astro-ph seminar 2021.11.04 (大澤)

Published in PASP

Proper Plasma Analysis Practice (PPAP), an Integrated Procedure of the Extinction Correction and Plasma Diagnostics: a Demo with an HST/WFC3 Image Set of NGC 6720

Toshiya Ueta (植田稔也)[1,2,3] and Masaaki Otsuka (大塚雅昭)[2]

In this work, we propose a proper plasma analysis practice (PPAP), an updated procedure of plasma diagnostics in the era of spatially-resolved spectroscopy. In particular, we emphasize the importance of performing both of the extinction correction and the direct method of plasma diagnostics simultaneously as an integrated process. This approach is motivated by the reciprocal dependence between critical parameters in these analyses, which can be resolved by iteratively seeking a converged solution. The use of PPAP allows us to eliminate unnecessary assumptions that prevent us from obtaining an exact solution at each element of the spectral imaging data. Using a suite of *HST*/WFC3 narrow-band images of the planetary nebula, NGC 6720, we validate PPAP by (1) simultaneously and self-consistently deriving the extinction, $c(\mathrm{H}\beta)$, and electron density/temperature distribution, ($n_e([\mathrm{S\,II}])$, $T_e([\mathrm{N\,II}])$), maps that are consistent with each other, and (2) obtaining identical metal abundance distribution maps, ($n(\mathrm{N}^+)/n(\mathrm{H}^+)$, $n(\mathrm{S}^+)/n(\mathrm{H}^+)$), from multiple emission line maps at different wavelengths/transition energies. We also determine that the derived $c(\mathrm{H}\beta)$ consists both of the ISM and circumsource components and that the ionized gas-to-dust mass ratio in the main ring is at least 437 and as high as about 1600. We find that, unless we deliberately seek self-consistency, uncertainties at tens of % can easily arise in outcomes, making it impossible to discern actual spatial variations that occurs at the same level, defeating the purpose of conducting spatially resolved spectroscopic observations.

Background

輝線比を用いたプラズマ状態 (T_e, n_e, $n(X)$) の診断では次のような近似が用いられることが多かった。

- 電子温度を決め打ちで密度に sensitive な輝線比を用いて n_e を求める。
- 電子密度を決め打ちで温度に sensitive な輝線比を用いて T_e を求める。
- 電子密度、温度を仮定して理論的に得られる輝線比との差異から extinction を求める。

こうした近似は計算器能力が限られていた時代のテクニックであり、現代であれば個人のトートパソコンで十分計算できる。
特に物理量の空間的な変化を議論したい IFU 観測でも上記の仮定を用いるのは気持ちが悪い
⇒ $\{n_e, T_e, c(\lambda), n(X)\}$ を同時に最適化するための手続きを示し、NGC 6720 で実証する。

Algorithm

dust geometry は foreground screen を仮定

$$I(\lambda) = I_0(\lambda) \times 10^{-c(\lambda)}.$$

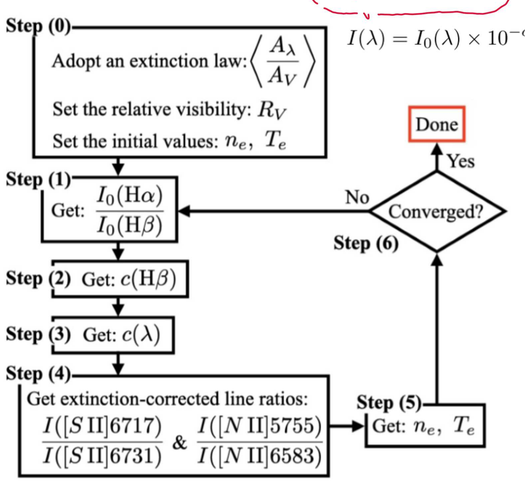
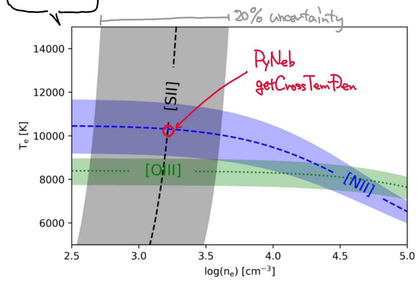


Figure 1. Schematic representation of PPAP, through which $c(\mathrm{H}\beta)$ and ($n_e([\mathrm{S\,II}])$, $T_e([\mathrm{N\,II}])$) are determined by iteration.

PPAP では iterative に consistent な解を探す。
initial guess から逐次 update することで不動点を求める。
収束判定はパラメタの変化がなくなった時。

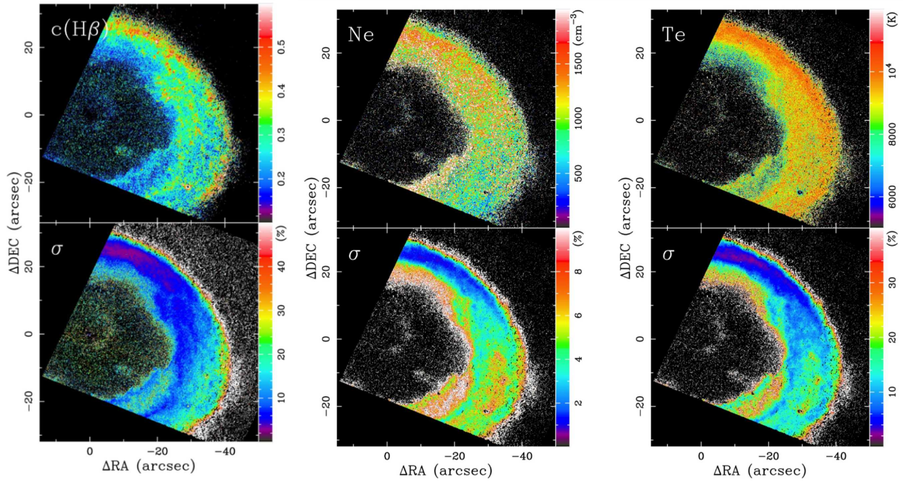
Hα, Hβ, [SII]λλ6716, 6731 [NeII]λλ5755, 6583 の6本の輝線を用いた例。

Step (4)



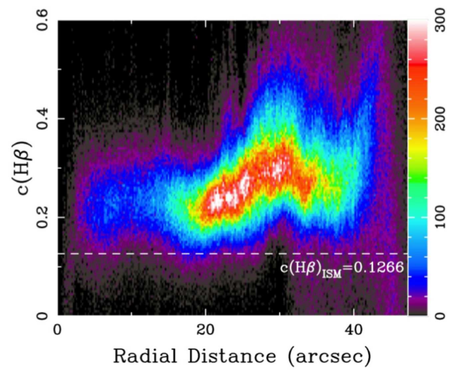
Demonstration

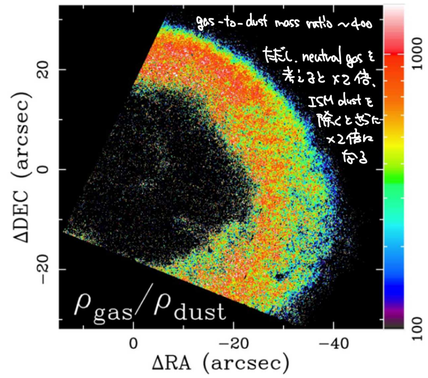
デモンストレーションに用いたデータは HST による NGC 6720 (惑星状星雲) の narrow band images
得られた extinction, n_e, T_e の空間分布を以下に示した。

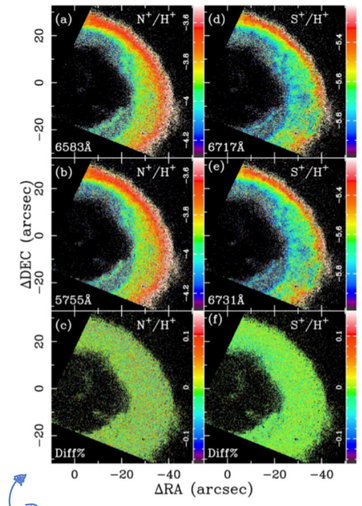


Filter	λ (Å)	Δλ (Å)	Official Description
FQ436N	4367.21	43.35	Hγ 4340 Å+[O III] 4363 Å
FQ437N	4371.09	29.99	[O III] 4363 Å
F469N	4688.14	49.68	He II 4686 Å
F487N	4871.42	60.40	Hβ 4861 Å
F502N	5009.70	65.29	[O III] 5007 Å
F547M	5451.08	649.14	Strömgren y (continuum)
FQ575N	5757.87	18.37	[N II] 5755 Å
F645N	6453.71	84.22	continuum
F656N	6561.45	17.65	Hα 6563 Å
F658N	6584.95	27.56	[N II] 6583 Å
FQ672N	6716.62	19.37	[S II] 6717 Å
F673N	6766.05	117.77	[S II] 6717/31 Å
FQ674N	6730.77	17.63	[S II] 6731 Å
FQ750N	7502.55	70.43	continuum
F953N	9530.92	97.04	[S III] 9532 Å

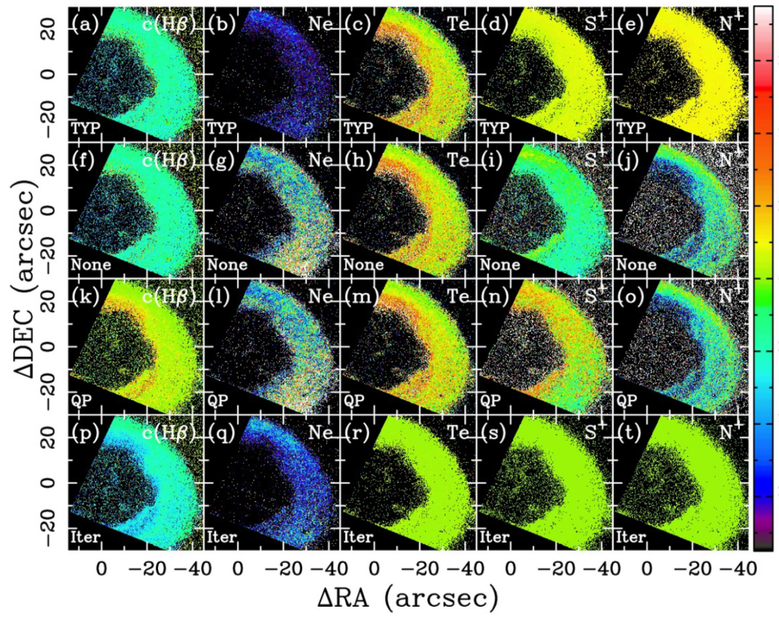
Table 1. *HST*/WFC3 filters used in the Program 12309. The quoted values are the bandpass average wavelength (λ) and bandpass rectangular width (Δλ) defined in PYSYNPHOT (Lim et al. 2015).







異なる line から求めた abundance がちゃんと一致する



- forced & uniform n_e, forced & uniform T_e, no iteration, no QP correction
- with n_e-T_e diagnostics, no iteration, no QP correction
- forced & uniform n_e, forced & uniform T_e, with QP correction, no iteration
- forced & uniform n_e, forced & uniform T_e, no QP correction, with iteration

1. Plasma diagnostics should really be performed with the extinction correction as an integrated iterative procedure for the best results.
2. We should remind ourselves that the theoretical Hα-to-Hβ ratio (or any H I line ratio) is a function of n_e and T_e and never a constant.
3. Imposing (n_e, T_e) constancy in plasma diagnostics will inject uncertainties at tens of % in the outcomes of the analyses. In the literature, such uncertainties are often attributed to the local fluctuations of physical conditions. In reality, the initial constancy assumption is what amplifies uncertainties: PPAP can resolve such local fluctuations.
4. As long as self-attenuation by the circumsource material is expected, it is wrong to adopt the ISM extinction value for target sources, as the non-negligible circumsource extinction will be surely missed (and make (n_e, T_e) incorrect).
5. By the same token, it is incorrect to indiscriminately adopt the empirical $A(V)$-to-N_{H} relation for ISM when some non-negligible amount of circumsource attenuation is expected, as the ISM relation implicitly assumes the gas-to-dust mass ratio of 100, which is not necessarily true for individual target sources.