Massive Outflows from Radio-Loud Quasars

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4C 37.43 Continuum
4C 37.43 [O III]
4C 37.43 E1
Keck II
LRIS

$F_\lambda$ (10$^{-17}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$)

- [Ne V] $\lambda 3346, 3425$
- [O III] $\lambda 3727$
- [Ne III] $\lambda 3869, 3967$
- H$\delta$
- H$\gamma$
- [O III] $\lambda 4363$
- He II $\lambda 4686$
- H$\beta$
- [O III] $\lambda 4959, 5007$

$\lambda_0$ (Å)
Characteristics of EELRs around Low-Redshift Quasars

- Generally show no morphological correlation with continuum optical or radio structure.
- Luminous EELRs virtually exclusively found associated with steep-spectrum quasars (Boroson & Oke 1984).
- Gas is photoionized by the quasar:
  - Metallicities typically are around 1/3 solar
  - Two density regimes:
    - Low density (~1 cm-3), ~ unity ff
    - High density (~400 cm-3), ~10^{-5} ff
- High density regions are in thin (~0.1 pc) filaments; lifetimes ~10^4 years.
Origin of Gas

❖ We can generally exclude:
   ▶ Gas deposited from cooling flows.
   ▶ Tidal debris.
   ▶ Superwinds from starbursts.

❖ We have good evidence that the most likely origin for the gas is a large-solid angle blast wave accompanying the launching of the radio jet.

❖ Total mass of gas up to $\sim 3 \times 10^{10} M_\odot$. 
3C 48 (R band)
PSF subtracted
3C 48 WFPC2 F555W

3C 48 QSO Spectrum (Gemini GMOS IFU)
3C 48 QSO Spectrum
(Gemini GMOS IFU)
Properties of the 3C48 Outflow

❖ The high-velocity component has $\sim 7 \times$ the luminosity of the classical narrow-line region.

❖ Projected velocity $\Delta v = 491 \pm 40$ km s$^{-1}$.

❖ Gupta et al. (2005) find C IV absorption in the quasar spectrum at $\Delta v = 780$ km s$^{-1}$.

❖ Total mass depends inversely on the density:
  ‣ From an upper limit of 100 cm$^{-1}$ (from [O II]), $M_H \geq 7 \times 10^8$ M$_\odot$.
  ‣ But strong [O III] indicates that most of the mass may be at 10 cm$^{-1}$ or less, in which case $M_H \geq 10^{10}$ M$_\odot$. 
Fu & Stockton (2007a)
Luminous EELRS in the local universe are exclusively associated with accretion of sub-solar-metallicity gas, most likely from the merger of a large, gas-rich, late-type galaxy.

- Correlation between EELRs and BLR gas gives the first direct evidence that gas from a merger can reach to within 1 pc of the supermassive black hole.

- Reason for restriction to sub-solar metallicities is not clear.
  - Possibly may be related to radiative coupling of quasar luminosity to dust and gas, delaying accretion and the production of the radio jet.
If luminous EELRs are, indeed, outflows initiated by shocks driven by radio jets, they may indicate another mode of feedback that could be important for galaxy formation in the early universe.

AGN feedback considered in recent discussions:
- “Quasar-mode” feedback—radiative coupling of quasar energy output to gas and dust.
- “Radio-mode” feedback—FR I radio jets keep cluster or group medium warm, preventing gas from cooling, accreting, and forming stars.

Mergers of gas-rich, sub-solar-metallicity objects with galaxies containing SMBHs are likely to be common in the early universe.
Assume $z = 2.5$, image FWHM $\sim 10$ mas with LGSAO $\rightarrow$ 80 pc resolution. Comparison with VLBI maps could clarify relation to the radio jet.

Would target CSS quasars with broad, double-peaked, or strongly asymmetric [O III] lines. Sample selection can be done with 4–8 m class telescopes.

Would also look for outflows in C IV absorption. Again, can be done with smaller telescopes.
Are the observations feasible?

❖ For definiteness, consider TMT/IRIS case with finest IFU scale (4 mas pixels).
❖ Assume quasar at $z = 2.5$, luminosity of HV outflow in [O III] ~ 10× that of 3C 48, and 30% throughput for telescope/instrument.
❖ Mean surface brightness gives ~ 0.002 e$^{-}$ s$^{-1}$ pixel$^{-1}$ per image plane at line half peak point.
❖ This may be pessimistic, since, at AO resolutions, the surface brightness of filaments, etc., may be much higher than the mean.
Instrumental Desiderata

❖ IFUs: Larger field, smaller spectral range vs. smaller field, wider spectral range?
  › LF option suitable for mapping distribution and velocity structure of the outflow.
  › SF much more efficient for obtaining lines needed for photoionization analysis to determine physical properties (e.g., total mass).

❖ IFUs: Slicer vs. lenslet + fiber designs?
  › Slicer approach probably preferred, if feasible.

❖ Detectors
  › Highly desirable to be sky-background limited between the airglow lines at \( R \gtrsim 4000 \) and at 4 mas pixel scale.