Search & Monitor of LBV/WR with N187 [Paα] Filter

N187[Paα]によるLBV/WR星探索・モニター

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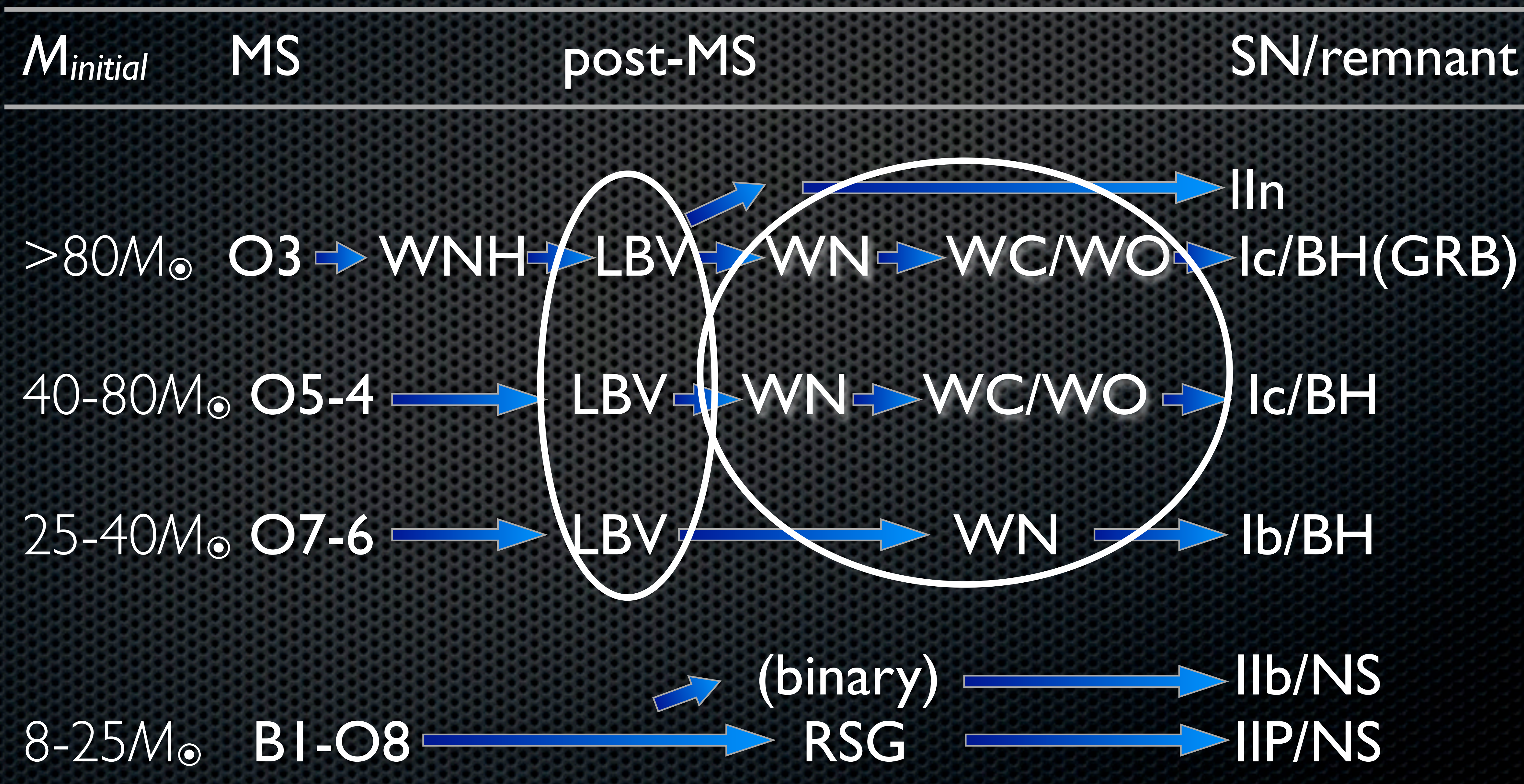
What are Wolf-Rayet Stars ?

"Conti scenario" cf. Conti 1976, Crowther 2007, Smartt 2009

mass, age, binarity, metallicity, rotation



Importances of Wolf-Rayet stars

▷ Limited (short) Life Time of ~ 0.5 Myr (~10% of total Life Time)

...... Clue to Age & Initial Mass Function

▶ Cluster of WR/LBV/RSG/YHG/OB

...... Good tracer of massive-star formation in massive-star clusters

(WR/O, WC/WN, LBV, BSG, YHG, RSG, ...)

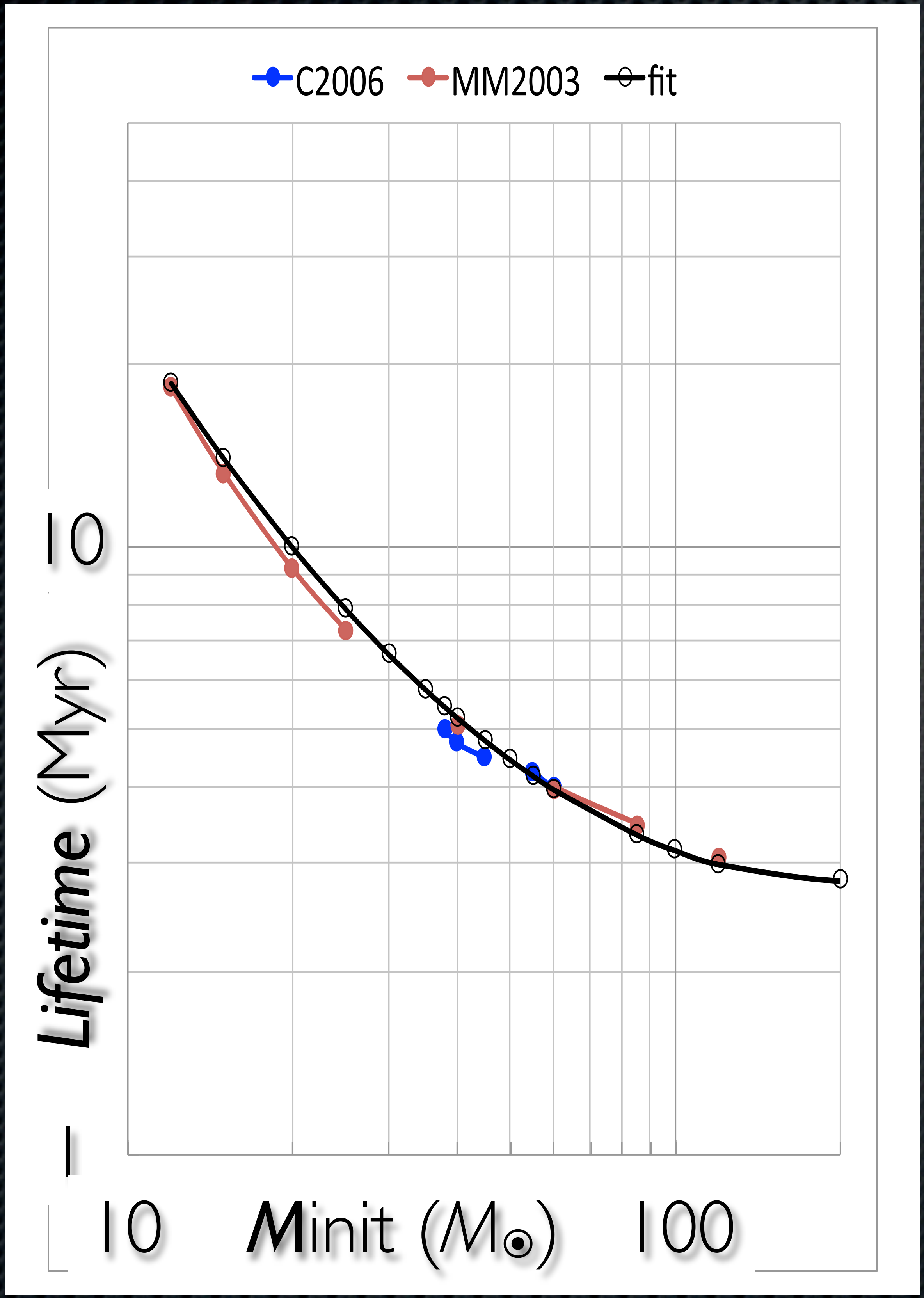
▶ Isolated WR stars ... where were they formed ?

▷ Mass Loss with strong Stellar Wind (>10^{-5} $M_{\odot}$/yr)

...... Evolution of massive stars

In spite of ~6000 expected number of WR in our Galaxy, only ~500 WR have ever discovered.

Lifetime of Massive Stars



Lifetime [H-b + He-b(~10%)]
cf. Crowther+ 2006; Meynet & Maeder 2003

9 $M_\odot$	30.5 Myr
25 $M_\odot$	7.3 Myr
40 $M_\odot$	5.1 Myr
60 $M_\odot$	4.0 Myr
85 $M_\odot$	3.5 Myr
120 $M_\odot$	3.1 Myr

fit: $\log(t/\mathrm{Myr})=0.55\{\log(M/M_\odot)-2.3\}^2+0.45$

WR	~0.4 Myr
LBV	~0.01 Myr ?

Cluster Age	LBV/WR/YHG/RSG
< 2.5 Myr	all stars remain in main-seq
2.5-3.5 Myr	super-massive stars evolve into LBV/WR
3.5-5 Myr	40~60 $M_\odot$ stars evolve into LBV/WR
> 5 Myr	all LBV/WRs have become SN YHG/RSGs appear

3 Clusters & Galactic Center Region

Quintuplet
l =+0.16 deg=+9'.6
b=−0.06 deg=−3'.6

Galactic Center Clusters (~0.4°)

Arches
l =+0.12 deg=+7'.2
b=+0.02 deg=+1'.2

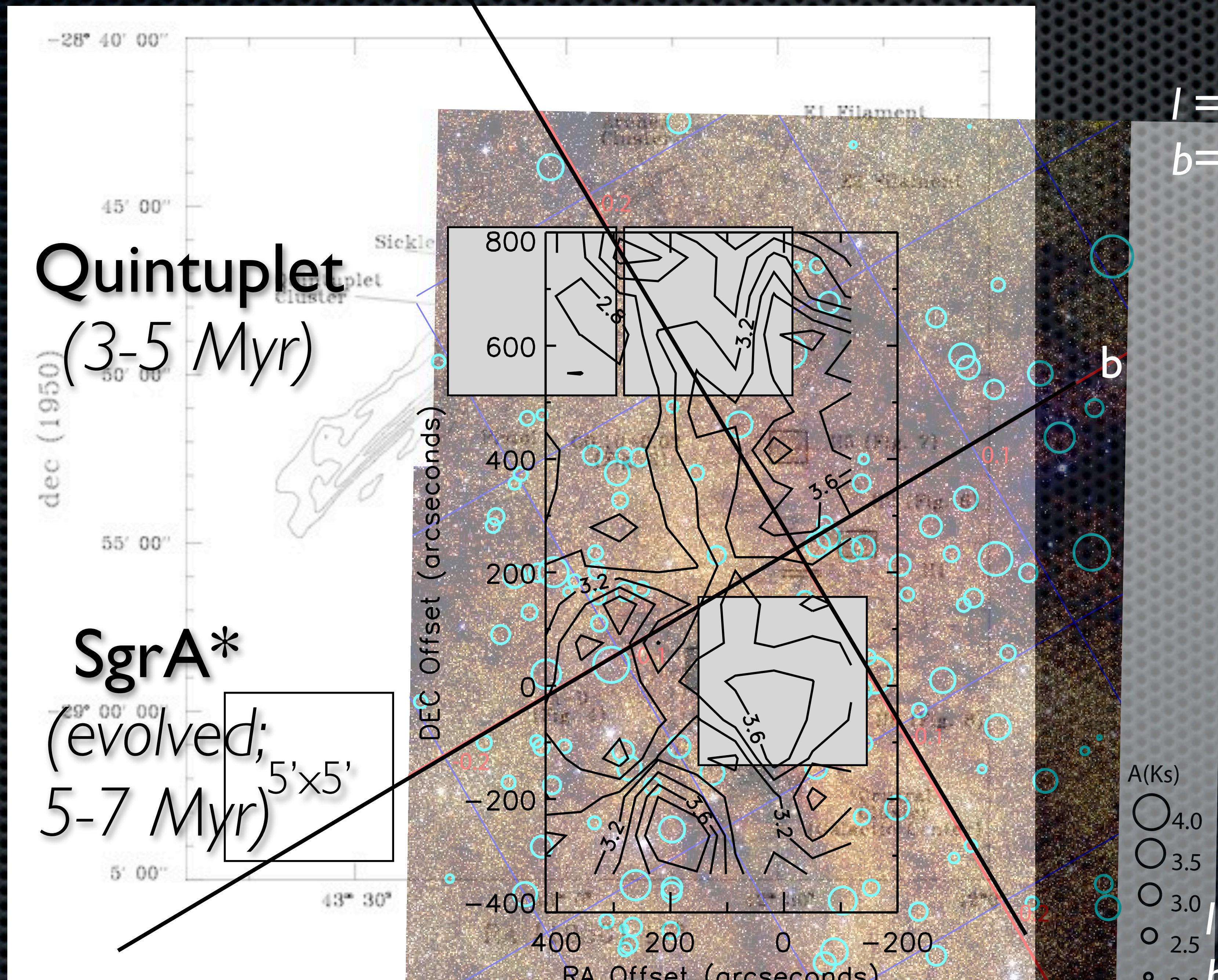


FIG. 1.—Six centimeter radio map of the Galactic center (Yusef-Zadeh & Morris 1987b), which illus... Nomenclature for the regions A–D and H1–H8 are from Yusef-Zadeh & Morris (1987b); nomenclature for the E1 and E2 Filaments is from Morris & Yusef-Zadeh (1989). The Central, Quintuplet, and Arches clusters are indicated by stars at the central location of the respective clusters. The

Fig. 23.—Extinction map (A_{K_s}), as inferred from the Lick data (Figer 1995). Sgr A* is located at (0, 0). The offsets are in arcseconds along right ascension and declination. See text for discussion.

1"=0.0388 pc
for D=8.0 kpc

SgrA*
D=8.28±0.33 kpc
1'=2.41 pc
RA=17h45m40.04s
Dec=−29°00'28.12"
(epoch2000.0)
l =−0.0557 deg=−3'.34
b=−0.0462 deg=−2'.77

Matsunaga+ 2011 Nature
Figer+ 2004

Methodology of WR stars search since 2000; with Infrared

[1] 2MASS & Spitzer/GLIMPSE

cf. Mauerhan, Dyk, Morris 2011,AJ,142,40

☆ strong free-free emission in NIR-MIR (WN & WC)

☆ dust thermal emission in MIR (WCLd)

★ color-color: J-H vs H-Ks, J-Ks vs Ks-[8.0], [3.6]-[4.5] vs [3.6]-[8.0]

[2] NIR-NBF(CIV, HeII, ...)

cf. Shara+ 2011,arXiv,1106,21965; 2009,AJ,138,402

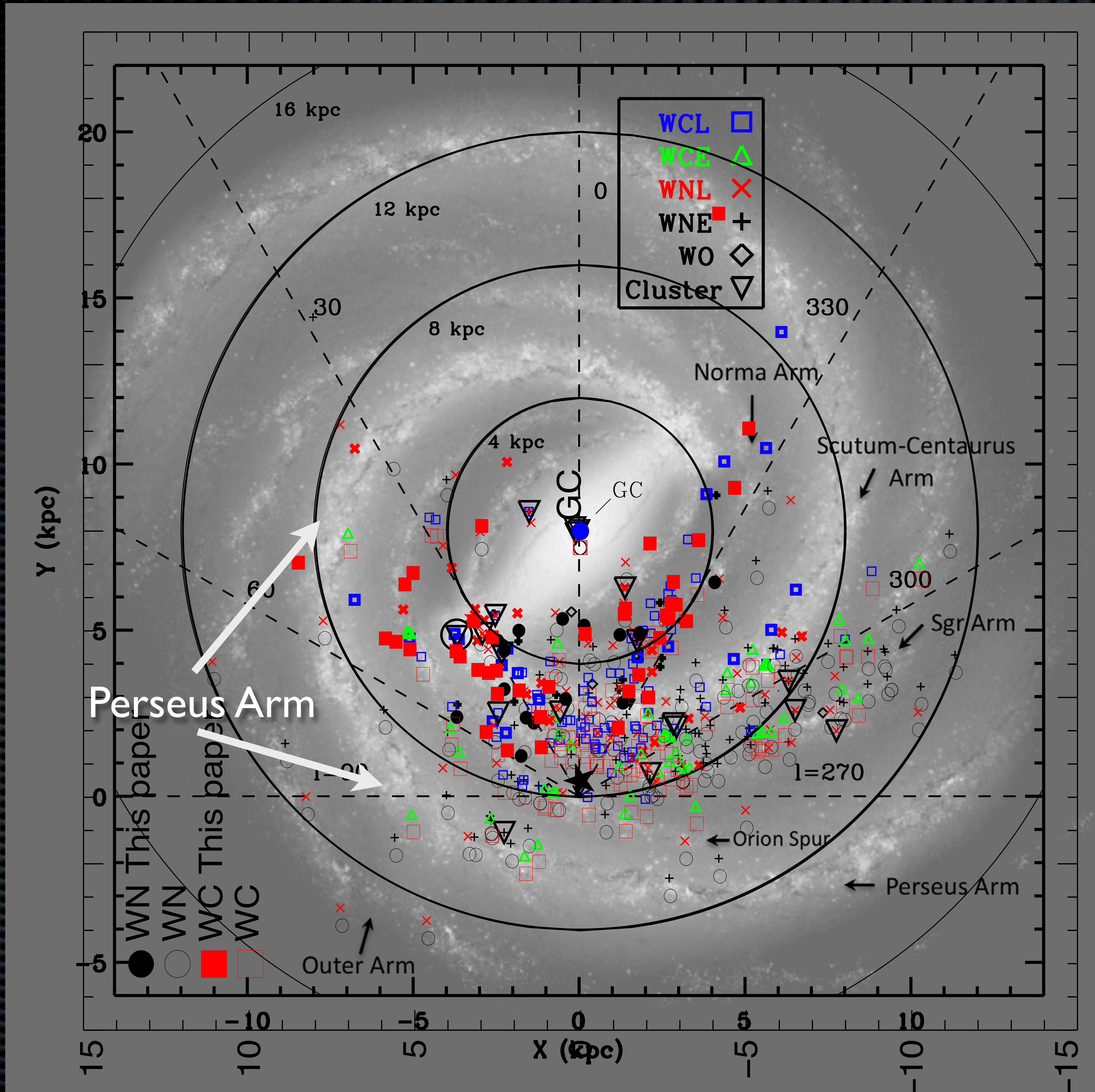
☆ strong line (HeII, CIV, ...) emission in NIR (WN & WC)

★ 6 [NBF] (K) system: [cont-1],[HeI],[CIV],[Br γ],[HeII],[cont-2] ... not simple!

Our choice !

★ 2 [NBF: CIV, HeII] + 1 [BBF: Ks] system ... so simple & effective !

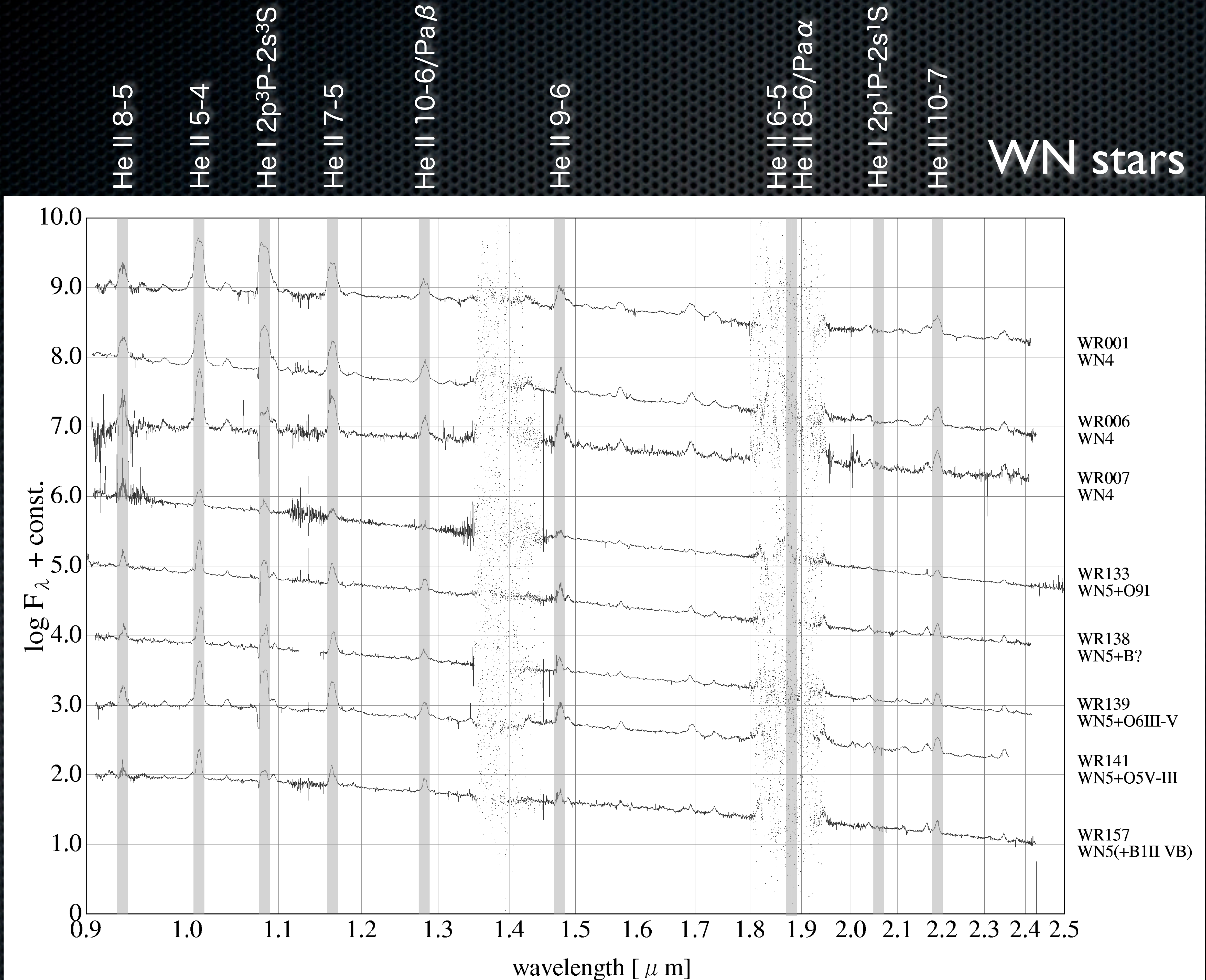
larger [CIV]/[Ks] for WCE, larger [HeII]/[Ks] for WN & WC
A_{Ks} from [NBF]/[Ks]



Shara+ 2011

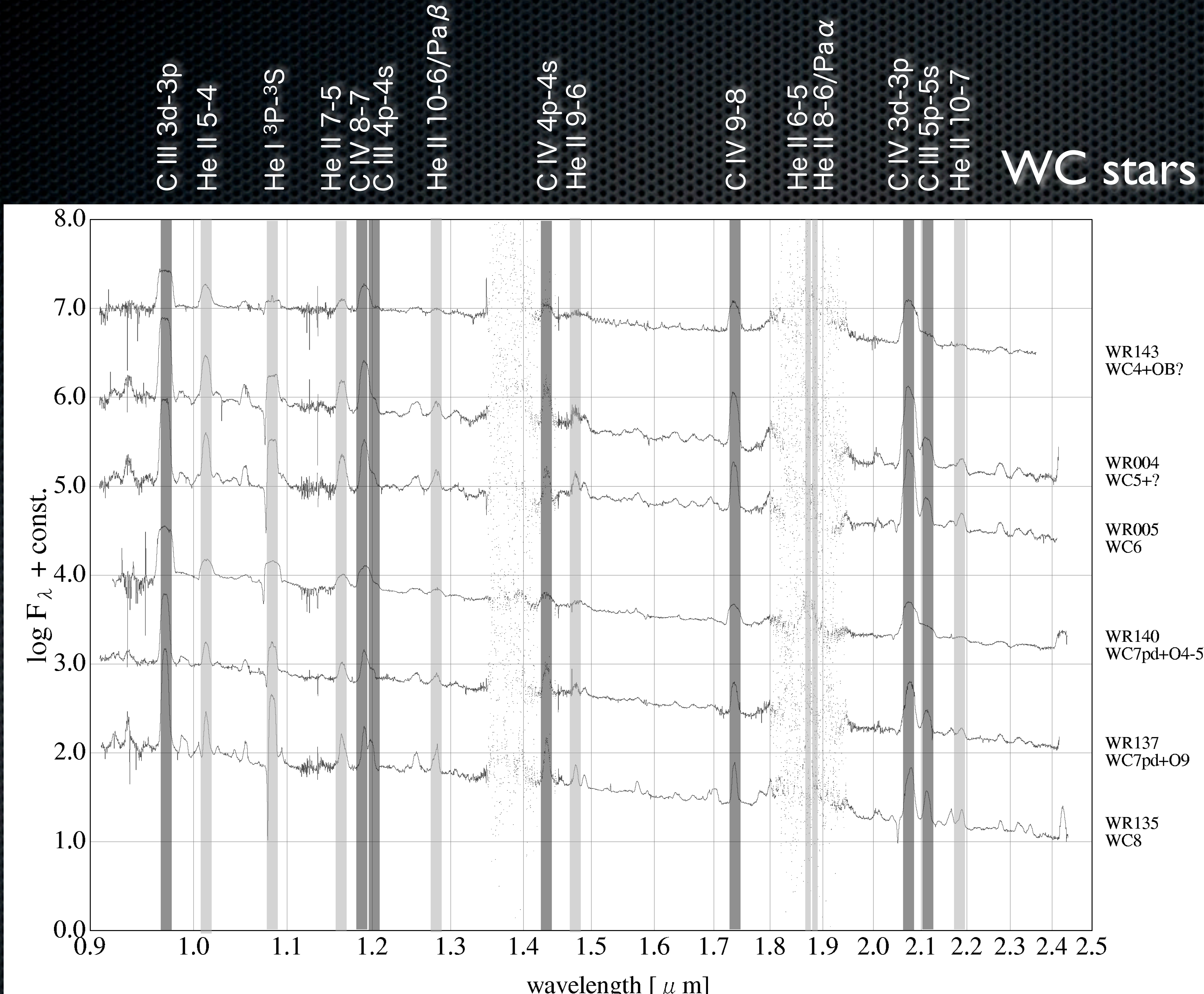
Mauerhan, Dyk,Morris 2011

WN stars



2012年 3月 15日 木曜日

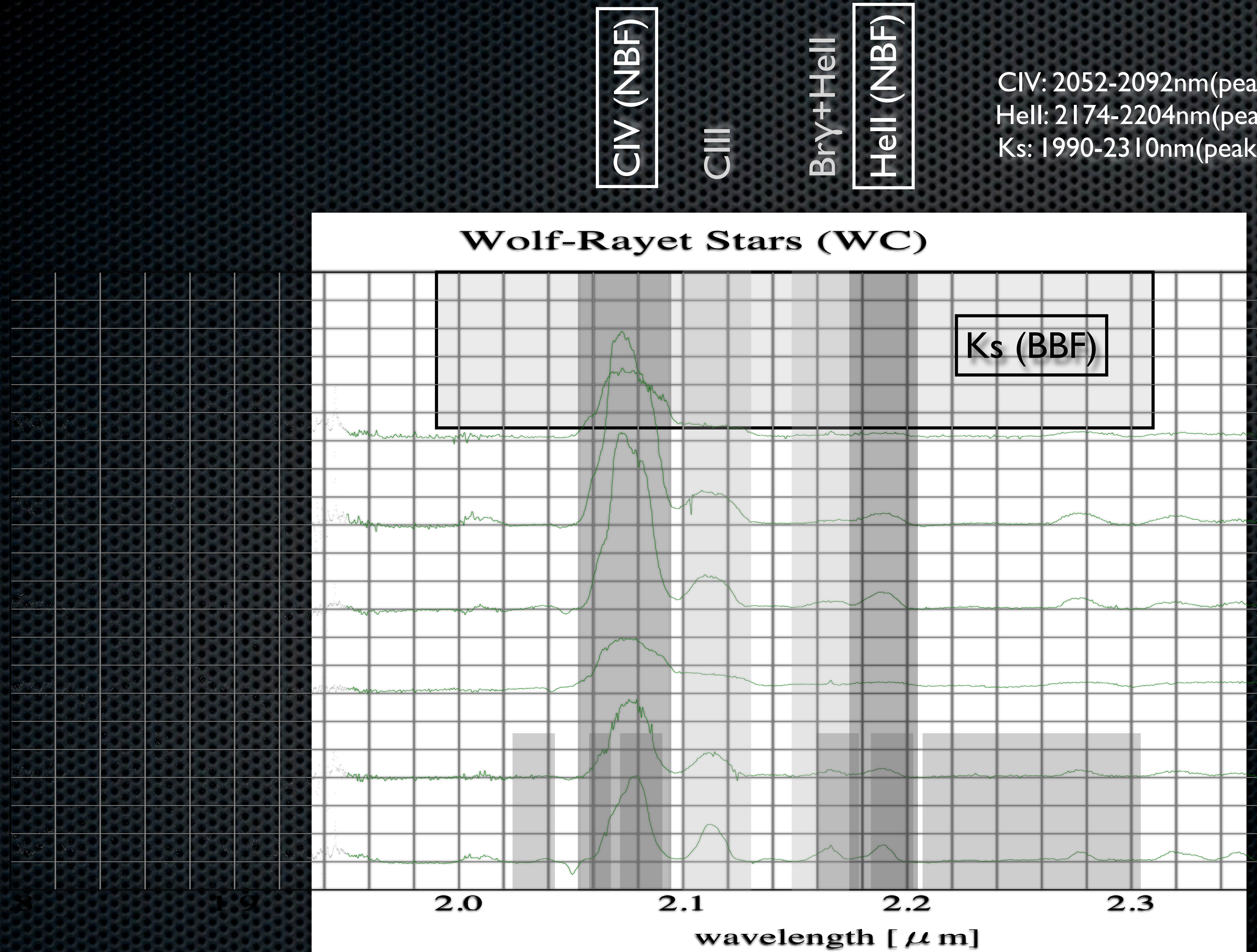
WC stars



2012年 3月 15日 木曜日

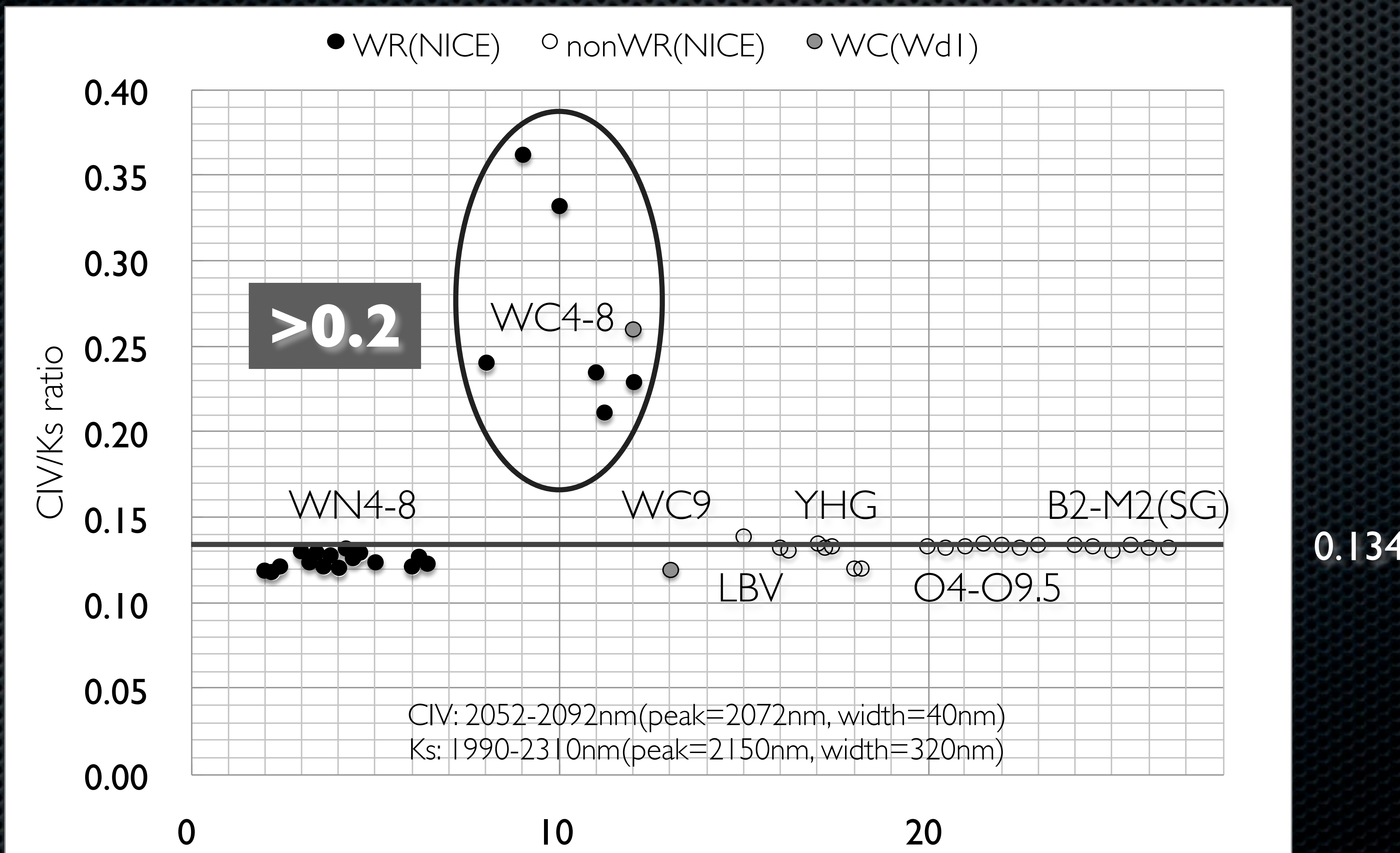
Details of Narrow-Band-Filter

CIV: 2052-2092nm(peak=2072nm, width=40nm)
HeII: 2174-2204nm(peak=2189nm, width=30nm)
Ks: 1990-2310nm(peak=2150nm, width=320nm)



Shara's filter system

Simulated CIV/Ks ratio based on NICE Spectra (WN,WC,LBV,YHG,O,B-MSG)



3-Filters Set: [2NBF(CIV&HeII)+BBF(Ks)]

miniTAO1.0m+ANIR

N207(CIV 2078), N187(HeII8-6+Paα 1875), Ks

★

GAO1.5m+GIRCS

N207(CIV 2078), N219(HeII10-7 2189), Ks

★

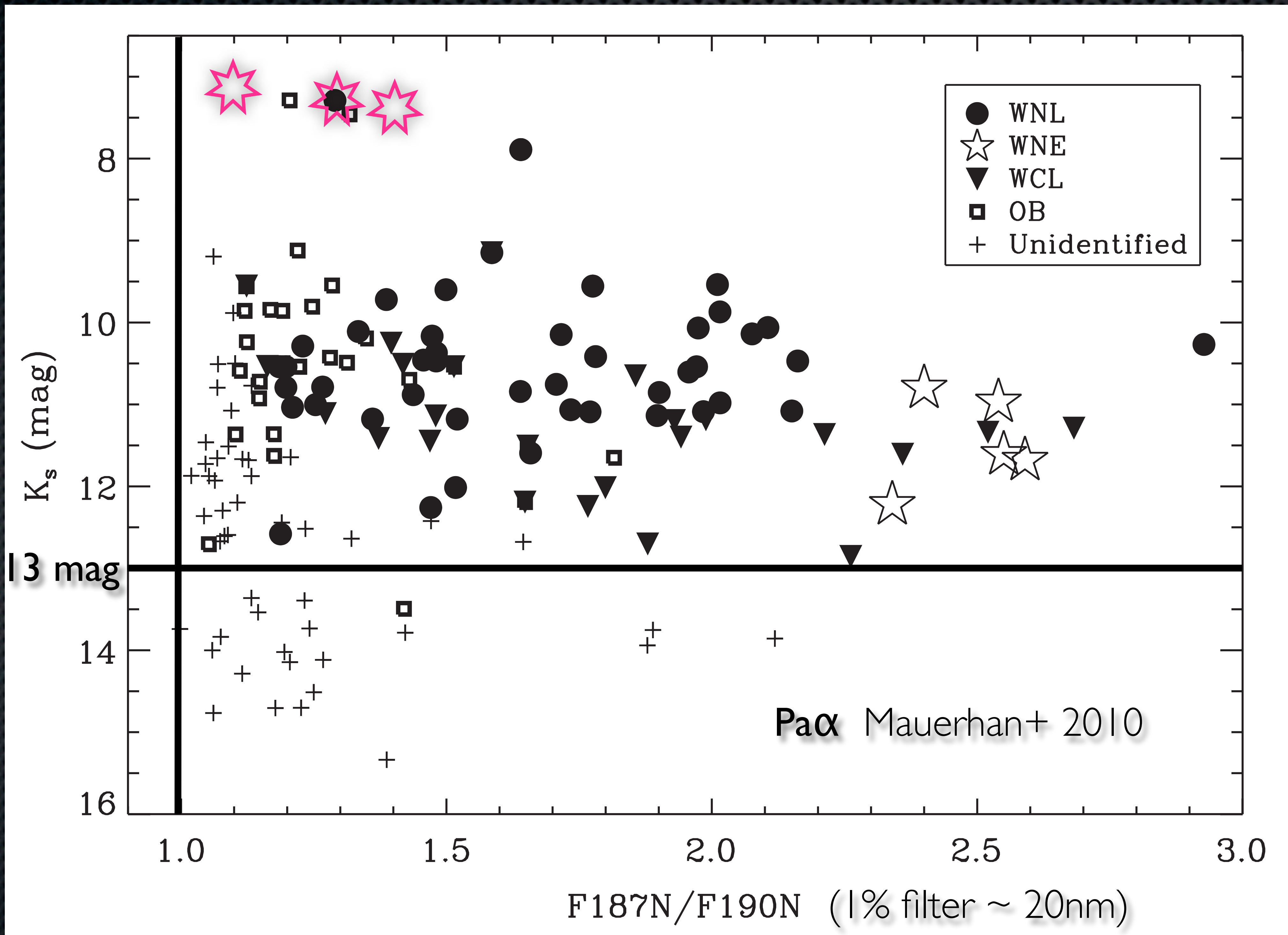
OAOWFC (planning)

N209(CIV 2078/CIII 2108), N218(HeII10-7 2189/Brγ 2166), Ks

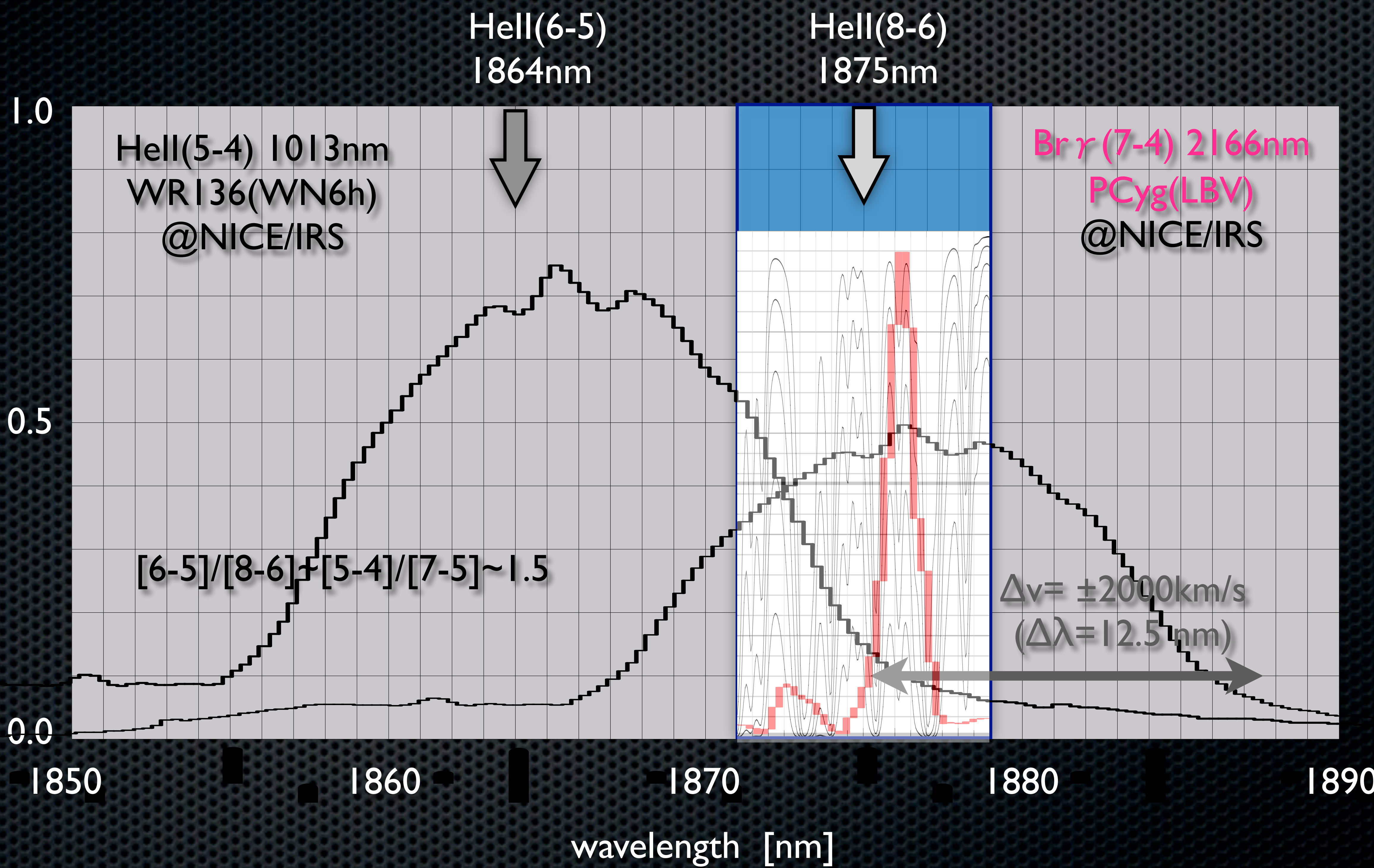
Expected stars from Paα survey

WNL & WCL (BSG) ... many
WNE & LBV ... small number but precious!
WCE ... with N207
YHG & RSG ... ??

1876nm: Paα, HeII(8-6), HeII(6-5)
WN/WC: strong(broad) HeII, but weak Paα
LBV: no HeII, but strong(narrow) Paα
=> 1876 feature is due to HeII, not Paα for WR



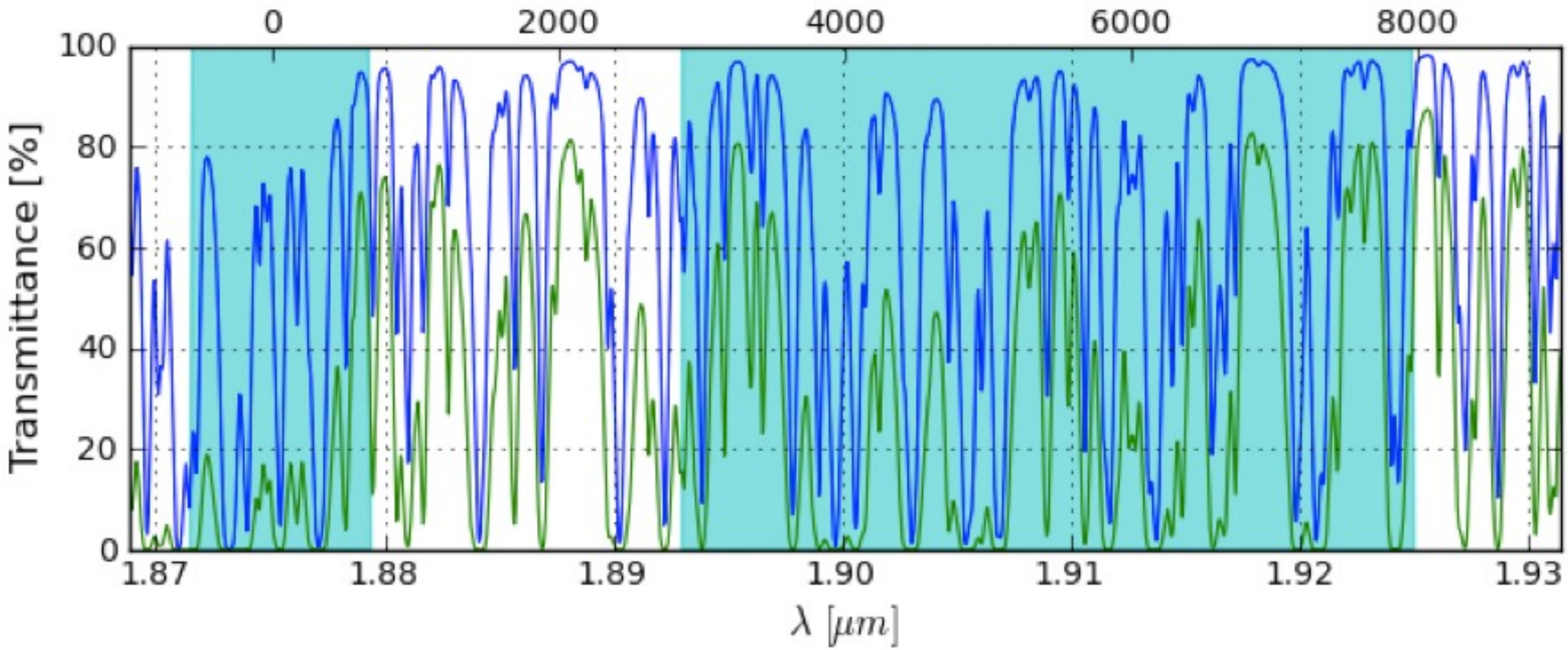
N187(Paα-filter):1871-1879nm
(peak=1875nm, width=8nm => ±640km/s)



Paα Filter of ANIR

Ks: 1990-2310nm(peak=2150nm, width=320nm)
N207: 2052-2092nm(peak=2072nm, width=40nm)
N187: 1871-1879nm(peak=1875nm, width=8nm)

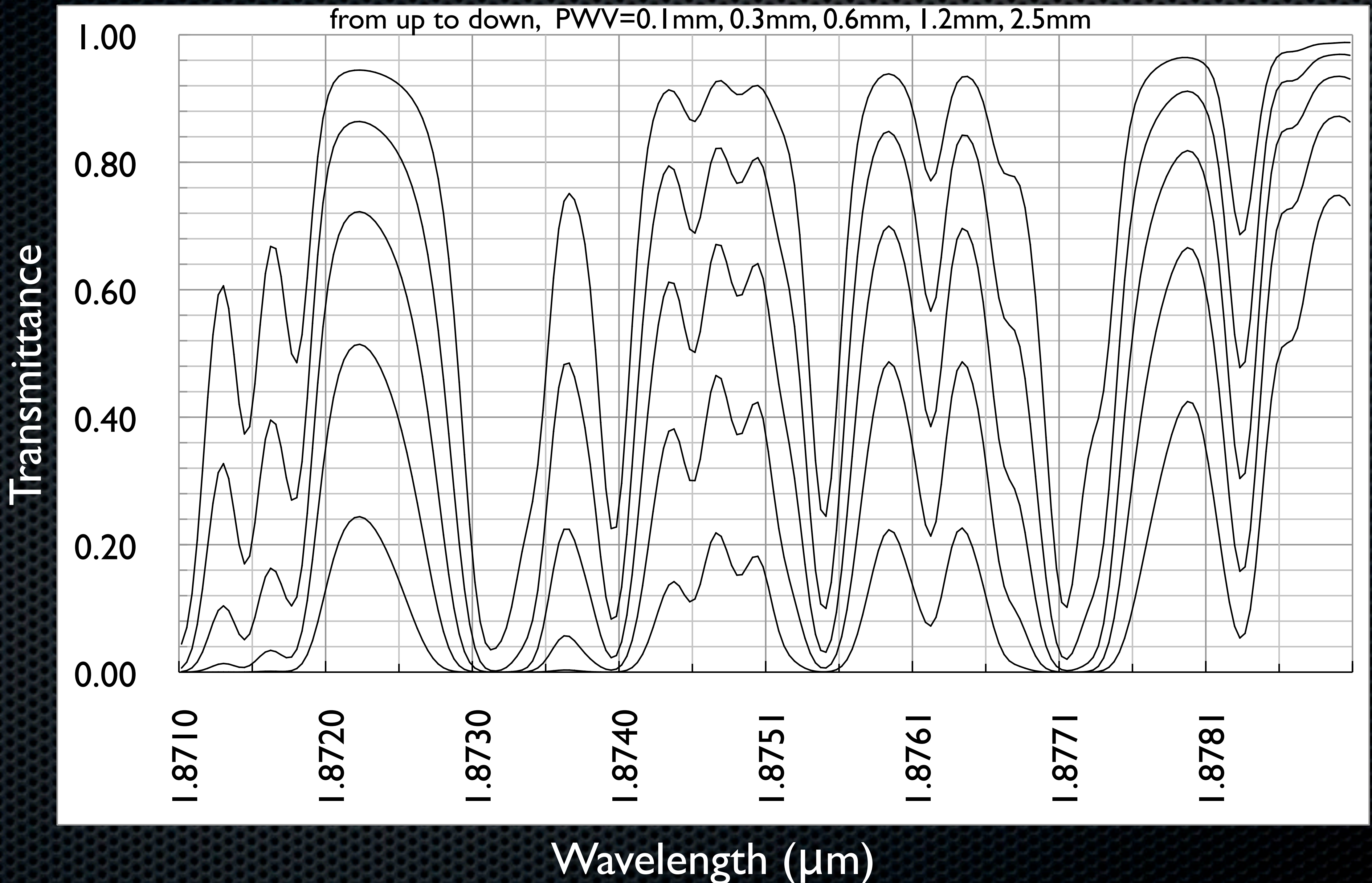
simulation: blue @ 5640m, green @ 2600m



Atmospheric Transmittance in Paα Filter Range

average transmittance (1871-1879nm) =
0.70 (0.1mm), 0.54 (0.3mm), 0.39 (0.6mm), 0.25 (1.2mm), 0.13 (2.5mm)

PWV @ TAO site: best < 0.1mm; nominal 0.3-0.6mm; worse > 1mm



N187/Ks Estimation

calculations for Quintuplet

N187: center=1875 nm, width=8nm (100%)

Ks: center=2150 nm, width=320nm (100%)

[1] "normal star": λ^(-4) spectrum

N187/Ks = **0.043**

[2] extinction A_{Ks}: λ^(-2.0) law ◀ N207/Ks

$A_{187}/A_{215} = \alpha_{187}$ = (1875/2150)^(-2.0) = 1.315

∴ $(I_{187}/I_{215})_{obs} = (I_{187}/I_{215})_{int} \times 10$^{−$A_{215} \times (\alpha_{187} - 1)$/2.5}

= $(I_{187}/I_{215})_{int} \times 10$^{−$A_{215}$×**0.126**}

~ $(I_{187}/I_{215})_{int} \times 10$^{−2.72×0.126} ~ **0.45** $(I_{187}/I_{215})_{int}$ for A_{215}=2.72

~ 0.043x0.45 ~ 0.0195

[3] atmospheric transmittance near 1875nm

~ **0.25-0.54** for PWV=1.2-0.3mm

N187/Ks ~ 0.0195x(0.25-0.54) ~ 0.0048-0.0105

measurements in Quintuplet

"normal stars": ~0.0063

A_{215}=2.72 mag & AT=0.32 (PWV=0.8mm)

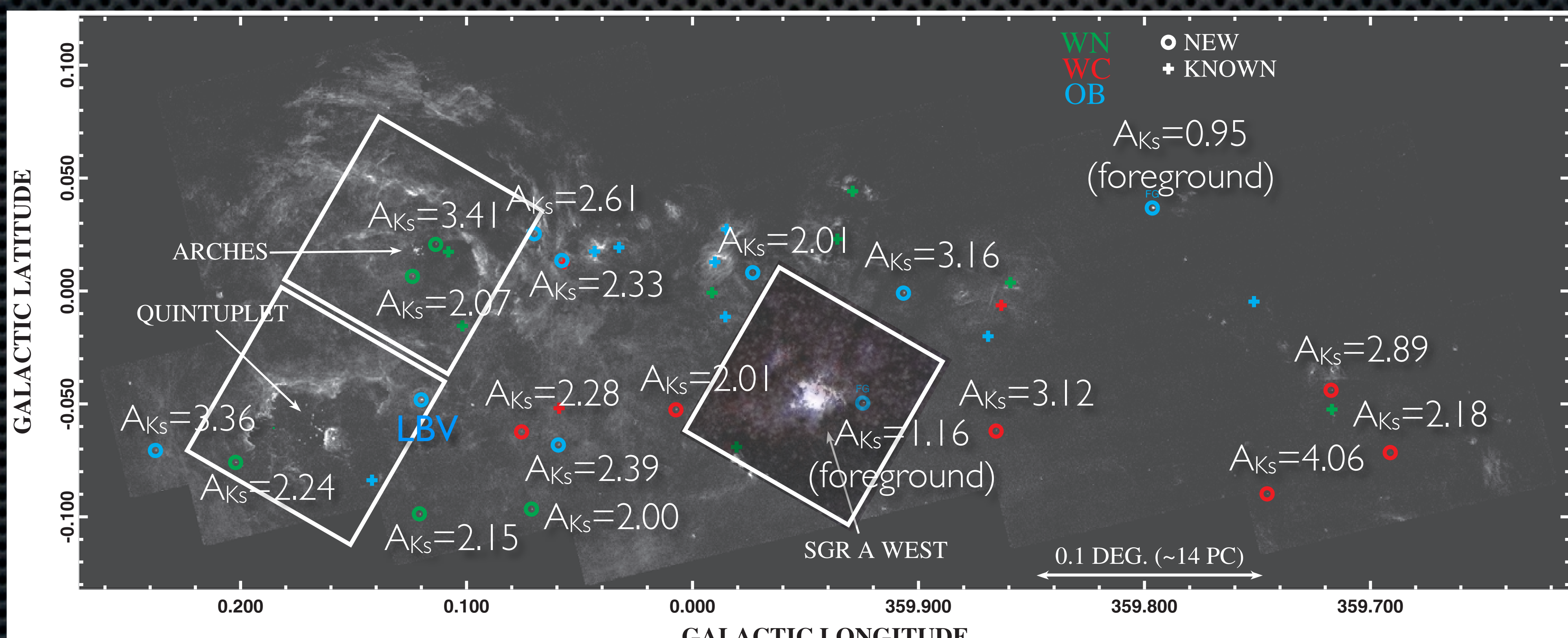
WR & LBV: 0.010~0.020 (excess relative to "normal stars"; x2-4)

CIV/Ks imaging of 3 Galactic Center clusters (5'x5')

Detection of known and candidates WR

Mauerhan+ 2010; Wang+ 2010
HST/NICMOS Paα survey image
~50% are stars in clusters; ~50% are isolated (inter-cluster) stars
extinction law from Nishiyama+ 2006

5.0' = 11.64 pc for R_0=8.0 kpc ANIR 5'x5' 39' x 15' = 91 x 35 pc

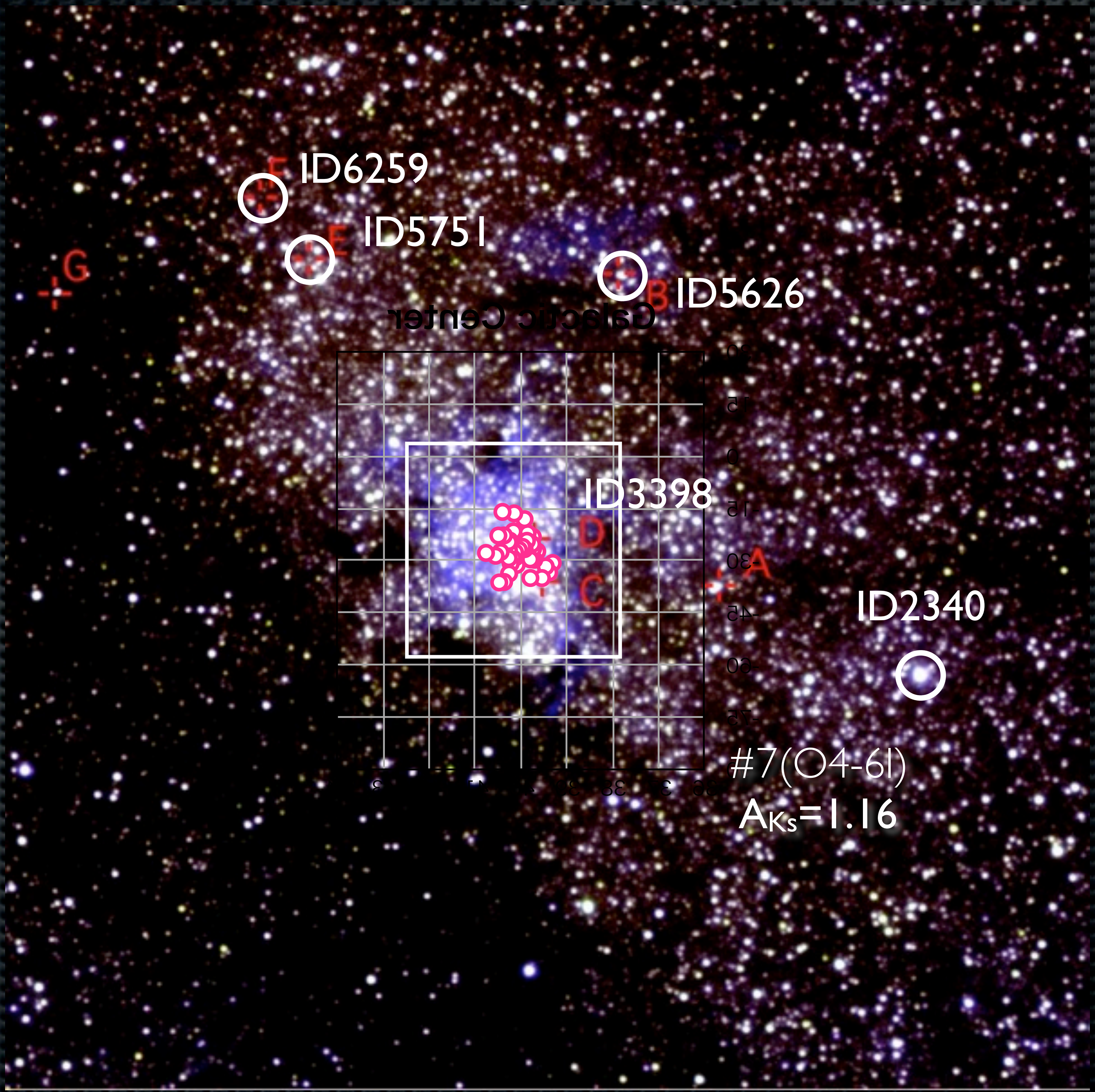


Galactic Center cluster

5.1'
1.0'

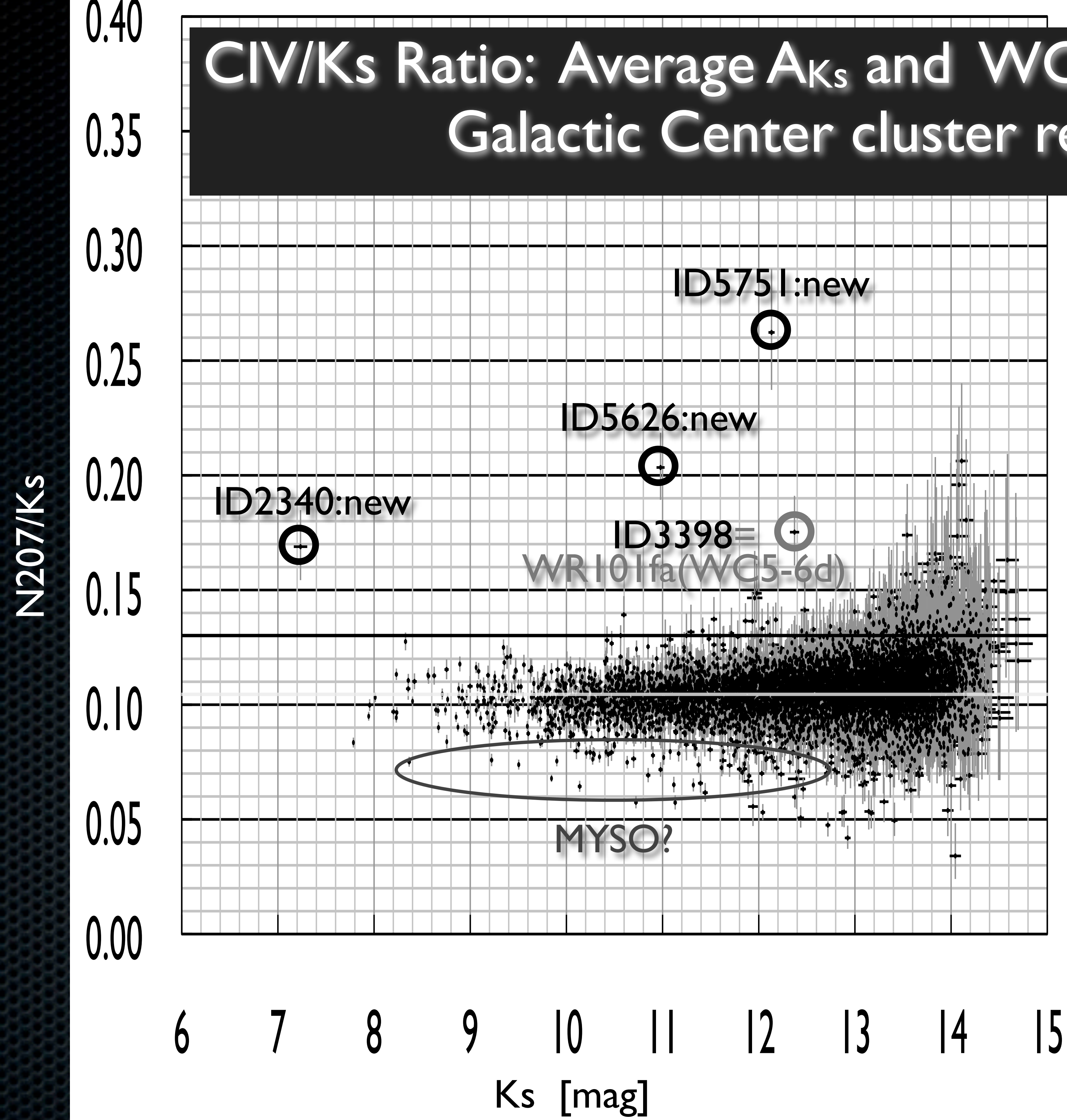
R(CIV) G(Ks) B(Paα)

[42WR]
WR100a(WN7)
WR101
a(WC8-9)
b(WN8)
c(WN9)
d(WC9)
da(WN7)
db(WN9)
dc(WN8)
dd(WN7)
de(WCLd)
df(WCLd)
dg(WCLd)
dh(WCLd)
di(WC9)
e(WN8)
ea(WCLd)
f(WC9)
fa(WC5-6d)3398
g(WC9)
h(WN8-WC9)



i(WC8-9)
j(WN9)
ja(WN9)
k(WN9)
l(WN9)
m(WN8-9)
ma(WC8-9)
n(WC8-9)
na(WCLd)
nb(WC)
nc(WN8)
nd(WN9)
o(WN5-6)
oa(WC9)
ob(WC9)
oc(WN9)
od(WCLd)
oe(WCLd)
of(WC9)
og(WCLd)
oh(WC9)
oi(WC9)

CIV/Ks Ratio: Average A_{Ks} and WC & MYSO Candidates Galactic Center cluster region (5'x5')



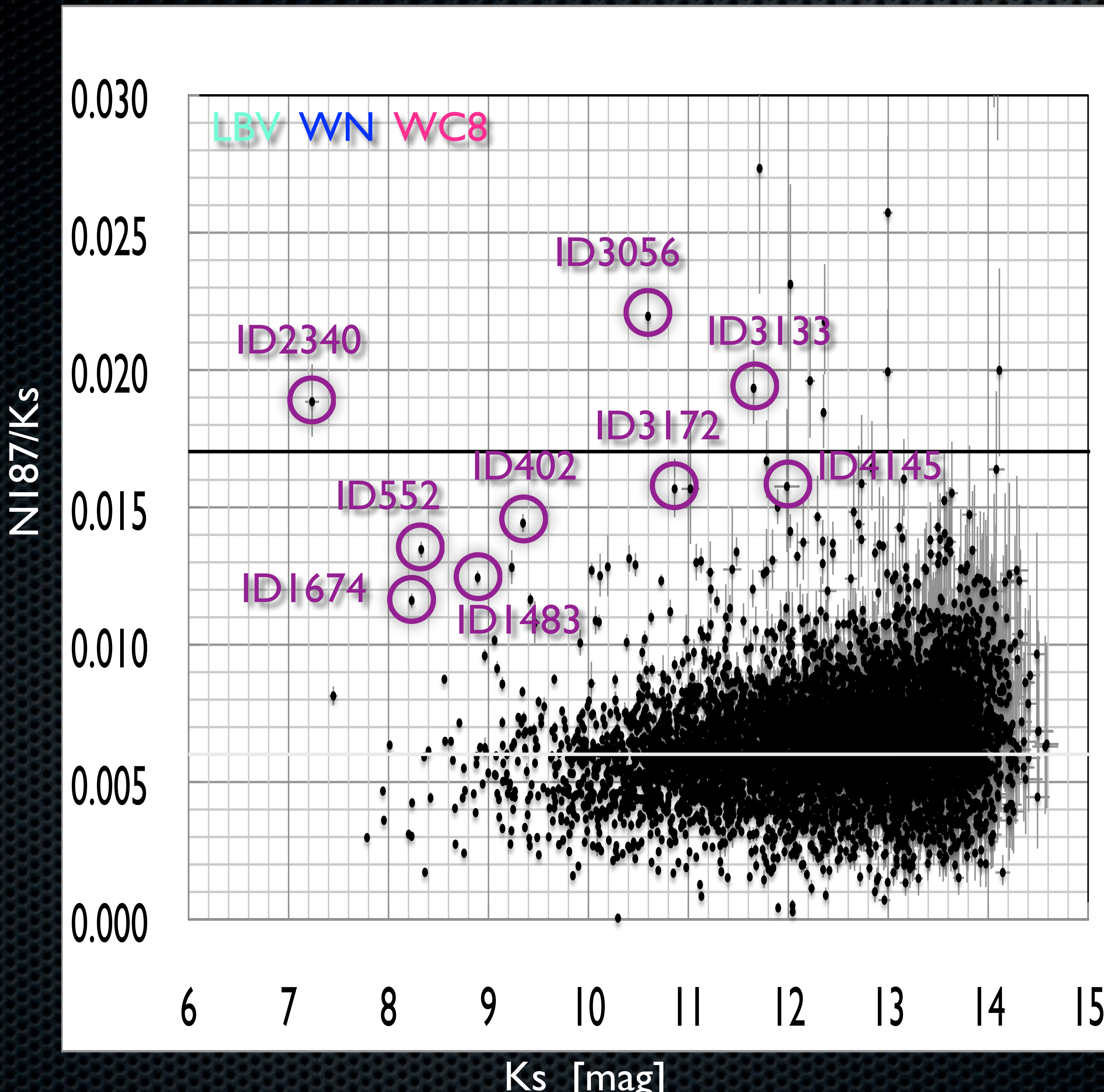
ID2340 0.166 > ~0.21 (WC7-8)
ID5626 0.200 > ~0.26 (WC7-8)
ID5751 0.258 > ~0.33 (WC5-6)
ID3398 0.172 > ~0.22 (WC7-8)

0.130 ... standard (zero-extinction)

0.1030 ... average in 8<Ks<12
A_{Ks}=3.21±1.2 mag (A_V=51 mag)

cf. A_K=2.8 in central 5"
(Stolte+ 2002; Martins+ 2008)

N187/Ks; Galactic Center cluster



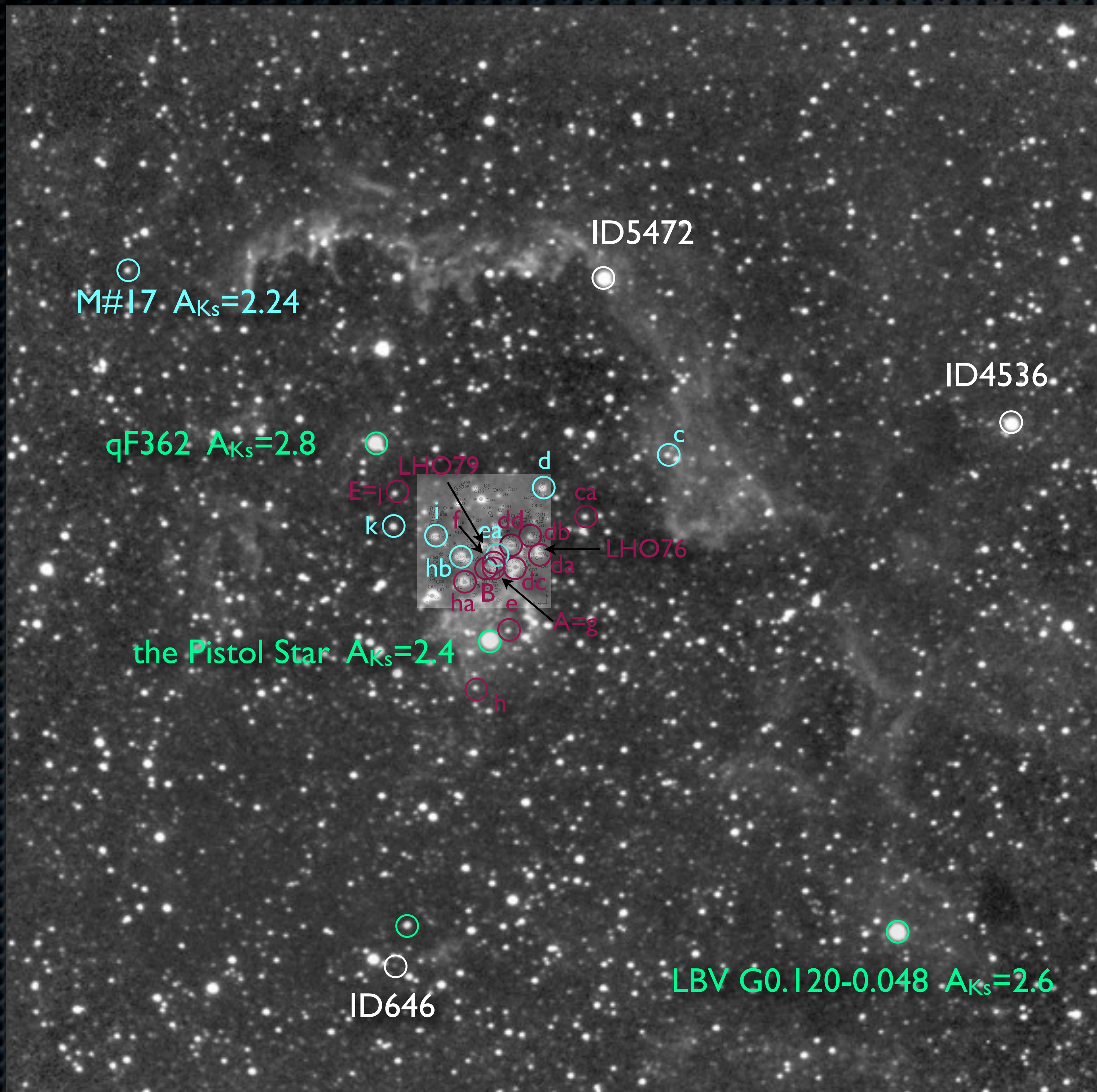
0.017 (A_{Ks}=3.21 & 100%AT)

0.0060 (A_{Ks}=3.21 & 35%AT)

... average in 7<Ks<12

Quintuplet cluster

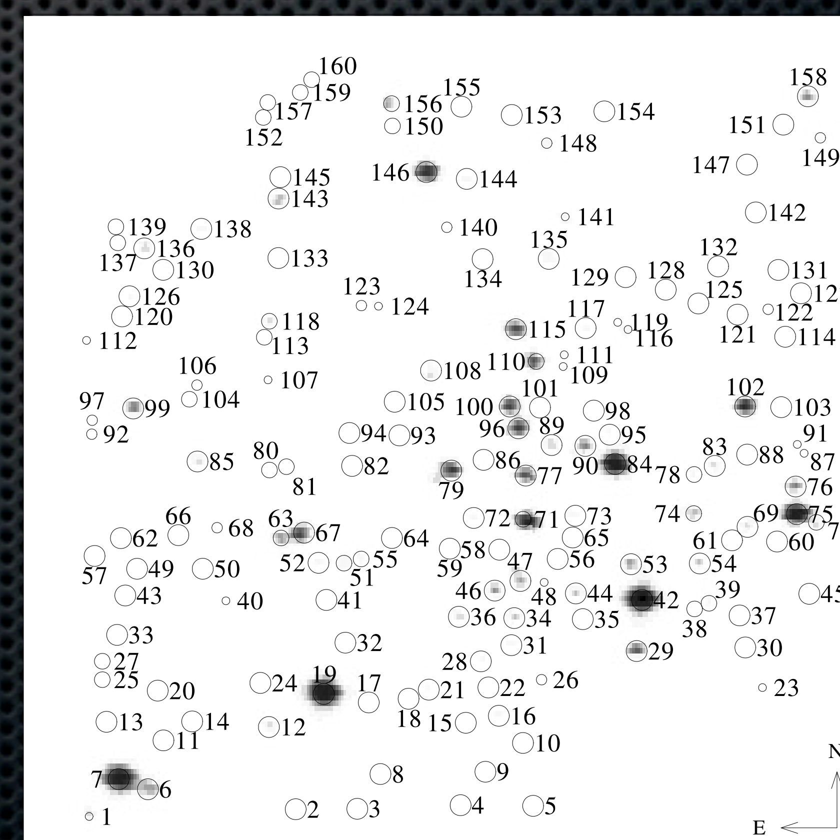
Paα



[19WR] WR102

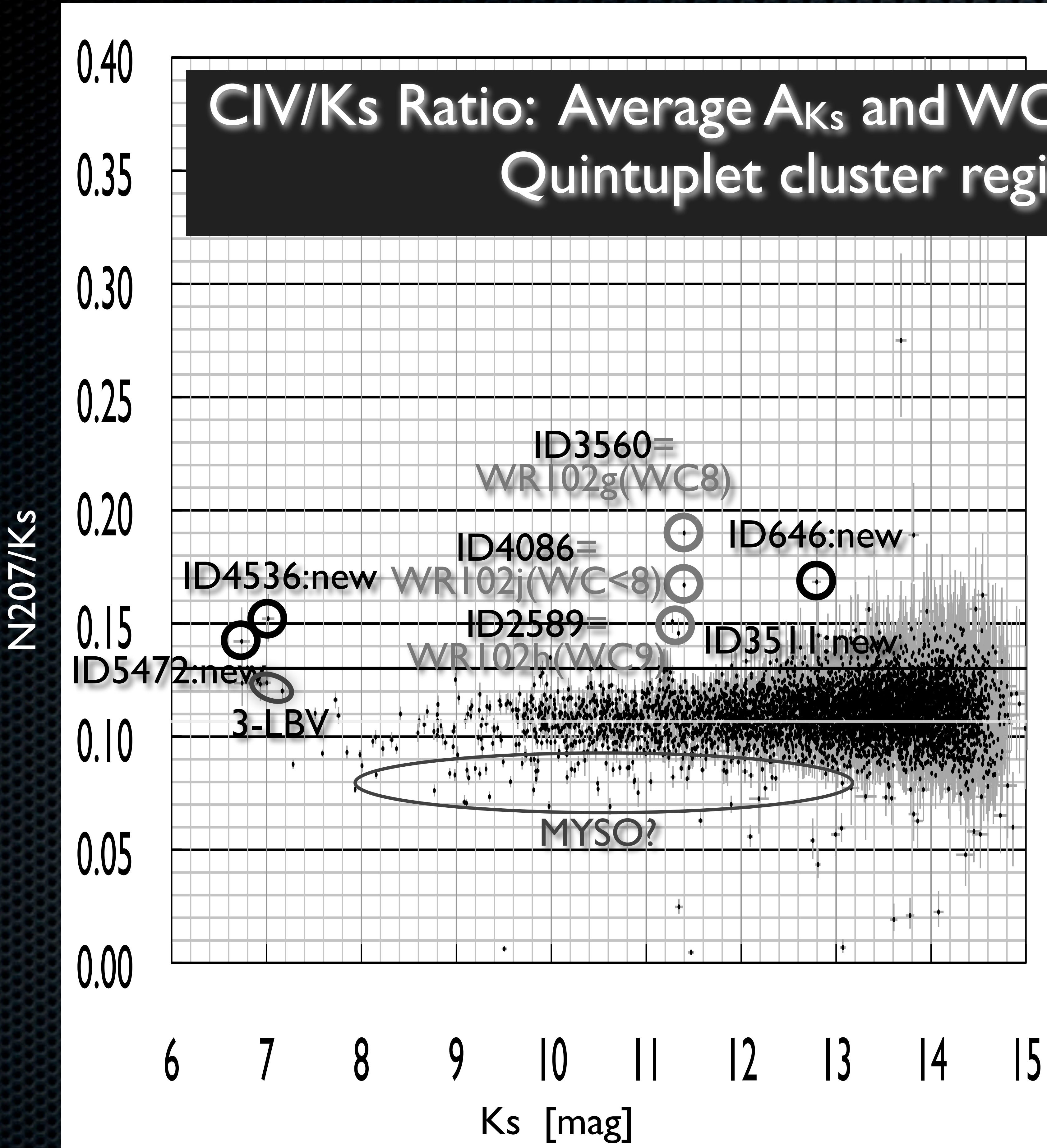
c(WN6)
ca(WC8-9)
d(WN9)=158
da(WC9?d)=75
76(WC9d)
79(WC9d)
db(WC9?d)=102
dc(WC9d)=42
dd(WC9d)=84

e(WC8)
ea(WN9)=71
f(WC8)=47
g(WC8)A=34
h(WC9)
ha(WC8/9d)=19
hb(WN9)=67
i(WN9)=99
j(WC<8)E
k(WN9)



Liermann2009

CIV/Ks Ratio: Average A_{Ks} and WC & MYSO Candidates
Quintuplet cluster region (5'x5')



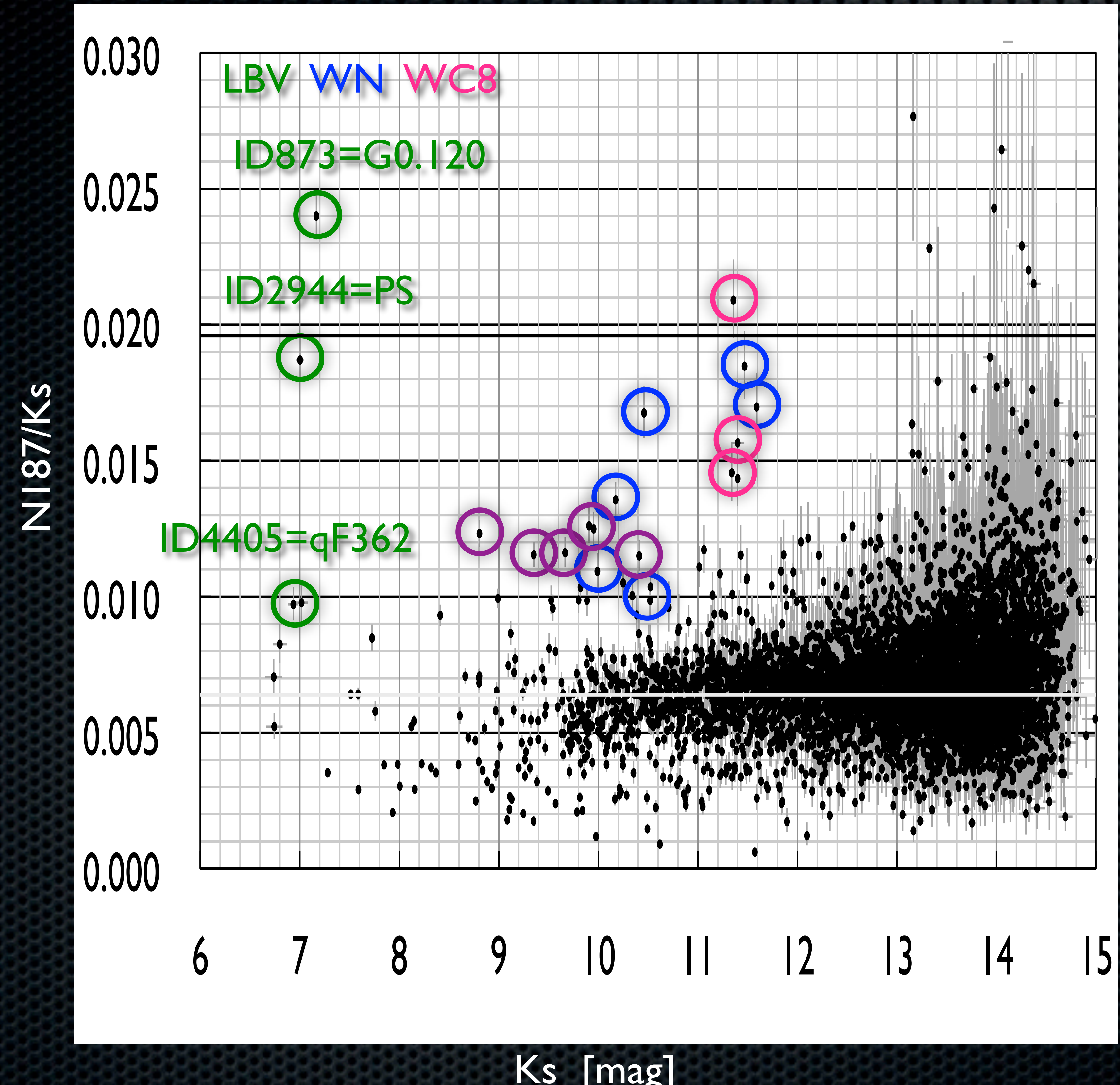
ID5472 0.149 > ~0.17 (WC7-8)
ID4536 0.159 > ~0.18 (WC7-8)
ID2589 0.158 > ~0.18 (WC7-8)
ID3511 0.152 > ~0.18 (WC7-8)
ID3560 0.199 > ~0.23 (WC7-8)
ID4086 0.175 > ~0.20 (WC7-8)
ID646 0.176 > ~0.20 (WC7-8)

0.130 ... standard (zero-extinction)

0.1067 ... average in 8<Ks<12

A_{Ks}=2.72±1.4 mag (A_V=44 mag)

N187/Ks; Quintuplet cluster



0.0195 (A_{Ks}=2.72 & 100%AT)

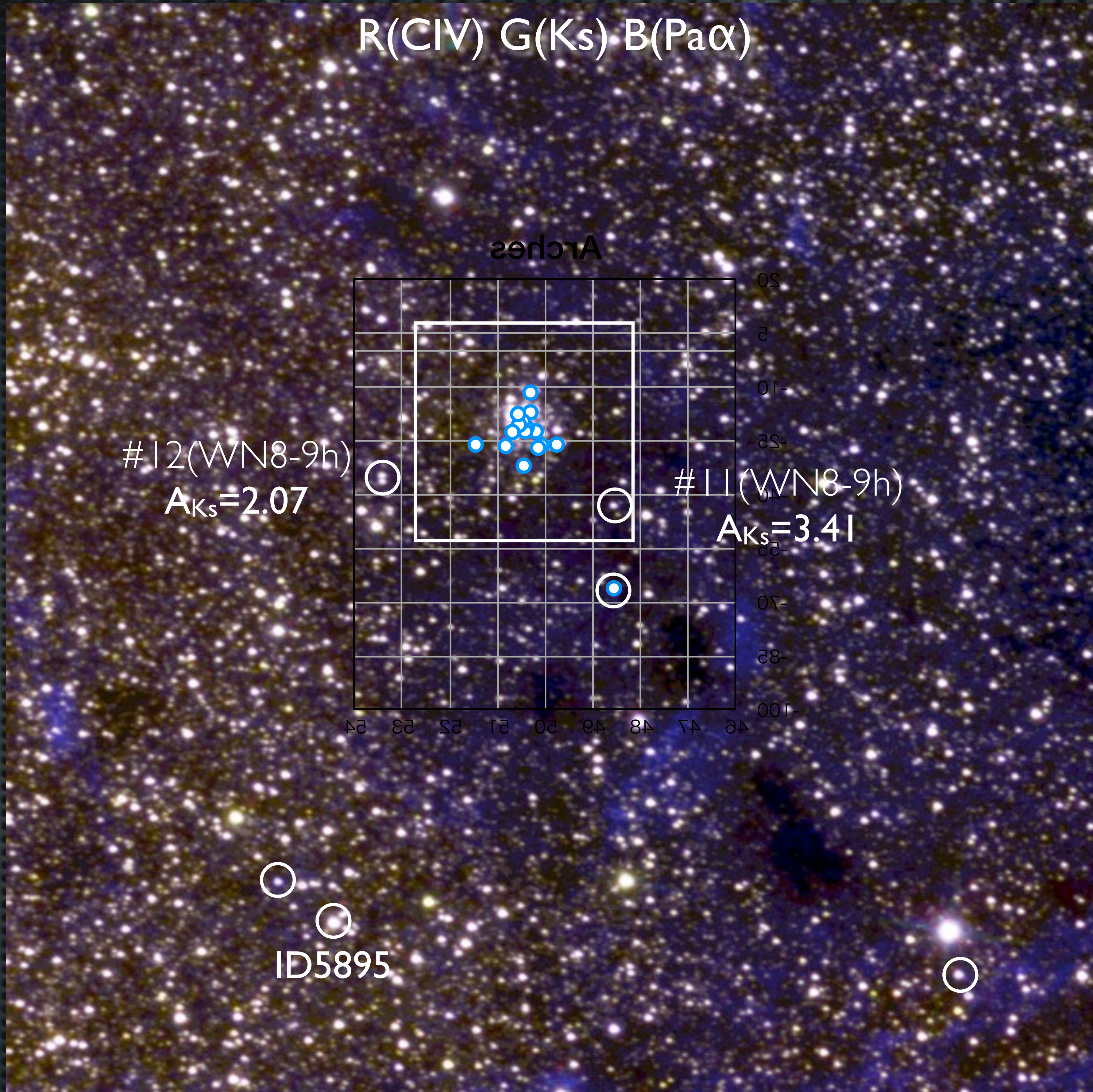
0.0063 (A_{Ks}=2.72 & 32%AT)

... average in 7<Ks<12

Arches cluster

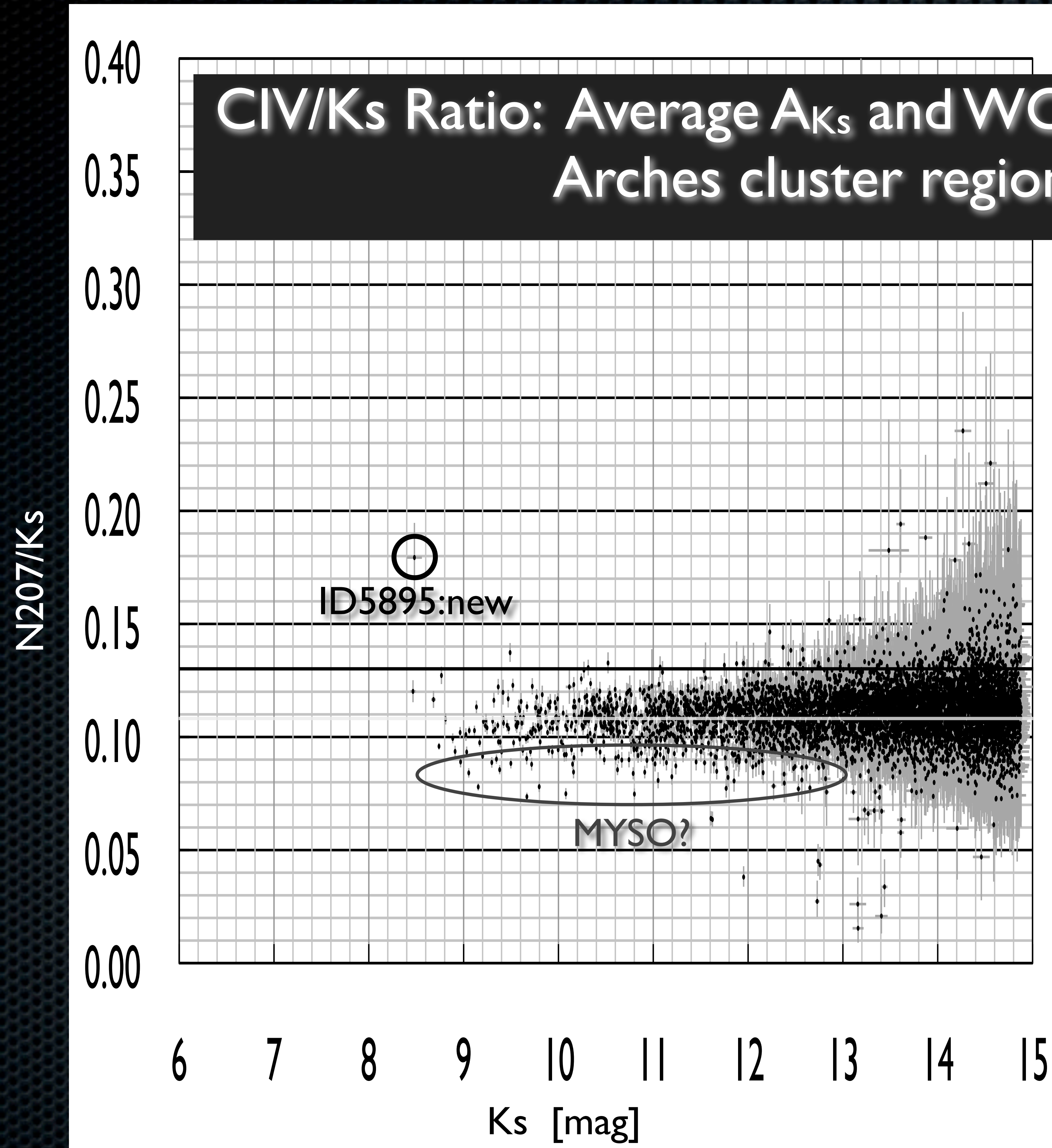
5.0'
1.0'

[16WR]
WR102
a(WN8)
aa(WN9)
ab(WN7)
ac(WN7)
ad(WN9)
ae(WN9)
af(WN9)
ag(WN9)
ah(WN9)
ai(WN9)
aj(WN9)
ak(WN6-7)
al(WN8)
ba(WN7)
bb(WN9)
bc(WN7)



Mauerhan+ 2010
WN8-9h

CIV/Ks Ratio: Average A_{Ks} and WC & MYSO Candidates
Arches cluster region (5’x5’)

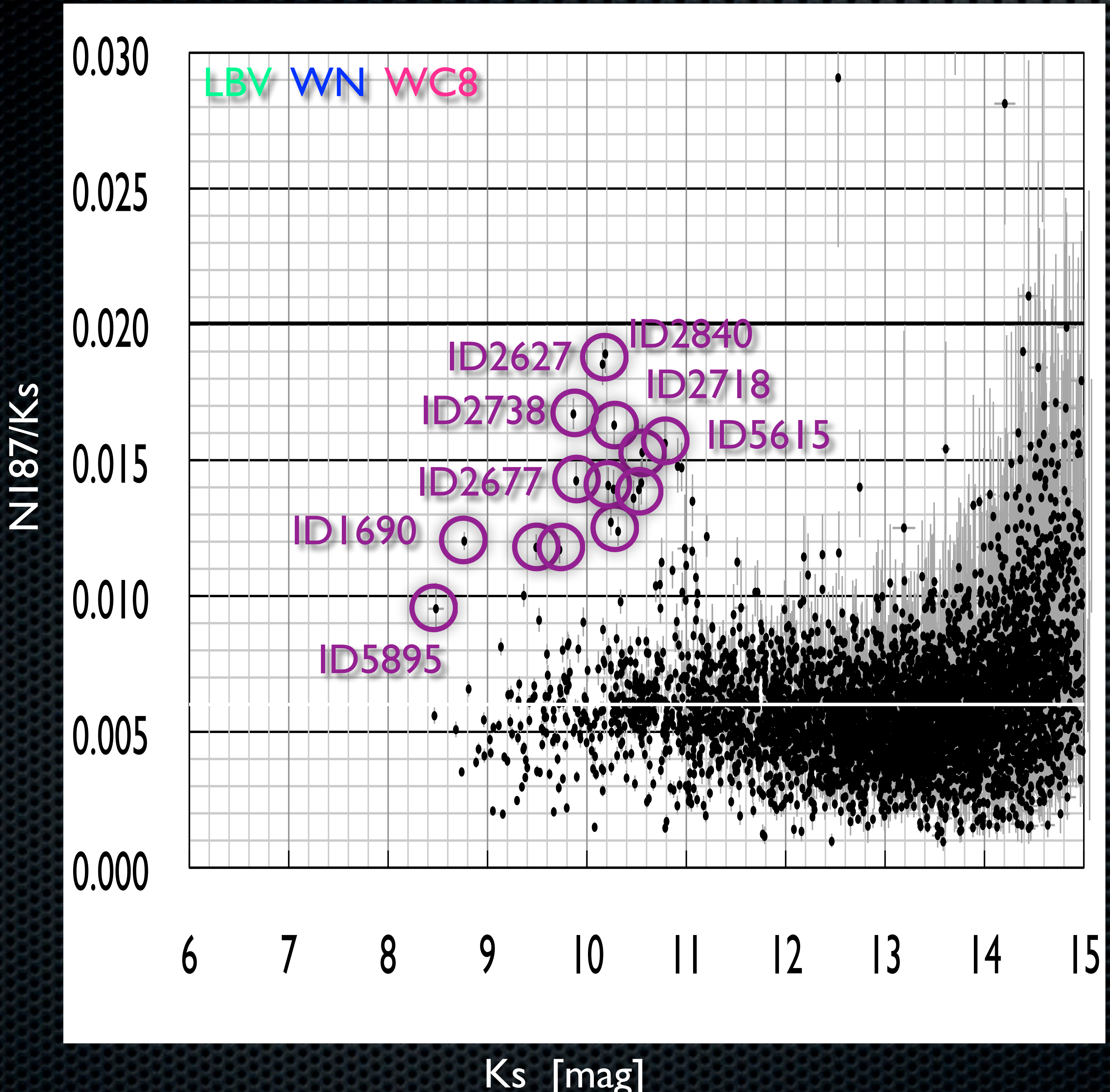


ID5895 0.182 > ~0.22 (WC7-8)

0.130 ... standard (zero-extinction)
0.1074 ... average in $7 < K_s < 12$
A_{Ks}=2.63±1.2 mag (A_V=42 mag)

#11: 0.110(WN8-9) => ~0.120
A_{Ks}=2.30 => 1.1 << 3.41(M10)
#12: 0.109(WN8-9) => ~0.120
A_{Ks}=2.43 => 1.1 << 2.07(M10)

N187/Ks; Arches cluster



0.020 (A_{Ks}=2.63 & 100%AT)

0.0060 (A_{Ks}=2.63 & 30%AT)
... average in 7<Ks<12

Time Variation of LBV (Quintuplet)

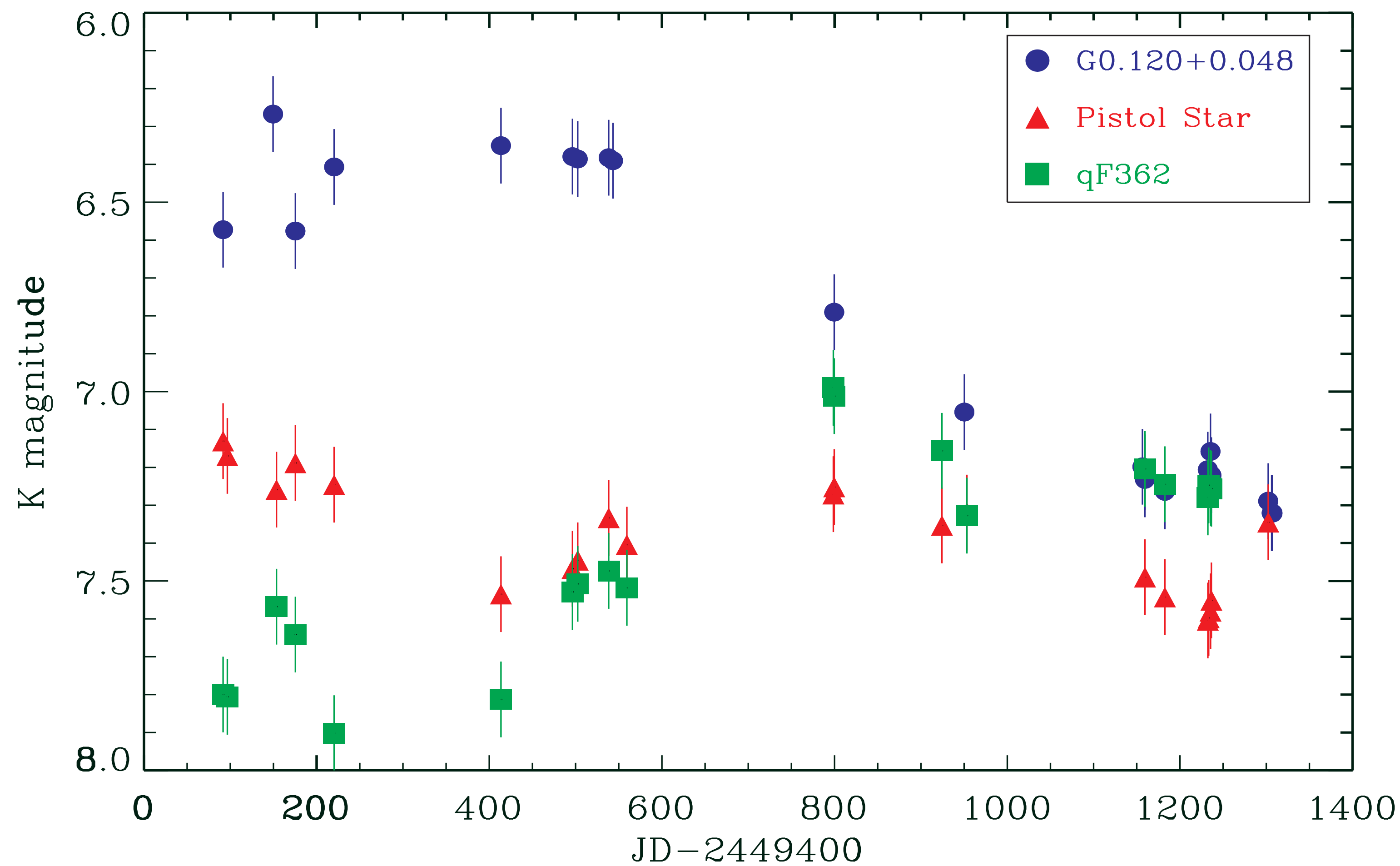
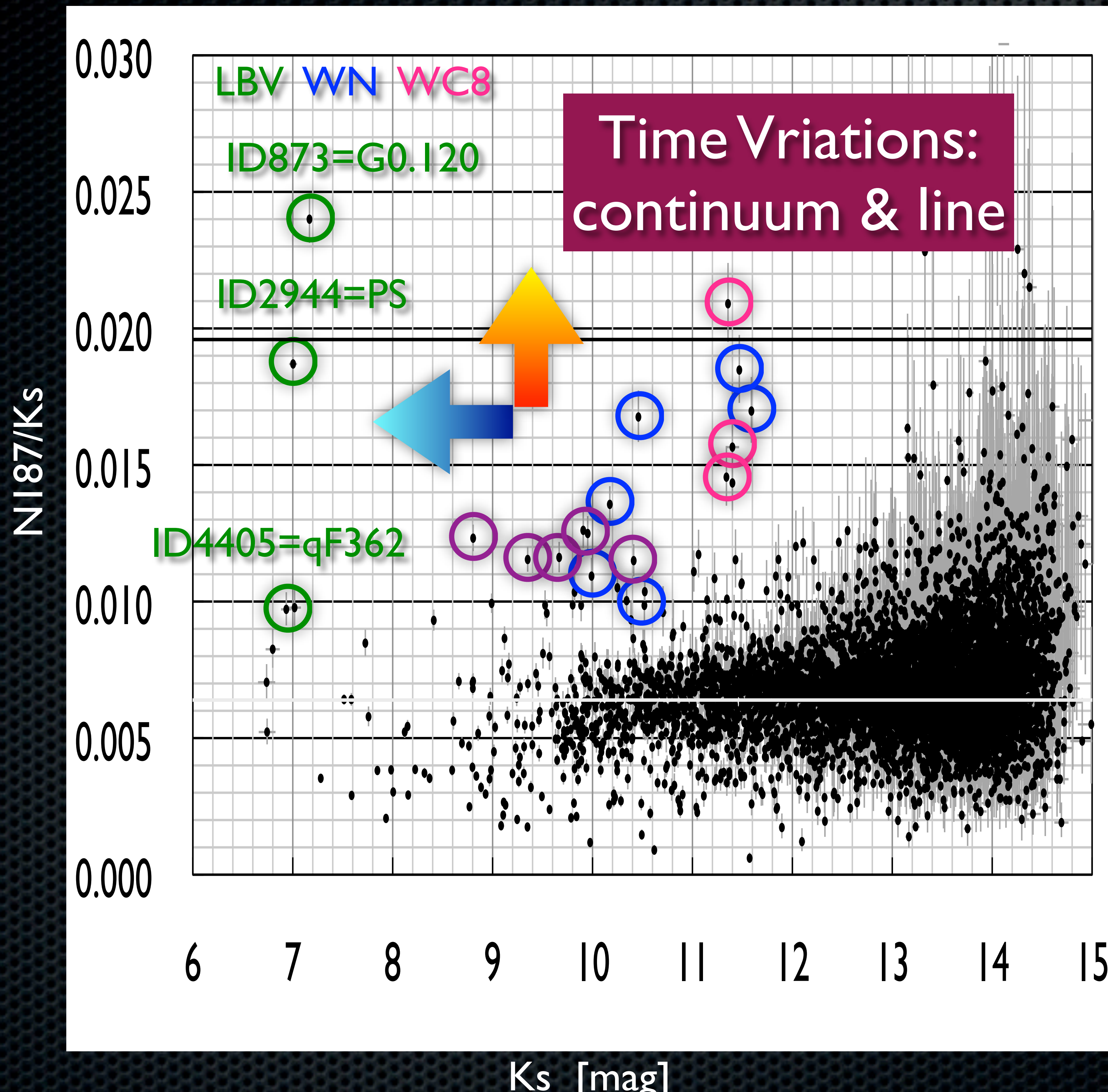


Figure 3. *K*-band light curves for LBV G0.120−0.048, the Pistol Star, and qF362. Photometric uncertainties are 0.1 mag, as derived using the nightly standard deviations in magnitude for standard stars used in Glass et al. (1999, 2001, 2002). The data for LBV G0.120−0.048 extend between 1994 May 19 and 1997 September 15, but are presented in Julian days for the figure.

(A color version of this figure is available in the online journal.)

N187/Ks; Quintuplet cluster



0.0195 (A_{Ks}=2.72 & 100%AT)

0.0063 (A_{Ks}=2.72 & 32%AT)
... average in 7<Ks<12