恒星演化过程中的关键核反应研究

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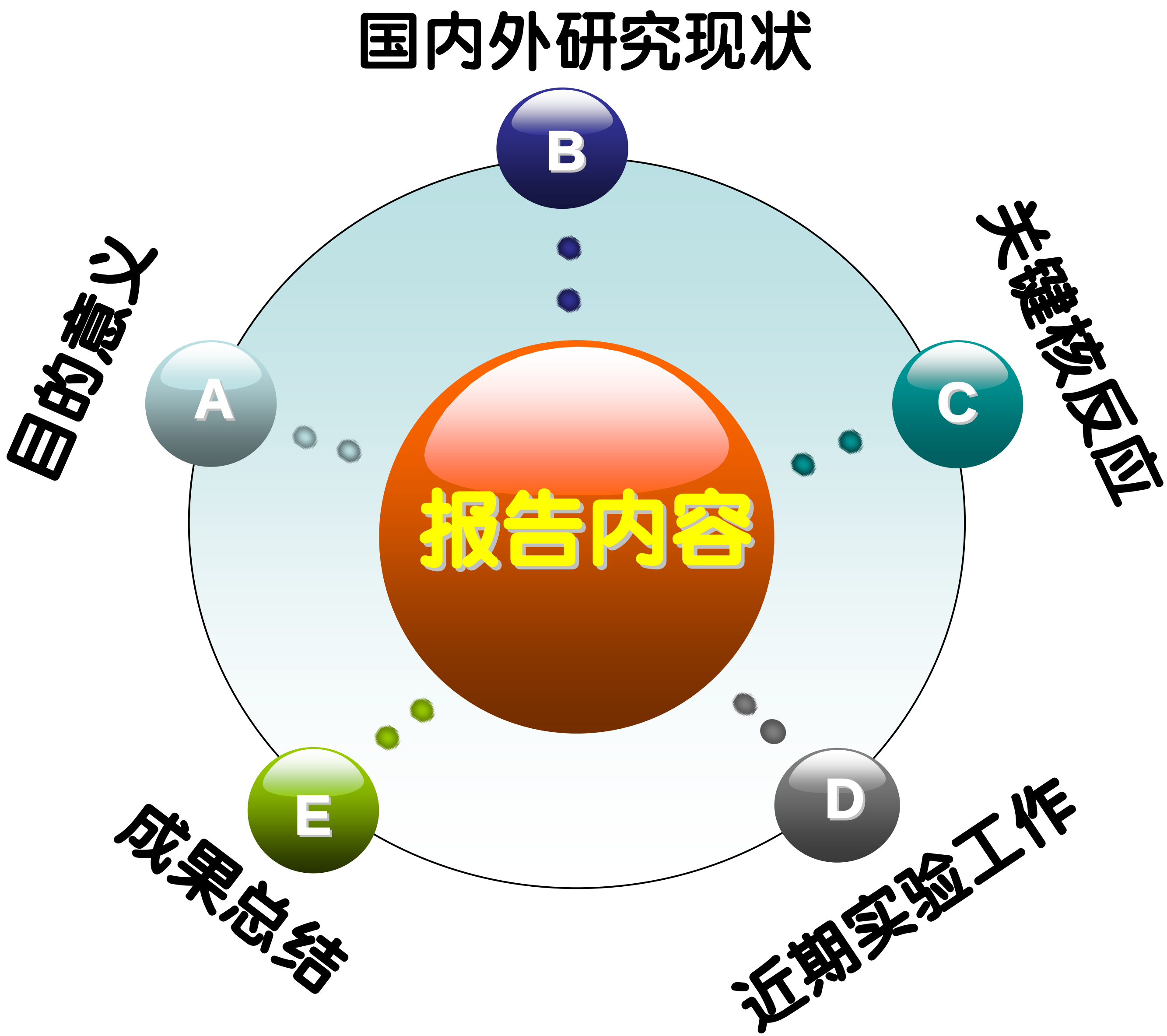
中国原子能科学研究

核物理所12室



国内外研究现状
B
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A
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报告内容
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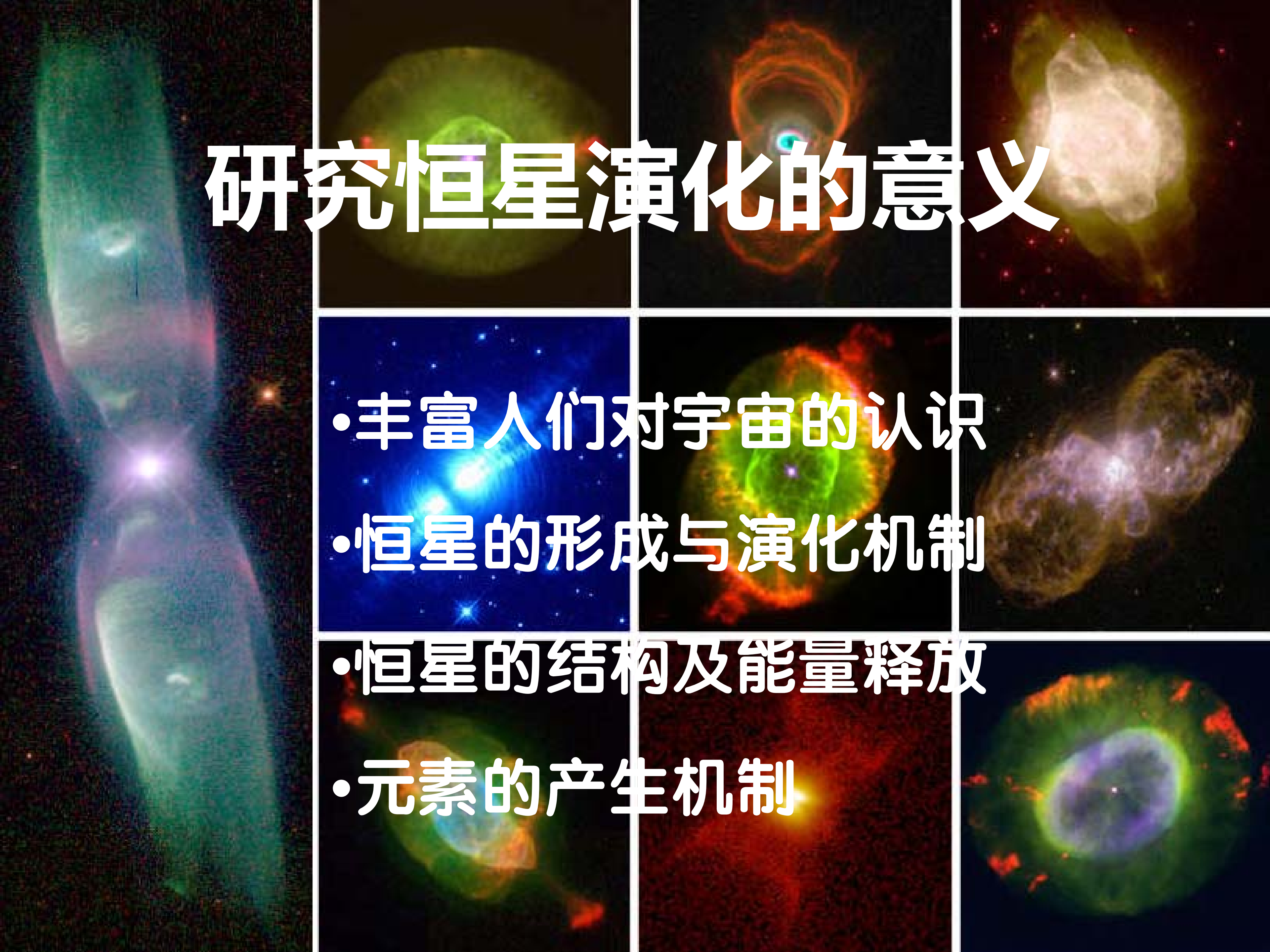
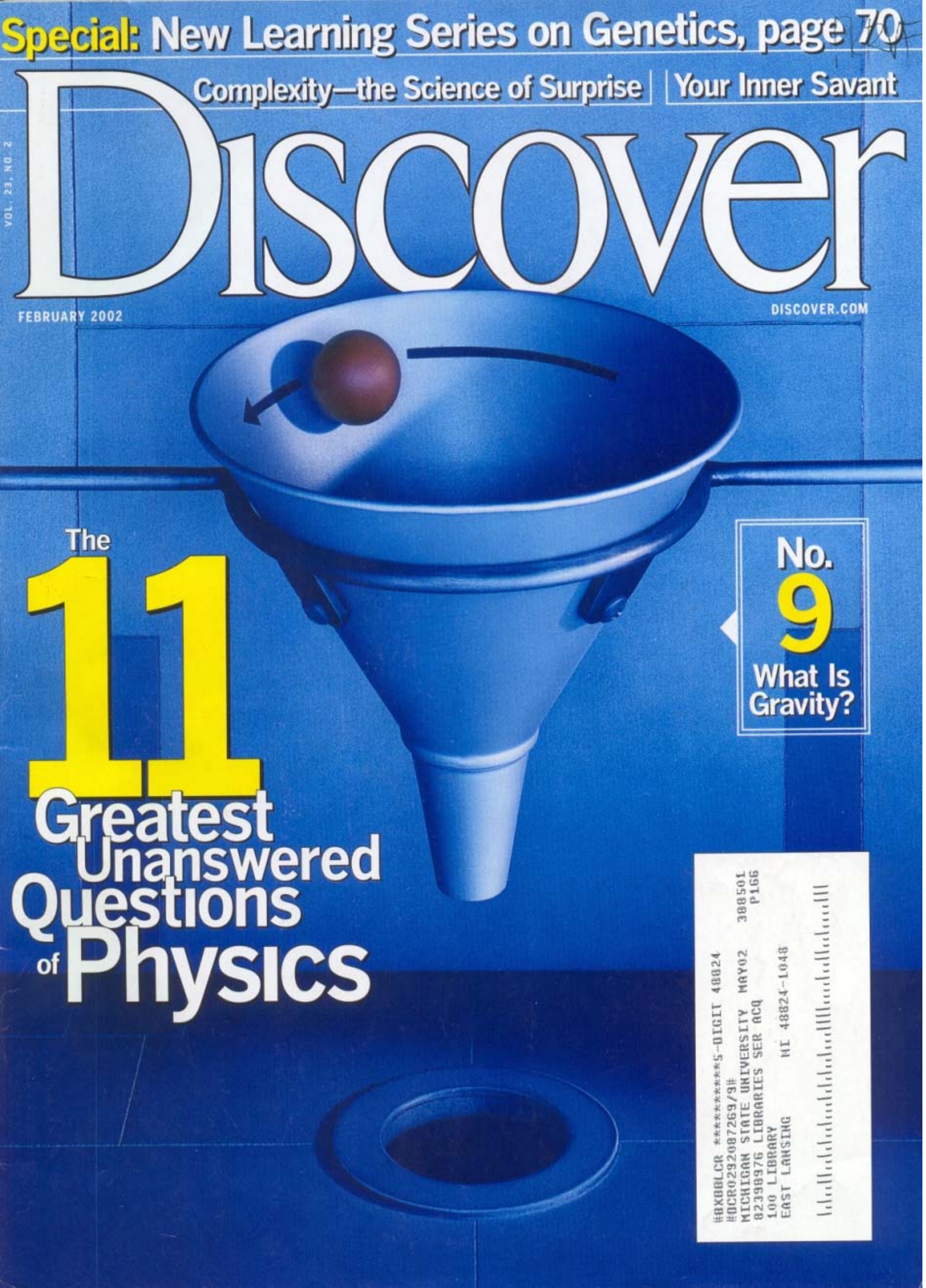
成果总结
D
近期实验工作



研究恒星演化的意义

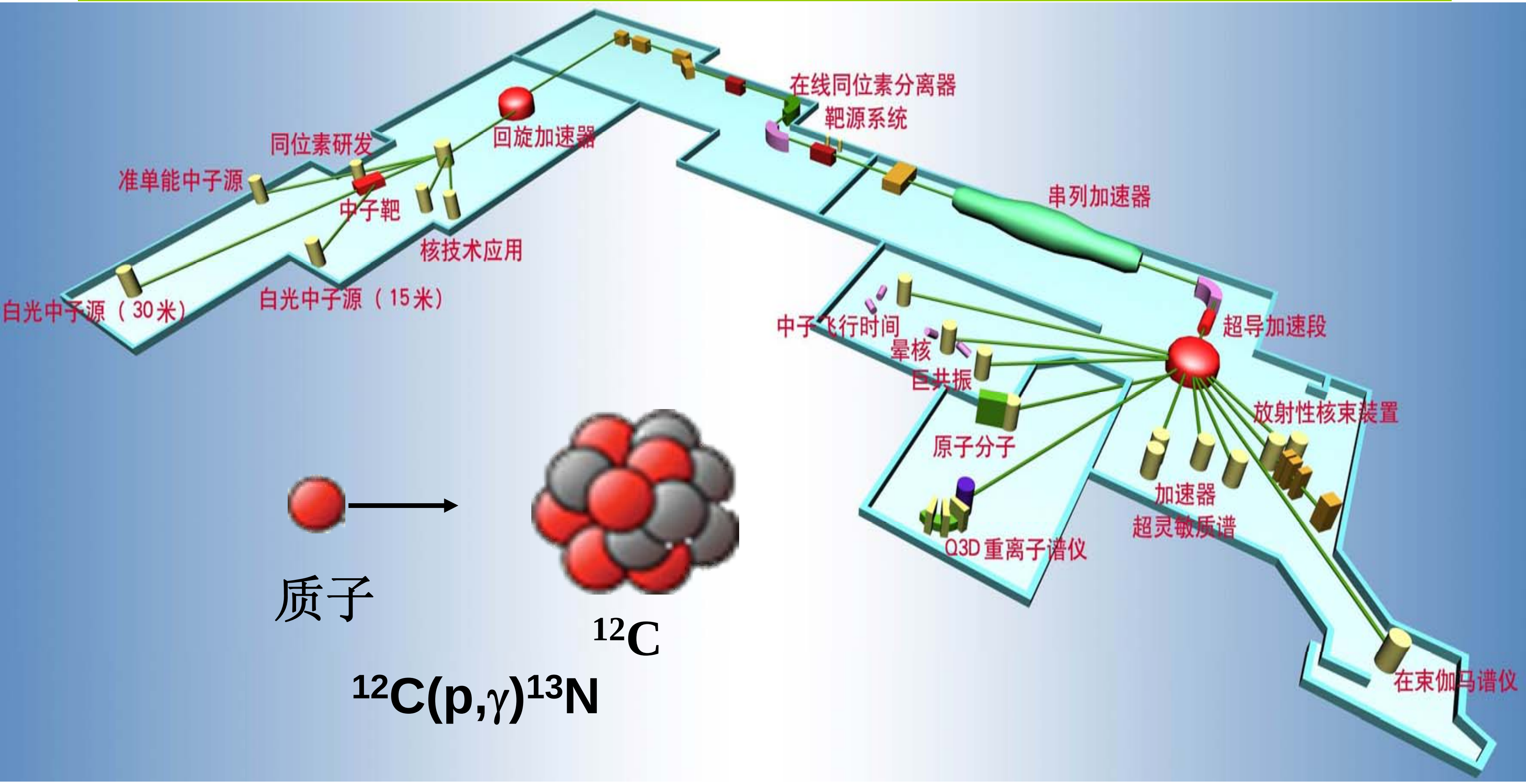
- 丰富人们对宇宙的认识
- 恒星的形成与演化机制
- 恒星的结构及能量释放
- 元素的产生机制



11个物理学未解之谜

- What is dark matter?
- What is dark energy?
- How were the heavy elements from iron to uranium made?
- Do neutrinos have mass (and how much)?
- Where do ultra-energy particles come from?
- Is a new theory of light and matter needed to explain what happens at very high temperature?
- Are there new states of matter at ultrahigh temperatures and densities?
- Are protons unstable?
- What is gravity?
- Are there additional dimensions?
- How did the Universe begin?

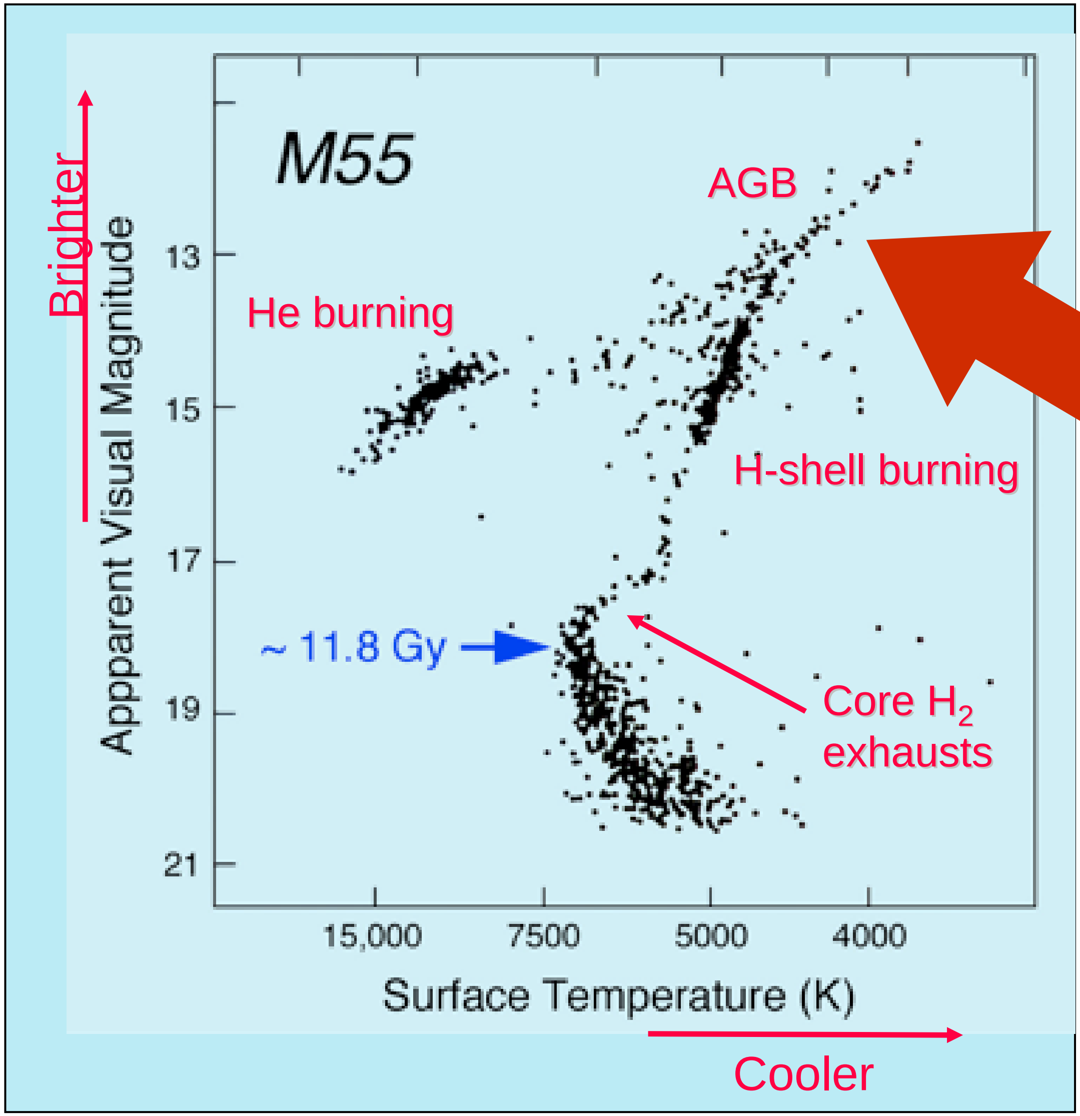
利用加速器研究天体核过程



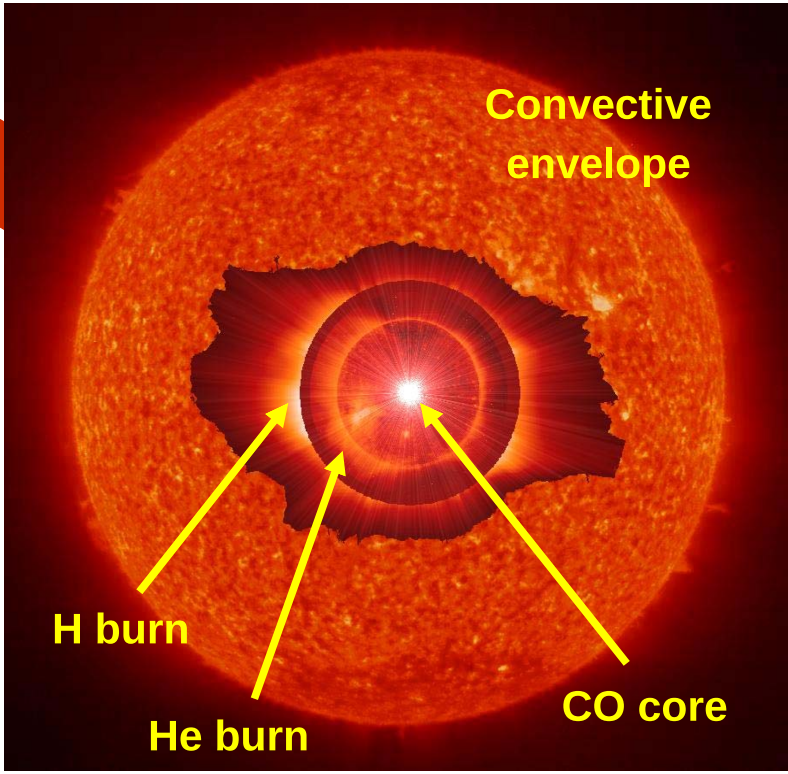
$^{12}C(p,\gamma)^{13}N$

核天体物理学家利用加速器产生的带电粒子束轰击靶原子，模拟宇宙中的元素合成和能量产生过程，从而阐释元素的起源、恒星的结构以及演化过程

恒星演化过程



Asymptotic Giant Branch Star



涉及^{13}C的关键核反应

s过程

s过程是恒星演化进程中最重要的核合成过程之一，铁以上的核素中有大约一半是通过该过程产生的；

中子源

发生s过程最可能发生的天体物理环境是AGB星；其中$^{13}C(\alpha,n)^{16}O$是最主要的中子源反应。

核反应

产生与消灭^{13}C的反应会影响恒星中^{13}C的丰度，进而影响中子的产生及重元素的生成。

产生和摧毁^{13}C的反应

产生^{13}C的反应

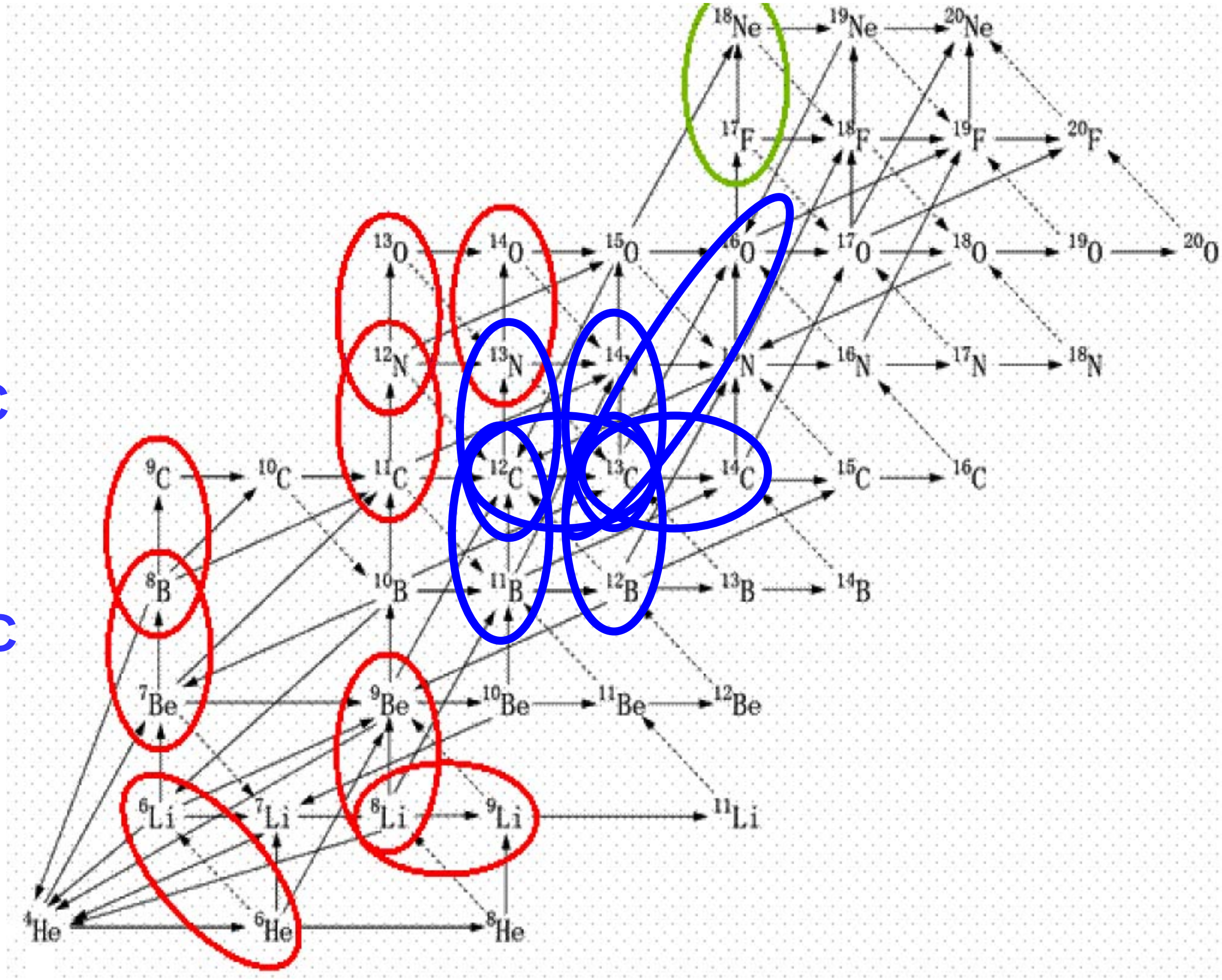
- $^{12}C(p,\gamma)^{13}N(\beta^{-})^{13}C$, $^{12}C(n,g)^{13}C$, $^{12}B(p,\gamma)^{13}C$

消灭^{13}C的反应

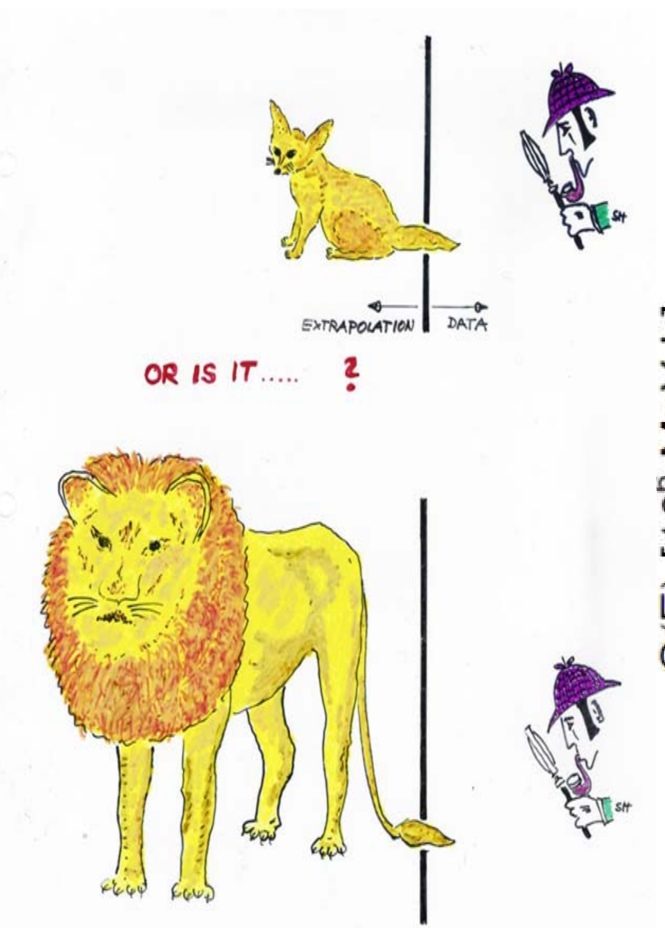
- $^{13}C(p,\gamma)^{14}N$, $^{13}C(n,\gamma)^{14}C$

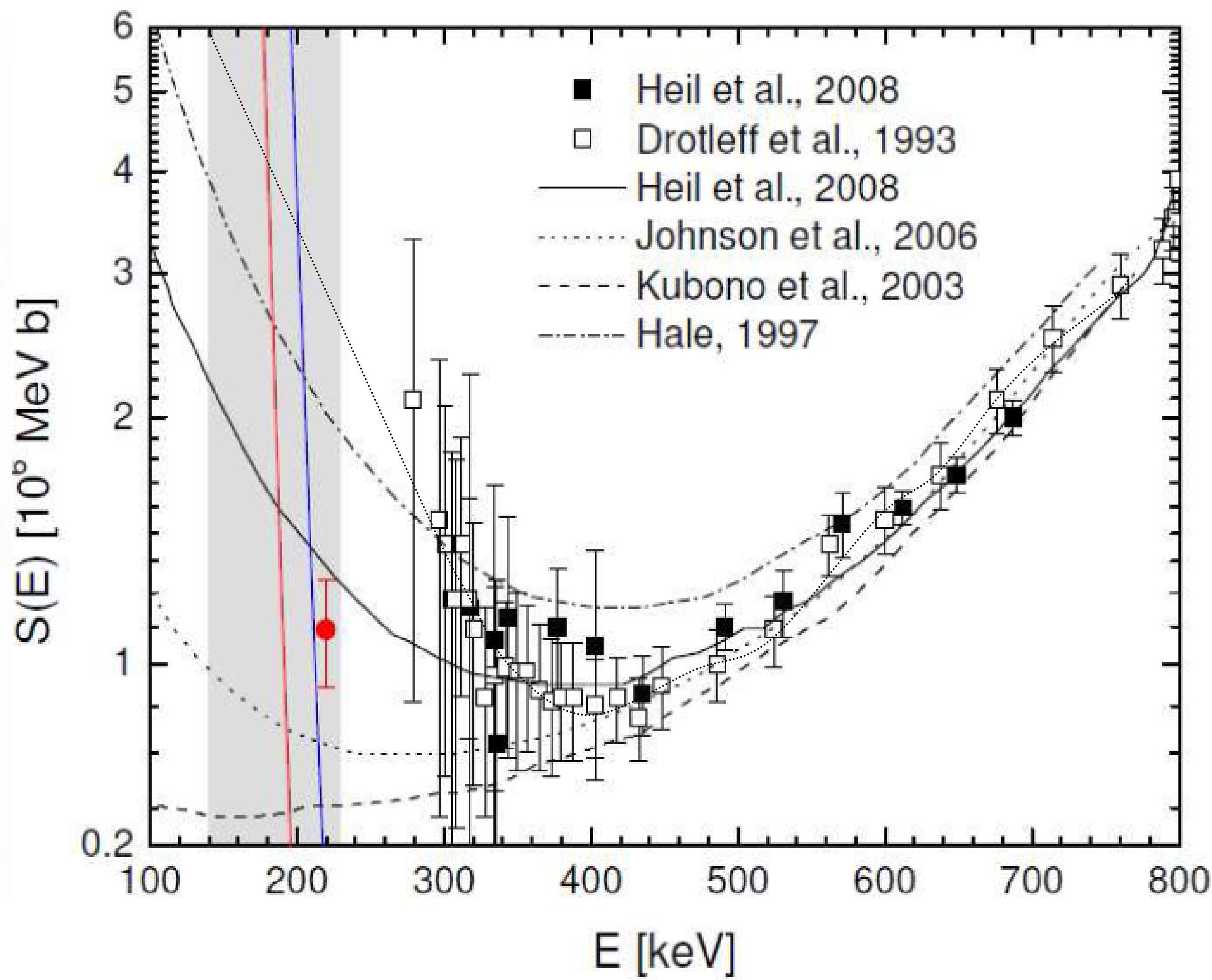
中子源反应

- $^{13}C(\alpha,n)^{16}O$

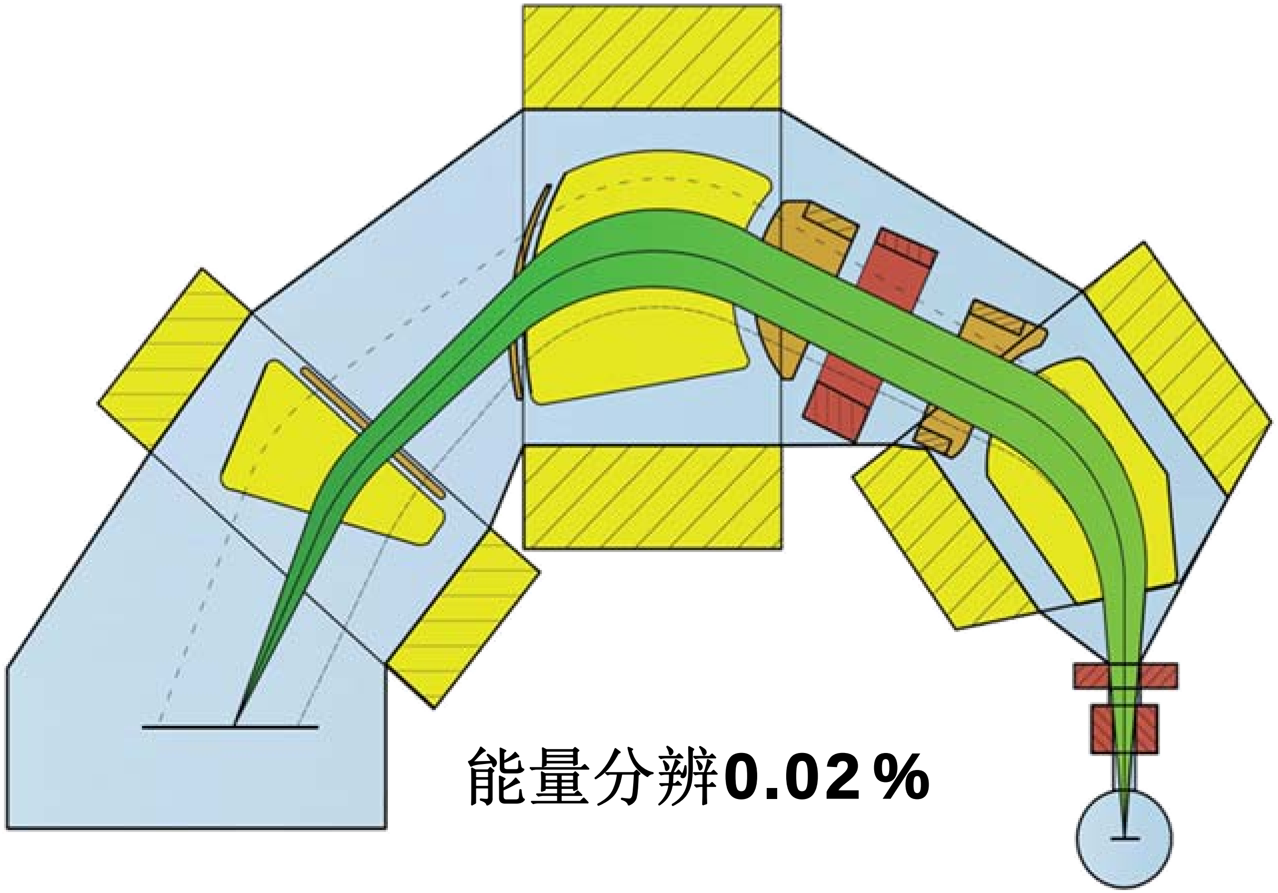


低能外推的不确定性


EXTRAPOLATION
DATA
OR IS IT..... ?


Heil et al., 2008
Drotleff et al., 1993
Heil et al., 2008
Johnson et al., 2006
Kubono et al., 2003
Hale, 1997
S(E) [10⁶ MeV b]
E [keV]
6
5
4
3
2
1
0.2
100
200
300
400
500
600
700
800

实验设备—Q3D磁谱仪



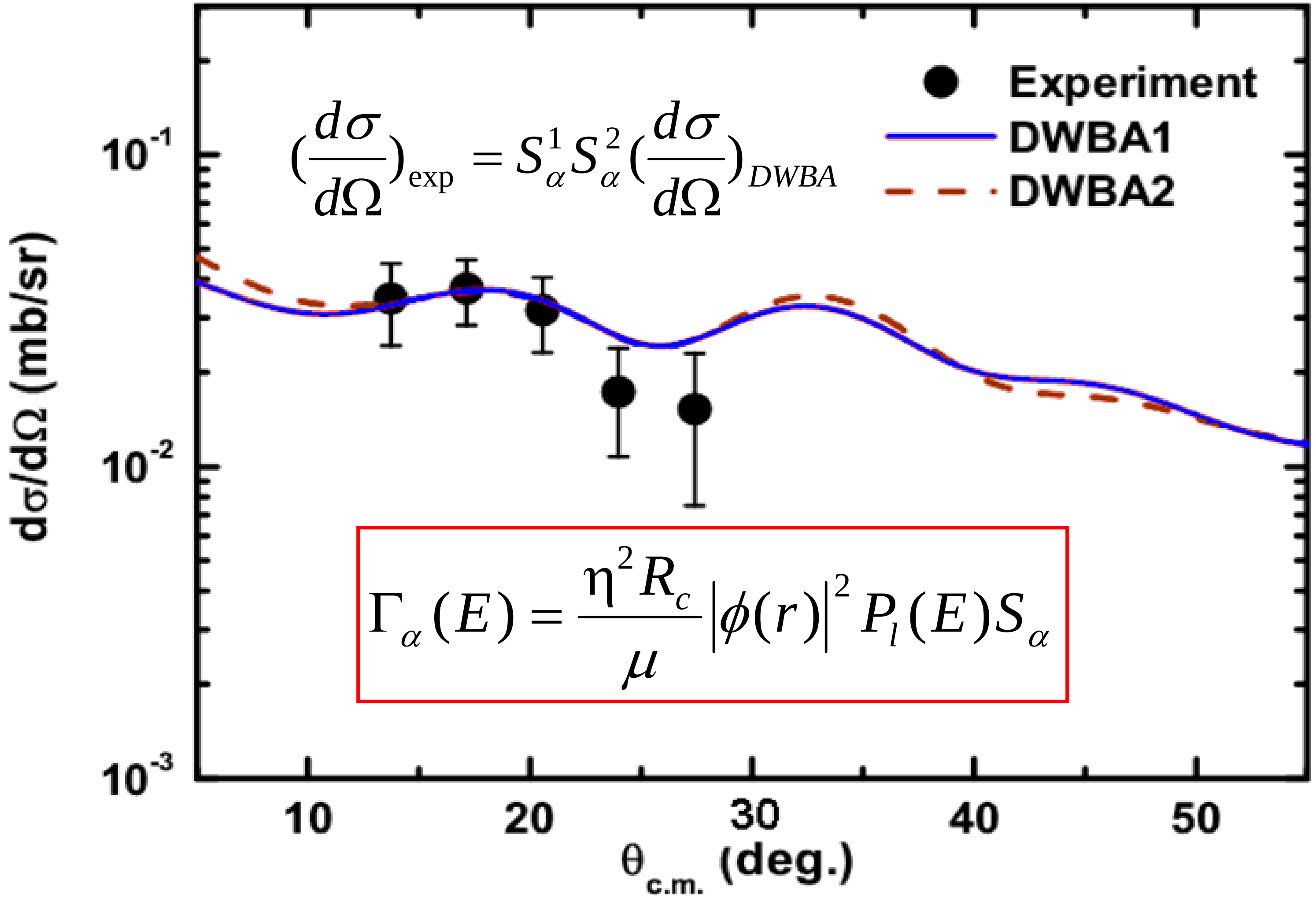
能量分辨**0.02%**

$^{11}B+^{13}C$

$^{7}Li+^{16}O$

$^{13}C(^{11}B,^{7}Li)^{17}O^*$
（6.36MeV）

由$^{13}C(^{11}B,^{7}Li)^{17}O^{*}$反应导出$^{17}O$ 阈下共振态的宽度

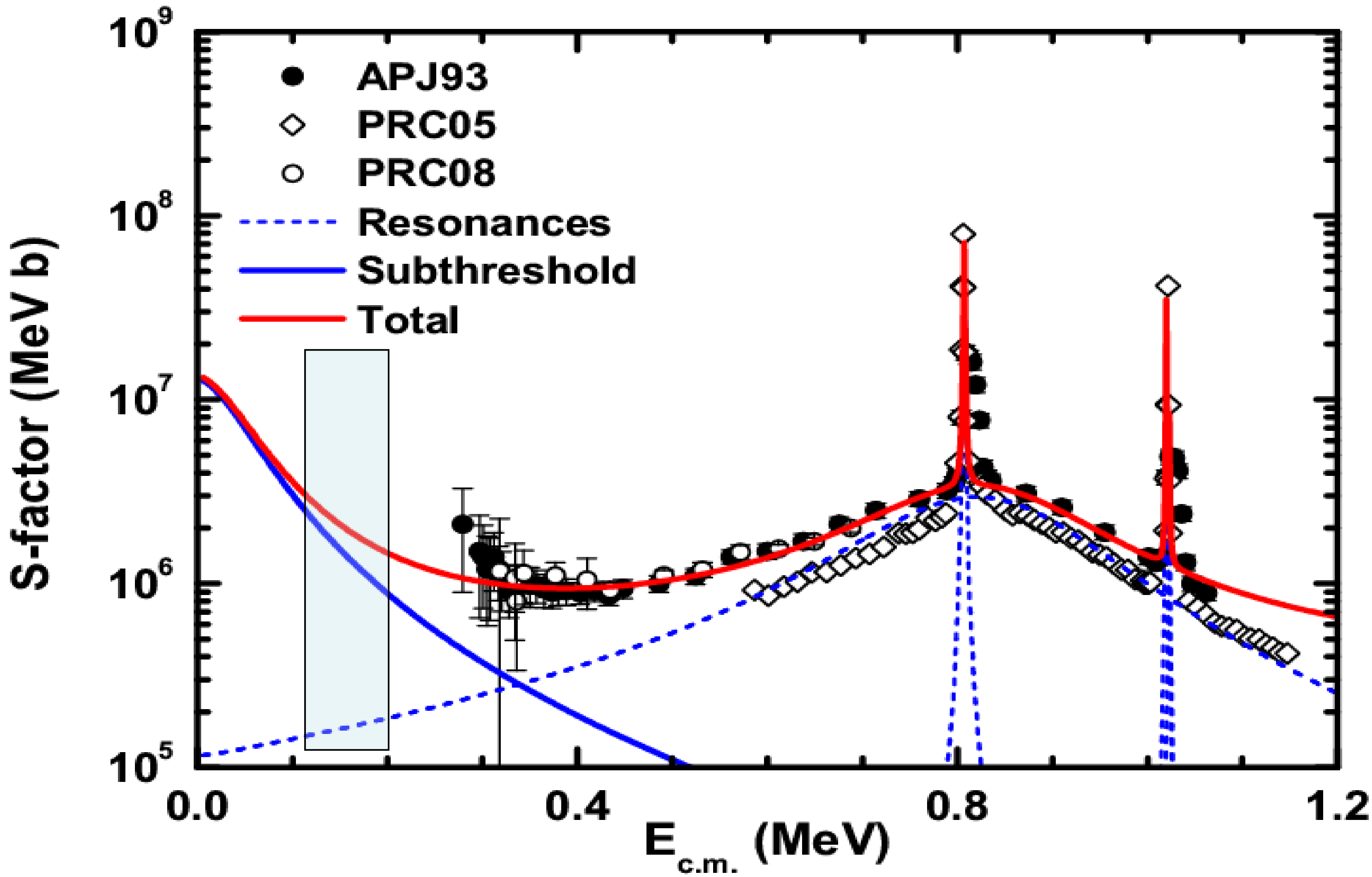


$$\left(\frac{d\sigma}{d\Omega}\right)_{\exp} = S_{\alpha}^{1} S_{\alpha}^{2} \left(\frac{d\sigma}{d\Omega}\right)_{DWBA}$$

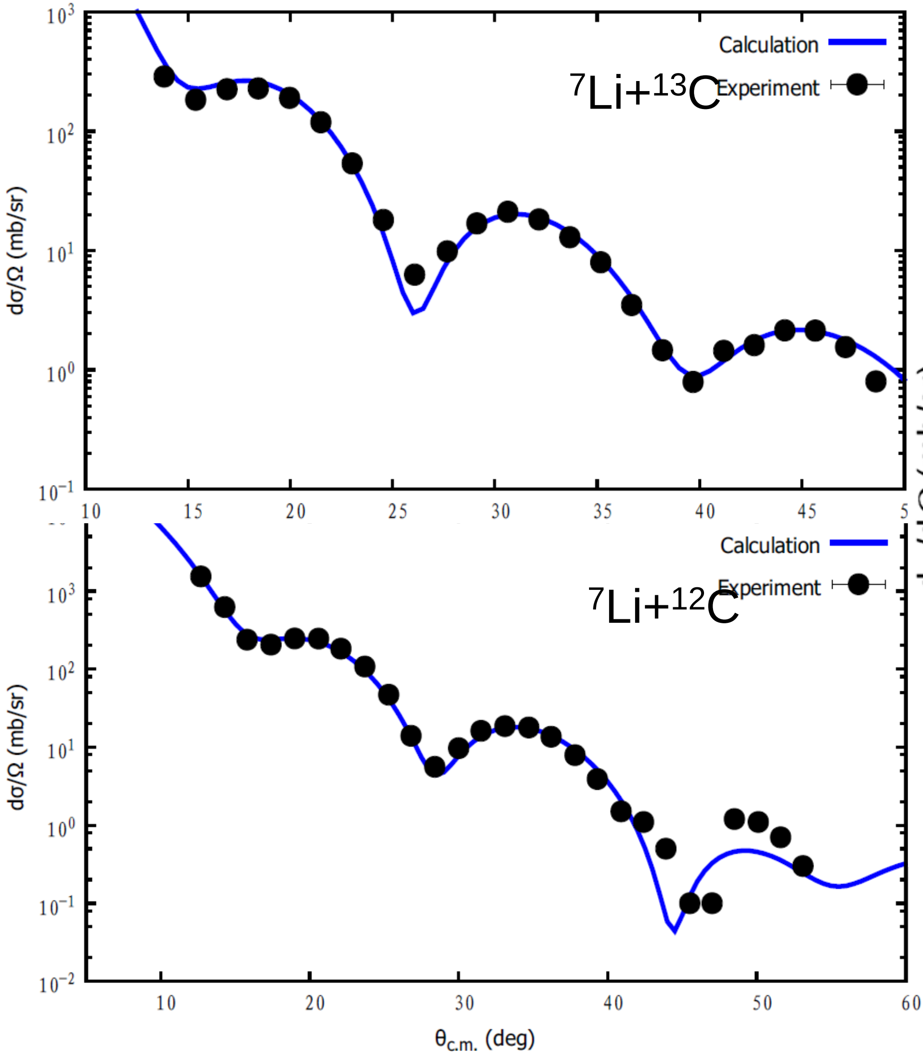
$$\boxed{\Gamma_{\alpha}(E) = \frac{\eta^{2} R_{c}}{\mu} \left|\phi(r)\right|^{2} P_{l}(E) S_{\alpha}}$$

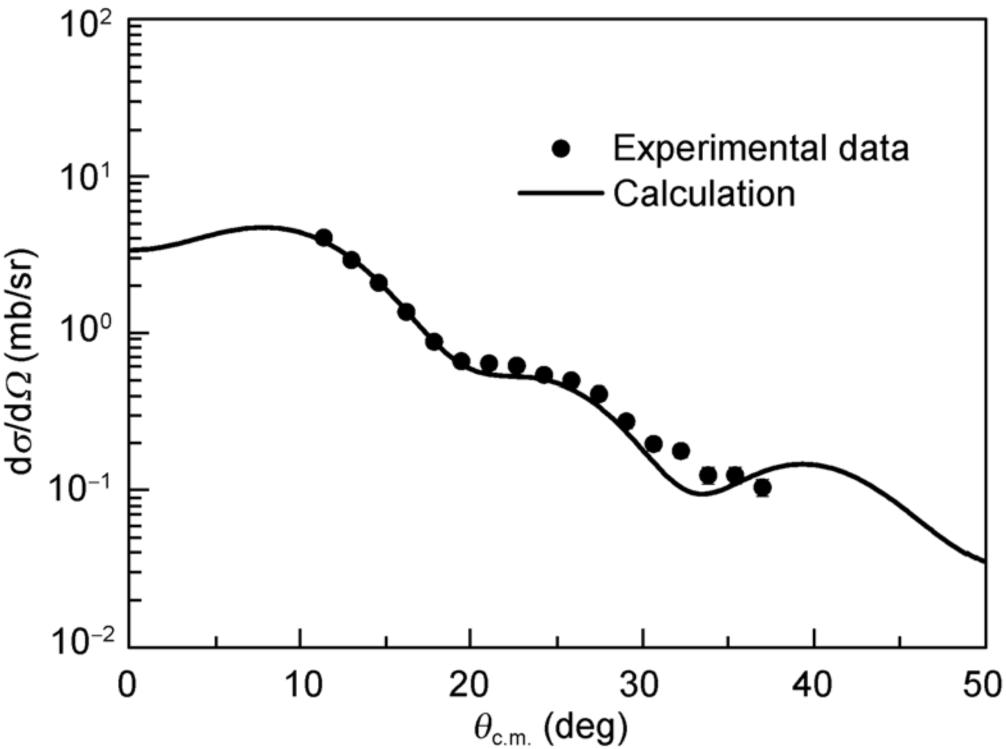
S_{α} = 0.40±0.12

$^{13}C(\alpha,n)^{16}O$反应的天体物理S因子

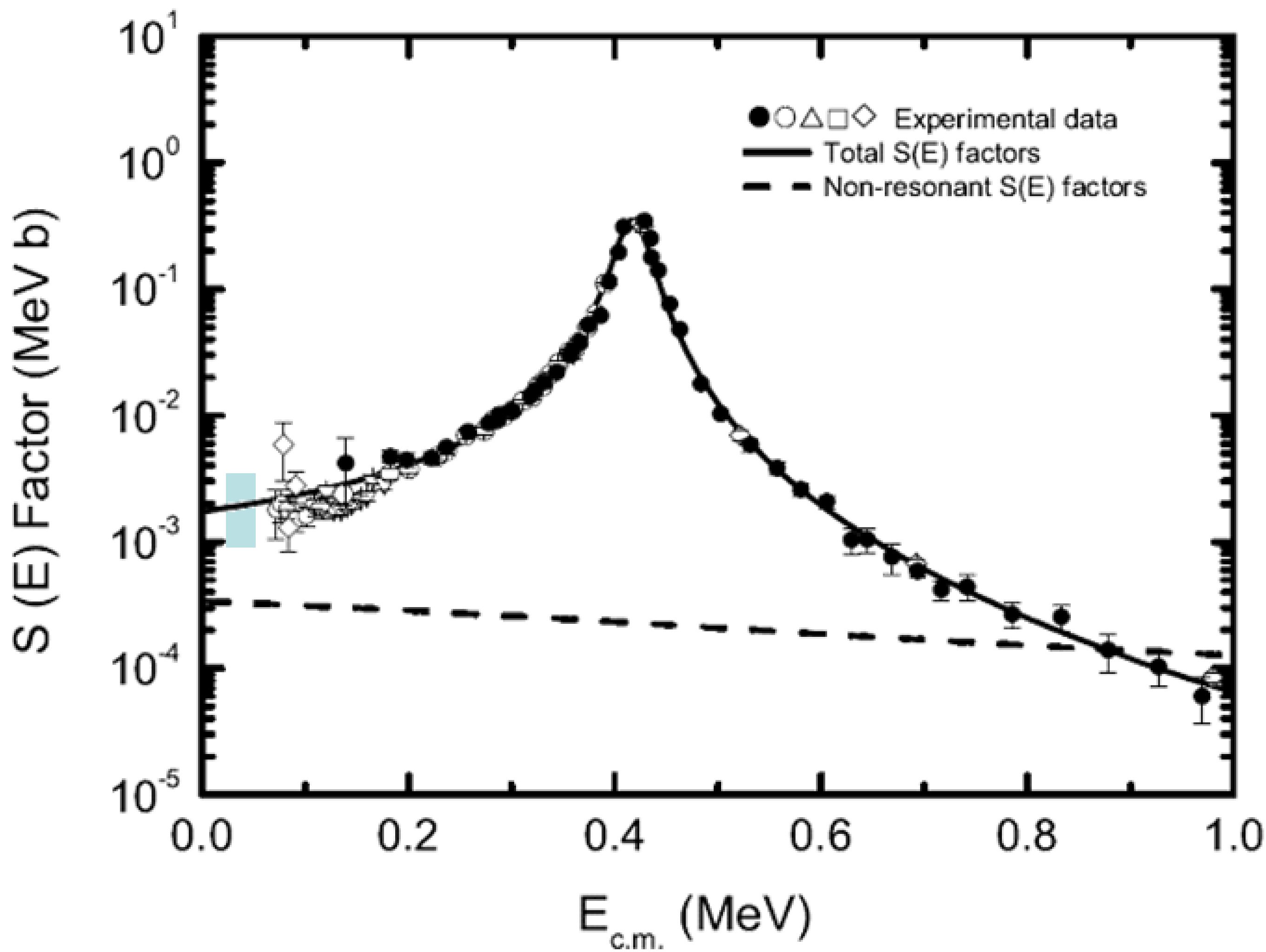


测量了$^{12,13}C(^7Li,^7Li)$与$^{12}C(^7Li,^6He)^{13}N$反应的角分布



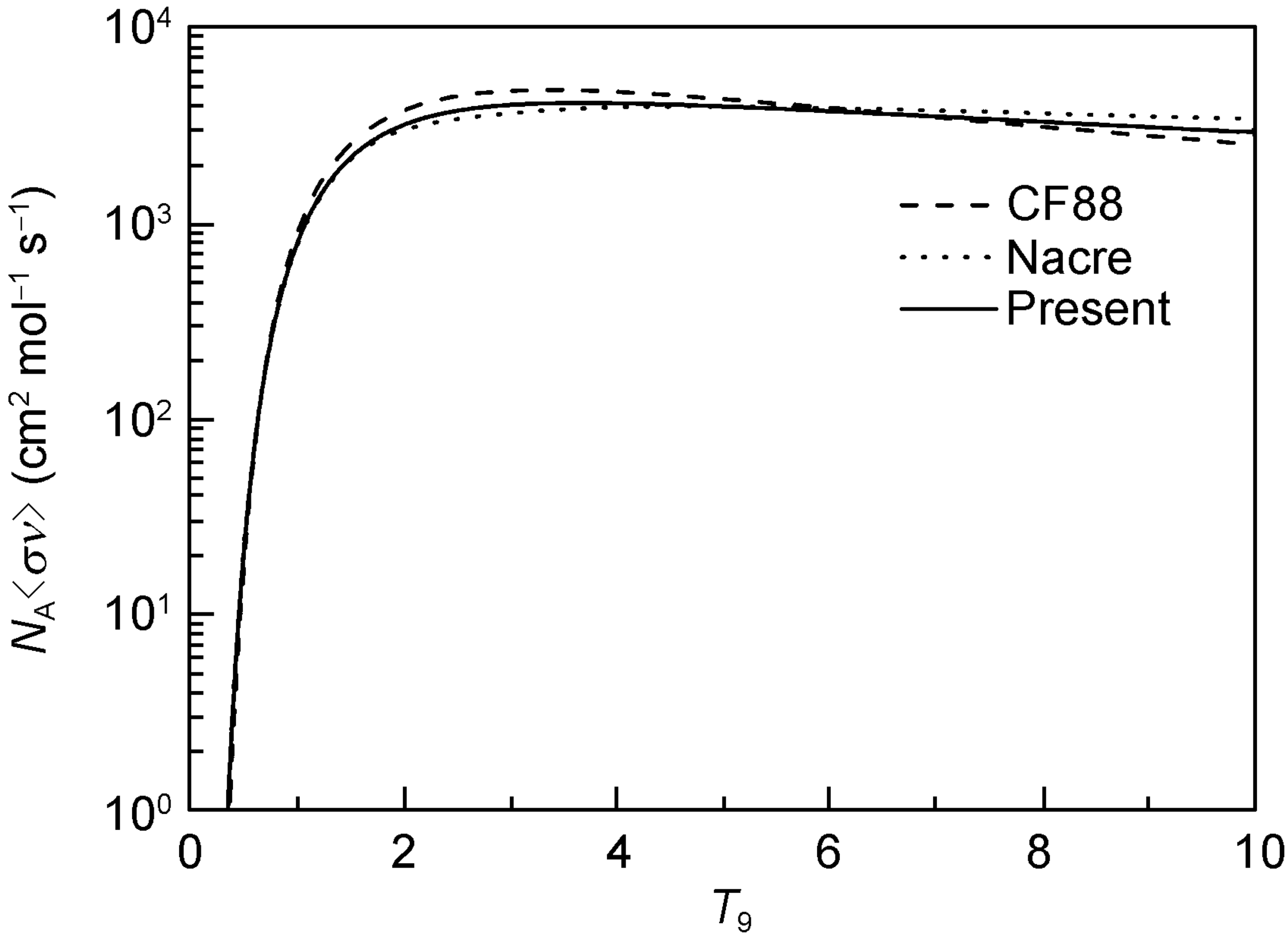


导出了$^{12}C(p,\gamma)^{13}N$天体物理S因子

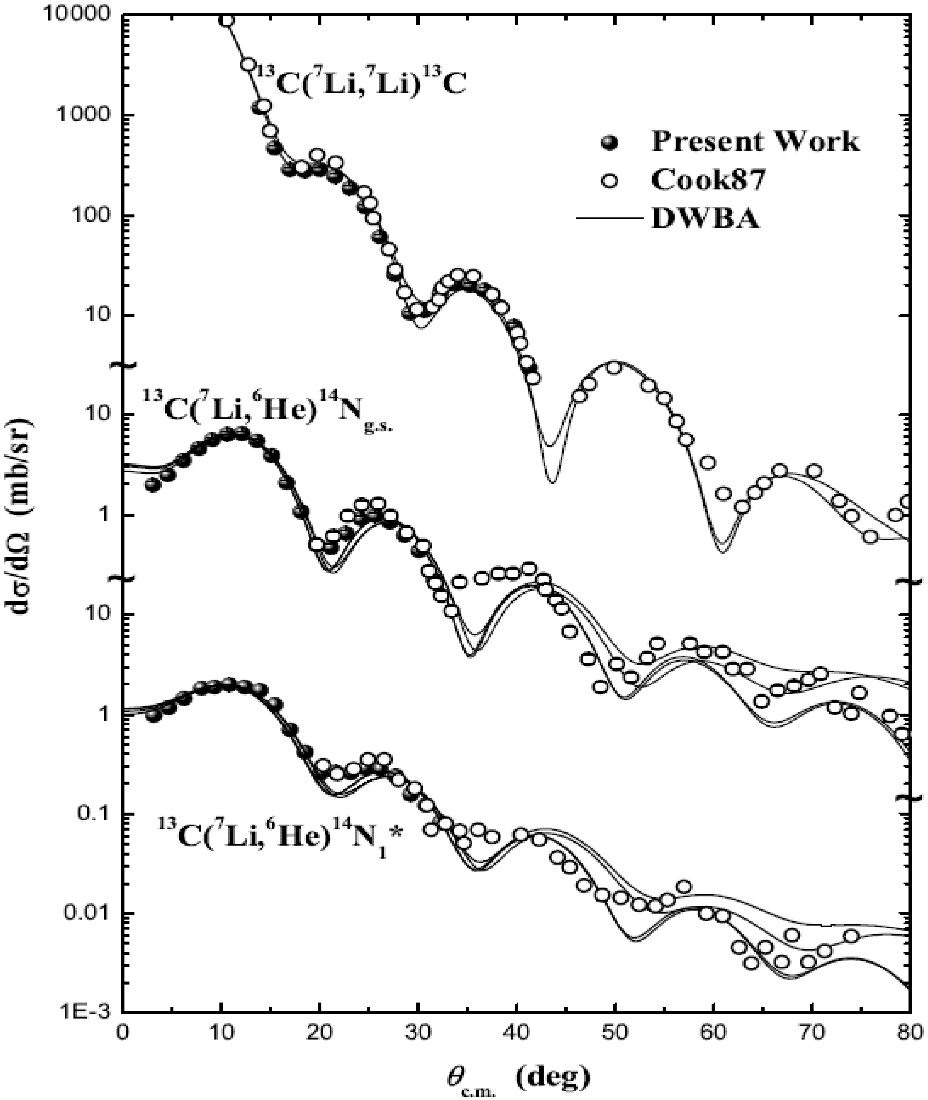


启动CNO循环的反应，^{13}N衰变后生成^{13}C，为中子源反应增加燃料

$^{12}C(p,\gamma)^{13}N$天体物理反应率



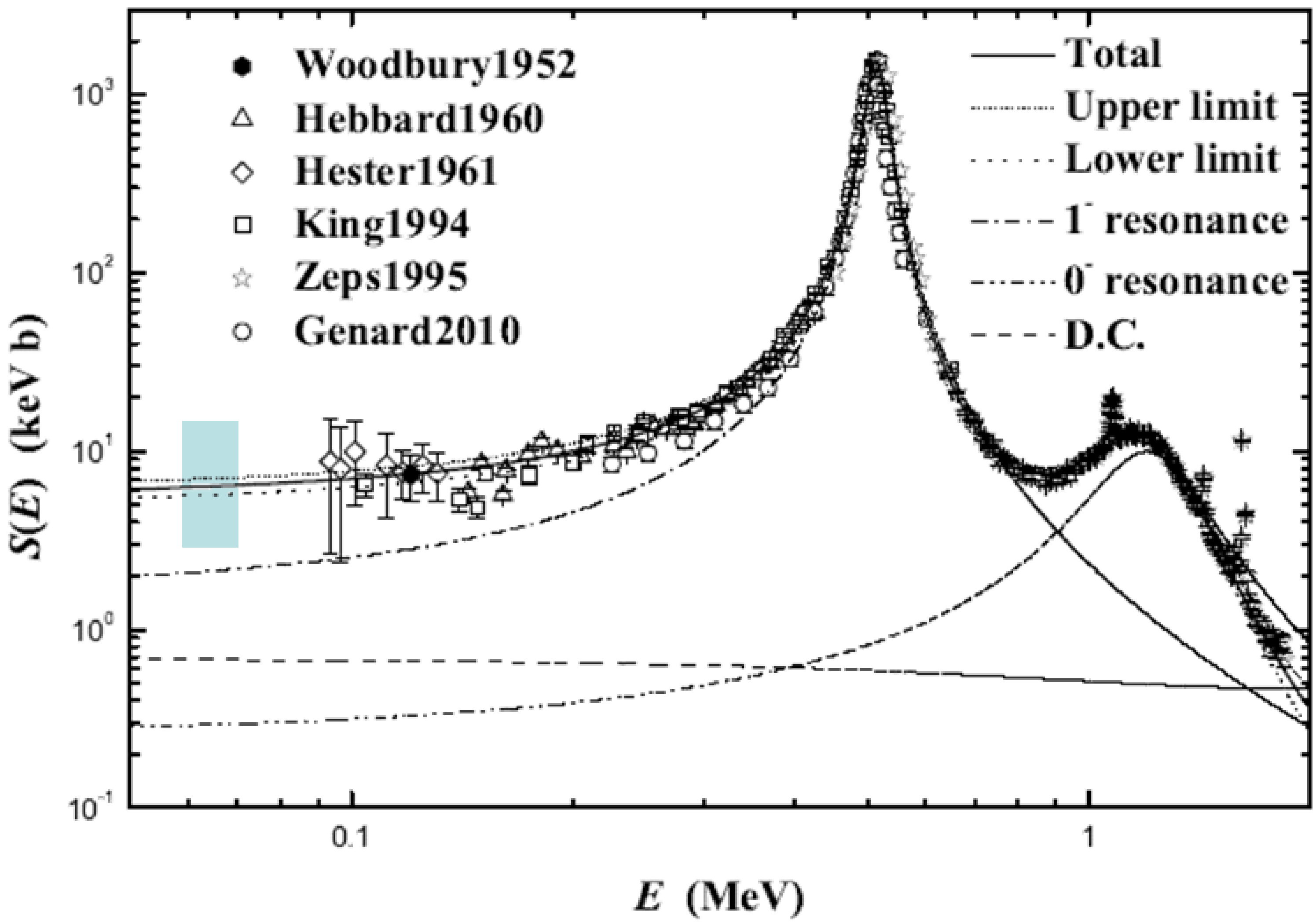
$^{13}C(^7Li, ^7Li/^6He)$反应的角分布



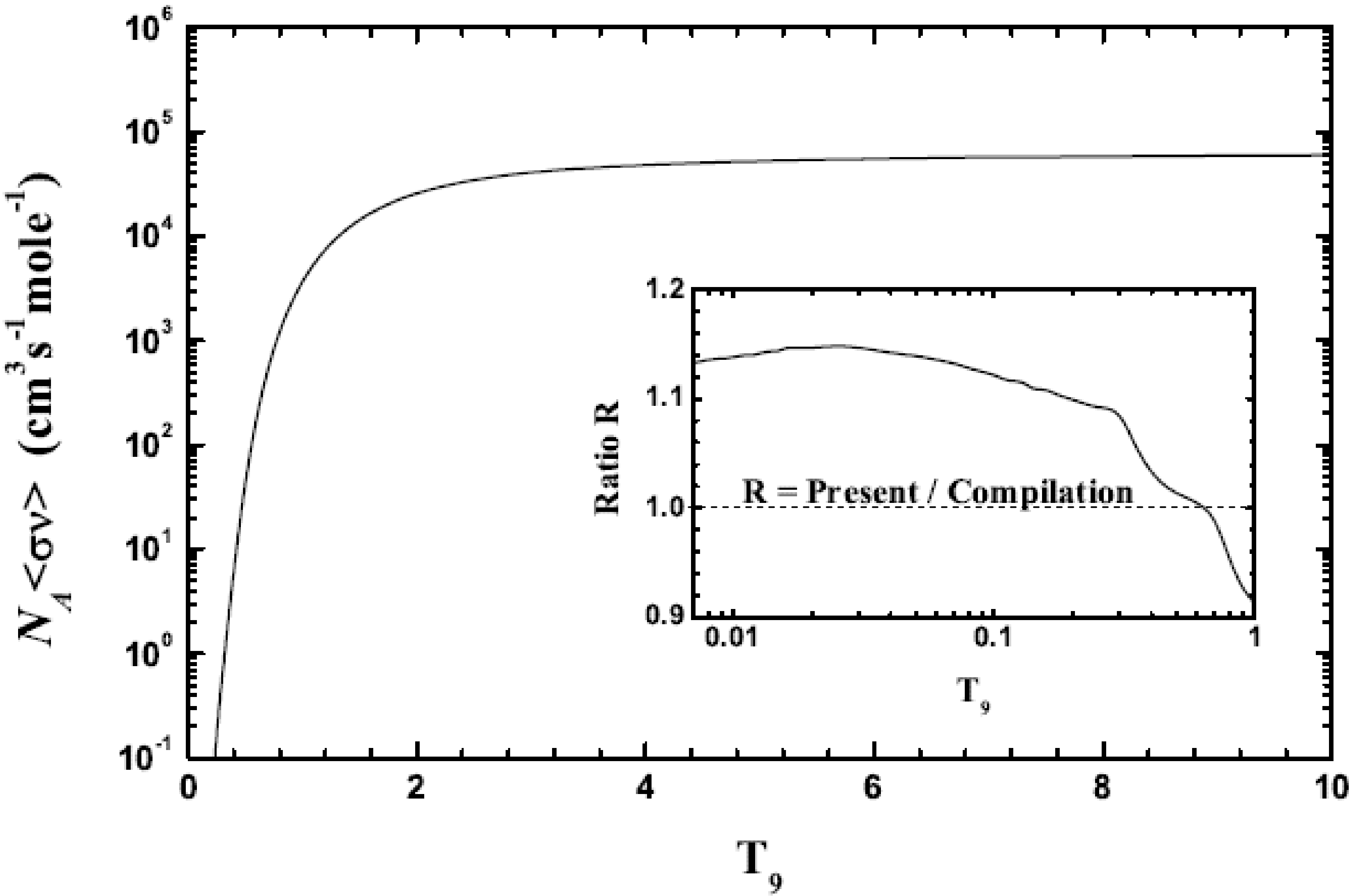
Channel	$^7Li + {}^{13}C$		$^6He + {}^{14}N$	
	Set Ⅰ	Set Ⅱ	Set Ⅲ	Set Ⅳ
U_V	159.0	198.75	124.88	131.65
r_R	0.63	0.52	0.52	0.60
a_R	0.81	0.90	1.02	0.91
W_V	8.16	8.70	15.37	7.14
r_I	1.33	1.31	1.30	1.31
a_I	0.78	0.73	0.54	0.7
r_C	1.25	1.0	1.0	1.0
χ^2/p		15.22	6.37	1.35

0.67±0.09 0.73±0.10

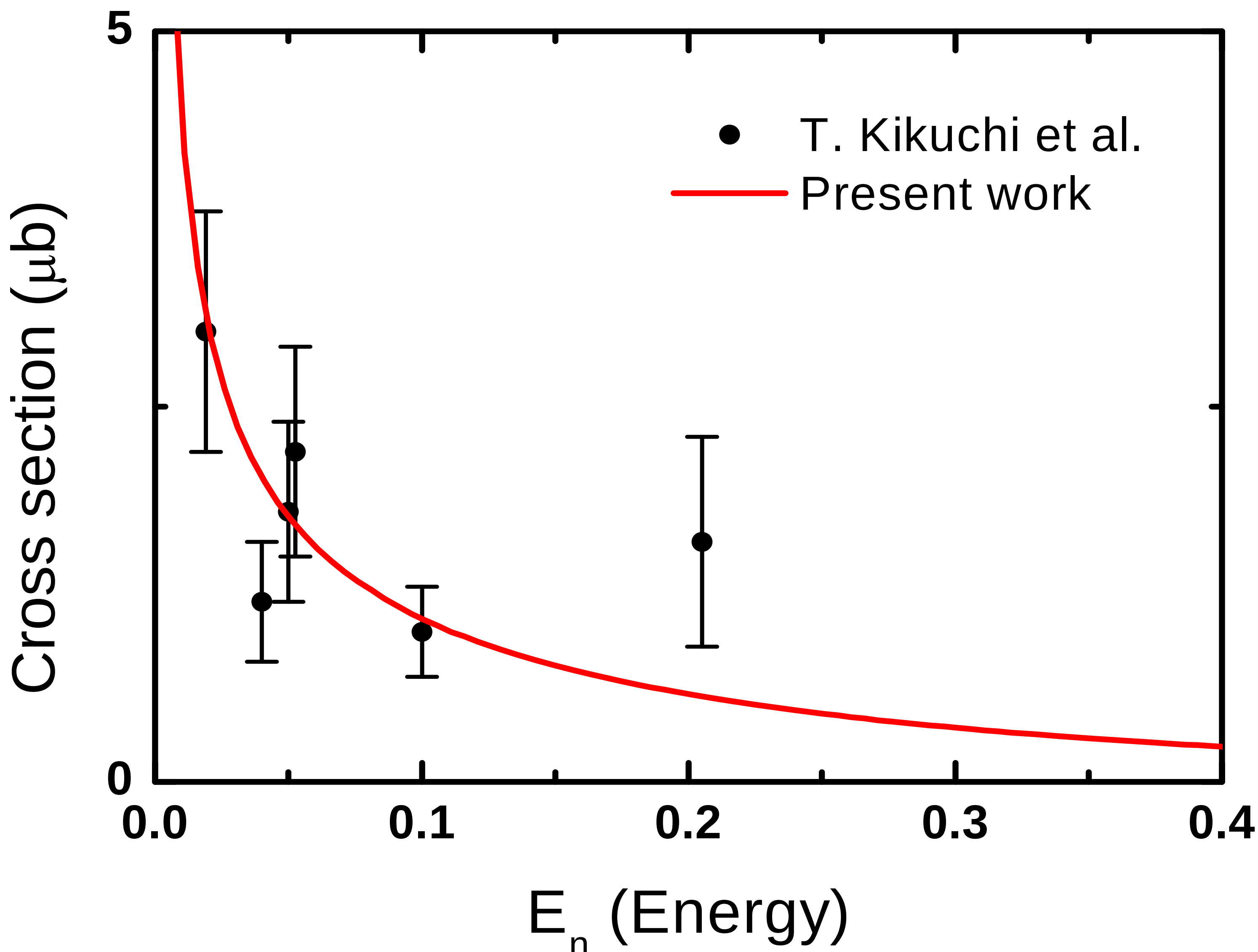
$^{13}C(p, \gamma)^{14}N$反应的天体物理S因子



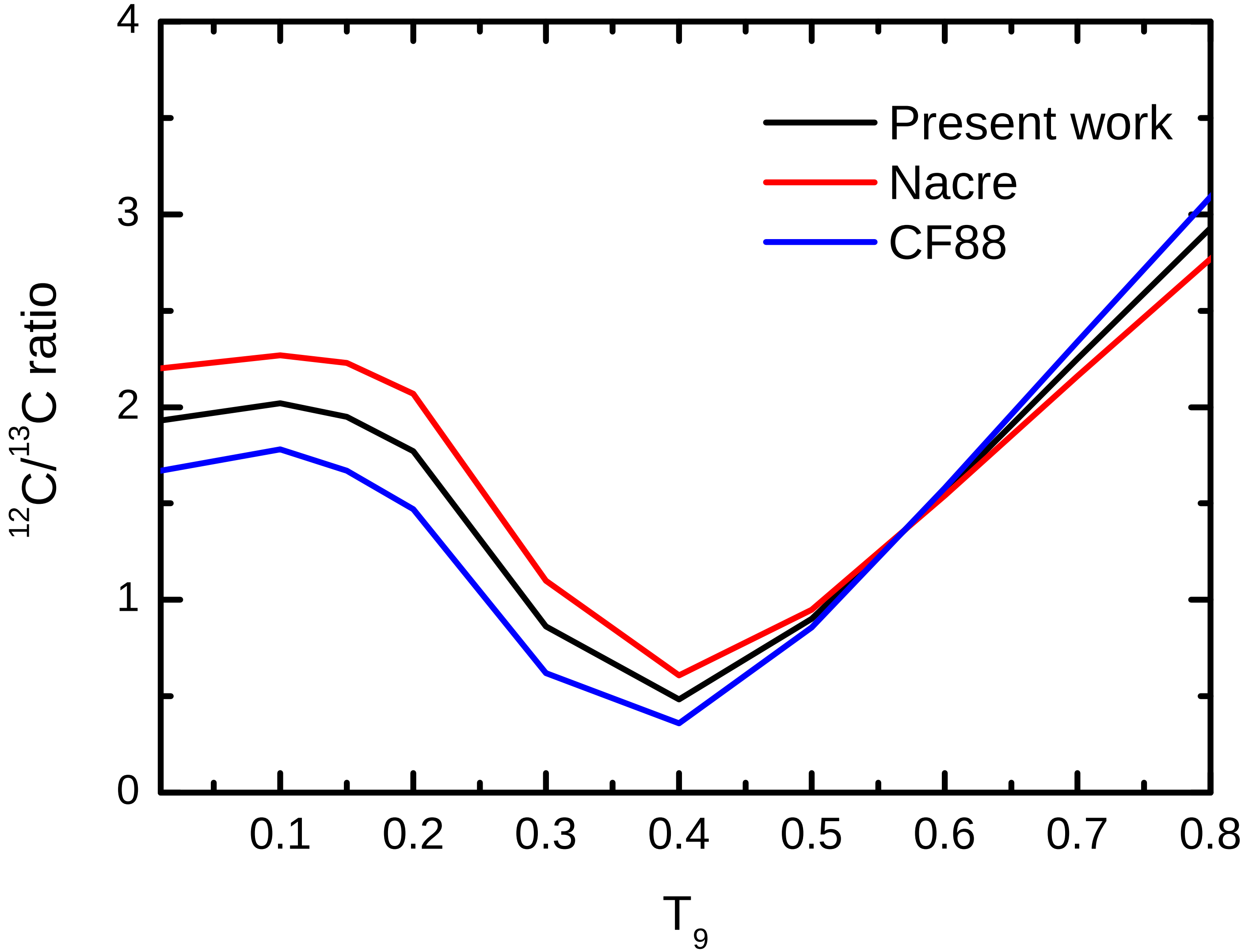
$^{13}C(p, \gamma)^{14}N$天体物理反应率



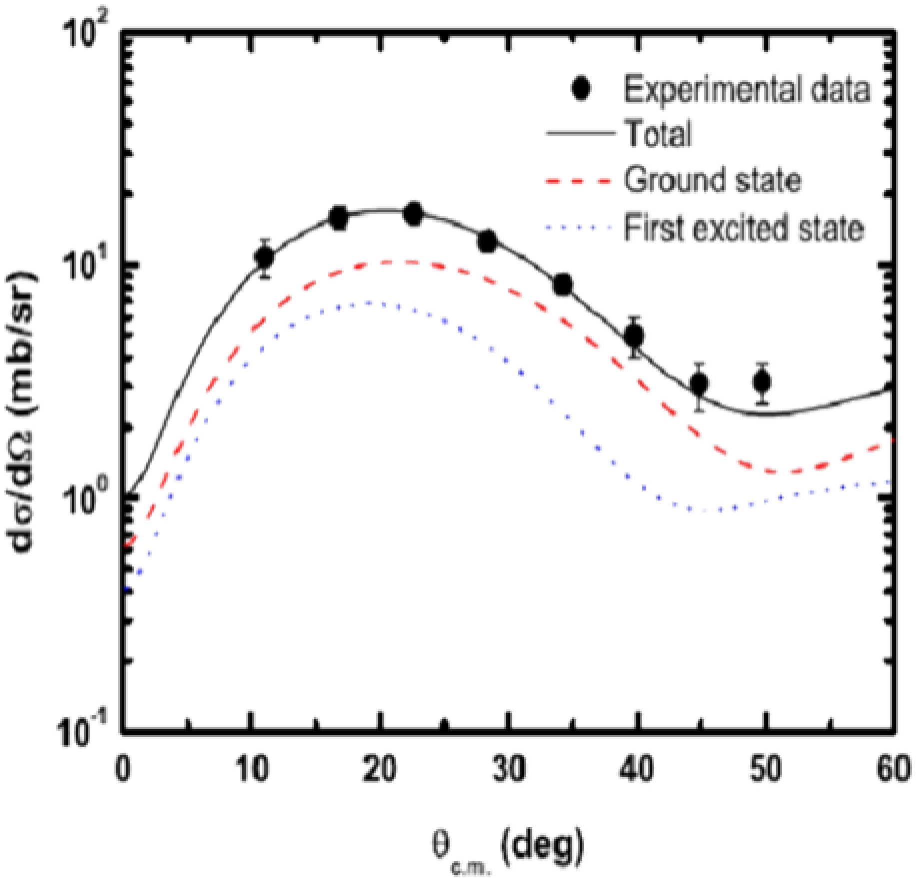
$^{12}C(n,\gamma)^{13}C$反应的激发函数



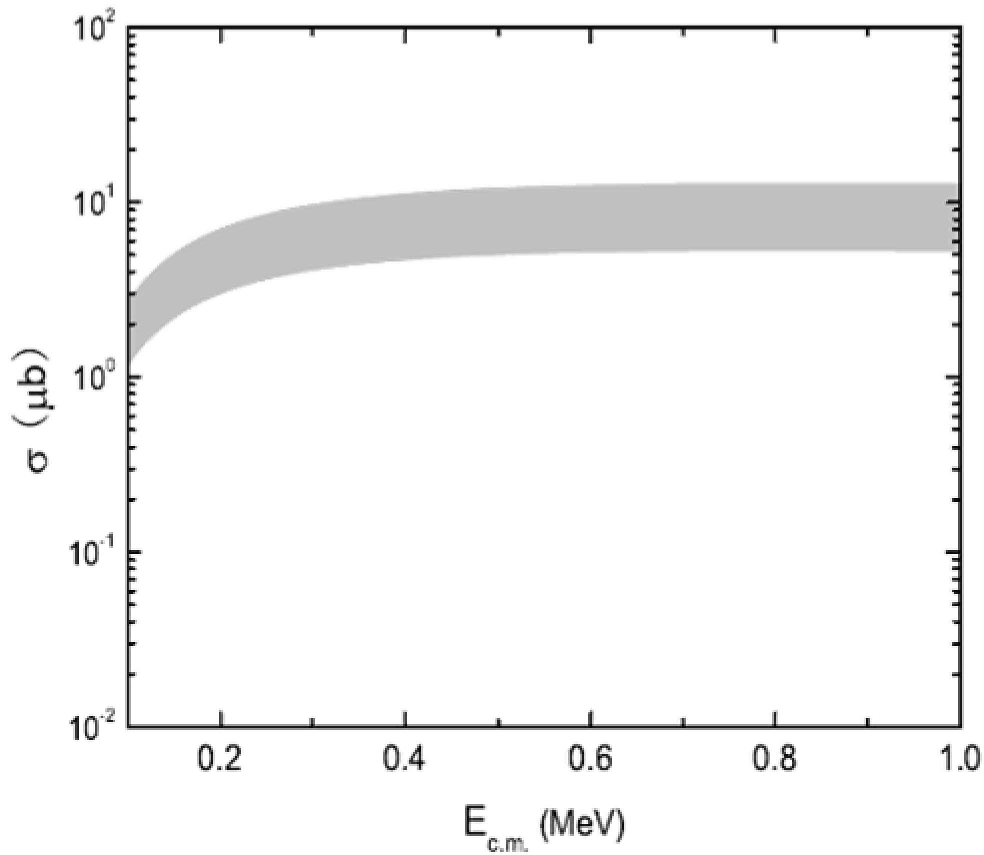
$^{12}C/^{13}C$比例随温度的变化曲线



$^6He(d,n)^7Li$反应与$^6He(p,\gamma)^7Li$反应的激发函数

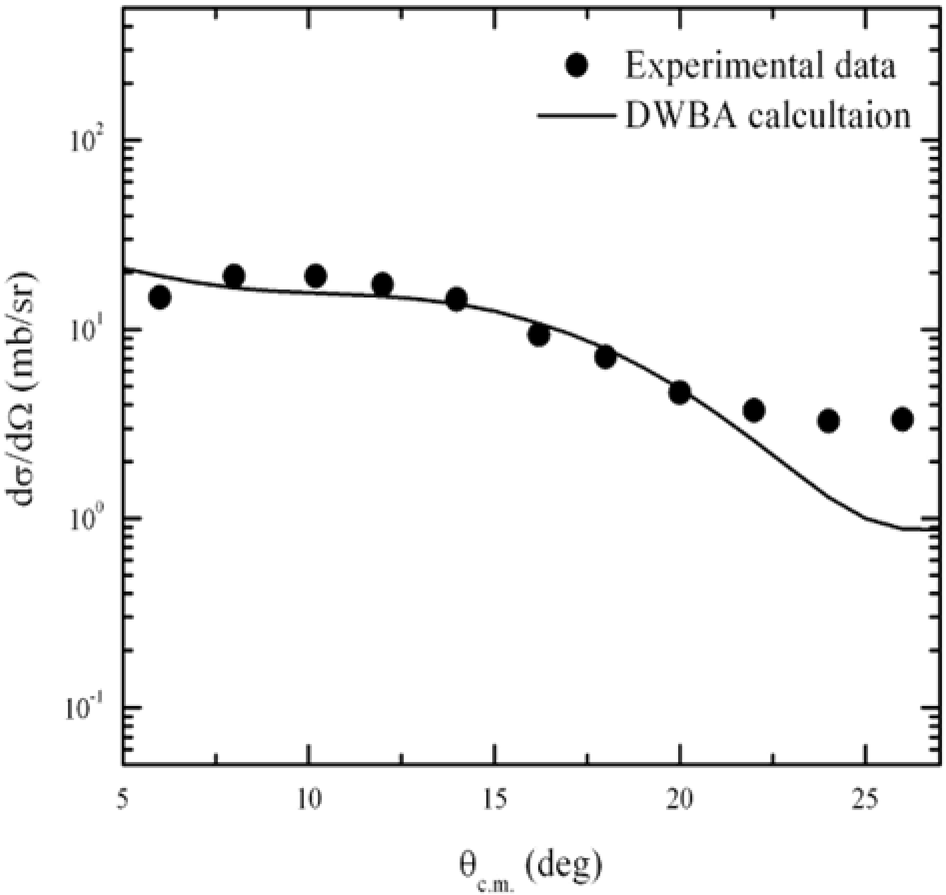


$^6He(d,n)^7Li$反应的角分布

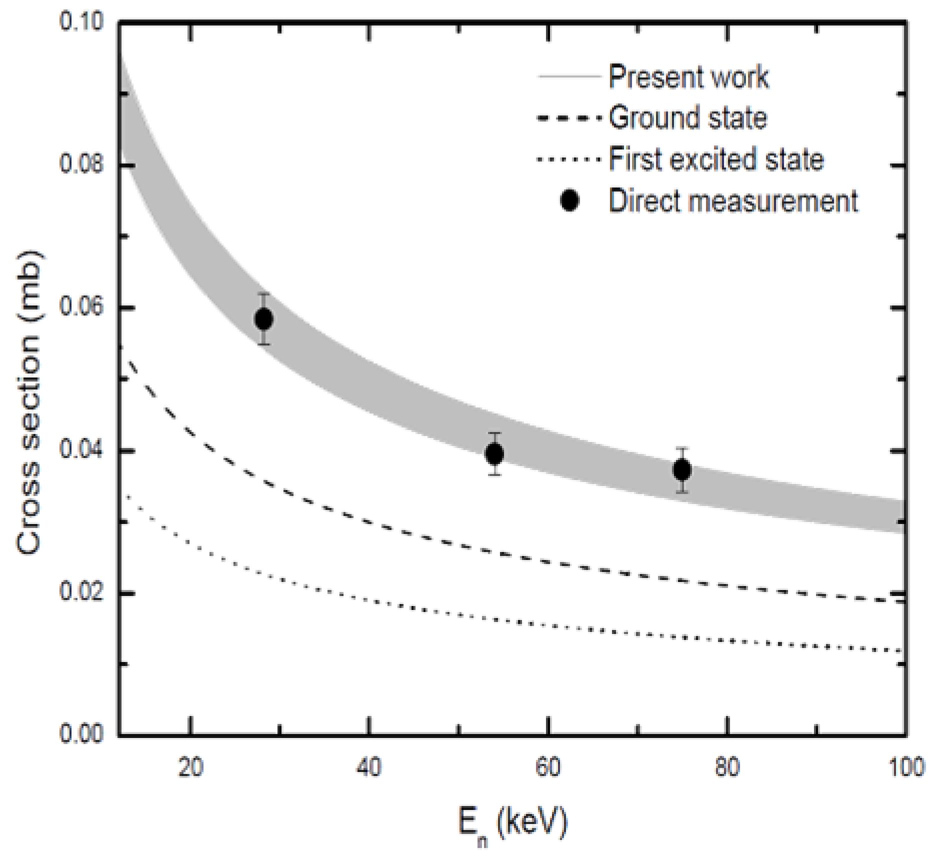


$^6He(p,\gamma)^7Li$反应的激发函数

$^{7}Li(^{6}Li, ^{7}Li)^{6}Li$反应与$^{6}Li(n, \gamma)^{7}Li$激发函数

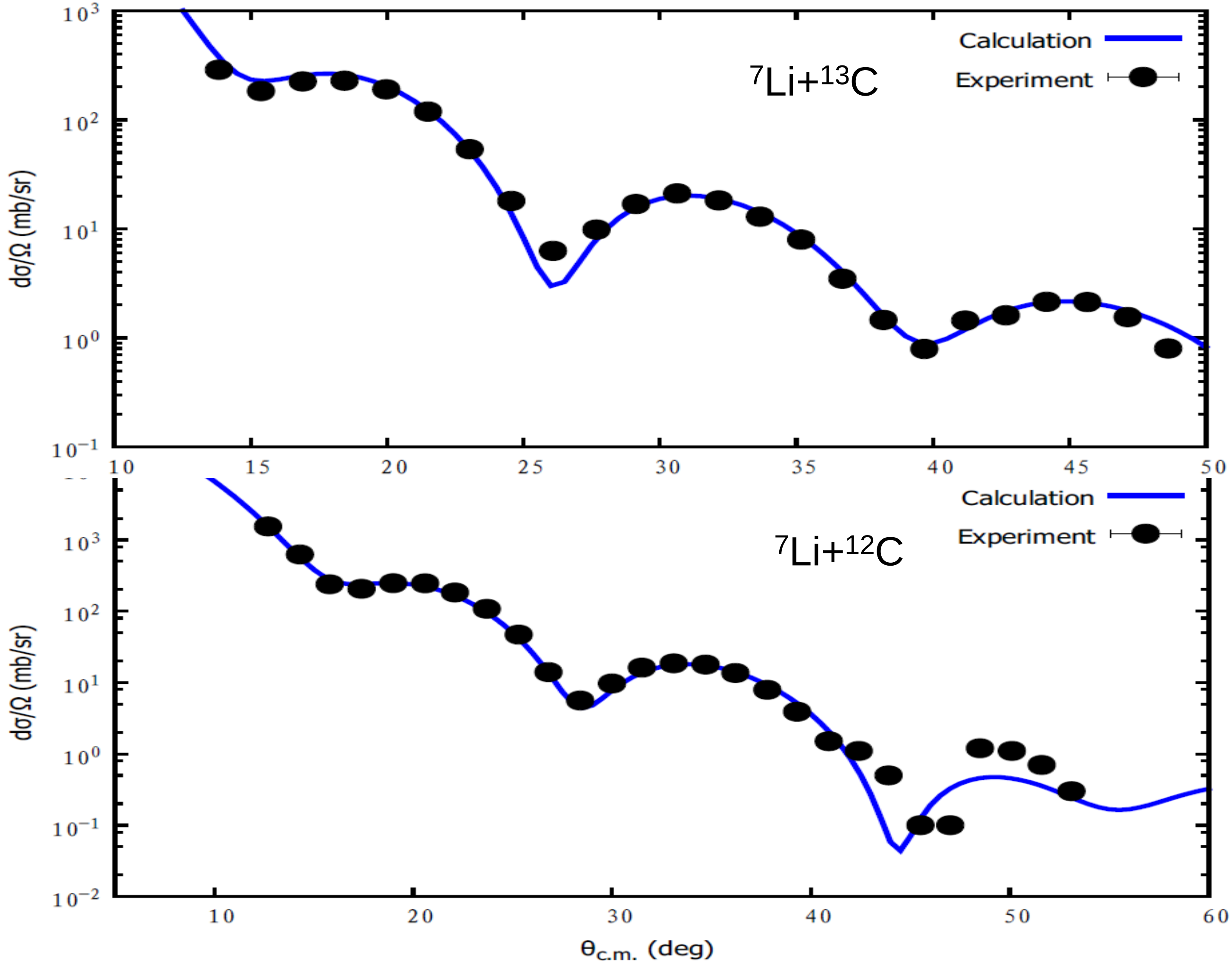


$^{7}Li(^{6}Li, ^{7}Li)^{6}Li$反应的角分布

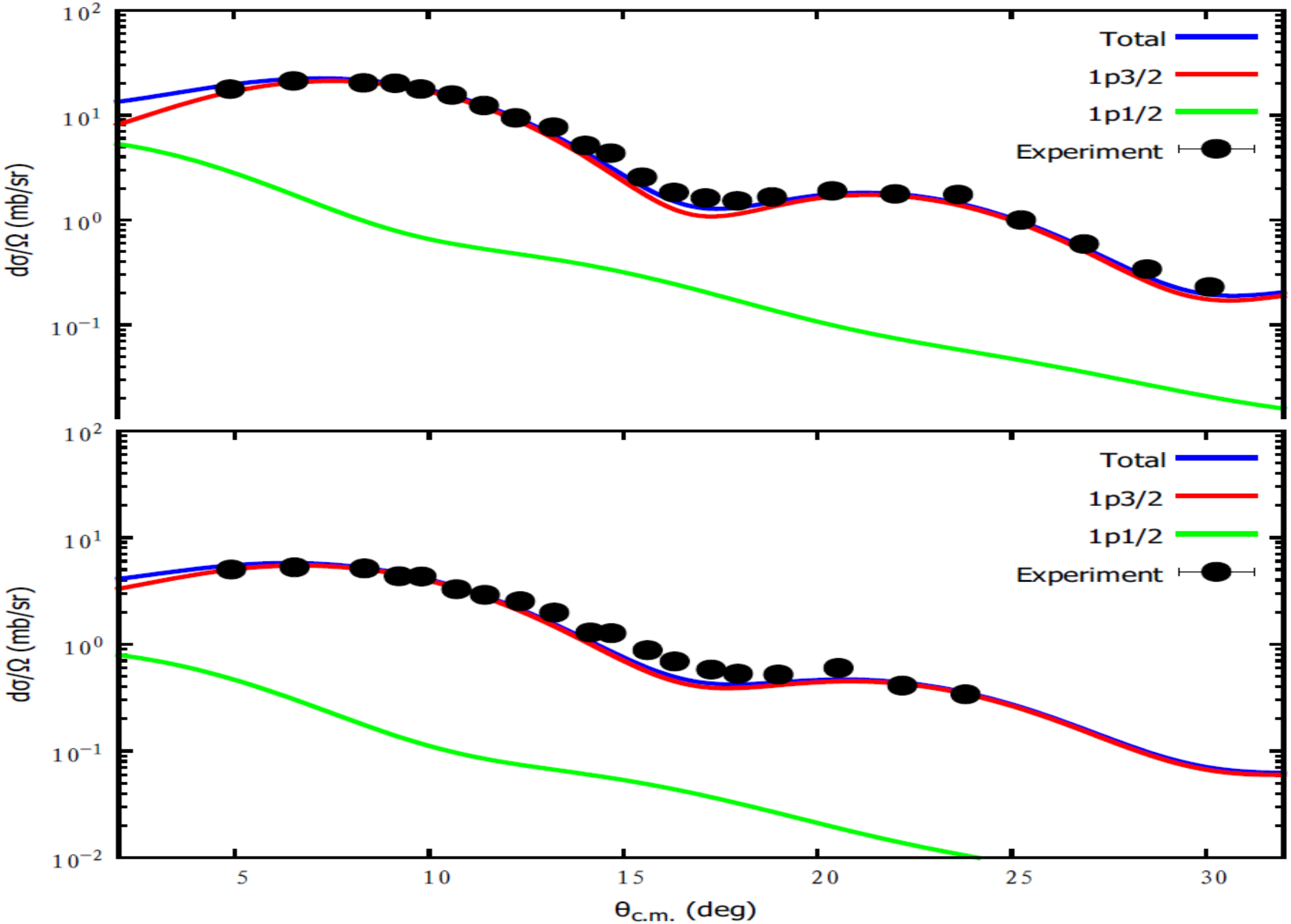


$^{6}Li(n, \gamma)^{7}Li$反应的激发函数

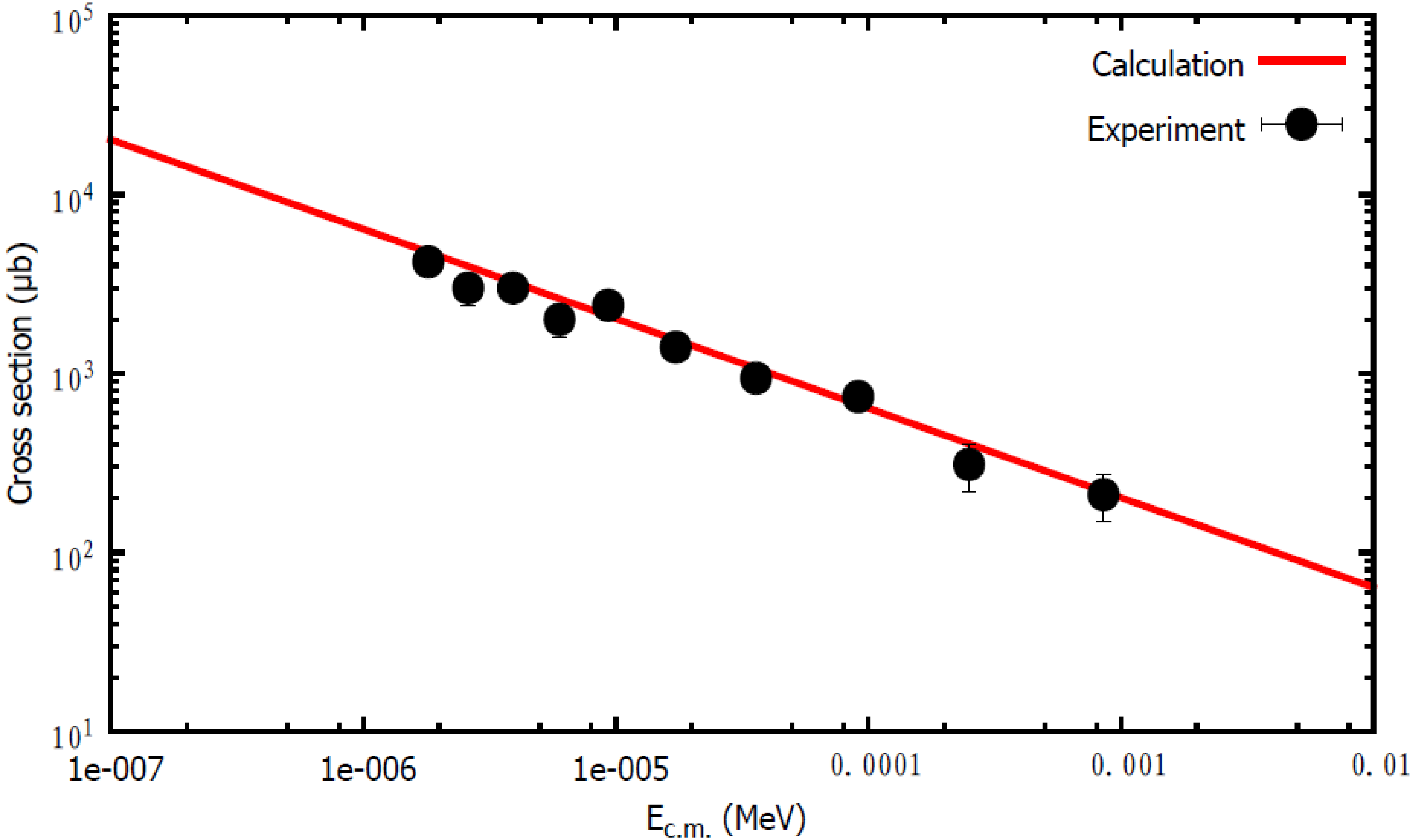
$^{7}Li+^{12,13}C$弹性散射的角分布



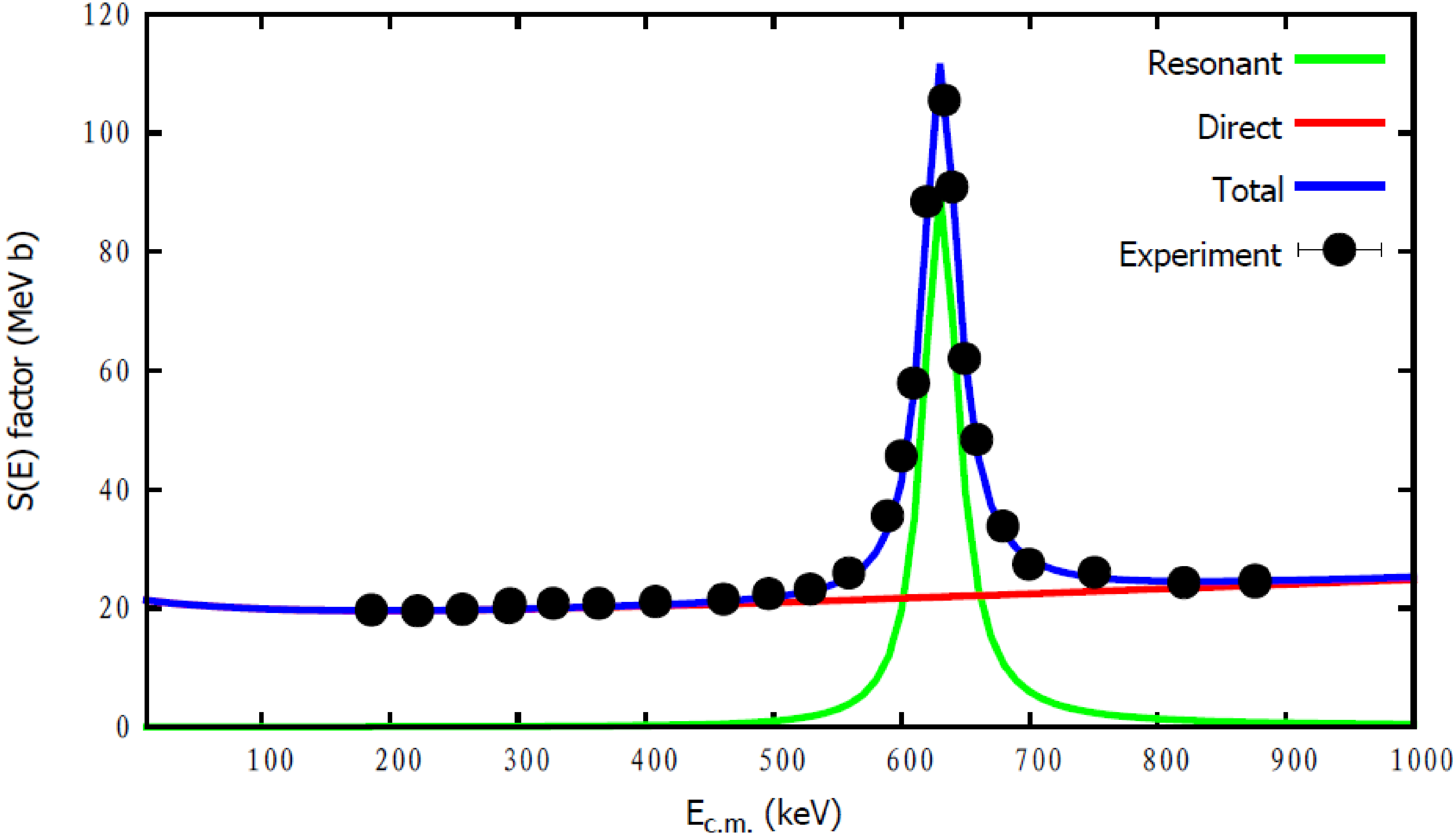
$^{13}C(^{7}Li,^{8}Li_{0,1})^{12}C$转移反应的角分布



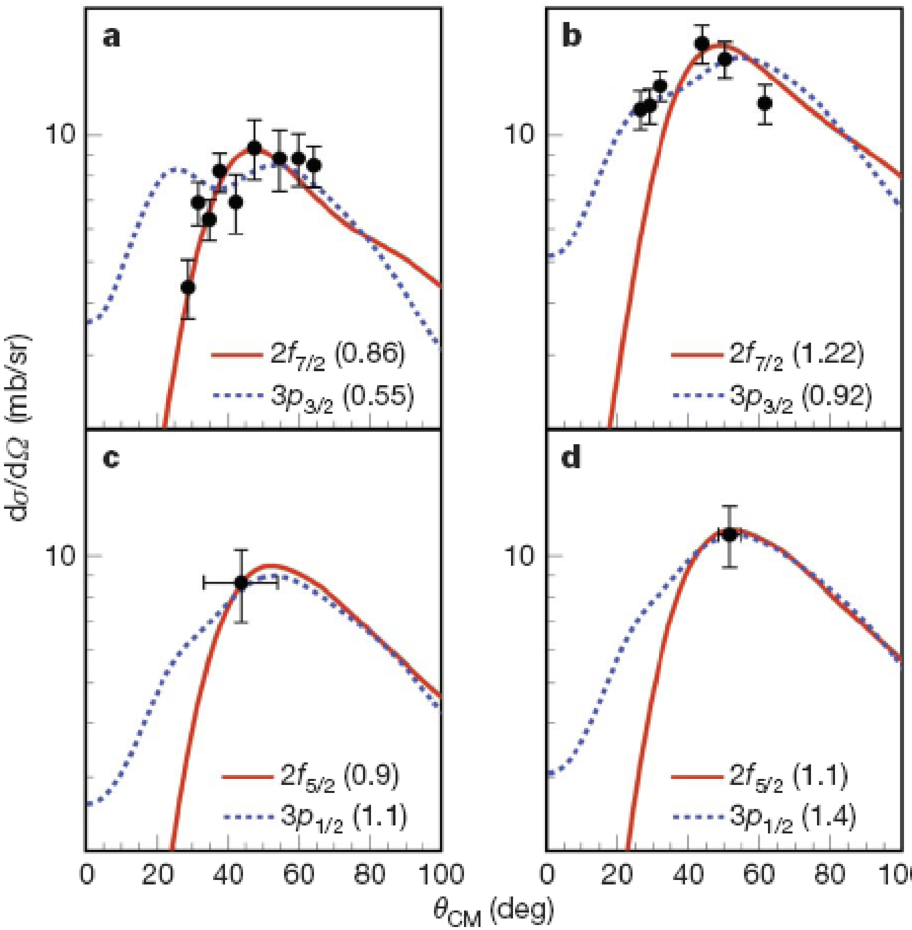
$^{7}Li(n,\gamma)^{8}Li$反应的激发函数



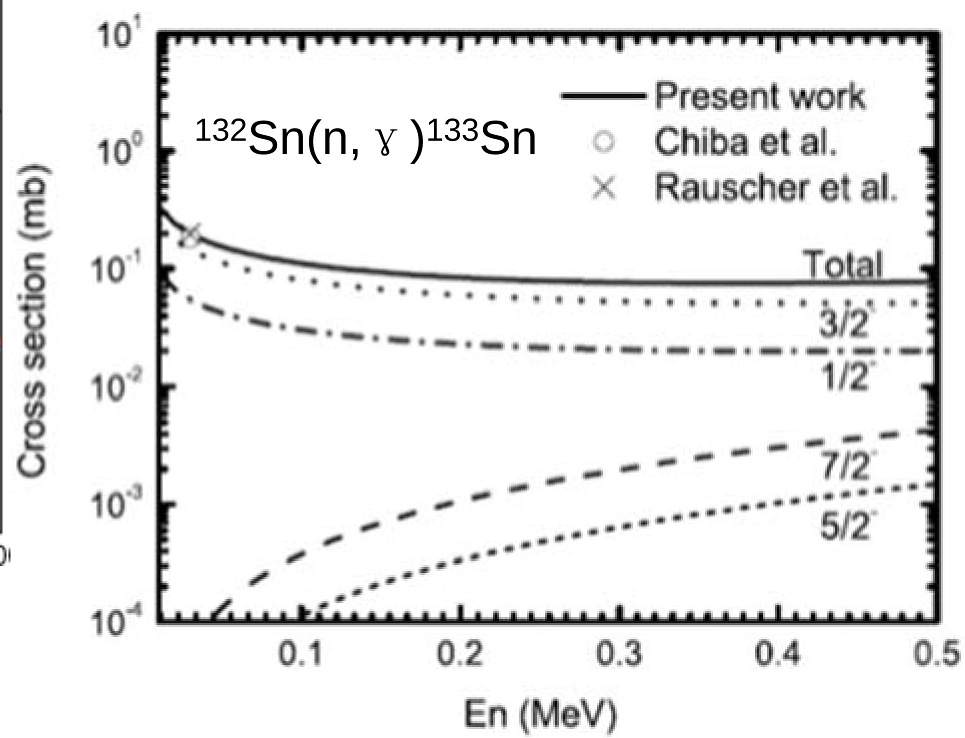
$^{7}Be(p,\gamma)^{8}B$反应的天体物理S因子



$^{132}Sn(n,\gamma)^{133}Sn$ from $^{132}Sn(d,p)^{133}Sn$



E_x (keV)	J^π	Configuration	S
0	$7/2^-$	$^{132}Sn_{gs} \otimes \nu_{f7/2}$	0.86 ± 0.16
854	$3/2^-$	$^{132}Sn_{gs} \otimes \nu_{p3/2}$	0.92 ± 0.18
$1,363 \pm 31$	$(1/2^-)$	$^{132}Sn_{gs} \otimes \nu_{p1/2}$	1.1 ± 0.3
2,005	$(5/2^-)$	$^{132}Sn_{gs} \otimes \nu_{f5/2}$	1.1 ± 0.2



Nature 465(2010 May)454

研究结果为影响因子较高的APJS引用

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 189:240–252, 2010 July doi:10.1088/0067-0049/189/1/240

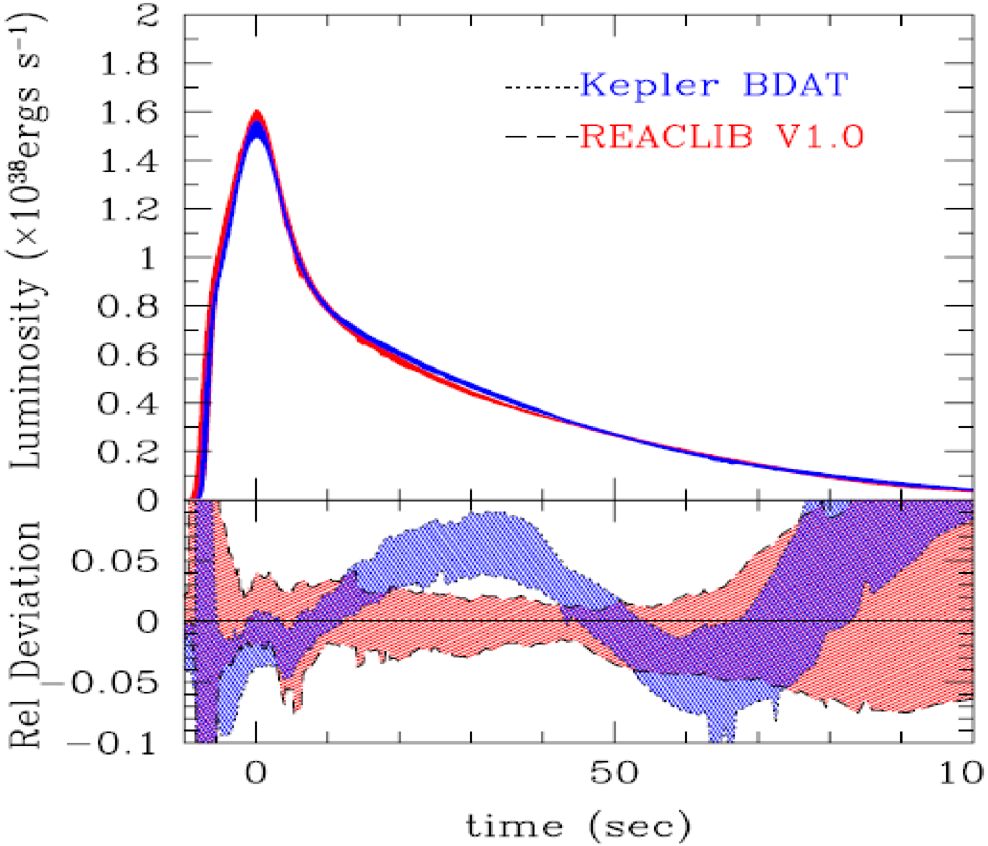
THE JINA REACLIB DATABASE: ITS RECENT UPDATES AND IMPACT ON TYPE-I X-RAY BURSTS

RICHARD H. CYBURT[1,2,9], A. MATTHEW AMTHOR[1,2,3], RYAN FERGUSON[1,2,3], ZACH MEISEL[1,2,3], KARL SMITH[1,2,3],

from Tang et al. (2004). We therefore adopt the most recent Li et al. (2006) results as our recommended value.

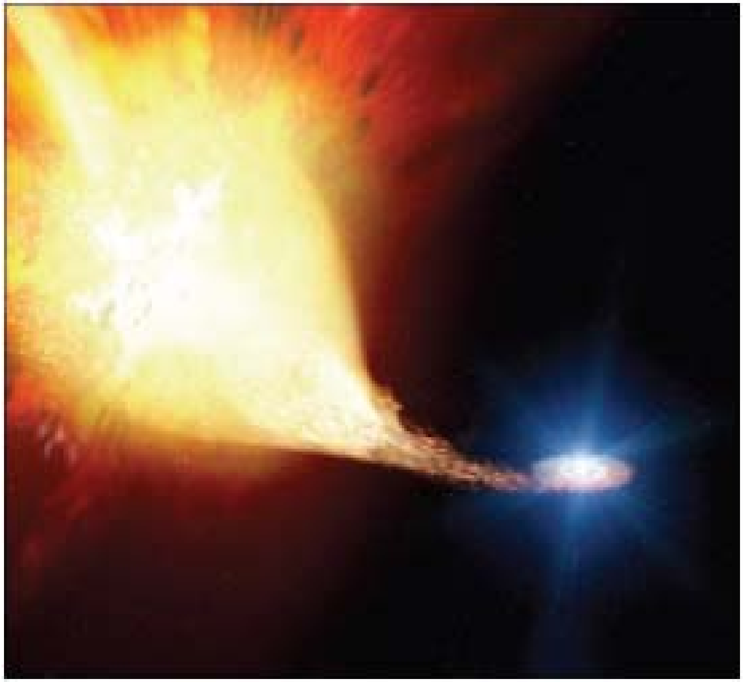
capture components. Therefore, we adopt the rate from Guo et (2006).

The previously found small discrepancies between model calculations and observations may be solved with a better understanding of the nuclear input.

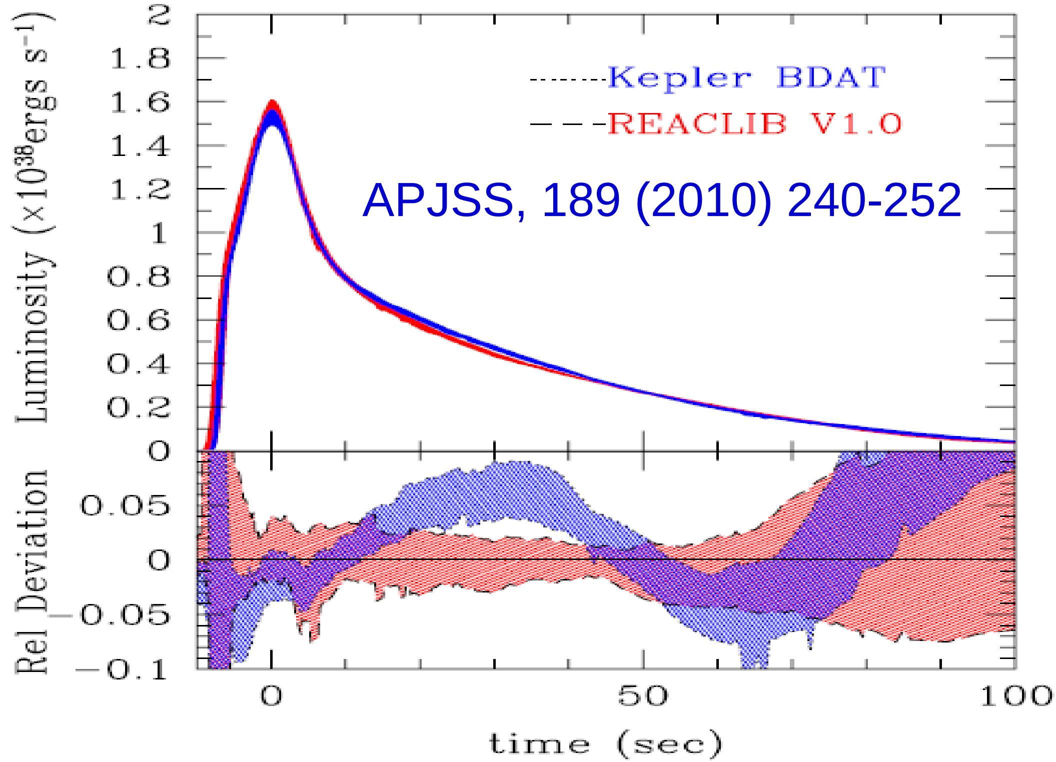


研究结果被应用情况

二十六项研究成果为EXFOR和REACLIB收录



X–射线暴



解决了模型计算与观察结果之间的矛盾，

^{13}N(p,γ)^{14}O与^{26}Si(p,γ)^{27}P被推荐为标准值

We therefore adopt the most recent Li et al. (2006) results as our recommended Value.

Therefore, we adopt the rate from Guo et al. (2006).

近两年来完成的工作

- 原初核合成锂丰度异常的研究
  - $^{2}H(^{6}He,^{7}Li)n$反应的实验研究
  - $^{6}Li(n,\gamma)^{7}Li$天体物理反应率
  - $^{7}Li(n,\gamma)^{8}Li$天体物理反应率
  - $^{6}He(p,\gamma)^{7}Li$天体物理S因子的间接测量
- 恒星演化过程中的关键核反应研究
  - $^{13}C(p,\gamma)^{14}N$反应的研究
  - $^{13}C(a,n)^{16}O$核天体物理反应的实验研究
  - $^{12}C(p,\gamma)^{13}N$反应的天体物理S因子
  - $^{7}Be(p,\gamma)^{8}B$反应的天体物理S因子
  - $^{132}Sn(n,\gamma)^{133}Sn$天体物理反应率

课题组成员照片


Thank You !