

原子核物理でつむぐrプロセス

-おわりに-

吉田 賢市

# 進む重力波観測

久徳

週に1個どころかこのところ1日1個ペース  
5/17, 5/18, 5/19, 5/21に2つ (FARは1年1個以下)

GraceDB – Gravitational Wave Candidate Event Database

UID	Labels	t_start	t_0	t_end	FAR (Hz)	UTC Created
<a href="#">S190521r</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242459856.453418	1242459857.460739	1242459858.642090	3.168e-10	2019-05-21 07:44:22 UTC
<a href="#">S190521g</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242442966.447266	1242442967.606934	1242442968.888184	3.801e-09	2019-05-21 03:02:49 UTC
<a href="#">S190519bj</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242315361.378873	1242315362.655762	1242315363.676270	5.702e-09	2019-05-19 15:36:04 UTC
<a href="#">S190518bb</a>	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242242376.474609	1242242377.474609	1242242380.922655	1.004e-08	2019-05-18 19:19:39 UTC
<a href="#">S190517h</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242107476.819517	1242107479.994141	1242107480.994141	2.373e-09	2019-05-17 05:51:23 UTC
<a href="#">S190513bm</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241816085.736106	1241816086.869141	1241816087.869141	3.734e-13	2019-05-13 20:54:48 UTC
<a href="#">S190512at</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241719651.411441	1241719652.416286	1241719653.518066	1.901e-09	2019-05-12 18:07:42 UTC
<a href="#">S190510g</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241492396.291636	1241492397.291636	1241492398.293185	8.834e-09	2019-05-10 03:00:03 UTC
<a href="#">S190503bf</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1240944861.288574	1240944862.412598	1240944863.422852	1.636e-09	2019-05-03 18:54:26 UTC
<a href="#">S190426c</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1240327332.331668	1240327333.348145	1240327334.353516	1.947e-08	2019-04-26 15:22:15 UTC
<a href="#">S190425z</a>	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1240215502.011549	1240215503.011549	1240215504.018242	4.538e-13	2019-04-25 08:18:26 UTC
<a href="#">S190421br</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239917953.250977	1239917954.409180	1239917955.409180	1.489e-08	2019-04-21 21:39:16 UTC
<a href="#">S190412m</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239082261.146717	1239082262.222168	1239082263.229492	1.683e-27	2019-04-12 05:31:03 UTC
<a href="#">S190408an</a>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1238782699.268296	1238782700.287958	1238782701.359863	2.811e-18	2019-04-08 18:18:27 UTC
<a href="#">S190405at</a>	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1238515307.863646	1238515308.863646	1238515309.863646	2.141e-04	2019-04-05 16:01:56 UTC



2019/5/22

原子核物理でつむぐrプロセス

5

中性子星関連イベントも複数か

原子核の情報

状態方程式

rプロセス

kilonova/macronova

木坂

engine-powered macronova

藤本

isomer for light-curve

# 銀河の化学進化の理解

本田  
平居  
山崎

観測と銀河形成シミュレーション

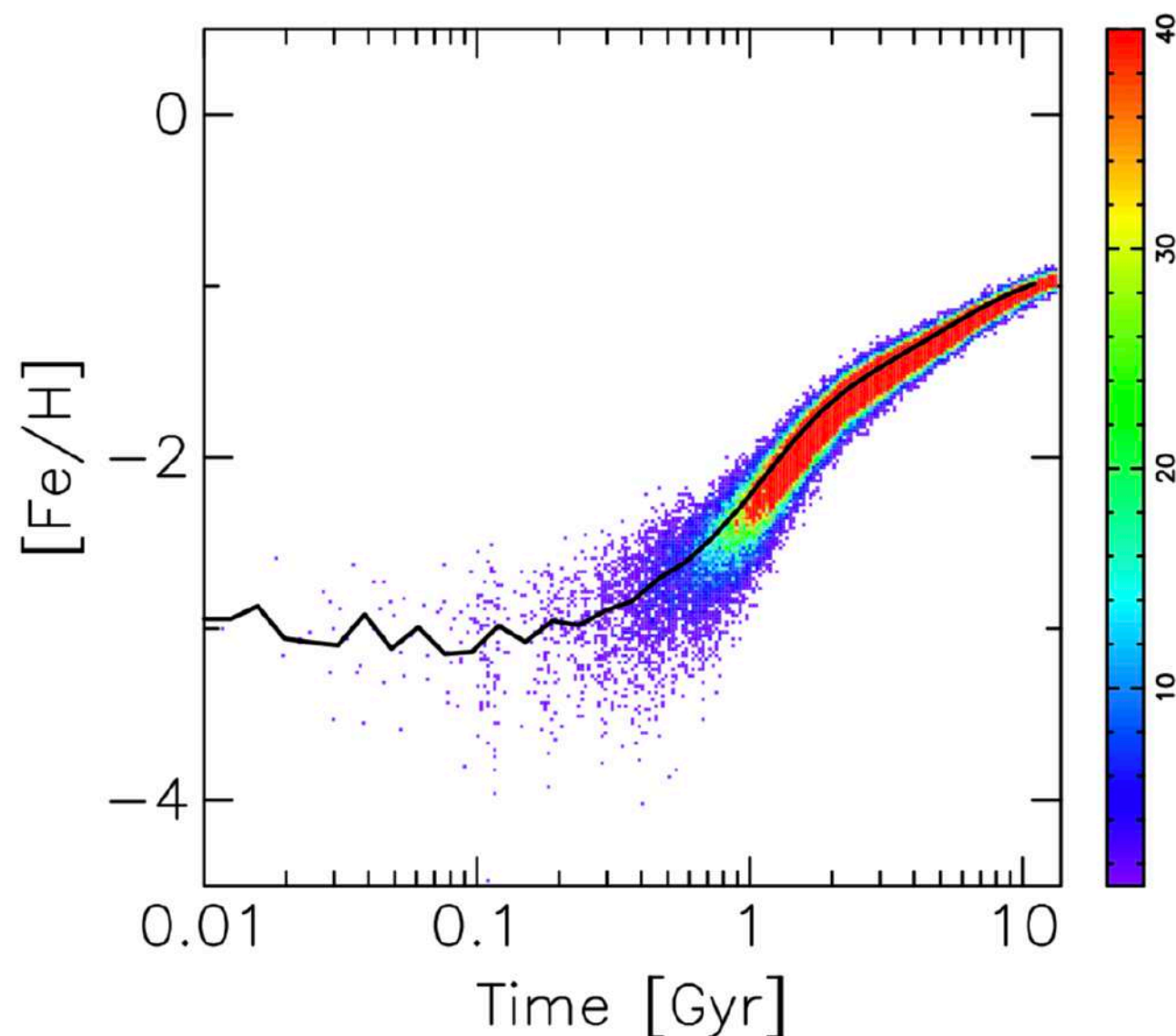
Hirai *et al.* (2015)

実証的研究

rプロセスの起源

超新星爆発

連星中性子星合体



# 進む数値相対論研究

rプロセスの初期条件

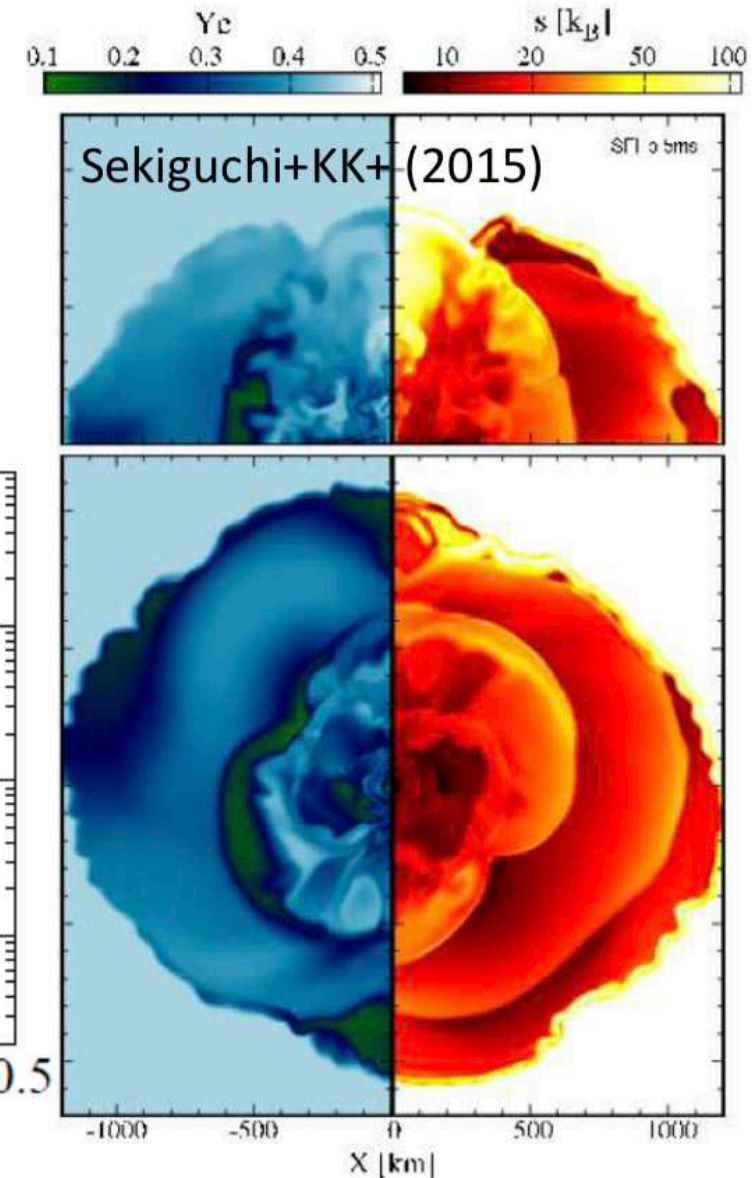
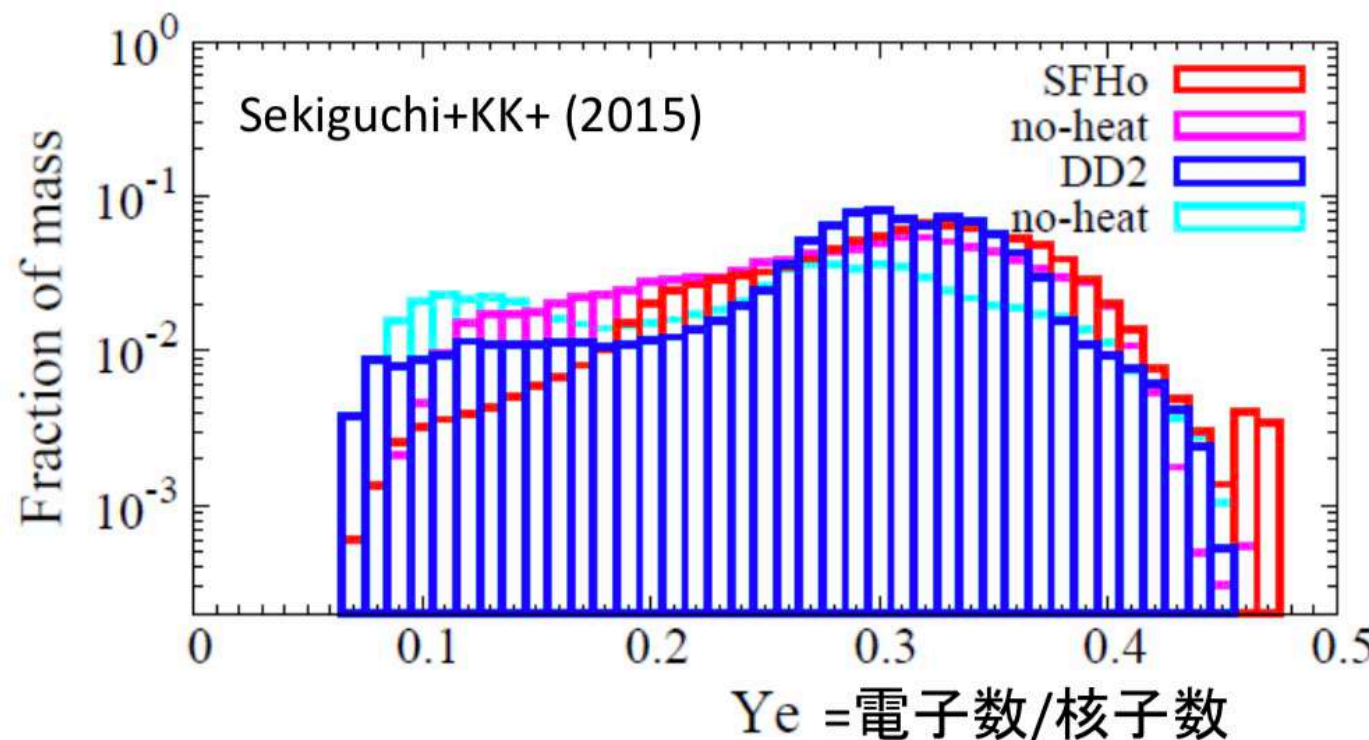
dynamical/viscous ejecta

多くの核種が関与

↔ SNe

## 力学的質量放出

幅広い中性子過剰度の物質が  
合体時の衝撃波や潮汐力で  
太陽質量の~1%が飛ばされる



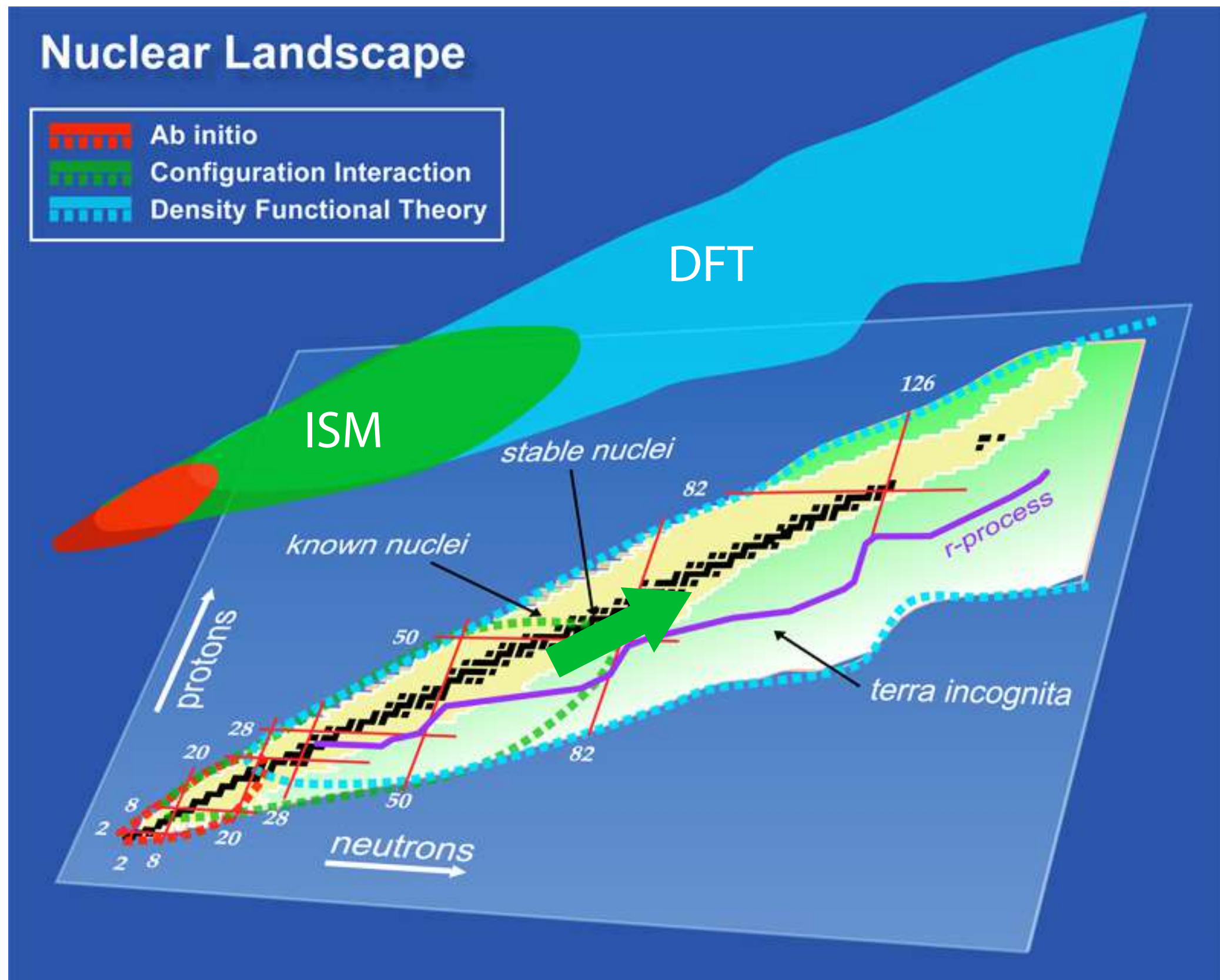
久徳  
関口





# 微視的立場から

核子の自由度からの量子多体問題





# Neutron-capture/dipole response

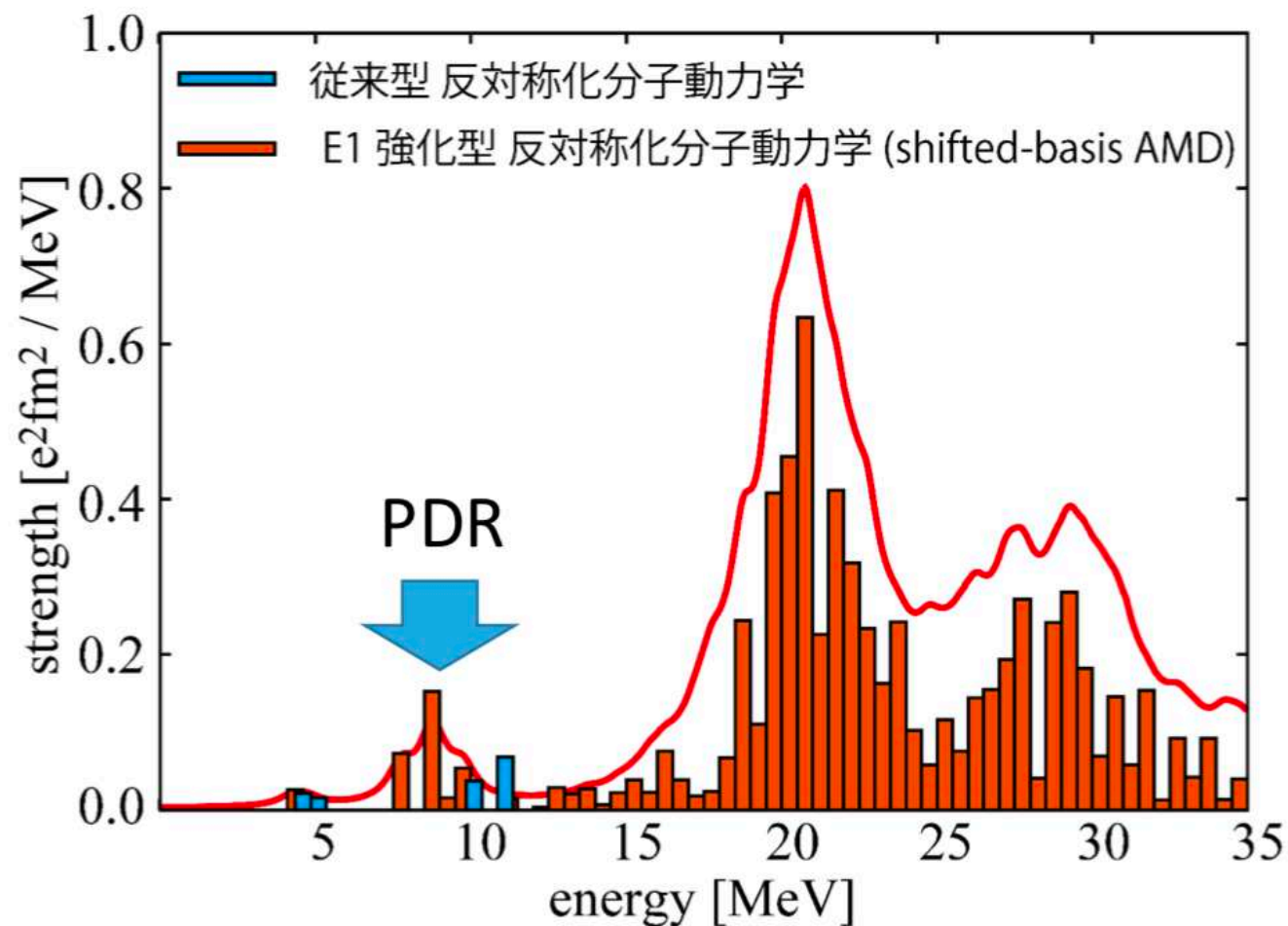
$$(\gamma, n) \Leftrightarrow (n, \gamma)$$

木村 クラスタ構造も記述できる微視的な理論

理論模型: 反対称化分子動力学によるE1共鳴の記述

◎  $^{26}\text{Ne}$ のPDRとGDR共に、記述可能  $\Rightarrow$  AMDでE1共鳴の研究が可能

◎ Gogny力を用いた他のQRPA計算と無矛盾な結果



# Neutron-capture/dipole response

$$(\gamma, n) \Leftrightarrow (n, \gamma)$$

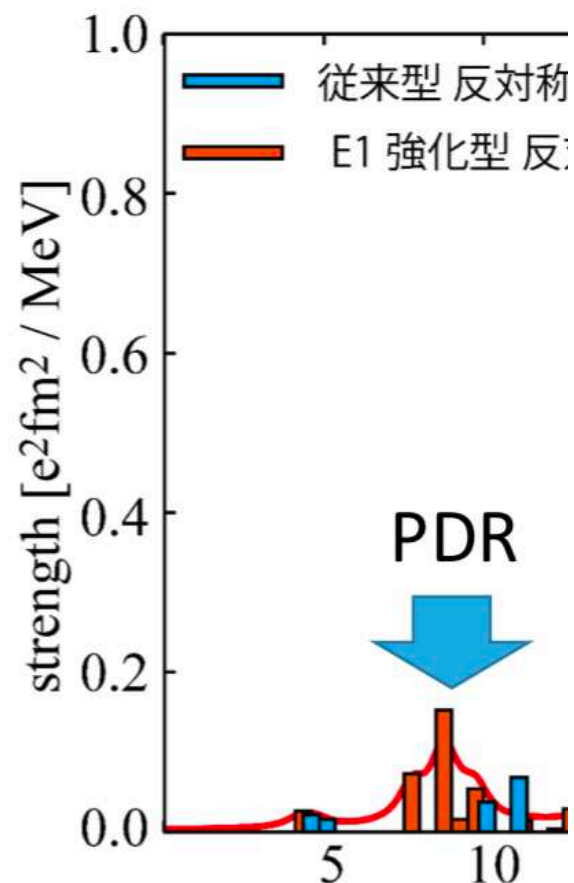
木村 クラスタ構造も記述できる微視的な理論

理論模型: 反対称化分子動力学によるE1共鳴の記述

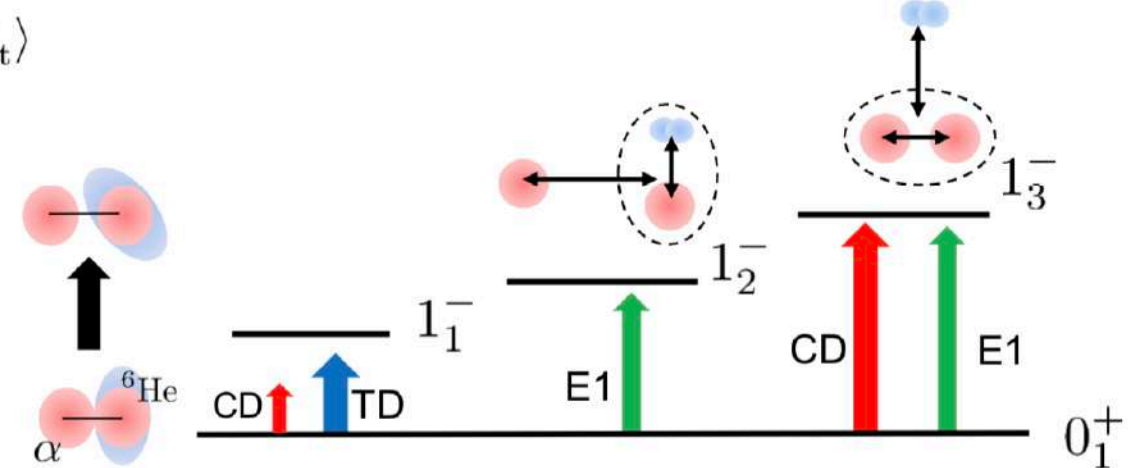
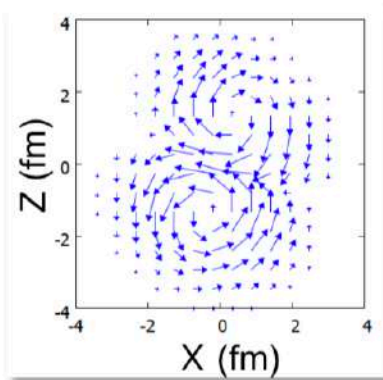
四方  
クラスターモード

## Excitation modes and Origin of strengths

- ◎  $^{26}\text{Ne}$ のPDRとGDR共に、記
- ◎ Gogny力を用いた他のQRI



$$\delta j(r) = \langle 1_{\text{int}}^- | j_{\text{nucl}}(r) | 0_{\text{int}}^+ \rangle$$

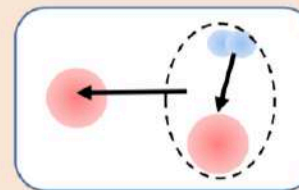


- ✓ 変形した $^{6}\text{He}$  clusterのvibrationによってvortical modeが生じる.
- ✓ わずかにCD強度を持つ.
- ✓ K=1 dominant.

E1・CD強度には二つのmodeが大きく寄与

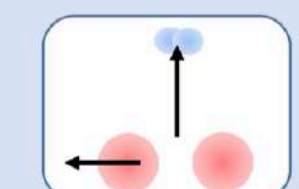


$1_2^-$  : 2つのmodeが逆位相で寄与



CD強度は打ち消し合い  
強いE1遷移のみ生じる

$1_3^-$  : 2つのmodeが同位相で寄与



E1・CD共に  
強い遷移が生じる

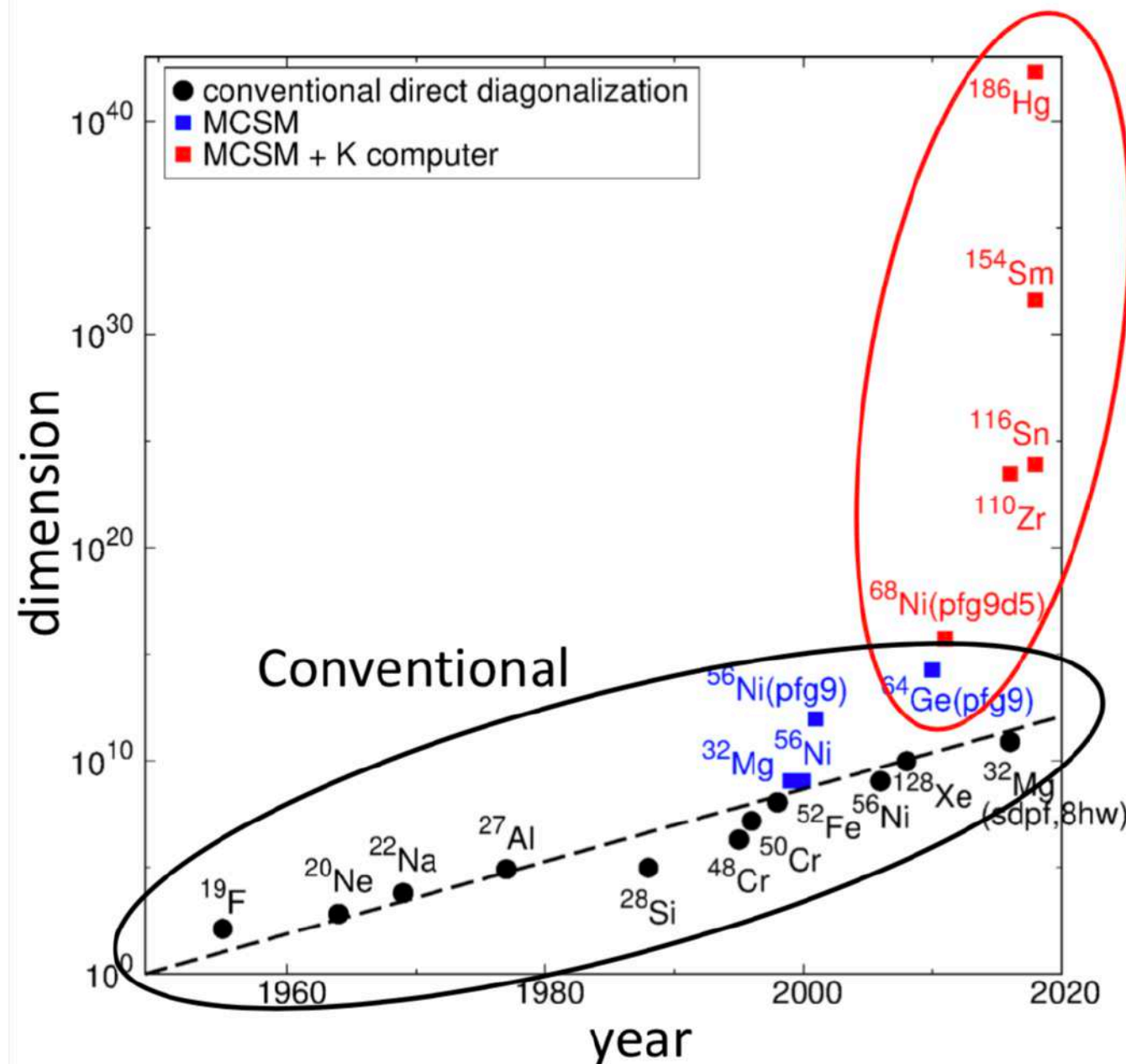


# ISMの進展

重い核のbeta-decay, E1 response

角田

## Monte Carlo shell model (MCSM)



Advanced MCSM

We can perform MCSM calculations in large model spaces. The largest case corresponds to  $\sim 10^{42}$

Dimension of Hamiltonian matrix for many-body states to be diagonalized in the conventional shell-model calculation

# DFTの進展

偶々核の基底状態



奇数核      加須屋

beta-decay      吉田

neutron-capture      松尾, 齊藤

spontaneous fission      鷺山

# DFTの進展

## DFT-based r-process nucleosynthesis in NSM

9/24

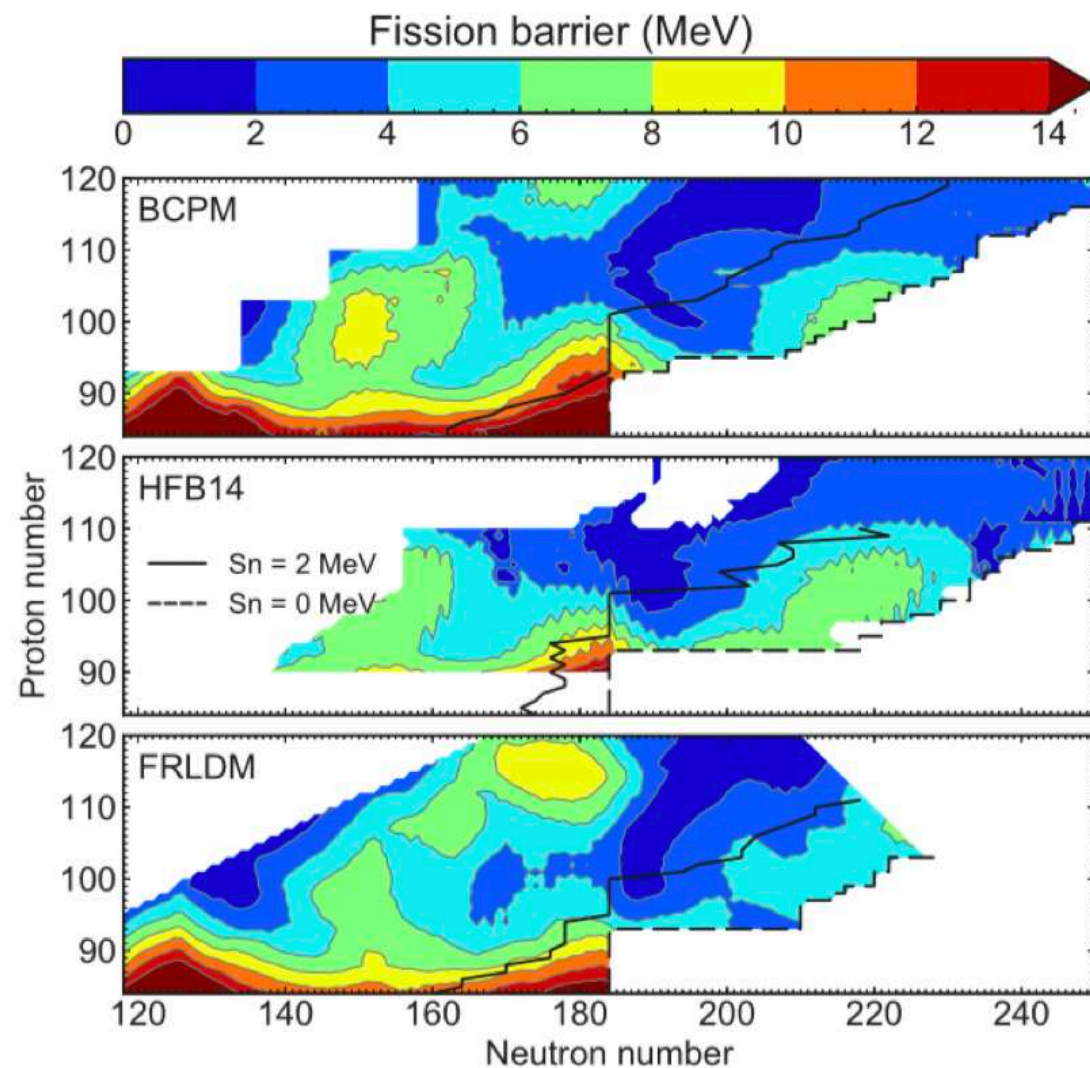
Fission properties of superheavy nuclei for  $r$ -process calculations Phys.Rev.C97,034323 (2018)

Samuel A. Giuliani,<sup>1,\*</sup> Gabriel Martínez-Pinedo,<sup>1,2,†</sup> and Luis M. Robledo<sup>3,‡</sup>

<sup>1</sup>Institut für Kernphysik (Theoriezentrum), Technische Universität Darmstadt, Schlossgartenstraße 2, 64289 Darmstadt, Germany

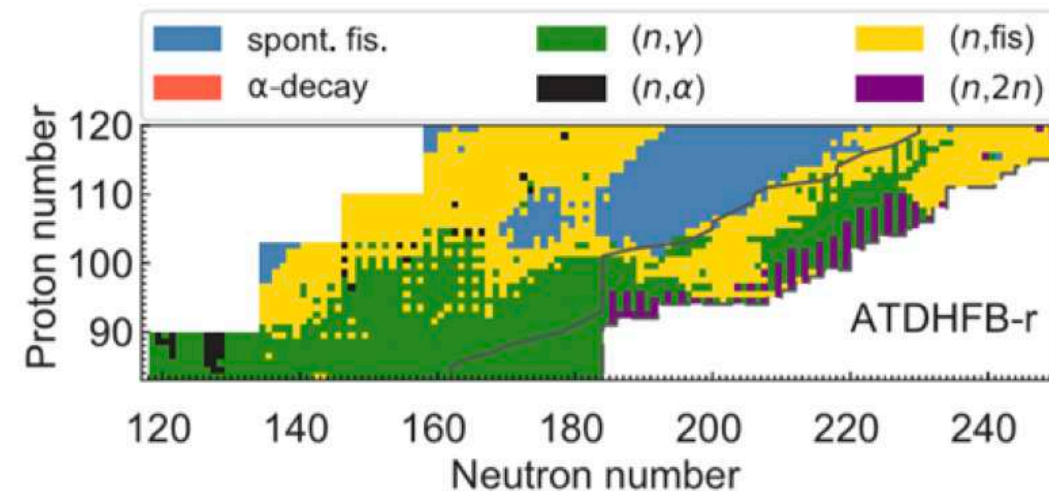
<sup>2</sup>GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

New BCPM EDF, Systematic calculations of fission  $\sim 3640$  nuclei



Potential energy surface  $V$   
Collective inertia  $M$

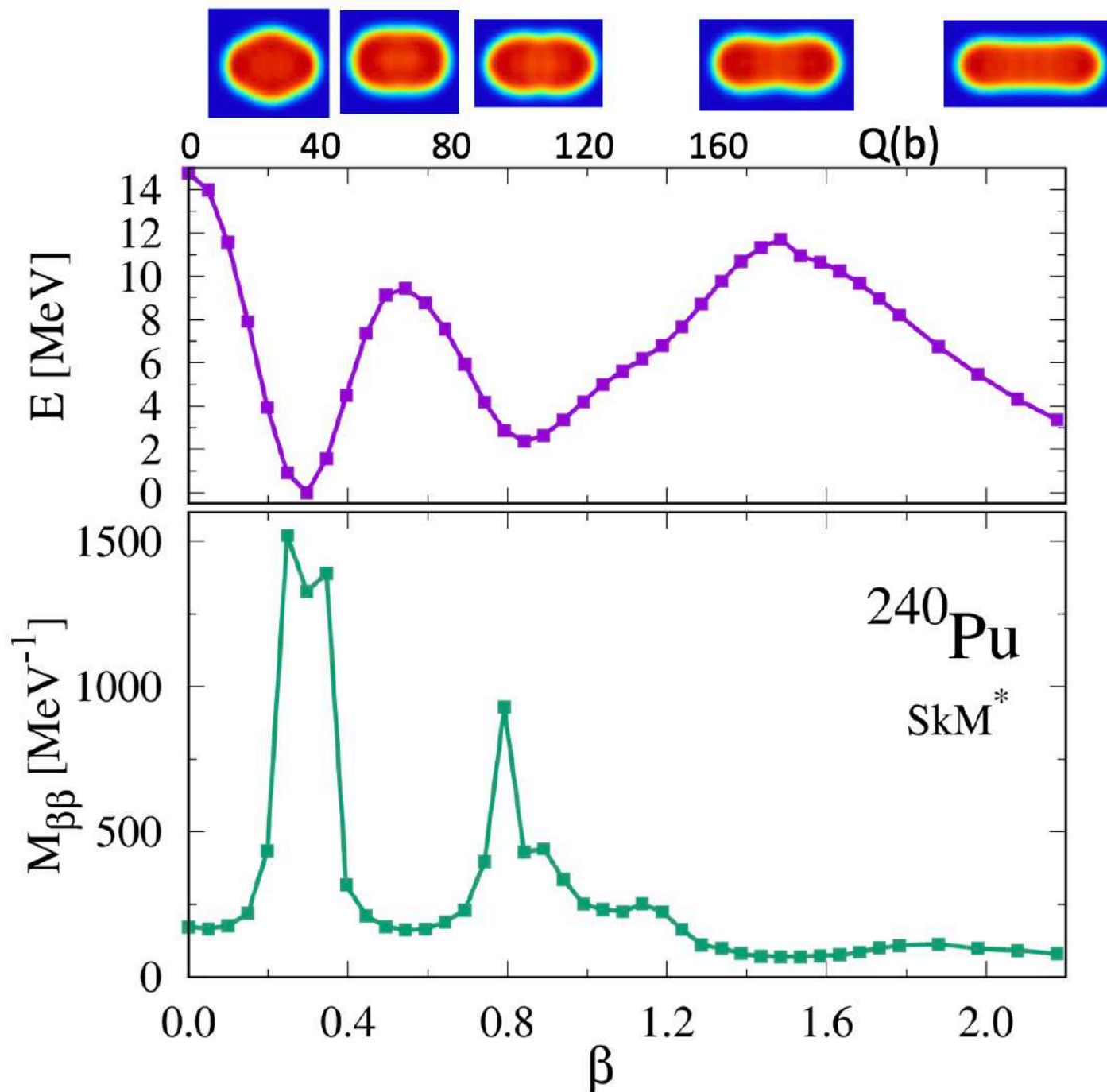
$$S = \int_{s_{\text{in}}}^{s_{\text{out}}} ds \sqrt{2\mathcal{M}(s)(V(s) - E)/\hbar^2}$$





# Result: Collective inertia along fission path

$^{240}\text{Pu}$  Fission barrier, collective inertia  $M_{\beta\beta}$



Large  $M_{\beta\beta}$  at g.s. & fission isomer

Small  $M_{\beta\beta}$  at large deformations

Sudden change of  $M_{\beta\beta}$  around potential minima

# 「核分裂は（特に）難しい」

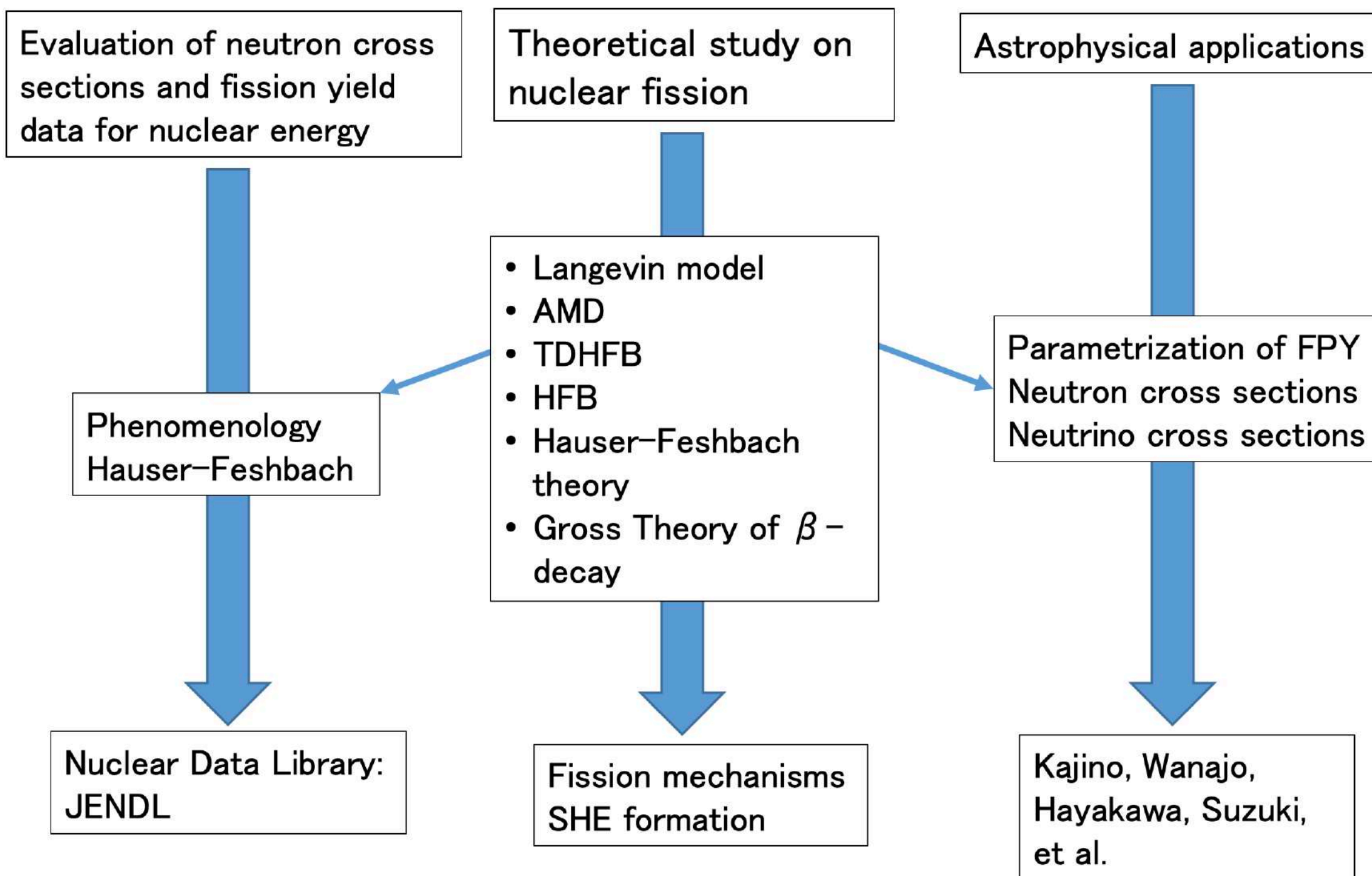
現象論的アプローチが必要

微視的＋現象論的も

天野，田中，石崎

千葉

## Fission study at Tokyo Tech.



# 「核分裂は（特に）難しい」

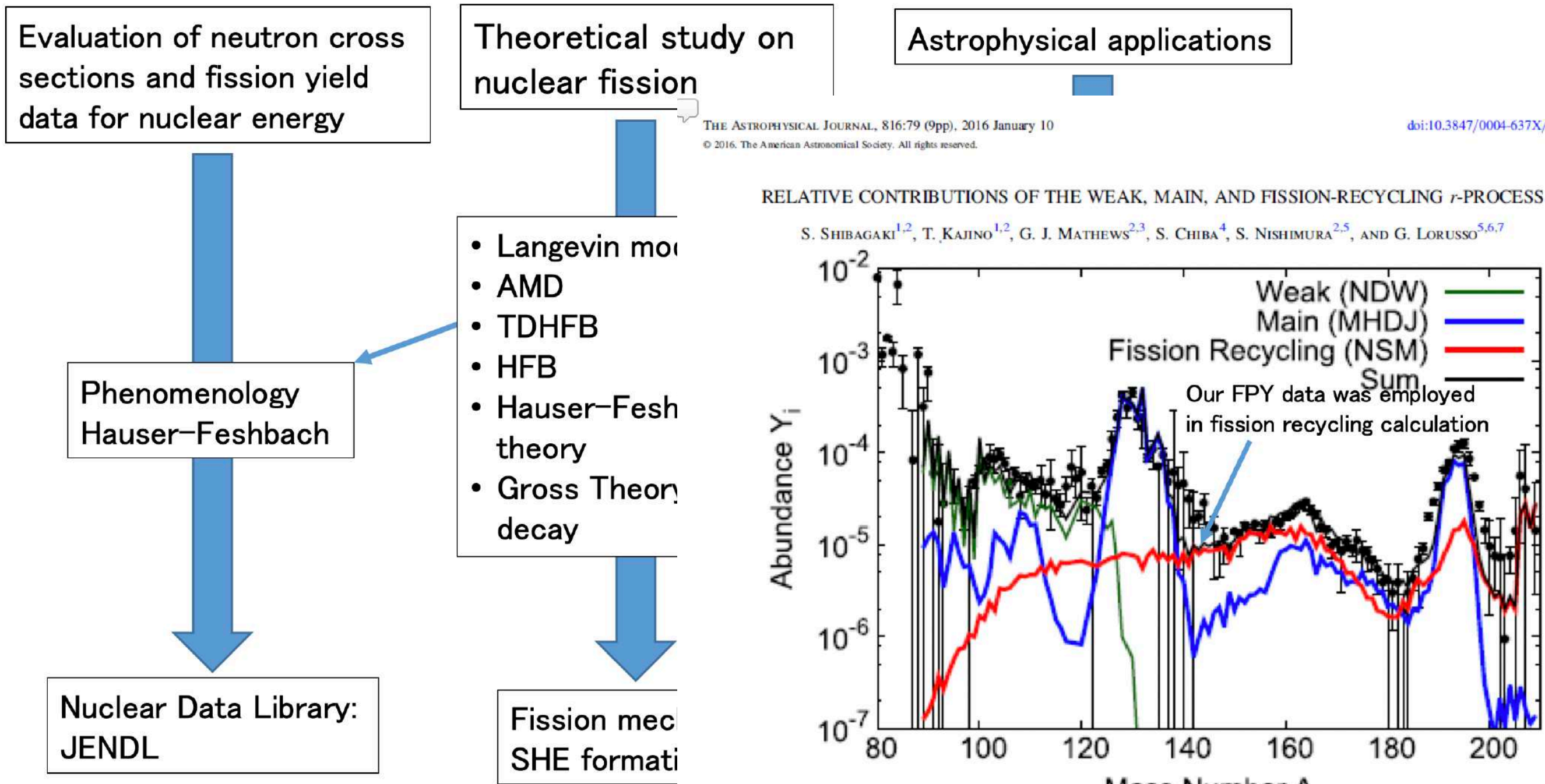
現象論的アプローチが必要

微視的 + 現象論的も

天野, 田中, 石崎

千葉

## Fission study at Tokyo Tech.

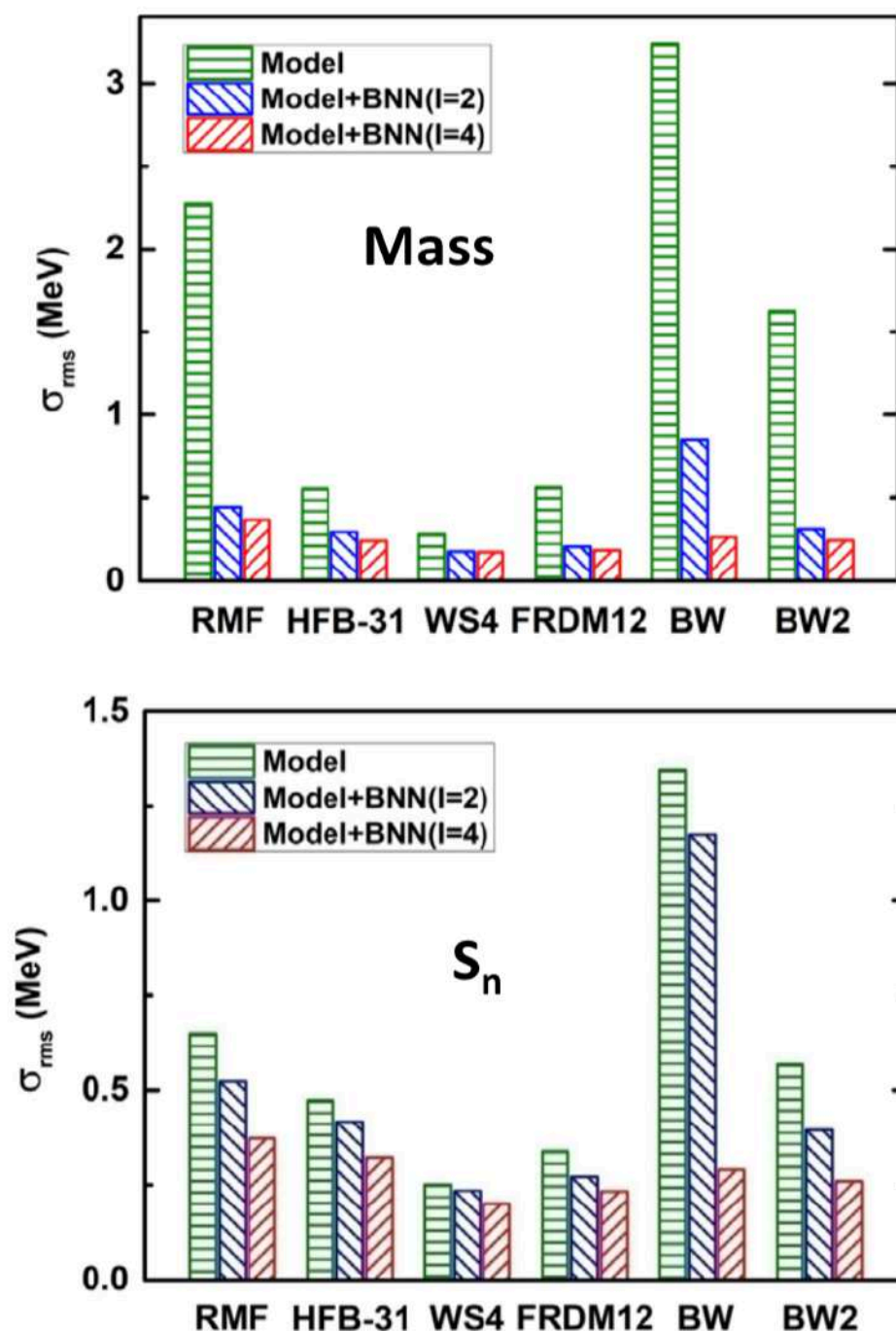




# 理論計算不定性の評価 Bayesian approach

Liang

## Rms deviations of mass and $S_n$



- The predictions of nuclear mass and neutron-separation energy are **significantly improved** with the BNN approach.
- After the improvement using the BNN approach with four inputs, the rms deviations are generally around **200 keV**.
- The BNN **with four inputs** is more powerful than the BNN with two inputs, especially for the neutron separation energy.

# 理論計算の不定性の評価

フロンティア領域での実験の定量的重要性

西村 (俊), 今井, 宮武

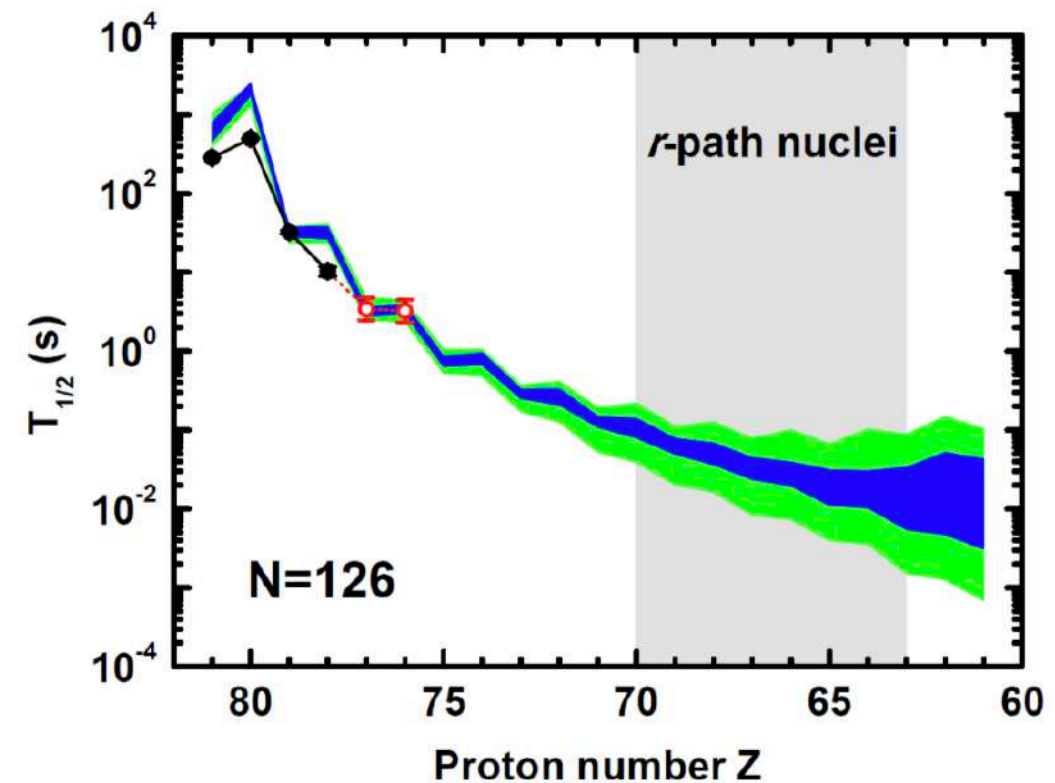
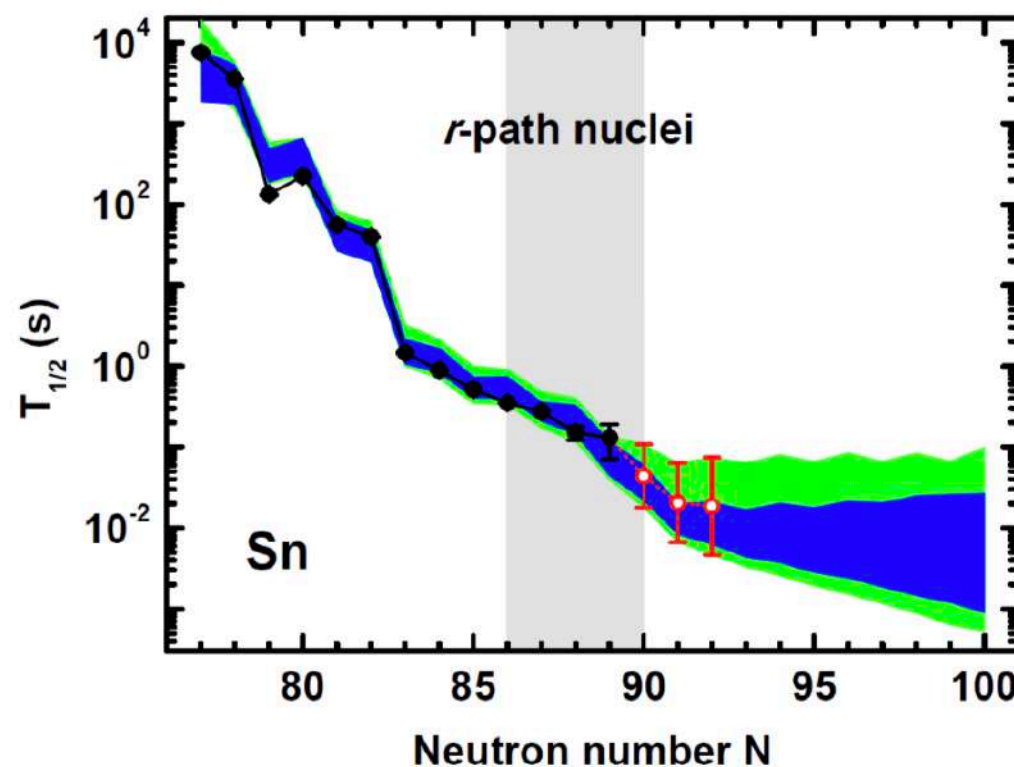
cf.

元素合成への不定性の伝搬

西村 (信)

Liang

## Predictions of nuclear half-lives



If we can further measure **three more  $\beta$ -decay half-lives** for each isotopes towards neutron-drip line

- the uncertainties of BNN predictions are similar in the training region
- they will **be decreased about 3 times** when extrapolate to the region far from known region.

# rプロセス

核物理の様々な現象の理解・記述が必要

## 複合科学

関与するすべての原子核の情報を実験的に得るのは不可能

理論への大きな期待（要求）

グループでの研究遂行

宇宙核理論の専門家＋共同研究

兼業理論屋の集まり

基研をうまく使いながらの緩い共同研究体制？

宇宙と原子核の定期的なコミュニケーション