The relative impact of stellar winds and ionizing radiation
- A puzzle?! -

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Puzzles of star formation
Castle Ringberg
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European Research Council

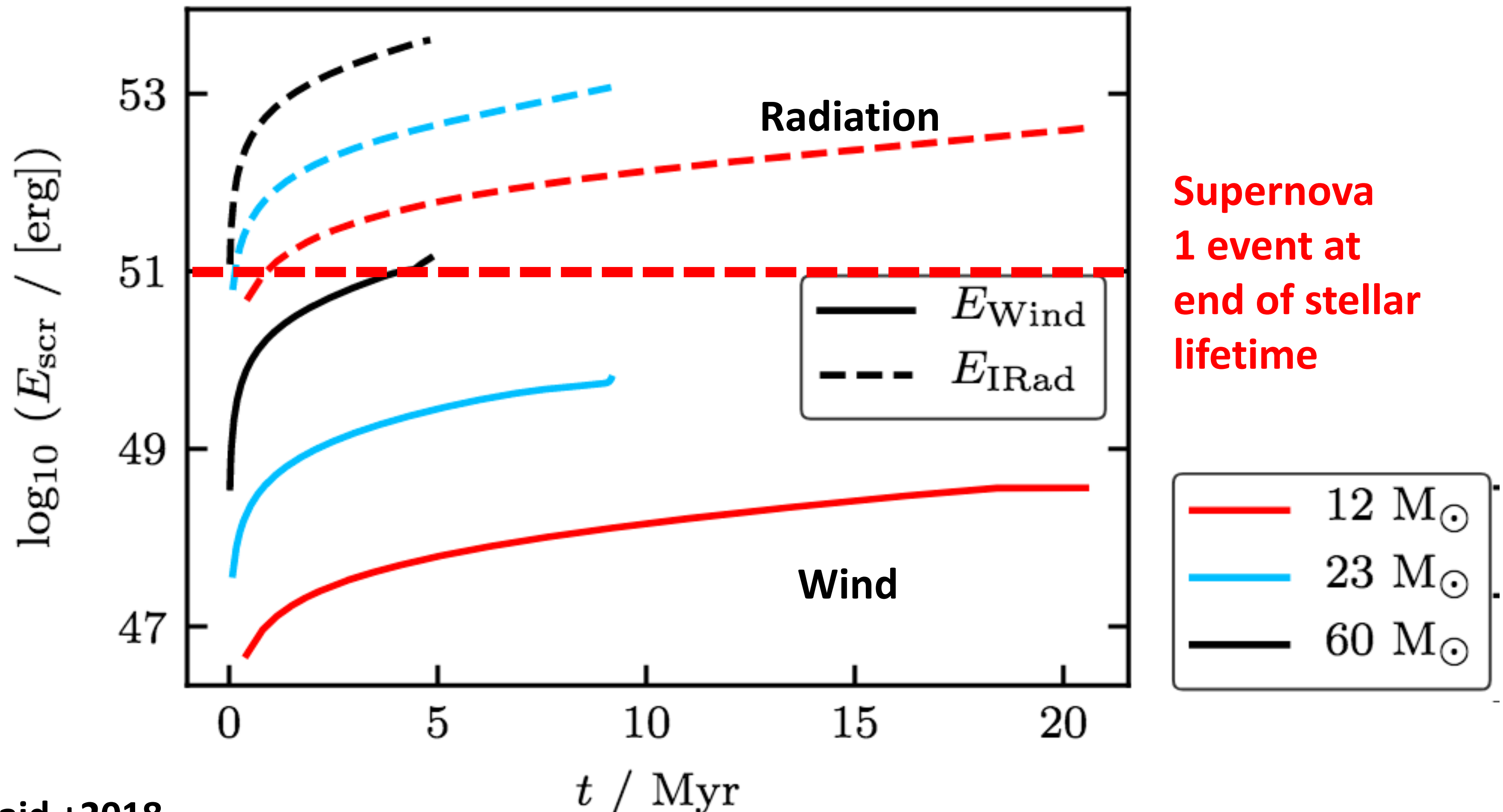
SFB 956 Cologne | Bonn

DFG Priority Program 1573 ISM-SPP Interstellar Medium

The SILCC project

GCS Gauss Centre for Supercomputing

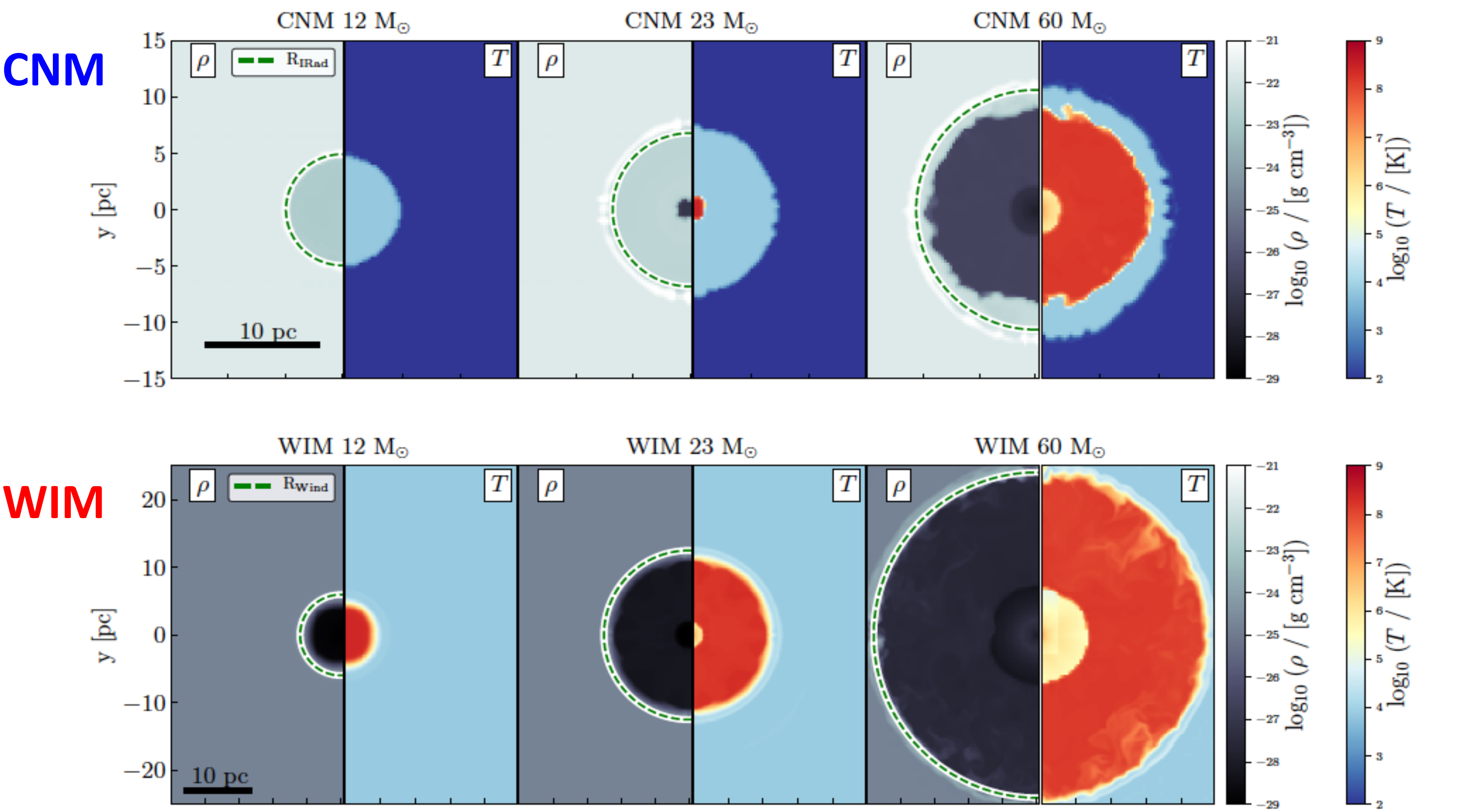
Energy input:
Stellar winds, ionizing radiation & Supernovae: How is this energy coupled to the ISM?



Supernova
1 event at end of stellar lifetime

see Haid +2018

Stellar winds vs. ionizing radiation:
Simulations with FLASH + TreeRay + Chemical Network
2 different environments of the massive star: CNM and WIM

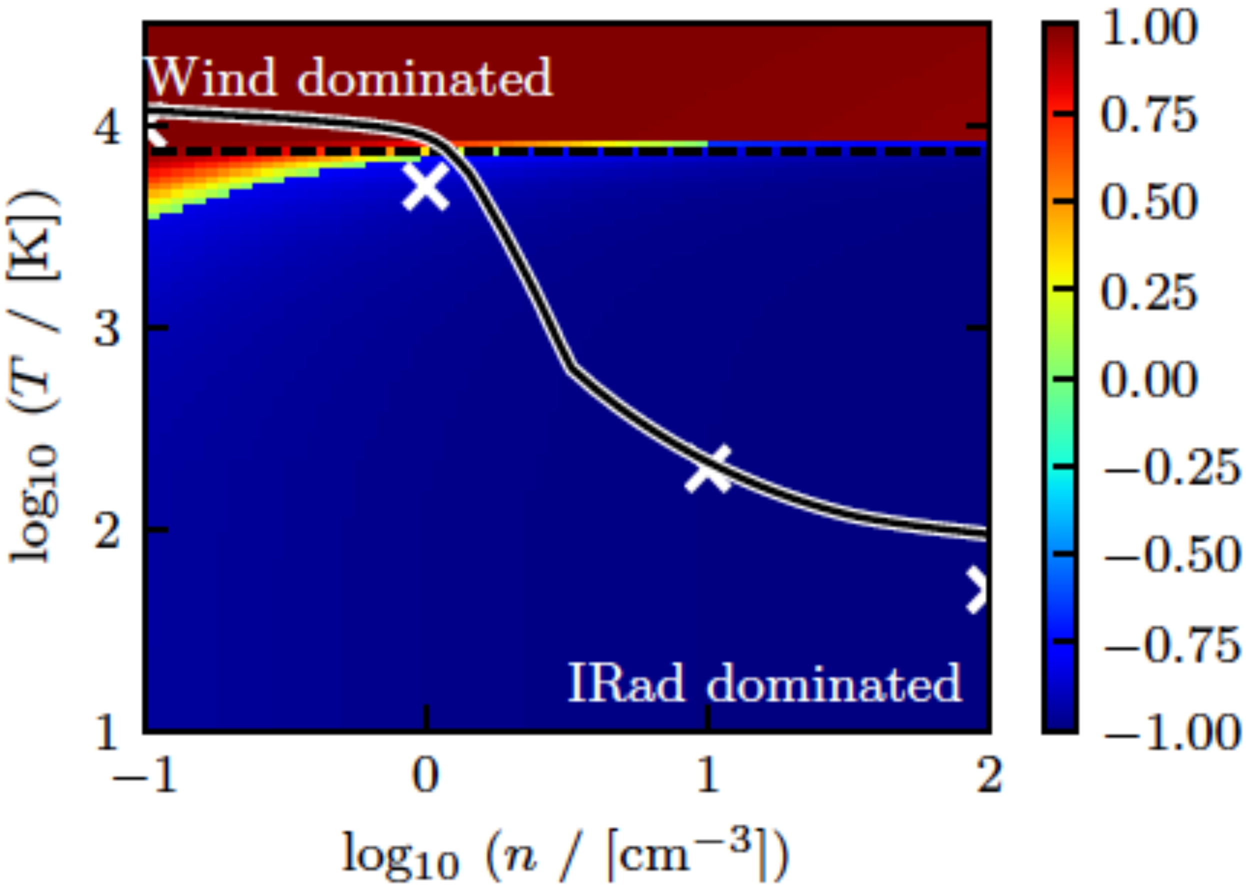


CNM: T=20 K, n=100 cm^{-3}; WIM: T=10^4 K, n=0.1 cm^{-3}

Haid et al. (2018a)

Momentum input:
Stellar winds vs. ionizing radiation:

Crosses: simulations; Line: equilibrium curve; Colour: Analytical calculation



Relative impact of wind and radiation

Here: for 23 $M_\odot$ star

$$I_\mathrm{p} \equiv \frac{p_\mathrm{Wind} - p_\mathrm{IRad}}{p_\mathrm{Wind} + p_\mathrm{IRad}}$$

Radiation does not couple in low density/ warm ambient medium ⇒stellar winds become dominant there!

Haid, SW+2018

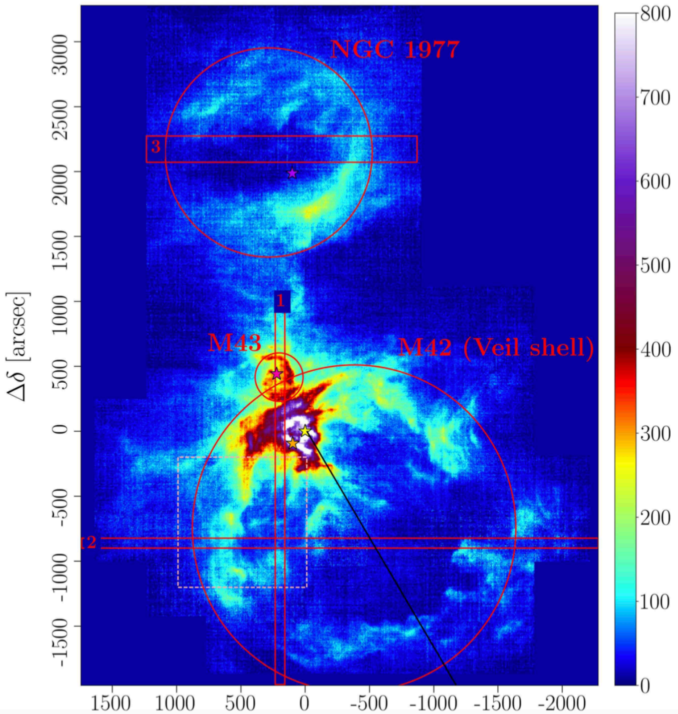
CNM: T=20 K, n=100 cm^{-3}; WIM: T=10^4 K, n=0.1 cm^{-3}

But what do the observations tell us?

Pabst+2019, +2020 argue that stellar wind is driving bubble expansion

Why: CII line observations show bubble expansion velocity of 13 km/s

Example: Orion



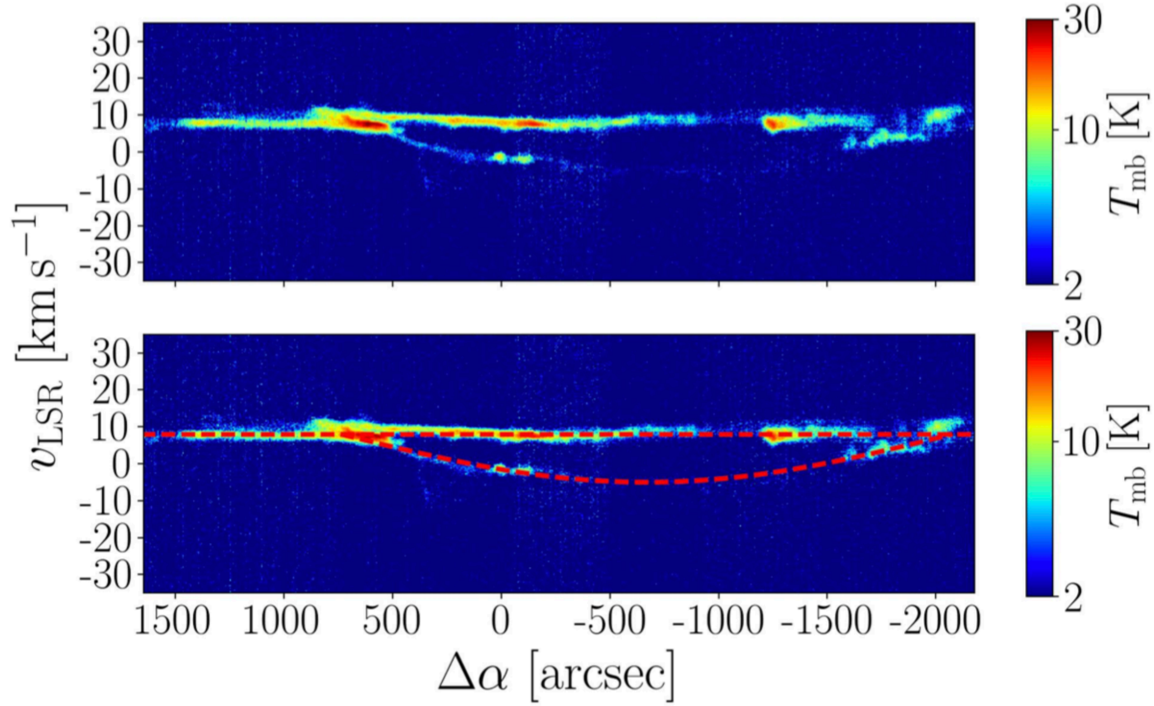


Fig. 5. [C II] pv diagram along horizontal position cut 2 indicated in Fig. 2 ($\Delta\delta = -907''$- $-831''$). The lower panel shows the same cut with the arc structure for an expansion velocity of $13\,\mathrm{km\,s^{-1}}$ on a background velocity of $8\,\mathrm{km\,s^{-1}}$ (red dashed lines).

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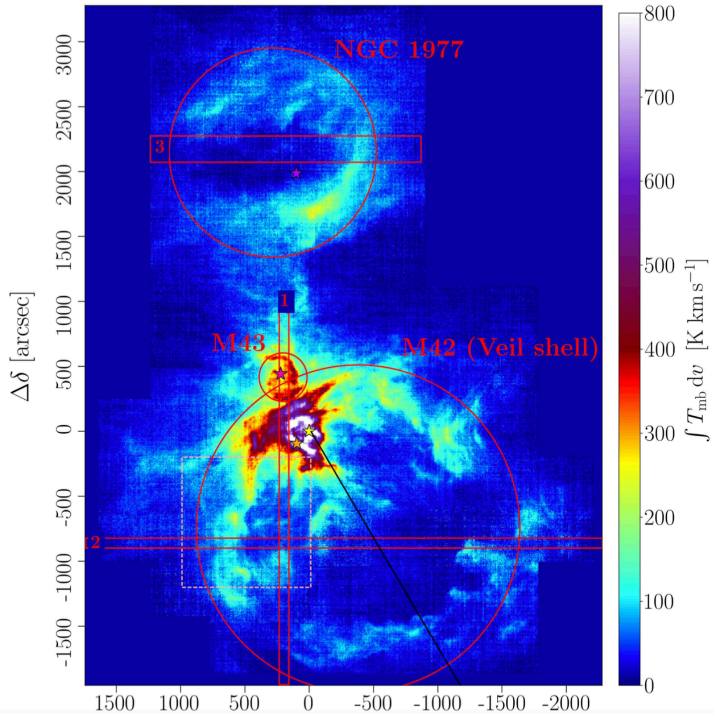


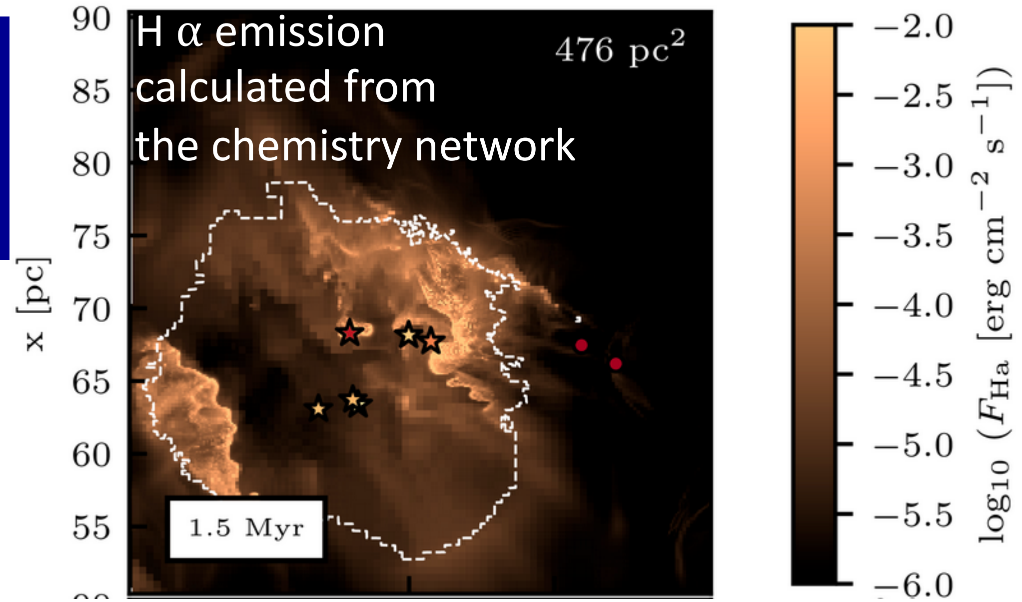
region	star	stellar type	$T_{\rm eff}$ [K]	$L_\star$ [$L_\odot$]	$L_{\rm w}$ [erg s^{-1}]	$M_{\rm shell}$ [$M_\odot$]	$v_{\rm exp}$ [km s^{-1}]	$E_{\rm kin}$ [erg]	t_0 [Myr]	$E_{\rm kin}/(L_{\rm w}t_0)$
M42	θ^1 Ori C	O7V	$3.9\cdot10^4$	$2.0\cdot10^5$	$8\cdot10^{35}$	1500	13	$2.5\cdot10^{48}$	0.2	0.5
M43	NU Ori	B0.5V	$3.1\cdot10^4$	$2.6\cdot10^4$	$\sim3\cdot10^{31}$	7	6	$3\cdot10^{45}$	0.02	50
NGC 1977	42 Ori	B1V	$2.5\cdot10^4$	$1.1\cdot10^4$	$\sim3\cdot10^{31}$	700	1.5	$2\cdot10^{46}$	0.4	40

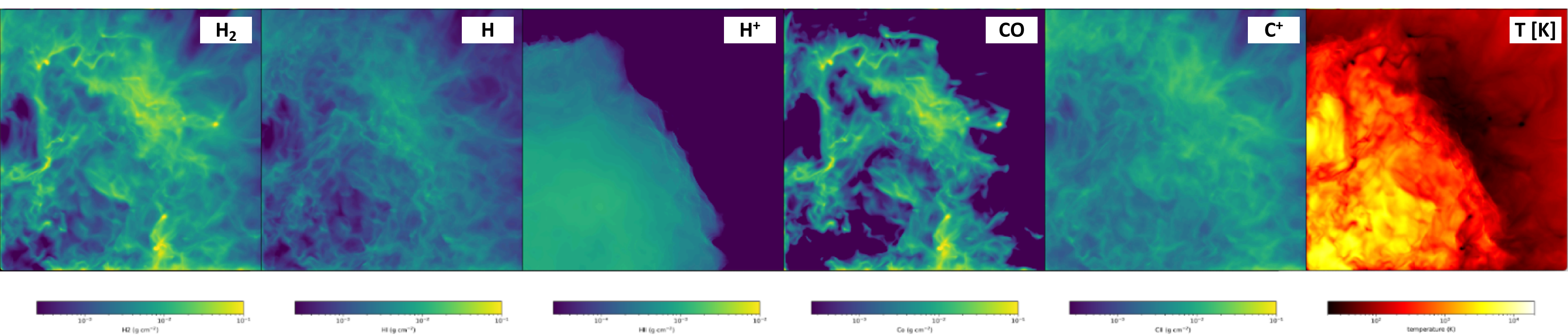
Table 8. Comparison of stellar parameters with bubble energetics of the three regions. In the last column, we take for t_0 the value derived from the stellar wind models; in case of M43 the lifetime derived from pressure-driven expansion is a third of that value, increasing the ratio $E_{\rm kin}/(L_{\rm w}t_0)$ by a factor of three. Stellar parameters of θ^1 Ori C are from Simón-Díaz et al. (2006), of NU Ori from Simón-Díaz et al. (2011), and of 42 Orionis from Hohle et al. (2010).

	M42 (Veil shell)	M43	NGC 1977
$\mathbb{N}_{\rm Lyc}$ [10^{47} s^{-1}]	70	1.5	1
$L_{\rm w}$ [$L_\odot$]	400	$\sim1.5\cdot10^{-2}$	$\sim1.5\cdot10^{-2}$
mass of neutral gas [$M_\odot$]	1500	7	700
mass of ionized gas [$M_\odot$]	24	0.3	16
$E_{\rm kin}$ of neutral gas [10^{46} erg]	250	0.3	2
$E_{\rm kin}$ of ionized gas [10^{46} erg]	6	–	–
$E_{\rm th}$ of ionized gas [10^{46} erg]	3	0.7	5
$E_{\rm th}$ of hot gas [10^{46} erg]	10	–	–
$L_{\rm FIR}$ [$L_\odot$]	$3.2\cdot10^4$	$8.5\cdot10^3$	$1.5\cdot10^4$
$L_{\rm [C\,II]}$ [$L_\odot$]	170	24	140

Models of HII Region expansion do not give high enough expansion velocities…

Zooming in on ionization fronts

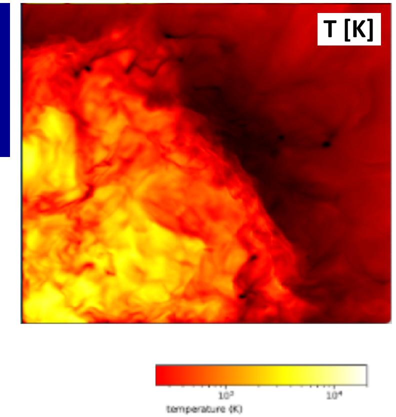




Simulations of an isolated HII region
expanding into a turbulent medium
by Sebastian Vider

S.Vider,SW+in prep.

Expansion of the ionization front (IF) vs time



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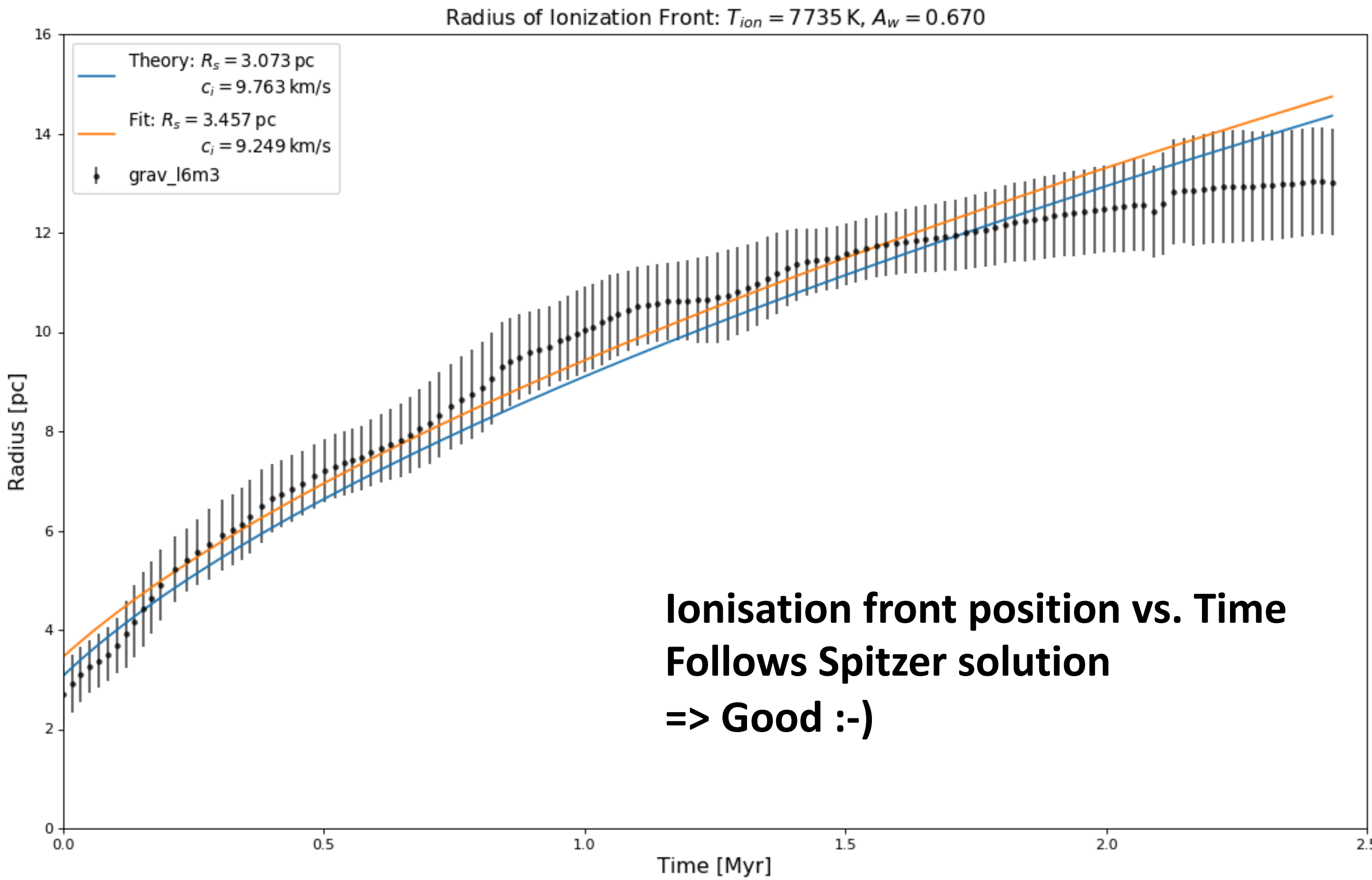
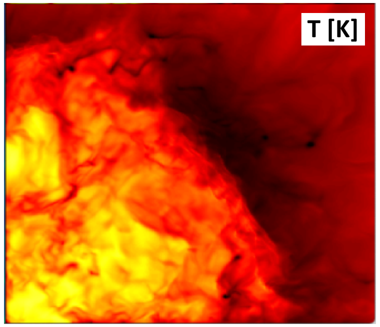
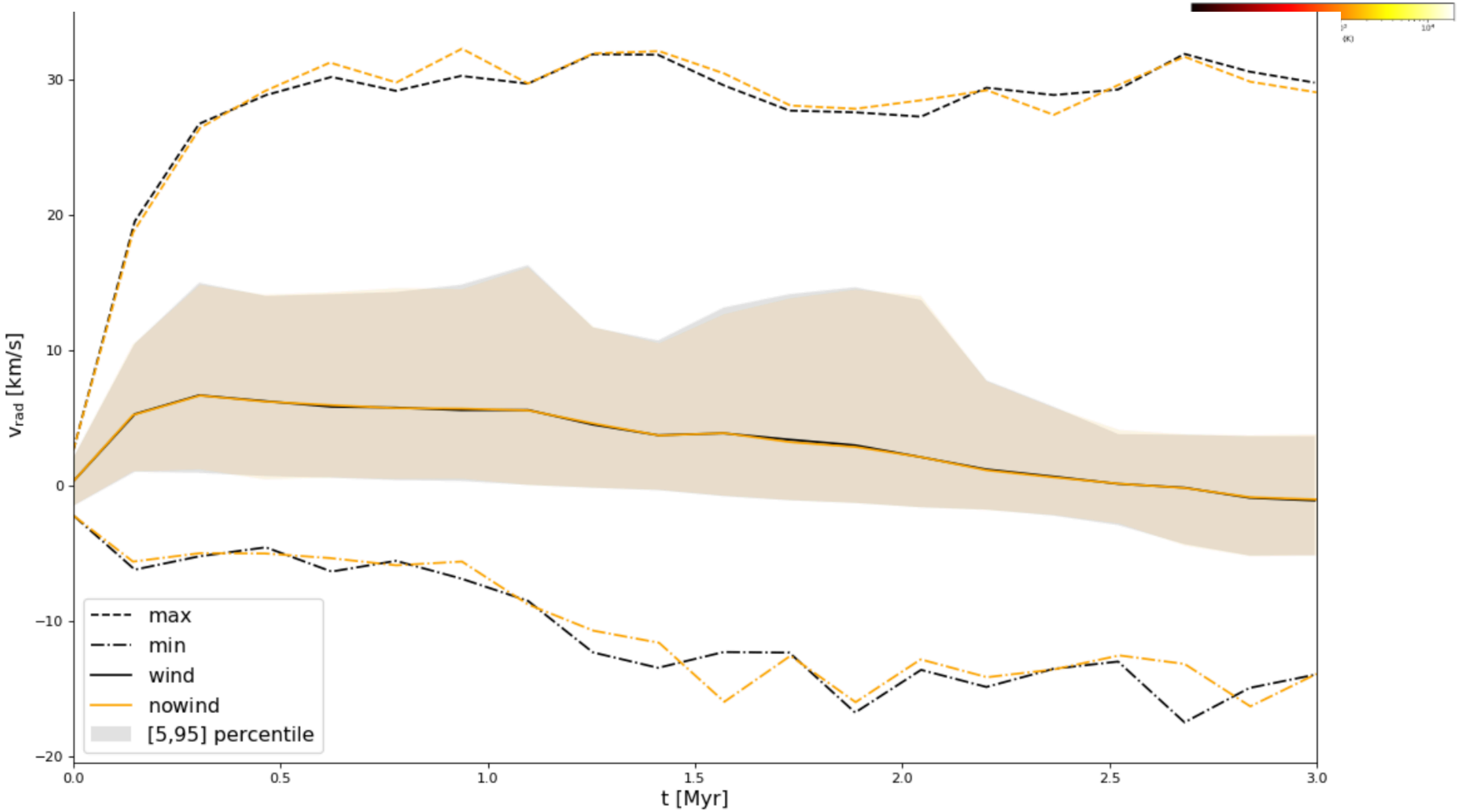


Ionisation front position vs. Time
Follows Spitzer solution
=> Good :-)

S.Vider,SW+in prep.

New run with wind+ionizing radiation vs. just ionizing radiation





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Puzzles

Questions:

- What is the relative impact of stellar winds and radiation?

$\Rightarrow$ Which tracers to use to get a good idea on the momentum input and energetics?

$\Rightarrow$ If observers are correct then the simulations are completely wrong

- How important are feedback bubbles for driving star formation
- Are molecular clouds short-lived? How important is feedback in the context of molecular cloud dispersal? Triggering vs. disruption

$\Rightarrow$ Differences for high-mass/low-mass molecular clouds

- Are all molecules destroyed when the cloud is dispersed?

And a (small-scale) star-formation question (not related but perhaps to be discussed on Wed):

- How much episodic vs smooth accretion onto protostars?
- What is the accretion spectrum? Hot-spot or not?