The Hamburg/RASS Catalogue of Optical Identifications of ROSAT-BSC X-ray Sources

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Outline

- Introduction: Sample characteristics
- Identification procedure
  - technique
  - object classes
- catalogue of source identifications
  - source statistics
  - nature of unidentified sources
  - comparison with other surveys
- X-ray/radio cross-correlation for AGN
  - radio-loud subsample
  - X-ray continuum
- Summary

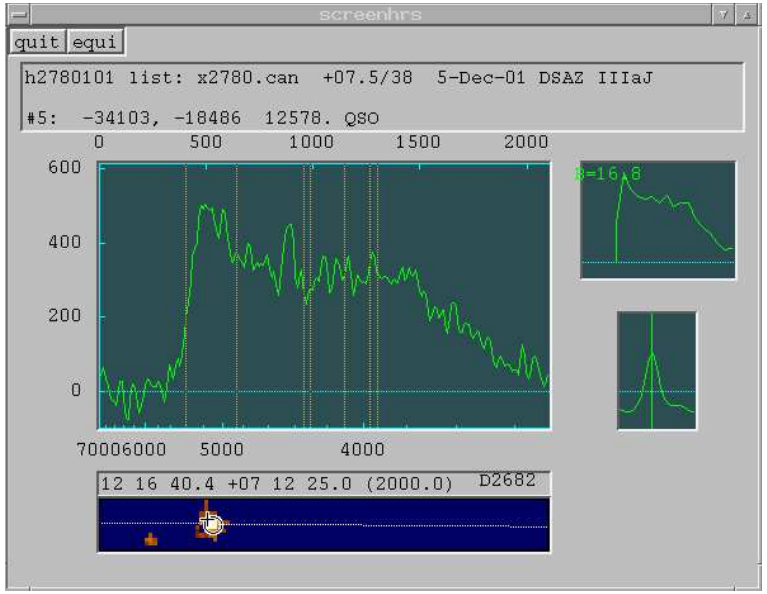
Introduction

- ROSAT Bright Source Catalogue (BSC) (Voges et al. 1999):
  - 18811 X-ray sources
  - count rate $\geq 0.05\,\mathrm{cts\,s^{-1}}$ in 0.1 – 2.4 keV energy range

- Hamburg/RASS:
  - optical identification of northern BSC sources
    - ▷ $DEC \geq 0°$
  - high galactic latitude:
    - ▷ $|b| \geq 30°$
  - in this region of the sky ($\sim 10\,000$ sq.degrees)
    - ▷ 5341 BSC sources
  - optical identification based on Hamburg Quasar Survey (HQS) Schmidt plates
    - ▷ collection of 567 prism plates ($5.5° \times 5.5°$) with $B_{\mathrm{lim}} \approx 18.5$
    - ▷ set of blue direct plates with $B_{\mathrm{lim}} \approx 20$

- first published version of Hamburg/RASS Catalogue (HRC vers. 2.0):
  - 4190 BSC sources (Bade et al. 1998, A&A 127, 145)

Identification technique



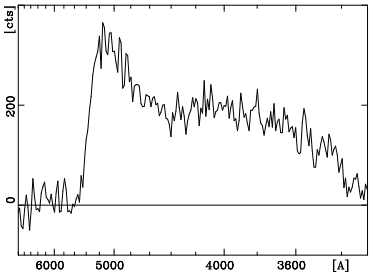
- digitized data base of scanned prism and direct plates (~ 400 GByte accessible online)
- find positions of visible objects within 60" around X-ray position
- extract spectra from data base
- interactive object classification

Object classes: Spectral classification

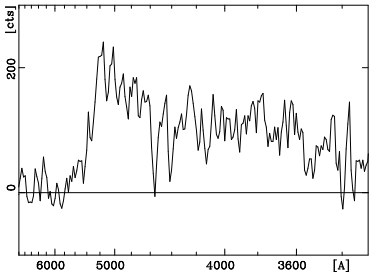
W-DWARF	white dwarf
CV	cataclysmic variable, exhibits Balmer emission
STAR-FG	G-band, Ca H&K absorption, point-like image
STAR-K	G-band, Ca H&K absorption, redder continuum than STAR-FG
STAR-M	continuum very red, TiO and CaI 4226Å absorption
GALAXY	red continuum, no emsiison lines, extended direct image
BLUE GALAXY	continuum blue, extended direct image
AGN	continuum blue, emission lines
QSO	continuum very blue, emission lines, point-like image
EBL-WK	continuum very blue, faint point-like image
BLUE-WK	blue continuum, faint point-like image
RED-WK	red continuum, faint point-like image
UNIDENT	none of the above defined classes assignable
OVERLAP	no classification possible due to overlapping spectra
SATURATE	no classification possible due to saturated spectrum
NONSENSE	spectrum of no use, e.g. plate defect, blend

Object classes I

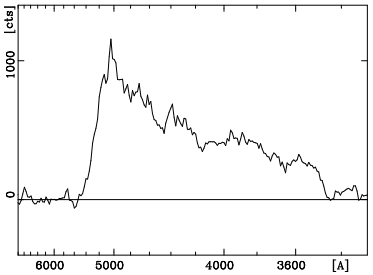
AGN



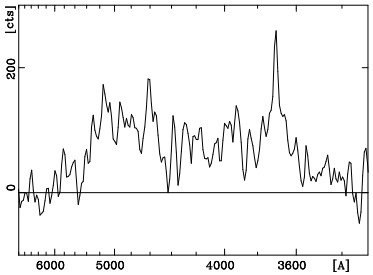
AGN (17.4, z=0.78)



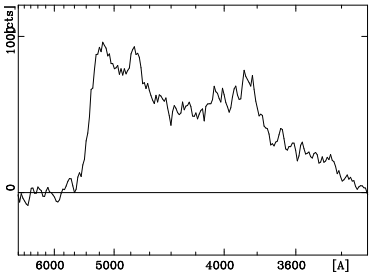
EBL-WK (18.9, z=1.00)



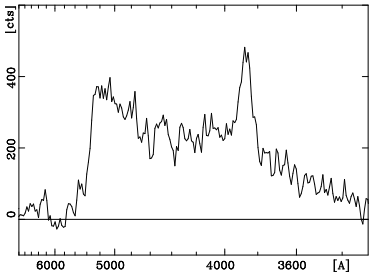
AGN (15.9, z=1.32)



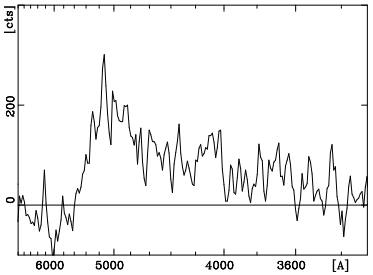
QSO (19.1, z=1.39)



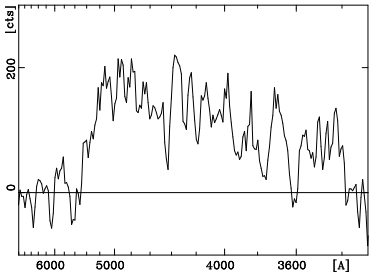
QSO (15.9, z=1.50)



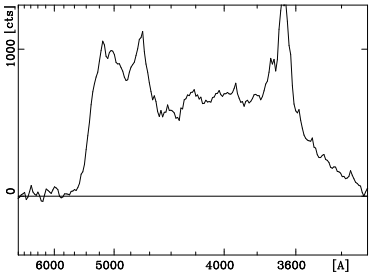
QSO (17.1, z=1.52)



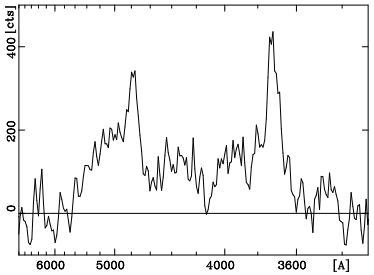
EBL-WK (18.5, z=1.66)



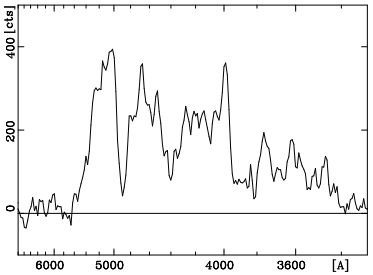
EBL-WK (17.5, z=1.83)



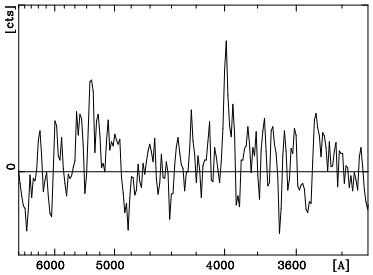
QSO (B=15.5, z=2.04)



QSO (18.2, z=2.07)



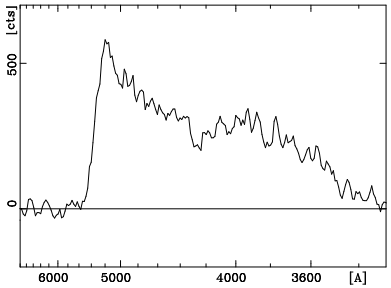
UNID (18.9, z=2.20)



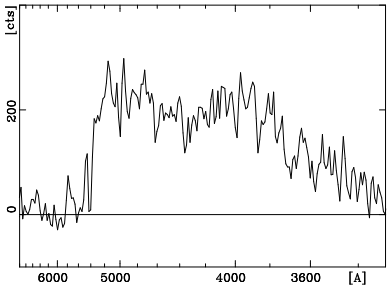
EBL-WK (19.4, z=2.24)

Object classes II

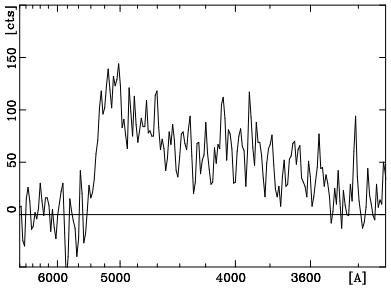
BL Lac objects



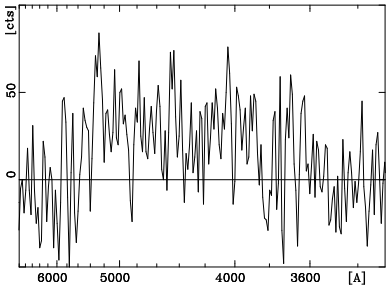
AGN (BL Lac, 17.0)



AGN (BL Lac, 18.0)

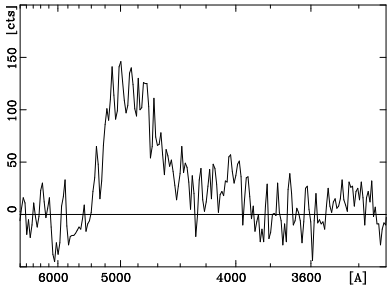


EBL-WK (BL Lac, 18.4)

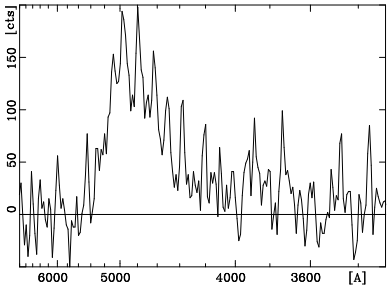


EBL-WL (BL Lac, 18.9)

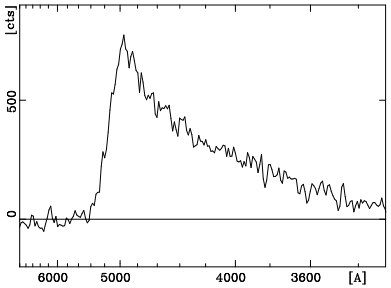
Galaxies



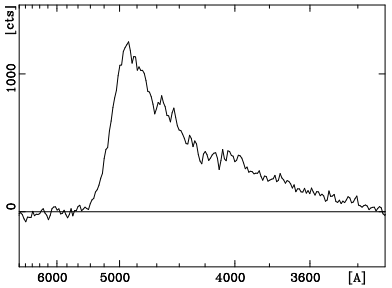
GAL (≈17.5)



GAL (≈17.5)



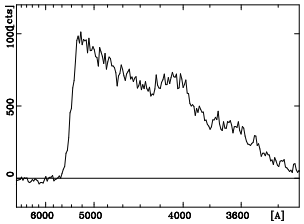
BLUE GAL (≈17)



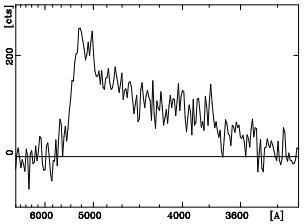
BLUE GAL (S0, ≈17)

Object classes III

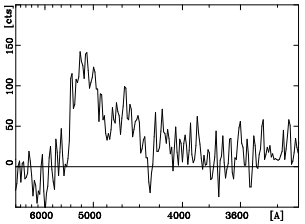
Stellar coronal emitters



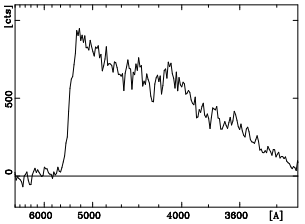
STAR-FG (F5V, 14.8)



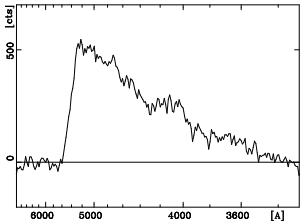
STAR-FG (F, 17.1)



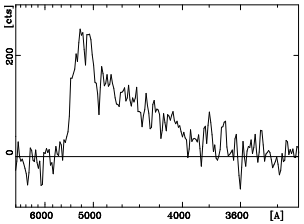
RED-WK (F, 17.3)



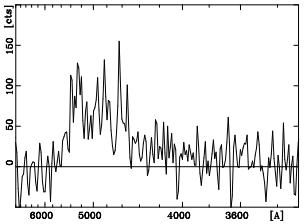
STAR-FG (G0, 15.0)



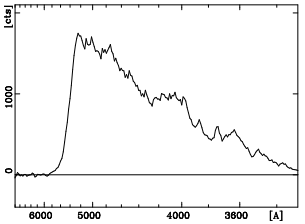
STAR-FG (G8V, 16.1)



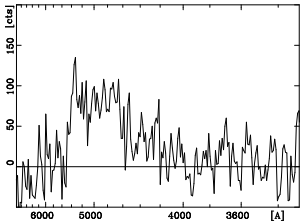
STAR-K (G, 17.4)



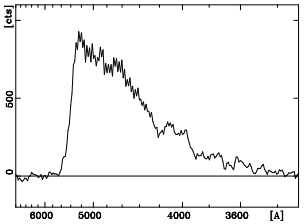
RED-WK (G, 18.3)



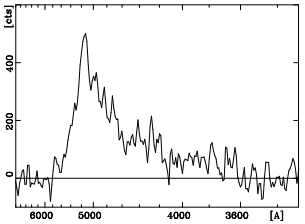
STAR-FG (K0, 14.2)



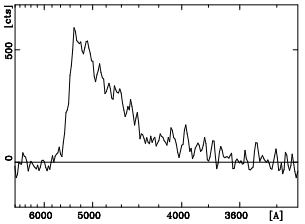
RED-WK (K3, 18.3)



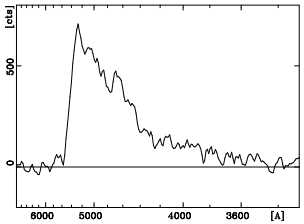
STAR-K (K7V, 15.1)



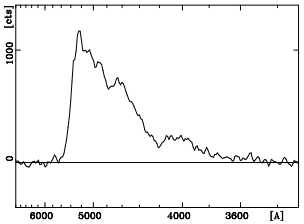
RED-WK (K, 16.8)



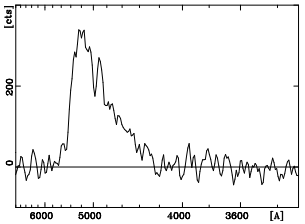
STAR-M (M2V, 16.8)



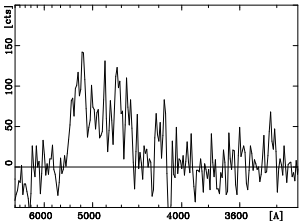
STAR-M (M3, 17.0)



STAR-M (M4V, 15.3)



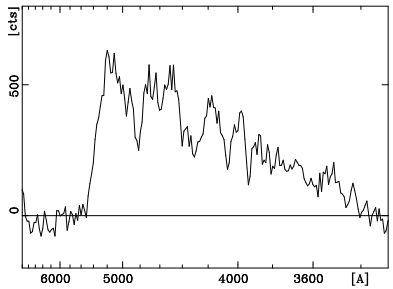
STAR-M (M7V, 16.1)



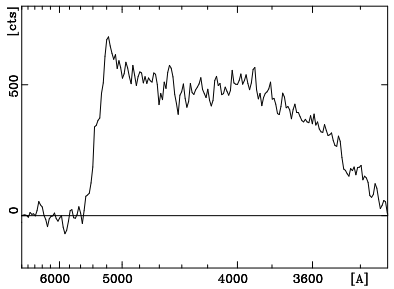
RED-WK (M, 18.7)

Object classes IV

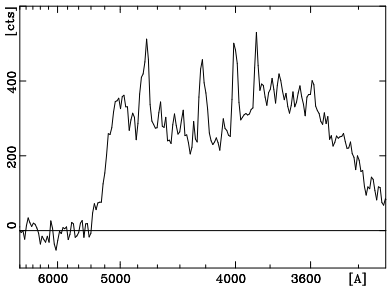
White dwarfs and CVs



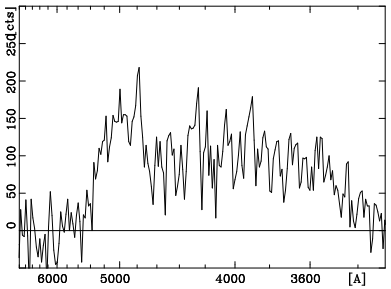
WD (DA5, 15.9)



WD (DB, 16.2)



CV (Dwarf Nova, 16.8)



CV (Dwarf Nova, 18.2)

Source identification

ID code	object category
1x	active galactic nucleus (AGN), incl. Sy, QSO, BL Lac
2x	galaxy
3x	galaxy cluster
5x	M star
6x	white dwarf
7x1	K star
7x2	F/G star
7x3	cataclysmic variable
7x4	bright star
8	no (unambiguos) identification, overlaps
803	no spectrum available for likely counterpart, e.g. overlap
0	no objects visible within 40" around the X-ray position ("blank field")

- reliability flag x:
  0 = "highly probable", 1 = "probable", 2 = "possible"

Section of the catalogue

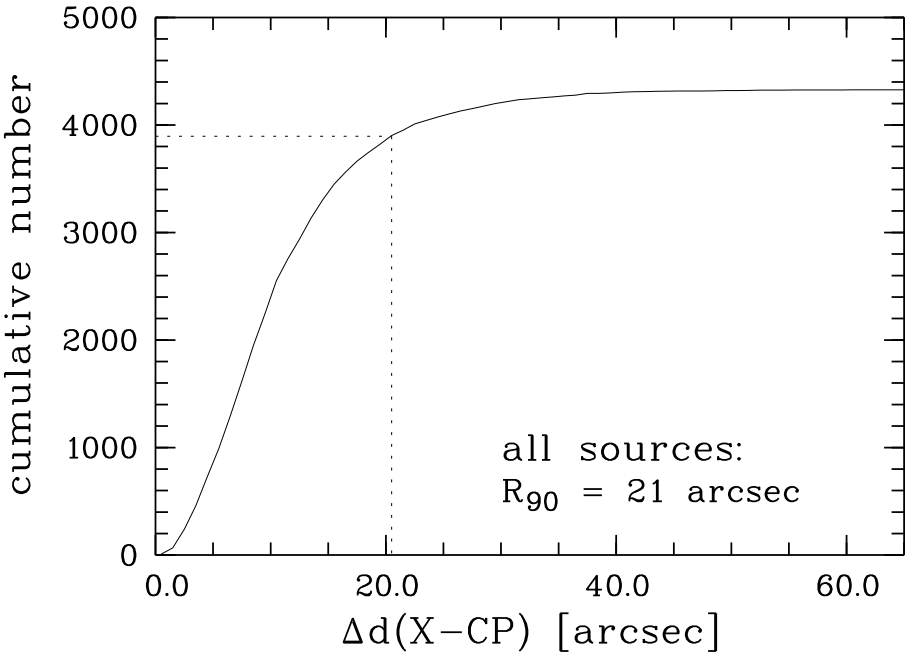
```
1RXS J100659.7+673249    0.174   0.021   0.86    0.07    0.09    0.12   14    2
RX J1007.0+6732  10 06 59.7  +67 32 49     9    P013208     703    000  961205
             +1  10 07  0.8  +67 32 45     6    -4     8    15.2  +1.4     CV

1RXS J100710.1+220312    0.621   0.041  -0.06    0.06   -0.11    0.09   18    7
RX J1007.1+2203  10 07 10.1  +22 03 12    28    P002449     10     000  020201
             +1  10 07 10.2  +22 02 59     1   -13    13    17.0  +0.3     AGN
              2  10 07 11.5  +22 03 37    19    25    32    18.2  +1.9     RED-WK
              3  10 07  8.8  +22 03 37   -18    25    31    17.6  +0.9     BLUE-WK

1RXS J100712.6+653511    0.105   0.016   0.80    0.12    0.39    0.14    9    1
RX J1007.2+6535  10 07 12.6  +65 35 11     9    P023208     10     000  961205
             +1  10 07 13.8  +65 34 59     7   -12    14    16.7  +0.1     QSO

1RXS J100717.8+203119    0.060   0.014   0.31    0.21    0.42    0.26    0    0
RX J1007.2+2031  10 07 17.8  +20 31 19    11    P029449     11     000  961205
             +1  10 07 17.0  +20 31 22   -11     3    11    18.6  +0.6     BLUE-WK
              2  10 07 19.1  +20 31 42    18    23    29    14.2  +0.8     OVERLAP
              3  10 07 19.1  +20 31 30    18    11    21    18.2  +0.7     STAR-FG

1RXS J100721.0+730603    0.062   0.015  -0.03    0.21    0.29    0.32    0    0
RX J1007.3+7306  10 07 21.0  +73 06 03    12    P019508     50     000  971203
              1  10 07 17.9  +73 05 22   -14   -41    43                    OVERLAP
              2  10 07 19.5  +73 05 29    -7   -34    35    19.6  +1.6     RED-WK
             +3  10 07 21.3  +73 06 10     1     7     7    16.0  +2.1     STAR-M
              4  10 07 26.0  +73 05 33    22   -30    37    18.9  +2.2     RED-WK

1RXS J100738.6+062128    0.348   0.030   0.15    0.09    0.02    0.11    9    1
RX J1007.6+0621  10 07 38.6  +06 21 28     8    P062551     704    000  971203
             +1  10 07 38.7  +06 21 22     2    -6     6   <10.0     *     SATURATE

1RXS J100743.6+500753    0.280   0.027  -0.54    0.07    0.18    0.19   26    7
RX J1007.7+5007  10 07 43.6  +50 07 53     9    P044090     10     000  961205
              1  10 07 41.7  +50 07 54   -18     0    18    18.4  +1.5     RED-WK
             +2  10 07 44.4  +50 07 44     8   -10    12    16.7  +0.0     QSO
              3  10 07 45.6  +50 07 10    19   -44    48    18.0  +0.7
```

Source statistics

code	class	number	fraction [%]
0	blank field	155	2.9
1	AGN	2215	41.5
2	galaxy	238	4.5
3	galaxy cluster	262	4.9
5	M star	197	3.7
6	white dwarf	45	0.8
7_1	K star	141	2.6
7_2	F-G star	45	0.8
7_3	CV	26	0.5
7_4	bright stars	1219	22.8
8	unidentified	604	11.3
803	no spectrum	194	3.6
Total:		5341	100

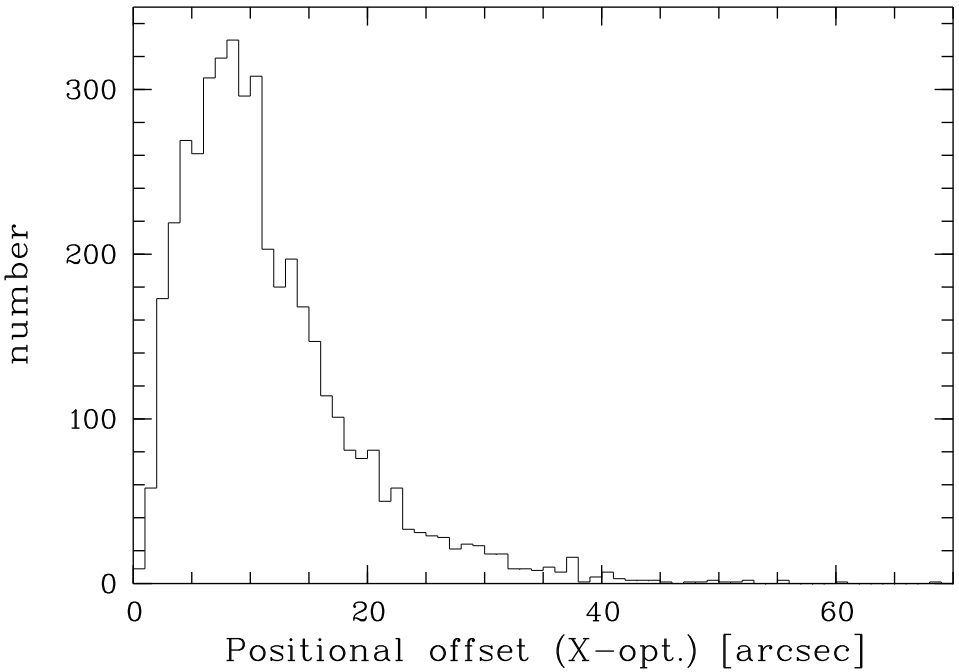
Positional offsets

cumulative positional offsets
for optical point sources

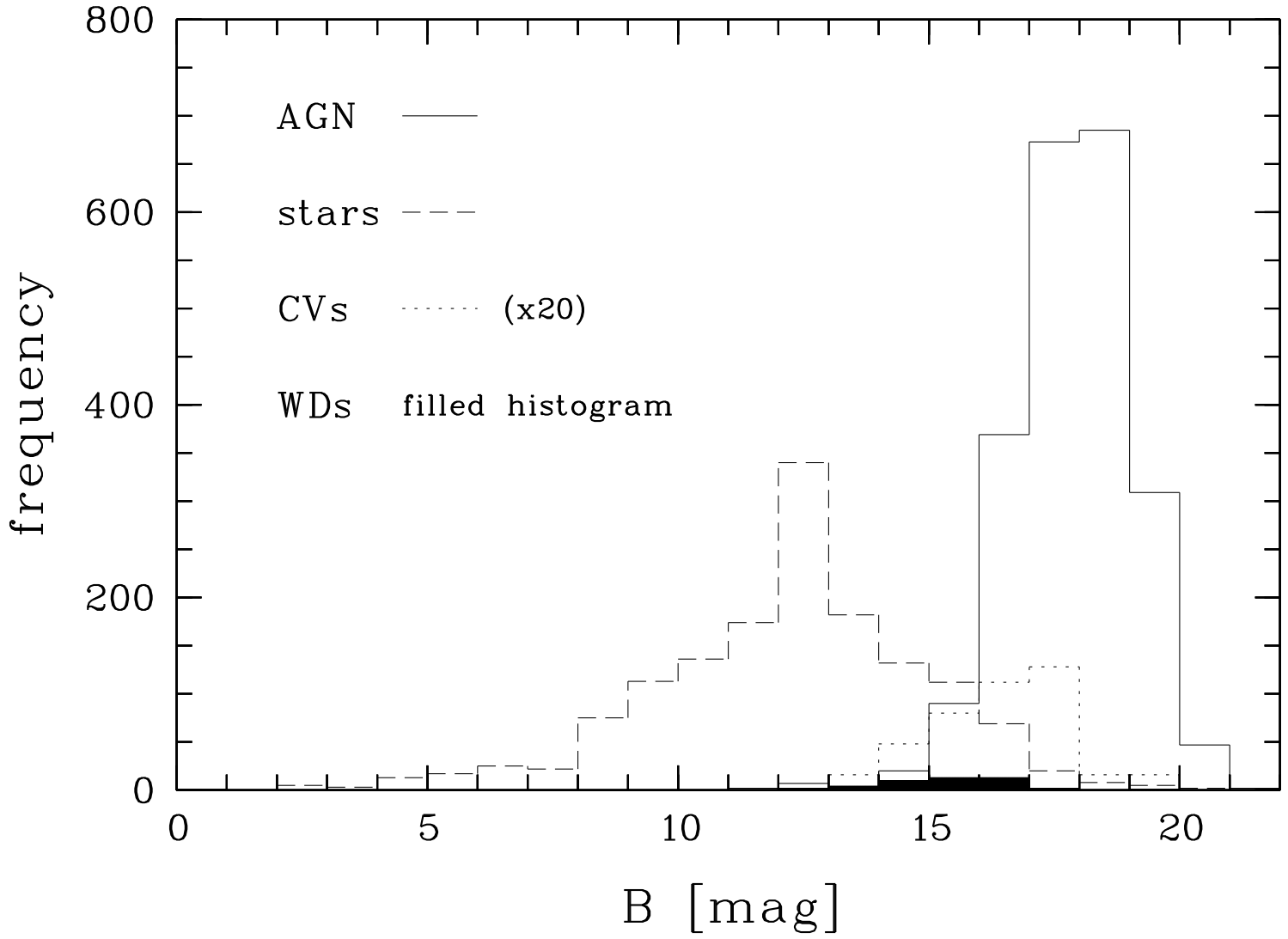


- 90% error circle: 21 arcsec

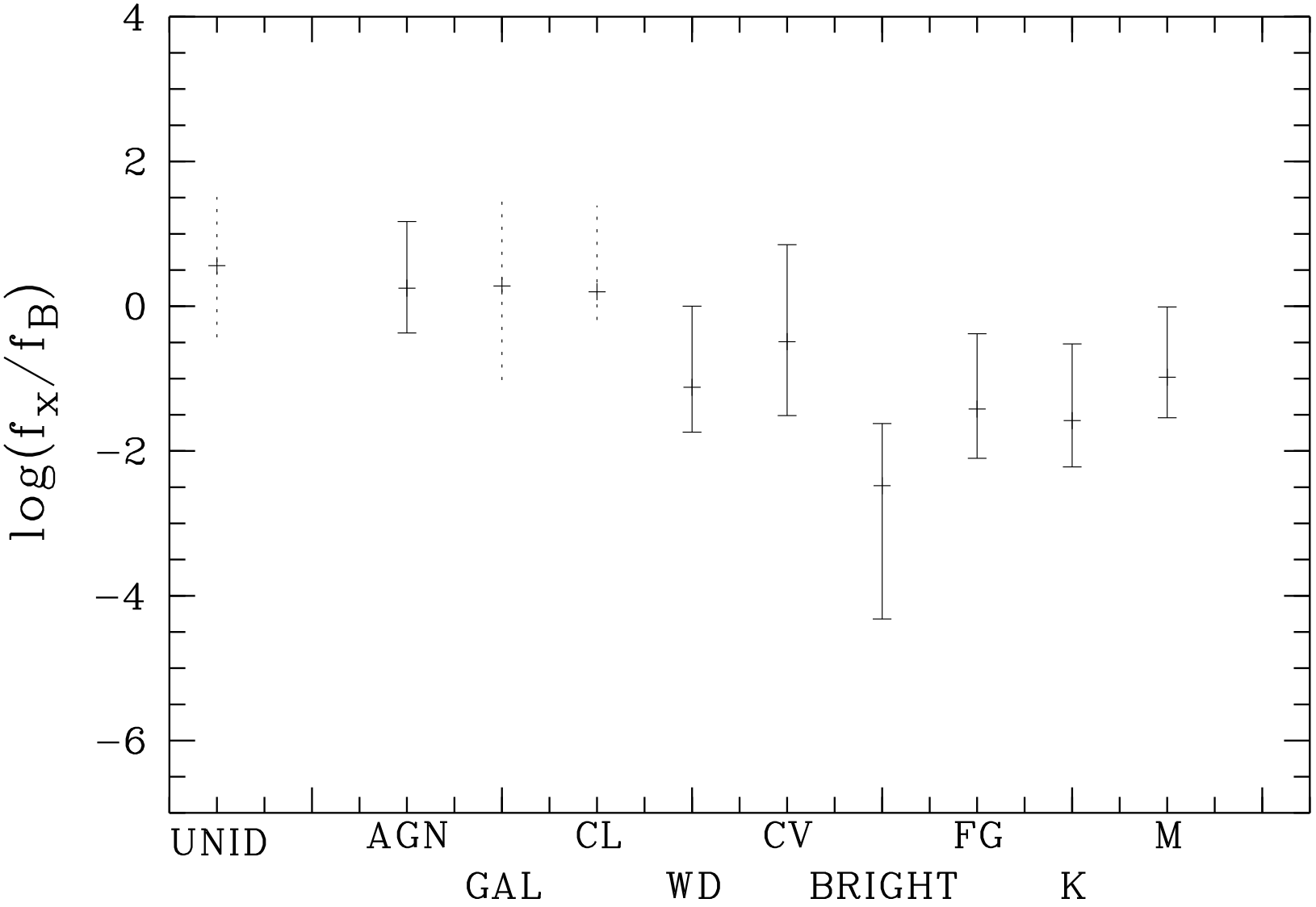
histogram of positional offsets



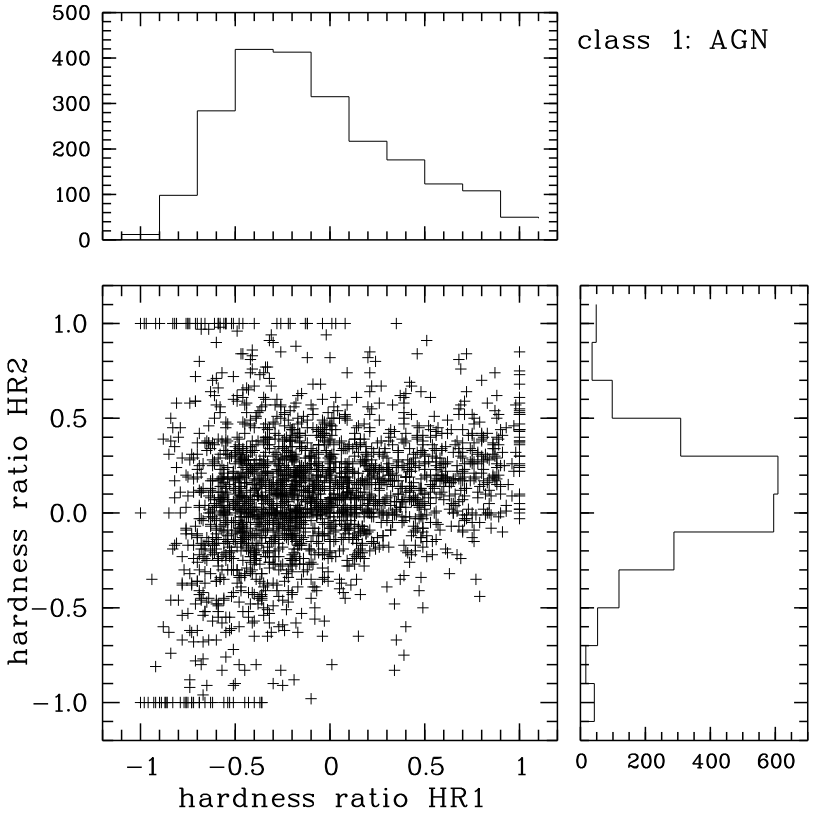
Optical brightness distribution

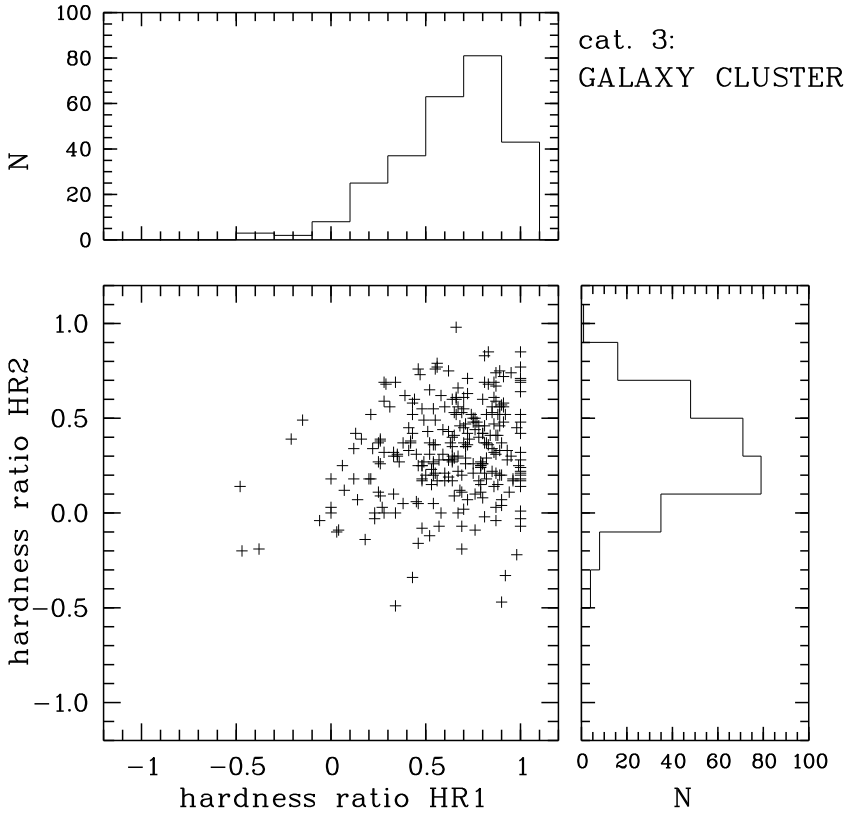


X-ray-to-optical flux ratio

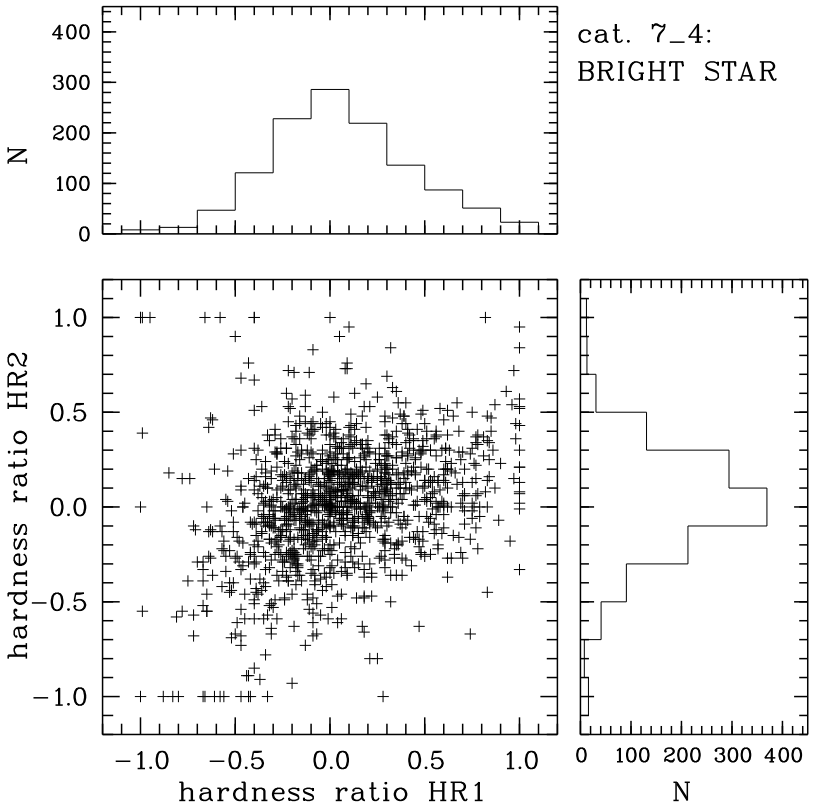


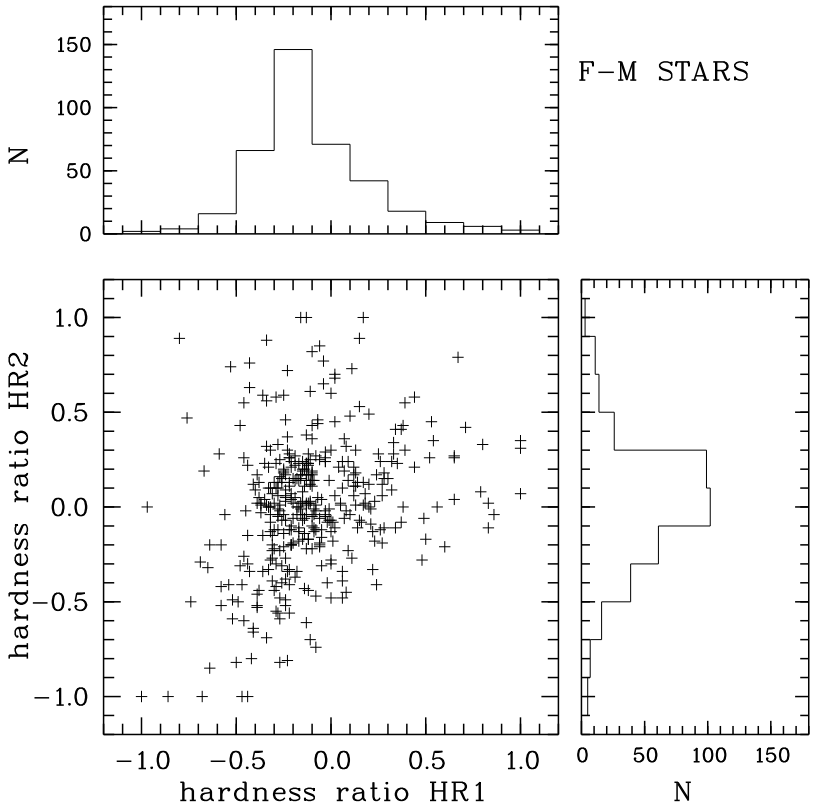
Hardness ratios: extragalactic sources



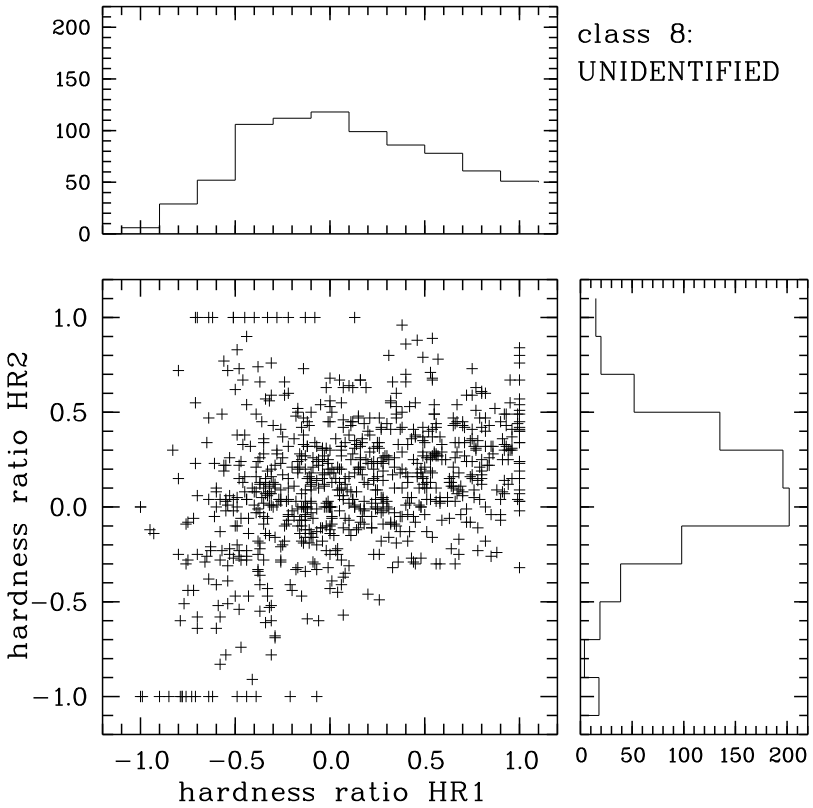


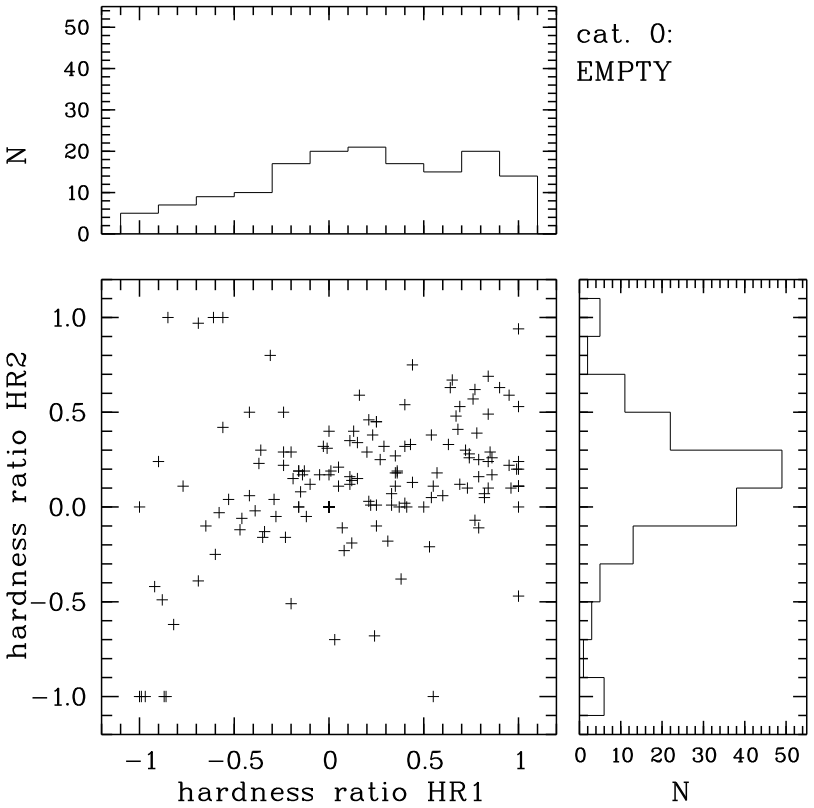
Hardness ratios: Stellar coronal sources



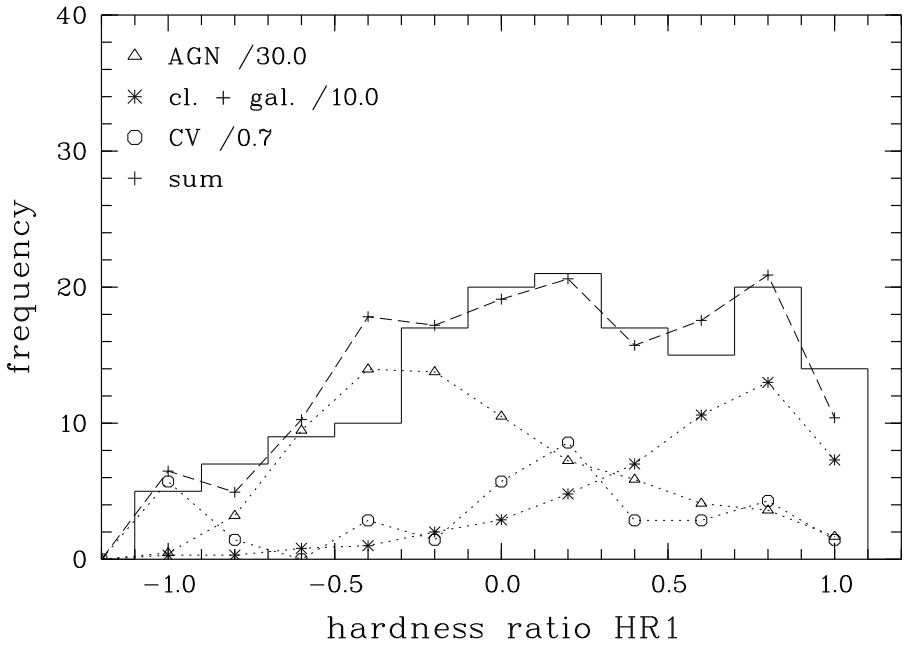


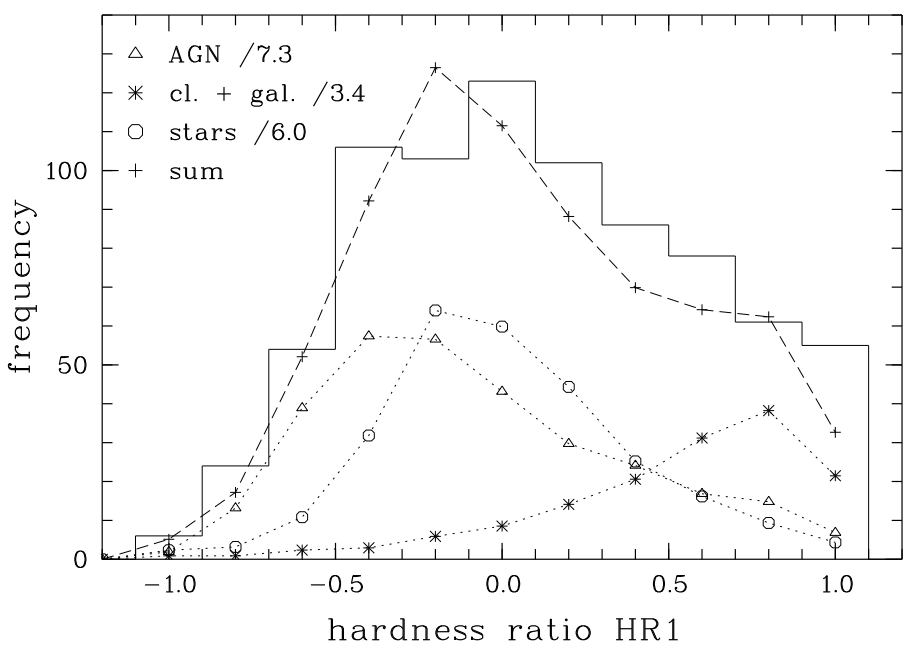
Hardness ratios: unidentified sources & blank fields





Hardness ratios: decomposition of blank fields & non-IDs





Blank fields:

- AGN: 45%
- galaxies & galaxy clusters: 30%
- CVs: 25%

unidentified sources:

- Stars: 40%
- AGN: 40%
- galaxies & galaxy clusters: 20%

Comparison of the HRC with other surveys

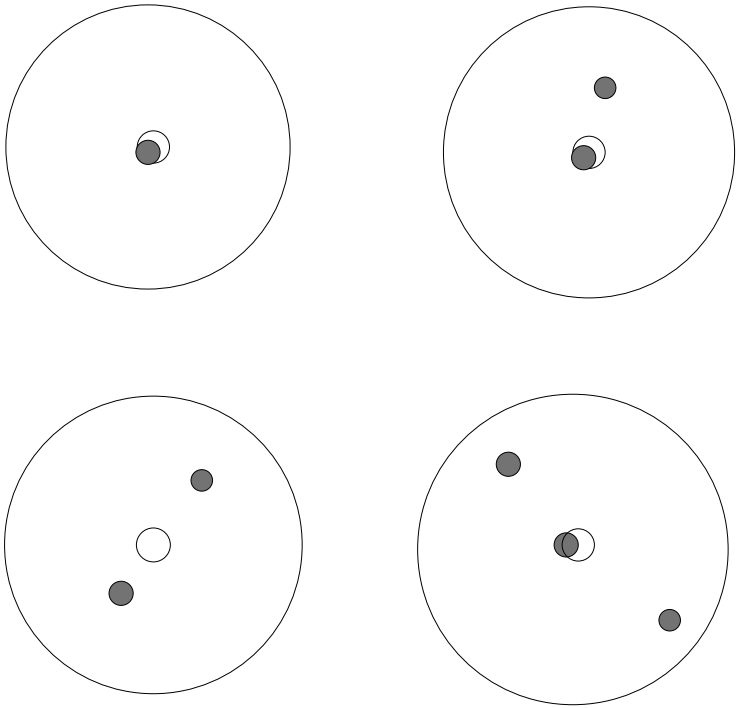
- Comparison of the **HRC** statistics with:
  - LSW-INAOE-MPE ("LSW"), RASS sample, $CR \geq 0.01 - 0.03\,\mathrm{cts\,s^{-1}}$ (Zickgraf et al. 1997, Appenzeller et al. 1998, Krautter et al. 1999)
  - NEP survey ("NEP"), RASS sample (Henry et al. 2001), $CR \gtrsim 0.001\,\mathrm{cts\,s^{-1}}$
  - EMSS (Stocke et al. 1991), EINSTEIN serendipitous survey, 0.3 – 3.5 keV

class	**HRC**	**HRC**$_{\mathrm{corr}}$	LSW[2]	NEP	EMSS
AGN[1]	42 (0.9)	49 (1.0)	46 (2.6)	52 (3.4)	55 (2.5)
galaxies	5 (0.3)	6 (0.3)	4 (0.8)	1 (0.5)	3 (0.6)
galaxy clusters	5 (0.3)	7 (0.4)	12 (1.3)	14 (1.8)	12 (1.2)
stars	31 (0.8)	38 (0.8)	36 (2.3)	34 (2.8)	26 (1.8)
unidentified	18 (0.6)[3]	–	2 (0.5)	1 (0.5)	4 (0.7)

Remarks: [1]including BL Lac objects, [2]without area I (Zickgraf et al. 1997), [3]includes 3% blank fields.

Radio emitting AGN (I)

- Cross-correlation of optical positions with the NVSS
  - search radius 15": search sources with core radio emission
  - search radius 90": search sources with lobe emission
  - alignment of radio-optical positions for cases of 2 or 3 radio sources within 90":
    * aligned if within $180^\circ \pm 25^\circ$



(cf. REX survey:

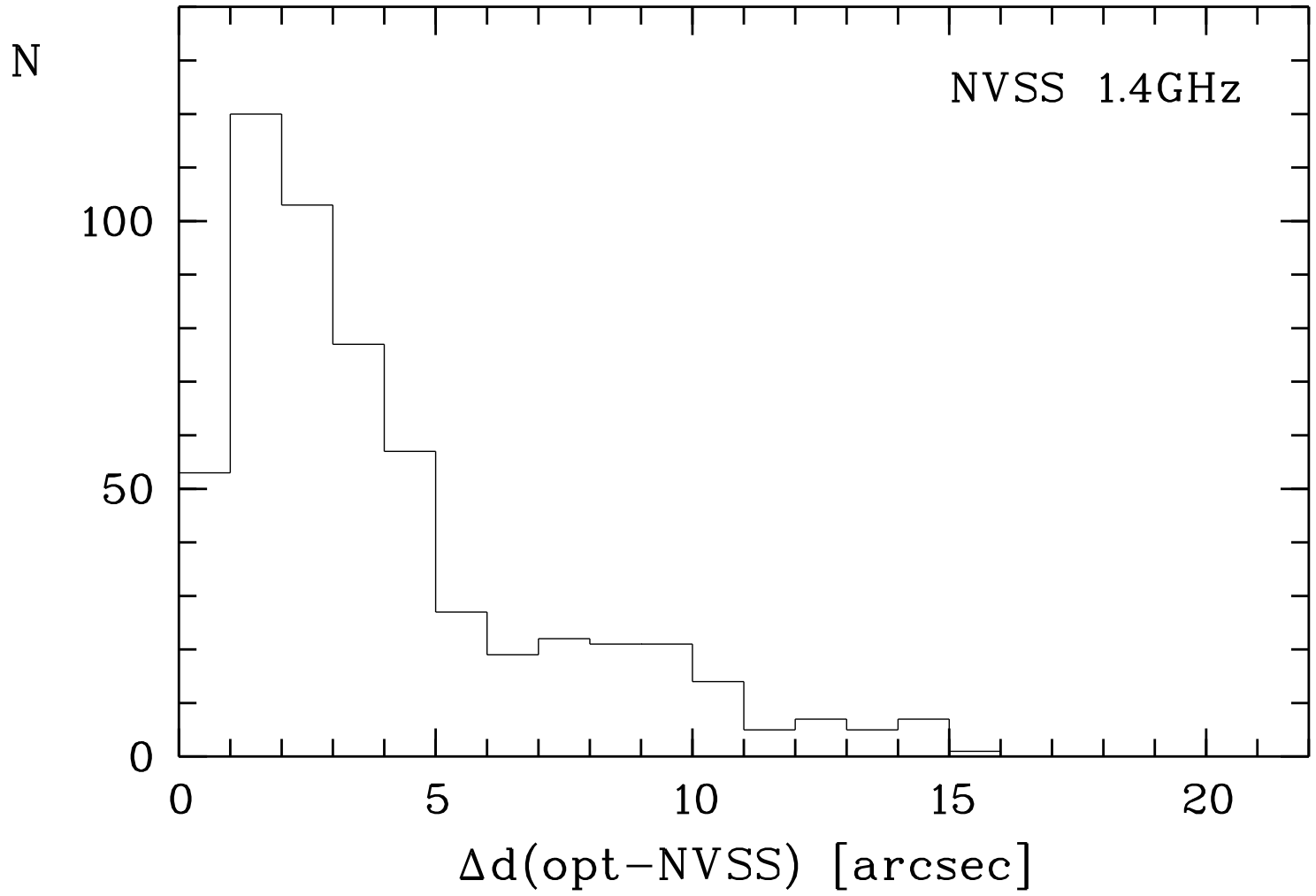
Caccianiga et al. 1999)

Radio emitting AGN (II)

type of NVSS source	$d(\mathrm{opt}-\mathrm{radio})$	N	comment
single	$d \leq 15''$	485	core-dominated AGN
$(N = 697)$	$15'' < d \leq 90''$	212	association questionable
double	1 component $d < 15''$	63	core-lobe AGN
$(N = 101)$	$d \geq 15''$ but aligned	27	lobe-dominated AGN
	$d \geq 15''$ not aligned	11	association questionable
triple	1 component $d < 15''$	11	core-lobe AGN
$(N = 14)$	$d \geq 15''$ but aligned	2	lobe-dominated AGN
	$d \geq 15''$ not aligned	1	association questionable

- for 588 of 2215 AGN 1.4 GHz radio emission from the NVSS

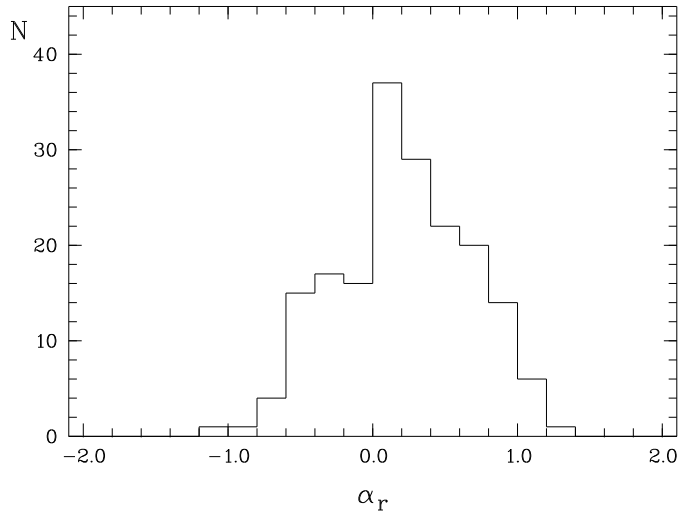
Radio emitting AGN (III)

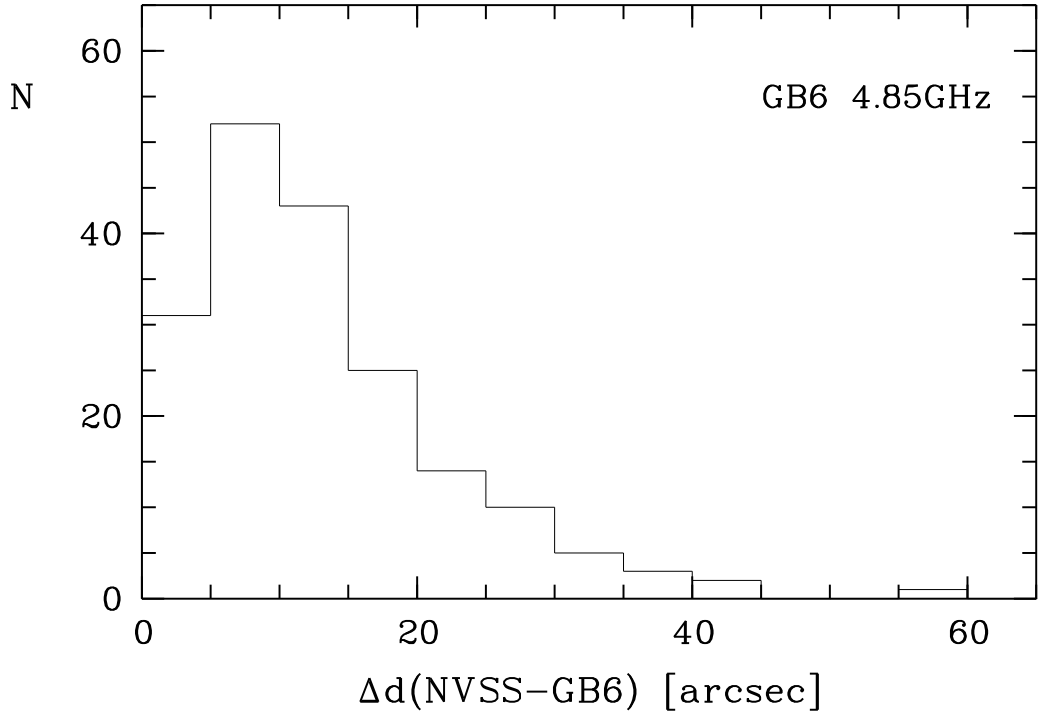


- core sources: 90% of the radio sources within 10" from the optical position

Radio emitting AGN (IV)

- cross-correlation with GB6 4.85 GHz radio survey, search radius 80”
- 330 sources, 90% within 58”
- cross-correlation of NVSS core sources and GB6 sources
- 183 positional matches within 40”
- mean spectral index $\alpha_{\rm r} = +0.1$





Radio-loud AGN

- extrapolation of 1.4 GHz flux to 8.4 GHz ($\alpha_{\rm r} = -0.5$ if no GB6 detection)
- radio-loud: $R = f_{\rm r}/f_{\rm opt} > 10$ (Kellermann et al. 1989)
- HRC: 22% of all AGN: $R > 10$, i.e. radio-loud
  - all but 4 of combined GB6/NVSS matches radio-loud
- comparison with other AGN surveys:

survey	band	fraction of radio-loud AGN
HRC	0.1 - 2.4 keV	22%
EMSS	0.3 - 3.5 keV	11% (Hooper et al.)
LBQS	optical	10% (Hooper et al.)
Palomar-Green	optical	19% (Hooper et al.)

X-ray continua of AGN

- power-law with photon index Γ, fix $N_{\rm H}$ at galactic column density
- fit photon index to hardness ratios HR1 and HR2 for object i with errors $\sigma(HR1)$ and $\sigma(HR2)$ by minimizing

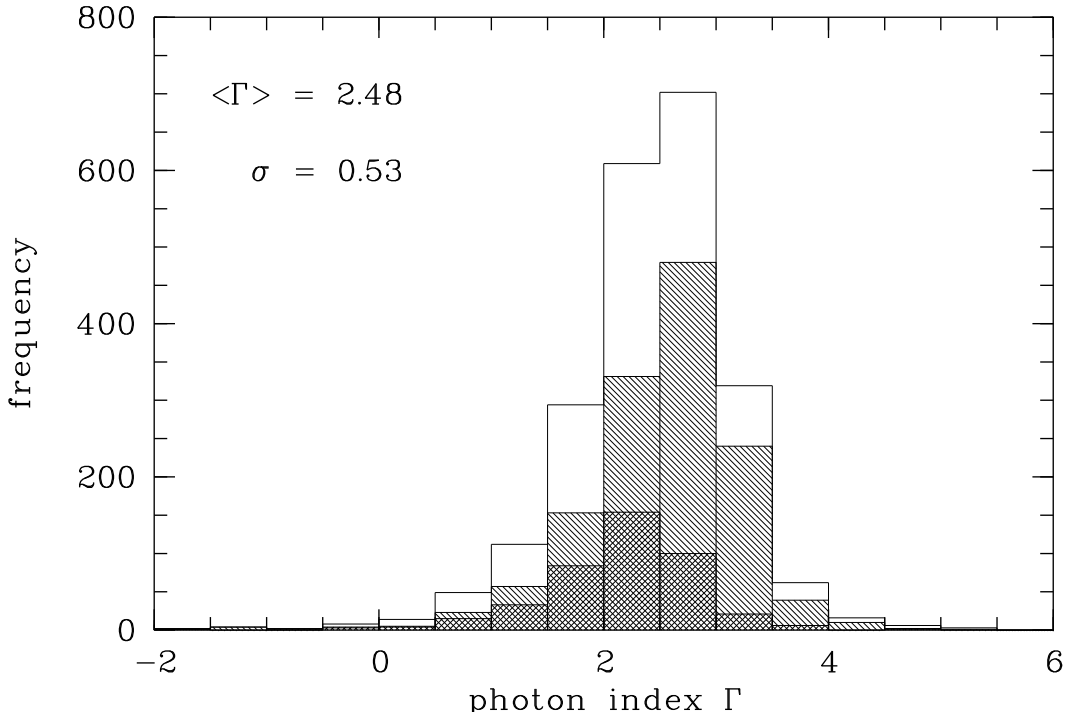
$$\Phi^2 = \sum_{k=1}^{2} \frac{(HRk_{\rm obs} - HRk_{\rm mod}(\Gamma_i, N_{\rm H}))^2}{\sigma(HRk)^2}, \quad k = 1, 2 \tag{1}$$

- determine sample mean of Γ_m and σ_Γ
  - Gaussian shape for frequency distribution of Γ_i with error σ_i from fit
  - intrinsic width of frequency distribution: σ_Γ
- maximum likelihood function

$$\mathcal{L} = \prod_{i=1}^{n} \frac{1}{\sqrt{2\,\pi({\sigma_\Gamma}^2 + {\sigma_i}^2)}}\, e^{-\frac{1}{2}\frac{(\Gamma_m - \Gamma_i)^2}{({\sigma_\Gamma}^2 + \sigma_i^2)}} \tag{2}$$

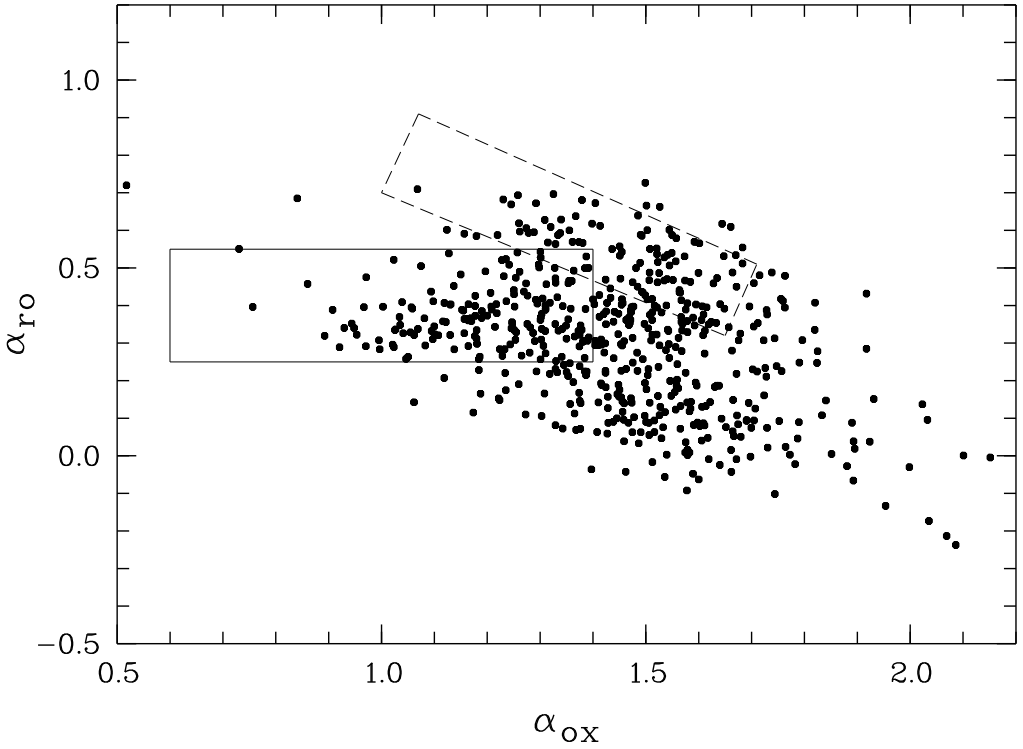
Radio-to-X-ray continua: AGN (I)

- Result of the fit
  - sample means:
    - ▷ radio-quiet: $\Gamma = 2.56 \pm 0.03$, $\sigma = 0.50 \pm 0.05$
    - ▷ radio-loud: $\Gamma = 2.22 \pm 0.05$, $\sigma = 0.48 \pm 0.05$
    - ▷ all AGN: $\Gamma = 2.48 \pm 0.03$, $\sigma = 0.53 \pm 0.03$



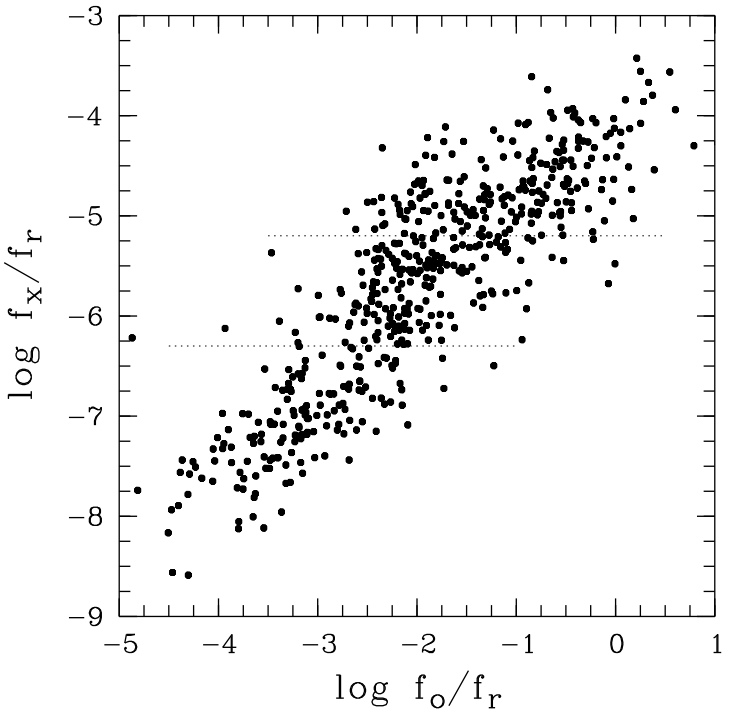
- steeper spectra than in the EMSS energy range (0.3 - 3.5 keV): $\Delta\Gamma \approx 0.5 - 0.6$
- "ultra-soft excess" below 0.3 keV

Radio-to-X-ray continua: AGN (II)



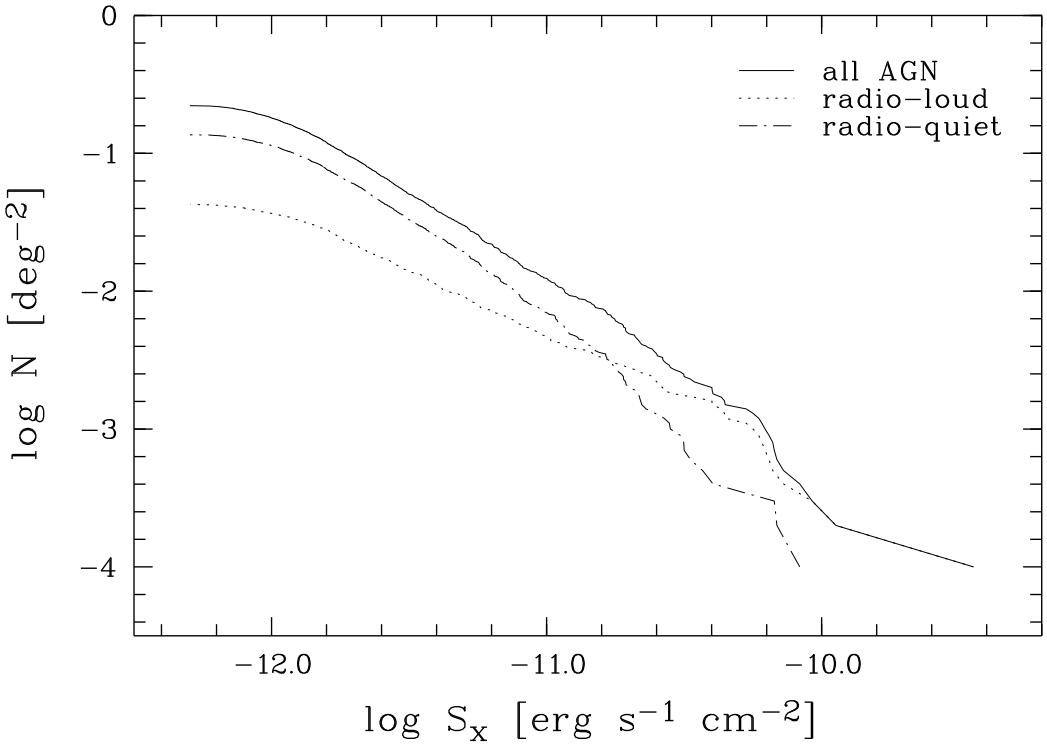
- $\alpha_{\rm ox} = -\log(f_x/f_r)/2.605$
- $\alpha_{\rm ro} = \log(f_r/f_o)/5.38$
- solid box: HBL
- dashed box: LBL

- above upper dashed line:
  222 HBL candidates
  $\leq 10\%$ HBL
- below lower dashed line:
  186 LBL/HPQ candidates
  $\leq 7\%$ LBL



$\log N - \log S$ distributions

- $N(> S) = k\, S^{-\alpha}$
  - Euclidean slope: $\alpha = 1.5$
- all AGN: $\alpha = 1.40 \pm 0.05$
- radio-quiet: $\alpha = 1.41 \pm 0.07$
- radio-loud: $\alpha = 1.27 \pm 0.09$
- consistent with Euclidean slope within $3\,\sigma$



Summary

- We presented a catalogue of optical identifications of 5341 northern high-galactic latitude X-ray sources from the RASS-BSC
- It contains $\sim 51\%$ extragalactic sources, $\sim 31\%$ galactic stellar X-ray emitters, 3% blank fields ($B_{\rm lim} \approx 20$), and 15% unidentified sources
- $\sim$41% of all sources are active galactic nuclei (Sy, QSOs, BL Lacs), or 49% if corrected for contribution from non-IDs and blank fields
- 22% of the AGN are radio-loud
- The HRC is a valuable data base for the selection of complete samples of soft X-ray emitters for detailed follow-up studies
- version 3.0 of the HRC available on http://www.hs.uni-hamburg.de/hrc.html