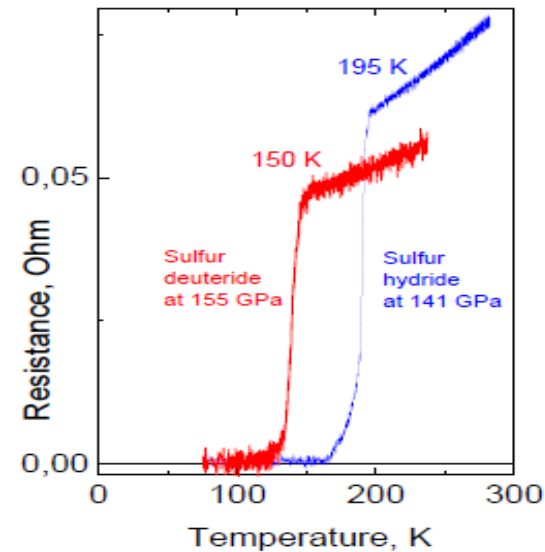
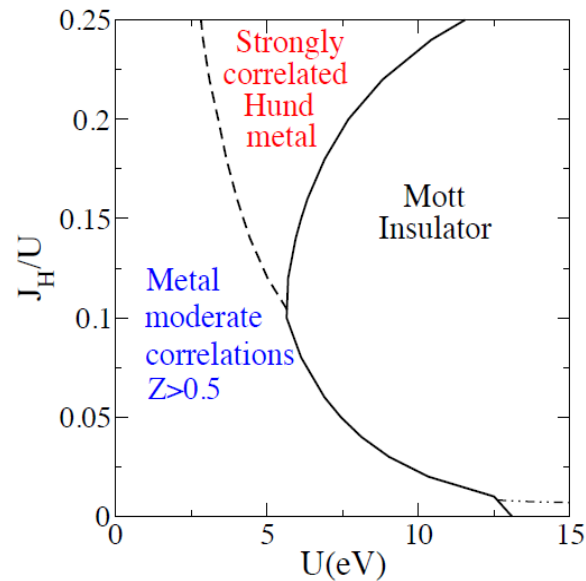


New perspectives in superconductors

E. Bascones

Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC)



Outline

☐ Talk I: Correlations in iron superconductors

- Introduction to iron superconductors
- Correlations in single-orbital. Cuprates
- Correlations in multiorbital systems.
 - Equivalent orbitals. The Hund metal
 - Unequivalent orbitals. Iron superconductors
- The magnetic state phase diagram
- Comparison with experiments. Iron superconductors in a (U, J_H) phase diagram

☐ Talk II: A few new superconducting materials

- Superconductivity and competing phases
 - CrAs and MnP
 - Ti-oxypnictides. Superconductivity emerging from a nematic state?
- New quasi-1D superconductors
- Hydrides. A new record for high- T_c ?

A few superconducting compounds

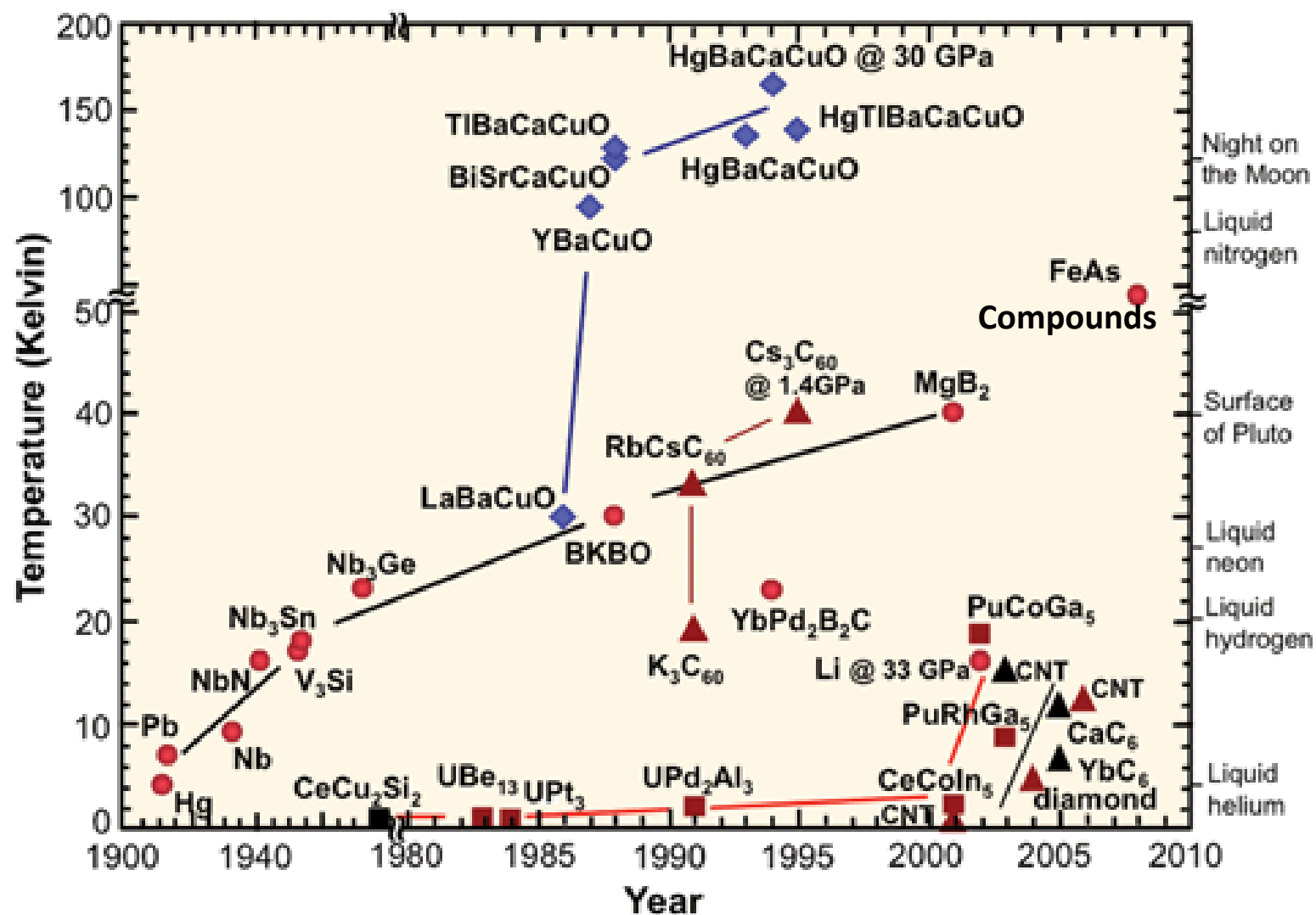


Fig: <http://www.ccas-web.org/superconductivity>

Superconducting families

Elements and simple compounds Nb, NbN	A15's Nb ₃ Ge	Doped semiconductors CB _x	Intercalated graphite C ₆ Ca
Hydrides (PdH)	Dichalcogenides NbSe ₂	Chevrel phases PbMo ₆ S ₈	Magnesium diborides MgB ₂
Bismuthates Ba _{1-x} K _x BiO ₃	Fullerenes RbCs ₂ C ₆₀	Borocarbides YPd ₅ B ₃ C _{0.3}	Bismuth sulfides YbO _{0.5} F _{0.5} BiS ₂
Heavy fermions and Pu superconductors UPd ₂ Al ₃ , PuCoGa ₅	Cuprates YBa ₂ Cu ₃ O ₇	Iron superconductors FeSe, LiFeAs	Organic spcs (charge transfer salts) (BEDT-TTF) ₂ X
Strontium ruthenate Sr ₂ RuO ₄	Layered nitrides Ca(THF)HfNCl	Ferrromagnetic superconductors UGe ₂	Non centrosymmetric superconductors SrPtSi ₃
Interface superconductivity LaAlO ₃ /SrTiO ₃	Hidrated cobaltites Na _x (H ₃ O) _z CoO ₂ .yH ₂ O	Topological superconductors Cu _x (PbSe) ₅ (Bi ₂ Se ₃) ₆	Aromatic hydrocarbides K _x -Picene

Hirsch et al, Physica C 514, 1 (2015)

3d based superconductors

Group→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
↓Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Superconductivity in CrAs and MnP

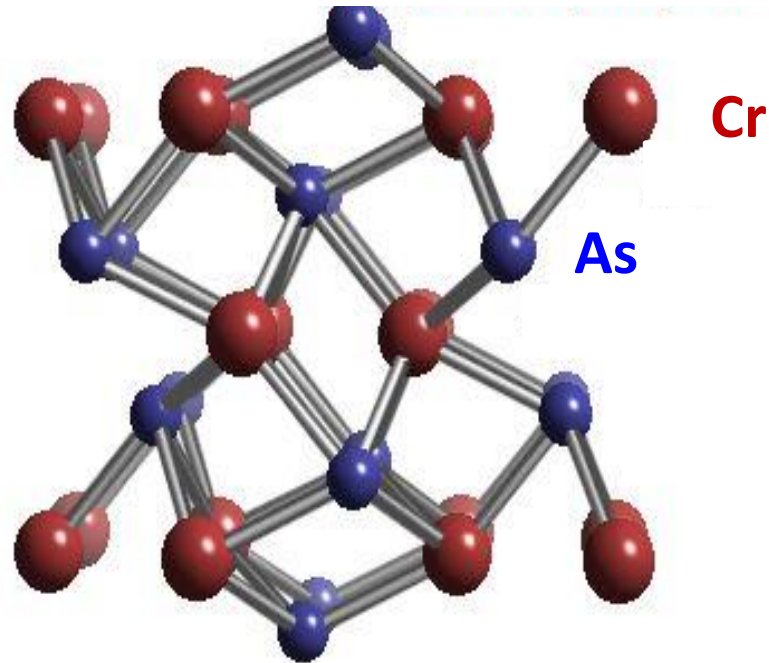
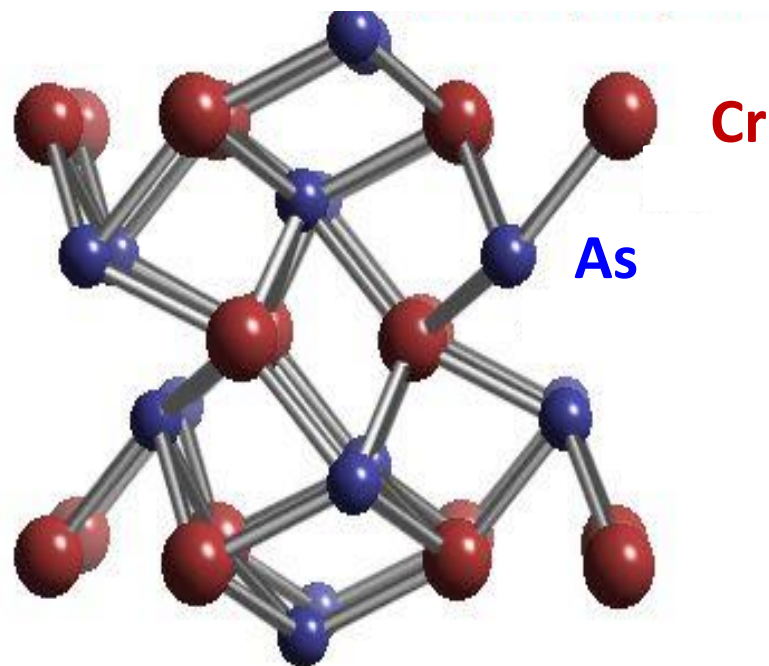
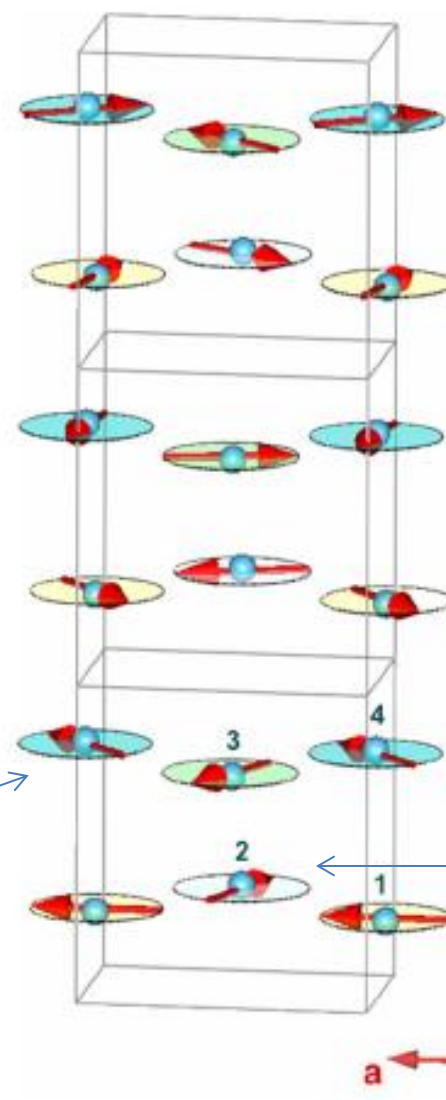


Fig:webelements.com

Superconductivity in CrAs and MnP



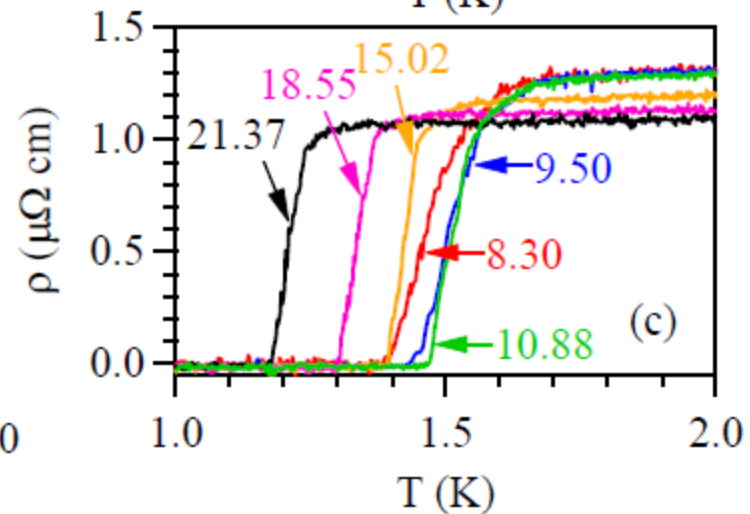
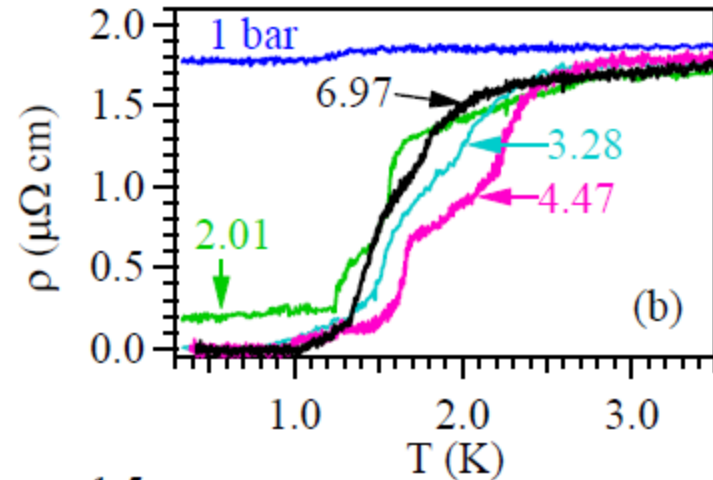
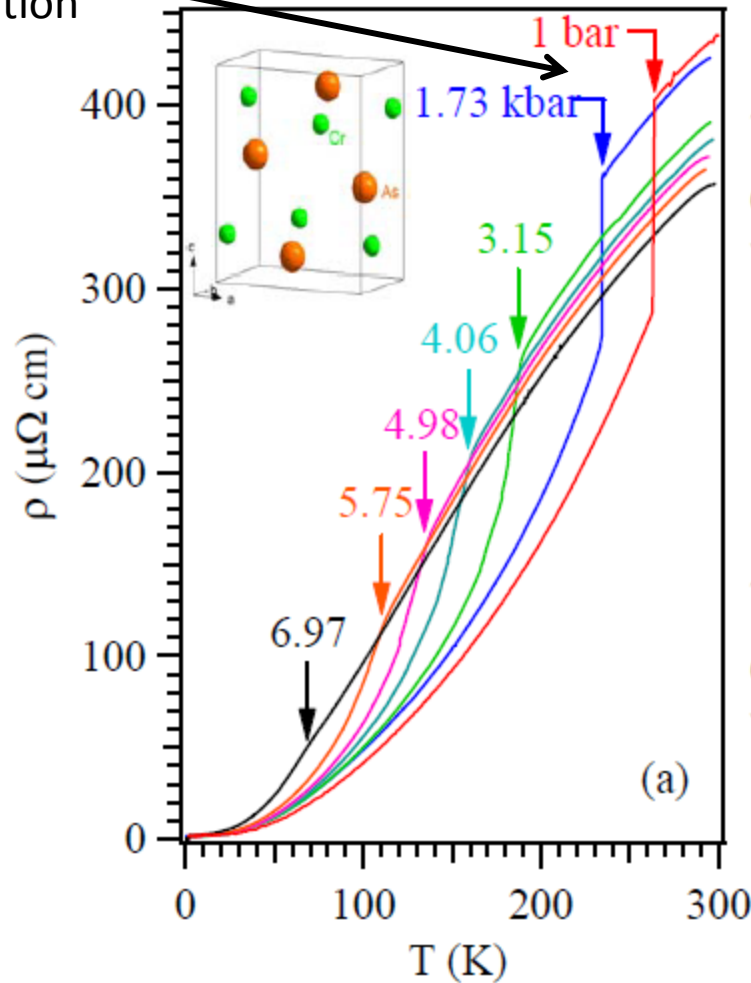
Magnetic moments in
ab plane



Double helical
Structure $m \sim 1.7 \mu_B$

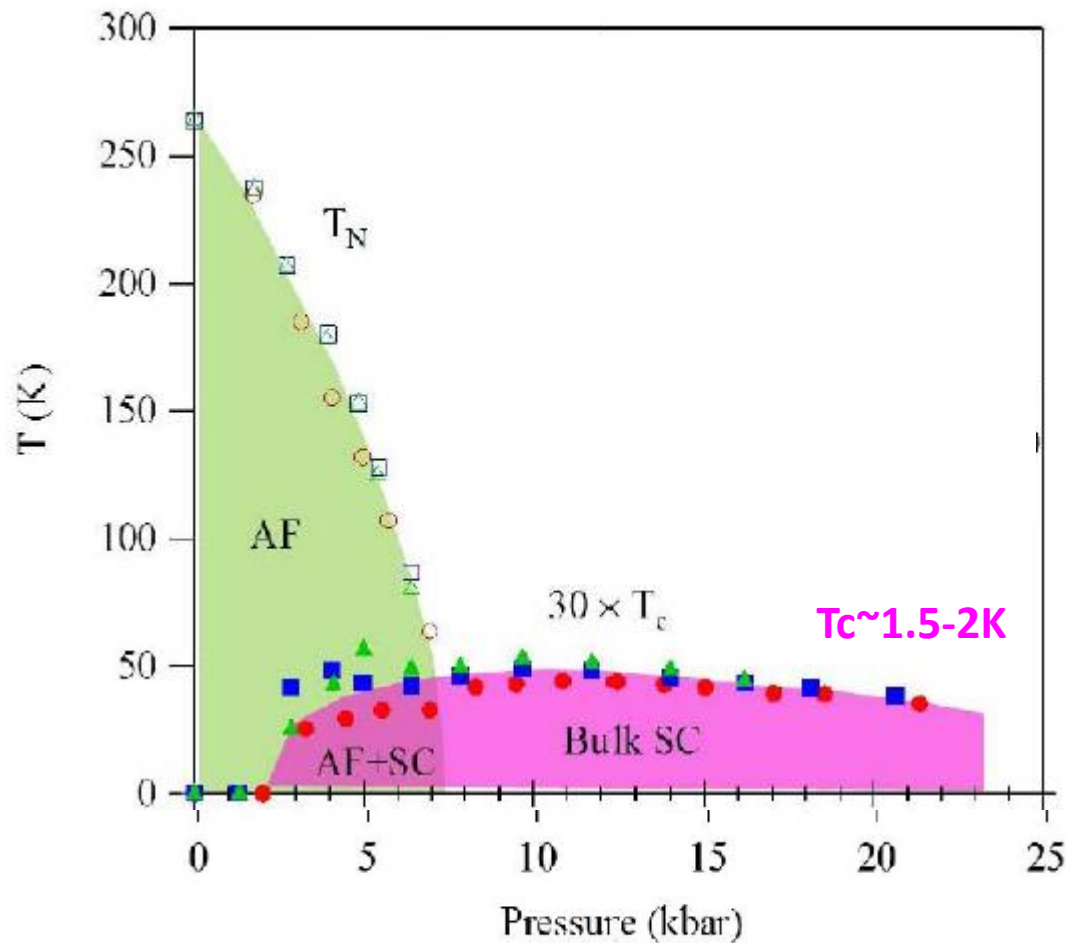
Superconductivity in CrAs and MnP

First order transition



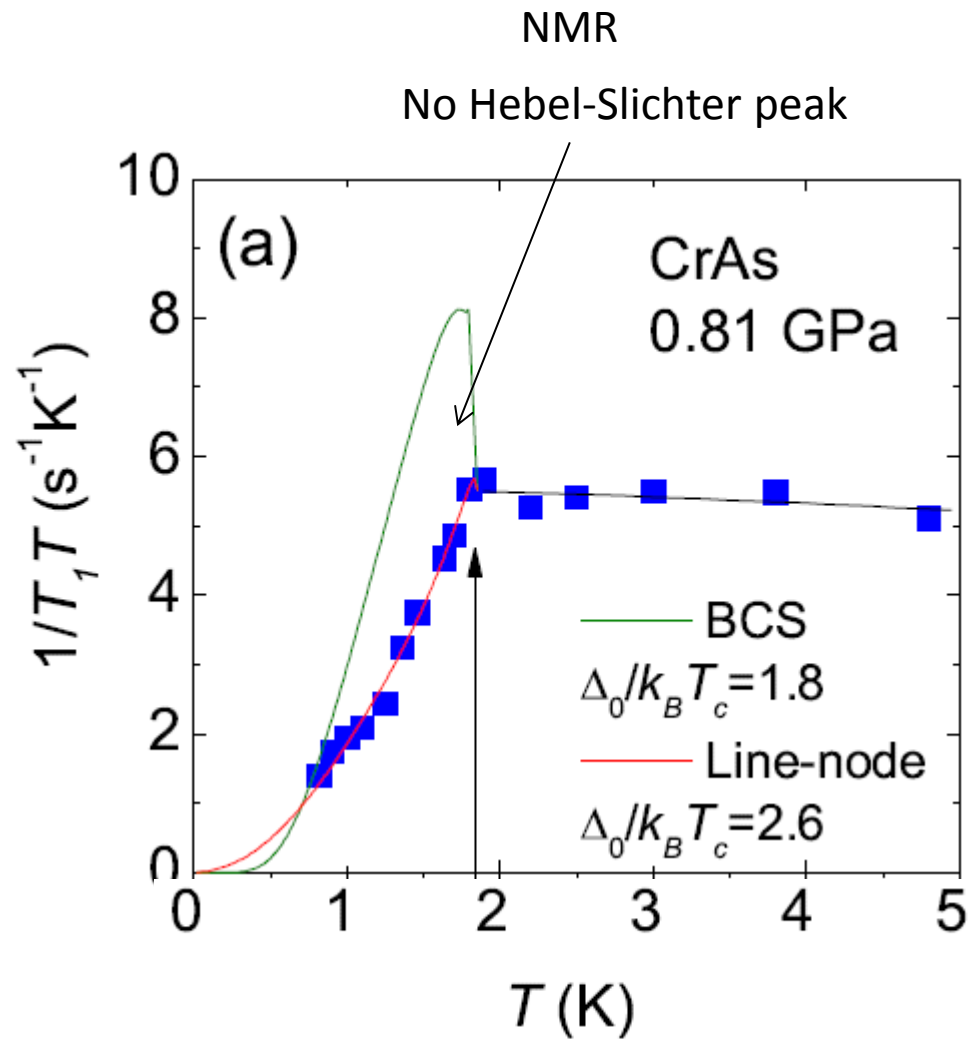
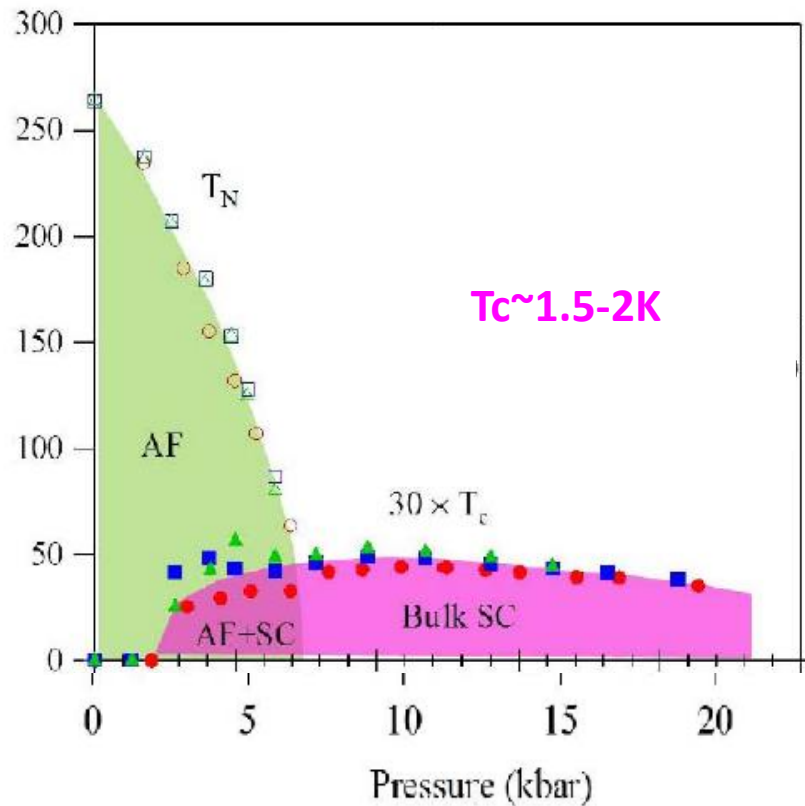
Wu et al, Nat. Comm. 5, 5508 (2014) Kotegawa et al, J. Phys. Soc. Jpn. 83, 093702 (2014)

Superconductivity in CrAs and MnP



Wu et al, Nat. Comm. 5, 5508 (2014) Kotegawa et al, J. Phys. Soc. Jpn. 83, 093702 (2014)

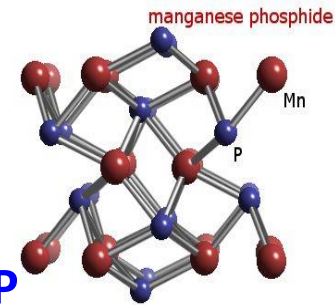
Superconductivity in CrAs and MnP



Wu et al, Nat. Comm. 5, 5508 (2014)

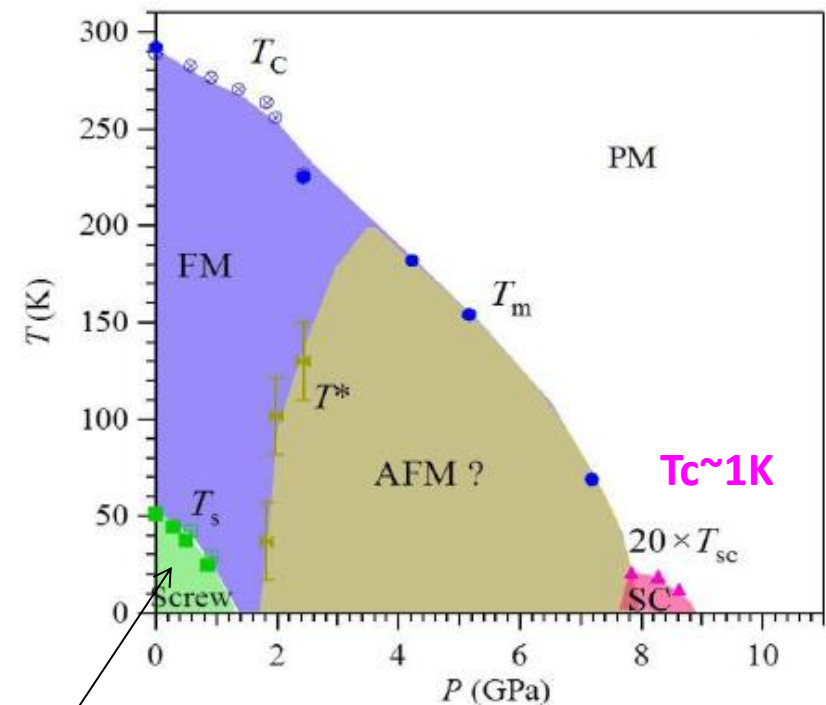
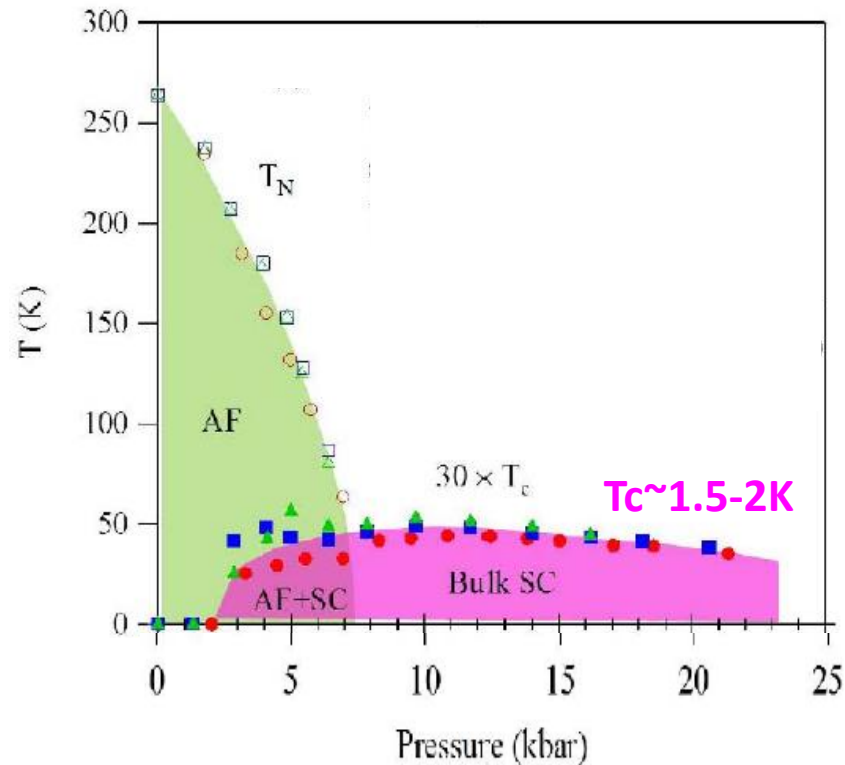
Kotegawa et al, Phys. Rev. Lett. 114, 117002 (2015)

Superconductivity in CrAs and MnP



CrAs

MnP



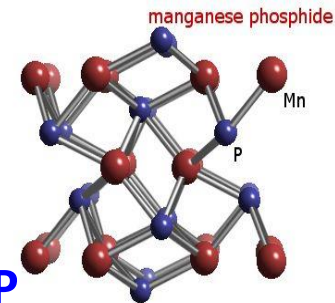
Helimagnet
 $\mu \sim 1.3 \mu_B$

MnP: First Mn-based
superconducting compound

Wu et al, Nat. Comm. 5, 5508 (2014)

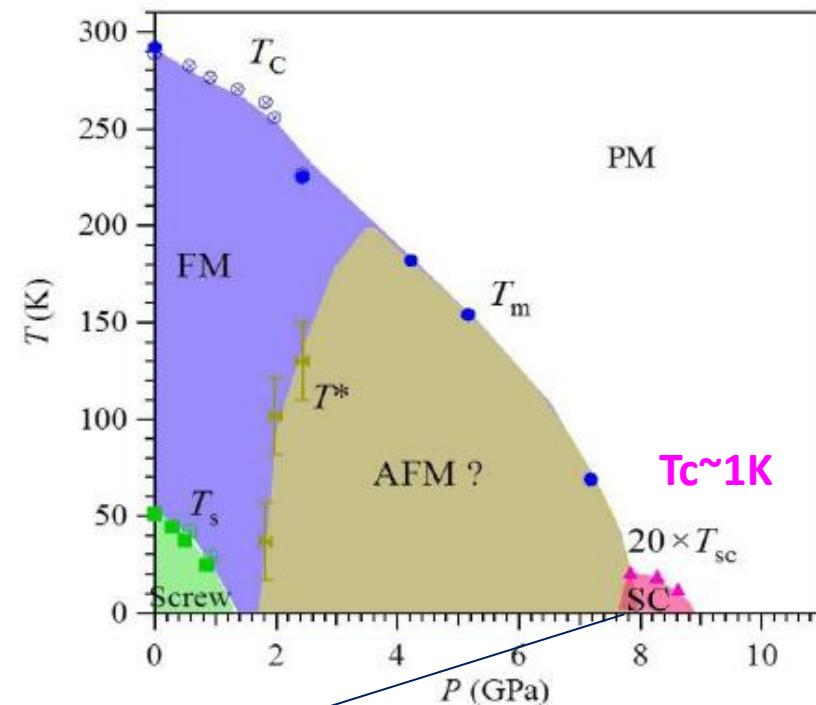
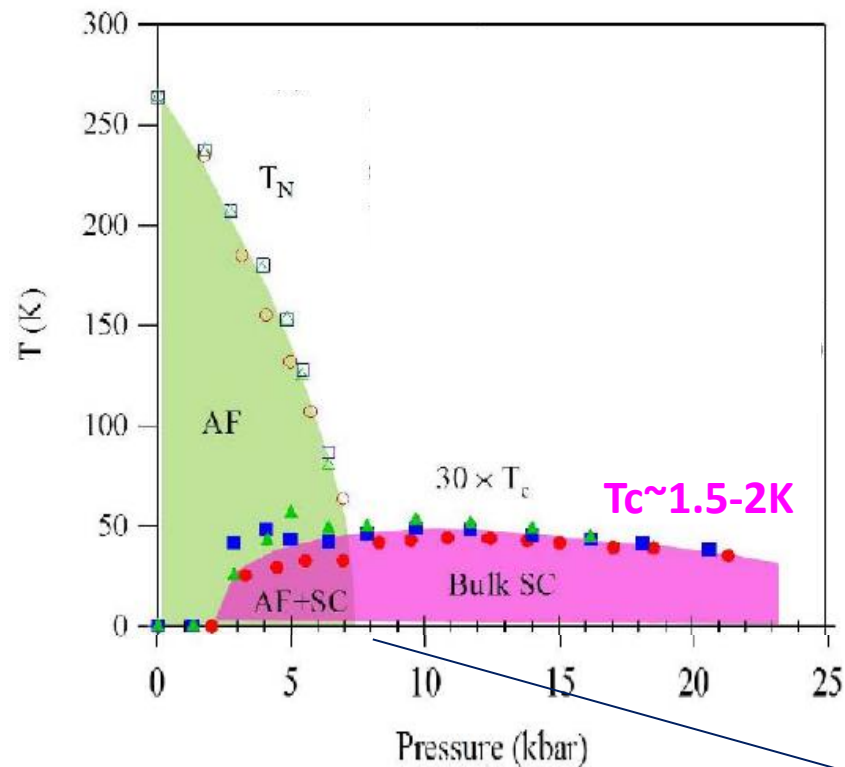
Cheng et al, Phys. Rev. Lett. 114, 117001 (2015)

Superconductivity in CrAs and MnP



CrAs

MnP



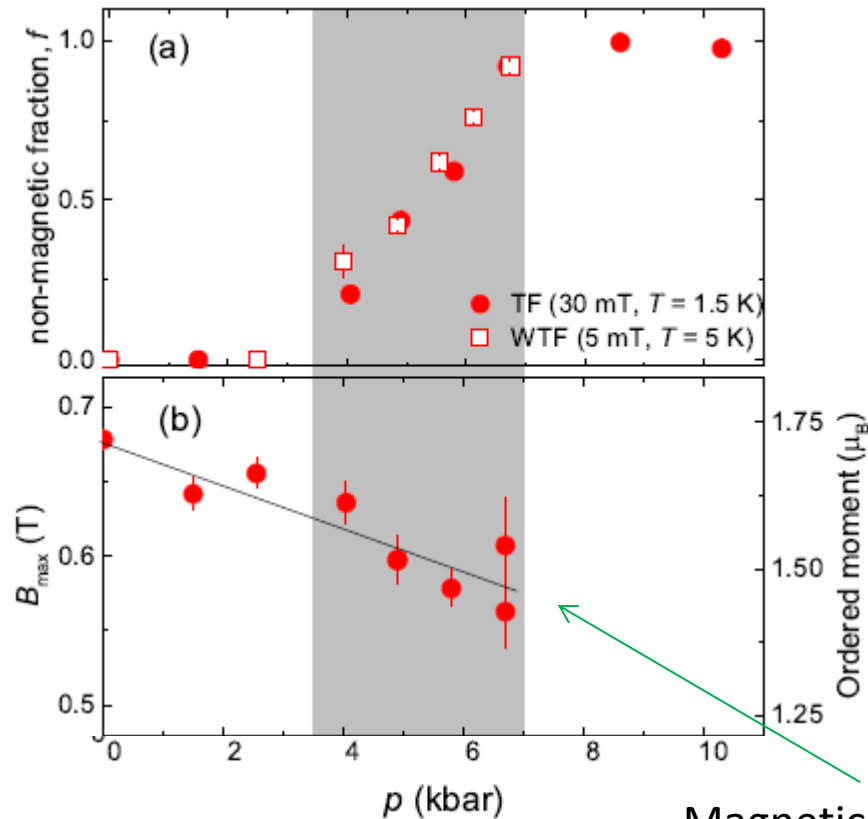
Quantum Critical Behavior?

Wu et al, Nat. Comm. 5, 5508 (2014)

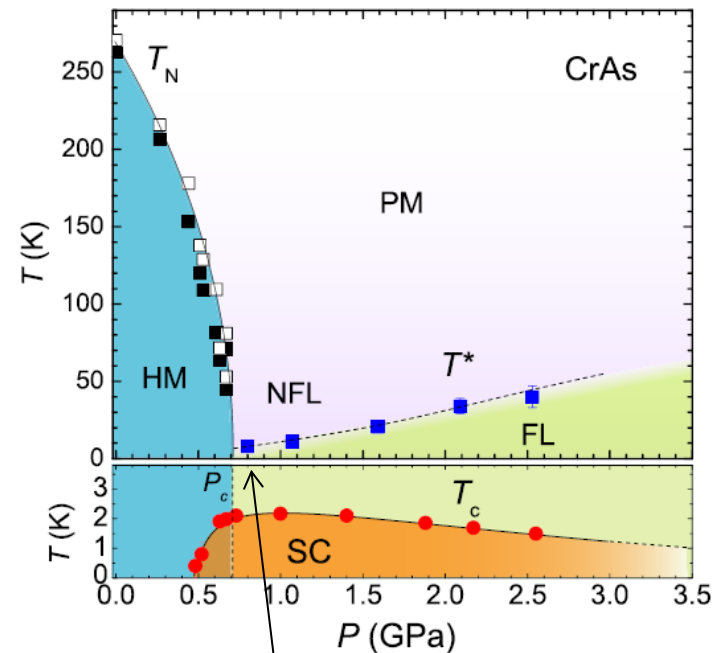
Cheng et al, Phys. Rev. Lett. 114, 117001 (2015)

Superconductivity in CrAs and MnP

- Initial claims in favour of QCP from CrAs and MnP from resistivity measurements
- In CrAs: First order transition and phase separation at P_c from NMR, neutron diffraction and muon spectroscopy



Magnetic moment jumps @ P_c

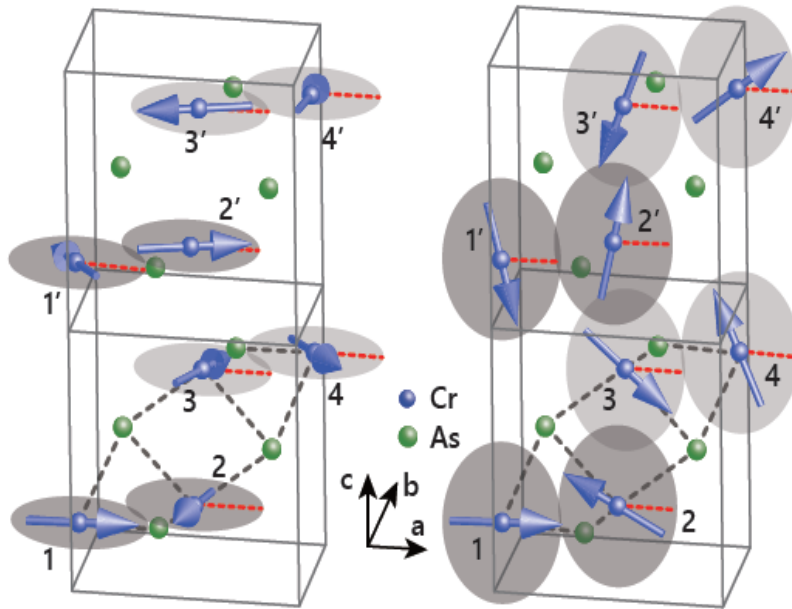


Finite T^* @ P_c

Superconductivity in CrAs and MnP

P=0 Gpa T=4 K

P=0.6 Gpa T=50 K



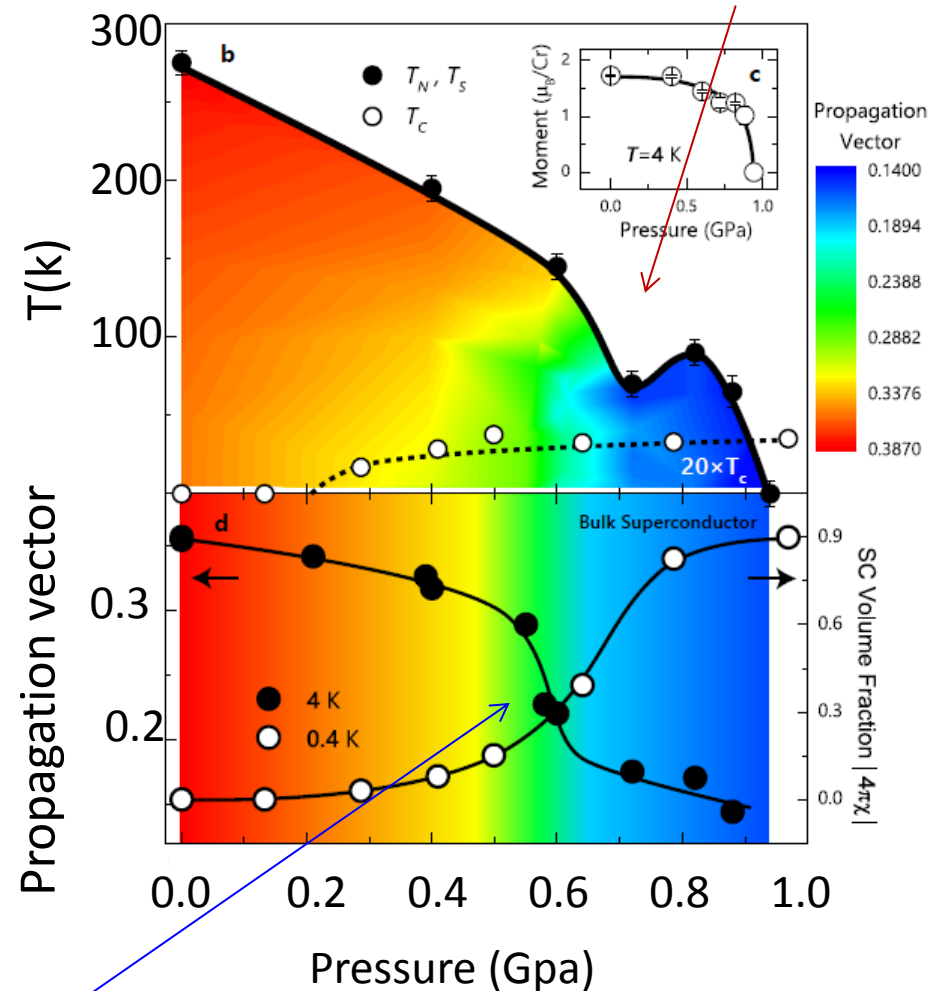
Spins in ab plane

$$\phi = -108^\circ$$

Spins in ac plane

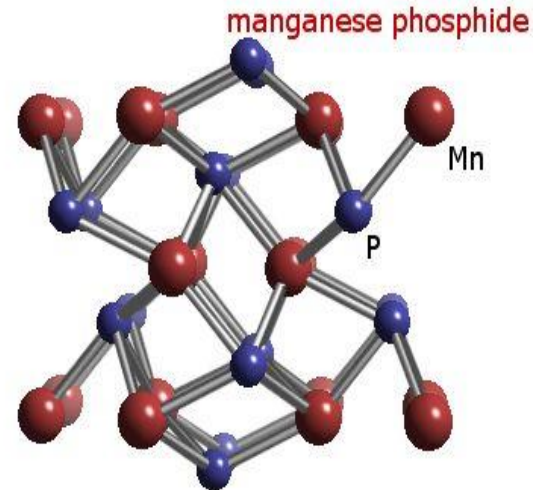
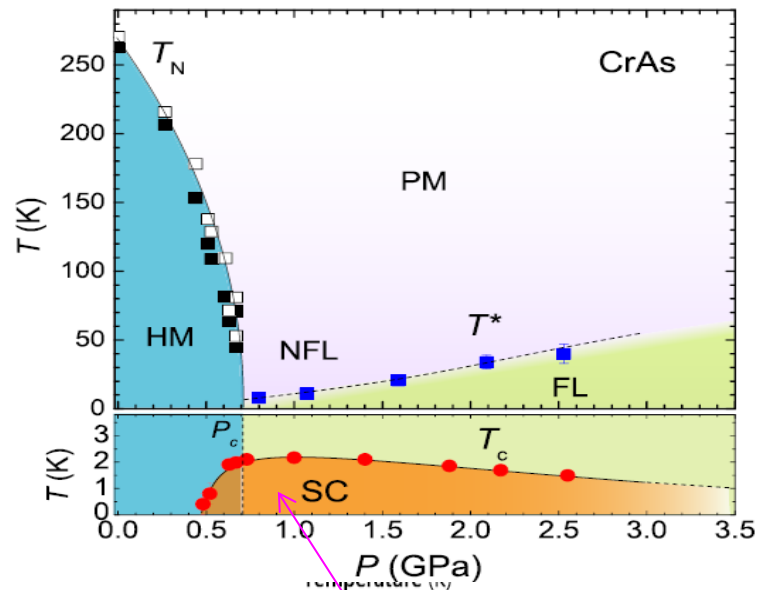
$$\phi = 172^\circ$$

Magnetic reorganization

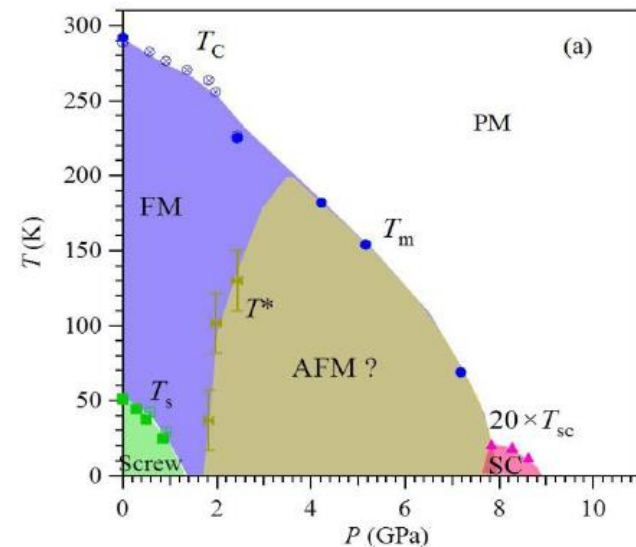
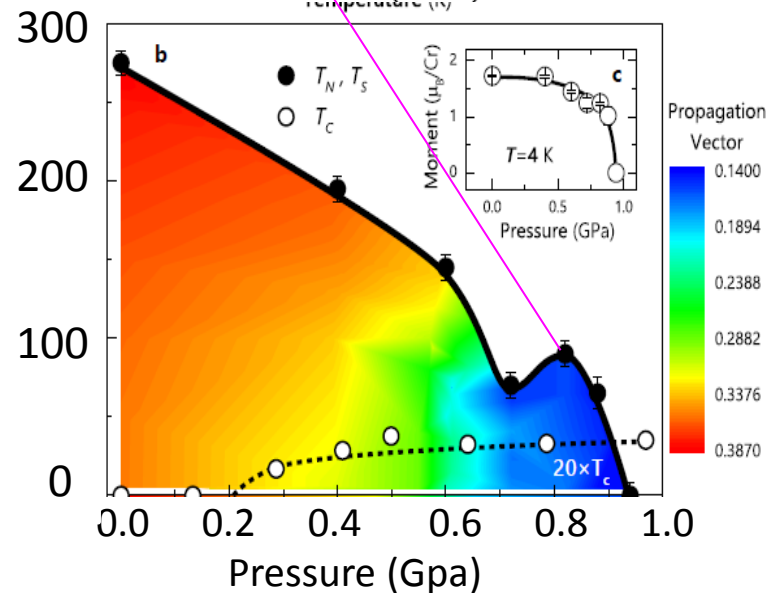


Change in
ordering vector k_c

Superconductivity in CrAs and MnP: Summary



Talk by J. Cheng
next week



Titanium oxypnictides ATi_2Pn_2O

$A = Na_2, Ba, (SrF)_2 \dots$

Nominal charge +2

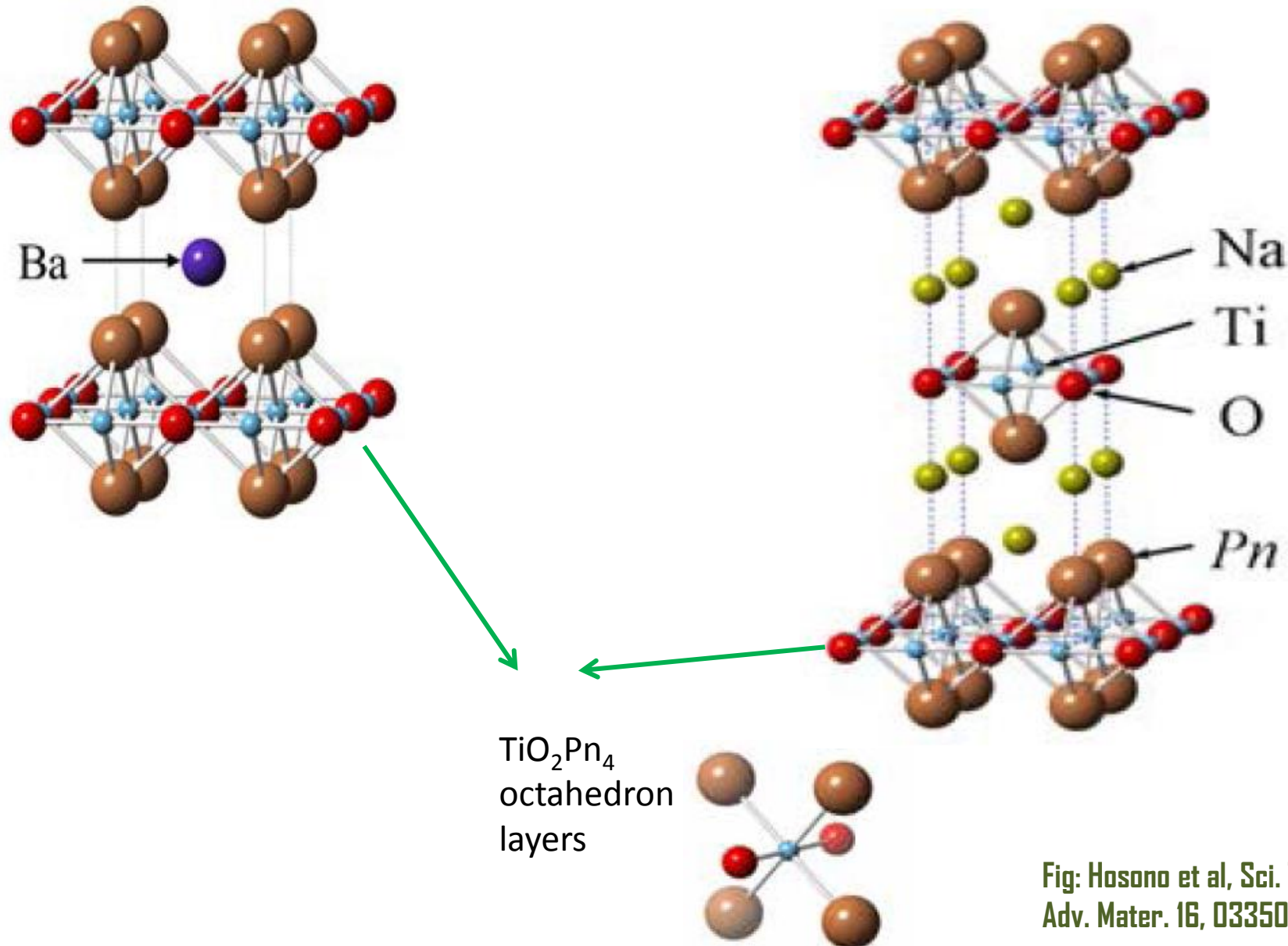


Fig: Hosono et al, Sci. Tech.
Adv. Mater. 16, 033503 (2015)

Titanium oxypnictides ATi_2Pn_2O

$A = Na_2, Ba, (SrF)_2 \dots$

Nominal charge +2

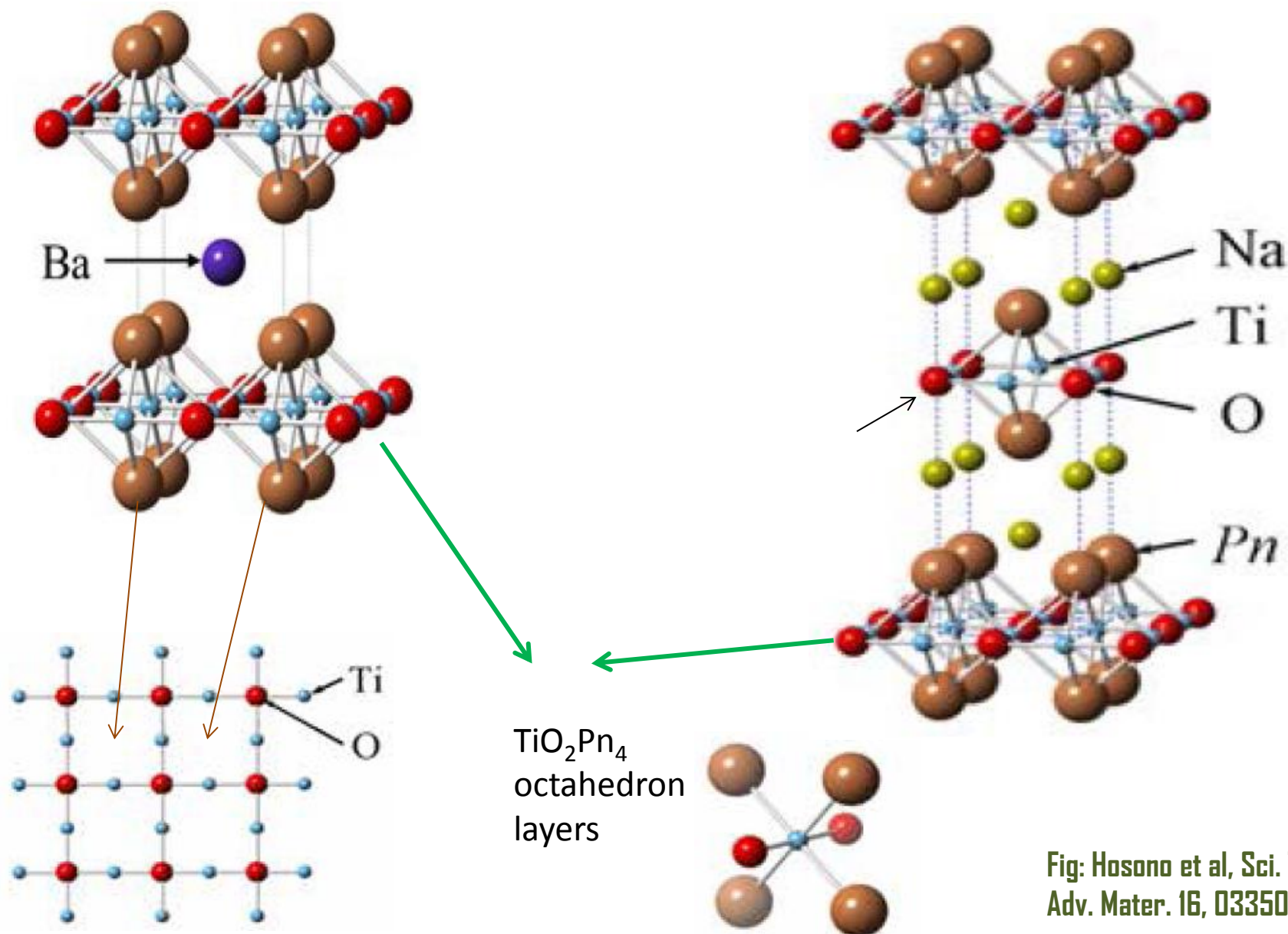


Fig: Hosono et al, Sci. Tech. Adv. Mater. 16, 033503 (2015)

Titanium oxypnictides $\text{ATi}_2\text{Pn}_2\text{O}$

$\text{A}=\text{Na}_2, \text{Ba}, (\text{SrF})_2 \dots$

Nominal charge +2

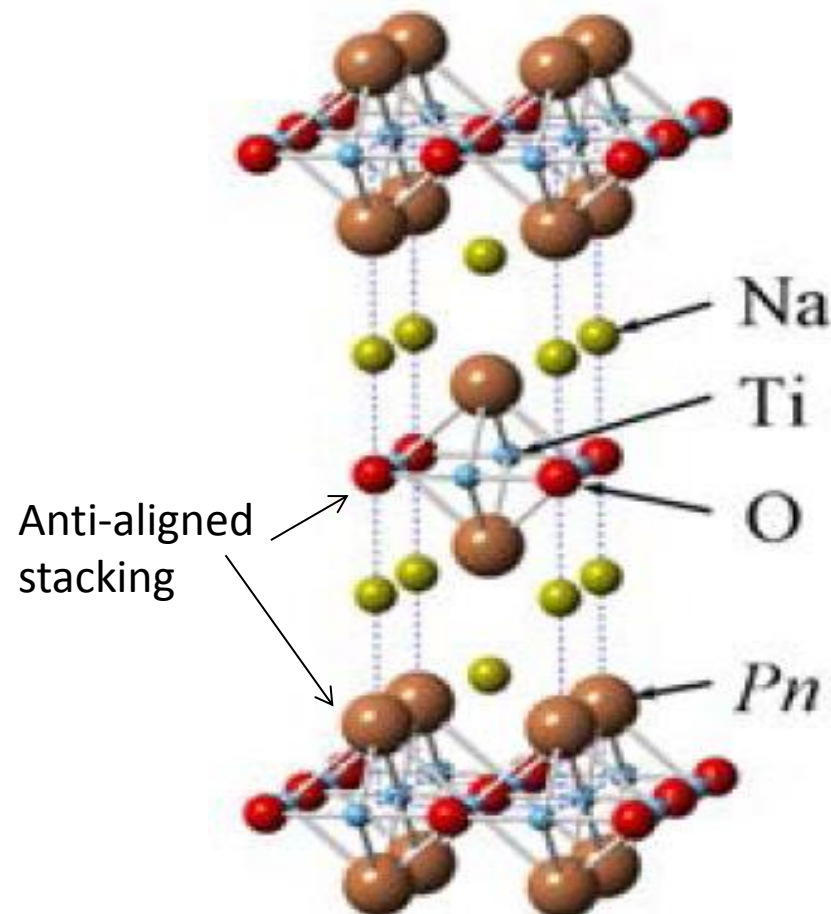
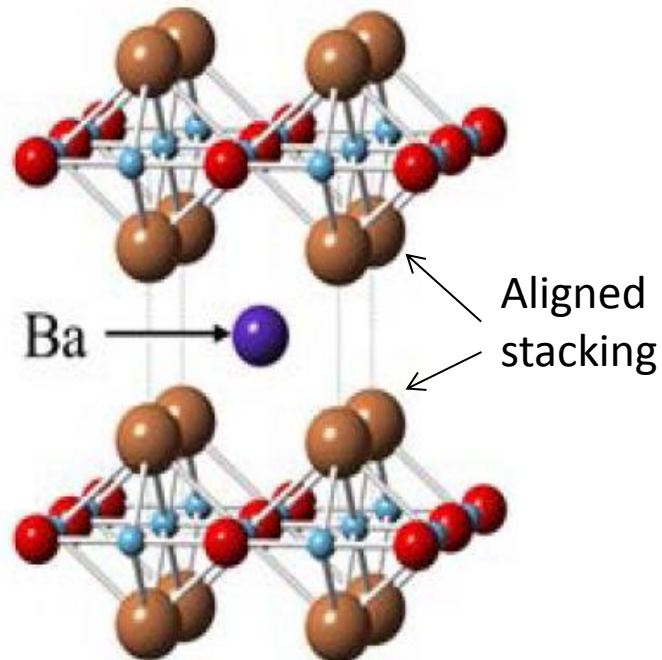
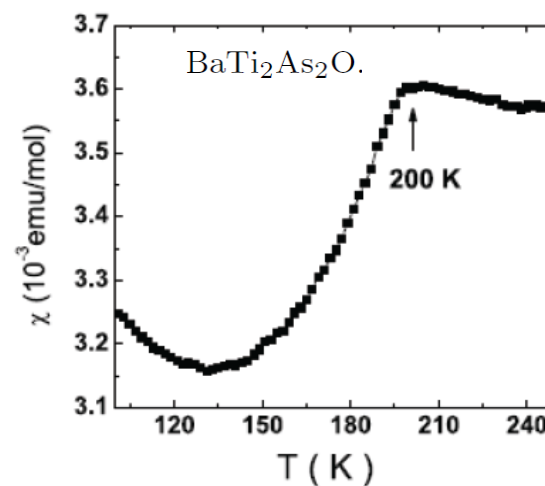
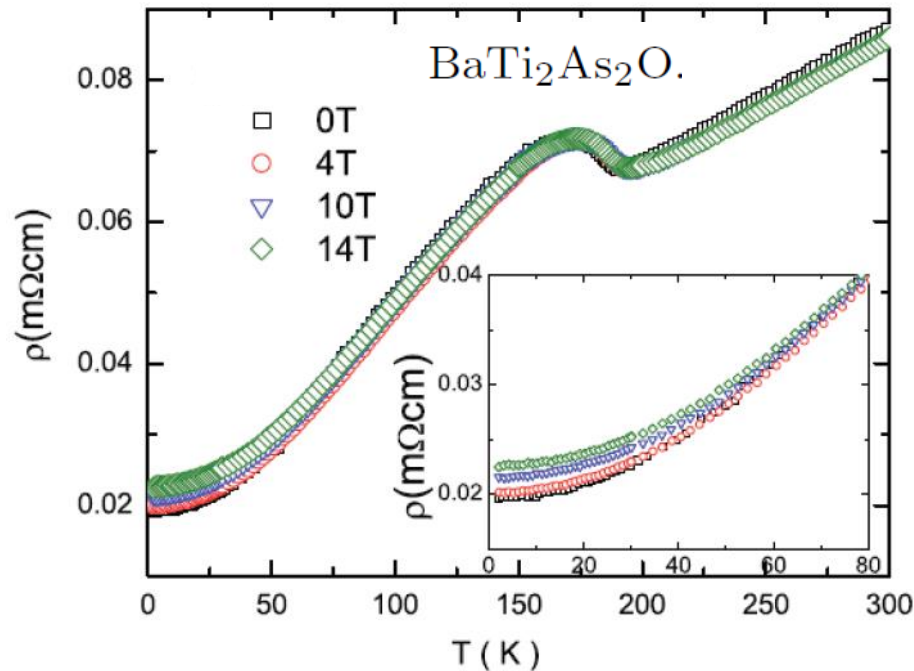


Fig: Hosono et al, Sci. Tech.
Adv. Mater. 16, 033503 (2015)

Titanium oxypnictides $\text{ATi}_2\text{Pn}_2\text{O}$: ordered state

- $\text{Na}_2\text{Ti}_2\text{As}_2\text{O}$: $T_s \sim 320$ K
- $\text{Na}_2\text{Ti}_2\text{Sb}_2\text{O}$: $T_s \sim 120$ K
- $\text{BaTi}_2\text{As}_2\text{O}$: $T_s \sim 200$ K

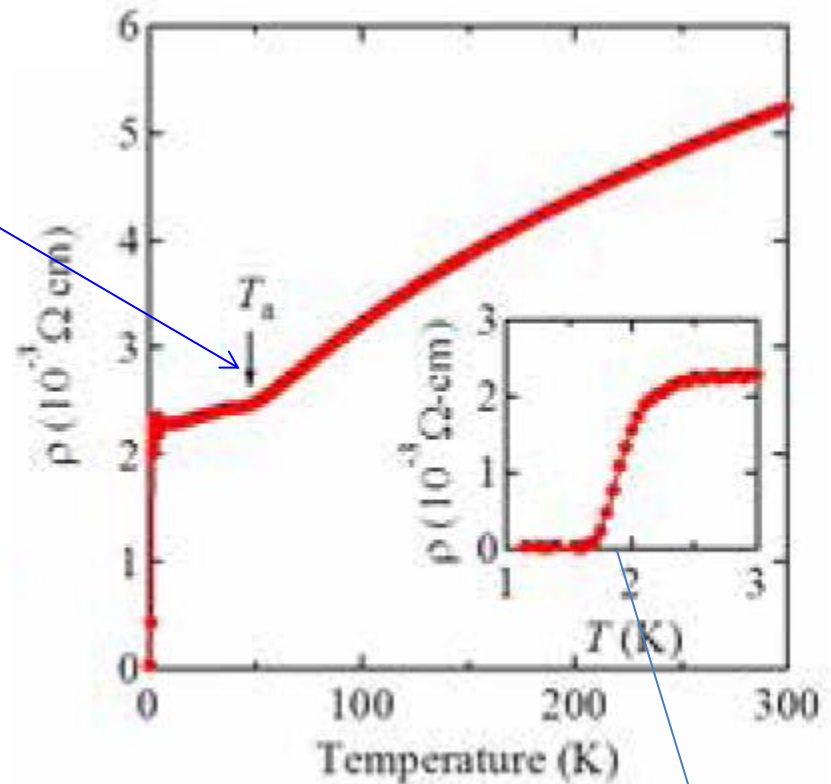


Wang et al,
J. Phys. Cond.
Mat. 22, 075702
(2010)

Lorenz et al, Int. J. Mod. Phys. B 28, 1430011 (2014)

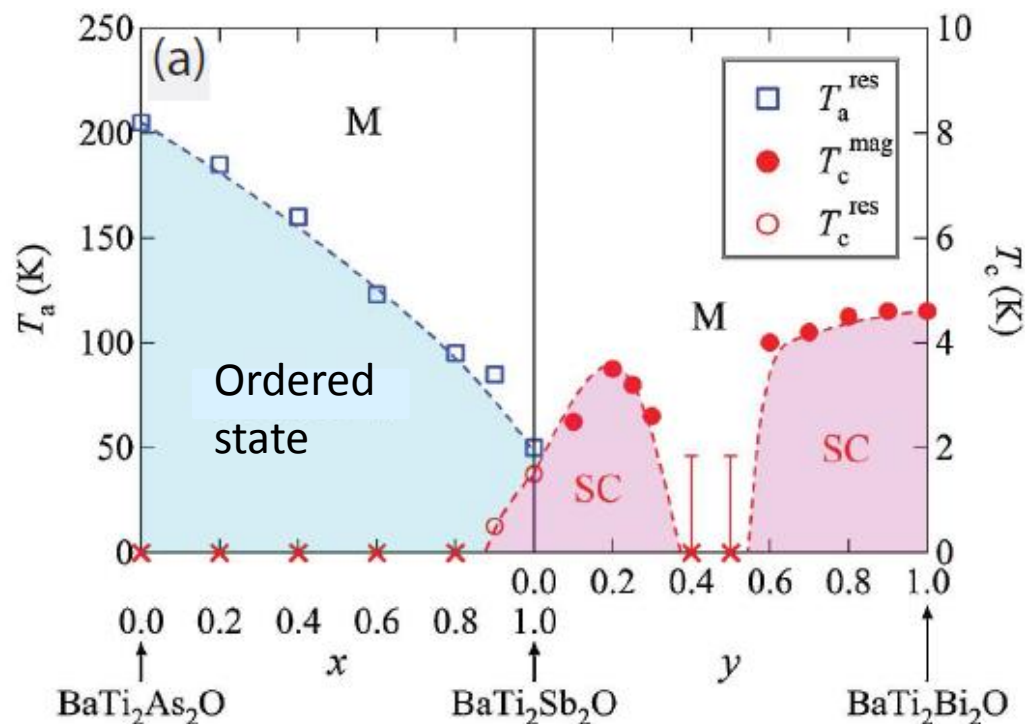
Superconductivity in $\text{BaTi}_2\text{Sb}_2\text{O}$

Transition $T_s \sim 54 \text{ K}$



Superconductivity $T_c \sim 1.2 \text{ K}$

Superconductivity in substituted BaTi₂Pn₂O



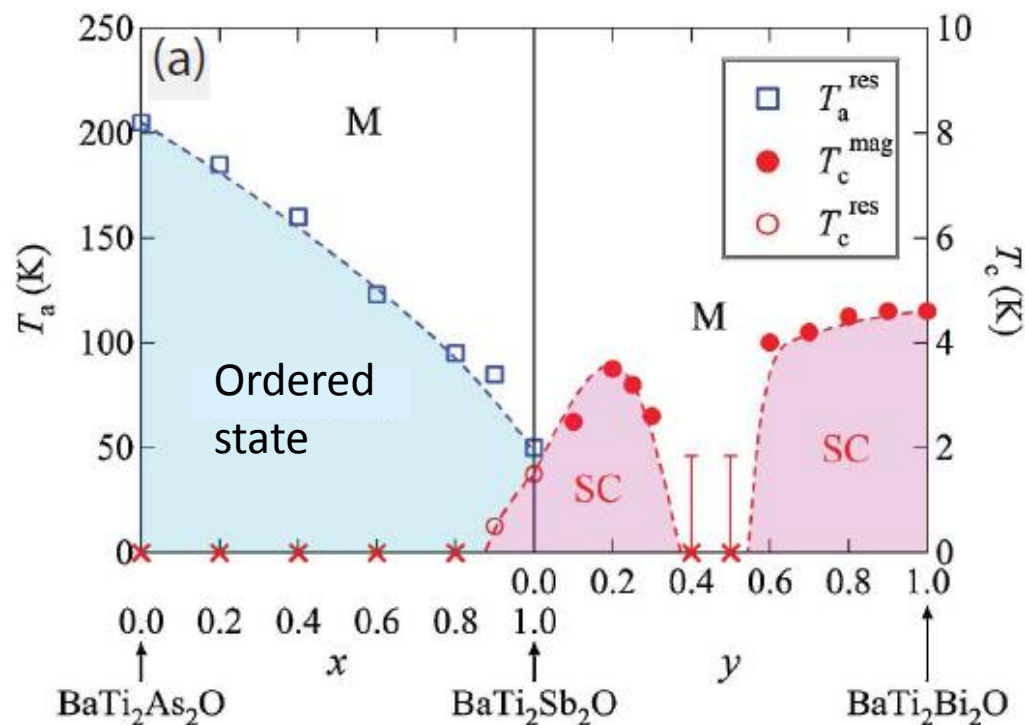
Tajima et al, J. Phys. Soc. Jpn. 82, 033705 (2013)

hydrogen 1 H 1.0079																		helium 2 He 4.0026																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
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sodium 11 Na 22.990		magnesium 12 Mg 24.305																aluminum 13 Al 26.982		silicon 14 Si 28.086		phosphorus 15 P 30.974		sulfur 16 S 32.065		chlorine 17 Cl 35.453		argon 18 Ar 39.948																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
potassium 19 K 39.098		calcium 20 Ca 40.078		scandium 21 Sc		titanium 22 Ti		vanadium 23 V		chromium 24 Cr		manganese 25 Mn		iron 26 Fe		cobalt 27 Co		nickel 28 Ni		copper 29 Cu		zinc 30 Zn		gallium 31 Ga		germanium 32 Ge		arsenic 33 As		selenium 34 Se		bromine 35 Br		krypton 36 Kr																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
rubidium 37 Rb 85.468		strontium 38 Sr 87.62		yttrium 39 Y 88.906		zirconium 40 Zr 91.224		niobium 41 Nb 92.906		molybdenum 42 Mo 95.94		technetium 43 Tc		ruthenium 44 Ru 101.07		rhodium 45 Rh 102.91		palladium 46 Pd 106.42		silver 47 Ag 107.87		cadmium 48 Cd 112.41		indium 49 In 114.82		tin 50 Sn 118.71		antimony 51 Sb 121.76		tellurium 52 Te 127.60		iodine 53 I 126.90		xenon 54 Xe 131.29																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
cesium 55 Cs 132.91		barium 56 Ba 137.33		lanthanum 57 La 138.905		cerium 58 Ce 140.12		praseodymium 59 Pr 140.908		neodymium 60 Nd 144.24		promethium 61 Pm		samarium 62 Sm 150.36		europium 63 Eu 151.964		gadolinium 64 Gd 157.25		terbium 65 Tb 158.925		dysprosium 66 Dy 162.50		holmium 67 Ho 164.930		erbium 68 Er 167.259		thulium 69 Tm 168.933		ytterbium 70 Yb 173.054		lutetium 71 Lu 174.967		hafnium 72 Hf 178.49		tantalum 73 Ta 180.948		tungsten 74 W 183.84		rhenium 75 Re 186.21		osmium 76 Os 190.23		iridium 77 Ir 192.22		platinum 78 Pt 195.08		gold 79 Au 196.967		mercury 80 Hg 200.59		thallium 81 Tl 204.38		lead 82 Pb 207.2		bismuth 83 Bi 208.98		polonium 84 Po		astatine 85 At		radon 86 Rn																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
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Uuq		unbinilium 141 Uub		unbinilium 142 Uuq		unbinilium 143 Uub		unbinilium 144 Uuq		unbinilium 145 Uub		unbinilium 146 Uuq		unbinilium 147 Uub		unbinilium 148 Uuq		unbinilium 149 Uub		unbinilium 150 Uuq		unbinilium 151 Uub		unbinilium 152 Uuq		unbinilium 153 Uub		unbinilium 154 Uuq		unbinilium 155 Uub		unbinilium 156 Uuq		unbinilium 157 Uub		unbinilium 158 Uuq		unbinilium 159 Uub		unbinilium 160 Uuq		unbinilium 161 Uub		unbinilium 162 Uuq		unbinilium 163 Uub		unbinilium 164 Uuq		unbinilium 165 Uub		unbinilium 166 Uuq		unbinilium 167 Uub		unbinilium 168 Uuq		unbinilium 169 Uub		unbinilium 170 Uuq		unbinilium 171 Uub		unbinilium 172 Uuq		unbinilium 173 Uub		unbinilium 174 Uuq		unbinilium 175 Uub		unbinilium 176 Uuq		unbinilium 177 Uub		unbinilium 178 Uuq		unbinilium 179 Uub		unbinilium 180 Uuq		unbinilium 181 Uub		unbinilium 182 Uuq		unbinilium 183 Uub		unbinilium 184 Uuq		unbinilium 185 Uub		unbinilium 186 Uuq		unbinilium 187 Uub		unbinilium 188 Uuq		unbinilium 189 Uub		unbinilium 190 Uuq		unbinilium 191 Uub		unbinilium 192 Uuq		unbinilium 193 Uub		unbinilium 194 Uuq		unbinilium 195 Uub		unbinilium 196 Uuq		unbinilium 197 Uub		unbinilium 198 Uuq		unbinilium 199 Uub		unbinilium 200 Uuq		unbinilium 201 Uub		unbinilium 202 Uuq		unbinilium 203 Uub		unbinilium 204 Uuq		unbinilium 205 Uub		unbinilium 206 Uuq		unbinilium 207 Uub		unbinilium 208 Uuq		unbinilium 209 Uub		unbinilium 210 Uuq		unbinilium 211 Uub		unbinilium 212 Uuq		unbinilium 213 Uub		unbinilium 214 Uuq		unbinilium 215 Uub		unbinilium 216 Uuq		unbinilium 217 Uub		unbinilium 218 Uuq		unbinilium 219 Uub		unbinilium 220 Uuq		unbinilium 221 Uub		unbinilium 222 Uuq		unbinilium 223 Uub		unbinilium 224 Uuq		unbinilium 225 Uub		unbinilium 226 Uuq		unbinilium 227 Uub		unbinilium 228 Uuq		unbinilium 229 Uub		unbinilium 230 Uuq		unbinilium 231 Uub		unbinilium 232 Uuq		unbinilium 233 Uub		unbinilium 234 Uuq		unbinilium 235 Uub		unbinilium 236 Uuq		unbinilium 237 Uub		unbinilium 238 Uuq		unbinilium 239 Uub		unbinilium 240 Uuq		unbinilium 241 Uub		unbinilium 242 Uuq		unbinilium 243 Uub		unbinilium 244 Uuq		unbinilium 245 Uub		unbinilium 246 Uuq		unbinilium 247 Uub		unbinilium 248 Uuq		unbinilium 249 Uub		unbinilium 250 Uuq		unbinilium 251 Uub		unbinilium 252 Uuq		unbinilium 253 Uub		unbinilium 254 Uuq		unbinilium 255 Uub		unbinilium 256 Uuq		unbinilium 257 Uub		unbinilium 258 Uuq		unbinilium 259 Uub		unbinilium 260 Uuq		unbinilium 261 Uub		unbinilium 262 Uuq		unbinilium 263 Uub		unbinilium 264 Uuq		unbinilium 265 Uub		unbinilium 266 Uuq		unbinilium 267 Uub		unbinilium 268 Uuq		unbinilium 269 Uub		unbinilium 270 Uuq		unbinilium 271 Uub		unbinilium 272 Uuq		unbinilium 273 Uub		unbinilium 274 Uuq		unbinilium 275 Uub		unbinilium 276 Uuq		unbinilium 277 Uub		unbinilium 278 Uuq		unbinilium 279 Uub		unbinilium 280 Uuq		unbinilium 281 Uub		unbinilium 282 Uuq		unbinilium 283 Uub		unbinilium 284 Uuq		unbinilium 285 Uub		unbinilium 286 Uuq		unbinilium 287 Uub		unbinilium 288 Uuq		unbinilium 289 Uub		unbinilium 290 Uuq		unbinilium 291 Uub		unbinilium 292 Uuq		unbinilium 293 Uub		unbinilium 294 Uuq		unbinilium 295 Uub		unbinilium 296 Uuq		unbinilium 297 Uub		unbinilium 298 Uuq		unbinilium 299 Uub		unbinilium 300 Uuq		unbinilium 301 Uub		unbinilium 302 Uuq		unbinilium 303 Uub		unbinilium 304 Uuq		unbinilium 305 Uub		unbinilium 306 Uuq		unbinilium 307 Uub		unbinilium 308 Uuq		unbinilium 309 Uub		unbinilium 310 Uuq		unbinilium 311 Uub		unbinilium 312 Uuq		unbinilium 313 Uub		unbinilium 314 Uuq		unbinilium 315 Uub		unbinilium 316 Uuq		unbinilium 317 Uub		unbinilium 318 Uuq		unbinilium 319 Uub		unbinilium 320 Uuq		unbinilium 321 Uub		unbinilium 322 Uuq		unbinilium 323 Uub		unbinilium 324 Uuq		unbinilium 325 Uub		unbinilium 326 Uuq		unbinilium 327 Uub		unbinilium 328 Uuq		unbinilium 329 Uub		unbinilium 330 Uuq		unbinilium 331 Uub		unbinilium 332 Uuq		unbinilium 333 Uub		unbinilium 334 Uuq		unbinilium 335 Uub		unbinilium 336 Uuq		unbinilium 337 Uub		unbinilium 338 Uuq		unbinilium 339 Uub		unbinilium 340 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Uuq		unbinilium 391 Uub		unbinilium 392 Uuq		unbinilium 393 Uub		unbinilium 394 Uuq		unbinilium 395 Uub		unbinilium 396 Uuq		unbinilium 397 Uub		unbinilium 398 Uuq		unbinilium 399 Uub		unbinilium 400 Uuq		unbinilium 401 Uub		unbinilium 402 Uuq		unbinilium 403 Uub		unbinilium 404 Uuq		unbinilium 405 Uub		unbinilium 406 Uuq		unbinilium 407 Uub		unbinilium 408 Uuq		unbinilium 409 Uub		unbinilium 410 Uuq		unbinilium 411 Uub		unbinilium 412 Uuq		unbinilium 413 Uub		unbinilium 414 Uuq		unbinilium 415 Uub		unbinilium 416 Uuq		unbinilium 417 Uub		unbinilium 418 Uuq		unbinilium 419 Uub		unbinilium 420 Uuq		unbinilium 421 Uub		unbinilium 422 Uuq		unbinilium 423 Uub		unbinilium 424 Uuq		unbinilium 425 Uub		unbinilium 426 Uuq		unbinilium 427 Uub		unbinilium 428 Uuq		unbinilium 429 Uub		unbinilium 430 Uuq		unbinilium 431 Uub		unbinilium 432 Uuq		unbinilium 433 Uub		unbinilium 434 Uuq		unbinilium 435 Uub		unbinilium 436 Uuq		unbinilium 437 Uub		unbinilium 438 Uuq		unbinilium 439 Uub		unbinilium 440 Uuq		unbinilium 441 Uub		unbinilium 442 Uuq		unbinilium 443 Uub		unbinilium 444 Uuq		unbinilium 445 Uub		unbinilium 446 Uuq		unbinilium 447 Uub		unbinilium 448 Uuq		unbinilium 449 Uub		unbinilium 450 Uuq		unbinilium 451 Uub		unbinilium 452 Uuq		unbinilium 453 Uub		unbinilium 454 Uuq		unbinilium 455 Uub		unbinilium 456 Uuq		unbinilium 457 Uub		unbinilium 458 Uuq		unbinilium 459 Uub		unbinilium 460 Uuq		unbinilium 461 Uub		unbinilium 462 Uuq		unbinilium 463 Uub		unbinilium 464 Uuq		unbinilium 465 Uub		unbinilium 466 Uuq		unbinilium 467 Uub		unbinilium 468 Uuq		unbinilium 469 Uub		unbinilium 470 Uuq		unbinilium 471 Uub		unbinilium 472 Uuq		unbinilium 473 Uub		unbinilium 474 Uuq		unbinilium 475 Uub		unbinilium 476 Uuq		unbinilium 477 Uub		unbinilium 478 Uuq		unbinilium 479 Uub		unbinilium 480 Uuq		unbinilium 481 Uub		unbinilium 482 Uuq		unbinilium 483 Uub		unbinilium 484 Uuq		unbinilium 485 Uub		unbinilium 486 Uuq		unbinilium 487 Uub		unbinilium 488 Uuq		unbinilium 489 Uub		unbinilium 490 Uuq		unbinilium 491 Uub		unbinilium 492 Uuq		unbinilium 493 Uub		unbinilium 494 Uuq		unbinilium 495 Uub		unbinilium 496 Uuq		unbinilium 497 Uub		unbinilium 498 Uuq		unbinilium 499 Uub		unbinilium 500 Uuq		unbinilium 501 Uub		unbinilium 502 Uuq		unbinilium 503 Uub		unbinilium 504 Uuq		unbinilium 505 Uub		unbinilium 506 Uuq		unbinilium 507 Uub		unbinilium 508 Uuq		unbinilium 509 Uub		unbinilium 510 Uuq		unbinilium 511 Uub		unbinilium 512 Uuq		unbinilium 513 Uub		unbinilium 514 Uuq		unbinilium 515 Uub		unbinilium 516 Uuq		unbinilium 517 Uub		unbinilium 518 Uuq		unbinilium 519 Uub		unbinilium 520 Uuq		unbinilium 521 Uub		unbinilium 522 Uuq		unbinilium 523 Uub		unbinilium 524 Uuq		unbinilium 525 Uub		unbinilium 526 Uuq		unbinilium 527 Uub		unbinilium 528 Uuq		unbinilium 529 Uub		unbinilium 530 Uuq		unbinilium 531 Uub		unbinilium 532 Uuq		unbinilium 533 Uub		unbinilium 534 Uuq		unbinilium 535 Uub		unbinilium 536 Uuq		unbinilium 537 Uub		unbinilium 538 Uuq		unbinilium 539 Uub		unbinilium 540 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* Lanthanide series

** Actinide series

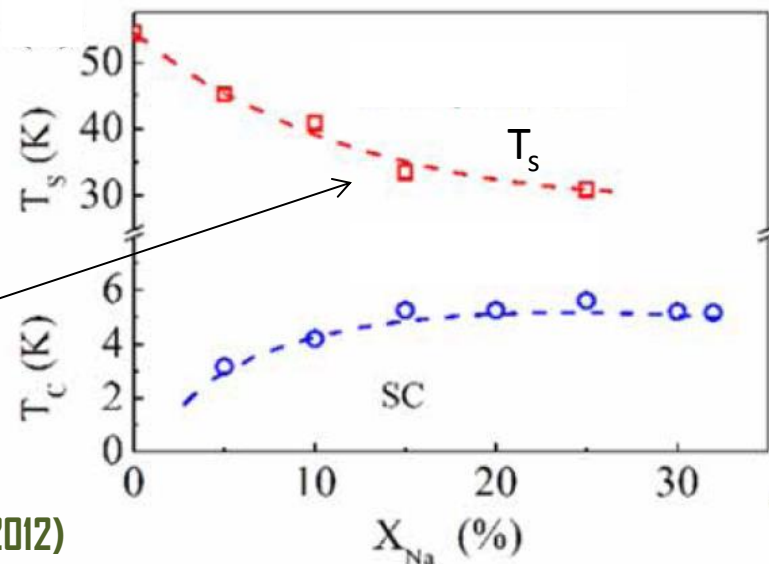
Superconductivity in substituted $\text{BaTi}_2\text{Pn}_2\text{O}$



Tajima et al, J. Phys. Soc. Jpn. 82, 033705 (2013)

Not completely suppressed

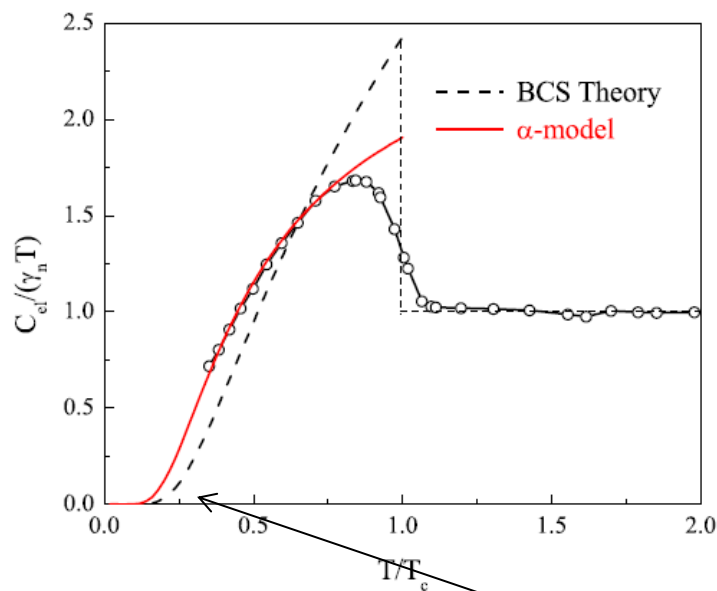
Hole-doping $\text{Ba}_{1-x}\text{Na}_x\text{Ti}_2\text{Pn}_2\text{O}$



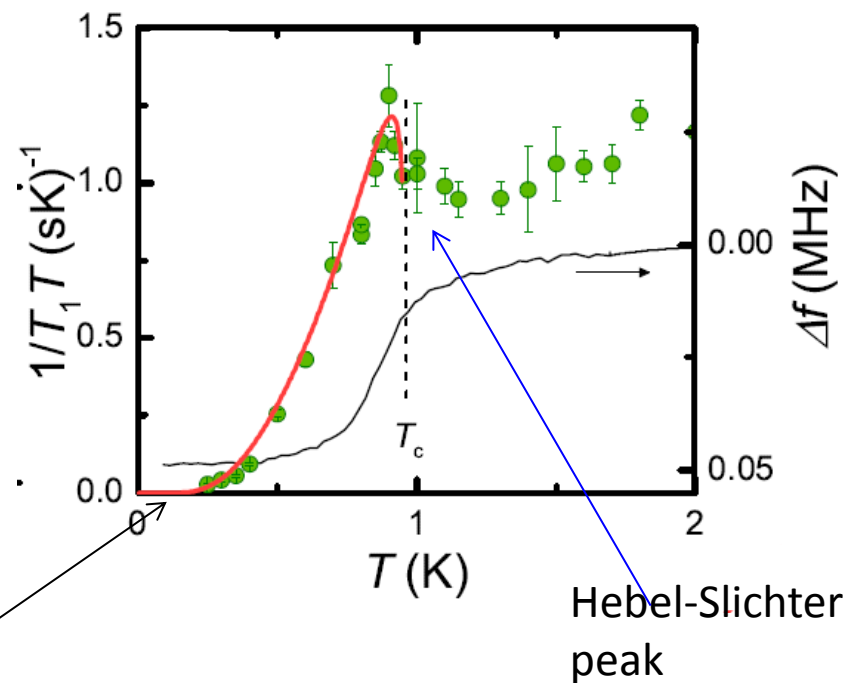
Doan et al, JACS. 134, 16520 (2012)

Superconductivity in BaTi₂Sb₂O

Specific heat



NQR



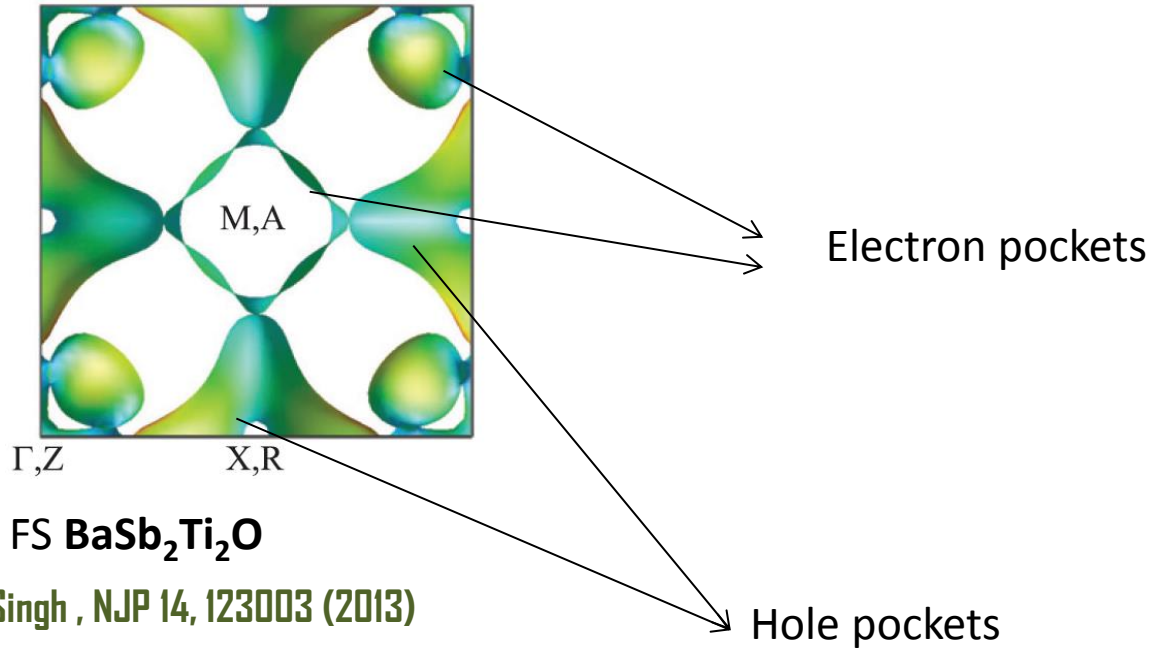
Fully gapped

Hebel-Slichter peak

Gooch et al, PRB 88, 064510 (2013) Kitagawa et al, PRB 87, 060510 (2013)

Nested Fermi surfaces in titanium oxypnictides

Small mass enhancement $\sim 1-1.5$

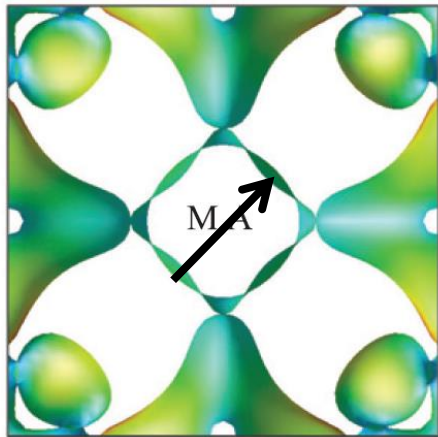


FS $\text{BaSb}_2\text{Ti}_2\text{O}$

Singh, NJP 14, 123003 (2013)

Nested Fermi surfaces in titanium oxypnictides

Small mass enhancement $\sim 1-2$



Na₂Sb₂Ti₂O ($T_s \sim 120\text{K}$, no SC)

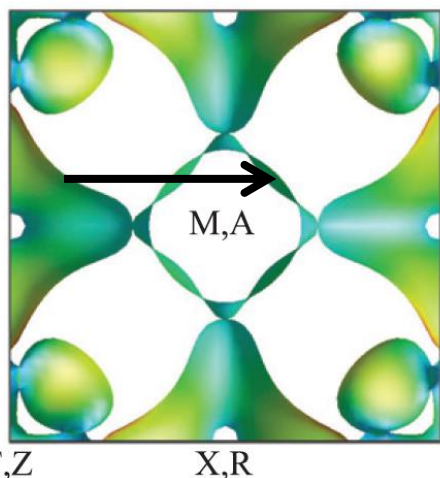
- Incommensurate CDW/SDW $Q_M = (0.22, 0.22, 0)\pi/a$
Pickett, PRB 58, 4335 (1998)
- Incommensurate CDW $Q_X = (0.27, 0, 0)\pi/a$ or $(0, 0.27, 0)\pi/a$
Possible second transition with Q_M
Biani et al, Inorg. Chem. 7, 5810 (1998)

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Biani et al, Inorg. Chem. 7, 5810 (1998)

Commensurate SDW

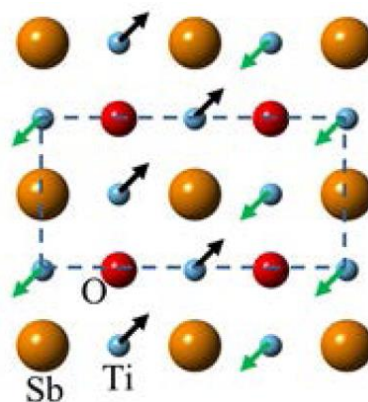
FS BaSb₂Ti₂O

Singh, NJP 14, 123003 (2013)

$$\mu \sim 0.5 \mu_B$$

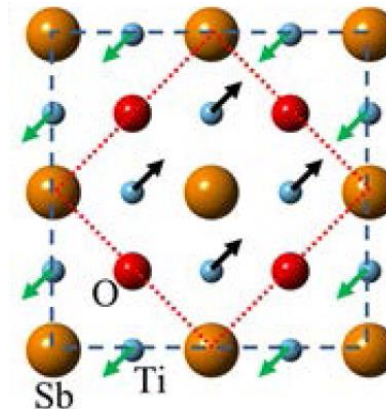
Wang & Lu, JPCM 25, 365501 (2013)

Na₂Sb₂Ti₂O ($T_s \sim 120$ K, no SC)



Double stripe SDW $Q_{XM} = (\pi, 0)$ or $(0, \pi)$

Na₂As₂Ti₂O ($T_s \sim 200$ K, no SC)

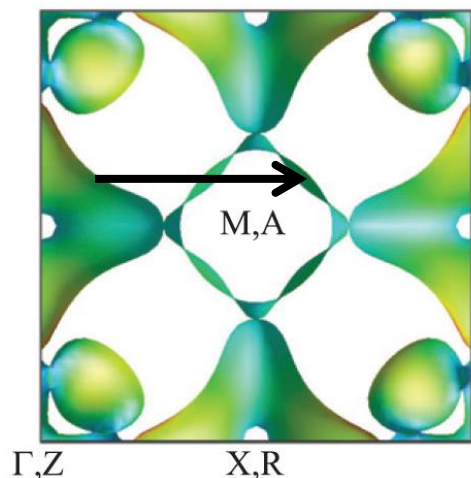


Blocked checkerboard SDW

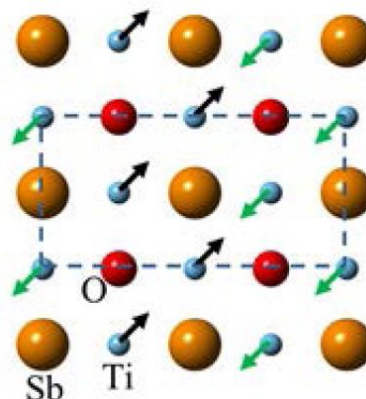
Fig: Hosono et al, Sci. Tech. Adv. Mater. 16, 033503 (2015)

Nested Fermi surfaces in titanium oxypnictides

Small mass enhancement $\sim 1-2$



BaSb₂Ti₂O ($T_s \sim 54$ K, $SC \sim 1.2$ K)

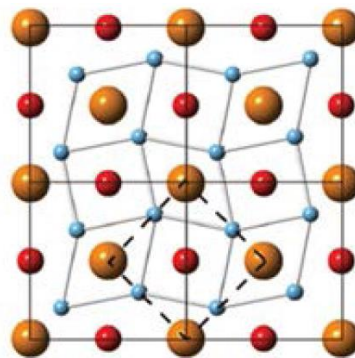


Double stripe SDW

$$Q_{XM} = (\pi, 0) \text{ or } (0, \pi)$$

$$\mu \sim 0.2 \mu_B$$

Singh, NJP 14, 123003 (2013)



CDW $Q = (\pi, \pi)$

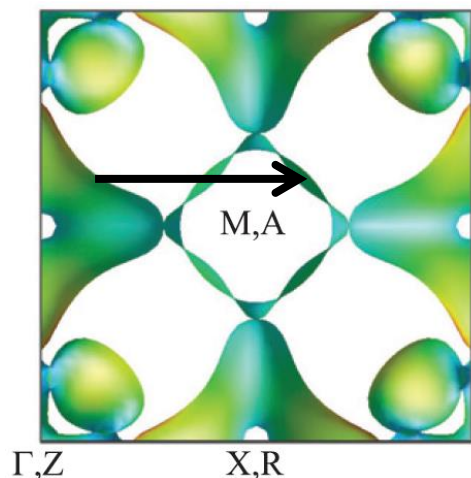
Phonon anomaly

Subedi, PRB 87, 054506 (2013)

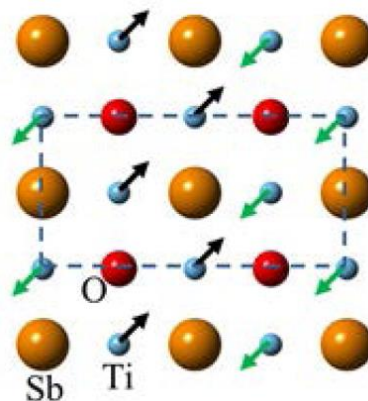
Fig: Hosono et al, Sci. Tech. Adv. Mater. 16, 033503 (2015)

Nested Fermi surfaces in titanium oxypnictides

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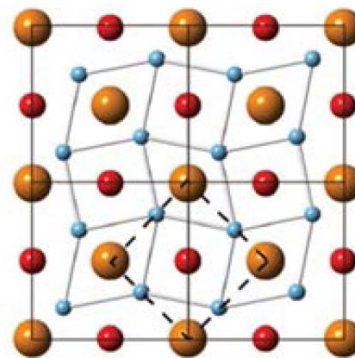
Double stripe SDW

$$Q_{XM} = (\pi, 0) \text{ or } (0, \pi)$$

$$\mu \sim 0.2 \mu_B$$

Magnetically
mediated SC **s[±]**

Singh, NJP 14, 123003 (2013)



CDW $Q = (\pi, \pi)$

Phonon anomaly

Phonon mediated
SC **s-wave**, $T_c \sim 5$ K

Subedi, PRB 87, 054506 (2013)

Fig: Hosono et al, Sci. Tech. Adv. Mater. 16, 033503 (2015)

A nematic state below T_s in titanium oxypnictides?

- ❑ NMR/NQR in **BaTi₂Sb₂O** at Sb site
 - Excludes Incommensurate CDW/SDW correlations.
 - Breaking of Tetragonal symmetry at Sb site

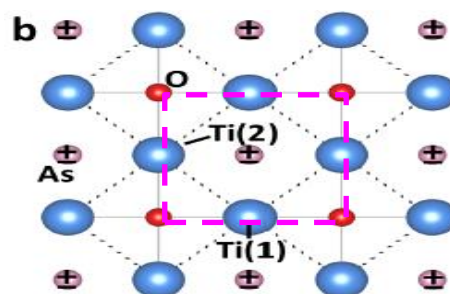
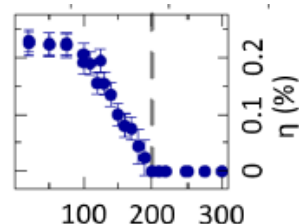
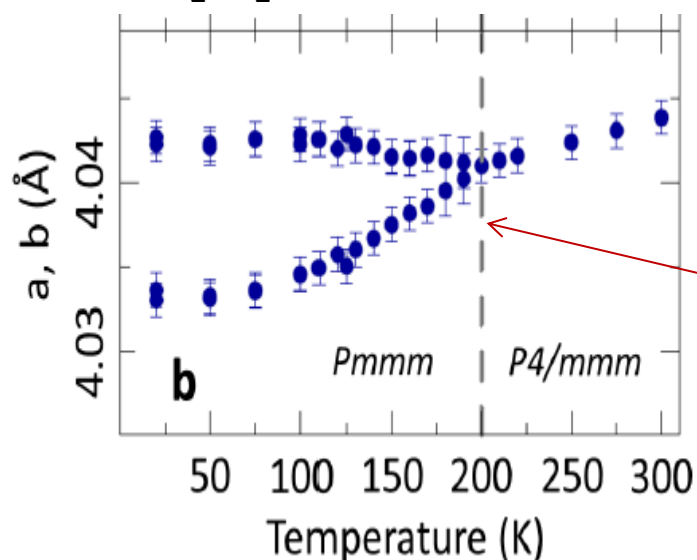
Kitagawa et al,
PRB 87, 060510 (2013)

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Kitagawa et al,
PRB 87, 060510 (2013)

BaTi₂As₂O ($T_s \sim 200$ K, no Sc)

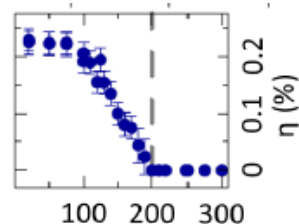
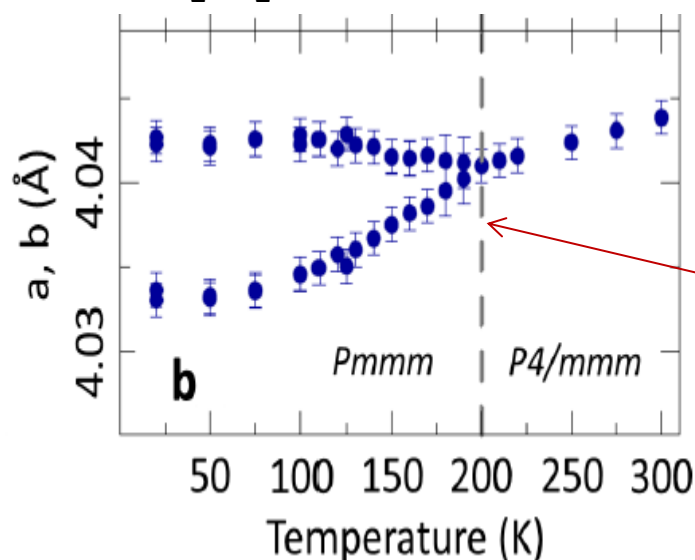


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Kitagawa et al,
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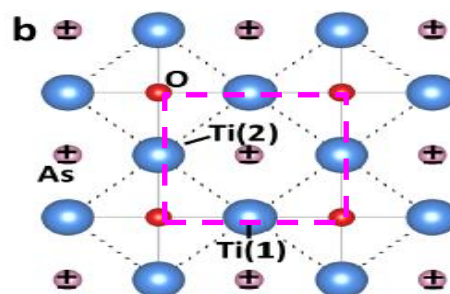
BaTi₂As₂O ($T_s \sim 200$ K, no Sc)



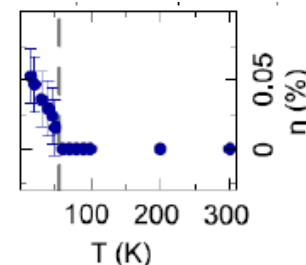
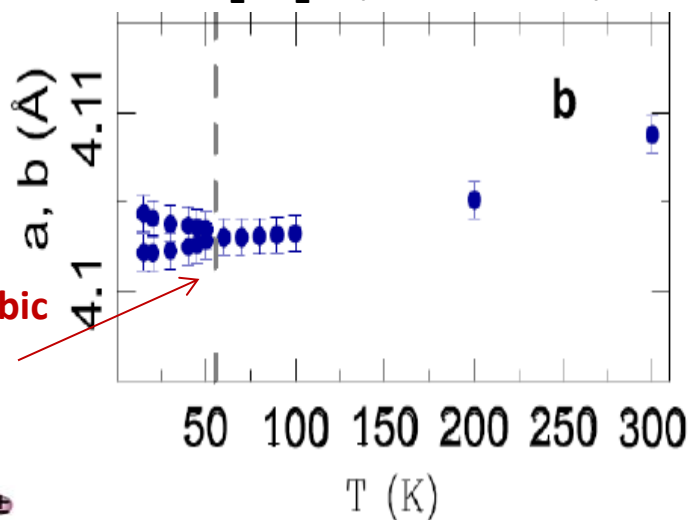
Neutron diffraction

Frandsen et al,
Nat. Comm. 5,
5761 (2014)

**Tetragonal-Orthorhombic
Structural transition**



BaTi₂Sb₂O ($T_s \sim 54$ K, Sc)

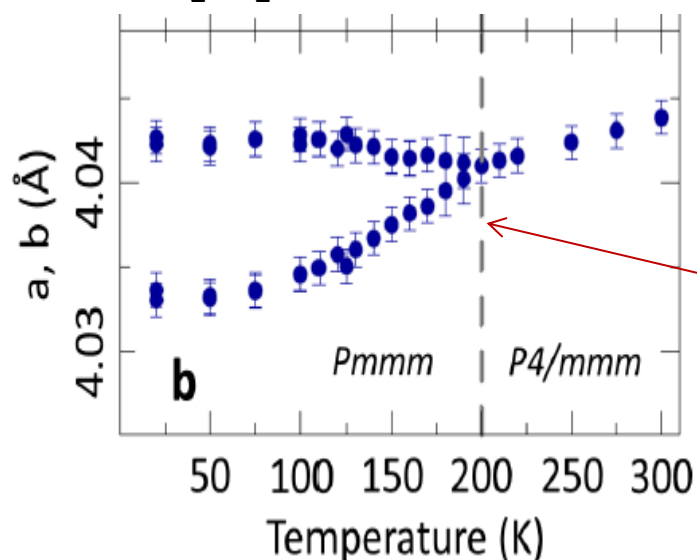


A nematic state below T_s in titanium oxypnictides?

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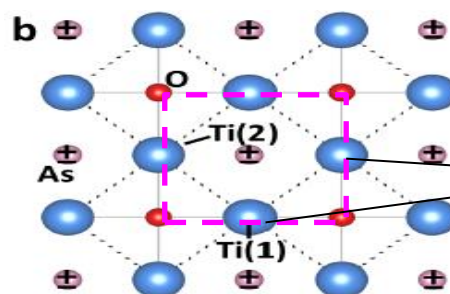
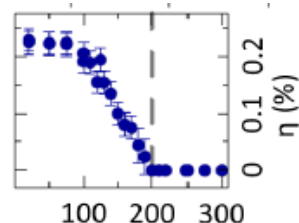
BaTi₂As₂O ($T_s \sim 200$ K, no Sc)



Neutron diffraction

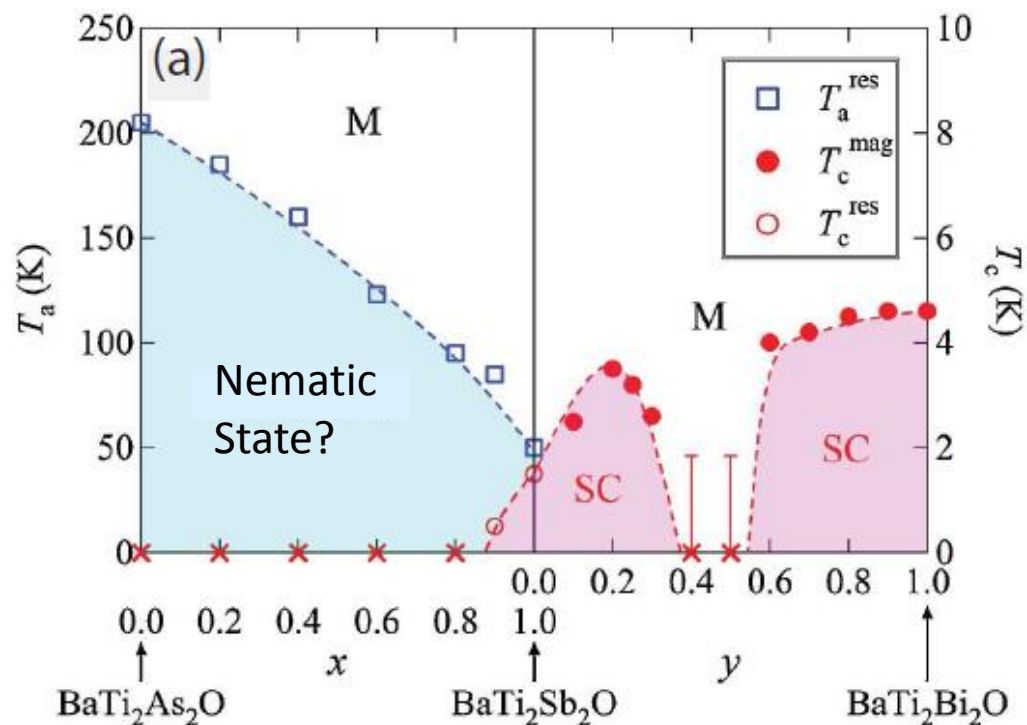
Frandsen et al,
Nat. Comm. 5,
5761 (2014)

Intra unit cell nematic state
with d-wave charge ordering

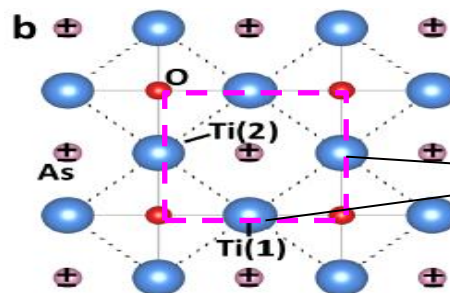
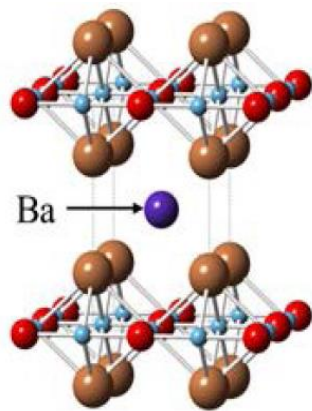


Different charge
filling

Superconductivity emerging from a nematic state?



Intra unit cell nematic state
with d-wave charge ordering



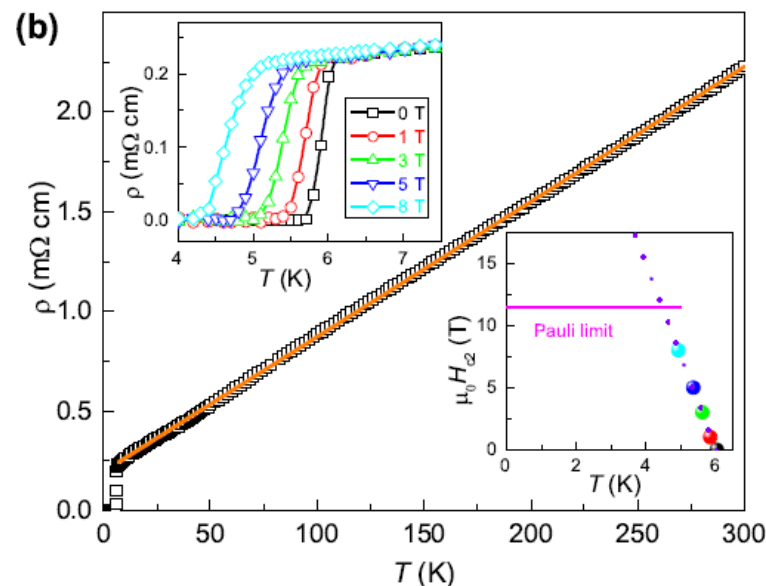
Different charge
ordering

Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds

$K_2Cr_3As_3$ $T_c \sim 6.1$ K

$Rb_2Cr_3As_3$ $T_c \sim 4.8$ K

$Cs_2Cr_3As_3$ $T_c \sim 2.2$ K



hydrogen 1 H 1.0079																	helium 2 He 4.0026				
lithium 3 Li 6.941	beryllium 4 Be 9.0122															boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305															aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc	titanium 22 Ti	vanadium 23 V	chromium 24 Cr	manganese 25 Mn	iron 26 Fe	cobalt 27 Co	nickel 28 Ni	copper 29 Cu	zinc 30 Zn	gallium 31 Ga	germanium 32 Ge	arsenic 33 As	selenium 34 Se	bromine 35 Br	krypton 36 Kr				
rubidium 37 Rb	strontium 38 Sr	yttrium 39 Y	zirconium 40 Zr	niobium 41 Nb	molybdenum 42 Mo	technetium 43 Tc	ruthenium 44 Ru	rhodium 45 Rh	paladium 46 Pd	silver 47 Ag	cadmium 48 Cd	indium 49 In	tin 50 Sn	antimony 51 Sb	tellurium 52 Te	iodine 53 I	xenon 54 Xe				
cesium 55 Cs	barium 56 Ba	lanthanum 57 La	cerium 58 Ce	praseodymium 59 Pr	neodymium 60 Nd	promethium 61 Pm	samarium 62 Sm	europium 63 Eu	gadolinium 64 Gd	terbium 65 Tb	dysprosium 66 Dy	holmium 67 Ho	erbium 68 Er	thulium 69 Tm	ytterbium 70 Yb	lutetium 71 Lu	hafnium 72 Hf				

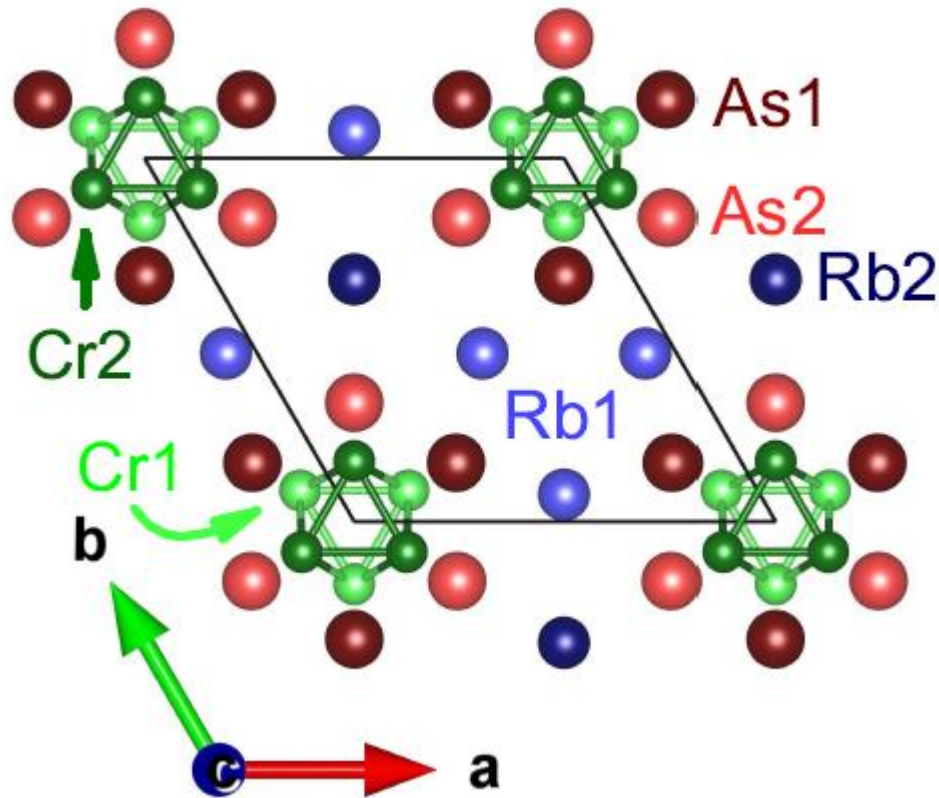
Bao et al, arXiv:1412.0067,
Tang et al, arXiv:1412.2596
Tang et al, arXiv: 1501.02065

* Lanthanide series

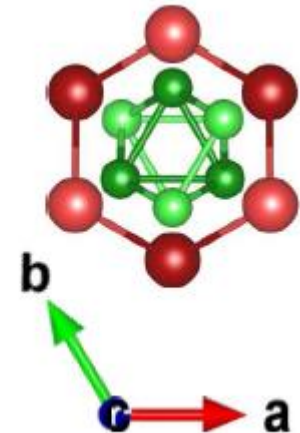
** Actinide series

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np	plutonium 94 Pu 239.04	americium 95 Am 243	curium 96 Cm 247	berkelium 97 Bk 247	californium 98 Cf 251	einsteinium 99 Es 252	fermium 100 Fm 257	mendelevium 101 Md 258	nobelium 102 No 259

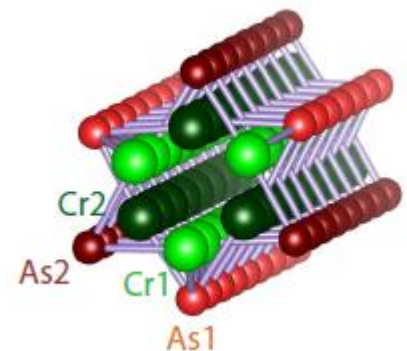
Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds



Quasi-1d lattice structure

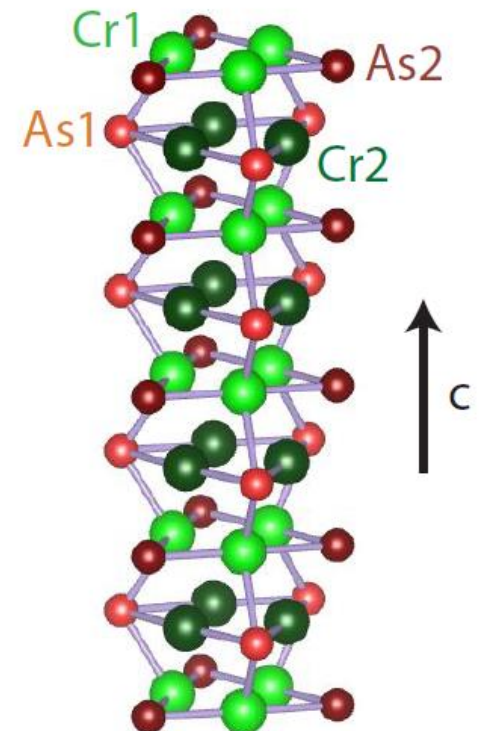
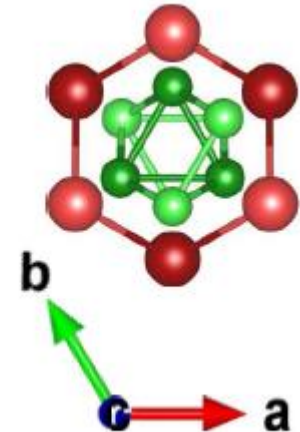
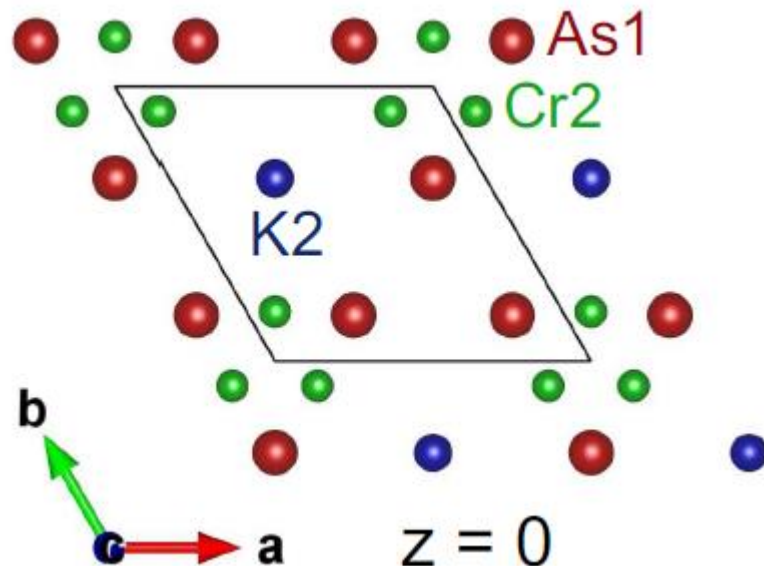
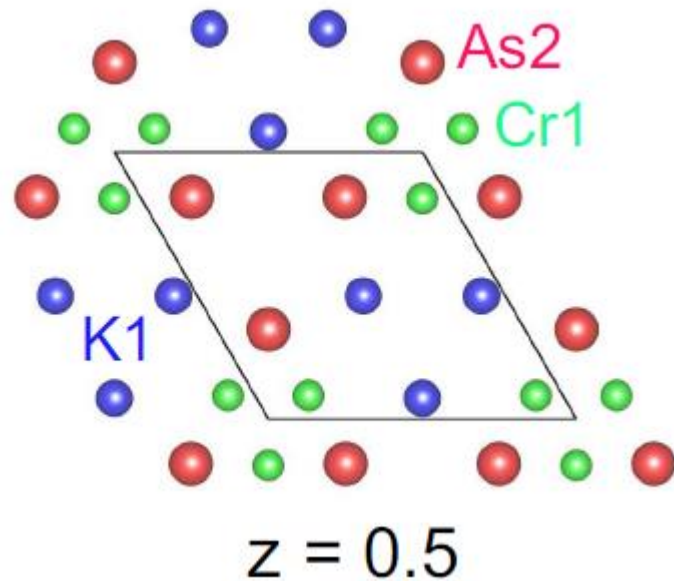


Double wall nanotubes
As (outer shell) Cr (inner shell)



Bao et al, arXiv:1412.0067

Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds



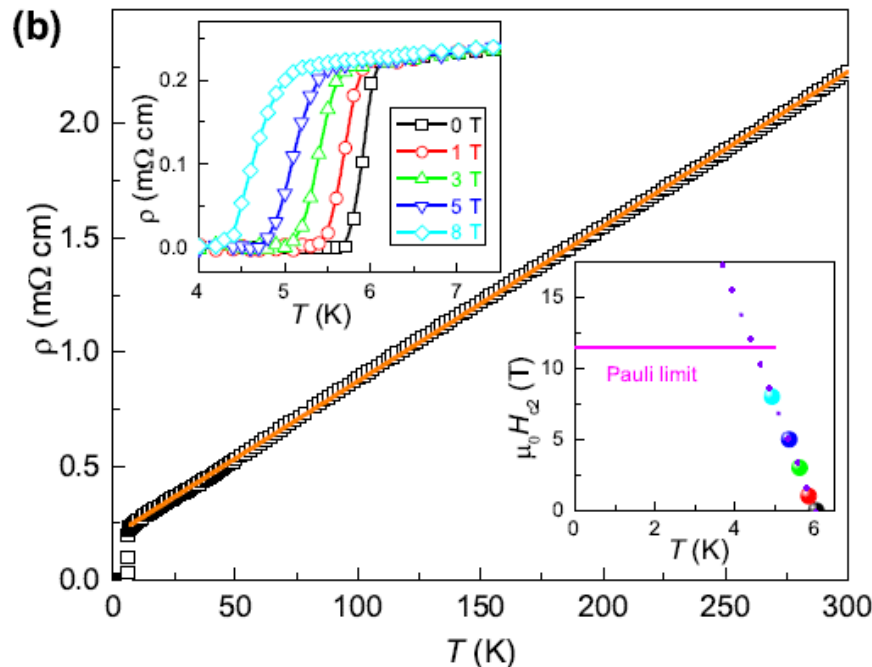
Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds

- ❑ Only very few quasi-1d superconducting materials
- ❑ Interacting 1d electronic systems : Luttinger liquids

Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds

- ❑ Only a few quasi-1d superconducting materials
- ❑ Interacting 1d electronic systems : Luttinger liquids
- ❑ Very large Sommerfeld constant γ ($C_e = \gamma T$) $\Rightarrow$ Correlated system

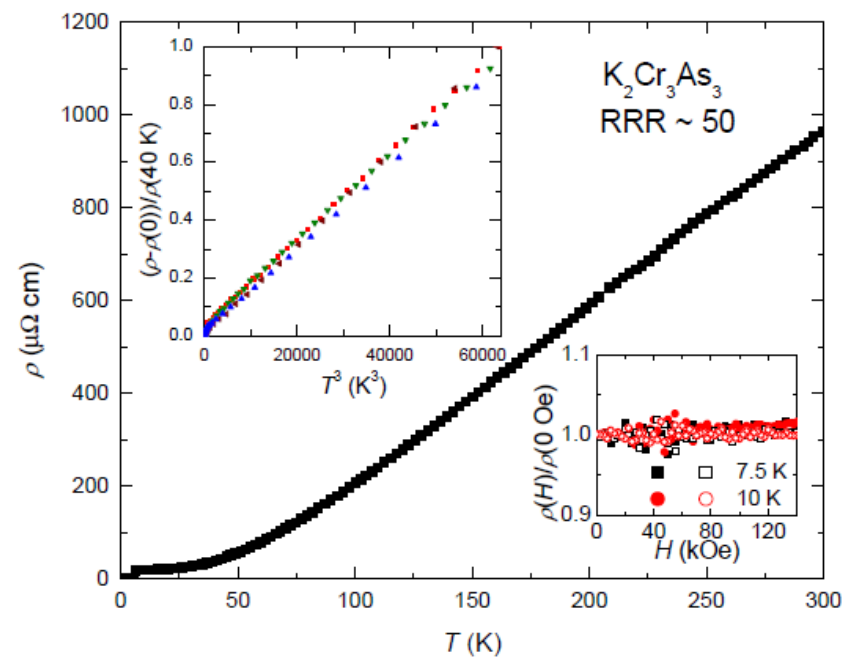
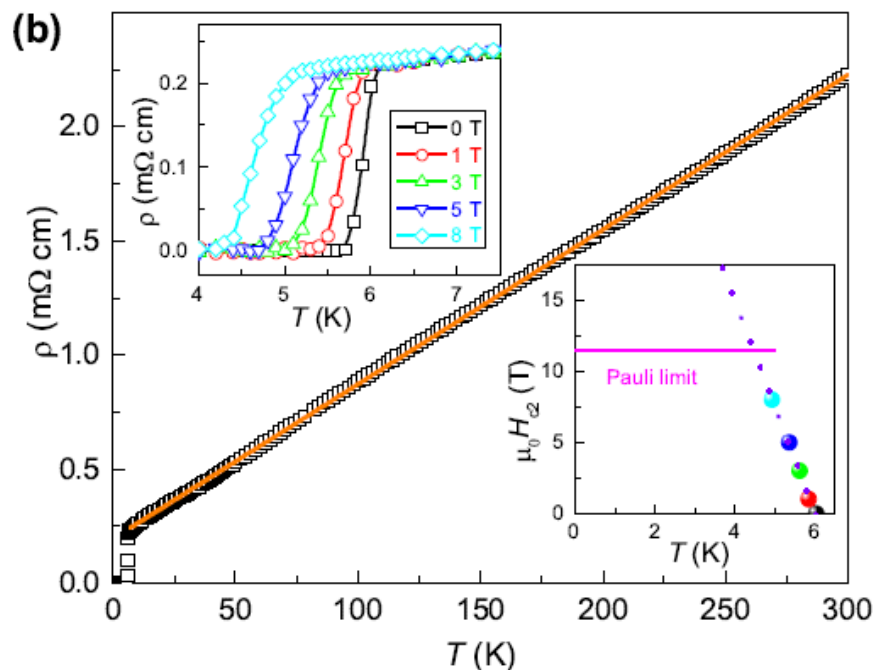
$$\gamma \propto m^* \sim 3-4 m \text{ in } K_2Cr_3As_3$$



Bao et al, arXiv:1412.0067

Superconductivity in Quasi-1d $A_2Cr_3As_3$ compounds

- ❑ Only a few quasi-1d superconducting materials
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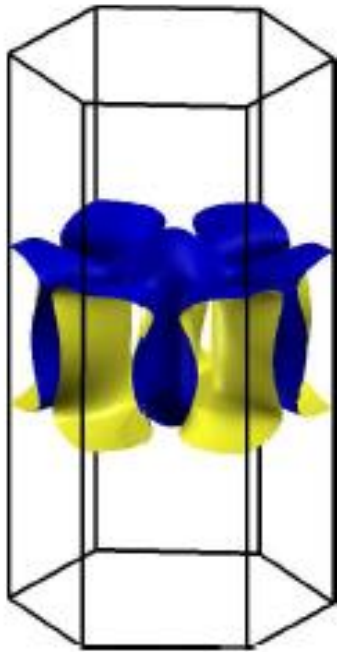


Bao et al, arXiv:1412.0067

Kong et al, arXiv:1501.01554

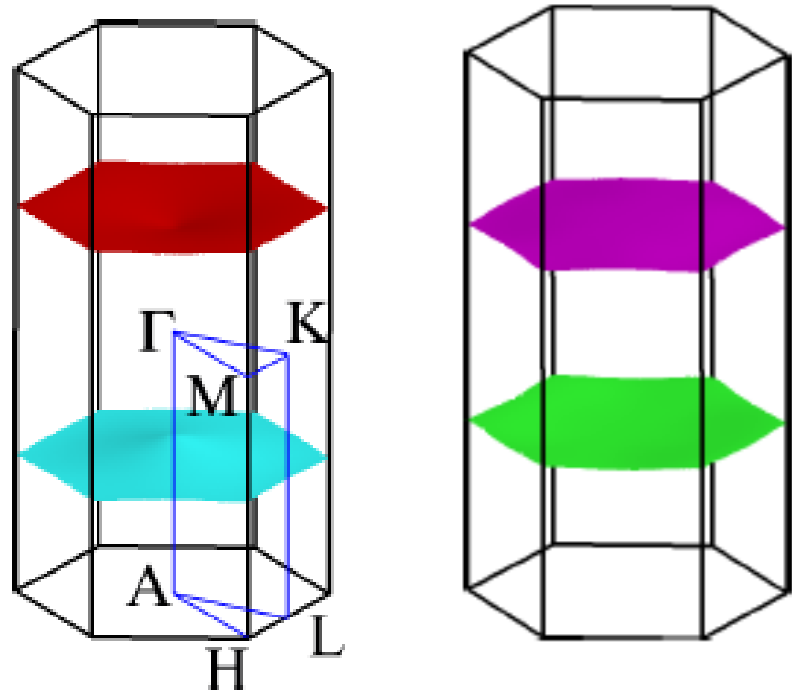
Quasi-1d $A_2Cr_3As_3$ compounds: Fermi surface

3d Fermi pocket



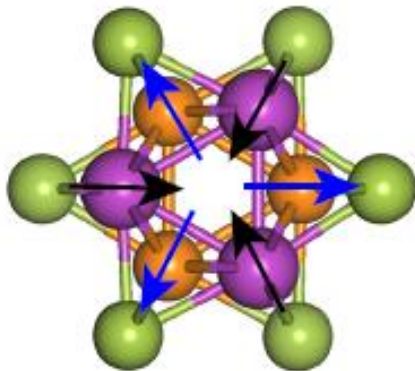
Large density of states

Quasi-1d Fermi pockets

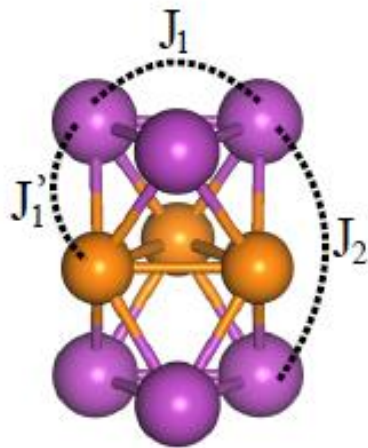


Jiang et al, arXiv:1412.1309

Magnetic tendencies

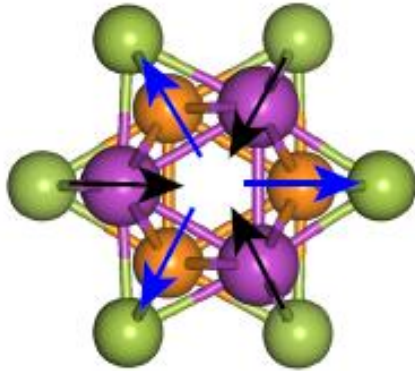


In-Out Coplanar
Antiferromagnetic Ordering
(ferromagnetic ordering along the chain)

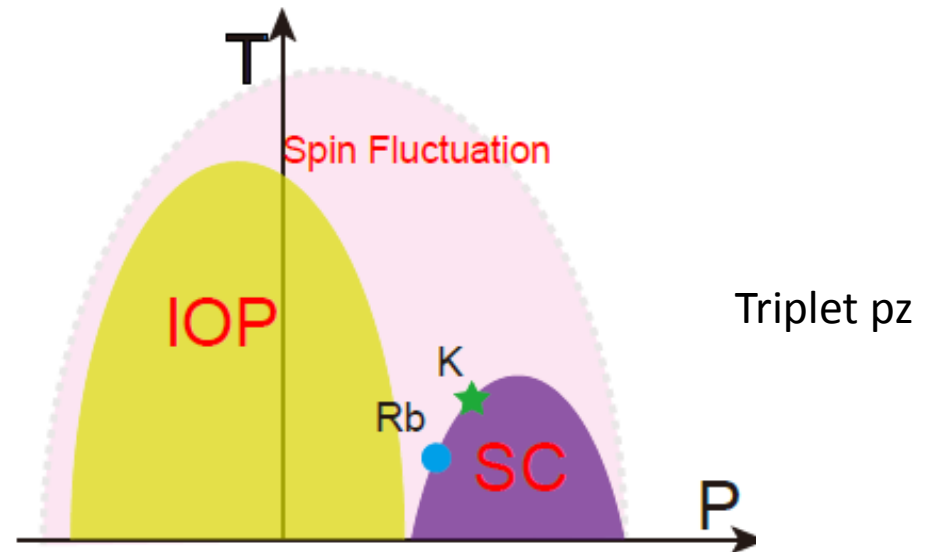
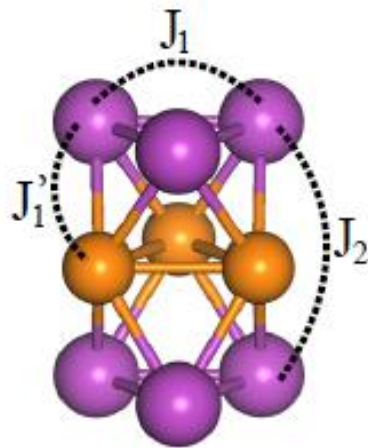


Wu et al, arXiv:1412.1309

Magnetic tendencies



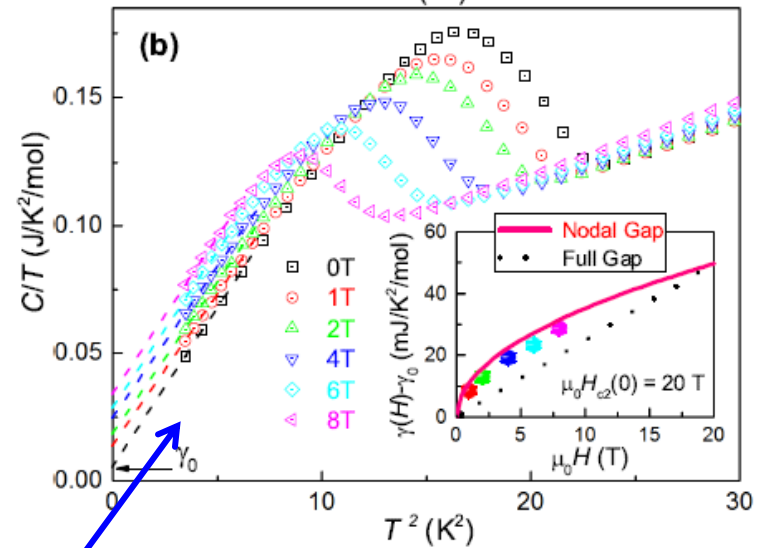
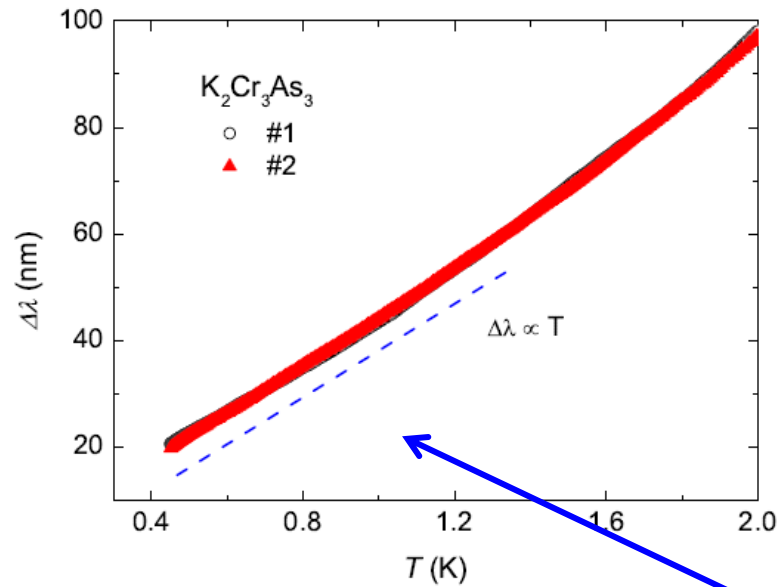
In-Out Coplanar
Antiferromagnetic Ordering
(ferromagnetic ordering along the chain)



Wu et al, [arXiv:1501.00412](https://arxiv.org/abs/1501.00412), [1503.06707](https://arxiv.org/abs/1503.06707)

Idea later supported by explicit calculations,; electron-phonon superconductivity also claimed

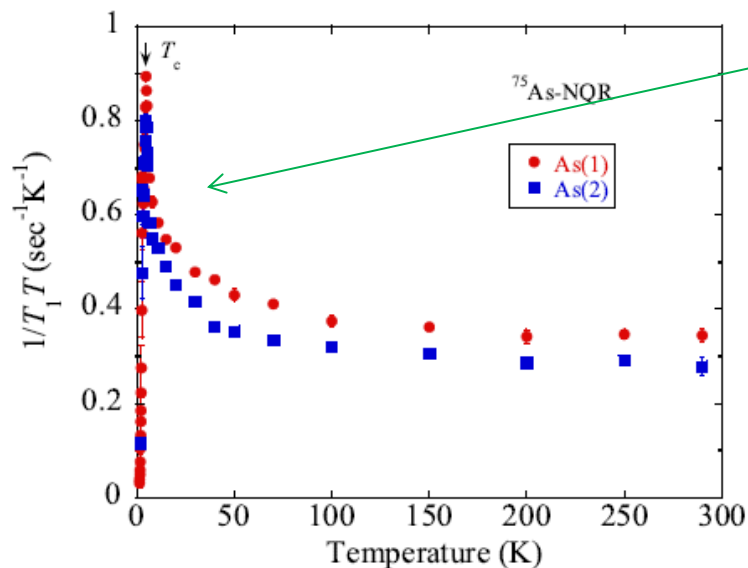
In favour of triplet superconductivity



It seems consistent with the presence of line nodes.

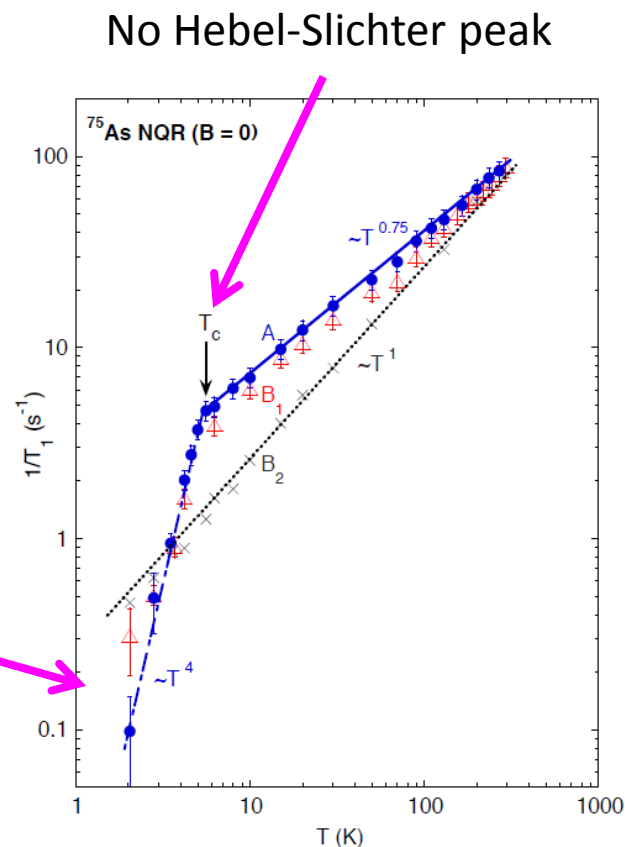
Pang et al, arXiv:1501.01880

In favour of triplet superconductivity



Enhancement of magnetic fluctuations
Towards T_c

Very small internal magnetic
Field detected by muon spectroscopy
0.003 G



No
exponential
suppression
at low T

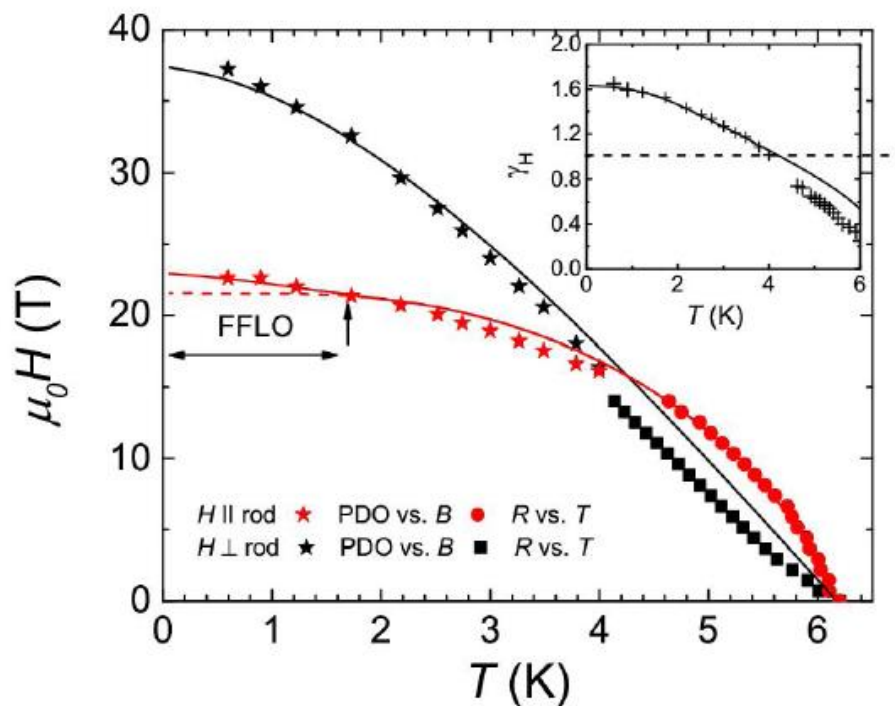
Zhi et al, arXiv:1505.05743

Zhi et al, arXiv:1501.00713

Against triplet superconductivity

- T_c insensitive to impurities
- H_c parallel to the chains Pauli limited.
 H_c perpendicular to the chains not Pauli limited.

Singlet pairing with
spins blocked along
the chain direction?



Talk G.Cao
Next week

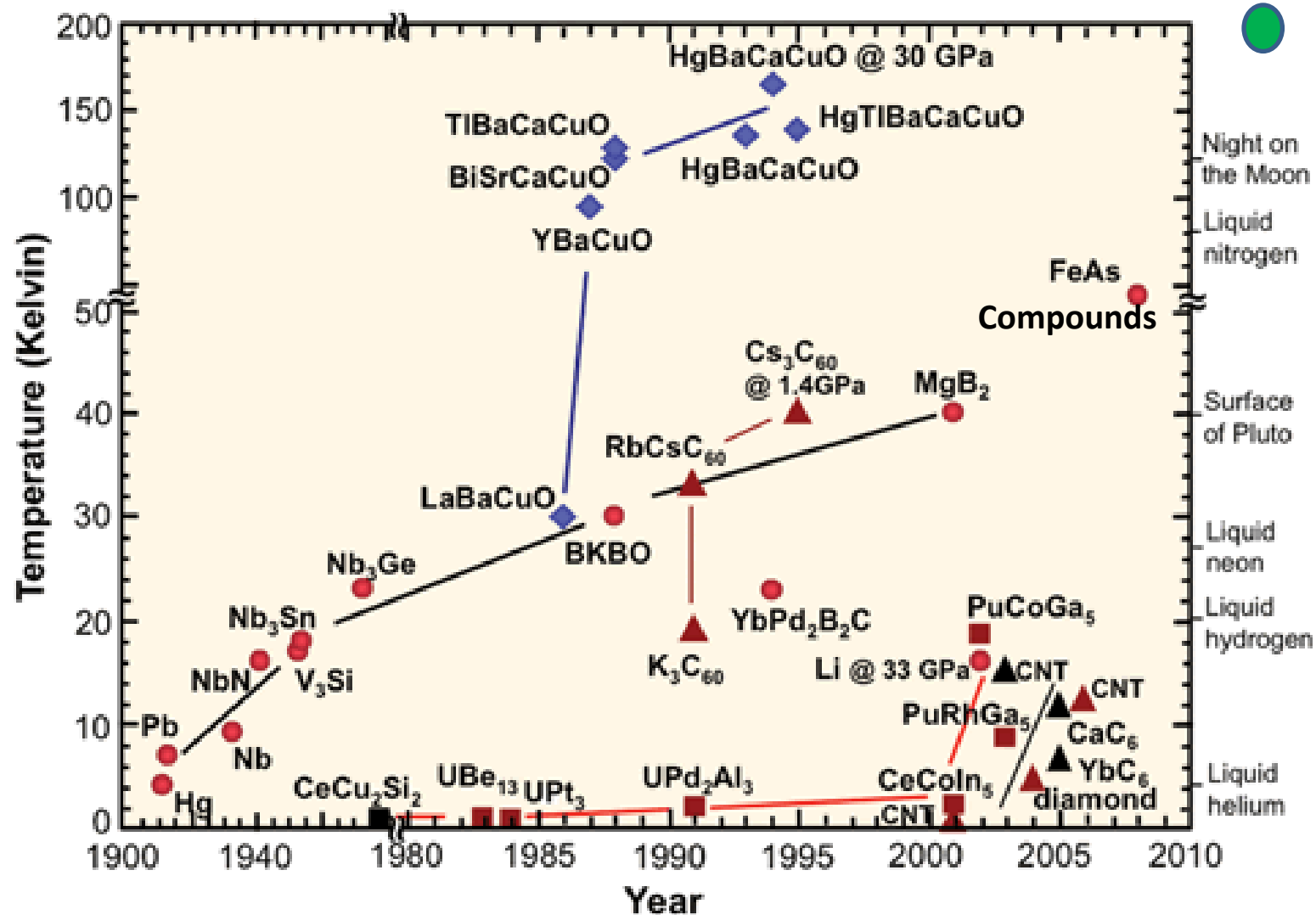


Fig: <http://www.ccas-web.org/superconductivity>

Metallic Hydrogen: a high- T_c superconductor?

$$T_c = \frac{\omega_{ln}}{1.2} \exp \left(\frac{-1.04(1 + \lambda)}{\lambda - \mu^*(1 + 0.62\lambda)} \right)$$

Characteristic
phonon frequency

Electron-phonon
coupling constant

Coulomb pseudopotential

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Large λ + high ω_{ln}  High T_c

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Metallic Hydrogen

Aschroft, PRL 21, 1748 (1968)

Metallic Hydrogen: a high- T_c superconductor?

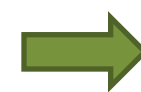
$$T_c = \frac{\omega_{ln}}{1.2} \exp \left(\frac{-1.04(1 + \lambda)}{\lambda - \mu^*(1 + 0.62\lambda)} \right)$$

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Coulomb pseudopotential

- ❑ Large ω_{ln} : small mass
- ❑ Large λ : as H^+ ion lacks inner structure.
strong bare electron ion interaction
- ❑ High Density of States. Small μ^* due to screening



$T_c \sim 10^2 \text{ K}$
(at present $\sim 240 \text{ K}$)

Aschroft, PRL 21, 1748 (1968)

Metallic Hydrogen: a high- T_c superconductor?

$$T_c = \frac{\omega_{ln}}{1.2} \exp \left(\frac{-1.04(1 + \lambda)}{\lambda - \mu^*(1 + 0.62\lambda)} \right)$$

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- ❑ Large λ : as H^+ ion lacks inner structure.
strong bare electron ion interaction
- ❑ High Density of States. Small μ^* due to screening

➡ $T_c \sim 10^2 \text{ K}$

but

$P_{H\text{-metal}} \sim 400 \text{ GPa}$

Aschroft, PRL 21, 1748 (1968)

Städele & Martin, PRL 84, 6070 (2000)

Hydrogen-rich alloys: high-T_c superconductors?

Hydrogen-rich covalent hydrides



M: C, Si, Ge, Sn
group IV

- High frequency phonons (H-ions)
- Compensated semimetal with high density of states
- Wideband (μ^* favourable)
- Large electron-ion interactions (H-M)
- Low and large q- electron-phonon coupling

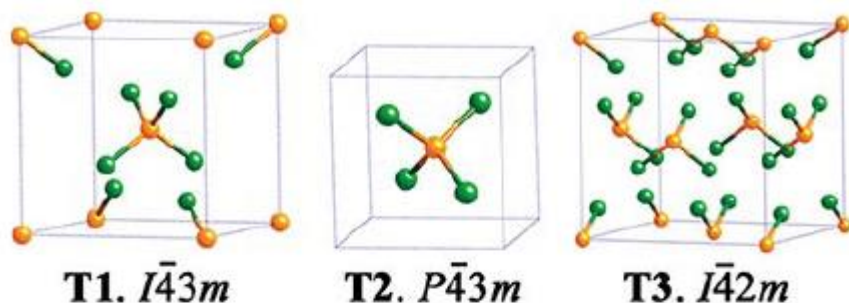
Possibility to tune T_c
through M substitutions


smaller P_{metal}

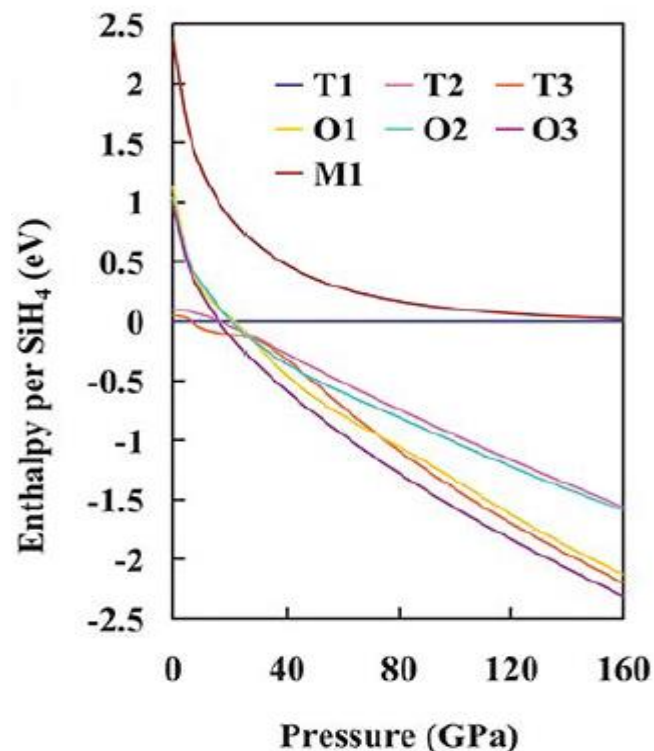
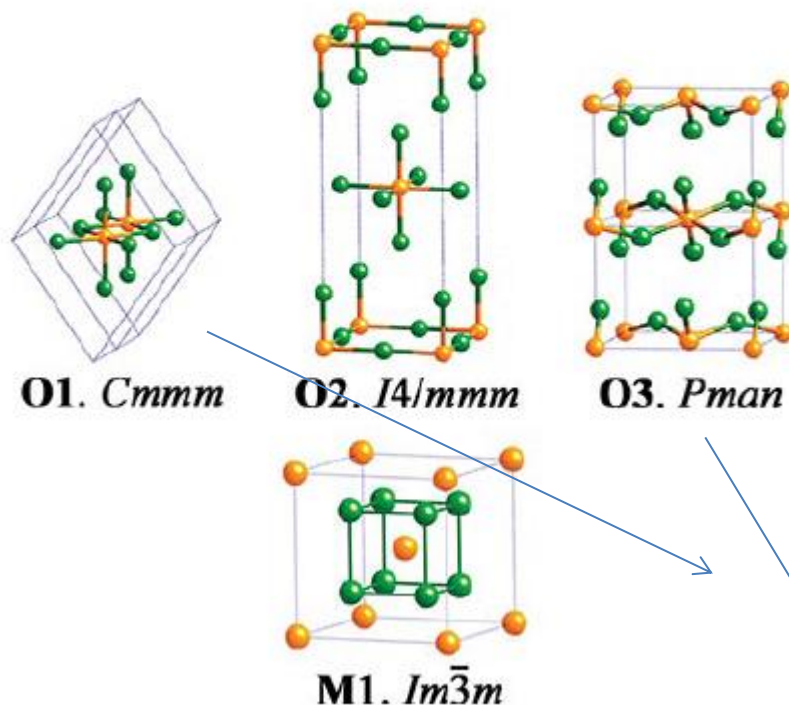
Aschroft, PRL 92, 187002 (2004)

Hydrogen-rich alloys: search for high-T_c superconductors

SiH₄: stability of different phases



Low pressure phases:
Insulating molecular crystals



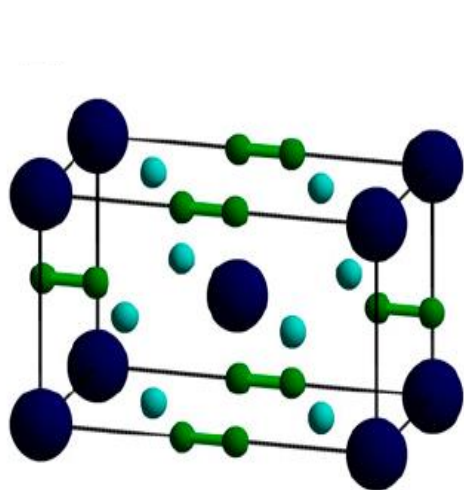
Compact **metallic** phases
at high pressure

Feng et al, PRL 96, 017006 (2006)

Hydrogen-rich alloys: search for high-T_c superconductors



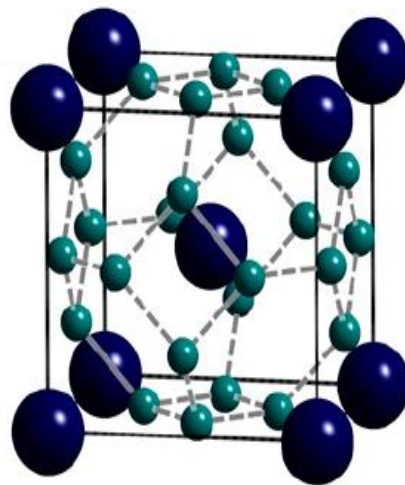
stability of different compositions & structures as a function of pressure



tI10



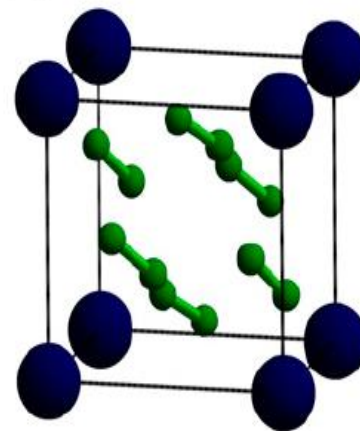
50-200 GPa



cI14



150-200 GPa



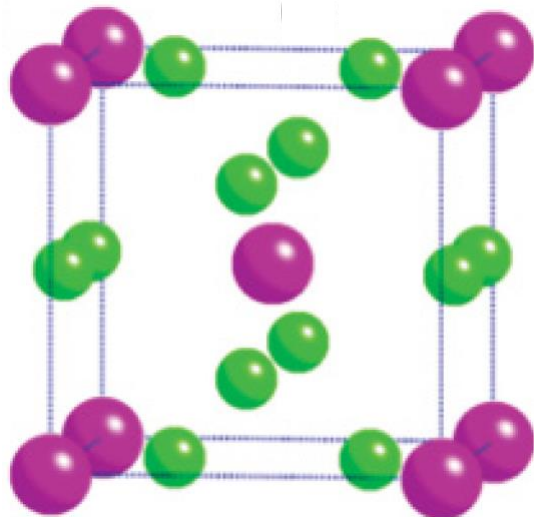
hR13



100-200 GPa

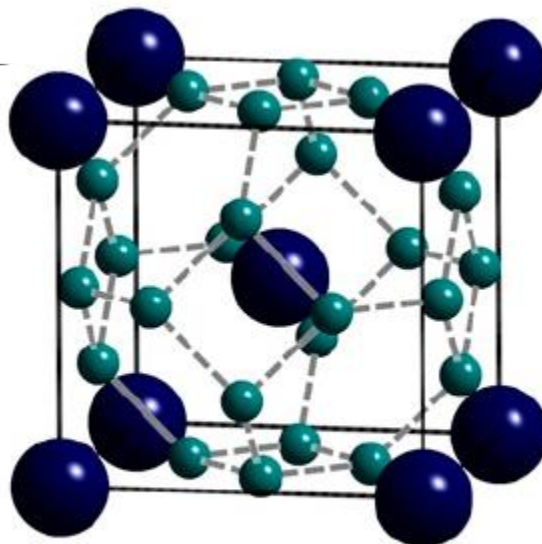
Wang et al, PNAS 109, 6463 (2012)

Hydrogen-rich alloys: search for high- T_c superconductors



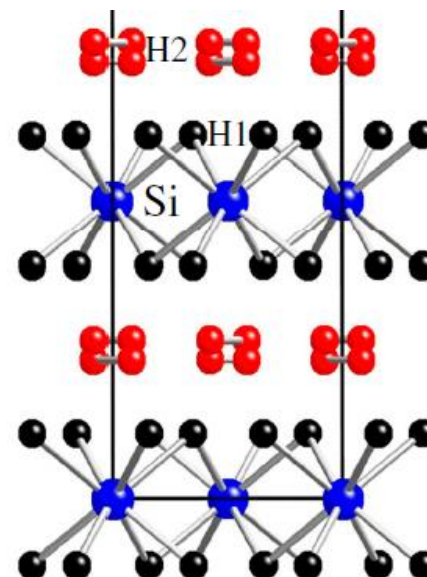
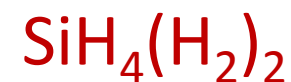
$T_c \sim 80 \text{ K @ } 160 \text{ GPa}$

Gao et al, PRB 84,
06411 (2011)



$T_c \sim 220 \text{ K @ } 150 \text{ GPa}$

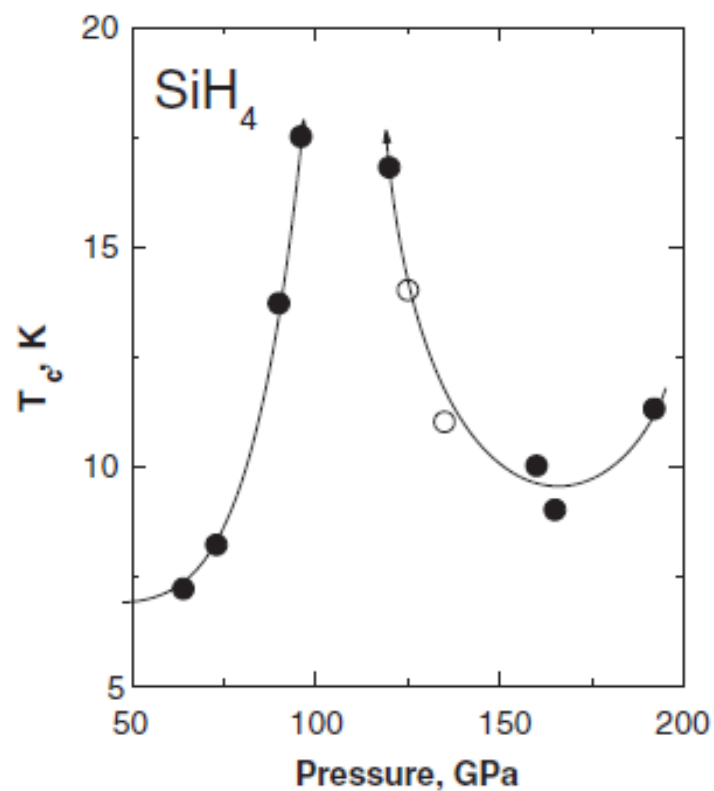
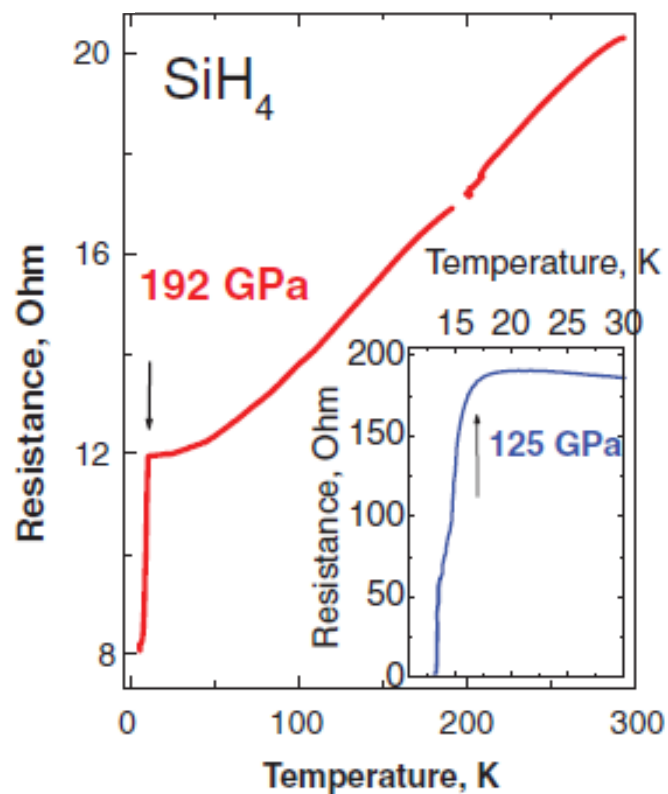
Wang et al, PNAS 109,
6463 (2012)



$T_c \sim 100 \text{ K @ } 250 \text{ GPa}$

Li et al, PNAS 107,
15708 (2010)

Superconductivity in SiH_4 under high-pressure



Eremets et al, Science 319, 1506 (2008)

Sulfur hydrides: search for high-Tc superconductors

H₂S under pressure

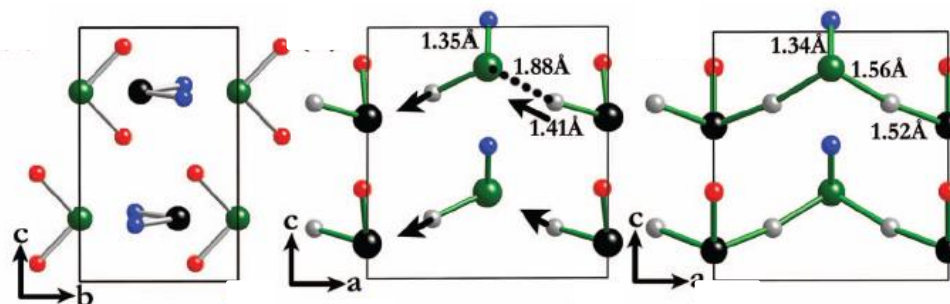
P2/c (P>8,7 GPa)

P2/c (8,7-29 GPa)

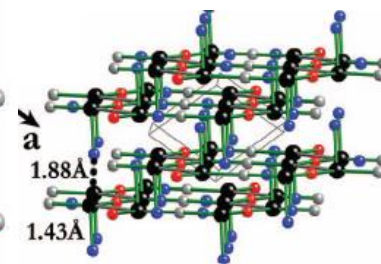
Pm2c1 (29-65 GPa)

P1 (80-158 GPa)

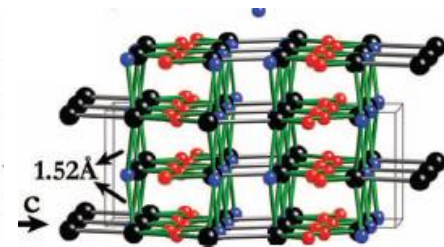
Cmca (P>158 GPa)



Li et al, J. Chem. Phys. 140, 174712 (2014)



Metallic P> 130 GPa
Tc~33-60 K



Metallic
Tc~80 K @158 GPa

Sulfur hydrides: search for high-Tc superconductors

H₂S under pressure

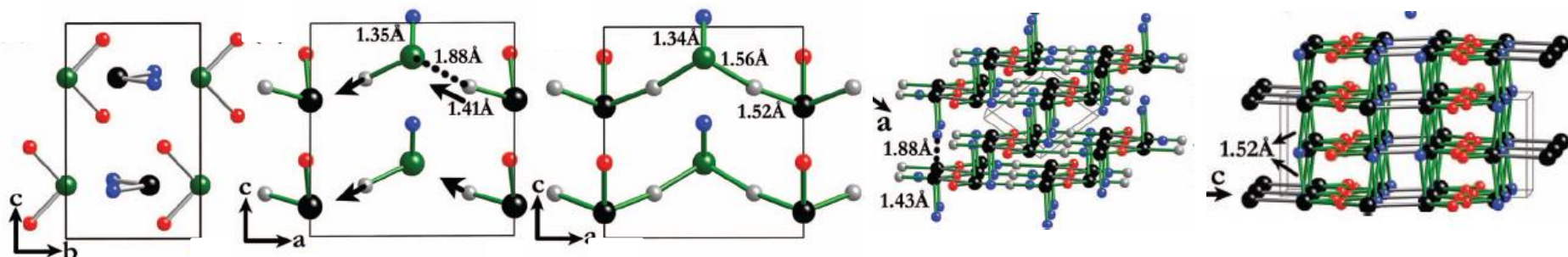
P2/c (P > 8,7 GPa)

Pc (8,7-29 GPa)

Pm2c1 (29-65 GPa)

P1 (80-158 GPa)

Cmca (P > 158 GPa)



Li et al, J. Chem. Phys. 140, 174712 (2014)

Metallic P > 130 GPa
Tc ~ 33-60 K

Metallic
Tc ~ 80 K @ 158 GPa

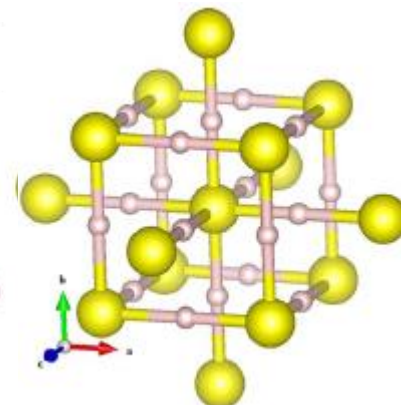
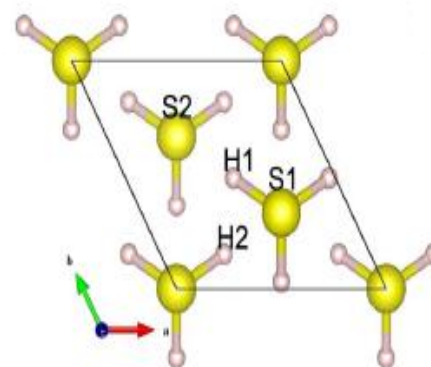
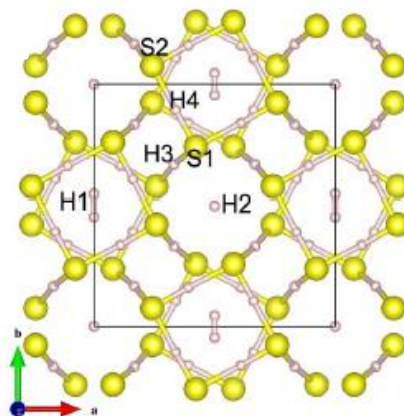
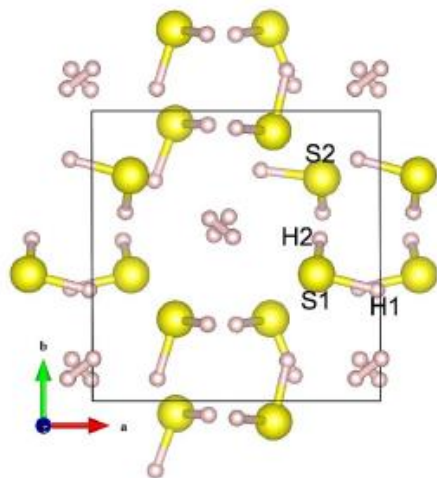
(H₂S)₂H₂ under pressure → H₃S

P1 (P < 37 GPa)

Cccm (37-111 GPa)

R3m (111-180 GPa)

I3-3m (P > 180 GPa)



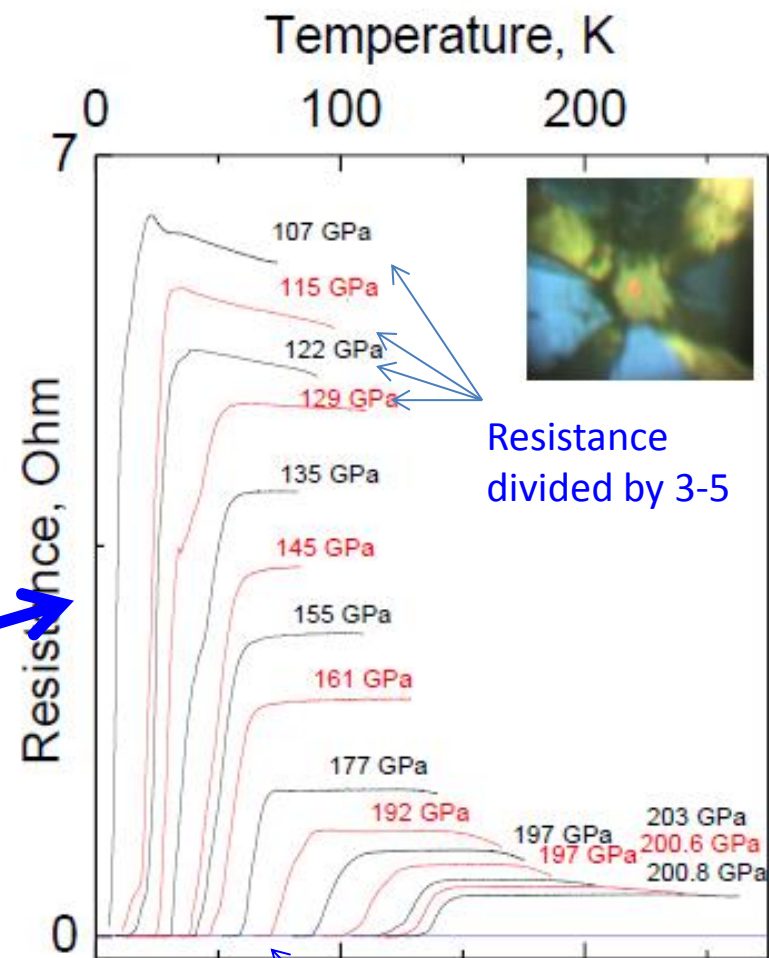
Duan et al, Sci. Rep. 4, 6968 (2014)

Metallic
Tc ~ 160 K

Metallic
Tc ~ 200 K

H₂S under high-pressure

- In electrical measurements it starts to conduct at $P \sim 50$ GPa
- At 90-100 GPa further drop in resistance.

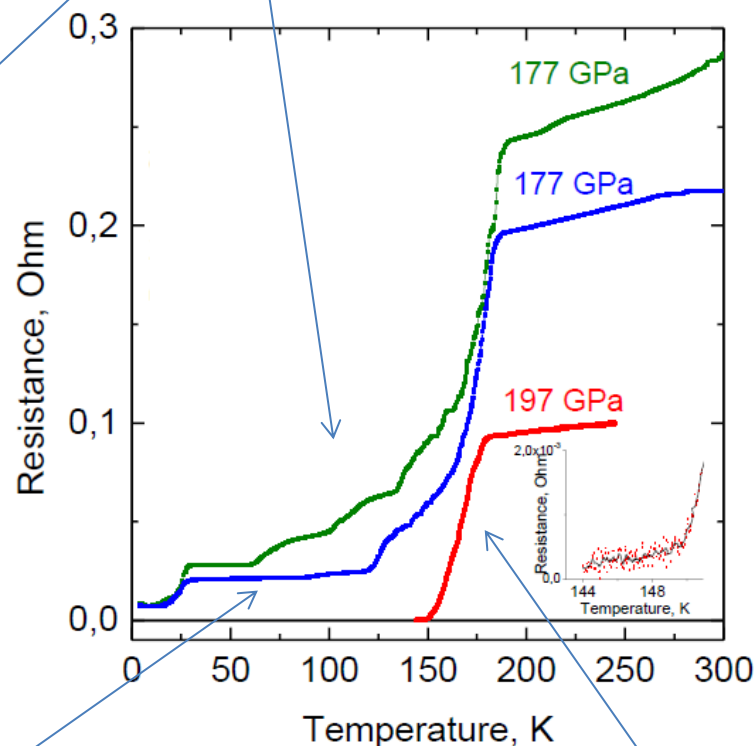
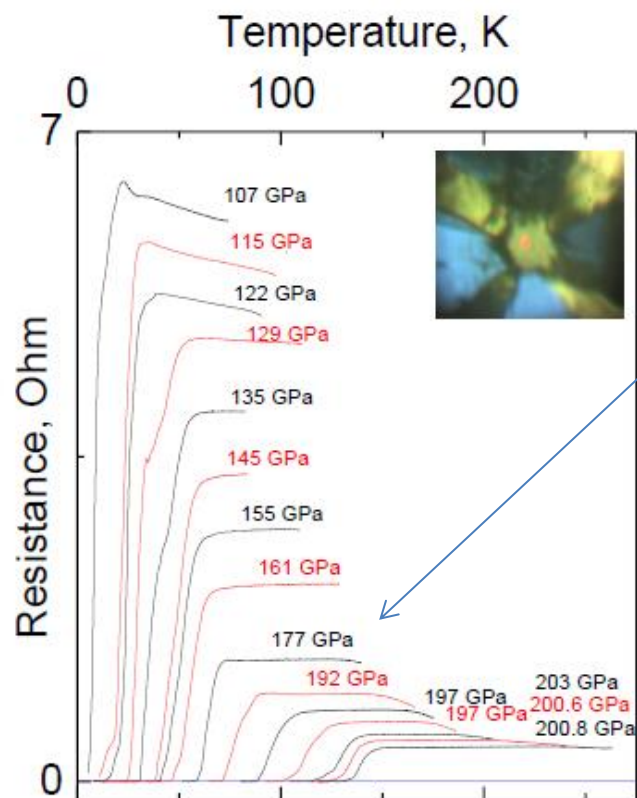


Sharp drop in resistance
with cooling at " T_c ".

Transition temperature
depends on pressure

H₂S under high-pressure

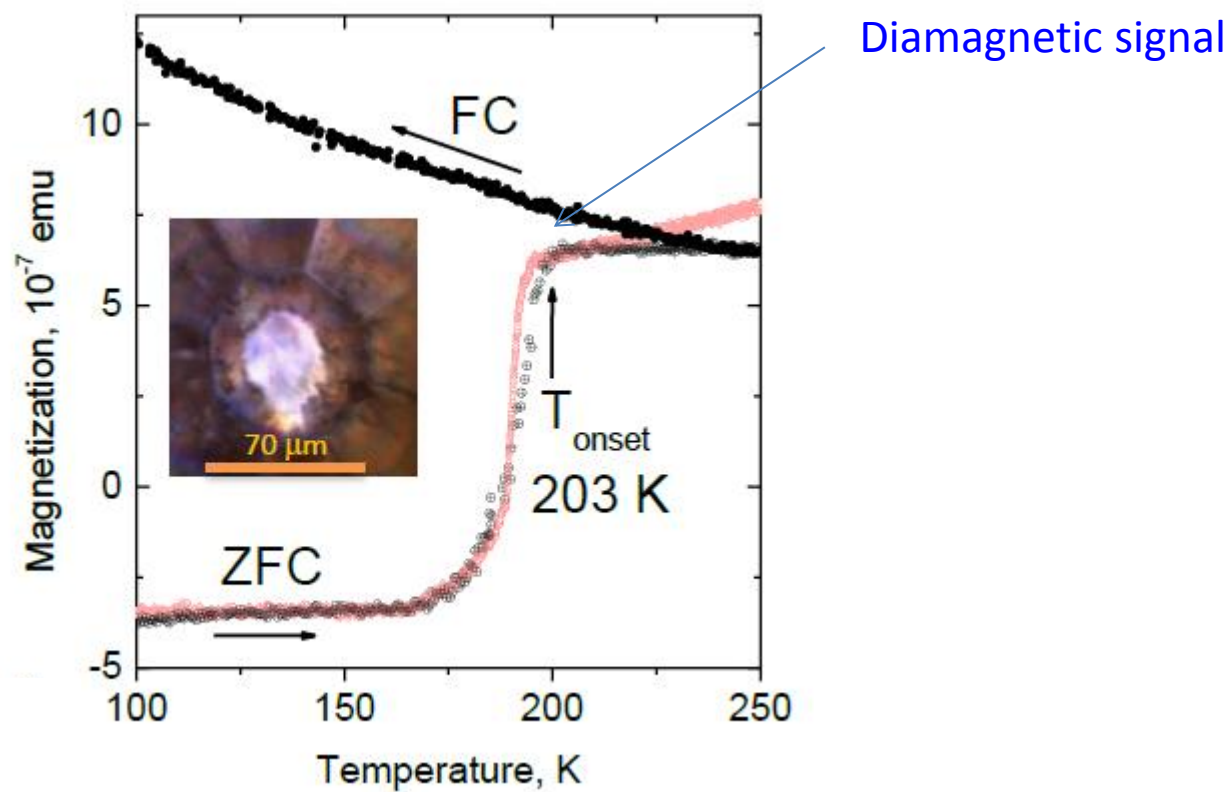
The transition temperature depends on the route followed to reach the Pressure & Temperature conditions



Temporary steps appear in some curves

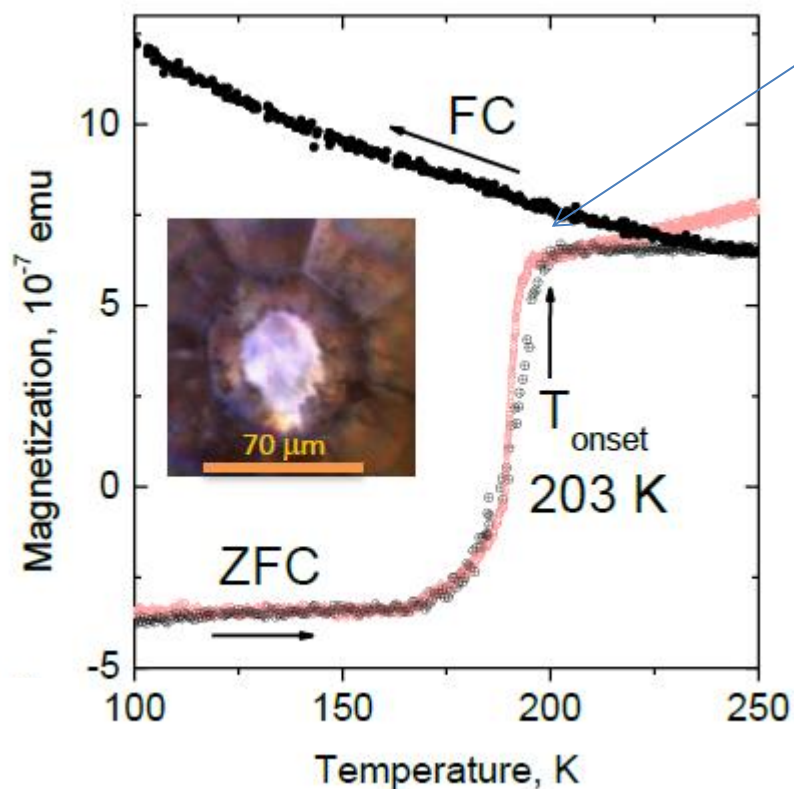
Broad transitions

H₂S under high-pressure



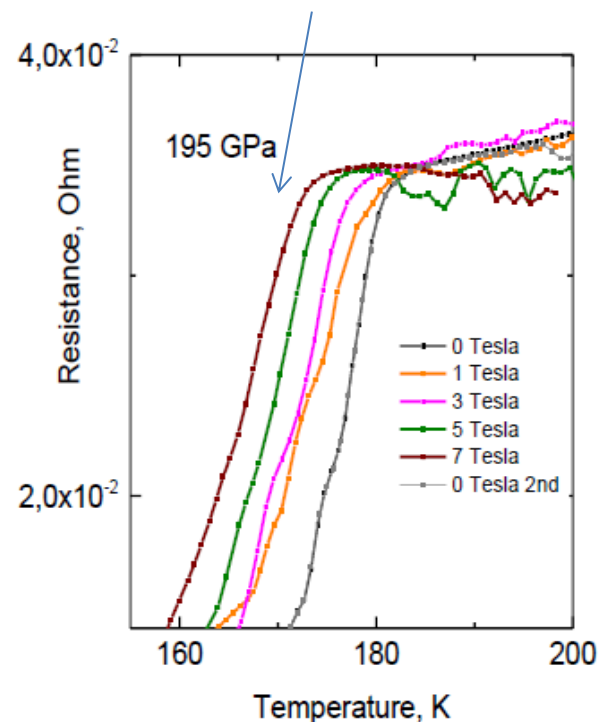
Drozdov et al, arXiv:1506.08190

H₂S under high-pressure



Diamagnetic signal

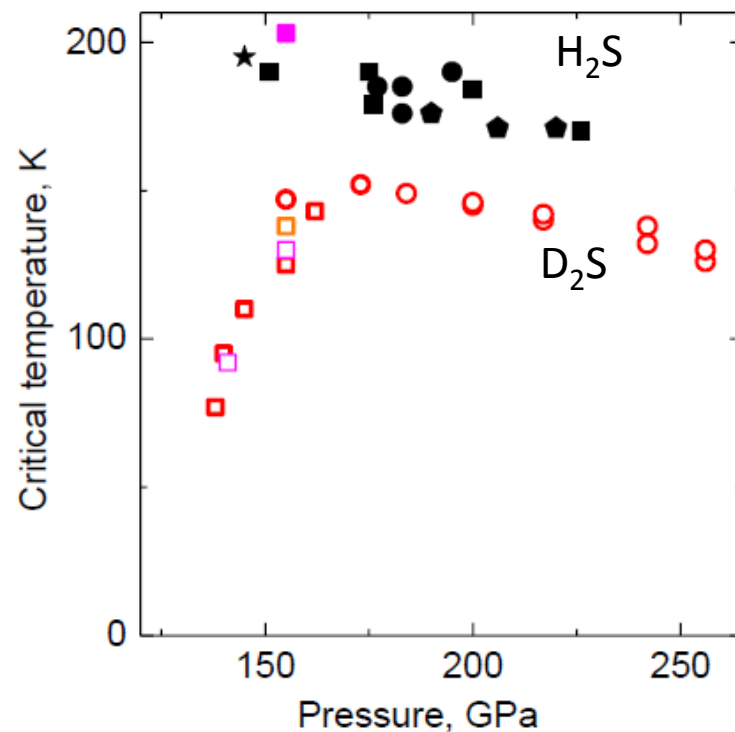
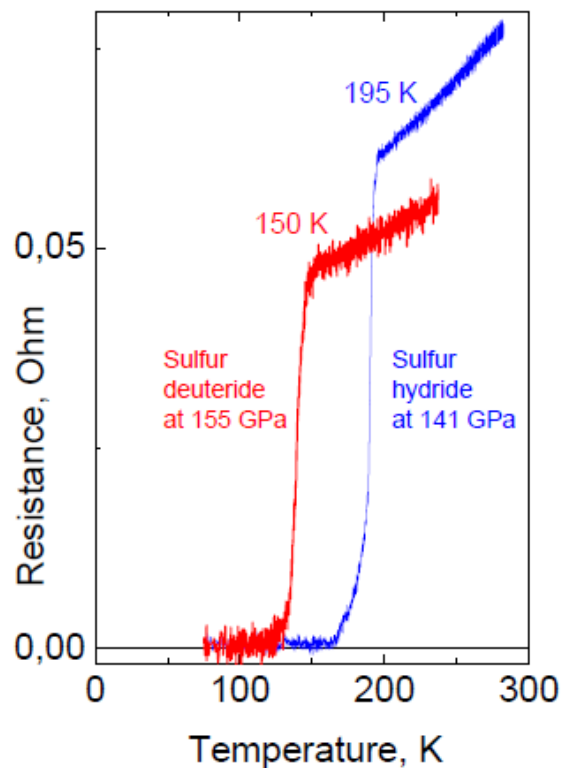
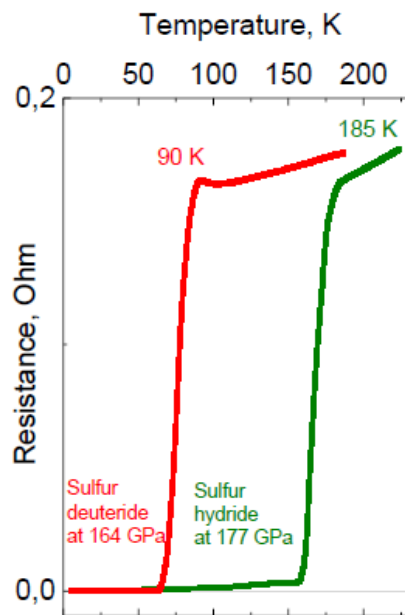
Transition temperature reduced with magnetic field



H₂S under high-pressure

Isotope effect

Annealed samples



H₂S under high-pressure

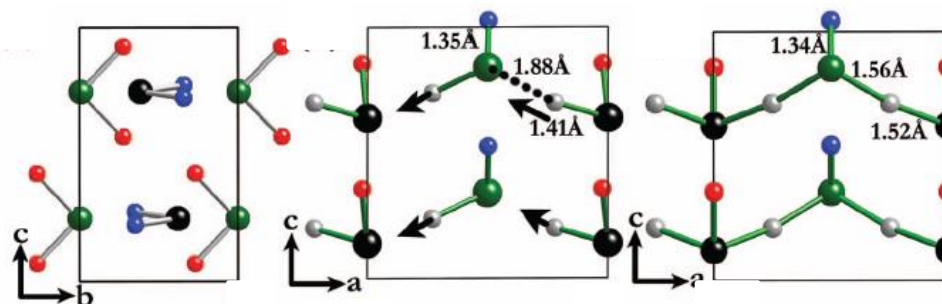
P2/c (P>8,7 GPa)

Pc (8,7-29 GPa)

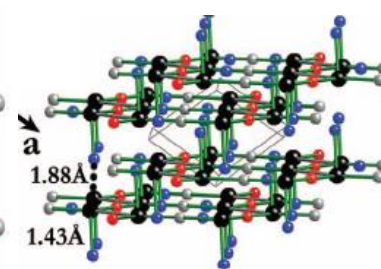
Pm2c1 (29-65 GPa)

P1 (80-158 GPa)

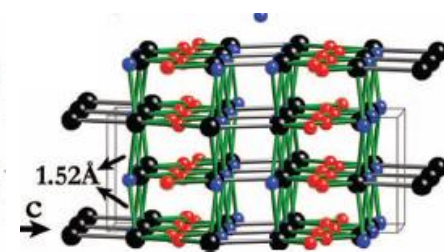
Cmca (P>158 GPa)



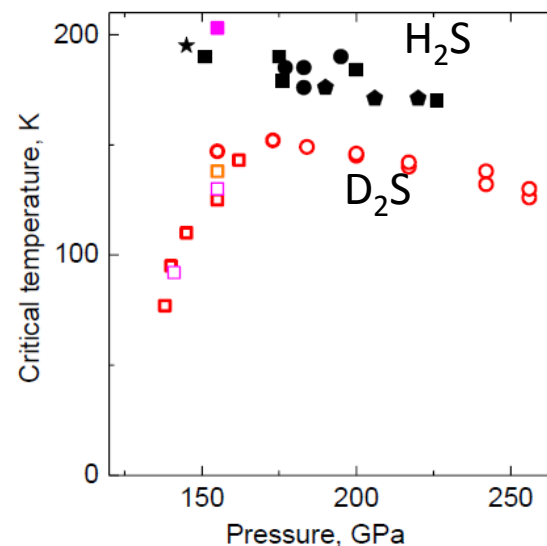
Li et al, J. Chem. Phys. 140, 174712 (2014)



Metallic P> 130 GPa
T_c~33-60 K



Metallic
T_c~80 K @158 GPa



Drozdov, Erements, Troyan arXiv:1412.0460

Drozdov et al, arXiv:1506.08190

H₂S under high-pressure

Stability of H₂S under pressure revisited

P2/c (P>8,7 GPa)

Pc (8,7-29 GPa)

Pm2c1 (29-65 GPa)

P1 (80-158 GPa)

Cmca (P>158 GPa)

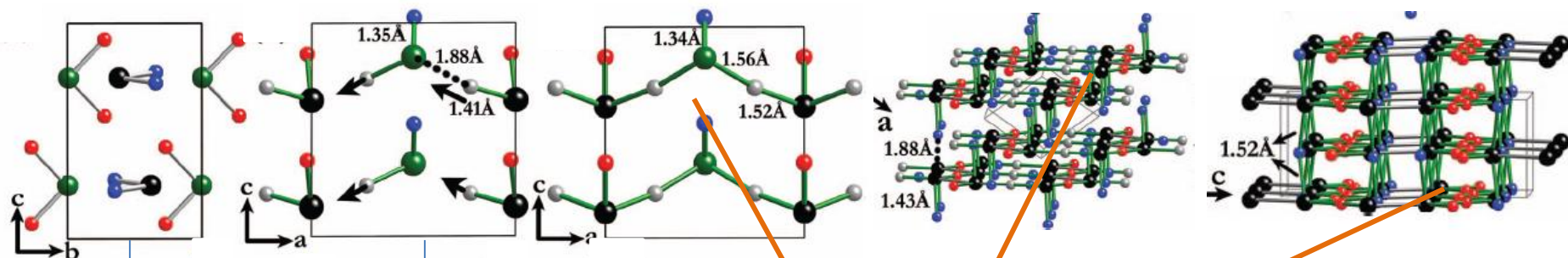


Fig: Li et al, J. Chem. Phys. 140, 174712 (2014)

Metallic P> 130 GPa
Tc~33-60 K

Metallic
Tc~80 K @158 GPa

P2/c (20-30 GPa)

Pc (30-50 GPa)

Not stable

Decomposition
@ 50 GPa

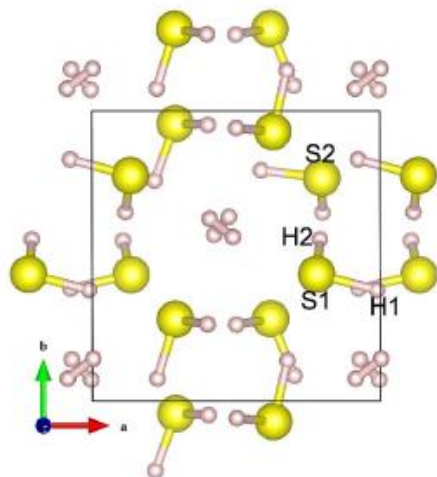


Duan et al, PRB 91, 180502 (2015), Bernstein et al, PRB 91, 060511 (2015), Errea et al, PRL 114, 157004 (2015)

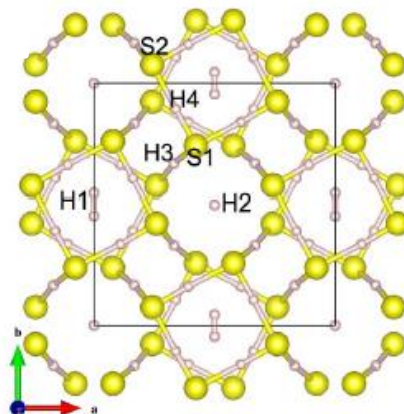
H₃S under high-pressure

(H₂S)₂H₂ under pressure $\longrightarrow$ H₃S

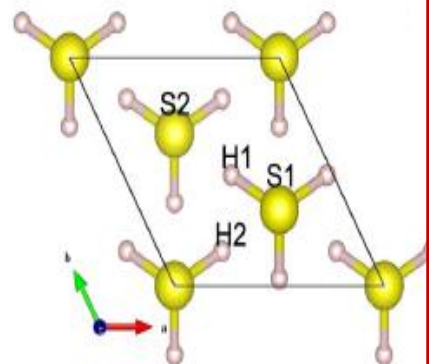
P1 (P < 37 GPa)



Cccm (37-111 GPa)

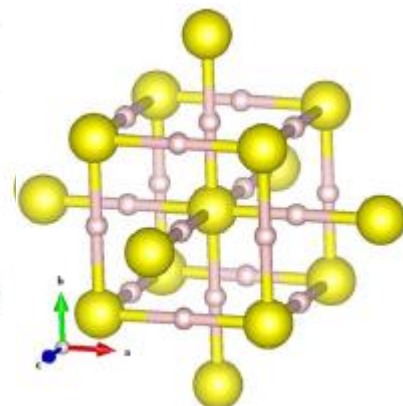


R3m (111-180 GPa)



Metallic
T_c ~ 160 K

I3-3m (P > 180 GPa)



Metallic
T_c ~ 200 K

H₃S under high-pressure: Calculations revisited

Different approximations/ab-initio codes

❑ T_c ~ 150-250 K @ 200 Gpa

$\lambda \sim 1.6-2.64$

$\omega_{ln} \sim 1160-1500$ K

$\mu^* \sim 0.1-0.16$

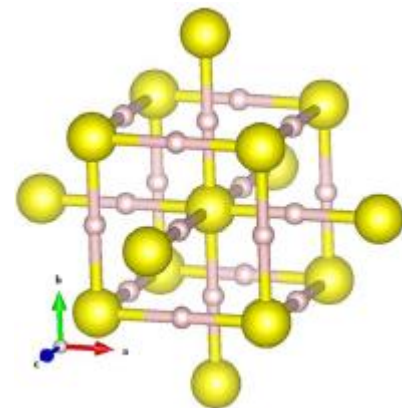
$$T_c = \frac{\omega_{ln}}{1.2} \exp \left(\frac{-1.04(1 + \lambda)}{\lambda - \mu^*(1 + 0.62\lambda)} \right)$$

❑ Large e-ph coupling: covalent bonds

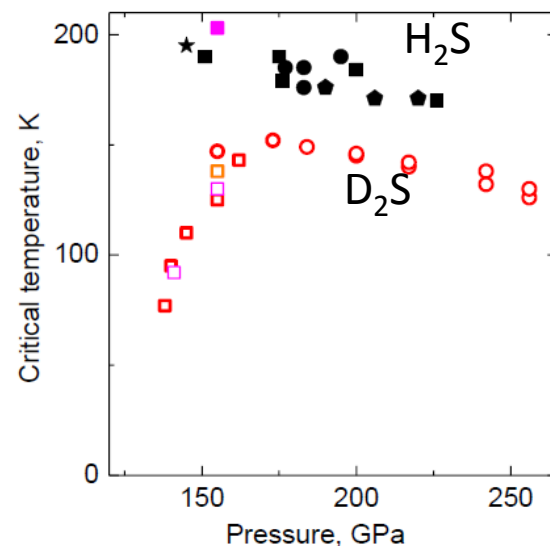
❑ Strongly anharmonic

(λ : 2.64 $\rightarrow$ 1.84, T_c: 250K $\rightarrow$ 194 K)

Isotope effect T_c ~ M^{-α} α: 0.5 $\rightarrow$ 0.35



Duan et al, Sci. Rep. 4, 6968 (2014)

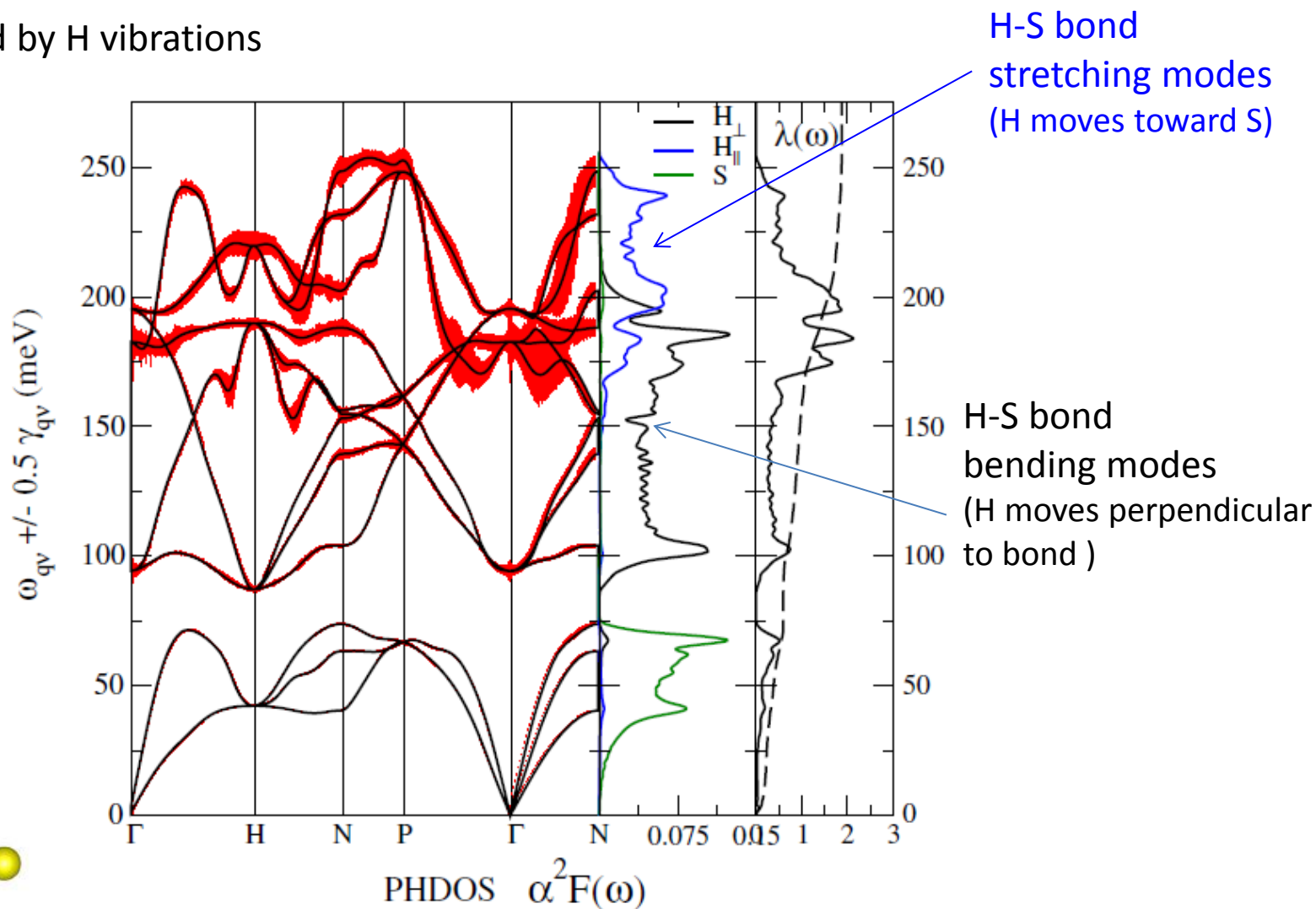


Drozdov et al, arXiv:1506.08190

Errea et al PRL 114, 157004(2015), Bernstein et al, PRB 91, 060511(2015),
Flores-Livas et al, arXiv:1501.06336, Akashi et al, arXiv: 1502.00936
Zhang et al, arXiv: 1502.02607, Heil-Boeri, arXiv: 1507.02522,

H₃S under high-pressure

Role played by H vibrations



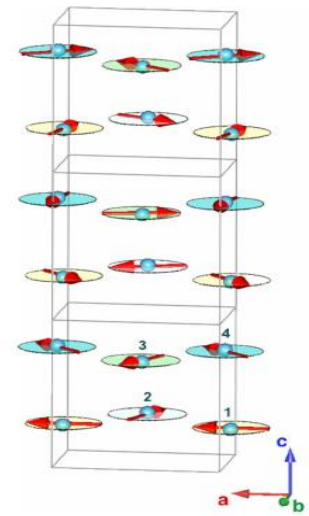
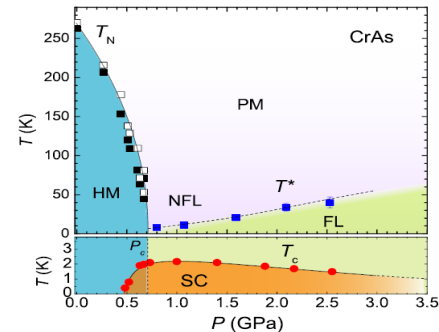
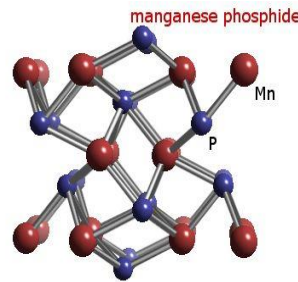
Errea et al, PRL 114, 157004 (2015)

Prospects for new high-Tc superconductors

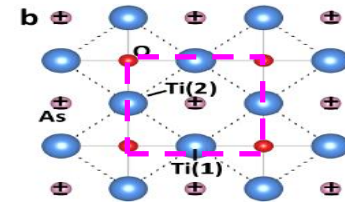
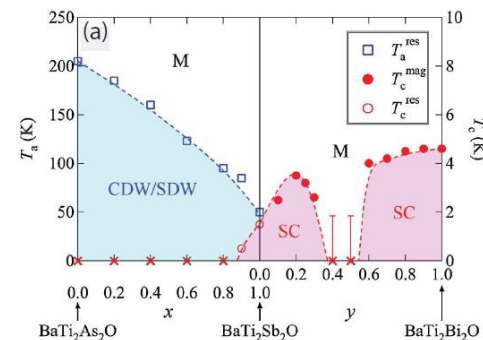
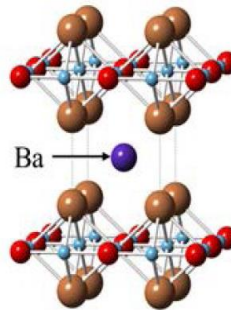
Material	Tc	Ref.
H ₂ Br	10 K @ 240 GPa	Duan et al, arXiv: 1504.01196
PtH	16 K @ 100 GPa	Szcesniak-Zemla, arXiv 1504.01349
H ₄ I	13.7 K @ 150 GPa	Shamp & Zurek, J.Phys. Chem 6, 4067 (2015)
HSe	39 K @ 250 GPa	Zhang et al, arXiv:1502.02607
PoH ₄	41.1 K @ 200 GPa	Liu et al, 1503.08587
GeH ₄ (H ₂) ₂	80 K @ 250 GPa	J. Phys. Chem. C 116, 5225 (2012).
GaH ₃	80 K @ 160 GPa	Gao et al, PRB 84, 06411 (2011)
SiH ₄ (H ₂) ₂	100 K @ 250 GPa	Li et al, PNAS 107, 15708 (2010)
H ₄ Te	104 K @ 170 GPa	Zhong et al, 1503.00396
H ₃ Se	116 K @ 200 GPa	Zhang et al, arXiv:1502.02607
GeH ₃	140 K @ 180 GPa	Abe & Aschroft. PRB 88, 174110 (2013).
H ₃ O _{0.5} S _{0.5}	164 K	Heil-Boeri, Phys. Rev. B 92, 060508 (2015)
CaH ₆	235 K @150 GPa	Wang et al, PNAS 109, 6463 (2012)

New perspectives in superconductors

□ **CrAs and MnP**, two new superconducting with an helimagnetic parent phase and a possible non trivial relation with magnetism

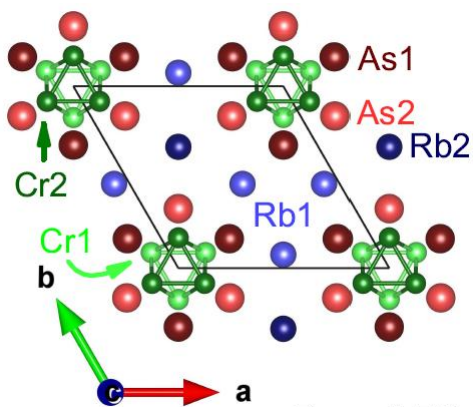


□ **Titanium oxypnictides**, superconductivity could emerge from a nematic state

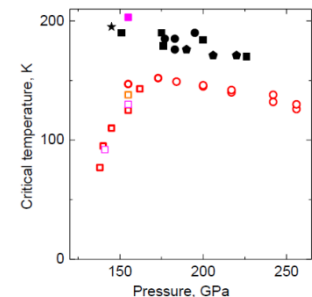
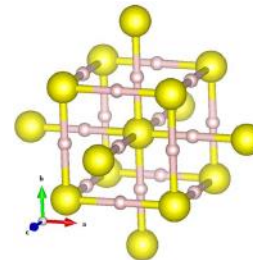


□ **Quasi-1d A2Cr3As3**

Triplet SC or Singlet with spin blocking?



□ **H₂S under pressure** Possible record of T_c Electron-phonon superconductor

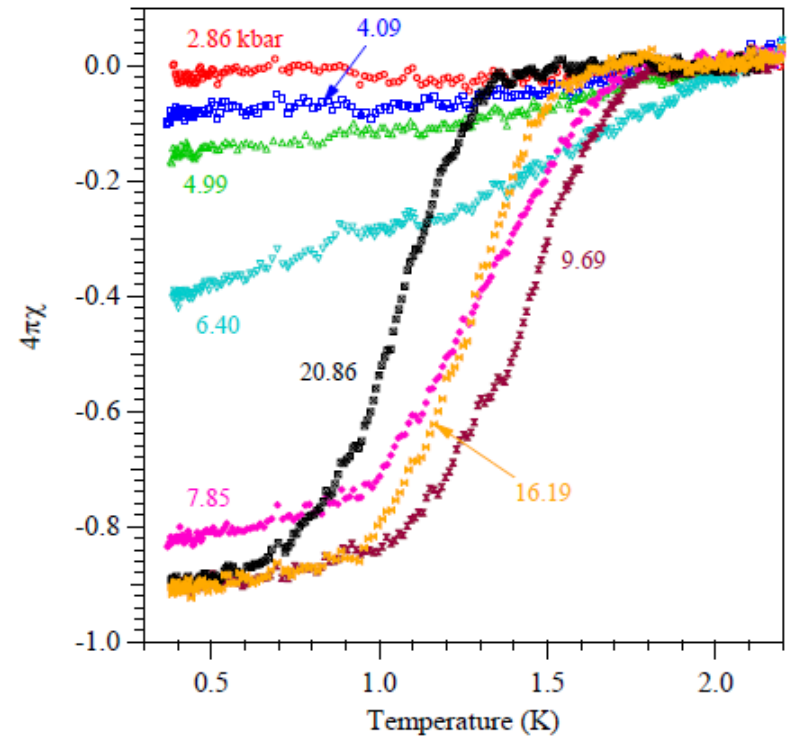
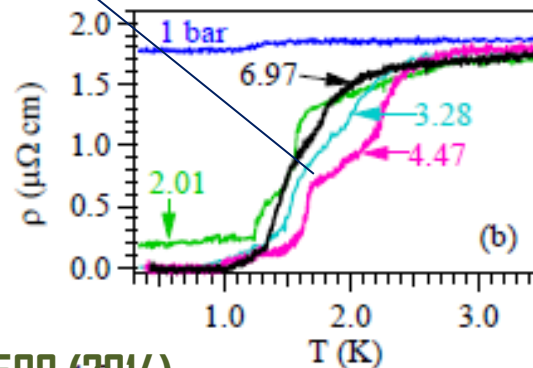
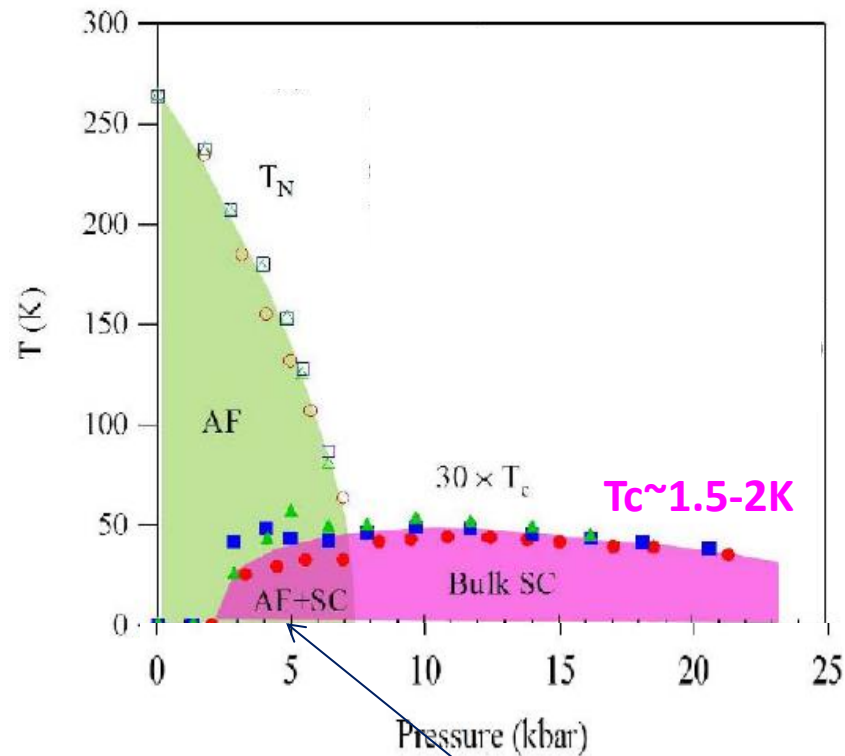


New perspectives in superconductors

- ❑ Many other recently discovered superconductors: $\text{Zr}_5\text{Sb}_{3-x}\text{Ru}_x$, $\text{Ta}_4\text{Pd}_3\text{Te}_{16}$, doped ferromagnetic semiconductor SmN , thermoelectric $\text{CsPb}_x\text{Bi}_{4-x}\text{Te}_6$, BiS_2 layered materials,
 - ❑ Dichalcogenides: metallic NbSe_2 , ... (CDW revisited, single layer),
semiconducting MoS_2 ... (superconductivity in gated single layer or high pressure)
 WTe_2 (SC under pressure suppressing magnetoresistance)
 - ❑ Strong activity in iron superconductors, cuprates, fullerenes, heavy fermions
- M. Capone, N. Hussey, Yakovenko talk**
- ❑ Superconductivity in heterostructures
 - ❑ Topological superconductivity and search for Majorana Fermions

J. Alicea, E.A Kim talk

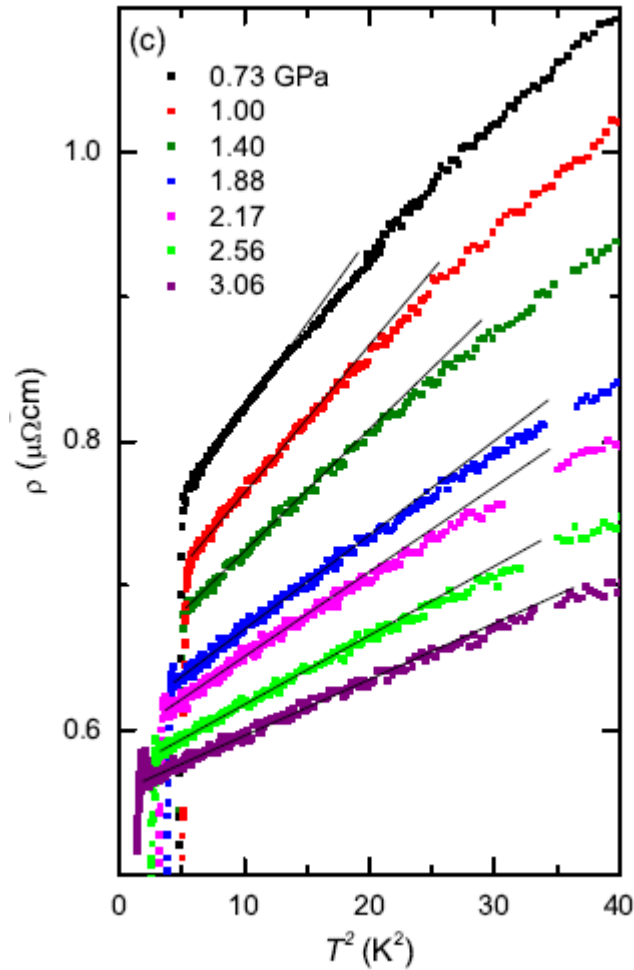
Superconductivity in CrAs



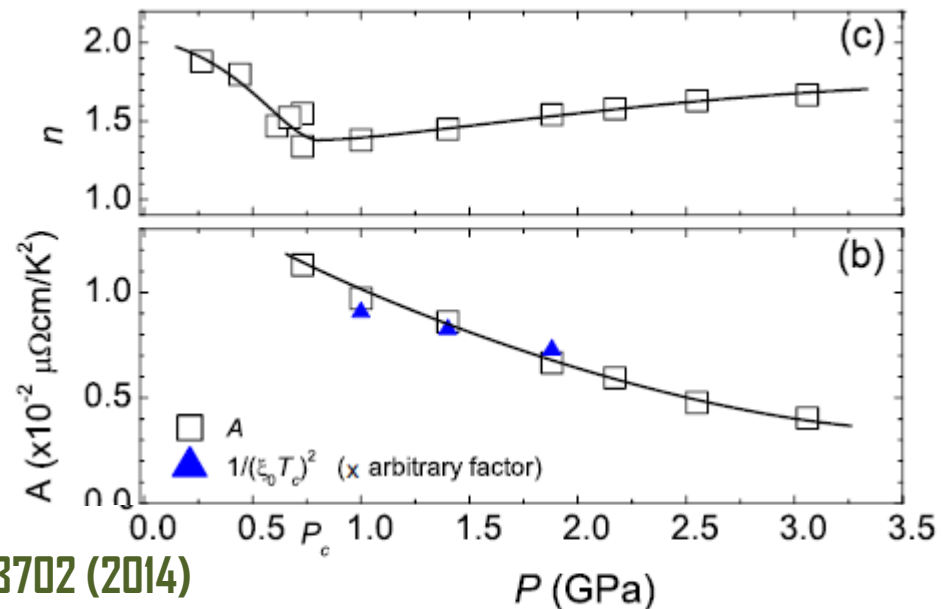
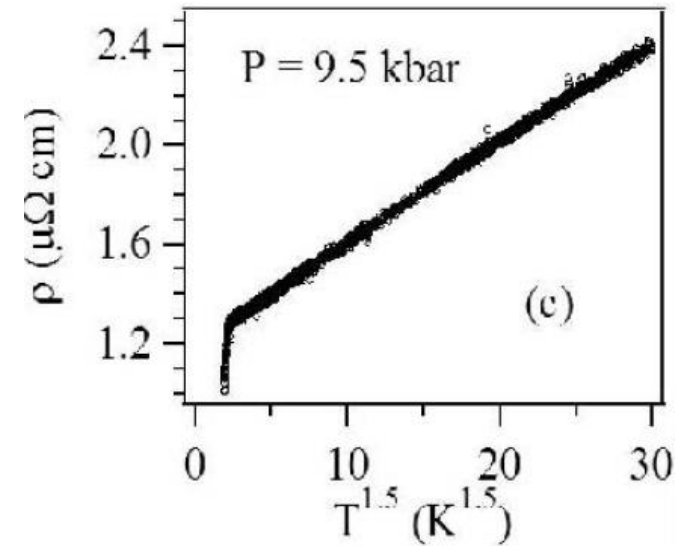
Coexistence of AFM and SC

Wu et al, Nat. Comm. 5, 5508 (2014)

Superconductivity in CrAs

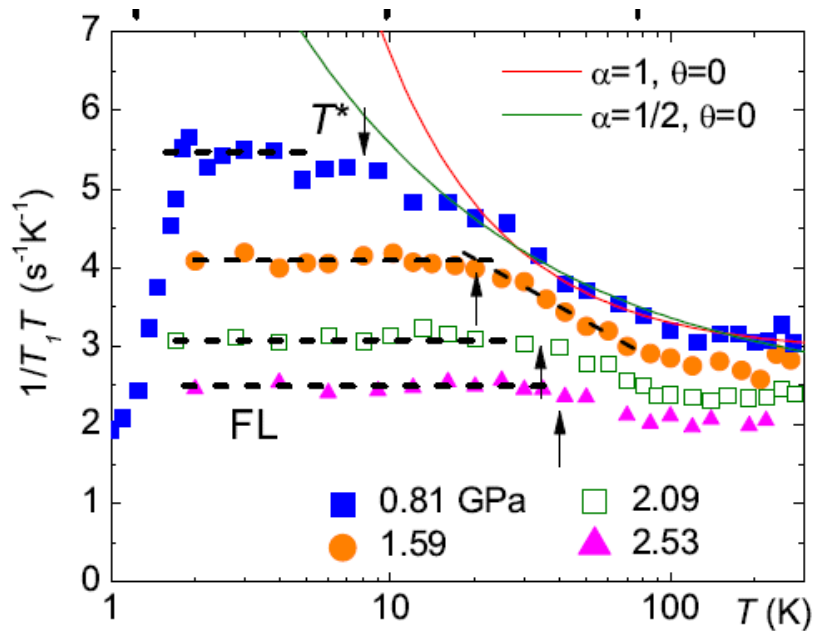


Wu et al,
 Nat. Comm. 5,
 5508 (2014)

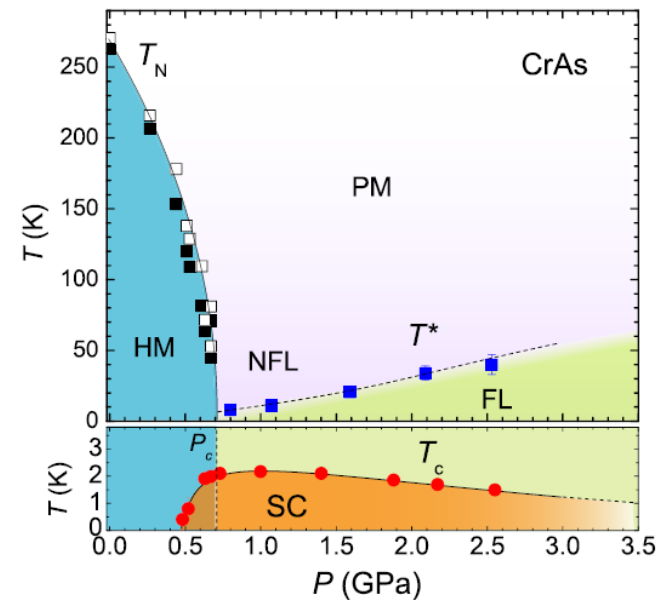


Kotegawa et al, J. Phys. Soc. Jpn. 83, 093702 (2014)

Superconductivity in CrAs

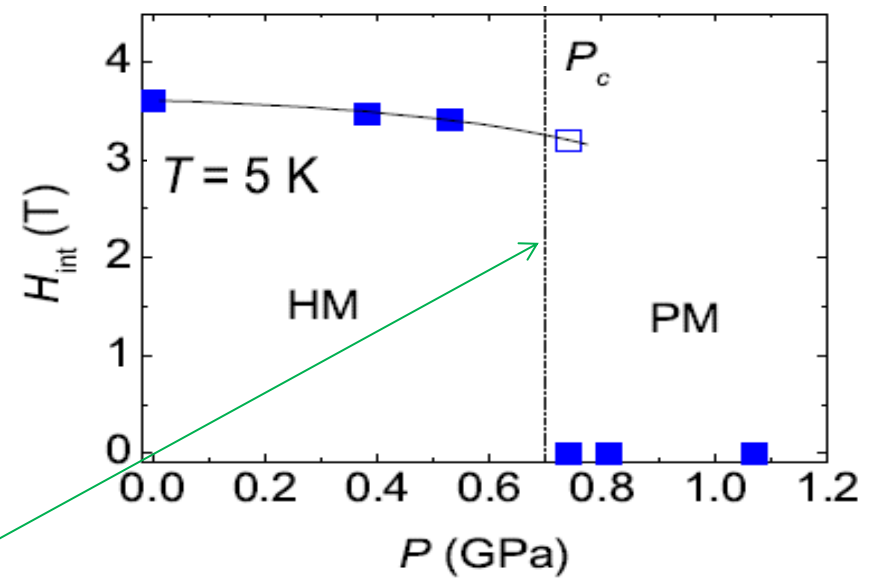
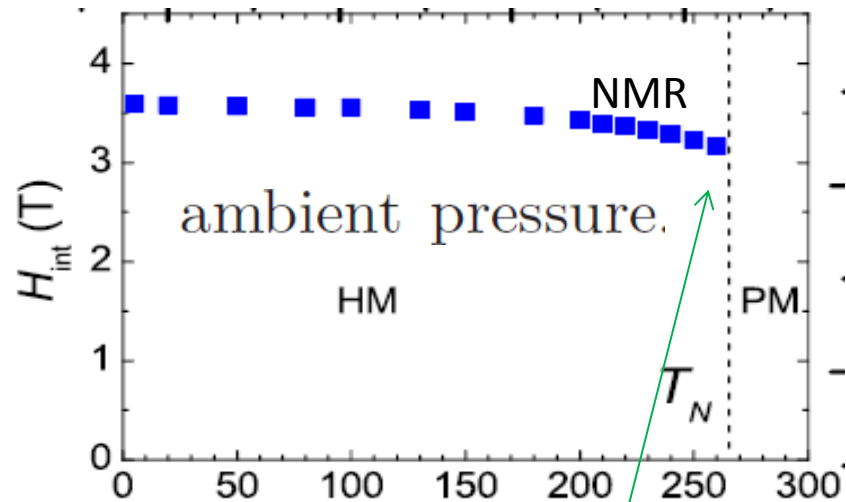


$$\frac{1}{T_1T} = \frac{A}{(T + \theta)^\alpha} + B$$

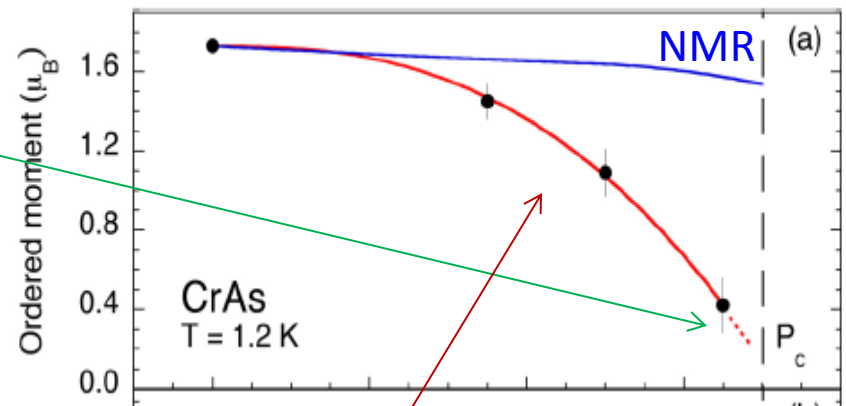


Kotegawa et al, Phys. Rev. Lett. 114, 117002 (2015)

Suppression of magnetism in CrAs



1st order phase transition

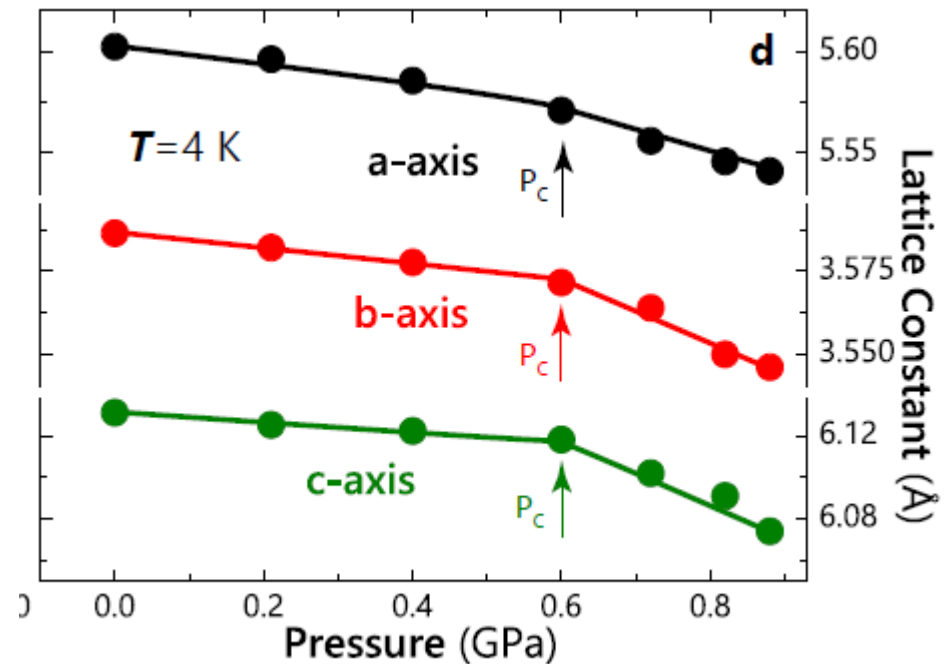
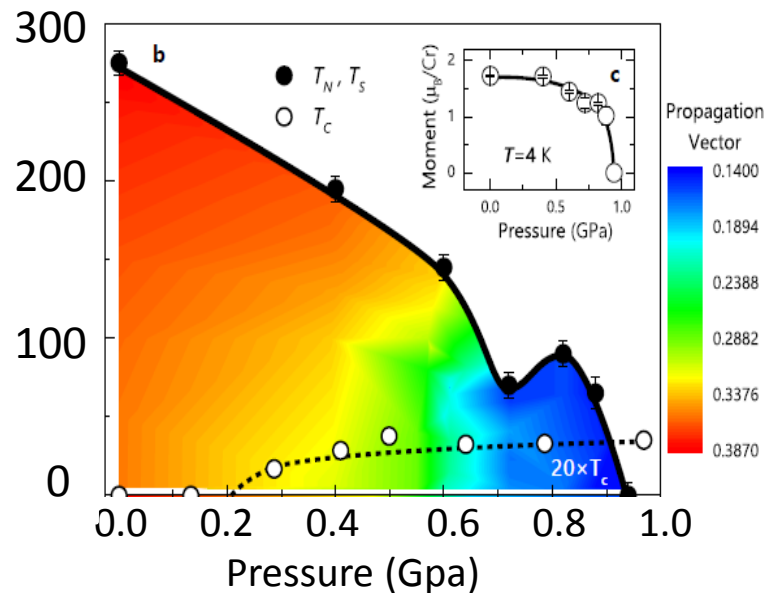
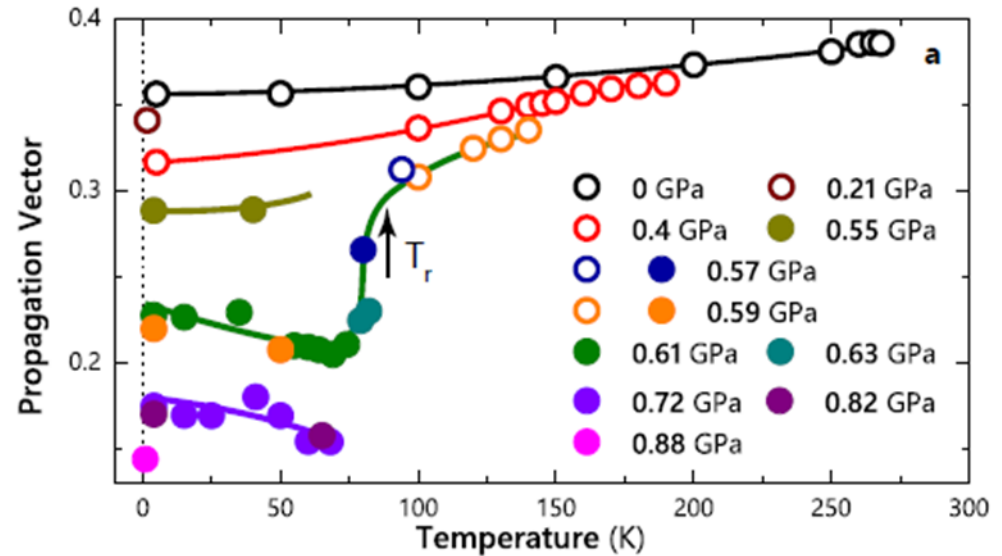
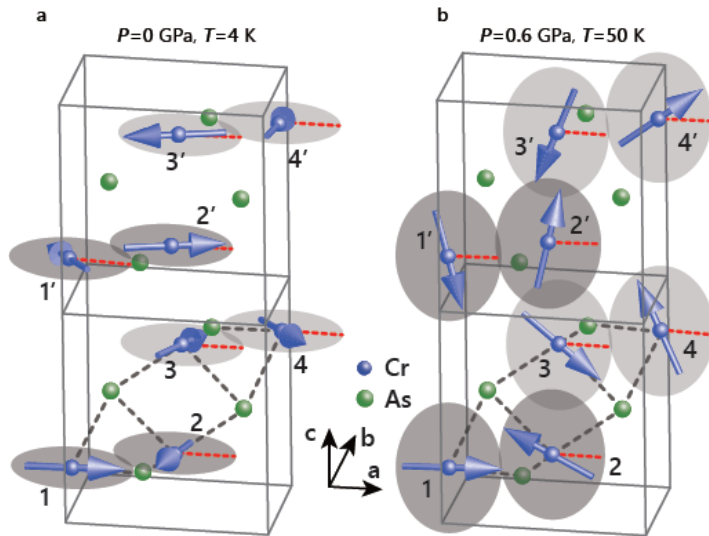


neutron diffraction

Kotegawa et al, Phys. Rev. Lett. 114, 117002 (2015)

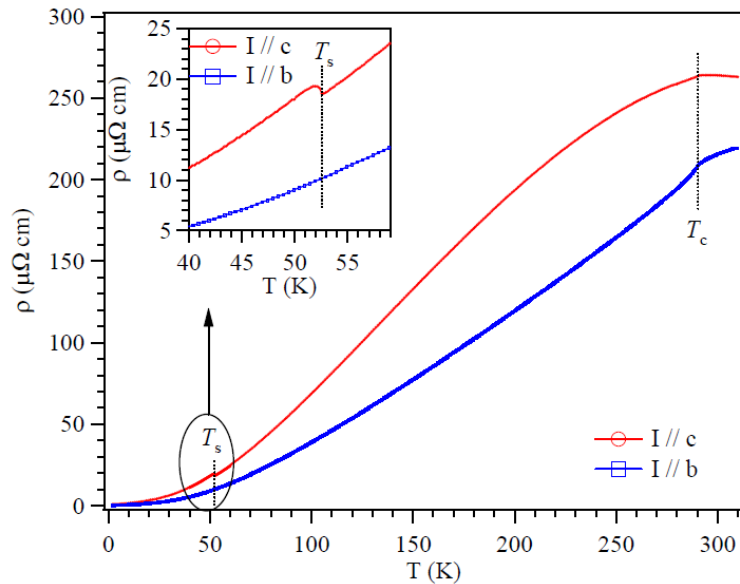
Keller et al, PRB 91, 020409 (2015)

Superconductivity in CrAs

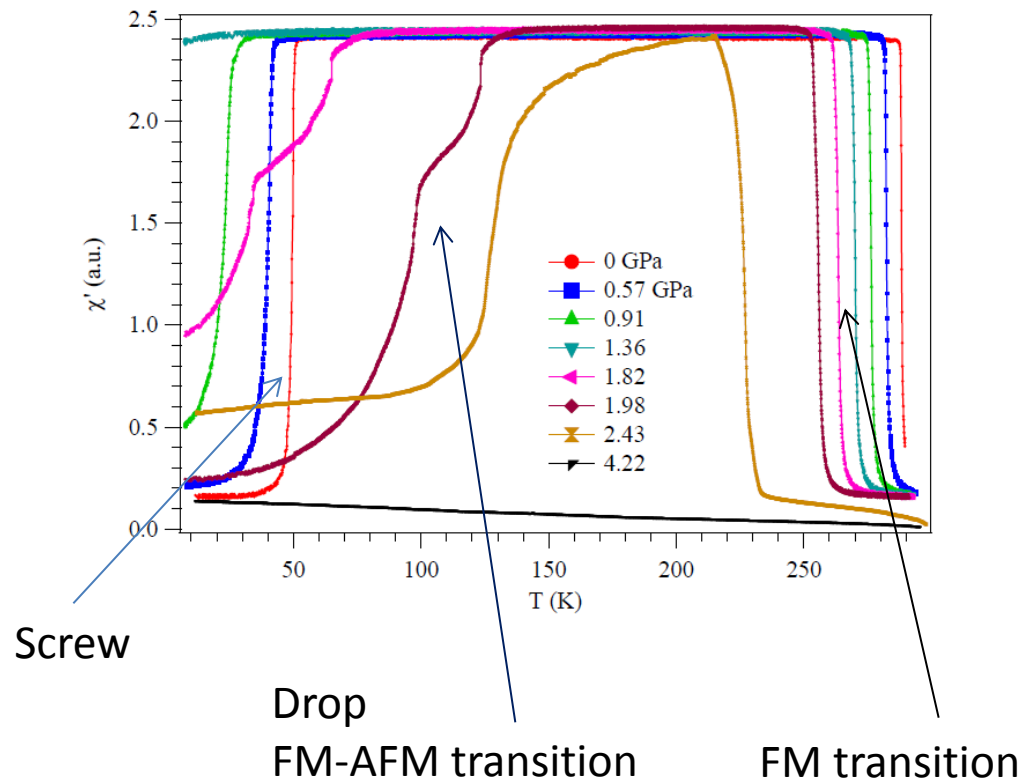


Superconductivity in MnP

Resistivity ambient pressure

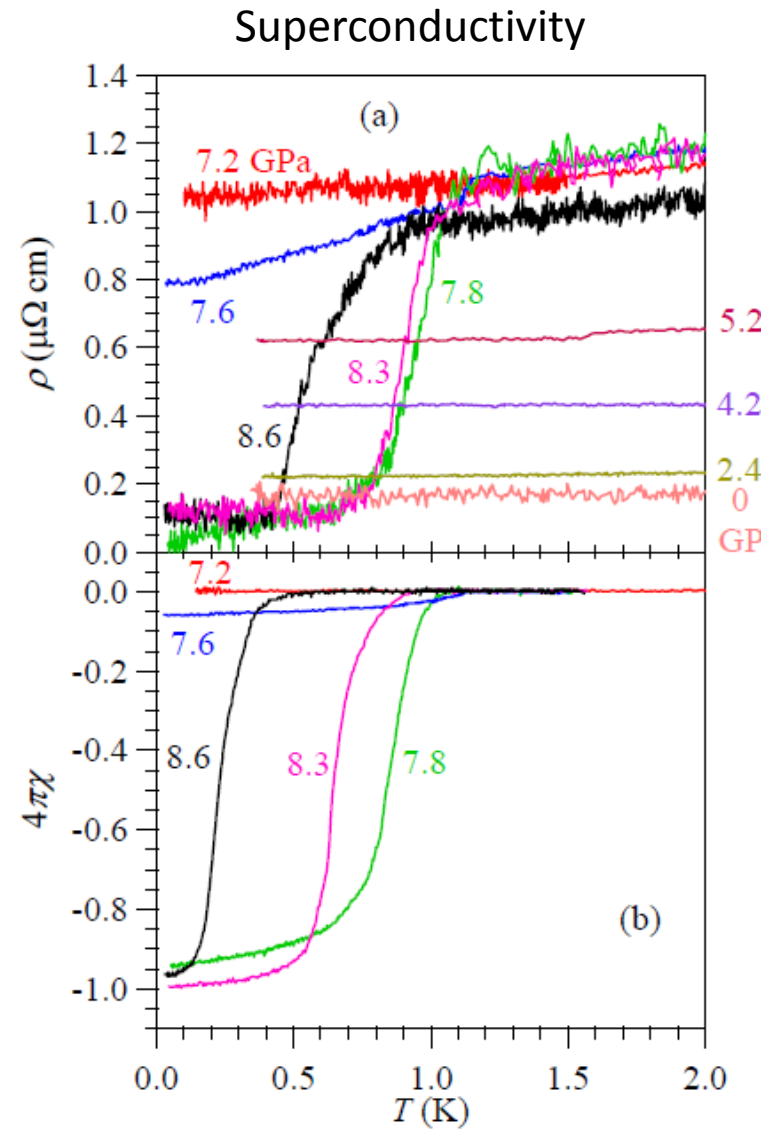
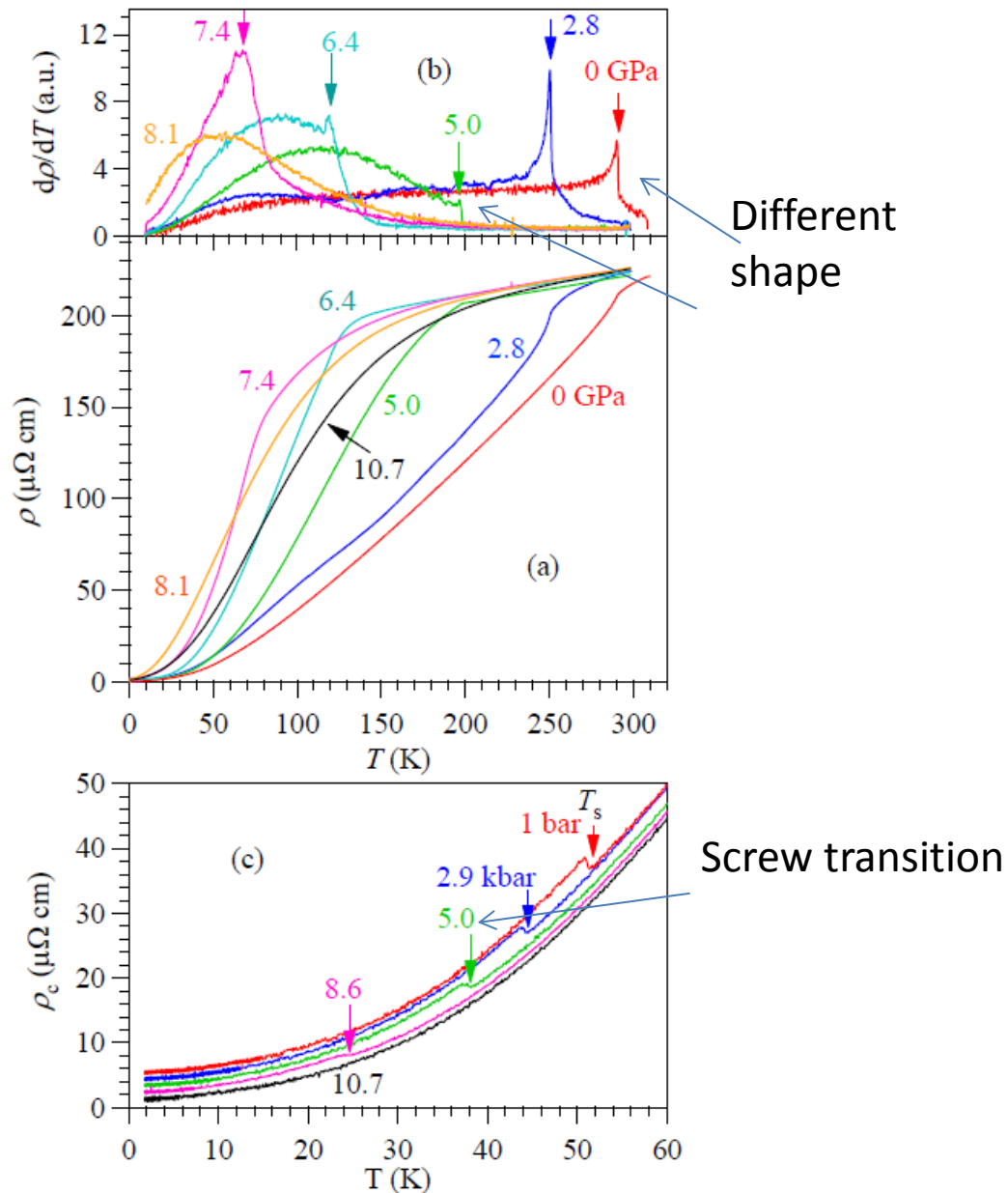


ac magnetic susceptibility :



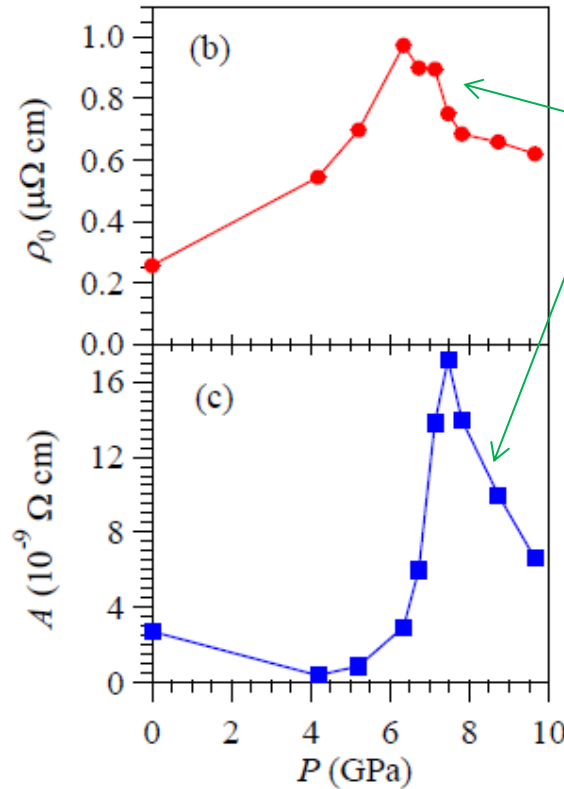
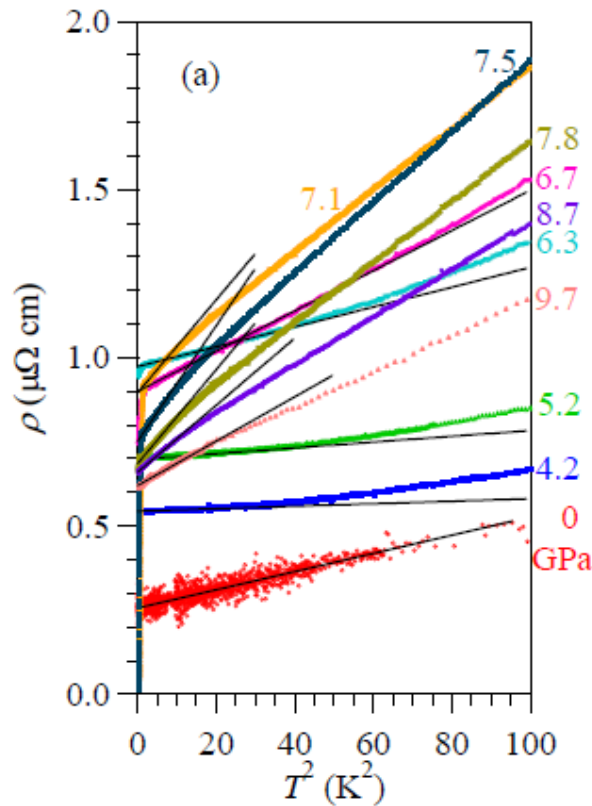
Cheng et al, Phys. Rev. Lett. 114, 117001 (2015)

Superconductivity in MnP



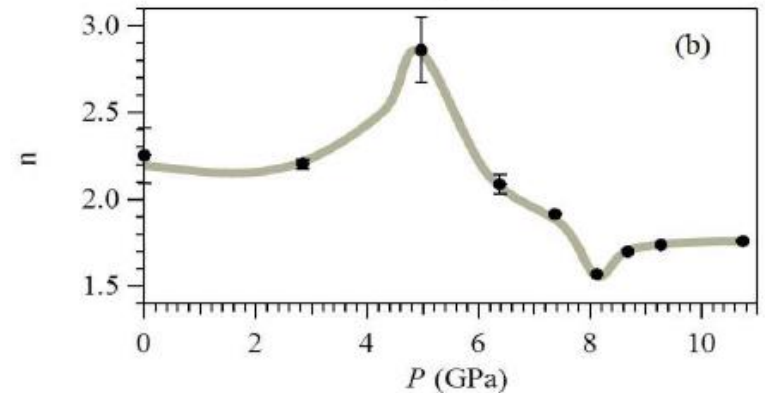
Cheng et al, Phys. Rev. Lett. 114, 117001 (2015)

Superconductivity in MnP



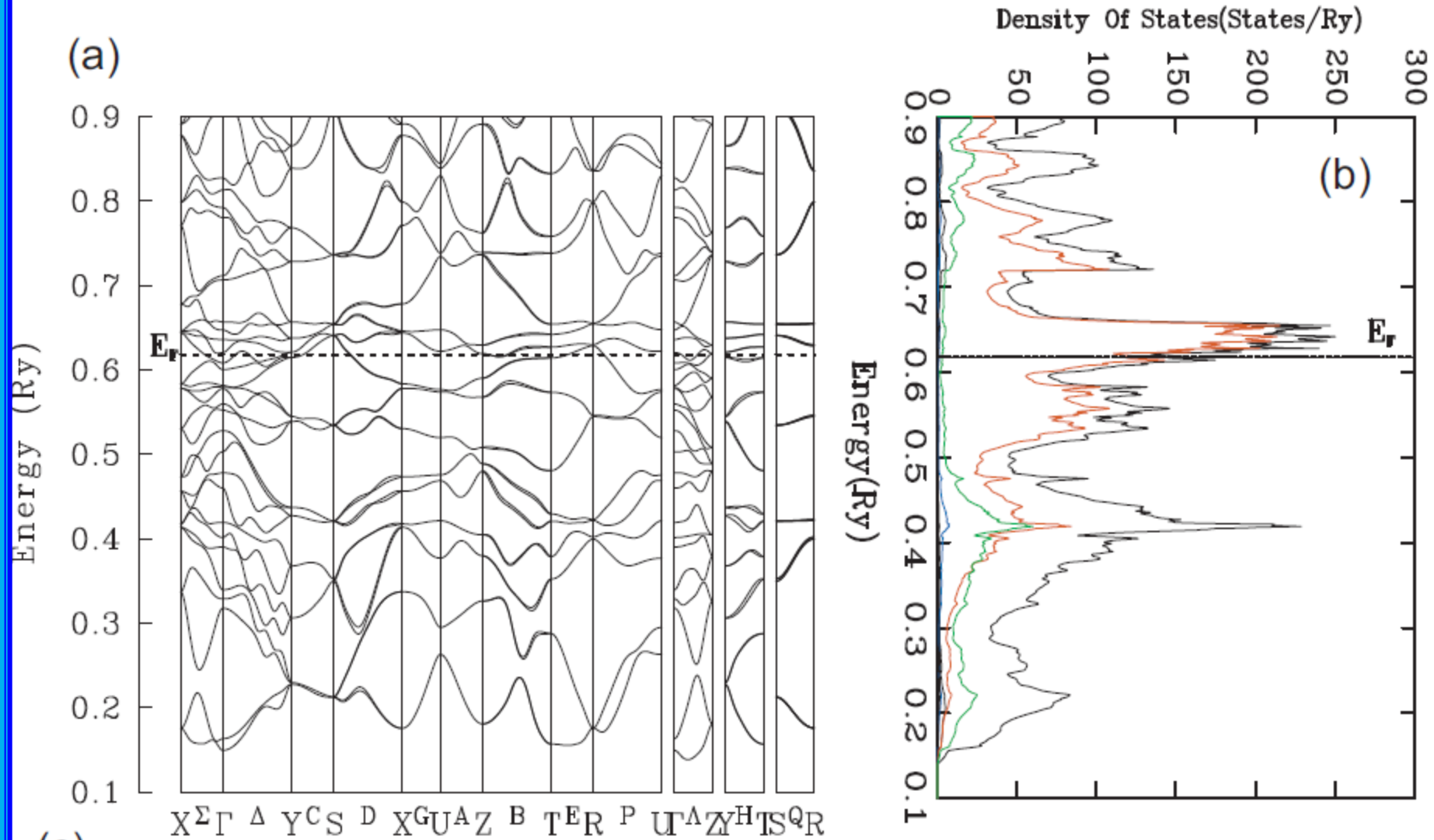
From fittings to
 $\rho = \rho_0 + AT^2$
 at low temperatures

From fittings to
 $P \propto T^n$
 at low temperatures



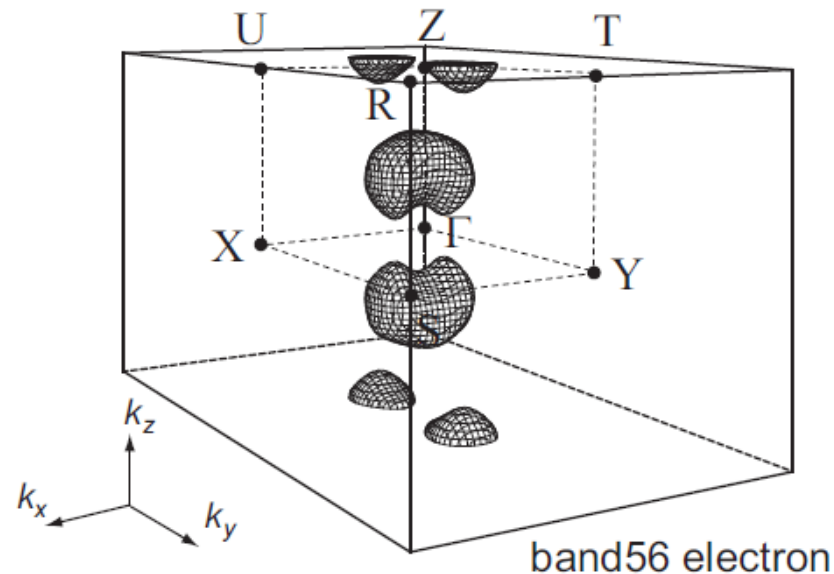
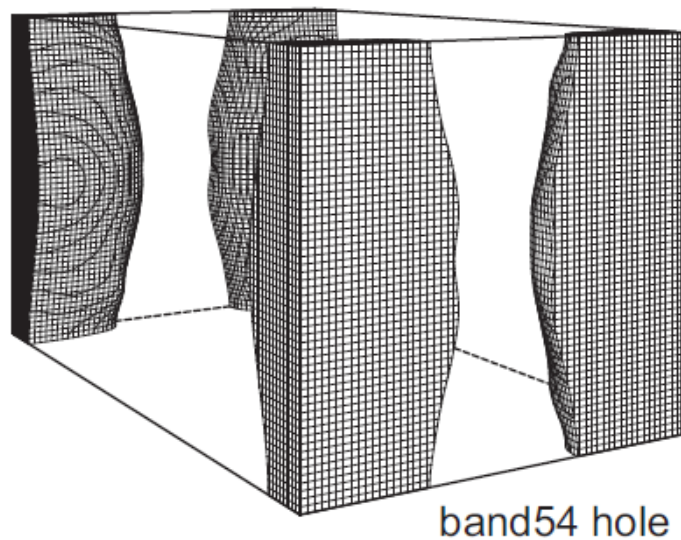
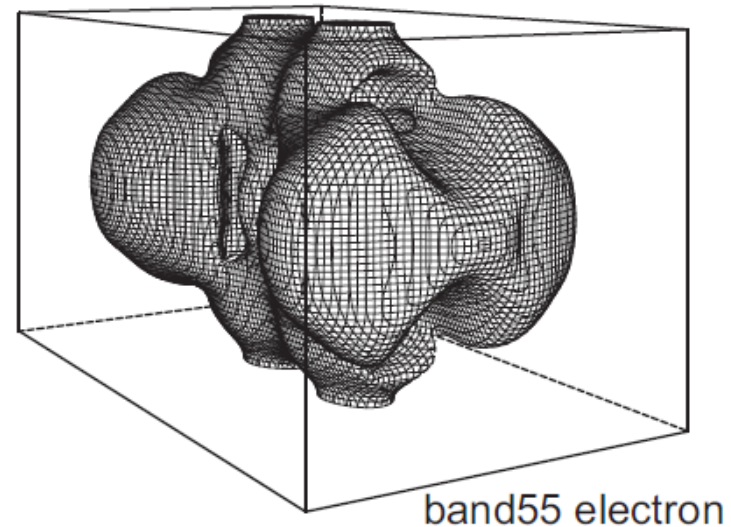
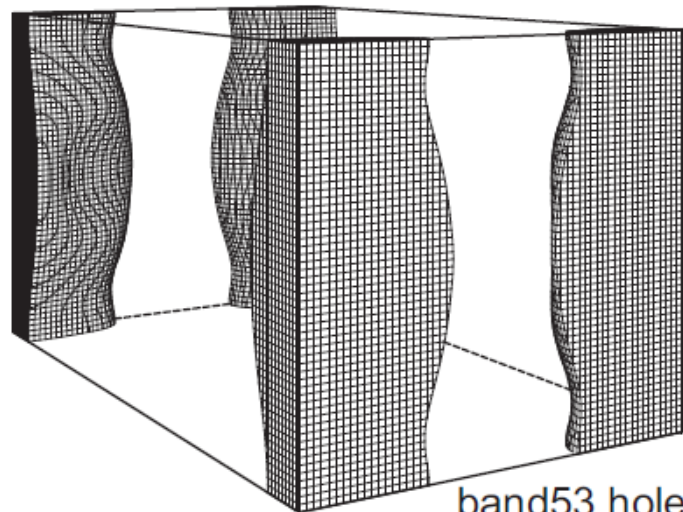
Cheng et al, Phys. Rev. Lett. 114, 117001 (2015)

Bandstructure CrAs



Kotegawa et al, Phys. Rev. Lett. 114, 117002 (2015)

Bandstructure CrAs

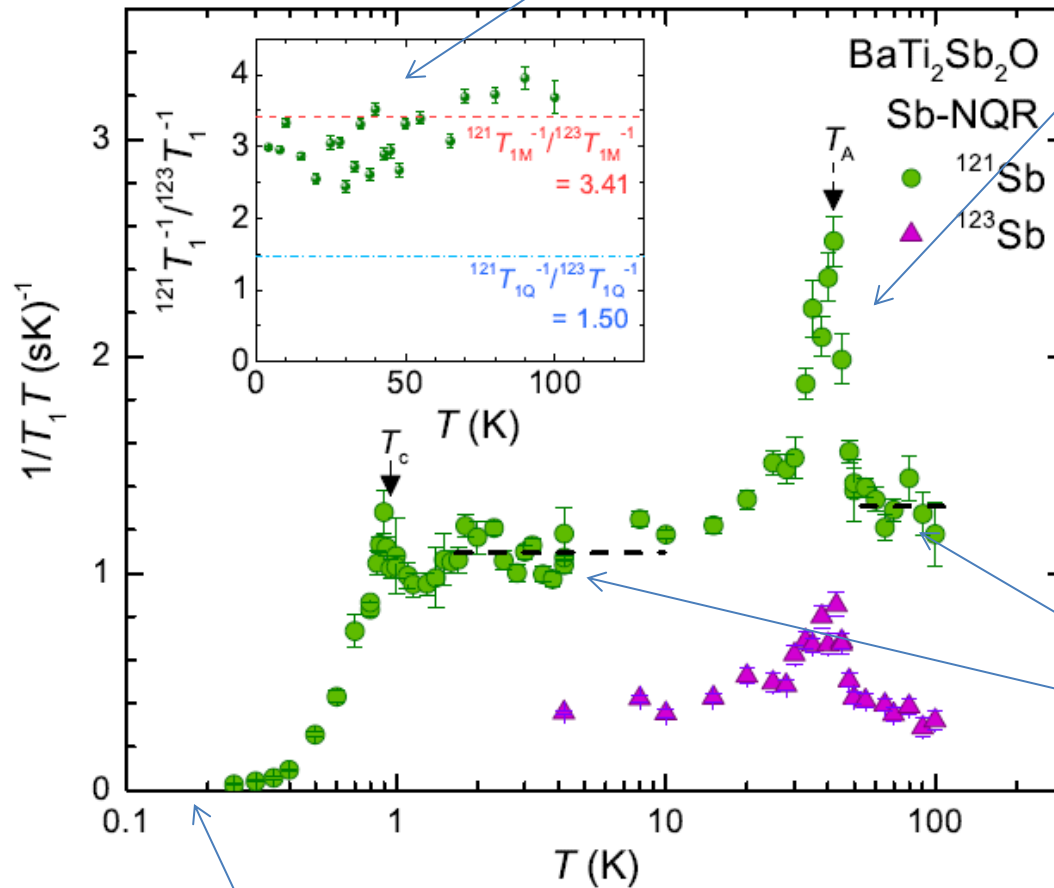


Kotegawa et al, Phys. Rev. Lett. 114, 117002 (2015)

Ti-superconductors

Nature of transition below T_s

Ti
Relaxation dominated by magnetic fluctuations which give ratio ~ 3.41 (EFG fluctuations give ratio 1.5). **Enhancement of magnetic fluctuations toward 40 K**



Kitagawa et al, PRB 87, 060510 (2013)

Suppression of density of states

Relaxation exponentially suppressed below T_c

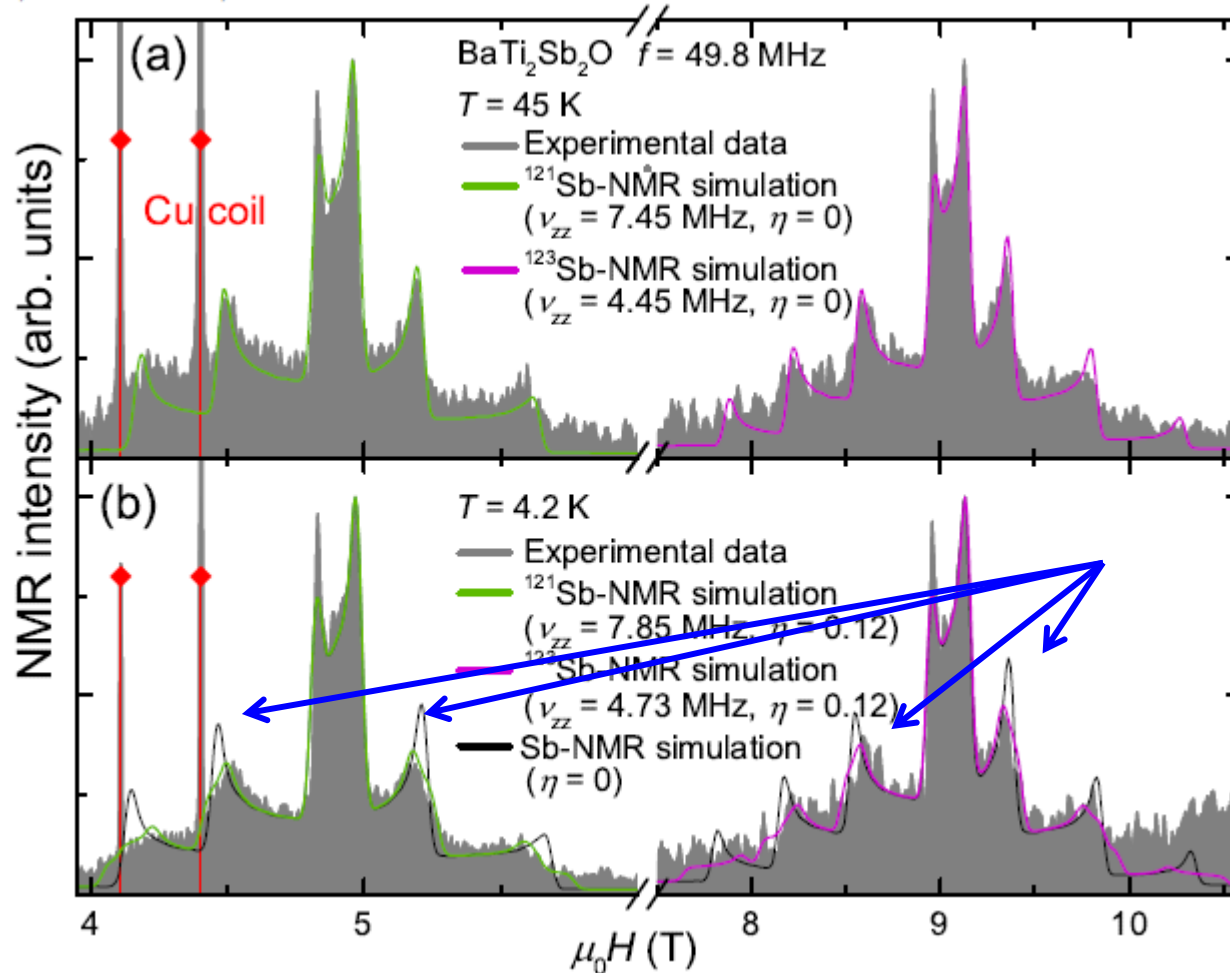
$I = 7/2$, Resonance transition frequencies

Ti-superconductors

Nature of transition below T_s

$$\nu_1 = \nu_{zz} \left(1 + \frac{109}{30} \eta^2 \right), \text{ and } \nu_2 = 2\nu_{zz} \left(1 - \frac{17}{30} \eta^2 \right)$$

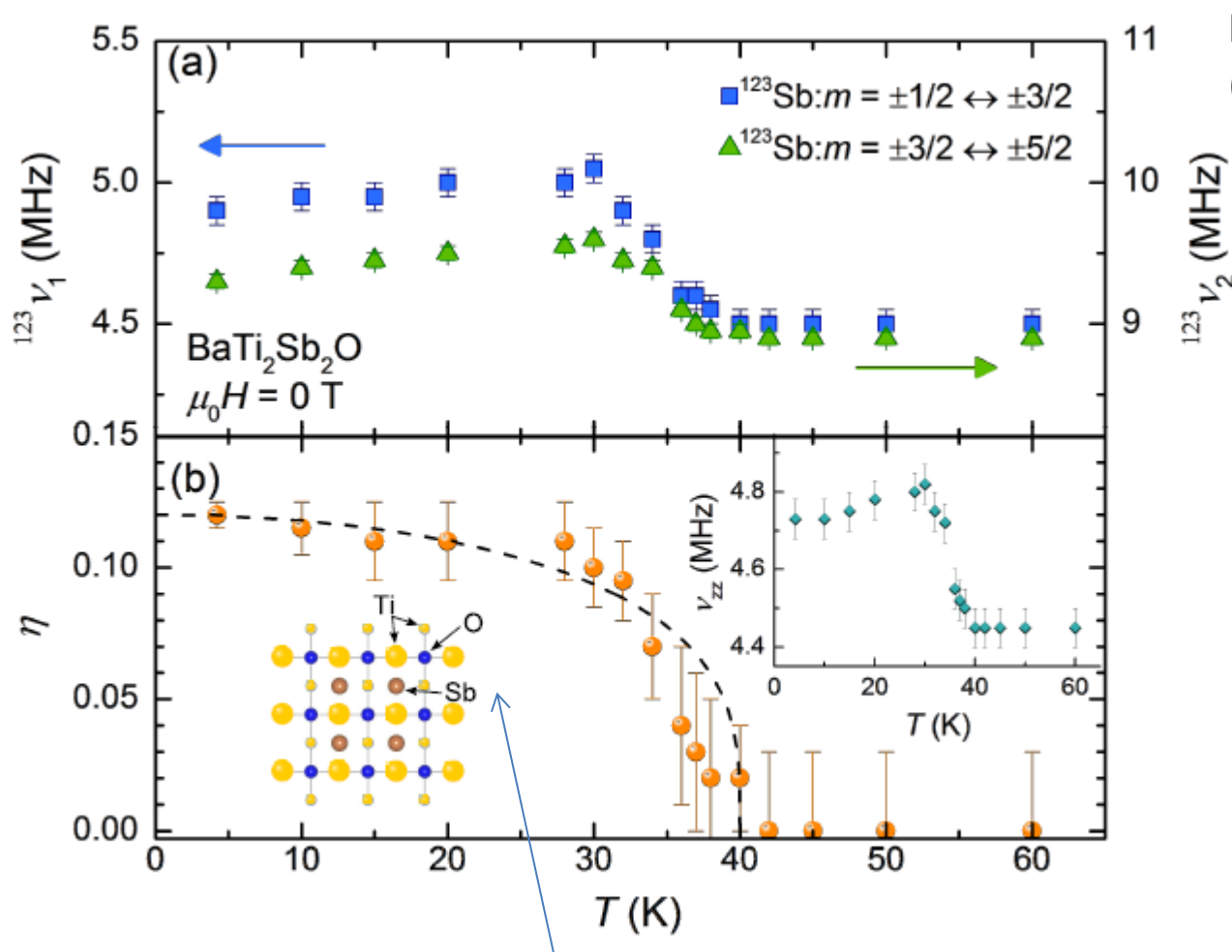
$\pm 1/2 \leftrightarrow \pm 3/2$ $\pm 3/2 \leftrightarrow \pm 5/2$ quadrupole frequency



Kitagawa et al, PRB 87, 060510 (2013)

With four-fold symmetry $\nu=0$ (asymmetry parameter)

Ti-superconductors, Nature of transition below T_s

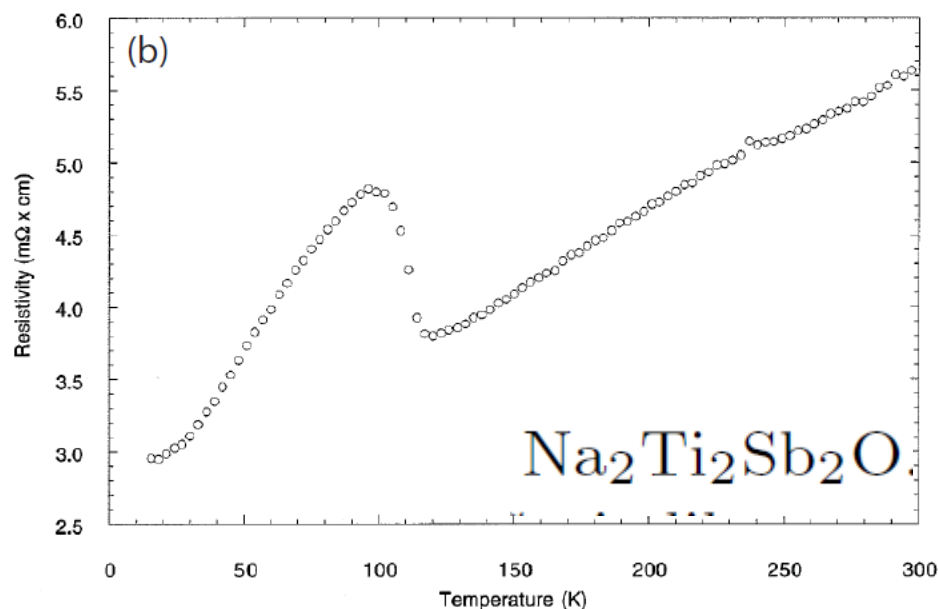


$\text{BaTi}_2\text{Sb}_2\text{O}$
($T_s \sim 54$ K, $T_c \sim 1$ K)

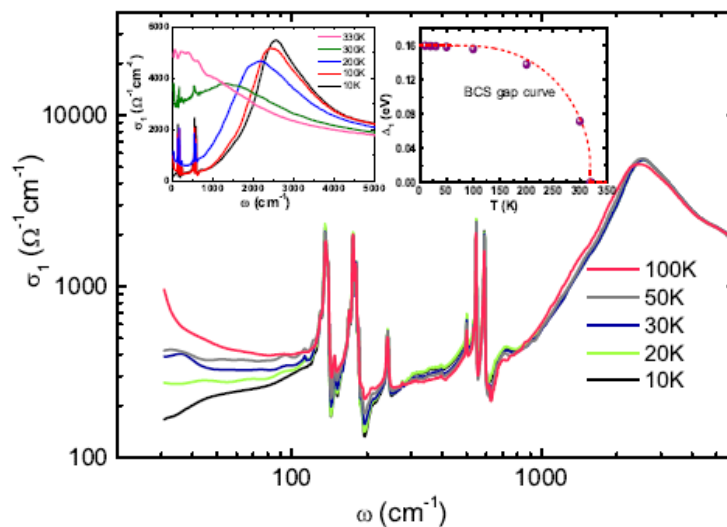
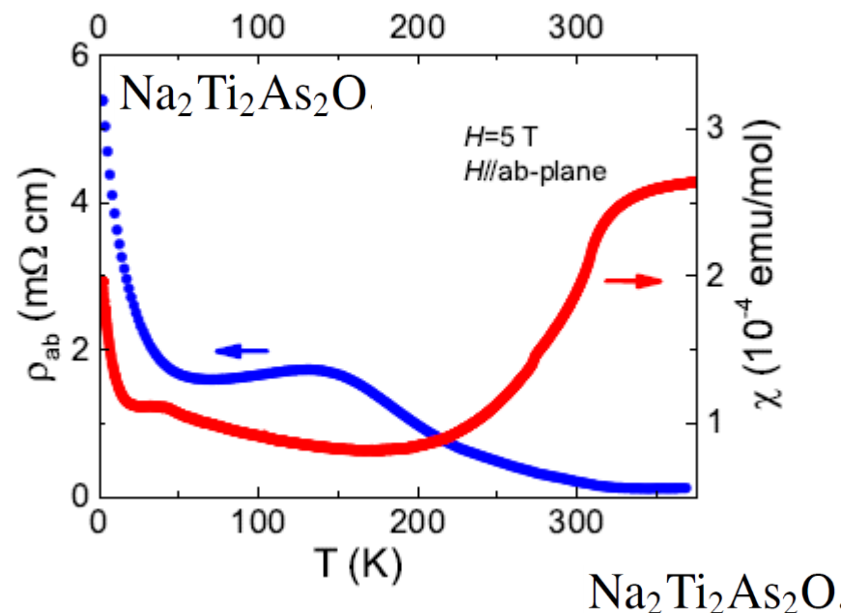
Kitagawa et al, PRB 87,
060510 (2013)

Order proposed: Different
charge densities at Ti sites

Ti-superconductors. Nature of transition below T_s



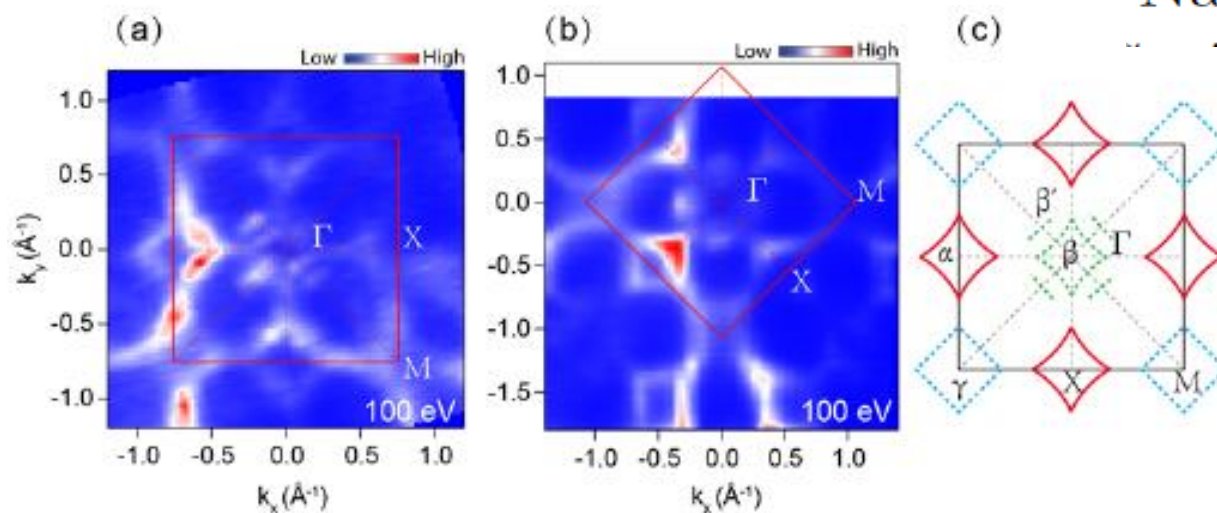
Axtell et al, Solid. State Chem. 134, 423 (1997)



Huang et al, Phys. Rev. B 89, 155120 (2014)

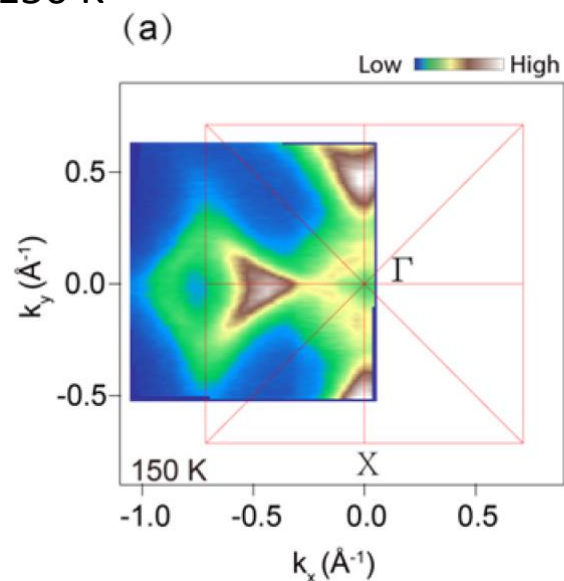
Fermi surface of titanium oxypnictides

15 K

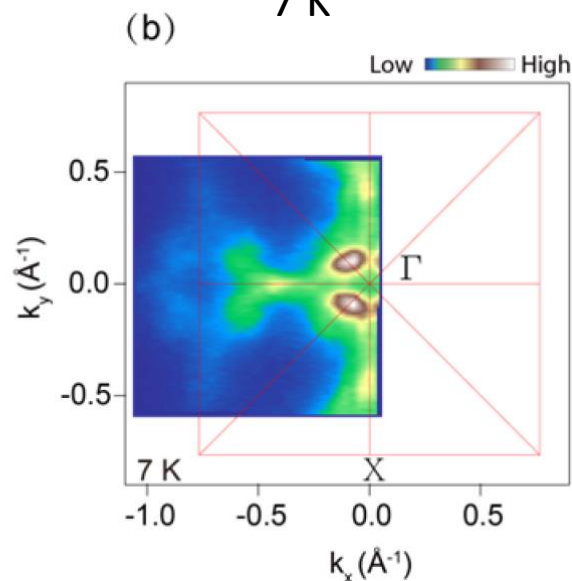


Tan et al,
Sci. Rep. 5, 9515 (2015)

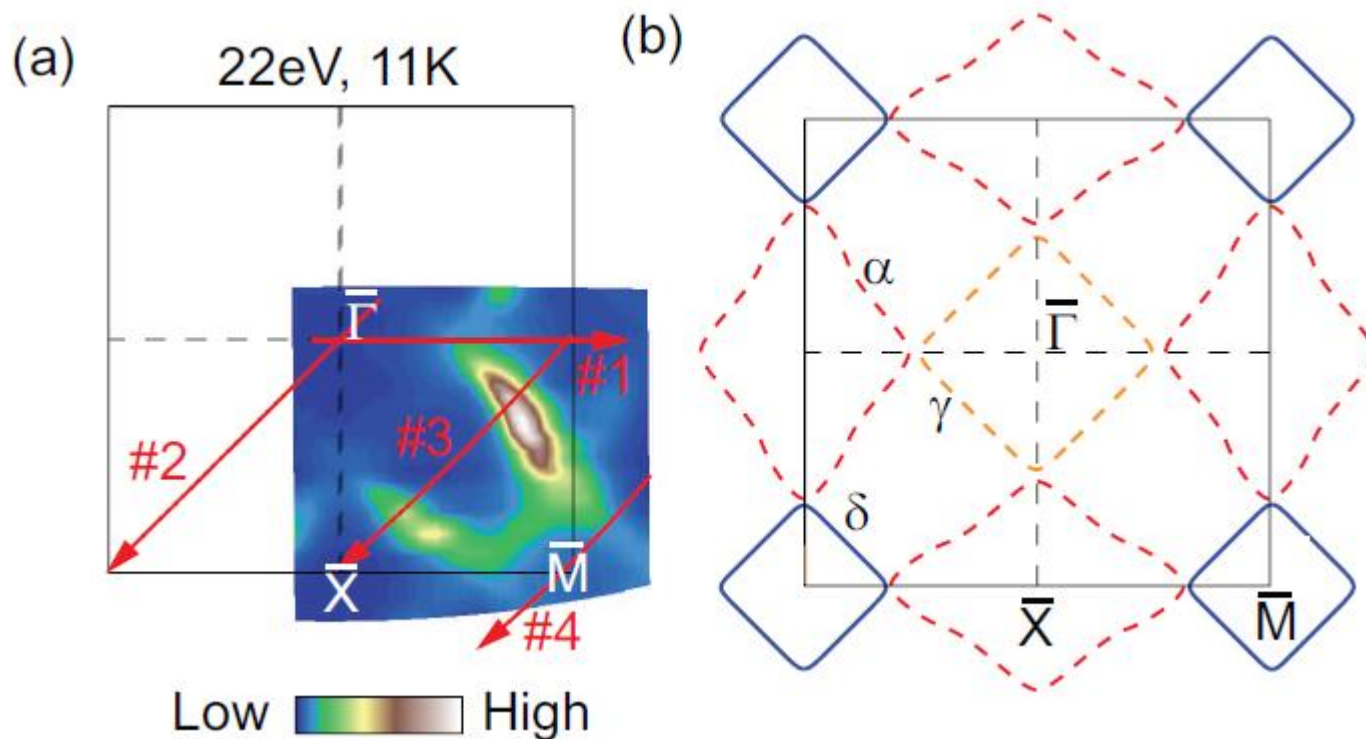
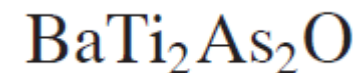
150 K



7 K

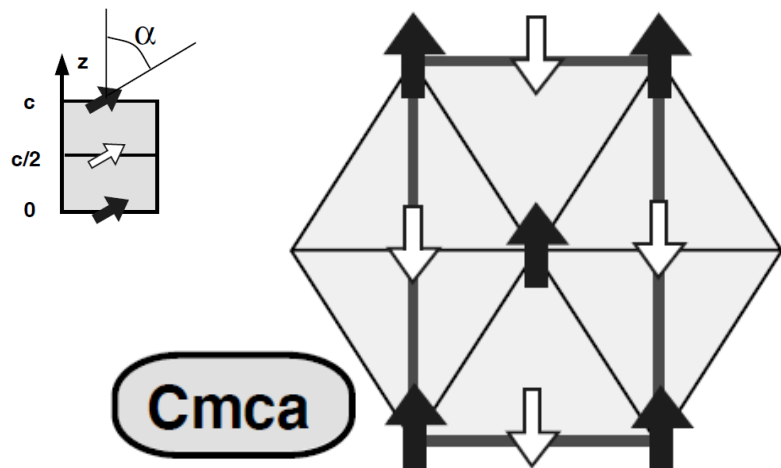


Fermi surface of titanium oxypnictides



Xu et al, Phys. Rev. B 89, 155108 (2014)

Metallic Hydrogen: a high-T_c superconductor?

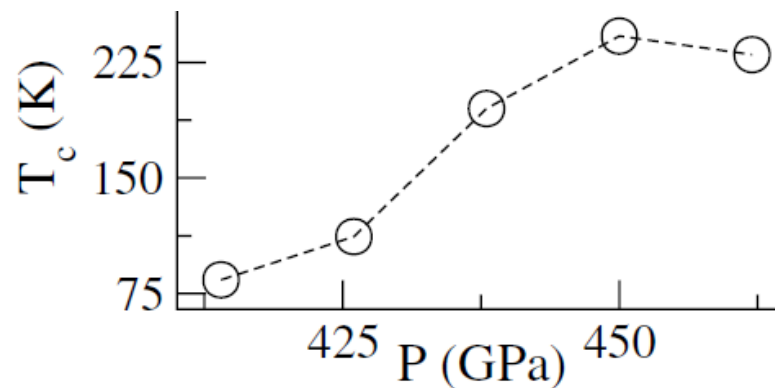
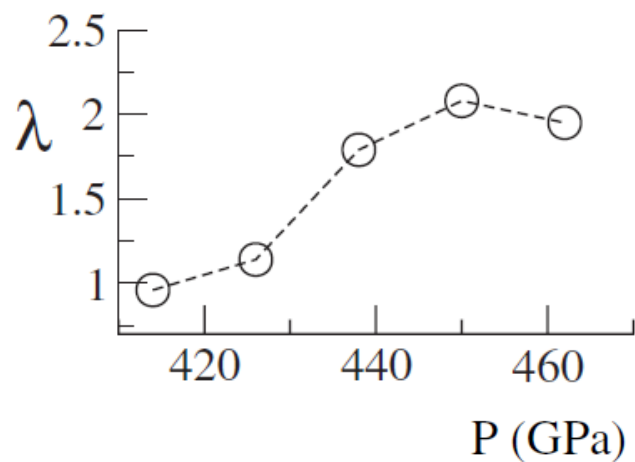


Expected Metallic Phase

H₂ molecules

P_{metal} ~400 GPa

Städele & Martin, PRL 84, 6070 (2000)



Cudazzo et al, PRL 100, 257001 (2008)