RFI Response Summaries

5 Rapid Science Summaries

Topic: Galaxy Evolution

Brad Peterson

Steve Kraemer

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UV Time Domain Studies of Active Galactic Nuclei

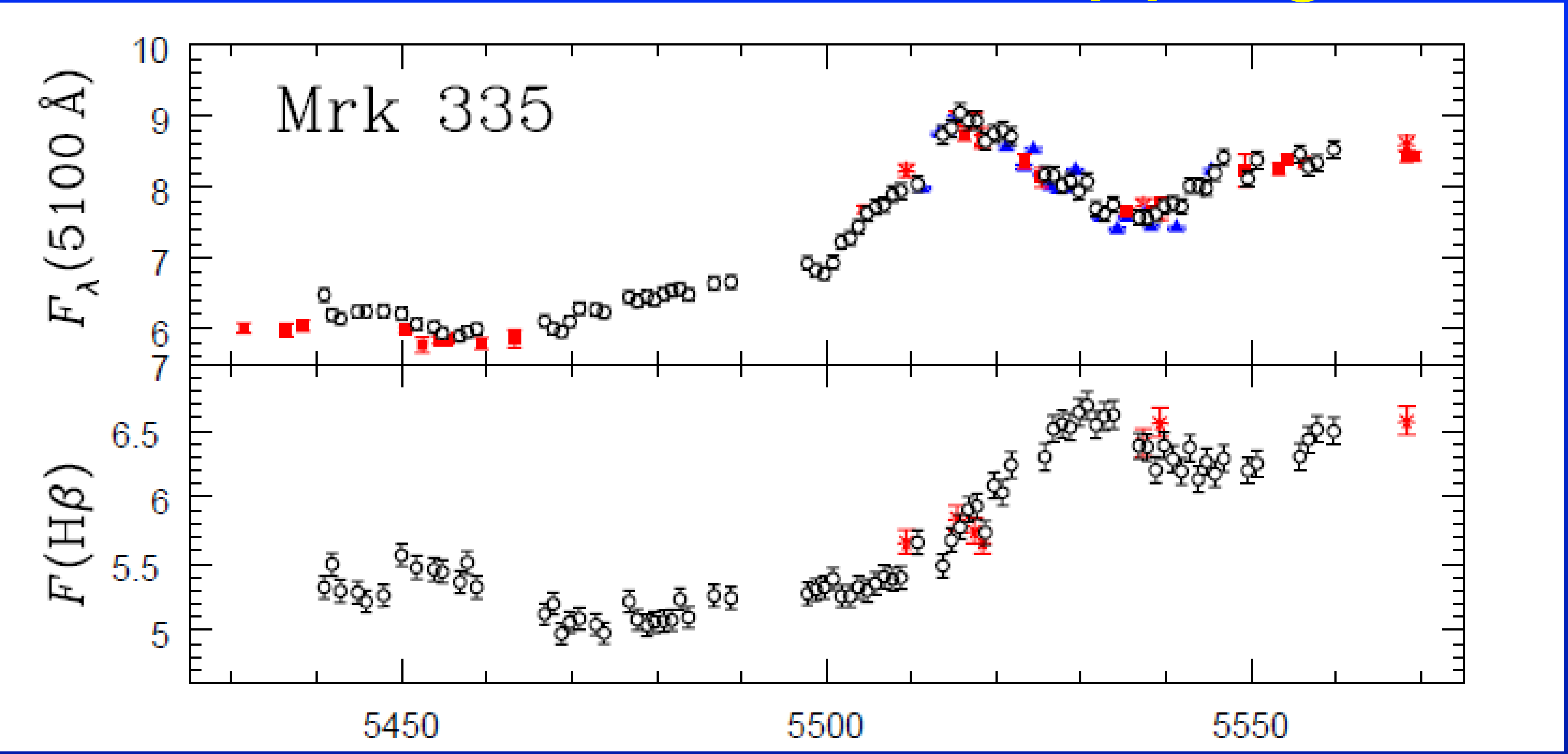
Bradley M. Peterson
The Ohio State University

RJ Assef (JPL), MC Bentz (GSU), E Dalla Bontà (Padua), KD Denney (Dark), G De Rosa (OSU), S Frank (OSU), MR Goad (Leicester), CJ Grier (OSU), K Horne (St Andrews), CS Kochanek (OSU), GA Kriss (STScI), A Marconi (Florence), S Mathur (OSU), A Pancoast (UCSB), M Pessah (NBI), RW Pogge (OSU), A Rafiee (Towson), T Treu (UCSB), M Vestergaard (Dark)

STScI

18 September 2012

Reverberation Mapping

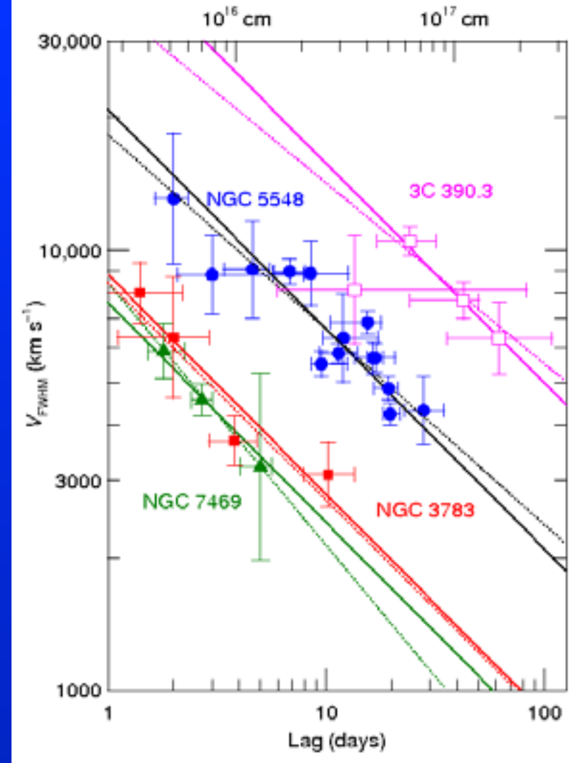


Emission line variations follow those in continuum with a small time delay (14 days here) due to light-travel time across the broad-line region (BLR).

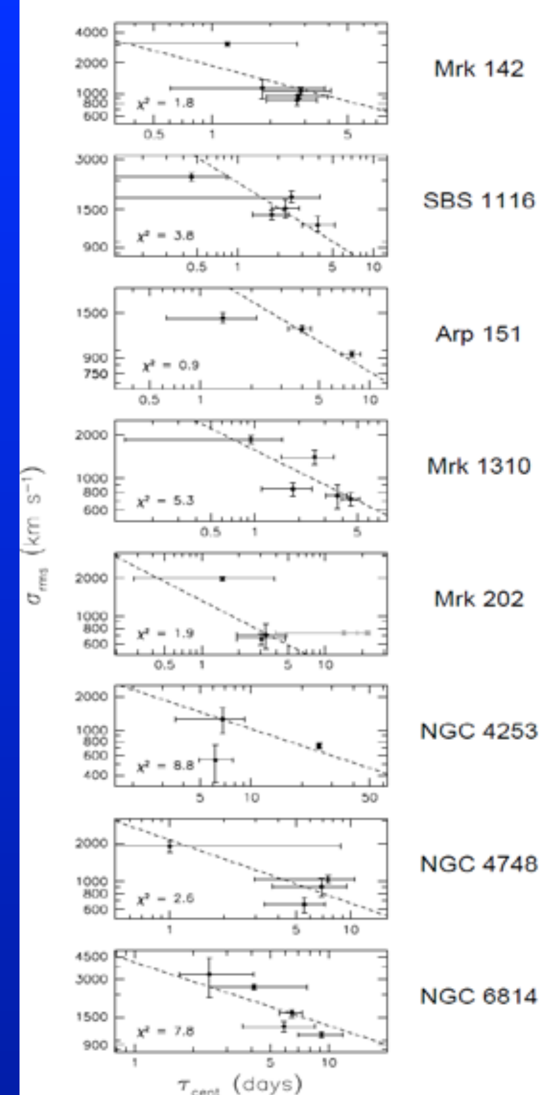
Grier et al. 2011, ApJ, 744, L4

A Virialized BLR

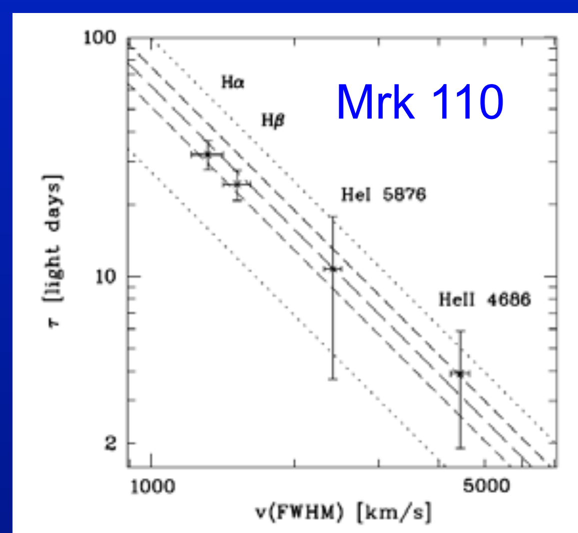
- $\Delta V \propto R^{-1/2}$ for every AGN in which it is testable.
- Suggests that gravity is the principal dynamical force in the BLR.
  - Caveat: radiation pressure!



Peterson & Wandel 2002

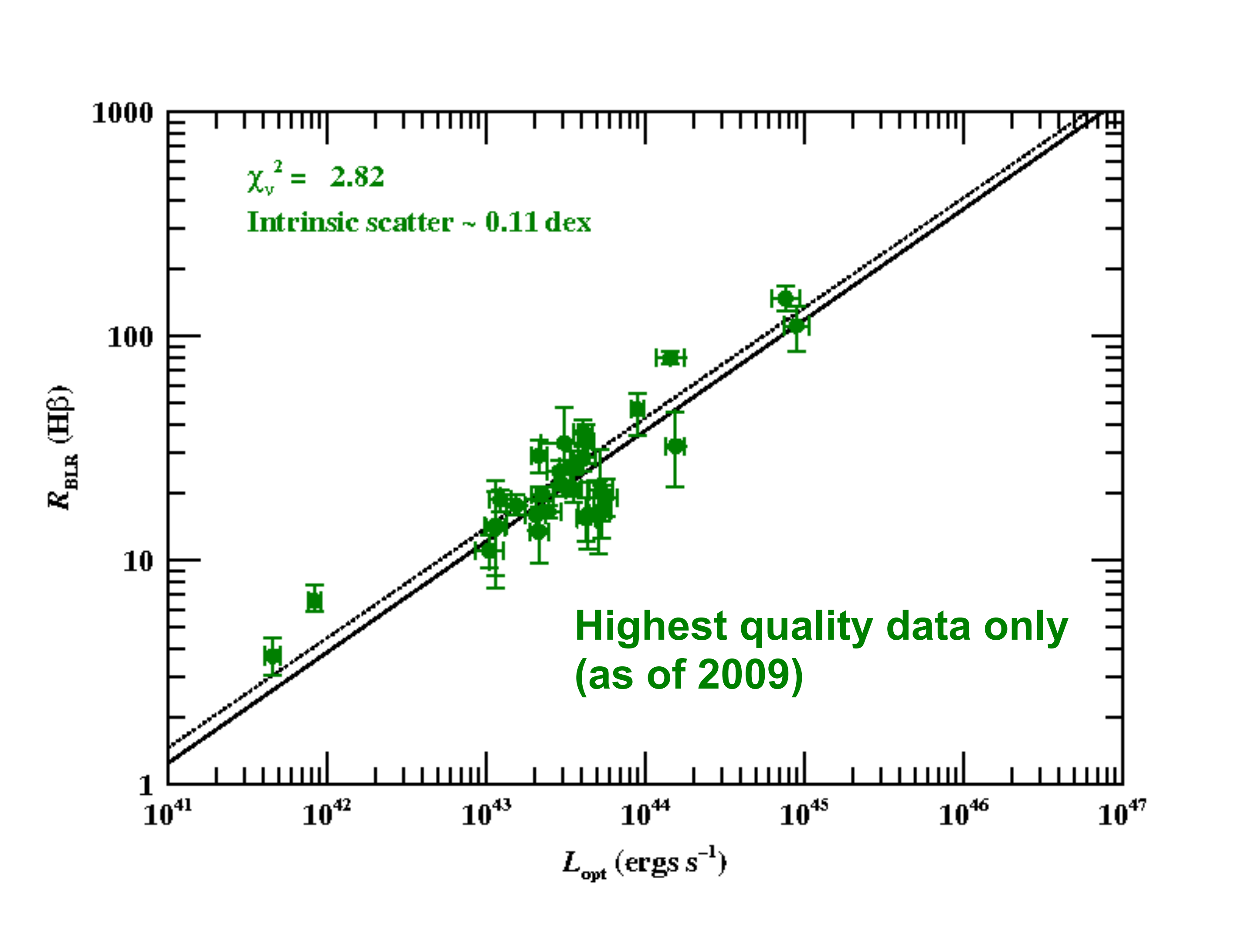


Bentz et al. 2009



Kollatschny 2003

Relationship Between BLR Radius and AGN Luminosity



Reverberation-Based Masses

"Virial Product" (units of mass)

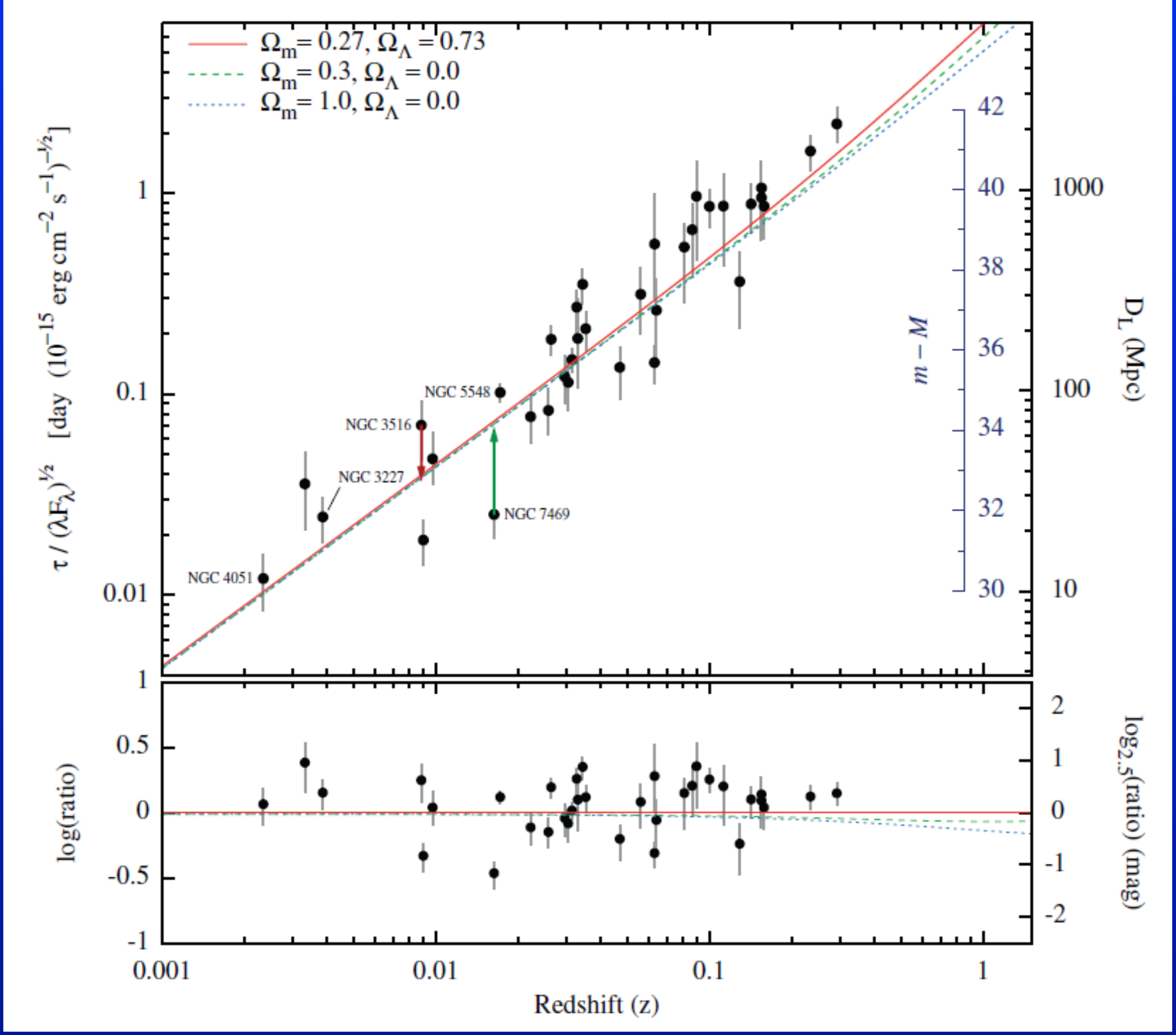
$$M_{\mathrm{BH}} = f \boxed{\underline{r\,\Delta V^2} / G}$$

Observables:
r = BLR radius (reverberation)
ΔV = Emission-line width

Set by geometry and inclination
(subsumes everything we don't know)

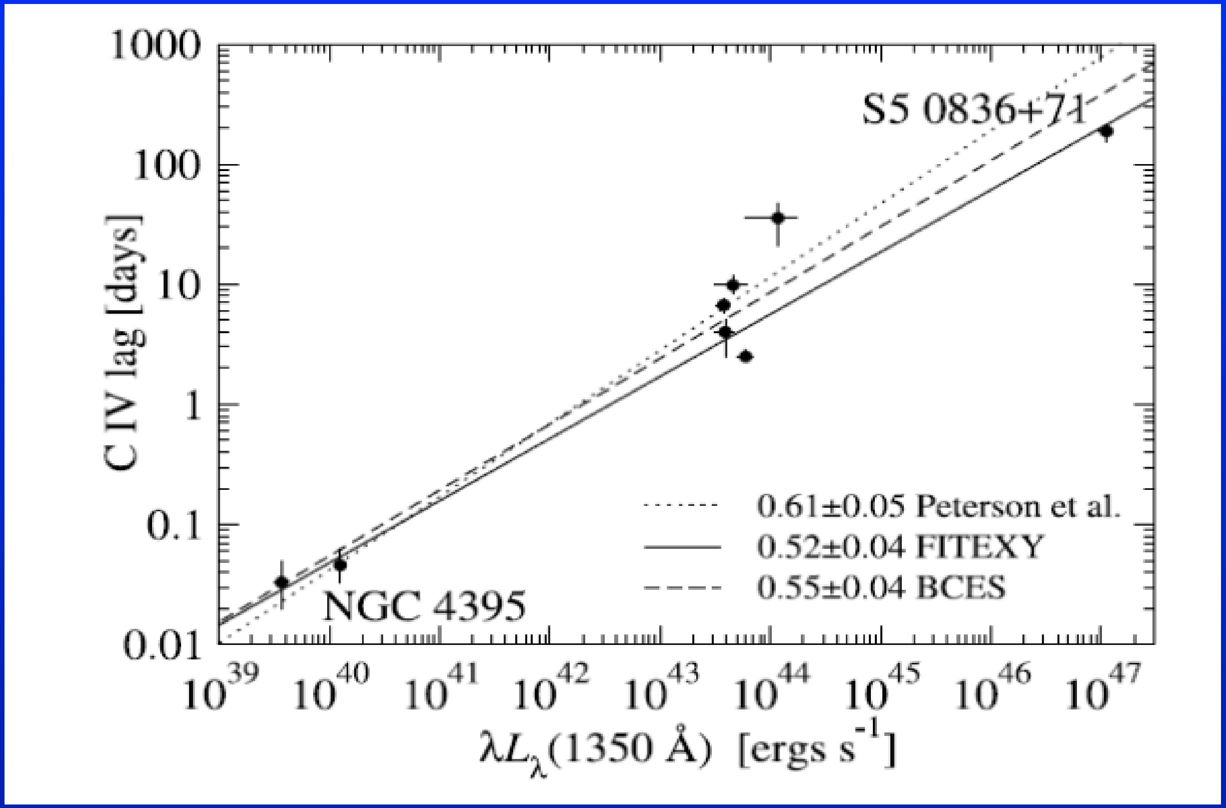
If we have independent measures of M_{BH}, we can compute an ensemble average $\langle f \rangle$

RM as a Cosmological Tool



Watson et al. 2011, ApJ, 744, L4

R-L for UV Lines (C IV λ1549)



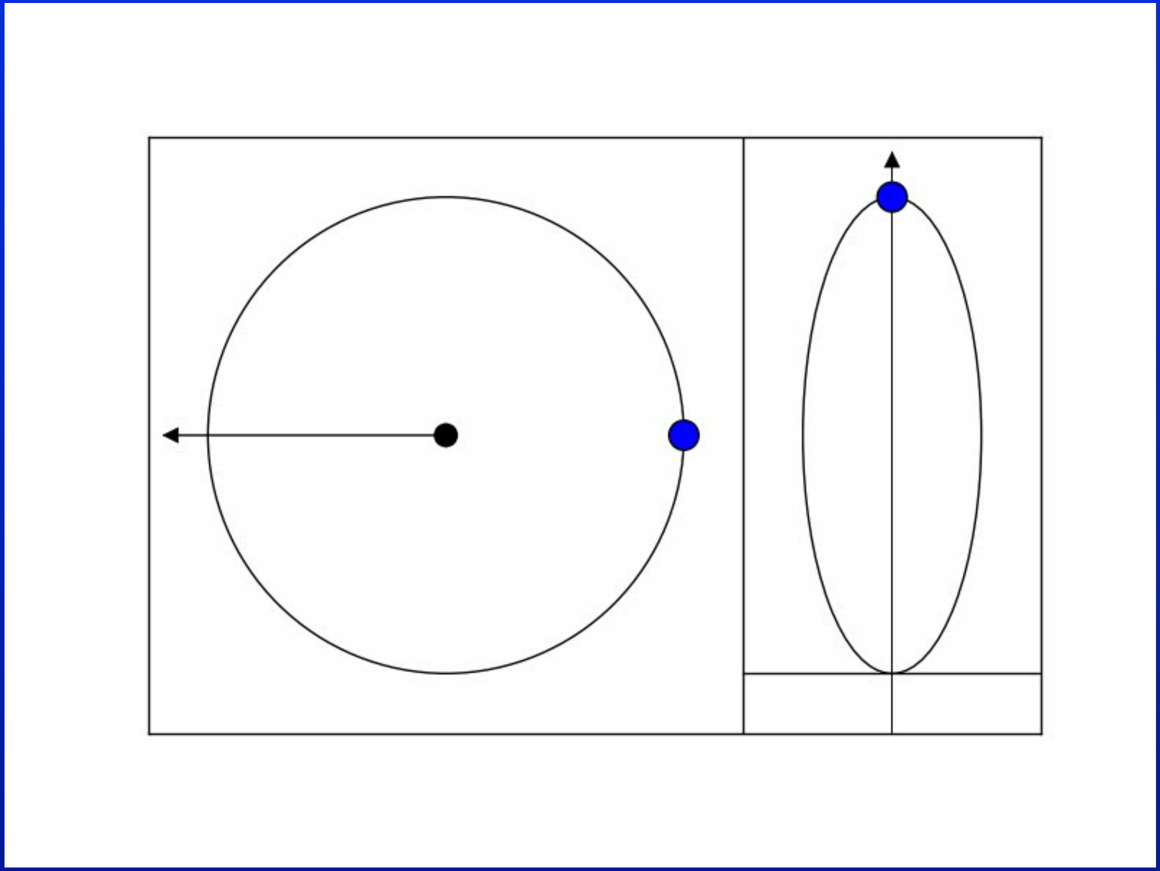
Few sources with C IV lags, and these are at least somewhat dubious

Kaspi et al. 2007, ApJ, 659, 997

Velocity-Delay Map

Configuration space

Velocity-Delay space



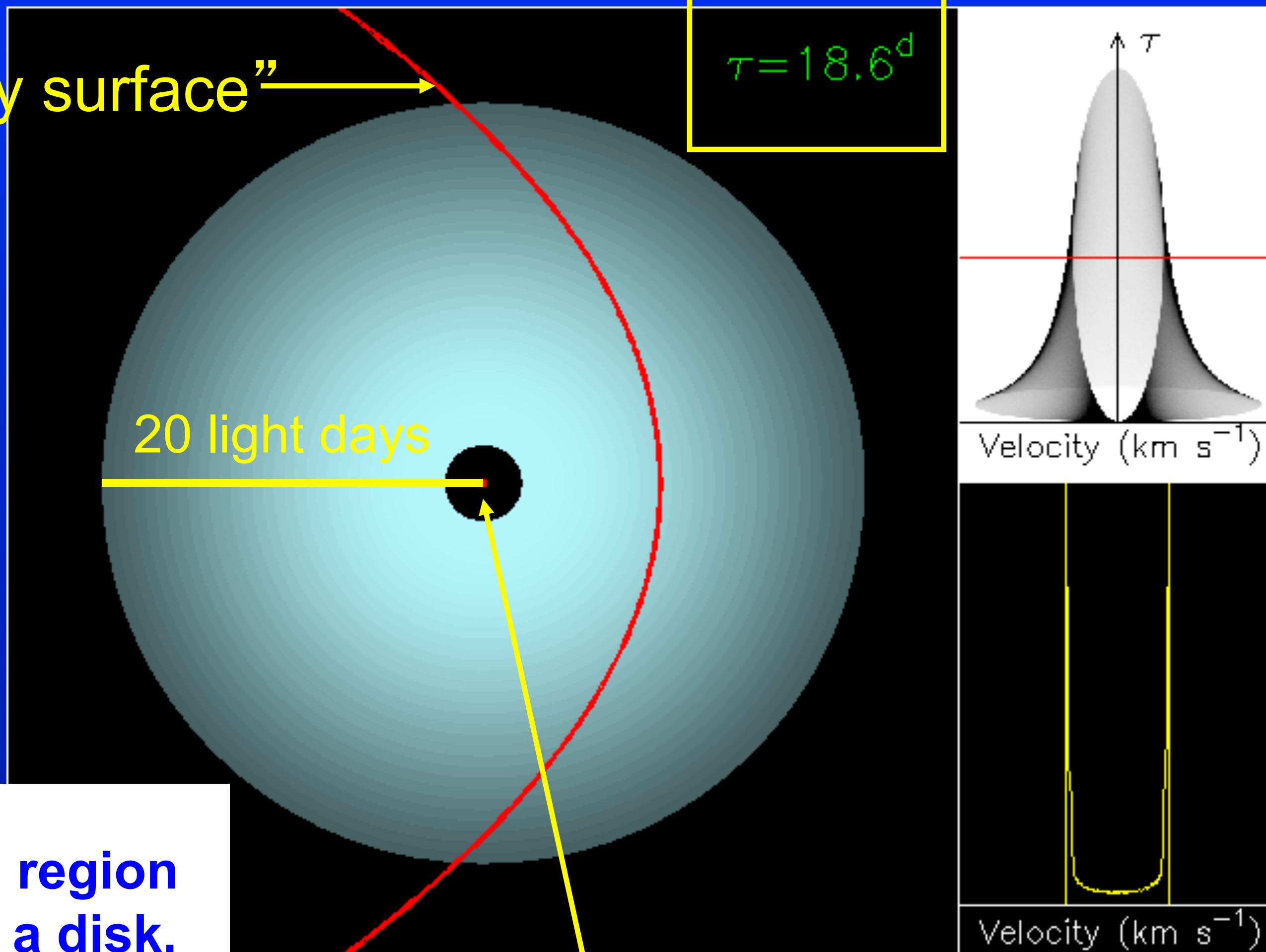
To observer

Time delay

Doppler velocity

Time after continuum outburst

“Isodelay surface”



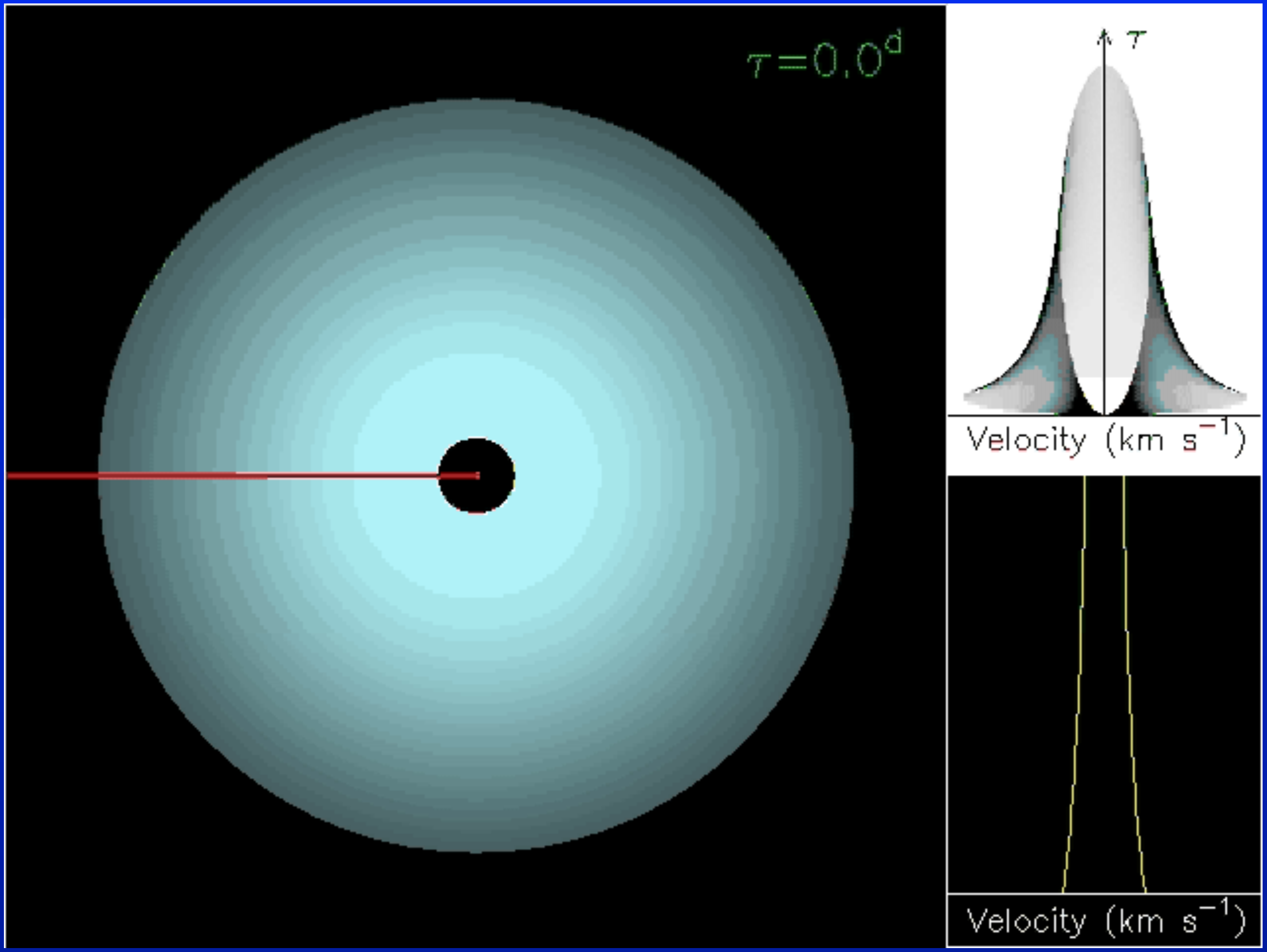
20 light days

Time delay

Broad-line region as a disk, 2–20 light days

Black hole/accretion disk

Line profile at current time delay



τ=0.0d
τ
Velocity (km s−1)
Velocity (km s−1)

Reverberation Response of an Emission Line to a Variable Continuum

The relationship between the continuum and emission can be taken to be:

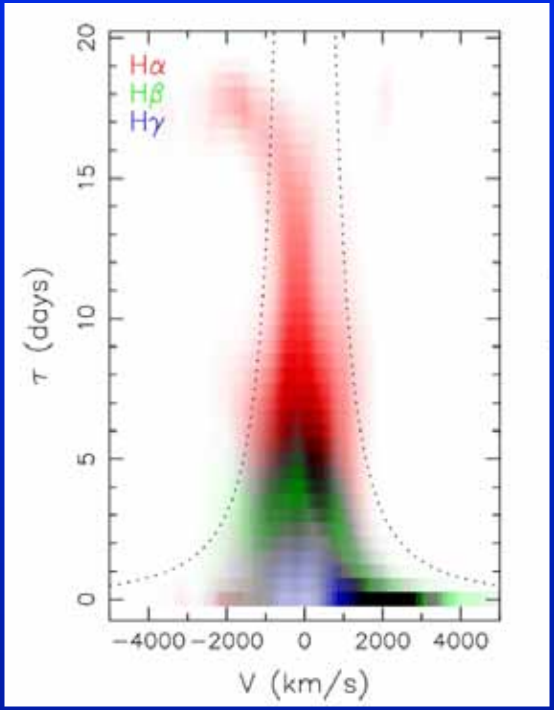
$$L(V,t) = \int \Psi(V,\tau)\, C(t-\tau)\, d\tau$$

Velocity-resolved emission-line light curve

"Velocity-delay map"

Continuum light curve

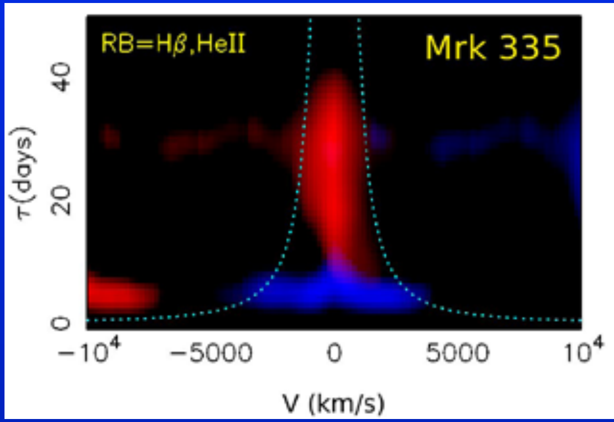
Velocity-delay map is observed line response to a δ-function outburst

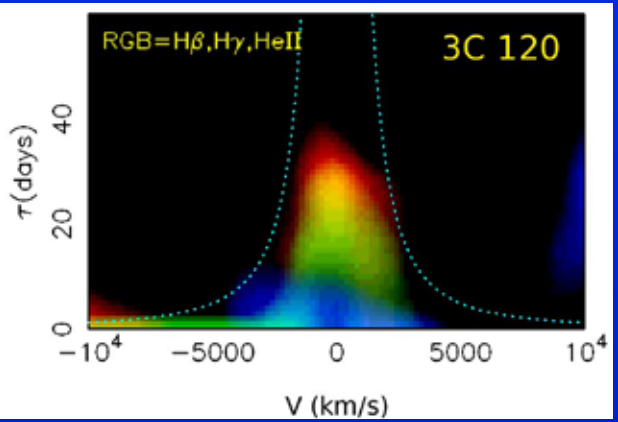


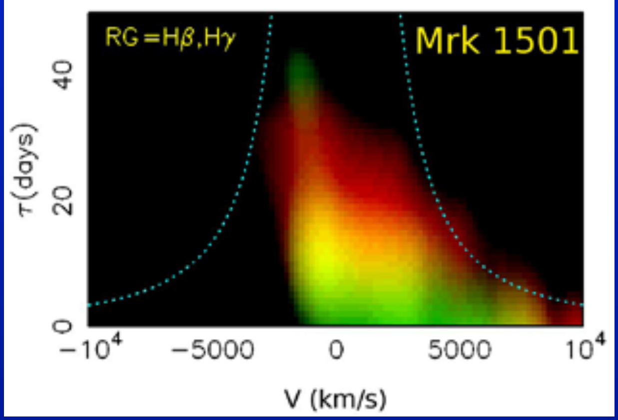
Arp 151

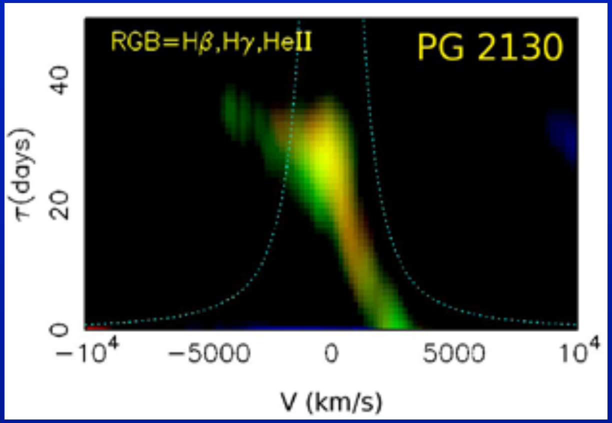
LAMP: Bentz et al. 2010

Optical Velocity Delay Maps Show Infall in Balmer Lines









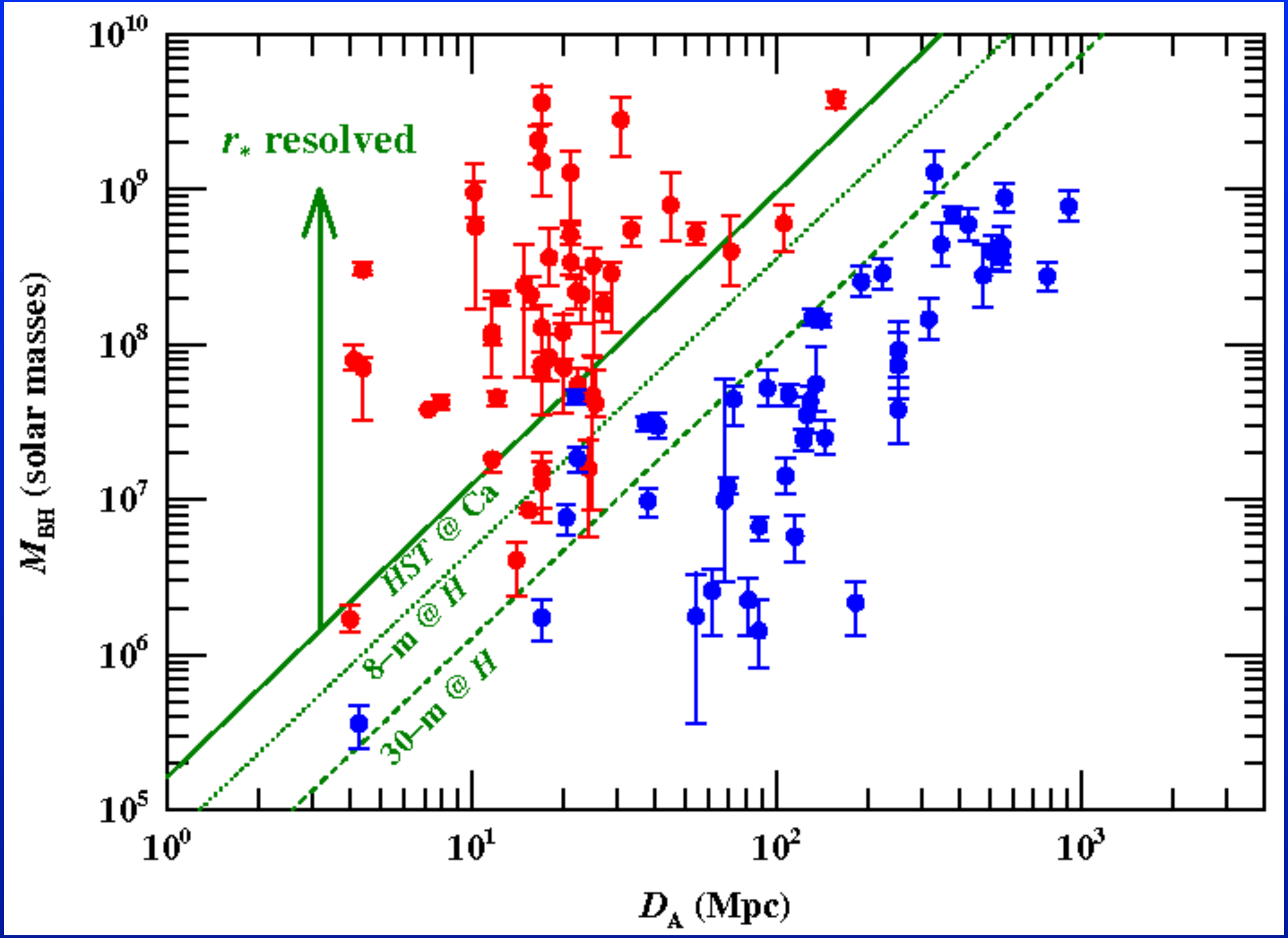
Grier et al. 2012, in preparation

UV RM Programs

1) Intensive monitoring to get UV velocity-delay maps to establish flow of high-ionization gas
   - Expect C IV to show outflow?
   - Sampling (NGC 5548): once per day for 180 days
   - For other sources, time sampling and duration both scale as $L^{1/2}$
2) Moderately high cadence programs to establish C IV *R-L*
   - Needed for high-*z* masses and cosmology ($z < 2$ must be done from space)
   - Sampling: ~40 observations, cadence and duration as $L^{1/2}$
   - Number of targets: ~7 (each 0.5 dex in range $41.0 \leq \log \lambda L_{\lambda}(1350\text{Å}) \leq 46.0$)

Stellar and gas dynamics requires resolving the black hole radius of influence r_*

Quiescent galaxies RM AGNs



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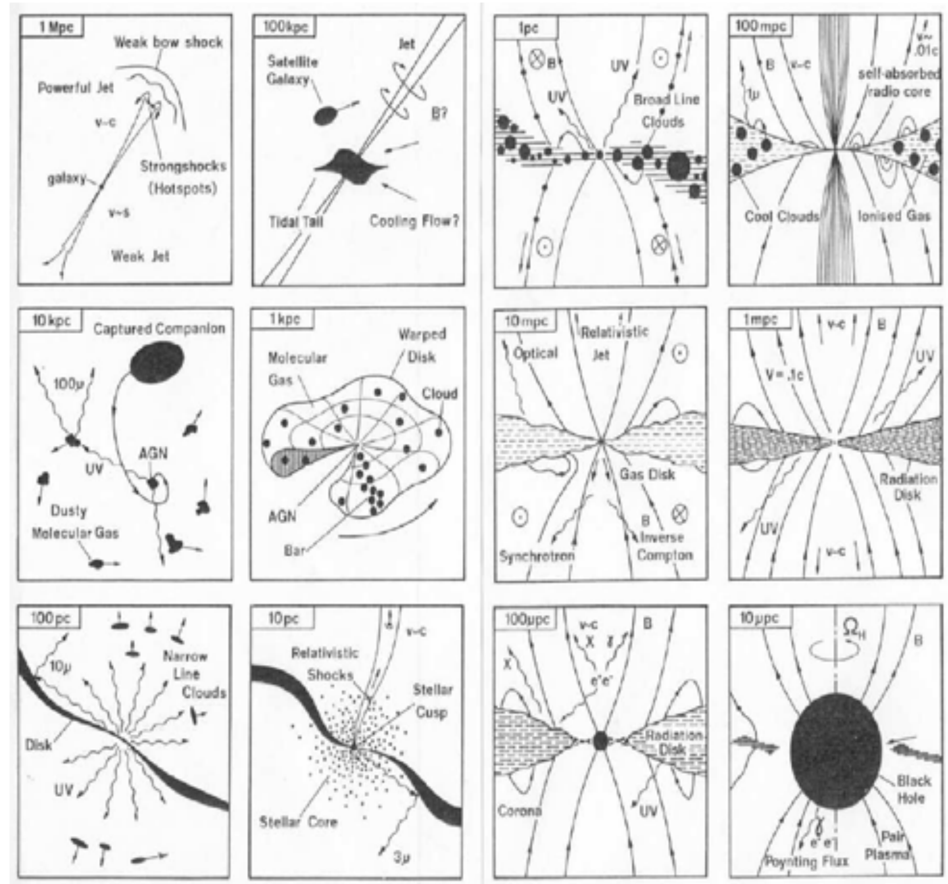
Active Galactic Nuclei and their role in Galaxy Formation and Evolution

Steve Kraemer (CUA), Rogier Windhorst (ASU), Kenneth G. Carpenter (NASA-GSFC),
Mike Crenshaw (GSU), Martin Elvis (CfA), and Margarita Karovska (CfA)

Presented at the UVIS COR RFI Workshop at STScI, 18 Sept., 2012

- The AGN phase is critical in galaxy evolution
    - The mass of the central Black Hole, the AGN "engine" is correlated with the mass of the galactic bulge
    - Suggests that the ignition of the AGN regulates build-up of bulge. But How?
    - As shown at right, the AGN can affect their surroundings over 12 orders of magnitude in size (Figure from R. Blandford, 1990)

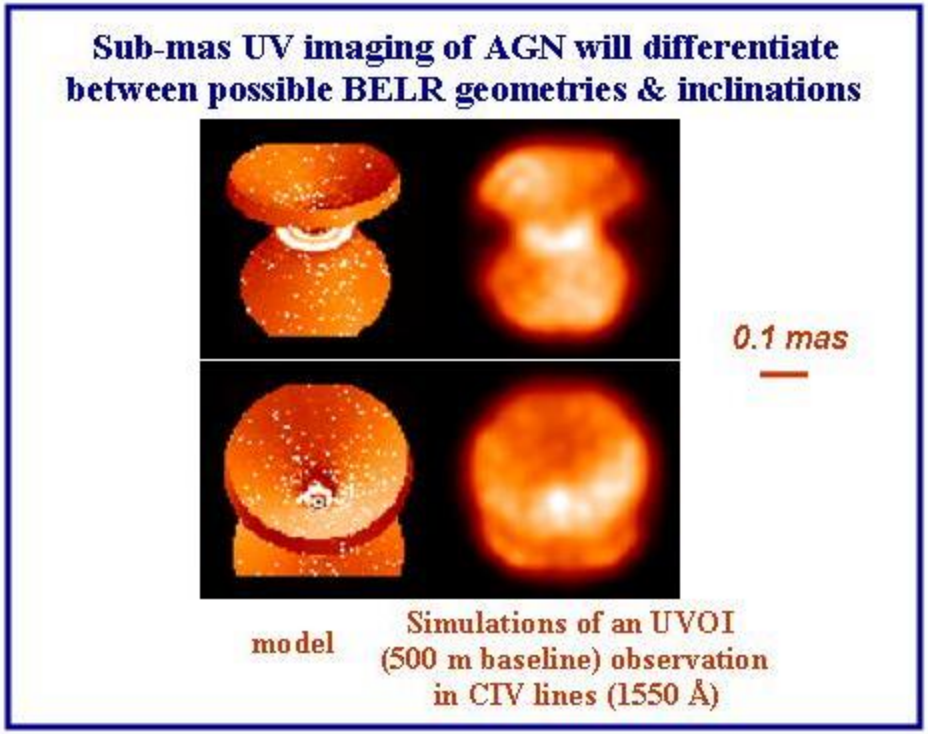


- AGN feedback?
    - ~50% of Type 1 AGN show evidence of mass outflows detected via UV and X-ray absorption (e.g. Crenshaw et al. 1999; Kaspi et al. 2001)
    - **How are these outflows driven and where do they arise?**

- The AGN can influence its host galaxy at scales ranging to Mpcs. However, in order to fully probe the critical role of the AGN in galaxy formation/ evolution, **new capabilities are required**
- Probing the inner structure of AGN requires optical/UV imaging at sub-milliarcsecond resolution
    - Can only be achieved with space-based, long baseline (0.5-1.0 km) observatories: UV/Optical interferometer (UVOI)

New Technology for multi-element sparse aperture telescopes and interferometers for UVOI:

1. Precision formation flying of 6 to 30 spacecraft
2. autonomous wave-front sensing and control of arrays.
3. Methodologies for ground-based validation of large-baseline, many element systems.



Science Requirements

- UV/Optical Spectral Imaging: the science goal is to map the emission-line structure of the outer Broad Line Region via narrow-band imaging of UV lines, e.g. Ly-α, CIV 1550Å, Mg II 2800Å. Continuum images are required at nearby wavelengths for continuum-subtraction. Re-observations on monthly timescales will be sufficient for probing changes in the emission-line gas.
- Field of View: > 4 X 4 mas
- angular resolution: ~0.1 mas
  - Requires outer primary mirror diameters of at least ~ 500m
- Spectral resolution: ~10Å
  - Corresponds to 2000 km/sec for CIV 1550Å. Better resolution would be desirable
- Wavelength band(s)
  - 1200-3000Å for continuum images
  - Need narrow bands ~10Å around emission lines.
  - Medium bands, ~100Å, for continuum subtraction
- Sensitivity
  - Ability to detect 5.0×10^{-14} ergs/cm^2/sec in CIV 1550Å

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Extragalactic Lyman-alpha Experiments in the Nearby Universe

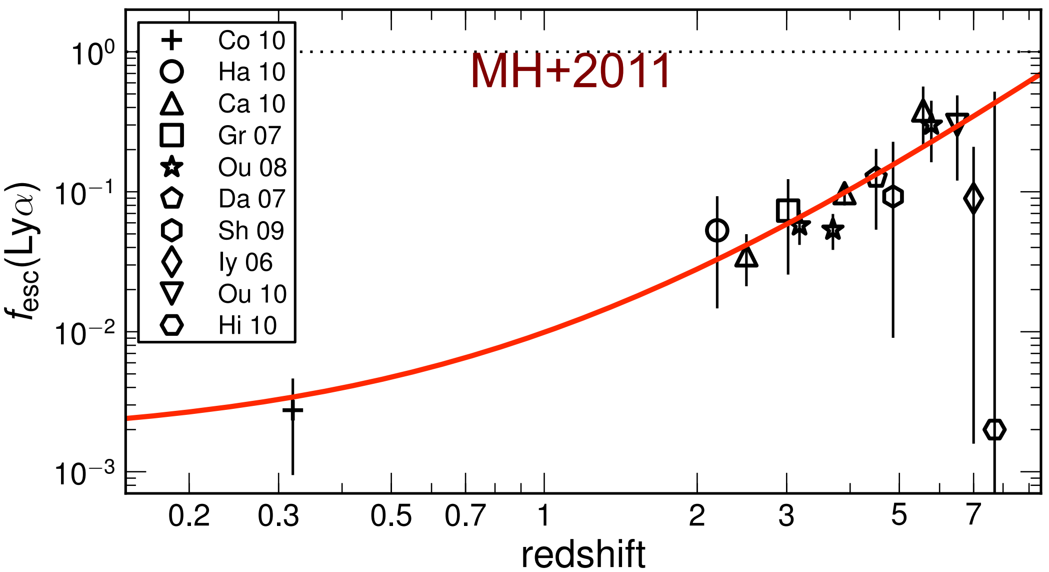
Matthew Hαyes

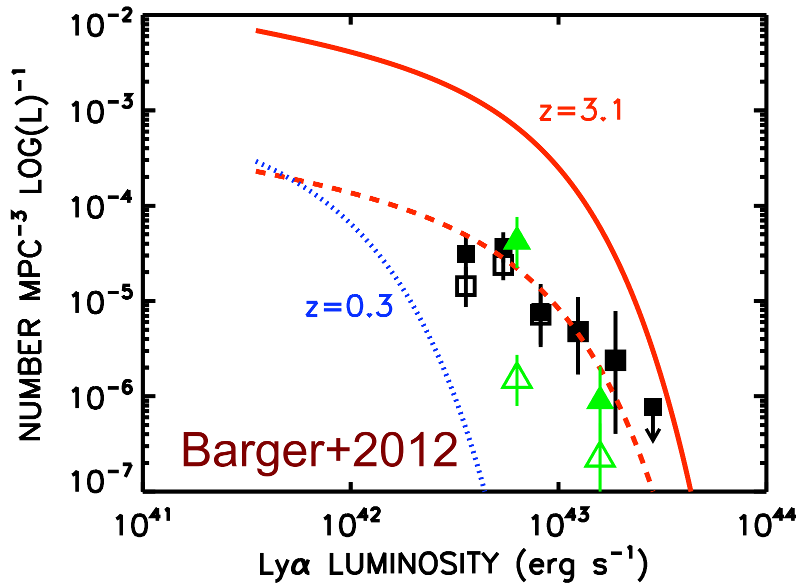
with: Goran Ostlin, J-Miguel Mas-Hesse, Hector Oti-Floranes, Daniel Kunth, Daniel Schaerer, Anne Verhamme

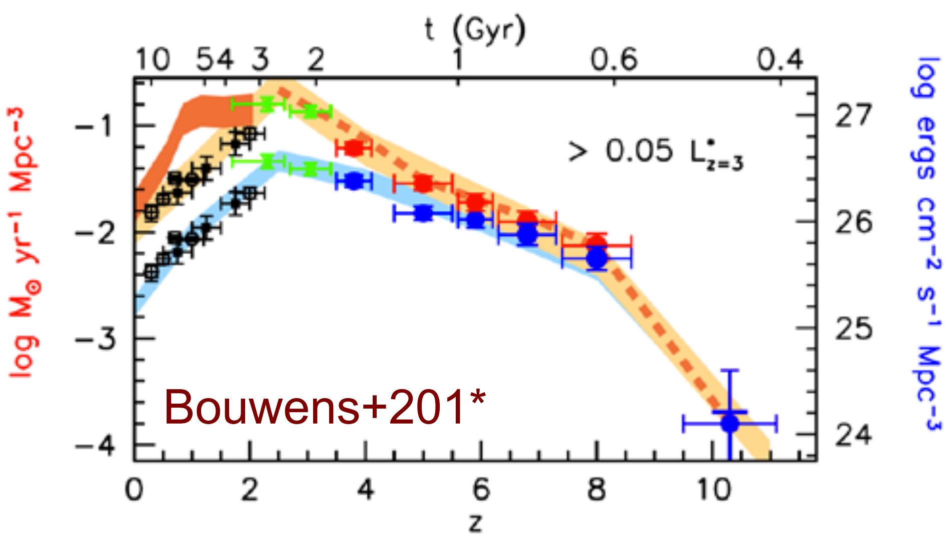
Science Context

- Lya major spectroscopic probe @ high-z
- Almost 2 decades of work done at z>2
- Probes (or could potentially):
  - Lowest mass galaxies at any epoch
  - Cosmic web
  - Dark clouds
  - Population III
- Reveals much about evolution of galaxies, dust contents, evolution, reionization etc

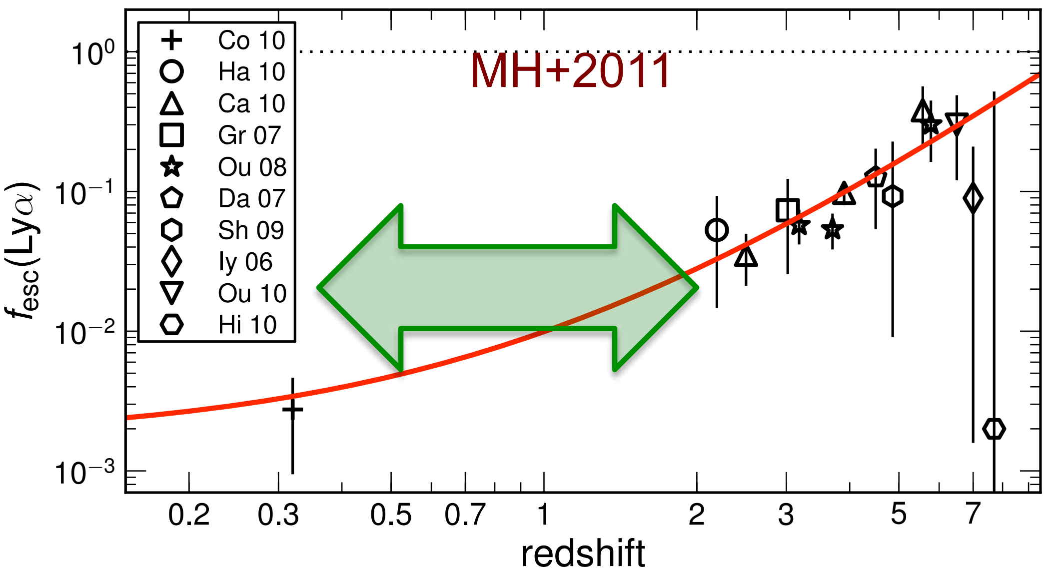
Science Context I – 2/3 of cosmic time

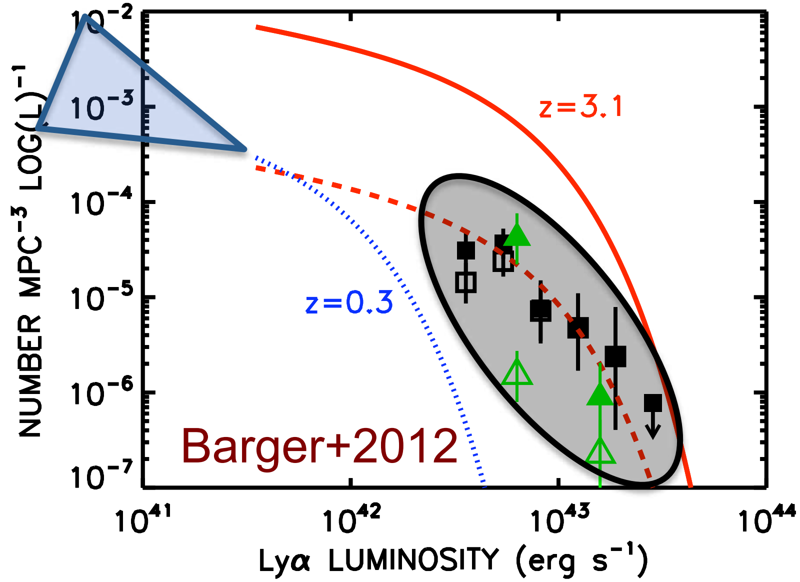


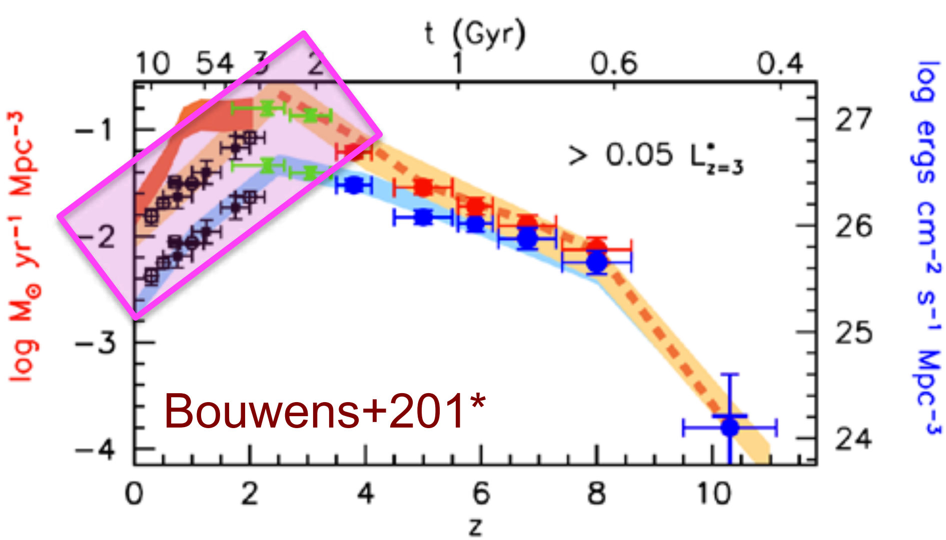




Science Context I – 2/3 of cosmic time







Current shortcomings I

- Latter 2/3 (z<2) of cosmic history not covered (includes all the decline of SFRD)
- Cannot determine Lya LF + EW distribution *at any redshift* where we can also determine what processes shape them!
- Lya resonance line – *what dictates transport?*

no telescope can do a deep blind UV survey

Surveying Lya to z = 2

- Fill in Lya statistics at z ~ 0.3 — 2
  - **UV survey telescope**
    - Probably spectrophotometry / slitless spectroscopy
    - Detect ~10^3 galaxies by Lya selection, and ~10^4 by UV → several bins of several hundred galaxies
    - Probe to < 10% L* at any given redshift bin
  - **Auxiliary data**
    - Optical/NIR spectra – Fiber spectrographs / EUCLID
    - Deep survey imaging fields – HST …
    - Direct HI measurements … ?

Surveying Lya to z = 2

- Detailed UV observations over same range
  - **Resolved spectroscopy around Lya**
    - UV absorption lines → gas covering fractions, stellar populations, kinematics
    - Higher *R* disperser, field restrictions [moveable slits, microshutter array,…] ?
  - **High-resolution ~narrowband imaging:**
    - probe very faint haloes, recover global fluxes, test efficiency of scatting
    - Small-scale variations in structure of ISM
    - Halo redshift evolution

Technical Requirements

- Mostly Spectroscopy, but some imaging capabilities :
  - slitless spectrophotometry – efficient surveying from redshift coverage
  - Intermediate *R* spectroscopy – detailed physical properties [slits or similar]
- Field(s) of View :
  - Fiducial survey : need >~0.1 deg^2. Survey camera FoV >~ 30 arcmin^2
  - Higher resolution modes can of course me smaller
- Physical / angular resolution(s)
  - Diffraction-limited performance not necessary. ~0.05 arcsec
- Spectral resolution(s)
  - R ~ 100 spectroscopy for surveying
  - R ~ 5,000 spectroscopy for detailed studies
- Wavelength band(s)
  - 1500 — 3600 AA, preferably down to restframe Ly-alpha
- Sensitivity
  - Integrated line flux down to ~e-16 cgs for survey

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GALAXY ASSEMBLY AND SMBH/AGN-GROWTH

Paul Scowen (ASU)

Rolf Jansen, Rogier Windhorst, James Rhoads, Sangeeta Malhotra, Daniel Stern, Robert O'Connell, Matt Beasley

MOTIVATION

- To address the question: How did galaxies evolve from the very first systems to the types we observe nearby?
- Driven by the recent advances in understanding the high redshift Universe, with many objects being found at $z>6$ and the need to understand Reionization
- The co-called "Cosmic Dawn" era represents the period ($z=6-8$) when the hydrogen reionization was complete
- During this period the first stars and galaxies formed, but there is a fundamental lack of understanding about how this happened – the lack of original metals means that cooling processes were very different
- Objects at $z>7$ are very faint and very rare – need widefield imaging and diffraction limited optics to be able to find and characterize targets

SPECIFIC COMPONENTS

- Evolution of the faint-end slope of the dwarf galaxy (DG) luminosity function (LF):
  - Due to steepening of the LF slope, it is possible that reionization could have been achieved by DG-generated ionizing photons – the critical quantity to understand is the escape fraction – the survey would answer this question with a statistically significant sample
- Tracing the Reionization history using Ly-α emitters:
  - A medium band survey would derive the LF of Ly-α emitters at $z>5.5$ over a wide angular area for a large sample – and address the evolution of the reionization of the IGM over time
- Lyman-continuum escape fraction of DGs and weak AGN:
  - We expect the escape fraction to be higher at higher redshifts because of the lack of metals – however this places a limit on how soon DGs could have started shining without removing all neutral-H in front of $z=6$ QSOs. This implies a downturn in the LF at $z>6.5$, which represents a rapid onset of the cosmic SFR between $z=6$-8

SPECIFIC COMPONENTS

- Hierarchical Galaxy Assembly:
  - Despite advances provided by the HST deep fields, the fine details of how galaxies assembled over z=0.5-5 are not understood
  - Better spatial sampling, depth and larger fields of view are needed – our survey would provide robust spectrophotometric redshifts for more than 5 million galaxies with m_{AB} ~28-30 mag with resolution down to a few kpc
- Epoch-dependent merger rates of galaxies:
  - Using the sample from above, we can trace the pair fraction and galaxy major merger rate down to $m_{AB} > 27$
  - Our survey would allow the mapping of the entire epoch-dependent merger rate history a full 3 mags fainter than has been possible
- Growth of super-massive black holes (SMBHs):
  - Using variability, our survey could measure the weak AGN fraction in more than 10^5 galaxies, down to m_{AB} ~28-30 mag at z<8 and thereby constrain how SMBH growth kept pace with galaxy assembly

FOUR CENTRAL QUESTIONS

- How did reionization progress during the era of 'Cosmic Dawn'? Was it an extended, a rather abrupt, or even a multiple event?
- How did the faint end of the galaxy luminosity function evolve from the onset of Pop II star formation till the end of the reionization epoch?
- How exactly did AGN and SMBH growth keep pace with the process of galaxy assembly? How did AGN growth decline with the galaxy merger rate and the cosmic SFR?
- Was there indeed an epoch of maximum merging and AGN activity around $z \simeq 1–2$ for the more massive galaxies, before the effects from the increasingly dominant Dark Energy kicked in? How does this peak epoch depend on galaxy total mass or bulge mass, and (how) does this support the galaxy downsizing picture?

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A UV/Optical/Near-IR Spectroscopic Sky Survey For Understanding Galaxy Evolution

Sally Heap, Jeffrey Kruk, Jane Rigby (NASA's GSFC),
Massimo Roberto (STScI)

Sources

Gunn+09, "Understanding the astrophysics of galaxy evolution: the role of Spectroscopic surveys in the next decade", white paper submitted to Astro2010

Ellis+12, "Extragalactic science and cosmology with the Subaru PFS", astro-ph/1206.0737v2

Scientific Goal & Investigation

Scientific Goals: To understand how galaxies evolved to form the familiar Hubble sequence of spirals and ellipticals and to establish which processes were responsible.

Scientific Investigation: To conduct a 0.2-1.7μ spectroscopic survey of at least 10^6 galaxies at z>0.8 in a mission lasting 3 years

Why Spectra? Only spectra can provide:
- accurate redshifts for coaddition, identification of clustering
- clean separation of continuum & emission-line flux
- kinematics of galaxies and galaxy cluster dynamics
- dust properties (extinction curve)
- physical conditions of the ISM, CGM and IGM
- evolution of the mass-metallicity relation
- co-evolution of galaxies & black holes

Why So Many Galaxies? To distinguish among the effects of accretion, mergers, star formation and feedback, growth of black holes; and to cover a wide variety of environments that govern star formation.

Why "only" ~1 million galaxy spectra?

Fermilab | Center for Particle Astrophysics

Projects: Sloan Digital Sky Survey (SDSS)

Visit this project's website

The Coma Cluster - a rich low redshift (z=0.0236) galaxy cluster in the SDSS

One million redshifts is the goal of the Sloan Digital Sky Survey (SDSS), the most ambitious astronomical survey ever undertaken. When complete, it will provide detailed optical images covering more than a quarter of the sky, and a 3-dimensional map of about a million galaxies and quasars. No less than 50,000 scientific papers, abstracts, and articles have resulted from this survey on topics ranging from asteroids and nearby stars to the large scale structure of the Universe; with more to come.

The SDSS completed its first phase of operations SDSS-I in June, 2005. Over the course of five years, SDSS-I imaged more than 8,000 square degrees of the sky in five bandpasses, detecting nearly 200 million celestial objects, and it measured spectra of more than 675,000 galaxies, 90,000 quasars, and 185,000 stars. Not only is this survey extremely ambitious, but it is also extremely accessible, the data being released to the scientific community and the general public in annual increments.

The SDSS uses a dedicated, 2.5-meter telescope on Apache Point, NM, equipped with two powerful special-purpose instruments. One is the 120-megapixel camera that can image 1.5 square degrees of sky at a time, about eight times the area of the full moon. The other is a pair of spectrographs fed by optical fibers can measure spectra of (and hence distances to) more than 600 galaxies and quasars in a single observation. A custom-designed set of software pipelines keeps pace with the enormous data flow from the telescope.

Lessons from SDSS:

(1) Identify the scientific requirements needed to answer the scientific question

(2) Identify the instrumentation needed to meet the scientific requirements

Our proposed survey is very ambitious: to follow on from SDSS

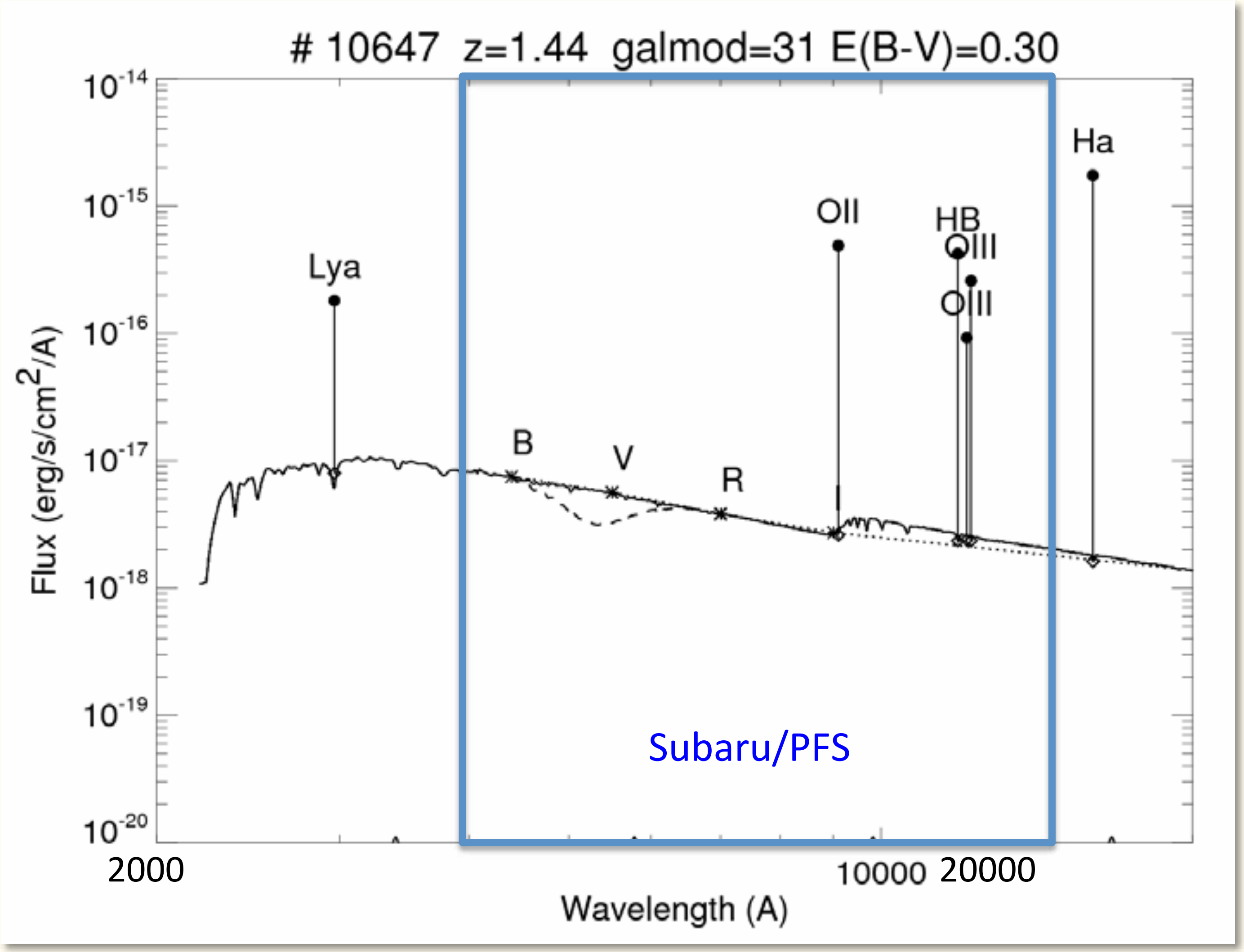
Galaxies:

SDSS is not JUST a redshift survey and imaging survey—it is a SPECTROPHOTOMETRIC survey; the spectra are superb and well calibrated, as is the surface photometry in the images. David Schlegel always reminds me that the excellence of the spectra was a well-kept secret worth keeping—we could have gotten the REDSHIFTS in much less time.

One of the primary purposes of the SDSS (at least in my mind) was to establish the properties of the galaxies in the universe at the present with precision, so that we would know what the (much smaller) samples of high-redshift objects from large telescopes might evolve INTO.

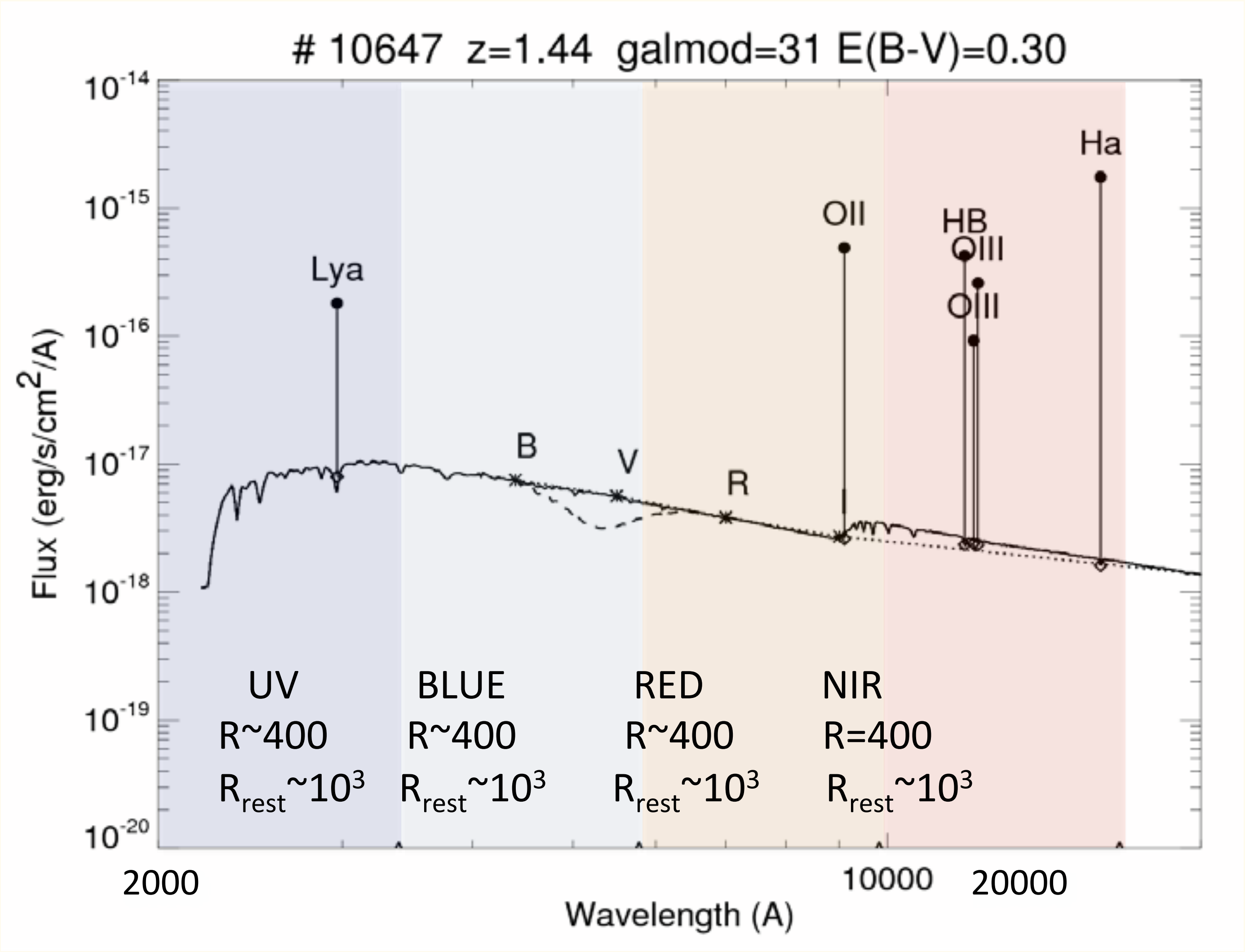
http://sdss2008.uchicago.edu/depot/gunn-james.pdf

The proposed UV-NIR spectroscopic survey will be more powerful than Subaru/PFS

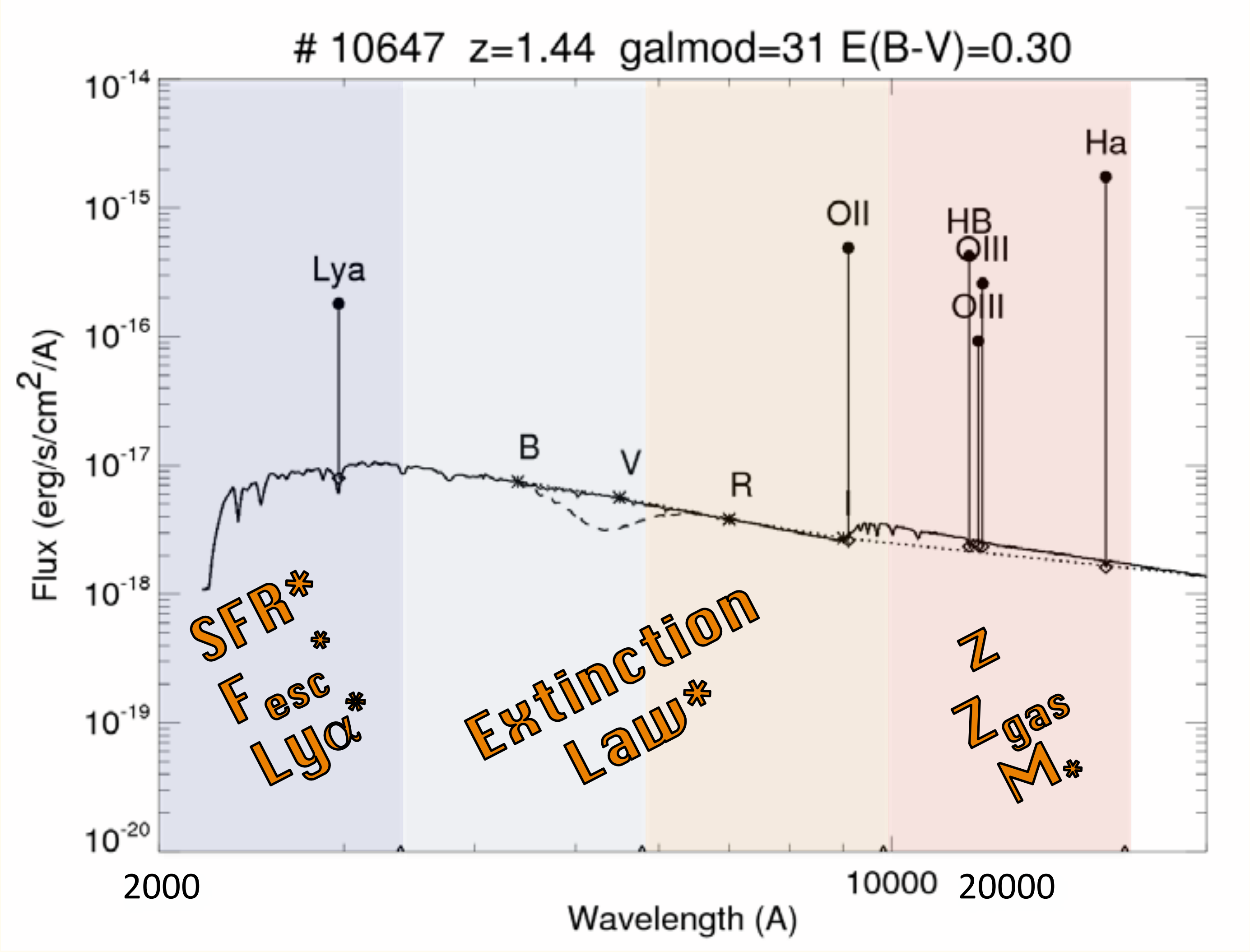


Why? Because of wider spectral range (UV-NIR) and no atmospheric problems

The UV-NIR Spectrograph Has 4 Channels



Scientific Value of UV-NIR Spectrum



Not just redshifts, which are easy to measure from emission lines,
but quantitative information on each galaxy's stars, gas, dust + CGM + IGM

Instrument/Performance Requirements

	Range under study
Telescope Diameter	0.5-2.4 m
Observation type	MOS Spectroscopy + Imaging
Field(s) of View	Ω=0.15 – 0.03 sq. deg
Angular resolution	0.94" – 0.39" (DMD mirror size)
Spectral resolving power	400-1000
Wavelength bands	4 channels together covering 0.2-1.7μ
Sensitivity	S/N per RE=7 in continuum
Dynamic range	CCD, MCT detectors
Other requirement(s)	>250X suppression of zodi over slitless Multi-object slit selector (DMD?) ≥400 galaxy spectra per exposure

Next Steps: Scientific & Technology Studies

SCIENTIFIC STUDIES

• *What is the smallest telescope* that can get good spectra (S/N=7 per RE) of at least 1 million z=0.8-2.0 galaxies?
Make simulations using the Cosmos Mock Catalog to find out.

* *Can a UV-NIR spectroscopic survey help to solve other problems*?Investigate other applications, e.g. extinction curves (Gordon+), LyC escape fraction (McCandless+), Lya (Martin+), massive stars (Wofford+) in z=1-2 galaxies

TECHNOLOGY STUDIES

* *Is a DMD-based spectroscopic survey feasible?*
Strawman slit selector is a 2000x1000 micromirror array (DMD) operating at -40 ^{o}C (for dark suppression) with a window (fused silica?) that transmits light over 0.2-1.7μ
Develop and implement a plan to bring the DMD to TRL 6

Backup Slide: WFIRST Spectroscopy & UV-NIR Spectroscopic Survey

	UV-NIR Spec. Survey	WFIRST
Scientific Goal	Optimized for 1 goal	Multiple goals
Telescope	1-m class	1.3 m
Orbit	Sun-sync. orbit at 700 km	Sun-Earth L2
Primary mission	3 years	5 years
Spectrographs	4 MOS **slit** spectrographs	**slitless** spectroscopy
Wavelength coverage	0.2-1.7 μ	0.7-2.4 μ?
Observation	Deep exposure (>3 hr) to measure stellar continuum	Medium exposure to measure emission-line λ
Limiting factor	Probably dark noise	High zodi background

WFIRST and UV-NIR Spectroscopic Survey are complementary

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Open Discussion