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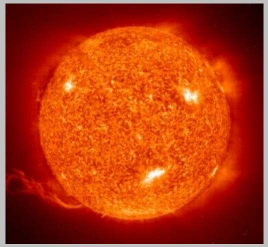
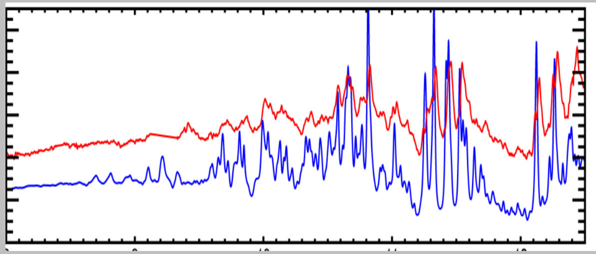

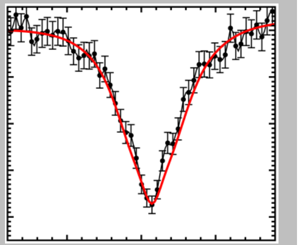
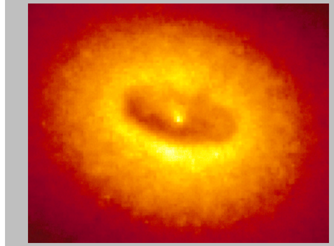
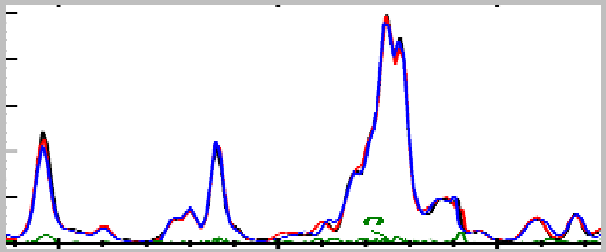

# Z Astrophysical Plasma Properties Collaborations

## -- Importance and challenges of HED benchmark experiments --

Taisuke Nagayama

7/31/2019

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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- What is ZAPP?
- Current ZAPP projects
- Goals of the breakout sessions

## ZAPP = Z Astrophysical Plasma Properties

Our goal is to perform at-parameter experiments to experimentally test plasma and spectra modeling

**Why should we test the models?**

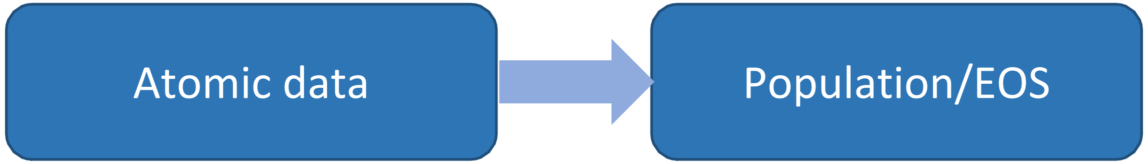
# Plasma and spectra modeling are complex; Models are used without sufficient experimental validations

Atomic data

- Energy
- Oscillator strength
- Cross-section
- Rate

# Plasma and spectra modeling are complex; Models are used without sufficient experimental validations

Population ≡ Probability for an ion being in each atomic state




- Energy
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- LTE/NLTE

# Plasma and spectra modeling are complex; Models are used without sufficient experimental validations

Population ≡ Probability for an ion being in each atomic state

Atomic data → Population/EOS

- Energy
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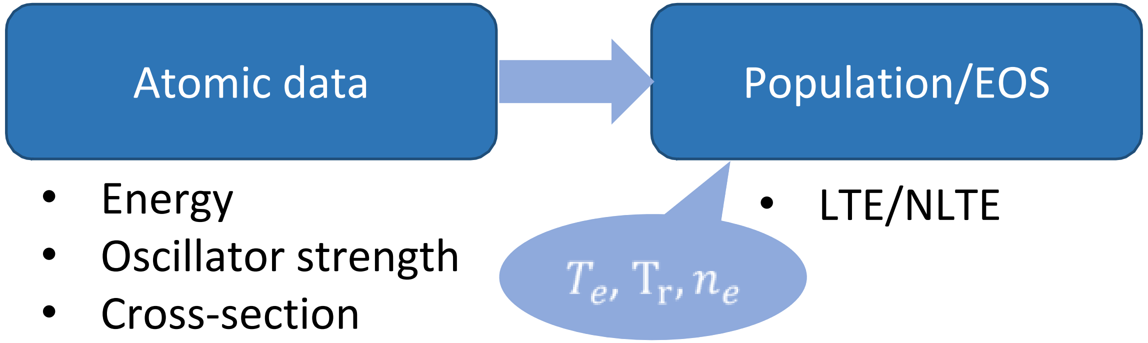
Population ≡ Probability for an ion being in each atomic state



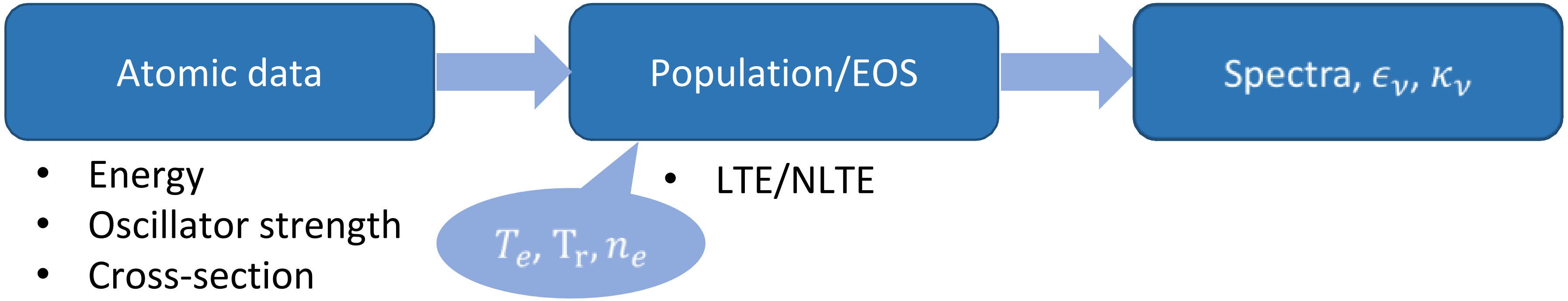

- Energy
- Oscillator strength
- Cross-section
- Rate

- LTE/NLTE

# Plasma and spectra modeling are complex; Models are used without sufficient experimental validations

Population ≡ Probability for an ion being in each atomic state

- Line broadening
  - Stark
  - Doppler
  - Natural
- Radiation transport




$\epsilon_\nu$ =emissivity

$\kappa_\nu$ =opacity

- Energy
- Oscillator strength
- Cross-section
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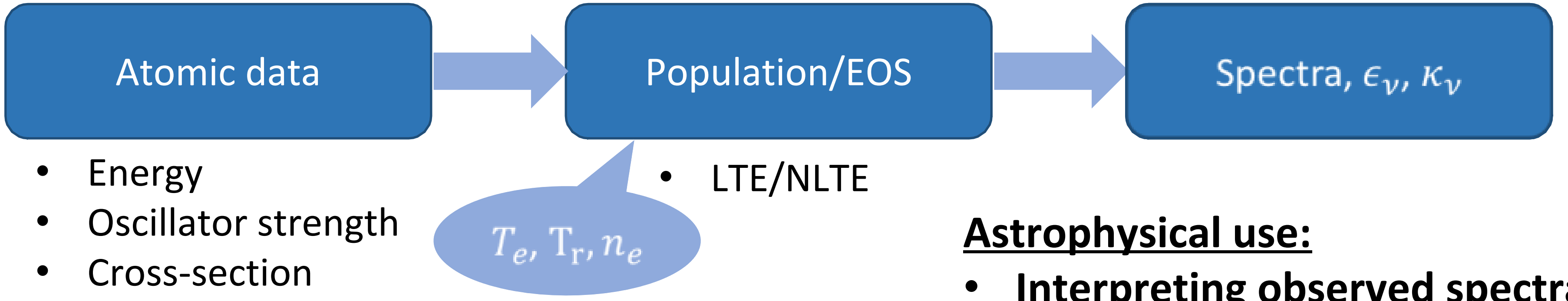
# Plasma and spectra modeling are complex; Models are used without sufficient experimental validations




- Energy
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**<u>Astrophysical use:</u>**

- **Interpreting observed spectra**
- **Modeling astrophysical objects (EOS, mean opacity)**

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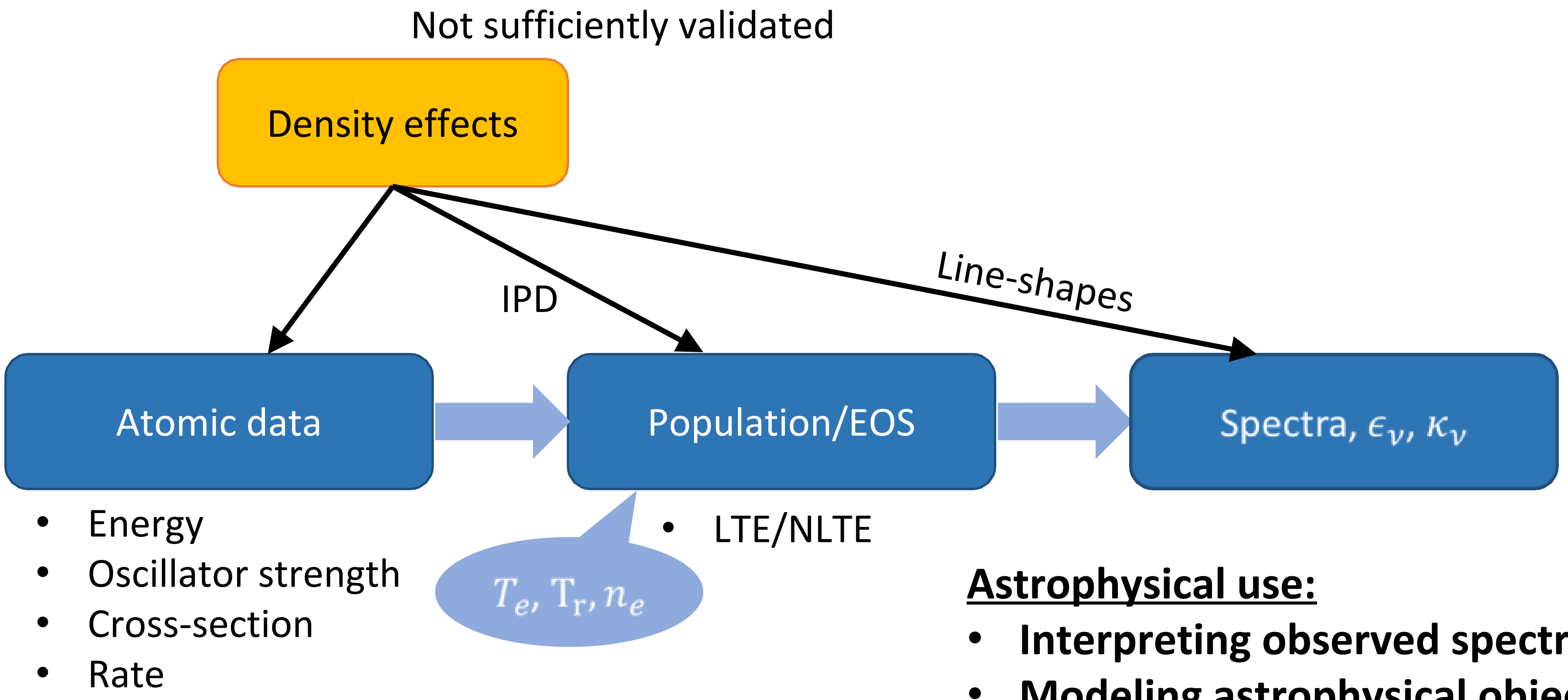


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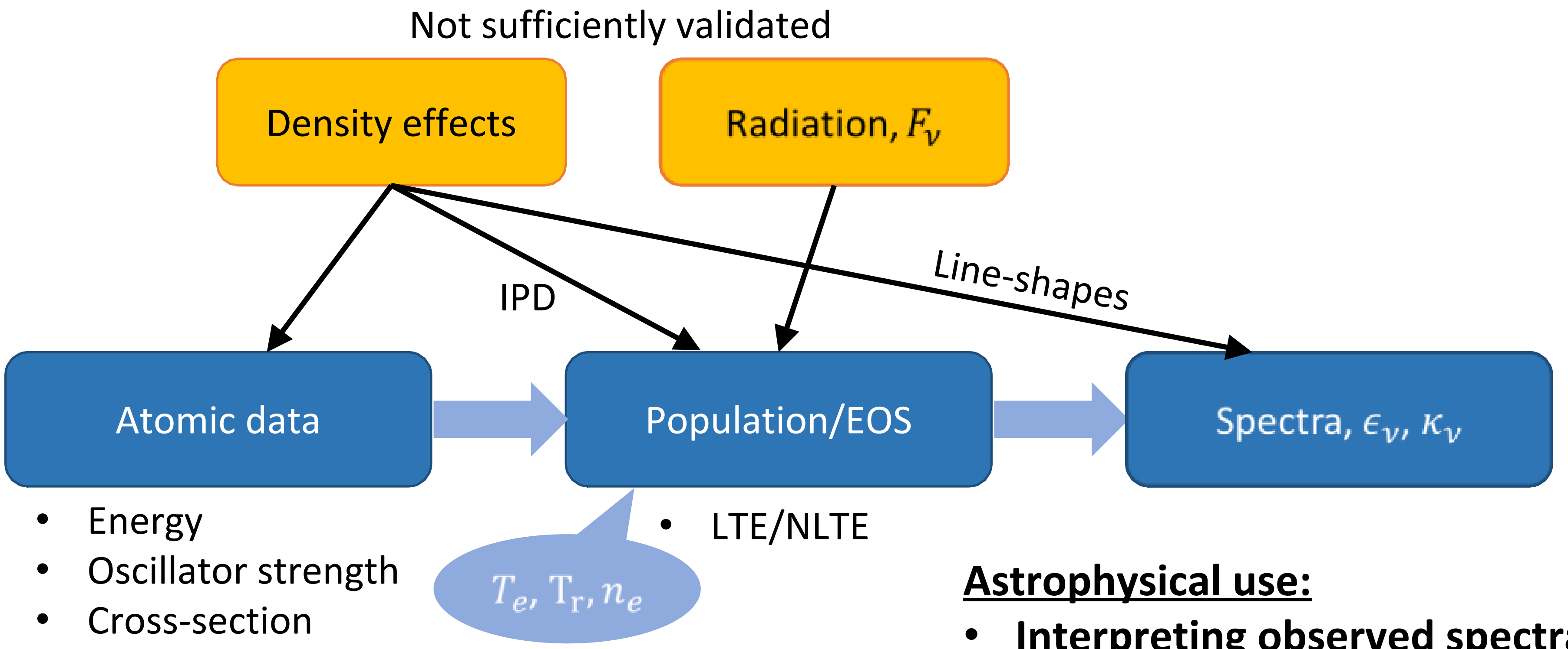


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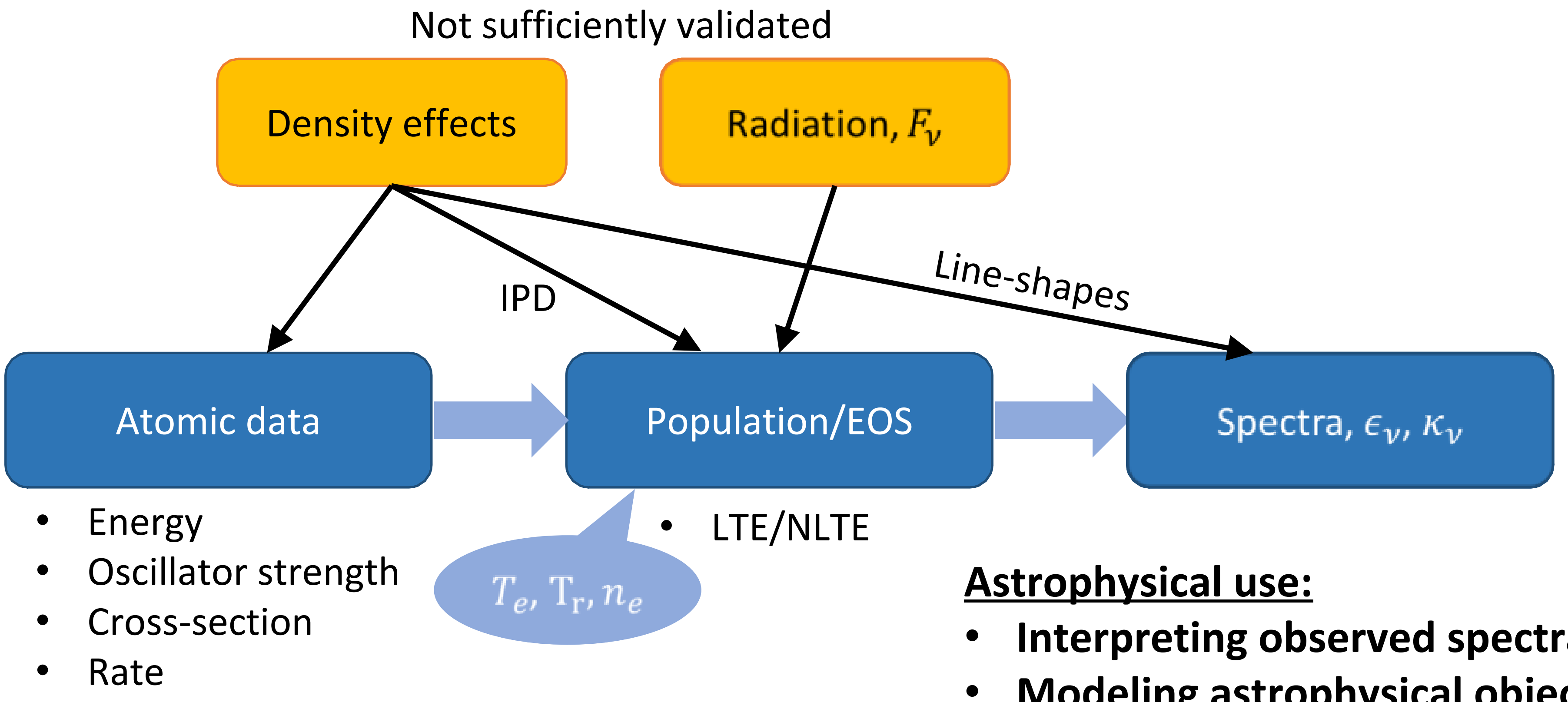


**Astrophysical use:**

- **Interpreting observed spectra**
- **Modeling astrophysical objects (EOS, mean opacity)**

- **Limited validations available for approximations at extreme conditions**
- **This produces unknown uncertainty to the data interpretations and model predictions**

# Mega-joule-class HED laboratories produce extreme conditions for many years, but …

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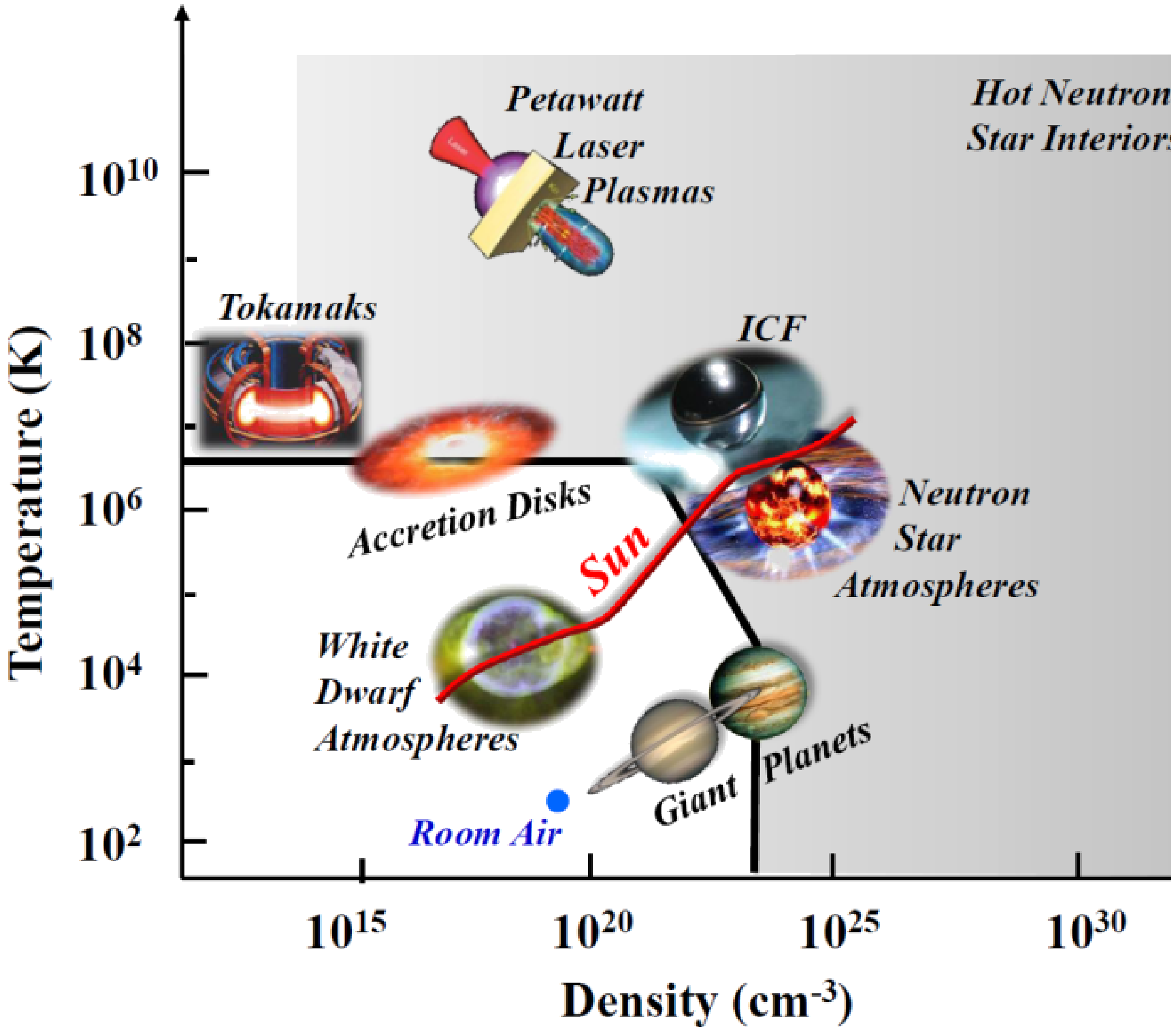
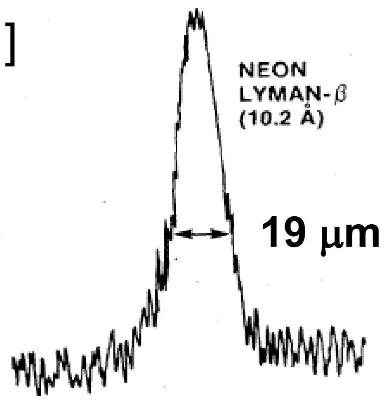



**Problem: Sample size used to be so small for benchmark experiments**

e.g., Laser fusion capsule [1]

T=300 eV,
ρ=0.26 g/cc
Size: 19 μm



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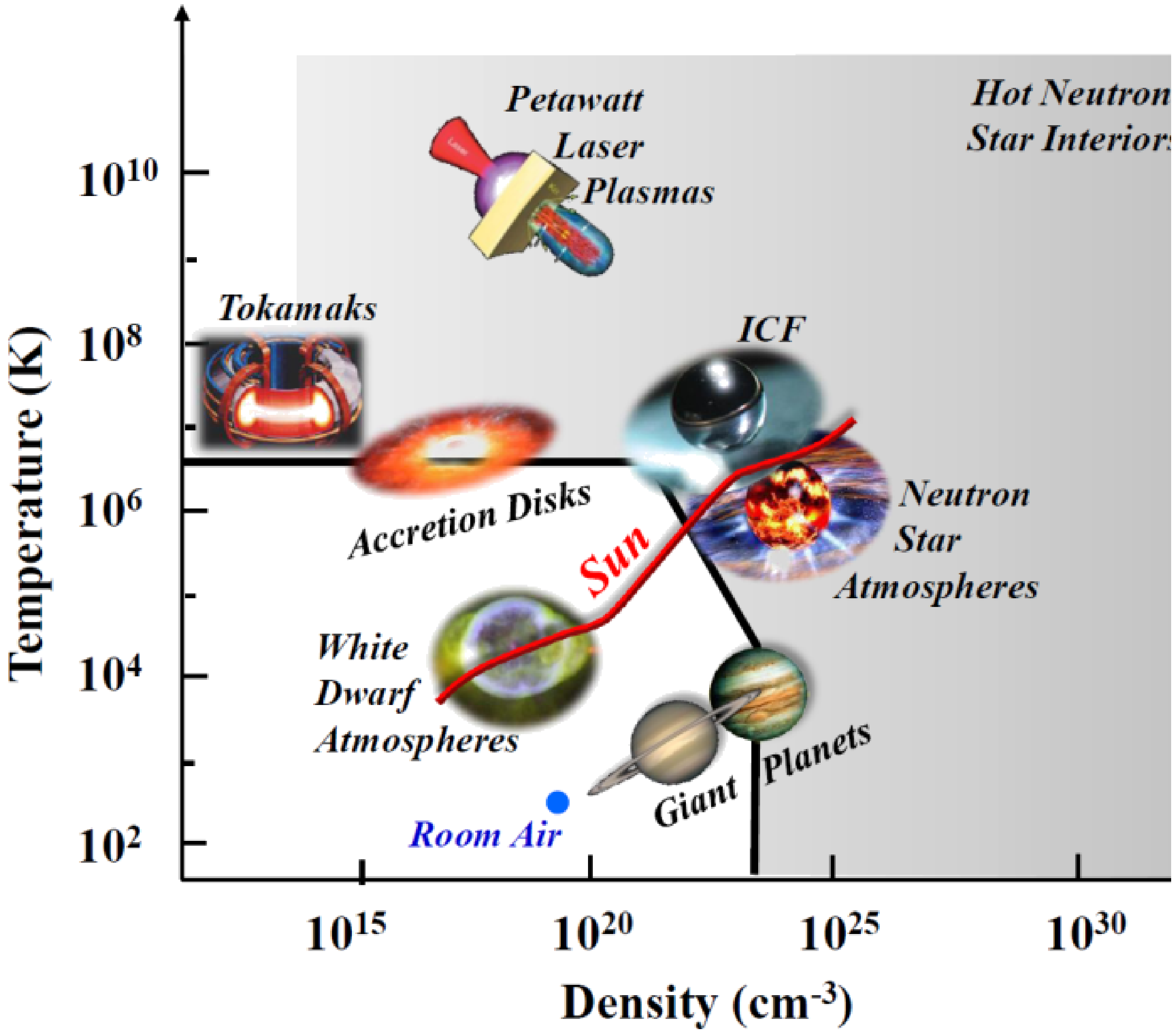


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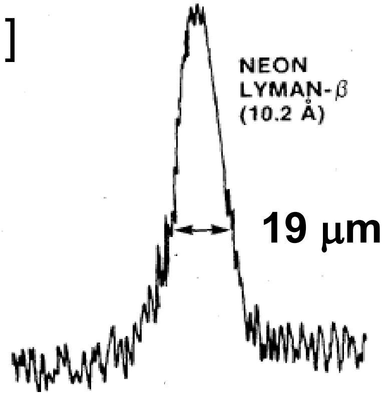

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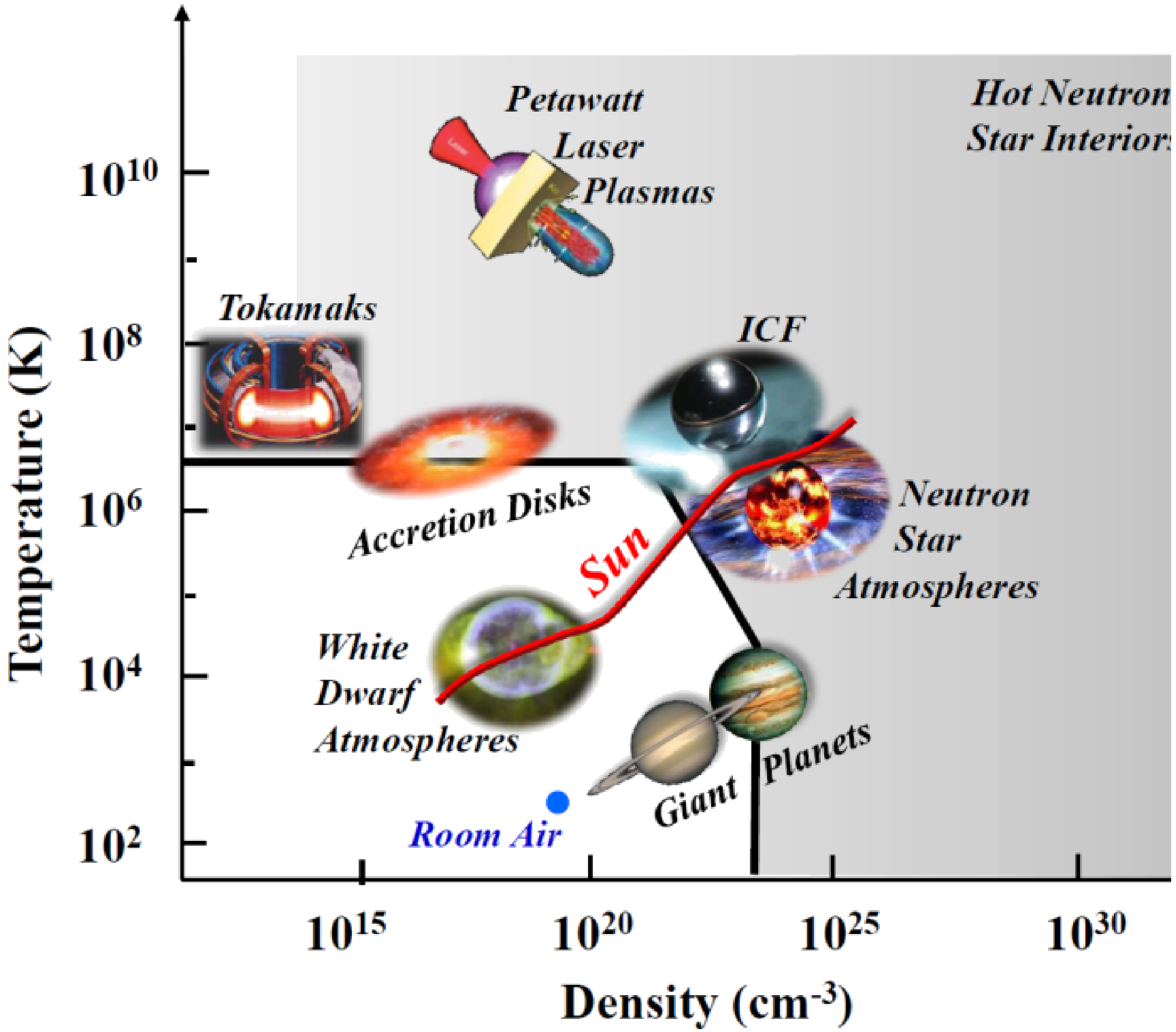


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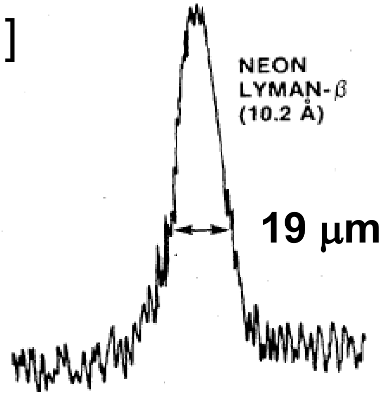



[1] Yaakobi, PRL, 1977

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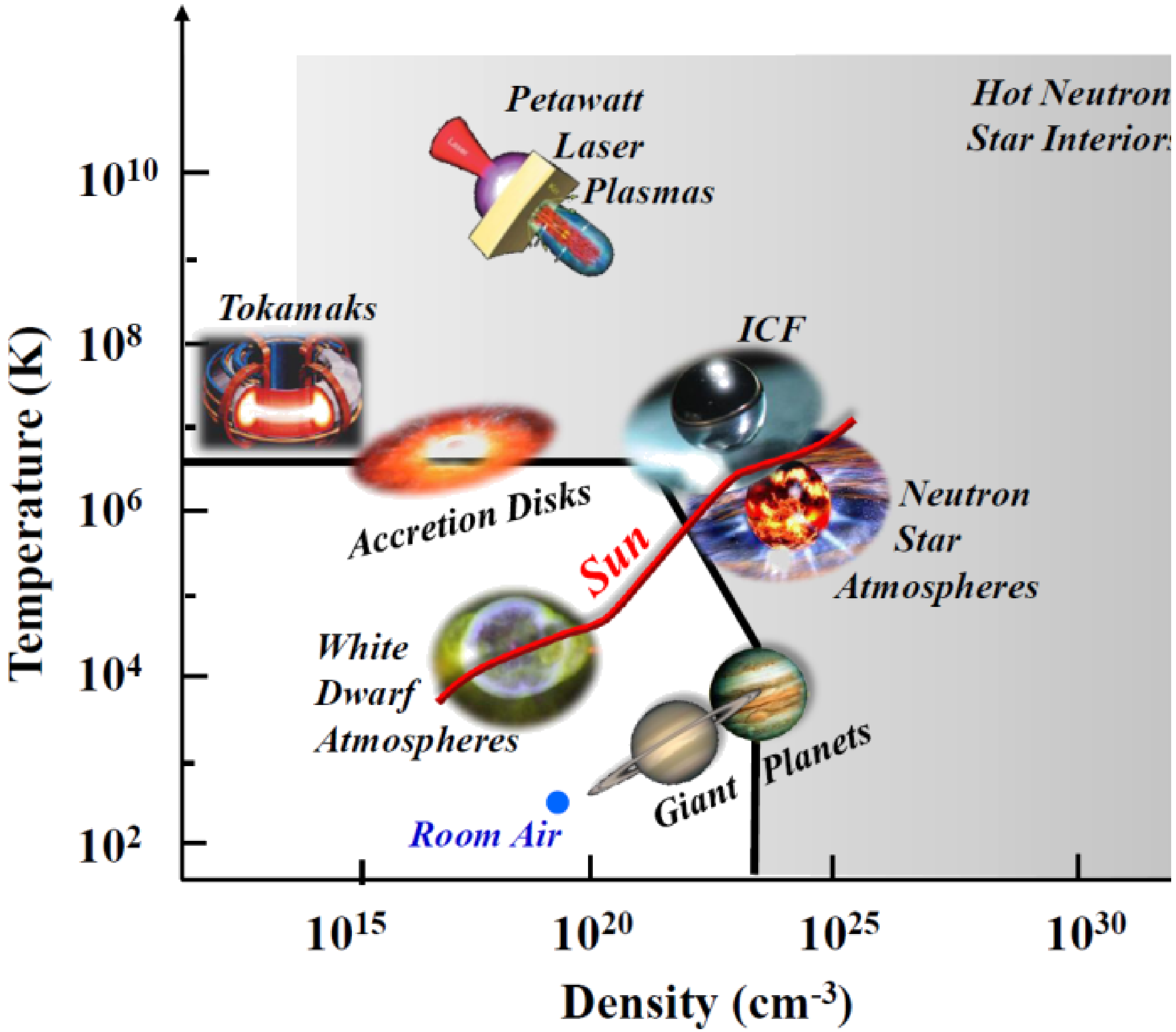


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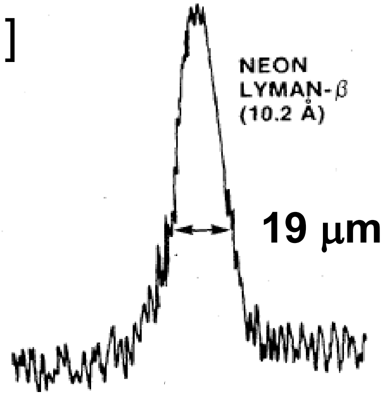


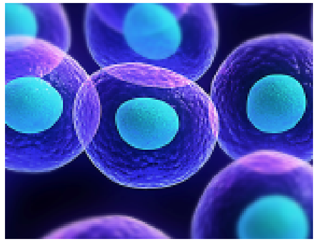

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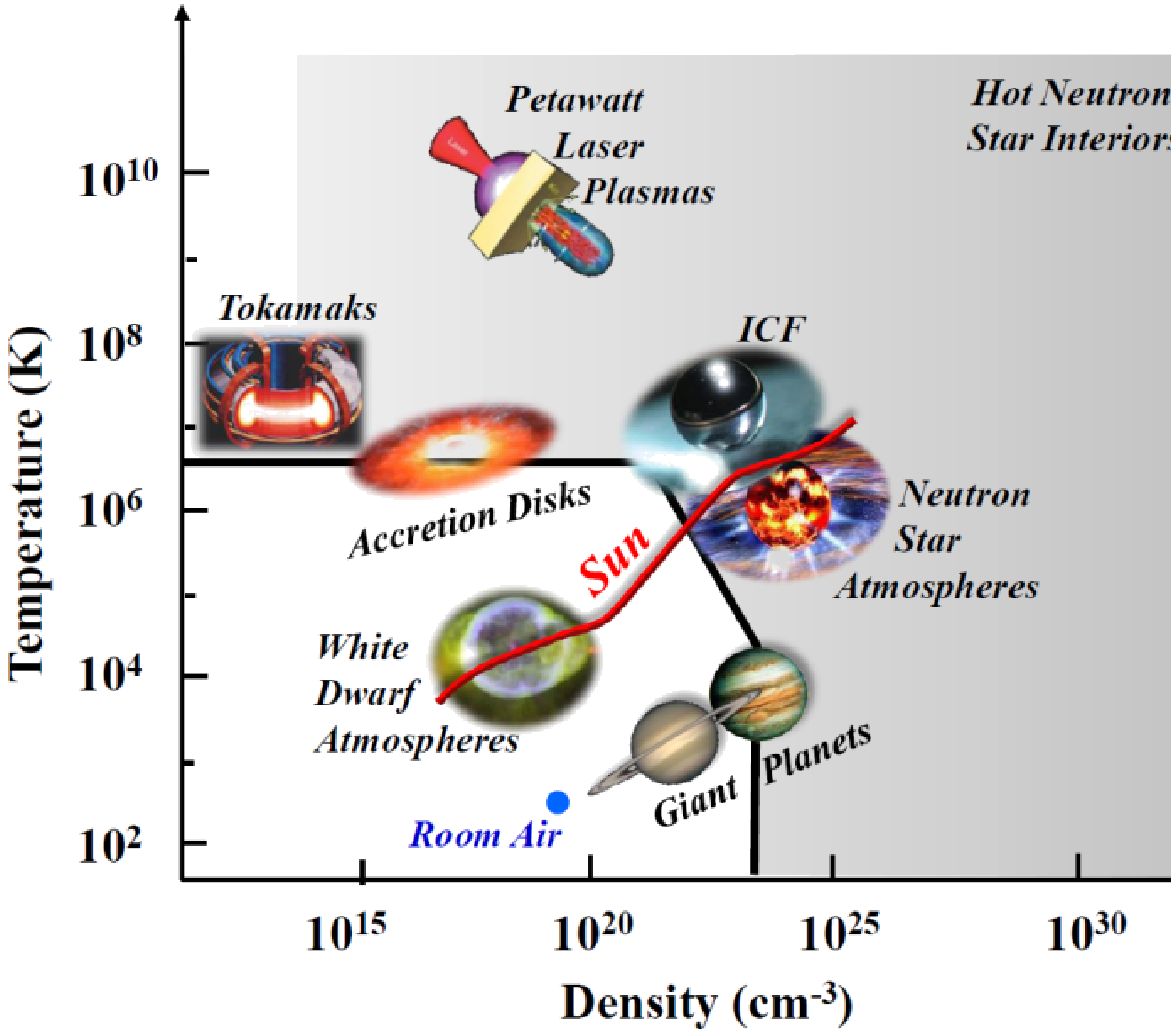
# What's new: now, we can create macroscopic enough quantities of astrophysical matter for detailed studies




Z machine at Sandia National Lab creates macroscopic plasma at fairly exotic conditions

**Fe opacity samples: *Size ~ 1 mm sand grain***

Achieved conditions:
$T$=150-200 eV
$n_e$=(1-10)x$10^{22}$ e/$cm^3$

***Z White Dwarf samples: ~ size of a phone***

Achieved conditions:
$T$=1-3 eV
$n_e$=(5-100)x$10^{16}$ e/$cm^3$

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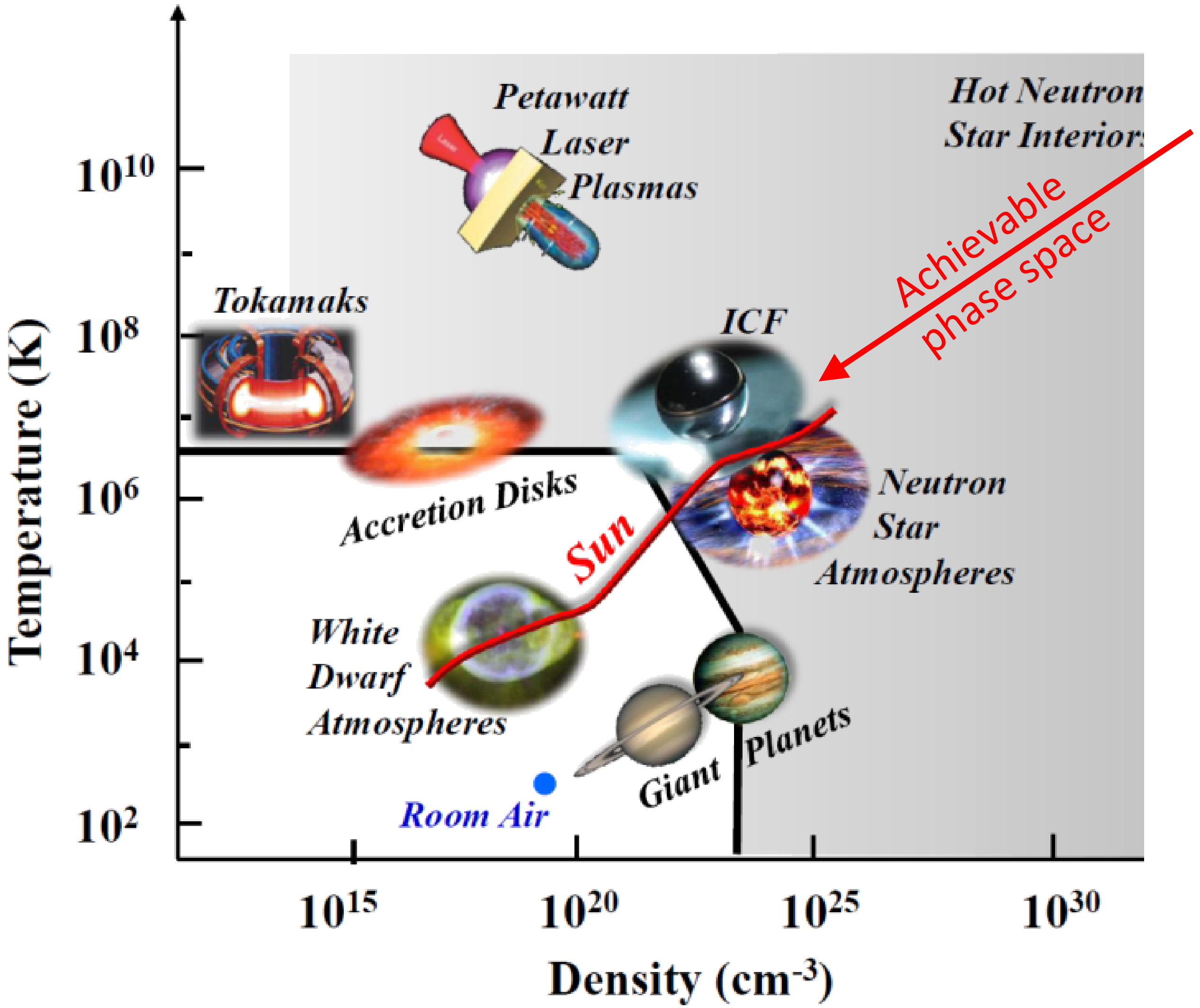


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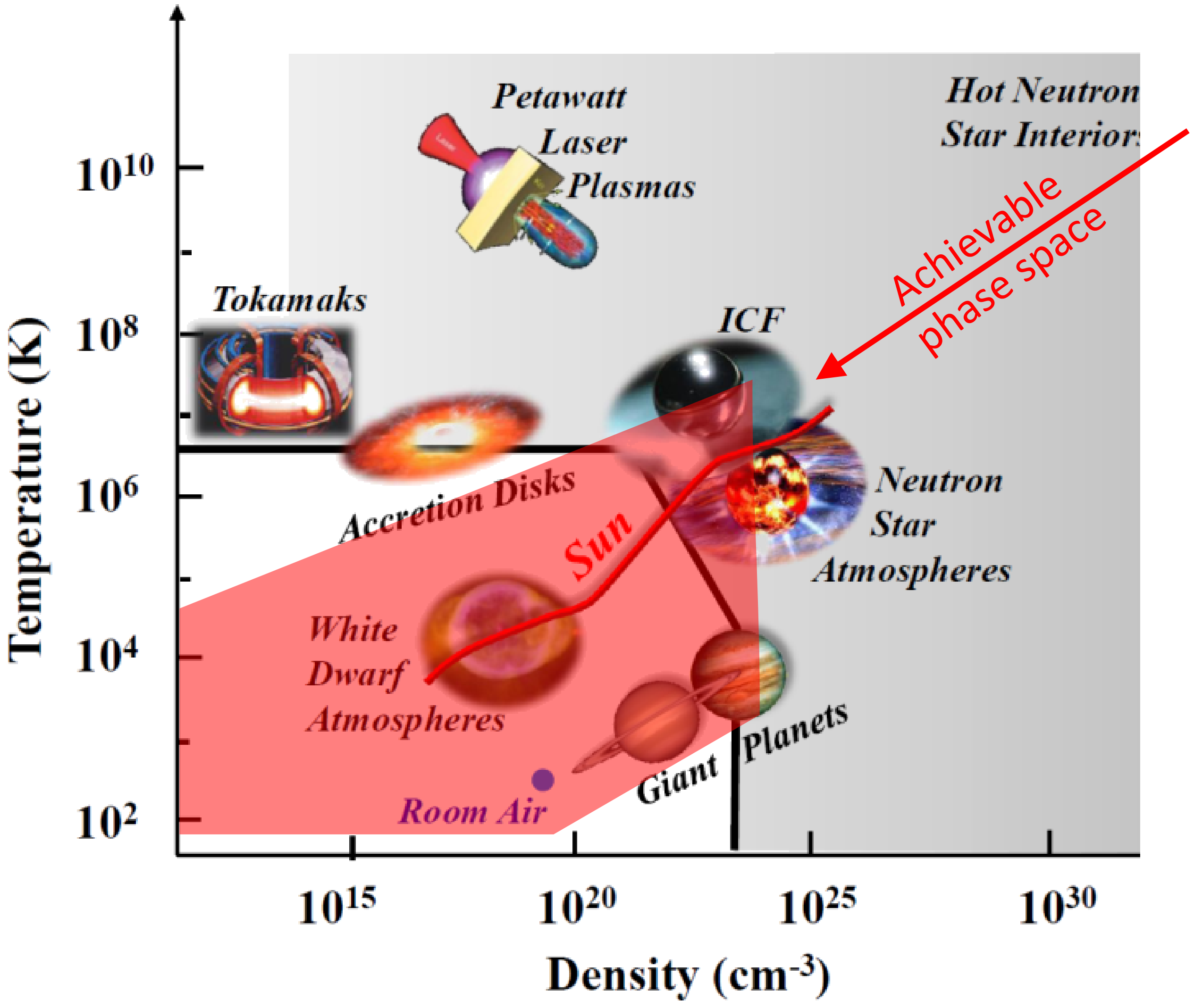


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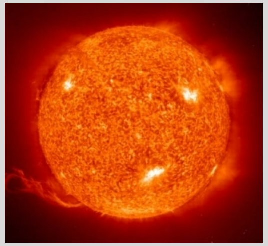
# ZAPP* campaigns simultaneously study multiple issues spanning 200x in temperature and $10^6$x in density

## Solar Opacity



**Question:**
Why can't we predict solar structure accurately enough?

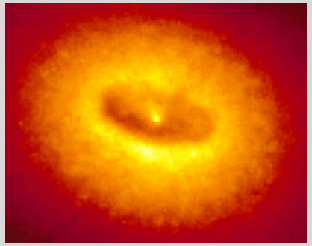
**Achieved Conditions:**
$T_e$ ~ 200 eV, $n_e$ ~ $10^{23}$ $cm^{-3}$

## White Dwarf Line-Shapes

**Question:**
Why doesn't spectral fitting provide the correct properties for White Dwarfs?

**Achieved Conditions:**
$T_e$ ~ 1 eV, $n_e$ ~ $10^{17}$ $cm^{-3}$

## Photoionized Plasma

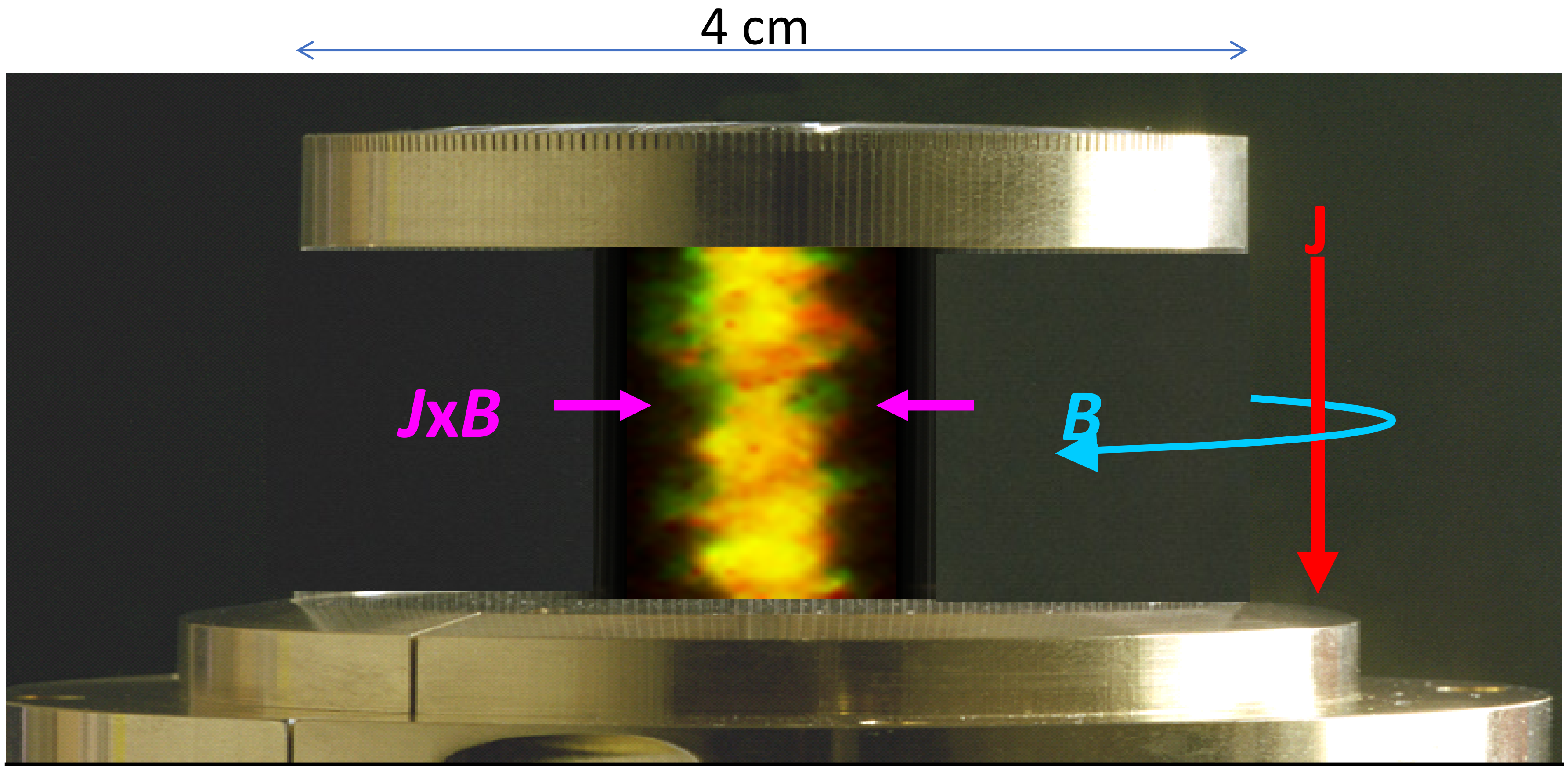


**Question:**
How does ionization and line formation occur in accreting objects?

**Achieved Conditions:**
$T_e$ ~ 20 eV, $n_e$ ~ $10^{19}$ $cm^{-3}$

*ZAPP = Z Astrophysical Plasma Properties

# The SNL Z machine uses 27 million Amperes to create x-rays




$P_{rad}$ ~ 220TW (±10%), $Y_{rad}$ ~ 1.6 MJ (±7%)

# The SNL Z machine uses 27 million Amperes to create x-rays, and perform multiple benchmark experiments simultaneously

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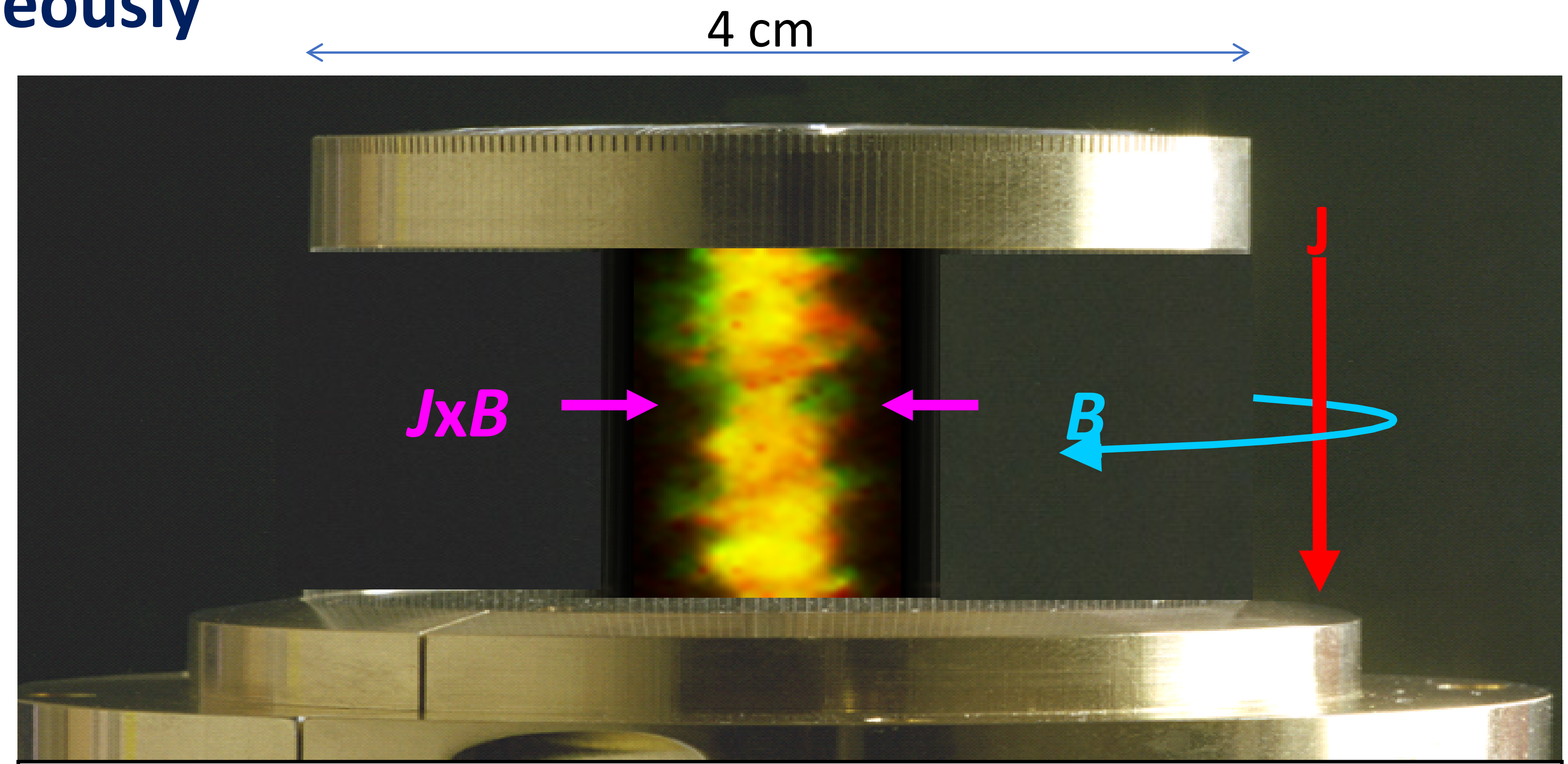


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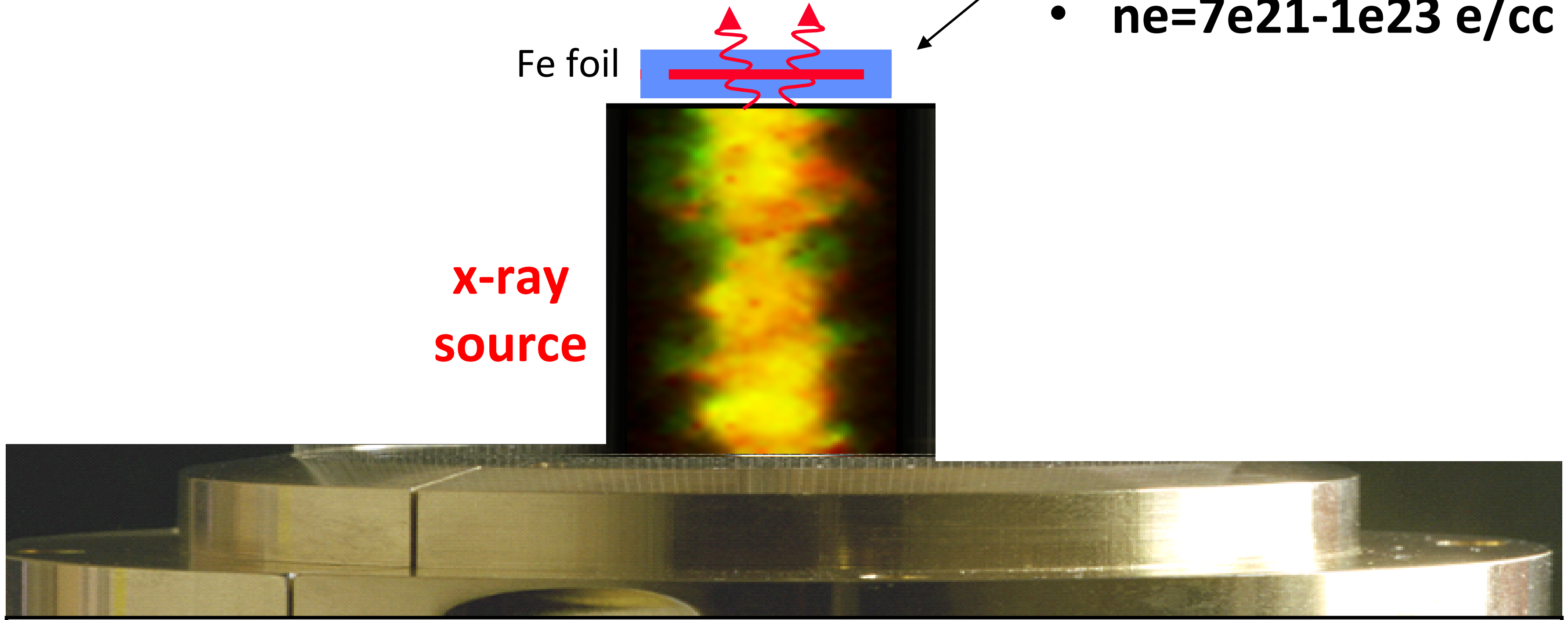
Sanford, *PoP* (2002); Bailey et al., *PoP* (2006); Slutz et al., *PoP* (2006); Rochau et al., *PPCF* (2007)

# The SNL Z machine uses 27 million Amperes to create x-rays, and perform multiple benchmark experiments simultaneously

Sandia National Laboratories

**Solar opacity sample**
- **T=150-200 eV**
- **ne=7e21-1e23 e/cc**

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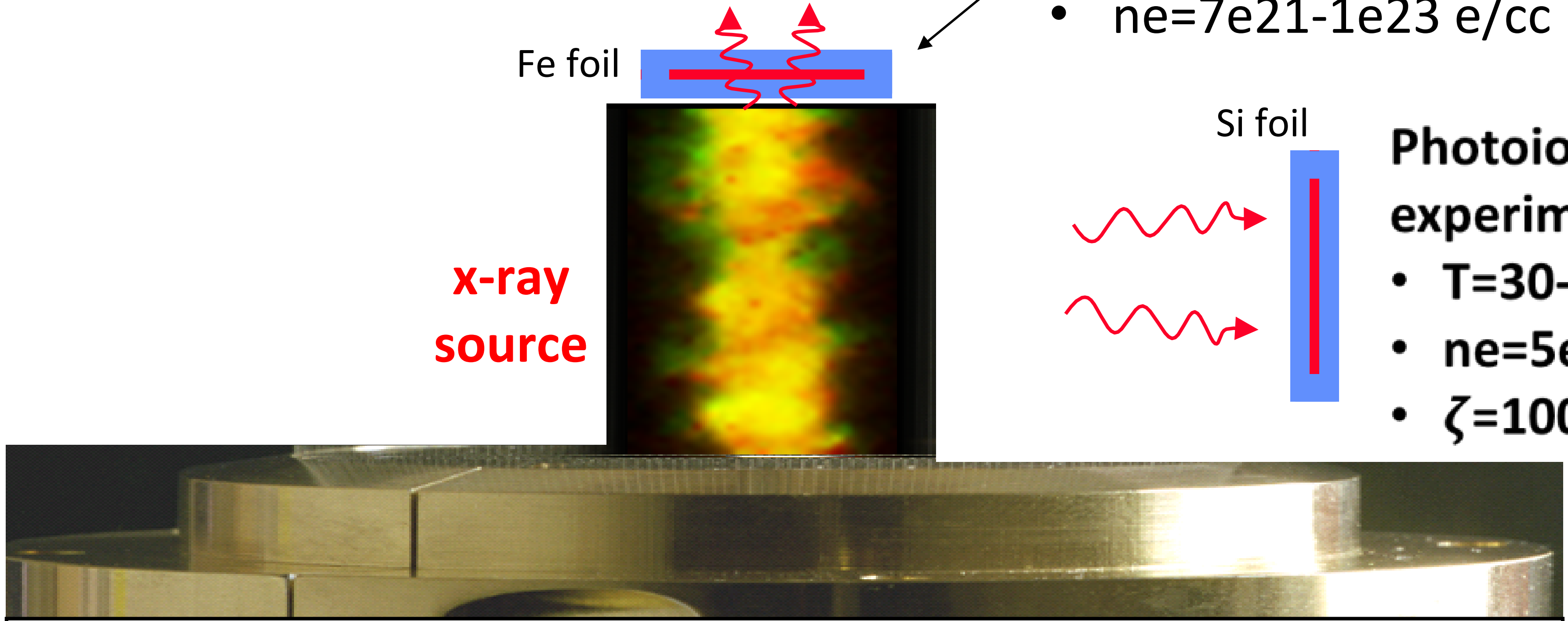


**Photoionized plasma experiments**
- **T=30-40 eV**
- **ne=5e16-1e17 e/cc**
- **ζ=100-1000**

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Sandia National Laboratories

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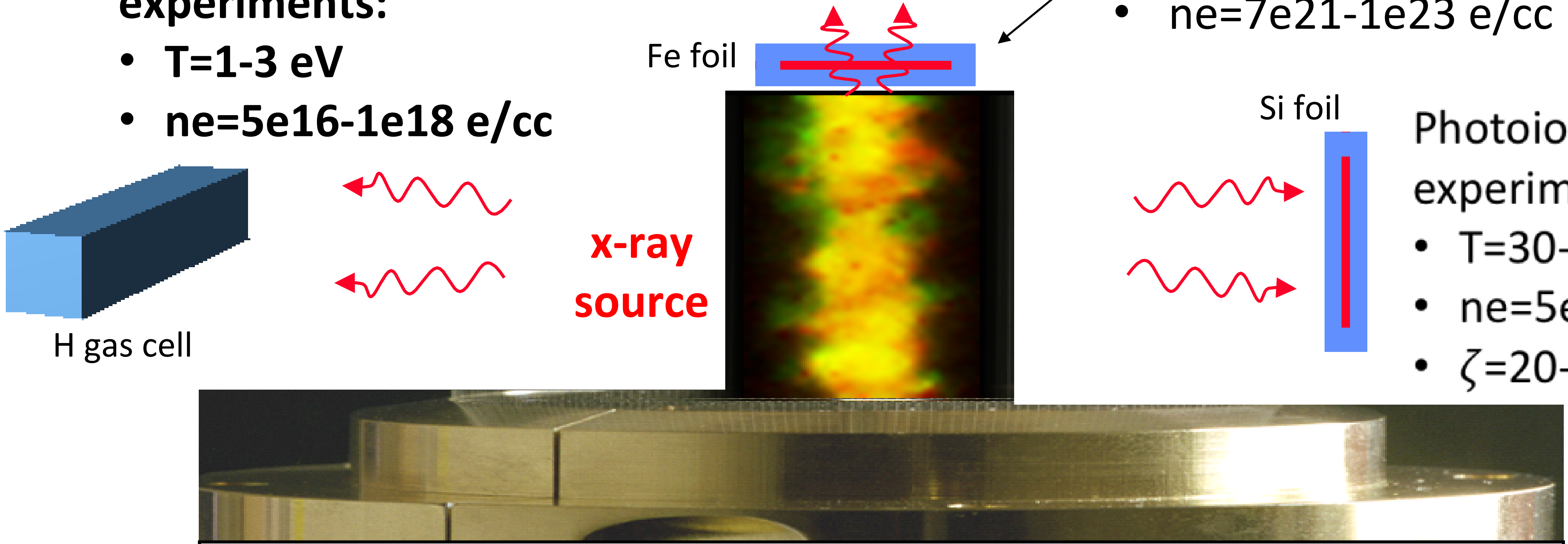
**White Dwarf experiments:**
- **T=1-3 eV**
- **ne=5e16-1e18 e/cc**




Photoionized plasma experiments
- T=30-40 eV
- ne=5e16-1e17 e/cc
- $\zeta$=20-1000

$P_{rad}$ ~ 220TW (±10%), $Y_{rad}$ ~ 1.6 MJ (±7%)

Single shot can perform multiple experiments at T=1-200 eV and ne=5e16-1e23 e/cc

Sanford, *PoP* (2002); Bailey et al., *PoP* (2006); Slutz et al., *PoP* (2006); Rochau et al., *PPCF* (2007)

# ZAPP* campaigns simultaneously study multiple issues

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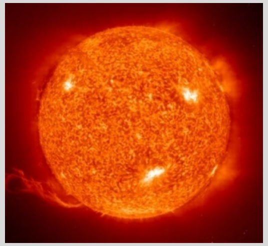
## Solar Opacity



**Question:**
Why can't we predict solar structure accurately enough?

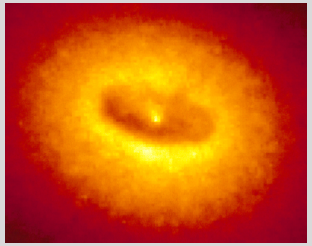
**Achieved Conditions:**
$T_e \sim 200$ eV, $n_e \sim 10^{23}$ cm$^{-3}$

## White Dwarf Line-Shapes

**Question:**
Why doesn't spectral fitting provide the correct properties for White Dwarfs?

**Achieved Conditions:**
$T_e \sim 1$ eV, $n_e \sim 10^{17}$ cm$^{-3}$

## Photoionized Plasma



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# ZAPP* campaigns acquire up to 60 spectra on a single shot

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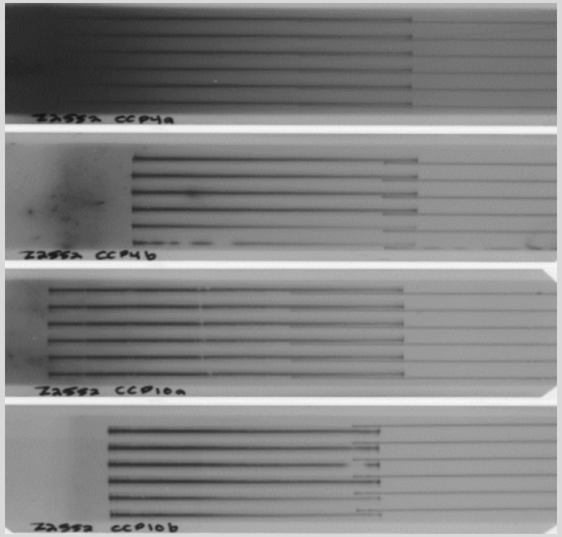
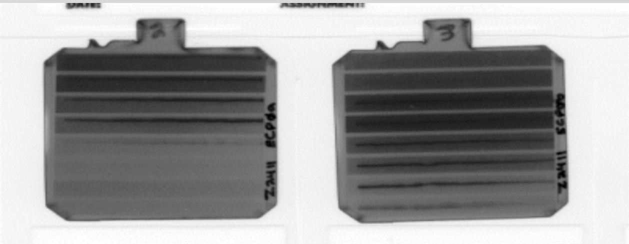
## Solar Opacity

24 Space-Resolved
Fe Absorption Spectra

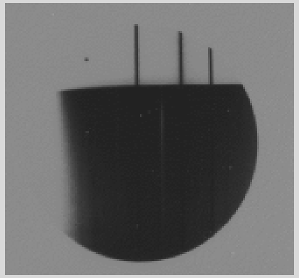


16 Time-Resolved
Fe Absorption Spectra



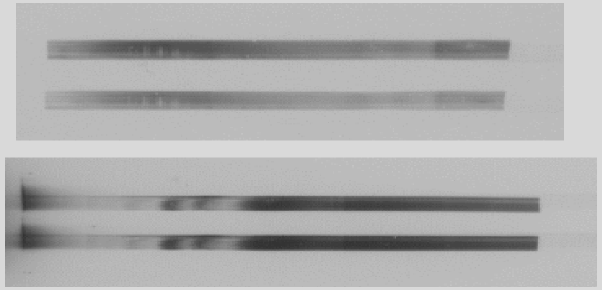
## White Dwarf Line-Shapes

3 Streaked
H Absorption Spectra

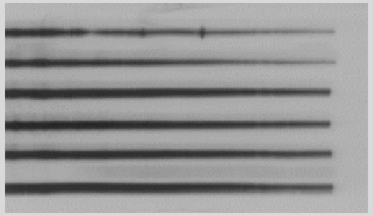


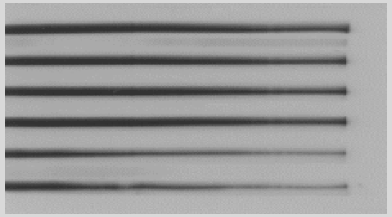
## Photoionized Plasma

4 Space-Resolved
Si Absorption Spectra



12 Space-Resolved
Ne Absorption Spectra





**We can repeat experiments to make sure the result; we can modify experiments to test hypotheses**

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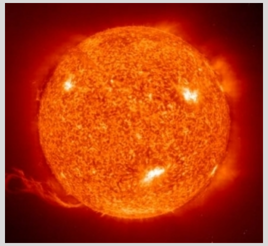

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Los Alamos NATIONAL LABORATORY EST. 1943

cea

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THE UNIVERSITY OF TEXAS AT AUSTIN

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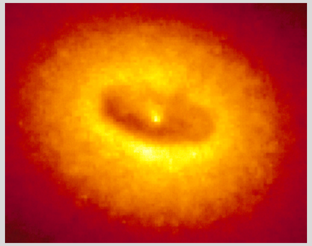

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UNIVERSITY OF MICHIGAN

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# Wootton Center for Astrophysical Plasma Properties (WCAPP) provides sustained funding to train laboratory astrophysicists

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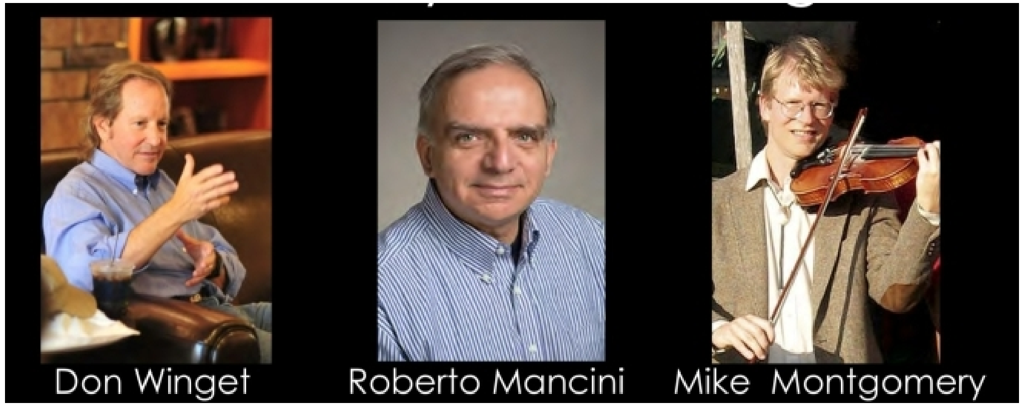
- Lab astrophysicists require specialized knowledge; they must understand:
  i. Astrophysical impact,
  ii. Model approximations and limitations,
  iii. Experimental feasibility and limitations

- CAPP* at University of Texas at Austin, provides:
  - Sustained funding to train students/postdocs for continuous growth of laboratory astrophysics
  - Resources and connections to experts in astrophysics, theory, and experiment




McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

U.S. DEPARTMENT OF ENERGY
Office of Science

* Contact R. Mancini at University of Nevada, Reno, or D. Winget and M. Montgomery at University of Texas.

# Goals of breakout sessions: Deepen mutual understanding between astrophysicists and ZAPP scientists

Sandia National Laboratories

Longstanding challenges:

- It is hard for:
  - HED experimentalists and theorists to learn astrophysical context
  - Astrophysicsts to understand what experimental results mean for their applications

Format:

- ZAPP scientists elaborate experiments and pose questions to astrophysicists
- Astrophysicists answer questions through mini presentations and follow-up discussions

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