Observations of Stellar Feedback on Small Scales

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In collaboration with:
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Conclusions

➡ Stellar feedback plays an important role at large and small scales

➡ Multiwavelength data can be used to assess observationally the relative role of different stellar feedback mechanisms in HII regions

➡ Using this approach, we studied 32 HII regions in the LMC and SMC, including 30 Doradus

➡ Radiation pressure drove the dynamics of 30 Doradus at early times, warm ionized gas pressure dominates otherwise

➡ Hot shocked gas (from stellar winds and SNe) is not dynamically significant in all 32 sources, possibly because it leaks

➡ Warm ionized gas drives the dynamics of 32 HII regions, although the dust-processed radiation field is significant in some sources

Importance of Feedback

Large Scale

Realistic stellar masses and bulges in galaxies (e.g., White & Rees 1978; Keres et al. 2009)

Formation of bulgeless dwarf galaxies (e.g., Mashchenko et al. 2008; Governato et al. 2010)

Galaxy luminosity function and the mass-metallicity relation (e.g., Kauffman et al. 1994; Cole et al. 1994; Somerville & Primack 1999)

Star formation efficiency on galactic scales (e.g., Kennicutt 1998)

Kpc-scale galactic winds (e.g., Veilleux et al. 2005)

Small Scale

Creates ISM phase structure (e.g., McKee & Ostriker 1977)

Low star formation efficiency in GMCs (e.g., Zuckerman & Evans 1974; Krumholz & Tan 2007)

Disruption & destruction of GMCs (e.g., Matzner 2002; Krumholz et al. 2006)

Possibly drives turbulence (e.g., Mac Low & Klessen 2004)

Possibly triggers star formation (e.g., Elmegreen 1998; Deharveng et al. 2005)

Uncertainty

Challenges: 1) lack of resolution / problem of scale
2) several modes of feedback
3) lack of observational constraints

In the Feedback Loop

Sources of feedback:

- ➡ Direct radiation from stars

  (Jijina & Adams 1996; Krumholz & Matzner 2009)

- ➡ Dust-processed radiation

  (Thompson et al. 2005; Murray et al. 2010; Andrews & Thompson 2011)

- ➡ Ionizing photons

  (Whitworth 1979; Dale et al. 2005)

- ➡ Stellar Winds / Supernovae

  (Yorke et al. 1989; Harper-Clark & Murray 2009; Rogers & Pittard 2013)

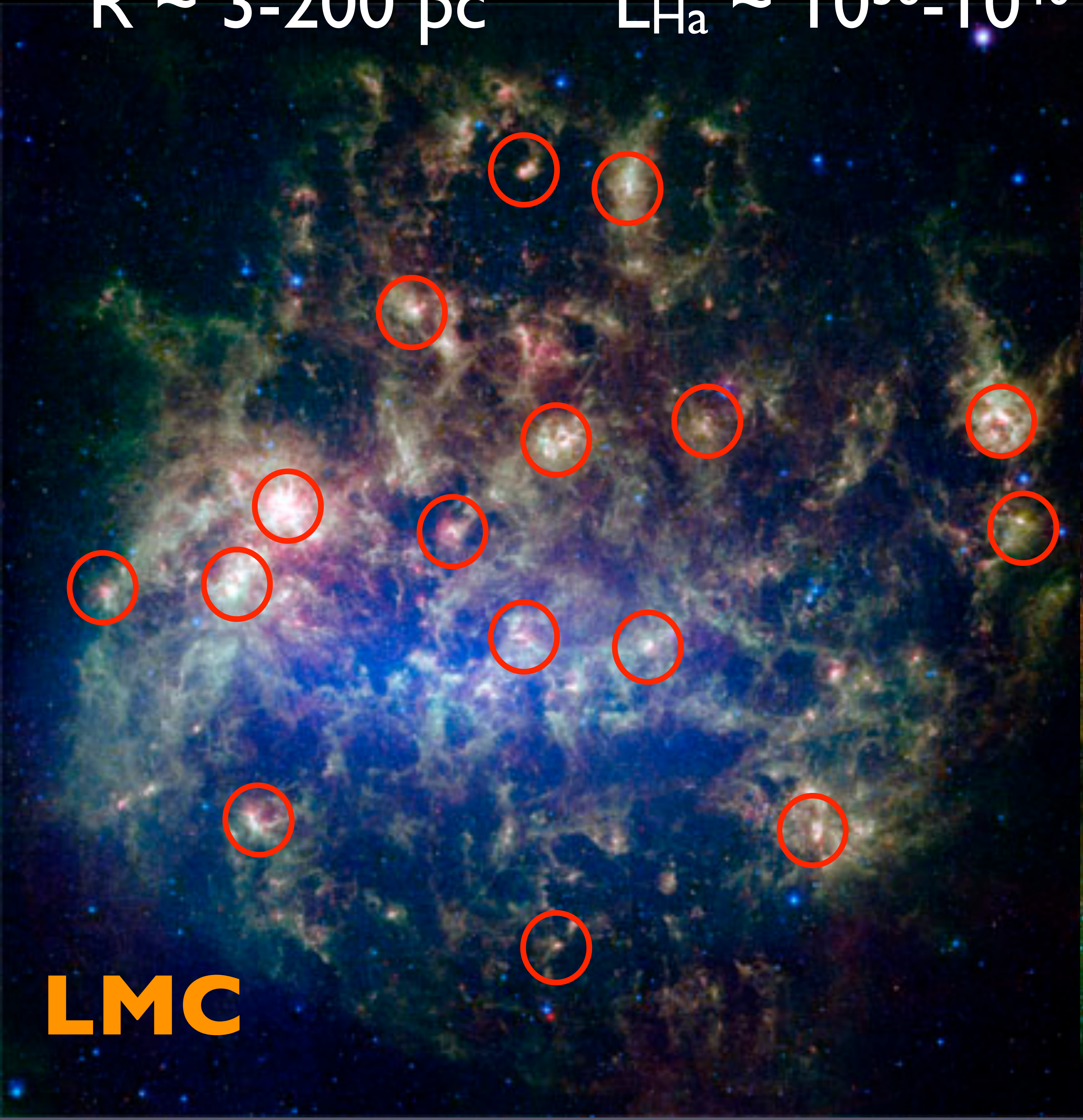
- ➡ Protostellar outflows/jets

  (Quillen et al. 2005; Cunningham et al. 2006; Li & Nakamura 2006; Nakamura & Li 2008; Wang et al. 2010)

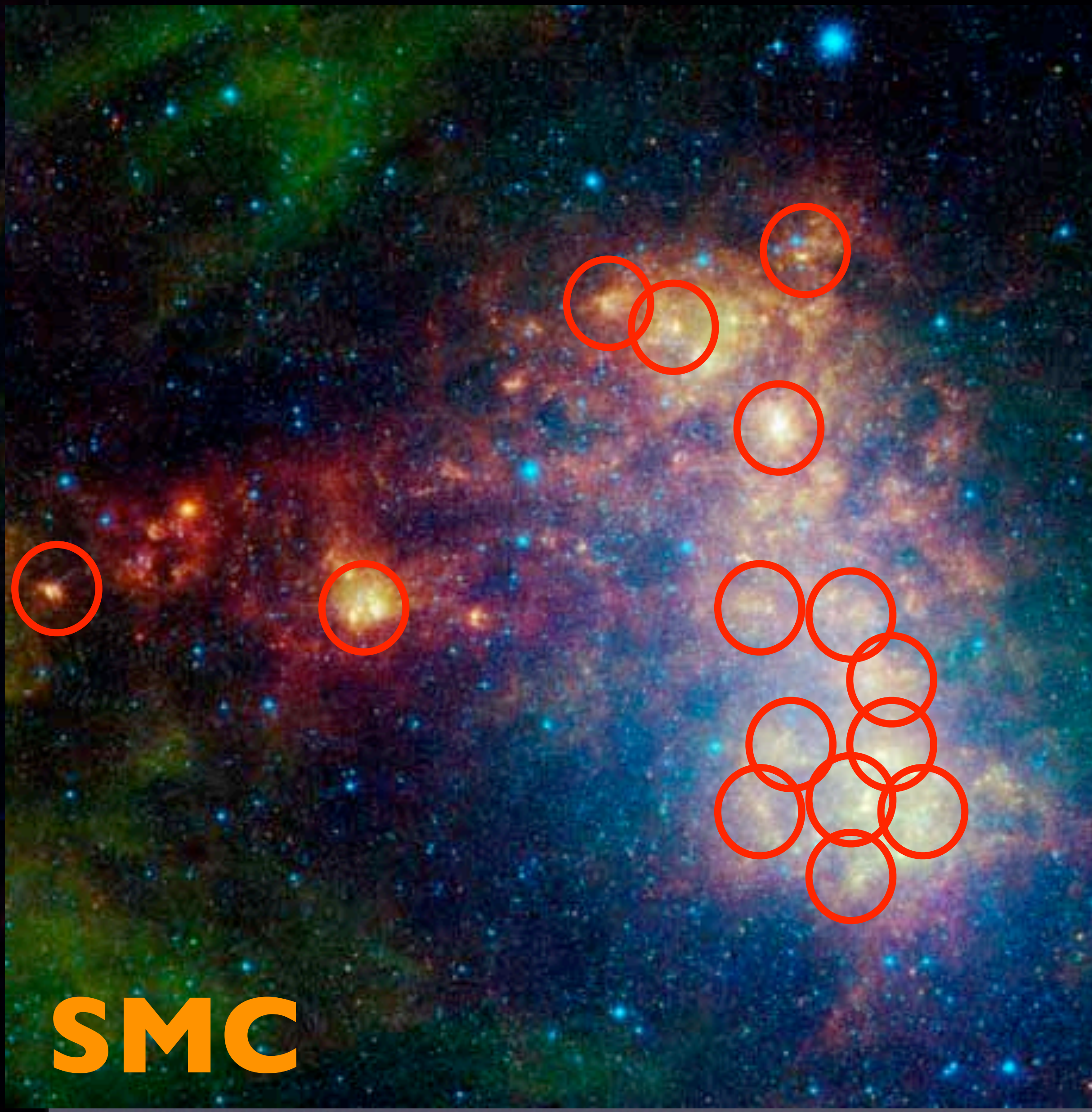
Approach: assess observationally the pressure associated with each feedback mechanism

HII Regions in the Magellanic Clouds

R ~ 3-200 pc $L_{Ha} \sim 10^{36}-10^{40}$ erg/s M ~ 300-5e4 M_{sun}



3.6um, 8um, 24um
(Spitzer SAGE Team)



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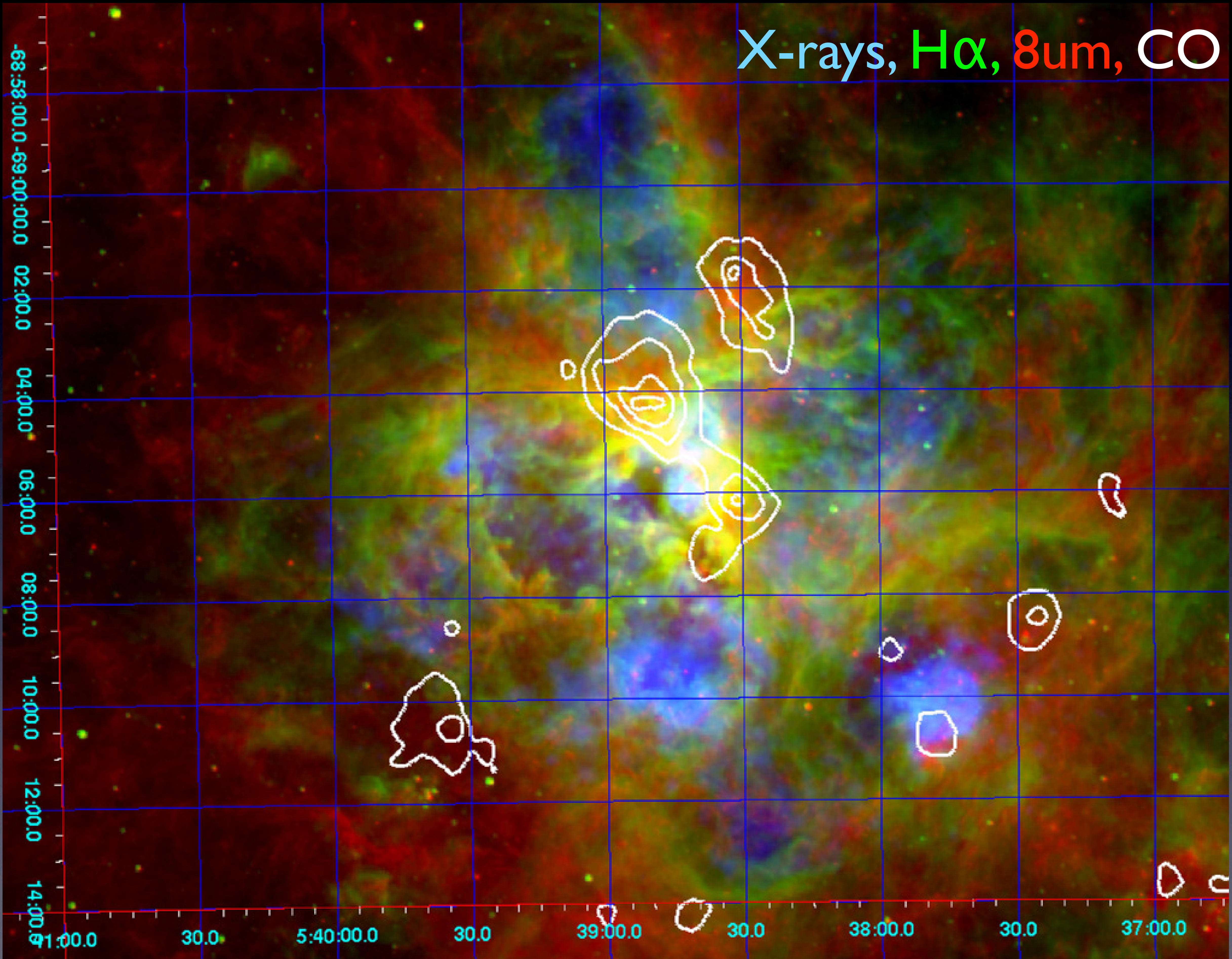
Test Case: 30 Doradus



X-rays, Hα, 8um, CO

Lopez et al. 2011

30 Doradus

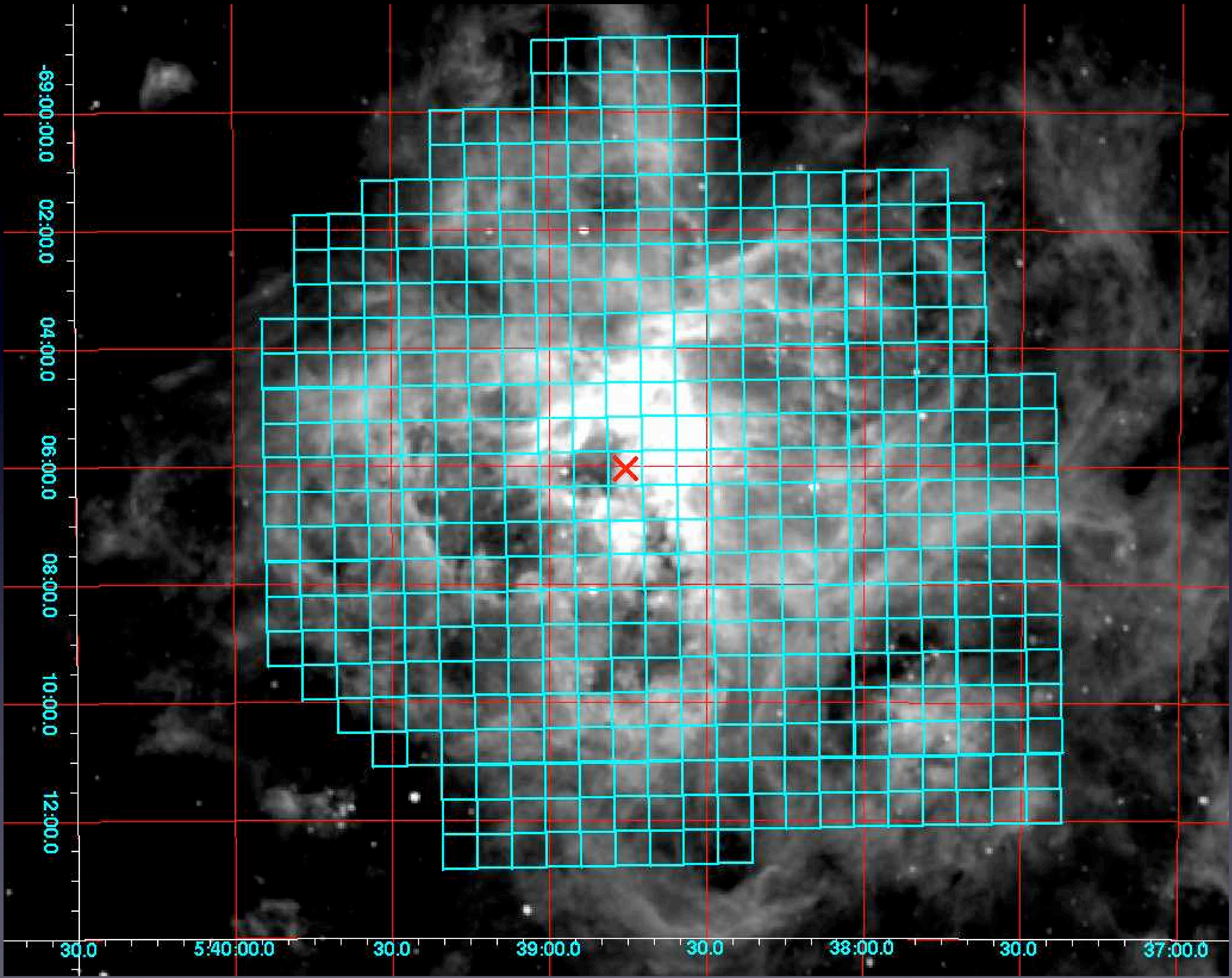


Image: Hα from MCELS (Smith et al. 1999)

Under Pressure

Pressure Source	Direct Radiation from stars
Relation	$P_{dir} = u_{\nu} = \Sigma \frac{L_{bol}}{4\pi r^2 c}$
Methods	UBV photometry $\rightarrow L_{bol}$
Data	Optical: HST PC (Malumuth & Heap), CTIO 0.9-m (Parker 1993), 2.2-m (Selman et al. 2005)

Hubble V-band; NASA/Trauger/Westfal

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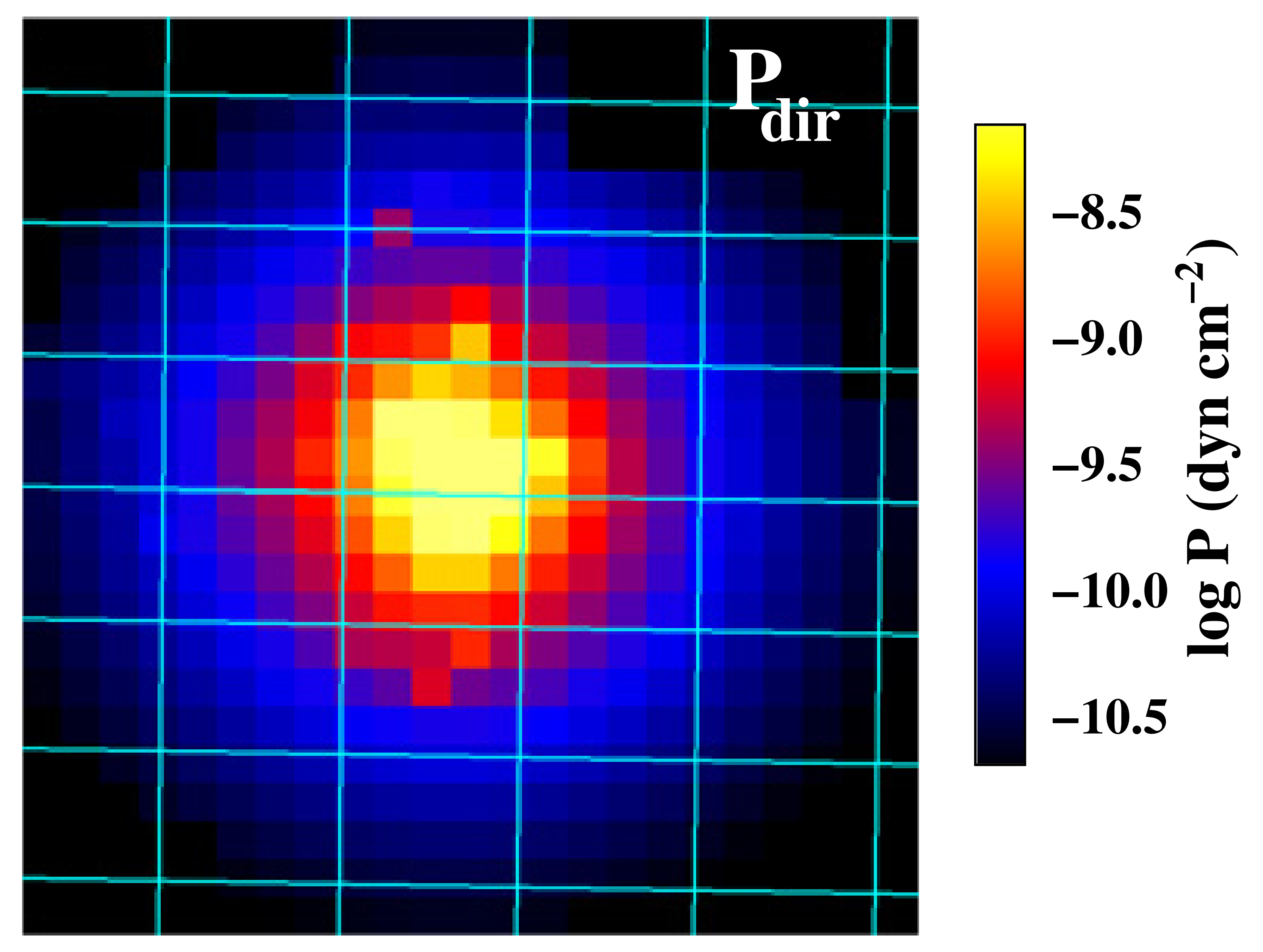
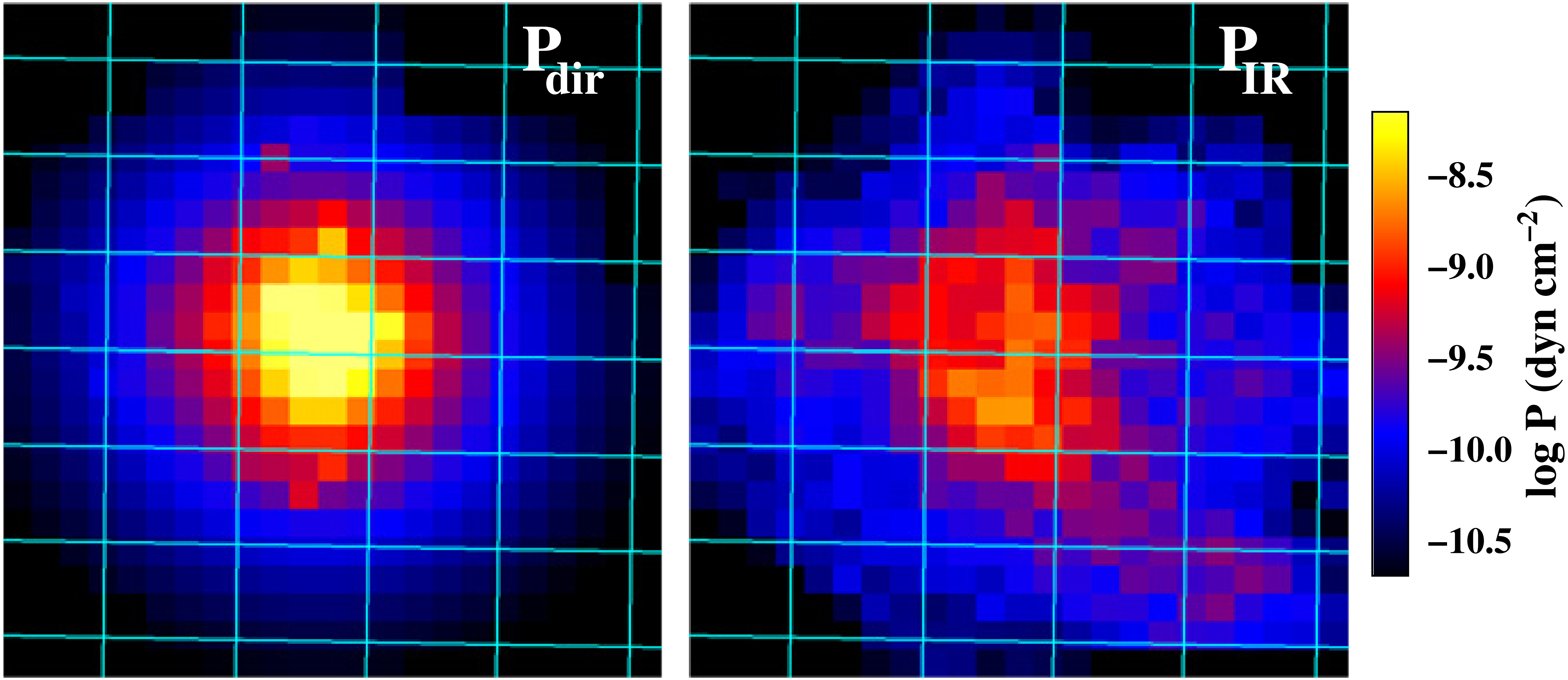


Under Pressure

Pressure Source	Direct Radiation from stars	Dust-Processed Radiation
Relation	$P_{dir} = u_\nu = \Sigma \frac{L_{bol}}{4\pi r^2 c}$	$P_{IR} = \frac{1}{3} u_\nu$
Methods	UBV photometry $\rightarrow L_{bol}$	IR SED modeling (Draine & Li 2007) $\rightarrow u_\nu$
Data	Optical: HST PC (Malumuth & Heap), CTIO 0.9-m (Parker 1993), 2.2-m (Selman et al. 2005)	Infrared: Spitzer SAGE Survey (Meixner et al. 2006): 8, 24, & 70 um

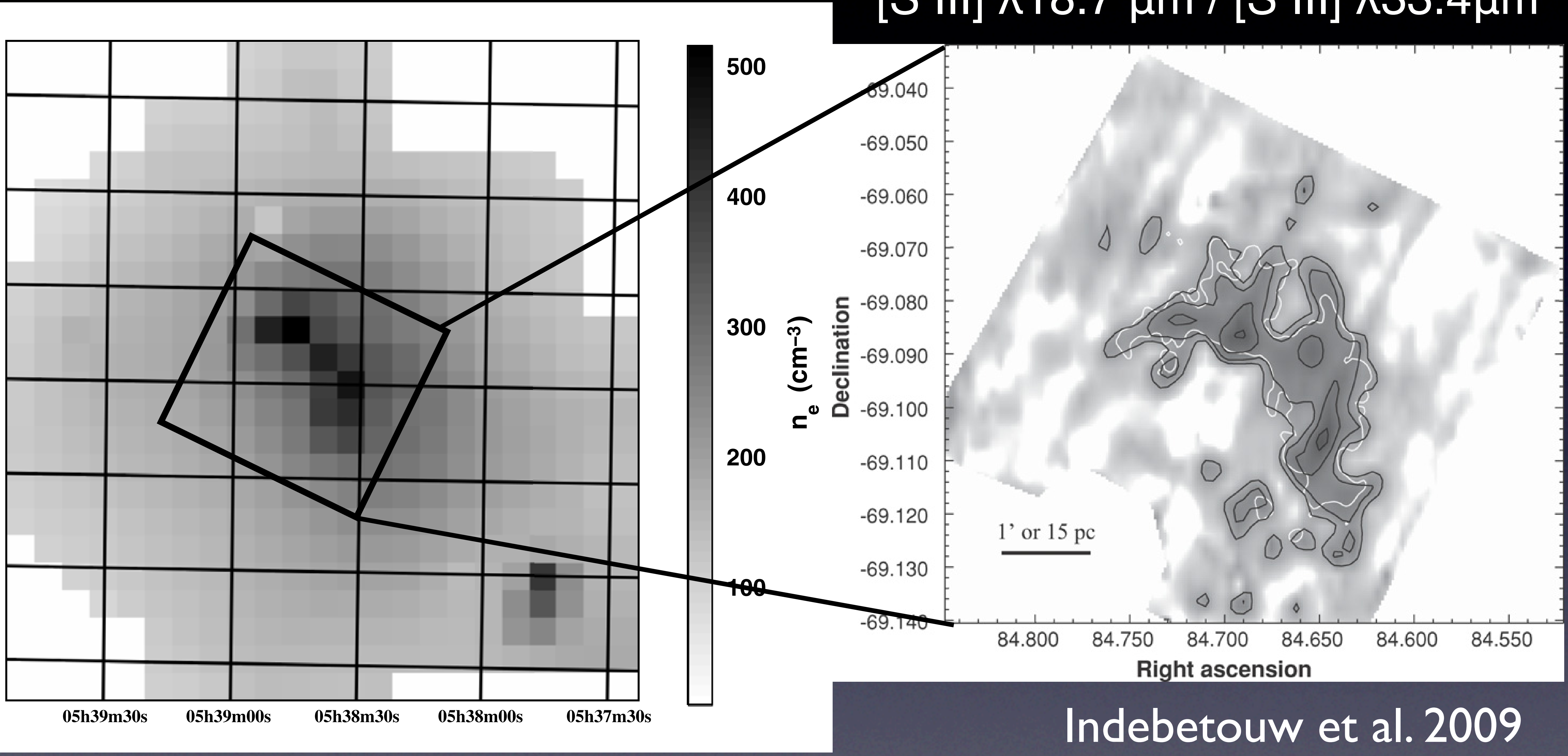
Dust-Processed Radiation Pressure



Under Pressure

Pressure Source	Direct Radiation from stars	Dust-Processed Radiation	Warm HII Gas
Relation	$P_{dir} = u_\nu = \Sigma \frac{L_{bol}}{4\pi r^2 c}$	$P_{IR} = \frac{1}{3} u_\nu$	$P_{HII} = 2\, n_e k T_{HII}$
Methods	UBV photometry → L_{bol}	IR SED modeling (Draine & Li 2007) → u_ν	Obtain n_e using flux density of free-free emission at 3.5-cm
Data	Optical: HST PC (Malumuth & Heap), CTIO 0.9-m (Parker 1993), 2.2-m (Selman et al. 2005)	Infrared: Spitzer SAGE Survey (Meixner et al. 2006): 8, 24, & 70 um	Radio: 3.5-cm ATCA+Parkes (Dickel et al. 2005)

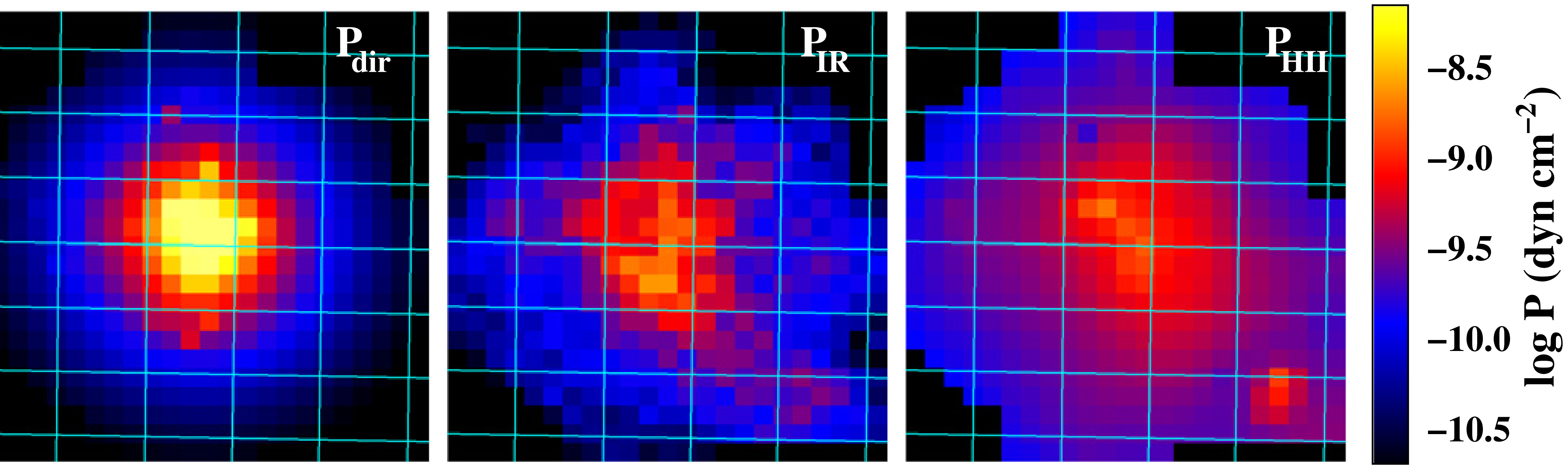
Warm HII Gas Pressure



[S III] λ18.7 µm / [S III] λ33.4µm

Indebetouw et al. 2009

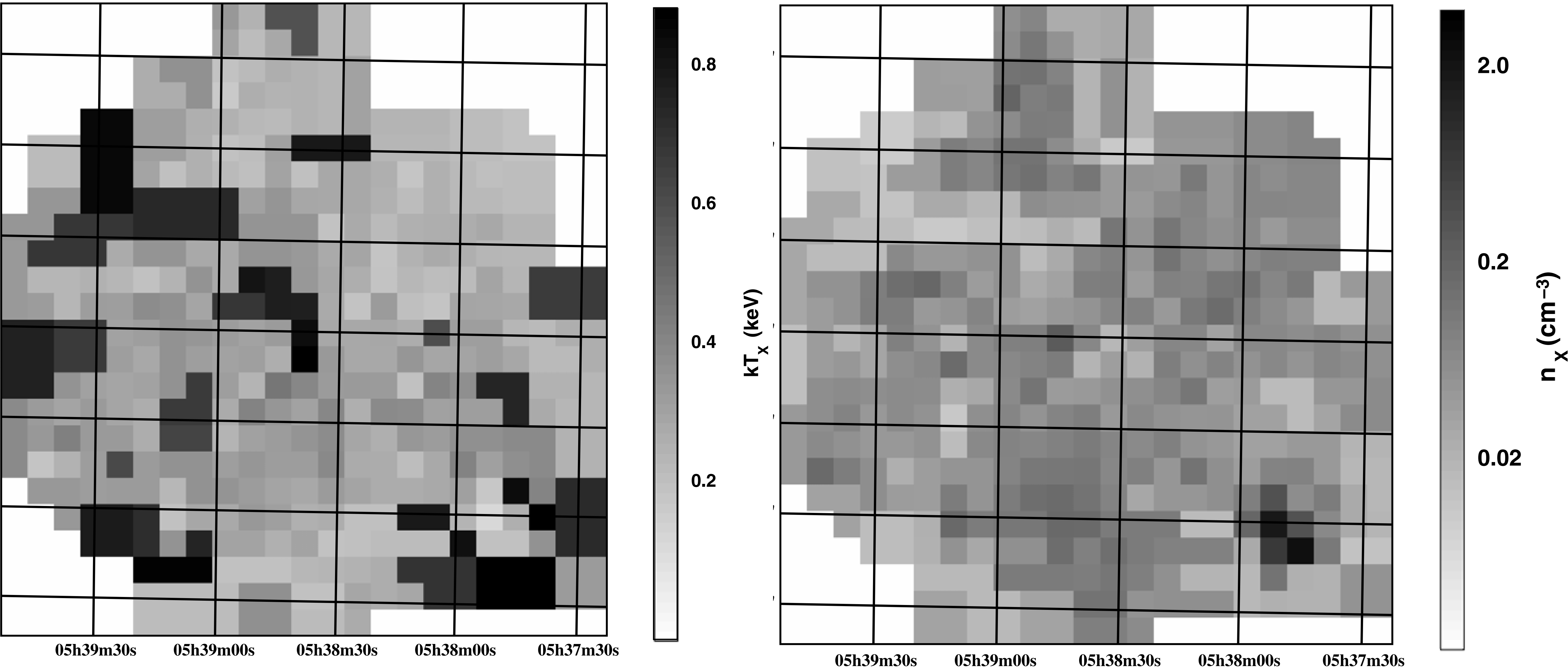
Warm HII Gas Pressure



Under Pressure

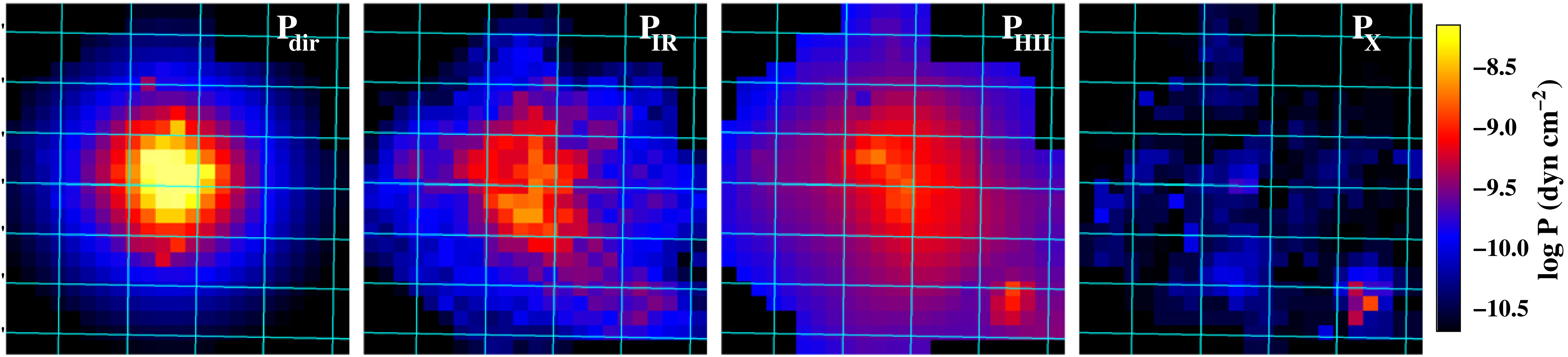
Pressure Source	Direct Radiation from stars	Dust-Processed Radiation	Warm HII Gas	Hot Shocked Gas
Relation	$P_{dir} = u_\nu = \Sigma \frac{L_{bol}}{4\pi r^2 c}$	$P_{IR} = \frac{1}{3} u_\nu$	$P_{HII} = 2\, n_e k T_{HII}$	$P_x = 2\, n_x k T_x$
Methods	UBV photometry $\rightarrow L_{bol}$	IR SED modeling (Draine & Li 2007) $\rightarrow u_\nu$	Obtain n_e using flux density of free-free emission at 3.5-cm	X-ray spectral modeling of bremsstrahlung
Data	Optical: HST PC (Malumuth & Heap), CTIO 0.9-m (Parker 1993), 2.2-m (Selman et al. 2005)	Infrared: Spitzer SAGE Survey (Meixner et al. 2006): 8, 24, & 70 um	Radio: 3.5-cm ATCA+Parkes (Dickel et al. 2005)	X-ray: Chandra X-ray (Townsley et al. 2006)

Hot X-ray Gas Pressure



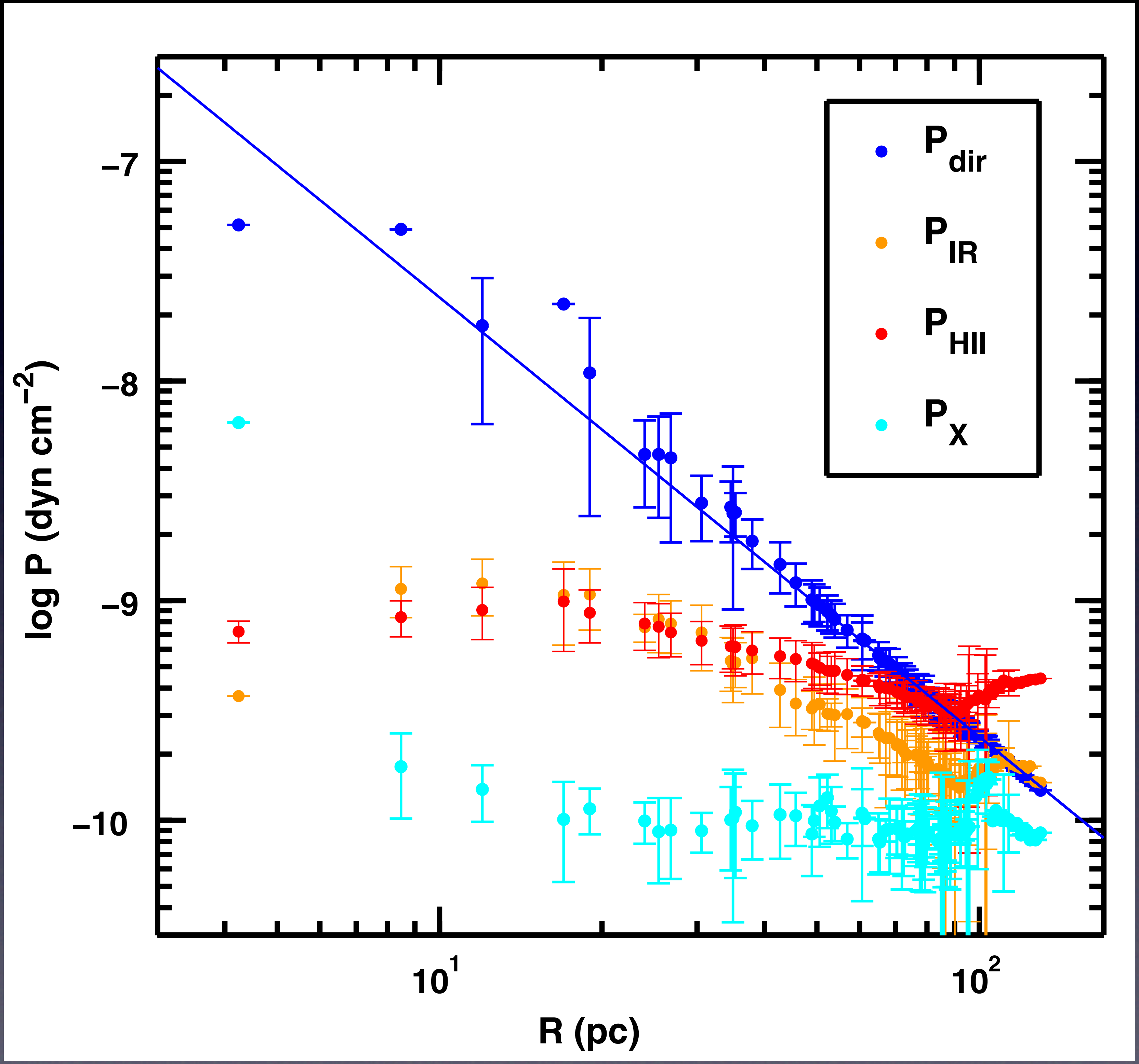
Lopez et al. 2011

All Together Now



Lopez et al. 2011

All Together Now



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P_{dir} dominates at R<75 pc

P_{HII} dominates at R>75 pc

P_{HII} ~ P_{IR} at R < 50 pc

P_X is not significant

HII Region Dynamics

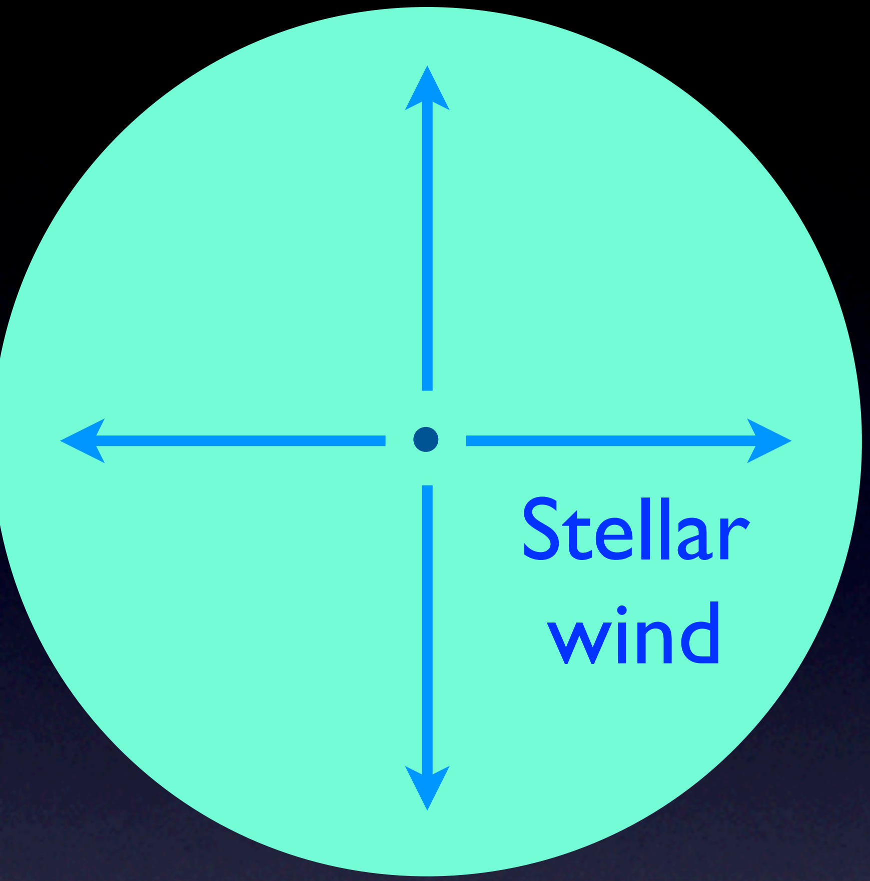
➡ In a radiation dominated HII region, there is:

- more momentum imparted to shell
- accelerated expansion at early times
- shell expands at $v_{shell} > v_{escape} > c_s$

➡ Radiation pressure imparts sufficient velocity to the gas for it to escape the cluster whereas warm gas does not (since $v_{escape} > c_s$)

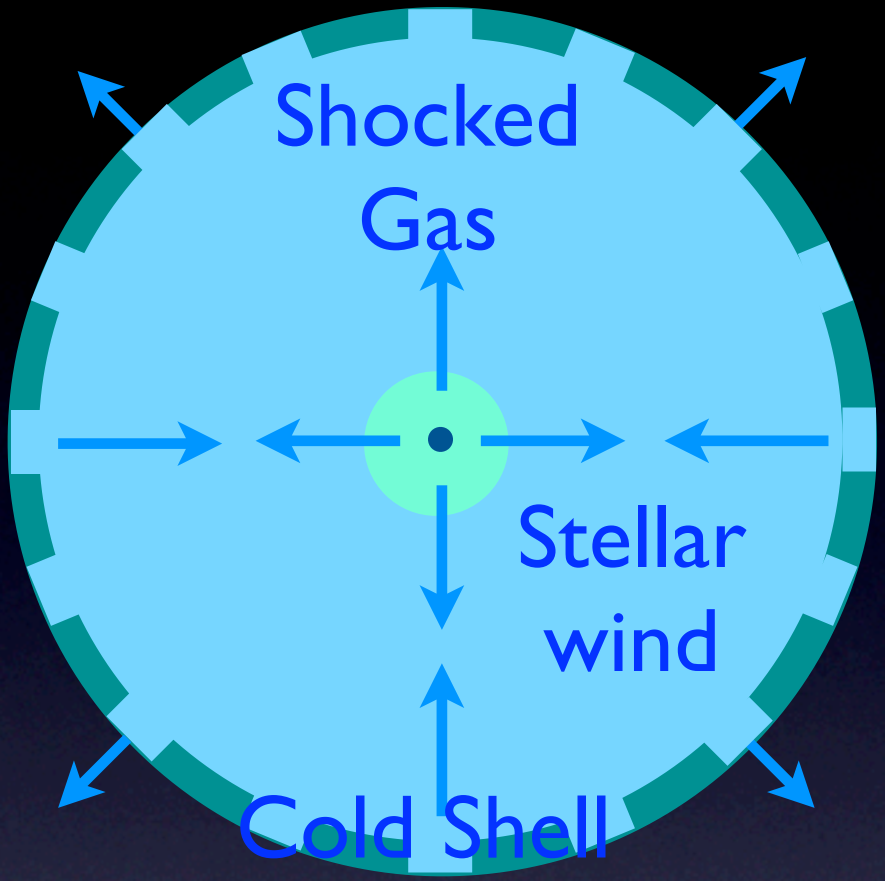
➡ Viable mechanism to expel gas from the star cluster and to halt star formation

Why is Hot Gas Pressure So Low?



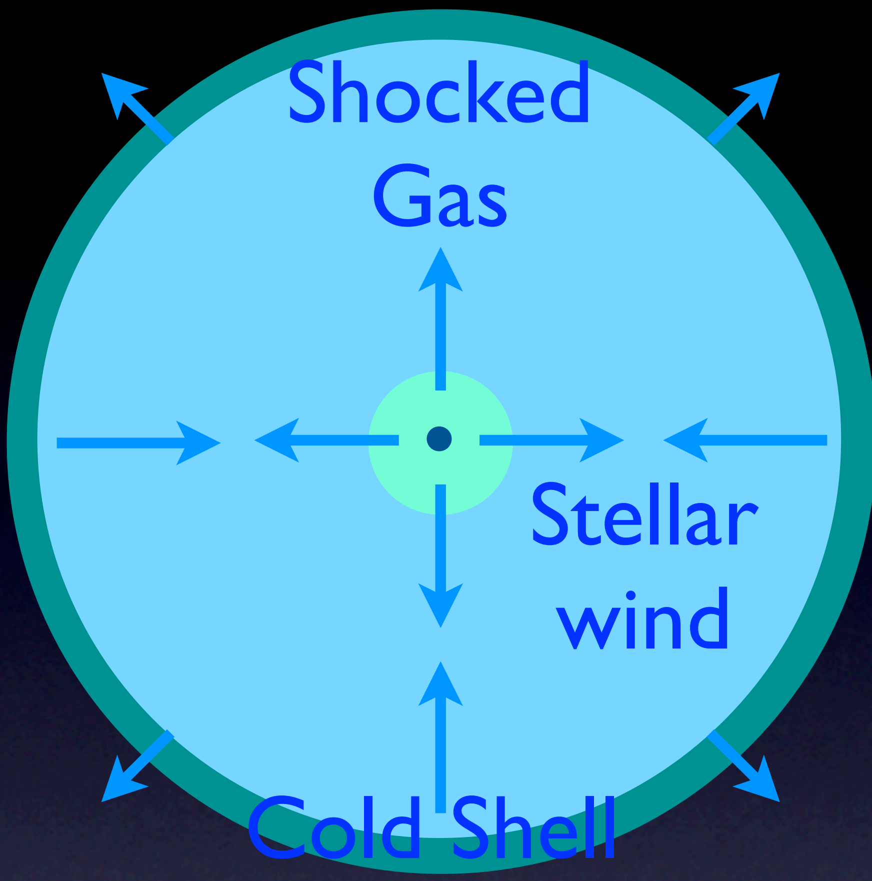
No
confinement:
Low pressure
Low luminosity

Chevalier & Clegg 1985



Partial
confinement:
Intermediate pressure
Intermediate luminosity

Harper-Clark & Murray 2009



100%
confinement:
High pressure
High luminosity

Castor et al. 1975;
Weaver et al. 1977

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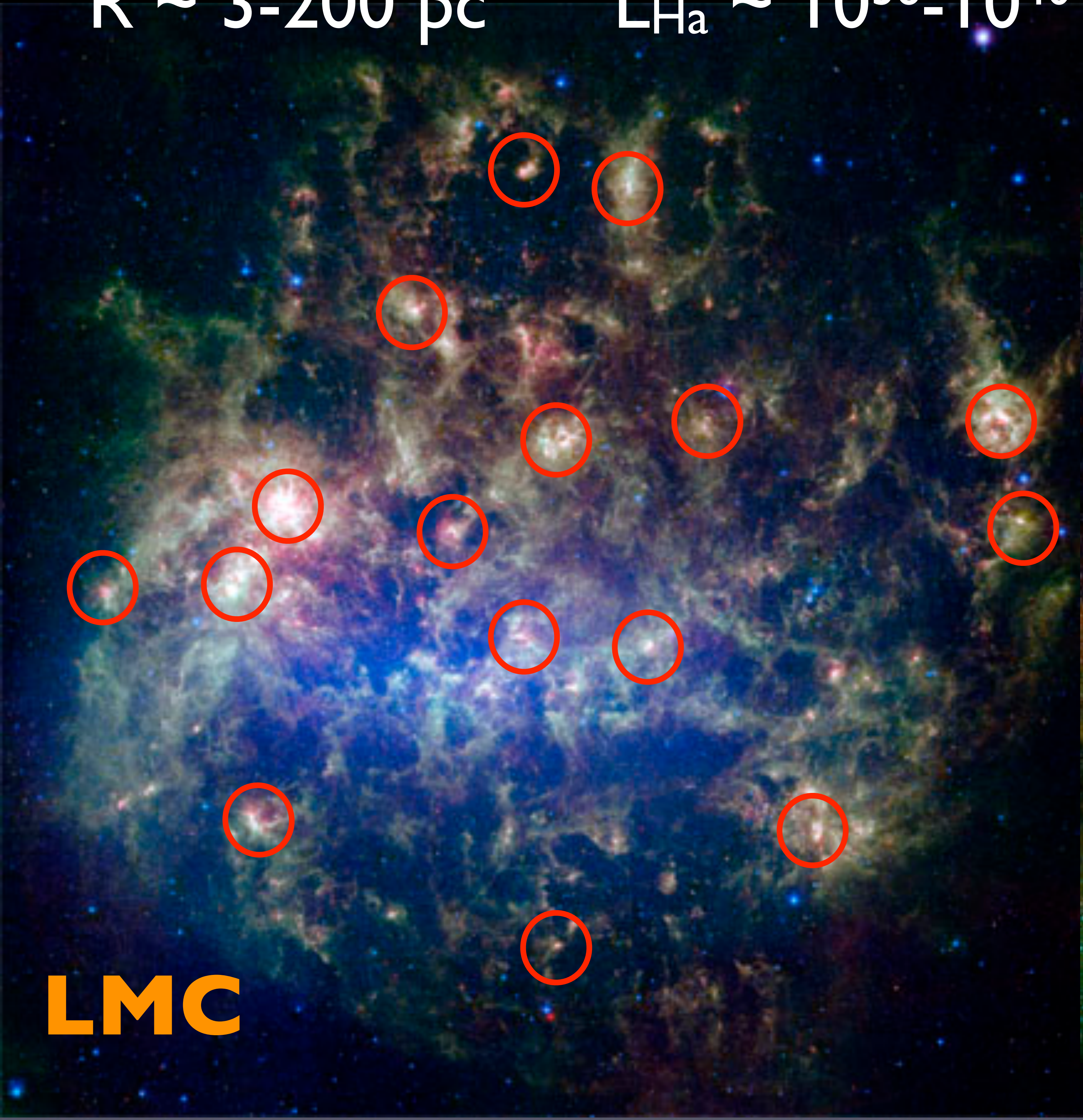

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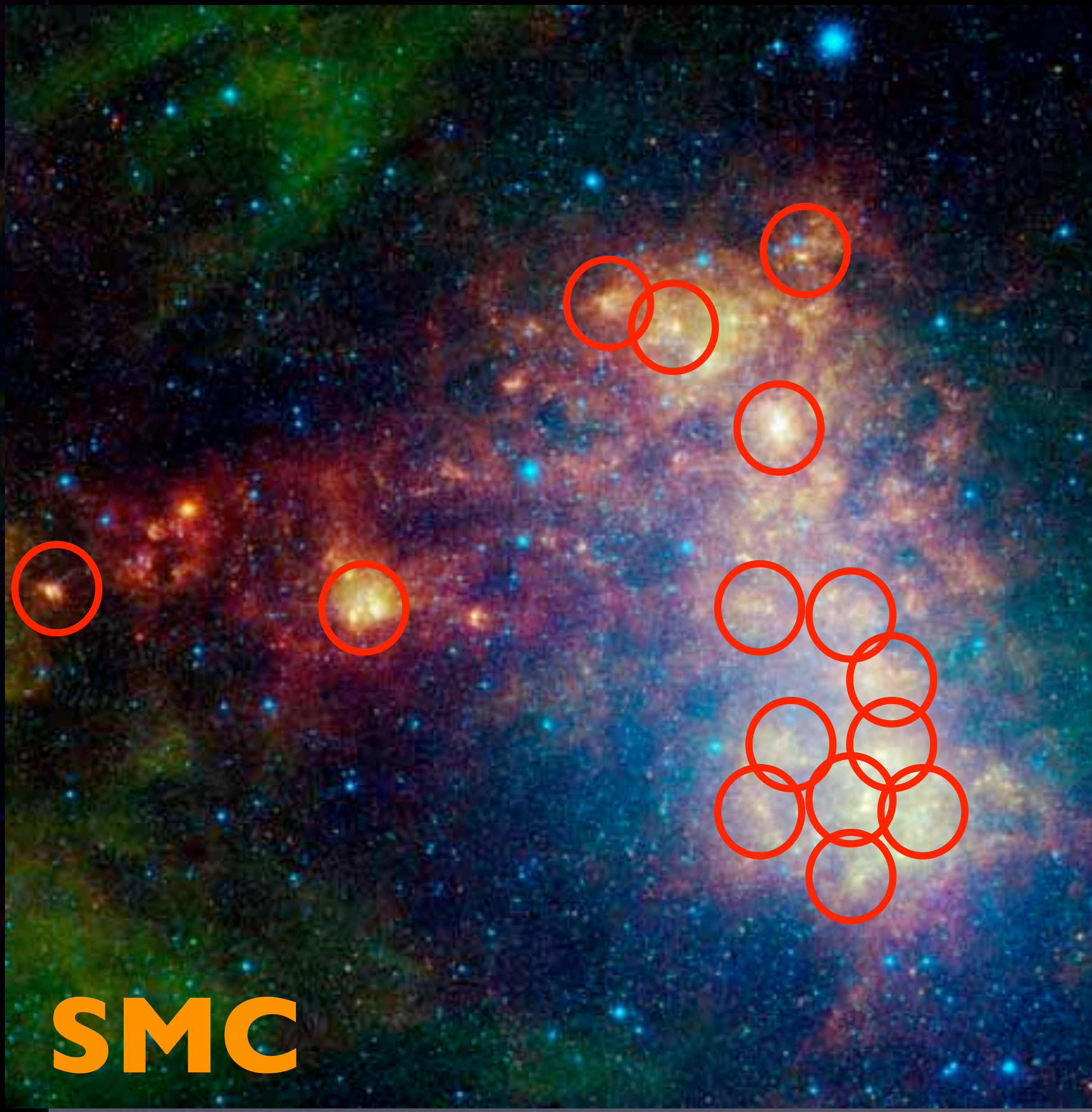

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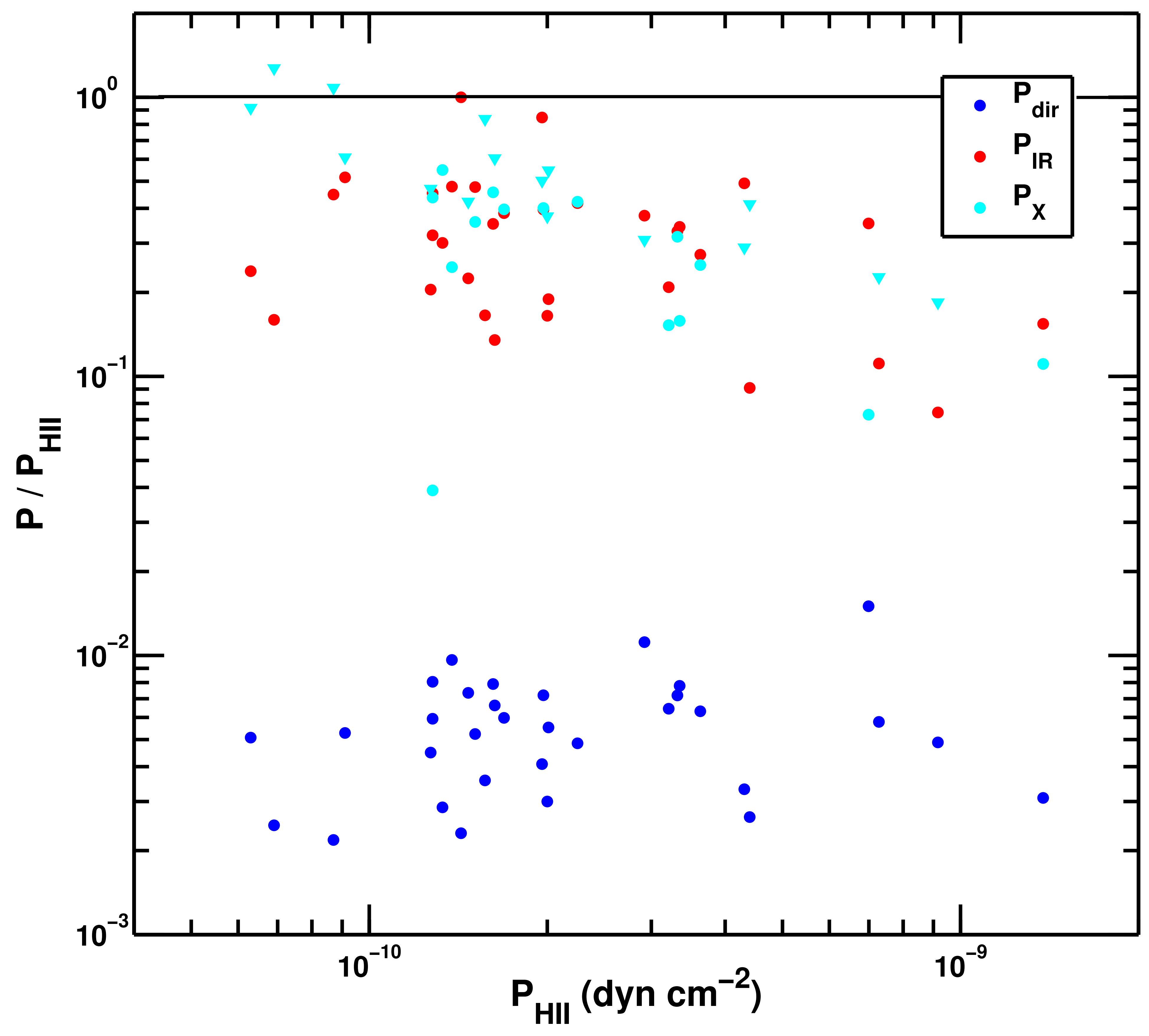

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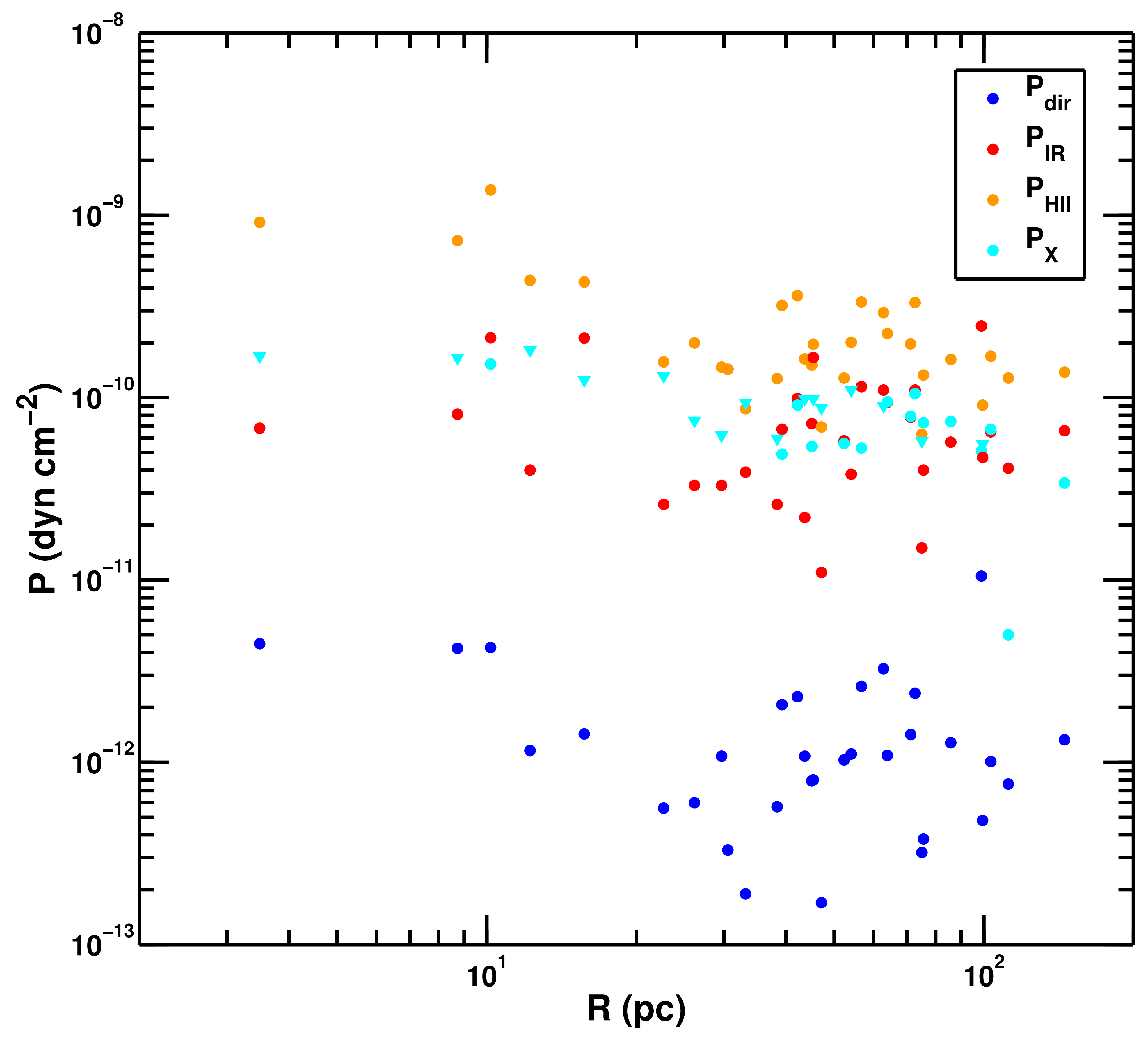

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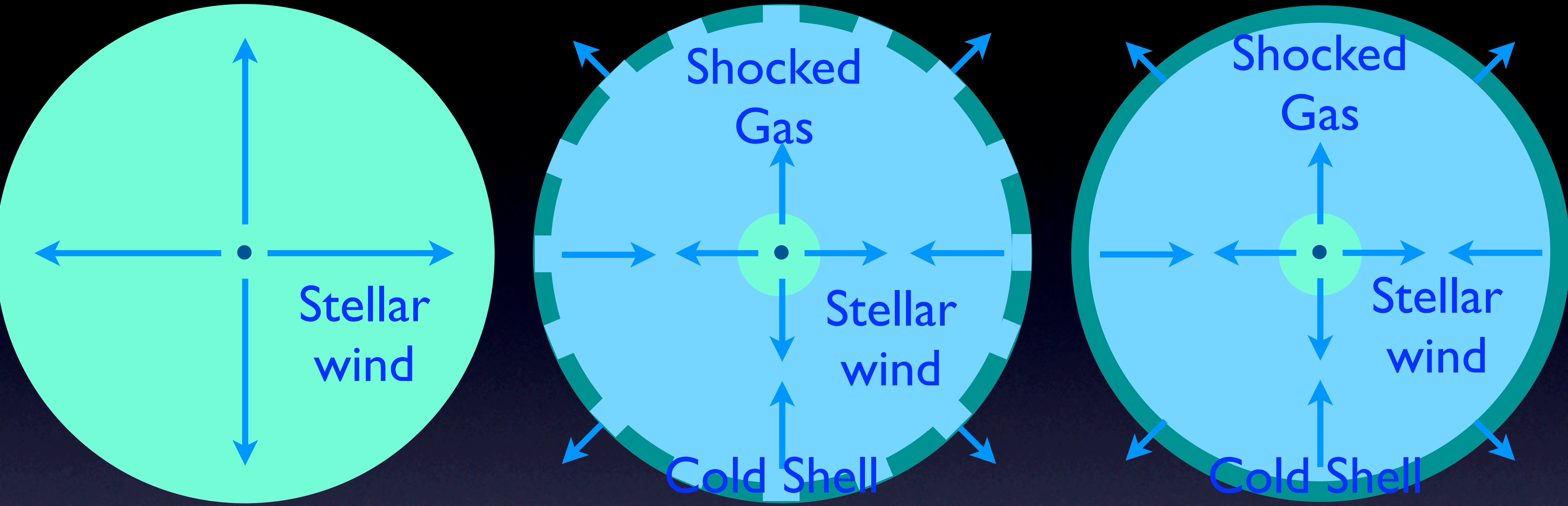


No confinement:
Low pressure
Low luminosity

Chevalier & Clegg 1985

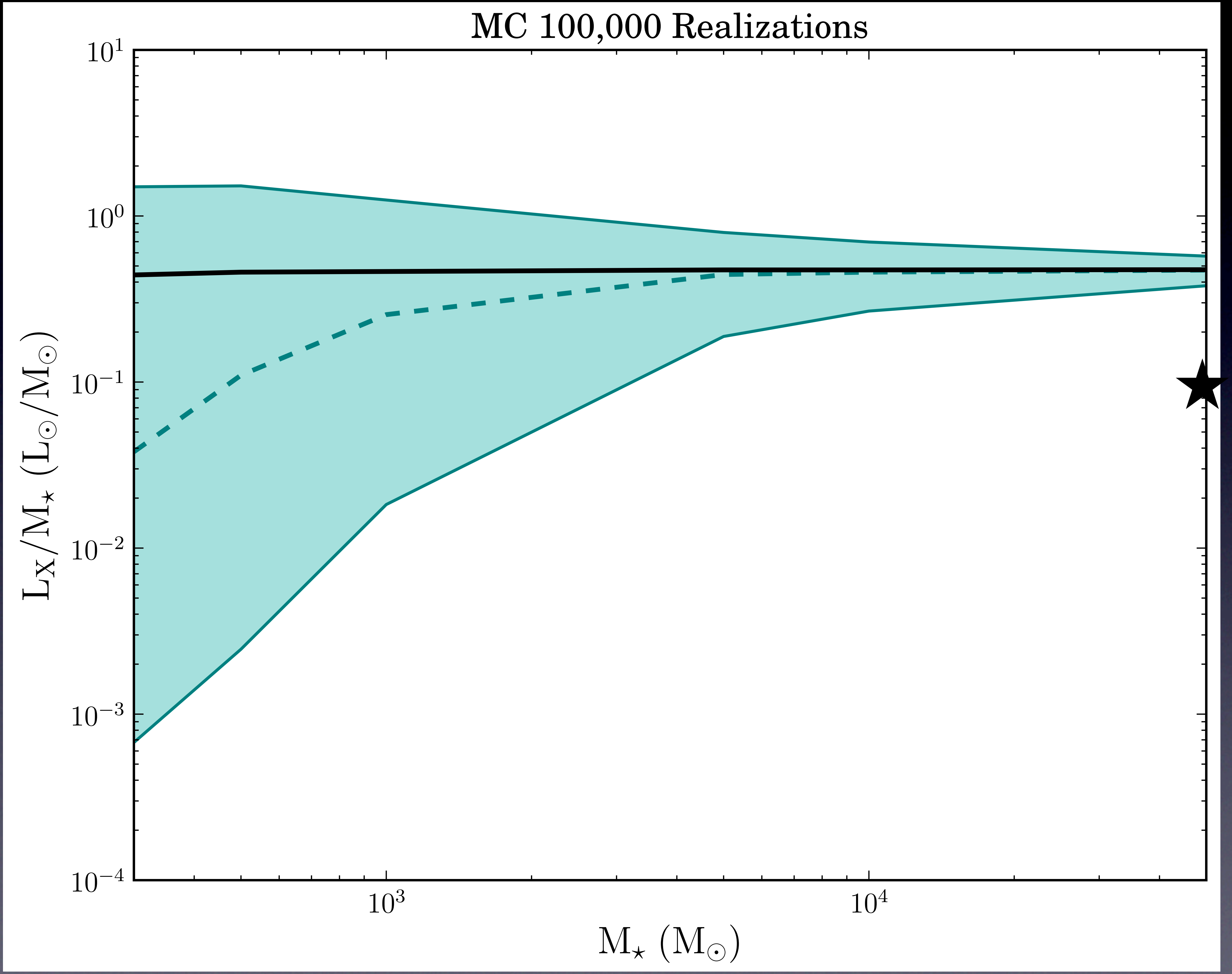
Partial confinement:
Intermediate pressure
Intermediate luminosity

Harper-Clark & Murray 2009

100% confinement:
High pressure
High luminosity

Castor et al. 1975;
Weaver et al. 1977

Gone with the Wind



Anna Rosen, PhD Thesis

Follow-Up Questions

- ➡ How do feedback properties change in different conditions?
- ➡ What about protostellar outflows?
- ➡ How should feedback be incorporated into galaxy formation/evolution simulations?
- ➡ What are the effects of feedback on nearby molecular gas (e.g., disruption of giant molecular clouds, driving of turbulence)?

Conclusions

➡ Stellar feedback plays an important role at large and small scales

➡ Multiwavelength data can be used to assess observationally the relative role of different stellar feedback mechanisms in HII regions

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Thank You!