Cosmology with AGN:
Can we use Quasars as Standard Candles?

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Can we use Quasars as Standard Candles?

*standard candle* for cosmological studies:

1. standard or standard-izable emission
2. easy to observe over a wide redshift range

**Quasars**

Very luminous objects up to high redshift (z\~7), but:

- **not stable** in their light output (duty cycle)
- vary in the wavelengths of light they produce
Starting point: the **non-linear relation** between X-ray and UV emission in quasars:

\[ \log L_{2 \text{ keV}} = \alpha \times \log L_{2500} + \beta \]

\[ \alpha \approx 0.6, \beta \approx 9, \text{ and } \sigma \approx 0.35 - 0.4 \]

\[ \log F_X = \alpha \ \log F_{UV} + (2 - 2\alpha) \ \log D_L + \beta' \]
Quasars as Standard Candles

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\[
D_L = \frac{(1+z)}{\sqrt{\Omega_k}} \sinh \left[ \sqrt{\Omega_k} \int_0^z \frac{dz}{H_0 \sqrt{\Omega_M (1+z)^3 + \Omega_\Lambda + \Omega_k (1+z)^2}} \right]
\]

\[
\Omega_k = 1 - \Omega_M - \Omega_\Lambda
\]

**Free parameters:** \(\Omega_M, \Omega_\Lambda, \beta, \alpha, \delta\) (intrinsic dispersion)
A Hubble Diagram for quasars

Literature: ~1250 QSOs with X-ray and UV measurements

~800 quasars

(no reddening, no galaxy contamination)

Risaliti & Lusso 2015
The non-linear relation between $L_X$ and $L_{UV}$ in quasars

- Which precision we can achieve in distance estimates with quasars?
- Is the method reliable (physical and observational systematic effects)?
- Is it possible to obtain significant results with the instruments available TODAY (XMM-Newton, Chandra...)

‘Quasars at all cosmic epochs’, Padova, 2-7 April 2017
The non-linear relation between $L_X$ and $L_{UV}$ in quasars

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NEW SAMPLE:

SDSS-DR7/DR12 + 3XMM-DR6
~7,500 quasars
(+COSMOS, Champ, High-z quasars....)
The non-linear relation between $L_X$ and $L_{UV}$ in quasars

All quasars with X-ray and UV observations

‘Quasars at all cosmic epochs’, Padova, 2-7 April 2017
The non-linear relation between $L_X$ and $L_{UV}$ in quasars

Homogeneous sample (clean from reddening, absorption, Eddington bias)

N = 2053
$\sigma = 0.28$

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Quasars as Standard Candles: the redshift (non) evolution

Scatter due to differences in Luminosity distances in each bin

\[ \delta = 0.30 \]
\[ \alpha = 0.55 \pm 0.06 \]

\[ \Delta \log z = 0.08 \]

\[ \delta = 0.28 \]
\[ \alpha = 0.60 \pm 0.05 \]

\[ \delta = 0.27 \]
\[ \alpha = 0.56 \pm 0.04 \]

\[ \langle z \rangle = 0.81 \]

\[ \langle z \rangle = 1.19 \]

\[ \langle z \rangle = 1.76 \]

\[ \text{~Redshift independent!} \]

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Quasars as Standard Candles: the New Hubble Diagram

Hubble Diagram with ~2,000 quasars
Quasars as Standard Candles: the physical relation
Dispersion in the Hubble Diagram

‘Quasars at all cosmic epochs’, Padova, 2-7 April 2017
Quasars as Standard Candles: tests of cosmology

\( w_0 - w_a \) contour plot \( (w = w_0 + w_a(1-a)) \)

CMB+BAO+WL

Planck Collaboration 2016
Quasars as Standard Candles: tests of cosmology

\[ w_0 - w_a \text{  contour plot  } \quad (w = w_0 + w_a(1-a)) \]

CMB+BAO+WL +SNe

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Quasars as Standard Candles: tests of cosmology

\( w_0-w_a \) contour plot

CMB+BAO+WL
+SNe
+QSOs

Planck Collaboration 2016
What do we need to probe cosmology with quasars?

**Surveys:**
- Increase of 3XMM catalog, Chandra PSC
- XXL, COSMOS: already ~30-40% of the sample
- Champ, Stripe 82, Deep fields ...
- NEW SHALLOW (~10-30 ks) SURVEYS: big increase a z>2

**Pointed observations of bright quasars at z>3**
~20/30 ks observations of 30 bright z>3 quasars
~15 quasars == 1 SN1a
All observations available today equivalent to 1 SN at z>3
What do we need to probe cosmology with quasars?

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**XMM (+SDSS) can populate the Hubble Diagram at z>2:**
- A unique, complementary cosmological probe at z=2-5
- Refined measurements of cosmological parameters, e.g. w(z)