Radiative Transfer of Resonance Lines

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MPA

RECAP
erc synergy grant

MAX-PLANCK-INSTITUT FÜR ASTROPHYSIK

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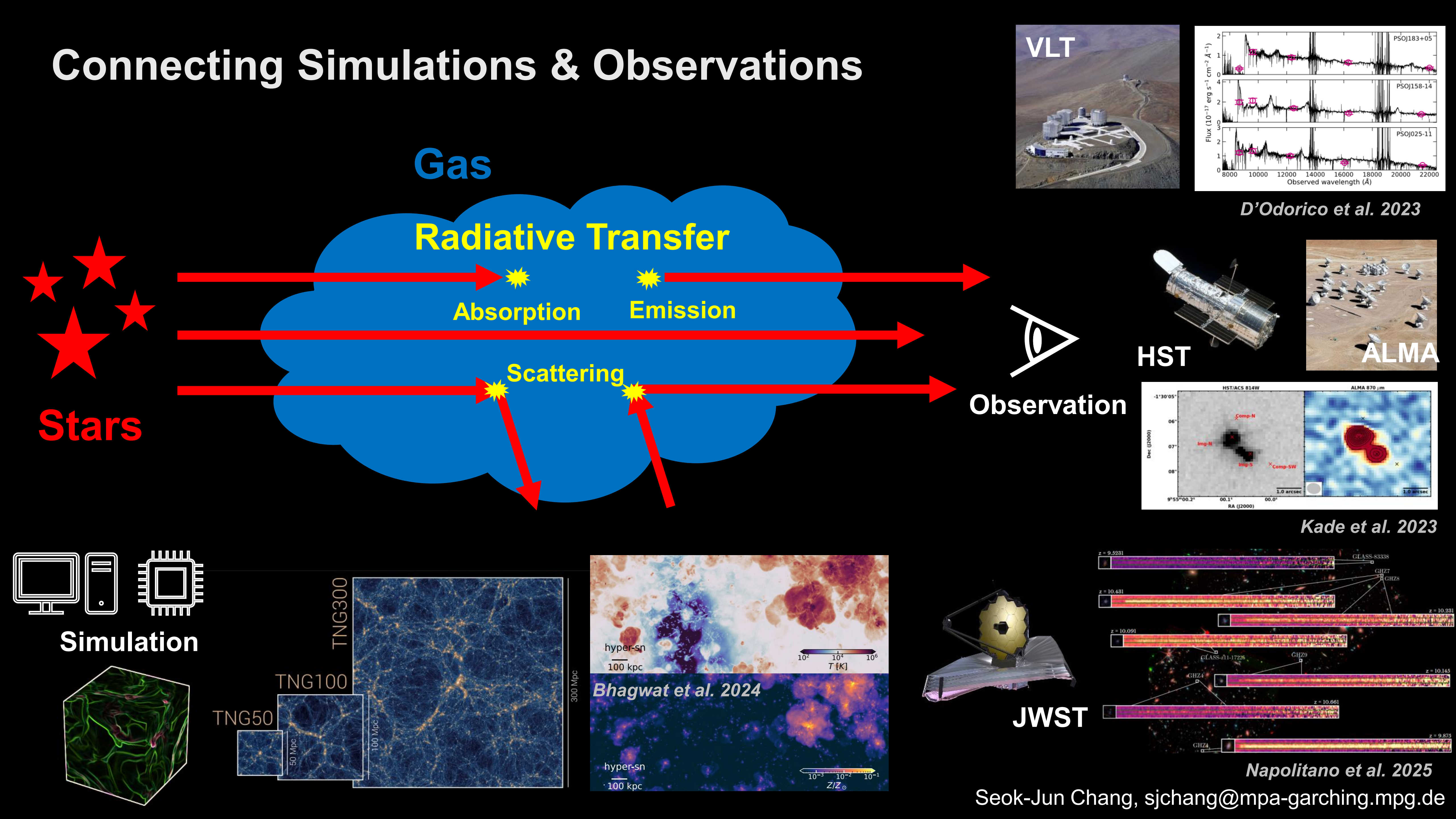
14 Nov 2025, 1st RECAP Meeting


Connecting Simulations & Observations
Gas
Radiative Transfer
Absorption
Emission
Scattering
Stars
Observation
VLT
PSOJ183+05
PSOJ158-14
PSOJ025-11
Observed wavelength (Å)
D'Odorico et al. 2023
HST
ALMA
HST/ACS 814W
ALMA 870 μm
RA (J2000)
Dec (J2000)
Kade et al. 2023
Simulation
TNG300
TNG100
TNG50
300 Mpc
100 Mpc
50 Mpc
hyper-sn
100 kpc
T [K]
Bhagwat et al. 2024
hyper-sn
100 kpc
JWST
Napolitano et al. 2025
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My Radiative Transfer Expertise & Experience

Code Developments

RT-Scat *(SJC et al. 2023a, SJC & Gronke 2024)*

- 3D Monte-Carlo Radiative Transfer
- Parallelized using MPI-Fortran/Open MP
- Lyman Alpha
- Metal Resonance Lines
- Hydrogen Balmer Lines
- Dust Scattering & Absorption
- Polarization with Quantum Mechanics
- Sub-grid Geometry for Small Clumps
- WF effect (coupling of the 21cm)
- Fitting Tool
- Peeling-Off Technique

STaRS *(SJC & Lee 2020)*

- 3D Monte-Carlo Radiative Transfer
- Raman & Rayleigh Scattering
- Accurate Cross Section of Higher Lyman Series with Quantum Mechanics

Studying Radiative Transfer in Diverse Environments

- **AGN & Little Red Dot (~ 1-10 pc)**
  SJC et al. 2015, 2017, 2025b
- **Symbiotic Stars (~ 0.1-1AU)**
  Lee et al. 2016, SJC et al. 2018b, SJC & Lee 2020
- **Planetary Nebulae & O/B nebulae (~ pc)**
  Choi et al. 2020, SJC et al. 2023b, Lim et al. 2025, SJC et al. 2018a, Lim et al. 2024
- **Protoplanetary Disk (~ 10-100 AU)**
  Herczeg et al. 2023, Arulanantham et al. 2023, SJC et al. 2024, Thanathibodee et al. 2024
- **Circumgalactic Medium (~ 10-100 kpc)**
  González Lobos et al. 2023, SJC et al. 2023a, SJC & Gronke 2024, Bolamperti et al. 2025, SJC et al. 2025a

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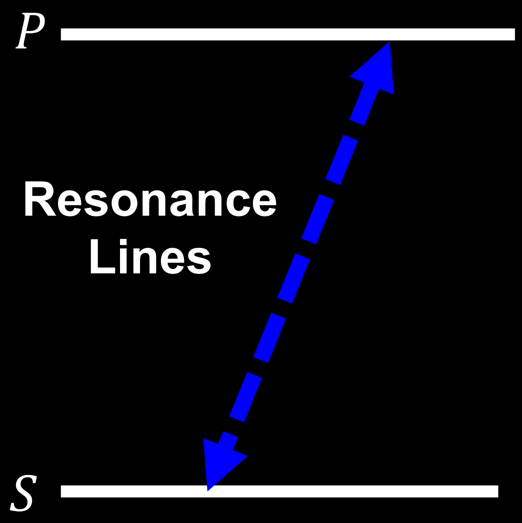
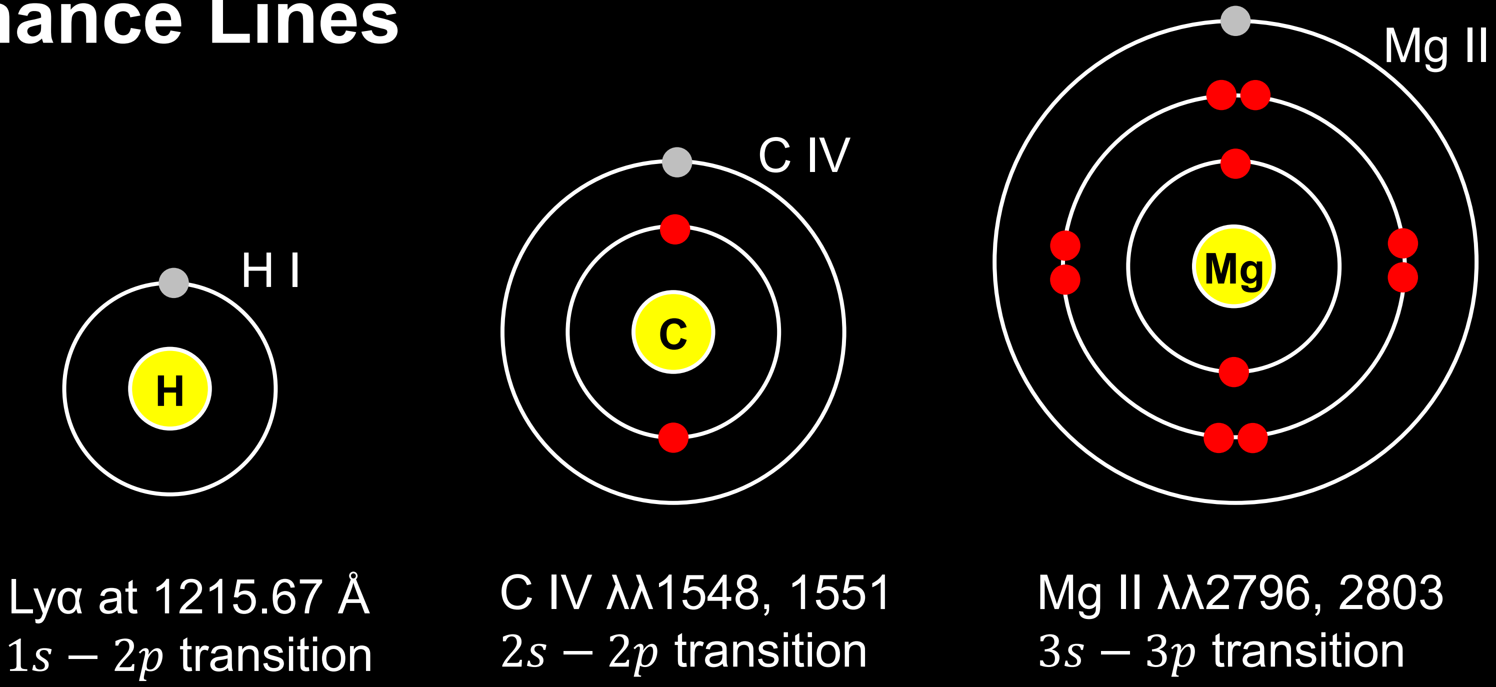
Lyα and Metal Resonance Lines





- Resonance lines arise from transitions between the ground S and the first excited P states.

- Notable examples are Hydrogen Lyman alpha (Lyα) at 1215.67 Å and resonance lines of metals such as Mg II, C IV, O VI, and N V.

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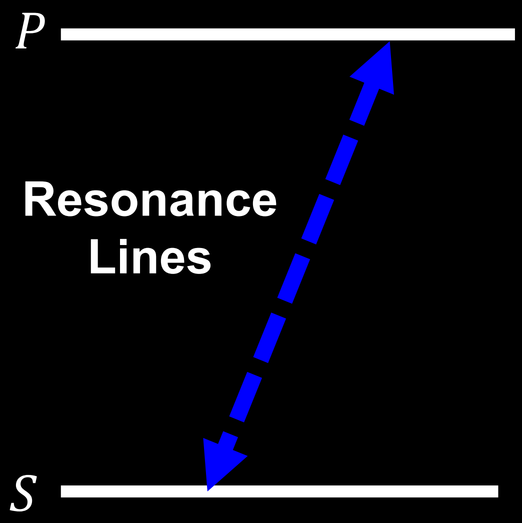
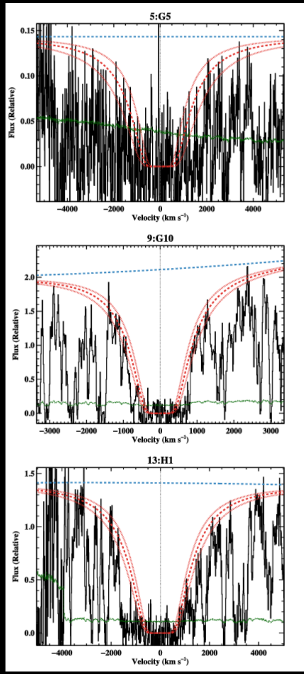
Lyα and Metal Resonance Lines

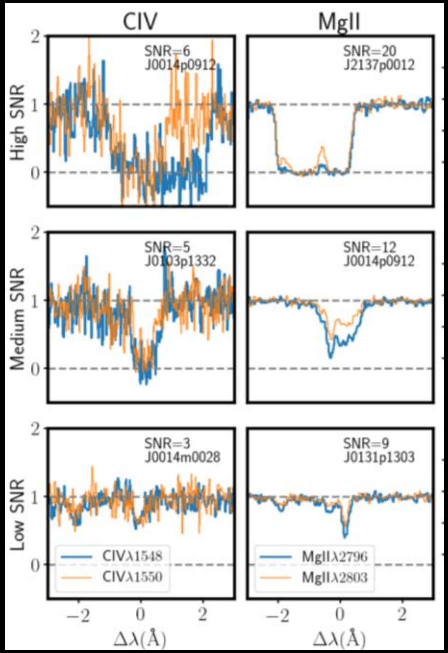


Fumagalli et al. 2014



Damped Lyα

Schroetter et al. 2021



C IV and Mg II absorption

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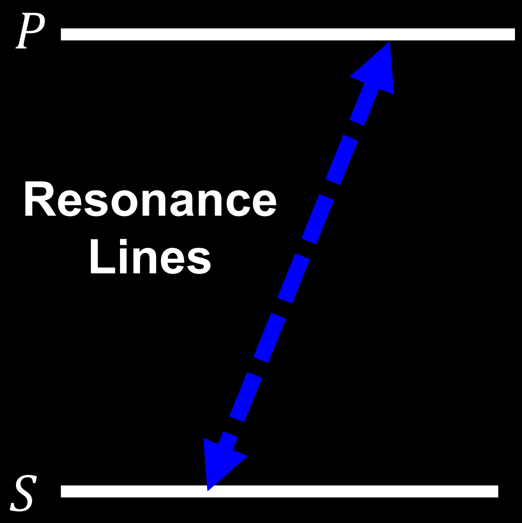
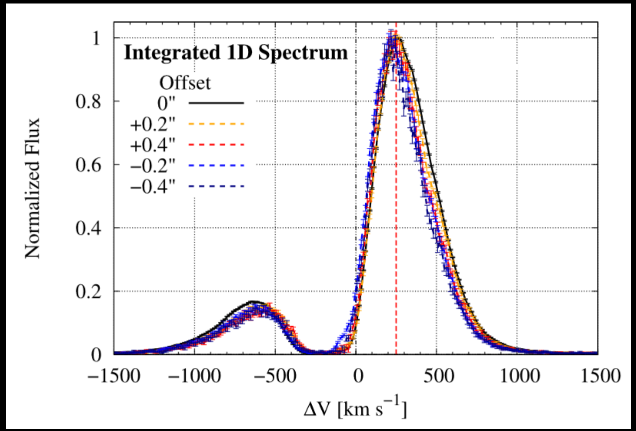
Lyα and Metal Resonance Lines

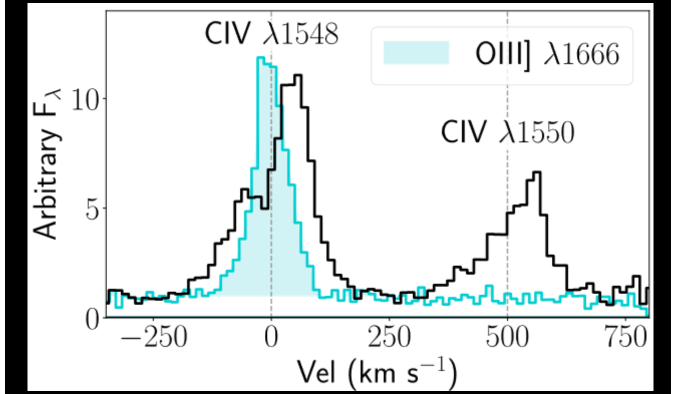


SJC+ 2024



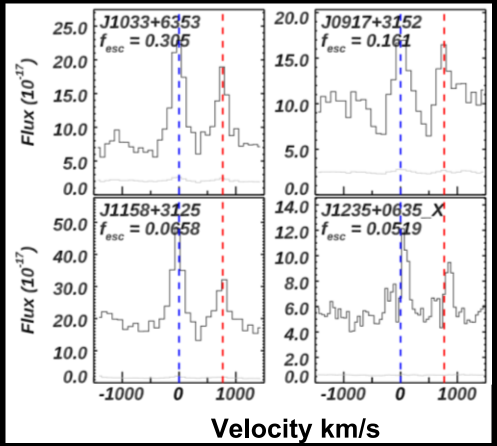
Lyα in T-Tauri Star, TW Hya

Berg+ 2019



C IV λλ1548, 1550
in star forming galaxies

Xu+ 2023



Mg II λλ2796, 2803
in star forming galaxies

- Resonance lines arise from transitions between the ground S and the first excited P states.
- Notable examples are Hydrogen Lyman alpha (Lyα) at 1215.67 Å and resonance lines of metals such as Mg II, C IV, O VI, and N V.
- These resonance lines act as the primary coolants in the shocked region through collisional excitation and in the ionized region through recombination processes ***(Osterbrock 1989, Draine 2011).***

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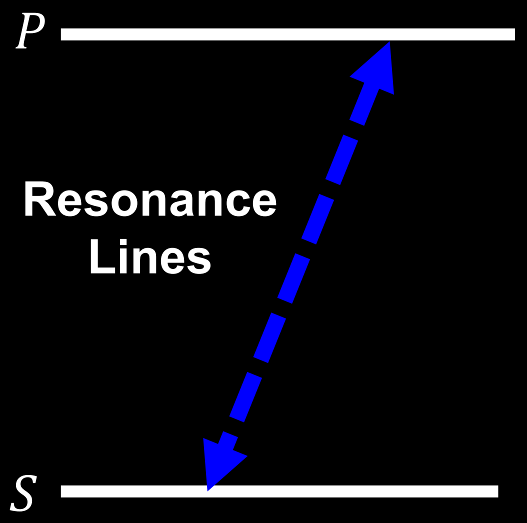
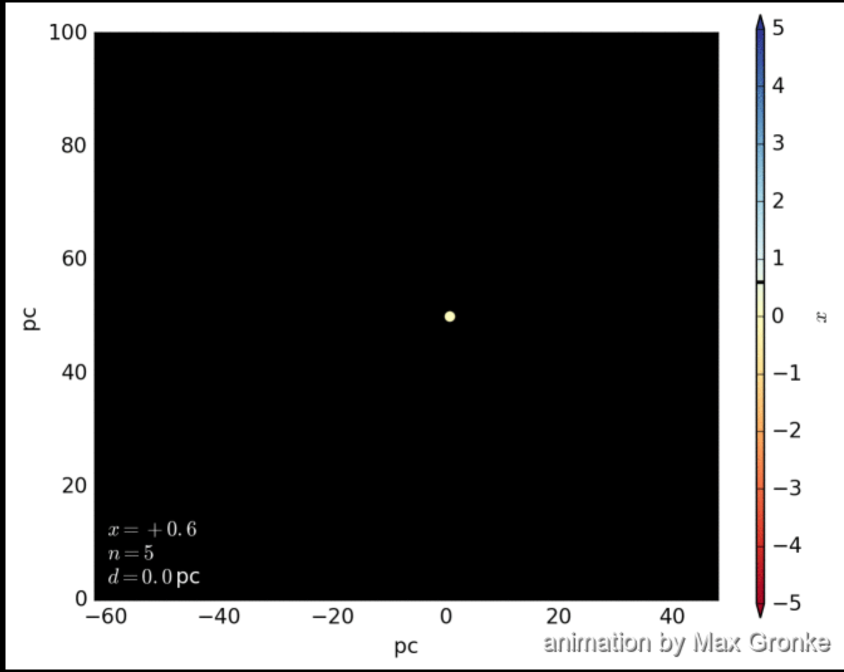
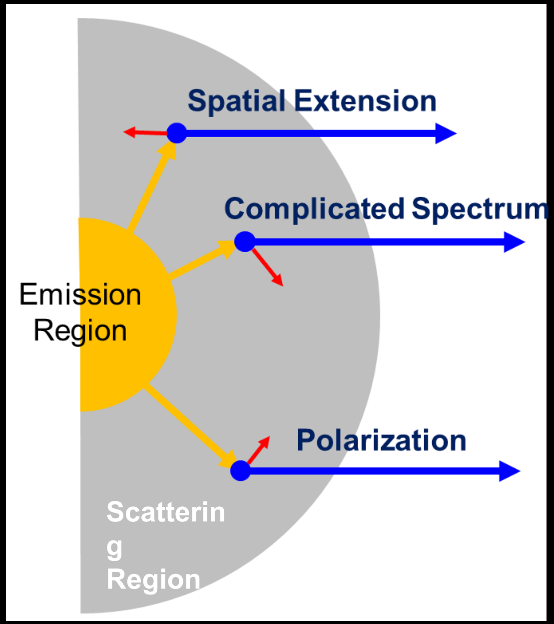
Lyα and Metal Resonance Lines







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- Notable examples are Hydrogen Lyman alpha (Lyα) at 1215.67 Å and resonance lines of metals such as Mg II, C IV, O VI, and N V.

- These resonance lines act as the primary coolants in the shocked region through collisional excitation and in the ionized region through recombination processes *(Osterbrock 1989, Draine 2011).*

- Due to their resonant nature, the physical properties of both **emission and scattering regions** are imprinted on resonance lines.
(see reviews, ***Dijkstra et al. 2019, Ouchi et al. 2020, also Chang et al. 2023, 2024, Chang & Gronke 2024***)

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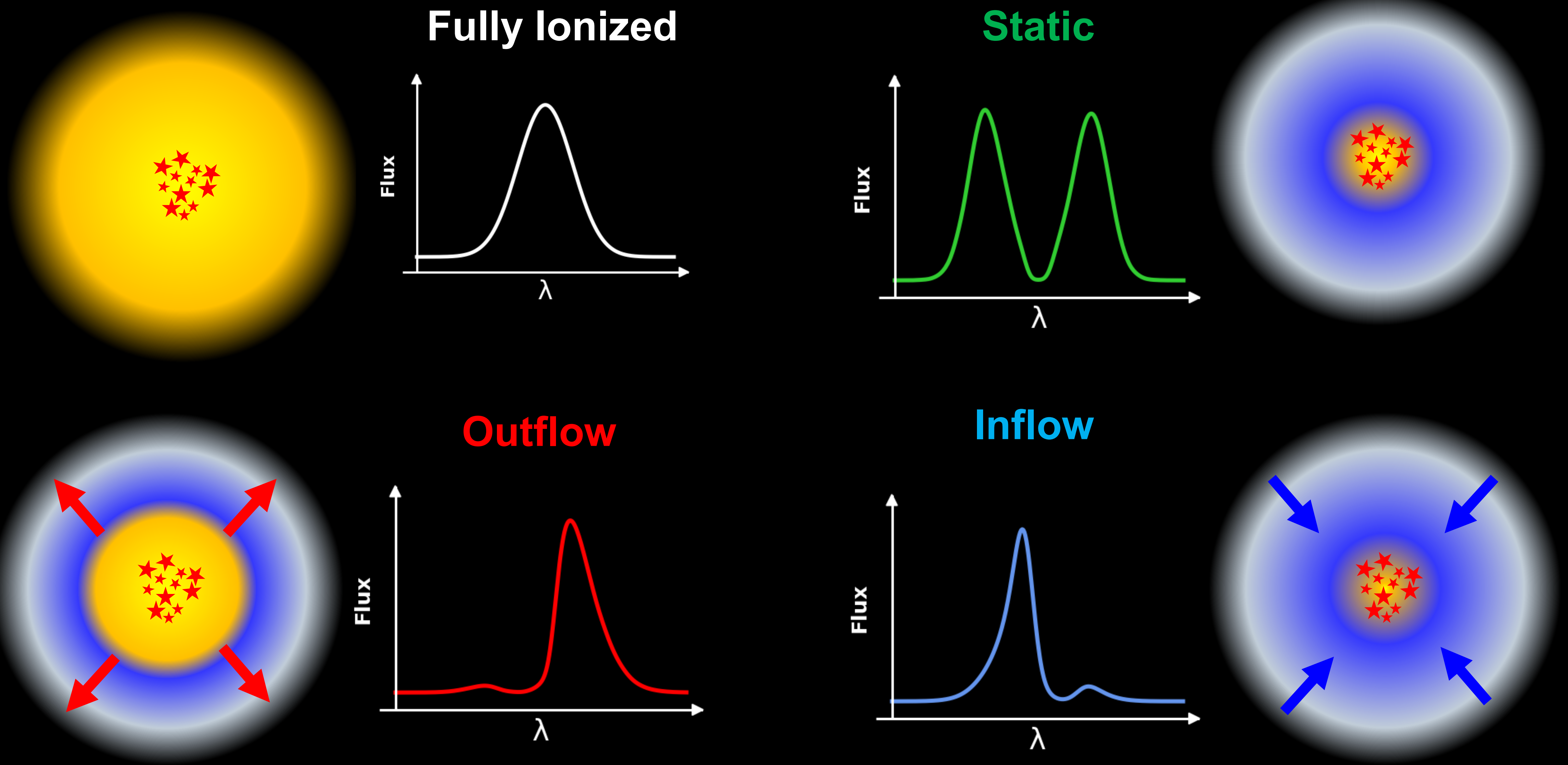
Lyα Radiative Transfer



Spectrum generated by RT-scat (**SJC & Gronke 2024**)

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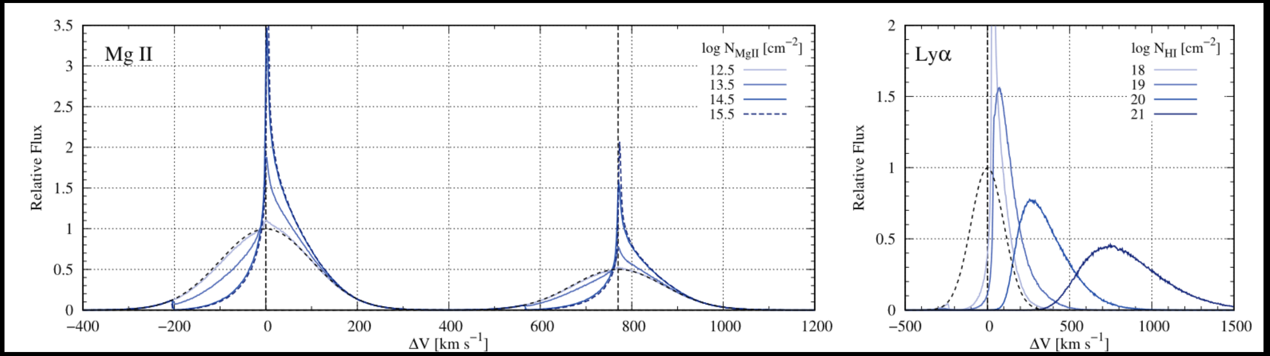
RT-Scat *(SJC et al. 2023, SJC & Gronke 2024)*

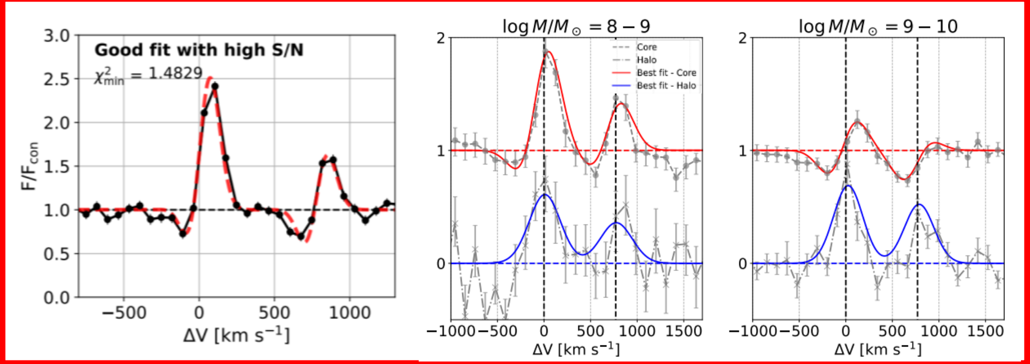
- 3D Monte-Carlo Radiative Transfer
- Parallelized using MPI-Fortran/Open MP
- Lyman Alpha & Metal Resonance Lines
- Dust Scattering & Absorption
- Polarization with Quantum Mechanics
- Balmer Lines
- Thomson scattering (electron scattering)
- Sub-grid Geometry for Small Clumps
- WF effect (coupling of the 21cm)
- Fitting Tool
- Peeling-Off Technique

SJC & Gronke 2024

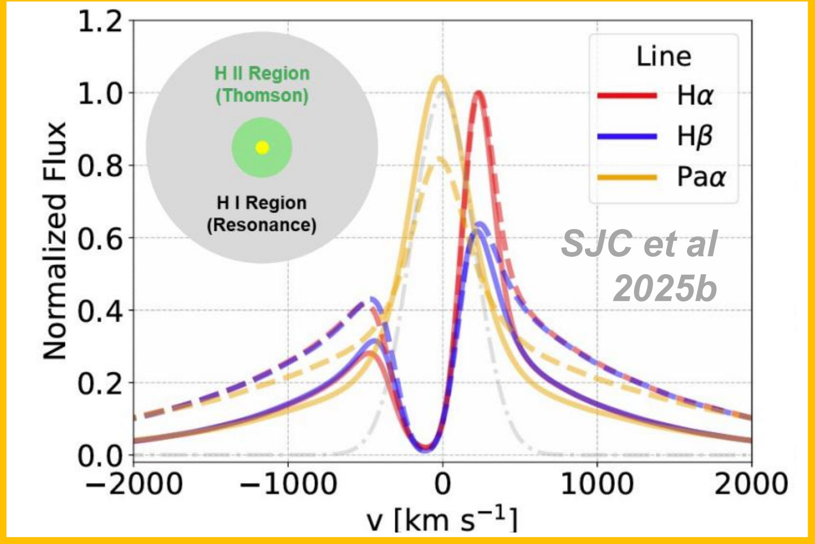


Simulated Spectra of Mg II and Lyα

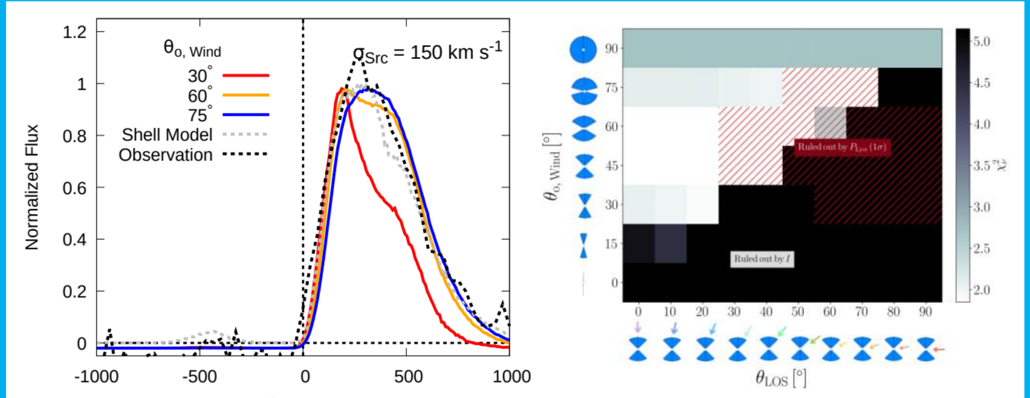
Modeling Mg II spectra of SFG *SJC et al. 2025a*



Balmer line transfer in LRD

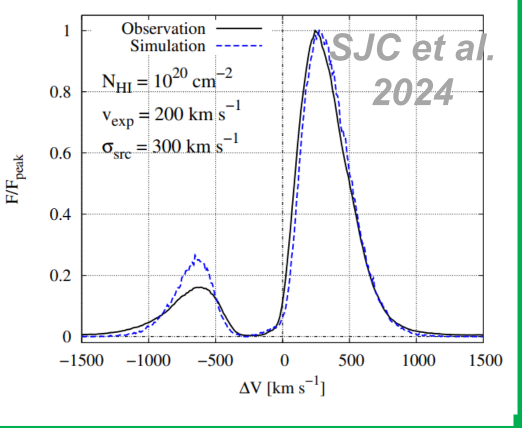


Polarized Lyα in SFG



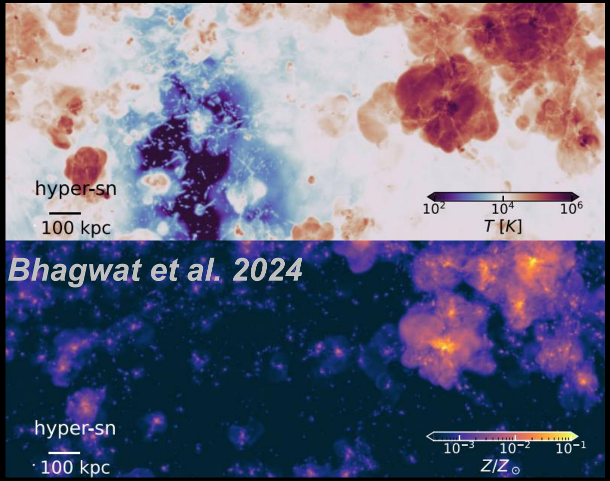
Bolamperti, SJC et al. 2025

Lyα in T-Tauri Stars



My Role in RECAP

Development of Radiative Transfer Scheme for Post-Processing



Snapshots of hydrodynamic simulations

RT Codes for Post-Processing include
- Photoionization by Radiation from Stars & AGN
- Collisional Excitation & Ionization
- Recombination
- Continuum Pumping

Photoionization by UV and X-ray
Ray-tracing to estimate the ionization state in CGM/IGM and their temperatures

Non-Resonance Lines (ex., Hydrogen Balmer lines, [O III], [C II], [N II])
Peeling-Off Technique for mock observations

Resonance Lines (Lyα and metal resonance lines such as Mg II, C IV, O VI)
Ray-tracing for scattering + dust absorption & scattering

Mock Absorption Spectra
Sub-grid model for multiphase gas

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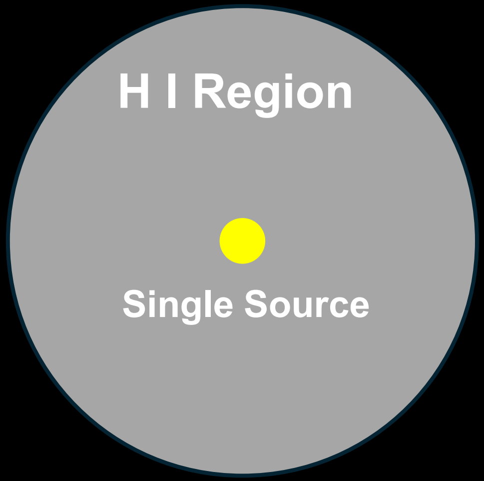
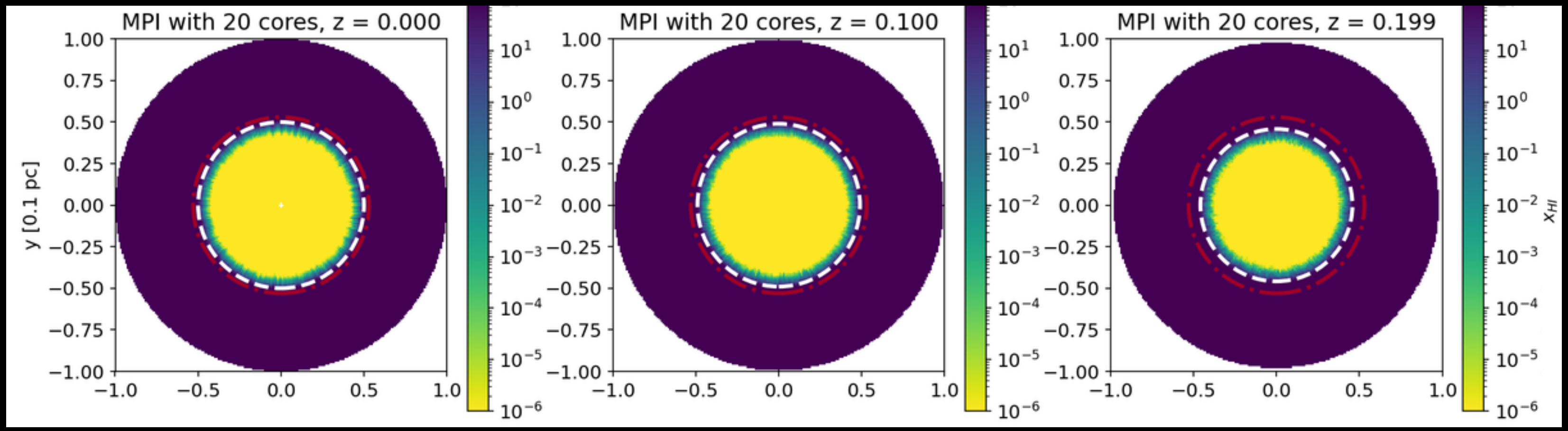
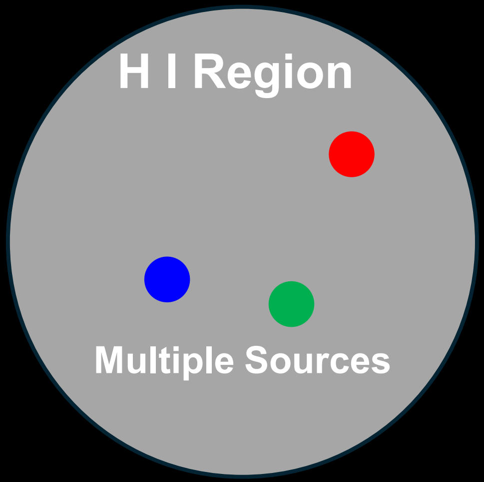
Preliminary Results of 3D RT for Photoionization

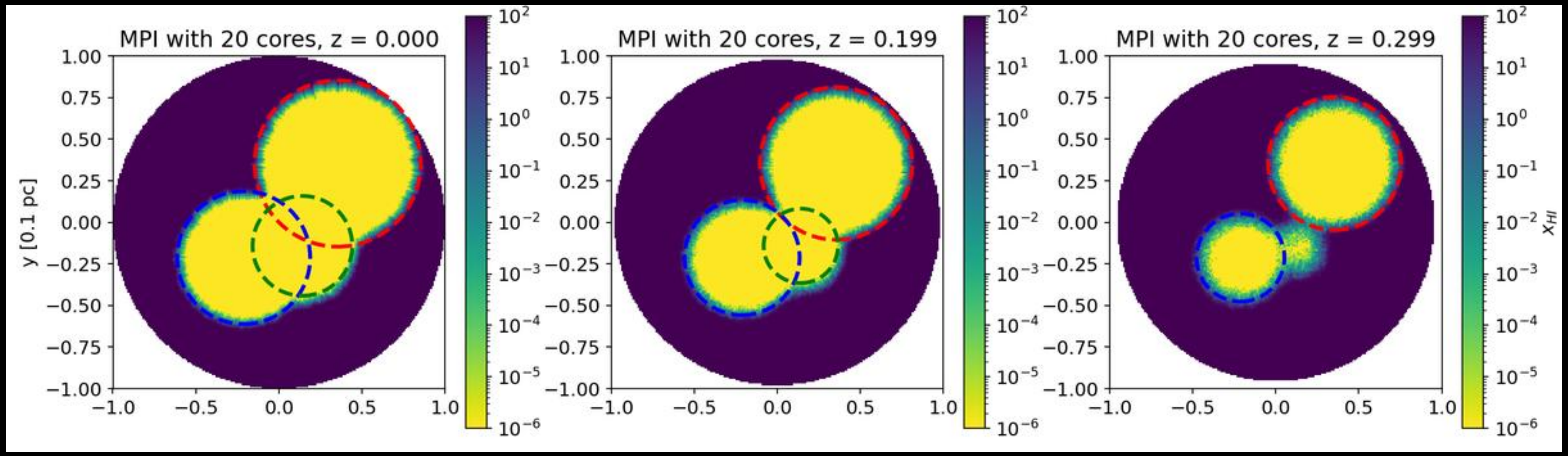


Single Source





Multiple Sources



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Acknowledgement & Disclaimer

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