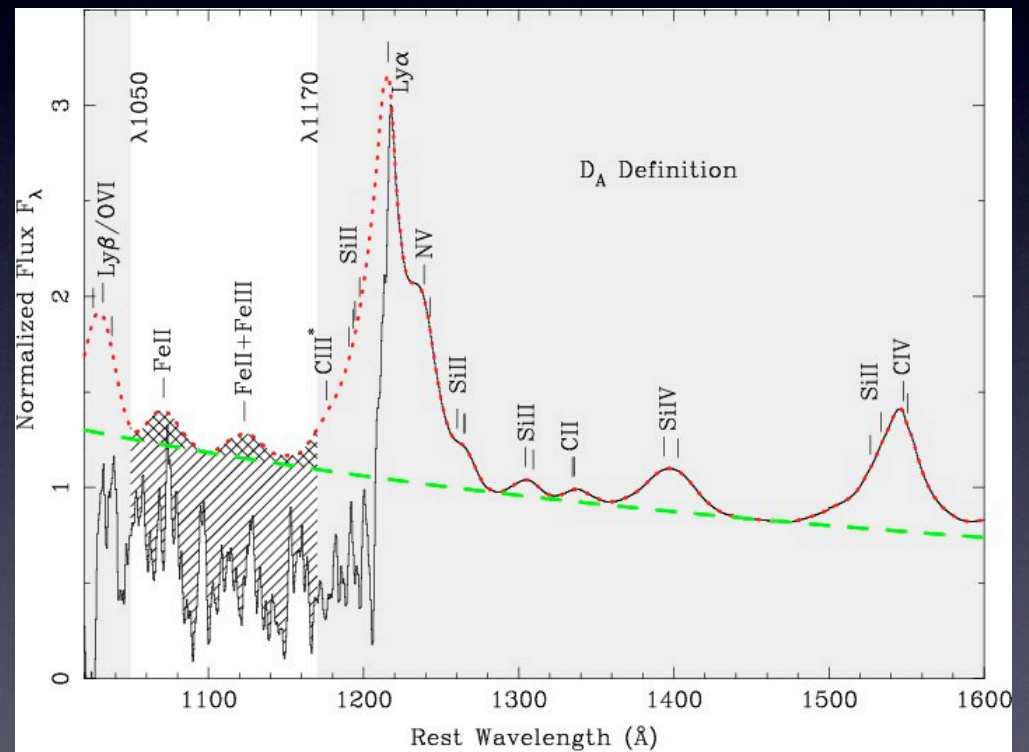
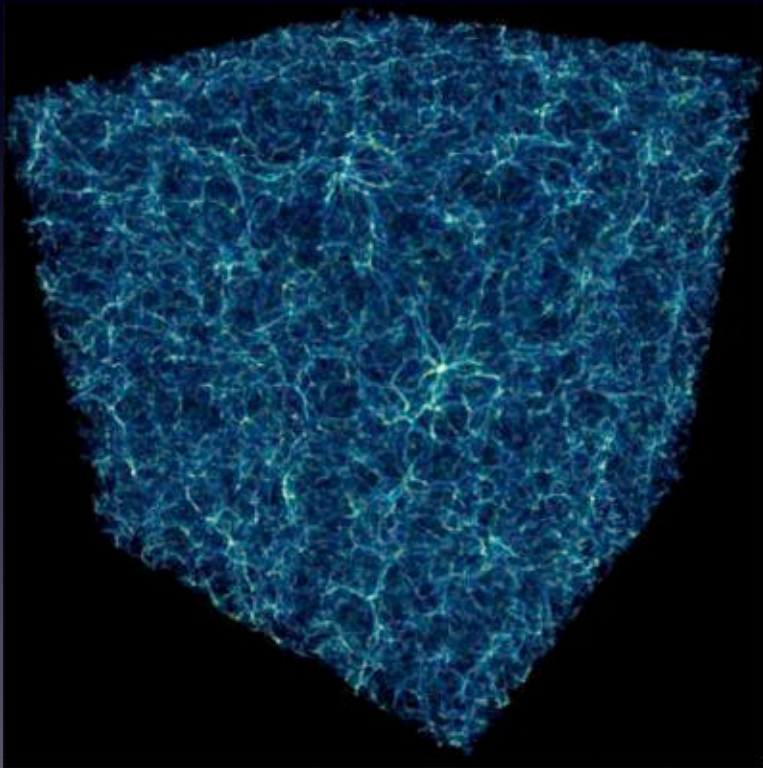


Quasar/LyAF Science & Cosmology

- Nao Suzuki (nsuzuki@lbl.gov)
Lawrence Berkeley National Lab:
Supernova Cosmology Project
- Menu
- Introduction to Ly alpha Forest
- Quasar/LyAF Key Projects
- LyAF BAO
- LyAF Forecast
- Quasar/LyAF Wish List

Quasar Ly alpha Forest



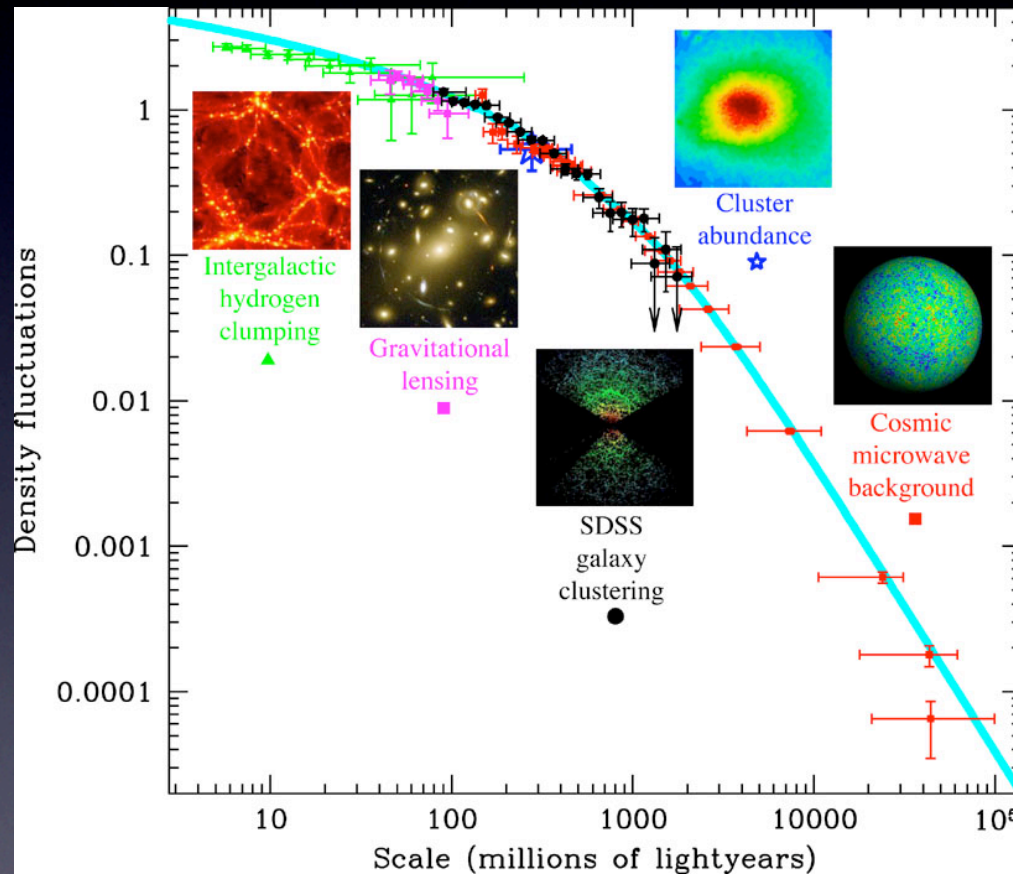
Quasar/LyAF : Advantage I : Probing high-z universe (2000 deg²)

mag	z=0.5	z=1.0	z=2.5	z=3.5	z=4.5	z=5.5	z=6.5	QSO	LyAF
16	67	60	25	36	0	0	0	155	28
17	414	463	185	40	54	0	0	1,110	233
18	1,960	2,860	1,070	198	32	19	0	6,120	1,300
19	6,820	13,100	5,360	876	123	12	0	26,300	6,380
20	16,200	37,200	19,400	3,500	429	44	0	76,700	23,300
21	27,500	69,300	45,300	11,300	1,400	138	3	155,000	53,200
22	33,600	104,000	35,600	26,900	4,120	399	16	245,000	107,400
23	19,300	144,000	106,000	47,600	10,300	1,090	53	328,000	164,700
Total	106,000	373,600	212,940	90,450	16,458	1,702	72	821,000	412,961

From LSST Bluebook arxiv/0912.0201

SDSS/DR7=100,000 Quasrs with 10,000 LyAF , BOSS 160,000 LyAF

LyAF : Advantage II : Small Scale Probe



Max Tegmark

- BAO
- Growth Factor
- Small Scale Power Spectrum
- slope $n : d \log n / dk$
- e-foldings of Inflation
- Upper limit of Neutrino mass
- Chemical Evolution in IGM

Quasar Spectrum Key Projects

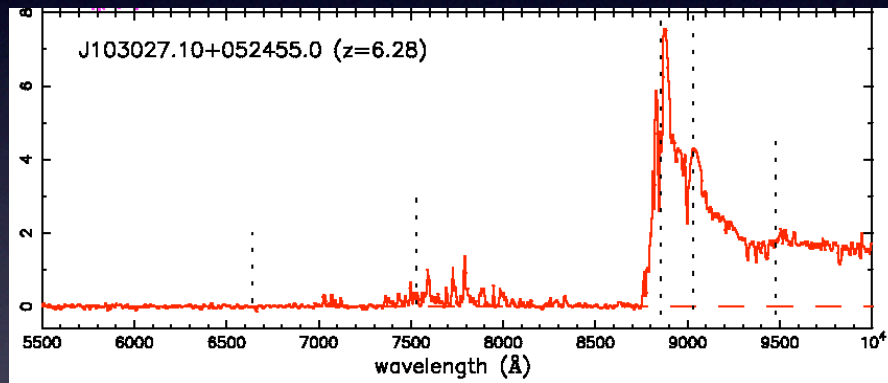
- I : IGM Ionization History
 - a) HI reionization $6 < z < 10$? (Imanishi san's talk)
 - b) **HeII reionization** $z = 3$
- **II: Chemical Evolution History**
- III: Absorber vs. Galaxy Correlation (Brice's talk)
- IV: Black Hole Mass & Mass Accretion Rates
- V : Cosmology
 - a) **BAO**, b) AP test, c) Growth Factor (Sep PFS), d) Power Spectrum
- $\Rightarrow$ expect to grow a community of 20 core people with 50 close collaborators (based on BOSS)

Key Project I : Ionization History (HI)

HI Reionization : $6 < z < 10$?

Important for the future of
21cm cosmology

Q. Inhomogeneity of UV or Density?



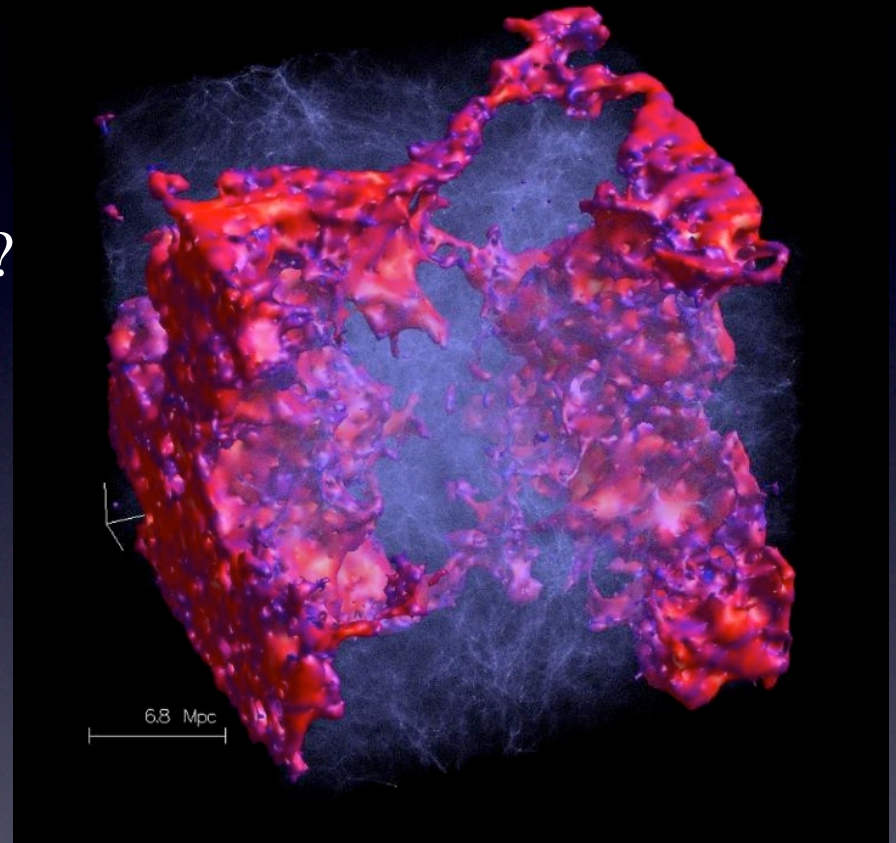
$z > 5$ quasars

Becker et al.

SDSS/DR7: 50 quasars

=> PFS: 2000 quasars

expect to find $z > 7$ quasars



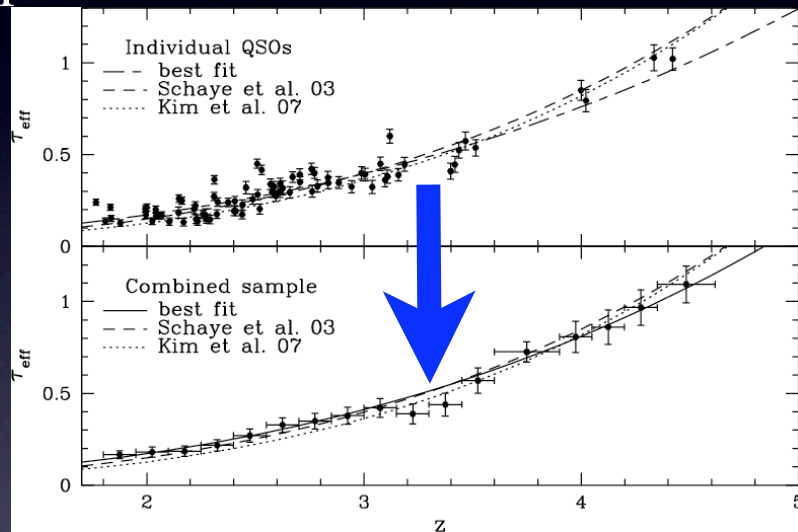
Baek et al (2010) :

Red: Neutral HI Blue: Ionized HI

Key Project I: Ionization History (HeII)

HeII Reionization : $z = 3.2??$

Important for the high energy UV photons and SFR $z < 3$.

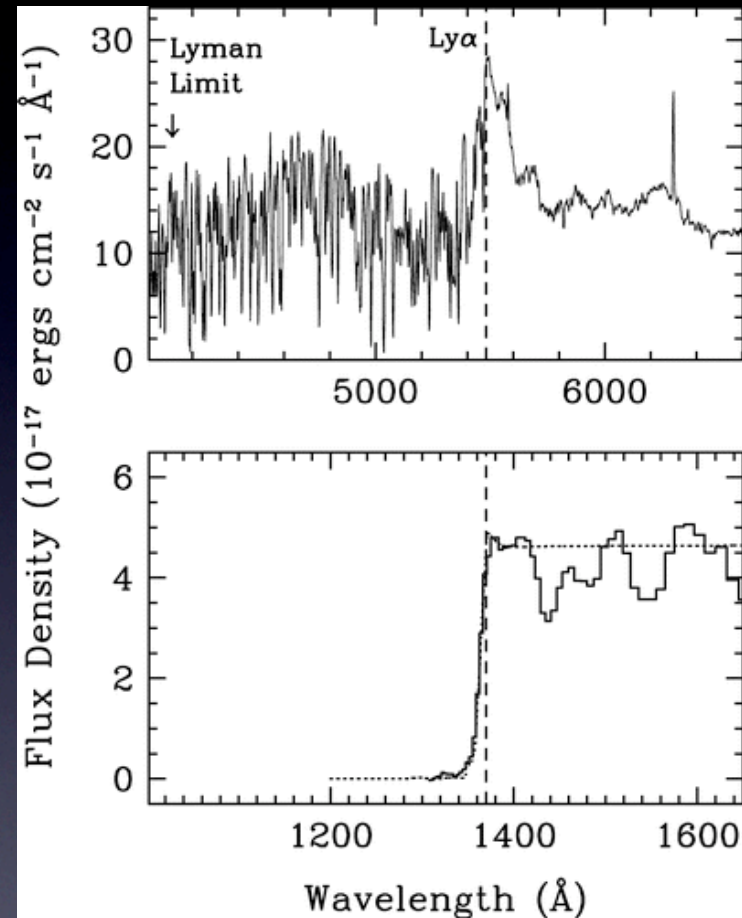


z vs. opacity : Dall'Aglio et al. (2008)

$z > 2.2$ quasars

SDSS/DR7: 10,000 quasars

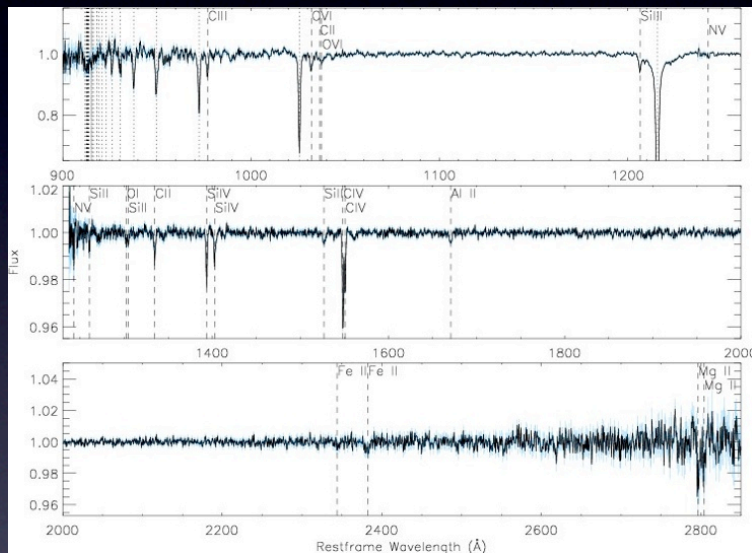
=> PFS: 500,000 quasars



Zheng et al (2008) : $z=3.51$ Quasar
HeII reionization has not happened
at $z=3.5$ ($304 \times (1.0+3.5)=1370$)

Key Project II: Chemical Evolution

Metal Absorbers (LLS/DLA)
Chemical composition ($0 < z < 8$)



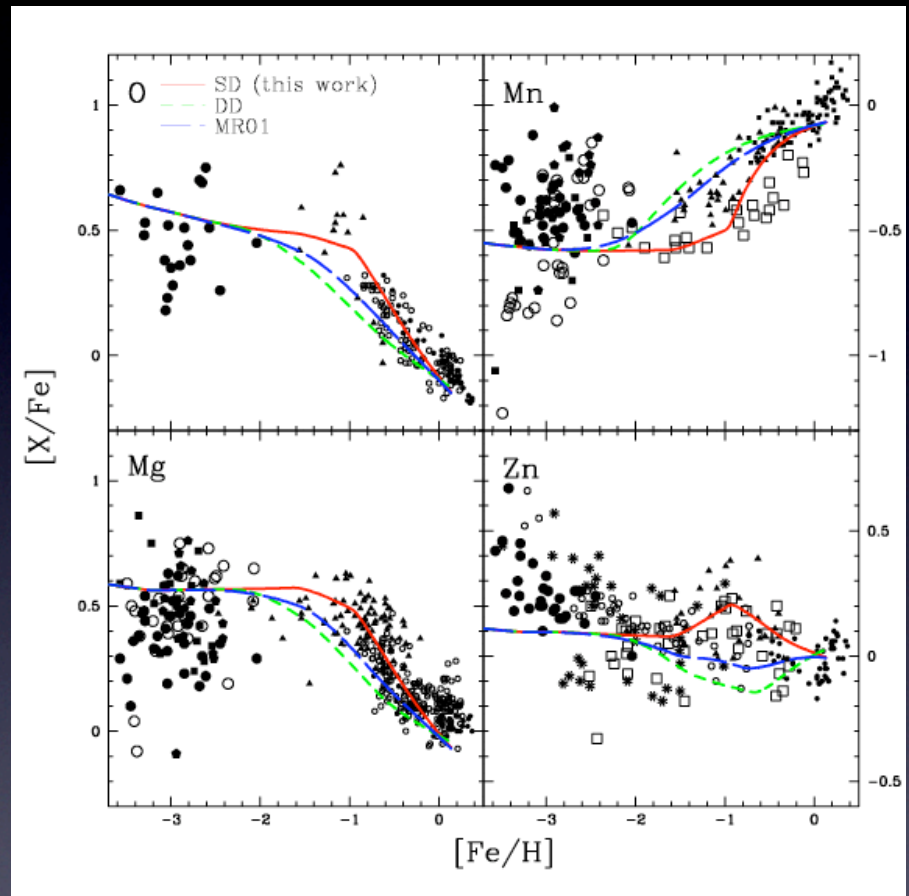
Composite Metal Lines : Pieri et al. (2010)

MgII : $0.35 < z < 3.64$,

CIV : $z > 1.6$

SDSS/DR7: 100,000 quasars

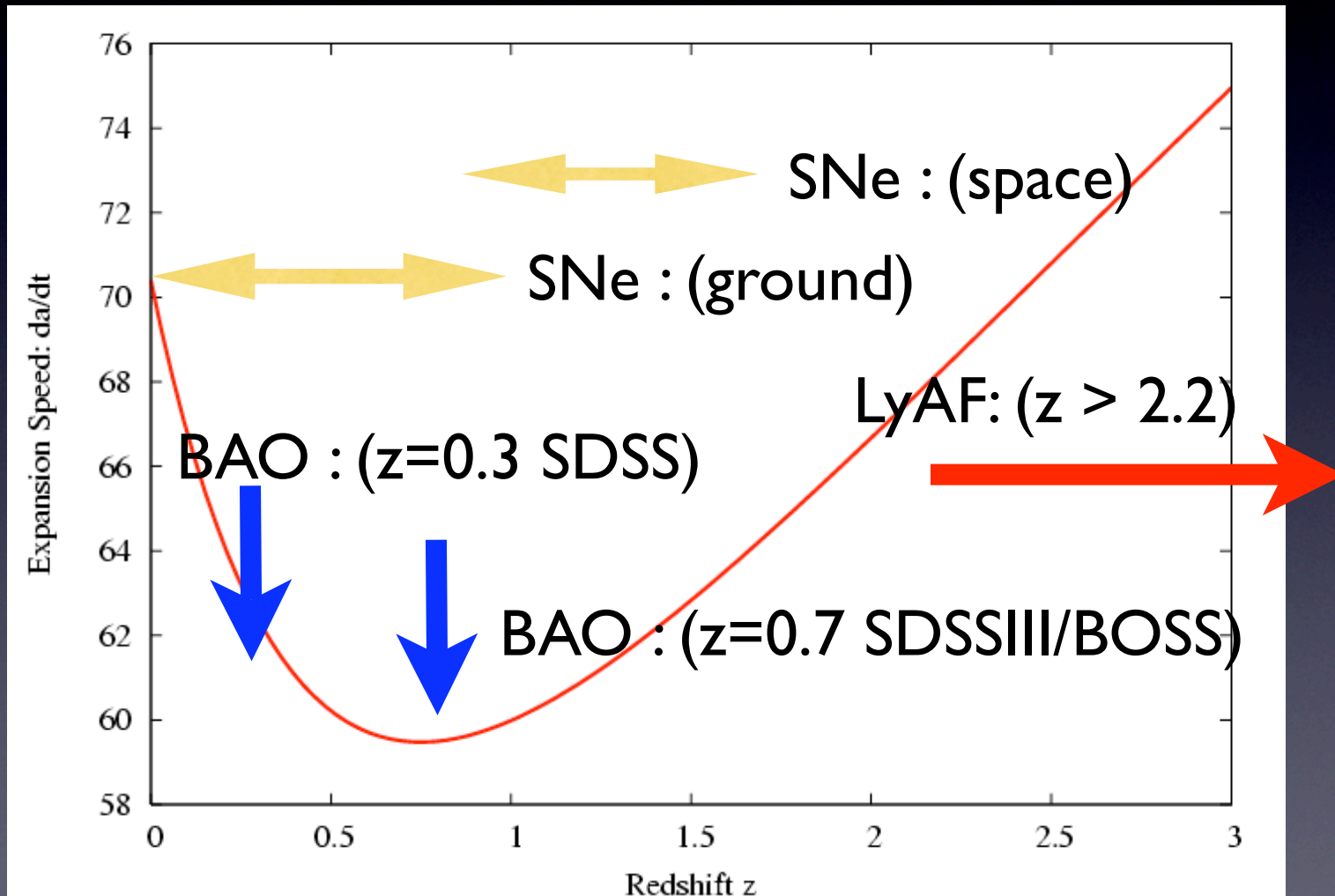
=> PFS: 1,000,000 quasars



Kobayashi & Nomoto (2009)
SNIa does not happen $[Fe/H] < -1.1$

Key Project V: Cosmology

From Deceleration to Acceleration



$w=P/\rho$: Equation of State today (statistical err < systematic err)

$$E \propto a^{-3(1+w)}$$

- $w=-1$: cosmological constant
- $w=0$: matter
- $w=1/3$: radiation

SNe + BAO + CMB

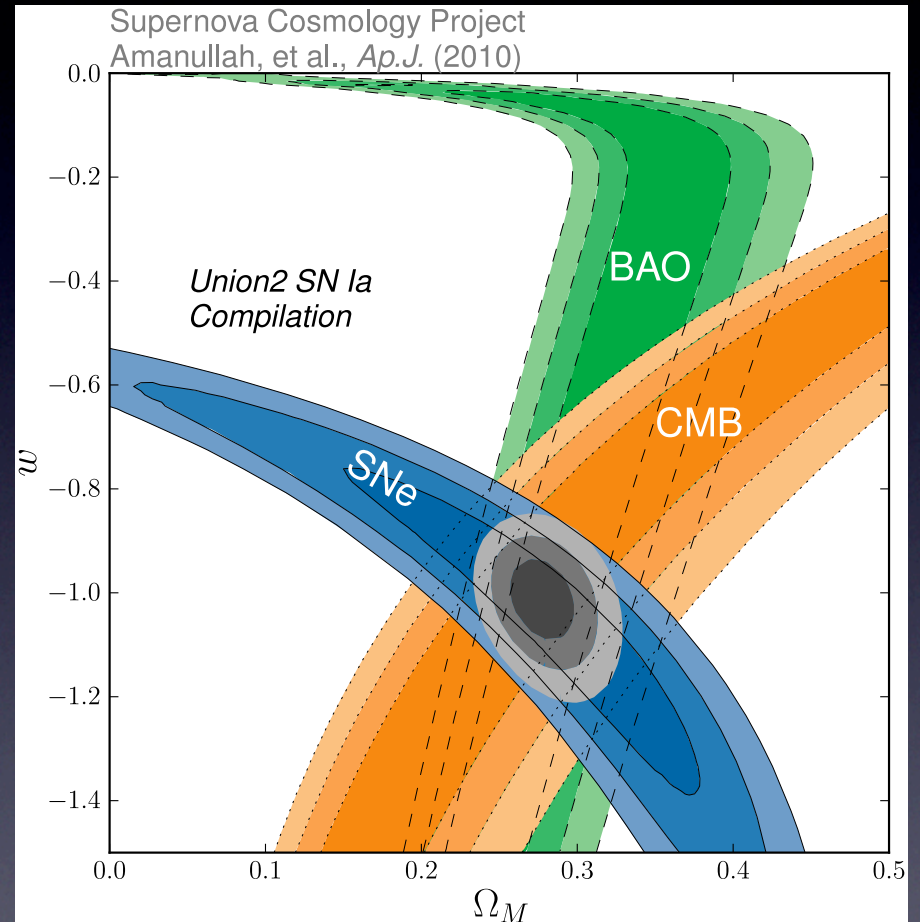
For a flat universe:

$$w = -0.997 \pm 0.052(\text{stat}) \pm 0.082(\text{sys})$$

For a non-flat universe

$$w = -1.038 \pm 0.056(\text{stat}) \pm 0.093(\text{sys})$$

SCP UNION2 Amanullah et al. 2010



Λ Business Market Values in 2010

Dark Energy Task Force (DETF)

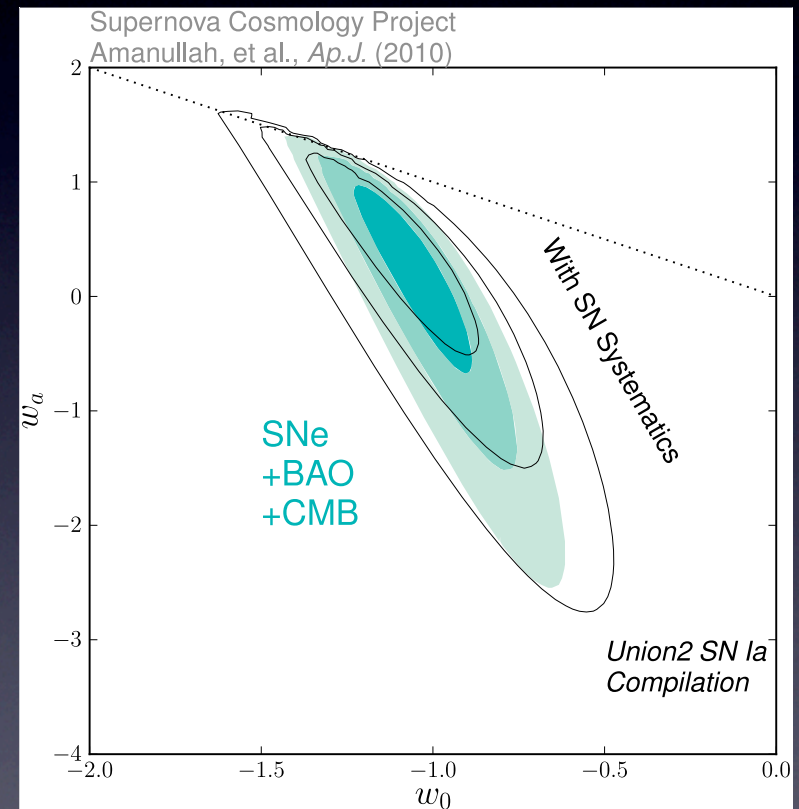
Figure of Merit : FoM
1

$$\frac{1}{\sigma(w_0)\sigma(w_a)}$$

$$w(a) = w_0 + (1-a)w_a$$

$$\text{FoM} = 1.0$$

(Amanulla et al 2010,
SCP UNION2)

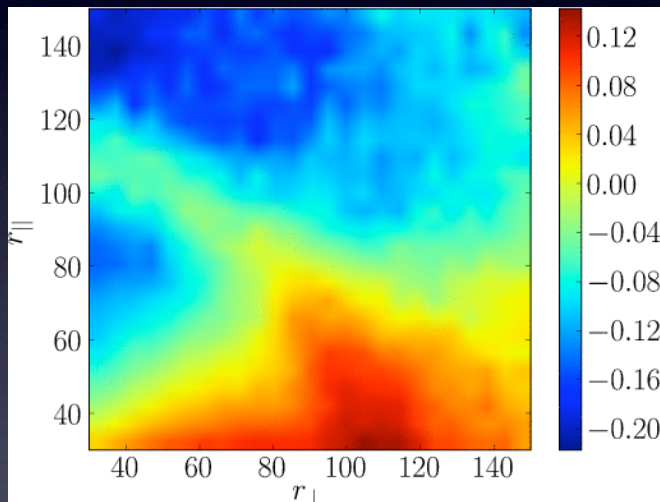


Key Project V: Cosmology LyaF BAO

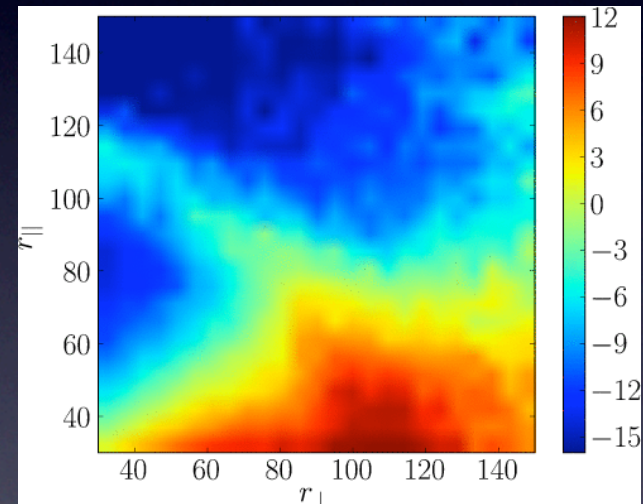
$$\xi_{ff}(r) = B(r)\xi_{\delta\delta}(r) + A(r)$$

$$\xi_{ff}(r)$$

$$\xi_{\delta\delta}(r)$$



Flux Fluctuation :
What we can observe
(correlation x: transverse y: radial)



Density Fluctuation:
What we want to know

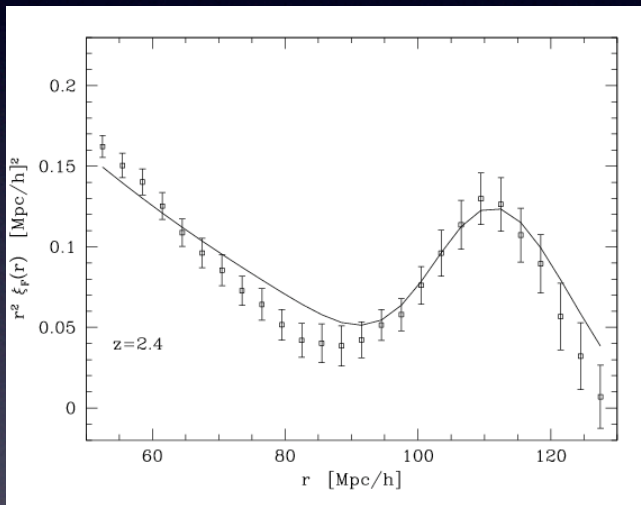
Simulation(3000³ Particle, Box 1500 Mpc/h) by Slosar et al. (2009)

Key Project V: Cosmology LyaF BAO

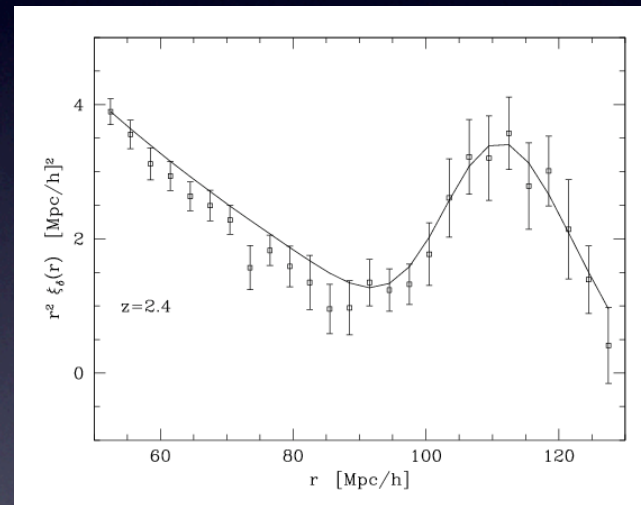
$$\xi_{ff}(r) = B(r)\xi_{\delta\delta}(r) + A(r)$$

$$\xi_{ff}(r)$$

$$\xi_{\delta\delta}(r)$$



Flux Fluctuation :
What we can observe
(correlation x: transverse y: radial)



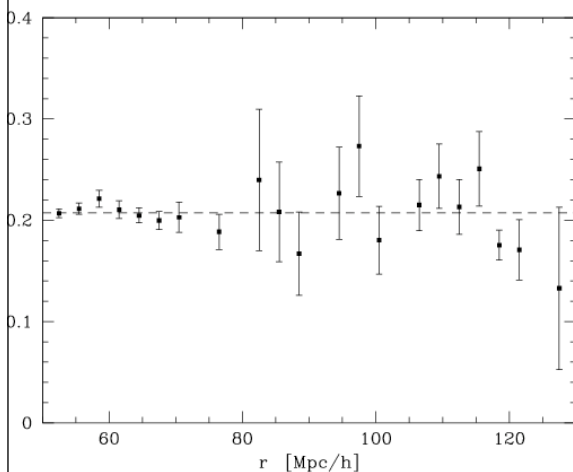
Density Fluctuation:
What we want to know

Simulation(4000^3 Particle, Box 700 Mpc/h) by White et al. (2010)

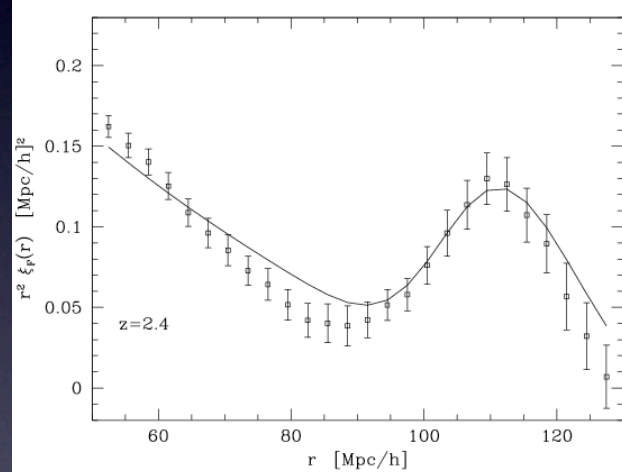
Key Project V: Cosmology LyaF BAO

$$\xi_{ff}(r) = B(r)\xi_{\delta\delta}(r) + A(r)$$

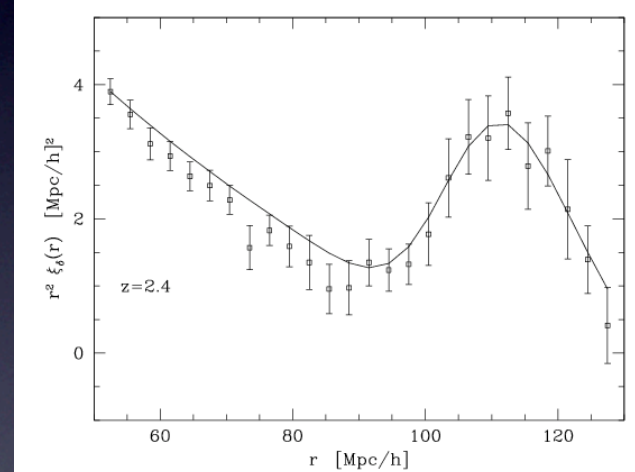
$$B(r) = \xi_{ff}(r)/\xi_{\delta\delta}(r)$$



Flux Bias:
Flux to Mass Translator
Bias $\Rightarrow$ Scale Independent!



Flux Fluctuation :
What we can observe
(correlation x: transverse y: radial)



Density Fluctuation:
What we want to know

Simulation(4000³ Particle, Box 700 Mpc/h) by White et al. (2010)

PFS Quasar BAO Survey at $z=2.64$

Probing high- z universe (2000 deg^2)

mag	exptime (min)	nights	N(quasar) (/deg ²)	N(fibers) (/1.8deg ²)	dH/H	dDa/Da	N(total)
21	10	21	8.8	32	0.049	0.091	17,600
22	20	41	22.5	81	0.021	0.035	45,000
23	48	99	45.0	162	0.015	0.021	90,000
24	120	246	76.6	276	0.013	0.017	153,200

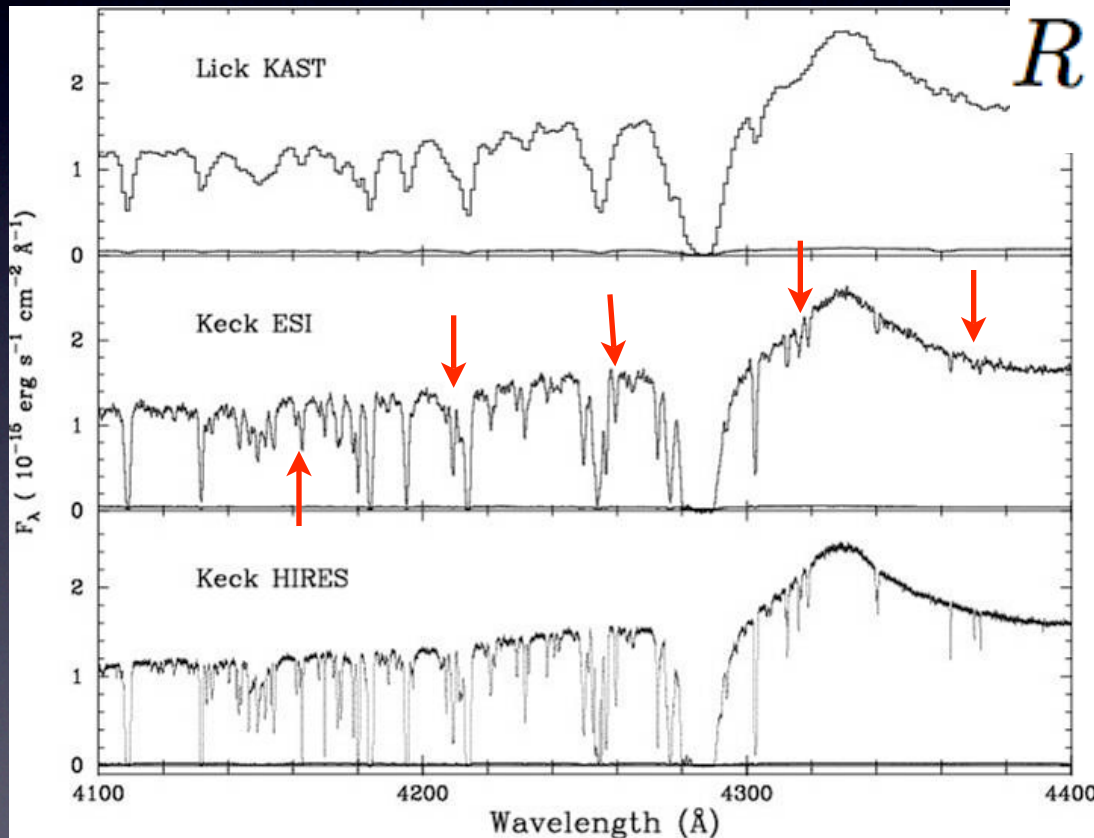
Based on McDonald & Eisentein (2007)

SDSS/DR7=10,000 LyAF , BOSS 160,000 LyAF with 8000 deg^2

LyAF Wish List

- Read-Out Noise $< 3e$ please!
- Wavelength Coverage=> Blue Side!
 $\lambda 3800-10000$ ($2.2 < z < 4$)
 $\lambda 3200-10000$ ($1.6 < z < 4$)
Note: Missing Range (BOSS): $1.6 < z < 2.2$
- Fiber:
20-50 quasars/deg² (mag dependent)
Success Rate: 50%
80-200 fibers/ 1.8 deg²
- Resolution:
R=2000 ($v=150\text{km/s}$) Good for LyAF BAO
R=4000 ($v=75\text{km/s}$) Metal Line Studies

Known Unknowns 1 : Metal Line Contamination High Resolution Helps



$$R = \frac{\lambda}{\Delta\lambda}$$

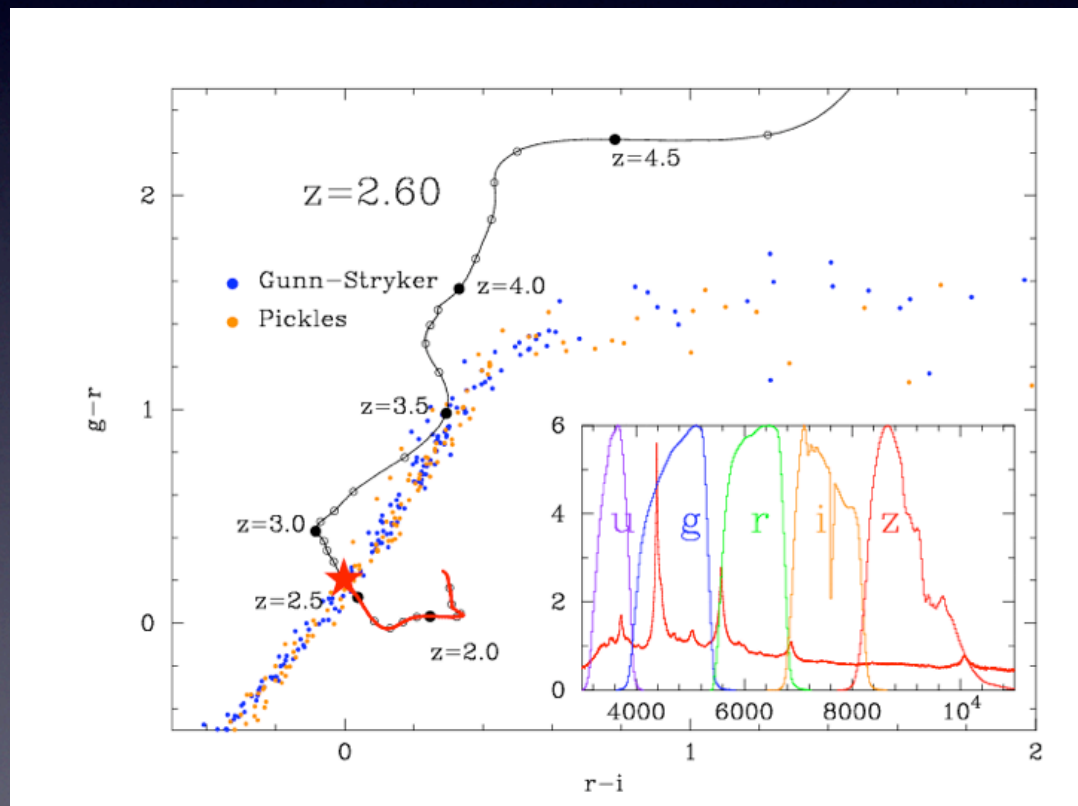
$$v = \frac{\Delta\lambda}{\lambda} c$$

- SDSS $R=2,000$
 $v=150\text{km/s}$
- LRIS $R=3,000$
 $v=100\text{km/s}$
- ESI $R=4,200$
 $v=72\text{km/s}$
- HIRES $R=37,500$
 $v=8\text{km/s}$

Known Unknown 2

Target Selection :

- Quasar Locus Crosses Stellar Locus at certain redshifts
- Variability!



Cosmology Wish List

- Needs to optimize each methods strength!!
- 1. Supernova Cosmology ($0.5 < z < 1.4$)
Synergy with Quasar/LyAF Science
a) Target Selection b) w complimentarity
- 2. Weak Lensing
- 3. Galaxy BAO ($0.7 < z < 1.4$)
- 4. LyAF BAO ($2.2 < z < 4$)
- 5. Cluster Counts
- 6. Growth Factor Measurement (WL, LyAF)

White Paper Revisions

- Aim FoM > 300 by optimizing Survey Strategies (SN+WL+CMB(planck)+BAO)
- Select Key Projects and Review
- S/N unit is not clear : /pix, /A, /FWHM?a)
Target Selection b) w complementarity
- Target Selection efficiency is not clear (for quasars, 50%)
- Survey Strategy is not clear (Wide or Pointed?)

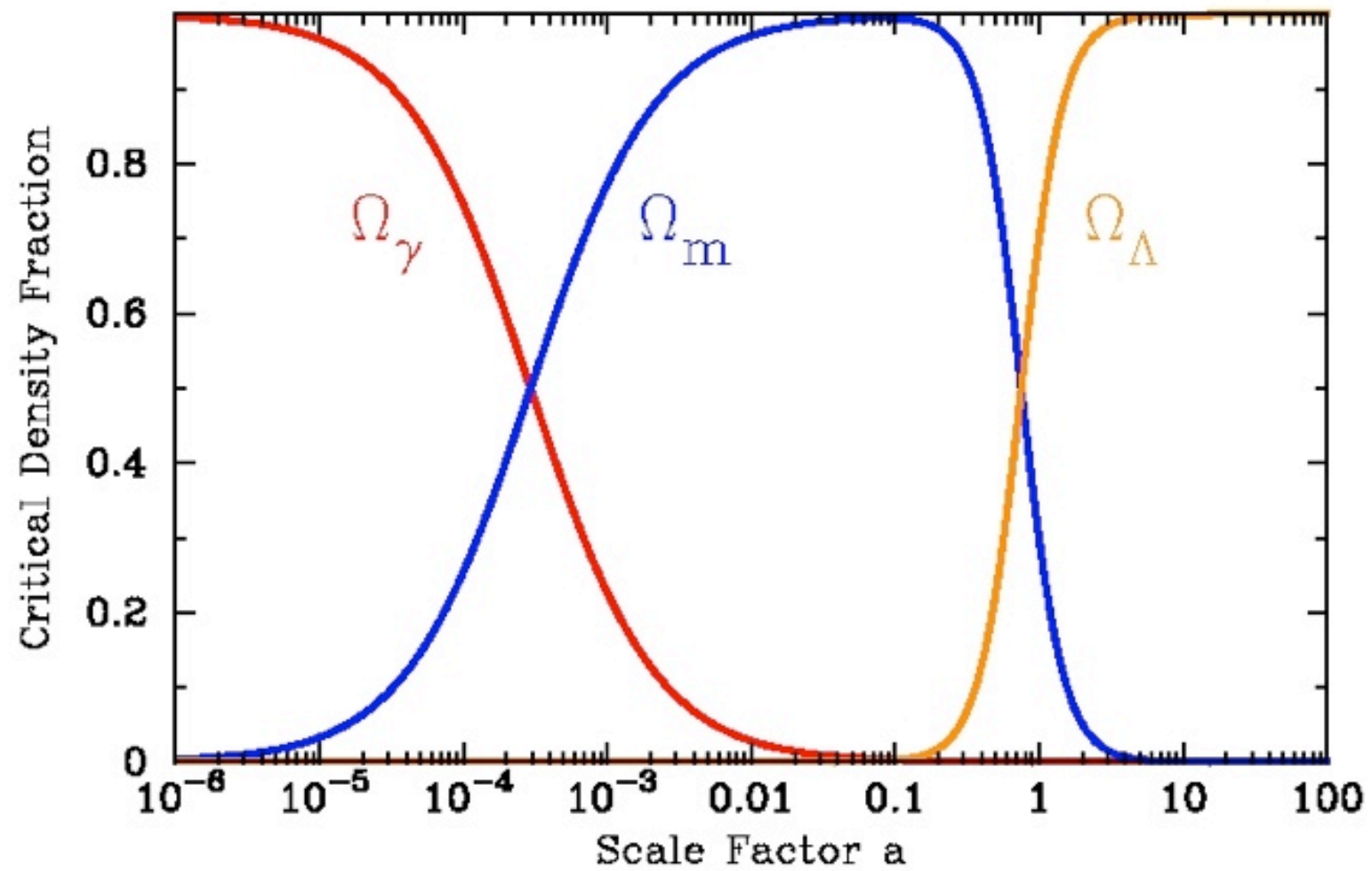
Cosmology in 2015-20

- Let's Aim FoM > 300 by optimizing Survey Strategies (SN+WL+CMB(planck)+BAO)
- Review Survey every 2 years and optimize strategies
- With TMT, JWST, LLST, and WFIRST the world would not be the same and PFS is the best choice not only for Japan but also for the world!!



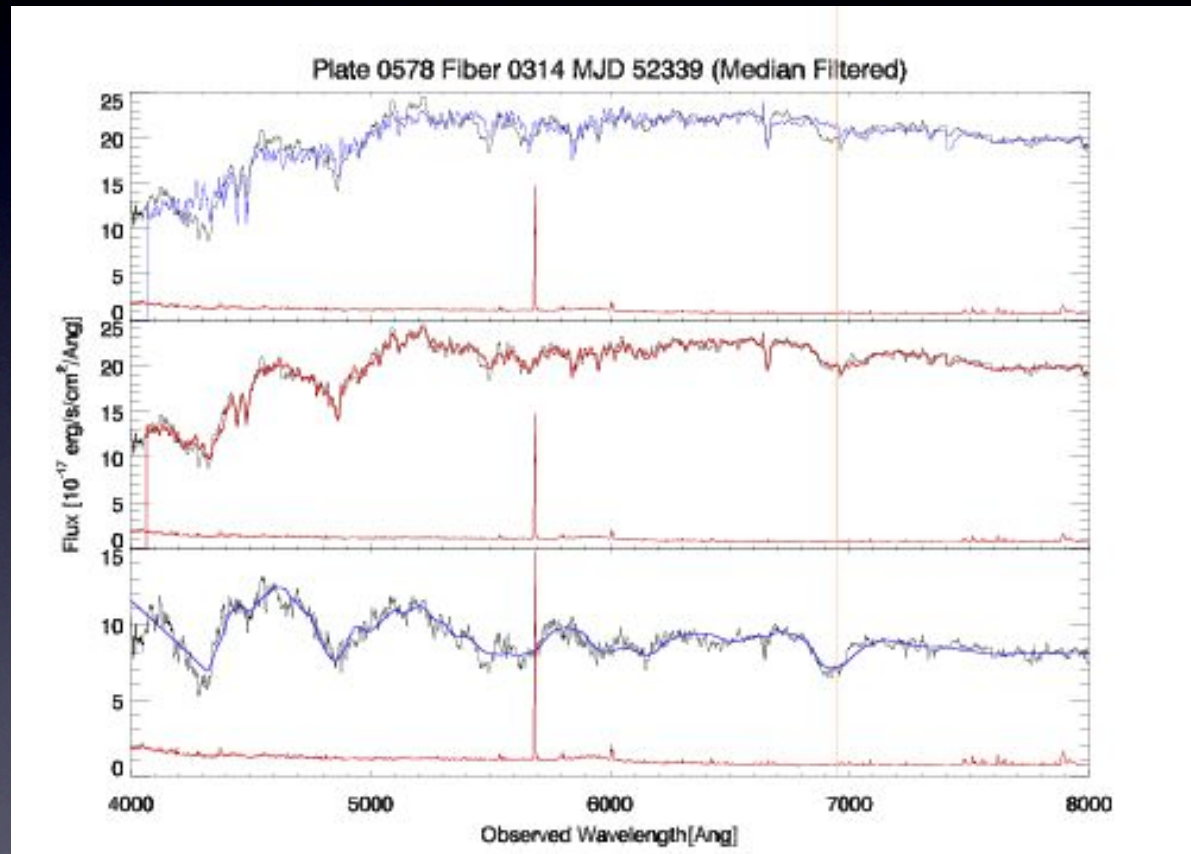
Back-up Slides

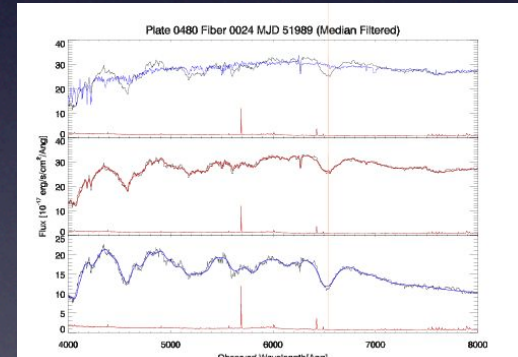
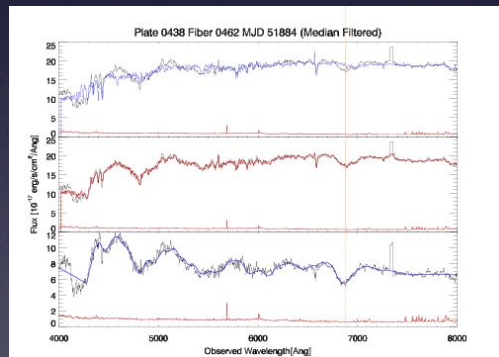
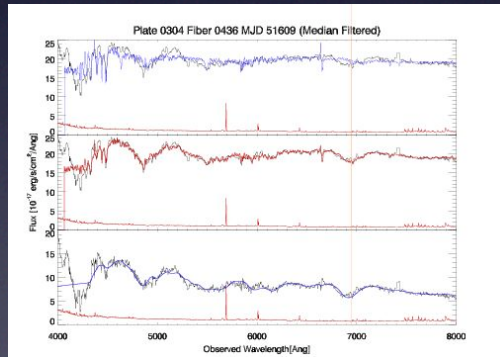
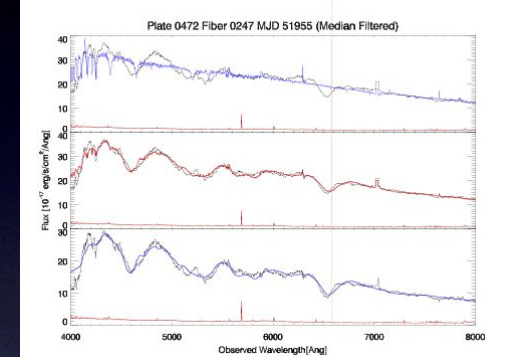
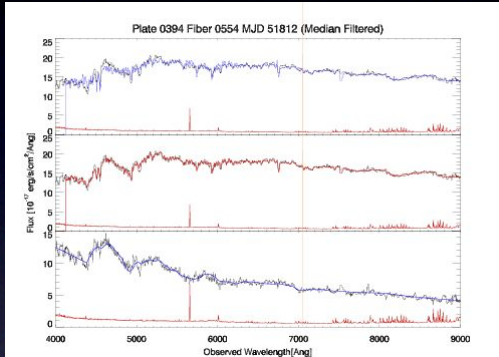
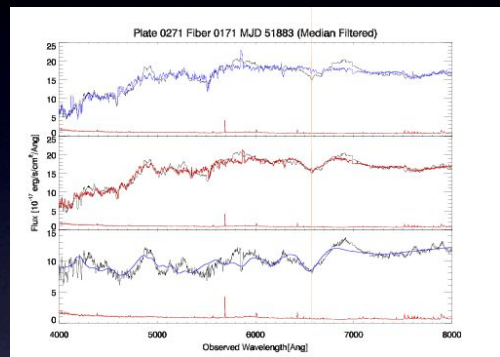
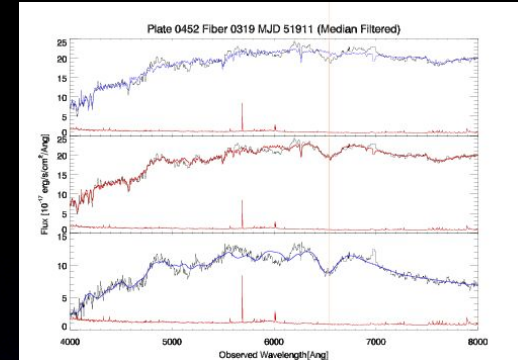
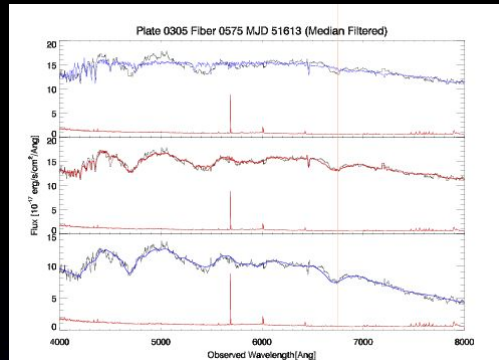
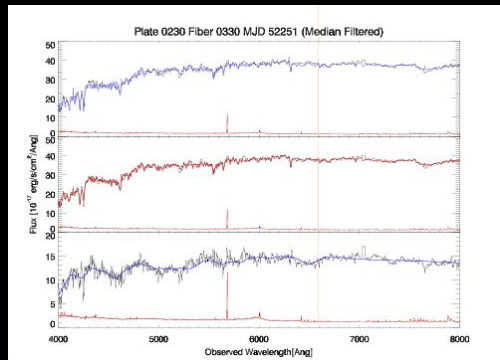
Density / Critical Density



Supernova Ia from SDSS DR7

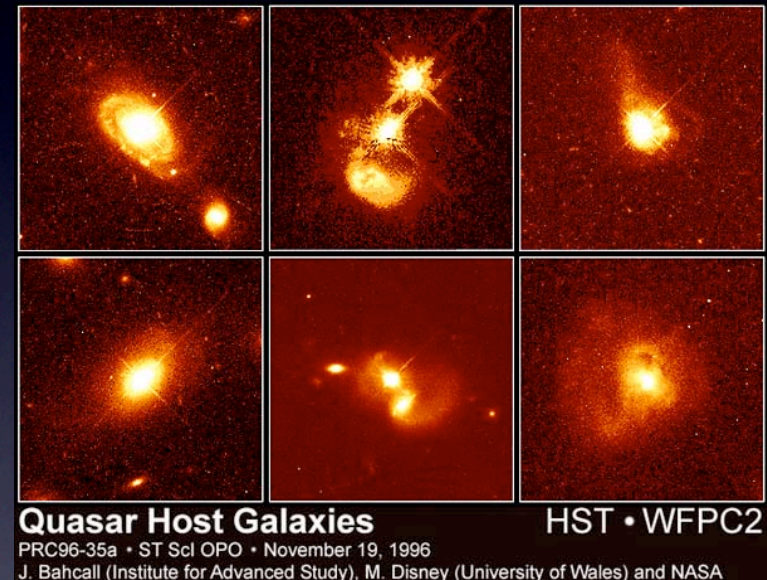
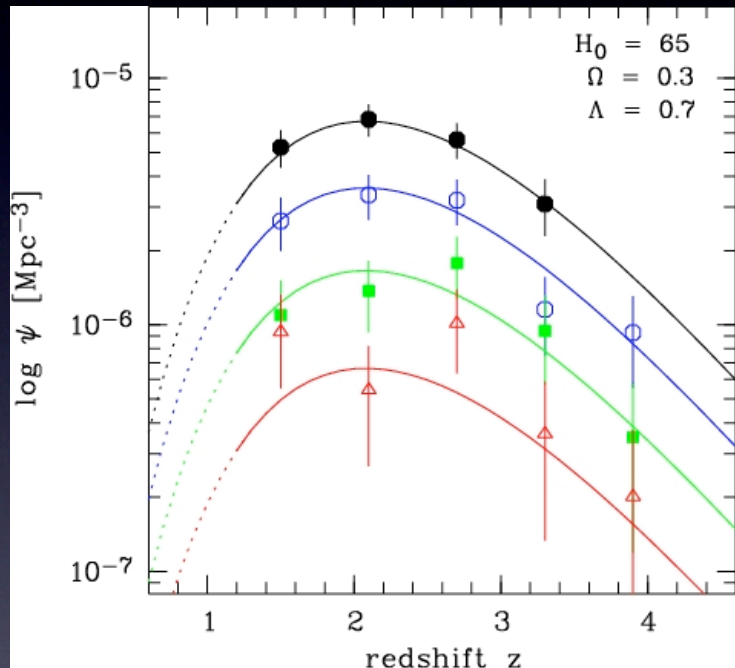
Janos Botyanszki, Kimberly Aller,
Josh Meyers (code), Nao Suzuki(eigen spectra)





SDSS DR7 : I SNIa / 6000 Galaxies

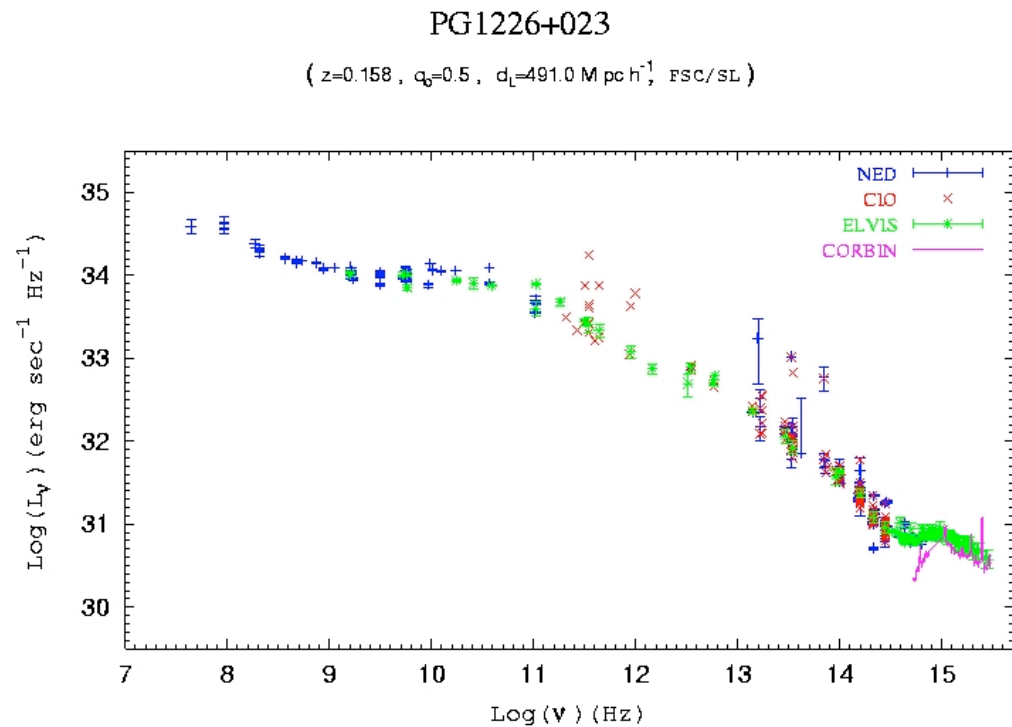
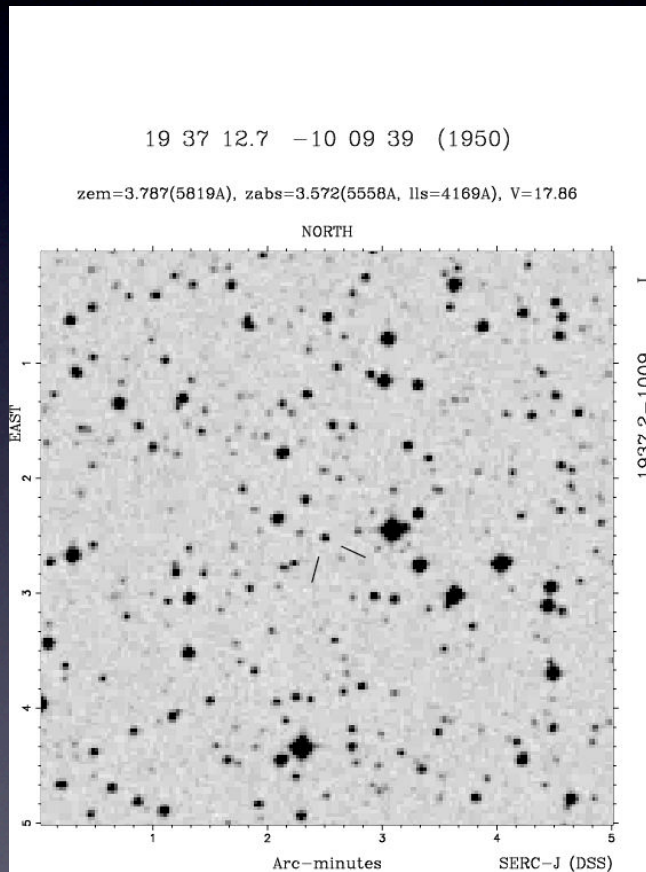
Quasar Basics 1: Number Density Evolution



- Red ($M < -27$) Green ($M < -26$) Blue ($M < -25$) Black ($M < -24$) :
Combo-17 Survey (MPG/ESO 2.2 m : Wolf et al. 2003)

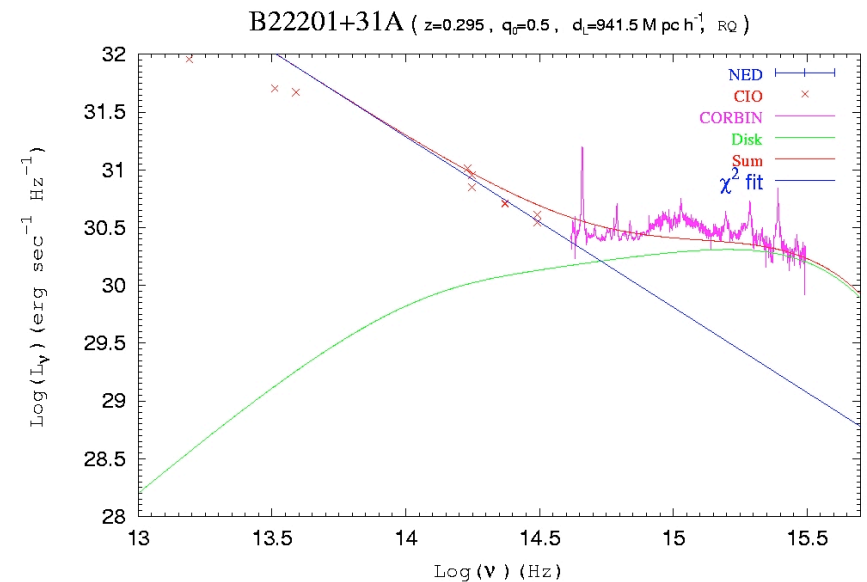
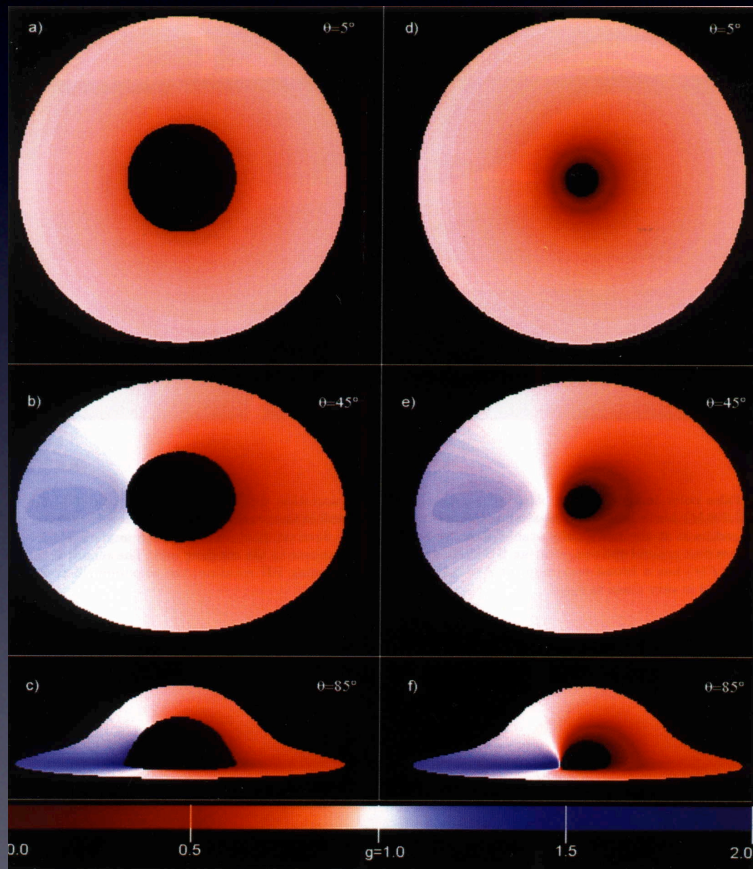
Quasar Basics 2 : SED

UV Excess



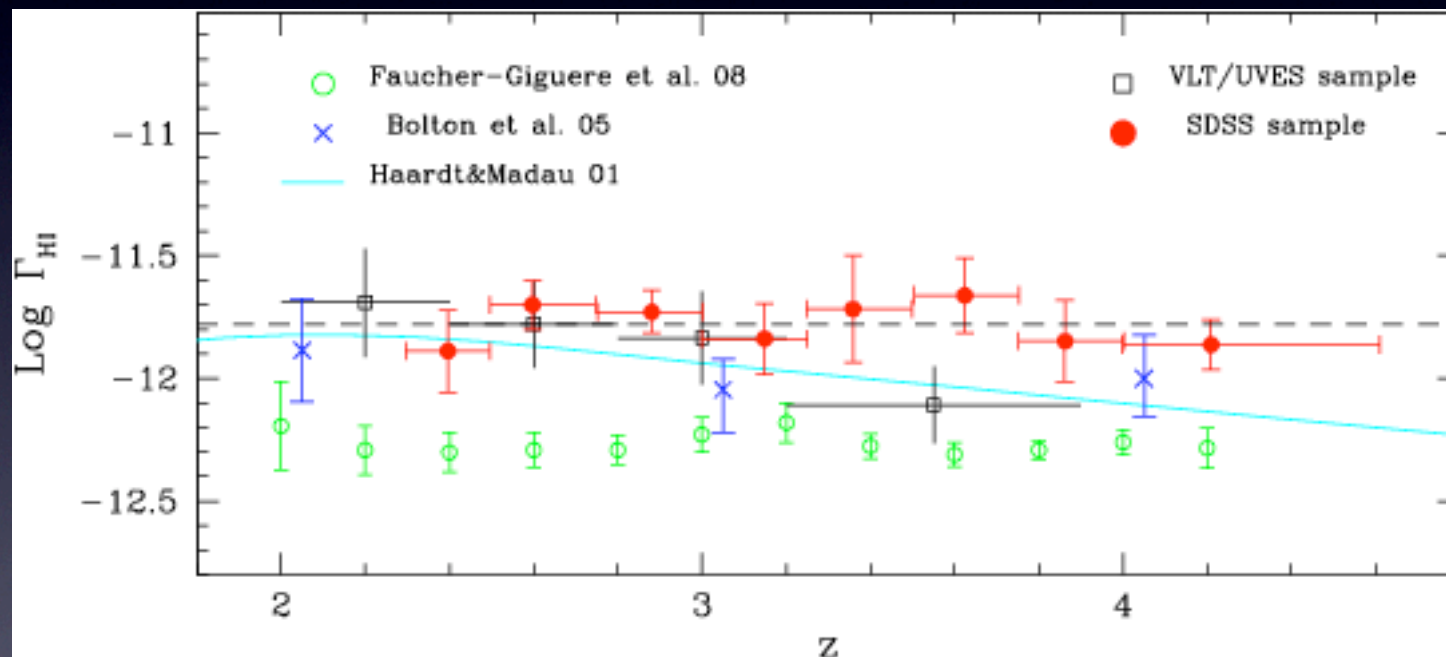
Physics of UV Excess

Accretion disk surrounds the
super massive black hole
SED(Mass, Accretion Rate)



Ionization Rate : 2009

Dall'Aglio et al 2009



HST Cluster SN Survey

Nao Suzuki & SCP
PI: Saul Perlmutter



SCP06K0 $z=1.415$	SCP06G4 $z=1.349$	SCP05D6 $z=1.315$	SCP06H5 $z=1.231$
SCP06R12 $z=1.212$	SCP06A4 $z=1.192$	SCP06N33 $z=1.188$	SCP06F12 $z=1.110$
SCP06C0 $z=1.092$	SCP06U4 $z=1.050$	SCP06E12 $z=1.030$	SCP05D0 $z=1.014$
SCP06C1 $z=0.980$	SCP06H3 $z=0.850$	SCP05P9 $z=0.821$	SCP06Z5 $z=0.623$

