Active Galactic Nuclei / Quasars and the Inter-Galactic Medium

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Thanks to AGN & IGM working groups (esp. C. Péroux, IGM chair)
Why AGN?

• Every massive galaxy has a central black hole (BH); possible that feedback from accretion onto the BH shuts down its growth and that of its host bulge/galaxy

• Luminous AGN - quasars - illuminate the universe in between us and them, enabling detailed study of the intergalactic and circumgalactic media

• Massive BHs in massive galaxies: rare density peaks

• Accretion physics ultimately responsible for multiwavelength emission from AGN, including variability and emission lines in rest-frame optical/UV
This Talk

- Some science highlights of luminous broad-line AGN
- Optical broad-line AGN can be targeted by their colours, variability, and multiwavelength properties.
- Narrow-line AGN will be found in galaxy surveys.
- In broad-line AGN, we have a direct view of the continuum source; in narrow-line AGN we do not. Large samples help test the details of this unification.
- Obscured and radiatively inefficient AGN will be found by cross-correlation with multiwavelength surveys: radio, far-IR (e.g., WISE), and X-ray (e.g., eRosita).
Quasars as Light Bulbs: the Intergalactic Medium

- R~2,000, S/N = 5/pixel (SDSS)
- R~5,000, S/N = 40/pixel (ngCFHT)
- R~20,000, S/N = 20/pixel (ngCFHT)

Transmitted fraction vs. $\lambda_{\text{obs}}$ [Angstrom]
Quasars as Light Bulbs: the Intergalactic Medium

$R \sim 6500$ MR-FC mode gets you Ly-$\alpha$ forest at $2 < z < 6$

$R \sim 45,000$ directly measures Ly-$\alpha$F thermal state
The Inter-Galactic Medium (IGM)

- Luminous quasars needed for high-SNR spectra of the Ly-α forest: low surface density of targets
- Damped Ly-α absorbers: rare, high-column absorbers
- Thus, good DLA statistics require large-area surveys
- Over 1000 DLAs known, mostly from SDSS
- But very few of those have the hi-res follow-up spectra needed to study abundances...
SWG compilation of 100-250 published DLA abundances
The Inter-Galactic Medium (IGM)

- Dark surveys (R~2000) for H I column density measurements in DLAs in quasars at all redshifts z>2
- Bright survey (R~20,000) for abundance studies in DLAs at redshifts 2.5<z<3 & 3.8<z<4.5 (S/N~20 in 1 hr, g<20.5)
- ngCFHT will be first to provide survey level statistics on DLA abundances & kinematics at high resolution
- With ~5 fibers/deg² over Bright survey, all ~50,000 z>2, g<20.5 quasars will have S/N>20 spectra @ R~20,000
- Dataset on DLAs (incl. rare high/low metallicity), C IV and Mg II absorbers; quasar outflow density diagnostics
Circum-Galactic Medium (CGM)

• CGM consists of the gas reservoirs around galaxies

• Can cross-correlate Ly-α or metal absorption lines in quasar spectra with nearby galaxies of known redshift

• Can measure flux transmitted through the Ly-α forest at the galaxy redshift $z$, as a function of quasar-galaxy projected separation

• Near galaxies, transmissivity goes down: reservoirs of neutral gas around Lyman-break galaxies at $z \sim 3$
Circum-Galactic Medium (CGM)

Adelberger et al. 2005

Adelberger et al. 2003

Adelberger et al. 2005

150 km/s

0.5 $h^{-1}$ Mpc, 150 km/s

1.5 $h^{-1}$ Mpc, 150 km/s

0.5 $h^{-1}$ Mpc, 280 km/s

1.5 $h^{-1}$ Mpc, 280 km/s

$T = 0.77 - (s/0.3 \, h^{-1} \, \text{Mpc})^{-1}$

Galaxy-Ly$\alpha$ separation / ($h^{-1}$ Mpc)
Circum-Galactic Medium (CGM)

- Prochaska + Hennawi “Quasars probing quasars” papers on subarcminute-scale projected quasar pairs: study circumgalactic medium of the foreground quasar in the background quasar’s spectrum

- DLAs often detected at foreground quasar redshifts

- Implies AGN emission is anisotropic and/or intermittent

- AGN lifetimes also probed by AGN luminosity function:
AGN Luminosity Function (LF)

- Double power law
- Hopkins, Richards & Hernquist 2007:
  - Faint slope constrains how long AGN accrete at sub-Eddington rates
  - Bright slope constrains how often BHs undergo brief Eddington-limited accretion episodes (quasars)

Ross et al. 2013, BOSS LF
AGN as halo tracers: Clustering

• AGN clustering constrains the masses of the dark matter halos that AGN inhabit

• Clustering plus luminosity function measurements constrains the distribution of AGN lifetimes (or, fractional lifetimes above a given luminosity)

• AGN lifetimes and their parameter dependences can be predicted by models of galaxy formation incorporating AGN feedback and thus can test such models (Booth & Schaye; Hopkins).
AGN Clustering

• Results at $z \leq 2.2$ indicate halo mass for optically luminous quasars is $\sim 4 \times 10^{12} \, h^{-1} \, M_{\text{Sun}}$ at all redshifts.

• At high redshift collapsed halos of that mass are rare, biased tracers of DM; at low redshift, less so.

• Hopkins+07 fit $z \leq 2.2$ observations and made predictions for $z \geq 2.2$ and different magnitude limits.

• Shen+07,09: clustering measurements limited by small number statistics at $z \geq 2.9$ even for full SDSS (need to go fainter... with ngCFHT!).
Hopkins+2007: dashed line today; dot-dash line w/ngCFHT.
X-ray AGN in more massive halos; later evolutionary stage?
AGN Clustering

- *ngCFHT can constrain models by pushing to fainter magnitudes* (also, higher redshifts).

- With a 6” minimum on-sky fiber separation, *ngCFHT will have the advantage of being able to probe quasar clustering on subarcminute scales* (‘1-halo’ clustering term from subhalo clustering).
AGN as accretion physics laboratories
AGN as matter swirling into BLACK HOLES, DUDE!
Quasars: what we know

A quasar is what happens when matter spirals into a supermassive black hole through an accretion disk and heats up. Different annuli in the disk emit thermal radiation at different temperatures, with blackbody peaks ranging from the far-ultraviolet to the mid-infrared.
Pereyra et al. 2006: SDSS composite spectrum fit by disc with $T^\ast = 70,000$ K
Pereyra et al. 2006: variable component of SDSS spectra fit by disc emission with $T^* = 93,000$ K
$T^* = 70,000 \text{ K}$ and $T^* = 93,000 \text{ K}$ ... and other evidence that discs are likely inhomogeneous (Dexter & Agol)
Quasars: what we know

• A quasar is what happens when matter spirals into a supermassive black hole through an accretion disk and heats up. Different annuli in the disk emit thermal radiation at different temperatures, with blackbody peaks ranging from the far-ultraviolet to the mid-infrared.

• The resulting UV-through-optical quasar spectrum is a power-law continuum plus broad (>10^3 km/s) emission lines from collisions & recombination in ionized gas.

• Above the disk, a wind is (often? usually?) launched.

• About 1 in 4 quasars seen w/ broad absorption troughs, 1000 to 30,000 km/s wide, outflowing up to 60,000 km/s.
Accretion disk wind simulations


Cross section of density in one quadrant of a disk + wind (2-D simulation)
Accretion disk wind simulations


Cross section of ionization level in one quadrant

Wind=Obscuring Torus?
Another potential "torus" (source of obscuration): turbulent inflow

Hopkins & Quataert 1007.2647

also, outflow:
Accretion disk wind simulations


Cross section of ionization level in one quadrant

Broad Emission Lines from rotating base of outflowing wind
Black Hole Masses in AGN

- **Goal:** AGN BH mass function over cosmic time

Single-epoch mass estimates can be made, but must be calibrated using multi-epoch reverberation (or ‘echo’) mapping.

Kelly & Shen 1209.0477

orange: measured BHMF, blue: inferred BHMF
Black Hole Masses and Reverberation Mapping

• Goal: BH mass function over cosmic time

• Single-epoch mass estimates can be made, but must be calibrated using multi-epoch reverberation (or ‘echo’) mapping

• To date, done almost exclusively at z<0.3; ngCFHT will extend to 1<z<4

• Ionizing continuum fluctuations precede emission-line fluctuations; time resolution is used to substitute for spatial resolution

• Peterson arXiv:1109.4181, Shen 1302.2643
Black Hole Masses and RM

• Broad Emission Line Region (BELR) gas responds to the gravity of the black hole; linewidths of $>10^3$ km/s mean gas is deep in the BH potential

• For a gas atom in a circular orbit, $M_{BH} = \frac{V^2 R}{G}$
Black Hole Masses and RM

- Broad Emission Line Region (BELR) gas responds to the gravity of the black hole; linewidths of $>10^3$ km/s mean gas is deep in the BH potential

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- For gas in circular orbits, $M_{BH} = f W^2 \frac{R}{G}$ where:
  - $W$ is a measure of the width of the emission line
  - $f$ is a geometrical and kinematic factor
Black Hole Masses and RM

- $M_{\text{BH}} = fW^2R/G$

- In Reverberation Mapping (RM), the BELR distance $R = c\tau$, where $\tau$ is the mean time delay between flux changes in the continuum and in the emission line.

- The scaling factor $f$ is measured by requiring that RM AGN match the $M_{\text{BH}}-\sigma_*$ relation, on average.

- Many factors are folded into $f$.

- Empirically, the scatter in RM $M_{\text{BH}}$ is very low.
Black Hole Masses and RM

- Reverberation mapping requires spectroscopy at:
  - low resolution
  - high-S/N (>30/resolution element at line center)
  - multiple epochs spanning \( t = 3 \tau \)
  - time sampling of \( \Delta t \) for time resolution of \( \sim 2 \Delta t \)
RM campaign with ngCFHT

- An efficient RM campaign at $z>0.3$ requires a high surface density of targets, which in turn requires:
  - a wide field of view
  - the ability to study faint targets
  - coverage for H$\beta$, Mg II, C IV at increasing redshift
  - time sampling over days, weeks, months, years: required: time dilation at high $z$, $R \sim L^{0.5}$, and need to observe until enough variation observed
- e.g., Czerny et al.1212.0472
RM campaign with ngCFHT

• Same pointing as the Dark-Deep survey (1.5 deg$^2$), adding 20% to time required (from 612 to 735 hours)

• ~545 broad-line AGN at all redshifts in that area, targeted in 5 of 6 D-D configurations, +1 new

• 17 visits per configuration (102 total), 6 hours each

• High-luminosity AGN at z~4 require 6 years for RM; low-luminosity AGN at z~1-2.5 require ~few months

• RM can cope with erratic time sampling (Zu et al.)

• Multi-epoch spectra also probe absorption variability
Watson et al. 2011 (1109.4632): Reverberation mapping as a distance measure

\[ R = c \tau \]

Empirically, \[ R \sim L^{0.5} \]

Flux \[ F \sim L/D^2 \]

\[ D \sim (L/F)^{0.5} \sim R/F^{0.5} \]

Thus, \( \tau/F^{0.5} \) is a potentially useful distance measure.
Quantity $\frac{\tau}{F^{0.5}}$ is a distance measure:

AGN Hubble diagram of $D$ vs. $z$ to $z=4$, intrinsic ±1σ scatter equals ±0.2 mag per object.

155 AGN at $z<1.7$, 120 AGN at $z>1.7$, assuming 50% $\tau$ measurement rate.
RM and Dark Energy at 0.2<z<4

Riess et al. “Gold” SN sample

ngCFHT AGN RM sample would match and...
RM and Dark Energy at 0.2<z<4

>4σ detection of any |Δw|>0.07 at 1.7<z<4

>4σ detection of |w_a|>0.1 where w(z)=w_0+w_a z/(1+z) (Mehta et al. 2012)
Key Points for AGN

- AGN science can be done using a small fraction of survey fibers (dark and bright time)

- AGN science will be enhanced by:
  - High UV/Blue sensitivity
  - Wide wavelength coverage (worth keeping R~6500 800-fiber “MR-FC” mode for PI projects on IGM)
  - Accurate spectrophotometry (continuum vs. emission or absorption line variability)
Inhomogeneous accretion discs and absorbers

QSO blast wave encounters moderately dense ISM cloud.

Shock wave propagates in cloud on crushing time $t_{cc}$, cloud is destroyed by K-H in $t_{KH} \approx 20t_{cc}$, and is accelerated to $\sim v_{sh}$ in $t_{drag}$.

At $t > t_{KH}, t_{drag}$, original cloud is shredded into cloudlets traveling at $\sim v_{sh}$ and compressed by hot post-shock gas.
Serendipity: Rare Objects in SDSS

• L and T dwarfs (Fan et al., Strauss et al.)
• Type 2 (narrow-line) quasars (Zakamska et al.)
• Nearby Cool White Dwarfs (Hall / Dufour et al.)
• Extreme Emission-Line Galaxies ("Green Peas")
• Low Accretion Rate Magnetic CVs (Szkody et al.)
• Infalling Broad Absorption Line quasars (Hall et al.)
• etc. (weak-lined quasars, hypervelocity stars, ...)

What is SDSS J115227.92+352221.6? Background quasar?
ngCFHT AGN Legacy Datasets

- low-res spectra of 375,000 $z<2.2$ quasars, 200-400,000 $2.2<z<4$ quasars, 26,000 $z>4$ quasars ($150-200/\text{deg}^2$) [Dark-Wide, Dark-Medium surveys]
- hi-res spectra of 50,000 $z>2$ quasars ($5/\text{deg}^2$) [Bright-time survey]
- 102 epochs of low-res spectra for 545 broad-line AGN for variability studies (continuum, emission, absorption) [Dark-Deep survey]

Mahalo!

BOSS quasar spectra