Theoretical Diagnostics for Narrow Line Regions of Active Galactic Nuclei

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ABSTRACT

Gas metallicity, ionization parameter, and gas pressure can affect the observed ratios of specific strong emission lines within galaxies. While the theoretical strong lines diagnostics for gas metallicity, ionization parameters, and gas pressure in star-forming regions are well-established, theoretical diagnostics for active galactic nuclei (AGNs) narrow line regions are still lacking. In Zhu et al. (2023), we presented a new AGN model that provides the best predictions for observations spanning the UV, optical, and infrared wavelengths. This paper presents a suite of theoretical diagnostics for the gas metallicity, ionization parameter, gas pressure, and the peak energy in AGN ionizing radiation field E_{peak} for AGN narrow-line regions spanning the UV and optical wavelengths. We investigate the model dependency on the ionization parameter, gas pressure, E_{peak}, and the nitrogen scaling relation and make recommendations on metallicity diagnostics that are most robust against these parameters. We test our new AGN metallicity diagnostics using optical galaxy spectra from Sloan Digital Sky Survey DR16. These tests show that the metallicities measured from different diagnostics in this paper are consistent within ~ 0.3 dex. We compare consistent HII and AGN diagnostics and demonstrate that HII and AGN diagnostics should not be used interchangeably. With a wide wavelength coverage, we anticipate that these AGN diagnostics will enable new metallicity studies of galaxies dominated by AGN.

Контекст

- Методы оценки металличности в галактиках с AGN в настоящий момент находятся на начальных стадиях разработки (вот уже 20+ лет)
- Для AGN самым правильным считается метод сильных линий, но просто так взять метод сильных линий для областей SF нельзя (и в этой статье показано почему)
- В этой статье подробно разбирается метод сильных линий, исследуется зависимость отношений сильных линий от многих параметров: металличности, ионизационного параметра, давления, E_peak и nitrogen scaling relation

…и это очень хорошо, ведь мы как раз собираемся мерить металличности в AGN ☺

the peak energy (Epeak) of the AGN radiation field
Может быть кто-то компетентно расскажет, что это такое?

Интересные сведения, почерпнутые из ведения

- SDSS DR16 galaxies spectra show that at least ~ 5% galaxies are Seyfert galaxies and ~ 10% galaxies are composite galaxies (where AGN contributes ~ 10% – 50% to the emission lines)
- In the literature, metallicity measurements in the NLRs of AGNs are generally performed in three ways: the Te method, the central intersect of radial abundance gradients, and the theoretical metallicity diagnostics:

- Te метод: не работает для галактик с низкой плотностью и низкой металличностью 12+log(O/H) < 8.7 galaxies (Stasiska 2005; Dors et al. 2015)
- Второй метод: “adopt the central intersect abundance of the radial abundance gradient derived in the outer star-forming regions of the galaxy as an approximation”
- Третий метод – метод сильных линий, основанный на теоретических моделях NLR AGN (работы Storchi Bergmann et al. 1998; Groves et al. 2004a; Feltre et al. 2016)

- Te method tends to systematically un derestimate the oxygen abundance of NLRs at an average level of ∼ 0.8 dex
- abundances obtained by central intersect of radial metallicity gradients in Pilyugin et al. (2015) are close to, within ∼ 0.3dex of the abundances derived from theoretical metallicity diagnostics

То есть Te метод использовать совсем никак нельзя

Существующие методы сильных линий для AGN в оптике (Storchi-Bergmann et al. (1998), Castro et al. (2017), Carvalho et al. (2020)) и УФ (Nagao et al. (2006), Dors et al. (2014, 2019)) основаны на разных моделях AGN, да еще и не согласуются между собой

Устройство типичной модели AGN: A typical AGN model contains an AGN ionization spectrum, descriptions of gas abundance, gas density structure, and dust properties, and a photoionization code to perform numerical calculations.

Цель данной работы:

- Based on comparison with observations, we recommended a new AGN model that can consistently predict observed UV, optical, and IR emission lines in NLRs.
- И разработанную диагностику можно будет использовать одновременно с разработанной диагностикой для SF областей в тех же галактиках: Because our new diagnostics use the MAPPINGS photoionization models and consistent abundance sets, our new AGN NLR diagnostics may be used in conjunction with the metallicity diagnostics for star-forming galaxies presented in Kewley et al. (2019b).

Модель AGN

- radiation model OXAF для генерации ионизующего излучения AGN

(Среди параметров модели самым важным оказался Epeak, и поэтому варьируется только он)

- Фотоионизация: We use the MAPPINGS version 5.20 photoionization code

(The latest available atomic data from CHIANTI version 10)

- Содержание элементов: based on the average abundance of 29 local B stars in the Milky Way

(содержания шкалируются линейно кроме He, C, N)

- For the density structure, we assume pressure equilib rium and allow the density to vary within the NLR.

И азот шкалируется 2 разными способами

У них разный наклон зависимости, что приводит к следующему:

“at the high metallicity end (12+log(O/H) ≈ 9.0), the N/O ratio derived from the ‘NHhigh’ N/O−O/H relation can be ∼ 0.4dex higher than the N/O ratio derived from the ‘NHlow’ N/O−O/H relation”

Почему так? Связано с физикой обогащения МЗС азотом. Есть два канала:

- core-collapse supernovae in the native gas cloud
- delayed nucleosynthesis from intermediate-mass stars in their giant phase

Но для разных типов галактик шкалирование может быть разным, например картину могут менять звезды WR если их много

Что получилось

- Similar to the situation in HII regions, many AGN metallicity diagnostics have small to moderate dependence on the ionization parameter (log(U)), gas pressure (P/k), and the peak energy (Epeak) of the AGN radiation field.

Далее я покажу оптические калибровки, так как мы работаем с оптикой, но в статье есть то же самое для УФ

А еще в статье приведено много зависимостей для ионизационного параметра и др

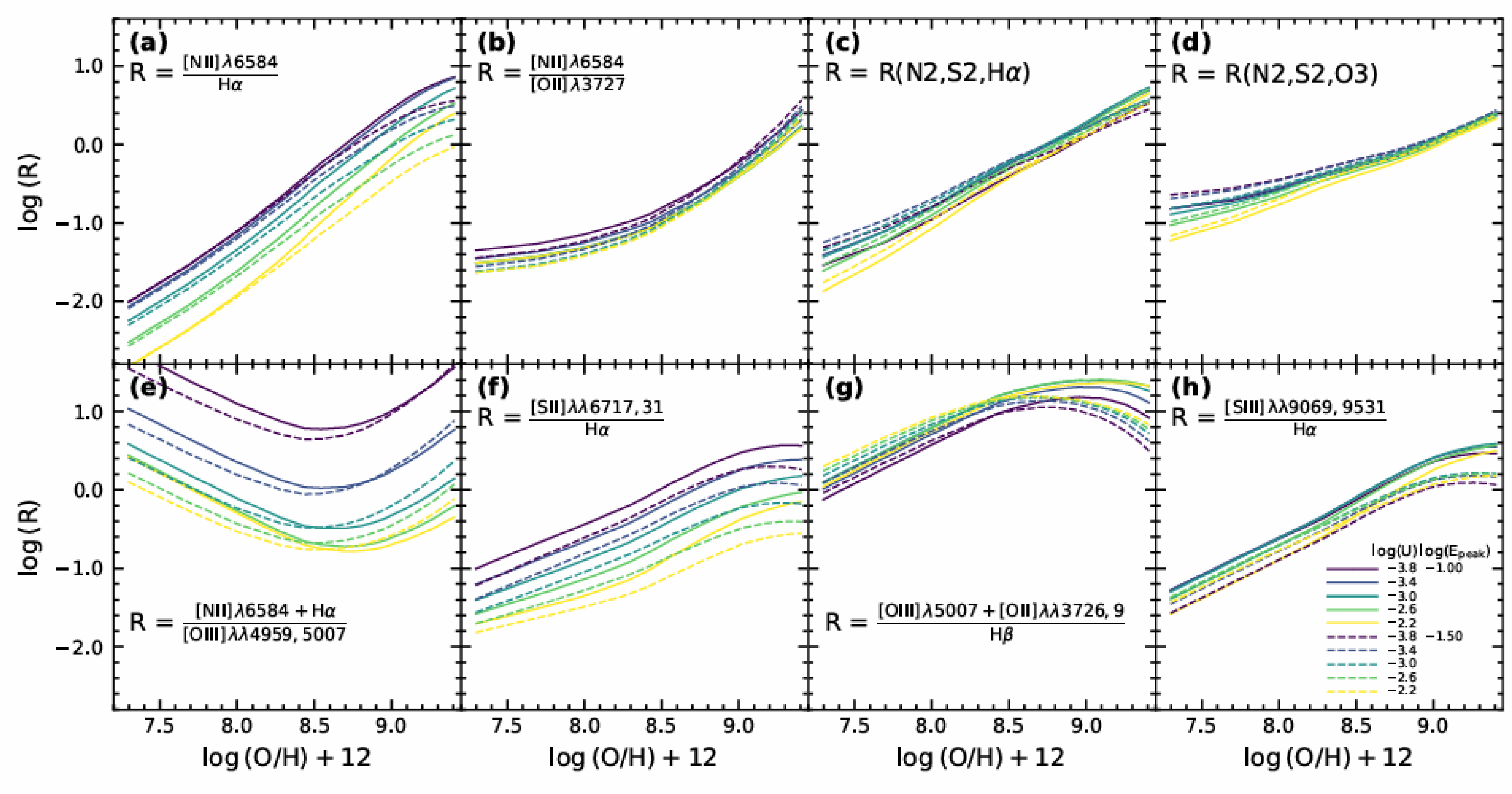


Figure 3. Optical metallicity diagnostics for the AGN narrow line regions as predicted by AGN models with $\log(P/k) = 7.0$, 'NHlow' nitrogen scaling relation, and varying ionization parameters ($\log(U) = -3.8, -3.4, -3.0, -2.6, -2.2$ correspond to colors from dark to bright) and varying peak energy in the AGN radiation field ($\log(E_{\rm peak}/{\rm keV}) = -1.0$ in solid lines and $\log(E_{\rm peak}/{\rm keV}) = -1.5$ in dash lines).

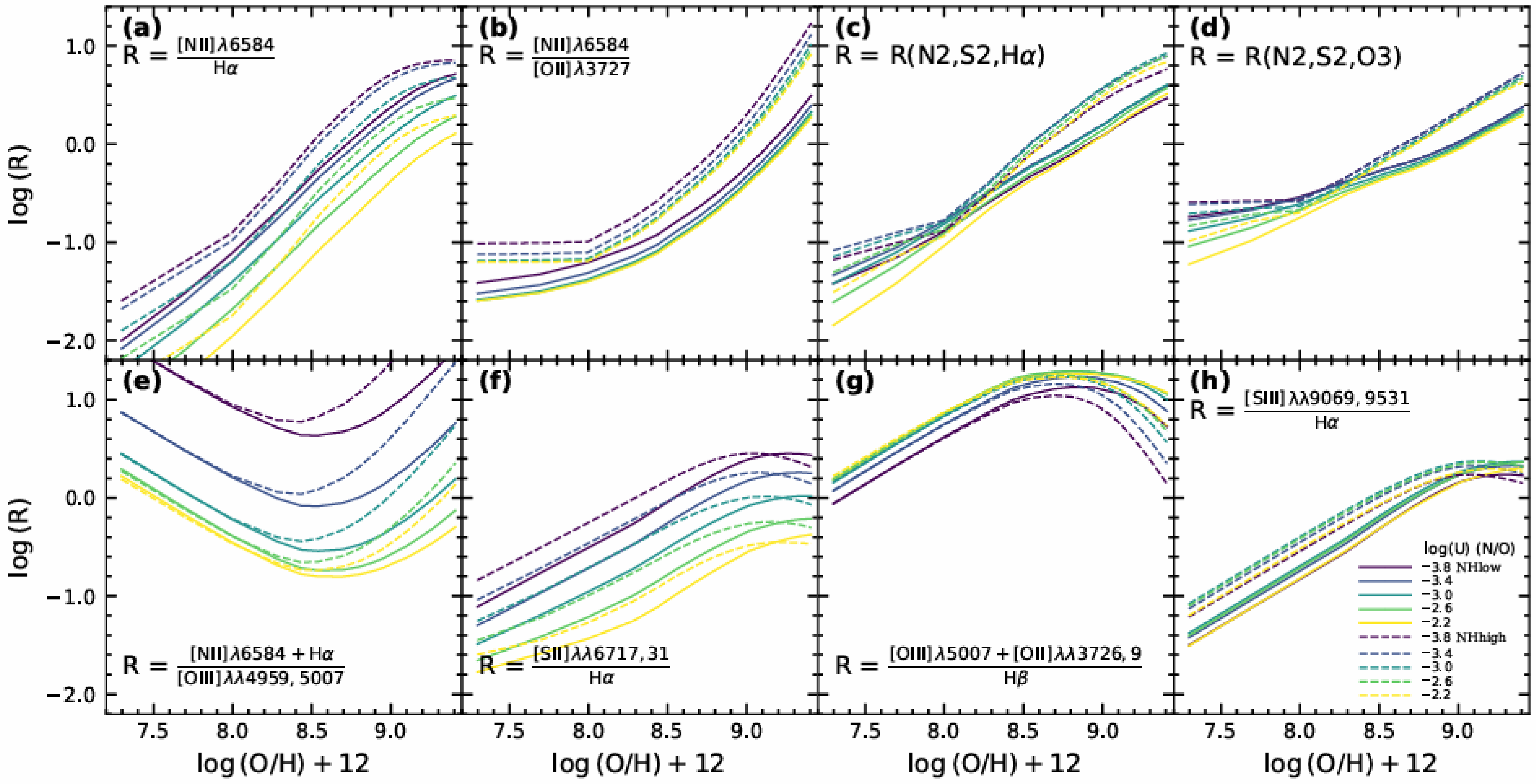


Figure 4. The effect of nitrogen scaling relation on optical metallicity diagnostics for the AGN narrow line regions as predicted by AGN models with $\log(P/k) = 7.0$ and $\log(E_{\rm peak}/{\rm keV}) = -1.5$. As in Figure 3, but with line styles representing the nitrogen scaling relation used in the AGN models ('NHlow' in solid lines and 'NHhigh' in dash lines).

В итоге, как считать металличность? Схема подсчета металличности итерационная

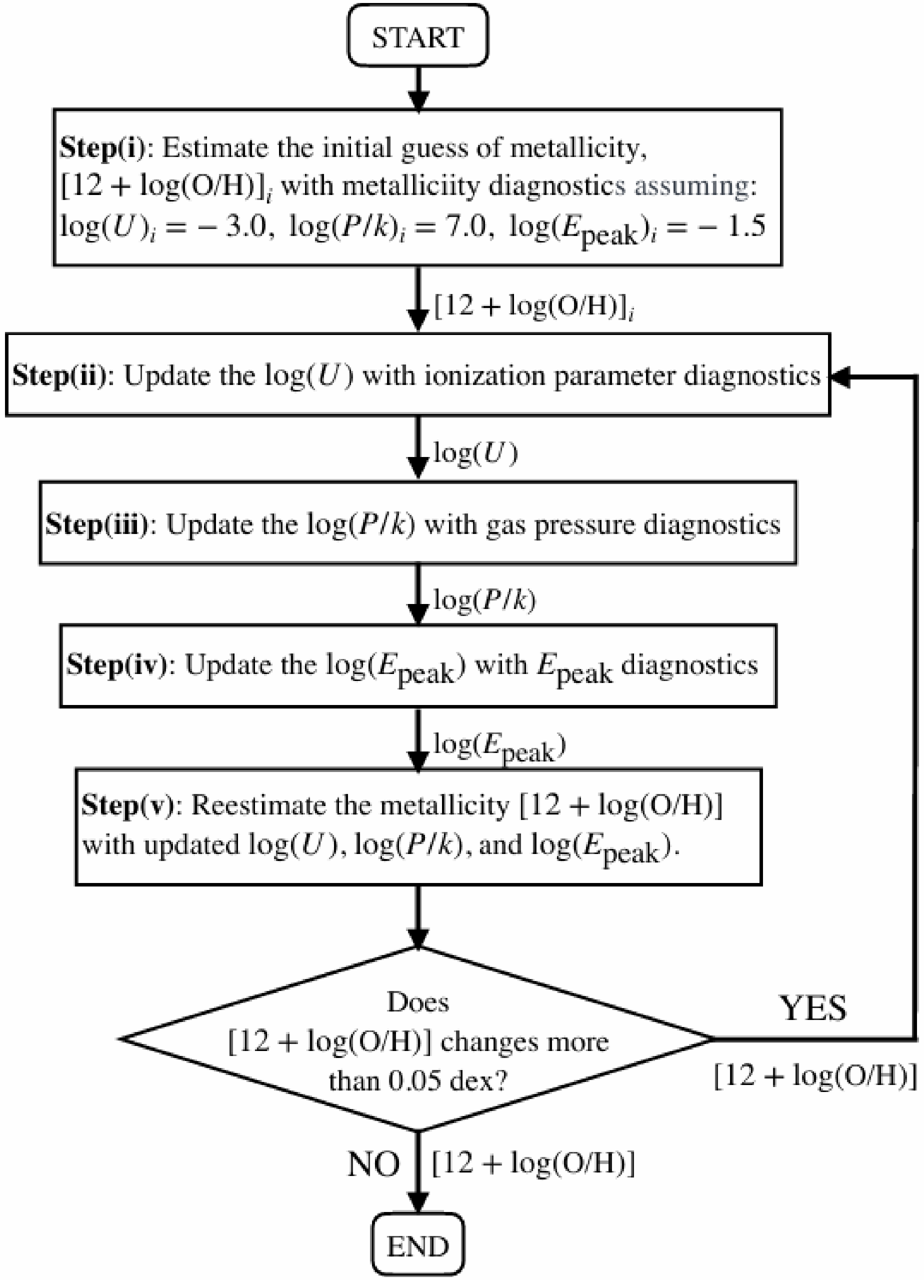


Figure 9. The logical flowchart for determining metallicity for AGN narrow line regions using theoretical diagnostics.

Тесты

This difference is a result of different dust assumptions in the two models. Our AGN model includes dust and dust depletion, while the AGN model in Carvalho et al. (2020) is dust-free.

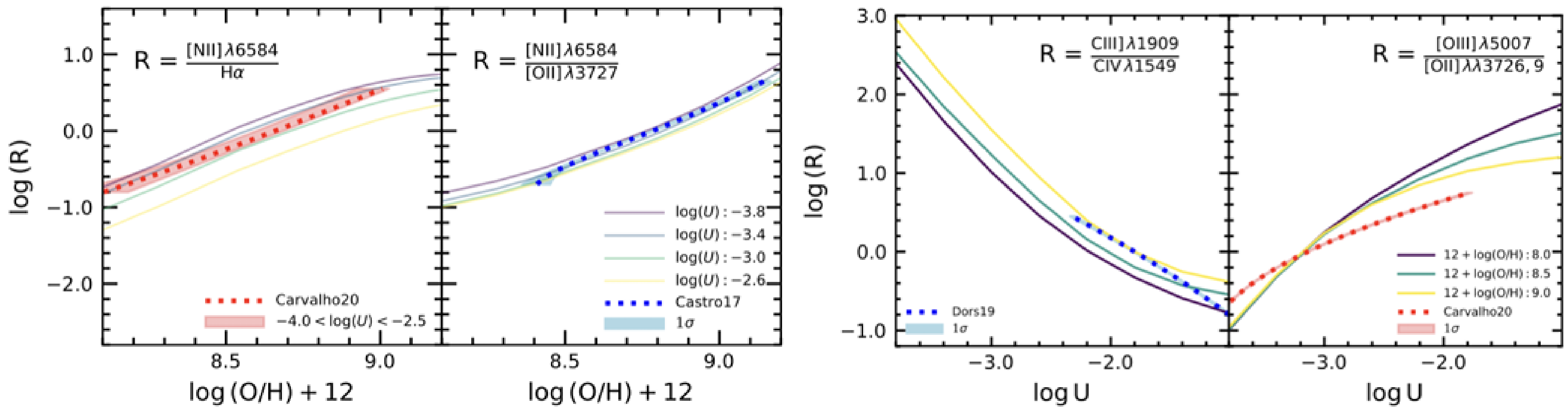
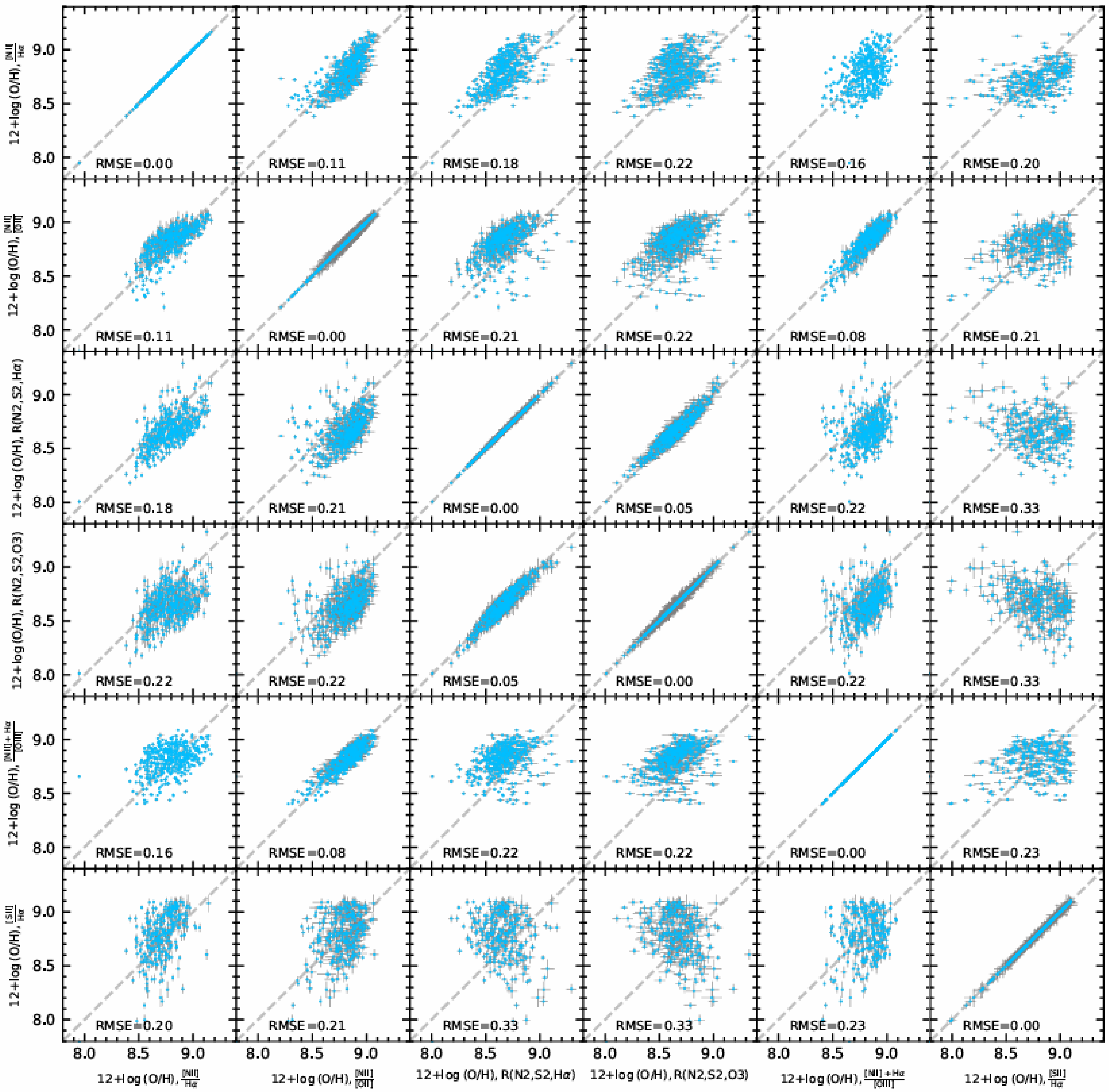


Figure 8. External testing the AGN metallicity diagnostics and ionization parameter diagnostics in this paper. The left panel shows the comparison of optical AGN metallicity diagnostics [N II]/Hα and [N II]/[O II] from this paper and those from Carvalho et al. (2020) and Castro et al. (2017). The right panel shows comparison of AGN ionization parameter diagnostic C III]/C IV and [O III]/[O II] from this paper and those from Dors et al. (2019) and Carvalho et al. (2020). In both panels, the diagnostics from this paper are derived from AGN models with $\log(P/k) = 7.0$, $\log(E_{peak}/\mathrm{keV}) = -1.5$, and 'NHhigh' nitrogen abundance scaling relation.

Сравнение калибровок из этой работы друг с другом for 460 Seyfert galaxies observed in SDSS DR16.

S/N для линий > 5



Диагностики для AGN и HII расходятся на больших металличностях

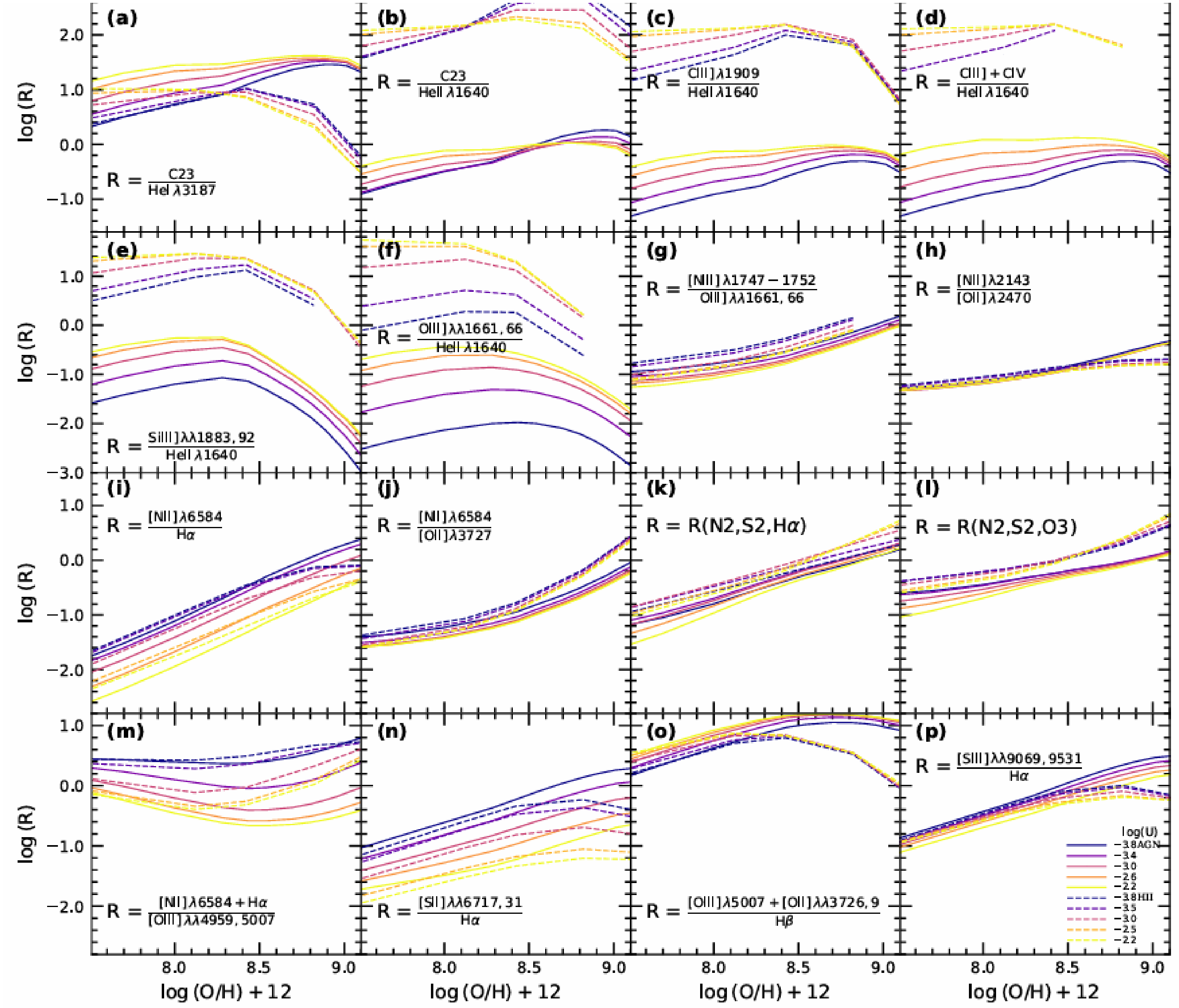


Figure 12. Comparing the UV and optical metallicity diagnostics for AGN narrow line regions (solid lines) and HII region (dashed lines) with varied ionization parameter ($\log(U) = -3.8, -3.4, -3.0, -2.6, -2.2$ correspond to colors from dark to bright). Both AGN and HII metallicity diagnostics are derived from models with the same gas pressure $\log(P/k) = 7.0$.

Результаты

We recommend the following metallicity diagnostics that are most robust against other parameters:

(a) N III] λ1747-52/O III] $\lambda\lambda 1660, 6$, only depend on the nitrogen scaling relation.

(b) [N II] λ6584/[O II] $\lambda\lambda 3727, 9$, R(N2,S2,Hα), and R(N2, S2, O3), only depend on the nitrogen scaling relation.

We compare consistent HII and AGN diagnostics and demonstrate that HII and AGN diagnostics should not be used interchangeably. We recommend the use of AGN diagnostics where AGN is expected to dominate the emission-line gas. We provide a description of which diagnostics may perform best in the event of contamination by HII gas in the aperture. The metallicity diagnostics that are least affected by the HII-AGN mixing are:

(i) UV diagnostic [N II] $\lambda\lambda 2139, 43$/[O II] $\lambda 2470$.

(ii) optical diagnostics [N II] $\lambda 6584$/Hα, [N II] $\lambda 6584$/[O II] $\lambda\lambda 3727, 9$, and [S III] $\lambda\lambda 9069, 9531$/H$\alpha$ at $12 + \log(\mathrm{O/H}) \lesssim 8.5$.