Solving Key Astrophysical Puzzles

Don Winget, Mike Montgomery, Roberto Mancini et al.

Wootton **C**enter for **A**strophysical **P**lasma **P**roperties

University of Texas, University of Nevada Reno,

Sandia **N**ational **L**aboratories

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Sandia National Laboratories

National Nuclear Security Administration

WCAPP also represents a collaboration among a large number of scientists from national labs and academia

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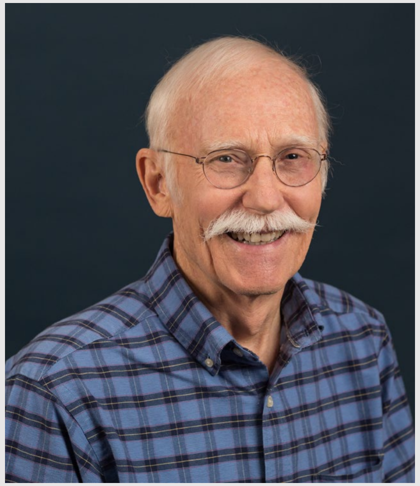

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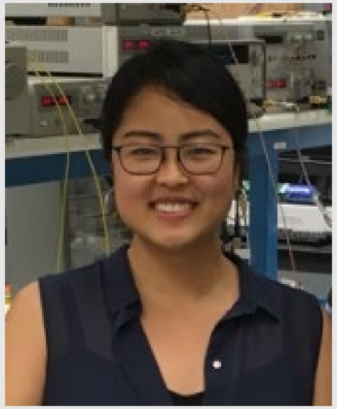

Patty Cho

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Post-Bacc and undergrad students currently working with WCAPP

Joseph Guidry

Bryce Hobbs

Malia Kao

We have improved visibility this year; grad school applications have *increased* by ~ 10 over first 2 years of WCAPP!

The WCAPP TEAM

The Sandia Team

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Photo unavailable

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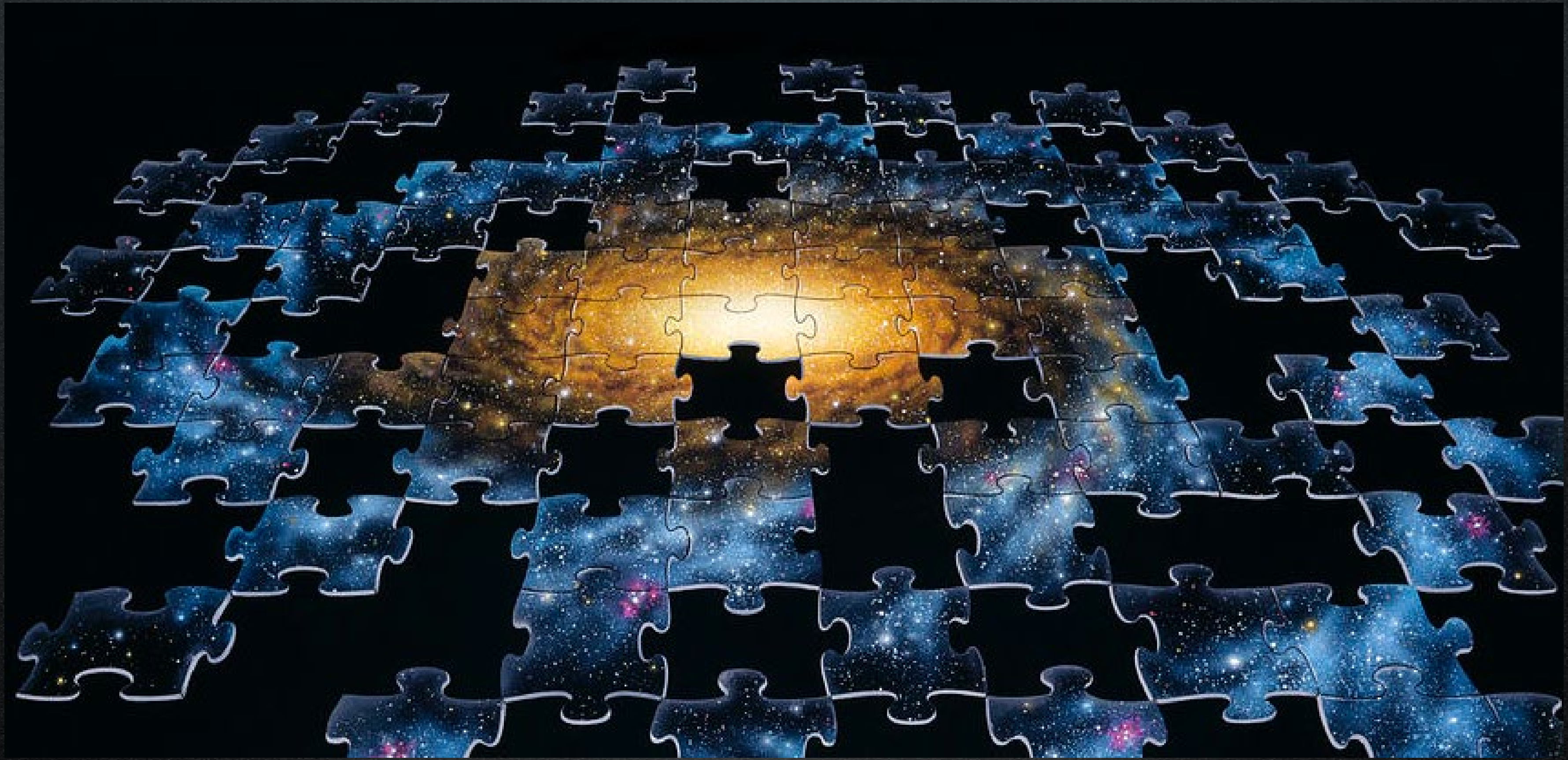
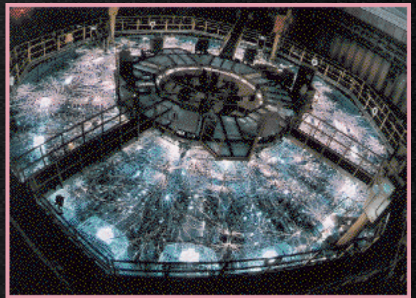
In research you try to see the pattern even with missing pieces…



For us, some of the missing pieces are "missing physics," the untested *Physics of Atoms*

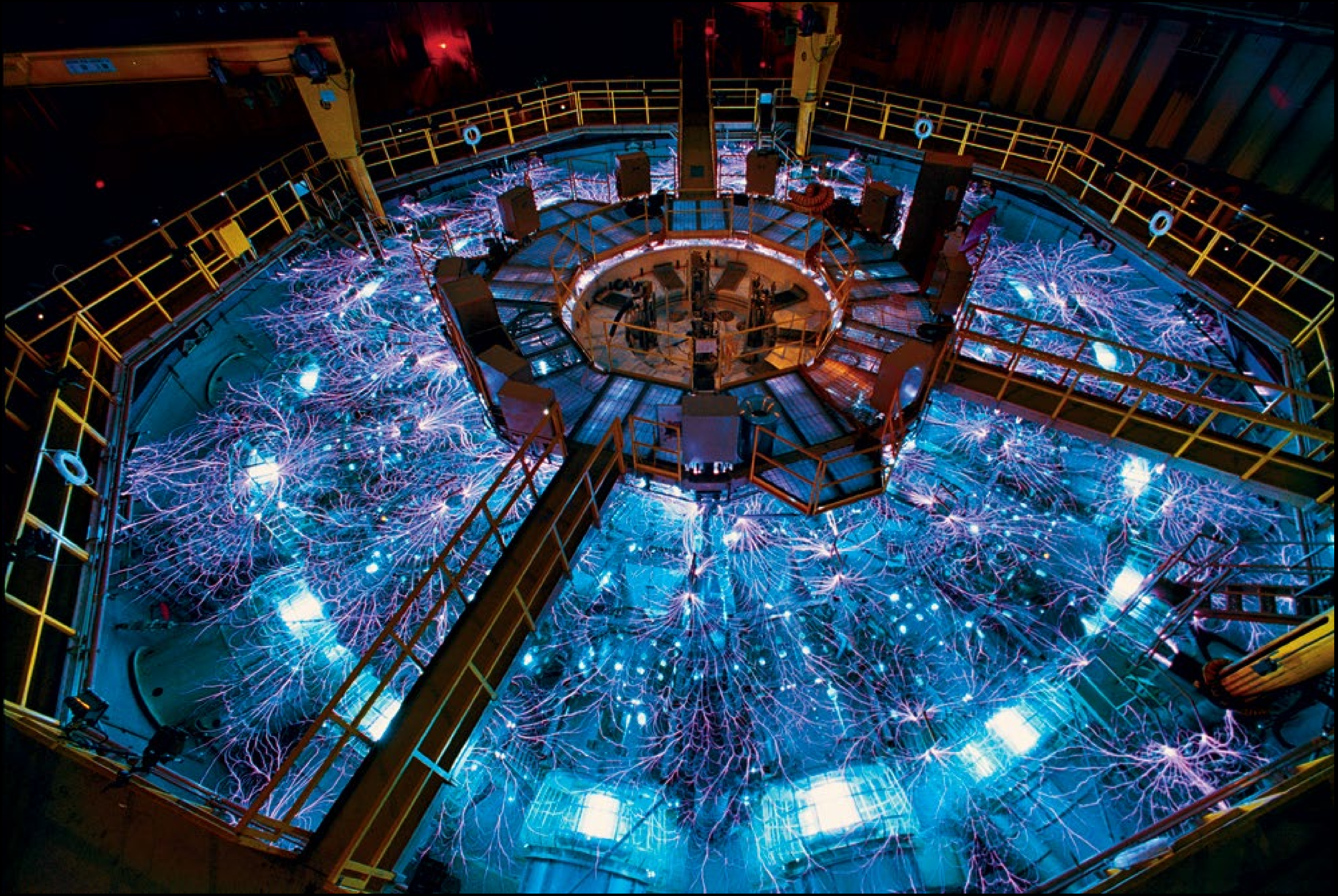


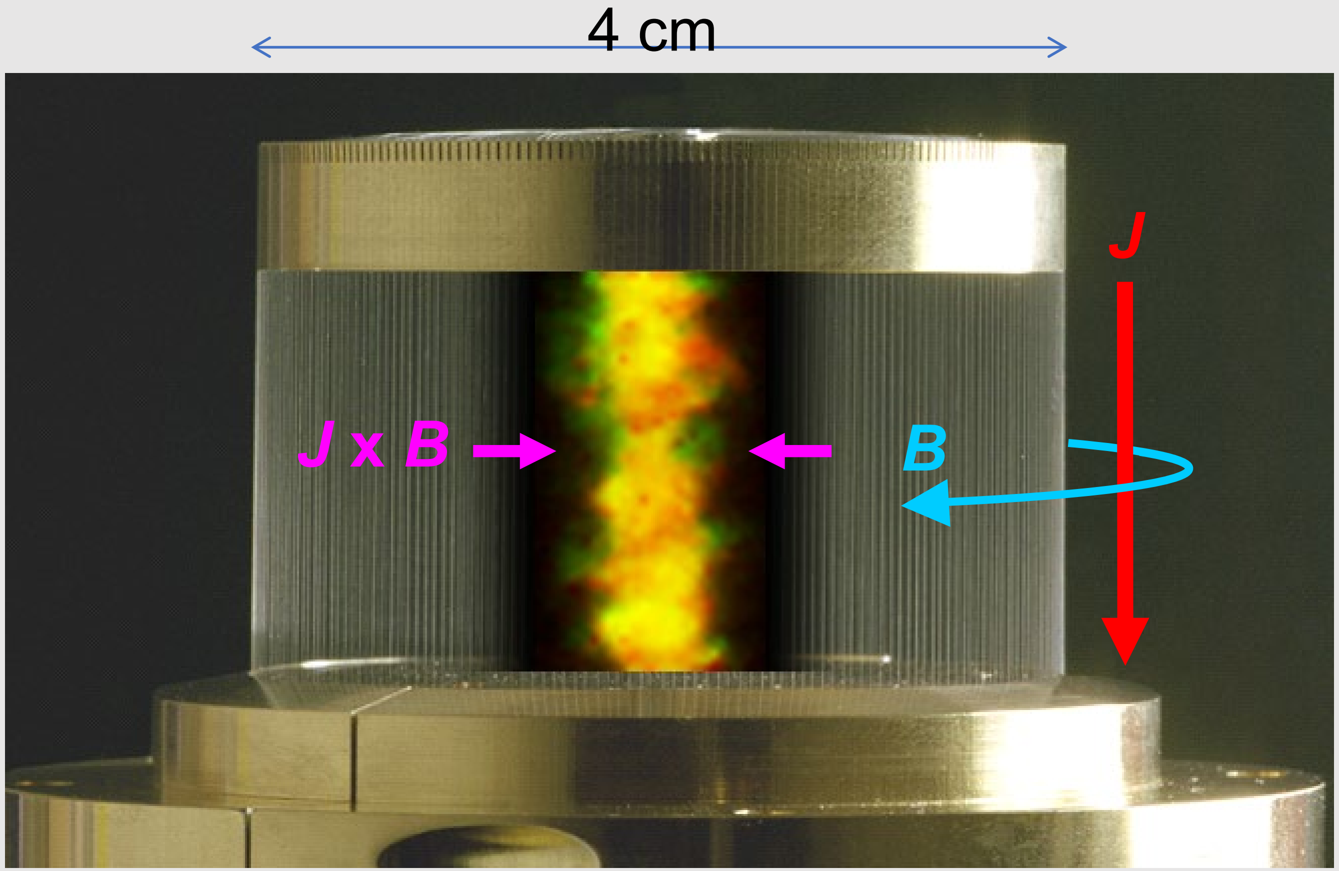
The scientific revolution in Astronomy:

Technologies like Z at SNL, NIF at LLNL, and Omega at LLE make possible *experiments under <u>Cosmic Conditions</u>*

EXAMPLES:

- Iron opacity in the interior of the Sun & Sun-like stars, Z
- New models of the Lunar origin, Z
- Experimental explorations of EoS under astrophysical conditions, NIF

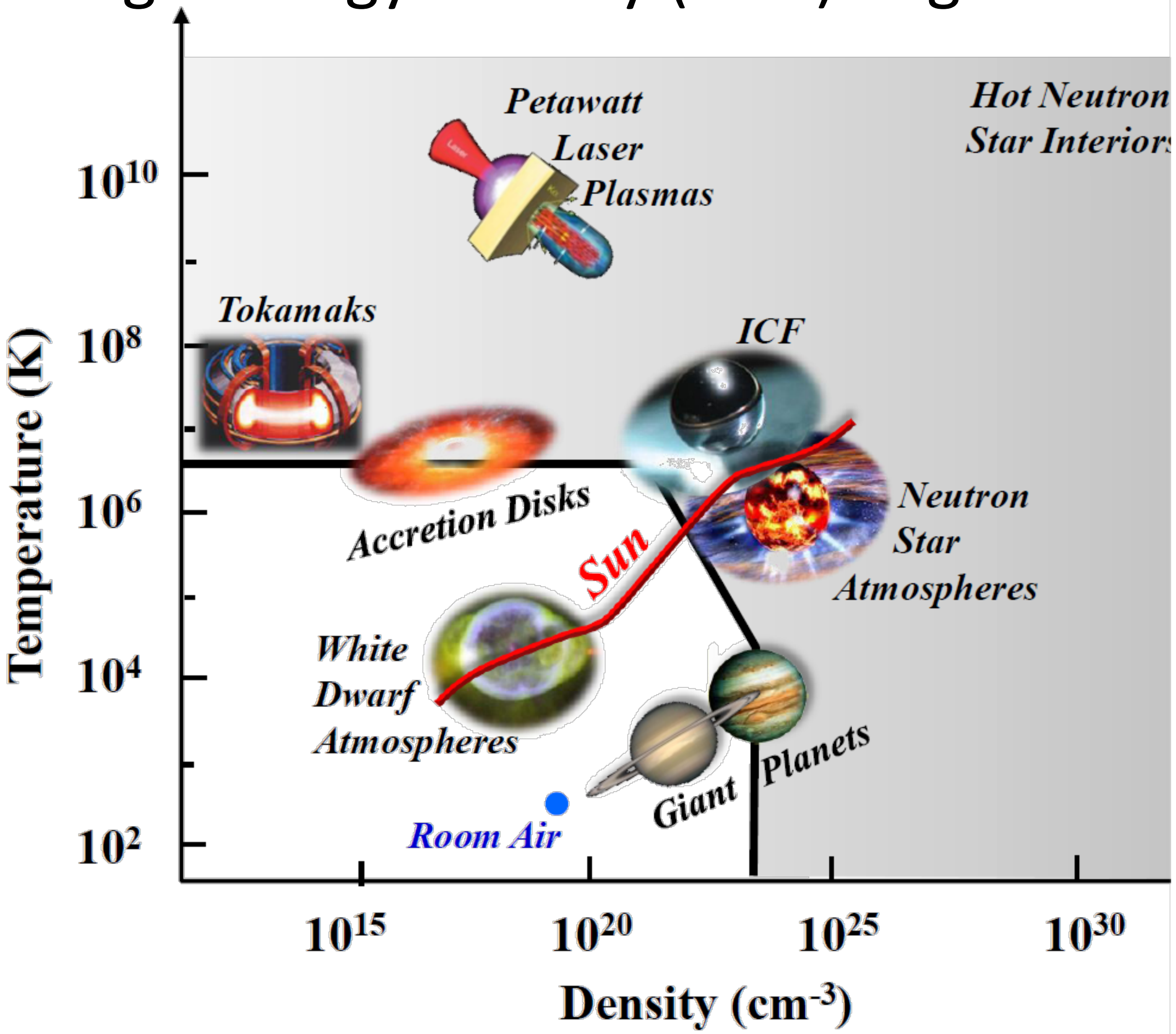




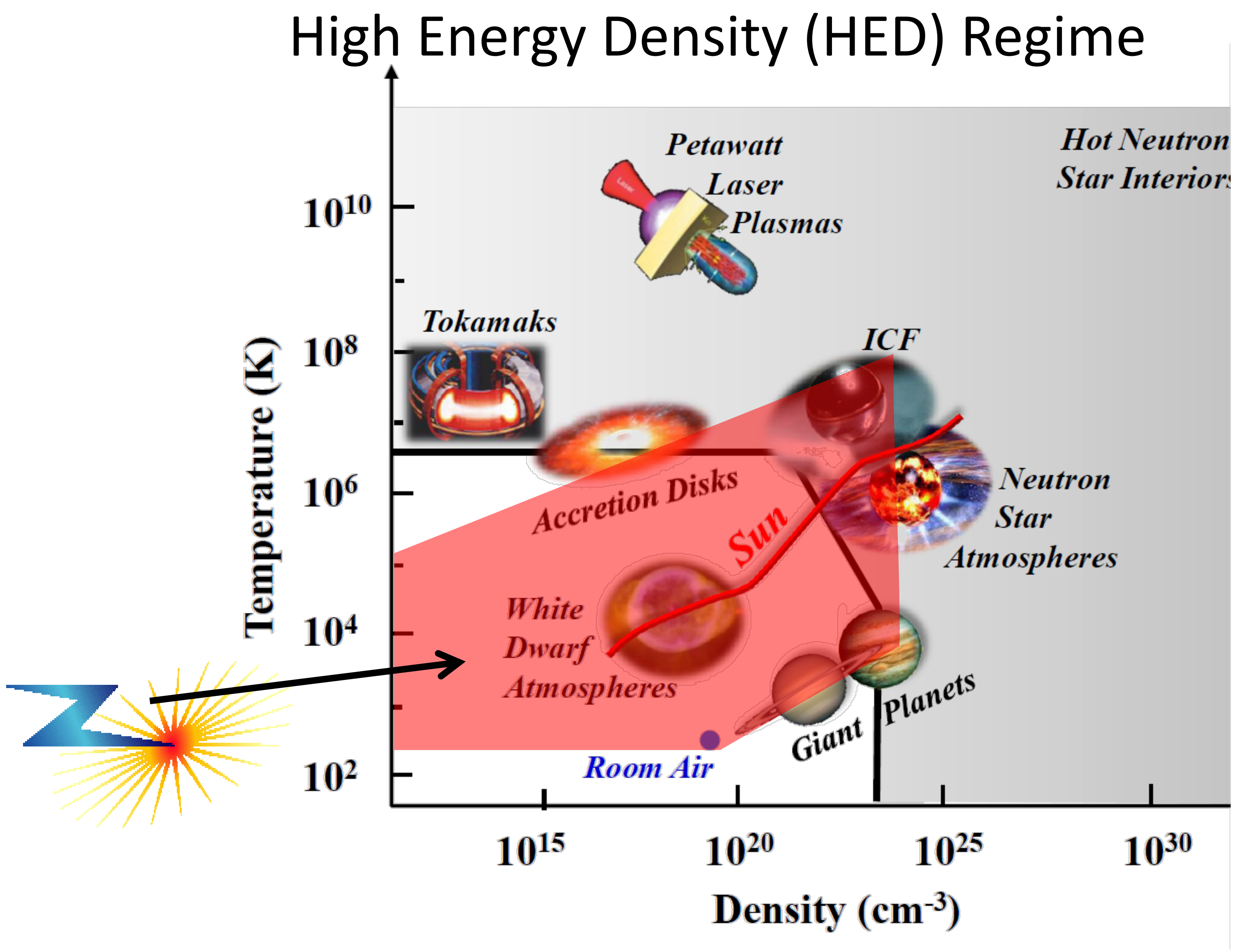
Z MACHINE USES 26 MILLION AMPERES TO CREATE INTENSE X-RAYS

Experiments on Z access a broad range of the energy-density phase space

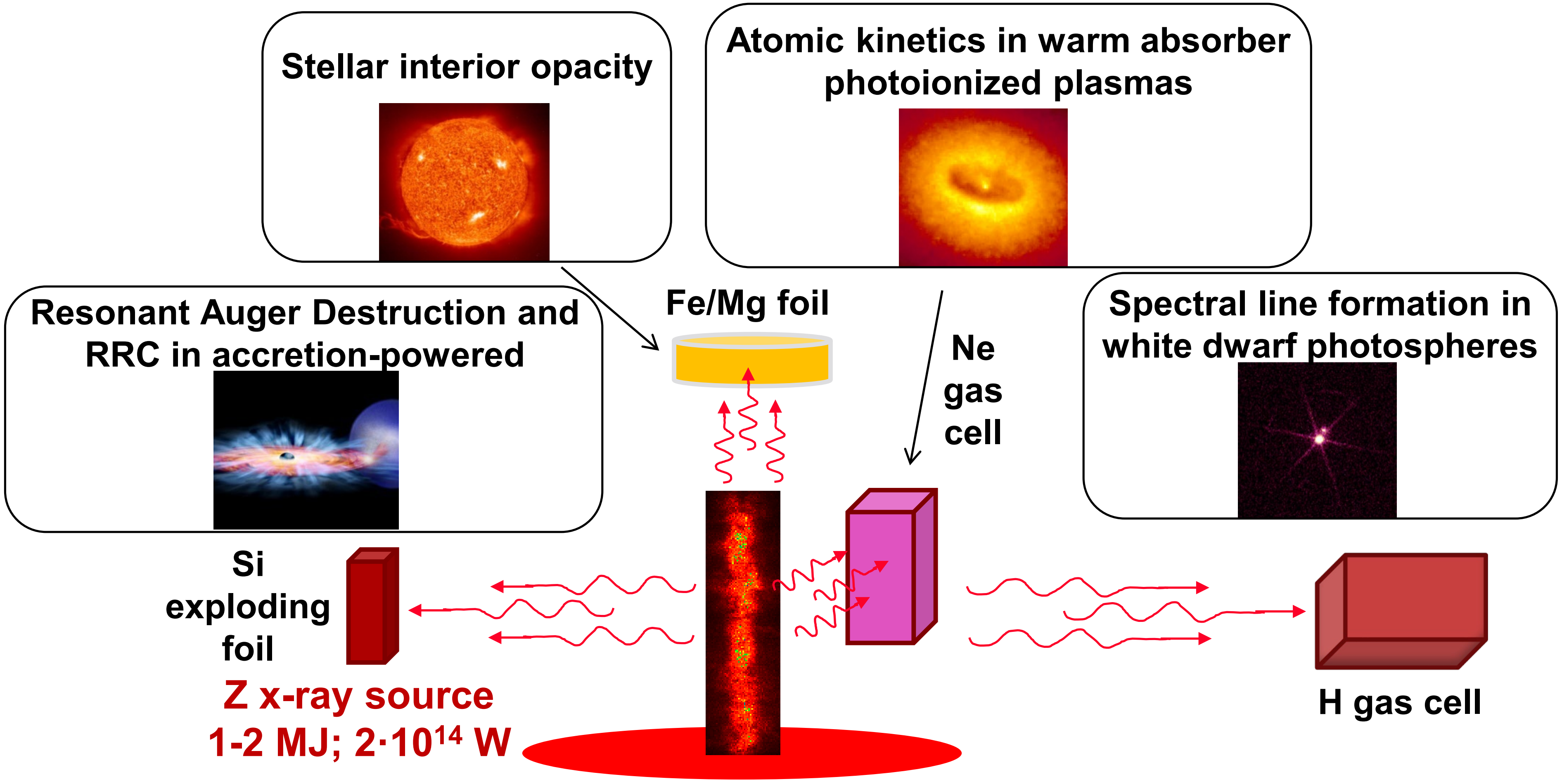
High Energy Density (HED) Regime



Experiments on Z access a broad range of the energy-density phase space



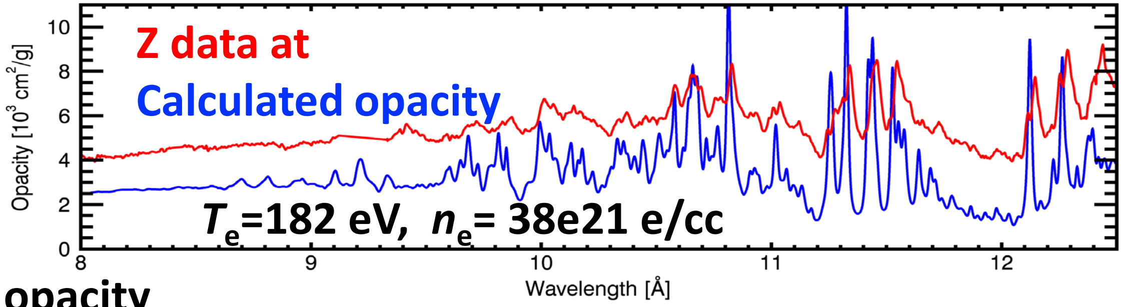
WCAPP experiments exploit megaJoules of x-rays to *simultaneously* address four separate astrophysics topics with experiments at astrophysical conditions

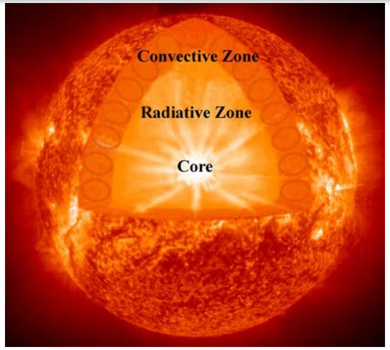


- Multiple samples are exposed to x-rays from Z on each shot
- Crucial for progress on oversubscribed MJ-class facility

The first Z oxygen opacity experiments address key challenges for resolving the solar problem.

Modeled and measured iron opacity disagree at solar interior conditions



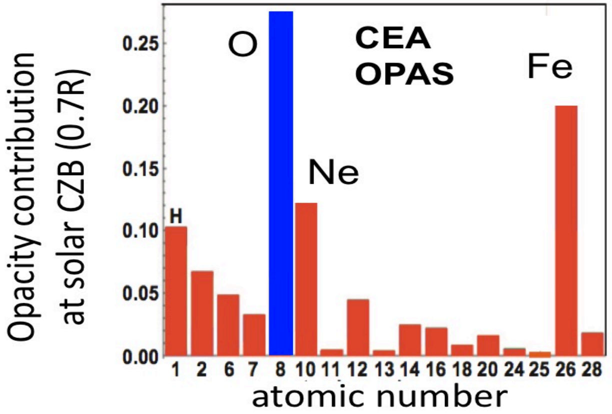


- Oxygen is a major contributor to solar opacity

→ Oxygen measurements are essential to resolve the solar problem

→ Oxygen opacity is also important for white dwarf stars

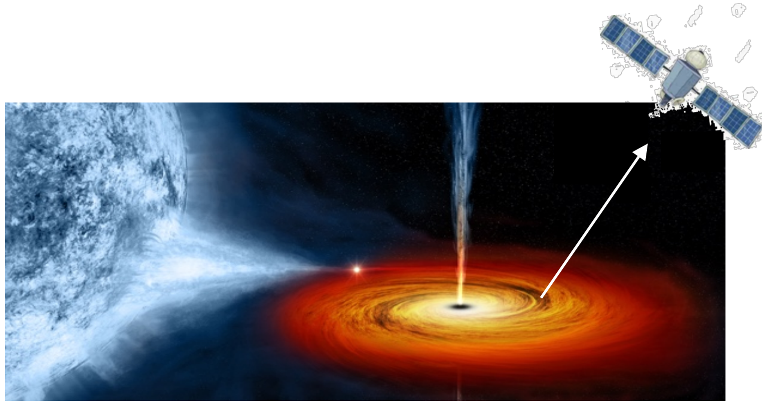
- <u>Opacity model questions:</u>
  - Ionization distribution
  - Line broadening
  - Continuum lowering – bound states mix with continuum
- <u>New Experiment challenges:</u>
  - Target fabrication
  - Extended wavelength range
  - Plasma diagnostics



Preliminary oxygen opacity measurement at T_e~160 eV, n_e ~ $8x10^{21}$ cm^{-3} provides foundation for future data at near solar interior conditions

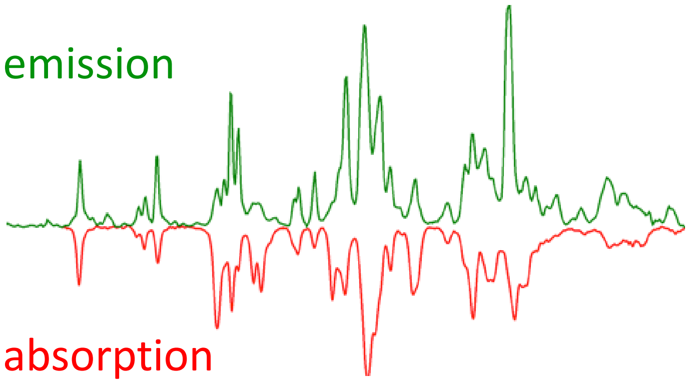
<u>Summary:</u> Z data can benchmark models of emission from photoionized accretion-powered plasmas

- Understanding X-ray Binaries and AGN accretion disks requires complex models that interpret observed spectra
  → These models are largely untested in the laboratory
  → Need benchmark quality data



- A photoionized silicon plasma with a measured drive radiation spectrum, density and temperature was created on Z

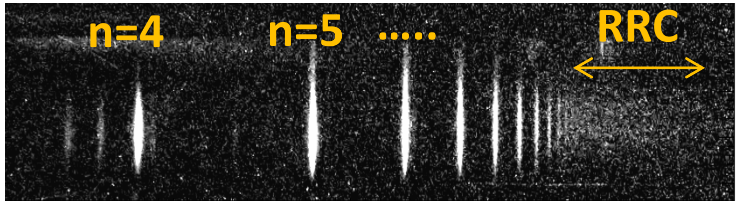
- Spectral absorption and emission are measured to high reproducibility enabling benchmark code comparison*



- Presently, models do not reproduce neither relative or absolute emission
  → How accurate are emission models for accretion-powered sources?

<u>Recent experimental developments:</u>

- First RRC from a photoionized plasma was obtained on Z → typical observation
- *Complete* He-like line series obtained on Z → high constrain on emission
- Ultra high resolution emission spectra → line identification
- First Fe spectrum to address the super-solar abundance problem
- Time-resolved emission measurements initial fielding → transient photoionization

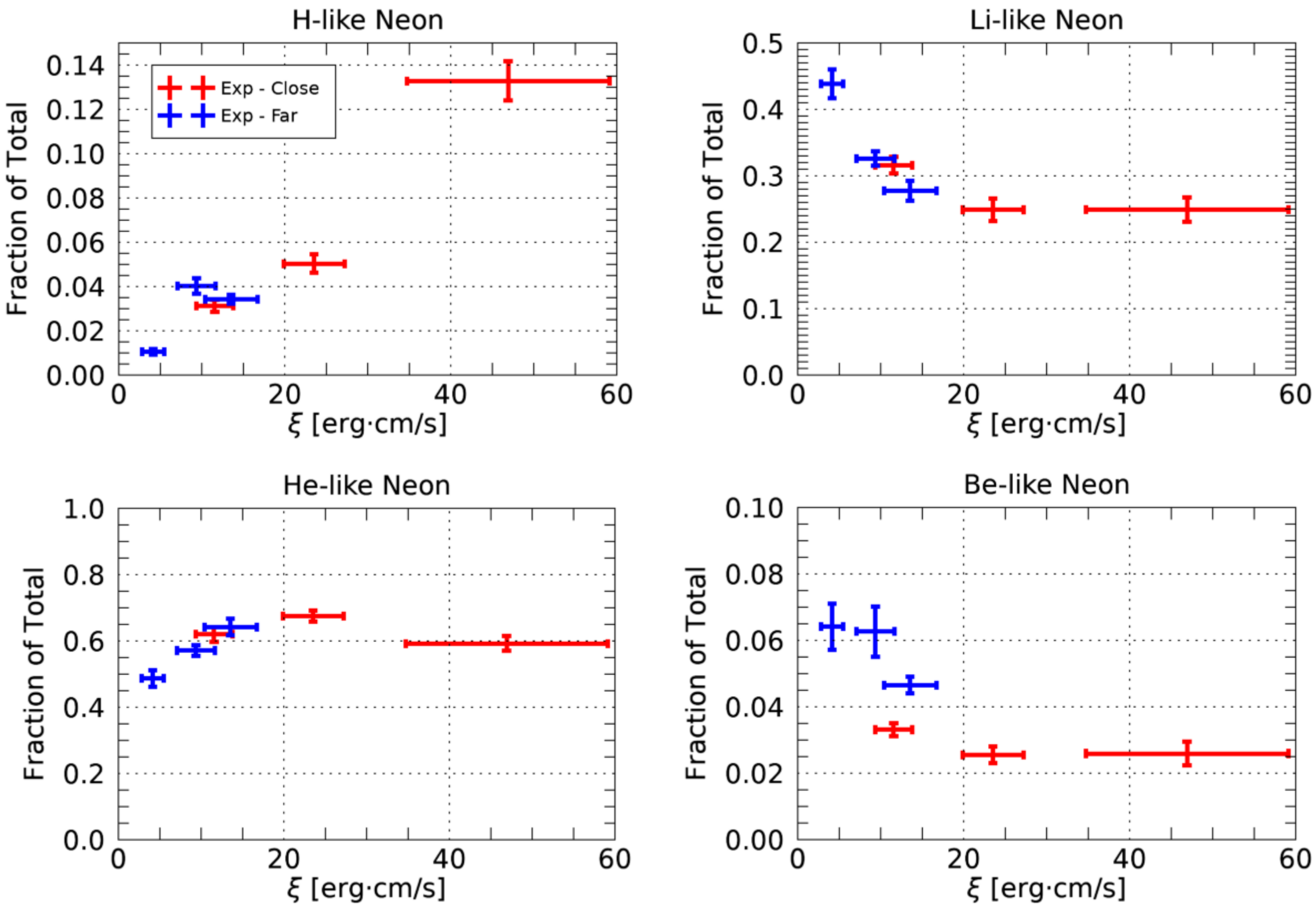


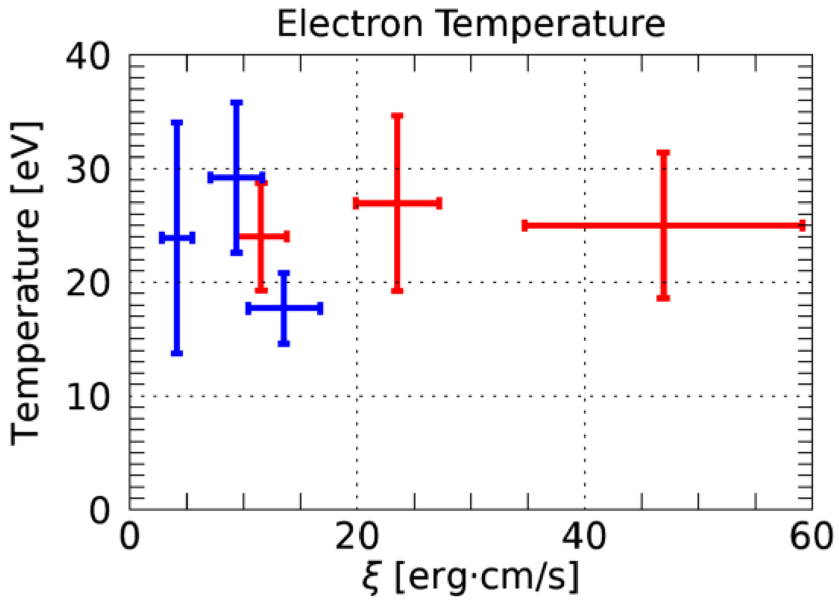
Si He-like emission

****G. Loisel, J. Bailey, D. Liedahl et al., PRL 119 (2017)***

Photoionized plasma trends in ionization and heating

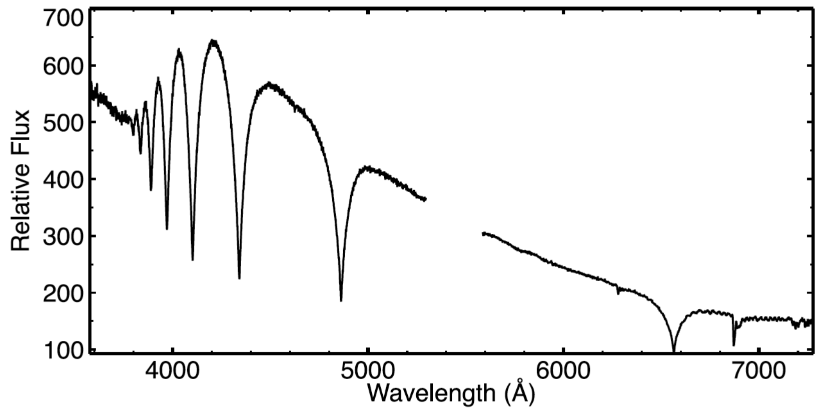
- ***Systematic*** measurements of heating[1] and ionization[2] as a function of ionization parameter
- Quantitative characterization of energy balance and ionization/recombination processes
- Data challenge modeling codes and is relevant for interpreting origin of disk accreting wind

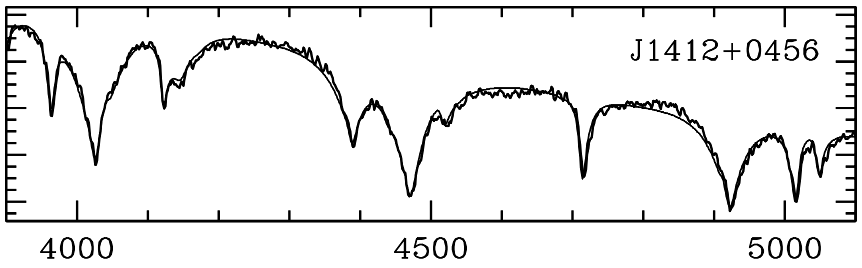


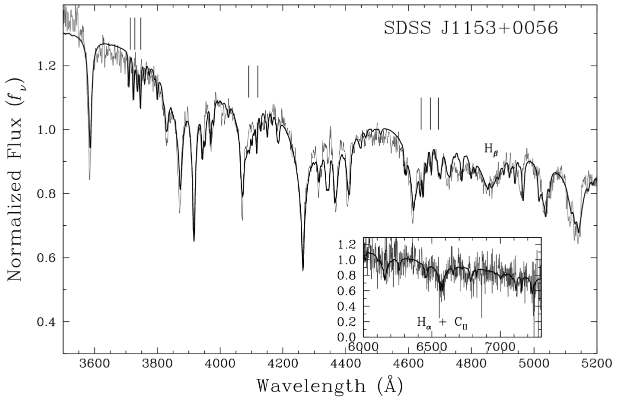


[1]R. C. Mancini et al, PRE **101**, 051201(R) (2020)
[2]D. C. Mayes et al, in preparation

The Importance of White Dwarf Spectra



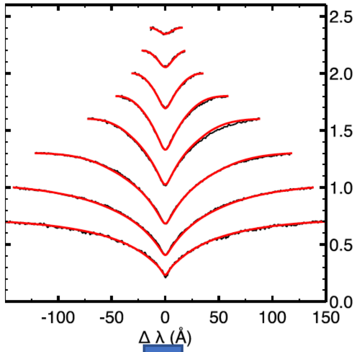




H

He

C



log g => Mass
Temperature
Composition

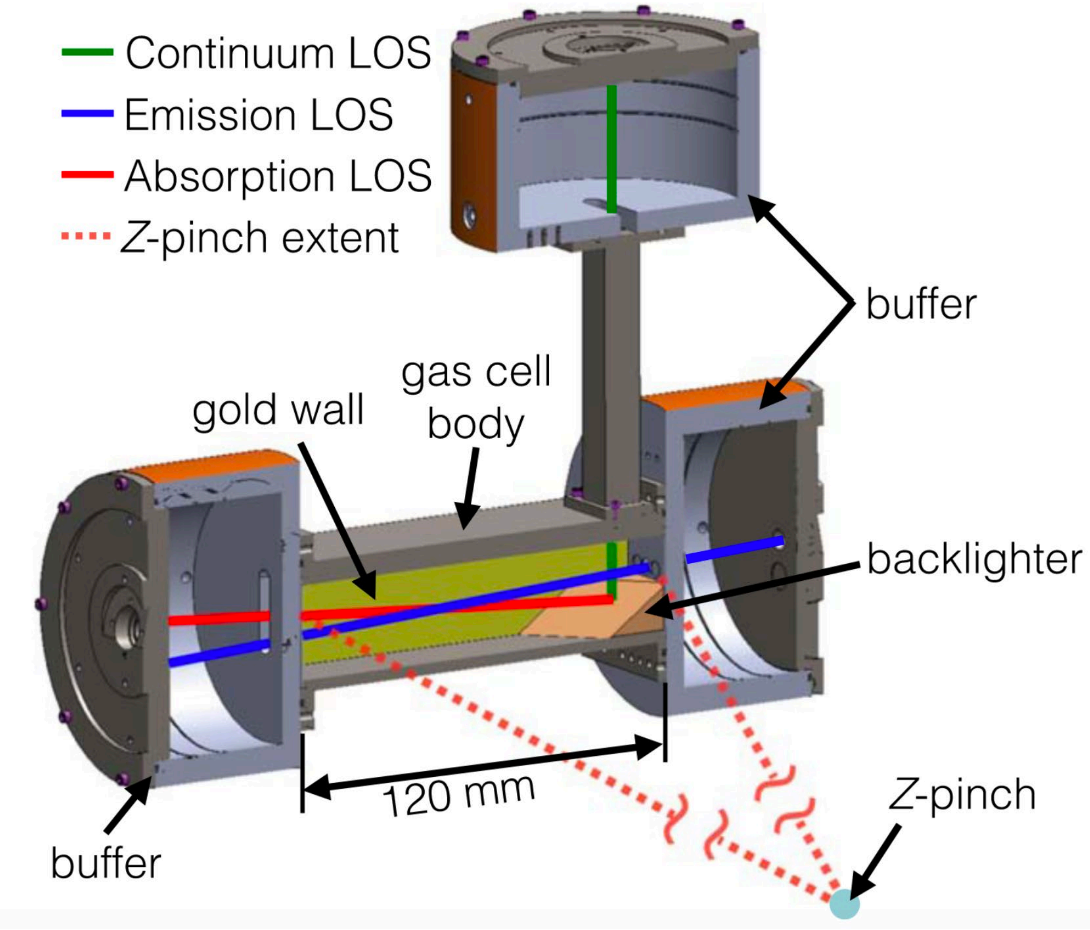
(b/c more massive WDs have smaller radii)

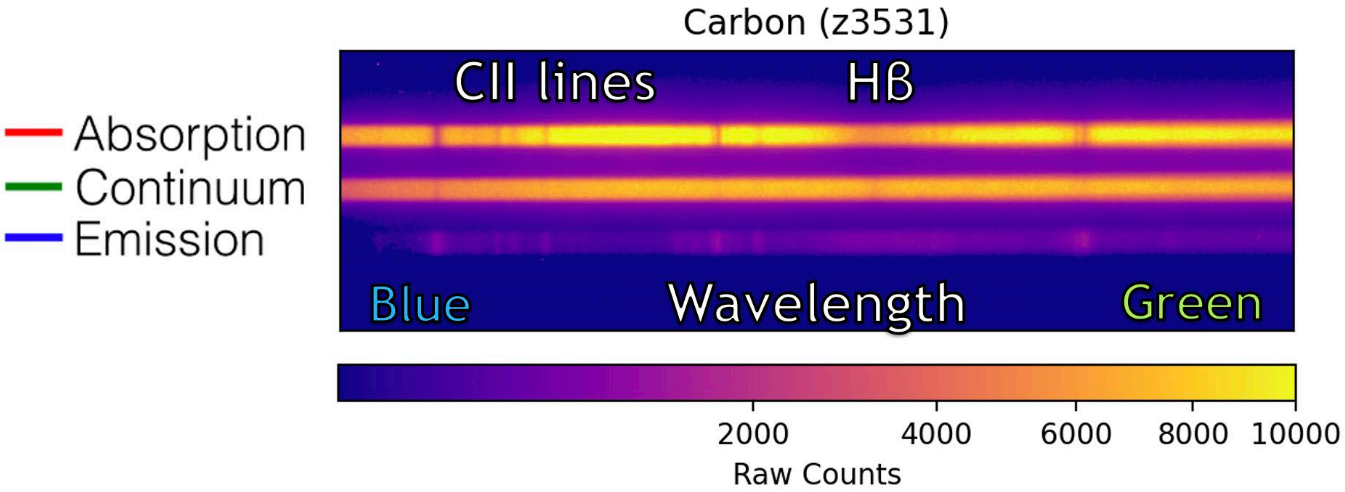
Age & History of the Galaxy

Interior Composition of Exoplanets

Precision Cosmology

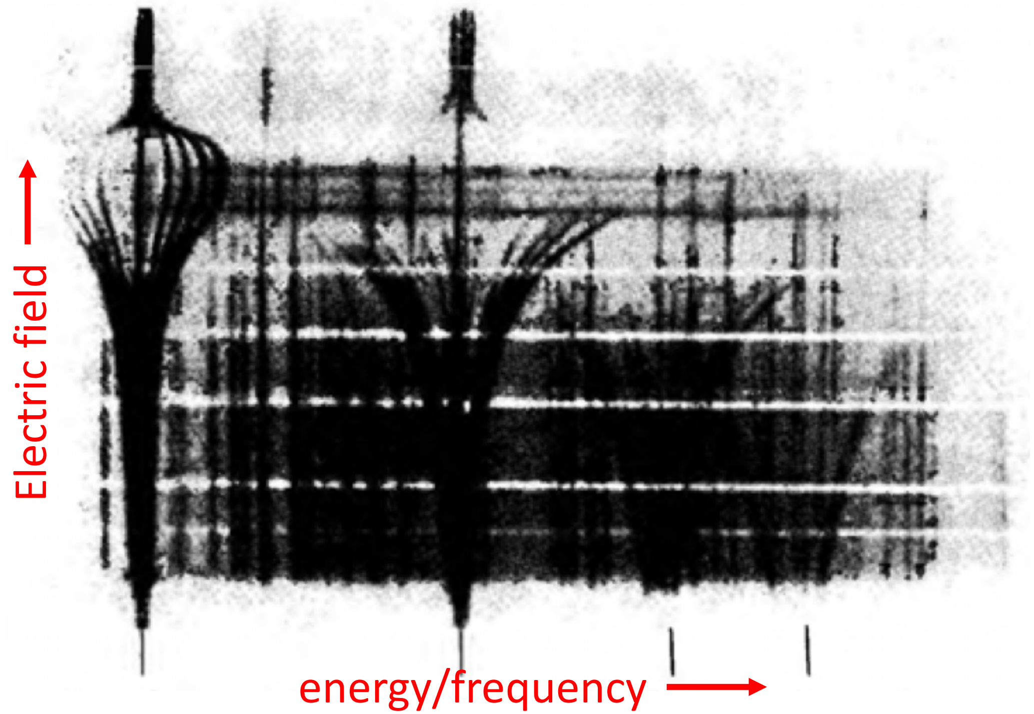
Hot DQ measurements at the Z machine

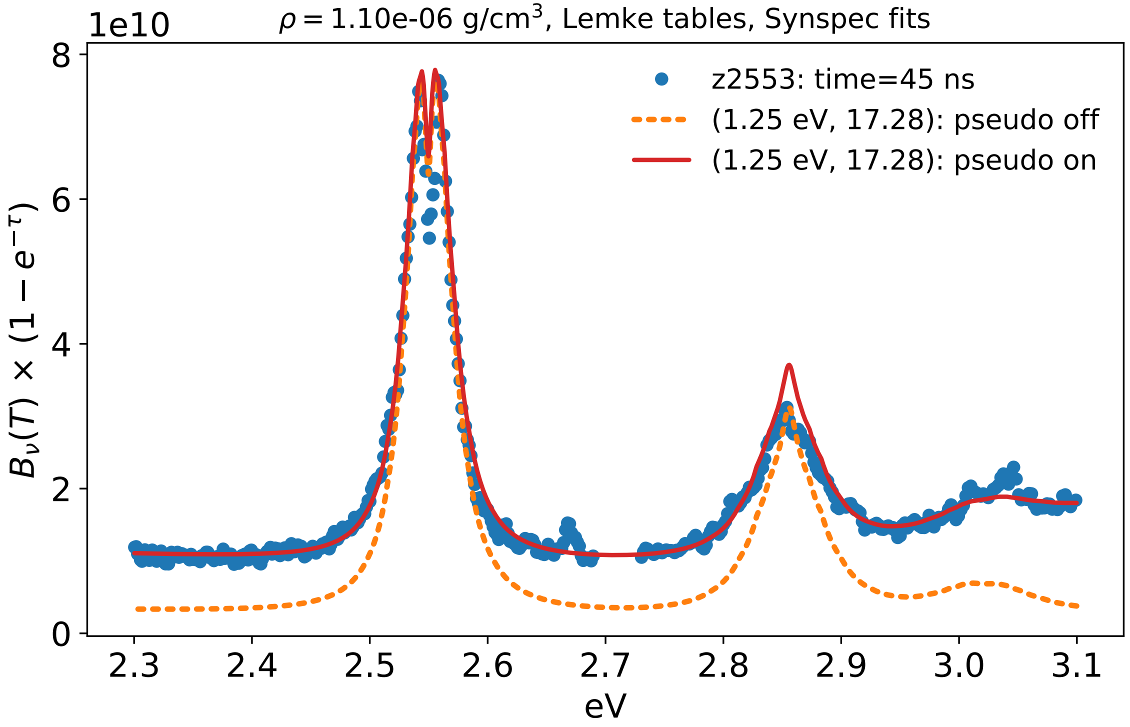




The Physics of Occupation Probability (OP)

Rausch and Traubenberg (1929—1931)

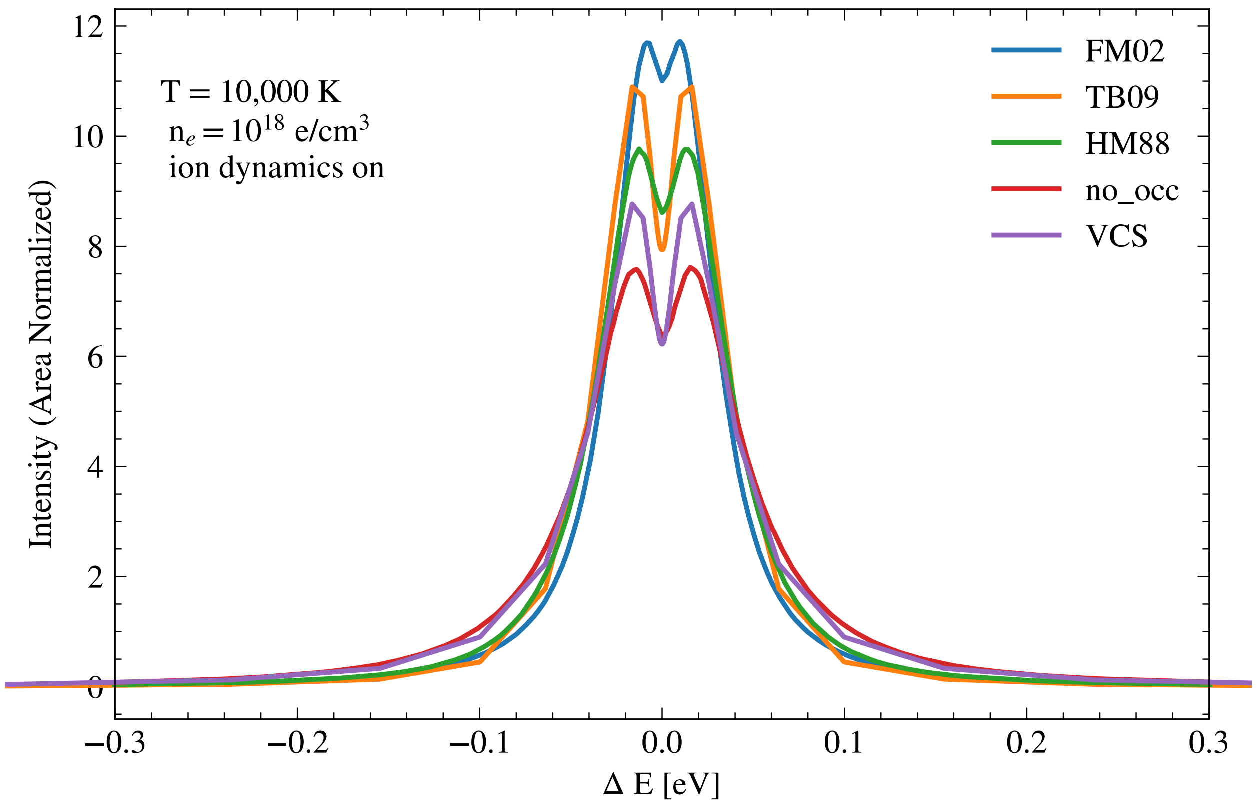


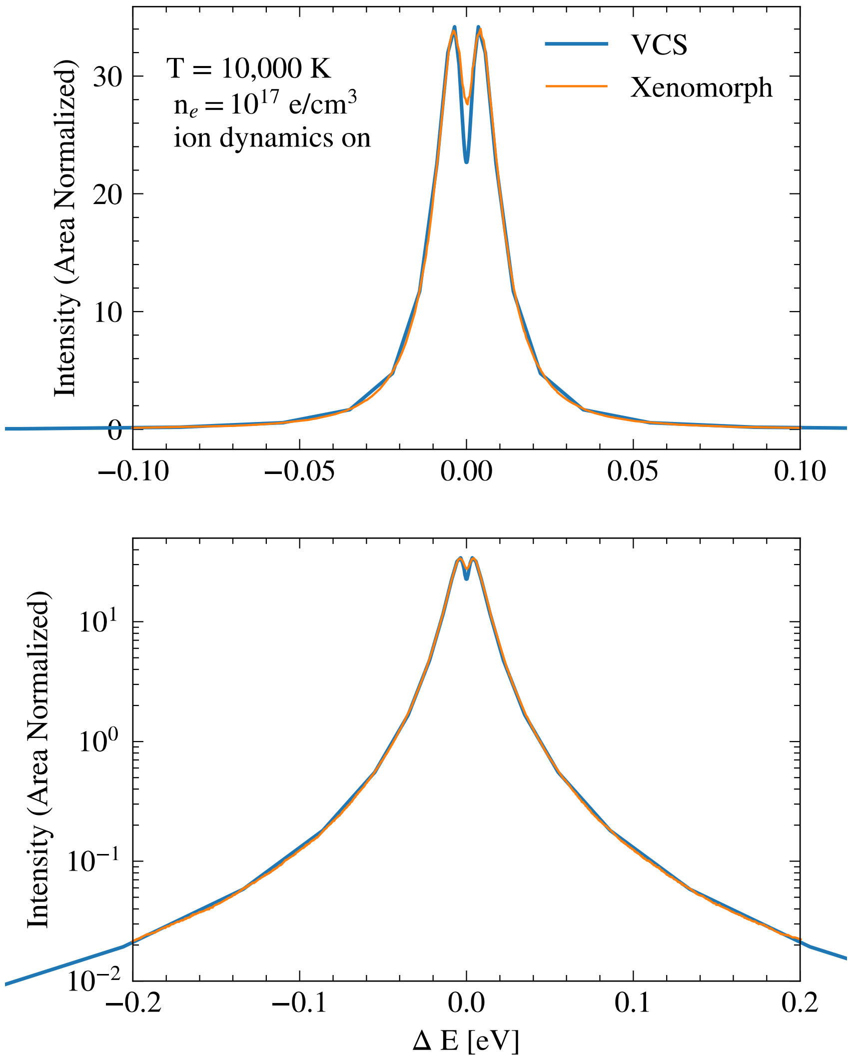


- Also called “continuum lowering” or “ionization potential depression”
- Due to the plasma environment, an atom can experience electric fields large enough that a bound electron may escape to the continuum or to a “collectivized” state
- This is not treated as a collisional or inelastic process
- An electron escaping by tunneling is an example that can decrease the occupation probability below 1.0
- There is a critical electric field (or distance of closest approach of the nearest ion) beyond which the state is assumed not to exist
- This process should modify the *strengths* and *shapes* of spectral lines

New Generation of Hydrogen Line Profiles for WD Stars

P. B. Cho, T. Gomez, M. H. Montgomery, B. H. Dunlap, M. Fitz Axen, B. Hobbs, I. Hubeny, T. Nagayama, and D. E. Winget





These profiles improve on the previous generation of calculations by including:

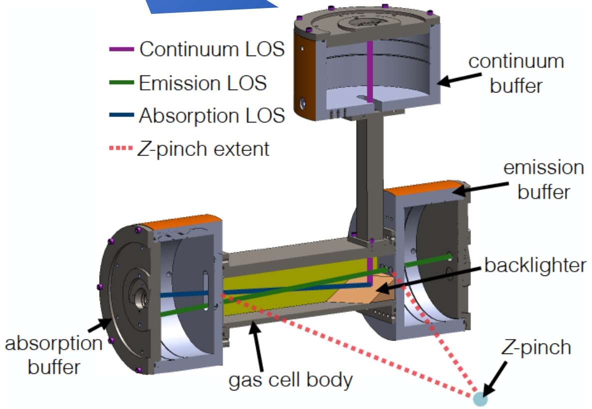
- Ion dynamics
- Higher-order multipole expansion for perturber electric fields
- Expanded basis set ("n+1" states included)

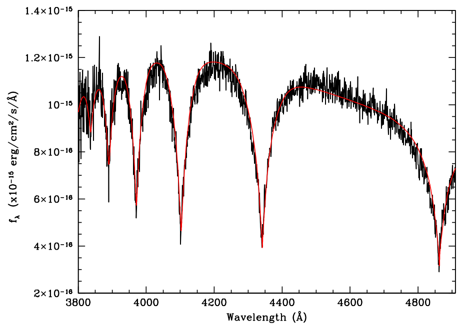
Astrophysical Feedback: Coming Full Cycle

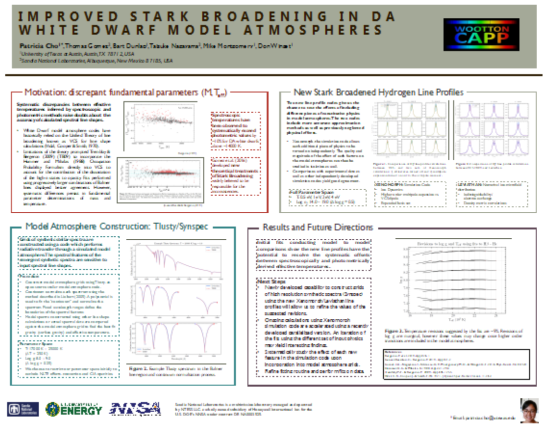
For our work to have quantitative implications for astrophysics, we have to take what we learn about single Te, ne plasmas on Z and incorporate this into a model white dwarf atmosphere.

Patty Cho is leading an effort to insert new H Lyman and Balmer line profiles (from **Thomas Gomez**) into the model atmosphere code TLUSTY (**I. Hubeny,** U. of Arizona), and we're starting to explore the impact of these new model atmospheres on our inferences about white dwarf stars. Completing the cycle for determining the quantitative implications for astrophysics.

Vidal et al. (1973) profiles







Another way of thinking Full Cycle!

Thanks!

WOOTTON CAPP