a given frequency, originates from synchrotron emission instead of by inverse Compton scattering, their cooling time t_{cool} (5.6) would be much shorter as well. In such sources, which are typically FR I radio sources, the synchrotron process itself probably accounts for the X-ray emission. This implies, on the one hand, very short cooling time-scales and therefore the increased necessity for a local acceleration of the electrons. On the other hand, the required energies for the electrons are very high, $\sim 100\,\mathrm{TeV}$. It is currently unclear which acceleration processes may account for these high energies.

Detecting radio jets at X-ray frequencies seems to be a frequent phenomenon: about half of the flat-spectrum radio QSO with jet-like extended radio emission also show an X-ray jet. All of those are one-sided, although the corresponding radio images often show lobes opposite the X-ray jets, reinforcing the necessity for Doppler favoritism also in the X-ray waveband.

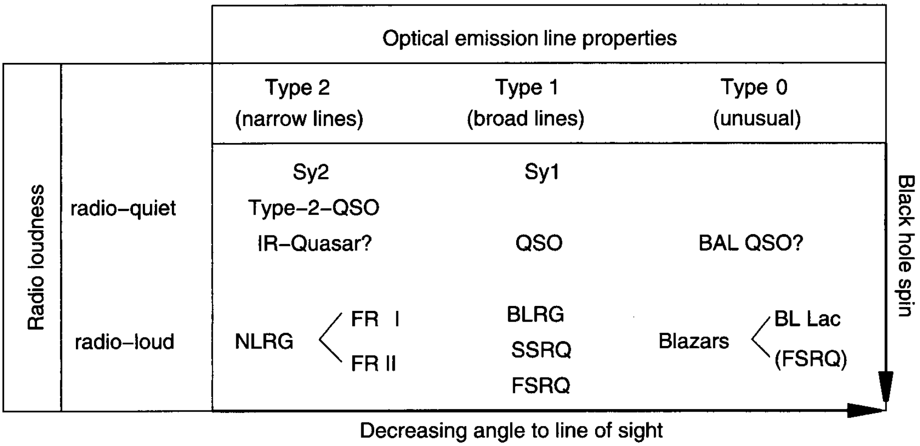
Finally, it should be mentioned that our attempts at finding a unification scheme for the different classes of AGNs have been quite successful. The scheme of unification is generally accepted, even though some aspects are still subject to discussion. One particular model is sketched in Fig. 5.36.

5.6 AGNs and Cosmology

AGNs, and QSOs in particular, are visible out to very high redshifts. Since their discovery in 1963, QSOs have held the redshift record nearly without interruption. Only in recent years have QSOs and galaxies been taking turns in holding the record. Today, several hundred QSOs are known with $z \geq 4$, and the number of those with $z > 5$ continues to grow since a criterion was found to identify these objects. This leads to the possibility that QSOs could be used as cosmological probes, and thus to the question of what we can learn about the Universe from QSOs. For example, one of the most exciting questions is how does the QSO population evolve with redshift – was the abundance of QSO at high redshifts, i.e., at early epochs of the cosmos, similar to that today, or does it evolve over time?

5.6.1 The K-Correction

To answer this question, we must know the luminosity function of QSOs, along with its redshift dependence. As we did for galaxies, we define the luminosity function $\Phi(L, z)\,\mathrm{d}L$ as the spatial number density of



		Optical emission line properties		
		Type 2 (narrow lines)	Type 1 (broad lines)	Type 0 (unusual)
Radio loudness	radio–quiet	Sy2 Type–2–QSO IR–Quasar?	Sy1 QSO	BAL QSO?
	radio–loud	NLRG < FR I FR II	BLRG SSRQ FSRQ	Blazars < BL Lac (FSRQ)

Fig. 5.36. This table presents a unification scheme for AGNs via the angular momentum of the central black hole and the orientation of the accretion disk with respect to the line-of-sight. The closer the direction of the jet is to the line-of-sight, the more the jet component dominates. Furthermore, the relative strength of the radio emission in this particular unified scheme is linked to the angular momentum of the black hole. The classification pattern shown here is only one of several possibilities, but the dependence of the AGN class on orientation is generally considered to be accepted

QSOs with luminosity between L and $L+\mathrm{d}L$. Φ normally refers to a comoving volume element, so that a non-evolving QSO population would correspond to a z-independent Φ. One of the problems in determining Φ is related to the question of which kind of luminosity is meant here. For a given observed frequency band, the corresponding rest-frame radiation of the sources depends on their redshift. For optical observations, the measured flux of nearby QSOs corresponds to the rest-frame optical luminosity, whereas it corresponds to the UV luminosity for higher-redshift QSOs. In principle, using the bolometric luminosity would be a possible solution; however, this is not feasible since it is *very* difficult to measure the bolometric luminosity (if at all possible) due to the very broad spectral distribution of AGNs. Observations at all frequencies, from the radio to the gamma domain, would be required, and obviously, such observations can only be obtained for selected individual sources.

Of course, the same problem occurs for all sources at high redshift. In comparing the luminosity of galaxies at high redshift with that of nearby galaxies, for instance, it must always be taken into account that, at given observed wavelength, different spectral ranges in the galaxies' rest-frames are measured. This means in order to investigate the optical emission of galaxies at $z \sim 1$, observations in the NIR region of the spectrum are necessary.

Frequently the only possibility is to use the luminosity in some spectral band and to compensate for the above effect as well as possible by performing observations in several bands. For instance, one picks as a reference the blue filter which has its maximum efficiency at ~ 4500 Å and measures the blue luminosity for nearby objects in this filter, whereas for objects at redshift $z \sim 1$ the intrinsic blue luminosity is obtained by observing with the I-band filter, and for even larger redshifts observations need to be extended into the near-IR. The observational problems with this strategy, and the corresponding corrections for the different sensitivity profiles of the filters, must not be underestimated and are always a source of systematic uncertainties. An alternative is to perform the observation in only one (or a few) filters and to approximately correct for the redshift effect.

In Sect. 4.3.3, we defined various distance measures in cosmology. In particular, the relation $S = L/(4\pi D_\mathrm{L}^2)$ between the observed flux S and the luminosity L of a source defines the luminosity distance D_L. Here both the flux and the luminosity refer to bolometric quantities, i.e., flux and luminosity integrated over all frequencies. Due to the redshift, the measured spectral flux S_ν is related to the spectral luminosity $L_{\nu'}$ at a frequency $\nu' = \nu(1+z)$, where one finds

$$S_\nu = \frac{(1+z)L_{\nu'}}{4\pi D_\mathrm{L}^2} \,. \tag{5.34}$$

We write this relation in a slightly different form,

$$S_\nu = \frac{L_\nu}{4\pi D_\mathrm{L}^2}\left[\frac{L_{\nu'}}{L_\nu}(1+z)\right] , \tag{5.35}$$

where the first factor is of the same form as in the relation between the bolometric quantities while the second factor corrects for the spectral shift. This factor is denoted the *K-correction*. It obviously depends on the spectrum of the source, i.e., to determine the K-correction for a source its spectrum needs to be known. Furthermore, this factor depends on the filter used. Since in optical astronomy magnitudes are used as a measure for brightness, (5.35) is usually written in the form

$$\begin{aligned} &m_\mathrm{int} = m_\mathrm{obs} + K(z) \\ &\text{with} \quad K(z) = -2.5 \log\left[\frac{L_{\nu'}}{L_\nu}(1+z)\right] , \end{aligned} \tag{5.36}$$

where m_int is the magnitude that would be measured in the absence of redshift, and m_obs describes the brightness actually observed. The K-correction is not only relevant for QSOs but for all objects at high redshift, in particular also for galaxies.

5.6.2 The Luminosity Function of Quasars

By counting QSOs, we obtain the number density $N(>S)$ of QSOs with a flux larger than S. We find a relation of roughly $N(>S) \propto S^{-2}$ for large fluxes, whereas the source counts are considerably flatter for smaller fluxes. The flux at which the transition from steep counts to flatter ones occurs corresponds to an apparent magnitude of about $B \sim 19.5$. Up to this magnitude, about 10 QSOs per square degree are found.

From QSO number counts, combined with measurements of QSO redshifts, the luminosity function $\Phi(L,z)$ can be determined. As already defined above,