Optical transitions in highly charged ions

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Motivation

- New optical clocks
- Search for α-variation

Plan

- Why highly charged ions?
- Requirements for high precision spectroscopy & α-variation search.
- How to find narrow optical transitions in HCI?
- Method.
- 10 perspective ions.
- Conclusions.

Advantages of HCI

- Smaller polarizabilities & smaller BBR shifts
- More species
- More flexibility
- Gradual changes along isoelectronic series allows to optimize properties
- High sensitivity to α-variation

Scalings with charge of the ion

Energy scale for ions:

$E_{val} \sim (Z_{ion}+1)^2$ Ry

Sensitivity coefficients:

$q = d\omega/d\alpha^2$

$q_{ion} \sim (Z_{ion}+1)^2 q_{atom}$

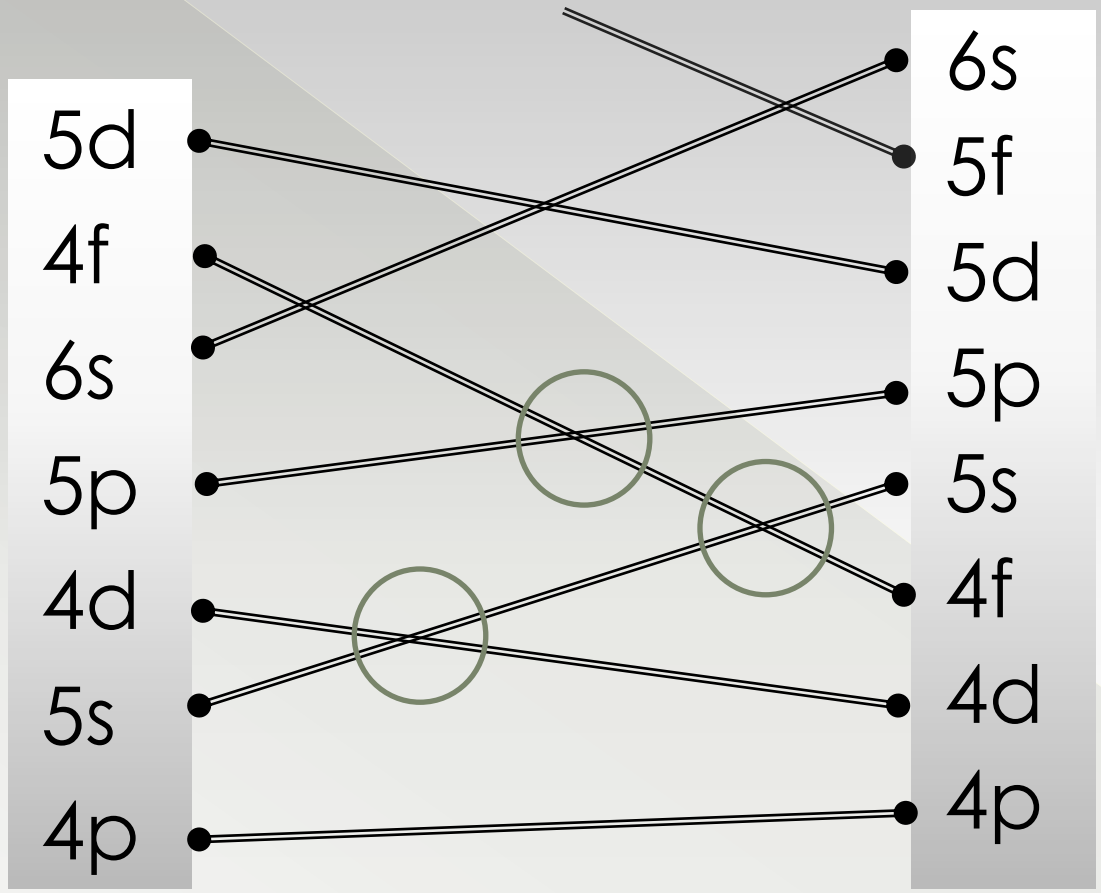
Relative shifts:

$(d\omega/\omega) = Q(d\alpha/\alpha)$

$Q = 2q/\omega$

$Q_{ion} \sim Q_{atom}$

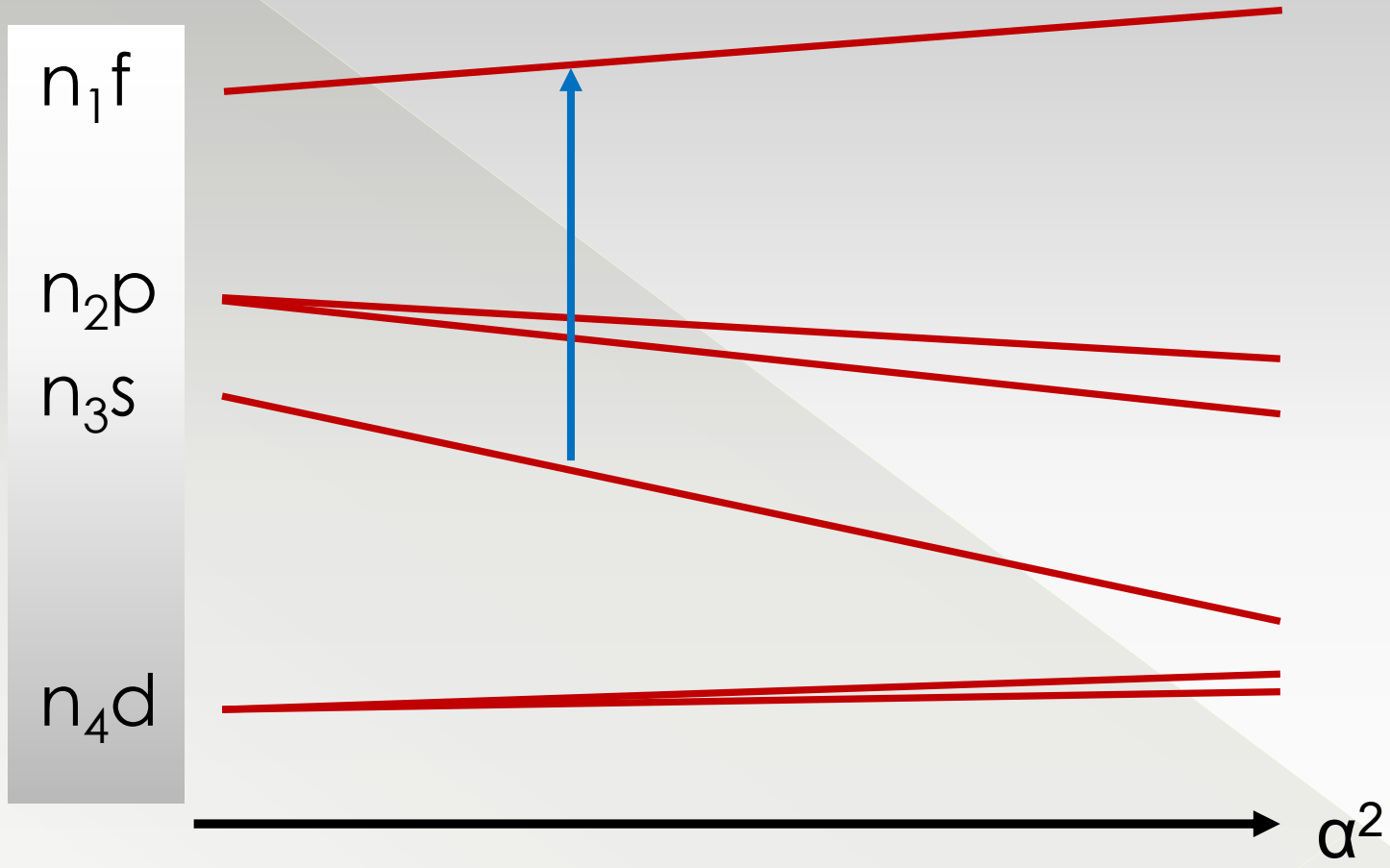
Filling order of shells



[Berengut, Dzuba, & Flambaum, 2010]

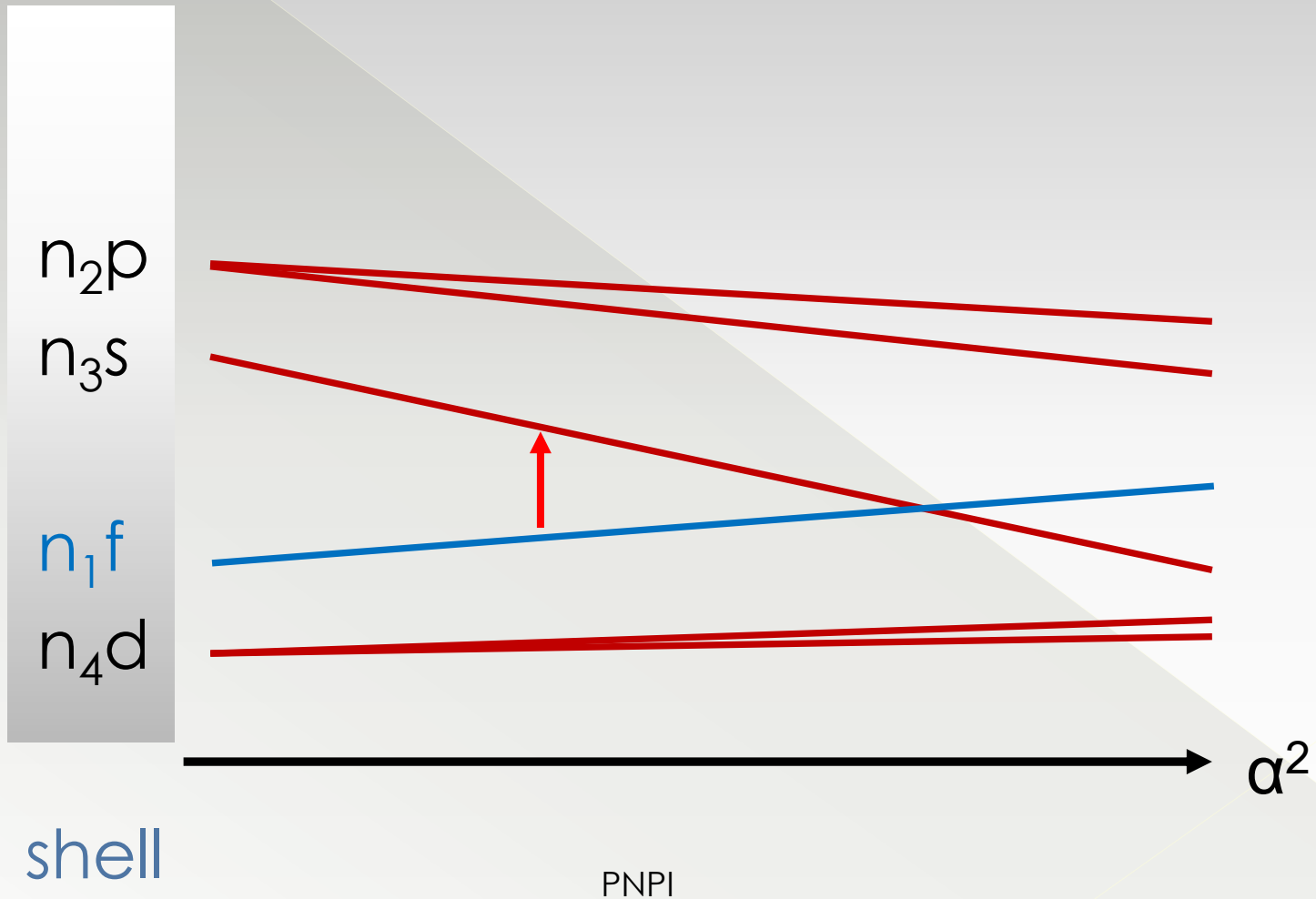
Atom HCI H-like ion

α-dependence



shell

α-dependence



Criteria:

long-lived metastable states	• transition frequencies to the ground states ranging between (0.1–1.8) × 10^{15} Hz
high sensitivity to α-variation	• transitions between different configurations
existence of stable isotopes	

Challanges

Experimental information on HCI is sparse

Theoretical predictions are not reliable because of the large cancellations near level crossings

We need state of the art calculations followed by experimental studies

Configuration interaction +all-order method

CI+AO method combines valence CI with linearized coupled cluster method for core-valence & core-core correlations

We use Dirac-Coulomb-Breit Hamiltonian in no-pair approximation

Leading QED corrections are included following Flambaum & Ginges (2005)

Choice of ions

We studied ions with one to four valence electrons. No systems with holes in the core shells were considered.

4^{th}-row: no useful crossings found.

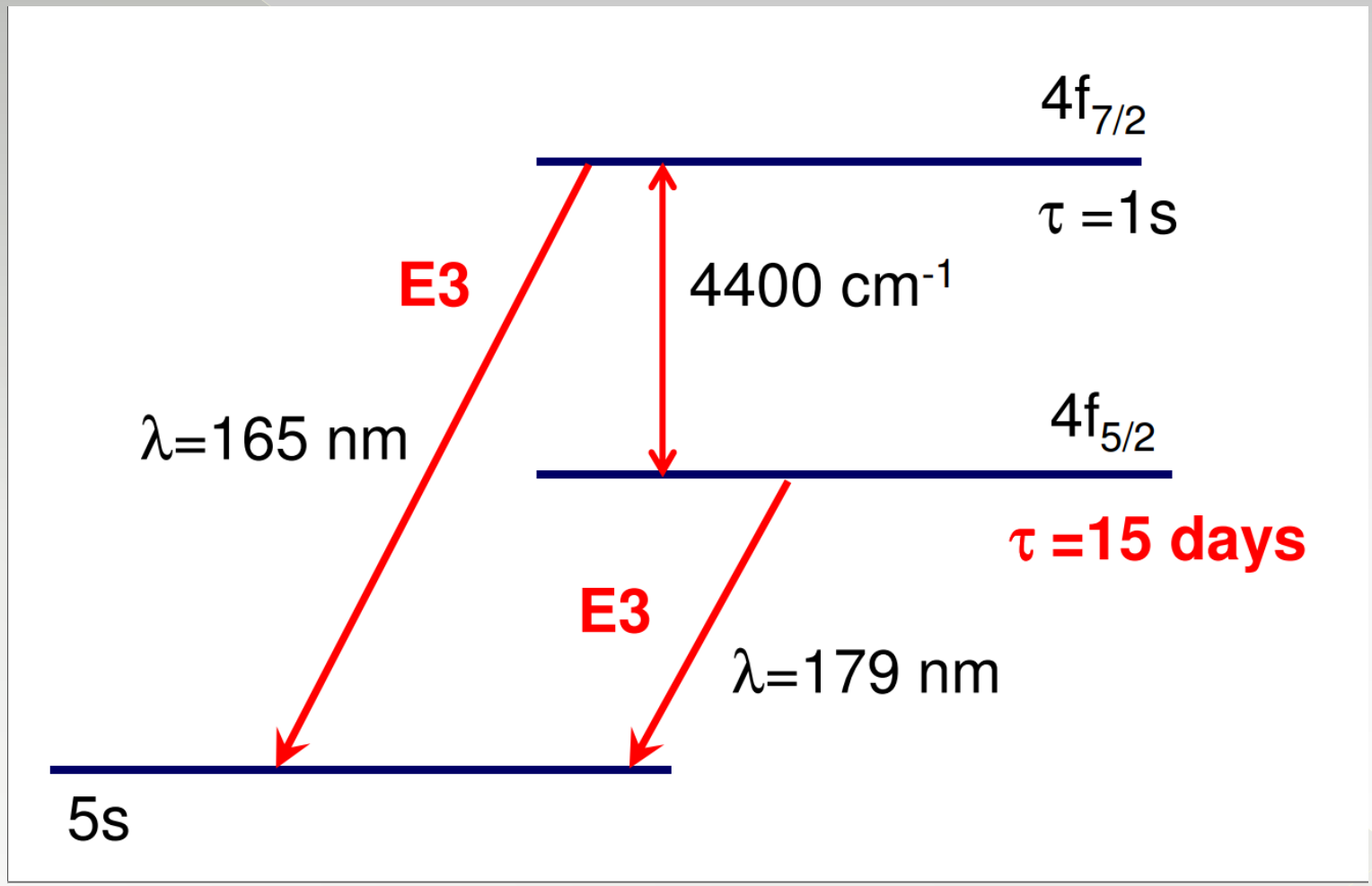
5^{th}-row: 10 ions from Ag-like, Cd-like, In-like, and Sn-like isoelectronic sequences satisfy our criteria.

6^{th}-row: level crossings occur for ions with no stable isotopes.

10 ions with narrow optical transitions

Valence electrons	Isoelectronic sequence	Level crossing	Ions
1	Ag-like	5s-4f	$Nd^{13+}$and Sm^{15+}
2	Cd-like	5s-4f	Nd^{12+} and Sm^{14+}
3	In-like	5p-4f 5s-4f	Pr^{10+}, Nd^{11+}, Sm^{13+}, and Eu^{14+}
4	Sn-like	5p-4f	Pr^{9+} and Nd^{10+}

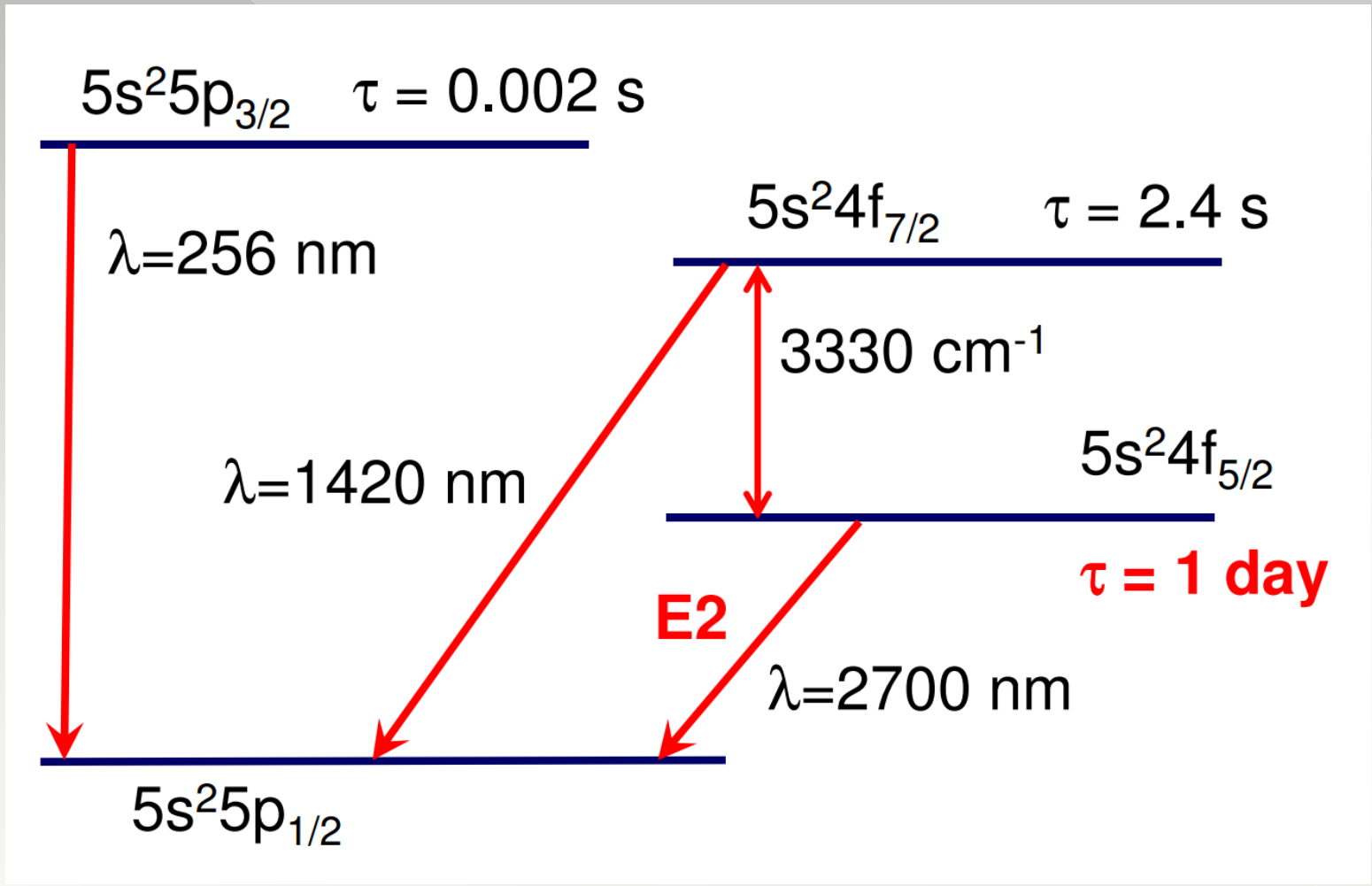
Ag-like Nd^{13+}



Q=3.6

Q=3.7

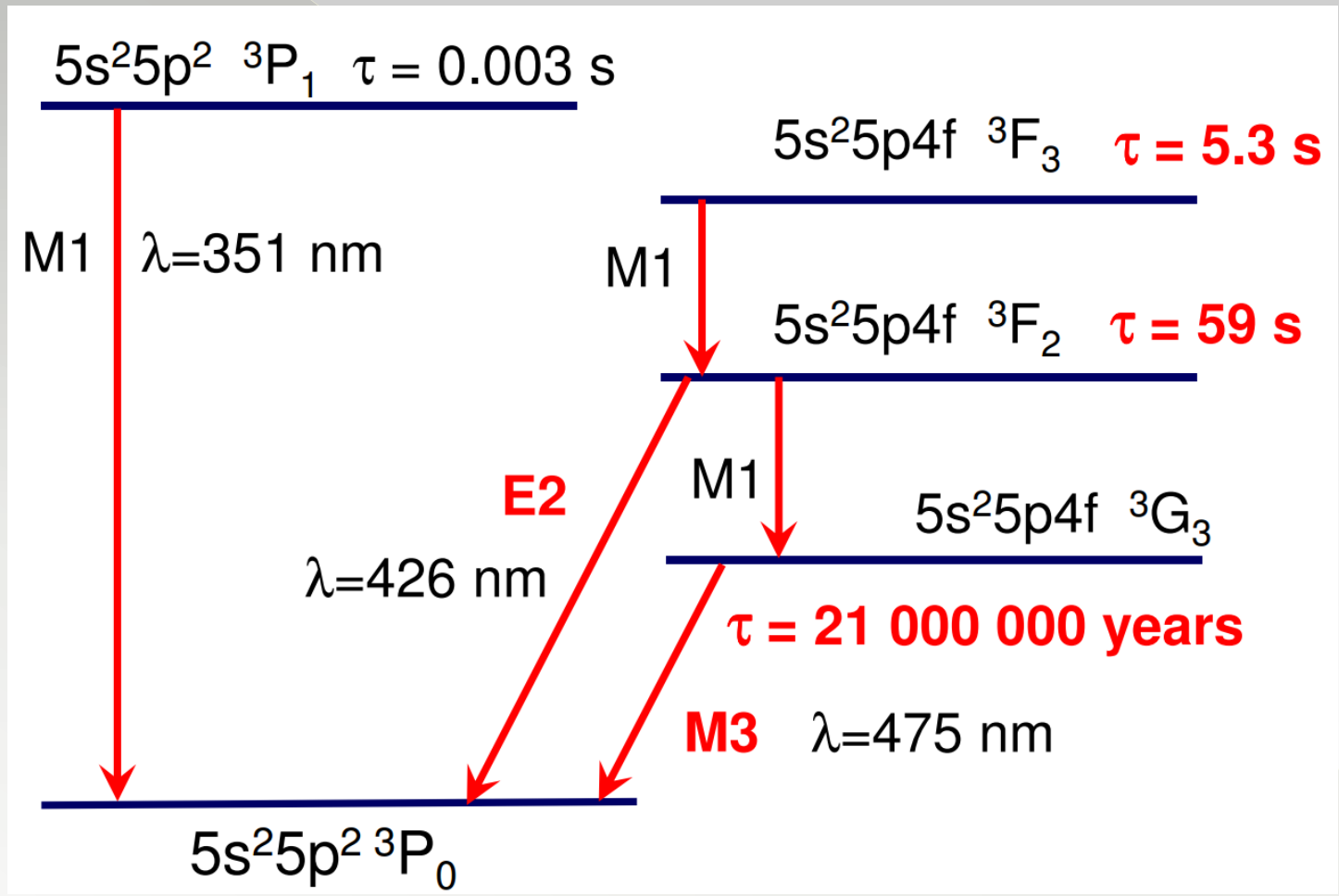
In-like Pr^{10+}



Q=22

Q=40

Sn-like Pr^{9+}



Q=3.8

Q=4.2

Conclusions

- We made first high precision calculations of level crossings in HCI.
- We identified 10 ions with narrow optical transitions and high sensitivity to α-variation.
- These ions can be further studied as candidates for next generation optical clocks.

Brief ad

We plan to publish our CI+MBPT package in Computer Physics Communications.

The β–version of the package is ready for download (Sergey Porsev).

For more details see:

1. M. S.Safronova et al, *Phys. Rev. Lett.*, **2014**, *113*, 030801
2. M. S.Safronova et al, *Phys. Rev. A*, **2014**, *90*, 042513
3. M. S.Safronova et al, *Phys. Rev. A*, **2014**, *90*, 052509

Спасибо!