Spectral Synthesis Models for AGN Winds and the Warm Absorber Using PHOENIX: Can we Constrain the winds?

Darrin Casebeer

University of Oklahoma, USA

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Partial List of Collaborators

- Peter Hauschildt (Hamburg)
- France Allard (Lyon)
- Jason Aufdenburg (NOAO)
- OU Collaborators:
  - Karen Leighly (Thesis Advisor)
  - Eddie Baron
  - David Branch
  - Darko Jevremovic
  - Sebastien Bongard
  - Aida Nava

Outline

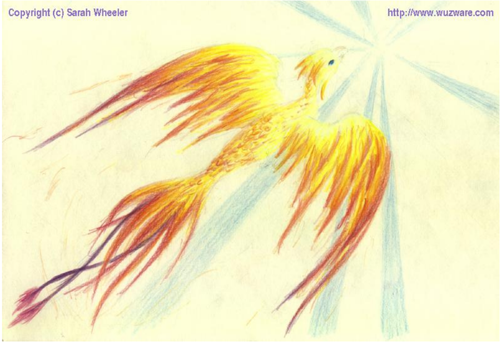
Motivation

Why study AGN winds?

- There is a black hole in every galaxy with a spheroidal component.
- There is a relationship between the mass of the black hole and the stellar velocity dispersion.
- Perhaps the AGN wind is the connection?

Outline

Background of PHOENIX



PHOENIX is a generalized stellar atmospheres code.
It is called PHOENIX because it has risen from the ashes of a number of earlier codes.

Springing from the Ashes

PHOENIX was initiated by Peter Hauschildt in the early 1990's and is under development by many different people including:

- Eddie Baron
- France Allard

There have been more than 300 papers on PHOENIX methods and results.
PHOENIX self-consistently solves the special relativistic radiative transfer equation with the OS/ALI method.

Special Relativistic Radiative Transfer Equation.

$$e\frac{\partial I}{\partial r} + \frac{\partial}{\partial \mu}(fI) + g\frac{\partial}{\partial \lambda}(\lambda I) + hI = \eta - \chi I$$

with

$e(r,\mu) = \gamma(\mu + \beta)$

$f(r,\mu) = \gamma(1-\mu^2)\left[\frac{1+\beta\mu}{r} - \gamma^2(\mu+\beta)\frac{\partial\beta}{\partial r}\right]$

$g(r,\mu) = \gamma\left[\frac{\beta(1-\mu^2)}{r} - \gamma^2\mu(\mu+\beta)\frac{\partial\beta}{\partial r}\right]$

$h(r,\mu) = \gamma\left[\frac{\beta(1-\mu^2)}{r} - \gamma^2(1+\mu^2+2\beta\mu)\frac{\partial\beta}{\partial r}\right]$

$\beta = \frac{v}{c}$

$\beta^2 = \frac{1}{1-\beta^2}$

η_ν is the emissivity

χ_ν is the total extinction

This is an integro partial-differential equation.

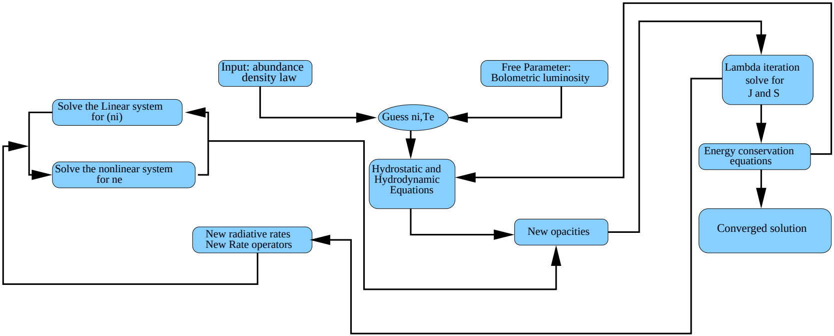
PHOENIX Input Parameters

PHOENIX's input parameters are physical.
They are for example:

- Luminosity
- Velocity of wind (depending on application)

Given a set of input parameters we iterate PHOENIX until the temperature and structure converge.

Flowchart for PHOENIX



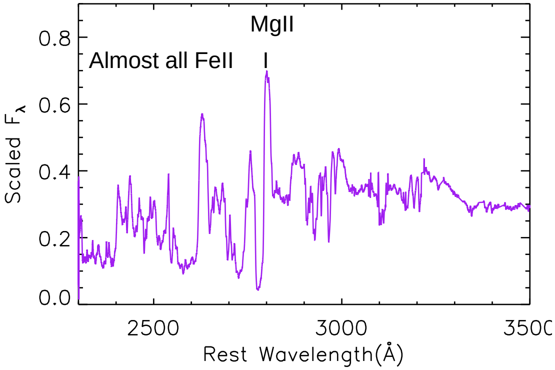
PHOENIX Model Outputs

PHOENIX calculates:

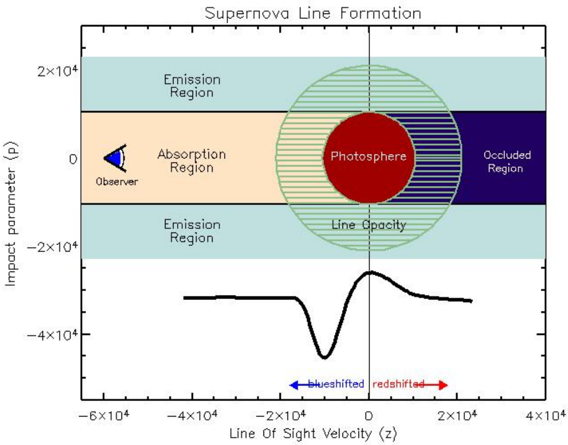
- The emergent spectra
- The acceleration in the gas
- The kinetic energy of the gas

Outline

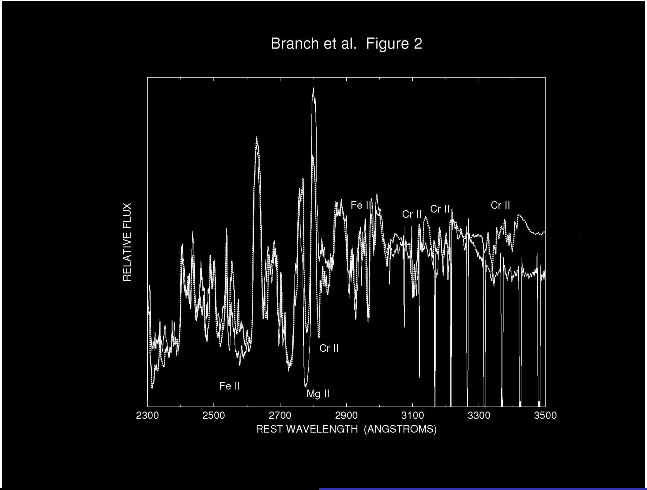
FIRST J121442.3+280329



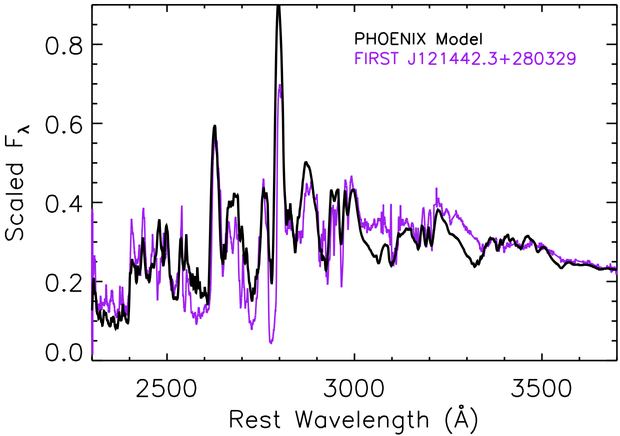
Spherically Symmetric Optically Thick Model Assumptions



FIRST J121442.3+280329 with SYNOW



UV FIRST J121442.3+280329 with PHOENIX

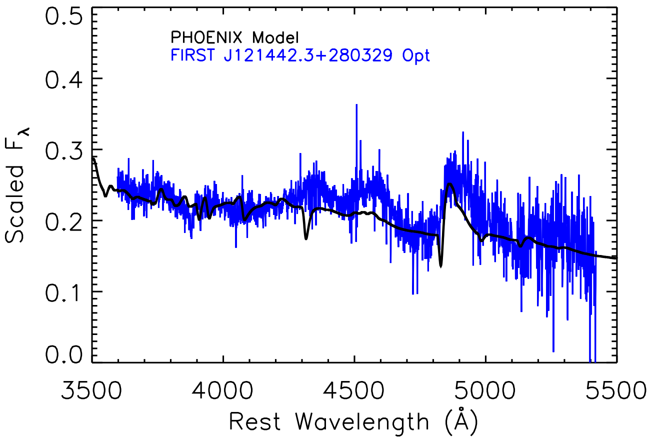


(Casebeer et al. in prep.)

Phoenix Model Parameters for FIRST J121442.3+280329

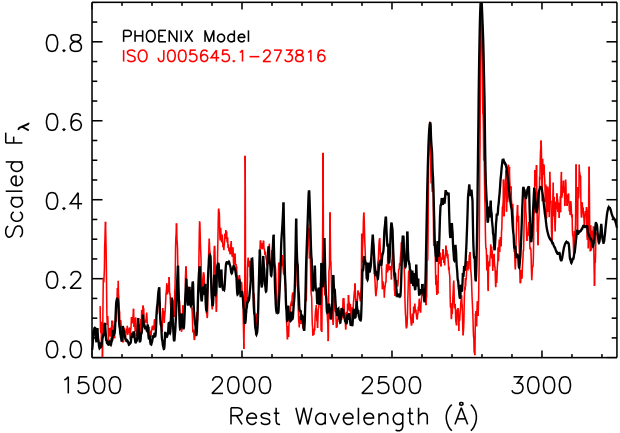
T_{model} K	V_{max} km/s	R_{o} cm	$Z_{\odot}$	PL index
4600	2100	1.4×10^{17}	1	7

Optical FIRST J121442.3+280329 with PHOENIX



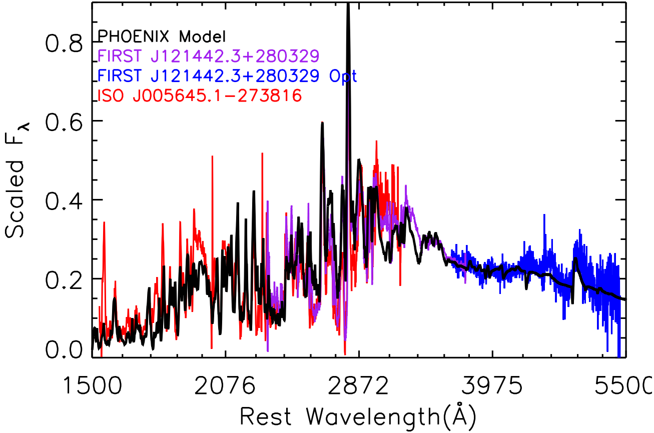
(Casebeer et al. in prep.)

FUV ISO J005645.1-273816 UV with PHOENIX



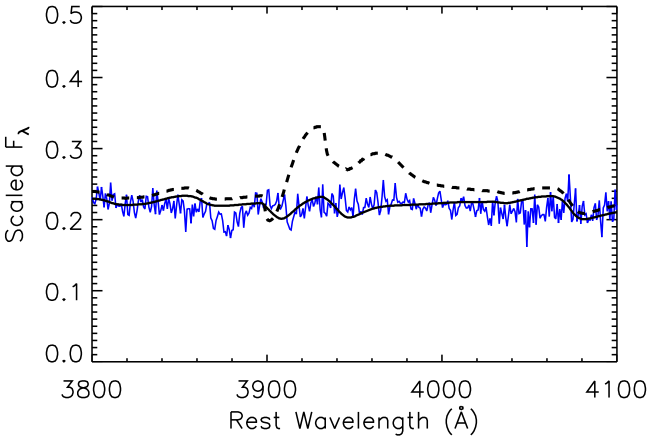
(Casebeer et al. in prep.)

FIRST and ISO Combined



(Casebeer et al. in prep.)

Optical FIRST NLTE effects CaII H&K

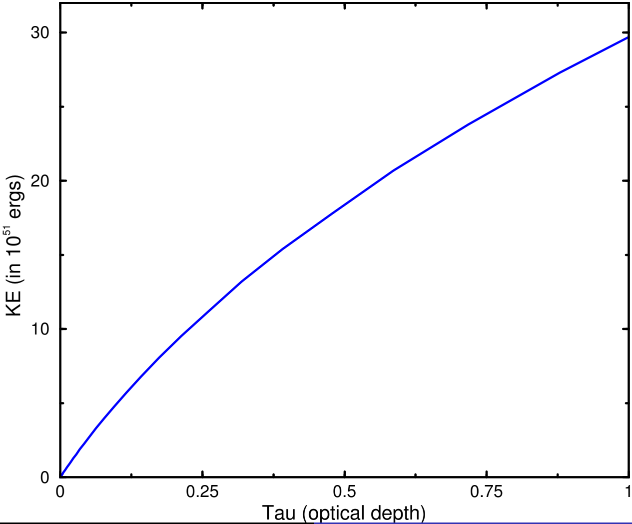


Phoenix NLTE Species Used

	I	II	III
H	30/435		
He	49/187	25/68	
Mg	273/835	72/340	91/656
Si	329/1871	93/436	155/1027
Ca	194/1029	87/455	150/1661
Fe	494/6903	617/13675	566/9721

PHOENIX has over 1 million lines for FeII with LTE included.

Physical Constraints from PHOENIX



Spherically Symmetric Outflows?

- BALQSOs are usually equatorial.
- PHOENIX/SYNOW models assume 100% global covering.
- However FeIILoBAL AGN may be a subset with very large global covering.

Spherically Symmetric Outflows?

- FeIILoBAL QSOs look different.
- However could be evolution (Becker et al. 2001).
- The intrinsic continuum is bluer in these objects(Reichart et al 2003).
- High redshift quasars may have larger fractions of BALQSOs (Maiolino et al. 2004).

Comparison of different AGN

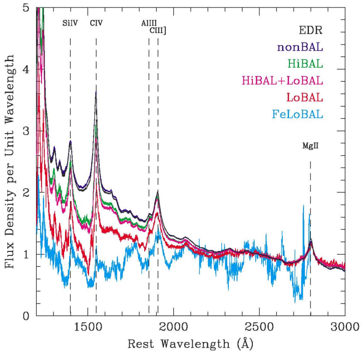


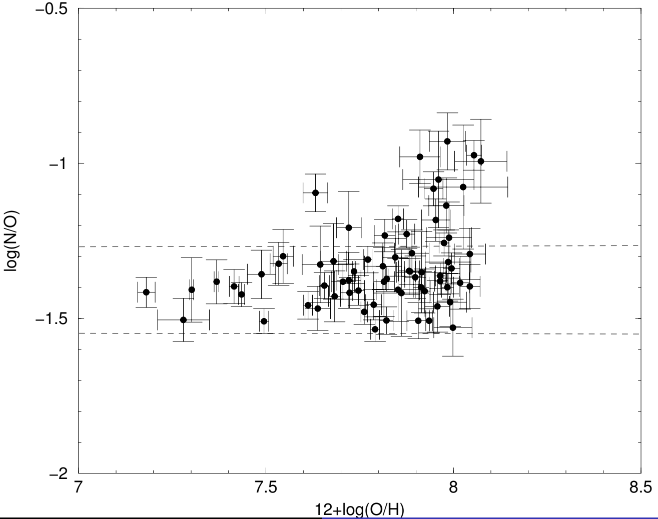
Fig. 1. Normalized, geometric composite spectra of (*top to bottom*) non-BALs (*blue*), the full EDR quasar sample (*black*), HiBALs (excluding LoBALs and FeLoBALs, *green*), HiBALs and LoBALs (all BALQSOs except for FeLoBALs, *magenta*), LoBALs (*red*), and FeLoBALs (*cyan*). The spectra are normalized at 2500 Å. Except for the FeLoBAL composite, which exhibits excess emission at long wavelengths, the spectra are similar at wavelengths above 2400 Å, but the BALQSO composite spectra show clear flux deficits at shorter wavelengths as compared with the non-BAL composite spectrum. The FeLoBAL composite includes only a small number of spectra and is for illustrative purposes only.

Finding Primary Nitrogen Abundance

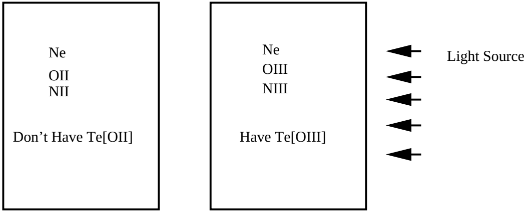
The CNO cycle produces both primary and secondary nitrogen.

- Primary nitrogen is inversely proportional to the metallicity.
- Secondary nitrogen is directly proportional to the metallicity.
- So if we want to study primary nitrogen abundance we need to look at low metallicity systems.

Low Metallicity, Low Mass, Emission Line Galaxies.

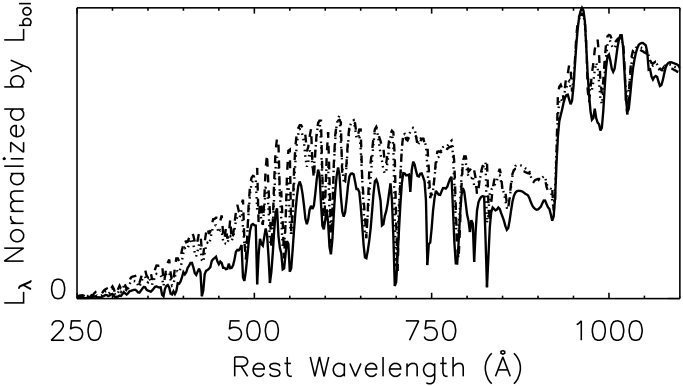


Why We Need Models.



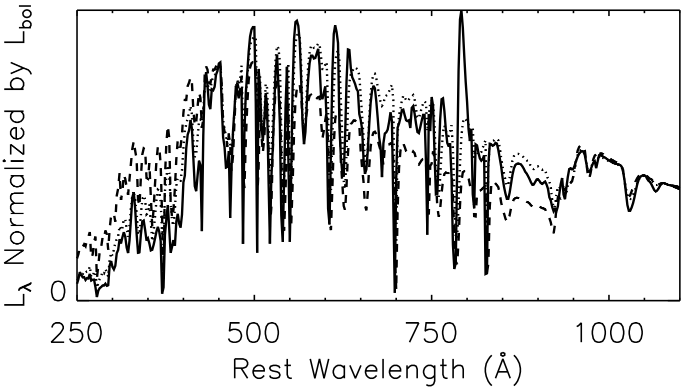
We need to relate Te[OII] to Te[OIII]
and N/O=ICF NII/OII
We want N/O

O Star Models $T_{model} = 43000^{\circ}K$

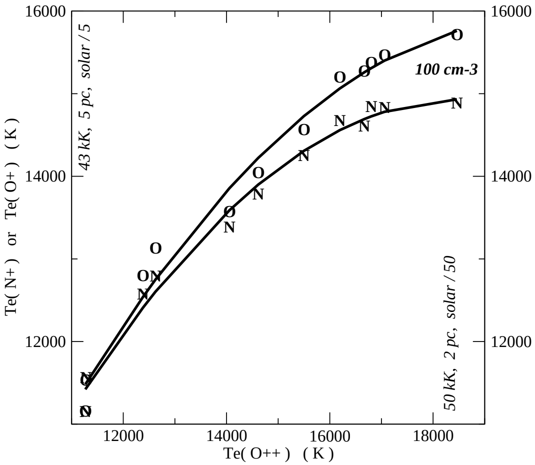


(nava et al. in prep.)

O Star Models $T_{model} = 50000^{\circ}K$



And Finding Te(OII) and Te(NII)



Results of O Star Modeling

- We control the SED (PHOENIX) and the HII region (CLOUDY).
- In addition we calculate models with very low metallicities (1/50) Solar).
- Also the SED and HII region have N and C scaled to O correctly.

Outline

What are some of the difficulties with AGN winds?

- The kinetic energy in quasar outflows is poorly understood because:
  - BALQSO troughs are frequently saturated yet are not black due to partial covering so column density is difficult to constrain.
  - The density and therefore the radius is difficult to constrain.
  - The covering fraction is difficult to constrain.
  - In addition all outflows may not see the same spectral energy distribution (SED).

How can the SED effect the wind?

- Observational reasons the SED may effect the wind:
  - Leighly & Moore (2004) found an anti-correlation between emission line strength and the overall hardness of the SED.
  - Reichard et al. (2003) find that BALQSOs in the SDSS may have intrinsically bluer continua.

How can the SED effect the wind?

Theoretical reasons the SED may effect the wind:

- A softer SED will drive a stronger more massive outflow.

Karen Leighly will talk about this in detail tomorrow morning.

How do we Parameterize the SED in terms of kT_{cut}?

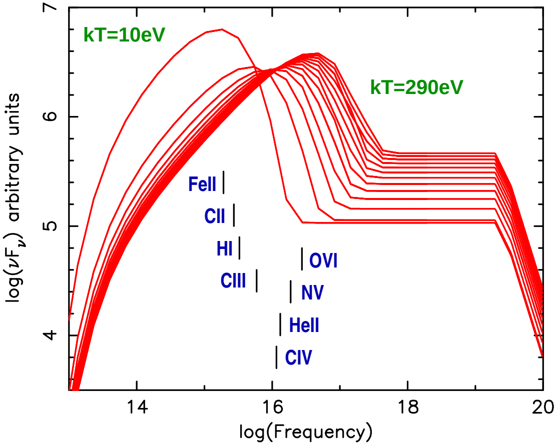
- AGN can be fit by a power-law with exponential cutoff.
- The luminosity is related the the cutoff temperature of the Big Blue Bump.

$$kT_{cut} \propto L^{-4} \tag{1}$$

- Observationally α_{ox} has a dependence on luminosity (Wilkes et al. 1994)
- with α_{ox} we can get relationship between uv and X-ray.
- and then by picking an appropriate quasar we can get the proportionality constant.

So our continua are parameterized by kT_{cut}

The Parameterized SED (Casebeer, Leighly and Baron 2006)



Using the Wind Model Package

- The O star modeling uses the PHOENIX wind model package.
- The wind model package is however a generic package for radiatively driven outflows.
- With the semi-empirical SED we can calculate accurate accelerations in AGN winds.

The Warm Absorber

- PHOENIX incorporates the CHIANTI and APED X-ray line databases.
- It could be possible to use PHOENIX model for modeling the warm-absorber.
- I hope to learn more from this workshop.

Conclusion

- Some FeIILoBAL AGN can be fit very well with an optically thick spherically symmetric model. (Casebeer et al. in prep.)
- PHOENIX is very useful for hot star winds. (Nava et al. in prep.)
- I am expanding PHOENIX to include the semi-empirical SED and will apply it to AGN very soon.

Supper Anyone?

Time for Supper?