New developments are paving the road to the use of quasars as distance indicators:

A “main sequence” organizes the diverse quasar properties and makes it possible to identify quasars in different accretion states

Even if major observational constraints indicate powerful high-ionization wind, part of the broad line emitting regions remains “virialized”
A MAIN SEQUENCE FOR TYPE-1 QUASARS

The “main sequence,” also known as the “eigenvector 1 sequence”

Radio, IR, UV and soft and hard X-ray properties change systematically along the sequence; the MS allows for the definition of spectral types

The sequence is a starting point to connect observational parameter spaces to theoretical parameter spaces of quasars seen as accreting systems

Two populations, A (wind dominated) and B (disk dominated, large fraction radio-loud) associated with a critical Eddington ratio and probably with different accretion modes

Extreme Pop. A: highly-accreting sources, of interest for cosmology

(Sulentic et al. 2000, 2002, c.f. Shen & Ho 2014)

(Wang et al. 2013; Marziani & Sulentic 2014)
Several methods aimed at obtaining the Hubble diagram for quasars

<table>
<thead>
<tr>
<th>Sources</th>
<th>Parameters</th>
<th>Basic equation</th>
<th>Reference</th>
<th>Virial</th>
</tr>
</thead>
<tbody>
<tr>
<td>extremely accreting quasars (xA)</td>
<td>Hard X-ray slope, velocity dispersion</td>
<td>$D_\bullet = \frac{1}{4\pi} \left[ \frac{l_0(1+a \ln \dot{m}<em>{15}) f</em>{\text{Bol}} R_0}{G\kappa_n} \right]^{1/2(1-\alpha)} \sqrt{\frac{V_{\text{FWHM}}^{1+(1-\alpha)\gamma}}{F_{5100}}}$</td>
<td>Wang et al.2013</td>
<td>V</td>
</tr>
<tr>
<td>extremely accreting quasars (xA)</td>
<td>virial velocity dispersion: FWHM(Hβ) Eddington ratio = const</td>
<td>$L \propto \text{FWHM}(\text{H}\beta)^4$</td>
<td>Marziani &amp; Sulentic 2014</td>
<td>V</td>
</tr>
<tr>
<td>general quasar populations</td>
<td>X-ray variability, velocity dispersion</td>
<td>$\log \frac{L}{\text{erg s}^{-1}} + 4 \log \frac{\text{FWHM}}{10^3 \text{km s}^{-1}} = \alpha \log \sigma_{\text{ms}}^2 + \beta.$</td>
<td>La Franca et al. 2014</td>
<td>V</td>
</tr>
<tr>
<td>mainly quasars at $z&lt;1$</td>
<td>Reverberation mapping time delay $\tau$</td>
<td>$\tau/\sqrt{F} \propto d_L$</td>
<td>Watson et al 2011, 2013; Czerny et al. 2013; Melia 2015</td>
<td></td>
</tr>
<tr>
<td>general quasar populations</td>
<td>non linear relation between soft X and UV</td>
<td>$\log(F_X) = \Phi(F_{UV}, D_L) = \beta' + \gamma \log(F_{UV}) + 2(\gamma - 1)\log(D_L)$</td>
<td>Risalti &amp; Lusso 2016</td>
<td></td>
</tr>
</tbody>
</table>

The physical foundation of xA-based methods is the Eddington ratio “asymptotic” behavior expected from optically thick ADAFs for dimensionless accretion rates $>> 1$

$$L_\bullet = \ell_0 \left(1 + a \ln \dot{m}_{15}\right) M_\bullet$$

e.g., Mineshige et al.2000; Wang et al. 2013; Sadowski et al. 2014
A virialized low-ionization broad emission line region present even at the highest quasar luminosities, coexists with high ionization winds

$\text{CIV$\lambda$1549 (high-ionization)}$ vs. $\text{H}\beta$ (low-ionization)

at low $z$, $L < 10^{47}$ ergs/s

at $z \sim 1.5$, $L > 10^{47}$ ergs/s

Marziani et al. 2010; Sulentic et al. 2007, Marziani et al. 2016

said parenthetically:

use of CIV as a black hole mass estimator can yield to a strong bias dependent on the location of the eigenvector 1 sequence
Extreme Pop. A sources
(super-Eddington accreting massive black holes (SEAMBHs))
Wang et al. 2003

Simple selection criteria from diagnostic line ratios
1) optical Fe II λ4570 blend/Hβ > 1.0
2) UV Al III λ1860/Si III]λ1892>0.5 & Si III]λ1892/C III]λ1909>1

Advantages | Drawbacks
---|---
Easy to recognize large samples up to z~ 4 | The physical basis of the selection criteria is poorly understood
relevant properties should scatter with small dispersion around a well defined mean | xA sources are poorly understood in terms of emission properties
Clustering around a limiting Eddington ratio, as expected from theory | Orientation effects on line width not known
consistent accretion disk properties, similar metal enrichment | Consistency of properties at high and low z barely tested

Very similar spectrophotometric properties over a range of L ~ 10^{44} - 10^{48} erg/s

\[ L(\delta v) \approx \left( \frac{z^2}{4\pi chG^2} \right) f_s \left( \frac{L}{L_{Edd}} \right)^2 \left( \frac{v}{v_\text{c}} \right) \left( \frac{n_H U}{n_H U_{\text{c}}} \right) (\delta v)^4, \]

Marziani & Sulentic 2014
Some relevant open issues

relevant for the use of quasars as distance indicators

The connection between physical (accretion) and observational space: the eigenvector 1 sequence is still poorly understood. A major feat would be the ability to assign to each quasar a value of $M_{\text{BH}}$, Eddington ratio, spin, and viewing angle with a relatively small uncertainty. (Well-suited for instruments with NUV/Vis/NIR multiplexing ability)

The accretion disk structure and its connection to the dynamics of the line emitting gas. (Theoretical modeling and line/continuum fitting)

The anisotropy and multifrequency properties of radio-quiet quasars

The metal enrichment of the broad line region from circumnuclear star formation (SPH, chemo-dynamical modeling of galactic nuclei)

The potential for cosmology is enormous.

Constraints from a sample of 400 mock quasars with $\text{rms} = 0.4 \text{ dex}$ over $1 < z < 3$ using the method based on xA and the supernova photometric survey (Campbell et al. 2013)