STaRS Gen 2: Sejong Radiative Transfer through Raman and Rayleigh Scattering in Dusty Medium

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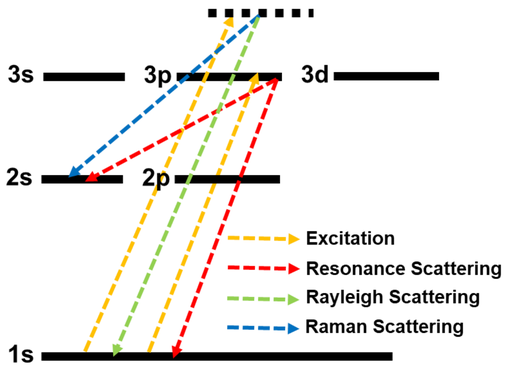
STaRS's Homepage
seokjun.weebly.com/stars.html

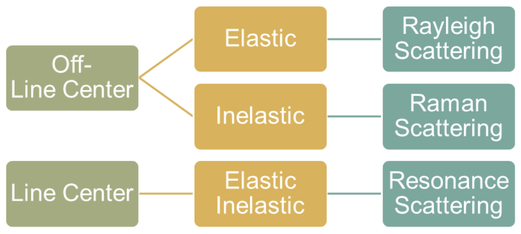
I. Abstract

Emission features formed through Raman scattering with atomic hydrogen provide unique and crucial information to probe the distribution and kinematics of a thick neutral region illuminated by a strong far-ultraviolet radiation source. We introduce a new 3-dimensional Monte-Carlo code to describe the radiative transfer of line photons subject to Raman and Rayleigh scattering with atomic hydrogen. In our **Sejong Radiative Transfer through Raman and Rayleigh Scattering (STaRS)** code, the position, direction, wavelength, and polarization of each photon is traced until escape. The thick neutral scattering region is divided into multiple cells. Each cell is characterized by its velocity and density, which ensures flexibility of the code in analyzing Raman-scattered features formed in a neutral region with complicated kinematics and density distribution. We are continuously developing **STaRS to adopt the absorption and scattering effect by dust.** This poster introduces STaRS and its current state and study.

II. Introduction

① Scattering with Atomic Hydrogen

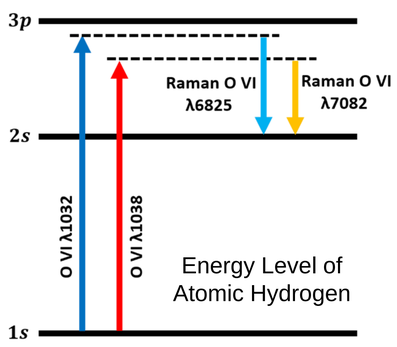


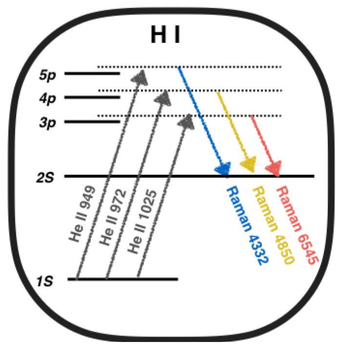


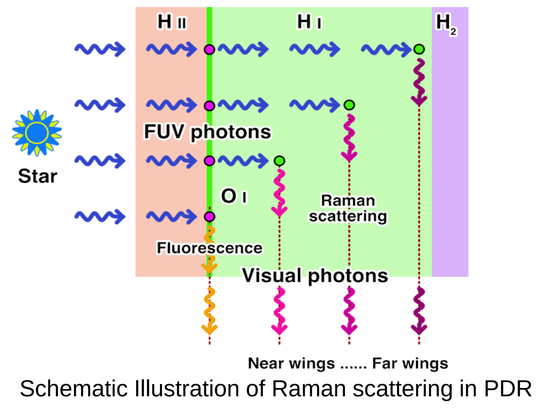
Type of Scattering with Atomic Hydrogen

- ❖ **Resonance scattering** occurs when the photon frequency coincides with a line transition between two states.
- ❖ Non-resonant scattering is classified into **Rayleigh and Raman scattering**.
- ❖ The excited hydrogen atom may de-excite into an excited state resulting in reemission of a lower energy photon, which is called ***Raman Scattering.*** If the de-excitation is made into the ground state, then result is an elastic scattering, which is also called ***Rayleigh scattering.***
- ❖ ***Raman scattered photons provide the information of a thick H I region and a hot emission region***

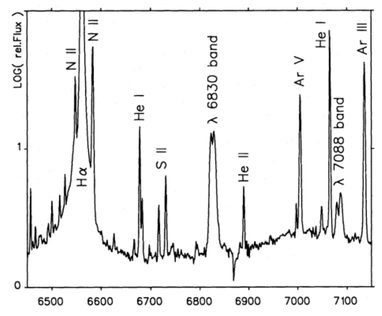
② Raman Scattered Features



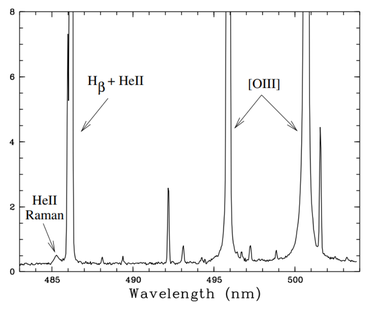




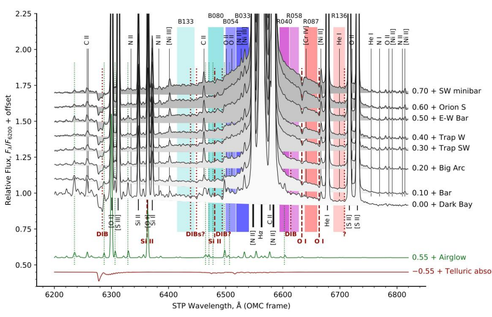
Schematic Illustration of Raman scattering in PDR



Raman O VI in V1016 Cyg
Schmid 1989

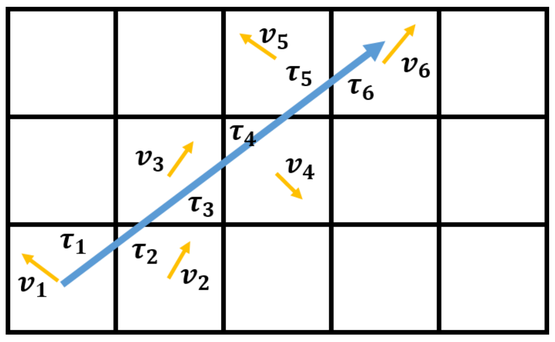


Raman He II 4850 in NGC 7027
Pequignot et al 1997



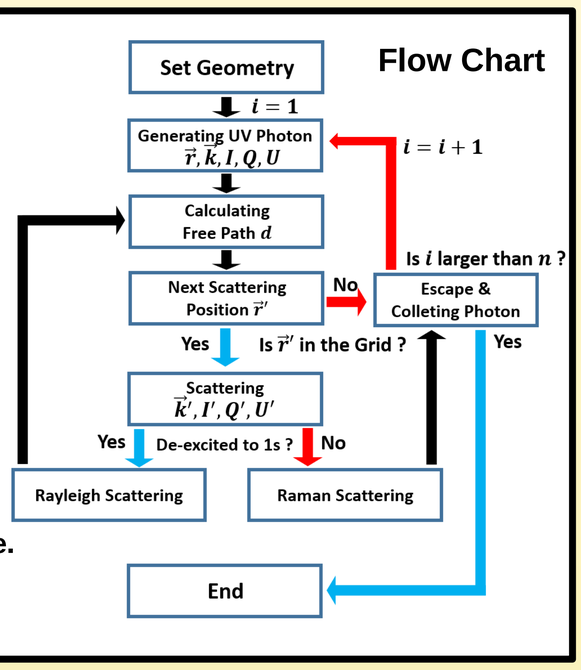
MUSE data of Raman Wing in Orion Nebular
Henney 2021

III. STaRS CODE

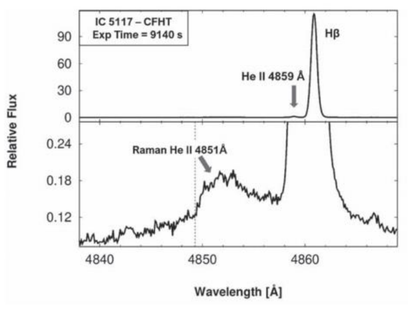


Grid-Based Geometry

- ❖ We adopted the grid-based geometry to describe **the complex velocity and density field.**
- ❖ The photon packet carries **a wavelength, a position, a direction, and a polarization state.**
- ❖ In each grid, **the physical conditions are taken to be uniform.**

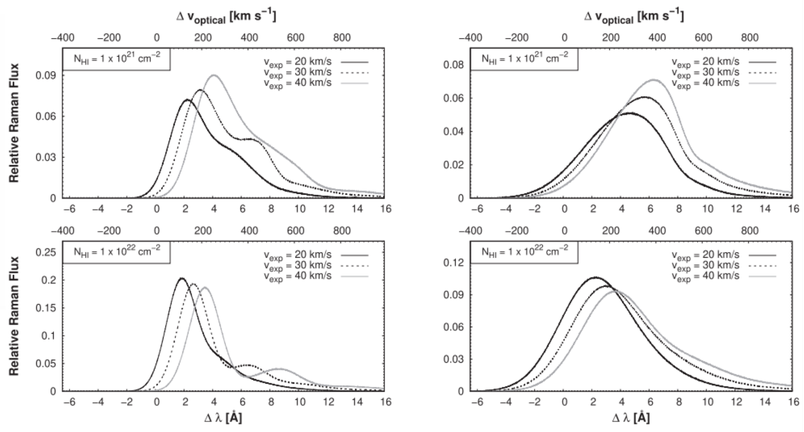


IV. First Adopting STaRS – Choi et al. 2020



Raman He II 4850 in IC 5117

Scattering Geometry



Raman He II in Expanding Medium

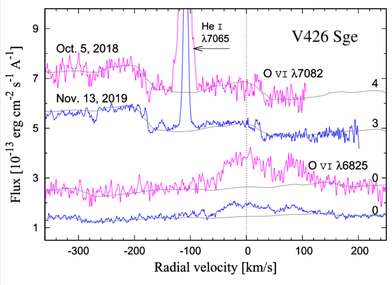
- ❖ Choi et al. 2020 computed the profiles of **Raman He II in expanding medium** to investigate redshifted Raman He II.
- ❖ Raman He II becomes more redshifted with increasing expanding velocity.
- ❖
- ❖ The width of Raman He II is broadened by expanding medium.
- ❖ **This paper is the first paper adopting STaRS Code.**

V. STaRS Gen 2 – Dusty Medium

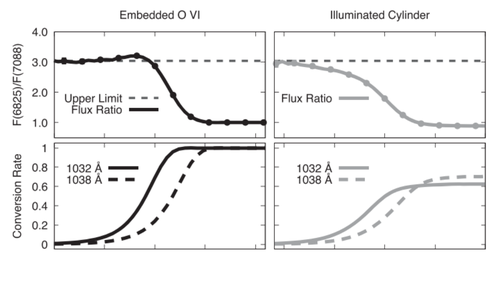
① What is new in STaRS Gen 2

- ❖ STaRS Gen 1 considers the pure H I region as a scattering medium.
- ❖ Far-UV radiation easily experiences dust extinction during traveling in H I region.
- ❖ **We adopt the dust extinction of scattering medium in STaRS Gen 2.**

② Why dust is required



Raman O VI 6825 in V425 Sge
Skopal et al. 2020



The ratio of Raman O VI lines
Lee et al. 2016

Lines	λ_c[Å]	σ_{tot} [cm^{-2}]	BR2
O VI 1032	1031.93	2.74×10^{-23}	0.18
O VI 1038	1037.62	6.13×10^{-24}	0.27

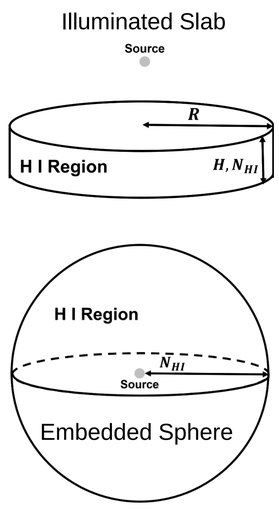
Hydrogen Scattering Cross Section
Chang et al. 2015

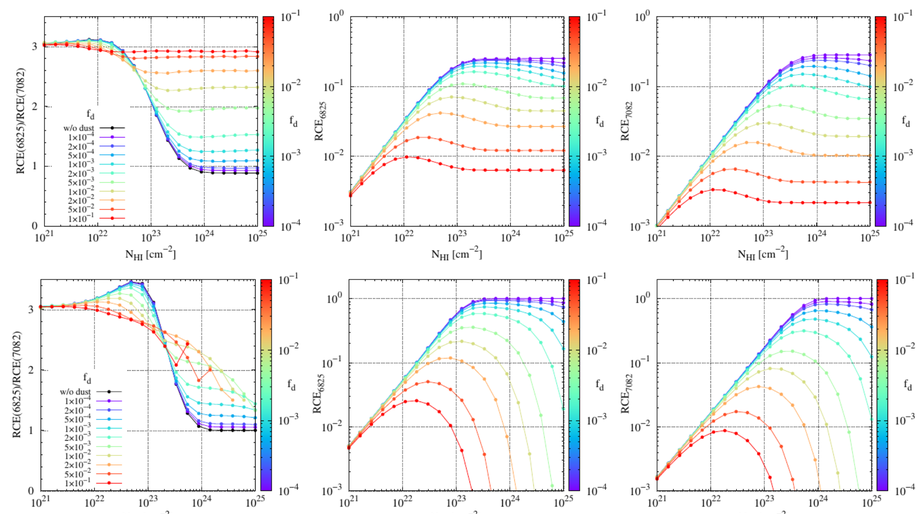
Wavelength [Å]	C_{ext} $[cm^2/H]$	albedo
1032	2.03×10^{-21}	0.28211
1038	2.01×10^{-21}	0.28399
6825	3.60×10^{-22}	0.67124
7082	3.41×10^{-22}	0.66887

Dust Scattering Cross Section
Draine 2003

- ❖ Skopal et al. 2020 reported that Raman O VI 7082 doesn't exist even for bright Raman O VI 6825.
- ❖ Lee et al. 2016 computed the range of the ratio of two Raman O VI lines from 0.8 to 3.5.
- ❖ We expect that **Raman O VI 7082 experiences more dust extinction because of Raman scattering cross section smaller than Raman O VI 6825**.
- ❖ Consequently, Raman ratio can increases due to the dust extinction.

③ Raman O VI Ratio and Raman Conversion Rate in Dusty Medium





- ❖ We consider the range of the dust fraction $f_c = 10^{-4} - 10^{-1}$.
- ❖ RCEs decrease with increasing f_c.
- ❖ In $N_{HI} < 10^{23} cm^{-2}$, as f_c increase, Raman ratio decreases due to the multiple scattering of O VI 1032
- ❖ In $N_{HI} > 10^{23} cm^{-2}$, as f_c increase, Raman ratio increases due to Raman scattering cross section.

Reference & Contact

Chang et al. 2015, ApJ, 814, 98
Chang & Lee 2020, JKAS, 53, 169 (STaRS Gen 1)
Choi et al. 2020, ApJ, 889, 2
Drain 2003, ApJ, 598, 1017
Lee et al. 2016, ApJ, 833, 75
Pequignot et al. 1997 A&A, 323, 217
Schmid 1989, A&A, 211,31
Skopal et al. 2020, A&A, 636, 77

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Summary and Future Work

- ❖ STaRS is the grid-based radiative transfer for Raman scattering with atomic hydrogen.
- ❖ STaRS Gen 1 was adopted in Choi et al. 2020 to investigate Raman He II in expanding medium.
- ❖ We adopt the dust extinction in STaRS Gen 2.
- ❖ We compute the ratio of Raman O VI and RCEs in the dusty H I region.
- ❖ As the dust fraction increase, RCEs decrease, and Raman ratio increases.
- ❖ We will adopt STaRS Gen 2 to study Raman He II in young PNe and Raman wings in PDR.

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