

大型光赤外線望遠鏡で探る宇宙再電離

大内 正己

東京大学宇宙線研究所

共同利用研究課題

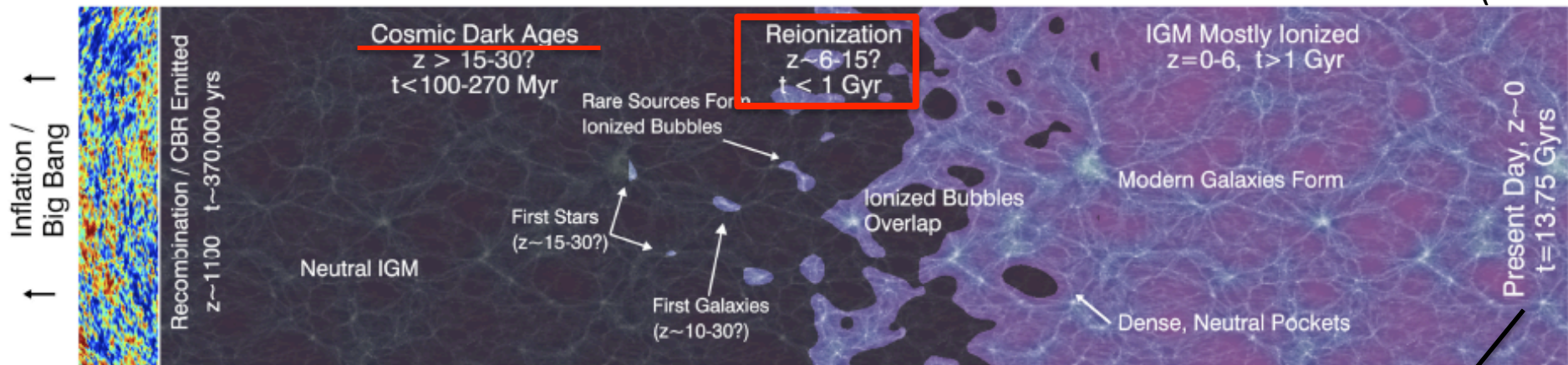
- 平成25年度
代表:大内正己 10万円(旅費)

参加研究者(旅費支給者を赤で示す):

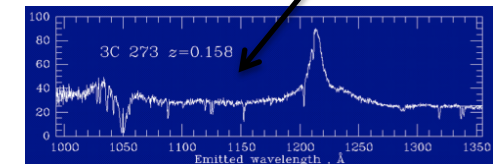
- (柏以外:10名) 嶋作一大、橋本拓也、篠木新吾、後藤亮介、川俣良太、Janice Lee、Jeff Cooke、Anne Verhamme、Yi-Kuan Chiang、Lucia Guaita
 - (柏:8名) 小野宜昭、百瀬莉恵子、ユマ・スラポン、中島王彦、今野彰、内藤嘉章、石垣真史、玉澤裕子
- HSC狭帯域フィルター関連(学振:基盤A:代表者:大内)

宇宙再電離

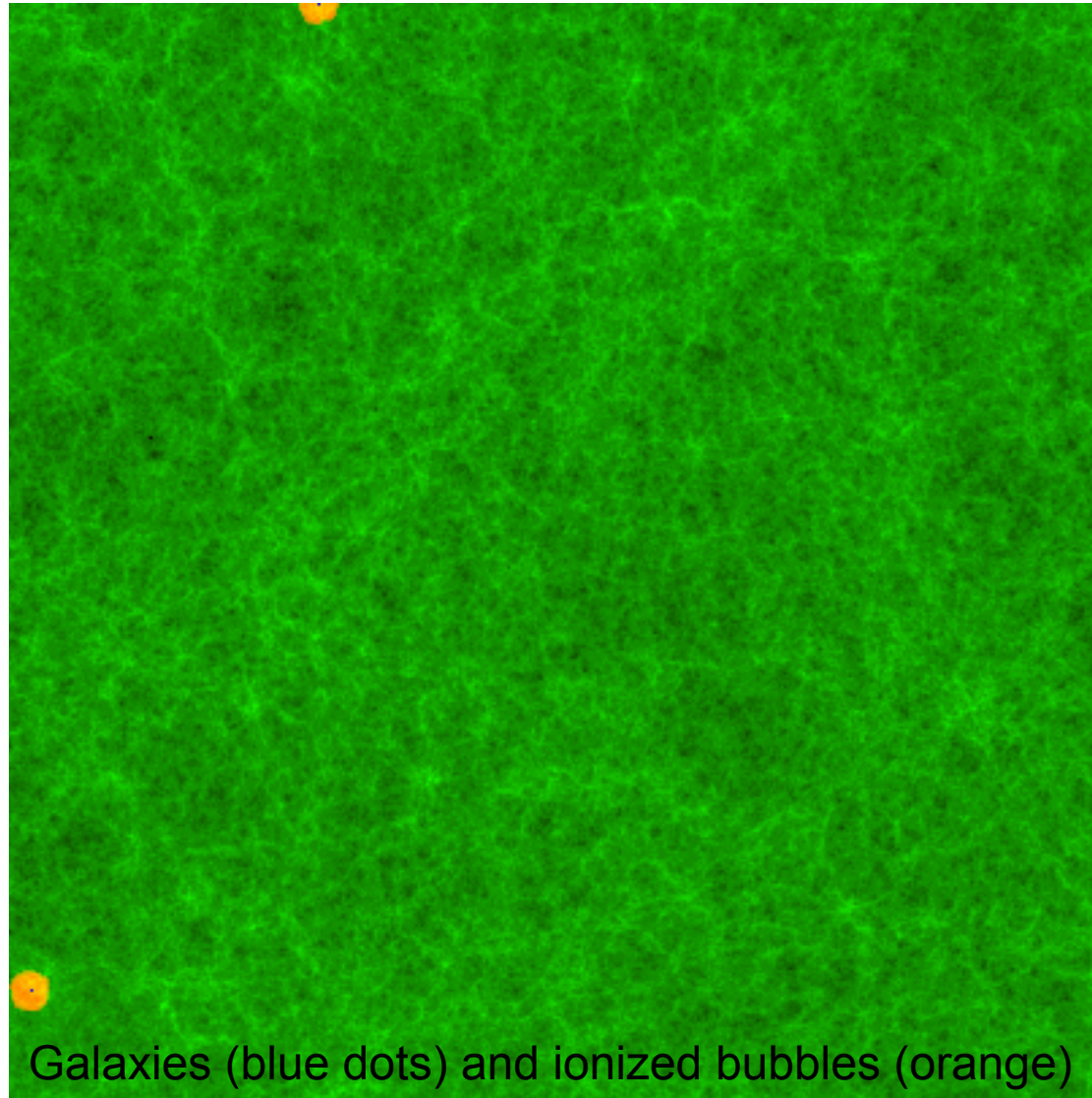
Robertson et al. (2010)



宇宙再電離:
中性水素で満たされた宇宙
→ 電離(現在)



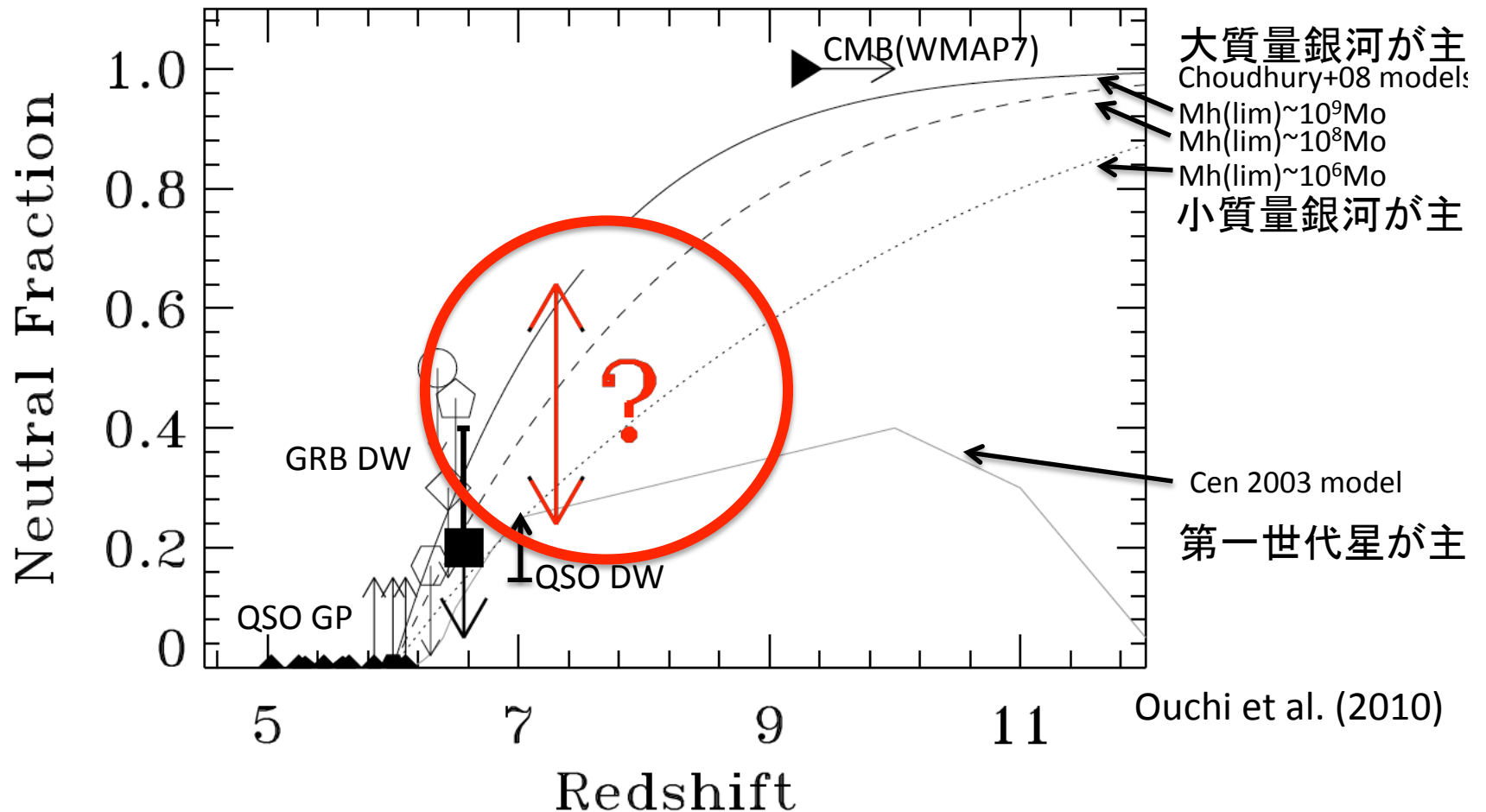
宇宙再電離



Numerical simulations
(Iliev et al. 2006)

Galaxies (or their star formation) are driving the cosmic reionization?
Not clear yet.

宇宙再電離の未解決問題



– QSO GP test ($z \sim 6$), QSO DW, and CMB TS τ ($z \sim 10$)

Sharp reionization (e.g. Fukugita+94) or extended reionization (Dunkley+09)?

宇宙再電離史は電離源に依存(モデル)

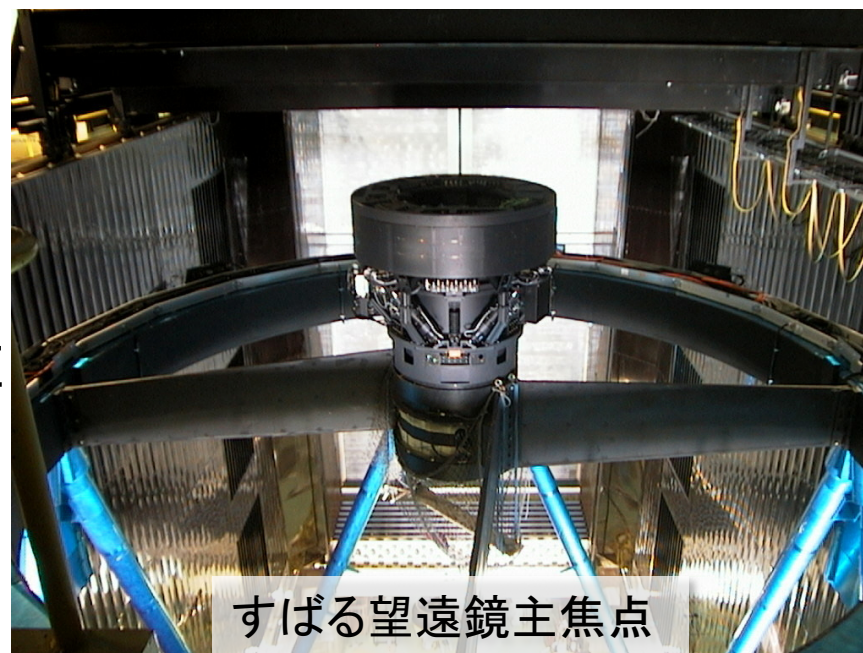
中性水素比の予言が分かれ、かつ現実的に観測可能な $z \sim 6-7$ を狙う。

次世代宇宙論観測に向けた準備研究 すばる望遠鏡HSCの狭帯域フィルター開発

- すばる望遠鏡主焦点超広視野可視撮像装置Hyper Suprime-Cam (HSC; 従来の10倍の探査能力)。2014年3月から探査観測(東京大学、国立天文台、プリンストン大学、台湾他)
- 高赤方偏移($z \sim 6-7$)にある約1万個の銀河を狭帯域フィルターで検出(銀河からのLyman α 輝線) \rightarrow Ly α DW吸収量から x_{HI}



すばるHyper Suprime-Cam(HSC) PFU



すばる望遠鏡主焦点

Probing Reionization History

Lya Damping Wing Absorption

Absorption cross section (\rightarrow voigt profile)

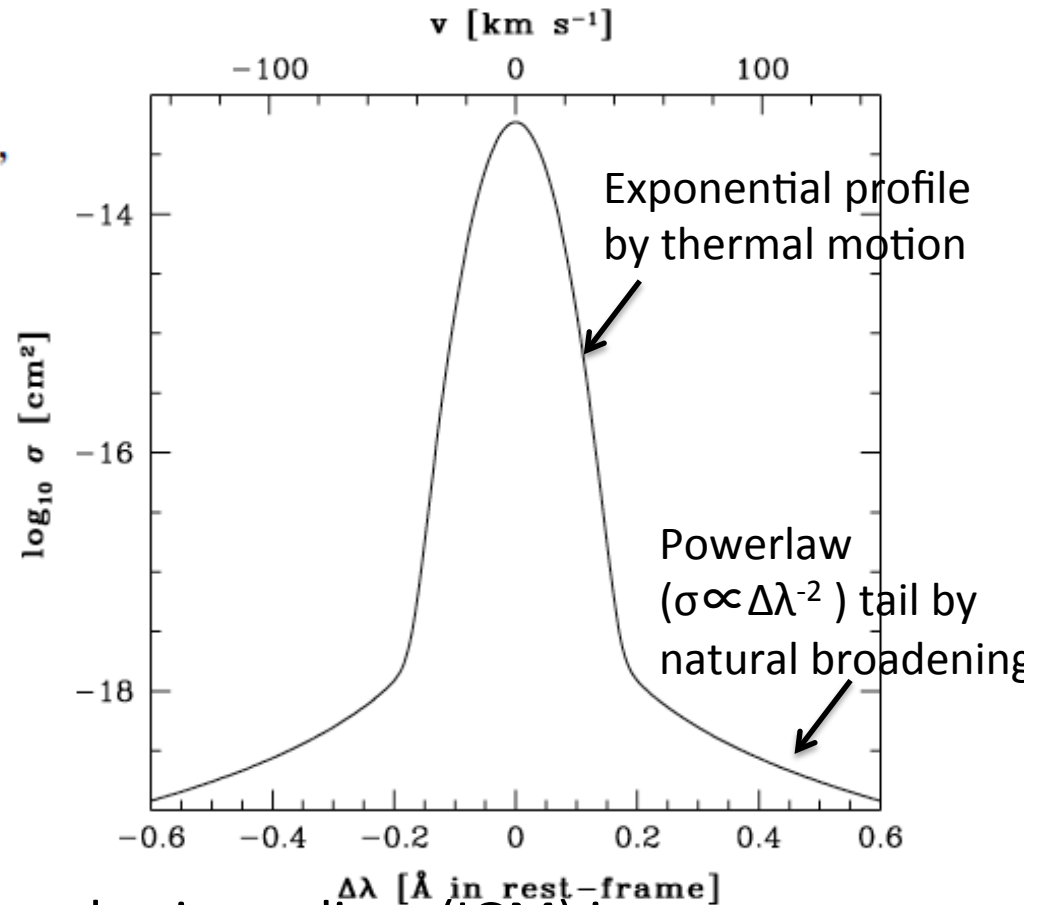
$$\sigma_V(v) = \int_{-\infty}^{\infty} M(v) \sigma_N(v - v_\alpha v/c) dv,$$

Maxwellian velocity distribution

$$M(v) = \left(\frac{m_H}{2\pi kT} \right)^{1/2} \exp \left(- \frac{m_H v^2}{2kT} \right),$$

Natural absorption cross section

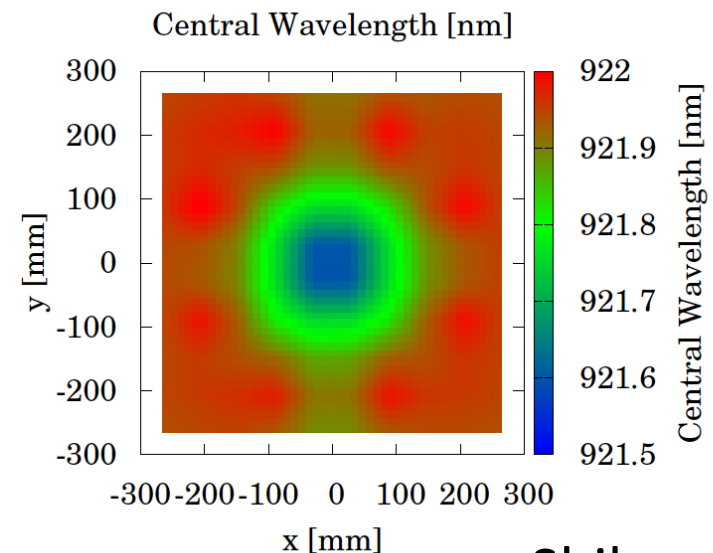
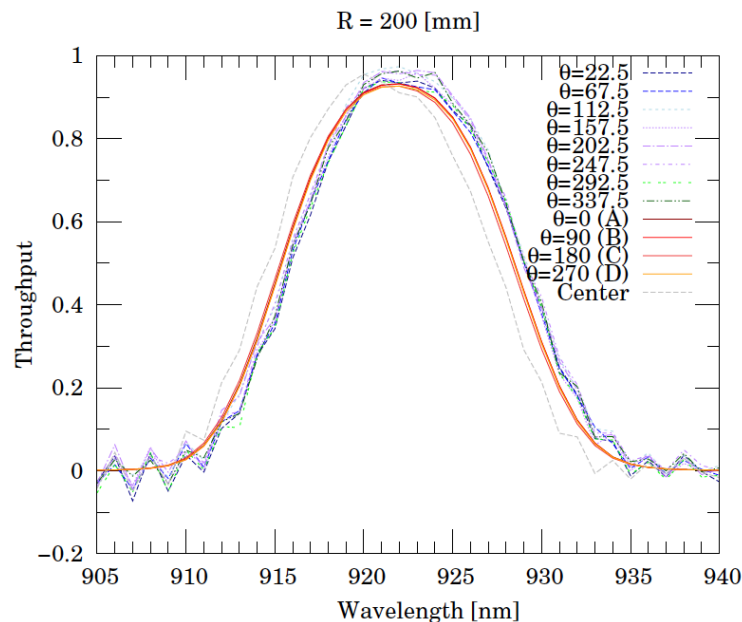
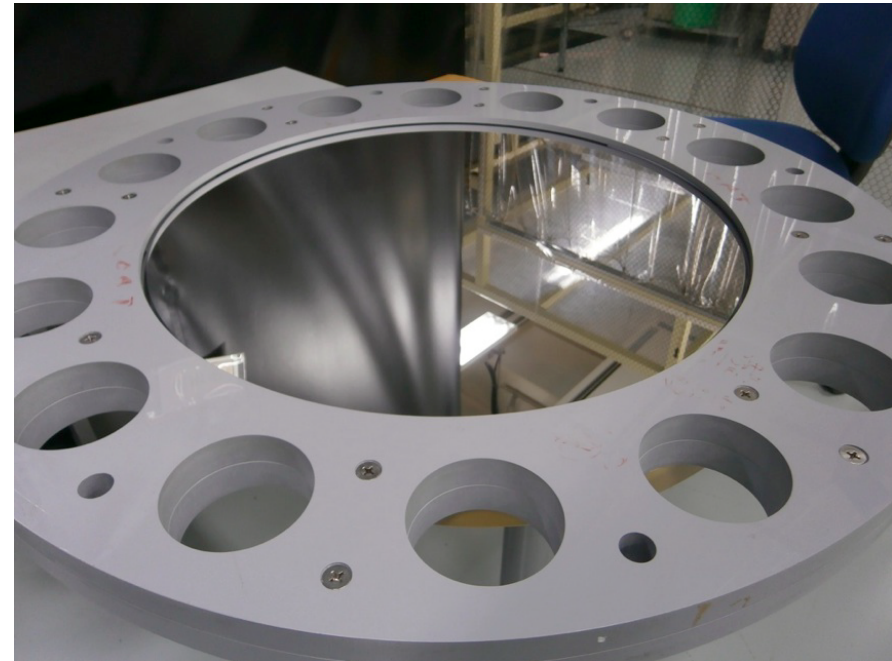
$$\sigma_N(v) = \frac{3\lambda_\alpha^2 A_{21}^2}{8\pi} \frac{(v/v_\alpha)^4}{4\pi^2(v - v_\alpha)^2 + (A_{21}^2/4)(v/v_\alpha)^6},$$



- Damping wing absorption of inter-galactic medium (IGM) just in front of the object (GRB, QSO, and galaxies)
 - \rightarrow density of neutral hydrogen
 - \rightarrow neutral hydrogen fraction, $x_{\text{HI}} = \langle n_{\text{HI}}/n_{\text{H}} \rangle$

大型HSC狭帯域フィルター NB921

- 2011年度からMaterion社と開発→スペック割れ・不具合→今年度完成
 - 中心波長のズレ: $<0.16\%$ ($<0.3\%$)
 - 中心波長の変化率: $<0.09\%CW/2cm$ ($0.15\%CW/2cm$)
 - ピーク透過率: $>90\%$ (75%以上)
 - FWHMのズレ: $<6\%$ ($\pm 10\%$ 以内)
- 現在は2枚目のNB973作成中



Shibuya et al.

2013年度の論文(14編)

- Yuma, Ouchi, Drake, Simpson, Shimasaku, Nakajima, Ono, Momose, Akiyama, Mori, and Umemura, "First Systematic Search for Oxygen-line Blobs at High Redshift: Uncovering AGN Feedback and Star Formation Quenching", *The Astrophysical Journal*, 779, pp.53-2013
- Ouchi, Ellis, Ono, Nakanishi, Kohno, Momose, Kurono, Ashby, Shimasaku, Willner, Fazio, Tamura, and Iono, "An Intensely Star-forming Galaxy at $z \sim 7$ with Low Dust and Metal Content Revealed by Deep ALMA and HST Observations", *The Astrophysical Journal*, 778, pp.102-2013
- Koekemoer, Ellis, McLure, Dunlop, Robertson, Ono, Schenker, Ouchi, Bowler, Rogers, Curtis-Lake, Schneider, Charlot, Stark, Furlanetto, Cirasuolo, Wild, and Targett, "The 2012 Hubble Ultra Deep Field (UDF12): Observational Overview", *The Astrophysical Journal Supplement Series*, 209, pp.3-2013
- Ono, Ouchi, Curtis-Lake, Schenker, Ellis, McLure, Dunlop, Robertson, Koekemoer, Bowler, Rogers, Schneider, Charlot, Stark, Shimasaku, Furlanetto, and Cirasuolo, "Evolution of the Sizes of Galaxies over $7 < z < 12$ Revealed by the 2012 Hubble Ultra Deep Field Campaign", *The Astrophysical Journal*, 777, pp. 155-2013
- Nakajima and Ouchi, "Ionization States of galaxies: Evolution, SFR-M_{star}-Z Dependence, and Ionizing Photon Escape", *ArXiv e-prints*, pp.arXiv: 1309.0207-2013
- Jiang, Egami, Fan, Windhorst, Cohen, Dav_e, Finlator, Kashikawa, Mechtley, Ouchi, and Shimasaku, "Physical Properties of Spectroscopically Confirmed Galaxies at $z \geq 6$. II. Morphology of the Rest-frame UV Continuum and Ly α Emission", *The Astrophysical Journal*, 773, pp.153-2013
- Jiang, Egami, Mechtley, Fan, Cohen, Windhorst, Dav_e, Finlator, Kashikawa, Ouchi, and Shimasaku, "Physical Properties of Spectroscopically Confirmed Galaxies at $z \geq 6$. I. Basic Characteristics of the Rest-frame UV Continuum and Ly α Emission", *The Astrophysical Journal*, 772, pp.99-2013
- Drake, Simpson, Collins, James, Baldry, Ouchi, Jarvis, Bonfield, Ono, Best, Dalton, Dunlop, McLure, and Smith, "Evolution of star formation in the UKIDSS Ultra Deep Survey field - I. Luminosity functions and cosmic star formation rate out to $z = 1.6$ ", *Monthly Notices of the Royal Astronomical Society*, 433, pp.796-811, 2013
- Dunlop, Rogers, McLure, Ellis, Robertson, Koekemoer, Dayal, Curtis-Lake, Wild, Charlot, Bowler, Schenker, Ouchi, Ono, Cirasuolo, Furlanetto, Stark, Targett, and Schneider, "The UV continua and inferred stellar populations of galaxies at $z \sim 7-9$ revealed by the Hubble Ultra-Deep Field 2012 campaign", *Monthly Notices of the Royal Astronomical Society*, 432, pp.3520-3533, 2013
- McLure, Dunlop, Bowler, Curtis-Lake, Schenker, Ellis, Robertson, Koekemoer, Rogers, Ono, Ouchi, Charlot, Wild, Stark, Furlanetto, Cirasuolo, and Targett, "A new multifield determination of the galaxy luminosity function at $z = 7-9$ incorporating the 2012 Hubble Ultra-Deep Field imaging", *Monthly Notices of the Royal Astronomical Society*, 432, pp.2696-2716, 2013
- Ashby, Willner, Fazio, Huang, Arendt, Barmby, Barro, Bell, Bouwens, Cattaneo, Croton, Dav_e, Dunlop, Egami, Faber, Finlator, Grogin, Guhathakurta, Hernquist, Hora, Illingworth, Kashinsky, Koekemoer, Koo, Labbe, Li, Lin, Moseley, Nandra, Newman, Noeske, Ouchi, Peth, Rigopoulou, Robertson, Sarajedini, Simard, Smith, Wang, Wechsler, Weiner, Wilson, Wuyts, Yamada, and Yan, "SEDS: The Spitzer Extended Deep Survey. Survey Design, Photometry, and Deep IRAC Source Counts", *The Astrophysical Journal*, 769, pp.80-2013
- Nakajima, Ouchi, Shimasaku, Hashimoto, Ono, and Lee, "First Spectroscopic Evidence for High Ionization State and Low Oxygen Abundance in Ly α Emitters", *The Astrophysical Journal*, 769, pp.3-2013
- Schenker, Robertson, Ellis, Ono, McLure, Dunlop, Koekemoer, Bowler, Ouchi, Curtis-Lake, Rogers, Schneider, Charlot, Stark, Furlanetto, and Cirasuolo, "The UV Luminosity Function of Star-forming Galaxies via Dropout Selection at Redshifts $z \sim 7$ and 8 from the 2012 Ultra Deep Field Campaign", *The Astrophysical Journal*, 768, pp.196-2013
- Robertson, Furlanetto, Schneider, Charlot, Ellis, Stark, McLure, Dunlop, Koekemoer, Schenker, Ouchi, Ono, Curtis-Lake, Rogers, Bowler, and Cirasuolo, "New Constraints on Cosmic Reionization from the 2012 Hubble Ultra Deep Field Campaign", *The Astrophysical Journal*, 768, pp.71-2013

まとめ

- 宇宙再電離過程と宇宙再電離源
- 大型光赤外線望遠鏡で宇宙再電離期 $z \sim 7$ を探る
 - $z \sim 7$ 銀河に見られるLy α damping wing吸収
 - 再電離過程 (+再電離源)
- 広領域Hyper Suprime-Cam探査の準備
 - NB921フィルター完成。14編の論文 (準備研究の結果)
 - 2種類目のフィルター作成中