QUASARS: CURRENT PROBLEMS

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Part the First: some important facts

I. Definition and history

1960 -- 3C48 identified with starlike optical source

1963 -- 3C273 likewise; broad emission lines identified at $z = 0.158$
($z = 0.367$ for 3C48, same year)

Definition from Schmidt, 1964:

a. Starlike, identified with radio source
b. variable
c. large UV excess
d. broad emission lines at high redshift

Today, several hundred are known; highest $z = 3.53$ as of two days ago.
Schmidt's definition only slightly revised:

a. starlike, may be strong compact radio source (only a few per cent)

d. may be narrow absorption lines at $z_{abs} \lesssim z_{em}$.

Point -- that our understanding of the phenemenon is little advanced over early sixties, despite much observational and theoretical effort. Still a botanical approach -- observe and classify.

II. Continuous Spectrum

1. Optical: $F_\nu \propto \nu^{-\alpha}$; $\alpha \sim 0.5 - 1.5$ usually
(about 20 per cent have α up to 6.0)

Radio: $\alpha_{rad} \sim 0.5$ for compact core, which exists in only a few per cent of optically identified QSO's; $L_{rad} \sim L_{opt}$ for these. Radio may be extension of optical in these objects. For radio quiet, $L_{rad} < 10^{-3} L_{c}$

X-ray: seen in 3C273 and many Seyfert/radio galaxy nuclei.

2. Variability of the continuum -- usually correlated with presence of strong radio core. Perry (1976) classifies types of variability:

a. Short term flucuations ($\lesssim$ 1 day)
b. long term flucuations ($\sim$ years)
c. Combination of (a) and (b)
d. Other

Variation at different frequencies is usually uncorrelated. Polarization also varies.

3. VLBI: complex structure of the radio core, $\sim$ 1 pc in size. Some double sources, some single/unresolved. Apparent superlight expansion in a few.

4. Synchrotron emission: if self-absorption turnover is seen, can derive radio source parameters (model dependent, however):

   $B \sim 10^{-4} - 10^{-2}$ g

   $U \sim 10^{53} - 10^{57}$ erg

   $u_{rel}/u_{mag} \sim 10 - 10^{6}$: particle dominated

   $u_{rad}/u_{mag} \sim 1 - 10^{3}$: may be Compton problem

5. Inverse Compton problem: variability $\Rightarrow$ small size $\Rightarrow$ high $u_{rad} \Rightarrow$ Compton lifetime $\ll$ synchrotron lifetime for electrons. Radiation should come out at frequencies $\gg$ radio. (Maximum brightness temperature, 10^{12} K).

6. If radio = synchrotron, is optical once Compton scattered? Or is it due to another (higher B, higher electron energy) region? Is the X-ray source Compton scattered optical emission?

III. Line Spectra

1. Emission lines

   a. Permitted lines: broad ($\Delta v_{int} \sim 10^{4}$ km s^{-1}) with internal "cloudlike" structure. Often asymmetrical. H, He, CIV, MgII, FeII . . . Occasionally with narrow core, though this is often weak in QSO's.

   b. Forbidden lines: OIII, NeV, OII, . . . Resemble narrow cores of Balmer lines, with $\Delta v_{int} \sim 10^{3}$ km s^{-1}.

   c. No definite cases of line variability, but a few single events reported. Little monitoring.

2. Absorption lines

   a. Seen in a few low-z objects (may not be in observable part of the spectrum; IUE recently found Lyα absorption in 3C273). Most high z objects show several absorption systems (distinct z_{abs} values $\neq z_{em}$).

b. $z_{abs} \lesssim z_{em}$ in most cases (a few have $z_{abs} > z_{em}$ but with $z_{abs} - z_{em} \ll z_{em}$). Can have relative Δv_{rel} (from $z_{em} - z_{abs}$) as high as 0.6c; more typical values are $10^3 - 10^4$ km s^{-1}.

c. Multiple systems -- can have Δz_{abs} from very small to ~ 1.0 in one object. Range of ionization states within one system: CII, SiII, NV, Lyα, . . . Also 21 cm absorption found at (optical) z_{abs} in a few -- 3C286, 1331+170 (I think).

Also many lines (hundreds) to the blue of Lyα; $\tau_{Ly\alpha} \lesssim 1$ clouds? Very narrow lines: $\Delta v_{int} \sim 10$ km s^{-1} (on the order of the sound speed in a gas at 10^4 K) -- this number may be resolution limited still. (Exceptions: P Cyg profiles, $\Delta v_{int} \sim 10^3$ km s^{-1}, seen in two or three -- e.g., PHL 5200.)

3. Lyman continuum absorption? Data still scanty; apparently seen in a few objects at $z_{abs} \sim z_{em}$; in a few at $z_{abs} < z_{em}$; in a few others either absent or at $z_{abs} \ll z_{em}$.

IV. Relation to other active nuclei

1. Seyfert nuclei (usually spiral galaxies)

Share broad optical emission lines and (in Seyfert 1's) the nonthermal continuum; X-ray sources, usually radio weak, with an extended ($\sim$100 pc) low luminosity source, no core.

2. Radio galaxy nuclei (usually elliptical galaxies)

Optical spectra akin to that of Seyferts; radio source strong and double, sometimes with compact core.

3. Lacertids

Starlike, with very weak spectral features and surrounding nebulosity with stellar absorption lines (cD's??) Violently variable, highly polarized.

Part the Second: current problems

I. State of the atmosphere

1. Current conception of geometry:

   A very small core with continuous emission (radio core, optical and X-ray) and containing the unspecified energy source

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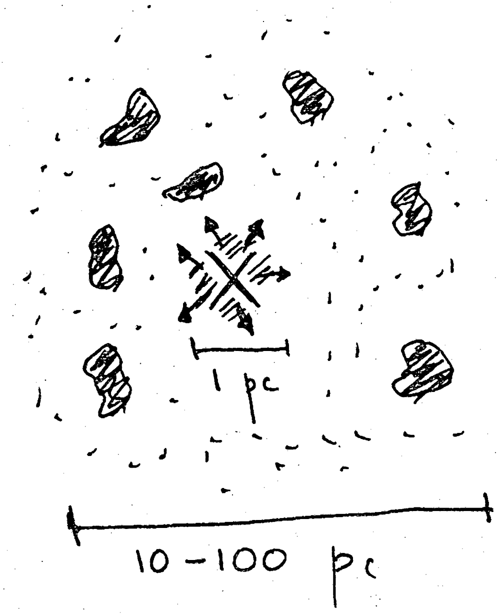
   an extended atmosphere with line emitting gas in clumps (most likely transient) perhaps in a hotter intercloud medium (which could be the extended radio source). "Clumps" may or may not be the source of the absorption lines.



2. Thermal state

   Forbidden line ratios $\Rightarrow n_e \sim 10^4$, $T_e \sim 10^4$. Broad permitted lines must arise in gas with $n_e > 10^7$ (quenching density for forbidden lines).

   Gas assumed photoionized by high energy photons from the core -- detailed calculations can explain line ratios fairly well if Balmer line self absorption is included and if optical continuum is extrapolated to higher energies.

3. Dynamics

   Want to explain Δv_{int} for emission lines, also high relative velocities of absorption lines (if they arise local to the QSO).

   Clouds in the picture above will feel radiation pressure -- enough to explain v_{int} but not the high velocity absorption. "Hot" expanding wind (relativistic wind, or shock heated) produces similar results.

   Alternatively: velocities may be due to infall -- accretion onto a massive central object -- or rotation/random motions. Less work has been done on such schemes.

II. Origin of the absorption

1. Due to intervening stuff? Would account for high velocity from the Hubble expansion -- also one definitely confirmed case would establish the cosmological nature of QSO's. However need <u>many</u> intervening (proto?)galaxies, with high ionization state and apparently "normal" abundances.

2. Physical conditions in absorbing gas: fine structure lines (absence or weakness) $\Rightarrow n_g \lesssim 10^3$ cm^{-3}; ionization state $\Rightarrow$ distance of cloud from QSO $\gtrsim$ kpc if ionized by central source (<u>however</u> recent work by Sarazin finds this does not hold if the lines are optically thick).

3. Possibly difficult to accelerate gas to $v \sim 0.6$ c while maintaining low internal velocities: $\Delta v_{int}/v_{\underline{re}\ QSO} \sim 10^{-3}$. (However this ratio also holds for nova ejecta!) (which <u>are</u> local)

4. Statistics of galaxy and protogalaxy sizes and spatial densities are obviously important, and as yet not really well known (notwithstanding the large number of papers pro and con the question). Burbidge (1977) calculated galactic coronae of size 50 - 100 kpc needed to explain the observed frequency of absorption systems. Note also, identification of lines or systems in a given object is very difficult and somewhat subjective.

5. Those with $z_{abs} \sim z_{em}$, and the P Cyg profiles, are generally accepted as being local to the QSO; the few 21-cm lines with $\Delta v_{int} \sim 5$ km s^{-1} and dimension $\sim$ tens of kpc (3C286, e.g.) are almost surely intervening; as for the rest . . .

III. What is the distinction between radio strong and radio quiet objects?

This hasn't been mentioned much in the literature as yet, but I find it intriguing: why do a few per cent of QSO's show the strong compact radio cores and the others not? There is no correlation of this with any other source property that I am aware of.

Is the radio source somehow turned off? Are the radiation or the relativistic particles themselves being absorbed? Is the radiation severely beamed? Do radio quiet QSO's not deserve the name?

IV. The central machine

Burbidge in a 1967 review listed models:

supernova clusters
stellar collisions
massive objects
quarks/matter creation
matter-antimatter annihilation
gravitational focusing of light from relatively faint objects

The first three are still with us. Rees (1976) lists

1. dense star clusters
2. massive pulsars/spinars
3. accretion onto a massive black hole

All three of these are still under investigation -- #3 is currently getting the most effort -- but as yet none interface well with the atmosphere models or with the wealth of observational bits and pieces.

Recent reviews:

Physica Scripta, 1978, Proceedings of 1977 Copenhagen QSO/Active Nuclei conference. To appear shortly in NRAO library

Rees, "Quasar theories", 1976 "Texas" conference on Relativistic Astrophysics, Boston

Weedman, 1977, _A.R.A.A._, "Seyfert Galaxies"

Strittmatter and Williams, 1976, _A.R.A.A._, "Line Spectra of QSO's"