Electron collision studies of M-shell iron ions motivated by astrophysics

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Collaboration

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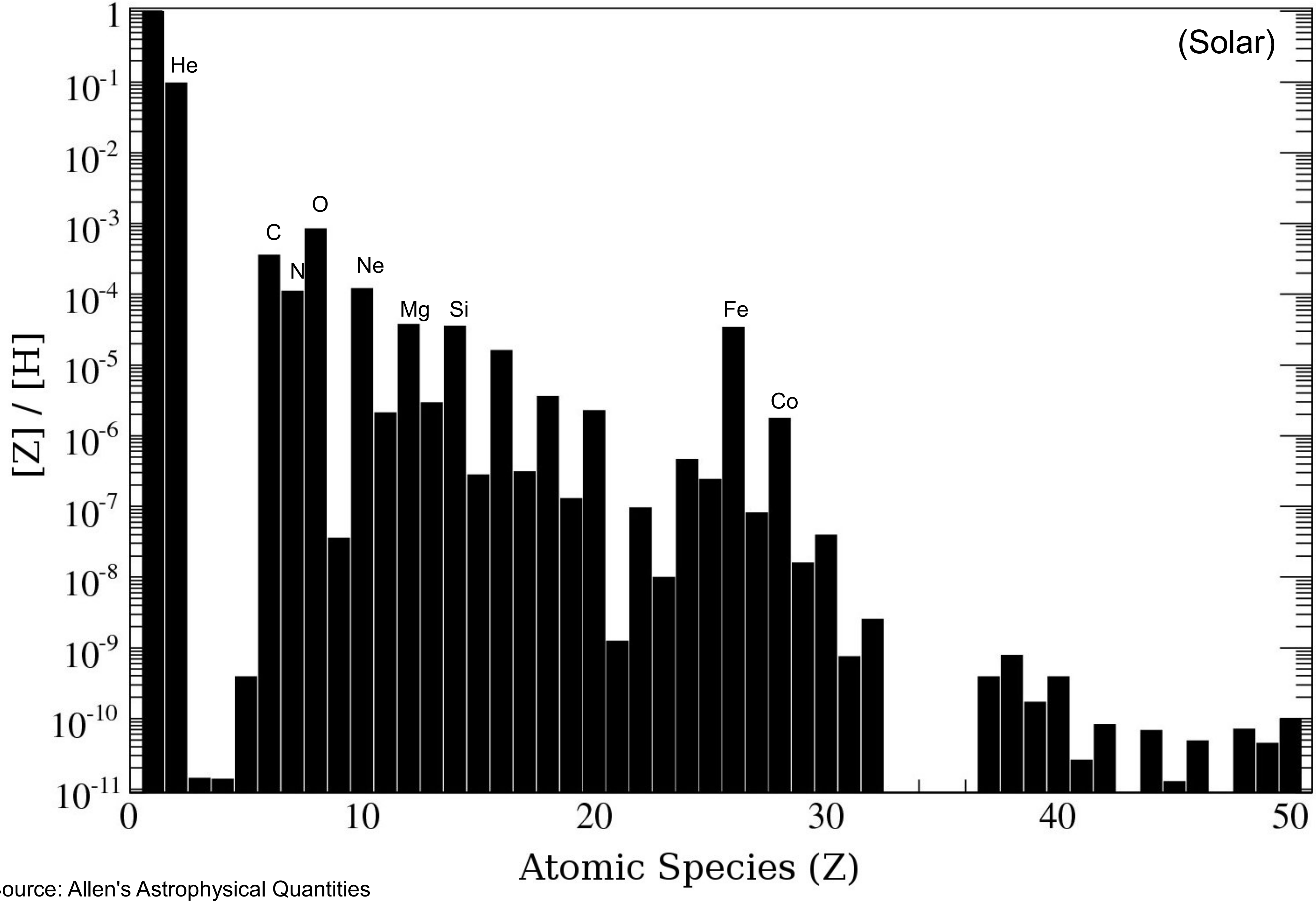
Outline

1. Motivation
2. Astrophysical plasmas
3. Charge state changing mechanisms: DR and EII
4. Experimental methods
5. Results
6. Summary

Motivation

- e^--ion collisions are important in many types of astrophysical plasmas
  - collision-dominated environments (e.g. supernova remnants, solar coronae)
  - radiation-dominated environments (e.g. active galactic nuclei, planetary nebulae)
- Heavy ions are cosmically abundant and important spectroscopic diagnostics (-> Iron)
- Astrophysical spectral analysis codes rely on precise data on recombination and ionization
- Merged beams in storage ring are proven experimental method
- Control of metastable populations by storage time
- Benchmarking theoretical calculations for "complicated" systems (e.g. M-shell ions)

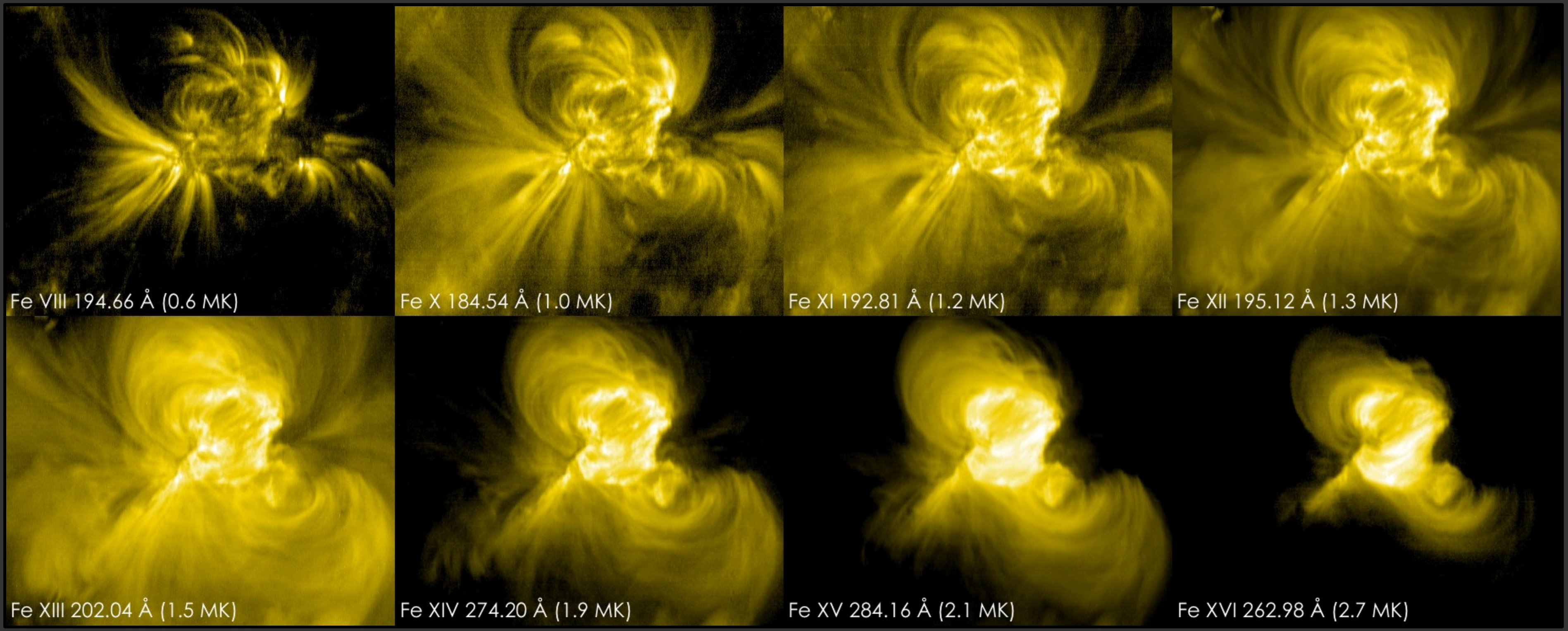
Cosmic Abundances of Elements



Source: Allen's Astrophysical Quantities

Astrophysical Plasmas: Collision driven

Solar Coronae

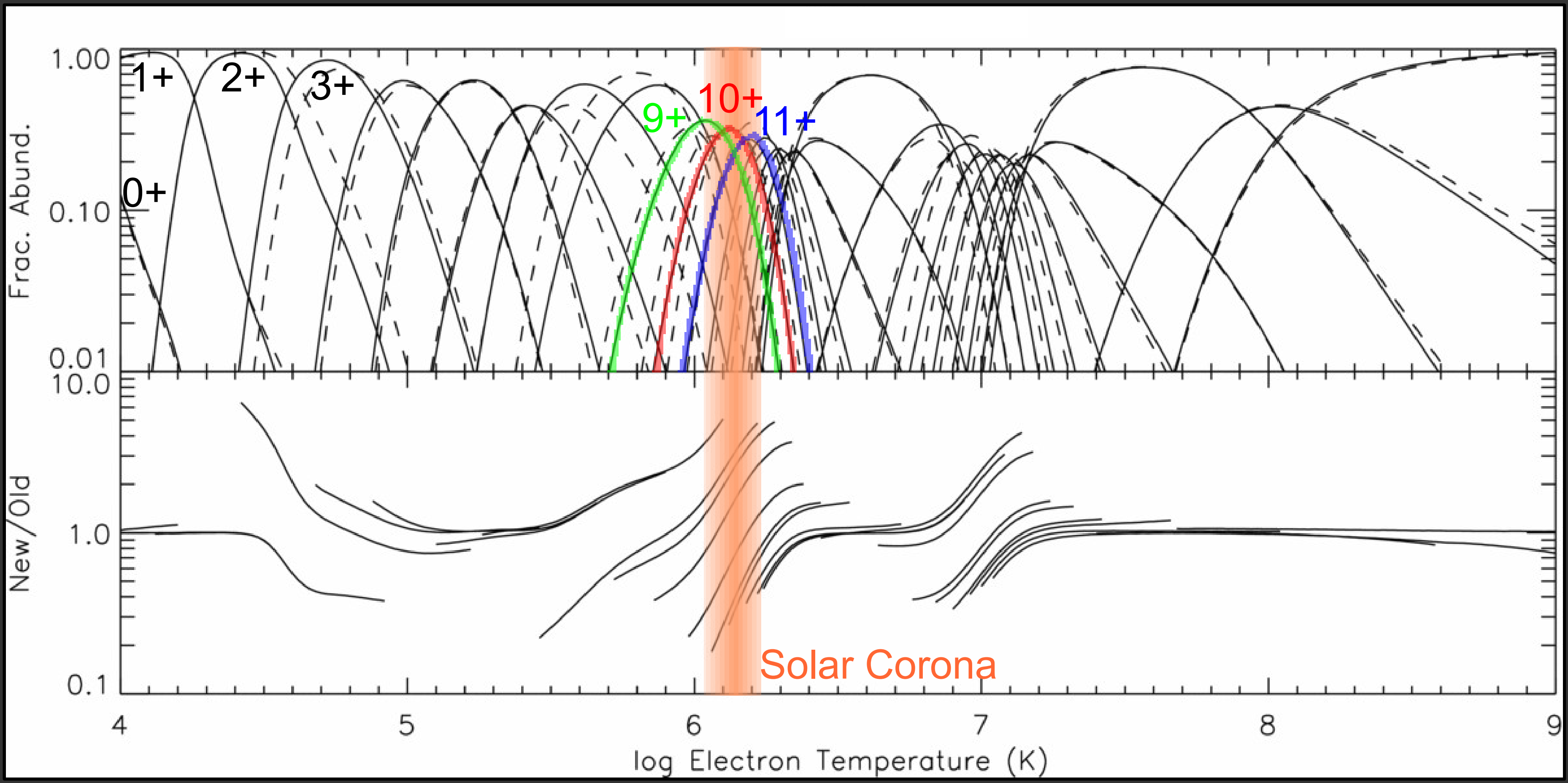


Warren (2008) / Hinode EIS

Corona temperature ~10^6 K
collisions are dominating the ionization process

CP Charge State Distributions

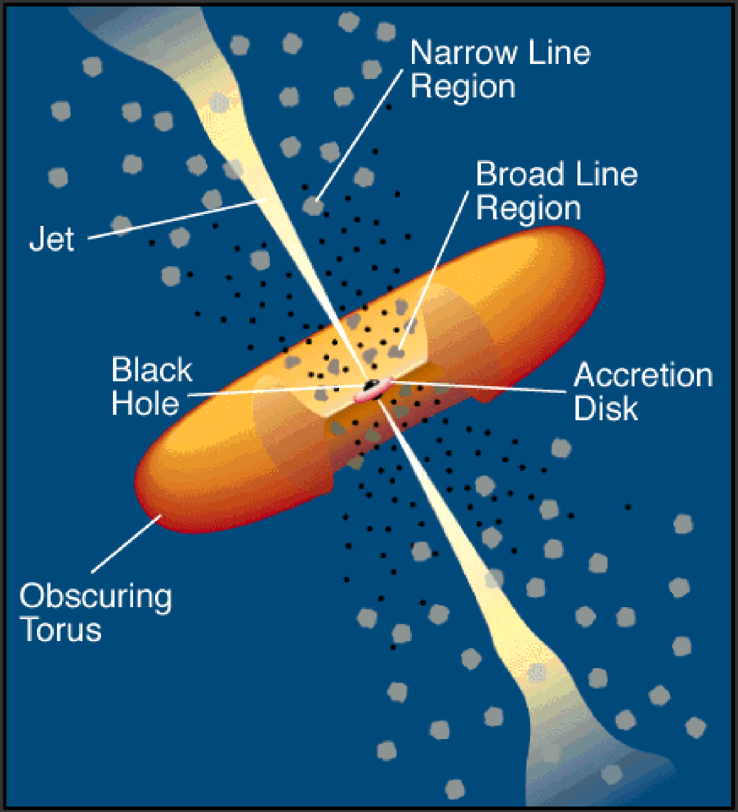
Iron in a collisionally ionized plasma
Balance of ionizing and recombining processes



"New": P. Bryans et al. (2009) "Old": Mazzotta, et al. (1998)

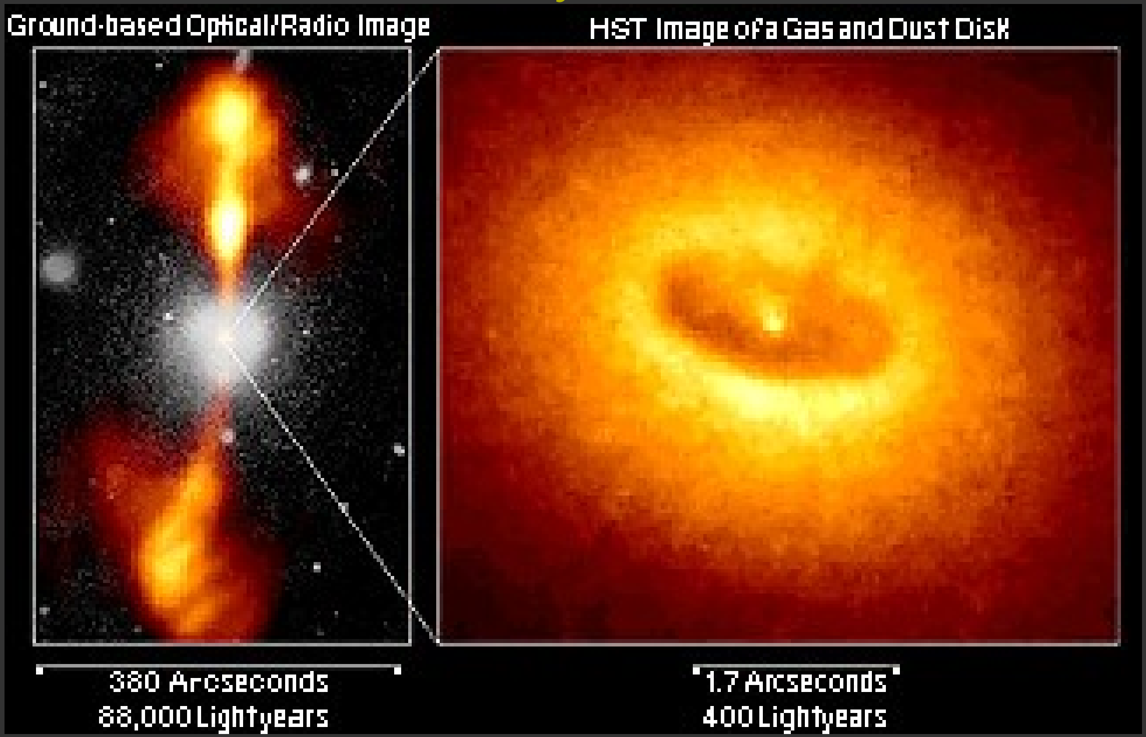
Astrophysical Plasmas: Photon driven

Active Galactic Nuclei (AGN)



AGN standard model
(Urry & Padovani 1995)

Ground Based and Hubble images of the Active Galaxy NGC 4261

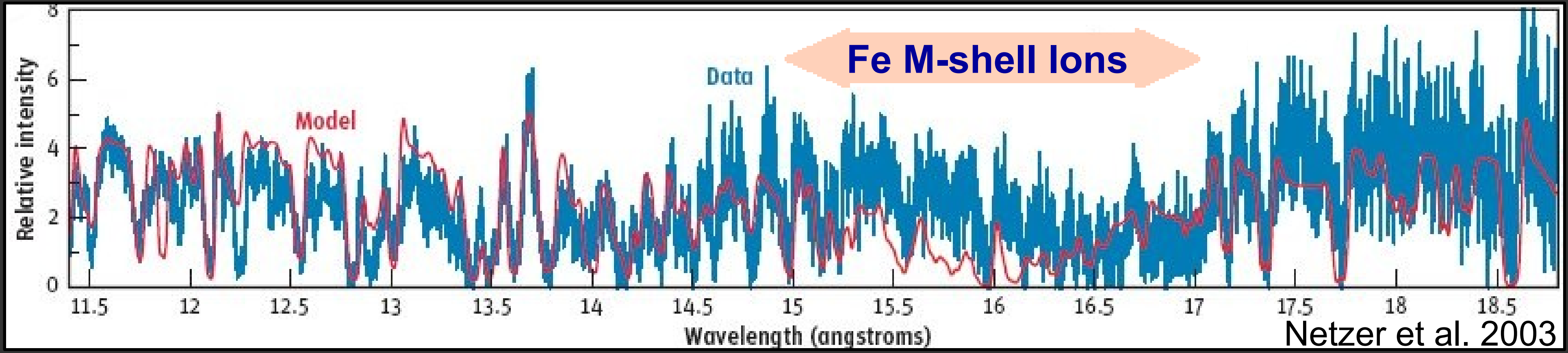


HST image credits: ESA / NASA

Intense radiation source → Photoionization drives plasma
High ionization stages at low T_e

AGN X-Ray observations

Chandra: X-ray Absorption Spectrum of NGC 3783

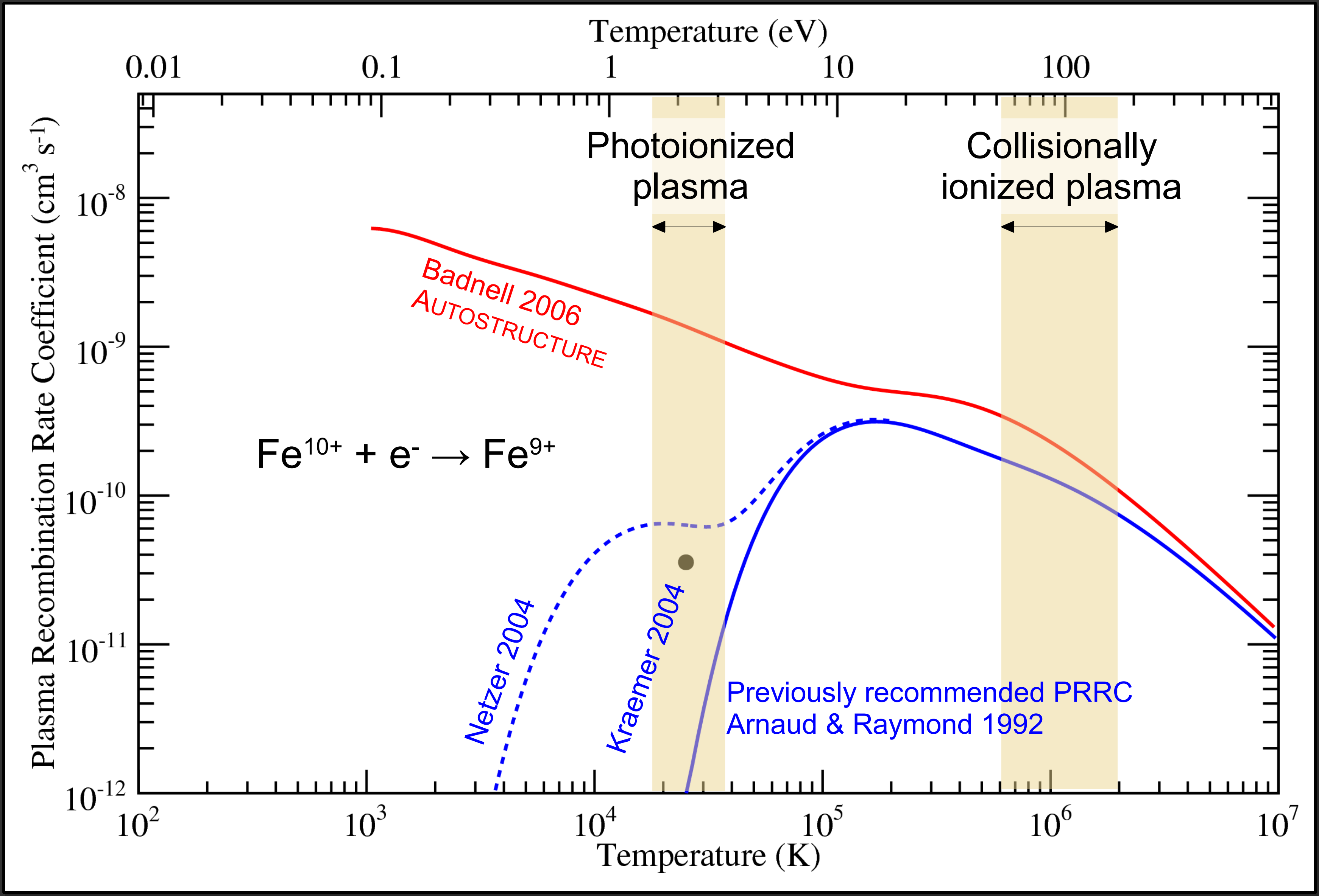


Unresolved transition array at 15-17 Å due to 2 → 3 excitation in Fe M-shell ions.

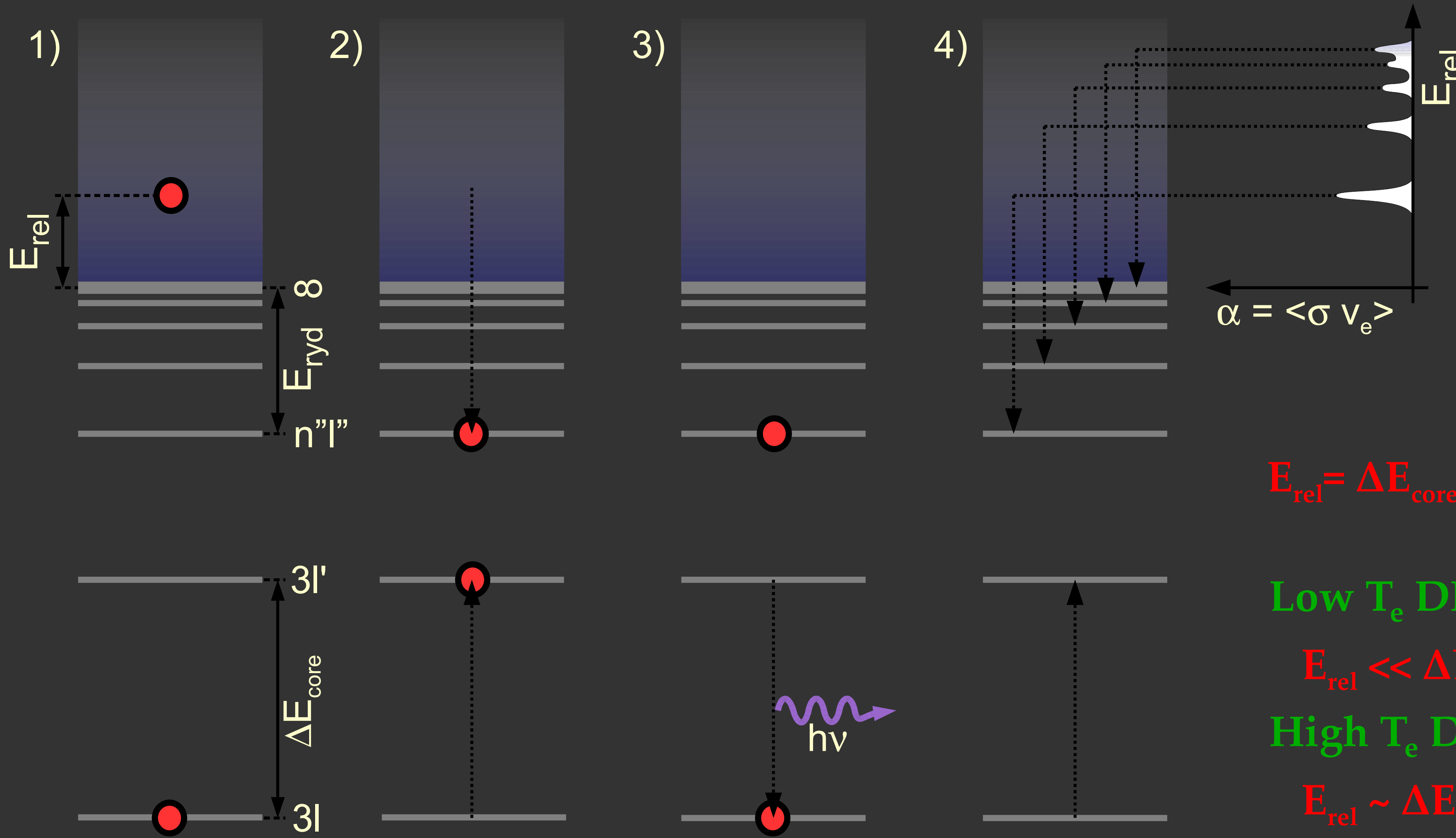
Astrophysical models predict features of 2nd and 3rd row elements, but for Fe the modelled charge state distribution overestimates higher ionization stages.

This has been attributed (Netzer 2004 and Kraemer, et al. 2004) to the absence of low-T_e recombination data for M-shell iron ions as a means to drive down the ionization stages

Plasma DR rate coefficient: Fe^{10+}



Dielectronic Recombination (DR)



$E_{rel} = \Delta E_{core} - E_{ryd}$

Low T_e DR:

$E_{rel} \ll \Delta E_{core}$

High T_e DR:

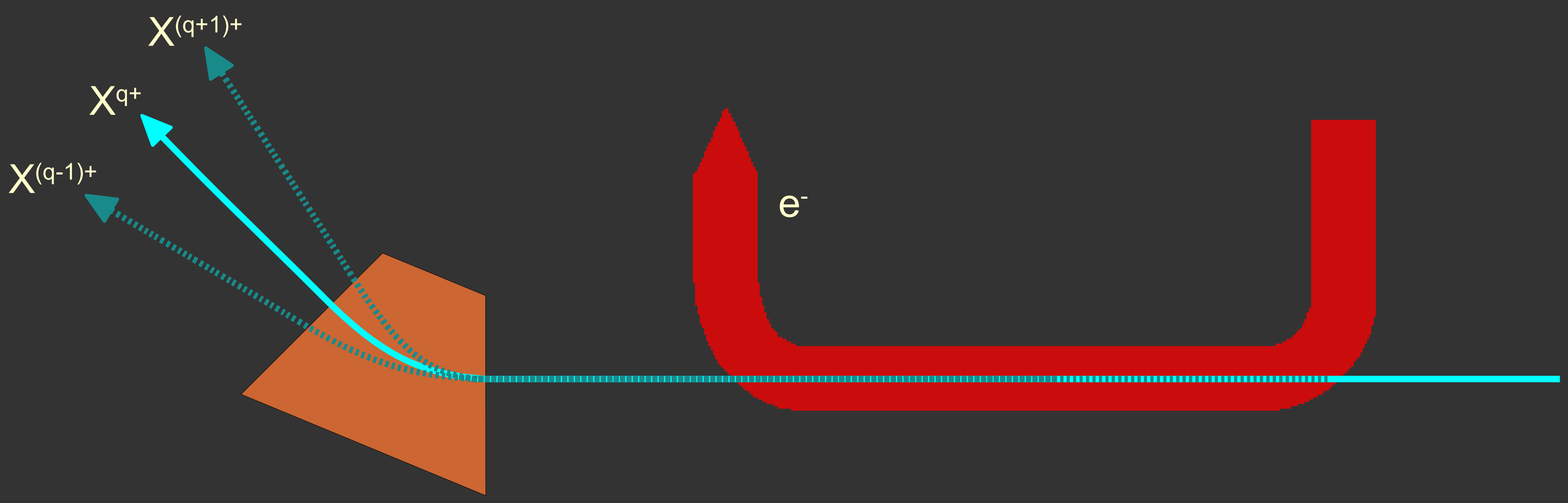
$E_{rel} \sim \Delta E_{core}$

$Fe^{q+} + e^- \longleftrightarrow (Fe^{(q-1)+})^{**} \longrightarrow (Fe^{(q-1)+})^{*} + h\nu$

Formation of the
DR Rydberg series

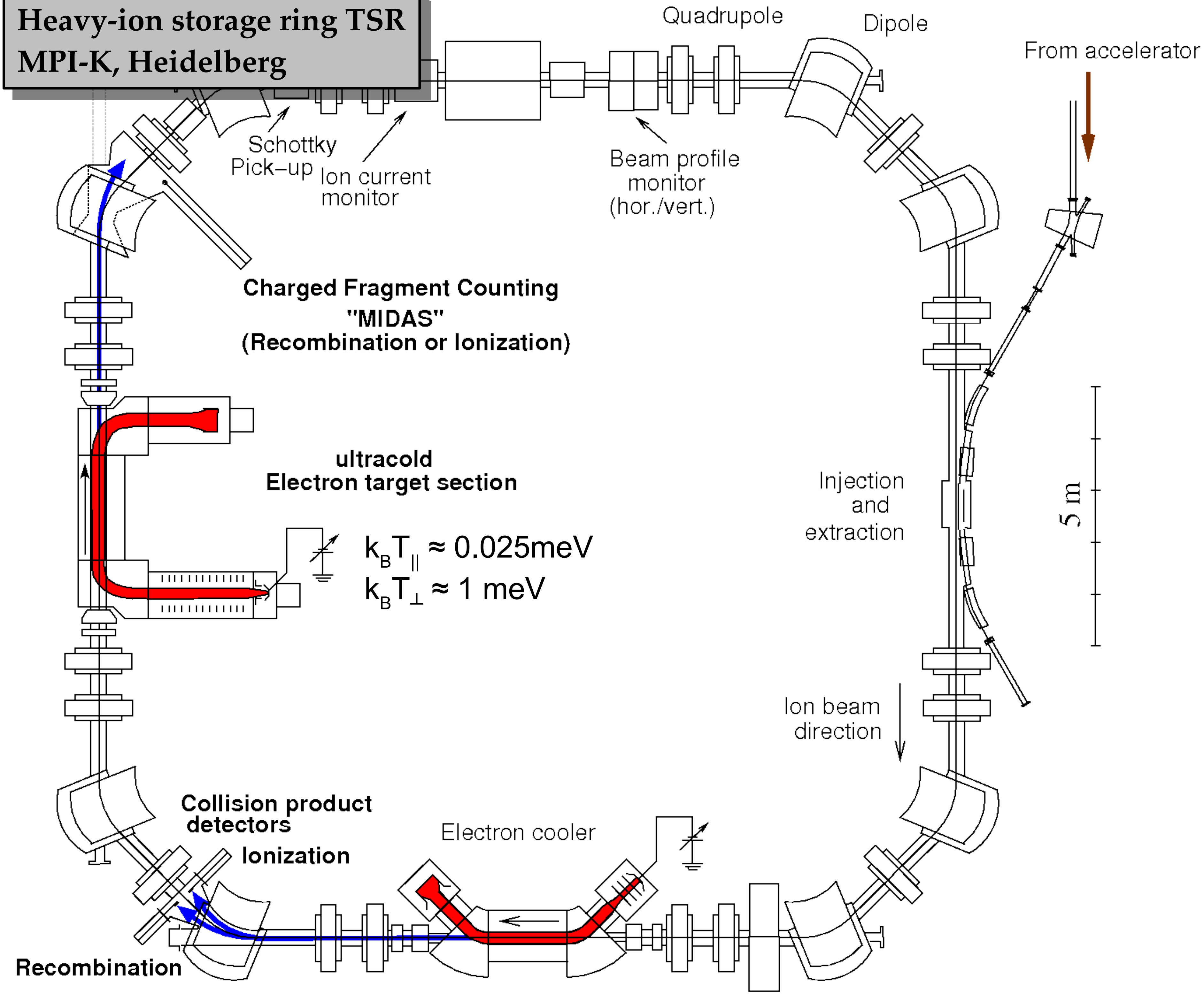
Merged Beams Setup

Ions and electrons are overlapped in colinear beams, this allows lowest collision energies

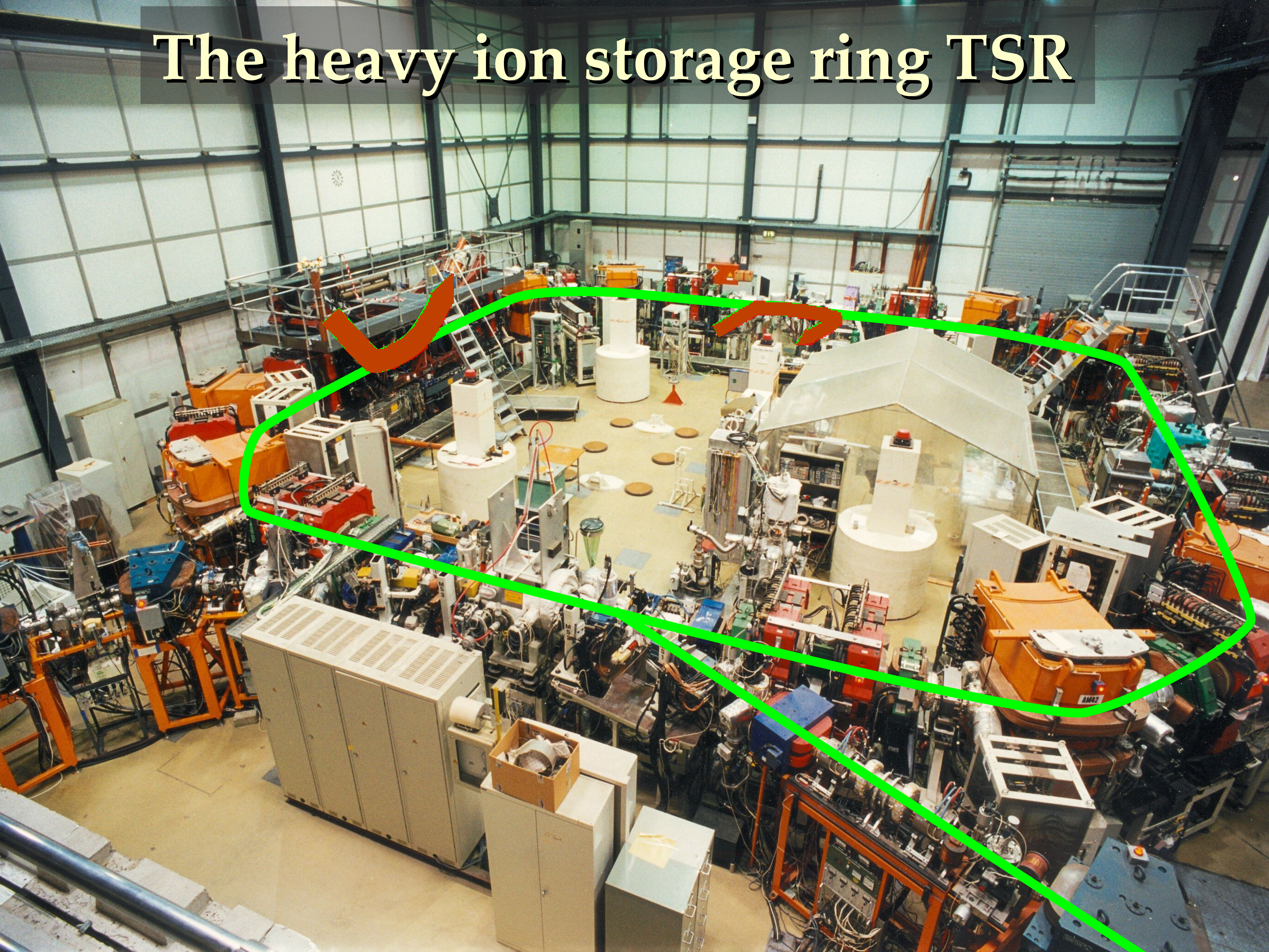


A downstream dipole separates products by charge state.
Fast scintillation^{DR} / CEM^{EII} detector allow single particle detection with $\varepsilon=1$

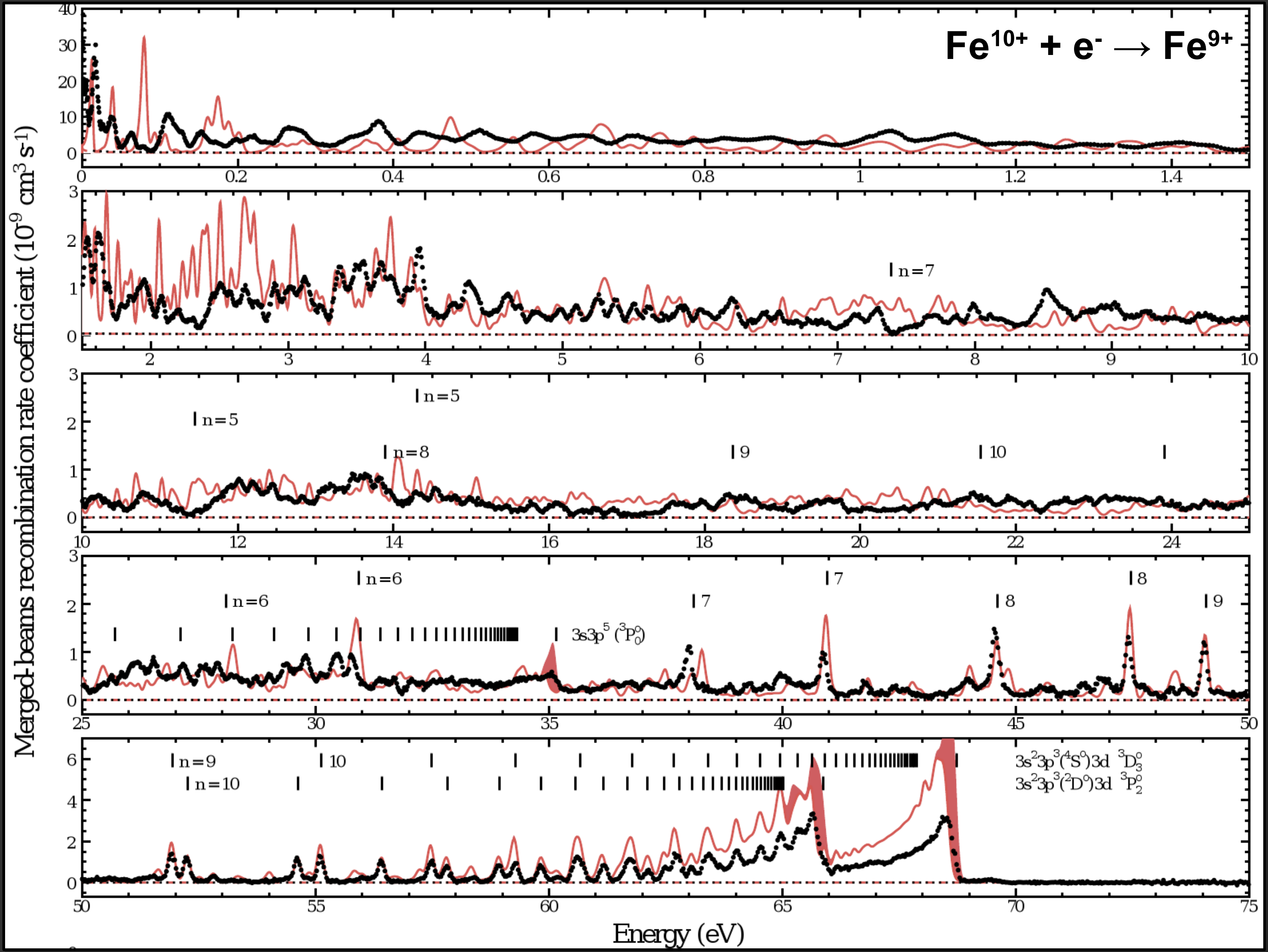
Heavy-ion storage ring TSR MPI-K, Heidelberg



The heavy ion storage ring TSR

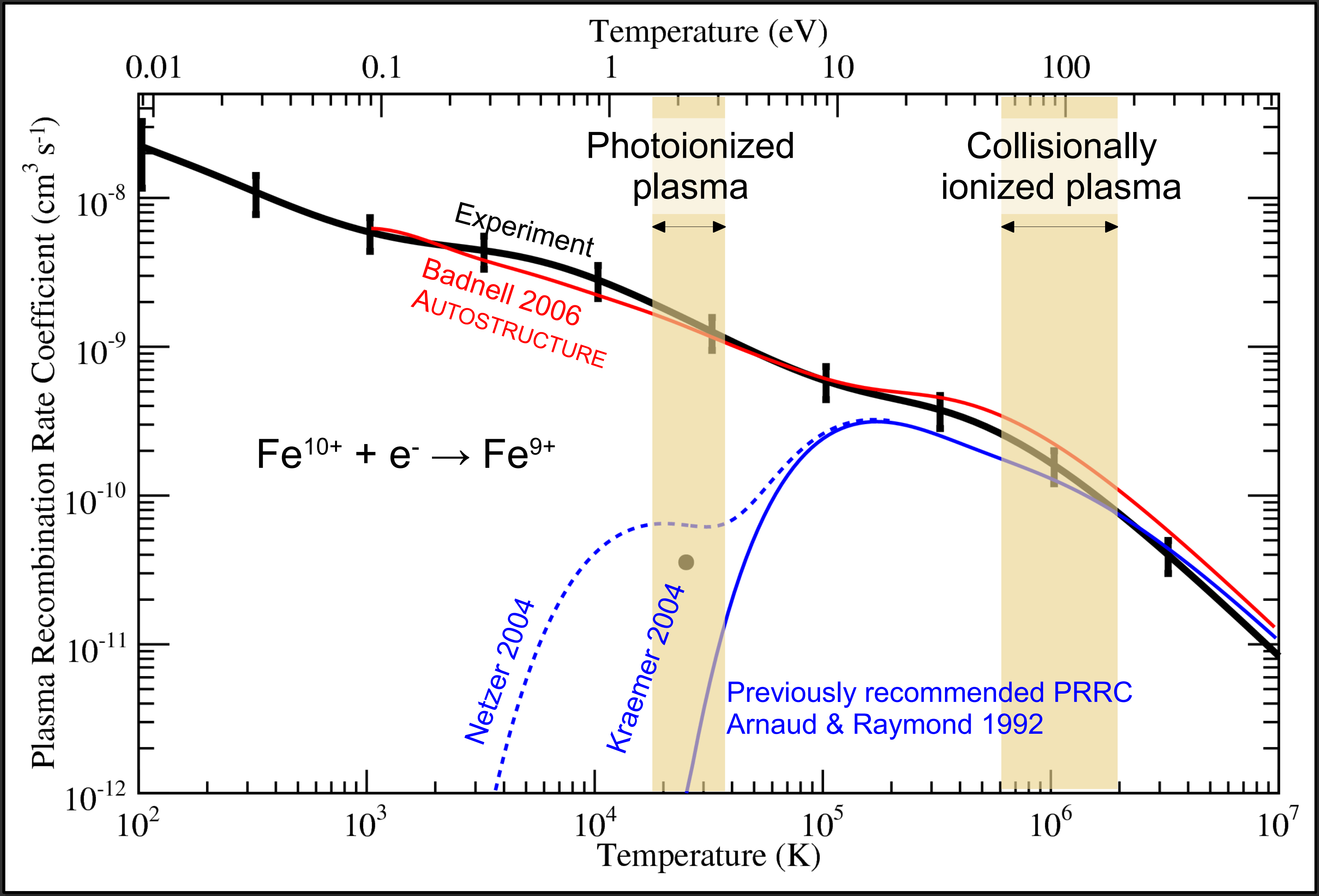


Merged Beams DR Rate coefficient: Fe^{10+}



Lestinsky, et al. (2009), Astrophys J. **698**, 648

Plasma recombination rate coefficient: Fe^{10+}



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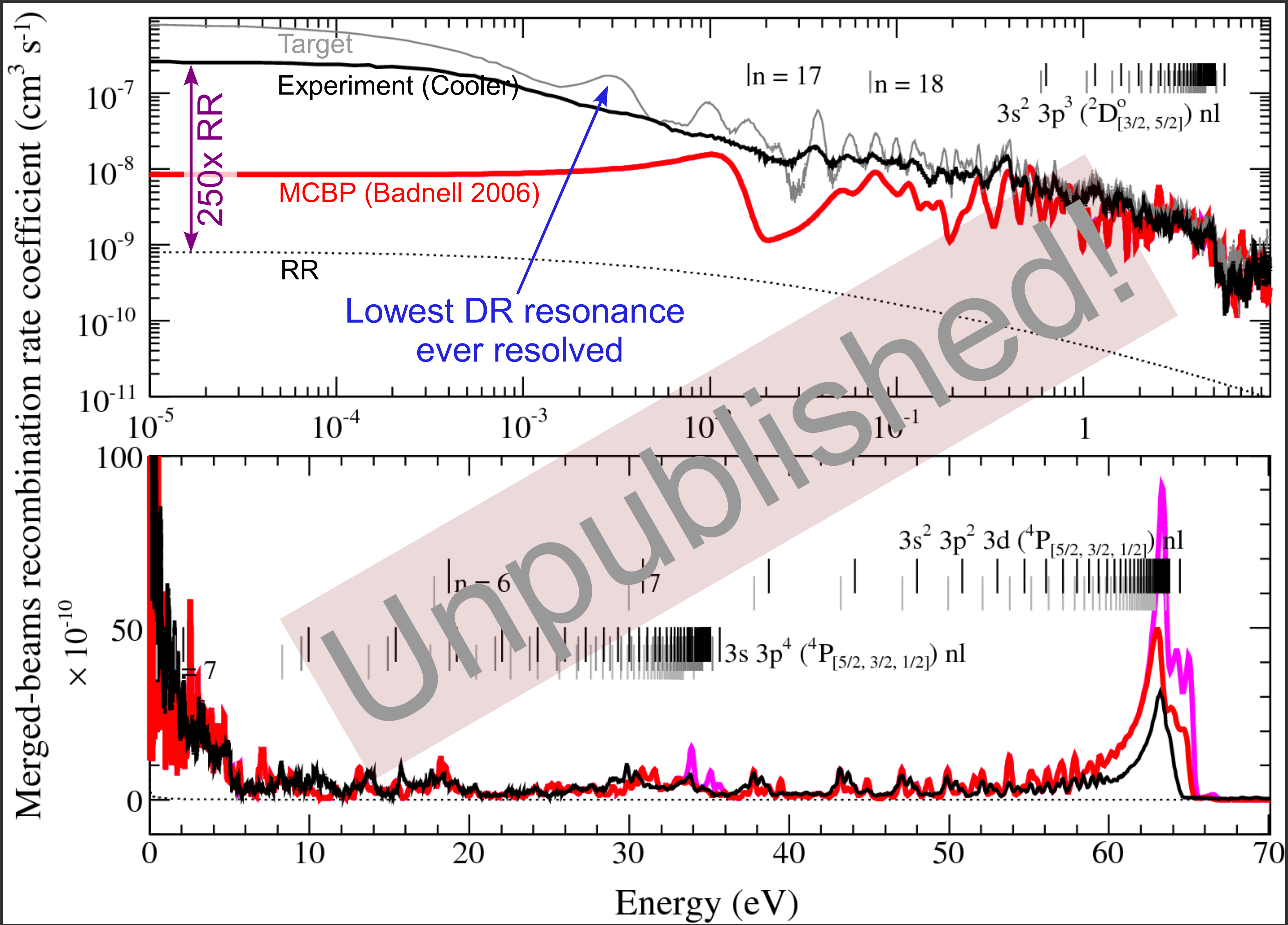
Experimental error bars at 90% CL

Merged Beams DR Rate coefficient: Fe^{11+}



O. Novotny, et al. (to be published)

The mysterious High-*n* discrepancy

Ion	$\alpha_{Exp}/\alpha_{Theo}$
Fe^{7+}	0.73
Fe^{8+}	0.86
Fe^{9+}	0.69
Fe^{10+}	0.5
Fe^{13+}	0.85
Fe^{14+}	0.69
Mg^{6+}	0.75
Mg^{7+}	0.5
Li-like	~1

- AUTOSTRUCTURE theory overpredicts resonance strengths at n≳10
  - but relative resonance strengths agree well
- Observed for various ions / charge states
- Observed in E-Target and ECOOL data
- Expt. analysis done by different people
- Loss of beam overlap can be excluded
- Is experiment selectively destroying high-*n* Rydberg levels?
  - ~~Field ionization~~
  - ~~Residual gas collsions~~
  - ~~secondary EII of Rydberg states~~
- Only ΔN=0 effect?

Summary

- Understanding charge state distributions is important for astrophysics
- Storage ring experiments provide reliable data
  - DR data for iron almost complete: $Fe^{22-13,11-7+}$
  - Other ion species to come
  - Expanding method to also include EII in future experiments
- MCBP theory shows consistent and characteristic deviation from experiment. (Is anyone concerned by that?)