Chasing High Redshift Faint Galaxies
- A Journey from Simulations to JWST -

Arghyadeep Basu

CNRS Postdoctoral researcher, CRAL, France

(with **Joki Rosdahl** (CRAL), **Jérémy Blaizot** (CRAL), **Hakim Atek** (IAP), et.al.)

Former PhD and bridge postdoc fellow at MPA Garching, Munich

More about me!

CRAL

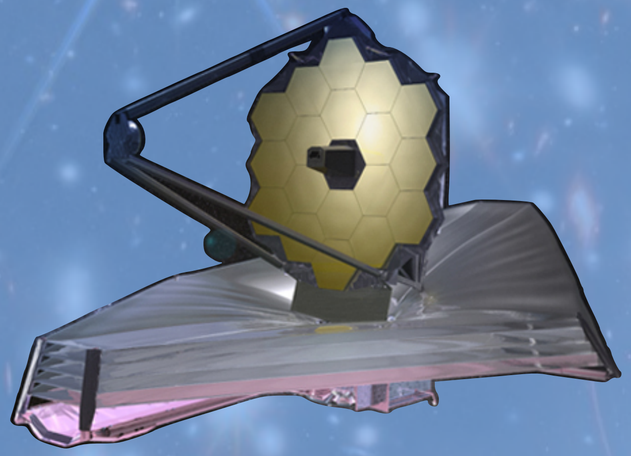
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

Thanks to everyone of you 👊

And the organizers :D

For great talks, for all the science, for extremely good food, strong coffees, :D

Since 2023.....



James Webb Space Telescope (JWST)

A highly magnified candidate for a young galaxy seen when the Universe was 500 Myrs old

Wei Zheng[1], Marc Postman[2], Adi Zitrin[3], John Moustakas[4],

Alberto Molino[8], Larry Bradley[2], Dan Coe[2], Leonidas A

Ford[1], Narciso Benítez[8], Tod R. Lauer[11], Stella Seitz[12], Ry

A Long Time Ago in a Galaxy Far, Far Away: A Candidate $z \sim 12$ Galaxy in Early JWST CEERS Imaging

Steven L. Finkelstein[1], Micaela B. Bagley[1], Pablo Arrabal Haro[2], Mark Dickinson[2], Henry C. Ferguson[3],
Jeyhan S. Kartaltepe[4], Casey Papovich[5,6], Denis Burgarella[7], Dale D. Kocevski[8], Marc Huertas-Company[9,10,11],

JWST/MIRI photometric detectio
in a galaxy at $z > 1$

Jakob M. Helton[1*], George H. Rieke[1], S
Zihao Wu[2], Daniel J. Eisenstein[2], Kevi
Stefano Carniani[3], Zhiyuan Ji[1], William M. Baker[4,5],
Rachana Bhatawdekar[6],
Stéphane Charlot[8], Jac
Eiichi Egami[1], Ben

Revealing galaxy candidates out to $z \sim 16$ with JWST observations of the lensing cluster SMACS0723

Hakim Atek[1★], Marko Shuntov,[1] Lukas J. Furtak[2], Johan Richard[3], Jean-Paul Kneib,[4]
Guillaume Mahler[5], Adi Zitrin[2], H. J. McCracken,[1] Stéphane Charlot,[1] Jacopo Chevallard[6] and
Iryna Chemerynska[1]

Early Results from GLASS-JWST. III. Galaxy Candidates at $z \sim 9$–15^*

Marco Castellano[1], Adriano Fontana[1], Tommaso Treu[2], Paola Santini[1], Emiliano Merlin[1], Nicha Leethochawalit[3,4,5],
[1], Mario Nonino[8], Diego Paris[1],
[9,10], Antonello Calabrò[1],
[15], Amata Mercurio[16],
[18,19], Benedetta Vulcani[20],
Italy; marco.castellano@inaf.it
, Los Angeles, CA 90095, USA
tralia
3D), Australia
ai, 50180, Thailand
INAF—OAS, Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via Gobetti 93/3, I-40129 Bologna, Italy
[7] Space Science Data Center, Italian Space Agency, via del Politecnico, I-00133, Roma, Italy
[8] INAF—Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy
ysics, Jadranska ulica 19, SI-1000 Ljubljana, Slovenia
rnia Davis, 1 Shields Avenue, Davis, CA 95616, USA
y of Technology, PO Box 218, Hawthorn, VIC 3122, Australia
Milano, via Celoria 16, I-20133 Milano, Italy

Two Remarkably Luminous Galaxy Candidates at $z \approx 10$–12 Revealed by JWST

Rohan P. Naidu[1,2,26], Pascal A. Oesch[3,4], Pieter van

A Census from JWST of Extreme Emission Line Galaxies Spanning the Epoch of Reionization in CEERS

Kelcey Davis,[1,*] Jonathan R. Trump,[1] Raymond C. Simons,[1] Elizabeth J. McGrath,[2] Stephen M. Wilkins,[3,4]
Pablo Arrab
Bren E. Back
Laura Bisig
Steven L. Finkelst
Ray A. Lucas

Extreme emission line galaxies detected in JADES *JWST*/NIRSpec – I. Inferred galaxy properties

ma Curtis-Lake[4], Jacopo Chevallard,[3] Alex J. Cameron[3],
ane Charlot[6], Mirko Curti,[7] Imaan E. B. Wallace[3],
is Willott,[10] Stacey Alberts,[11] Daniel J. Eisenstein[12],
D. Johnson,[12] Marcia Rieke,[11] Brant Robertson,[14]

The Astrophysical Journal, 974:41 (17pp), 2024 October 10 https://doi.org/10.3847/1538-4357/ad6867
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Identification of High-redshift Galaxy Overdensities in G

Jakob M. Helton[1], Fengwu Sun[1], Charity Woodrum[1], Kevin N. Hainline[1],
Marcia J. Rieke[1], George H. Rieke[1], Stacey Alberts[1], Daniel J. Eisenstein[2], San

NEWS FEATURE

JWST Sees More Galaxies than Expected

February 9, 2024 • *Physics* 17, 23

The new JWST observatory is revealing far more bright galaxies in the early Universe than anyone predicted, and astrophysicists have more than one explanation for the puzzle.

PAPER

A hidden population of active galactic nuclei can explain the overabundance of luminous $z > 10$ objects observed by JWST

Sahil Hegde, Michael M. Wyatt and Steven R. Furlanetto

Published 13 August 2024 • © 2024 IOP Publishing Ltd and Sissa Medialab

Journal of Cosmology and Astroparticle Physics, Volume 2024, August 2024

Citation Sahil Hegde *et al* JCAP08(2024)025

DOI 10.1088/1475-7516/2024/08/025

Authors

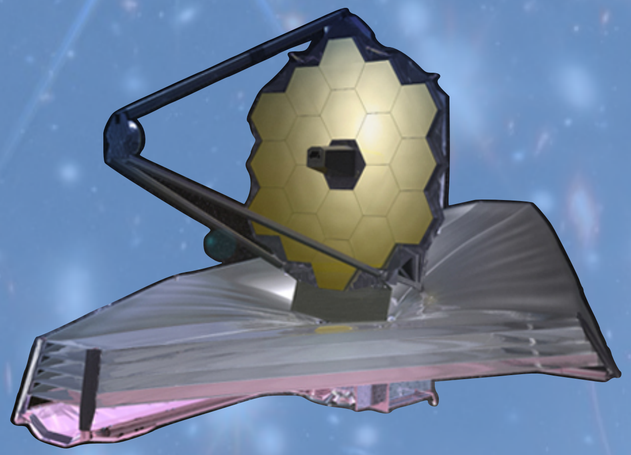
JWST-discovered AGN: Evidence of heavy obscuration in the type 2 sample from the first stacked X-ray detection

A. Comastri[1] ★, G. Lanzuisi[1], F. Vito[1], S. Marchesi[2,1,3], M. Brusa[2,1], R. Gilli[1],
I. Juodžbalis[4,5], R. Maiolino[4,5,6], G. Mazzolari[7,1], G. Risaliti[8,9], J. Scholtz[4,5] and C. Vignali
2,1

Since 2023.....

Galaxy formation theory became more interesting

- Interesting observations -



James Webb Space Telescope (JWST)

Too many UV-bright galaxies

High star formation efficiency

Extreme emission lines

Rapid metal enrichment

Unexpected dust content

Possible hidden AGN population

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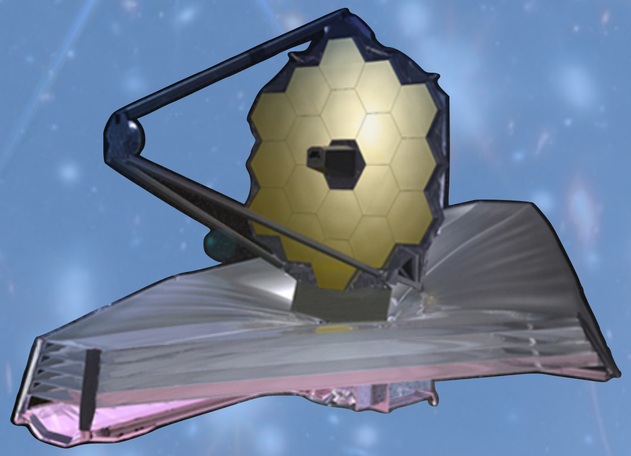


James Webb Space Telescope (JWST)

Too many UV-bright galaxies

High star formation efficiency

Extreme ionizing conditions

Rapid metal enrichment

Unexpected dust content

Are these observations strange or is there a lack in our basic understanding ?

Possible hidden AGN population

Traditionally most cosmological simulations are tuned to reproduce z=0 results

Now JWST helps us to look at high redshift and refine the galaxy formation physics

Traditionally most cosmological simulations are tuned to reproduce z=0 results

→

Now JWST helps us to look at high redshift and refine the galaxy formation physics

Way forward

Simulating first billion years
Is easier, smaller in volume, can be done with super-high resolution.

Or some other way, utilize existing simulations ?

Atek+2025 (+all the following papers)

NEW PAPER Today on ArXiV

Version April 28, 2026
Preprint typeset using LaTeX style openjournal v. 09/06/15

A GLIMPSE OF THE 99%: A CENSUS OF THE FAINTEST GALAXIES DURING THE EPOCH REIONIZATION AND ITS IMPLICATIONS FOR GALAXY FORMATION MODELS

Hakim Atek[1*], Iryna Chemerynska[1], Lukas J. Furtak [2,3], Johan Richard[4], John Chisholm[2,3], Vasily Kokorev[2,3], Michelle Jecmen[2,3], Damien Korber[5], Ryan Endsley[3], Richard Pan[6], Arghyadeep Basu[4], Jeremy Blaizot[4], Rychard Bouwens[7], Meriam Ezziati[1], Sylvain Heurtier[1], Kristen. B. W. McQuinn[8,9], Marcie Mun[1], Julian B. Muñoz[3], Pascal Oesch[6,10], Joakim Rosdahl[4], Alberto Saldana-Lopez[11], Seiji Fujimoto[12,13]

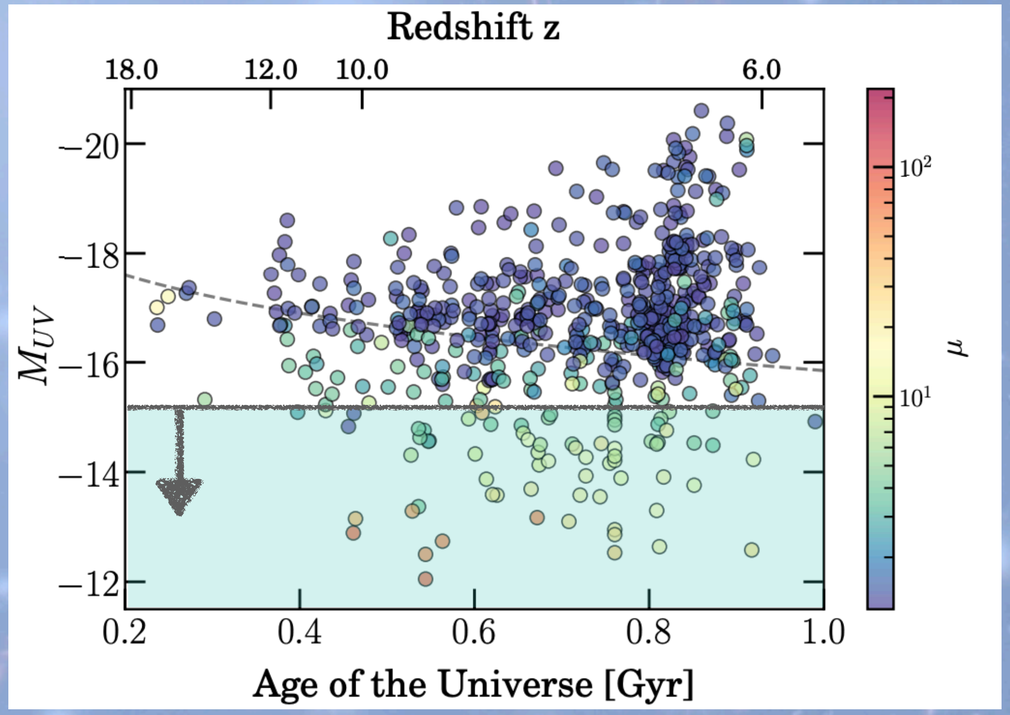
JWST GLIMPSE survey

deep imaging survey targeting **gravitationally lensed** fields (galaxy cluster Abell S1063), exposure times ranging from 20 to 40 hours per filter

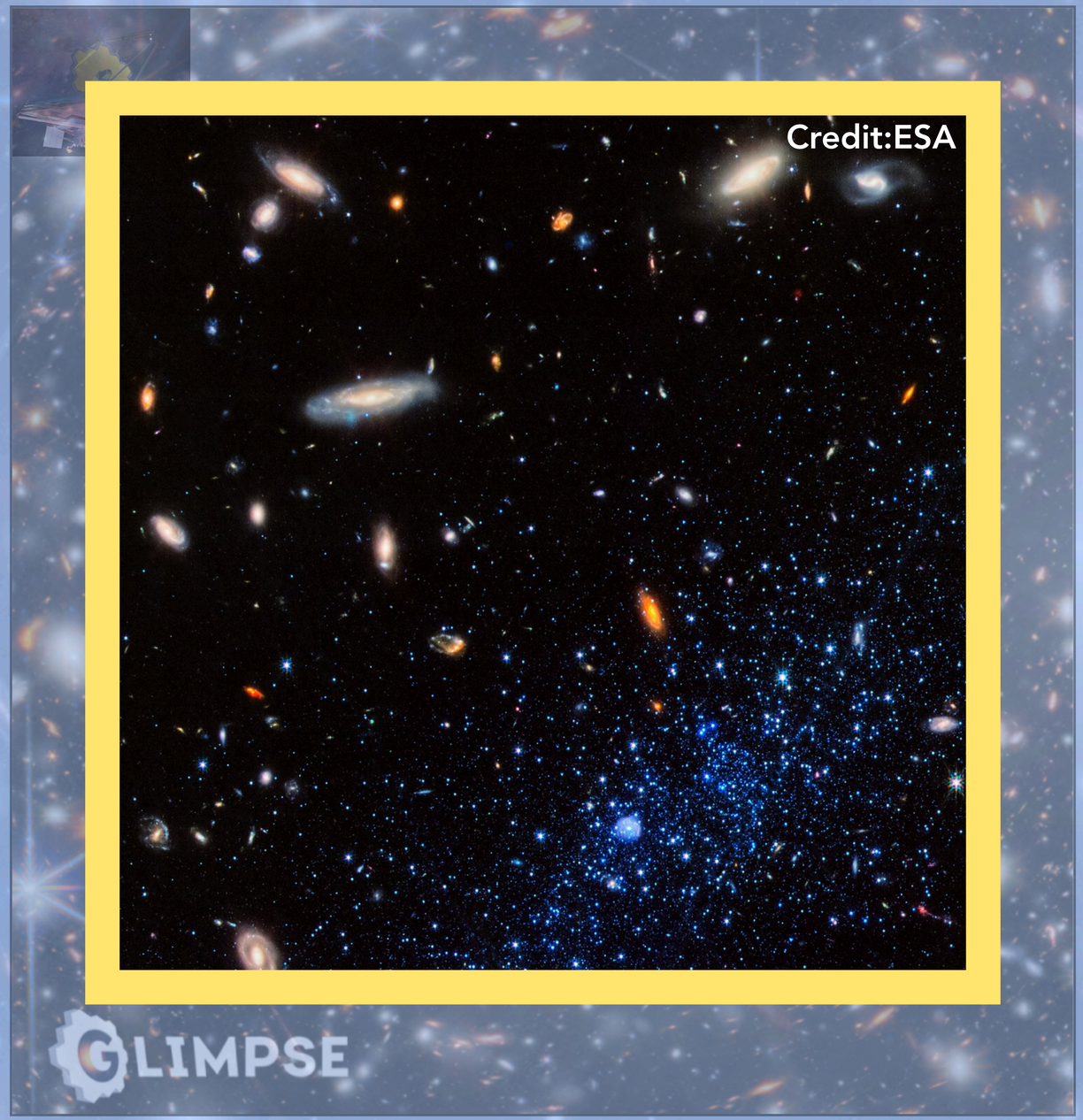
Faintest galaxies ever observed!!!

We can now observe galaxies upto $M_{UV} = -12$

(Imagine looking at Leo P dwarf galaxy at z = 10)



Atek+2025 (+all the following papers)



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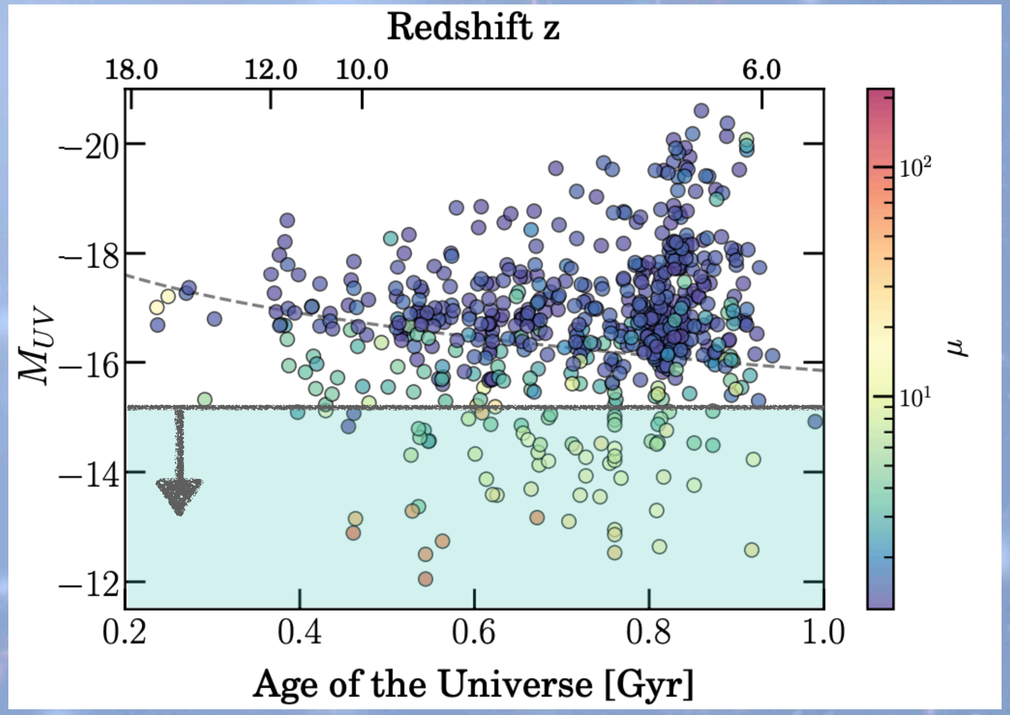

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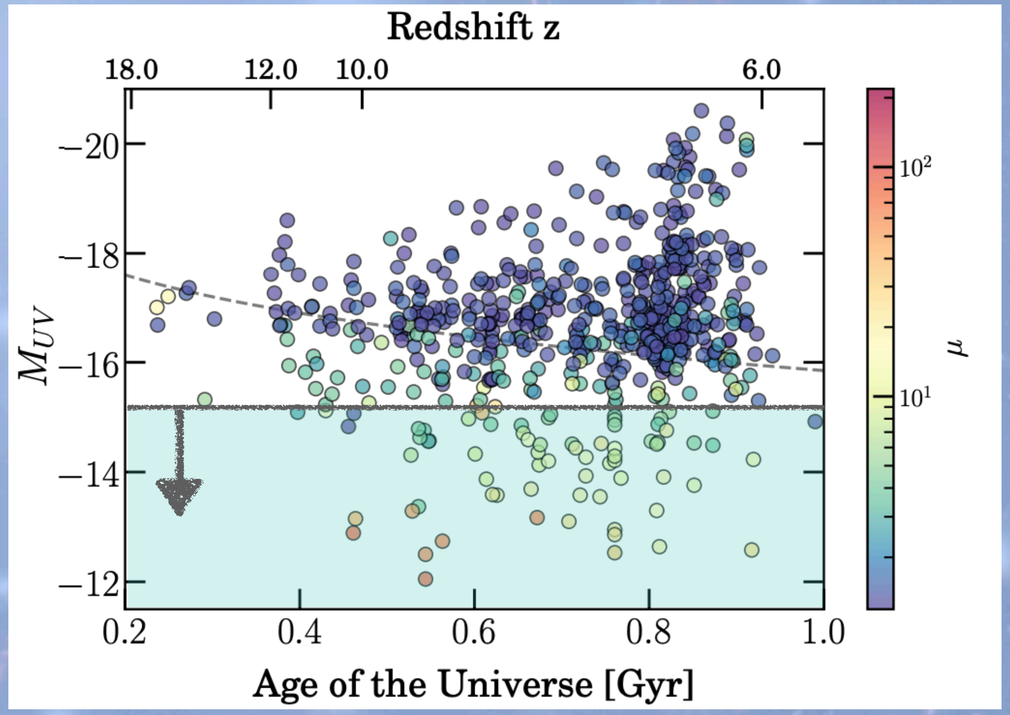

Why ‘faint’ galaxies are important ?

faint in UV emission!

Faint galaxies trace the early galaxy formation physics

Faint galaxies are primarily less massive objects, more in numbers in Universe

Easier to simulate

Perfect ‘canvas’ for exploring complicated effects (ie. Feedbacks)

Dominating candidates in ionizing photon budget

Why ‘faint’ galaxies are important ?

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Dominating candidates in ionizing photon budget

Main questions to explore

How **feedback** impact the star formation ?

How **stochastic star formation** shapes the **UV luminosity function** (count of UV bright objects in different luminosity bins)

Are **faint galaxies enough to ionize** the Universe? Or is competition between **galaxies vs AGNs** revived?

How much does the stochastic star formation and feedback affect the **observabilities of the faint objects**?

How much **cosmic variance** impacts the properties?

Rosdahl+2018,2022 (+all the following papers)

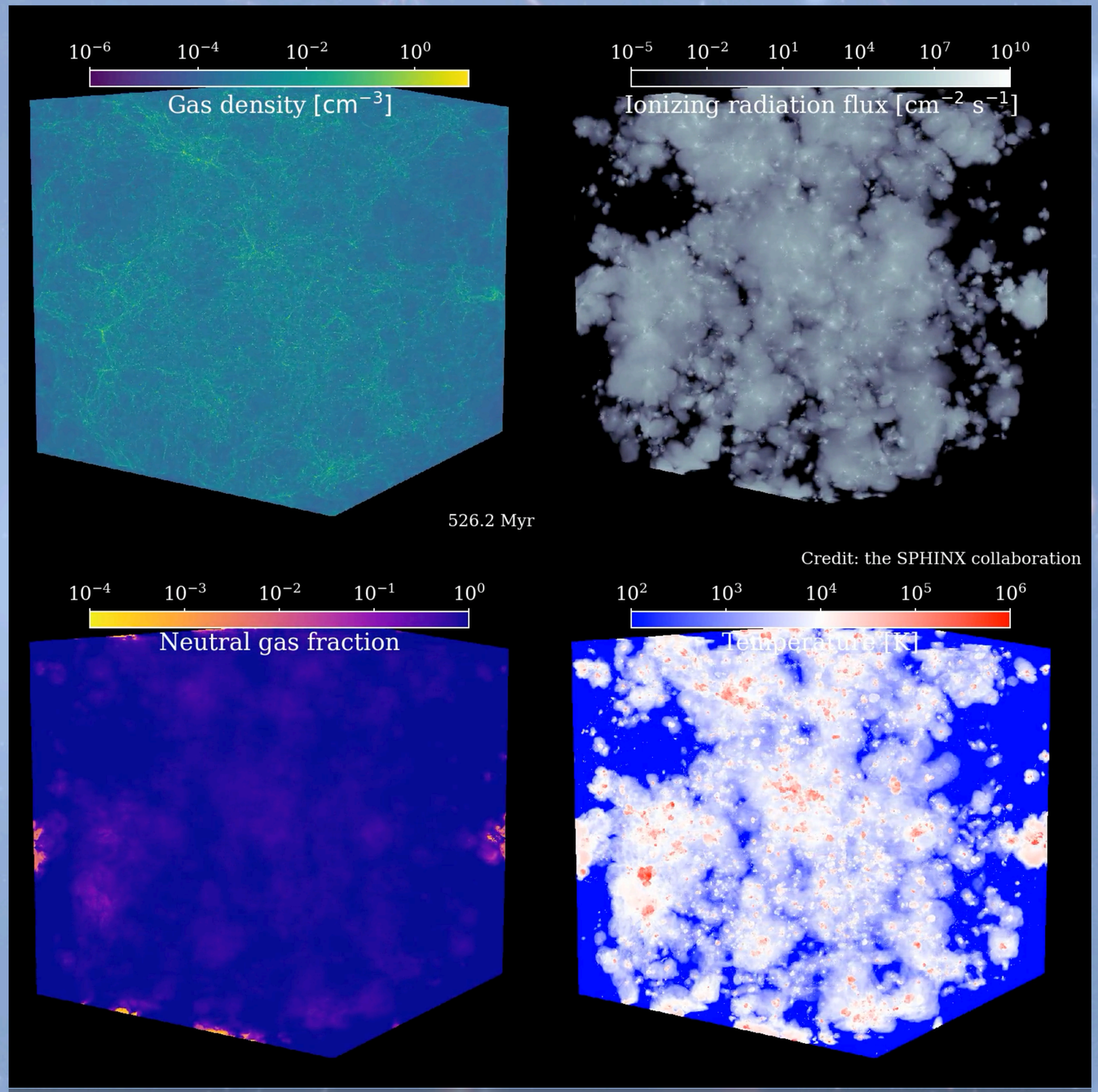
SPHINX simulation

Cosmological radiation-hydrodynamic simulation

Run with **RAMSES-RT** (AMR + on-the-fly ionizing radiative transfer)

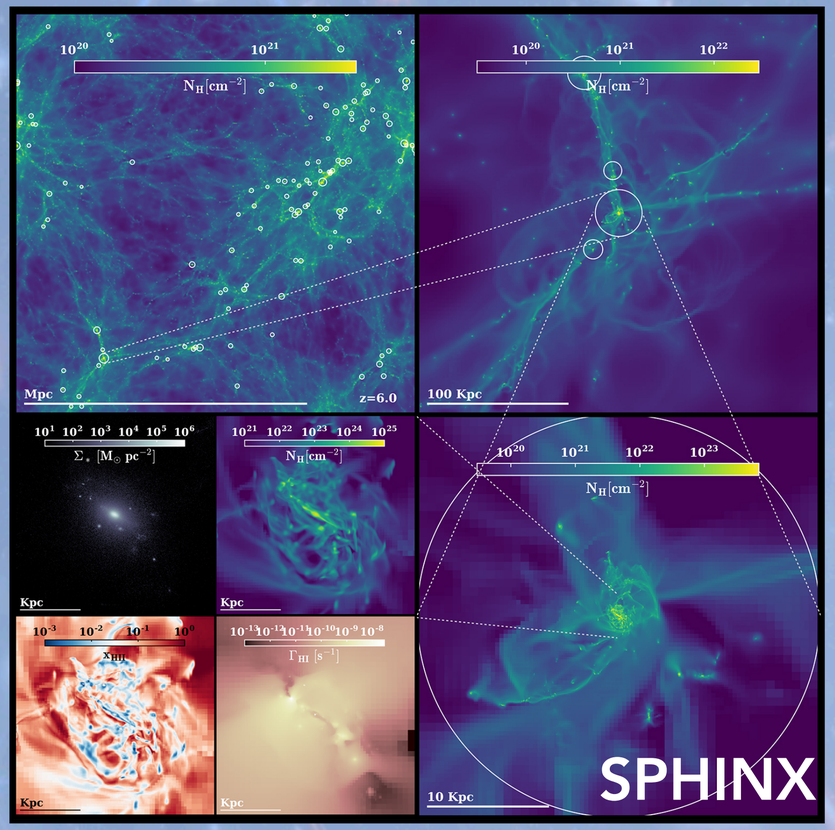
Box size: 5–10–20 cMpc/h

Resolution: ≈ 10-11 pc (physical) at z ≈ 6, star particles ≈10^3 M⊙



Why SPHINX20 simulation is very useful and relevant?

Rosdahl+2018



$$V_{SPHINX20} \simeq V_{eff,GLIMPSE}$$

SPHINX20 has enough statistical sample of galaxies having $M_{UV} = -12$

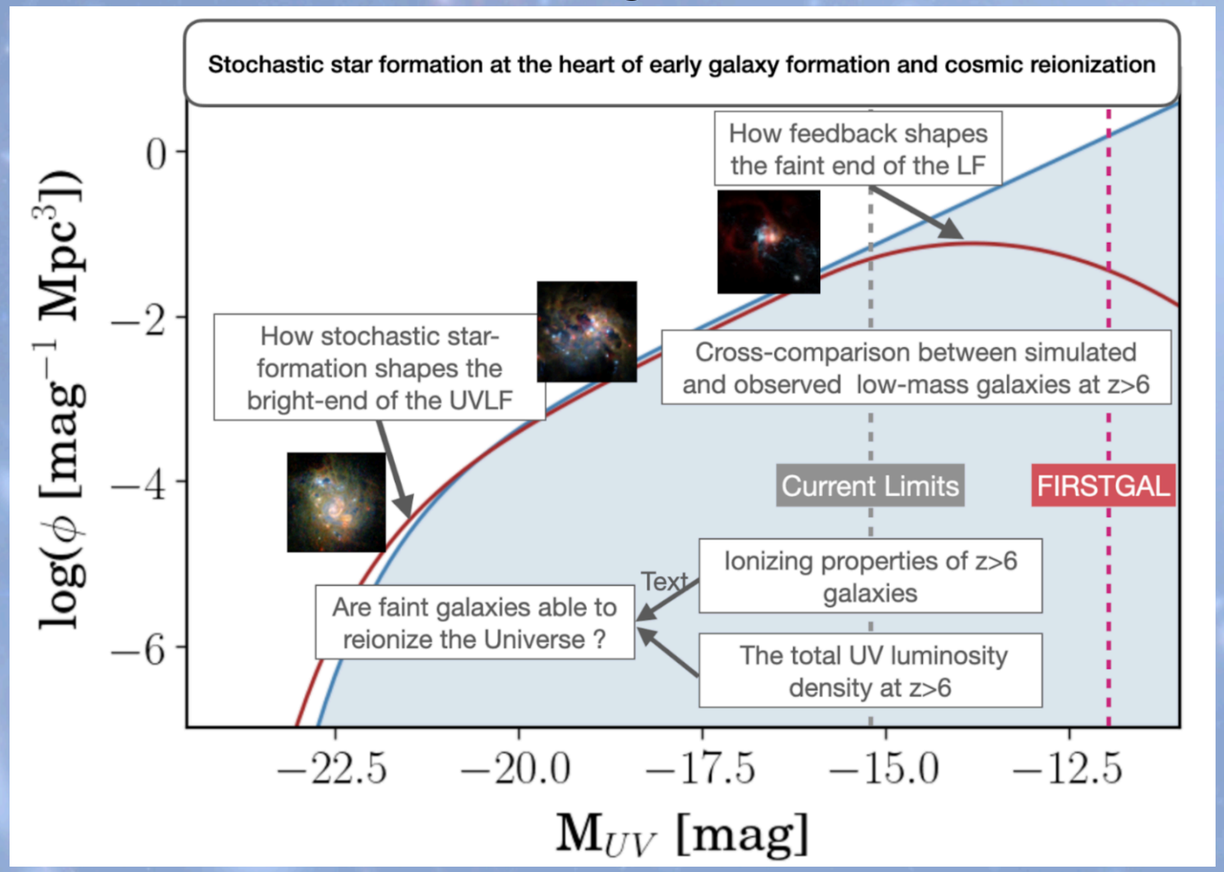
Decent sample in SPHINX20 at GLIMPSE focused redshifts

FIRSTGAL project

AAPG2024	FIRSTGAL		PRC
Coordinated by:	Hakim ATEK	Duration 48 months	ANR Requested Funding **713 k€**
CES 31 Physique subatomique et astrophysique			

Unveiling the hidden population of galaxies from Cosmic Dawn to Cosmic Reionization

Primary Goals



People involved in the project (and me!)


Joki Rosdahl (CRAL)


Jérémy Blaizot (CRAL)


Marta Volonteri (IAP)


Hakim Atek (IAP)


Johan Richard (IAP)


Yohan Dubois (Paris Obs)


Adelaide Claeyssens (CRAL)


Stephane Charlot (IAP)


Thibault Garel (Univ of Geneva)


Maxime Trebitsch (Paris Obs)


Marcie Mun (IAP)

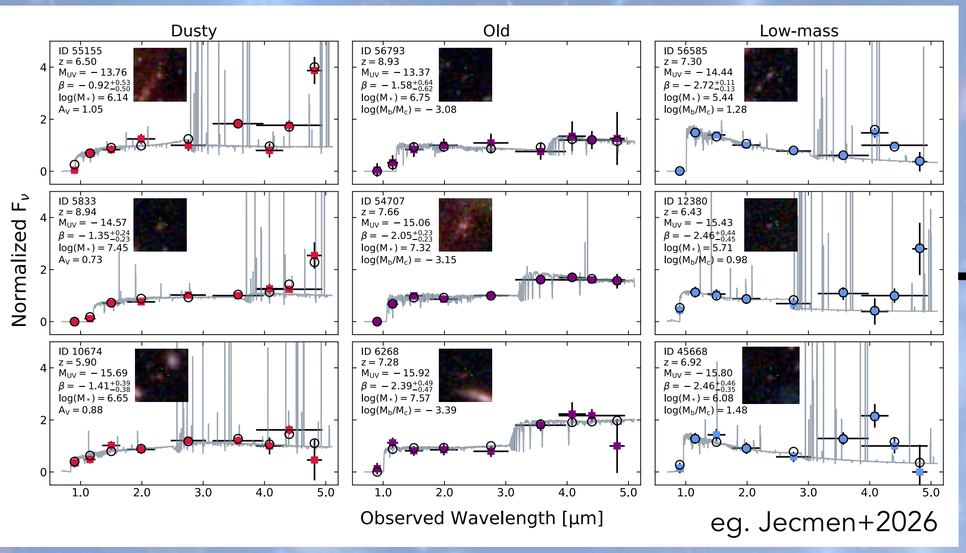

Julia Shouse (CRAL)


Meriem Ezziati (IAP)

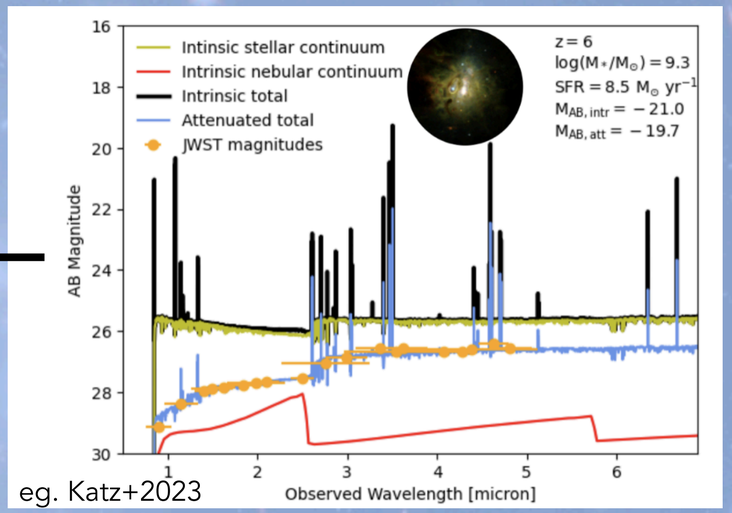

Sylvain Heurtier (IAP)

Paired analysis

‘Real’ observation



‘Mock’ observation



1-to-1 Matching

- photometry

- redshift

Find out the **closest** match

(χ^2 minimisation)

Compare the full spectra

Compare the intrinsic properties

Sphinx DR 1 (Katz+2023)

sample of galaxies having
SFR $\geq 0.3 \mathrm{M}_{\odot} \mathrm{yr}^{-1}$

at redshifts 10, 9, 8, 7, 6, 5, 4.64

a total of 1,380 galaxies

Each galaxy is viewed from 10 different directions

~ 14,000 mocks

spectra of the stellar continuum, nebular continuum, and 52 nebular emission lines + intrinsic properties of the galaxies.

Sphinx DR 1 (Katz+2023)

sample of galaxies having
SFR $\geq 0.3 M_{\odot} yr^{-1}$

at redshifts 10, 9, 8, 7, 6, 5, 4.64

Missing very faint galaxies

Difficult for paired analysis with GLIMPSE

Statistically small sample

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~ 14,000 mocks

spectra of the stellar continuum, nebular continuum, and 52 nebular emission lines + intrinsic properties of the galaxies.

Sphinx full DR

sample of galaxies having
$M_{UV,int} \lesssim -12$

Wider redshift range : 16 < z < 4.6

Roughly a total of ~ 100,000 galaxies

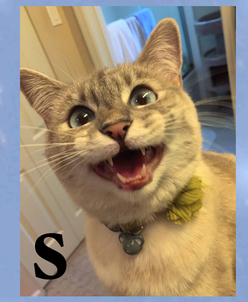
10 different directions

52 or more emission lines

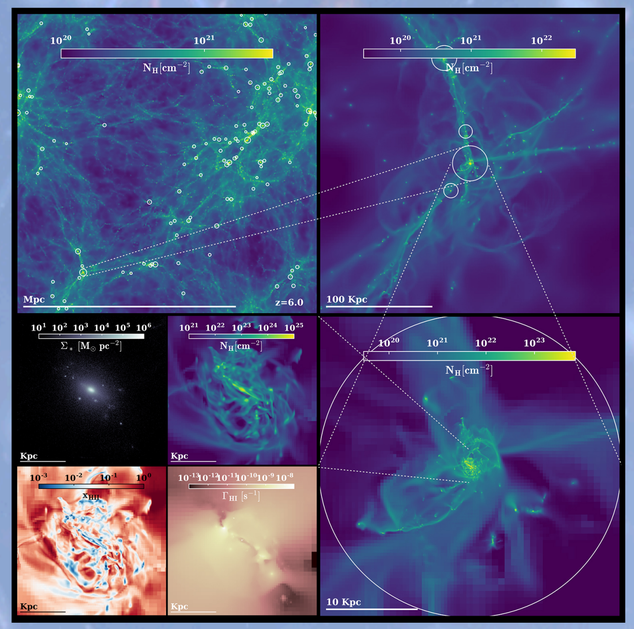
GLIMPSE specific observational effects?

Computationally more expensive :'(
Need to have more efficient pipeline!!

Pipeline for generating ‘mock’ observations



Rosdahl+2018



We have gas, stars, halo properties from simulation

generate `intrinsic’ emission (stellar and nebular continuum and line emissions)

Use : BPASS, CLOUDY

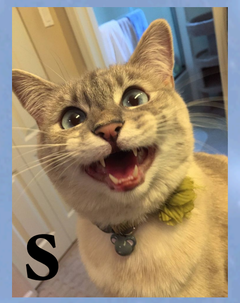
Apply physical effects (through radiative transfer and dust attenuation)

Use : RASCAS

Convolve with telescope effects (PSF, Filter, noise)

produce observables (images, magnitudes, color, spectra)

Pipeline for generating ‘mock’ observations



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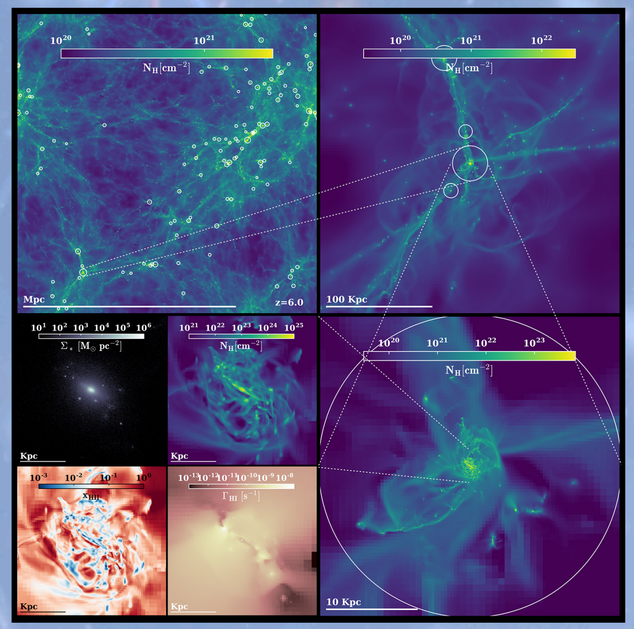

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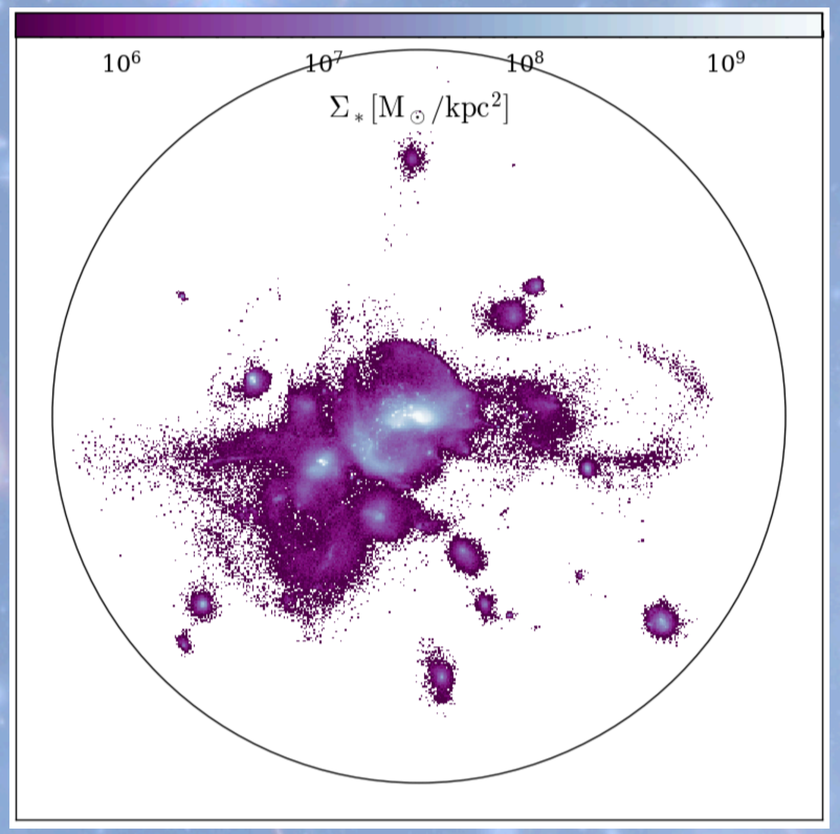
How to get stellar continuum ?



SPHINX - one object

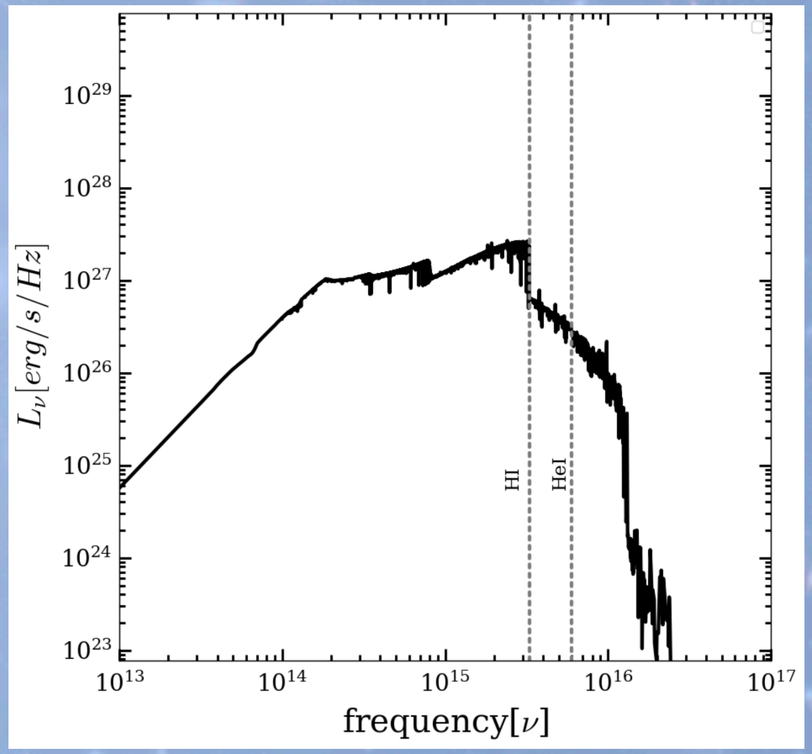
Get age, mass, metallicity of stars

↓

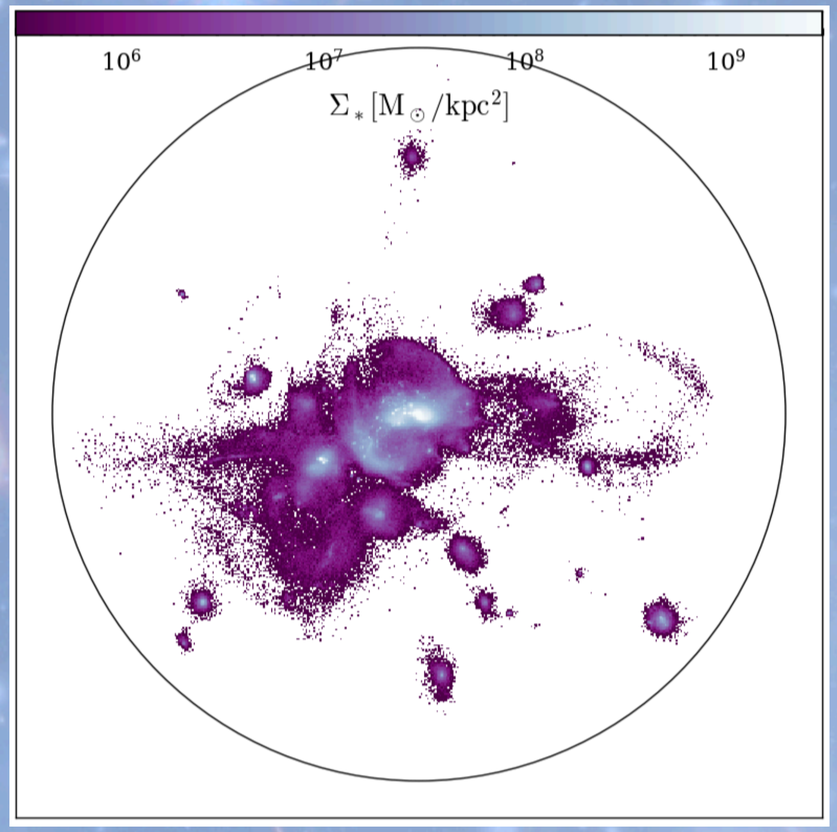
Use BPASS to get spectra for each star

↓

Make composite BPASS spectra



How to get stellar continuum ?



SPHINX - one object

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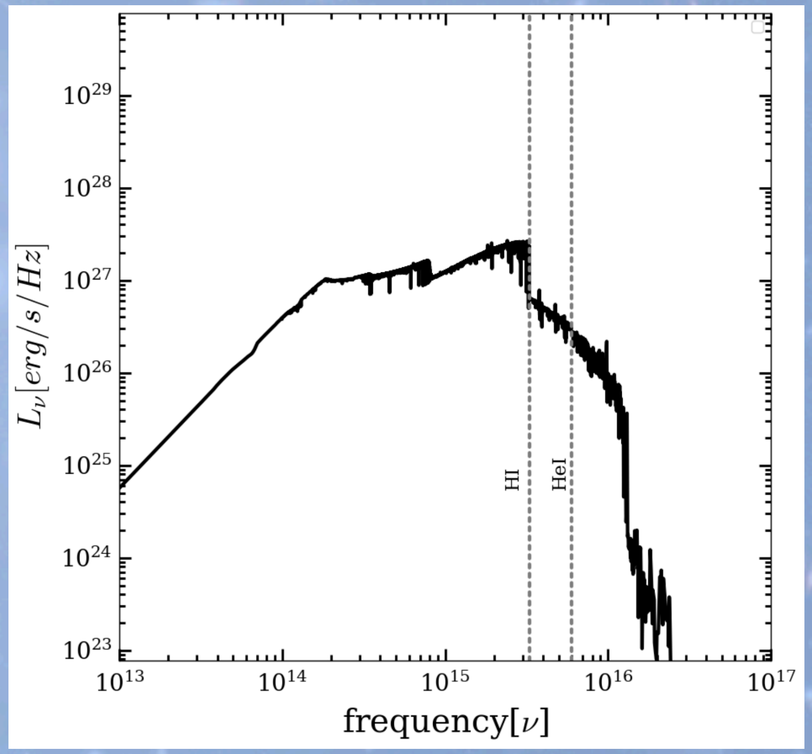
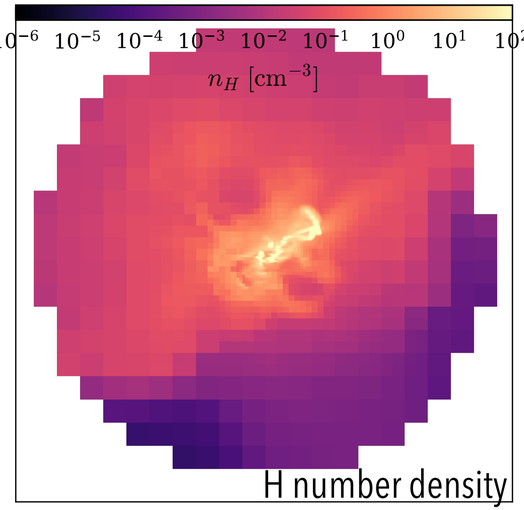
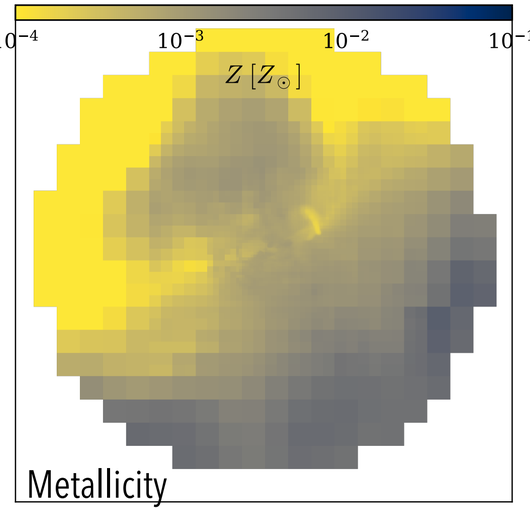
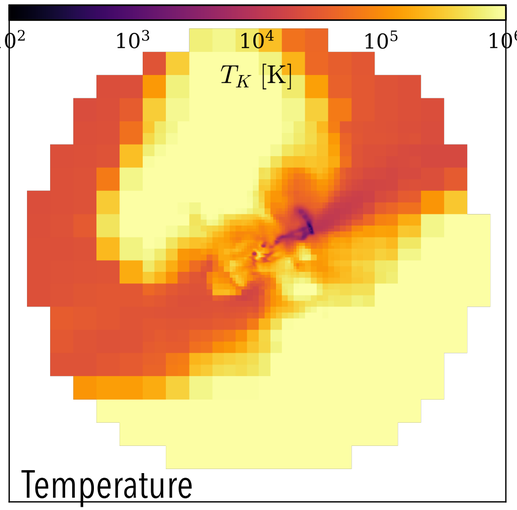


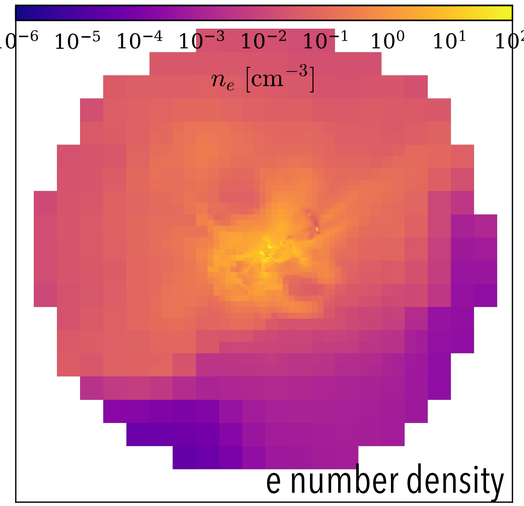
But, getting **nebular continuum and line emission** is **tricky**, need to **postprocess SPHINX** !

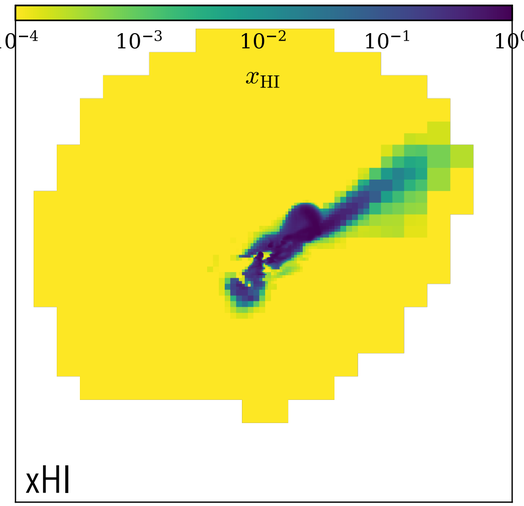
How to get nebular emission ?

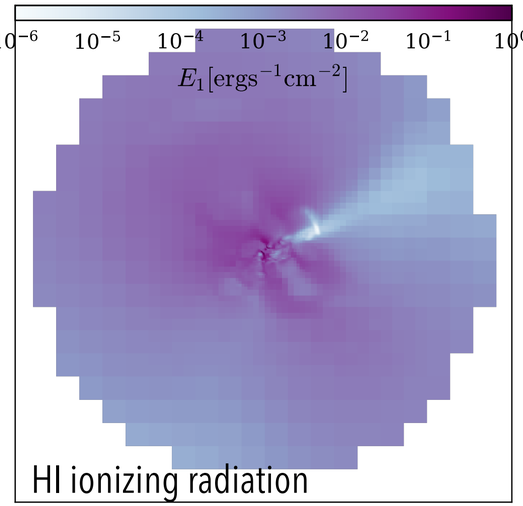












Preliminary result for one halo.....

We use CLOUDY!

z = 10

$$M_{halo} = 4.6 \times 10^8 M_\odot$$

$$M_* = 6.9 \times 10^6 M_\odot$$

$$SFR_{10} = 0.4\ M_\odot/yr$$

~ 116933 cells !!!

Preliminary result for one halo.....

CLOUDY setup* - 1-zone model

Input :

H number density

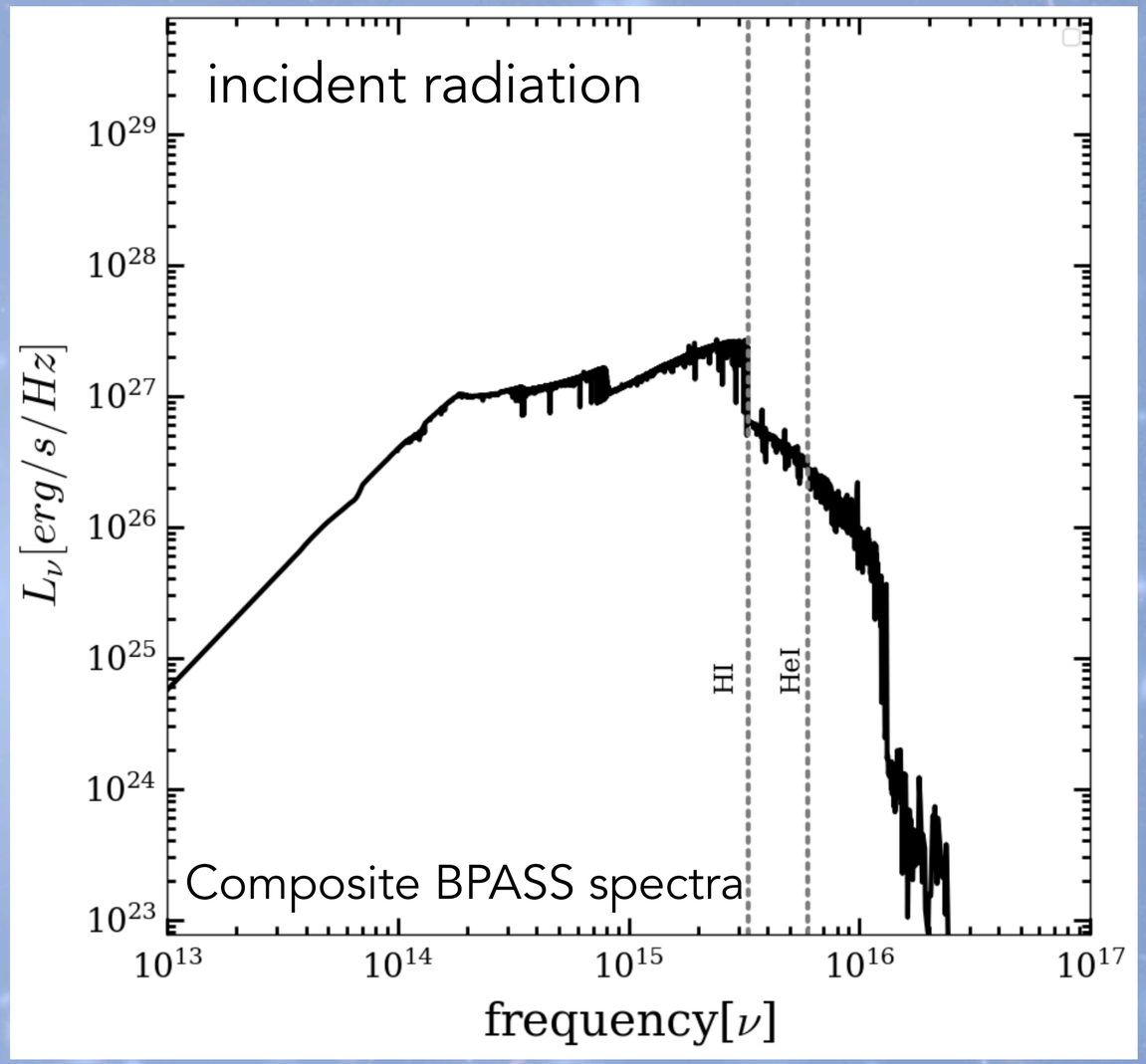
temperature

metallicity

electron number density

radiation intensity

incident radiation spectral shape



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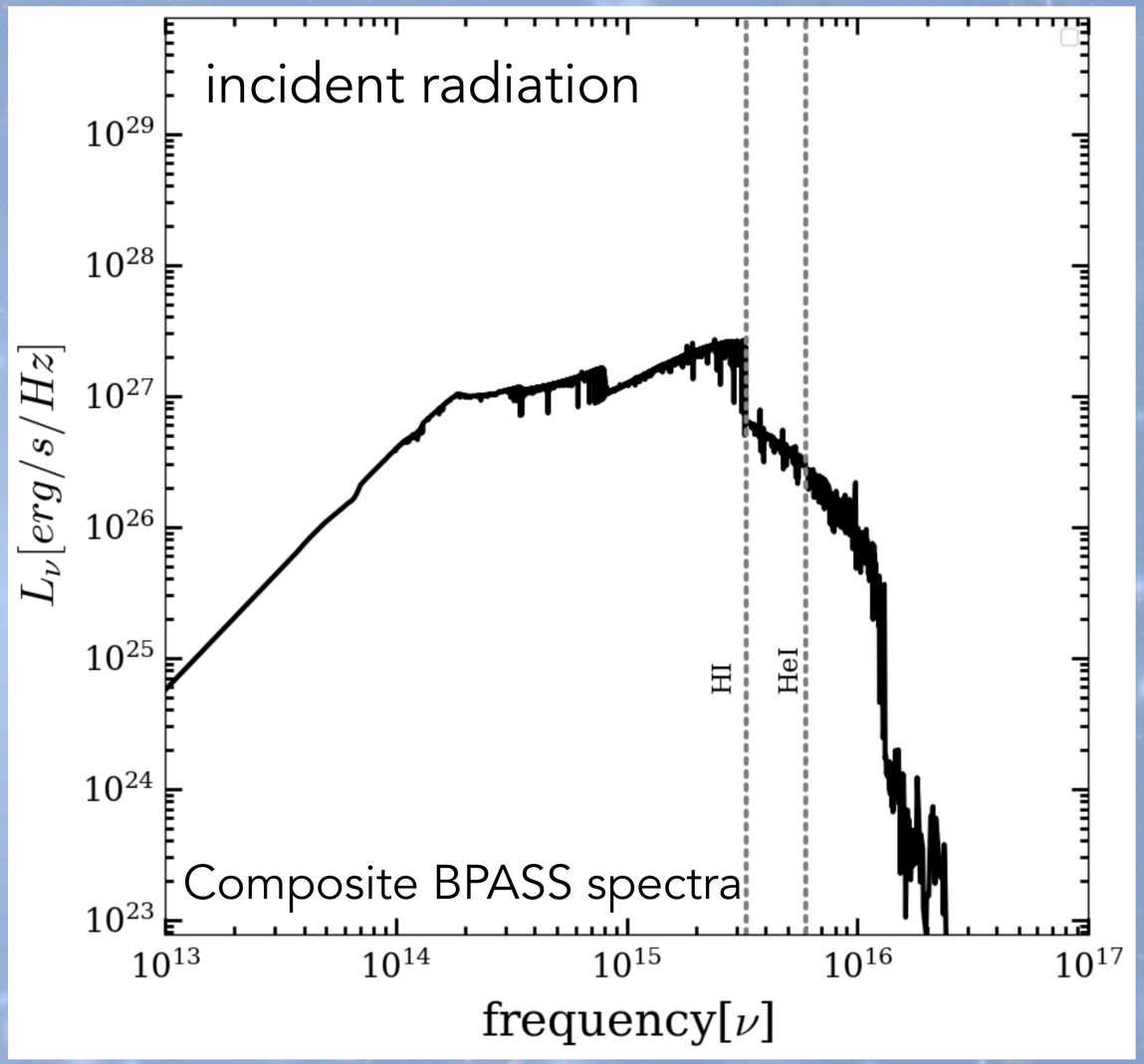


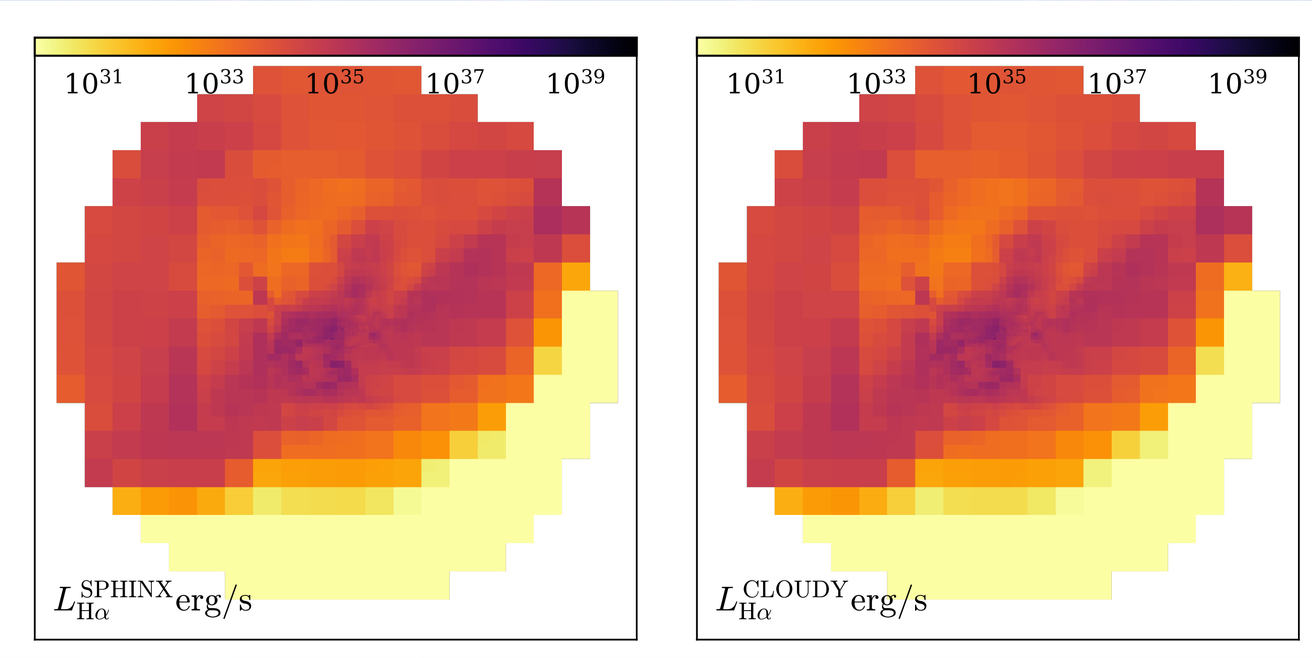
*** Highlights : constant temperature (no thermal equilibrium), fixed electron number density (no charge conservation)**

Preliminary Result

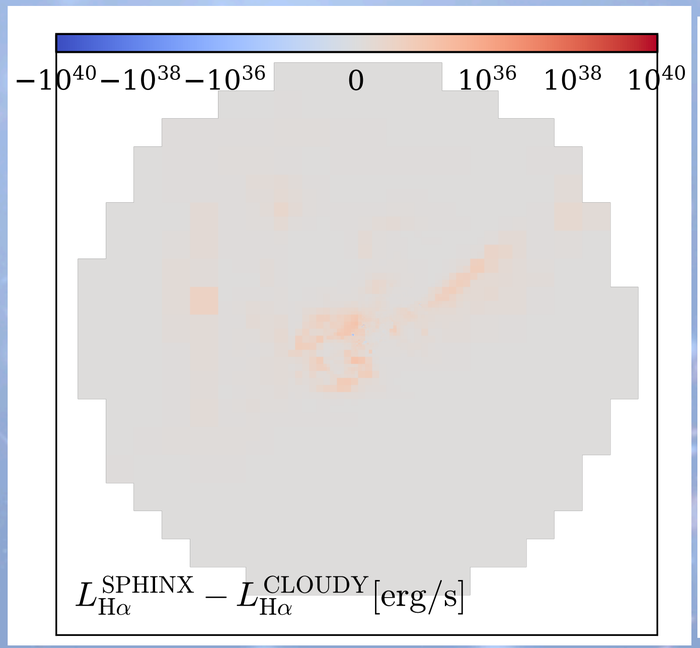
Hα Luminosity

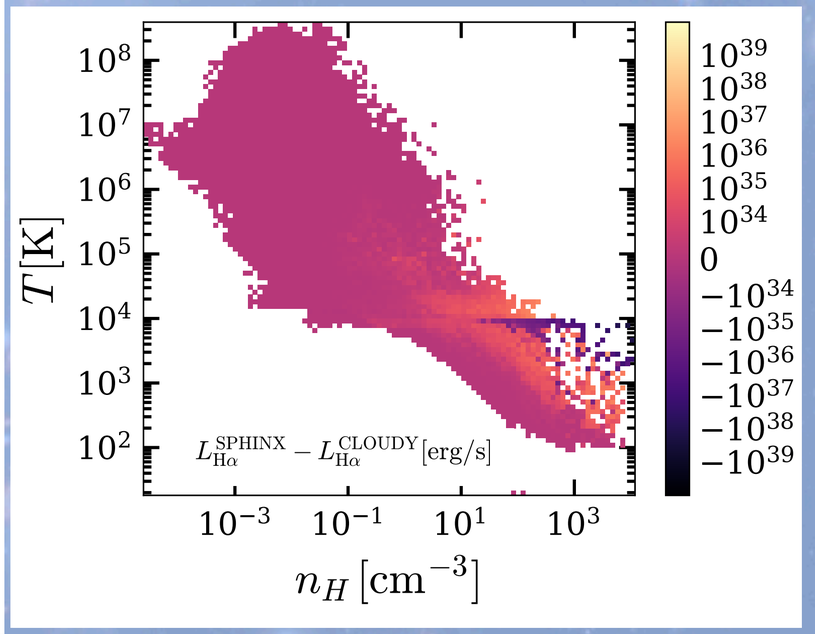
$$\log_{10}(L_{\mathrm{H}\alpha}^{\mathrm{total,SPHINX}}) = 40.63053$$

$$\log_{10}(L_{\mathrm{H}\alpha}^{\mathrm{total,CLOUDY}}) = 40.63093$$

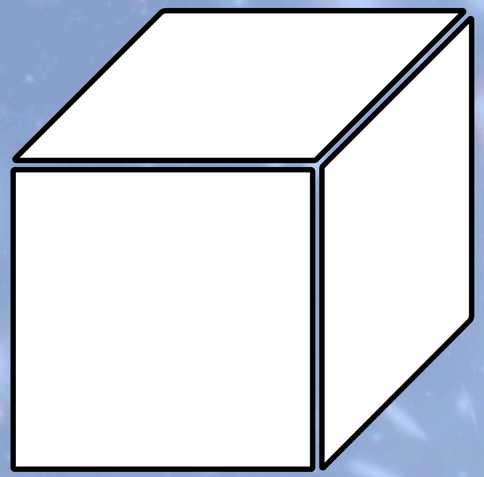


Very Consistent result





Understanding / analyzing limitations of RAMSES-RT

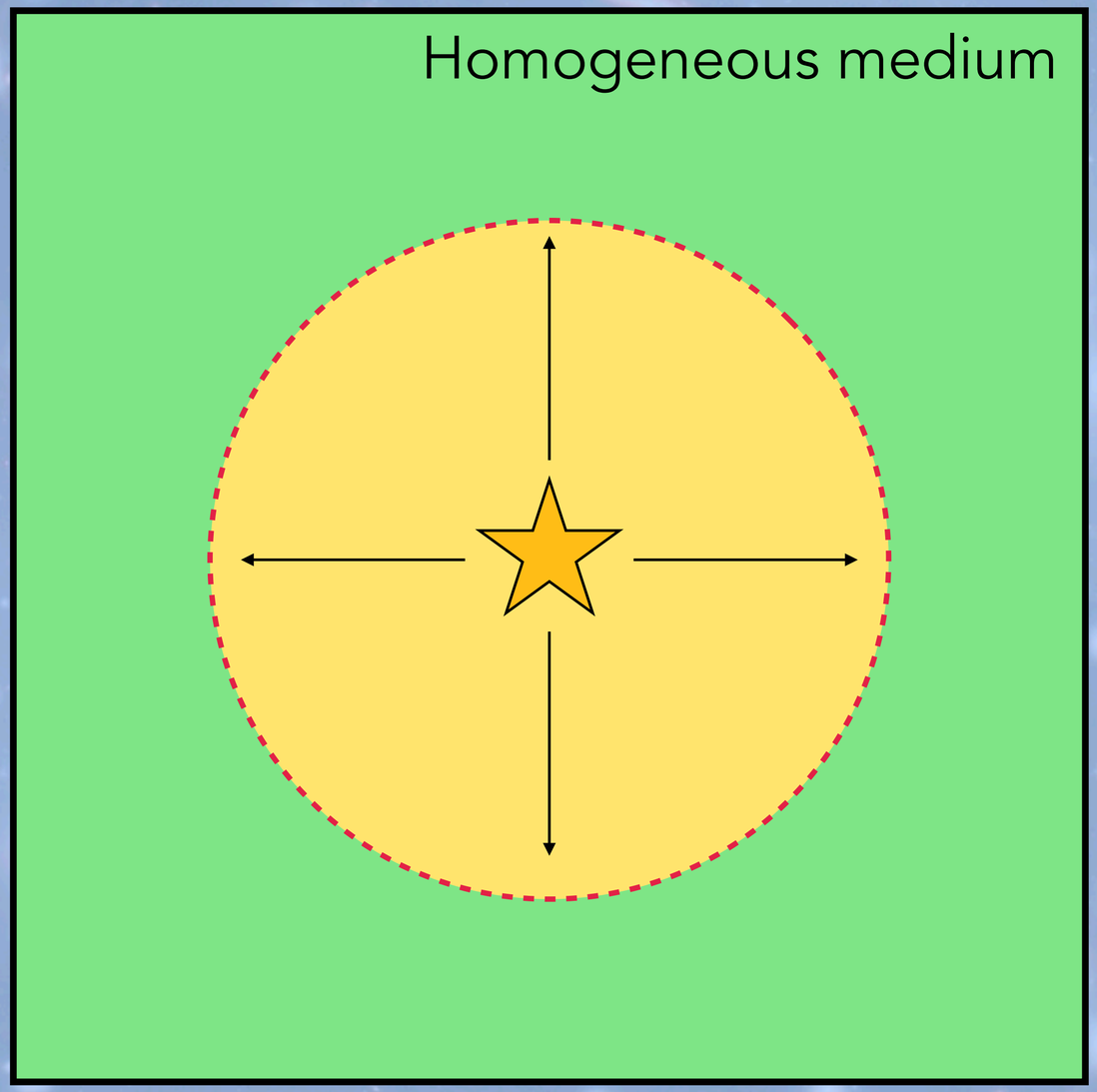


One RAMSES-RT cell

Is RAMSES-RT accurate in predicting SS ?

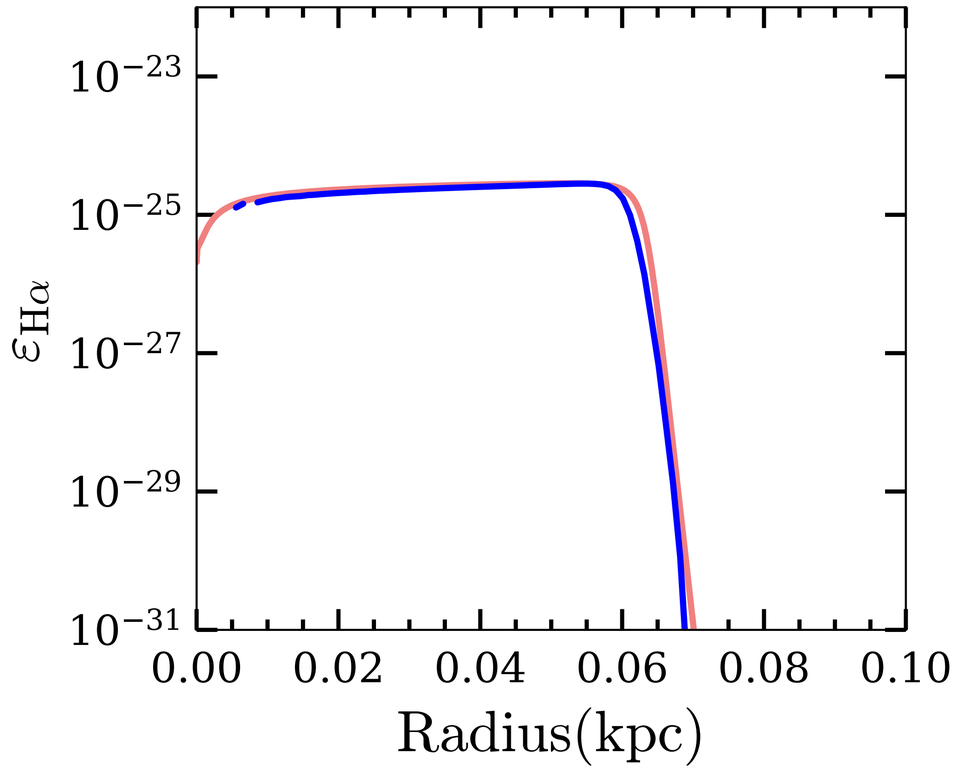
Upto what resolution it works well ?

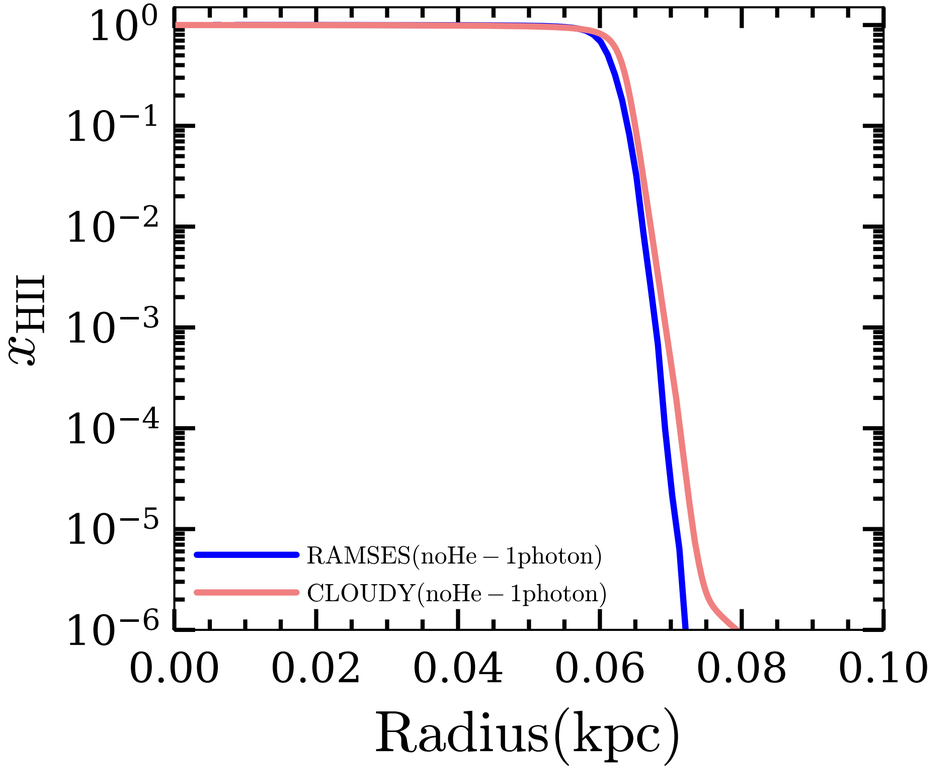
Basic Comparison test : 3D RAMSES-RT vs 3D CLOUDY



Only Hydrogen + monochromatic radiation

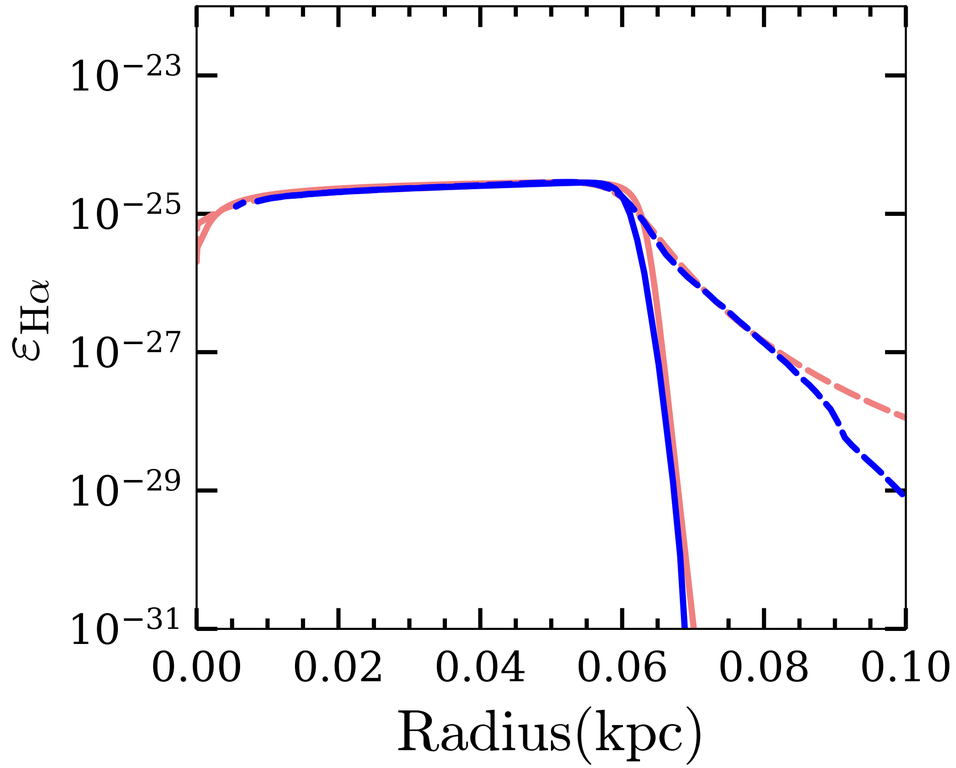
$\Delta x = 3.125$ pc

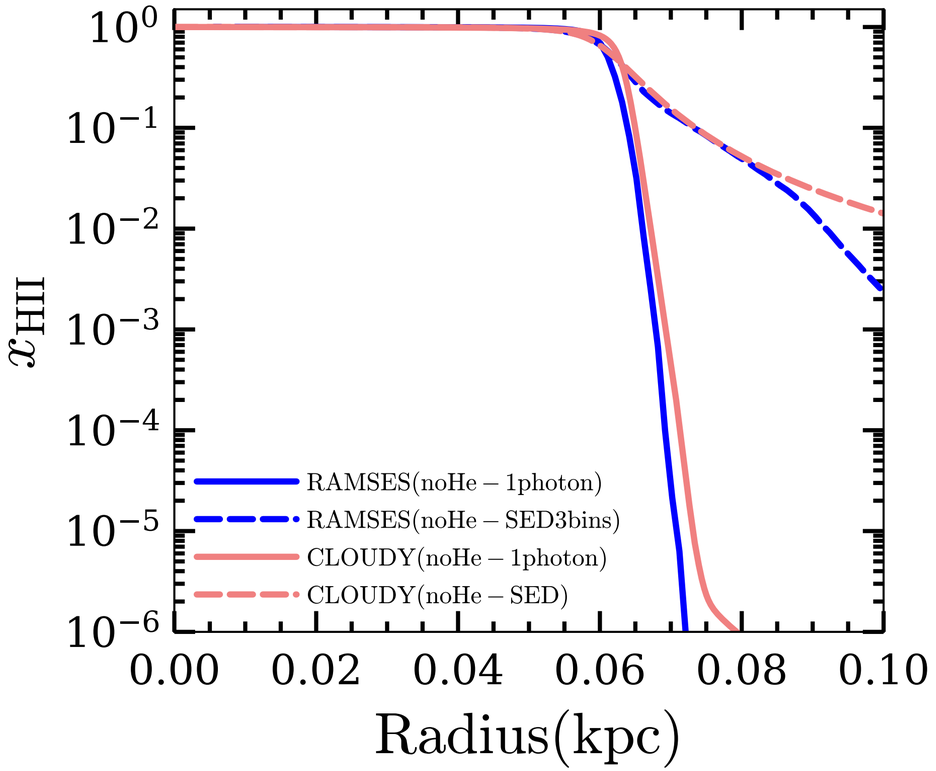




Only Hydrogen + SED (3 bins in RAMSES-RT)

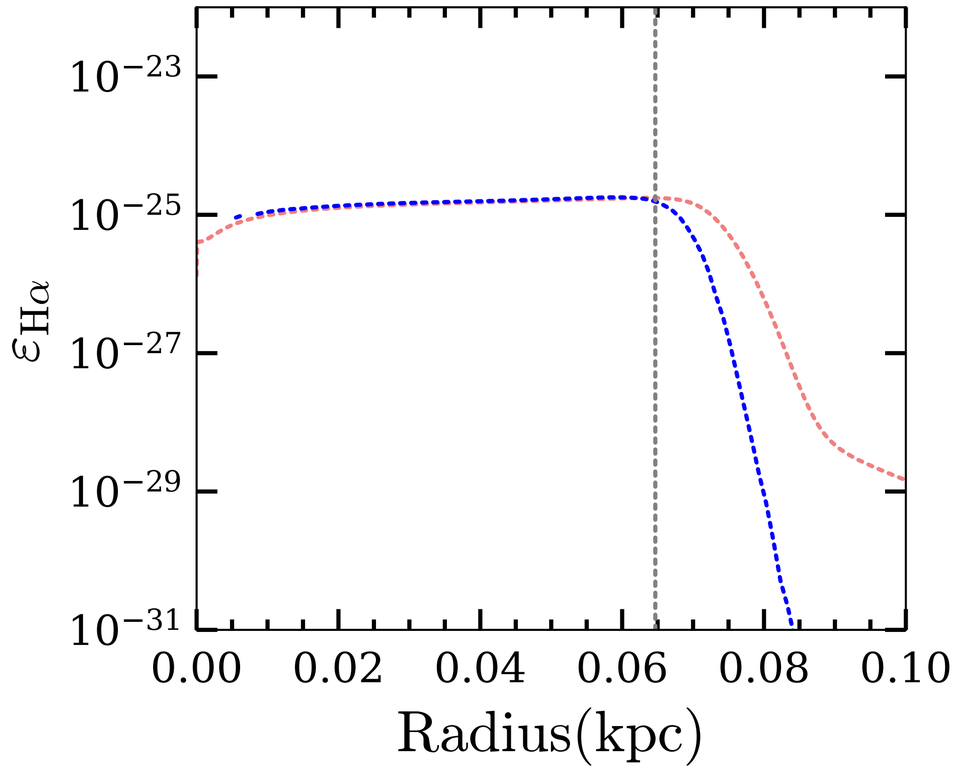
$\Delta x = 3.125$ pc

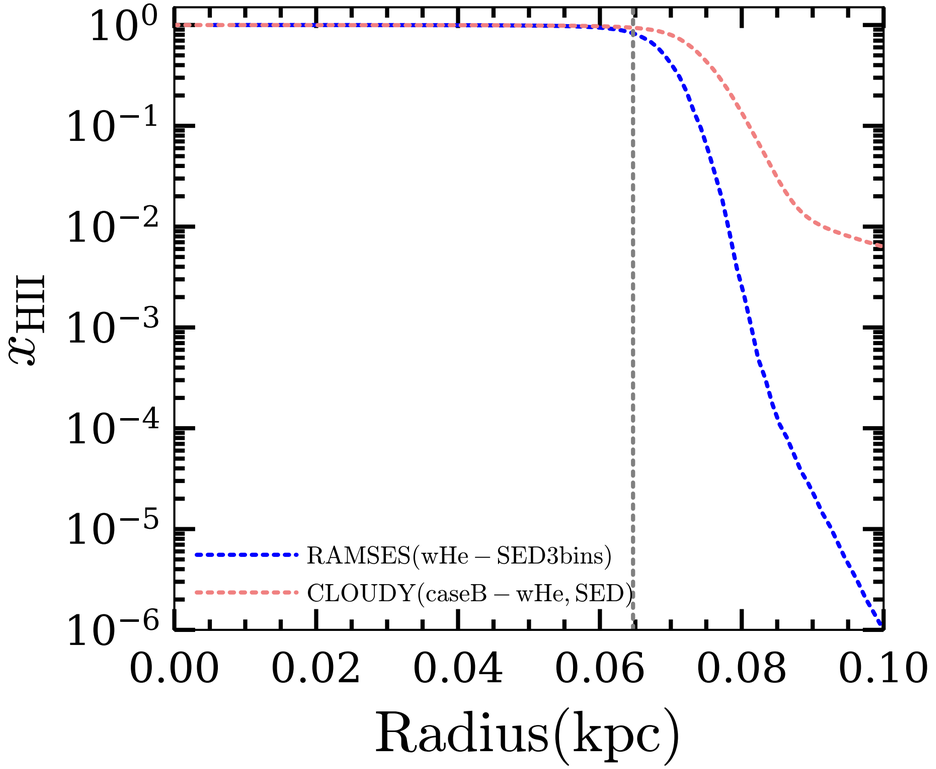




Hydrogen + Helium + SED (3 bins in RAMSES-RT)

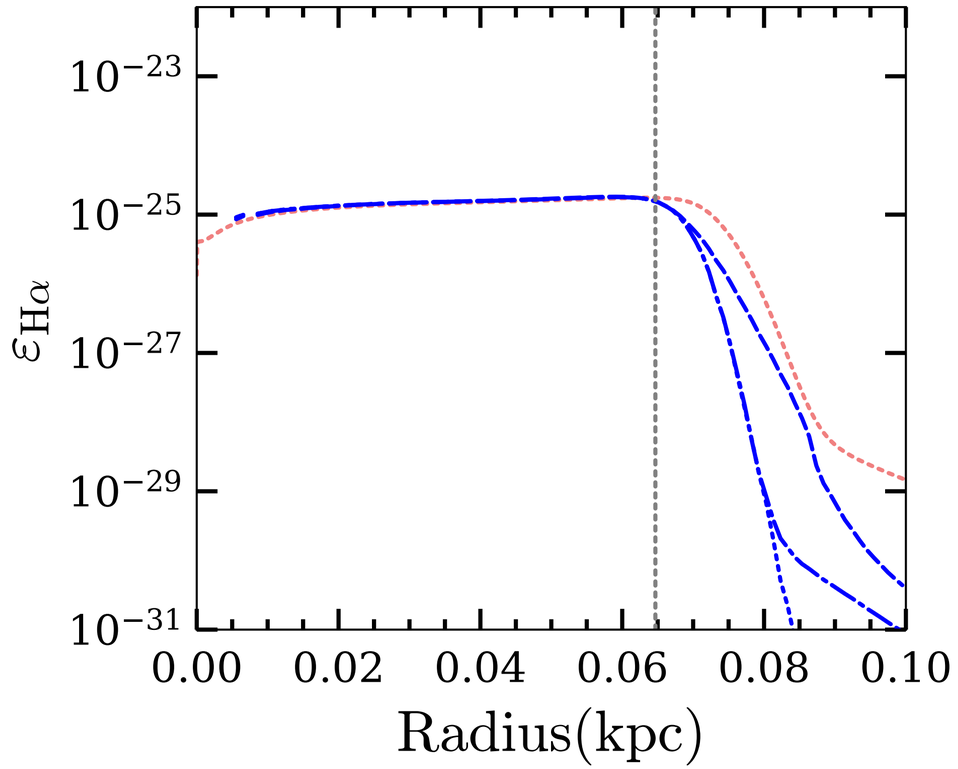
$\Delta x = 3.125$ pc

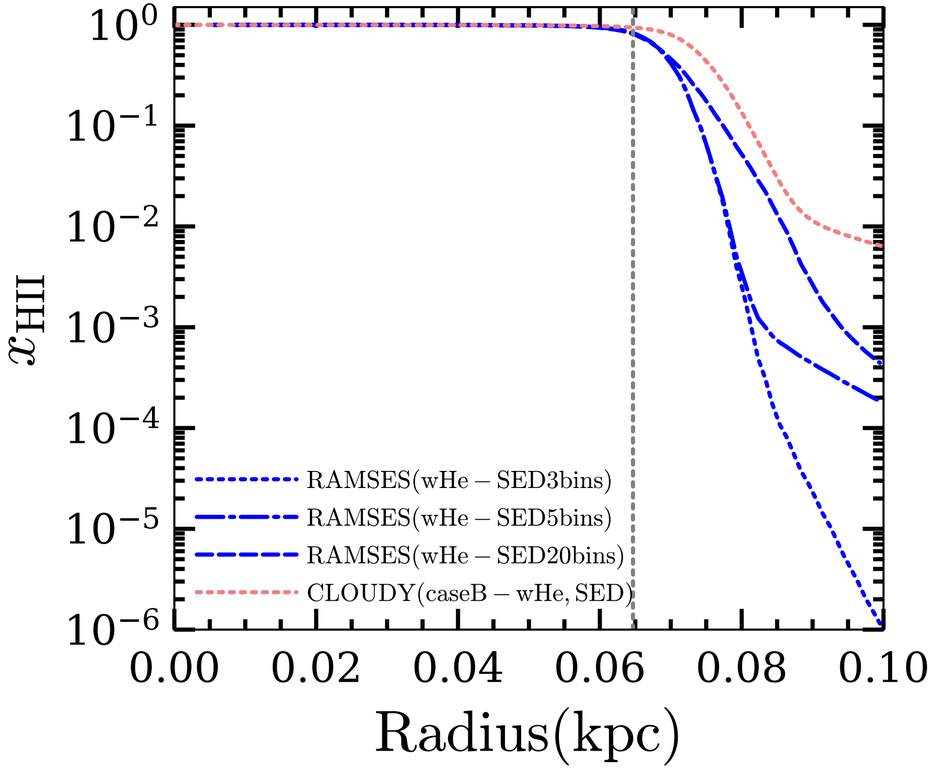




Hydrogen + Helium + SED (3/5/20 bins in RAMSES-RT)

$\Delta x = 3.125$ pc





Hydrogen + Helium + metals + radiation

?

Work in progress

Changing resolutions

?

Work in progress

Summary and discussion points

Catch me if you can

Paired analysis between ‘mock’ and ‘real’ observations will be essential

SPHINX20 full DR is coming soon!

Prediction from CLOUDY works well, but still need to be extra-careful, **so any suggestions/ comments are more than welcome** :D

Feeling shy to ask questions ?
Reach out to me -
arghyadeep.basu@univ-lyon1.fr

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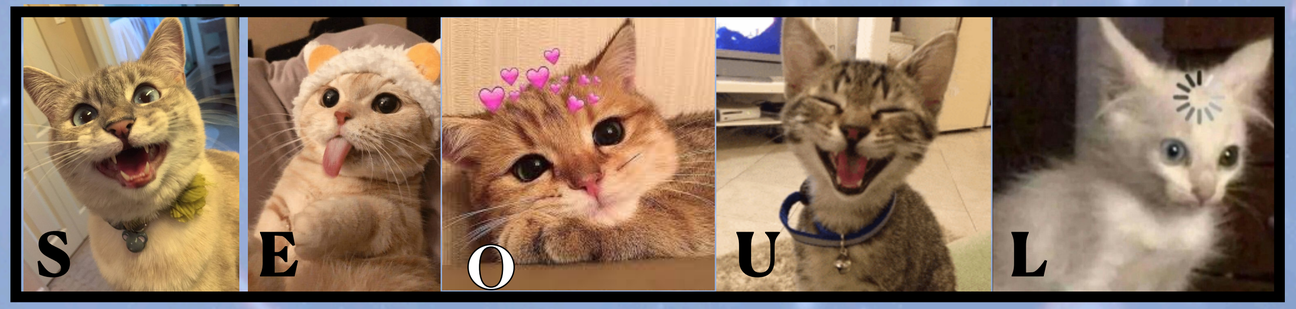

Cheers to **Seoul**, Thank you :-D

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*Disclaimer : No cats are harmed and I am also not harmed by any cat