Galaxy Zoo: The Fundamentally Different Co-Evolution of SMBHs and Their Early- and Late-type Host Galaxies

Schawinski et al. 2010, ApJ, 711, 284

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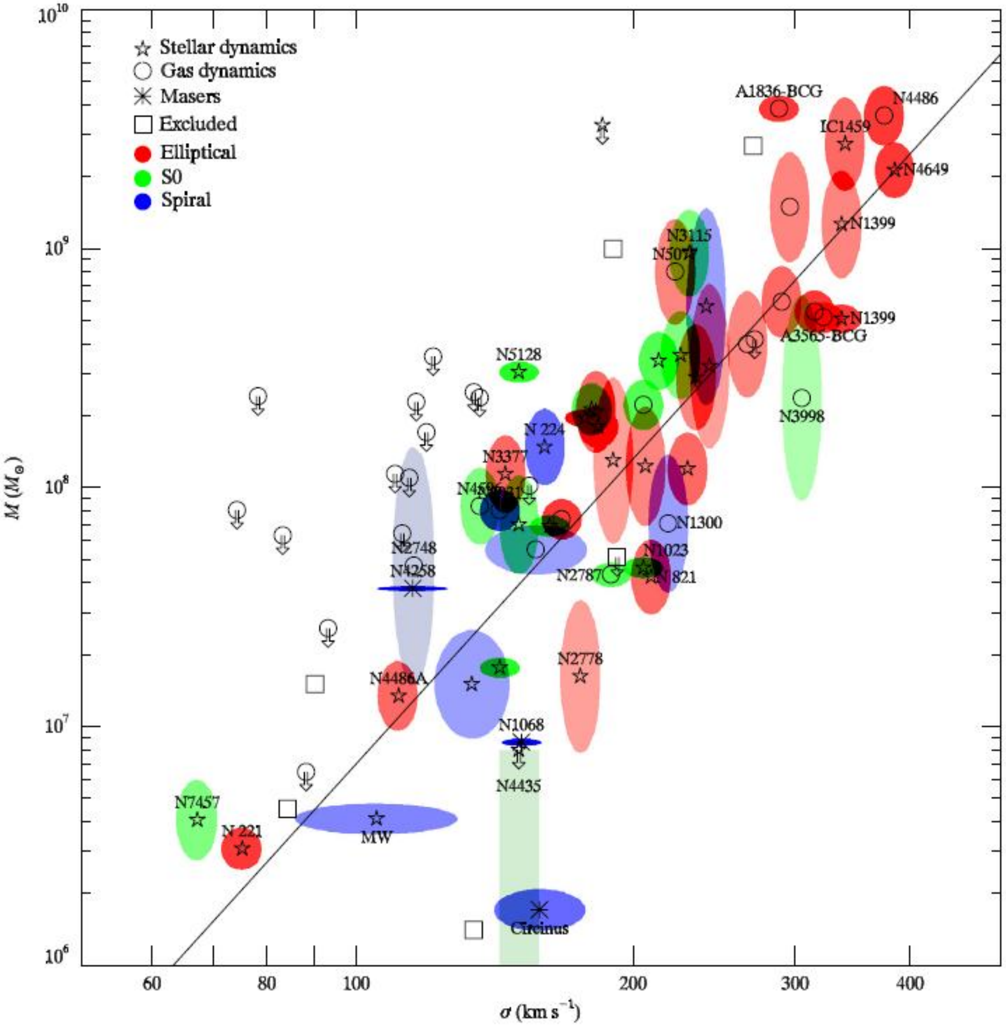
2012年度 院生雑誌会 2012/5/23 @大輪講

“Co-Evolution”

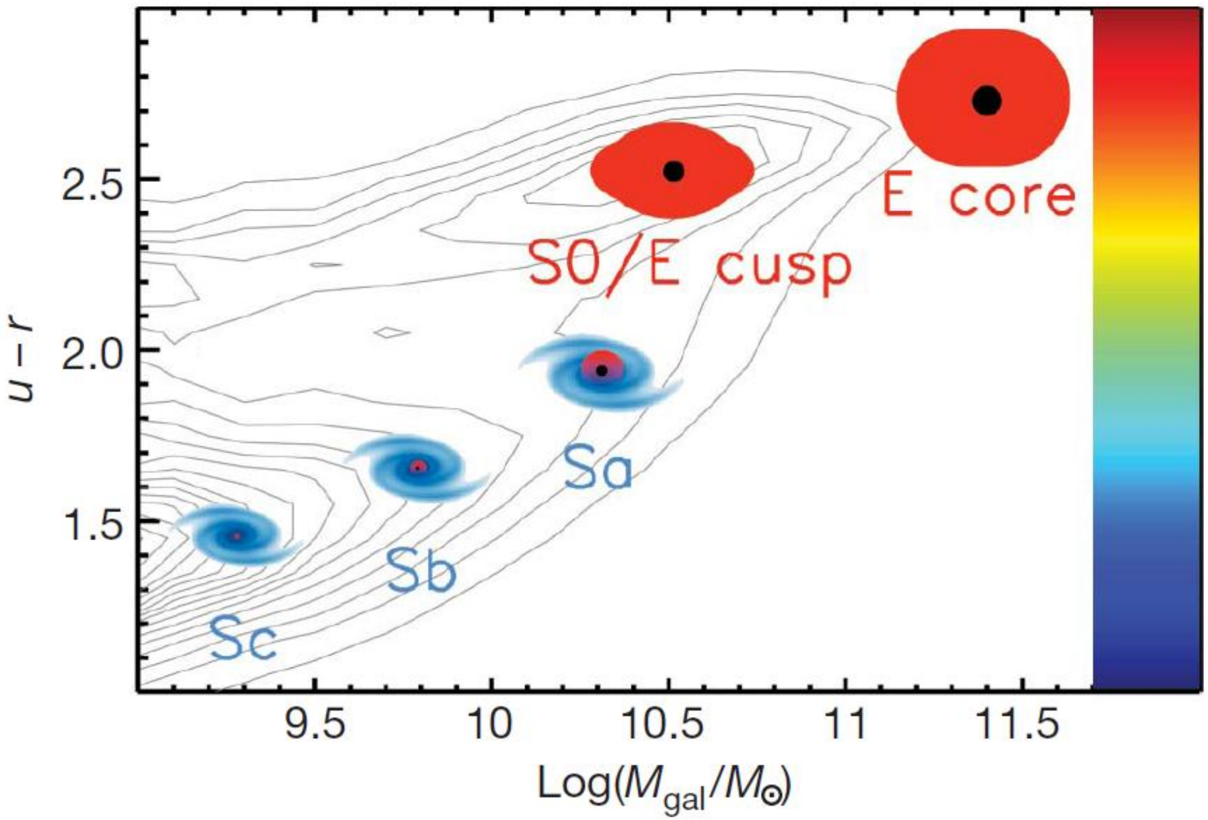


M_{BH}-σ_* relation

Gultekin+09

SMBHと母銀河バルジは共進化してきた!

Color-Mass Diagram



Cattaneo+09

近傍銀河の2派閥： **Blue Cloud(BC)**, **Red Sequence(RS)**

両種族の谷間: **Green Valley(GV)**

This Work

- AGNと母銀河をつなぐ物理を知りたい.
- <u>母銀河の形態別</u>に, AGNと母銀河の性質を調べる.
  - SMBH: L[OIII], M_{BH}, L[OIII]/M_{BH}.
  - Host:　u-r color, M_*, σ_*, AGN fraction.
- Late-/Early-typeでの違いが見えてきた.

- SDSSは天体数が多く, 目視による形態分類がムリ.
  - Manual inspection(Color, Concentration).
  - Visual inspection(Galaxy Zoo project).

~Number Fraction, Time Fraction~

院生=銀河
休憩中の院生=ただの銀河
研究中の院生=AGN母銀河

- 院生という種族:
  - 各院生の生活時間帯はランダム.
  - 各院生のスケジュールは無相関.
  - 院生は, 1日計8時間机に向かって研究する.
- 部屋を覗いた際, 机に向かっている院生は何人期待されるか: N_{exp} = 330人 × (8h/24h) = 110人.
- ではN_{obs} = 80人だったら, 院生の典型的な研究時間は:

  x_{exp} = 24h × (N_{obs}/330人) = 5.8 h.
- 院生がactiveに研究する時間の割合(duty cycle):

  duty cycle = 5.8h/24h = 0.24 or 24%.

  = N_{obs}/N_{total} -> **Number fraction**

Galaxy Selection

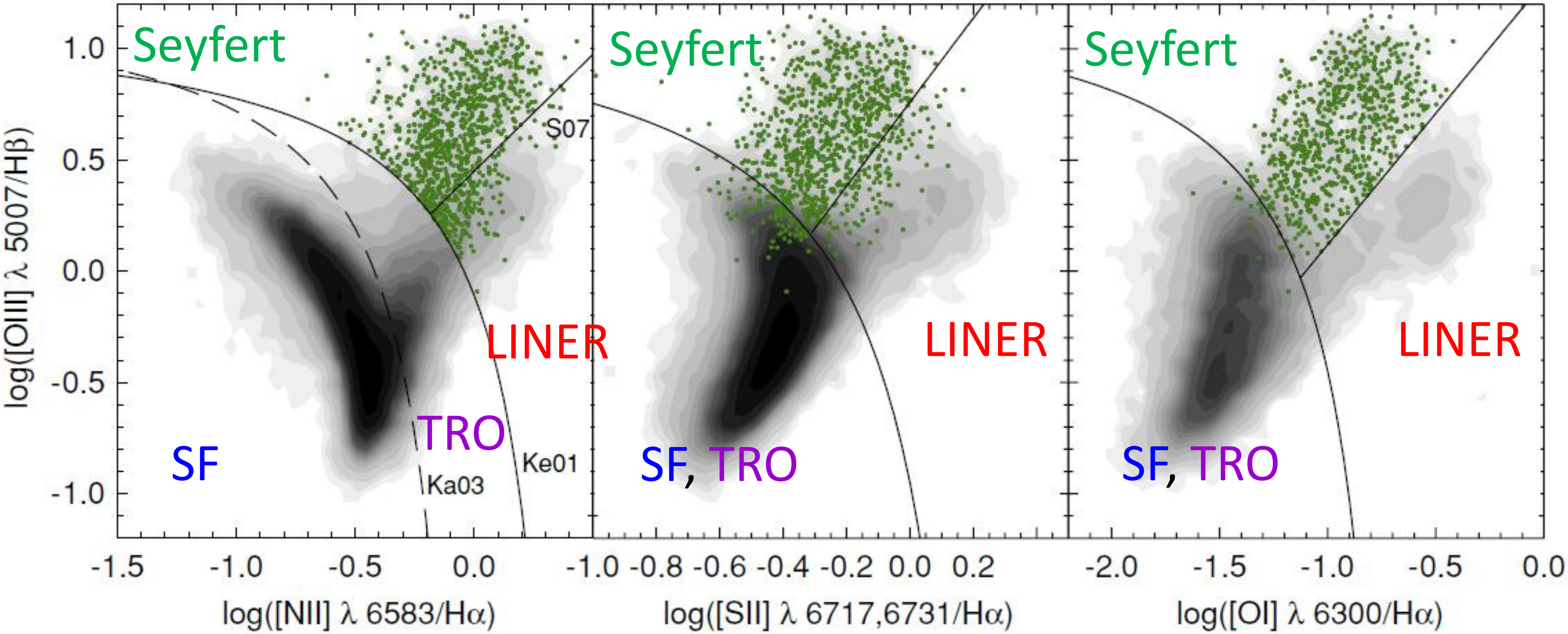
- Catalog:
  - SDSS DR7, 分光タイプ“GALAXY”.
- Selection criteria:
  - $0.02 < z < 0.05$ (-> 1.2-1.9 kpc in 3”)
  - $r < 17$ AB mag,
  - $M_{z,Petro} < -19.5$ AB mag,
- 47675 galaxies.
  - 16246 Late-type, 22483 Indeterminate, 8928 Early-type.
  - Late/Earlyには, 市民投票の80%以上の一致を要求.

Observational quantities

- σ_*, M_{BH}:
  - 分光データからσ_*を求める.
  - M_{BH}は, M-σ関係を使って焼き直しただけ.
- M_*:
  - u, g, r, i, zに, 星種族合成モデルでスペクトルフィット.
  - 母銀河の全星質量.
- u-r:
  - K補正はせず, 引いただけ.
- 各輝線のフラックス:
  - 分光データから・・・.
  - L[OIII]には, dust extinctionの補正をしてある.

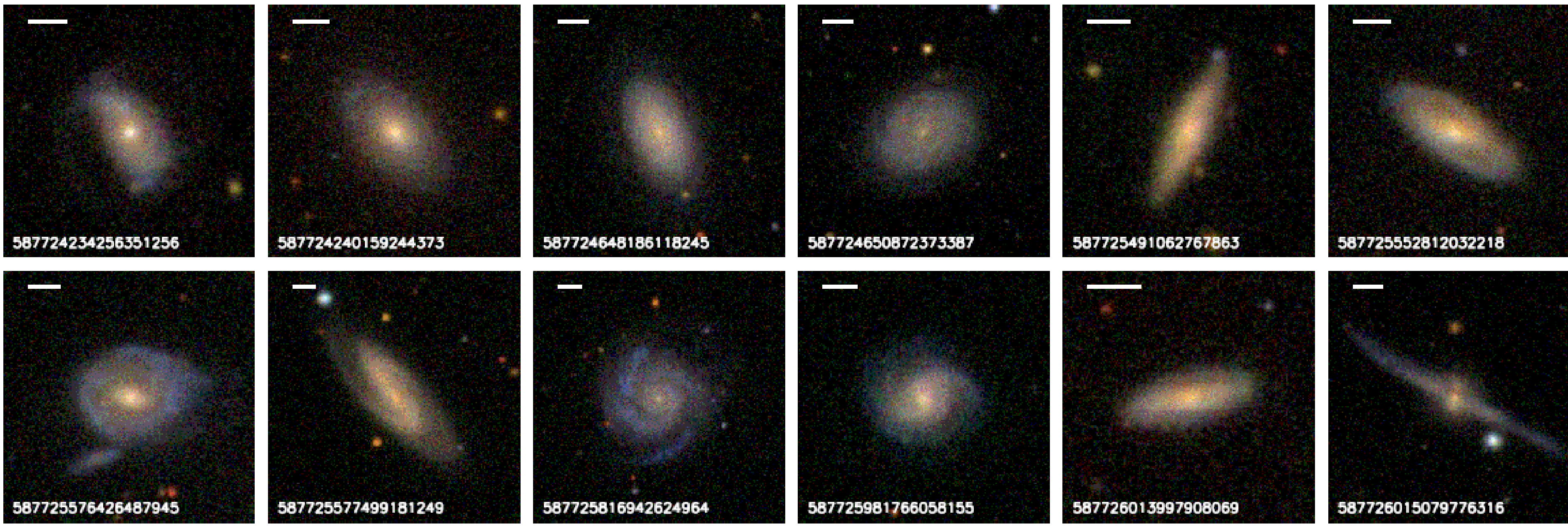
AGN Selection

942/47675天体.



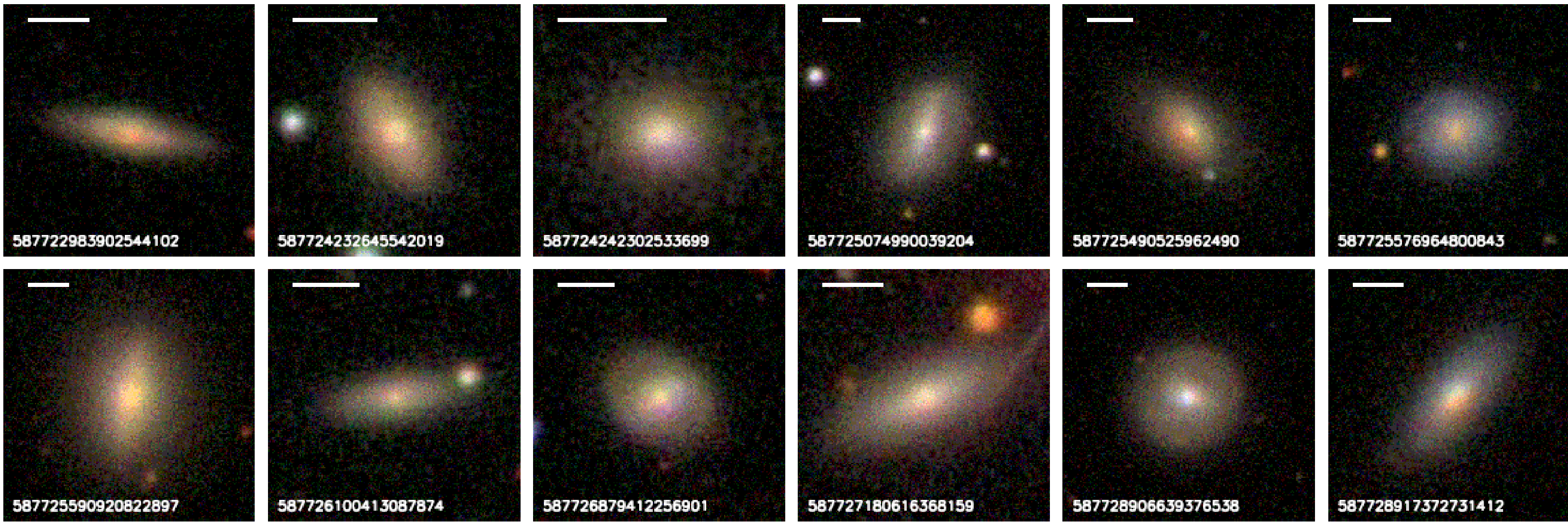
輝線診断：Seyfert classのみAGNとして扱う.
SF, TROは, OB star起源の輝線が混ざるから除外.
LINERは, post-AGB star起源が疑われるから除外.

Late-type AGN host



White bar -> 5kpc.

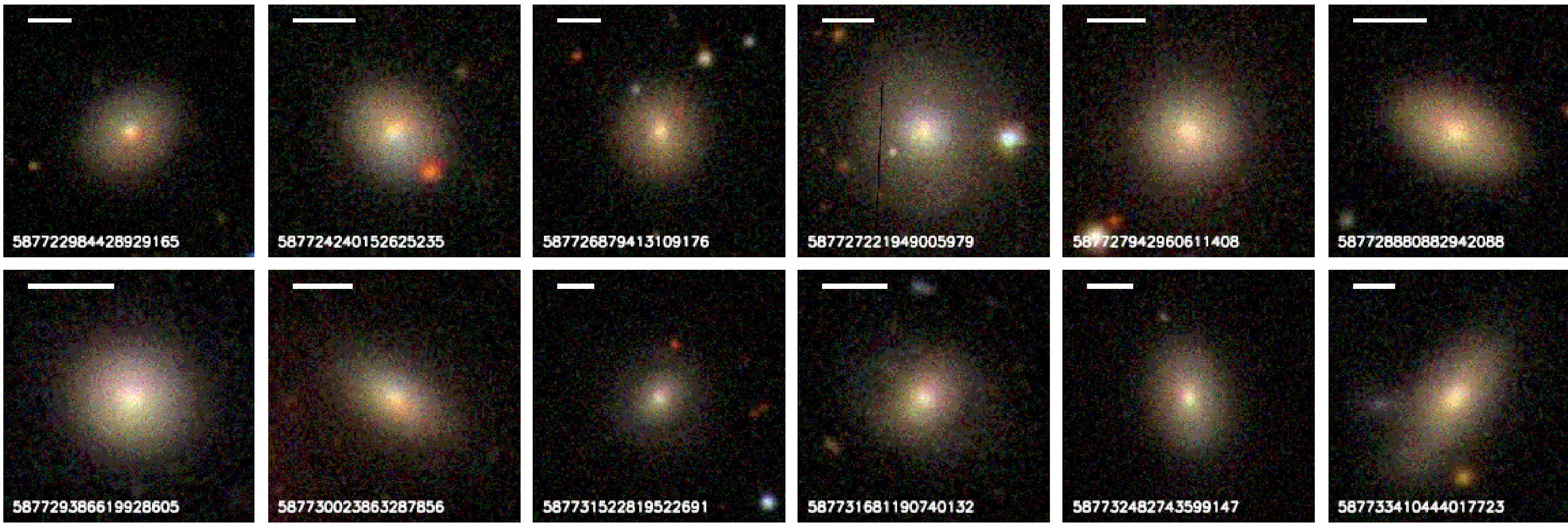
Indeterminate AGN host



White bar -> 5kpc.

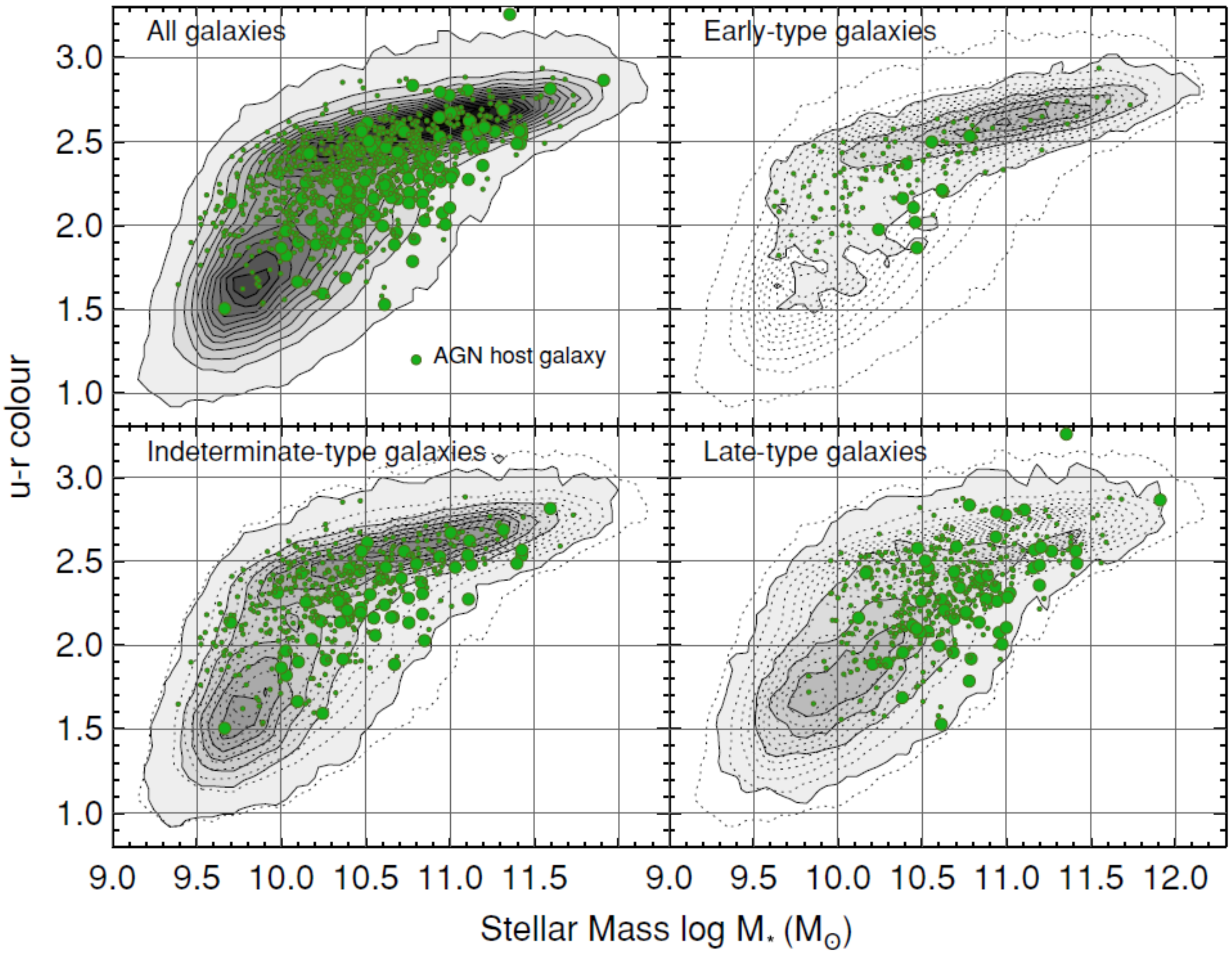
Intermediateでなく, indeterminate.

Early-type AGN host



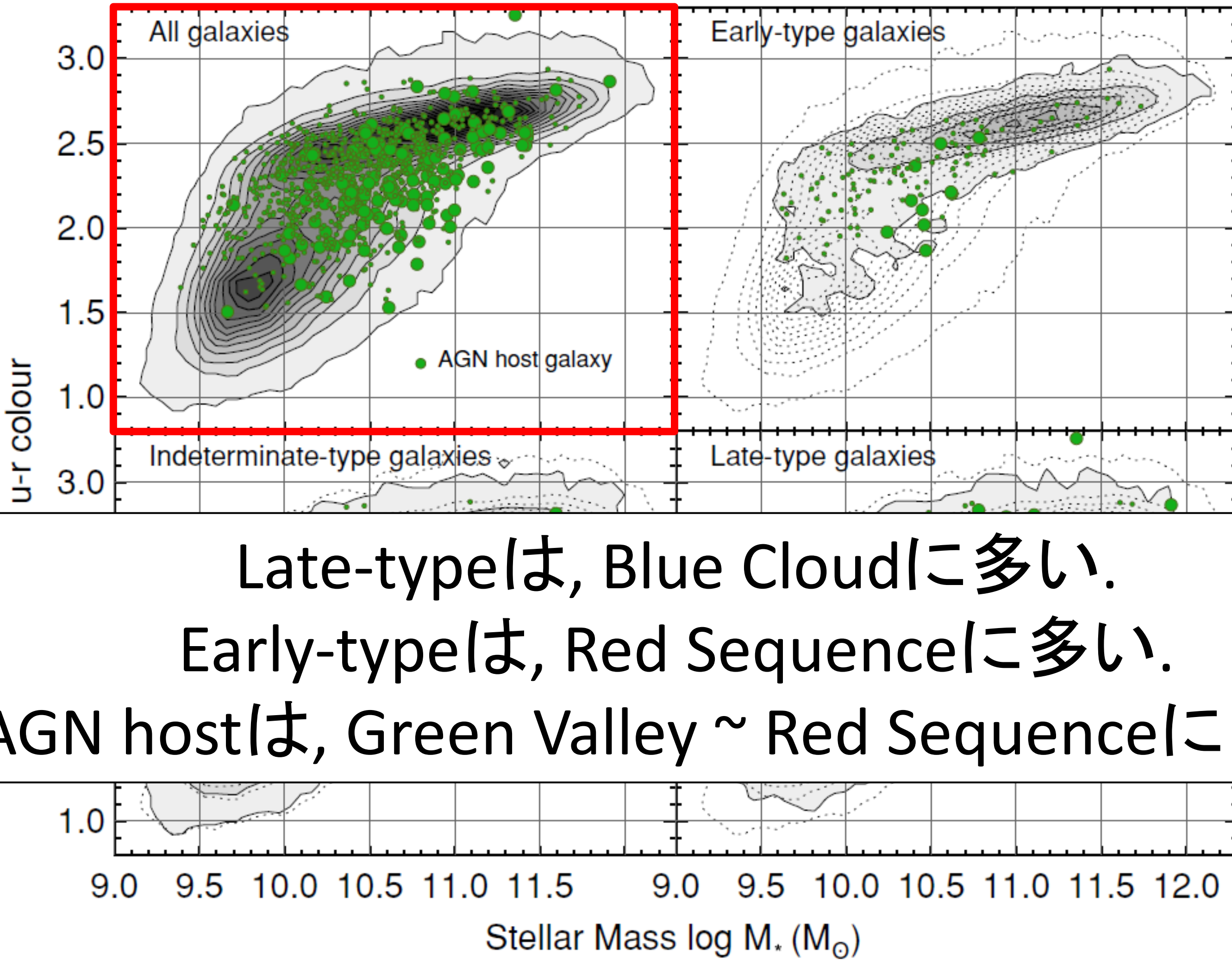
White bar -> 5kpc.

Color-Mass Distribution 1



大丸: L[OIII]>10^{41} erg/s, 小丸: L[OIII] < 10^{41} erg/s.

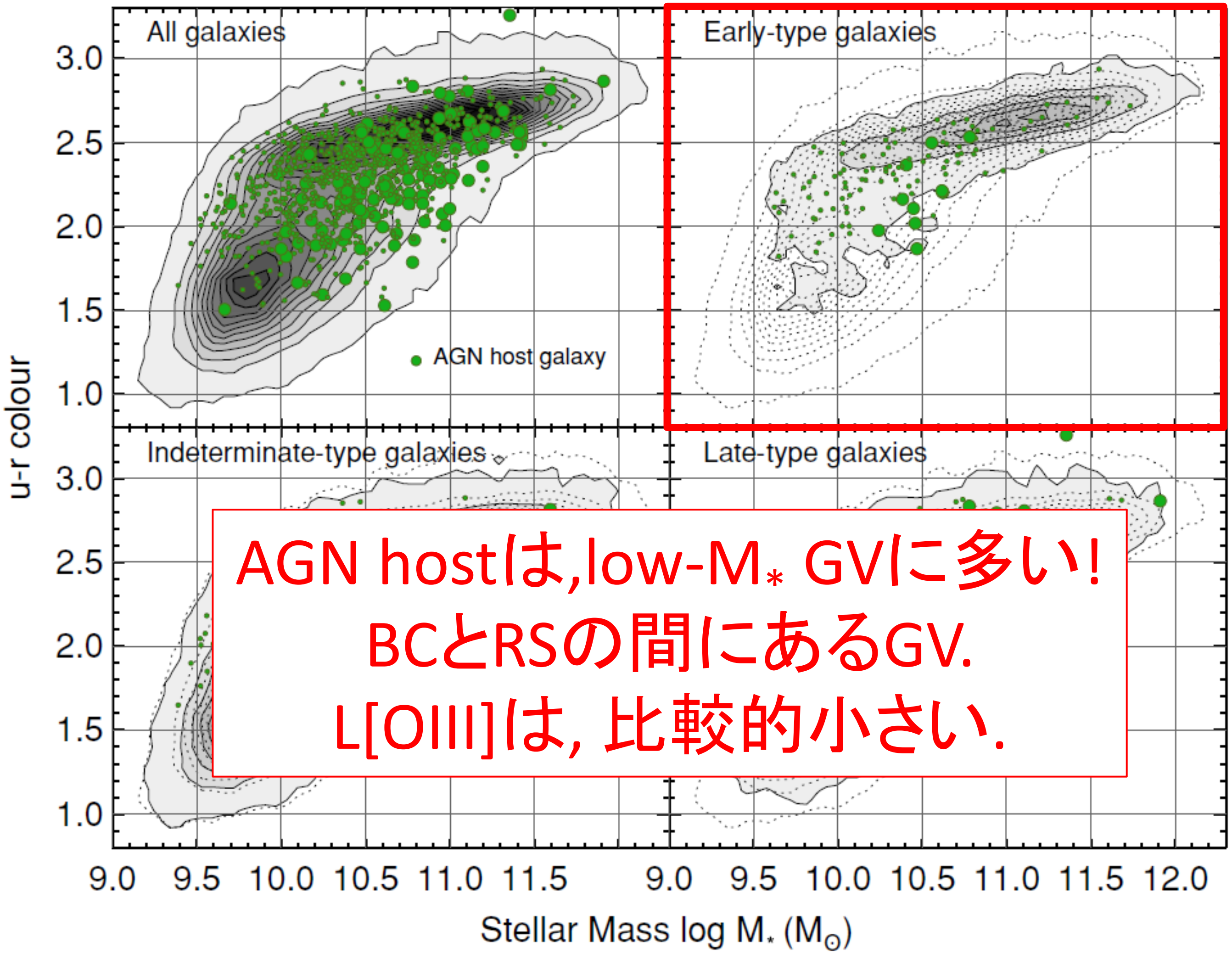
Color-Mass Distribution 1



Late-typeは, Blue Cloudに多い.
Early-typeは, Red Sequenceに多い.
AGN hostは, Green Valley ~ Red Sequenceに多い.

大丸: L[OIII]>10^{41} erg/s, 小丸: L[OIII] < 10^{41} erg/s.

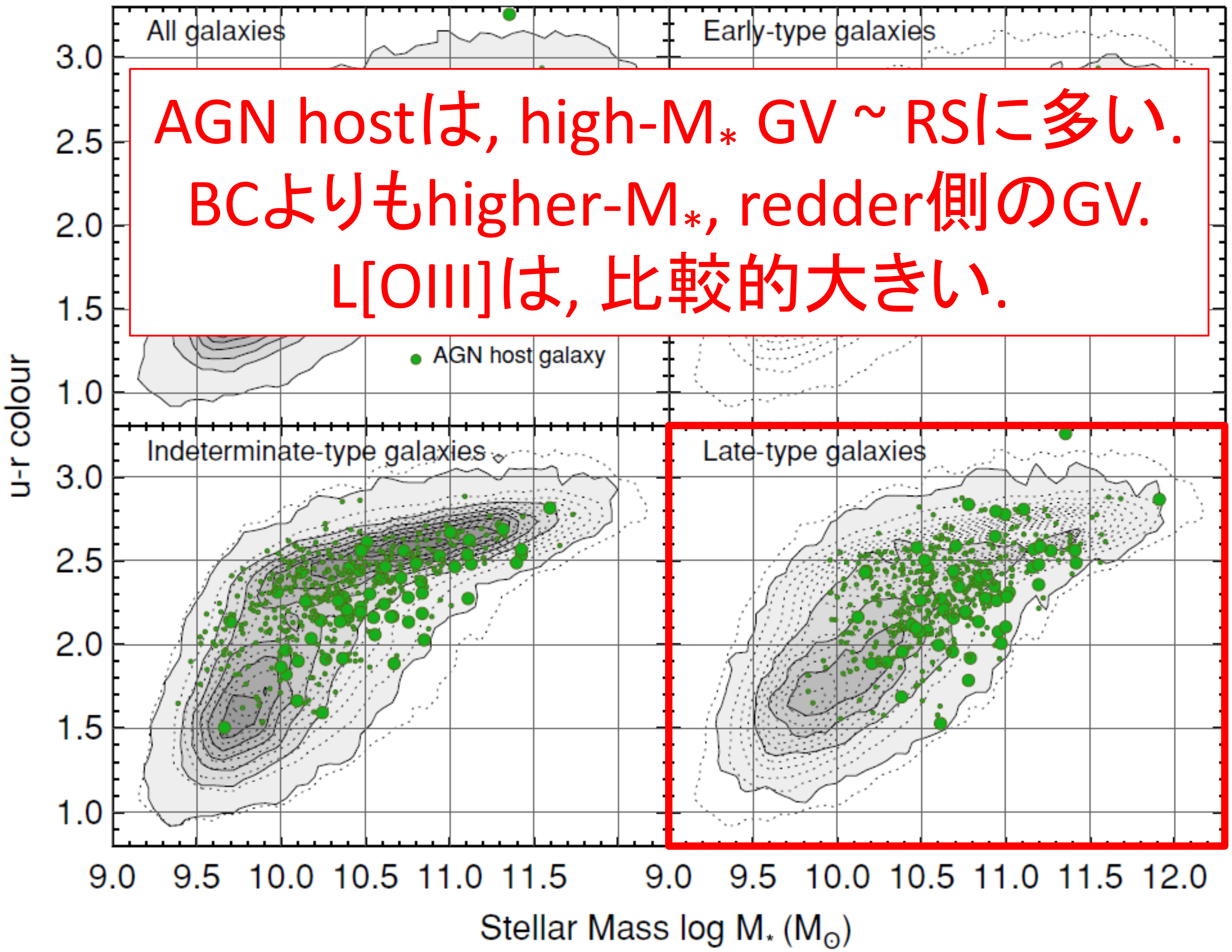
Color-Mass Distribution 1



AGN hostは,low-M* GVに多い!
BCとRSの間にあるGV.
L[OIII]は, 比較的小さい.

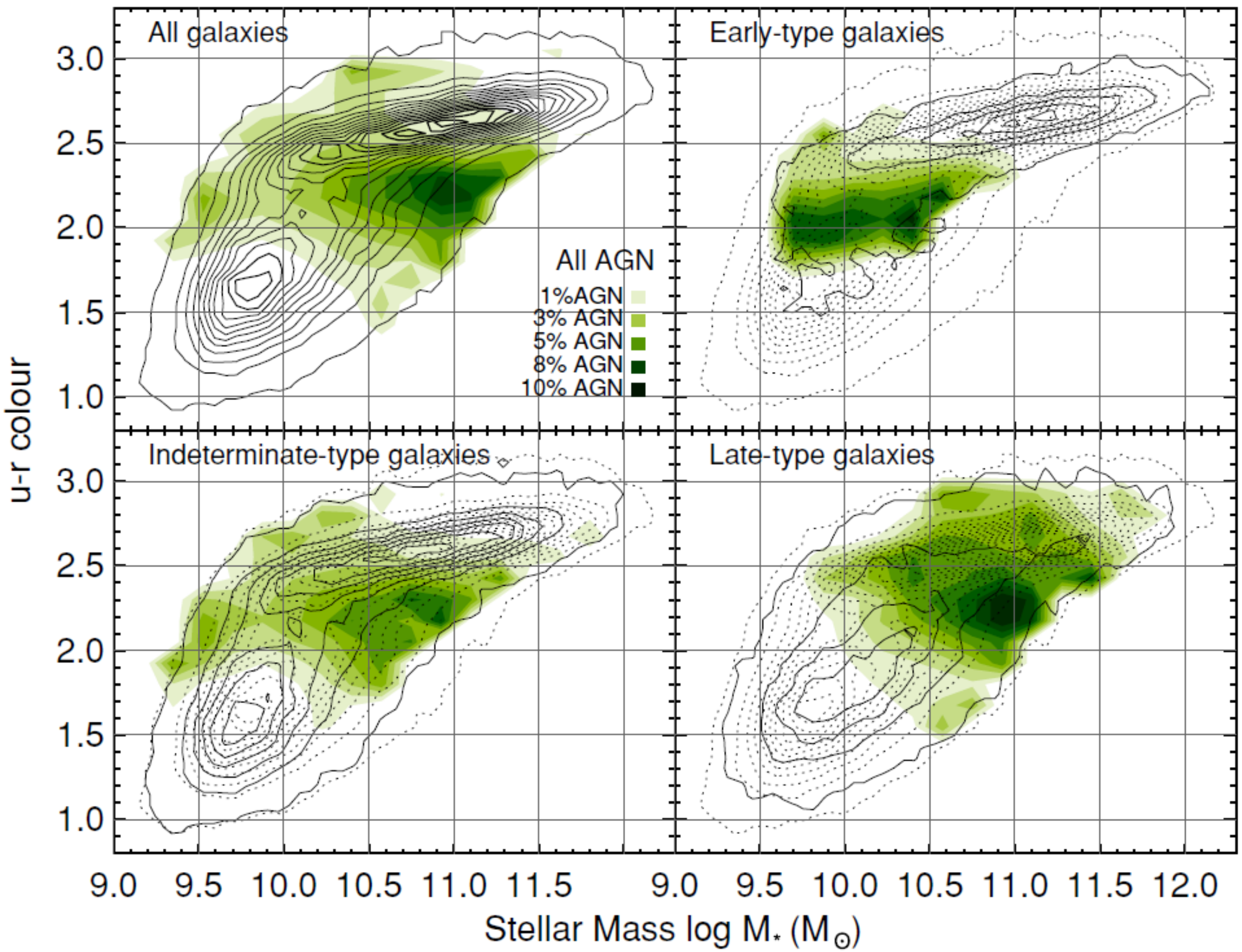
大丸: L[OIII]>10^{41} erg/s, 小丸: L[OIII] < 10^{41} erg/s.

Color-Mass Distribution 1



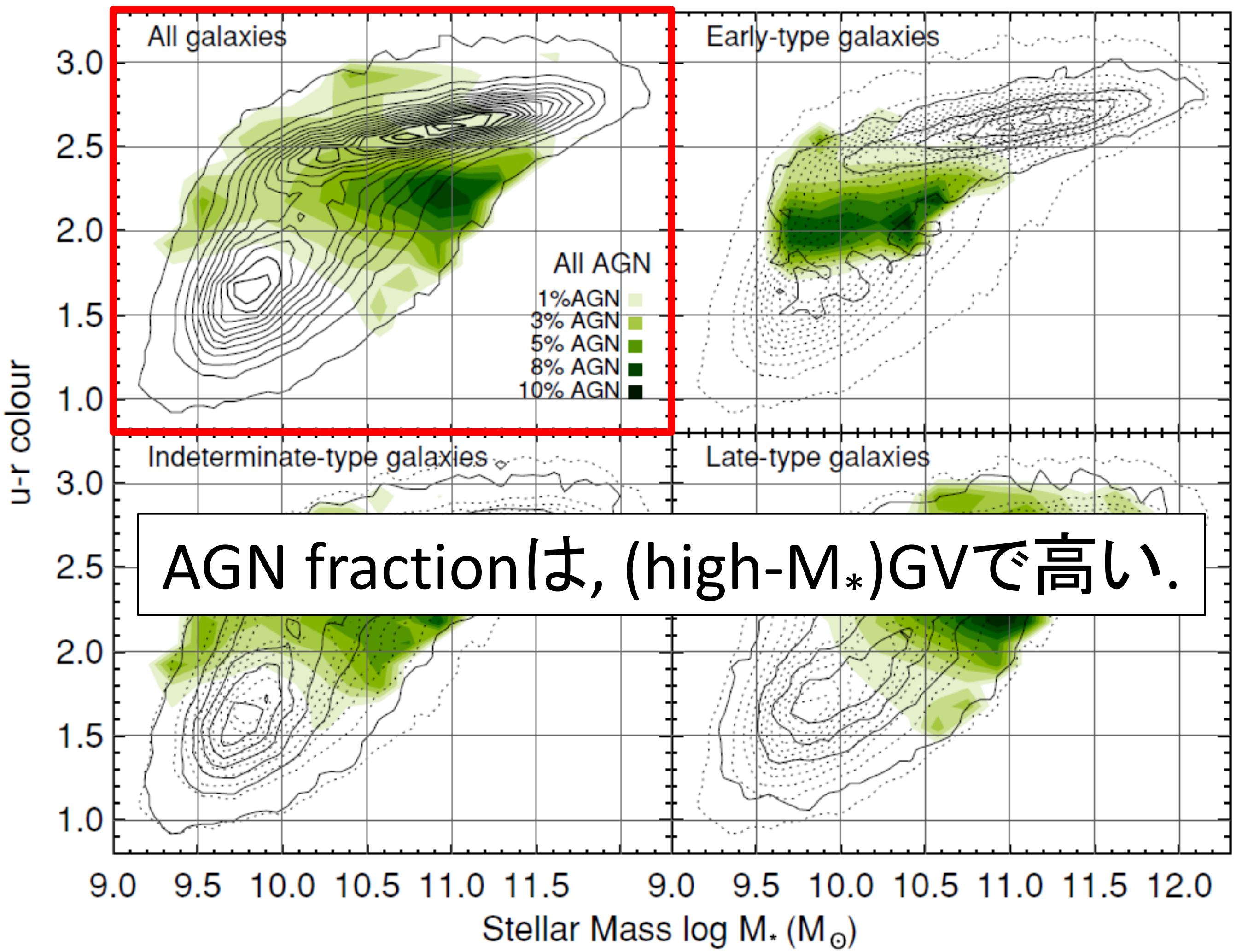
大丸: L[OIII]>10^{41} erg/s, 小丸: L[OIII] < 10^{41} erg/s.

Color-Mass Distribution 2



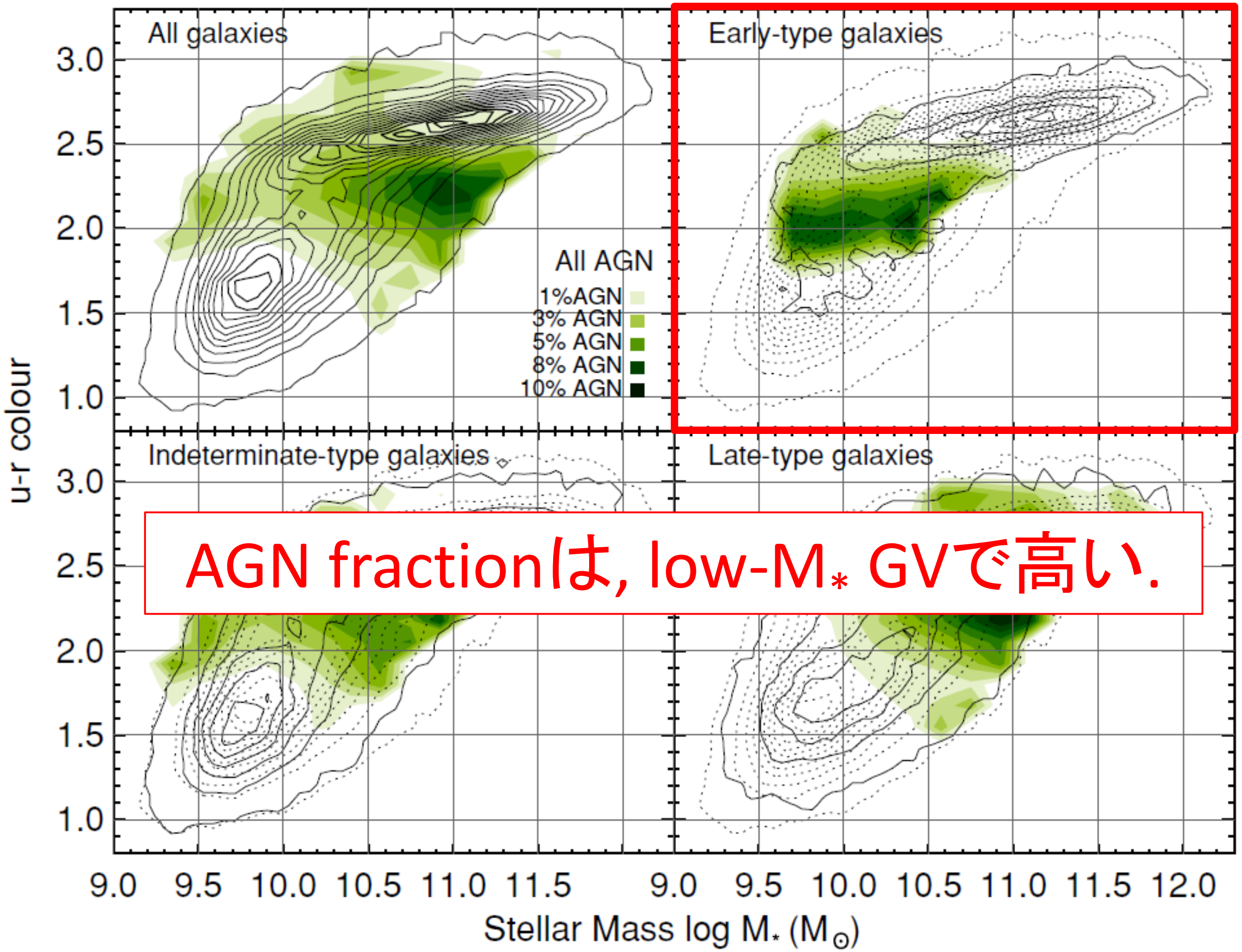
AGN fraction = Seyfert/galaxy total

Color-Mass Distribution 2



AGN fraction = Seyfert/galaxy total

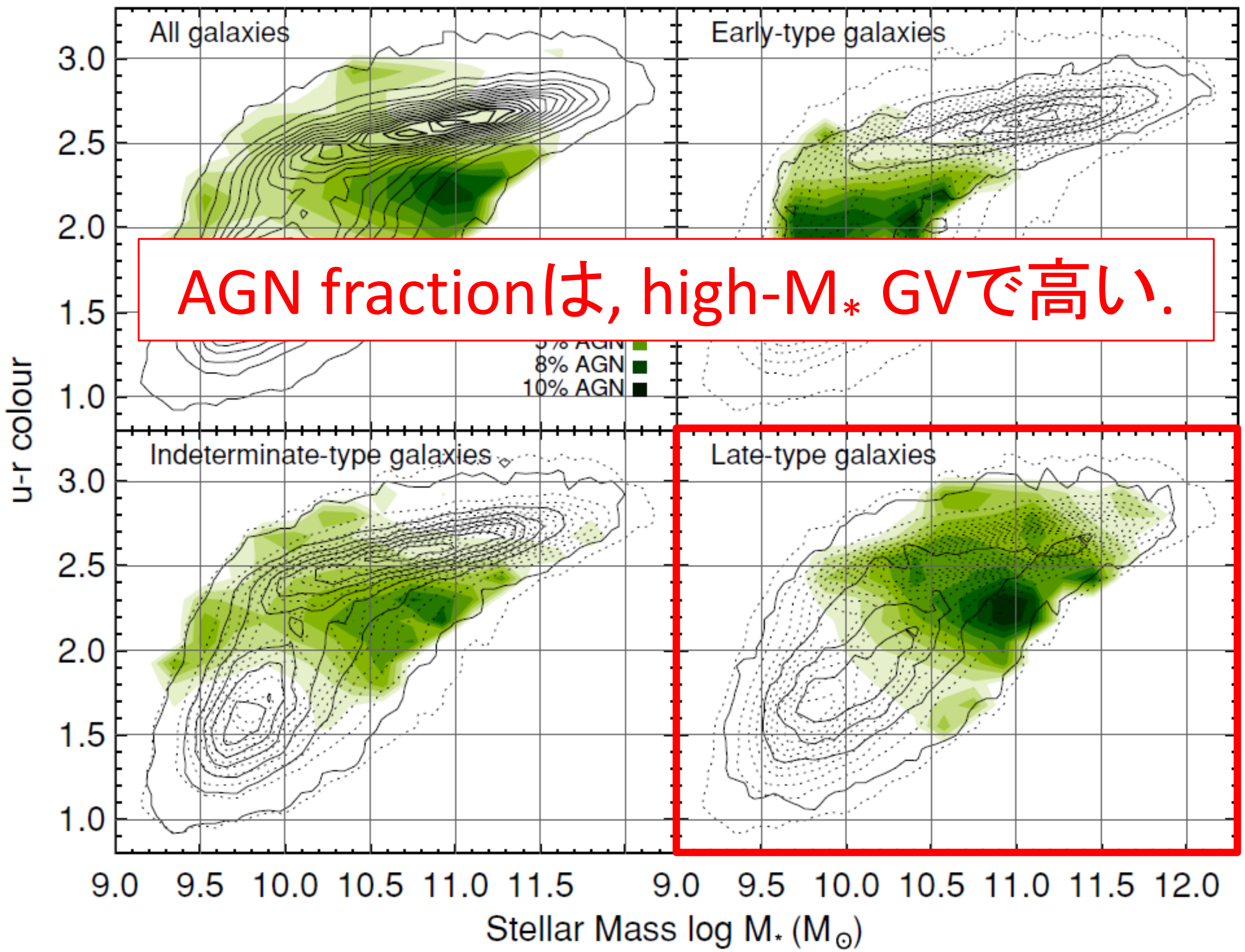
Color-Mass Distribution 2



AGN fractionは, low-M_* GVで高い.

AGN fraction = Seyfert/galaxy total

Color-Mass Distribution 2

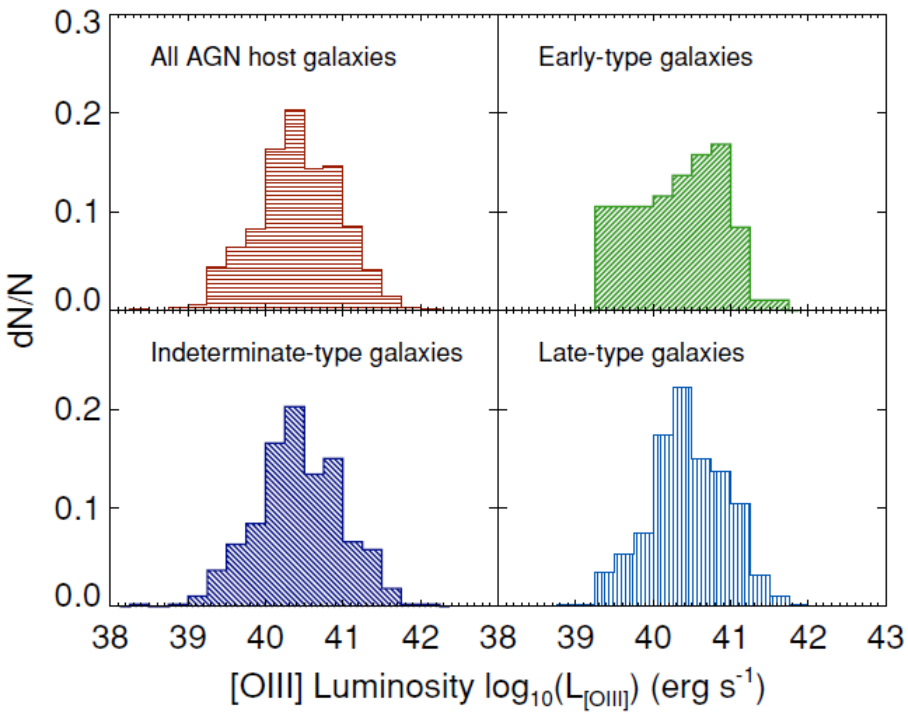


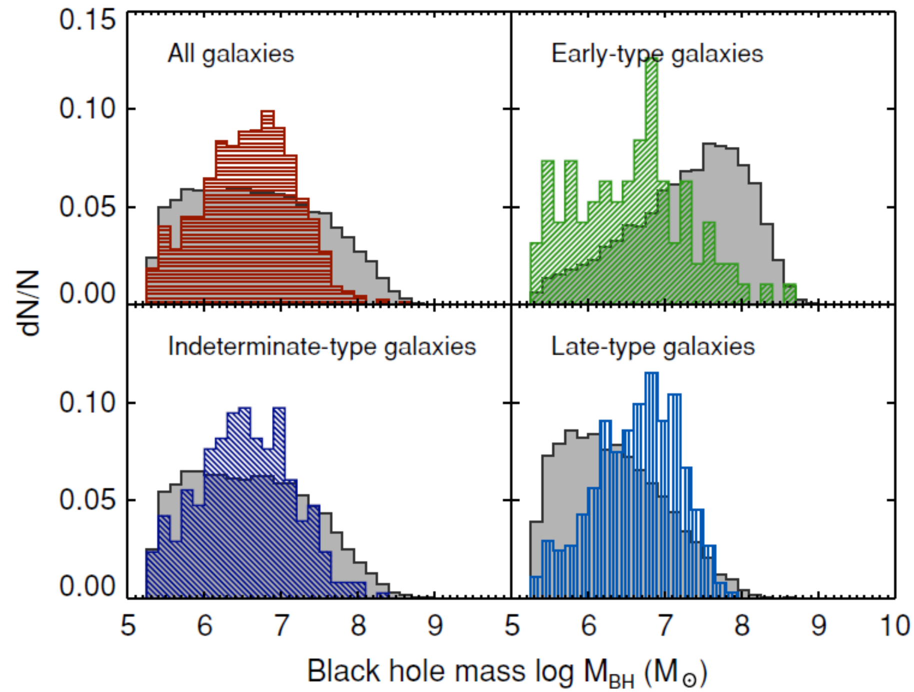
AGN fractionは, high-M_* GVで高い.

AGN fraction = Seyfert/galaxy total

L[OIII], M_{BH} distribution

Stripe: AGN, gray: non-AGN





典型値は, 同程度(但し, 分布は異なる).
M_{BH}は, Late-typeの方がやや重い?

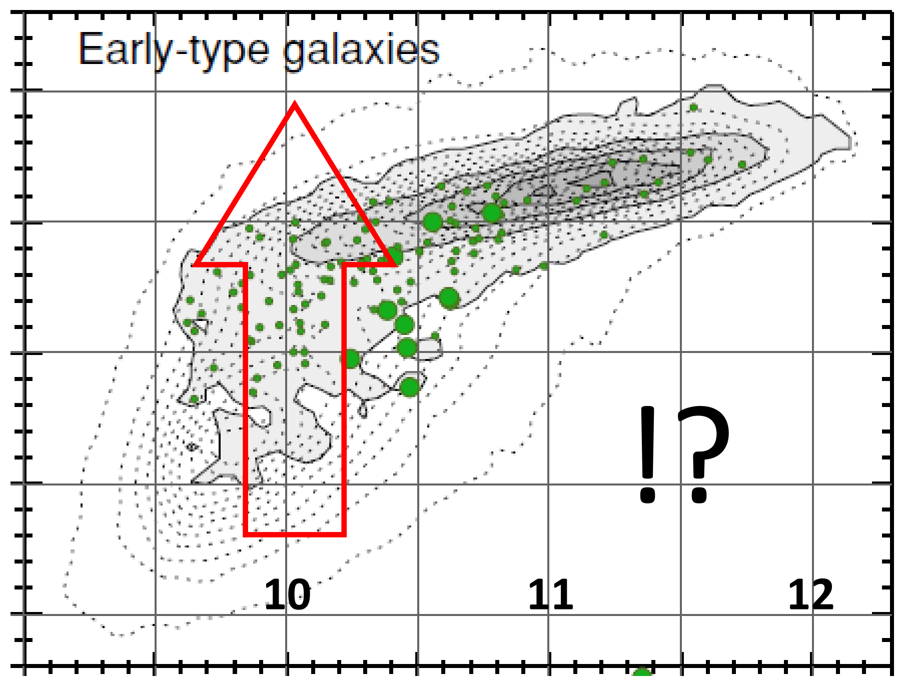
Summary of Figs.

- Late-type:
  - High-M_* Green Valley ~ Red Sequenceに多い.
  - High-M_* Green Valleyでduty cycleが高い.
  - L[OIII] 大, high Eddington ratioでのduty cycleが低い.
- Early-type:
  - Low-M_* Green Valleyに多い.
  - Low-M_* Green Valleyでduty cycleが高い.
  - L[OIII] 中, high Eddington ratioでのduty cycleが高い.
- M_{BH}, L[OIII], L[OIII]/M_{BH}:
  - 典型値は, Late-/Early-typeともに同程度.
  - 分布は異なる.

Co-evolution in Early-type

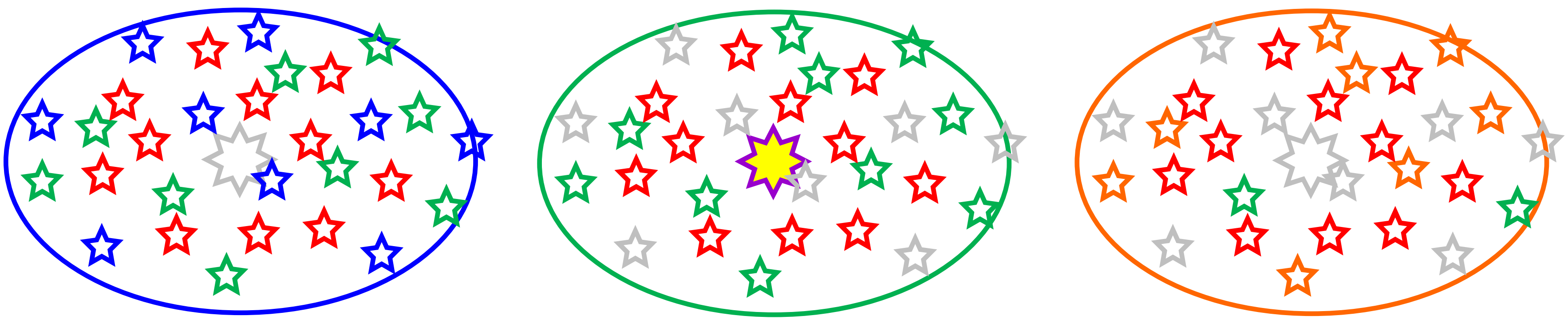
- **Blue-to-Red transition:**
  - SFが止む(@BC) -> AGN発動(@GV) -> 老いた星のみ(@RS)
  - AGN放射によって, SFが止まった?(AGN feedback)
  - SFが止まった直後に, AGNが光り出す?(AGN fueling/trigger)
  - SF -> AGNには, Δt~100-500 Myrのラグがある.

Low-M_* GVの上下に, BCとRSがいる事が決め手.



Co-evolution in Early-type

Blue-to-Red transition in low-M_* early-type galaxy



@ Blue cloud

@ Green Valley

↓

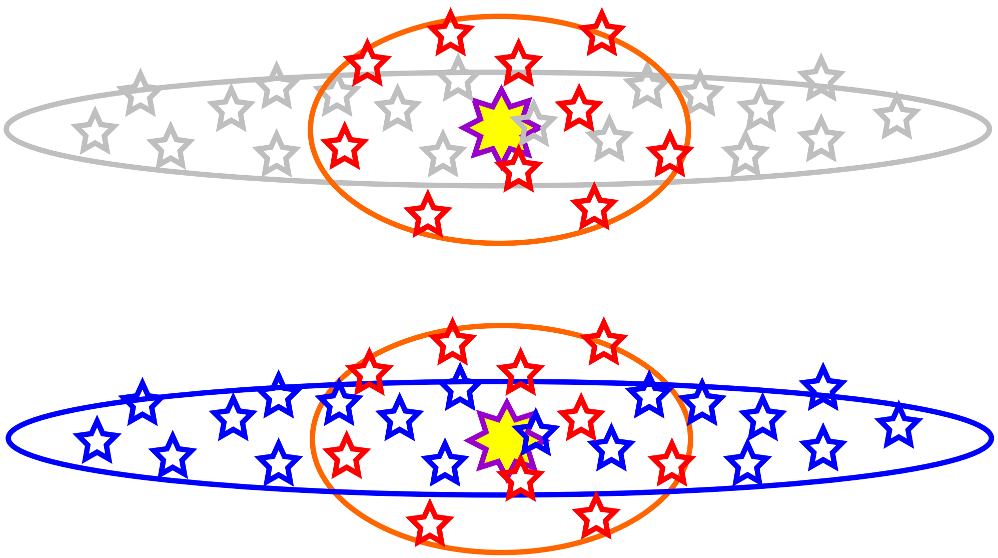
AGN host!!

@ Red Sequence

~100-500 Myr.

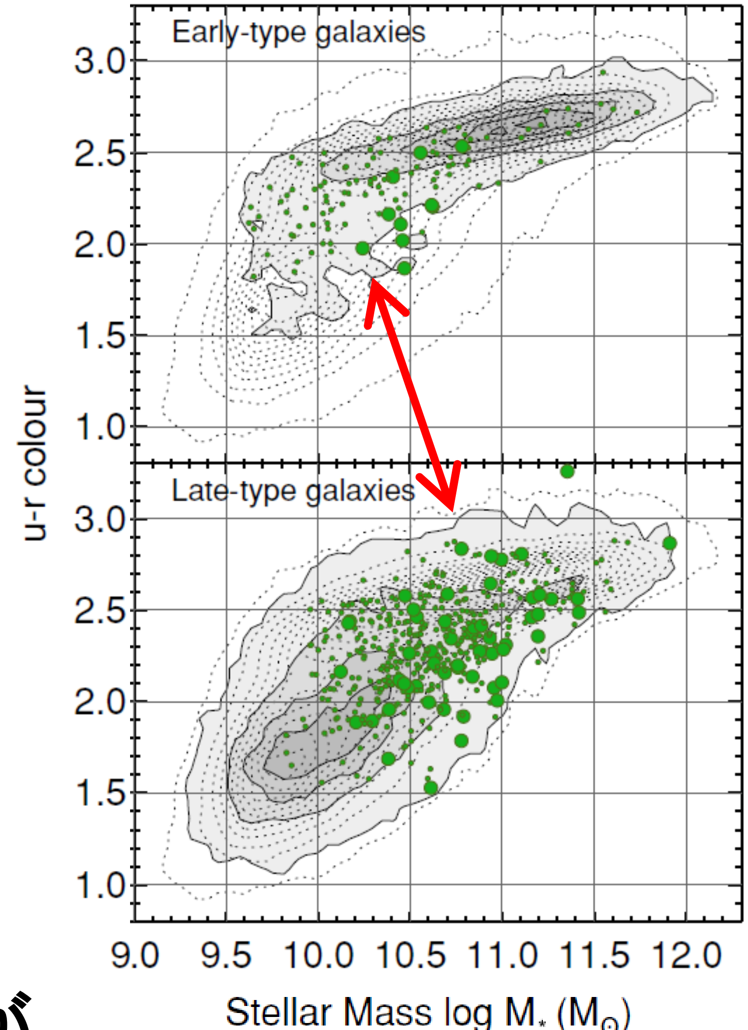
One explanation of M_* difference.

Early-/Late-type AGN host



$M_{*,\,bulge}$ ~ 10^{10} $M_\odot$ -> SMBHと関係?

$M_{*,\,disk}$ ~ $10^{10\text{-}11}$ $M_\odot$ -> ???



Late-type AGN hostでは, stellar <u>disk</u>が $10^{10\text{-}11}$ $M_\odot$まで育ちつつ, <u>green</u> colorでAGNが発動する?

Co-evolution(?) in Late-type

× Late + Late major merger:

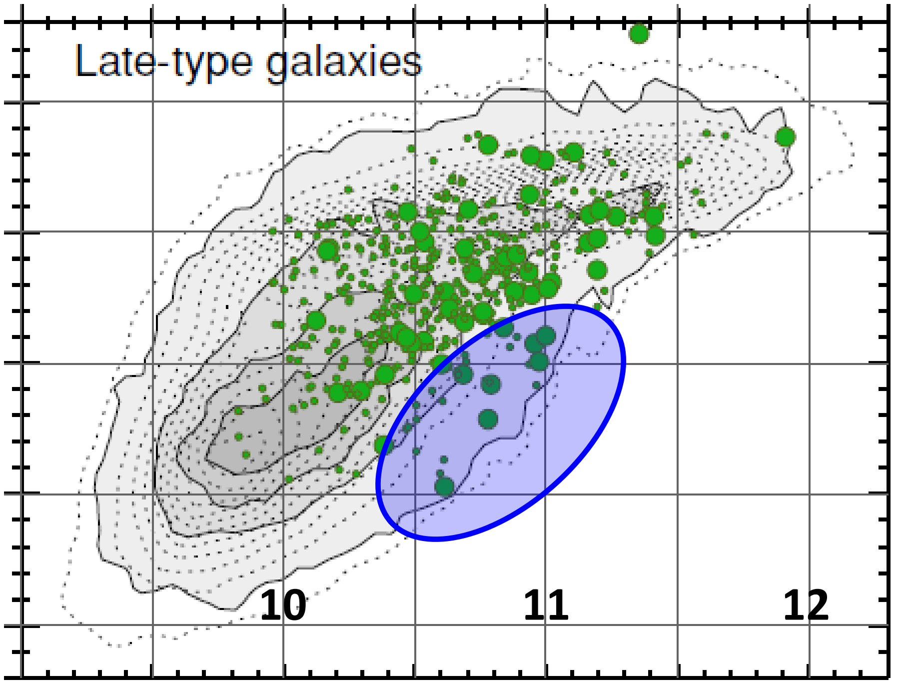
<- 物質を落とす事ができるので, AGNが絡む!

Diskよ育て!!

<- diskが残らない.

<- Late+Lateでは, 青くなってしまう.

High-M_*, blue late-typeは少ない.



- Green color
- Disk dominated
- Host mass $M_* \sim 10^{11}\ M_\odot$

High-M_* GVの下に, BCがいない.
Massive disk込みでgreen color.
-> Early-typeのモデルは不可.

Co-evolution(?) in Late-type

× Late + Early minor merger:

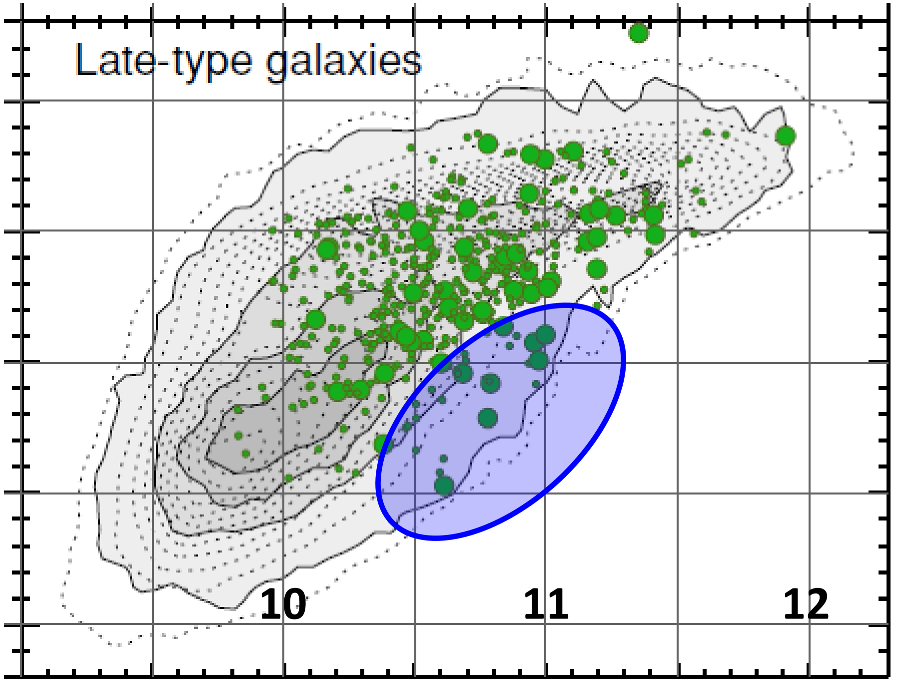
Late = 10^{10} $M_\odot$, Early = 10^{11} $M_\odot$

<- green colorになりそう, bulgeが卓越してしまう.

Late = 10^{11} $M_\odot$, Early = 10^{10} $M_\odot$

<- 青くなってしまう.

High-M_*, blue late-typeは少ない.

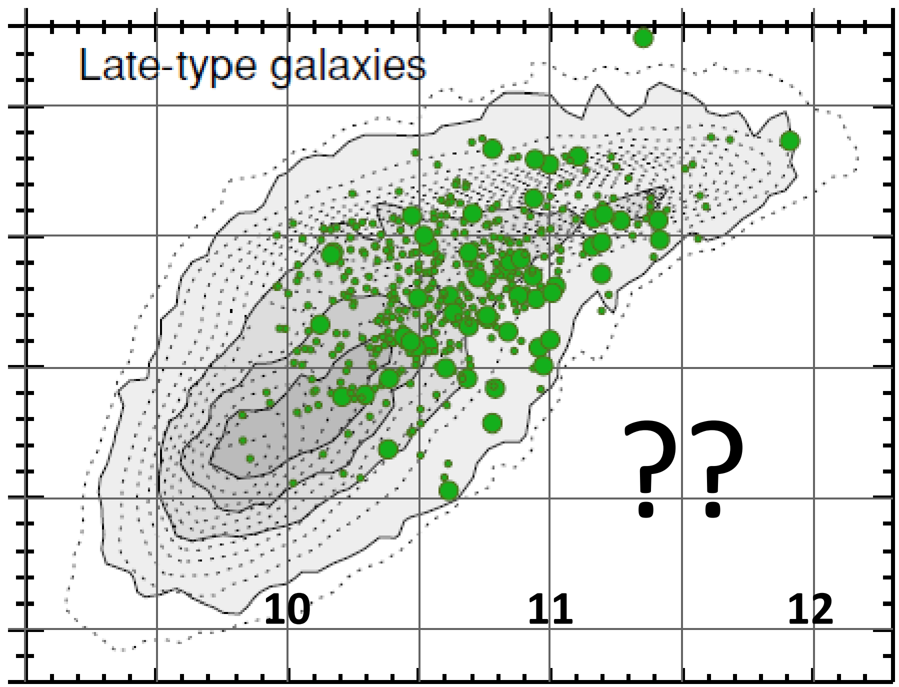


- Green color
- Disk dominated
- Host mass M_*~10^{11} $M_\odot$

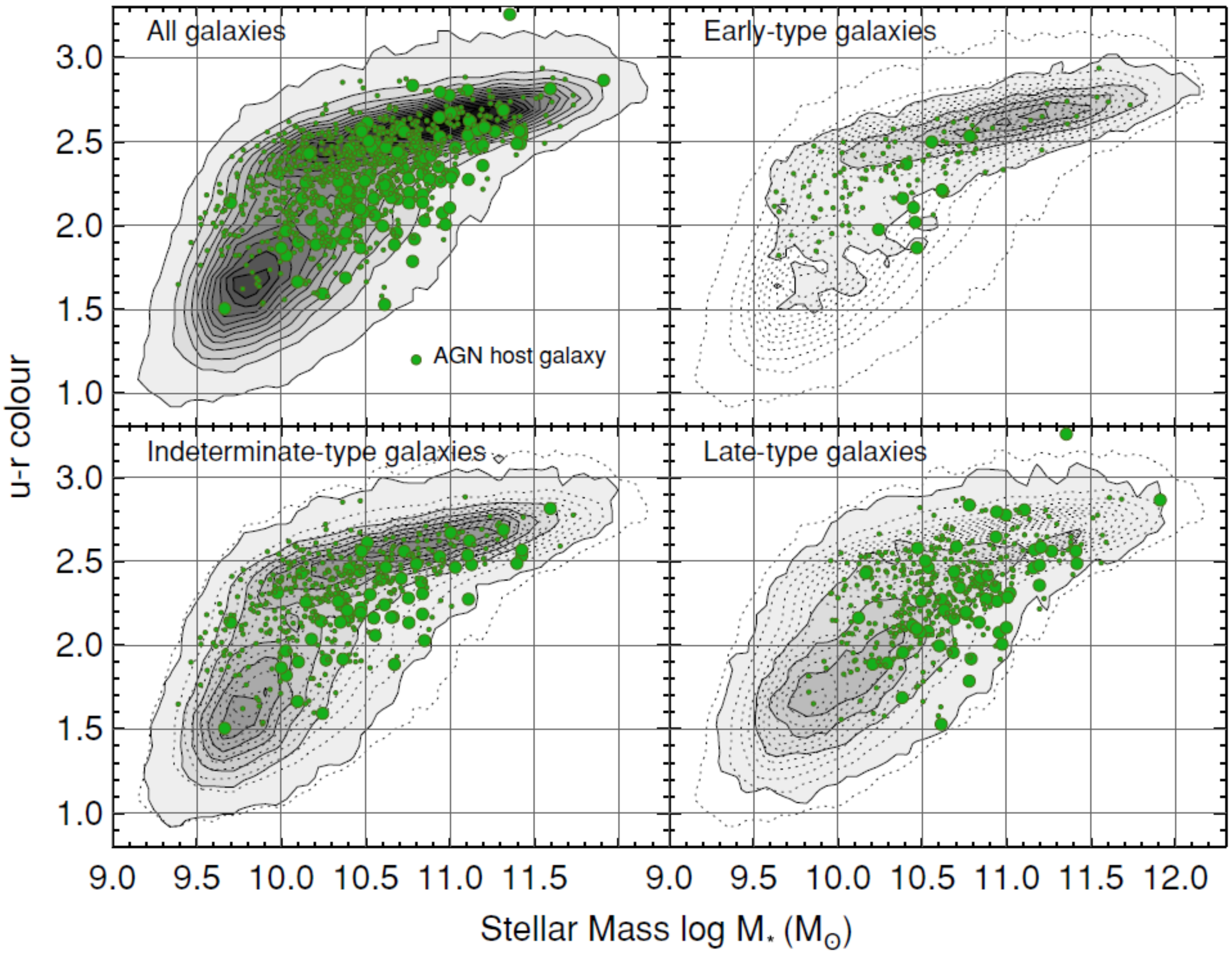
High-M_* GVの下に, BCがいない.
Massive disk込みでgreen color.
-> Early-typeのモデルは不可.

Co-evolution(?) in Late-type

AGNは, late-typeの進化には,
強く影響しないかも. . .



End



All galaxies
Early-type galaxies
Indeterminate-type galaxies
Late-type galaxies
AGN host galaxy
u-r colour
1.0
1.5
2.0
2.5
3.0
9.0
9.5
10.0
10.5
11.0
11.5
12.0
Stellar Mass log M_* ($M_\odot$)

Classification result

Table 1
Galaxy Morphology Statistics from Galaxy Zoo

Galaxy Morpholgy Class	Number	Percentage
Late type	16246	34.1
Indeterminate type	22483	47.2
Early type	8928	18.7
All	47675	100

AGN properties

Table 2

Typical [O III] λ5007 luminosities, Eddington Ratios, and Black Hole

Host Galaxy Morphology	Number	Percentage of Host Galaxies	Mean $\log L[\mathrm{O\,III}]$ ($\mathrm{erg\,s^{-1}}$)	Median $\log L[\mathrm{O\,III}]$ ($\mathrm{erg\,s^{-1}}$)
Late types	402	42.68%	40.40	40.39
Indeterminate types	431	45.75%	40.40	40.39
Early types	109	11.57%	40.27	40.30
All	942	100%	40.38	40.38

Masses of AGNs by Host Galaxy Morphology

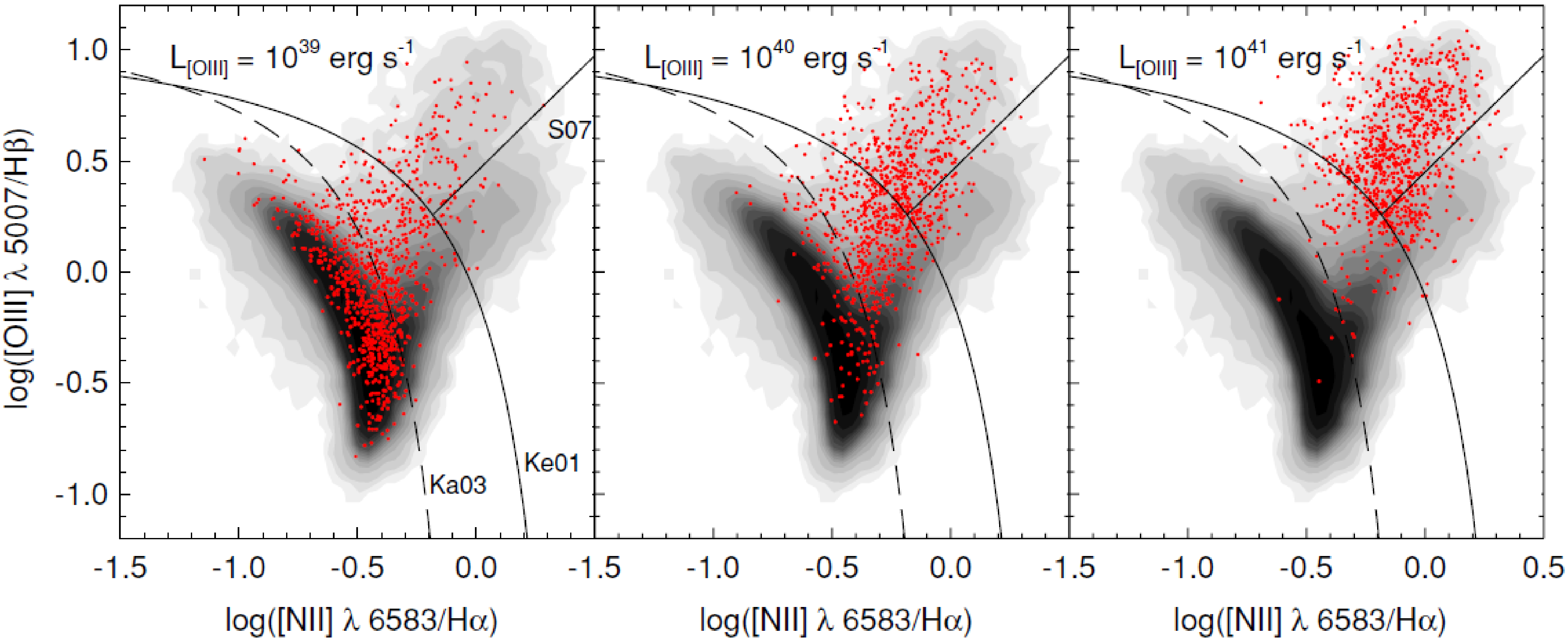
Mean $\log L[\mathrm{O\,III}]/\sigma^4$	Median $\log L[\mathrm{O\,III}]/\sigma^4$	Mean $\log M_{\mathrm{BH}}$ ($M_\odot$)	Median $\log M_{\mathrm{BH}}$ ($M_\odot$)
0.295	0.306	6.52	6.63
0.456	0.442	6.52	6.63
0.326	0.397	6.36	6.45
0.372	0.370	6.43	6.53

~Eddington Ratio~

- 質量降着率をEddington限界降着率で割った量.
  - SMBHの身の丈を考慮した“相対”質量降着率.
  - L[OIII]$\propto L_{bol} \propto dM/dt$, $M_{BH} \propto dM_{Edd}/dt$より, L[OIII]/$M_{BH}$で代用.

1. 林君が, カレーを3杯/hの速さで食す.
   - 遅い! (-> Eddington ratioが低い状態)
   - この時, 降着円盤は放射不良に(RIAF/ADAF).
2. 私が, カレーを3杯/hで食す.
   - 普通!? (-> Eddington ratioがそこそこの状態)
   - この時, 降着円盤はよく光る(Standard accretion disk).
3. 小食の人が, カレーを3杯/hで食す.
   - ムリ. (-> Eddington ratioが1以上)

Completeness check



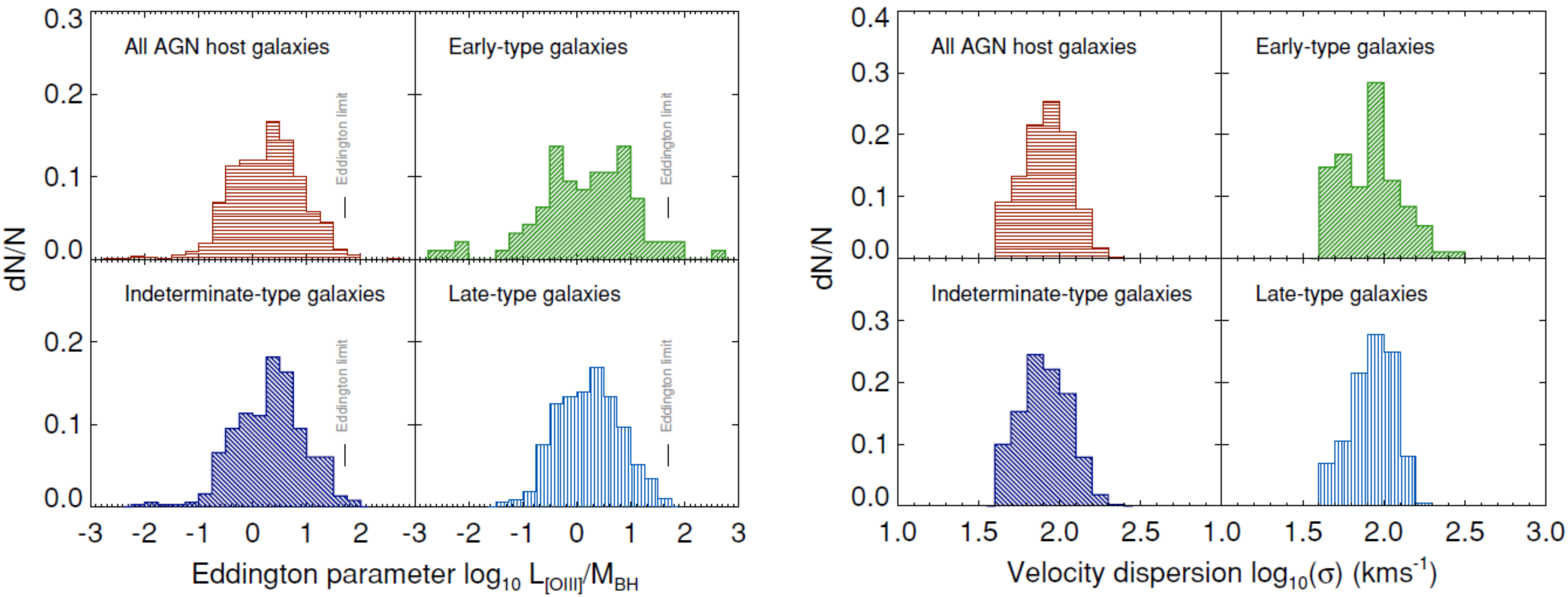
AGN起源のL[OIII]が,

L[OIII] > 10^{39} erg/s; 14.2%はAGNに分類される-> ×

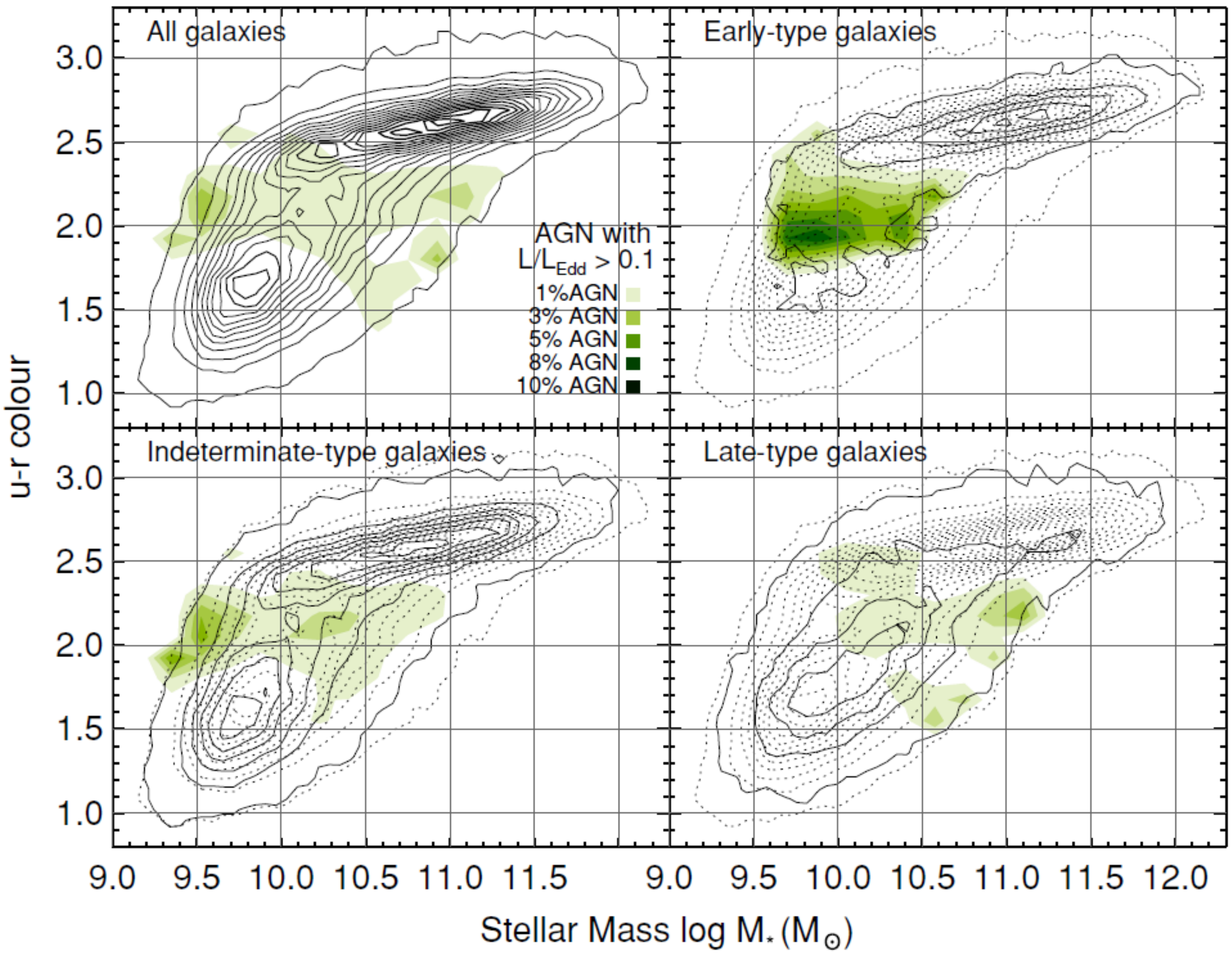
L[OIII] > 10^{40} erg/s; 45.6%はAGNに分類される-> ×

L[OIII] > 10^{41} erg/s; 87.1%はAGNに分類される-> ○

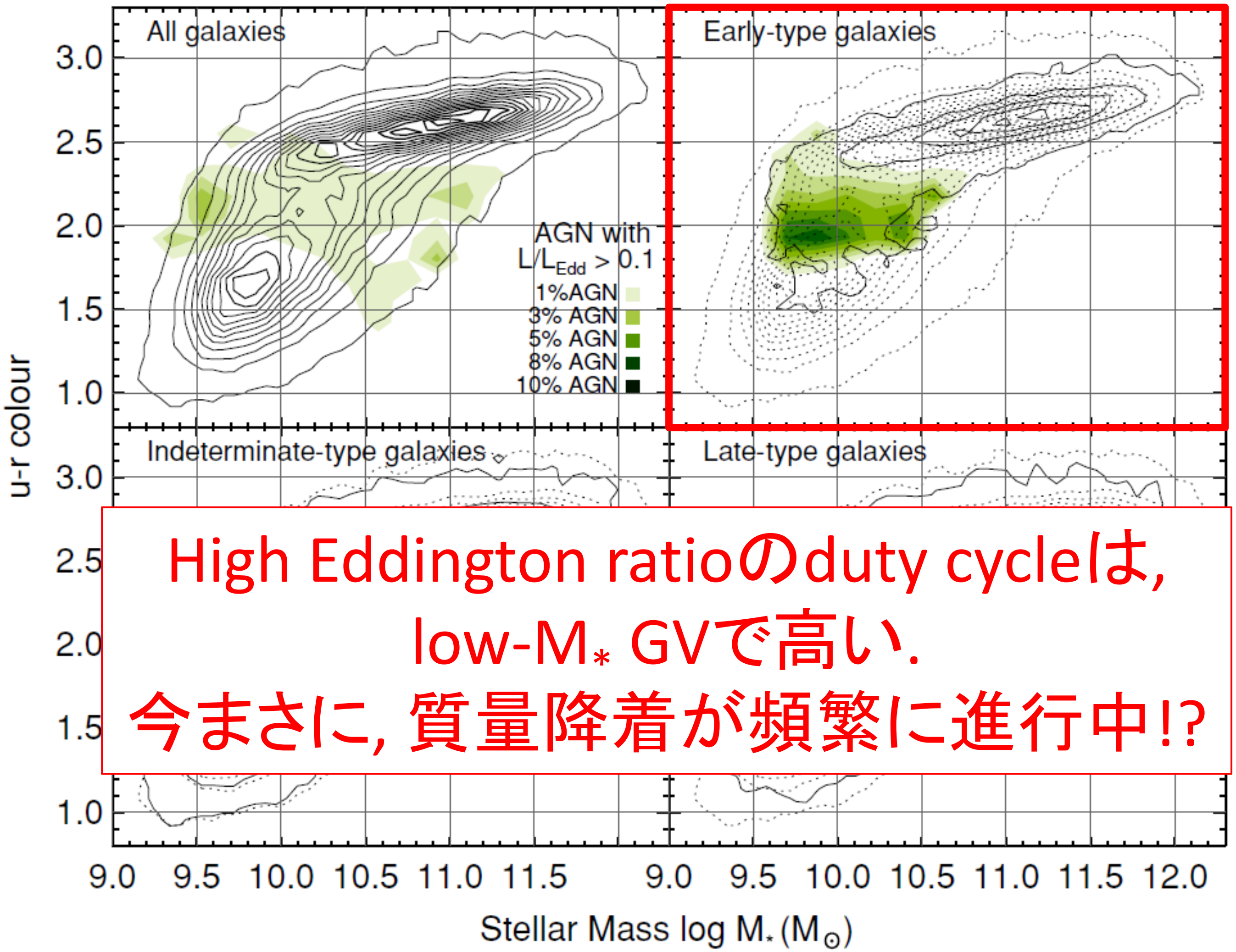
σ_*, L[OIII]/M_{BH} distribution



Color-Mass Distribution 3



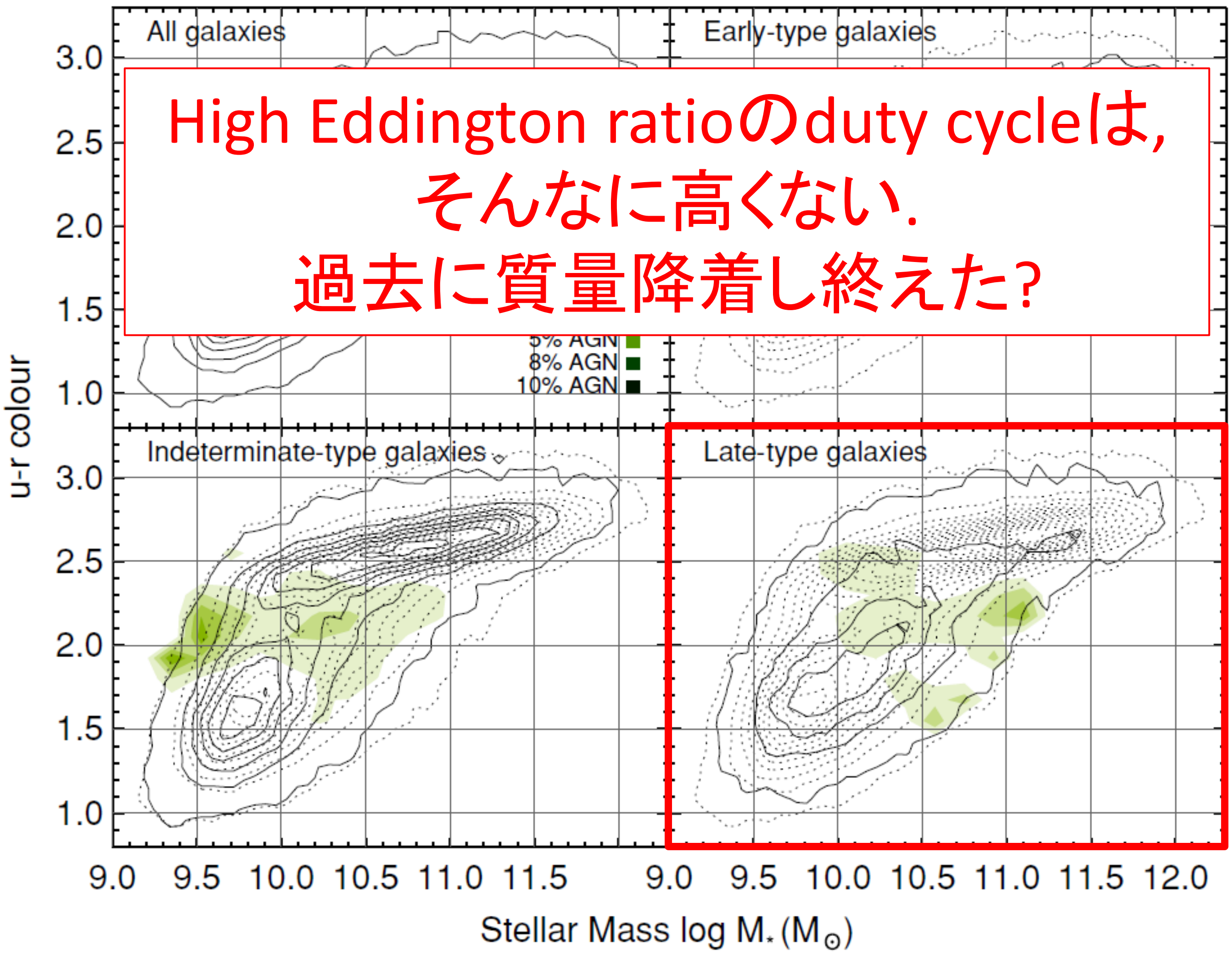
Color-Mass Distribution 3



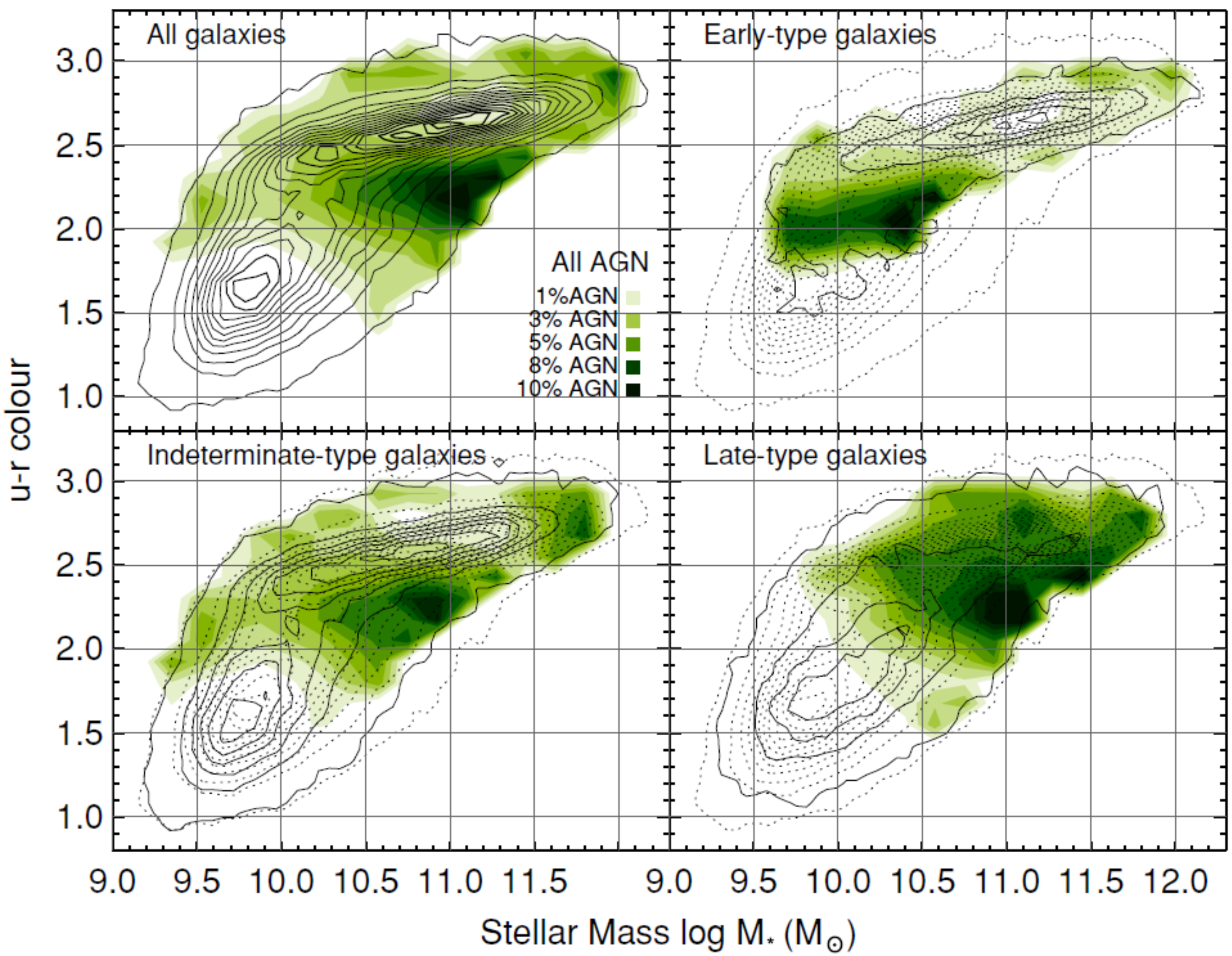
High Eddington ratioのduty cycleは,
low-M* GVで高い.
今まさに, 質量降着が頻繁に進行中!?

Color-Mass Distribution 3

High Eddington ratioのduty cycleは,
そんなに高くない.
過去に質量降着し終えた?



Color-Mass Distribution 4



AGN = Seyfert + LINERとした場合のAGN fraction map.