What is dark matter?

Comprehensive study of the huge discovery space in dark matter

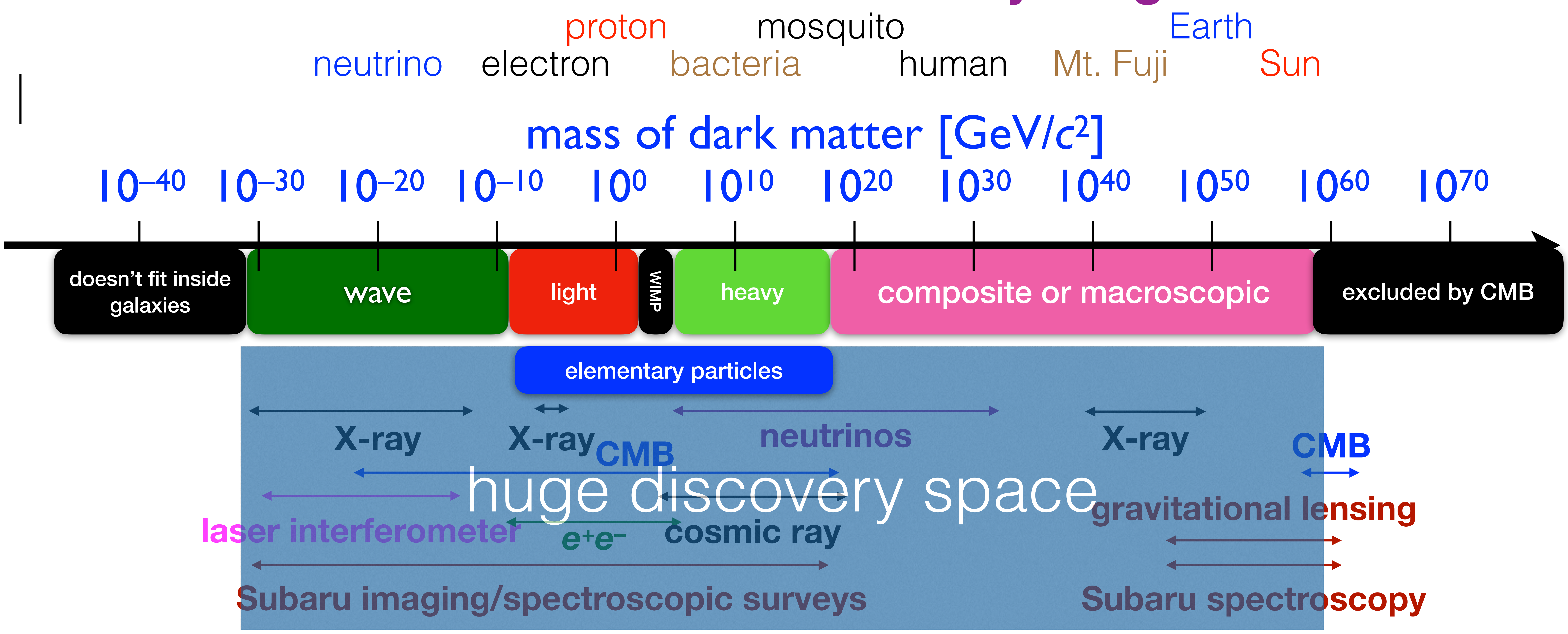
PI: Hitoshi Murayama（Kavli IPMU、Berkeley）

Yukawa Institute, Kyoto, March 7, 2024

東京大学 THE UNIVERSITY OF TOKYO
BERKELEY LAB
KAVLI IPMU INSTITUTE FOR T
MATHEMATICS O

Main point: **Dark Matter exists**, but **unknown type of matter**

Search so far has been limited to **tiny range of masses**



we challenge **discovery space** not studied
so far due to theoretical prejudices

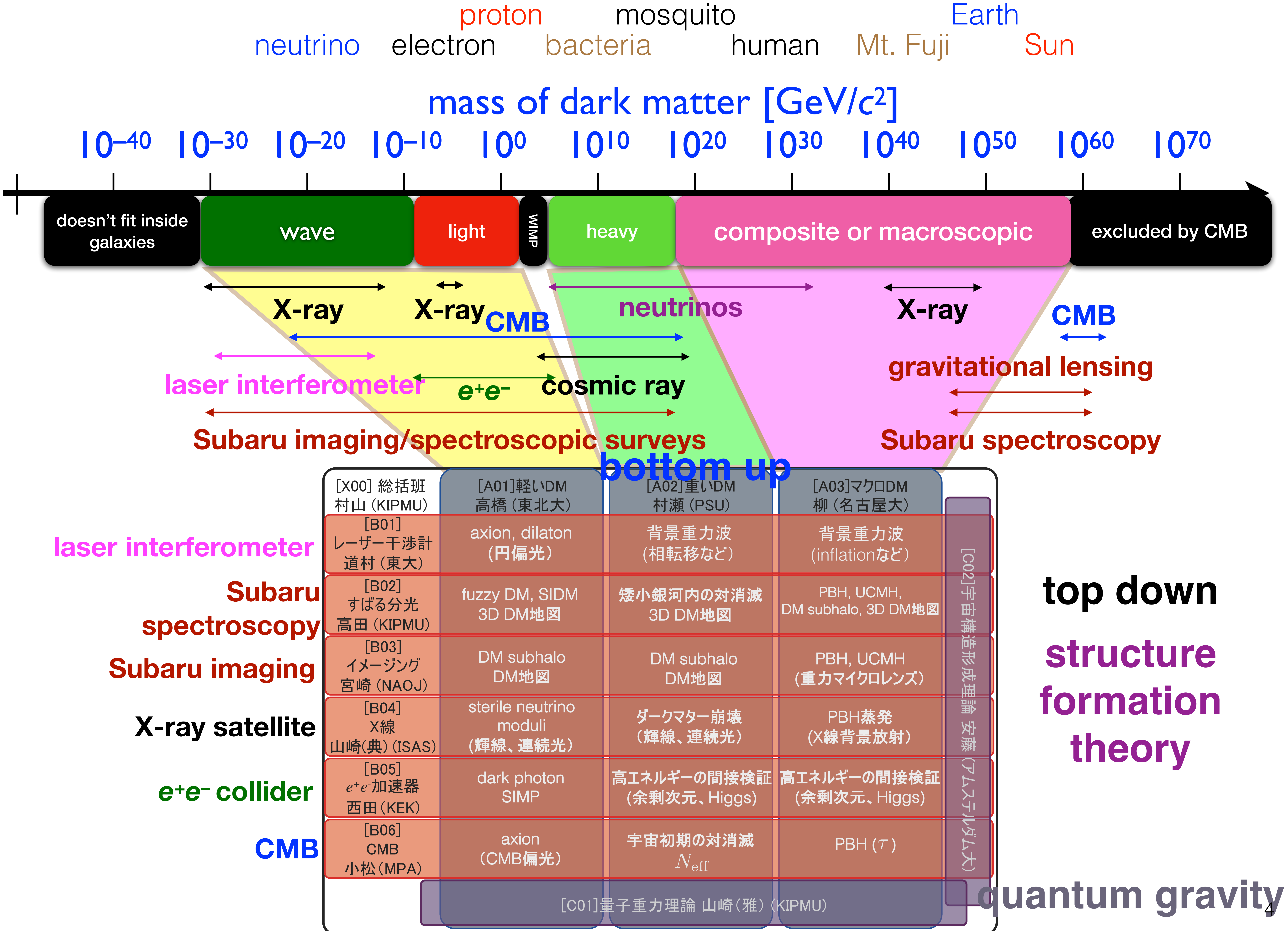
revolutionize dark matter research in Japan

cross-field research beyond traditional barriers

exploit existing facilities in unanticipated fashion

strategy

- world competitive experiments > $100M
- use excellent existing facilities in Japan
  - exploitation for unforeseen purposes
  - B01：KAGRA（UTokyo）black hole mergers
  - B02, B03：Subaru（NAOJ）galaxy evolution
  - B04：XRISM（JAXA）supernova remnants
  - B05：Belle II（KEK）CP violation
  - B06：Simons Array（intl team incl KEK, IPMU etc）verify inflation theory



proton
mosquito
Earth
neutrino
electron
bacteria
human
Mt. Fuji
Sun
mass of dark matter [GeV/c²]
10⁻⁴⁰ 10⁻³⁰ 10⁻²⁰ 10⁻¹⁰ 10⁰ 10¹⁰ 10²⁰ 10³⁰ 10⁴⁰ 10⁵⁰ 10⁶⁰ 10⁷⁰
doesn't fit inside galaxies
wave
light
WIMP
heavy
composite or macroscopic
excluded by CMB
X-ray
X-ray
CMB
neutrinos
X-ray
CMB
gravitational lensing
laser interferometer
e+e−
cosmic ray
Subaru imaging/spectroscopic surveys
Subaru spectroscopy
bottom up
[X00] 総括班 村山 (KIPMU)
[A01]軽いDM 高橋 (東北大)
[A02]重いDM 村瀬 (PSU)
[A03]マクロDM 柳 (名古屋大)
laser interferometer
[B01] レーザー干渉計 道村 (東大)
axion, dilaton (円偏光)
背景重力波 (相転移など)
背景重力波 (inflationなど)
Subaru spectroscopy
[B02] すばる分光 高田 (KIPMU)
fuzzy DM, SIDM 3D DM地図
矮小銀河内の対消滅 3D DM地図
PBH, UCMH, DM subhalo, 3D DM地図
Subaru imaging
[B03] イメージング 宮崎 (NAOJ)
DM subhalo DM地図
DM subhalo DM地図
PBH, UCMH (重力マイクロレンズ)
X-ray satellite
[B04] X線 山崎(典) (ISAS)
sterile neutrino moduli (輝線、連続光)
ダークマター崩壊 (輝線、連続光)
PBH蒸発 (X線背景放射)
e+e− collider
[B05] e+e-加速器 西田 (KEK)
dark photon SIMP
高エネルギーの間接検証 (余剰次元、Higgs)
高エネルギーの間接検証 (余剰次元、Higgs)
CMB
[B06] CMB 小松 (MPA)
axion (CMB偏光)
宇宙初期の対消滅 Neff
PBH (τ)
[C02]宇宙構造形成理論 安藤 (アムステルダム大)
[C01]量子重力理論 山崎(雅) (KIPMU)
top down
structure formation theory
quantum gravity

本領域で期待される成果

	アプローチ	施設	サイエンス	新しいデータ
	レーザー干渉計	KAGRA	アクシオン	グループの承認次第
laser interferometer	レーザー干渉計	テーブルトップ	アクシオン	期間内
	レーザー干渉計	KAGRA	B–L ゲージボソン	期間内
	分光観測	すばる	自己相互作用	期間内
Subaru spectroscopy	分光観測	すばる	ファジーダークマター	期間内
	分光観測	すばる	矮小銀河中の DM 対消滅	期間内
	イメージング	すばる	DM ３次元地図	期間内
Subaru imaging	イメージング	すばる	矮小銀河の個数，空間分布	期間内
	イメージング	すばる	原始ブラックホール	期間内
	X 線観測	XRISM	ステライルニュートリノ	期間内
X-ray satellite	X 線観測	XRISM	弦理論モデュライ	期間内
	X 線観測	テーブルトップ	アクシオン	期間内
	e^+e^- 加速器	SuperKEKB	ダークフォトン	期間内
e^+e^- collider	e^+e^- 加速器	SuperKEKB	SIMP	期間内
	e^+e^- 加速器	ILC	余剰次元	将来計画
CMB	CMB	ACT/SPT/SA	アクシオン	期間内
	CMB	ACT/SPT/SA	晴れ上がり時期の対消滅	期間内

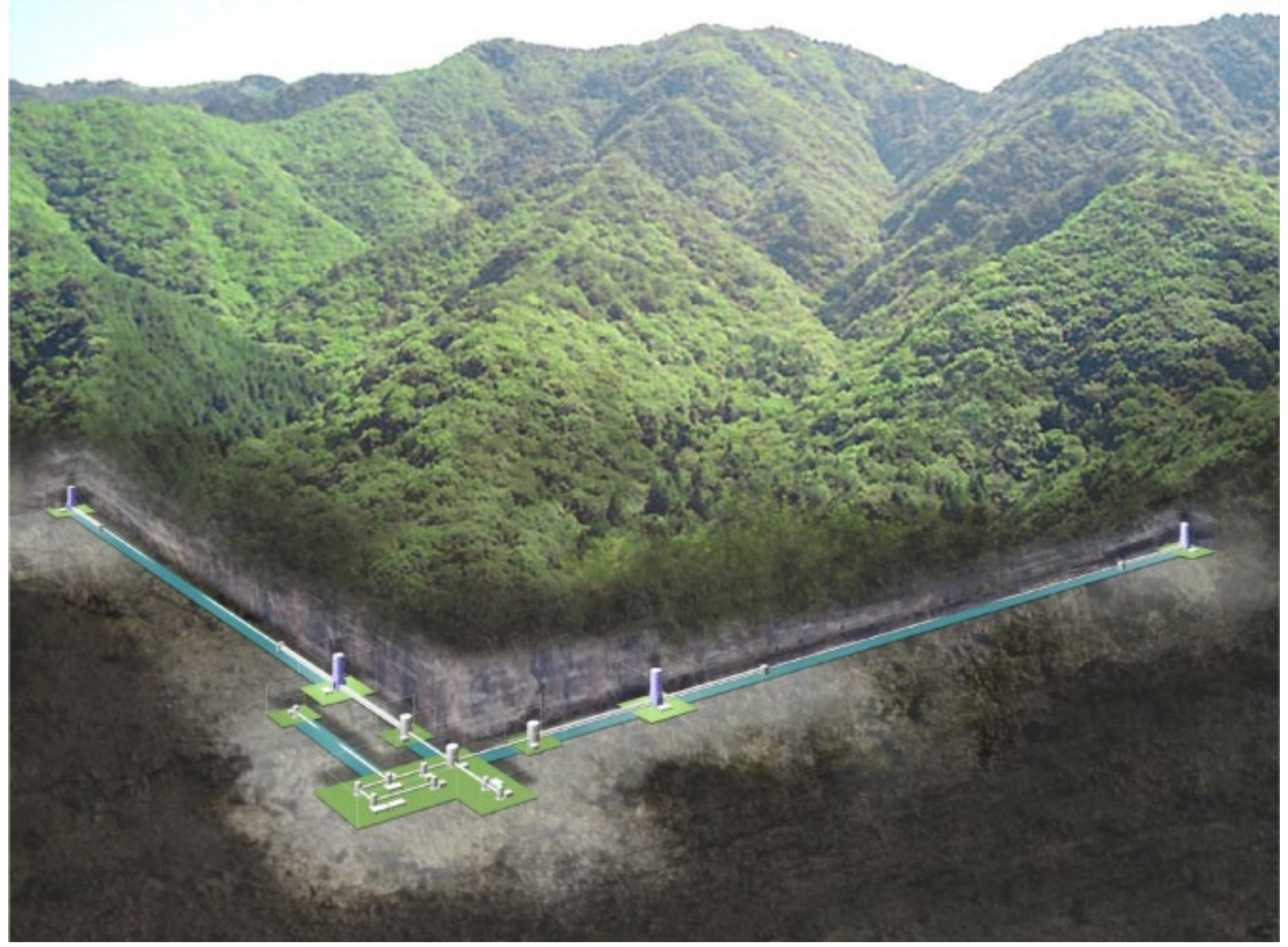
B01

KAGRA after earthquake

Masayuki Nakahata

主要プロジェクトの状況

KAGRA



- KAGRAは重力波国際観測ネットワークのアジアでの拠点であり、国内外の研究者約400人が参加する国際共同利用研究。
- LIGO-Virgo-KAGRA国際共同観測O4aに昨年5月24日から4週間参加し、その後、感度向上のために干渉計コミッショニングを再開した。2024年元旦の能登半島地震で防振装置が被災し、現在は復旧作業（数か月かかる見込み）を進めている。
- O4後は、重力波観測とアップグレード作業を繰り返してゆく予定であり、4台の同時観測によるマルチメッセンジャー天文学を発展させていく。次の10年に向けたタスクフォースが発足した。

B02, B03

Topics & Announcements

Announcements

Back to Topics & Announcements

Regarding the suspension of Subaru Telescope night observation (Final Report)

March 4, 2024
Last updated: March 6, 2024

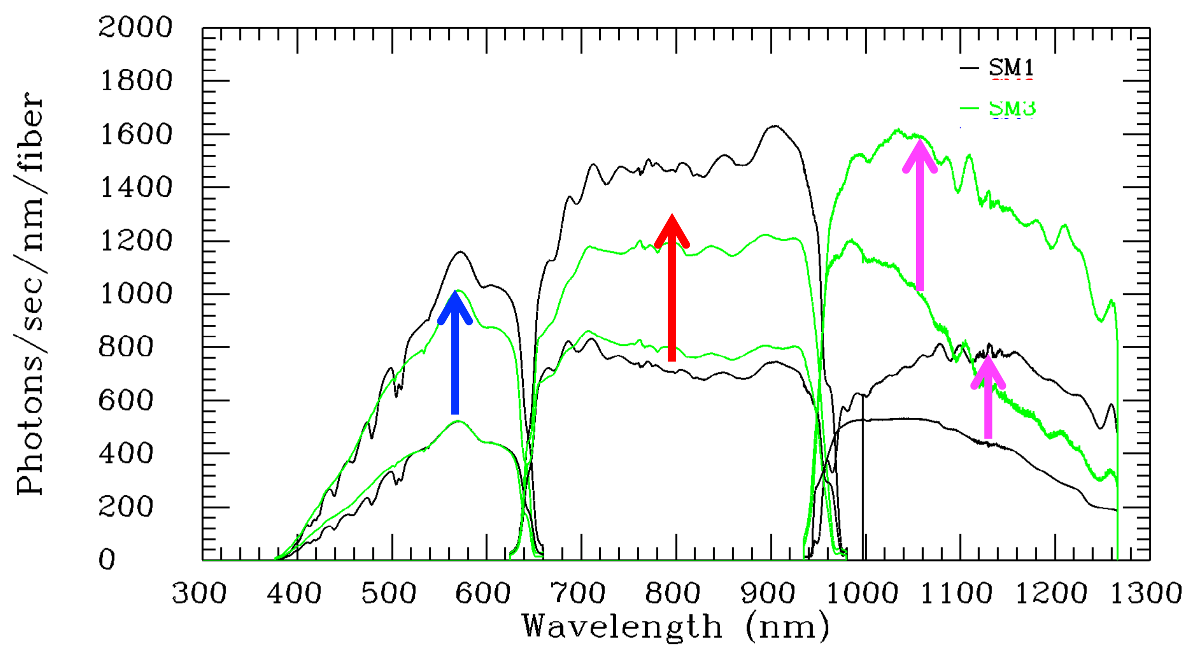
We would like to inform you about the situation after the sixth report (February 15, 2024, Hawaii local time).

As previously reported, ① the abnormal reading of load sensors at the fixed points of the primary mirror was resolved (restored to the nominal values) by replacing the load sensors, and ② the repair work for the damages on the primary mirror was completed. Having confirmed these, we analyzed the accuracy of the telescope's pointing direction and the shape of the primary mirror and confirmed that there were no problems. Therefore, we restored the telescope and resumed night observations on March 3rd (Hawaii local time).

We sincerely apologize for the long period of inconvenience caused to those planning to observe. We will continue to strive to create scientific results through various night observations under open-use observation.

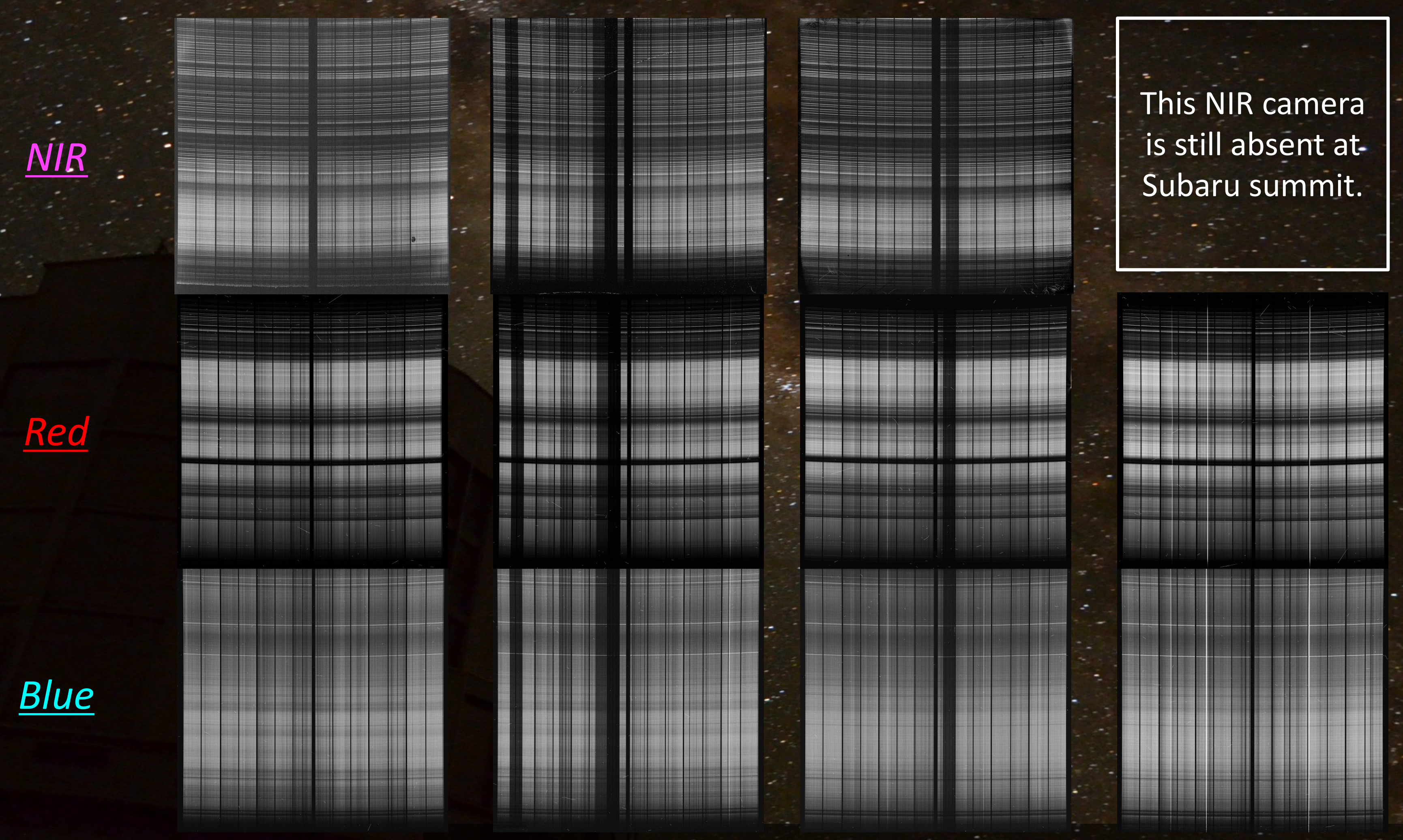
B02

Preliminary results from the latest quartz spectra after grating orientation error was fixed



- The Low-Resolution grating orientations were all fixed in Nov.
- Quartz spectra before Nov (only SM1 and SM3 were at Subaru at that time) were compared → The throughput has been recovered by a factor of ~1.5-2 in all the bands.

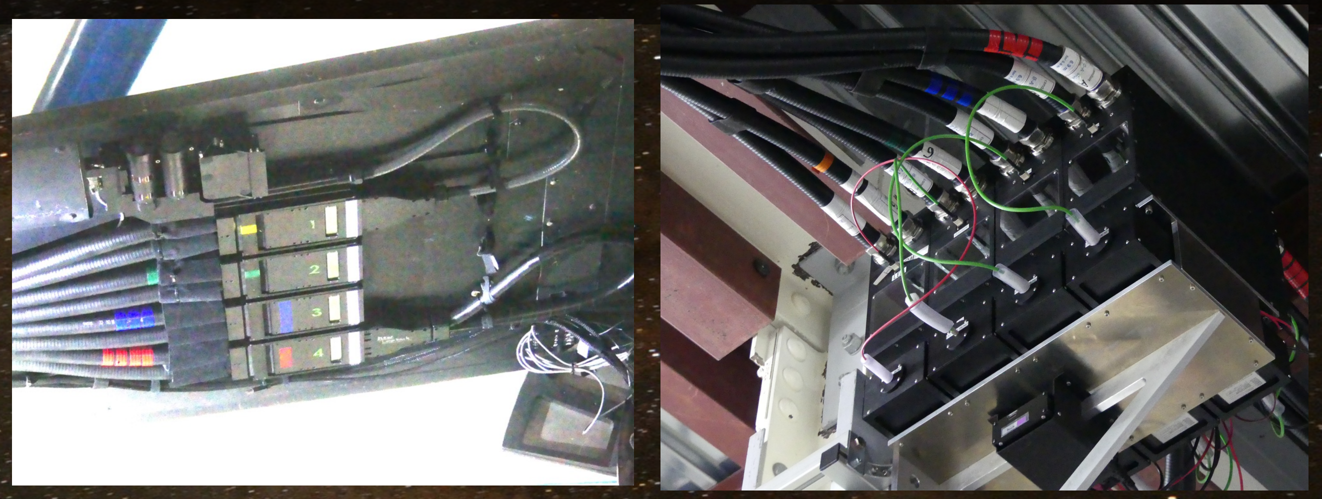
Dec in 2023: On-telescope data acquisition run (with Telescope kept pointing to Zenith)

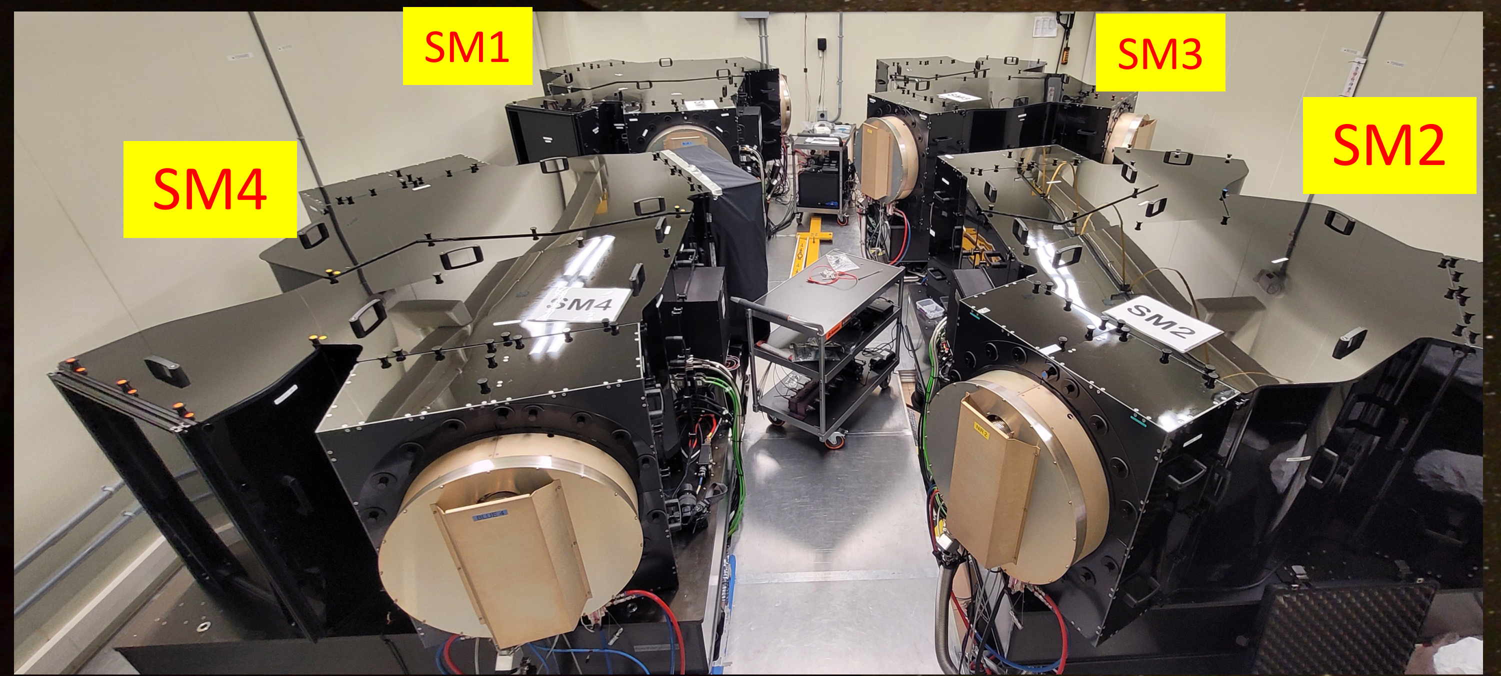


All spectra from a ***SINGLE*** exposure (twilight sky on Dec 22, 2023)

Feb, May & Nov 2023: Remaining fiber cables & spectrograph modules were implemented.

All Cable four Bs on the telescope spider (left) and on the IR3 floor (right)

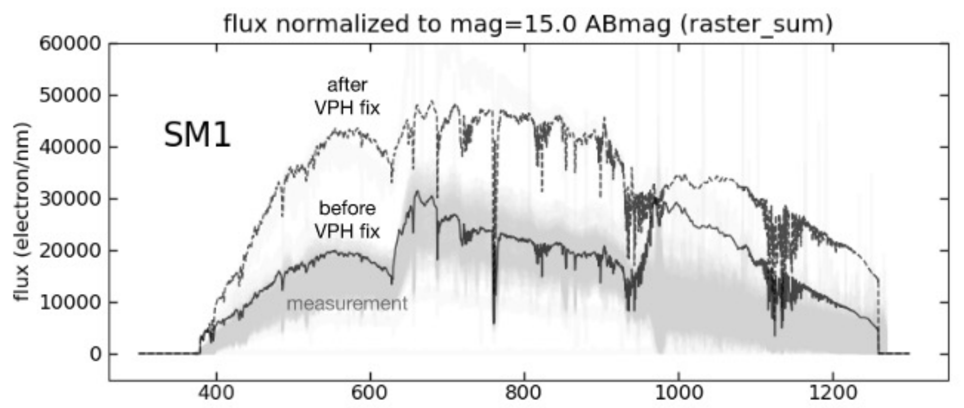


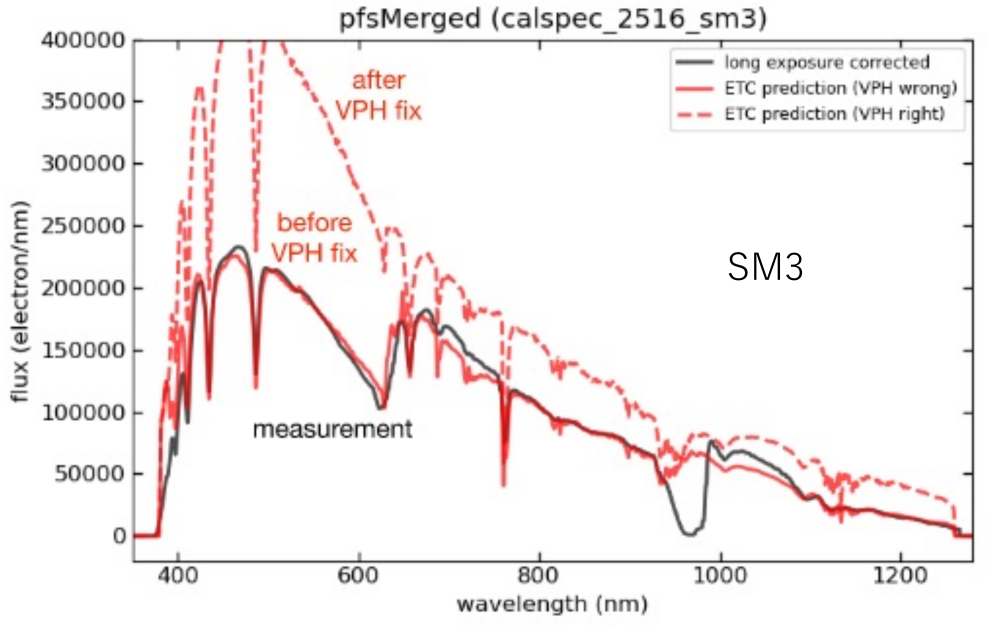


All four modules @Spectrograph Clean Room (SCR)

3	試験観測
5	SM4 用近赤外カメラ敷設
-6/3	試験観測
(TBC)	***PFSすばる戦略枠プロポーザル締切***
中	SM1 用近赤外カメラ再敷設
上旬	***Open use readiness review***
	Call for Proposal for S25A
期	試験観測
	科学運用開始（S25A）

ばる戦略枠(SSP)サーベイ:
0 夜を最速 5 年 (i.e. 最大 36 夜/セメスタ)

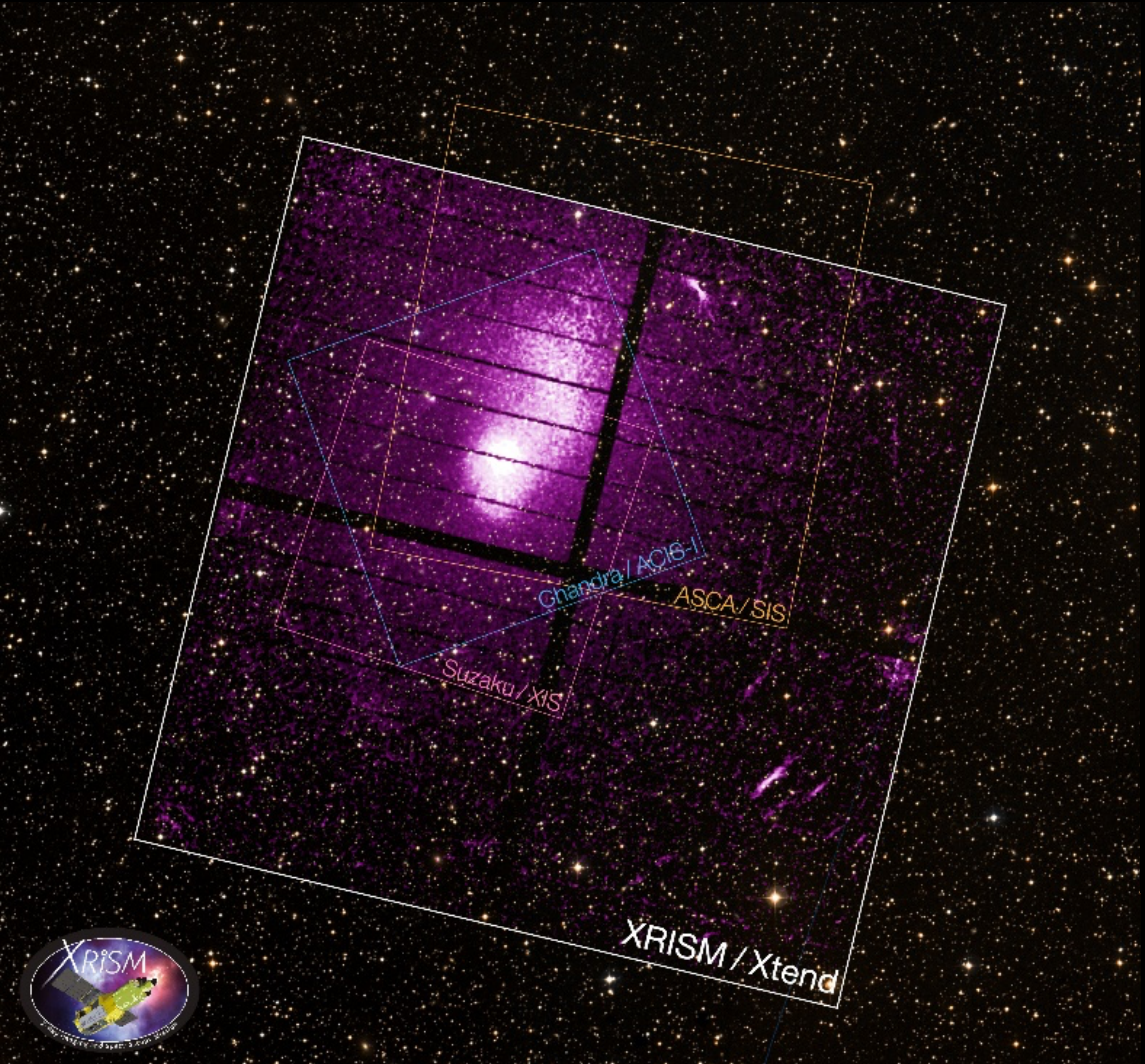




誤取付VPHを考慮したETCによる予測("before VPH fix")と 7 月の試験観測データ(黒線, フラックス較正前, SM1[上], SM3 [下])との比較。

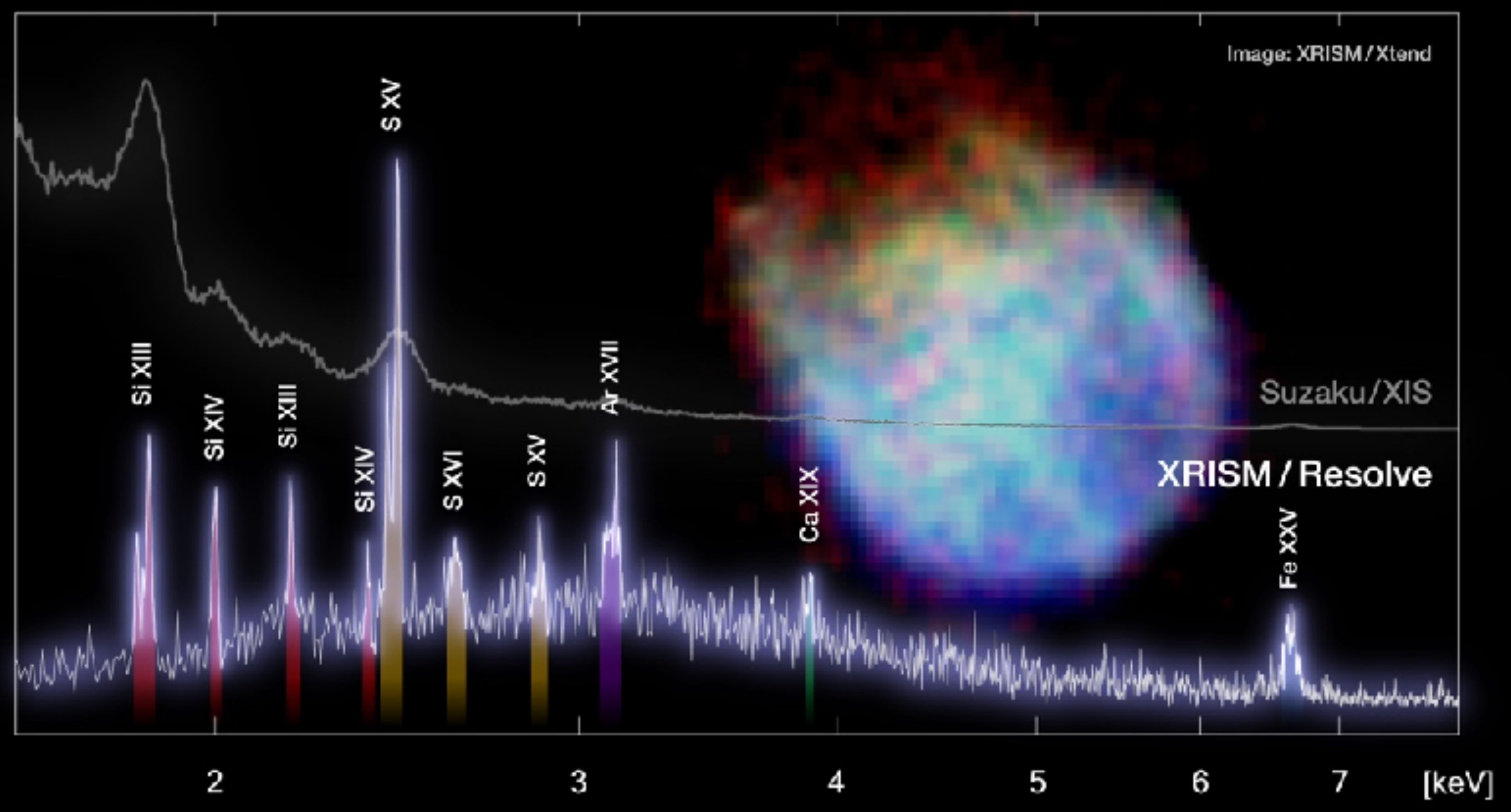

akameeba

B04



X-ray Image of Galaxy Cluster Abell 2319 Captured by **XRISM Xtend**

X-ray Spectrum of Supernova Remnant N132D Measured by **XRISM Resolve**

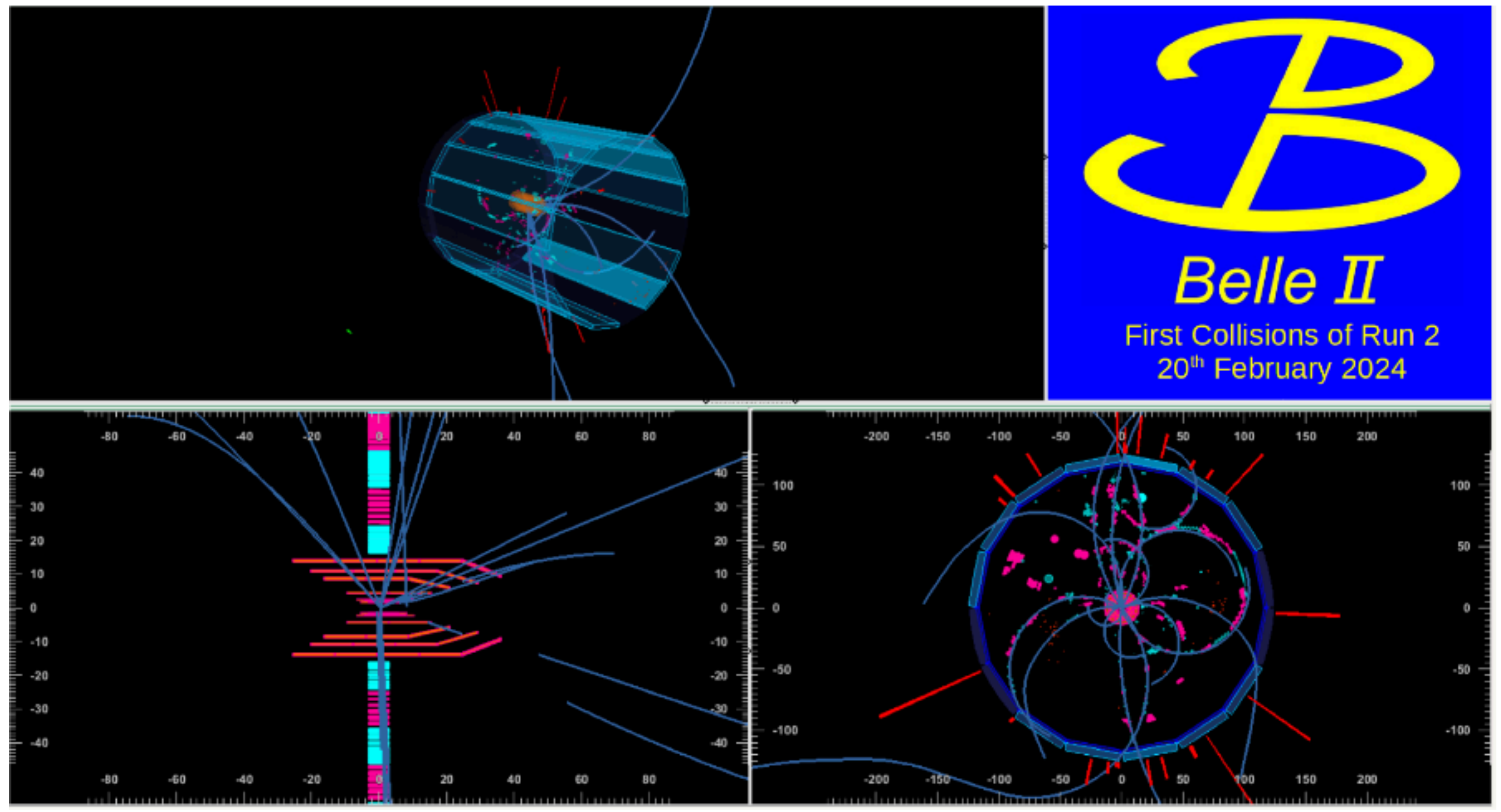


Phase 3 Run2開始

B05

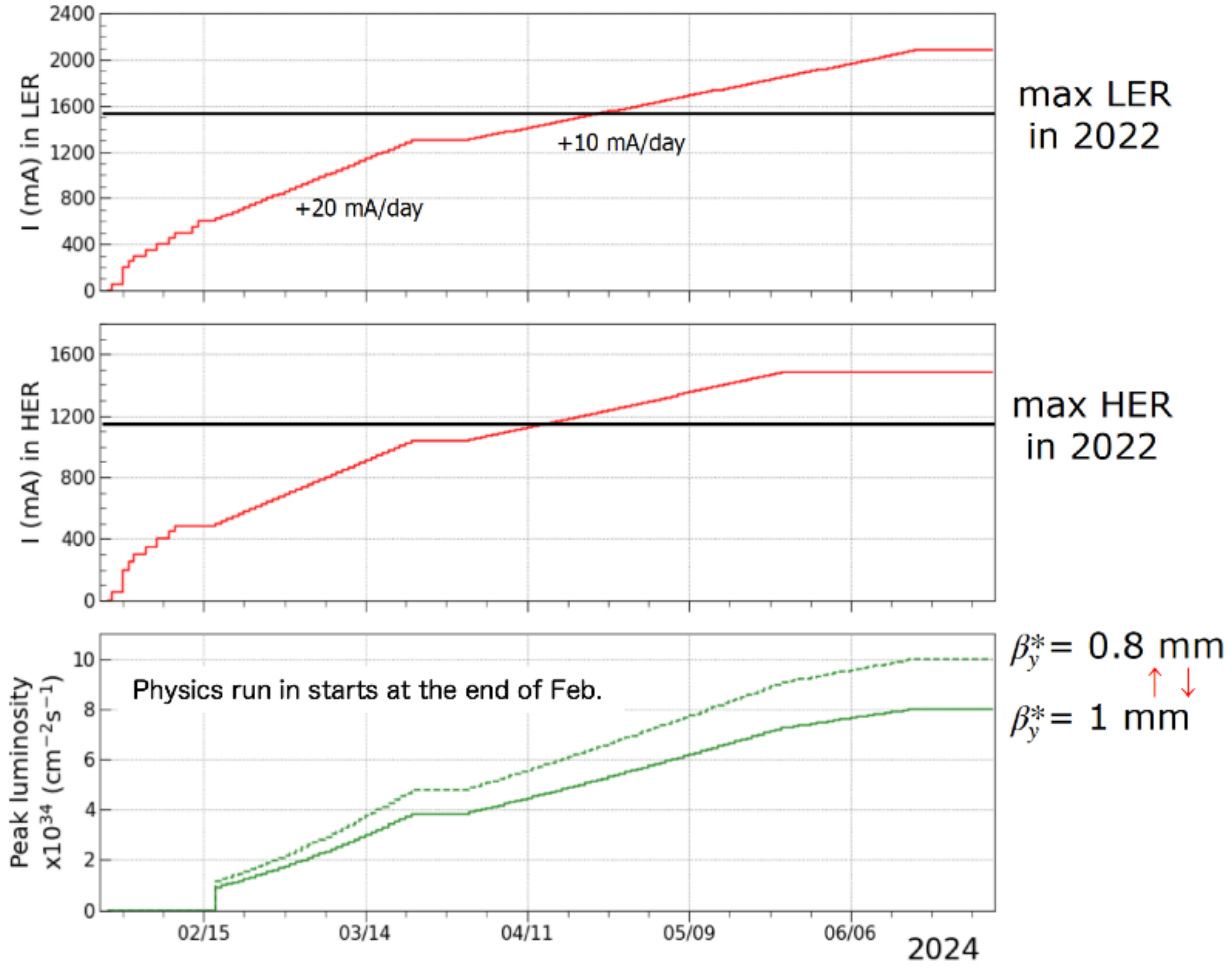
- Resumed operation since January 29, 2024 after LS1
- The first collision was observed on February 20

Target for 2024 run
- Run stably at $10^{35}cm^{-2}s^{-1}$
- Reach $150fb^{-1}$ per month
- Exceed 1 ab^{-1}



Y. Ohnishi

Current and luminosity



Toru Iijima

3/3/2024

Eiichiro Komatsu

Nature Reviews Physics **4**, *452–469 (2022)*

B06

REVIEWS

Check for updates

New physics from the polarized light of the cosmic microwave background

Eiichiro Komatsu[1,2]

Abstract | The current cosmological model requires new physics beyond the standard model of elementary particles and fields, such as dark matter and dark energy. Their nature is unknown and so is that of the initial fluctuations in the early Universe that led to the creation of the cosmic structure we see today. Polarized light of the cosmic microwave background (CMB) may hold the answer to these fundamental questions. Here, I discuss two phenomena that could be uncovered in CMB observations. First, if the physics behind dark matter and dark energy violates parity symmetry, their coupling to photons should have rotated the plane of linear polarization as the CMB photons have been travelling for more than 13 billion years. This effect is known as 'cosmic birefringence'. A tantalizing hint of such a signal has been found with a statistical significance of 3σ. Second, the period of accelerated expansion in the very early Universe, called 'cosmic inflation', might have produced a stochastic background of primordial gravitational waves (as yet unobserved). These might have been generated by vacuum fluctuations in spacetime or by matter fields and could be measurable in the CMB polarization. The goal of observing these two phenomena will influence how data from future CMB experiments are collected, calibrated and analysed.

The standard cosmological model, called ΛCDM, includes new physics beyond the standard model (SM) of elementary particles and fields[1]. Λ denotes Einstein's cosmological constant, which is the simplest (yet one of the most difficult to understand)[2,3] candidate for the dark energy responsible for the accelerated expansion of the Universe[4,5]. CDM stands for cold dark matter, which accounts for 80% of the matter density in the Universe[6]. Neither the existence of dark matter nor that of dark energy is predicted by the SM.

Yet this is perhaps not the most surprising thing about the standard cosmological model. A less-known underlying assumption, not contained in the name of ΛCDM, is the idea that the origin of all structures in the Universe (such as galaxies, stars, planets and life) was a quantum-mechanical vacuum fluctuation generated in the early Universe[7–11]. The observed properties of cosmic structures, most notably those of the afterglow of the primordial fireball Universe called the cosmic microwave background (CMB), agree with this idea[12,13].

The polarized light of the CMB may help to answer questions such as what the physical nature of dark matter and dark energy is, or what generated the initial quantum vacuum fluctuation and how. These are important questions, and there are already measurements of CMB polarization from two space missions, the NASA Wilkinson Microwave Anisotropy Probe (WMAP)[14] and the European Space Agency (ESA) Planck[15], as well as from a host of ground-based[16–21] and balloon-borne[22] experiments. The rate at which the sensitivity of CMB experiments has improved over the past two decades is staggering: the noise level has dropped by three orders of magnitude, nearly exponentially with time.

Even more sensitivity is expected from upcoming CMB polarization experiments, including ground-based observatories such as the Simons Observatory[23], the South Pole Observatory[24] and CMB Stage-4[25], and a space mission, LiteBIRD[26], led by the Japan Aerospace Exploration Agency (JAXA). These experiments will reduce the noise level by another order of magnitude. At the current stage, not only the statistical uncertainty, but also the systematic uncertainty (including both the instrumental and astrophysical ones) must be controlled with unprecedented precision. What kind of systematics should be better characterized, and how well, depends on what kind of new physics one wishes to discover from such observations.

In this Review, I focus on two new developments in the quest for new physics. First, CMB polarization is sensitive to physics violating parity symmetry under inversion of spatial coordinates[27]. I discuss a tantalizing hint for such a signal, called 'cosmic birefringence'[28–30], in the polarization data obtained by Planck[31–33]. The statistical significance is currently about 3σ. If confirmed with

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[2]Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI), University of Tokyo, Chiba, Japan.
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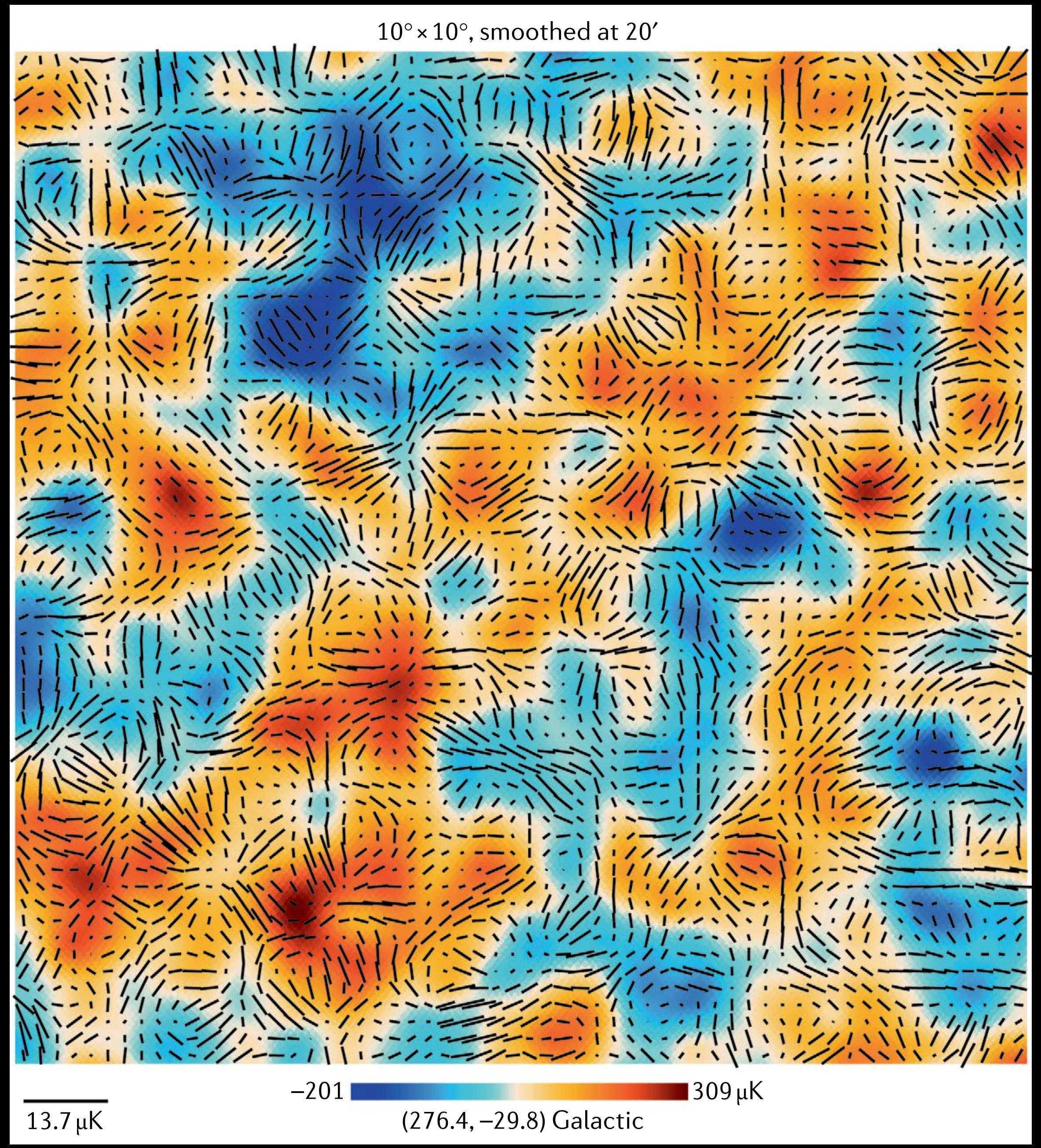
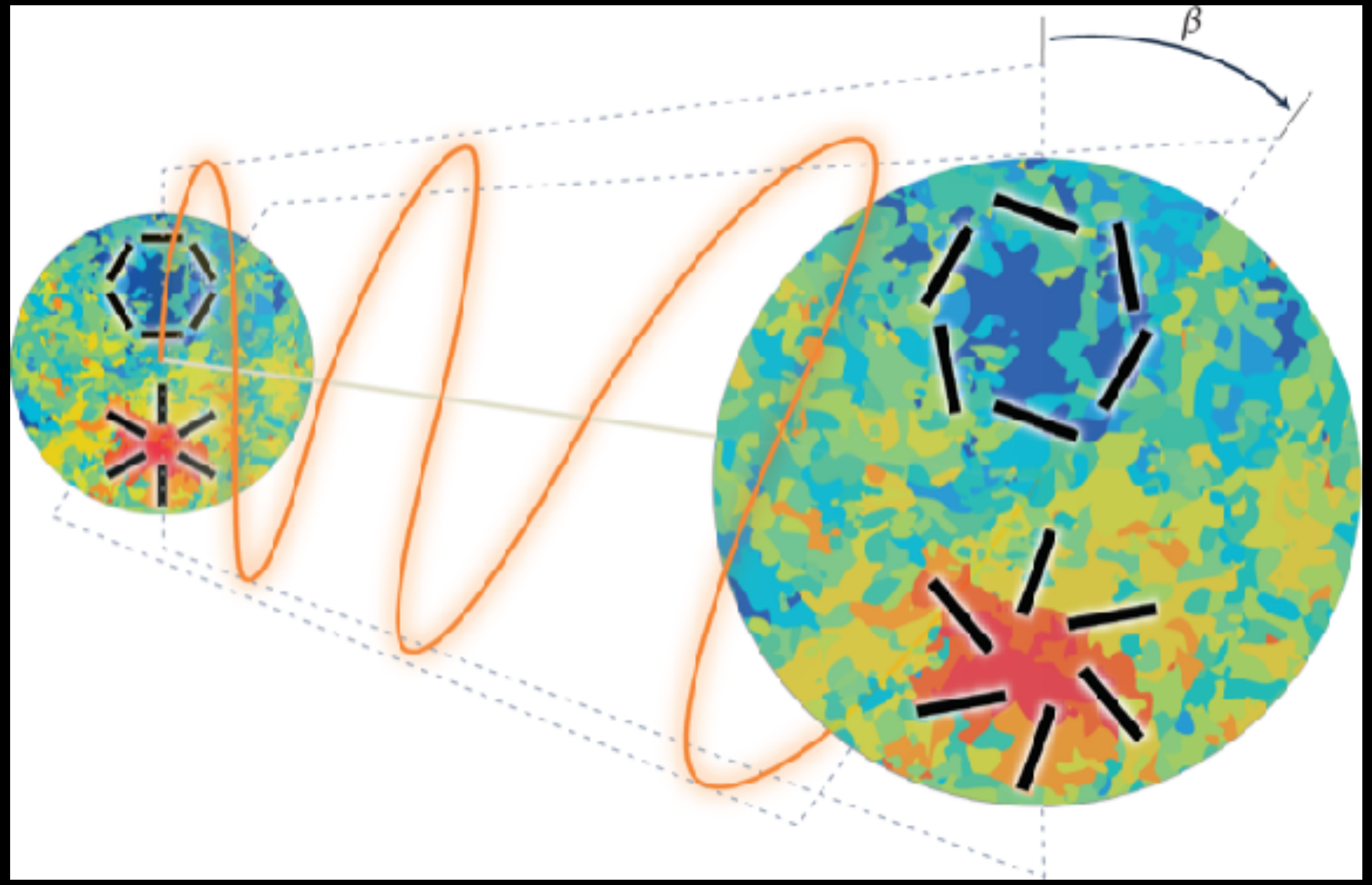
https://doi.org/10.1038/s42254-022-00452-4



宇宙背景放射(CMB)の偏光の観測データ



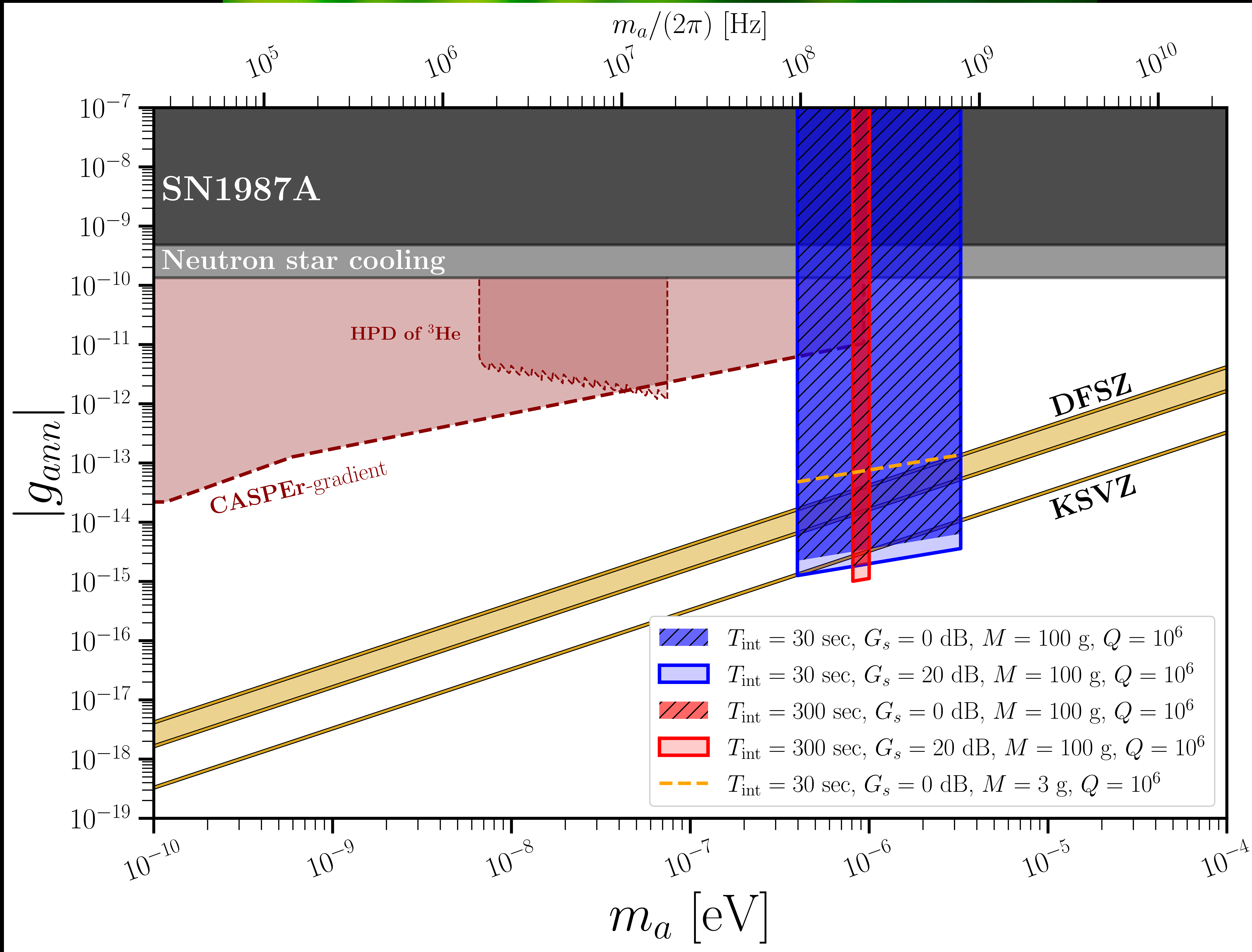
宇宙背景放射(CMB)の光子が
アクシオンによる複屈折で偏光面が回転?

X00: Axion Dark Matter detection with superfluid ^3He

Axion detection via superfluid ^3He ferromagnetic phase and quantum measurement techniques

So Chigusa, Dan Kondo, Hitoshi Murayama, Risshin Okabe, Hiroyuki Sudo, arXiv:2309.09160

- Motivation for axion is not just dark matter but also the strong CP problem
- Essential to detect its coupling to nucleons, but difficult
- A1 phase of superfluid 3He is ferromagnetic
- can detect axion coupling to macroscopic nucleon spin
- further enhanced by quantum information technology to beat the standard quantum limit



本領域で期待される成果

	アプローチ	施設	サイエンス	新しいデータ
laser interferometer	レ being fixed 計	KAGRA	アクシオン	グループの承認次第
	レ improving 計	テーブルトップ	アクシオン	期間内
	レ being fixed 計	KAGRA	B–L ゲージボソン	期間内
Subaru spectroscopy	分光観測	すばる	自己相互作用	期間内
	From Spring 2025	すばる	ファジーダークマター	期間内
	分光観測	すばる	矮小銀河中の DM 対消滅	期間内
	イメージング	すばる	DM ３次元地図	期間内
Subaru imagin	HSC survey completed	すばる	矮小銀河の個数，空間分布	期間内
	イメージング	すばる	原始ブラックホール	期間内
X-ray satellite	X 線観測 engineering data	XRISM	ステライルニュートリノ	期間内
	X 線観測	XRISM	弦理論モデュライ	期間内
	X procured?	テーブルトップ	アクシオン	期間内
e^+e^- collider	e^+e^- 加速器 now running	SuperKEKB	ダークフォトン	期間内
	e^+e^- 加速器	SuperKEKB	SIMP	期間内
	e^+e^- 加速器	ILC	余剰次元	将来計画
CMB	C discovery?	ACT/SPT/SA	アクシオン	期間内
	CMB	ACT/SPT/SA	晴れ上がり時期の対消滅	期間内

Mid-term Evaluation

令和５年度科学研究費助成事業「学術変革領域研究（A）」に係る中間評価結果

領域番号	20A203	領域略称名	ダークマター
研究領域名	ダークマターの正体は何か？- 広大なディスカバリースペースの網羅的研究		
領域代表者名 （所属等）	村山　斉 （東京大学・カブリ数物連携宇宙研究機構・教授）		

（評価結果）

Ａ＋（研究領域の設定目的に照らして、期待以上の進展が認められる）

（評価結果の所見）

ダークマターは、宇宙論や宇宙物理学的要請からその存在は確実視されているが、その正体は不明のままである。本研究領域では、我が国が保有している世界的レベルの研究施設の有効利用を軸に、質量にして 90 桁の範囲に及ぶ総合的探査を進めており、既に期待以上の成果も出てきている。特に、アクシオンダークマターに関しては、宇宙背景放射の複屈折の存在など、ブレークスルーとなる可能性の高い結果が得られている。

多くの研究分野を含む研究領域ではあるが、領域代表者のリーダーシップの下、適切に運営されており、若手研究者の斬新なアイデアによる研究や分野間の融合研究も多く行われている。

研究期間後半では、前半で得られた観測結果の統計的有意性を示すことが重要である。また、これからデータが取得されるプロジェクトに依存する計画や技術開発が進行中の計画もあるが、これらにおいても、本研究領域終了までにダークマター探索が進むことを期待したい。