Using Photoionization Modeling and Line Diagnostics to Quantify Feedback from AGN Driven Outflows

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Outline

- Motivation
- Sample, Data, Analysis
- Photoionization Modeling
  - Diagnostic Constraints
  - Model Inputs
  - Model Selection
- Results

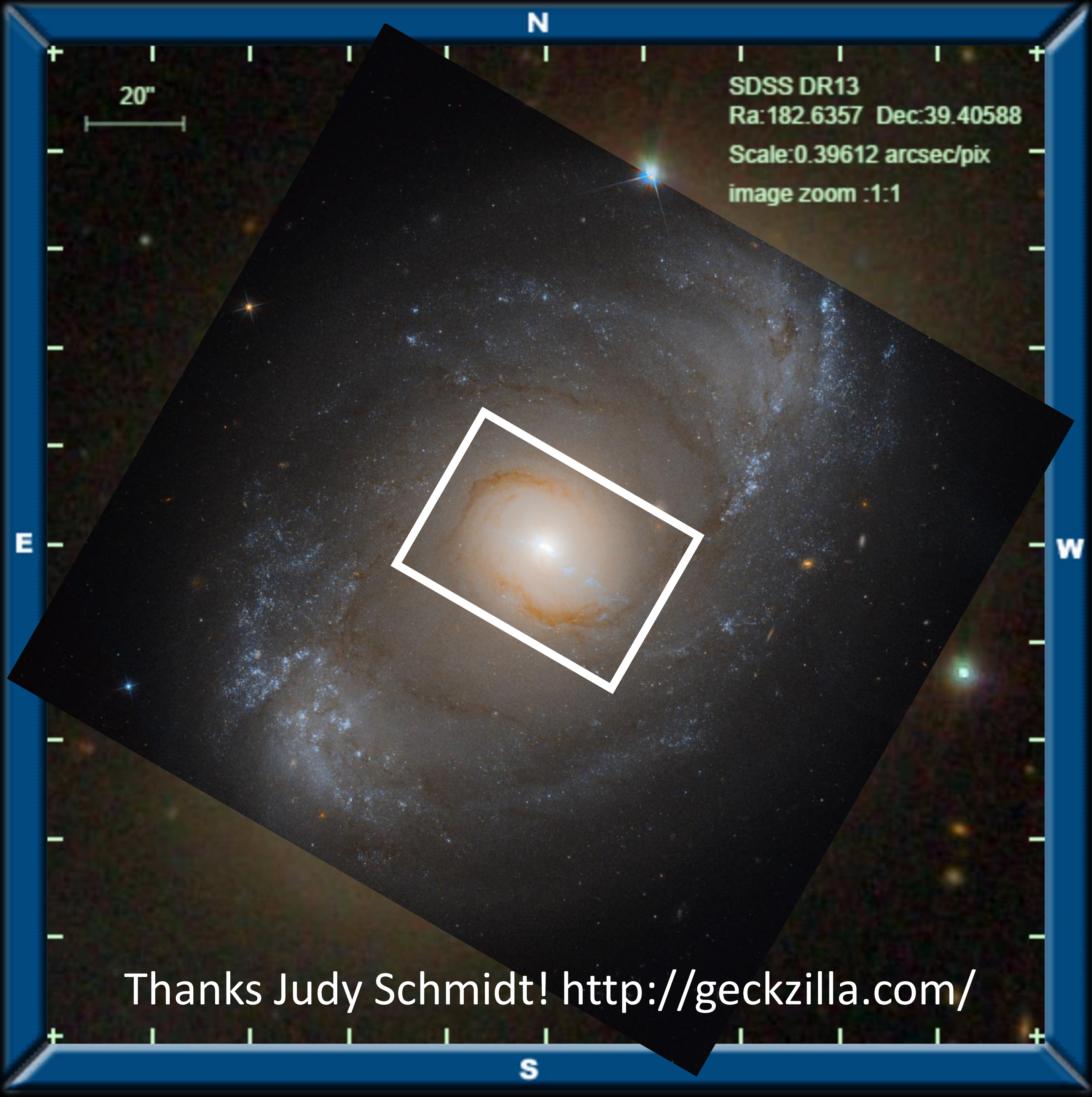
Phoenix, AZ March 2018

Walking the line

Simulating Line Emission from Galaxies

The Big Picture

- NLR: ionized gas ~ 1-1000 pc
  - Outflow or disturbed kinematics
- ENLR: ionized gas > 1000 pc
  - Primarily rotational kinematics
- Feedback from Outflows
  - Interaction with host galaxy



Outflows in the NLR of NGC 4151

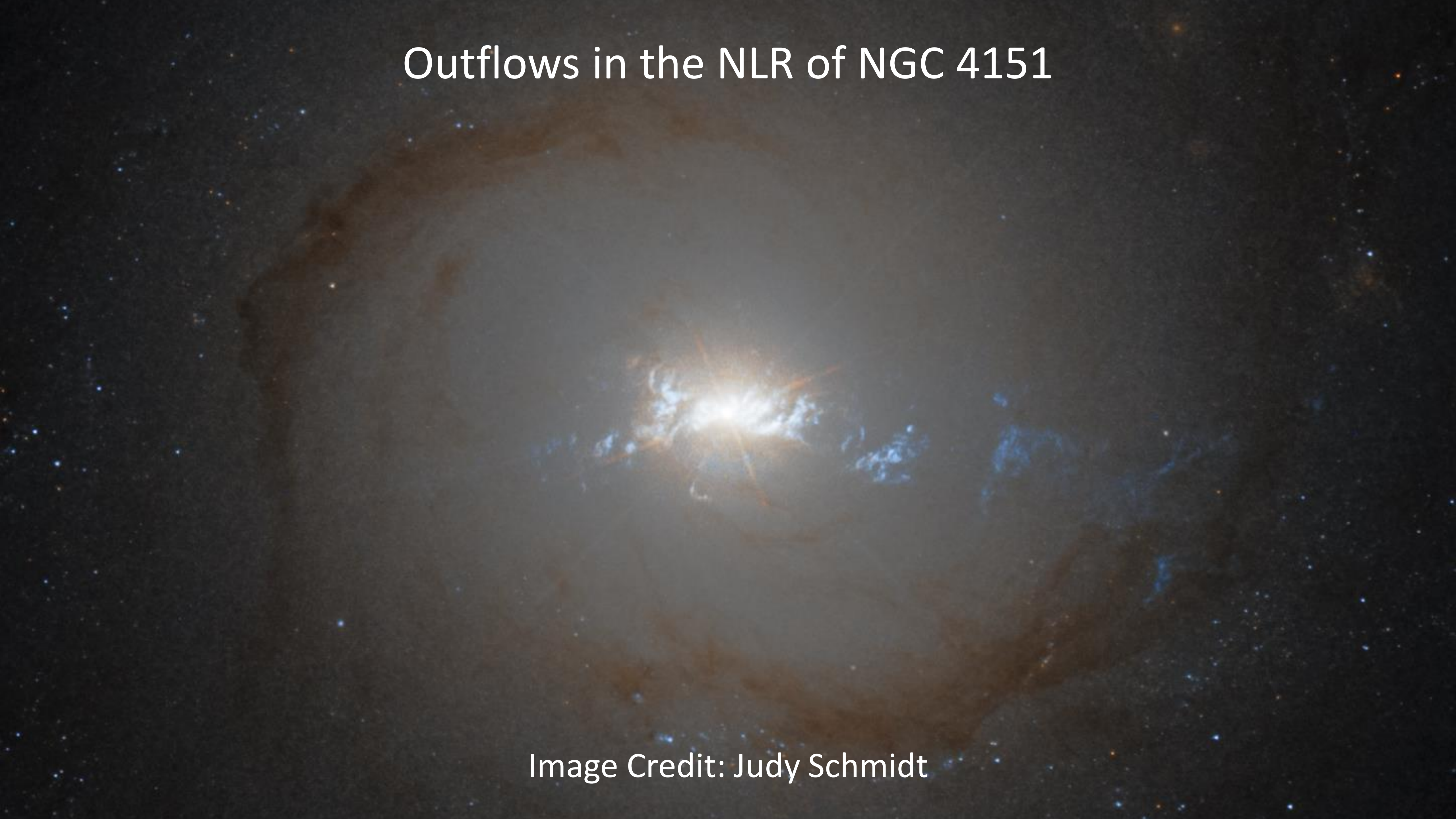


Image Credit: Judy Schmidt

Motivation

- AGN drive powerful outflows that may provide galaxy scale feedback
- Fischer et al. (2013) found 17/53 Seyferts with clear biconical outflows
- Must quantify outflow rates $\dot{M} = \left(\frac{Mv}{\delta r}\right)$ and kinetic energies $\mathrm{E} = \left(\frac{Mv^2}{2}\right)$
- Need spatially resolved measurements and detailed models
- Exploring the assumptions that go into simpler techniques

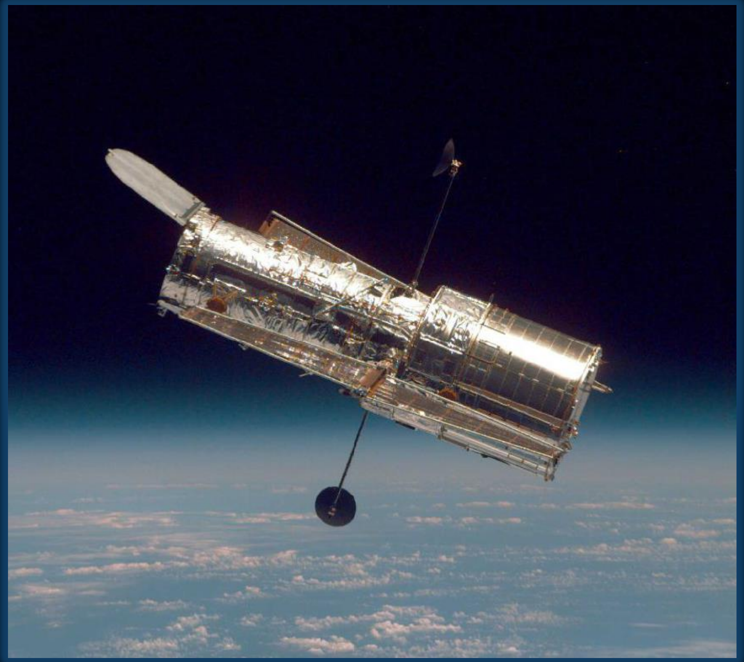
The Sample: Nearby AGN with Outflows

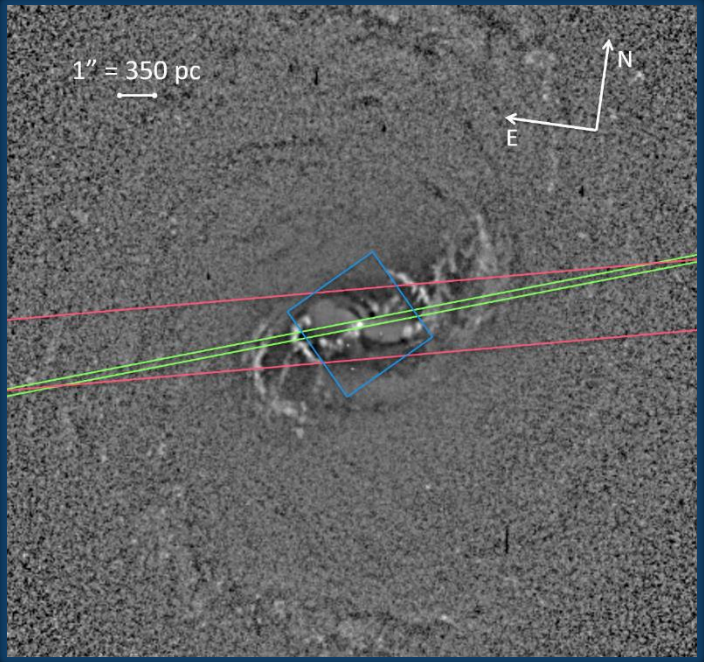
Markarian 573 – 72 Mpc
(arXiv:1802.07734)

Markarian 34 – 213 Mpc
(In Progress)

Observations

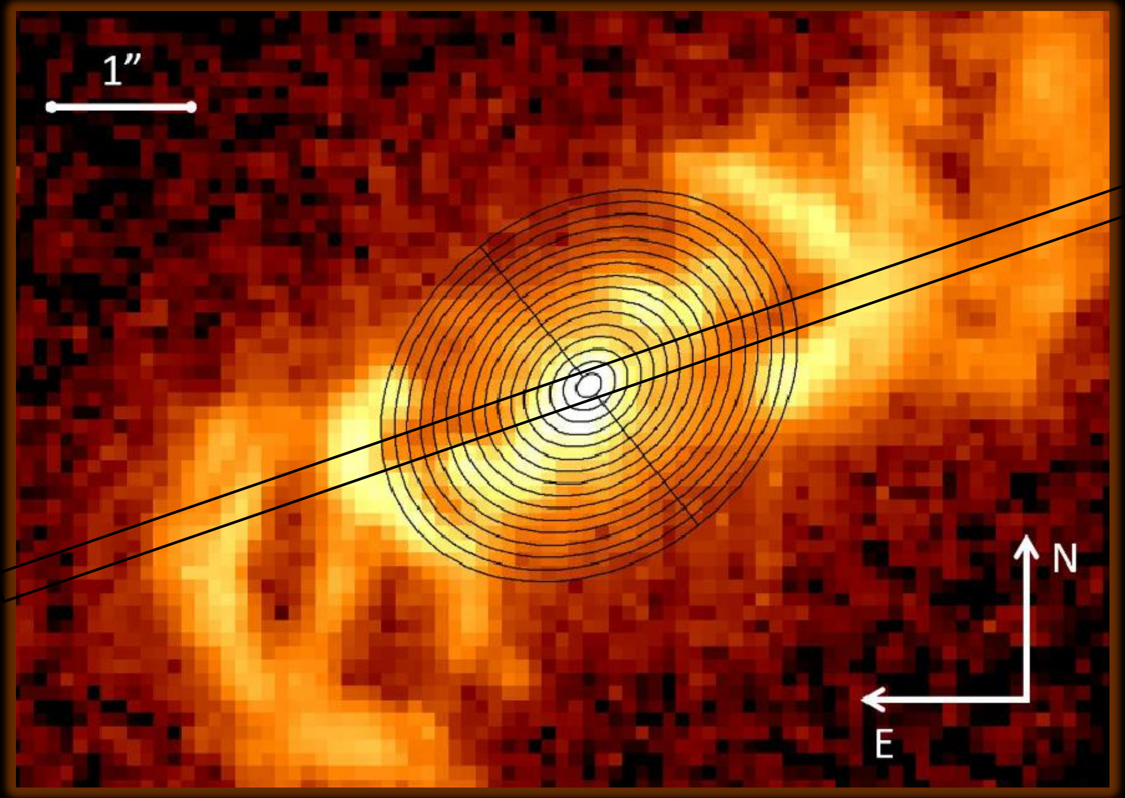
- Hubble Space Telescope (HST) Space Telescope Imaging Spectrograph (STIS)
  - low/medium dispersion, 0.2” slit, high spatial resolution, moderate S/N
- Apache Point Observatory (APO) Dual Imaging Spectrograph (DIS)
  - Medium dispersion, 2.0” slit, lower spatial resolution, high S/N

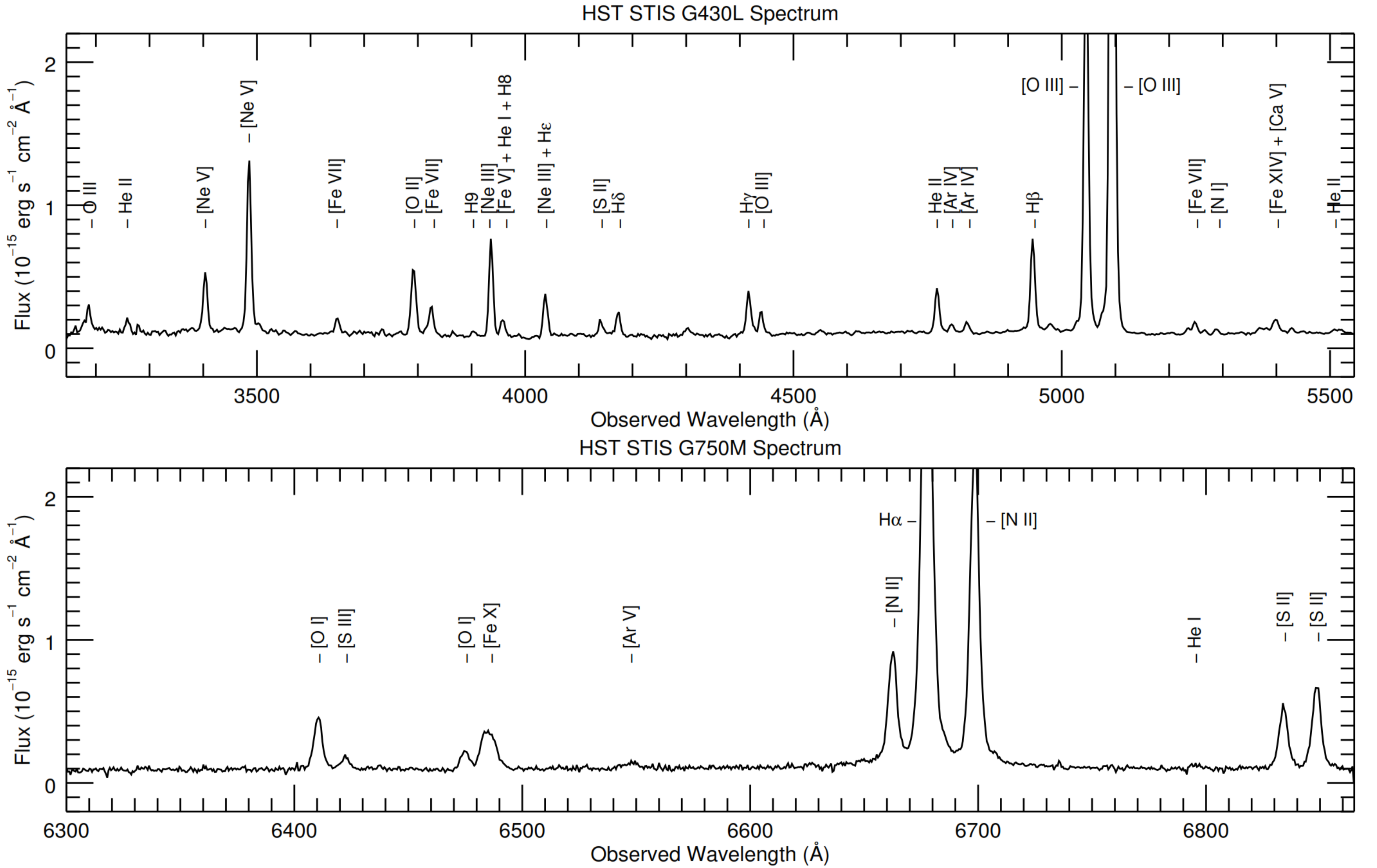




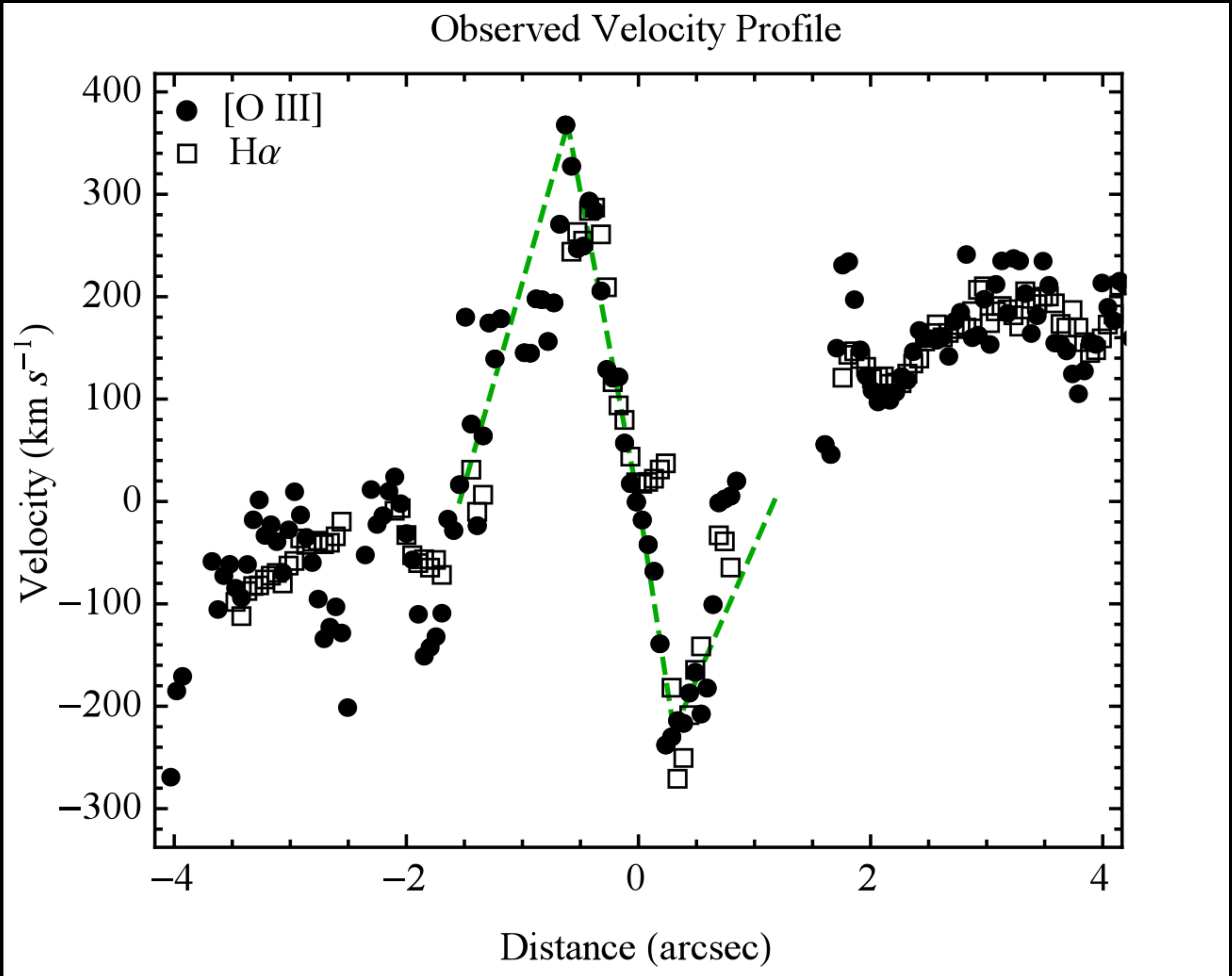
Analysis

- Fit [O III] in spectra with gaussians. Use as a template for other lines
- Get line ratios, correct for reddening
- Model each position with Cloudy
- Calculate flux to mass scale factor
- Use scale factor and [O III] image to get $M(r)$





HST STIS G430L Spectrum
Flux (10^-15 erg s^-1 cm^-2 Å^-1)
Observed Wavelength (Å)
O III
He II
[Ne V]
[Ne V]
[Fe VII]
[O II]
[Fe VII]
H9
[Ne III]
[Fe V] + He I + H8
[Ne III] + Hε
[S II]
Hδ
Hγ
[O III]
He II
[Ar IV]
[Ar IV]
Hβ
[O III]
[O III]
[Fe VII]
[N I]
[Fe XIV] + [Ca V]
He II
HST STIS G750M Spectrum
[O I]
[S III]
[O I]
[Fe X]
[Ar V]
[N II]
Hα
[N II]
He I
[S II]
[S II]


Observed Velocity Profile
[O III]
Hα
Velocity (km s⁻¹)
Distance (arcsec)
400
300
200
100
0
−100
−200
−300
−4
−2
0
2
4

Photoionization Modeling

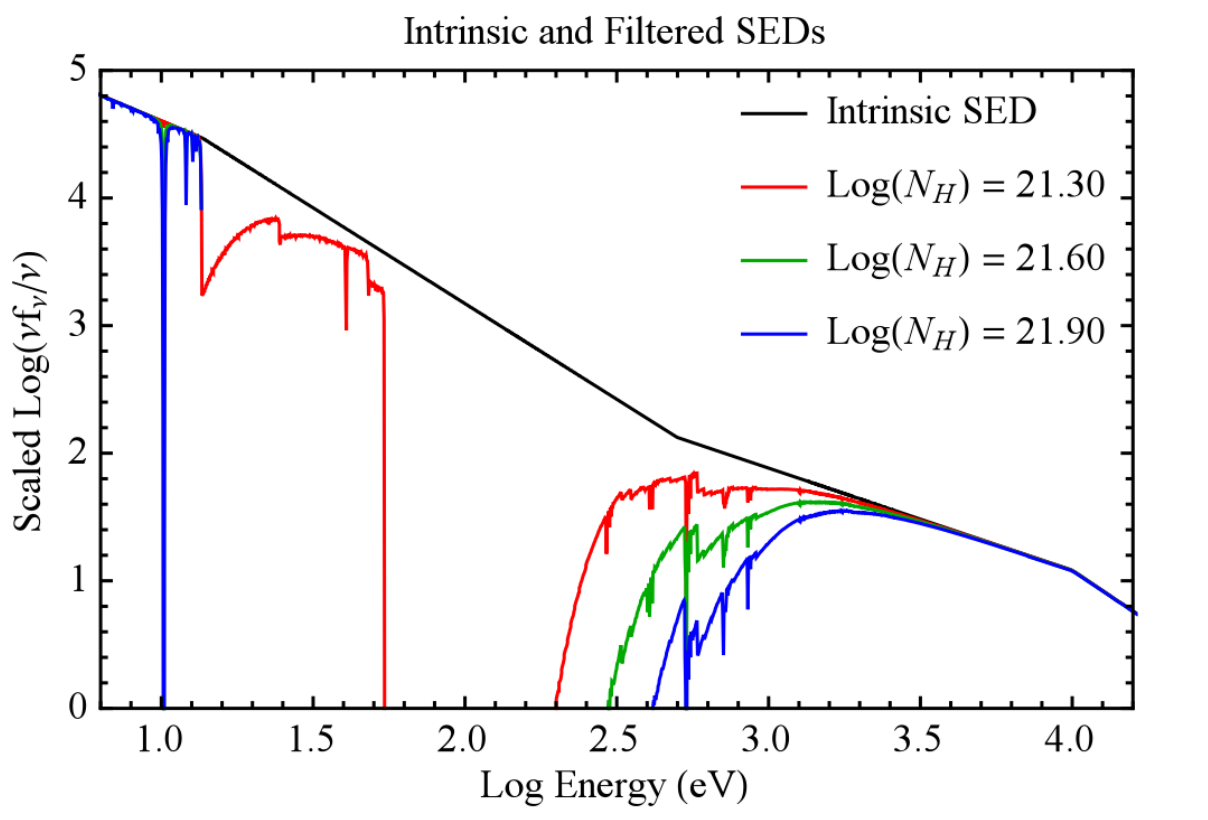
- Multi-component models with Cloudy v13.04 (Ferland et al. 2013)
- Quasi co-located gas with different physical conditions
- “HIGH”, “MED”, and “LOW” ionization components
- Input power law SED, abundances, dust, depletions
- Run grids constrained by diagnostics and geometry
- Compare observed line ratios to composite models normalized to Hβ

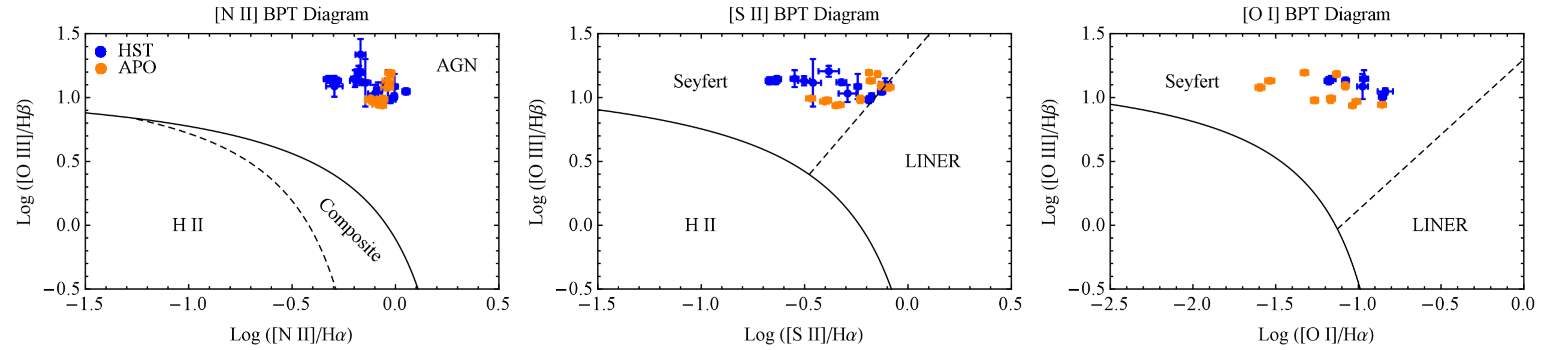
$$U = \frac{Q(H)}{4\pi r^2 n_H c}$$

Model Inputs: SED

- Power Law $L_\nu \propto \nu^\alpha$
  - $\alpha = -1.0$ for $E < 13.6eV$
  - $\alpha = -1.5$ for $13.6eV$ to $500eV$
  - $\alpha = -0.8$ for $E > 500eV$
  - Low/High E cutoffs

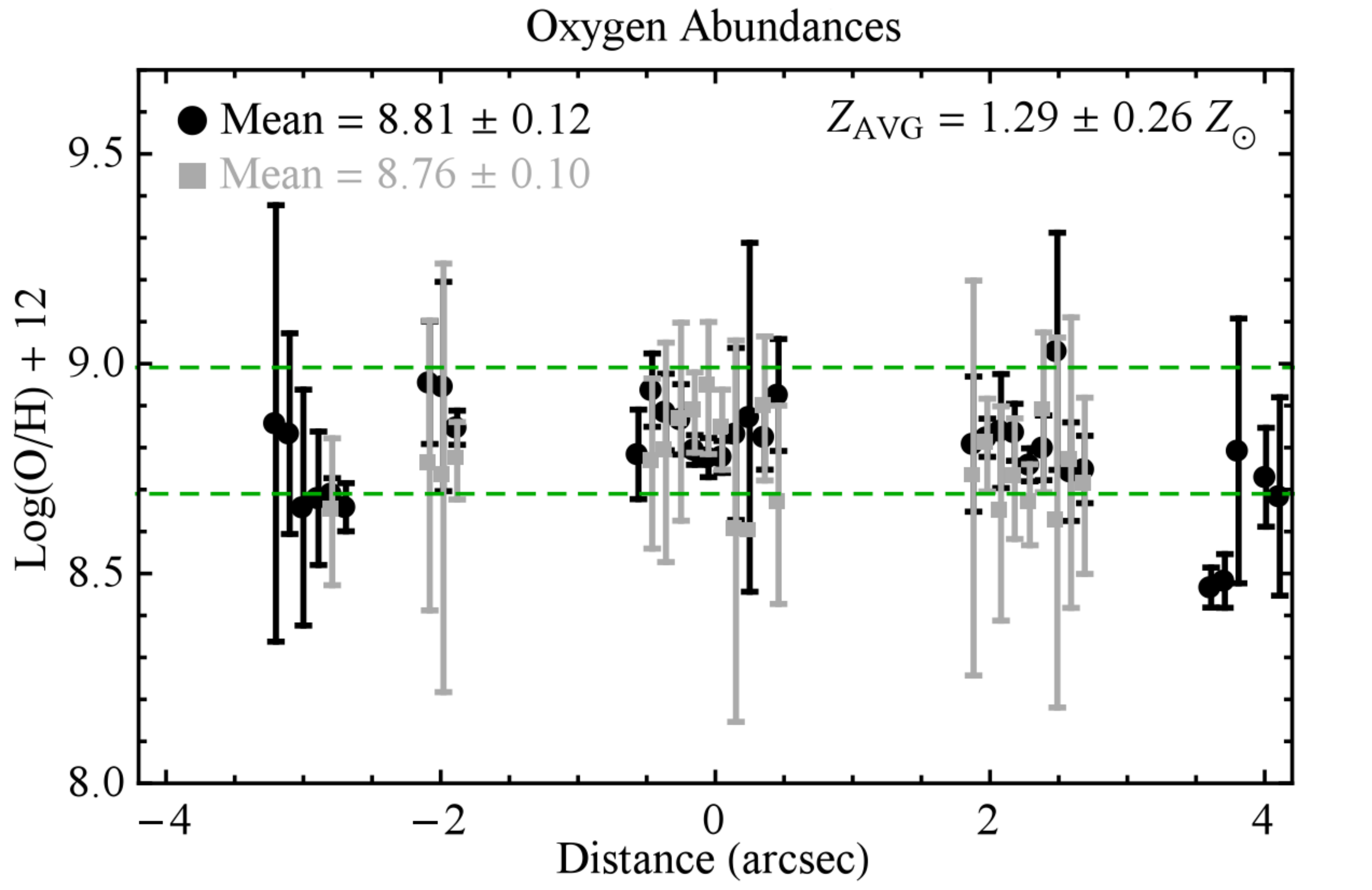
- Absorbed SED for LOW ION
  - Log(N_H) = 21.5 - 21.6



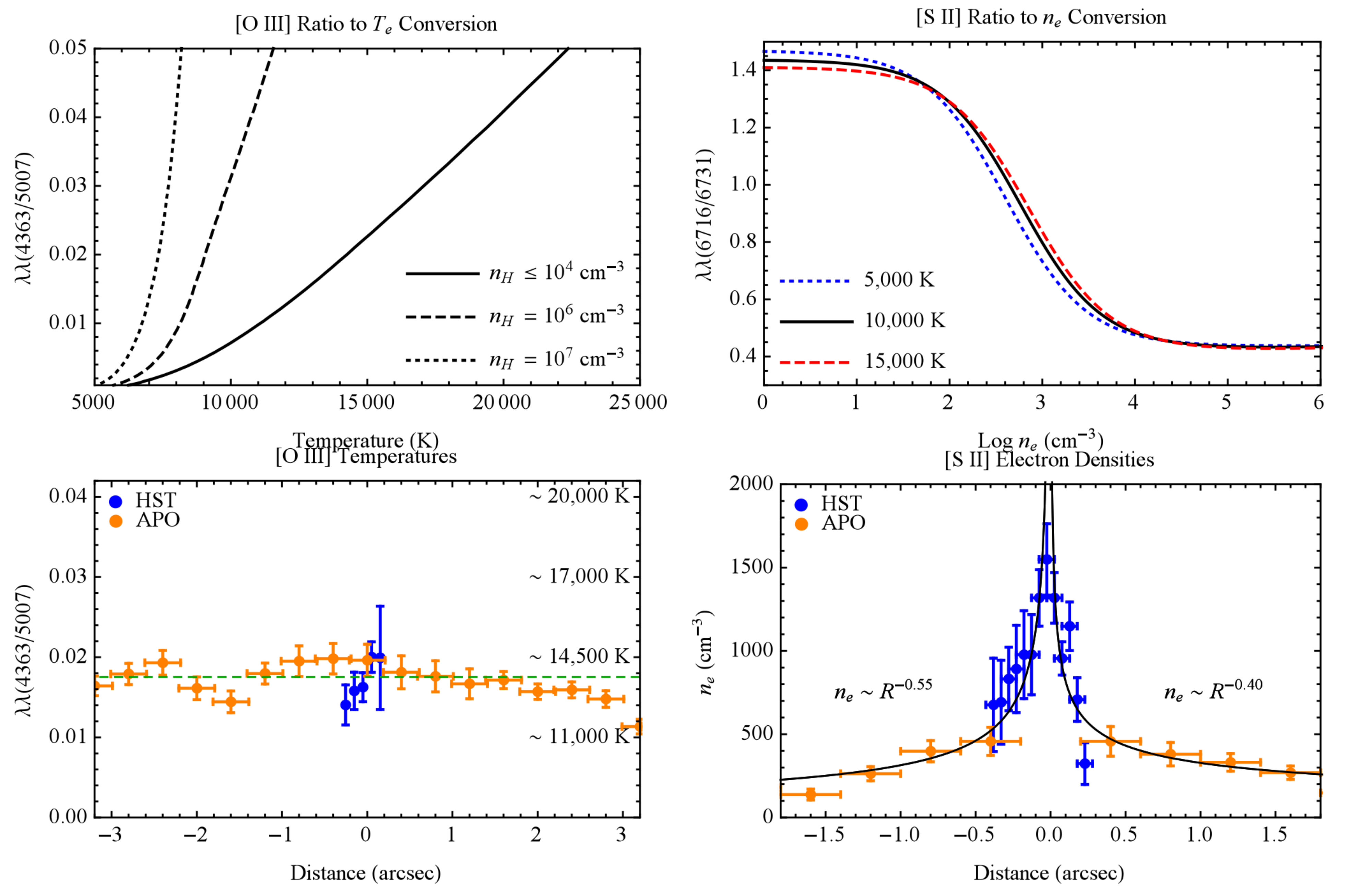


Model Inputs: Abundances

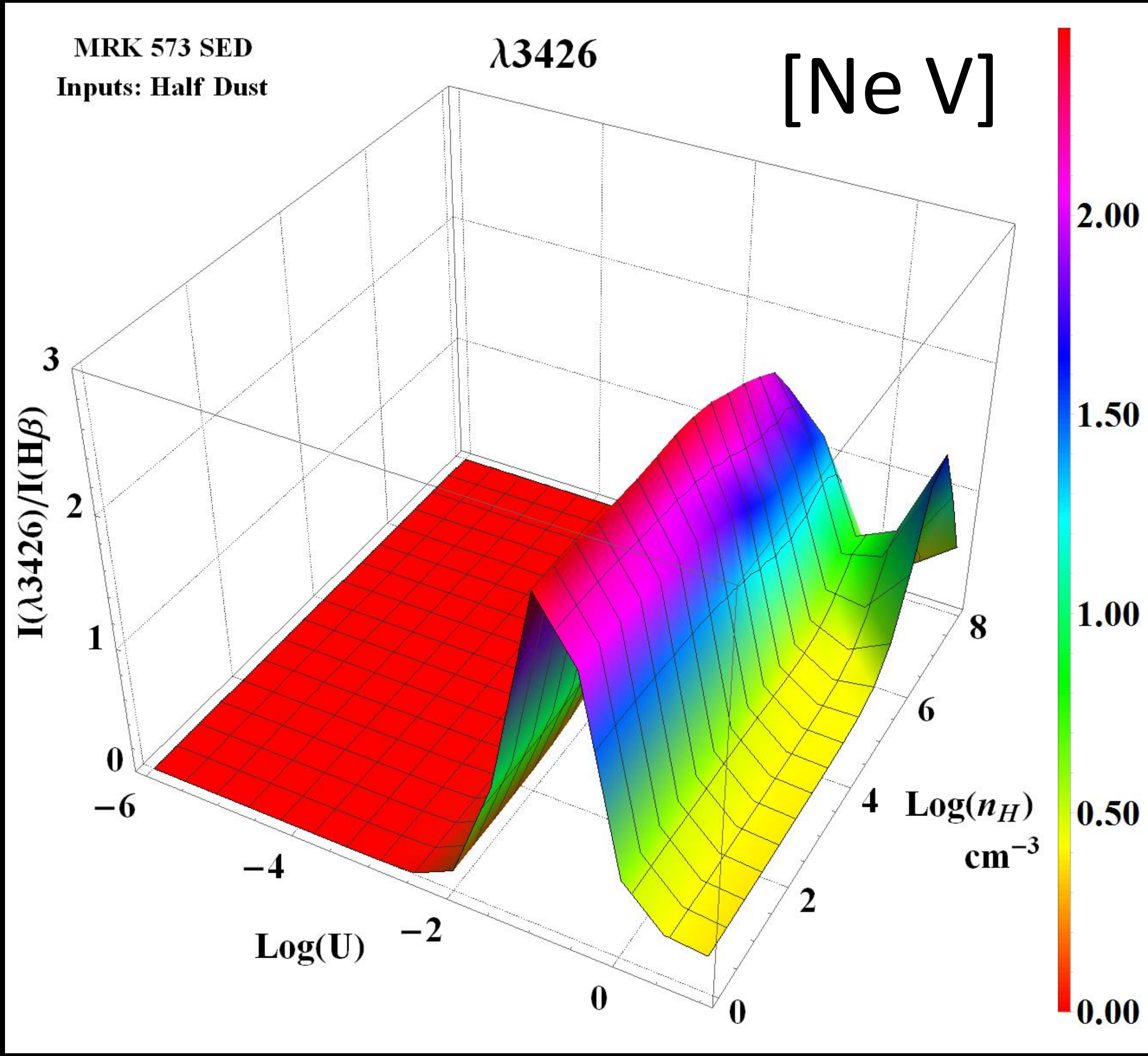
- Determine observationally
- Oxygen abundance:
  - Storchi-Bergmann et al. 1998
  - Castro et al. 2017
- Mean = 1.29 $Z_\odot$
- Dust and depletions

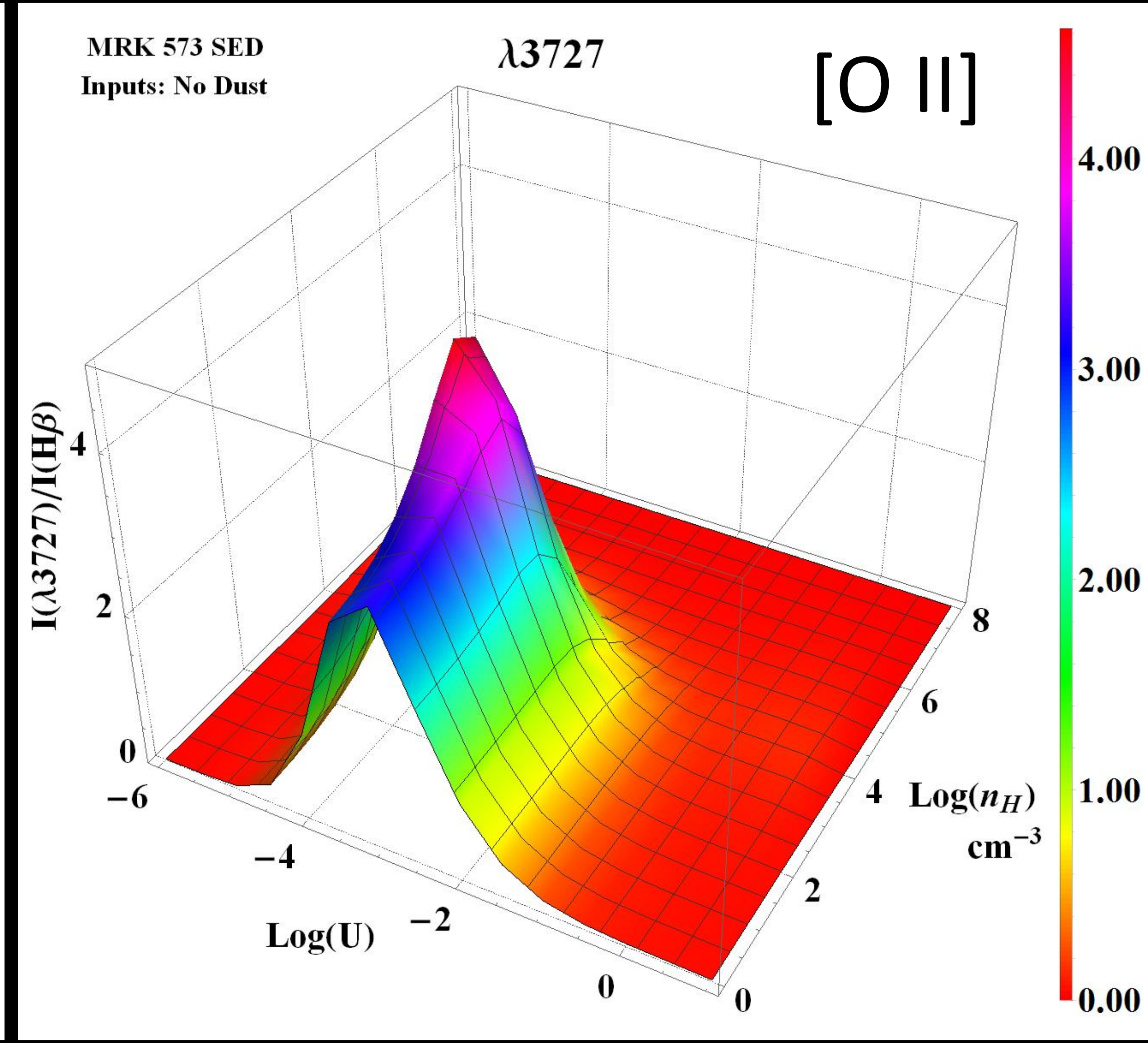


Model Constraints



Model Output Line Ratios



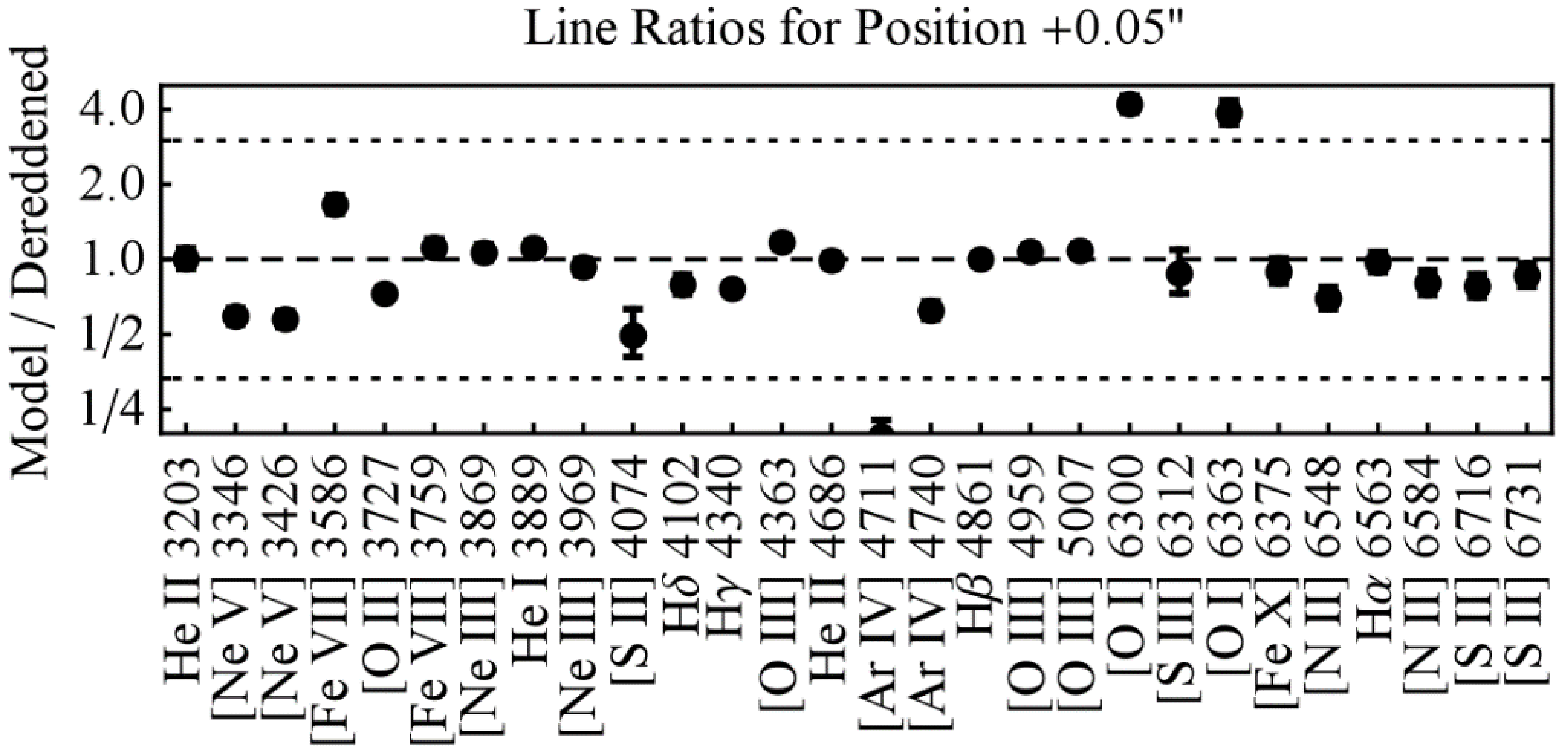


Final Models

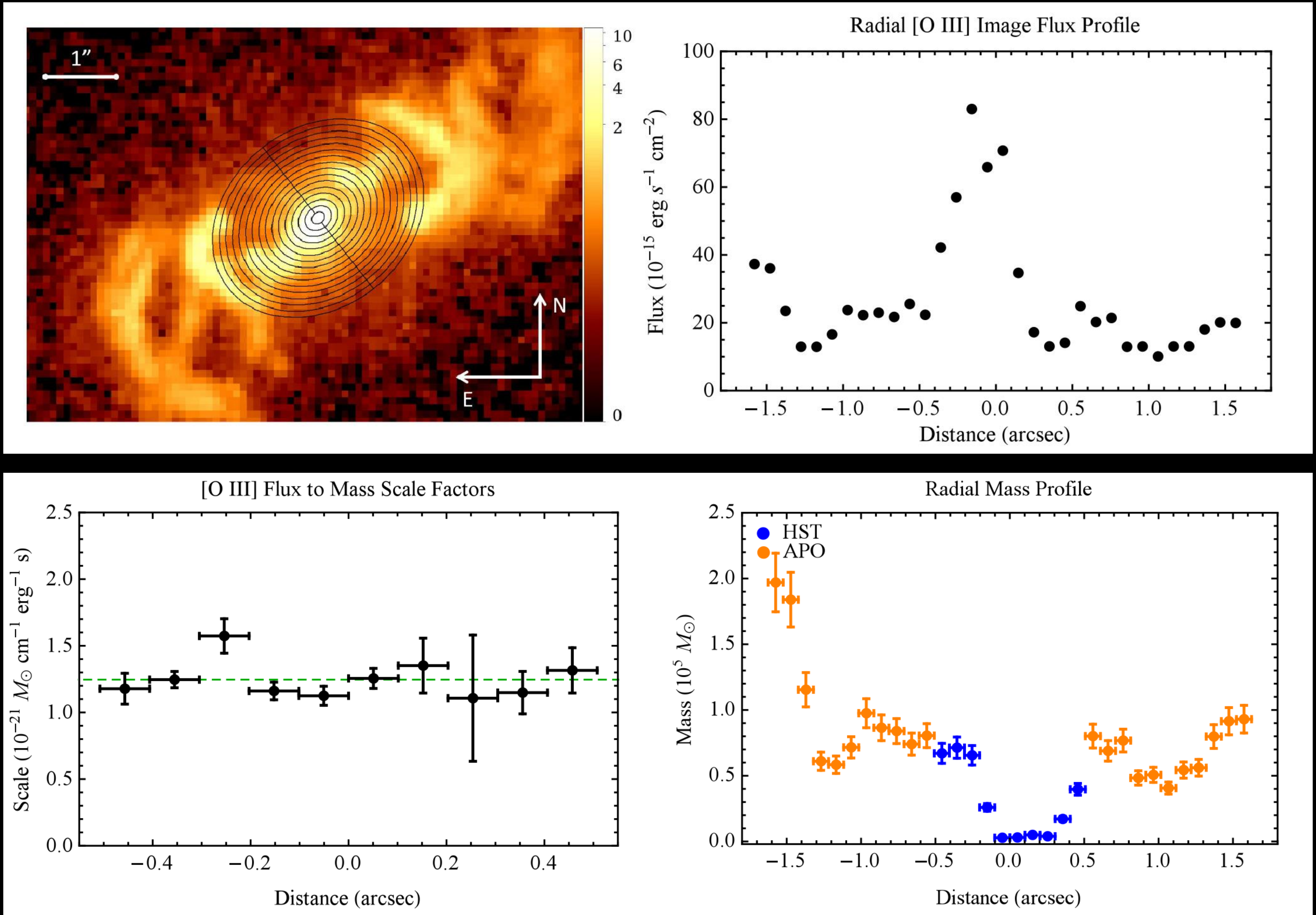
- Examine area, depth, and thickness of final model for physical consistency
- Use models to calculate mass: $M \propto N_H \left(\frac{L(H\beta)_{obs}}{F(H\beta)_{mod}}\right)$, then $S = \left(\frac{M \cdot n_H}{F_{[O\,III]}}\right)$

CLOUDY MODEL PARAMETERS

Distance from Nucleus (arcsec)	Comp ION Name	Ionization Parameter Log(U) (unitless)	Column Density Log(N_H) (cm^{-2})	Number Density Log(n_H) (cm^{-3})	Dust Content Relative to ISM	Input SED Type (I/F)	Fraction of Total Model	Log($F_{H\beta}$) Model Flux (cgs)
0.05	High	-0.70	19.80	4.37	0.0	I	0.25	-1.01
0.05	Med	-1.40	21.40	5.07	0.5	I	0.60	1.43
0.05	Low	-2.61	22.60	3.90	0.5	F	0.15	0.57

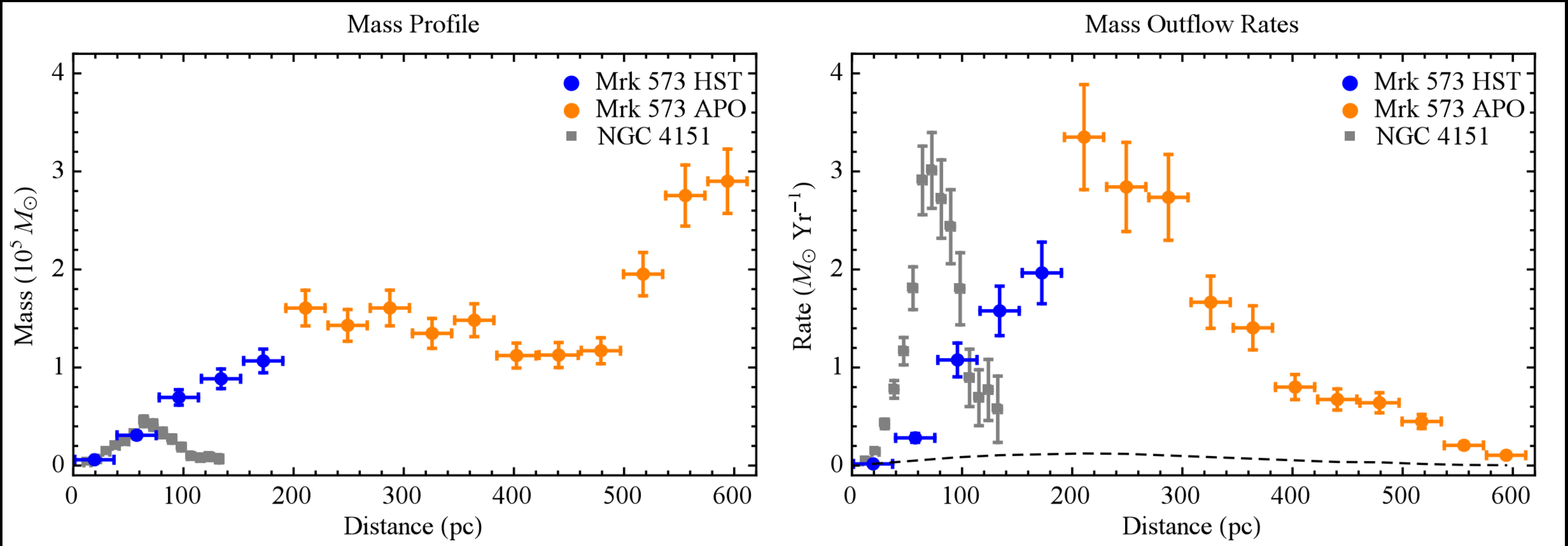


Line Ratios for Position +0.05"
Model / Dereddened
4.0
2.0
1.0
1/2
1/4
He II 3203
[Ne V] 3346
[Ne V] 3426
[Fe VII] 3586
[O II] 3727
[Fe VII] 3759
[Ne III] 3869
He I 3889
[Ne III] 3969
[S II] 4074
Hδ 4102
Hγ 4340
[O III] 4363
He II 4686
[Ar IV] 4711
[Ar IV] 4740
Hβ 4861
[O III] 4959
[O III] 5007
[O I] 6300
[S III] 6312
[O I] 6363
[Fe X] 6375
[N II] 6548
Hα 6563
[N II] 6584
[S II] 6716
[S II] 6731

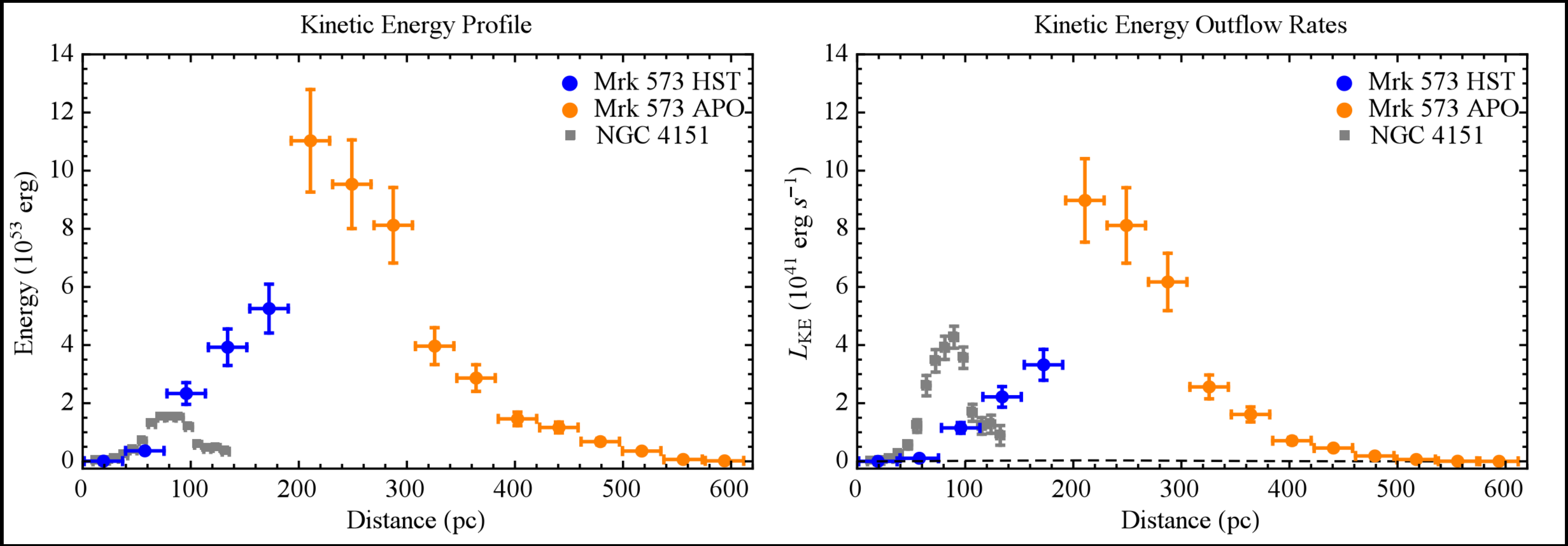


1″
N
E
10
6
4
2
0
Radial [O III] Image Flux Profile
Flux (10^{-15} erg s^{-1} cm^{-2})
Distance (arcsec)
[O III] Flux to Mass Scale Factors
Scale (10^{-21} $M_\odot$ cm^{-1} erg^{-1} s)
Distance (arcsec)
Radial Mass Profile
HST
APO
Mass (10^5 $M_\odot$)
Distance (arcsec)

Revalski et al. 2018 - arXiv:1802.07734



Revalski et al. 2018 - arXiv:1802.07734



Summary

- Multi-component models needed at small radii to capture physical conditions
- We will also develop a streamlined methodology for additional AGN studies
- Additional work needed to characterize the hot X-ray and cold molecular gas
- Will compare results with SFRs and feedback models, not straightforward
- For model comparisons, focus on energetics not mass outflow rates