Scattered Radiation and Unified Model of Active Galactic Nuclei

Hee-Won Lee
Department of Physics and Astronomy
Sejong University
2015. 1. 27

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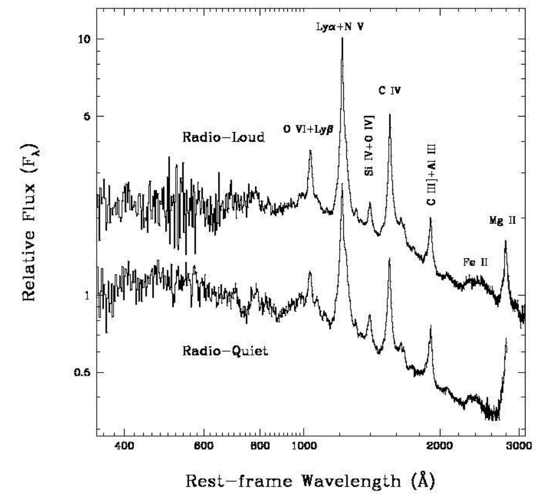
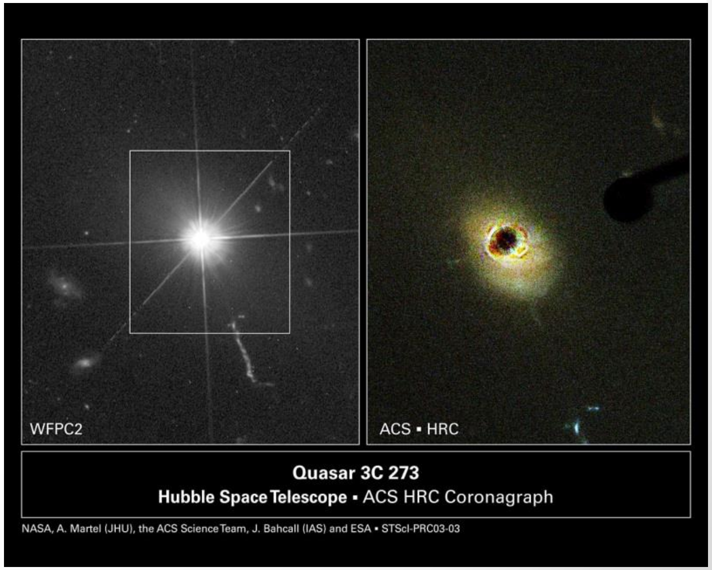
Active Galactic Nuclei

- Featureless continuum + Emission Lines.
- AGN include Seyfert galaxies and radio galaxies, QSO's and quasars.
- Significant Variability

- Emission lines are divided into broad emission lines and narrow emission lines.

- Broad Permission Lines (5000 km/s)
- Narrow Forbidden Lines (500 km/s)





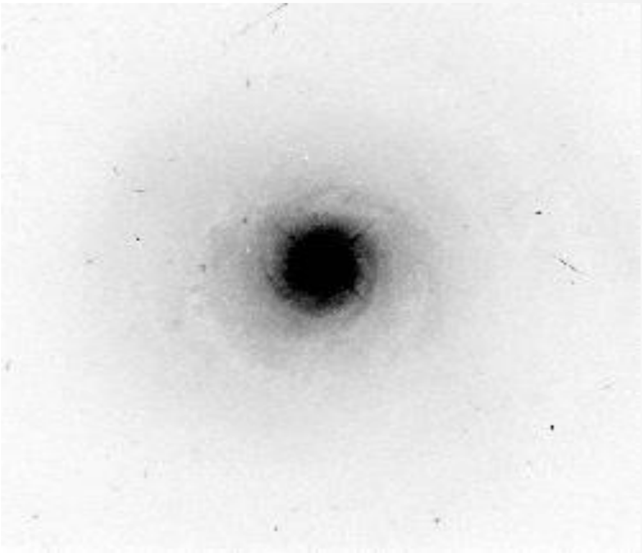
Classification by Line Spectra

- Type 1 AGN

-Exhibit Both Broad and Narrow Lines

-Type I Seyfert Galaxies

-Broad Line Radio Galaxies



- Type 2 AGN

-Exhibit Only Narrow Lines

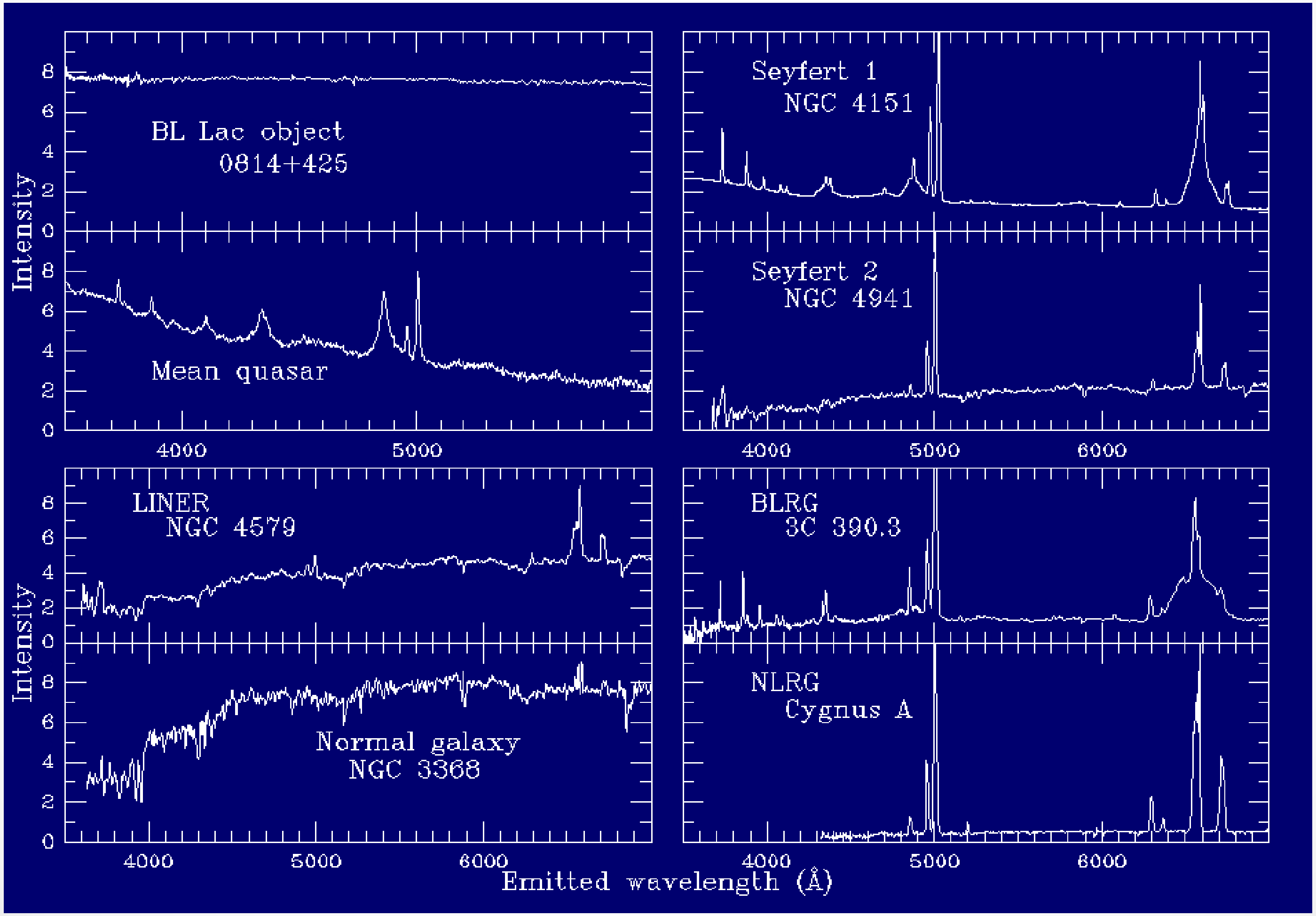
-Type 2 Seyfert Galaxies

-Narrow Line Radio Galaxies

#Broad Absorption Line Quasar

#Type 2 Quasar

AGN Spectra (W. Keel)



Line Emitting Regions of AGN

- Broad Emission Line Region

-Located <0.1 pc

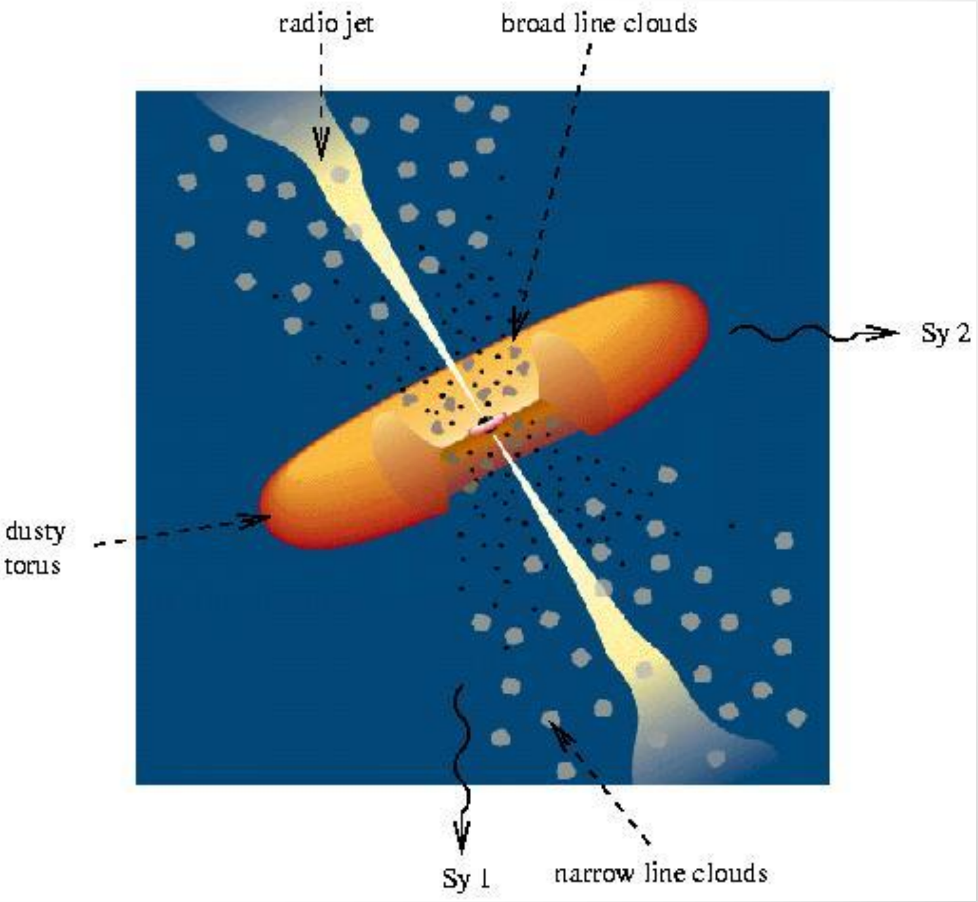
-High density

- Narrow Emission Line Region

-Extended to 100 pc

-Low density

#Reverberation Mapping



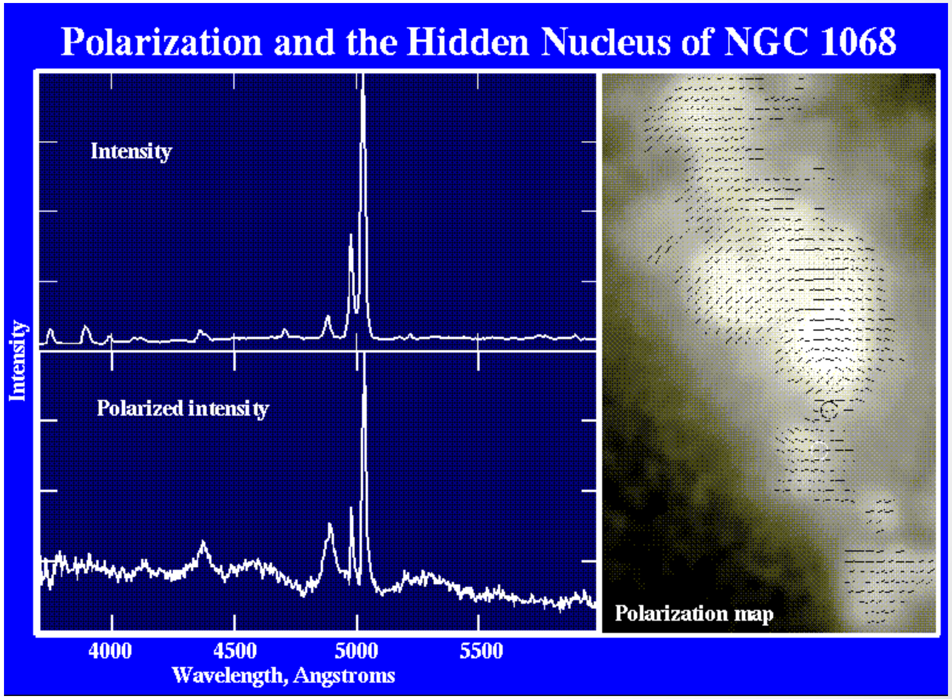
Spectropolarimetry of Seyfert Galaxies

- Hidden broad emission line photons can be observed in the scattered spectra that are characterized by **strong polarization**
- **Spectropolarimetry of NGC 1068 by Miller Goodrich & Mathews (1991)**

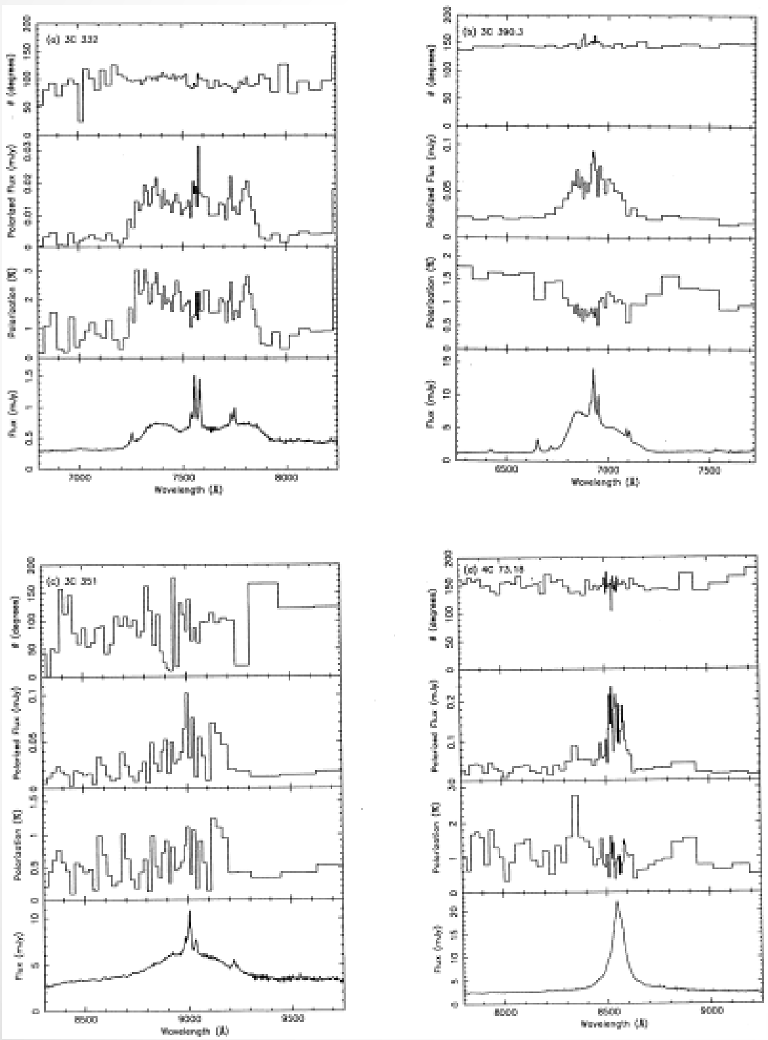
- Polarized Broad Hβ
- Unpolarized Narrow [O III] 4959, 5007

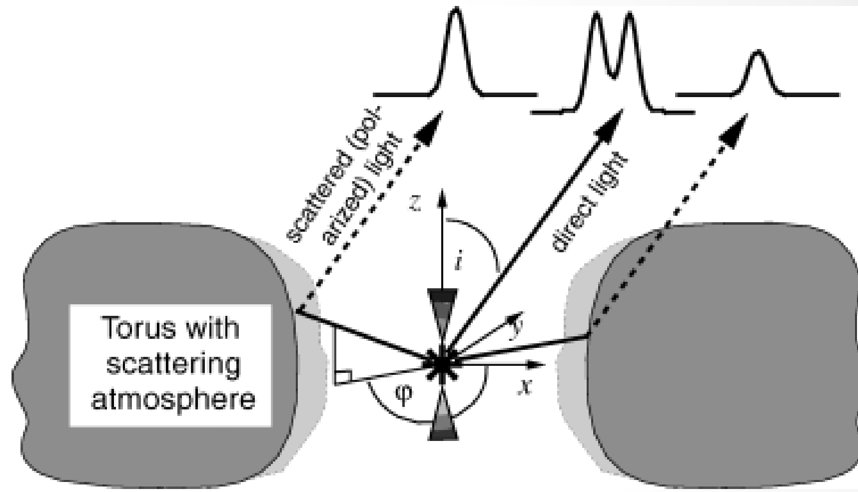
- Electron Scattering

-Uniform polarization degree and position angle



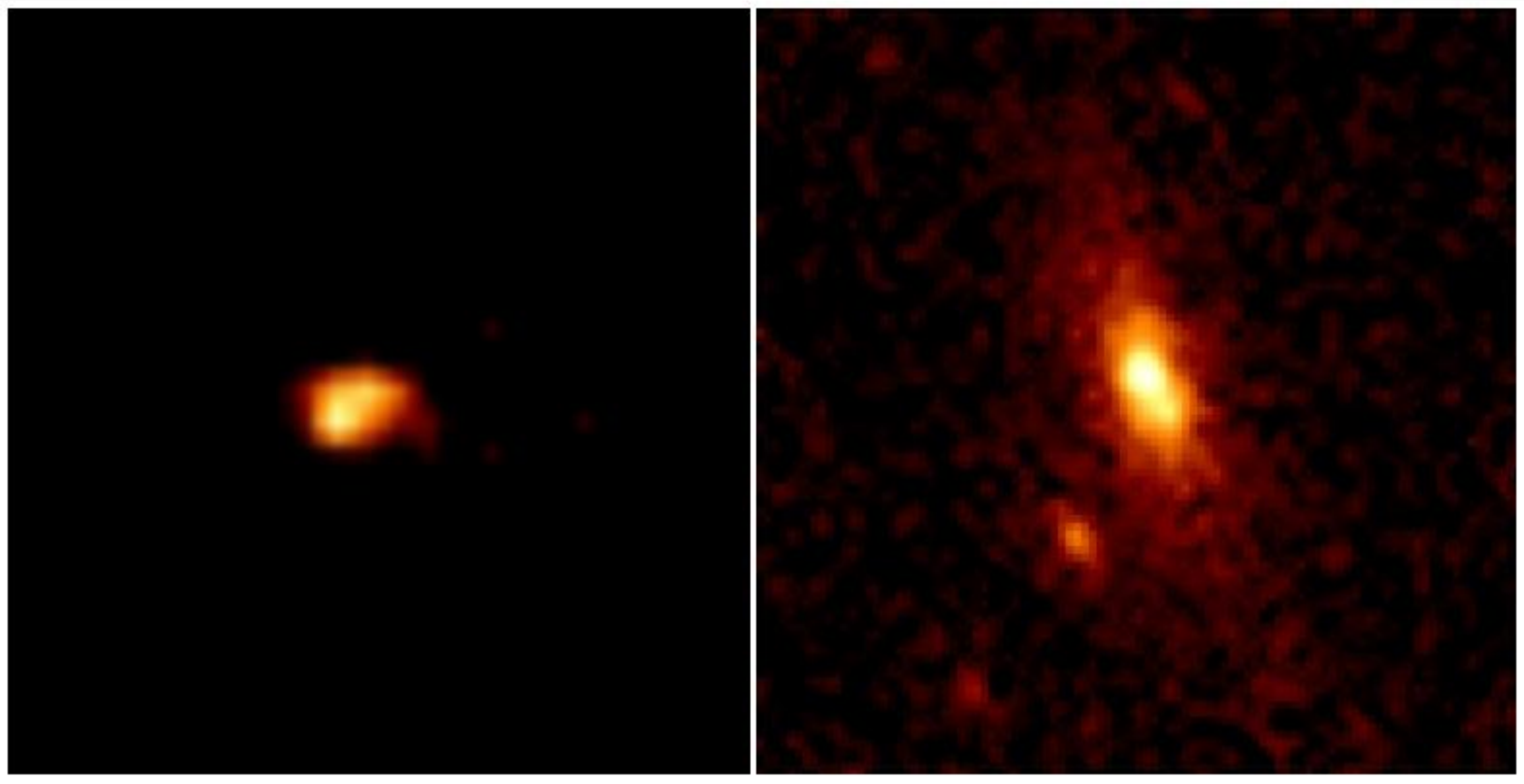
Spectropolarimetry of Broad Line Radio Galaxies



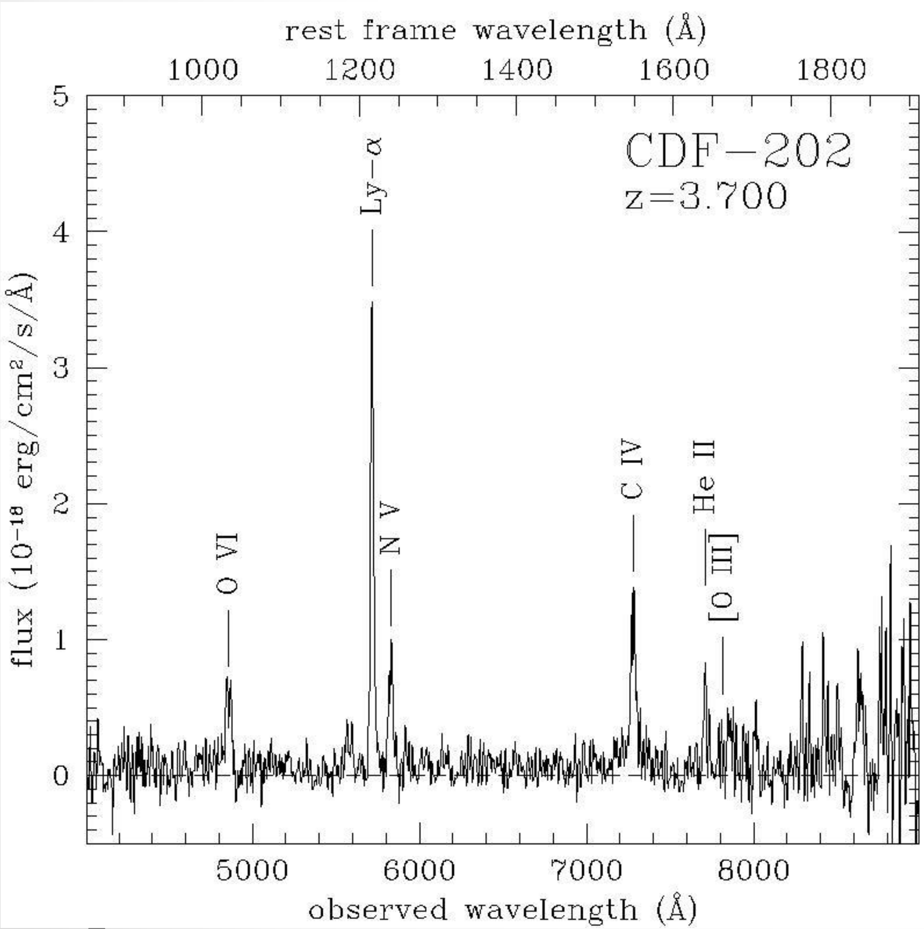


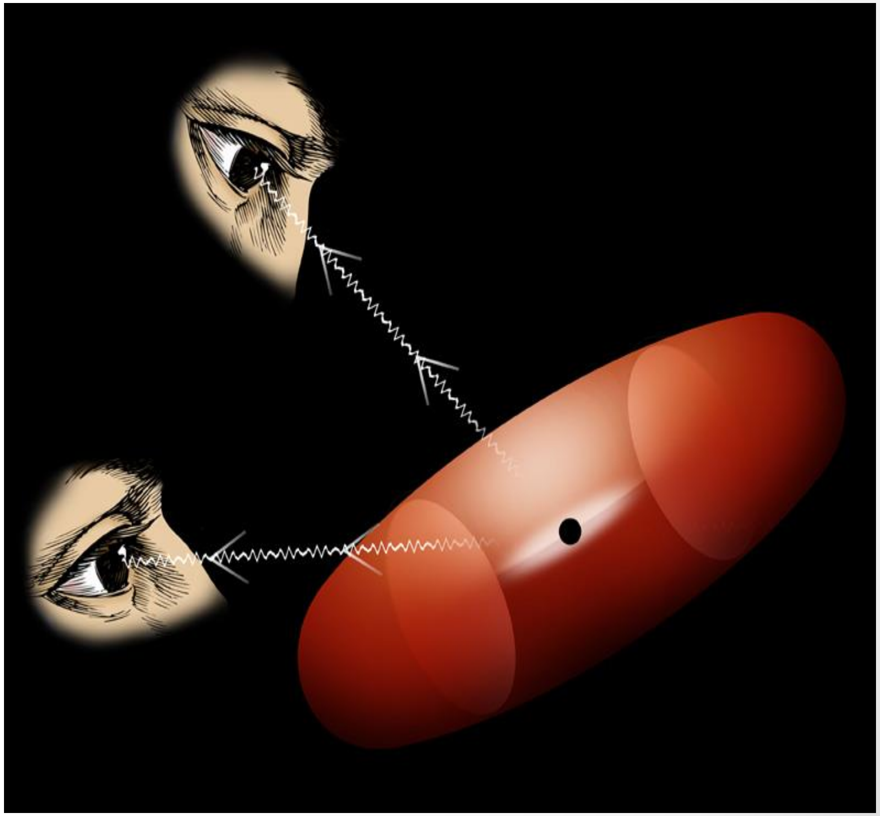
Polarimetry provides a natural mirror allowing indirect views of hidden regions

Type 2 Quasars



Spectrum of Type 2 Quasar





Cosmic X-ray Background

- AGNs are believed to be responsible for most of the Cosmic X-ray background radiation.
- CXB exhibits characteristic bump at 30-40 keV.
- Soft X-ray parts are almost completely accounted for by AGNs.
- We need a significant population of obscured AGN in order to explain the bump at 30-40 keV.
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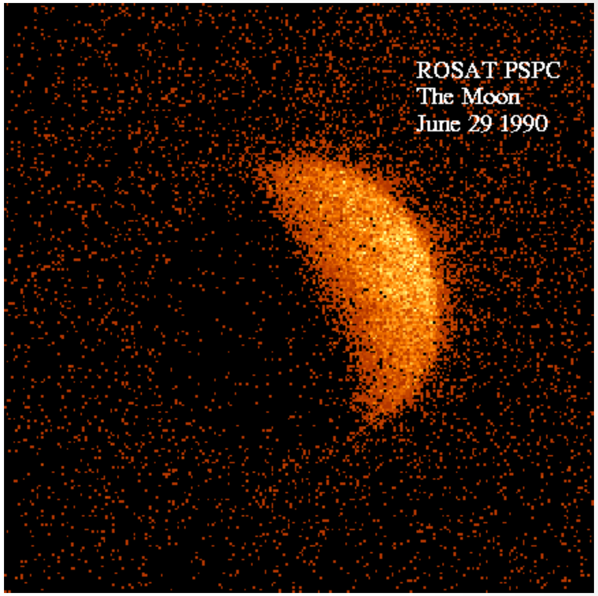
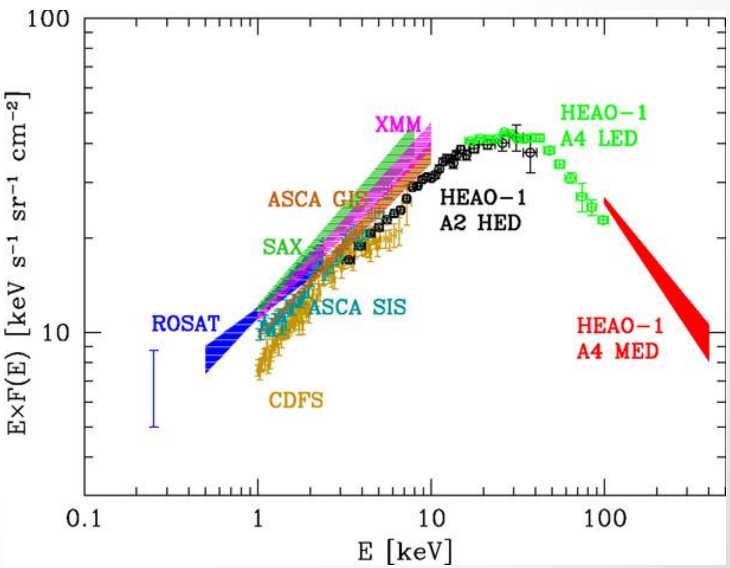
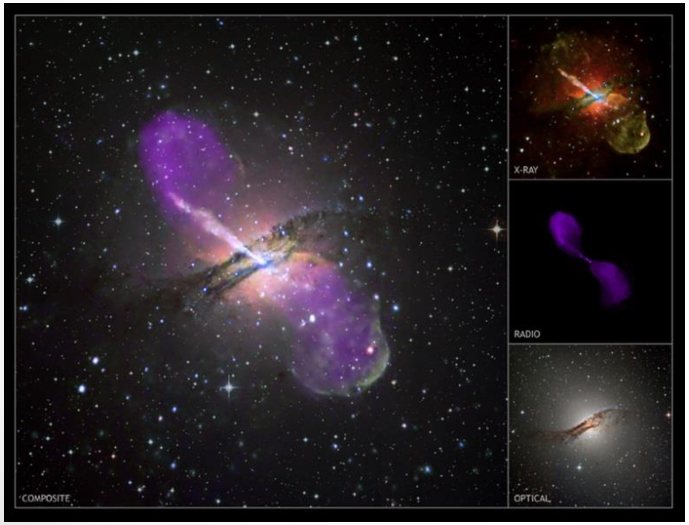




X-ray View and Compton Scattering

- AGNs are high energy radiation source.
- Power laws are invoked for high energy spectra of AGN.
- The Compton scattering by a thick component in AGN produces a bump .
- Monte Carlo simulation for the Compton process can be useful.



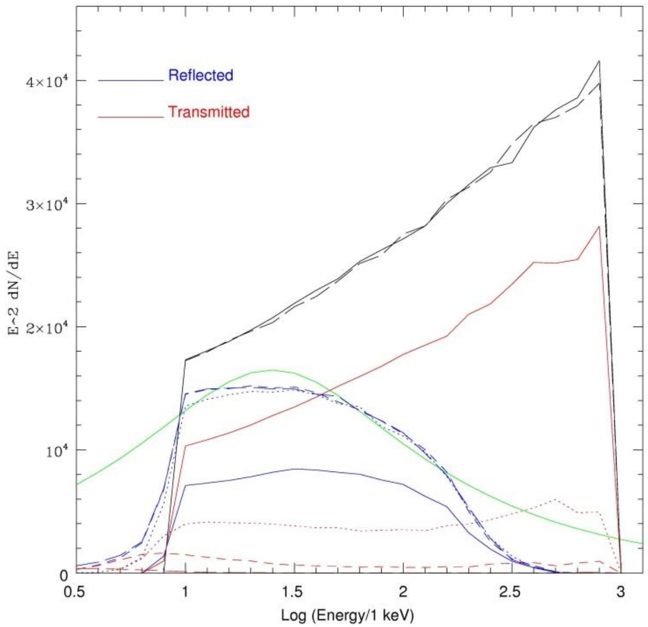
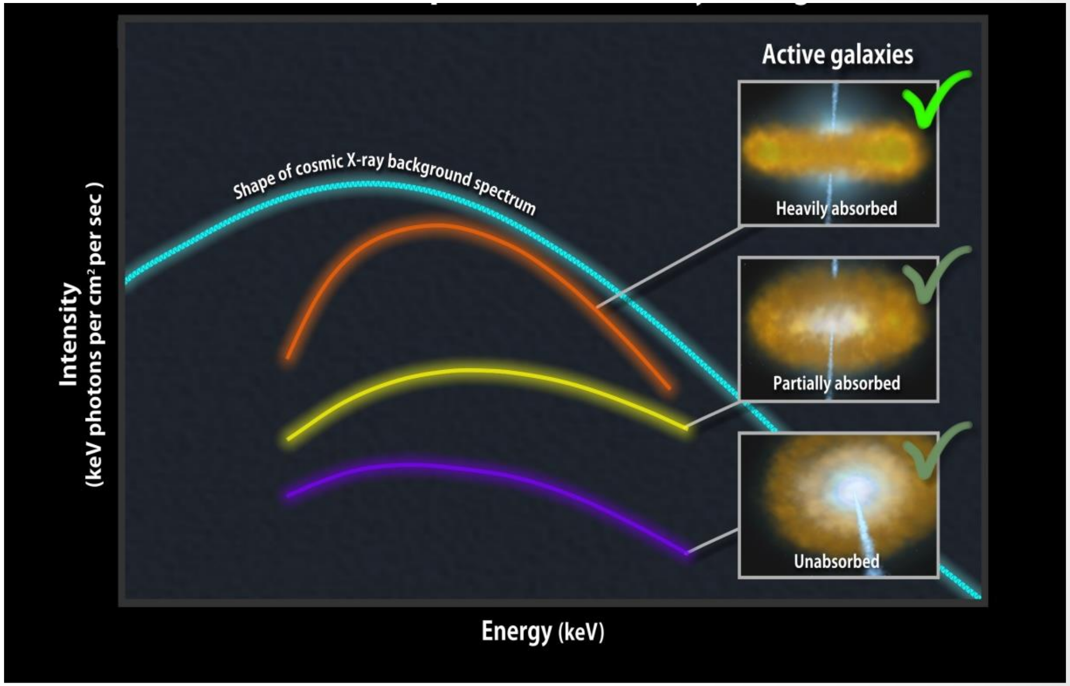


Figure 2: Emergent spectra from a slab with various Thomson optical depths for oblique incidence. THE VERTICAL AXIS IS SHOWN IN LINEAR SCALE (WILL CHANGE TO LOG SCALE SOON). The white line shows the input spectrum, and the green line shows the spectra given by $(\frac{E}{25\ \mathrm{keV}} + \frac{25\ \mathrm{keV}}{E})^{-0.6}$ for reference.

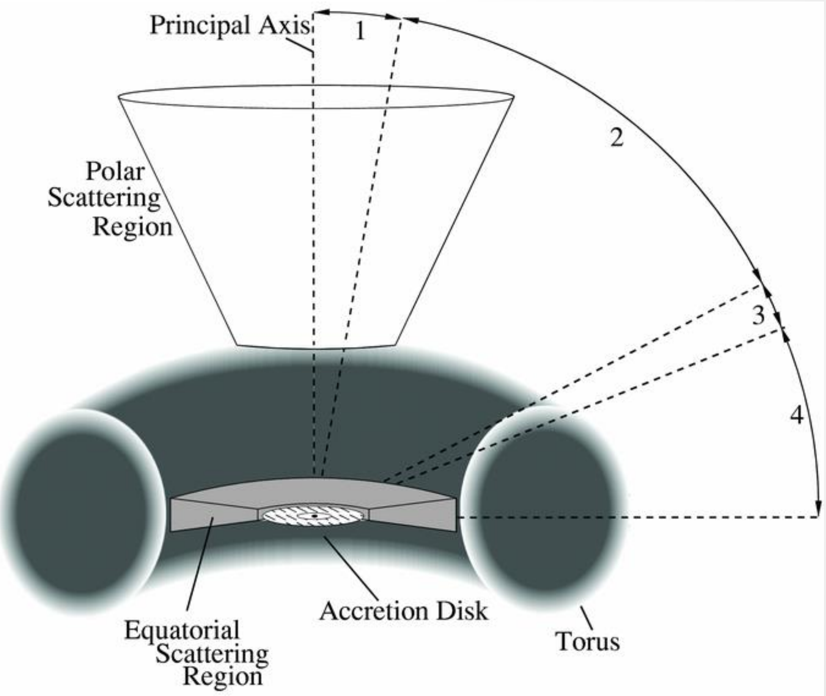
CXB and Hidden AGN

- Unobscured AGN+Partially Obscured AGN+Completely Obscured AGN.
- From unabsorbed AGN, low energy part is quite enhanced.
- Obscured AGNs are mainly responsible for high energy part, due to inverse Compton effect.



Optically Thick Torus

- An essential ingredient for the unified model of AGN.
- X-ray study shows N_HI of order 10^{23} cm^{-2}.
- Ionized hydrogen, neutral hydrogen and molecular hydrogen may coexist.
- Torus is transparent to hard X-rays, reprocesses soft X-rays to produce IR excess.

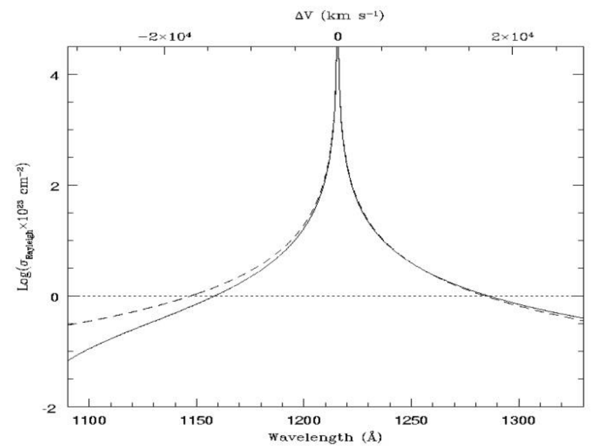


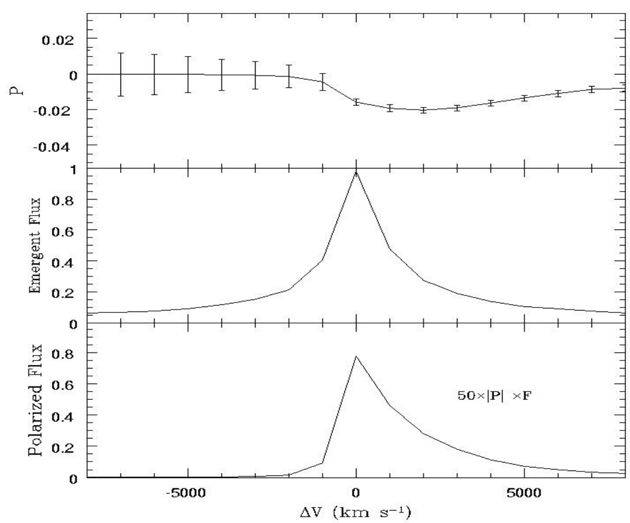
Rayleigh Scattering Cross Section

For HI col density 10^{22} cm^{-2} Rayleigh scattering optical depth of unity corresponds to $\Delta v = 2 \times 10^4$ km/s

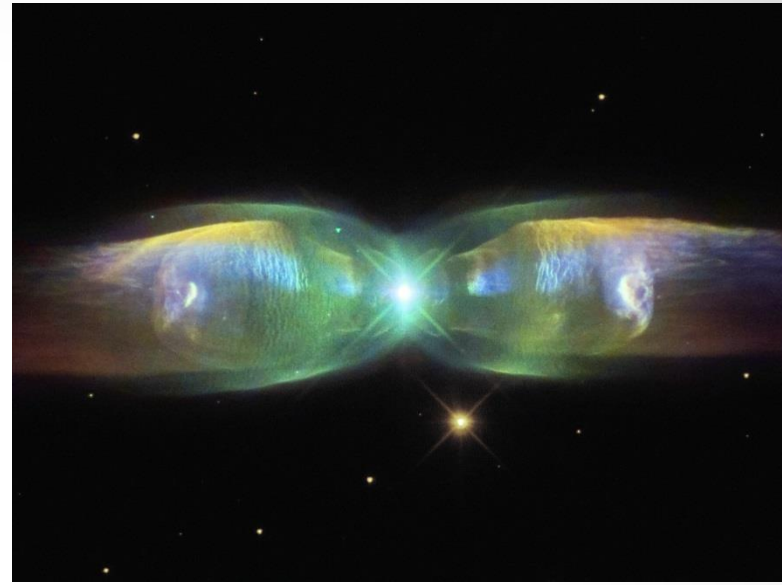
This is comparable to the velocity scale of Broad Emission Line Region

Rayleigh scattered Ly alpha should be strongly polarized.



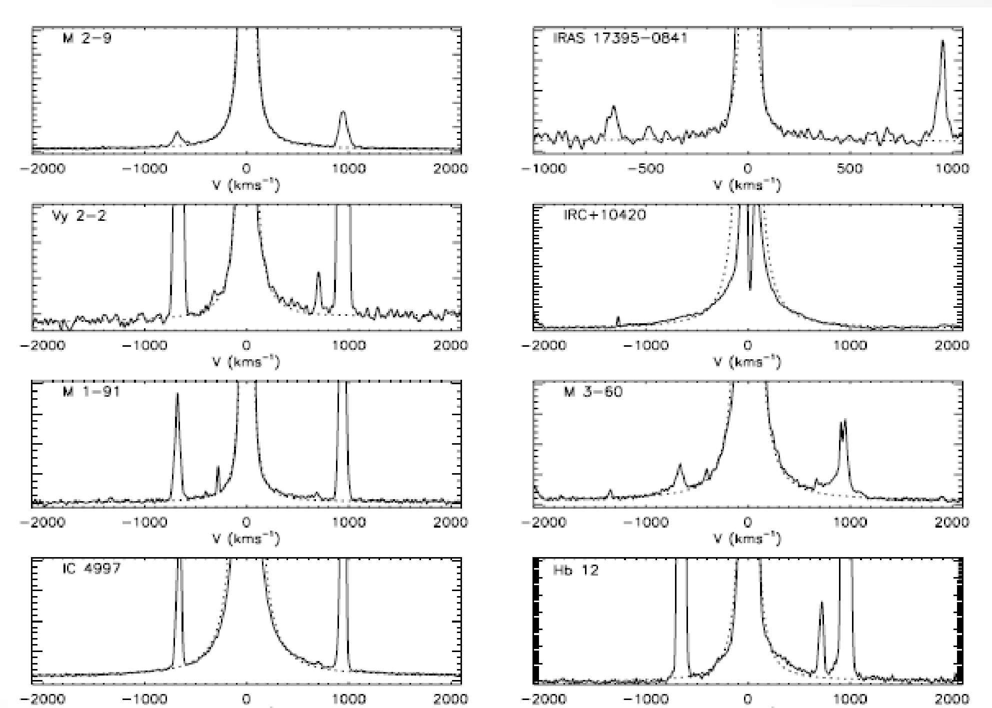


Broad Balmer Wings

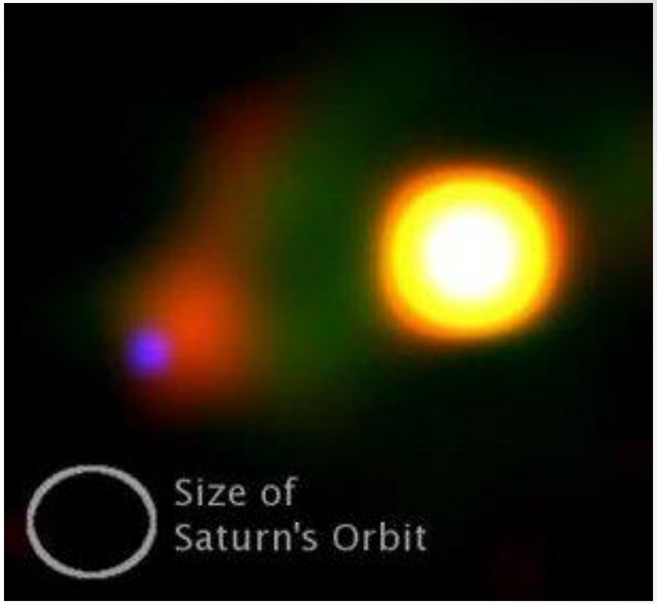


Broad Balmer wings appear to be present in many celstial objects including symbiotic stars and young planetary nebulae.

Wings are formed by fast moving material or by scattering with fast moving electrons.



Broad Balmer Wings in Symbiotics

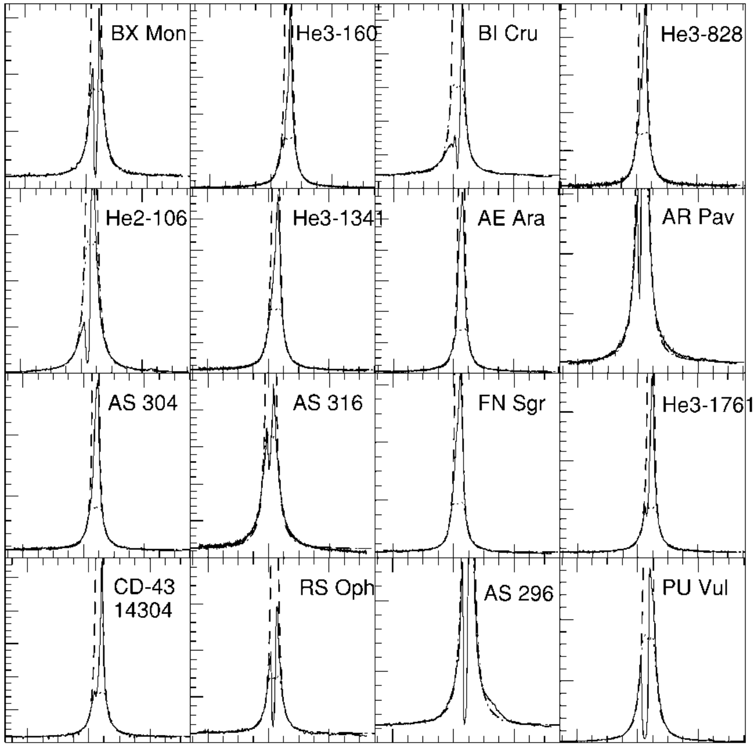


Symbiotic stars are wide binary systems of a hot white dwarf and a mass losing giant.

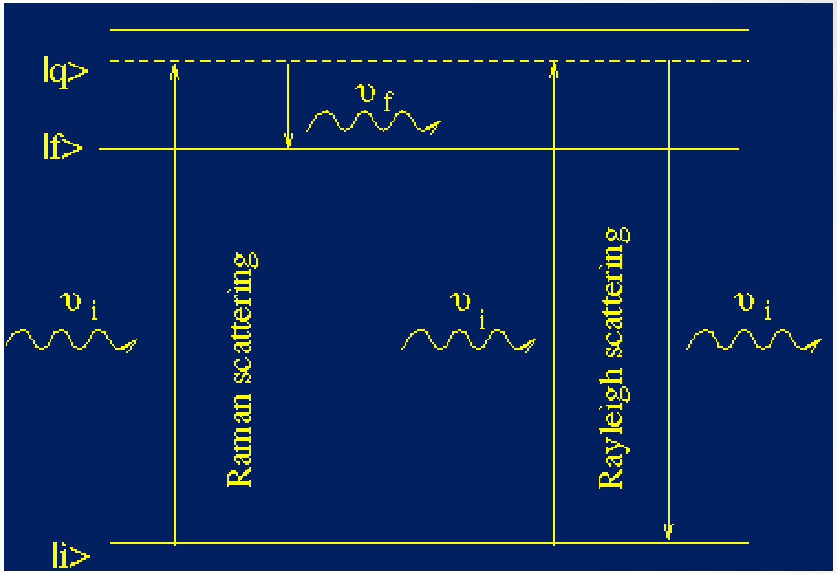
Broad Balmer wings are almost ubiquitous.

Central absorption is also common.

Raman scattering is also an interesting possibility.



Raman Scattering by Atomic Hydrogen



In the radiative interaction of atomic hydrogen, inelastic scattering branches are available for far UV photons more energetic than Lyman alpha.

This is because the scattering hydrogen atom may de-excite into 2s or other excited level.

Rayleigh scattered Ly alpha should be strongly polarized.

Examples of Raman Scattering by HI

1. Ly beta → H alpha
2. Ly gamma → H beta
3. Continuum around Ly beta → H alpha wing
4. Continuum around Ly gamma → H beta wing

Scattering Cross Section

2

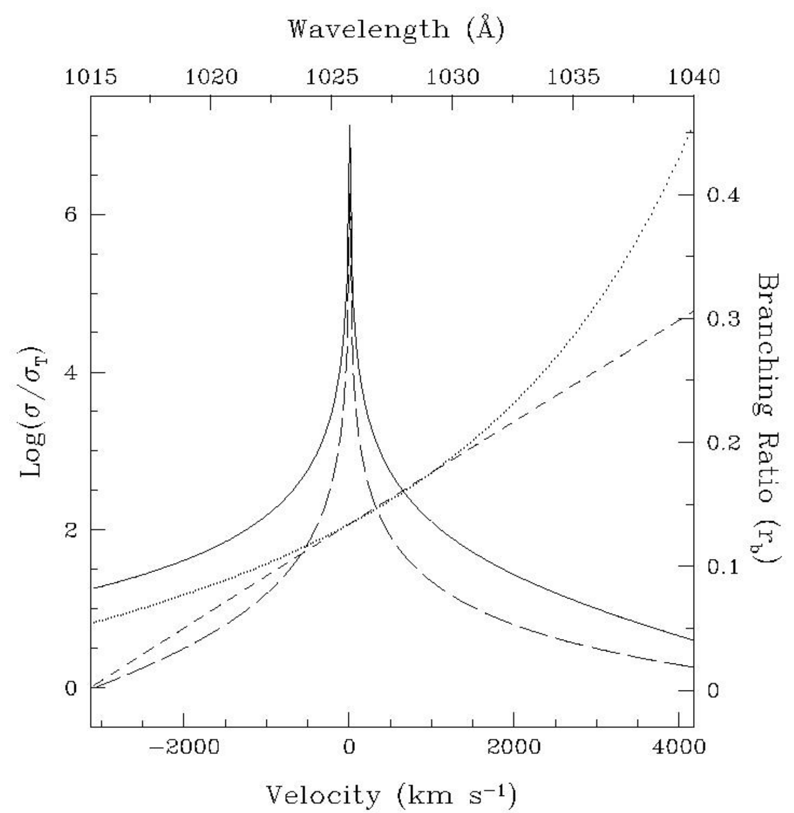
2nd Order Time Dependent Perturbation Theory
- Kramers-Heisenberg Formula

Rayleigh Scattering

$$\left(\frac{d\sigma}{d\Omega}\right)_{Ray} = r_0^2 \left| \frac{1}{m\hbar} \sum_I \left(\frac{\omega(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{AI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{IA}}{\omega_{IA}(\omega_{IA}-\omega)} - \frac{\omega(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{AI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{IA}}{\omega_{IA}(\omega_{IA}+\omega)} \right) \right|^2,$$

Raman scattering

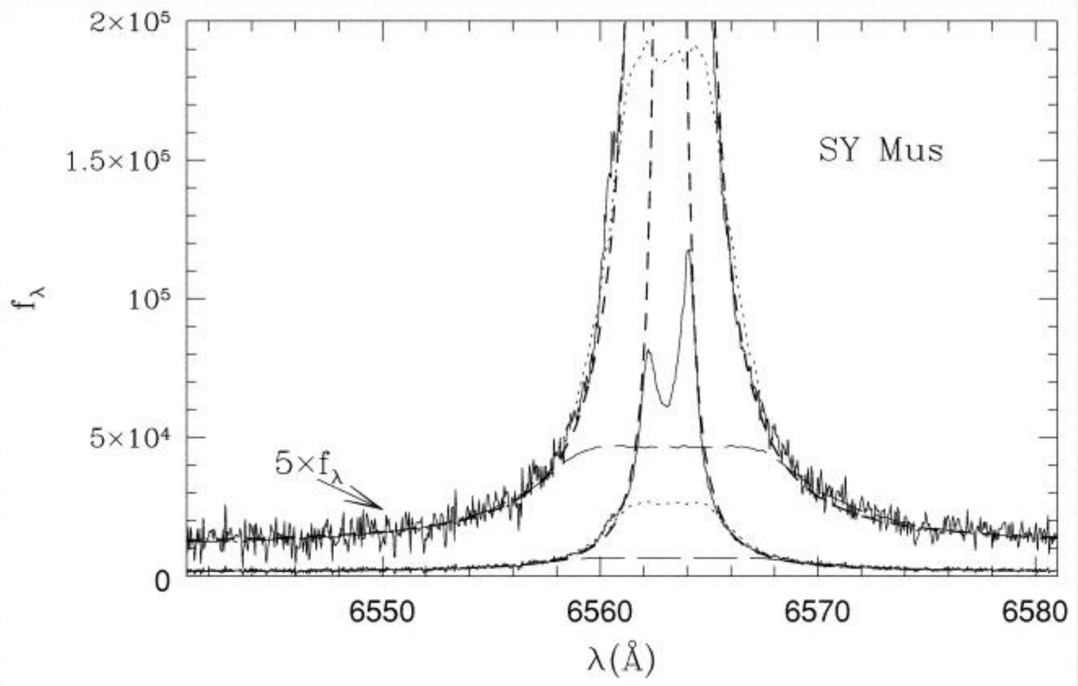
$$\left(\frac{d\sigma}{d\Omega}\right)_{Ram} = r_0^2 \left(\frac{\omega'}{\omega}\right) \left| \frac{1}{m\hbar} \sum_I \left(\frac{(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{BI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{IA}}{\omega_{IA}-\omega} + \frac{(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{BI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{IA}}{\omega_{IA}+\omega'} \right) \right|^2,$$



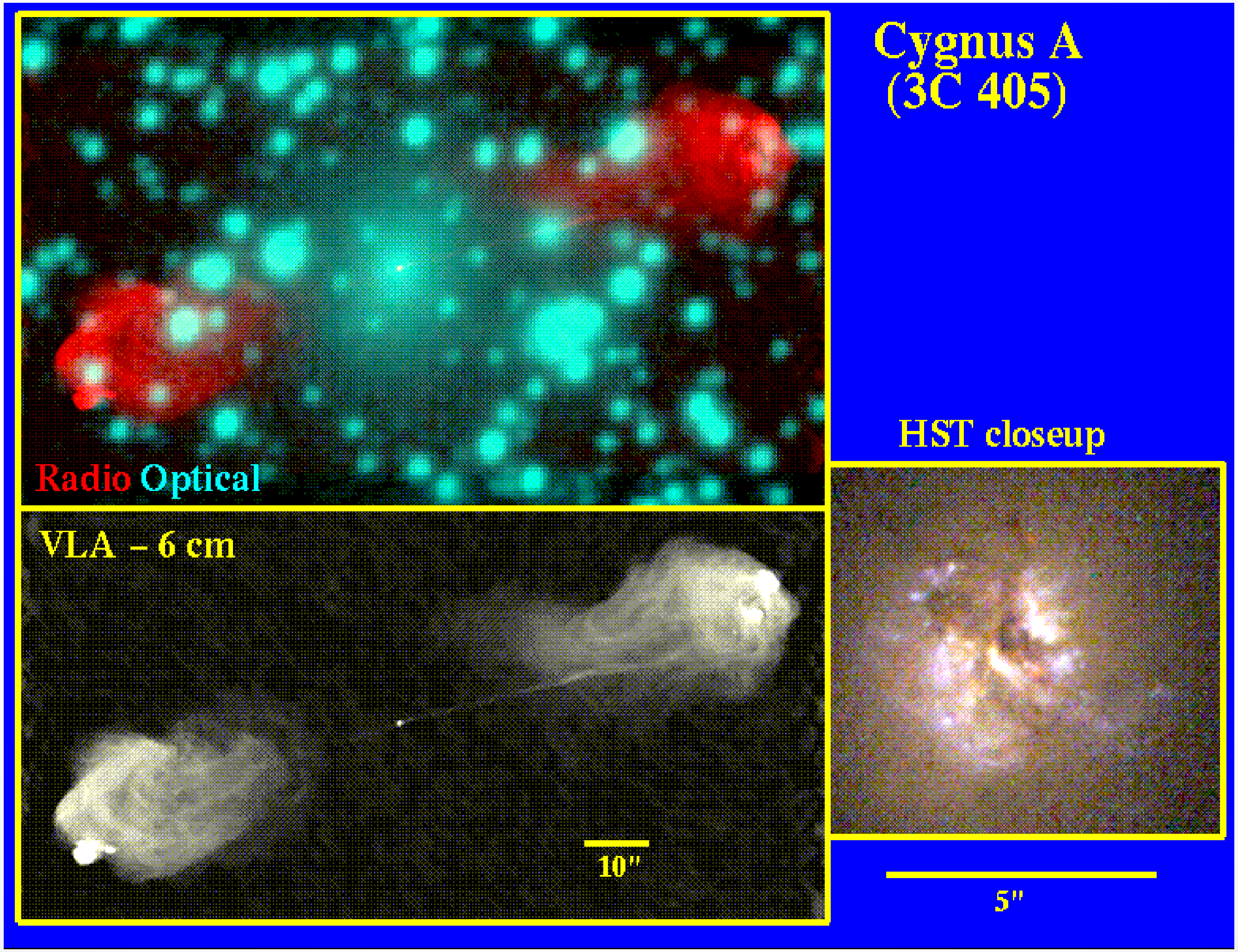
Raman Scattering by Atomic Hydrogen

Raman scattered Balmer wings will have profiles that are proportional to the scattering cross section.

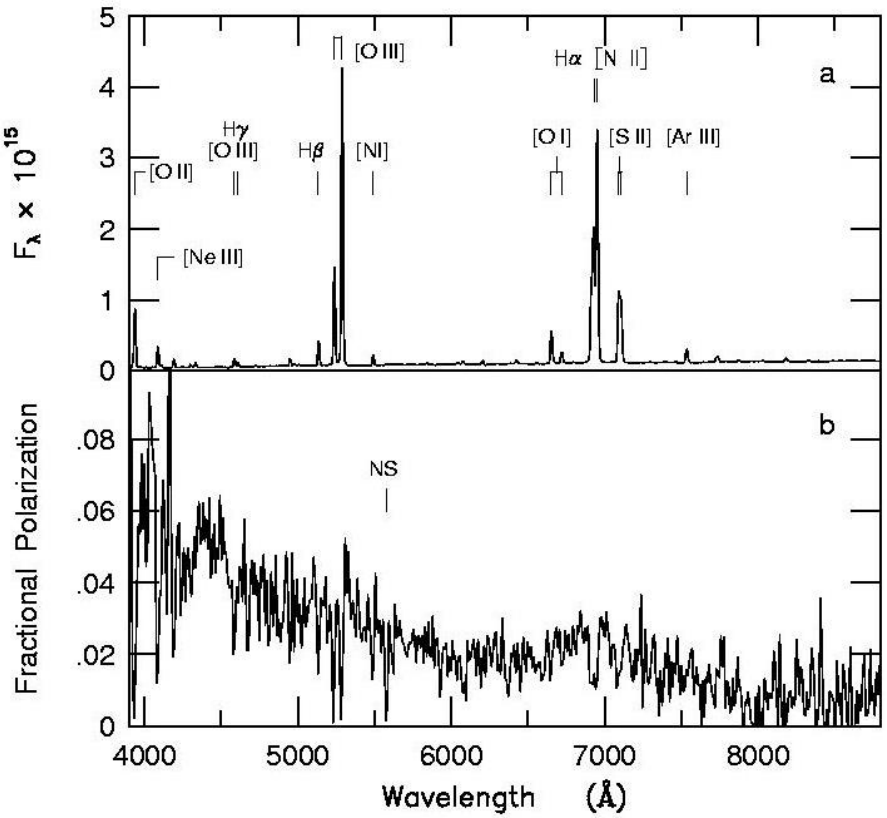
To a first approximation the profile will be proportional to $\Delta\lambda^{-2}$

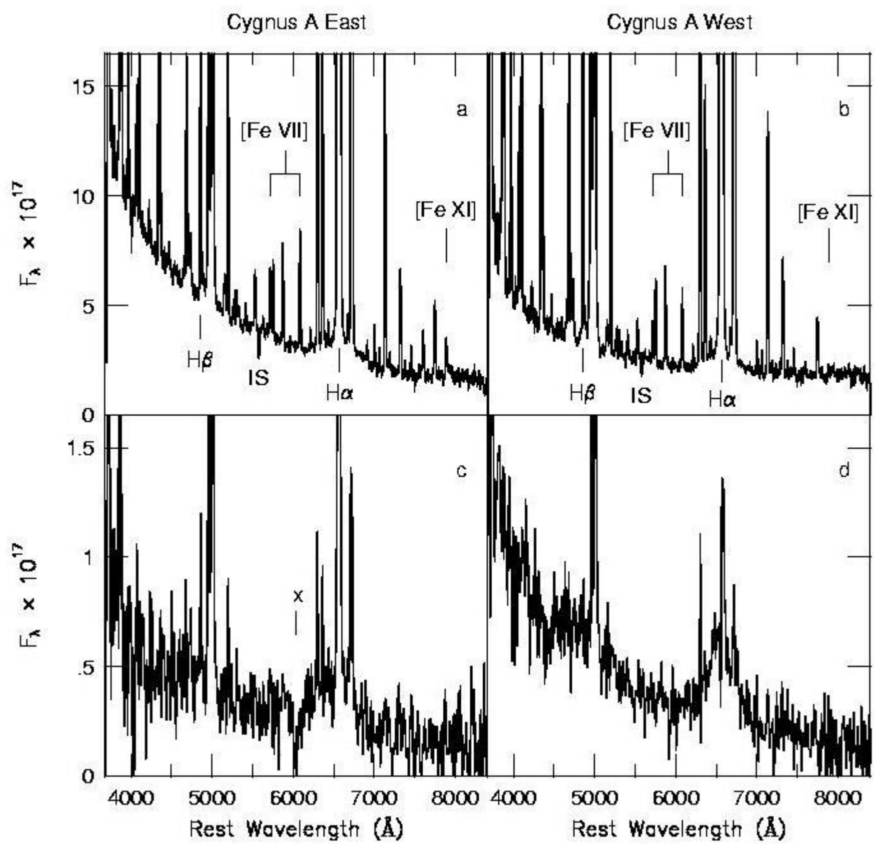


The Narrow Line Radio Galaxy Cyg A



Spectropolarimetry of Cyg A



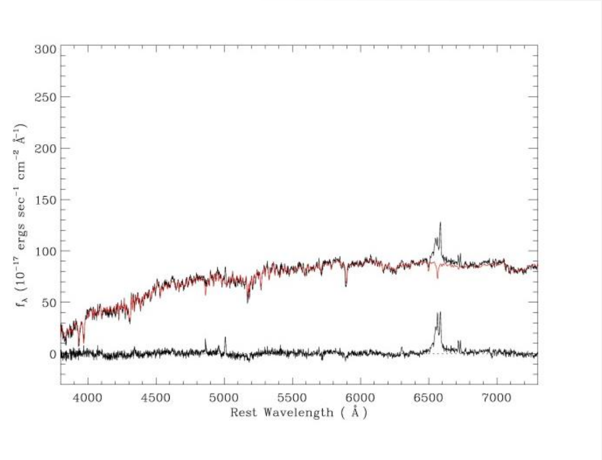


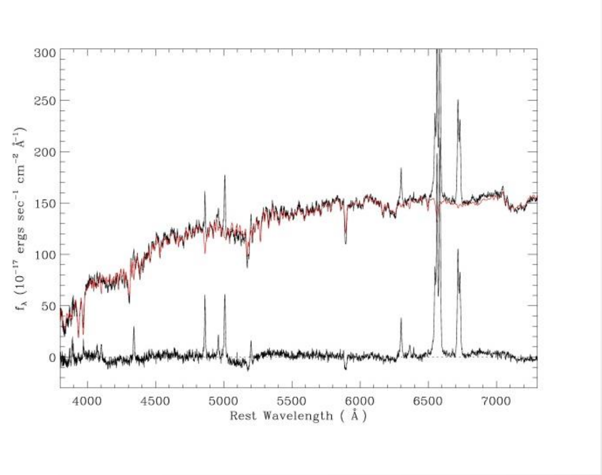
Balmer wings in AGNs of SDSS

H alpha emission lines in AGN also accompany broad wings.

As in planetary nebulae and symbioitc stars, fast bipolar outflow can be a primary candidate for wing formation.

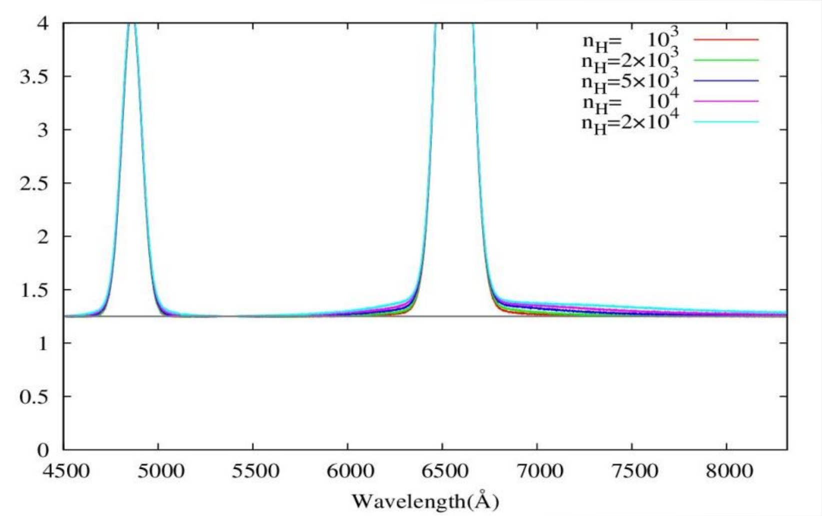
In a model of BALQ a highly fast disk wind is also an interesting possibility.

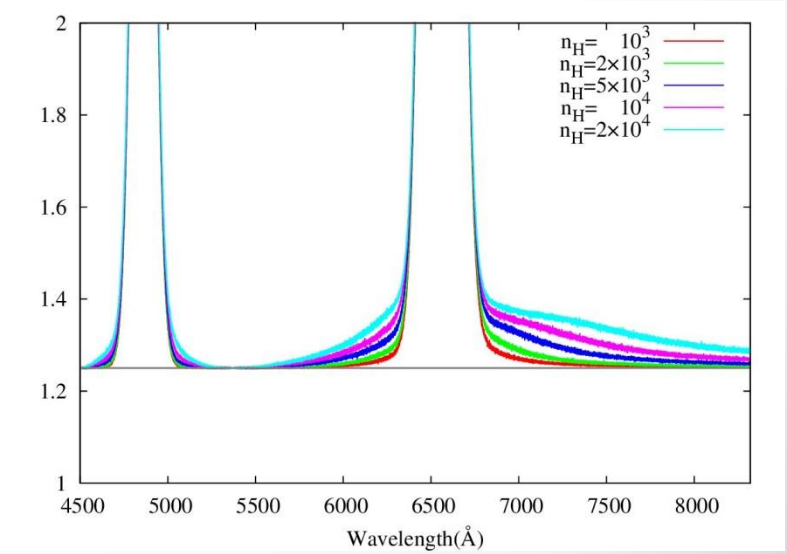




Raman Balmer Wings in AGN (1)

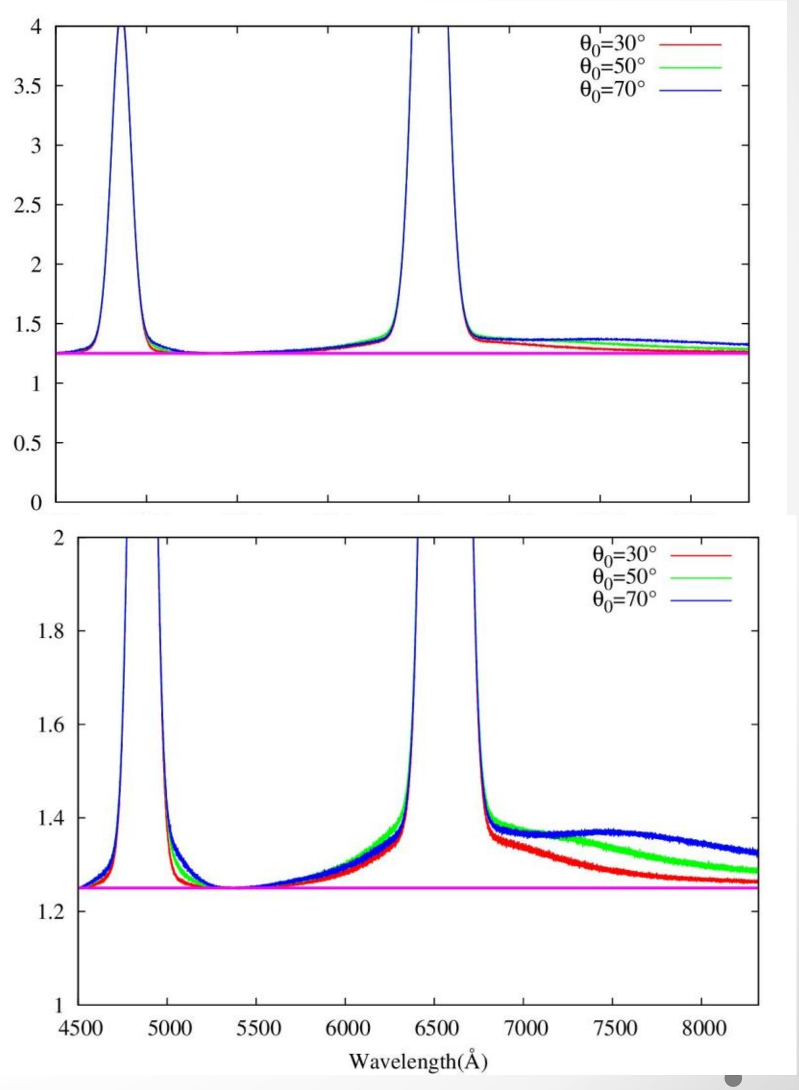
- Assuming a power-law continuum, we prepare far UV and optical continuum.
- Far UV continuum is incident upton an optically thick torus.
- Balmer alpha photons are collected.





Raman Balmer Wings in AGN (2)

- When the optical depth increases, we may have stronger red wing due to increasing branching ratio for Raman scattering.
- This is in contrast with the relativistic effect, which enhances blue part.



Summary

- Emission spectroscopy is an important and interesting tool to investigate symbiotic stars and AGN.
- Symbiotics are a candidate for type Ia supernovae and AGNs are essential sources for cosmic evolution.
- Survey science and follow-up emission spectroscopic studies are expected to shed much light on our understanding of the universe.