

すばるHSCによる AGNサイエンスと今後の展望

鳥羽 儀樹 (国立天文台)

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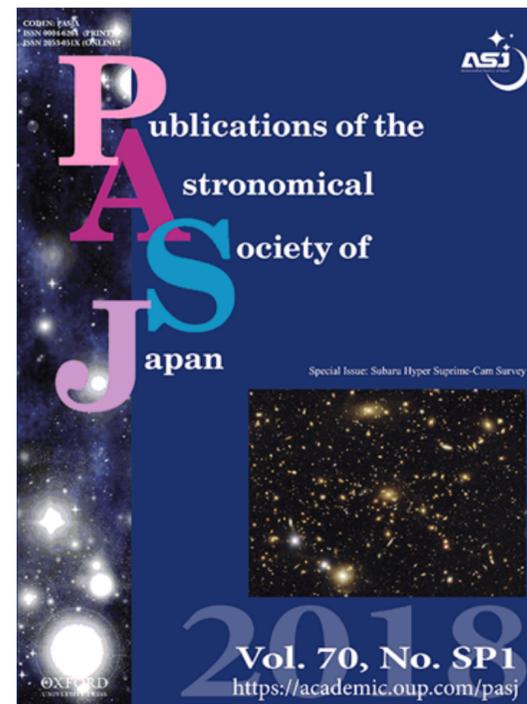
- 👁️ Hyper Suprime-Cam (HSC)
 - IR-selected AGN
 - Radio-selected AGN
 - eROSITA・X-ray-selected AGN

- 👁️ 今後の展望

- eROSITAとHSCによるサイエンス
 - 銀河合体
 - 高光度、低光度AGN
- PFS、Rubin/LSST

すばるHSC特集号 (2018年1月)

天文月報2019年4月号より



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HSC特集(3)

HSCで探る巨大ブラックホールと活動銀河核

長尾 透¹, HSC-AGN Working Group

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視野の広さと感度の高さを兼ね備えたすばる望遠鏡Hyper Suprime-Cam (HSC)を用いた可視光広域撮像サーベイは、暗くて数密度が低い活動銀河核 (AGN) を探査するには最適な観測です。HSCサーベイの初期データを用いて、多数の国内外の研究者がさまざまな種族のAGNを系統的に探査した結果、各種AGNの統計的性質や新たな描像が次々に明らかになってきました。ここでは、活動銀河核およびそのエネルギー源である巨大ブラックホールについて、HSCサーベイによってどんなことがわかってきたのかをご紹介します。

1. はじめに

今は昔、すばる望遠鏡が共同利用観測を開始したのは2000年のことでした。このすばる望遠鏡の素晴らしい初期成果の熱もまだ冷めやらぬ2003年に、光赤外分野の将来計画について考える検討会が発足し、当時まだ大学院生だった私もサイエンス検討班の活動銀河核 (AGN) グループの議論に加えていただく機会があったのは、本当に幸いなことでした。次に取り組むべき計画は地上超大型望遠鏡か、それともスペース望遠鏡か、という熱い議論が各サイエンス課題ごとに行われましたが、和田桂一氏 (現鹿兒島大) がチーフだったAGNグループでは、そのどちらとも異なる提言を行いました。「すばる望遠鏡のような広視野をもつ8m級の地上望遠鏡を占有的に使用し、1,000平方度級の高感度広域サーベイを行って、新たなパラメータスペースでAGNサンプルを構築すべし」という提言です。当時の私には、そんな夢のようなサーベイが実現する日がくるなどとは想像もできませんでしたが、「広さと深さを兼ね備えたサーベイ」が必要であることは検討会での議論から明

らかでした。そしてこれ以降、当時のすばる望遠鏡の主力カメラだったSuprime-Camを使えば数十平方度のサーベイなら可能かもしれないといった議論 (これは現放送大の谷口義明氏によりSubaru Wide-Field AGN Survey, 略してSWANSと名づけられました) や、COSMOS天域 (ハッブル宇宙望遠鏡による宇宙進化サーベイがカバーする領域) の約2平方度のSuprime-Camデータを用いた可視光クェーサー探査^{1),2)} (これは現国立天文台の池田浩之氏による、小規模ながらも先駆的な研究でした) など、今から思い返せばHyper Suprime-Cam (HSC) によるAGNサーベイにつながるさまざまな取り組みが行われ、徐々に可視光広域AGN探査に向けた国内の機運が高まっていきました。

HSCプロジェクトが発足し、HSCすばる戦略枠観測 (HSC-SSP) に向けたサーベイ立案の検討が開始されると、SWANS検討チームを発展的に解消して国際化する形でHSC-AGNワーキンググループ (WG) のコアが形成されるようになりました。このHSC-AGN WGは発足当初は筆者 (長尾透) とプリンストン大のMichael Strauss氏 (長尾透) がチェアとして全体のとりまとめを行い、2018

HSC-SSP によるAGNサイエンス



Hyper Suprime-Cam (HSC)

満月の典型的な見かけの大きさ (視直径 0.5 度角)

Andromeda Galaxy (M31)

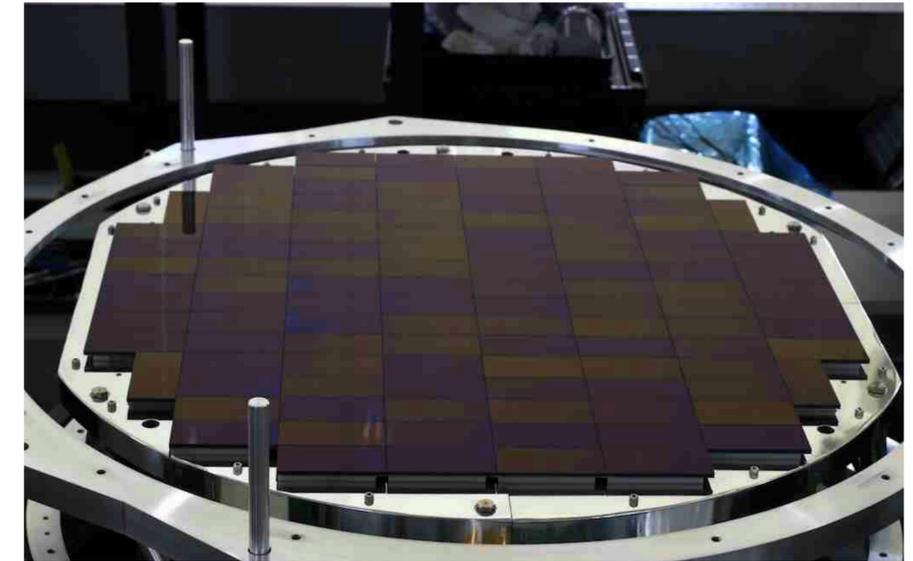
1.5 degree

Suprime-Cam
ファーストライト
(1999年1月公開)

Suprime-Cam
(2001年9月公開)

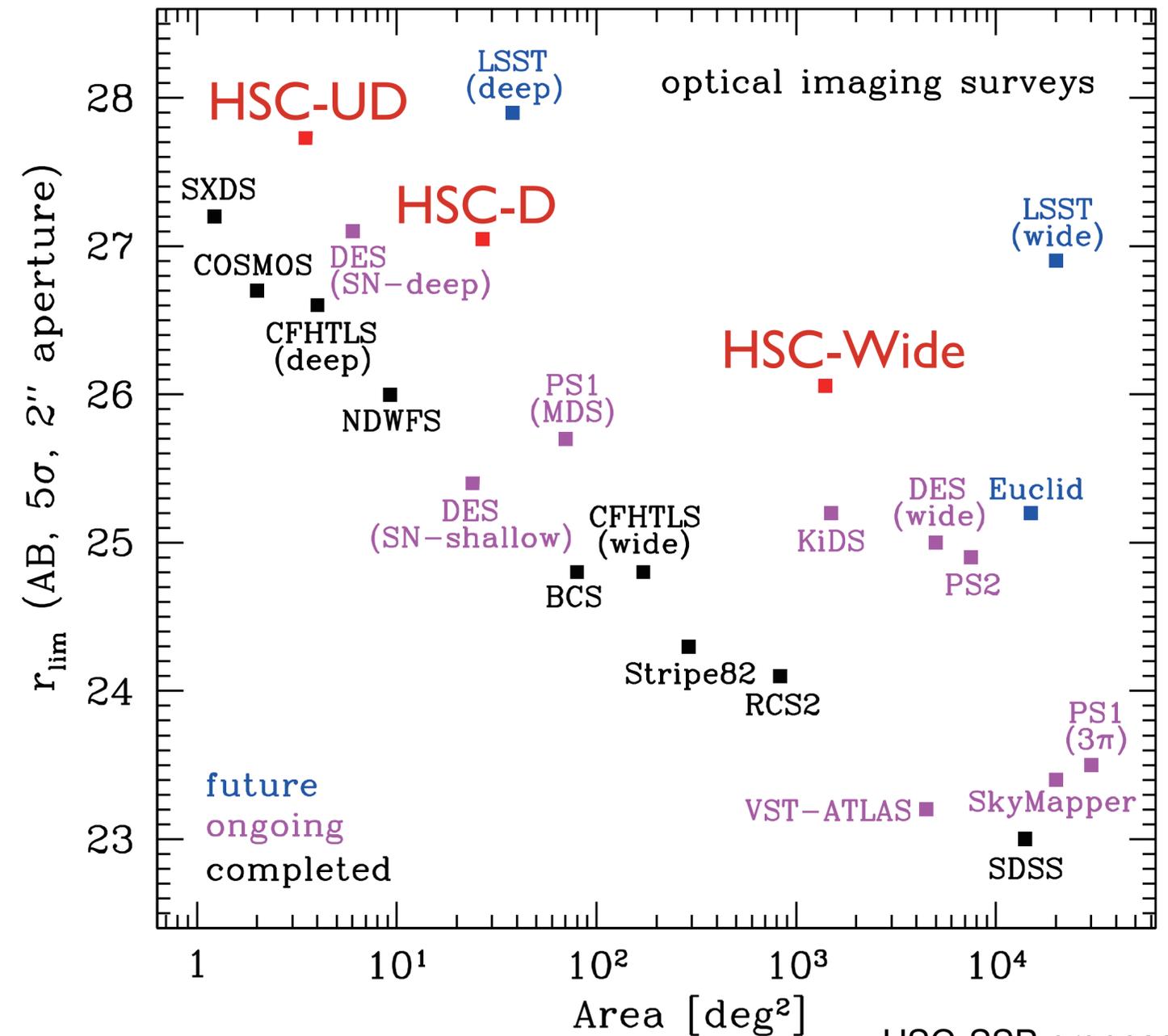
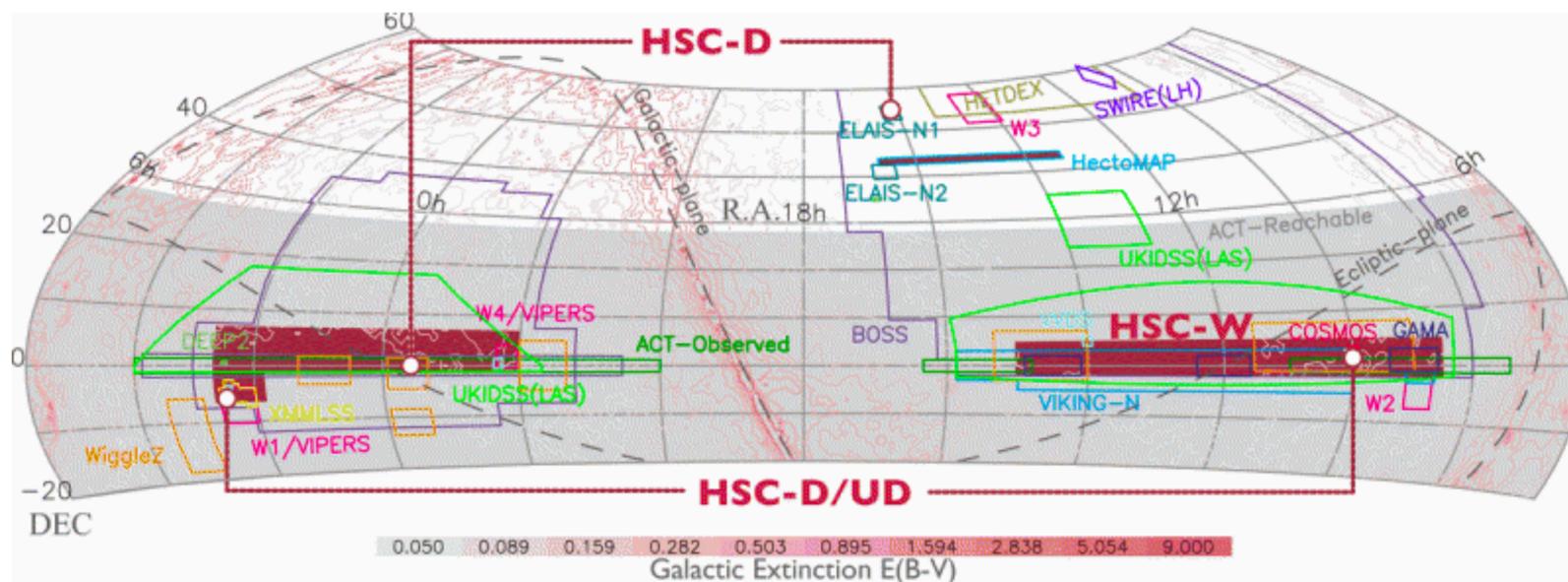
Hyper Suprime-Cam
(2013年7月公開)

The image shows a comparison of the fields of view of three astronomical cameras. On the left is a full moon, labeled with its typical apparent size of 0.5 degrees. In the center is the Andromeda Galaxy (M31), with a yellow double-headed arrow indicating a 1.5-degree width. On the right is a small inset image of the galaxy. Below these are three camera images: a small diamond-shaped field for Suprime-Cam (first light, Jan 1999), a larger rectangular field for Suprime-Cam (Sep 2001), and a very large circular field for Hyper Suprime-Cam (Jul 2013).



HSC Subaru Strategic Program (HSC-SSP)

- 330晩 (2014.3-2022.1) を投入 **【完遂】**
- 約1000平方度にわたる 5-band 撮像データ
- 約30平方度にわたる 5-band (+ 4 narrow-band) データ
- 2024年5月頃に**最終カタログが内部公開予定**



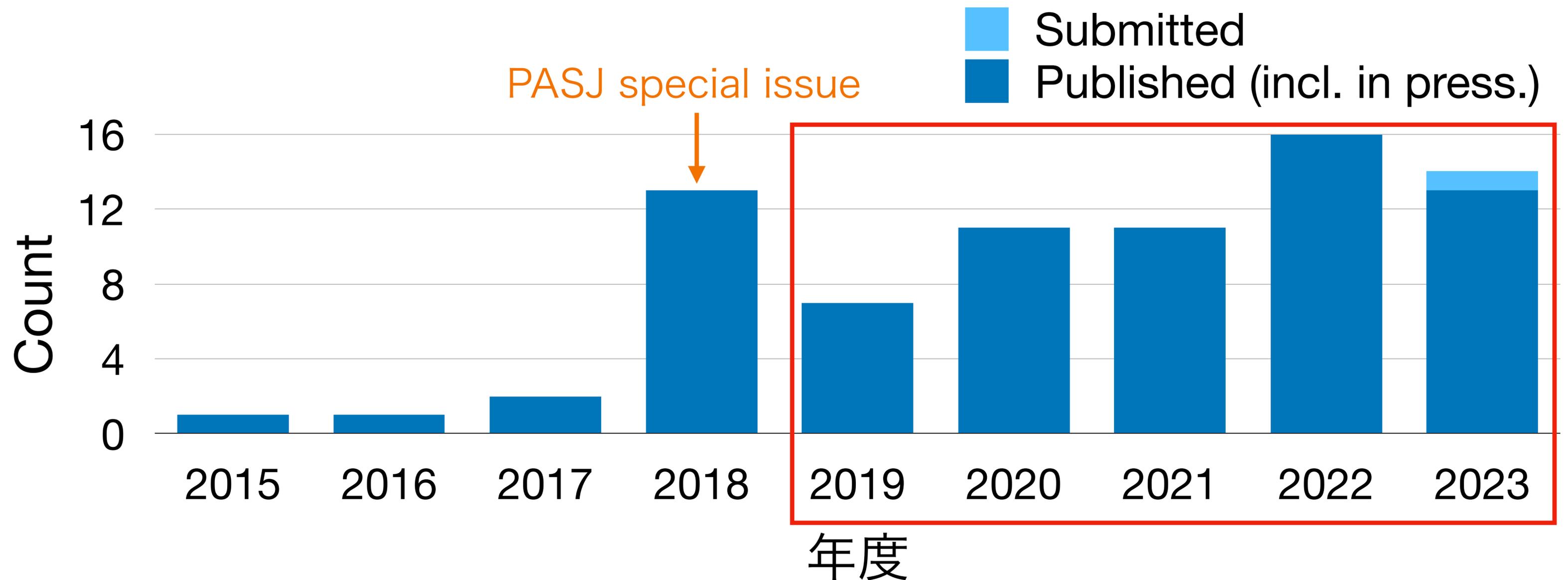
HSC-SSP proposal より

<https://hsc.mtk.nao.ac.jp/ssp/survey/>

AGN sciences with HSC-SSP: Publication Status

※ HSC-SSP AGN WG member による成果のみ掲載

これまでに約80本の論文が発表済み



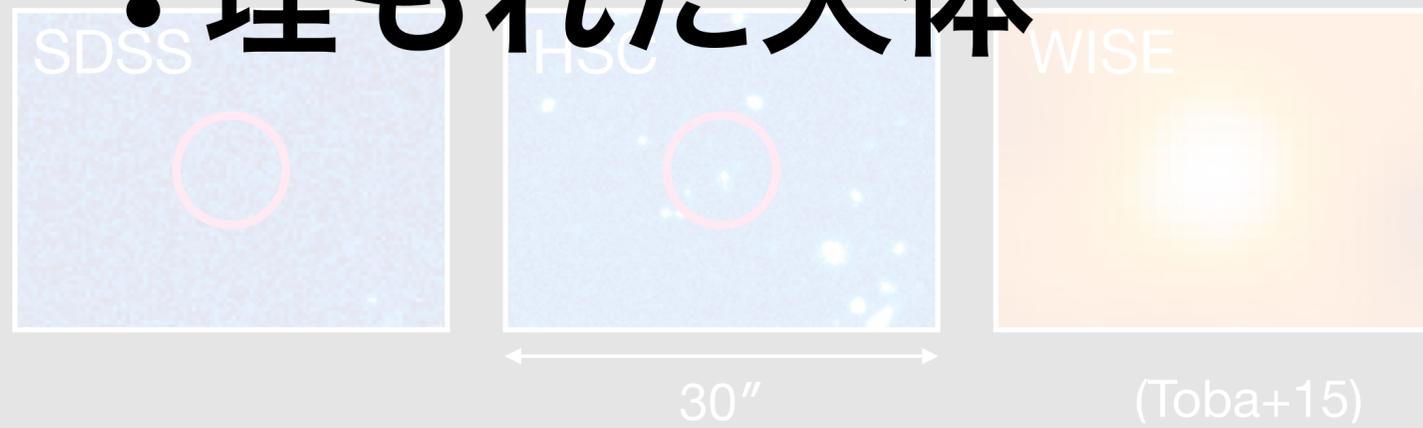
(広視野に加えて) HSCのここがすごい!



High sensitivity

- 遠方天体

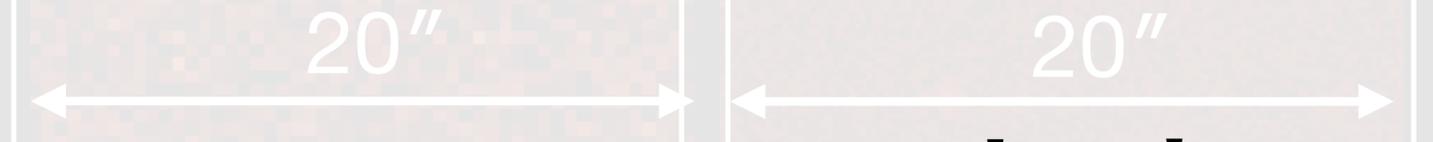
- 埋もれた天体



High image quality

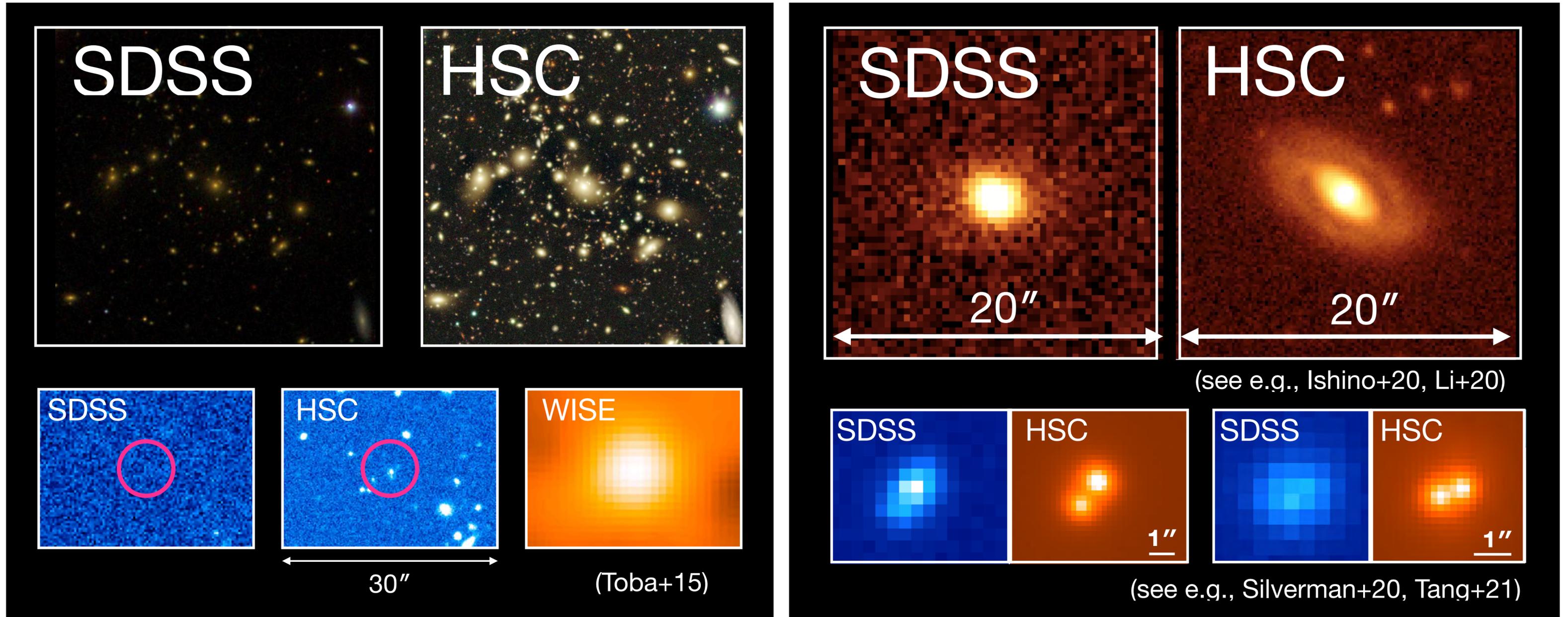
- AGN母銀河形態

- dual-AGN 探査



(see e.g., Silverman+20, Tang+21)

(広視野に加えて) HSCのここがすごい！



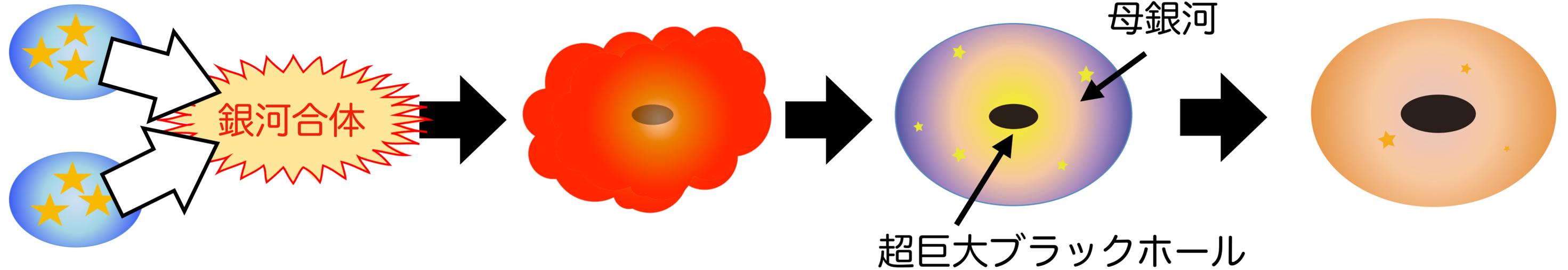
超巨大ブラックホール・母銀河の成長、進化

ガスが豊富な銀河

塵に埋もれたAGN

クエーサー

楕円銀河



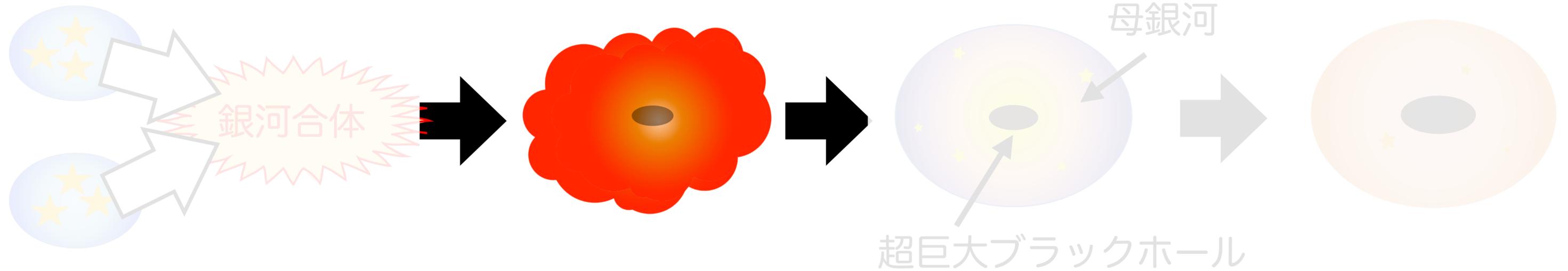
超巨大ブラックホール・母銀河の成長、進化

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塵に埋もれたAGN

クエーサー

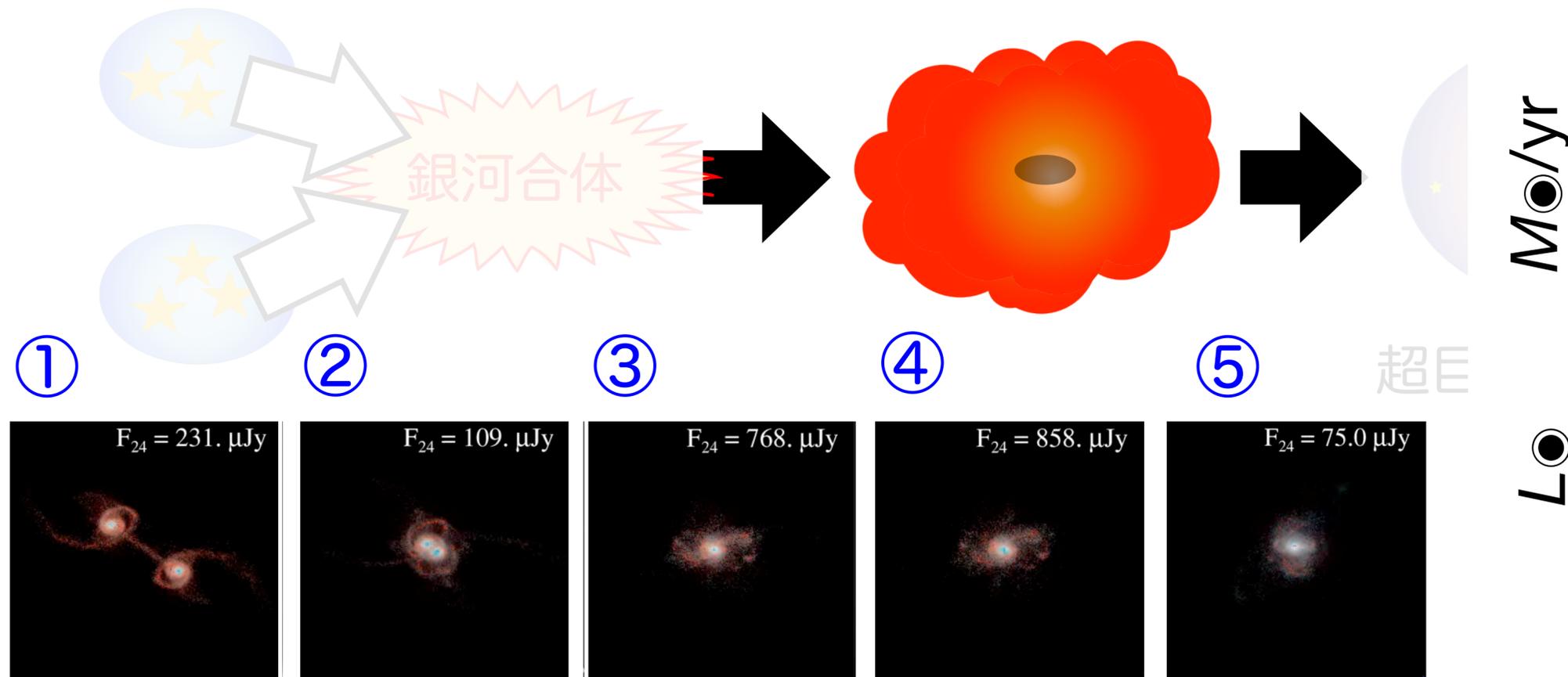
楕円銀河



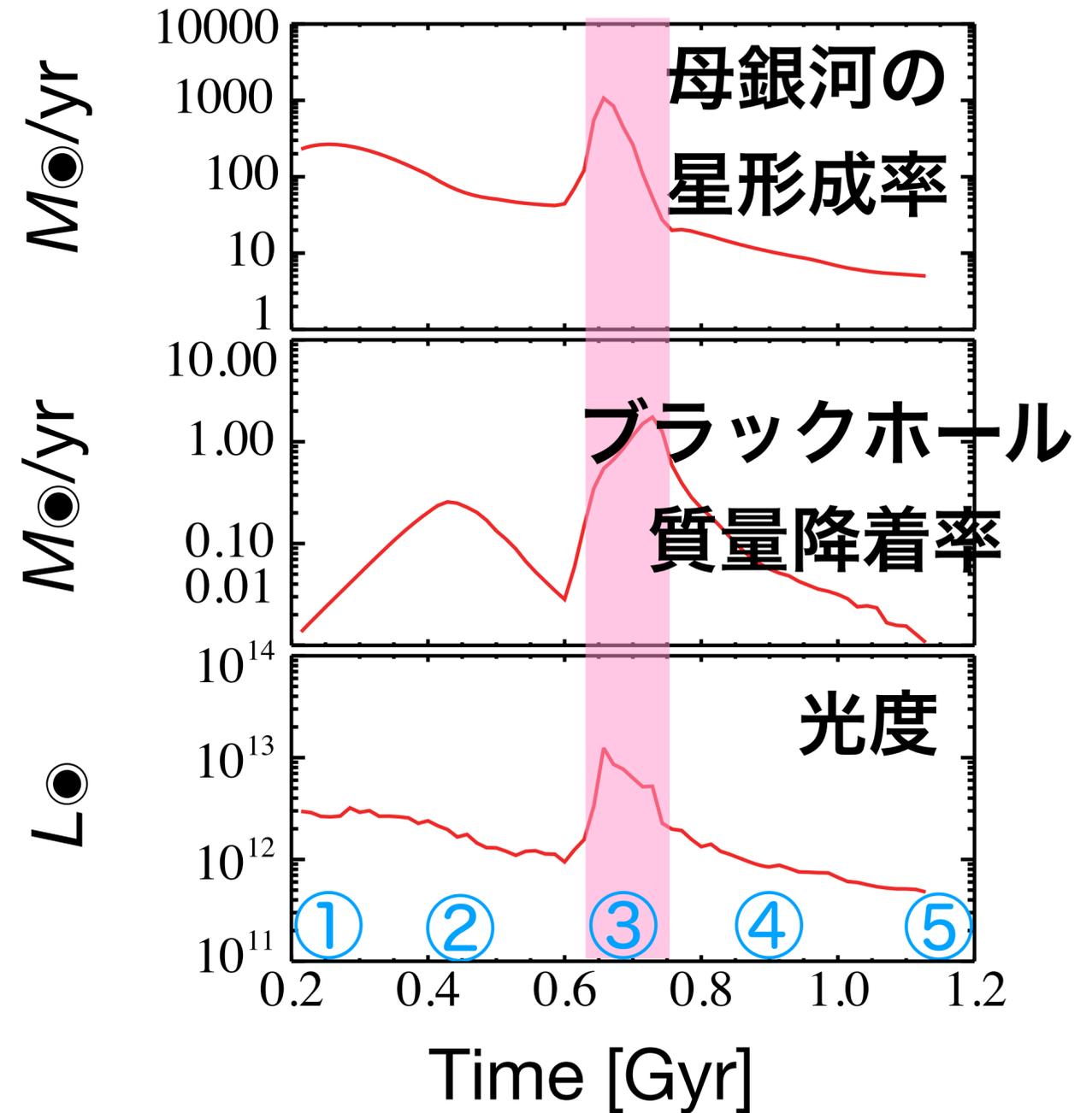
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ガスが豊富な銀河

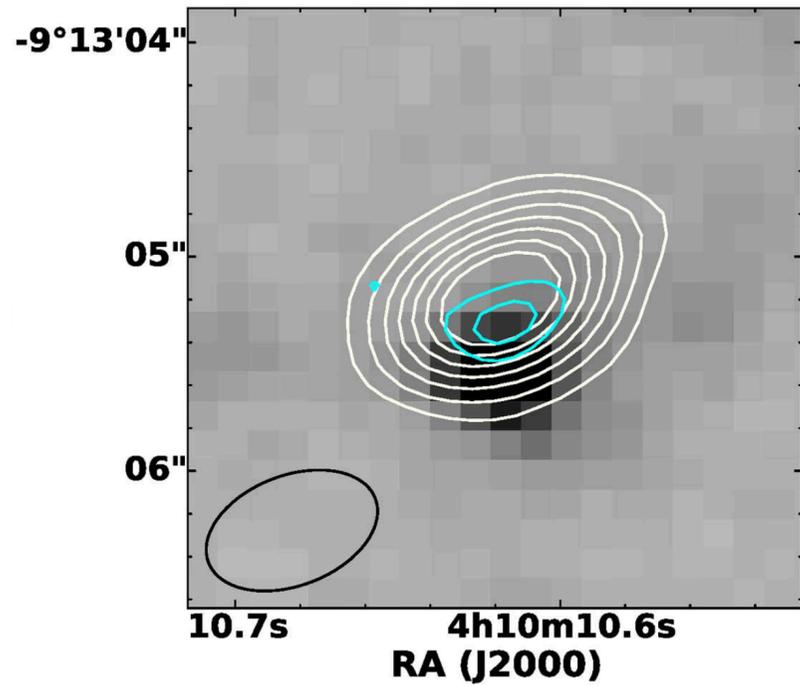
塵に埋もれたAGN



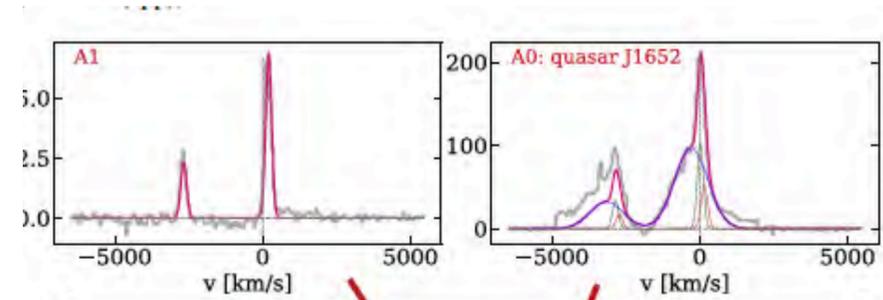
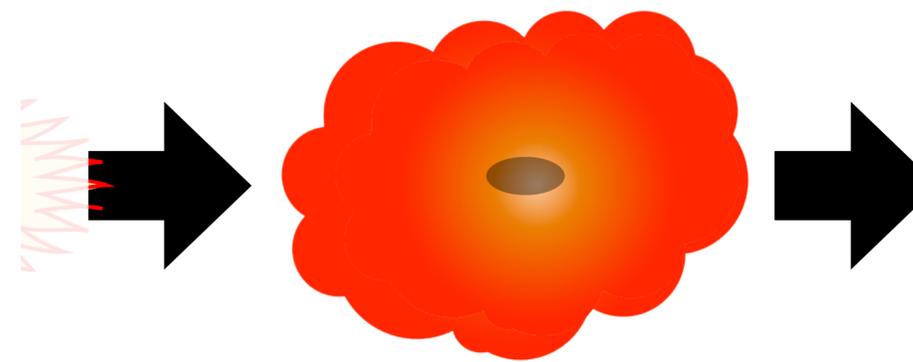
Narayanan et al. (2010)



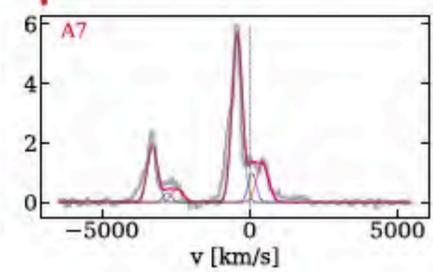
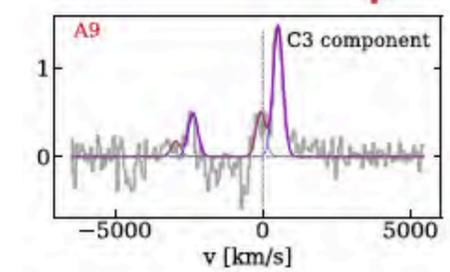
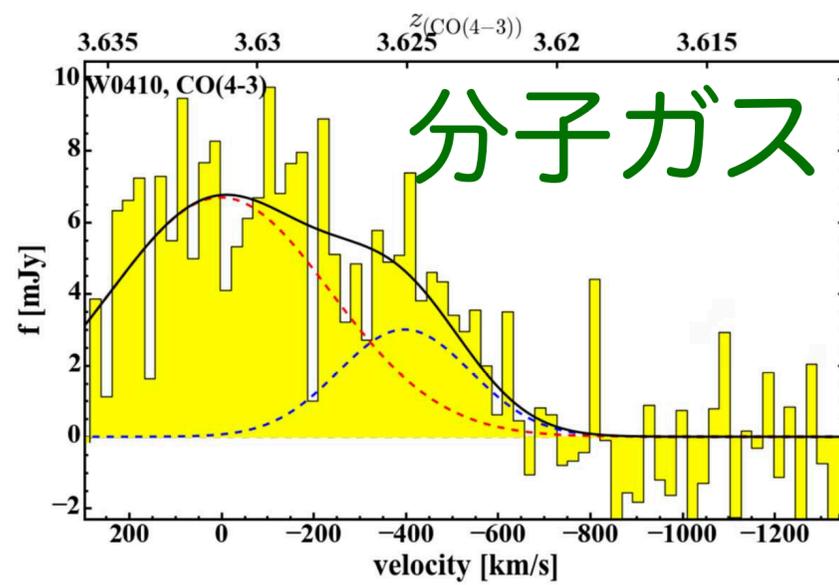
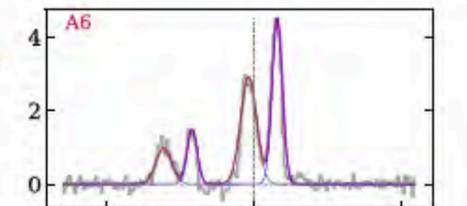
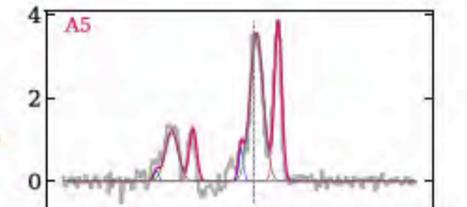
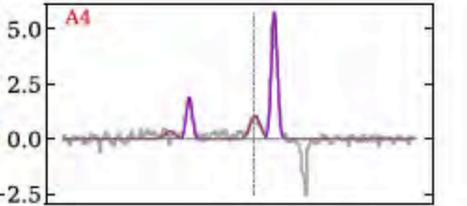
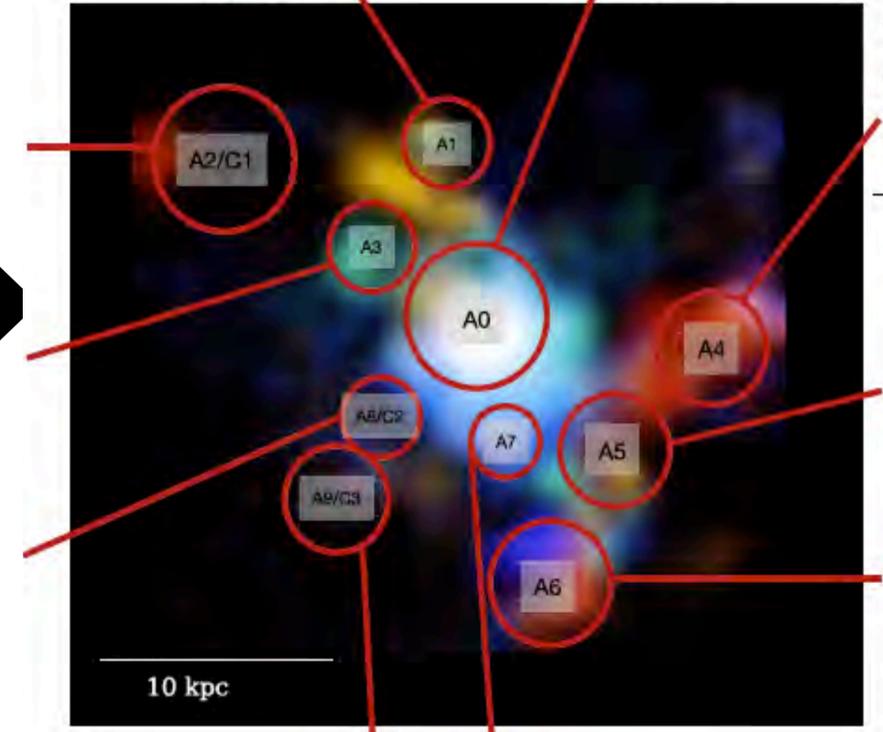
超巨大ブラックホール・母銀河の成長、進化



塵に埋もれたAGN



電離ガス



Wylezalek+22

Fan+18

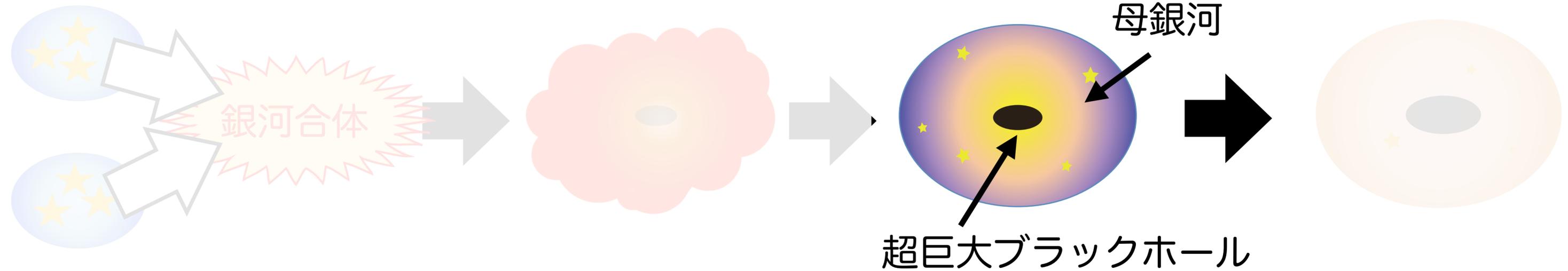
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ガスが豊富な銀河

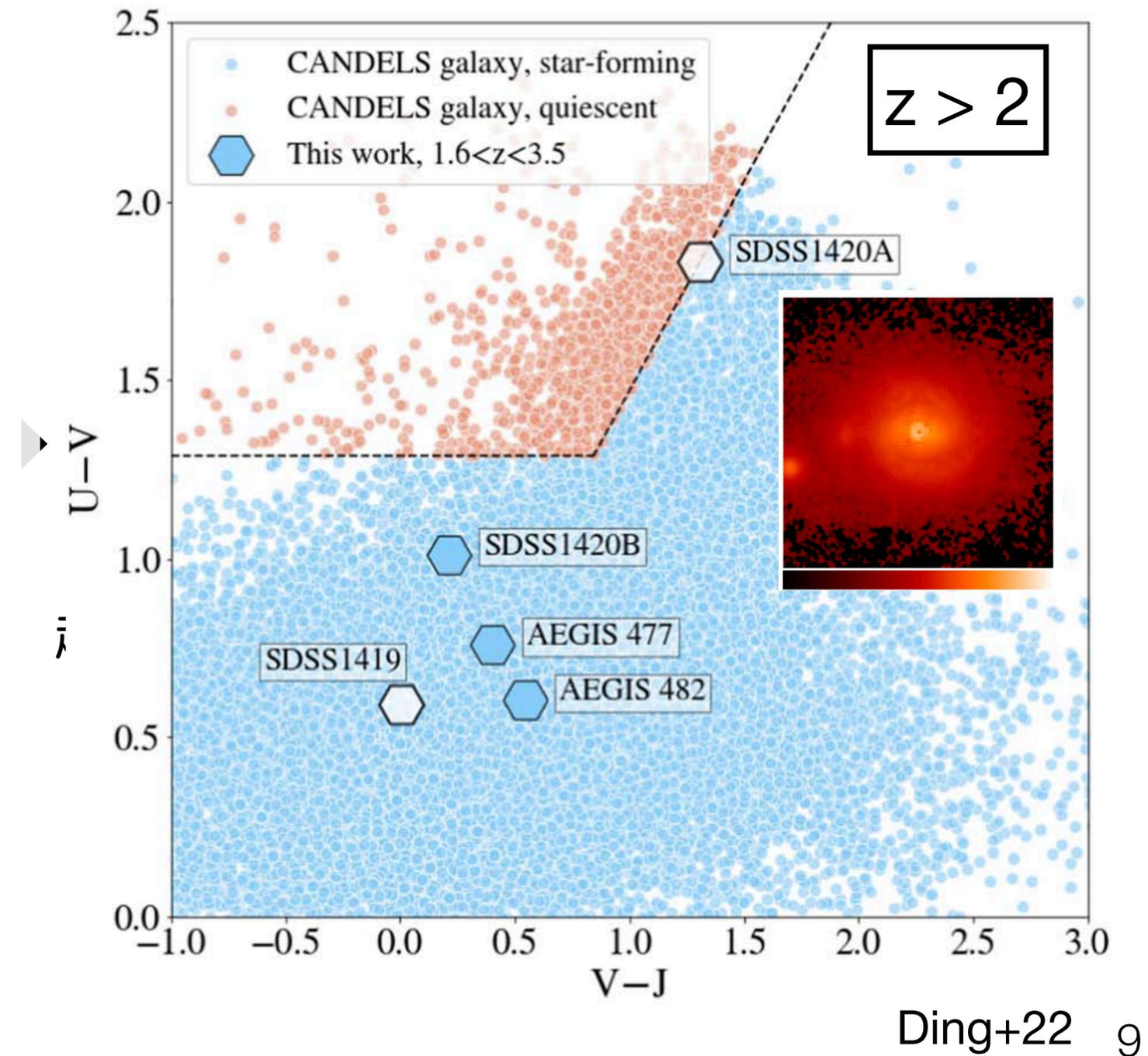
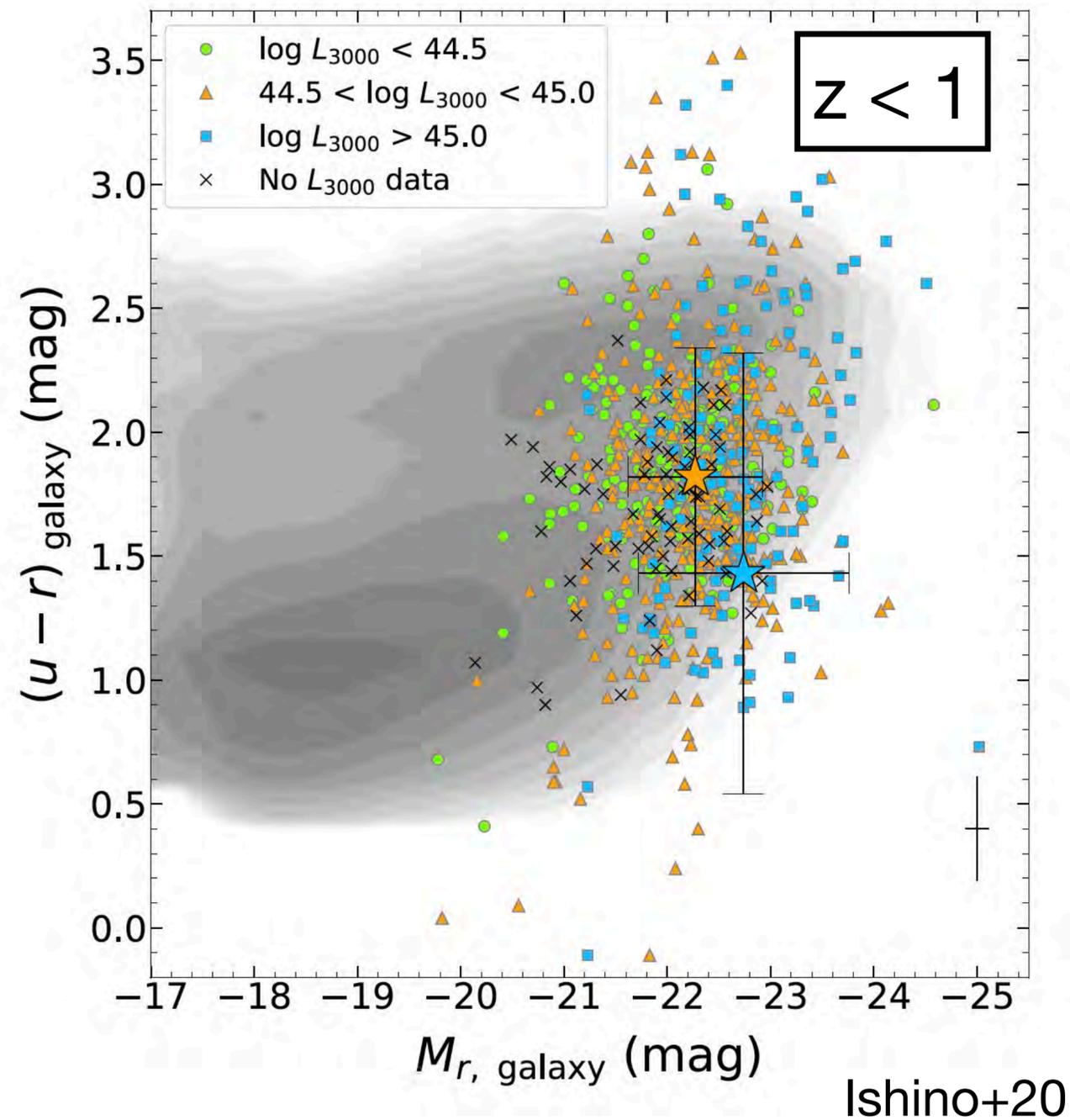
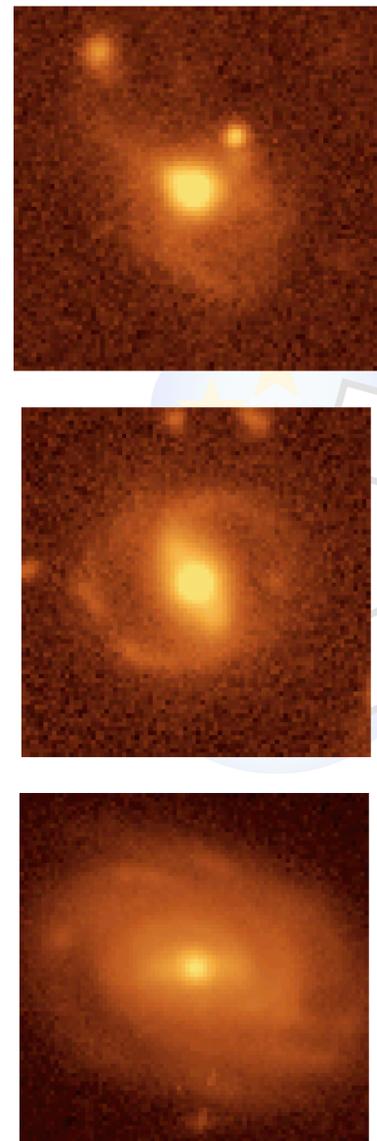
塵に埋もれたAGN

クエーサー

楕円銀河



超巨大ブラックホール・母銀河の成長、進化



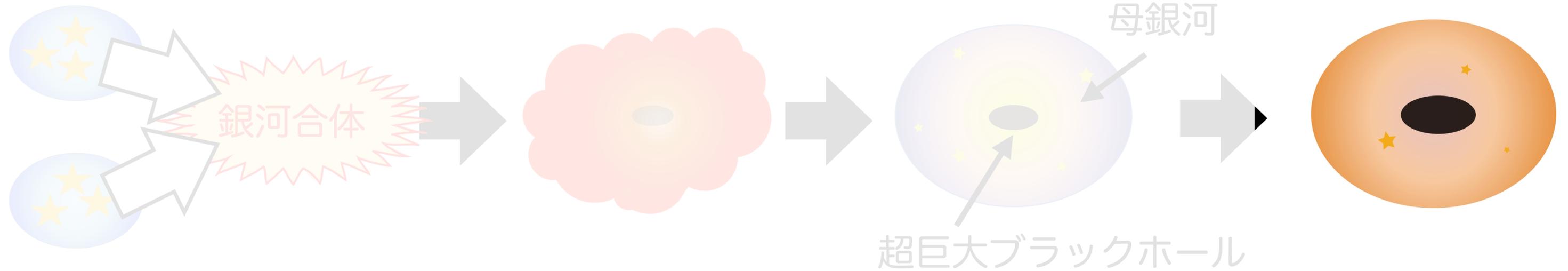
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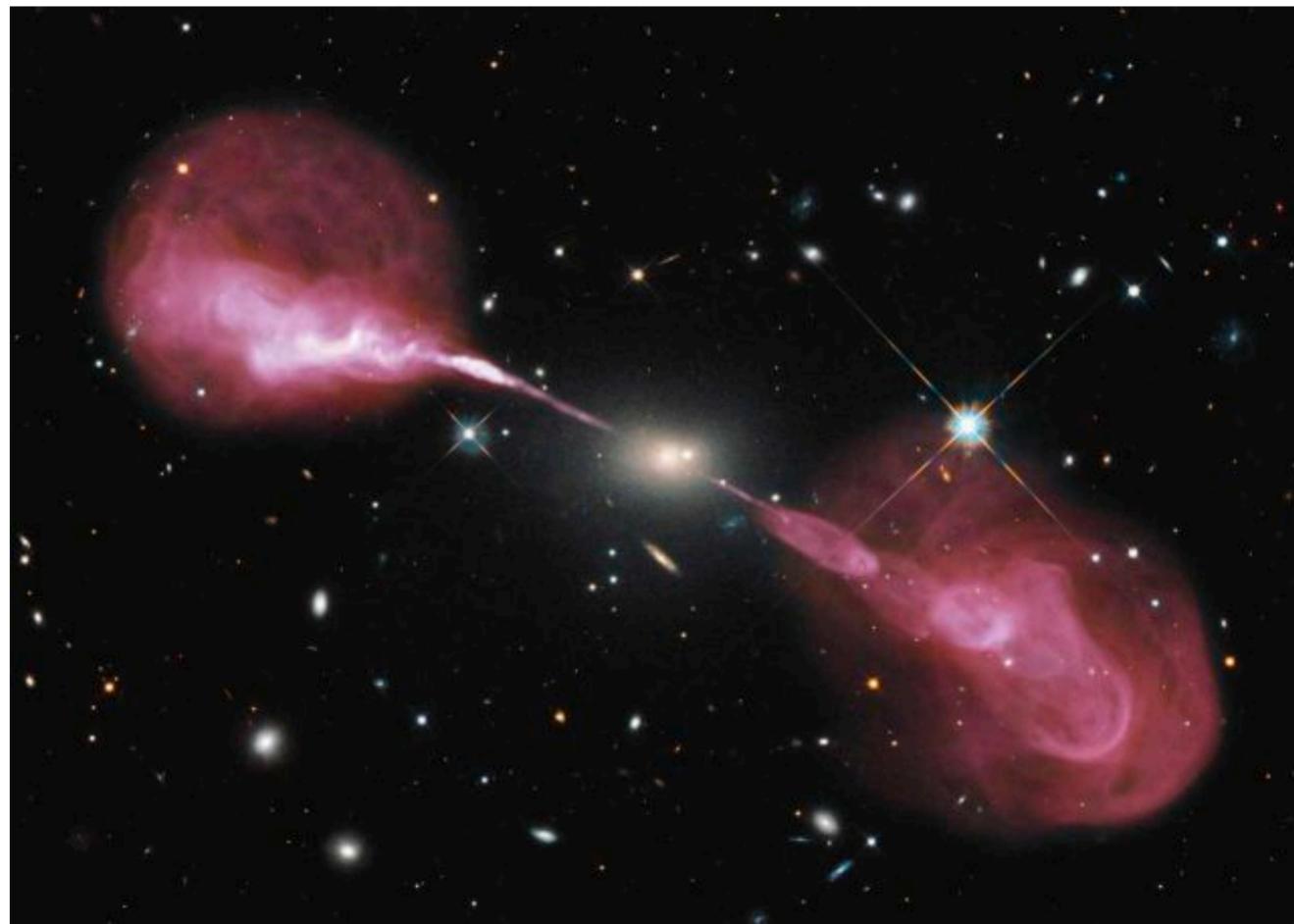
塵に埋もれたAGN

クエーサー

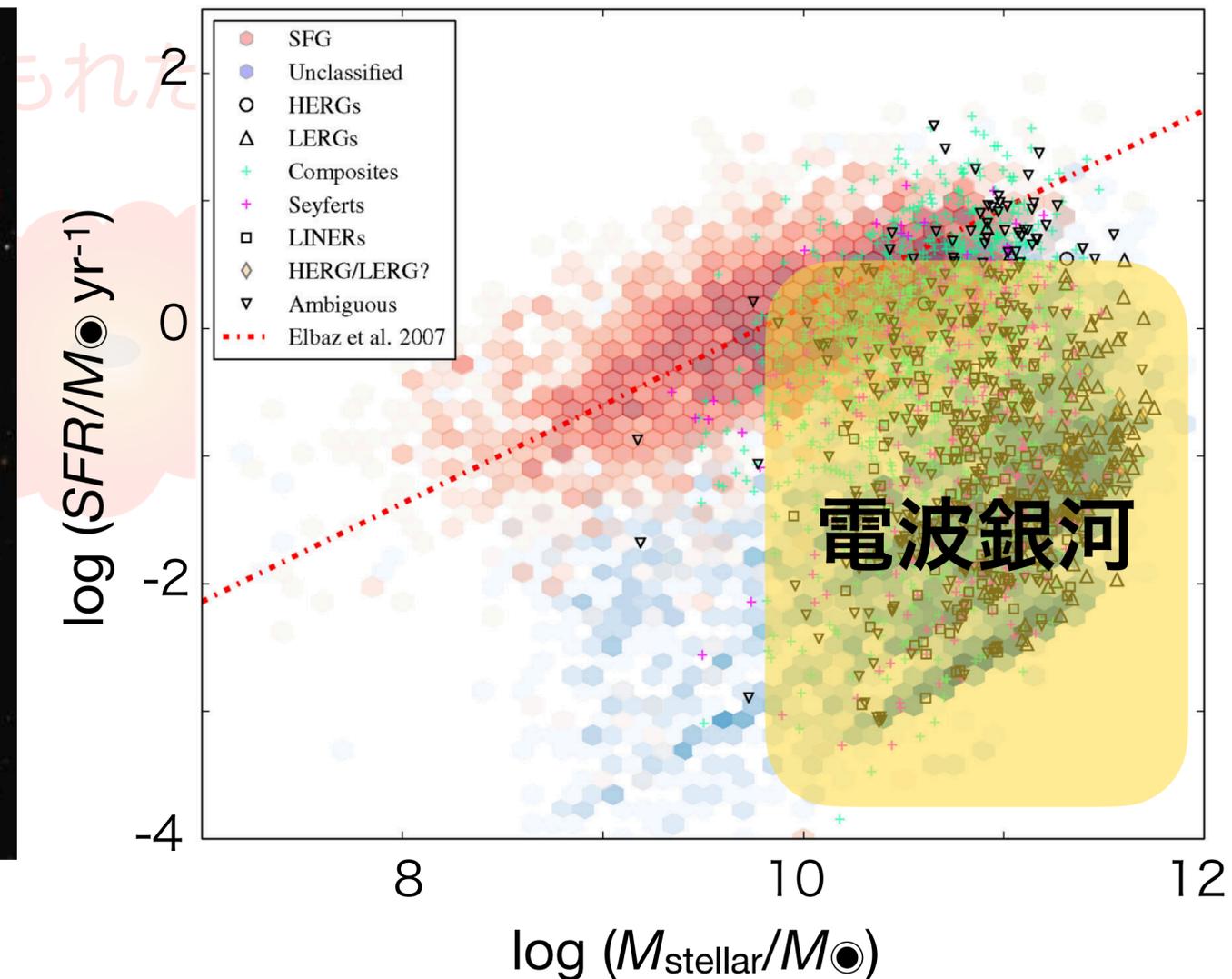
楕円銀河



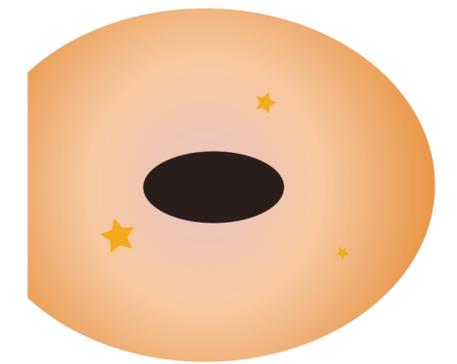
超巨大ブラックホール・母銀河の成長、進化



<https://esahubble.org/images/opo1247a/>



楕円銀河



Gürkan+18

超巨大ブラックホール・母銀河の成長、進化

ガスが豊富な銀河

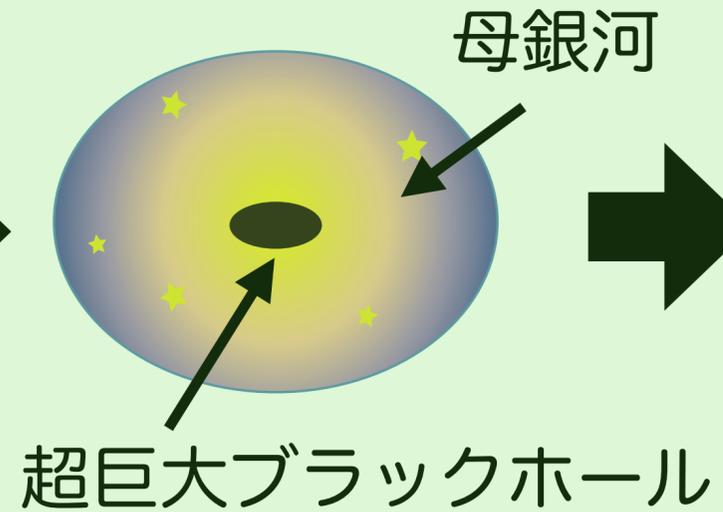


環境効果

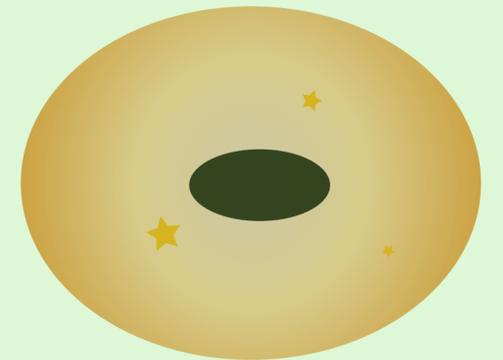
塵に埋もれたAGN



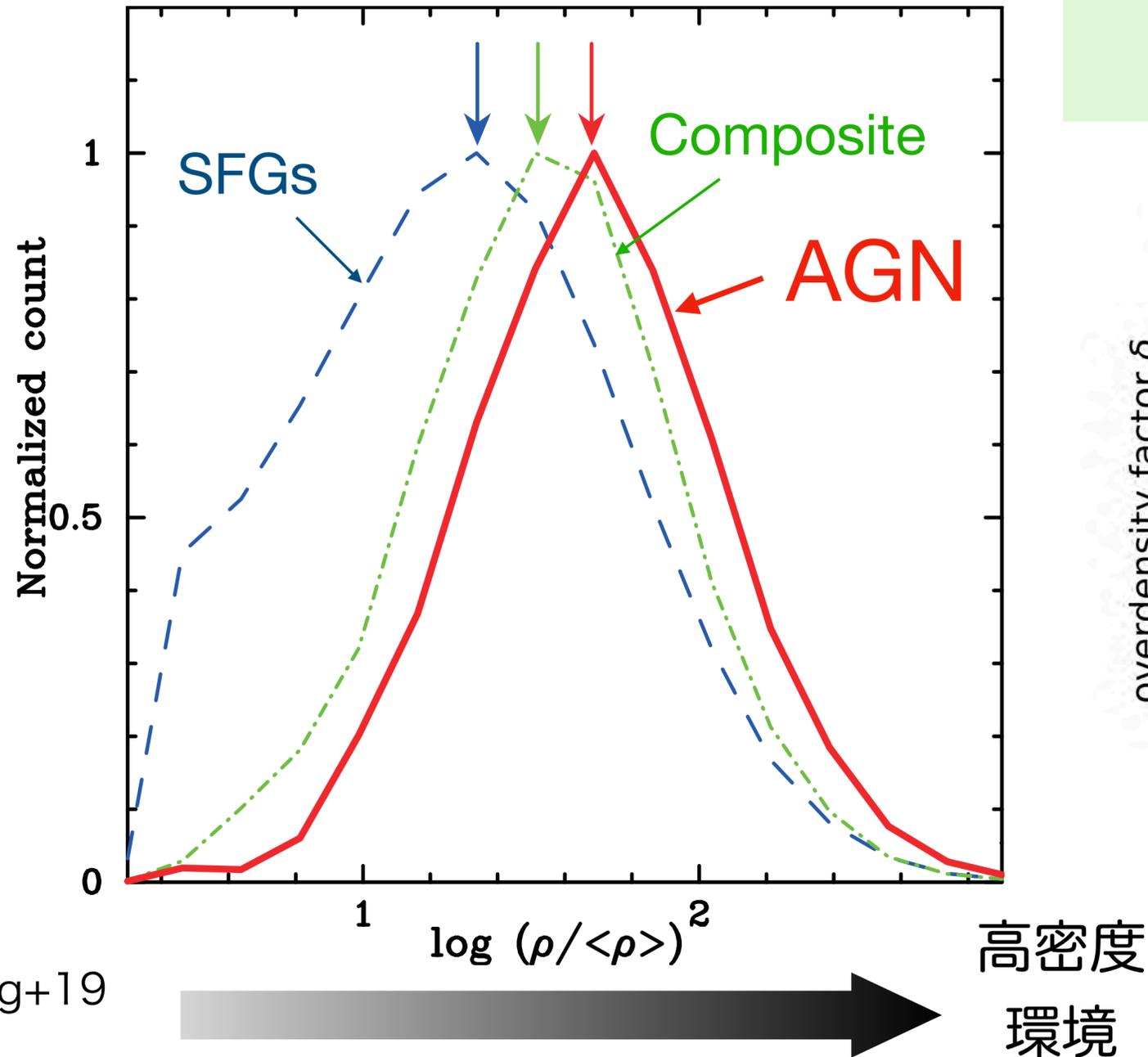
クエーサー



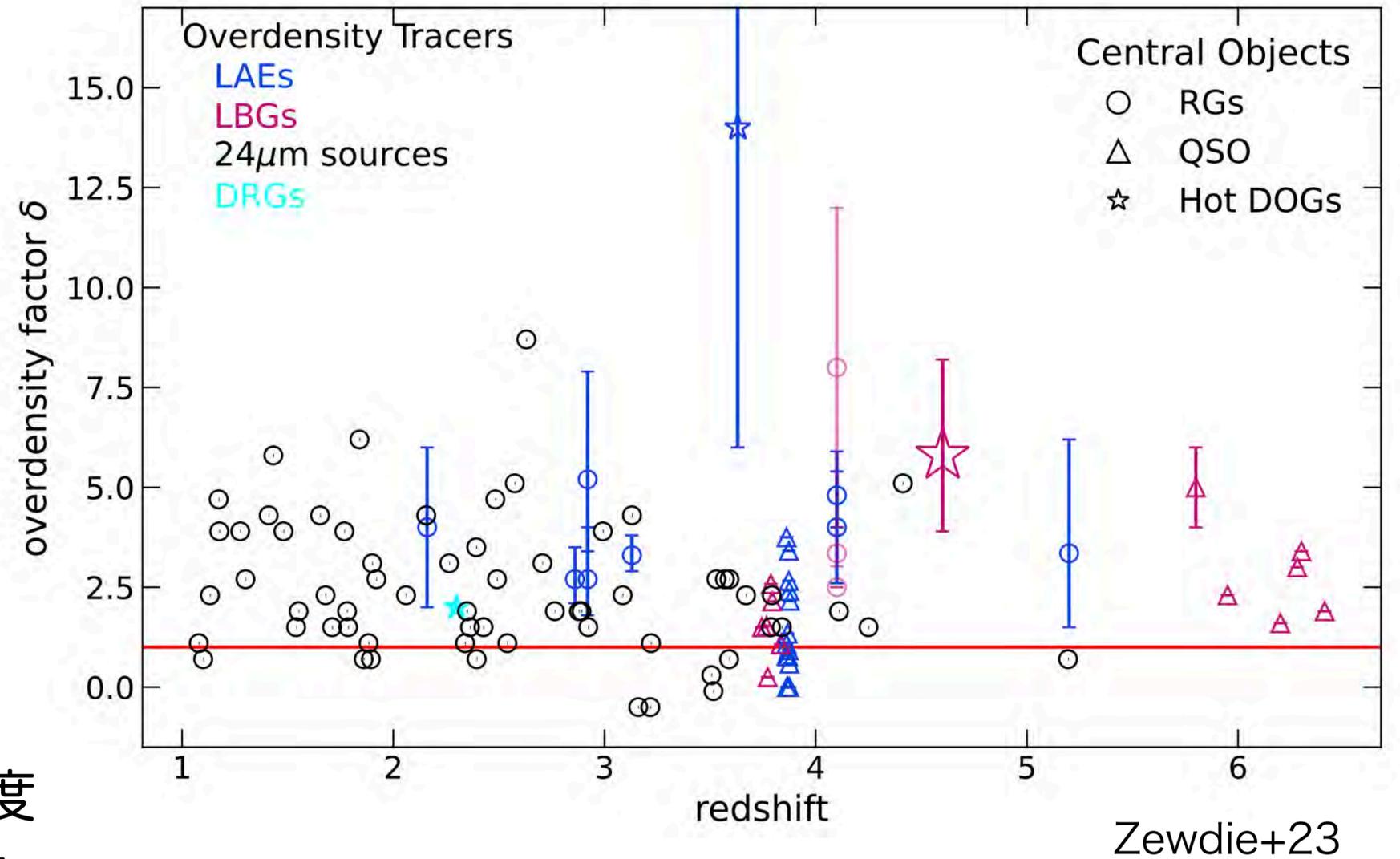
楕円銀河



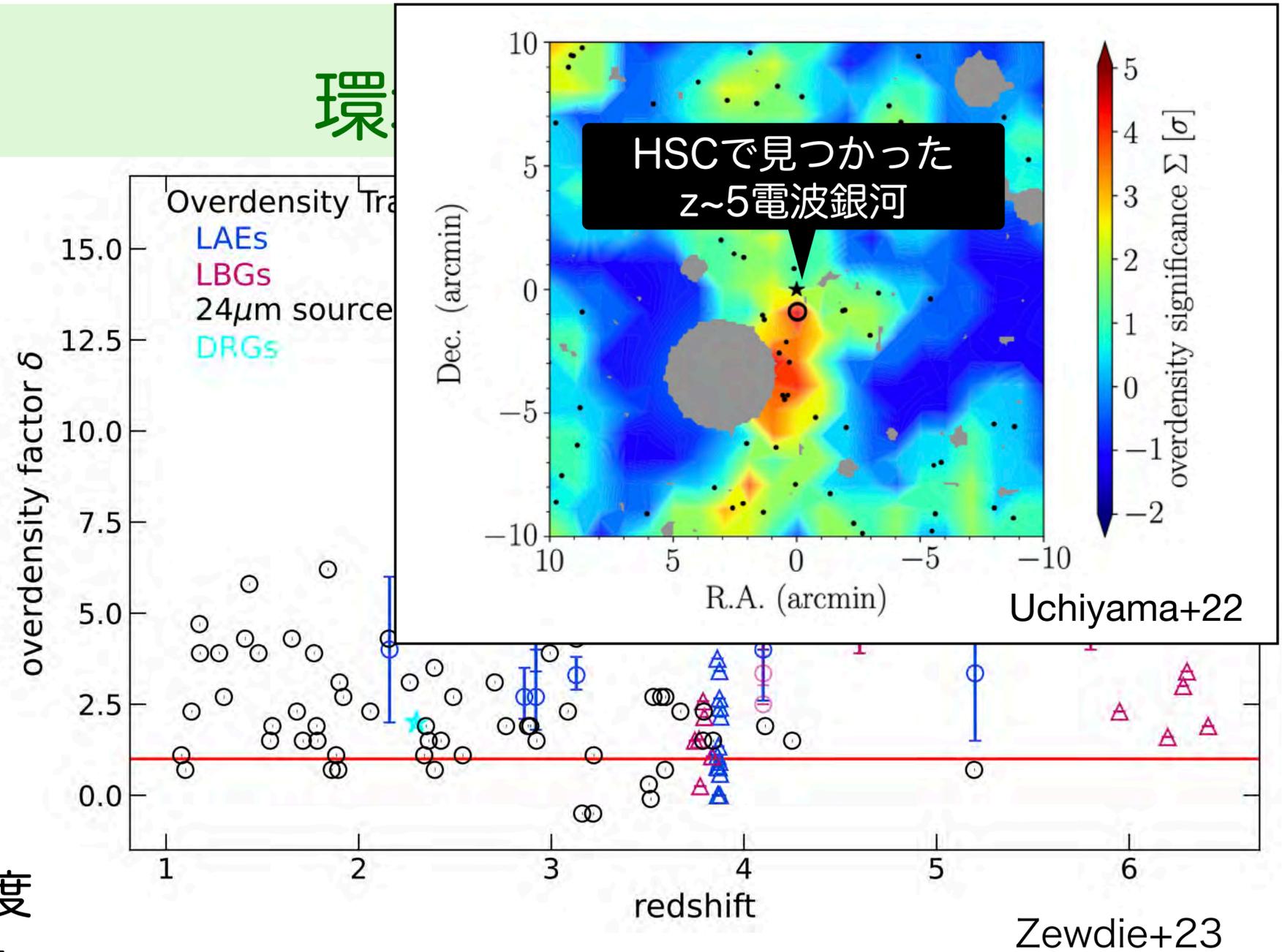
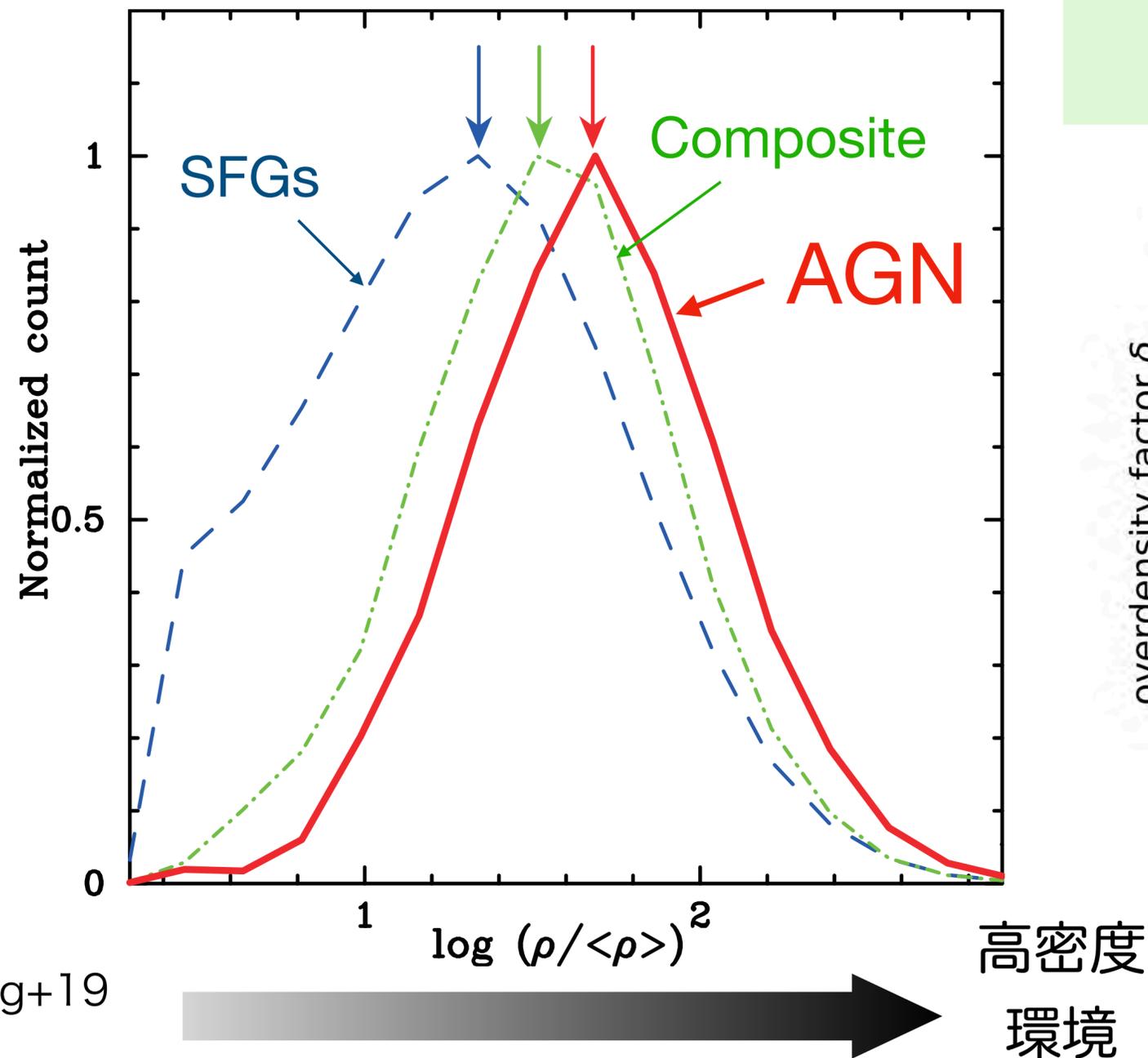
超巨大ブラックホール・母銀河の成長、進化



環境効果



超巨大ブラックホール・母銀河の成長、進化



超巨大ブラックホール・母銀河の成長、進化

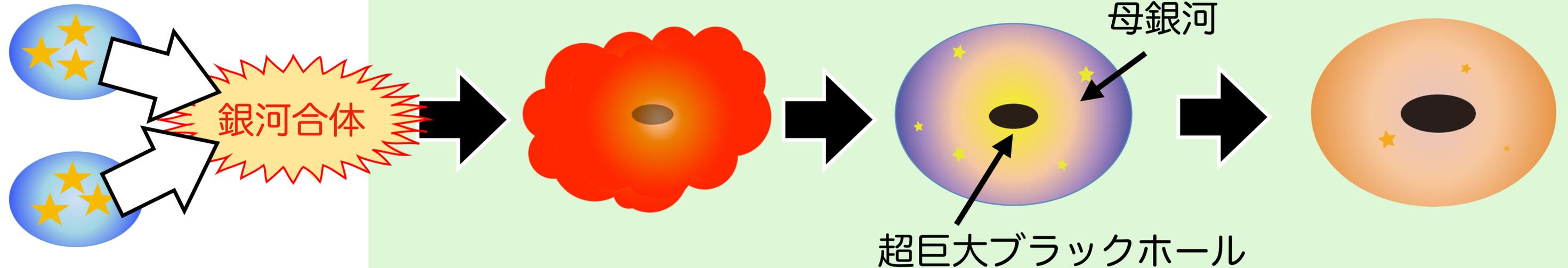
環境効果

ガスが豊富な銀河

塵に埋もれたAGN

クエーサー

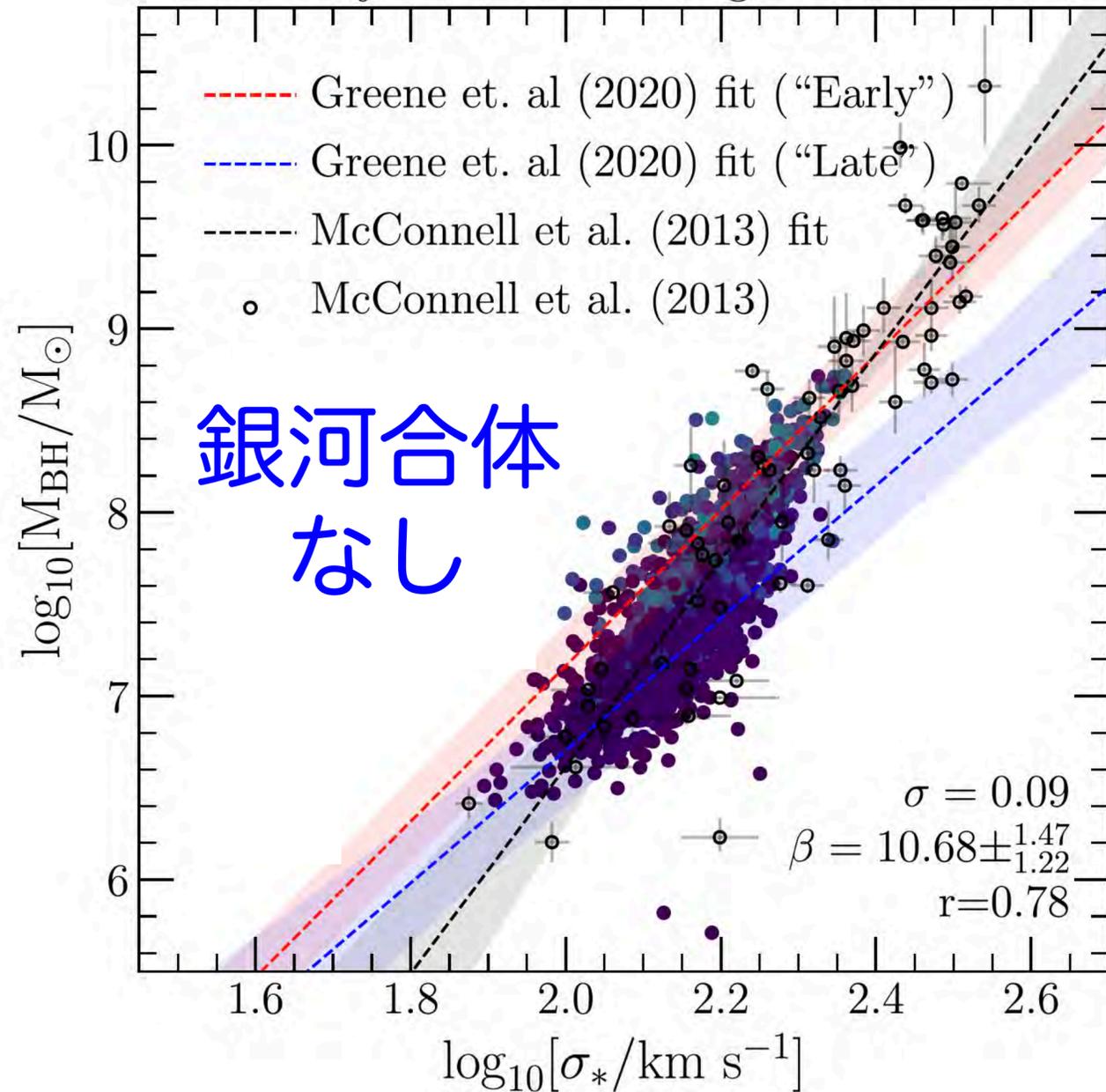
楕円銀河



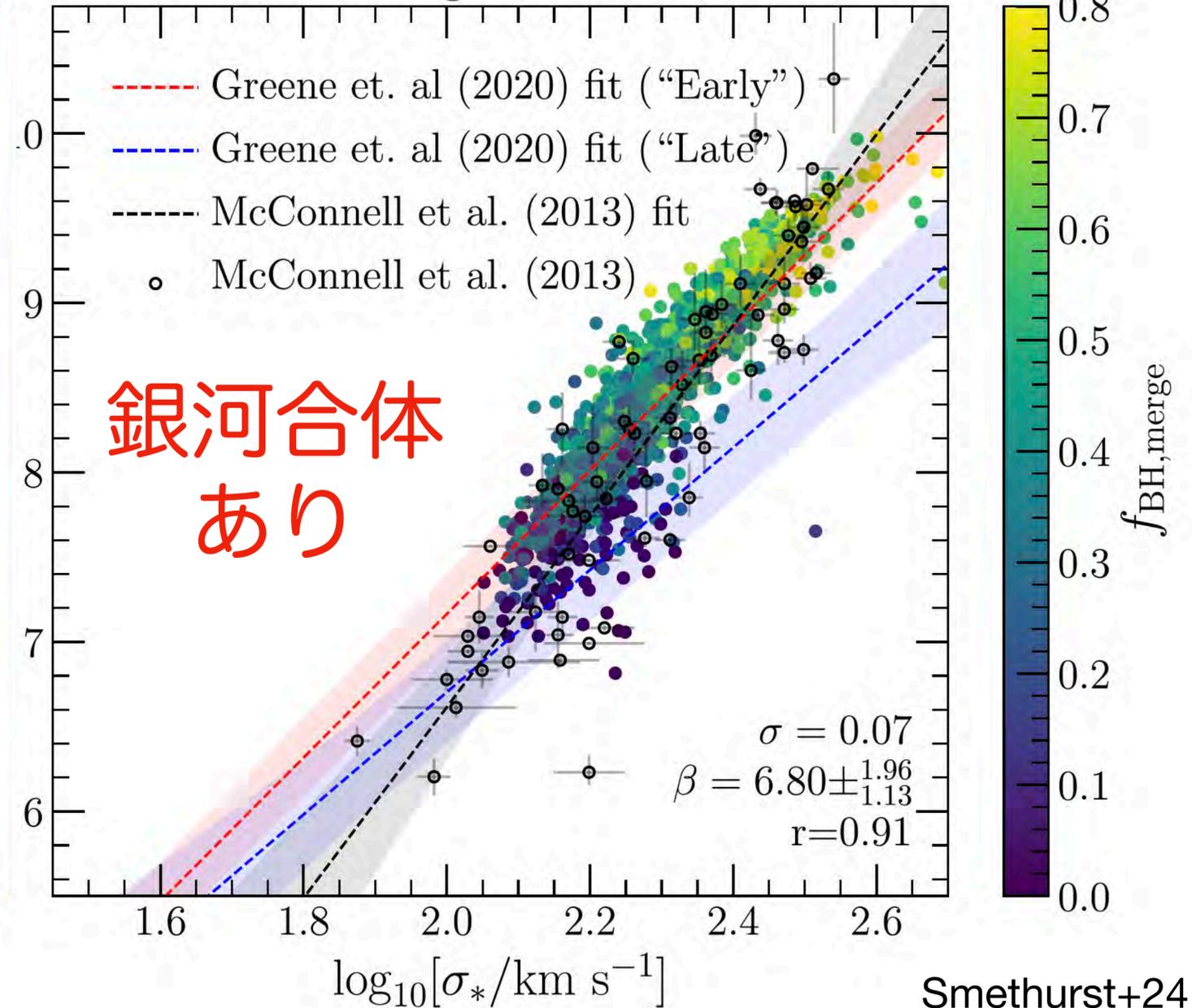
そもそもこのシナリオがどのくらい正しいのか・普遍的なのか

超巨大ブラックホール・母銀河の成長、進化

No major or minor mergers since $z=2$



> 3 mergers since $z=2$



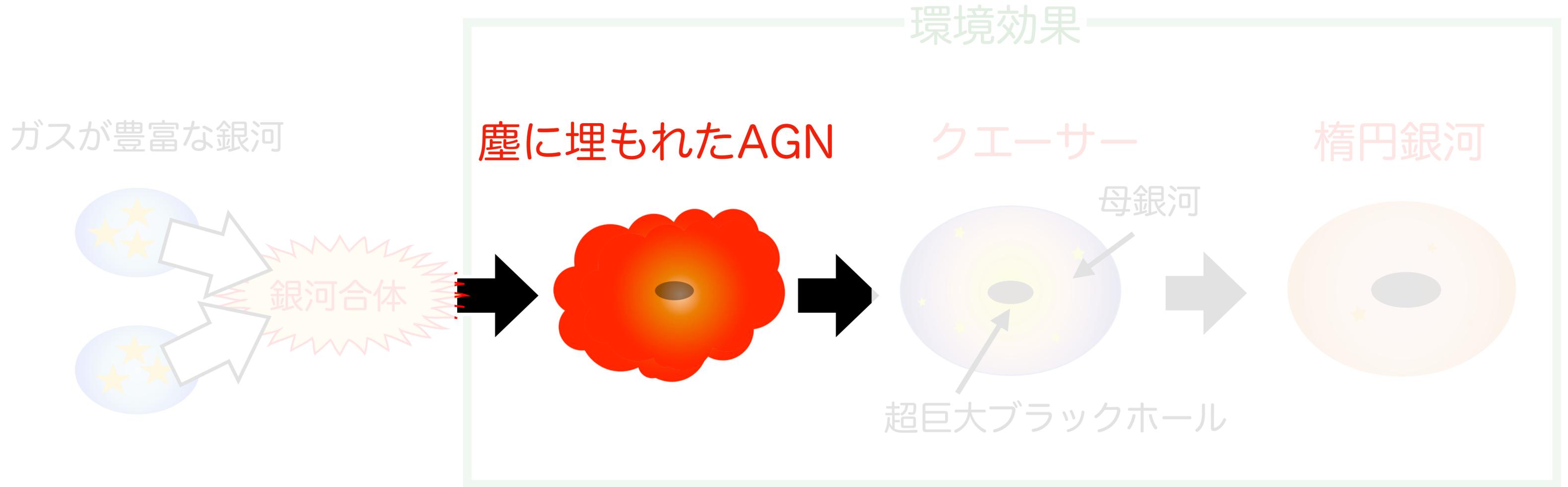
ガス

そも

e.g., Sa

すばるHSC によるAGNサイエンス

IR-AGN



Dust-obscured galaxies (DOGs)



$$i - [22] > 7.0 \text{ (AB mag)}$$

物理量	典型値
個数密度	$\phi \sim 10^{-7} [\text{Mpc}^{-3}]$
DM halo mass	$M_h \sim 10^{13.6} M_\odot$
星質量・星形成率	$M_{\text{stellar}} \sim 10^{10} M_\odot$ $\text{SFR} \sim 10^{2-3} M_\odot/\text{yr}$
ダスト・ガス質量	$M_{\text{dust}} \sim 10^8 M_\odot$ $M_{\text{gas}} \sim 10^{10} M_\odot$
副産物	Compton-thick AGN 極超高光度赤外線銀河

赤外線フラックス

Radio-loud DOGs
(Fukuchi, Ichikawa+)

IR-bright DOGs
(Toba+)

BluDOGs
(Noboriguchi+)

IR-faint DOGs
(Dey+)

類似性
(登口さん講演)

JWST ERO

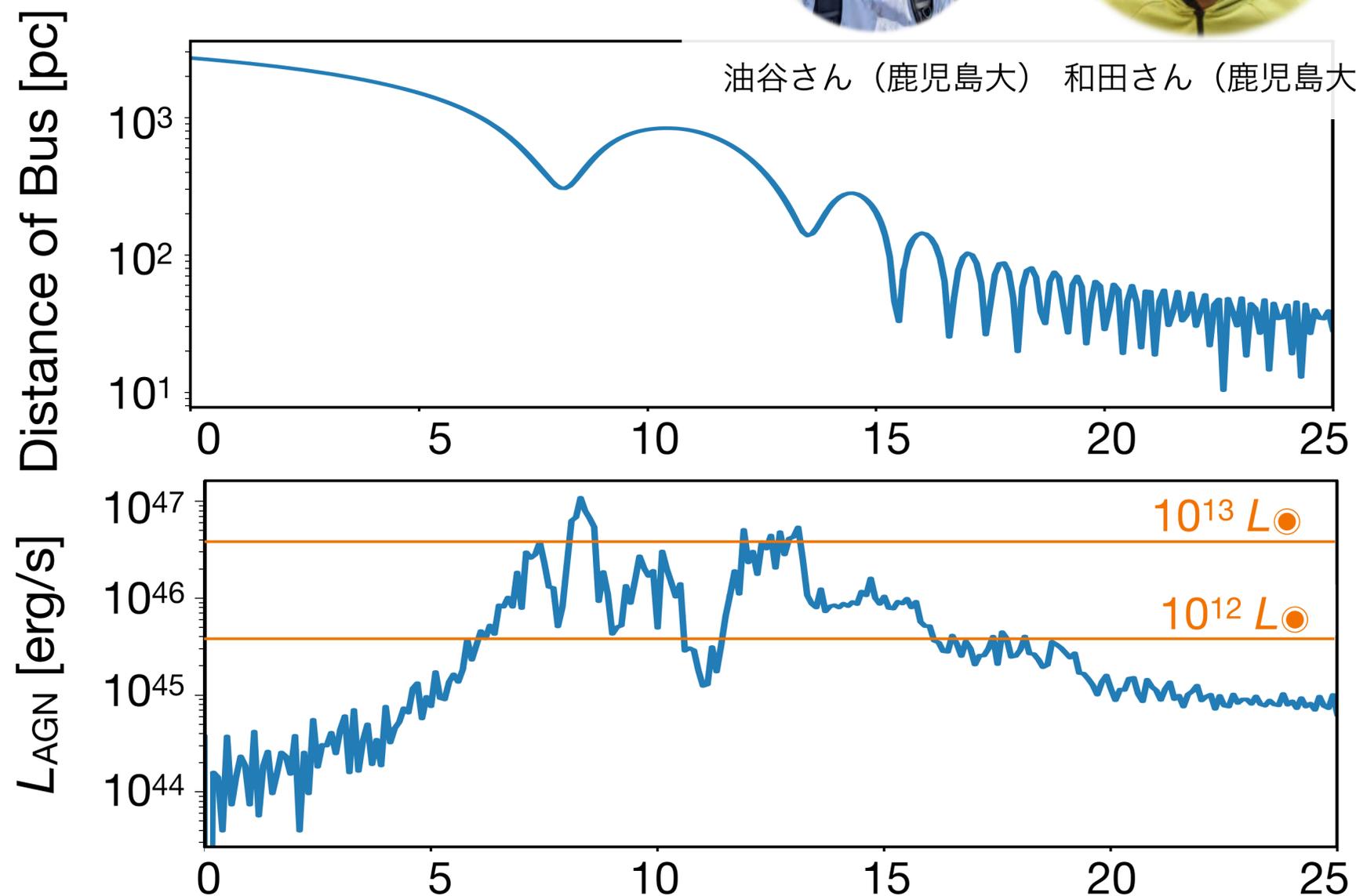
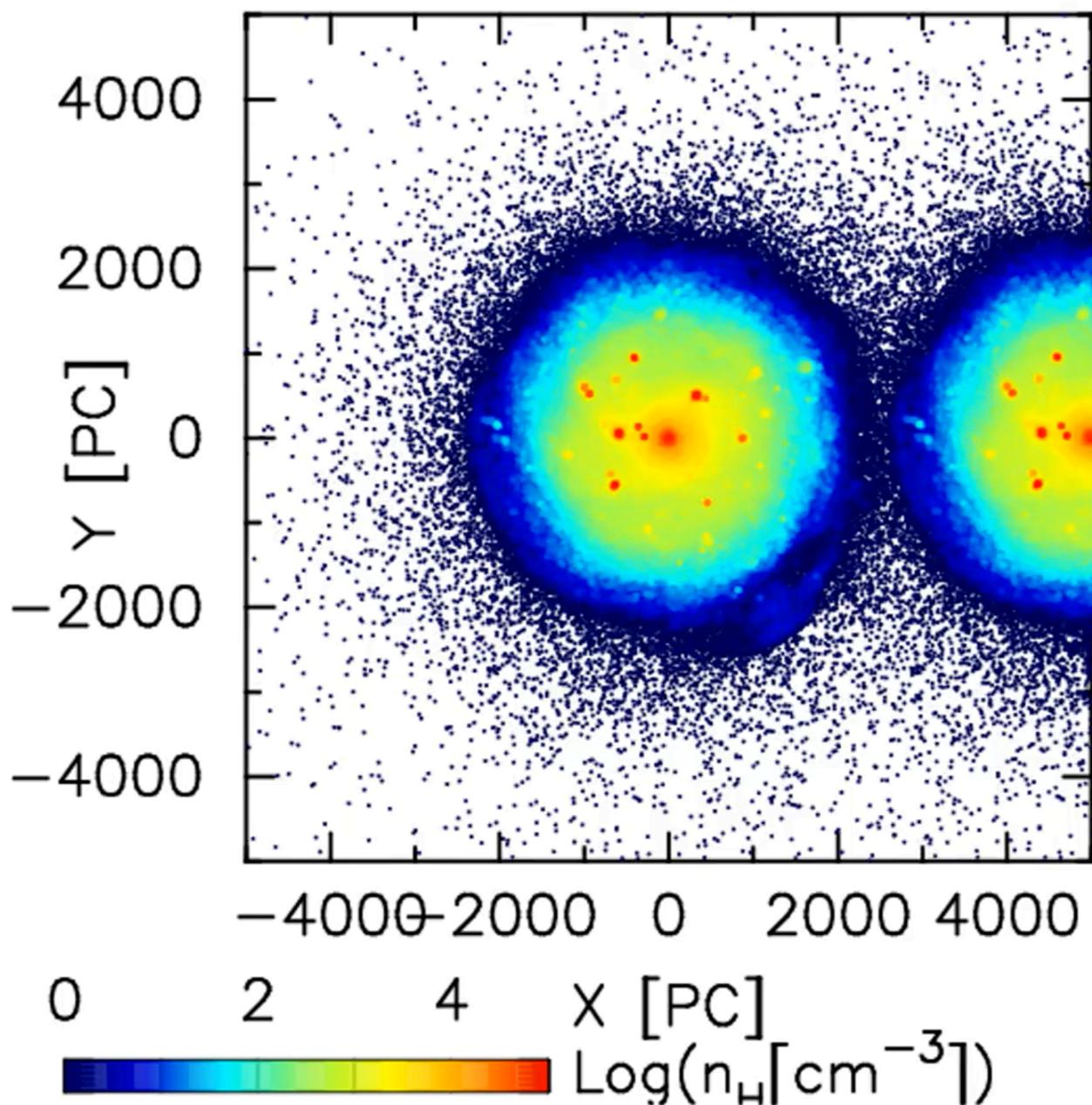
探査面積

See Toba+15,16,17abcd,18,20ab; Noboriguchi+19, 22, 23; Fukuchi+24

理論との連携: 銀河合体シミュレーション



T=1002.9Myr



油谷さん (鹿児島大) 和田さん (鹿児島大)

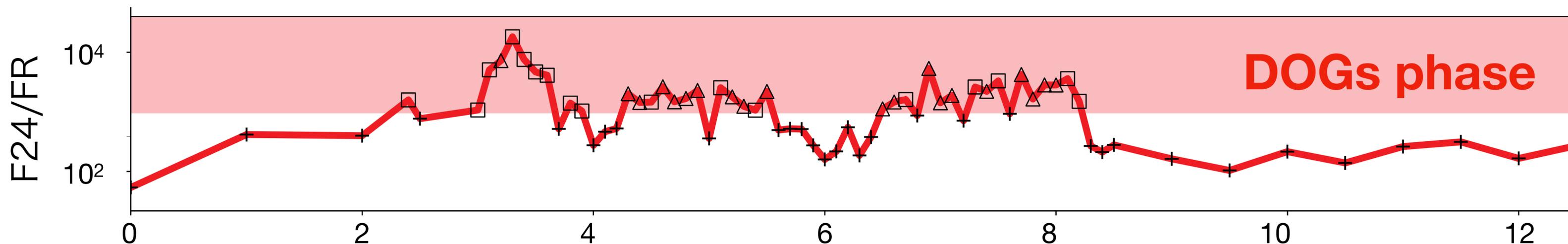
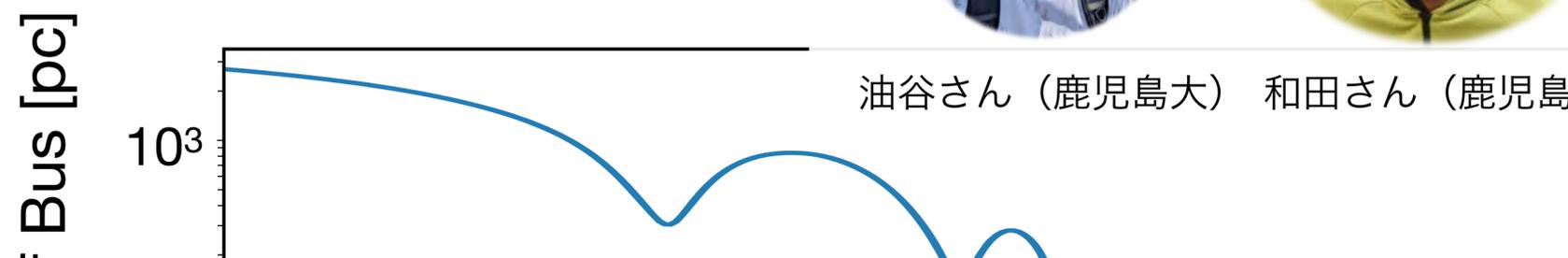
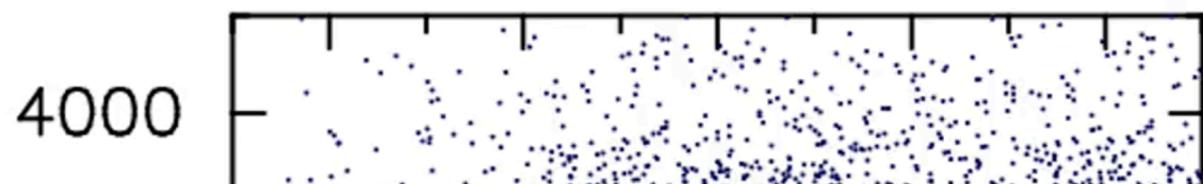
ある銀河合体からの経過時間 (10⁶ 年)

理論との連携: 銀河合体シミュレーション

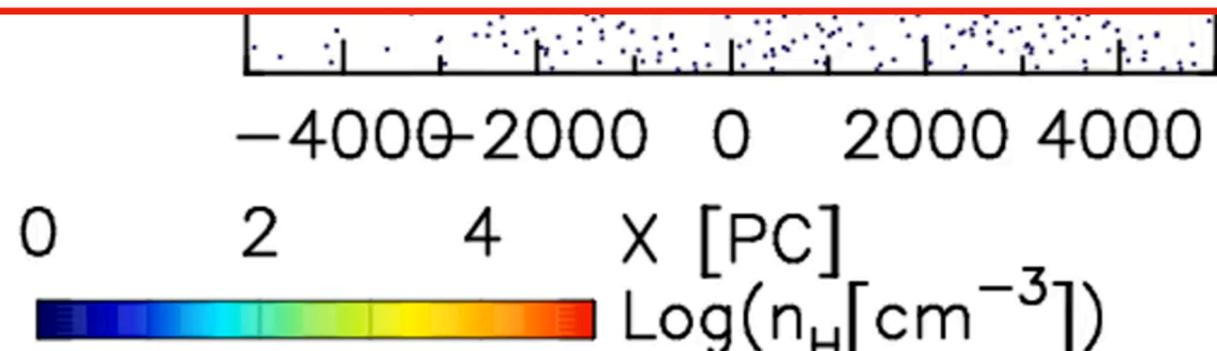


油谷さん (鹿児島大) 和田さん (鹿児島大)

T=1002.9Myr



ある銀河合体からの経過時間 (10⁶ 年)

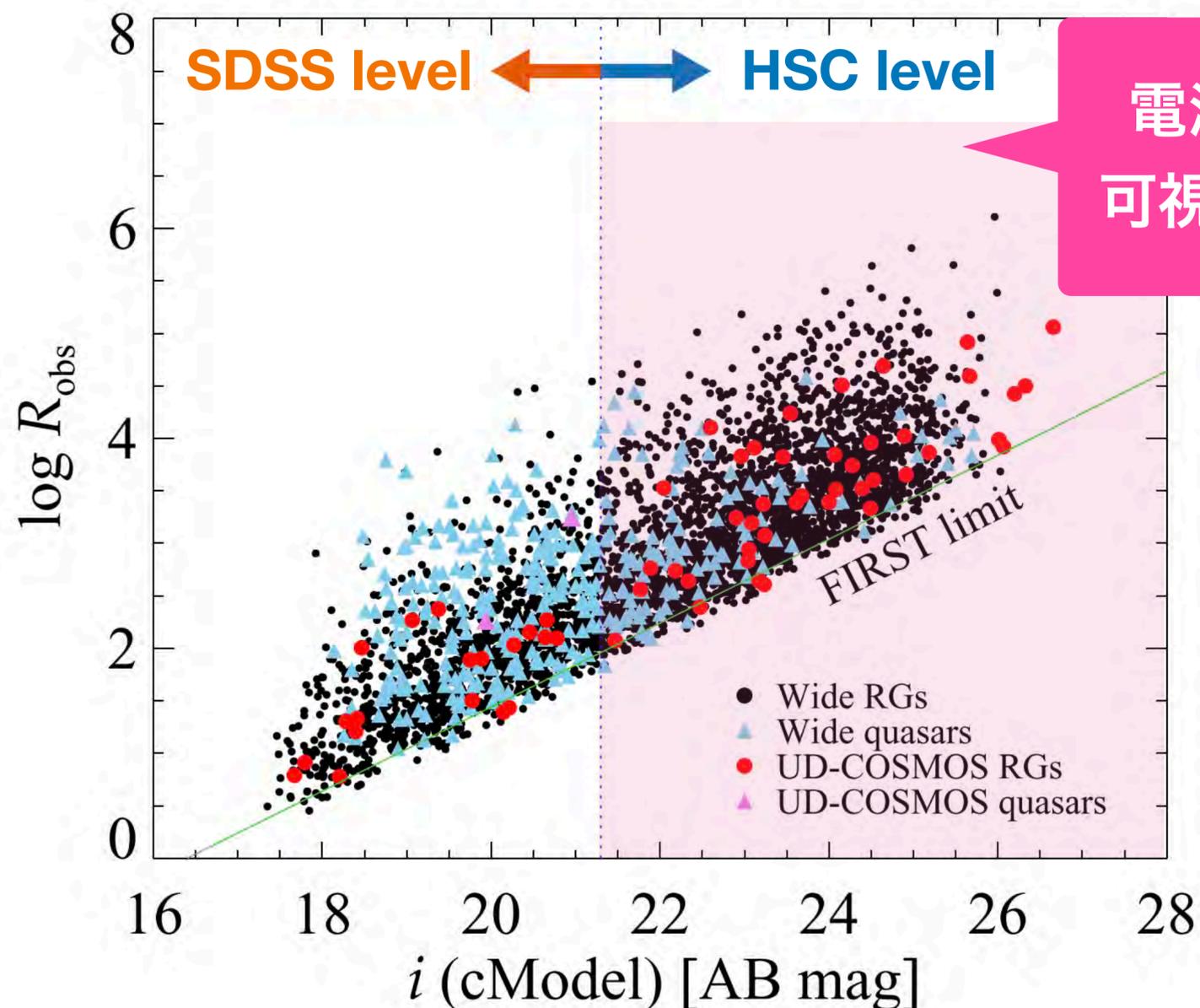


すばるHSC によるAGNサイエンス

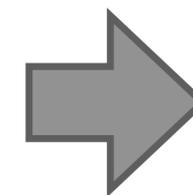
Radio-AGN



A Wide and Deep Exploration of Radio Galaxies with Subaru HSC (WERGS)



山下さん



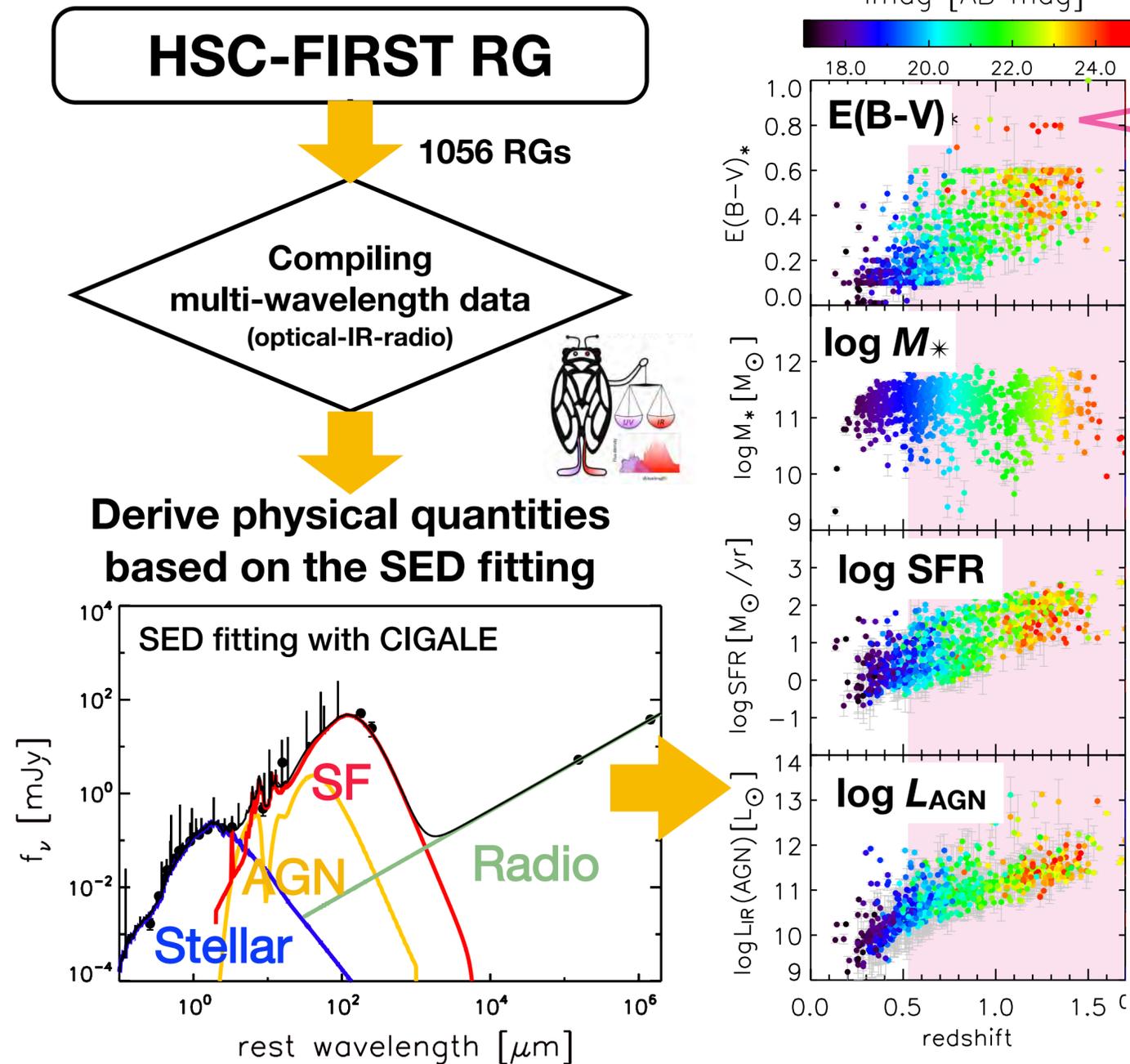
市川さん (早稲田大)



内山さん (NAOJ)

- Paper I: Yamashita et al. 2018, ApJ, 866, 140
- Paper II: Toba et al. 2019. ApJS, 243, 15
- Paper III: Yamashita et al. 2021, ApJ, 921, 511
- Paper IV: Ichikawa et al. 2021, ApJ, 921, 511
- Paper V: Uchiyama et al. 2022, ApJ, 926, 76
- Paper VII: Uchiyama et al. 2022, ApJ, 934, 68
- Paper IX: Uchiyama et al. 2022, PASJ, 74, L27
- eFEDS: Ichikawa et al. 2023, A&A, 672, A171

New parameter space for HSC-RGs



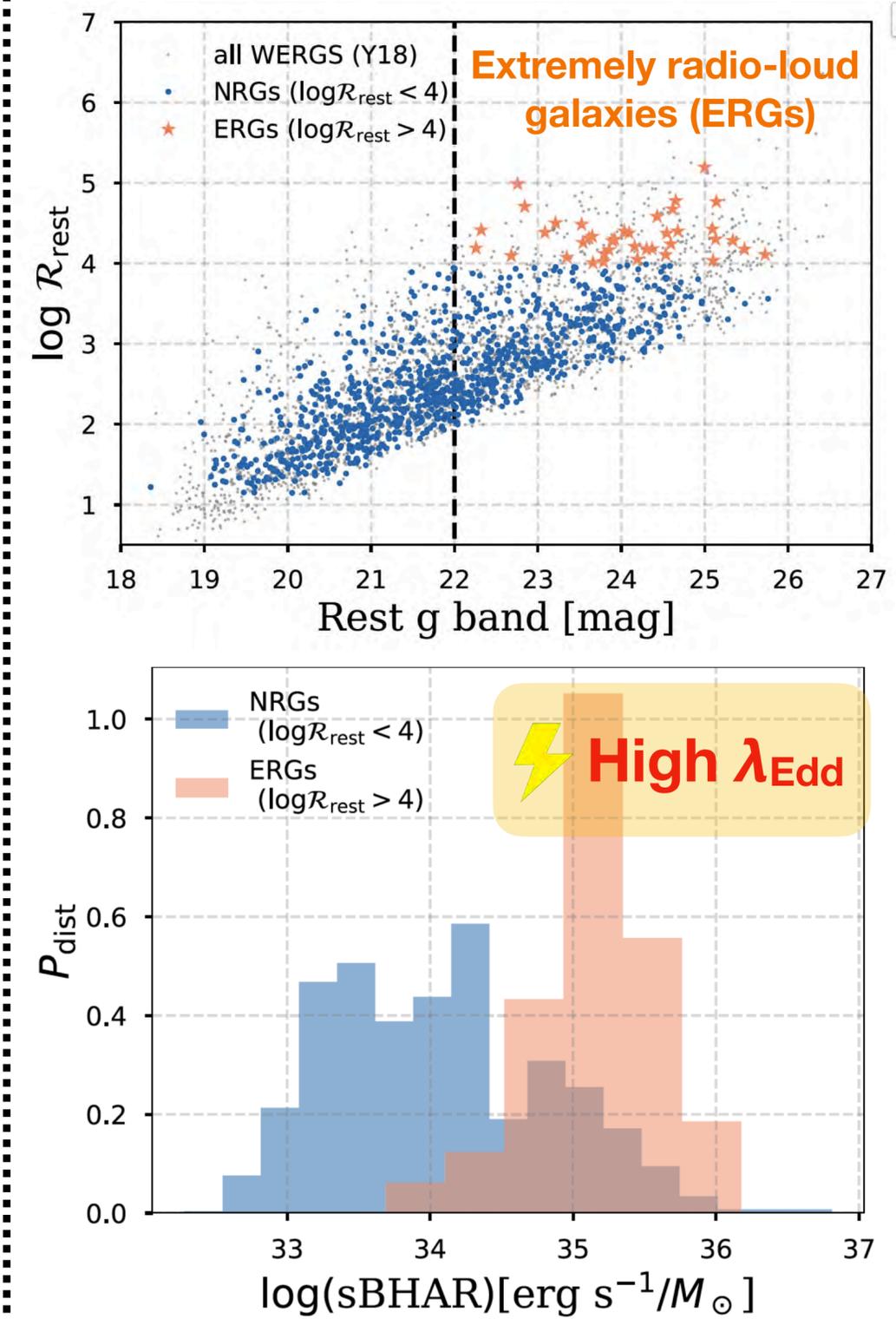
We explore a new parameter space (luminous RGs at $z > 0.5$)

Key results!

- ⚡ Dusty
- ⚡ Less massive
- ⚡ High SFR
- ⚡ High LAGN

Classical view of RGs

- No dust
- Massive host
- Low SFR



すばるHSC によるAGNサイエンス

X-ray AGN

eROSITA衛星

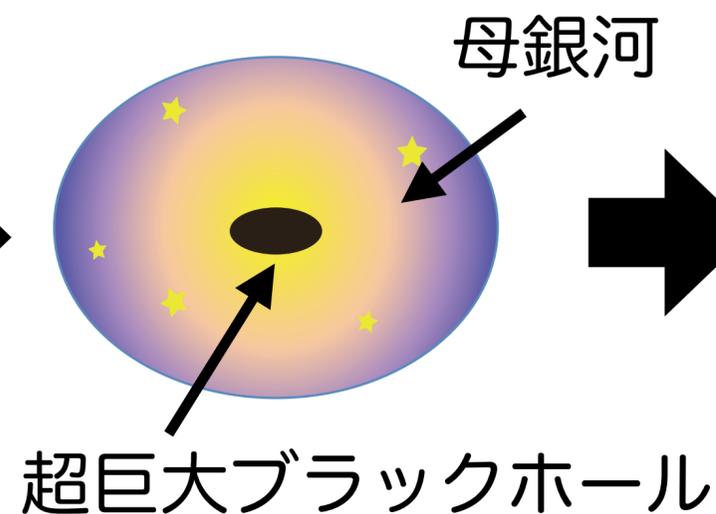


環境効果

AGN

クエーサー

楕円銀河



Spectr-Roentegn-Gamma (SRG)

- ロシアとドイツの共同X線衛星ミッション
- 2019年7月13日に打ち上げ
- ROSAT以来、約20年ぶりのX線全天探査が主目的

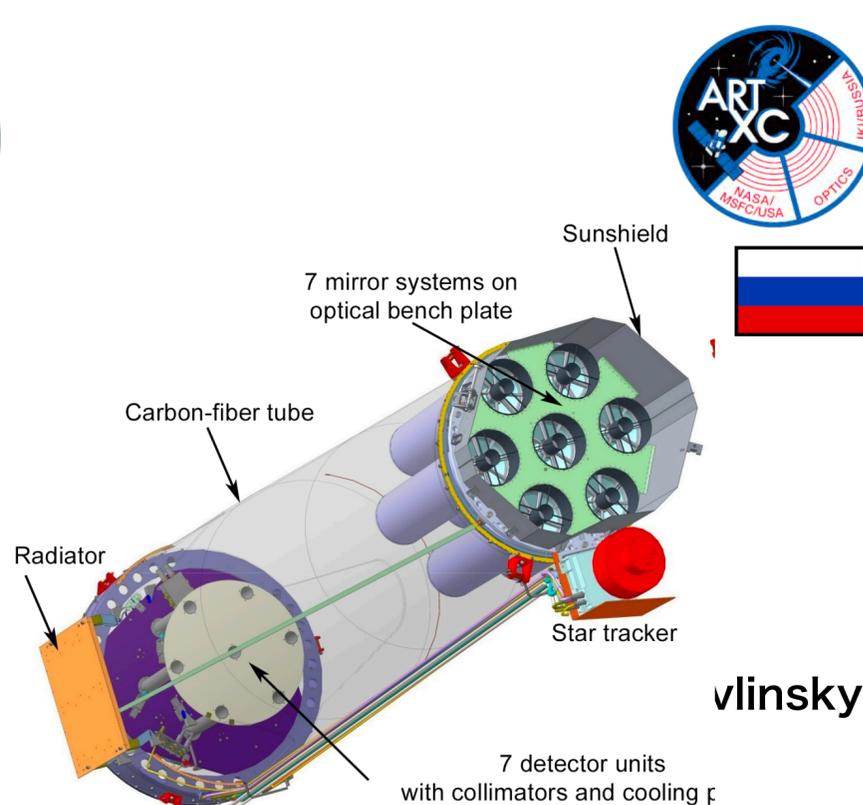
eROSITA

extended ROentgen Survey with an Imaging Telescope Array



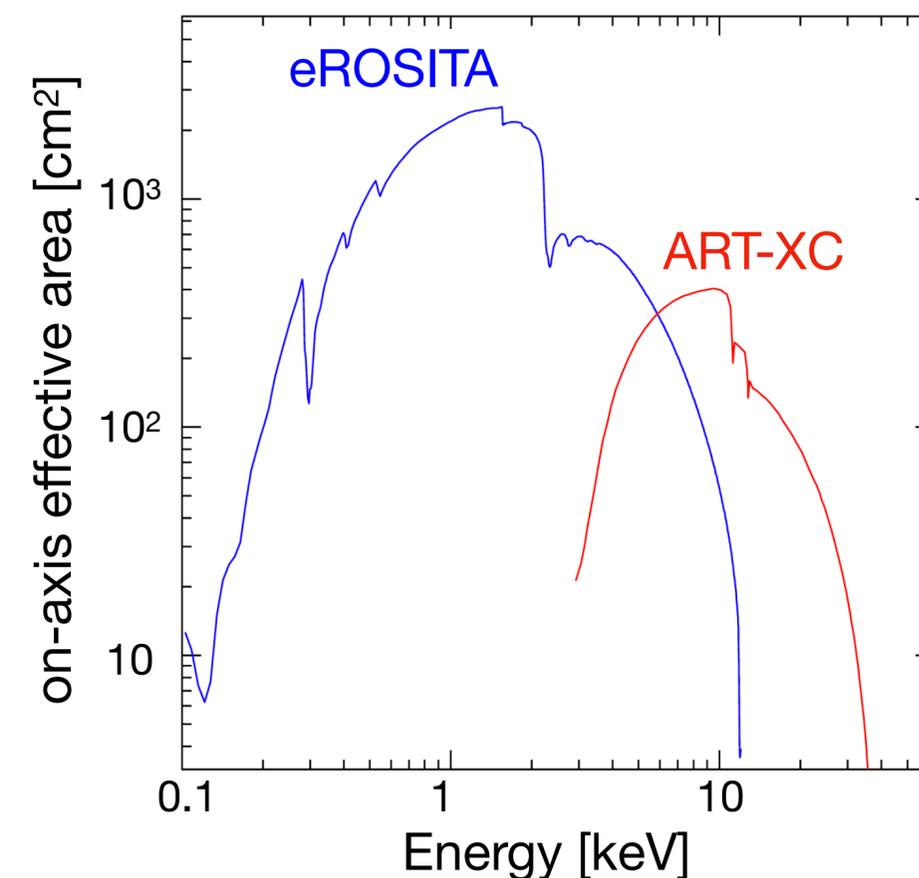
ART-XC

Astronomical Roentgen Telescope X-ray Concentrator



vlinsky+21

	eROSITA	ART-XC
Energy band (keV)	0.3-10	4-30
FoV	1°	36'
Angular resolution	~15"	~45"



eROSITA mission

※ eROSITA All-Sky Survey

- 半年に1回全天をスキャン (eRASS)※
- これを8回繰り返す (eRASS1-eRASS8)
- ただし、Cal-PV フェイズは別

Cal-PV

eRASS

Date	Event
2019/7/13, 15:31 MSK ⁽⁺⁾	Launch.
2019/7/13, 17:31 MSK ⁽⁺⁾	Insertion into L2 trajectory and separation from Block-DM03 space tug.
2019/7/13, 17:39 MSK ⁽⁺⁾	First eROSITA telemetry received.
2019/7/22	First trajectory correction maneuver.
2019/7/23	Telescope cover opens. Outgassing period begins.
2019/8/06	Second trajectory correction maneuver.
2019/8/22	Camera cool-down. Start of camera commissioning.
2019/9/15	Commissioning first light with 2 TMs ^(*) [LMC].
2019/10/16-18	First light with all 7 TMs ^(*) [LMC]. End of extended commissioning.
2019/10/18	Calibration and performance verification program begins.
2019/10/21	Third trajectory correction maneuver and insertion into L2 Halo orbit.
2019/12/8	Calibration and performance verification program ends.
2019/12/12	All-sky survey begins.

Notes. ⁽⁺⁾MSK: Moscow time (= UTC + 3h). ^(*)TMs: Telescope modules.

全天探査進行状況とデータ公開プラン

	started	completed	Data release
Cal-PV	October 2019	December 2019	EDR (2021)
eRASS1	December 2019	June 2020	DR1 (2024)
eRASS2	June 2020	December 2020	
eRASS3	December 2020	June 2021	
eRASS4	June 2021	December 2021	DR2 (2025?)
eRASS5	December 2021	?	

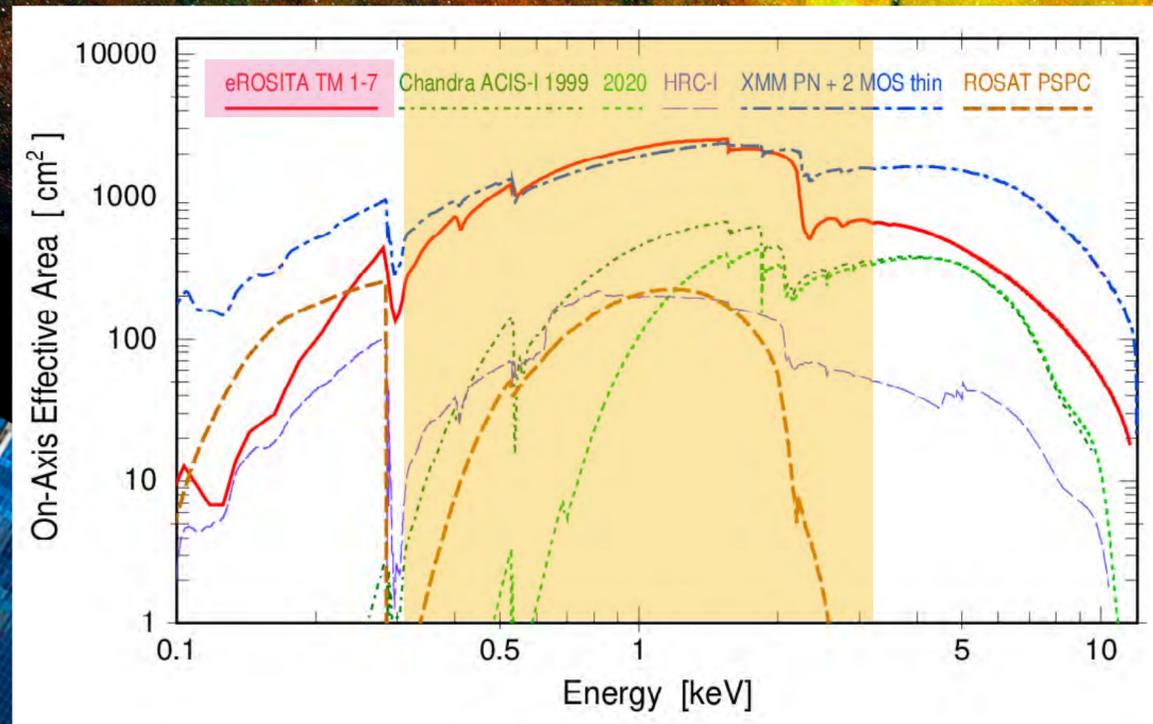
eROSITA was put into **safe mode** on 26.02.2022 and is currently not taking data

Our deepest view of the X-ray sky

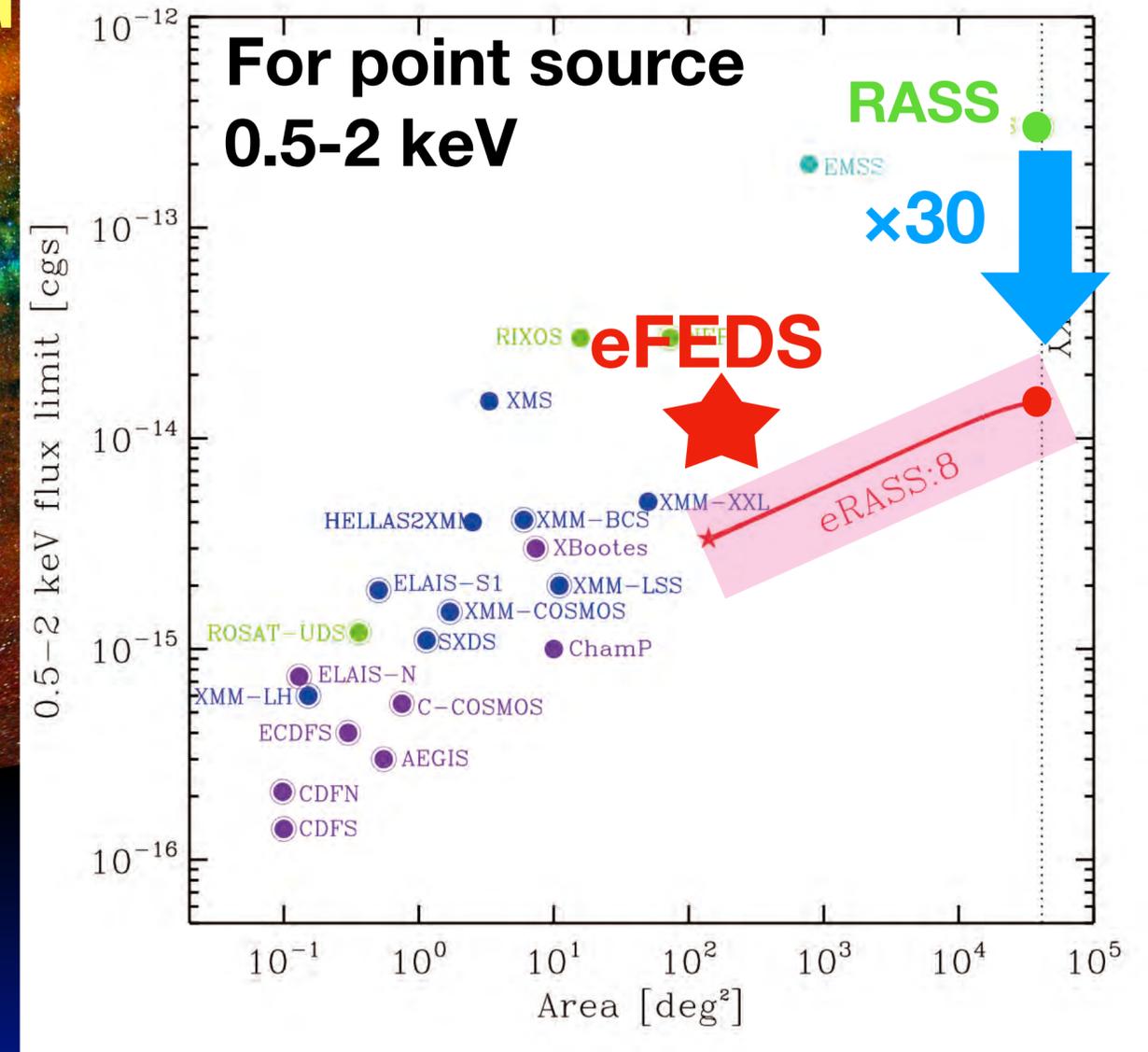
SRG/eROSITA

0.3-2.3 keV (RGB)

- ~1.1 million X-ray sources (~80%: AGN)
- 20,000 galaxy clusters up to $z \sim 1$.



Predehl et al. (2020)



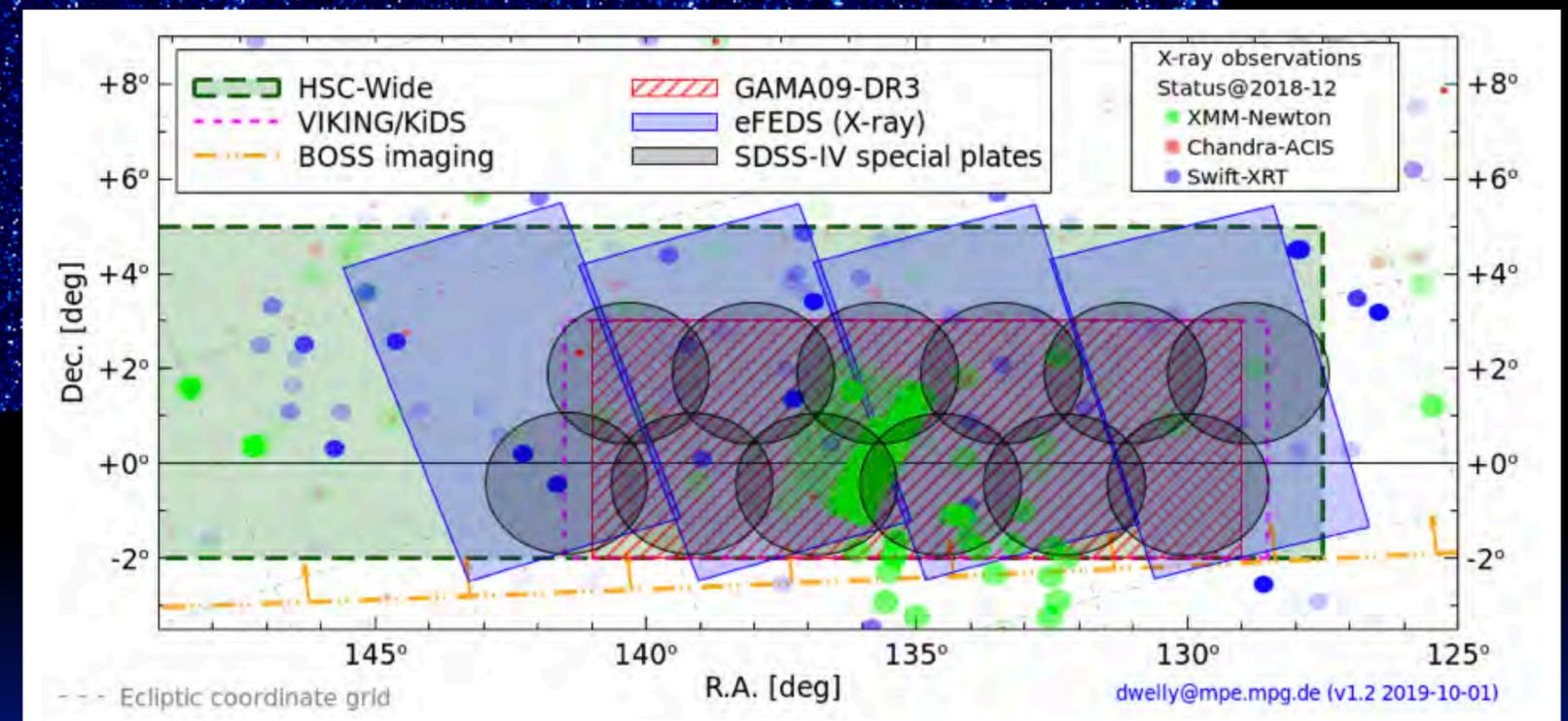
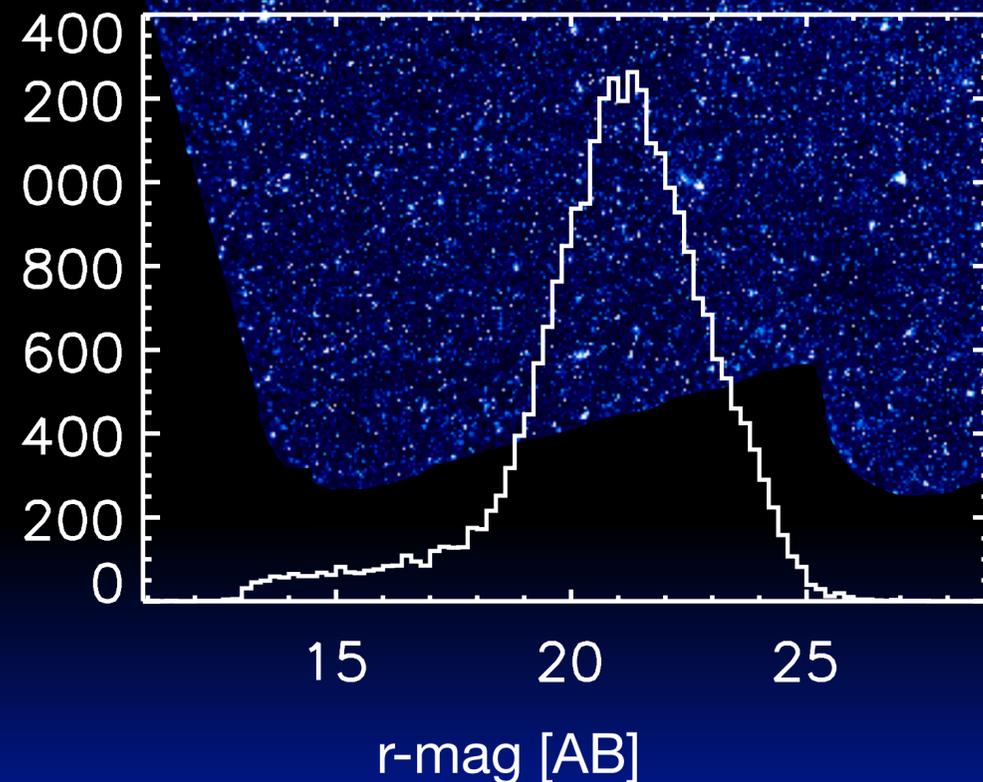
Merloni et al. (2012)

eROSITA Final Equatorial Depth Survey (eFEDS)

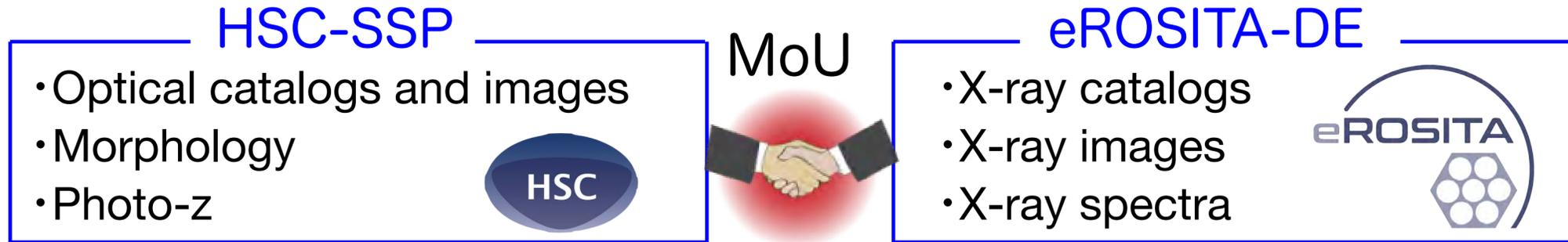
2 deg

140 deg² exposures for ~2.5 ks.

- ~**27,000** X-ray point sources were detected (~85%: AGN).
- ~99% sources have the optical counterparts of the Legacy Survey DR8 (LS8) and Subaru Hyper Suprime-Cam (HSC).
- ~24% sources have spectroscopic redshifts (the number of spec-z sources will be increased through the SDSS IV collaboration).

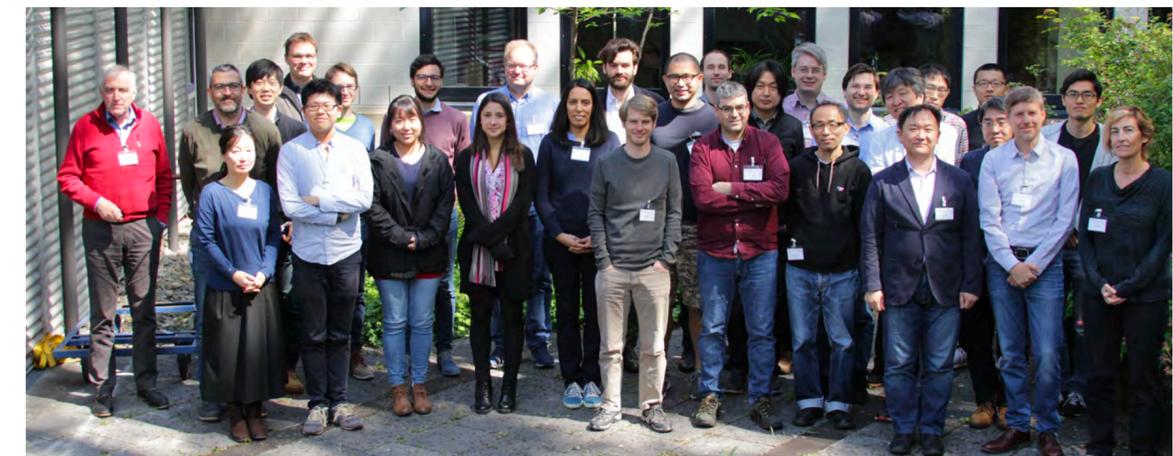


HSC-eROSITA AGN working group (since 2018~)



- April 23-26, 2018 @ MPE (face-to-face)
- May 13-16, 2019 @ MPE (face-to-face)
- Jan 23, 2020 @ Kyoto U. (HSC-AGN meeting joint section, online)
- July 6-9, 2020 @ zoom (eROSITA-DE Consortium Meeting, online)
- June 21-24, 2021 @ zoom (eROSITA-DE Consortium Meeting, online)

 Mara Salvato	 Yoshiki Toba	 Tohru Nagao	 Johan Comparat
A1 eFEDS catalog	A2 Muiti- λ analysis	A3 SMBH evolution	A4 AGN clustering
Sub-project PIs Y.Toba M.Salvato J.Silverman A.Merloni	Sub-project PIs Y.Terashima M.Brusa K.Iwasawa T.Liu T.Boller K.Ichikawa A.Merloni M.Oguri G.Lamer T.Kawamuro A.Rau U.Kobayashi A.Merloni	Sub-project PIs M.Akiyama J.Wolf Y.Ueda K.Nandra	Sub-project PIs M.Akiyama J.Comparat



2019年 eROSITA-HSC collaboration meeting @ MPEにて

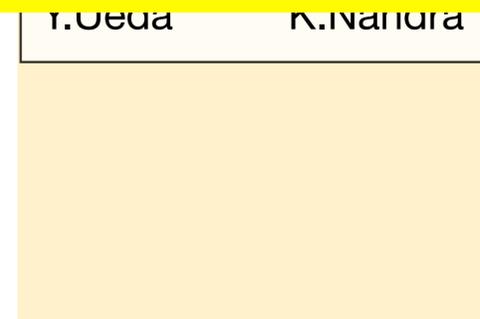
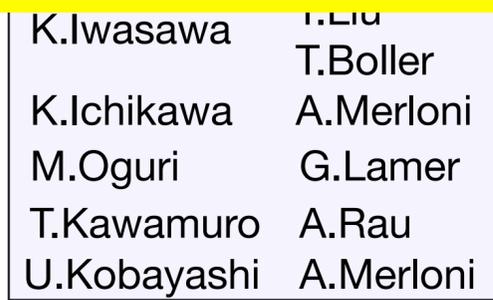
~50 colleagues from eROSITA-DE and HSC belong to some sub-projects and working together.

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- May 13-16, 2019 @ MPE (face-to-face)

**HSC-eROSITA collaboration を通じて
eROSITA internal data に基づく
AGNサイエンスができる！**



2019年 eROSITA-HSC collaboration meeting @ MPEにて

~50 colleagues from eROSITA-DE and HSC belong to some sub-projects and working together.

eFEDS-AGN catalog

- 21952個のAGNについてX線情報を公開
- Bayesian spectral fitting code (BXA: Buchner+14) を使って、各種物理量 (e.g., photon index, N_H) を計算
- Photo-z の計算では HSC-based photo-z (dNNz: Nishizawa+) も併用 (see also Salvato et al. 2022, A&A, 661, A3)。



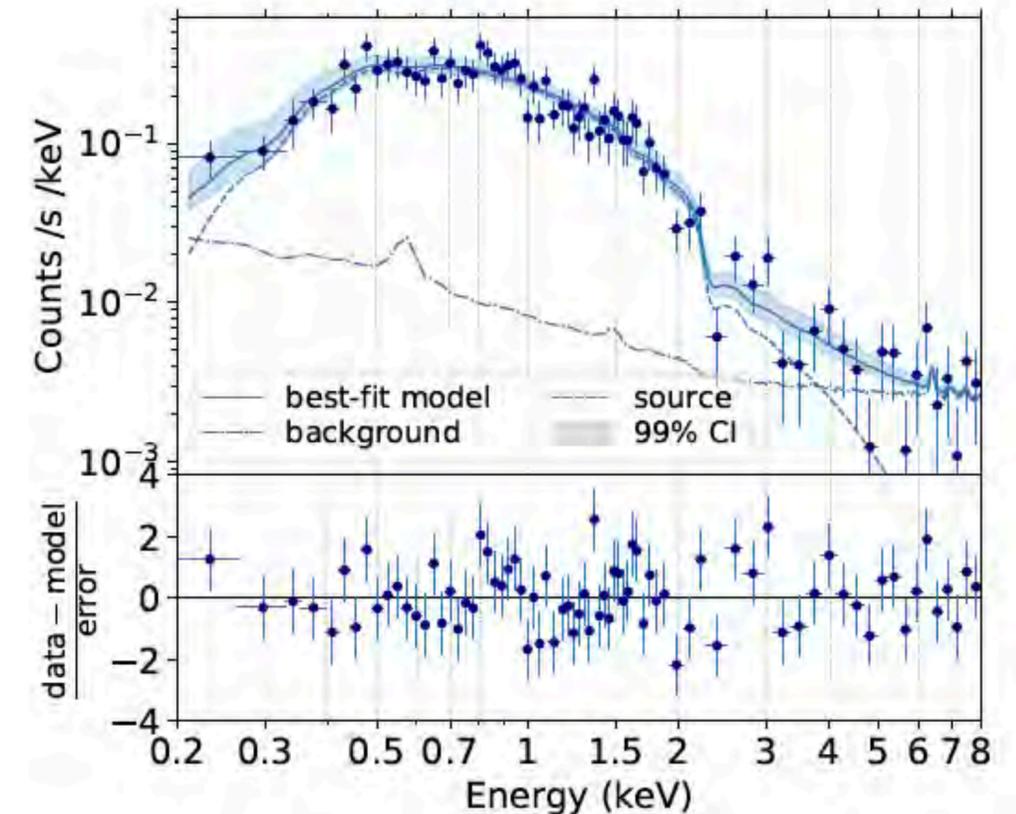
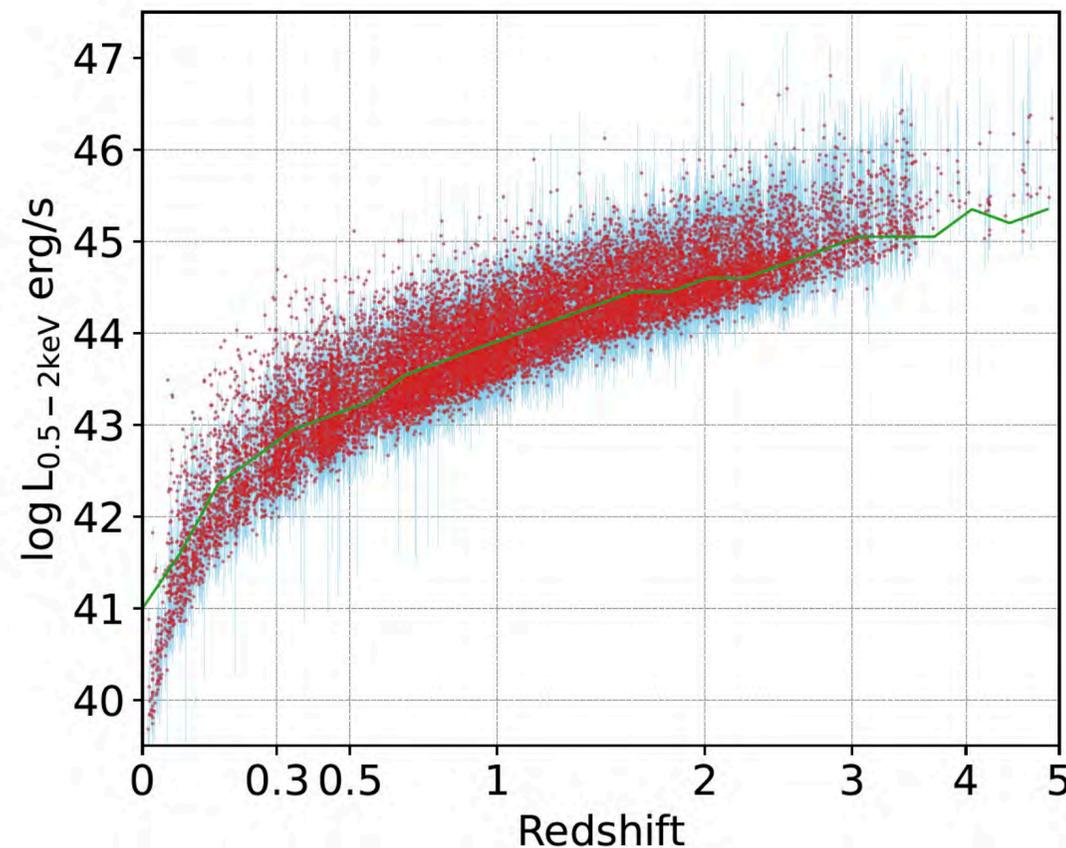
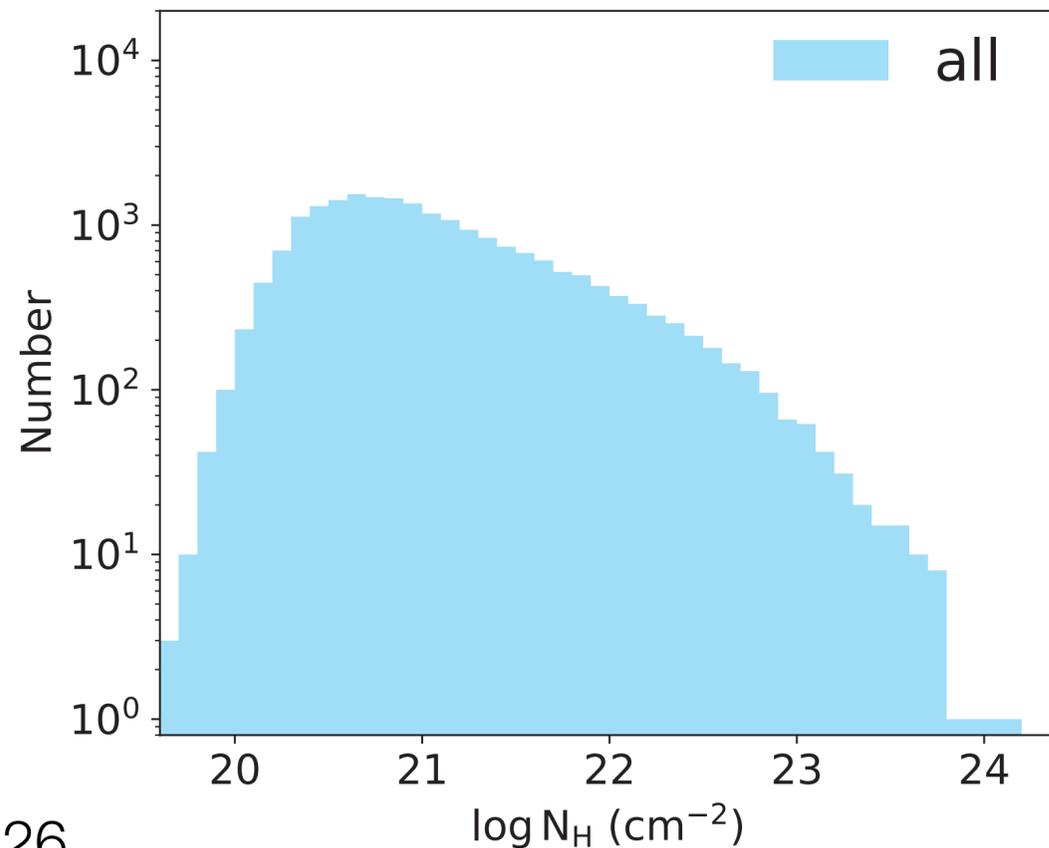
Mara Salvato
(MPE)



西澤さん
(岐阜聖徳学園大学)



Teng Liu
(MPE)



Li et al. 2022, A&A, 661, A5

eFEDS-AGN catalog

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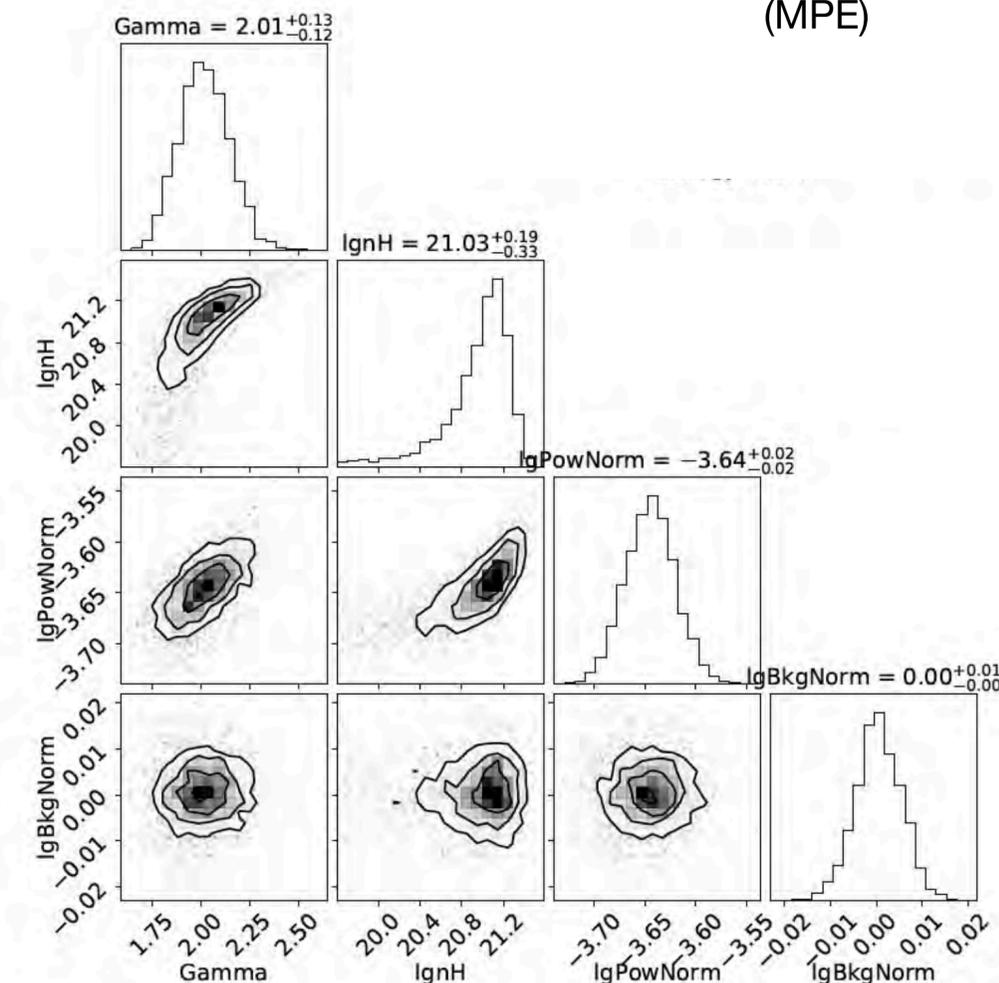
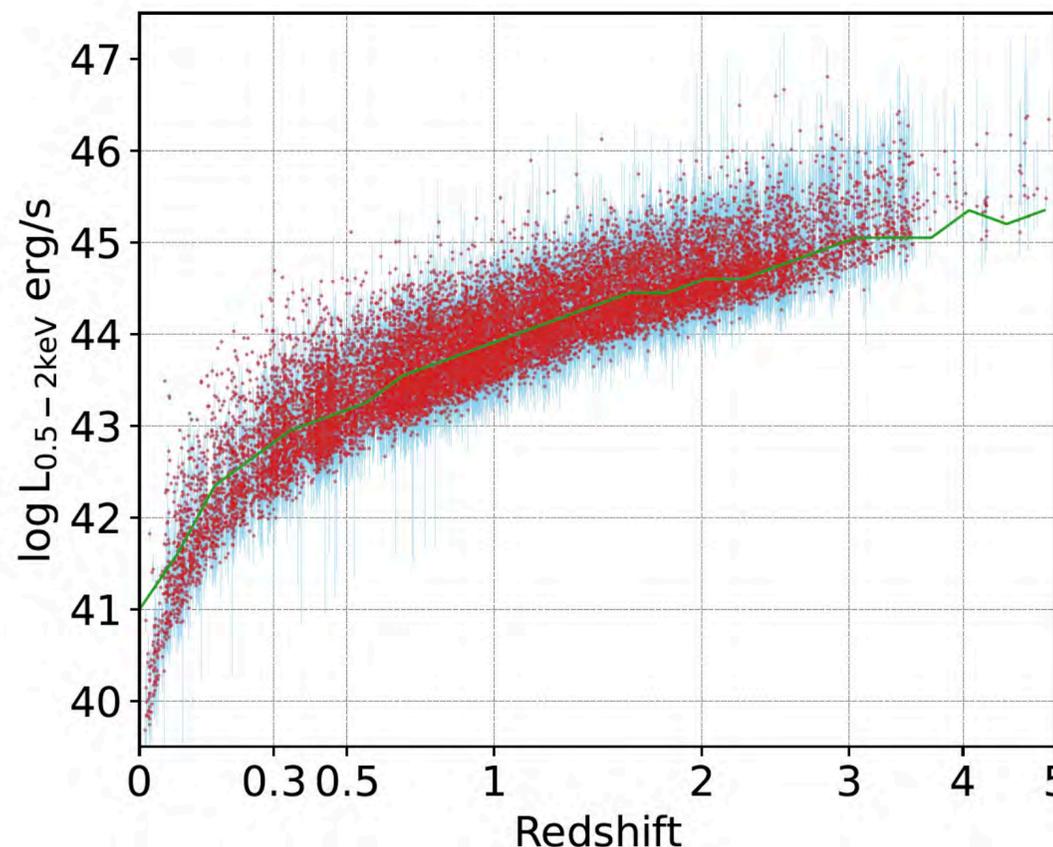
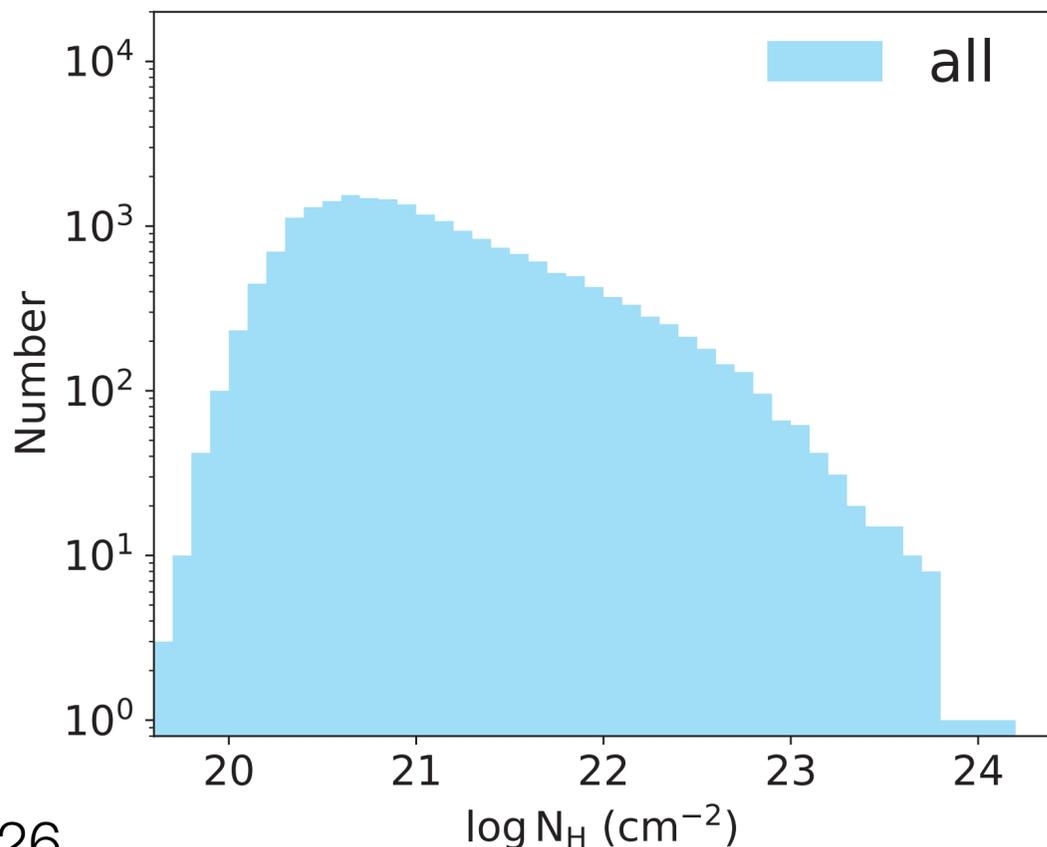
Mara Salvato
(MPE)



西澤さん
(岐阜聖徳学園大学)

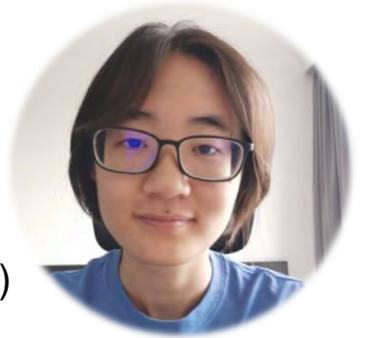


Teng Liu
(MPE)



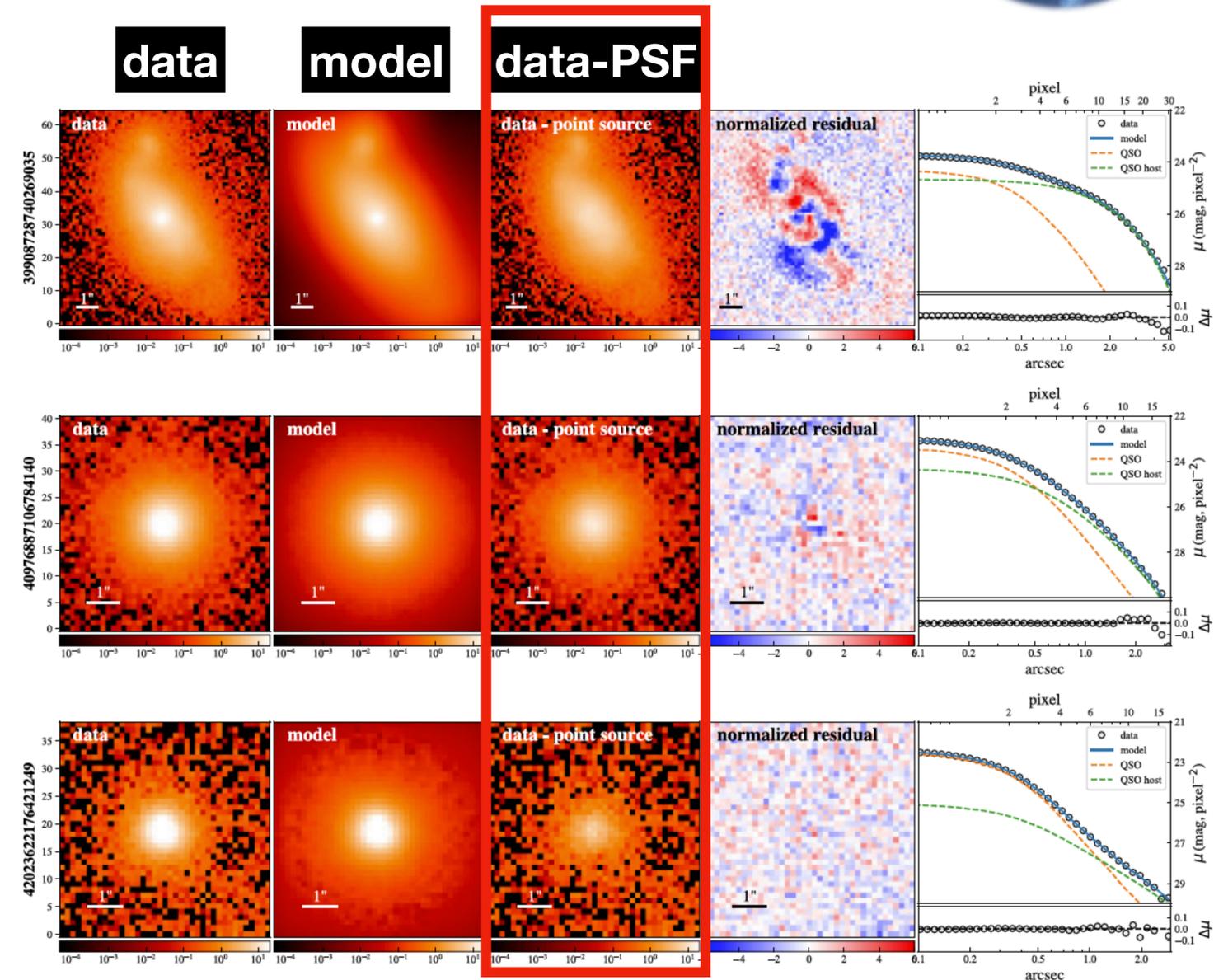
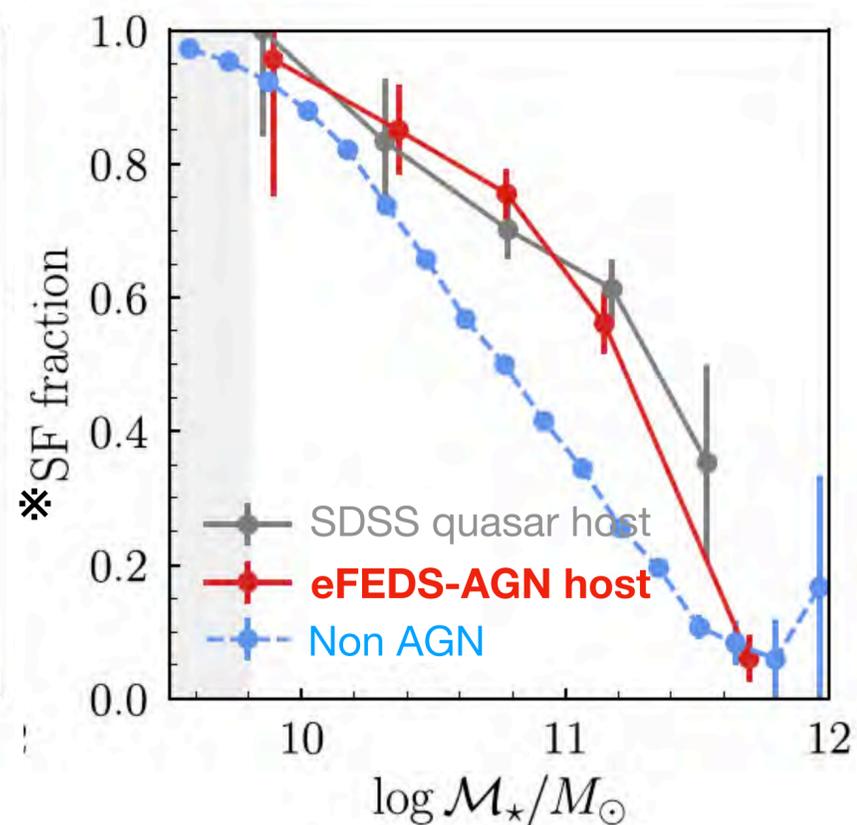
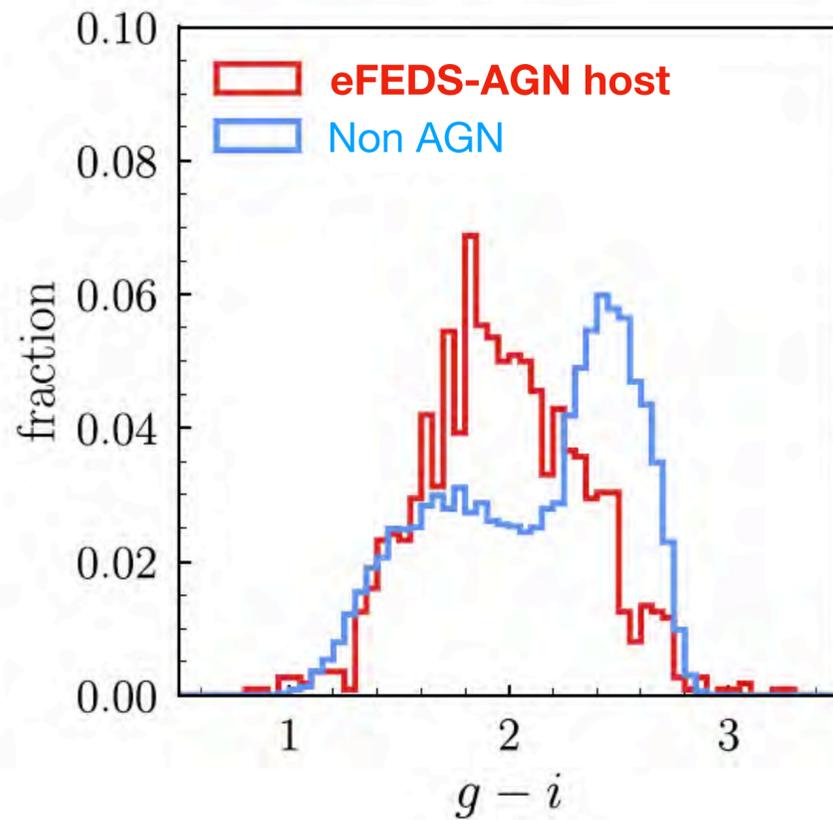
Li et al. 2022, A&A, 661, A5

eFEDS-AGN host properties viewed with HSC



Junyao Li
(Univ. of Illinois)

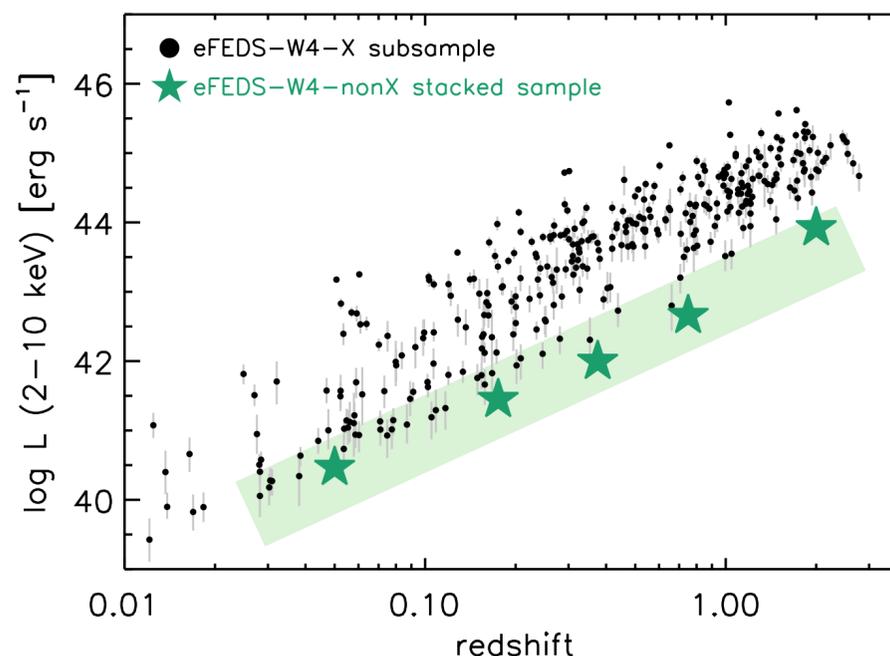
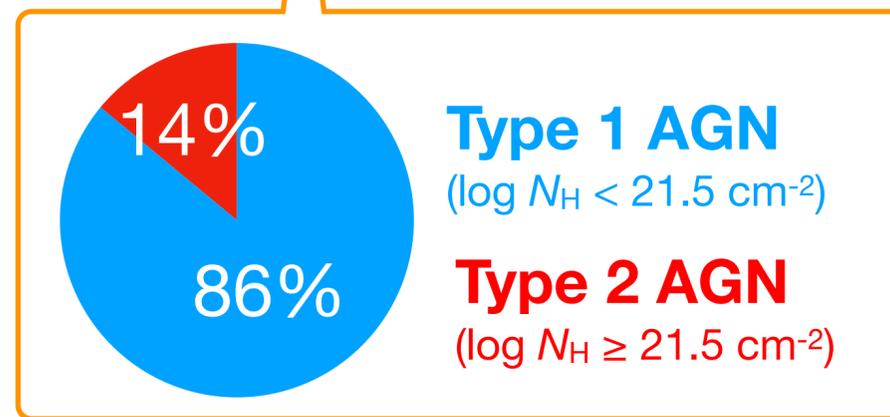
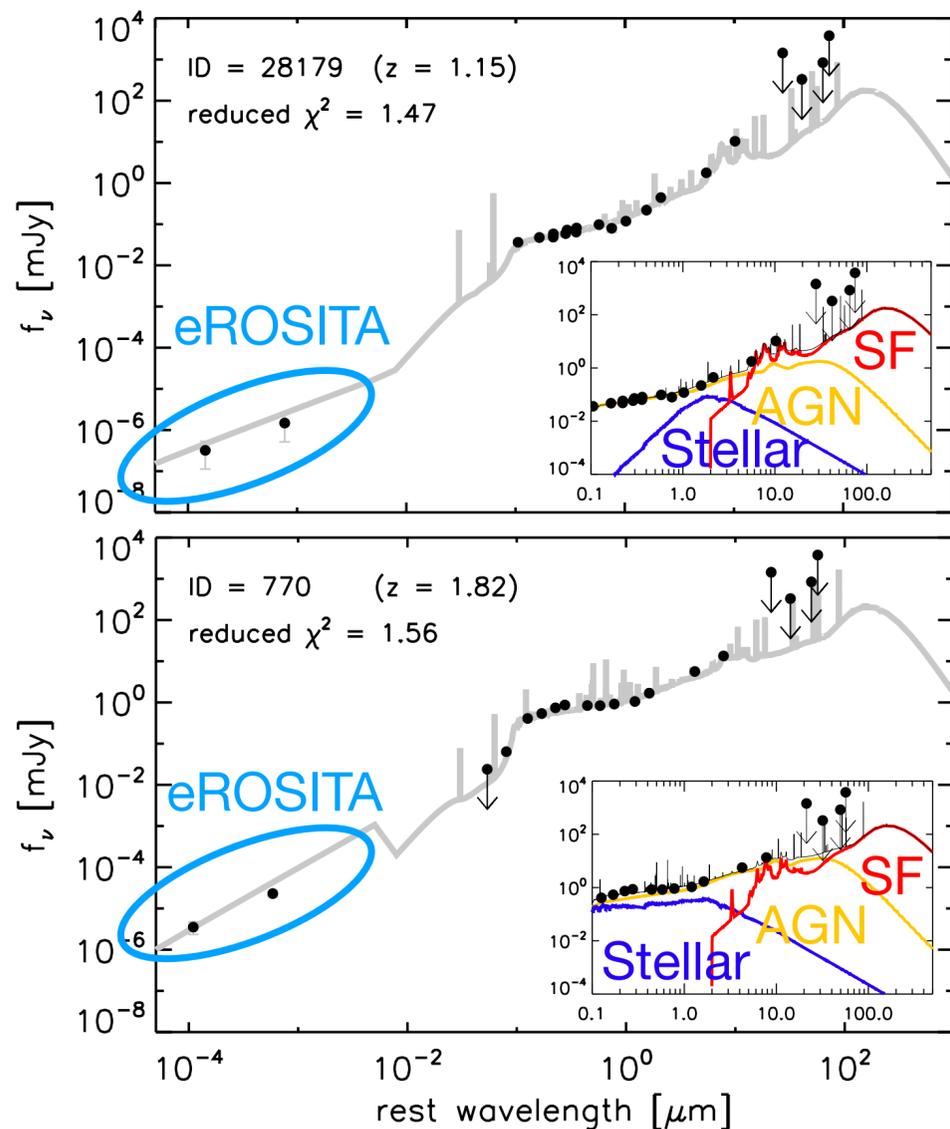
- eFEDSで見つかったAGNに対して、HSC image 2D-decomposition を用いて母銀河成分を抽出
- X-ray AGN母銀河は青くて、特に小・中質量銀河は星生成活動が比較的活発な可能性を示唆



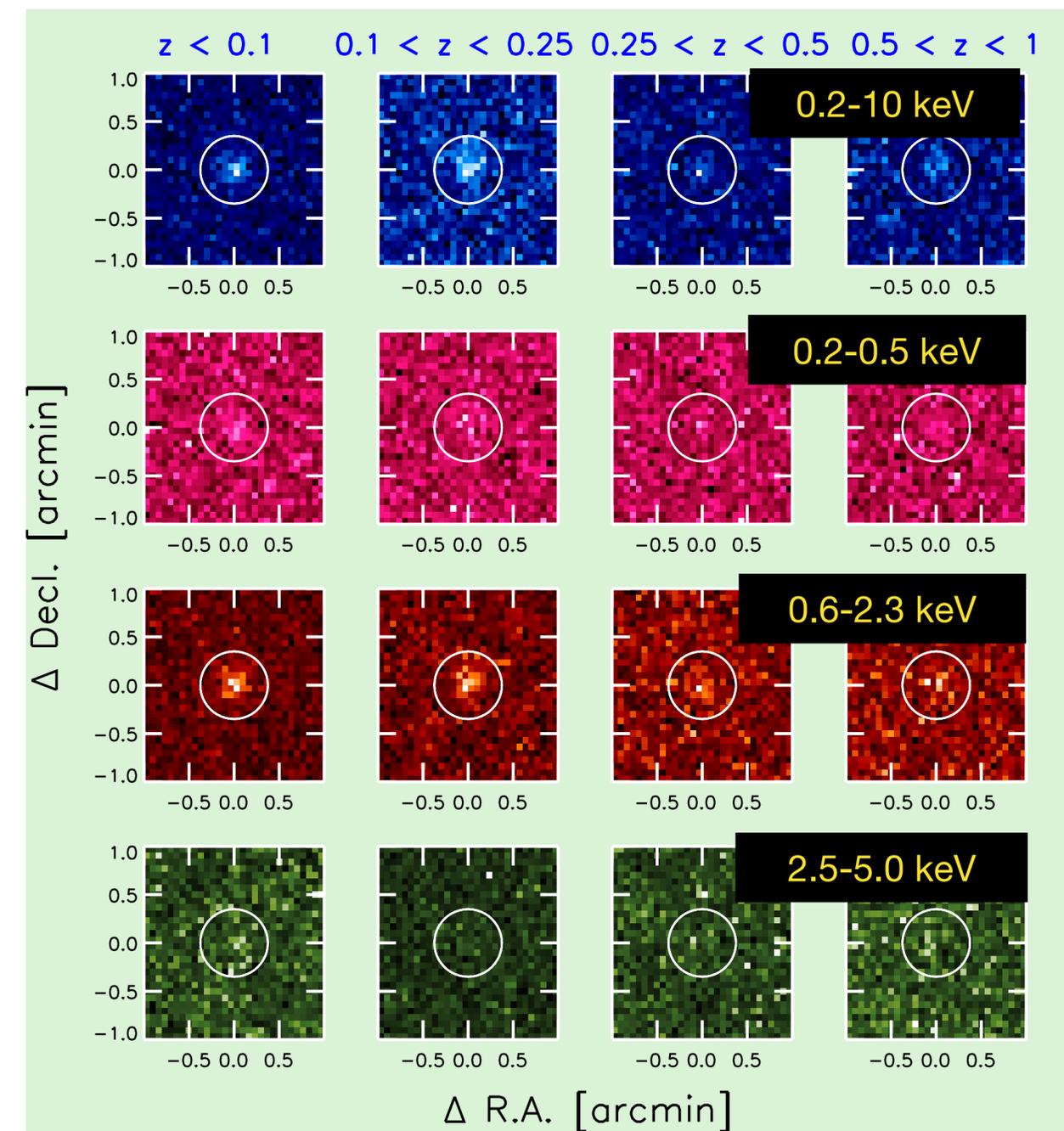
* SFGs are classified by *urz* diagram (Kawinwanichakij+21).

eROSITA view of WISE-AGN

eROSITAで受かった 692個のWISE sources に対して、SED fitting 等を実施し、物理量を計算



7,088個のeROSITA未検出 WISE天体 X線スタッキング

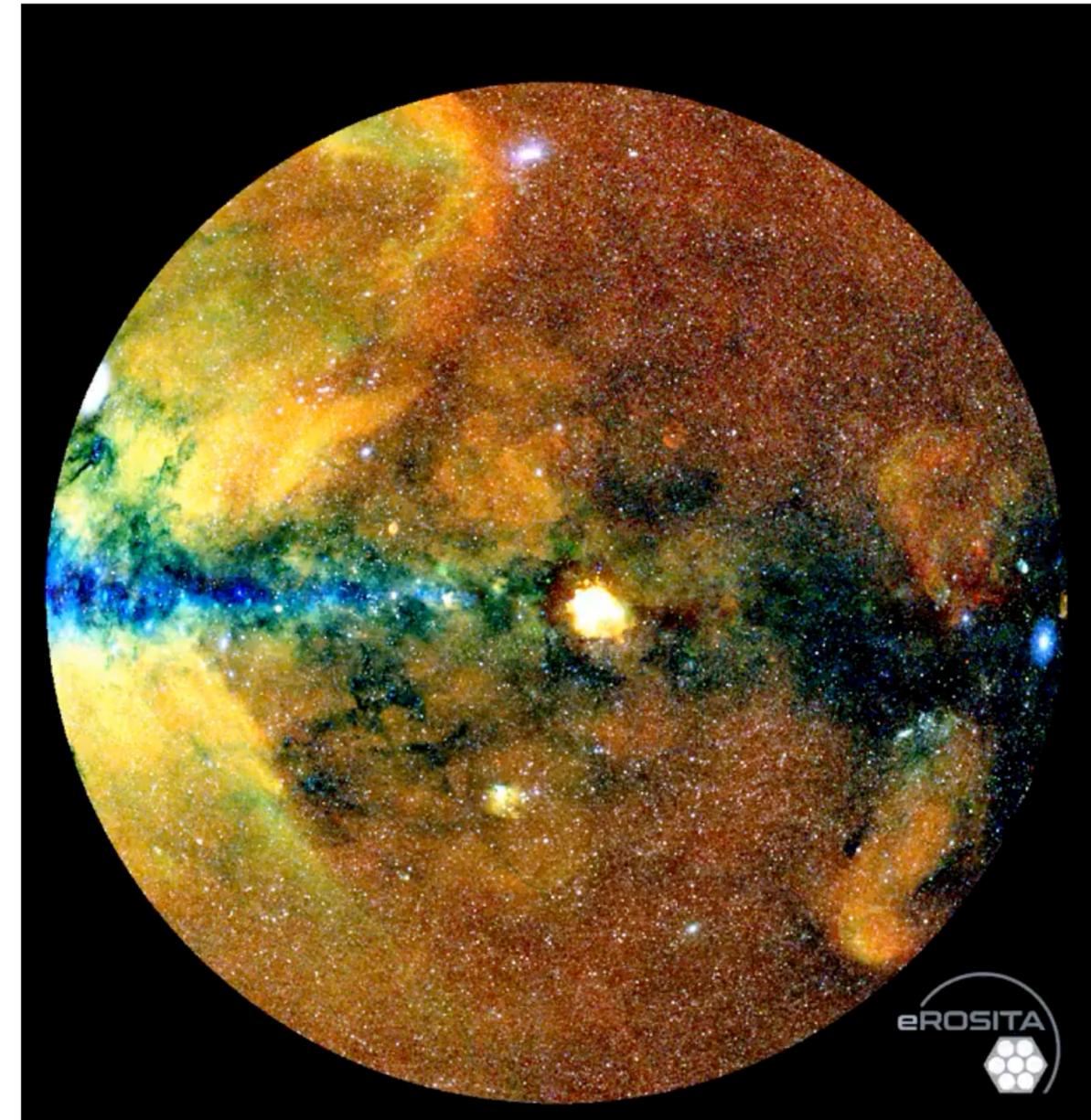
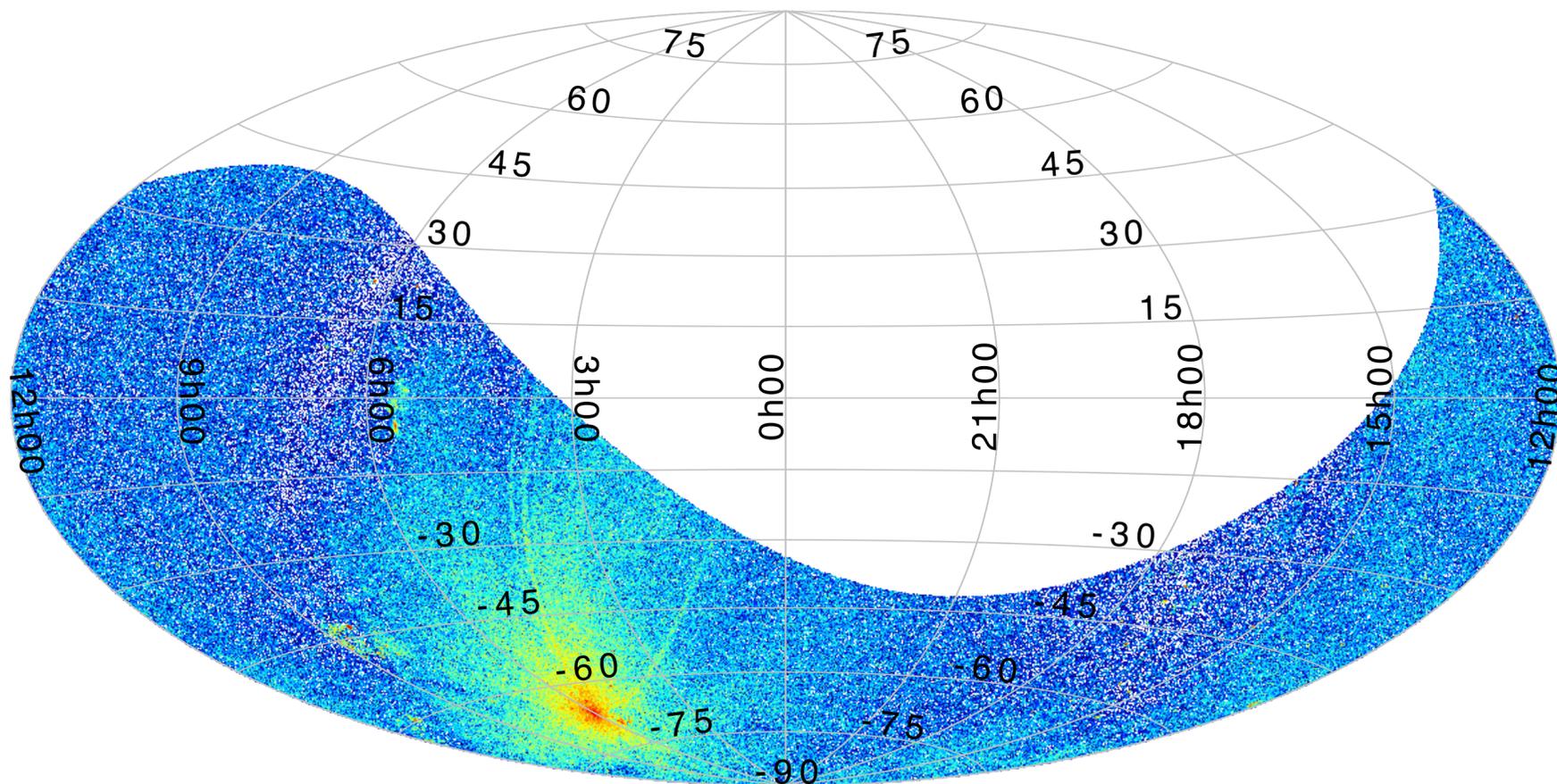


eROSITA All Sky Survey (eRASS)

Release date: January 31, 2024

<https://erosita.mpe.mpg.de/dr1>

- 2019年12月から2020年11月までの観測データ
- **約93万個**のX線天体 (0.2-2.3 keVで検出) が収録



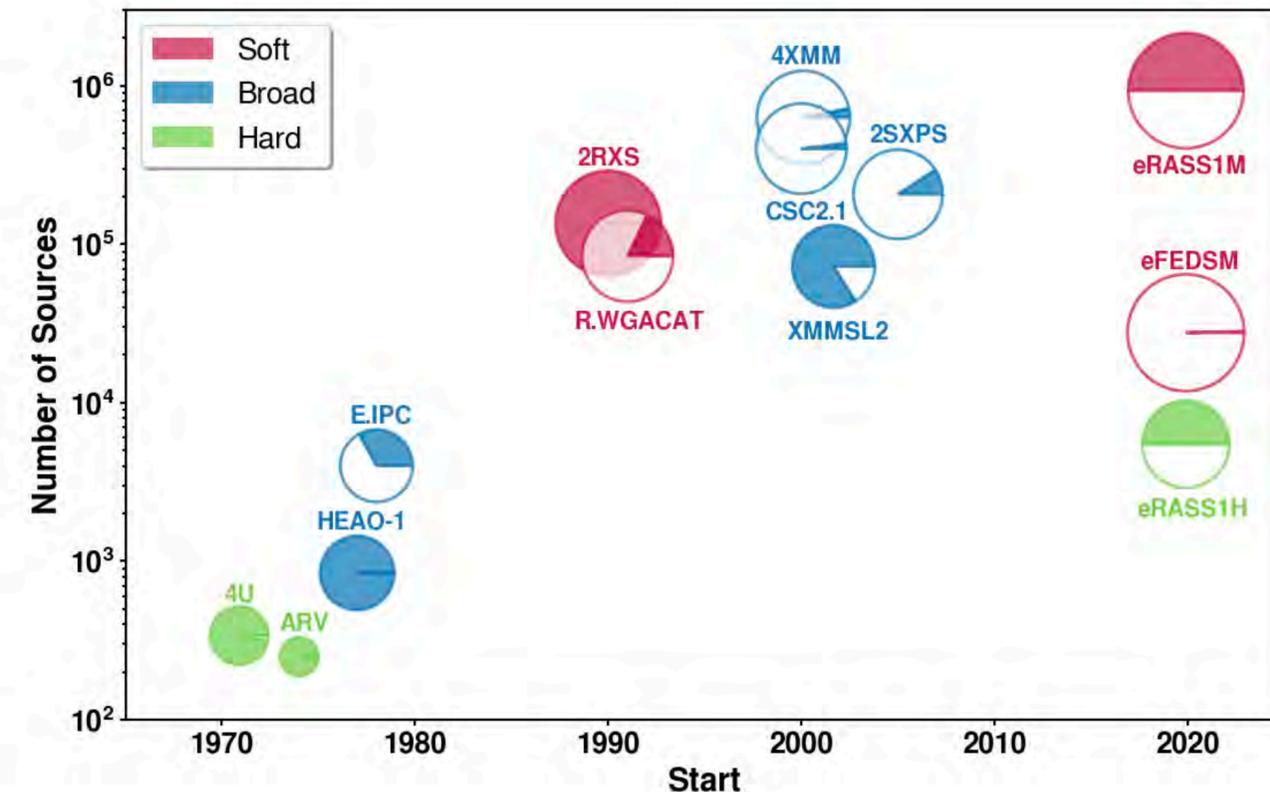
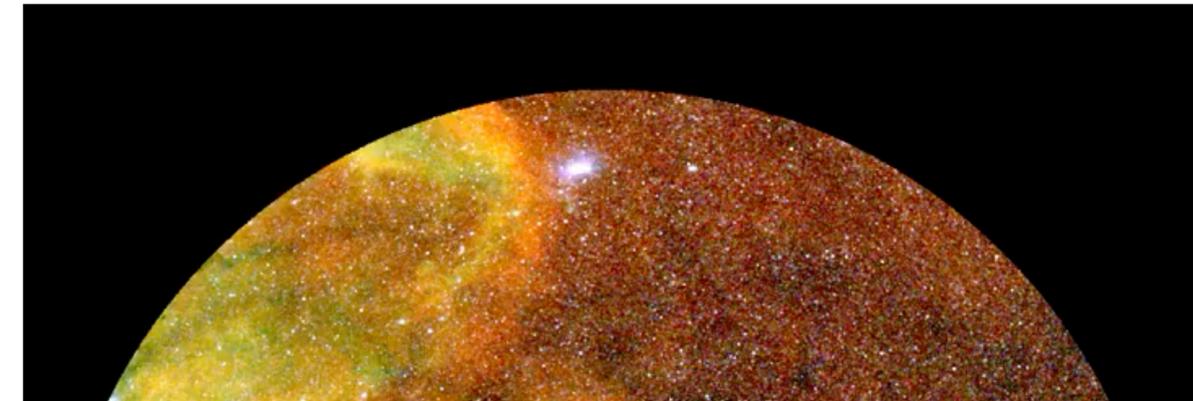
eROSITA All Sky Survey (eRASS)

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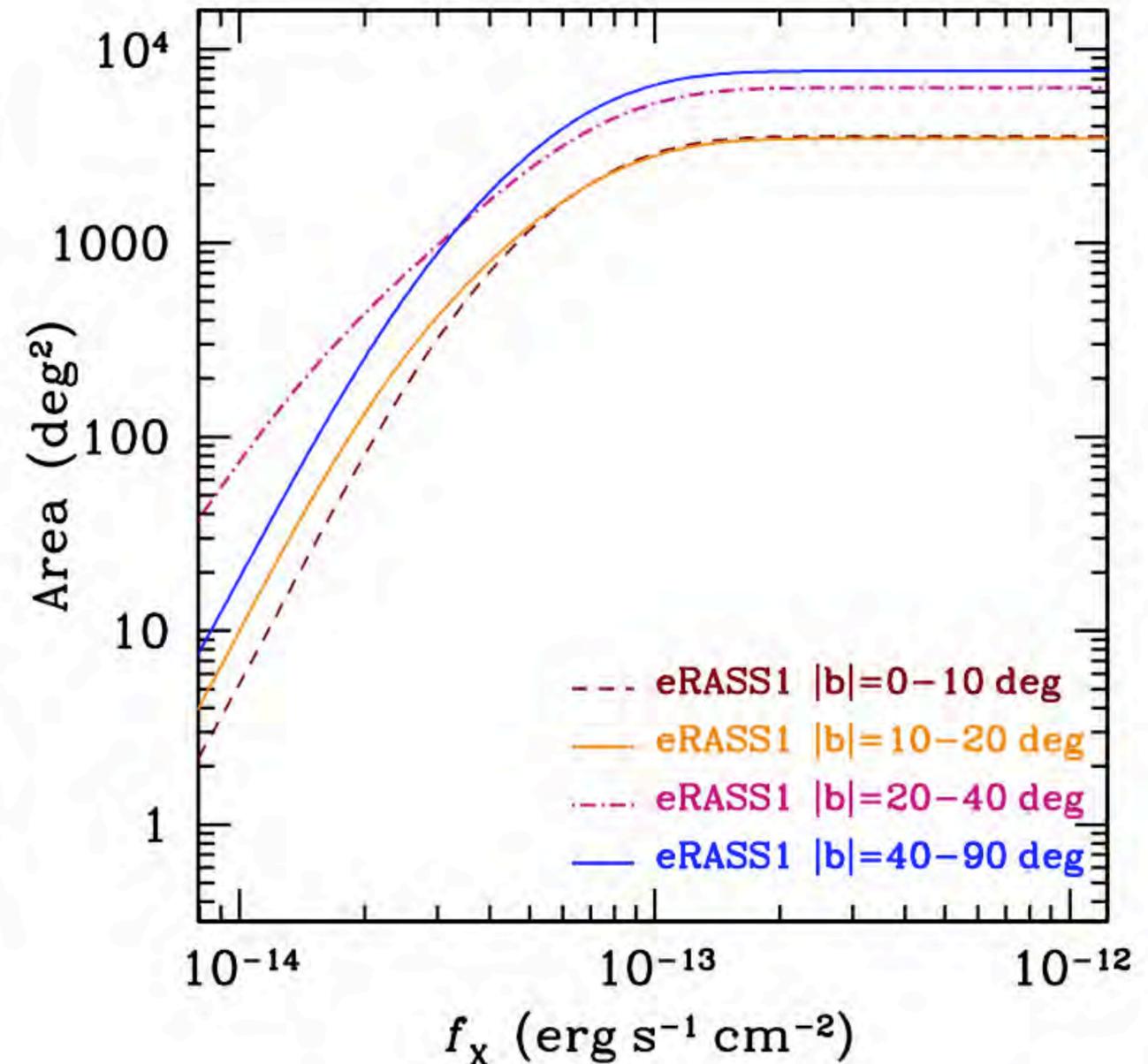
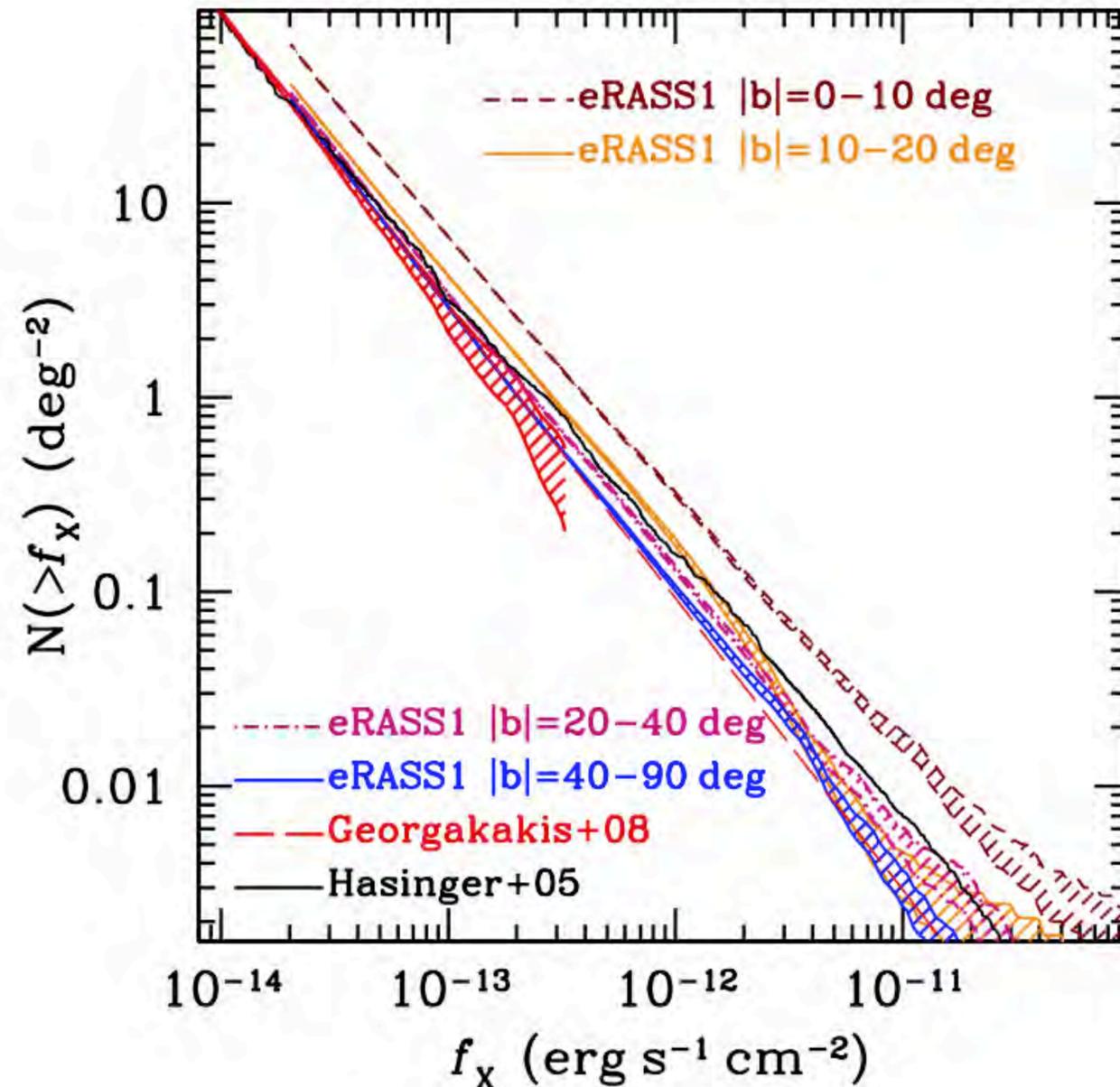
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Catalogue [Mission]	N_{objects}	Time span	f_{Area}	Energy coverage
4U [Uhuru]	339	1970–1972	0.97	2.0–6.0 keV
3A [Ariel-V]	250	1974–1979	1.0	2.0–10 keV
A1 [HEAO-1]	842	1977–1978	1.0	0.25–25 keV
IPC [<i>Einstein</i>]	4000	1978–1981	0.33	0.3–3.5 keV
2RXS [ROSAT]	135 000	1990	1.0	0.1–2.4 keV
WGACAT [ROSAT]	84 000	1991–1995	0.18	0.1–2.4 keV
CSC2.1 [<i>Chandra</i>]	400 000	1999–2022	0.019	0.2–7.0 keV
4XMM-DR12 [<i>XMM-Newton</i>]	630 000	2000–2022	0.031	0.2–12 keV
4XMM-DR12 Hard [<i>XMM-Newton</i>] ^(*)	456 000	2000–2022	0.031	2–5 keV
XMMSL2 [<i>XMM-Newton</i>]	72 000	2001–2014	0.84	0.2–12 keV
2SXPS [<i>Swift</i>]	206 000	2005–2018	0.092	0.3–10 keV
eFEDS [SRG/eROSITA]	27 000	2019	0.033	0.2–2.3 keV
eRASS1 Main [SRG/eROSITA]	930 000	2019–2020	0.5	0.2–2.3 keV
eRASS1 Hard [SRG/eROSITA]	5466	2019–2020	0.5	2.3–5.0 keV

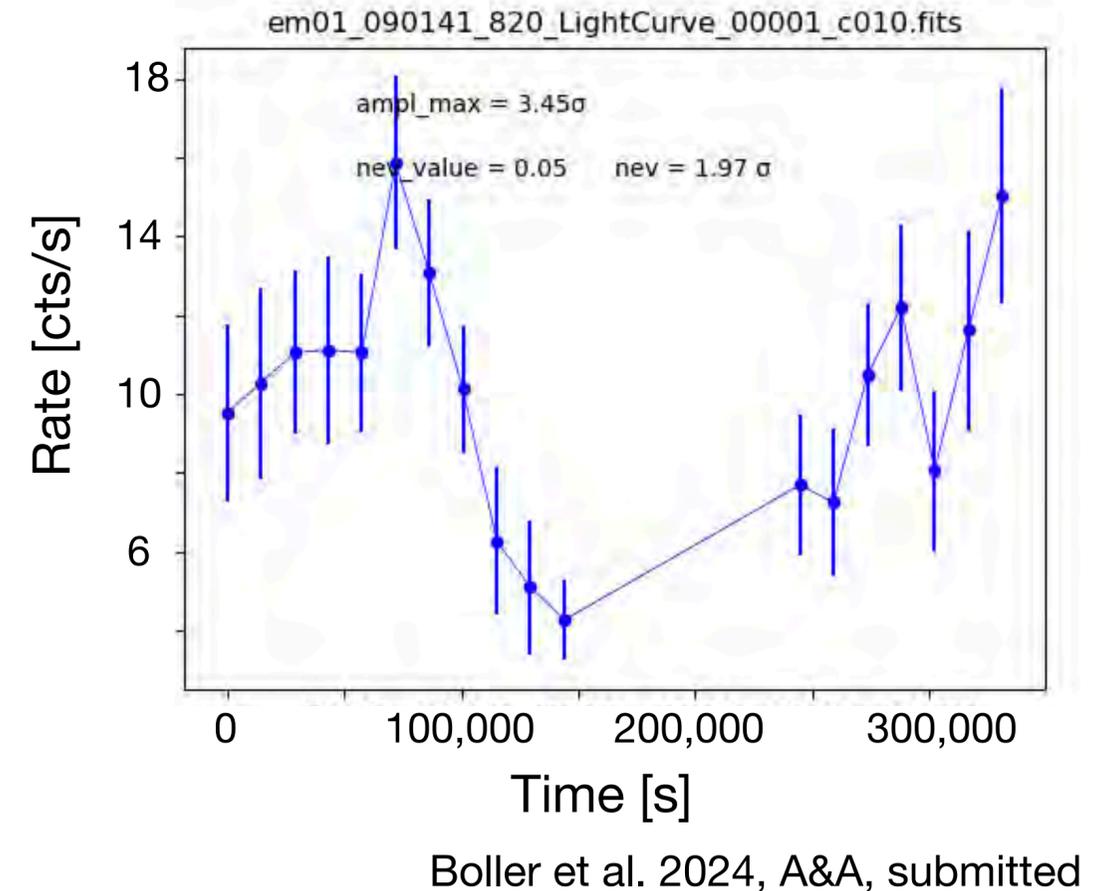


eROSITA All Sky Survey (eRASS)



eRASS1 TIPS

- 各種カタログ
 - Optical counterparts (TBA)
 - AGN spectral properties (TBA)
 - X-ray variability (Boller et al. 2024)
 - 128,669 (net count > 10) 天体中、557天体に変動の兆候あり。内10% 程度がAGN
- フラックス上限値 (Tubín-Arenas et al. 2024, A&A, 682, A35)
- X-ray stacking (後述)



Upper limit for a single position

<https://erosita.mpe.mpg.de/dr1/erodat/upperlimit/single/>

Find an upper limit on the sky for a single sky position. Please either enter a position directly (in decimal degrees or sexagesimal), or give an object name and click resolve, to find the position using the Sesame name resolver.

Please see [this page](#) and [Tubín-Arenas et al. \(2024\)](#) for further details. Both Tubín-Arenas et al. (2024) and Merloni et al. (2024) should be referenced if these upper limits are used.

Object name:
 Longitude: Latitude: Coordinate System:
 Band:

Upper limit

The flux upper limit in band 024 at the position R.A.=180.00000, Dec=-45.00000 is 4.50862e-14 erg s⁻¹ cm⁻².

Upper limit details

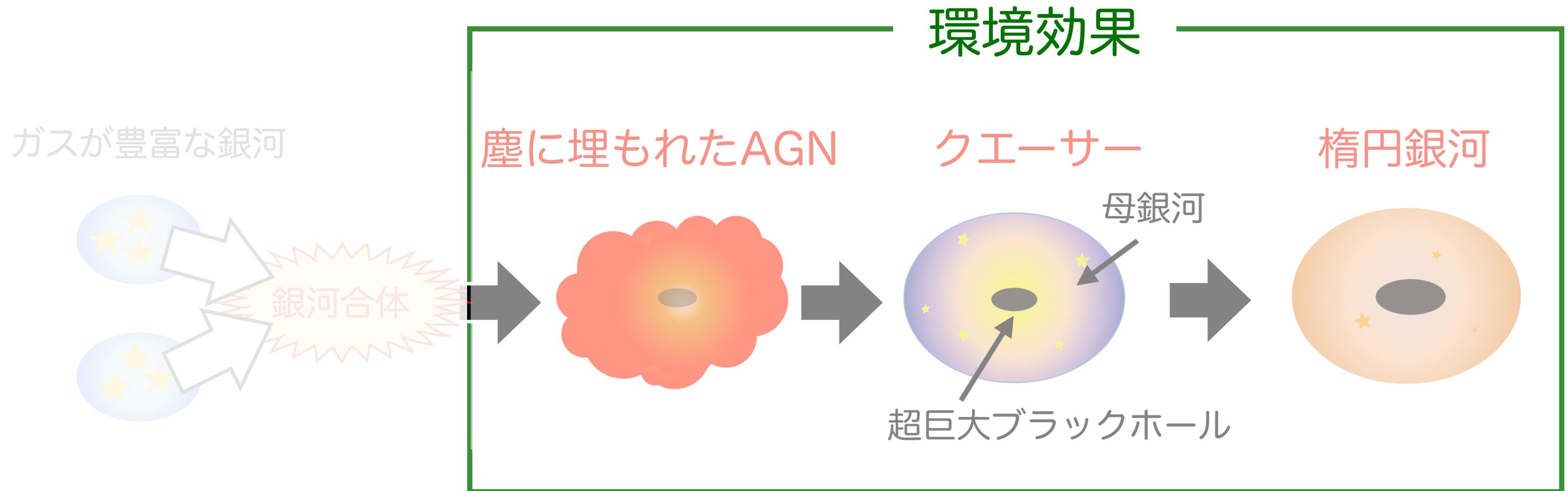
Entry	Description	Unit	Value
healpix	HEALPix index	-	45779430016
Count	Observed counts	Counts	0
Bkg_counts	Background counts	Counts	0.762026
Bkg_SourceMap	Source-map counts (used as background)	Counts	0.762577
Exposure	Exposure time	s	182.847
Flag_pos	Close-neighbor flag	-	0
UL_B	Flux upper limit based on background map	erg s ⁻¹ cm ⁻²	4.50862e-14
UL_S	Flux upper limit based on source map	erg s ⁻¹ cm ⁻²	4.50862e-14
field	Sky tile	-	180135

Nearby sources from DR1_Main within 2.0 arcmin

Show entries

Distance (arcmin) ▲	iauname	detuid	ra	dec	ext	ext_like	det_like_0	mL_rate_1	mL_flux_1	Products	More
No data available in table											

すばるHSC によるAGNサイエンス



AGNの発現と環境効果

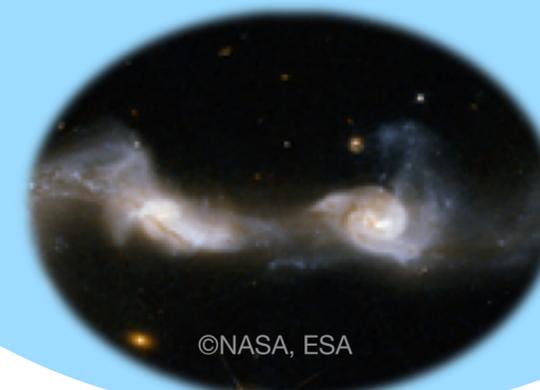
AGN activity

- AGN fraction
 - Number fraction
 - Power fraction

Cluster-Cluster Mergers



Galaxy-Galaxy Mergers



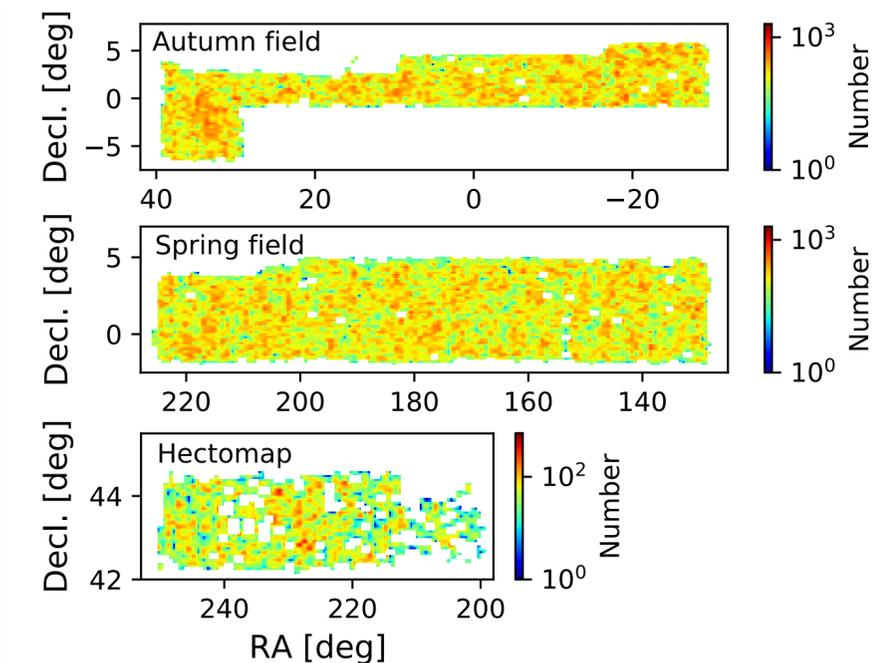
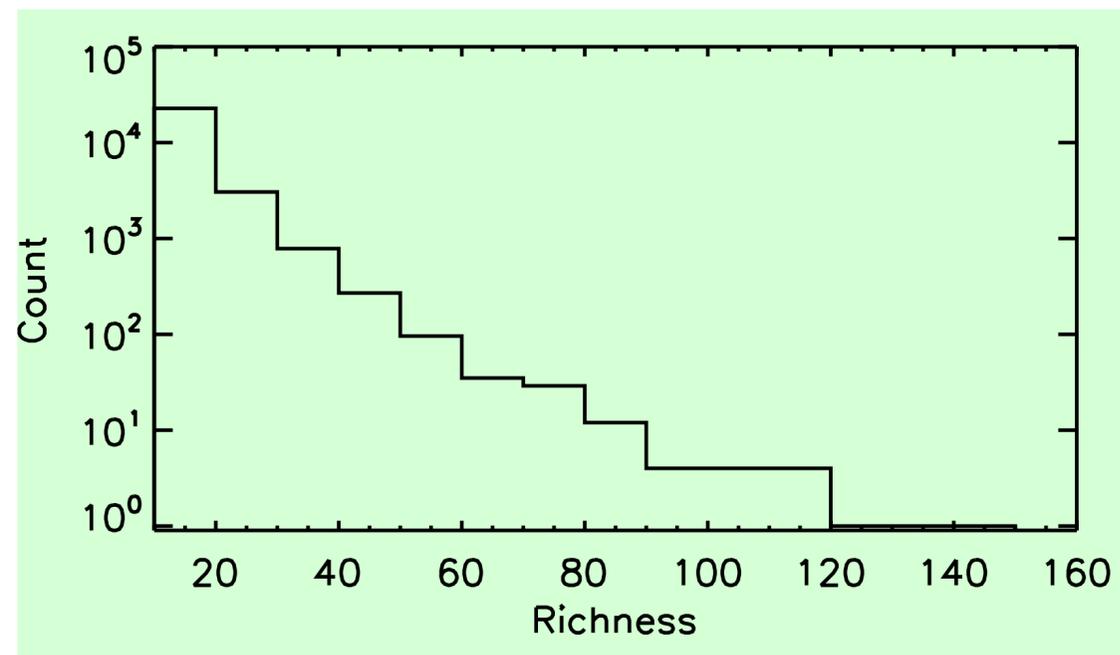
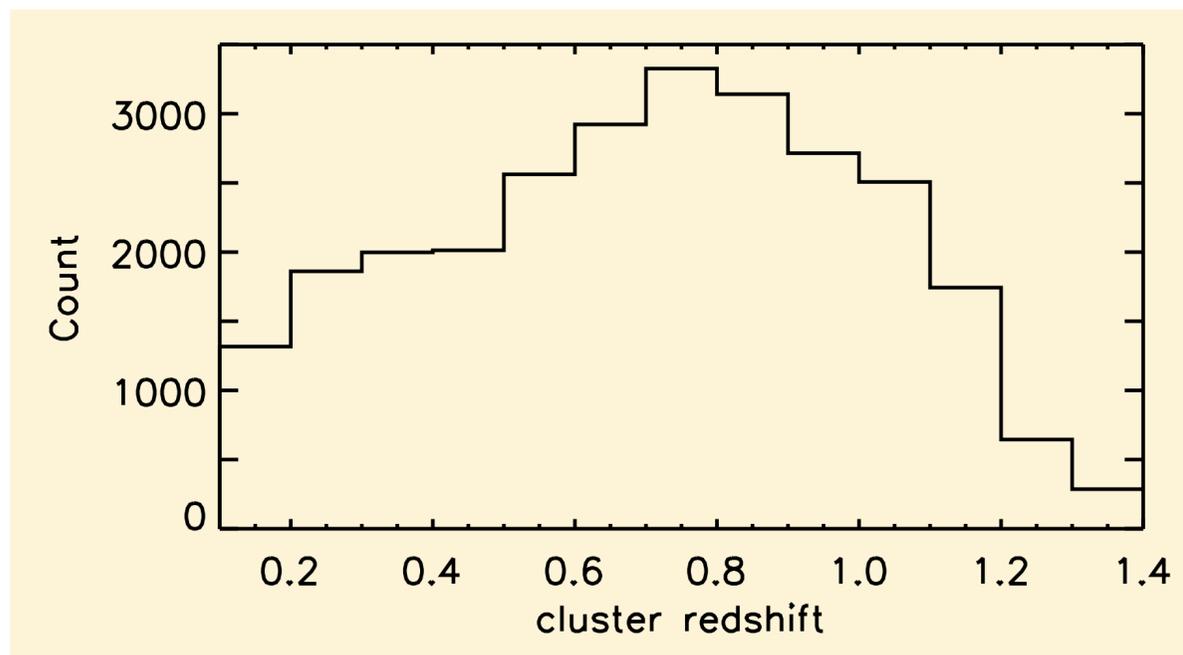
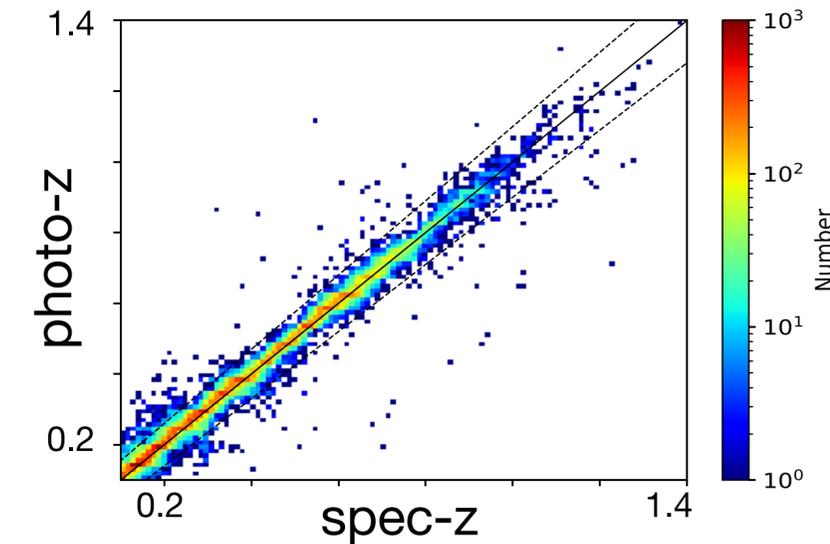


大栗さん (千葉大)

HSC-selected galaxy clusters (CAMIRA)

A **C**luster finding **A**lgorithm based on **M**ulti-band **I**dentification of **R**ed sequence **gA**laxies (Oguri 2014) is applied to the HSC data (Oguri et al. 2018).

Survey area (deg ²)	Redshift	Richness	Number	
			Cluster	Member galaxies
~1027	$0.1 < z_{cl} < 1.4$	> 10	27,037	1,052,529

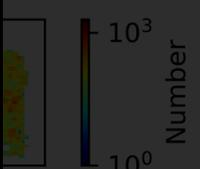
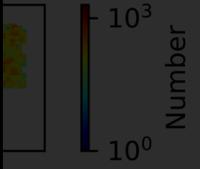
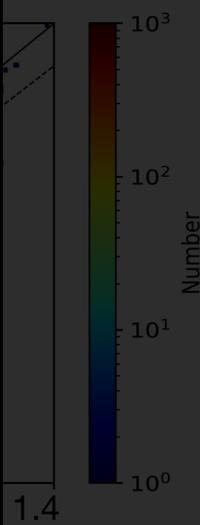
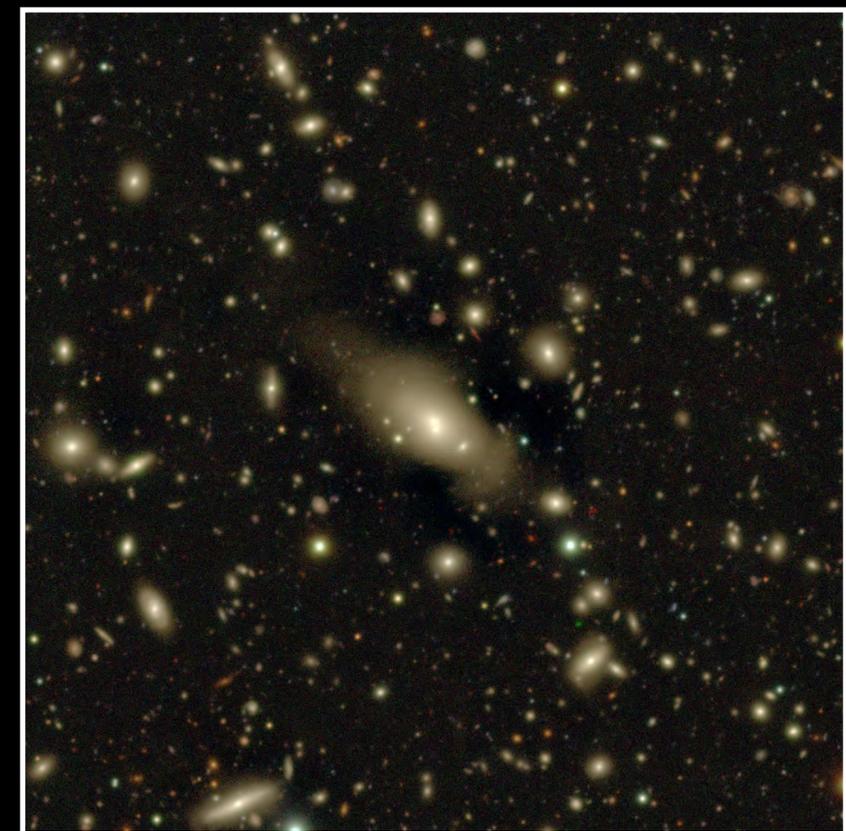
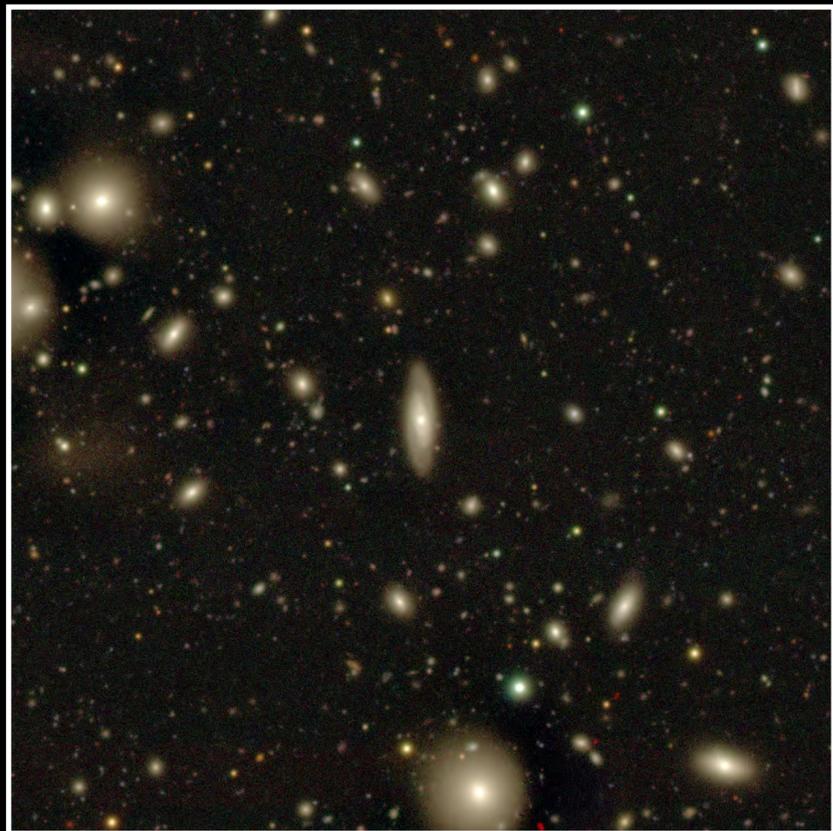
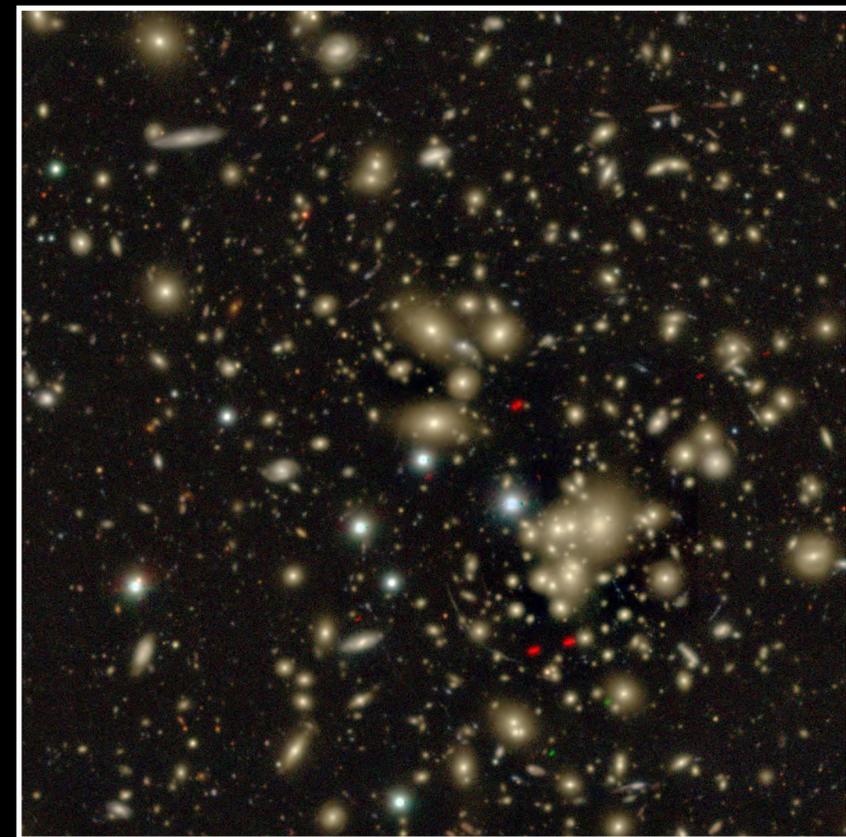
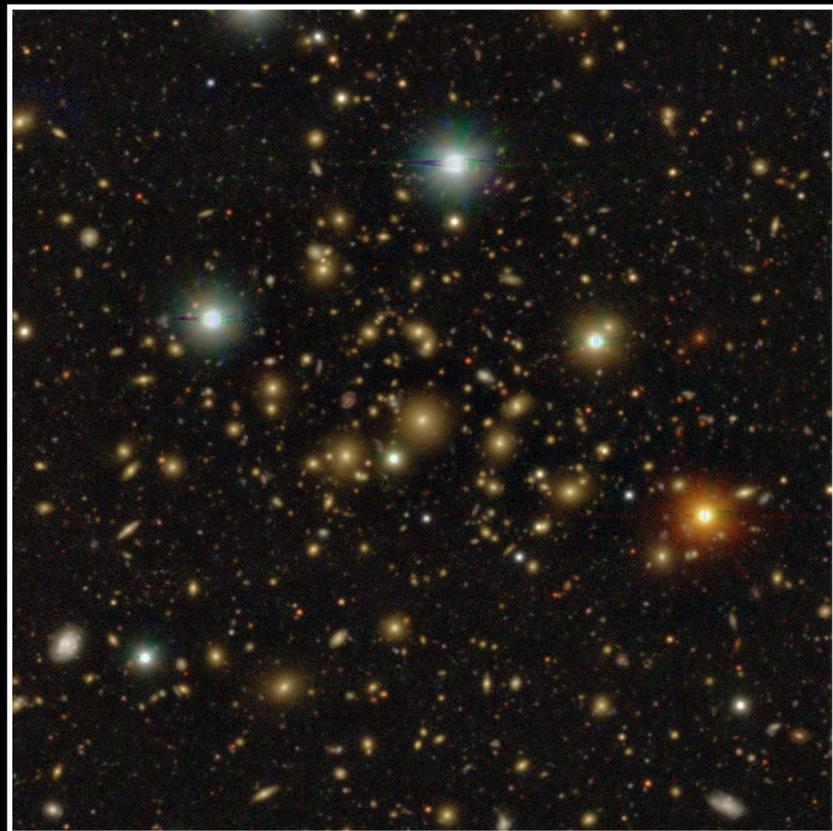


CAMIRA gallery ($N_{\text{mem}} > 100$)



Πανεμορφη ✨

2 arcmin



HSC

A Cluster
gAlaxies

Survey
(deg

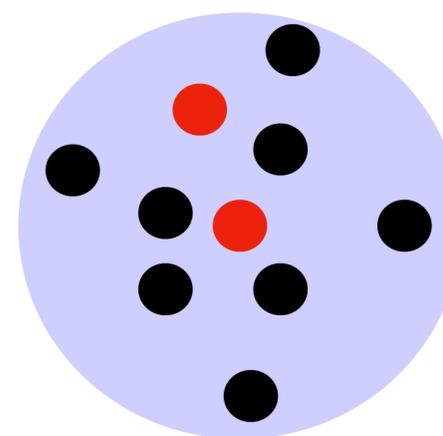
~102

Count
3000
2000
1000
0

See also e.g.,

AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

●メンバー銀河

●AGN

$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



橋口さん（奈良女）

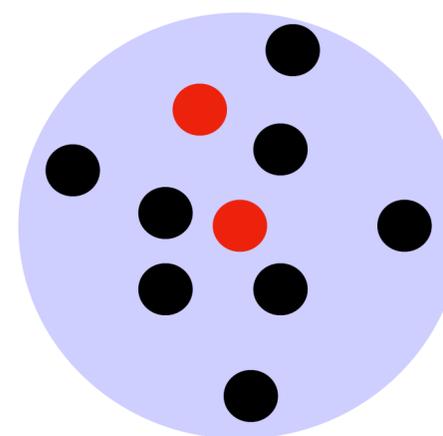
🤔 AGN fraction はフィールドと銀河団でどちらが高いのか？

🤔 AGN fraction は赤方偏移に依存するのか？

🤔 AGN fraction は銀河団の中心部と外縁部で違いはあるのか？

AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

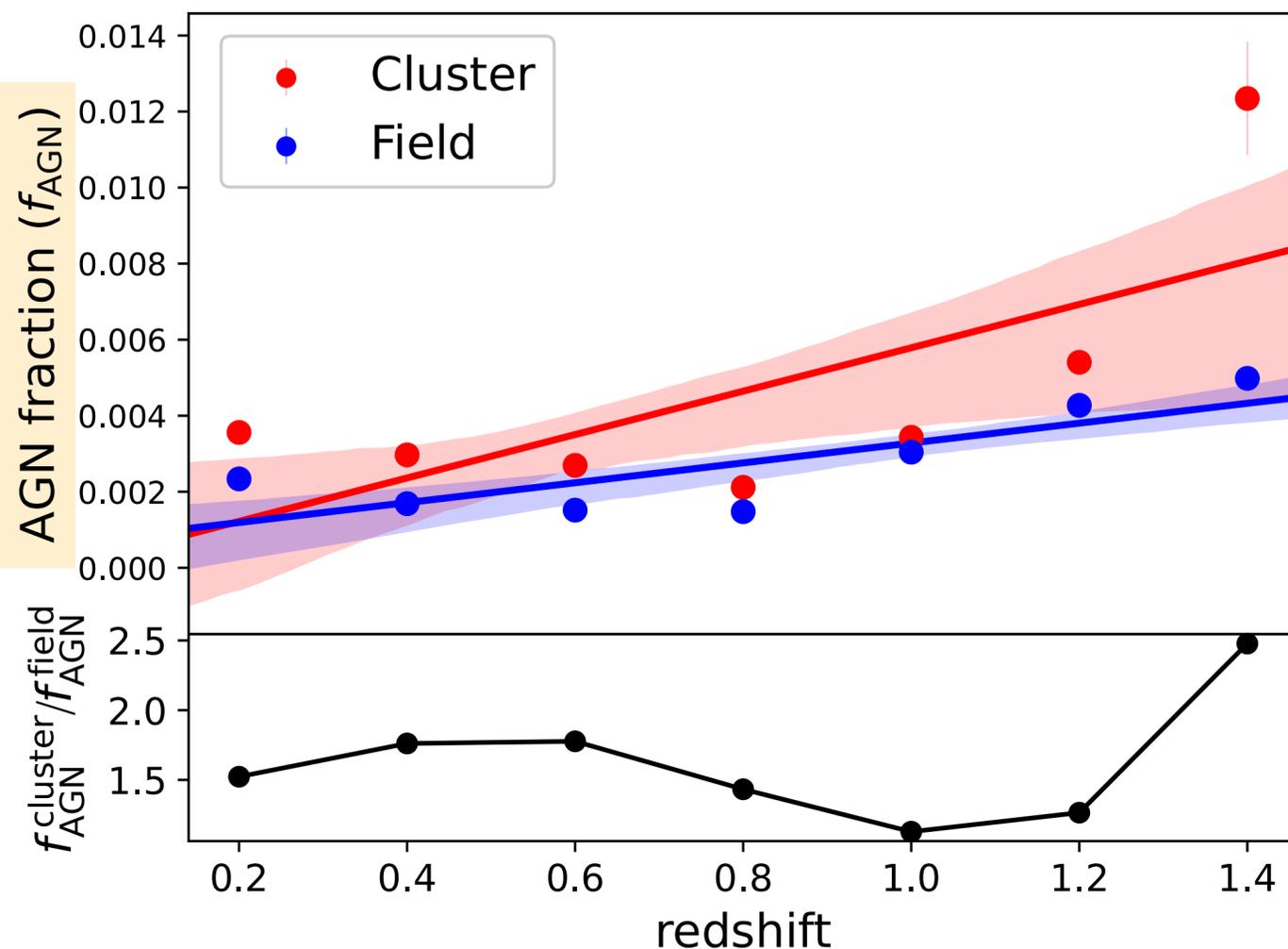
●メンバー銀河

●AGN

$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



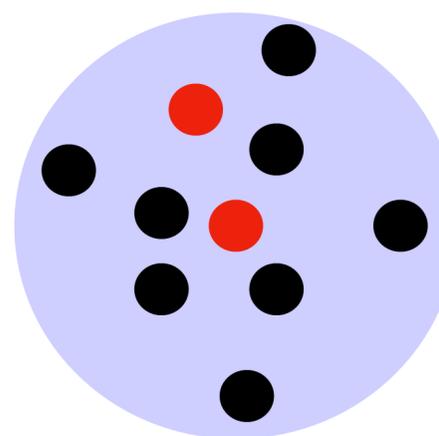
橋口さん（奈良女）



🤔 AGN fraction は 銀河団の中心部と外縁部で違いはあるのか？

AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

●メンバー銀河

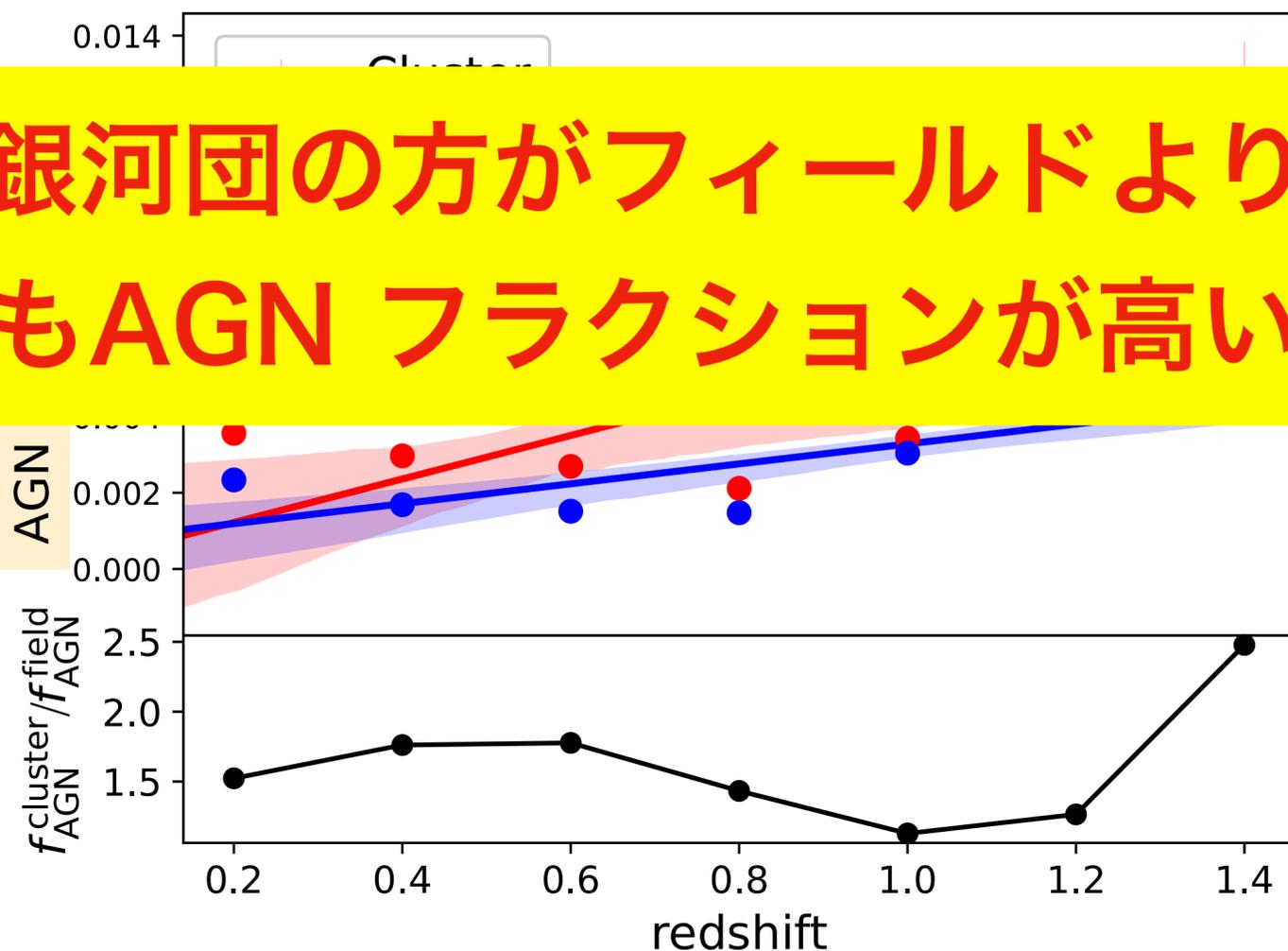
●AGN

$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



橋口さん（奈良女）

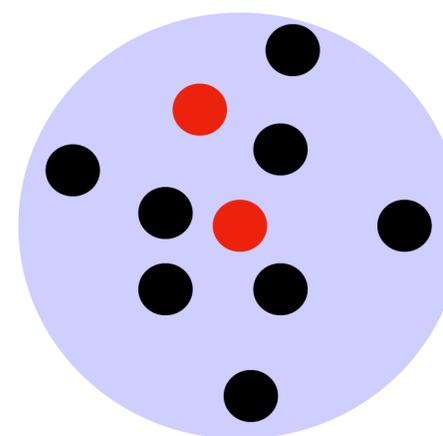
銀河団の方がフィールドよりもAGN フラクションが高い



🤔 AGN fraction は 銀河団の中心部と外縁部で違いはあるのか？

AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

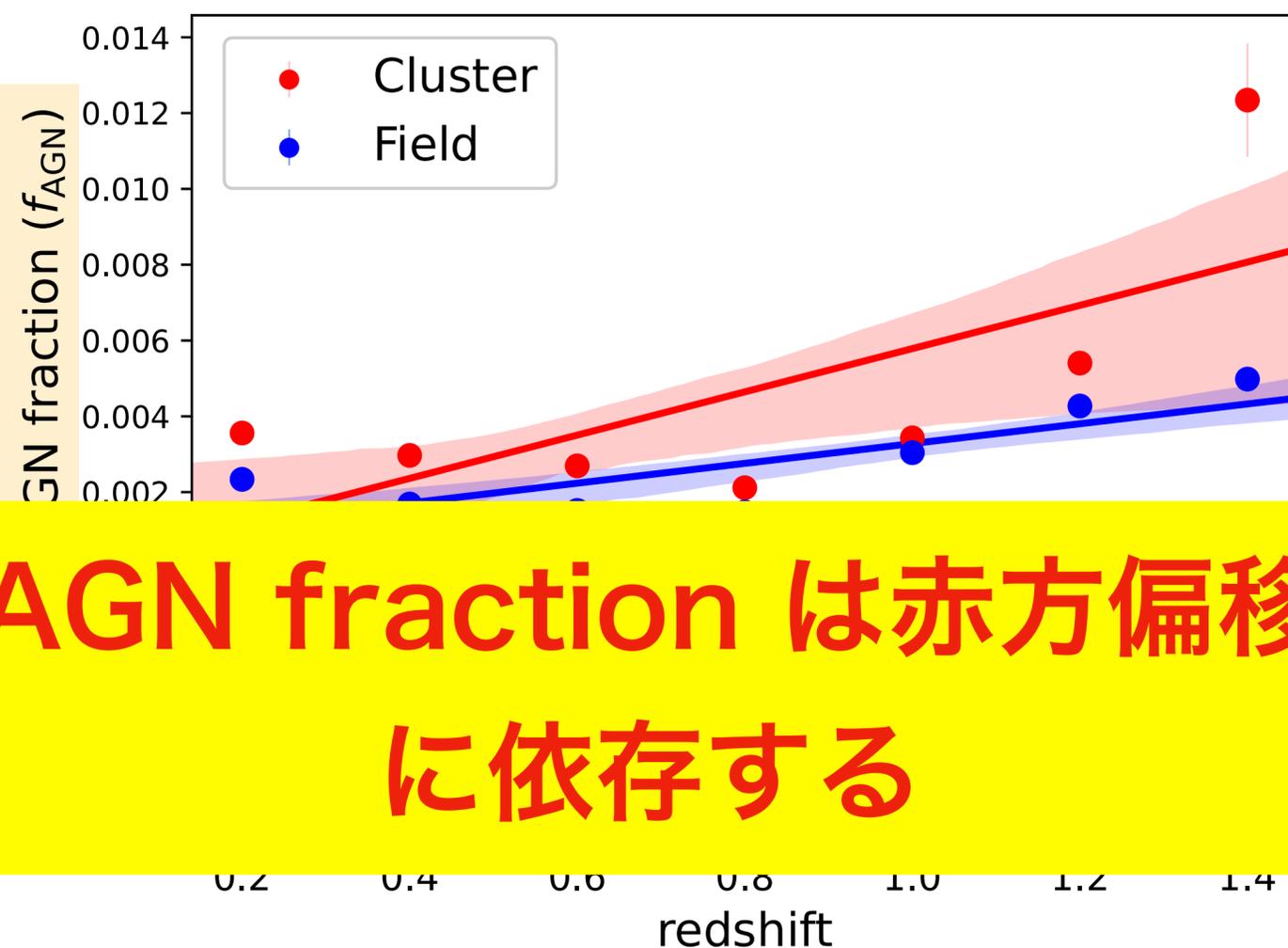
●メンバー銀河

●AGN

$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



橋口さん（奈良女）

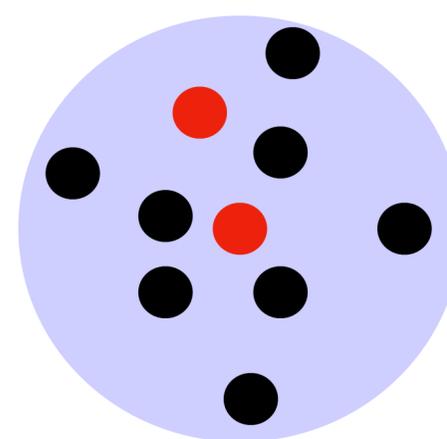


**AGN fraction は赤方偏移
に依存する**

🤔 AGN fraction は 銀河団の中心部
と外縁部で違いはあるのか？

AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

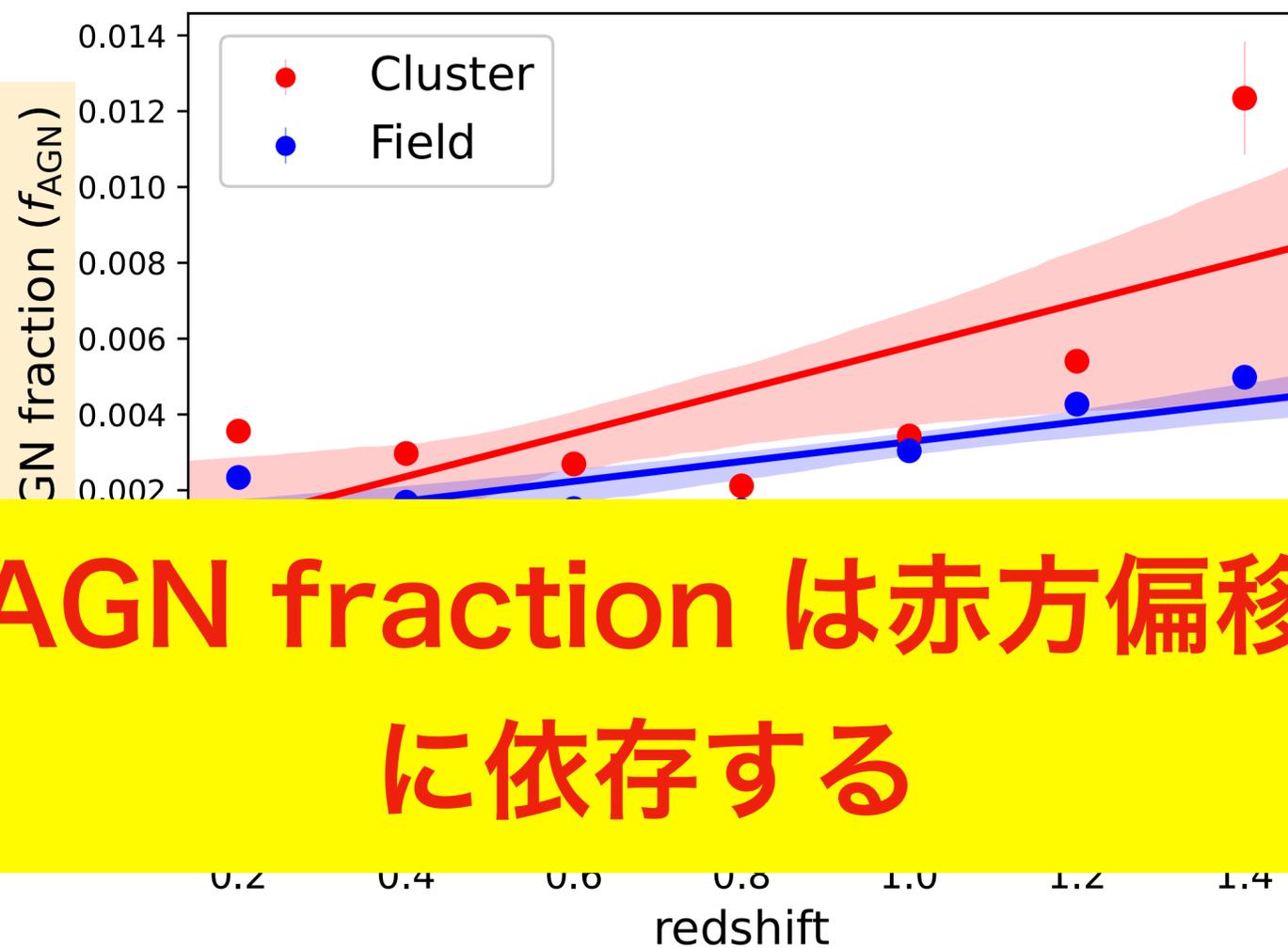
●メンバー銀河

●AGN

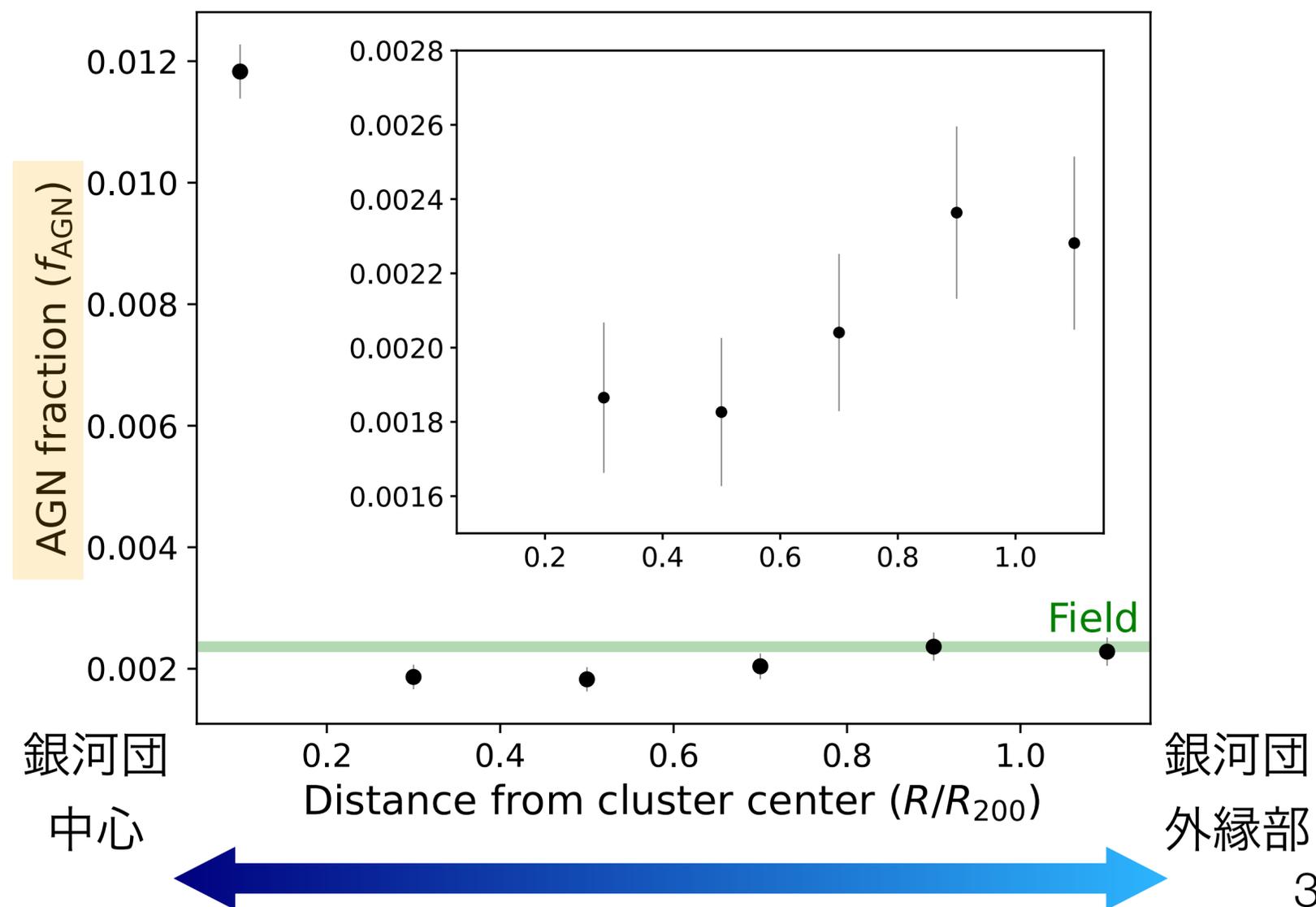
$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



橋口さん（奈良女）

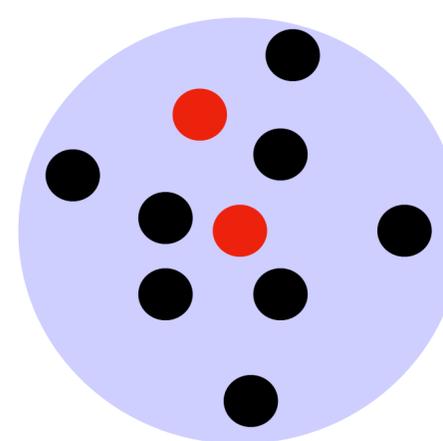


**AGN fraction は赤方偏移
に依存する**



AGN number fraction

- 多波長（赤外、電波、X線）でAGNを同定
- AGN number fraction を計算



銀河団

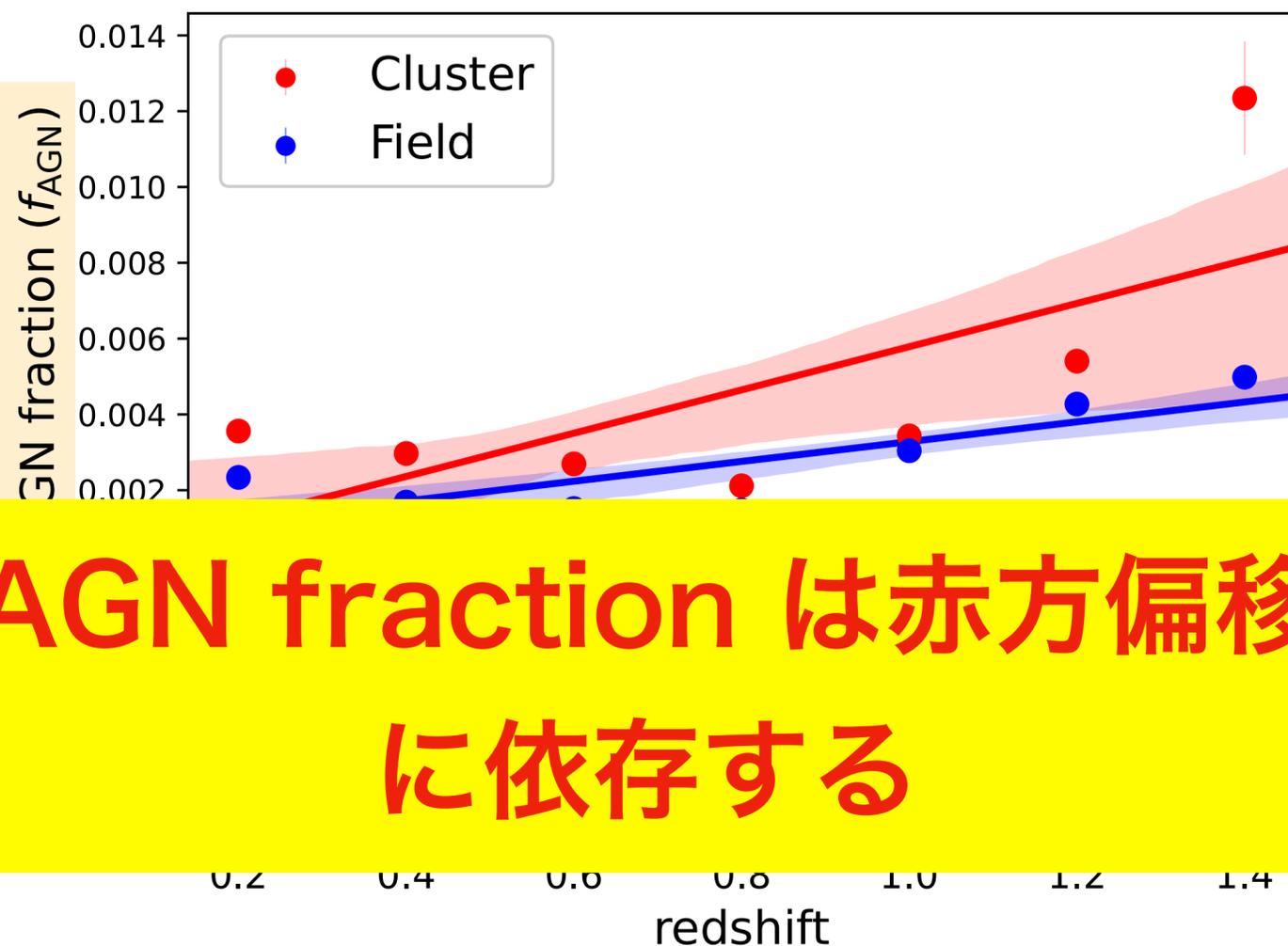
●メンバー銀河

●AGN

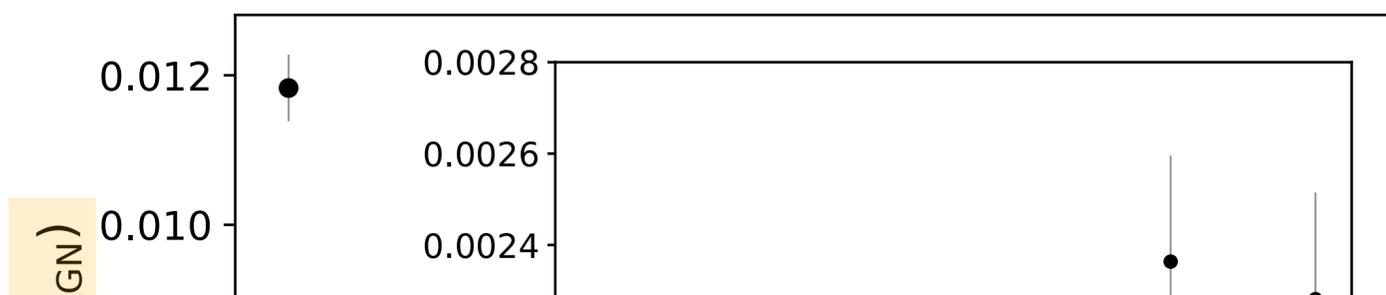
$$f_{\text{AGN}} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$



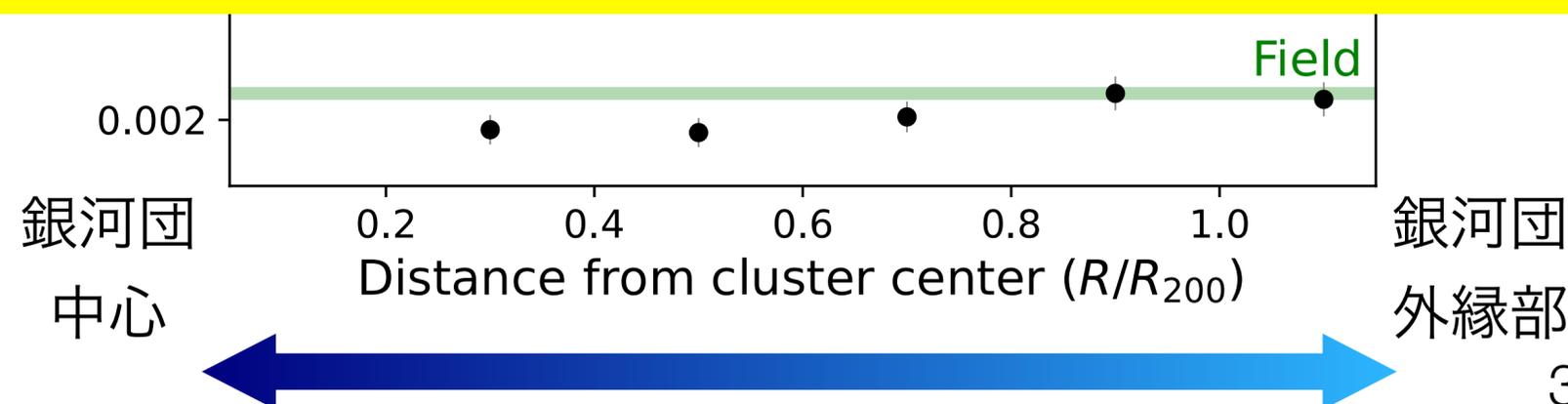
橋口さん（奈良女）



AGN fraction は赤方偏移
に依存する

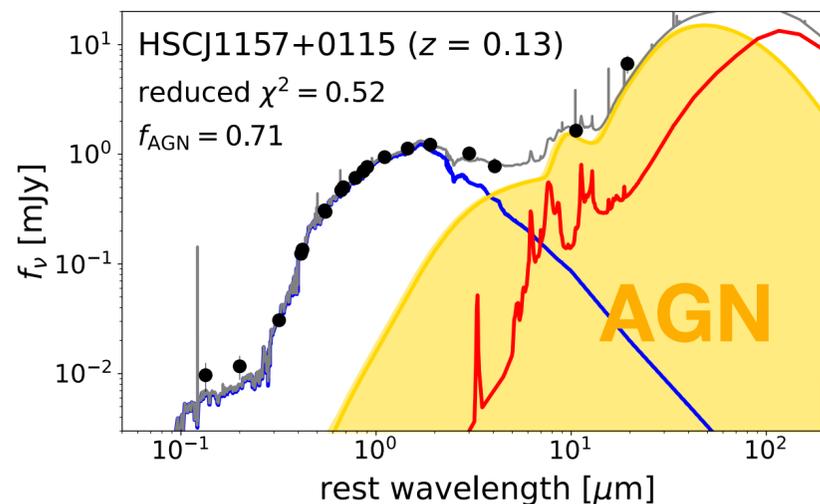
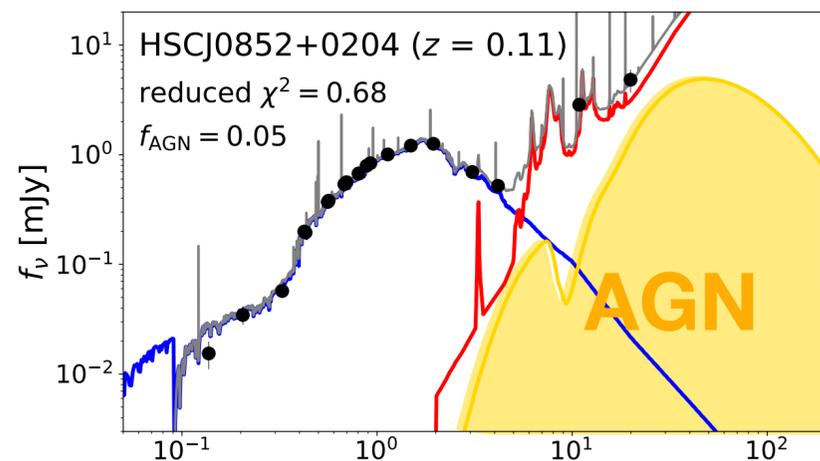


特に銀河団中心でAGN
fraction が高い



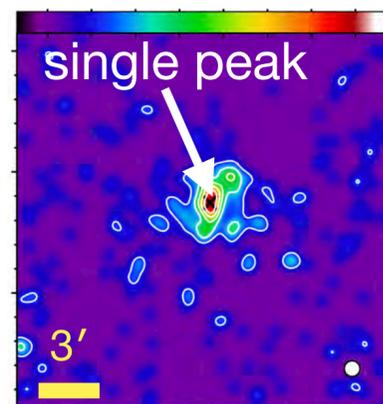
AGN power fraction

- 各天体について多波長SED fitting を実施
- AGN power fraction を計算

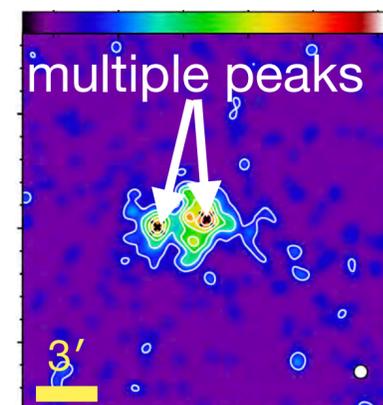


Toba et al. 2024, ApJ, in press.

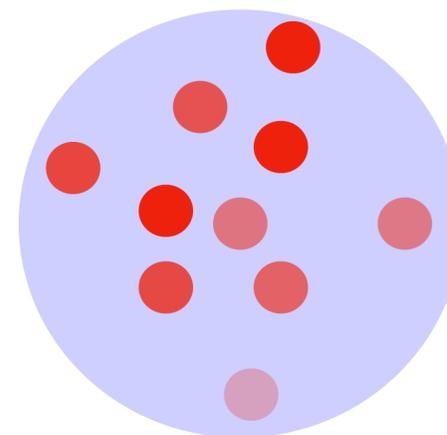
Relaxed cluster



Merging cluster



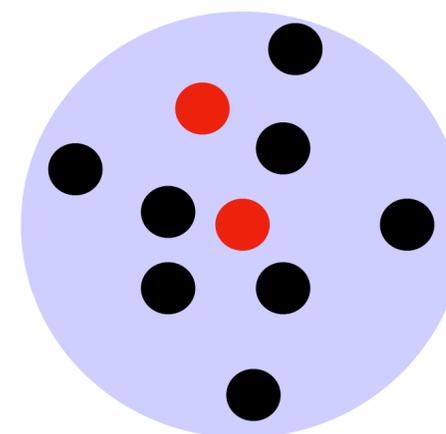
Okabe et al. (2019)



銀河団

すべてのメンバー銀河に対して
 $L_{IR} (AGN) / L_{IR}$ を計算

$$f_{AGN}^{cl} = \frac{\sum w_{mem}^i f_{AGN}^i}{\sum w_{mem}^i}$$



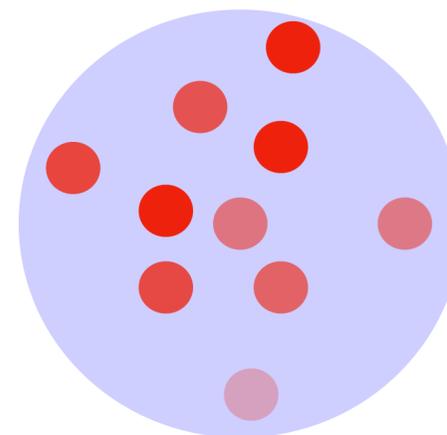
銀河団

●メンバー銀河
●AGN

$$f_{AGN} = \frac{\text{AGNの数}}{\text{メンバー銀河の数}}$$

AGN power fraction

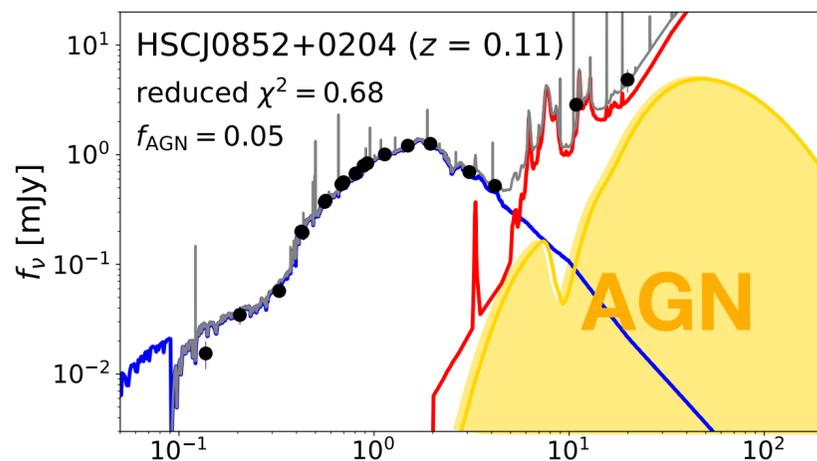
- 各天体について多波長SED fitting を実施
- AGN power fraction を計算



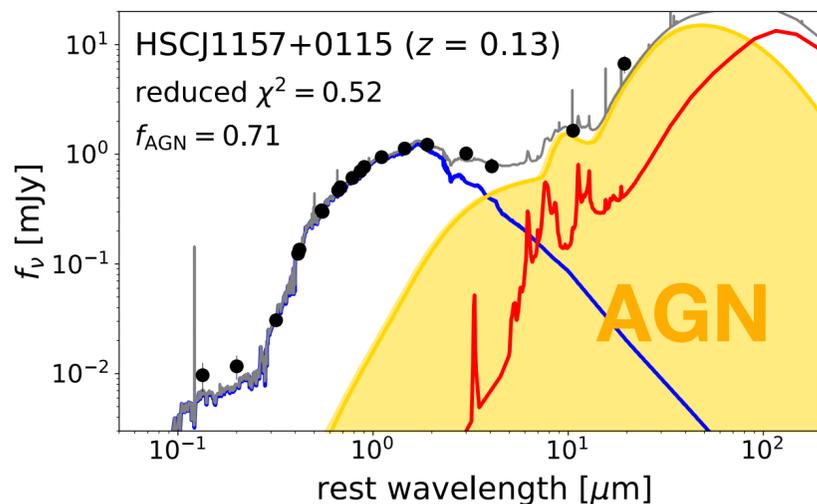
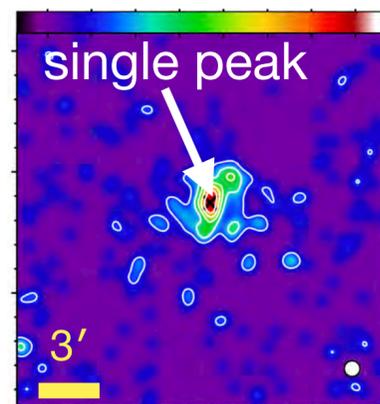
銀河団

すべてのメンバー銀河に対して
 $L_{IR} (AGN) / L_{IR}$ を計算

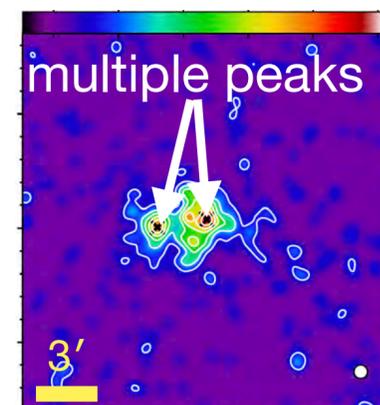
$$f_{AGN}^{cl} = \frac{\sum w_{mem}^i f_{AGN}^i}{\sum w_{mem}^i}$$



Relaxed cluster



Merging cluster

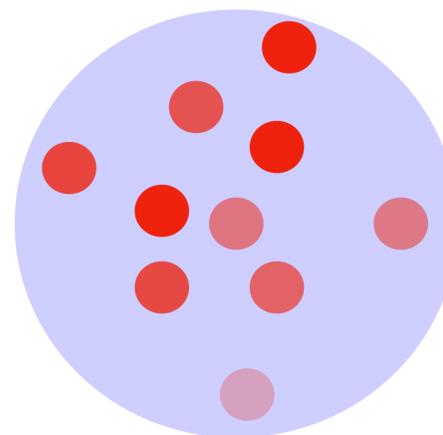


🤔 銀河団同士の合体はAGNの発現
にどのように寄与するのか？

Okabe et al. (2019)

AGN power fraction

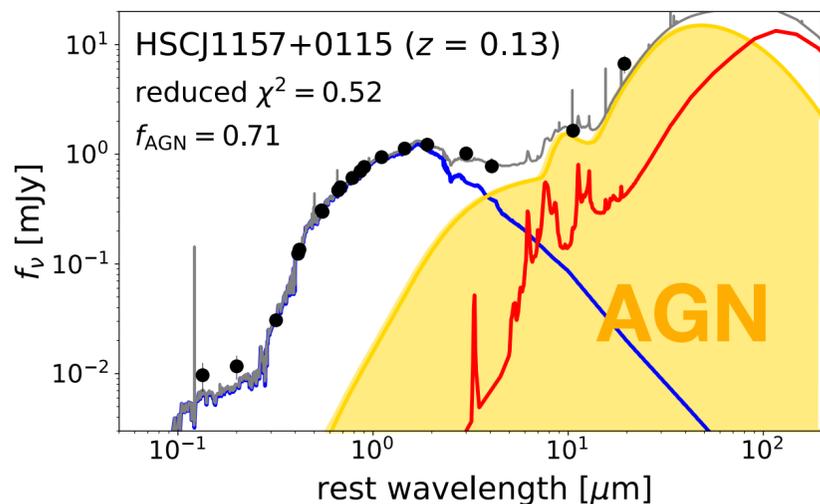
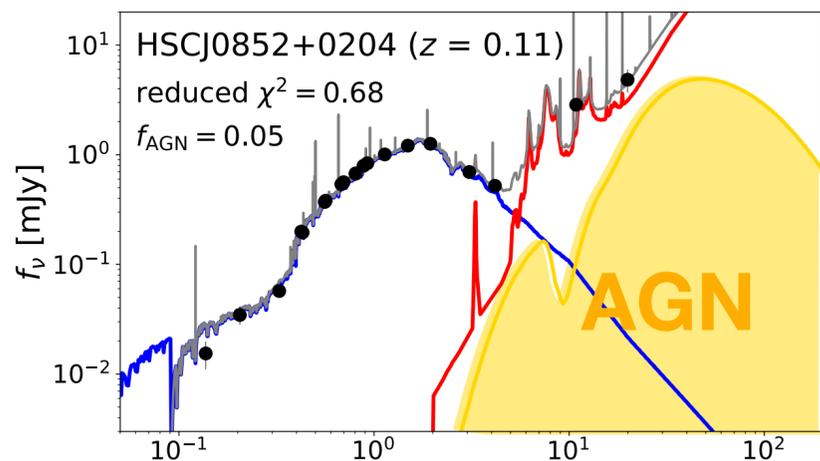
- 各天体について多波長SED fitting を実施
- AGN power fraction を計算



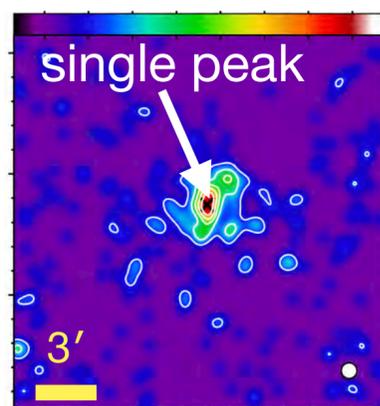
銀河団

すべてのメンバー銀河に対して
L_{IR} (AGN)/L_{IR} を計算

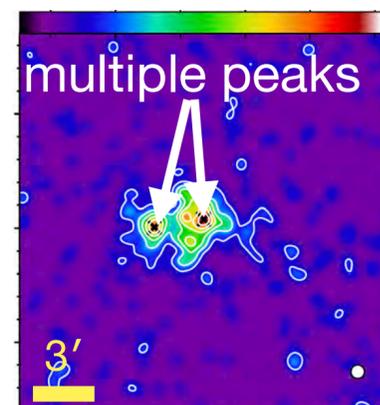
$$f_{\text{AGN}}^{\text{cl}} = \frac{\sum w_{\text{mem}}^i f_{\text{AGN}}^i}{\sum w_{\text{mem}}^i}$$



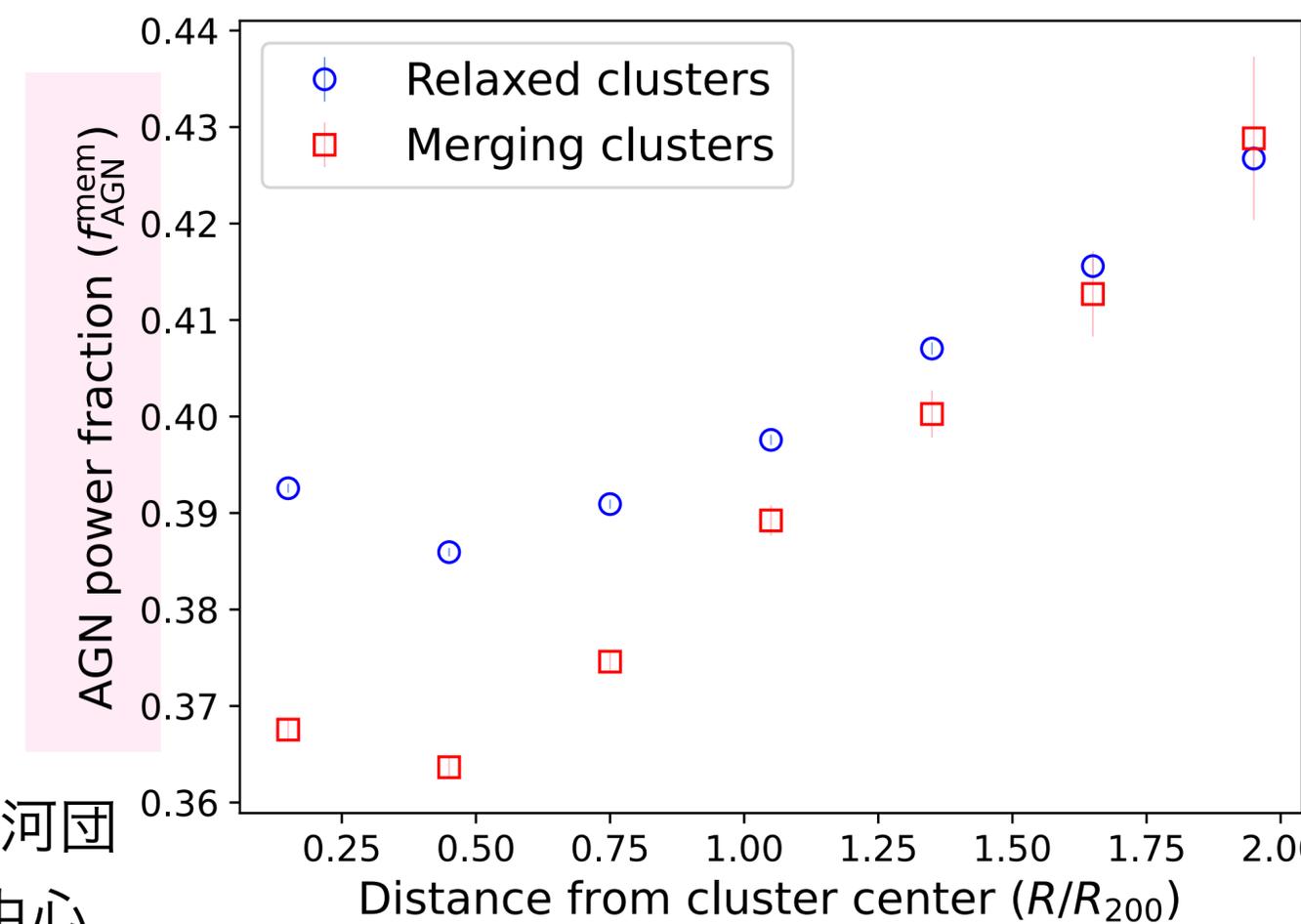
Relaxed cluster



Merging cluster



Okabe et al. (2019)

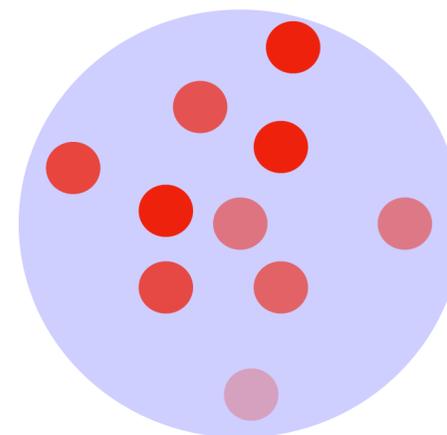


銀河団
中心

銀河団
外縁部

AGN power fraction

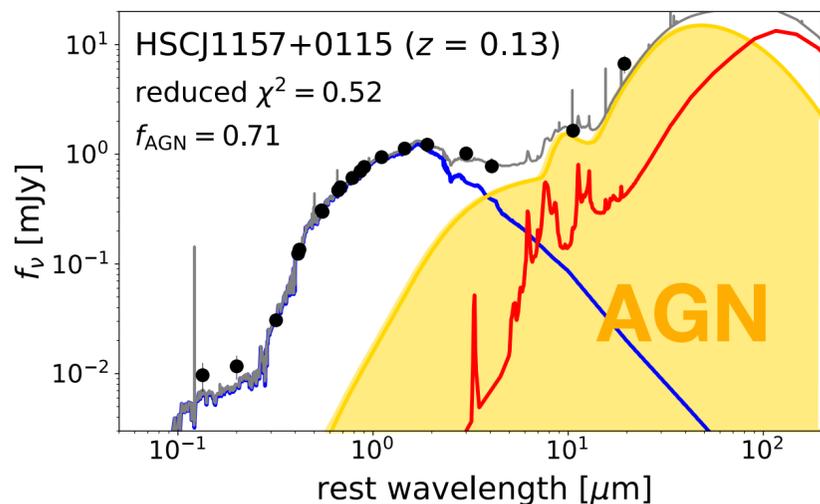
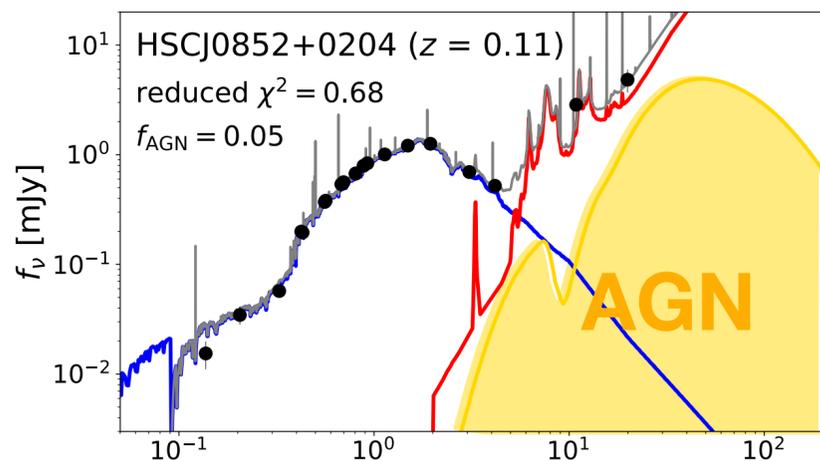
- 各天体について多波長SED fitting を実施
- AGN power fraction を計算



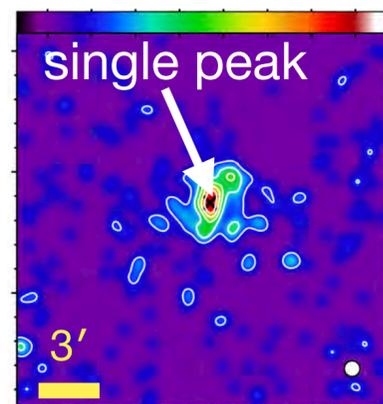
銀河団

すべてのメンバー銀河に対して
LIR (AGN)/LIR を計算

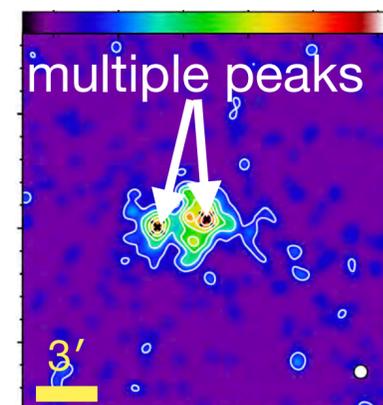
$$f_{AGN}^{cl} = \frac{\sum w_{mem}^i f_{AGN}^i}{\sum w_{mem}^i}$$



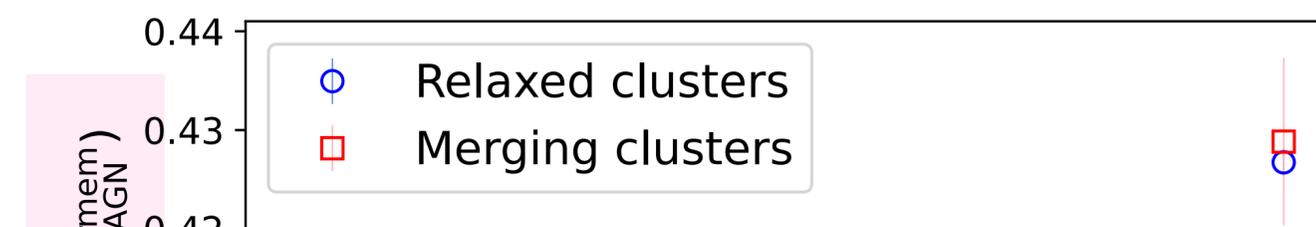
Relaxed cluster



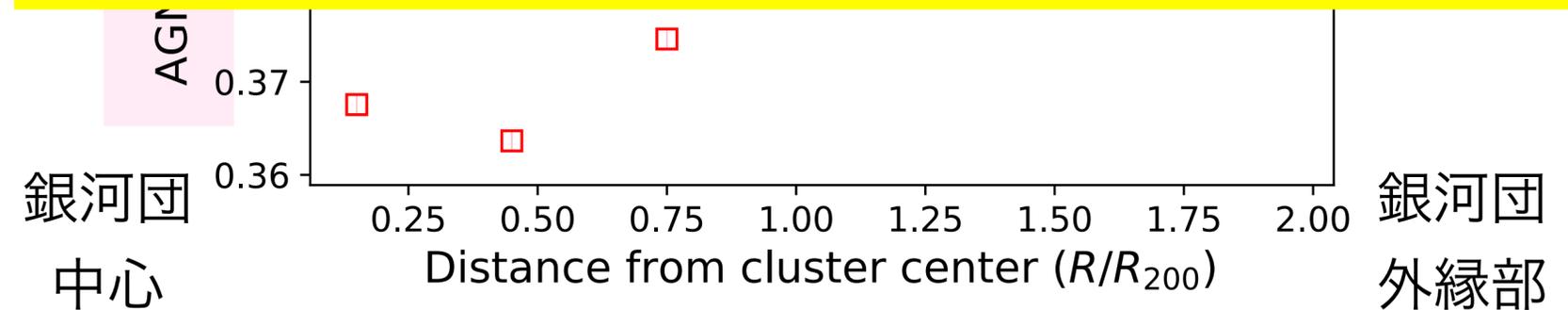
Merging cluster



Okabe et al. (2019)



**Merging 銀河団外縁部で
AGNが卓越？**



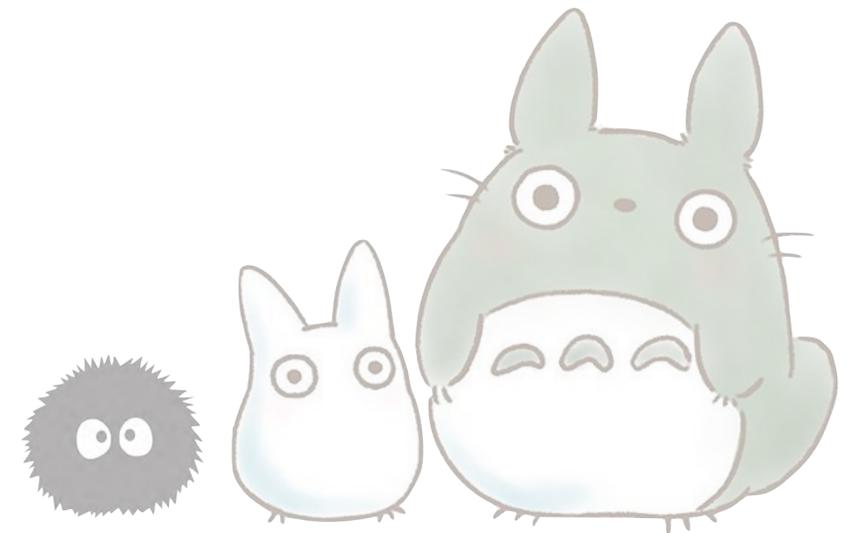
銀河団
中心

銀河団
外縁部



今後の展望

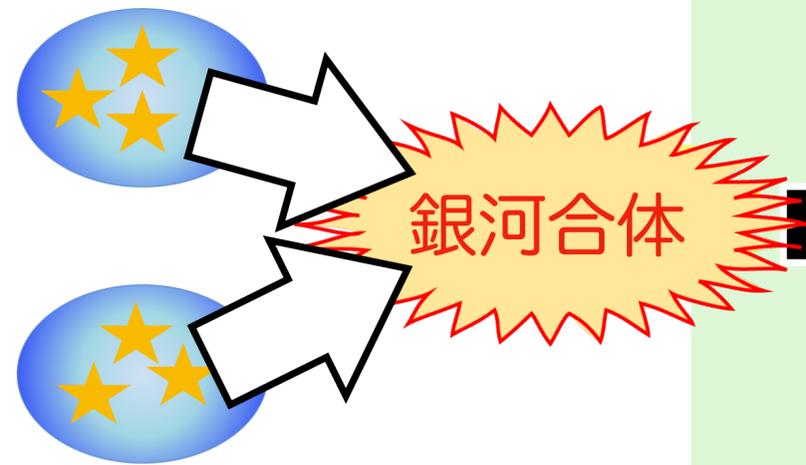
- eROSITA関連（3つの話題）
- 将来ミッション（PFS・Euclid/LSST）



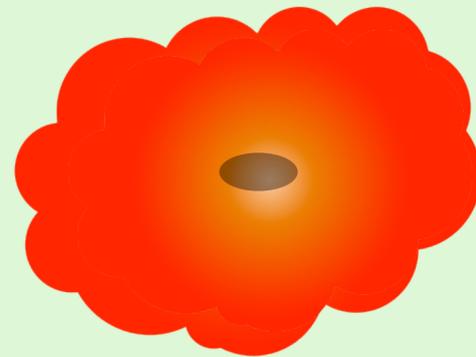
銀河合体・高光度AGN・低光度AGN

環境効果

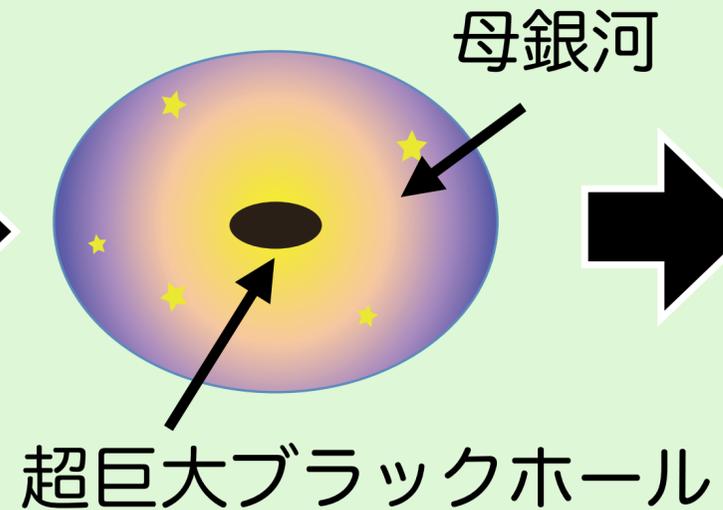
ガスが豊富な銀河



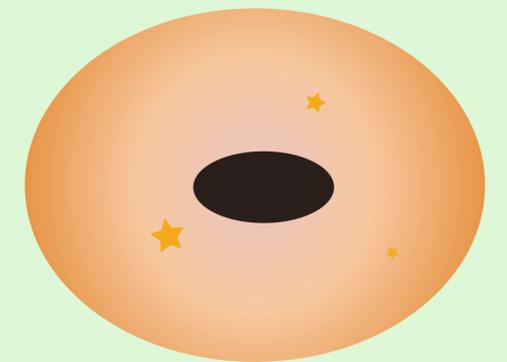
塵に埋もれたAGN



クエーサー



楕円銀河



そもそもこのシナリオがどのくらい正しいのか・普遍的なのか

銀河合体・高光度AGN・低光度AGN

① 銀河合体/dual AGN/binary

環境効果



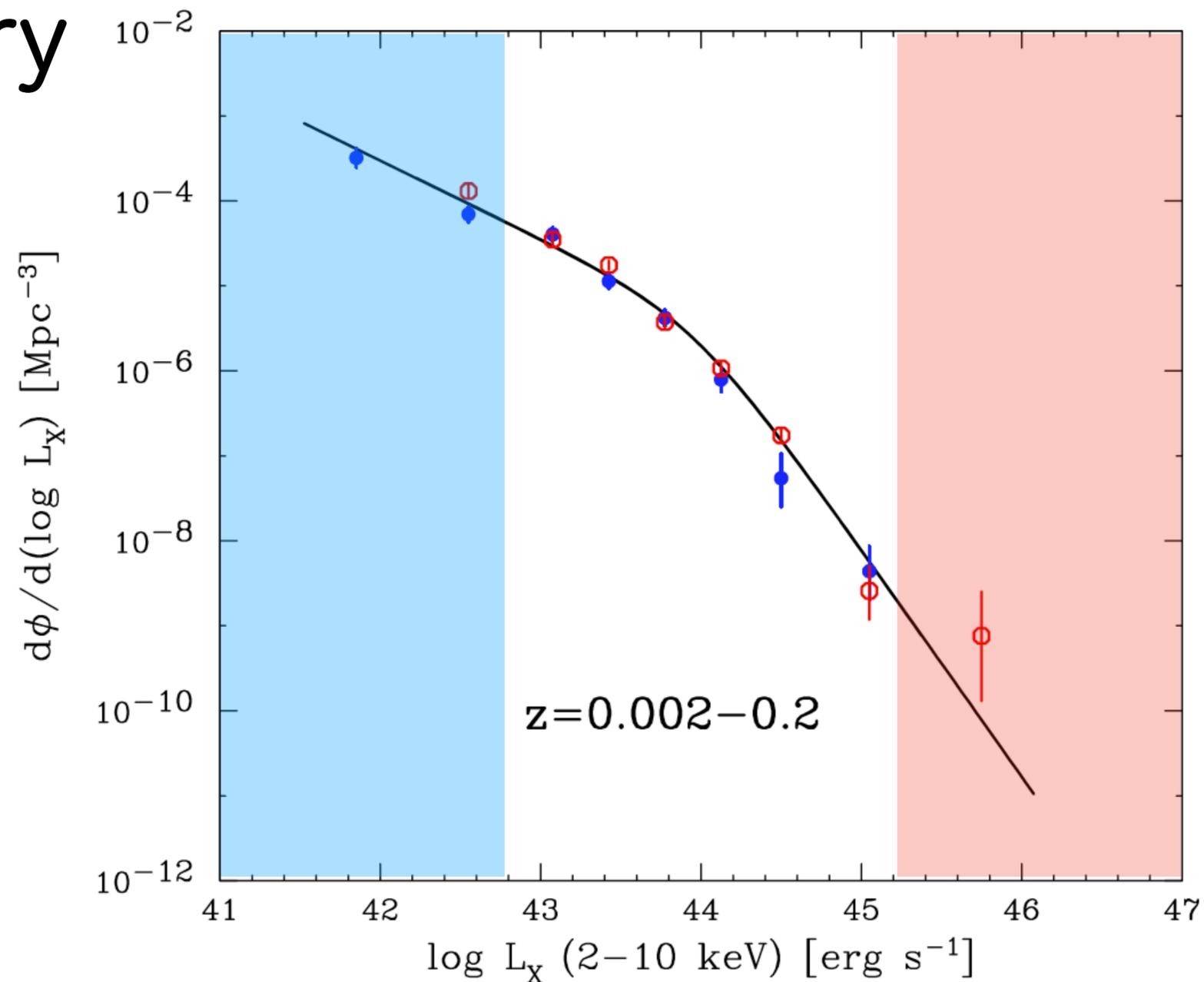
そもそもこのシナリオがどのくらい正しいのか・普遍的なのか

銀河合体・高光度AGN・低光度AGN

① 銀河合体/dual AGN/binary

② 宇宙一明るいAGN探査・
素性調査

③ 検出限界以下の暗い or
埋もれたAGN調査



銀河合体・高光度AGN・低光度AGN

① 銀河合体/dual AGN/binary

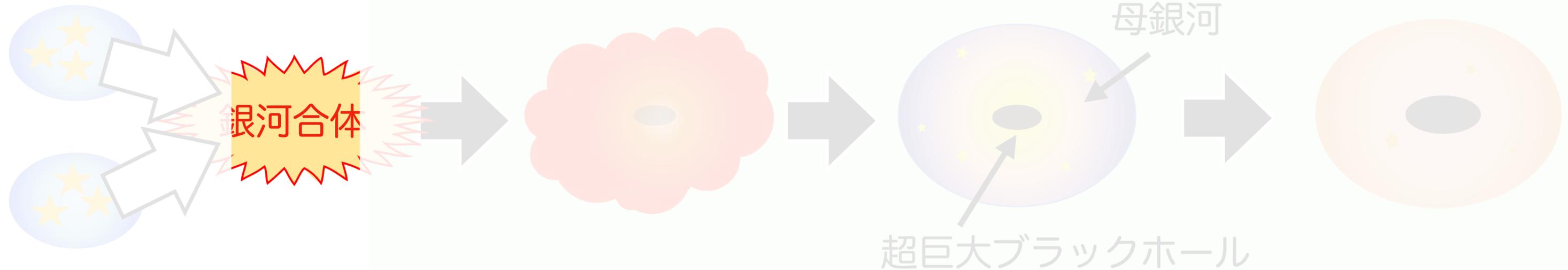
環境効果

ガスが豊富な銀河

塵に埋もれたAGN

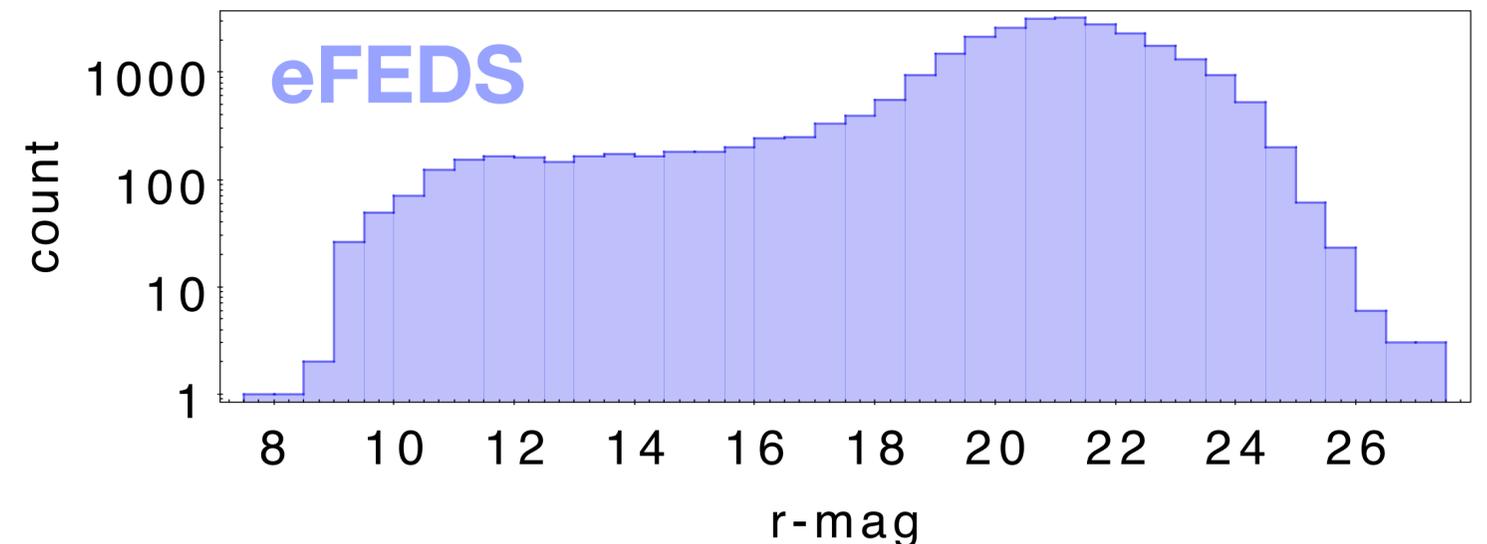
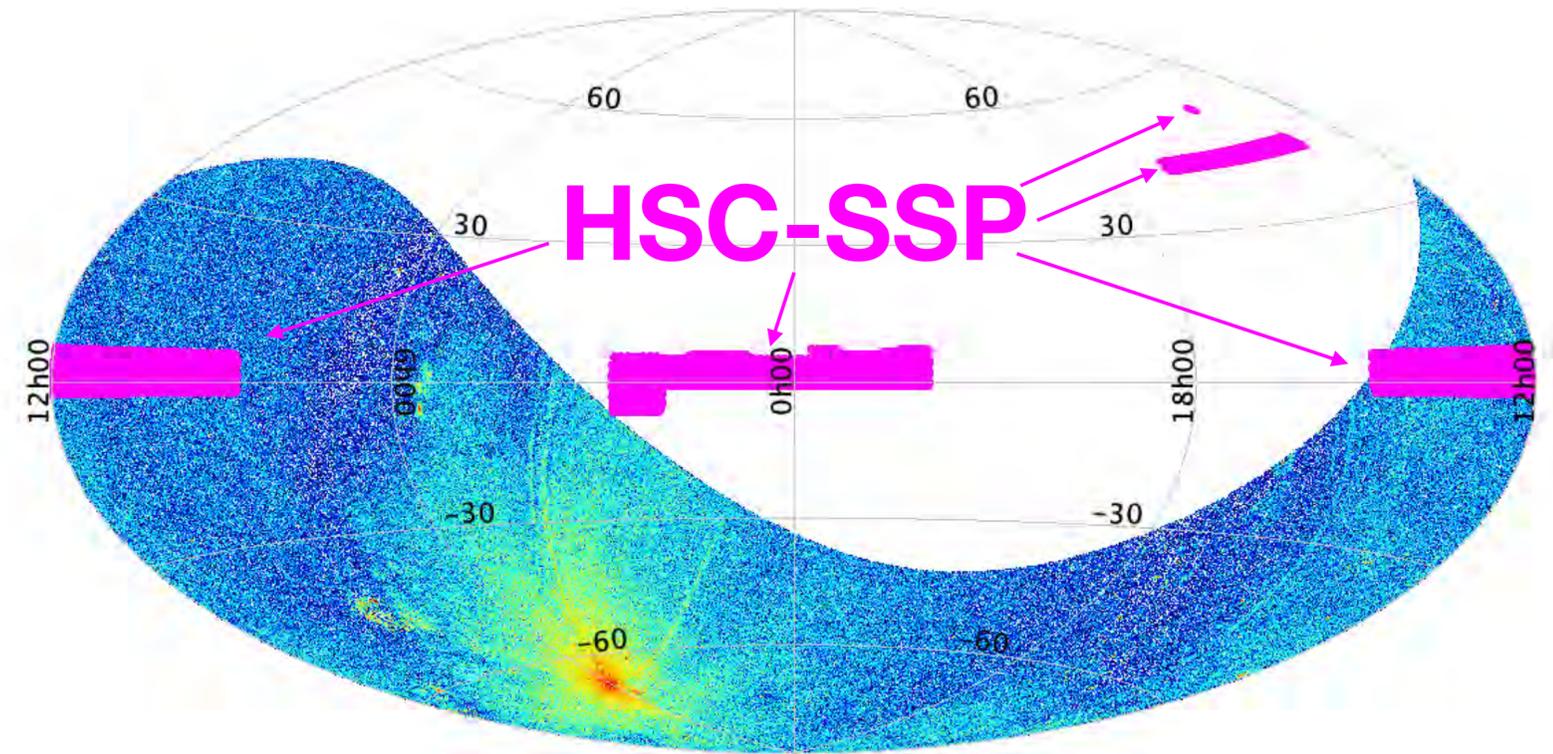
クエーサー

楕円銀河



eRASS1とHSCで切り開くサイエンス

- HSC-SSPとのオーバーラップは
~700 deg²
- eFEDSの経験を踏まえるとeRASS1
X-ray sources の 可視光対応天体探
しはSDSSで十分そう..
- HSC の deep photometry との相性
は微妙 😓
- **HSC の利点である image quality が
生きるサイエンス**が良さそう

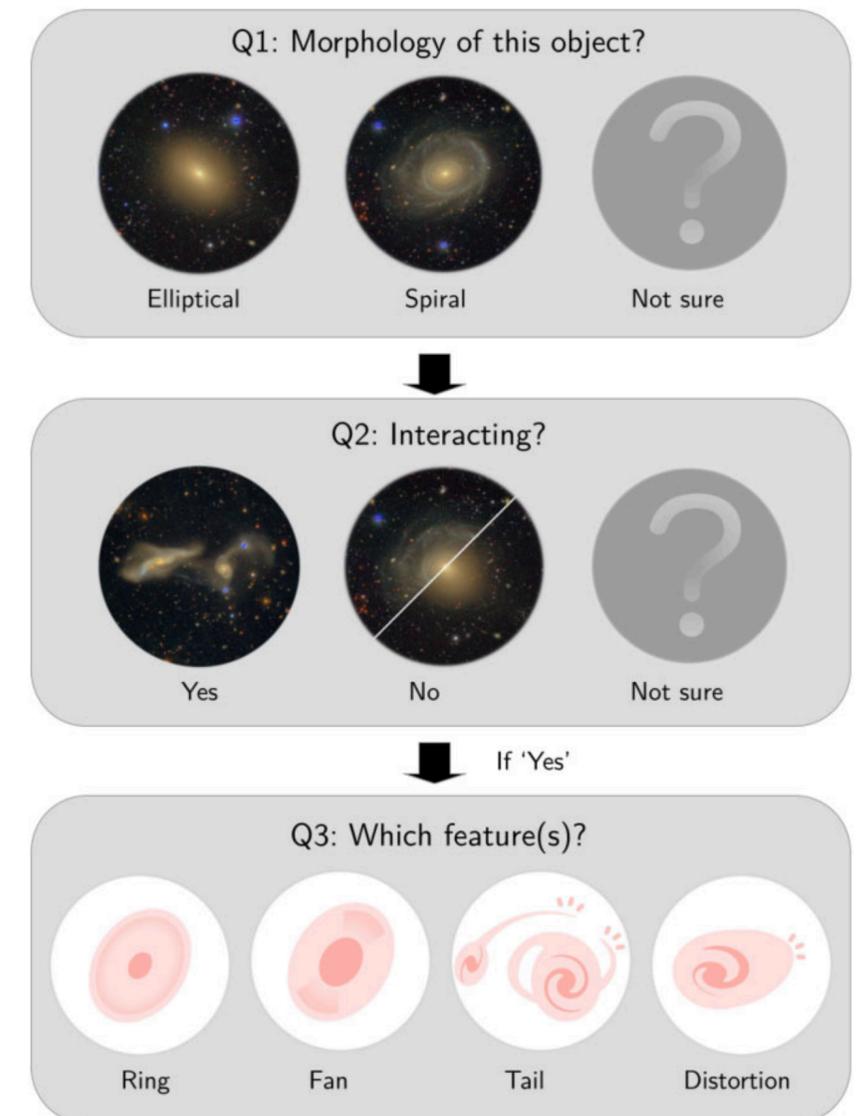
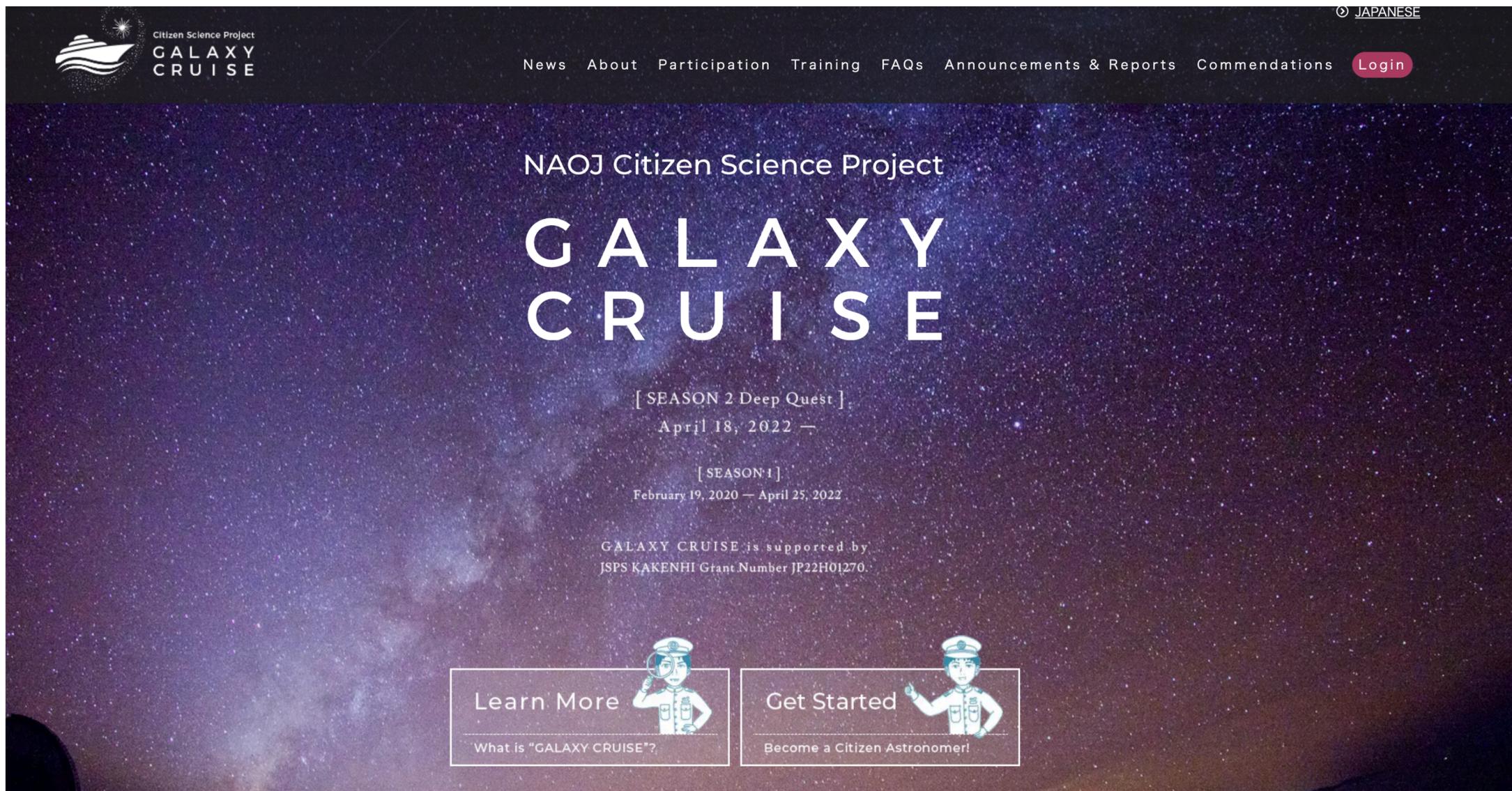




A citizen science: GALAXY CRUISE

GALAXY CRUISE collected over two million independent classifications of **20686 galaxies at $z < 0.2$** .

田中さん (NAOJ)

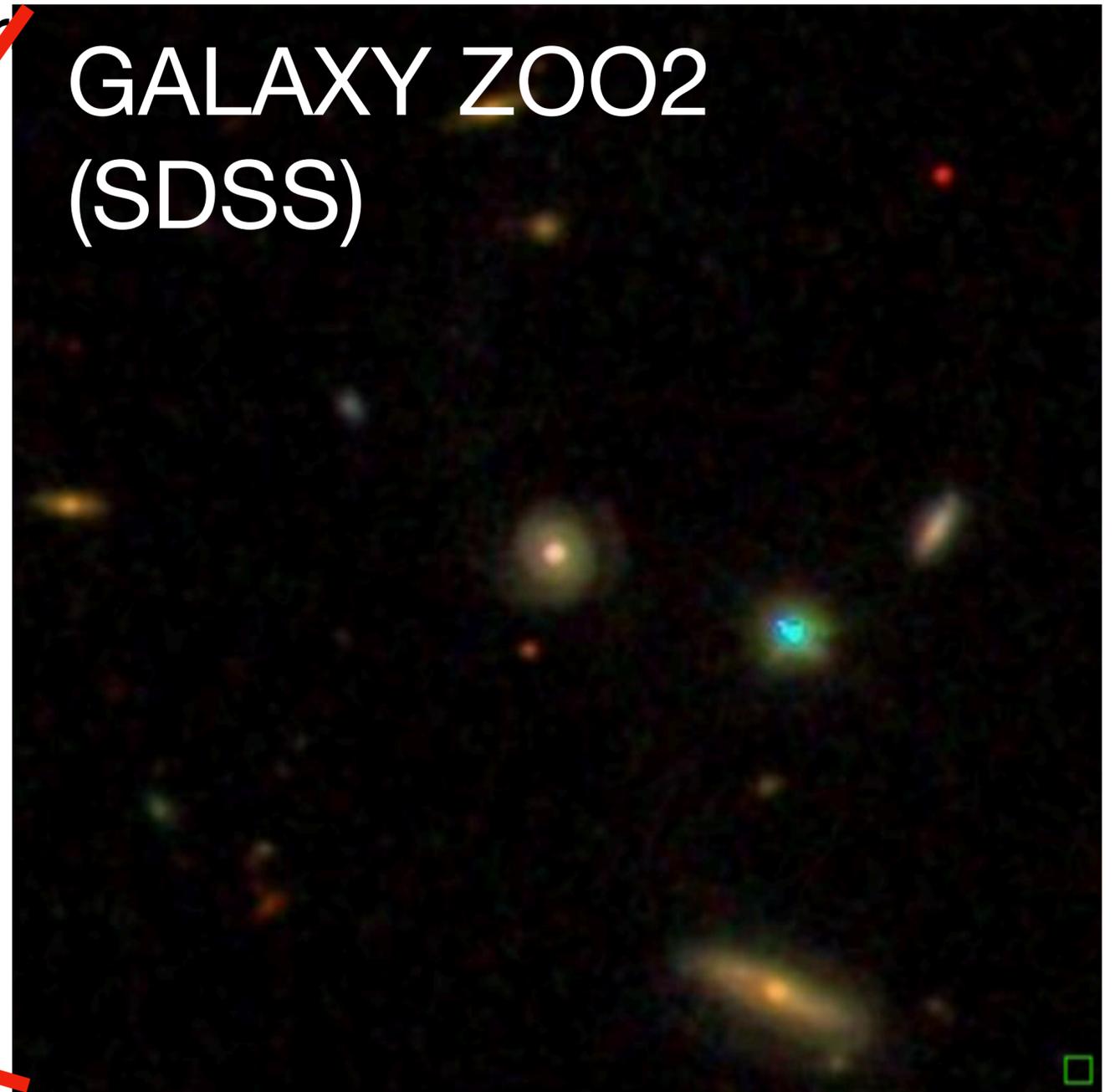
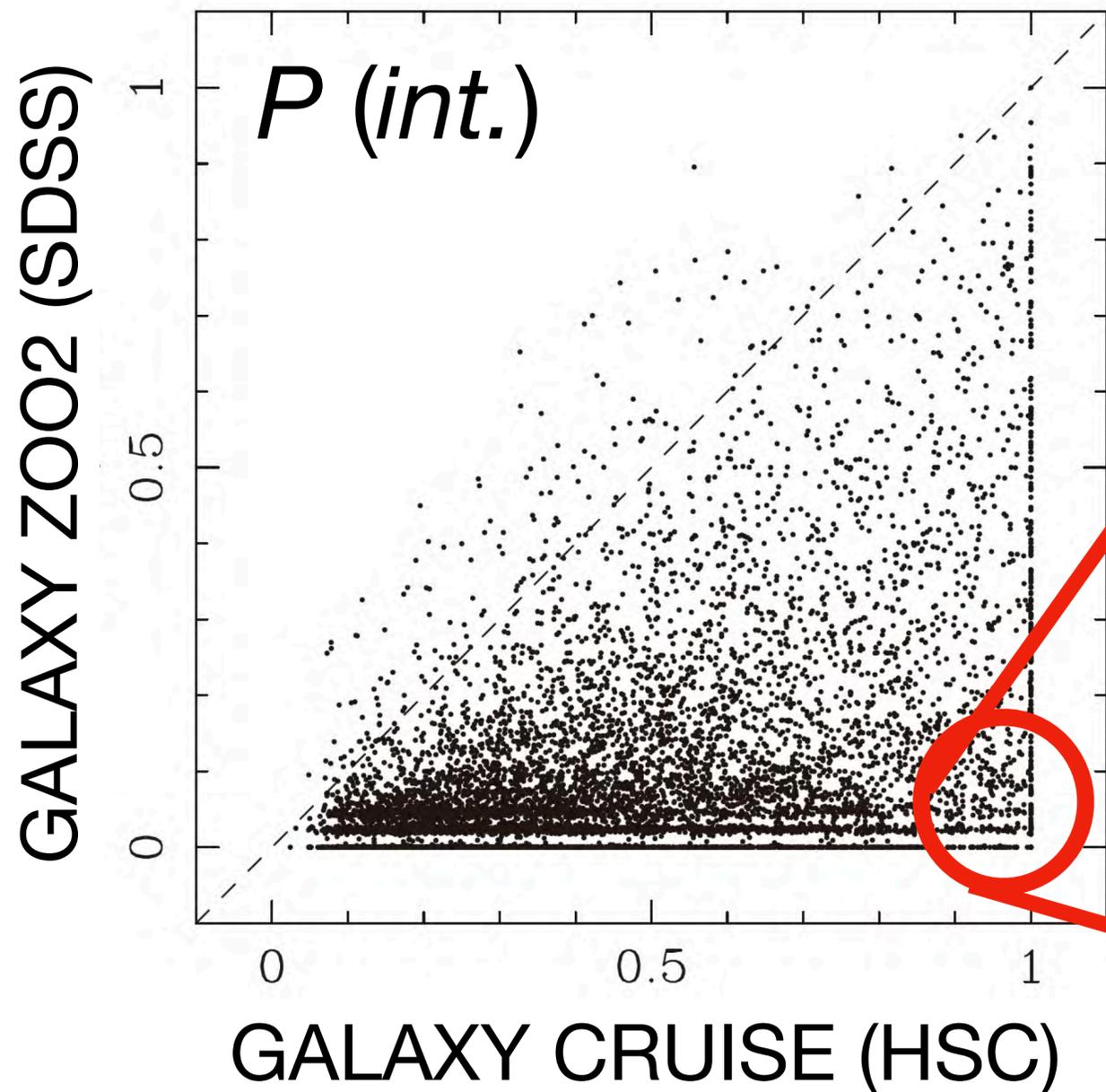


<https://galaxycruise.mtk.nao.ac.jp/en/>

Tanaka et al. 2023, PASJ, 75, 986

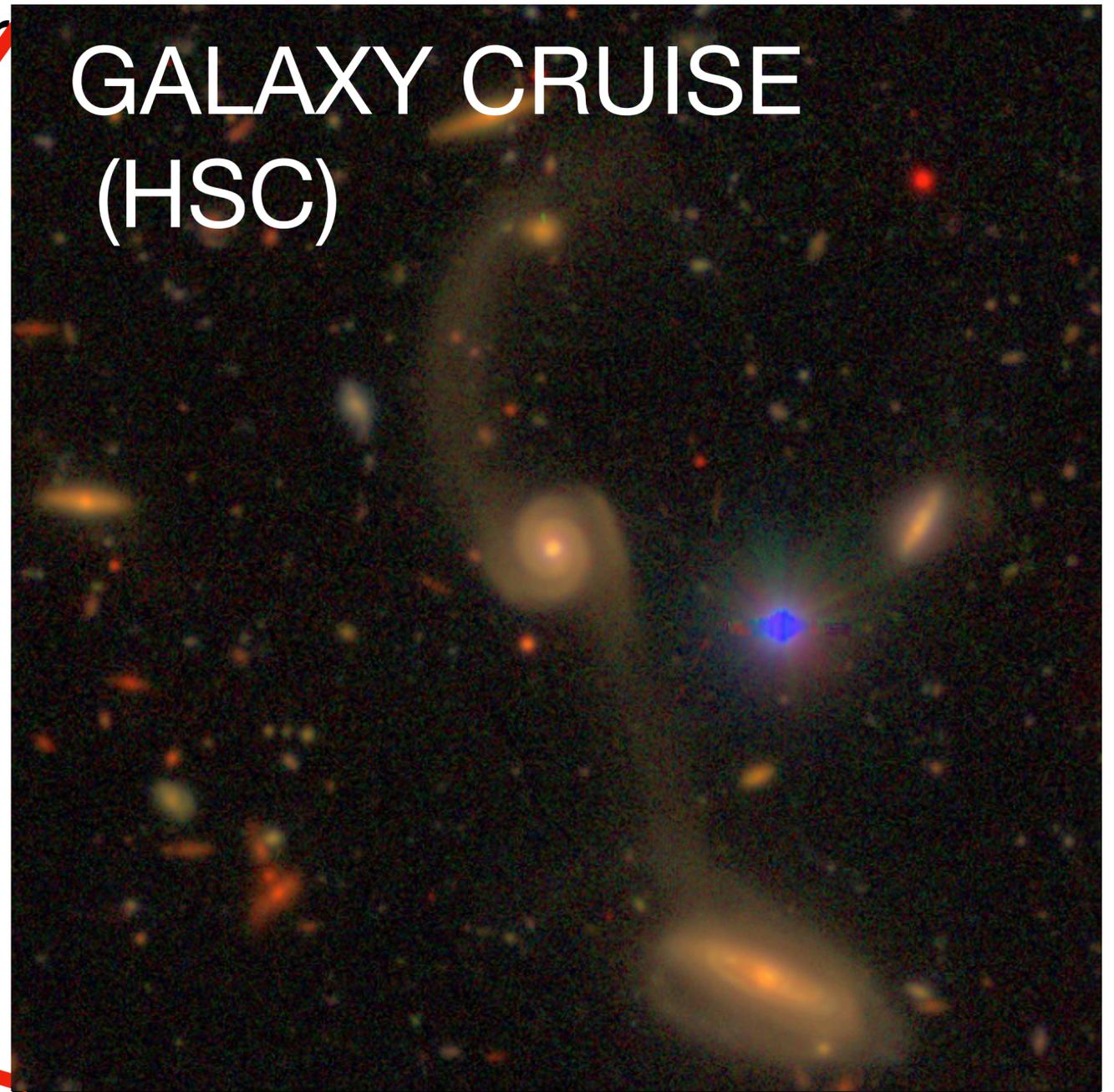
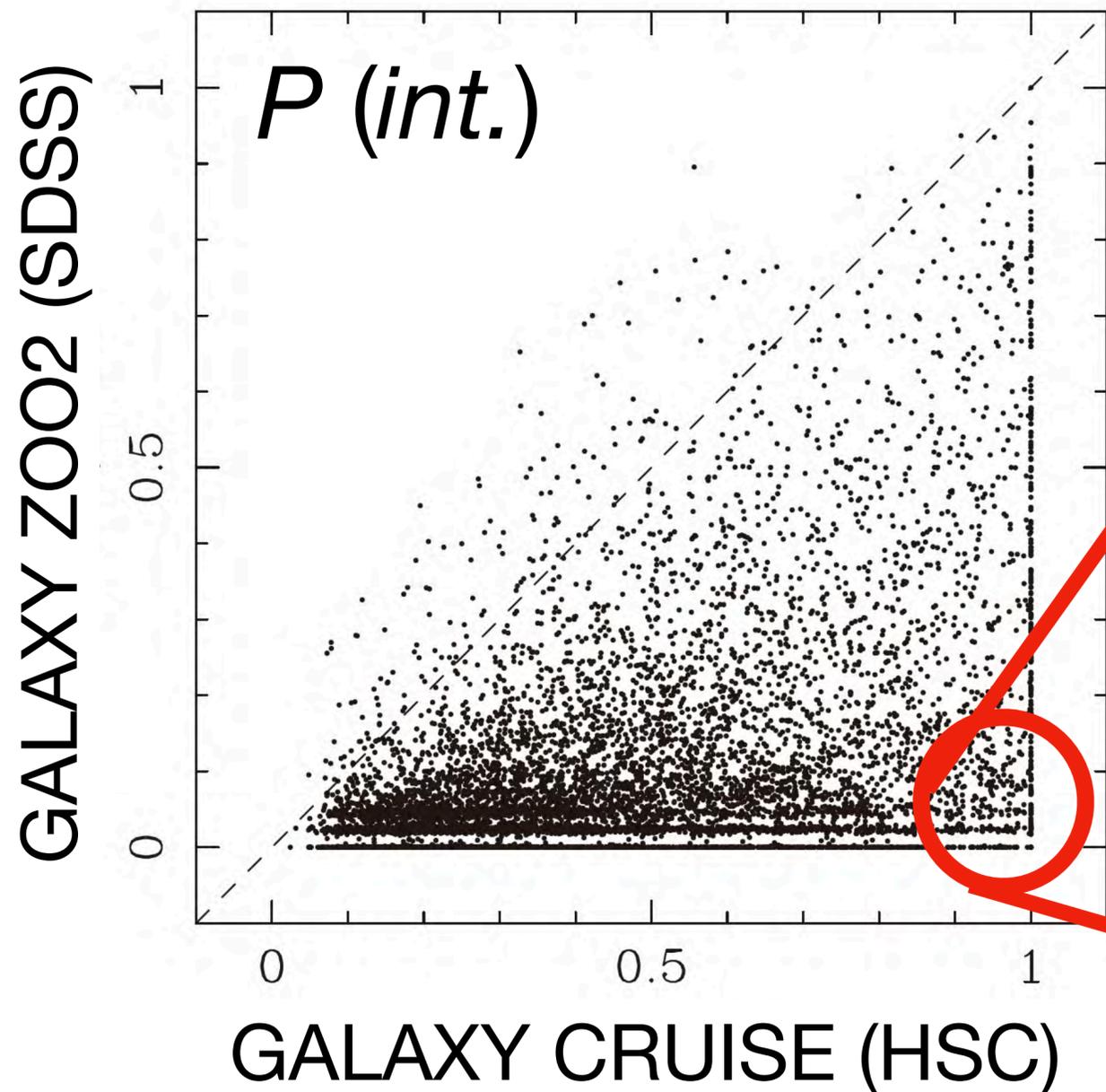
GALAXY CRUISE (HSC) vs. GALAXY ZOO (SDSS)

P (*int.*): the fraction of people who vote for inter

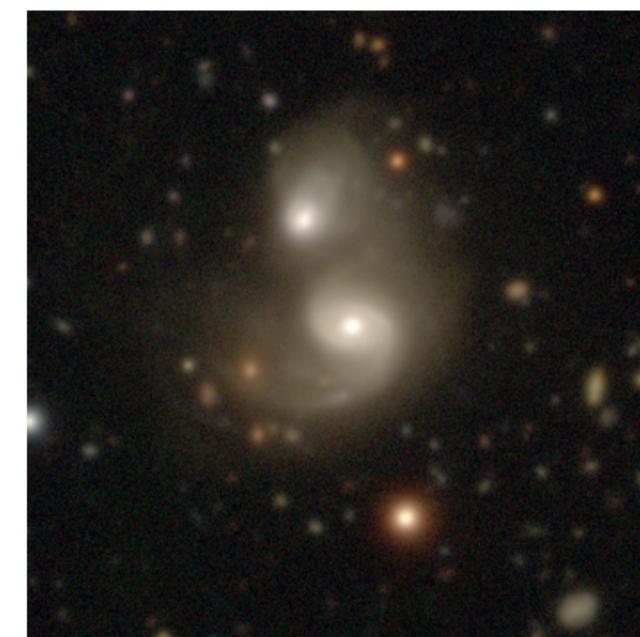
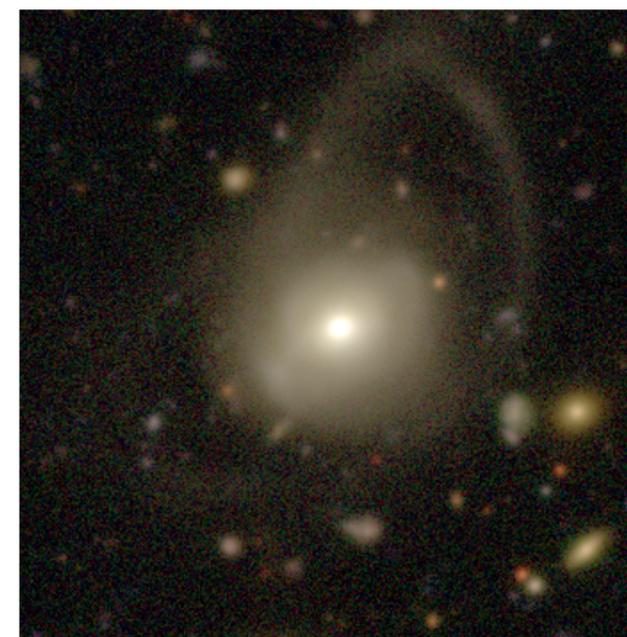
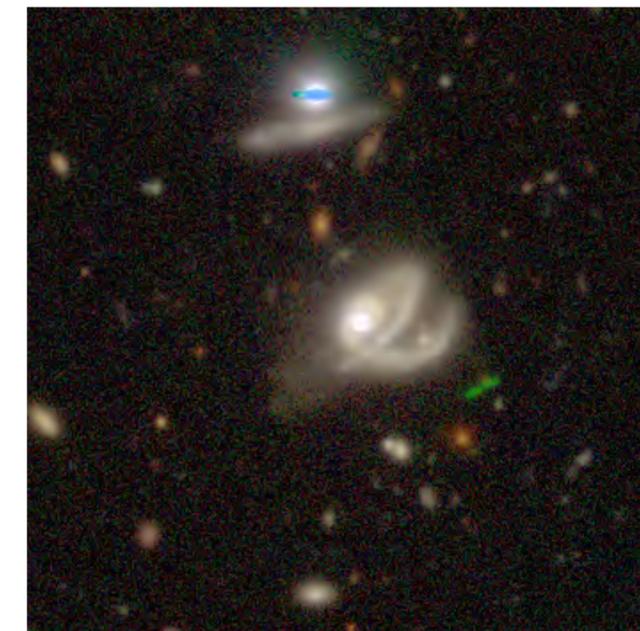
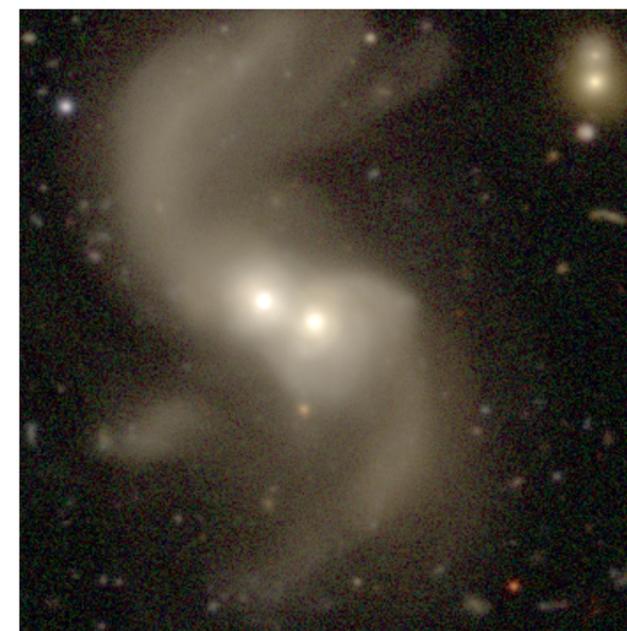
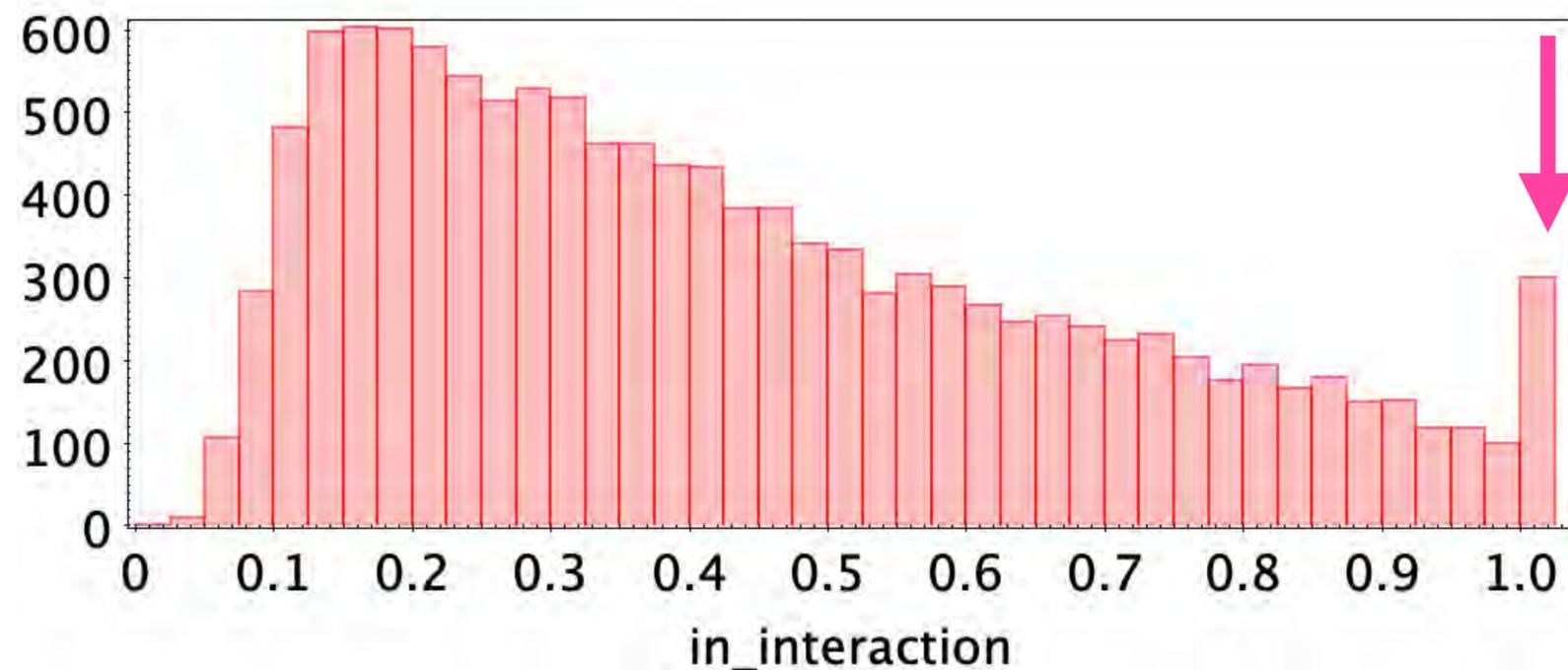
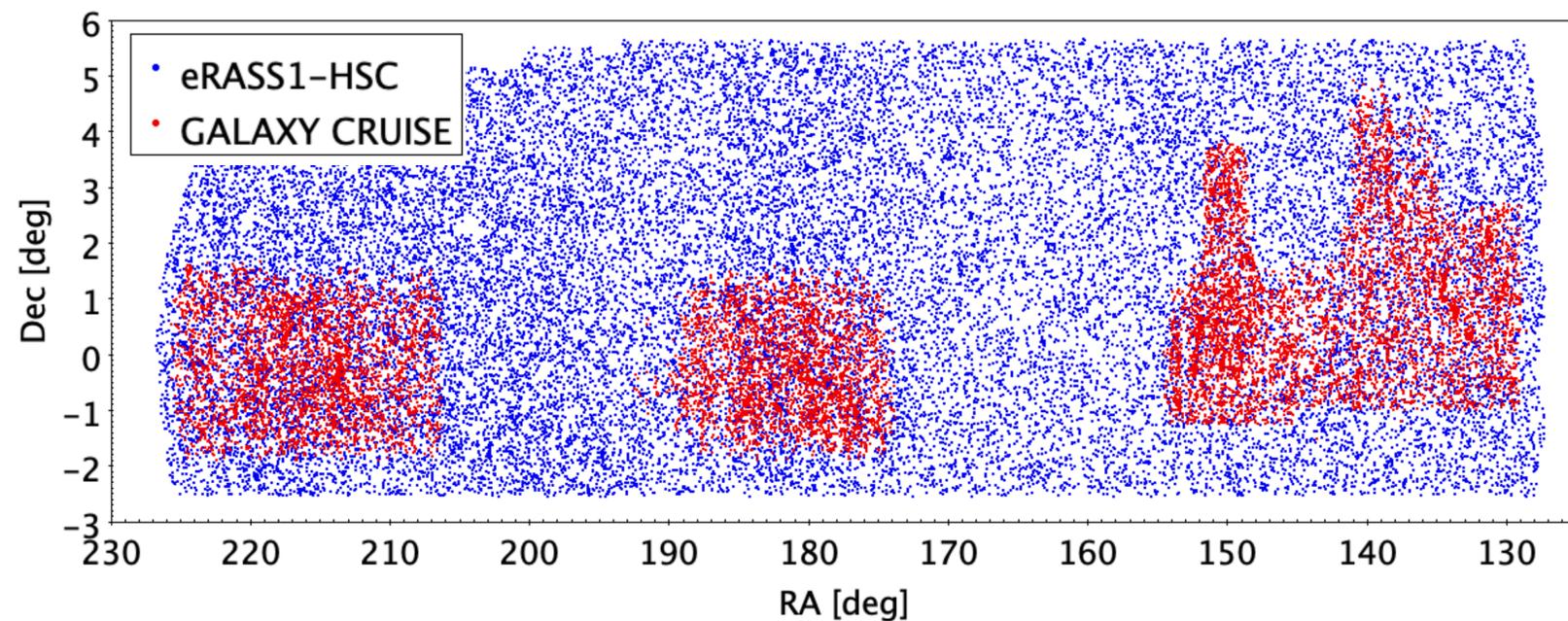


GALAXY CRUISE (HSC) vs. GALAXY ZOO (SDSS)

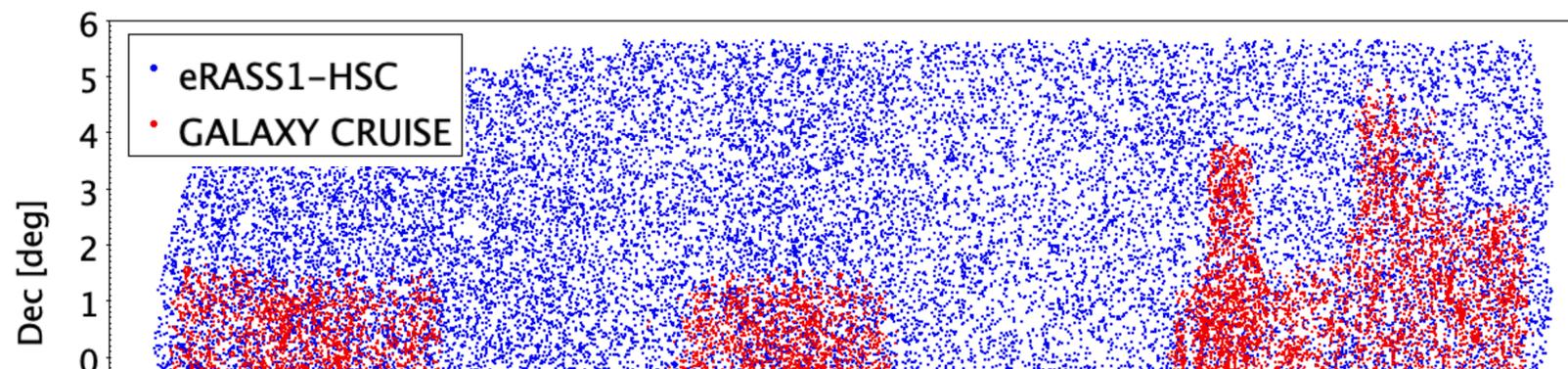
P (*int.*): the fraction of people who vote for inter



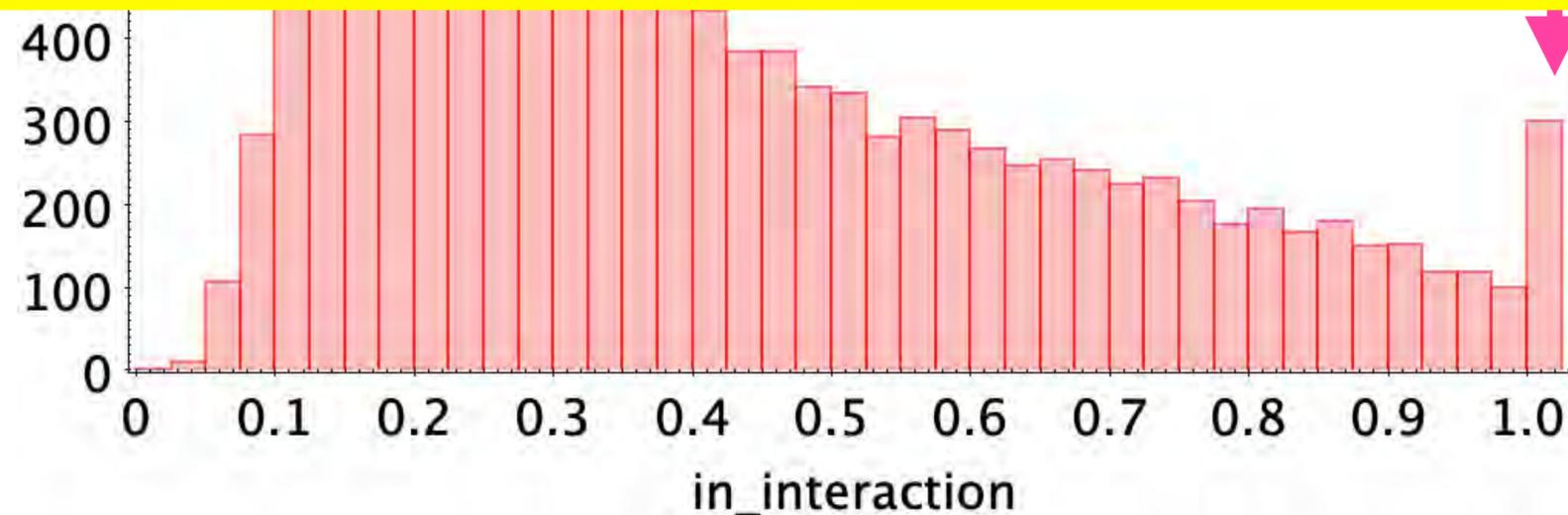
Interacting galaxies in the eRASS1-HSC footprint



Interacting galaxies in the eRASS1-HSC footprint

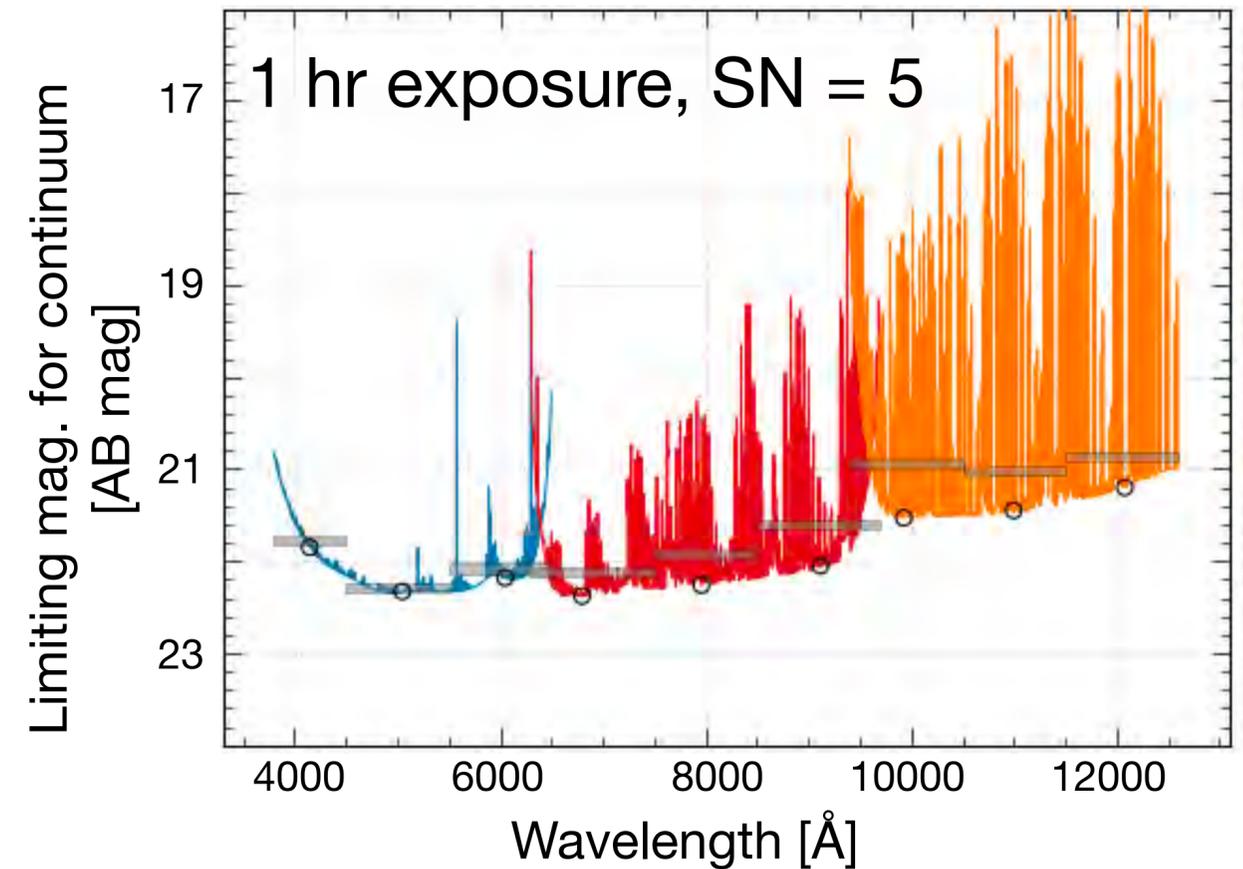


どのくらいのX-ray AGN 母銀河に
銀河合体の兆候があるかを調べる



Prime Focus Spectrograph

- 直径 1.3 度角の広い視野内にある最大 **2400 天体** について同時分光
- 可視光から近赤外線に渡る広い波長範囲をカバー
- **S25A (2025.02~) からの科学運用開始**を目指す



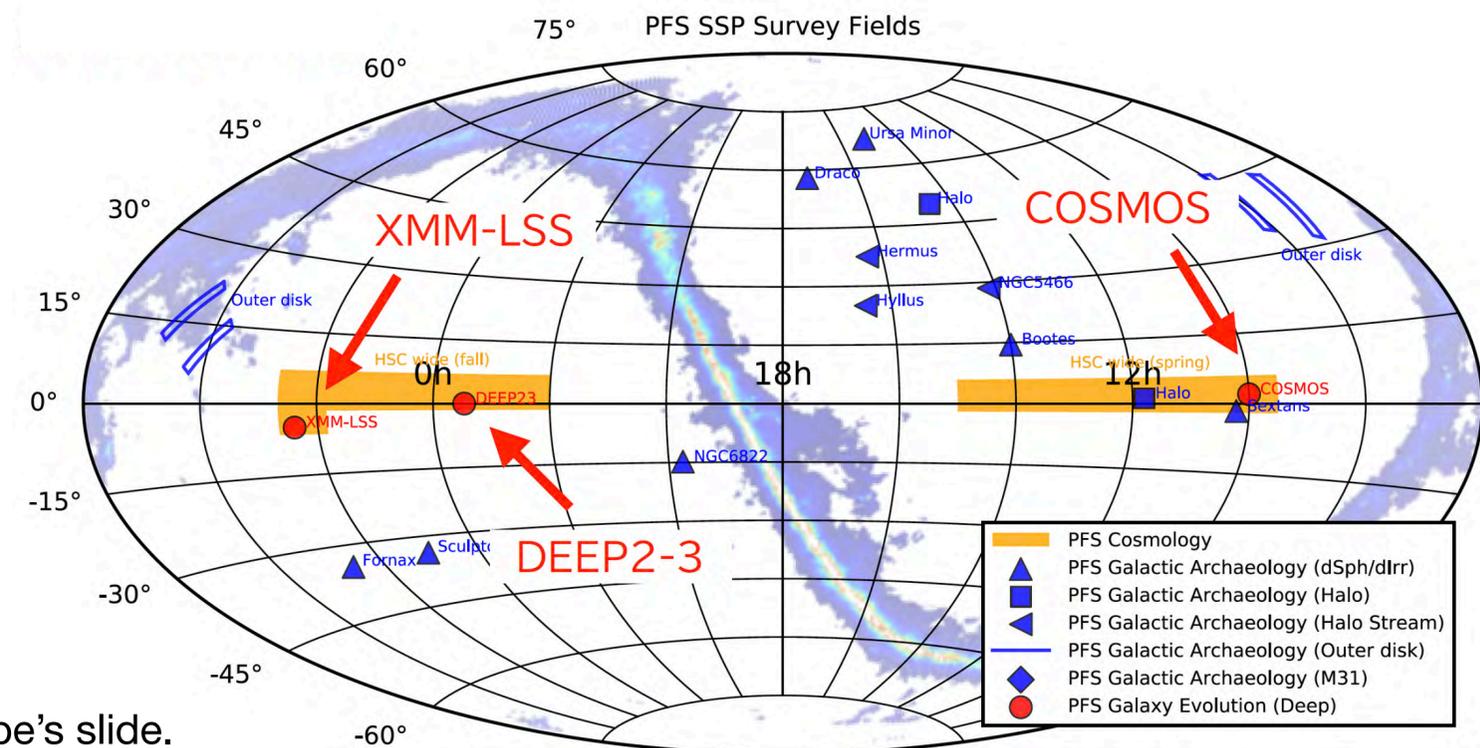
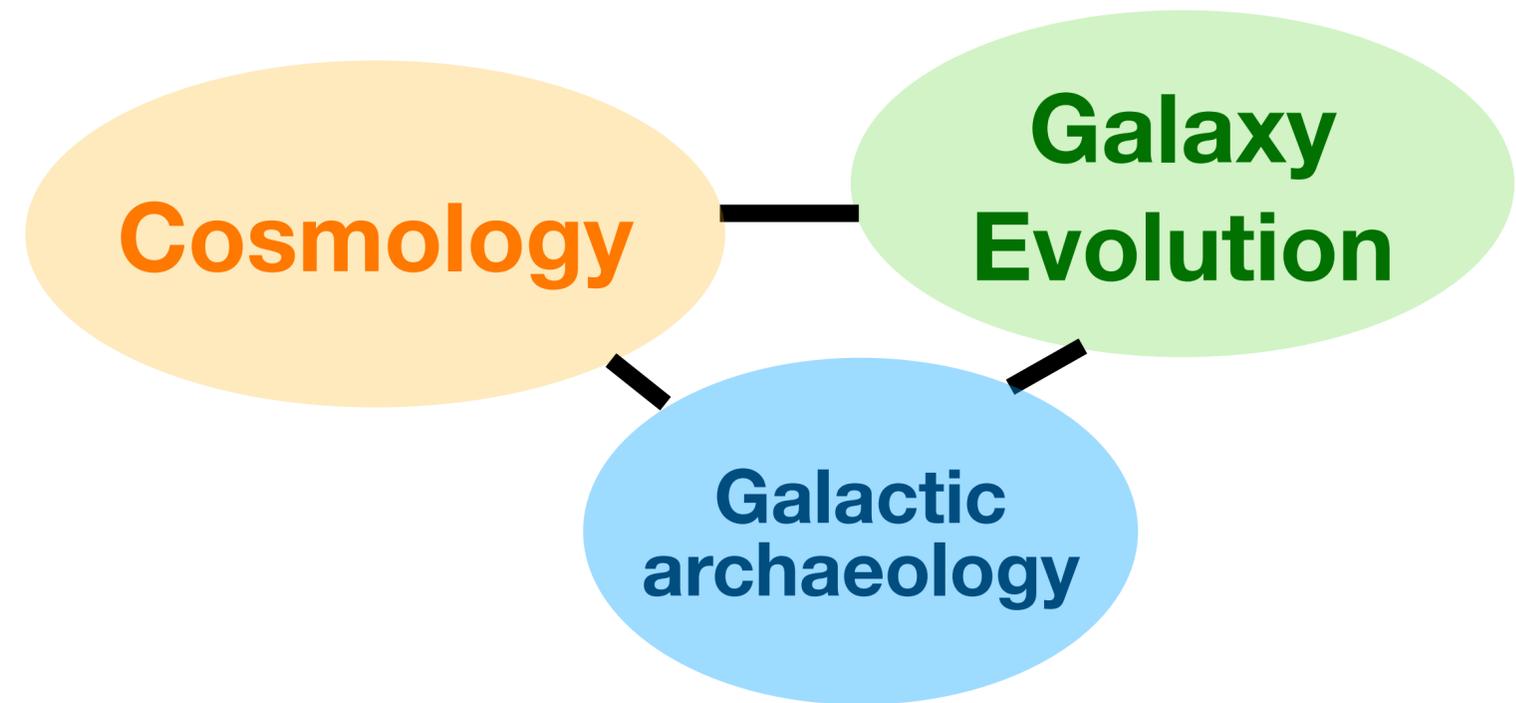
<https://pfs.ipmu.jp/research/performance.html>

Spectral arms	Blue	Red		NIR
		Low res.	Mid res.	
Spectral coverage [Å]	3800-6500	6300-9700	7100-8850	9400-12600
Spectral resolution [Å]	~2.1	~2.7	~1.6	~2.4
Resolving power	~2300	~3000	~5000	~4300

<https://pfs.ipmu.jp/research/parameters.html>

PFS-SSP

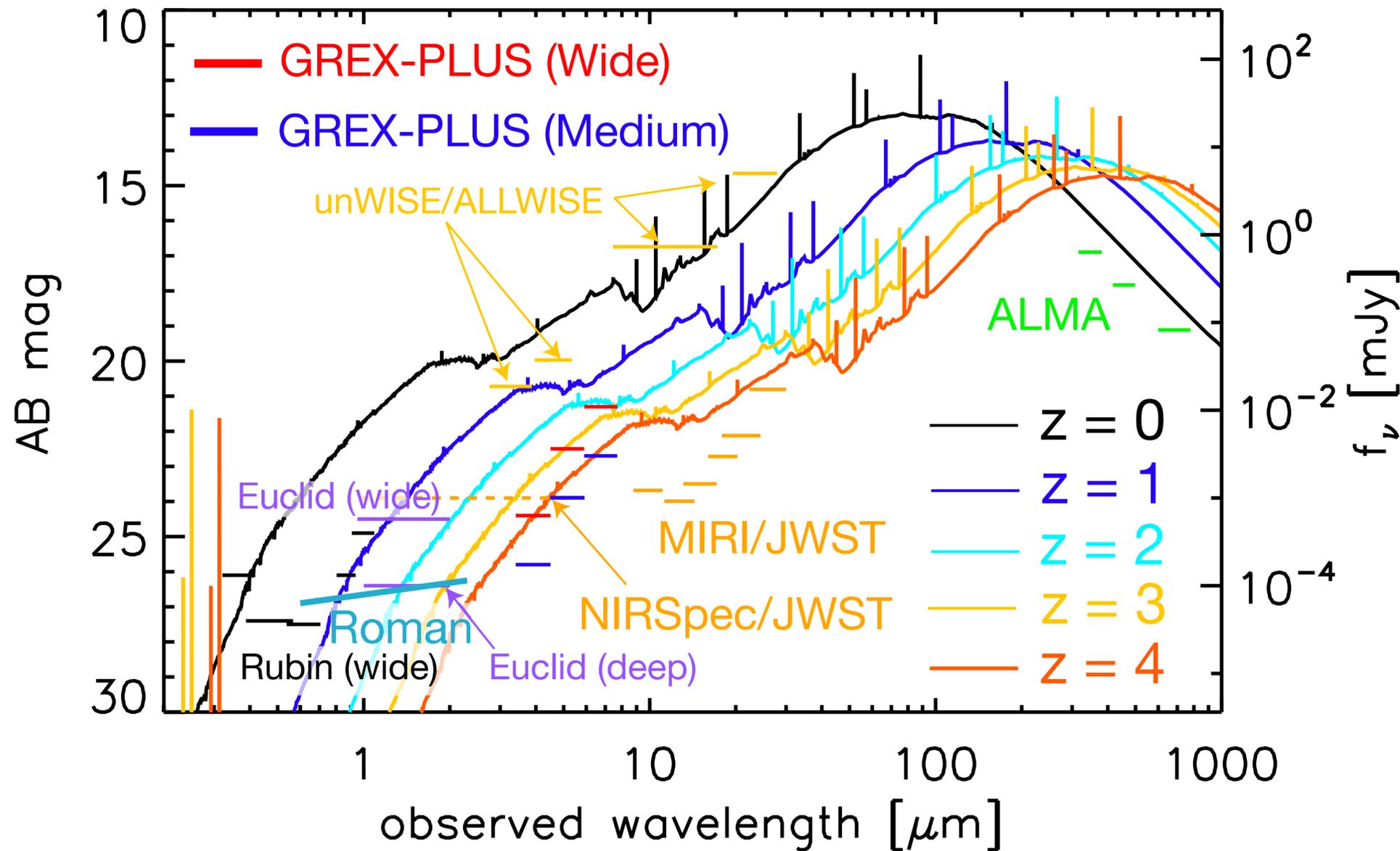
- 5年間で最大360夜の観測計画
- 3つのサイエンスの柱
 - Cosmology (CO): HSC-wide 領域
 - Galaxy evolution (GE): HSC-Deep 領域
 - Galactic archaeology (GA)
- **AGN subWG** (chair: 鳥羽)
 - 特に1年目の観測に向けてサイエンス検討やターゲット選択を実施中



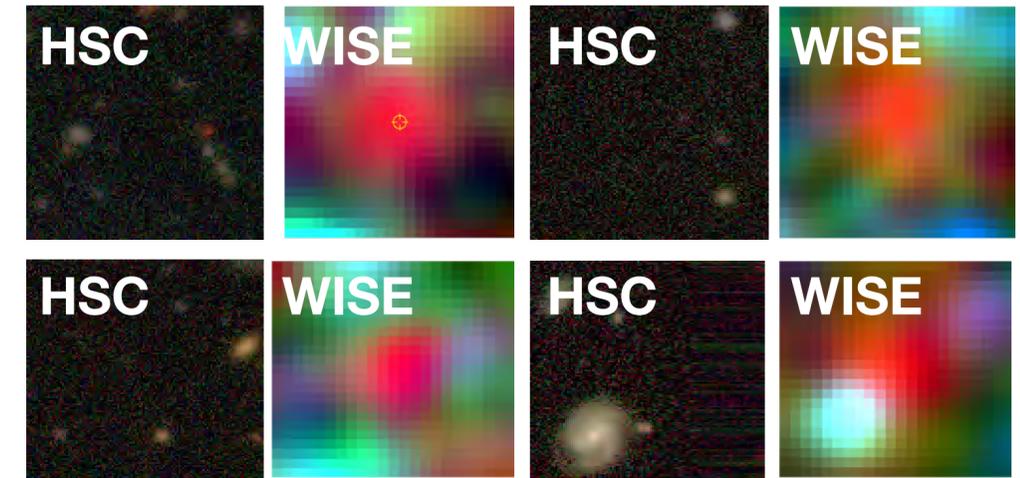
© From Kiyoto Yabe's slide.

AGN sciences with Euclid and Rubin/LSST

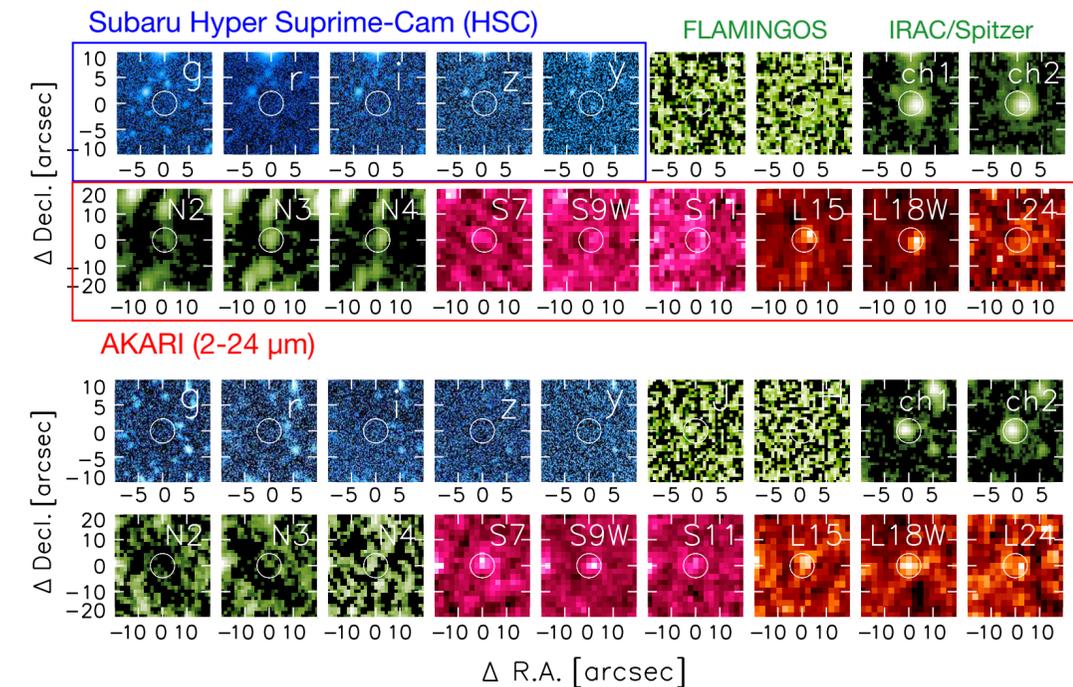
LSST-dark AGN探査



HSC-dark WISE sources



HSC-dark AKARI sources



AGN across the sky:

new windows opened by HSC and other wide-field surveys

Date: August 26-28, 2024

Venue: Hokkaido Information University

8月に北海道でお会いしましょう～

SCIENTIFIC RATIONALE

One of the most critical issues in astronomy and astrophysics today is to understand when and how supermassive black holes (SMBHs) have formed and evolved across cosmic history. The Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) has been extremely powerful in this field, producing a variety of scientific results, from the host galaxies in the local universe to the most distant quasars. Additionally, once wide-area imaging/spectroscopic observations with Subaru PFS, Euclid, Rubin/LSST, and Roman become available, AGN science can be anticipated to advance. The aim of this conference is to share what we have learned about the growth history of SMBHs through the HSC-SSP and discuss strategies to advance the heritage toward the future. We invite all researchers who are leading or interested in AGN studies based on wide-field survey data to this conference. Any AGN sciences/proposals with those facilities is welcome.



observed wavelength [μm]

Δ R.A. [arcsec]

Summary

👁️ すばるHSCによるAGNサイエンス

高感度

- 可視光線/電波/X線で明るい、可視光線で暗い天体
- AGNの発現と環境

高解像度

- X-ray AGNの母銀河

新たなパラメータスペースの開拓
統計的研究

👁️ 今後の展望

- eRASS1-HSC による銀河合体調査
- AO追観測による dual AGN探査
- Optical variability を通じた SMBH binary探査
- せいめい望遠鏡追観測による HyLIRGs 探査
- SCUBA-2 追観測によるELIRGs素性調査
- X-ray スタッキング解析
- PFSを用いたAGNサイエンス
- LSST/Euclid によるAGNサイエンス

END

