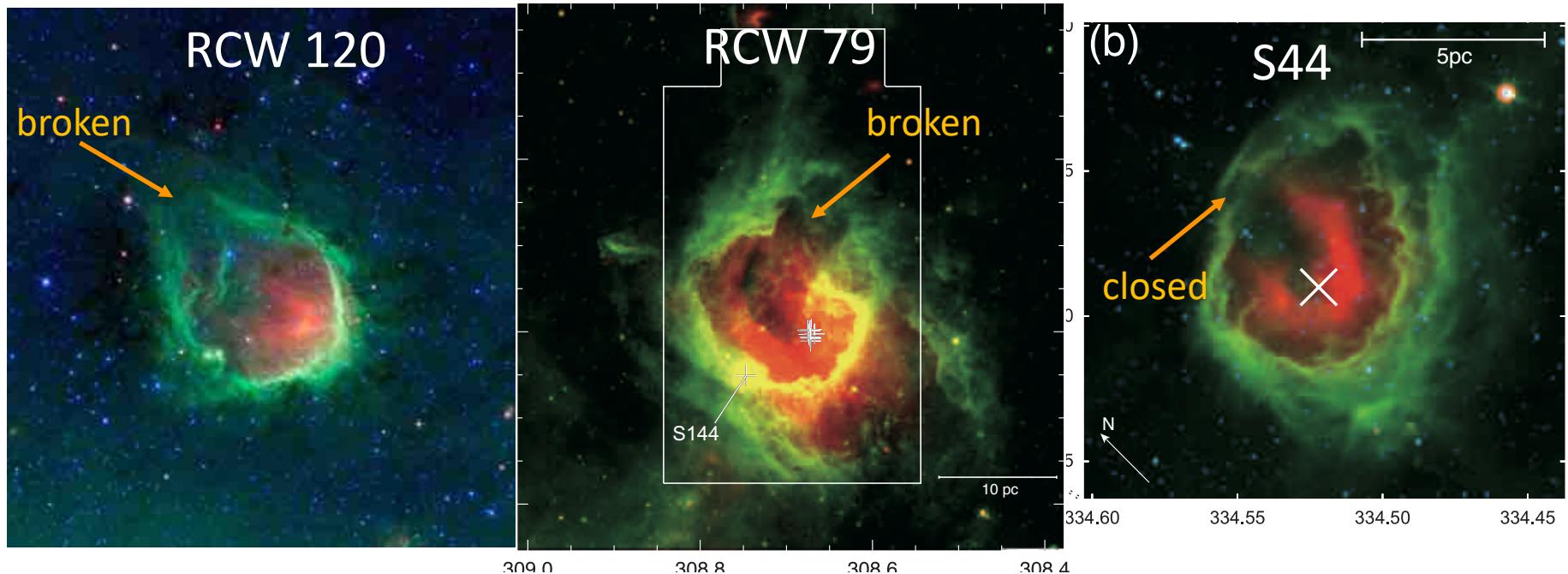


ALMAでのSpitzer Bubble の観測

2018/12/11 河野 樹人

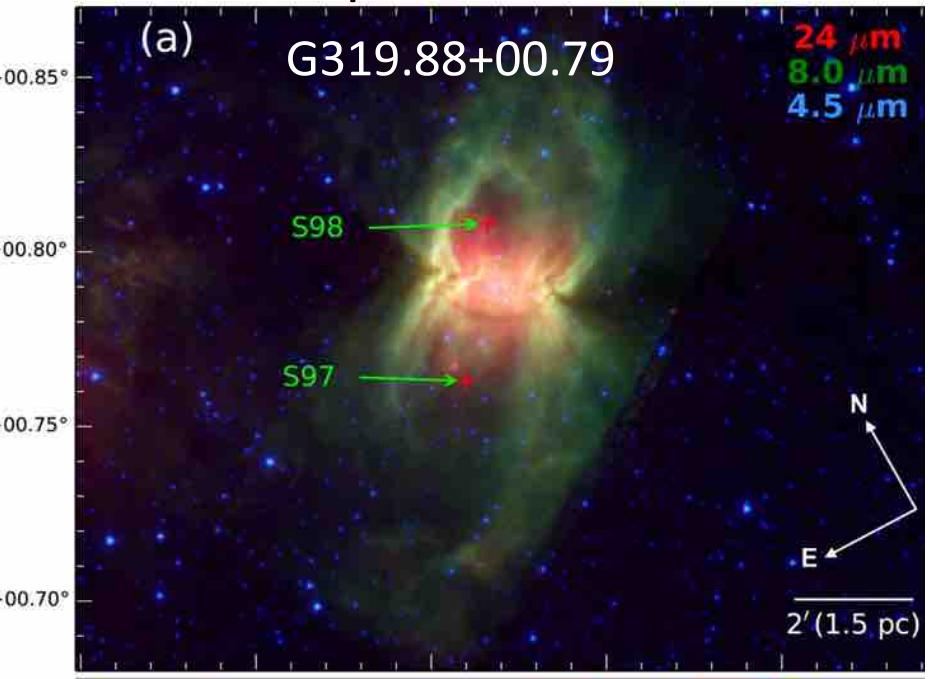
Spitzer bubble



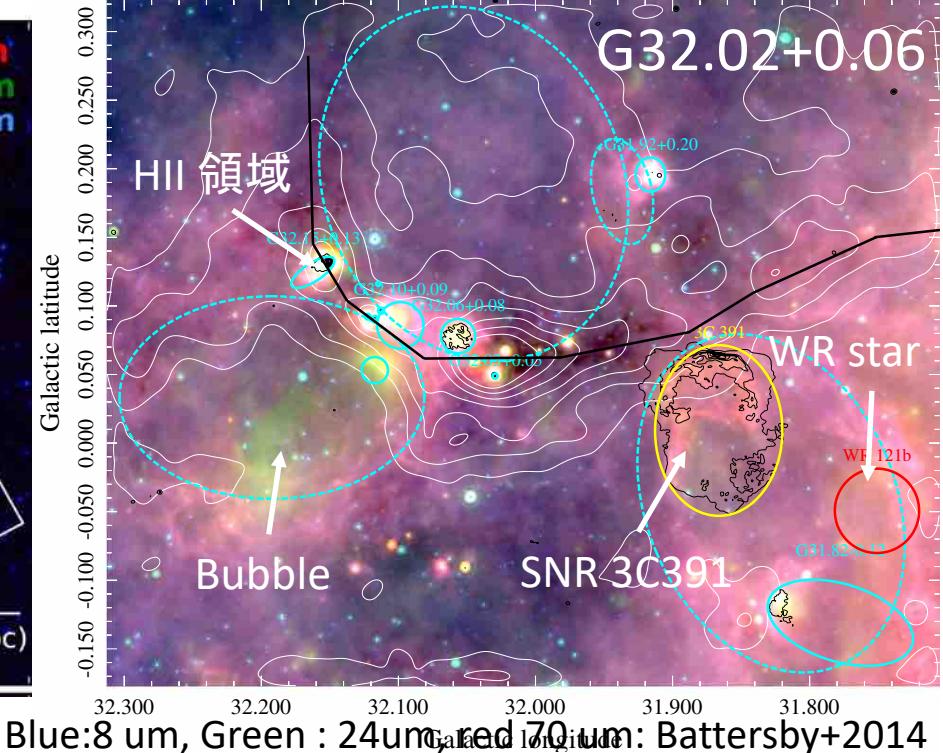
- GLIMPSEデータを用いてChurchwell+06,07 によって同定
- 大部分は大質量星を内包したHII領域
- 8 um (PAH + hot dust)でシェル構造
- 主な種類(赤外線データからのmorphology による分類)
 - Closed, Broken, Bipolar, Multipleなど

Spitzer bubble

Bipolar bubble



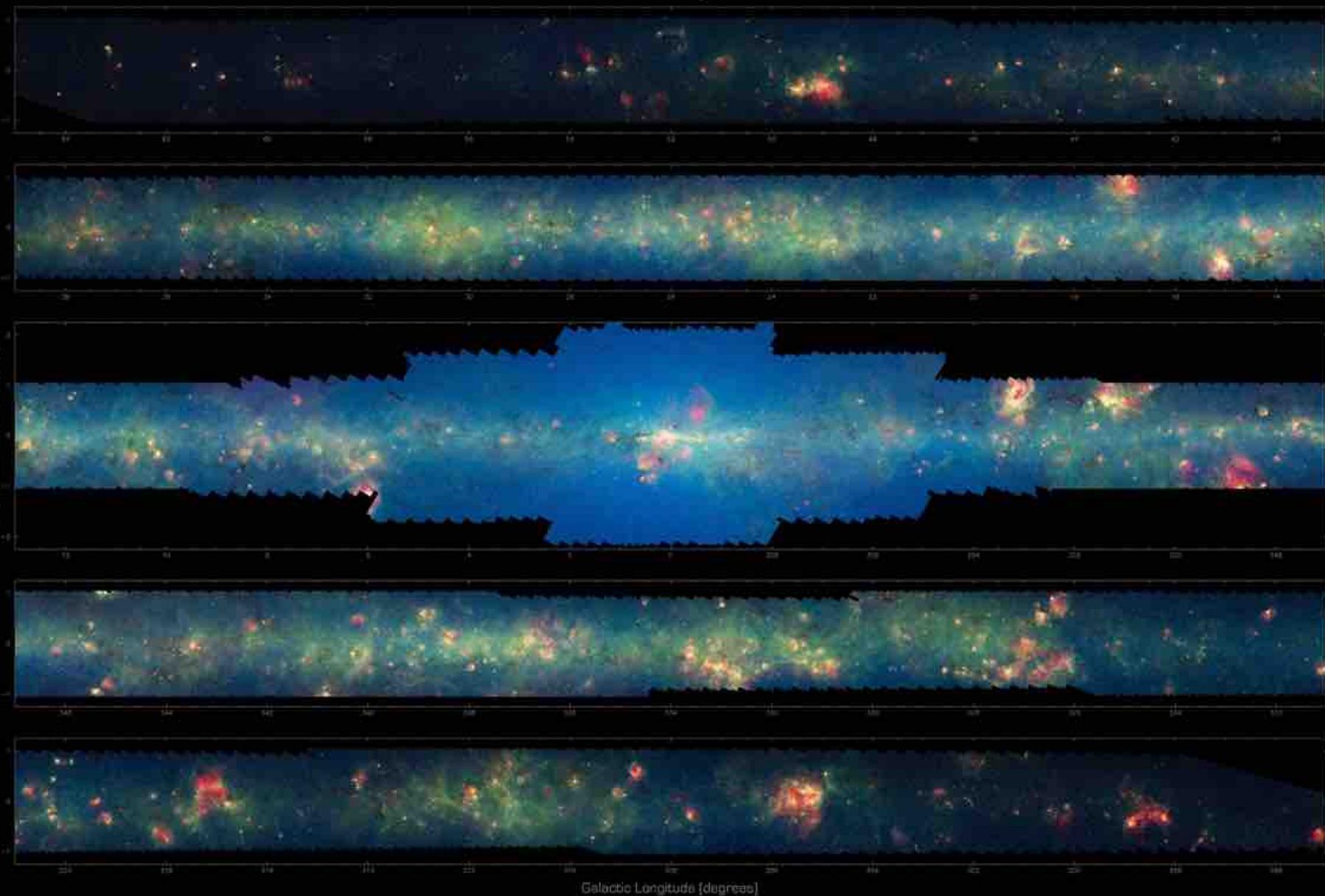
Multiple bubble



Blue:8 um, Green : 24um, red 70 um: Battersby+2014

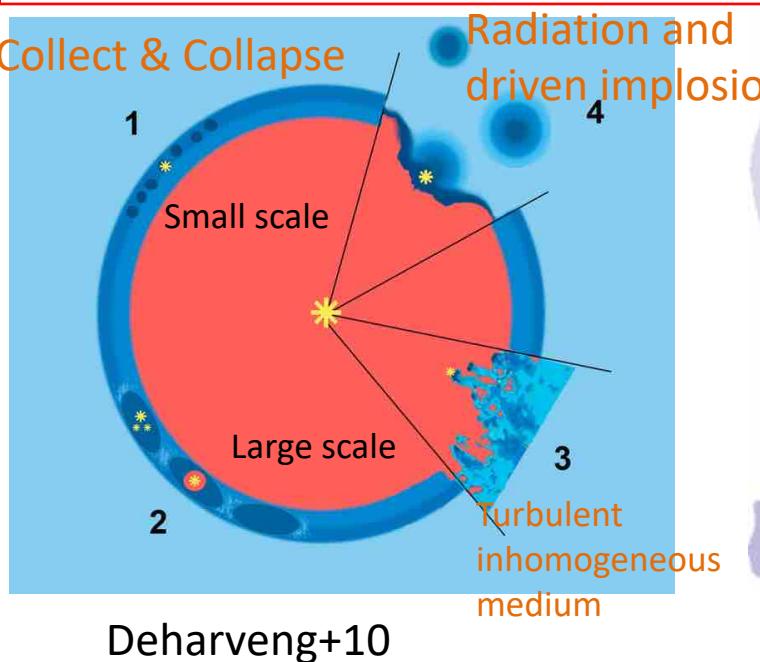
- GLIMPSEデータを用いてChurchwell+06,07 によって同定
- 大部分は大質量星を内包したHII領域
- 8 um (PAH + hot dust)でシェル構造
- 主な種類(赤外線データからのmorphologyによる分類)
 - Closed, Broken, Bipolar, Multipleなど

THE INFRARED MILKY WAY: GLIMPSE/MIPSGAL (3.6-24 microns)



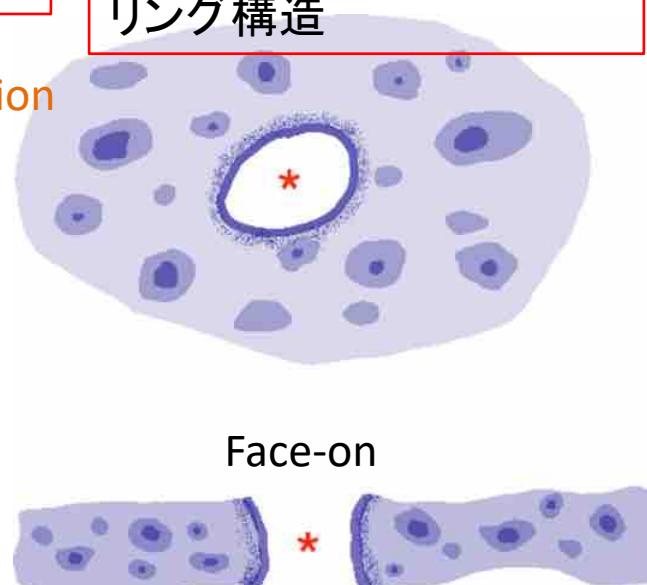
Spitzer bubble と星形成シナリオ

1. HII領域の膨張による誘発的星形成



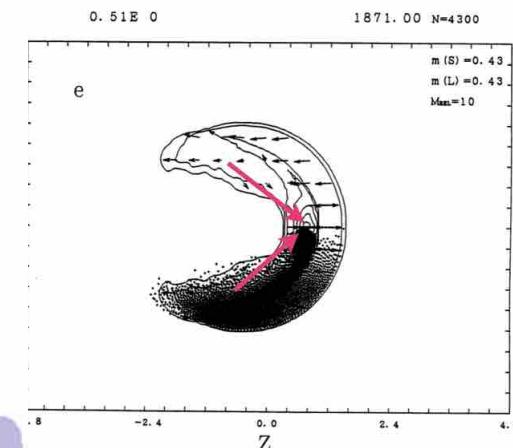
Deharveng+10

2. シート状分子雲による リング構造



Beaumont & Williams 2010

3. 分子雲衝突による バブル形成

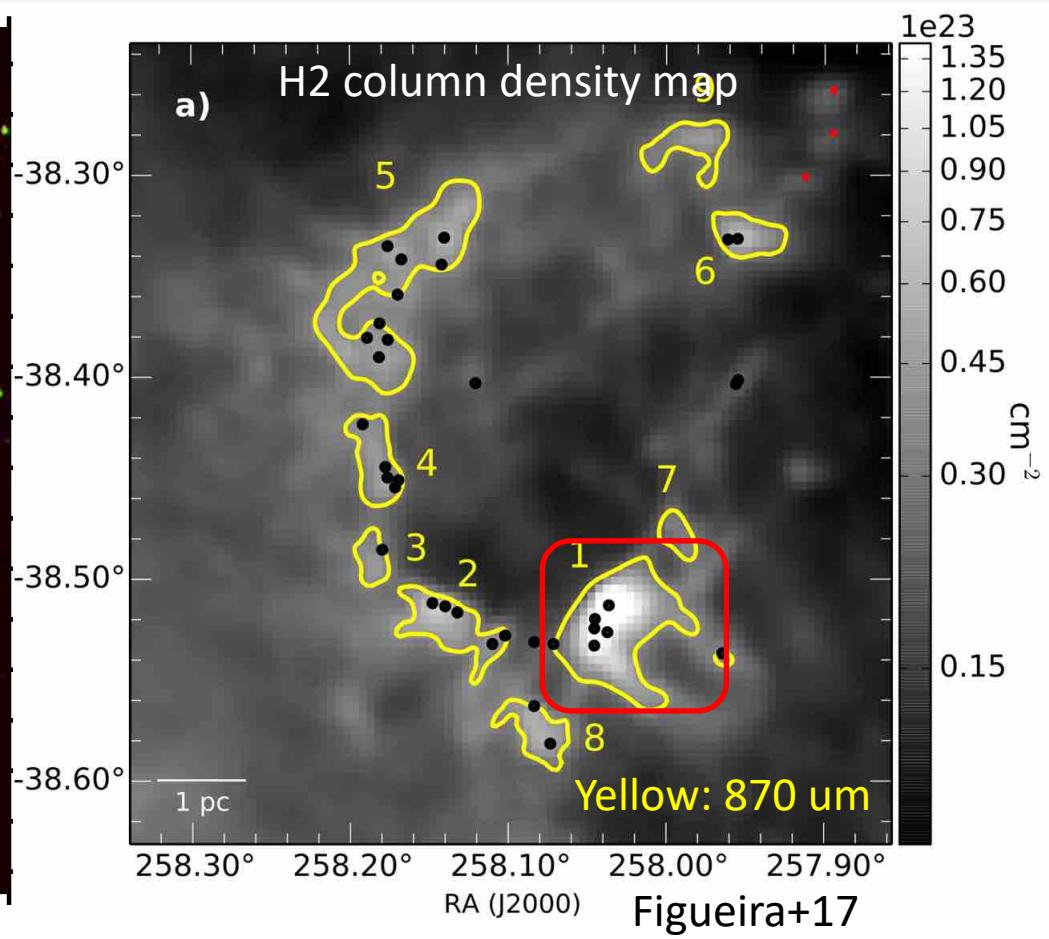
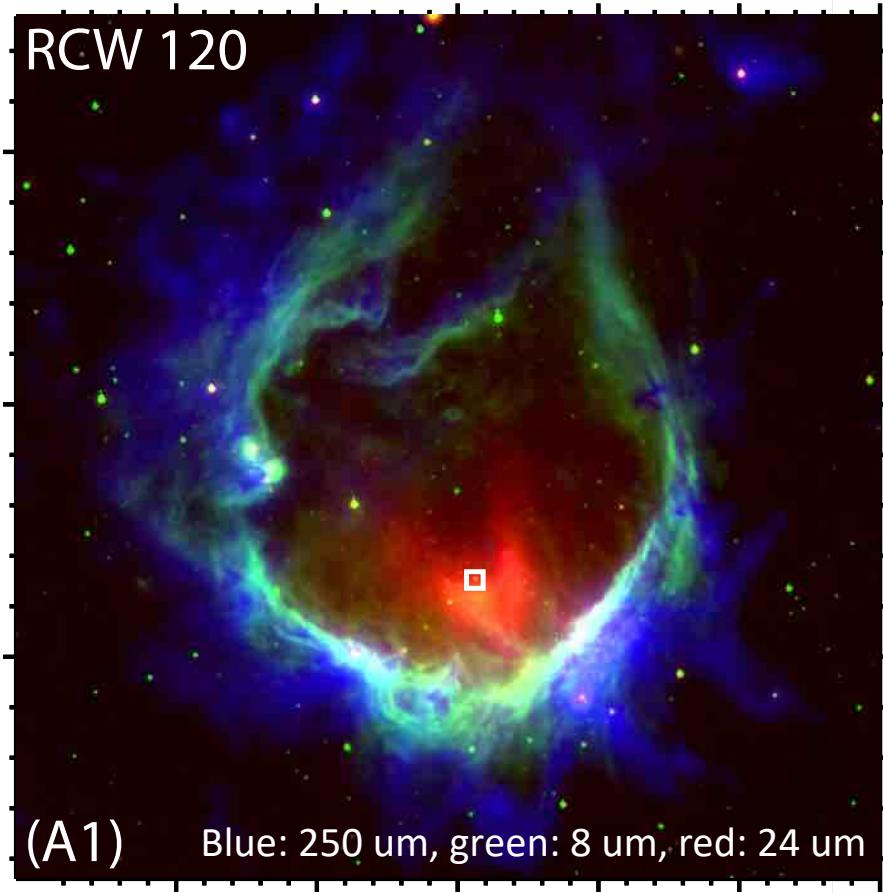


Habe & Ohta 1992

1. 膨張シェルによる周囲の星間物質の掃き集めが星形成を誘発
2. COの速度構造から膨張運動が観測されない-> リング構造??
3. 分子雲同士の衝突によってバブルが形成

ALMA 高分解能観測によって、どのメカニズムが最も有力か示したい。

Spitzer bubble: RCW 120

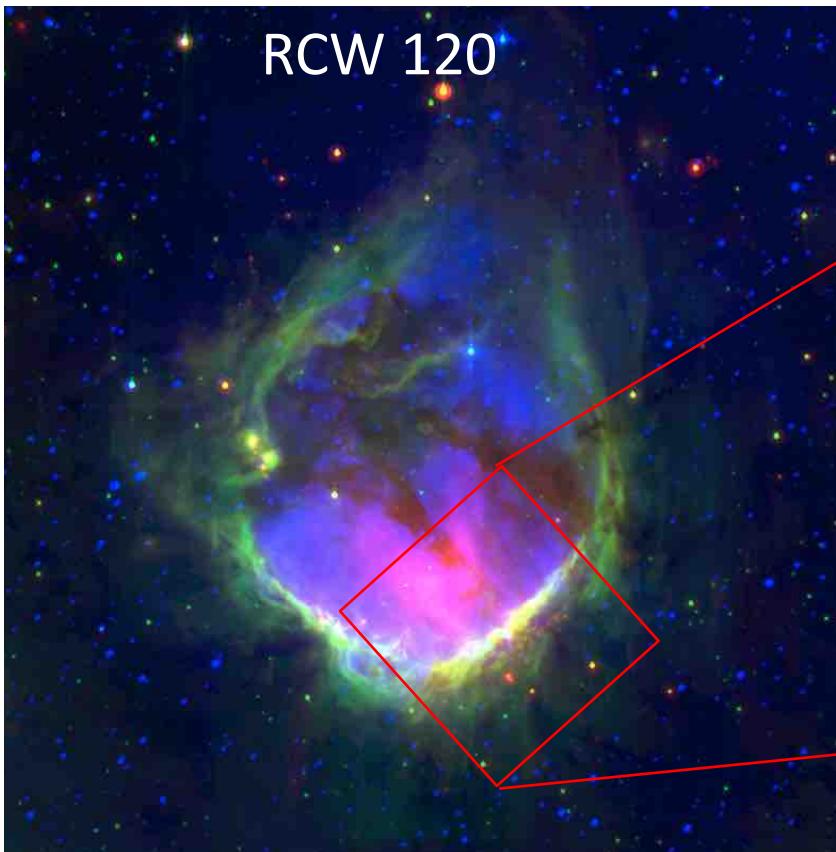


- Churchwell+06 によって同定
- 距離 : 1.3 kpc
- 8 μm でリング構造
- 24 μm でアーク構造
- 励起星 O8 型 (Martins+10)

- 励起星はバブル中心からオフセットした位置に存在
- バブル周囲にdust condensation
- 膨張シェルモデル(Dehanveng+10)と分子雲衝突モデル(Torii+15)が議論

RCW 120: バブルの中心と端での星形成

RCW 120



Blue : H α , green : 8 um, red : 24 um

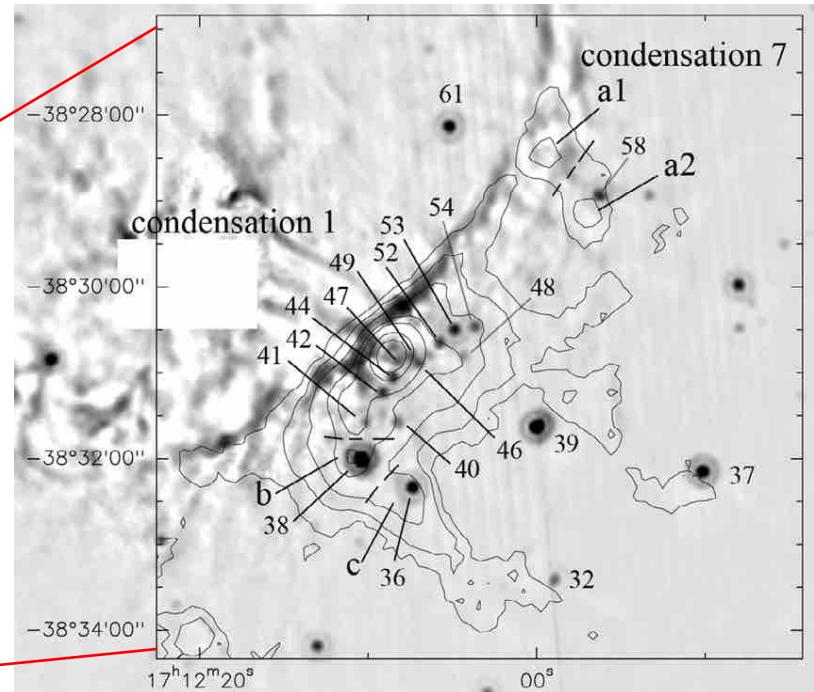


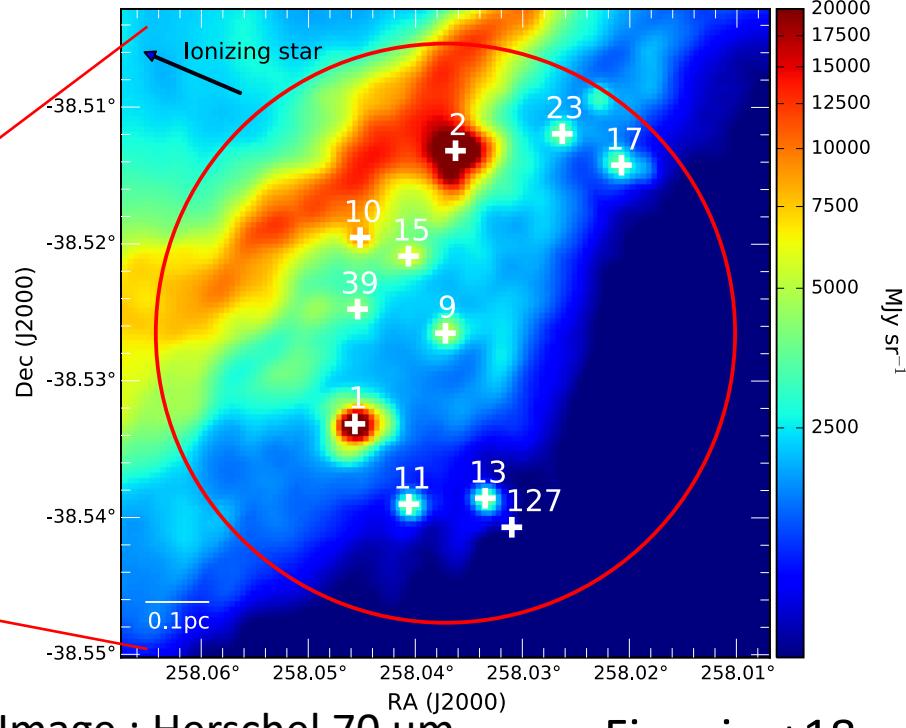
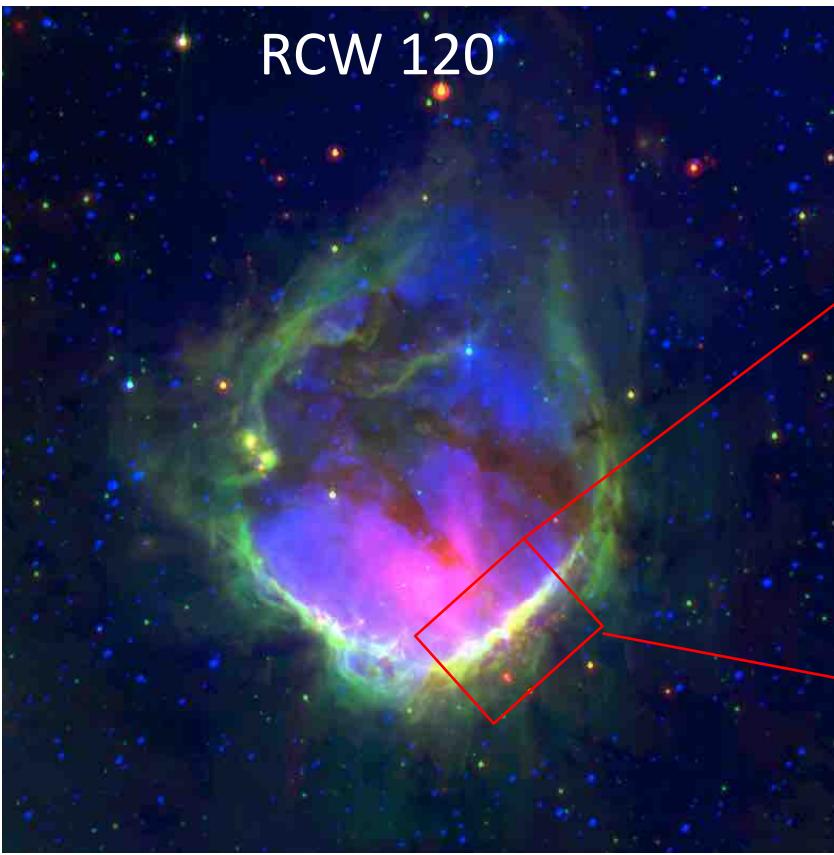
Image : 24 um
Contour : 870 um

Deharveng+10

- バブルの端で、cold dust condensation が形成
- 最もmassive なのはバブルの南側 (condensation 1)
- Condensation 1でYSO が集中

RCW 120: バブルの中心と端での星形成

RCW 120



Blue : H α , green : 8 μm , red : 24 μm

- バブルの端で、cold dust condensation が形成
- Condensation 1でYSO が集中
- 0.1 pc程度の compact source で構成
- Core 2 が最もmassive

Herschel で同定したコアの物理量とfragmentの関係

Table 1. Properties of the *Herschel* cores using the *getsources* (+*getimages*) algorithm.

Id	α		δ	T_{env} (K)	M_{env} (M_{\odot})	L_{bol} (L_{\odot})	$n_{\text{H}_2}^a$ (cm^{-3})	M_{Jeans} (M_{\odot})	N_{frag}	M_{frag} (M_{\odot})
	J2000 ($^{\circ}$)									
1	258.04577	-38.53338	17.0 ± 0.2	85 ± 6	234 ± 28	$(3.0 \pm 0.2) \times 10^5$	0.8	2	10.6 ± 0.7	
2	258.03624	-38.51317	16.9 ± 0.2	376 ± 21	856 ± 93	$(1.3 \pm 0.1) \times 10^6$	0.4	5	73 ± 3.6	
9	258.03749	-38.52663	13.1 ± 0.2	97 ± 14	49 ± 12	$(3.4 \pm 0.5) \times 10^5$	0.5	2	25.8 ± 1.6	
10	258.04524	-38.51956	11.1 ± 0.4	252 ± 41	46 ± 17	$(8.7 \pm 1.4) \times 10^5$	0.3	2	15.5 ± 1.4	
11	258.04073	-38.53926	14.2 ± 0.4	31 ± 9	24 ± 11	$(1.1 \pm 0.3) \times 10^5$	1.1	1	7.4 ± 0.5	
13	258.03352	-38.53886	16.3 ± 0.8	8 ± 3	23 ± 9	$(2.8 \pm 1.0) \times 10^4$	2.5	2	6.8 ± 0.8	
15 ^b	258.04084	-38.52110	12.8 ± 0.5	81 ± 15	38 ± 15	$(2.8 \pm 0.5) \times 10^5$	0.5	1	3.5 ± 0.6	
39	258.04560	-38.52532	12.8 ± 0.3	97 ± 17	42 ± 13	$(3.4 \pm 0.5) \times 10^5$	0.5	3	72.2 ± 2.7	
17	258.02078	-38.51440	12.8 ± 0.2	122 ± 17	51 ± 13	$(4.2 \pm 0.6) \times 10^5$	0.4	0	0	
23	258.02648	-38.51204	11.9 ± 0.4	130 ± 21	37 ± 13	$(4.5 \pm 0.7) \times 10^5$	0.4	0	0	
127	258.03146	-38.54054	10.8 ± 0.3	80 ± 17	12 ± 5	$(2.8 \pm 0.6) \times 10^5$	0.4	0	0	

Notes. Columns are: (1) identification number, (2,3) J2000 coordinates, (4) envelope temperature, (5) envelope mass, (6) bolometric luminosity, (7) volume density, (8) Jeans mass, (9) number of fragments inside the core, and (10) total mass of the fragments. ^(a) The volume density was computed assuming a size of 0.1 pc and $n_{\text{H}_2} = M_{\text{core}} / (\mu \text{m}_{\text{H}} \times (4/3)\pi \times 0.1 \text{ pc}^3)$. ^(b) SED fitting carried out without 160 and 250 μm and consequently no aperture correction was carried out.

Figueira+18

- Core 2が最もmassive
- Fragmentの数も最多
- Core 17,23,127に対応するfragmentなし

ALMAによるcondensation 1に対する観測

RCW 120

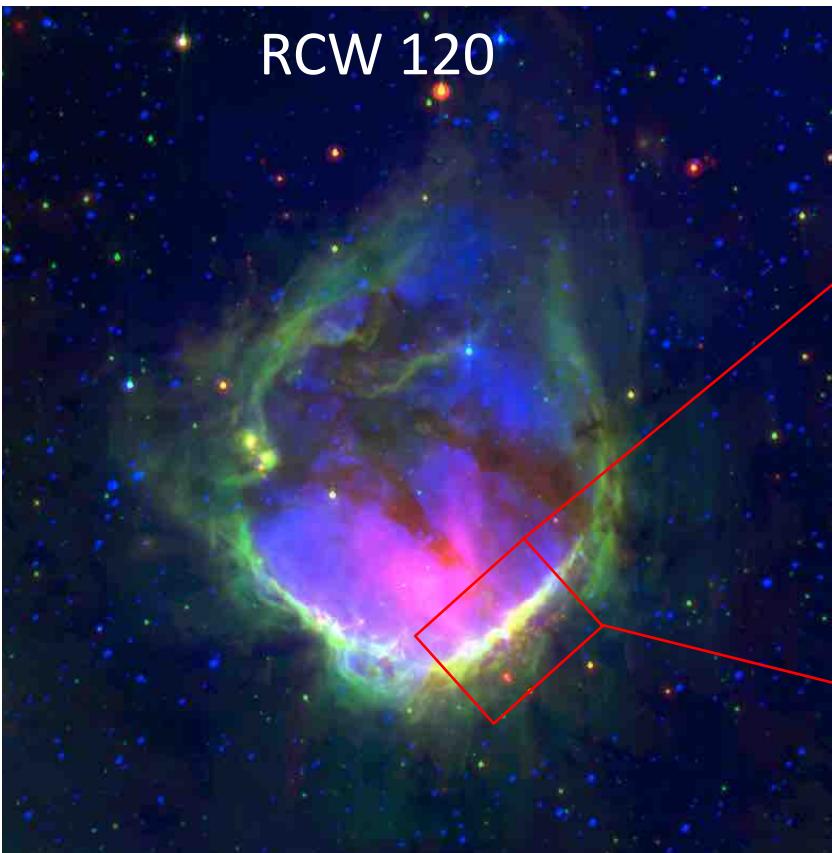
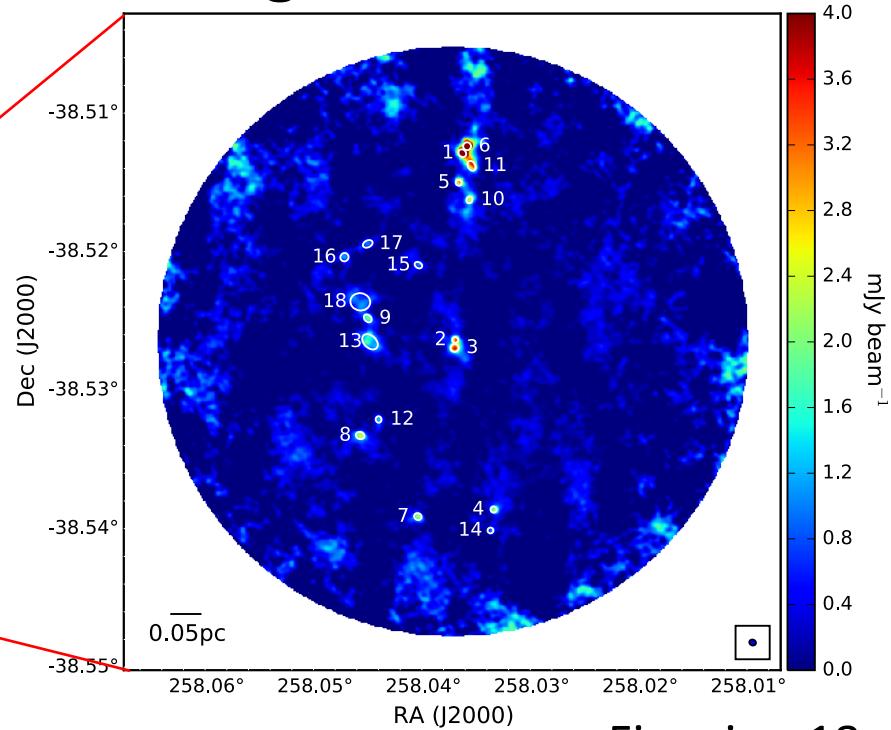


Image : ALMA 3mm



Figueira+18

Blue : H α , green : 8 um, red : 24 um

- ALMA Cycle4 観測

- Band 3 (N₂H⁺, SO₂, 3mm continuum)
- 分解能: 0.01 pc
- Lineの結果は別論文で議論 (in preparation)

- Getsources アルゴリズムを用いて 0.01 pcスケール18個のsourceを同定
- Core 2が最もmassiveでfragment

ALMA 3mm continuumで同定したfragmentの物理量

Table 2. Properties of the fragments detected with ALMA at 3 mm.

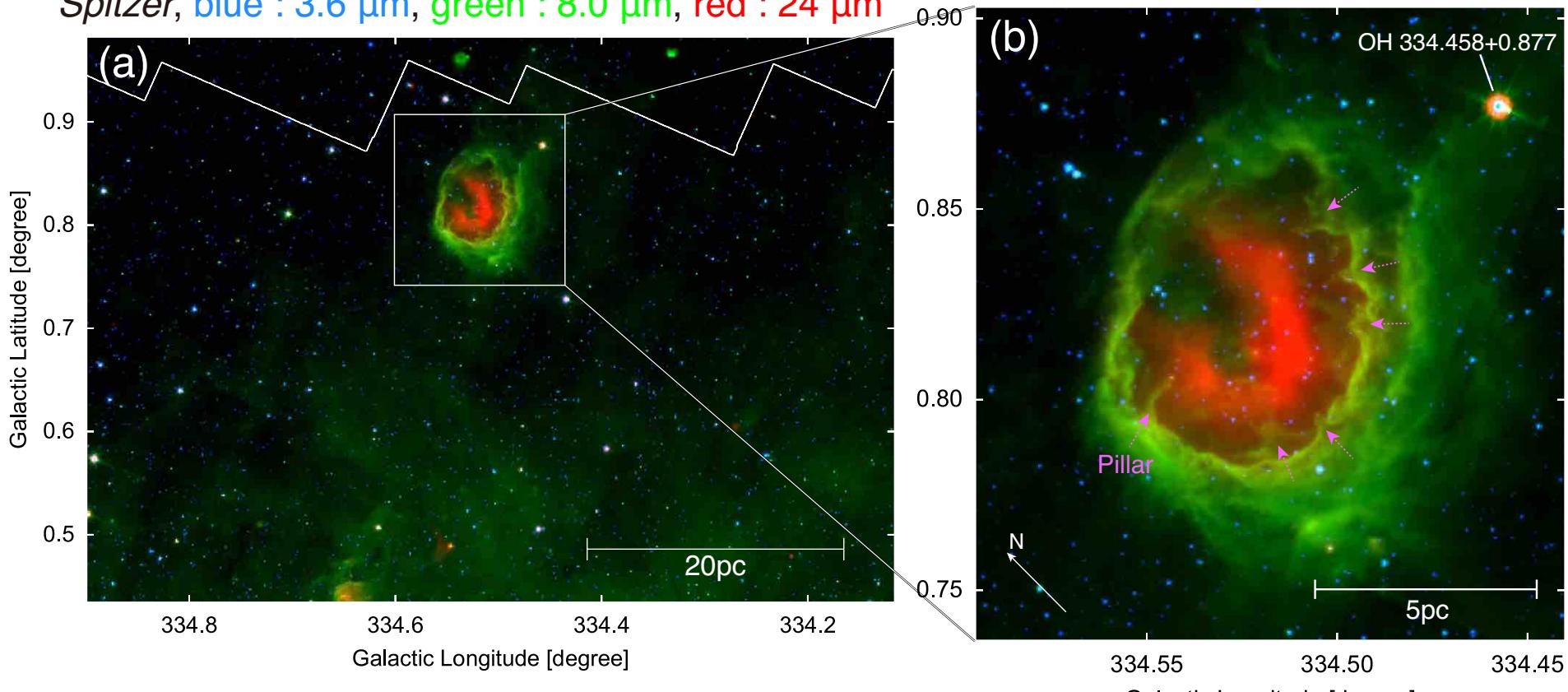
Herschel core	Id	α	δ	M_{frag} (M_{\odot})	Size (mpc)
		J2000 (°)			
Core 1	8	258.0457	-38.5333	7.7 ± 0.4	8.7
	12	258.0440	-38.5321	2.8 ± 0.3	3.1
Core 2	1	258.0363	-38.5129	27.4 ± 0.6	8.6
	5	258.0366	-38.5150	5.8 ± 0.6	2.5
	6	258.0358	-38.5124	19.1 ± 1	8.8
	10	258.0356	-38.5163	5.1 ± 0.7	4.3
	11	258.0354	-38.5138	15.7 ± 0.6	10.8
Core 9	2	258.0369	-38.5264	8.2 ± 0.7	1.6
	3	258.0370	-38.5269	17.6 ± 0.9	9.3
Core 10	16	258.0471	-38.5204	7.7 ± 0.8	9.6
	17	258.0450	-38.5194	7.8 ± 0.6	9.9
Core 11	7	258.0404	-38.5391	7.4 ± 0.5	6.9
Core 13	4	258.0334	-38.5386	4.8 ± 0.4	3.1
	14	258.0337	-38.5401	2.1 ± 0.5	10.0 ^a
Core 15	15	258.0403	-38.5210	3.5 ± 0.6	6.0
Core 39	9	258.0450	-38.5248	8.7 ± 0.4	8.1
	13	258.0448	-38.5265	31.6 ± 0.7	22.4
	18	258.0457	-38.5236	31.8 ± 1.5	28.8

Notes. Columns are: (1) fragment's Id, (2,3) J2000-coordinates, (4) mass assuming the temperature of the hosting core (see Table 1), and (5) deconvolved size. ^(a) The size of this source cannot be deconvolved.

- これらのfragmentは将来的に大質量星になる可能性
- Fragmentはどのように形成されたのか?
 - 衝突圧縮?
 - 膨張圧縮?

孤立したSpitzer bubble S44

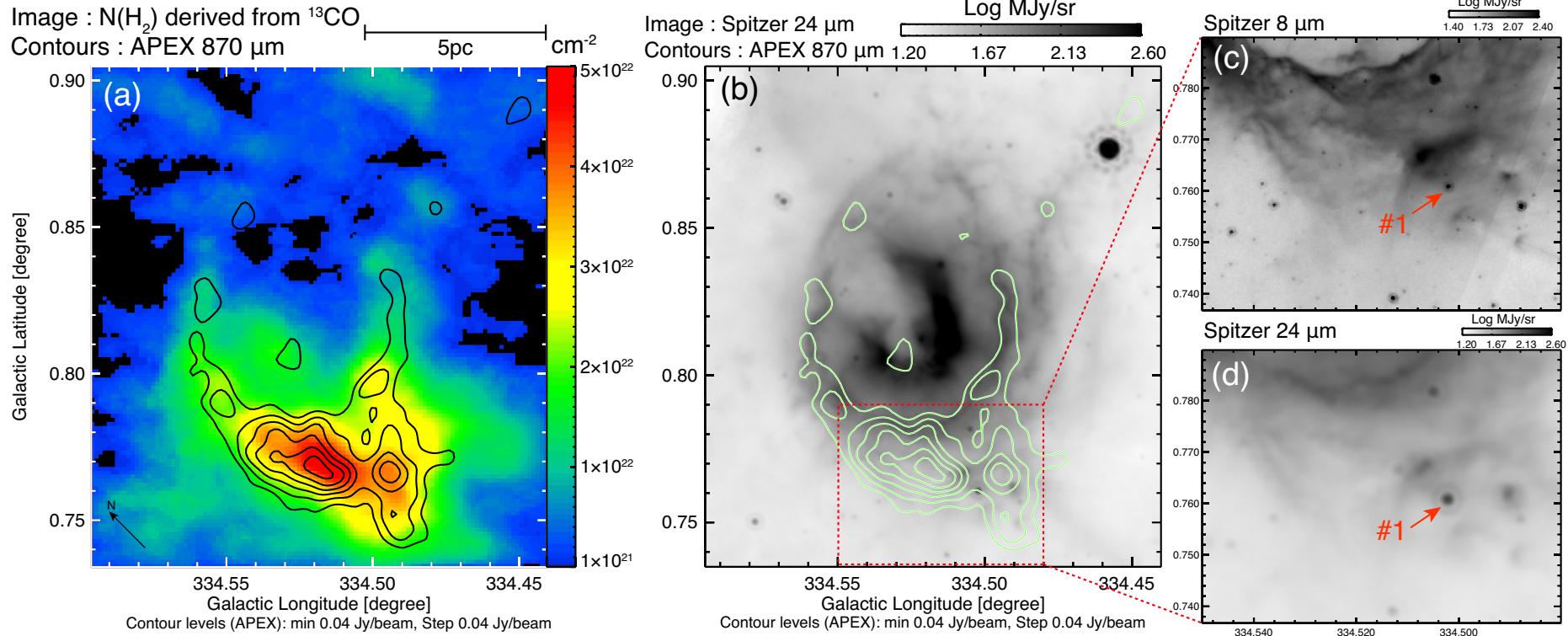
Spitzer, blue : 3.6 μm , green : 8.0 μm , red : 24 μm



- Churchwell+06 によって同定
- 距離 : 4.6 kpc (Churchwell+06)
- 励起星はO8.5-9と推定 (Kohno+18)
- 8 μm でリング構造
- バブル中心に向かってpillar 構造
- 24 μm でアーク構造

分子雲衝突によるO型星形成モデルを提案 (Kohno+18)

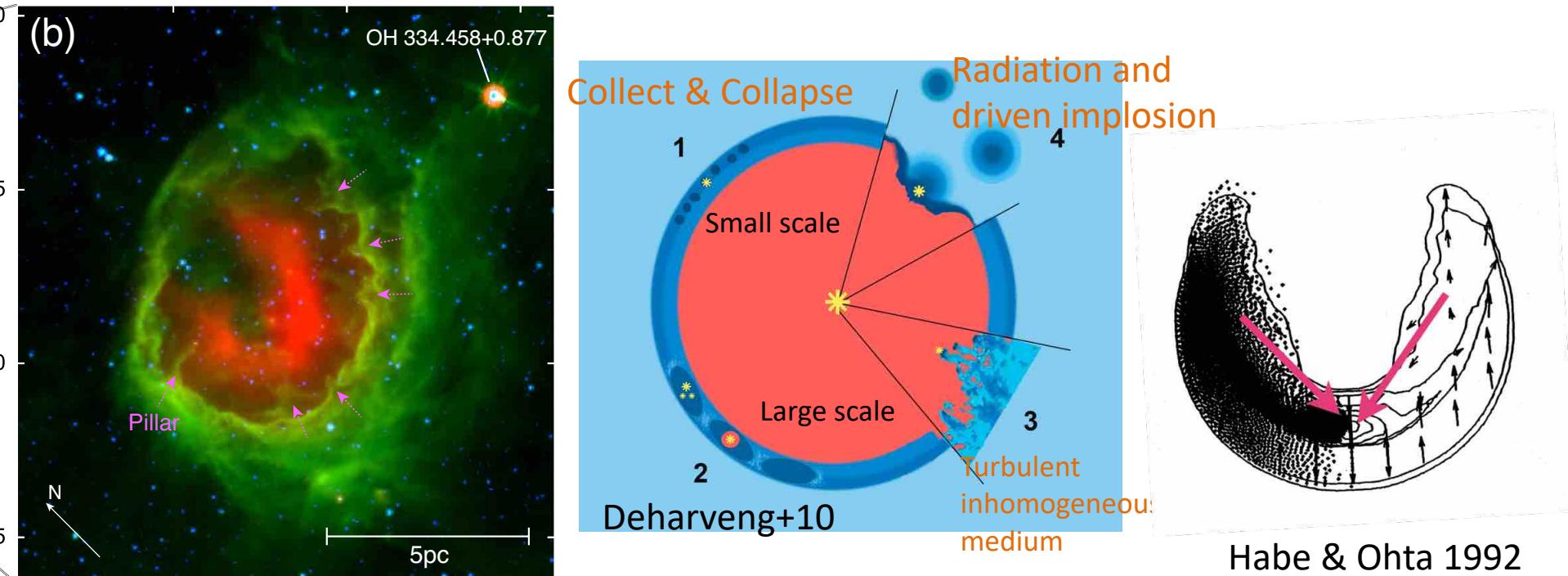
S44: バブルの中心と端での星形成



- ^{13}CO column densityがバブルの南側でピーク
- Column density は非対称構造
- バブルの端で、cold dust condensation が形成
- バブルの端で class II YSO が存在

RCW 120の場合と類似

膨張モデルと分子雲衝突モデル

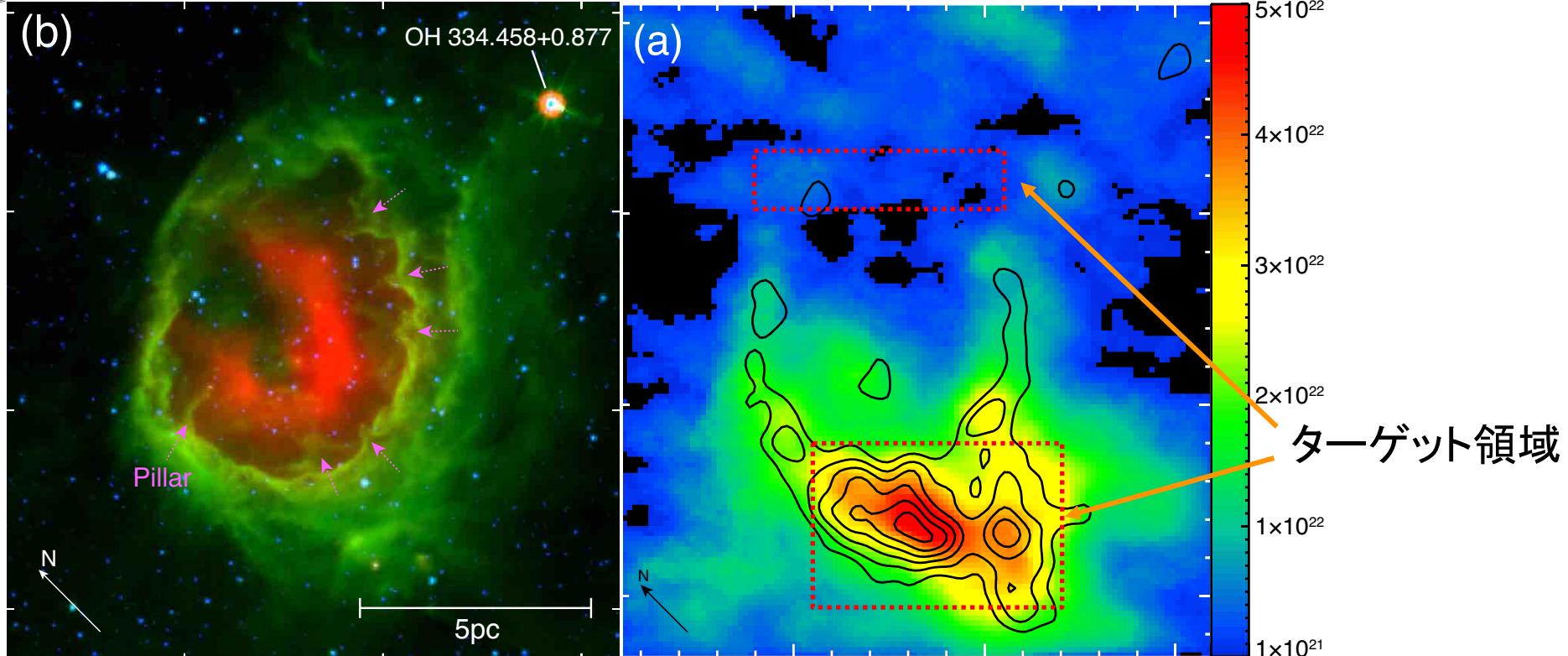


- ・ バブルの端で圧縮が起きるの点は共通
- ・ 膨張モデルは対称構造 (励起星を中心に等方的に圧縮)
- ・ 衝突モデルは非対称構造 (衝突方向で強い圧縮)

ALMA 高分解能観測によって、衝突モデルの妥当性を示したい

ALMA の観測提案

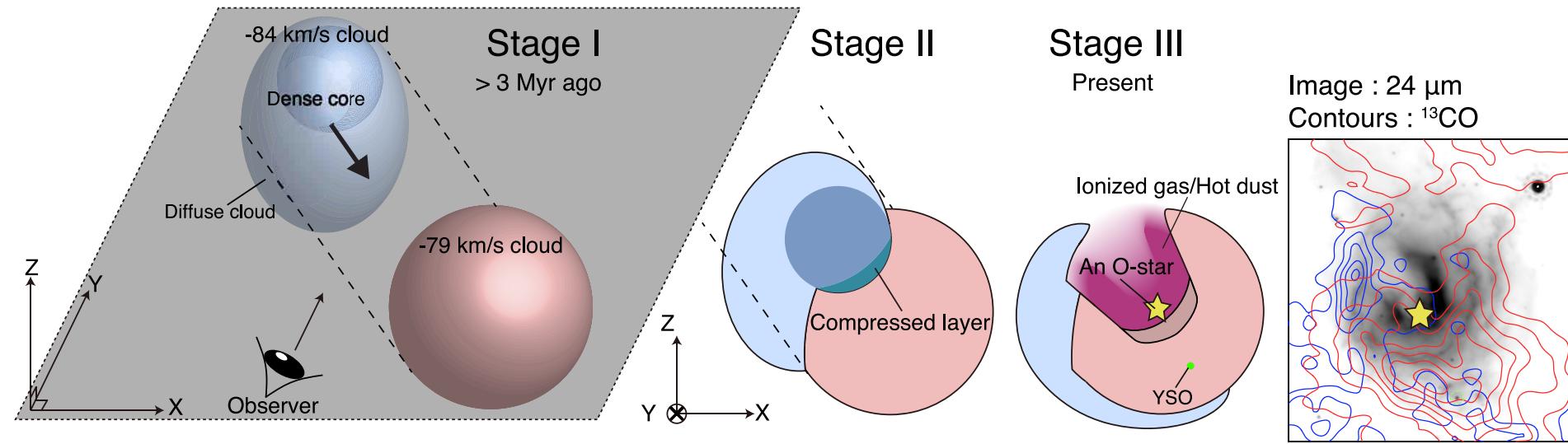
Image: column density
Contour: 870 um



- バブルの北側と南側での非対称性の検証
- Dust condensation 内部構造の理解
 - Continuum?
- 速度構造の理解
 - CO, その他?
- 圧縮, 衝突の物理過程の追求
 - SiO: shock tracer

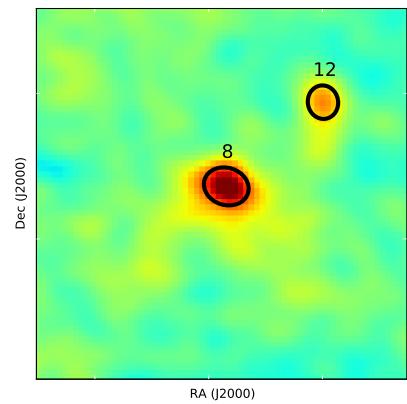
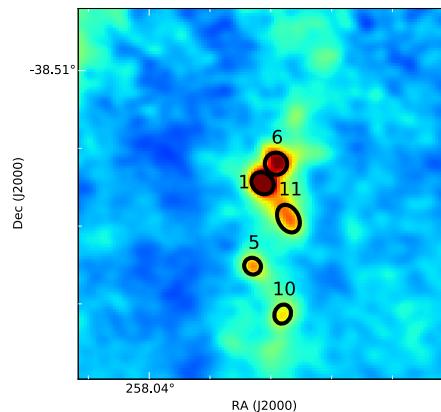
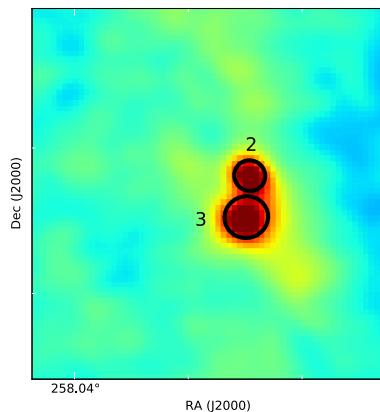
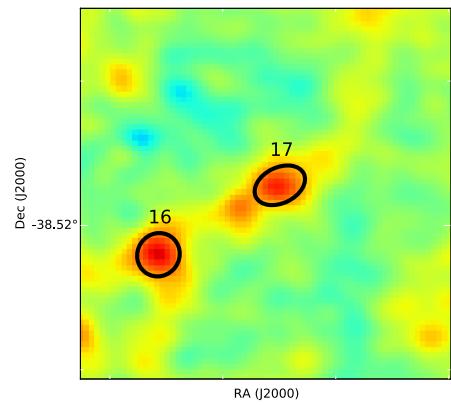
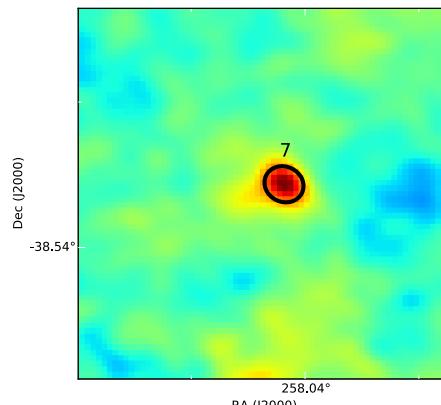
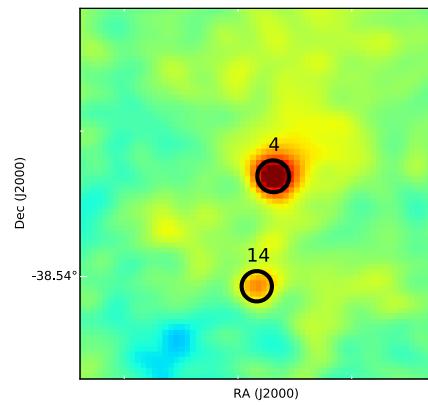
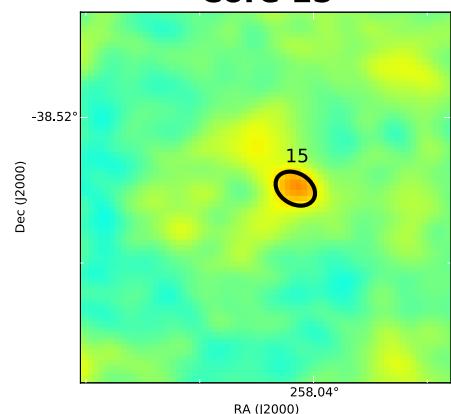
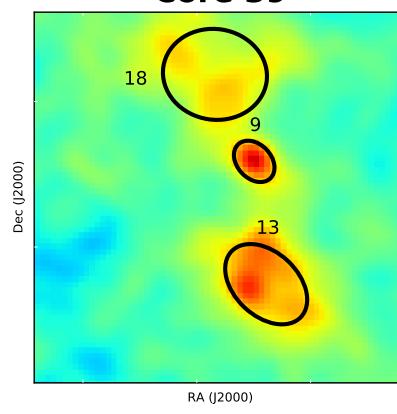
- 必要な空間分解能
- 選定するLineの妥当性
- 現実的な時間内で観測可能?

S44における分子雲衝突モデル (Kohno+18)



- Stage I: 2つの分子雲が近づく
- Stage II: 衝突によって境界層が強く圧縮
- Stage III: 圧縮層でO型星が形成

分子雲衝突モデルで孤立したO型星の起源が説明可能

Core 1**Core 2****Core 9****Core 10****Core 11****Core 13****Core 15****Core 39**

3 - What is the prevalence of massive-star formation triggered by HII regions?

⇒ The ATLASGAL survey shows the cold dust emission at 870 μ m, and thus the distribution of the neutral material associated with HII regions *Schuller et al. 2009, A&A, 504, 415*

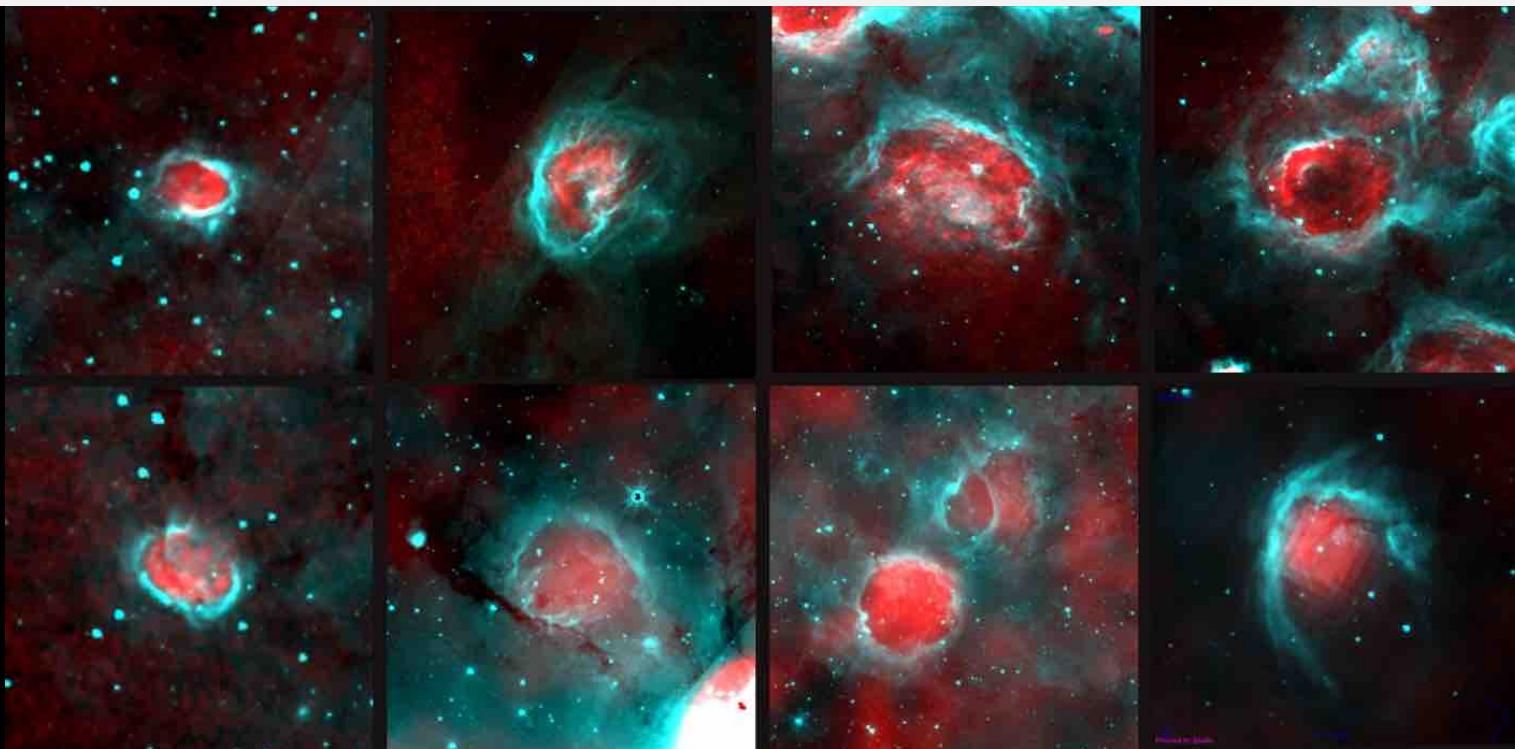
65 bubbles have enough resolution to study the cold dust distribution

13 bubbles have associated compact or UC HII regions (adjacent to the IF, in the PDR)

6 more have 6.7 GHz associated methanol masers (signature of massive SF)

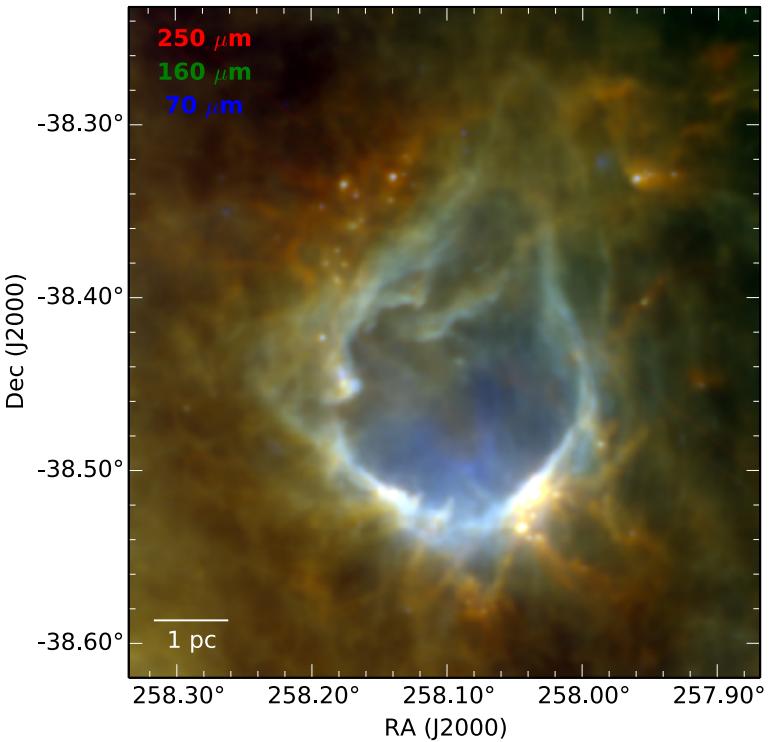
Thus more than 29% of the HII regions enclosed in bubbles have triggered the formation of massive stars

Deharveng et al., submitted to A&A

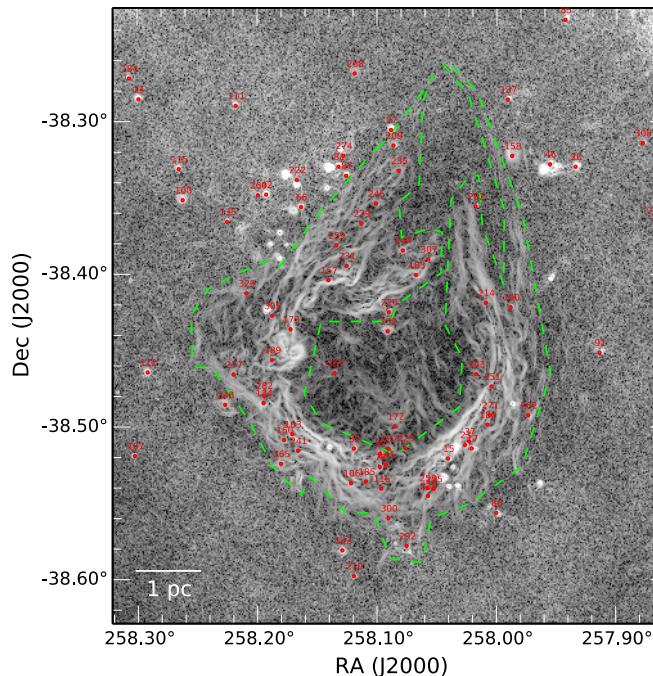
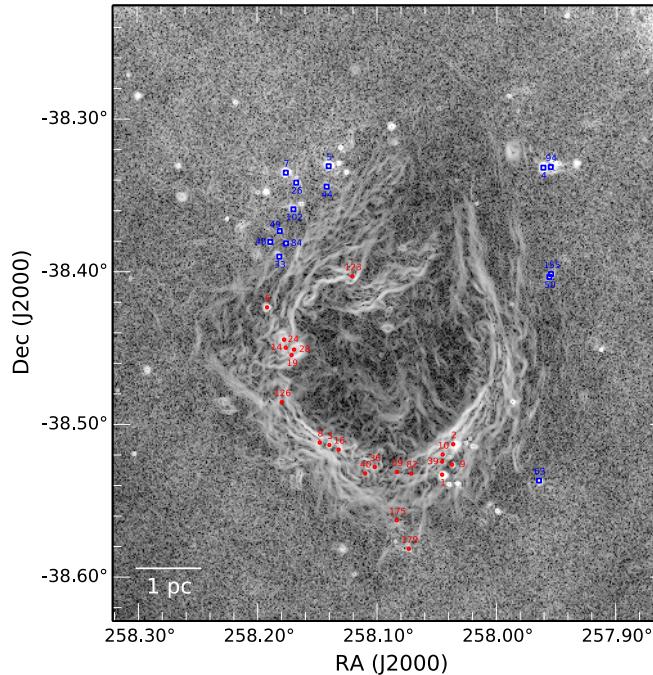


Spitzer 8 μ m radio-continuum (MAGPI, VGPIS, GB6)

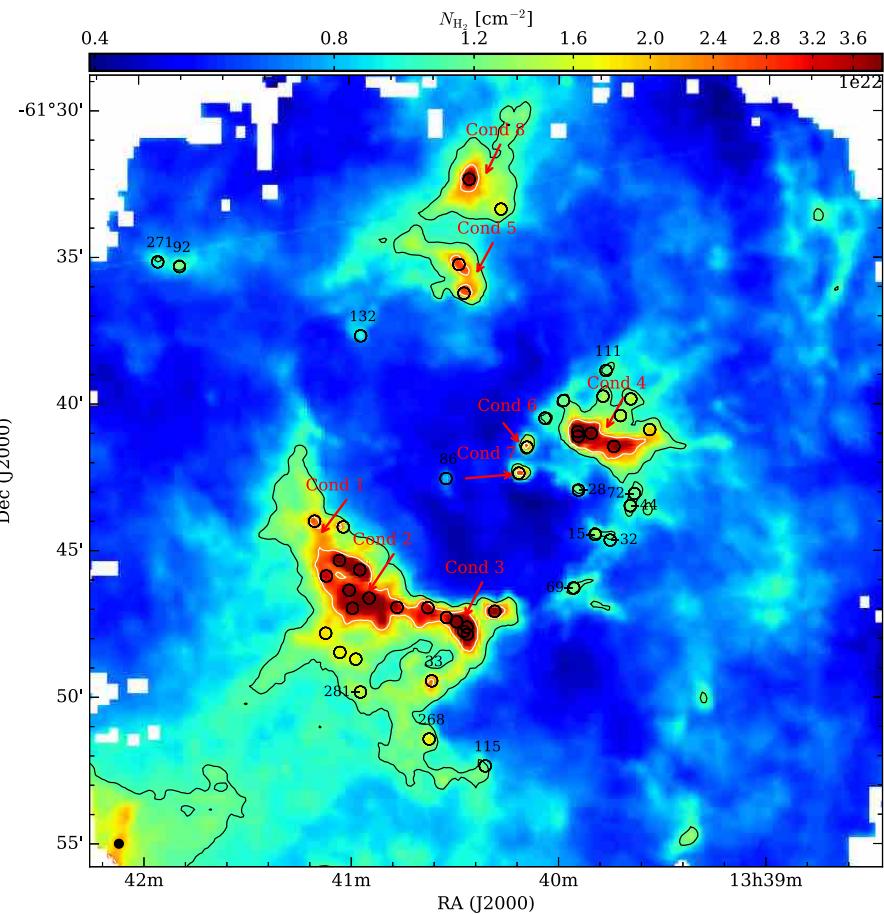
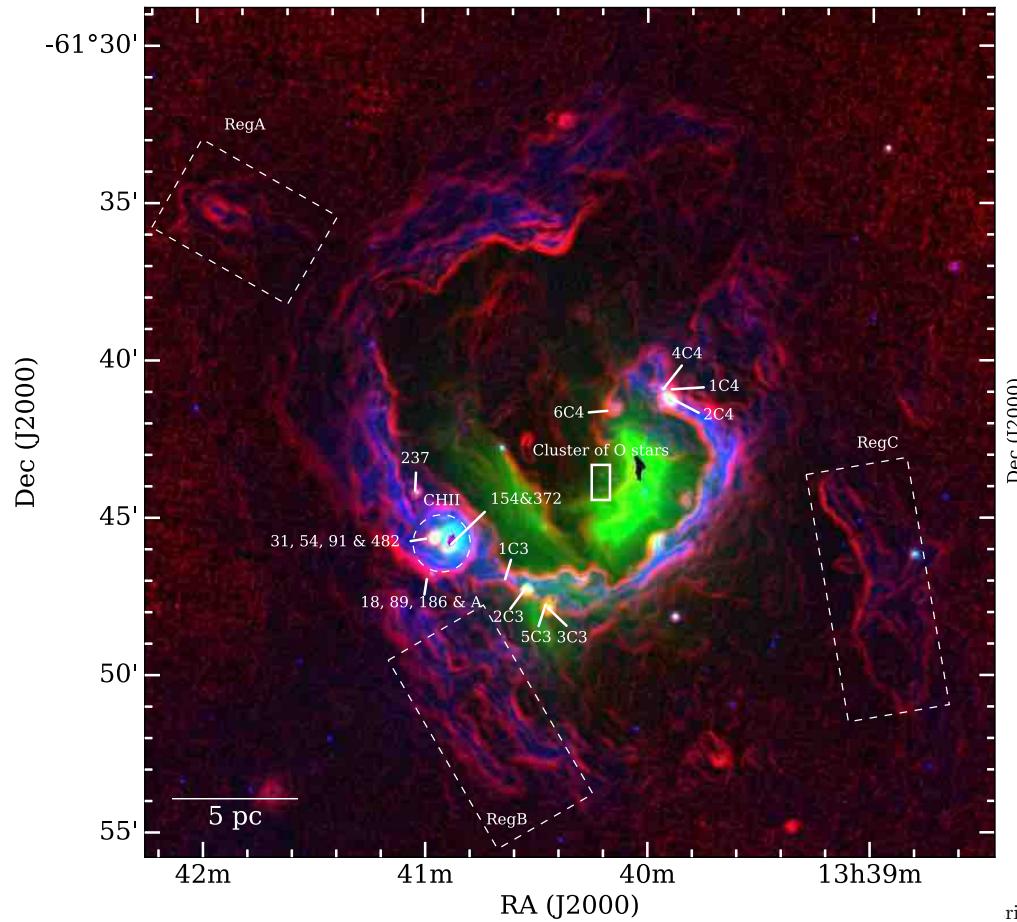
RCW 120の compact source



Figueira+2017

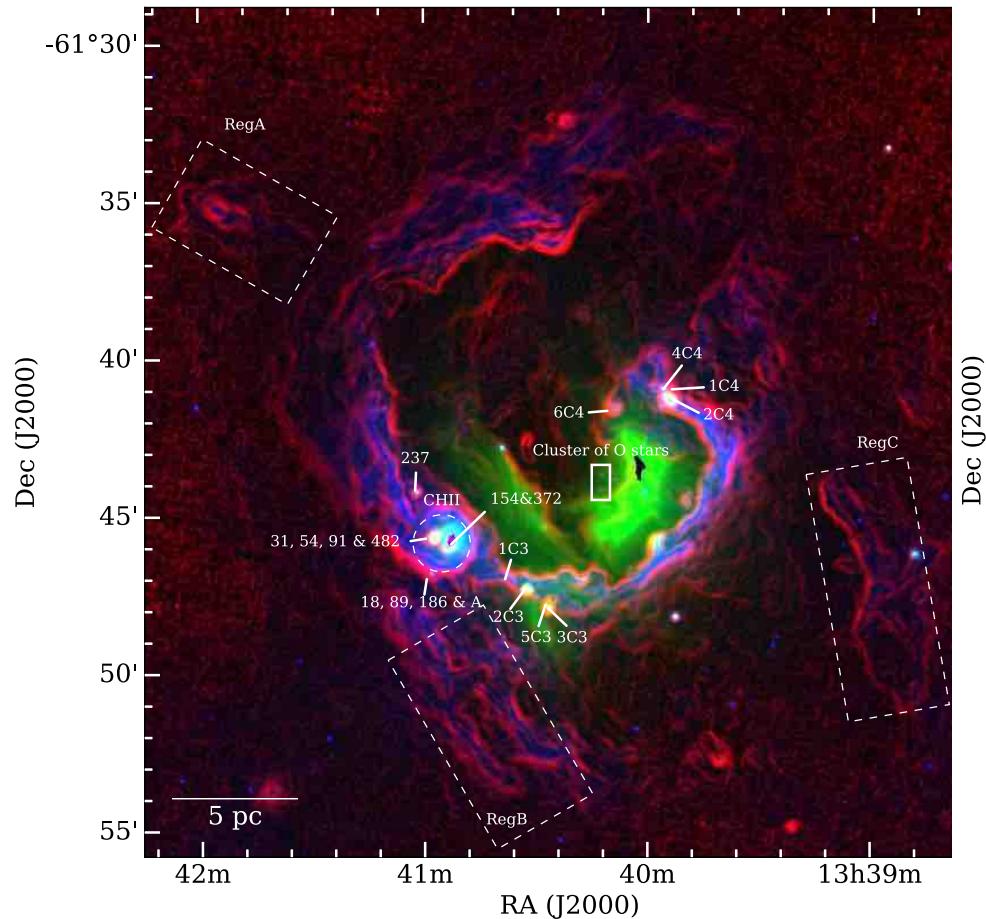


RCW 79 のcompact source



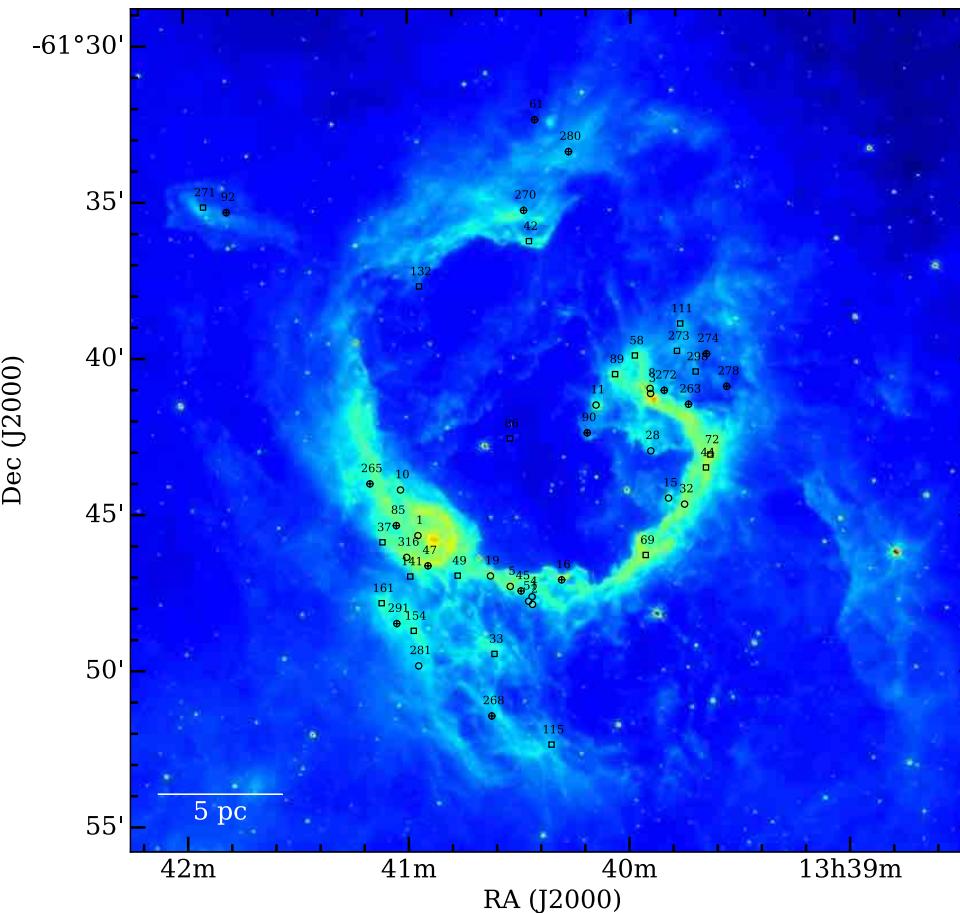
tribution of 50 compact sources overlaid on the high-resolution ($18''2$) column density map. The b
white contours delineate the gas in the compressed layer (above $N_{\text{H}_2} = 11 \times 10^{21} \text{ cm}^{-2}$ marked with the black
and the gravitationally dominated gas (above $N_{\text{H}_2} = 23 \times 10^{21} \text{ cm}^{-2}$ marked with the white contour, see S
respectively. The arrows pinpoint the eight condensations as named by ZA06. A beam size of $18''2$ is shown
black full circle on the bottom left.

RCW 79 のcompact source



Blue : 8um, green : 24 um, red 70 um

Fig. 12: Fifty compact sources superimposed on the *Spitzer* 8 μm image. Class 0, IM, and I objects (see Sect. 3) are plotted as plus circles, squares, and circles, respectively.



膨張によるバブル非対称構造の解釈

A&A 566, A75 (2014)

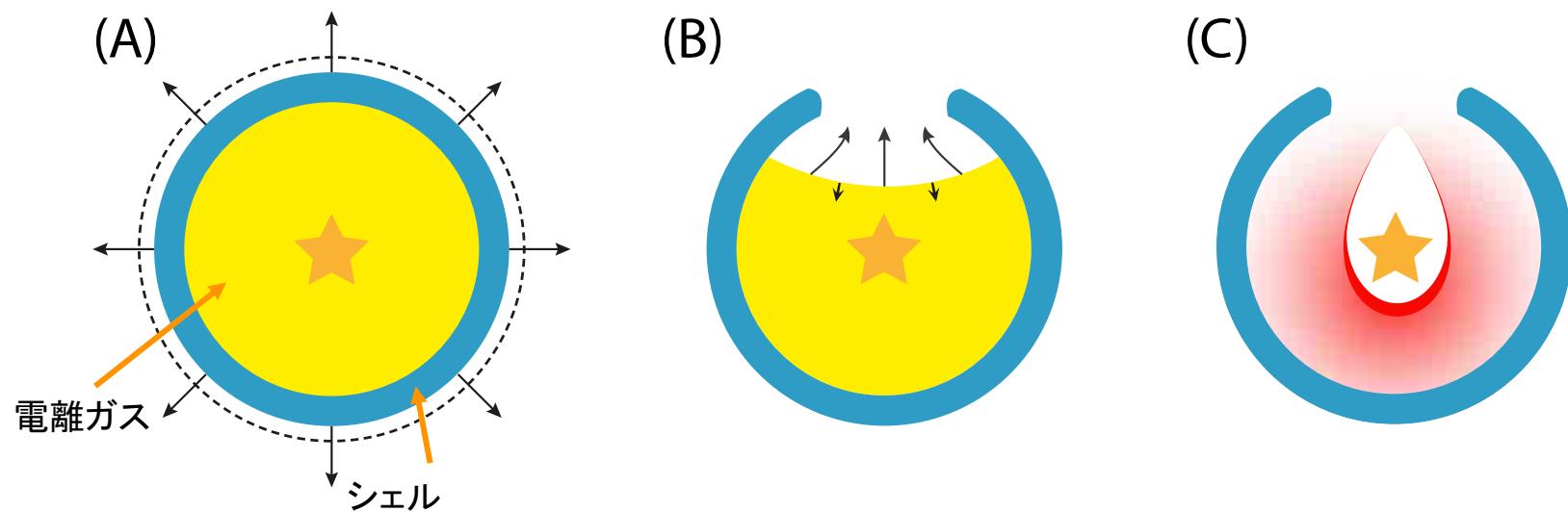
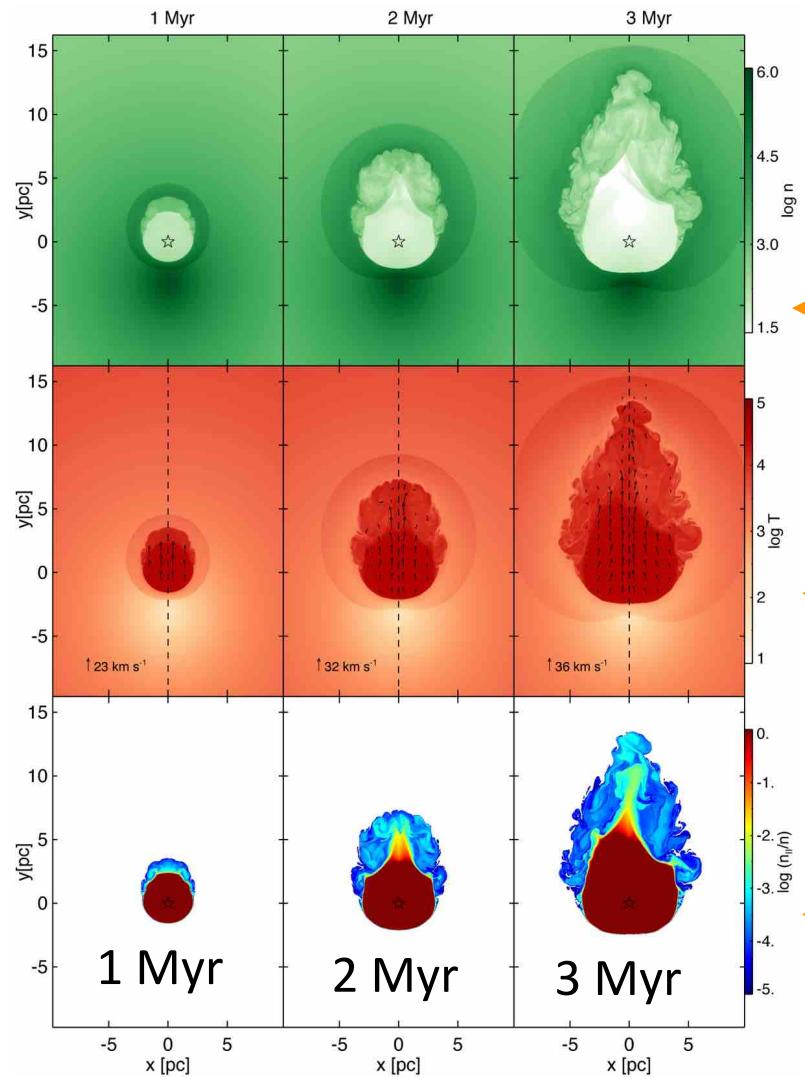


Fig. 2. A) Overpressure of the hot, ionized interior (yellow) will cause the bubble to expand inside the natal cloud, sweeping up neutral gas in a dense shell (blue) ([Spitzer 1978](#)). If the expansion is supersonic, a shock front forms on the neutral side of the shell (dashed line). B) If the ionized gas contains a density gradient and/or the bubble is punctured, a flow of ionized gas will stream towards lower density and ultimately into the surrounding ISM, relieving the bubble from its pressure ([Tenorio-Tagle 1979](#)). C) Dust is dragged along in an ionized flow, where “upstream” dust approaching the ionizing source will be heated and halted by radiation pressure, resulting in a *dust wave* or *bow wave* ([Ochsendorf et al. 2014](#); and see Sects. 3.2 and 4), which can be traced at mid-infrared wavelengths (red).

Ochsendorf+ 2014



バブル中心からOffsetした励起星からの膨張シミュレーション

Number density

Temperature

Ionization fraction

Fig. 3. Two-dimensional hydrodynamical simulation of an expanding HII region offset from the center of a Bonnor-Ebert sphere. From top to bottom rows: the logarithm of number density n , temperature T , and ionization fraction n_{II}/n of a slice through the yz -plane at the location of the star are shown. We trace the velocity of the gas in the three-dimensional simulation along the dashed line (see Fig. 4A). Each column corresponds to a snapshot of the simulation at 1–3 Myr. The vectors represent the velocity field in the middle row; the legend indicates the maximum velocity.