Analysis of X-Ray Nike Spectra from Highly-Charged High-Z Ions

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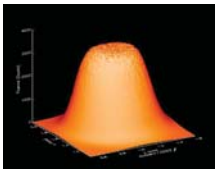
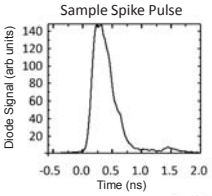
Nike Laser Target Facility

Sample Target Focal Profile



Sample Spike Pulse



Current Nike operating parameters:
- 248 nm central wavelength, KrF laser
- Echelon-free ISI beam smoothing, 1-2 THz bandwidth
- Total laser energy: 2-3 kJ
- 44 main beams; 12 backlighter beams
- Main beam focal profile: 0.2-1.2 mm FWHM
- Main beam pulse duration: 0.4-12 ns
- Main beam overlapped intensity:
  - typical ~$1x10^{14}$ W/cm^2 (4 ns pulse, 0.75 mm FWHM spot)
  - up to 1-$2x10^{15}$ W/cm^2 (0.4 ns pulse, 0.2 mm FWHM spot)

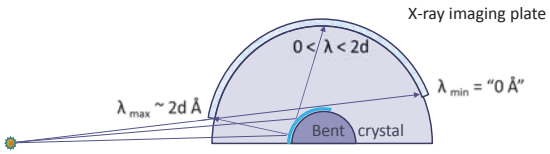
NRL Nike *spectroscopy* program

- Successful development and application of state-of-the-art monochromatic x-ray imaging and spectroscopic techniques for study of IC plasma instabilities
  - Analysis of Richtmeyer-Meshkov and Raleigh-Taylor instabilities
  - X-ray imaging with spherically bent crystals
  - Measurement of relativistic electron transport
  - Use of bent Bragg-Fresnel lenses for imaging

Goals

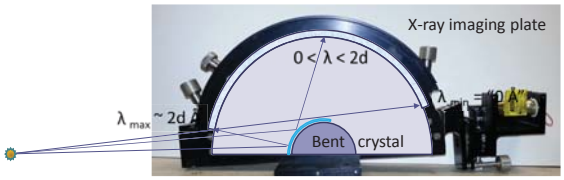
- Test spectroscopic equipment for NIF
  - Convex crystal spectrometer
  - Spherical imaging spectrometer
- Identify new spectral lines for plasma diagnostics
- Provide accurate x-ray spectra for validation of NLTE plasma kinetics codes (cf. NLTE Code Comparison Workshops)

Generic outline of convex crystal spectrometer



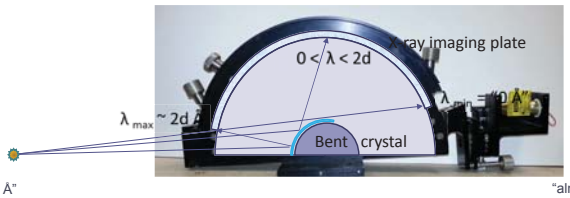
Crystal : **mica**
2d = 20 Å
Working orders of reflection:
n= 1,2,3,5,7.....
λ/Δλ > 1000

Nike half-moon convex crystal spectrometer



Crystal : **mica**
2d = 20 Å
Working orders of reflection:
n= 1,2,3,5,7.....
λ/Δλ > 1000

Nike half-moon convex "full range" crystal spectrometer with the reference spectra of H- and He-like Al and Si and Ne-like Y, Zr, Nb, Mo and Ag

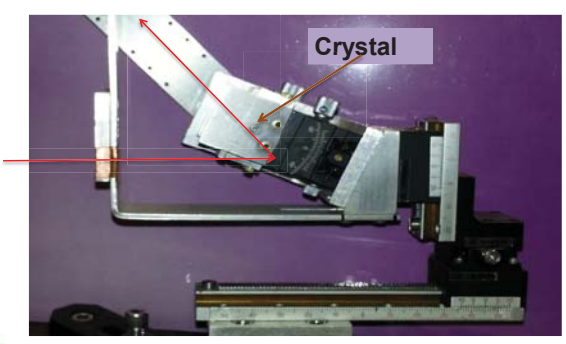


"almost 0 Å" "almost 20 Å"

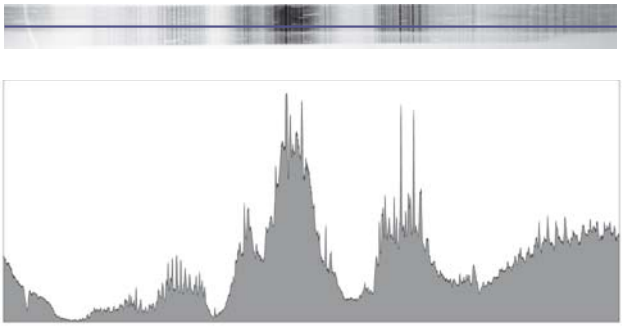
Spherical crystal spectrometer

Detector

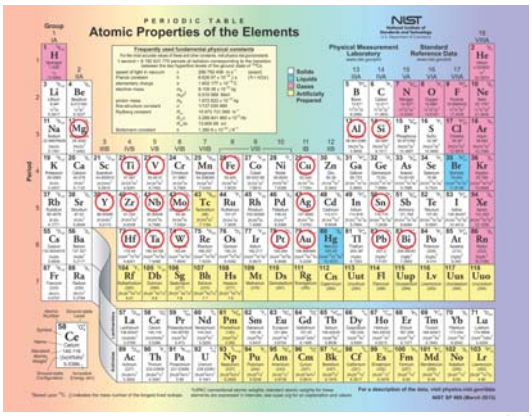
Quartz 6.68Å
λ/Δλ > 2000



W spectra: **irradiated foil (few tens of μm)** : 7-8 shots



Measured elements (as of Sep 2014)

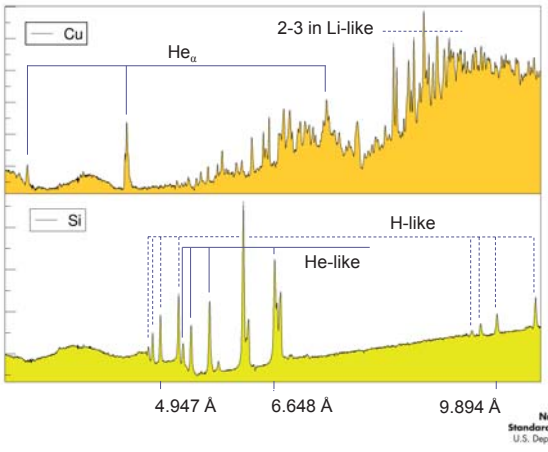


Primary observed ions

- **H-like** (1s) and **He-like** ($1s^2$) ions
  - **Mg, Al, Si**
- **Ne-like** ($2s^22p^6$) and **adjacent ions**
  - **Y, Mo, Ag,...**
- **Ni-like** ($3d^{10}$) and **adjacent ions**
  - **W, Pt, Au,...**

Element	Seq.	IP (eV)
Si	H	2673
Mo	Ne	4259
Ag	Ne	5558
Hf	Ni	3741
W	Ni	4057
Pt	Ni	4715
Au	Ni	4888

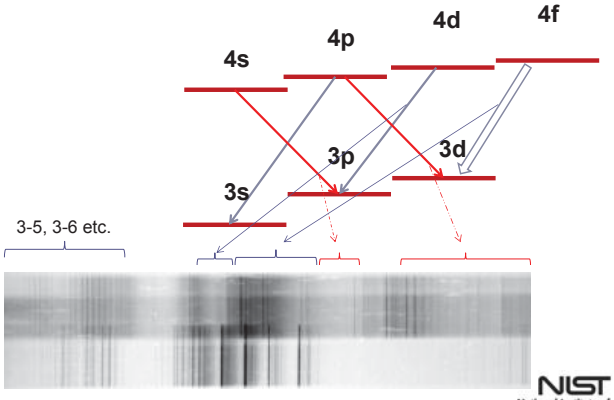
Cu and Si spectra

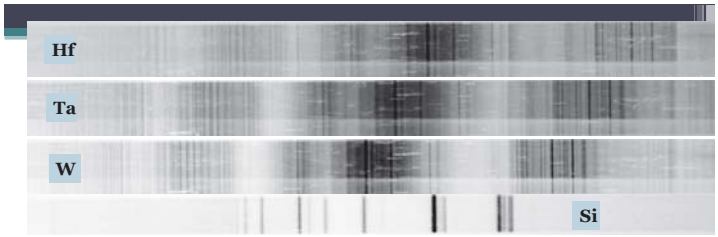


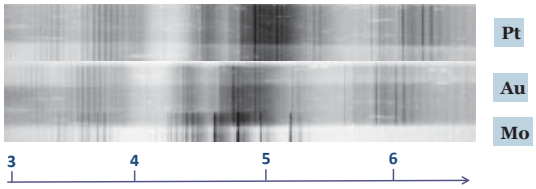
Collisional-radiative modeling

- **Flexible Atomic Code** (Gu, 2003)
  - Relativistic model potential w/ some QED
  - Level energies
  - Radiative and autoionization probabilities
  - Collisional cross sections
  - Cross sections fit and databased
- **NOMAD** (Ralchenko & Maron, 2001)
  - Time-dependent collisional-radiative code for non-Maxwellian plasmas
    - CX, laser pumping, parabolic states.....
  - Steady state
  - Opacity (escape factor for populations, radiative transfer for spectra)
  - IP lowering (Stewart & Pyatt)
  - Typically **[Ga]-[Fe]** ions, **~35,000** levels

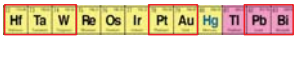
Energy level structure for Ni-like ions



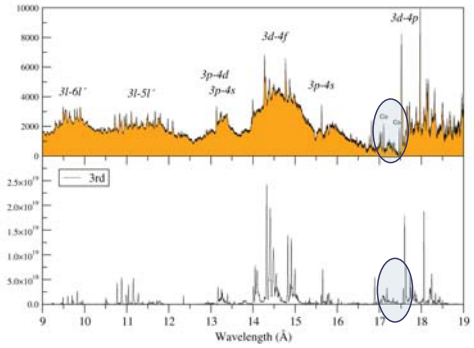




Isoelectronic sequence of Ni-like ions

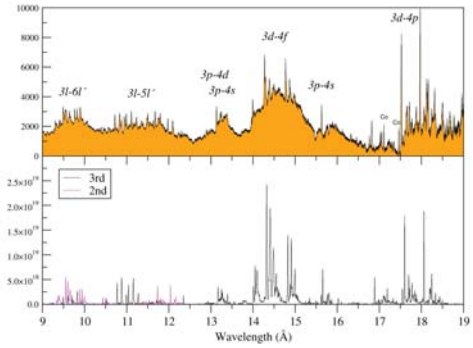


Au shot, Nov 2013



T_e = 2100 eV
$n_e = 3\times10^{20}$ cm^{-3}
R = 0.2 mm

Au shot, Nov 2013



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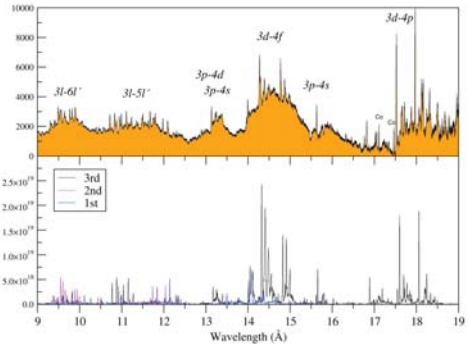

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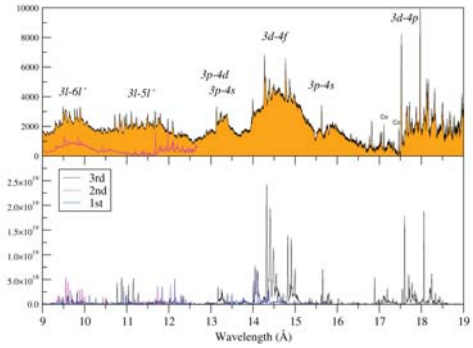

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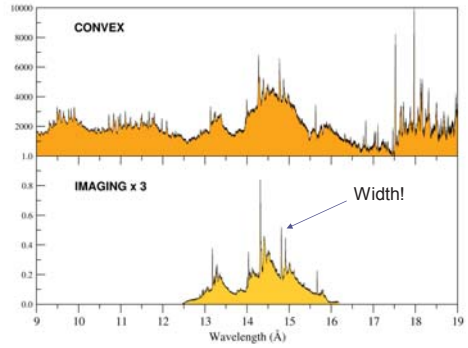
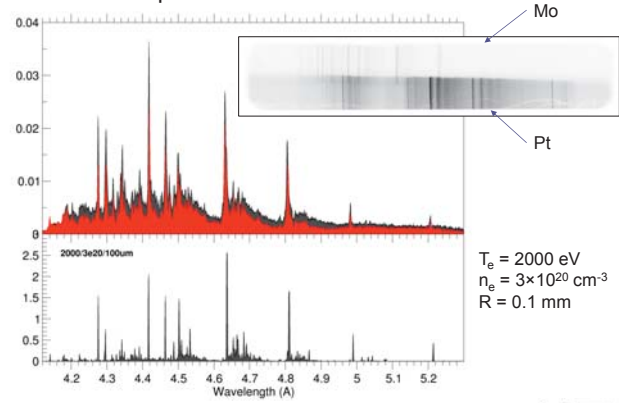
Au: convex Nov 2013 vs focusing May 2014



Mainly 3rd order,
7-8 shots
λ/Δλ~1000

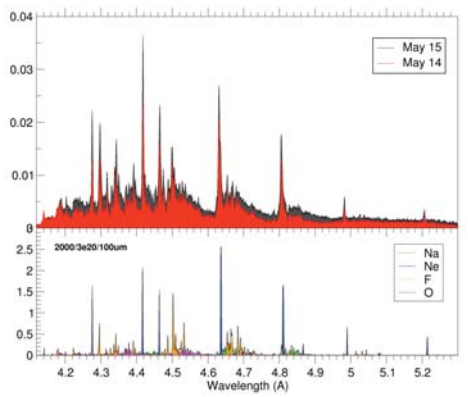
1st order,
1 shot,
attenuated
λ/Δλ~2000

Mo reference spectrum



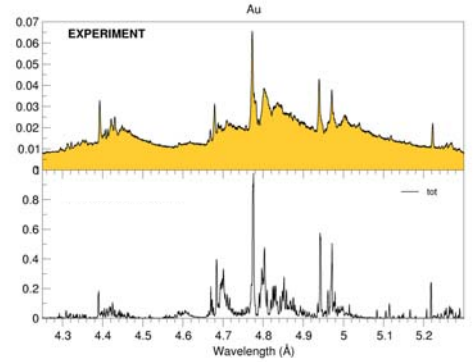
T_e = 2000 eV
n_e = 3×10^{20} cm^{-3}
R = 0.1 mm

Mo reference spectrum



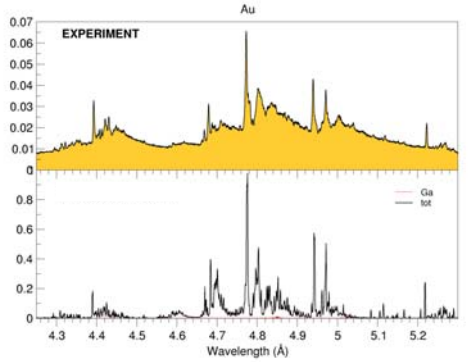
Mo Ne-like:
IP = 4259 eV

Au: focusing spectrometer : **one shot**



T_e = 1900 eV
n_e = 10^{21} cm^{-3}
R = 0.2 mm

Au: focusing spectrometer, May 2014



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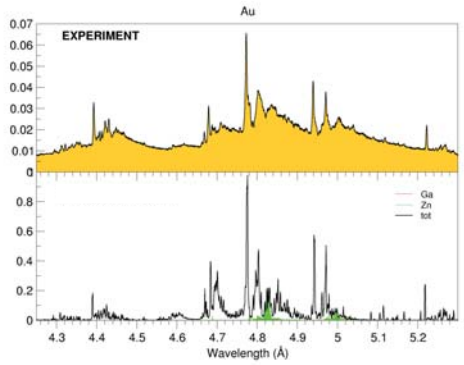
Au: focusing spectrometer, May 2014



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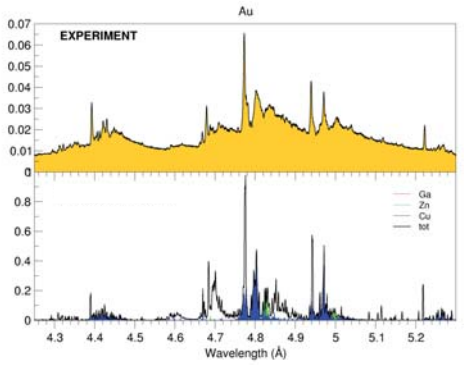

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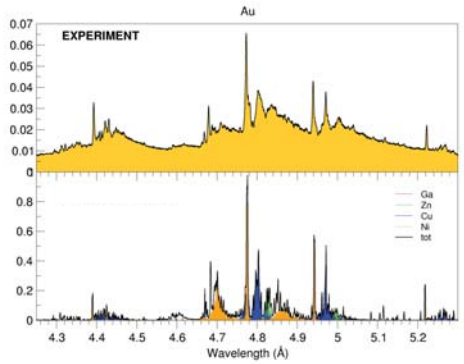

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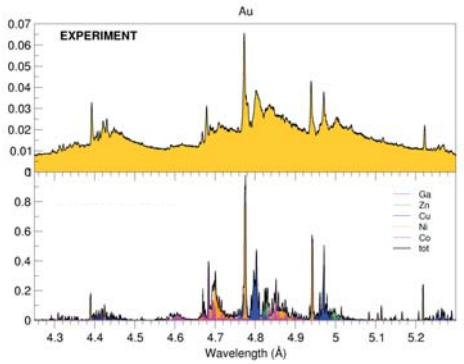

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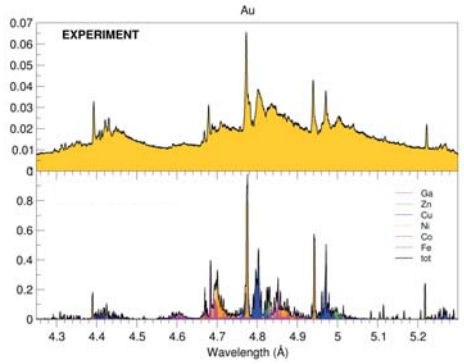
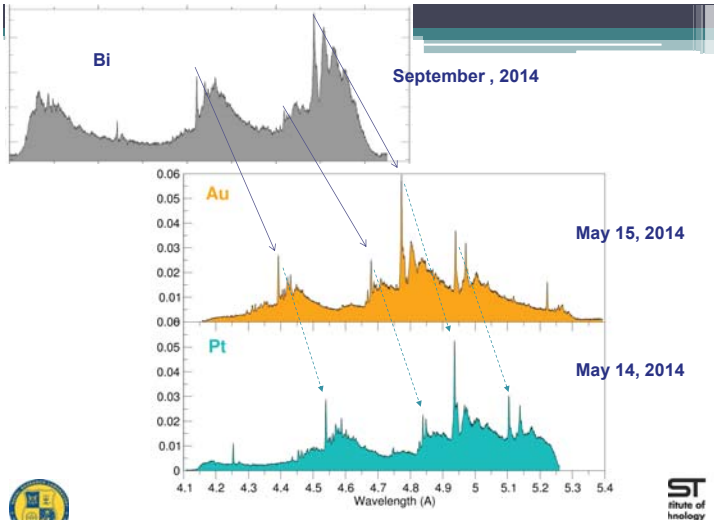
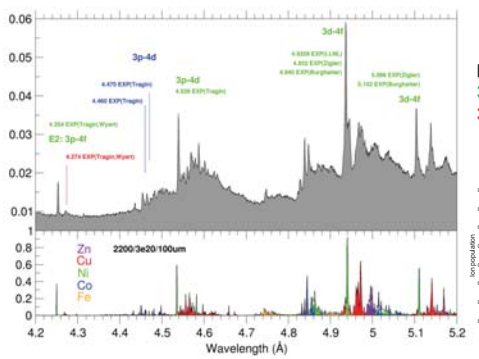


T_e = 1900 eV
n_e = 10^{21} cm^{-3}
R = 0.2 mm

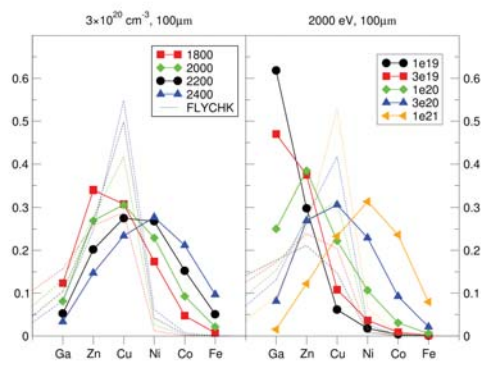


Pt : focusing, May 2014



E2 lines:
$3p^63d^{10}$-$3p^53d^{10}4f$
$3p^63d^{10}4s$-$3p^53d^{10}4s4f$

Ionization distribution: NOMAD vs FLYCHK



http://nlte.nist.gov/FLY

Conclusions

- New spectroscopic system on Nike KrF laser allows high-accuracy measurements of x-ray spectra for low-, mid- and high-Z elements (Mg to Bi)
- Typical electron temperatures and densities for irradiated foil experiments are about 2000 eV and 10^{21} cm^{-3}
- The measured spectra make up an accurate testbed for NLTE kinetic codes (NLTE-9?)
- Collaborations are **very** welcome

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