Atomic data for Astrophysics

Opacity and Radiative acceleration

Workshop PNPS - Astrophysique de laboratoire

Données atomiques pour la physique stellaire

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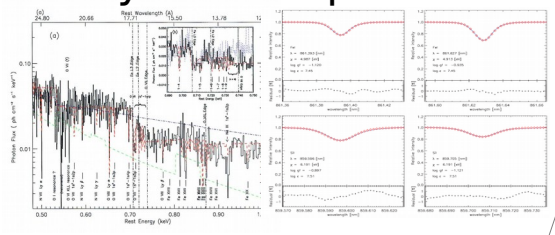
Claude Zeippen (LERMA – Obs. Paris)
IPOPv2 Team (Opacity Project – Iron Project)

Atomic data for Astrophysics

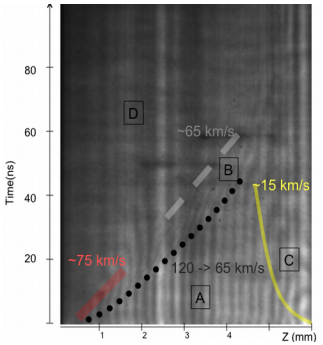
Atomic data – Opacities – Radiative accelerations

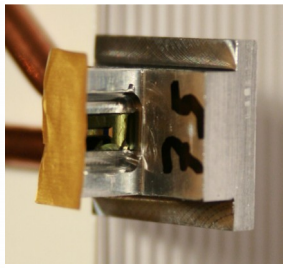
Spectroscopy
Synthetic spectra



Atomic data

Experiments
Calibration, experimental path, scalling (PALS, LULI, LMJ)





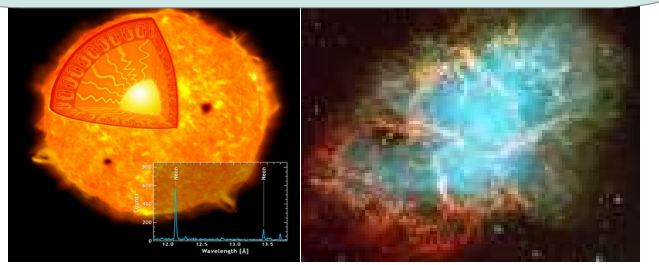
Opacities – Radiative accelerations

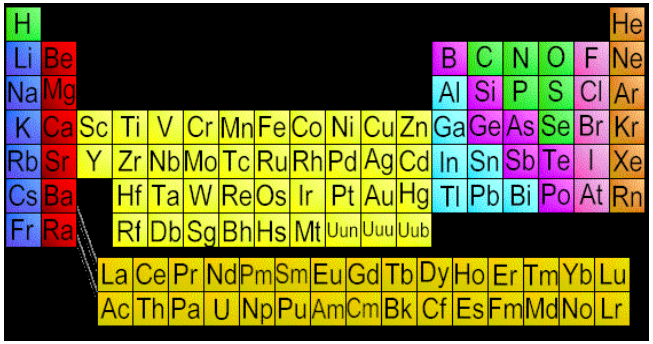
Atmosphere modeling

Stellar models
Characteristics : mass, radius, composition metalicity
Evolution: turnoff, variability

Chemical evolution of the ISM and Galaxies

Age of globular clusters





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Atomic data – Opacities – Radiative accelerations

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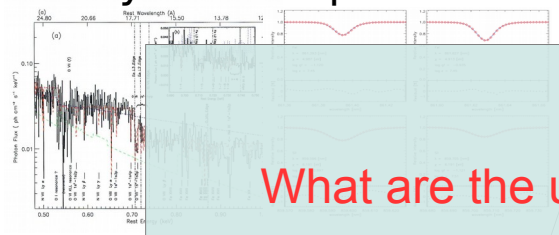
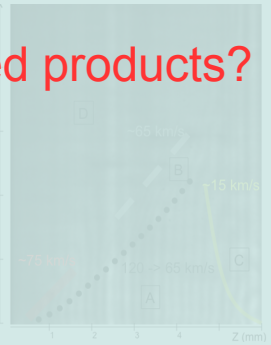




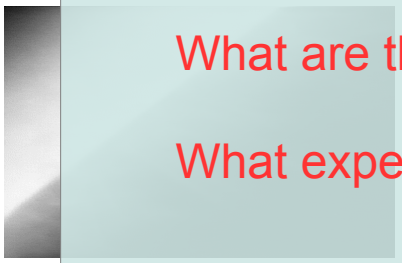
What are the uncertainties attached to atm. Data and derived products?

How do they propagate on application?

What are their limitation for experiments and applications?

What experiments are available / douable to help improve them?

Atmosphere modeling



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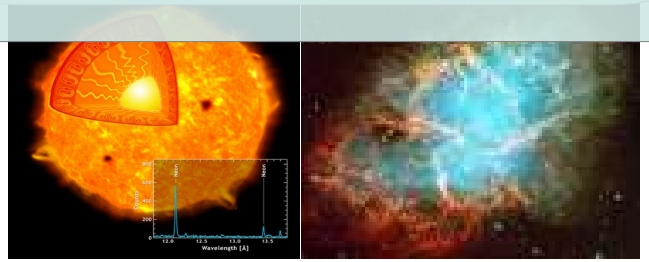
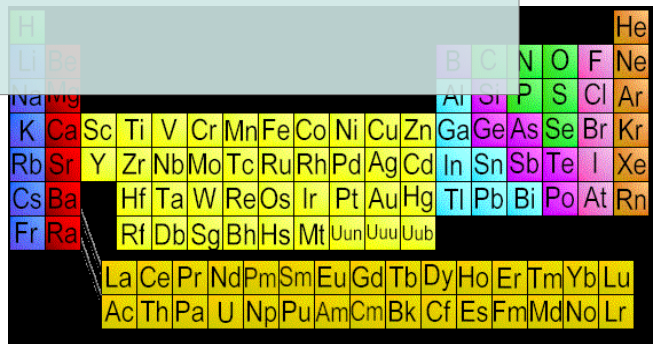
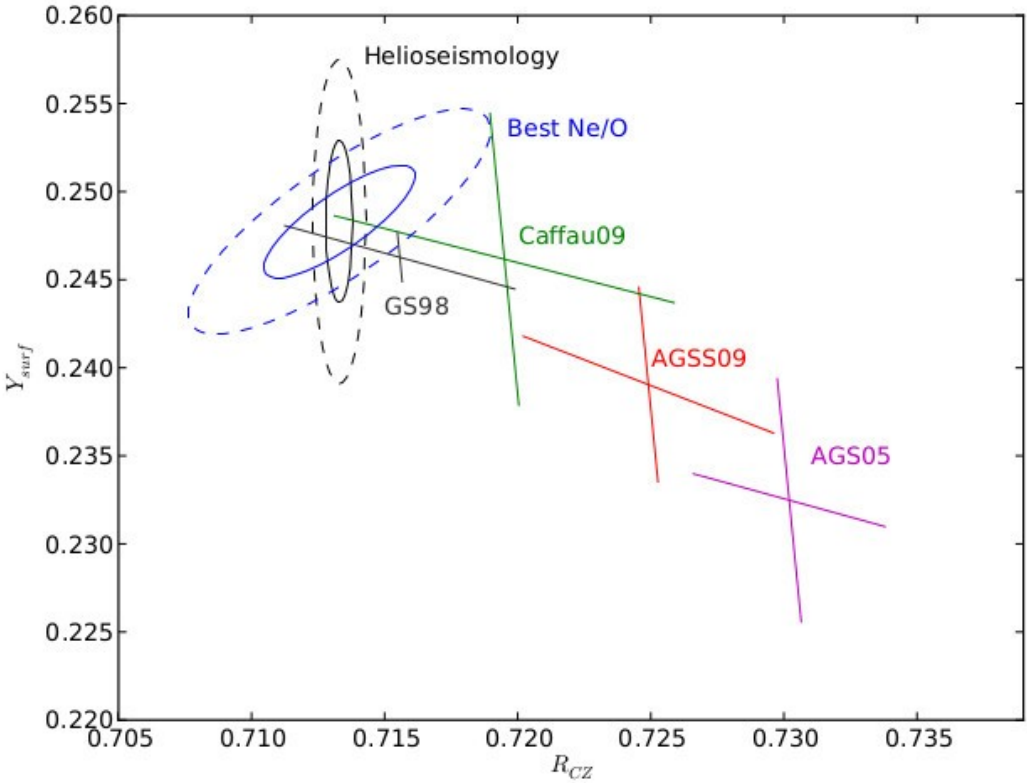
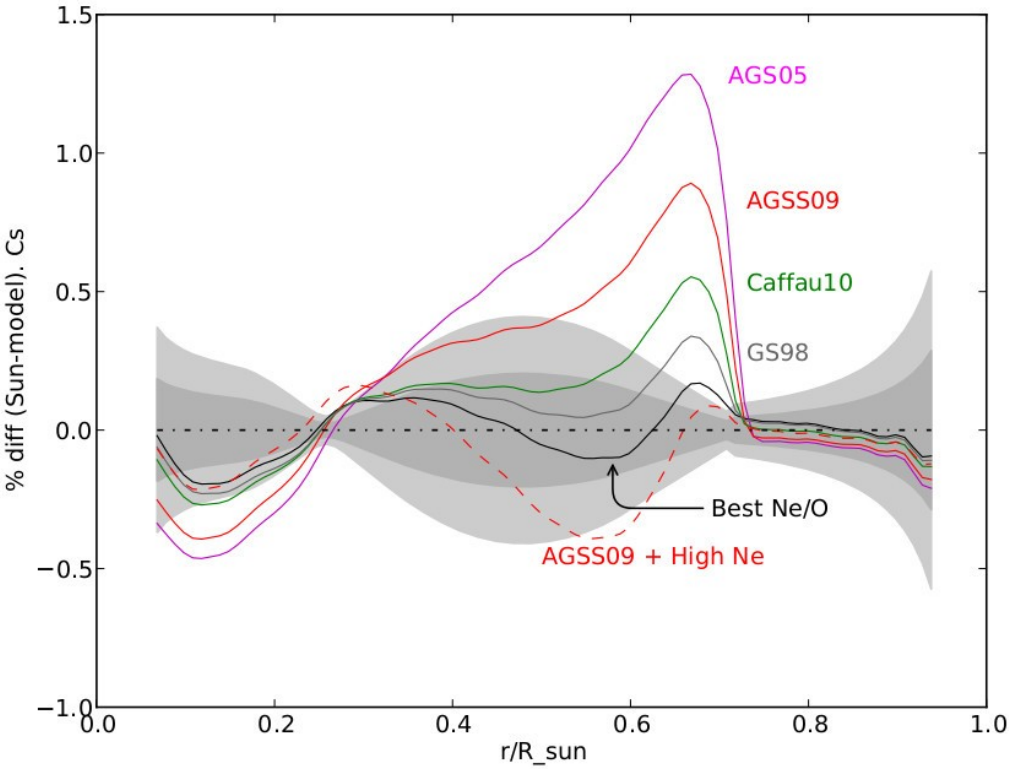




Atomic data for Astrophysics

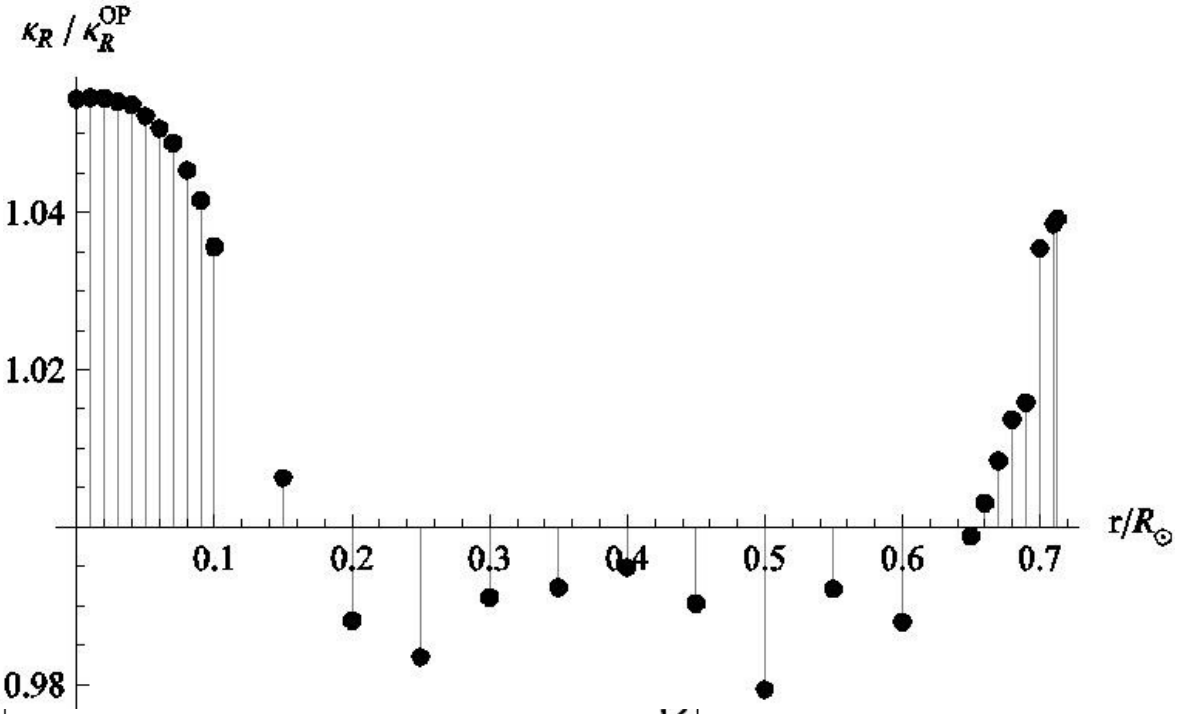
Mean opacities and Solar composition

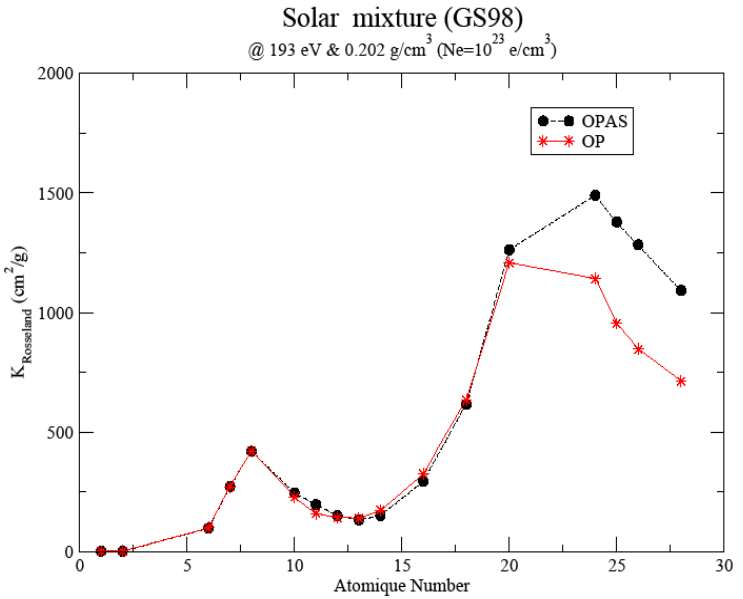


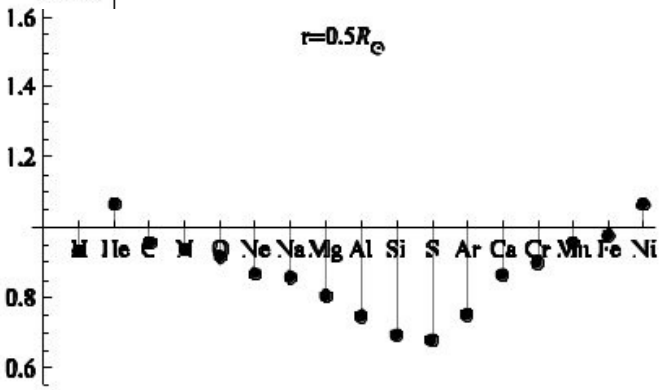


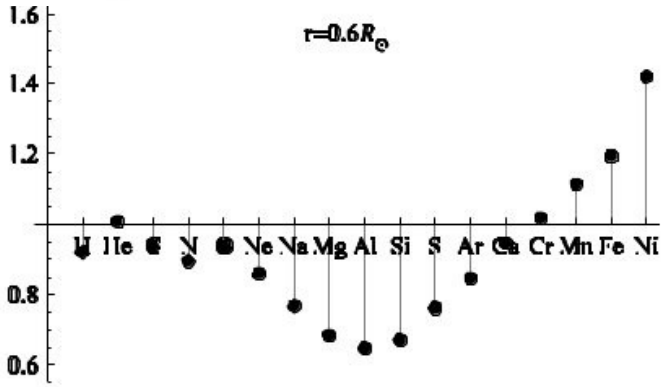
Atomic data for Astrophysics

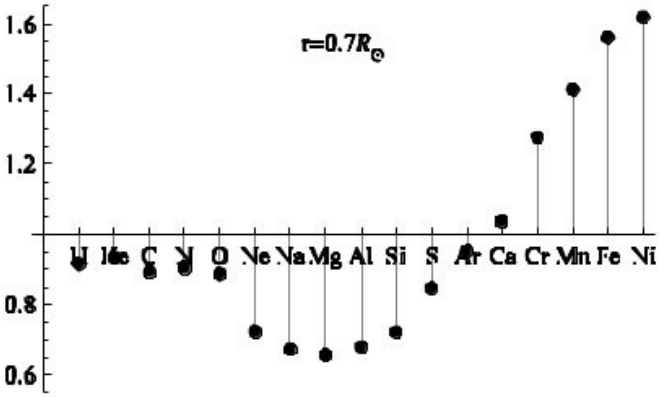
Discrepancies for element specific mean







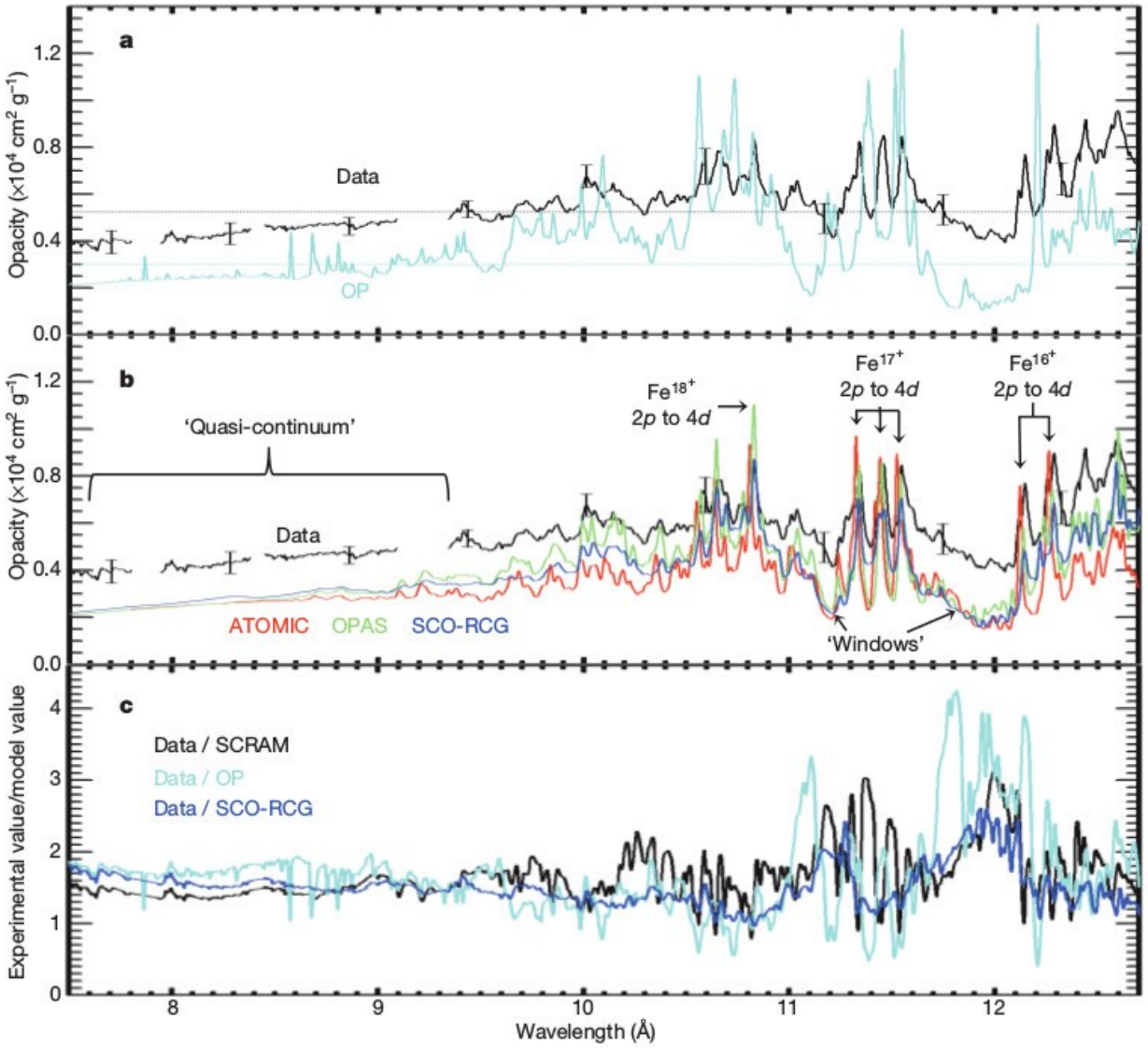




Blancard et al. 2012

Atomic data for Astrophysics

… and for the detailed monochromatic opacities .



J. Bailey et al. 2015,
Comparaisons Experiment- Theory
Exp vs OP, ATOMIC, OPAS, SCO-RCG

Theory vs Experiment: Fe at
T=150 eV – Ne = 8.6 10^{21} cm^{-3}

Atomic data for Astrophysics

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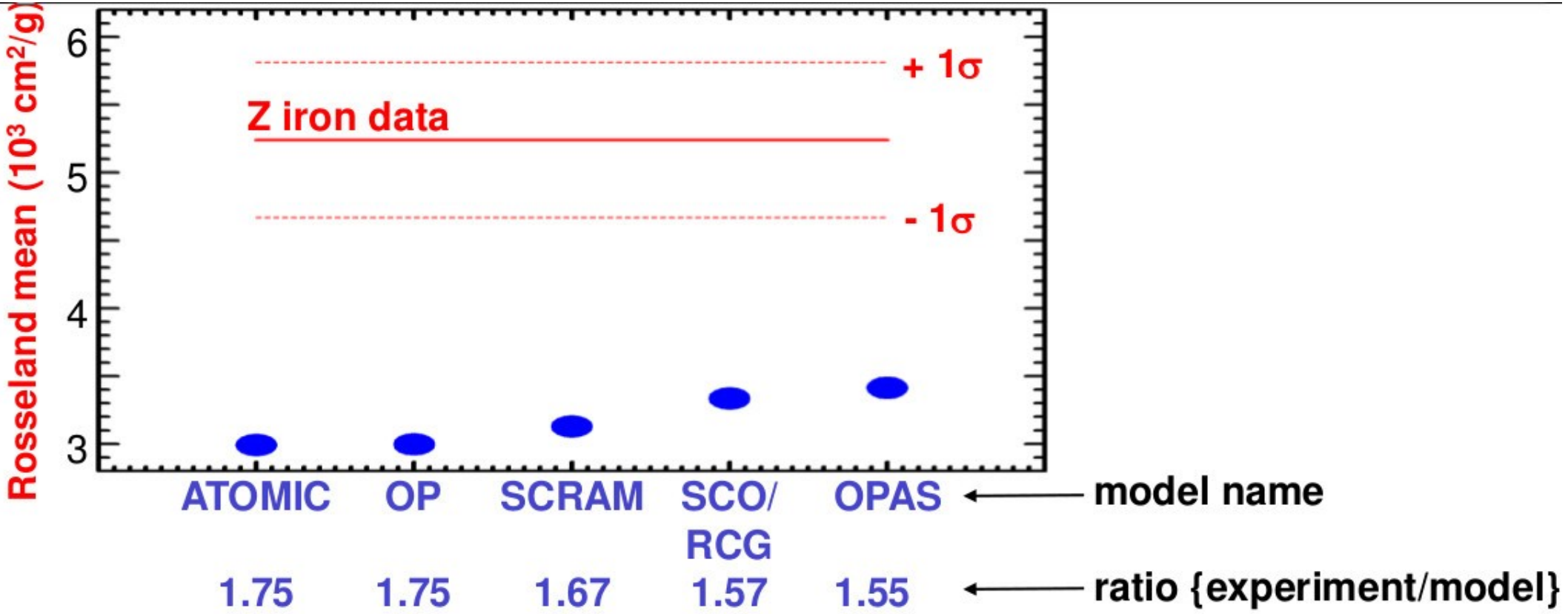


J. Bailey et al. 2016, Experiment vs Theory

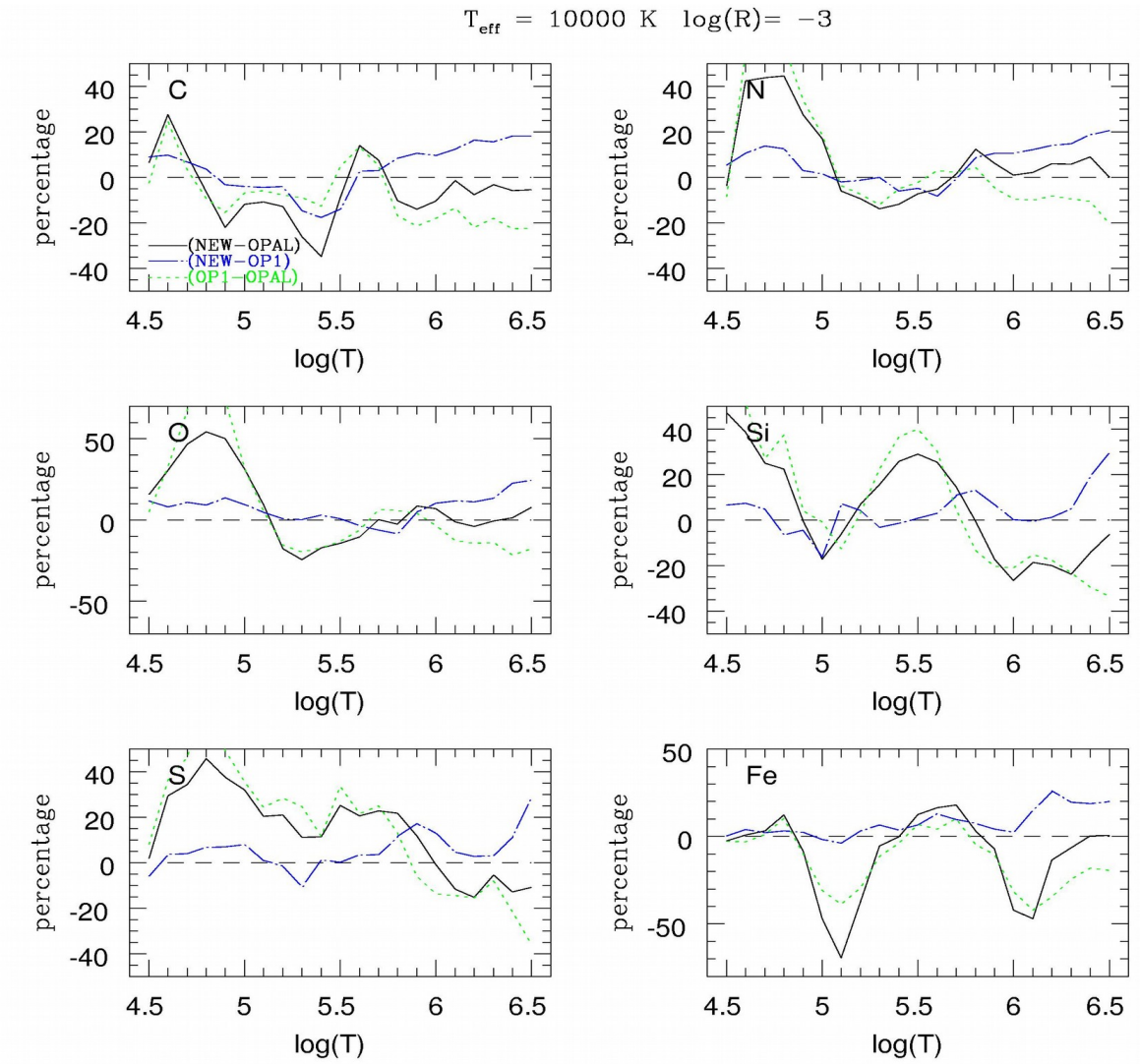
How about radiative acceleration?

First new atomic data and new monochromatic opacities

Comparison OP-OPAL

- Données OPAL extraites de travaux précédents par digitalisation des courbes.
- Même Structure stellaire
  - ➔ Simulation d'étoiles HB ou de masse intermédiaire
- Trend: Z ↗ Diff . ↗

Delahaye & Pinsonneault (2005)



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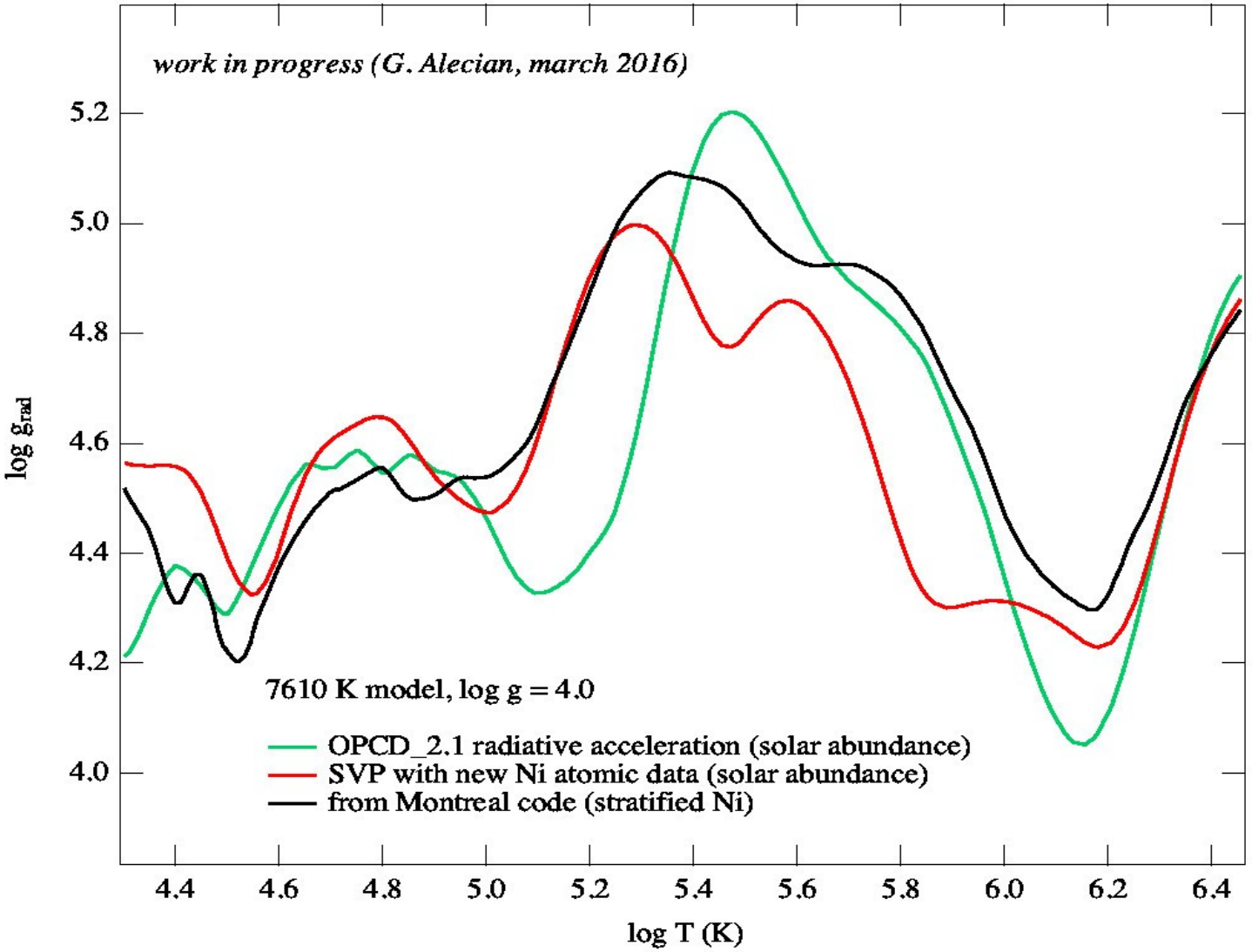


Atomic data for Astrophysics

Opacities

- 3 Steps:
  - Determination of levels populations and ionic fractions (Equation of State - EOS)
  - Calculation of raw atomic data (Atm. Phys)

    E-levels, radiative data (oscillator strengths , Photoionization cross sections)
  - Derive Monochromatic and mean opacities

    Broadening , near the hedge extrapolations for PI
- Method:

  Several approaches for different physical conditions and elements

Chemical approach	vs	***Physical approach***
The Opacity-Iron Project		***CEA, LANL, LLNL***
Free – isolated atoms/ions		Average atom + simplified atm. data
Density effect: Occupation probability		No approximation for Plasma effects
approximations 'MHD eos'		

  - Codes
    - Autostructure/Superstructure — Hulac, Cowan, ATOMIC, FAC
    - BP-RMATRIX suite of codes — OPAS, OPAL, LEDCOP, SCO-RCG
  - Aims

High quality atomic data on db	High quality eos on db
Monochromatic and mean opacities db + server	Mean opacities
Radiative accelerations on db	

Atomic data for Astrophysics

Opacities: What could be wrong?

- Ionic Fractions and level populations = EOS
- Raw atomic data (Atm. Phys)

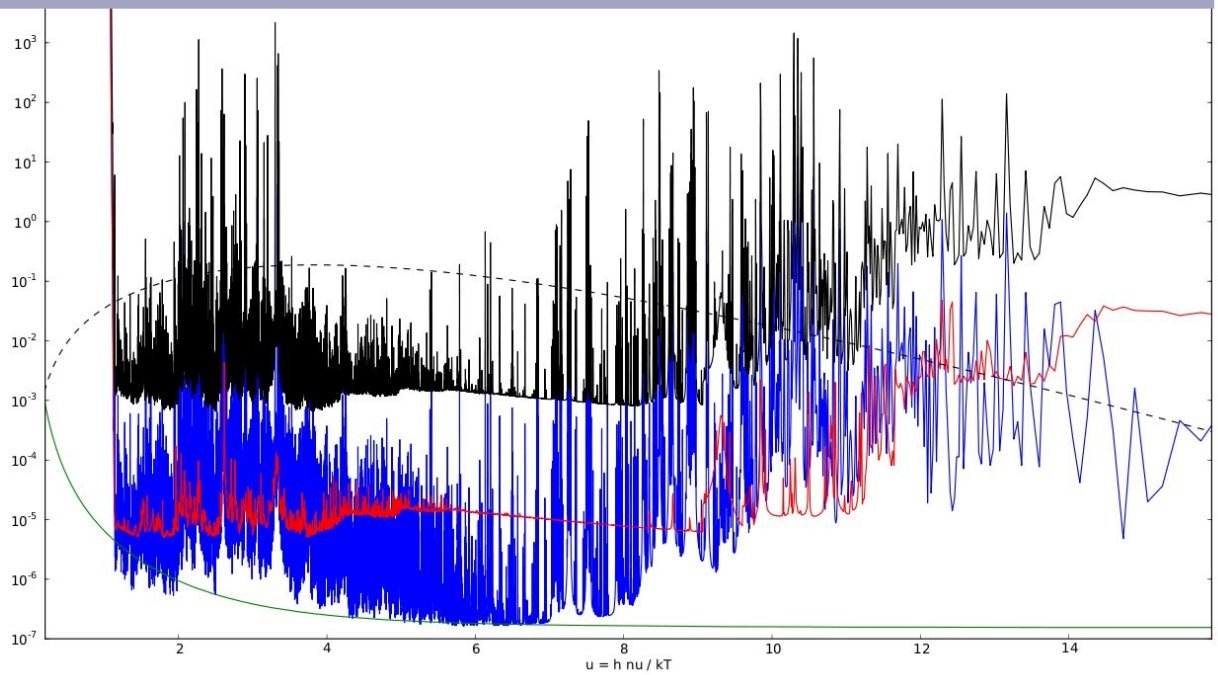
  E-levels, radiative data (oscillator strengths , Photoionization cross sections)
- Monochromatic and mean opacities

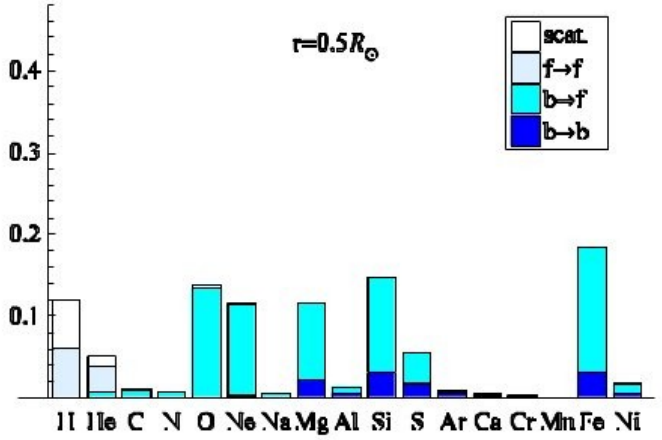
  Broadening , near the hedge extrapolations for PI
- Experiment

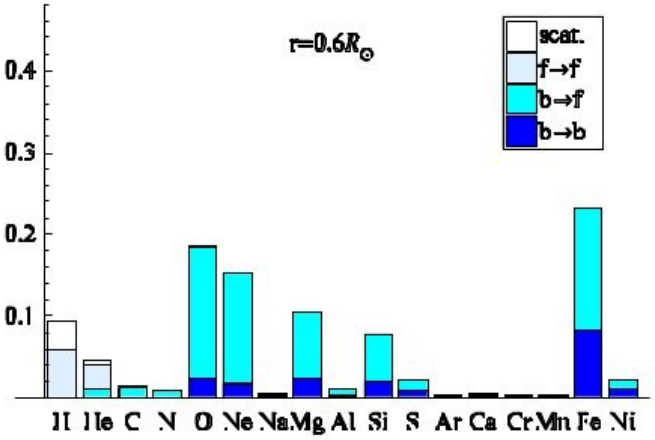
Different components of opacities

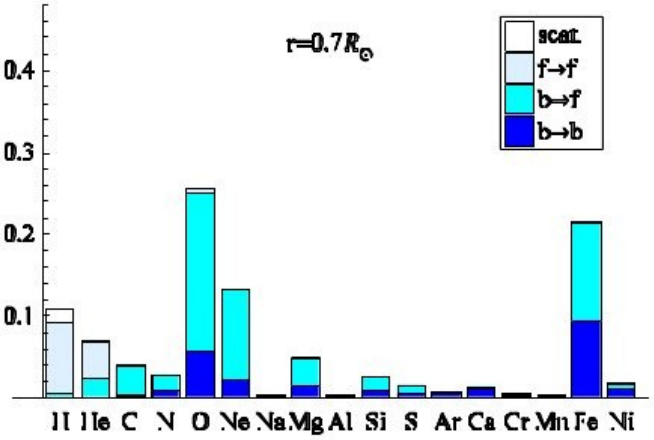
Bound-Bound vs Bound-Free vs Free-Free

- Depending on conditions, Bound-Free dominates opacity contribution in the total opacity
  - Bound-Bound (Blue)
  - Bound-Free (Red)
  - Free-Free (Green)
  - Total*100 (Black)









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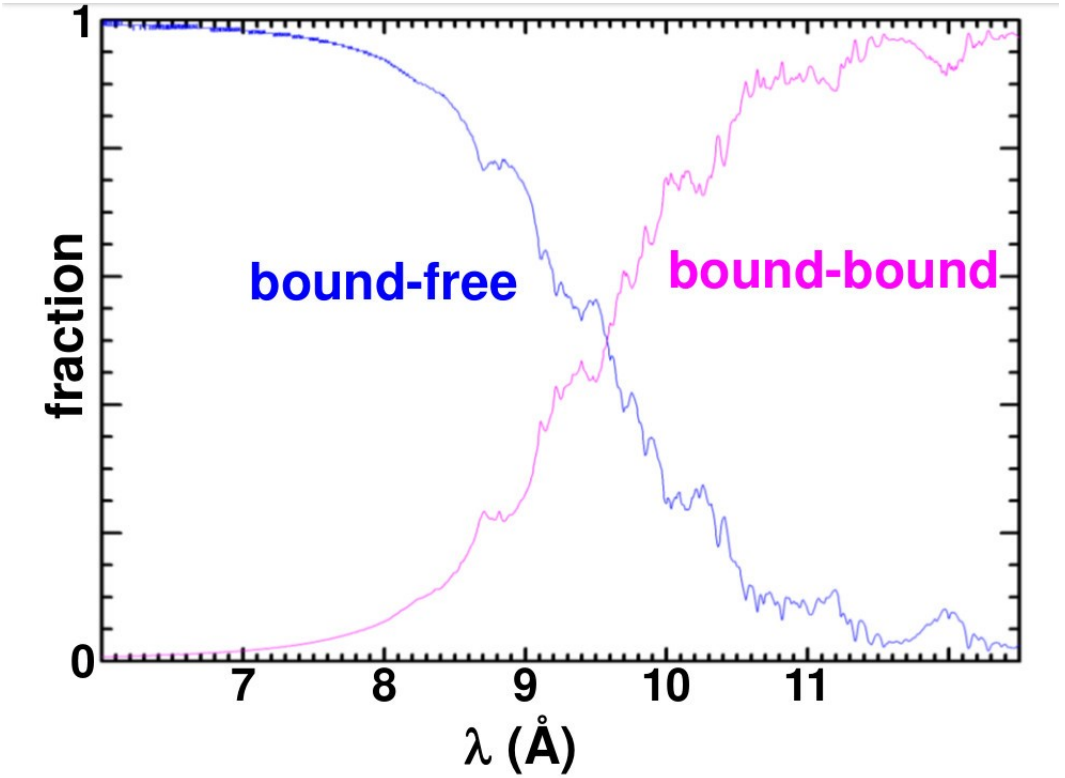
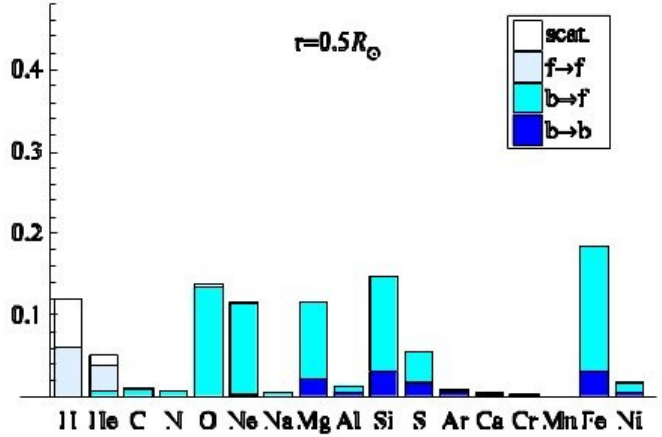
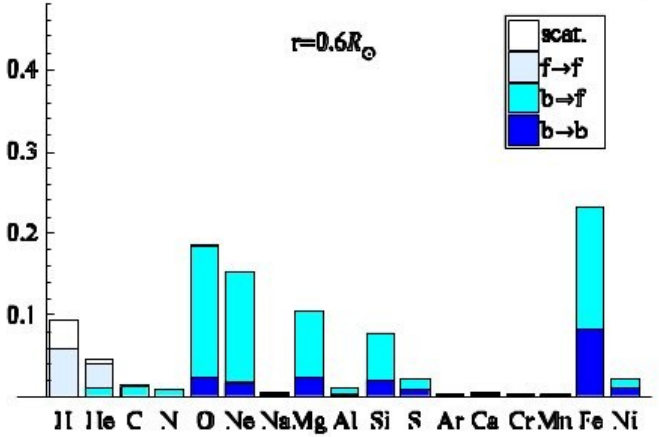






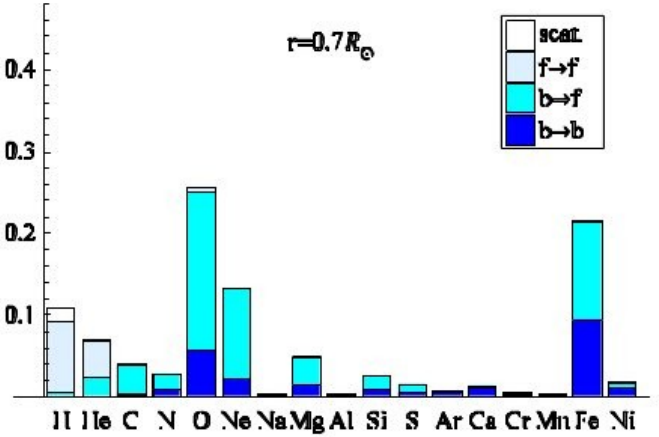
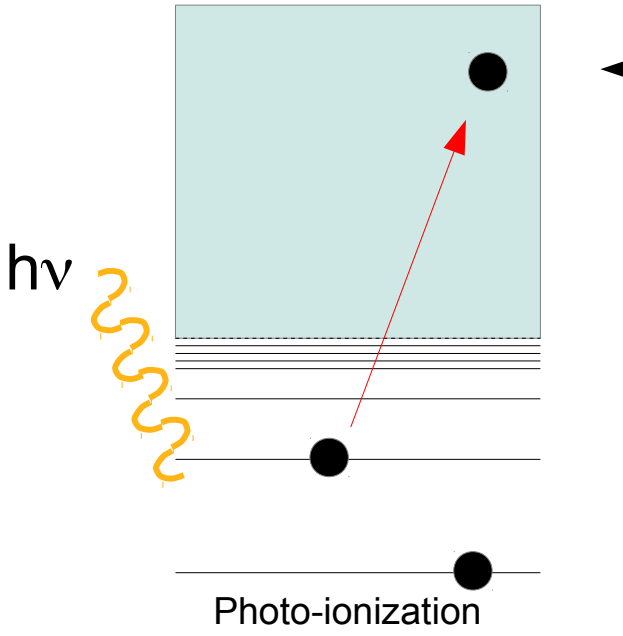


Photo-ionization – Bound-Free

Two codes – Two approaches

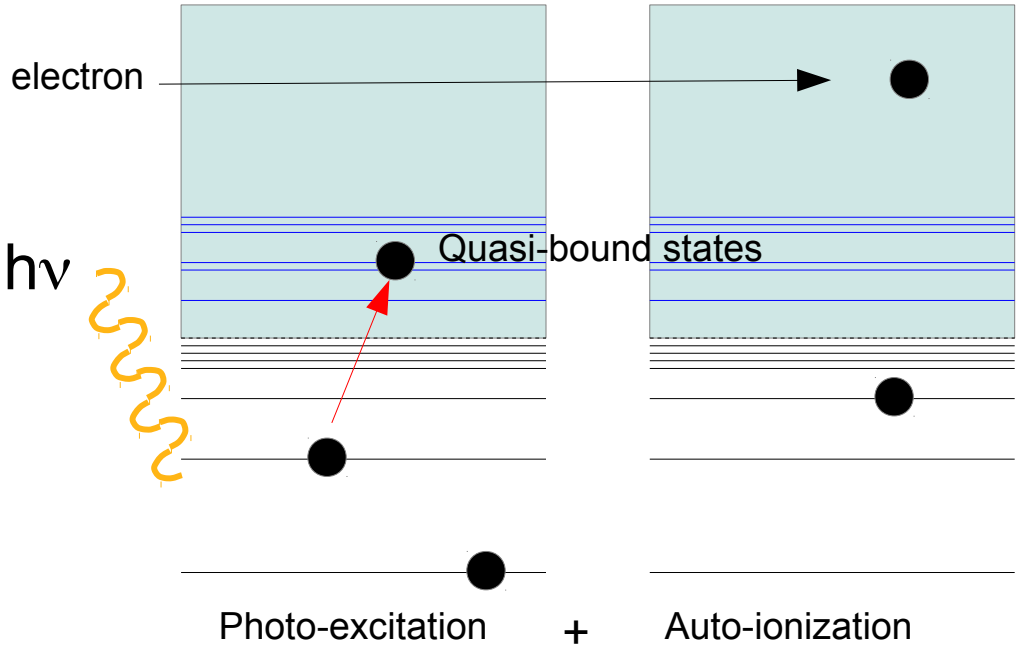
Direct Process

$A^{(n+1)+} + h\nu \rightarrow A^{n+} + e^-$



Indirect Process

$A^{(n+1)+} + h\nu \rightarrow A'^{\,n(n+1)+} \rightarrow A'^{\,n+} + e^-$



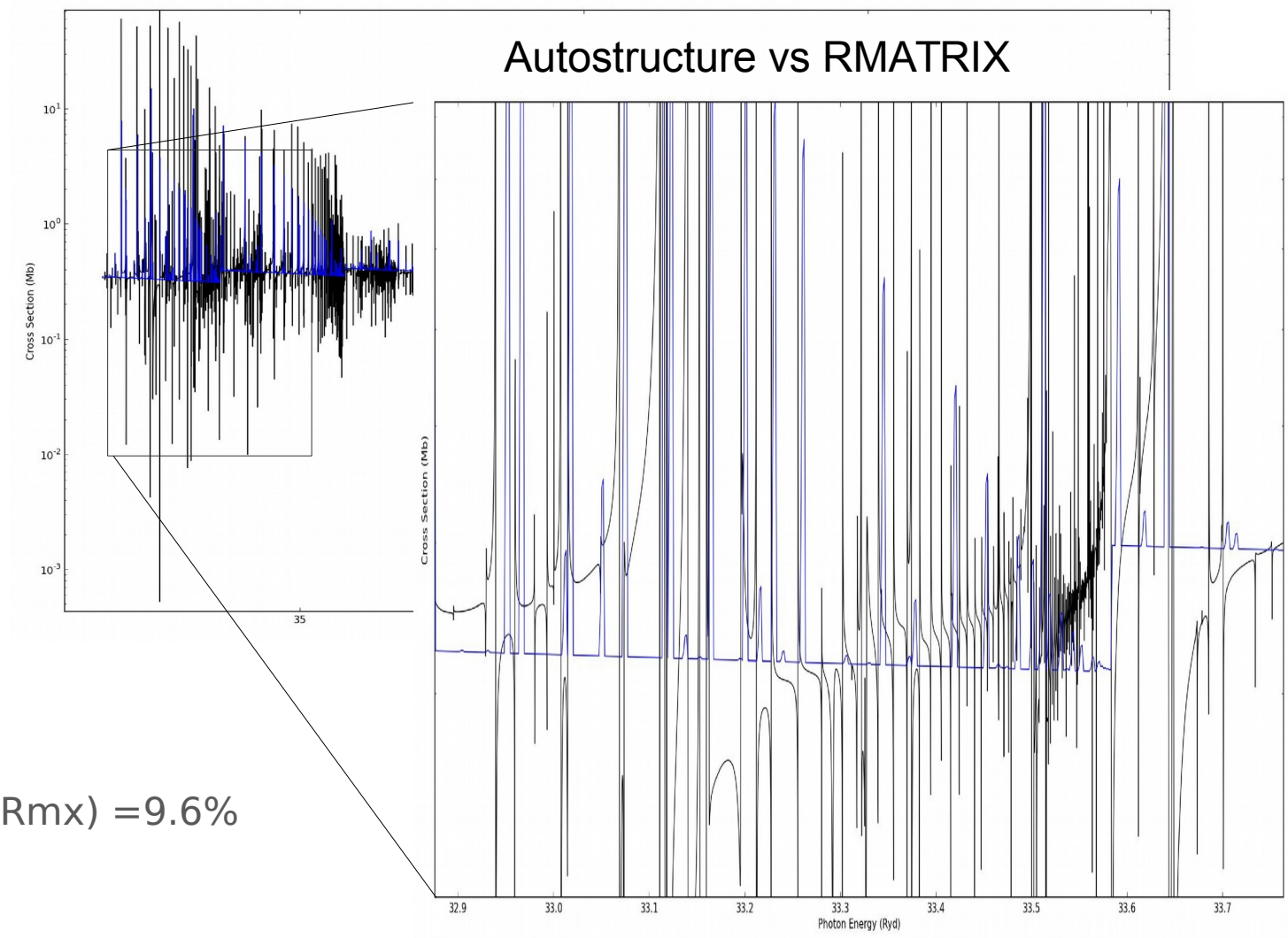
Autostructure: 2 distinct processes – 2 “independent” calculations

Rmatrix: One unique calculation – Resonances directly included.

Coupling of resonances

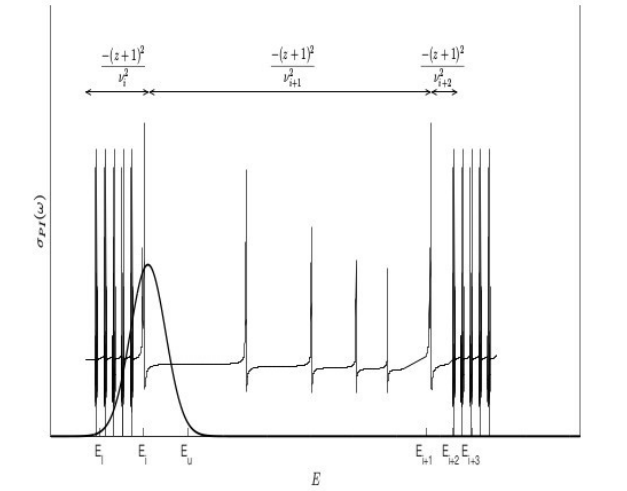
Ni XIV +hν → Ni XV+e$^-$ - Ground state photoionization

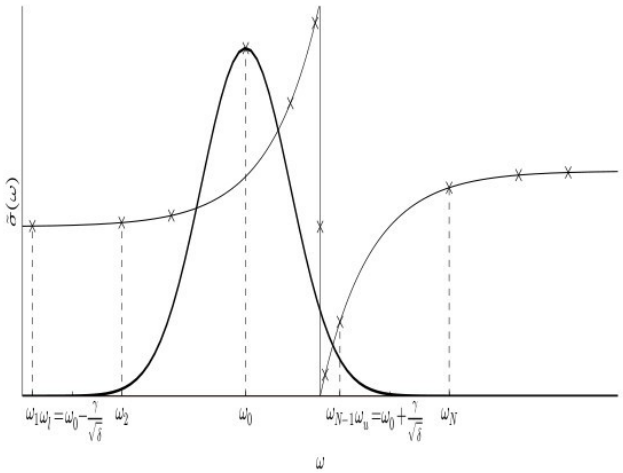
- 2 methods: Autostructure & BP-RMATRIX
  - AS (Blue): Direct PI & Indirect PI – two distinct calculations
  - BPRM (Black): interferences between resonances and background PI
- Results for GS:
  - $(\kappa_R(Rmx)-\kappa_R(AS))/\kappa_R(Rmx) = 9.6\%$

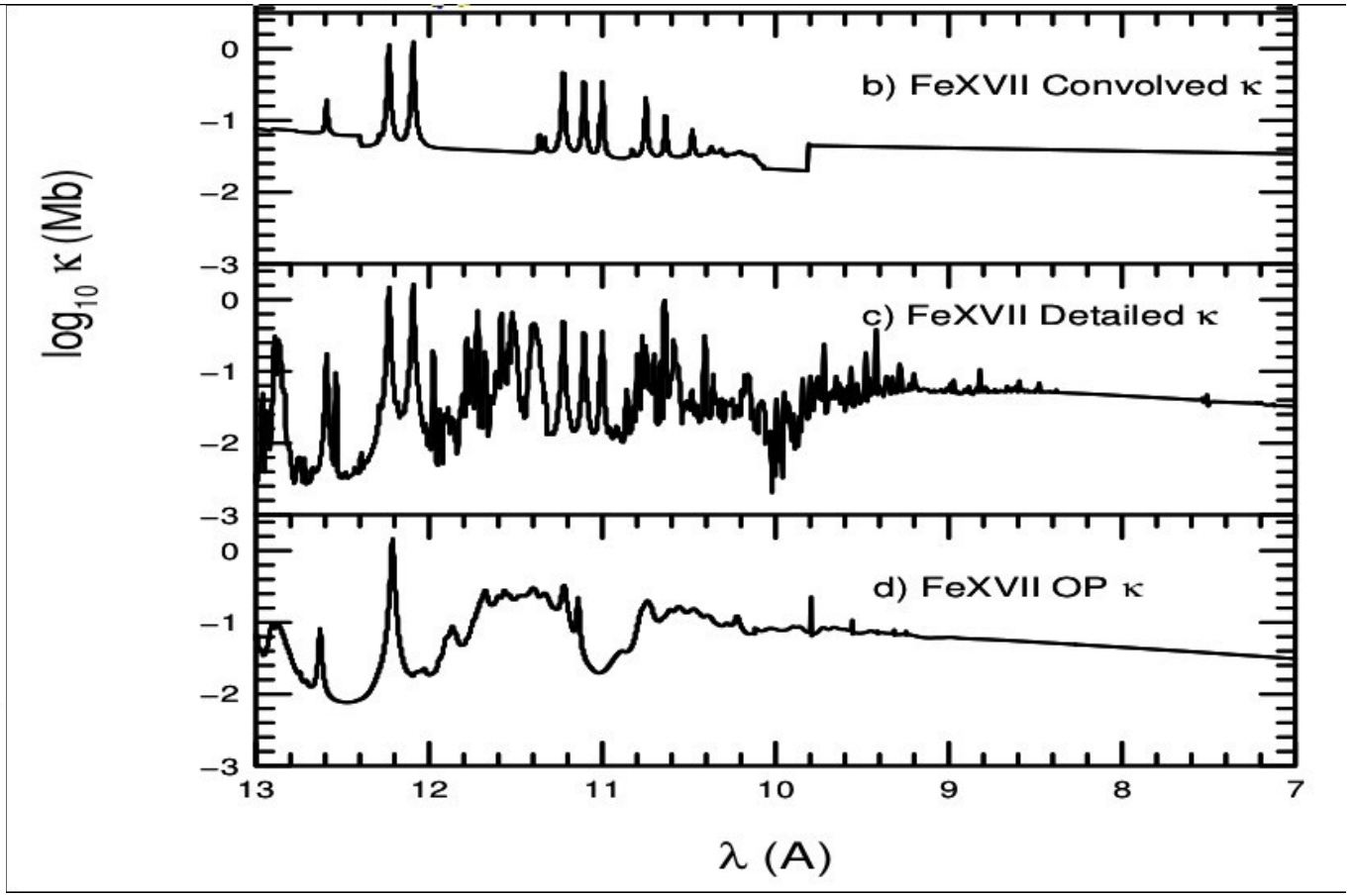


Broadening of resonances – Fe XVII test

Fe XVII +hν → Fe XVIII+e$^-$ - Broadening







Pradhan 2016, Nahar & Pradhan 2016

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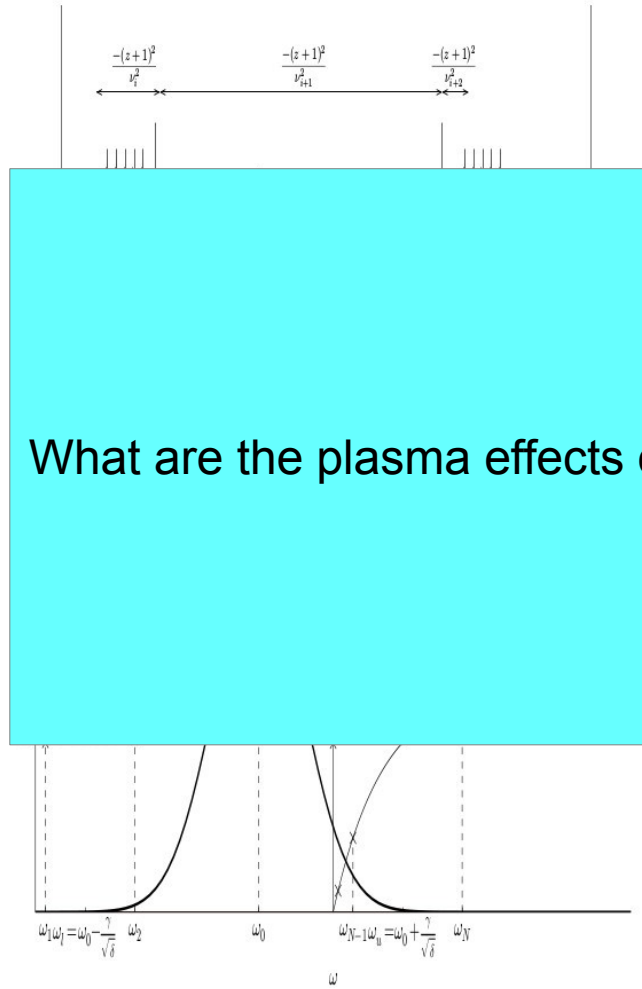
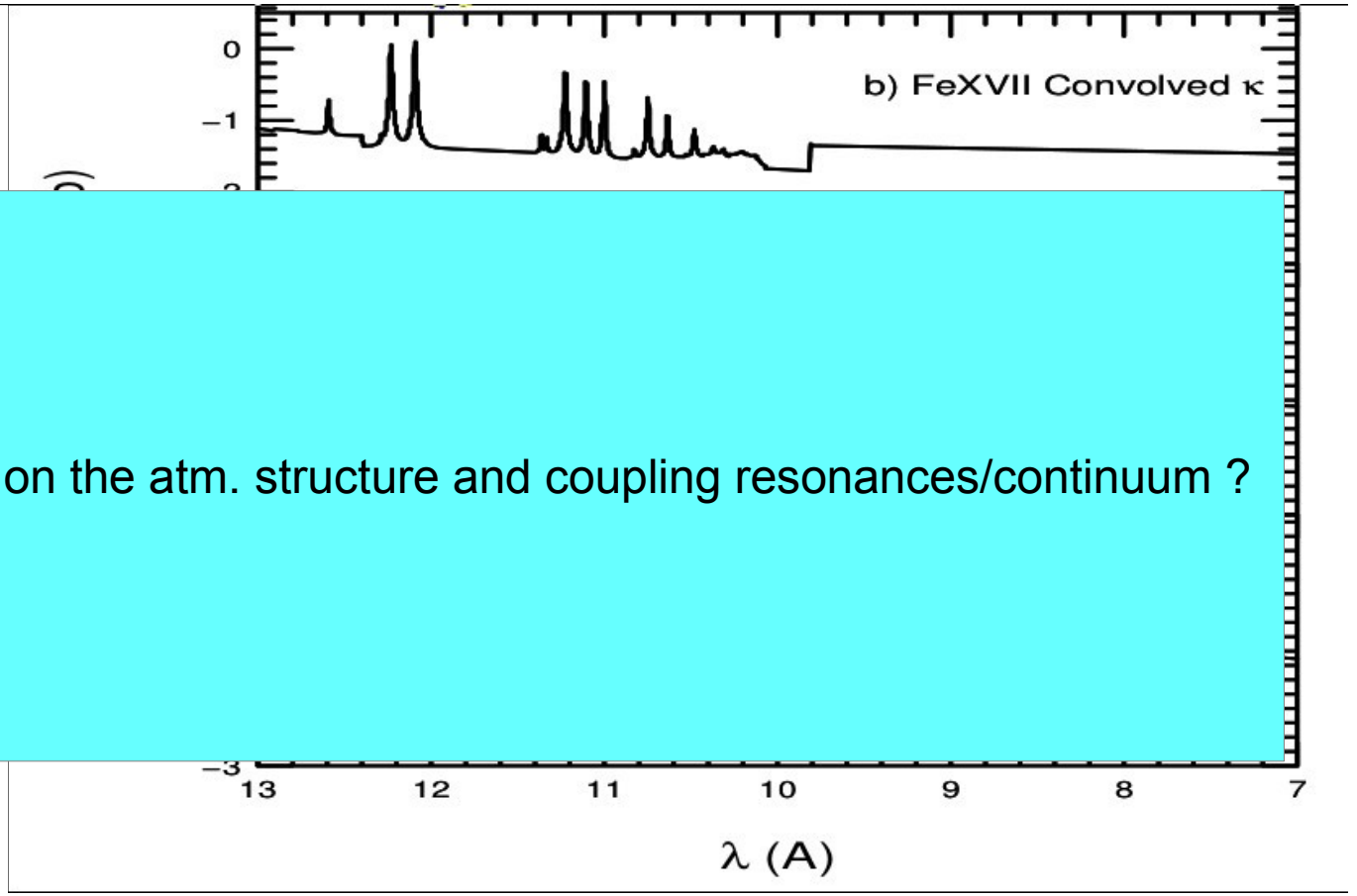


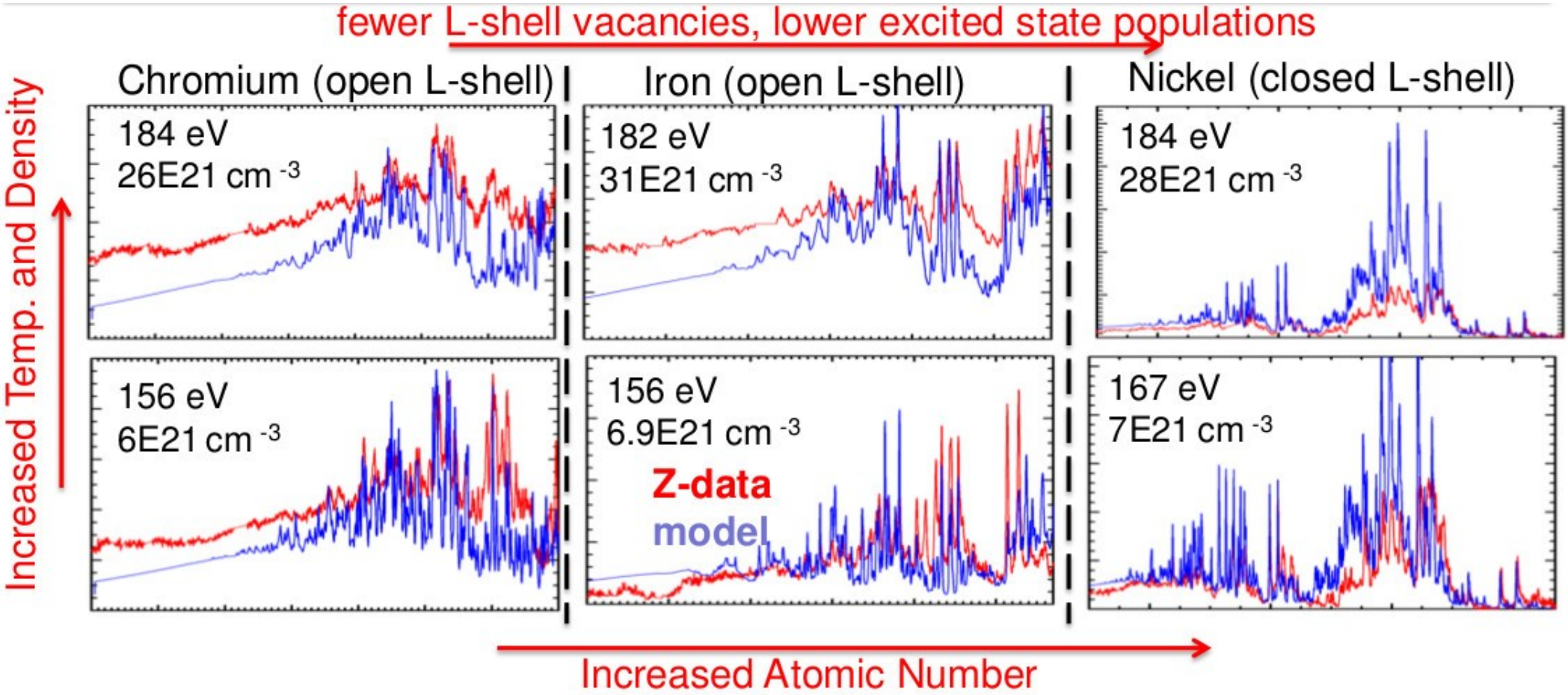


What are the plasma effects on the atm. structure and coupling resonances/continuum ?

Pradhan 2016, Nahar & Pradhan 2016

Any other ideas?

Cr, Fe and Ni



Bailey et al. 2016

Lots of activities
Theory – Experiments – Applications cycle

Theoretical Atomic Data

Codes:

- The Iron Project & The Opacity Project (IPOPv2)
  - BPRM vs DARC vs Autostructure
  - Broadening
  - EOS
- Others:
  - LANL – DW code vs OP – DW AutoStructure
- Optimization of codes for heavy elements

Workshop in 2017:
Physical (OPAL-OPAS-LEDCOP ...) vs Chemical (IPOPv2)

Applications Modelisation/Simulation

Stellar Structure & evolution:

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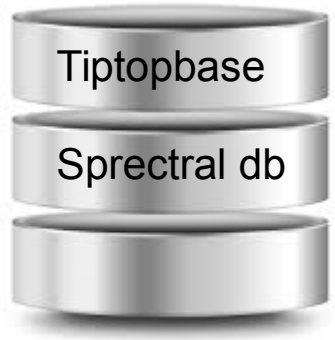

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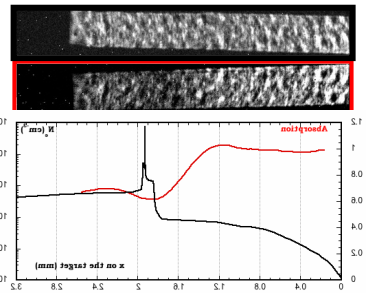

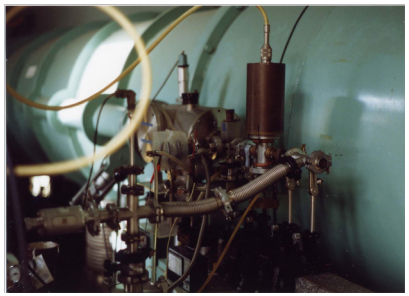

Prospective

- Experiments on intense laser (LMJ)?
  - Rejected!
- Photoionization experiment?
  - To be designed

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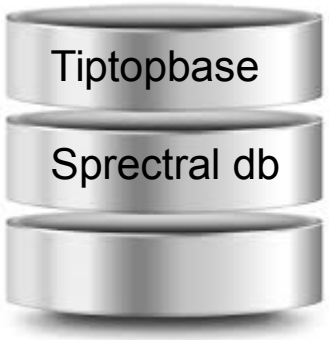

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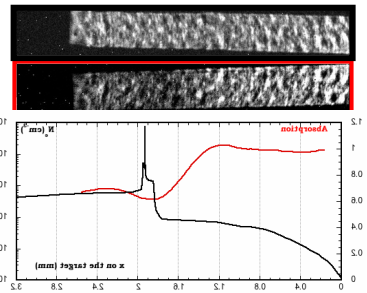

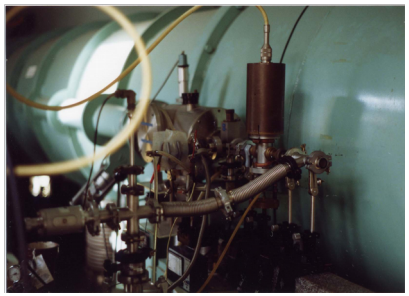

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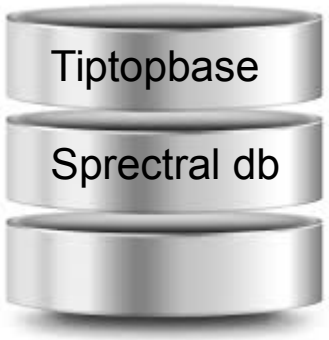

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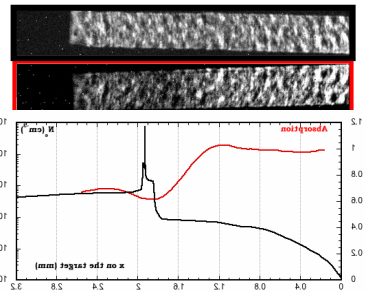

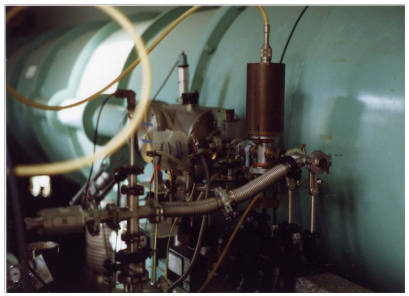

Prospective

- Experiments on intense laser (LMJ)?
  - Rejected!
- Photoionization experiment?
  - To be designed

Lots of activities
Theory – Experiments – Applications cycle

Theoretical Atomic Data

Codes:

- <u>The Iron Project & The Opacity Project (IPOPv2)</u>
  - BPRM vs DARC vs Autostructure
  - Broadening
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- <u>Others:</u>
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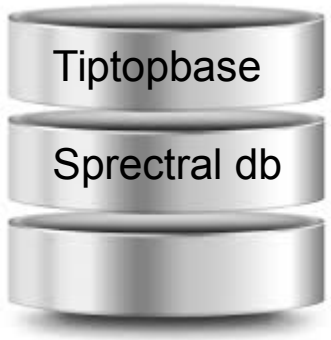
Workshop in 2017:
Physical (OPAL-OPAS-LEDCOP ...) vs Chemical (IPOPv2)



Applications Modelisation/Simulation

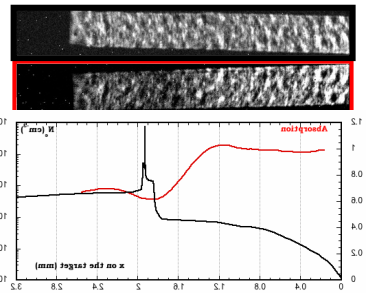
Stellar Structure & evolution:

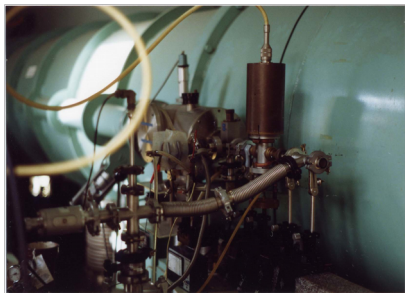
- New opacity tables with high density grid in T,Ne and compositions**.**
- Radiative acceleration - benchmarking

Code:

- Yale Rotational Evolution Code (YREC)

Experiments





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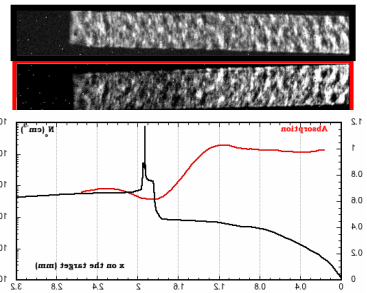

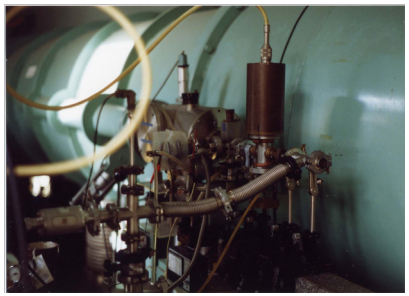

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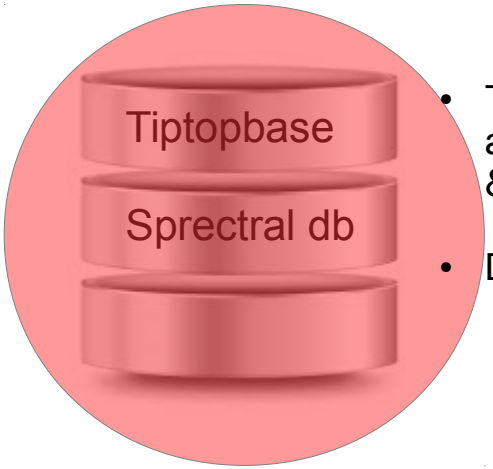

- Tools for data analysis, comparison & visualization for users
- Data quality estimation

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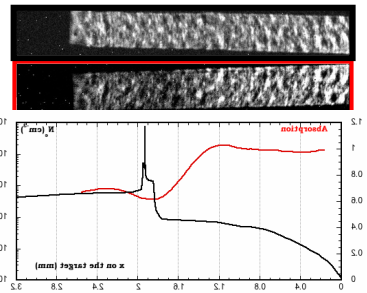

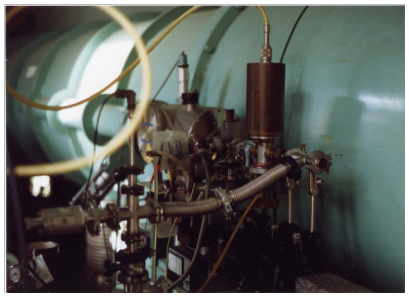

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