CINP ICPN Canadian Institute of Nuclear Physics
Institut canadien de physique nucléaire

DEGENERATE NEUTRON CAPTURE WITHIN NEUTRON STAR CRUSTS

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THE DISCUSSION

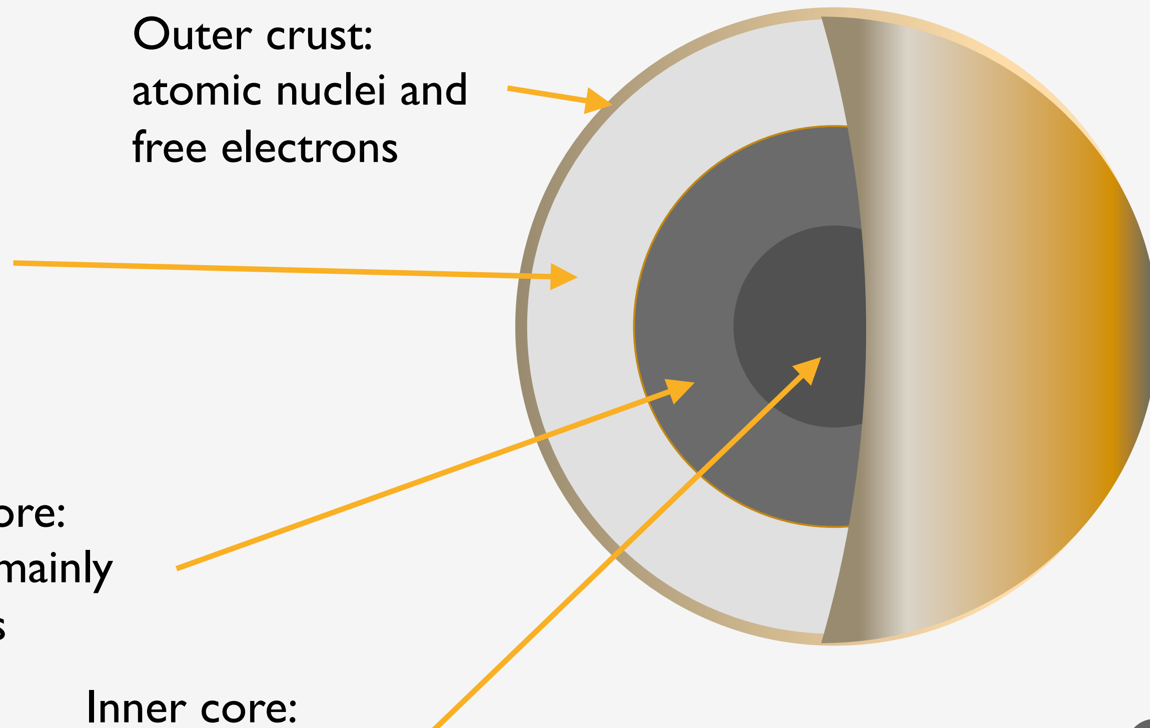
Neutron stars and their thermodynamics.

Capture rates within the neutron star.

Degeneracy correction example.

Degeneracy and different nuclear models.

THE LAYERS OF A NEUTRON STAR



WHY BOTHER WITH REACTION RATES?

- Type 1 x ray burst[(1)]
- Lasts approximately one day, gradually dies off
- Involve production of proton-rich nuclei/heavy nuclei[(1)]
- Observable related to the neutron star

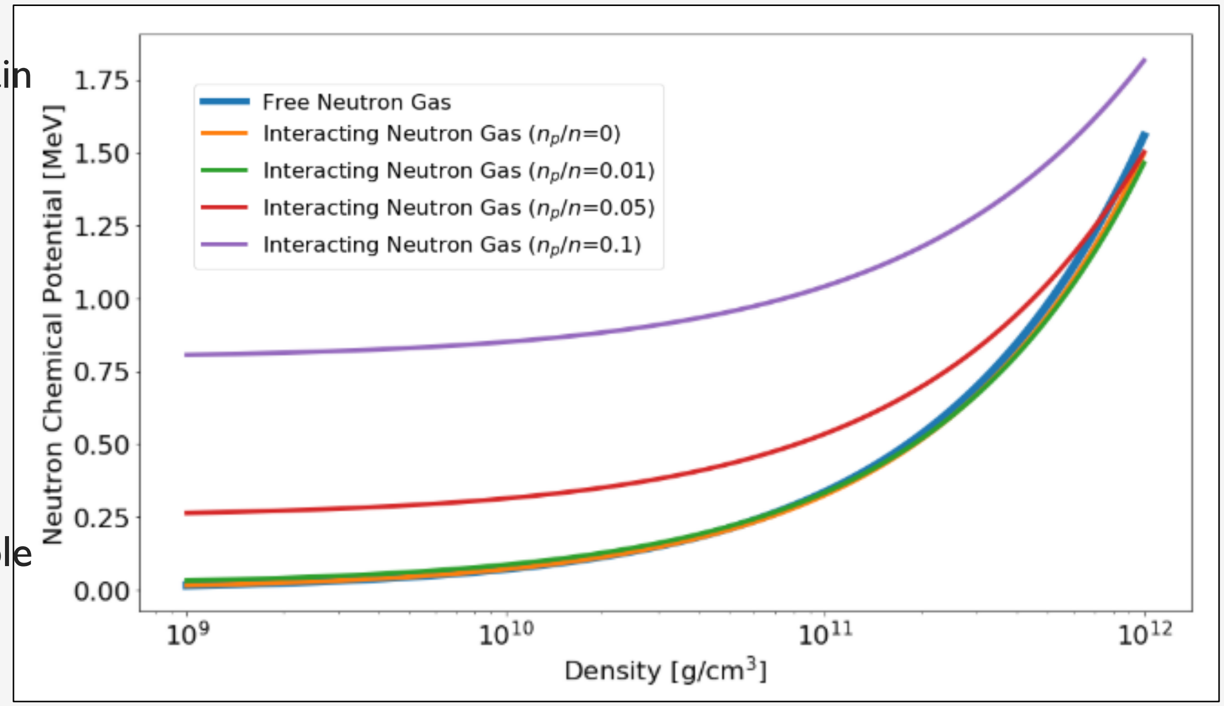
(1) P. Haensel and A.Potekhim and D.Yakolev, *Springer*. **2007**, 1, 517.

THERMODYNAMICS OF A NEUTRON STAR

- Choose temperature domain of 0.01 MeV to 1 MeV

- Chemical potential derived from ab inito energy with an empirical expansion.(3)

- Chemical potential domain of 0.5 to 1 MeV is acceptable



(3) K. Hebeler, J. M. Lattimer, C. J. Pethick, and A. Schwenk, Astrophys. J. 773, 11 (2013).

HOW TO MODEL IT?

- $\langle \sigma^* v \rangle = \sqrt{2/m}\, \frac{1}{N} \int_0^\infty E\, \sigma^*(E)\, f(E,T,\mu)\, dE$

To a decent approximation, $\sigma^*(E) \approx \sigma(E)$ (2)

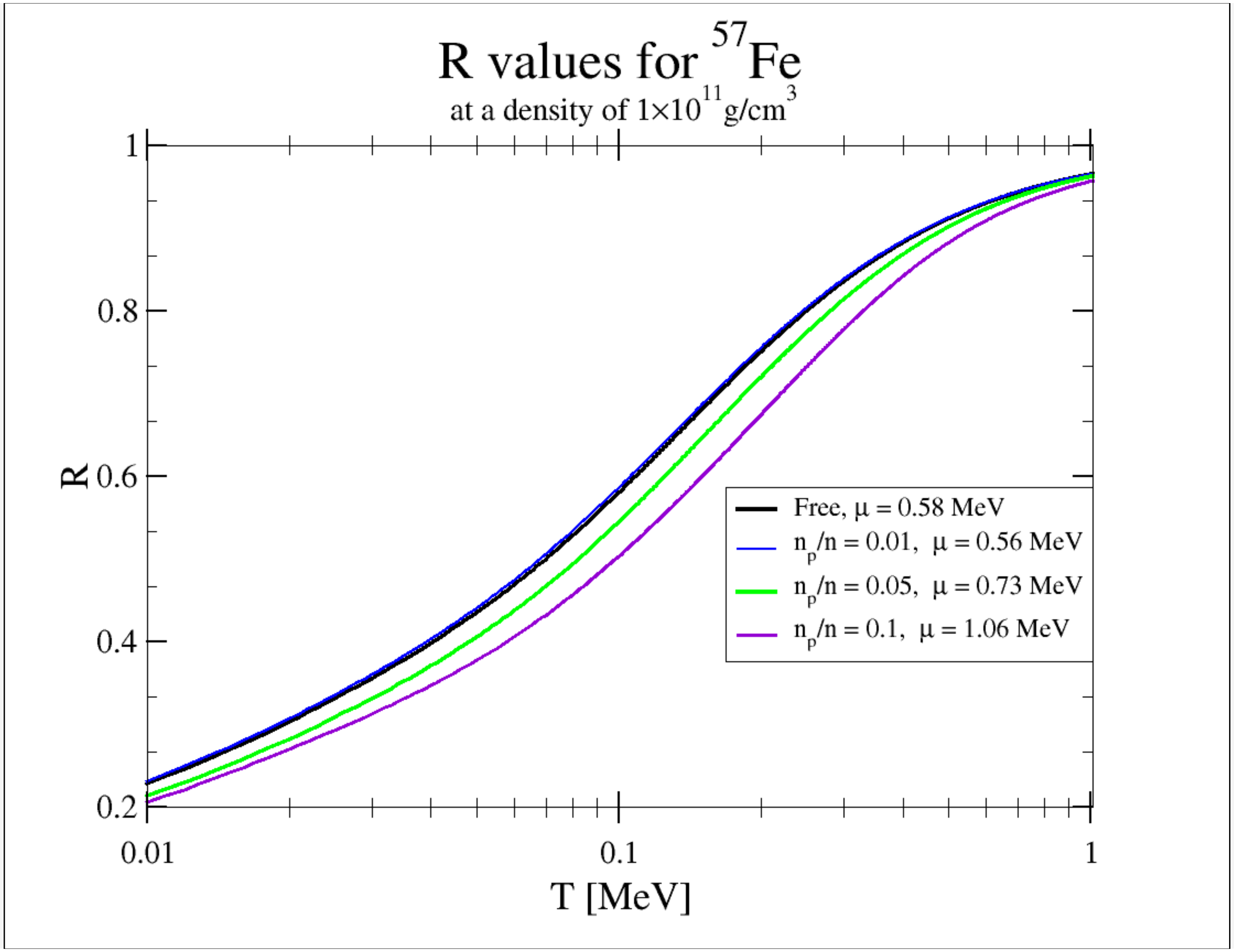
(2) Shternin, P.S.; Beard,M.;Wiescher,M.;Yakovlev,D.G. **2018** *Astro.Phys.*

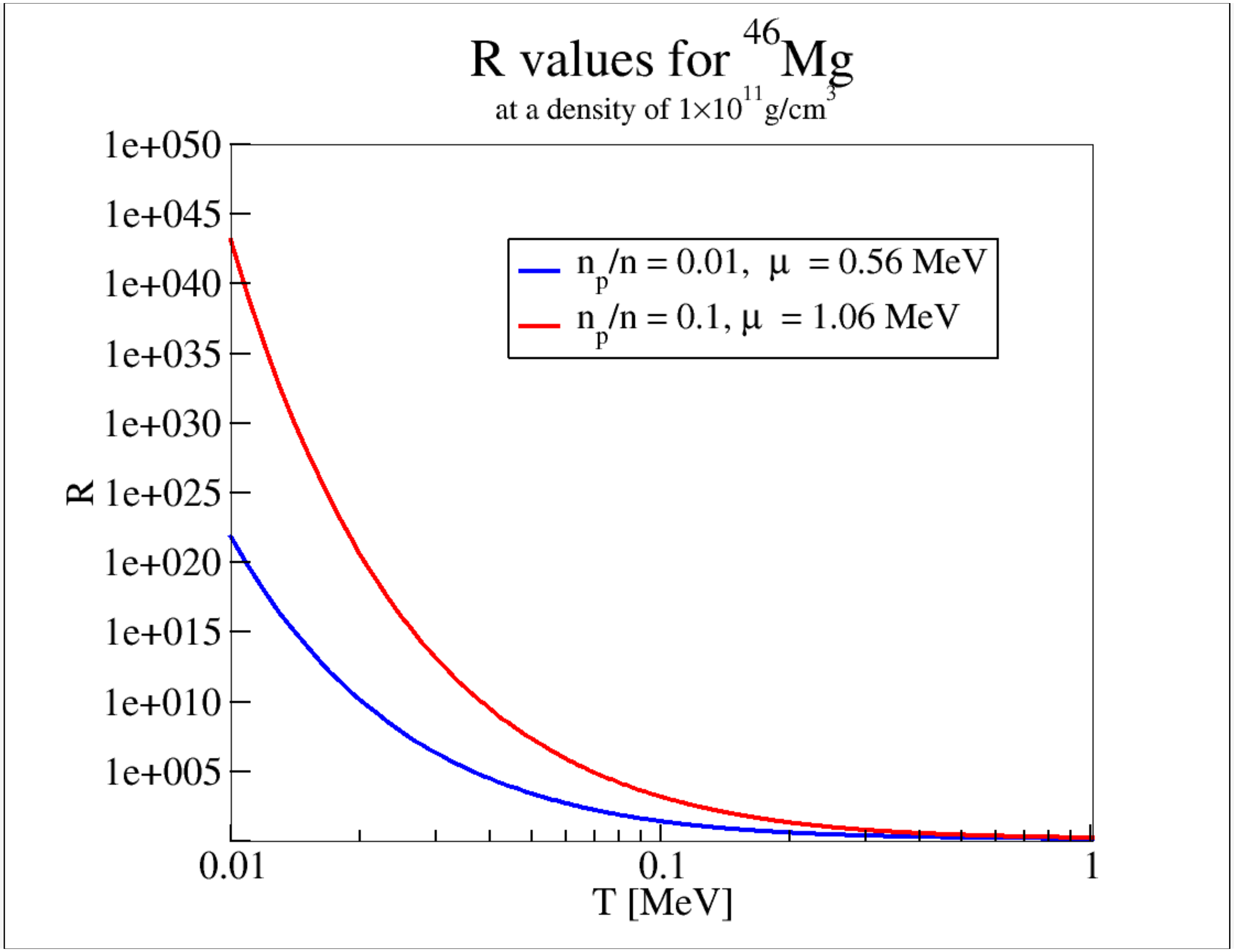
DEGENERACY CORRECTION

- Currently all simulations use Maxwell-Boltzmann distributions

- Degeneracy is accounted for with Fermi-Dirac distribution.

$$R=\langle \sigma v \rangle_{FD} / \langle \sigma v \rangle_{MB}$$

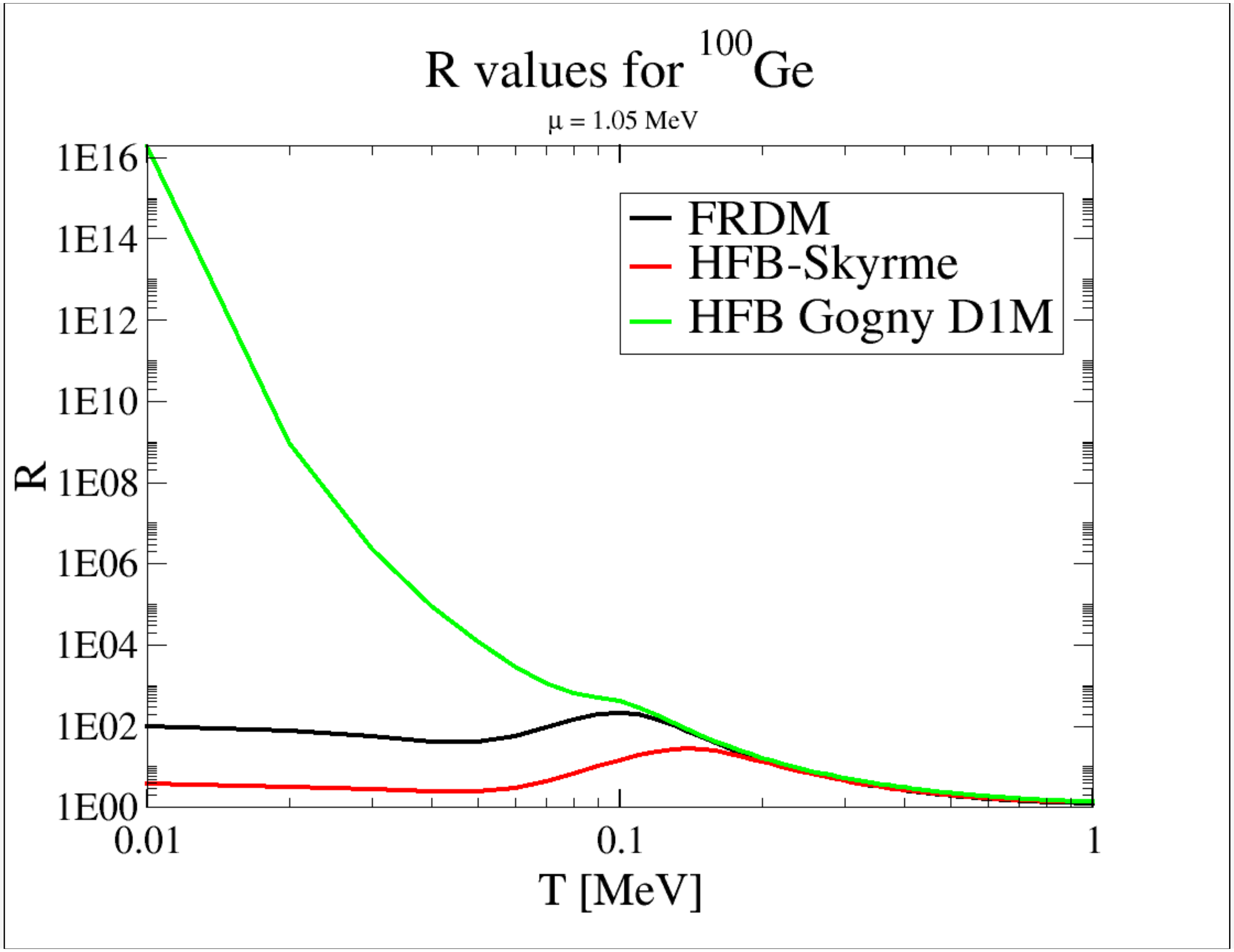

R values for 57Fe
at a density of 1×10^11 g/cm^3
R
0.2
0.4
0.6
0.8
1
0.01
0.1
1
T [MeV]
Free, μ = 0.58 MeV
n_p/n = 0.01, μ = 0.56 MeV
n_p/n = 0.05, μ = 0.73 MeV
n_p/n = 0.1, μ = 1.06 MeV



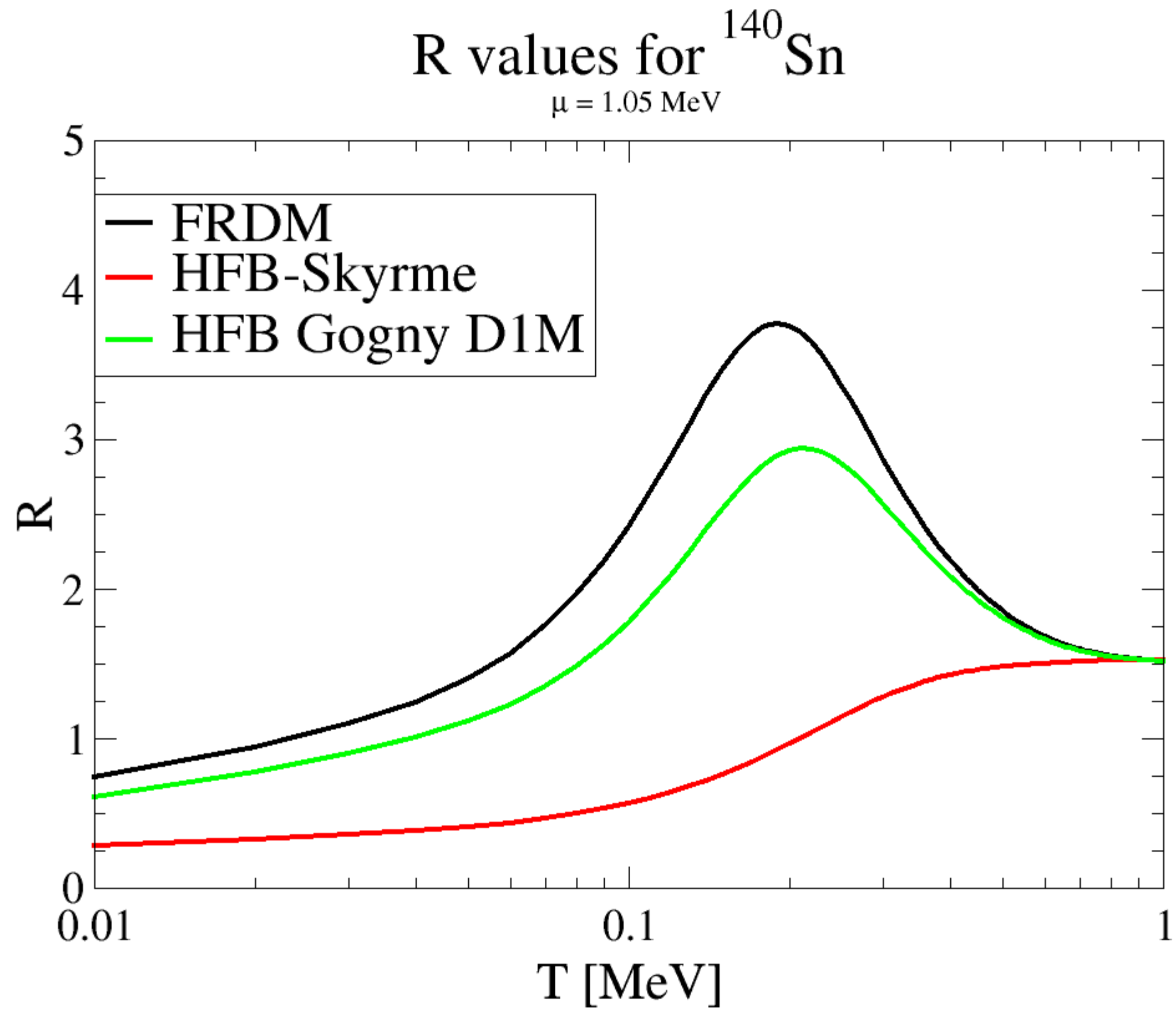
R values for ^{46}Mg
at a density of 1×10^{11} g/cm^3
1e+050
1e+045
1e+040
1e+035
1e+030
1e+025
1e+020
1e+015
1e+010
1e+005
R
0.01
0.1
1
T [MeV]
$n_p/n = 0.01$, $\mu = 0.56$ MeV
$n_p/n = 0.1$, $\mu = 1.06$ MeV

DIFFERENT MODELS AND NEUTRON DEGENERACY

- As target nuclei become neutron rich, Cross sections must rely on theoretical models. Investigate 3 mass models
- 1) Mollers mass tables (FRDM)
- 2) HFB-Skyrme
- 3) HFB-Gogny D1M



R values for ^{100}Ge
μ = 1.05 MeV
FRDM
HFB-Skyrme
HFB Gogny D1M
R
1E16
1E14
1E12
1E10
1E08
1E06
1E04
1E02
1E00
0.01
0.1
1
T [MeV]



R values for 140Sn
μ = 1.05 MeV
FRDM
HFB-Skyrme
HFB Gogny D1M
R
T [MeV]
0
1
2
3
4
5
0.01
0.1
1

CONCLUSION AND FURTHER RESEARCH

- Need for degeneracy corrections at low temperature, especially for ashes.

- Must be careful in selecting the mass model for neutron rich nuclei

- Further work will include excited states into capture rate calculation

THANK YOU!