

Röntgenspektroszkópiák az anyagszerkezet-kutatásban

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- 1) általános bevezető, módszerek csoportosítása, eszközök
- 2) legfontosabb röntgenabszorpciós technikák
- 3) specifikusabb módszerek: XES, RXES, XMCD

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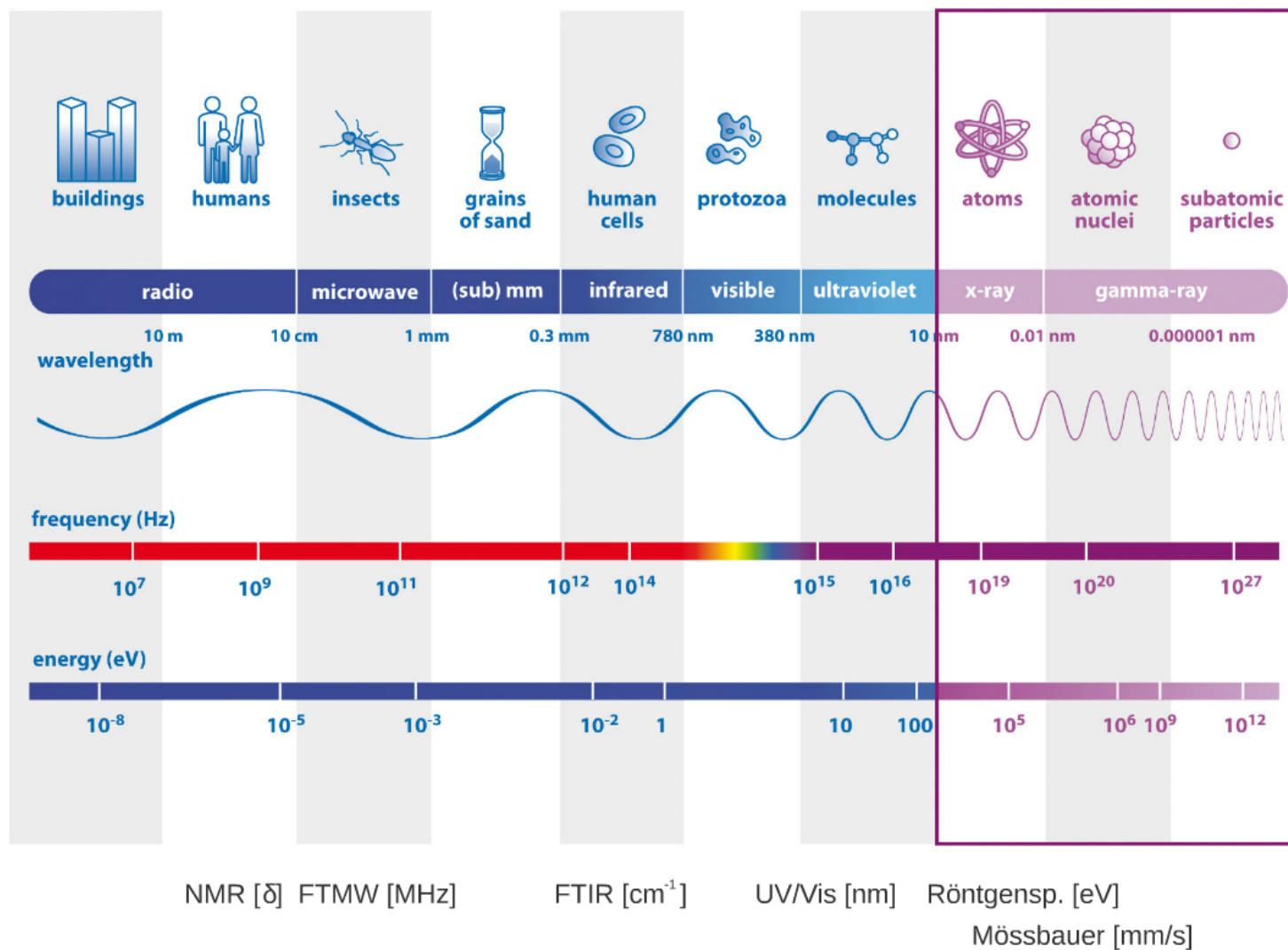
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pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

elsősorban keményröntgen-energiatartomány (kb. 4-20 keV):



elsősorban keményröntgen-energiatartomány (kb. 4-20 keV):

- jellemzően 3d/4d átmenetifémek törzselektronjait ionizáljuk: pl. Fe 1s elektron kötési energiája 7112 eV (<http://xdb.lbl.gov/>)

Table 1. Binding energies (in eV) of the 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f, 5s, 5p, 5d, 5f, 6s, 6p, 6d, 6f, 7s, 7p, 7d, 7f, 8s, 8p, 8d, 8f, 9s, 9p, 9d, 9f, 10s, 10p, 10d, 10f, 11s, 11p, 11d, 11f, 12s, 12p, 12d, 12f, 13s, 13p, 13d, 13f, 14s, 14p, 14d, 14f, 15s, 15p, 15d, 15f, 16s, 16p, 16d, 16f, 17s, 17p, 17d, 17f, 18s, 18p, 18d, 18f, 19s, 19p, 19d, 19f, 20s, 20p, 20d, 20f, 21s, 21p, 21d, 21f, 22s, 22p, 22d, 22f, 23s, 23p, 23d, 23f, 24s, 24p, 24d, 24f, 25s, 25p, 25d, 25f, 26s, 26p, 26d, 26f, 27s, 27p, 27d, 27f, 28s, 28p, 28d, 28f, 29s, 29p, 29d, 29f, 30s, 30p, 30d, 30f, 31s, 31p, 31d, 31f, 32s, 32p, 32d, 32f, 33s, 33p, 33d, 33f, 34s, 34p, 34d, 34f, 35s, 35p, 35d, 35f, 36s, 36p, 36d, 36f, 37s, 37p, 37d, 37f, 38s, 38p, 38d, 38f, 39s, 39p, 39d, 39f, 40s, 40p, 40d, 40f, 41s, 41p, 41d, 41f, 42s, 42p, 42d, 42f, 43s, 43p, 43d, 43f, 44s, 44p, 44d, 44f, 45s, 45p, 45d, 45f, 46s, 46p, 46d, 46f, 47s, 47p, 47d, 47f, 48s, 48p, 48d, 48f, 49s, 49p, 49d, 49f, 50s, 50p, 50d, 50f, 51s, 51p, 51d, 51f, 52s, 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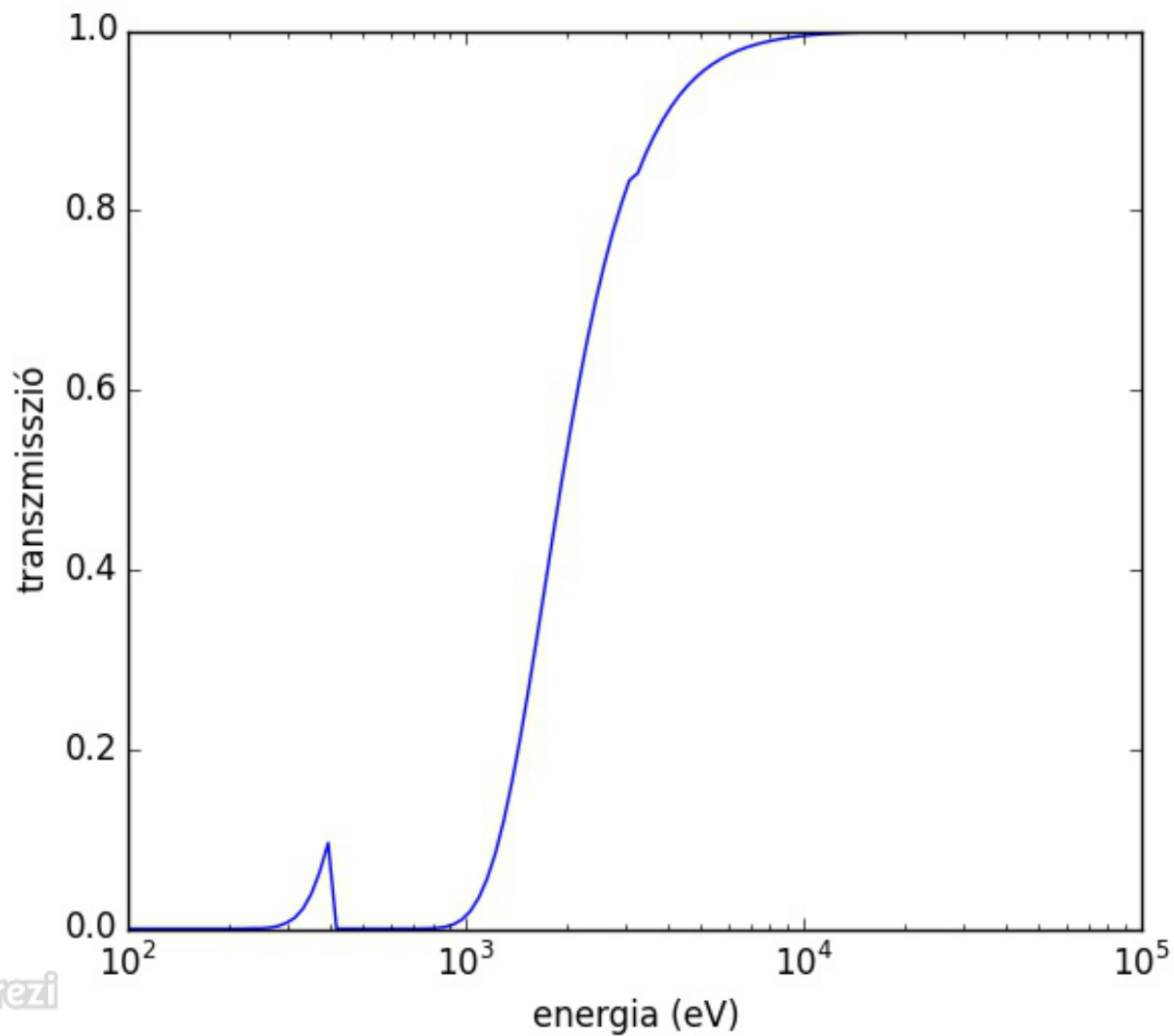
Table 1-1. *Electron binding energies, in electron volts*

Element	K 1s	L ₁ 2s	L ₂ 2p _{1/2}	L ₃ 2p _{3/2}	M ₁ 3s
23 V	5465	626.7†	519.8†	512.1†	66.3†
24 Cr	5989	696.0†	583.8†	574.1†	74.1†
25 Mn	6539	769.1†	649.9†	638.7†	82.3†
26 Fe	7112	844.6†	719.9†	706.8†	91.3†
27 Co	7709	925.1†	793.2†	778.1†	101.0†
28 Ni	8333	1008.6†	870.0†	852.7†	110.8†
29 Cu	8979	1096.7†	952.3†	932.7	122.5†
30 Zn	9659	1196.2*	1044.9*	1021.8*	139.8*
31 Ga	10367	1299.0*b	1143.2†	1116.4†	159.5†
32 Ge	11103	1414.6*b	1248.1*b	1217.0*b	180.1*
33 As	11867	1527.0*b	1350.1*b	1322.6*b	204.7*

elsősorban keményröntgen-energiatartomány (kb. 4-20 keV):

- jellemzően 3d/4d átmenetifémek törzselektronjait ionizáljuk: pl. Fe 1s elektron kötési energiája 7112 eV (<http://xdb.lbl.gov/>)

Table 1. Binding energies (in eV) of the 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f, 5s, 5p, 5d, 5f, 6s, 6p, 6d, 6f, 7s, 7p, 7d, 7f, 8s, 8p, 8d, 8f, 9s, 9p, 9d, 9f, 10s, 10p, 10d, 10f, 11s, 11p, 11d, 11f, 12s, 12p, 12d, 12f, 13s, 13p, 13d, 13f, 14s, 14p, 14d, 14f, 15s, 15p, 15d, 15f, 16s, 16p, 16d, 16f, 17s, 17p, 17d, 17f, 18s, 18p, 18d, 18f, 19s, 19p, 19d, 19f, 20s, 20p, 20d, 20f, 21s, 21p, 21d, 21f, 22s, 22p, 22d, 22f, 23s, 23p, 23d, 23f, 24s, 24p, 24d, 24f, 25s, 25p, 25d, 25f, 26s, 26p, 26d, 26f, 27s, 27p, 27d, 27f, 28s, 28p, 28d, 28f, 29s, 29p, 29d, 29f, 30s, 30p, 30d, 30f, 31s, 31p, 31d, 31f, 32s, 32p, 32d, 32f, 33s, 33p, 33d, 33f, 34s, 34p, 34d, 34f, 35s, 35p, 35d, 35f, 36s, 36p, 36d, 36f, 37s, 37p, 37d, 37f, 38s, 38p, 38d, 38f, 39s, 39p, 39d, 39f, 40s, 40p, 40d, 40f, 41s, 41p, 41d, 41f, 42s, 42p, 42d, 42f, 43s, 43p, 43d, 43f, 44s, 44p, 44d, 44f, 45s, 45p, 45d, 45f, 46s, 46p, 46d, 46f, 47s, 47p, 47d, 47f, 48s, 48p, 48d, 48f, 49s, 49p, 49d, 49f, 50s, 50p, 50d, 50f, 51s, 51p, 51d, 51f, 52s, 52p, 52d, 52f, 53s, 53p, 53d, 53f, 54s, 54p, 54d, 54f, 55s, 55p, 55d, 55f, 56s, 56p, 56d, 56f, 57s, 57p, 57d, 57f, 58s, 58p, 58d, 58f, 59s, 59p, 59d, 59f, 60s, 60p, 60d, 60f, 61s, 61p, 61d, 61f, 62s, 62p, 62d, 62f, 63s, 63p, 63d, 63f, 64s, 64p, 64d, 64f, 65s, 65p, 65d, 65f, 66s, 66p, 66d, 66f, 67s, 67p, 67d, 67f, 68s, 68p, 68d, 68f, 69s, 69p, 69d, 69f, 70s, 70p, 70d, 70f, 71s, 71p, 71d, 71f, 72s, 72p, 72d, 72f, 73s, 73p, 73d, 73f, 74s, 74p, 74d, 74f, 75s, 75p, 75d, 75f, 76s, 76p, 76d, 76f, 77s, 77p, 77d, 77f, 78s, 78p, 78d, 78f, 79s, 79p, 79d, 79f, 80s, 80p, 80d, 80f, 81s, 81p, 81d, 81f, 82s, 82p, 82d, 82f, 83s, 83p, 83d, 83f, 84s, 84p, 84d, 84f, 85s, 85p, 85d, 85f, 86s, 86p, 86d, 86f, 87s, 87p, 87d, 87f, 88s, 88p, 88d, 88f, 89s, 89p, 89d, 89f, 90s, 90p, 90d, 90f, 91s, 91p, 91d, 91f, 92s, 92p, 92d, 92f, 93s, 93p, 93d, 93f, 94s, 94p, 94d, 94f, 95s, 95p, 95d, 95f, 96s, 96p, 96d, 96f, 97s, 97p, 97d, 97f, 98s, 98p, 98d, 98f, 99s, 99p, 99d, 99f, 100s, 100p, 100d, 100f, 101s, 101p, 101d, 101f, 102s, 102p, 102d, 102f, 103s, 103p, 103d, 103f, 104s, 104p, 104d, 104f, 105s, 105p, 105d, 105f, 106s, 106p, 106d, 106f, 107s, 107p, 107d, 107f, 108s, 108p, 108d, 108f, 109s, 109p, 109d, 109f, 110s, 110p, 110d, 110f, 111s, 111p, 111d, 111f, 112s, 112p, 112d, 112f, 113s, 113p, 113d, 113f, 114s, 114p, 114d, 114f, 115s, 115p, 115d, 115f, 116s, 116p, 116d, 116f, 117s, 117p, 117d, 117f, 118s, 118p, 118d, 118f, 119s, 119p, 119d, 119f, 120s, 120p, 120d, 120f, 121s, 121p, 121d, 121f, 122s, 122p, 122d, 122f, 123s, 123p, 123d, 123f, 124s, 124p, 124d, 124f, 125s, 125p, 125d, 125f, 126s, 126p, 126d, 126f, 127s, 127p, 127d, 127f, 128s, 128p, 128d, 128f, 129s, 129p, 129d, 129f, 130s, 130p, 130d, 130f, 131s, 131p, 131d, 131f, 132s, 132p, 132d, 132f, 133s, 133p, 133d, 133f, 134s, 134p, 134d, 134f, 135s, 135p, 135d, 135f, 136s, 136p, 136d, 136f, 137s, 137p, 137d, 137f, 138s, 138p, 138d, 138f, 139s, 139p, 139d, 139f, 140s, 140p, 140d, 140f, 141s, 141p, 141d, 141f, 142s, 142p, 142d, 142f, 143s, 143p, 143d, 143f, 144s, 144p, 144d, 144f, 145s, 145p, 145d, 145f, 146s, 146p, 146d, 146f, 147s, 147p, 147d, 147f, 148s, 148p, 148d, 148f, 149s, 149p, 149d, 149f, 150s, 150p, 150d, 150f, 151s, 151p, 151d, 151f, 152s, 152p, 152d, 152f, 153s, 153p, 153d, 153f, 154s, 154p, 154d, 154f, 155s, 155p, 155d, 155f, 156s, 156p, 156d, 156f, 157s, 157p, 157d, 157f, 158s, 158p, 158d, 158f, 159s, 159p, 159d, 159f, 160s, 160p, 160d, 160f, 161s, 161p, 161d, 161f, 162s, 162p, 162d, 162f, 163s, 163p, 163d, 163f, 164s, 164p, 164d, 164f, 165s, 165p, 165d, 165f, 166s, 166p, 166d, 166f, 167s, 167p, 167d, 167f, 168s, 168p, 168d, 168f, 169s, 169p, 169d, 169f, 170s, 170p, 170d, 170f, 171s, 171p, 171d, 171f, 172s, 172p, 172d, 172f, 173s, 173p, 173d, 173f, 174s, 174p, 174d, 174f, 175s, 175p, 175d, 175f, 176s, 176p, 176d, 176f, 177s, 177p, 177d, 177f, 178s, 178p, 178d, 178f, 179s, 179p, 179d, 179f, 180s, 180p, 180d, 180f, 181s, 181p, 181d, 181f, 182s, 182p, 182d, 182f, 183s, 183p, 183d, 183f, 184s, 184p, 184d, 184f, 185s, 185p, 185d, 185f, 186s, 186p, 186d, 186f, 187s, 187p, 187d, 187f, 188s, 188p, 188d, 188f, 189s, 189p, 189d, 189f, 190s, 190p, 190d, 190f, 191s, 191p, 191d, 191f, 192s, 192p, 192d, 192f, 193s, 193p, 193d, 193f, 194s, 194p, 194d, 194f, 195s, 195p, 195d, 195f, 196s, 196p, 196d, 196f, 197s, 197p, 197d, 197f, 198s, 198p, 198d, 198f, 199s, 199p, 199d, 199f, 200s, 200p, 200d, 200f, 201s, 201p, 201d, 201f, 202s, 202p, 202d, 202f, 203s, 203p, 203d, 203f, 204s, 204p, 204d, 204f, 205s, 205p, 205d, 205f, 206s, 206p, 206d, 206f, 207s, 207p, 207d, 207f, 208s, 208p, 208d, 208f, 209s, 209p, 209d, 209f, 210s, 210p, 210d, 210f, 211s, 211p, 211d, 211f, 212s, 212p, 212d, 212f, 213s, 213p, 213d, 213f, 214s, 214p, 214d, 214f, 215s, 215p, 215d, 215f, 216s, 216p, 216d, 216f, 217s, 217p, 217d, 217f, 218s, 218p, 218d, 218f, 219s, 219p, 219d, 219f, 220s, 220p, 220d, 220f, 221s, 221p, 221d, 221f, 222s, 222p, 222d, 222f, 223s, 223p, 223d, 223f, 224s, 224p, 224d, 224f, 225s, 225p, 225d, 225f, 226s, 226p, 226d, 226f, 227s, 227p, 227d, 227f, 228s, 228p, 228d, 228f, 229s, 229p, 229d, 229f, 230s, 230p, 230d, 230f, 231s, 231p, 231d, 231f, 232s, 232p, 232d, 232f, 233s, 233p, 233d, 233f, 234s, 234p, 234d, 234f, 235s, 235p, 235d, 235f, 236s, 236p, 236d, 236f, 237s, 237p, 237d, 237f, 238s, 238p, 238d, 238f, 239s, 239p, 239d, 239f, 240s, 240p, 240d, 240f, 241s, 241p, 241d, 241f, 242s, 242p, 242d, 242f, 243s, 243p, 243d, 243f, 244s, 244p, 244d, 244f, 245s, 245p, 245d, 245f, 246s, 246p, 246d, 246f, 247s, 247p, 247d, 247f, 248s, 248p, 248d, 248f, 249s, 249p, 249d, 249f, 250s, 250p, 250d, 250f, 251s, 251p, 251d, 251f, 252s, 252p, 252d, 252f, 253s, 253p, 253d, 253f, 254s, 254p, 254d, 254f, 255s, 255p, 255d, 255f, 256s, 256p, 256d, 256f, 257s, 257p, 257d, 257f, 258s, 258p, 258d, 258f, 259s, 259p, 259d, 259f, 260s, 260p, 260d, 260f, 261s, 261p, 261d, 261f, 262s, 262p, 262d, 262f, 263s, 263p, 263d, 263f, 264s, 264p, 264d, 264f, 265s, 265p, 265d, 265f, 266s, 266p, 266d, 266f, 267s, 267p, 267d, 267f, 268s, 268p, 268d, 268f, 269s, 269p, 269d, 269f, 270s, 270p, 270d, 270f, 271s, 271p, 271d, 271f, 272s, 272p, 272d, 272f, 273s, 273p, 273d, 273f, 274s, 274p, 274d, 274f, 275s, 275p, 275d, 275f, 276s, 276p, 276d, 276f, 277s, 277p, 277d, 277f, 278s, 278p, 278d, 278f, 279s, 279p, 279d, 279f, 280s, 280p, 280d, 280f, 281s, 281p, 281d, 281f, 282s, 282p, 282d, 282f, 283s, 283p, 283d, 283f, 284s, 284p, 284d, 284f, 285s, 285p, 285d, 285f, 286s, 286p, 286d, 286f, 287s, 287p, 287d, 287f, 288s, 288p, 288d, 288f, 289s, 289p, 289d, 289f, 290s, 290p, 290d, 290f, 291s, 291p, 291d, 291f, 292s, 292p, 292d, 292f, 293s, 293p, 293d, 293f, 294s, 294p, 294d, 294f, 295s, 295p, 295d, 295f, 296s, 296p, 296d, 296f, 297s, 297p, 297d, 297f, 298s, 298p, 298d, 298f, 299s, 299p, 299d, 299f, 300s, 300p, 300d, 300f, 301s, 301p, 301d, 301f, 302s, 302p, 302d, 302f, 303s, 303p, 303d, 303f, 304s, 304p, 304d, 304f, 305s, 305p, 305d, 305f, 306s, 306p, 306d, 306f, 307s, 307p, 307d, 307f, 308s, 308p, 308d, 308f, 309s, 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392p, 392d, 392f, 393s, 393p, 393d, 393f, 394s, 394p, 394d, 394f, 395s, 395p, 395d, 395f, 396s, 396p, 396d, 396f, 397s, 397p, 397d, 397f, 398s, 398p, 398d, 398f, 399s, 399p, 399d, 399f, 400s, 400p, 400d, 400f, 401s, 401p, 401d, 401f, 402s, 402p, 402d, 402f, 403s, 403p, 403d, 403f, 404s, 404p, 404d, 404f, 405s, 405p, 405d, 405f, 406s, 406p, 406d, 406f, 407s, 407p, 407d, 407f, 408s, 408p, 408d, 408f, 409s, 409p, 409d, 409f, 410s, 410p, 410d, 410f, 411s, 411p, 411d, 411f, 412s, 412p, 412d, 412f, 413s, 413p, 413d, 413f, 414s, 414p, 414d, 414f, 415s, 415p, 415d, 415f, 416s, 416p, 416d, 416f, 417s, 417p, 417d, 417f, 418s, 418p, 418d, 418f, 419s, 419p, 419d, 419f, 420s, 420p, 420d, 420f, 421s, 421p, 421d, 421f, 422s, 422p, 422d, 422f, 423s, 423p, 423d, 423f, 424s, 424p, 424d, 424f, 425s, 425p, 425d, 425f, 426s, 426p, 426d, 426f, 427s, 427p, 427d, 427f, 428s, 428p, 428d, 428f, 429s, 429p, 429d, 429f, 430s, 430p, 430d, 430f, 431s, 431p, 431d, 431f, 432s, 432p, 432d, 432f, 433s, 433p, 433d, 433f, 434s, 434p, 434d, 434f, 435s, 435p, 435d, 435f, 436s, 436p, 436d, 436f, 437s, 437p, 437d, 437f, 438s, 438p, 438d, 438f, 439s, 439p, 439d, 439f, 440s, 440p, 440d, 440f, 441s, 441p, 441d, 441f, 442s, 442p, 442d, 442f, 443s, 443p, 443d, 443f, 444s, 444p, 444d, 444f, 445s, 445p, 445d, 445f, 446s, 446p, 446d, 446f, 447s, 447p, 447d, 447f, 448s, 448p, 448d, 448f, 449s, 449p, 449d, 449f, 450s, 450p, 450d, 450f, 451s, 451p, 451d, 451f, 452s, 452p, 452d, 452f, 453s, 453p, 453d, 453f, 454s, 454p, 454d, 454f, 455s, 455p, 455d, 455f, 456s, 456p, 456d, 456f, 457s, 457p, 457d, 457f, 458s, 458p, 458d, 458f, 459s, 459p, 459d, 459f, 460s, 460p, 460d, 460f, 461s, 461p, 461d, 461f, 462s, 462p, 462d, 462f, 463s, 463p, 463d, 463f, 464s, 464p, 464d, 464f, 465s, 465p, 465d, 465f, 466s, 466p, 466d, 466f, 467s, 467p, 467d, 467f, 468s, 468p, 468d, 468f, 469s, 469p, 469d, 469f, 470s, 470p, 470d, 470f, 471s, 471p, 471d, 471f, 472s, 472p, 472d, 472f, 473s, 473p, 473d, 473f, 474s, 474p, 474d, 474f, 475s, 475p, 475d, 475f, 476s, 476p, 476d, 476f, 477s, 477p, 477d, 477f, 478s, 478p, 478d, 478f, 479s, 479p, 479d, 479f, 480s, 480p, 480d, 480f, 481s, 481p, 481d, 481f, 482s, 482p, 482d, 482f, 483s, 483p, 483d, 483f, 484s, 484p, 484d, 484f, 485s, 485p, 485d, 485f, 486s, 486p, 486d, 486f, 487s, 487p, 487d, 487f, 488s, 488p, 488d, 488f, 489s, 489p, 489d, 489f, 490s, 490p, 490d, 490f, 491s, 491p, 491d, 491f, 492s, 492p, 492d, 492f, 493s, 493p, 493d, 493f, 494s, 494p, 494d, 494f, 495s, 495p, 495d, 495f, 496s, 496p, 496d, 496f, 497s, 497p, 497d, 497f, 498s, 498p, 498d, 498f, 499s, 499p, 499d, 499f, 500s, 500p, 500d, 500f, 501s, 501p, 501d, 501f, 502s, 502p, 502d, 502f, 503s, 503p, 503d, 503f, 504s, 504p, 504d, 504f, 505s, 505p, 505d, 505f, 506s, 506p, 506d, 506f, 507s, 507p, 507d, 507f, 508s, 508p, 508d, 508f, 509s, 509p, 509d, 509f, 510s, 510p, 510d, 510f, 511s, 511p, 511d, 511f, 512s, 512p, 512d, 512f, 513s, 513p, 513d, 513f, 514s, 514p, 514d, 514f, 515s, 515p, 515d, 515f, 516s, 516p, 516d, 516f, 517s, 517p, 517d, 517f, 518s, 518p, 518d, 518f, 519s, 519p, 519d, 519f, 520s, 520p, 520d, 520f, 521s, 521p, 521d, 521f, 522s, 522p, 522d, 522f, 523s, 523p, 523d, 523f, 524s, 524p, 524d, 524f, 525s, 525p, 525d, 525f, 526s, 526p, 526d, 526f, 527s, 527p, 527



elsősorban keményröntgen-energiatartomány (kb. 4-20 keV):

- jellemzően 3d/4d átmenetifémek törzselektronjait ionizáljuk: pl. Fe 1s elektron kötési energiája 7112 eV (<http://xdb.lbl.gov/>)

Table 1. Binding energies (in eV) of the 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f, 5s, 5p, 5d, 5f, 6s, 6p, 6d, 6f, 7s, 7p, 7d, 7f, 8s, 8p, 8d, 8f, 9s, 9p, 9d, 9f, 10s, 10p, 10d, 10f, 11s, 11p, 11d, 11f, 12s, 12p, 12d, 12f, 13s, 13p, 13d, 13f, 14s, 14p, 14d, 14f, 15s, 15p, 15d, 15f, 16s, 16p, 16d, 16f, 17s, 17p, 17d, 17f, 18s, 18p, 18d, 18f, 19s, 19p, 19d, 19f, 20s, 20p, 20d, 20f, 21s, 21p, 21d, 21f, 22s, 22p, 22d, 22f, 23s, 23p, 23d, 23f, 24s, 24p, 24d, 24f, 25s, 25p, 25d, 25f, 26s, 26p, 26d, 26f, 27s, 27p, 27d, 27f, 28s, 28p, 28d, 28f, 29s, 29p, 29d, 29f, 30s, 30p, 30d, 30f, 31s, 31p, 31d, 31f, 32s, 32p, 32d, 32f, 33s, 33p, 33d, 33f, 34s, 34p, 34d, 34f, 35s, 35p, 35d, 35f, 36s, 36p, 36d, 36f, 37s, 37p, 37d, 37f, 38s, 38p, 38d, 38f, 39s, 39p, 39d, 39f, 40s, 40p, 40d, 40f, 41s, 41p, 41d, 41f, 42s, 42p, 42d, 42f, 43s, 43p, 43d, 43f, 44s, 44p, 44d, 44f, 45s, 45p, 45d, 45f, 46s, 46p, 46d, 46f, 47s, 47p, 47d, 47f, 48s, 48p, 48d, 48f, 49s, 49p, 49d, 49f, 50s, 50p, 50d, 50f, 51s, 51p, 51d, 51f, 52s, 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6 C	284.2*								
7 N	409.9*	37.3*							
8 O	543.1*	41.6*							
9 F	696.7*								
10 Ne	870.2*	48.5*	21.7*	21.6*					
11 Na	1070.8†	63.5†	30.65	30.81					
12 Mg	1303.0†	88.7	49.78	49.50					
13 Al	1559.6	117.8	72.95	72.55					
14 Si	1839	149.7*b	99.82	99.42					
15 P	2145.5	189*	136*	135*					
16 S	2472	230.9	163.6*	162.5*					
17 Cl	2822.4	270*	202*	200*					
18 Ar	3205.9*	326.3*	250.6†	248.4*	29.3*	15.9*	15.7*		
19 K	3608.4*	378.6*	297.3*	294.6*	34.8*	18.3*	18.3*		
20 Ca	4038.5*	438.4†	349.7†	346.2†	44.3 †	25.4†	25.4†		
21 Sc	4492	498.0*	403.6*	398.7*	51.1*	28.3*	28.3*		
22 Ti	4966	560.9†	460.2†	453.8†	58.7†	32.6†	32.6†		

Table 1-1. Electron binding energies, in electron volts, for the elements V to Ag in their natural form

Element	K 1s	L ₁ 2s	L ₂ 2p _{1/2}	L ₃ 2p _{3/2}	M ₁ 3s	M ₂ 3p _{1/2}	M ₃ 3p _{3/2}	M ₄ 3d _{3/2}	M ₅ 3d _{5/2}	N ₁ 4s	N ₂ 4p _{1/2}
23 V	5465	626.7†	519.8†	512.1†	66.3†	37.2†	37.2†				
24 Cr	5989	696.0†	583.8†	574.1†	74.1†	42.2†	42.2†				
25 Mn	6539	769.1†	649.9†	638.7†	82.3†	47.2†	47.2†				
26 Fe	7112	844.6†	719.9†	706.8†	91.3†	52.7†	52.7†				
27 Co	7709	925.1†	793.2†	778.1†	101.0†	58.9†	59.9†				
28 Ni	8333	1008.6†	870.0†	852.7†	110.8†	68.0†	66.2†				
29 Cu	8979	1096.7†	952.3†	932.7	122.5†	77.3†	75.1†				



pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

röntgenfotonok abszorpciója és emissziója

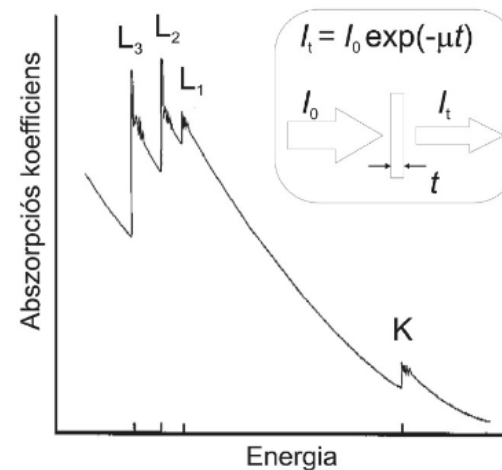
XAS:
röntgenabszorpciós spektroszkópia

XANES:
röntgenabszorpciós él körüli szerkezet

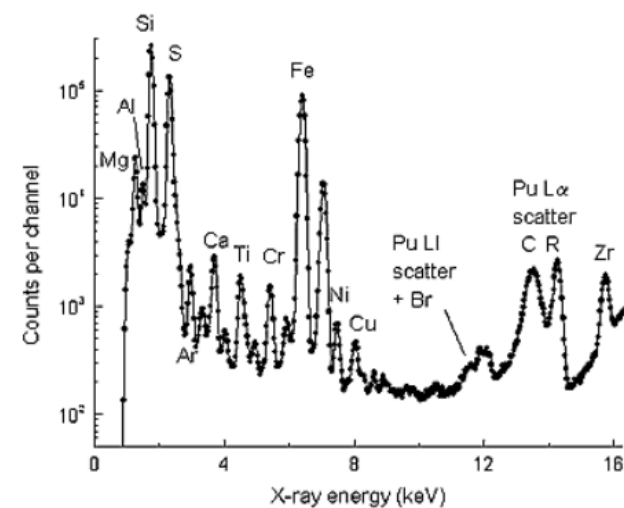
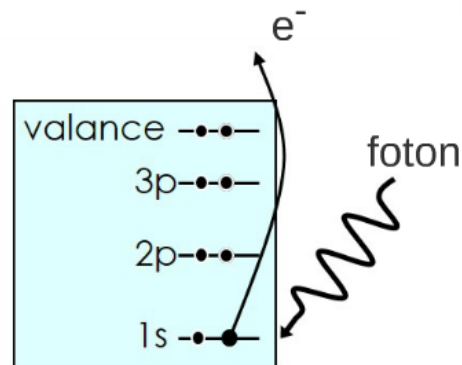
EXAFS:
kiterjesztett röntgenabszorpció
finomszerkezete

XRF:
röntgenfluoreszcencia

XES:
röntgenemissziós
spektroszkópia



E_{foton}^{-3} + abszorpciós élék

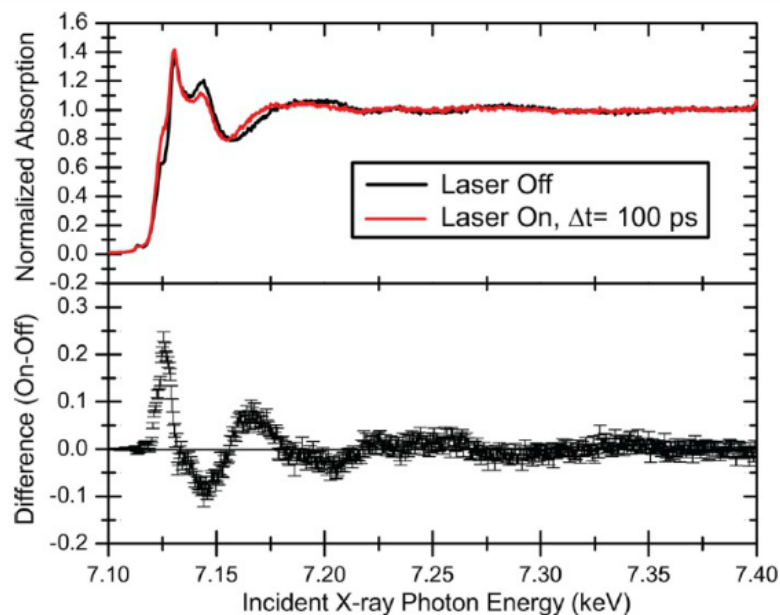


Spirit Mars-szonda XRF mérése

pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

nagy energiefelbontás: információban gazdag részletek

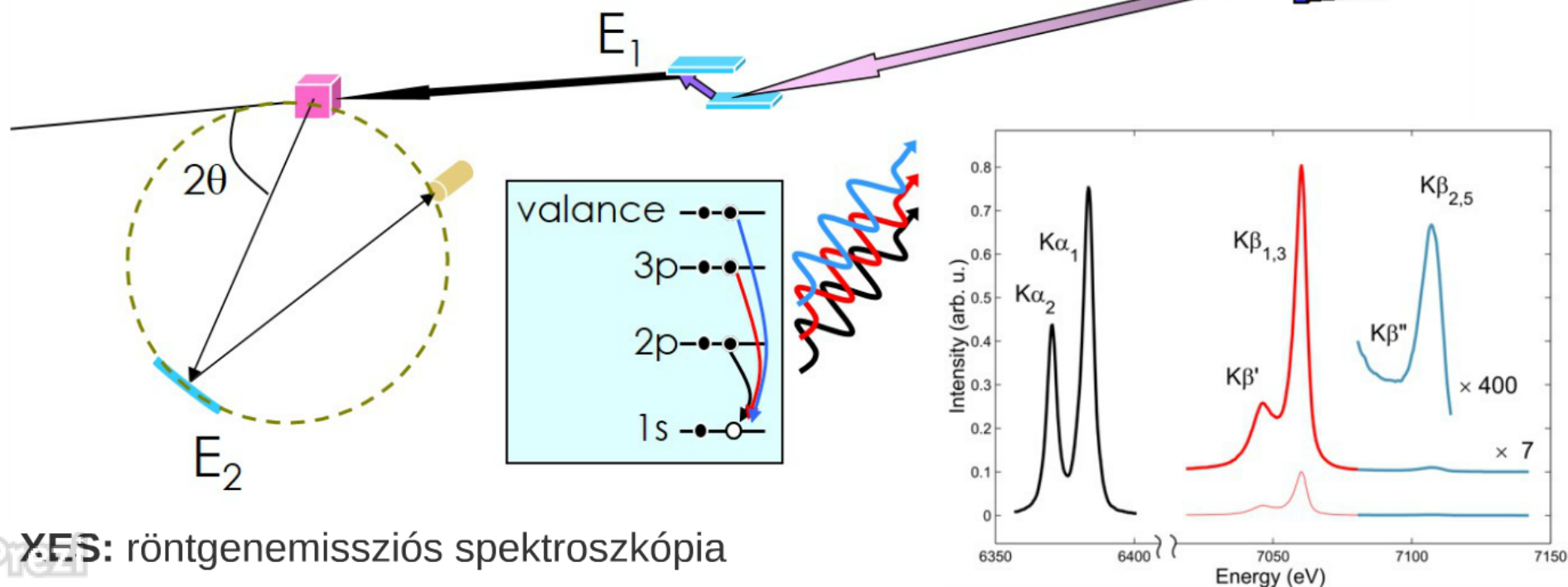


XANES:

röntgenabszorpciós él körüli szerkezet

EXAFS:

kiterjesztett röntgenabszorpció
finomszerkezete



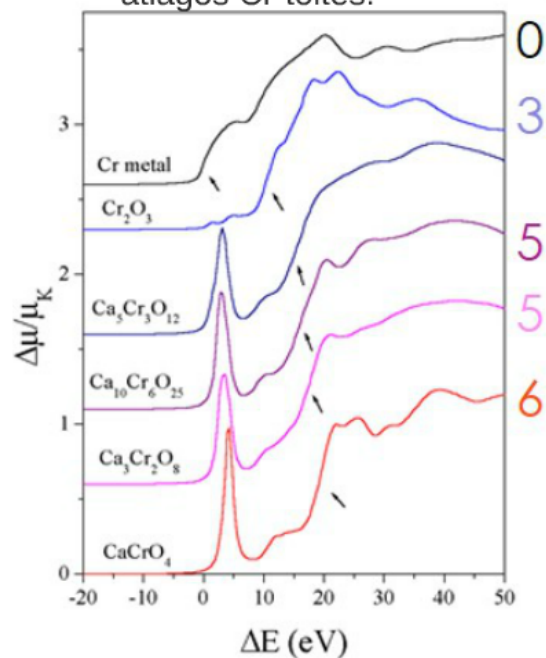
XES: röntgenemissziós spektroszkópia

nagy energiefelbontás: információban gazdag részletek

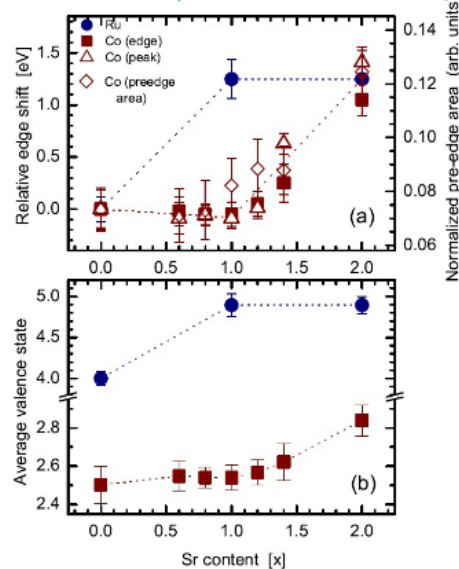
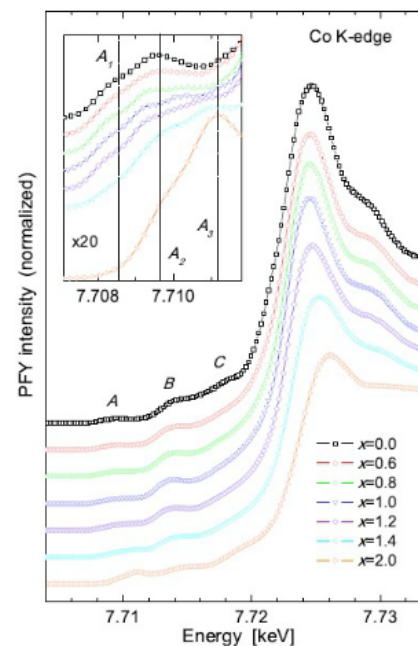
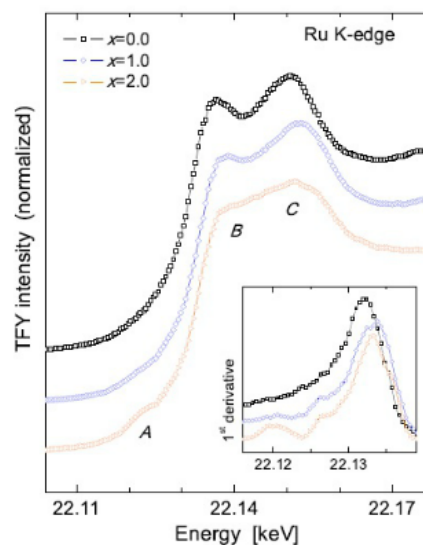
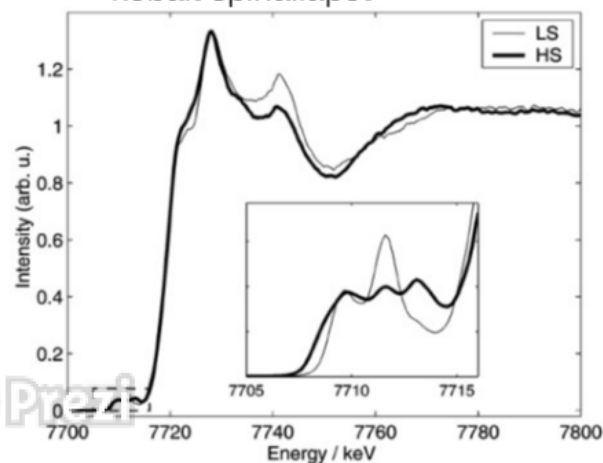
XANES:

röntgenabszorpciós él körüli szerkezet

átlagos Cr-töltés:



kobalt spinállapot



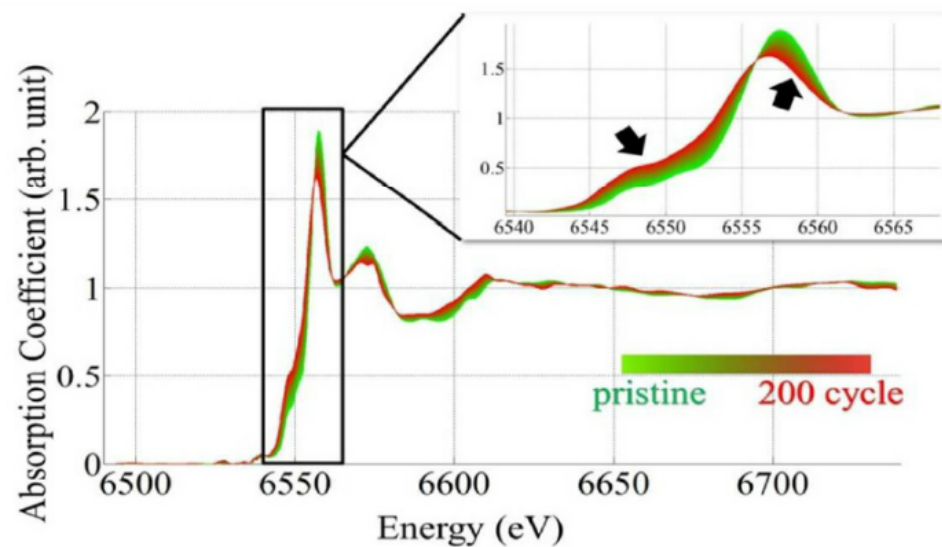
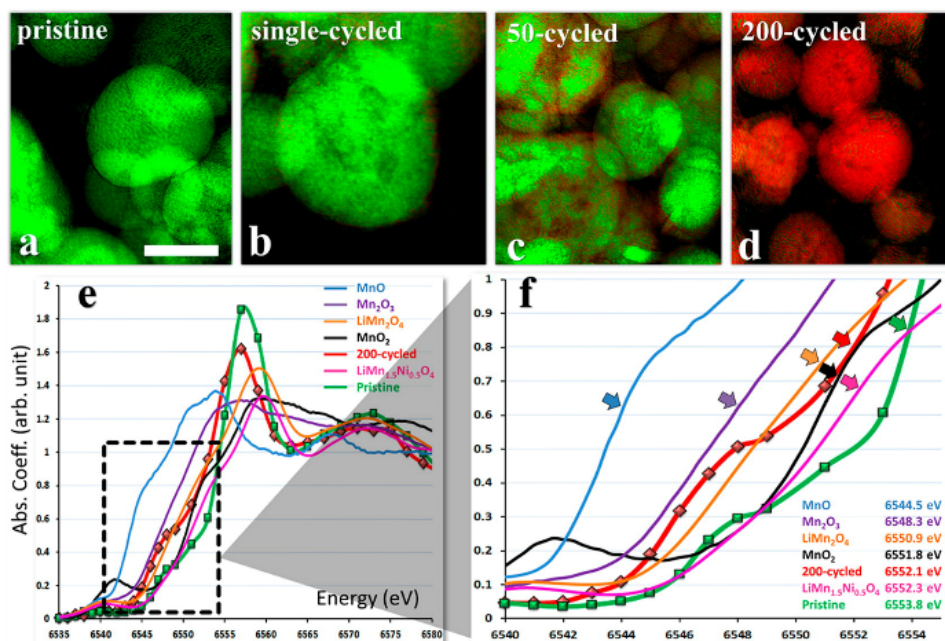
Prof.

pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

nagy térfelbontás:

- szinkrotronoknál elég kicsi a nyaláb divergenciája, tovább fókuszálható résekkel (mm), tükrökkel (néhány 10 mikrométer) vagy Fresnel-féle zóna lemezekkel (nanométeres nagyságrend)



SLAC SSRL szinkrotron (USA) 6-2c nyalábja,
Li1.2 Mn0.525 Ni0.175 Co0.1 O2 katód Mn K-él XANES spektrumai,
30 nm-es térfelbontással.

Balra: mangánionok töltéseloszlása (zöld: oxidált kiindulási állpaot, piros: redukált végállapot).

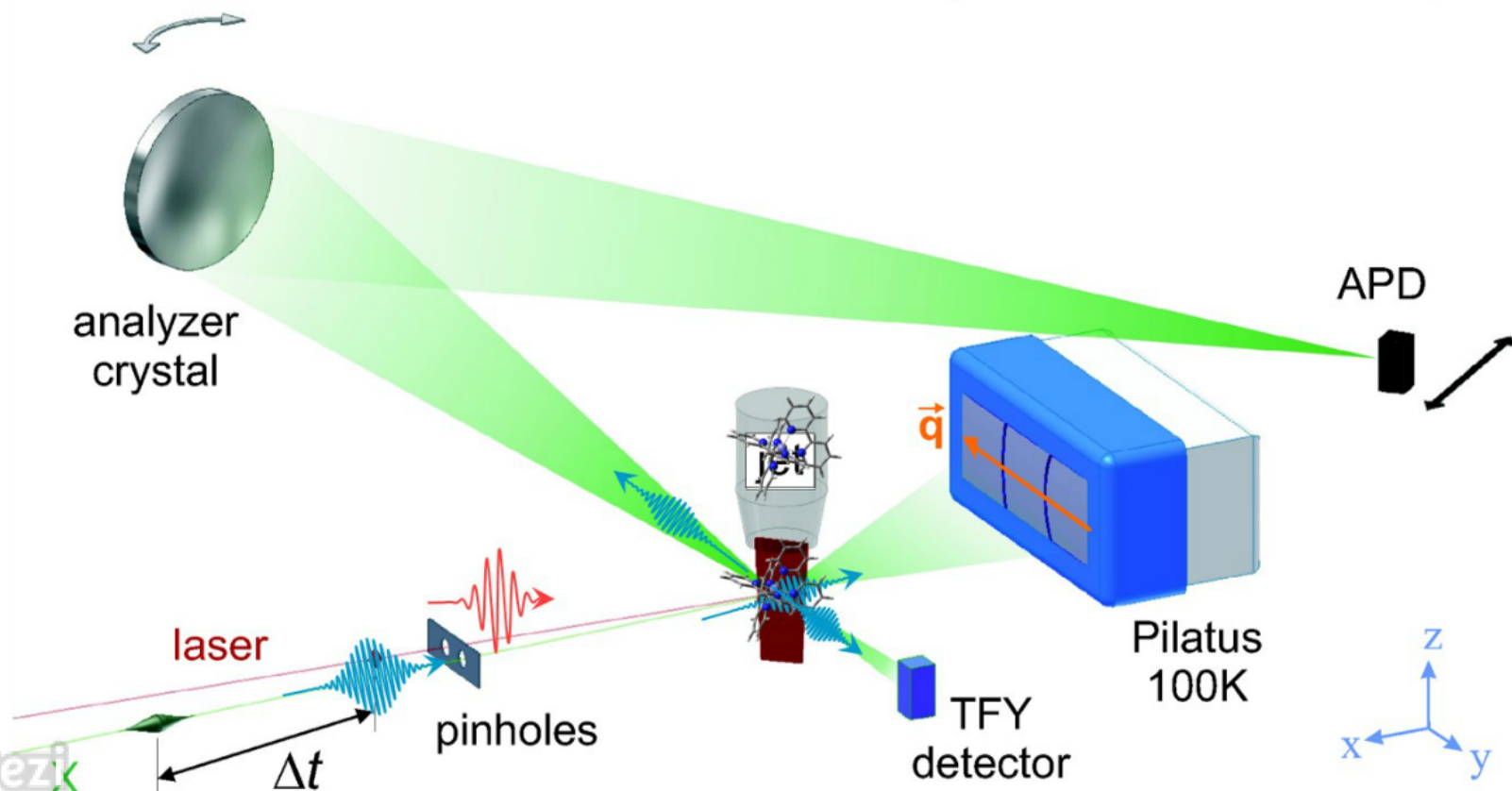
pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

nagy időfelbontás:

- Szinkrotronokban futó töltött részecskecsomagok (általában elektronok) hossza kb. 100 ps, a csomagok közti követési távolság pl. 170 ns (ESRF 16 csomag módja). Pumpa-szonda módszerrel kb. 100 ps időfelbontással lehet mérni.
- Szabadelektron-röntgenlézerekben mindez kb. néhány **10 fs**!

G. Vankó et al., Angew. Chem. Int. Ed. 50 (2010) 5610.
K. Haldrup, G. Vankó, et al., J. Phys. Chem. A 116 (2012) 9878.
G. Vankó et al., J. Electron Spectrosc. Relat. Phenom. 188 (2013) 166.

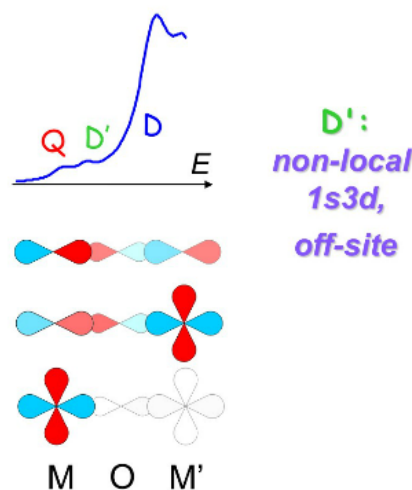
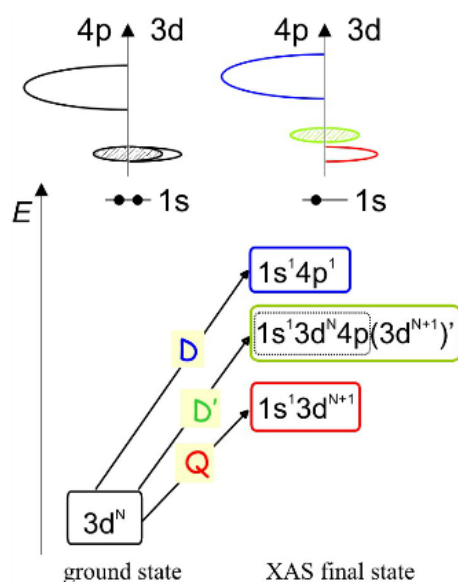
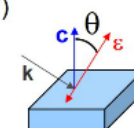
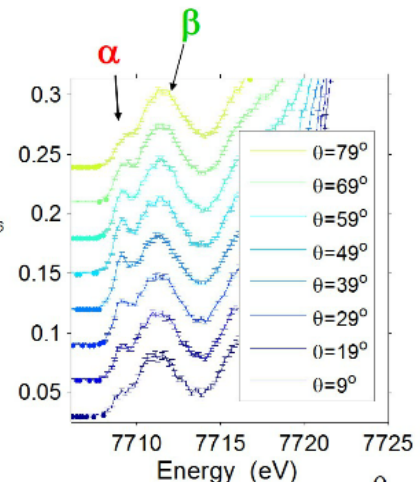
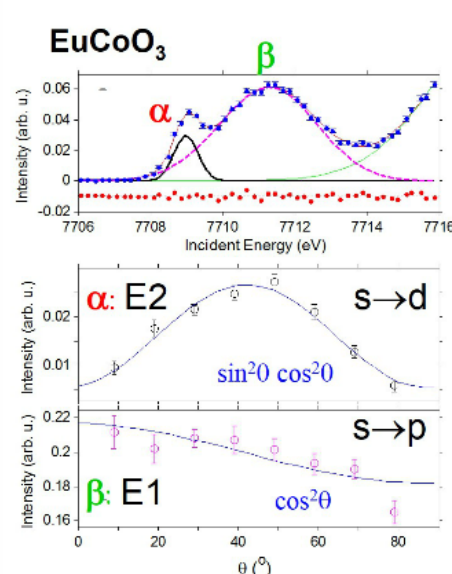
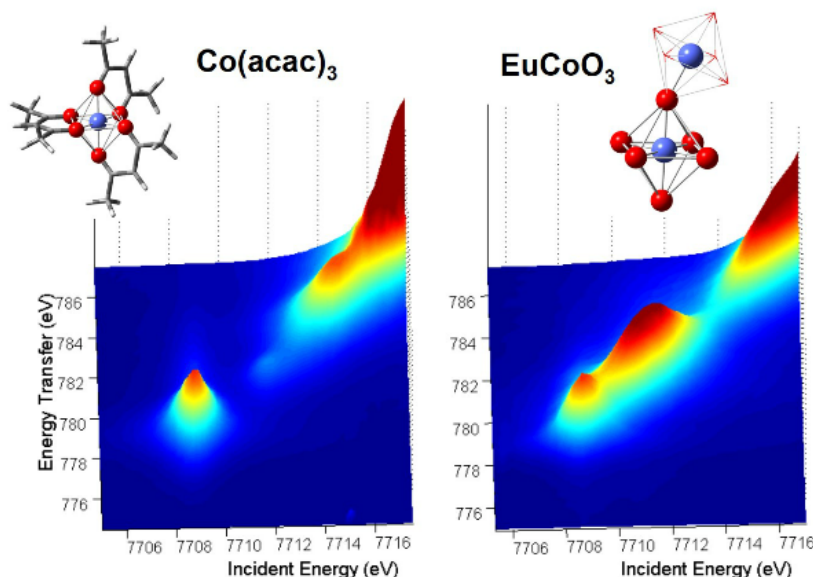


pontosítsunk:

- elsősorban keményröntgen-energiatartomány (kb. 4-20 keV)
- röntgenfotonok abszorpciója és emissziója
- nagy energiafelbontás
- esetenként nagy térfelbontás
- esetenként nagy időfelbontás
- esetenként polarizációfüggés

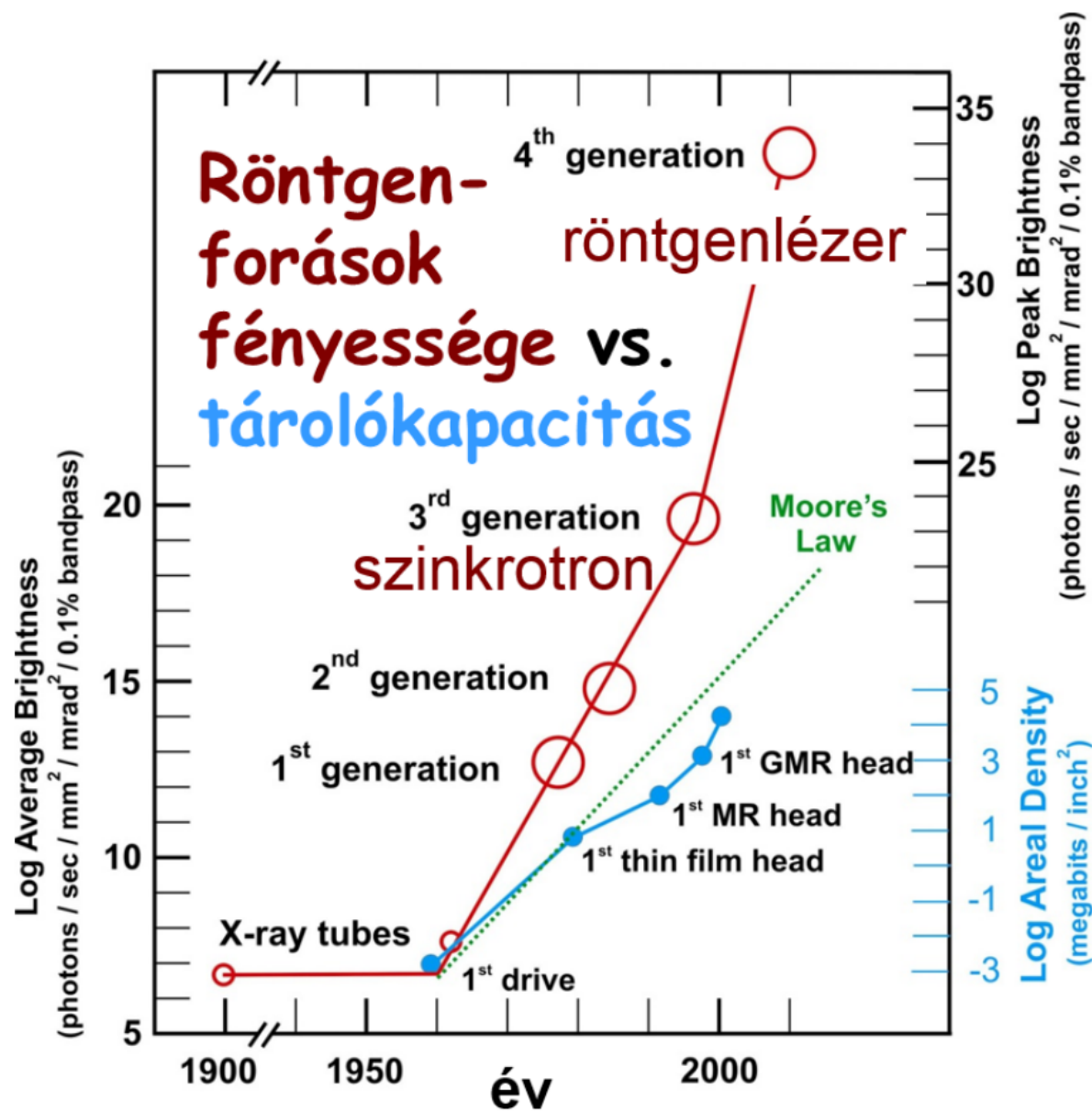
polarizációfüggés:

- szinkrotronokban a röntgennyaláb lineárisan polarizált - polarizációfüggő mérések is lehetségesek



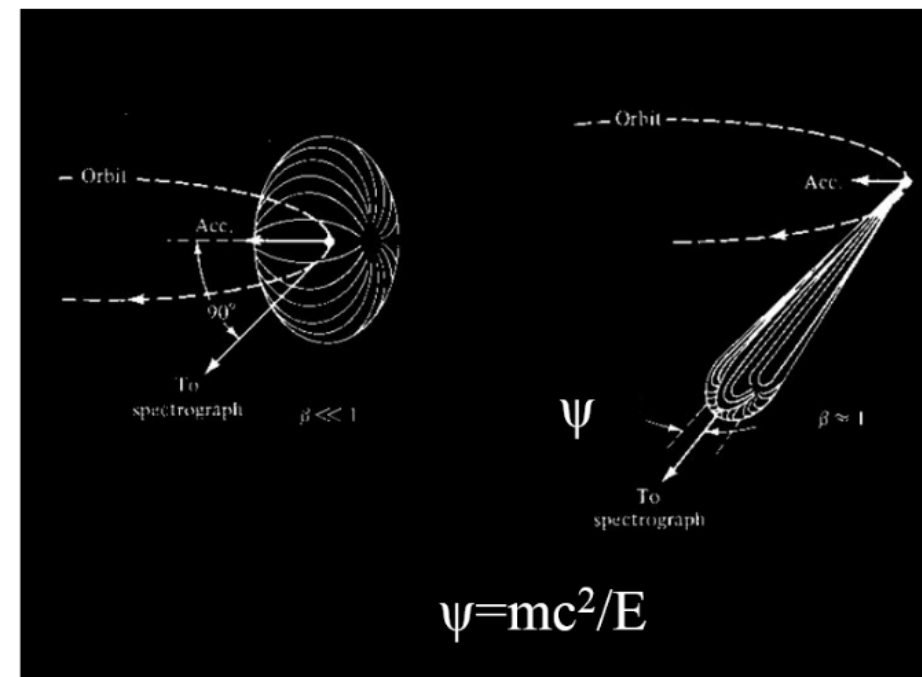
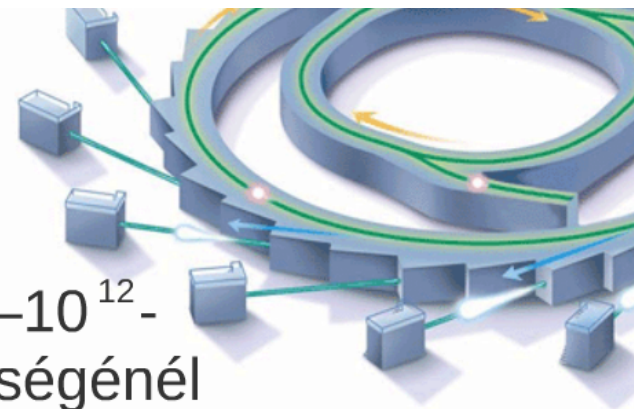
kivitelezés:

- röntgenforrás
- energiafelbontás / pásztázás
- detektálás



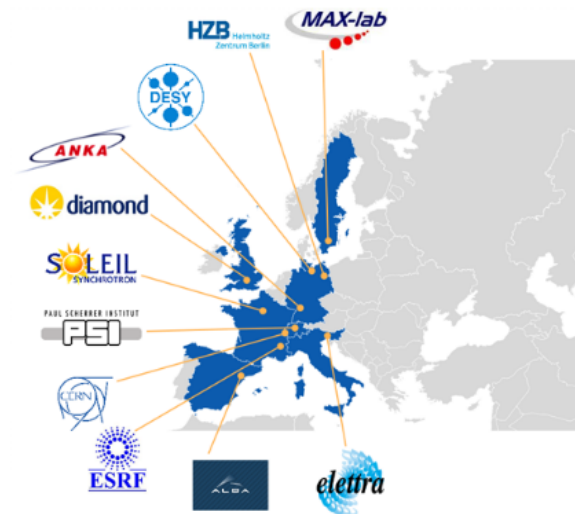
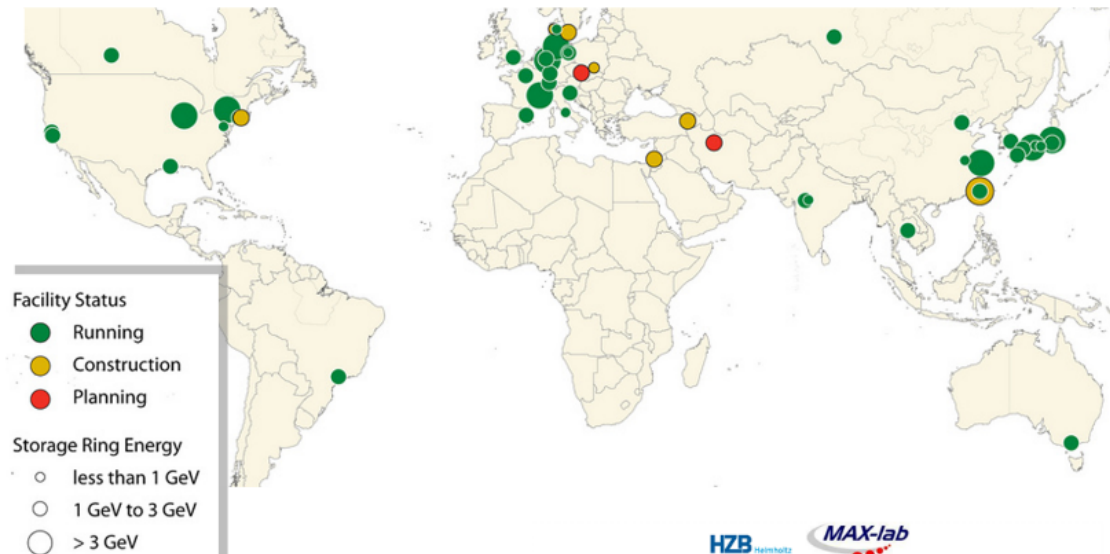
szinkrotron

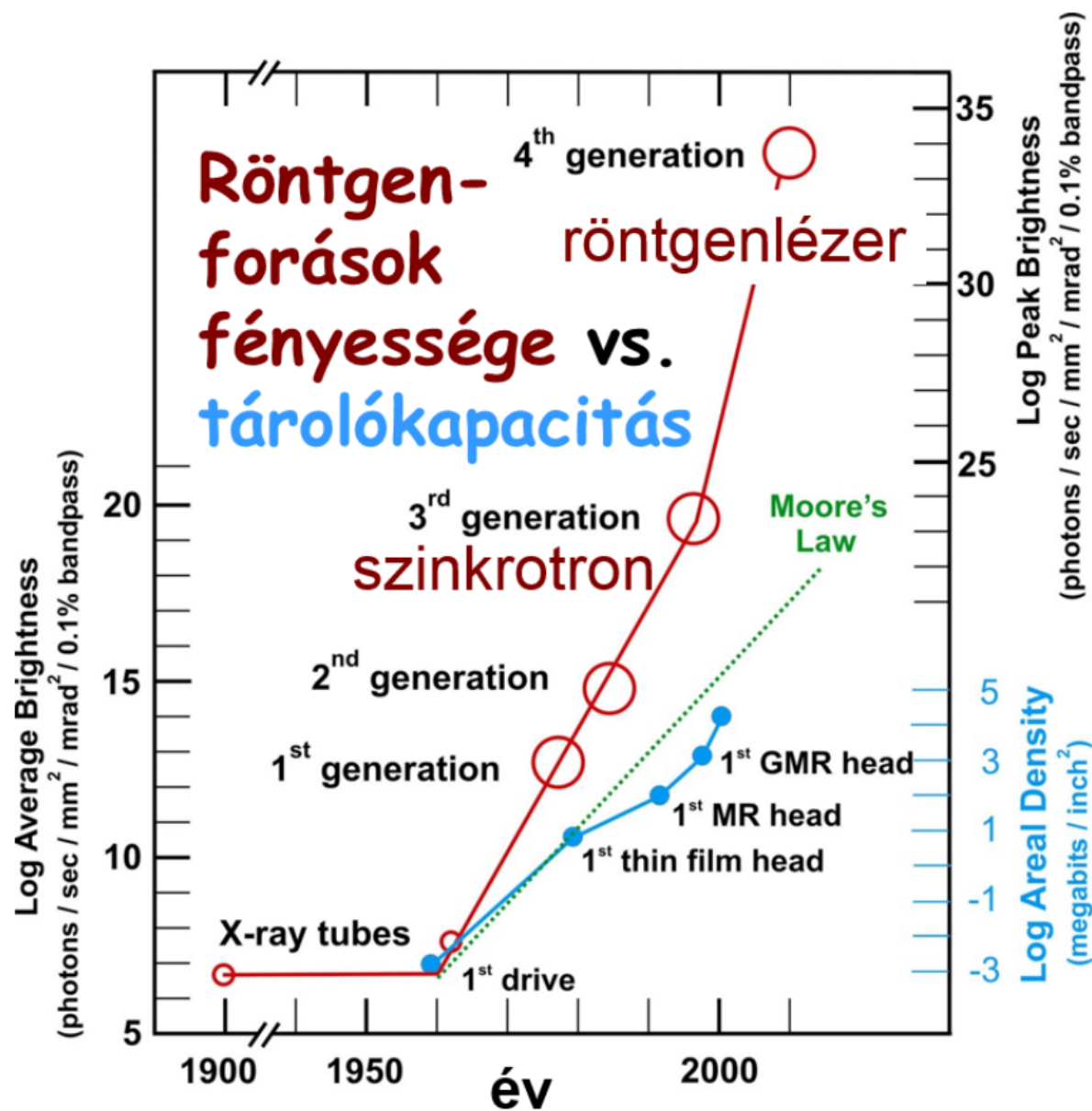
- fényessége (fotonok száma/vertikális szög) 10^6 – 10^{12} -szerese a hagyományos röntgencsövek fényességénél
- energiatartománya nagyon széles (infravöröstől kemény röntgenig), és általában folytonos eloszlású
- pályasíkbán általában lineárisan polarizált
- alapvetően jól kollimált (függőleges divergencia: 0,1–1 mrad)
- lehetséges pulzált sugárzás előállítása (impulzushossz: 10^{-10} s, periódusidő: 10^{-6} – 10^{-8} s (változtatható))



szinkrotron

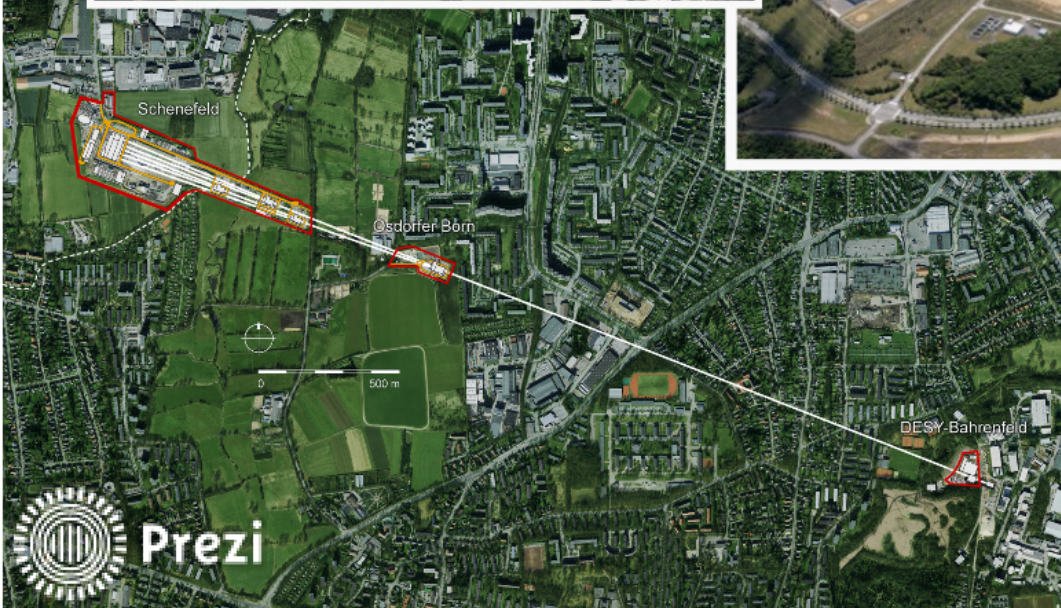
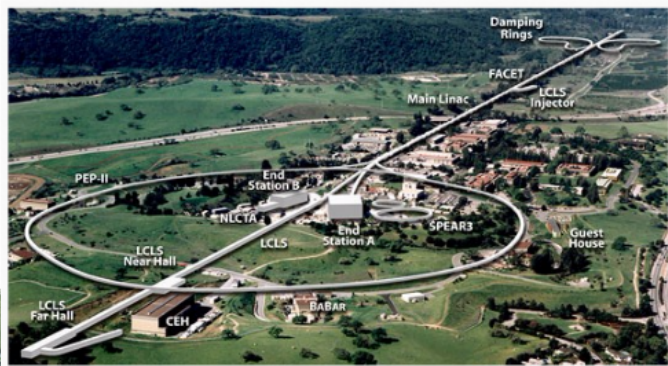
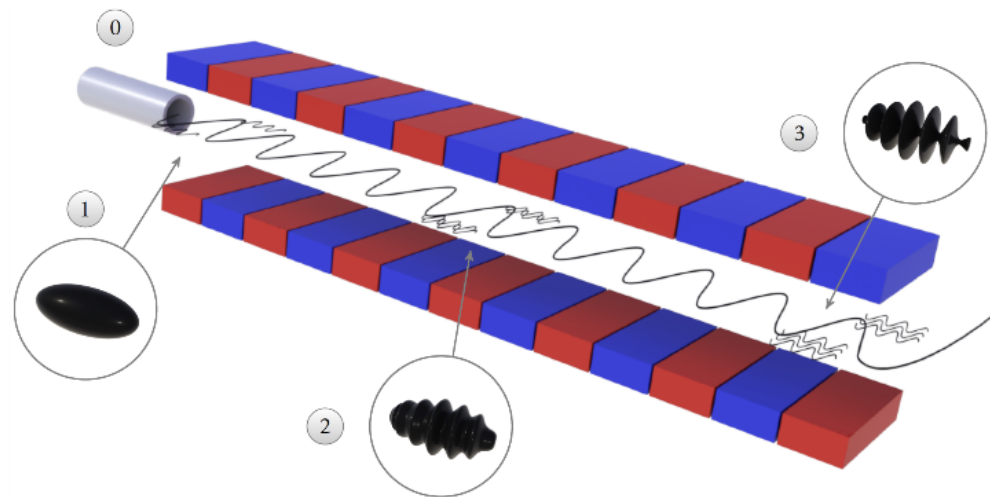
- 4 nagy szinkrotron: ESRF (EU), Petra III (Németo.), APS (USA), Spring8 (Japán) és néhány tucat kisebb
- rezsi: kb. 100 M€ / év
- pályázati rendszer a mérésekre
- rövid, intenzív mérések (tipikusan néhány nap, napi 24h)
- komoly szakmai támogatás a helyi kutatóktól
- ESRF: pénzügyi támogatás (utazás, szállás stb.) a nyertes kutatóknak a magyar éves hozzájárulás ellenében



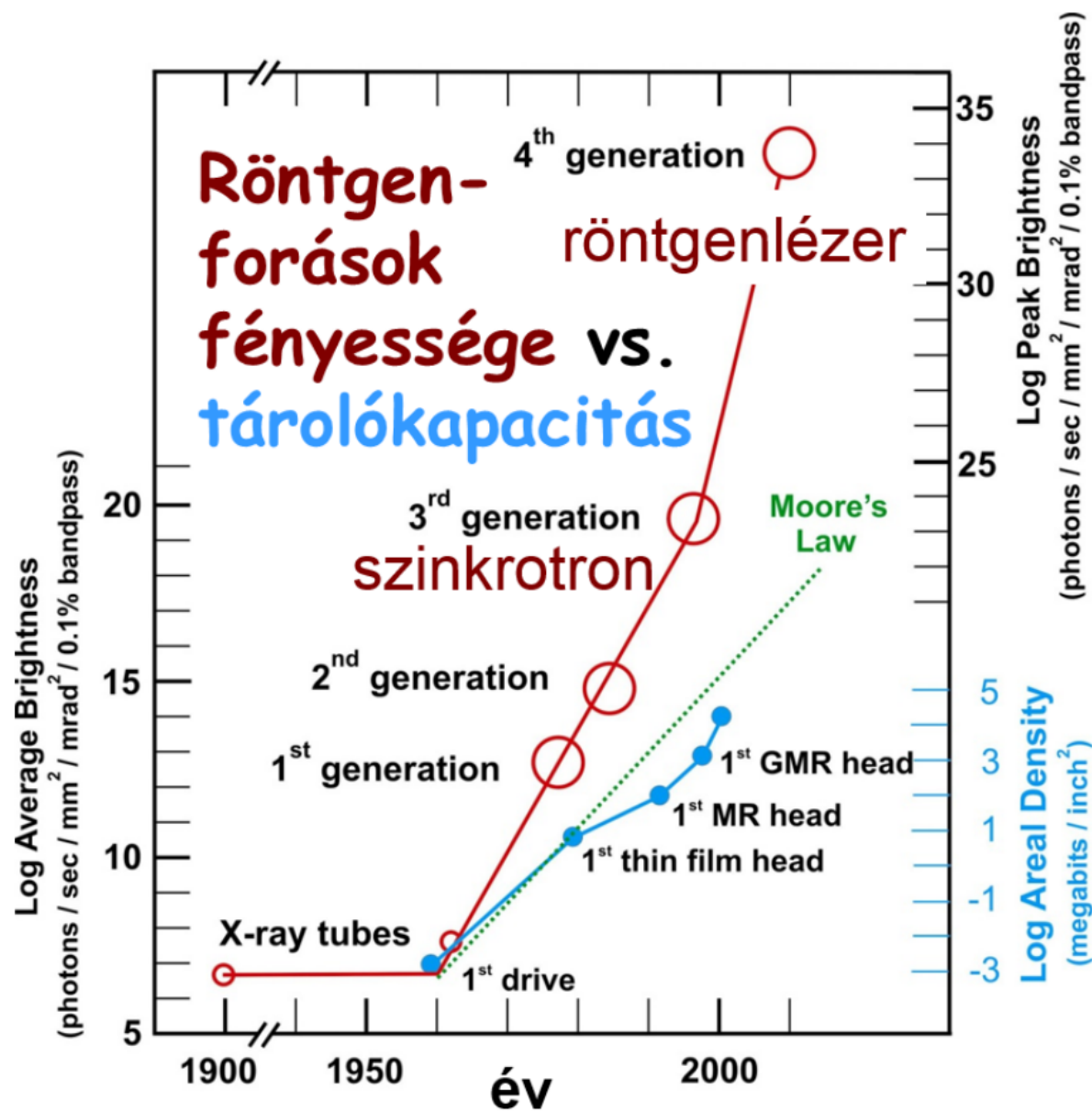


szabadelektron-röntgenlézer

- ultrarövid impulzusok
(10 fs = 0,01 ps = 10^{-14} s)
- óriási fényesség

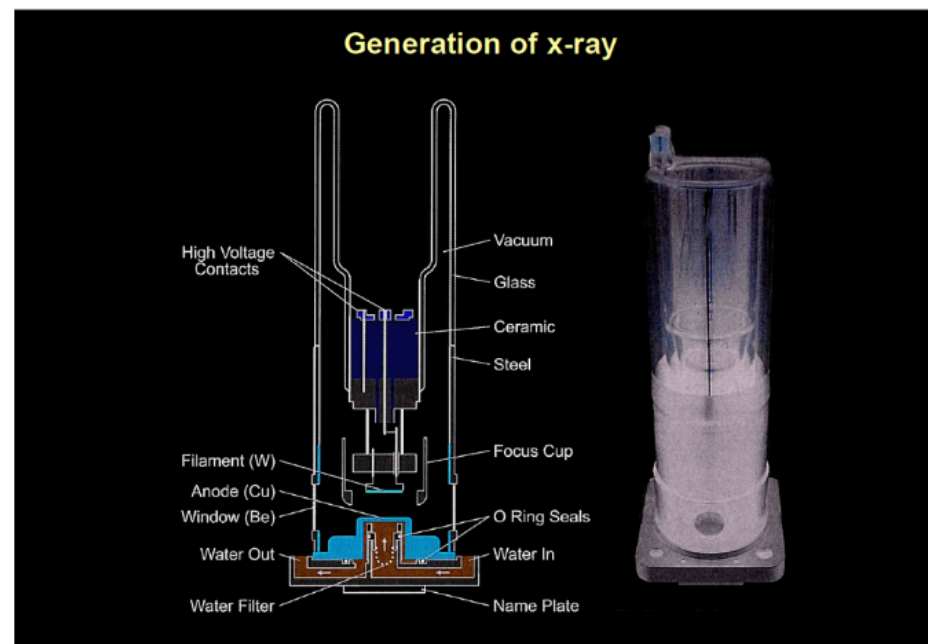
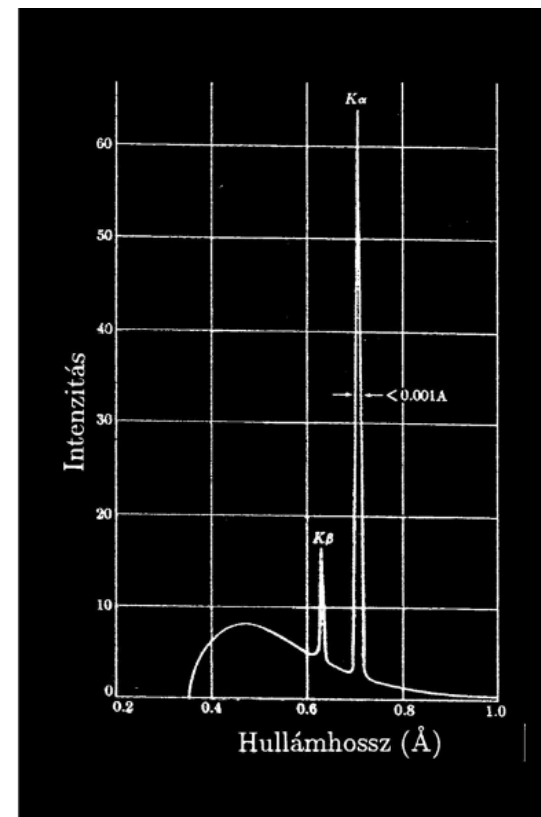


- kb. 500M USD építési költség
- 1M USD napi rezsi



labor röntgenforrások

- kb. 0,01M USD beszerzési költség
- stabil, szabályozható intenzitás
- közepes forrásméret (1*1 mm, 10*0.1 mm)
- nem polarizált
- az energiaspektruma egy folytonos részből és néhány karakterisztikus vonalból áll
- alkalmazások: diffrakció, fluoreszcencia, képalkotás

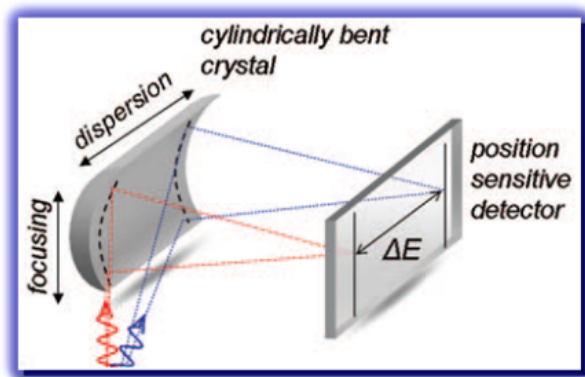
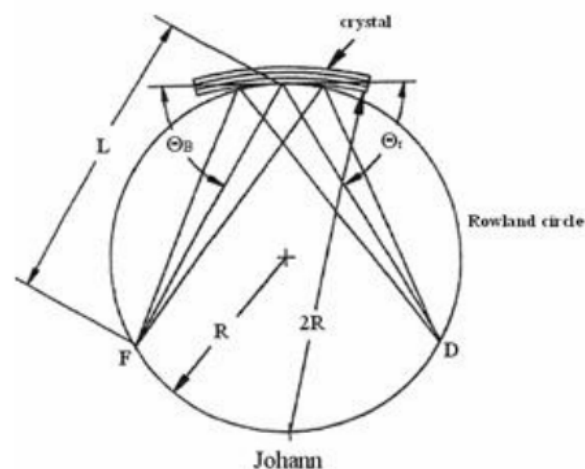
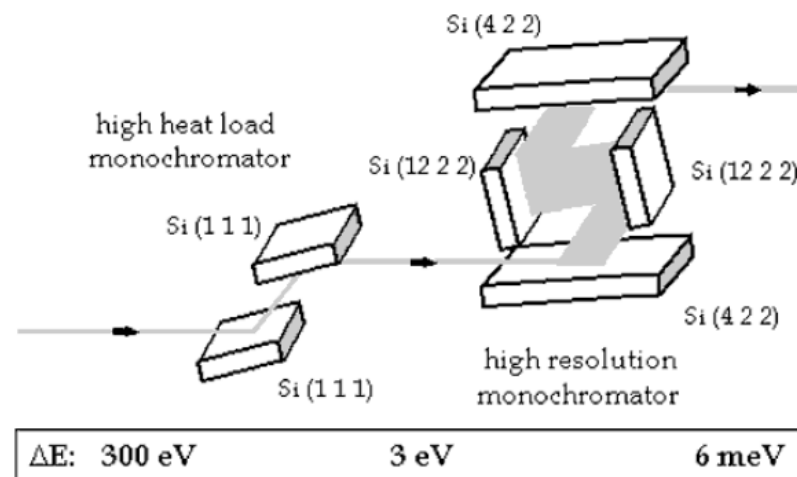


kivitelezés:

- röntgenforrás
- energiafelbontás / pásztázás
- detektálás

energiafelbontás

- Bragg-diffrakció egykristályokon: minden harmonikus egy adott hullámhosszra ad konstruktív interferenciát
- gerjesztő röntgensugár: először egy nagy hőtehelésű dupla (általában channel cut) egykristály monokromátor; utána több monokromátor kristálpár igény szerint
- minta után kisebb szintén egykristály (Si, Ge) analizátorok
 - Johann-elrendezés: pontfókusz, egy energia
 - Hámos-féle elrendezés: vonalfókusz, teljes spektrum diszperzív leképzése

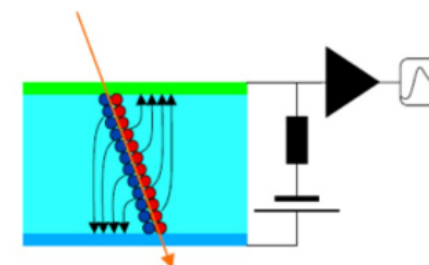
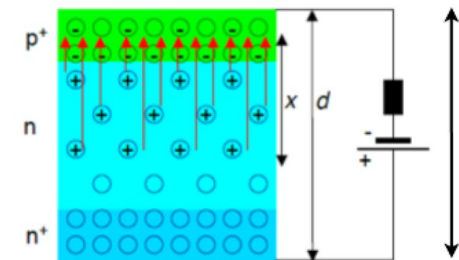
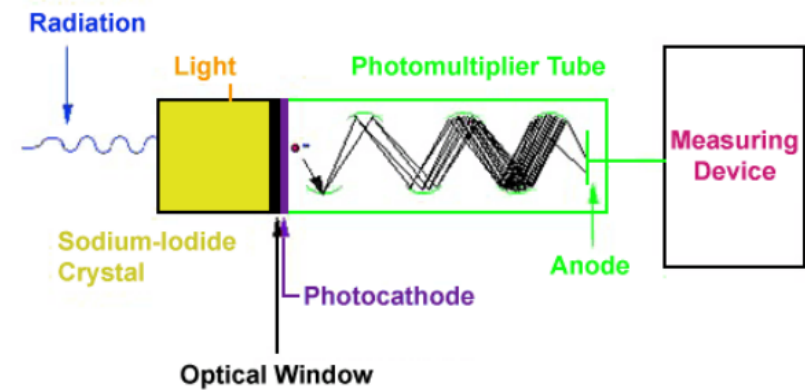
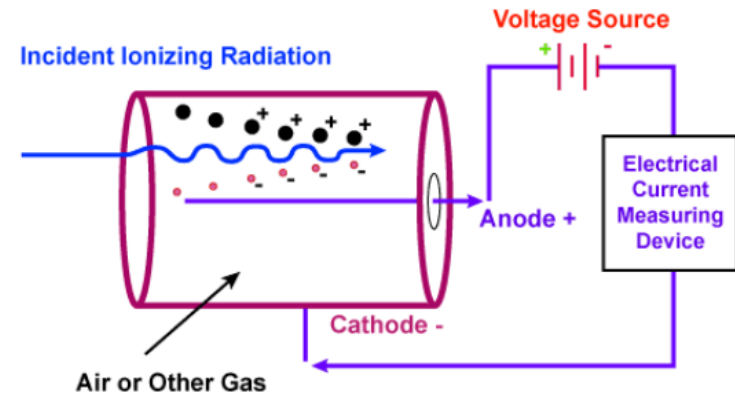


kivitelezés:

- röntgenforrás
- energiafelbontás / pásztázás
- detektálás

detektálás

- ionizációs detektorok:
 - nagy intenzitásokra
 - kis veszteséggel
- szcintillációs detektorok
 - közepes energiateljesítmény
 - jó detektálási hatékonyság
 - lassú
- félvezető detektorok
 - (relatív) nagy energiateljesítmény
 - jó hatásfok
 - gyors / kis holtidő
 - alacsony háttér
 - kis méret - pixeldetektorok



kivitelezés:

- röntgenforrás
- energiafelbontás / pásztázás
- detektálás