Unveiling the Massive Stars in the Galactic Center (GC)

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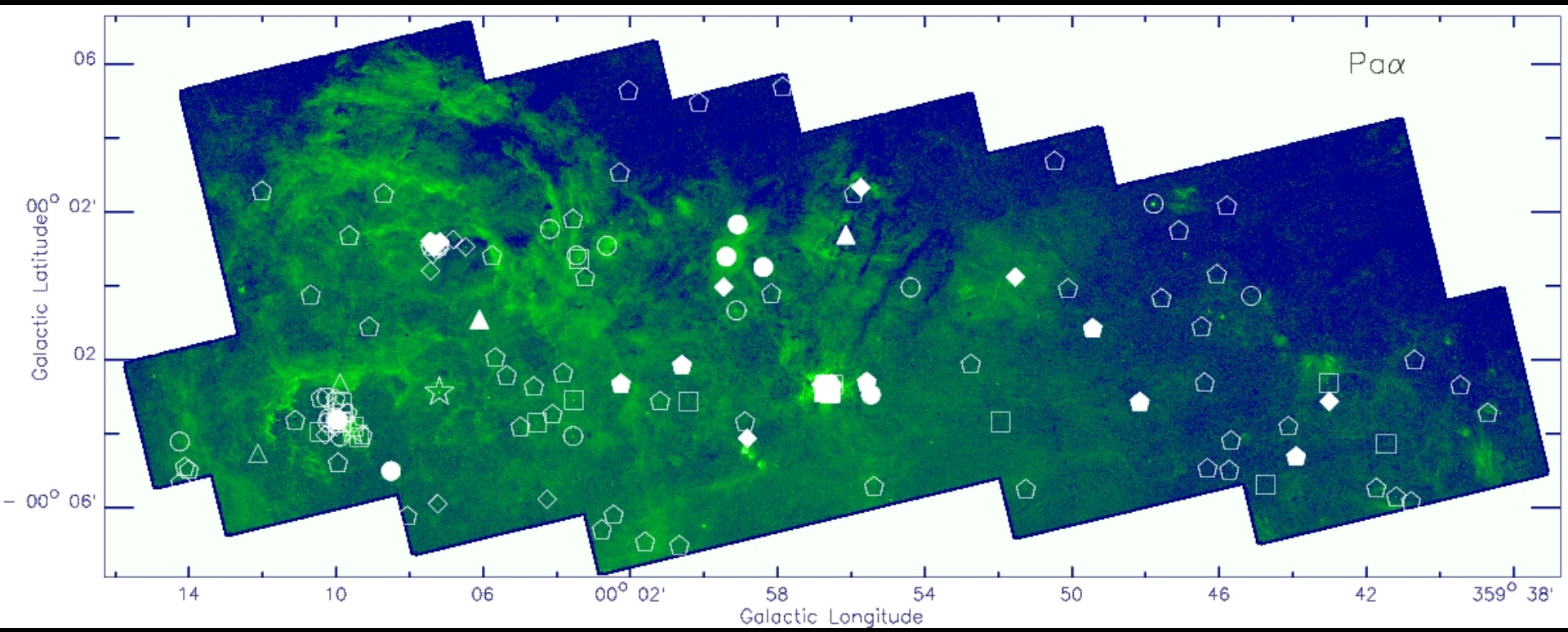
Introduction

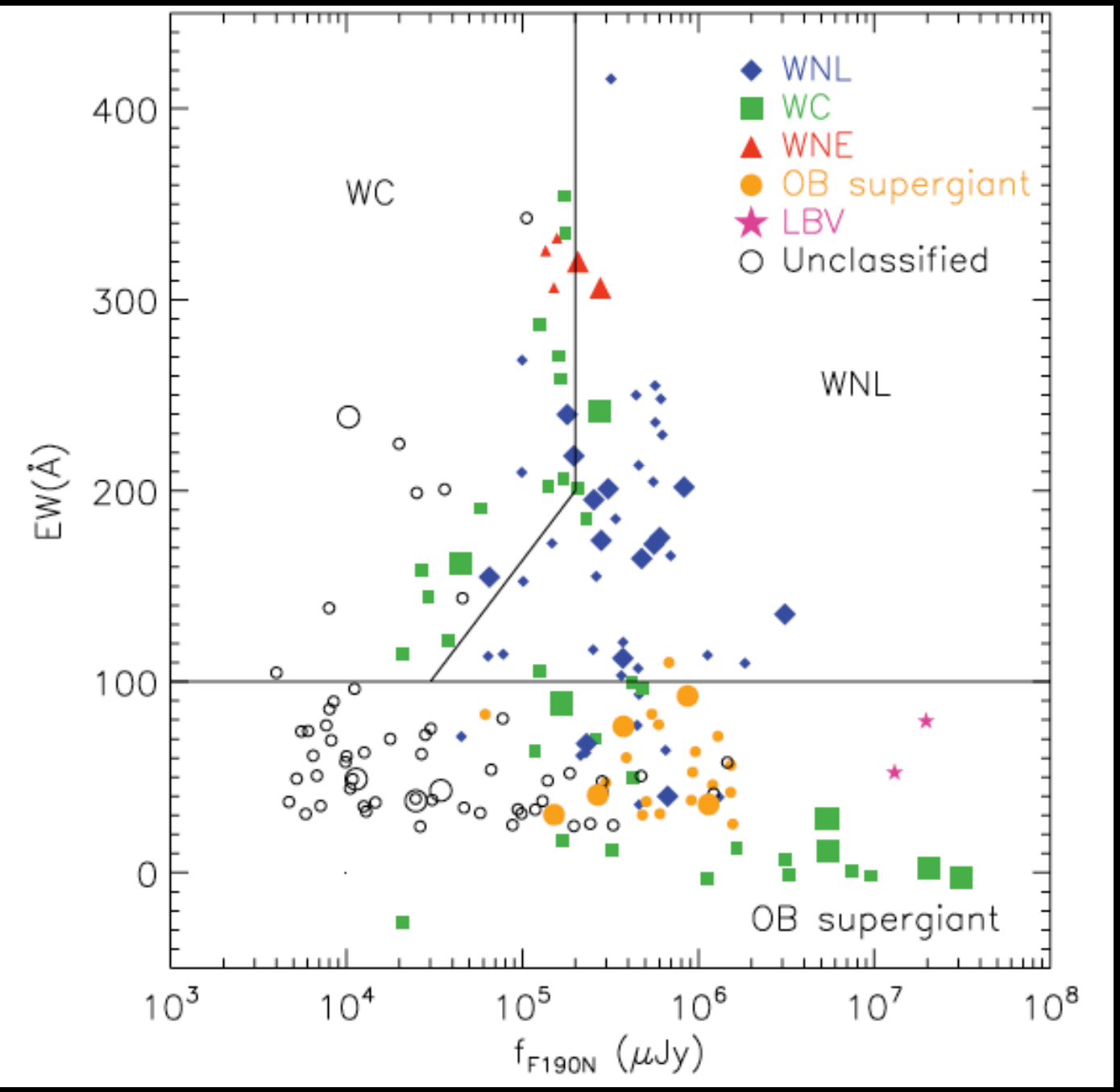
- Galactic Center is the only galactic nucleus, where we can resolve individual young massive stars near a SMBH
  - The star formation mode near a SMBH
  - The properties of the clusters
  - The star formation efficiency

- Three star clusters in the Galactic Center, the Arches, Quintuplet and Central Clusters
- More and more `field' evolved massive stars found in the GC
  - HII regions, Cotera+99
  - Narrow-band filters from ground-based telescope, Homeier+03
  - X-ray and near-IR counterparts, Mauerhan+09
  - Paschen-α emission lines, Dong+11

HST/NICMOS Paα GC SURVEY



180 Paα emitting sources, ~80 outside of the three clusters
Diamond: WN, Square: WC, Triangle: WNE, Circle: OB supergiant, Star: LBV, Pentagon: Unclassified, solid symbol: with X-ray counterparts



Intrinsic F190N magnitude vs Equivalent Width at F187N

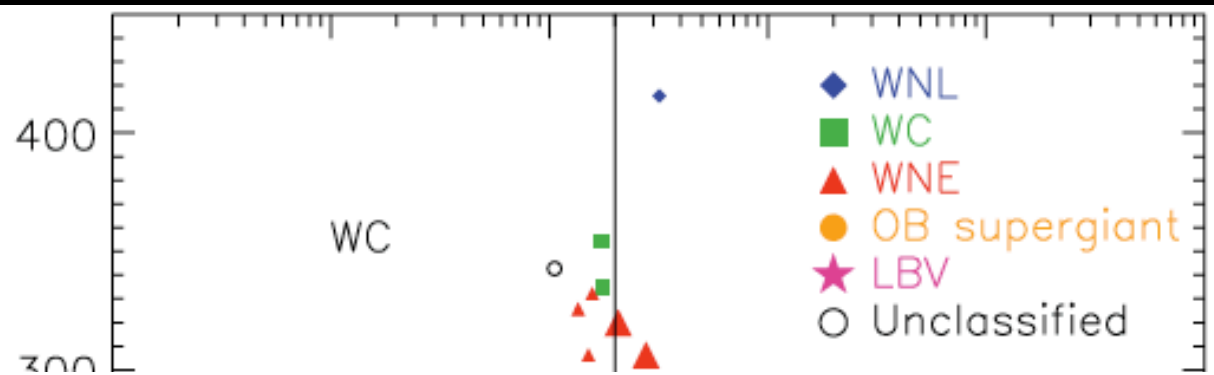
WN: large EW, correlation between the EW and F190N, although with large uncertainty. The WN with smallest F190N consistent with that predicted by Figer et al 1995. We should detect most of the WN

WC: large EW range, determined by the dust component

O supergiant: small EW, weaker wind

Unclassified: combination of dusty WC and OIF+

Dong+12



Intrinsic F190N magnitude vs Equivalent Width at F187N

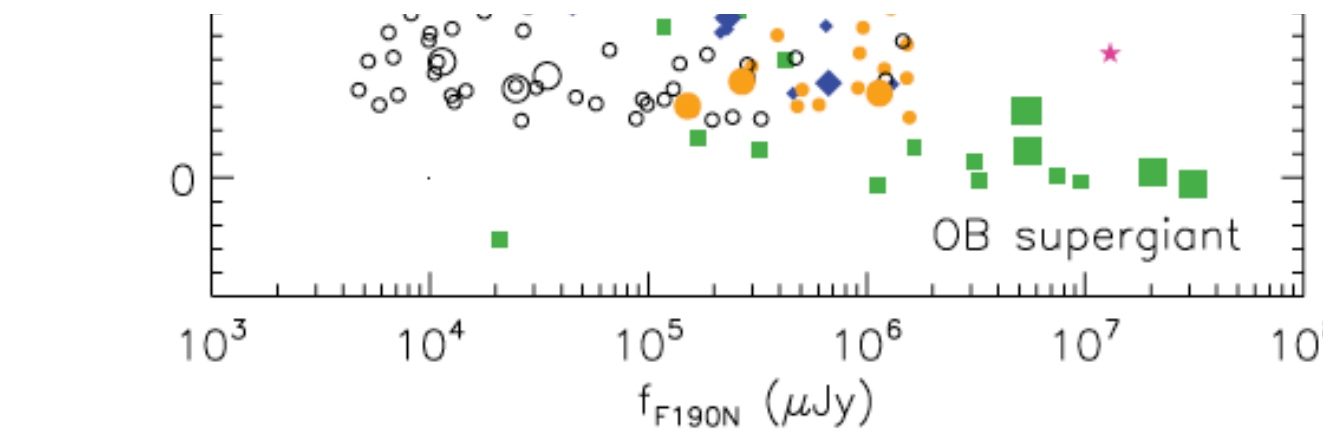
WN: large EW, correlation between the EW and F190N, although

Table 5
Distribution of WR Subtypes in the GCR

Group	WNE	WNL	WCE	WCL	WR_{tot}	WC/WN	WCL/WC	WC/WR_{tot}	References
GCR "isolated"	2	14	0	10	26	0.63	1.00	0.38	1, 2, 3, 4, 5, 6
Arches	0	15	0	0	15	n/a	0.00	0.00	7
Quintuplet	1	4	0	11	16	2.20	1.00	0.69	2, 8, 9
Central	1	17	1	12	31	0.72	0.92	0.42	10
GCR total	4	50	1	33	88	0.63	0.97	0.39	...

References. (1) This work; (2) Mauerhan et al. 2010b; (3) Cotera et al. 1999; (4) Homeier et al. 2003; (5) Muno et al. 2006; (6) Mikles et al. 2006; (7) Figer & Kim 2002; (8) Liermann et al. 2009; (9) Figer et al. 1999c; (10) Paumard et al. 2006.

Mauerhan et al 10c



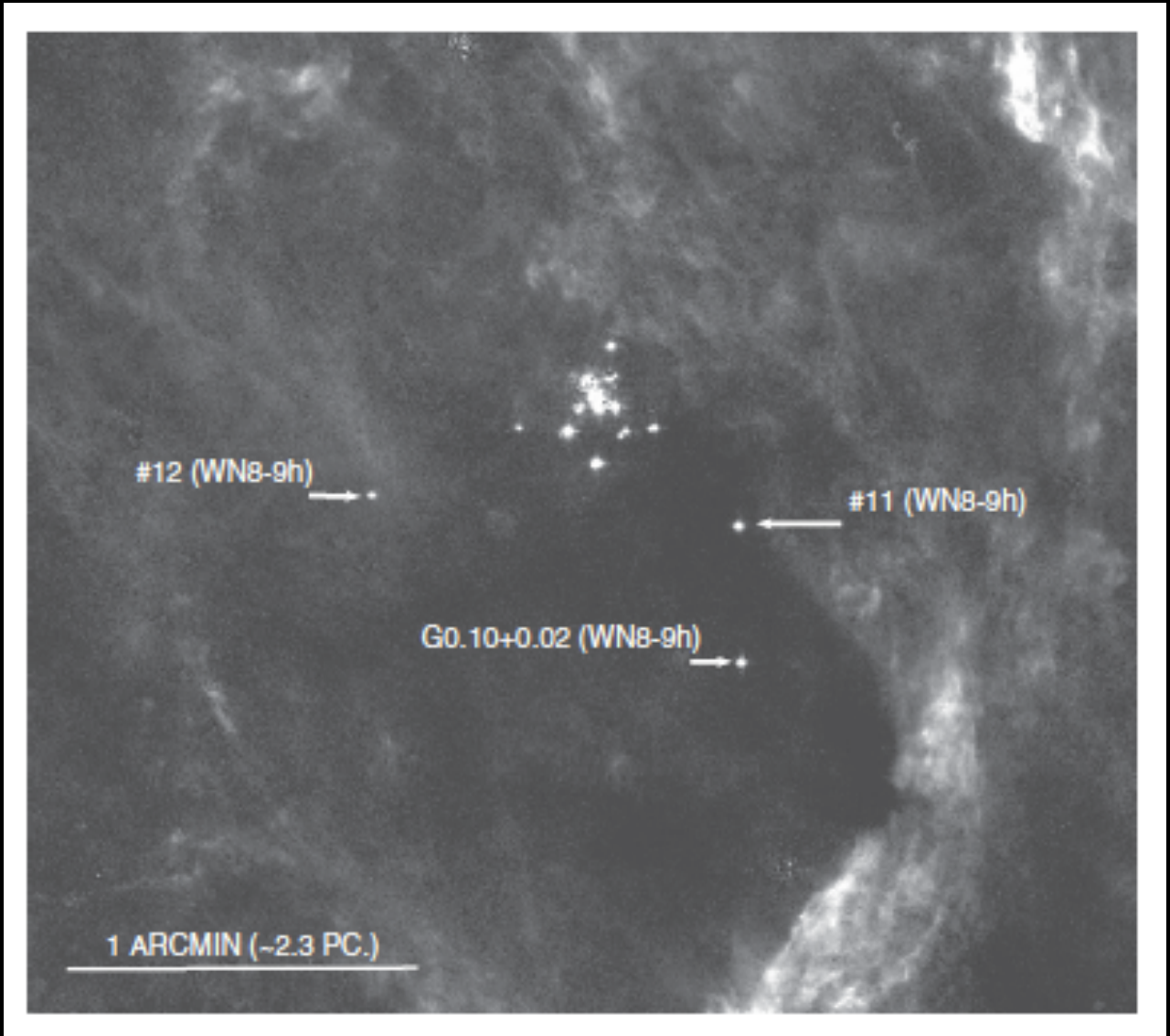
O supergiant: small EW, weaker wind

Unclassified: combination of dusty WC and OIF+

Dong+12

The origin of the `field' evolved massive stars

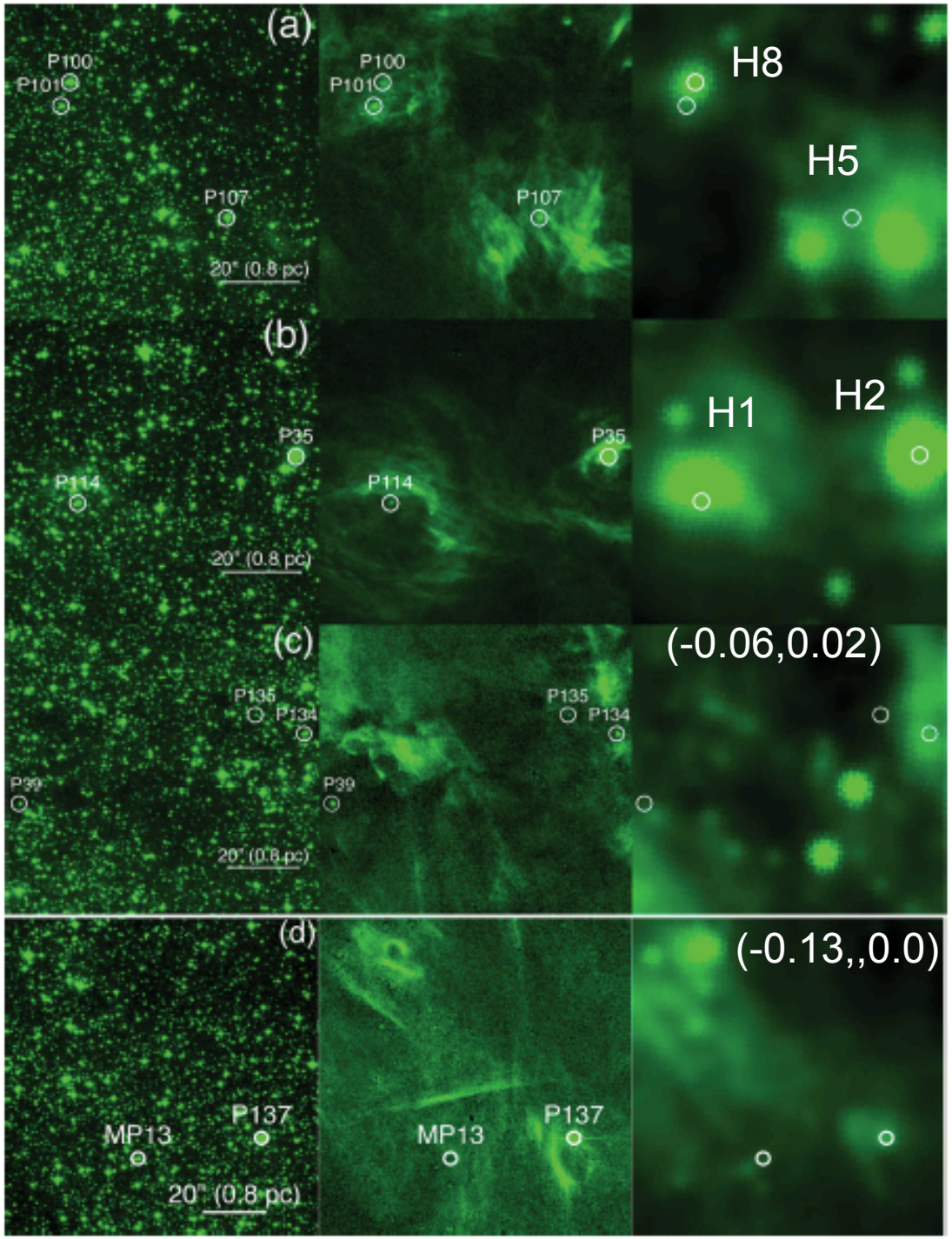
- Massive stars prefer to form in clusters
- Two possible origins
  - Previous members of the three star clusters



three field evolved massive stars (WN 8-9 h) near the Arches Cluster
less than 1-2 pc in projection, Mauerhan+10

The origin of the `field' massive stars

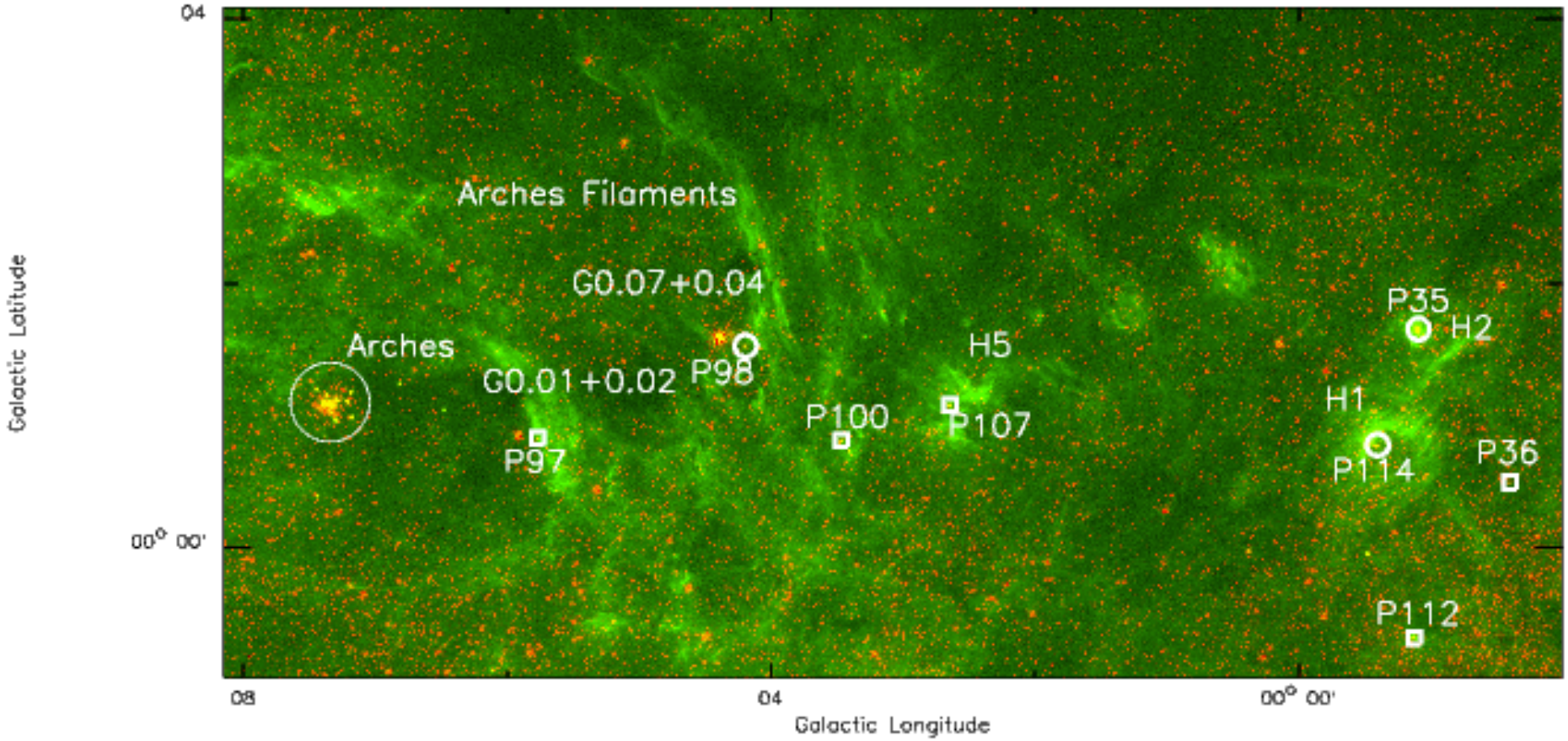
- Massive stars preferred to form in clusters
- Two possible origins
  - Previous members of the three star clusters
  - Stars belong to isolated small star clusters
    - Sgr A A-D, Yusef-Zadeh+10, Mills+11
    - SiO clumps found near Sgr A*, potential early star formation process, Yusef-Zadeh+13



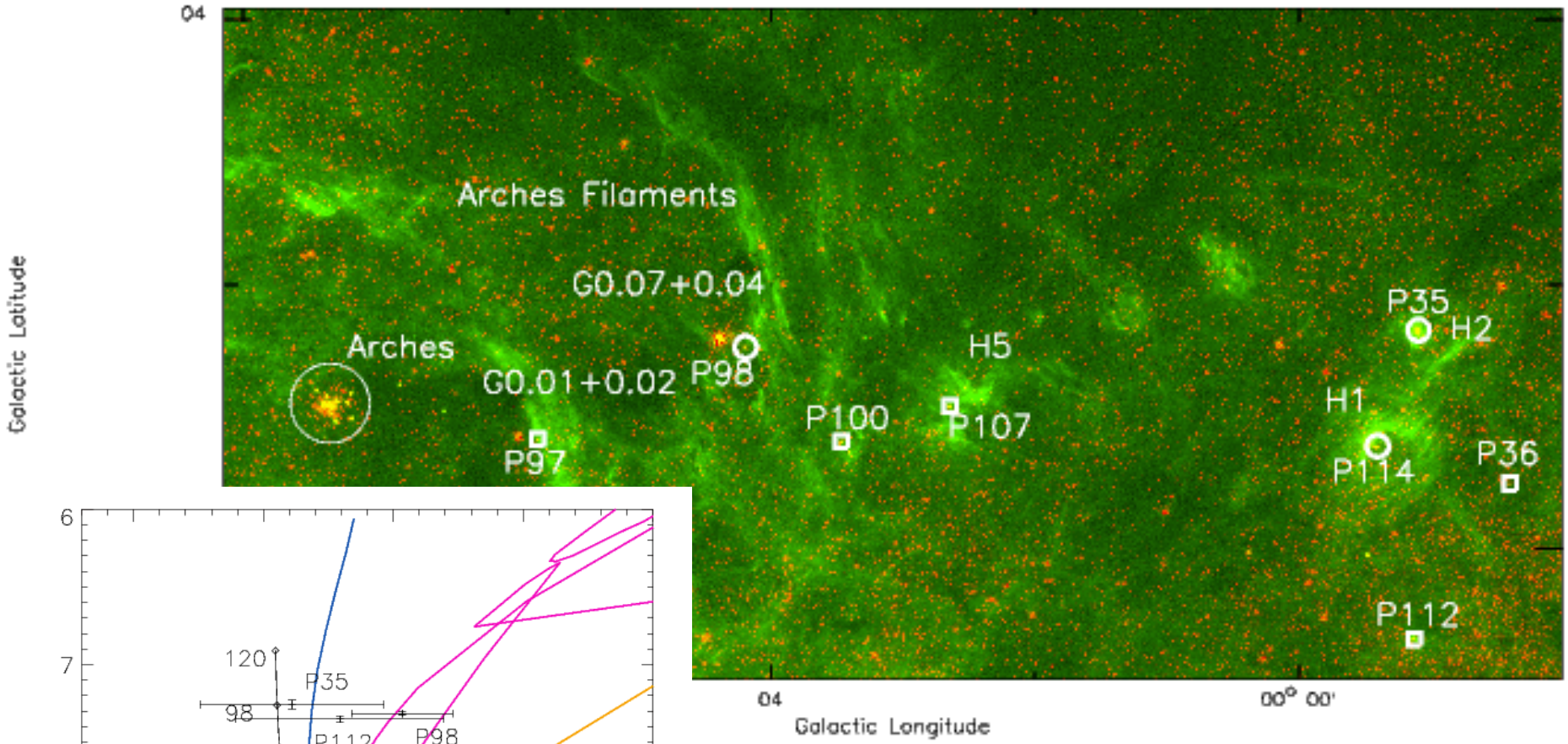
Evolved massive stars with nearby HII regions.

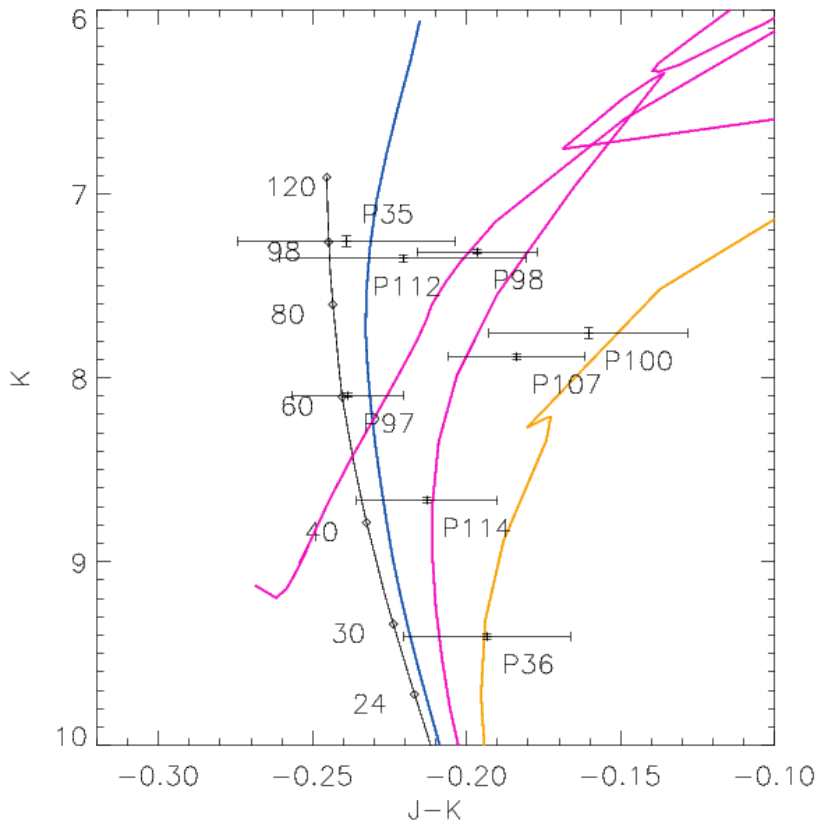
Evolved massive stars could provide enough UV photons to ionize the HII regions

Gemini GNIRS/NIFS Spectroscoph



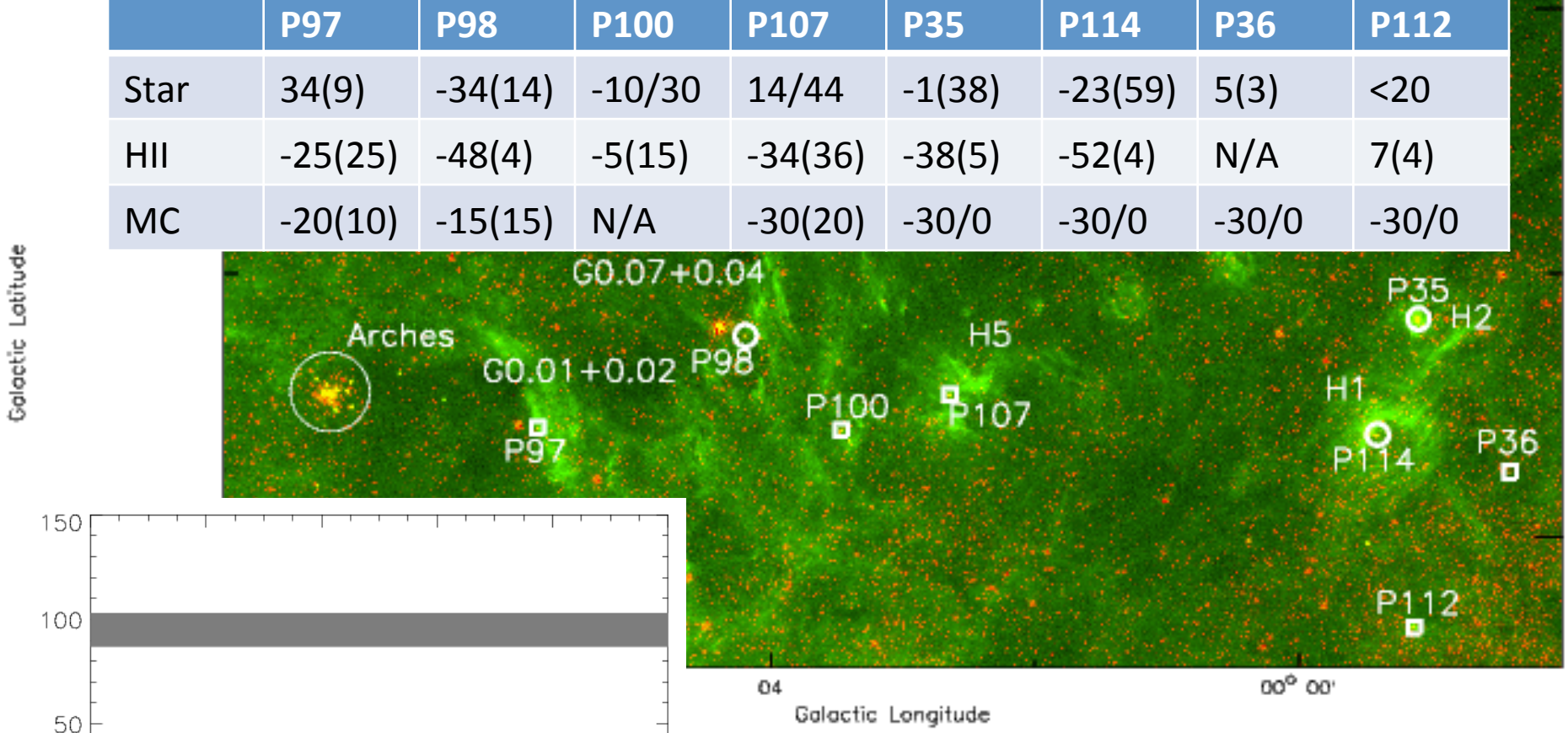
GNIRS: H and K bands, three sources, NIFS: K band, five sources
Aim: Using radial velocities to derive the relationship between stars, nearby HII regions and the Arches cluster
Method: He II 2.189, NIII 2.247/2.251 doublets

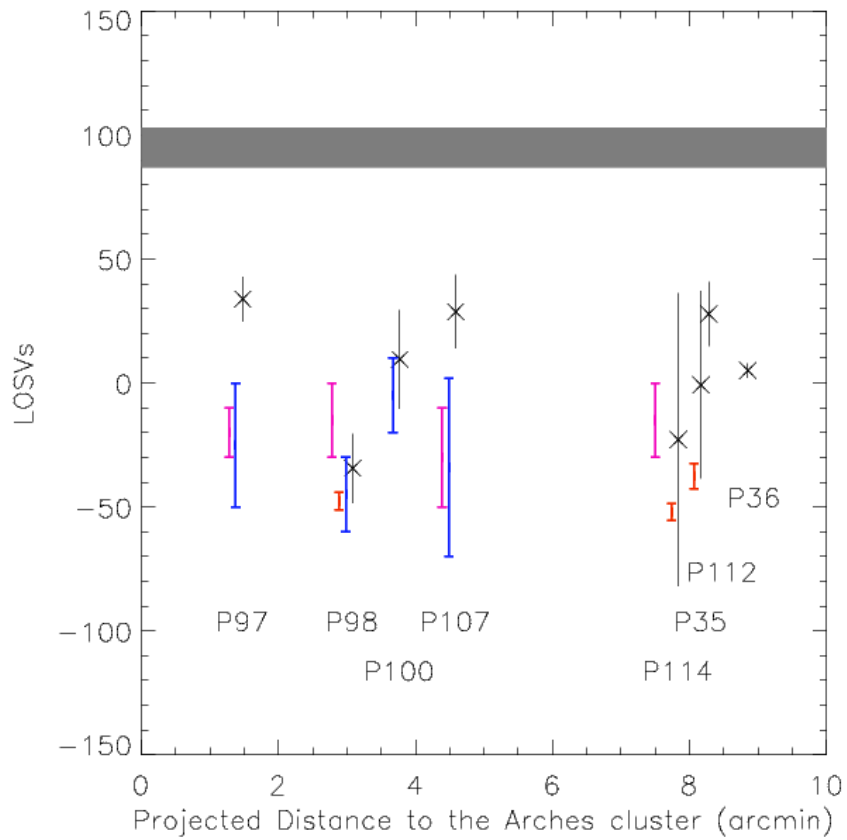




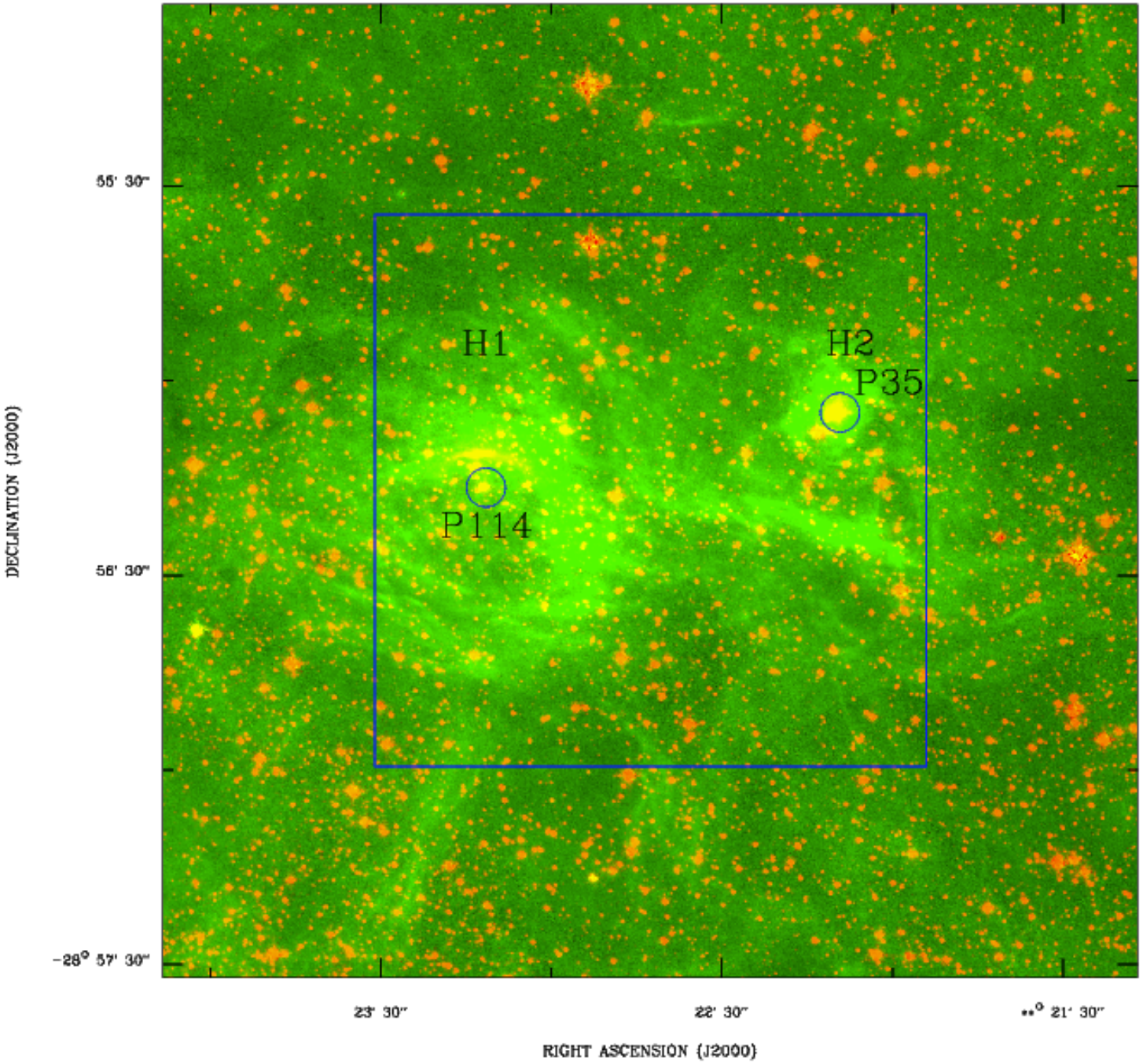
Proper motion: assuming the stars ejected from the Arches cluster when they were formed.
The 3D velocity relatively to the Arches cluster: ~60-140 km/s, low limit.
unreddened CMD: Lines: Genova, 1, 2, 4, 6.3 Myr
These eight stars are < 7 Myr old
P100, P107 and P36 are older than the Arches cluster.

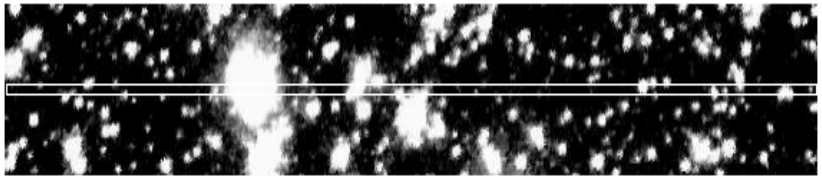
	P97	P98	P100	P107	P35	P114	P36	P112
Star	34(9)	-34(14)	-10/30	14/44	-1(38)	-23(59)	5(3)	<20
HII	-25(25)	-48(4)	-5(15)	-34(36)	-38(5)	-52(4)	N/A	7(4)
MC	-20(10)	-15(15)	N/A	-30(20)	-30/0	-30/0	-30/0	-30/0



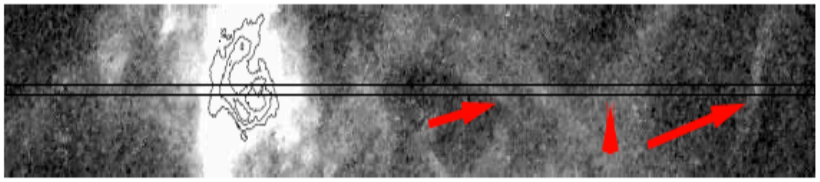


Grey shaded area: the Arches cluster -98(8) km/s Figer+02
`cross’ : eight massive stars
Red lines: nearby HII regions from Brγ
Blue lines: nearby HII regions from H92α, Lang et+01
Cyan lines: nearby molecular clouds, Serabyn & Guesten, 87, Tsuboi+99, 11

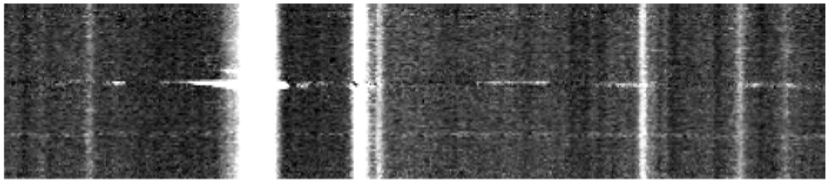

H1
H2
P35
P114
55' 30"
56' 30"
-28° 57' 30"
23' 30"
22' 30"
21' 30"
DECLINATION (J2000)
RIGHT ASCENSION (J2000)



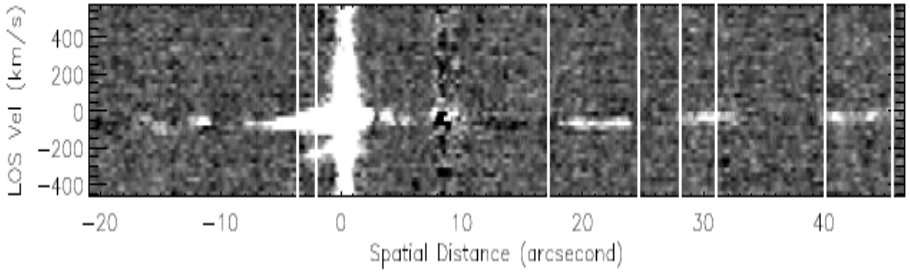
HST F190N image



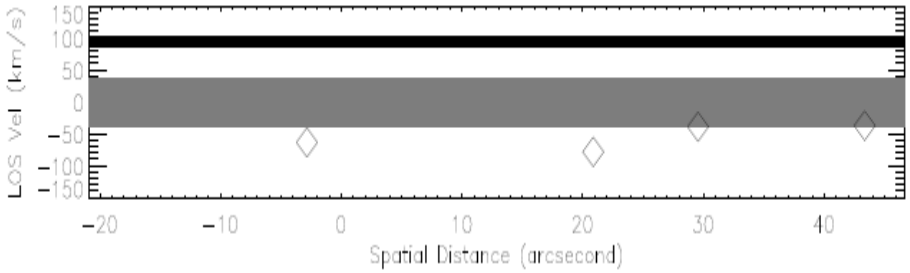
HST Paα image



Gemini GNIRS spectrum around Br_Y

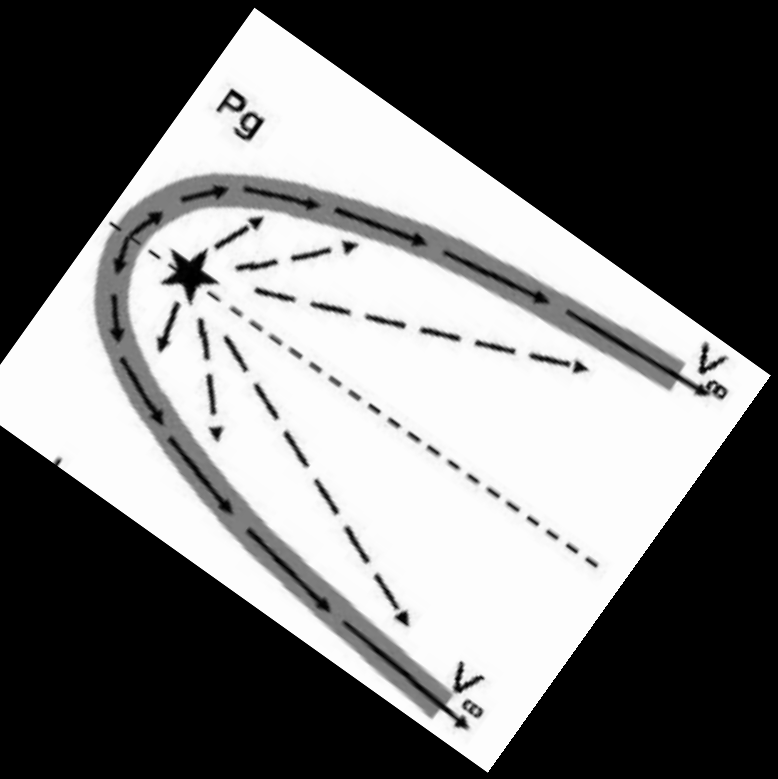


Remove the stellar continuum



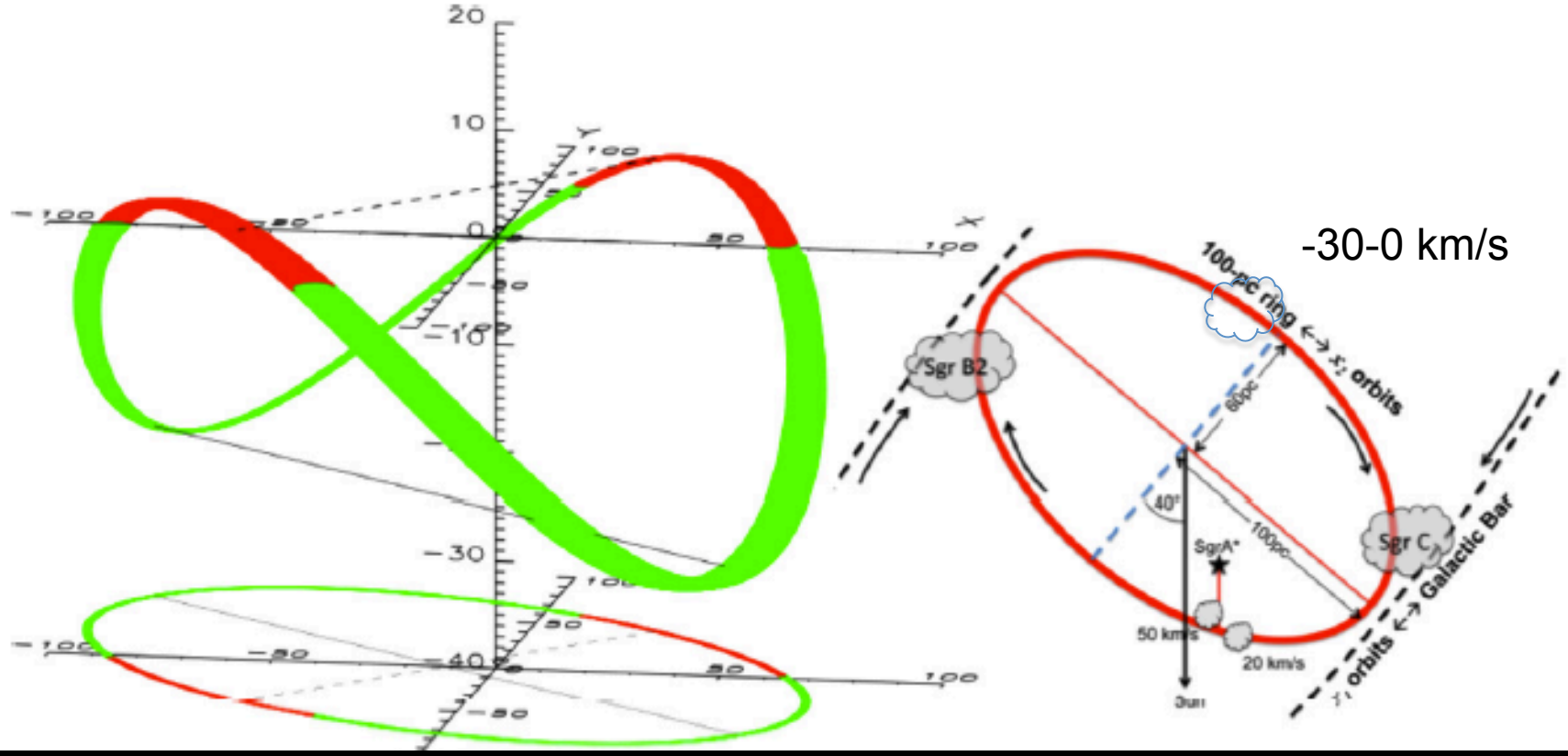
Black: the Arches cluster, -98(8) km/s
Grey: P35
Diamond: ionized gas

P35 in H2. The ionized gas is blueshifted, compared to the stars and nearby molecular clouds. No H_2 2.121. Not the bow shock, Pressure-driven flow model?



Zhu Qing-Feng+08

Pressure-Driven flows:
Stars is nearly stable relatively to the ISM
Stas have strong stellar wind
1)Stars are in front of the molecular cloud
2)No H_2 2.121 micron needed
3)The radial velocity of the ionized gas can be accelerated to very high



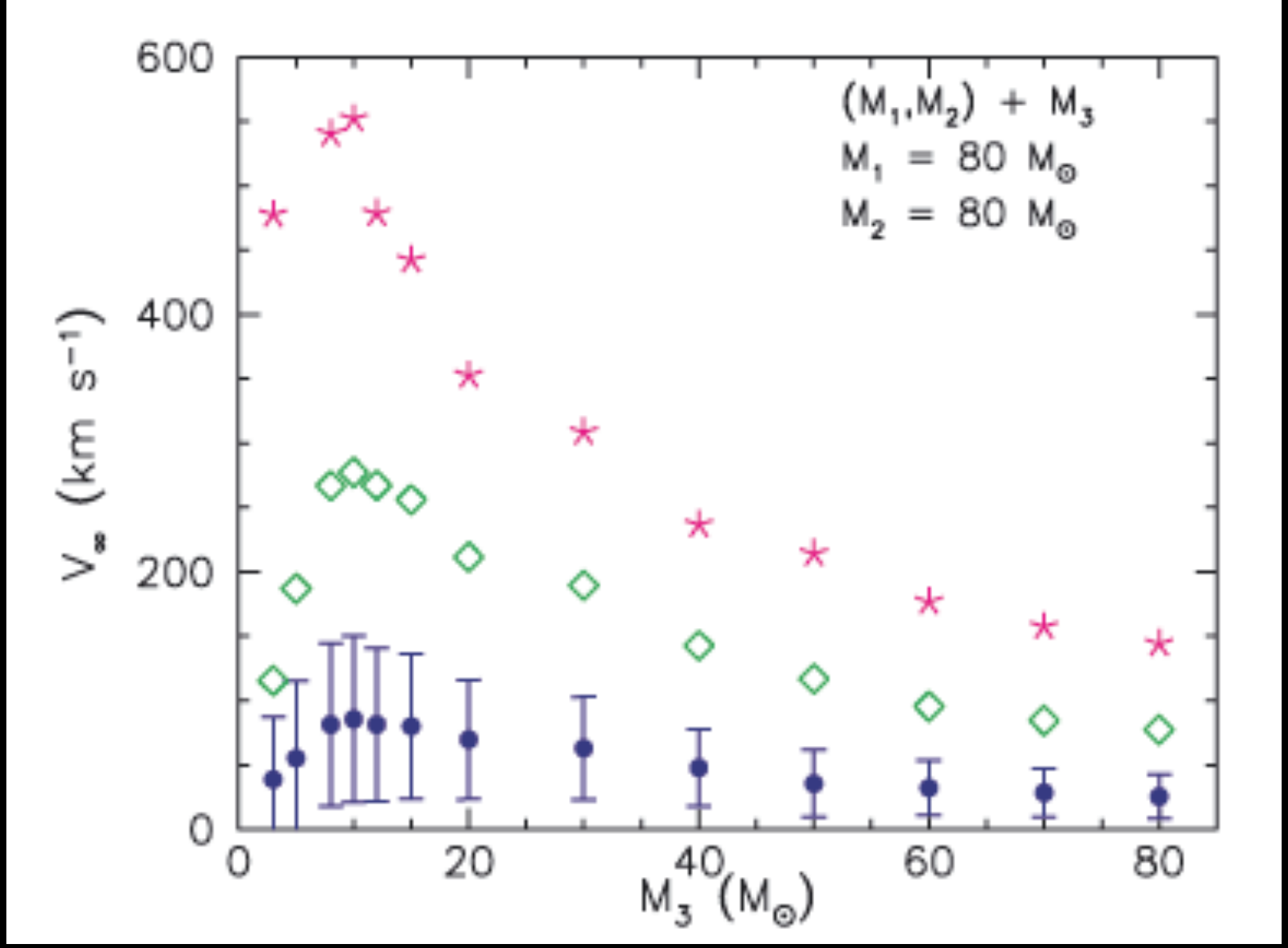
Molinari+11

Molecular clouds follow a ∞ shape, the orbital period is ~ 3Myr, -30-0 km/s is behind the Sgr A* now. -30-0 km/s and Sgr A* could meet ~2 Myr ago. The strong stellar wind in the Central cluster triggered the star formation in H1/H2.

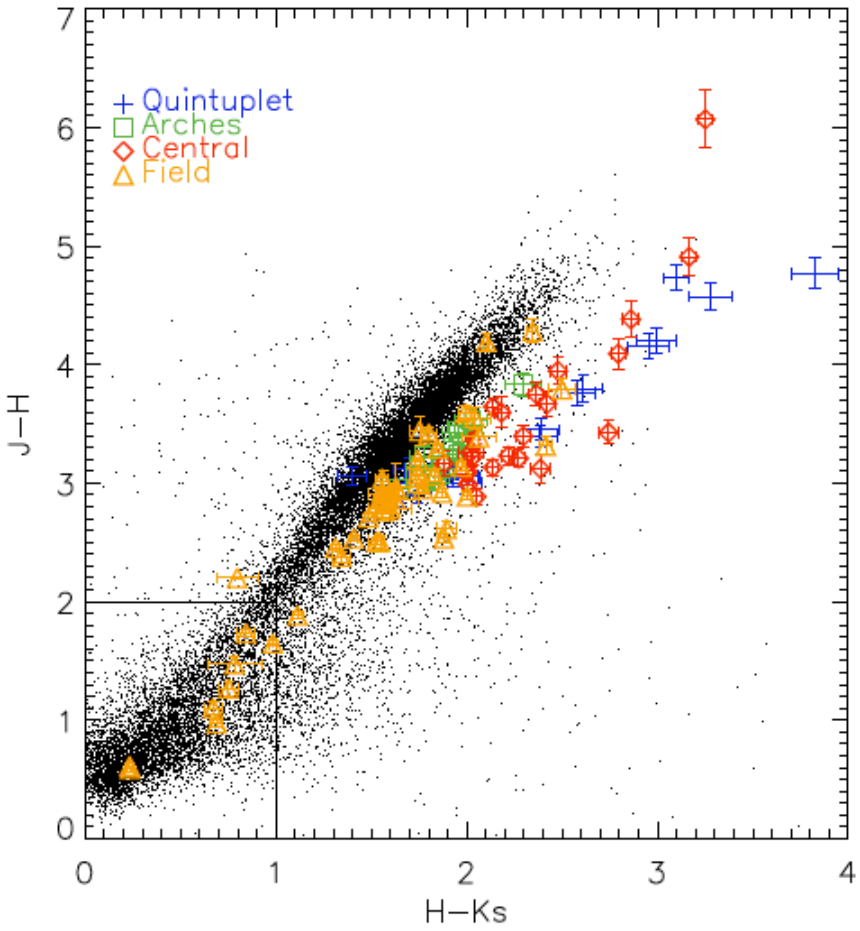
Summary

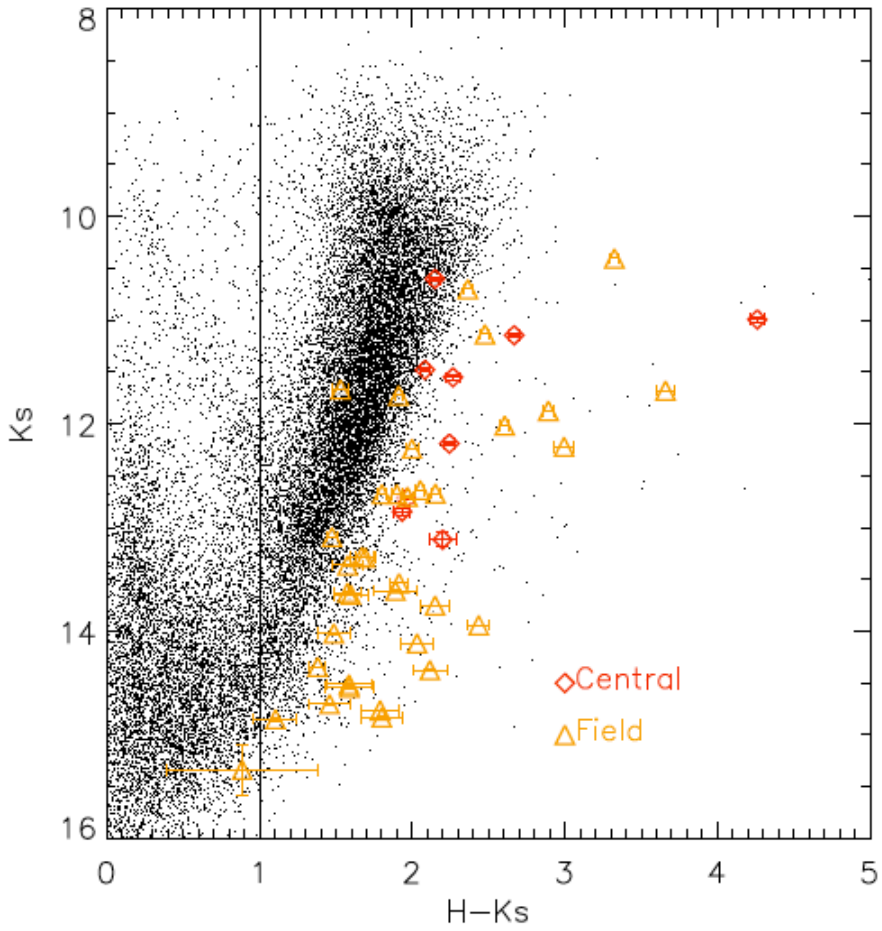
- Evolved Massive Stars pervade the GC
- Most WN stars have been identified, but we still miss many WC stars and O supergiants
- Our new Gemini GNIRS/NIFS spectra
  - A new O If+ star, P97, <1.5' (3.6 pc) from Arches cluster, potential former members
  - H5, a runaway star, interlopers unassociated to nearby molecular cloud
  - H1/H2, pressure-driven flow model, indicating in-situ star formation


Thank you



Simulation of 3-body interaction
Gvaramadze+11. Circle: mean velocity. Diamond: top 10%. Star: top 1%.
The eight stars could be ejected from the Arches cluster

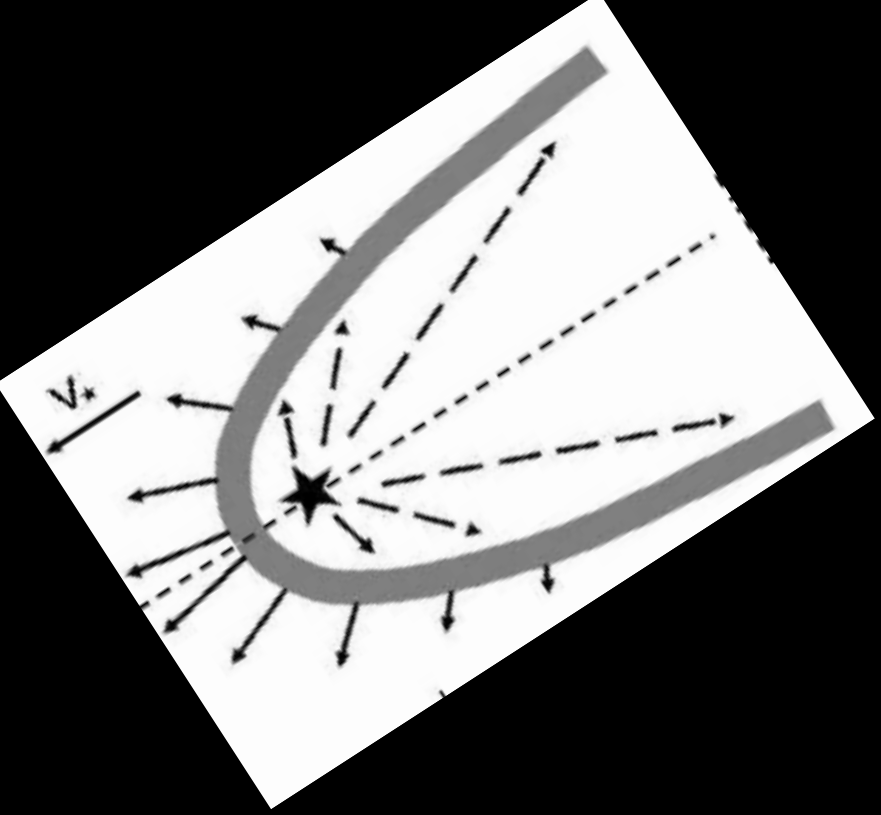




Dong et al., 2012

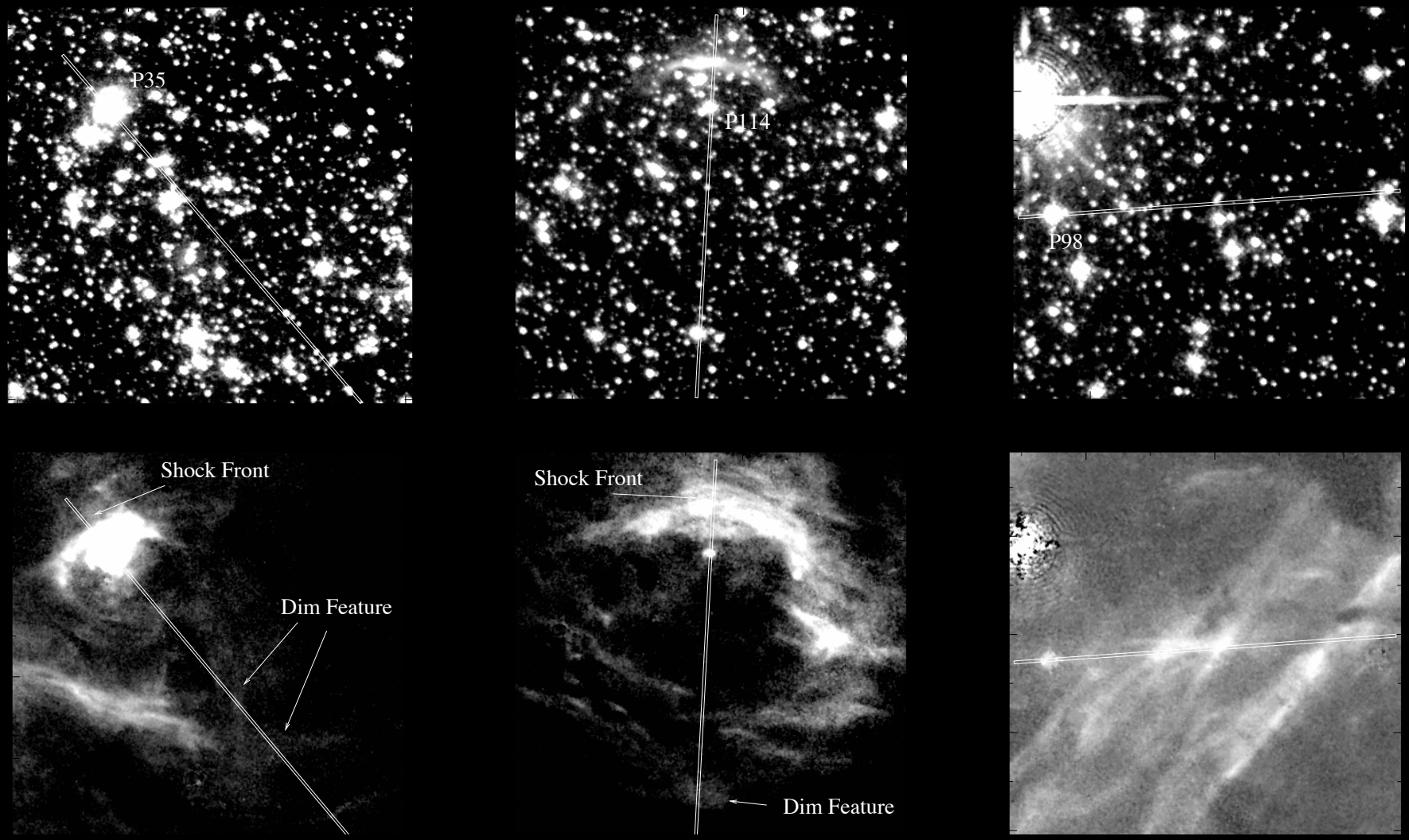
color-magnitude diagram for Paα emitting sources
near-IR magnitude from SIRIUS and 2MASS catalog
Black dots: SIRIUS GC catalog, most of them are Red Clump, Red Branch Stars and asymptotic giant branch stars.
Color symbols: Paα emitting sources in and outsider the three clusters

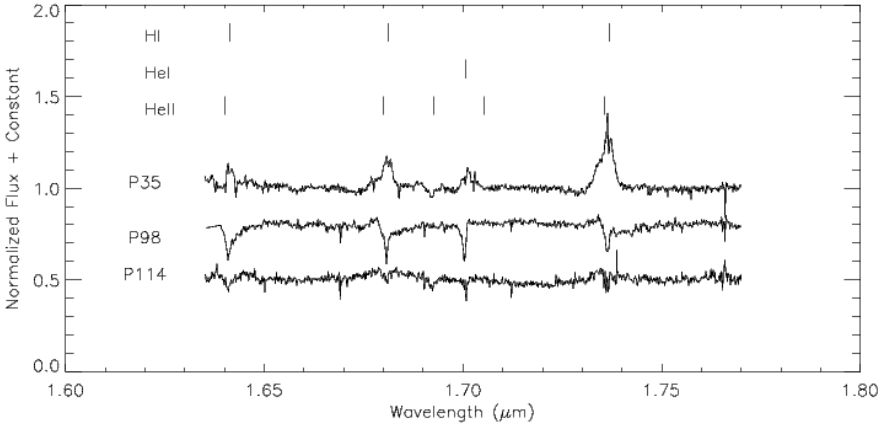
Most of the `field' Paα emitting sources are indeed in the GC

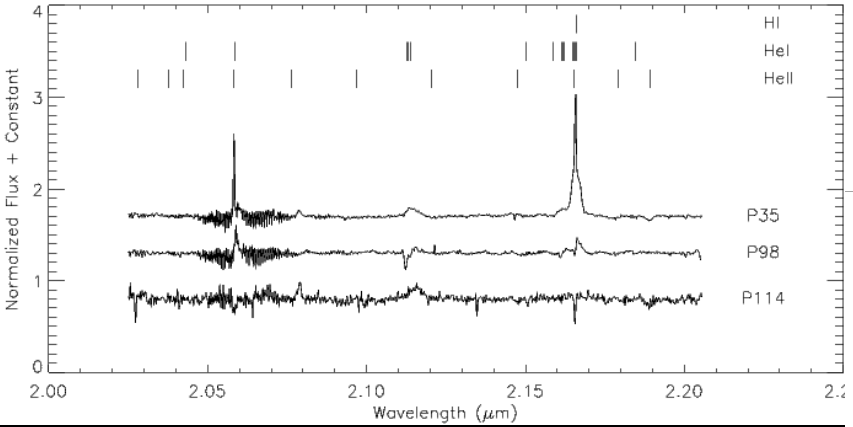


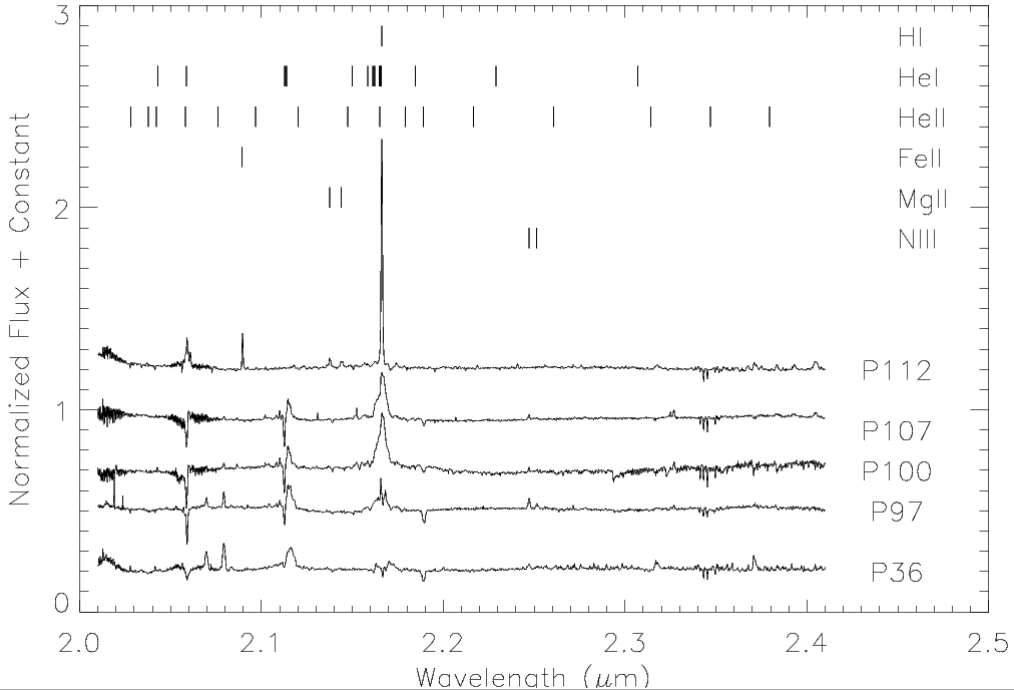
Zhu Qing-Feng+08

Bow shock:
Stars quickly move into the ISM
1)Stars are behind the molecular cloud
2)H_2 2.121 micron shock lines
3)Near the vertex, the radial velocity of the ionized gas is roughly equal to the radial velocities of the massive stars


P35
P114
P98
Shock Front
Dim Feature
Shock Front
Dim Feature


HI
HeI
HeII
P35
P98
P114
Normalized Flux + Constant
Wavelength (μm)


HI
HeI
HeII
P35
P98
P114
Normalized Flux + Constant
Wavelength (μm)


HI
HeI
HeII
FeII
MgII
NIII
P112
P107
P100
P97
P36
Normalized Flux + Constant
Wavelength (μm)