平成３０年度

京都大学大学院理学研究科

# Ｄ３発表会アブストラクト

（平成３１年１月２１日）

物　理　学　第　二　分　野

# D3 発 表 会

日時　　平成31年1月21日(月) 9時～
場所　　理学研究科5号館 525号室
発表時間　15分＋5分(質問)

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《目　次》

9． The Gluon Wigner Distribution with the gluon saturation effects　萩原　慶一　（11:40）

午　後

10． Development of a high pressure Xe gas TPC for $0\nu\beta\beta$ decay search　潘　晟　（13:00）

11． 大質量星形成における輻射フィードバックの多次元効果　福島　肇　（13:20）

12． $^{16}$Oの$E0$遷移と$^{12}$C+$\alpha$クラスター構造　松野　秀昭　（13:40）

13． Quantum Entanglement, Fidelity Susceptibility, and Scrambling from AdS/CFT correspondence　宮地　真路　（14:00）

14． Gamow-Teller transitions in the light N=Z odd-odd nuclei　森田　皓之　（14:20）

15． Functional-renormalization-group aided density-functional theory
- ab-inito description of ground and excited states of quantum many-body systems -　横田　猛　（14:40）

# Gravitational Wave Emission from Rapidly Rotating Very Massive Stars

基礎物理学研究所　宇宙グループ　打田晴輝

**Abstract** We compute gravitational waves emitted by the collapse of a rotating very massive star (VMS) core leading directly to a black hole in axisymmetric numerical-relativity simulations. We find that gravitational waves will be one of the targets for the third-generation detectors such as Einstein Telescope.


Gravitational collapse induced by pair instability (PI) is one of the final fates of very massive stars (VMSs) with mass $\gtrsim 100 M_\odot$. Several observations suggest the existence of VMSs in the universe (e.g., [1]). However, their formation and evolution process are still highly unknown. It is suggested that when a rotating VMS collapses to a BH, strong gravitational waves would be emitted [2,3]. If the signal from this event can be observed, we can obtain the information about the internal structure of the VMS, which is considered to be of great use for understanding the nature of VMSs. Also, if the detected signal is from the Population III (PopIII) VMS, we can also obtain the information about the nature of the PopIII stars, which are closely related to the evolution of the universe. To study the observability and properties of gravitational waves from this event, we perform axisymmetric numerical relativity simulations of the gravitational collapse of a rotating PopIII VMS.

We select a progenitor star with the initial mass of $M_{\rm ZAMS}=320\ M_\odot$ (ZAMS: zero-age main sequence) and rotating rigidly with the rotation velocity of 50% of the Kepler rotation at its surface. One-dimensional (1D) stellar evolution calculation is performed from the ZAMS stage until the central temperature reaches $\sim 10^{9.2}$ K including the effects of hydrodynamical instabilities on the transport of angular momentum. At this stage, we map the resulting 1D stellar evolution model onto two-dimensional (2D) grids for axisymmetric gravitational collapse simulations as an initial condition. To consider the cases where the angular velocity is decreased due to other additional angular momentum transport mechanisms, we simulate several rotation models for which the angular velocity is multiplied by a factor of 0.1-0.8.

We find that gravitational waves are composed of a short precursor and ringdown oscillation associated with the formed BH for all the models. The peak strain amplitude and the corresponding frequency of the axisymmetric mode of gravitational waves are $\sim 10^{-22}$ and $\approx$300-600Hz for an event at the distance of D=50Mpc. Such gravitational waves will be detectable only for $D \lesssim 10$Mpc by the second generation detectors, advanced LIGO, advanced VIRGO, and KAGRA, even if the designed sensitivities for these detectors are achieved. However, the third-generation detectors such as Einstein Telescope will be able to detect such gravitational waves for an event up to D~100Mpc.

**References**

[1] Crowther, P. A., et al., MNRAS, **458**, 624 (2016)
[2] M. Shibata et al., ApJ, **818**, 157 (2016)
[3] H. Uchida et al., ArXiv e-prints, 1809.10502 (2018)

# Model-independent study on the internal structure of exotic hadrons

基礎物理学研究所　原子核理論グループ　　神谷　有輝

**Abstract** To investigate the internal structure of exotic hadrons, we develop a method to distinguish the origin of an eigenstate from the positions of the poles and zeros of the scattering amplitude. Applying the method to $I = 0$ $\bar{K}N$-$\pi\Sigma$ amplitude, we discuss the structure of the $\Lambda(1405)$ baryon.


One of the most significant achievements in recent hadron physics is the discovery of many candidates of exotic hadron states, which are not assigned to the simple $q\bar{q}$ meson nor $qqq$ baryon. By identifying their internal structure and acquiring the knowledge of the favored quark configuration, the understanding of the non-perturbative region of the Quantum Chromo Dynamics (QCD) can be gradually deepened.

To identify a candidate of the exotics, we have to consider the various possible structures that are consistent with its quantum numbers. However, it is very difficult to distinguish which model description is the most appropriate to describe the internal structure of hadrons because of the model dependence. To avoid the theoretical uncertainty, we need to discuss the structure based on the quantities that can be uniquely determined from the experimental observables. As such quantities, the on-shell scattering amplitude of the two-body scattering is the fundamental physical quantity which has the abundant information on the eigenstate. Thus, by deriving the relation between the on-shell scattering amplitude and the structure of the eigenstate, we can develop the method to investigate the exotic hadron candidates without model dependence.

In this talk, we discuss the relation between the analytic structure of the scattering amplitude and the origin of an eigenstate. We introduce the zero coupling limit (ZCL) of the coupled-channel amplitude and we show that the origin of the eigenstate is distinguished from the behavior of the eigenstate pole in the ZCL. Based on the topological nature of the phase of the scattering amplitude, it is shown that if the eigenstate has the hidden channel origin, the pole must encounter with the Castillejo–Dalitz–Dyson (CDD) zero [1-2], which is defined as the zero of the scattering amplitude, in the ZCL. We show that the origin of the eigenstate can be distinguished by analyzing the positions of the poles and CDD zeros. As an application to the candidate of the exotic hadrons, we discuss the structure of the $\Lambda(1405)$ baryon. From the positions of the poles and zeros of the isospin $I = 0$ $\bar{K}N$-$\pi\Sigma$ amplitude, we conclude that the origin of the high-mass (low-mass) pole of the $\Lambda(1405)$ baryon is in the $\bar{K}N$ ($\pi\Sigma$) channel [3].

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[1] L. Castillejo, R. H. Dalitz, and F. J. Dyson, Phys. Rev. 101, 453 (1956).

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# Kinematics of Conformal Field Theory and Diagrams in AdS Space

素粒子論研究室　　京野秀紀

**Abstract** We discuss kinematic aspects of *d*-dimensional Euclidean conformal field theory and diagrams in (*d+1)*-dimensional Euclidean AdS space. Through an orthogonal basis called the conformal partial wave, conformal block decompositions of four-point functions and four-point diagrams are systematically obtained. We will show some examples and applications.


Conformal field theories (CFTs) appear in various places in theoretical physics, for example, string theory, critical phenomena, etc. In such theories, the *d*-dimensional Poincare symmetry is enhanced to the conformal symmetry which is described by $SO(1,d+1)$. Due to the enhanced symmetry, the dynamics of theories is strongly restricted. The attempt to constrain CFTs under some physical assumptions is called the conformal bootstrap. It is known that this approach works very well in two-dimensions in which the conformal symmetry is enhanced further to the Virasoro symmetry.

Recently, there are some developments in ($d>2$)-dimensional CFT. In CFT, the conformal symmetry restricts correlation functions, and two- and three-point functions are determined completely except for an overall constant. The first non-trivial quantities are four-point functions, and they are usually analyzed by expanding them in terms of building blocks called the conformal blocks. In [1], it is found that the conformal blocks are characterized as eigenfunctions of the conformal Casimir equation, and the explicit form of conformal block is derived. Based on this result, numerical approaches for conformal bootstrap are developed in this decade [2].

Another recently discussed concept is the conformal partial wave (CPW) introduced as an orthogonal basis for the eigenfunctions of the conformal Casimir equation. Thanks to the orthogonality, CPW gives us a systematic way to obtain the conformal block expansion of any four-point functions. This procedure is packaged as the so-called OPE inversion formula. This formula can also be applied to four-point diagrams in $(d+1)$-dimensional Euclidean AdS space, and then CPW is lifted to AdS space and can be interpreted as a bulk diagram. There, a harmonic function in AdS space plays an essential role, and we can see that the orthogonality of CPW comes from properties of the harmonic function. The application to AdS diagrams would be useful not only to investigate the AdS/CFT correspondence, but also as a technique to calculate CFT four-point functions.

In this talk, we introduce the inversion formula and see how the method works using some simple correlation function and AdS diagrams. We will also mention the crossing kernel which is the inner product between CPWs in different channels. Through the crossing kernel, for example, t-channel exchange diagrams or conformal blocks can be decomposed into s-channel CPWs. We will discuss the actual calculation of crossing kernel and possible applications to bootstrap approaches. This talk is based on my recent works [3-5].

**References**

[1] F. Dolan and H. Osborn, Nucl.Phys.B 628, 491 (2004).
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[5] H. Y. Chen and H. Kyono, in preparation.

# Weyl invariance of string theories in generalized supergravity backgrounds

素粒子論研究室　　坂本純一

**Abstract** A recent important progress of string theory is the discovery of generalized supergravity. Remarkably, the equations of motion can be reproduced from the requirement of the kappa-symmetry. However, the quantum consistency is not clear. In this talk, we discuss the Weyl invariance of a bosonic string in generalized supergravity backgrounds.


A recent important progress of string theory is the discovery of generalized supergravity [1,2]. The novel effective theory was originally discovered in the recent study of ingerable deformations of the $AdS_5 \times S^5$ superstring [1]. The characteristic feature of this theory is that the equations of motion contains a Killing vector field *I*. The Killing vector *I* generates the trace of the non-geometric *Q*-flux, so that many solutions of generalized supergravity can be regarded as *T*-folds [3].

The remarkable fact is that the equations of motion of generalized supergravity can be reproduced from the requirement of the kappa-symmetry in the Green-Swartz formalism. Originally, it is well known that the on-shell constraints of type II supergravity ensure the kappa-symmetry of the string sigma model in the Green-Swartz formulation [4,5]. Furthermore, it had been conjectured that the kappa-symmetry requires the type II supergravity equations. However, after about thirty years, Tseytlin and Wulff [2] had reproduced the equations of motion of type II generalized supergravity by solving the kappa-symmetry constraints on spacetime fields. In this way, an old fundamental problem of string theory had been resolved.

The kappa-symmetry is a local fermionic symmetry to obtain the correct fermionic on-shell degrees of freedom of the Green-Swartz superstring theory. Therefore, the Tseytlin-Wulff's result indicates the classical consistency of a string in generalized supergravity backgrounds. However, at the quantum level, it is not clear that string theory can be consistently defined on such backgrounds.

In this talk, we consider the Weyl invariance of bosonic string theory on generalized supergravity backgrounds. An important observation in [6] is that the Double Field Theory, a *T*-duality manifest formulation of the massless sector of string theory, can reproduce both the usual and generalized supergravity from a single action. By using this result, we construct a possible counterterm to cancel the Weyl anomaly of a bosonic string in generalized supergravity backgrounds [6]. This is a generalization of the Fradkin-Tseytlin term, and the modified term is characterized by the Killing vector *I* in the generalized supergravity equations. We further show that the counterterm is definitely local [7]. In this sense, the usual supergravity backgrounds and the generalized supergravity backgrounds can be treated on an equal footing in string theory.

**References**

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# $K_L \to \pi^0 \nu \nu$ 崩壊探索における背景事象の研究

高エネルギー研究室　　篠原智史

**Abstract** The KOTO experiment aims to observe the CP-violating rare decay, $K_L \to \pi^0 \nu\nu$, at J-PARC. We took data in 2016-2018 with a new barrel photon veto detector. We present the analysis status for the data including the neutron induced background with a large amount of control sample.


CP 対称性の破れは素粒子物理における標準理論の枠組みで説明される（小林・益川理論）。しかし、現在の物質優勢宇宙を説明するまでには至っておらず、標準理論を超えた新たな物理（新物理）の寄与が必要である。$K_L \to \pi^0 \nu \nu$ 崩壊は CP 対称性を直接破る崩壊モードで、標準理論で予測される崩壊分岐比は $3.0 \times 10^{-11}$ と非常に小さく、分岐比の理論的な不定性も 1%程度と小さく抑えられている［1］。このため、新物理が崩壊に寄与していた場合の変化を大きく捉えることが可能である。

KOTO 実験は $K_L \to \pi^0 \nu \nu$ 崩壊の探索を目的とした実験であり、茨城県東海村に位置する大強度陽子加速器施設（J-PARC）で行われている。KOTO 実験は 2013 年に物理ランを開始し実験感度 $1.3 \times 10^{-8}$ を達成した［2］。2015 年の物理ランでは 2013 年の実験感度を約 10 倍更新した結果を発表し［3］、 2016 年以降も 2017 年, 2018 年と物理ランを行って 2015 年物理ランの約 1.5 倍多いデータを取得している。

$K_L \to \pi^0 \nu \nu$ 崩壊の終状態は $\pi^0$ の崩壊による２つのγと観測されないνである。信号事象の同定は、２つのγを CsI カロリメータで検出し、その他には何も検出されないということを veto 検出器で全崩壊領域を覆い保証することで行う。

KOTO 実験における $K_L \to \pi^0 \nu \nu$ 崩壊探索の背景事象は、$K_L$ 崩壊由来と中性子反応由来の事象の２つに大別される。$K_L$ 由来の背景事象は、veto 可能なγが２つしかない $K_L \to 2\pi^0$ 崩壊の背景事象を抑えることが鍵である。この $K_L \to 2\pi^0$ 崩壊背景事象を 1/3 に削減するデザインの円筒型光子検出器(インナーバレル)が 2015 年の物理ラン後にインストールされ（Fig. 1)、2016 年以降の物理ランを行った。

中性子由来の背景事象は中性子が CsI カロリメータに入射し、反応を起こしてクラスターを生成後に再び中性子が放出され別のクラスターを生成することで背景事象となる。2015 年の物理解析では中性子背景事象を評価するためのコントロールサンプルの統計量が少ないことが問題になっていた。このため、2016, 2017, 2018 年の物理ランでは中性子コントロールサンプルを 2015 年解析の統計量の約 9 倍多く取得した。

本講演では上記の新しい円筒型光子検出器、中性子コントロールサンプルを用いて 2016, 2017, 2018 年以降に取得した物理データの背景事象の研究について報告する。

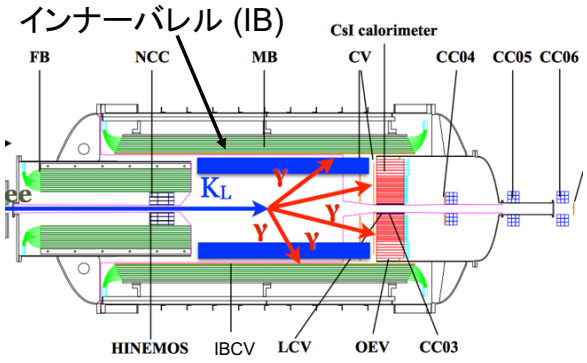


Fig. 1. Schematic view of KOTO detectors and new barrel photon veto detector (IB).

**References**

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# Phases of Supersymmetric Gauge Theories on the Three-Sphere

基礎物理学研究所素粒子論グループ　　清水数馬

**Abstract** Three-dimensional supersymmetric gauge theory has been studied and provided us many interesting results. This is mainly due to recent development of localization techniques. We found that results from a localization technique cannot be interpreted by following flat-space intuition and discussed them in relation to the flat-space point of view.


Three-dimensional supersymmetric gauge theory has been studied in various contexts such as understanding non-perturbative effects of gauge theories, which are necessary to understand strongly coupled theory represented by the low energy physics of the quantum chromodynamics (QCD). The recent development of localization techniques for supersymmetric field theory enables us to approach its non-perturbative aspects because for some quantities, the techniques reduce the path integral needed to calculate their expectation value to an ordinary finite-dimensional integral. As a result, many new and interesting results have been obtained. However, a localization technique usually requires a supersymmetric theory to be defined on a compact manifold to avoid infrared divergence. Therefore, the results from localization techniques should not be interpreted by following flat-space intuition, in particular, for non-conformal theory. However, there is little research which discusses results obtained from the localization methods for non-conformal theory in viewpoints mentioned above. In our recent works [1,2,3,4,5], we found that the results from a localization technique cannot be interpreted by directly following flat-space intuition and discussed them in relation to the flat-space point of view.

In this presentation, I would like to talk about my work [5]. In my work, we investigated the general behavior of the partition function in the infinite mass limit through considering mass-deformed supersymmetric QCD.　In the infinite limit, results obtained from a localization technique can be associated with those in flat space. Thus, we attempt to interpret the partition function in the flat-space language. In particular, mass-deformed supersymmetric QCD provides us to a simpler partition function and then, is suitable for achieving our goal. We found that in the infinite mass limit a point of the flat-space vacuum moduli space can dominantly contribute to the partition function and it corresponds to that of the effective theory at the point. This vacuum selection does not always agree with flat-space intuition. This result leads us to understand the problem that which flat-space supersymmetric vacua survive after coupling the curved background geometry and to shed lights understanding our previous results in [1,2,3], in which the partition function of a mass-deformed Chern-Simons theory (mass-deformed ABJM theory [6,7]) exhibits such a singular behavior in terms of the flat-space supersymmetric vacua,

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# MeV ガンマ線望遠鏡 ETCC 気球実験 SMILE-2+

宇宙線研究室　　竹村泰斗

**Abstract** We developed a new ETCC for SMILE-2+, which has the effective area of 0.5 $cm^2$ for 662 keV. We launched SMILE-2+ balloon on April, 2018 at Australia and observed Crab nebula during 5 hours. By the quick analysis, we obtained an excess of 4σ at the detection of Crab nebula.


MeV ガンマ線天文学は、核ガンマ線から元素プロセスの様相、遠方 GRB 観測により初代星の情報、炭素、酸素の励起ガンマ線観測により粒子加速の解明、など様々な宇宙・天体現象の情報が得られると期待されている。しかし、MeV ガンマ線天文学は、1991 年に打ち上げられた CGRO 衛星の COMPTEL[1]以降全天望遠鏡は存在せず、停滞しているのが現状である。この停滞は、宇宙線と衛星筐体の相互作用により発生する大量のバックグラウンドが取り除けないことや、既存の望遠鏡の Point Spread Function(PSF)が大きく広がっていることに起因している。そこで我々はこの問題を解決すべく電子飛跡検出型コンプトンカメラ(ETCC)[2,3]を開発している。ETCC は電子飛跡情報により到来ガンマ線の方向を一意に再構成する。これにより、既存の MeV ガンマ線望遠鏡では成しえなかった正確かつ 10 度程度の PSF(50% include @662 keV)を ETCC は有しており、この PSF により注目領域外からのバックグラウンドを 2 桁以上取り除く。

ETCC の MeV ガンマ線望遠鏡としての天体観測能力を実証すべく、sub-MeV において明るいかに星雲と銀河中心電子陽電子消滅線をターゲットとして 2018 年 4 月 7 日、豪州にて気球実験 SMILE-2+を実施した。しかし、従来の ETCC は 300 keV 以上のガンマ線に対して有効面積が急減し SMILE-2+には不適であった。SMILE-2+用の望遠鏡として、ガス領域から逃げ出す高エネルギー電子事象(escaped electron event)(図 1)を測定可能とする改良を加えた新しい ETCC の設計、作製、試験[4]を 2017 年に行った。SMILE-2+ ETCC は地上試験の結果、662 keV のガンマ線において有効面積~0.5 $cm^2$(図 2)、PSF ~15 度の観測要求を満たす値を示した。SMILE-2+気球は高度 39 km、約 26 時間水平浮遊し、浮遊時間のほとんどにおいて ETCC システムは健全に動作し、かに星雲を約 5 時間、銀河中心を約 8 時間観測することに成功した。その後 ETCC システムと観測データを無事回収した。かに星雲の初期解析の結果、200-400 keV において 4σの有意度を得た(図 3)。気球実験により得られたガンマ線計数率と、ETCC の地上試験から求めた性能値から推定した計数率は一致している。本発表では SMILE-2+ ETCC の地上試験と SMILE-2+フライト、かに星雲解析の初期成果について発表する。また、本発表における地上試験、かに星雲解析は従来解析 fully contained e- event のみを取り扱ったものである。

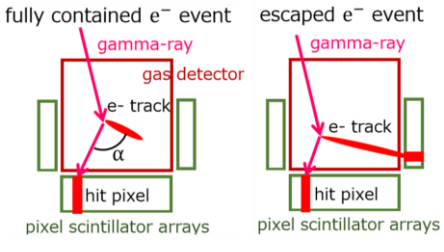


図 1 二つの解析手法

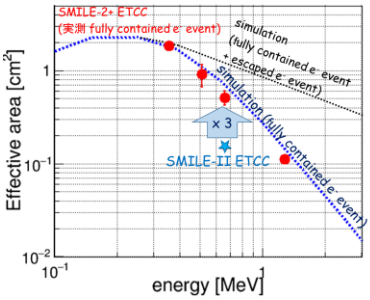


図 2 SMILE-2+ ETCC 有効面積

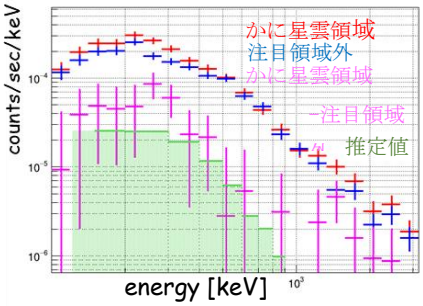


図 3 SMILE-2+気球実験により得られたかに星雲からのガンマ線の計数率

**References**

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# 宇宙重力波干渉計を用いた短周期連星パルサーの観測に向けて

天体核研究室　　西野裕基

**Abstract** We propose a strategy to detect radio pulses from a short-period Galactic neutron star binary. The Laser Interferometer Space Antenna has the potential to detect such a binary and could offer precise information on the sky position and binary parameters. These data could assist radio pulsar surveys significantly.


連星中性子星は2つの中性子星からなる連星で、我々の銀河系内でこれまでに10例以上が電波で検出されている。特に軌道周期が短い連星中性子星は、軌道運動に対する一般相対論的な効果を測定可能で、一般相対論の検証などに用いられてきた。これまでに発見されている最も短い軌道周期の連星中性子星はPSR J1946+2052の1.88時間であるが[1]、より短い軌道周期の連星を見つけることができれば重力理論への制限や中性子星の強い磁気圏同士の相互作用を調べる試金石となることが期待される。LIGO-Virgoの観測チームによって、この近傍の宇宙での連星中性子星合体率が、誤差は大きいものの、$1540\ \mathrm{Gpc^{-3}year^{-1}}$と推定されている[2]。我々の銀河系に相当する大きさの銀河が近傍宇宙に約$0.01\ \mathrm{Mpc^{-3}}$の密度で存在するという推定を用いれば[3]、1つの銀河あたり連星中性子星の合体率はおよそ$1.5\times10^{-4}\ \mathrm{year^{-1}}$と考えられる。これから銀河系内の連星中性子星の数を見積もると、軌道周期が10分以下の連星中性子星が0(10)程度は存在すると期待される。軌道周期が10分程度の連星中性子星はおよそ3ミリヘルツの重力波を放出する。これは2030年代の運用に向けて計画中の宇宙重力波干渉計The Laser Interferometer Space Antenna (LISA)で主な観測対象となる周波数帯でもある。例えば、地球から10 kpc離れた1.4-1.4太陽質量の連星中性子星ならば、2年間の観測でLISAは信号雑音比200程度で重力波を検出する能力を有する予定である。このような高い信号雑音比で観測すれば、連星の方向や連星パラメータを極めて精度よく決定することが可能である。連星中性子星の形成過程を考慮すると、これらの連星の一方は磁場が弱く電波放出の活動性も穏やかであるのみならずビーミング率が高いパルサーである可能性が高いため、電波望遠鏡による観測も期待できる。

そこで、LISAを用いて短周期パルサーを発見する戦略について議論する[4]。まず、LISAの重力波解析で連星の方向がわかれば、全天探査と比べ必要な観測時間を大幅に減らすことができる。それだけではなく、短周期連星の電波パルスはDoppler効果による不鮮明化のために信号雑音比が下がってしまうことが考えられる。LISAによる軌道運動の位相の情報を用いることで、電波パルスの変調を補正しコヒーレントに足し上げることが可能となる。そのため、これまでに発見できなかったような暗いパルサーであっても高い信号雑音比で電波パルスを検出できるようになる。LISAと同時期に運用される可能性が高いSquare Kilometer Array (SKA)はアンテナ面積が100万平方メートルにも達する世界最高性能の電波干渉計となる予定である[5]。LISAの情報を最大限に利用してSKAでパルサー探査を行うことで、銀河系内にある軌道周期が10分以下の連星中性子星を発見できると期待できる。

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# The Gluon Wigner Distribution with the gluon saturation effects

Nuclear Theory Group Yoshikazu Hagiwara

**Abstract** We investigate the gluon phase space distribution, called the gluon Wigner distribution, of the nucleon/nucleus at small Björken x. We also show how to access the gluon Wigner distribution from measurements.


To understand the detailed structure of the nucleon, it is strongly required to investigate the multi-dimensional parton distribution functions. Recently, the Wigner functions, which are phase space distribution functions of the parton depending on both position and momentum, have been studied. These Wigner functions are called the generating functions of the parton distribution functions because all the parton distribution functions are obtained by integrating or fixing the parameters in the Wigner function.

In high energy scattering, it is often the case that the Björken variable x is small. In the small x region, the number of gluons is large, and the interior of the nucleon/nucleus is filled with the gluons. In this situation, the effects of the recombination process of gluons cannot be negligible and the number of gluons becomes saturated inside the nucleon/nucleus. This phenomenon is called gluon saturation. It is possible to incorporate the gluon saturation effects into the scattering amplitude by solving the rapidity evolution equation, called the Balitsky-Kovchegov equation (BK equation) or B-JIMWLK equation. Then it is important and urgent tasks to know the small-x behavior of multi-dimensional parton distribution functions.

It has been shown that a Wigner distribution can be described by quark and anti-quark pair(dipole)-nucleon scattering amplitudes. To obtain the Wigner distribution, we need to solve the impact parameter dependent BK equation. We have found that we can regard the BK equation as an equation with only one variable, incorporating the SO(3) symmetry of the BK equation, and we can have accurate solutions. We have evaluated the dipole Wigner distribution using these solutions and investigated its properties [1]. As a result of my calculation, we confirmed that these functions have a positive peak at the momentum characteristic of gluon saturation physics.

In what kind of scattering process are the Wigner distributions obtained? It has been suggested that the Wigner distributions can be obtained approximately from the di-jet production in deep inelastic scattering of the nucleon so far. We have shown that the Wigner distribution can be constructed from the scattering cross section of the ultra-peripheral diffractive di-jet production [2]. The momentum transfer is very small in this scattering process, so it is possible to establish a one to one correspondence between the cross section and the Wigner distribution. This can be studied at the LHC.

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# Development of a high pressure Xe gas TPC for Ovββ decay search

高エネルギー物理学研究室　　潘 晟

**Abstract** We are developing a high-pressure Xe gas TPC for neutrinoless double beta decay search. Our detector has a unique cellular readout structure which uses electroluminescence light to detect ionization signals with high energy resolution. We developed a small size prototype detector and evaluated our detector concept. We are going to develop a large size prototype detector to get know-how of enlargement.



ニュートリノがマヨラナ性を持つか否かという問いは現代物理学に残されている重要な問いのひとつであり、物質優勢宇宙やニュートリノの質量起源を解明するための大きな鍵となっている[1][2]。ニュートリノのマヨラナ性を確かめられるほぼ唯一の手段がニュートリノレス二重ベータ崩壊の観測であるが、我々は高圧キセノンガスを用いた Time Projection Chamber(TPC)を用いてこれを探索することを目指している。セル化された検出面内で電離電子をエレクトロルミネッセンス光に変換して信号を読み出す機構が最大の特徴であり、これによって一次荷電粒子の飛跡再構成および高いエネルギー分解能でのエネルギー測定が可能となる。我々のエネルギー分解能の目標は $^{136}$Xe の二重ベータ崩壊の Q 値である 2.4 MeV で 0.5%(FWHM)である。また、高圧ガスを用いることで大質量の崩壊核を容易に達成できる。

現在、我々は試作検出器を用いた原理検証および性能評価を行っている。原理検証のための試作機として、検出領域：φ10cm×9cm の円柱体積を持つ小型 TPC を製作し運用および性能評価を行った。キセノンを 4 気圧および 8 気圧封入し、122 keV と 356 keV のガンマ線を照射して性能評価行った[3]。356 keV のピークに対しては、2.58%(FWHM)のエネルギー分解能を得た(Fig.1)。他のピークから得られたエネルギー分解能と組み合わせることで、Q 値に外挿して 0.8～1.7%(FWHM)@2.4 MeV のエネルギー分解能が達成できる見込みであることを示した。

また、大型化に向けた研究としてφ50cm×50cm 程度の大型試作機の開発を行っている。小型試作機では信号読み出し機構のセル間隔は 7.5mm ピッチであったが、大型化に伴ってピッチの拡大を試みた。初めに 13mm ピッチのセルの読み出し機構を製作し、小型試作機を用いてテストを行った。13mm ピッチでは十分な性能を示すことができなかったが、得られたデータと詳細なシミュレーションを比較することで検出器の理解を深めることに成功した(Fig.2)。この結果を元にピッチの最適化を行った。

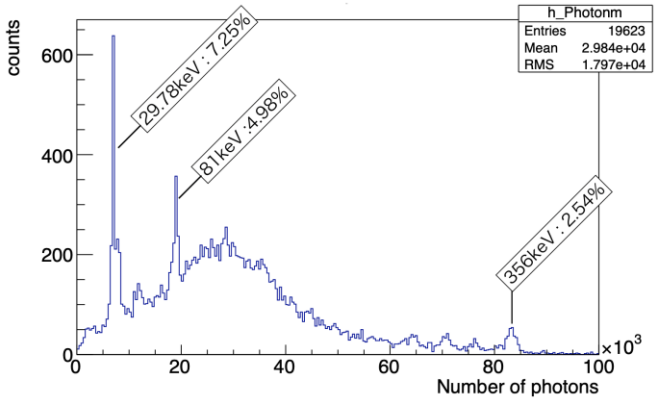


Fig.1 Spectrum of number of photons.

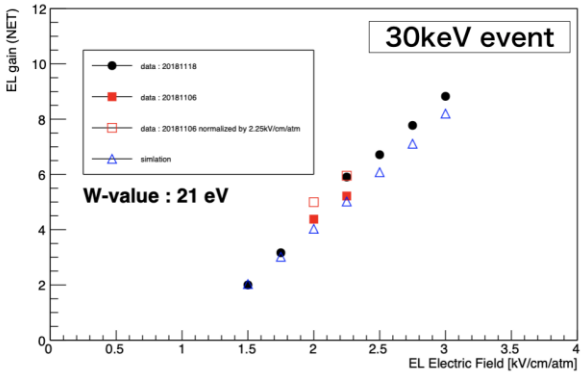


Fig.2 EL gain (NET) : data and simulation

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# 大質量星形成における
# 輻射フィードバックの多次元効果

天体核研究室　　福島　肇

**Abstract** We performed 2D radiation-hydrodynamics simulations for massive star formation. We find that low-metal stars are more massive than solar metal stars in the cases with spherically symmetric accretions or accretion rates larger than $4\times10^{-3}$ $M_\odot yr^{-1}$.


大質量星形成では、原始星質量増加に伴い光度も大きくなり、輻射フィードバックが質量降着に影響を与える可能性がある。銀河系における大質量星形成では、ダスト粒子が受ける輻射圧により質量降着が抑制される[1, 2]。一方、初代星形成では、ガス中にダスト粒子が含まれないため、HII 領域形成で生じる圧力差により質量降着が抑制される(UV フィードバック)[3, 4]。これらの中間金属量を持つ低金属量星については、どちらの輻射フィードバックが支配的であるか知られていなかった。また、大質量星質量の金属量依存性についても議論が続いている段階である。

本研究では、輻射圧および UV フィードバックの両方を含みかつ金属量依存性まで考慮した 2 次元輻射流体コードを開発した。このコードは、公開コードである「PLUTO」に非平衡化学、輻射輸送、星進化やα粘性を加えたコードとなっている。得られた各雲質量に対する星形成効率は下図に示す。最初に、雲質量が $250M_\odot$の場合において、1 次元球対称計算を行った。金属量が $1Z_\odot$の場合には、輻射圧により原始星質量が $30M_\odot$で質量降着が止められてしまう。一方、金属量が $10^{-2}Z_\odot$の場合には、フィードバックは有効とならず、大部分のガスは落下する。２次元計算では、原始星周囲に降着円盤が形成される効果により、$1Z_\odot$において星は $150M_\odot$とより大質量となる。逆に、$10^{-2}Z_\odot$では 160 $M_\odot$と UV フィードバックの強度は弱まり、太陽金属量の場合とほぼ同程度の質量をもつ星が形成される。また、雲質量の増加について、500, $10^3M_\odot$の場合に計算を行った。$1Z_\odot$の場合には星形成効率は図に示すように 0.5 と一定であるが、$10^{-2}Z_\odot$の場合には星質量の増加に伴い星形成効率も増加している。これは、降着率が $4\times10^{-3}$ $M_\odot yr^{-1}$を超えることで、原始星半径の膨張・有効温度の低下が起こり、UV フィードバックが弱くなるためである。本研究により、高降着率や球対称に近い降着を伴う星形成では UV フィードバックの影響が小さくなるため、低金属量星形成ではより大質量星が形成されることがわかった。

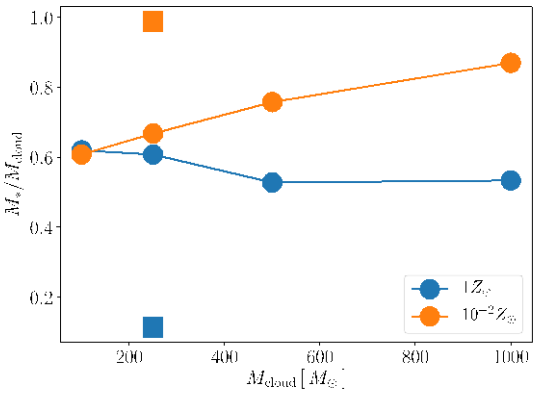


Fig 1. The star formation efficiencies for various cloud masses.
Circles and Squares correspond to 1D and 2D simulations.

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# $^{16}$O の $E0$ 遷移と $^{12}$C+αクラスター構造

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**Abstract** In $^{16}$O, the $0^+$ energy levels and the $E0$ transition matrix elements from the ground state are investigated. The $E0$ transition is found out to be sensitive to the intrinsic spin structure and weak coupling structure of $^{12}$C+α cluster states.


本研究は $^{16}$O の $E0$ 遷移と $^{12}$C+αクラスター構造に関する研究である．$E0$ 遷移は元々重い原子核の構造，或いは巨大共鳴が現れる高エネルギー領域における現象として注目されていた．しかし，$^{12}$C において基底状態 $0_1^+$から 3αクラスター構造を持つ $0_2^+$状態への $E0$ 遷移が大きいこと，また $^{11}$B における $^{11}$B(d,d')実験と反対称化分子動力学による理論計算から $^{11}$B の $3/2_3^-$状態は基底状態 $3/2_1^-$からの $E0$ 遷移が大きく，$^{12}$C の $0_2^+$状態と似たような 2α+t クラスター構造を持つことから，$E0$ 遷移は軽い核のクラスター構造と関係すると主張されている[1].

$^{16}$O について，その第一励起状態の角運動量とパリティは $J^\pi=0^+$ ($0_2^+$)である．この負パリティ状態はシェル模型による $0p$ 閉殻構造から $1s0d$ 軌道への 1-particle and 1-hole 励起では説明できないものであり，mysterious zero plus state と呼ばれていたが, 現在では $^{12}$C+αクラスター構造を持つことがよく知られている[2]．$^{16}$O の基底状態からの $E0$ 遷移強度が(α,α')散乱によって測定[3]され，平均場理論に基づく乱雑位相近似計算[4]と比較されている．これによると，乱雑位相近似計算は高エネルギー領域における実験値を再現するが，低エネルギー領域に現れる遷移強度のピークを再現することができない．一方で，クラスター構造を仮定すると $^{16}$O の基底状態から低エネルギー領域に存在する励起状態への $E0$ 遷移を説明できる[5]．しかし，文献[5]は 4αクラスター模型による計算であり，模型計算にクラスターの崩れの効果は取り込まれていない.

本研究では，特に $^{12}$C+αクラスター構造の $^{12}$C 部分に着目して $^{16}$O の基底状態からの $E0$ 遷移とクラスター構造の関係を調べた[6]. 本研究では核子の交換に関する反対称化の操作を完全に行った微視的模型で $^{12}$C クラスター部分の 3α構造 $^{12}$C(3α)とαクラスターが崩れた $0p_{3/2}$ 閉殻構造 $^{12}$C($0p_{3/2}$)の両方を扱った上で，基底状態からの $E0$ 遷移を計算した．また，$^{12}$C 部分の回転を考慮して $^{12}$C+αクラスターを弱結合的に扱った場合と 4αクラスターが正三角錐型に配置された場合を比較した.

本研究により以下の 2 つの知見が得られた．第 1 に $^{12}$C クラスター部分が 3α構造である $^{12}$C(3α)+αクラスター構造に対して $^{12}$C クラスター部分が $0p_{3/2}$ 閉殻的である $^{12}$C($0p_{3/2}$) +αクラスター構造を加えて計算を行うことで，$0_1^+$状態から $0_2^+$状態への $E0$ 遷移が抑制されることが分かった．これは $E0$ 遷移がスピン $S$ を変化させない為，スピンが 0 の $0p$ 閉殻的な構造を持つ $0_1^+$状態からの $E0$ 遷移は，スピンが 0 の $^{12}$C(3α)+αクラスター構造を持つ $0_2^+$状態には起こりやすいが, 有限のスピンを持つ $^{12}$C($0p_{3/2}$) +αクラスター構造が混ざると $0_2^+$状態と $0_1^+$状態のスピン構造に差が生じるからである．第 2 に $0p$ 閉殻的な構造を持つ基底状態からの $E0$ 遷移は 4αクラスターが正三角錐型に配置された構造に対して起こりやすく，4αクラスターが正三角錐型に配置された場合の計算に対して $^{12}$C 部分の回転を考慮して $^{12}$C+αクラスターを弱結合的に扱うと模型空間に 4αクラスターが平面的に配置された構造が取り込まれ, 基底状態からの $E0$ 遷移が抑制されることが分かった. クラスターを弱結合的に扱うことはエネルギー準位を正確に記述するのに必要であるだけでなく，基底状態からの $E0$ 遷移を正しく表すにも必要である．本研究の結果は Progress of Theoretical and Experimental Physics 誌に掲載されている[6]。

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# Quantum Entanglement, Fidelity Susceptibility, and Scrambling from AdS/CFT correspondence

Yukawa Institute for Theoretical Physics Masamichi Miyaji

**Abstract** I consider several quantum information theoretic quantities and phenomena from the viewpoint of AdS/CFT correspondence. First I will consider fidelity susceptibility, which measures the distance between states, and propose its counterpart in gravity. Then I apply fidelity susceptibility to scrambling, and show how fidelity susceptibility can capture scrambling. Finally, I will consider entangling and disentangling operations in CFT, and study their counter part in gravity, and effects on CFT states .


In this thesis, I will study several phenomena and quantities which are intimately related to quantum information theory, using AdS/CFT correspondence. AdS/CFT correspondence is the conjecture on the equivalence between quantum gravity on Anti de Sitter(AdS) space and quantum field theory on the boundary of AdS.

I will first study fidelity susceptibility, which measures distance between quantum states, using AdS/CFT correspondence. I will propose a holographic dual of fidelity susceptibility, is given by the volume of maximal volume bulk time slice, anchored from the boundary time slice. This proposal enables us to compute fidelity susceptibility of states which evolve non trivially in time.

Then I will apply fidelity susceptibility to study the phenomenon called scrambling. When the initial excitation is completely mixed with the environment, we call the excitation is scrambled. I will show that the particular configuration of fidelity susceptibility can capture scrambling, and I will describe how this picture is consistent with the proposed holographic dual of fidelity susceptibility.

Finally, I will consider non local operation in both CFT and gravity. Such operation corresponds to changing entanglement structure. And I will also study how entanglement structure and averaged null energy are changed by such non local operations in CFT, and also how the dual gravity evolves in time.

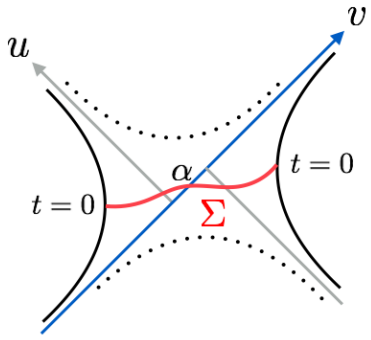


Fig. 1. Maximal volume time slice in Shock wave geometry.

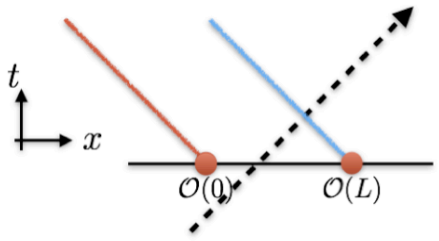


Fig.2. Propagation of null energy density after entangling operation in CFT.

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# Gamow-Teller transitions in the light N=Z odd-odd nuclei

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**Abstract** I have investigated the Gamow-Teller transitions in the light N=Z odd-odd nuclei by using the antisymmetrized molecular dynamics. These GT transitions occur between the two-nucleon pairs such as neutron-neutron and proton-neutron pairs which restore SU(4) symmetry. The important point is that the proton-neutron pairs spatially develop and make cluster structures.


N=Z odd-odd nuclei are singular subjects in nuclear physics. There are competing isovector (T=1) and isoscalar (T=0) states in the low-lying spectra, where isovector and isoscalar proton-neutron correlations play important roles.

The recent studies of the mean-field calculations and the experiments have found the strong Gamow-Teller (GT) strengths near the isobaric analog state in the low-lying regions. These states are called low-energy super Gamow-Teller (LeSGT) transitions which correspond to degeneracy of isovector and isoscalar states of the proton-neutron pairs, that is, SU(4) symmetry in the nuclei.

These phenomena have been limitedly discussed for the pf-shell nuclei. It is expected to expand the idea to the lighter nuclei. However, the mean-field methods are not stable for describing clustering phenomena which are broadly found in the light nuclei.

In this talk, I show a new framework which can deal with proton-neutron correlations and clustering in the same footing. I call this method isospin projected antisymmtrized molecular dynamics (Tβγ-AMD) [1].

By using this method, I have investigated the Gamow-Teller transitions between the N=Z+2 nuclei to the N=Z odd-odd nuclei in the *p*-shell [2]. I have found the strong Gamow-Teller transitions exhausting 50% of the sum-rule in $^{6}$He($0_1^+1$)→$^{6}$Li($1_1^+0$), $^{10}$Be($0_1^+1$)→$^{10}$B($1_1^+0$), and $^{14}$C($0_1^+1$)→$^{14}$N($1_2^+0$). In these states, the isoscalar proton-neutron pairs make the low-lying spectra in the final states of $^{6}$Li($1_1^+0$), $^{10}$B($1_1^+0$), and $^{14}$N($1_2^+0$). These pairs show clustering nature which play important role to realize SU(4) symmetry.

I have also applied the Tβγ-AMD to $^{22}$Na comparing with $^{10}$B and comprehensively investigated SU(4) symmetry in the light deformed N=Z odd-odd nuclei [3]. The proton-neutron pairs are formed at surfaces of the prolately deformed cores ($^{20}$Ne=$^{16}$O+α, $^{8}$Be=2α) in both nuclei. I have obtained the Gamow-Teller strengths $^{22}$Ne($0_1^+1$) →$^{22}$Na($1_{1,2}^+0$) whose summation exhausts 50% of the sum-rule value, but the strengths are fragmented into the half. This indicates that SU(4) symmetry of the proton-neutron pairs is broken as a result of spin-orbit interactions on quadrupole deformations. In fact, $^{22}$Na($1_{1,2}^+0$) have different K-quanta, which are defined in the deformed state, with K=0 and K=1. Each state contains proton-neutron pair with anti-aligned spin ($S_z$=0) and with aligned spin ($S_z$=1), respectively.

**References**

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# Functional-renormalization-group aided density-functional theory - ab-inito description of ground and excited states of quantum many-body systems -

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**Abstract** We formulate the functional-renormalization-group aided density-functional theory (FRG-DFT) for infinite homogeneous matter. The applications of the FRG-DFT to infinite nuclear matter and two-dimensional homogeneous electron gas are presented. These demonstrations show that the FRG-DFT describes ground and excited states in a unified manner and is applicable to more-than-one-dimensional realistic models.


The functional renormalization group (FRG) is a fundamental tool in the field theory. One of recent significant developments regarding the FRG is an attempt to employ it for the formulation of the density functional theory (DFT) [1,2], which we call the functional-renormalization-group aided density-functional theory (FRG-DFT). The FRG-DFT is expected to become a powerful approach for the fundamental problems of the DFT such as the microscopic determination of the energy density functional and the analyses of excited states involving the large-amplitude collective dynamics.

In this presentation, our works on the FRG-DFT toward the unified description of the ground and excited states in realistic models are presented. Together with my collaborators, I formulate the FRG-DFT for infinite homogeneous matters [3] and apply it to two models [3-5].

In the first application, we calculate the equation of state (EOS) [3] and the density-density spectral function [4] of the one-dimensional homogeneous matter composed of spinless Fermions with a non-local interaction showing a short-range repulsion and a long-range attraction like the nuclear force. We find that the saturation energy extracted from the EOS coincides with that obtained from the Monte Carlo (MC) calculation within a few percent. Moreover, the spectral function is found to reproduce a notable feature of the non-linear Tomonaga-Luttinger liquid that the spectral function has singularities at the edge of its support on the lower-energy side. This application is the first study in which the ground and excited states are analyzed in a unified manner with the FRG-DFT.

The second application is the analysis of the two-dimensional homogeneous electron gas (2DHEG) [5]. This is the first example in which a more-than-one-dimensional realistic model is analyzed. The correlation energies are calculated for various Wigner-Seitz radii and found to completely reproduce the exact result in the high-density limit. In the finite density case, we find that the result with the FRG-DFT shows good agreement with the MC results in the higher-density case, although the discrepancy between FRG-DFT and MC results becomes larger as the system becomes dilute.

Our results suggest that the FRG-DFT is a promising method which is applicable to more-than-one-dimensional realistic quantum many-body systems and realizes the unified description of the ground and excited states.

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