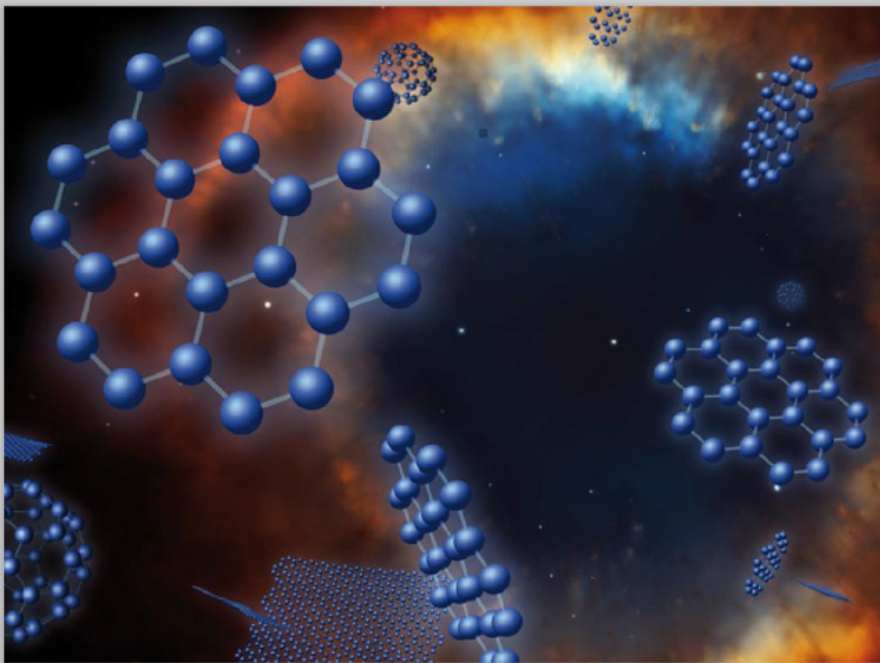


# N-band ground-based observations of PAHs

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Grain Formation Workshop/銀河のダスト研究会 2012.11.30



(Image Archives in JPL/NASA)

awa  
kyo)

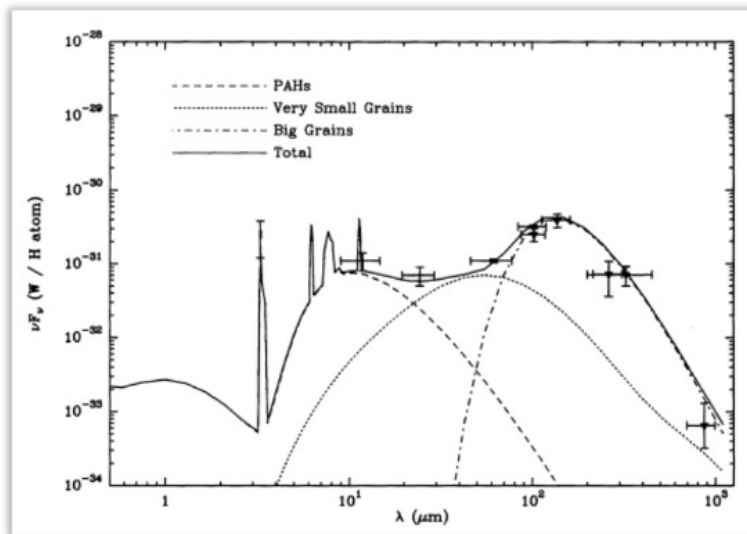
11.30

OL  
PAH

# Observational Aspects of PAHs

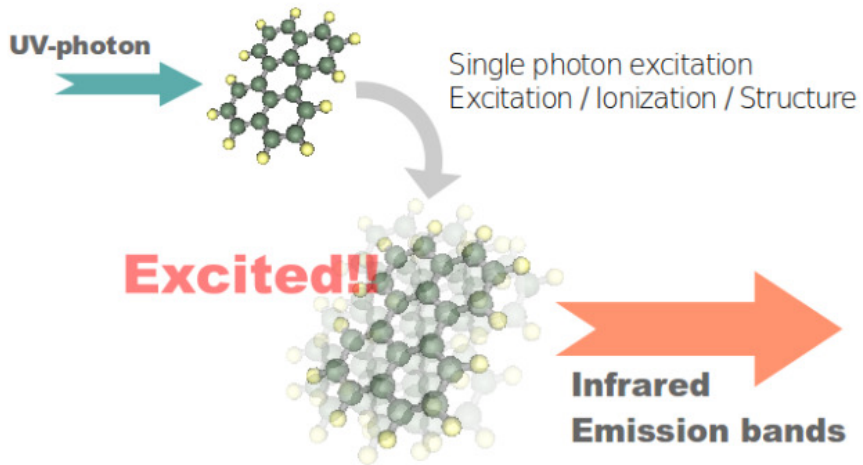
PAHの性質は観測にどのようにしてあらわれるか

## 3-Component Dust Model

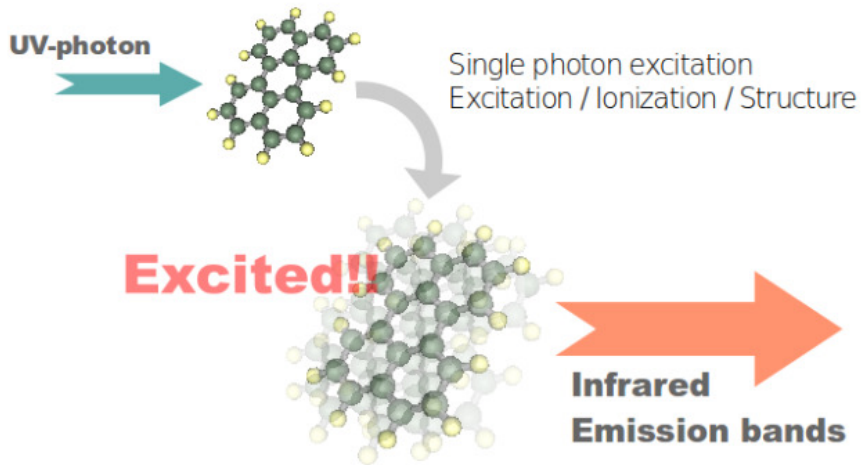


(Désert et al. 1990)

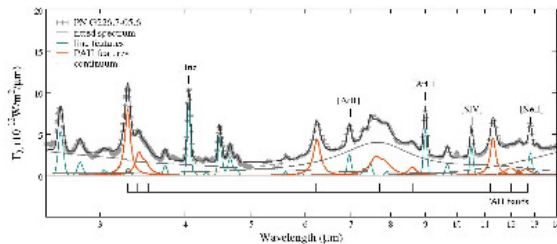
## PAH excitation



## PAH excitation



## PAHでISMの物理量を測る



- intensity  $\rightarrow I_{\text{UV}} \times N_{\text{PAH}}$
- excitation  $\rightarrow$  hardness of UV
- ionization  $\rightarrow I_{\text{UV}}/n_{e^-}$

PAHの異なるバンドの組み合わせることで、  
ISMの輻射環境を調べることができる

# Ground-based Observations

advantages of ground-based observations

高い空間分解能

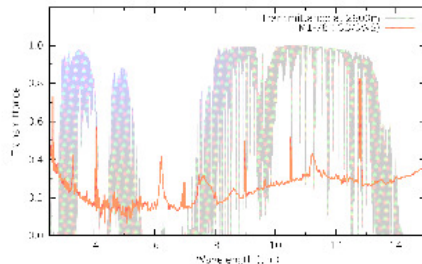
⇒ **個々の天体を分解**して物理環境を議論できる

衛星による高感度観測にたいして**相補的**

available bands in ground-based observations

L: 3.3, 3.4, & 3.5  $\mu\text{m}$  bands

N: 8.6, 11.0, & 11.3  $\mu\text{m}$  bands

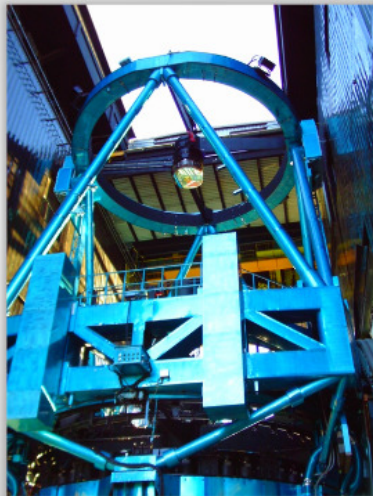




# すばる望遠鏡 COMICS による観測

- 中間赤外線分光・撮像装置 (N,Q)
- 高い空間分解能
  - FWHM~0.4" at 10 $\mu$ m
- narrow, middle-band filters
- N-band low-resolution spectroscopy
  - PAH の研究に適した構成

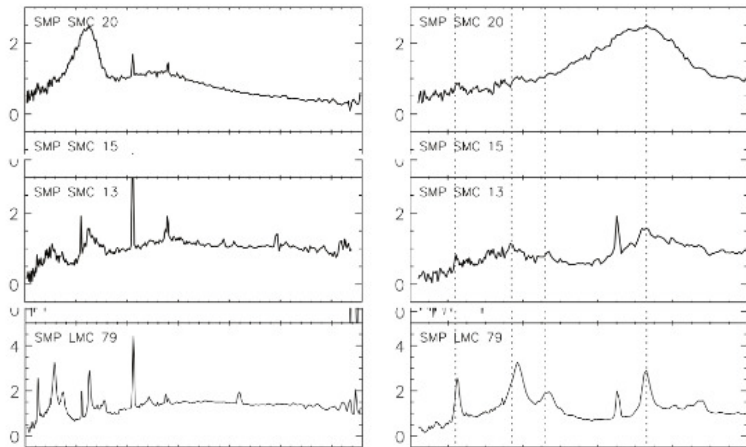
系内の天体を空間分解して観測,  
PAH emission と物理環境を結びつける



# Results

- Planetary Nebula: PNG095.2+00.7  
PAH intensity  $\rightarrow$  UV opacity
- Compact HII Region: M1-78  
PAH ionization  $\rightarrow$  UV intensity

## MIR evolution (post-AGB $\rightarrow$ PN)

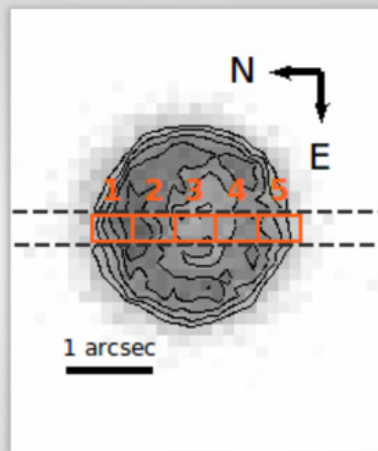


the Spitzer/IRS spectra of PNe in the Large and Small Magellanic Clouds  
Stanghellini, et al. (2007)

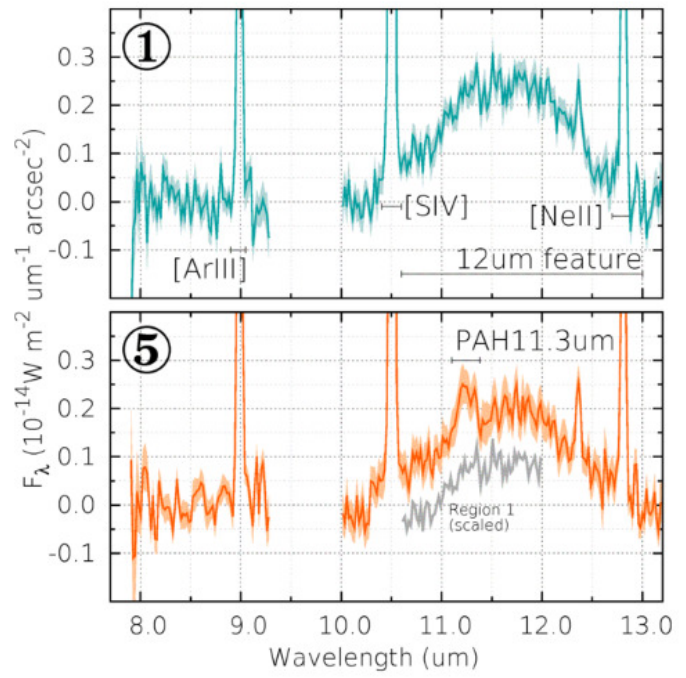
# PN G095.2+00.7

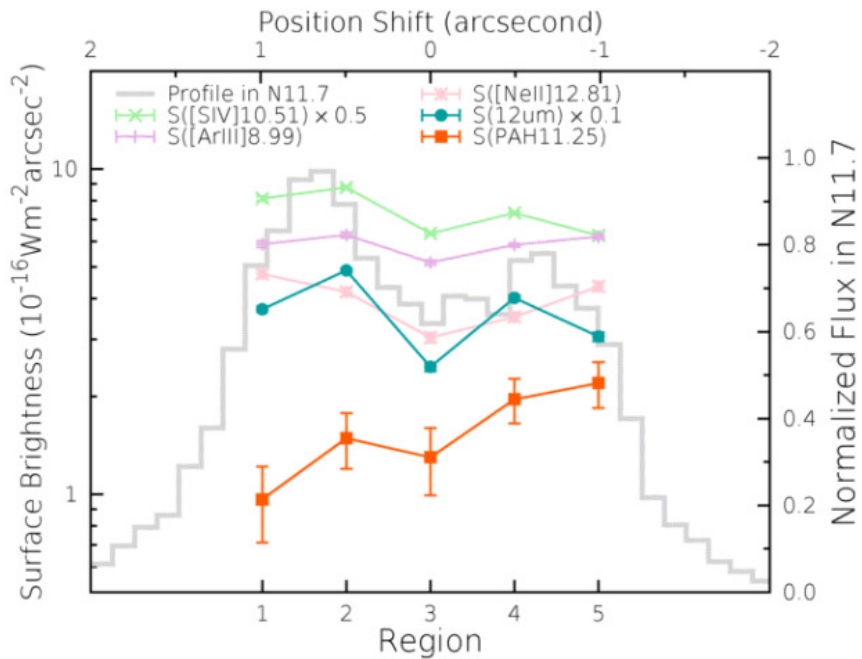
C-rich planetary nebula  
shell-like morphology

- $T_{\text{eff}} \simeq 58,000 \text{ K}$  (Lumsden+ 2001)
- $\theta = 1.3''$  (Aaquist & Kwok 1990)
- $d = 2.3 \text{ Kpc}$  (Chan+ 1992)
- IRAS color:  $F_{25}/F_{60} \simeq 2.0$
- Age:  $t^{\dagger} \simeq 900 \text{ year}$



<sup>†</sup> dynamical age, (size/velocity)





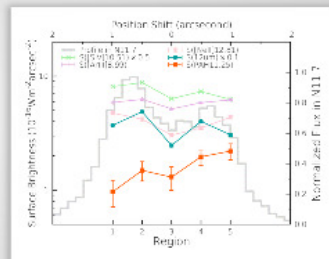
# Spatial Distribution of PAH emissions

星周物質の分布は shell-like, PAH 分布は not shell-like

- 南側は北側よりも PAH 放射が 2 倍以上強い
- intrinsic な分布の違いとは考えにくい
- PAH が破壊されたような兆候もない

シェルの南北で UV intensity が異なっている

- PAH emission は UV intensity に比例
- 星周物質の濃度は南北で 10% 程度の差
- 観測結果は UV thick ( $A_v \sim 3$ ) な環境を示唆
- 可視の観測から推定された  $A_v$  は 4.3 程度 (Abazajian+ 2009, Dobashi 2011)



PNG095.2+00.7 の PAH emission 分布は  
UV opacity の違いによって説明できる

赤外では optically thin  $\leftrightarrow$  紫外では optically thick

post-AGB ~ PN における赤外スペクトル進化に  
UV opacity の変化が関わっている可能性を示唆

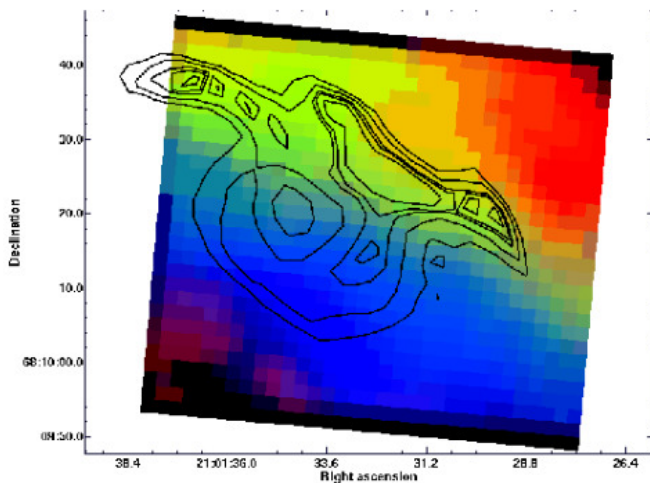
若くサイズの小さい星雲  $\Rightarrow$  UV thick, 高温ダスト  
進化, 星雲の膨張  $\Rightarrow$  UV thin, PAH excited, ダスト冷える

(Ohsawa+ 2012)



# NGC 7023

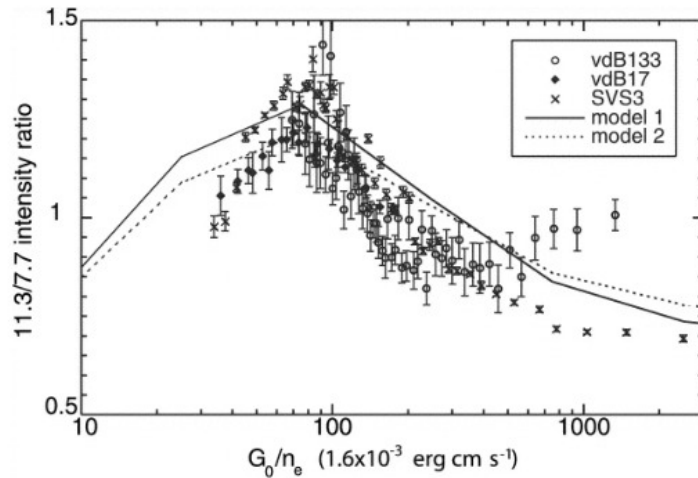
Berné et al. (2007)



blue: ionized PAHs, green: neutral PAHs, red: VSGs

# Reflection Nebulae

Bregman et al. (2005)

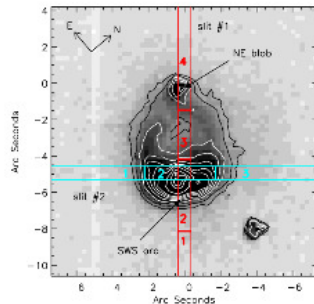


11.3/7.7: neutral/ionized ratio,  $G_0/n_e$  ionization parameter

# M1-78

compact H<sub>II</sub> region

- $\theta \sim 10''$
- $d \sim 8.9 \text{ Kpc}$  (beyond the Perseus arm)
- two ionizing sources (NE blob & SW arc)
- strong PAH emissions (ISO/SWS)
- hot dust emission  $\sim 10\mu\text{m}$

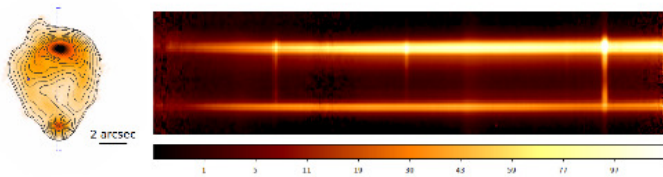


Martín-Hernández et al. (2008)

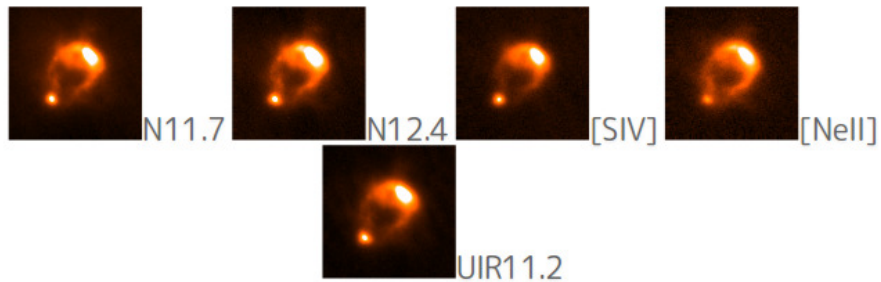
PAH と輻射の interaction を研究するのに適した天体  
NE blob の素性がわかっていない (WR star?)

# Results

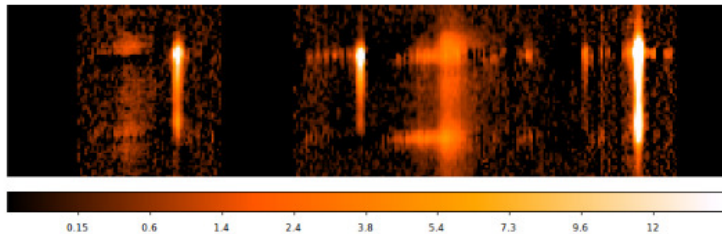
## 2-dimensional spectrum



## Images



## Continuum Subtracted



	8.6 $\mu\text{m}$	[SIV]	11.0 $\mu\text{m}$	11.2 $\mu\text{m}$	[NeII]
SW arc	✓	✓	✓	✓	✓
Center	?	✓	✓?	✓	✓
NE blob	?	—	✓	✓	?

# Ionization Parameter

## Photo-ionization against Recombination

PAH ionization is controlled by  $U/n_e$  (Bakes et al. 2001).

We approximate  $U$  and  $n_e$  as

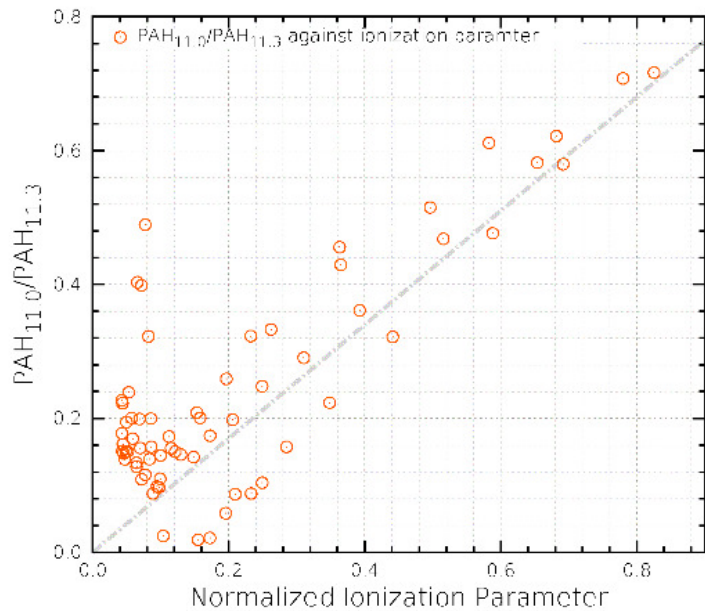
$$U \propto \frac{L_{\text{NE}}}{(r - r_{\text{NE}})^2 + \delta r^2} + \frac{L_{\text{SW}}}{(r - r_{\text{SW}})^2 + \delta r^2}$$
$$n_e \propto \sqrt{I(\text{Br}\gamma)}$$

$L_{\text{NE}}, L_{\text{SW}}$ : luminosities of ionizing stars in NE blob and SW arc, respectively.

$r - r_{\text{NE}}, r - r_{\text{SW}}$ : distances from NE blob and SW arc, respectively.

$\delta r$ : artificially included to avoid a zero-division.

# PAH Ionization



PAH

●

●

○

○

0.4

0.2

0.0

PAH<sub>110</sub>/PAH<sub>113</sub>

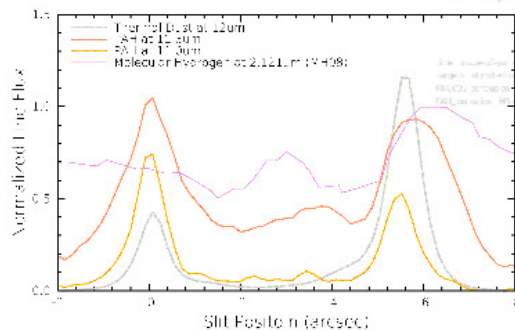
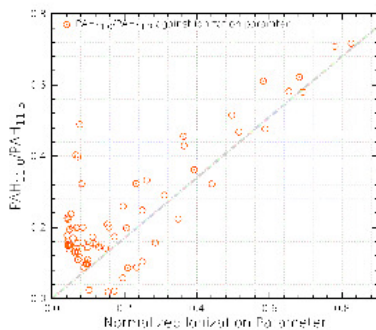
0.0

0.2

0.4

# PAH Ionization

- PAH11.0/11.3 $\mu$ m ratio は PAH ionization をトレース
- M1-78 の結果は  $L_{NE} : L_{SW} \simeq 1 : 2.5$  を示唆
  - M1-78 の輻射環境は SW が支配的という先行研究と矛盾しない
  - PAH emission から励起源の luminosity を推定できる



Thank you for your time!!



## Blind Signal Separation method

2D spectrum is decomposed by  $S = T \times A$ , where

$S$ : 2-dimensional spectrum array ( $n \times \lambda$ )

$T$ : template array ( $k \times \lambda$ )

$A$ : coefficient array ( $n \times k$ )

$n$ : slit position,  $\lambda$ : wavelength,  $k$ : number of components

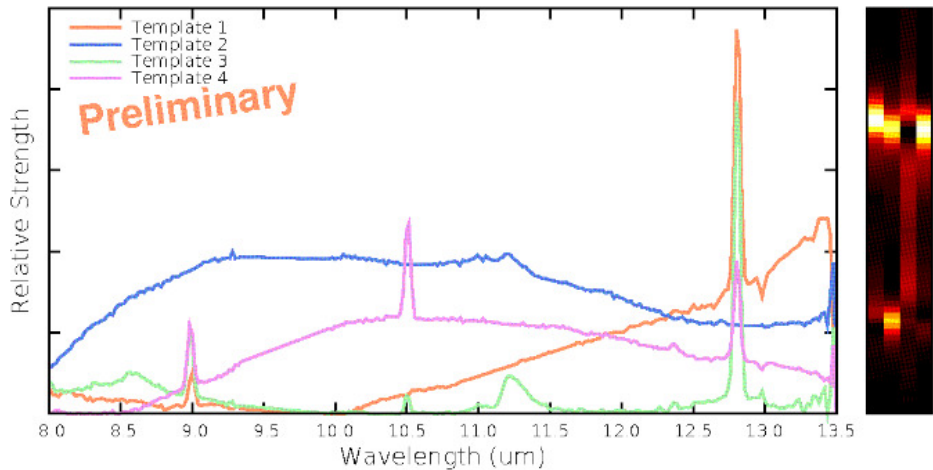
$T$  and  $A$  are obtained by minimizing

$$\chi^2 = \sum_{n,\lambda} \frac{(S_{n,\lambda} - (TA)_{n,\lambda})^2}{\sigma_{n,\lambda}^2} + a \sum_{k,\lambda} T_{k,\lambda}^2 + b \sum_{n,k} A_{n,k}^2,$$

under  $T_{k,\lambda} > 0$  and  $A_{n,k} > 0$  ( $\forall n, k, \lambda$ ).

# BSS decomposition

## non-negative signal separation



# Summary

## Investigation of PAHs based on ground-based observations

- PN, H<sub>II</sub> region を Subaru/COMICS で観測
- PAH emission の空間的な変化を調べた

### PN G095.2+00.7

- PAH emission の強度分布を UV intensity の違いから説明
- PN の赤外スペクトル進化に UV opacity が強く関わっている可能性を示唆

### H<sub>II</sub> region, M1-78

- PAH11.0/11.3 μm ratio は PAH 電離度のよい指標になることを確認
- PAH の観測から励起源の luminosity を制限

PAH emission は星間環境のプローブとして活用できる

Thank you for your time!!

File: paheffects\_wavelength\_resolution2\_figures.pdf; parameters: groundBased filter  
wlen: standard4000; target: G095; spectra: F0505; F0505\_filters: F0505\_results  
F0505\_results; script: 202207\_0208M20C; target: H1-G; H1-G\_results: H1-G\_spectrum  
PAH\_results; H1-78; paheffects: H1-78; paheffects\_summary: summary