

## Fiorella Lucia Polles

### Studies:

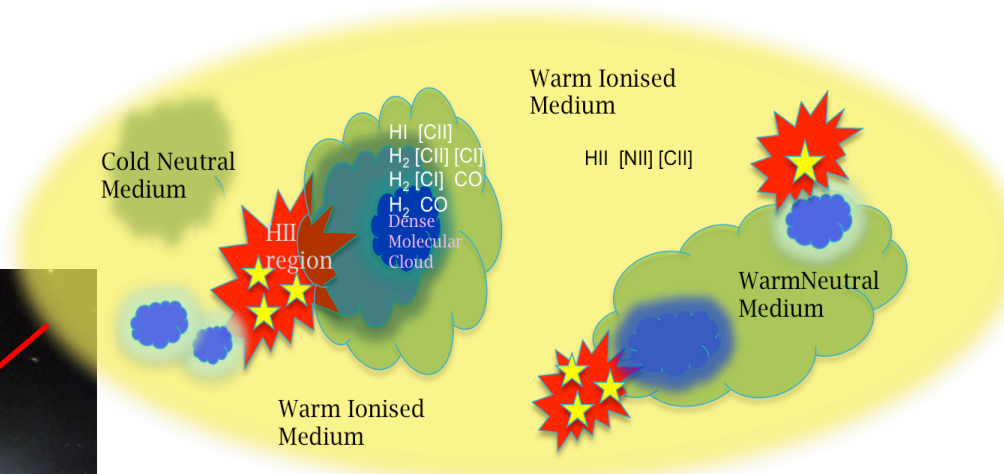
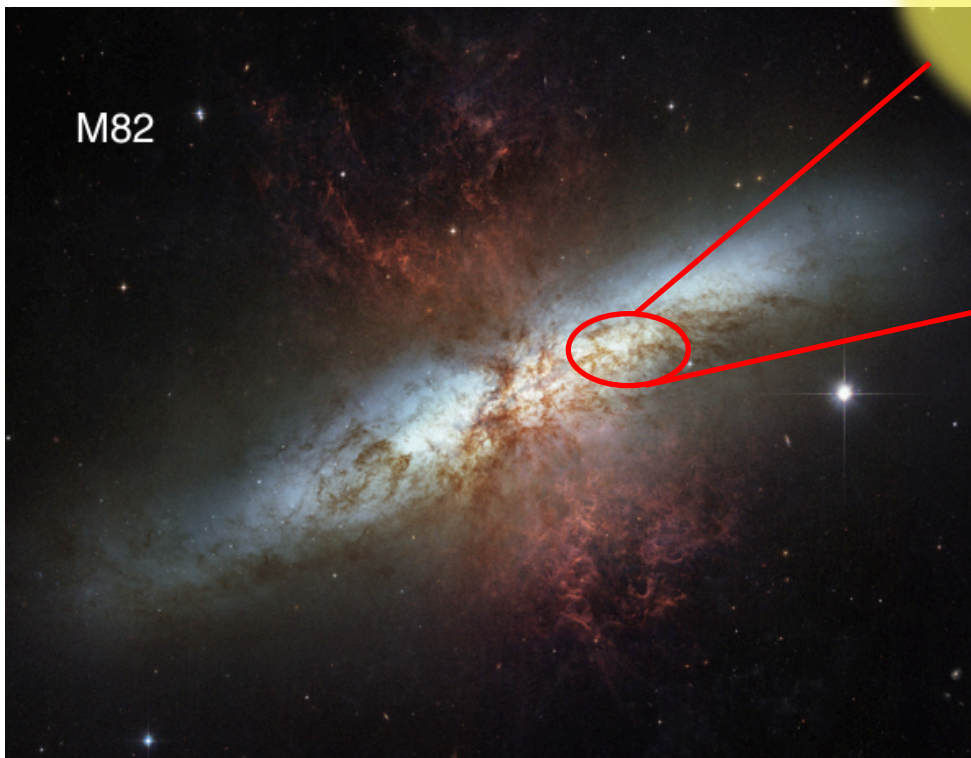
- Bachelor degree in Physics, 2011, University Milano-Bicocca, Milan, Italy
- Master degree in Astrophysics, 2014, University Milano-Bicocca, Milan, Italy

### Why CEA/Irfu/Sap?

I was looking for a PhD position in Europe. I found the project proposed by Suzanne Madden very interesting because it involves observation and modeling on the study of galaxies

## Modeling the Interstellar medium of Starburst Galaxies

Starburst galaxies: galaxies showing high star formation activity



Interstellar Medium (ISM): is the gas and dust that exist in the space between the stars in a galaxy

Advisor: Suzanne Madden



## Why this project?

- What are the **physical conditions of the gas and dust** in the different galactic phases in the wide variety of galaxies?
- How do **metallicity<sup>1</sup>, star formation activity, relative fraction of ISM phases**, etc. affect the local condition of star formation and ISM within galaxies?
- Which is the **best strategy to model the ISM**?

<sup>1</sup> **Metallicity** (Z) is the mass fraction of the galaxy that is not hydrogen or helium

- Introduction
  - I. Galaxy: stars, dust and gas
  - II. Low-metallicity galaxies
  - III. Pilot of our project: IC10
- Modeling IC10 ISM
  - I. Data set
  - II. Different tracers for different ISM phases
  - III. Cloudy: photodissociation and photoionization code
  - IV. Modeling the first phase: ionized gas
- Future work



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Recycling:  
fragmentation and  
condensation

STARS

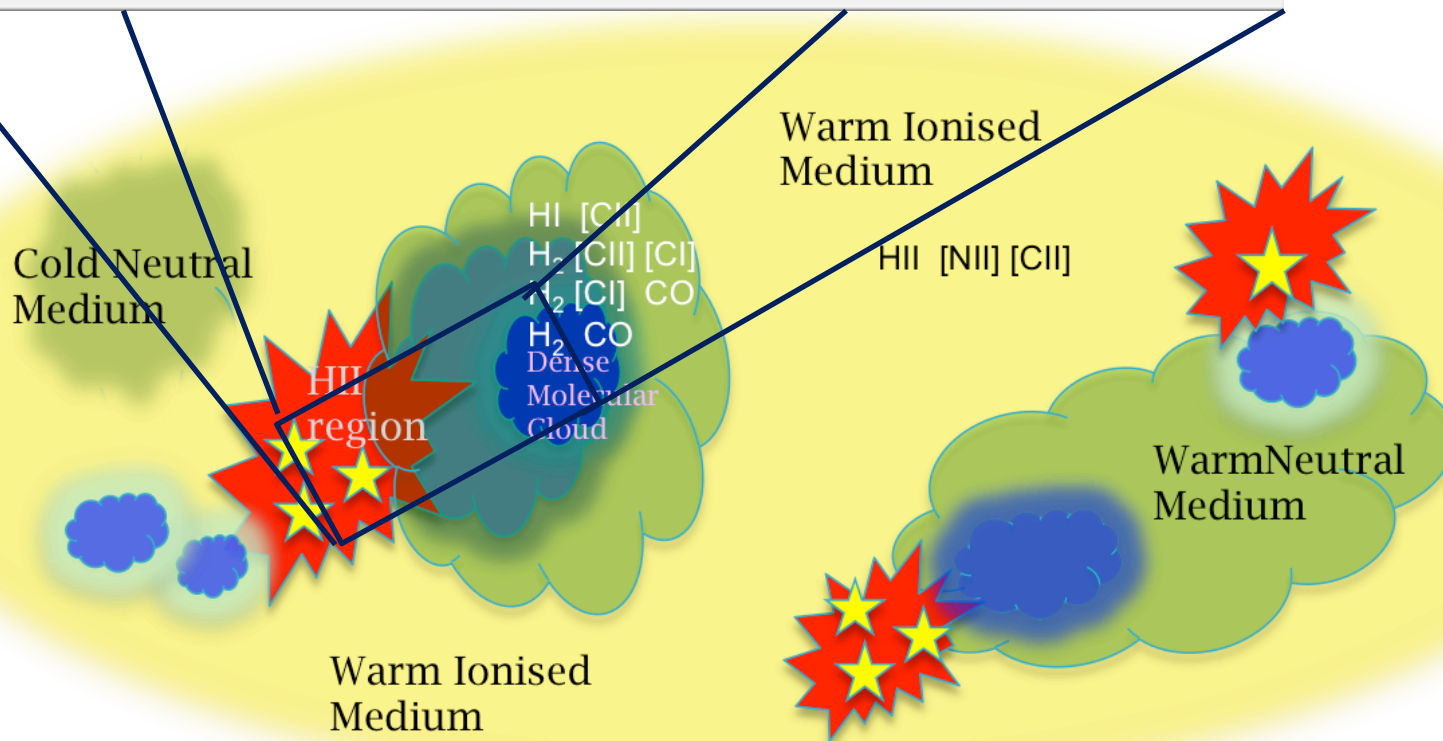
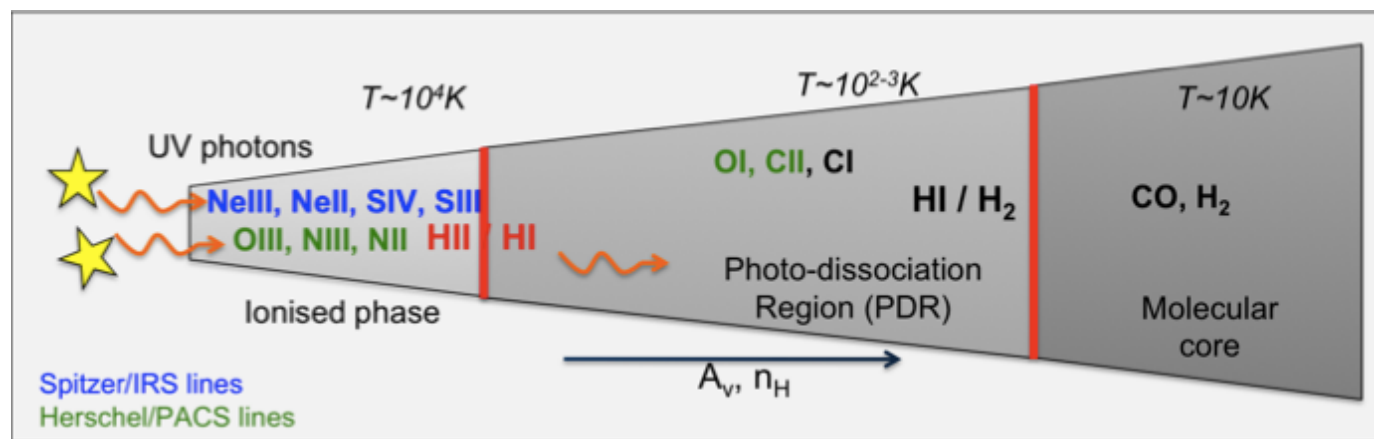
Stellar  
evolution

ISM =  
gas + dust

Dispersal and  
mixing

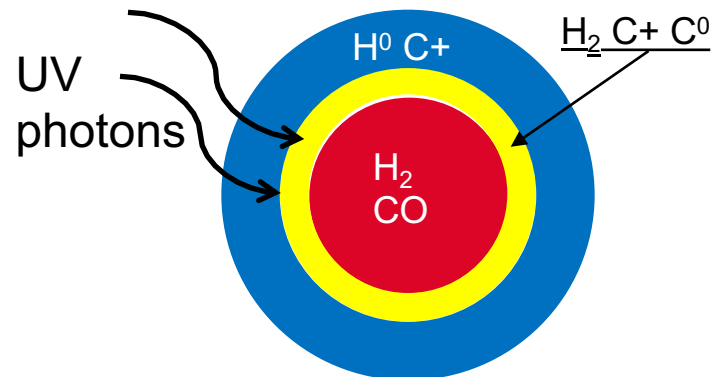
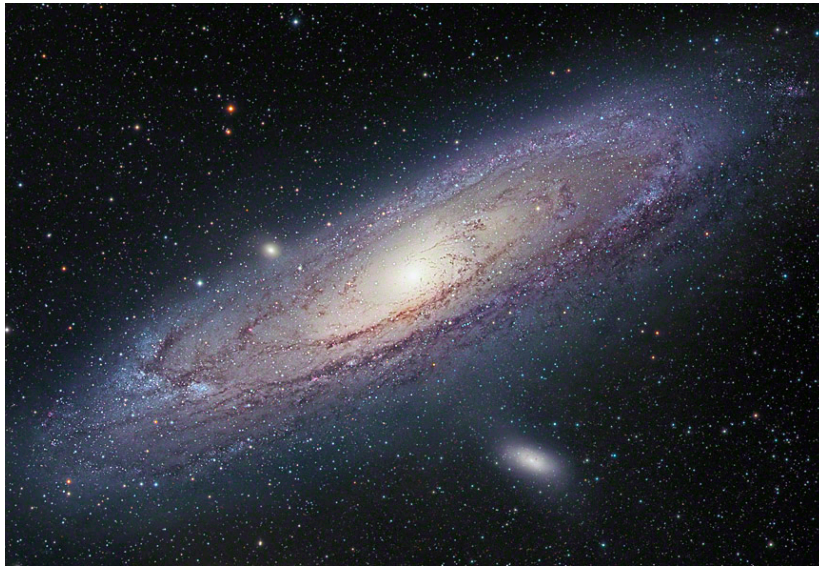
SUPERNOVA

# THE COMPLEX MULTIPHASE INTERSTELLAR MEDIUM (ISM) OF GALAXIES

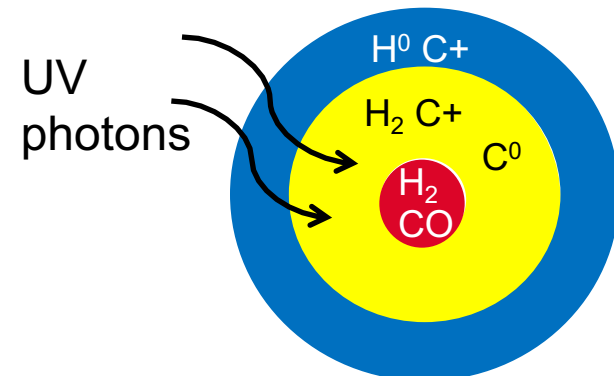
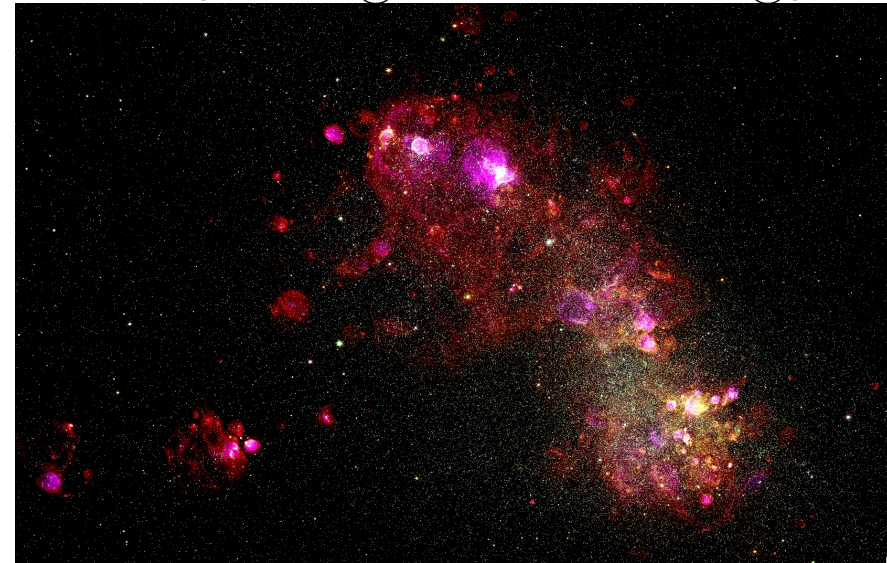




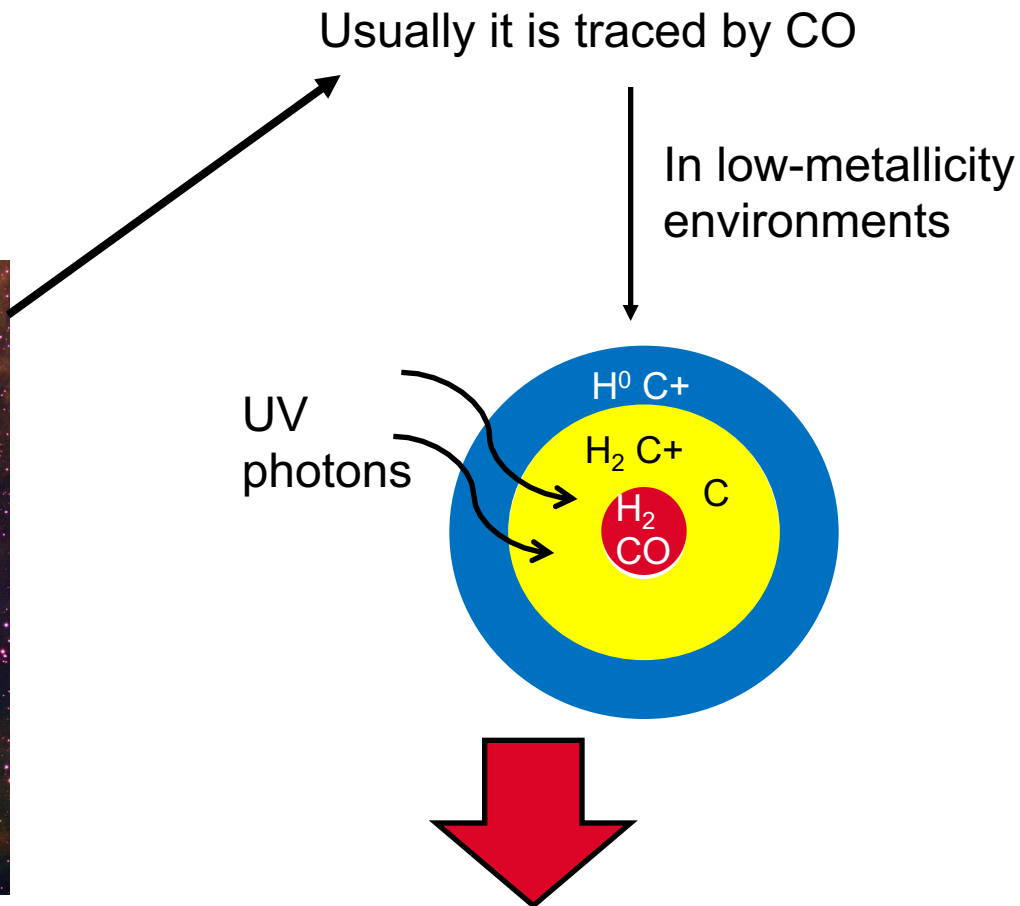
## Solar metallicity ( $Z_{\odot}$ )



## Low metallicity ( $1/2 Z_{\odot} < Z < 1/40 Z_{\odot}$ )

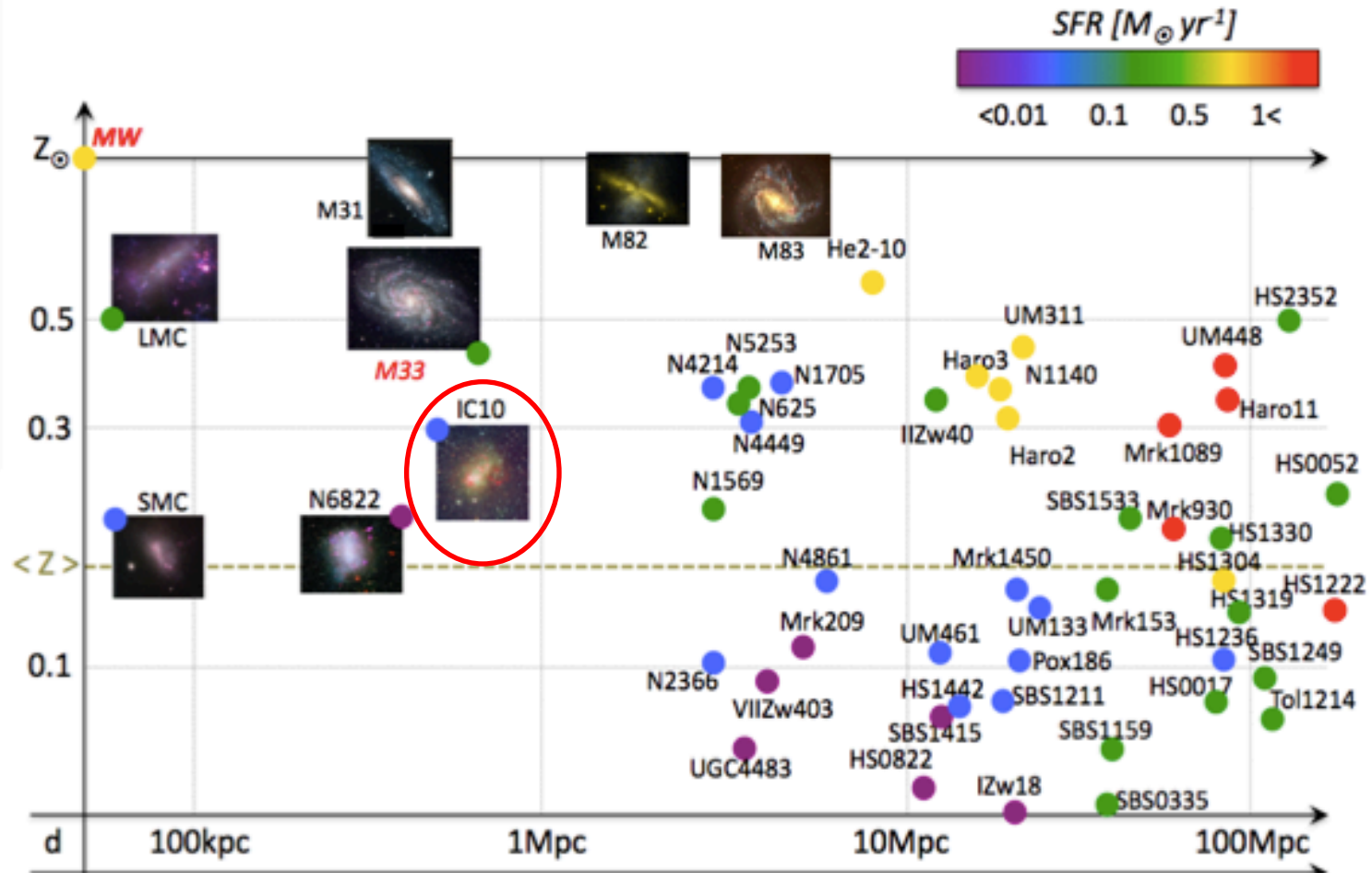


Molecular clouds are dense and cold molecular gas and dust where the new stars form

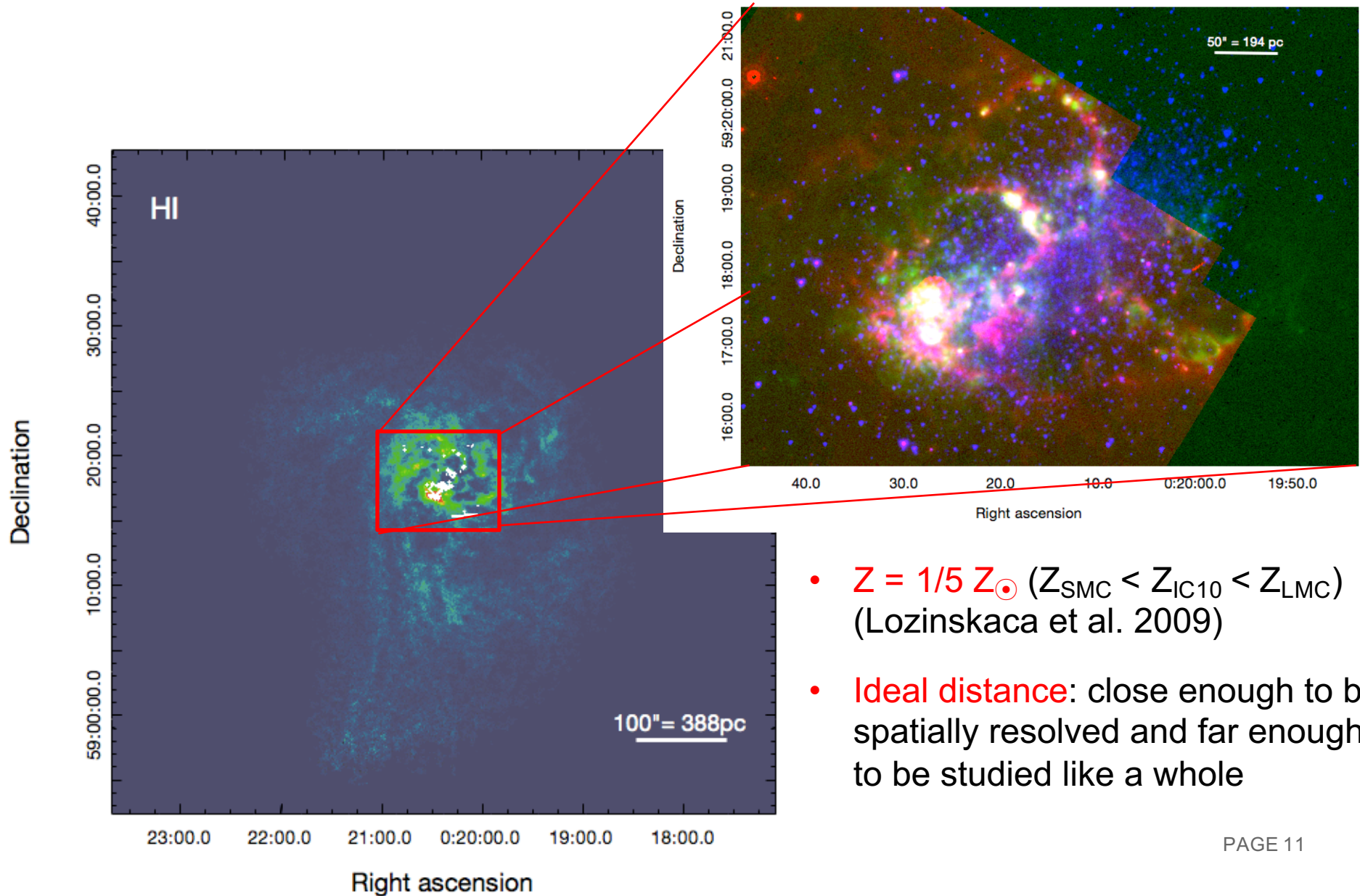


[CII] should traces the molecular gas

# IRREGULAR DWARF GALAXY: IC10







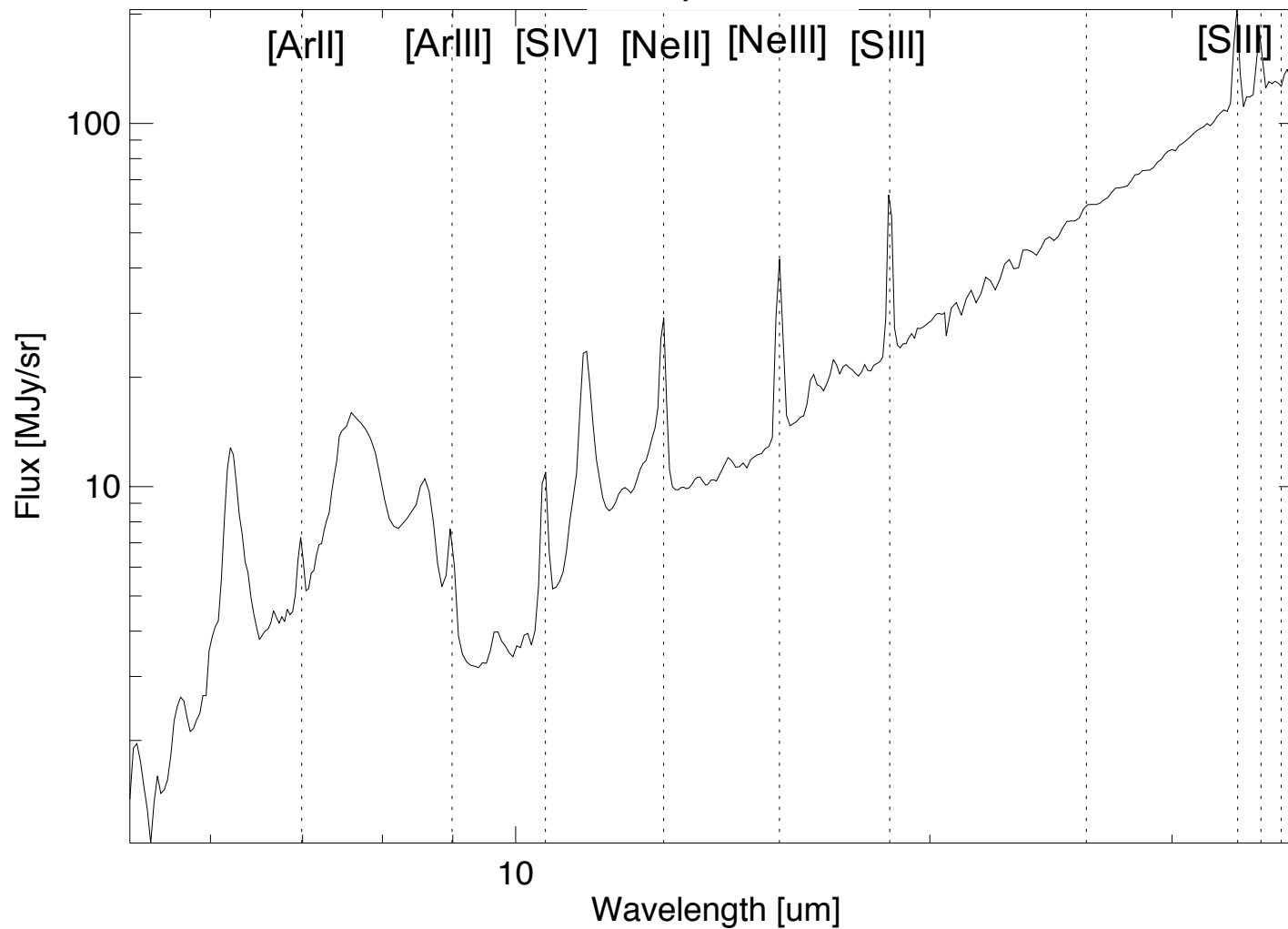
- Study the effect of star formation on the **physical properties of ISM** in **low-metallicity environments**
- **Model in self-consistent way** the different gas phases
- Which phase of the ISM dominants at the **different scales**?

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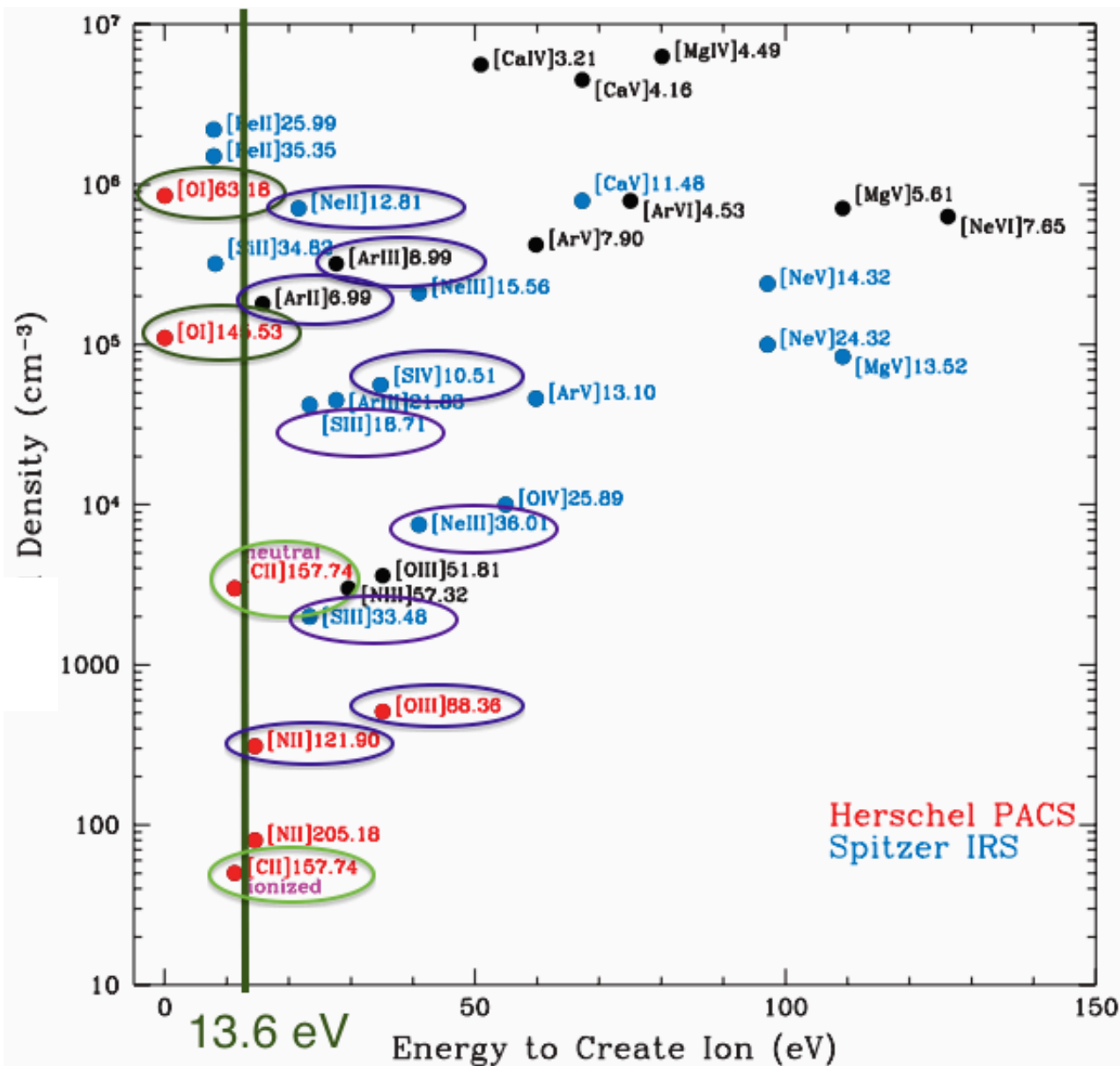
## Spectroscopy

Species	$\lambda$ [ $\mu m$ ]	Instr.	<i>FWHM</i> [arcsec]	Species	$\lambda$ [ $\mu m$ ]	Instr.	<i>FWHM</i> [arcsec]
H $\alpha$	656.3[ <i>nm</i> ]	Perkins Telescope	2.3	[NeV]	24.32	<i>Spitzer</i> /IRS	10
[ArII]	6.99	<i>Spitzer</i> /IRS	3.7	[FeII]	25.99	<i>Spitzer</i> /IRS	10
[ArIII]	8.88	<i>Spitzer</i> /IRS	3.7	[OIV]	25.89	<i>Spitzer</i> /IRS	10
[SIV]	10.51	<i>Spitzer</i> /IRS	3.7	H2 0-0 S(0)	28.22	<i>Spitzer</i> /IRS	10
H2 0-0S(2)	12.27	<i>Spitzer</i> /IRS	3.7	[SIII]	33.48	<i>Spitzer</i> /IRS	10
Hhu $\alpha$	12.37	<i>Spitzer</i> /IRS	3.7	[SiII] <sup>(b)</sup>	34.81	<i>Spitzer</i> /IRS	10
[NeII]	12.81	<i>Spitzer</i> /IRS	3.7	[NeII]	36.01	<i>Spitzer</i> /IRS	10
[NeV]	14.32	<i>Spitzer</i> /IRS	3.7	[OI]	63.18	<i>Herschel</i> /PACS	9.5
[NeII]	15.55	<i>Spitzer</i> /IRS	3.7	[OIII]	88.36	<i>Herschel</i> /PACS	9.5
H2 0-0S(1)	17.03	<i>Spitzer</i> /IRS	3.7	[NII]	121.90	<i>Herschel</i> /PACS	9.8
[FeII]	17.94	<i>Spitzer</i> /IRS	3.7	[OI]	145.52	<i>Herschel</i> /PACS	11
[SIII]	18.71	<i>Spitzer</i> /IRS	10	[ClI] <sup>(b)</sup>	157.74	<i>Herschel</i> /PACS	12
[ArIII]	21.83	<i>Spitzer</i> /IRS	10	CO lines		<i>Herschel</i> /FTS	
[FeII]	22.93	<i>Spitzer</i> /IRS	10	H <sub>I</sub>	21[ <i>cm</i> ]	VLA	6
				CO (1-0)		IRAM/PdBI	



Spitzer/IRS spectrum

# MULTIPHASE ISM



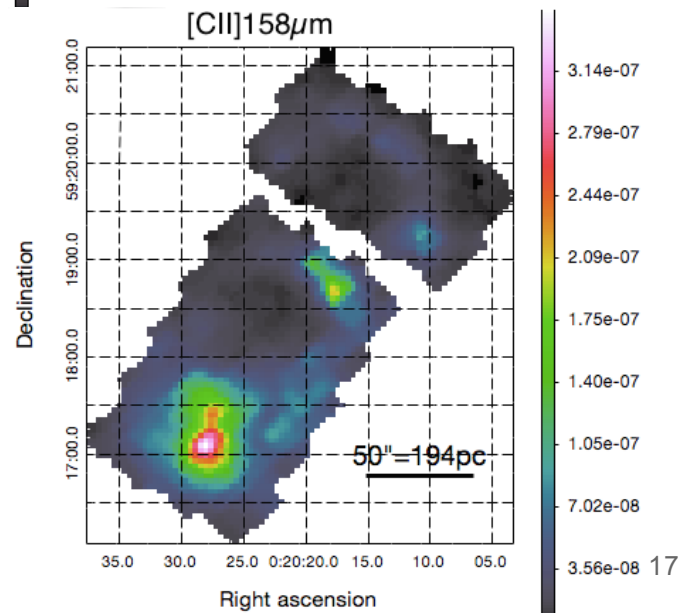
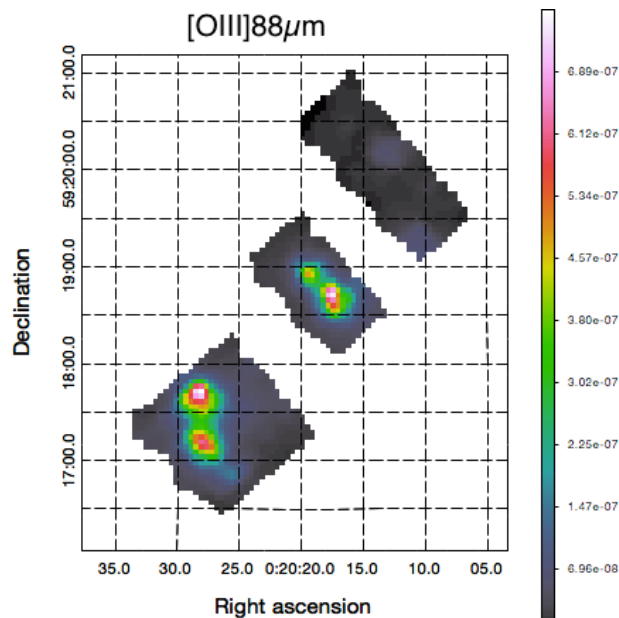
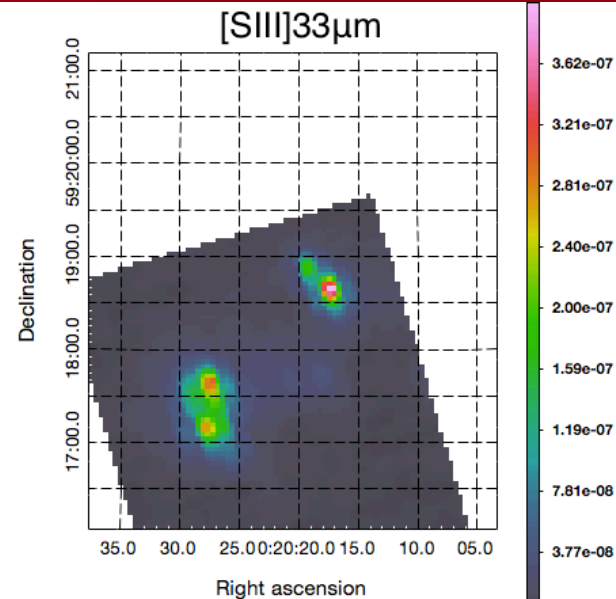
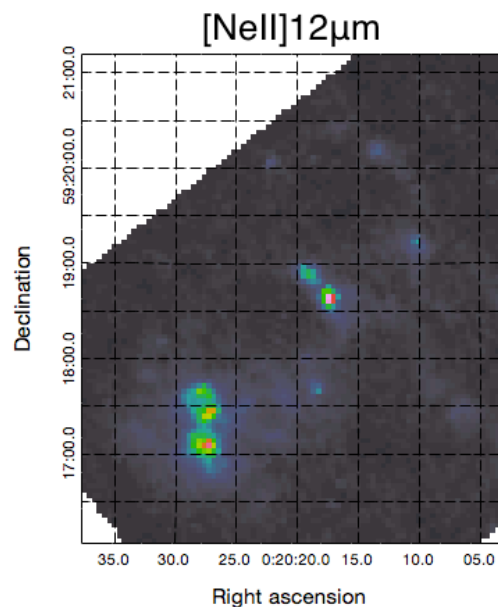
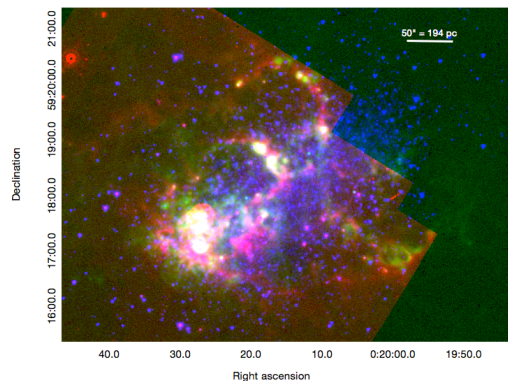
Neutral gas

Ionized gas

Neutral/Ionized gas

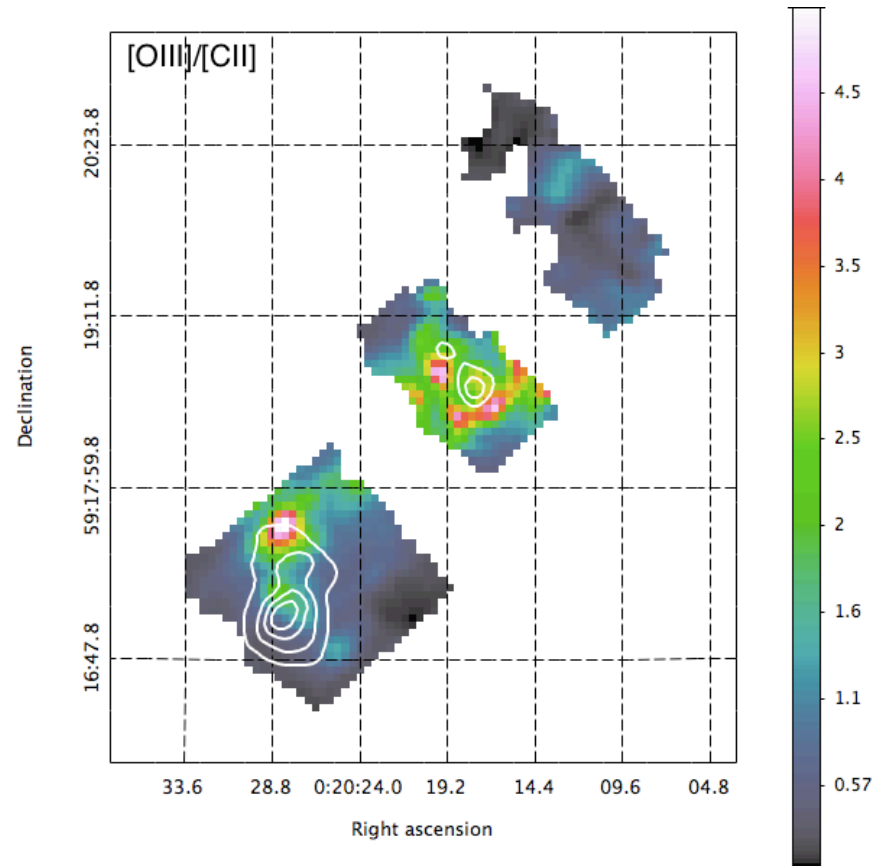
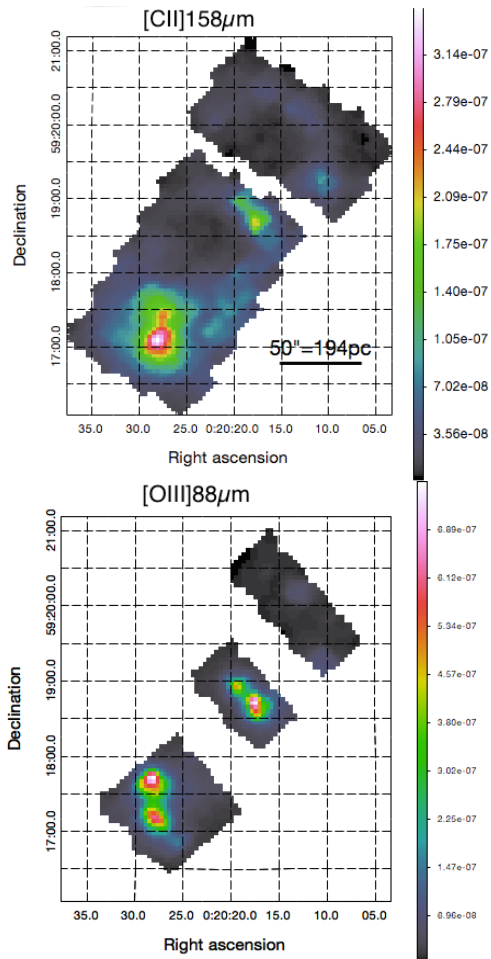


## Infrared spectroscopy data



## [CII] 158 $\mu\text{m}$ & [OIII] 88 $\mu\text{m}$

- [CII] 158 $\mu\text{m}$  is one of the brightest FIR line
- [OIII] 88 $\mu\text{m}$  is the line with highest ionization energy (35 eV)

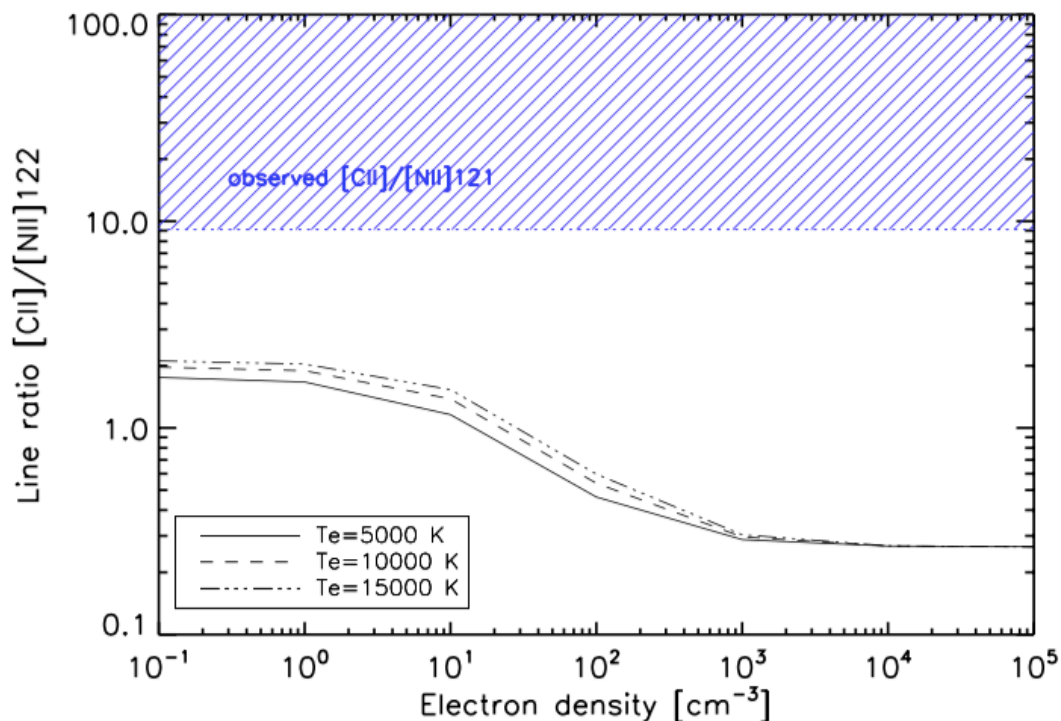
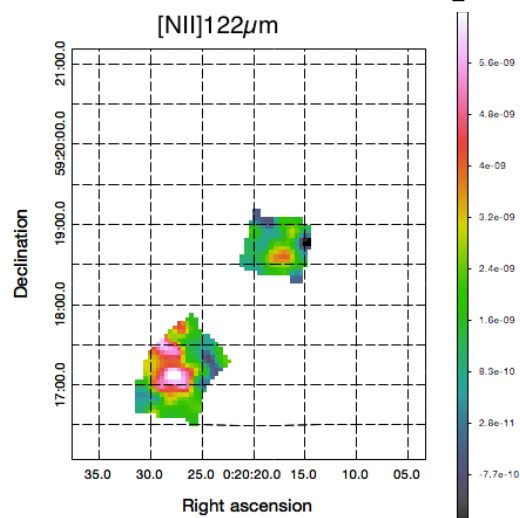
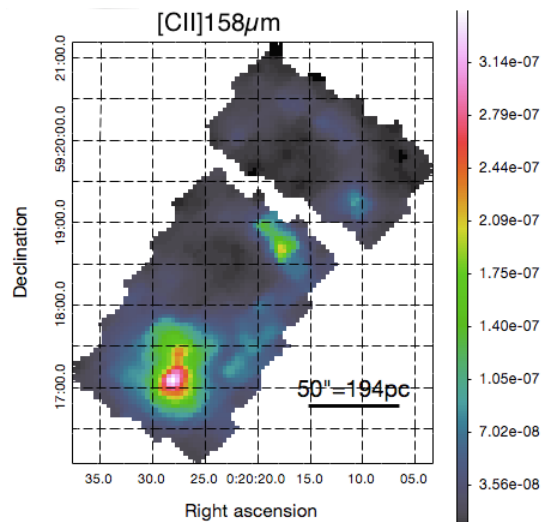


[OIII] brighter  
than [CII]

➤ suggests high  
filling factor of  
diffuse ionized  
gas

## [CII] 158 $\mu\text{m}$ & [NII] 122 $\mu\text{m}$

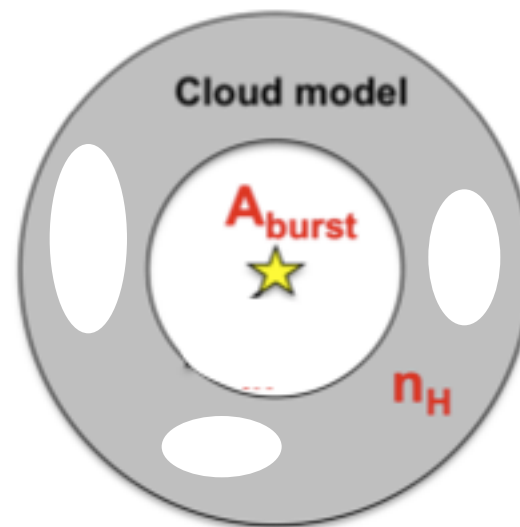
[CII] comes from ionized and neutral gas



- [NII] is very faint ➤ this map does not cover totally star forming regions
- Most of [CII] comes from PDR in the region covered by [NII], at least 98%

## Input:

- Radiation field striking the cloud, age of the stellar cluster
- Element abundances
- Initial hydrogen density
- Ionization parameter (ratio of hydrogen-ionizing photon to total-hydrogen density)

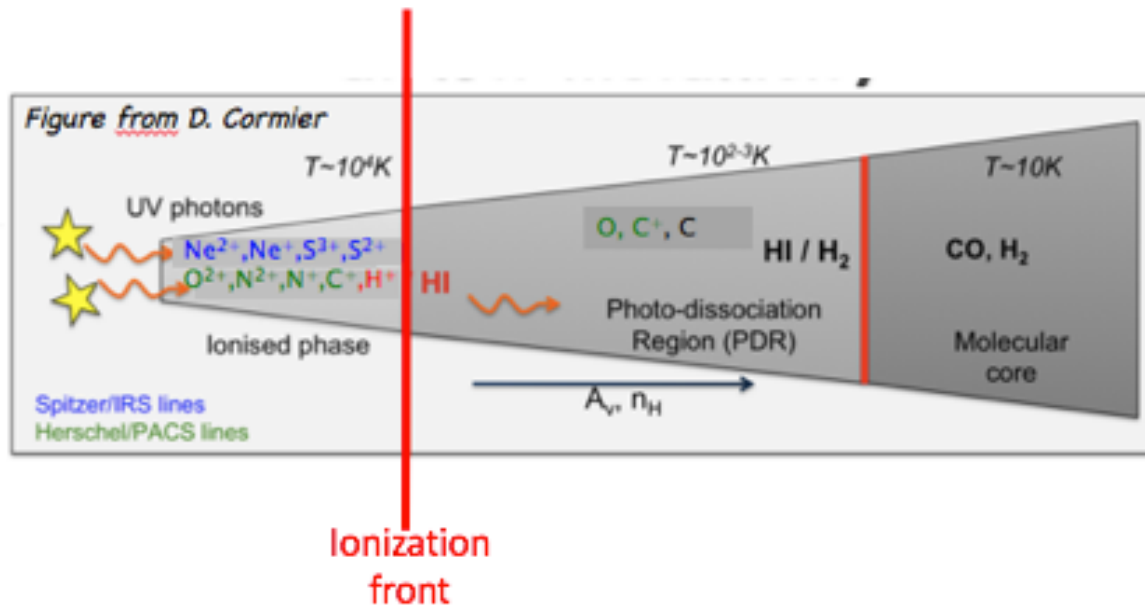


## Output:

- Line intensity
- Continuum (in particular dust emission)
- Physical properties:  $T_e$ , pressure, extinction (depth), filling factor ...



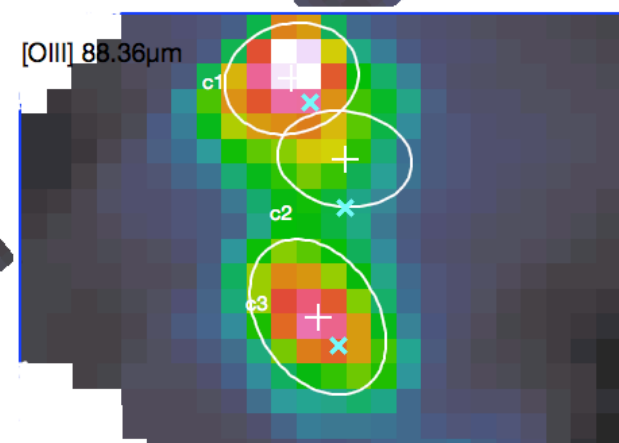
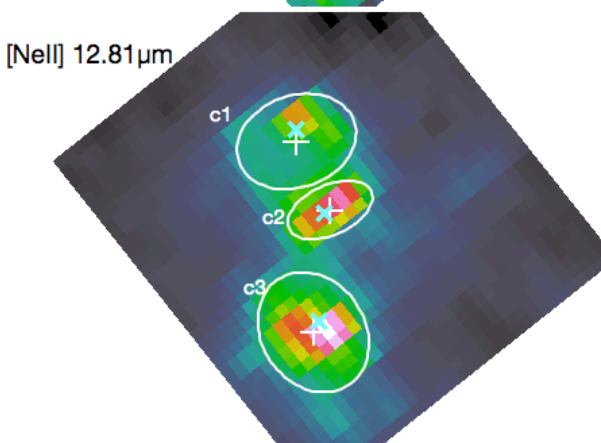
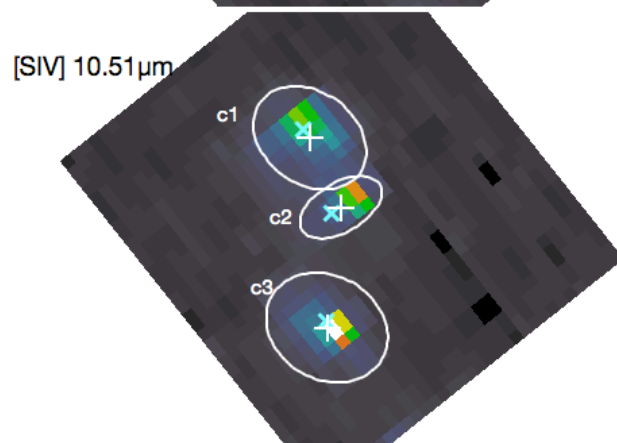
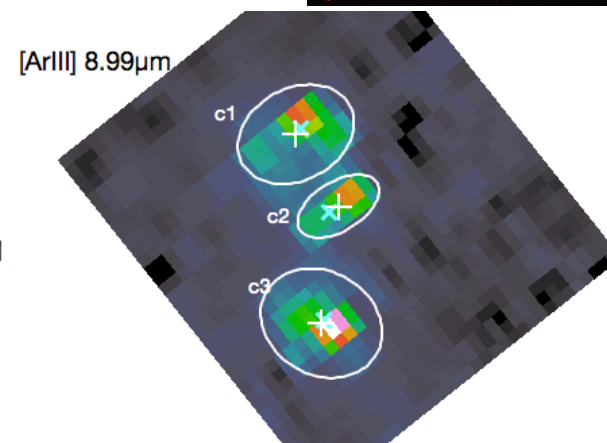
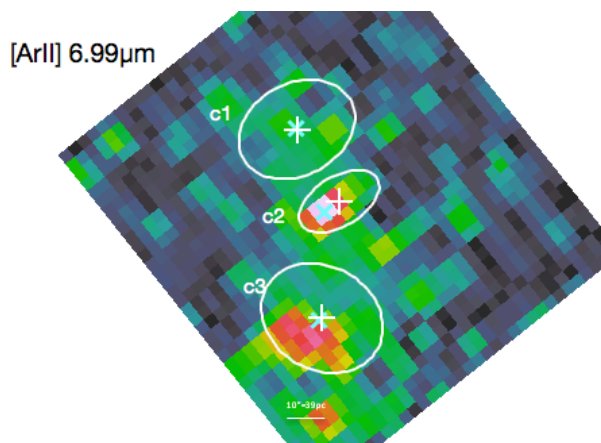
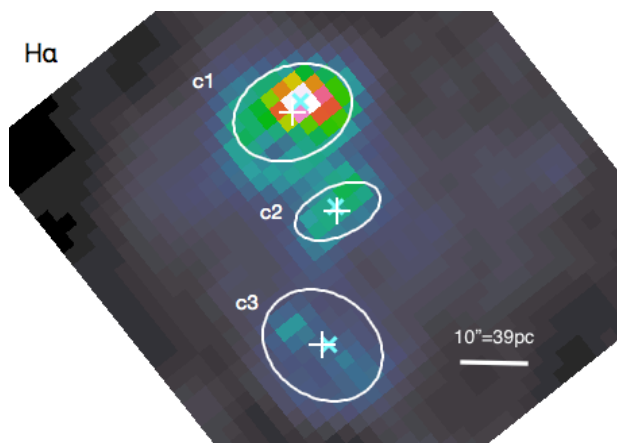
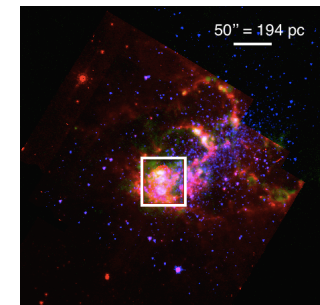
1. Stop the model at the ionization front
2. Use the HII region parameter as input for the PDR modeling



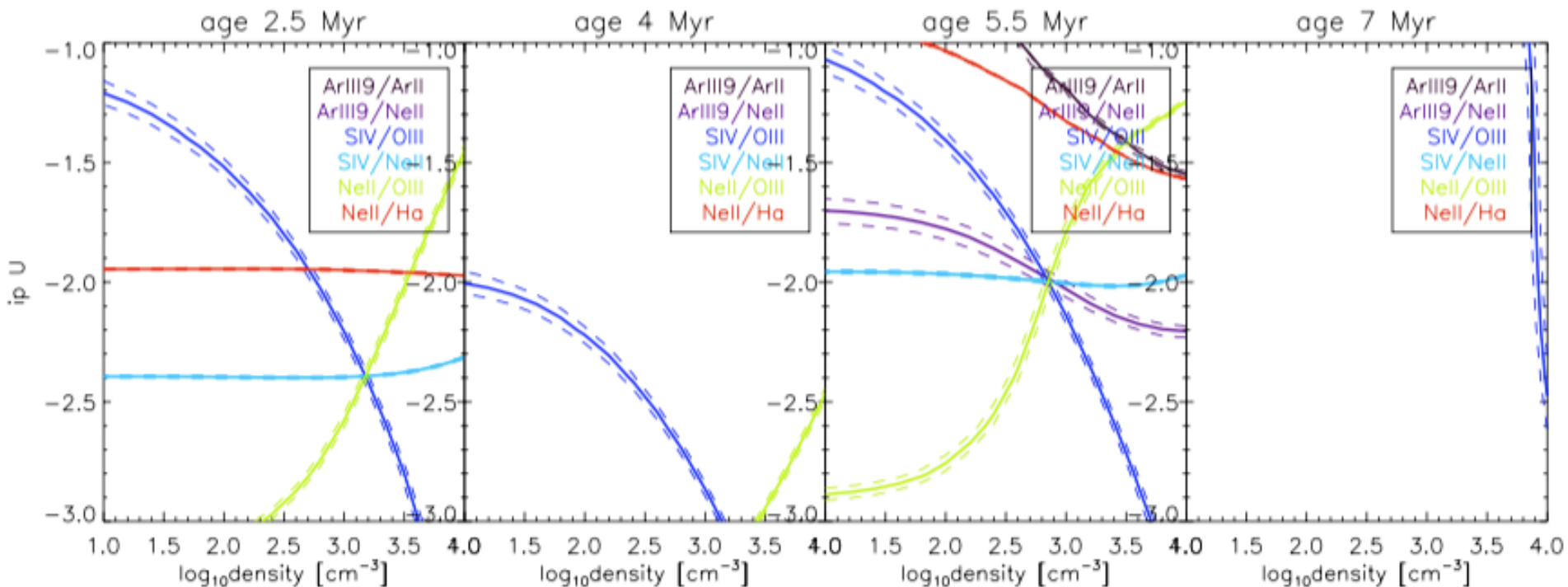
## Central region: identification of star forming regions

Calculate the flux for each clump

We fitted the data with 3 gaussian functions ➤ we identify the different star forming regions

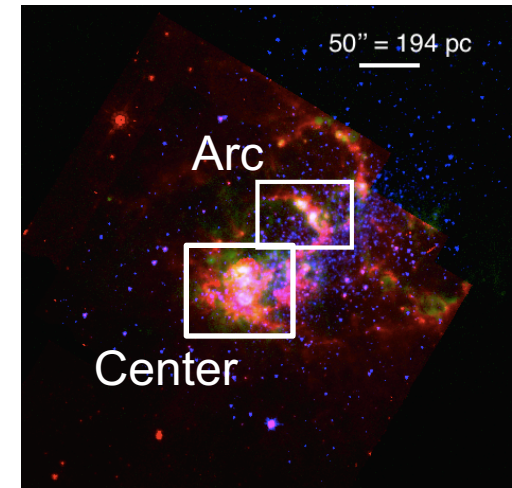


## Example of result: clump center-c2





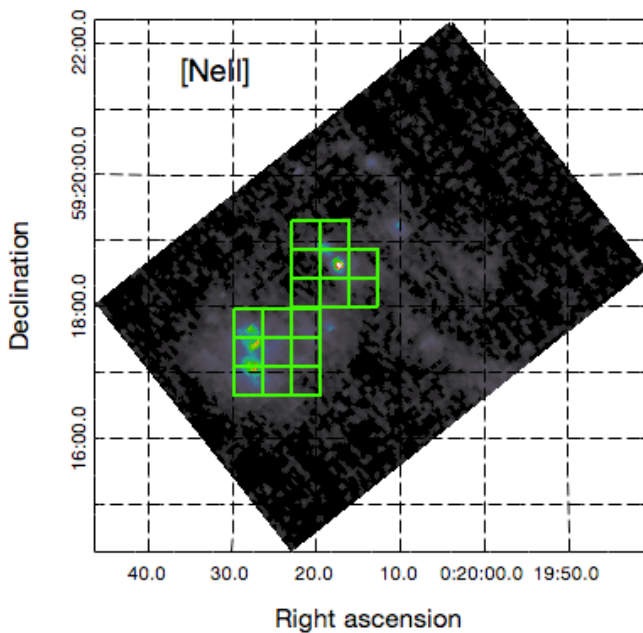
<i>Region</i>	$E(B - V)$	<i>age</i> [Myr]	<i>ip U</i>	<i>density</i> [ $\text{cm}^{-3}$ ]
<i>Center c1</i>	$\sim 0.8$	5.5	-1.4	$10^{2.2}$
<i>Center c2</i>	$\sim 1.8$	5.5	-2.0	$10^{2.8}$
<i>Center c3</i>	2.2	5.5	-2.2	$10^{3.0}$
<i>Arc c1</i>	2.45	5.5	-2.4	$10^{3.2}$
<i>Arc c2</i>	2.60	3.0	-2.2	$10^{3.8}$



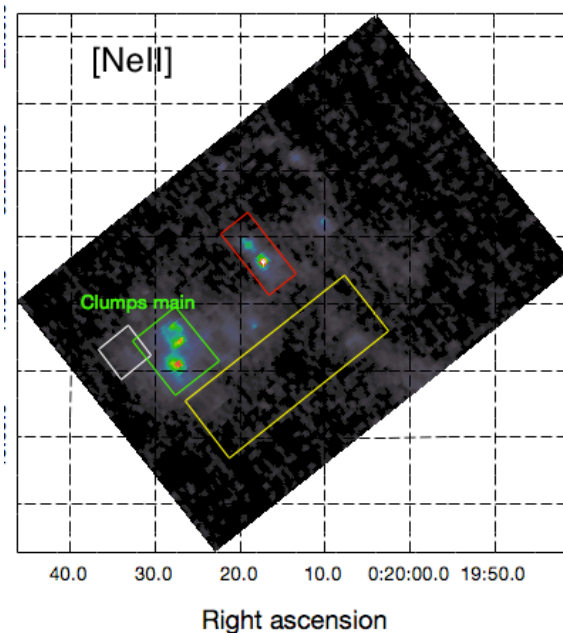
- Our results of the Central region are in good agreement with the previous studies (no previous studies of the ISM for the Arc region)
- We can see a wide range of physical properties between the region Center c1 and the region Arc c2:
  - Center c1 looks more evolved
  - Arc c2 looks more dense and compact

We looked at **different positions and sizes** to study the **different ionized phases** and understand what we see when we **mix several** phases

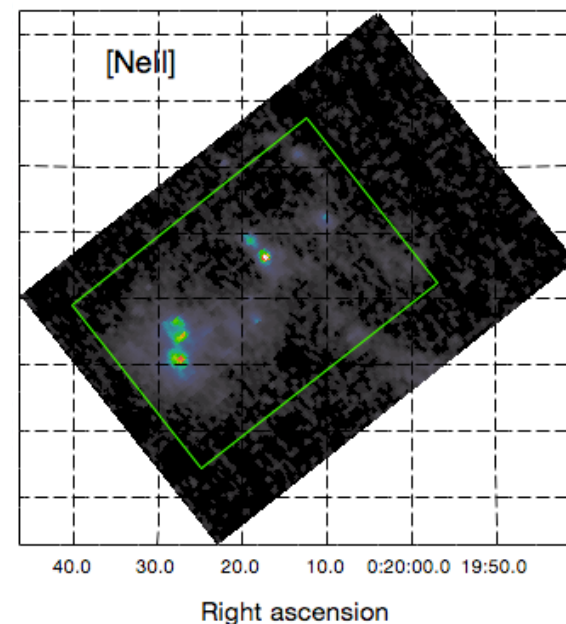
Pixel by pixel



Larger scale



Main body



It is necessary to have several ionized phases when we look at larger scales

## Summary (Polles et al. in prep.)

- IC10 allows us to study the effect of star formation on the ISM phases in **low-metallicity environments**, which is not possible when we look at unresolved high-redshift galaxies
- The **ISM is very porous** allowing hard photons to travel to large distances
- **[CII]** emission seems to be arising mostly **from PDRs**
- We are setting the **method** to model in **self-consistent way** the ISM phases
- Modeling all the tracers we are able to determine the **physical properties for each cluster**: physical properties of the different clumps cover a wide range of values
- It is necessary to have several ionized phases when we look at larger scales

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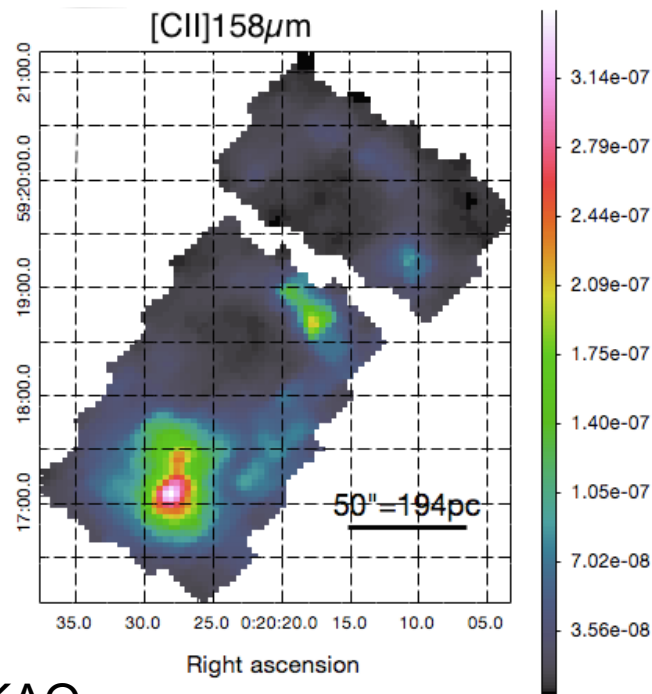
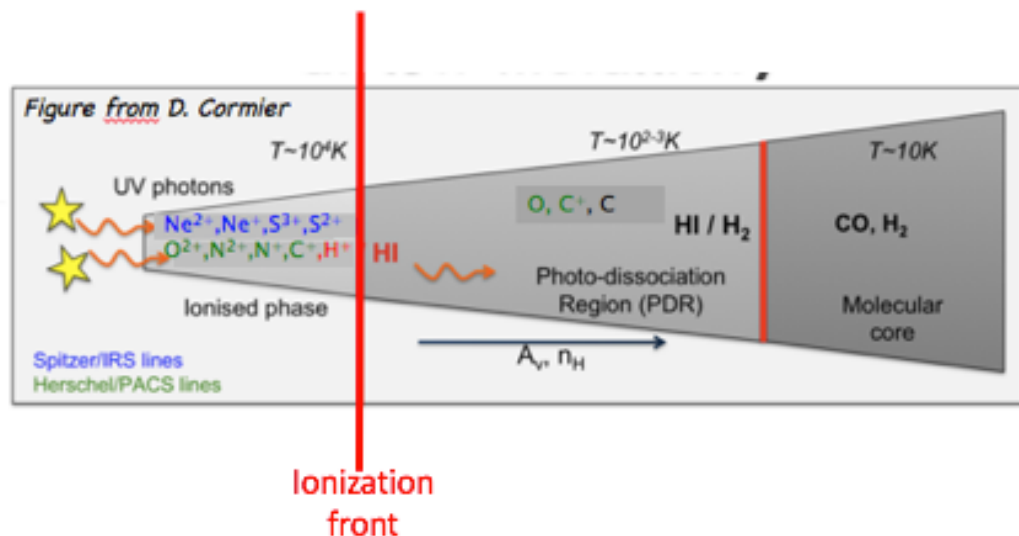
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## Modeling the Photo – Dissociation Region (PDR) (Polles et al. 2017)

### Strategy: Cloudy

We will study the physical properties of the PDR regions by propagating the ionized gas results into the PDR region.



Large quantity of  $\text{H}_2$  traced by [CII] (KAO, Madden et al. 1997)

## Next object: starburst galaxy metal rich (Polles et al. 2017)

We want to compare some of the ISM properties of IC10 with the ISM properties of metal-rich galaxy:

- Starburst
- Solar metallicity
- At the similar scale of IC10
- Well studied
  - wide coverage of MIR-FIR lines







THANKS FOR YOUR  
ATTENTION



# IRREGULAR DWARF GALAXY: IC10

