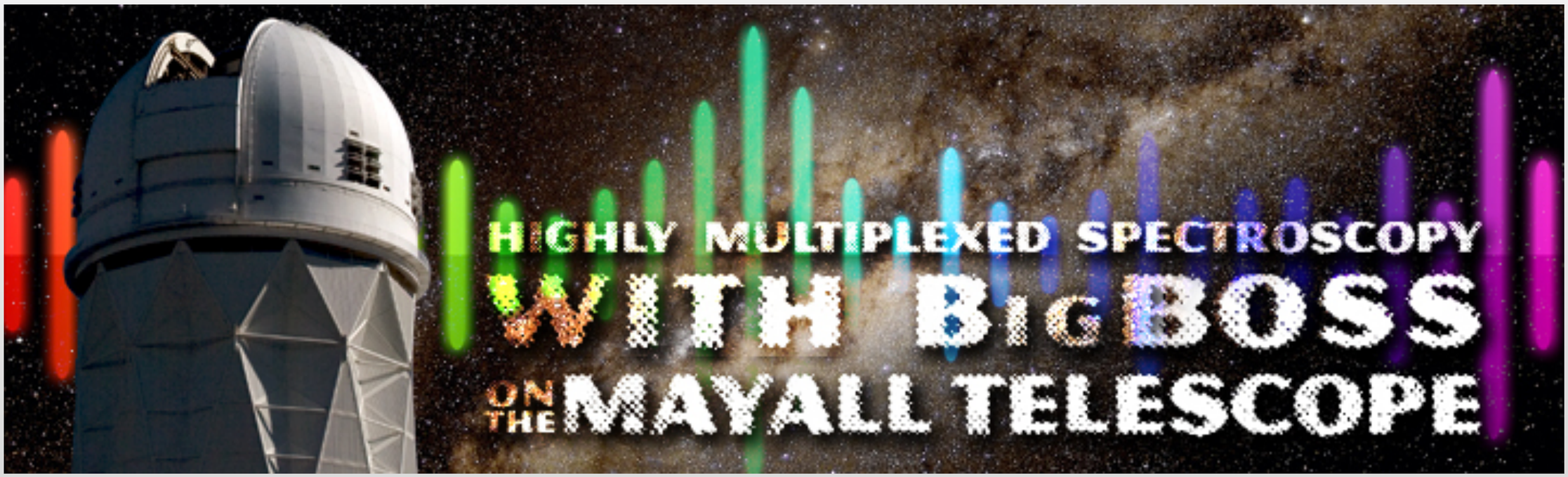
Diffuse Media Science with BigBOSS



J. Xavier Prochaska
Interstellar Medium Program of Studies (IMPS)
UCO/Lick Observatory
UC Santa Cruz

Diffuse Media

My (loose) definition: $n_H < 1\ cm^{-3}$

- Intergalactic Medium (IGM; >>1 Mpc)
- Intracluster Medium (ICM; ~1Mpc)
- Circumgalactic Medium (CGM; ~100kpc)
- 'Ambient' Interstellar Medium (ISM; 10kpc)

} >99% of the volume
} >90% of z~0 baryons

- Constituents
  - Gas, metals, dust
  - Neutral and ionized gas
  - Accreting and outflowing material

Diffuse Media

My (loose) definition: $n_H < 1\ cm^{-3}$

- Intergalactic Medium (IGM; >>1 Mpc)
- Intracluster Medium (ICM; ~1Mpc)
- Circumgalactic Medium (CGM; ~100kpc)
- 'Ambient' Interstellar Medium (ISM; 10kpc)

} >99% of the volume
} >90% of z~0 baryons

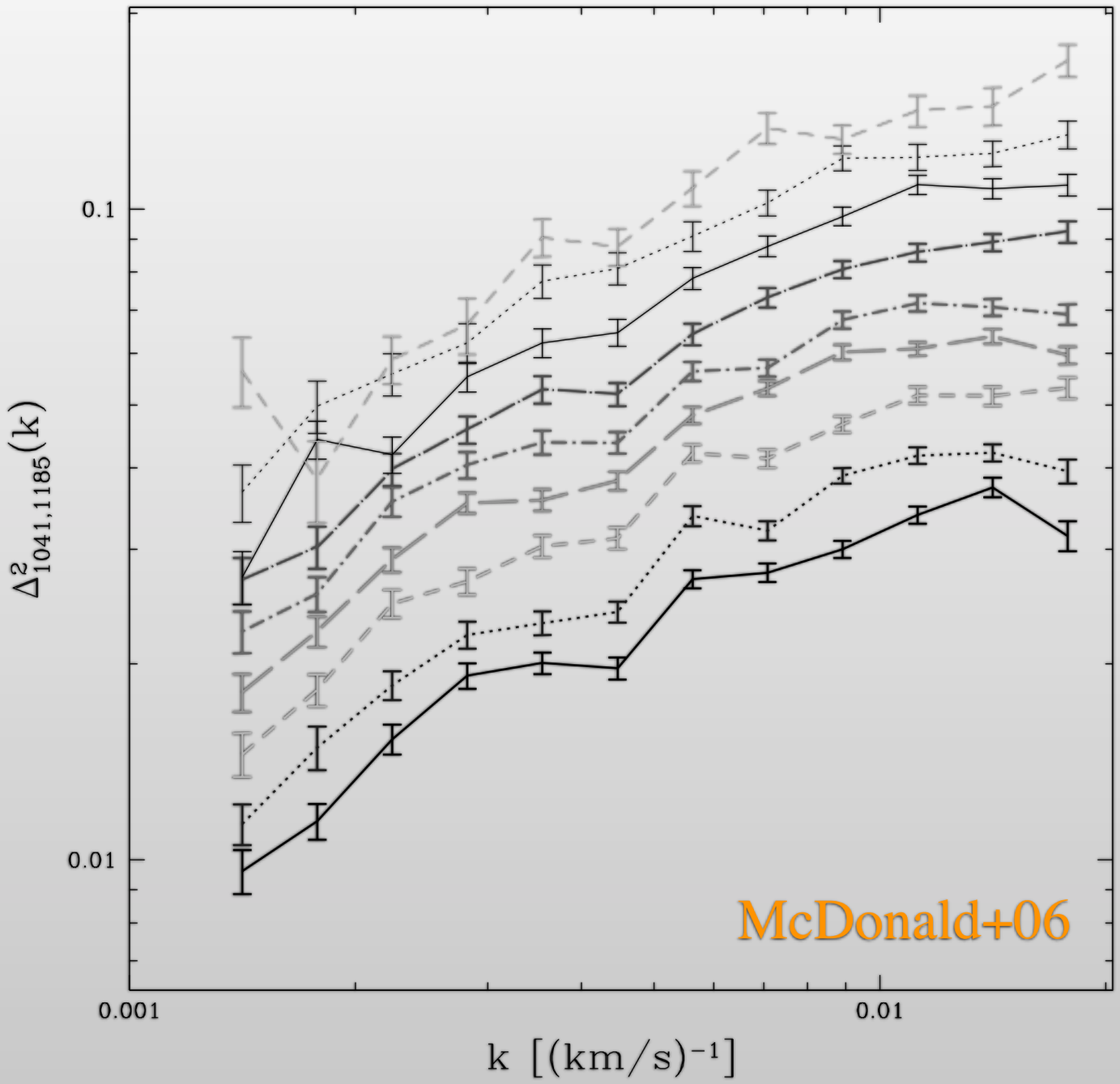
- Constituents
  - Gas, metals, dust
  - Neutral and ionized gas
  - Accreting and outflowing material

The Diffuse Medium has too low density to be detected in emission beyond the local universe.

Absorption is King+Queen

Science with Diffuse Media

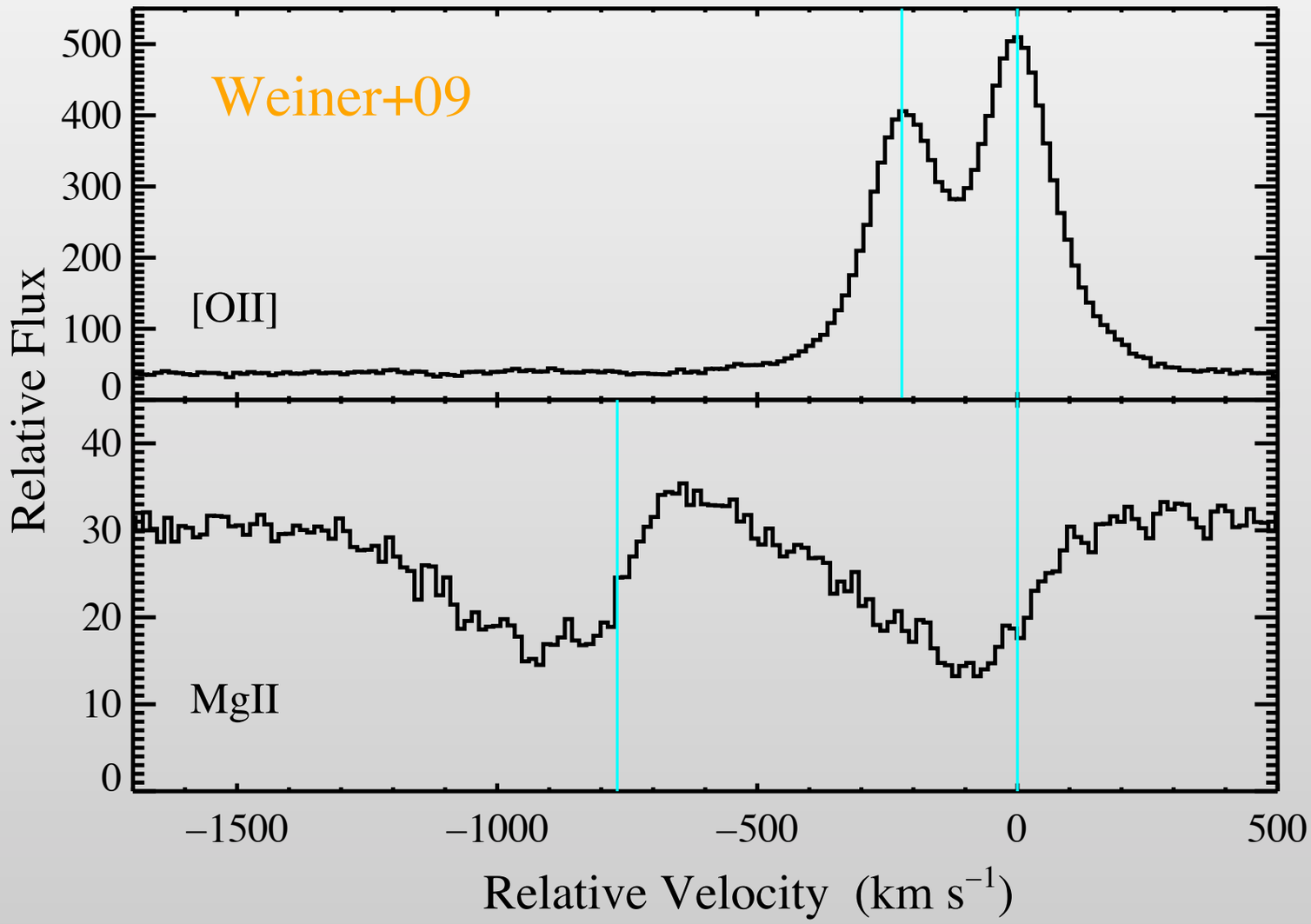
- **Cosmology**
  - BAO
  - Power spectrum
    - ✦ Non-gaussianity
  - Baryonic Census
    - ✦ Gas, metals, dust
  - Characterizing the IBL



Highly Multiplexed

Science with Diffuse Media

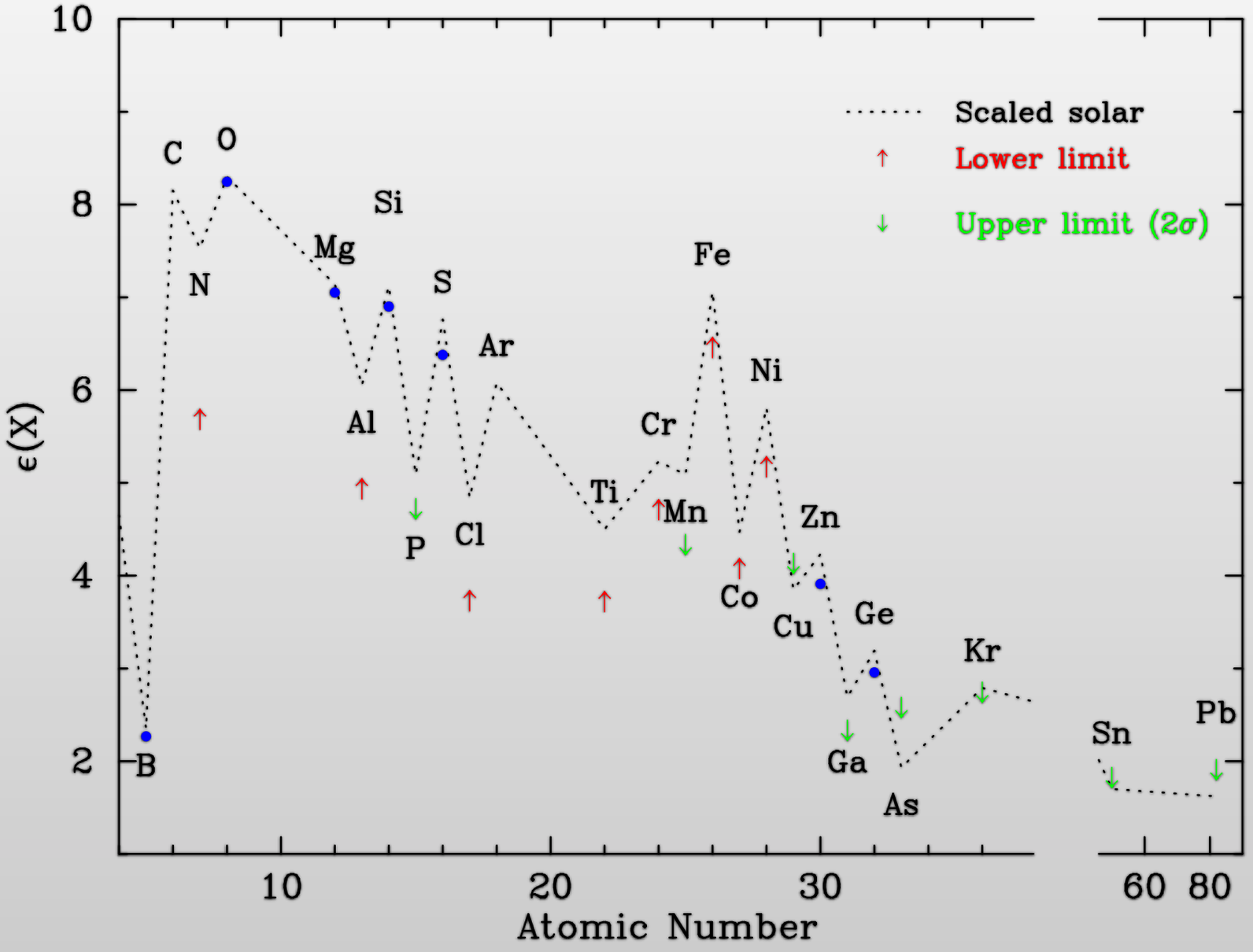
- **Galaxy Formation**
  - ISM dynamics
  - Chemical evolution
  - Gas accretion
  - Feedback processes
    - ✦ Energy, gas, metals
  - Mergers (tidal debris)



Highly Multiplexed

Science with Diffuse Media

Prochaska+03

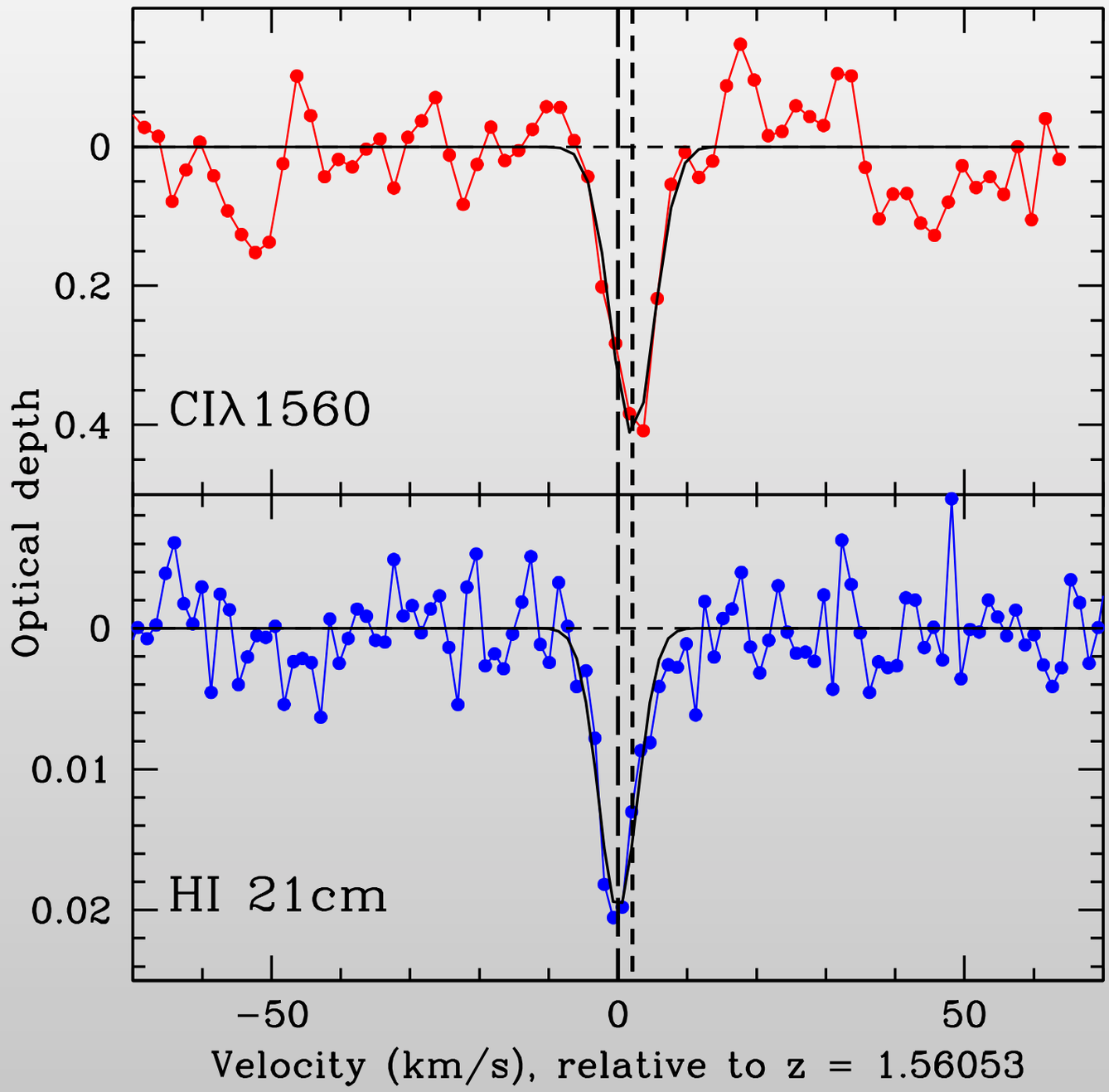


- Star Formation
  - Formation of H_2
  - Dust depletion
  - Nucleosynthetic yields

Science with Diffuse Media

- ‘Fundamental’ Physics
  - Evolution of the physical constants
  - Neutrino mass

Kanekar+10

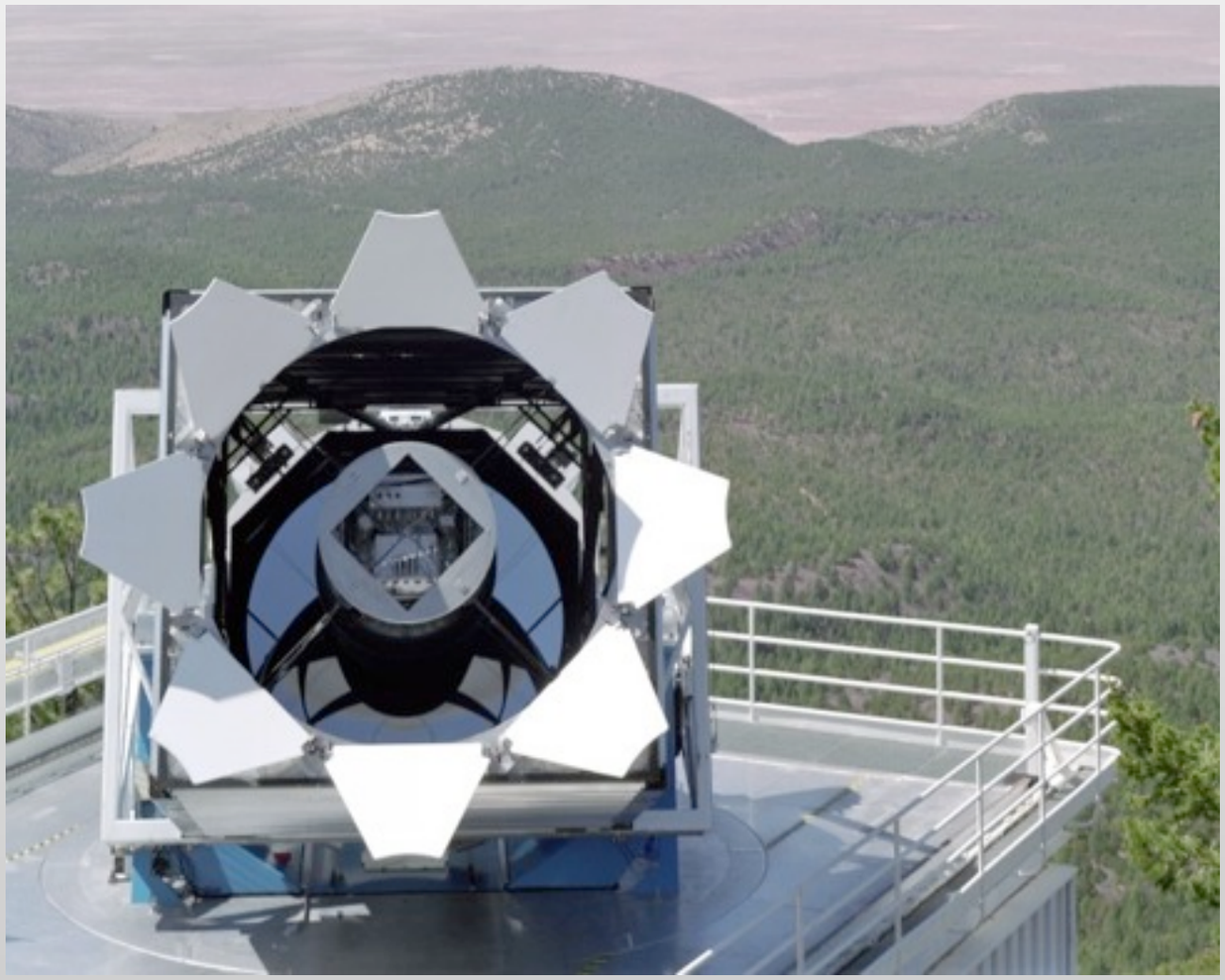


DM: Lessons from SDSS

(Focus on the Quasar Spectroscopy of SDSS)

- Advantages
  - Sample size
  - Spectrophotometry

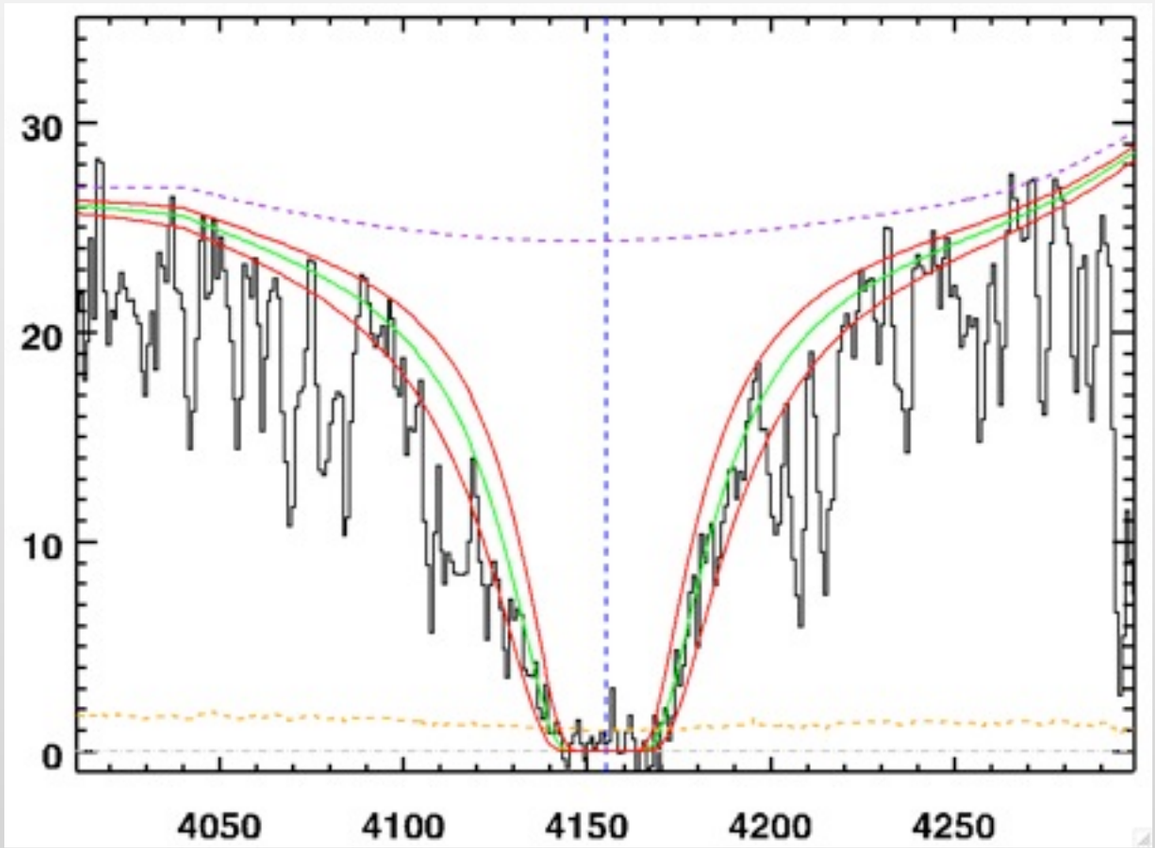
- Disadvantages
  - Spectral resolution
  - Limited blue coverage
    - Higher density of UV transitions at higher energies



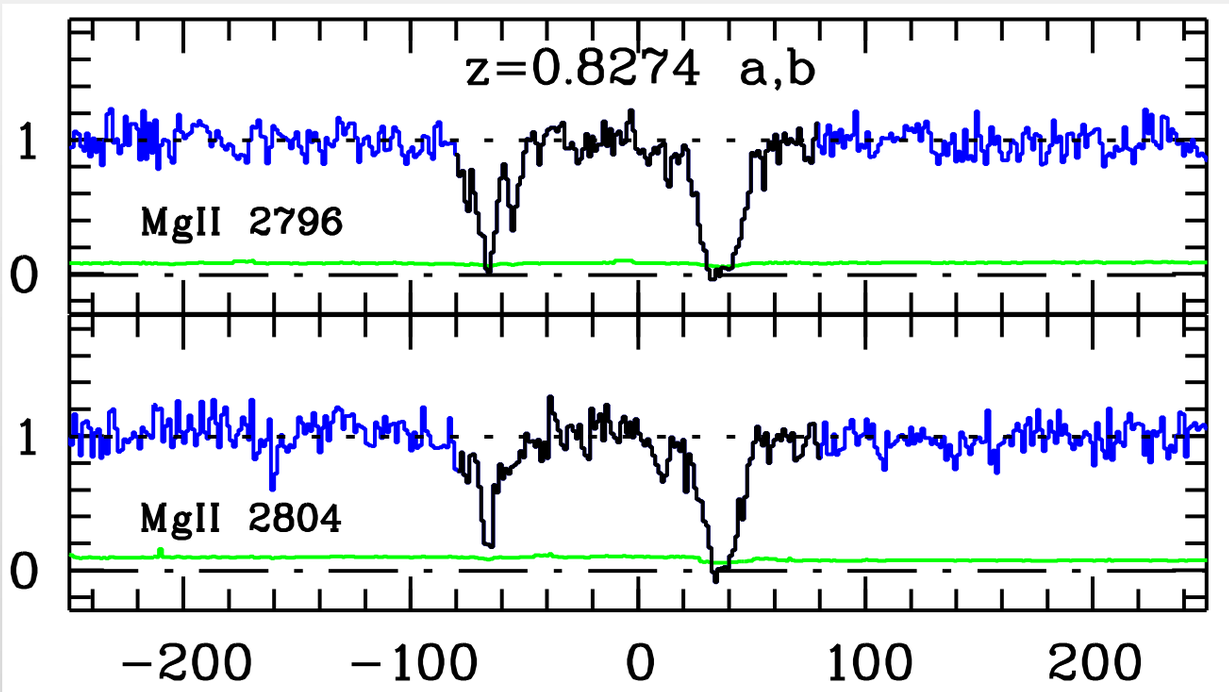
Highly Multiplexed

SDSS: Absorber Surveys

Damped Lya Systems (ISM)



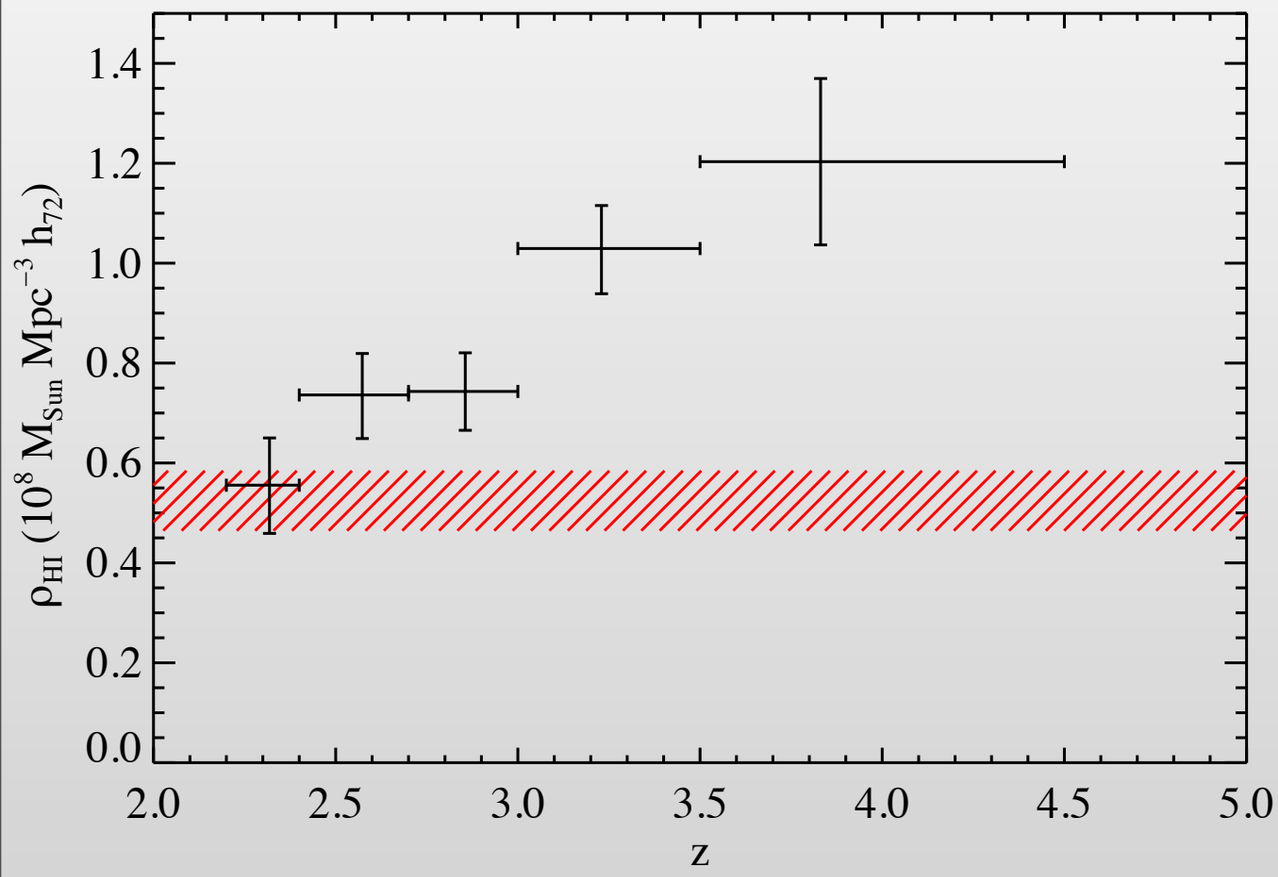
MgII Systems (ISM/CGM)



- 100,000 quasars
  - Semi-automated searches
  - Human vetting was tractable
- Spectrophotometry not essential

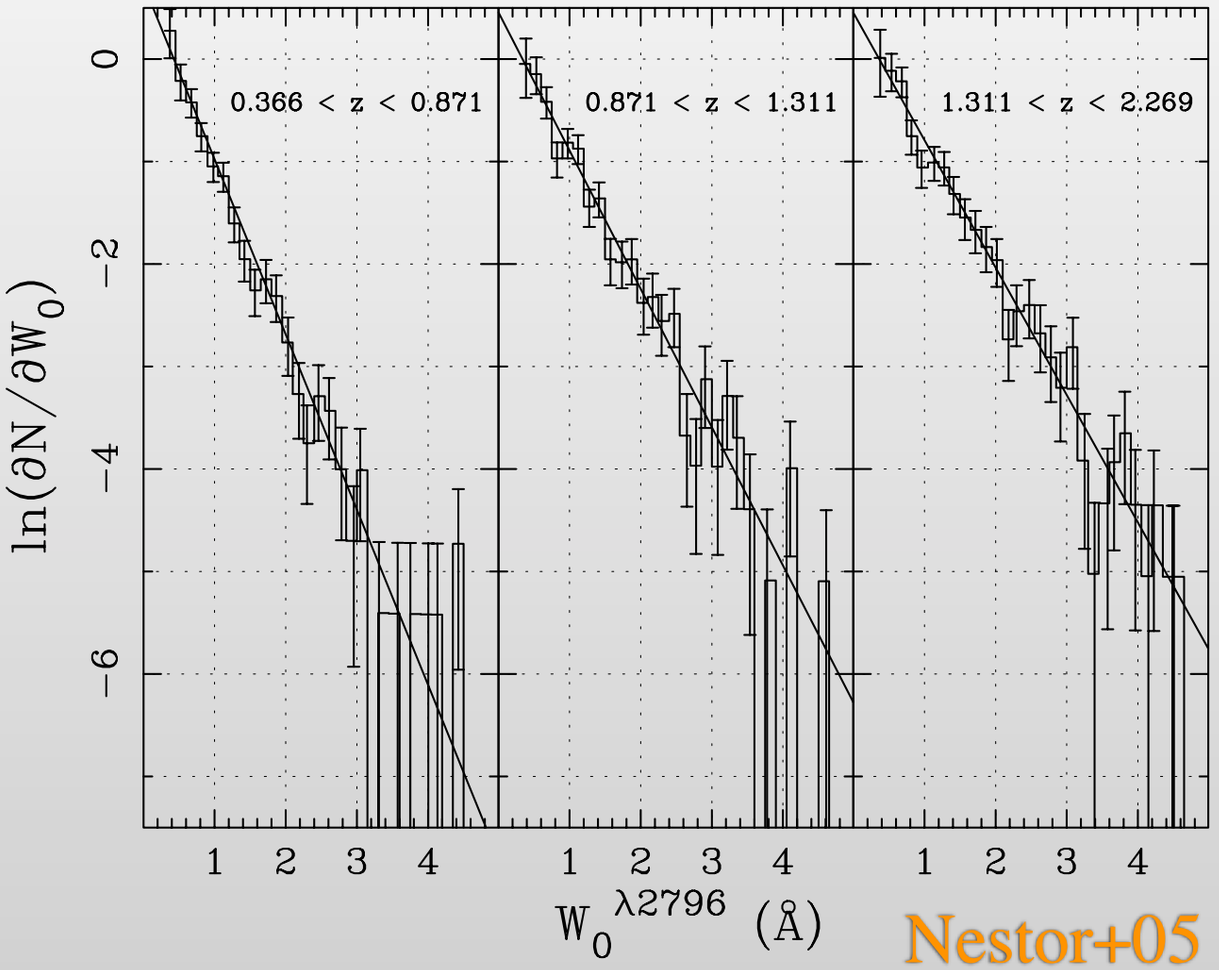
SDSS: Absorber Surveys

Damped Lya Systems (ISM)



Prochaska+09

MgII Systems (ISM/CGM)



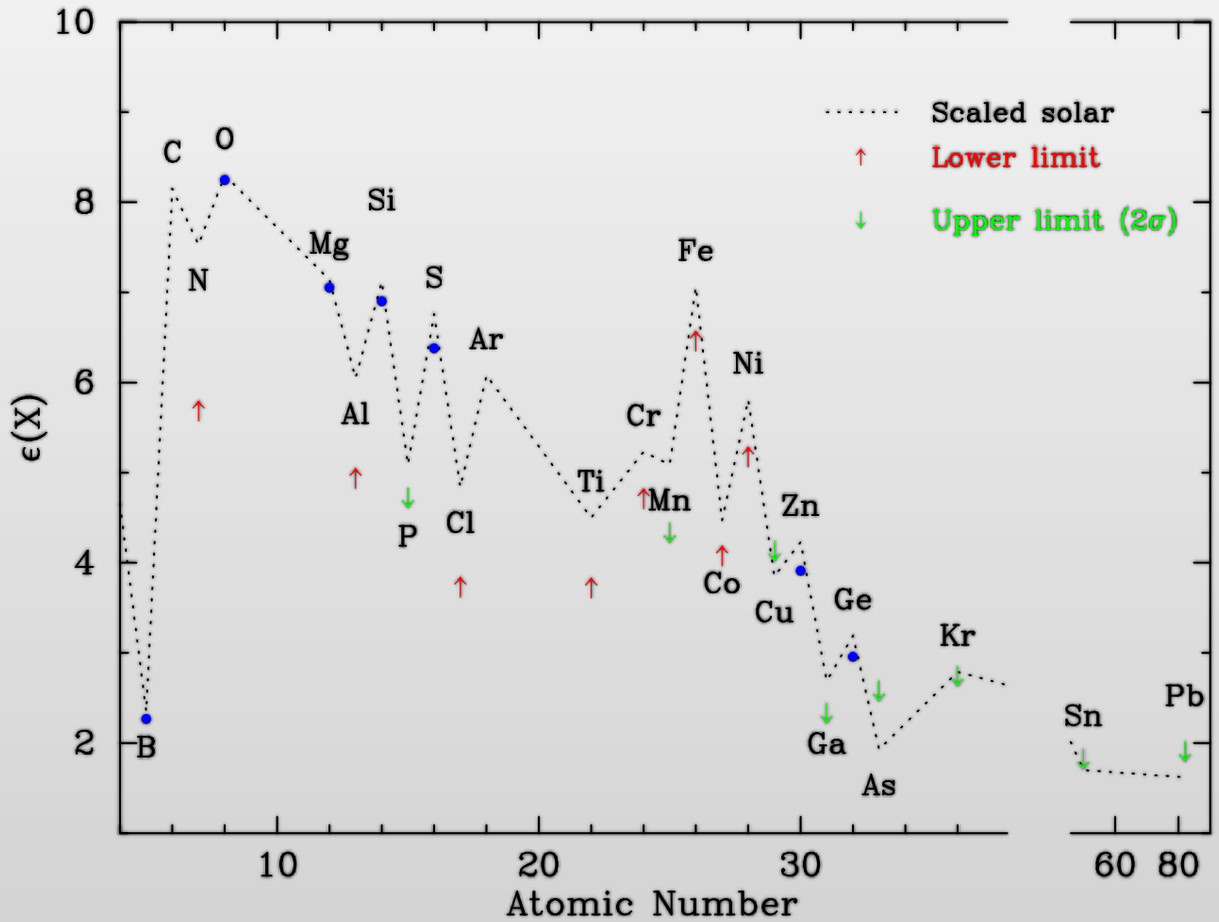
Nestor+05

- Primary science (from counting absorbers)
  - Limited by systematics (e.g. dust), not statistics
  - Additional sample size may have limited value
- Mainly comes for 'free' in the main survey

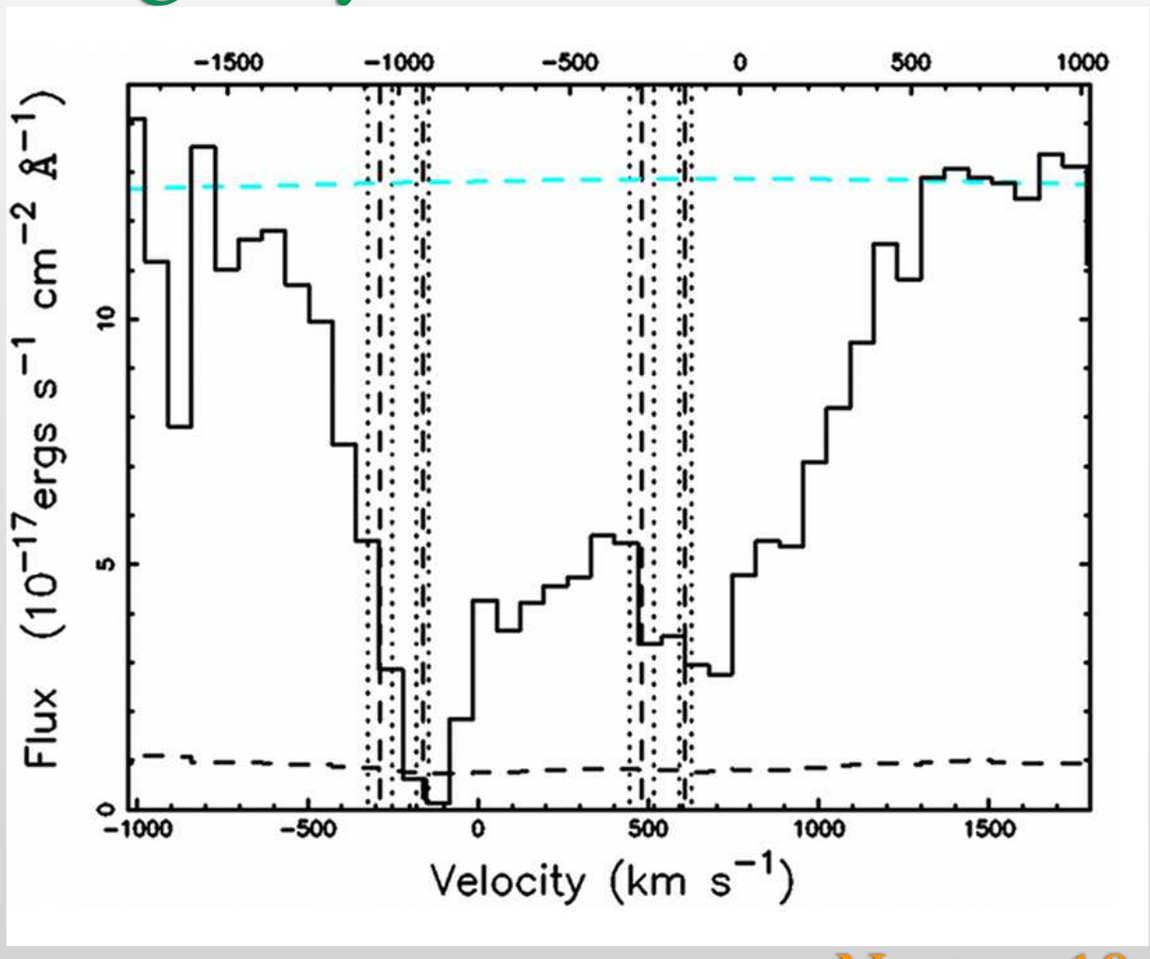
Highly Multiplexed

SDSS: Needles in the Haystack

Damped Lya Systems (ISM)



MgII Systems (ISM/CGM)



Nestor+10

- Tails of the distributions
  - In metallicity, kinematics, HI, dust content, etc.
  - Rarer than 1/100
- Push physical processes to their limits

Highly Multiplexed

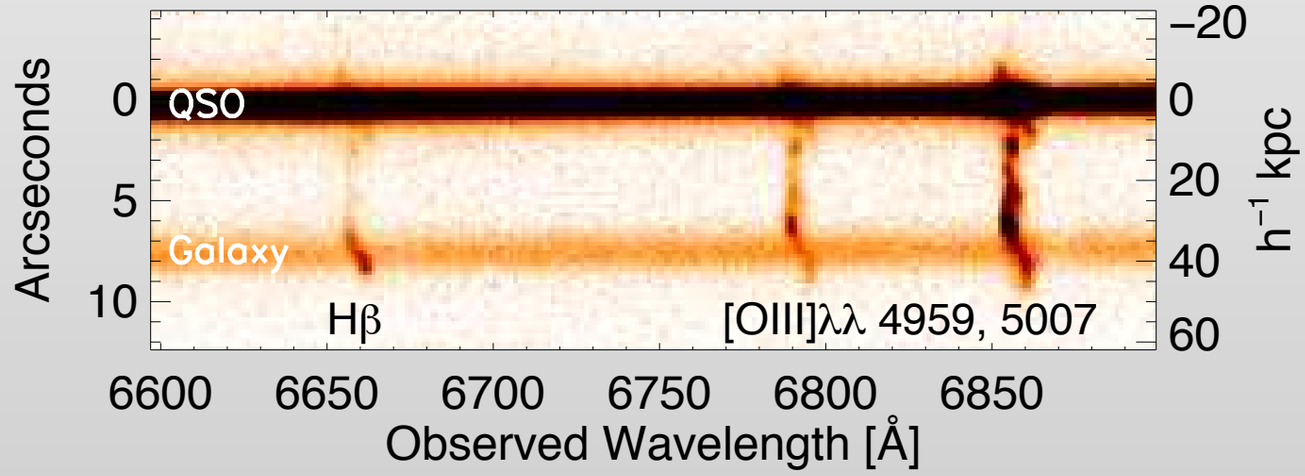
SDSS: Needles in the Haystack

Quasar/Quasar Pairs

Hennawi+06

Quasar/Galaxy Pairs

daSilva+10
Chen+10
Tumlinson+11



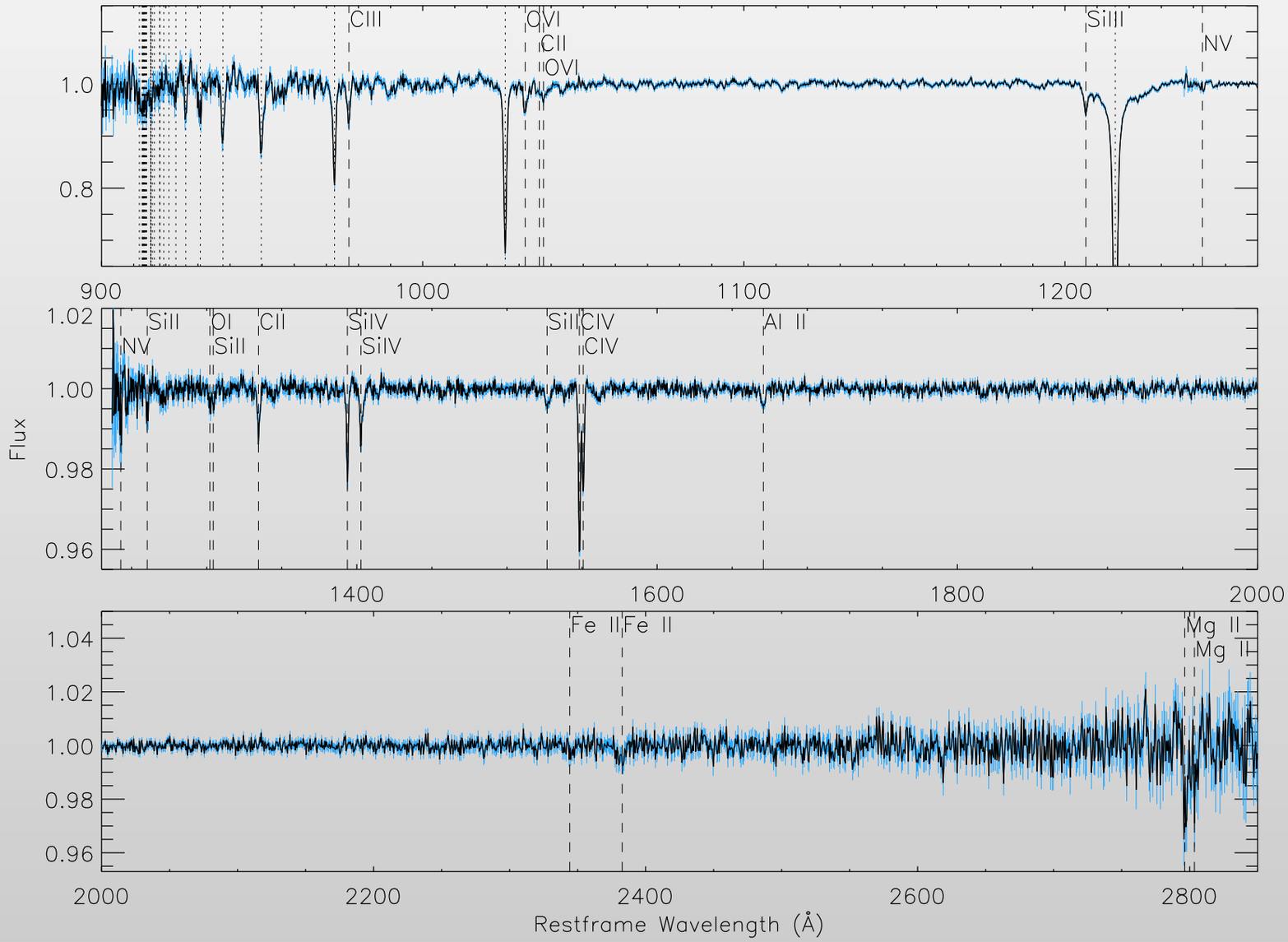
- Rare configurations
  - Physical or projected
  - Sensitive probes of kpc scales (CGM)
- Target selection critical

Highly Multiplexed

SDSS: Smoothing the Samples

Stacked spectra (Absorber frame)

Pieri+10

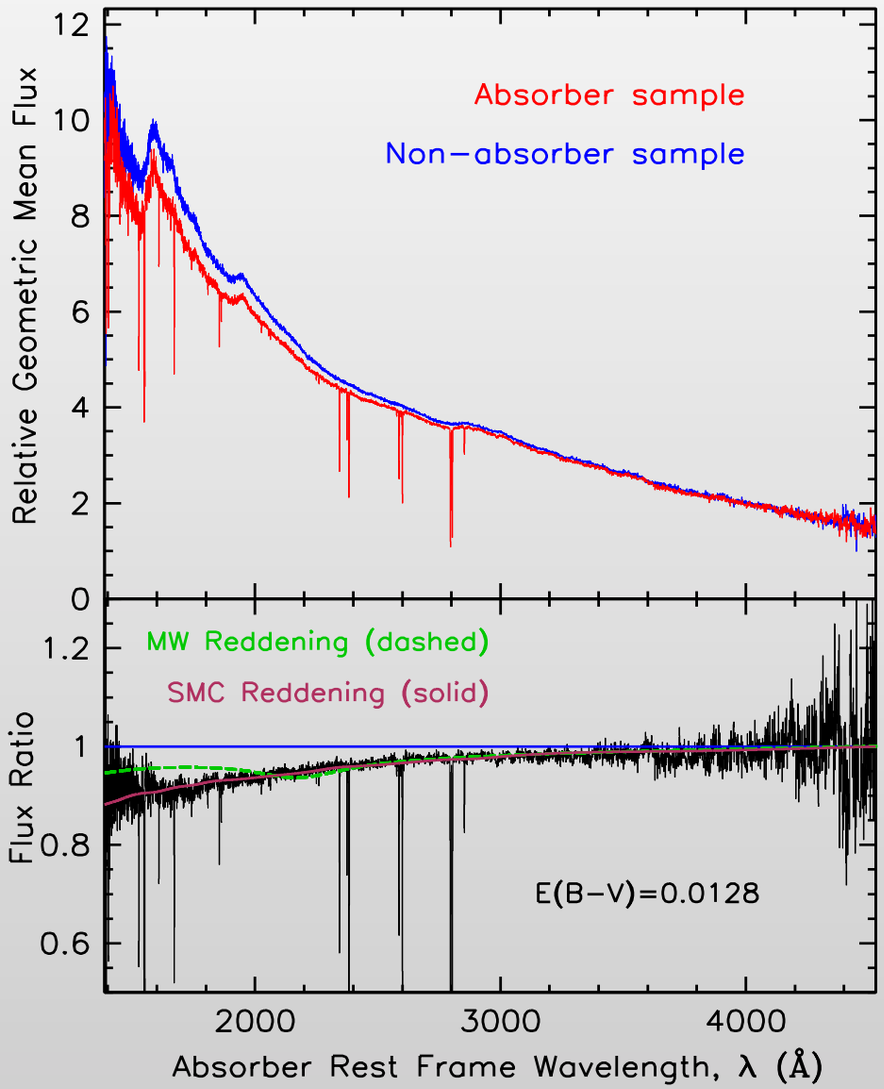


- Great for visualization of absorption lines
  - Spectrophotometry not essential
- Limited physical measurement

Highly Multiplexed

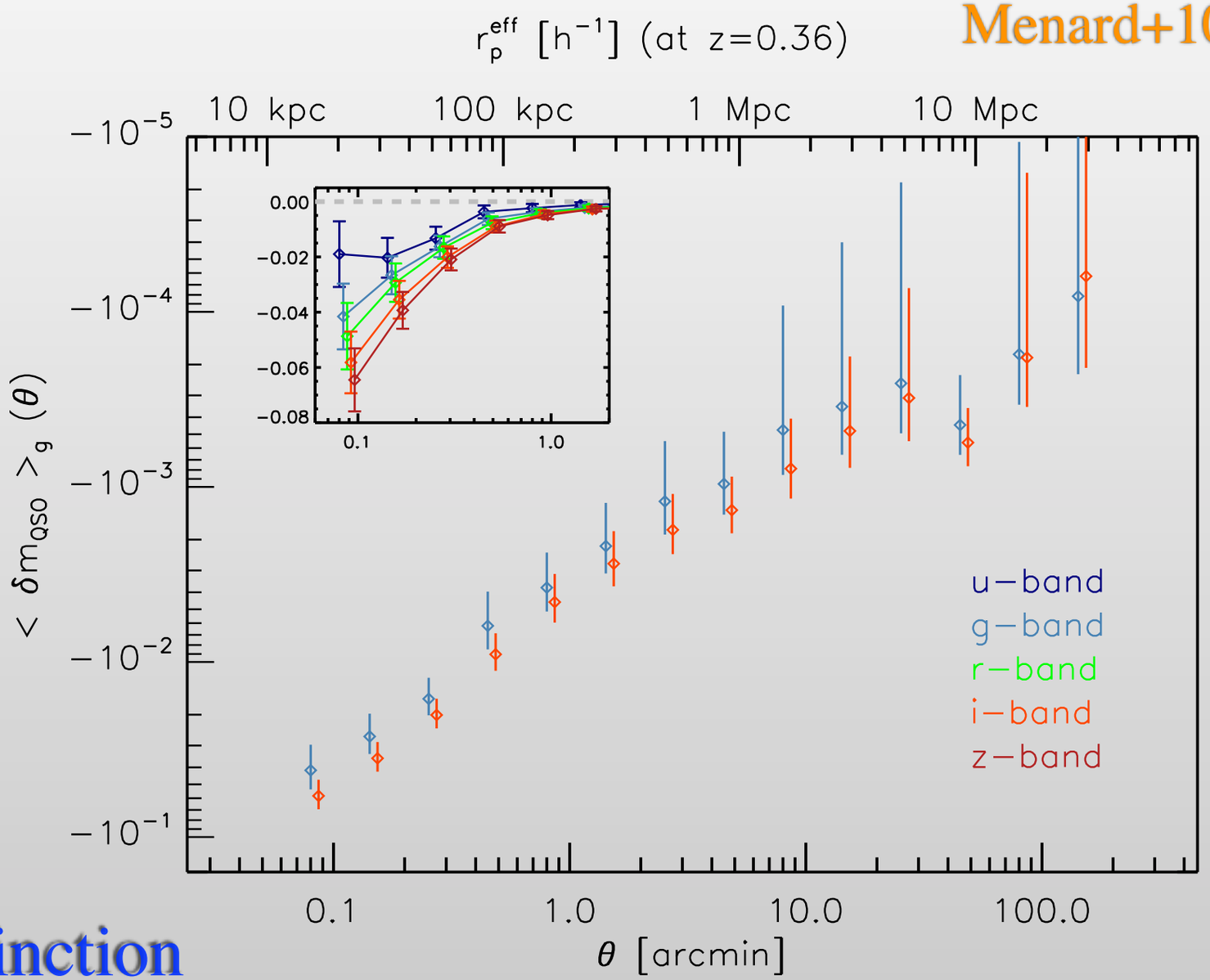
SDSS: Smoothing the Samples

Stacked spectra (Absorber frame)



York+06

Menard+10



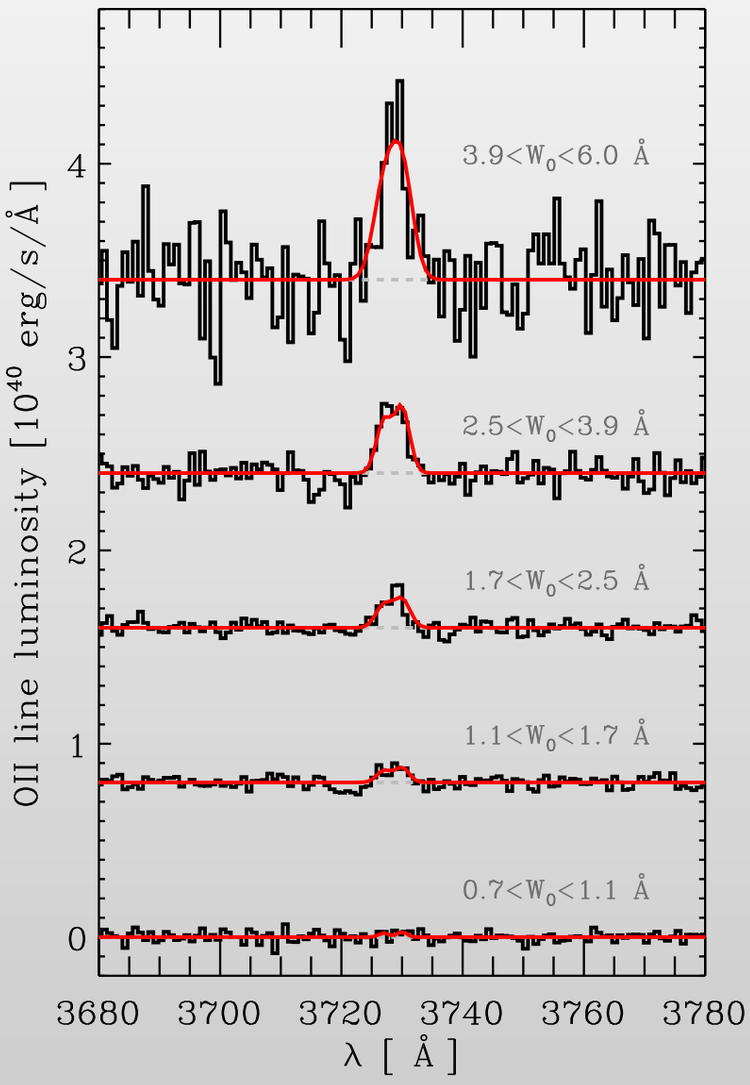
- **Dust extinction**
  - Map diffuse dust to tens of kpc
  - Extinction law (SMC)
  - Spectrophotometry (and photometry) critical

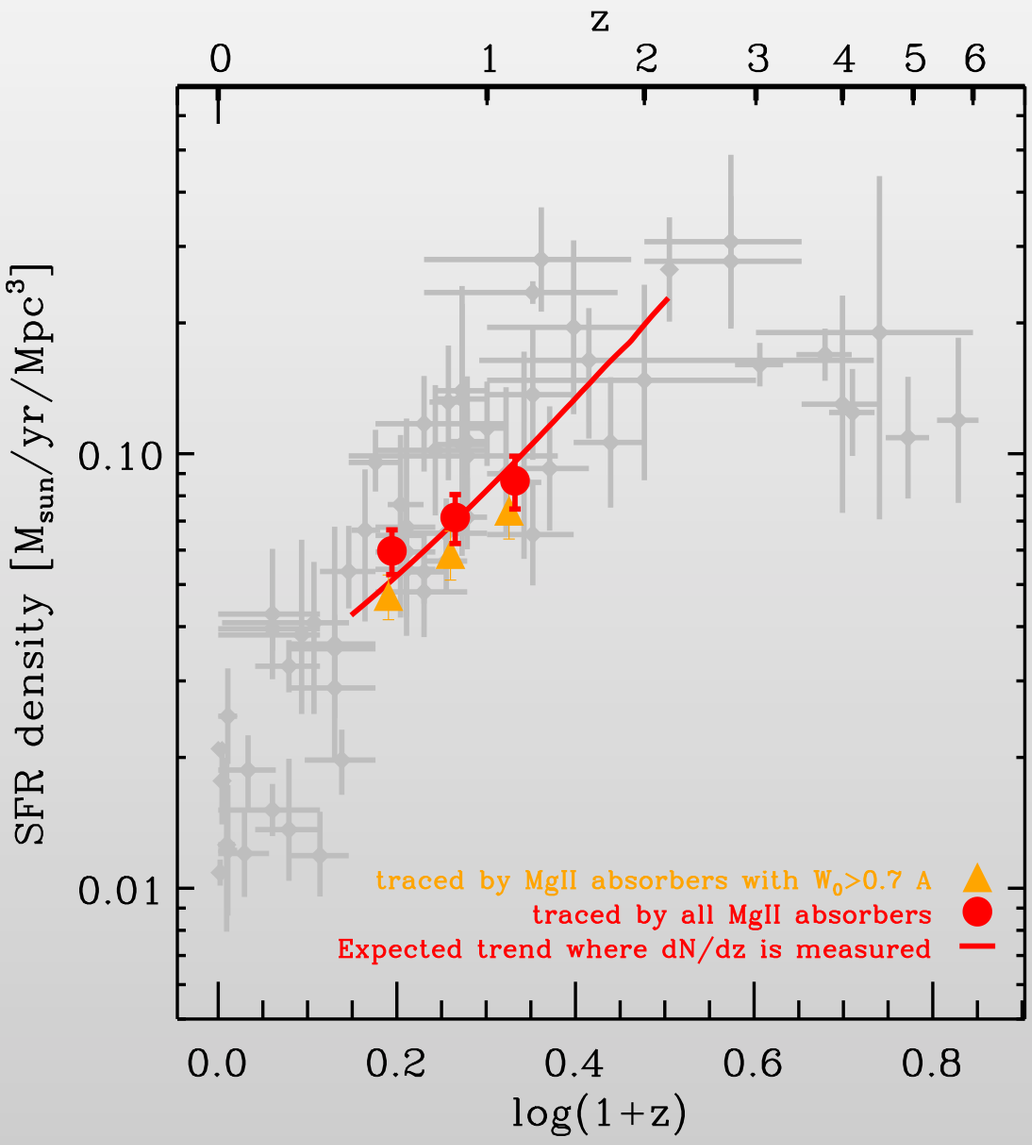
Highly Multiplexed

SDSS: Smoothing the Samples

Stacked spectra (Absorber frame)

Menard+11





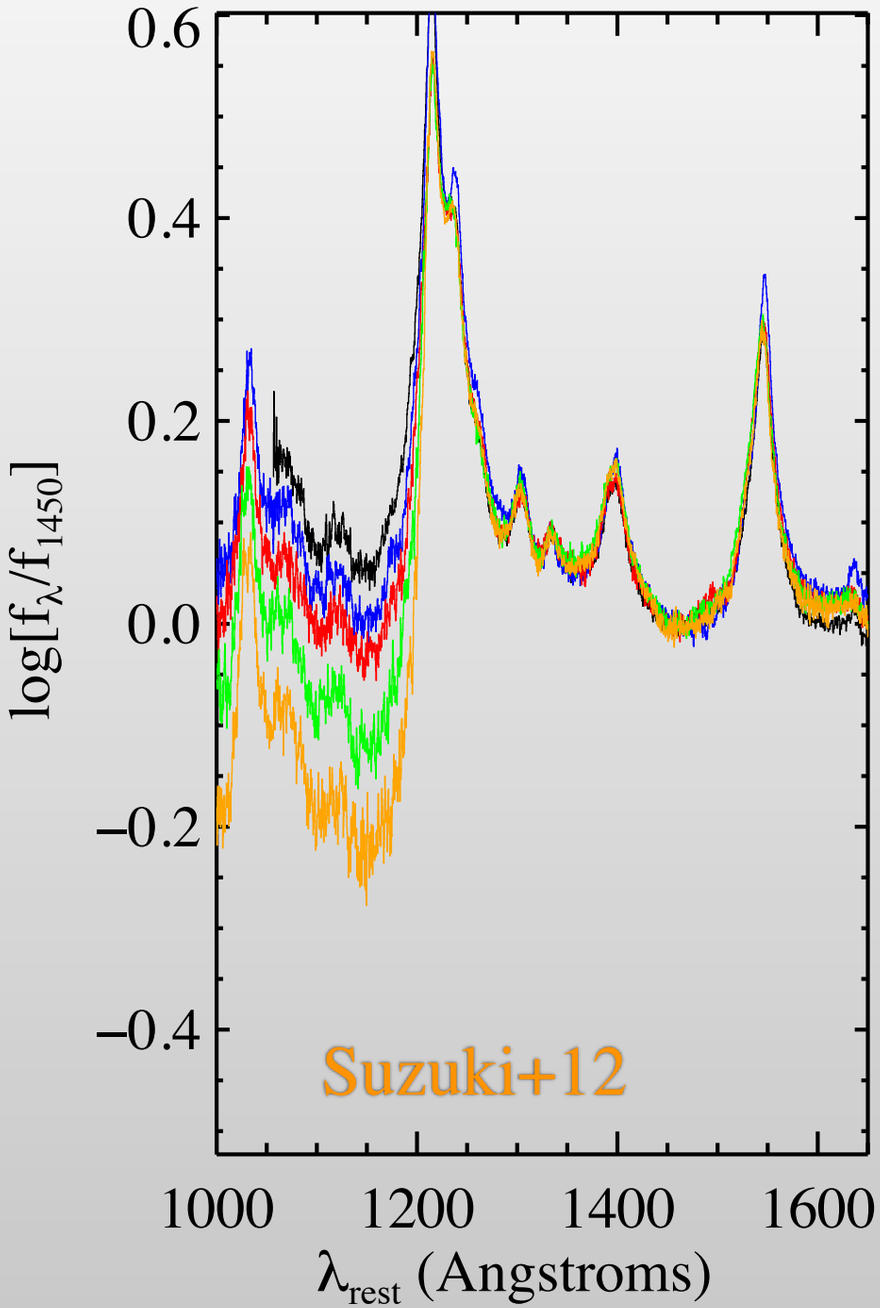
- Coincident [OII] emission
  - Spectrophotometry critical
- Cosmological SFR density from diffuse gas tracer

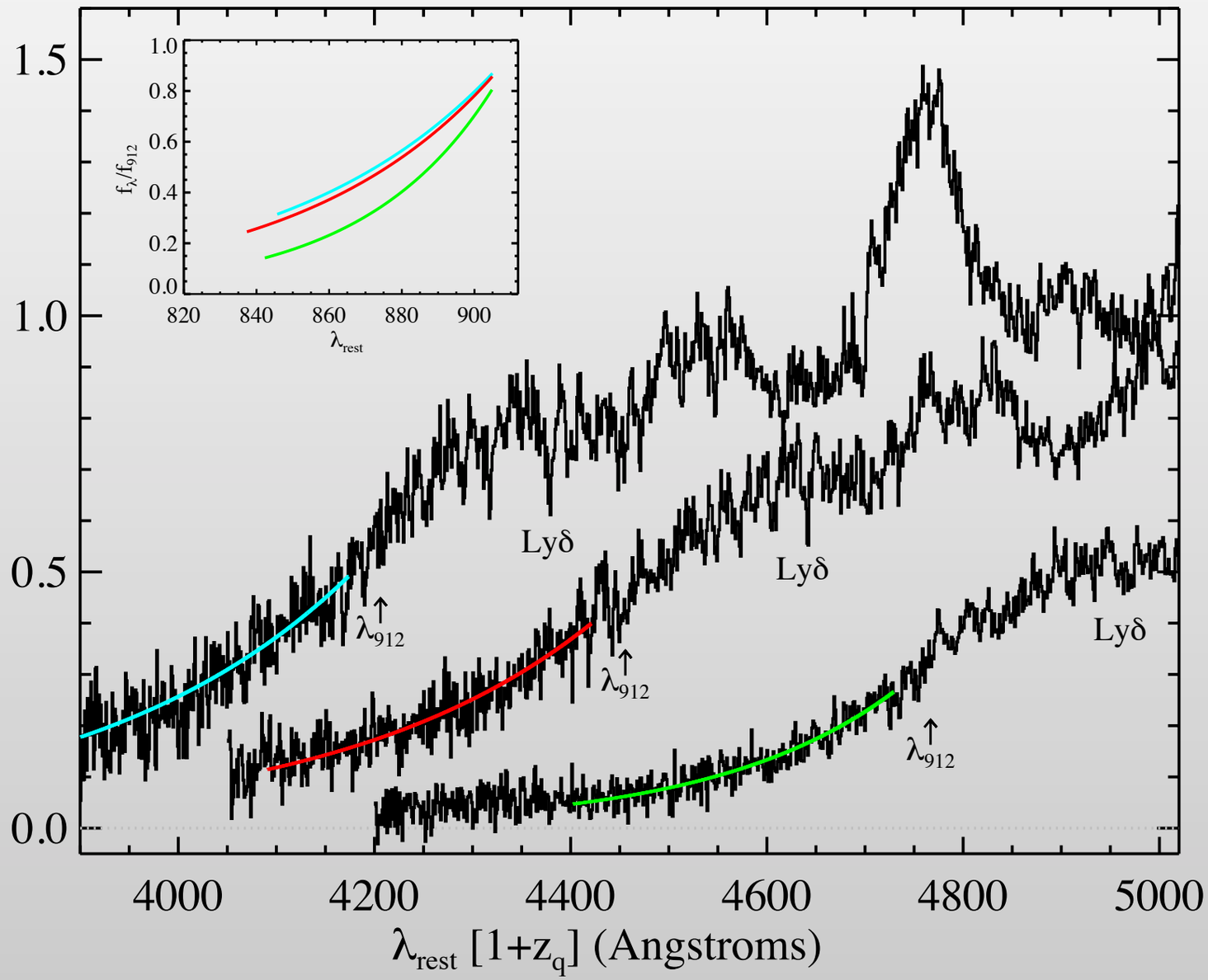
Highly Multiplexed

SDSS: Smoothing the Samples

Stacked spectra (Quasar frame)

Prochaska+09





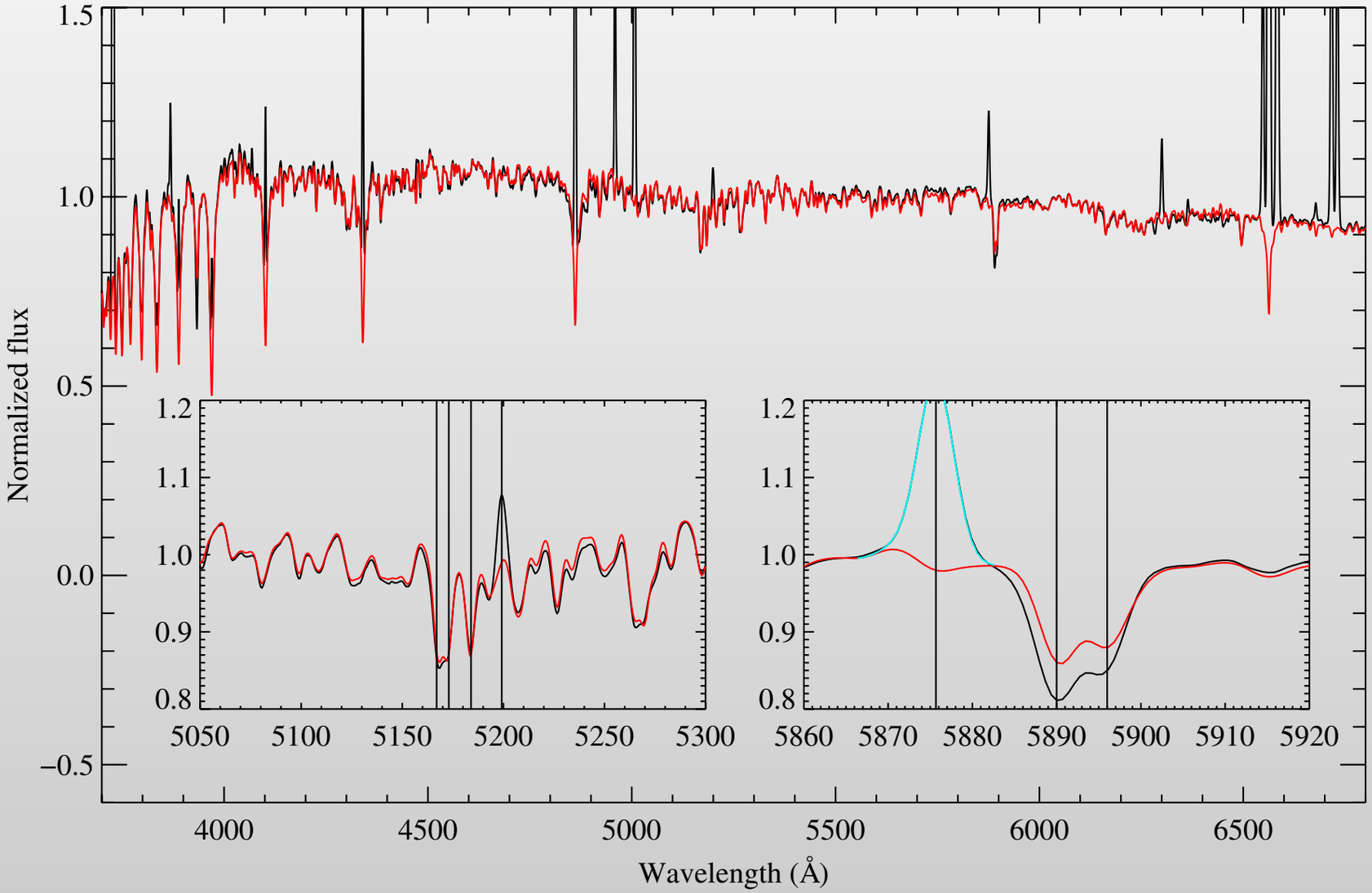
- Average IGM opacity
  - Lya forest (D_A)
  - Mean free path

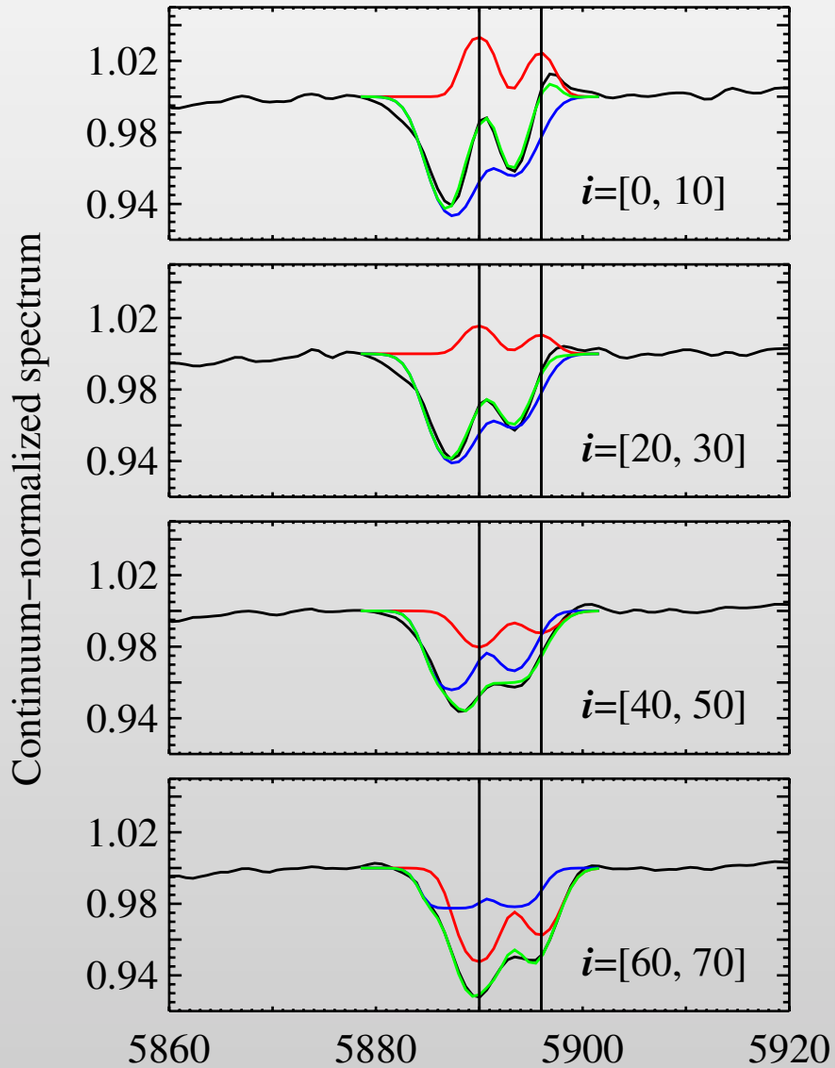
Highly Multiplexed

SDSS: Smoothing the Samples

Stacked spectra (SF galaxies)

Chen+10





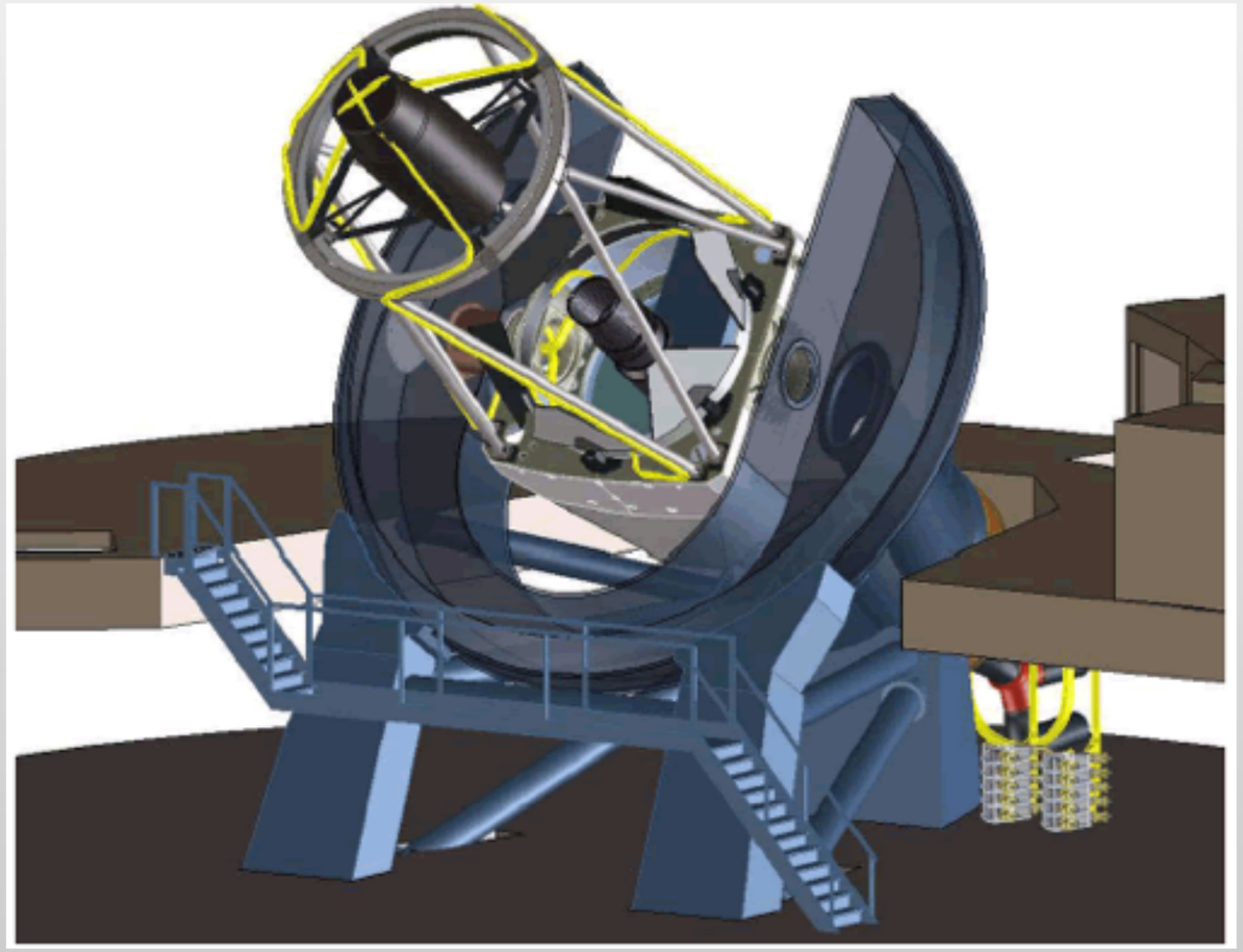
- Search for Galactic-scale winds
  - Offset NaI absorption
  - Correlate with galaxy properties (e.g. inclination)

Highly Multiplexed

BigBOSS Requirements: Diffuse Media

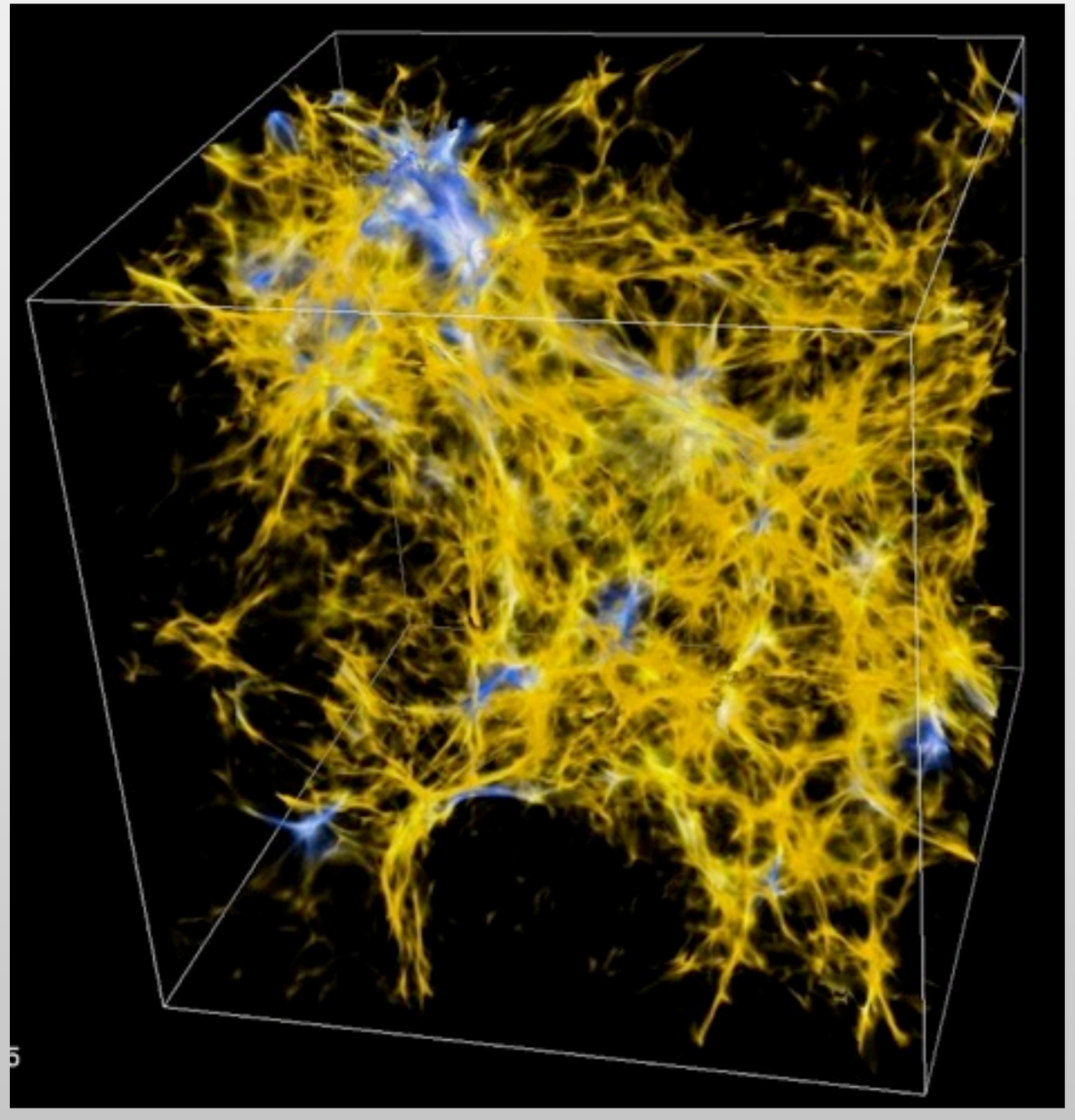
(My) Technical requirements; not targeting

- Signal-to-noise
  - >5 for individual absorbers
- Wavelength coverage
  - Bluer is better; nuff' said
- Spectral resolution
  - R=3,000 is too low to faithfully measure column densities
    - Physical quantity
  - R=5,000 is tantalizing
    - Would require very high S/N (>20)
- Spectrophotometry
  - Critical to 'smoothing' experiments
    - Relative more than absolute
  - Can high precision be achieved with 1.5'' fibers?



Open Science Topics/Questions in DM

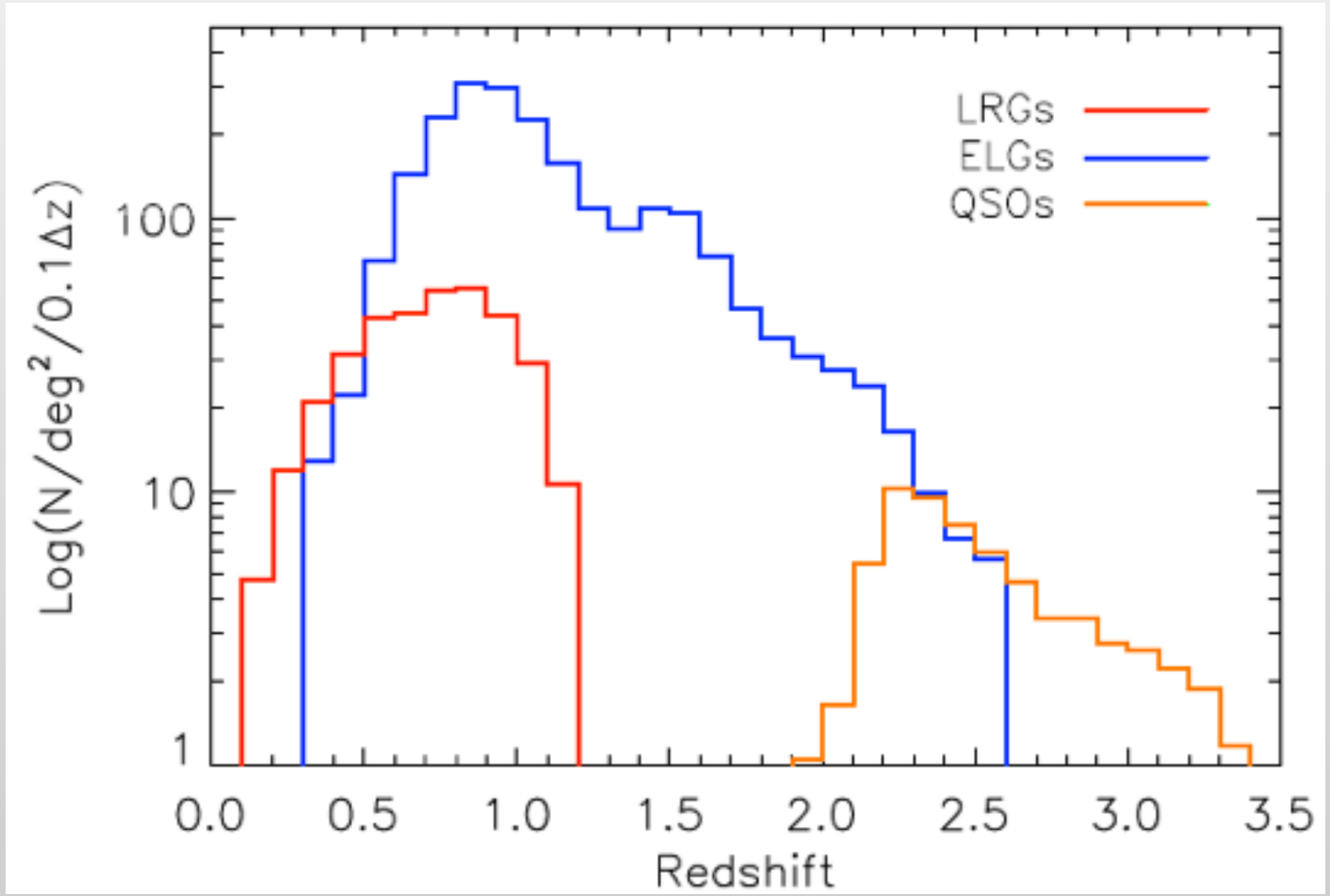
Some of which lie beyond BigBOSS



- Enrichment of the z<1 IGM
  - Do metals extend beyond the CGM?
- HI Reionization at z>6
  - HeII reionization at z~3, too
- Extent/Mass/Energy of Feedback
  - SF-driven (SNe, radiation)
  - Quasar-driven
- WHIM or not a WHIM?
- Thermal history of the IGM
  - Blazars?!
- Dust beyond SF regions
  - Distribution, composition
- Morphology of the ISM

DM: Community-based BB Projects

- **Main survey**
  - Faint quasar spectroscopy across the sky
    - ✦ Unprecedented absorber statistics
  - Needles in the haystack
    - ✦ May require targeting non-standard sources
- **Piggy-back mode**
  - Community fibers
  - Key for rare objects on the sky
- **Full instrument**
  - High-spatial mapping of diffuse medium
  - Requires high-density of sources
    - ✦ Challenging for absorption studies

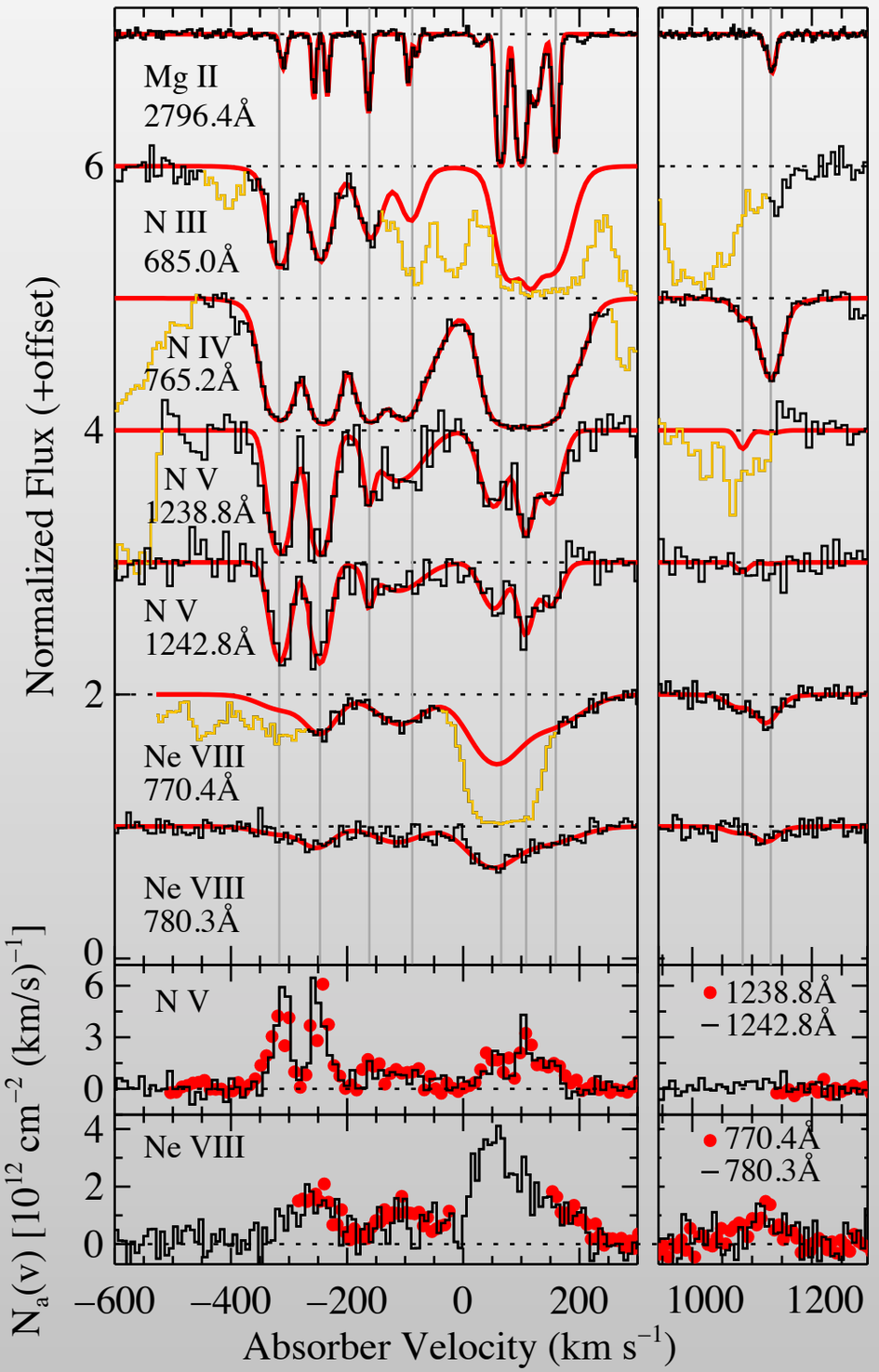


DM: Community-based BB Projects

Getting the ball rolling…

IGM/Galaxy Connection at z<1

Tripp+11



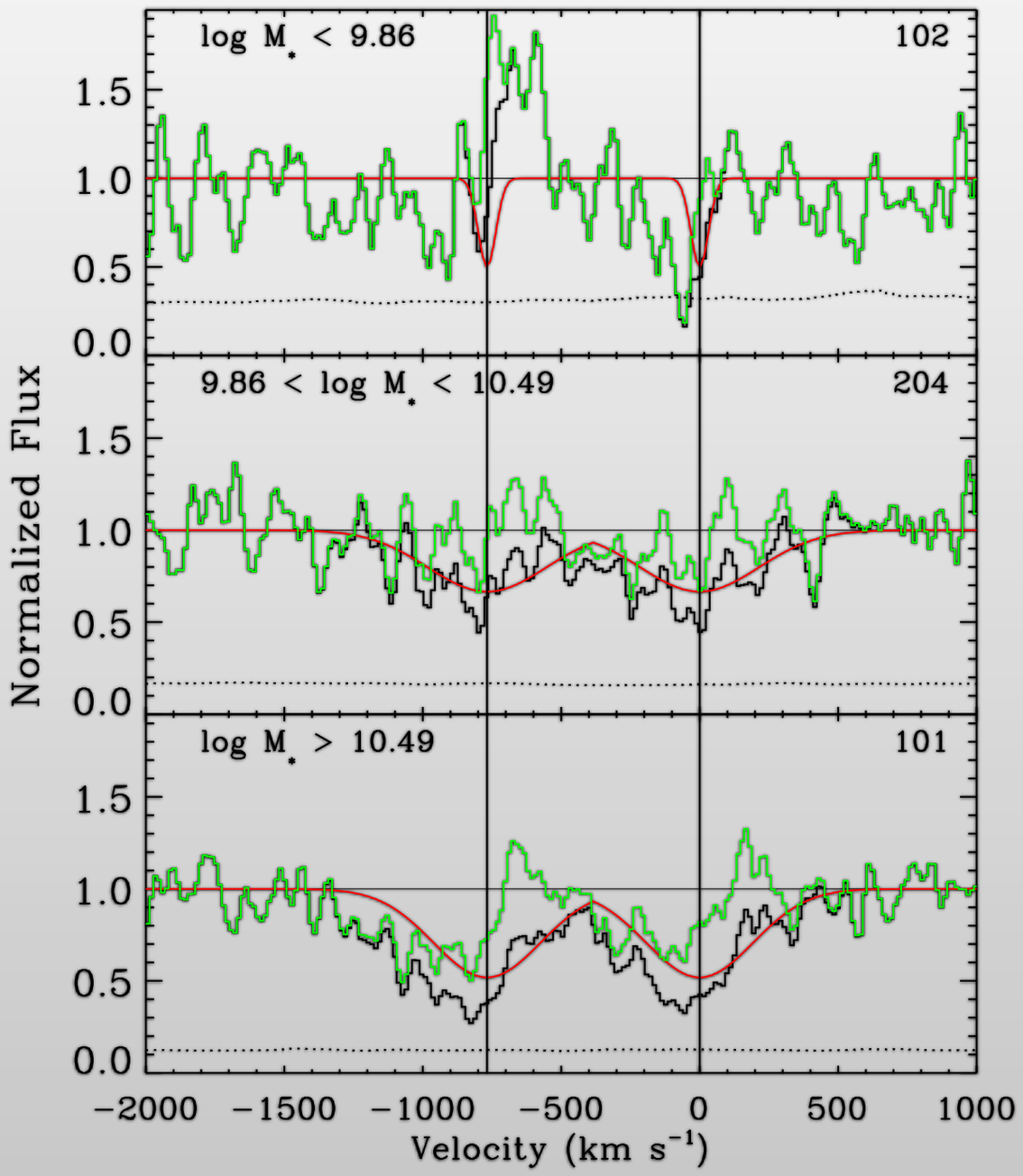
- Science
  - CGM characterization
  - Environment/gas connection
  - Galactic feedback
  - 'Mapping' the cosmic web
- Observations
  - HST/COS will obtain exquiste UV spectra of several 10's quasars
    - High S/N
    - Coverage of range of ionization states
  - Dedicated+deep galaxy survey on small and medium scales
    - 100kpc to tens of Mpc
    - sub-L* => R~23mag

Highly Multiplexed

Characterizing Galactic-Winds at z~0.5

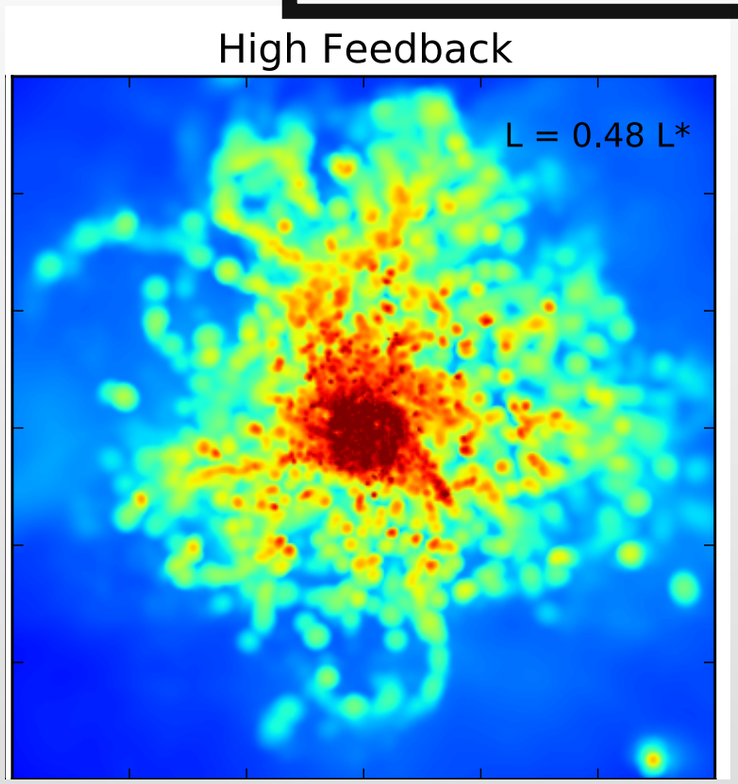
- **Science**
  - Nature of feedback across cosmic time
    - ✦ z~0, z~1, z>2 are under heavy study
  - Connect to galaxy properties (AGN,SF)
- **Observations**
  - Target 50,000+ SF galaxies at z~0.5
    - ✦ e.g. 10 dedicated fibers per BB pointing
    - ✦ r<22mag with S/N~1 in the continuum
    - ✦ Coverage of FeII, MgII, NaI absorption
  - Stacked spectra (for most analysis)
  - BOSS project underway
- **Ancillary**
  - Incredible dataset for studying SF galaxies at modest redshift
  - Galaxy/galaxy tomography
- **Can this be extended to z>1?**

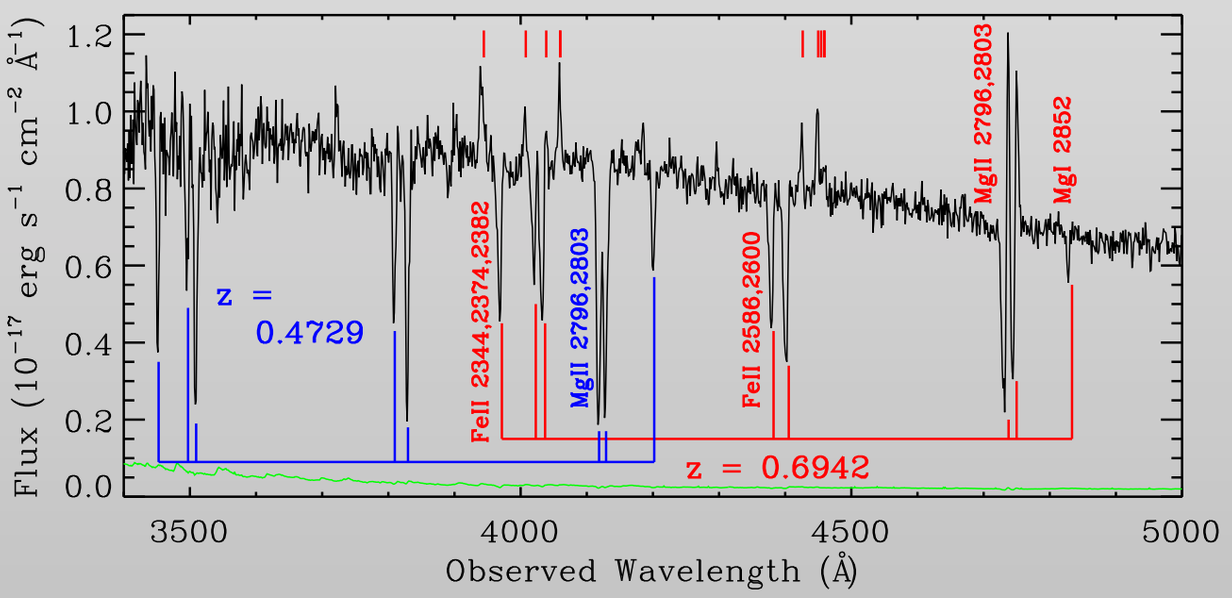
Rubin+10



Highly Multiplexed

Mapping the CGM at z~0.5



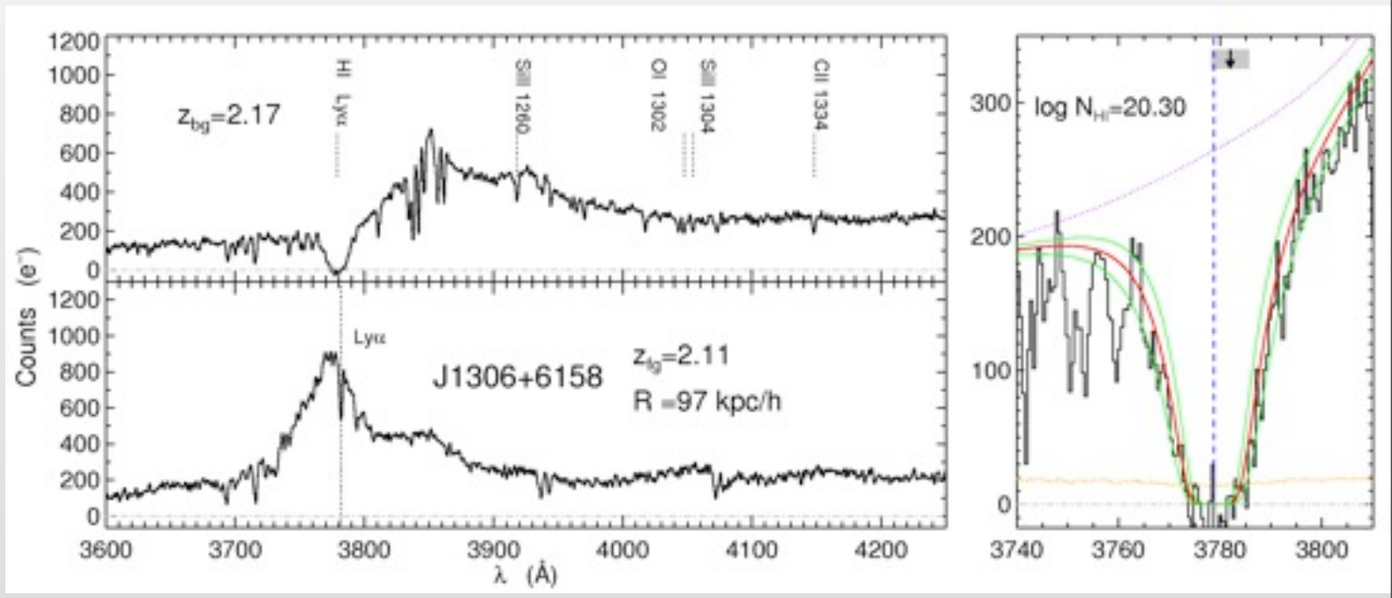


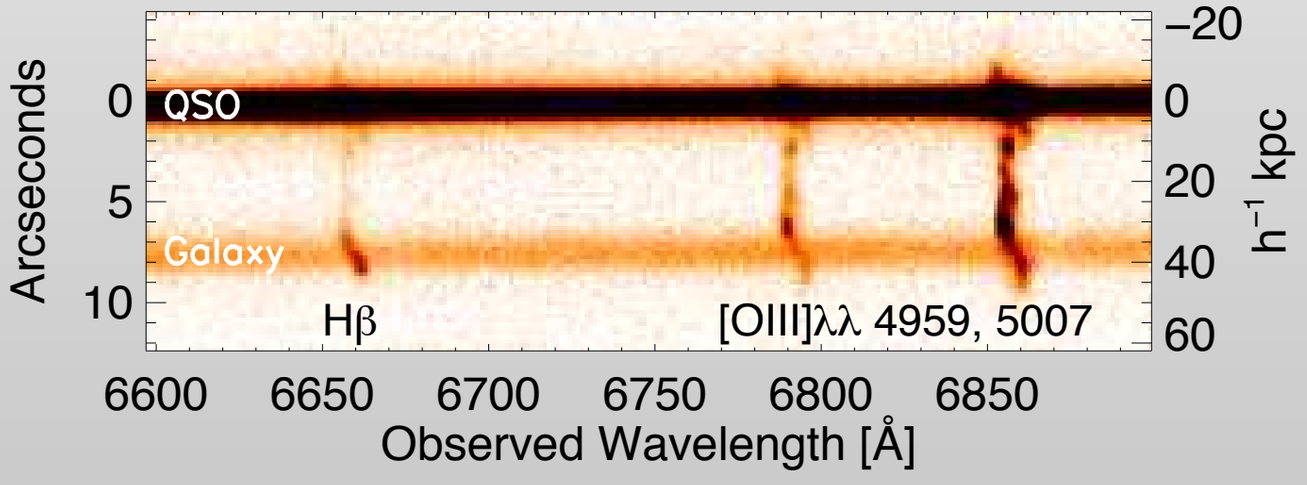
Highly Multiplexed

- Science
  - Census of metals, dust, gas in the CGM of galaxies
    - Propagation of metals to the IGM (feedback)
  - Reservoir for future SF ("recycling")
- Observations
  - Require probes (ideally multiple) on projected scales of a few hundred kpc
    - BB provides coverage of FeII, MgII
  - Need target galaxies (see previous slide)
    - Rare configurations => Select fibers
    - Could re-map BB fields too
    - LRGs too
  - Background sources
    - Quasars, SF galaxies
    - Leverage existing SDSS/BOSS spectra
  - Stacked and individual spectra

Close QQ and QG Pairs at all z

- **Science**
  - CGM of quasars and galaxies
    - ✦ Gas, metal, dust distributions
  - Small-scale feedback processes
  - IGM thermal history, enrichment
  - Quasar triggering
  - Galaxy/galaxy mergers
- **Observations**
  - Target any/all sources within a few arcseconds of a known QSO
    - ✦ SDSS and BOSS
- **Ancillary**
  - Tremendous follow-up value

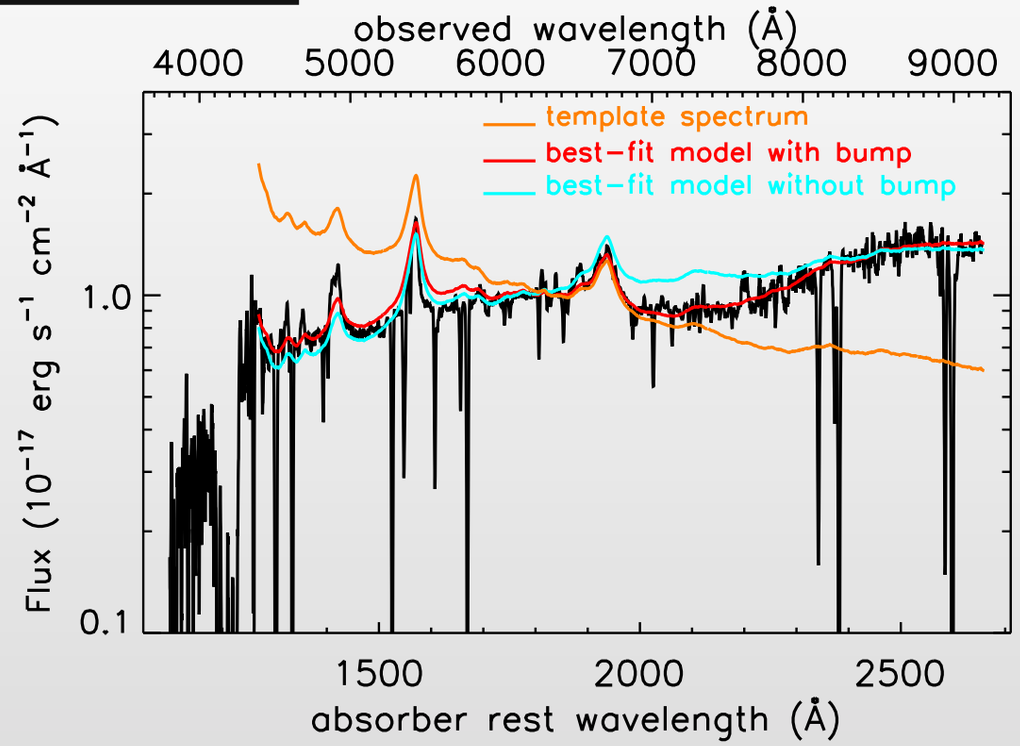




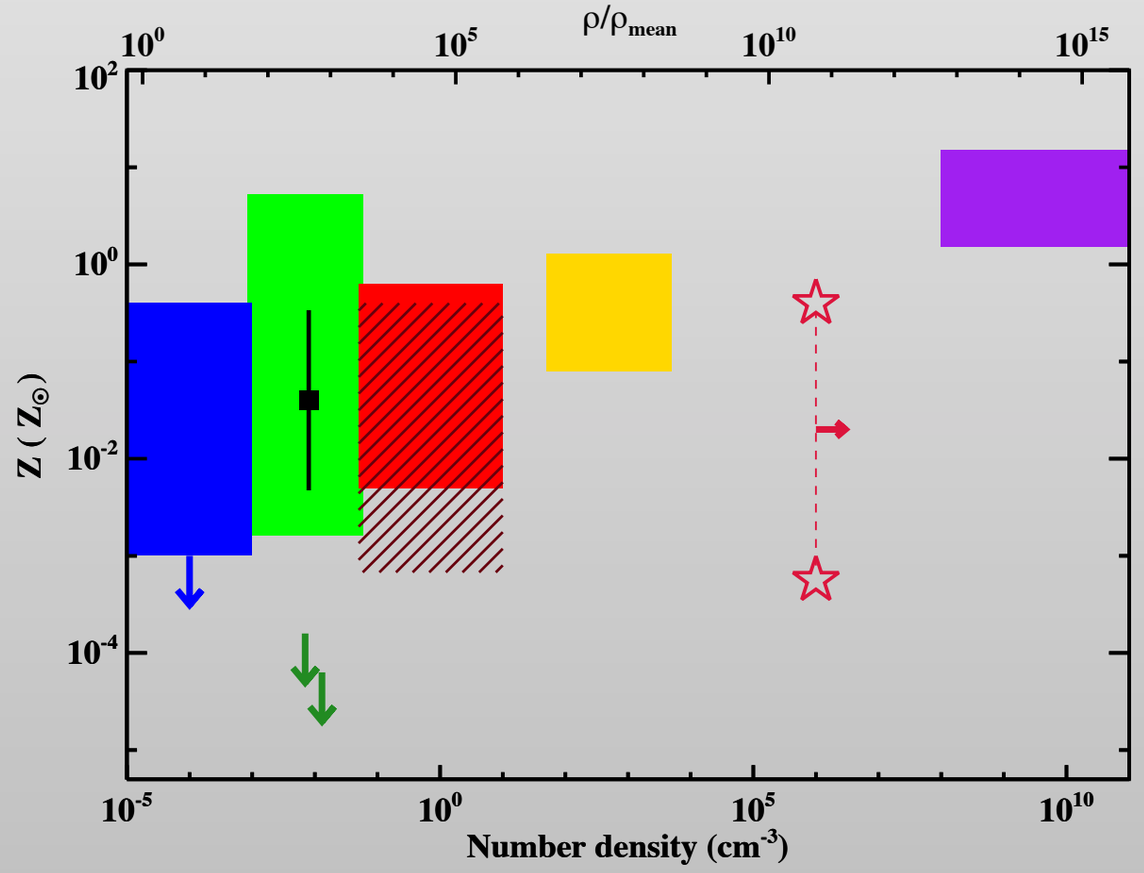
Highly Multiplexed

Needles

- **Science**
  - Highly enriched gas
    - ✦ Dust production; nucleosynthesis
  - "Metal-free" gas
    - ✦ BBN; feedback; PopIII stars
  - HeII reionization
  - High z IGM
- **Observations**
  - Targeting matters
    - ✦ Quasars with highly reddened color
    - ✦ Quasars within the stellar locus
    - ✦ Fainter quasars at z>4
  - BB offers an unprecedented opportunity to target the unknown



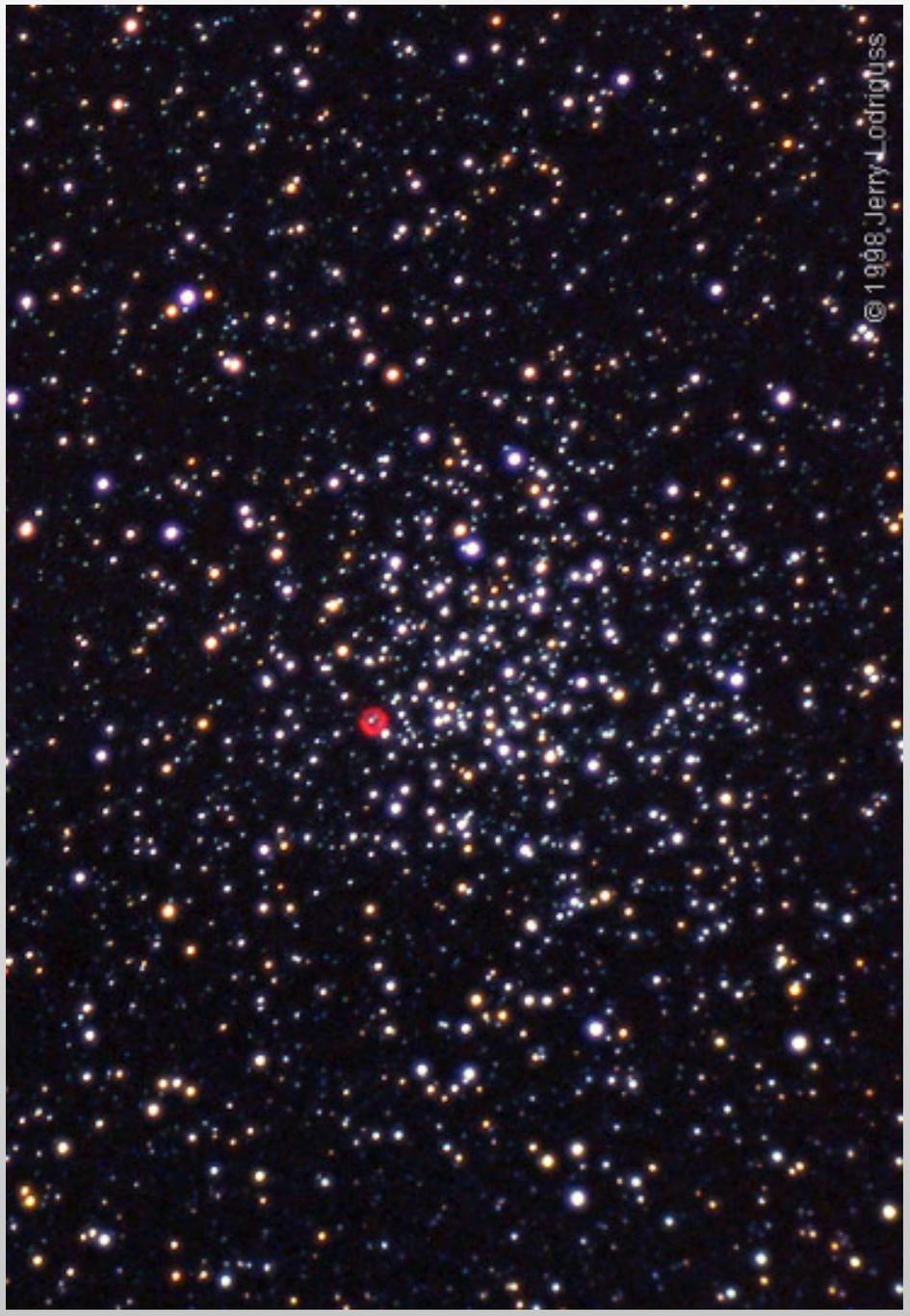
Jian-Guo+11



Fumagalli+11

Highly Multiplexed

Small-scale structure of the ISM



- Science
  - Density structure of the neutral ISM
  - Morphology of atomic ‘clouds’
- Observations
  - Target large stellar clusters on the sky
    - ✦ Open clusters?
  - High S/N spectra for NaI, CaII absorption
    - ✦ Not optimal ions, but only options
  - Examine kinematic, spatial variations
- Ancillary
  - High S/N spectra will enable characterization of stellar atmospheres

Extinction Maps of Local Galaxies

- Science
  - Galactic-scale feedback
    - Traced by metals/dust
  - Dust formation/destruction
  - Characterization of the diffuse ISM
- Observations
  - Choose nearby galaxies
    - Large angular extent
    - ~100kpc in the BB field-of view
  - Target (R<22 sources)
    - Galactic stars -- Galactic extinction
    - Quasars, red-and-dead galaxies
  - Photometry will be essential