Laser and particle beam interaction with ionized matter and perspectives for fusion energy

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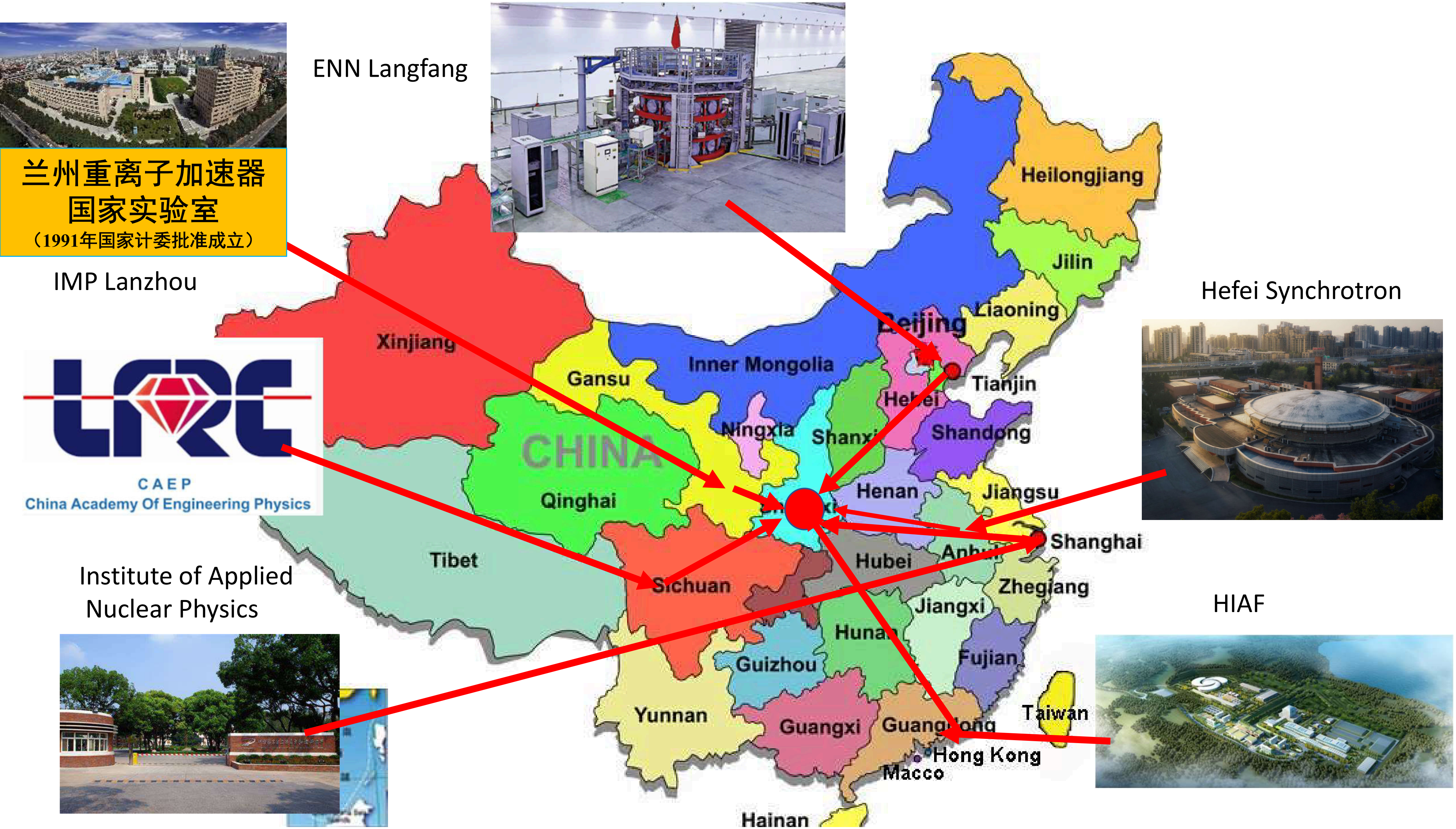
NIPP 2021, Moscow



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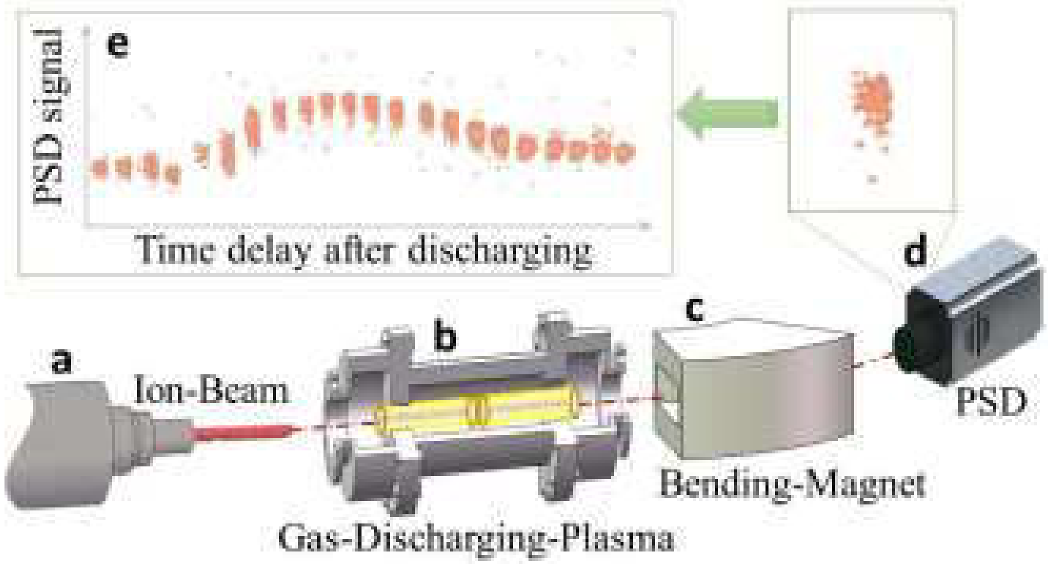
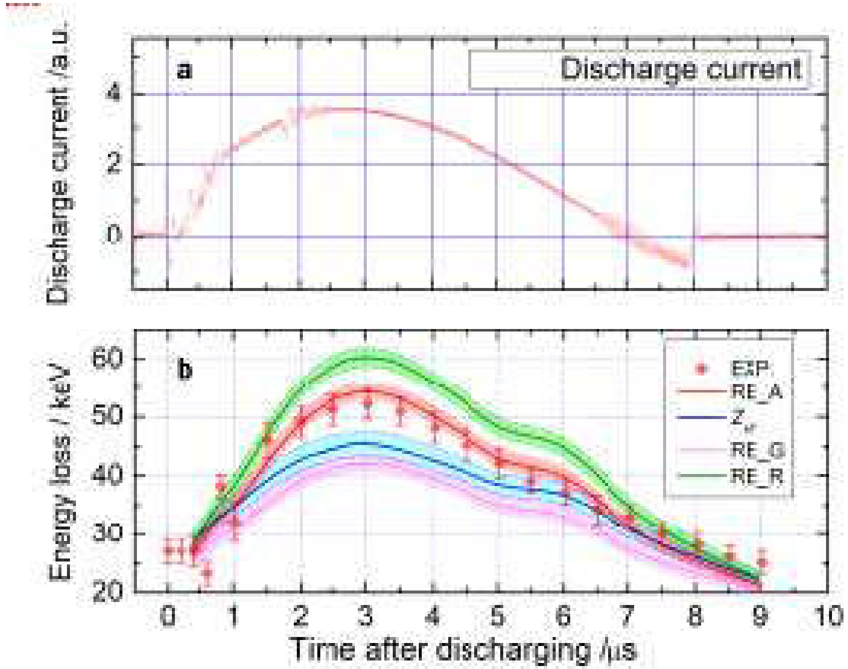
Programme

- Energy loss of Ions in Plasma
- Laboratory Astrophysics
- Proton Boron Fusion
- Outlook

First Experimental Evidence for the Significant Contribution of Projectile Excited States to the Stopping of Slow Helium Ions in Hydrogen Plasma

Yong-Tao Zhao, Yan-Ning Zhang, Bin He, Rui Cheng, Chun-Lei Liu, Xian-Ming Zhou, Jie-Ru Ren, A. A. Golubev , and 霍迪





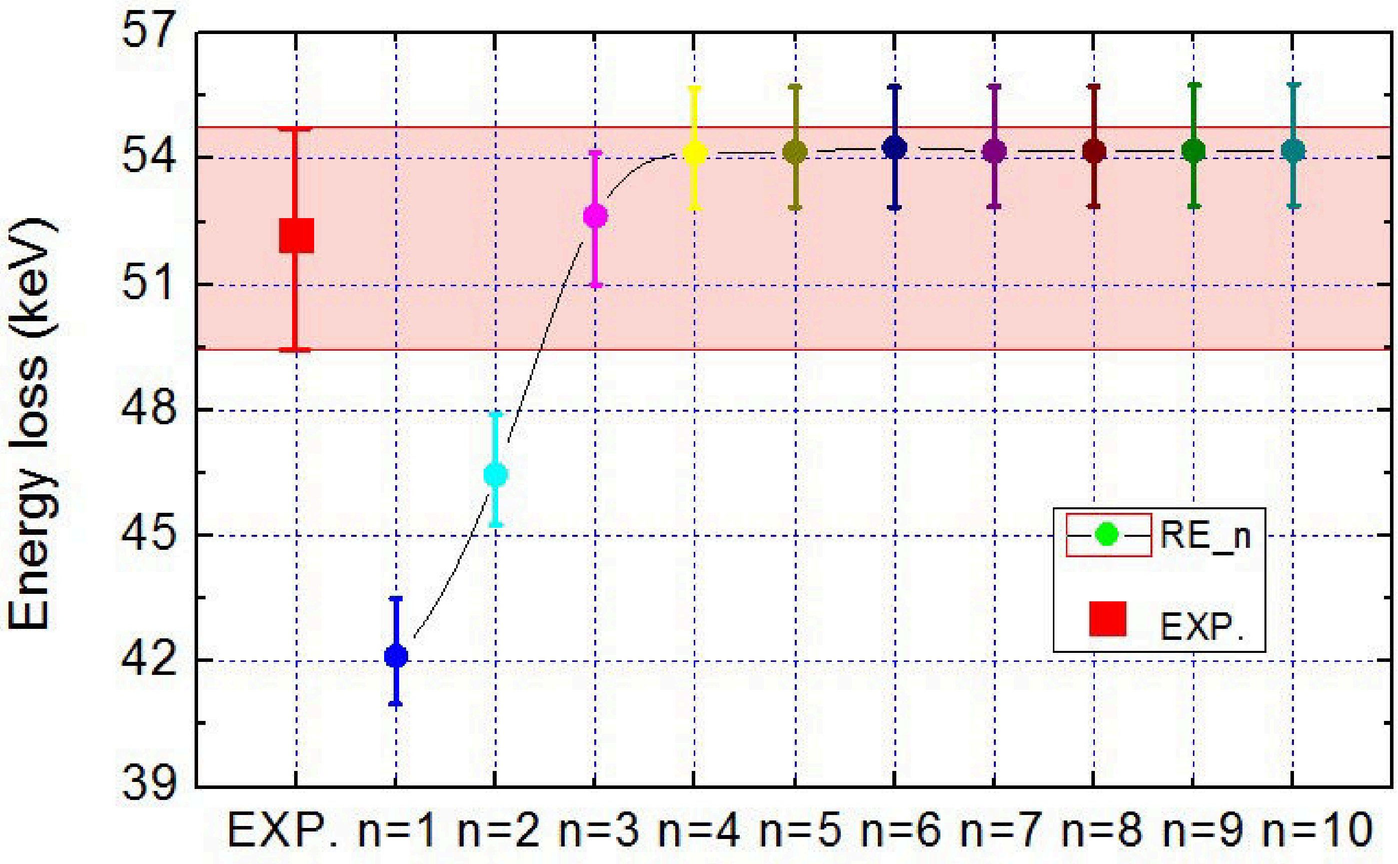
Energy Loss Calculation

$$S = \sum_i P(i)S(i) = \sum_i [P(i)S_b(i)n_b + P(i)S_f(i)n_f]$$

$$\mathrm{S}_f = \frac{e^2}{\pi v_p^2}\int_0^\infty \frac{dk}{k}\left|Z_p - \rho(k)\right|^2 \int_{-kv_p}^{kv_p} d\omega\, \omega\, \mathrm{Im}\left(-\frac{1}{\varepsilon(k,\omega)}\right)$$

$$\Delta E = \int S dx$$

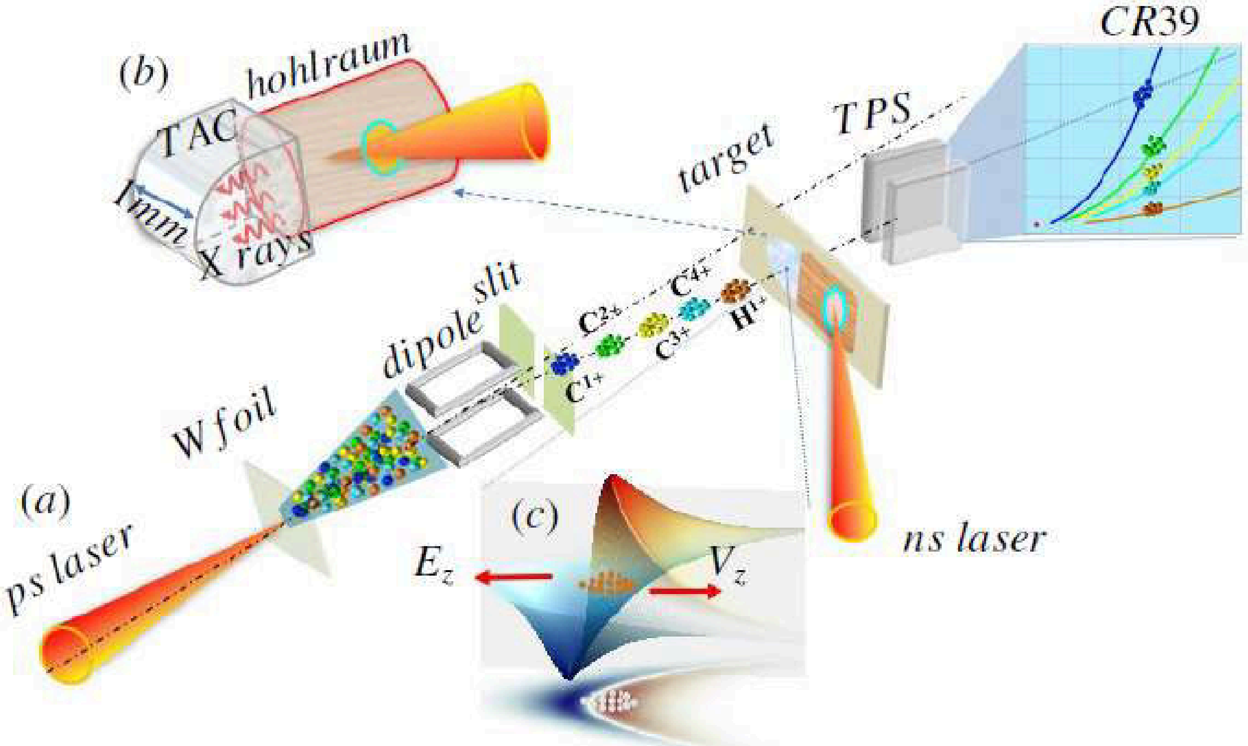
enchmark Experiment to Prove the Role of Projectile
Excited States Upon the Ion Stopping in Plasmas

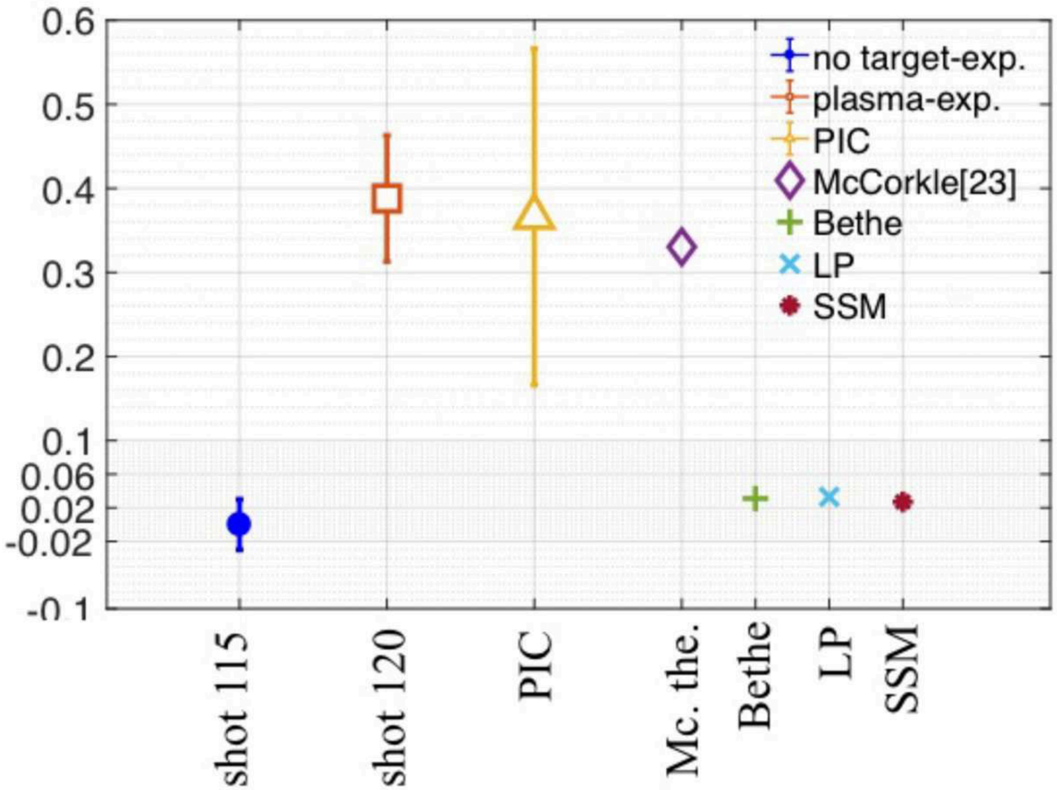


Physical Review Letters Volume 126 **Issue** 11 **Article Number** 115001 **DOI** 10.1103/PhysRevLett.126.115001 **Published** MAR 15 2021

Anomalous stopping of laser-accelerated intense proton beam in dense ionized matter

Jieru Ren, Zhigang Deng, Wei Qi, Benzheng Chen, Bubo Ma, Xing Wang, Shuai Yin1, Jianhua Feng, Wei Liu, Zhongfeng Xu, 霍迪, Shaoyi Wang, Quanping Fan, Bo Cui, Shukai He, Zhurong Cao, Zongqing Zhao, Leifeng Cao, Yuqiu Gu, Shaoping Zhu, Rui Cheng, Xianming Zhou, Guoqing Xiao, Hongwei Zhao, Yihang Zhang, Zhe Zhang , Yutong Li, Dong Wu,Weimin Zhou & Yongtao Zhao

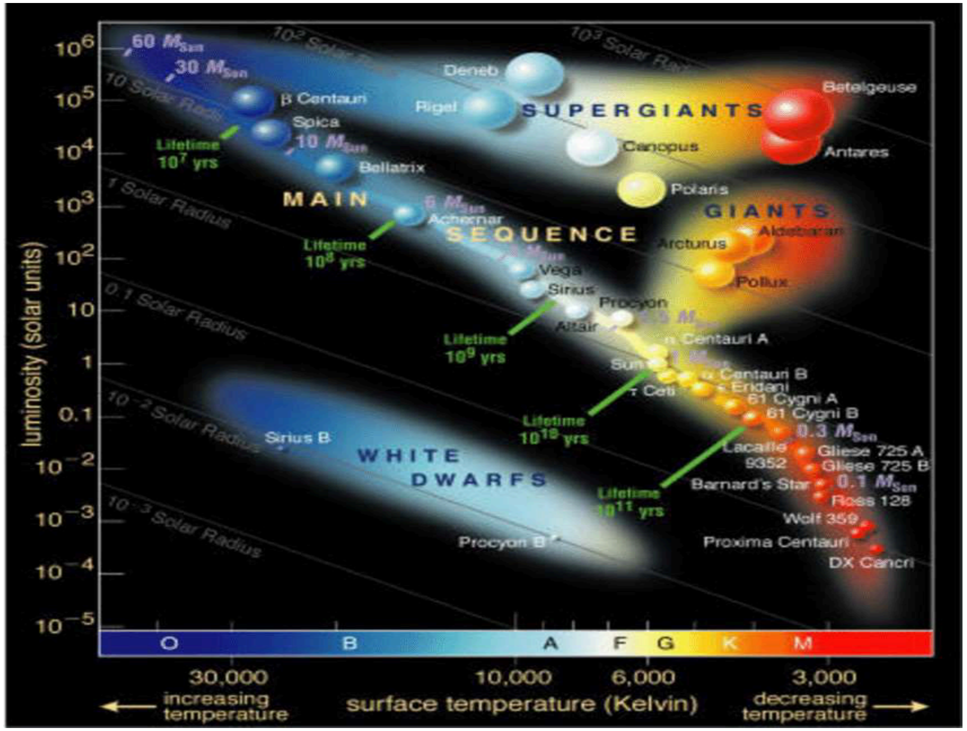




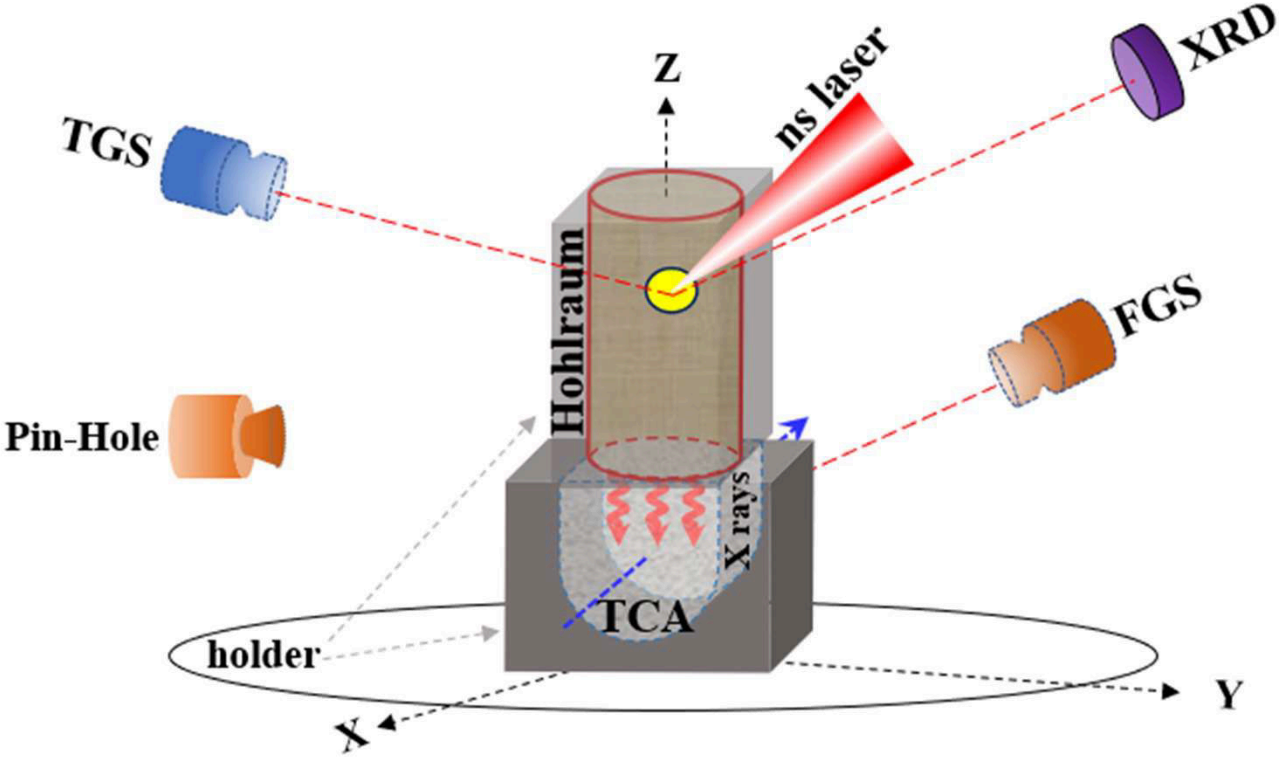
Nature Communication Volume 11 **Issue** 1 **Article Number** 5157 **DOI** 10.1038/s41467-020-18986-5
Published OCT 14 2020 **Document Type** Article

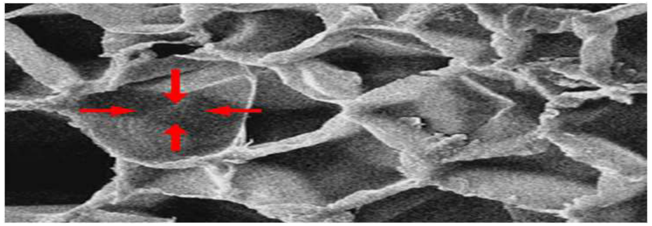
Laboratory Observation of C and O Emission Lines of White Dwarf H1504+65-like atmosphere model

Bubo Ma, Jieru Ren, , Zhigang Deng, Wei Qi, 霍迪， Shangyi Wang, Rui Cheng, Quanping Fan, Yong Chen, Yongtao Zhao



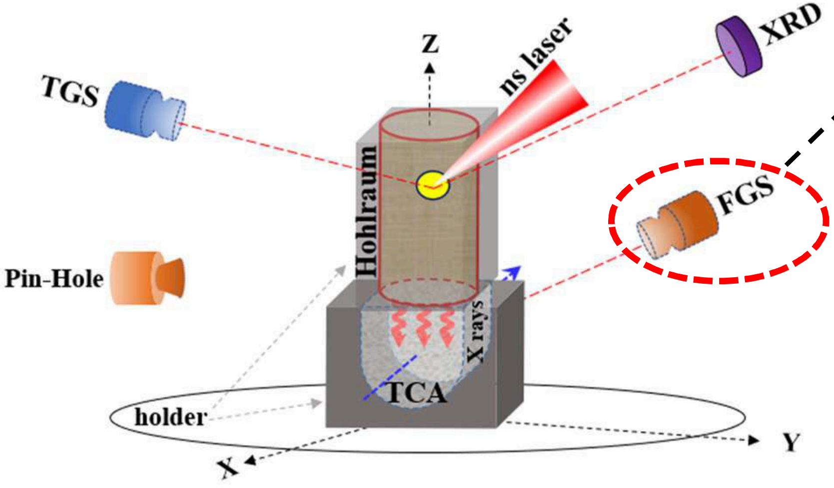
Experiment set up at the XG-III laser facility of Laser Fusion Research Center in Mianyang

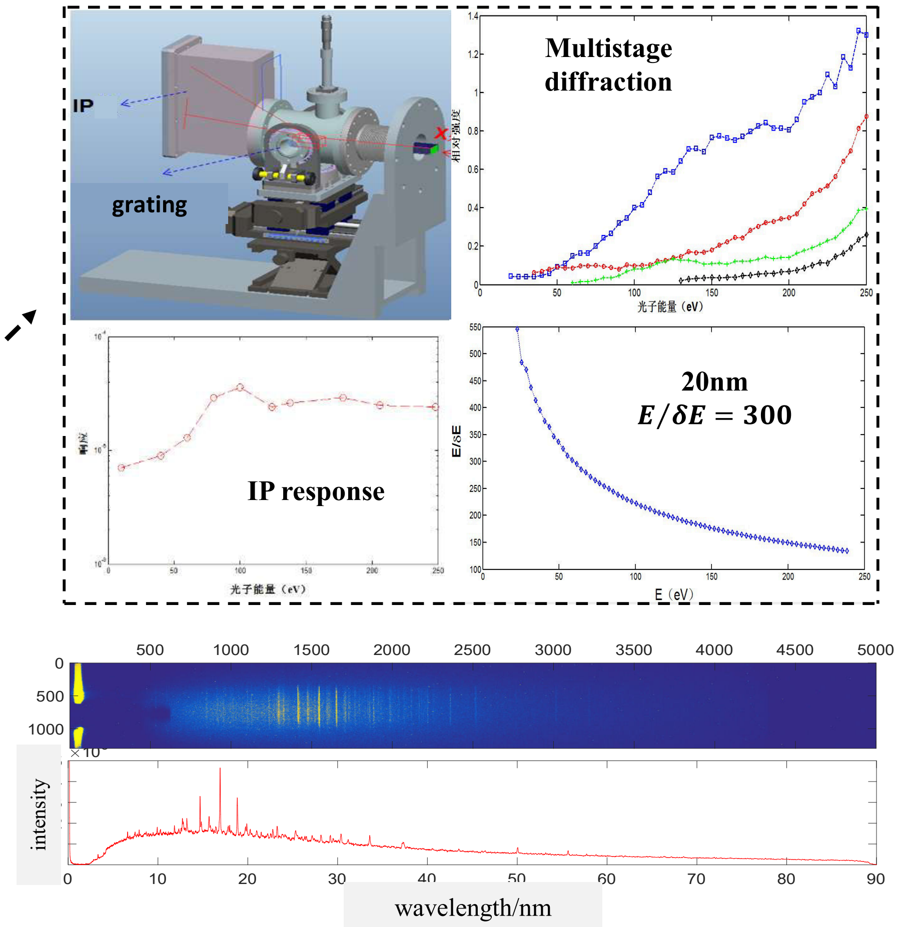




02. Experimental Set up

- **Laser:** ns-150J, 2ns, 100μm, 532nm;
- **Target:** Hohlraum diameter-1mm
  $C_9H_{16}O_8$foam, density- 2mg/cc,
- **Detector:** TGS \ PH \ XRD \ FGS



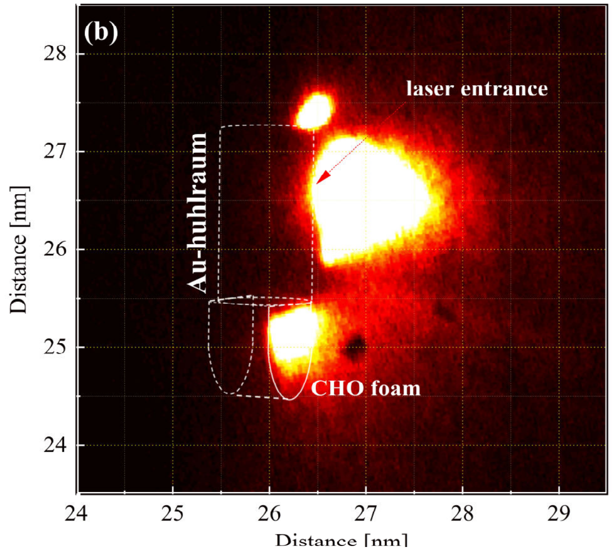


The high resolution flat grating spectrometer (FGS) is used to plasma diagnostic

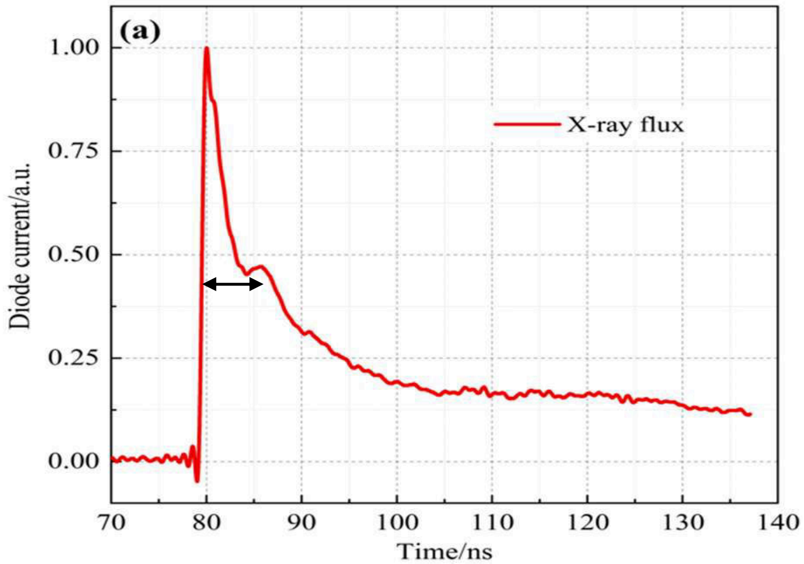
Plasma generation and diagnostic

Well characterized plasma target and X-ray diode diagnostics

X-ray Pinhole Image



X-ray diode spectra

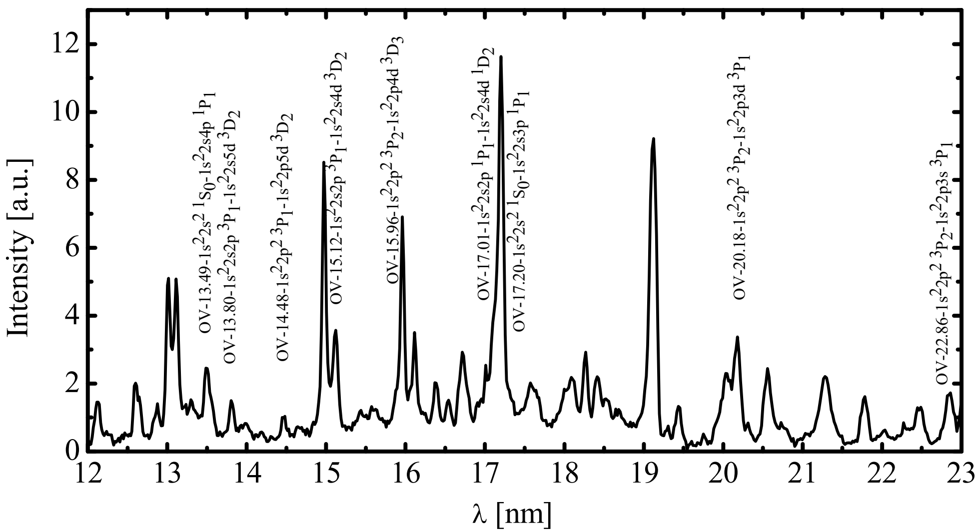


The XRD signals indicate that the effective heating time of the Hohlraum X rays is about 6ns

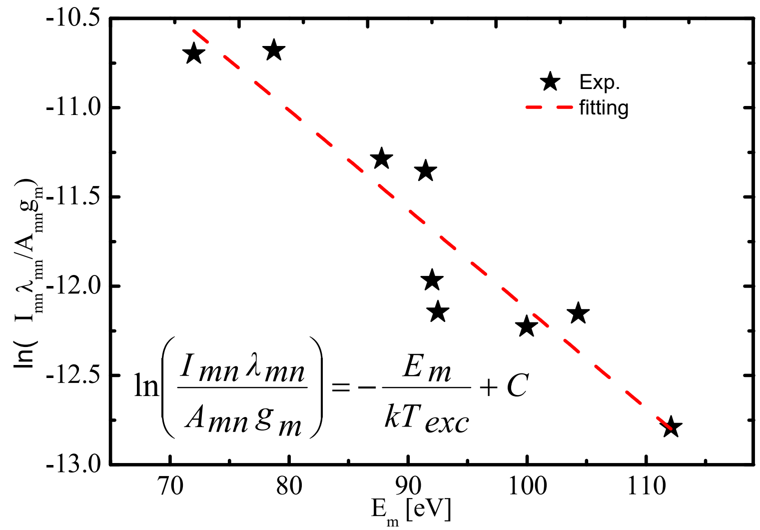
Plasma diagnostic

plasma temperature diagnostic (Flat-field grating spectrometer)

Plasma emission lines



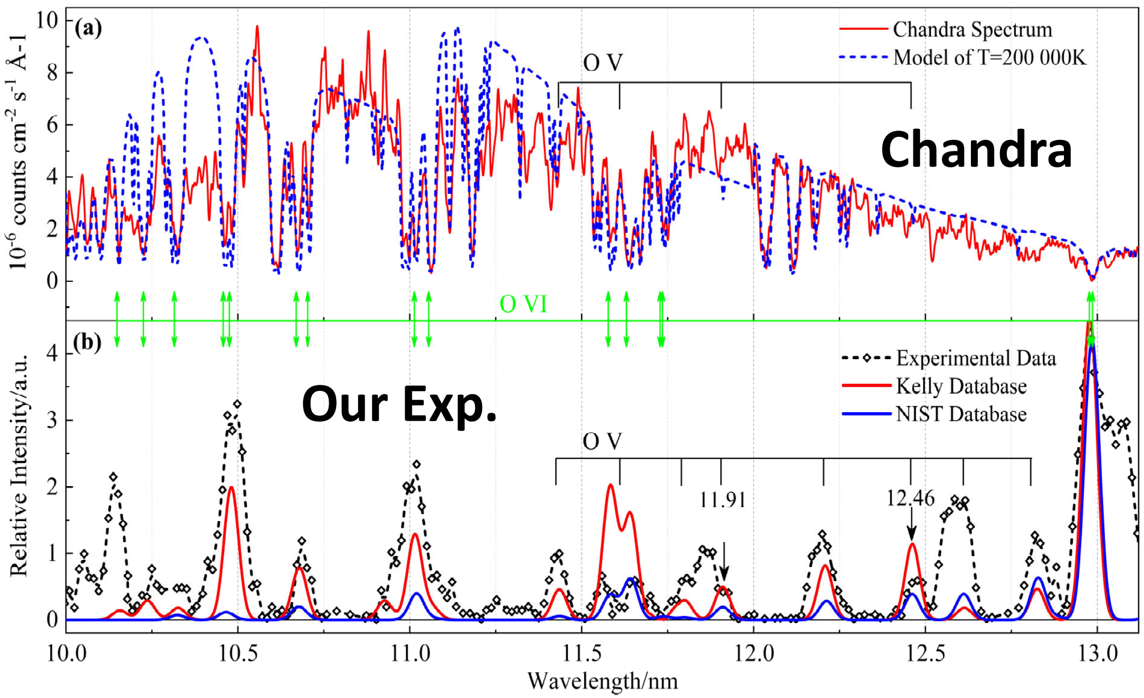
Boltzmann plot method



The Boltzmann plot of the spectral-lines indicated the foam plasma temperature is ~17eV

According to FLYCHK, The average ionization degree is about $C^{3.8+}H^{0.98+}O^{4.5+}$, $n_e=4*10^{20}$ cm^{-3}

Identification and comparison in 10-13nm

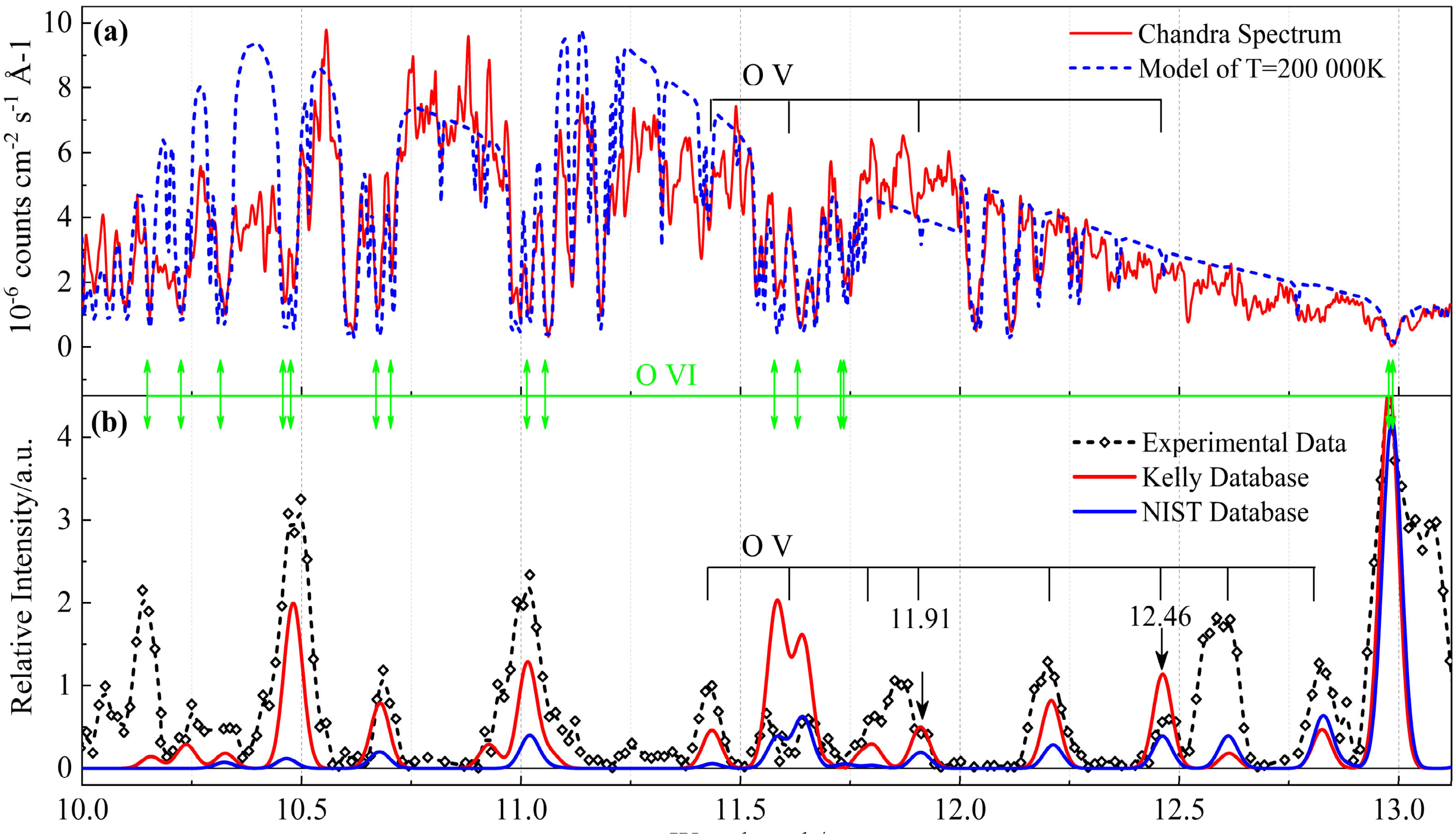


λ/nm	Trans.	Kelly	NIST	H1504+65 [a]	H1504+65 [b]
10.14	2p-11d	10.157		10.151	
10.24	2p-10d	10.237		10.230	
10.32	2p-9d	10.321	10.32	10.321	
10.48	2p-8s	10.481	10.48	10.481	
10.68	2p-7d	10.679	10.67	10.679	
11.01	2p-6d	11.015	11.02	11.015	11.023 Ne VII
11.43	**2s-8p**	**11.435**	**11.43**	**Ne VI**	**11.441**
11.56	2s-4p	11.583	11.58	11.582	11.582
11.65	2p-5d	11.642	11.64	11.642 **Ne VII**	11.643 **Ne VII**
11.78	$2s^2$-2p4d	11.800	11.80		
11.90	2s-6p	11.910	11.91		11.913
12.20	2s-5p	12.208	12.21		12.201
12.47	2s-5p	12.462	12.46	12.46	12.469
12.61	2p-8d	12.613	12.61		12.624
12.81	2p-7d	12.825	12.83		12.849
12.98	2p-4d	12.978	12.98	12.978	12.984

[a] A & A,2004, 421.3 [b] A & A,1999, 347(1)

- **Consistent O VI position with the strongest intensity**

The identified Ne lines may contain the contribution of O V, Two O V lines predicted by the model at 11.910 nm and 12.461 nm are observed


(a)
Chandra Spectrum
Model of T=200 000K
O V
O VI
10^{-6} counts cm^{-2} s^{-1} Å-1
0
2
4
6
8
10
(b)
Experimental Data
Kelly Database
NIST Database
O V
11.91
12.46
Relative Intensity/a.u.
0
1
2
3
4
10.0
10.5
11.0
11.5
12.0
12.5
13.0

- **A plasma sample with a similar temperature and composition ratio as the white dwarf was created in the laboratory.**

- **Our result filled the gap of white dwarf in the 14-80 nm and provides support for the line identifications and model benchmark.**

- **Our method of creating a well-defined, long-living uniform plasma sample will also be applied in laboratory astrophysics in the future to study a broader range of cosmic conditions.**

Energy from Nuclear Fusion and the p11B Project

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on behalf of p11B project team of

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IMP 中国科学院近代物理研究所 Institute of Modern Physics, Chinese Academy of Sciences

The p11B fusion project

Boron: 10.811 g/mol,

Z= 5

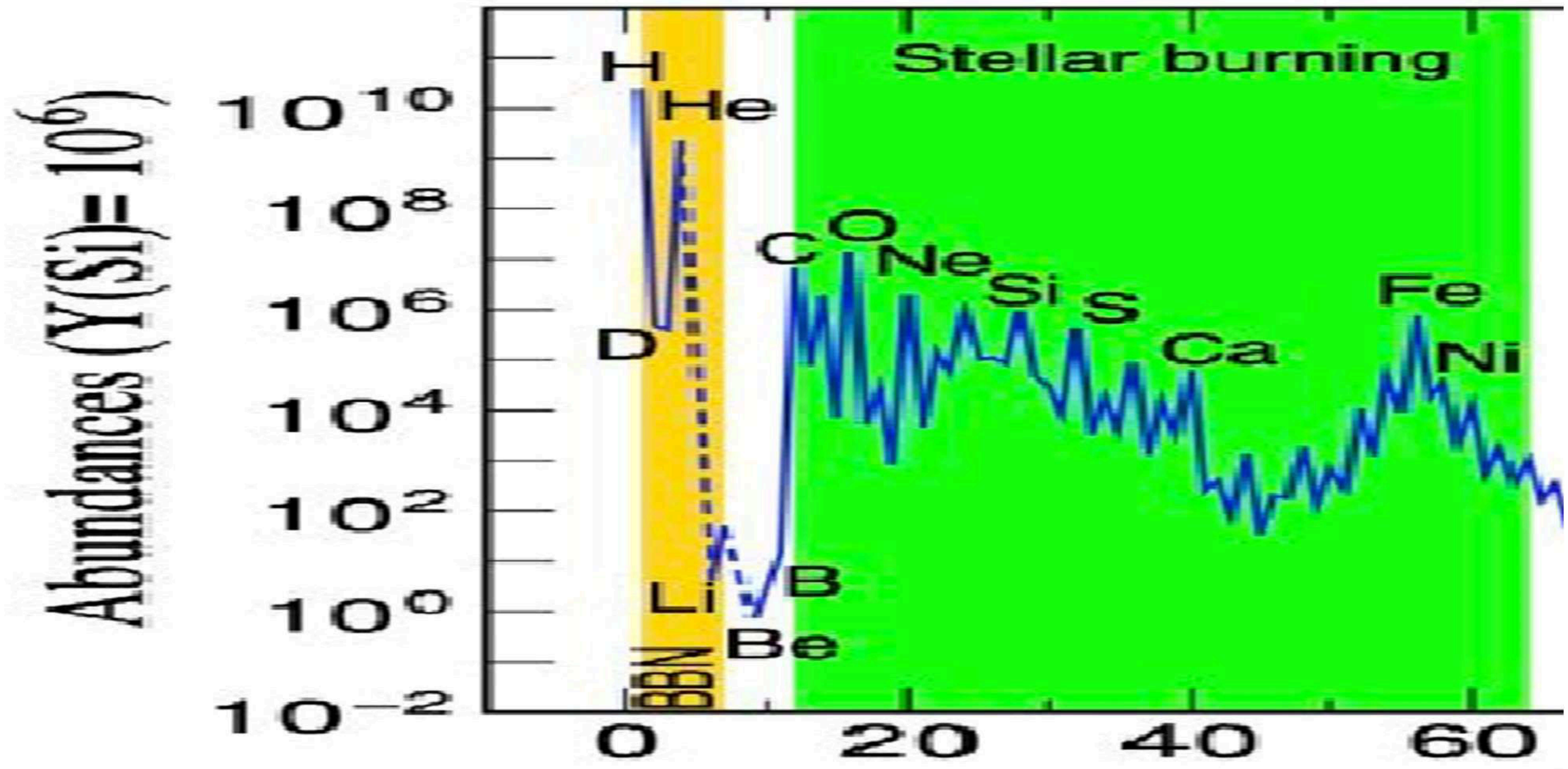
$^{11}B \approx 80\%$ $^{10}B \approx 20$

$\rho = 2.34 g/cm^3$;

Melting point 2349 K

Cost per kg about 2200€

650 mg·kg^{-1} (LD_{50}, Rats, oral)

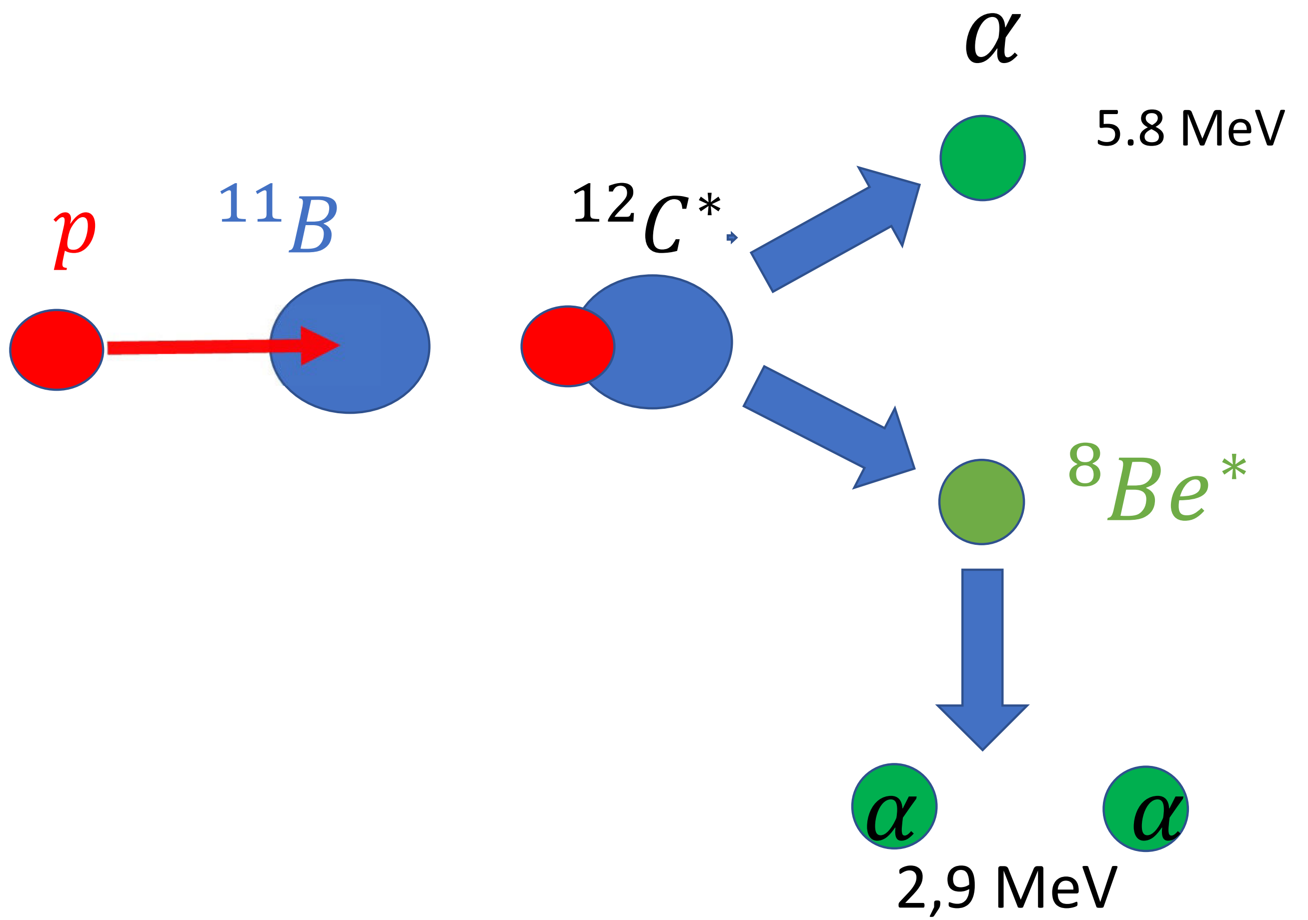


Simulated r-abundance normalized to solar

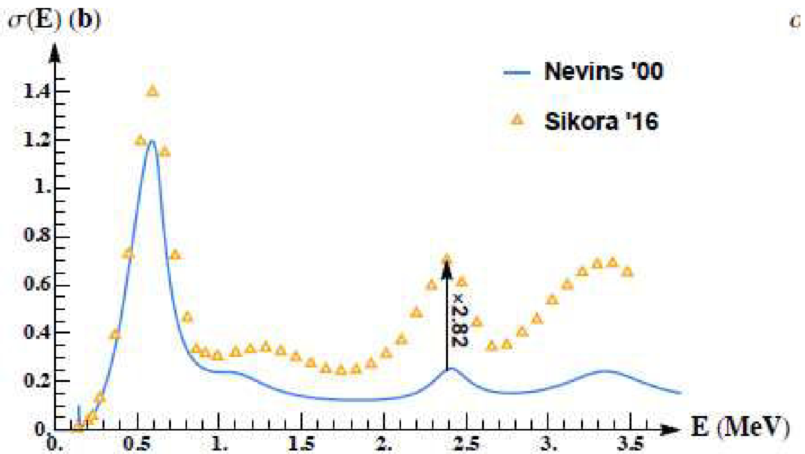
B		R-process simulation for Boron
5.101980e-09	Ba	by Bowen Jiang (GSI)
3.133204e-11	3.304903e-10	28.07.2021

Neutron Star Merger (figure from Wikipedia)

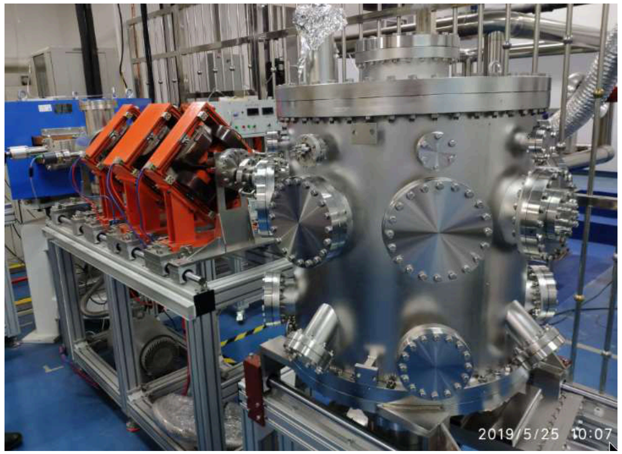
The p11B Fusion Reaction at $E_o = 612\ keV$



New Measurements of Cross sections



High Voiltage Platform and Beamline at XJTU



Yang Li VIII-1 May 30th, ICMRE 2019

We need data on:

H11B fusion cross section up to 6 MeV

Boron Plasma opacity

EOS of Boron

Energy loss of Alpha particles in burning H11B plasma