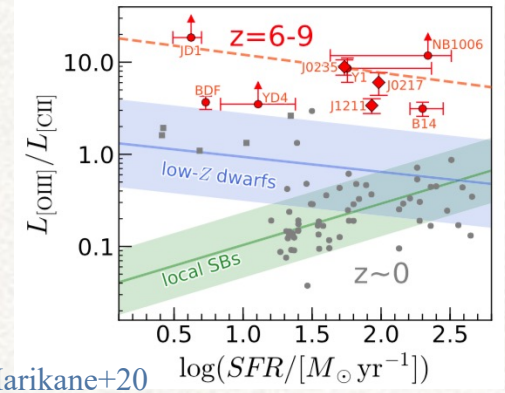
Relation between BPT and FIR Diagrams in Photo-ionization Modeling

Yuma Sugahara 菅原悠馬 (NAOJ / 早稲田)

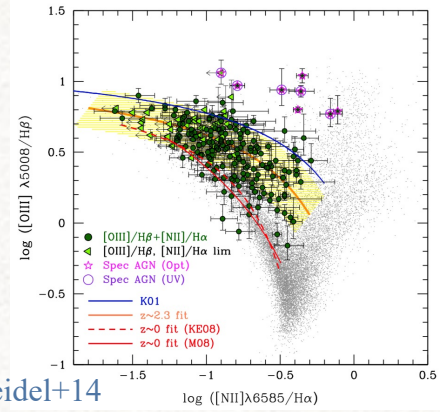
Collaborators:
井上昭雄, 札本佳伸 (早稲田), 橋本拓也 (筑波), 山中郷史 (鳥羽商船)

Aim of This Study

- Backgrounds
  - ALMA [OIII] 88 & [CII] 158 μm lines at high-z
  - Optical lines at z ~ 0–2
  - Both opt. & FIR observations for local galaxies

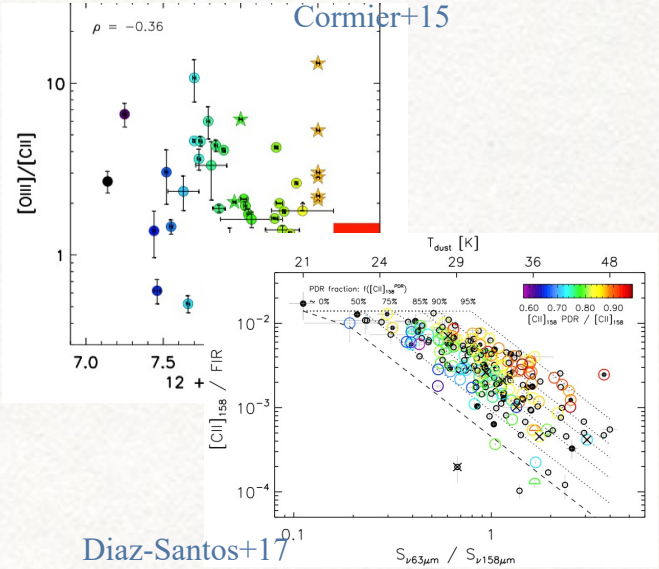


Harikane+20



Steidel+14

Cormier+15

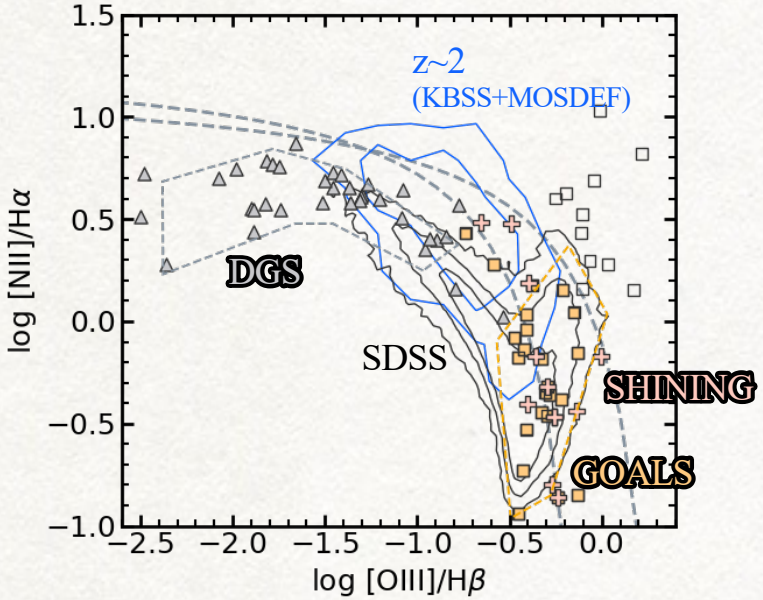


Diaz-Santos+17

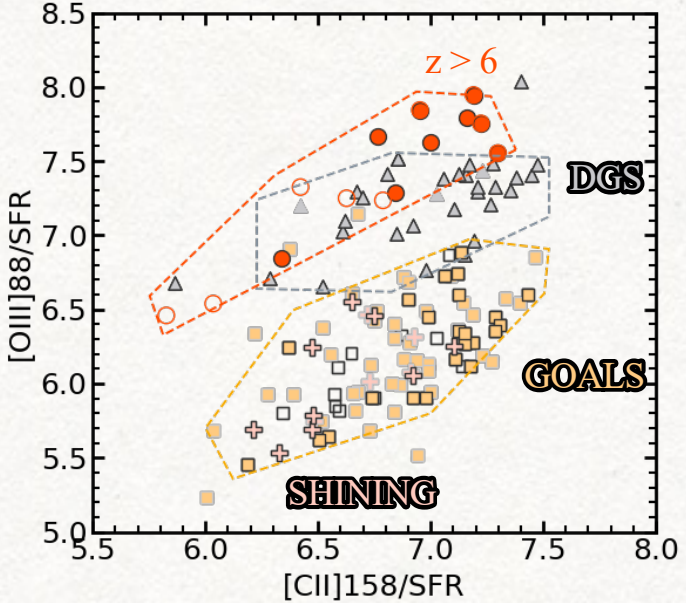
Are there any simple models to explain optical and FIR line ratios?

Observational Datasets in Literature

- BPT diagram



- FIR [OIII]/SFR-[CII]/SFR diagram



Are there any simple models to explain BPT and FIR diagrams?

Cloudy Model

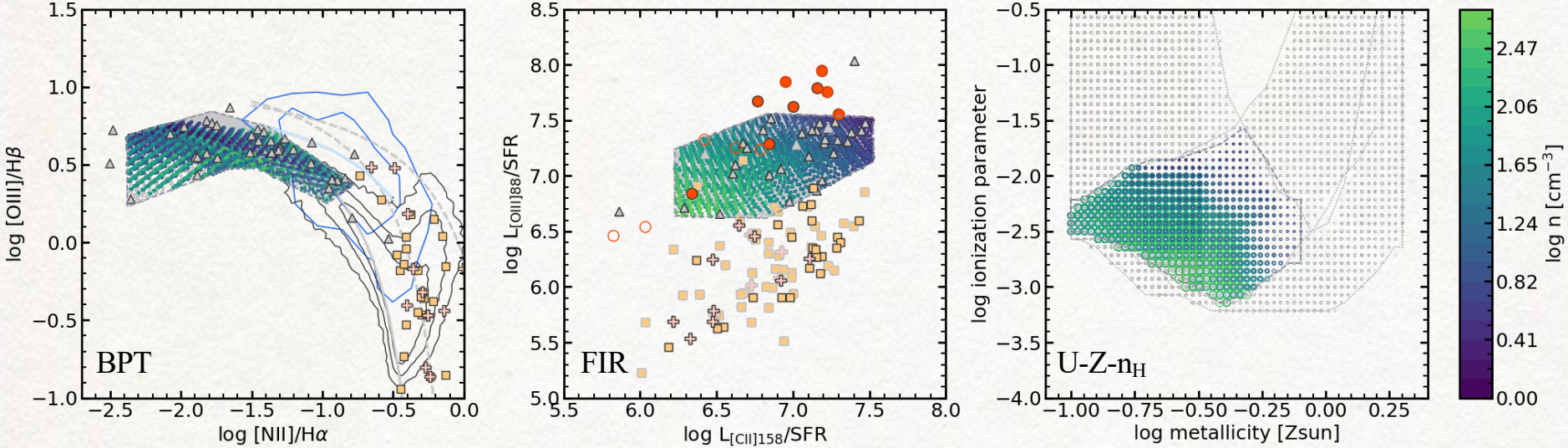
- Photo-ionization code: CLOUDY v17.01
- Fiducial model
  - plane-parallel geometry
  - constant pressure
  - SB99 1Myr; SB99/BPASS cst. 10 Myr
  - $Z_* = Z_{gas}$
  - local N/O abundance relation
  - Solar C/O abundance ratio
  - PDR covering fraction = 1
  - output SFR $\propto$ Hα
- Free nebular parameters in this work
  - Ionization parameter **U**; hydrogen density $\mathbf{n_H}$; gas metallicity $\mathbf{Z_{gas}}$

$$U = \frac{1}{c}\frac{\text{ionizing photon number flux/cm}^{-2}\text{s}^{-1}}{\text{hydrogen density/cm}^{-3}}$$

Fiducial model reproduces observations?

- Dwarf Galaxy Survey

SSP: SB99 1Myr burst
$1 < n_H < 3000$ cm^{-3}

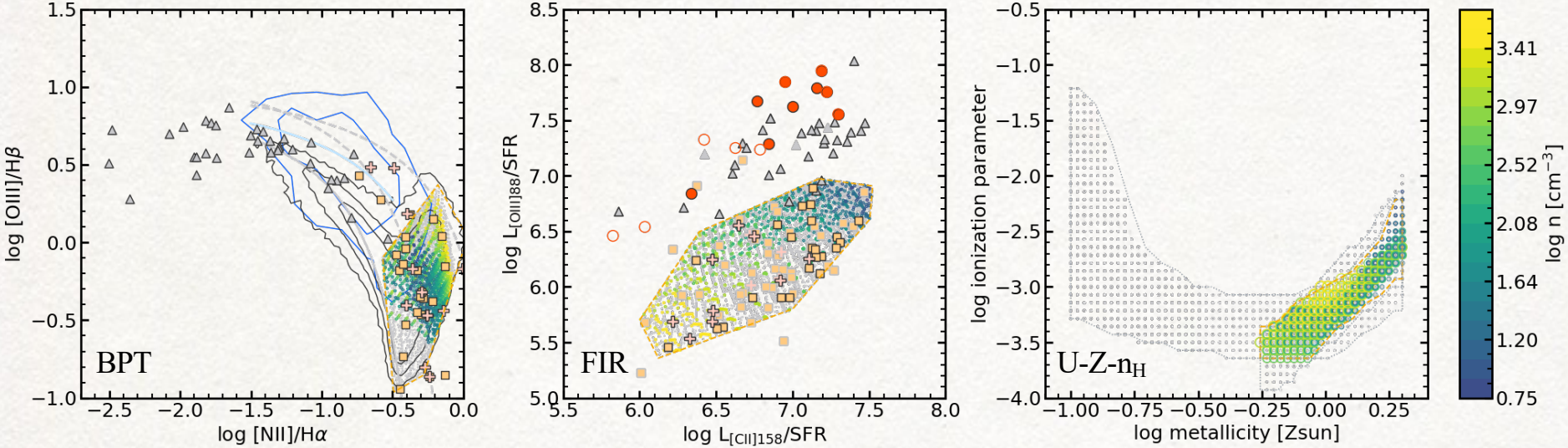


- Cloudy models in BPT + FIR region → U, Z, n_H
- reasonable nebular parameters

Fiducial model reproduces observations?

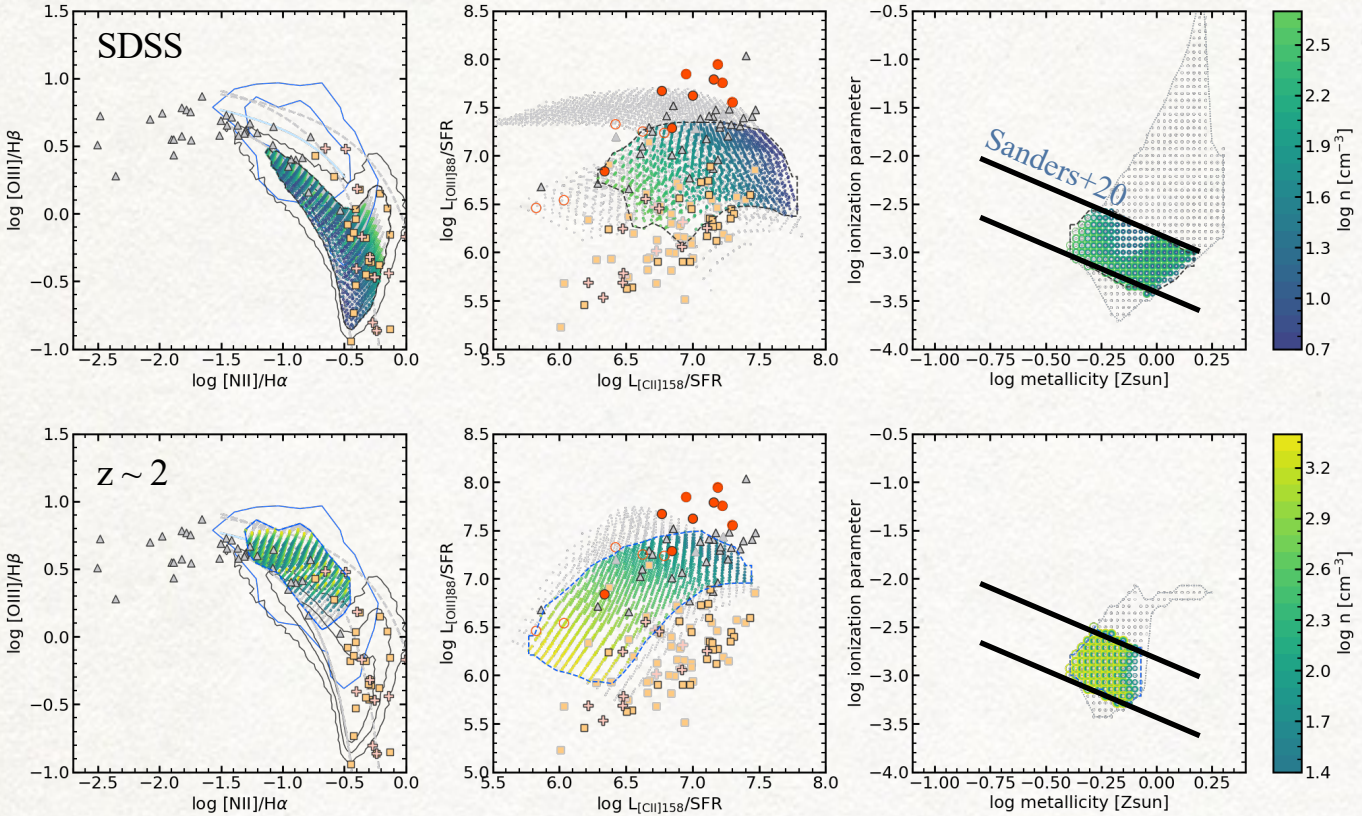
- GOALS survey

SSP: SB99 1Myr burst
$3.5 < n_H < 35000$ cm^{-3}



- Cloudy models in BPT + FIR region → U, Z, n_H
- !Caution! AGN contribution

Distributions of optical galaxies in FIR

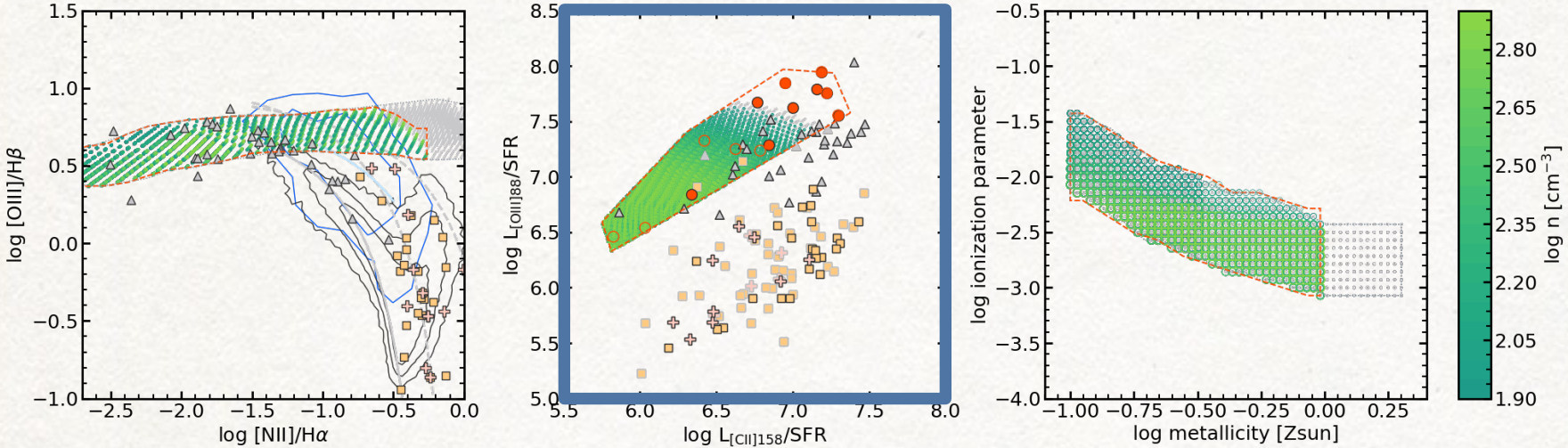


SB99 10Myr const
$5 < n_H < 500$ cm^{-3}

BPASS 10Myr const
$25 < n_H < 2500$ cm^{-3}

Prediction of BPT diagram at z > 6

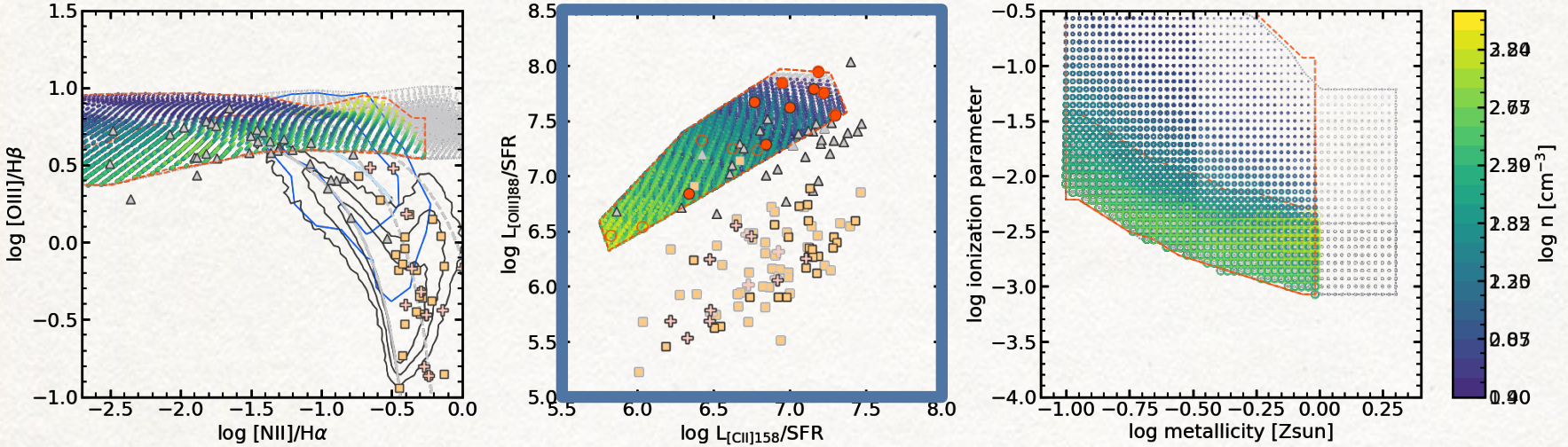
BPASS 10Myr const
$80 < n_H < 750\ cm^{-3}$



- Reason of high [OIII]88/SFR → Uncertainty of SFR?
  - possibly high dust temperature → current SFR underestimated?
  - UV+FIR SFR smaller than Ha SFR?

Prediction of BPT diagram at z > 6

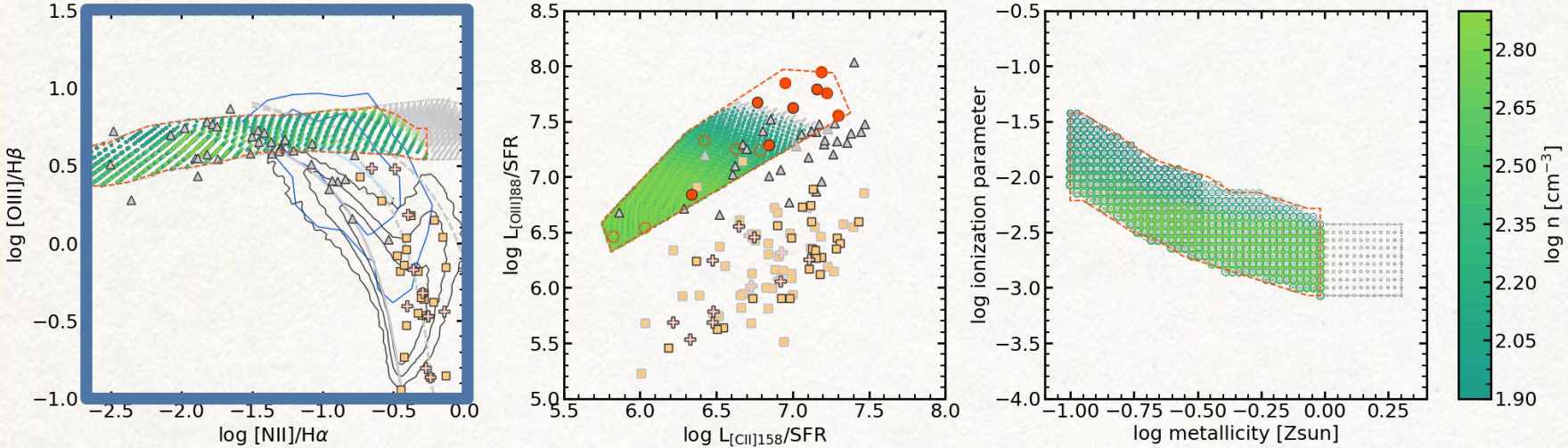
BPASS 10Myr const
$80 < n_H < 750\ cm^{-3}$



- Reason of high [OIII]88/SFR
  - possibly high dust temperature → current SFR underestimated?
  - UV+FIR SFR smaller than Ha SFR?
  - high U + low n_H?

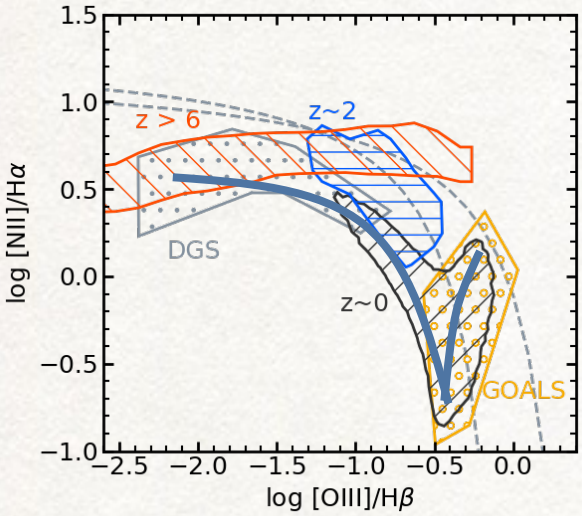
Prediction of BPT diagram at z > 6

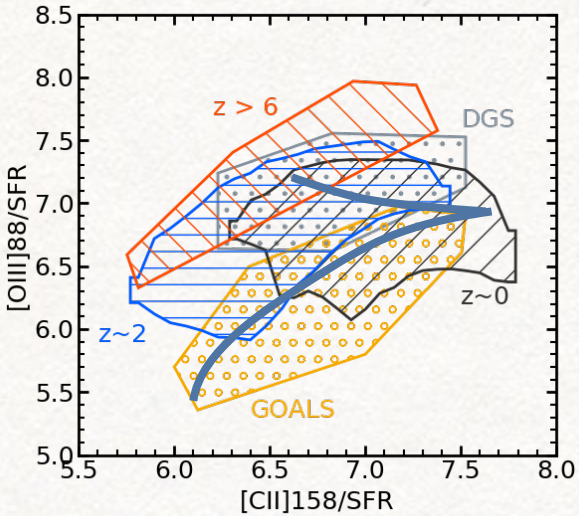
BPASS 10Myr const
$80 < n_H < 750\ cm^{-3}$

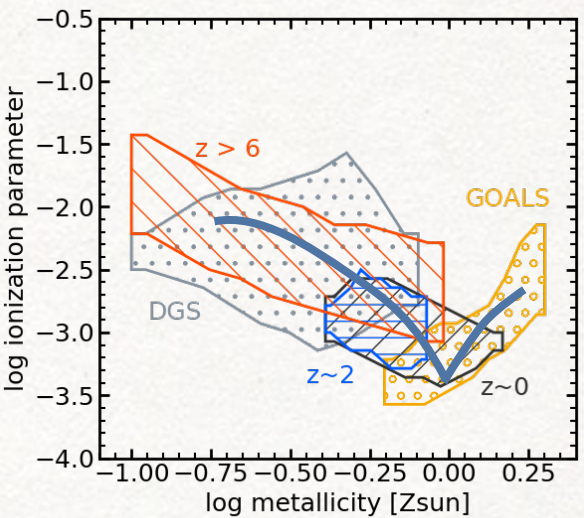


- Flat distribution on BPT diagram
  - [OIII] & Hβ fluxes can be predicted from SFR, and will be confirmed by JWST
  - [NII]/Ha can determine metallicity

Summary of Results

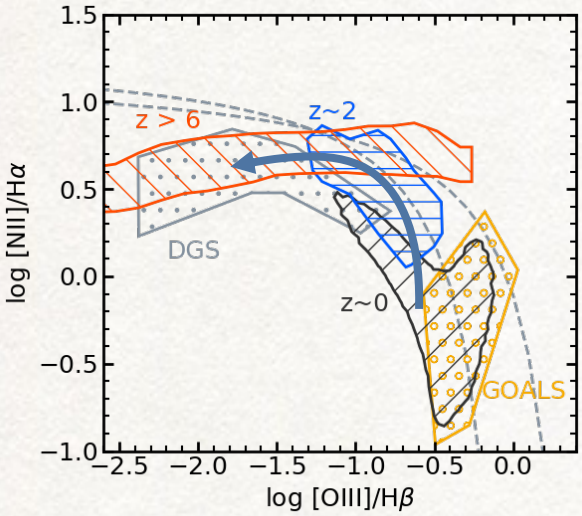


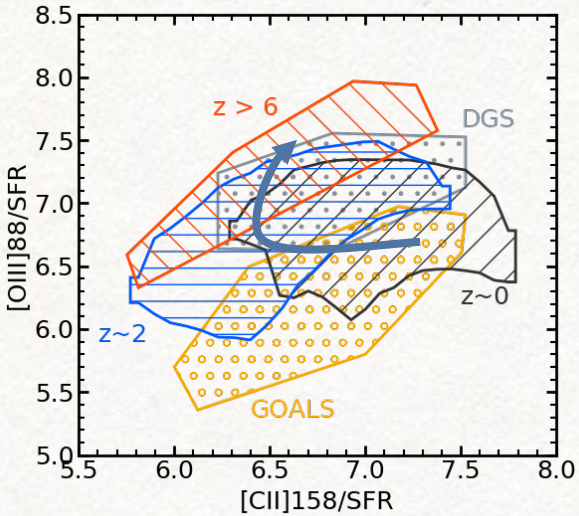


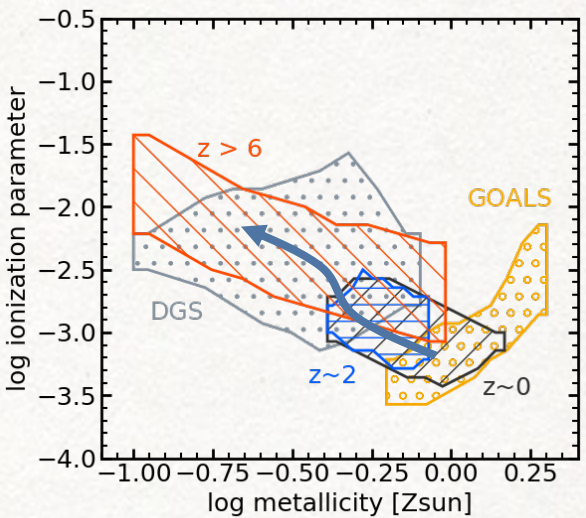


- We can see: 1. relations at z ~ 0

Summary of Results







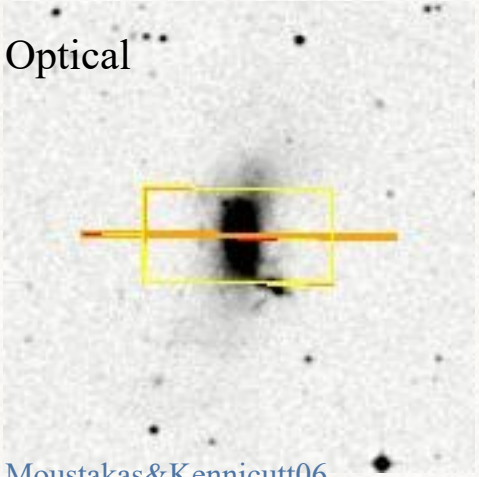
- We can see: 1. relations at z ~ 0

  2. evolution from z ~ 0 to >6

Caveats

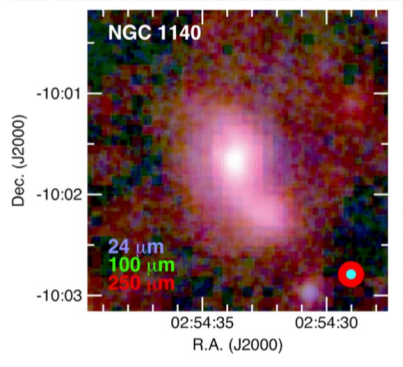
1. Difference in FoV b/w optical and FIR observations

Optical



Moustakas&Kennicutt06

FIR



Madden+15

2. Contributions from DIG

3. These are preliminary results