Theoretical and Experimental Opacity Activities for a good interpretation of helio & asteroseismic probes

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and

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- Motivations
- The radiative interior of Sun and solar-type stars
- The envelop of massive stars
- How to measure

SoHO COROT KEPLER SDO PICARD

Strong development of solar and stellar seismology

1995-2015

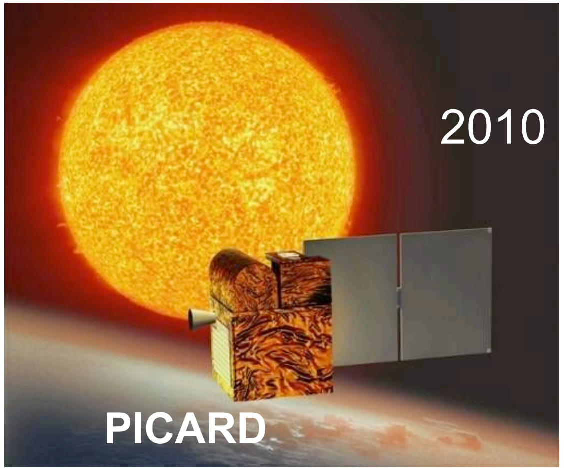
COROT
2006-2012

2008

KEPLER

HMI/SDO

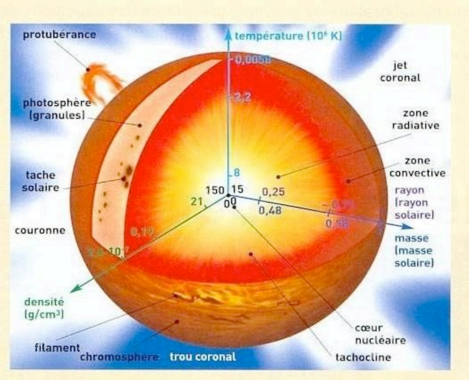
2010



2010

PICARD

Parallel program to progress both on dynamics and microphysics of radiative zones



« Our understanding of the Universe comes first from our knowledge of stars »

H. Bethe

Stellar evolution equations based on the microscopic description of the stellar plasma

Radiative interior of low mass stars

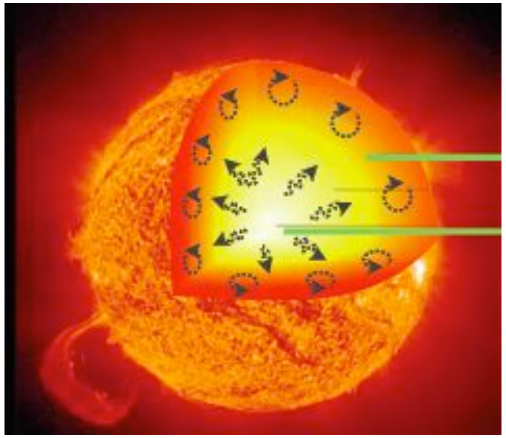
Radiative transport

ionization of the different species

- $dT/dr = - 3/ 4ac [kr /T^3] [L(r)/ 4p r^2]$ energy is transported by photons
- **opacity coefficients (mean Rosseland value) depend directly on the composition**

Envelope of massive stars

radiative transport +radiative acceleration: energy photon spectrum



Low mass stars

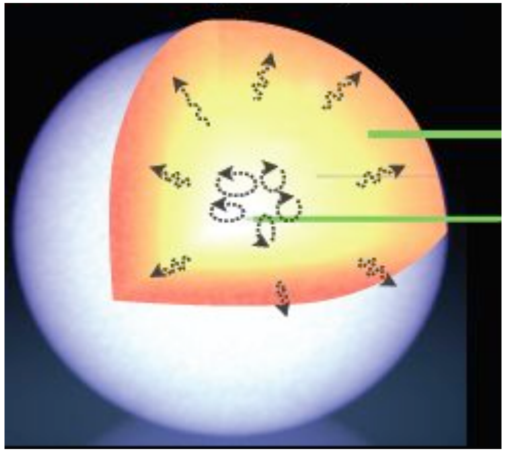
SOHO

SDO

PICARD

COROT

KEPLER



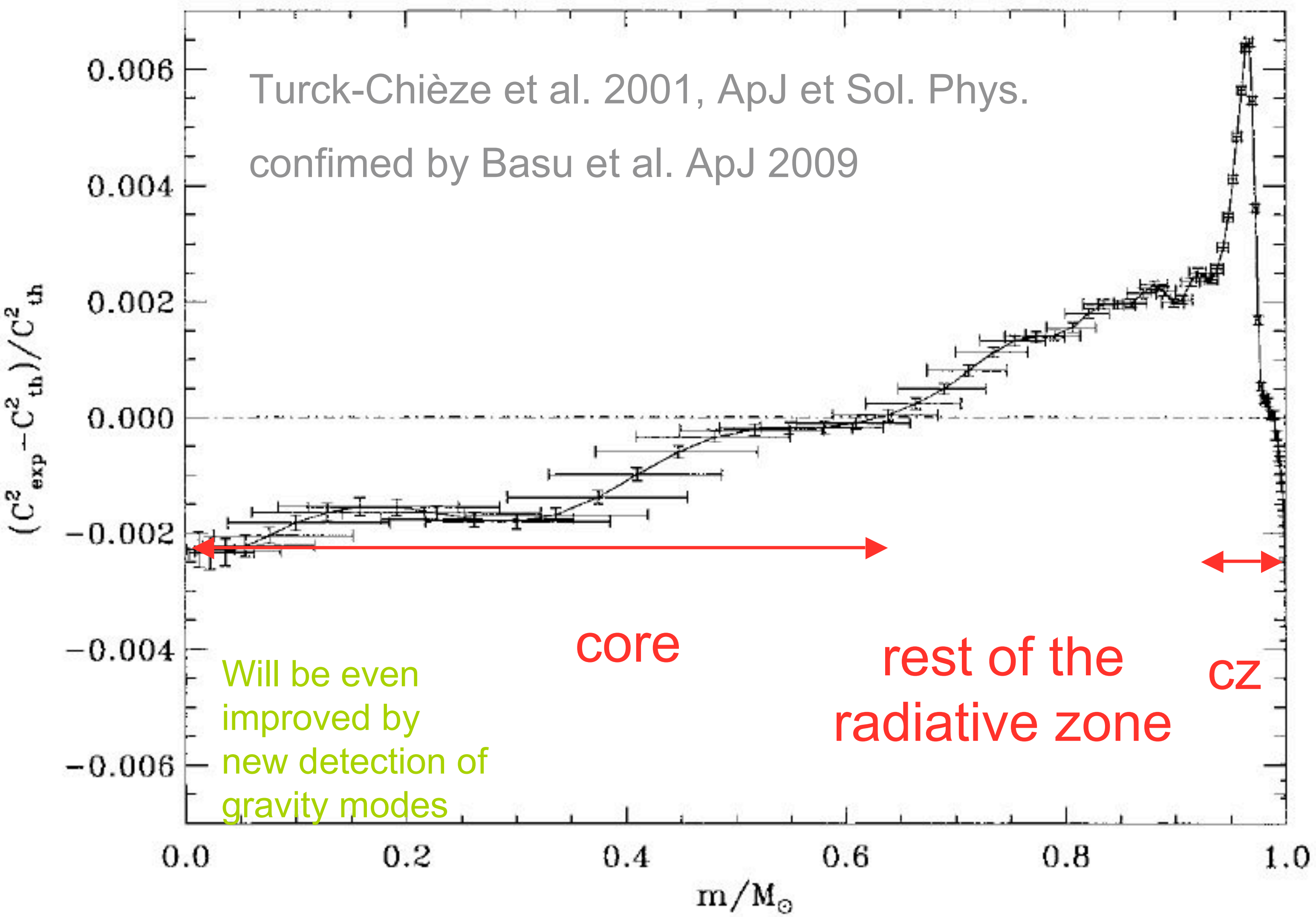
Stars > 1.5 solar mass

COROT,

KEPLER

PLATO

Extraction of the difference of the square of the sound speed + density profiles between observation and model in using the frequencies of GOLF et MDI /SoHO

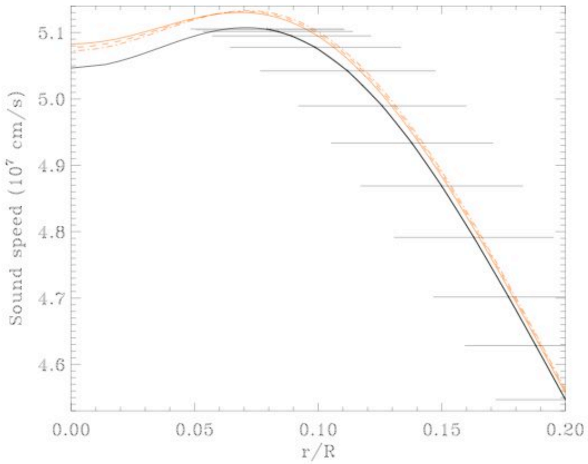


Turck-Chièze et al. 2001, ApJ et Sol. Phys.

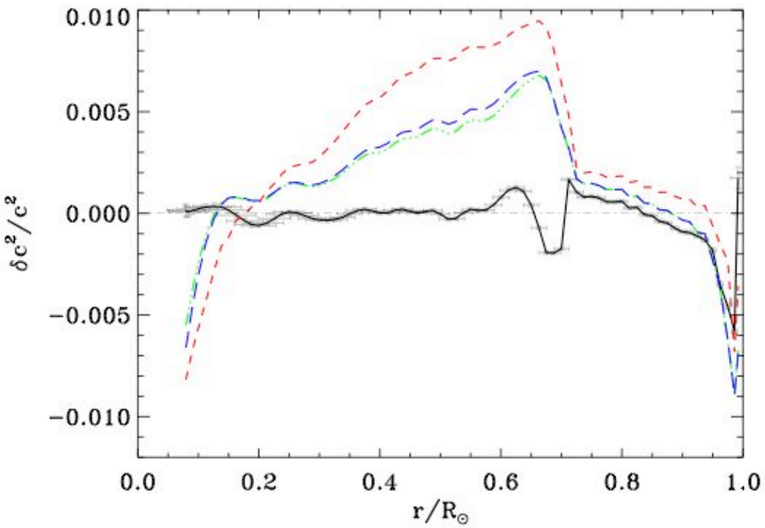
confimed by Basu et al. ApJ 2009

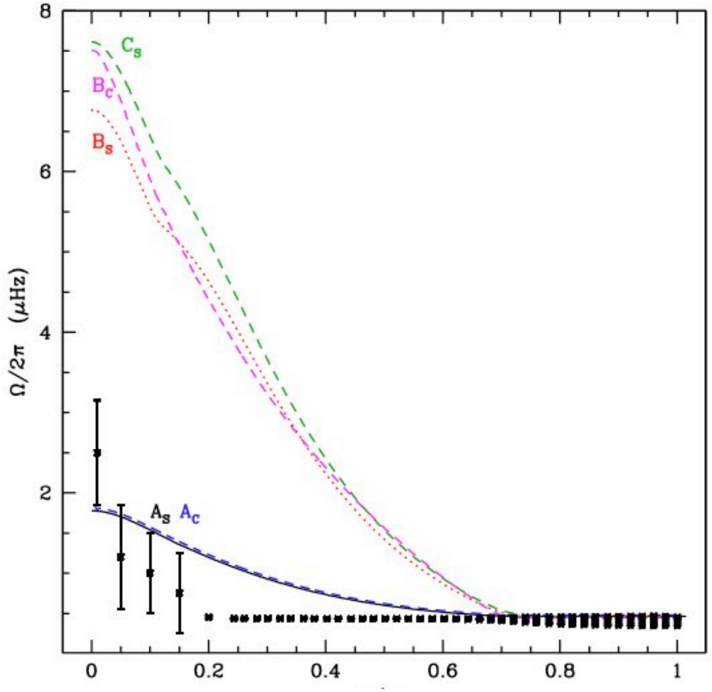
Will be even improved by new detection of gravity modes

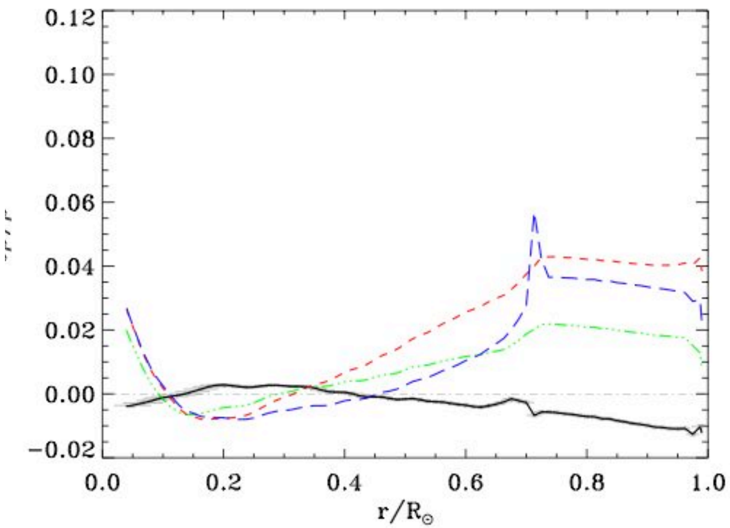
See posters Dia-7 and Model-15



T-C, Piau, Couvidat 2010







T-C, Palacios, Maques, Nghiem, ApJ 2010

Opacity coefficients in the central radiative zones of solar-like stars

contribute to a precise determination of the solar central temperature and to the longevity of stars

$dT/dr = - 3/ 4ac\ [\kappa\rho\ /T^3]\ [L(r)/ 4\pi\ r^2]$

Livermore opacities Iglesias and Rogers 1996, 2000

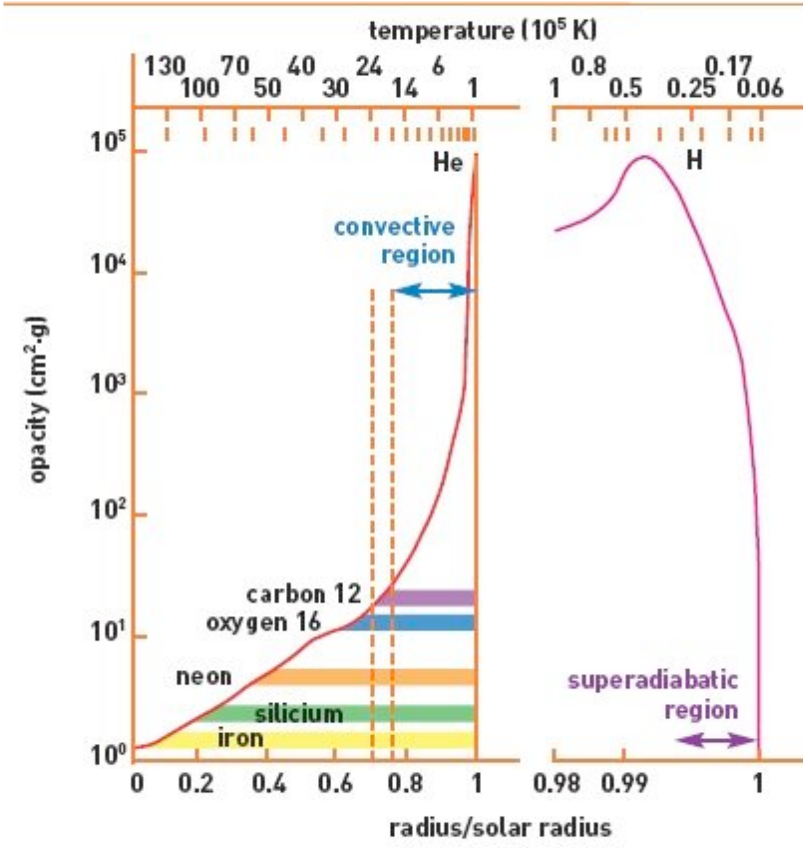
OPAL tables can be done for different compositions

Spectra generally not distributed

OP tables with spectra

Seaton et al., Badnell et al.

Solar case

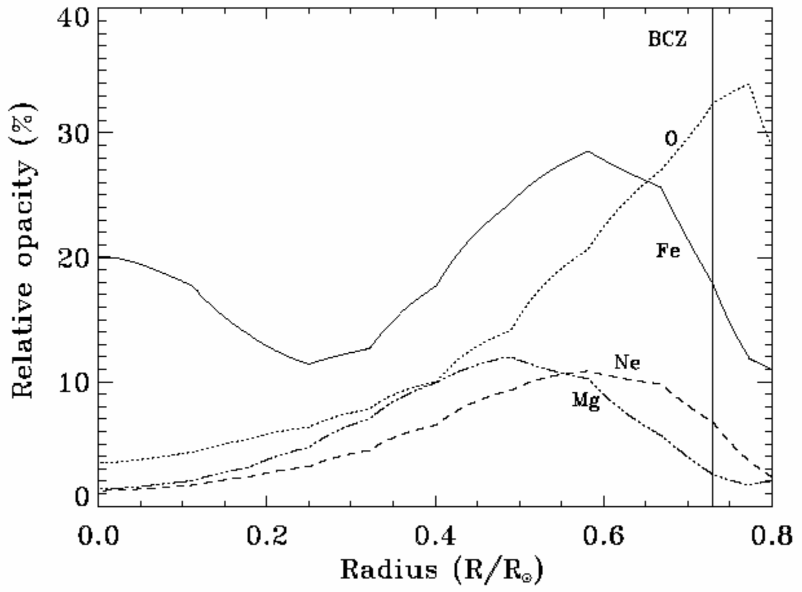


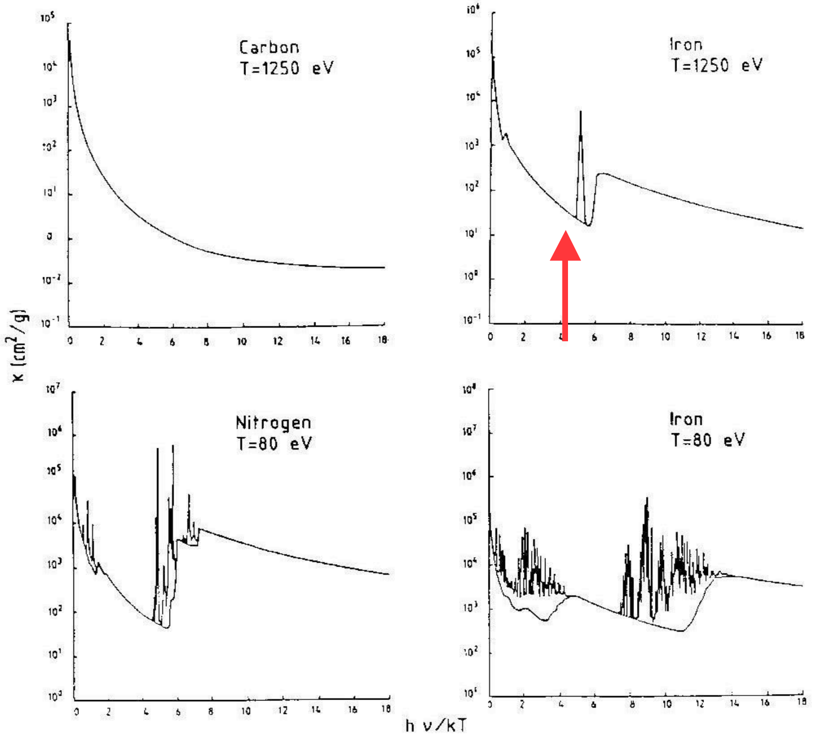
Lifetime of 0.8 $M_\odot$ Z= 0.001 14.33 Gyr

Lifetime of 0.8 $M_\odot$ Z= 0.02 22 Gyr

Turck-Chièze et al. Phys. Rep. 230, 1993 using Los Alamos library 1982

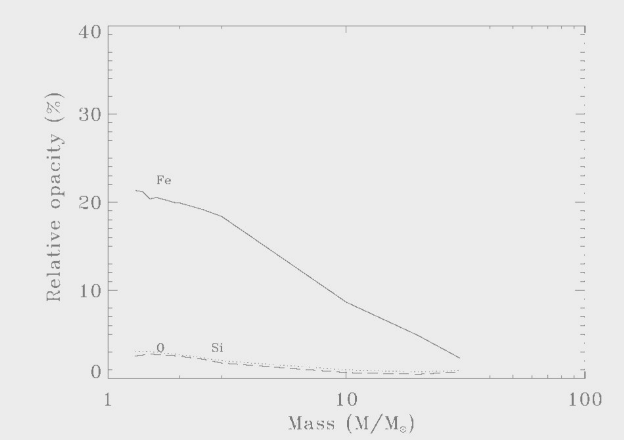
Turck-Chièze et al. Phys. Reports, 1993, Phys. Rev. Lett 2004, Turck-Chièze et al. HEDP 2010





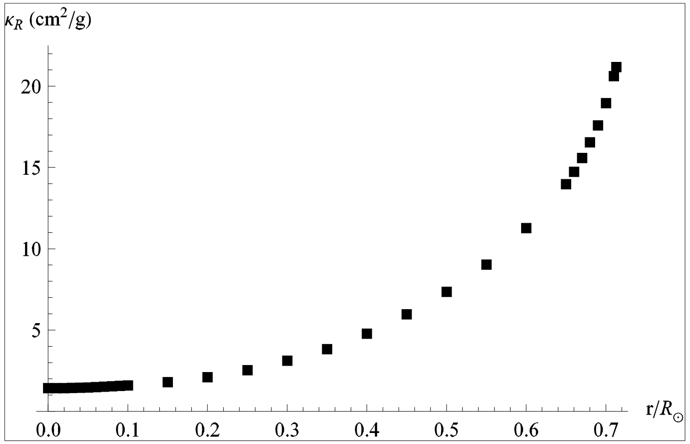
Iron (10^{-4}), among the Z elements dominates in the solar interior and then oxygen (about 10^{-3})

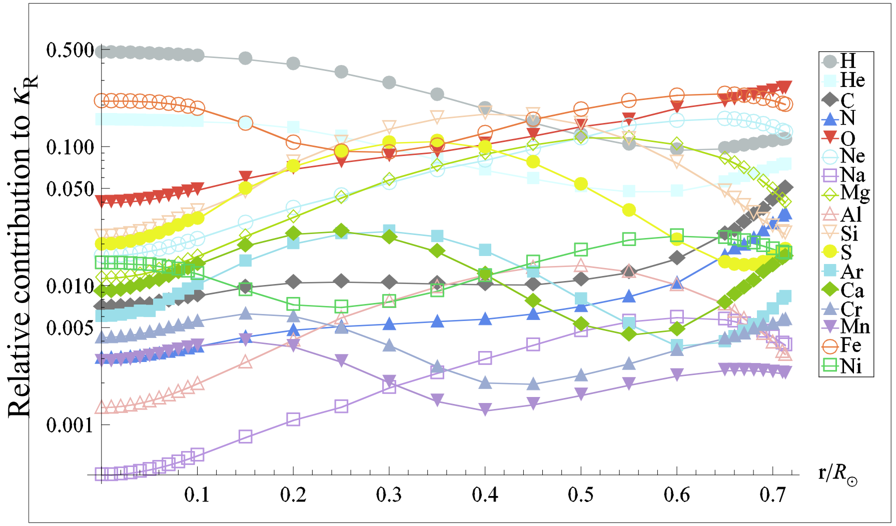
Asplund composition and OPAL opacities

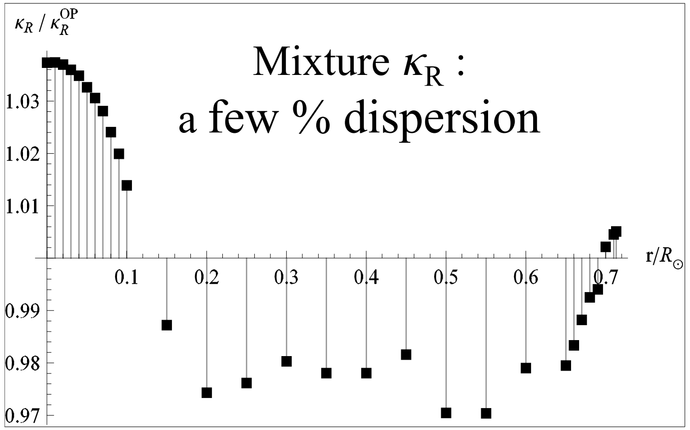


At the BCZ the iron plays less and less role because it becomes totally ionized when mass increases

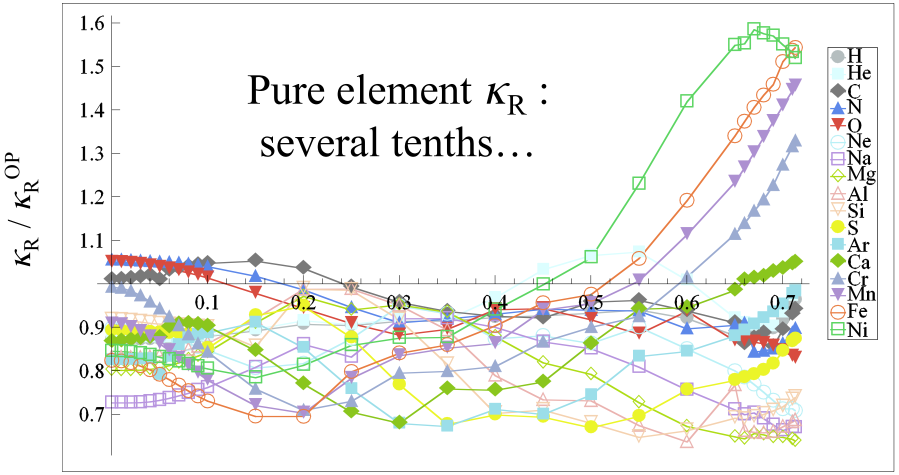
OPAS vs OP Blancard, Cosse and Faussurier 2010







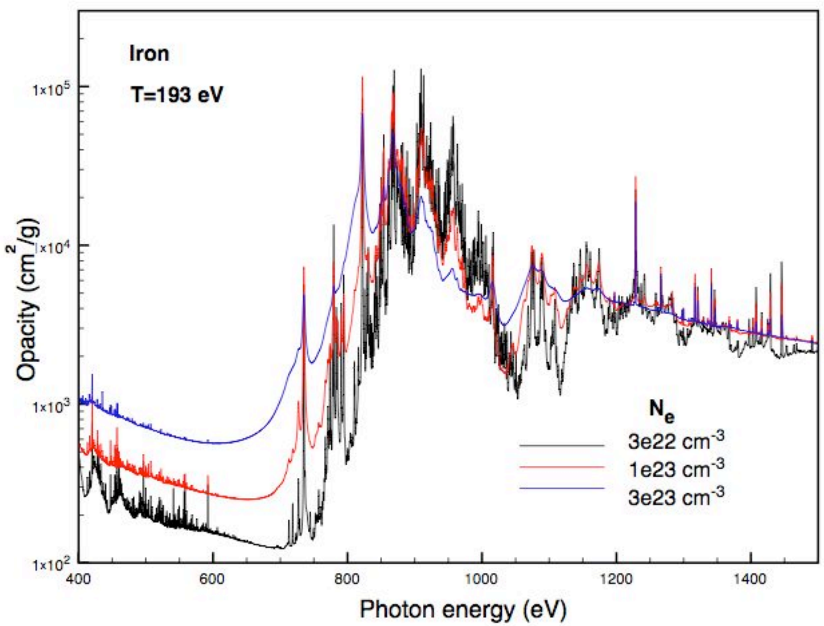
Mixture κ_R :
a few % dispersion

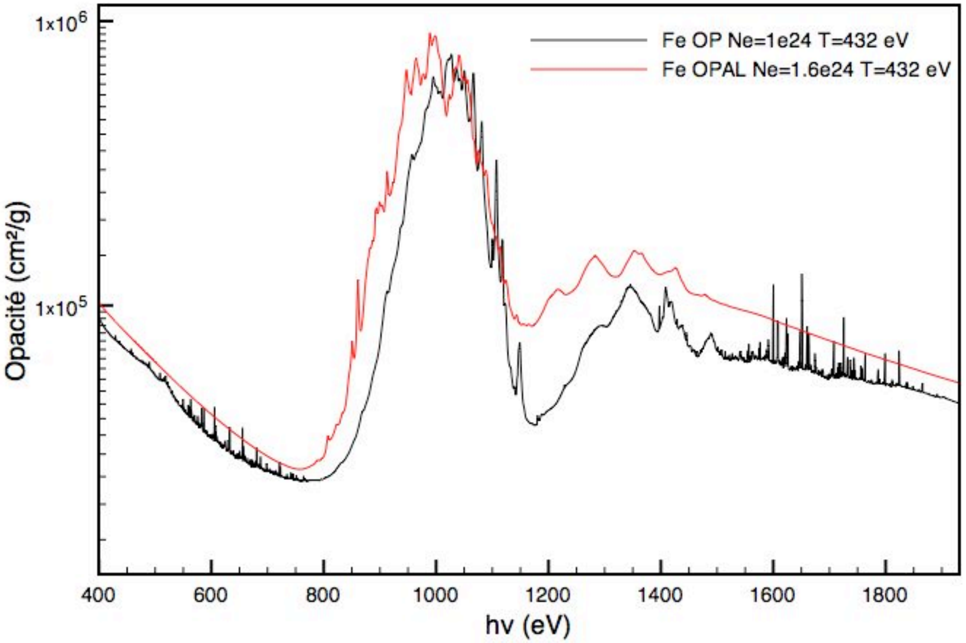


Pure element κ_R :
several tenths…

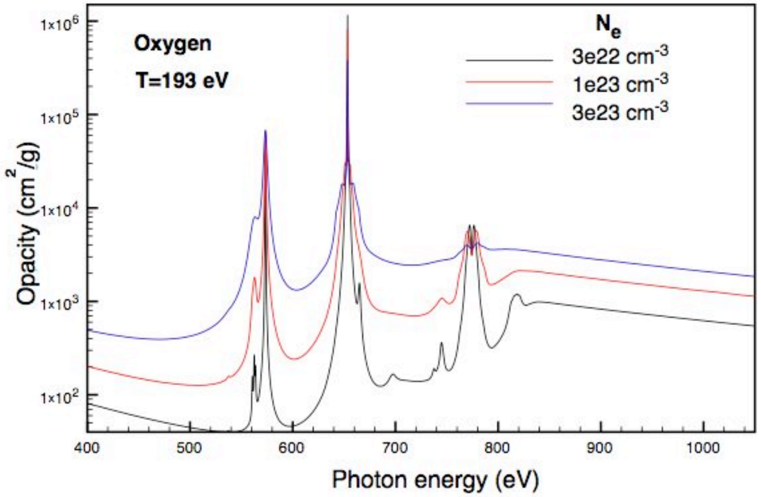
iron and oxygen

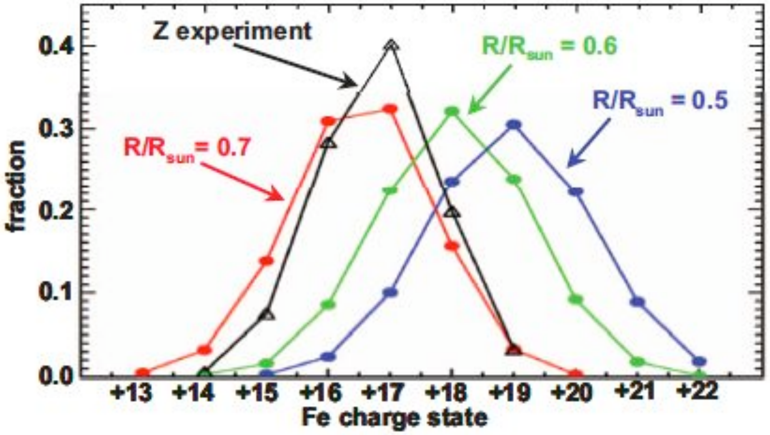
Bailey et al. 2009 Turck-Chièze et al. 2009





Phys. Plasmas 16, 058101 (2009)



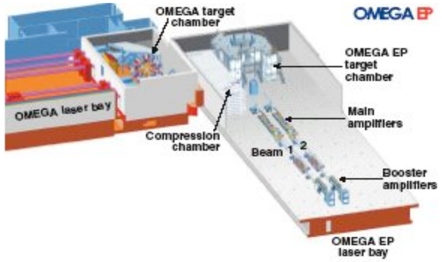


Large Laser facilities are developing in the world together with Z machines

LMJ Bordeaux France
Military CEA facility 1,8 MJ 3 ω_0

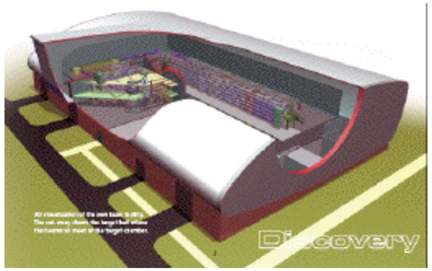
NIF USA 1,8 MJ 3 ω_0
Military Livermore facility

LIL Bordeaux France 7.5 kJ 3 ω_0+ PETAL 3,5 kJ - 7 PW?



OMEGA EP Rochester 30 kJ ns 3 ω_0
+ 5 kJ – 2 PW

FIREX 1 Osaka Japon 10 kJ 2 ω_0
+ 10 kJ – 1 PW



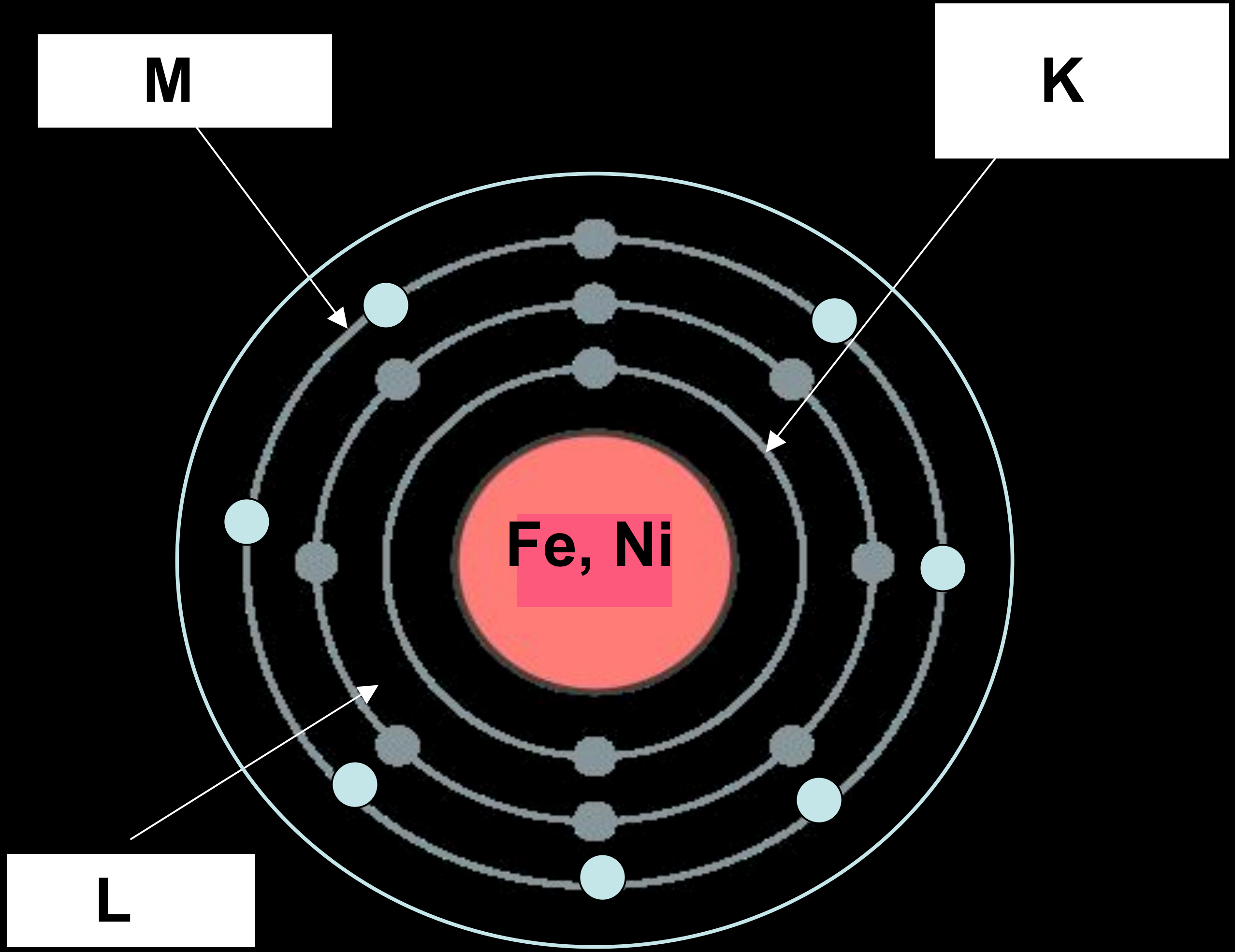
ORION UK 5 kJ ns 3 ω_0
To 1 kJ - 2 PW

VULCAN UK 2,8 kJ ns 1 ω_0
To 400 J - 1 PW

Academic facility
LULI Palaiseau France 2 kJ ns 1 ω_0
+ 30 J 100 TW

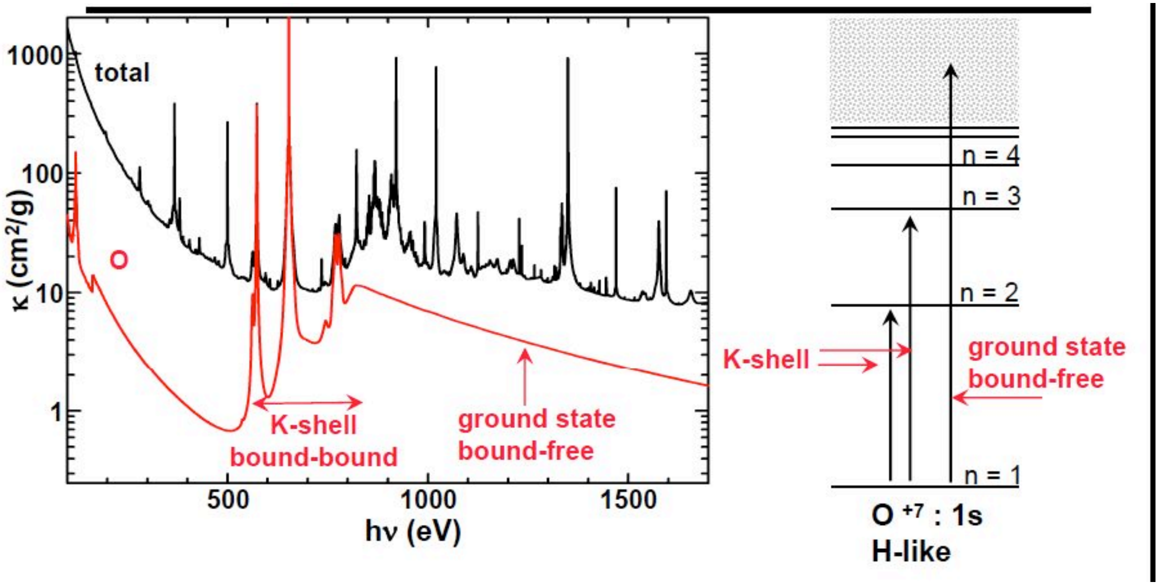
SANDIA Z machine

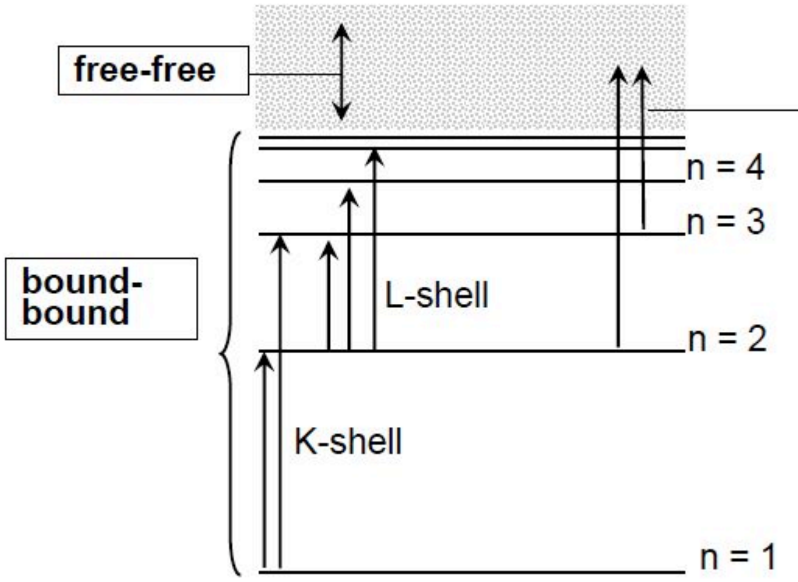
Radiative envelopes

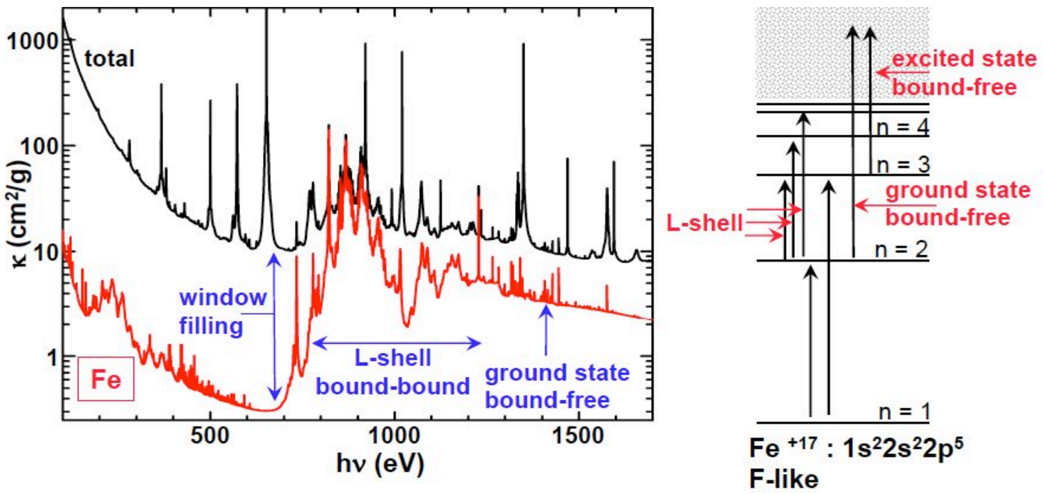


Near the base of
the convective zone

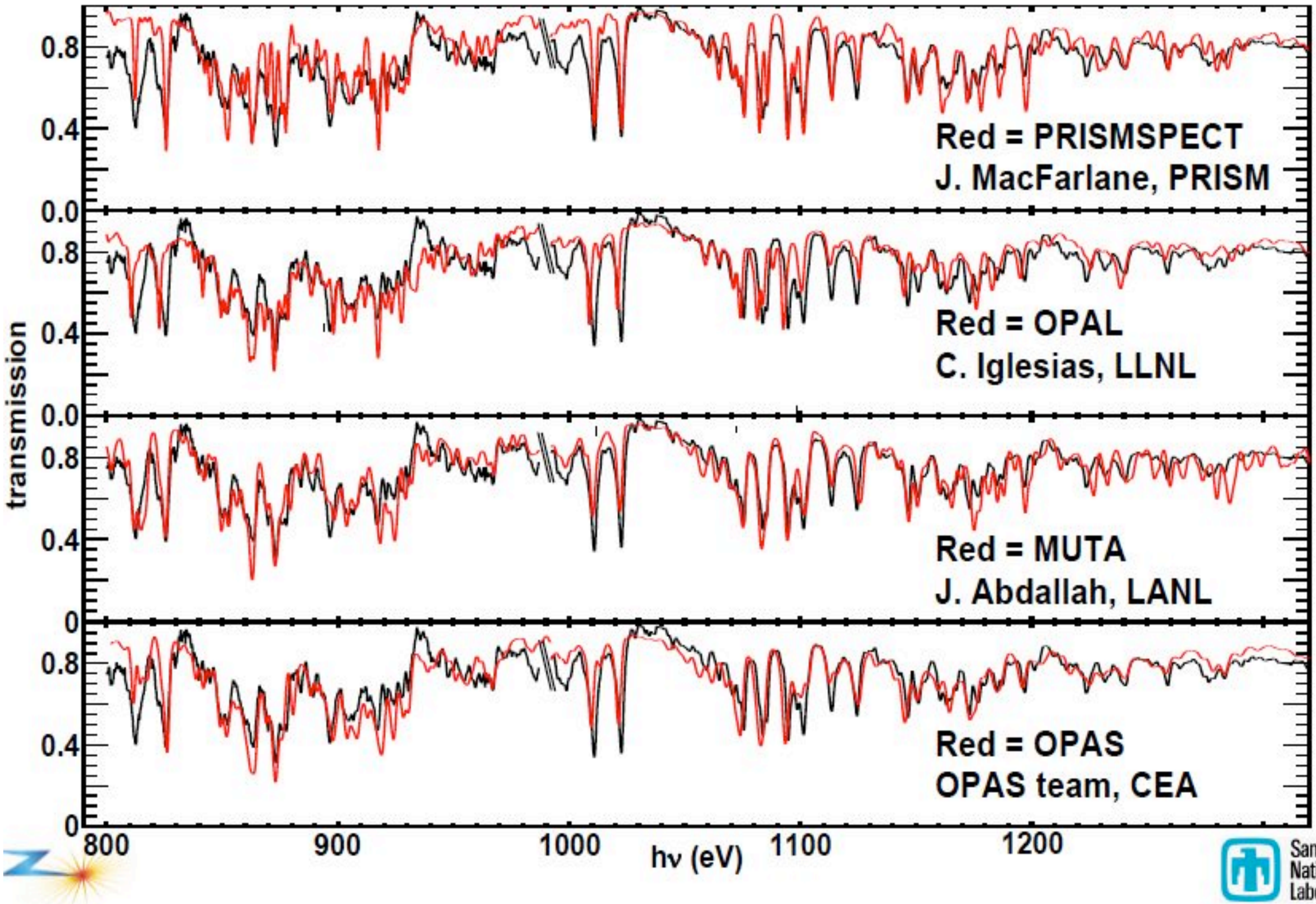
Fe^{8+}







The roles of these processes depends on ionization

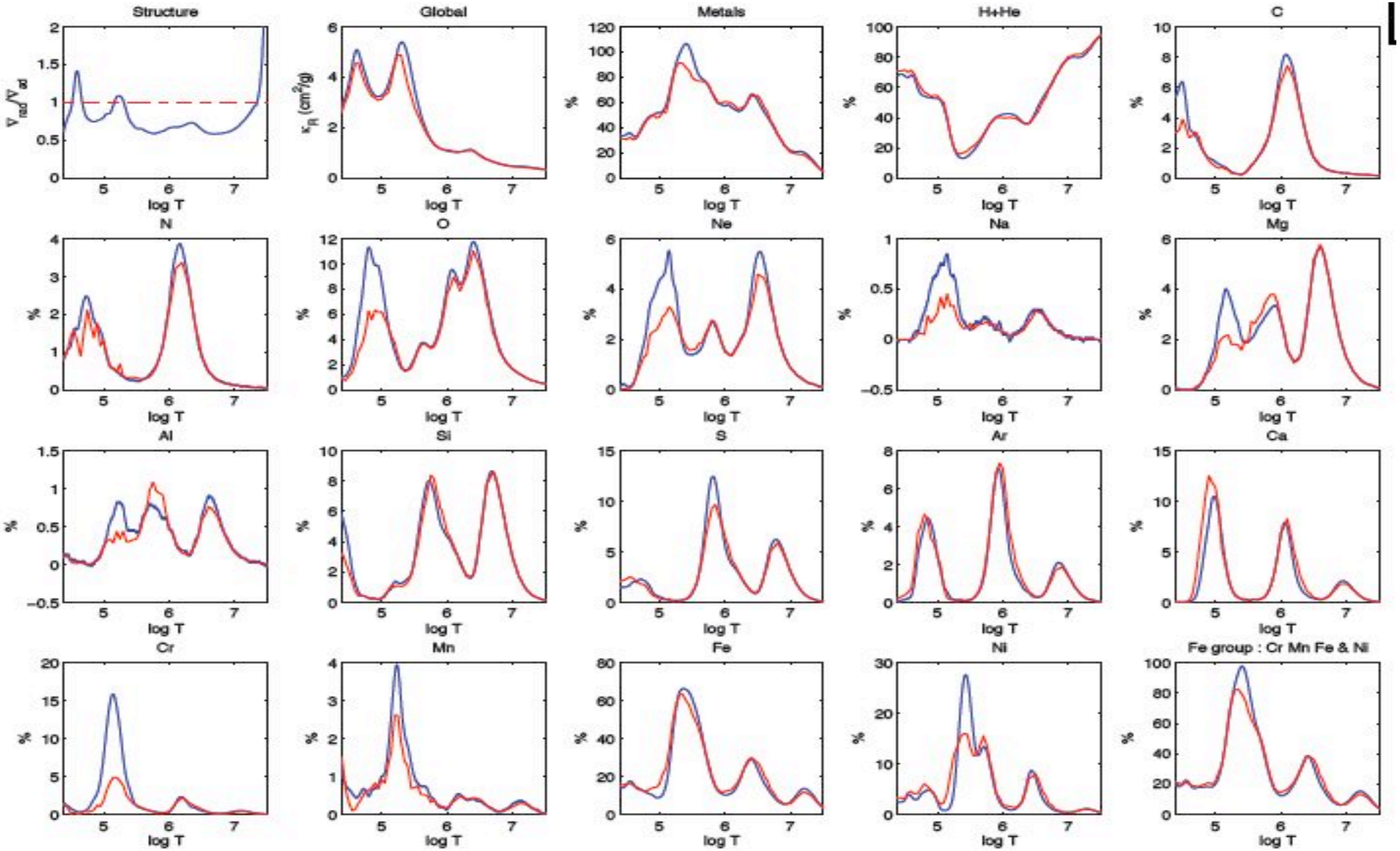


Bailey et al. PRL 2007 **at 156±6 eV 6.9 ± 1.7 10^{21}cm^{-3} about 1.7Mdegrees**

More massive stars: Case of a β Cepheid of 10 $M_\odot$

OP (blue) and OPAL (red)

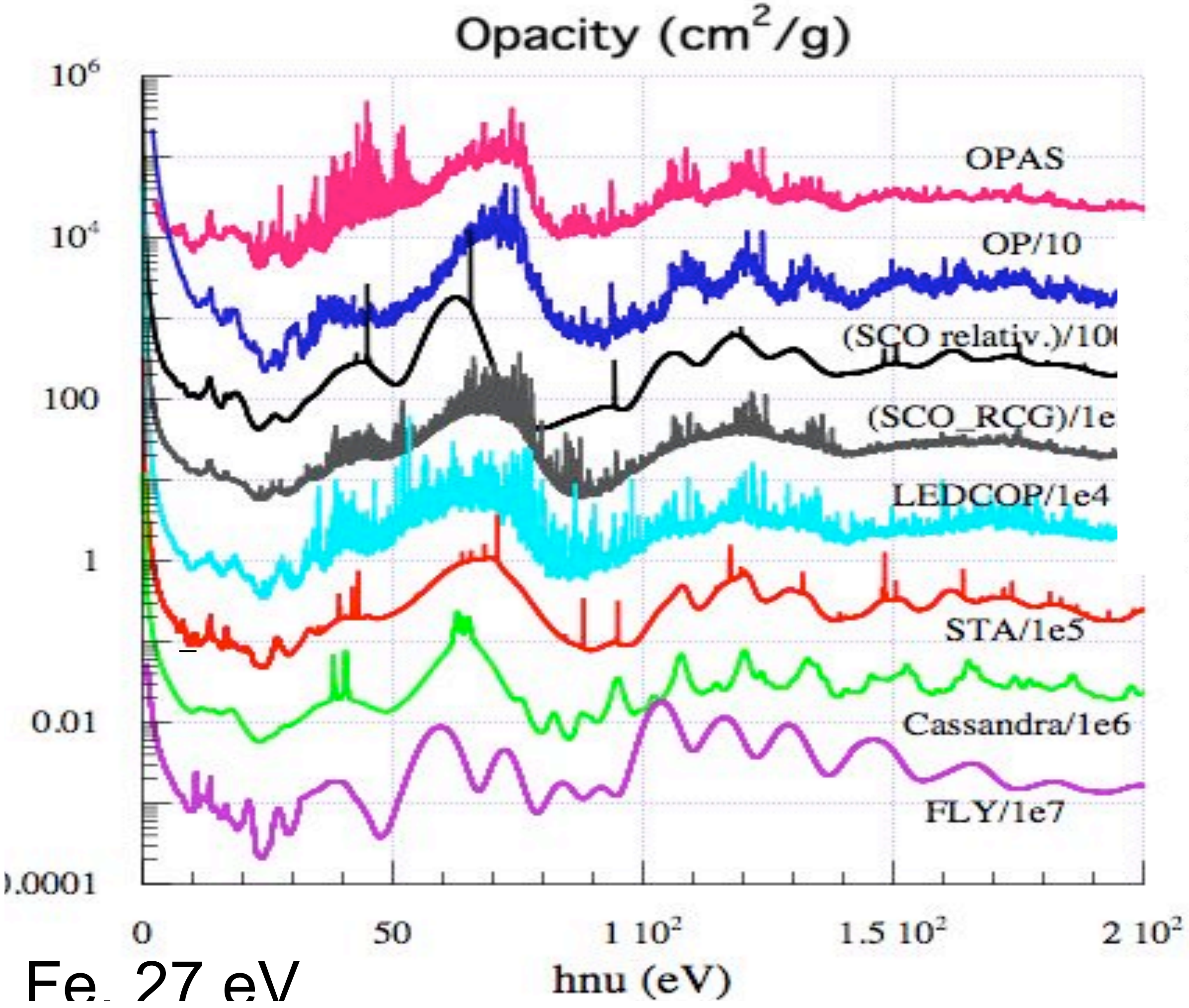
Patmyatnykh 1999, Delahaye et al. 2005 Turck-Chièze et al., 2010, Astro. Space Sc.



Comparison of Fe opacity spectra
7 different teams including OP

Turck-Chièze et al. 2010, Astrophysics & Space Science

Gilles et al. 2010, A&A suppl.

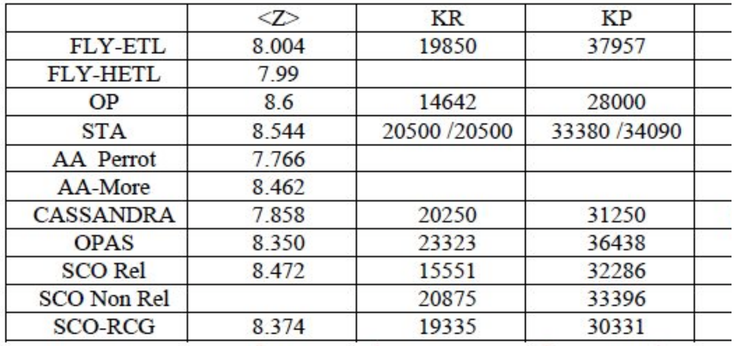


Fe. 27 eV

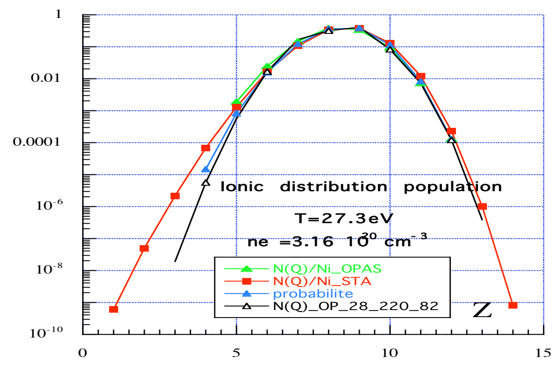
OPAS and SCO-RCG
CEA

LEDCOP Los Alamos

Not Livermore !

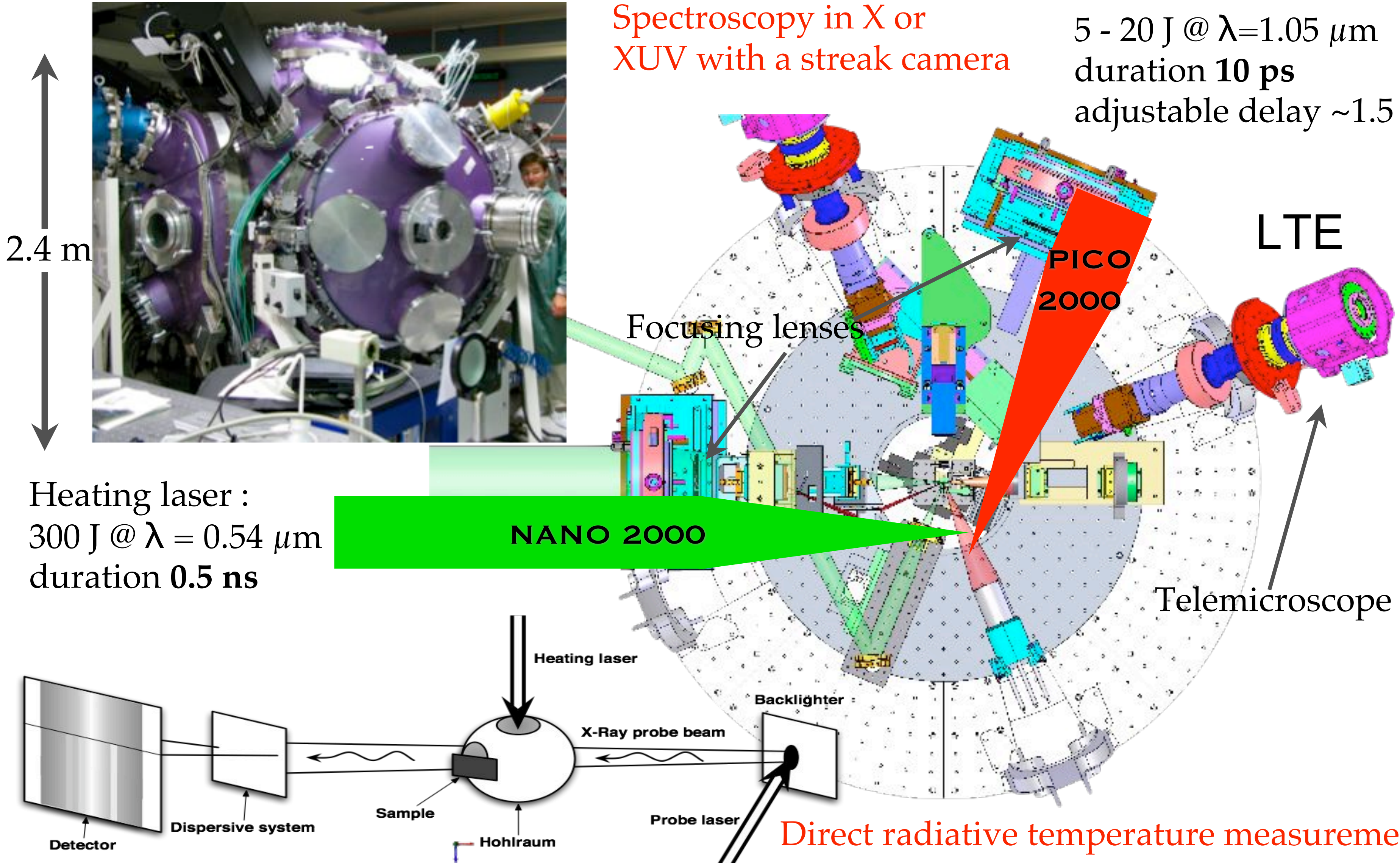


	<Z>	KR	KP
FLY-ETL	8.004	19850	37957
FLY-HETL	7.99		
OP	8.6	14642	28000
STA	8.544	20500 /20500	33380 /34090
AA Perrot	7.766		
AA-More	8.462		
CASSANDRA	7.858	20250	31250
OPAS	8.350	23323	36438
SCO Rel	8.472	15551	32286
SCO Non Rel		20875	33396
SCO-RCG	8.374	19335	30331



PRINCIPLE OF THE MEASUREMENTS AT LOW TEMPERATURE

LULI 2000 FACILITY



Spectroscopy in X or XUV with a streak camera

Probe laser:
5 - 20 J @ λ=1.05 μm
duration **10 ps**
adjustable delay ~1.5 ns

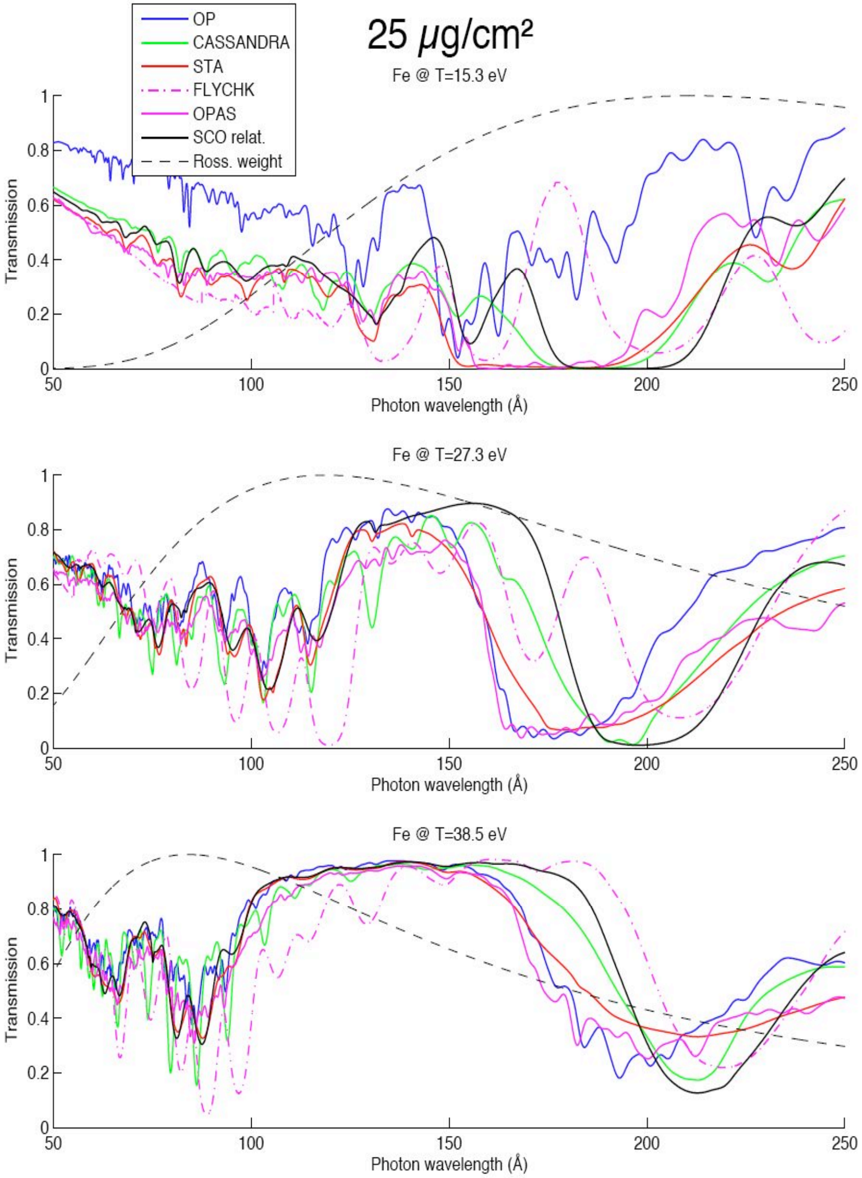
LTE

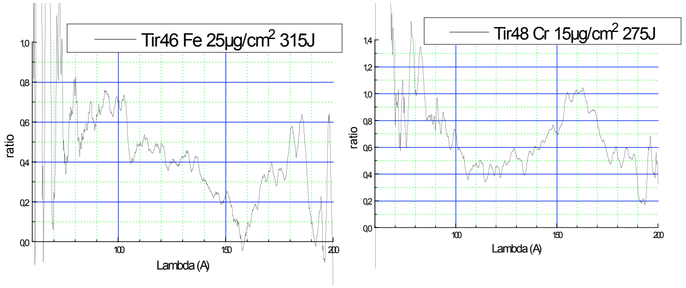
Heating laser :
300 J @ λ = 0.54 μm
duration **0.5 ns**

Direct radiative temperature measurements

Transmission spectra

$$T(\nu) = I(\nu)/I_0(\nu) = \exp - \tau(\nu), \quad \tau(\nu) = \kappa(\nu)\rho x$$

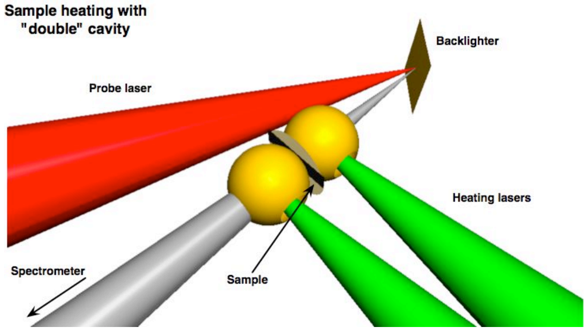




Cr, Fe, Ni preliminary spectra

Difficulties to solve

- avoid the saturation of the spectra,
- perform the conditions in T and density with small temperature gradient on the foil
- stay in LTE



A lot of challenges to solve

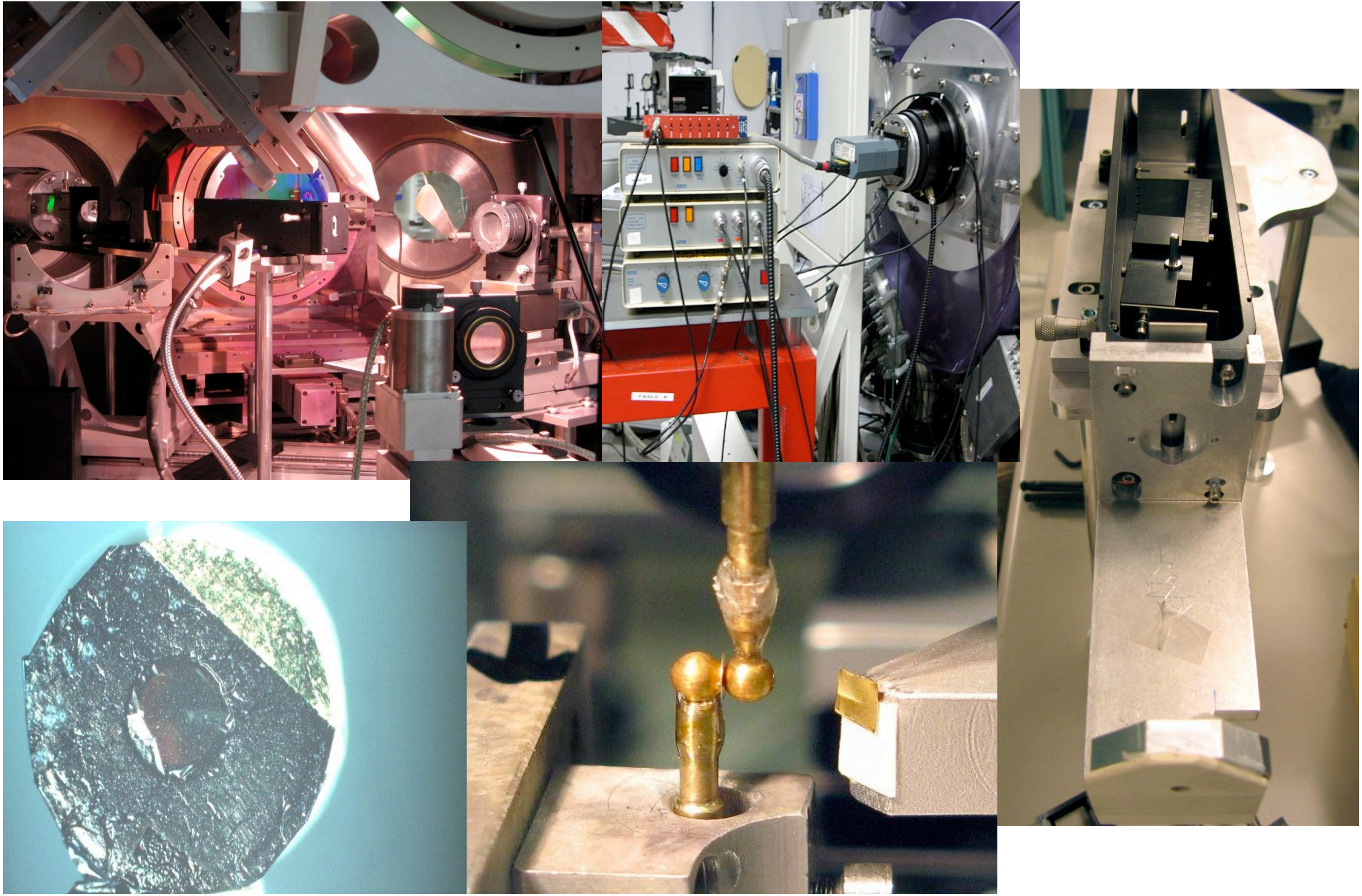
On the theoretical comparisons

On the experimental measurements

But a team has been built with a lot of complementary expertises to better estimate the microscopic physics of radiative zones

A meeting between astrophysicists and plasma physicists is planned for 4-5 th November 2010

Challenges expérimentaux



Measurements of absorption spectra at moderate temperature

Germanium

- 1995 - Quantitative measurements of mid-Z opacities.

Perry et al. JQSRT 54, 317

- 1997 - Opacity measurements: extending the range and filling in the gaps. *Back et al.*

Iron

- 1992 - Spectroscopic absorption measurements of an iron plasma.

Springer et al. Phys Rev Lett 69 3735 + aluminim, holmium

- 1995 - XUV opacity measurements and comparisons with models.

Winhart et al. JQSRT 54, 437

- 2000 - Opacity studies of iron in the 15-30 eV temperature range.

Chenais-Popovics et al.ApJ Suppl 127, 275

Nickel

- 2002 - L-band x-ray absorption of radiatively heated nickel.

Chenais-Popovics et al. Phys Rev E, 65, 6413

Germanium, Zinc, Copper and Iron

- 2008 - X-ray absorption around 20 eV to study spin-orbit splitting in the absorbing 2p-3d transitions and configurational line broadening.

Loisel et al. 2008 HEDP

Chromium, Iron, Nickel

- 2010 - XUV absorption around 27 eV for stellar envelopes