“The Large Scale Structure of the Orion Nebula.”

CAMK

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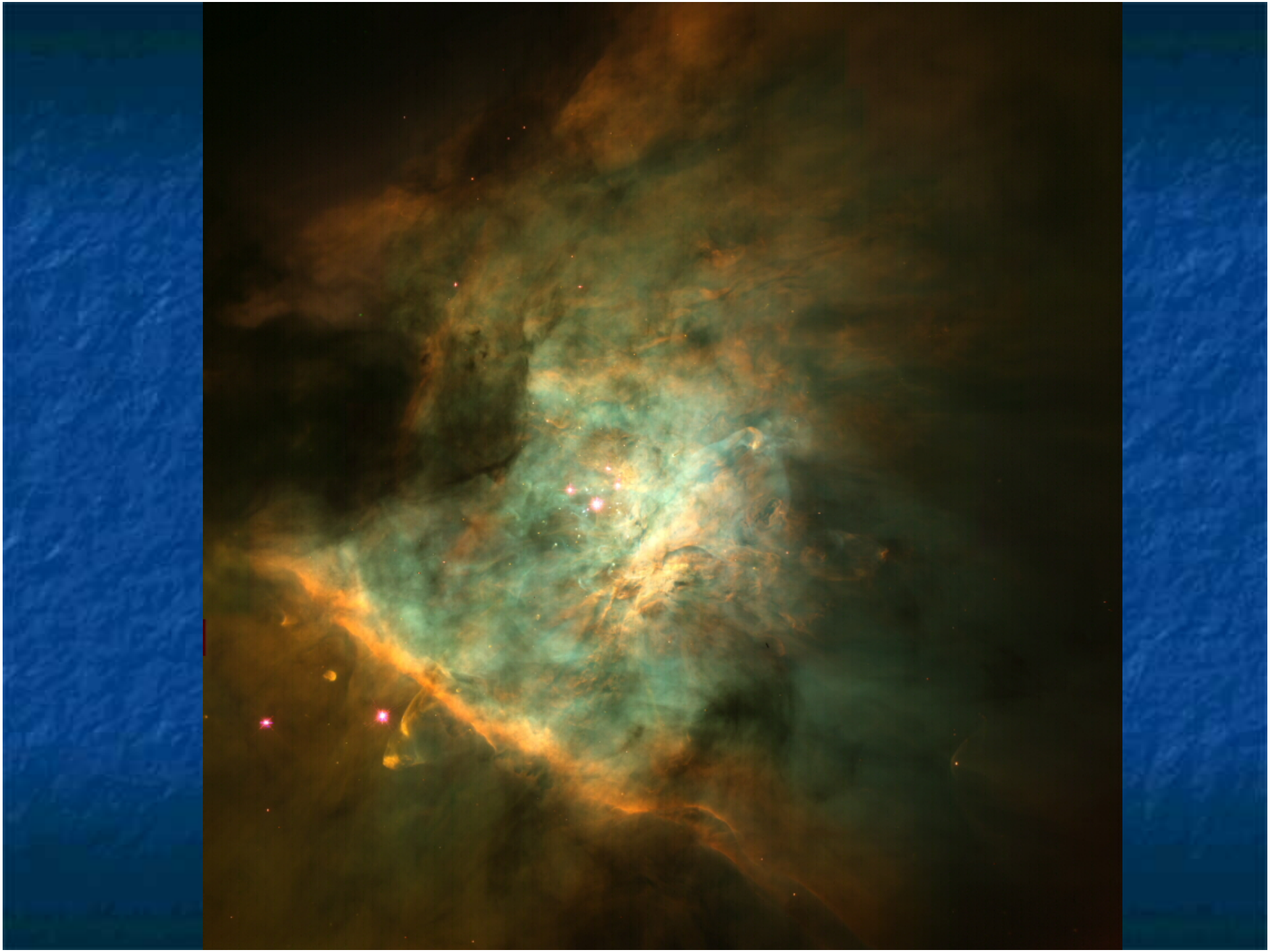
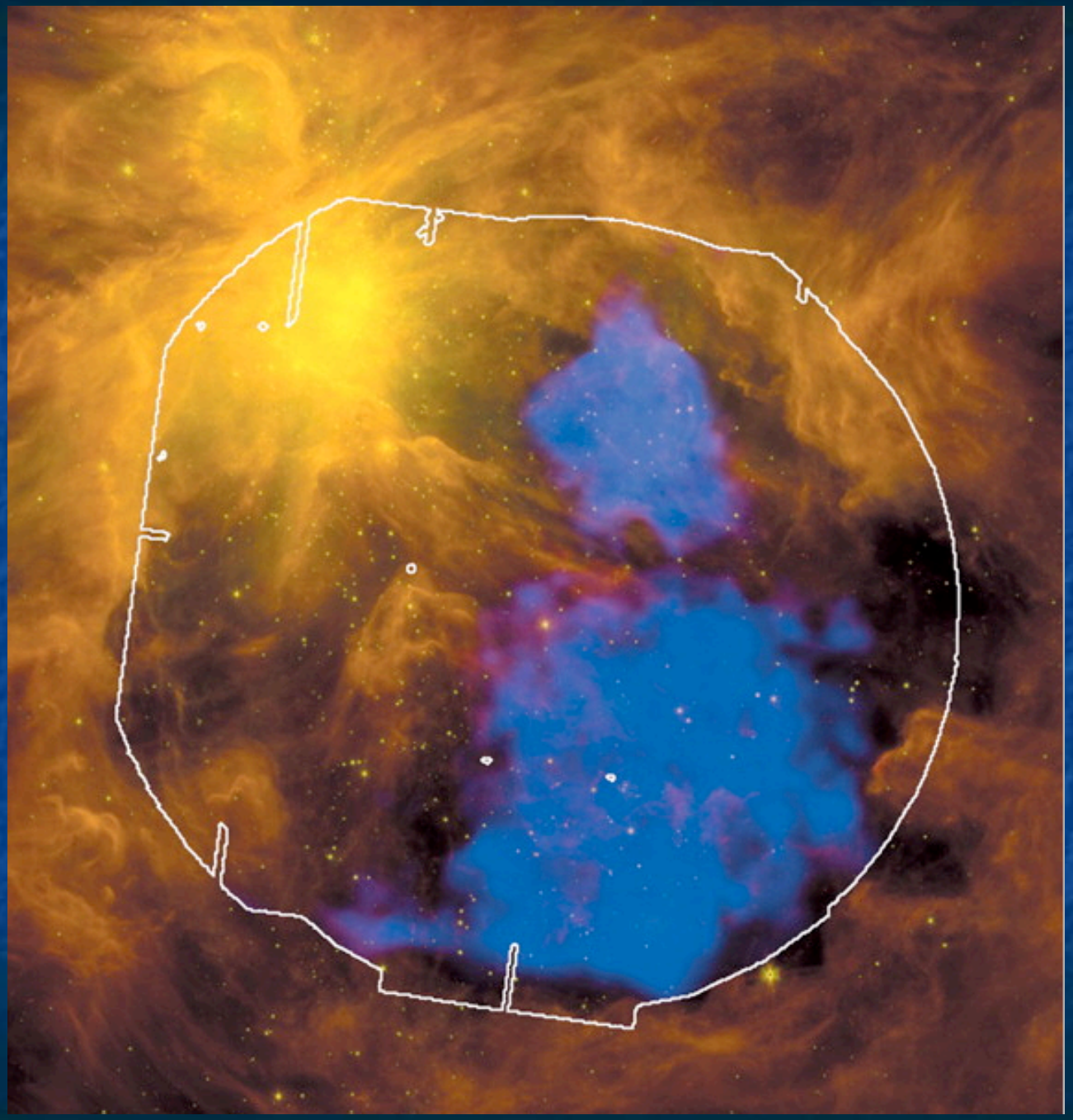
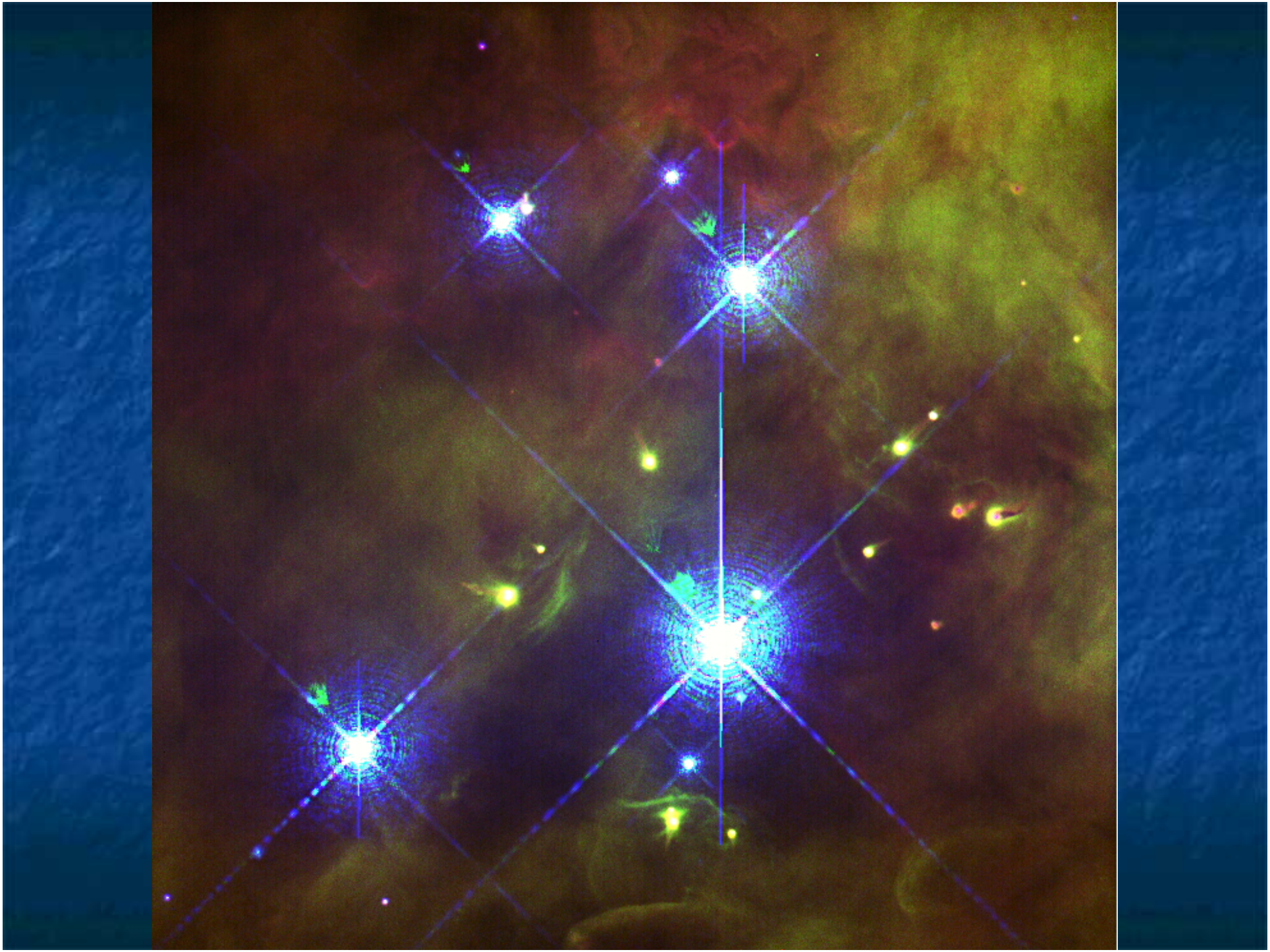
The Orion Nebula-A 50 Year Study.

- I trained with the late D.E. Osterbrock and Rudolph Minkowski, both experts on gaseous nebulae.
- My approach is that one must understand the best example of a class of objects before generalizing about more distant samples.
- The mechanisms operating in Orion almost certainly apply to the more distant objects.

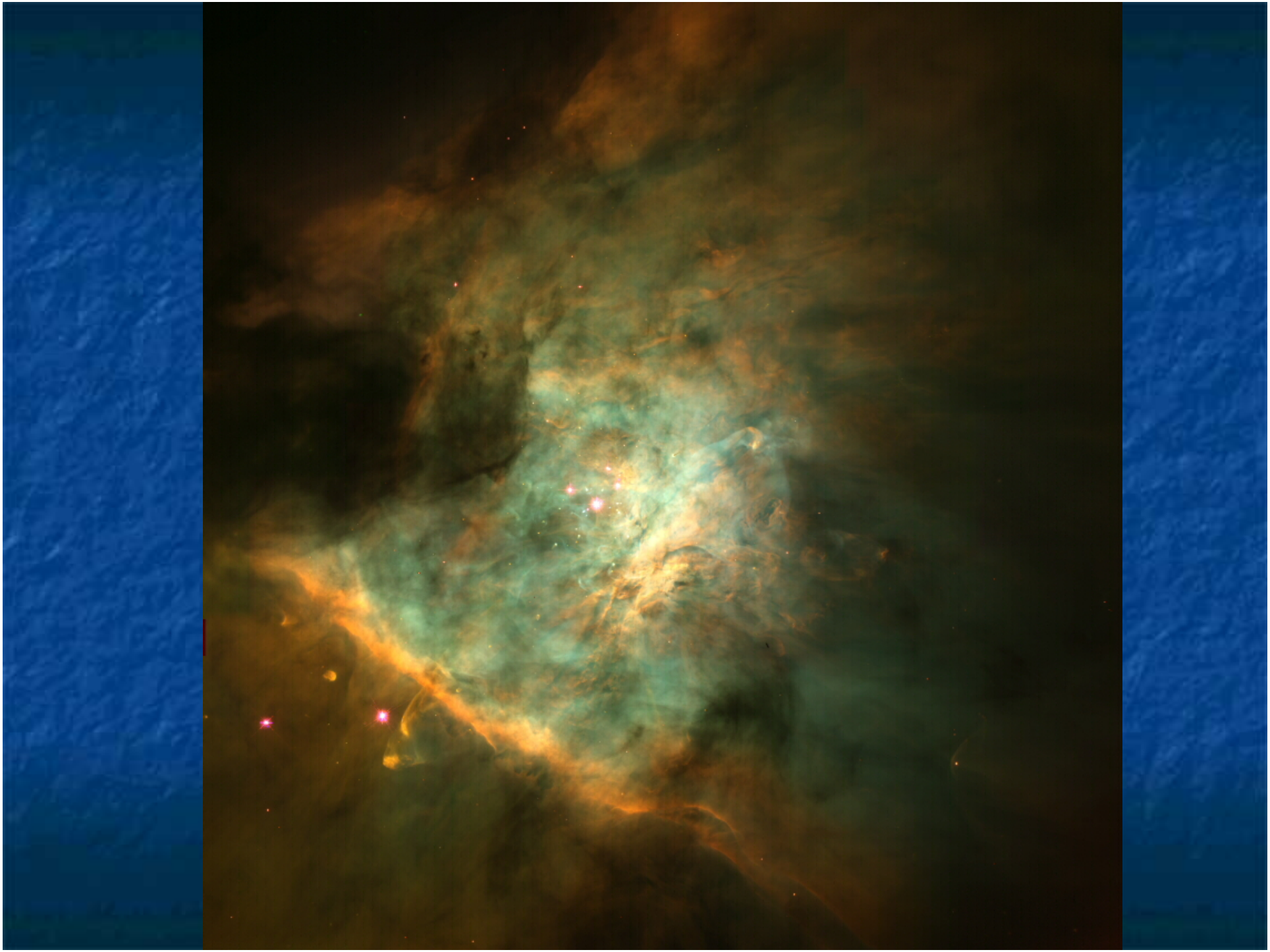






The Orion Nebula Cluster

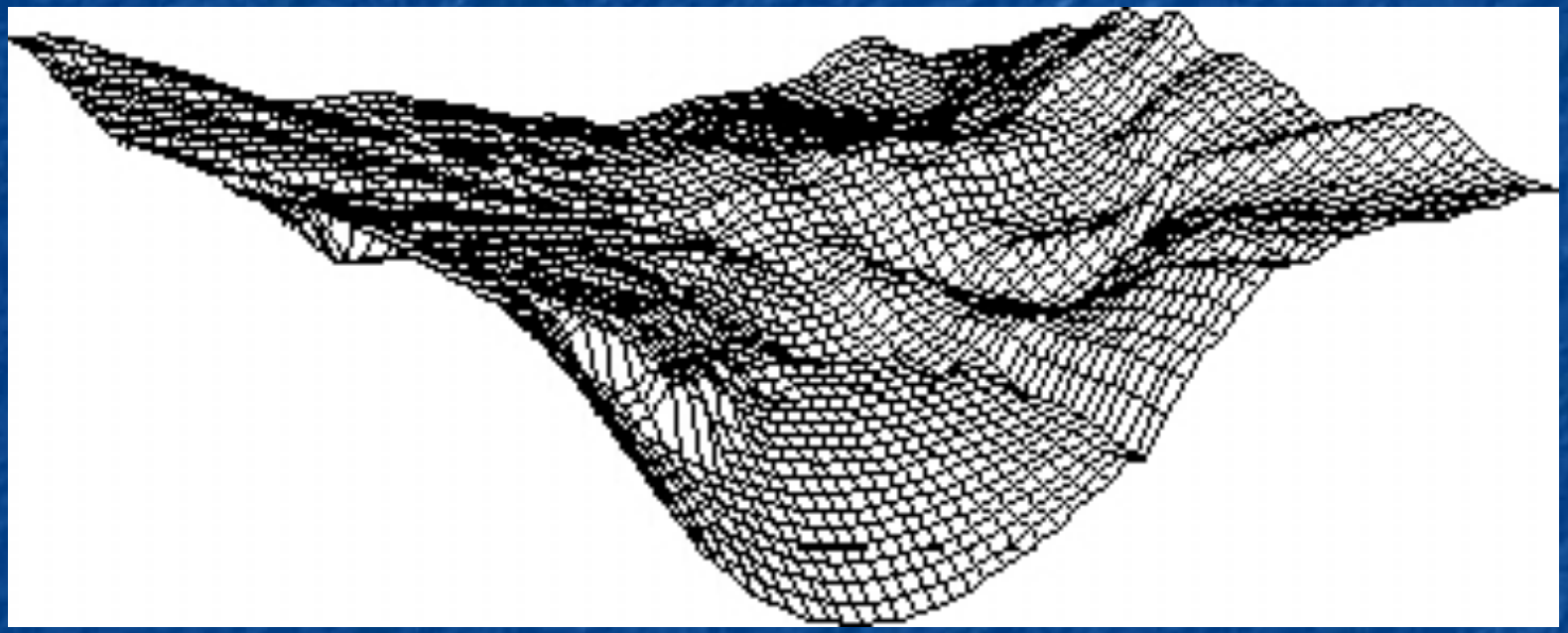
- Centered on the Trapezium stars.
- Scale height for distribution is 0.18 pc (80”).
- Age is quite protostar-collapse-model dependent, single most characteristic number is 1,000,000 years.
- Velocity dispersion is about 2 km/sec.



Conditions within the Ionized Layer

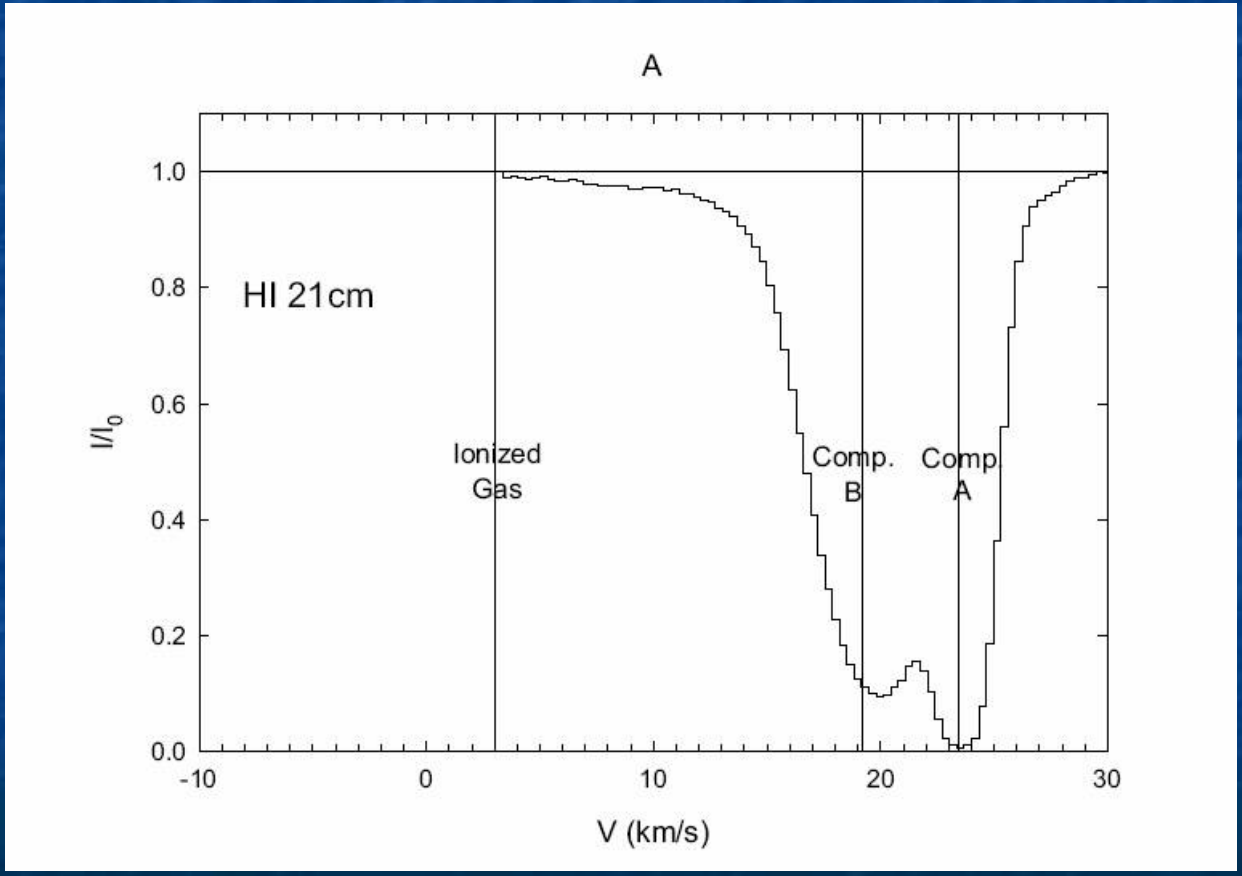
Zone	PDR	Ion.Fr.	LowIon.	Med.Ion.
Key Ion	H^o	H^+	He^o	He^+
Tracers	CO,CII	[OI],[SII]	[OII],[NII]	[OIII],HeI,[ClIII]
V_{sun}(km/s)	28	25.5	18.8+/-1.5	17.9+/-1.3
Density (cm^{-3})	10^5	>6,000	7,000	4,000
Depth (pc)	?	10^{-4}	$2x10^{-3}$	0.12

Form of the Main Ionization Front



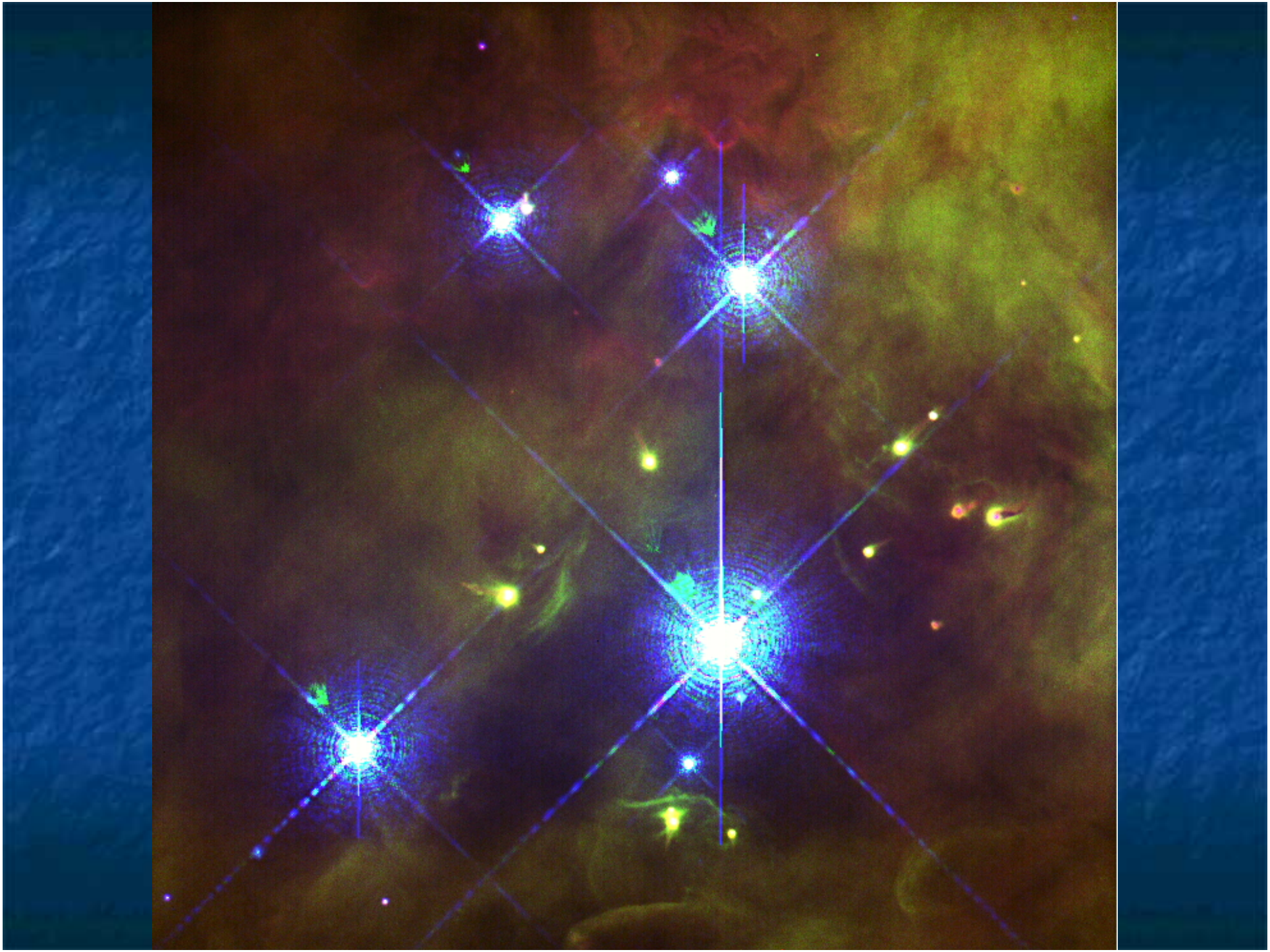
The dominant ionizing star (θ^1 Ori C) lies 0.3 pc in front of the Main Ionization front.
The area depicted is 0.8x0.8 pc. Emissivity scale height is 0.06 pc.

Veil 21-cm Absorption

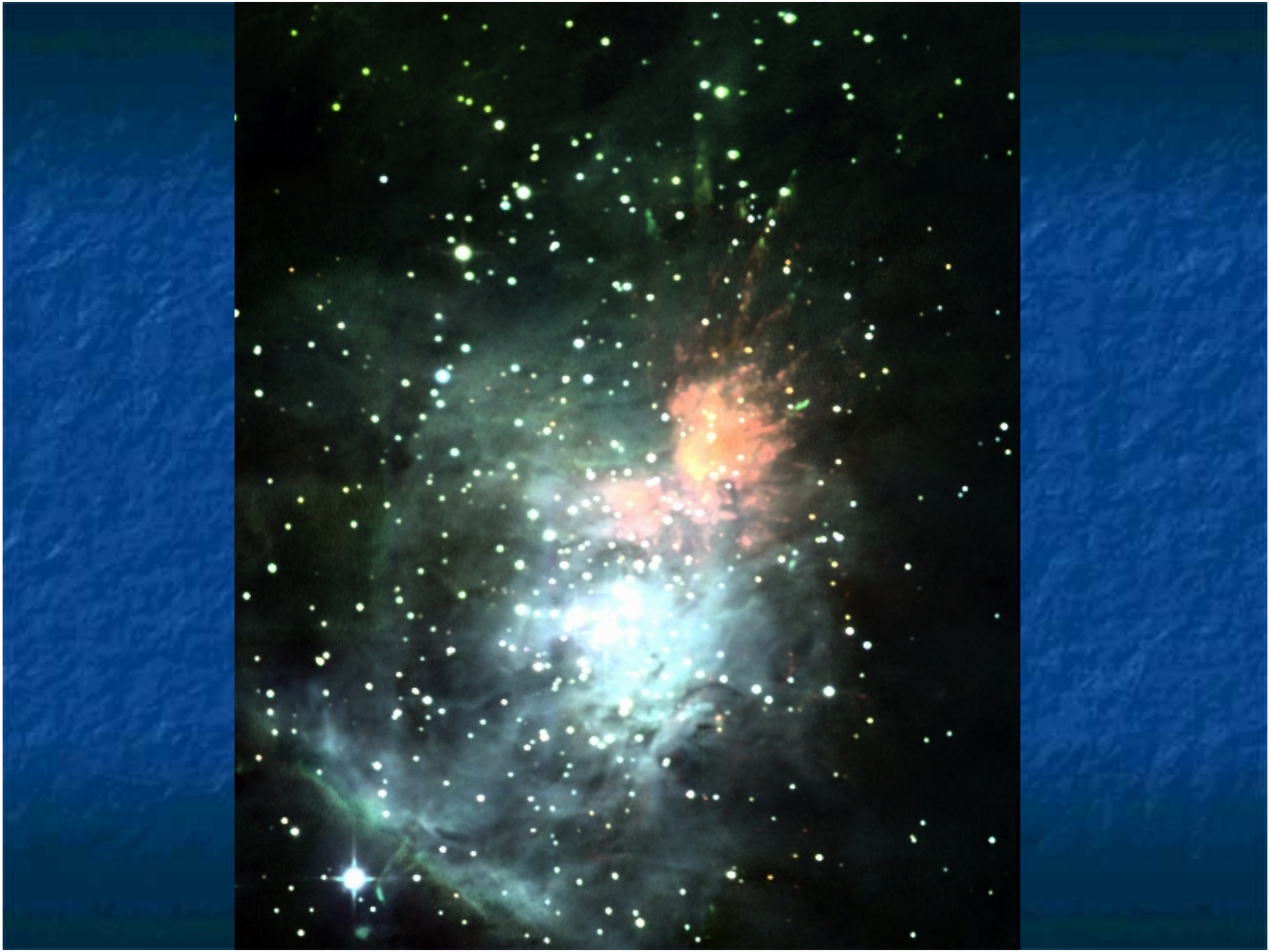


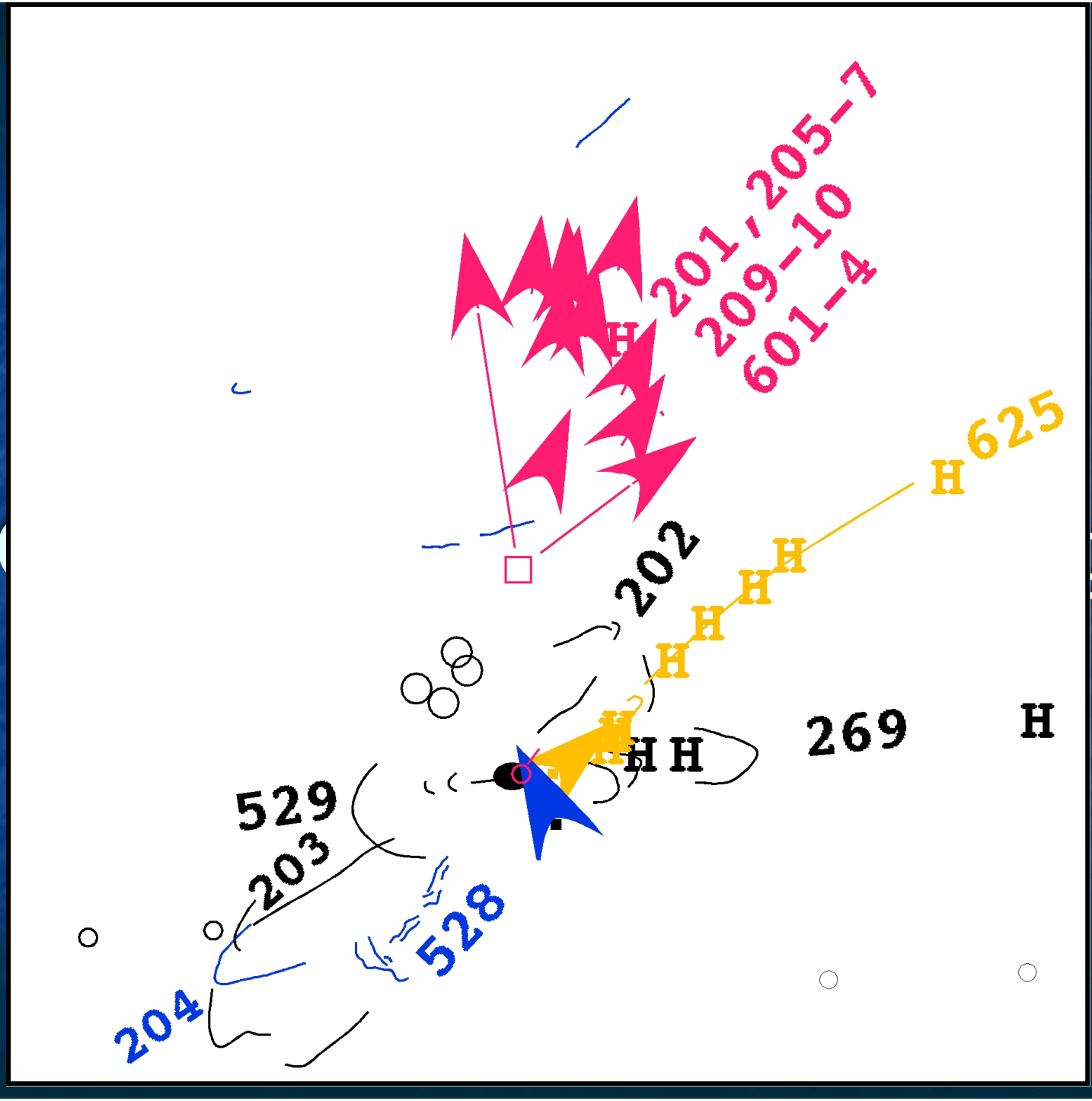
We have an approximate model for the nebula and excellent images, so we can make a 3-D simulation.

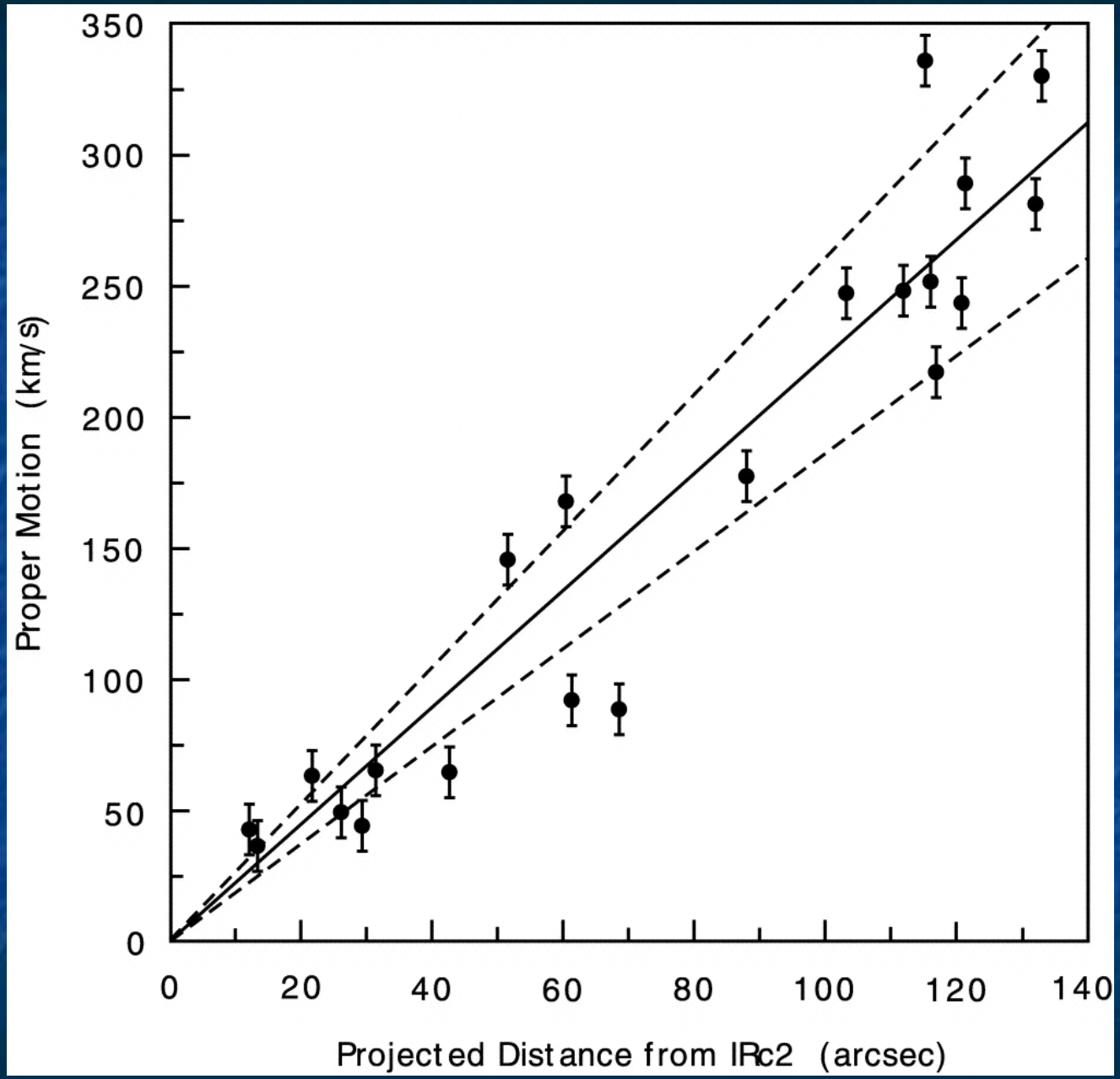
The first star formation region is the Orion Nebula Cluster, centered on the Trapezium.

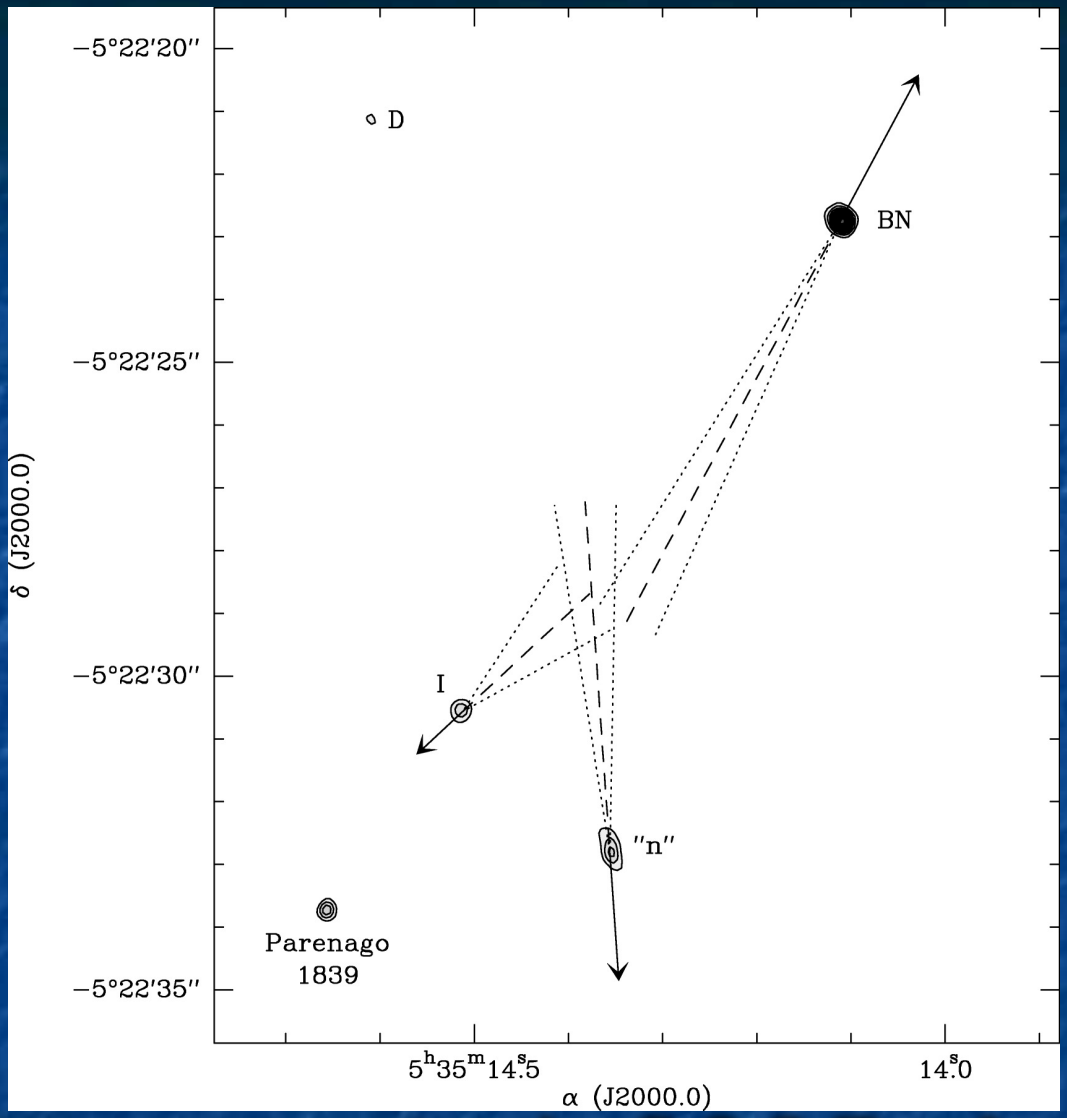


The second star formation region is the BN-KL hidden infrared region.



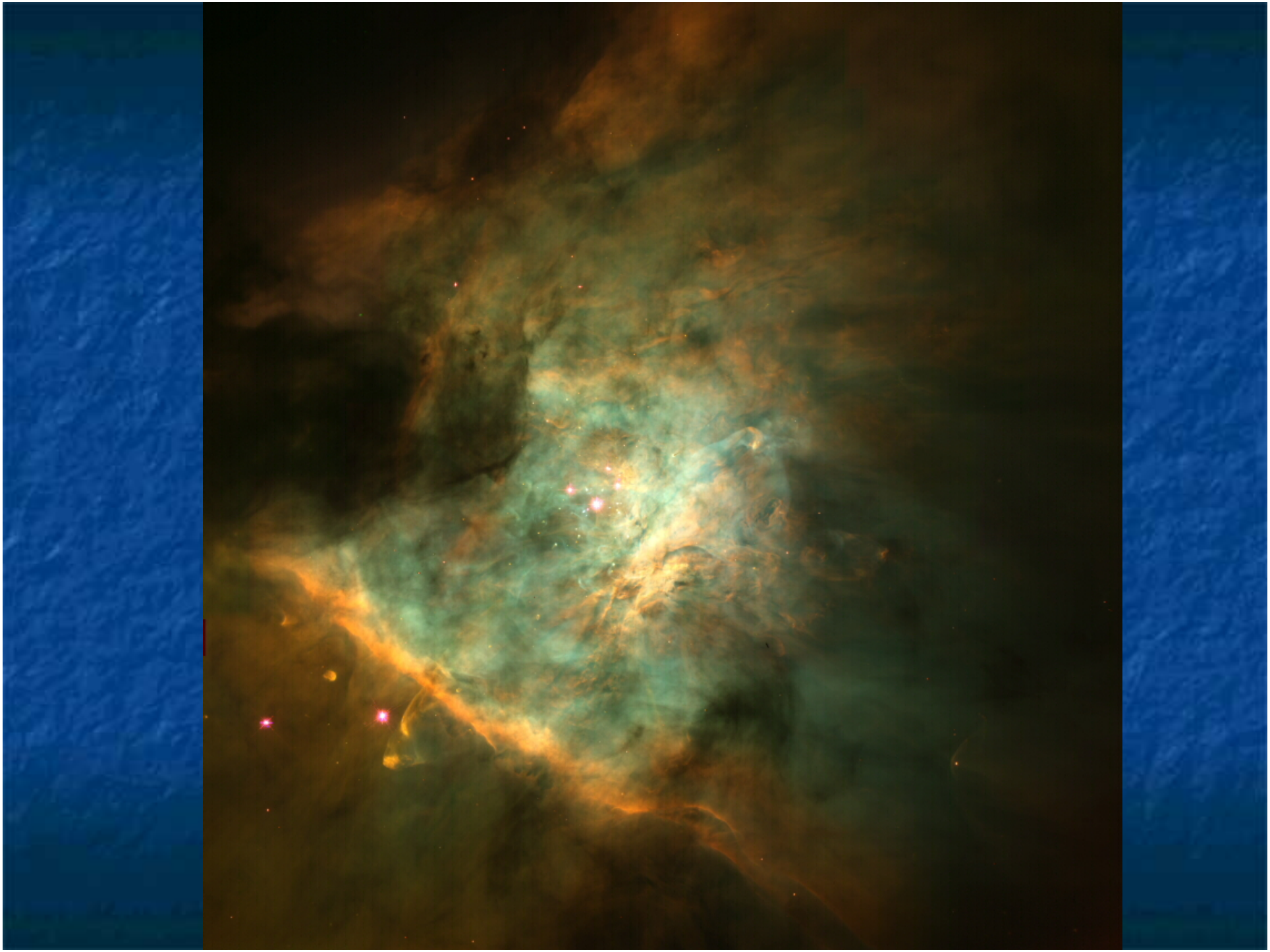

201, 205–7
209–10
601–4
H
625
H
H
H
H
H
202
H H
269
H
529
203
528
204

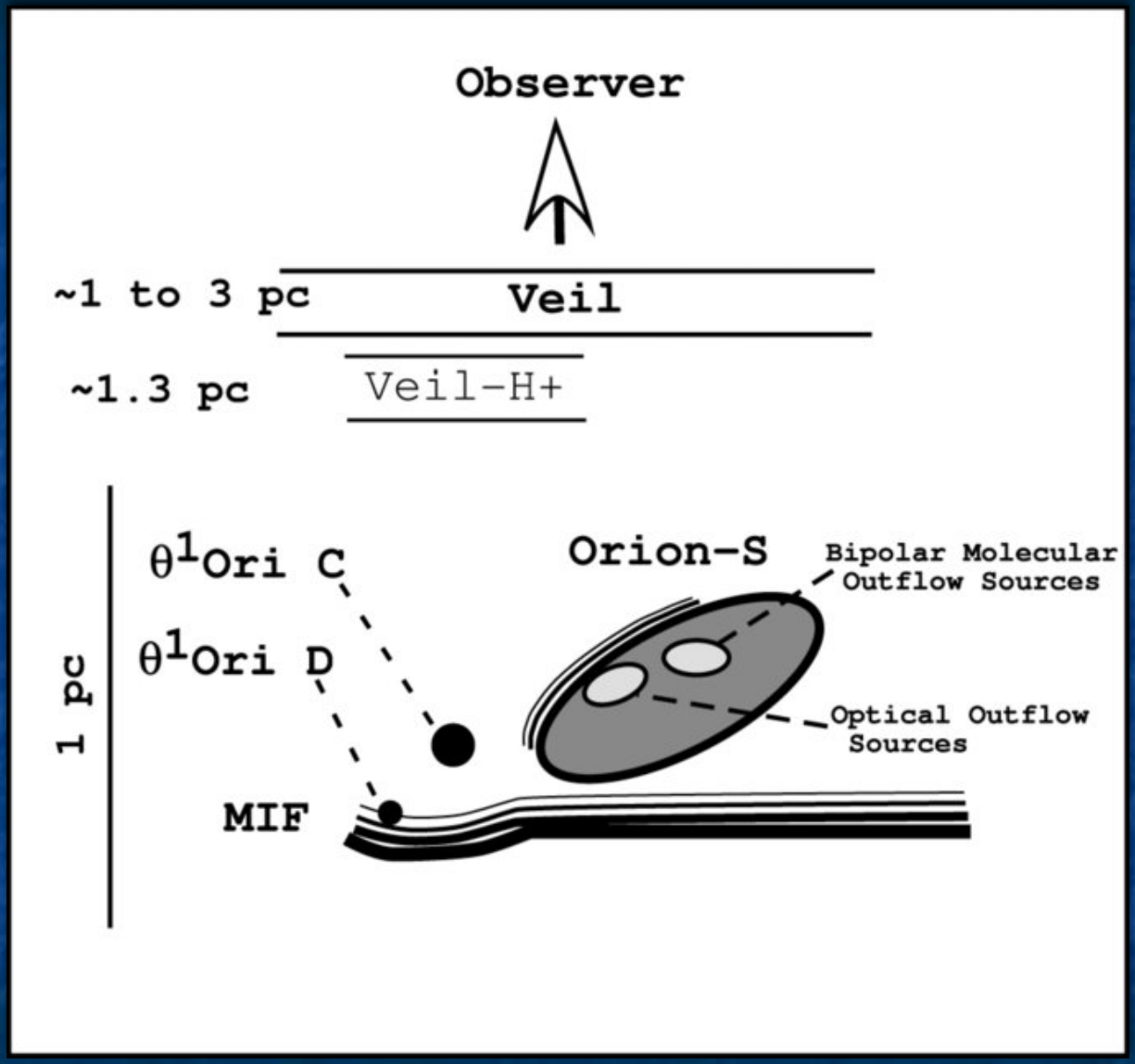

Proper Motion (km/s)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Projected Distance from IRc2 (arcsec)

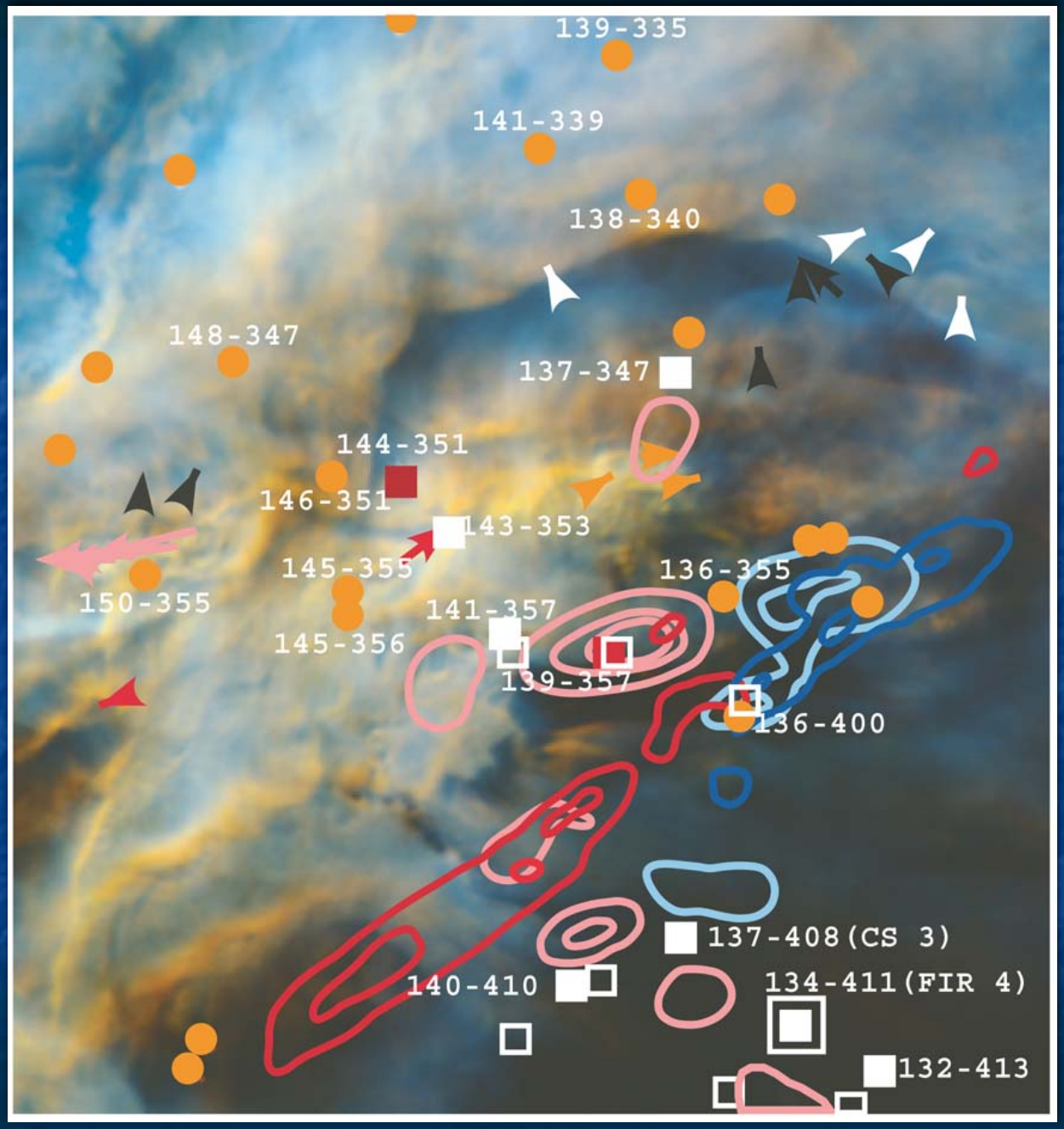


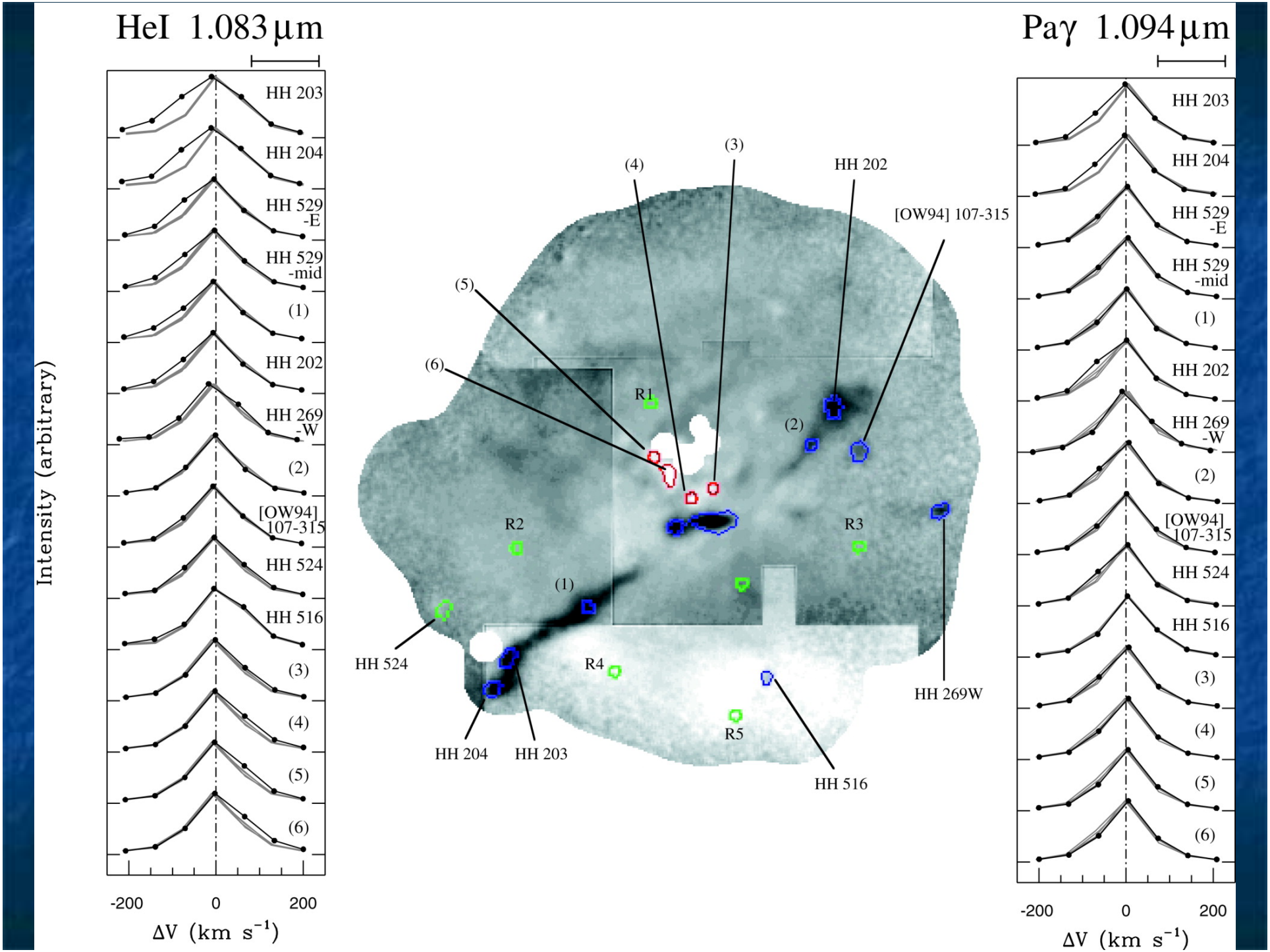
L. Gomez et al. 2005, ApJ, 635, 1166

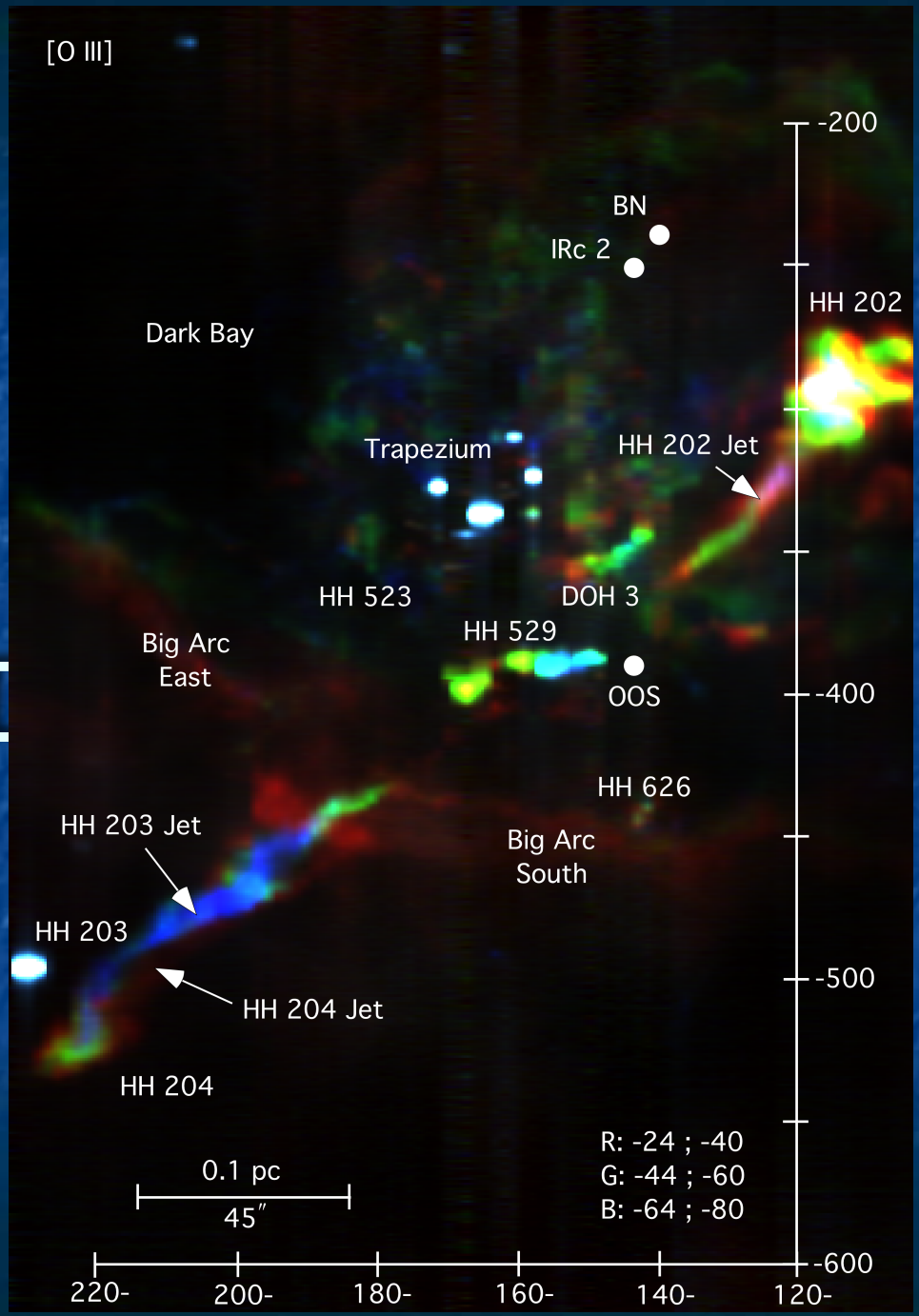
The Orion-S region is the third center for recent star formation in Orion.

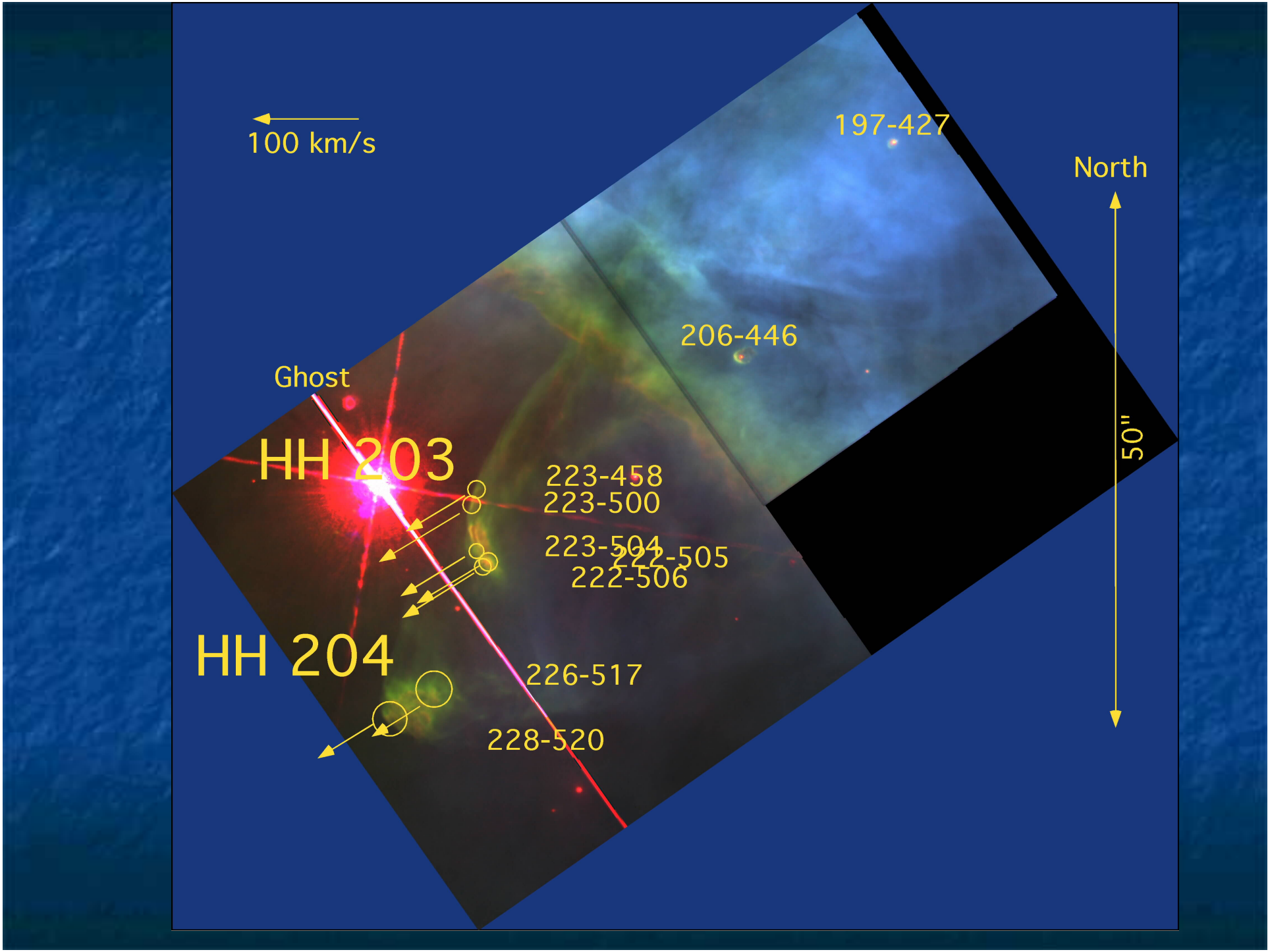



Observer
~1 to 3 pc
Veil
~1.3 pc
Veil-H+
1 pc
θ1Ori C
θ1Ori D
MIF
Orion-S
Bipolar Molecular Outflow Sources
Optical Outflow Sources


139-335
141-339
138-340
148-347
137-347
144-351
146-351
143-353
145-355
136-355
150-355
141-357
145-356
139-357
136-400
137-408(CS 3)
140-410
134-411(FIR 4)
132-413


HeI 1.083 µm
Paγ 1.094 µm
Intensity (arbitrary)
HH 203
HH 204
HH 529 -E
HH 529 -mid
(1)
HH 202
HH 269 -W
(2)
[OW94] 107-315
HH 524
HH 516
(3)
(4)
(5)
(6)
-200
0
200
ΔV (km s⁻¹)
R1
R2
R3
R4
R5
HH 524
HH 204
HH 203
HH 516
HH 269W

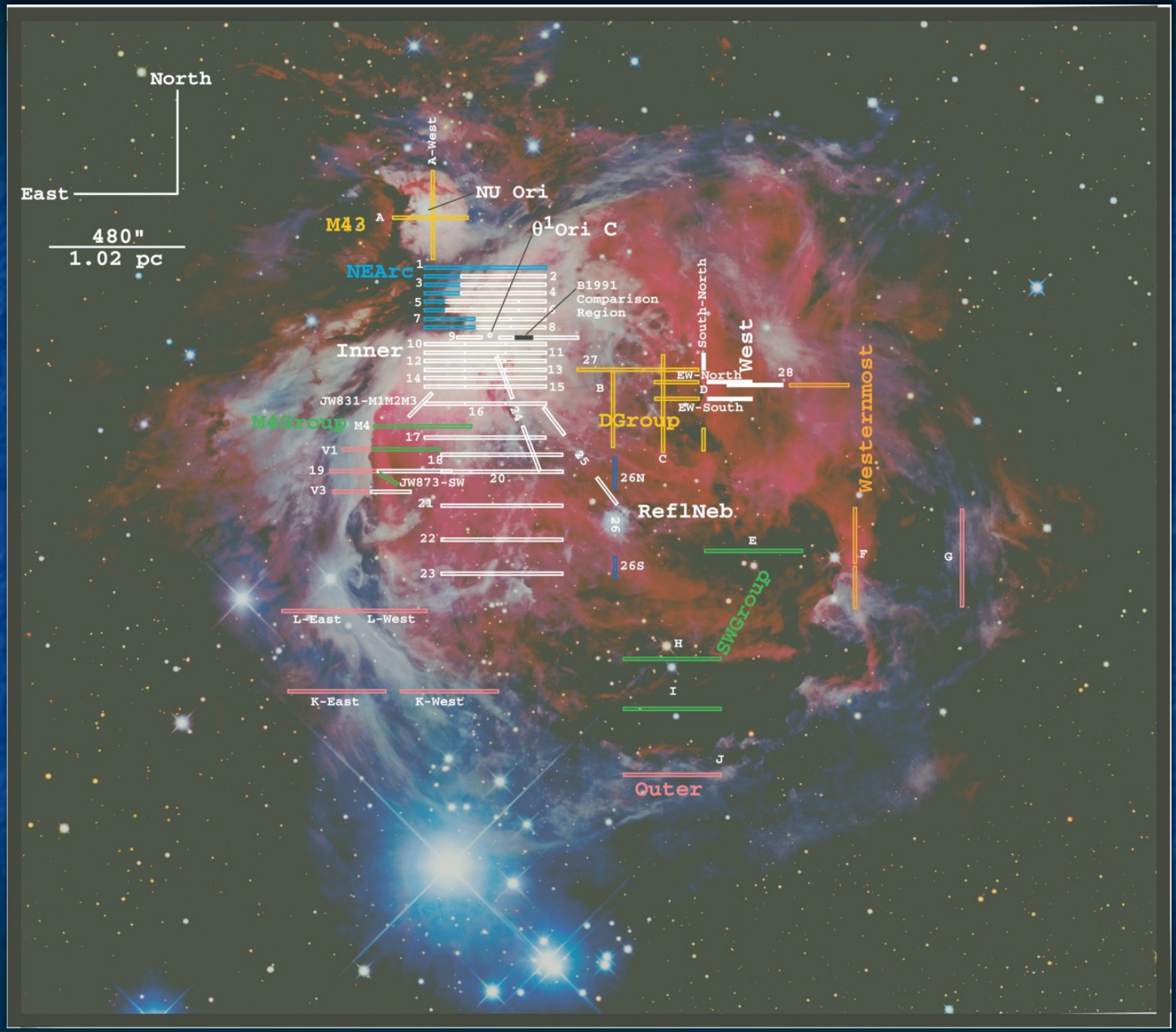

[O III]
BN
IRc 2
HH 202
Dark Bay
Trapezium
HH 202 Jet
HH 523
DOH 3
HH 529
Big Arc
East
OOS
HH 626
HH 203 Jet
Big Arc
South
HH 203
HH 204 Jet
HH 204
0.1 pc
45″
R: -24 ; -40
G: -44 ; -60
B: -64 ; -80
-200
-400
-500
-600
220-
200-
180-
160-
140-
120-

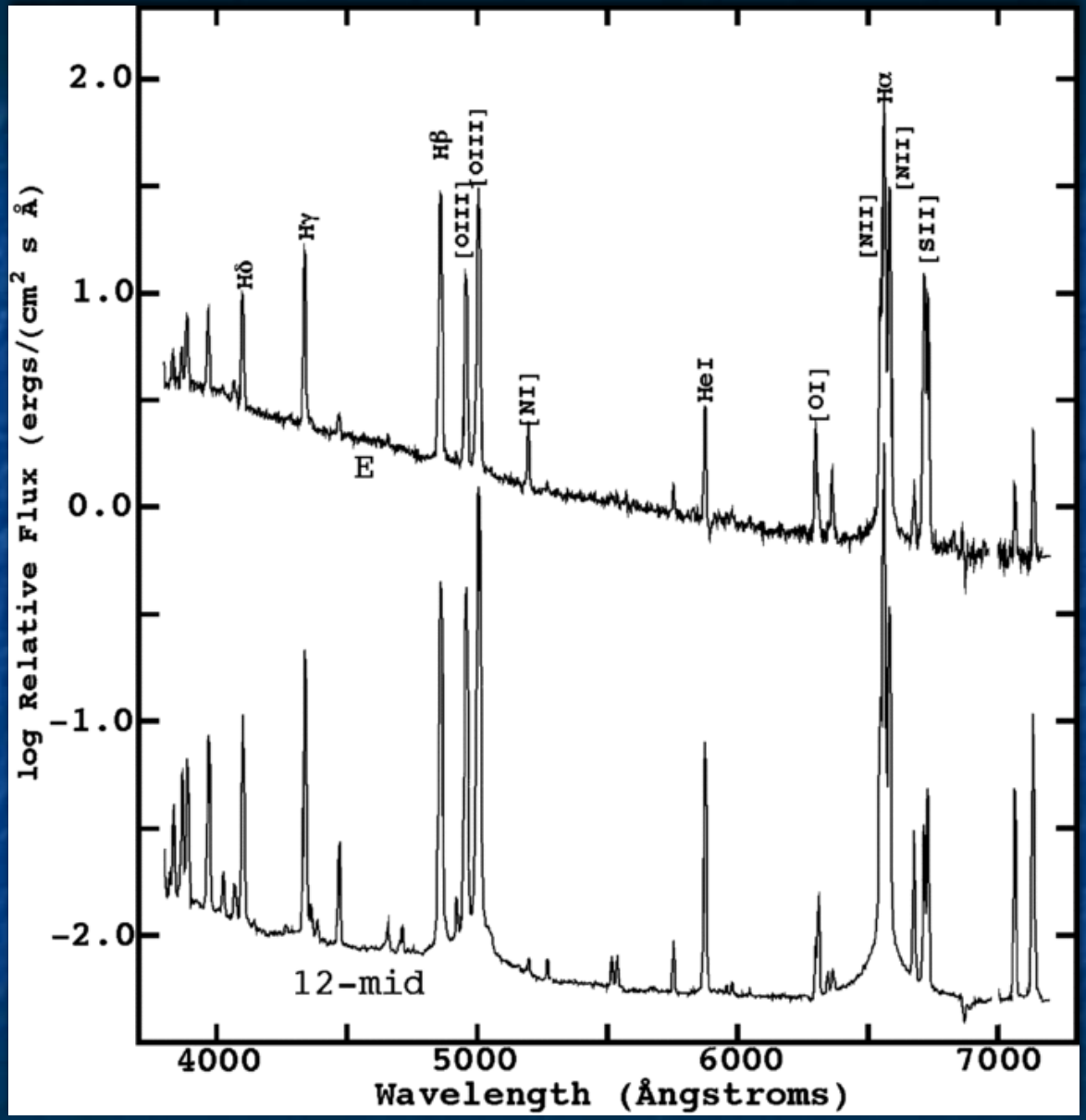

100 km/s
197-427
North
206-446
Ghost
50"
HH 203
223-458
223-500
223-504
222-505
222-506
HH 204
226-517
228-520

Was there an earlier period of massive star formation?

- Blaauw & Morgan (1954) argued for AE Aur (O9.5)and μ Col (09.5/B0V) being runaways from Orion.
- Gies & Bolton (1986) said that ι Ori (O9III+B1III) was also involved.
- Hoogerwerf et al. (2001) used Hipparchos data to get distances.
- Spatial velocities + gravitational field model allows one to calculate the earlier positions and 'VOILA', a common origin 2.5 mya.

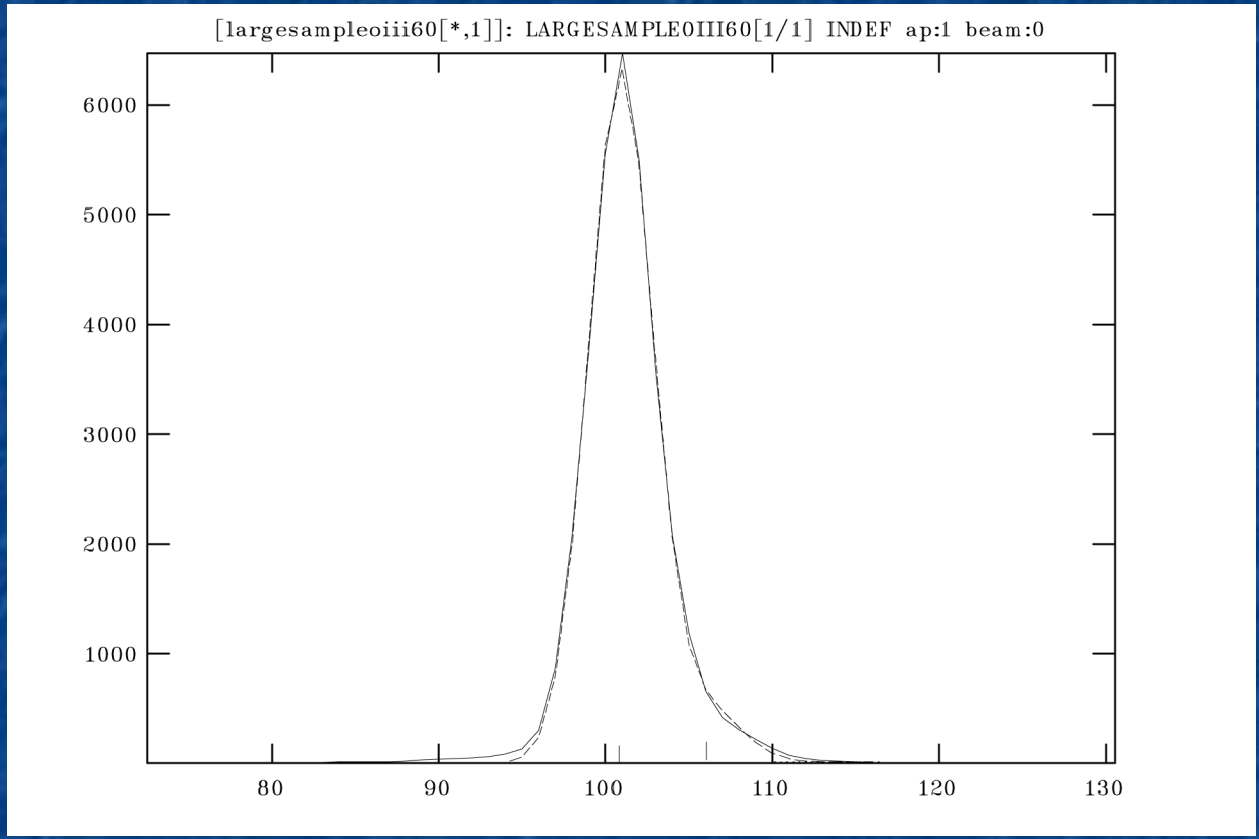
Determination of the Structure of the Extended Orion Nebula.

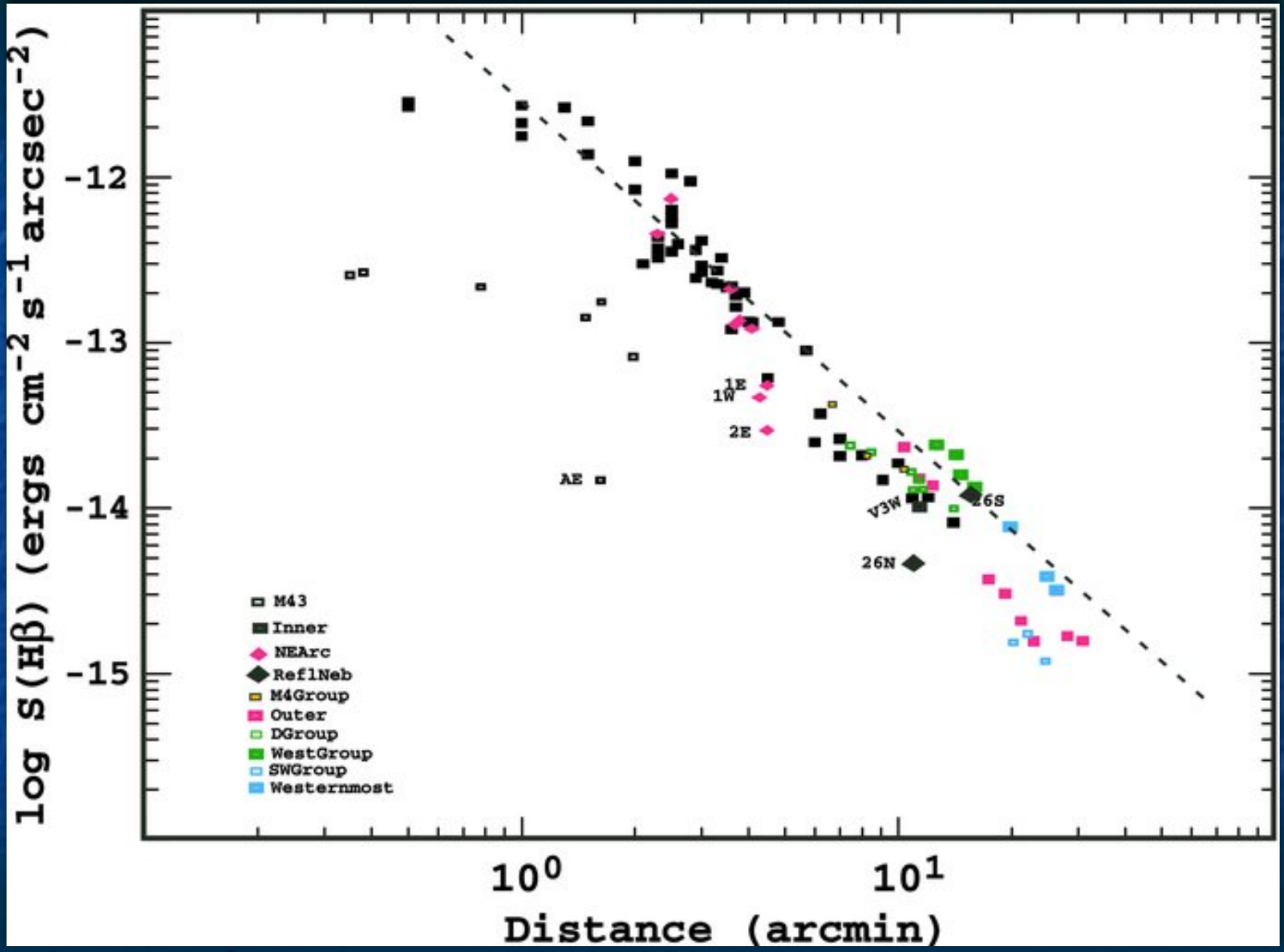

North
East
480"
1.02 pc
A-West
NU Ori
M43
A
θ1Ori C
NEArc
1
2
3
4
5
7
8
9
B1991
Comparison
Region
South-North
West
Inner
10
11
12
13
14
15
27
28
EW-North
EW-South
B
D
JW831-M1M2M3
16
24
M4Group
M4
DGroup
17
V1
18
19
25
C
26N
JW873-SW
20
V3
21
ReflNeb
26
22
E
F
G
Westernmost
23
26S
L-East
L-West
SWGroup
H
K-East
K-West
I
J
Outer

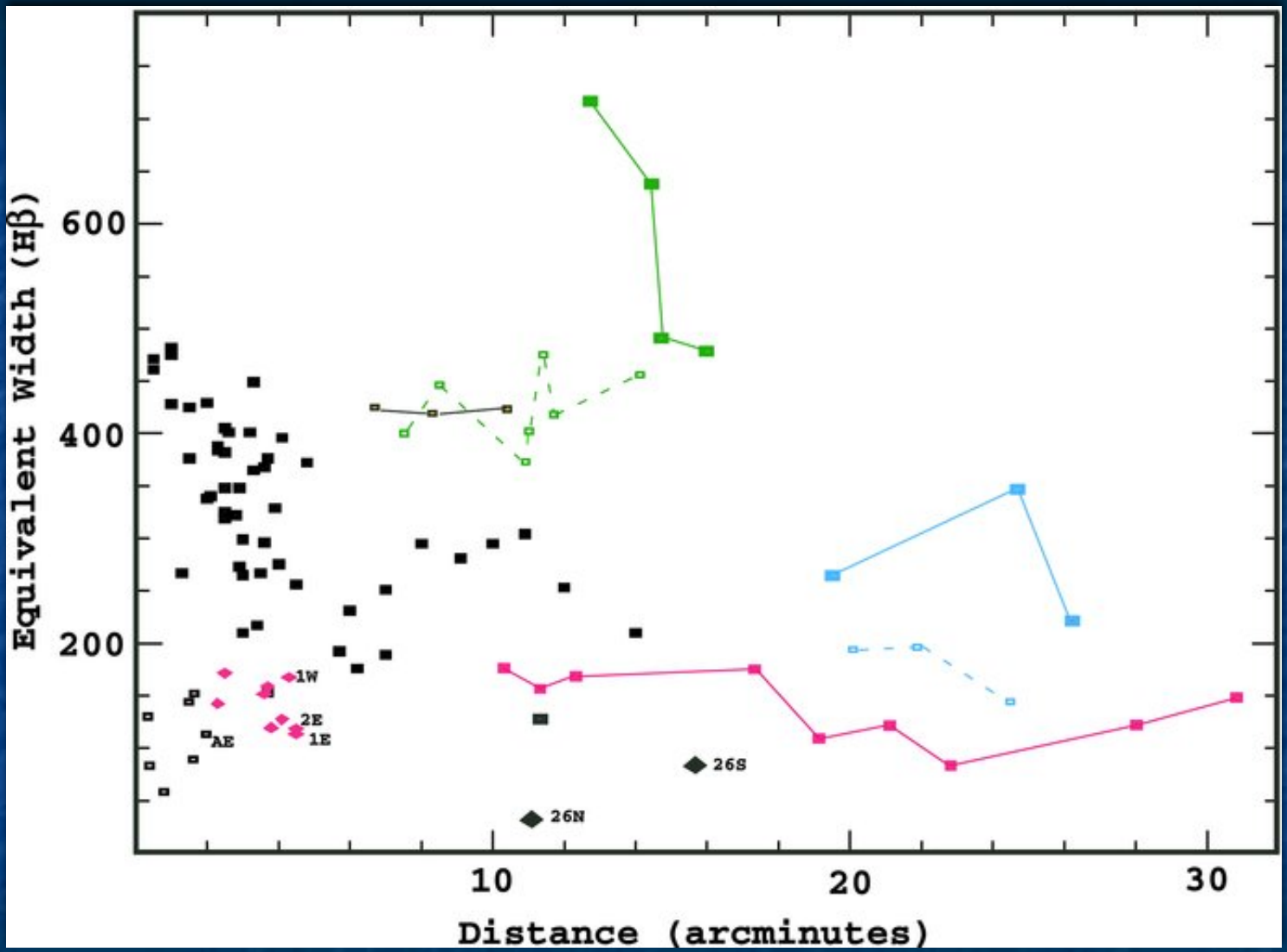

log Relative Flux (ergs/(cm^2 s Å)
2.0
1.0
0.0
-1.0
-2.0
4000
5000
6000
7000
Wavelength (Ångstroms)
Hδ
Hγ
Hβ
[OIII]
[OIII]
[NI]
HeI
[OI]
[NII]
Hα
[NII]
[SII]
E
12-mid

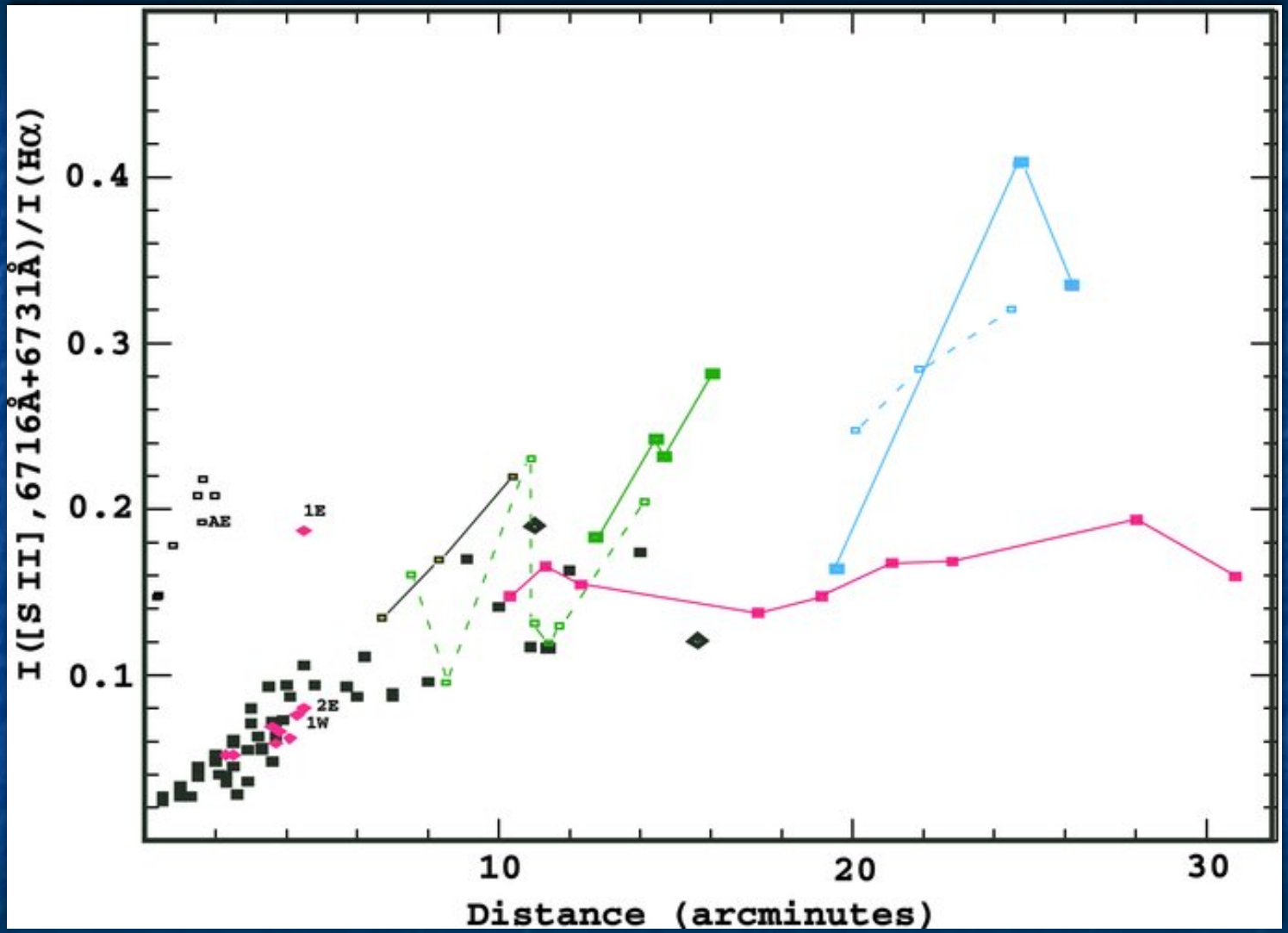
Scattered Light

- The gas and dust density rise within the PDR behind the ionization front, forming a diffuse “mirror”. Most of the scattering of starlight and emission lines occurs there.
- [OIII] emission was known to be polarized.
- The velocity difference between the emitting and scattering layers doubles the redshift of the scattered light, making it visible in high resolution spectra.

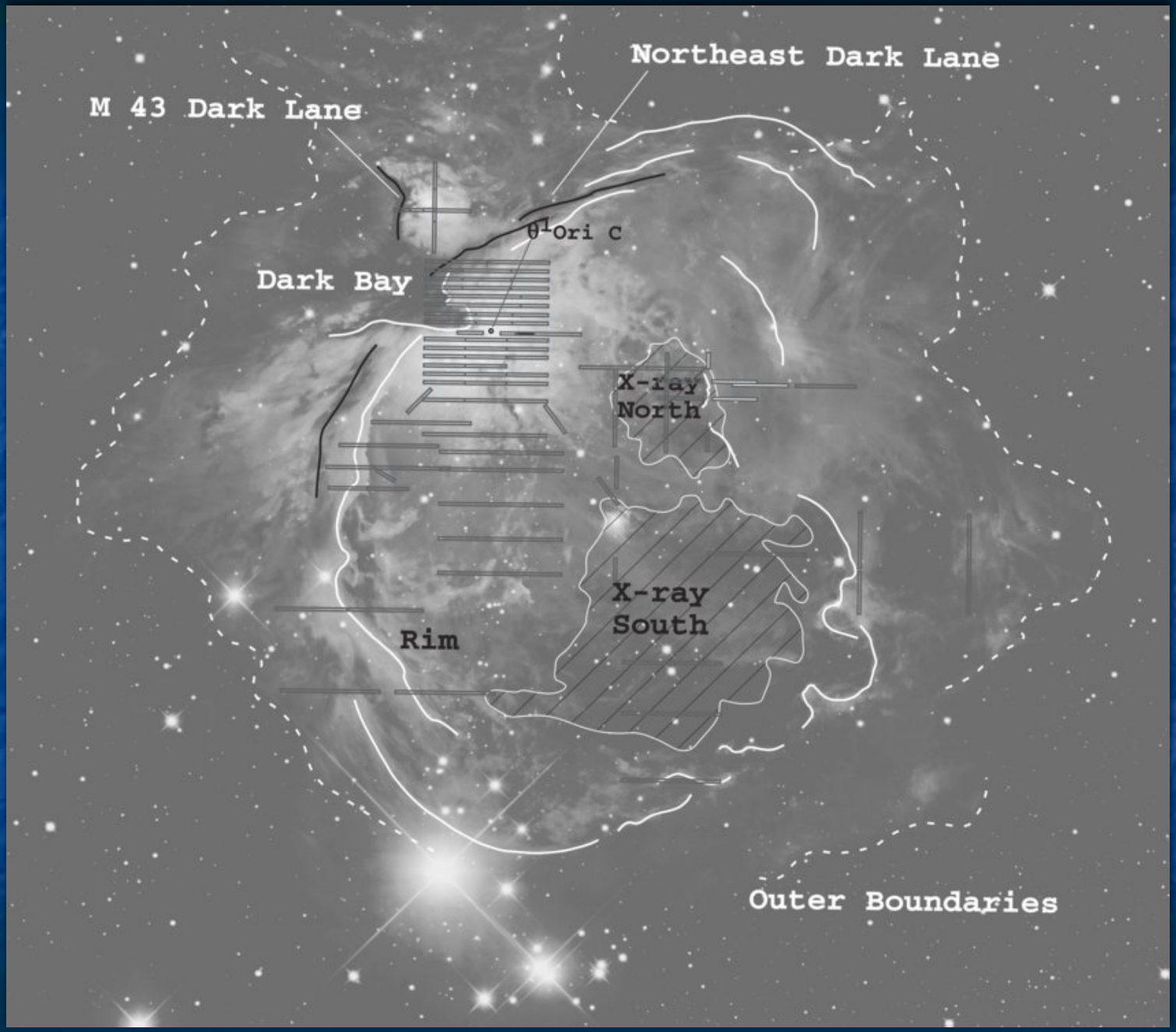

[largesampleoiii60[*,1]]: LARGESAMPLEOIII60[1/1] INDEF ap:1 beam:0
6000
5000
4000
3000
2000
1000
80
90
100
110
120
130

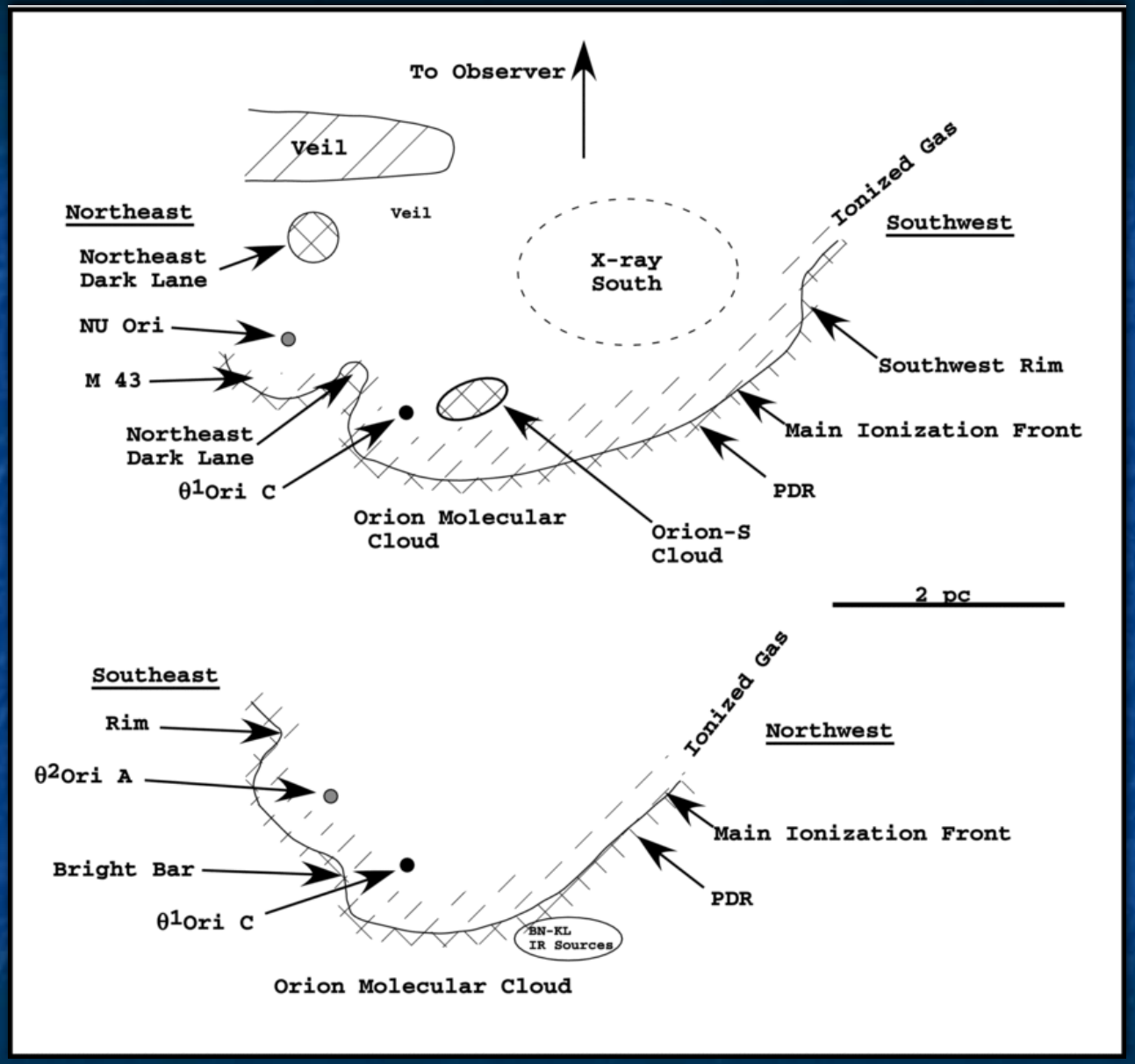

log S(Hβ) (ergs cm^{-2} s^{-1} arcsec^{-2})
-12
-13
-14
-15
10^0
10^1
Distance (arcmin)
1E
1W
2E
AE
V3W
26S
26N
M43
Inner
NEArc
ReflNeb
M4Group
Outer
DGroup
WestGroup
SWGroup
Westernmost


Equivalent Width (Hβ)
600
400
200
10
20
30
Distance (arcminutes)
1W
2E
1E
AE
26S
26N


I([S II],6716Å+6731Å)/I(Hα)
0.4
0.3
0.2
0.1
AE
1E
2E
1W
10
20
30
Distance (arcminutes)

Beyond about 8’ most of the light is scattered light originally emitted in the central region of the nebula.


Northeast Dark Lane
M 43 Dark Lane
θ1Ori C
Dark Bay
X-ray
North
X-ray
South
Rim
Outer Boundaries


To Observer
Veil
Veil
Northeast
Northeast
Dark Lane
NU Ori
M 43
Northeast
Dark Lane
θ1Ori C
Orion Molecular
Cloud
X-ray
South
Ionized Gas
Southwest
Southwest Rim
Main Ionization Front
PDR
Orion-S
Cloud
2 pc
Southeast
Rim
θ2Ori A
Bright Bar
θ1Ori C
BN-KL
IR Sources
Ionized Gas
Northwest
Main Ionization Front
PDR
Orion Molecular Cloud

Do We Really Understand the Physics of Orion?

- We're not able to explain almost half of the energy in the nebular ionized gas (line broadening component).
- The presence of an outer hot-shocked region seen in x-rays poses real problems about why we don't see this closer to the Trapezium (Guedel et al. 2008).

Conclusions

- There are three regions of massive-star formation in Orion, two of them lying behind the nebula.
- The Extended Orion Nebula is shaped by photoionization processes, but illuminated primarily by scattered light from the Huygens Region.
- There are many unresolved questions about the small-scale physics that prevails.