

# Photoionization models finally compatible with empirical calibrators?

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# Summary

- ▷ Models for the CALIFA HII regions
  - ▷ I: Hybrid models. *Astronomy and Astrophysics*, 2016, **594**, A37
  - ▷ II: Models using genetic method.
- ▷ Adding [OIII]4363: reducing the paquet size
- ▷ MAPPINGS differs from Cloudy!

# CALIFA for dummies

*Calar Alto Legacy Integral Field Spectroscopy Area survey*

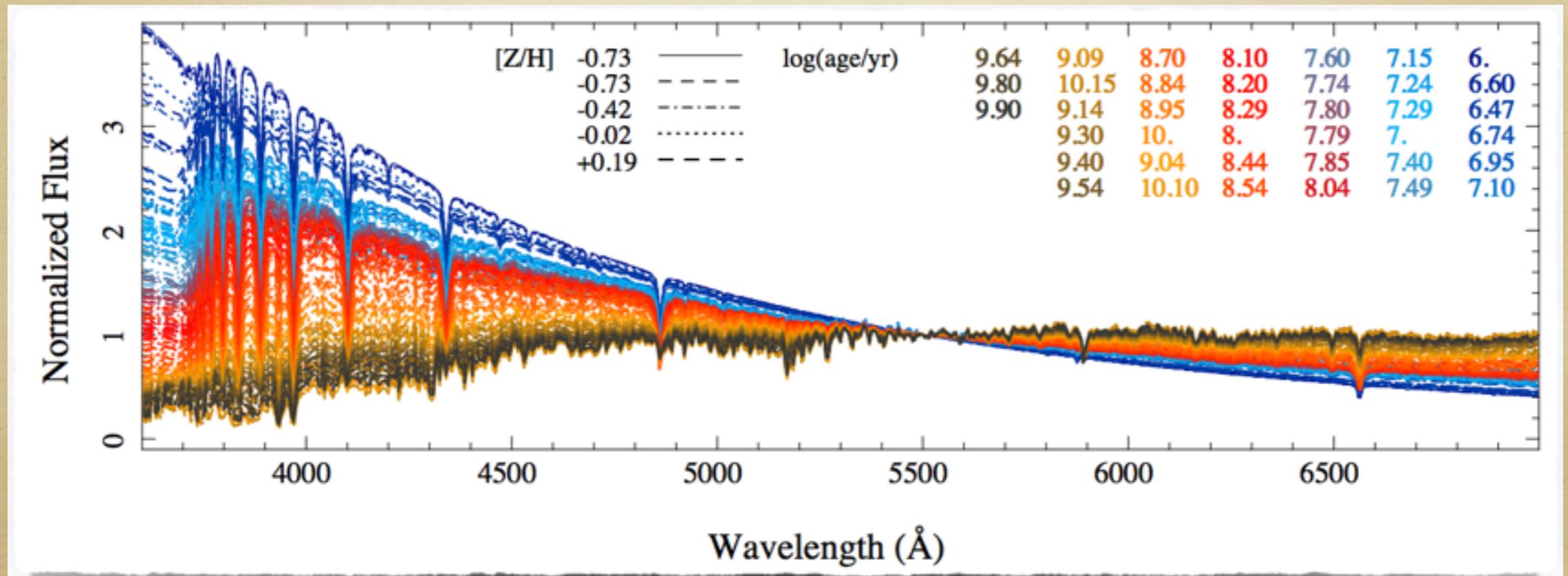
- ~ 600 galaxies observed with the PMAS/PPAK IFU spectrophotometer mounted on the Calar Alto 3.5m telescope.
- $R \sim 1650$ , lambda in [3700-7000AA]
- ~ 20,000 giant HII regions defined by HIIEXPLORER (Sánchez et al. 2012)

# FIT3D

« A fitting tool for the analysis of the spectroscopic properties of the stellar populations and the ionized gas derived from moderate resolution spectra of galaxies »

Sanchez et al., (2006, 2015)

# The gsd156 SSP sample



- Cid-Fernandes et al., 2013 (STARLIGHT)
- 4 metallicities
- 39 ages

# Photoionization models

## P-space

- SED
  - shape (softness:  $T^*$ , age)
  - intensity
- Gas
  - density
  - abundances
    - O/H
    - N/O
    - etc...
- Distance source-gas
- Morphologie (O or //)



## O-space

- Halpha, Hbeta
- [NII]6584
- [OII]3727
- [OIII]5007
- [OIII]4363
- or [NII]5755

# Photoionization models

## hybrid models

### P-space

- SED
  - shape (softness:  $T^*$ , age)
  - intensity
- Gas
  - density
  - abundances
    - O/H ( $O_3N_2$ )
    - N/O
    - etc...
- Distance source-gas
- Morphologie (O or //)

FIT3D

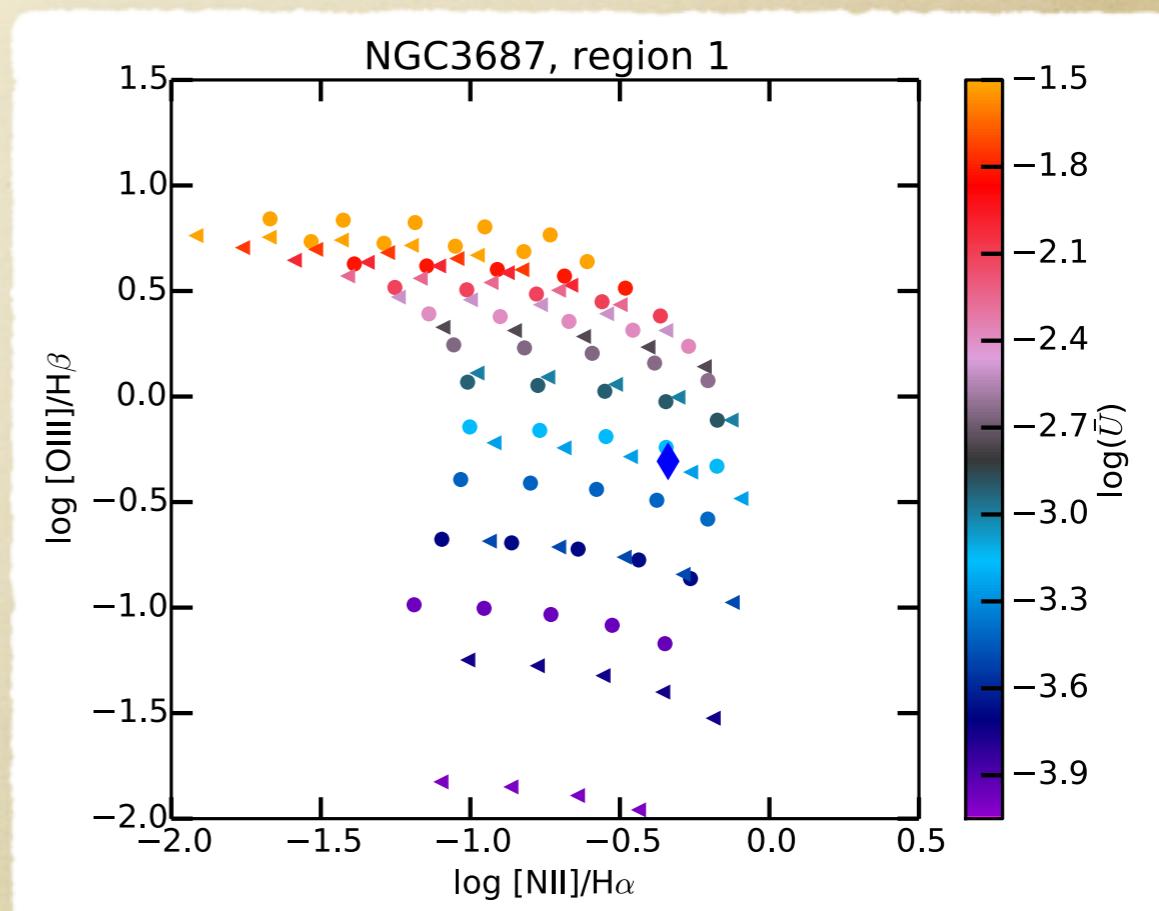
U

### O-space

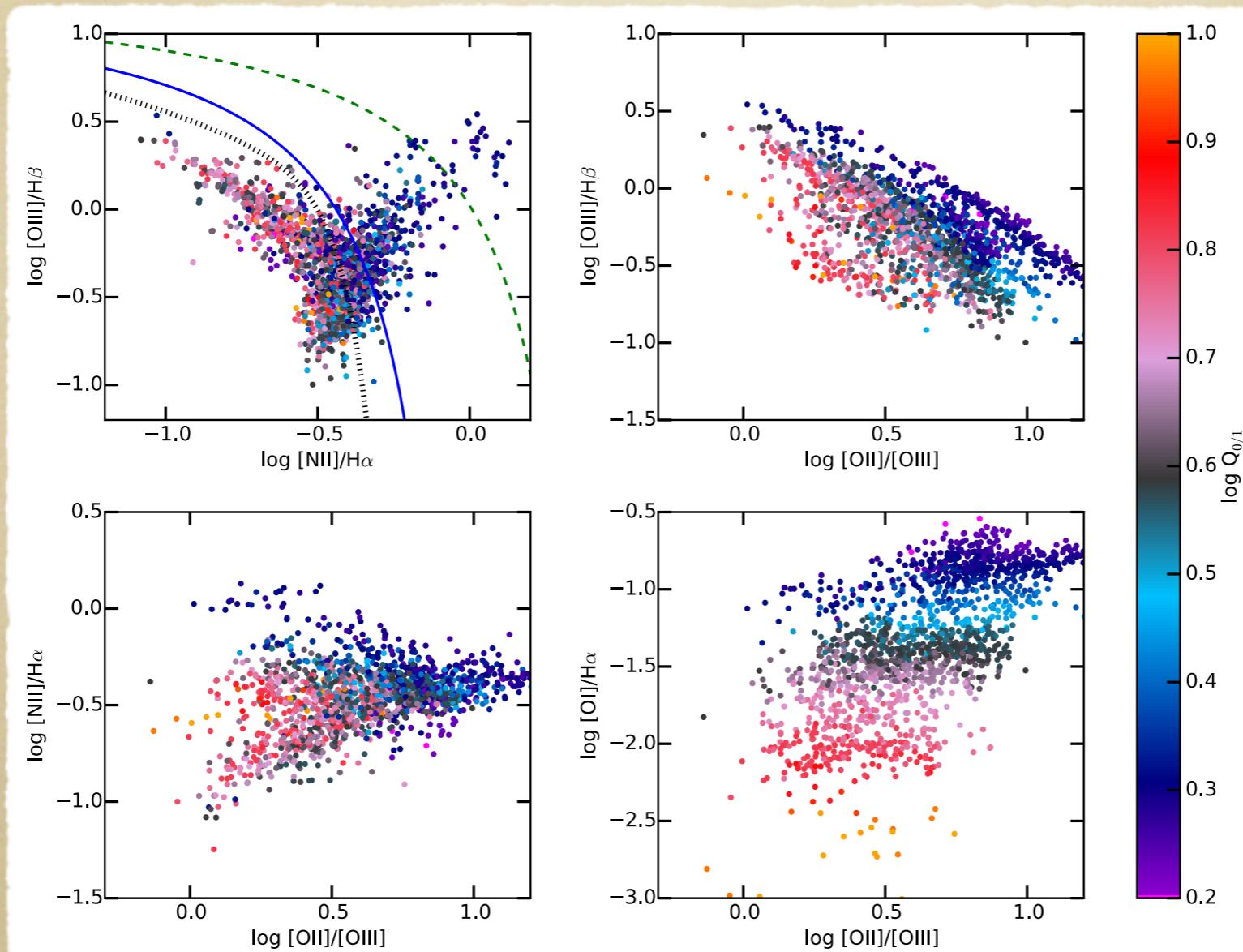
- Halpha, Hbeta
- [NII]6584
- [OII]3727
- [OIII]5007
- No [OIII]4363  
nor [NII]5755

# $\log(U)$ and N/O grids

- ▷ For each region ( $> 9000$ ): 11 values of  $\log(U)$ , 5 values of N/O, 2 morphologies (O or //) and 2 values for O/H -> 220 models with adapted SED and O/H. -> **Determination of  $\log(U)$  and N/O.**
- ▷ O/H from O3N2 (Marino+13).
- ▷ A total or  $\sim 2$  millions models are run for the meta-grid (*that's why O/H is not free!*)
- ▷ A posteriori selection of the models that fits [OII].



# BPT diagrams



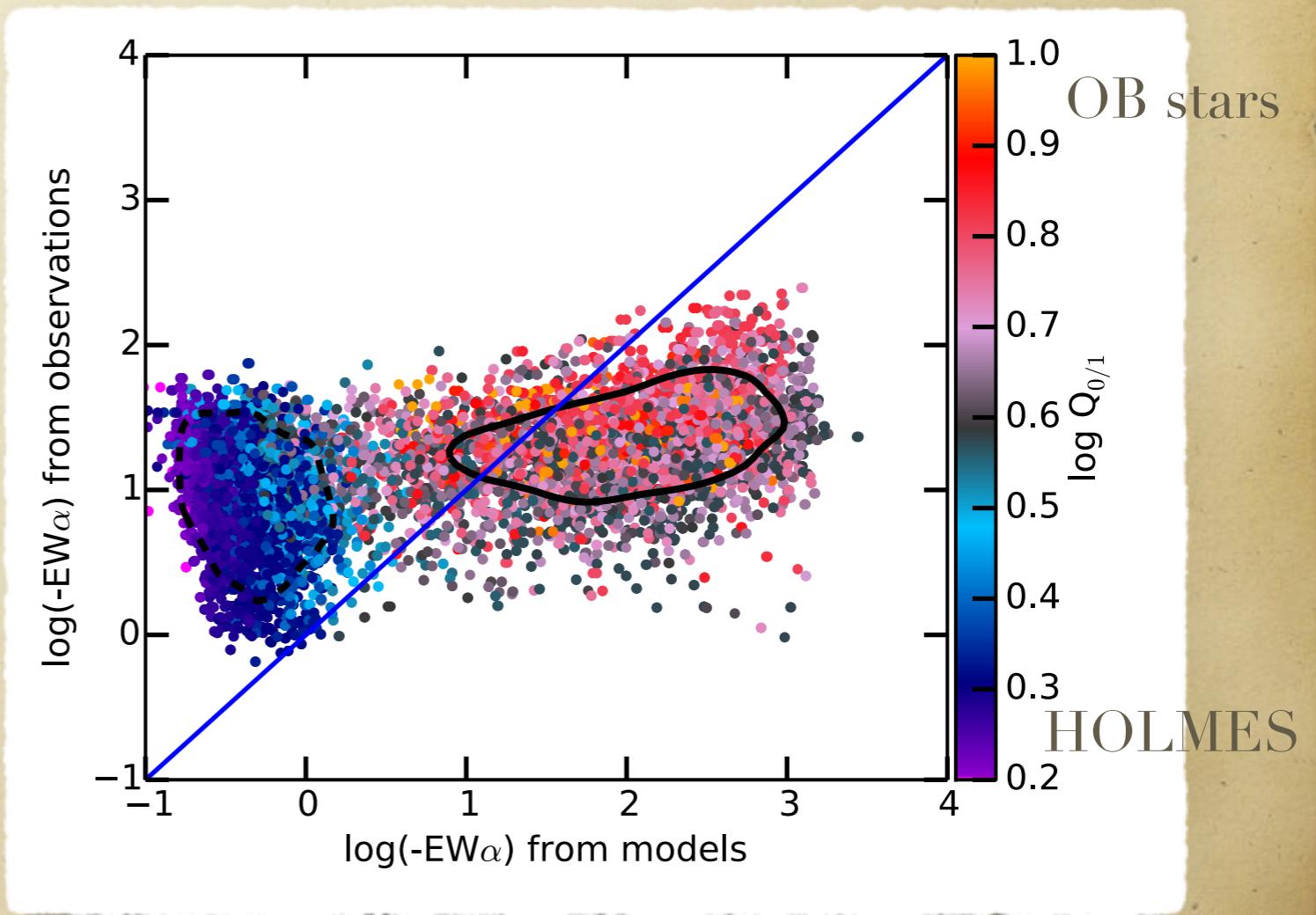
OB stars

HOLMES

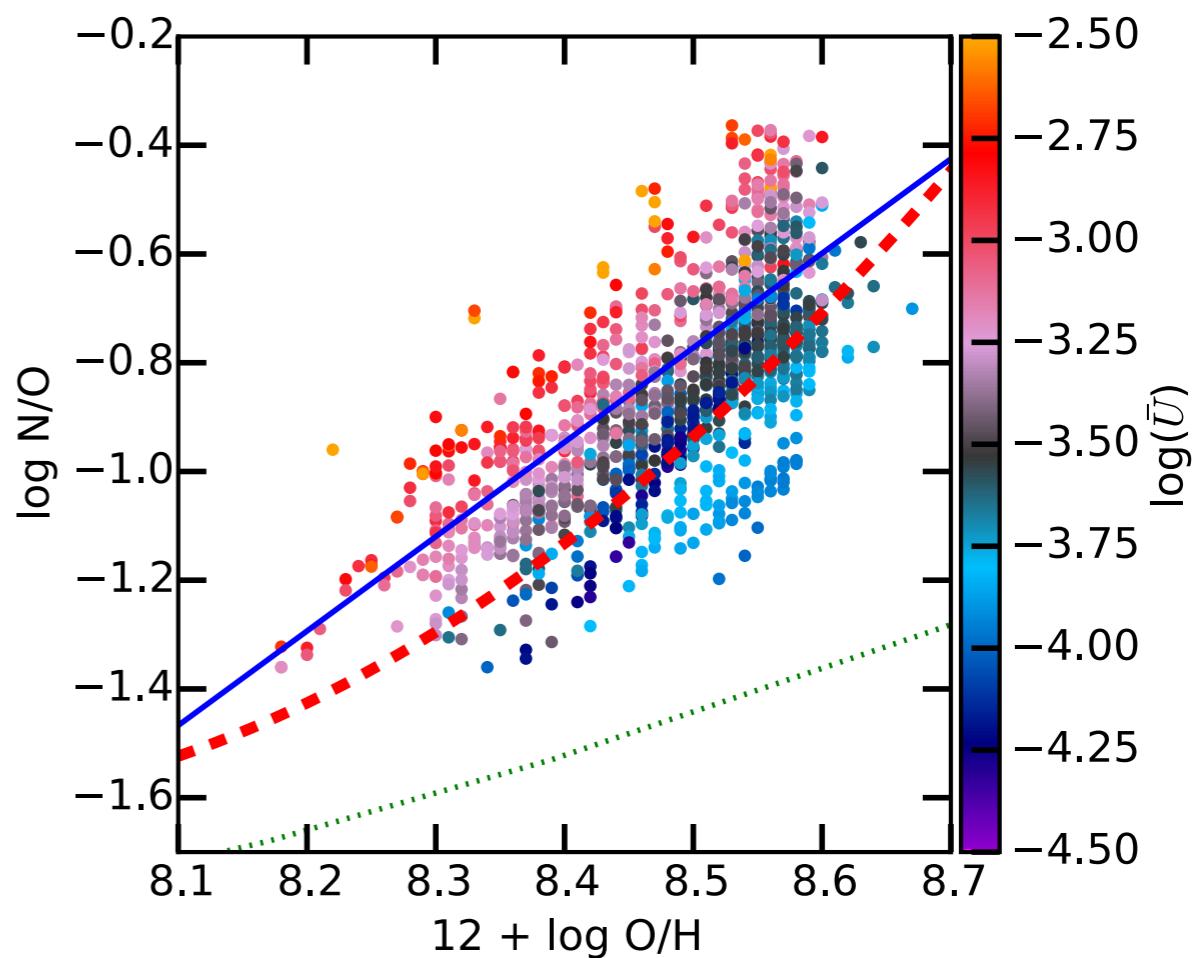
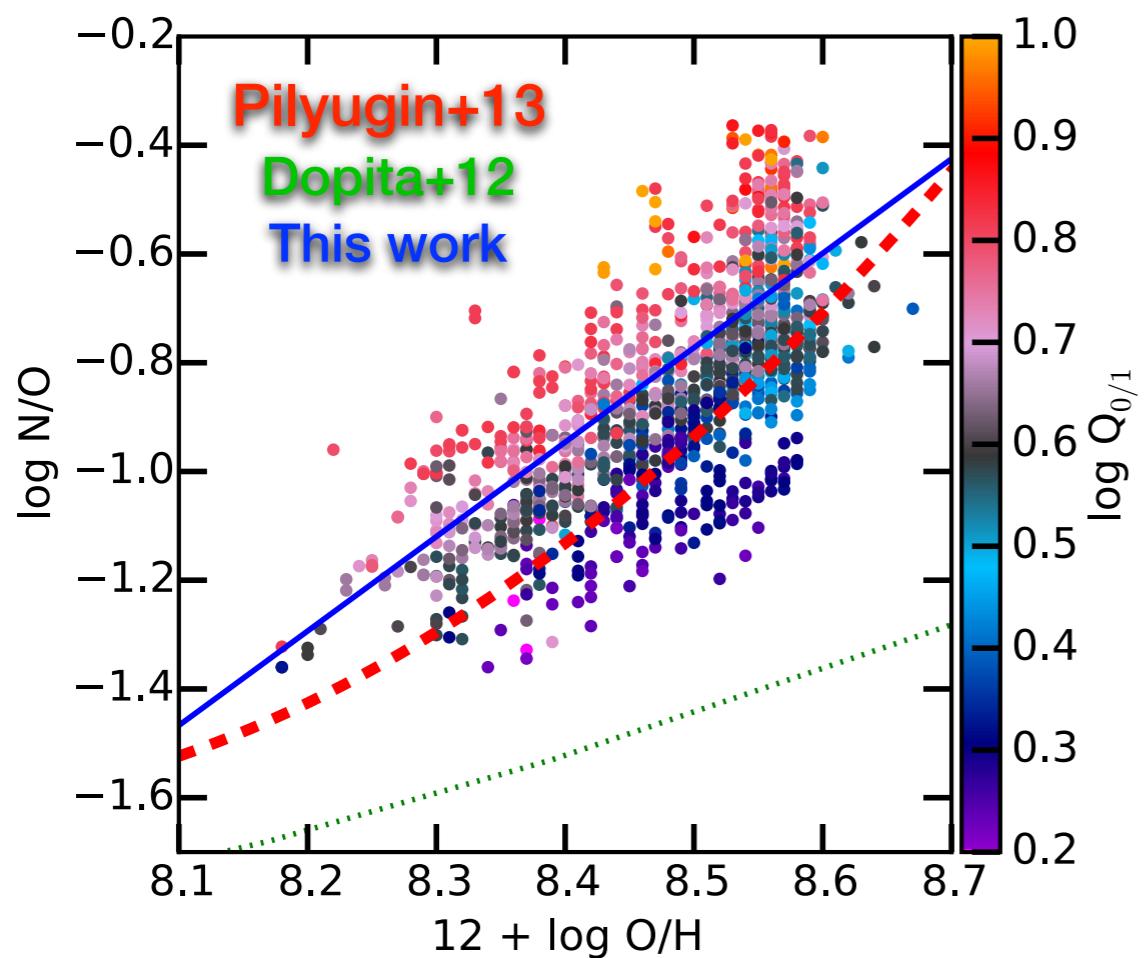
*HOLMES: Hot Low Mass Evolved Stars*

# Equivalent widths

- ❖ Halpha Eq. width disagreement between models and observations:
  - ❖  $\text{obs} < \text{mod}$ : leaking ( $\sim 80\%$ ). OB
  - ❖  $\text{mod} < \text{obs}$ : missing ionizing photons (pb...). HOLMES (or whatever it is)



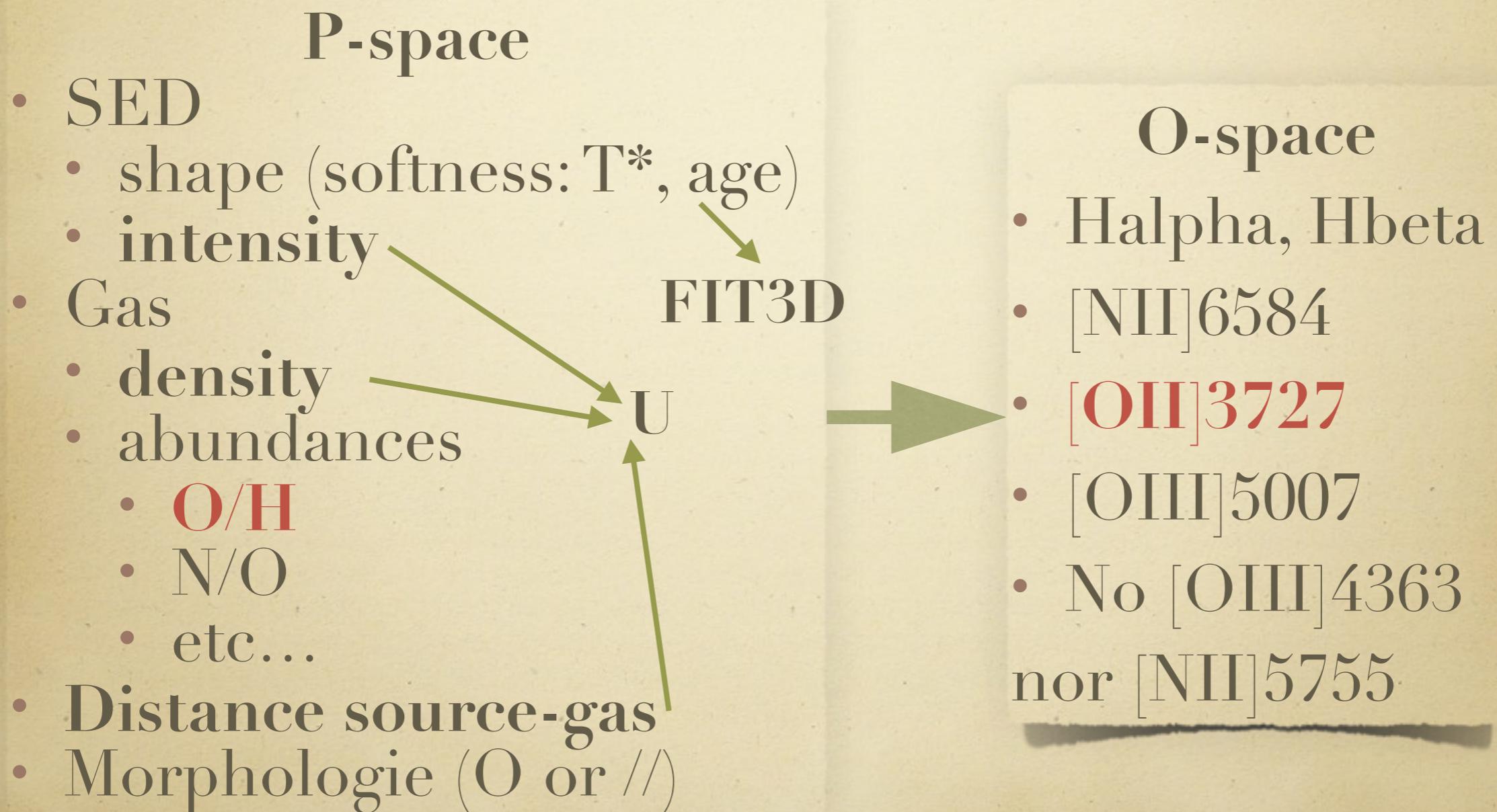
# N/O vs. O/H



N/O vs. O/H: our results are closer to the ones from Pilyugin et al. than to Dopita et al.

# Photoionization models

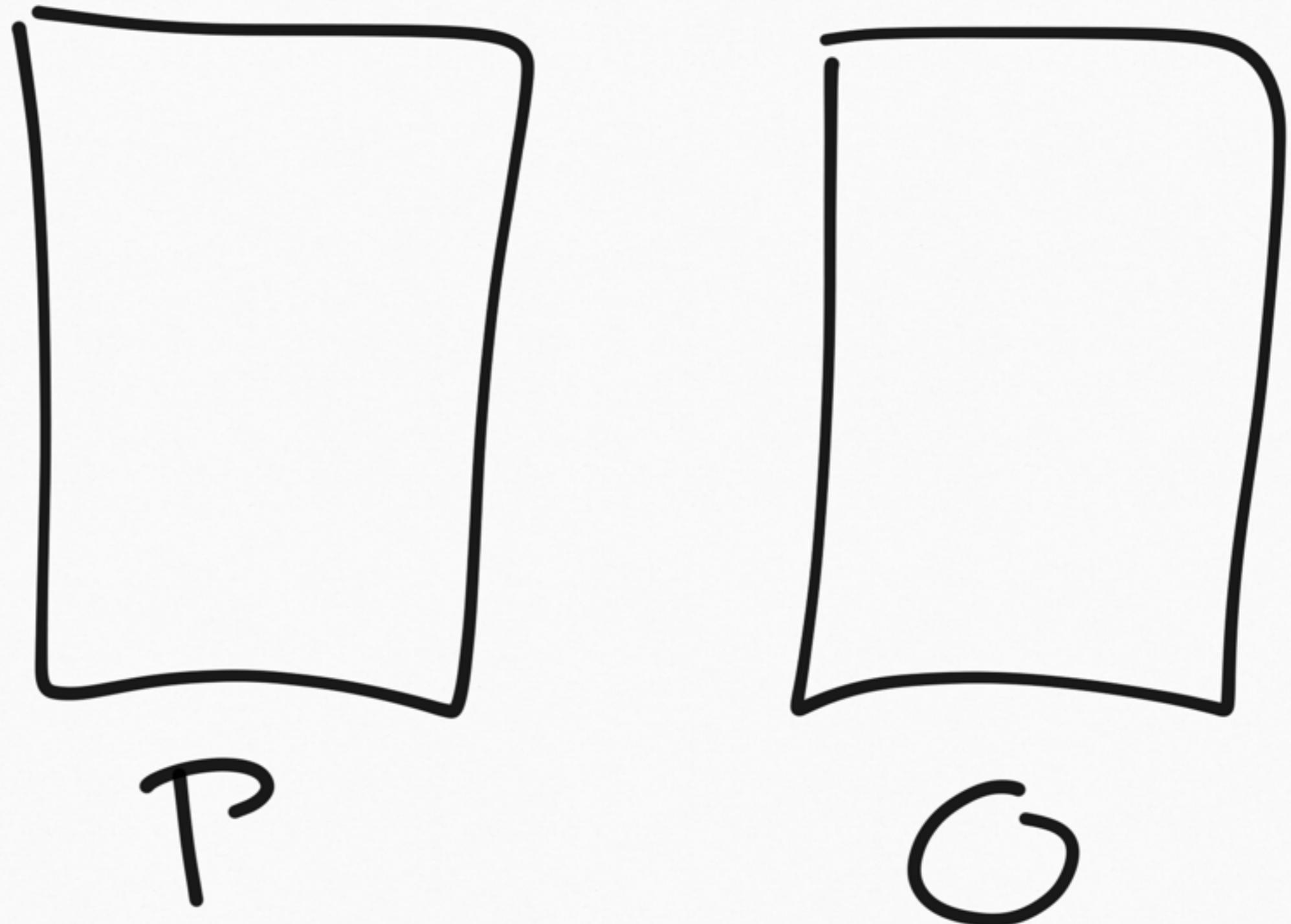
## phase II



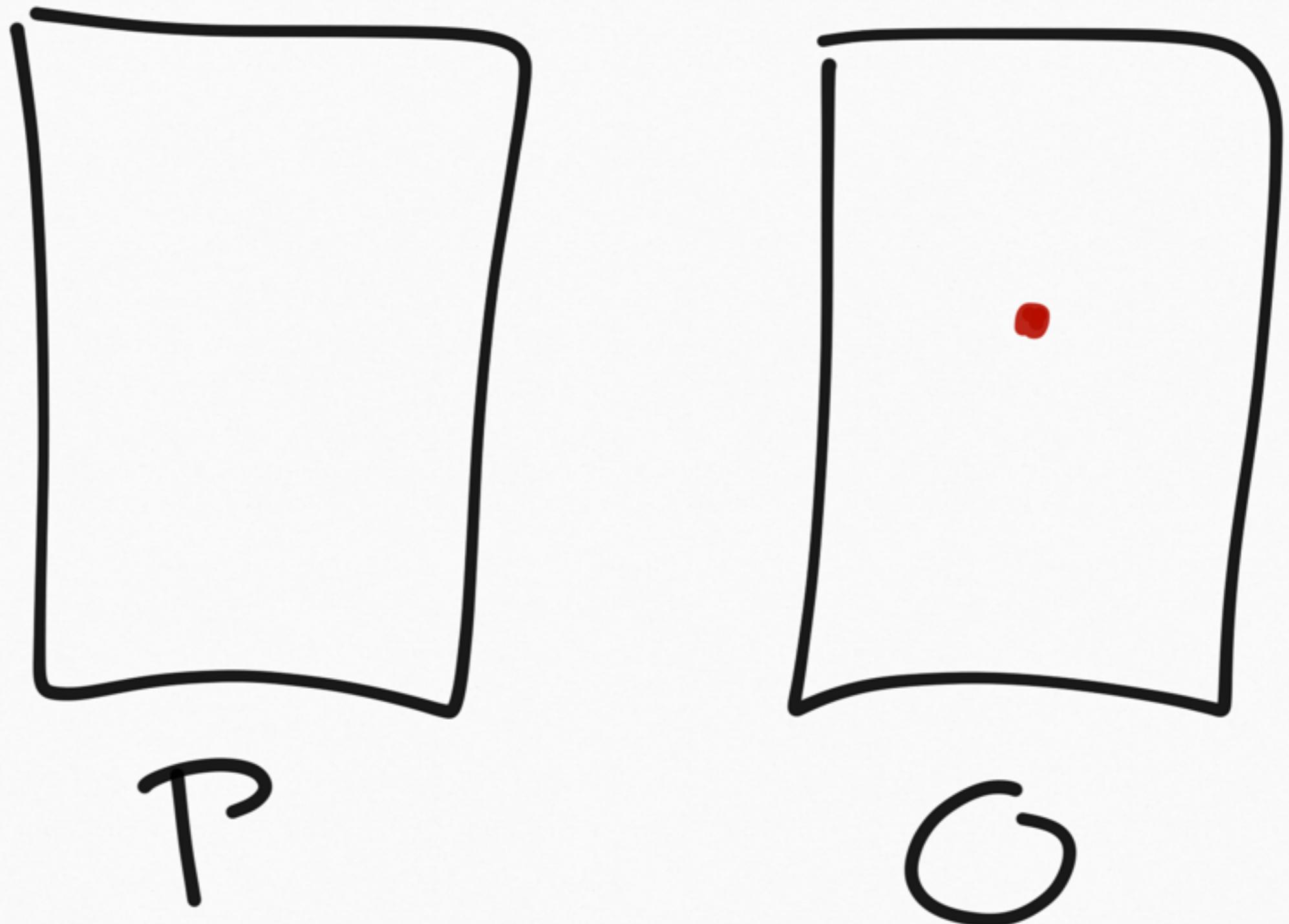
# Genetic method

- ▷ Looking for the models that fit  $[\text{NII}]/\text{Ha}$ ,  $[\text{OII}]/\text{Hb}$  and  $[\text{OIII}]/\text{Hb}$  simultaneously.
- ▷ Genetic process:
  - ▷ **selection:** the models that fit the best the 3 lines are selected. Need for a distance and a criteria, that may evolve.
  - ▷ **evolution:** each selected model gives children by shaking its inputs ( $\log U$ ,  $\text{O/H}$ ,  $\text{N/O}$ ). The « energy » of the shake may evolve.
  - ▷ Kind of MCMC.

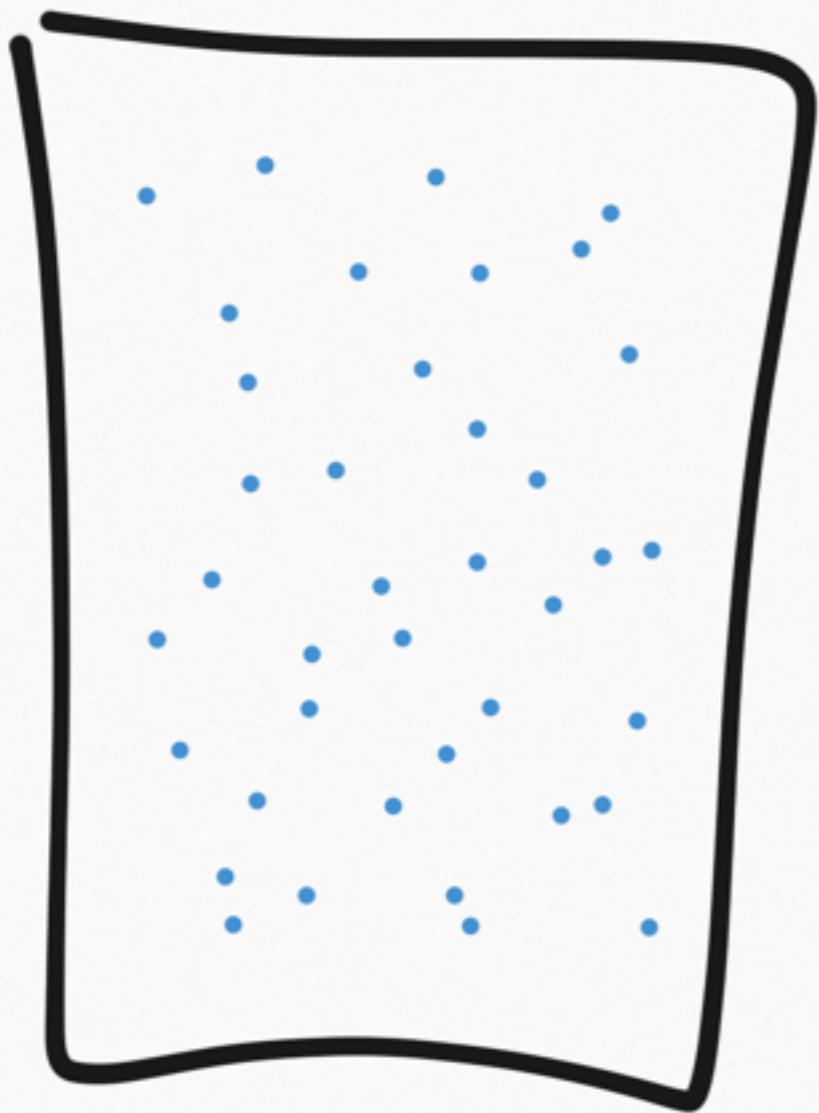
# P-space and O-space



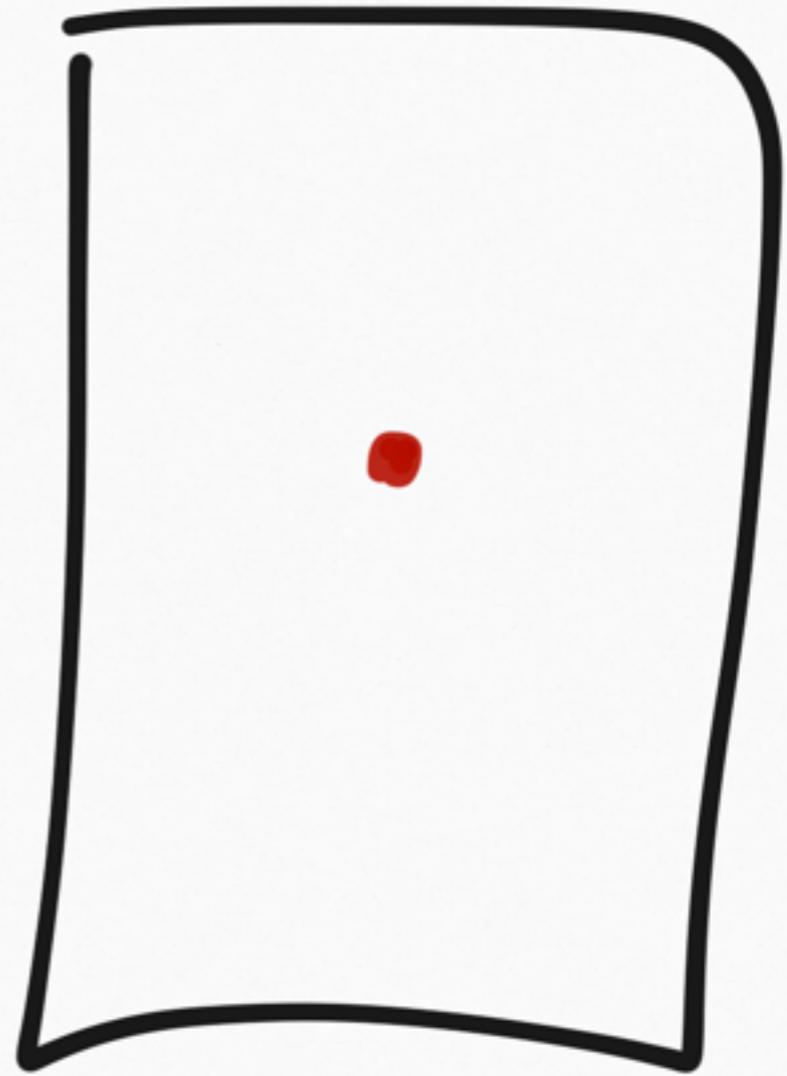
1 observation = 1 point in  
multi-dimentional O-space



A grid of models = various points in  
multi-dimensional P-space

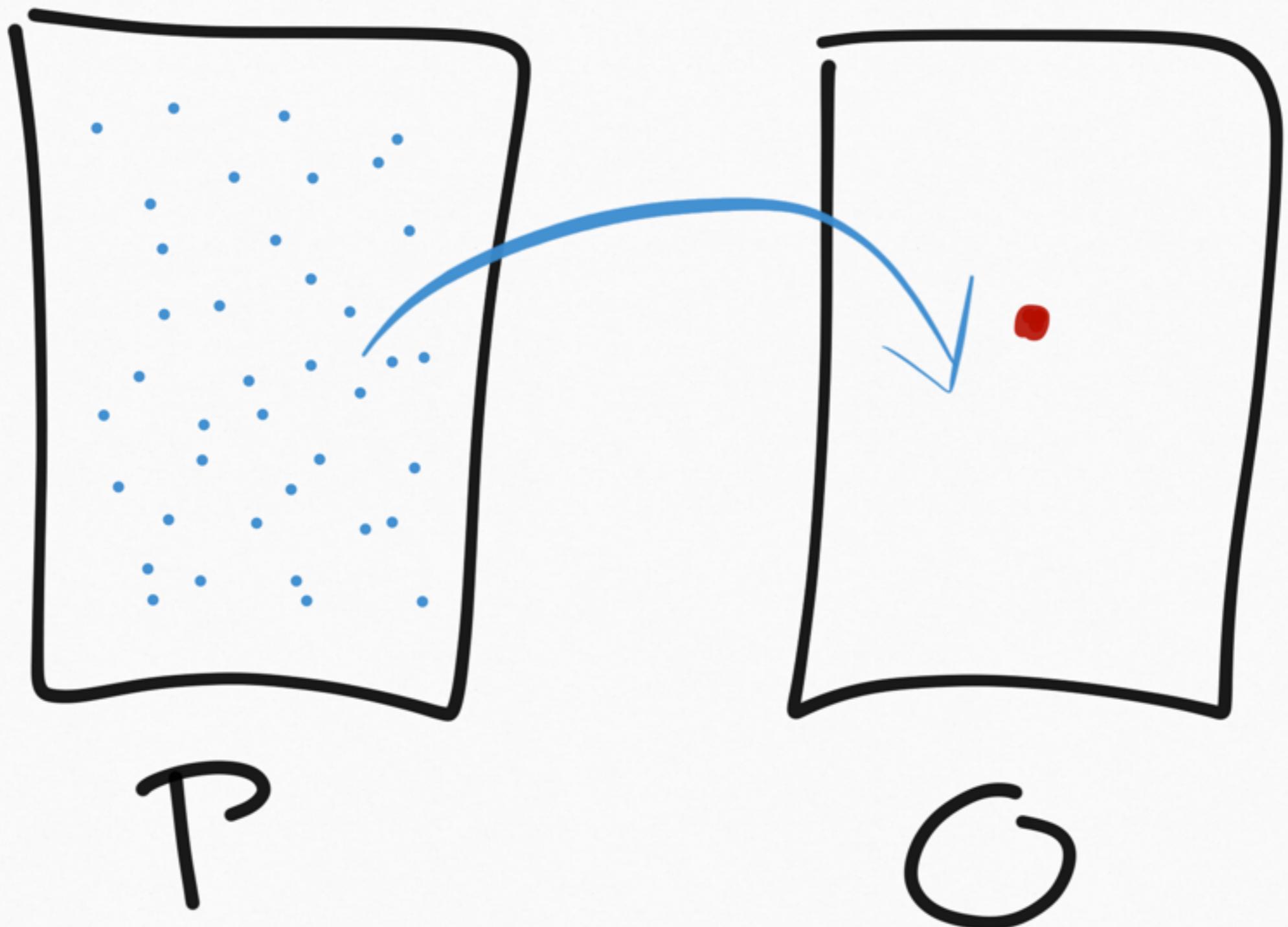


P

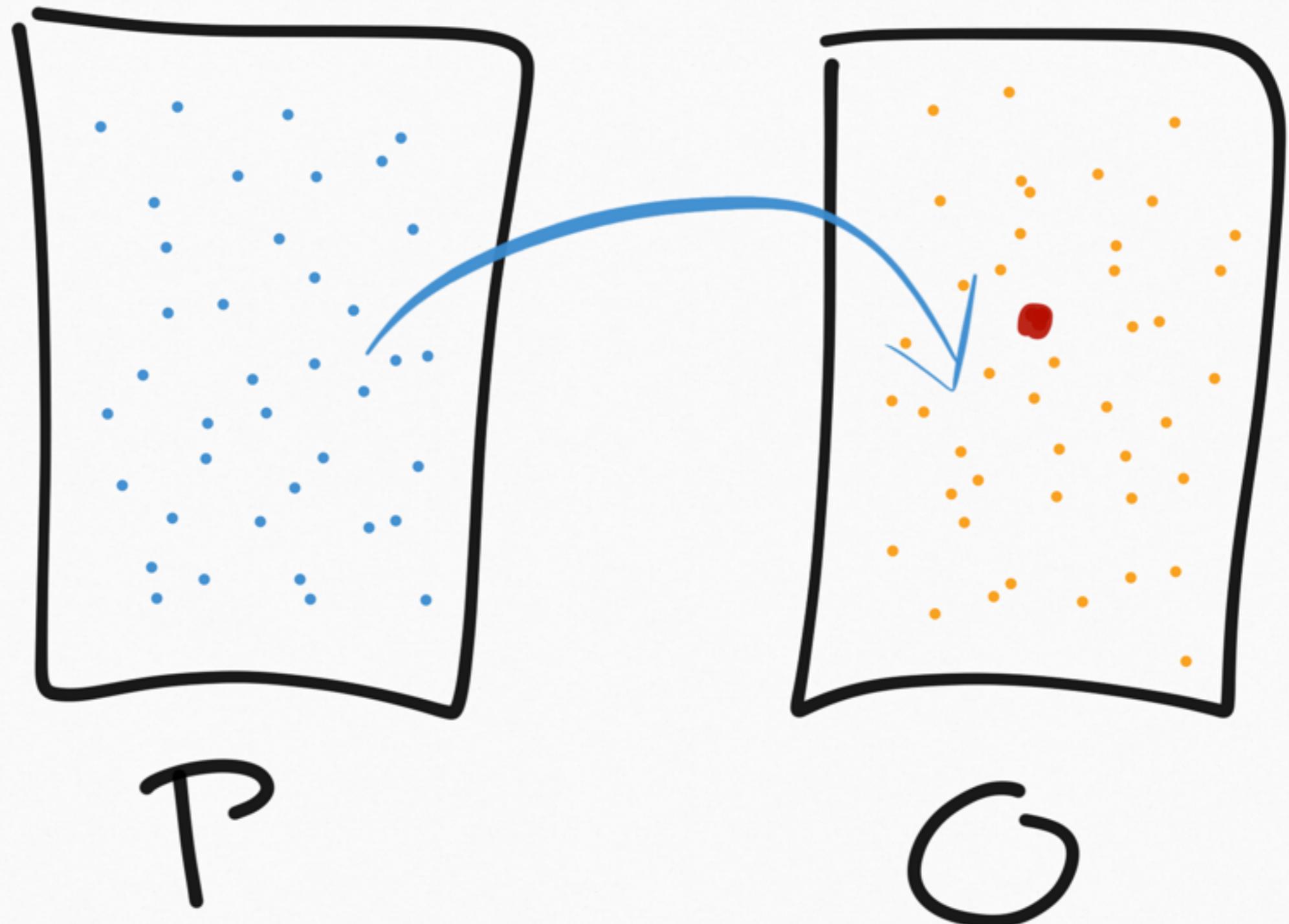


G

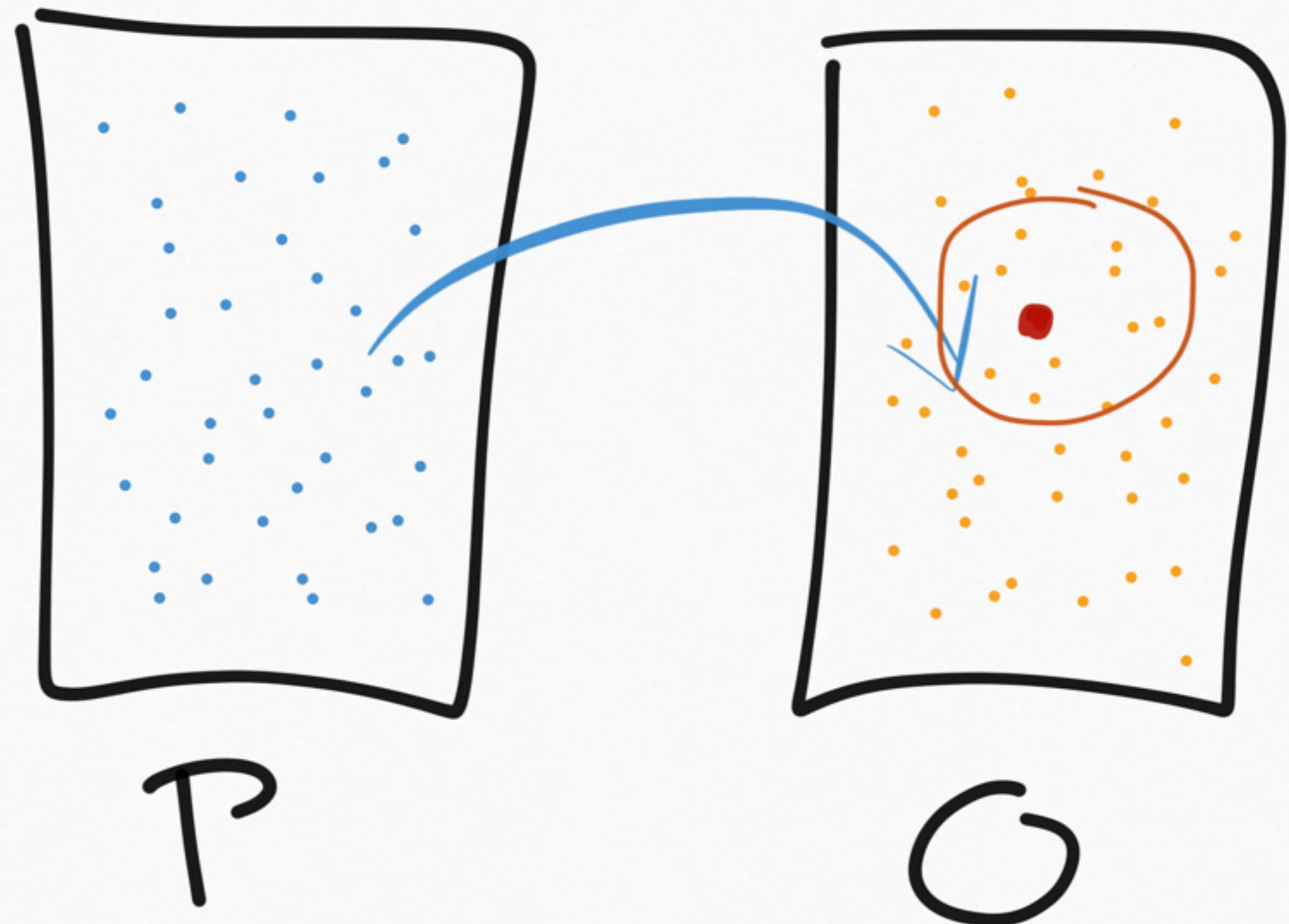
# Running models

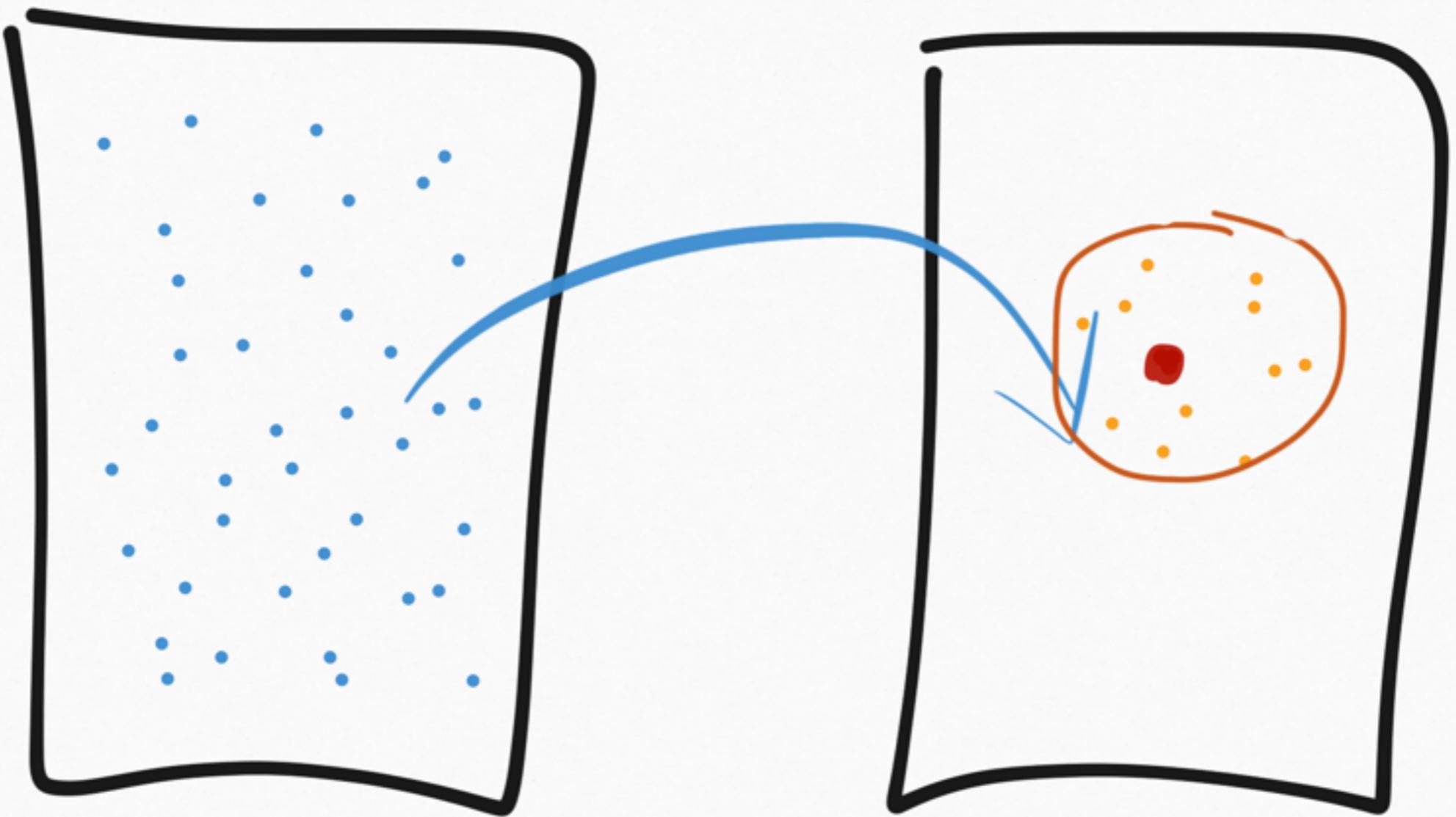


Results of the models =  
grid of points in O-space



Selecting the best models,  
closest to the observation

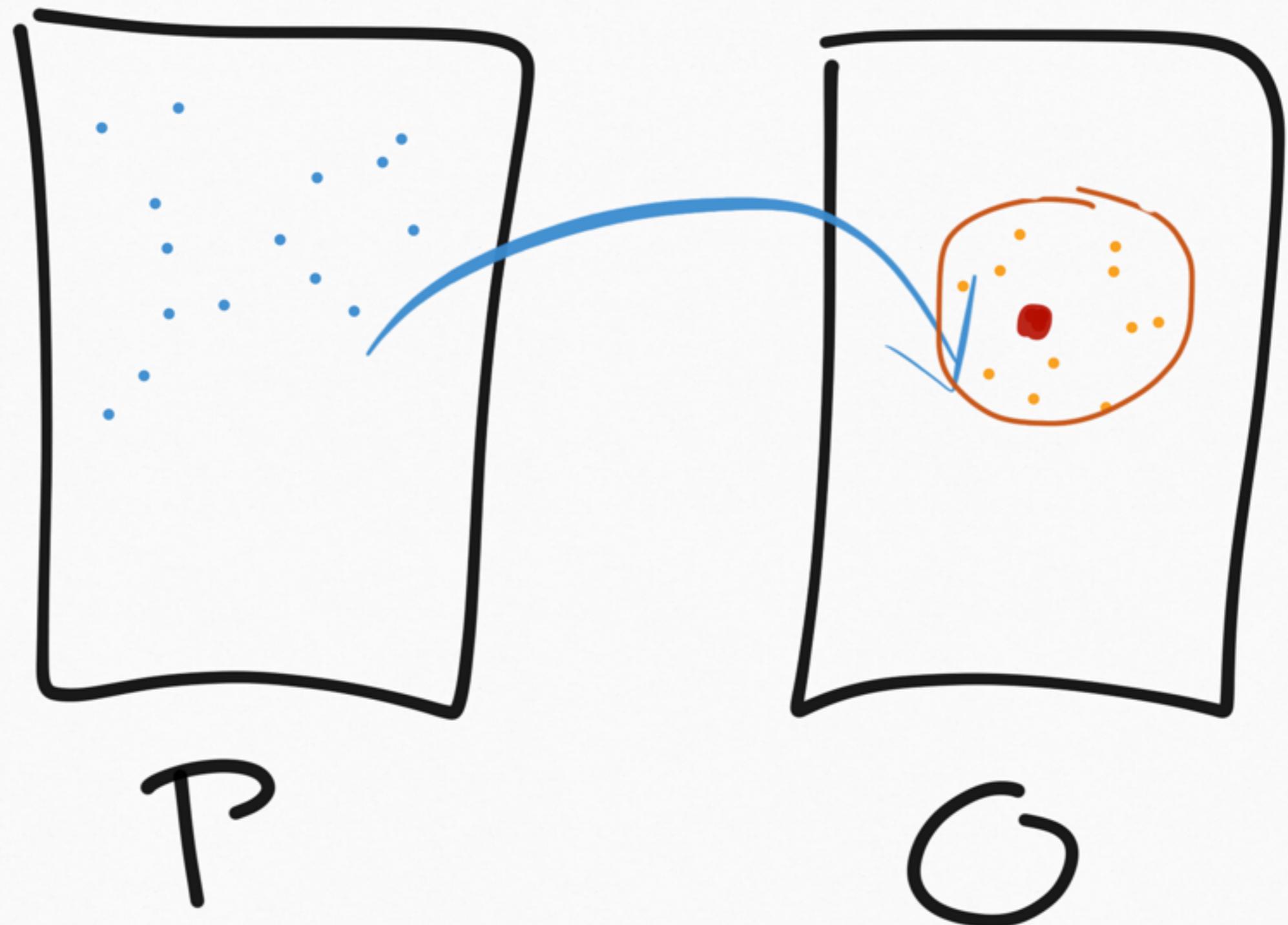


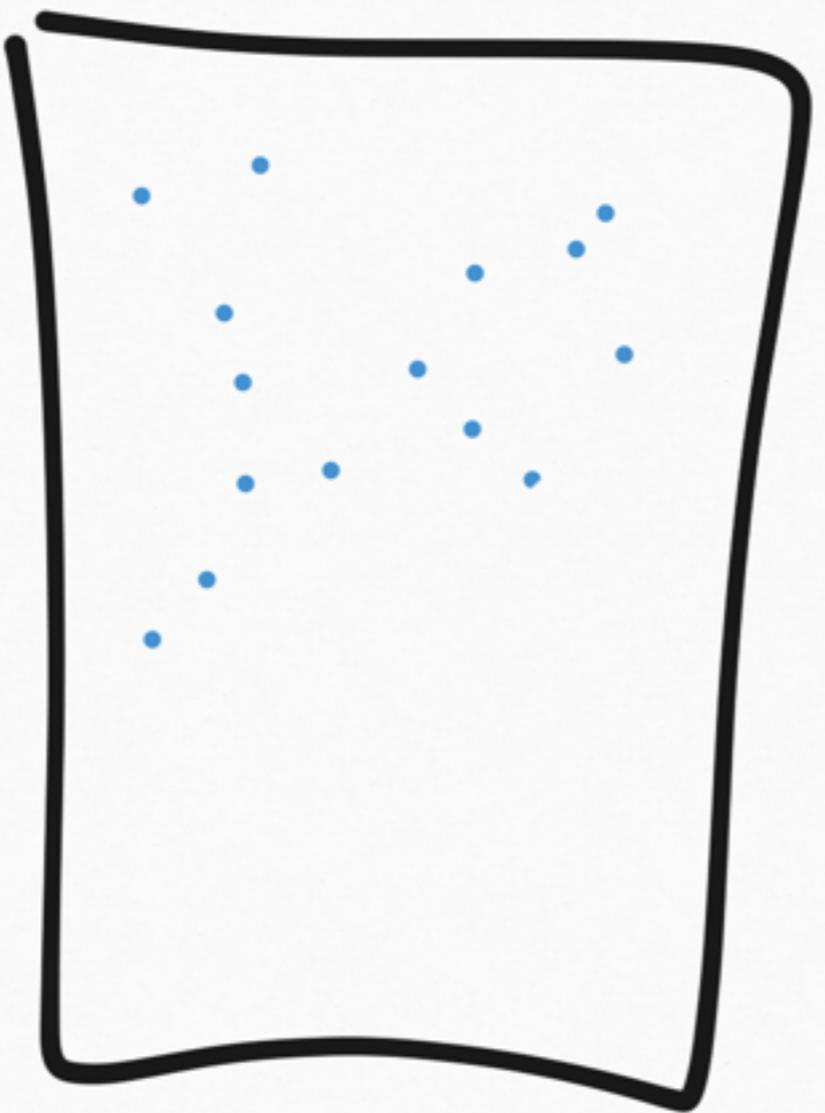


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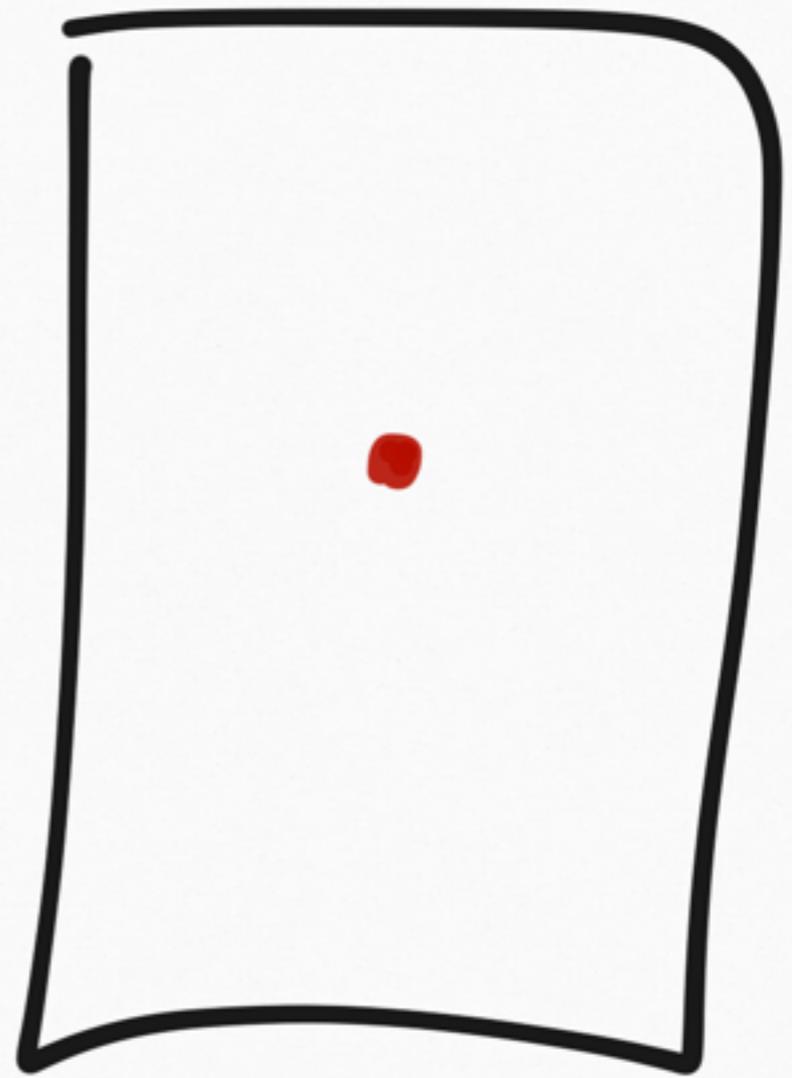
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Only a subset of models  
survive in the P-space



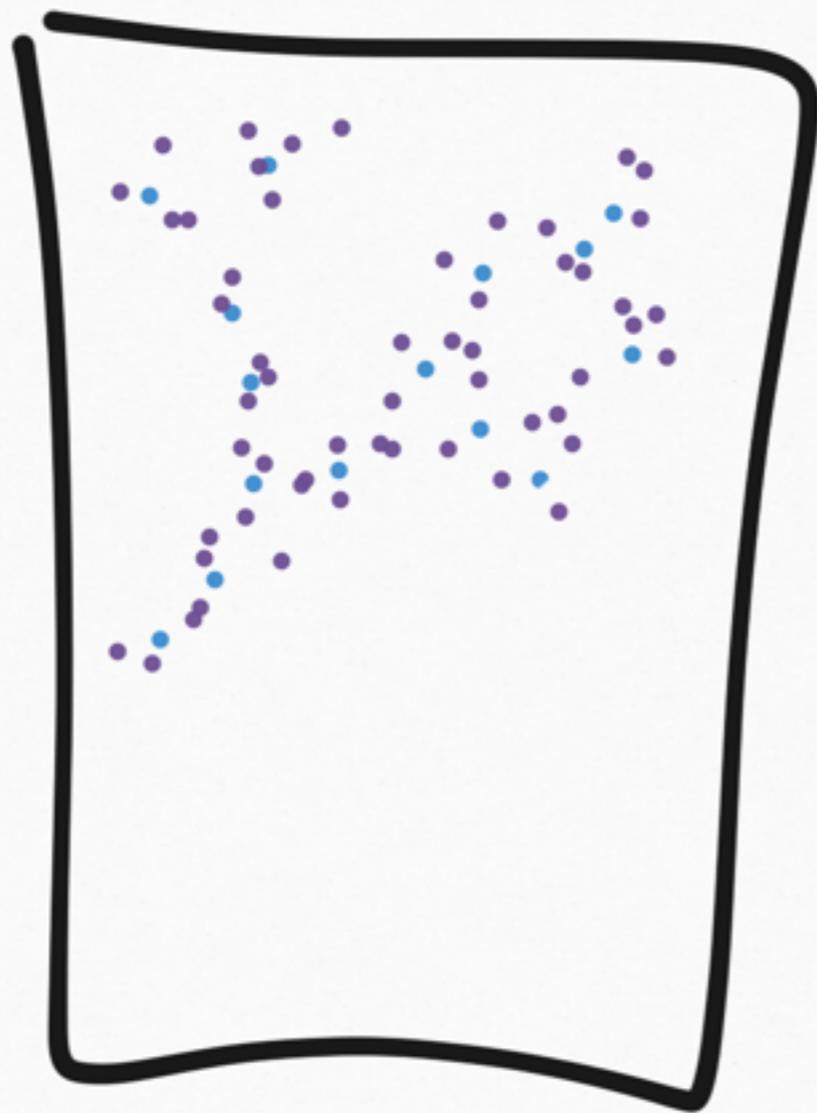


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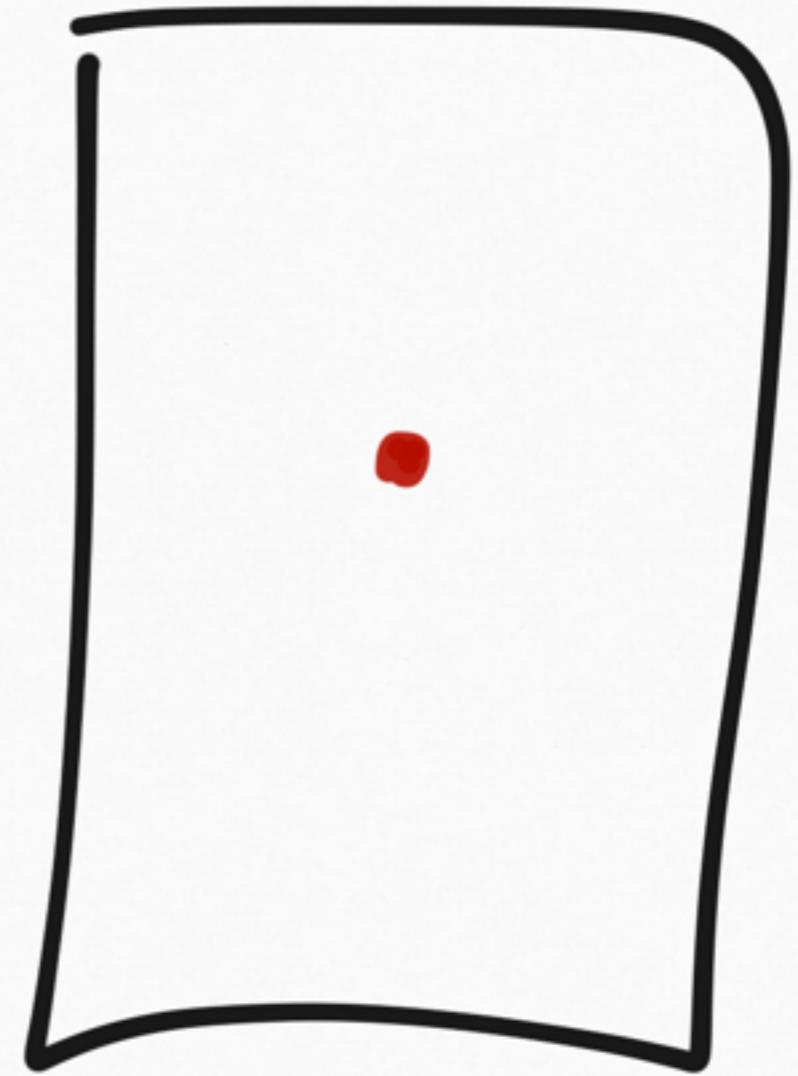


G

Each selected model have children,  
close to them

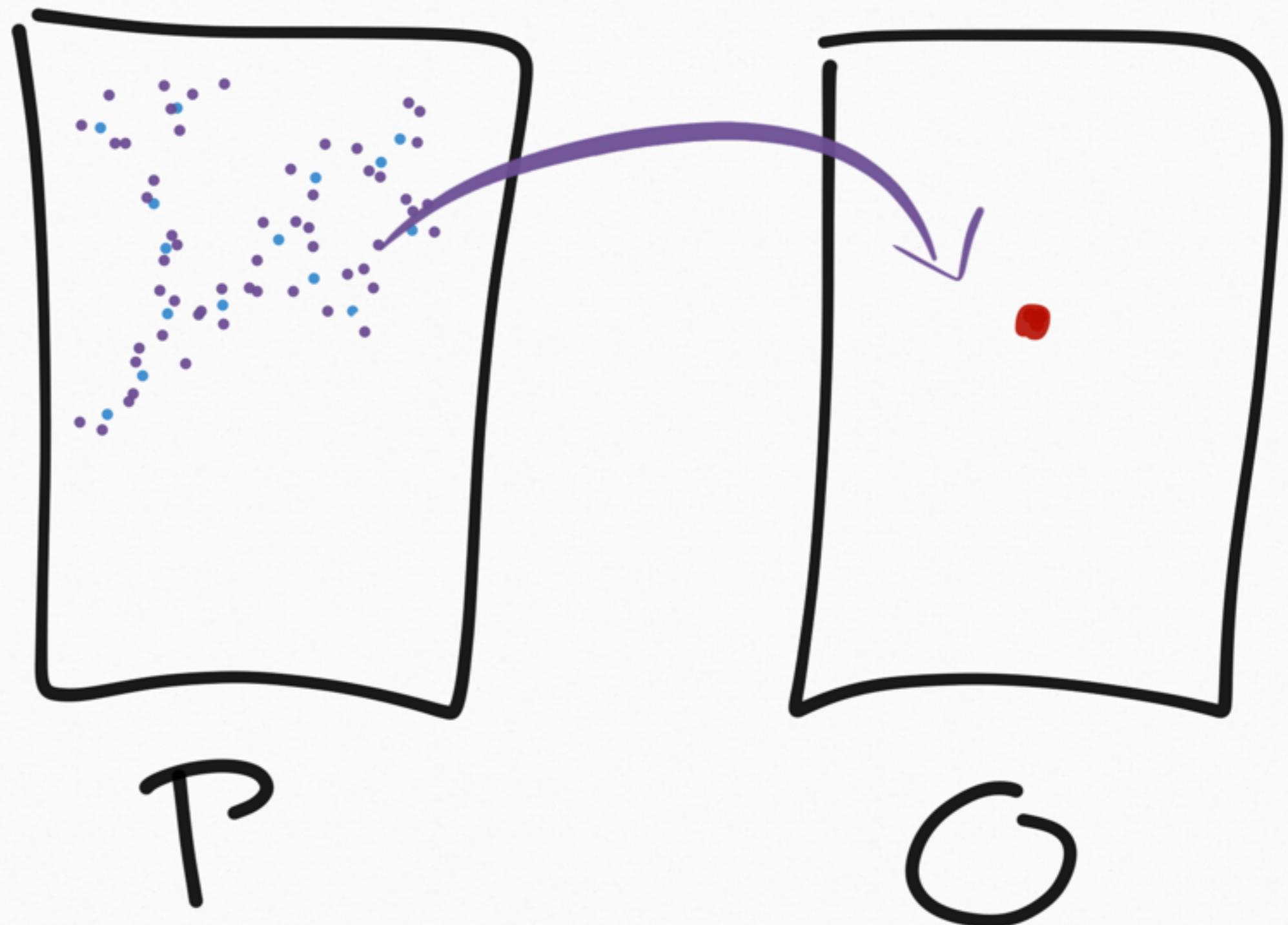


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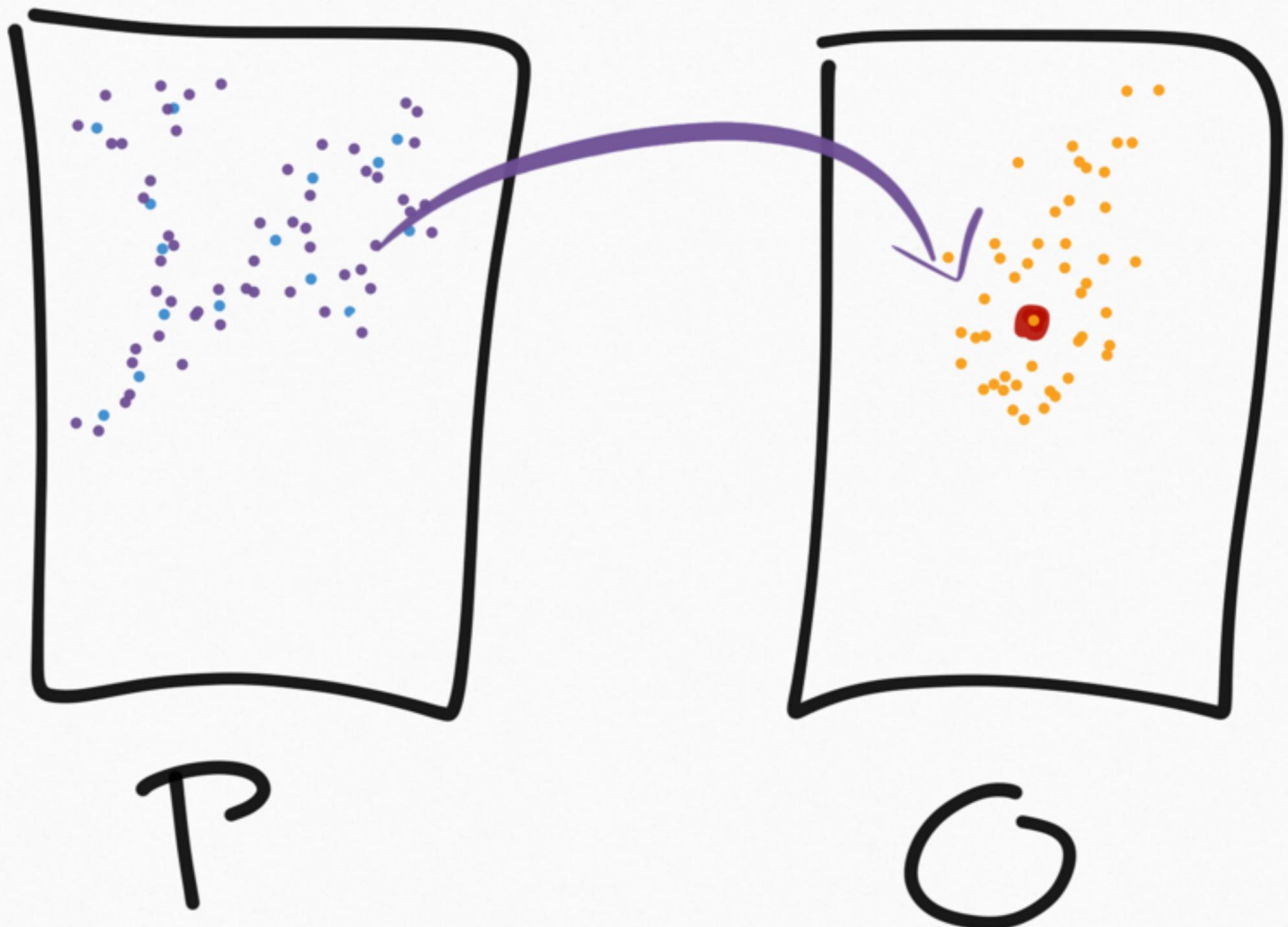


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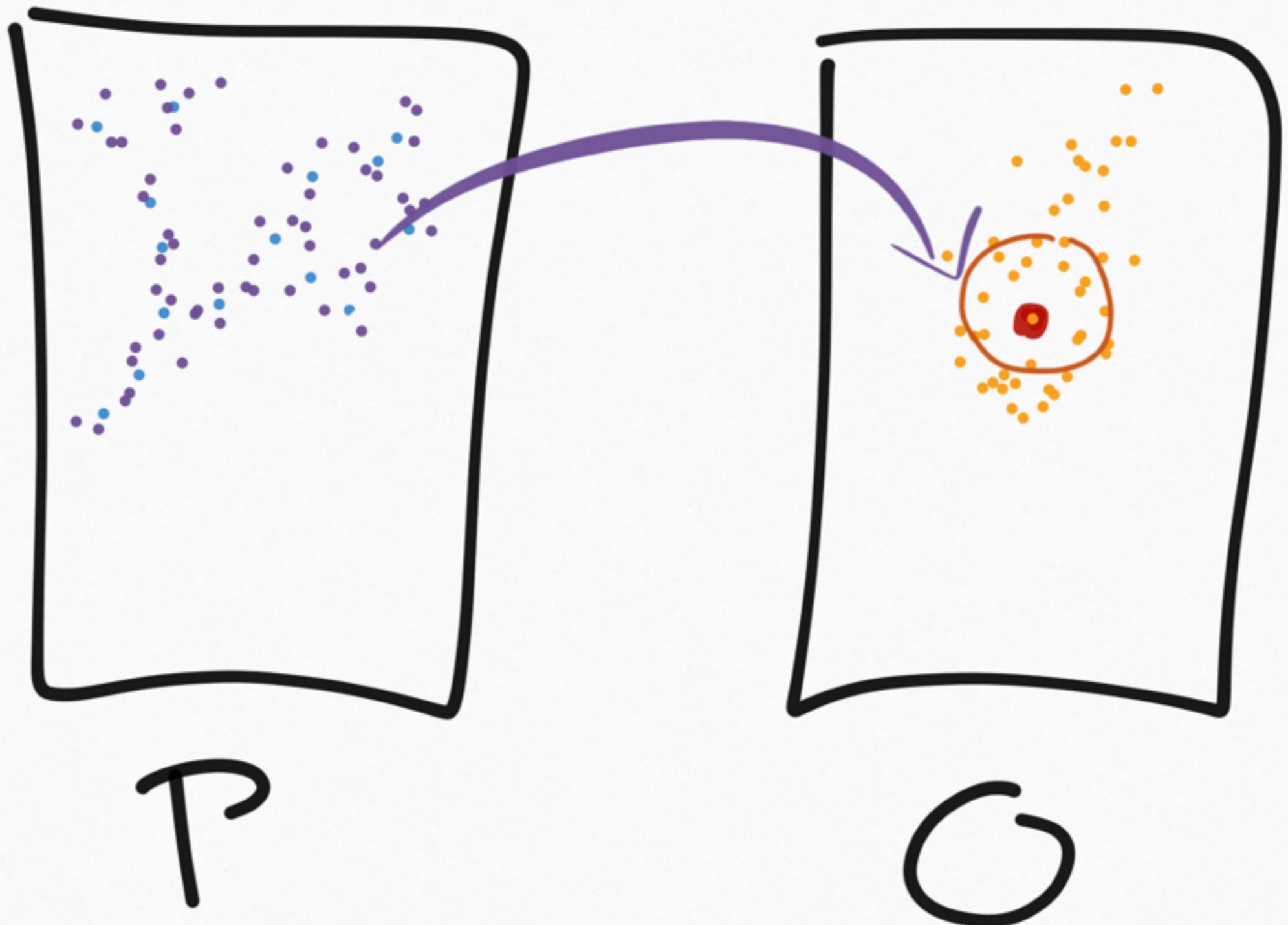
A new generation is run

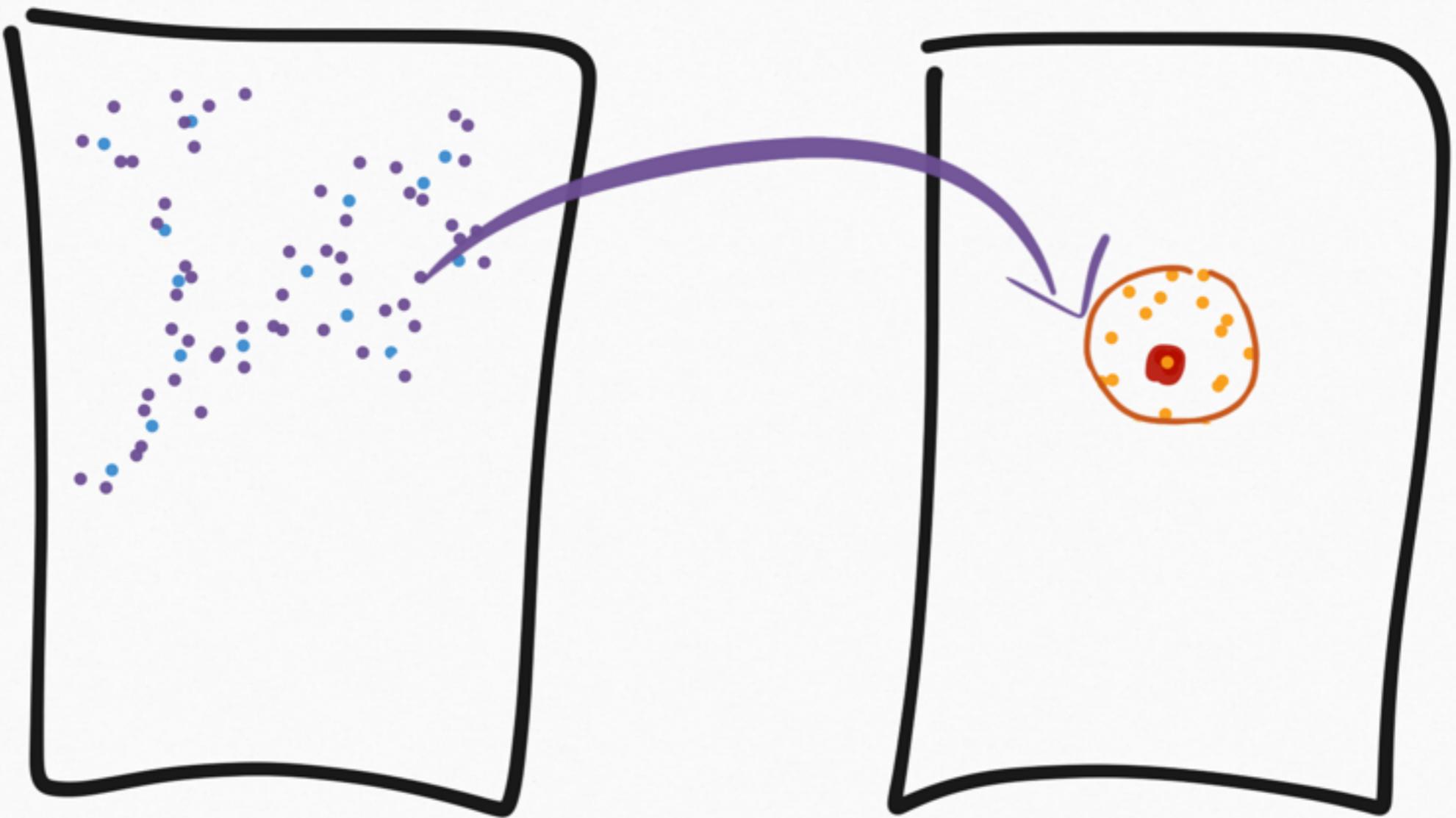


giving a new set of models in O-space



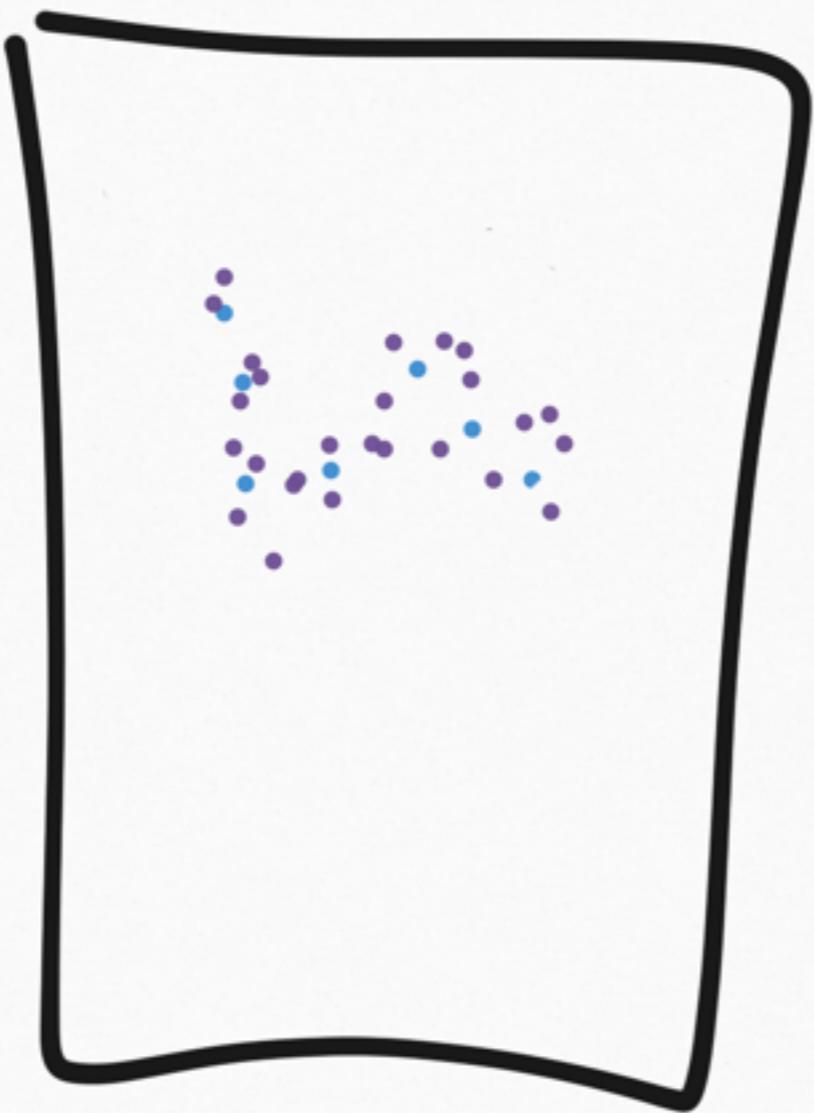
A new selection is done, more selective than the previous one



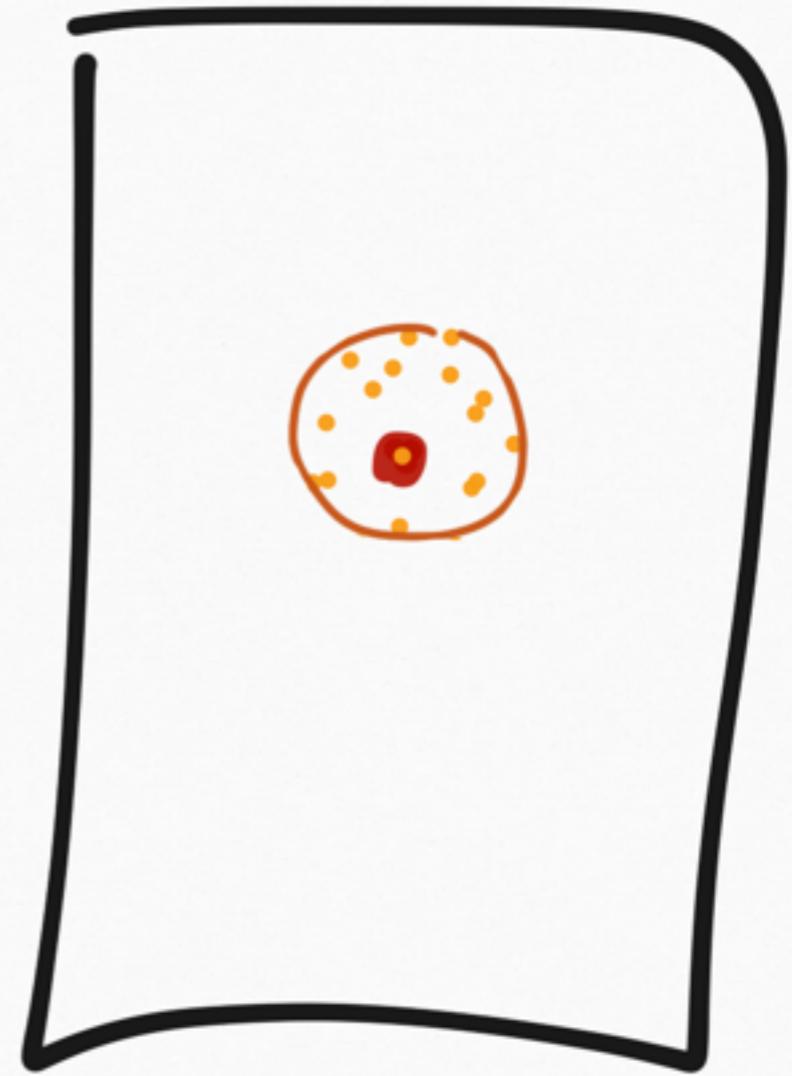


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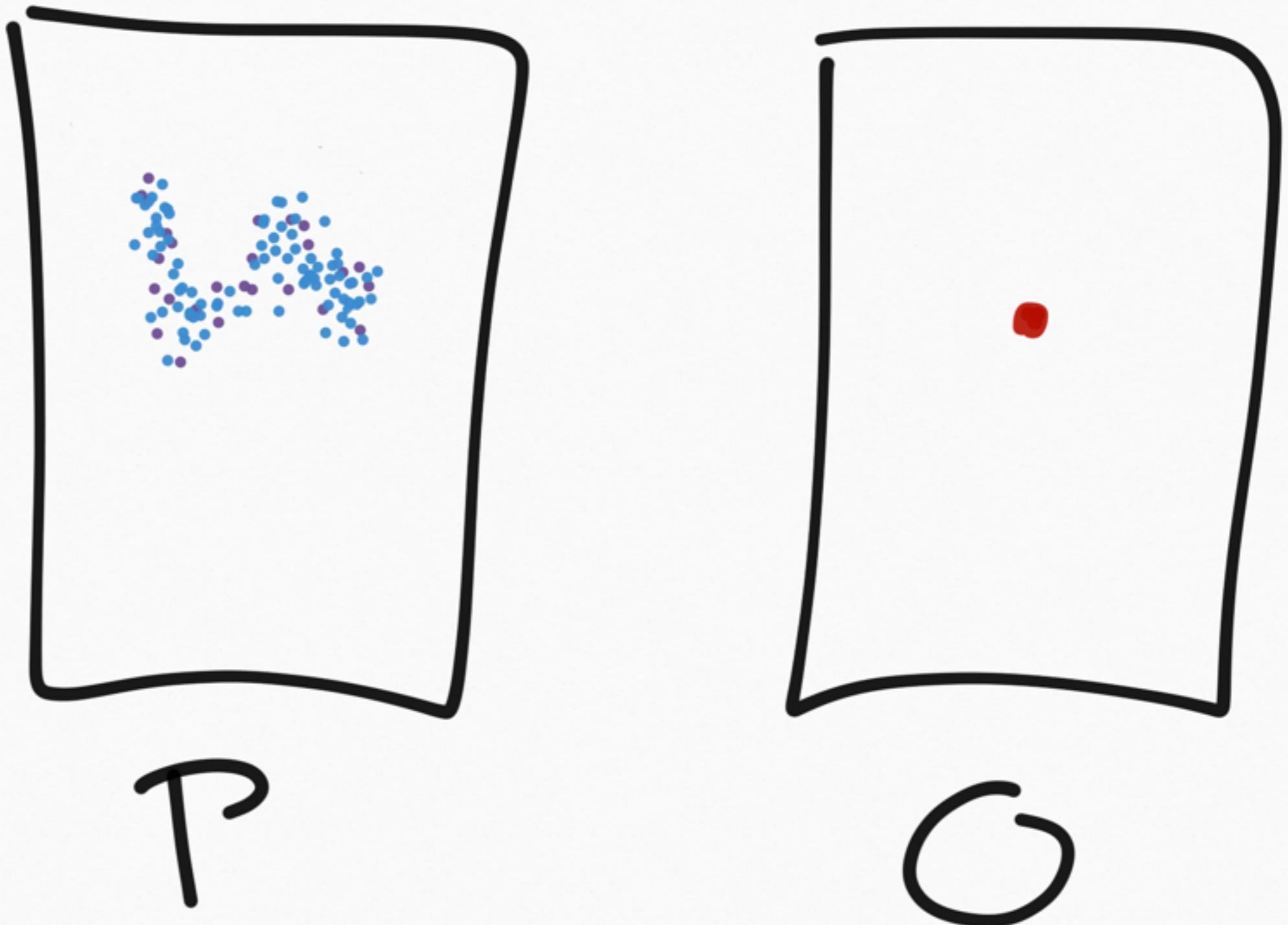


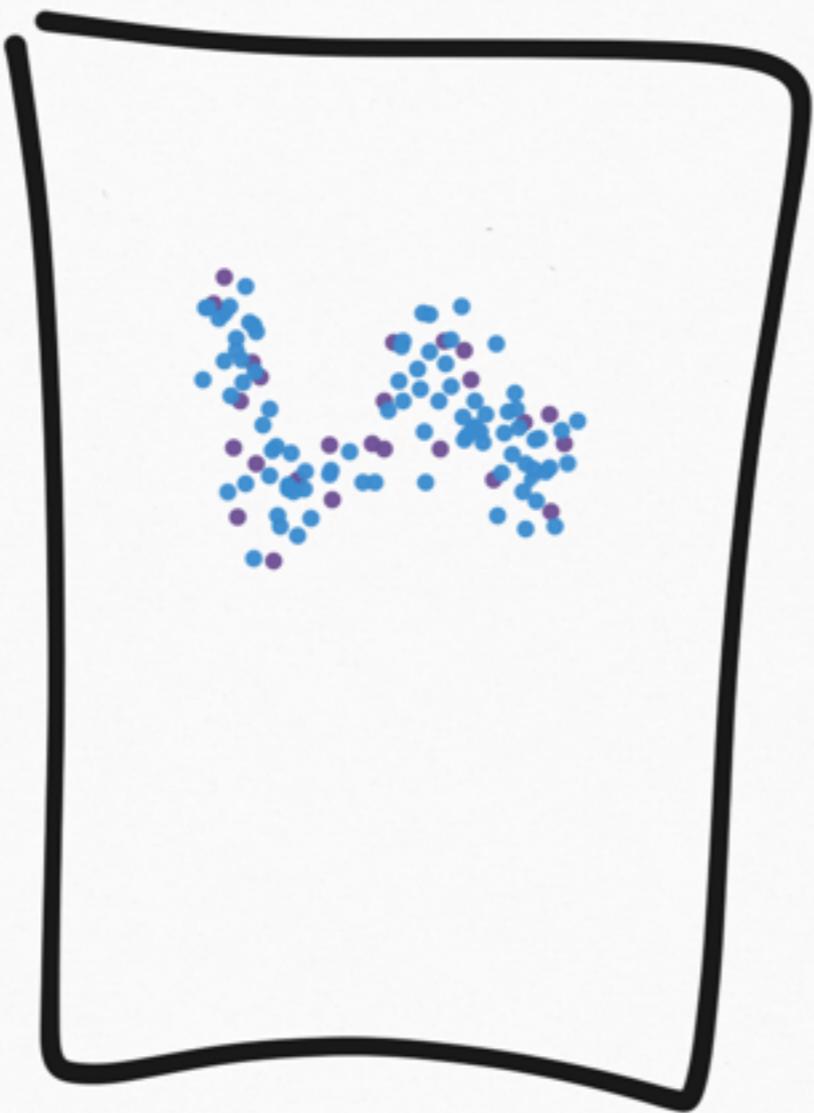
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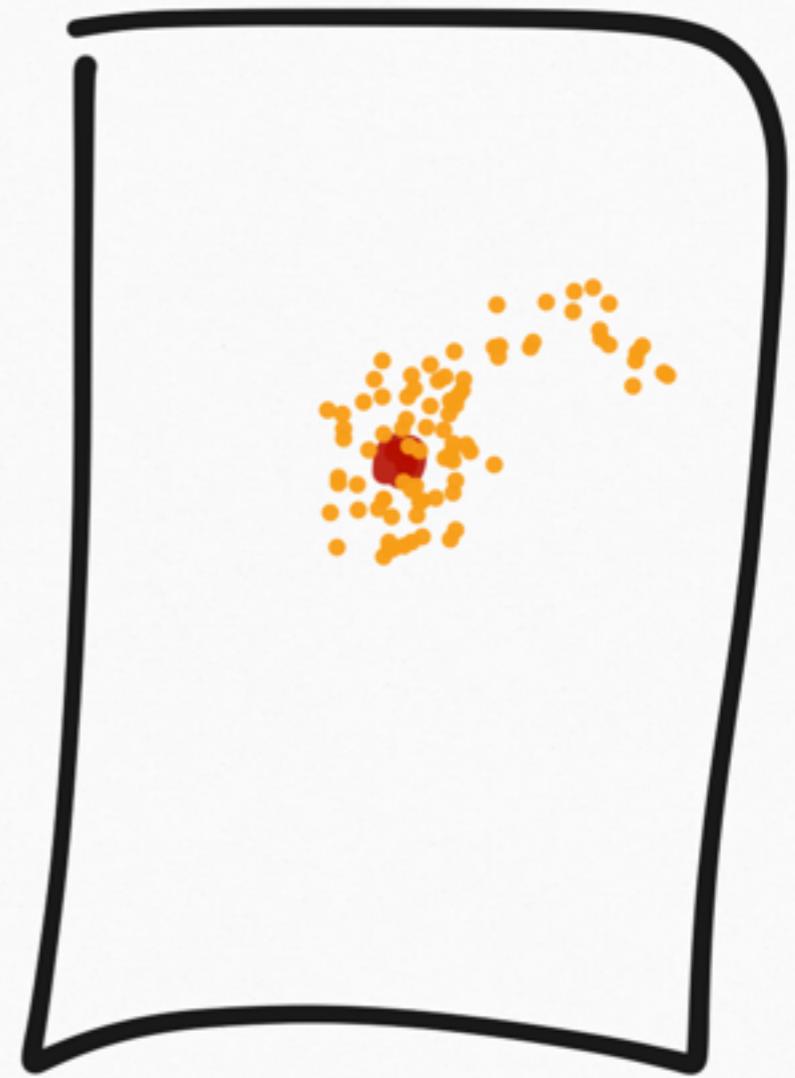
G

A new generation of children,  
closest to their parents



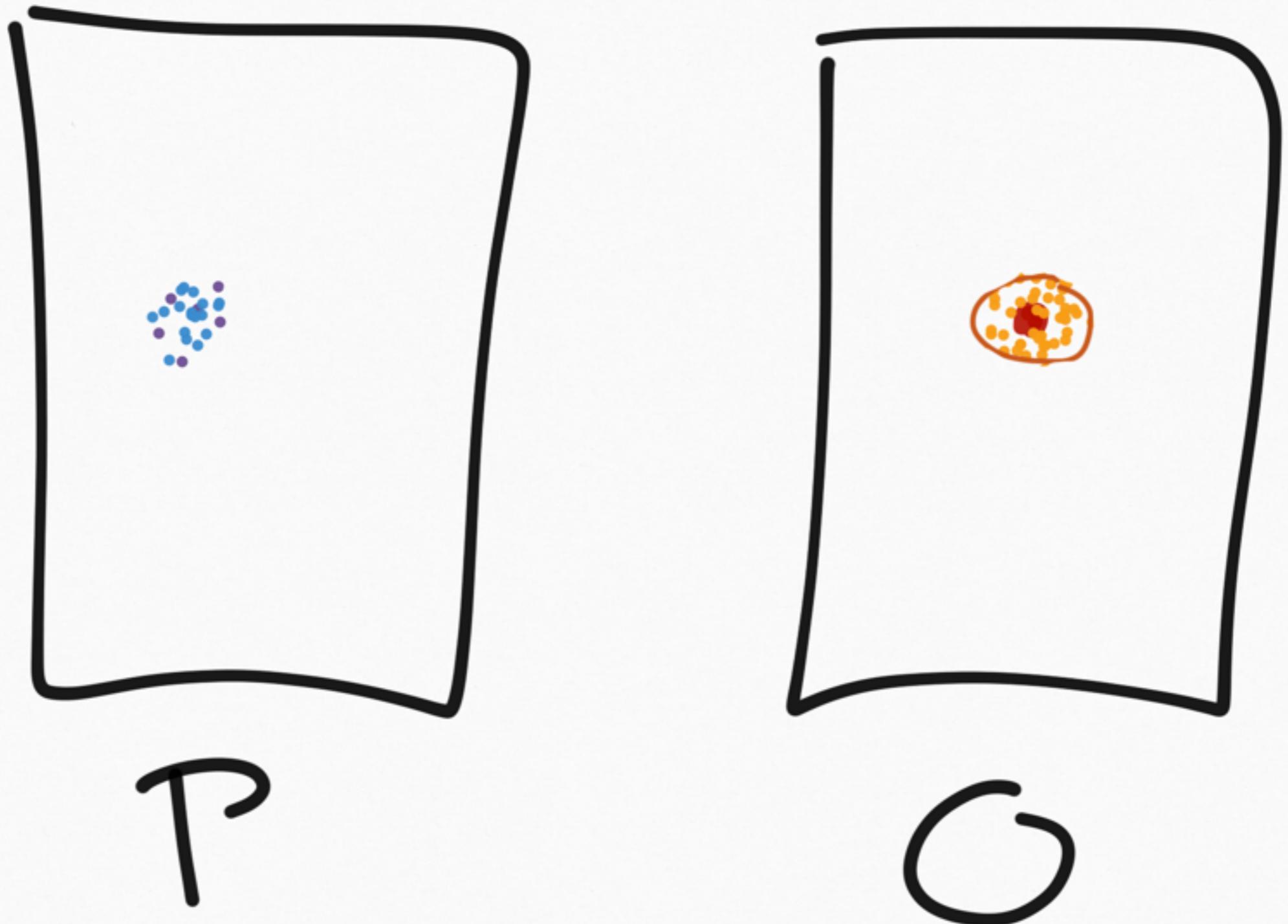


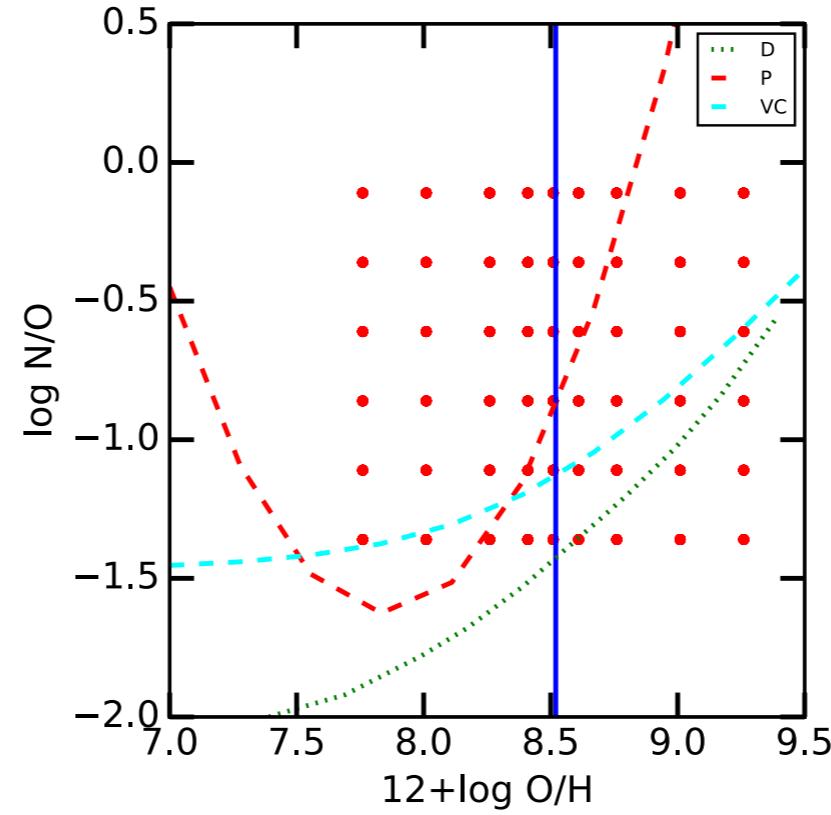
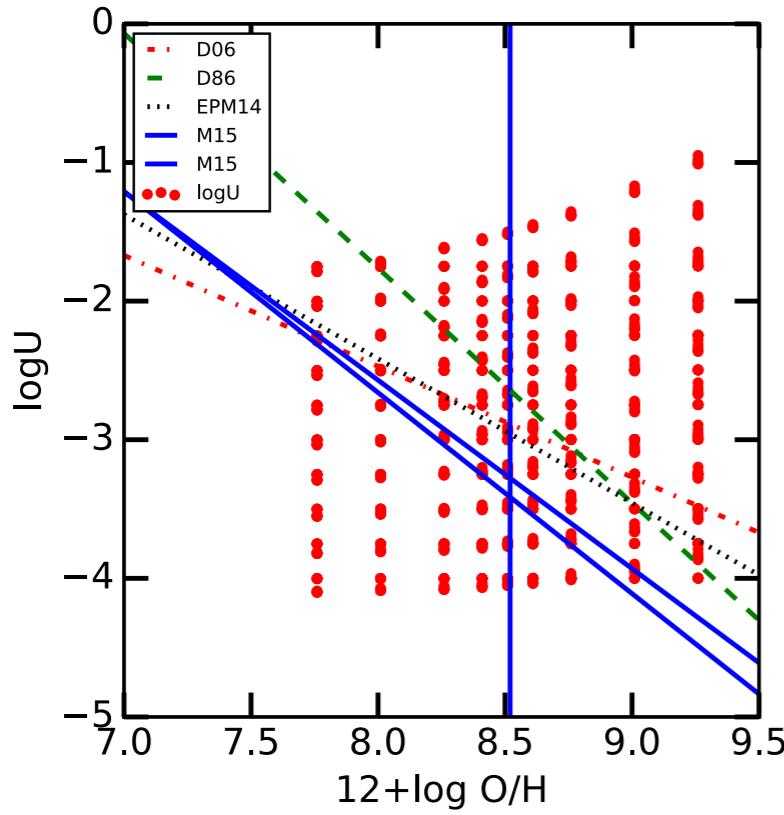
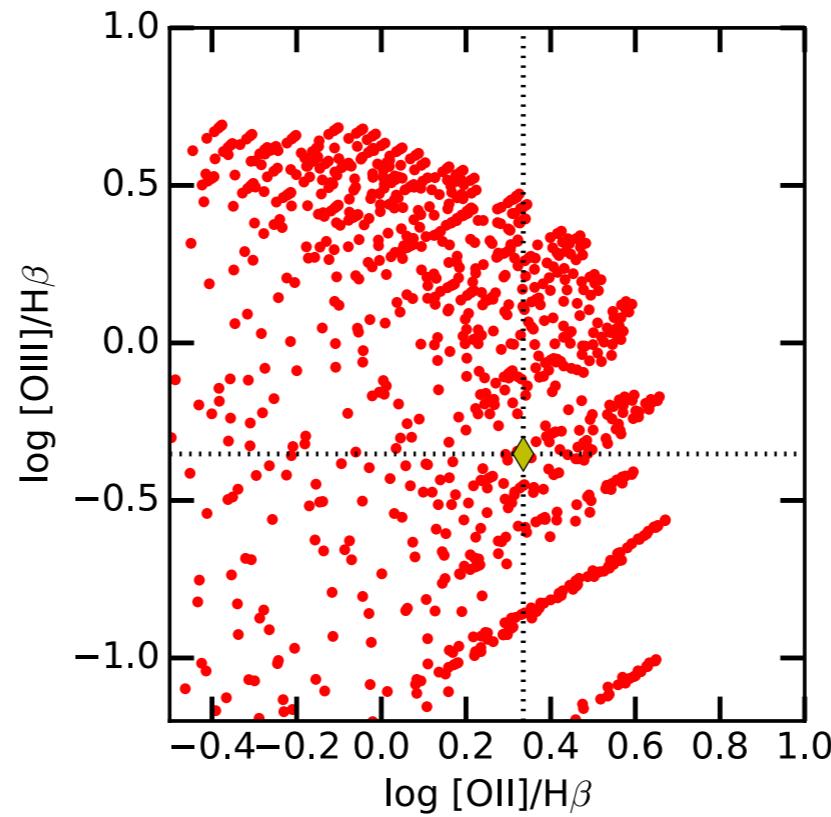
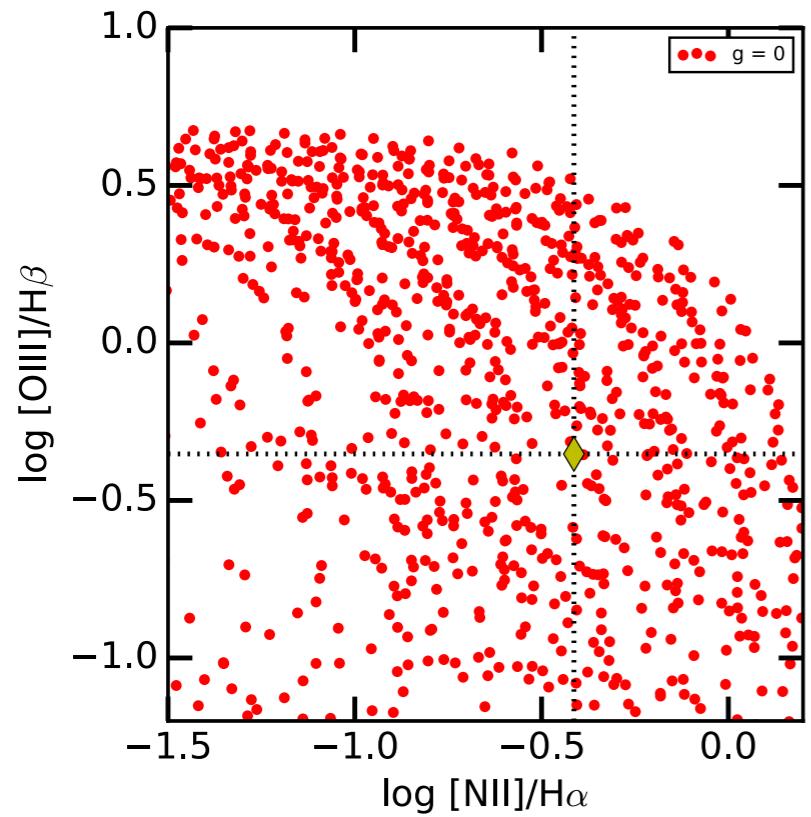
P



G

# Converging to the solution(s)



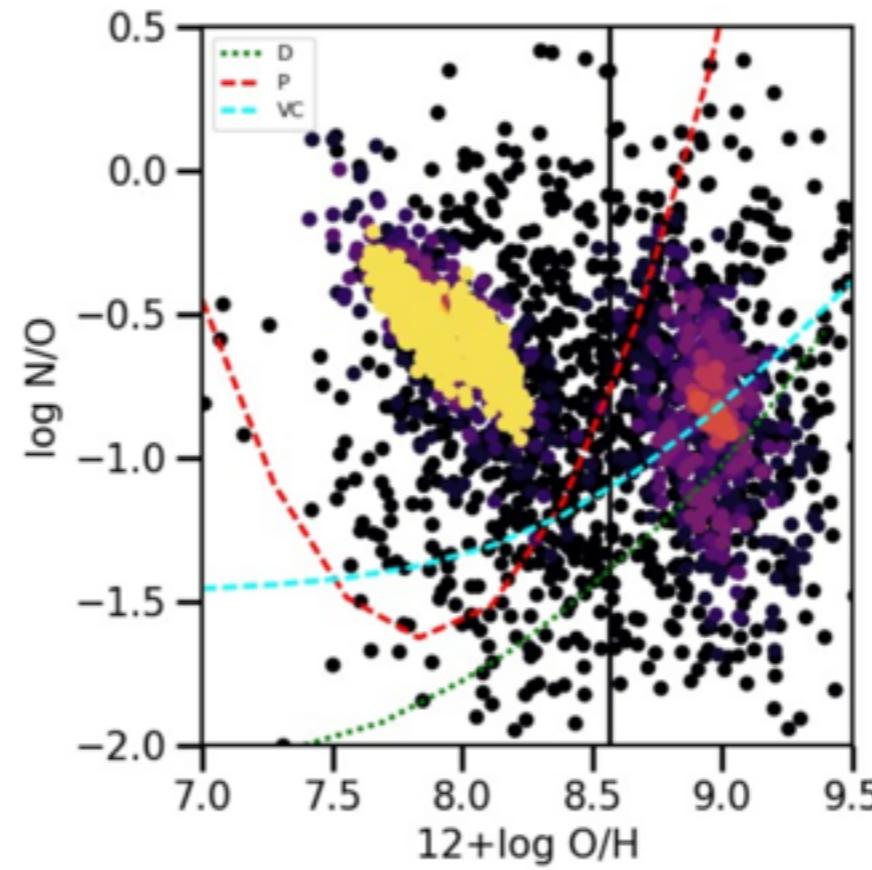
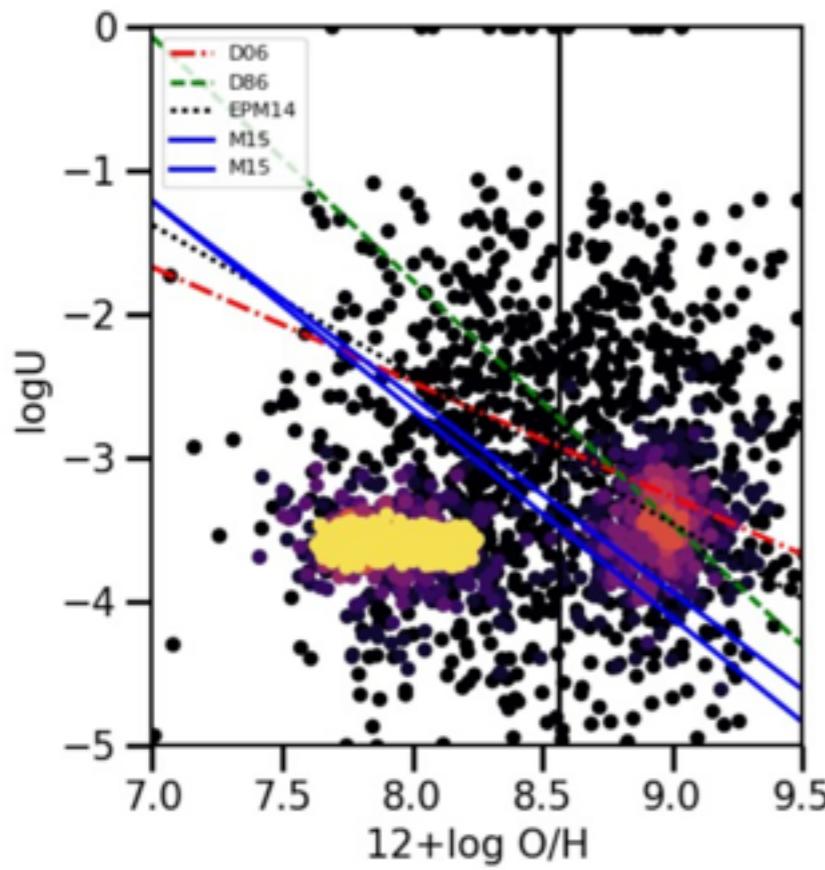
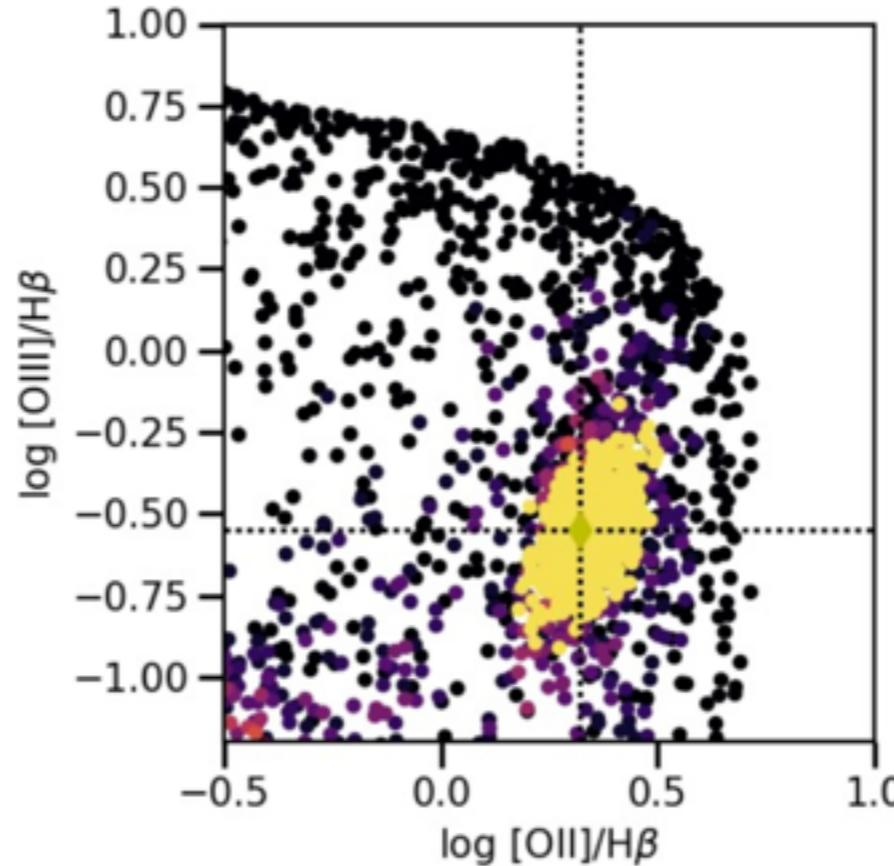
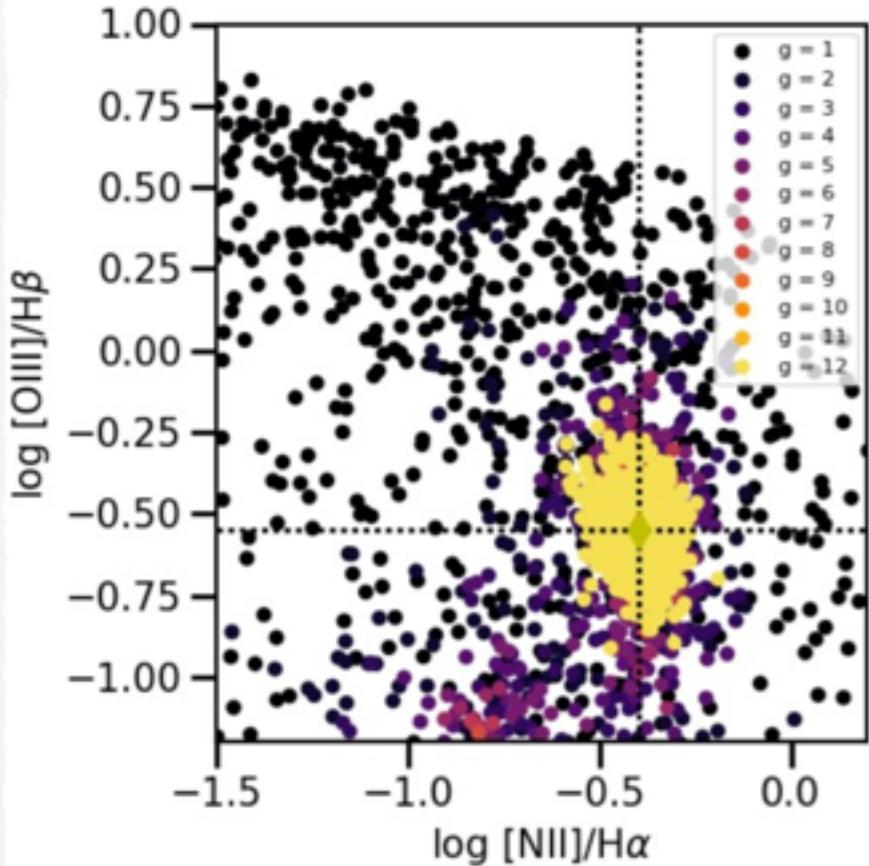


# O-space

# P-space

1st generation:

- regular grid in the P-space
- no regular in O-space : no linear

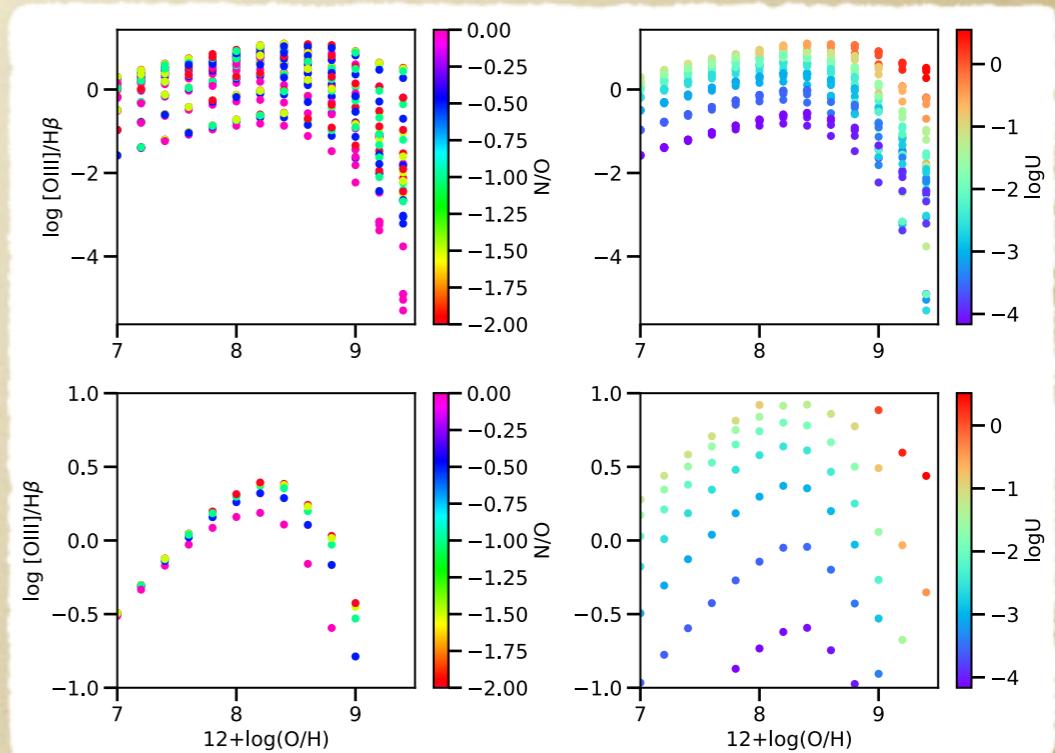


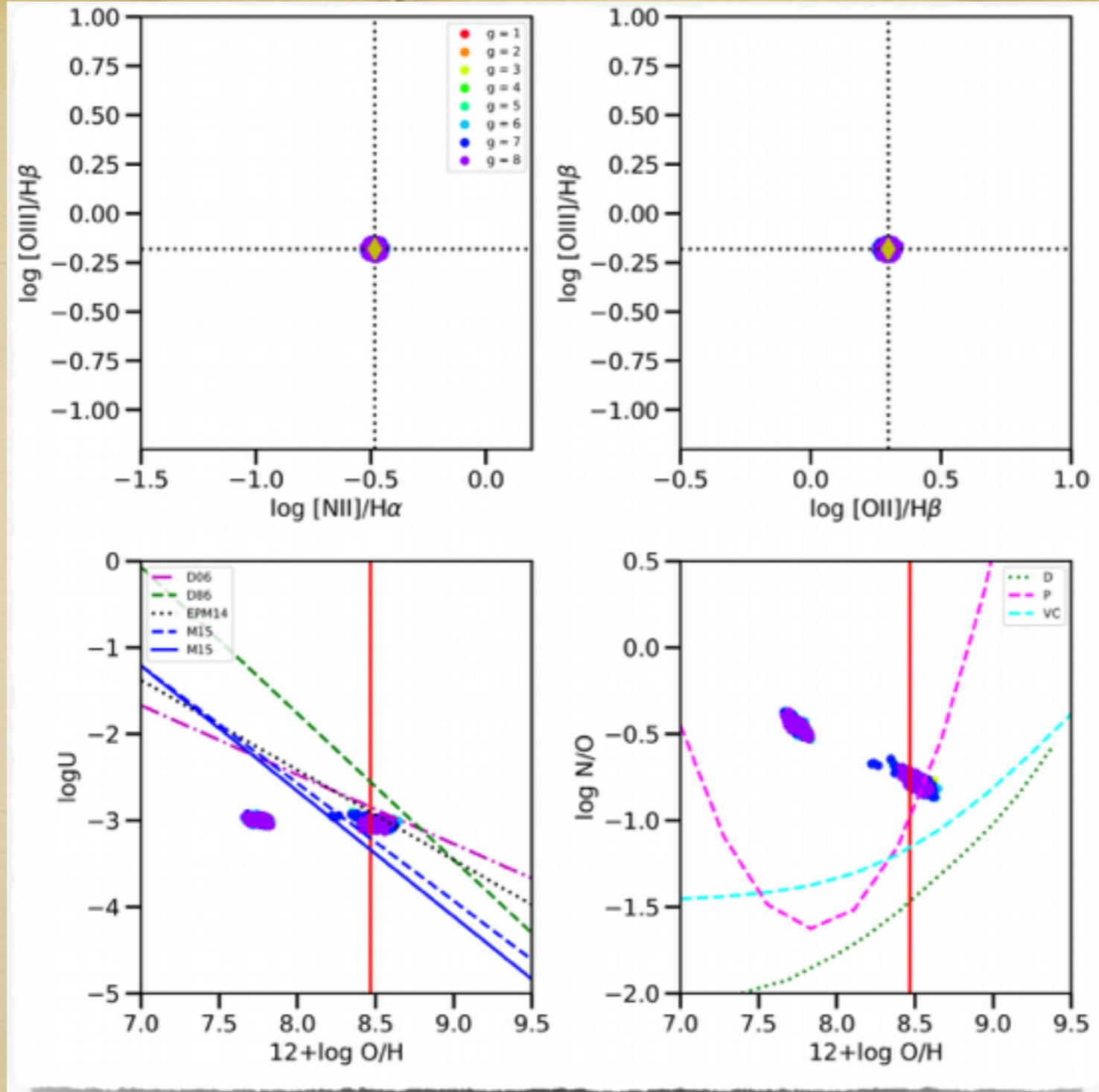
Converging to  
one or two  
solutions.

May loose a  
solution on  
the way.

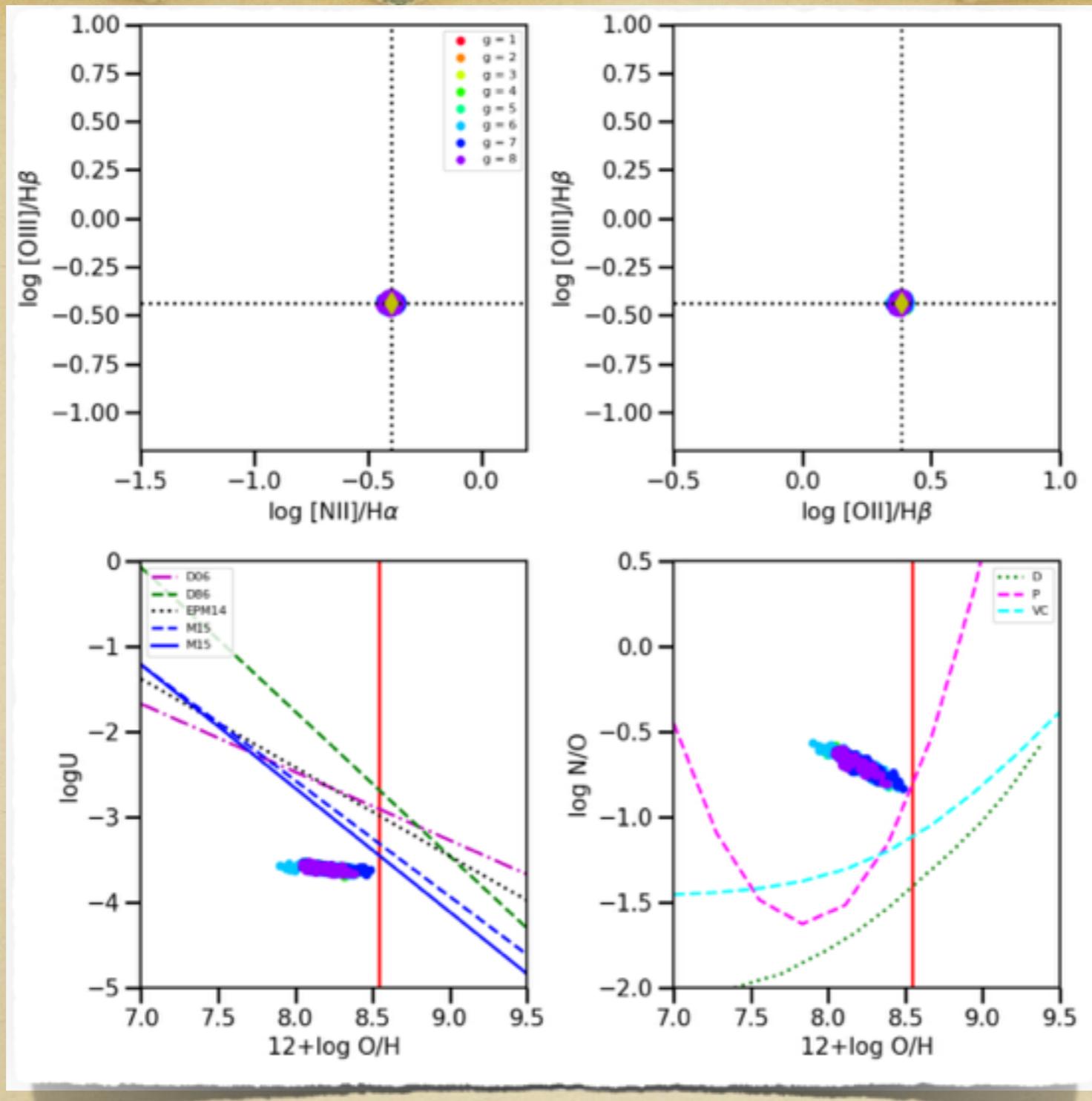
# Clustering

- ▷ To take into account the bivariate solutions, we used clustering method.
- ▷ Each dynasty evolves on its trajectory.
- ▷ No solution(s) lost.



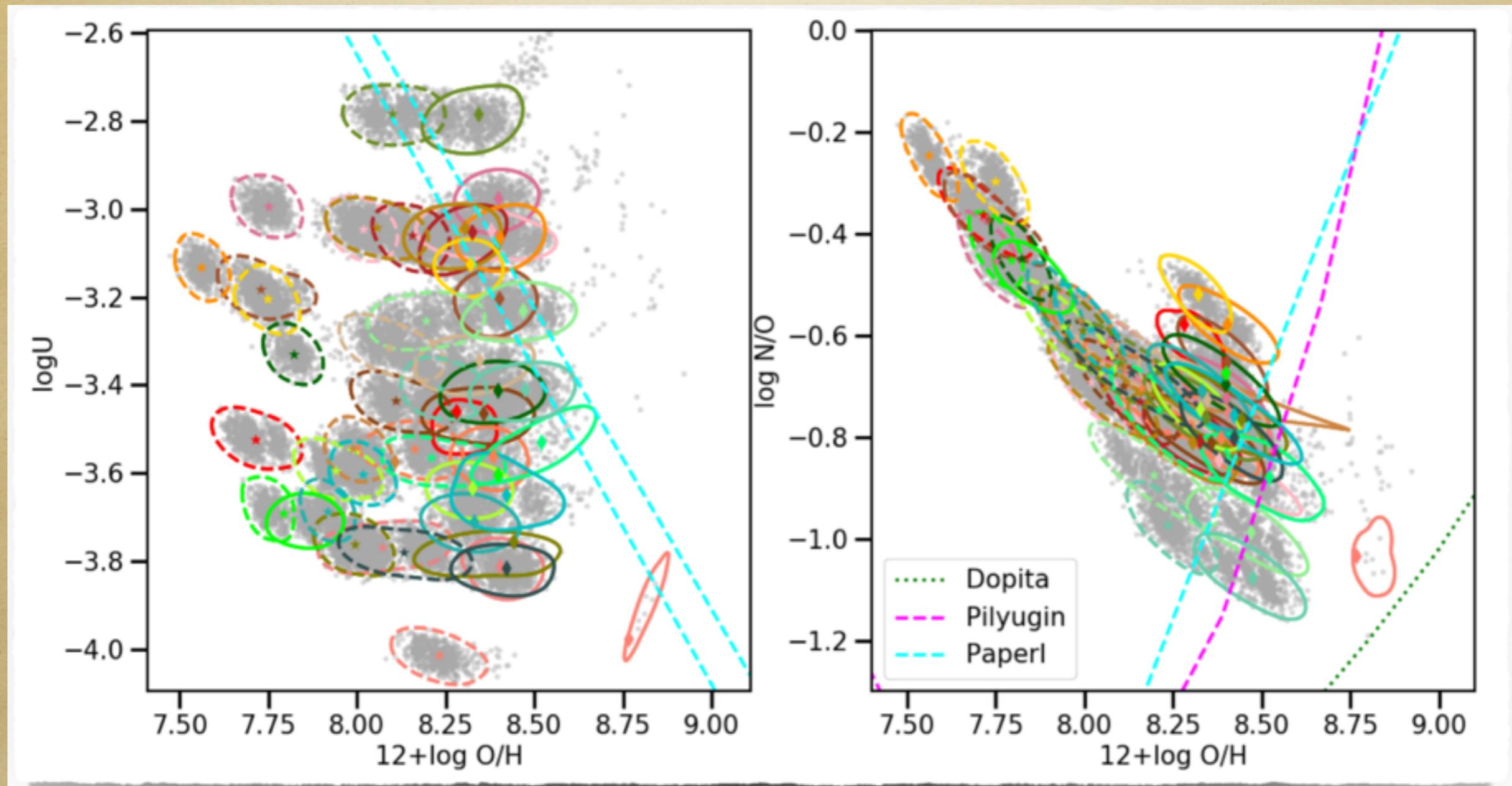


Keeping only fitting models: 2 solutions appear.

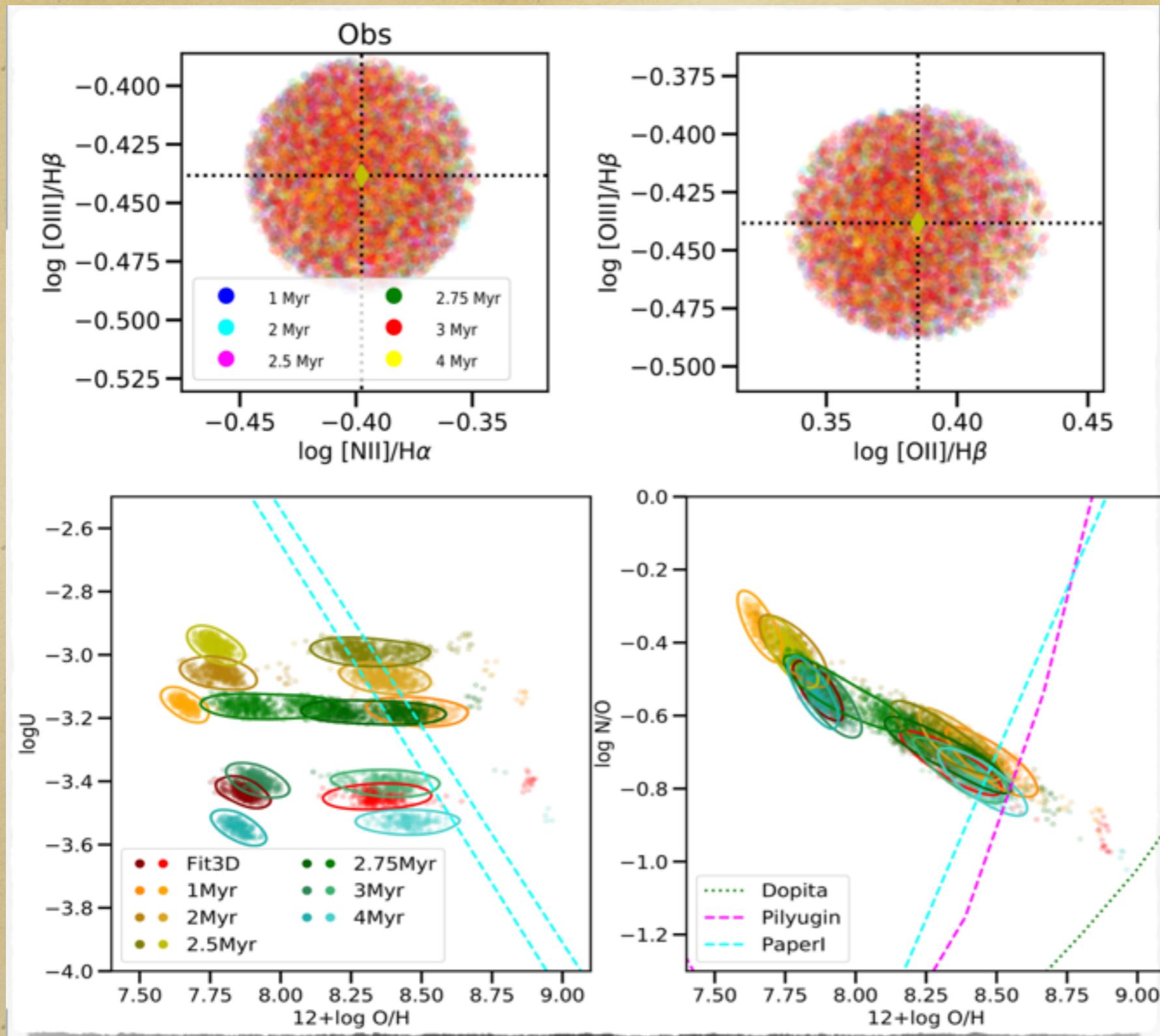


For other objects, it may also be a continuum joining the 2 solutions.

# Results



Any model can be the « right » one, centroid has no meaning.



Effect of the stellar burst age: small changes in O/H and N/O, but considerable changes in U (hardness in SED  $\leftrightarrow$  ionization state).

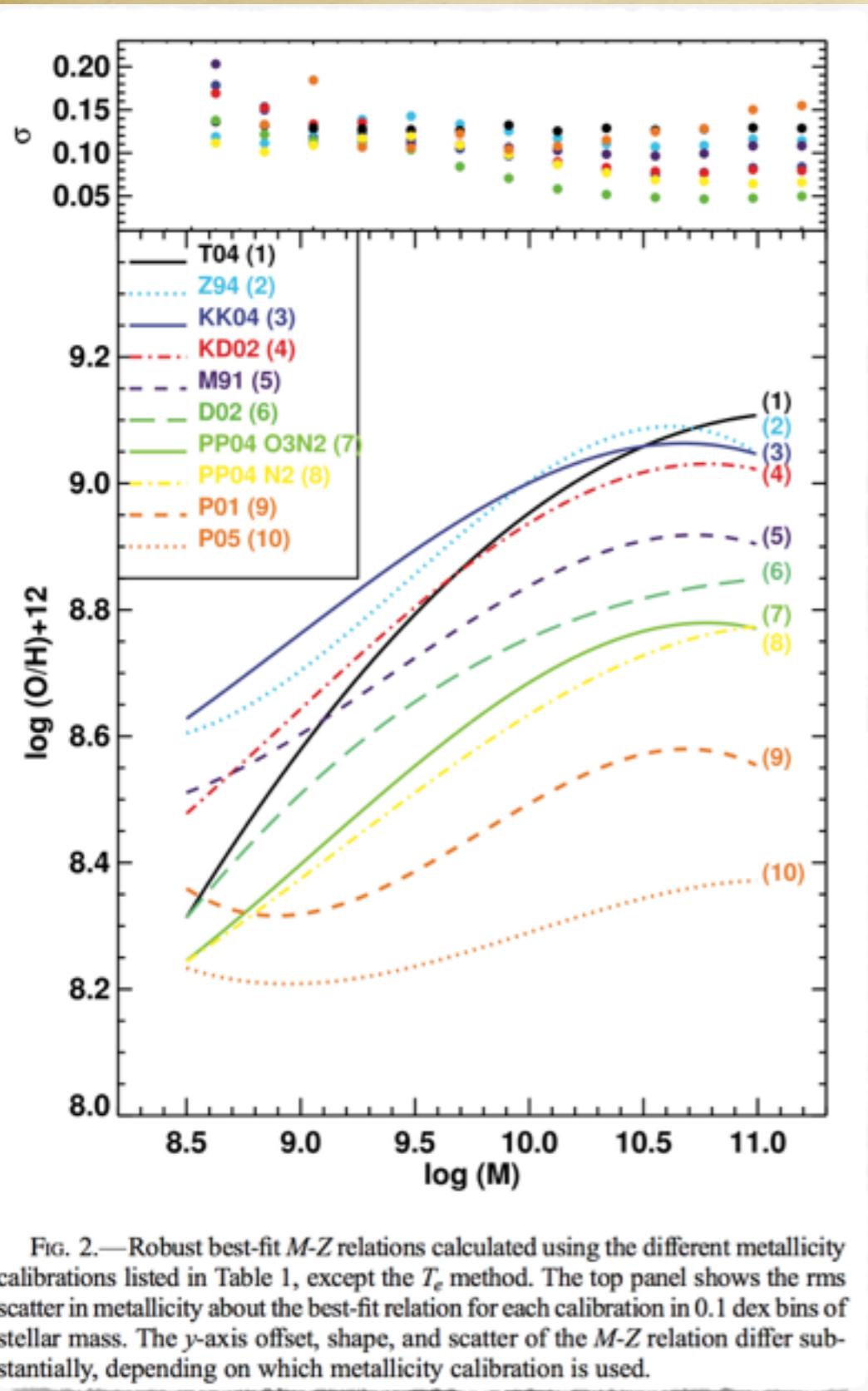
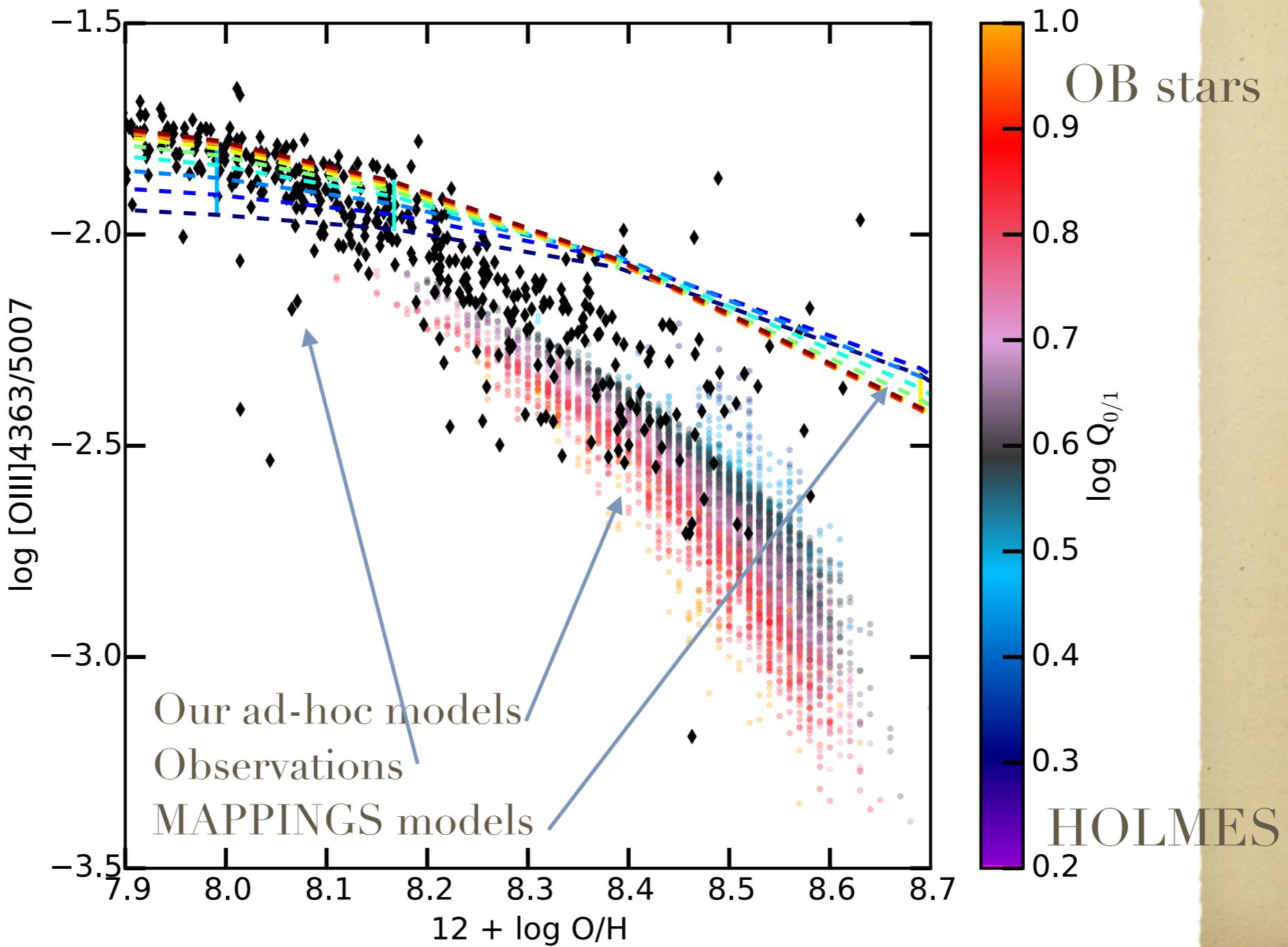


FIG. 2.—Robust best-fit  $M$ - $Z$  relations calculated using the different metallicity calibrations listed in Table 1, except the  $T_e$  method. The top panel shows the rms scatter in metallicity about the best-fit relation for each calibration in 0.1 dex bins of stellar mass. The y-axis offset, shape, and scatter of the  $M$ - $Z$  relation differ substantially, depending on which metallicity calibration is used.

## Abundance discrepancies (the other one)

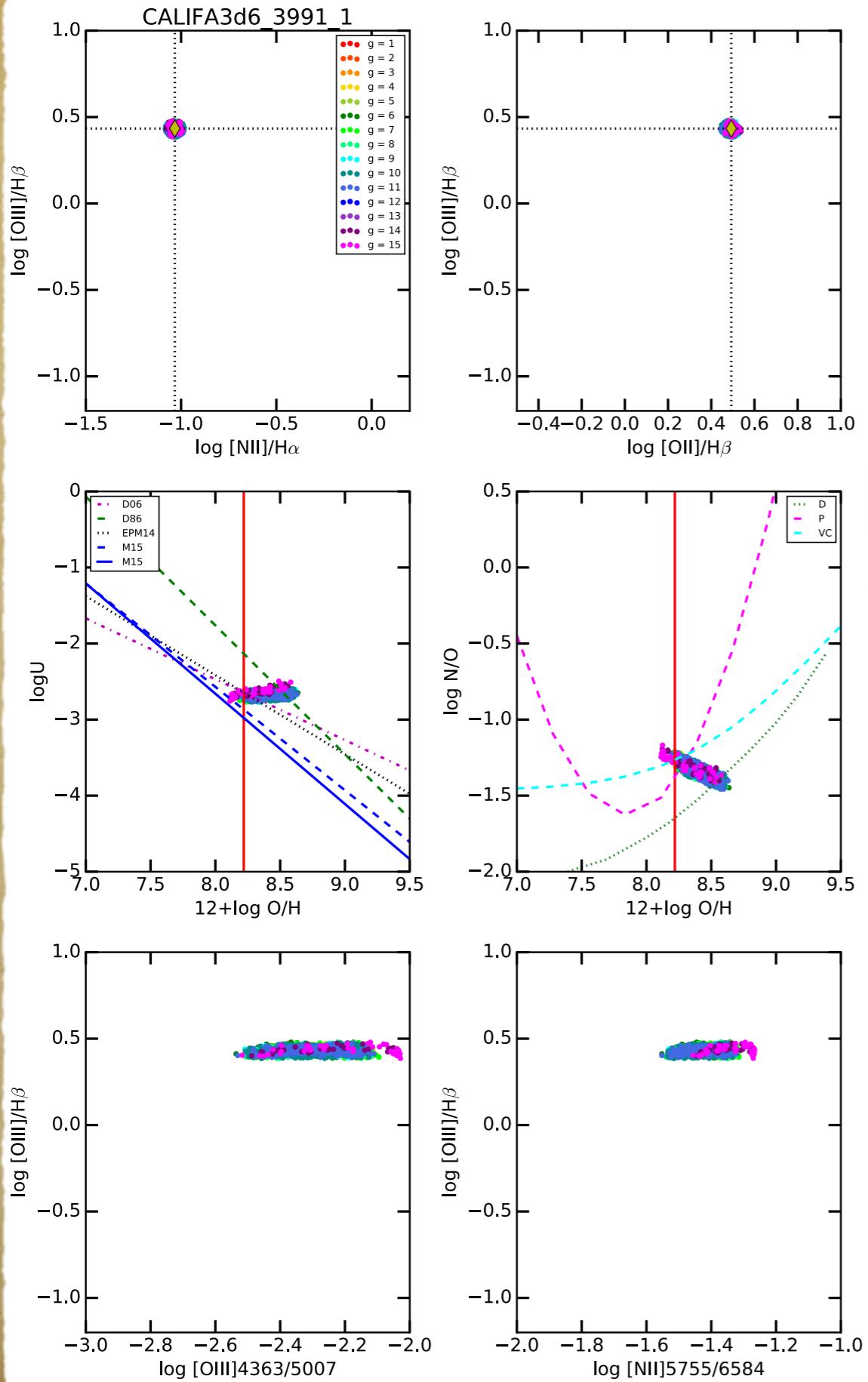
- ▷ Since Kewley+08 we face a discrepancy between abundances determined using empirical calibrators and fotoionization models, the latest being higher.

# [OIII] 4363/5007



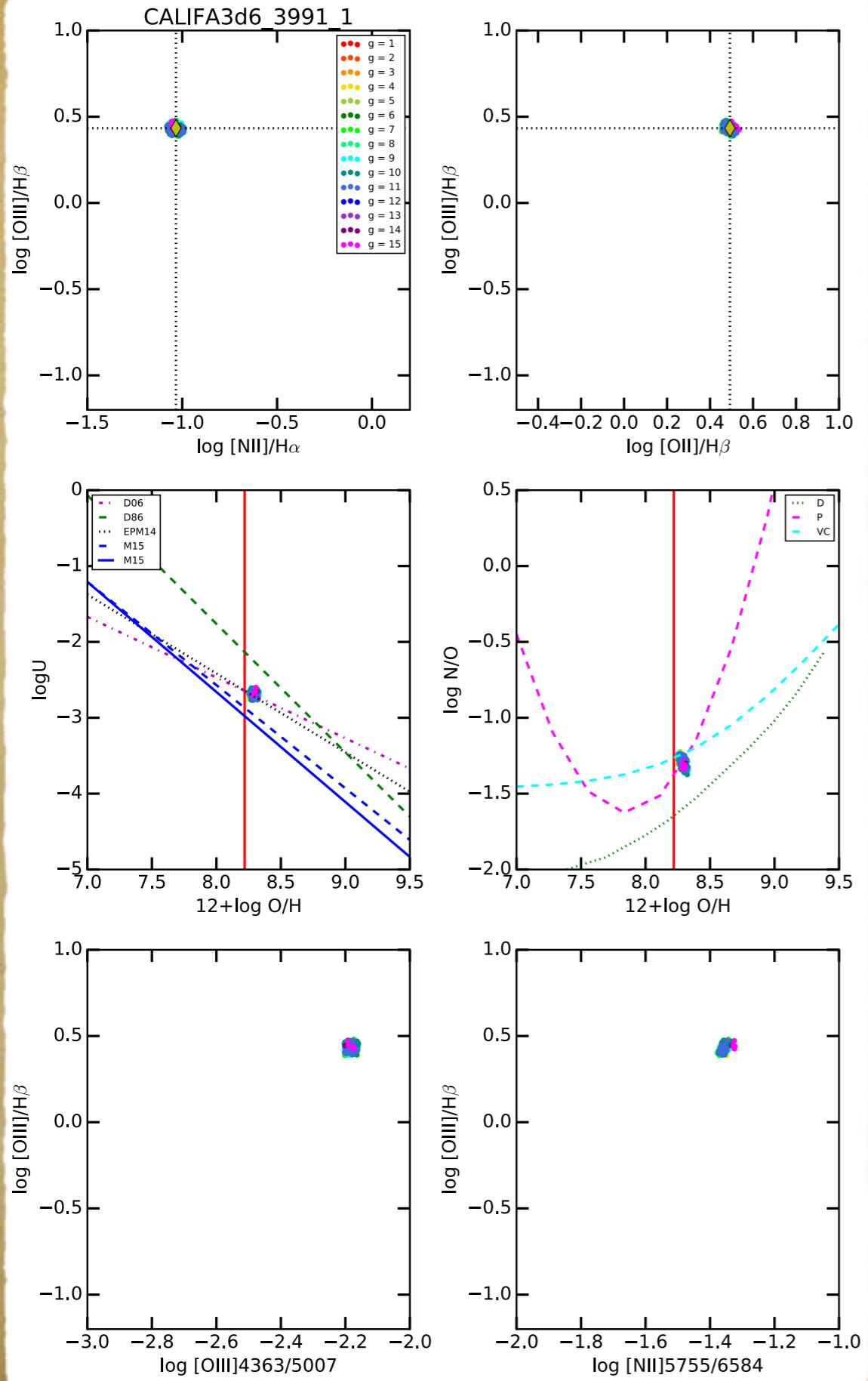
# What happens if we add [OIII]4363?

We select the only few 5 regions with [OIII]4363 well observed, and add the fitting of its intensity as posterior constraint.



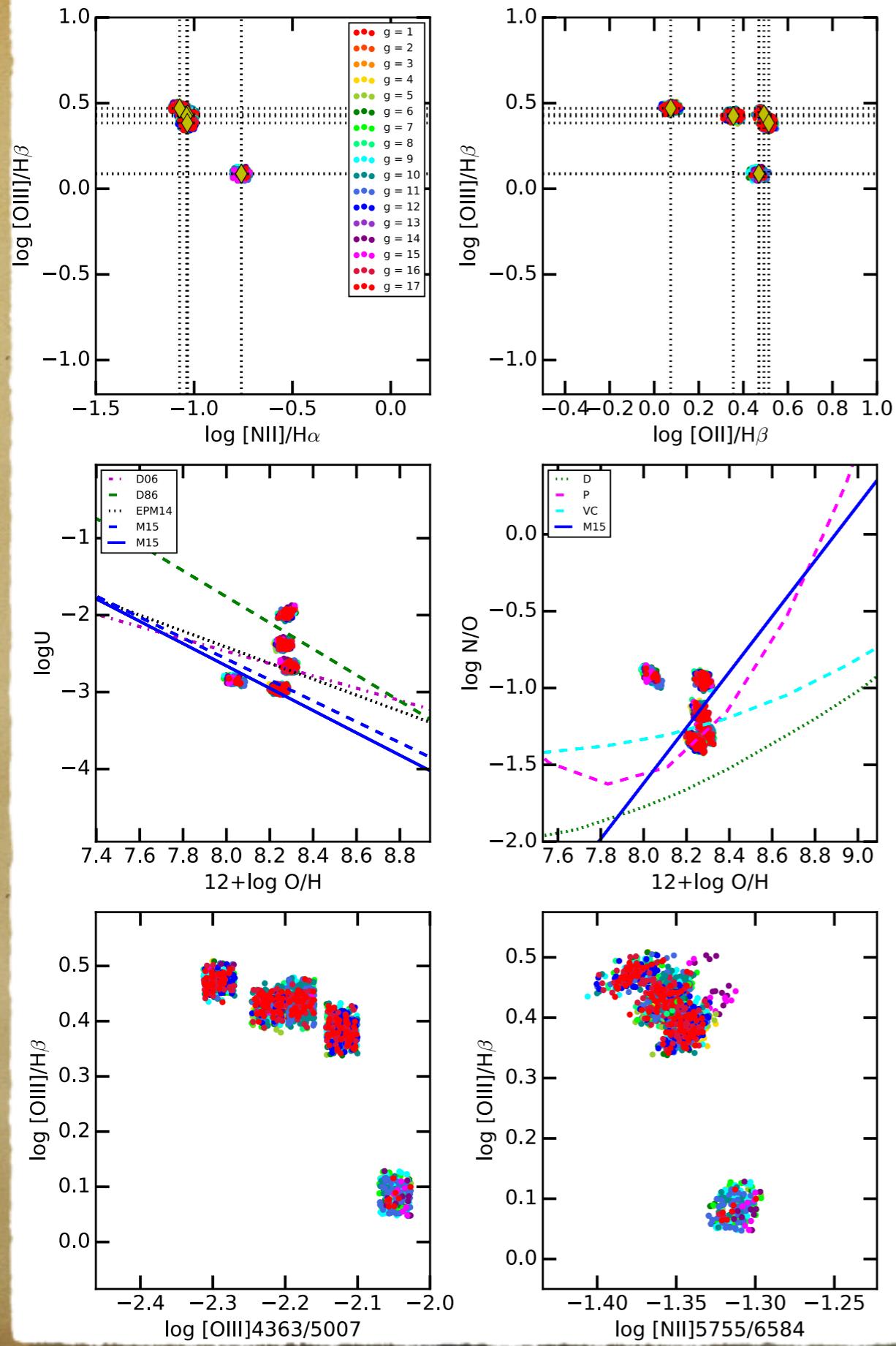
The different solutions present a significant scatter on  $[\text{OIII}]_{4363}$  and  $[\text{NII}]_{5755}$ .

This may be used to determine which one is the right one.



Once  $[\text{OIII}]4363$  is used as additional constraint, a single solution in  $\log U$ ,  $N/\text{O}$  and  $\text{O}/\text{H}$  appears.

This solution is compatible with the Pilyugin and Maroni relations, and NOT with the Dopita's one.



# 5 regions

# Effect of the SED

- ▷ The same results are obtained when using **Starburst99** instead of **Popstar**, and using old populations, or new ones with **rotation**.
- ▷ The difference between our new results and the ones obtained by the Australian group should be explored.
- ▷ The problem is in the equilibrium Te: differences in the **heating** (SED?) or in the **cooling** (atomic data?).

# Future work

## WORK IN PROGRESS (Carlos Espinosa PhD)

- ▷ CALIFA DR for the emission lines: more regions with auroral lines.
- ▷ Need to redo the job more carefully for all the available regions.
- ▷ Explore the possible reasons of the discrepancies.

*Thank you so much  
Mike  
for this wonderful  
conference!!!*

