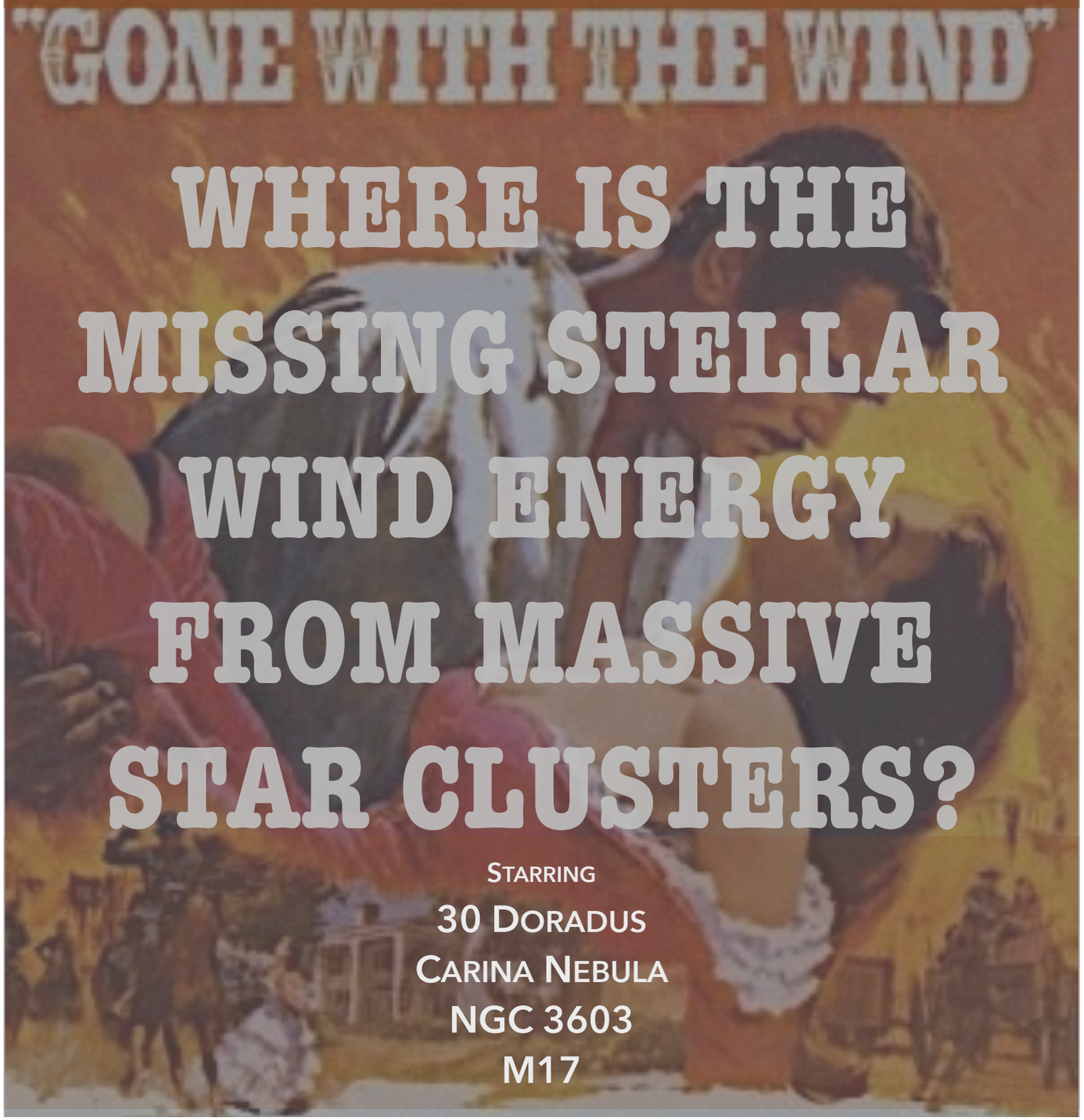
ANNA ROSEN (UCSC) PRESENTS



WHERE IS THE MISSING STELLAR WIND ENERGY FROM MASSIVE STAR CLUSTERS?

STARRING

30 DORADUS

CARINA NEBULA

NGC 3603

M17

PRODUCED BY

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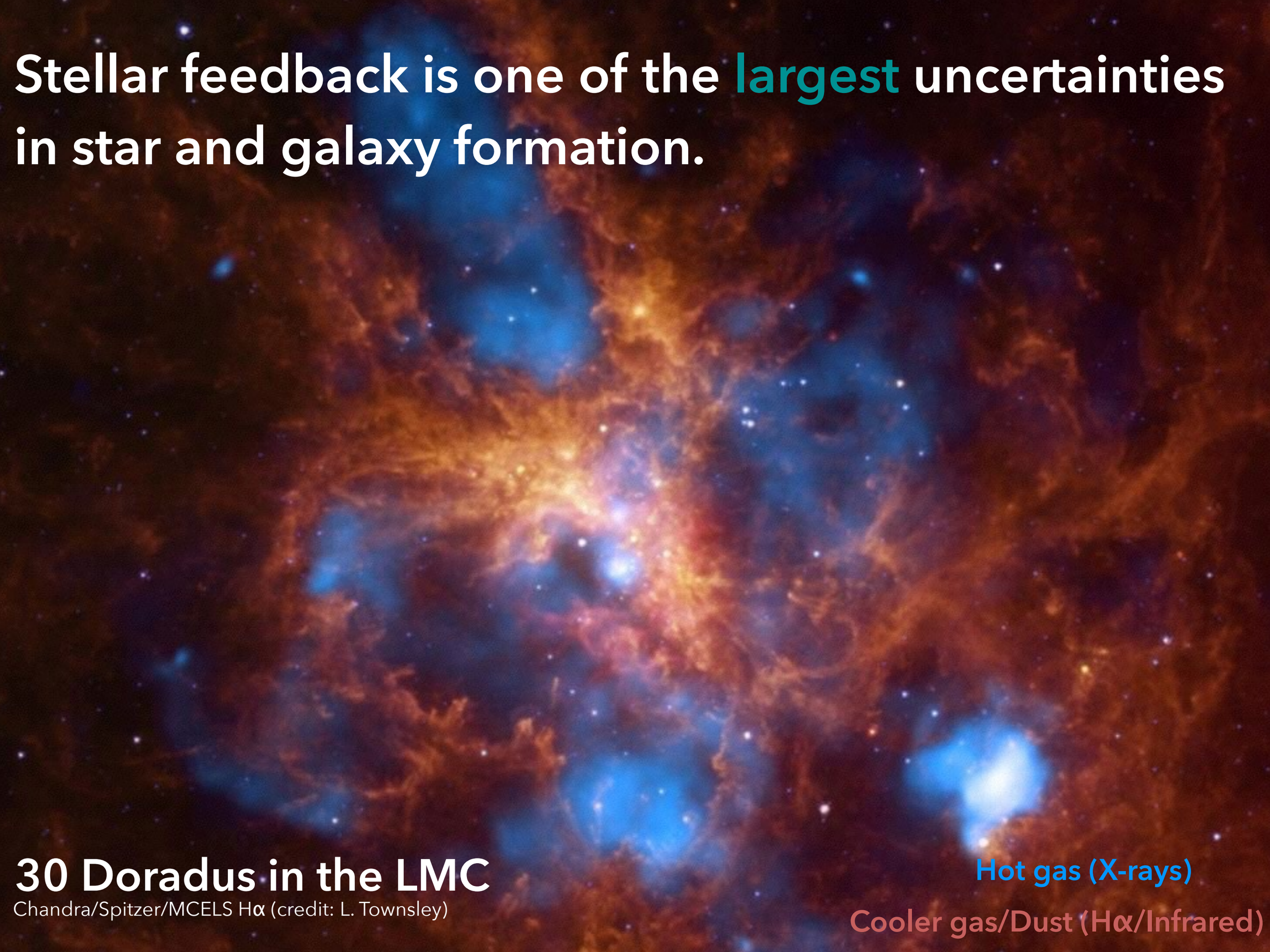
SOUL OF HIGH MASS STAR FORMATION, PUERTO VARAS, CHILE; MARCH 17, 2015

UNIVERSITY OF CALIFORNIA SANTA CRUZ

NSF

Stellar feedback is one of the largest uncertainties in star and galaxy formation.



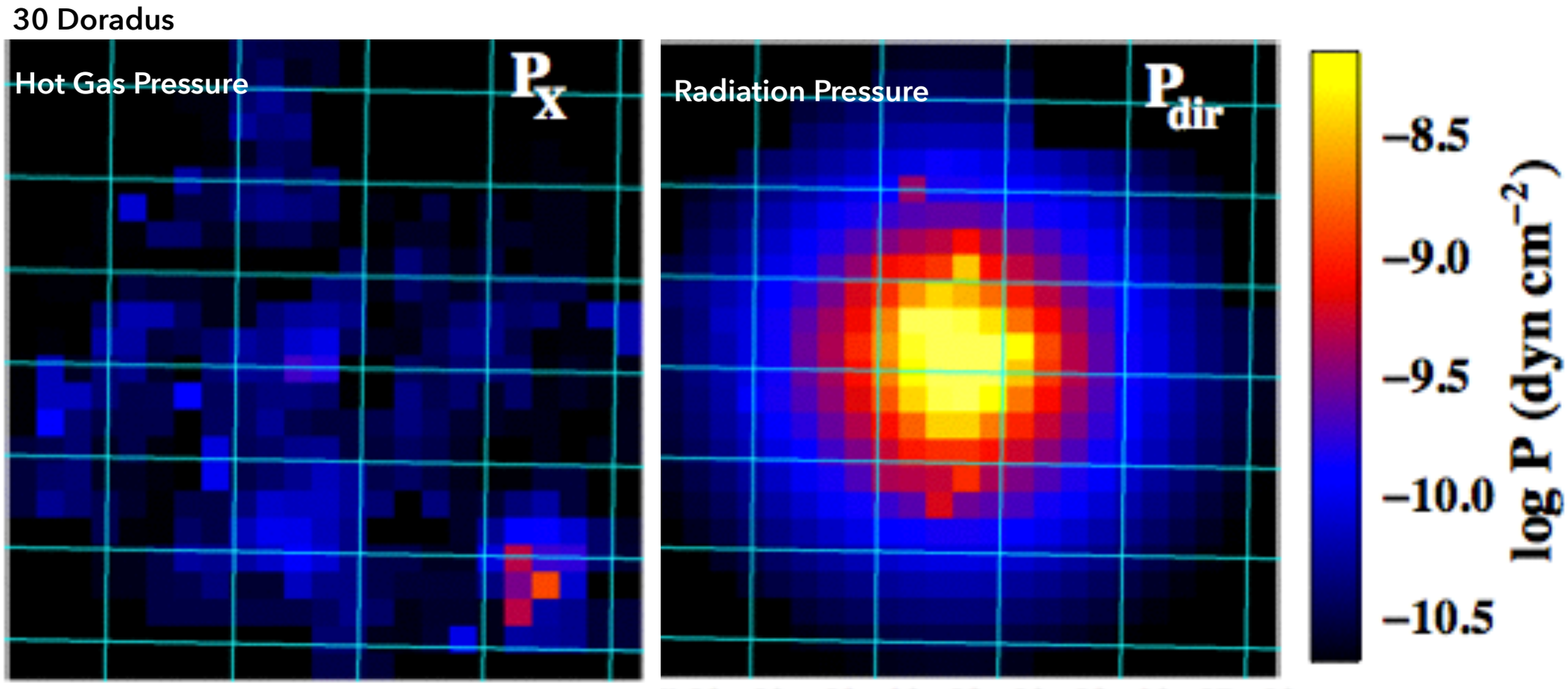
30 Doradus in the LMC

Chandra/Spitzer/MCELS Hα (credit: L. Townsley)

Hot gas (X-rays)

Cooler gas/Dust (Hα/Infrared)

X-ray observations of HII regions suggest that the shock-heated gas is not dynamically important (Dunne+03, Harper-Clark & Murray+09, Lopez+11)



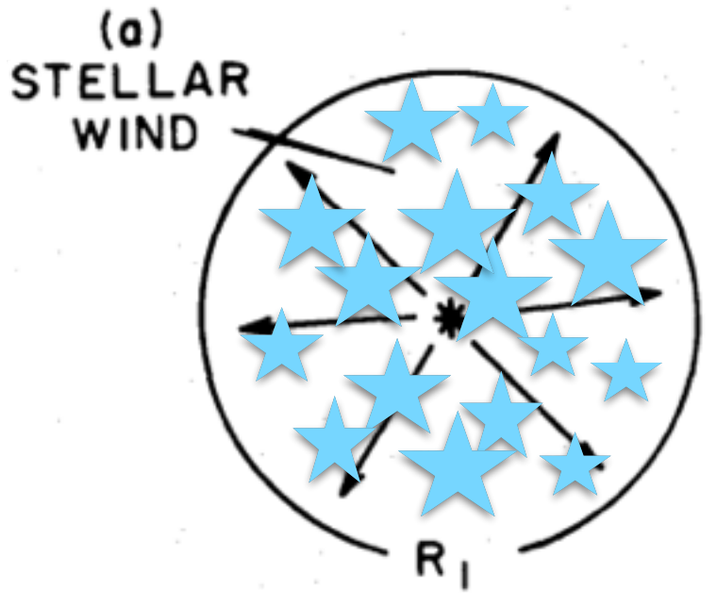
Lopez+2011

$$\frac{L_{\rm w} t_{\rm cl}}{V} \gg \frac{3}{2} n k_{\rm B} T_{\rm X}$$

…so where's the missing energy?

- Our model and HII region requirements
- Description of how we account for the missing energy
- Our results and how they affect our understanding for stellar winds as an important feedback mechanism in star formation

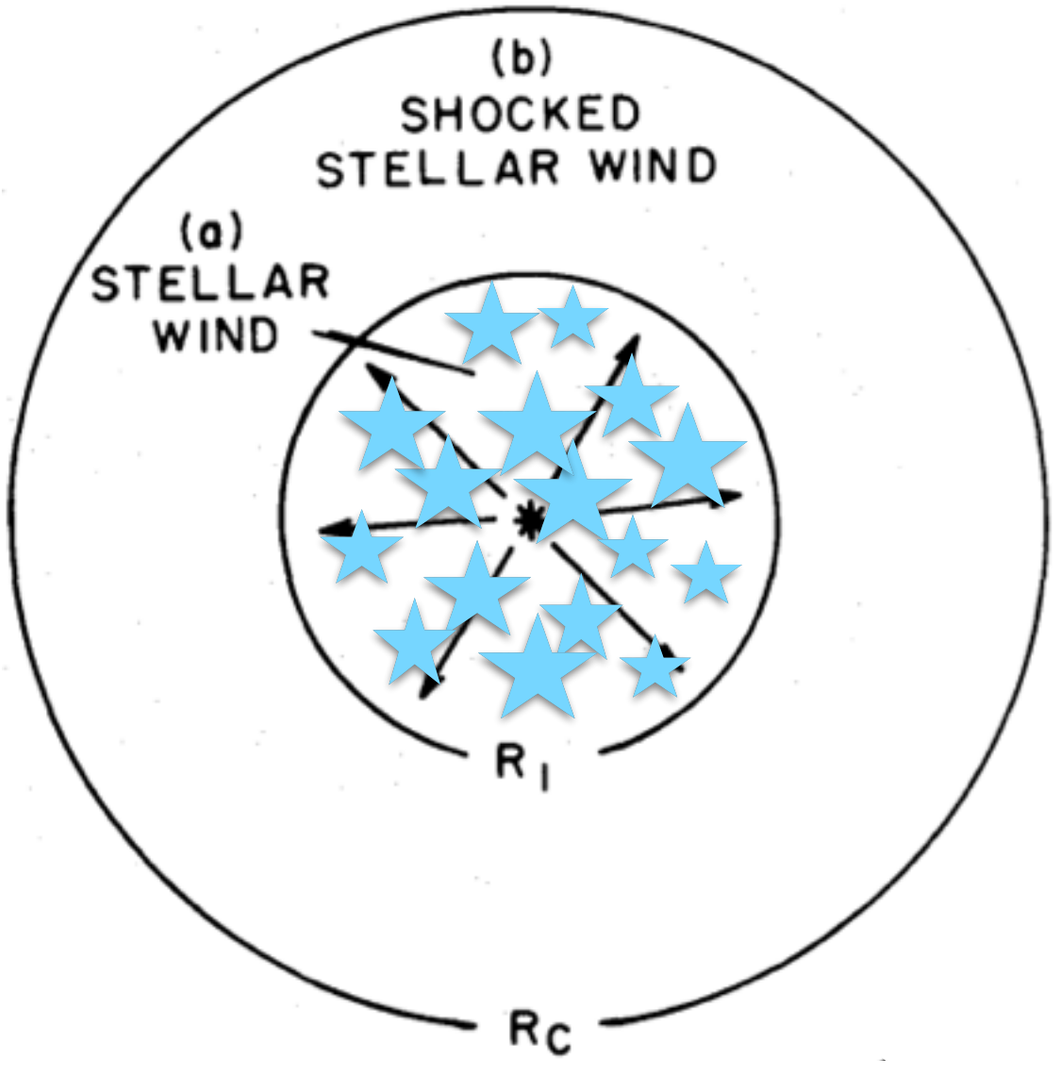
Our Model



Castor+1975, Weaver+1977

(1) Require spectral typing of massive stars in HII region to estimate total L_w

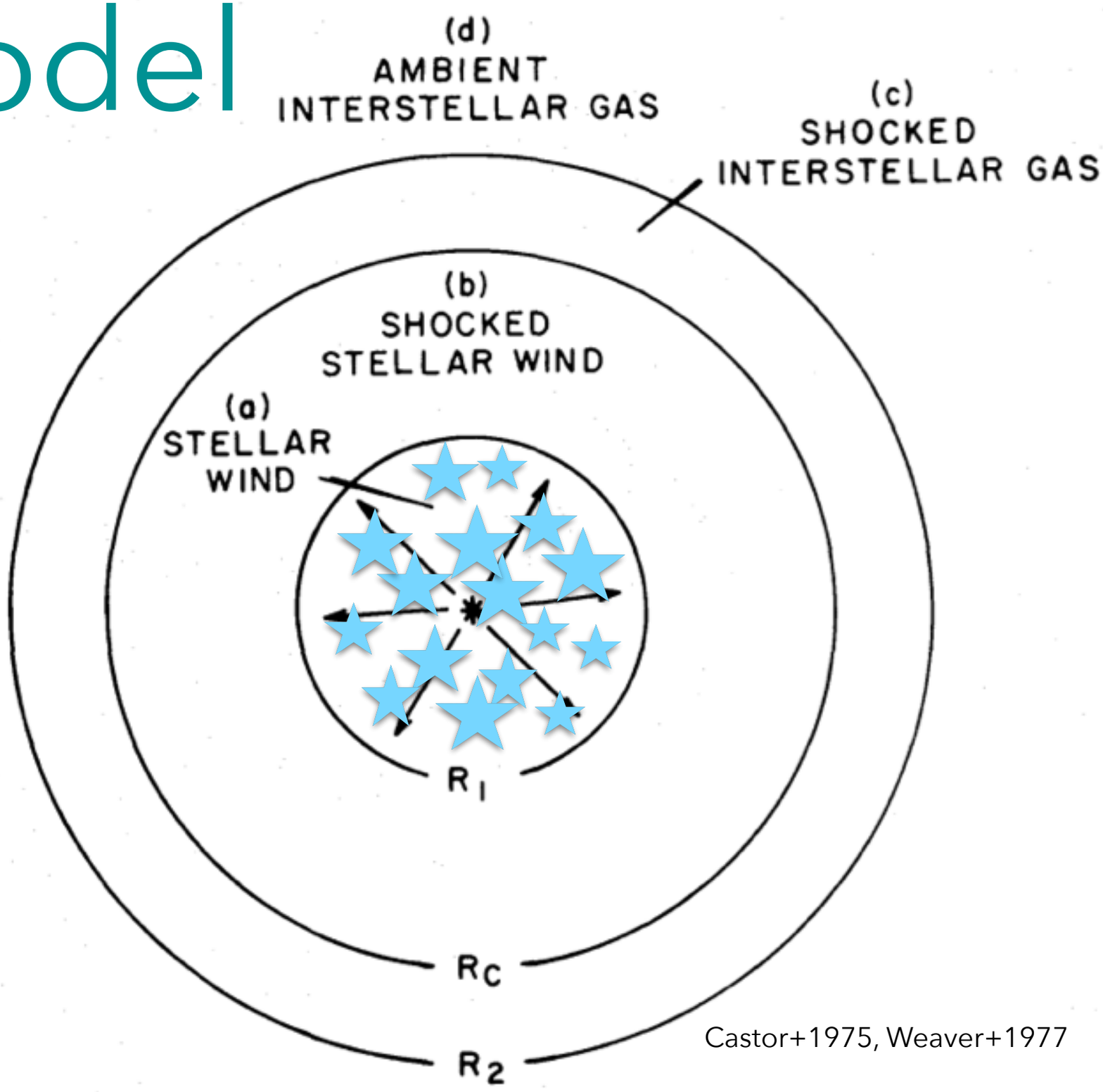
Our Model



Castor+1975, Weaver+1977

(2) Require X-ray observations to characterize the properties of the hot gas

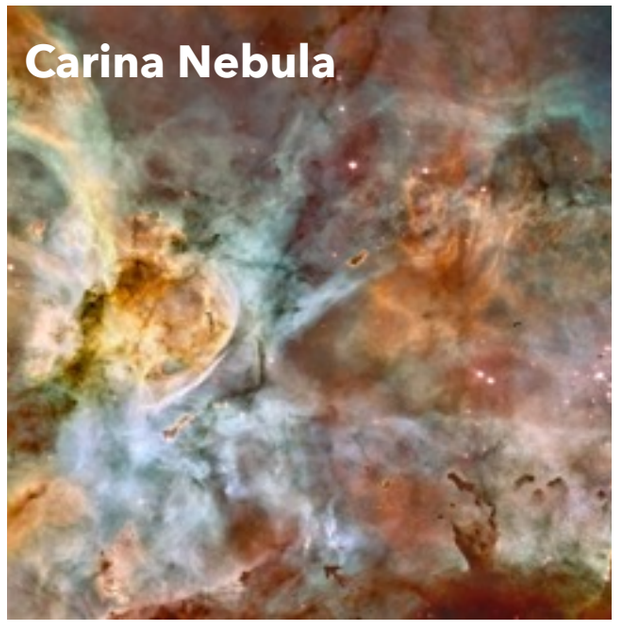
Our Model



Castor+1975, Weaver+1977

(3) Require radio observations to determine the HII region radius and shell expansion rate

Our HII Region Sample



(NASA)

Name	D (kpc)	R_{sh} (pc)	v_{sh} (km s^{-1})	t_{cl} (Myr)	log L_{bol} ($L_\odot$)	L_w (10^{37} erg s^{-1})	L_x (10^{35} erg s^{-1})	T_X (10^6 K)
30 Doradus	50	100	25	2	8.4	224	45.0	7.4
Carina	2.3	20	20	3	7.23	35.0	1.71	4.5[a]
NGC 3603	7.0	21	20	1	–	62.0	2.6	6.2[a]
M17	2.1	5.8	25	1	6.58	1	0.2	5.3[a]

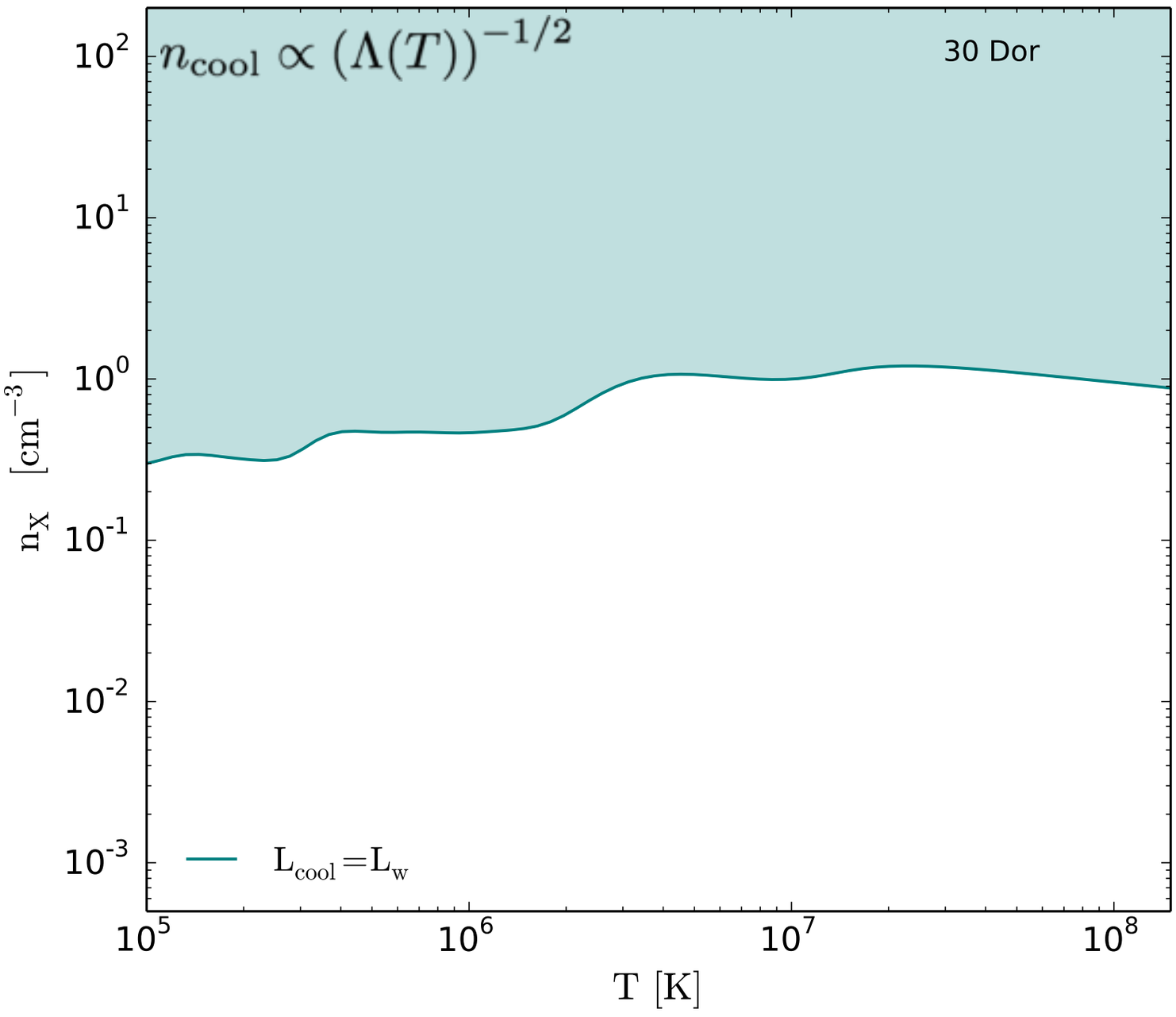
[a]Temperatures shown are surface-brightness-weighted values from Townsley et al. (2011c) .

30 Doradus: Lopez+2011, Doran+2013, Lopez+2013; Carina: Smith 2000,Smith 2006, Smith & Brooks 2007,Townsley+2011c; NGC 3603: Balick+1980, Crowther & Dessart 1998, Townsley+2011c; M17: Clayton+1985, Dunne+2003, Townsley+2003, Hoffmeister+2008, Townsley+2011c

Avenues that the hot gas can transfer energy

L_{cool}: Radiative cooling of the hot gas

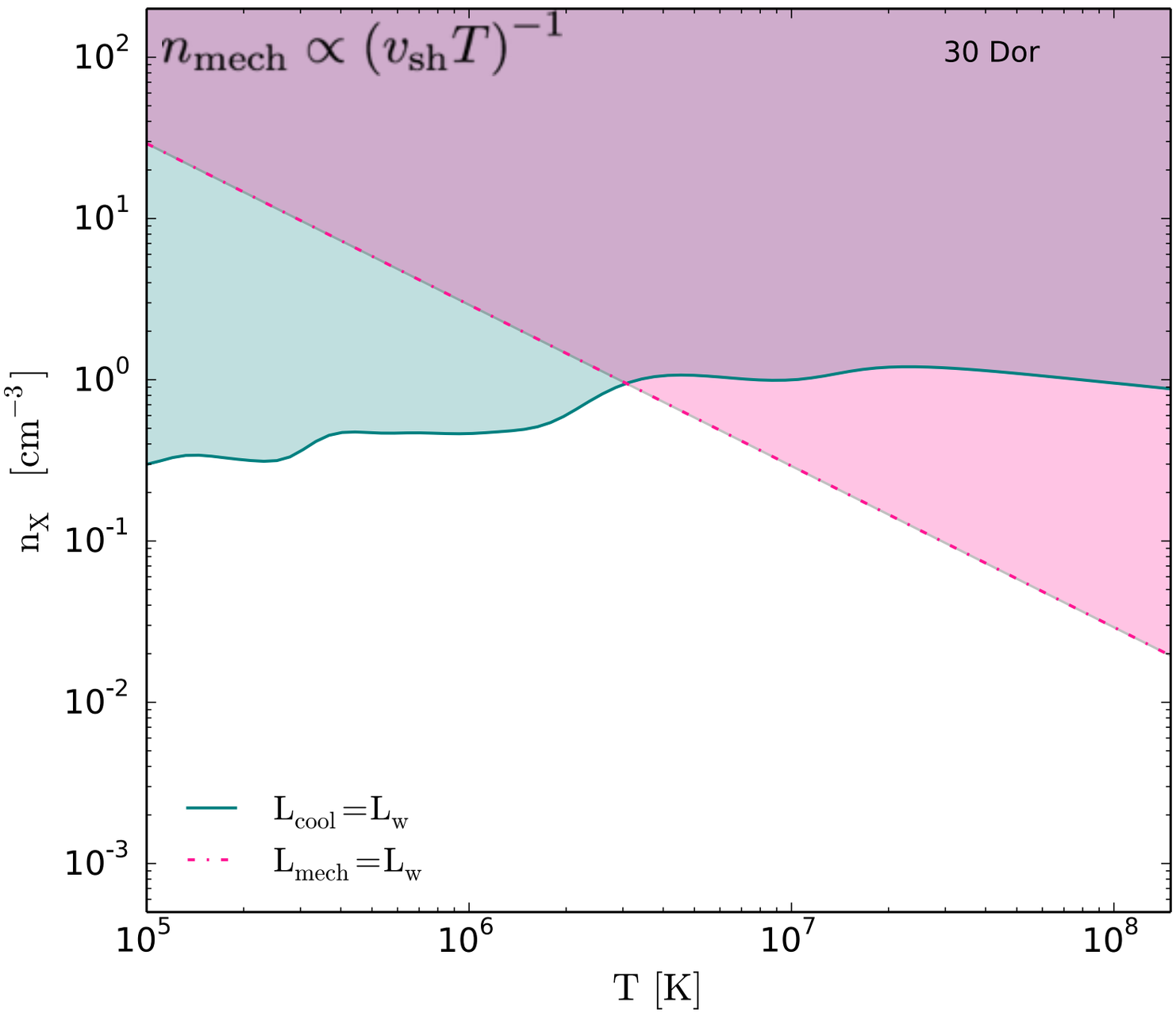
(Castor+1975, Weaver+1977, Dere+1997, Draine 2011)



Avenues that the hot gas can transfer energy

L_{mech}: Mechanical work on the dense shell

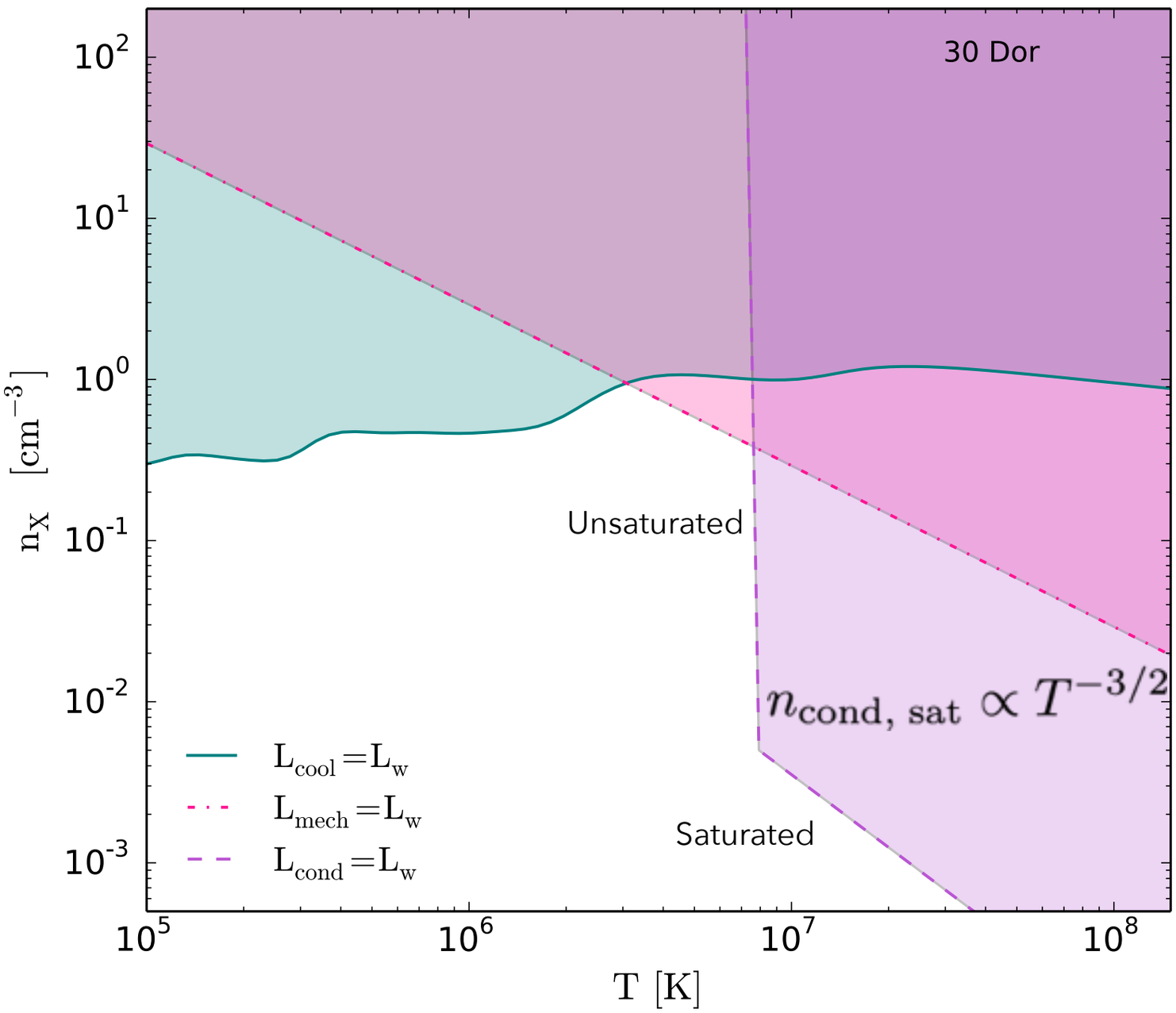
(Castor+1975, Weaver+1977)



Avenues that the hot gas can transfer energy

L_{cond}*: Laminar Thermal Conduction of the Hot Electrons

(Spitzer 1962, Cowie & McKee 1977)

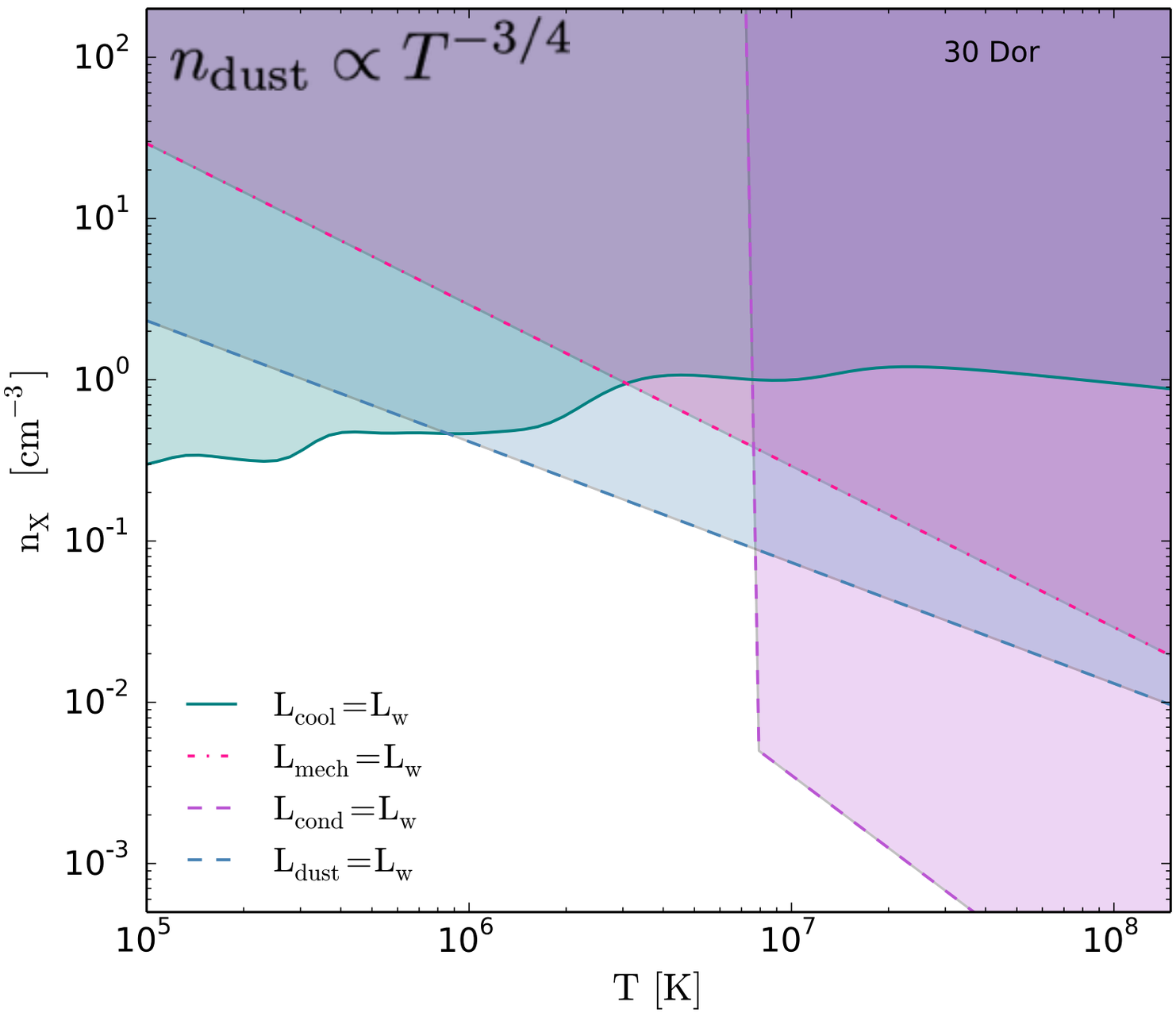


(* conservative estimate)

Avenues that the hot gas can transfer energy

L_{dust}*: Collisional Heating of Dust Grains

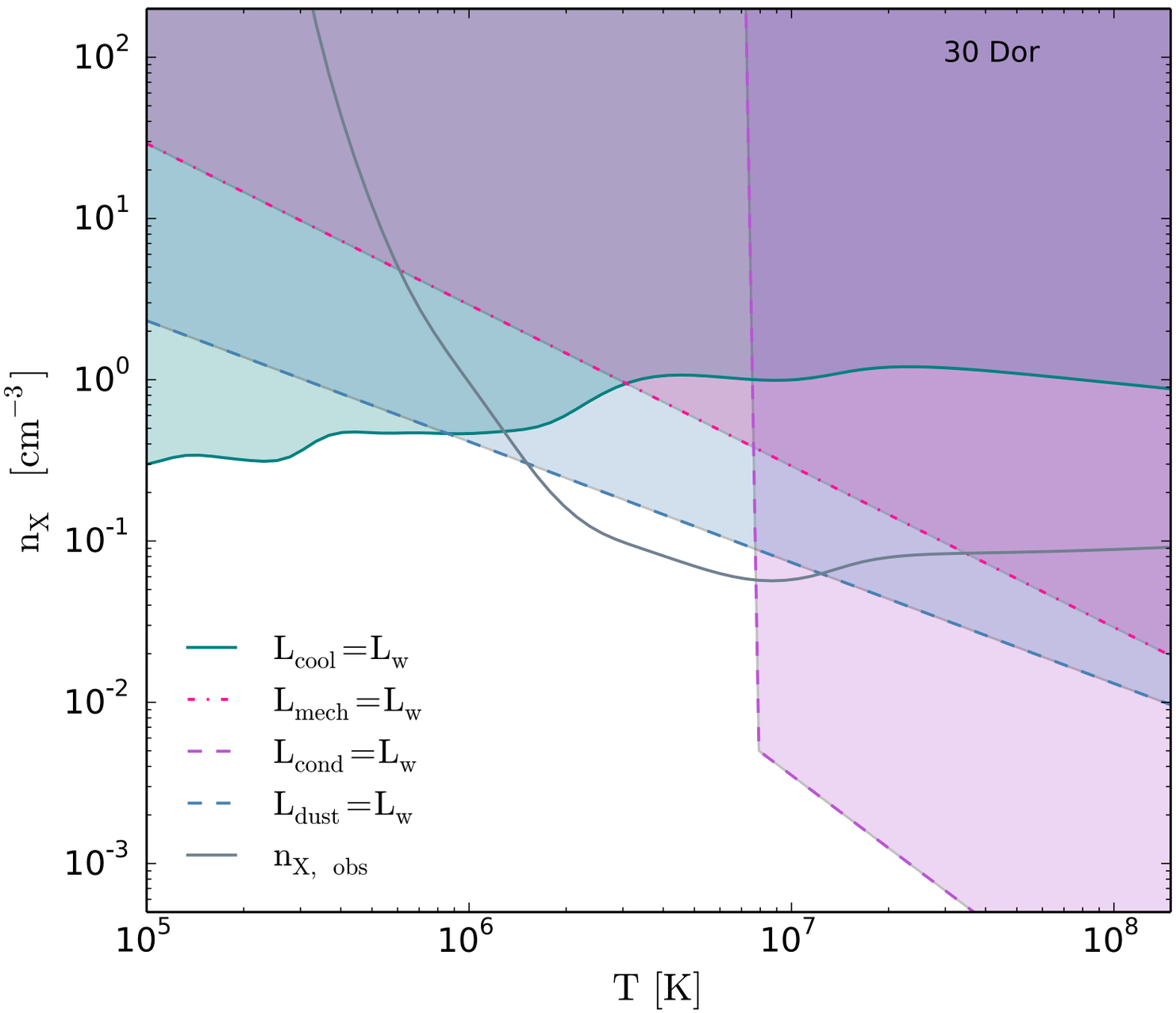
(Dwek 1987, Smith+1996, Draine 2011, Krumholz 2013)



(* conservative estimate)

$L_{X,obs}$ constrains hot gas density and temperature

$$L_{\mathrm{X,\,obs}} = 0.9 n_{\mathrm{X}}^2 V \int_{\nu_0}^{\nu_1} j_\nu(T, Z) d\nu$$



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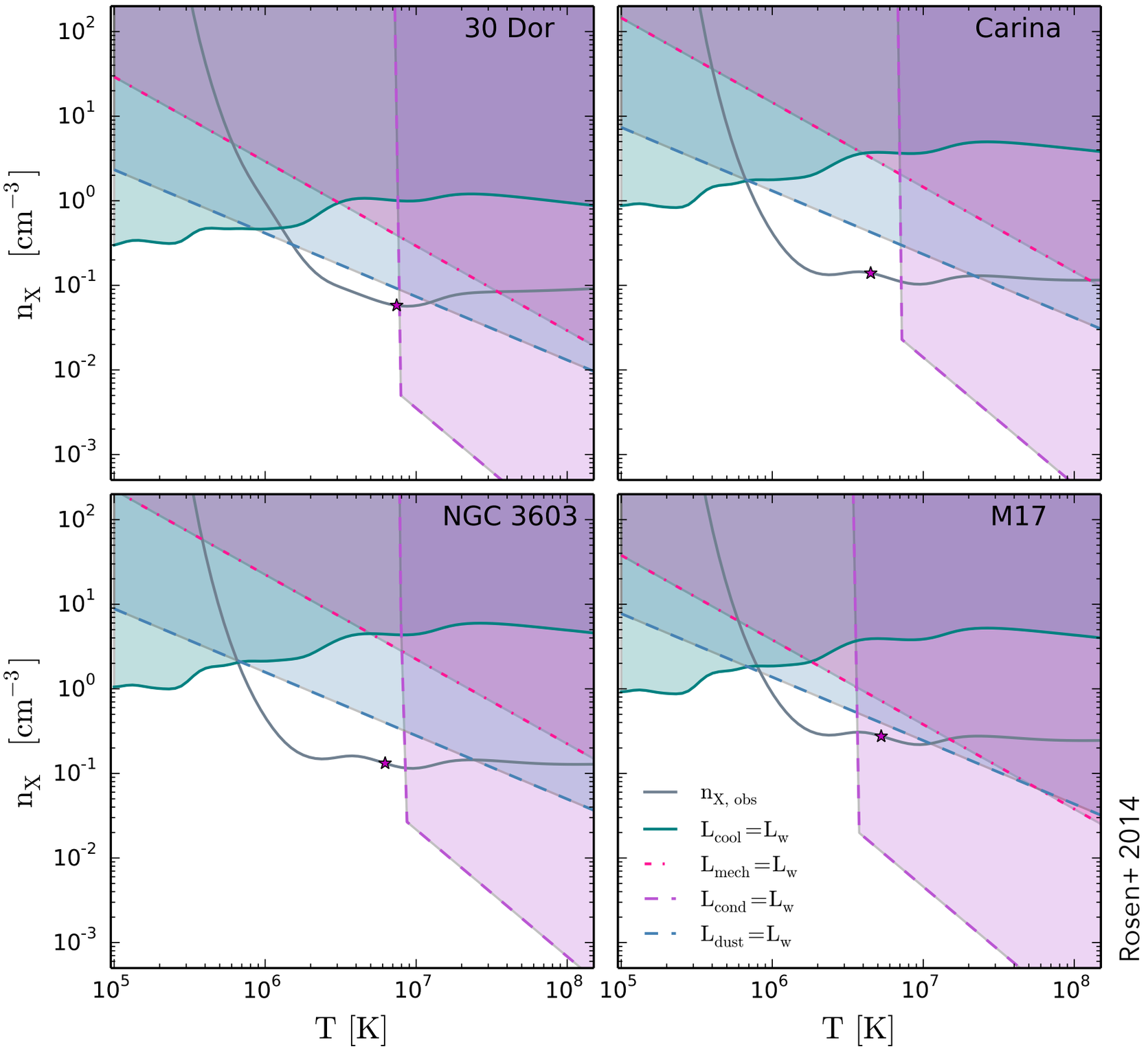
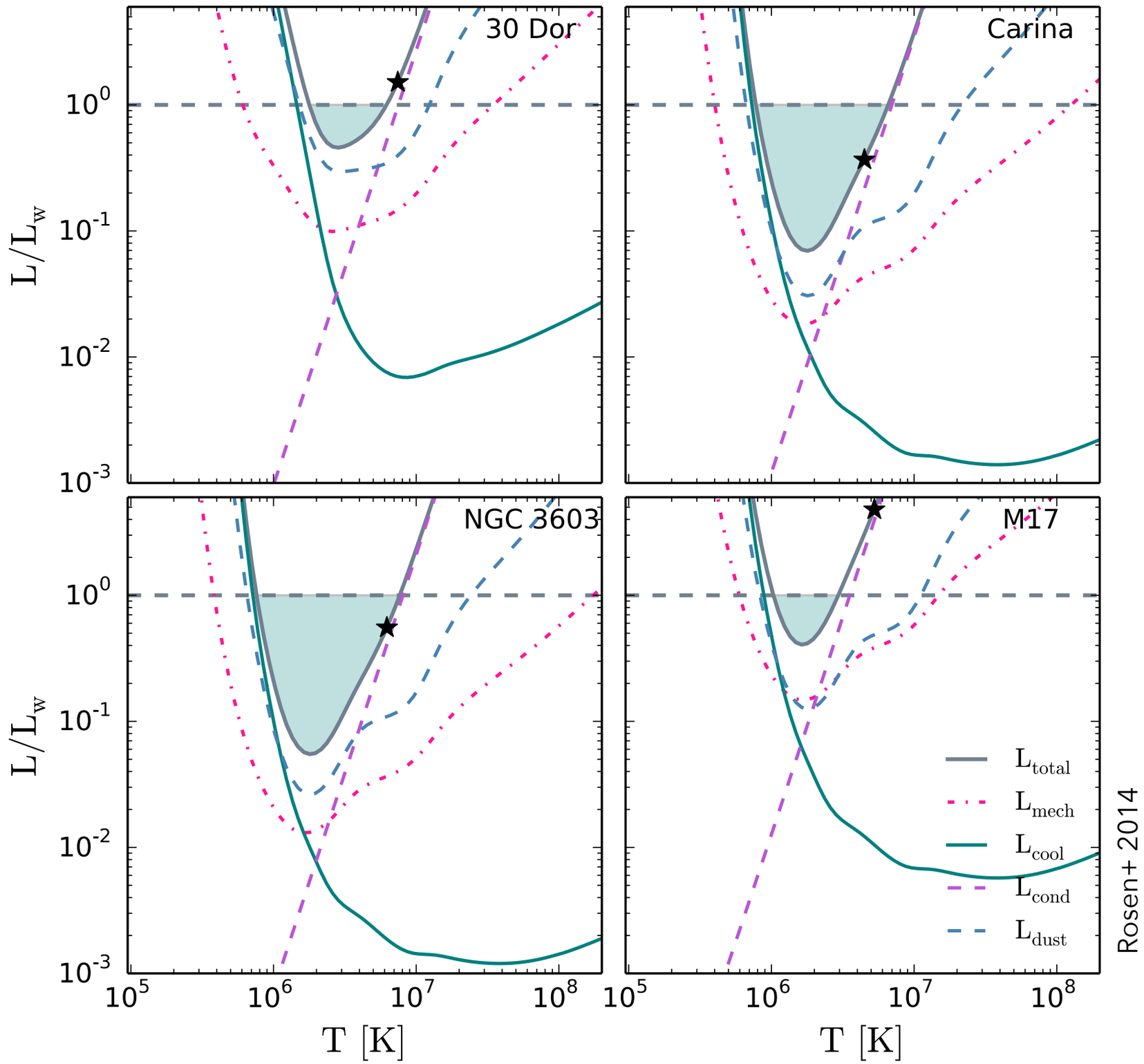


★=spectral fitted temperatures

Accounting for the missing energy



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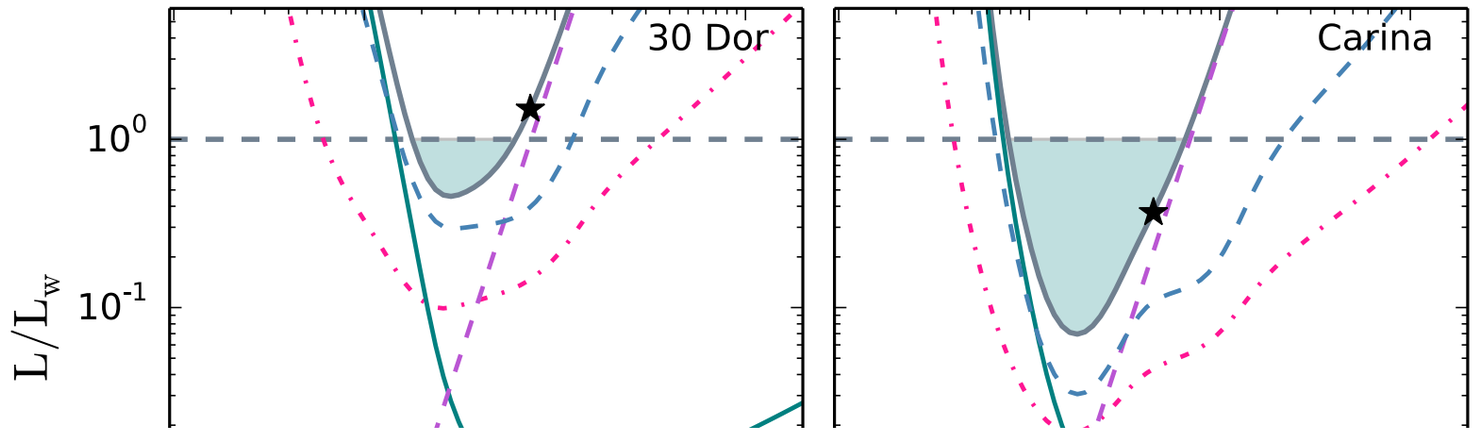
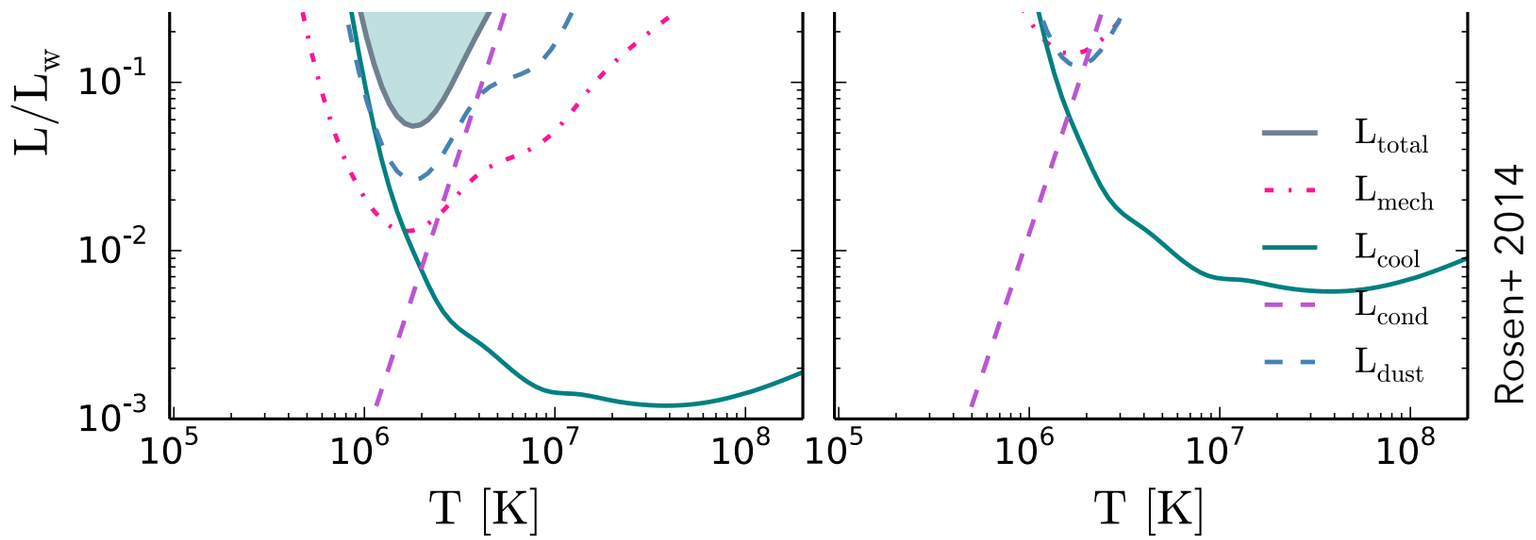
Accounting for the missing energy

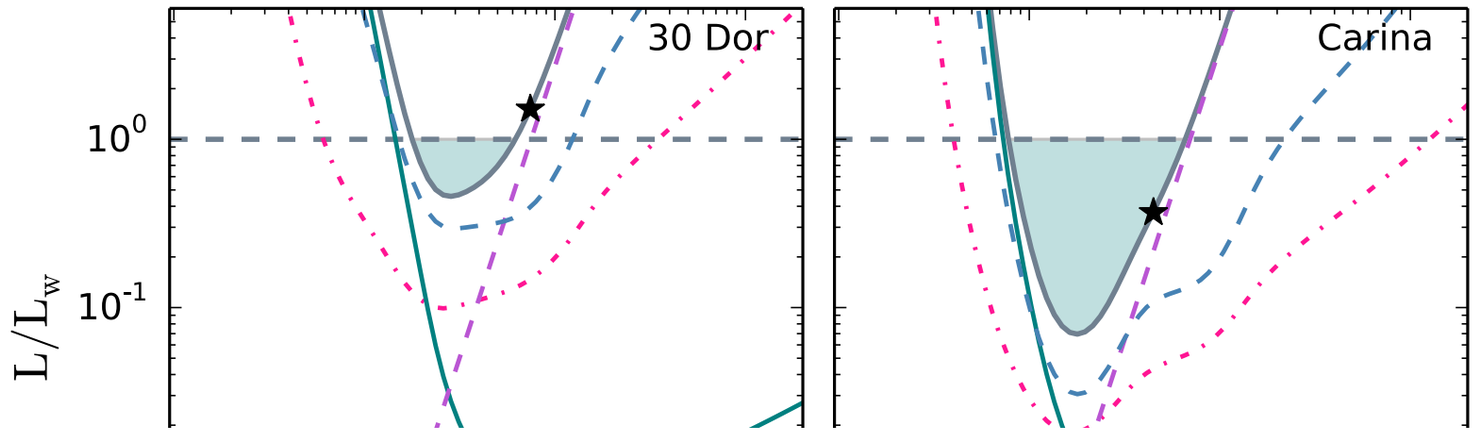


Name	n_X [cm^{-3}]	L_{cool}/L_w	L_{mech}/L_w	L_{cond}/L_w	L_{dust}/L_w
30 Doradus	0.058	0.37%	15%	< 97%	< 40%
Carina	0.14	0.16%	4.3%	< 22%	< 11%
NGC 3603	0.13	0.10%	3.7%	< 41%	< 11%
M17	0.27	0.55%	38%	< 392%	< 48%



Hot gas not strongly coupled with the ISM.

Accounting for the missing energy



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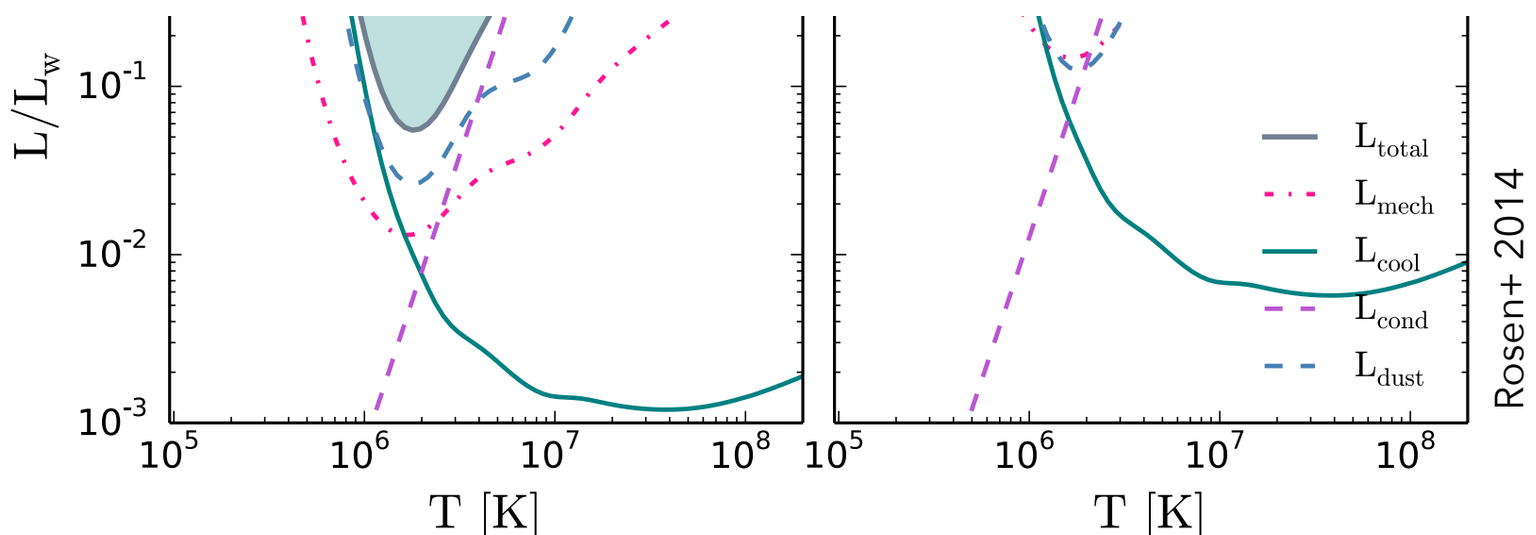
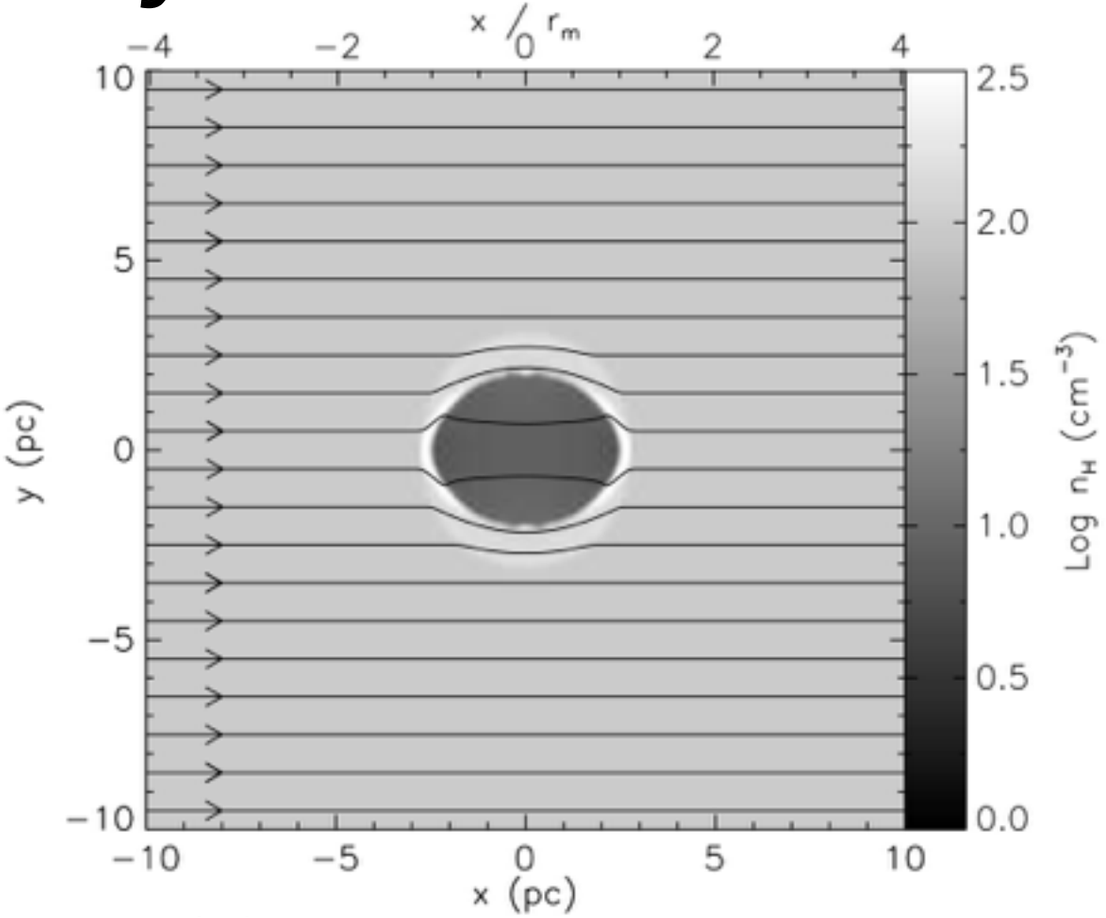


Could winds be important for young, compact HII regions?

Ways Out: Where's the Missing Energy?



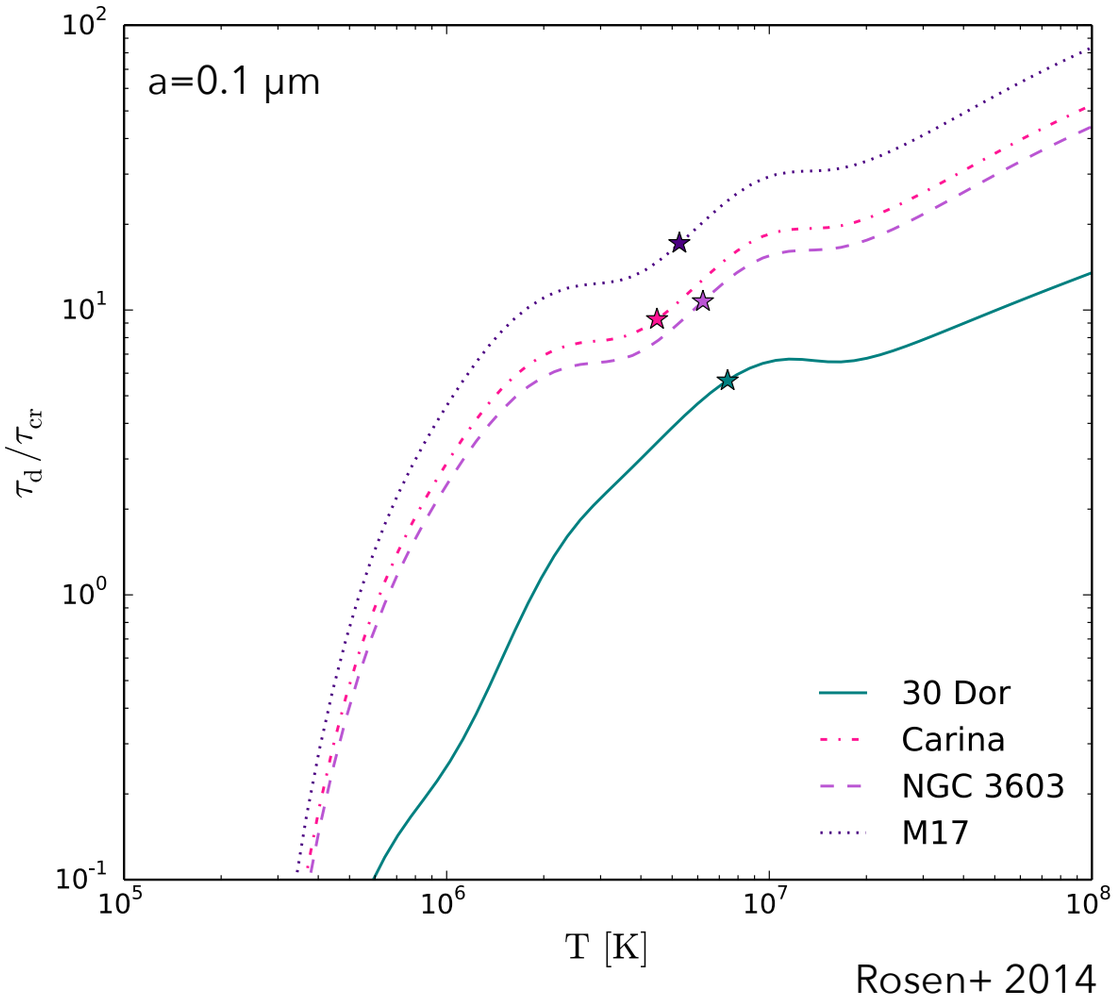
Krumholz+2007

Thermal conduction?

Probably not.

Dust heating via collisions?

It might help.

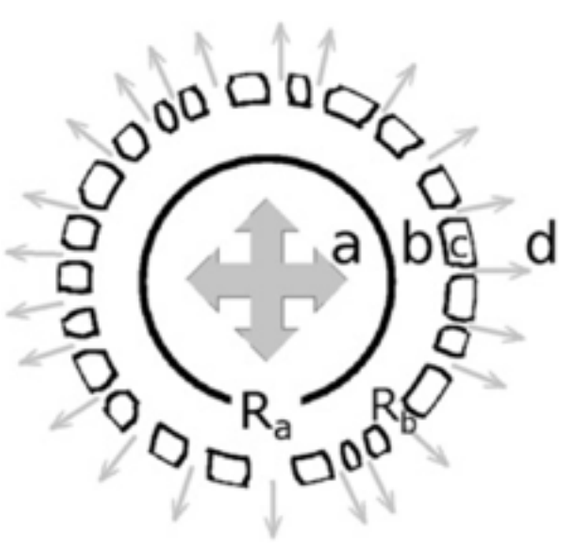


Rosen+ 2014

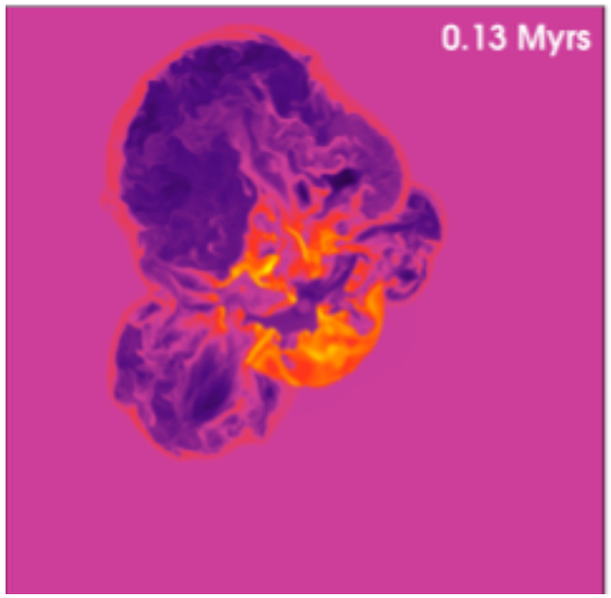
Ways Out: Where's the Missing Energy?

Physical leakage of the hot gas

(Harper-Clark & Murray 2009, Rogers & Pittard 2013, Dale+2014)



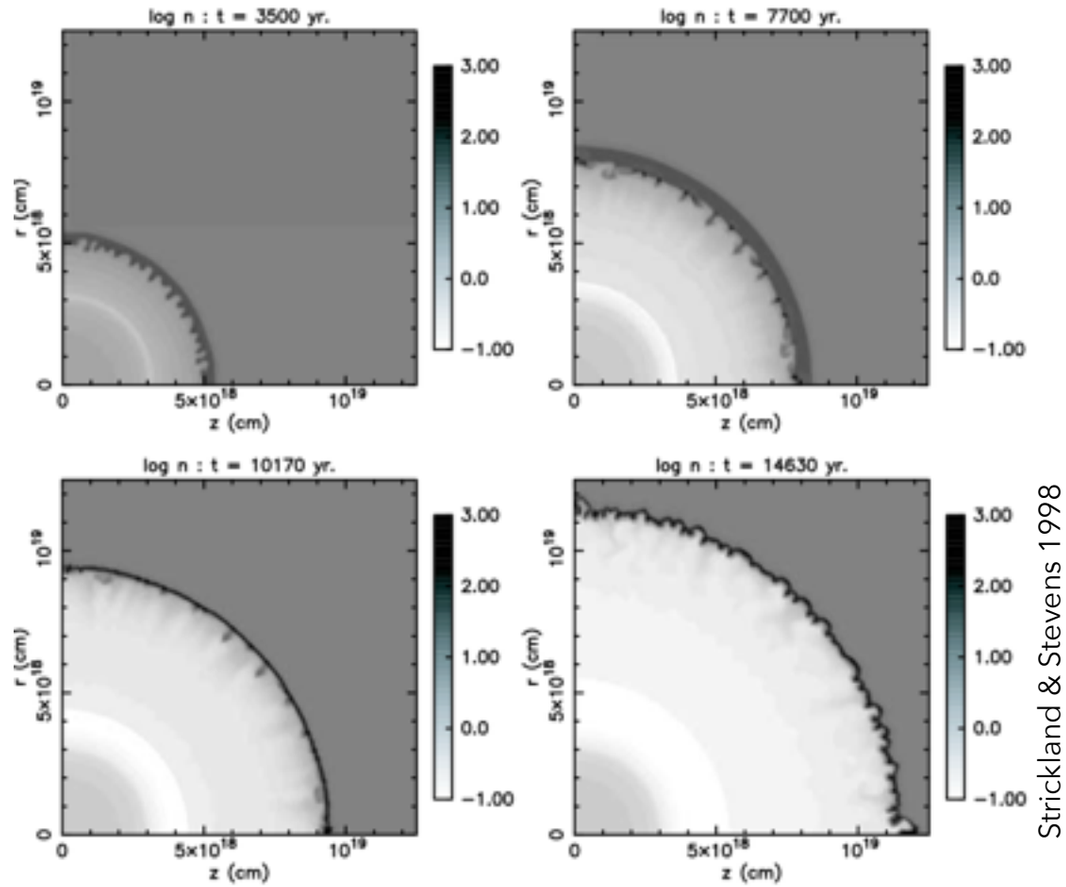
Harper-Clark & Murray 2009



Rogers & Pittard 2013

Rapid mixing of cold and hot gas via turbulent conduction

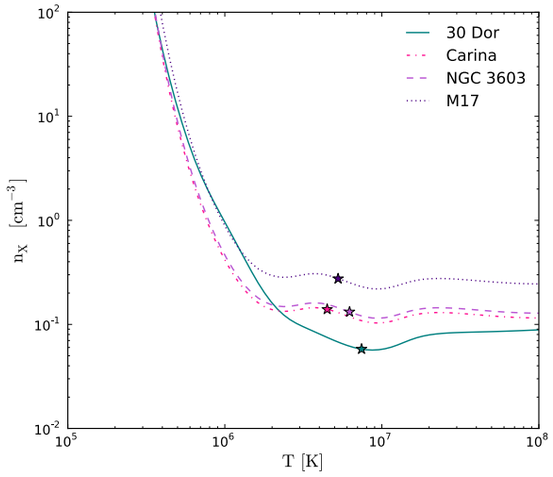
(McKee+1984, Strickland & Stevens 1998, Nakamura+2006)

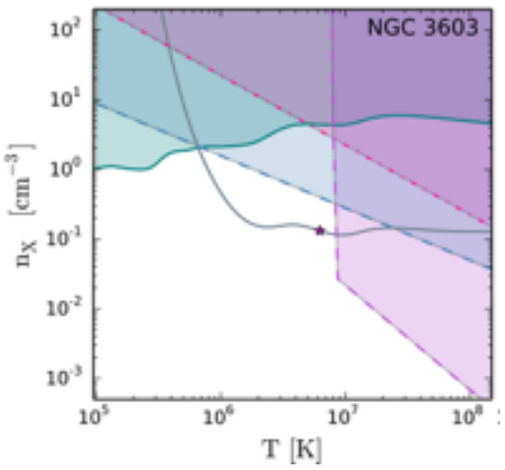


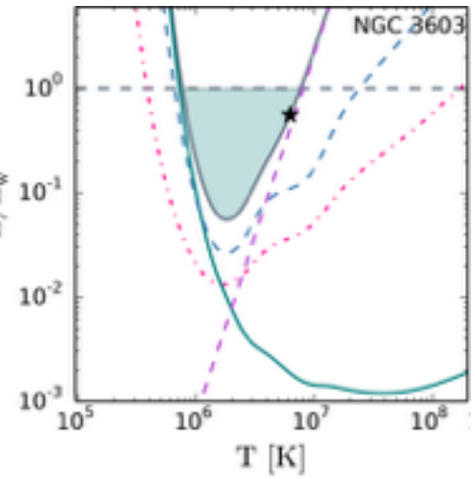
Strickland & Stevens 1998

Summary

X-ray emission constrains physical properties of the shock-heated material in HII regions.



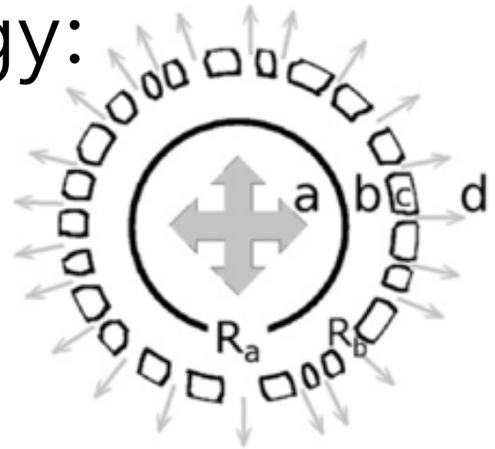




Bulk of the wind energy does not go mechanical work. Maybe winds important during early formation?

Accounting for the bulk of the stellar wind energy:

- Physical leakage
- Turbulent mixing of cold and hot gas



Thank you! Questions?

Hubble panoramic image of the Carina Nebula (NASA)