The HII EOS in Resolved ObjectS
a Survey Of Nearby Galaxies

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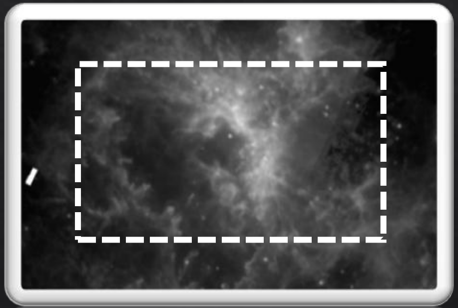
NGC 3603
77 O-stars

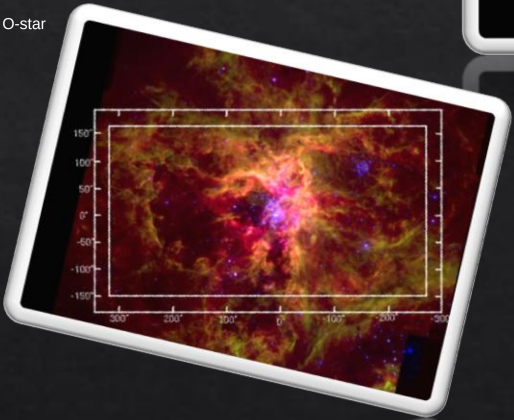
M17 - 10 O-stars

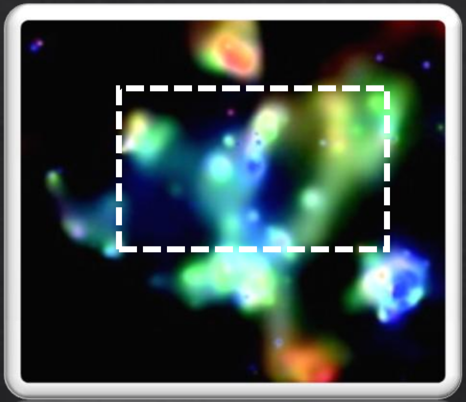
ORION - 1 O-star

A Starburst Next Door



Radiation and HII Region Pressure





Hot X-ray Region Pressure

Results

4/22/2014


STAND STRONG
TRACE
0
1
2
3
4
5
6
7
8
9
10
PROGRESS

Feedback

X-Ray Plasma	Radiation	HII Region Gas
Thermalized Shocks from Stellar Winds and Supernovae $T = 10^6 – 10^7$ K $n(H) < 0.1$	Dominated by ionizing photon momentum Non-Isotropic Pressure Term- Think Force on Shell	Photoionized $T = 10^4$ K $n(H) = 10 – 1000$ cm^{-3}

If a tree falls in the forest and no one is there to hear it, does it make a sound?

No.

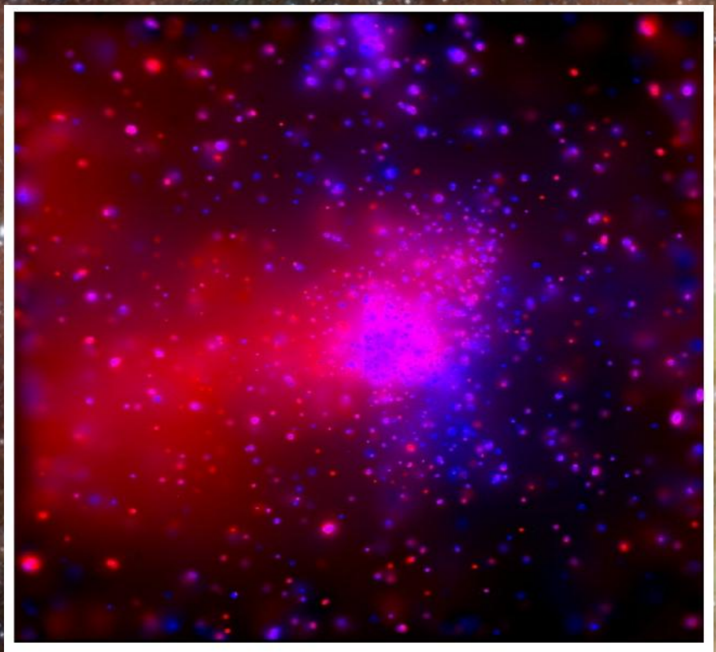
Scientific American 1884; Mann and Twiss 1910

If a massive star emits a photon and there is not gas to interact with, does it exert a pressure?

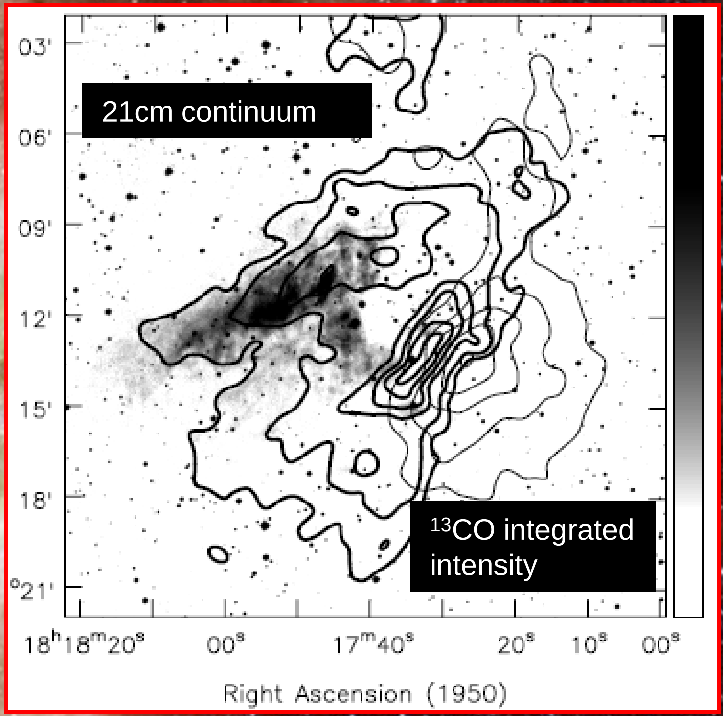
That is the question?

Pellegrini 4/15/2014

M17



Chandra X-ray Image

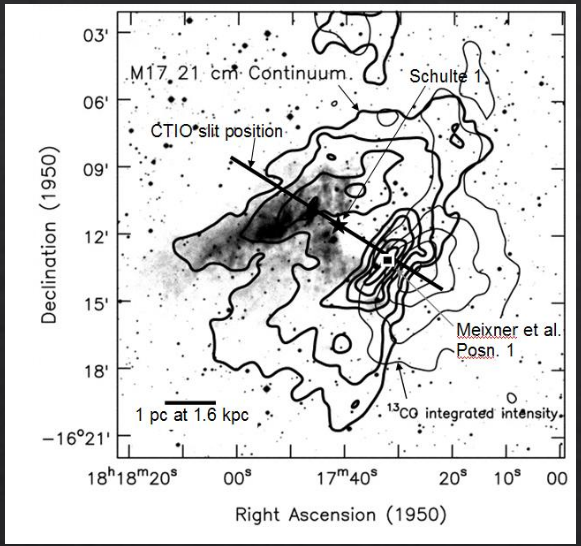


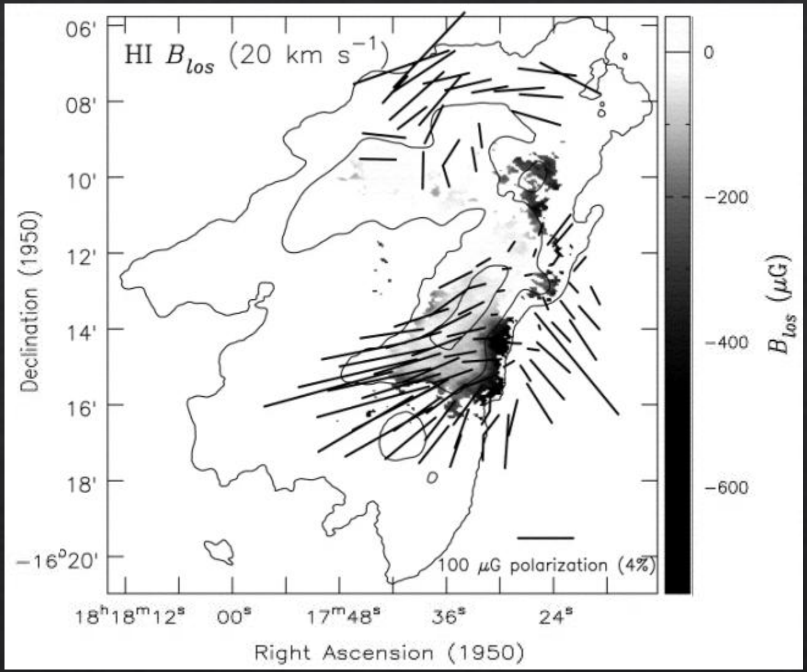
4/22/2014

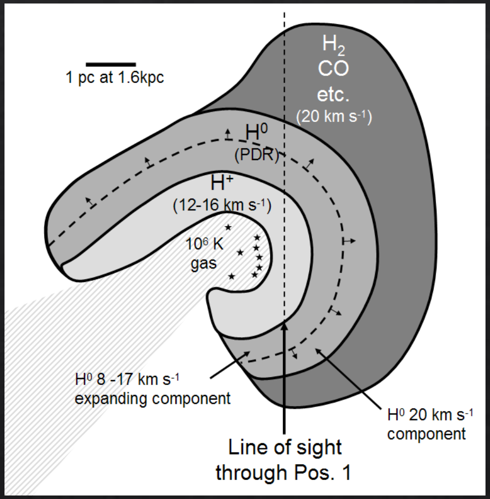
R = 8μm, O=5.8 μm, G=4.5 μm, B=3.6 μm

Image credit: Robert Hurt, Matthew Povich

M17
Magnetic Field







Brogan & Troland (2001)

M17
SFR EOS

Equation of State first proposed and tested by Pellegrini et al. 2007

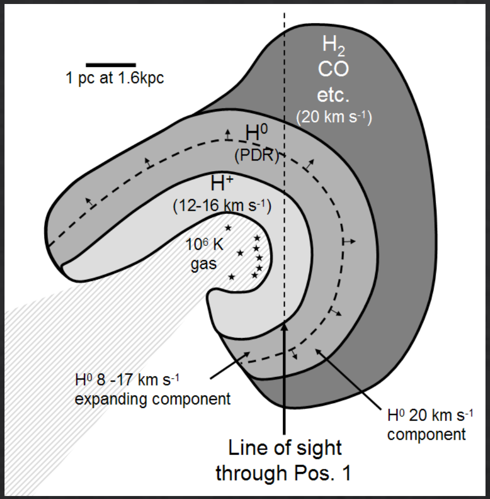
$$P_{tot} = P_0 + P_{gas} + P_{stars} + P_{\vec{B}} + P_{turb} + P_{CR}.$$

$$P_{stars} = \int a_\nu \, \sigma_\nu \, dr = \frac{Q_0 h\bar{\nu}}{4\pi c \, r_1^2}$$

$$P_{\vec{B}}(r) = \frac{\left|\vec{B}(r)\right|^2}{8\pi} = \left(\frac{n}{n_0}\right)^2 \frac{\left|\vec{B}(r_0)\right|^2}{8\pi}$$

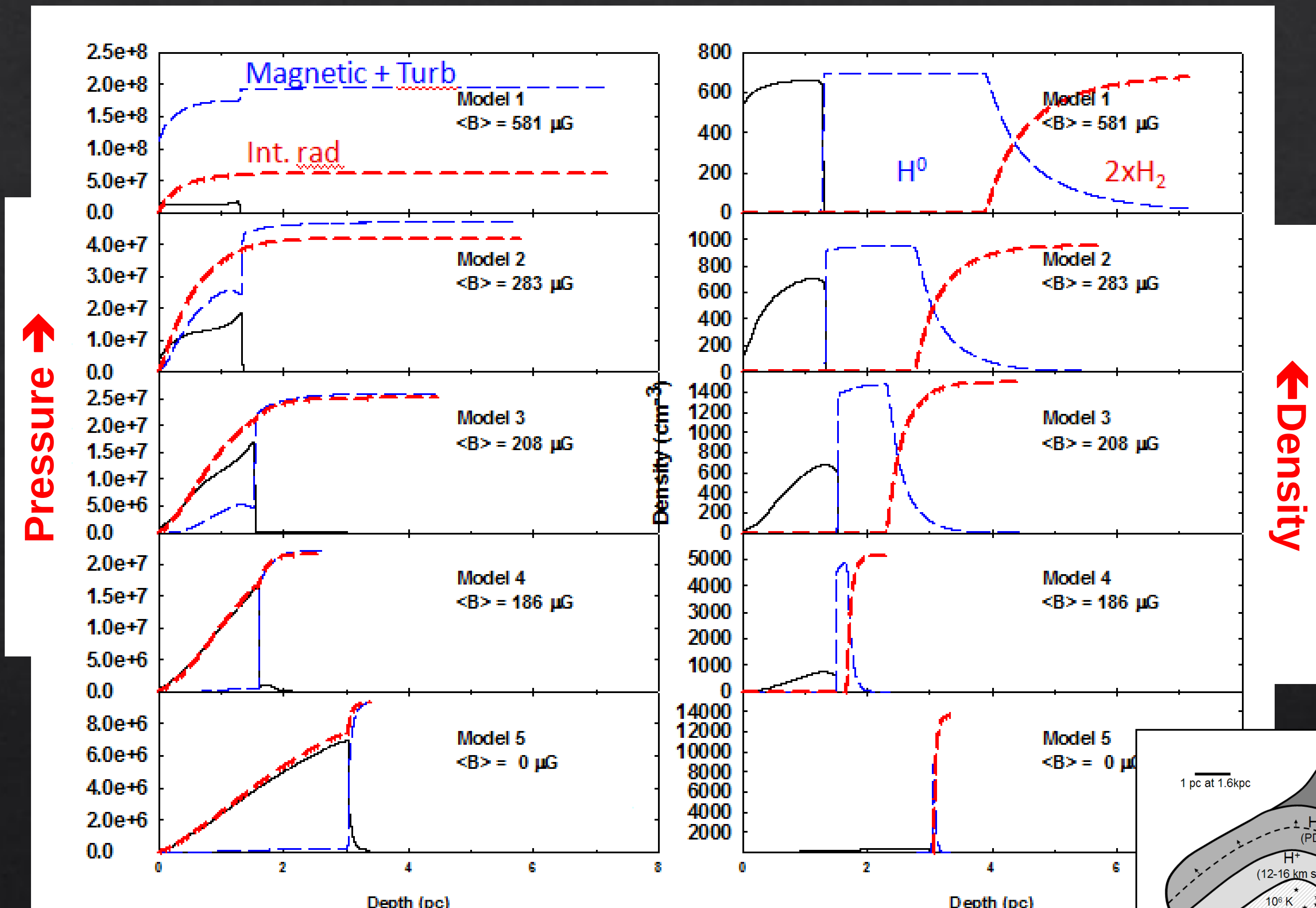
$$P_{CR}(r) = \gamma P_{\vec{B}}(r)$$

$$P_0 = P_{X-ray}$$

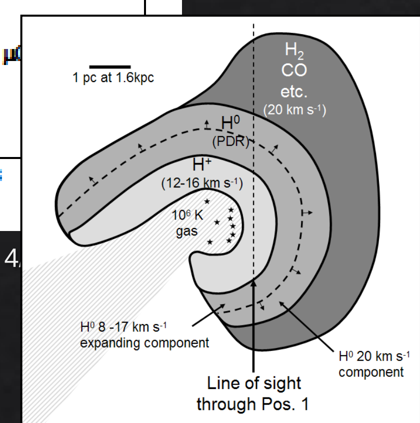


Pellegrini et al. 2007

M17



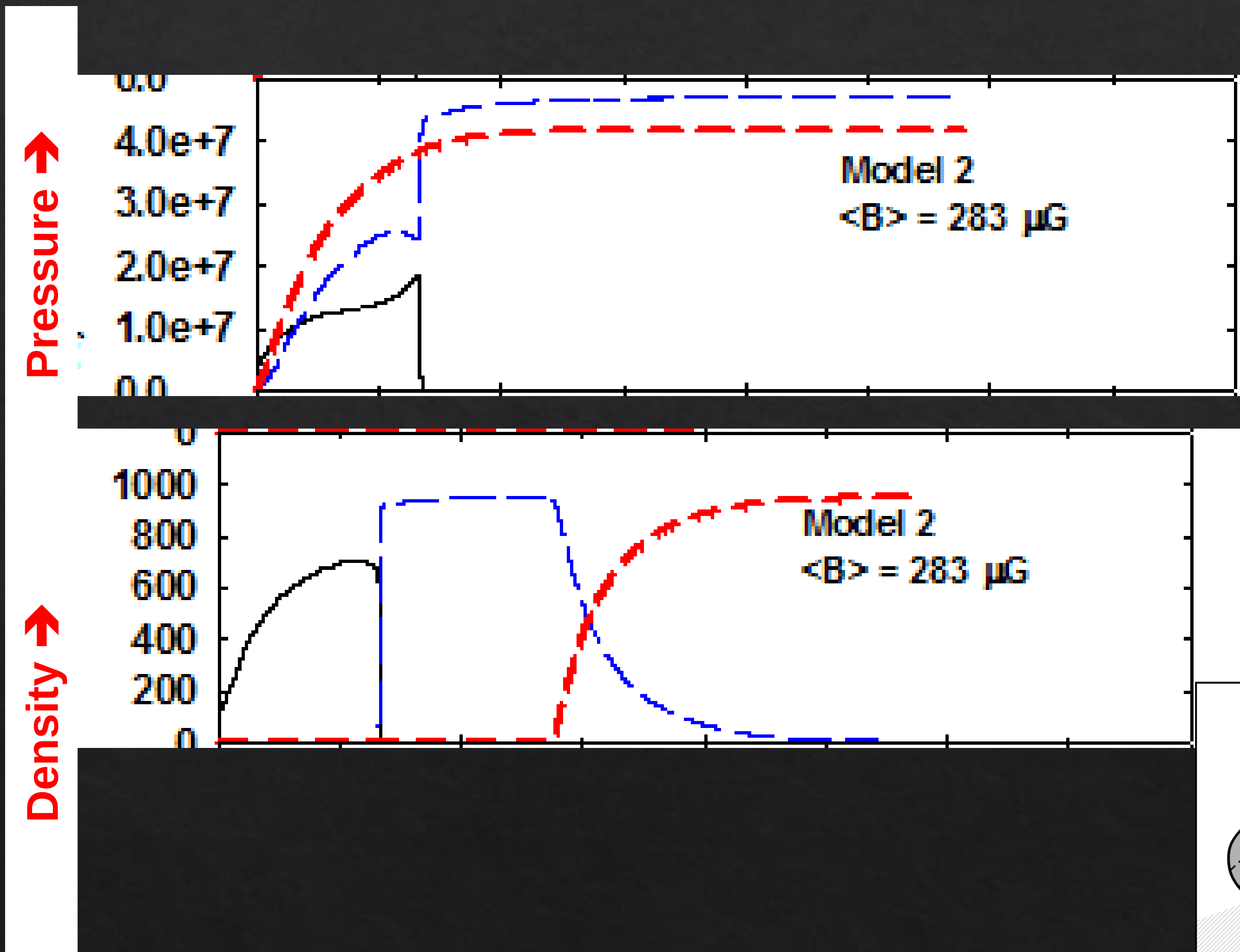
Magnetic + Turb
Int. rad
Model 1
<B> = 581 μG
Model 2
<B> = 283 μG
Model 3
<B> = 208 μG
Model 4
<B> = 186 μG
Model 5
<B> = 0 μG
Pressure
Density
H^0
$2xH_2$
Density (cm^{-3})
Depth (pc)
Depth (pc)

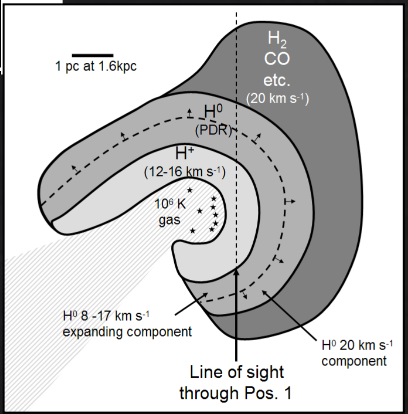


1 pc at 1.6kpc
H_2
CO
etc.
(20 km s^{-1})
H^0
(PDR)
H^+
(12-16 km s^{-1})
10^6 K
gas
H^0 8 -17 km s^{-1}
expanding component
H^0 20 km s^{-1}
component
Line of sight
through Pos. 1

4

M17

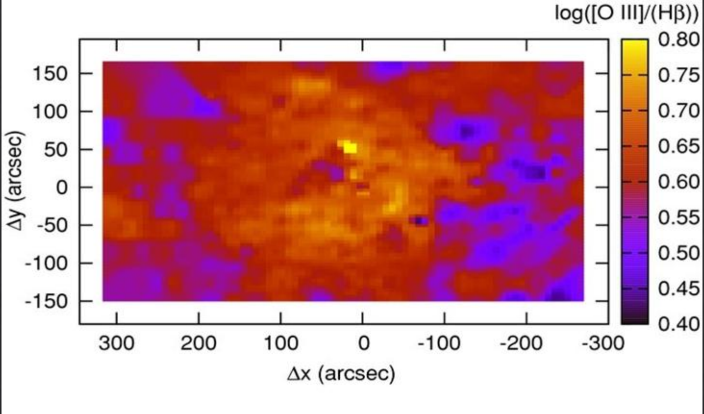

Pressure
4.0e+7
3.0e+7
2.0e+7
1.0e+7
0.0
Model 2
<B> = 283 µG
Density
1000
800
600
400
200
0
Model 2
<B> = 283 µG

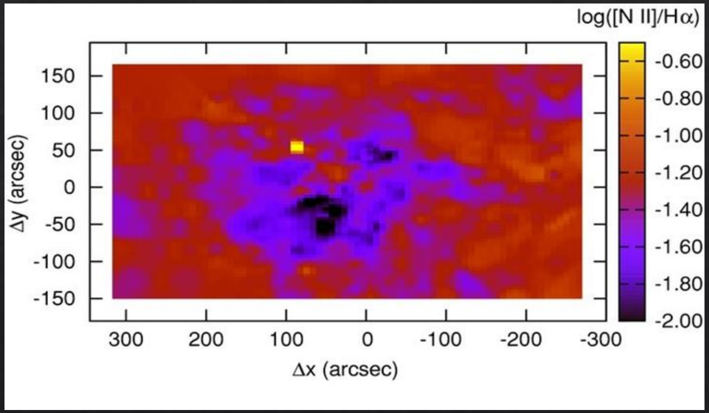

1 pc at 1.6kpc
H_2
CO
etc.
(20 km s-1)
H^0
(PDR)
H^+
(12-16 km s-1)
10^6 K
gas
H^0 8 -17 km s-1
expanding component
H^0 20 km s-1
component
Line of sight
through Pos. 1

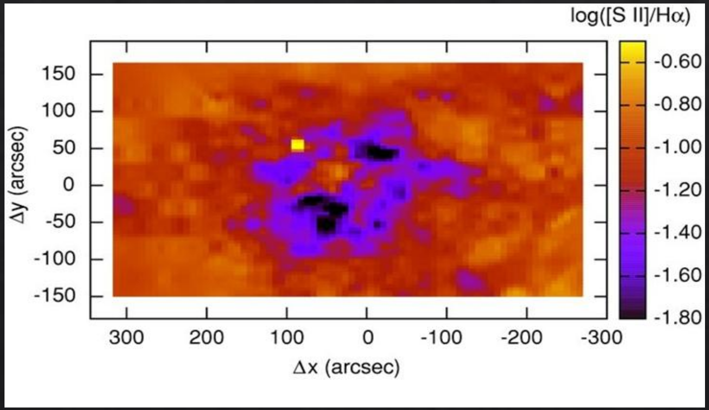
Detailed Ionization Balance

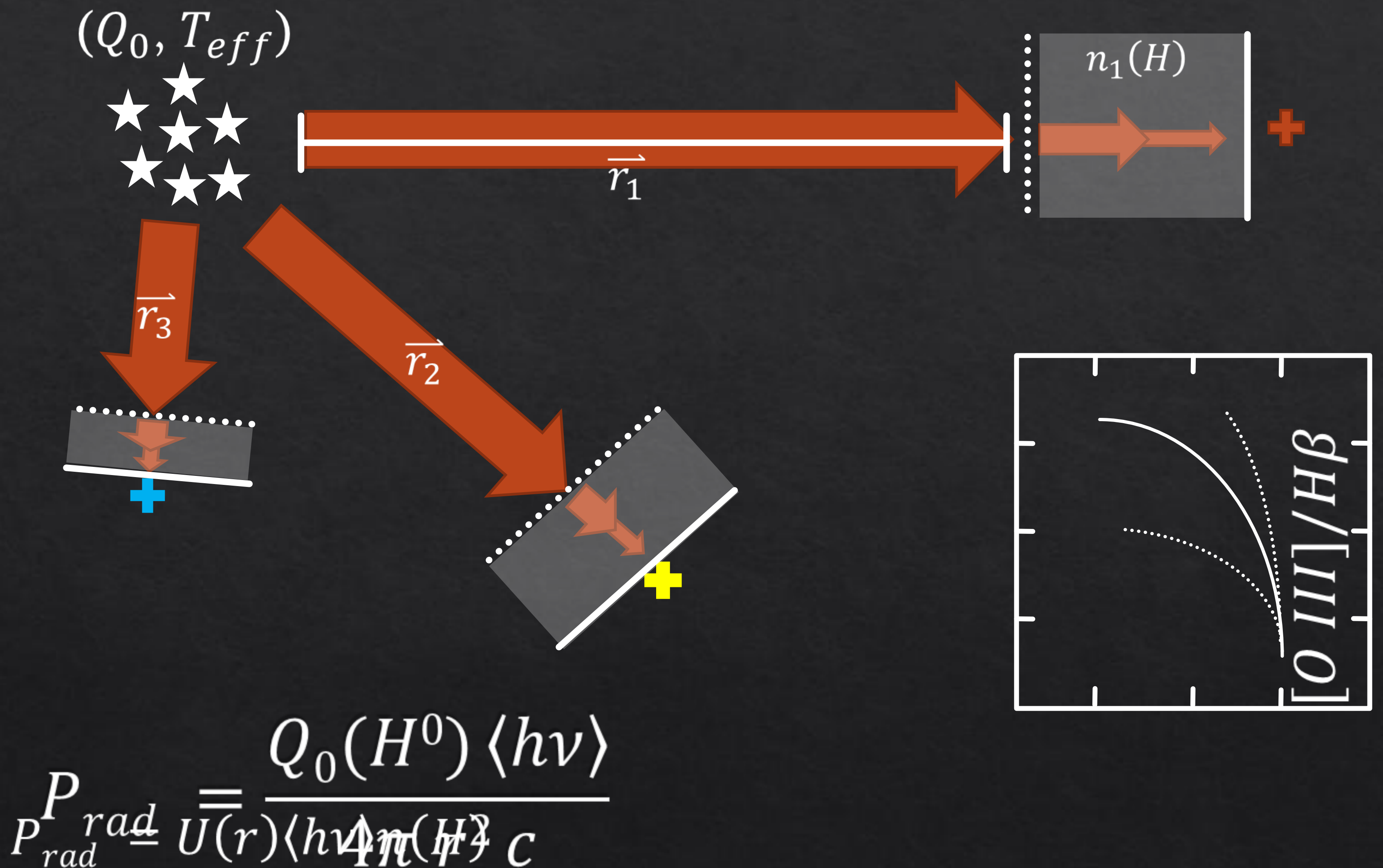
Photoionization Models
- Z
- T_{eff}
- Dust
- $U(n_0, r_0)$
- EOS: $n(r,T)$

Nebular Emission
- H^+, O^{++}, Ar^{++}
- O^+, N^+, S^+



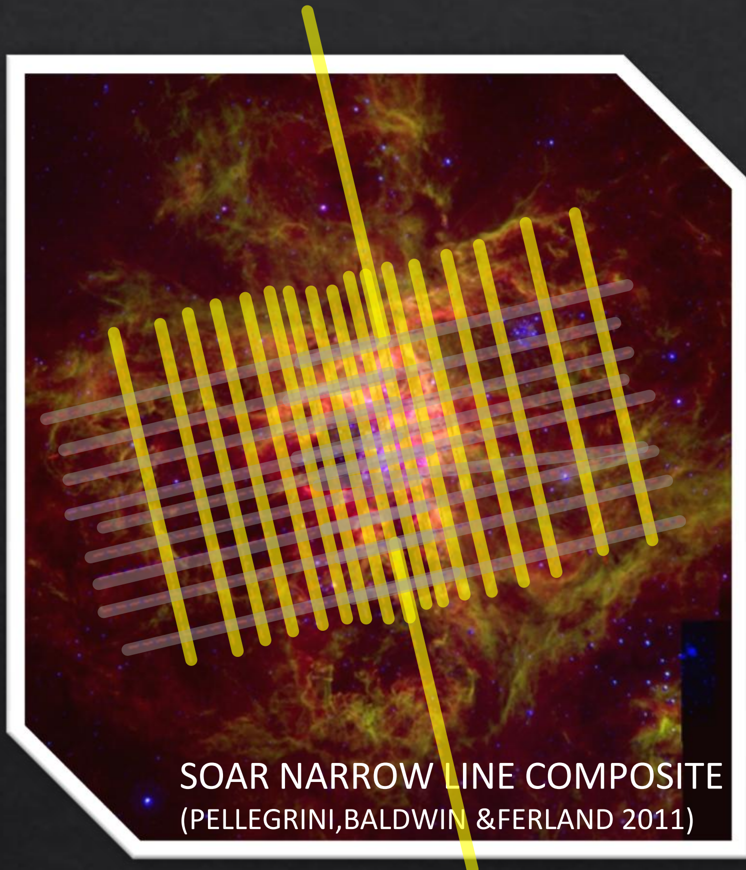






(Q_0, T_{eff})
$\overrightarrow{r_1}$
$n_1(H)$
$\overrightarrow{r_3}$
$\overrightarrow{r_2}$
$[O\ III]/H\beta$
$P_{rad} = \frac{Q_0(H^0)\langle h\nu\rangle}{4\pi r^2 c}$

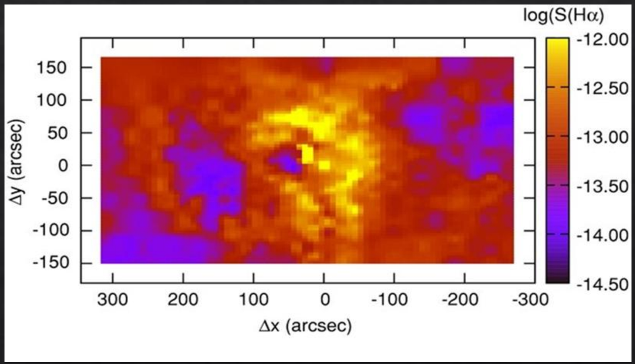
Optical Ionized Gas survey

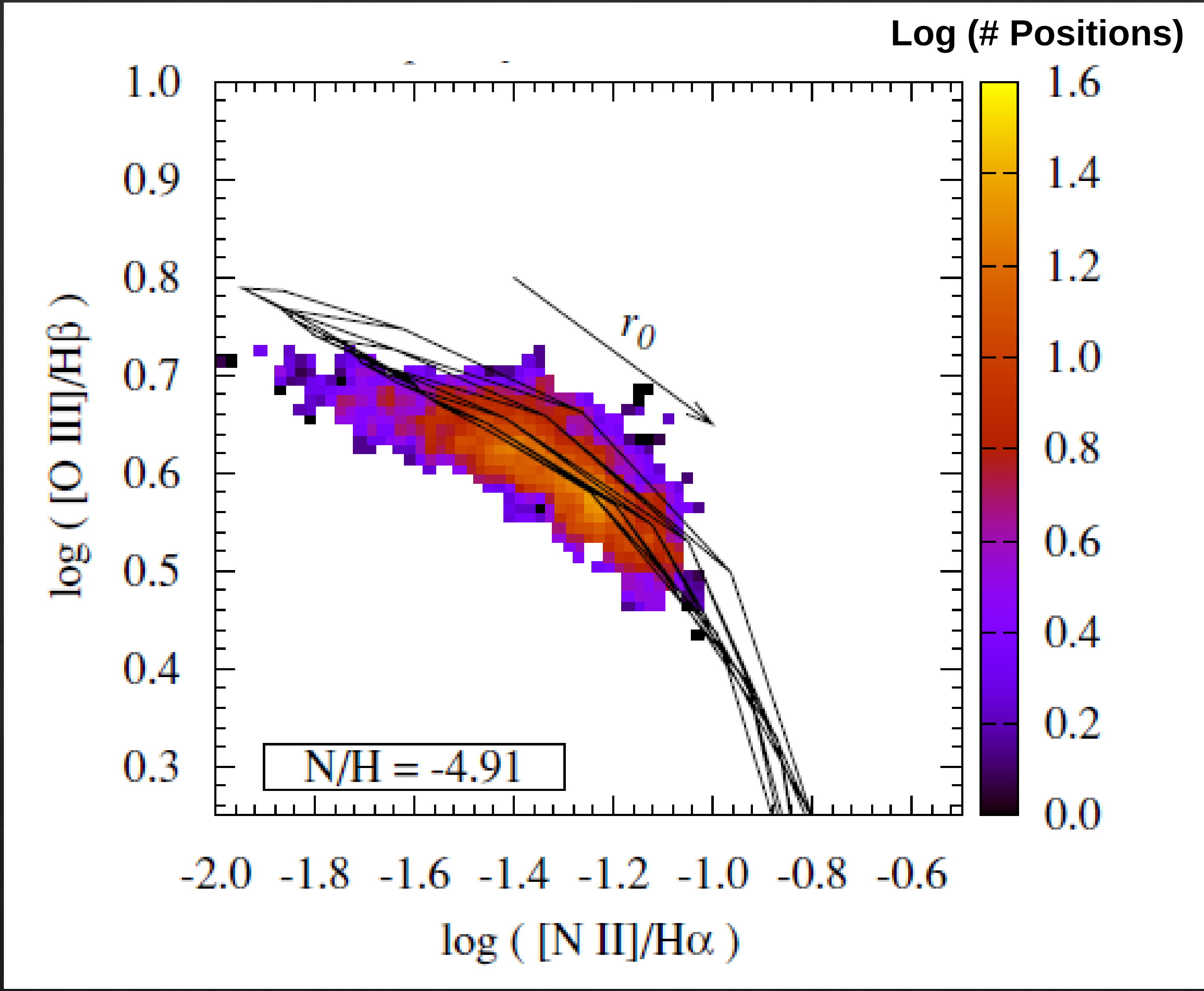


Hα 6563, Hβ 4861
He I 5875, 7065

[OIII] 4364,4959,5007
[ArIII] 7135

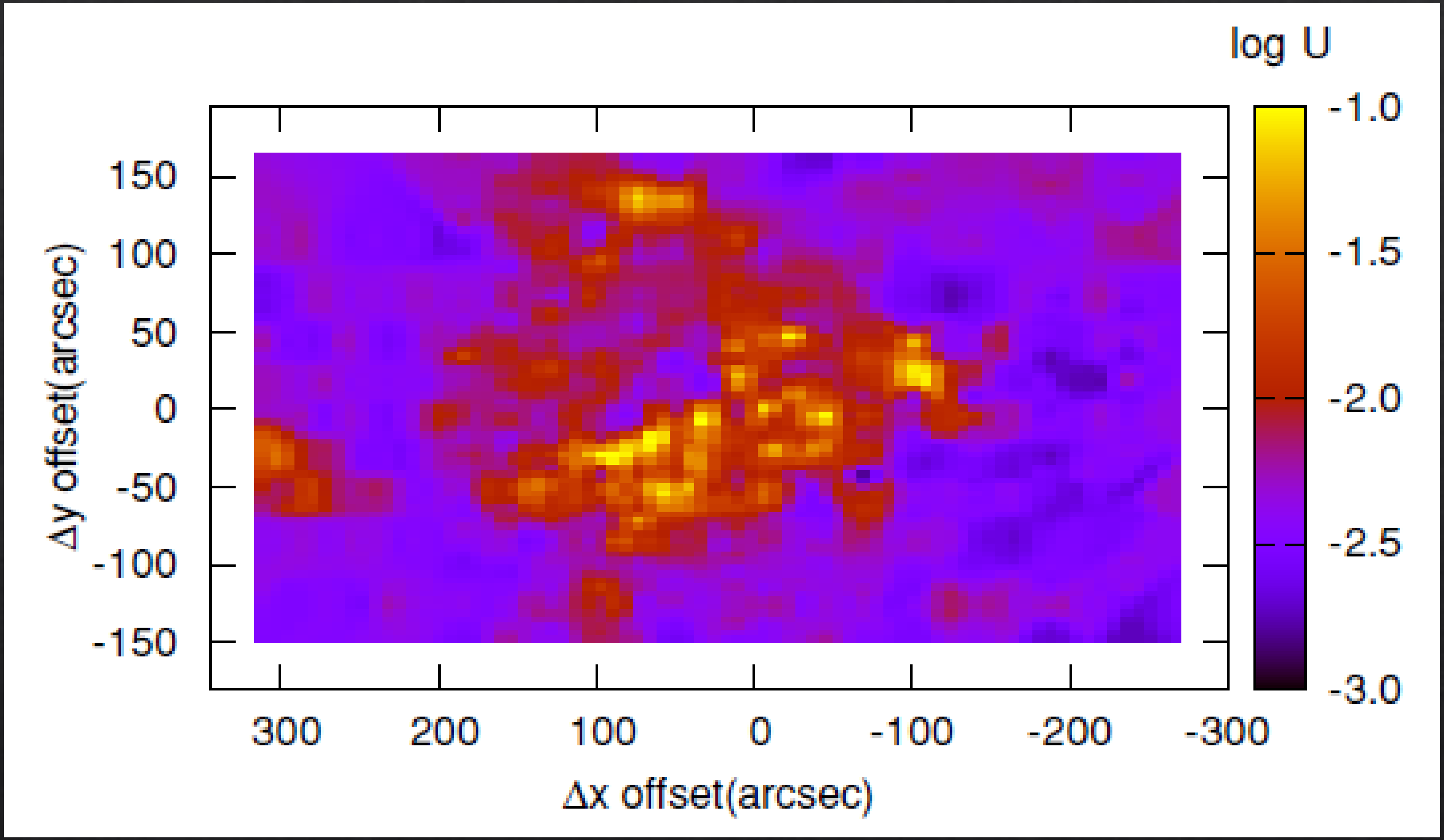
[O II] 7325
[N II] 6548,6584
[S II] 6717, 6731

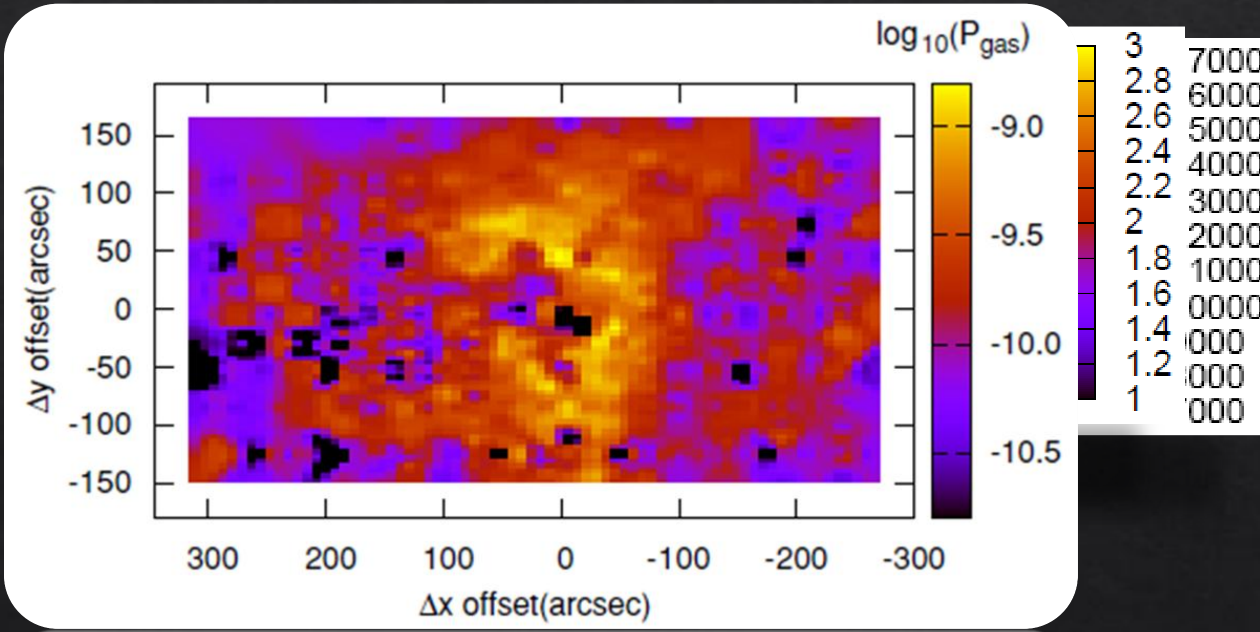




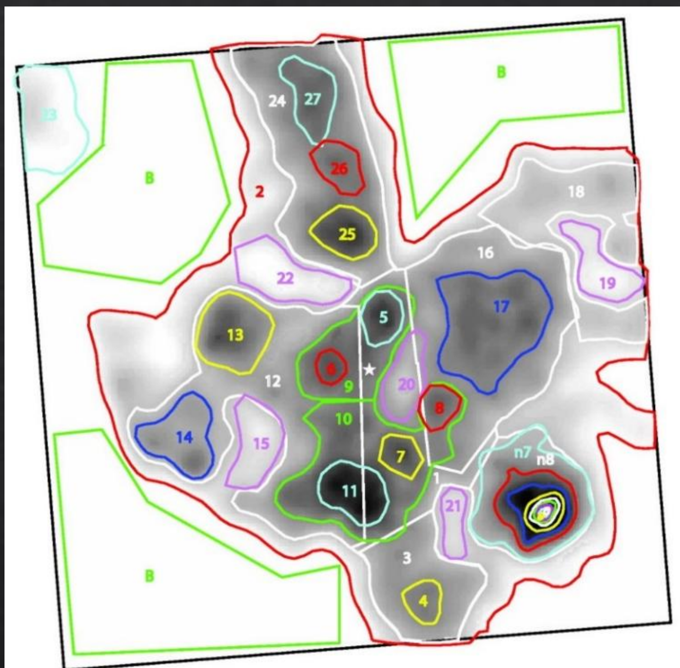
Log (# Positions)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
log ([O III]/Hβ)
r_0
N/H = -4.91
-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6
log ([N II]/Hα)

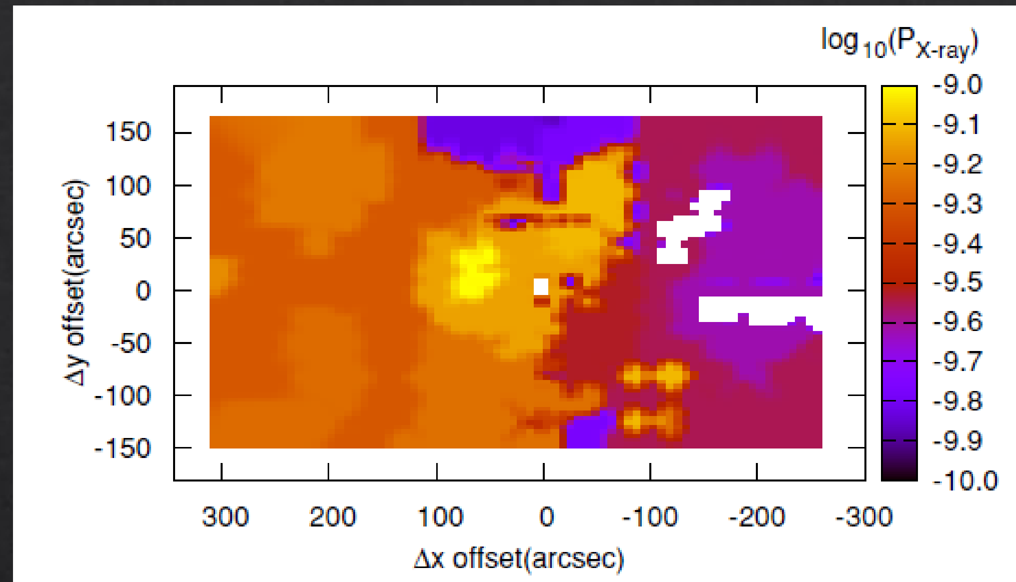
$$P_{rad} = U(r)\langle h\nu\rangle\, n(H)$$




log$_{10}$(P$_{gas}$)
Δy offset(arcsec)
150
100
50
0
-50
-100
-150
300
200
100
0
-100
-200
-300
Δx offset(arcsec)
-9.0
-9.5
-10.0
-10.5
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
7000
6000
5000
4000
3000
2000
1000

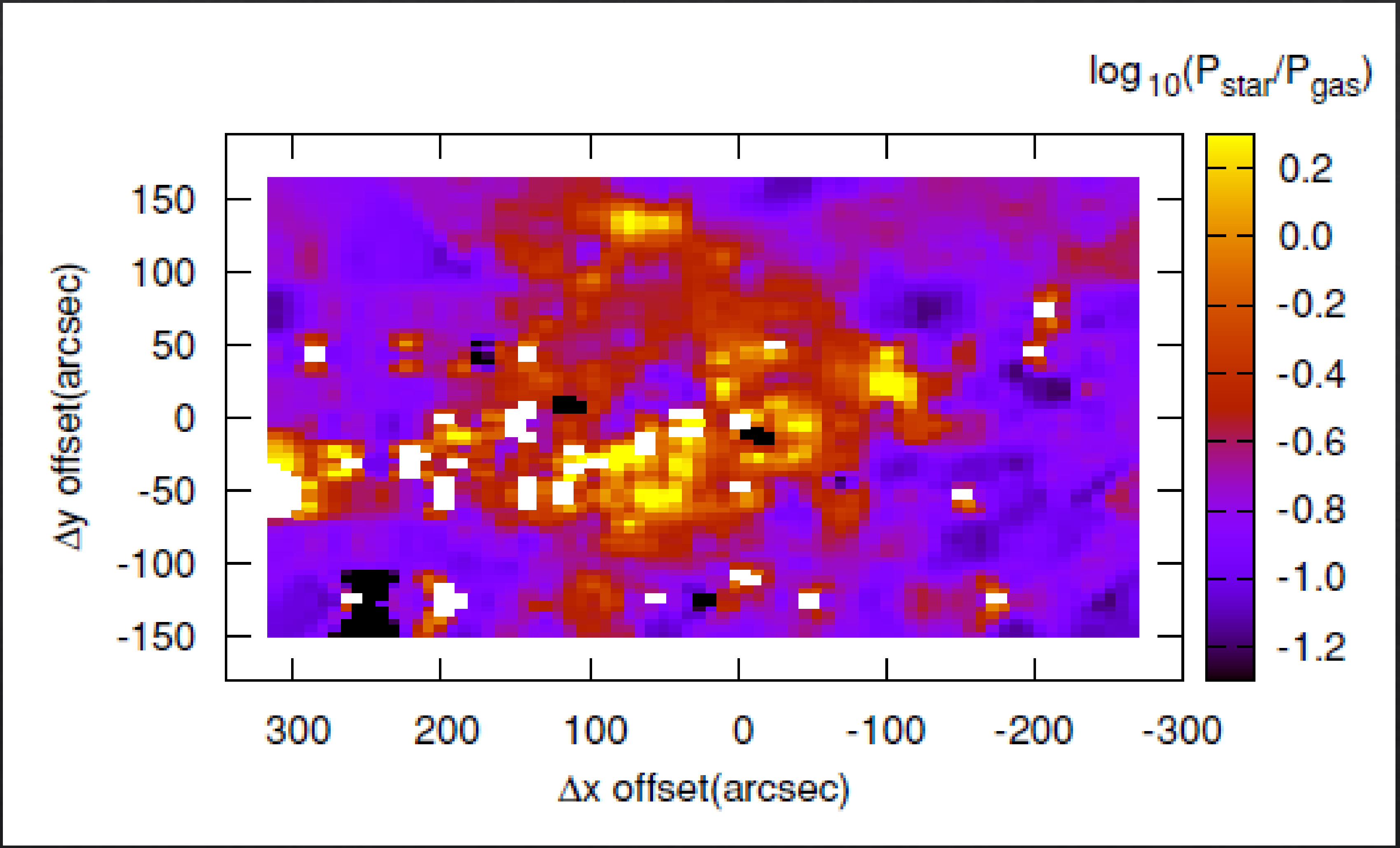
Townsley et al. 2006, AJ, 131, 2140



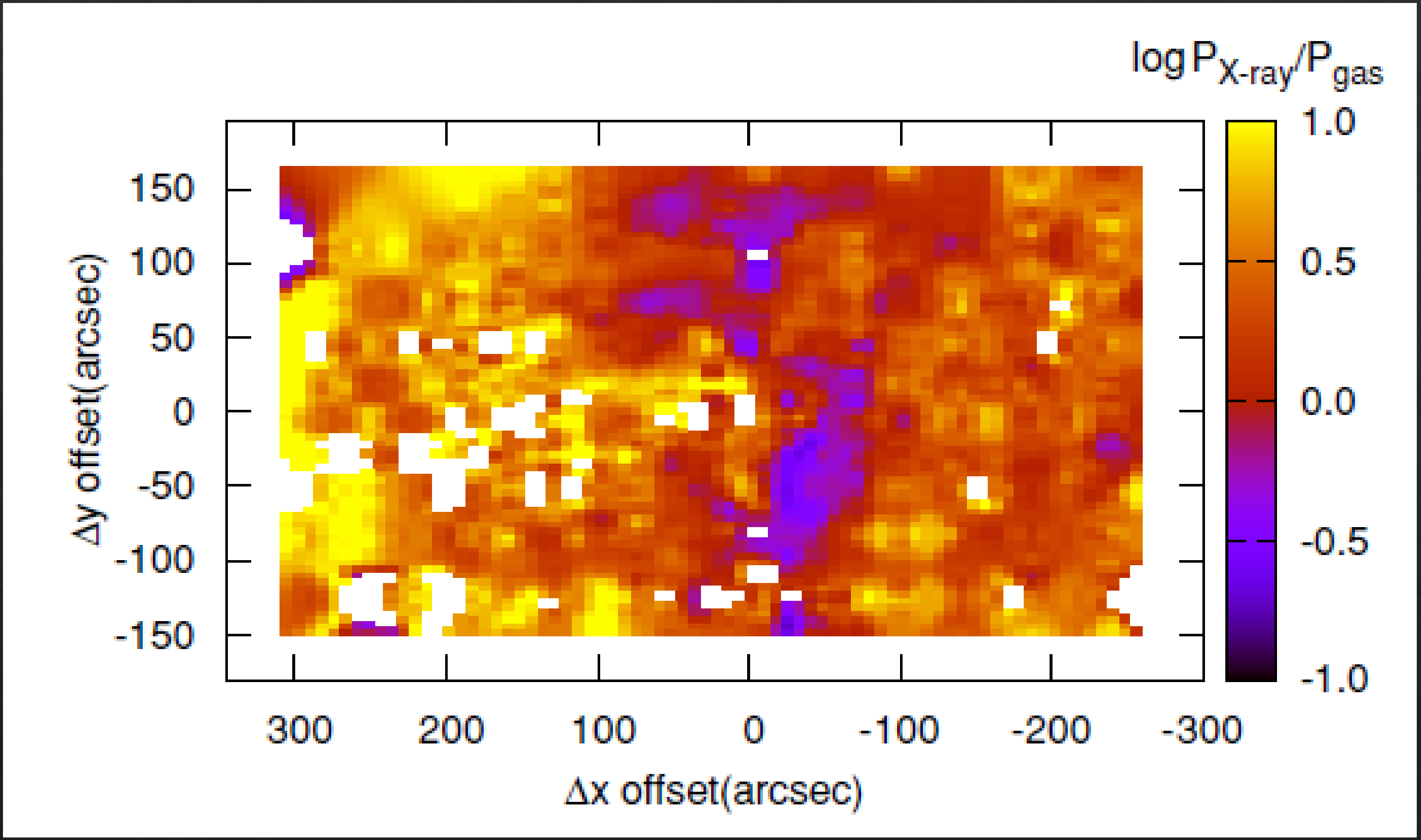


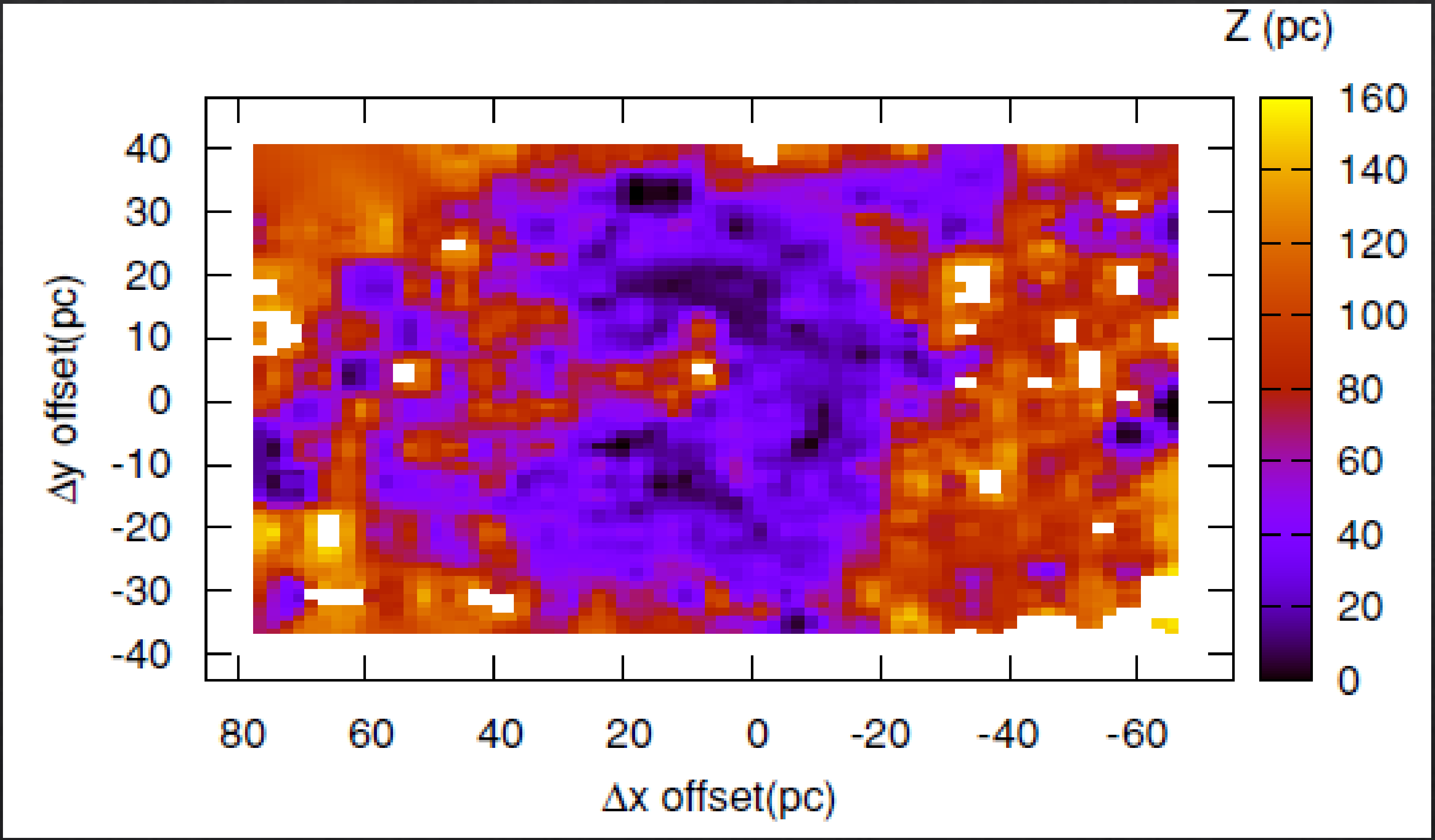
$$L_X = \Lambda\, n_e^2 V_X$$

$$P_X = T_X \times \sqrt{\frac{L_X}{\Lambda\, V_X}}$$



log 10(P star/P gas)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Δy offset(arcsec)
150
100
50
0
-50
-100
-150
300
200
100
0
-100
-200
-300
Δx offset(arcsec)

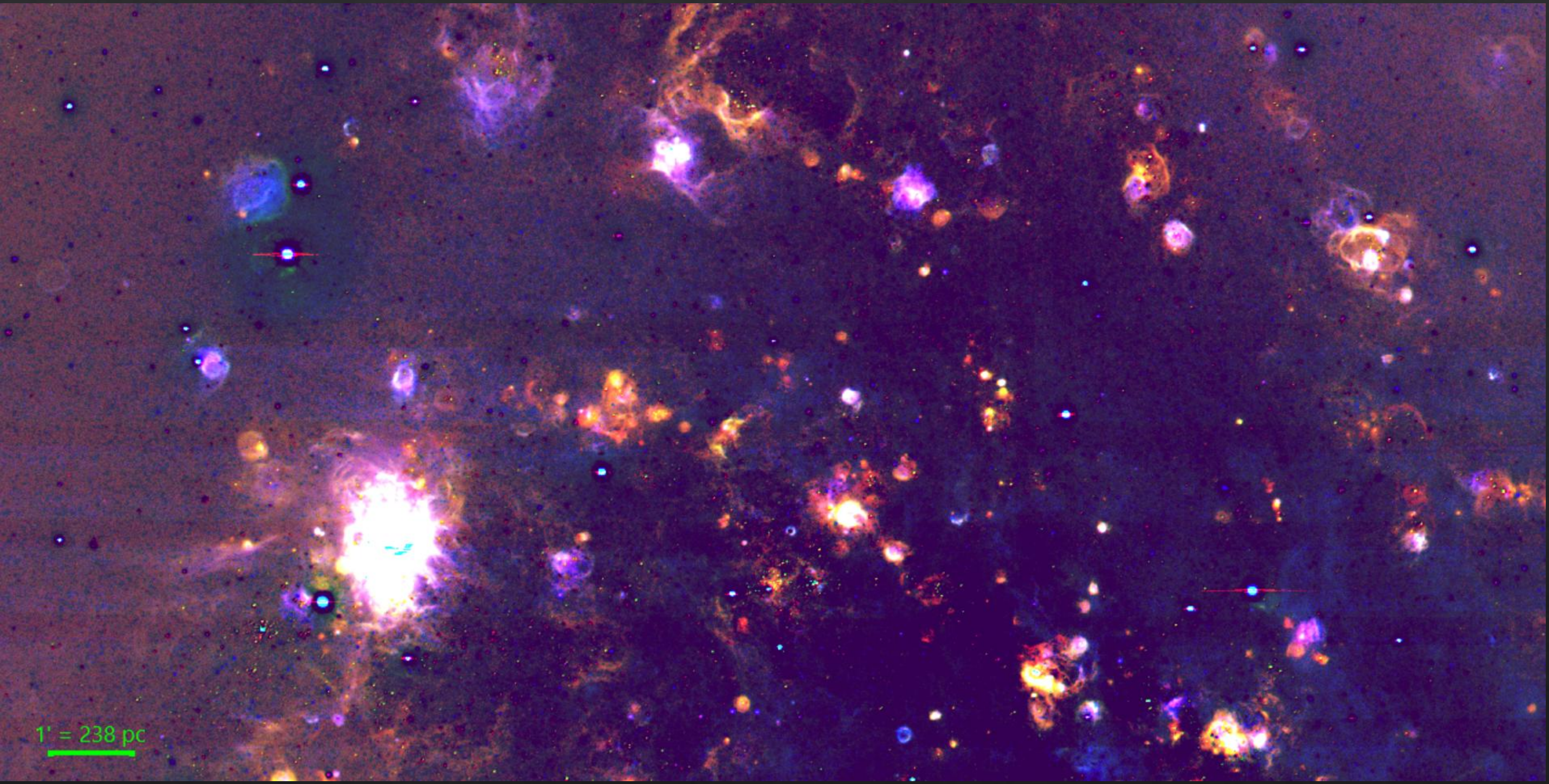

log $P_{X\text{-ray}}/P_{gas}$
1.0
0.5
0.0
-0.5
-1.0
150
100
50
0
-50
-100
-150
Δy offset(arcsec)
300
200
100
0
-100
-200
-300
Δx offset(arcsec)


Z (pc)
160
140
120
100
80
60
40
20
0
40
30
20
10
0
-10
-20
-30
-40
Δy offset(pc)
80
60
40
20
0
-20
-40
-60
Δx offset(pc)

Feedback Summary

	30 Doradus	M17	Orio
Q(H) s^{-1} Log R (cm) Age (Myr)	52.0 19.8 – 22.5 25	50.0 17.9 1	 ≤
$\frac{P_{rad}}{P_{gas}}$	<0.1-0.4	2	
$\frac{P_{X}}{P_{gas}}$	1-10	0.2	
$\frac{P_{\vec{B}}}{P_{gas}}$	?	2	

M33



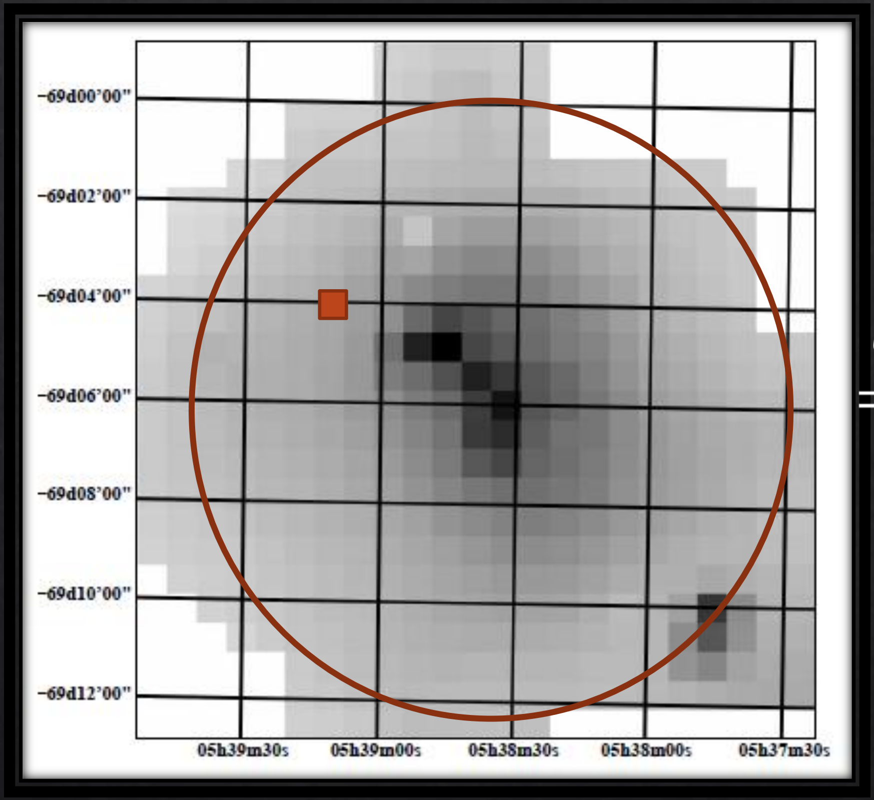
Red Ha; Blue [OIII]; Green [OII]

Conclusion

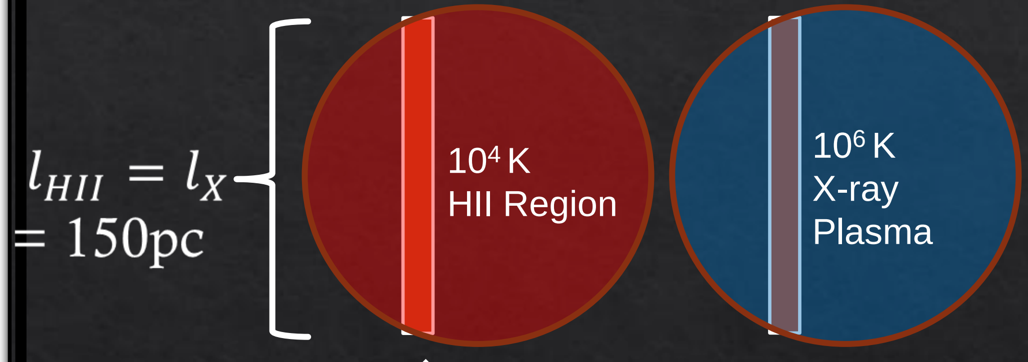
- Feedback Mechanisms
  - X-ray vs HII Gas vs Radiation
  - Dominance changes with age
- 3-d Gas distribution is **CRITICAL**
  - over simplification ➔
    - 100x over prediction in P_{rad}
    - 10x under prediction $P_{X\text{-}ray}$

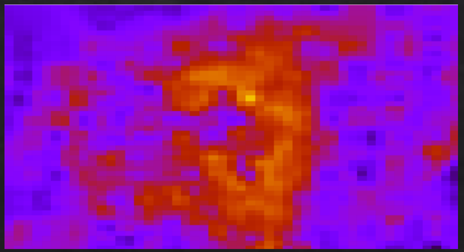
Difference in Gas Pressure (HII Region and X-Ray Plasma)

$$P_{gas} = T$$



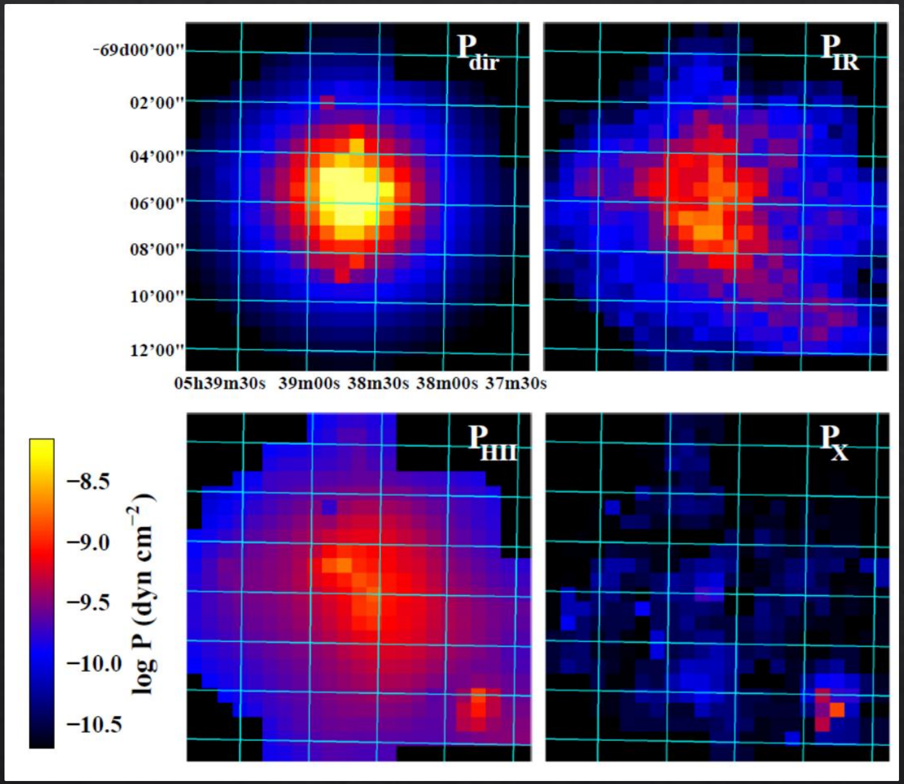
Density map from Lopez et al. 2011





Density map from Pellegrini+2012

Difference in Radiation Pressure (Direct Starlight)



Lopez et al. 2011

Feasibility ?

Does Lopez+2011 overestimate energetics?
The assumption by L11 of spherical gas with unity filling factor is relatable to the Strongmen radius.

Using L11 minimum density of 200 cm^{-3} and $Q_0=10^{52}$ s^{-1} →

$$R_S = \left(\frac{3Q_0}{4\pi\alpha\, n_H^2}\right)^{\frac{1}{3}} = 39\,pc$$

However, the asserted R_s =150, or a volume 52 × larger than can be ionized given the assumptions.