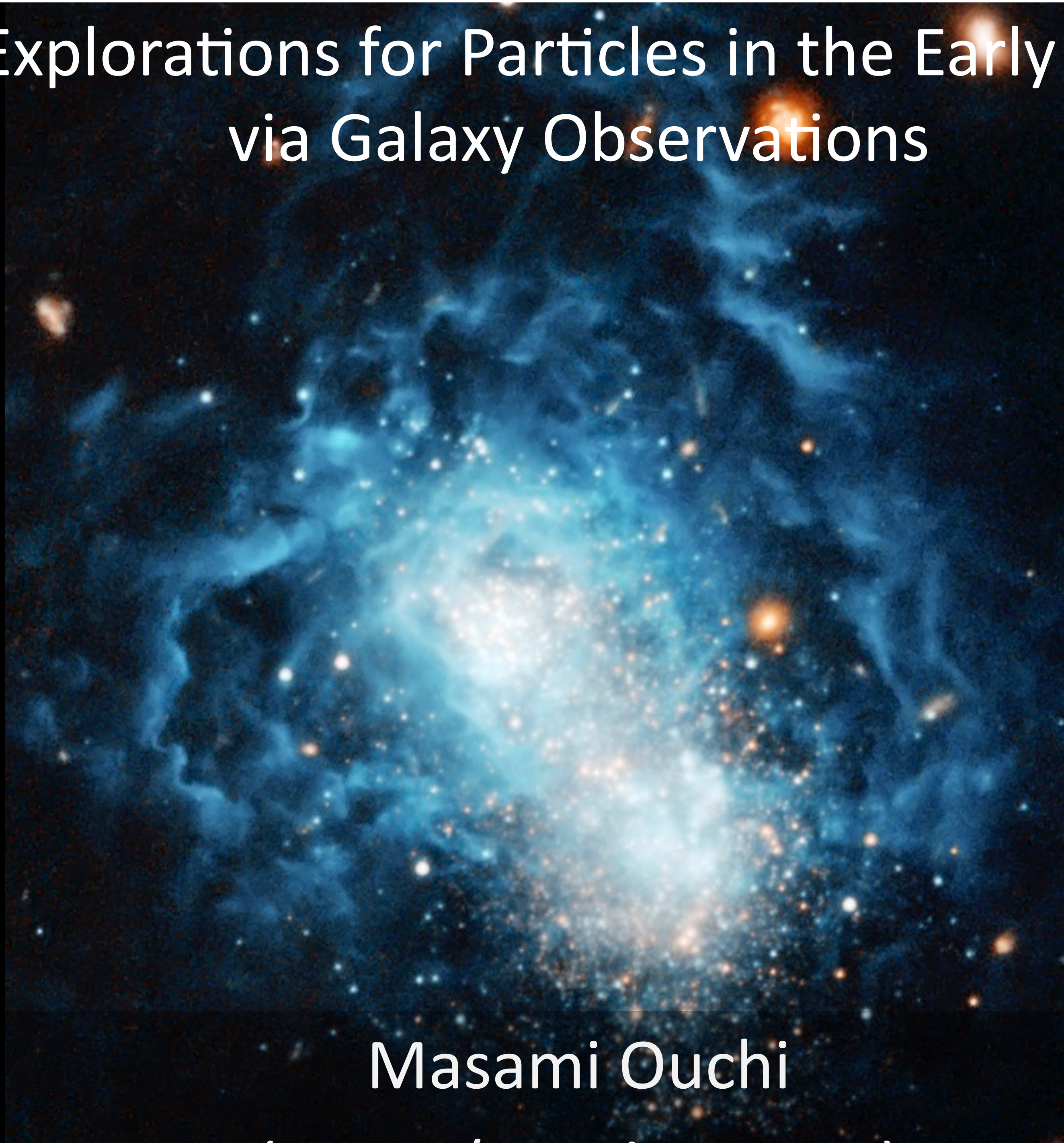
New Explorations for Particles in the Early Universe via Galaxy Observations

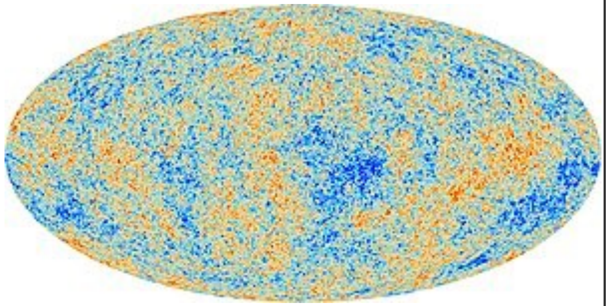


Masami Ouchi

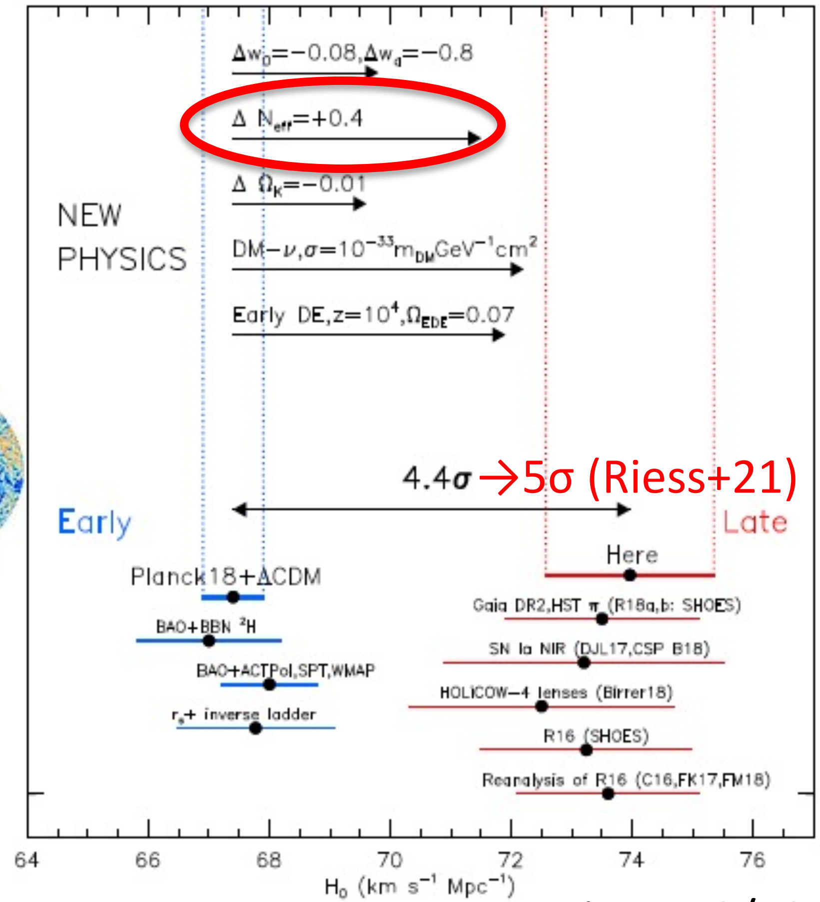
(NAOJ / U.Tokyo ICRR)

Hubble Tension Puzzle and Primordial He Abundance

z=1100
Cosmic Microwave Background(CMB)



Planck Collaboration



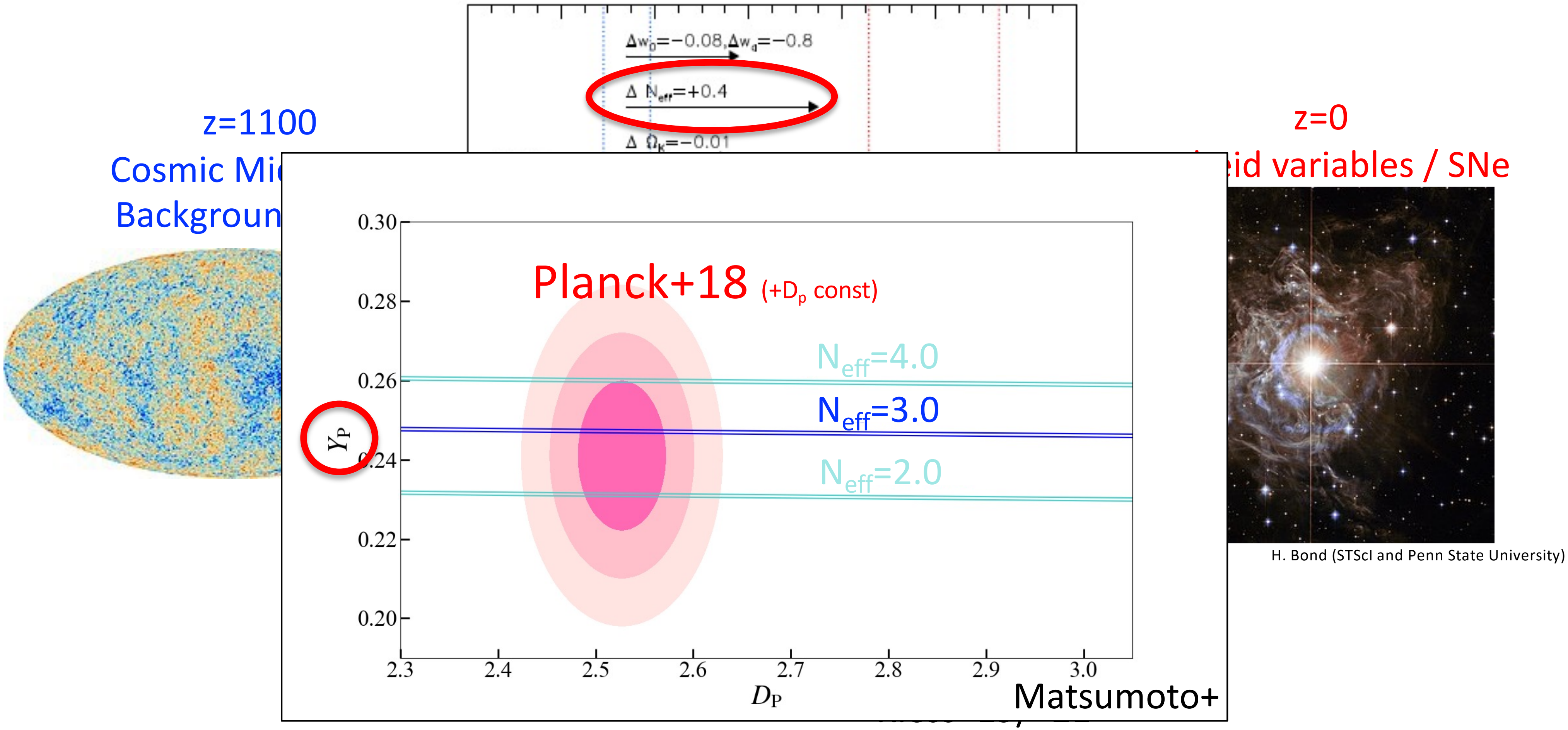
Riess+19/+21

z=0
Cepheid variables / SNe

H. Bond (STScI and Penn State University)

- Puzzling Hubble Tension
  - H_0=67.4±0.5 (CMB; Planck+18) vs. 73.0±1.0 (Cephid/SNeIa) in km/s/Mpc
  - Scenario: effective number of neutrino, N_{eff}, higher than standard value N_{eff}=3.046 (by ΔN_{eff} ~0.4)?
  - N_{eff} has not been determined in laboratory. N_{eff} is sensitive to primordial He (D) abundance, Y_p and D_p.
- Present constraint w primordial He Y_p (Planck+18) & deuterium D_p (QSO abs sys) → ΔNeff ~ 1

Hubble Tension Puzzle and Primordial He Abundance



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Determining
Primordial He Abundance Y_p

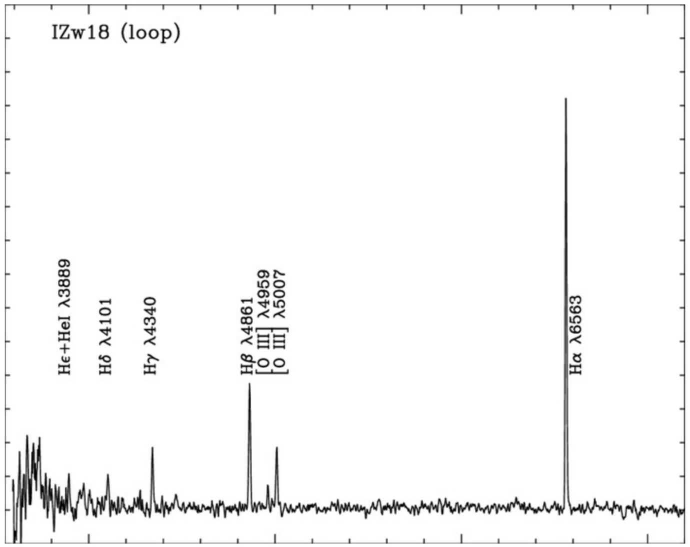
- Unlike primordial D or Li determinations,
  - Detectable He lines: neither in inter-galactic medium (IGM) nor stars

- Y_p determination →He emission lines from ionized gas in galaxies
  - especially extremely metal poor galaxies (EMPGs) whose gas is nearly primordial

- Observing EMPGs, i.e. primordial galaxies.

  →Y_p determination

  Needing characterizing EMPGs (also useful for galaxy formation in their early phase)



EMPG Obs Projects

Extremely Metal-poor Representatives Explored by the Subaru Survey (EMPRESS)

- EMPRESS
  - Subaru HSC/SSP deep&wide imaging
  - Subaru/FOCAS and Keck/LRIS,DEIMOS opt follow-up spec.

  → EMPG search and characterization

- EMPRESS HRS
  - Magellan MagE Spec (Rauch et al.)
  - Deep mid-high resolution spec

  → Velocity disp, outflows, and blue lines

- EMPRESS 3D (Subaru intensive; 2021-)
  - Subaru FOCAS/IFU 3Dspec
  - Subaru IRCS+SWIMS near-infrared spec

  → Primordial He, dynamics, 3D struc.

Subaru Telescope

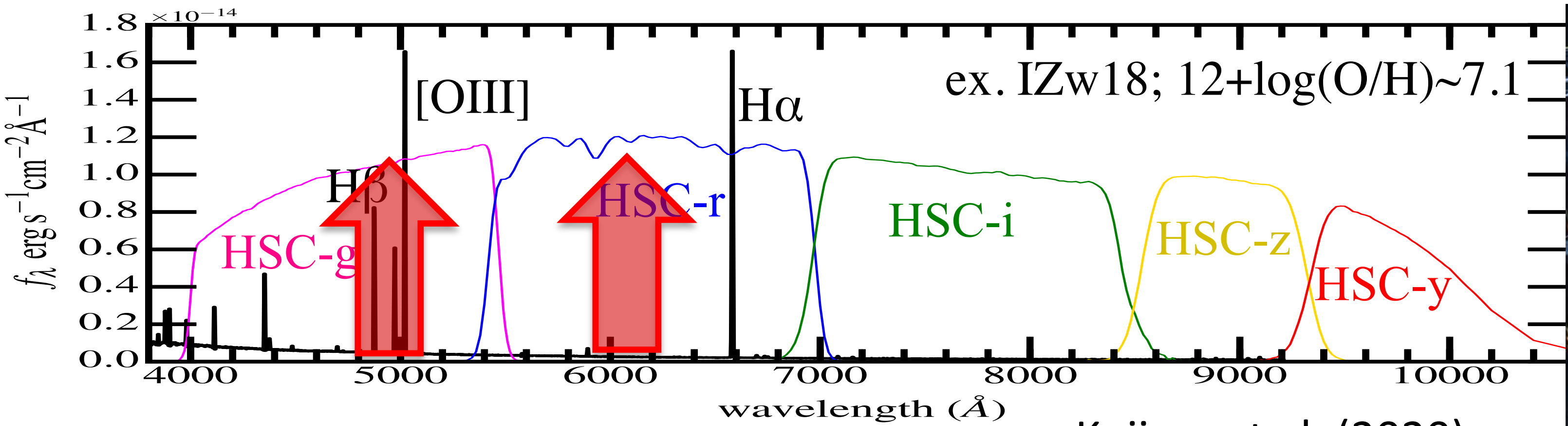
Keck Telescope

https://www.photonics.com/Articles/New_Laser_on_Keck_II_Telescope_Inspires/a47411

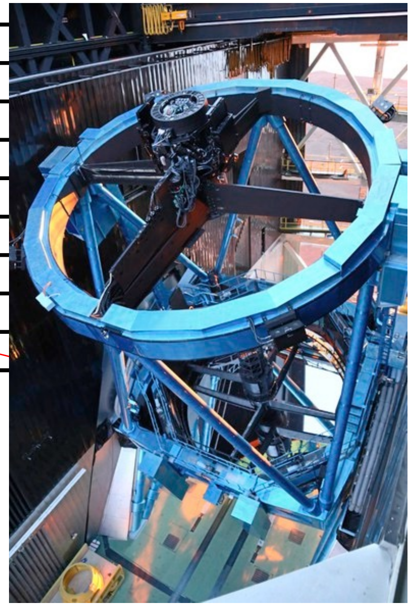
Magellan Tel.

https://obs.carnegiescience.edu/Magellan

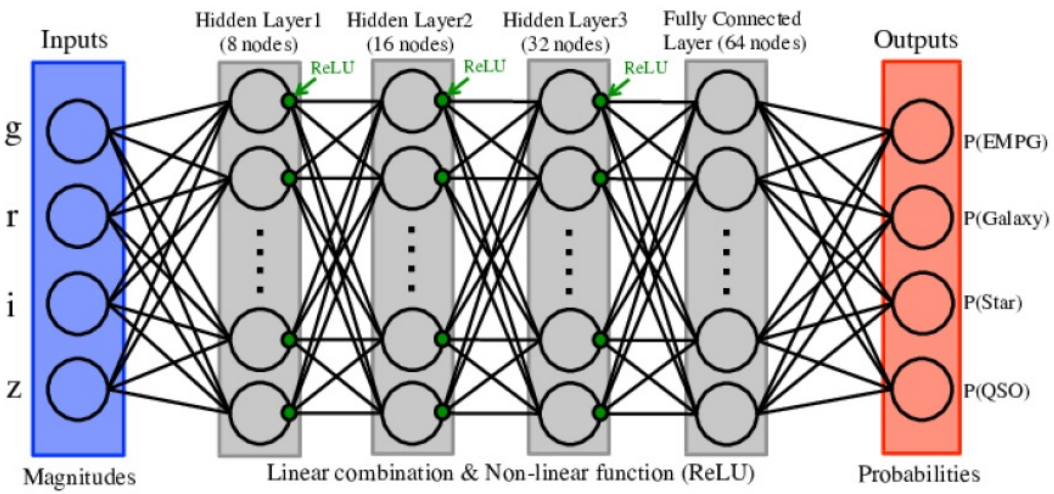
EMPG Search (EMPRESS)



Kojima et al. (2020)



+ Machine learning (ML) technique

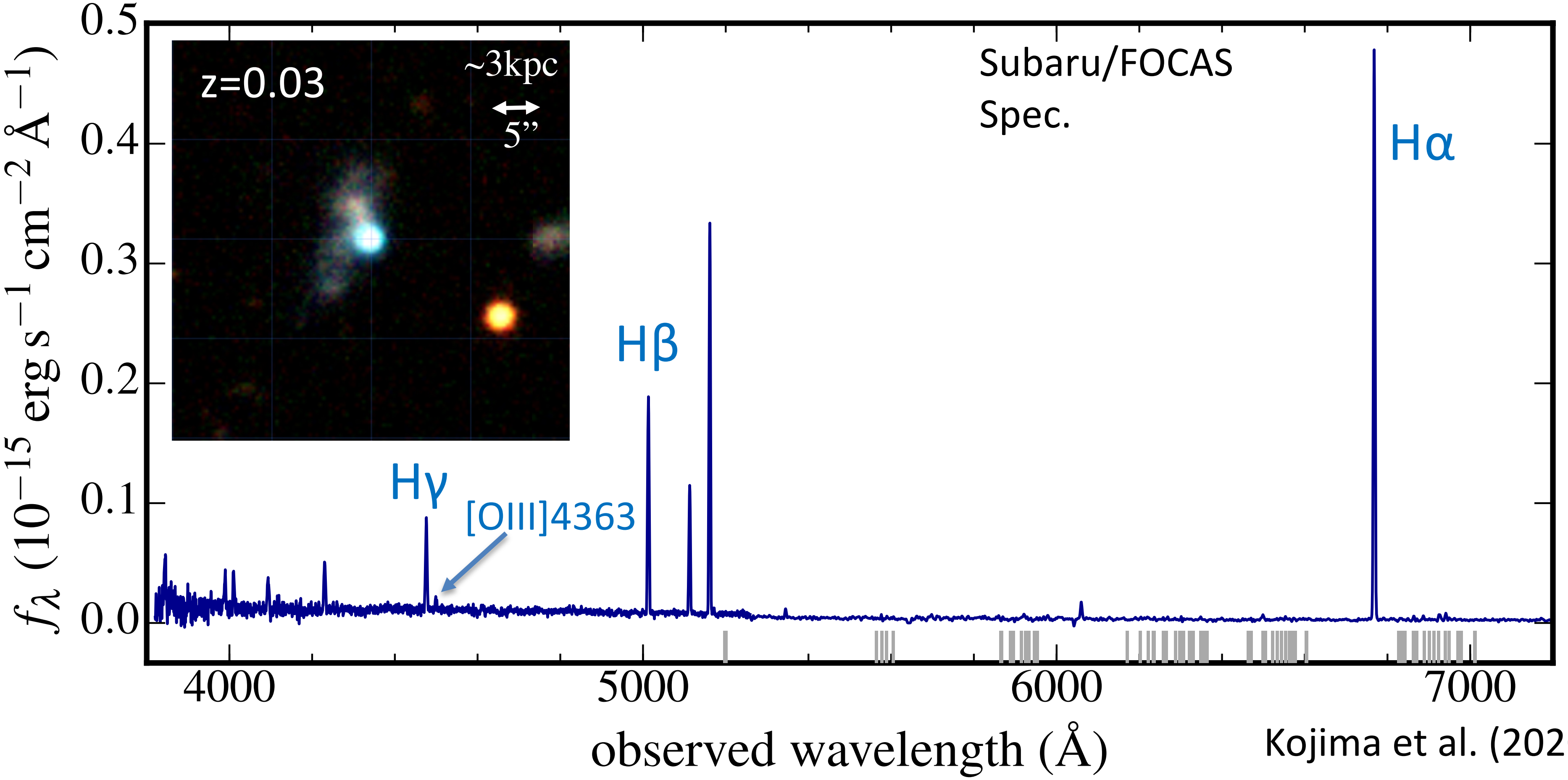


SED models (30,000 × 4)

Beagle	Chevallard & Charlot 2016
Stellar model	Castelli & Kurucz 2004
QSO composite	Selsing et al. 2016

Follow-up Spectroscopy

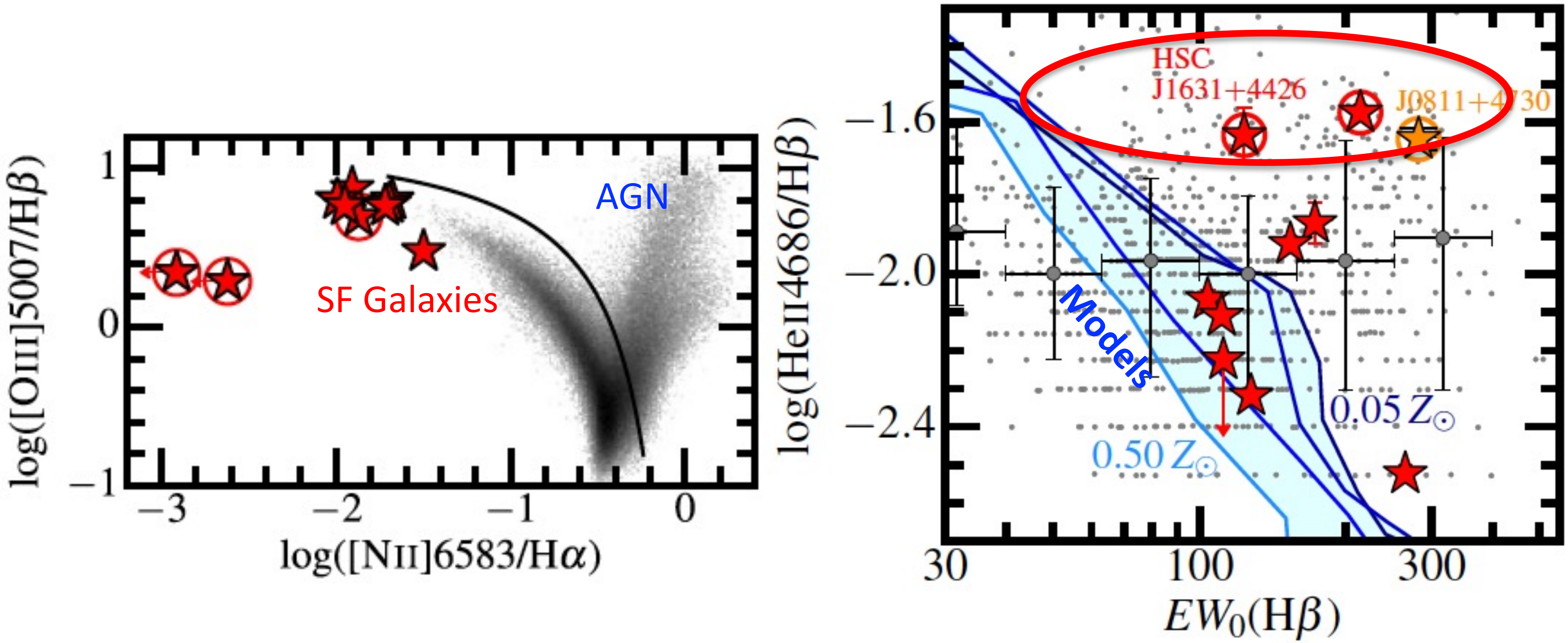
EMPG (HSC J1631+4426)



Kojima et al. (2020)

- So far, ~20 new EMPGs down to $M^*=5 \times 10^4$ Mo are successfully identified
  - New ML methods (Light GBM; Nishigaki et al. in prep.)
  - See 4 papers (Kojima+20, 21, Isobe+21, 22)

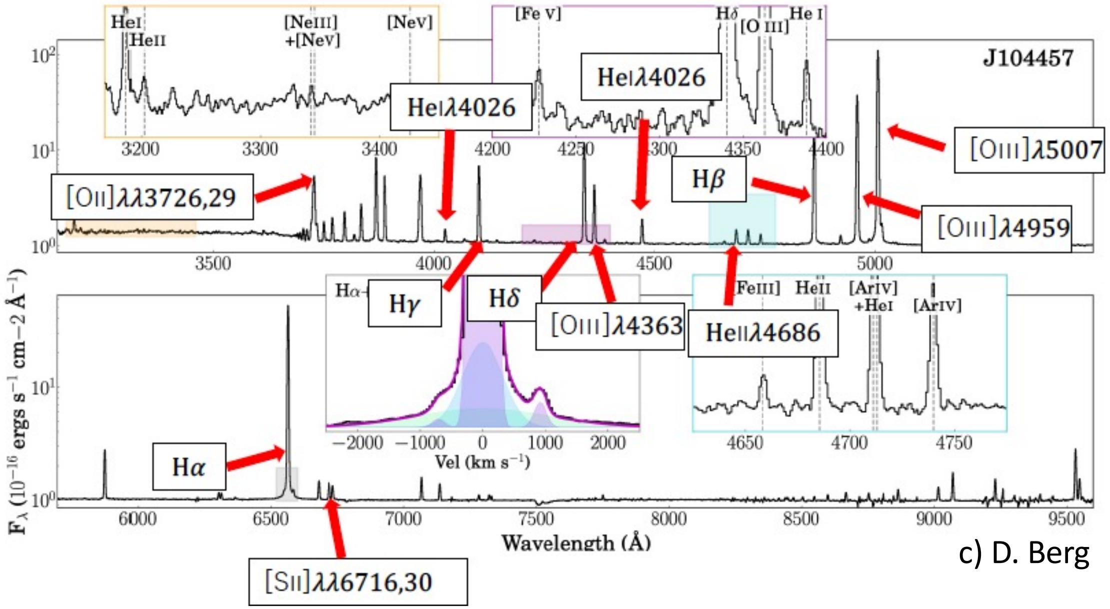
Strong High Ionization (HeII) Lines



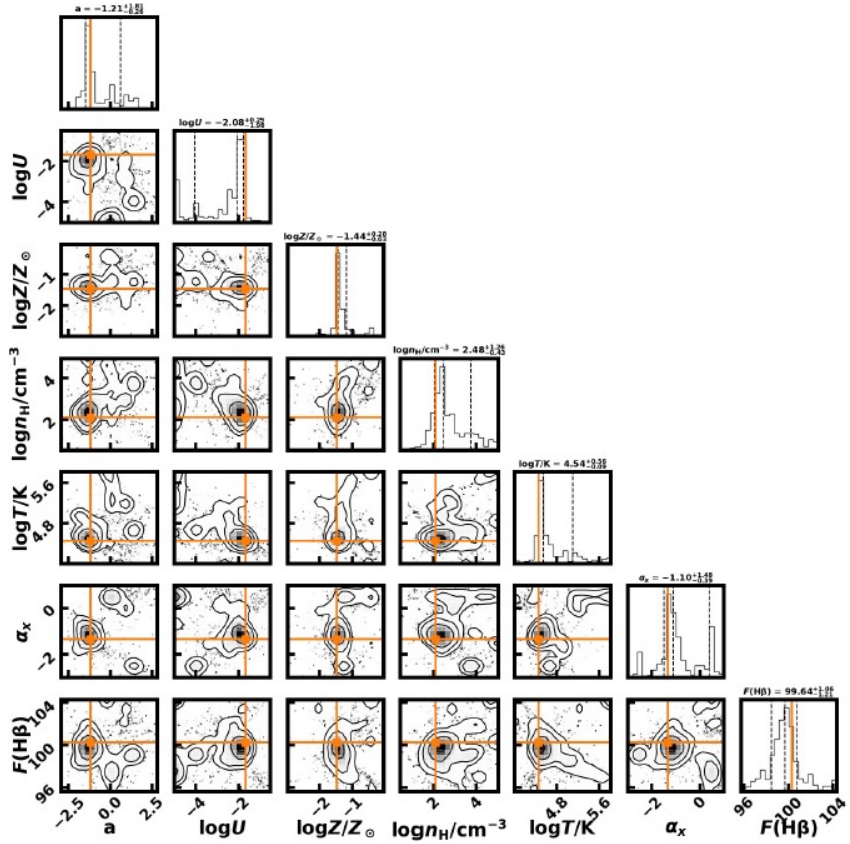
Kojima et al. (2020,21)

- No clear signatures of AGN, but
  too strong HeII4686 (54.4eV) against H (13.6eV)
- What is the ionizing source?
- Ionizing spectra are absorbed and cannot be directly observed.

Too Strong HeII (54eV) Line
Origins of High Energy Photons?



c) D. Berg



Umeda et al. 2022

- Unobserved spec (200-900A) → ~10 emission + MCMC (CLOUDY models): 7 parameters (spec shape +Z, U, n_H,Q)
- Power law needed -> Non stellar sources should exist.
- Diversity in shape: Very young stellar ages only ~2-6 Myr
  -> Small age differences can make the diversity

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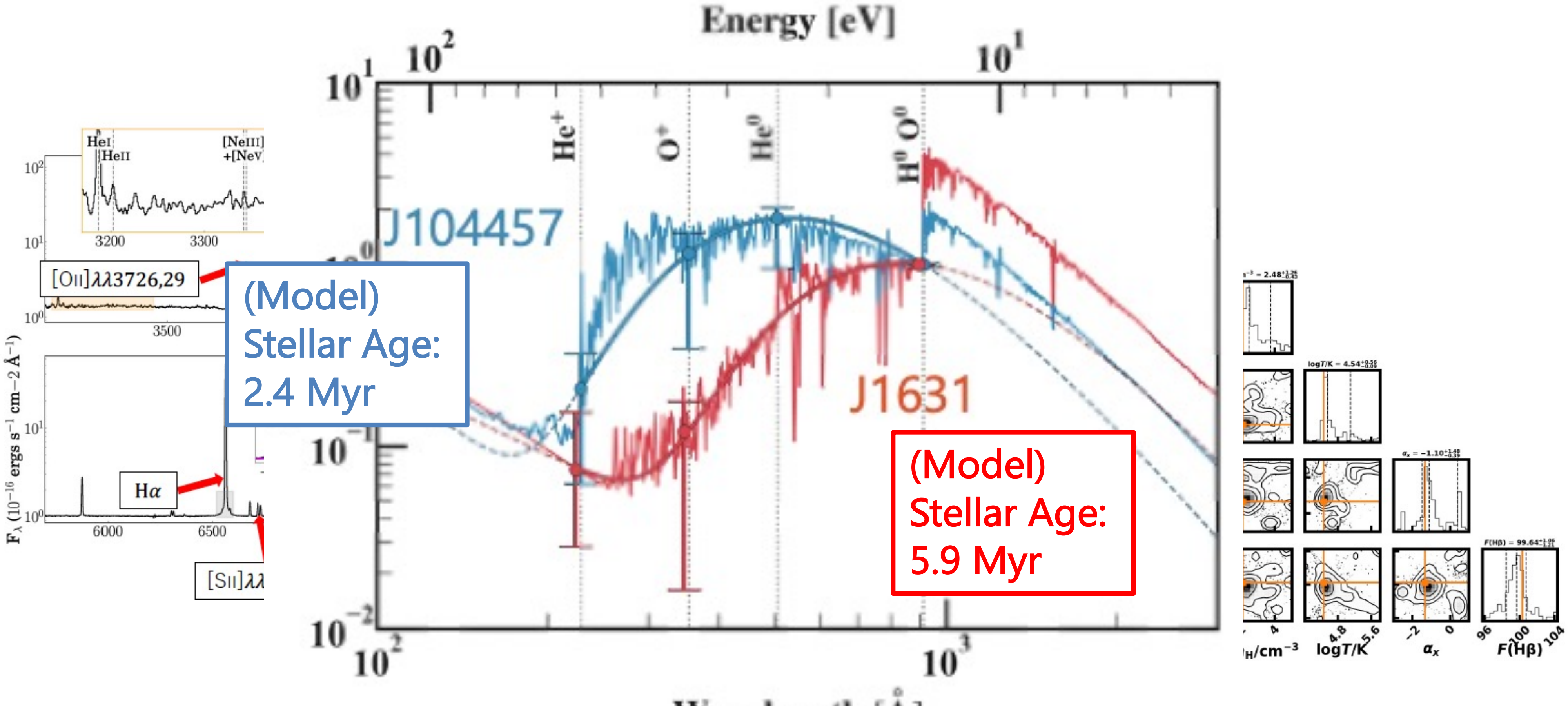

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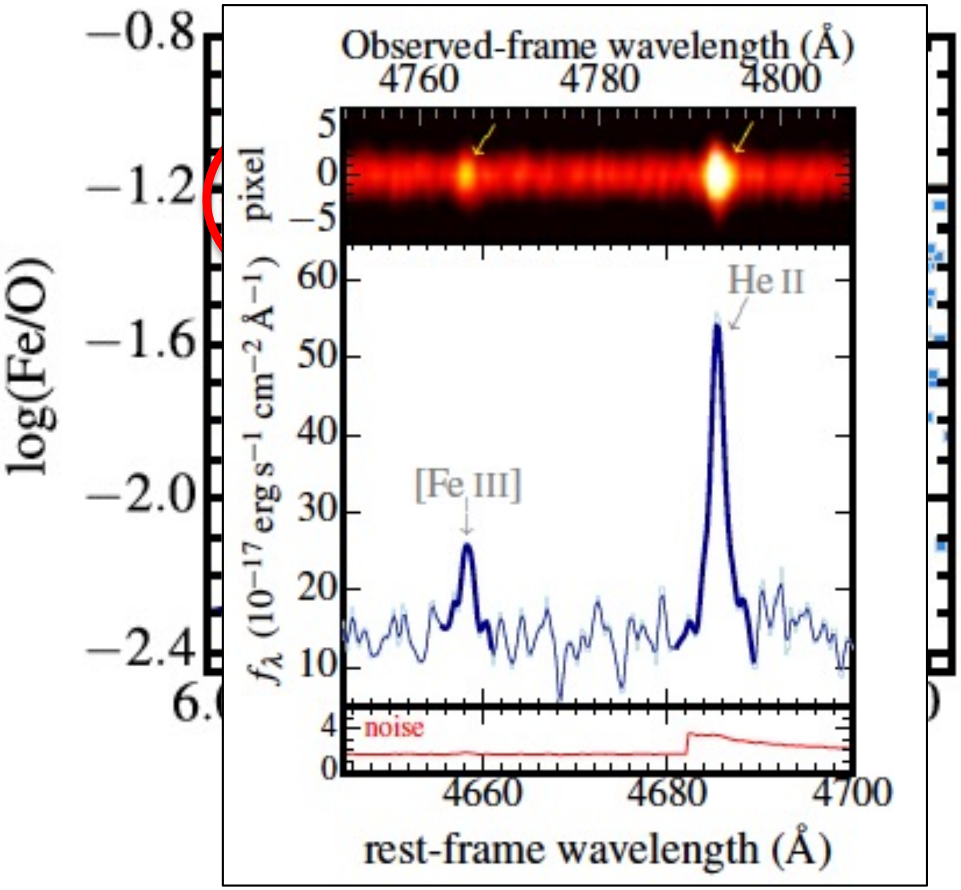
Interesting Spectral Features



Kojima et al. (2021)

- Excessive Fe abundance (Fe/O) ~ 1.0 (Fe/O)sun
- Type Ia supernovae (SNeIa)? → Too young (≲10Myr)

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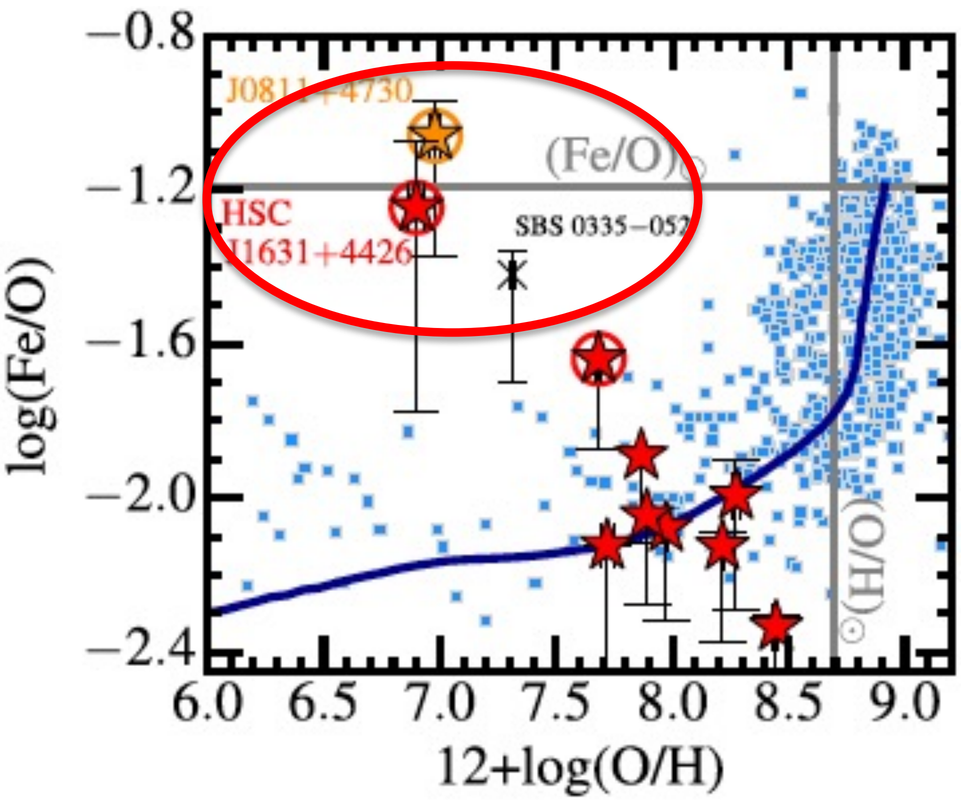

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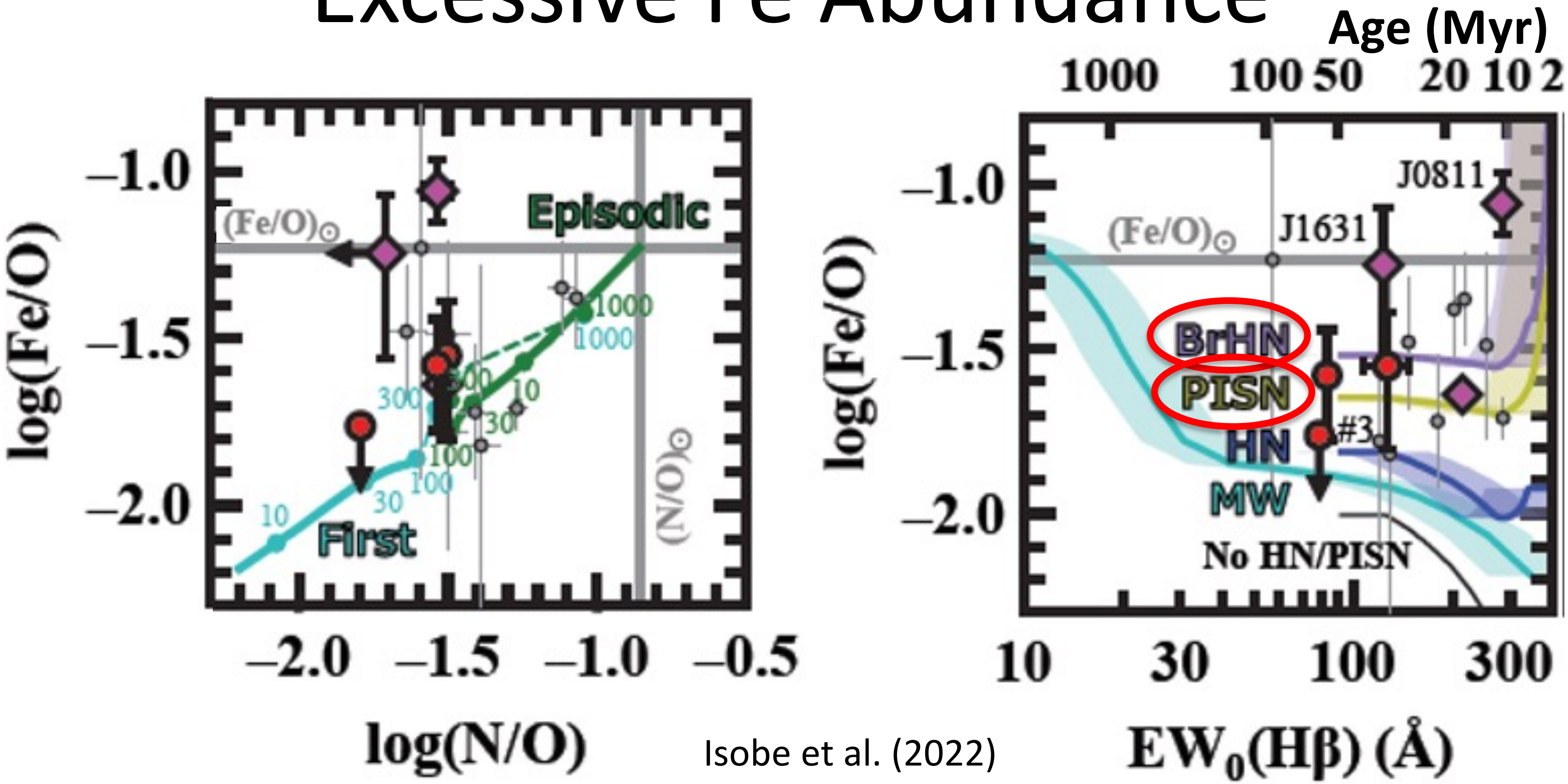
Excessive Fe Abundance



Isobe et al. (2022)

- High (Fe/O) ~ (Fe/O)sun
  - Young, but episodic SF w past SNIa?-> Don't explain 2 EMPGs by low (N/O)
  - Dust depletion cannot explain it.
  - Why? Pair-instability SNe (PISNe) or bright hypernovae (HNe) enrichment dominated?

Near Infrared Spectroscopy for Y_p Determination

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  - → Dynamics, 3D struc., and primordial He

Subaru Telescope

Keck Telescope

https://www.photonics.com/Articles/New_Laser_on_Keck_II_Telescope_Inspires/a47411

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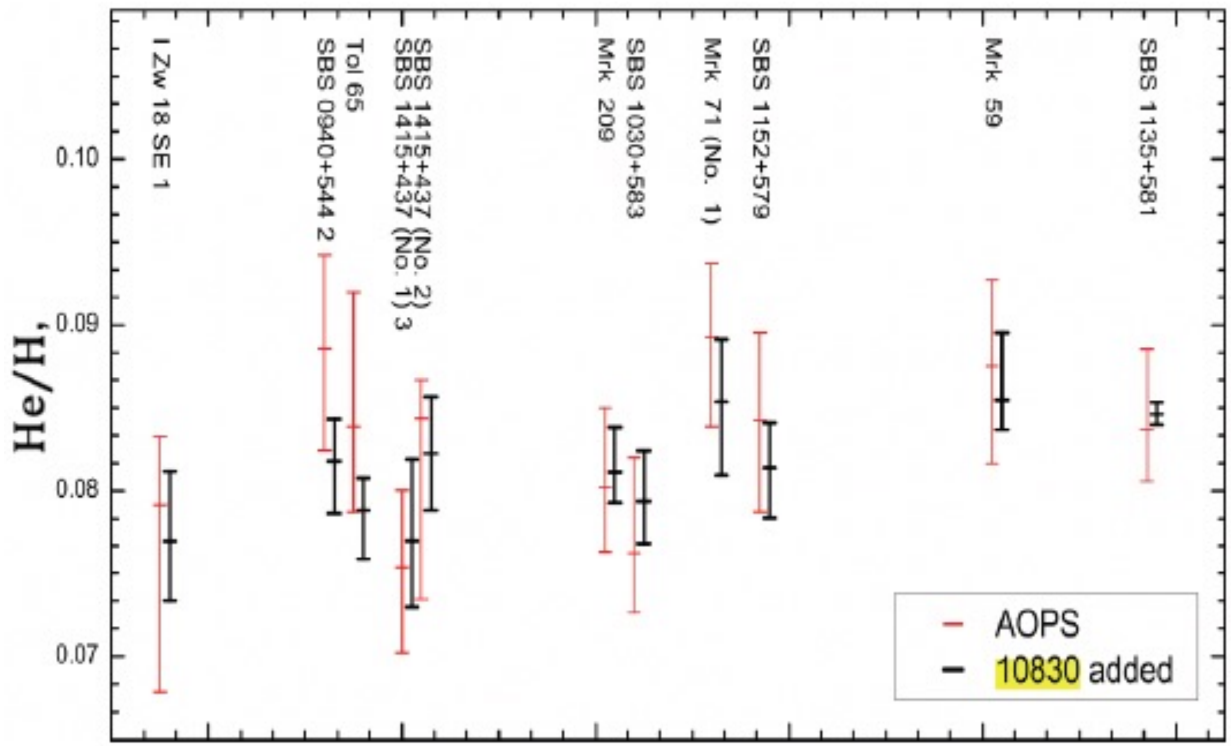
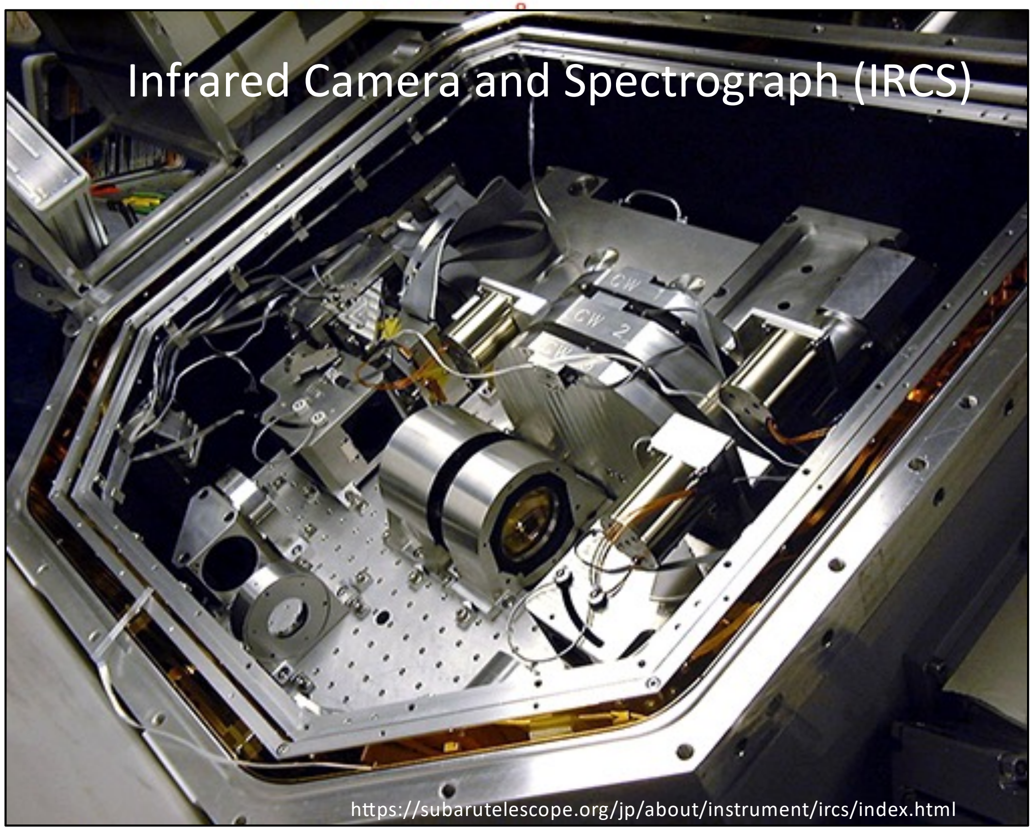
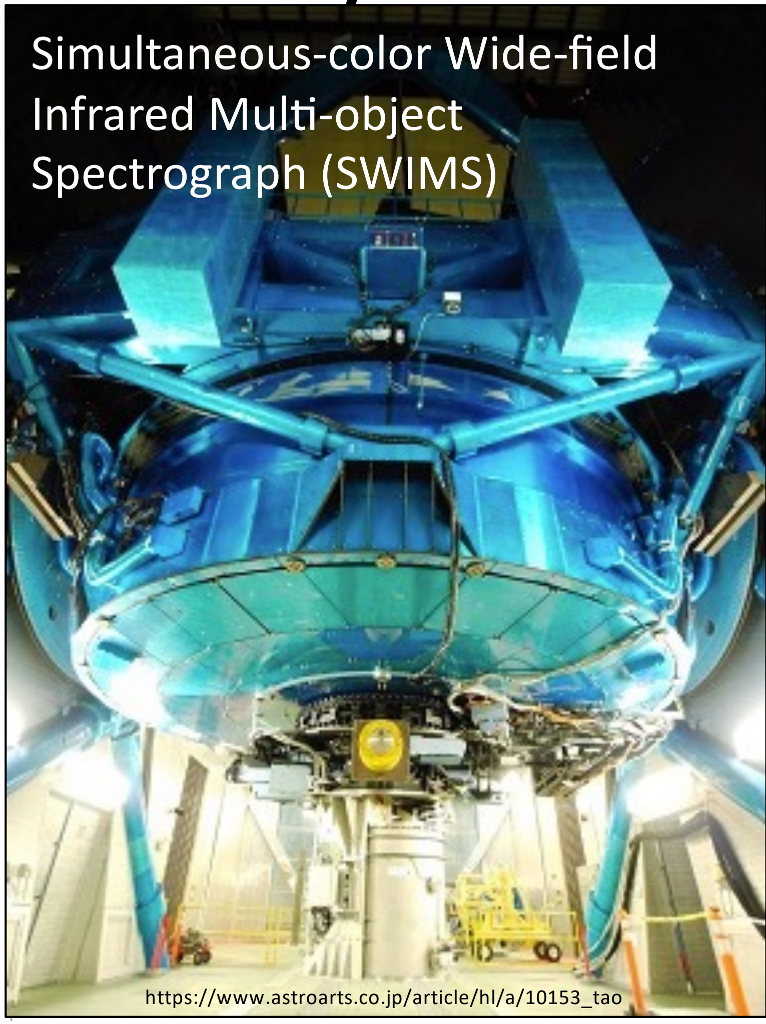
Primordial He Abundance Y_p



- Uncertainty of gas density is a major error sources for He/H
- Resoving problems of density uncertainties w near-infrared HeI10830 lines (evaluating amount of collisional de-excitation)

He Abundance: Analyses


Infrared Camera and Spectrograph (IRCS)
https://subarutelescope.org/jp/about/instrument/ircs/index.html


Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS)
https://www.astroarts.co.jp/article/hl/a/10153_tao

- NIR spec. w IRCS+SWIMS
  – Quadrupling the number of EMPGs (3→13 EMPGs)
- MCMC fitting w 14 hydrogen and He lines
  – 8 nebular param incl. He abundance

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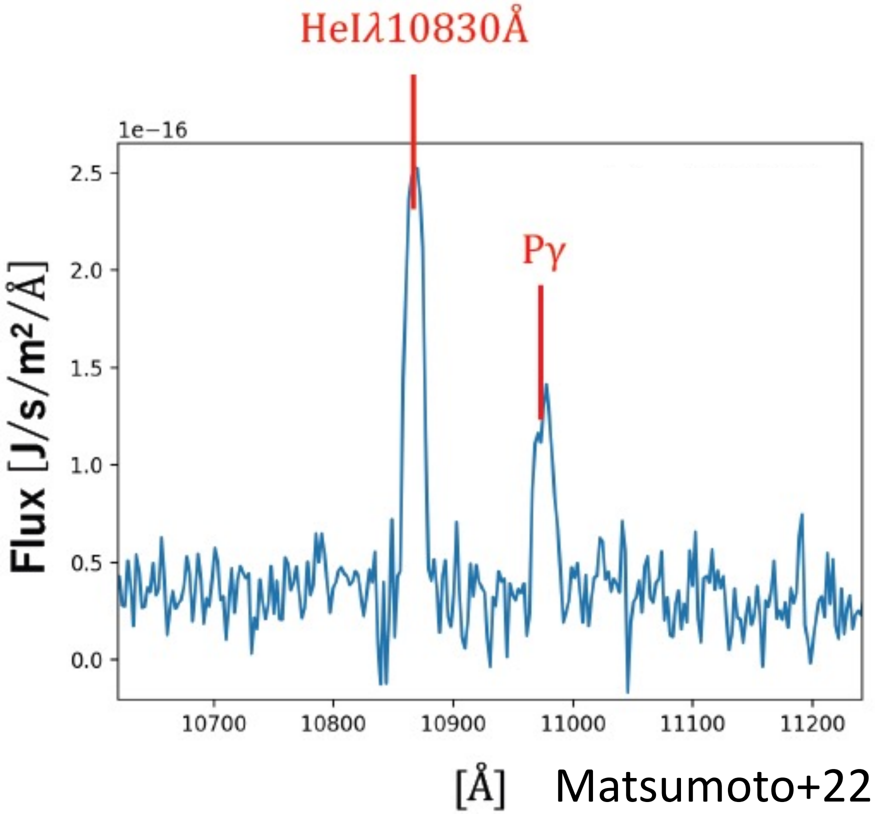

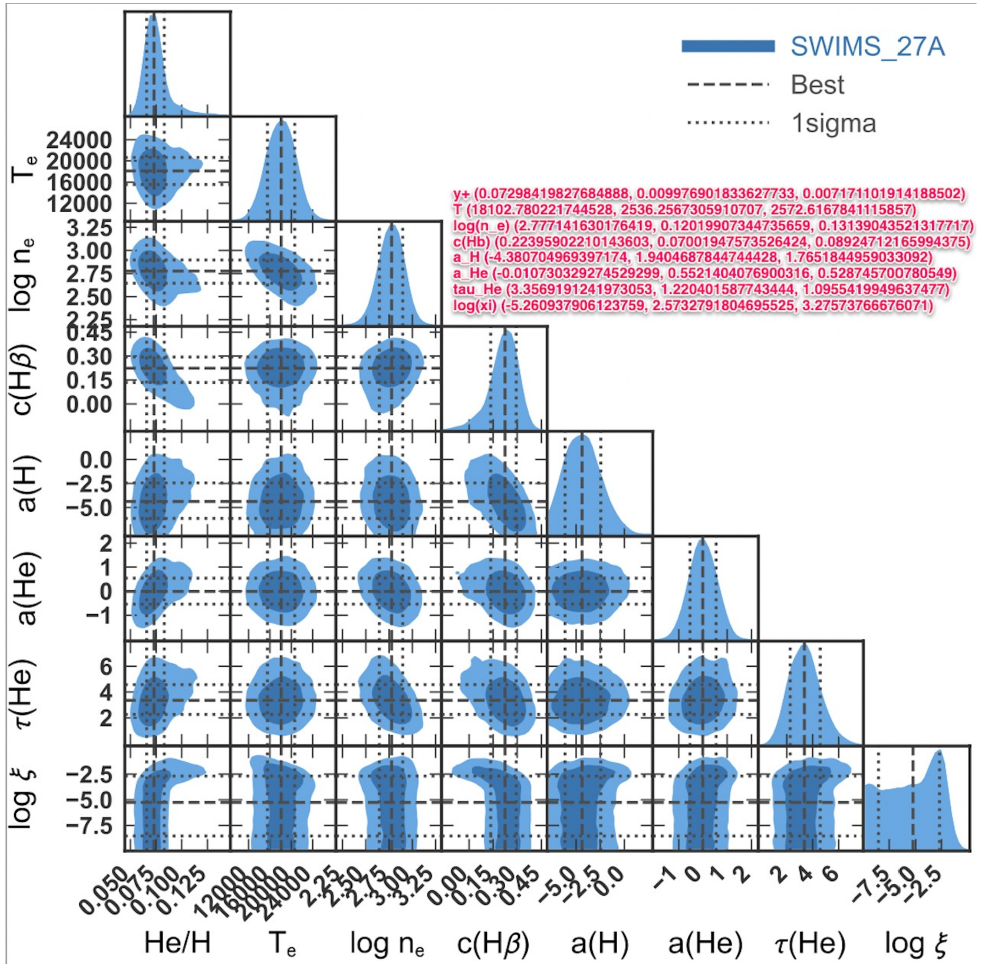

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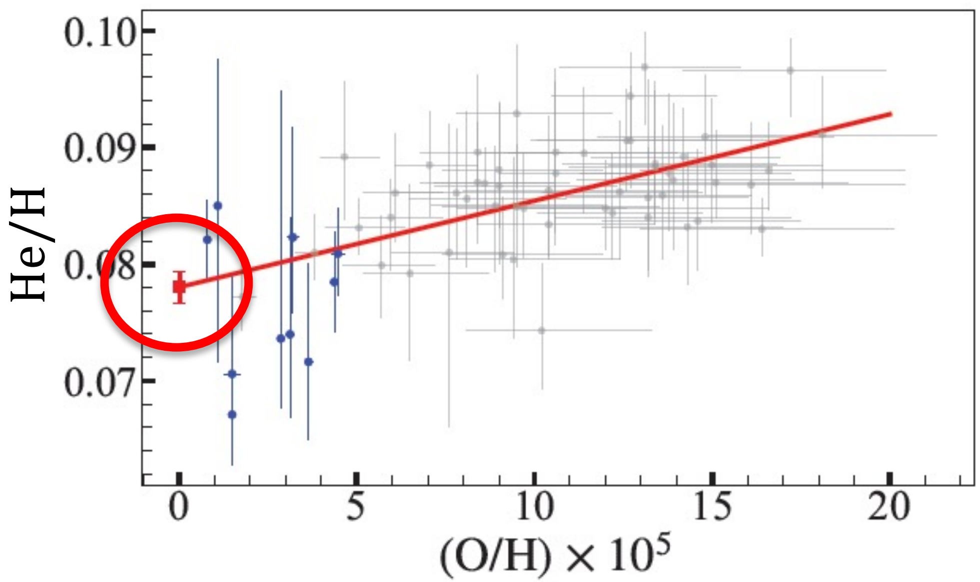
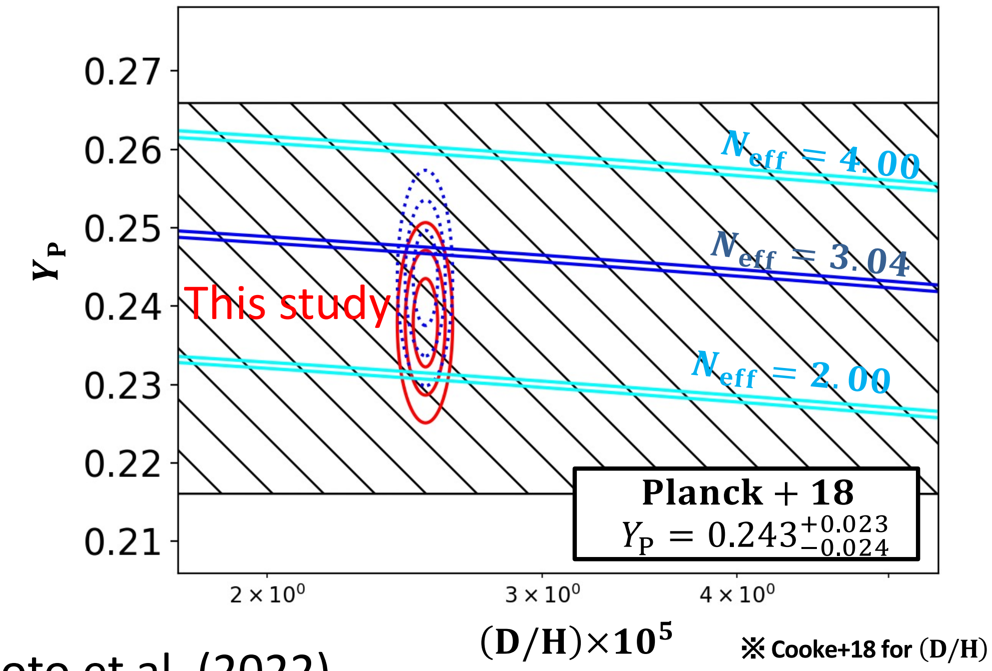
Y_p Determination

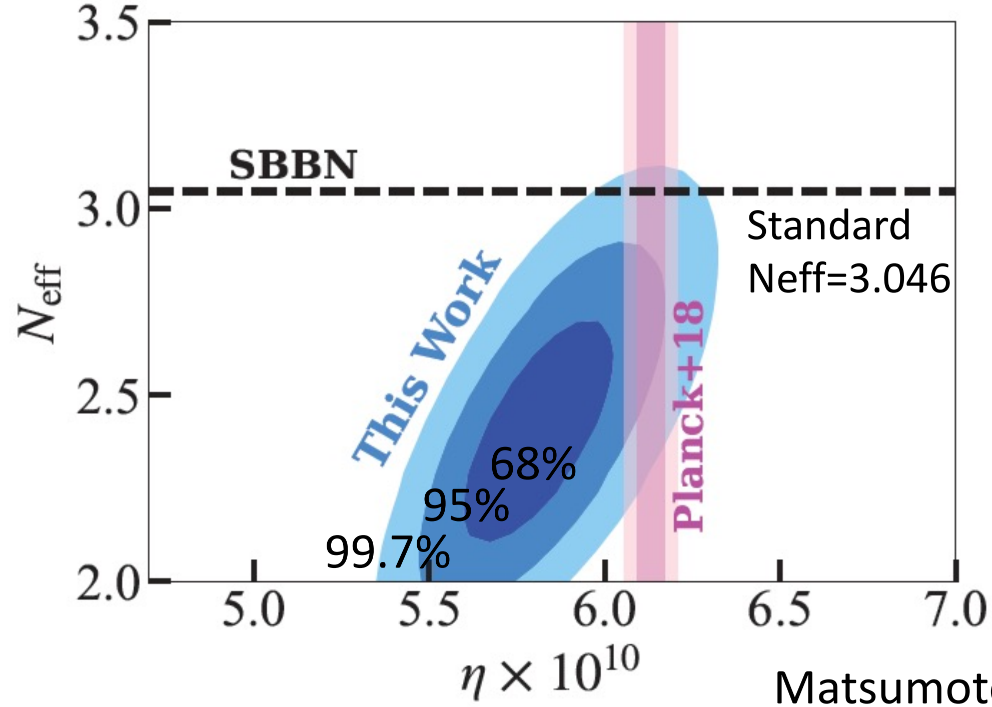


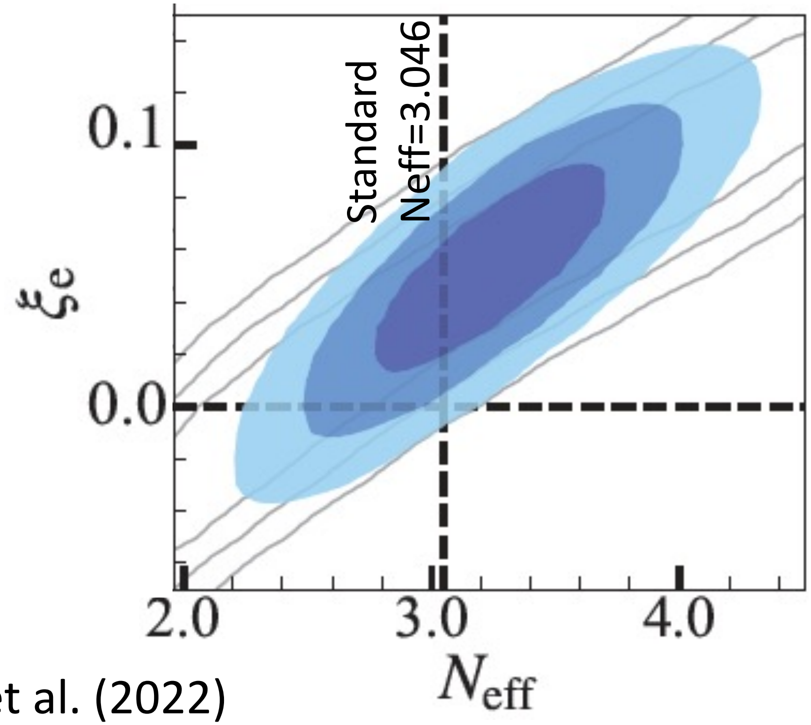


Matsumoto et al. (2022)

- He/H=0.078±0.0013 -> Y_p = 0.2379+0.0031/-0.0030
- Consistent with Planck+18 (+ prev. Y_p), but significantly better than the one of Planck+18
- Relatively small Y_p

Tension with Standard Model? Or Non-Zero Lepton Asymmetry?

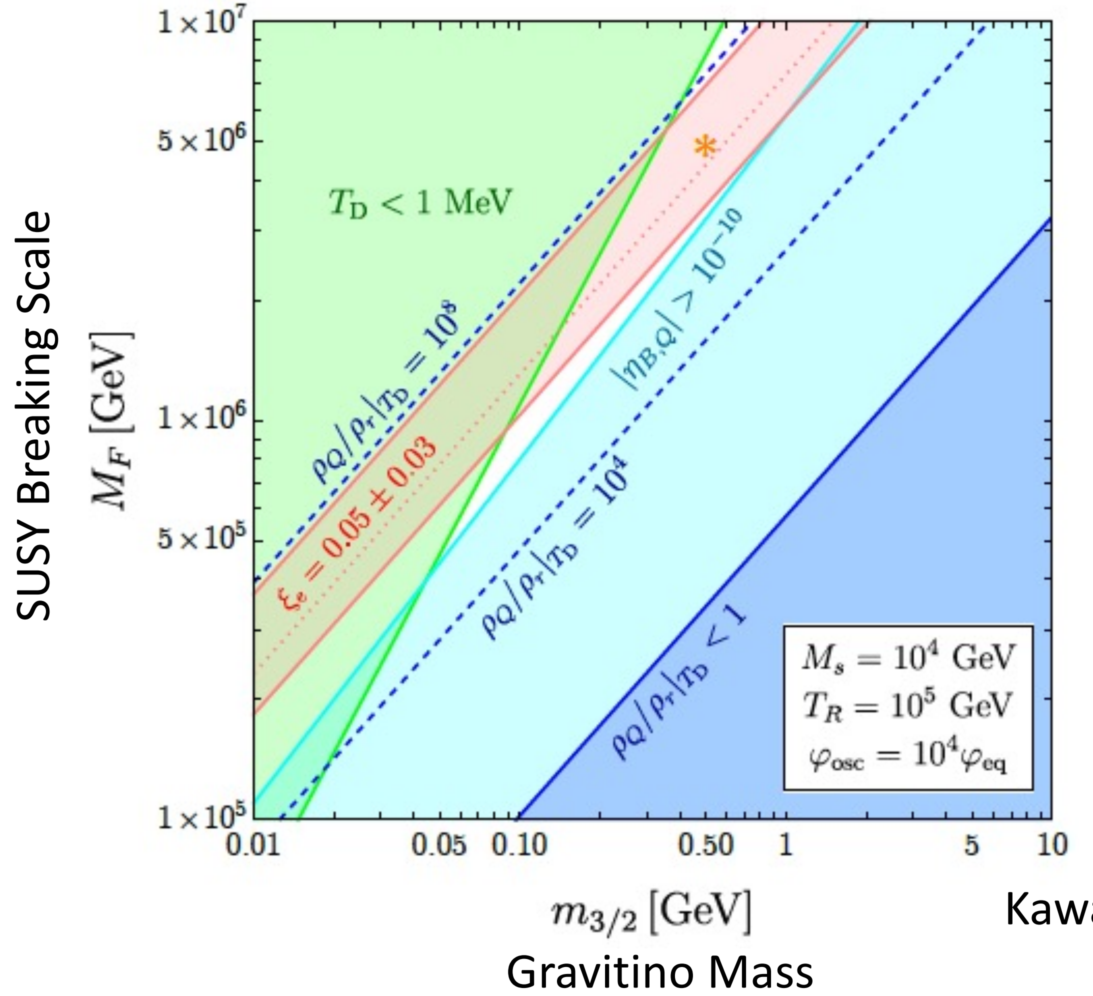




Matsumoto et al. (2022)

- Relatively small N_{eff}. Tension with standard model (N_{eff}=3.046)?
- Introducing Lepton asymmetry
  - Lepton asymmetry ξ_e>0 (2σ), while N_{eff} is as large as N_{eff}~3.5
    → explaining the Hubble tension?

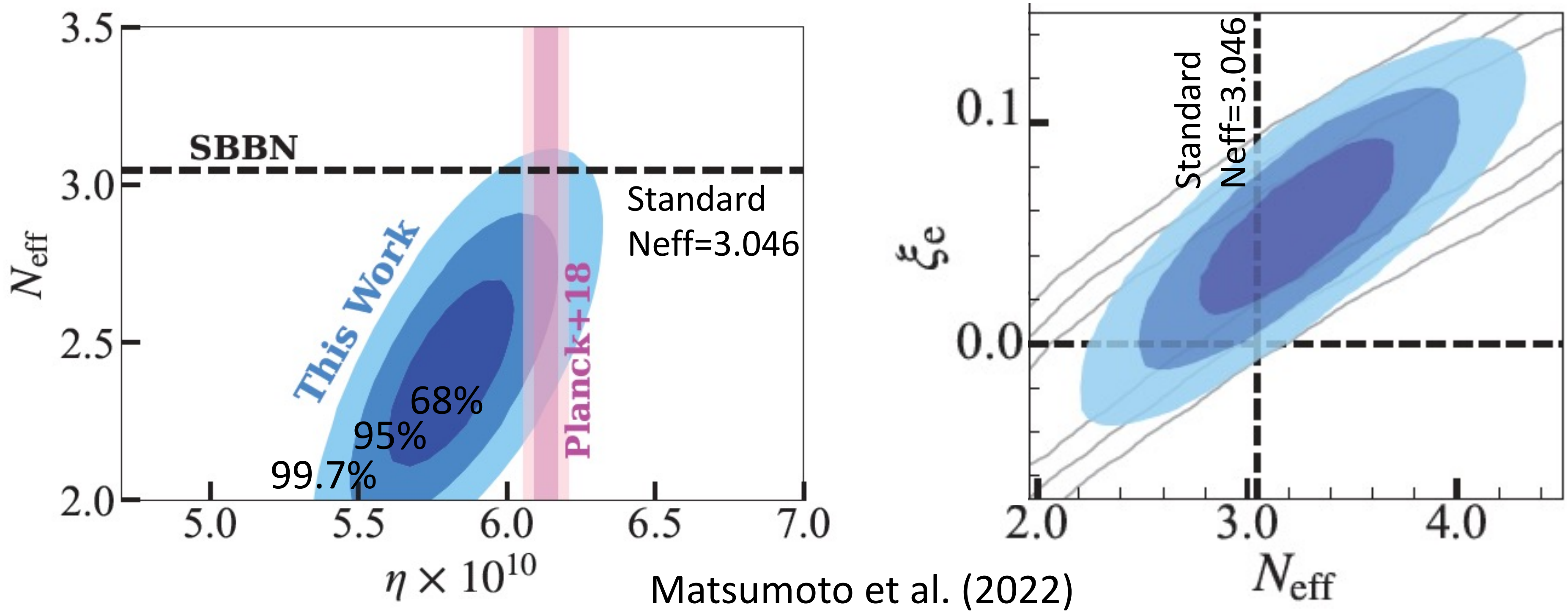
How Can the Large $\xi_e \sim 0.05$ Be Explained?



Kawasaki & Murai (2022)

- In the Affleck-Dine (AD) mechanism for lepton number generation
- Non-topological solitons (L-balls) are produced
  - Lepton number is confined in the L-balls → Large lepton number
- Is the large lepton number allowed under the other constraints?
  - L-ball decay temperature and fine-tuning

Tension with Standard Model? Or Non-Zero Lepton Asymmetry?



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    → explaining the Hubble tension?

Summary

- Recent progresses on primordial He abundance determination by galaxy observations

- EMPRESS: By Subaru imaging/spec and Keck+Magellan spec.
  - Searching for EMPGs with deep-wide Subaru images
    - ~20 new EMPGs incl. the most metal poor galaxy Z=0.016 Zo (HSC J1631+4426)
  - Too strong HeII (high ionization) emission
    - Hidden non-thermal source. Diversity of ionization spectrum explained by stellar ages
  - Excessive Fe abundance in EMPGs by spectroscopy
    - Signatuers of PISNe (or bright HNe)?
  - Moderately small primordial He abundance: Y_p=0.2379+0.0031/-0.0030
    - ~2σ tension with the standard cosmology (Neff=3.046)? Lepton asymmetry??

EMPRESS project continues. Stay Tuned!!