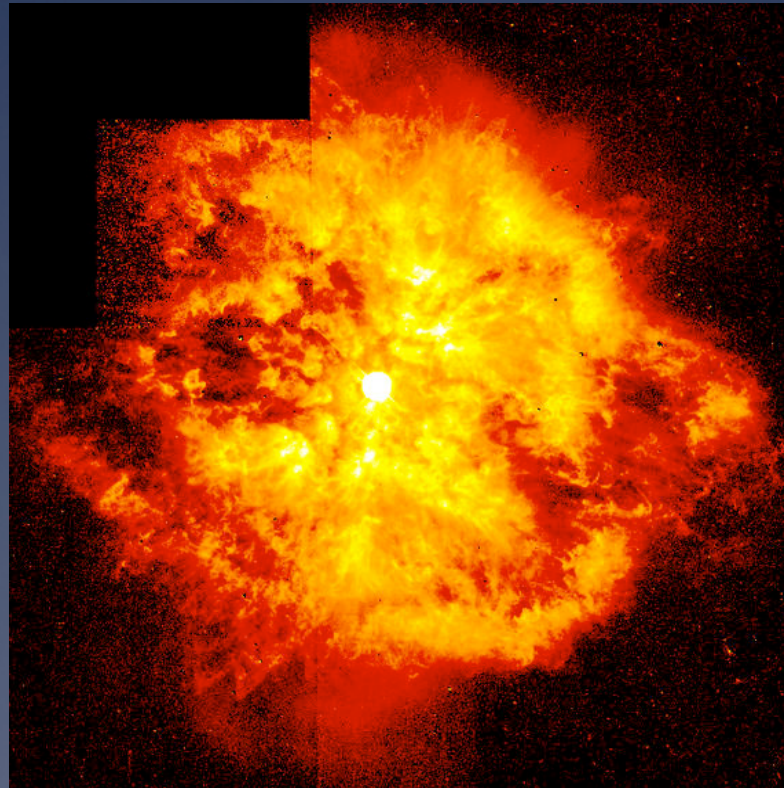


Investigation of Nature of Massive Star Cluster as the Progenitors of SNe by NIR Narrow-band Imaging Observation



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Co-I : Masuo TANAKA (IoA/UoT) 、 Shin-ichiro Okumura (JSGA)

1/26

1. 研究目的

- ❖ 星形成（領域）の形成と進化、IMF
- ❖ 星間物質や銀河進化に大きな影響を及ぼす大質量星の研究

❖ 大質量星：WR, LBV, YHG, RSG, BSG, OB*

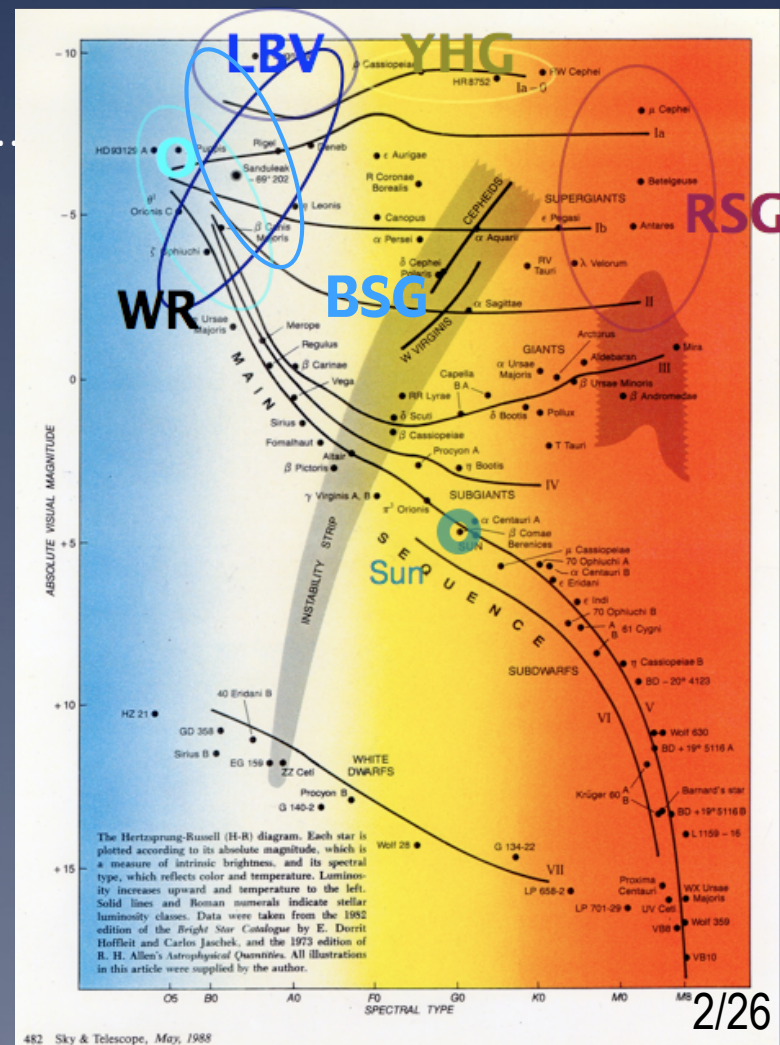
❖ WR星

- ・ 超新星の源
- ・ エネルギー、ダスト供給
- ・ 可視光の探索では、期待される数の
～10-20%しかない。（@銀河系内）

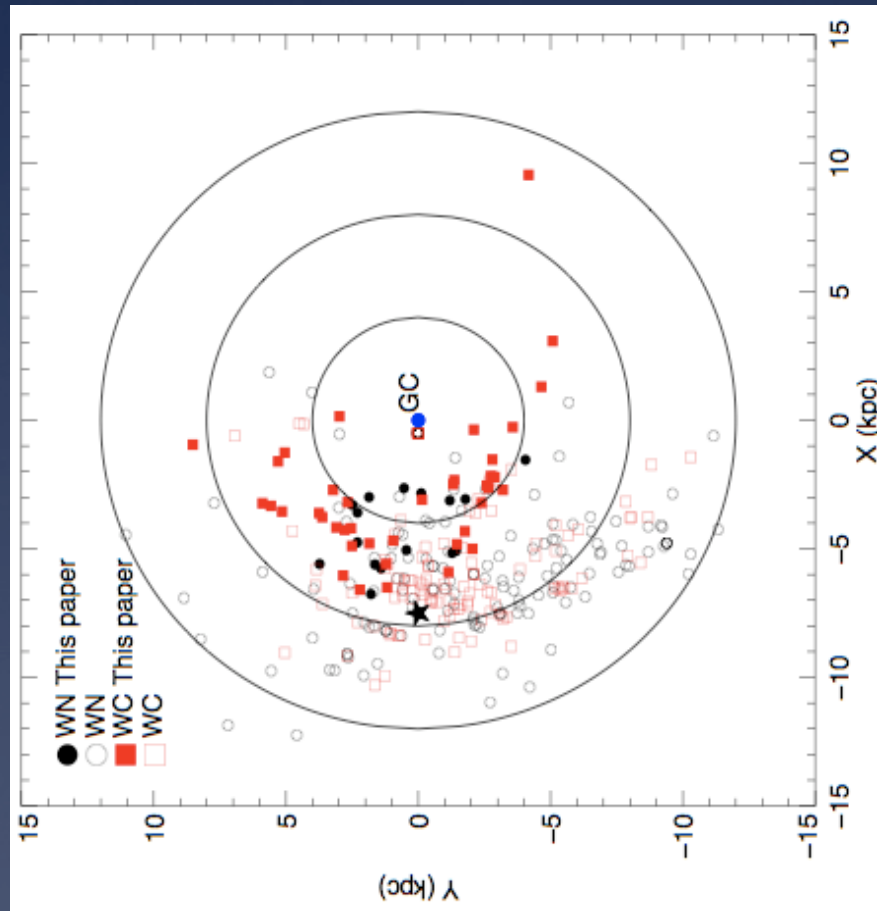
Extinction? Narrow survey?

❖ WC型WR星の探索

- ・ 減光が大きな領域（大質量星形成領域）
での赤外線による探索（現在進行中）
- ・ 広い領域の探索サーベイ（本提案）



1-2. Distribution of WR stars in Our Galaxy



Shara et al. 2011

$$N_{WR}(R) = \underbrace{N_{0,WR}}_{\text{Number density of WR}} \exp\left\{-\underbrace{(R - R_0)}_{\text{Radial distribution}} / \underbrace{\alpha_{WR}}_{\text{Radial distribution}}\right\}$$

Number density of WR

Radial distribution

R : Distance from GC

R_0 : Distance from GC to the Sun

Total number of WR within Galaxy ...

$$\Sigma_{WR}(<R) = \int_0^R N_{WR}(R') 2\pi R' dR'$$

$$\Sigma_{WR}(<R) \approx 6200 \{1 - (1 + R/1.66) \exp(-R/1.66)\}$$

for $N_{0,WR} = 2.87 \text{ kpc}^{-2}$, $\alpha_{WR} = 1.66 \text{ kpc}$

$$\Sigma_{WR}(<R) \approx 2500 \{1 - (1 + R/2.24) \exp(-R/2.24)\}$$

for $N_{0,WR} = 2.20 \text{ kpc}^{-2}$, $\alpha_{WR} = 2.24 \text{ kpc}$

in Current catalogue : 290WN + 10WN/WC + 227WC + 4WO = **531**

Shara et al. 2011, Mauerhan et al. 2011

small number... ↑

2. 観測手法（と成果）

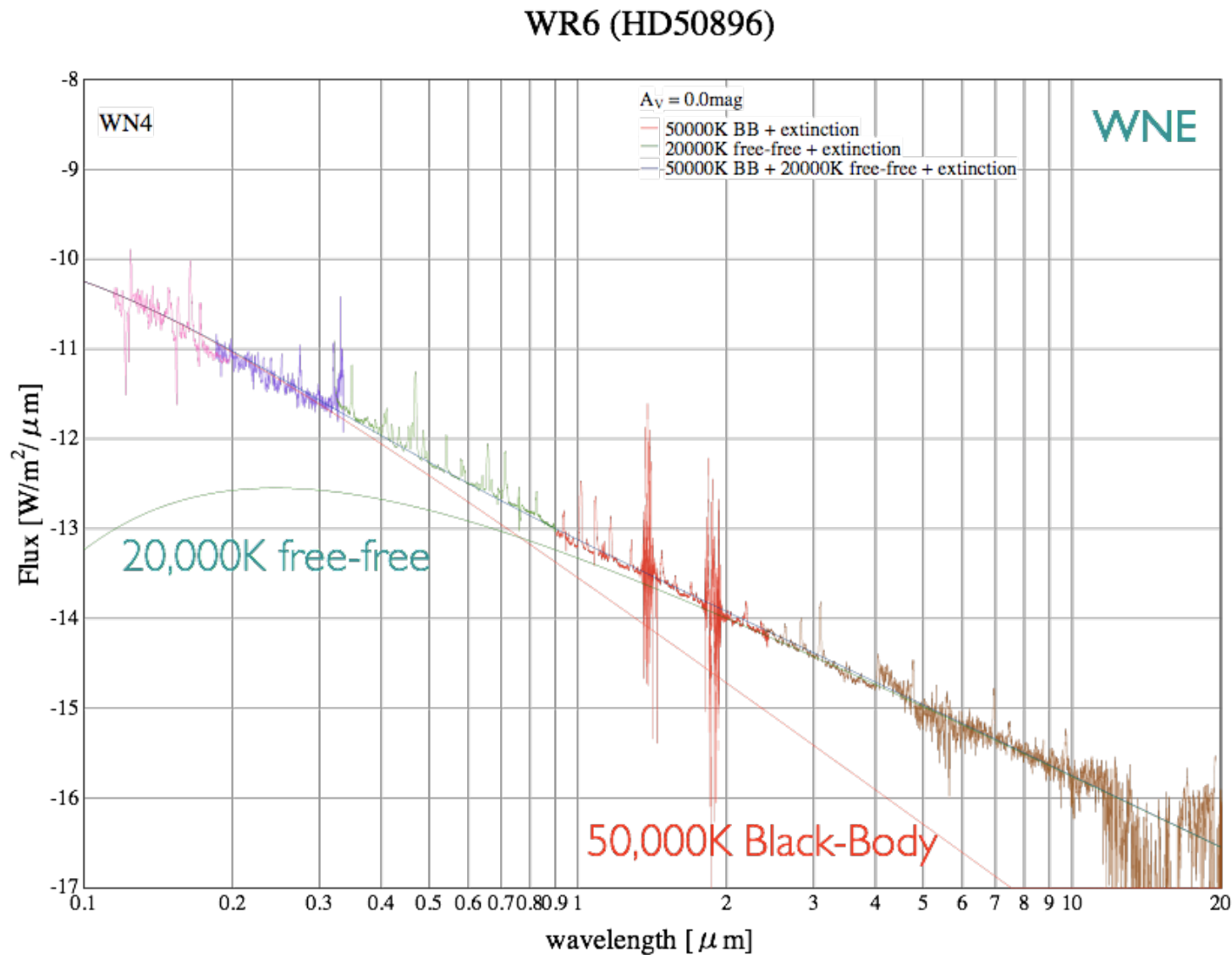
観測手法

- ❖ 大質量星に特徴的な輝線に着目
 - ❖ 狭帯域フィルター＋ブロードバンドフィルターを組み合わせたイメージング（分光）観測
 - ❖ 領域厳選探索サーベイ & 広域探索サーベイ
-

得られる（期待される）成果

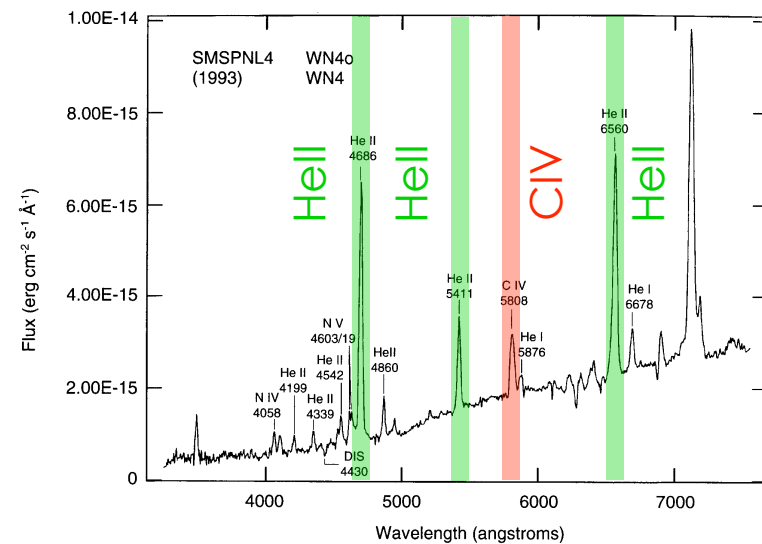
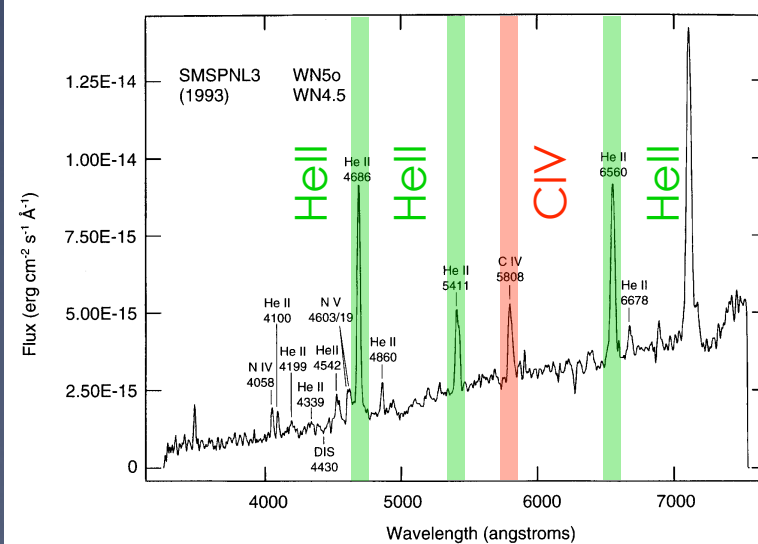
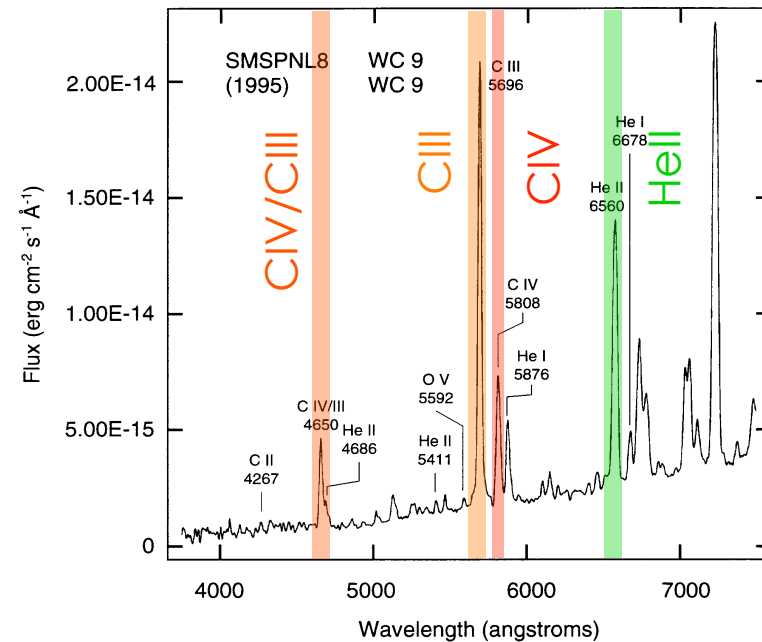
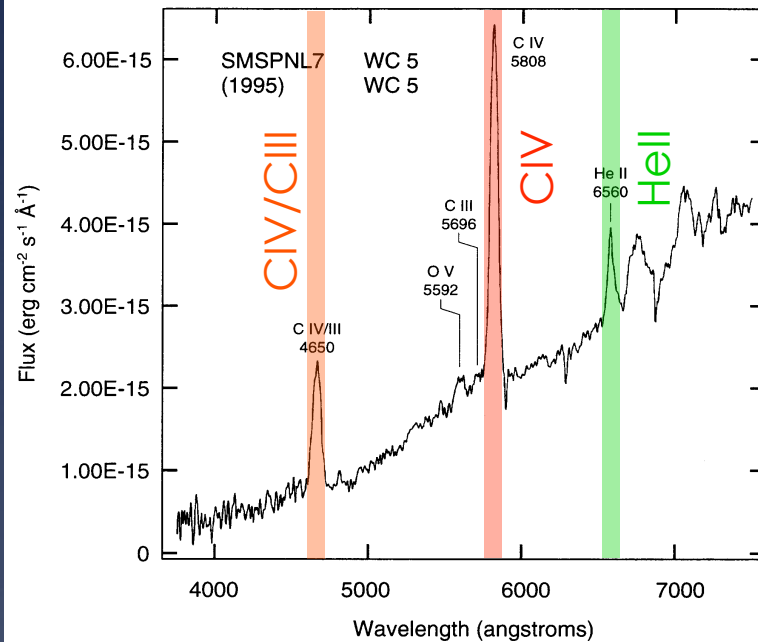
- ❖ 超新星母天体としての大質量星（WR星）の発見
- ❖ 星形成領域（大質量星クラスター）の星間減光
- ❖ 低質量星も含めた星形成領域全体のIMF：high mass endは？
- ❖ 大質量星の質量と年齢

3. Sample spectrum of WN/WR (wide range)

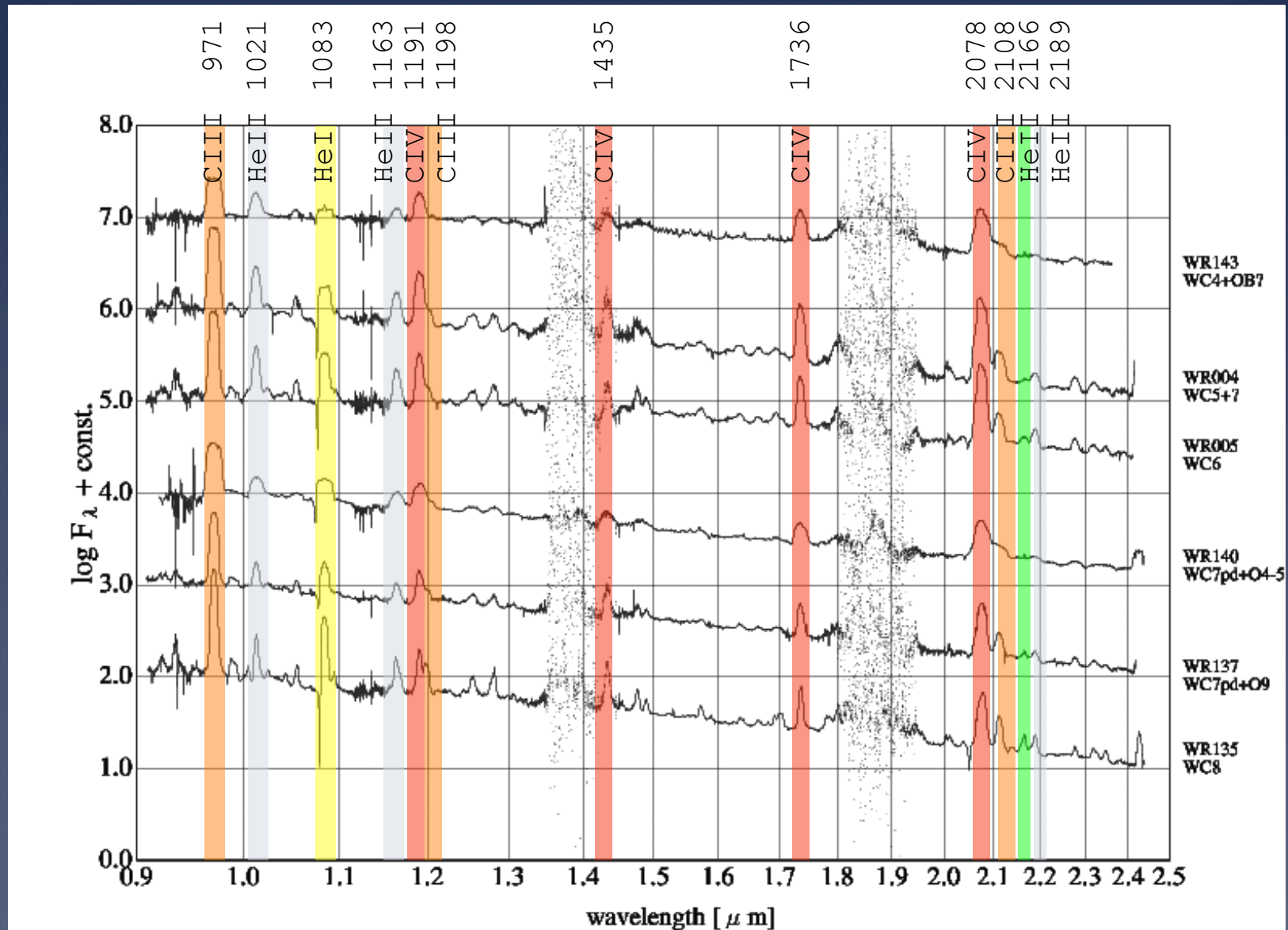


3. Sample spectrum of WN/WR (optical)

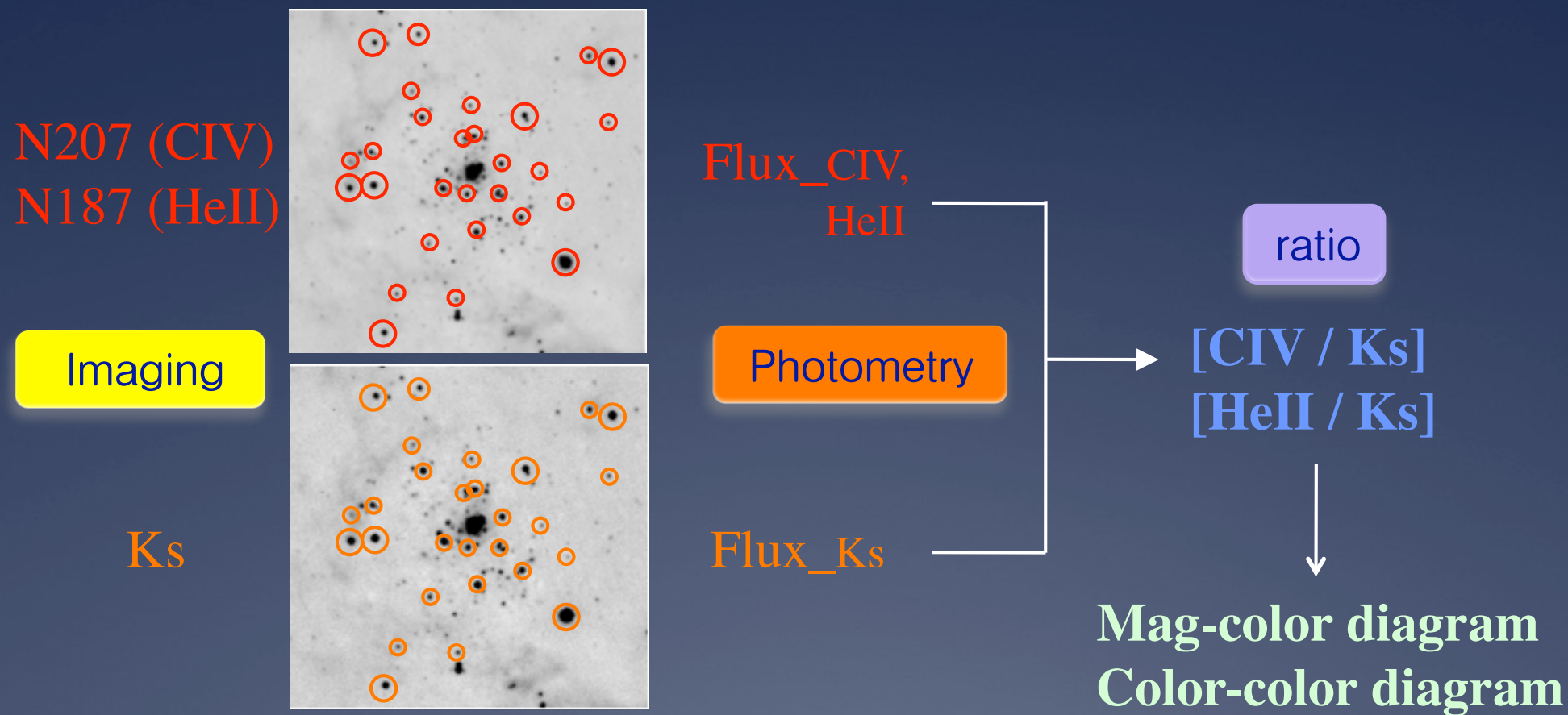
Shara et al. 1999



3. Sample spectrum of WN/WR (NIR)



4. 観測手法 ~ basic method



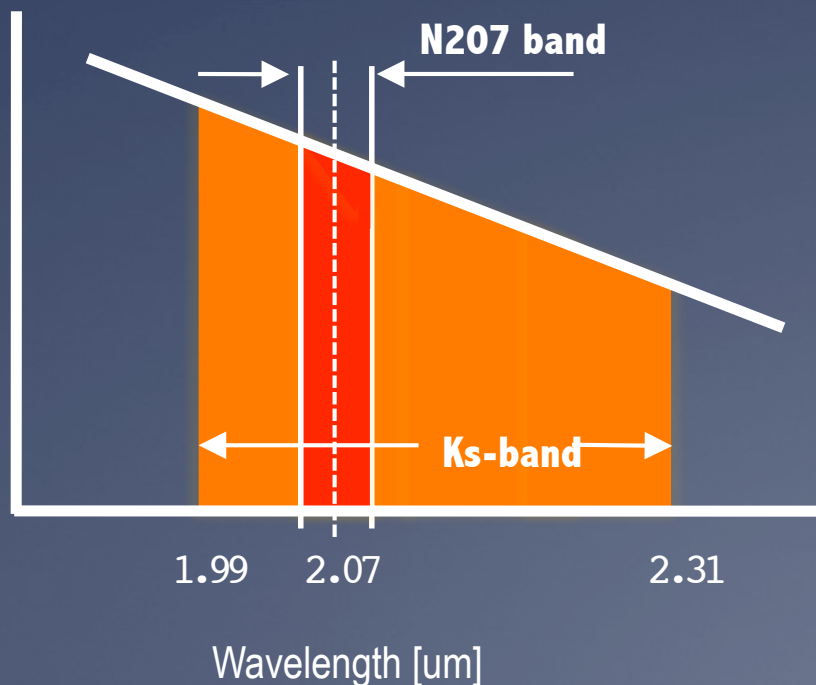
- : Many sources can be checked **simultaneously**.
- △ : **FOV is limited** by detector size and optical design.
- ▲ : **Spectroscopy is needed** after picked-up.

4. 観測手法 ~ with narrow-band

Comparing to N207-band (red area) and Ks-band (orange area)
[CIV/Ks] ratio becomes to be **large** for CIV emission stars ; early type WC/WR

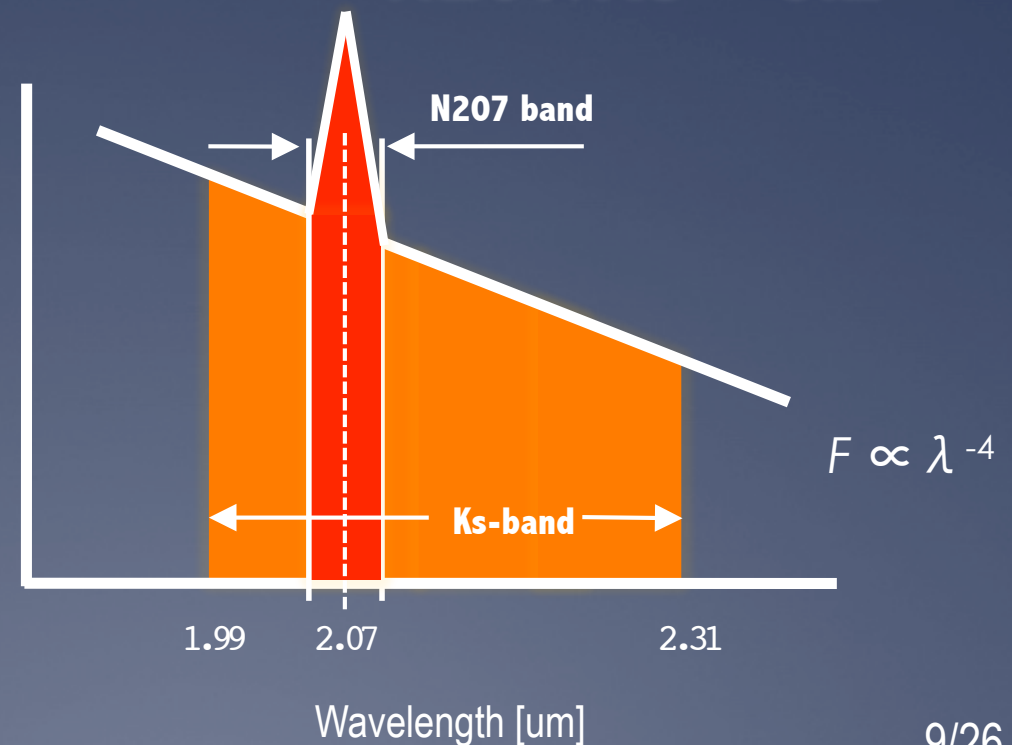
no CIV line object

→ **N207/Ks ~ 0.13**



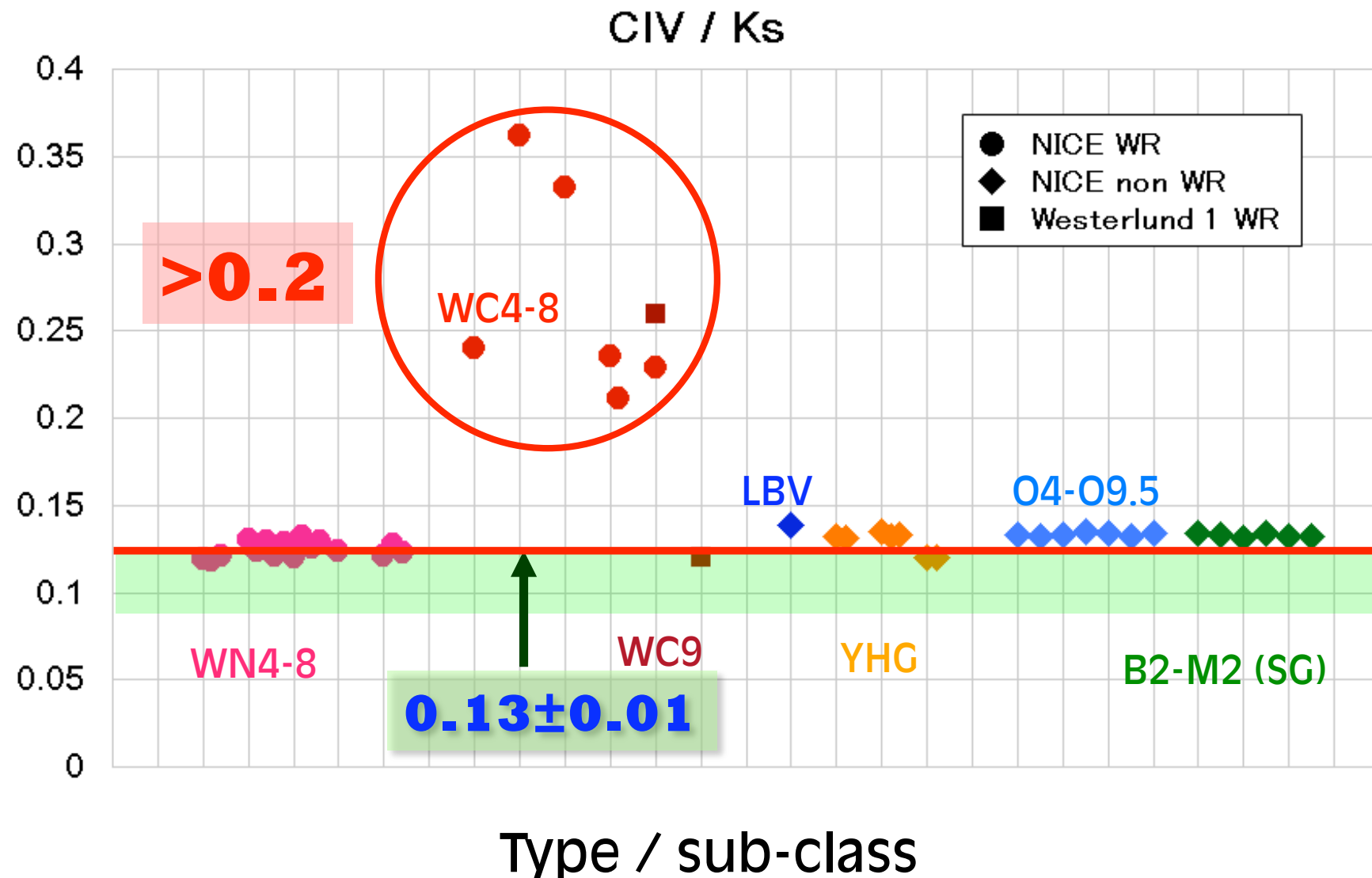
With CIV line object

→ **N207/Ks > 0.2**

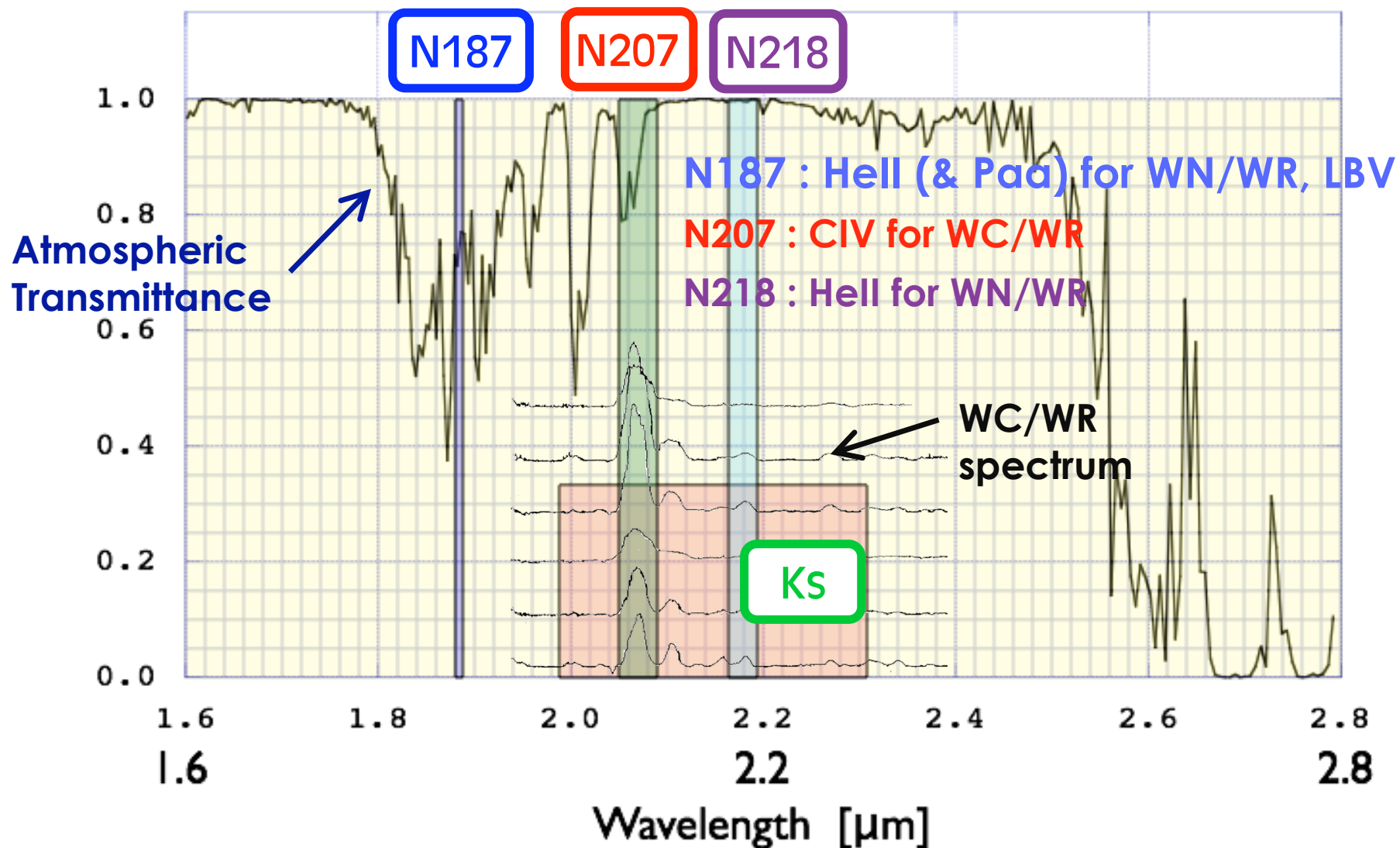


4. 観測手法 ~ with narrow-band

❖ [N207/Ks] ratio calculated from observed spectra by NICE



4. 観測手法 ~ unique filter system



5. 観測

Telescope : miniTAO (the University of Tokyo Atacama Observatory, Chile)

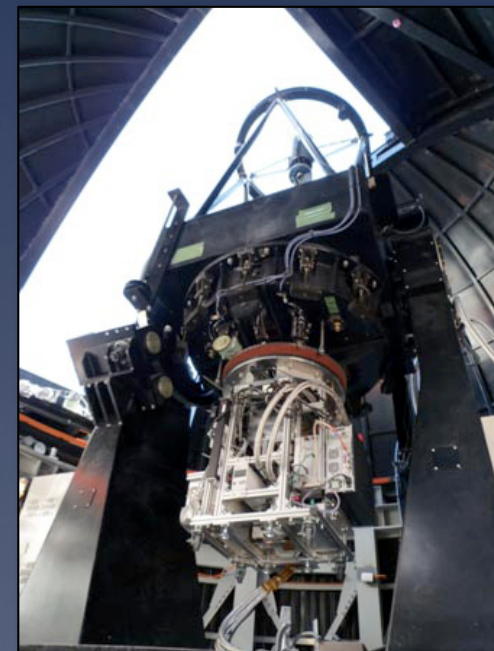
- ▶ 5640m Altitude → N187 (Paa)

Instrument : ANIR (Atacama Near-Infrared Camera)

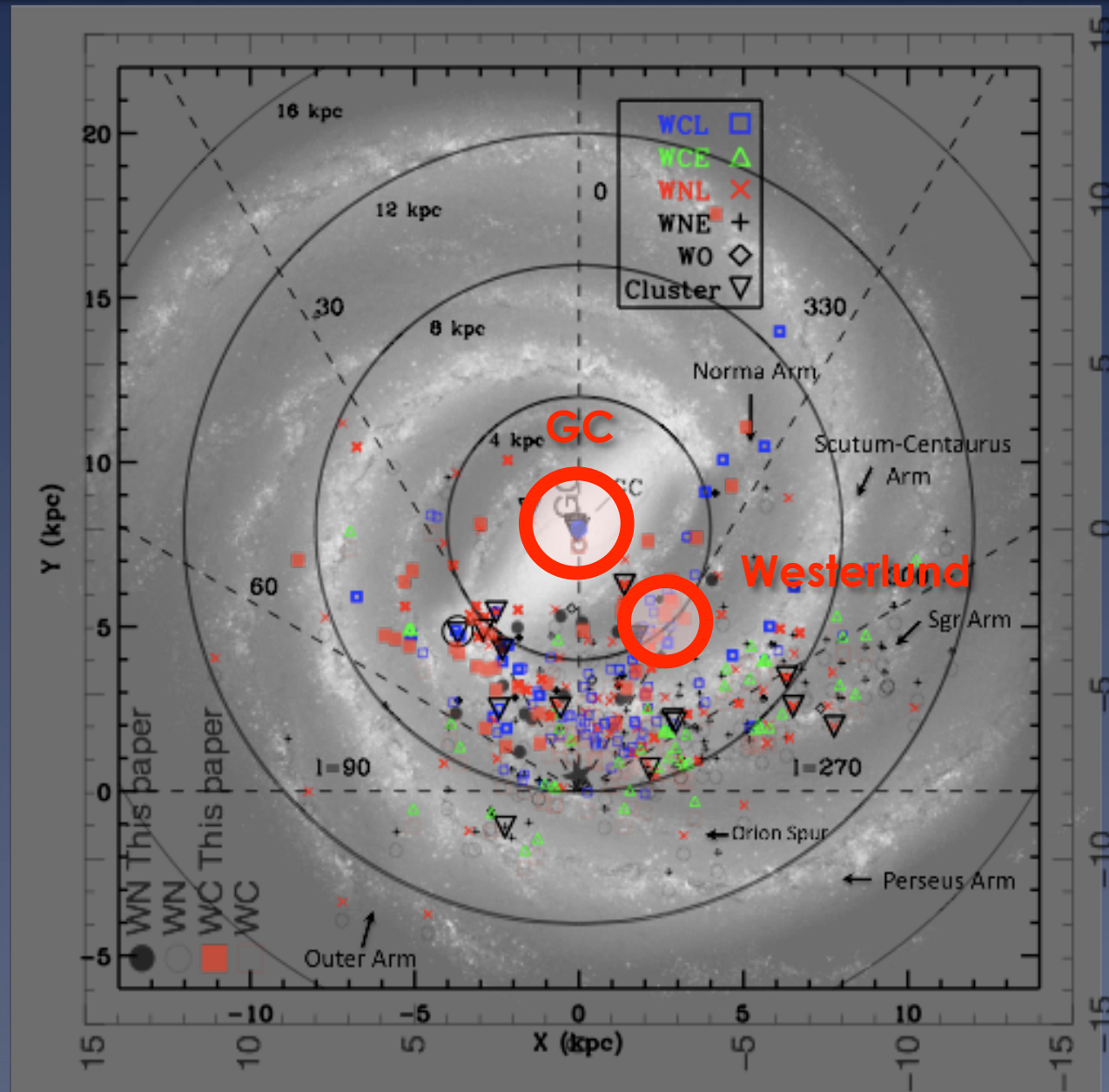
- ▶ Ks, N187 (Paa, Hell), N207 (CIV)
- ▶ HAWAII array (1024 x 1024), 0.3"/pix → 5'x5' FOV

Observation

- ▶ GC clusters (2009 Jun, 2011 Apr)
- ▶ LMC/30 Dor (2010 Oct, 2011 Oct, 2012 Nov)
- ▶ Westerlund 1 & 2 (2011 Apr/May)



6. 観測領域

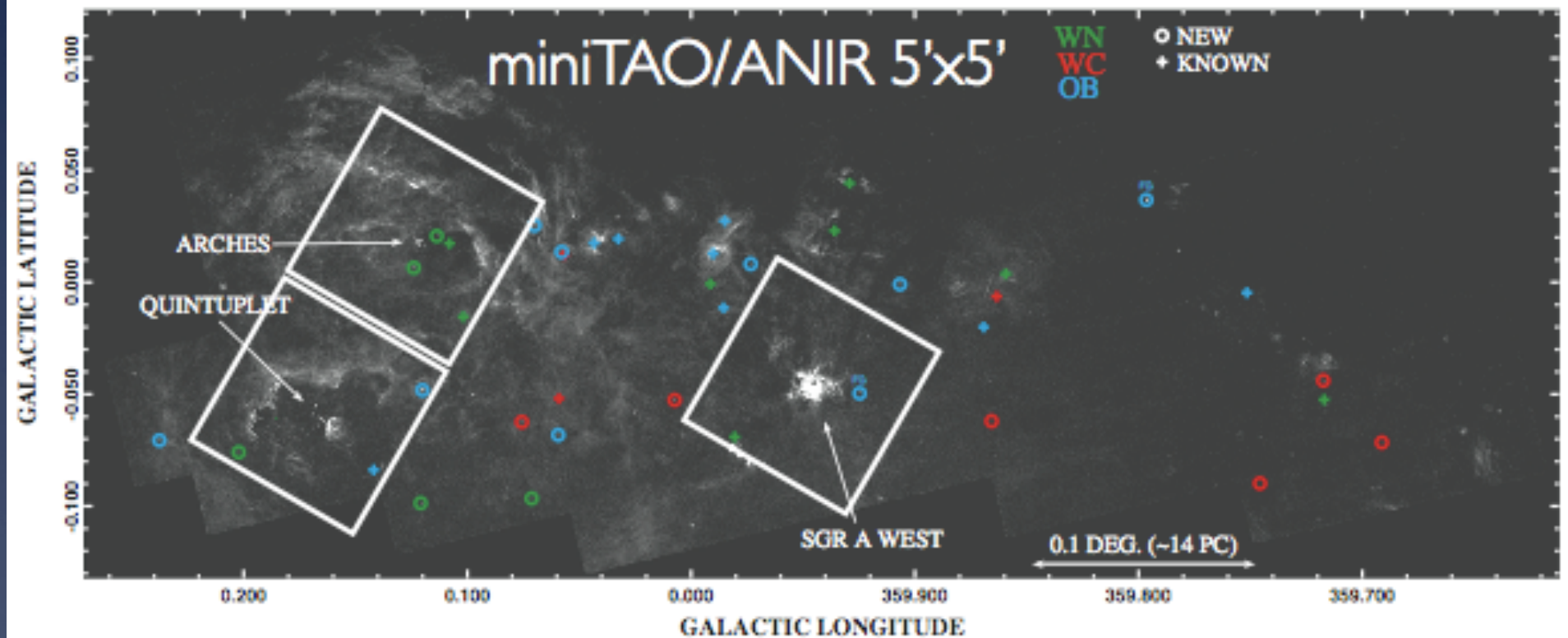


Shara et al.
2011

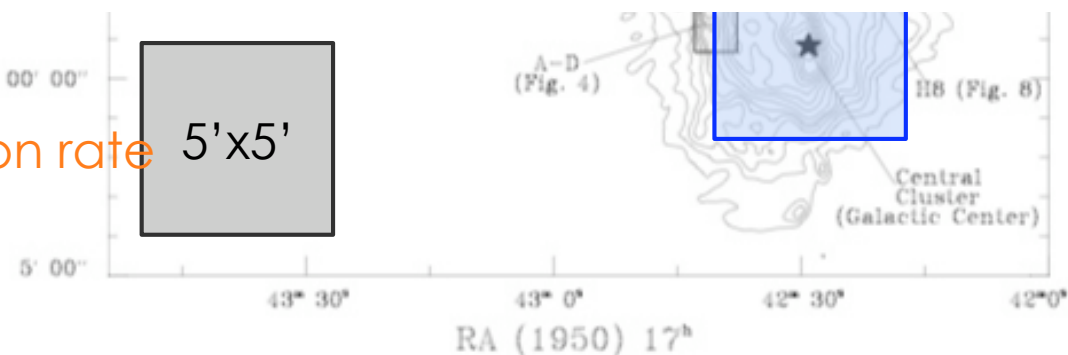
Mauerhan,
Van Dyk, &
Morris 2011

Figure 10. Galactic distribution of WRs and selected WR-bearing clusters plotted over the Galactic model of Churchwell et al. (2009). New identifications are marked as bold symbols. The figure axes are in units of kpc, with the location of the Sun at the origin. Dotted lines mark several values of constant Galactic longitude (l). The

7. Galactic Center Regions

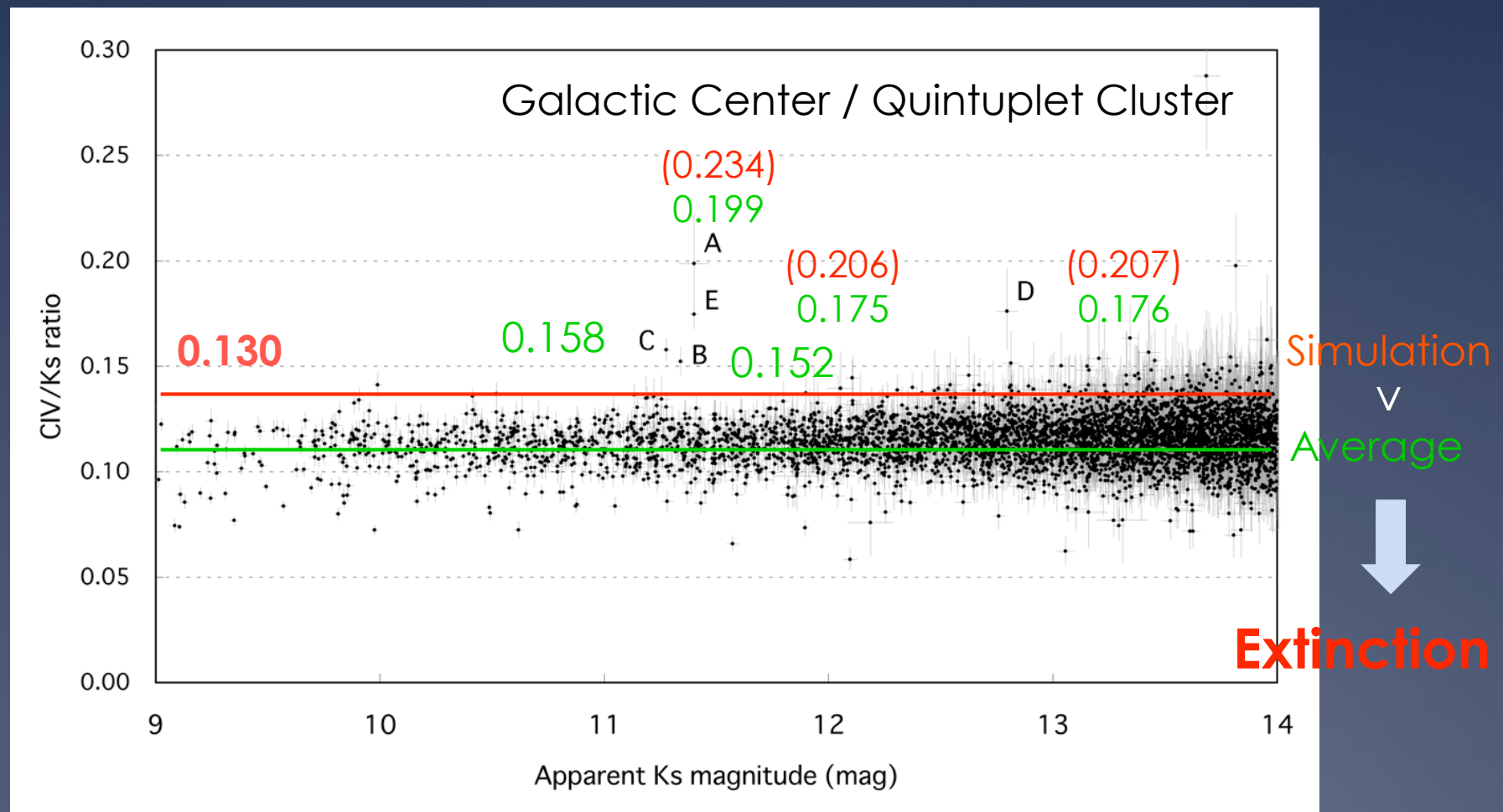


- High metallicity
- High starformation rate
- High extinction

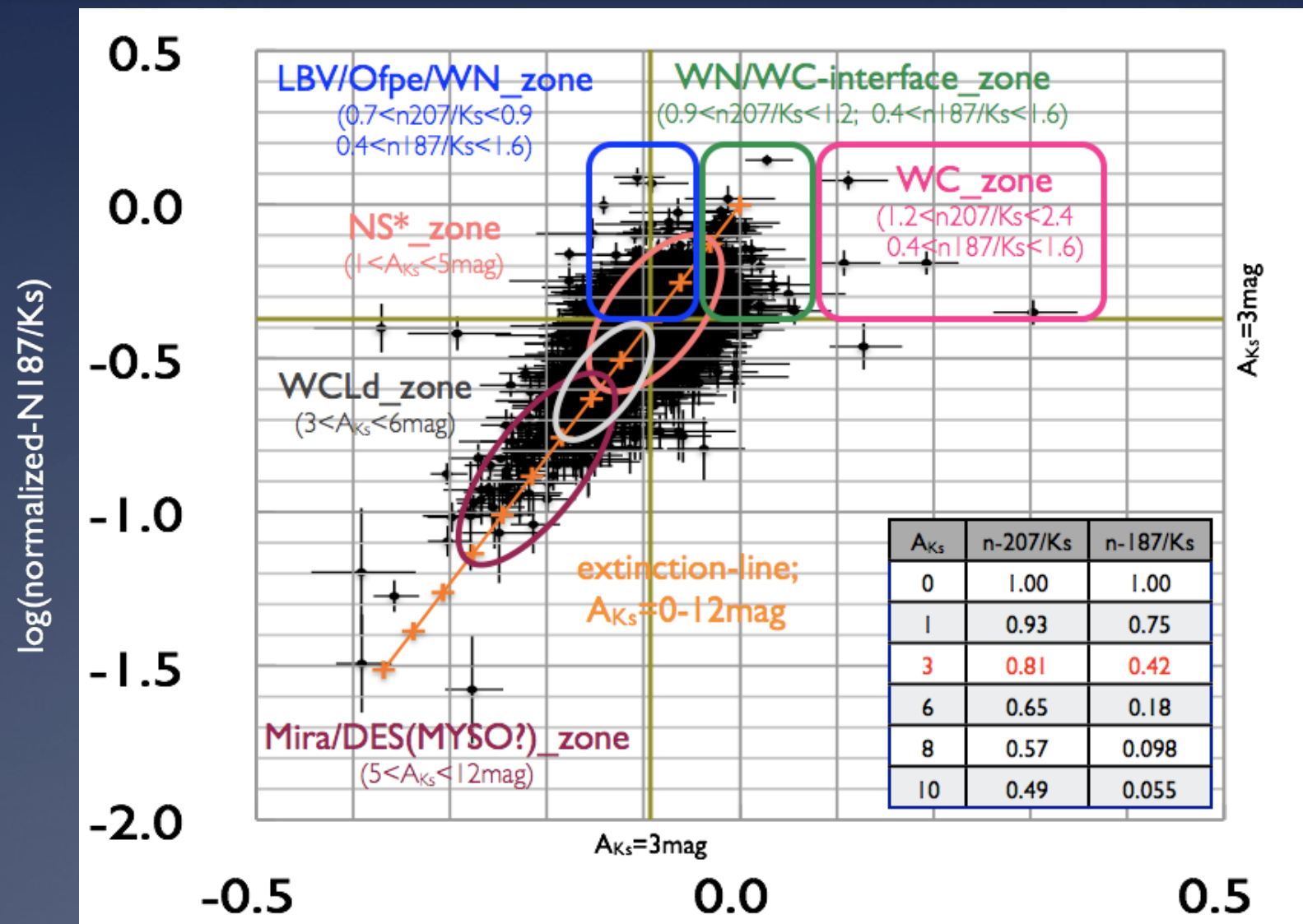


7-1. Galactic Center Regions : Color-Ks mag diagram

- ❖ excess天体 → WC型WR星 (既知 or 候補天体)
- ❖ simulation値と平均値の差 → extinction



7-2. Galactic Center Regions : N207-N187 Diagram for $A_{K_s}=3\text{mag}$

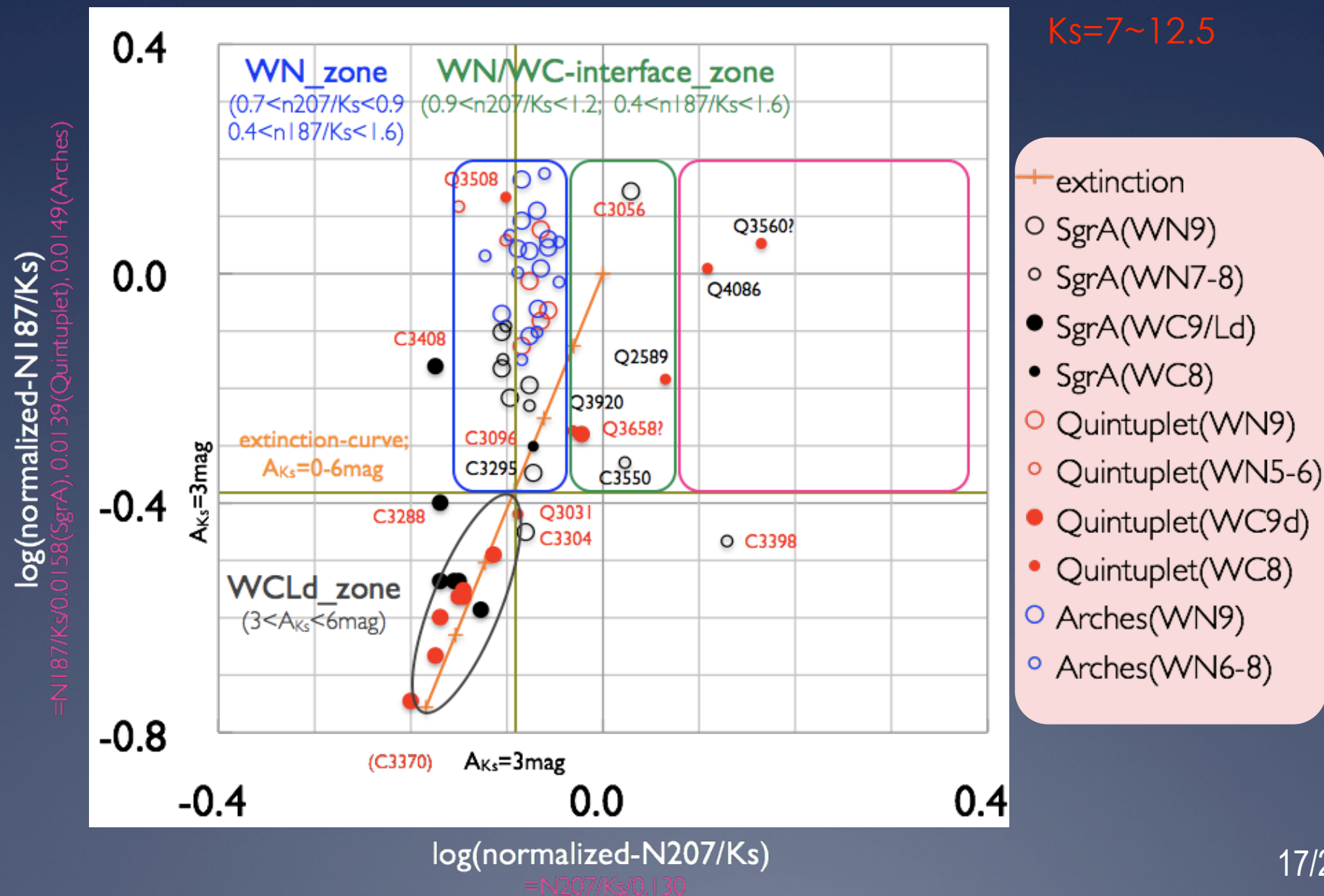


NS*: normal stars including RG/RSG

$\log(\text{normalized-N207/Ks})$

extinction line; $\log(\text{normalized-N207/Ks}) = -0.0307 A_{K_s}$, $\log(\text{normalized-N187/Ks}) = -0.126 A_{K_s}$

7-3. Galactic Center Regions : known WR stars



7-3. Galactic Center Regions : extinction map

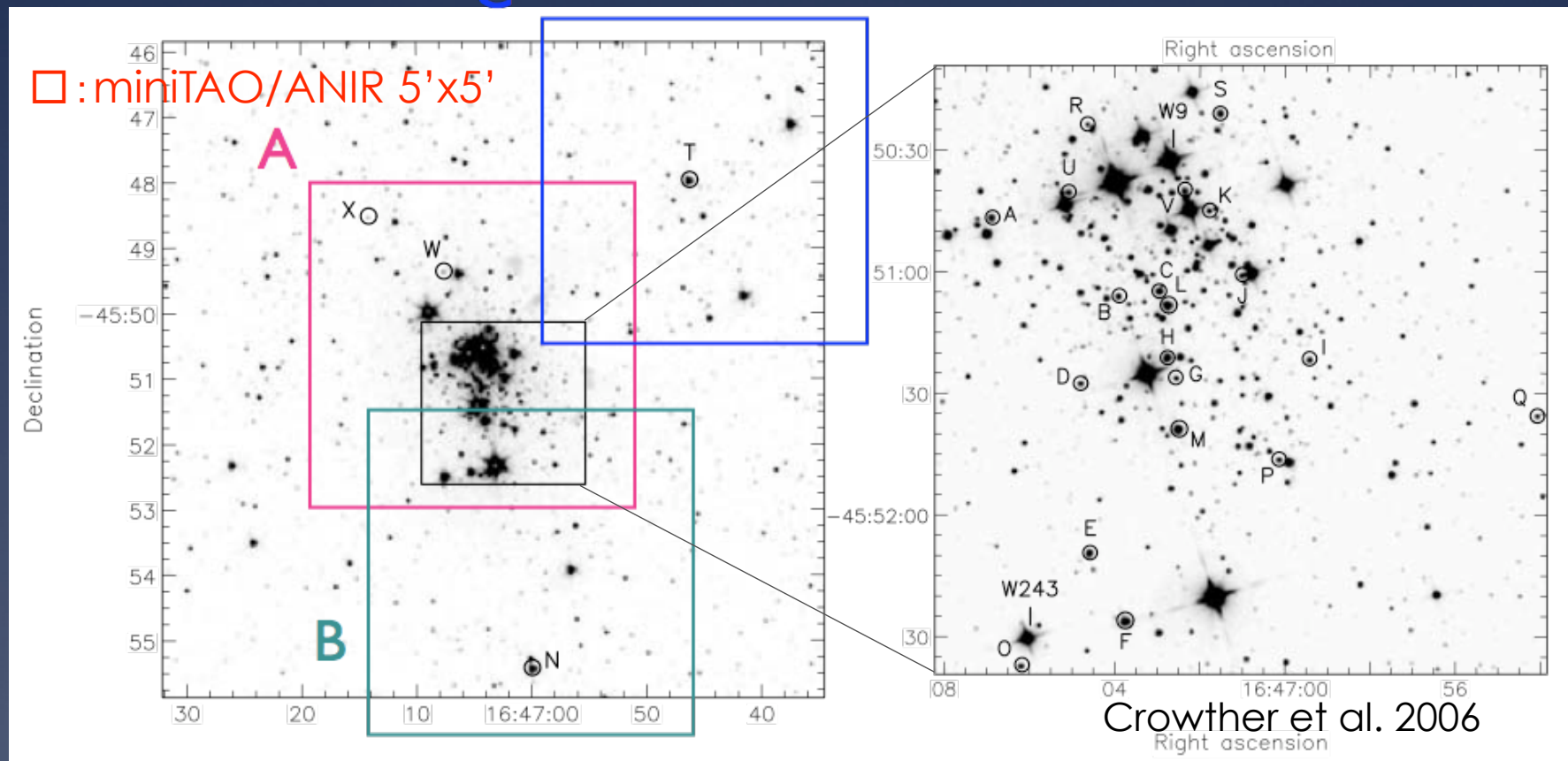
Distribution of A_{K_s} from N207/Ks in the Center Cluster area

total	3.12	3.59	3.56	3.28	3.07	3.13	3.37	3.06	2.73	3.20
900	3.19	3.74	3.26	2.23	3.32	2.93	2.94	2.64	2.76	2.99
800	3.67	3.03	3.04	2.69	2.83	2.46	3.01	3.12	2.33	2.88
700	2.99	3.47	3.64	3.33	2.23	3.08	3.21	2.94	2.29	3.02
600	3.21	3.28	3.42	3.98	2.95	3.22	3.26	2.81	2.67	3.26
500	3.09	3.81	4.22	2.90	2.86	3.18	3.93	2.69	2.50	3.13
400	2.83	3.98	3.41	3.51	3.47	2.88	3.23	3.44	3.07	3.25
300	2.53	4.29	5.06	4.68	3.09	3.58	3.32	2.90	2.30	3.32
200	3.43	4.34	4.19	3.92	4.74	4.30	4.24	3.69	3.53	4.00
100	2.42	3.33	3.86	4.23	4.70	2.65	3.35	4.16	3.29	3.48
XY	100	200	300	400	500	600	700	800	900	total

30" grid

8. Westerlund

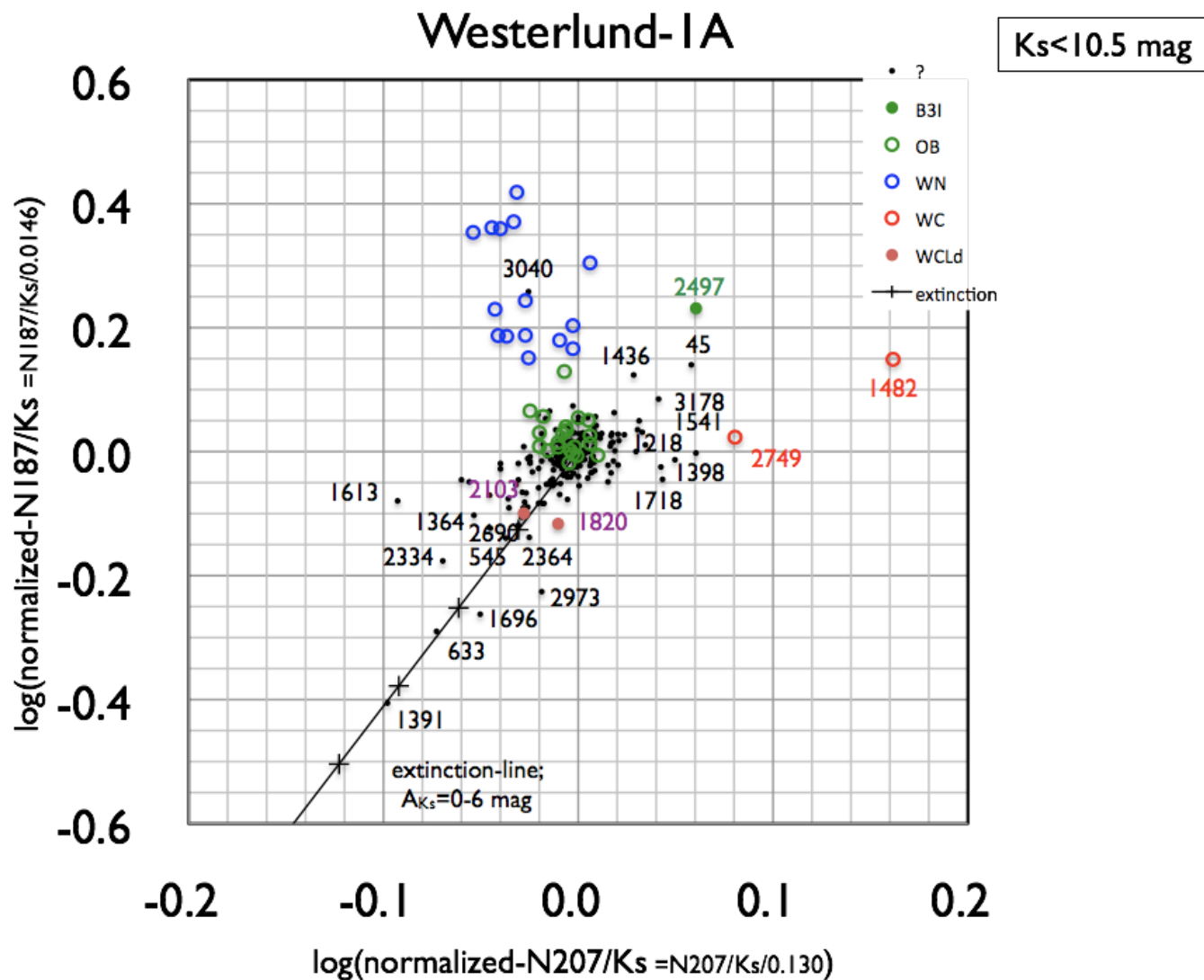
❖ 広い観測領域 (cf : Crowther et al. 2006)



- Many type of massive stars
- High metallicity
- Nearby Starburst cluster

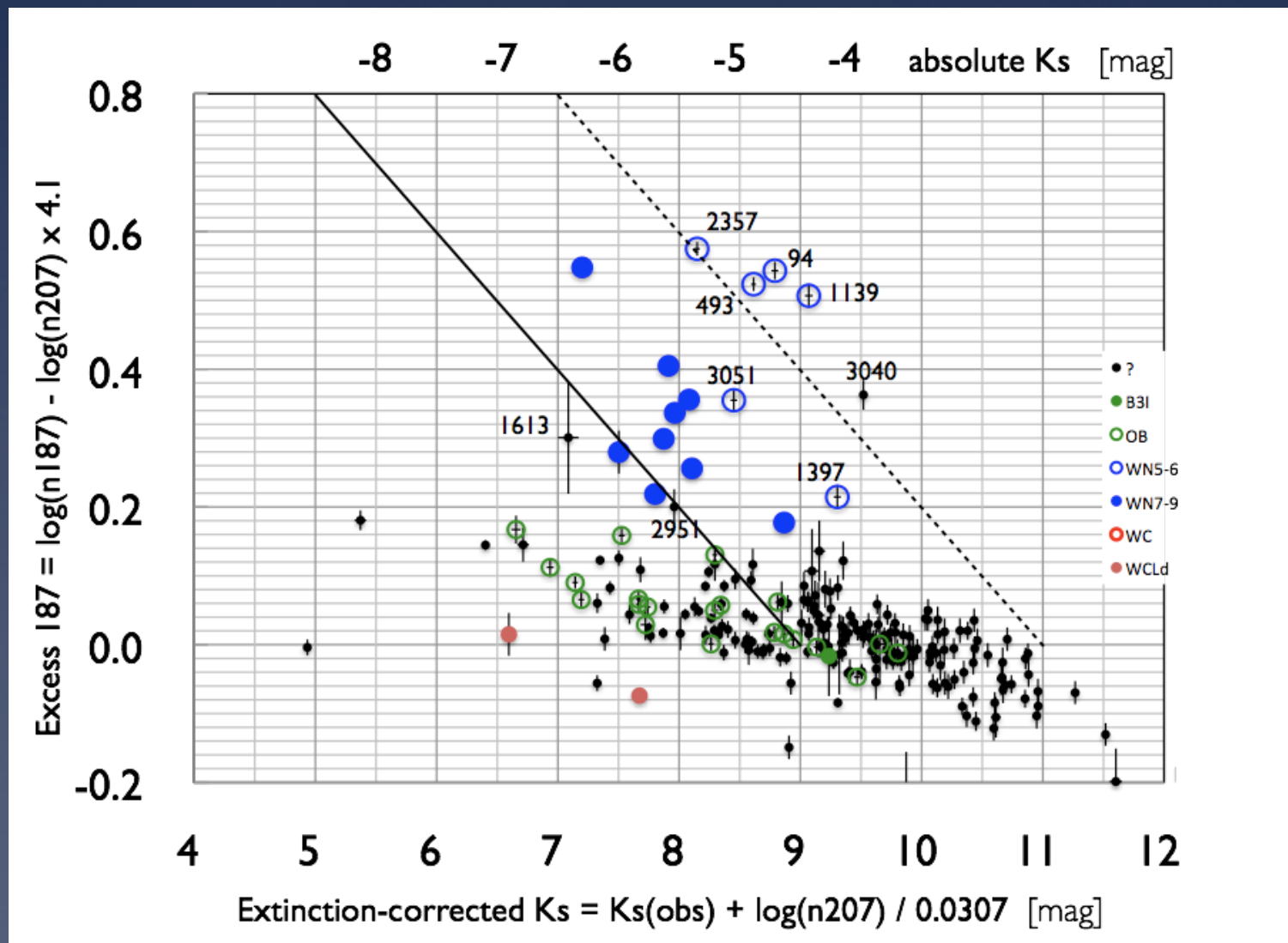
8-1. Westerlund : Color-color diagram

❖ 既知の天体の同定とzone分離



8-2. Westerlund : 187 Excess vs Ks mag

❖ WN型星はKsが明るいほどN187が超過

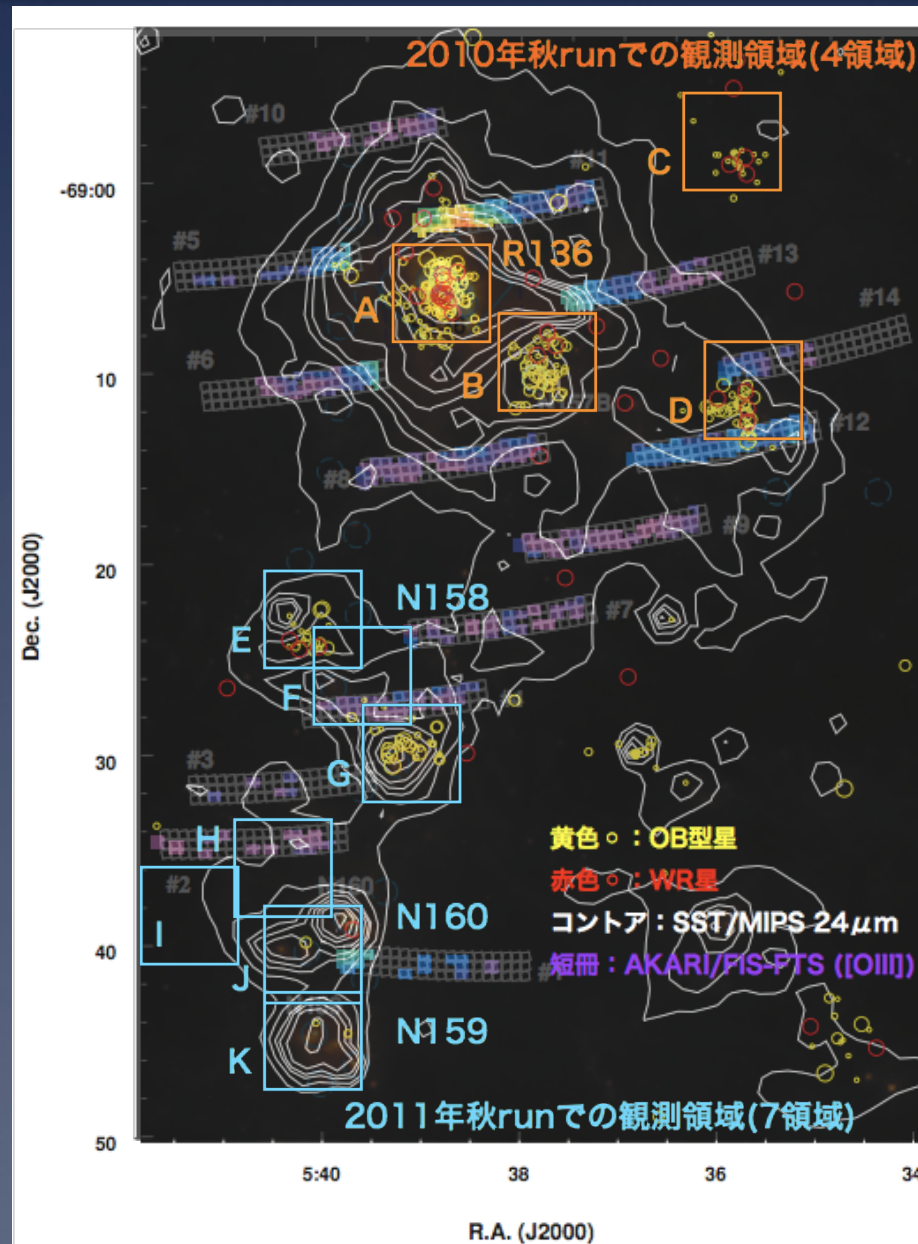


9. LMC/30Dor

old

Age / evolution

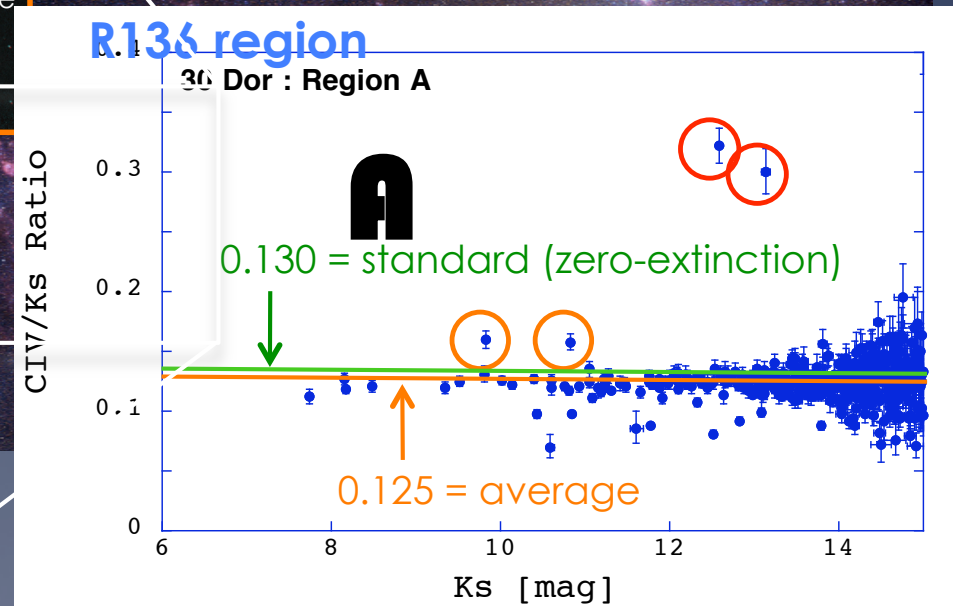
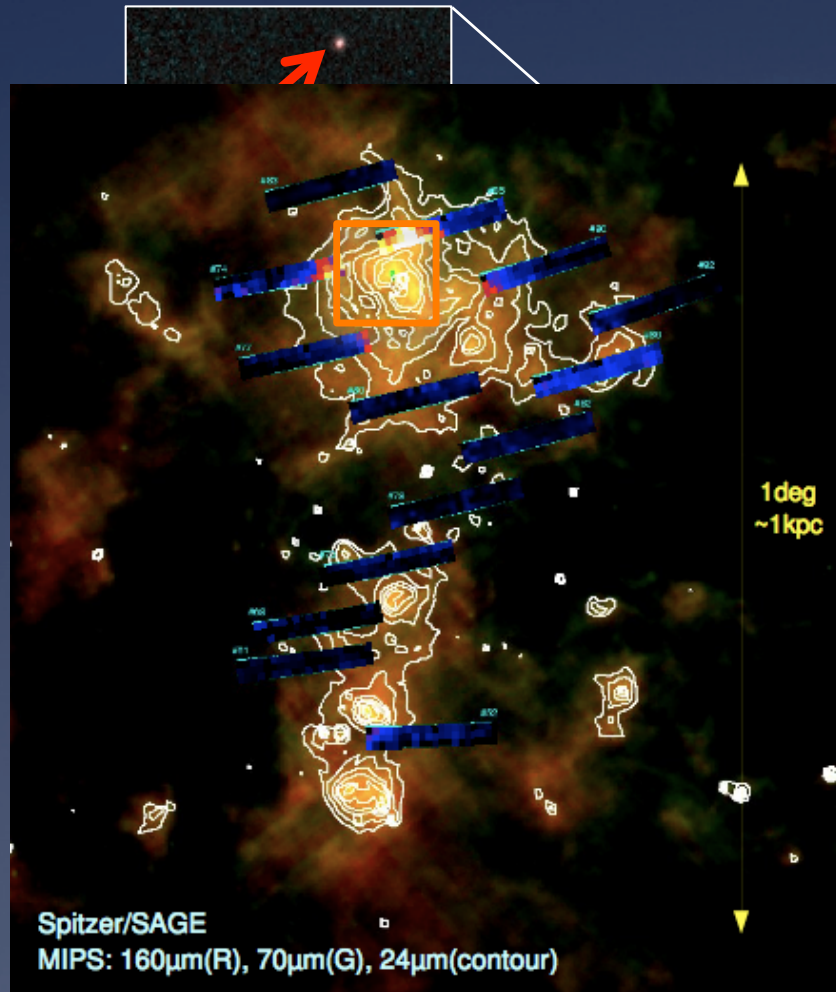
young

- low metallicity
- Huge massive star-forming region
- Wide range in evolution, age

9-1. LMC/30Dor : Image & Color-Ks mag diagram

- low metallicity
- Huge massive starforming region
- Wide range in evolution, age



9-2. LMC/30Dor : Components

Young



Old

Components	A	B	C	D	E	F	G	H	I	J	K
Diffuse (HI gas) ¹	○	⊙	×	▲	▲	○	⊙	▲	○	▲	▲
Dense (CO core) ²	-	-	-	-	-	-	3	2	-	3	3
YSO ³	3	2	1	1	4	1	1	3	1	1	5
Main Sequence (B) ⁴	37	33	19	16	11	3	17	0	0	0	2
Main Sequence (O) ⁴	107	38	0	17	8	1	12	0	0	1	0
LBV ⁵	0	0	0	0	0	0	1	0	0	0	0
WR (WN) ⁶	21	5	3	6	1	0	1	0	0	1	0
WR (WC/WO) ⁶	3	0	0		2	0	0	0	0	0	0
SNR ⁷	-	-	-	-	●	-	-	-	-	-	-

1 : Staveley-Smith et al. 2003

2 : Johansson et al. 1998

3 : Whitney et al. 2008, Seale et al. 2009, Shimonishi et al. 2010

4 : Bonanos et al. 2009

5 : Bonanos et al. 2009, Schnurr et al. 2008

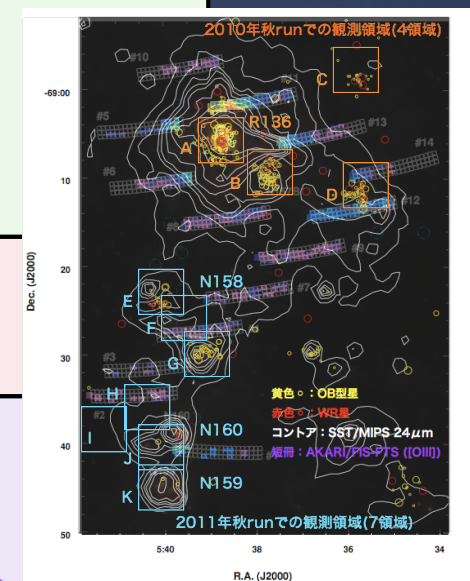
6 : Breysacher, Azzopardi, & Testor 1999

7 : Sasaki et al. 2008

9-3. LMC/30Dor : Evolution

❖各領域のmain componentから、進化段階・年齢が推定できる？
(但しIMFに強く依存)

Status \ Age	Pre-MS	MS	Post-MS	SN/SNR
Diffuse (HI gas) Dense (CO core) (Massive) YSO				
Main Sequence (B) Main Sequence (O)			C	
Luminous Blue Variable Wolf-Rayet (WN) Wolf-Rayet (WC/WO)				
Supernova (SNR)				E



10. まとめ

研究の目的

- ❖ 星形成（領域）や銀河進化に大きな影響を及ぼす大質量星(クラスター)の研究
 - ▶ 大質量星の生まれる環境は？
 - ▶ どのくらいの質量の星が生まれてくるのか？
 - ▶ どのように進化・消滅していくのか？

進行中の研究

- ❖ 大質量星形成領域の狭帯域フィルターによる撮像観測
 - ▶ 二色図による星の種族の分離
 - ▶ 星形成領域の進化段階や年齢の推定
 - ▶ candidateの発見
 - ▶ extinctionの見積もり

展開研究（今回の提案）

- ❖ より広域、幅広い進化段階の探索サーベイ観測
- ❖ 多種の天体の探索
- ❖ 候補天体の分光観測
- ▶ **ANIR**による継続観測
- ▶ 新フィルターによる探索
- ▶ **SWIMS** etc...