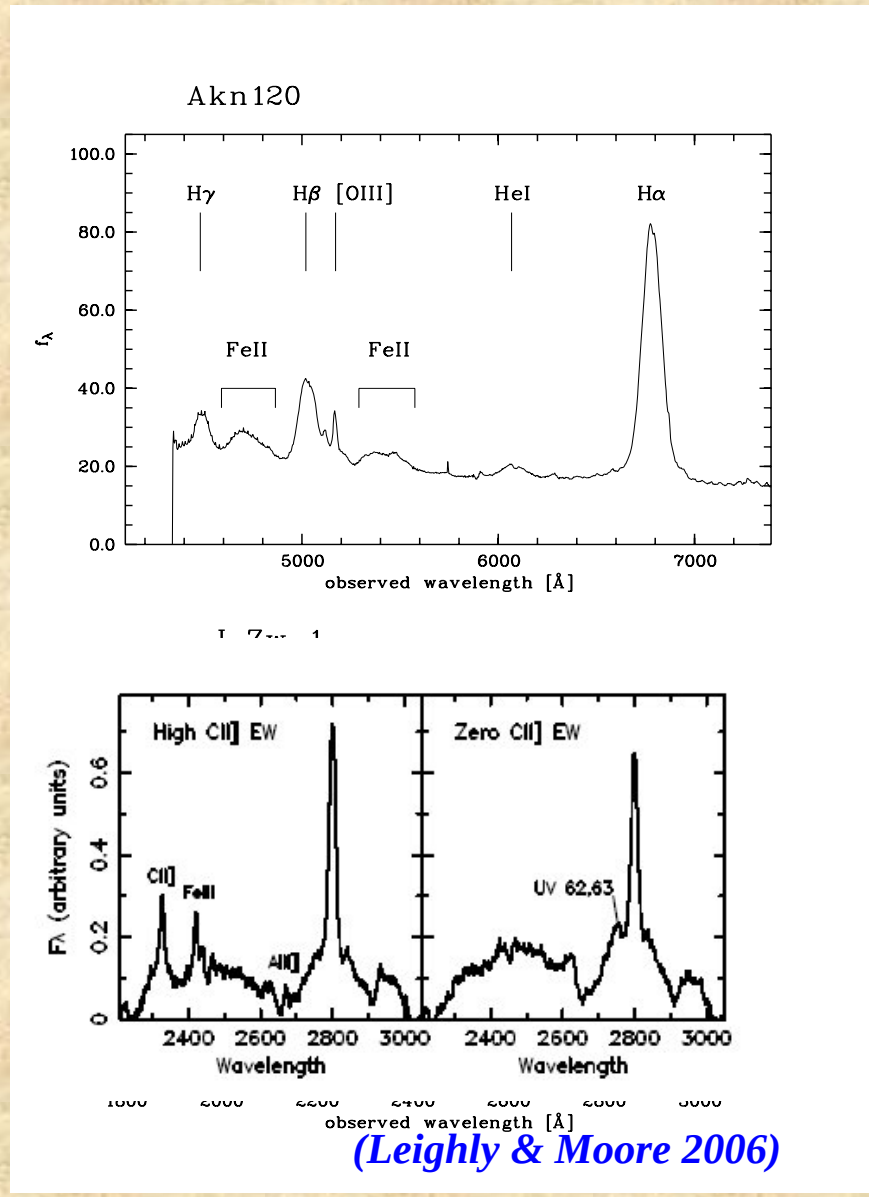
just in progress: GeminiN/NIRI and NICMOS/HST

SDSS1030+0524	23.23	6.28
SDSS1048+4638	22.40	6.23
SDSS1208+0010	22.75	5.27
SDSS1306+0356	22.58	5.99
SDSS1630+4012	23.04	6.05
SDSS2216+0013	21.78	4.99

I – Iron / α-Element Ratio as Cosmological Clock

- **prominent FeII emission blends are located in the optical (Hβ) and in the ultraviolet (MgII)**
- **relative iron abundance may be useful to date the first star formation epoch**





(Leighly & Moore 2006)

FeII / MgII Ratio ---- The Idea

- α-elements (e.g., O, Mg, Si) are produced predominantly by massive stars on short time scales
- the dominant source of Fe is ascribed to intermediate mass stars in binary systems, ending in SNIa explosions

→ significant different time scales of the release of α-elements and iron to the ISM (t □ 1 Gyr; e.g. *Yoshii et al.1996*), however Matteucci & Recchi (2001) and Friaça & Terlevich (1998) suggested that this delay may be ~0.2 - 0.4 Gyr for spheroidal galaxies

→ **Fe/α-element ratios can be employed as a cosmological clock**

→ **measurement of FeII UV and MgII2798**

→ **necessity of IR spectroscopy of high redshift quasars**

The FeII Emission Spectrum

- **First detailed models of the FeII emission spectrum were calculated by Netzer (1980); Netzer & Wills (1983); Wills, Netzer, & Wills (1985); and Joly (1987,1993), Collin et al.(1988), Ferland & Persson (1989)**

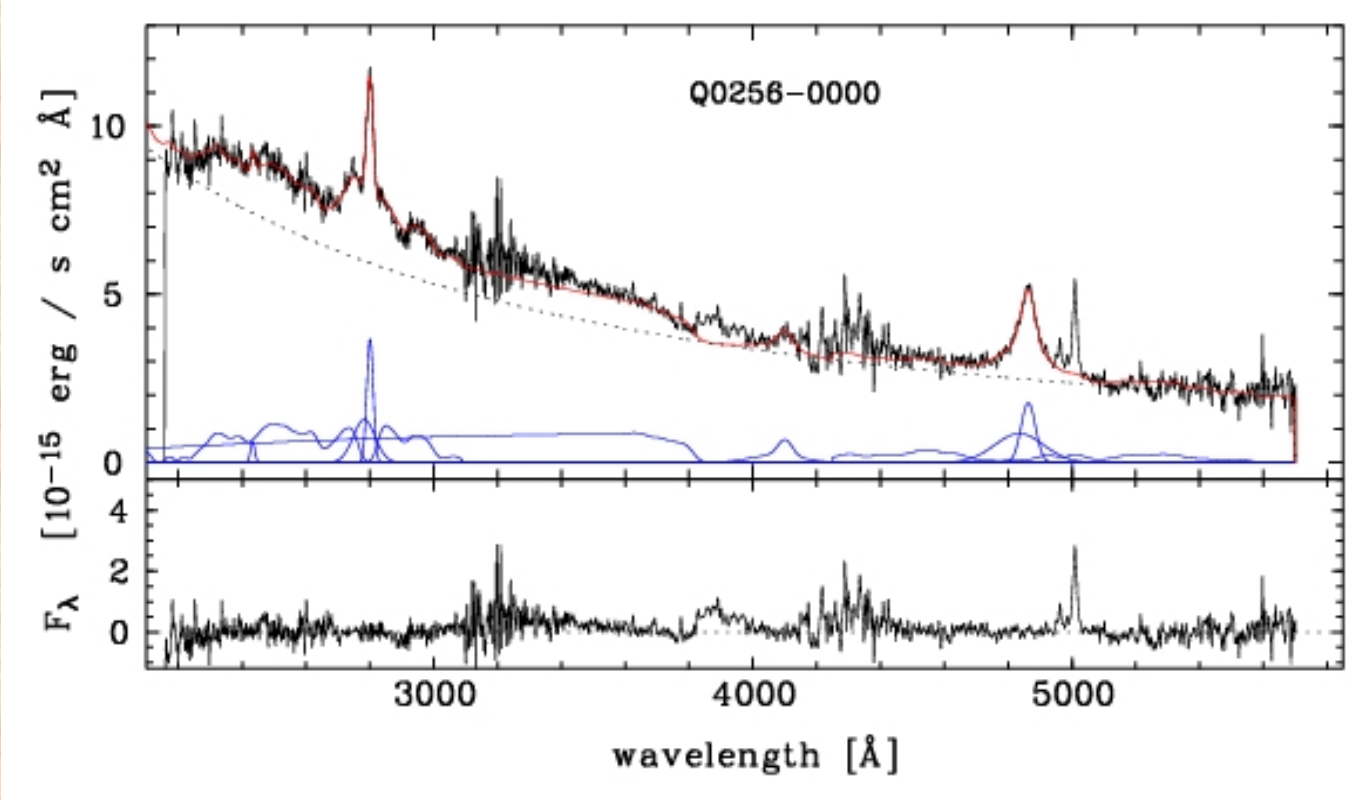
- **Model calculations of FeII emission spectra still face sever problems**
  (Sigut & Pradhan 1998,2003; Sigut, Pradhan, & Nahar 2004; Verner et al.1999,2003; Baldwin et al.2004; Leighly & Moore 2006)

- **FeII spectrum sensitive to**
  - **several 100.000 transitions**
  - **density**
  - **radiation transfer (e.g. line pumping)**
  - **micro-turbulence**
  - **excitation and ionizing SED**
  - **metallicity**

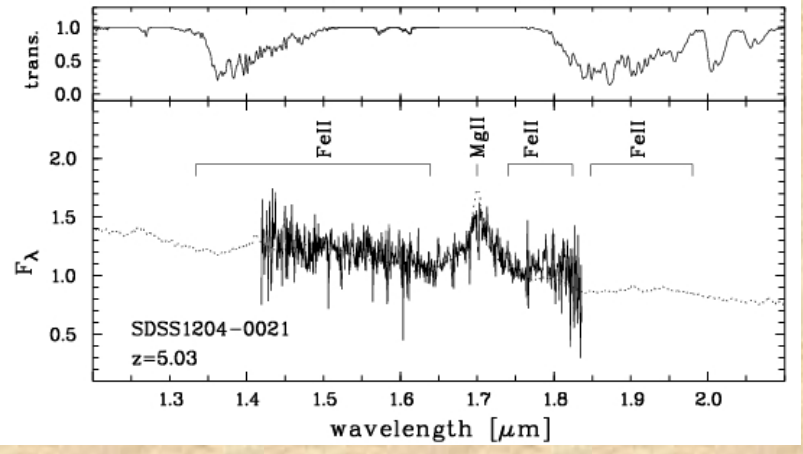
→ **empirical iron emission templates** ***(Boroson & Green 1992; Vestergaard & Wilkes 2001; Veron-Cetty, Joly, & Veron 2004)***

Multi-component fit to measure the FeII flux

- power law continuum
- Balmer continuum emission
- MgII2798, Hβ
- FeII template (model, observed, composite)

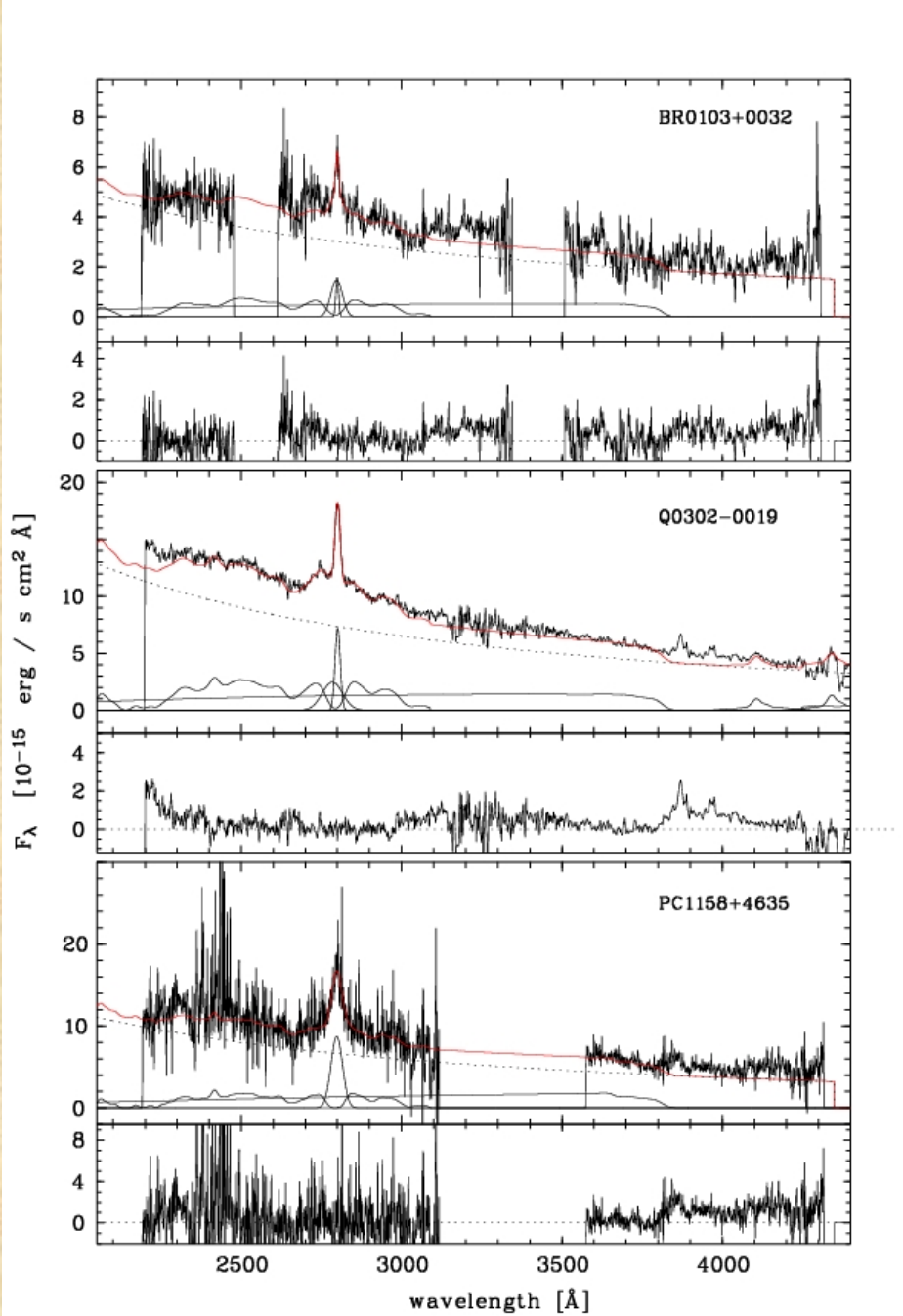


Observational Constraints

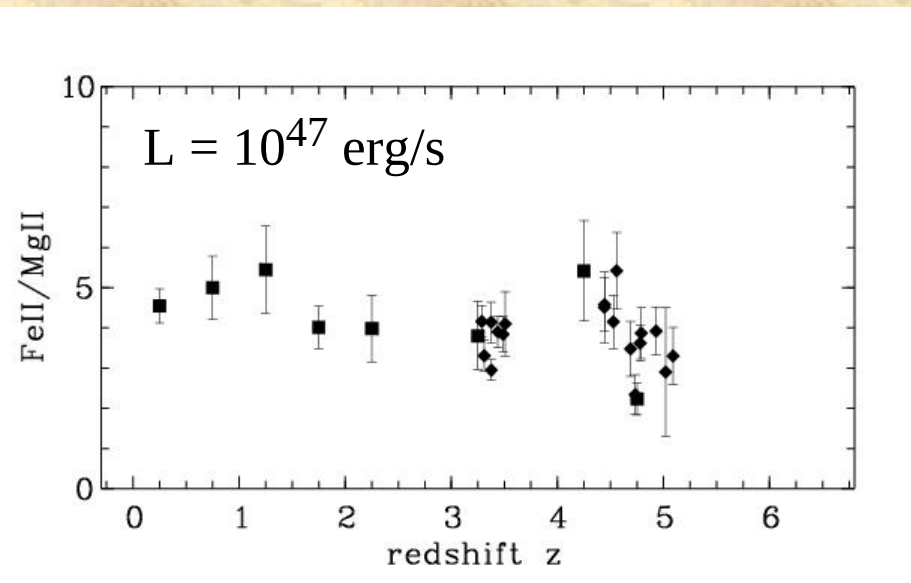


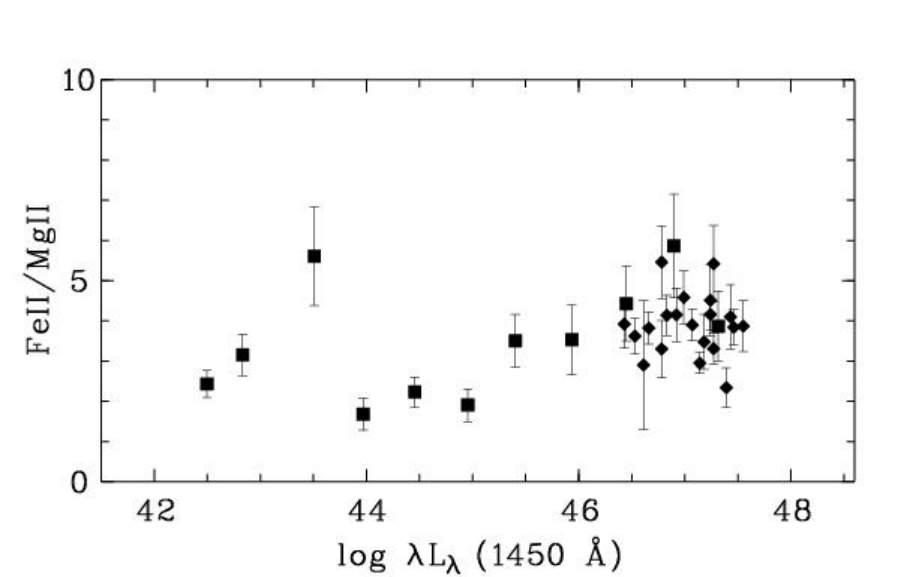
a large continuum range is one of the most important constraints

→ **reliable continuum fit**



Results on FeII/MgII



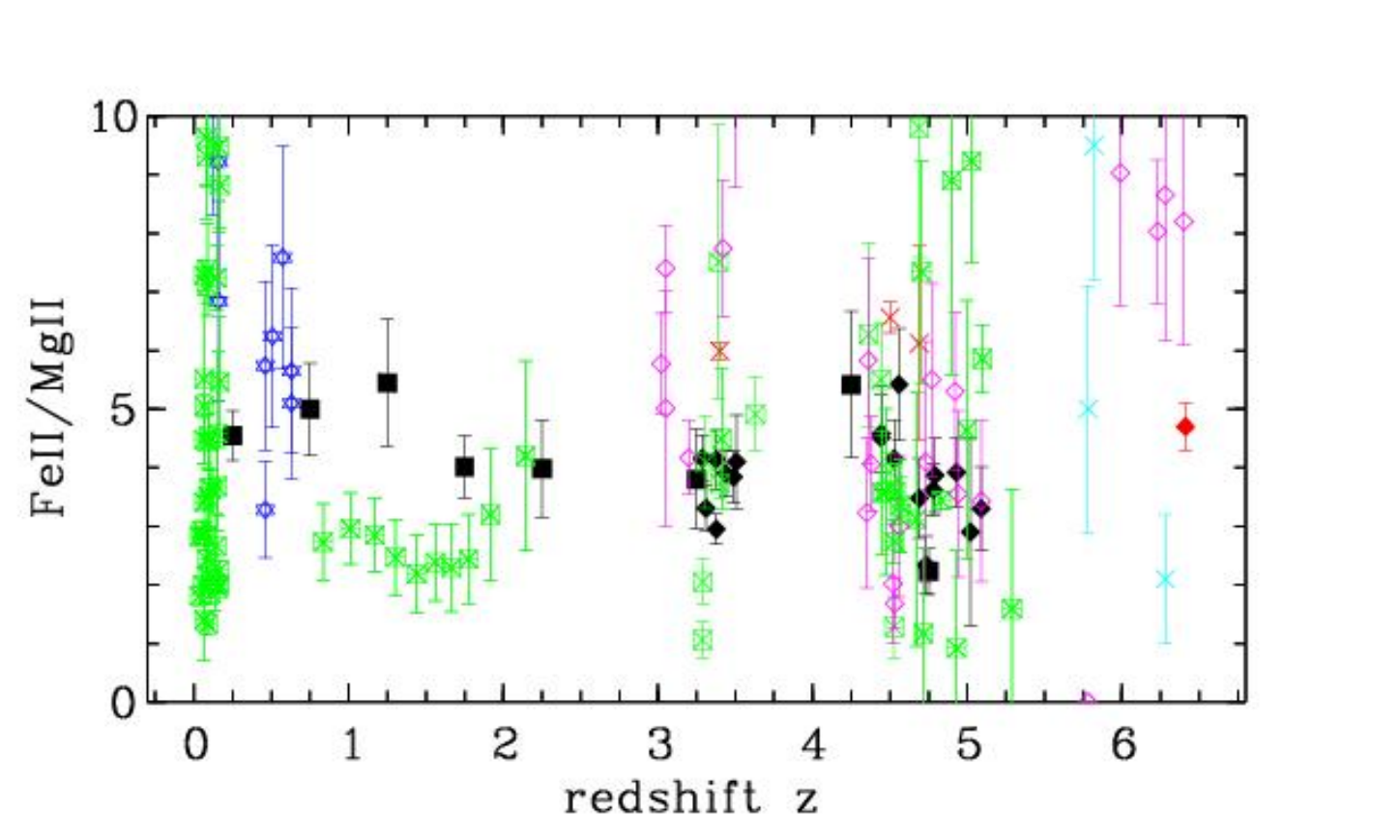


FeII/MgII line ratio of z ≃ 3.4 and z ≃ 4.7 quasars in comparison with ratios based on composite quasar spectra of comparable luminosity

lack of strong evolution of the FeII/MgII ratio at least to redshifts of z ≃ 5

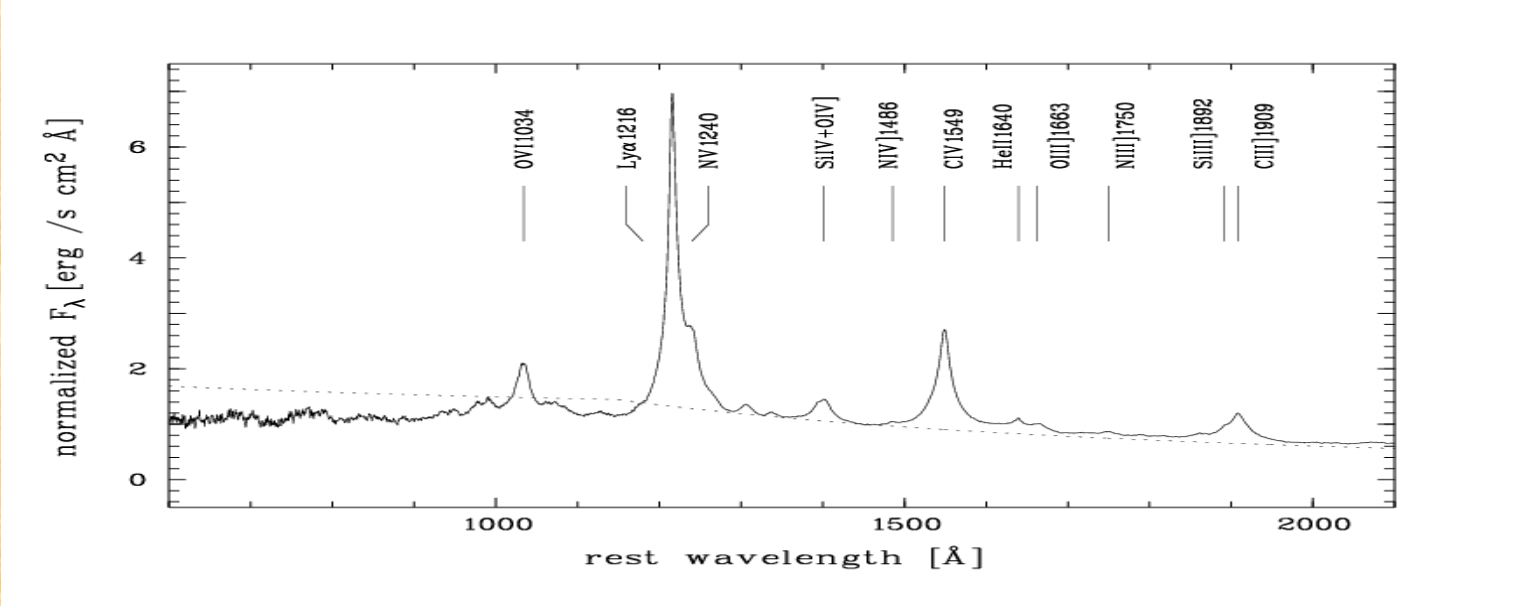
No clear trend of the FeII/MgII ratio with luminosity, large scatter at high and low L.
However, for L ≳ 10^{44} erg/s a weak trend of increasing FeII/MgII toward higher L.

Comparison with other Studies



Iwamuro et al. 2002,2004; Thompson, Hill, & Elston 1999; Wills, Netzer, & Wills 1985; Barth et al.2003; Freudling, Corbin, & Korista 2003; Maiolino et al.2003

II - UV Emission Line Diagnostics and Metallicity



- **early studies of BLR abundances were based on NIV]1486, OIII]1663, NIII]1750, and CIII]1909 ⟶ at least solar up to several times solar metallicity** *(Shields 1976;Davidson 1977;Baldwin & Netzer 1978;Osmer 1980;Gaskell 1982;Uomoto1984)*

- **recent studies on high-z quasars (z > 3) indicate several times $Z_{\odot}$**
  (Hamann & Ferland 1992,1993; Ferland et al.1996; Dietrich et al. 1999,2003; Dietrich & Wilhelm-Erkens 2000; Hamann et al. 2002; Warner et al.2002; Nagao et al. 2006; Dhanda et al. 2007)

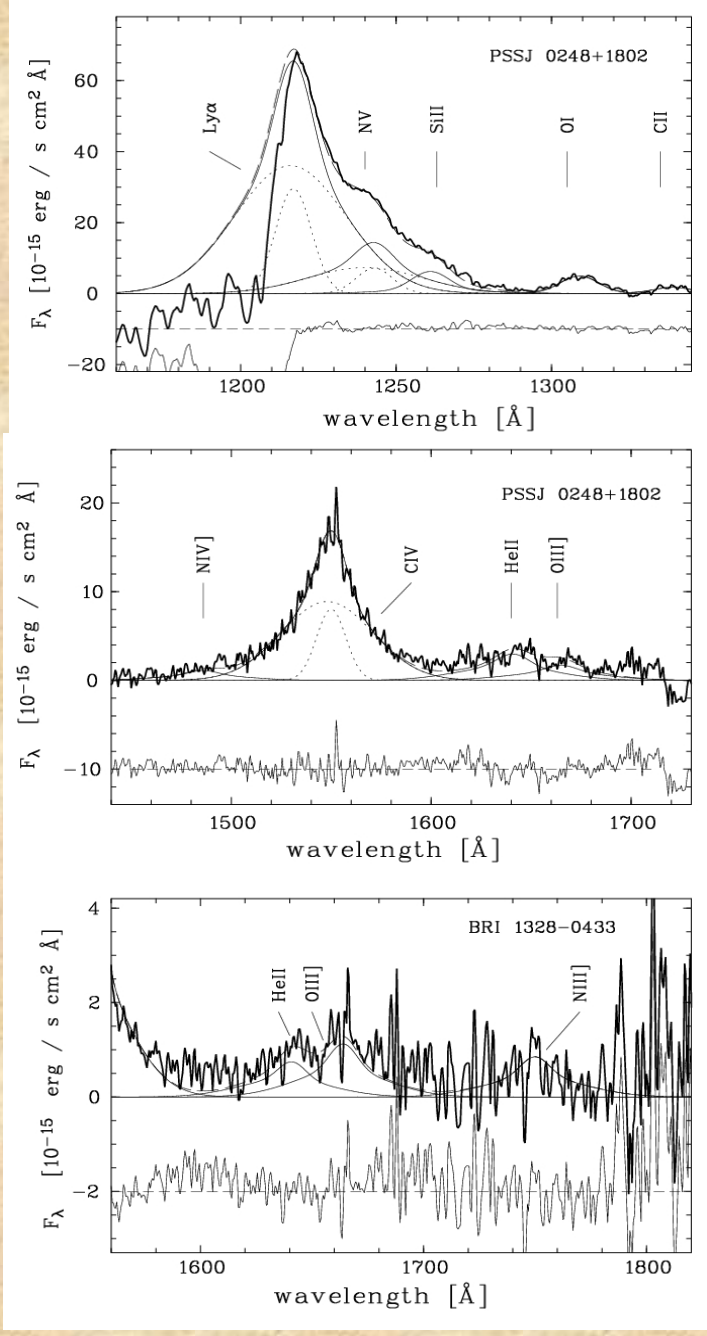
- **high elemental abundances also have been detected based on intrinsic absorption lines** *(e.g., Møller et al.1994; Petitjean et al.1994; Hamann 1997; Pettini 1999; Kuraszkiewicz et al.2003; Fields et al.2006)*

- the quasar spectra are shifted to their rest frame and corrected for FeII and FeIII emission using an empirical emission template

  (Vestergaard & Wilkes 2001)

- the CIV1549 emission line profile was fitted with a broad and narrow Gaussian profile that are used as templates to measure the line strength of other emission lines

- OVI1034 is corrected for Lyα forest absorption, assuming that the same fraction of continuum and emission line flux are absorbed

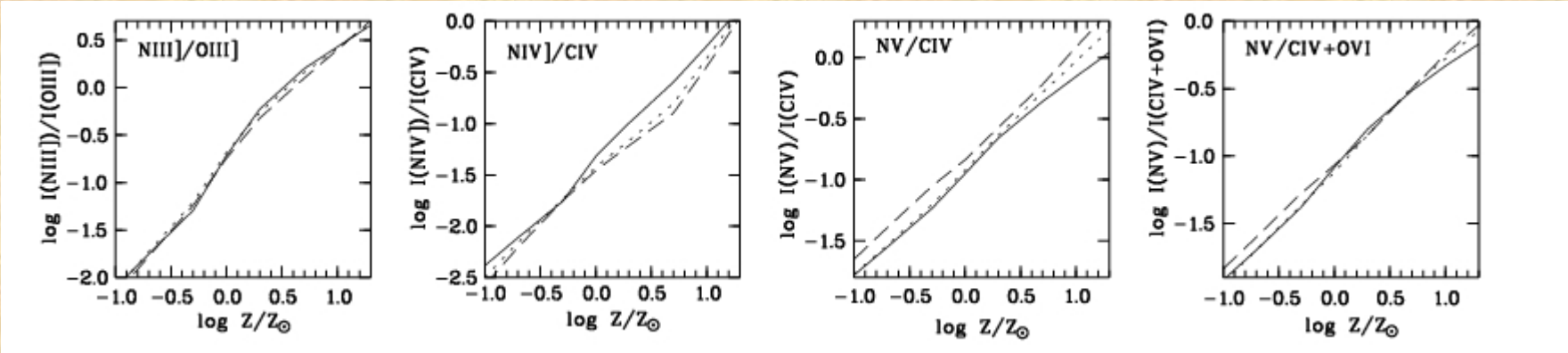


Hamann et al. (2002) studied in great detail the dependence of emission line ratios from gas metallicity and the shape of the ionizing continuum

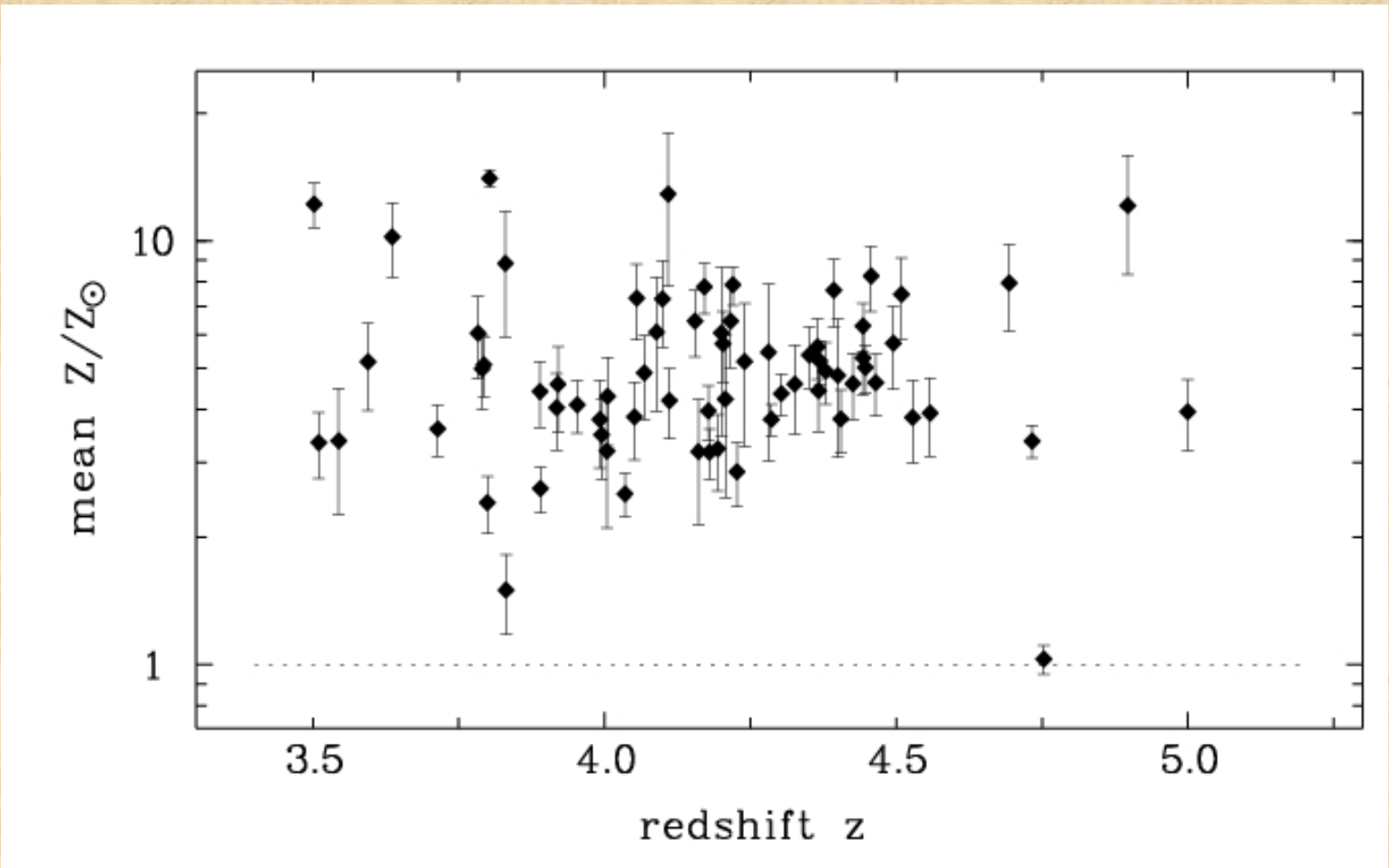
- **grids of photoionization models, employing CLOUDY** *(Ferland et al.1998)* **for a wide range of gas density, input continuum shapes, and metallicities**

- **nitrogen line ratios are of particular interest --- assuming that secondary N production is the dominant source for N → N/O □ O/H → N/H □ Z^2**

- **this strong scaling of N abundance is observed for HII regions with elemental abundances above ~1/3 to 1/2 $Z_{\square}$** *(Pagel & Edmunds 1981; van Zee et al.1998; Izotov & Thuan 1999; Henry et al.2000; Pettini et al. 2000; Pilyugin et al. 2002)*



(Hamann et al.2002)



(Dietrich et al. 2003)

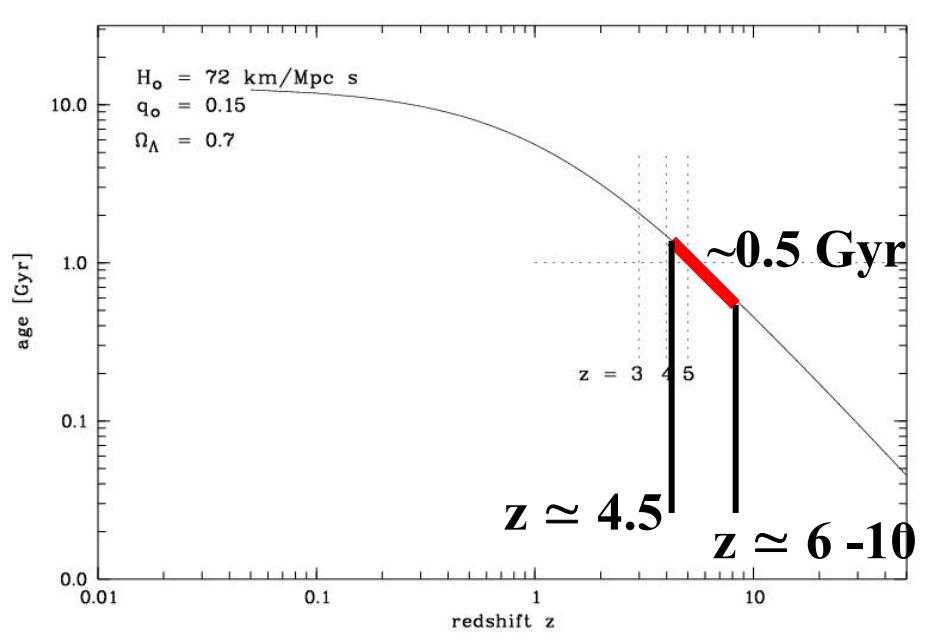
mean metallicity of the BLR gas at high redshift

→ **4 to 5 times $Z_{\square}$ ($Z/Z_{\square}$ = 5.3 ± 0.3)**

The Epoch of Preceding Star Formation

- several evolutionary models have been suggested to explain the observed chemical composition

- super-solar metallicities can be achieved in single zone models *(e.g., Arimoto & Yoshii 1987; Hamann & Ferland 1992,1993; Matteucci & Padovani 1993; Gnedin & Osteriker 1997),* as well as in more recent multi-zone models *(e.g., Friaça & Terlevich 1998; Romano et al.2002; Granato et al.2004; DiMatteo et al.2004)*

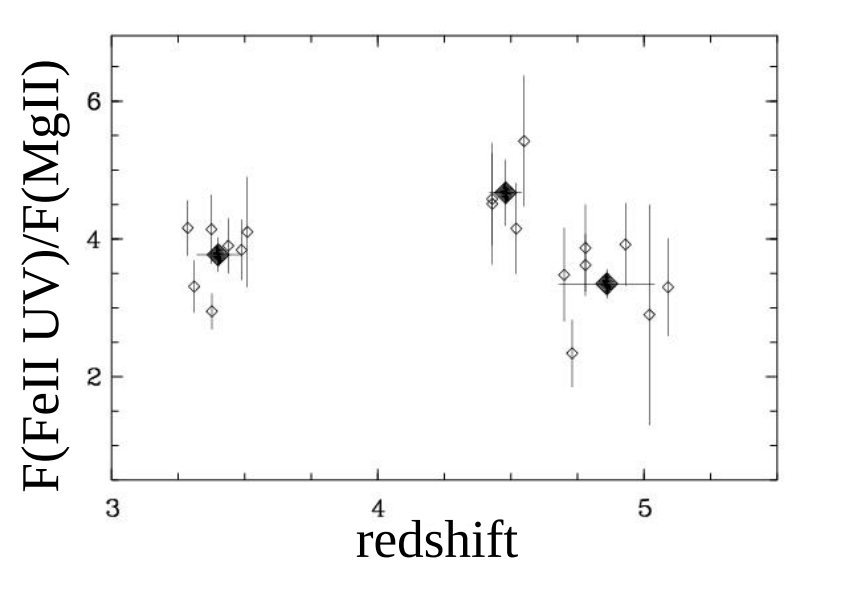


(H_o = 72 km/s Mpc, Ω_Λ = 0.7, Ω_M = 0.3)

assuming a short period of intense star formation (~0.5 Gyr) in the quasar host galaxies at high redshifts

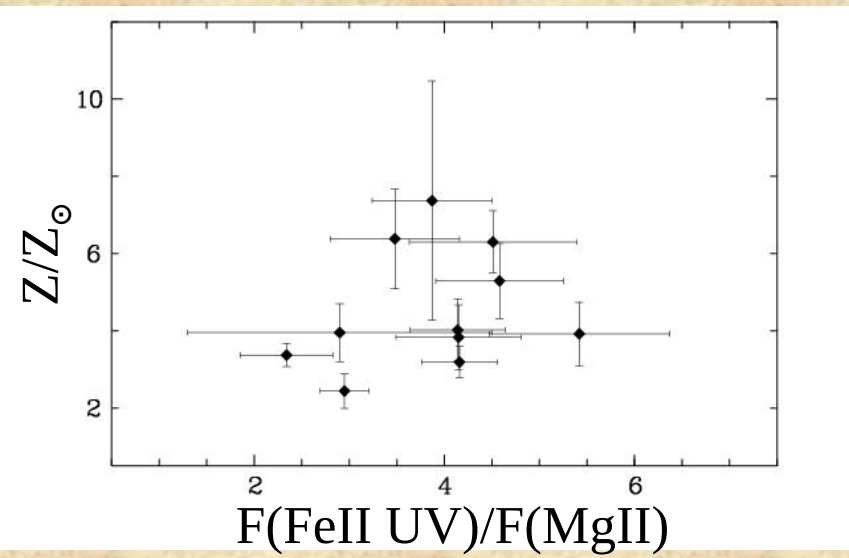
→ **the star formation epoch should have started at z = 6 to 10**

Future Work



By grouping the measurements of FeII/MgII for the high-z quasars there appears to be a weak tendency for lower FeII/MgII ratios for quasars with $z \gtrsim 5$.

Of course more measurements are needed at redshifts $z \simeq 6$



Although gas metallicity is not the dominant parameter of FeII emission it is interesting whether there is a trend with gas metallicity.
So far no trend at all but again more measurements are needed.

Summary

- lack of evolution of the FeII/MgII line ratio up to $z \simeq 5$
- UV spectra of high-z quasars (70 with $z > 3.5$) analyzed

  ➔ 4 to 5 times solar gas metallicity

recent galaxy evolution models can achieve several times solar metallicity within 0.5 Gyr and suggest quasar activity in early formation phases, delayed by ~ 0.5 Gyr, following the star formation epoch

first intense star formation started at z = 6 … 10