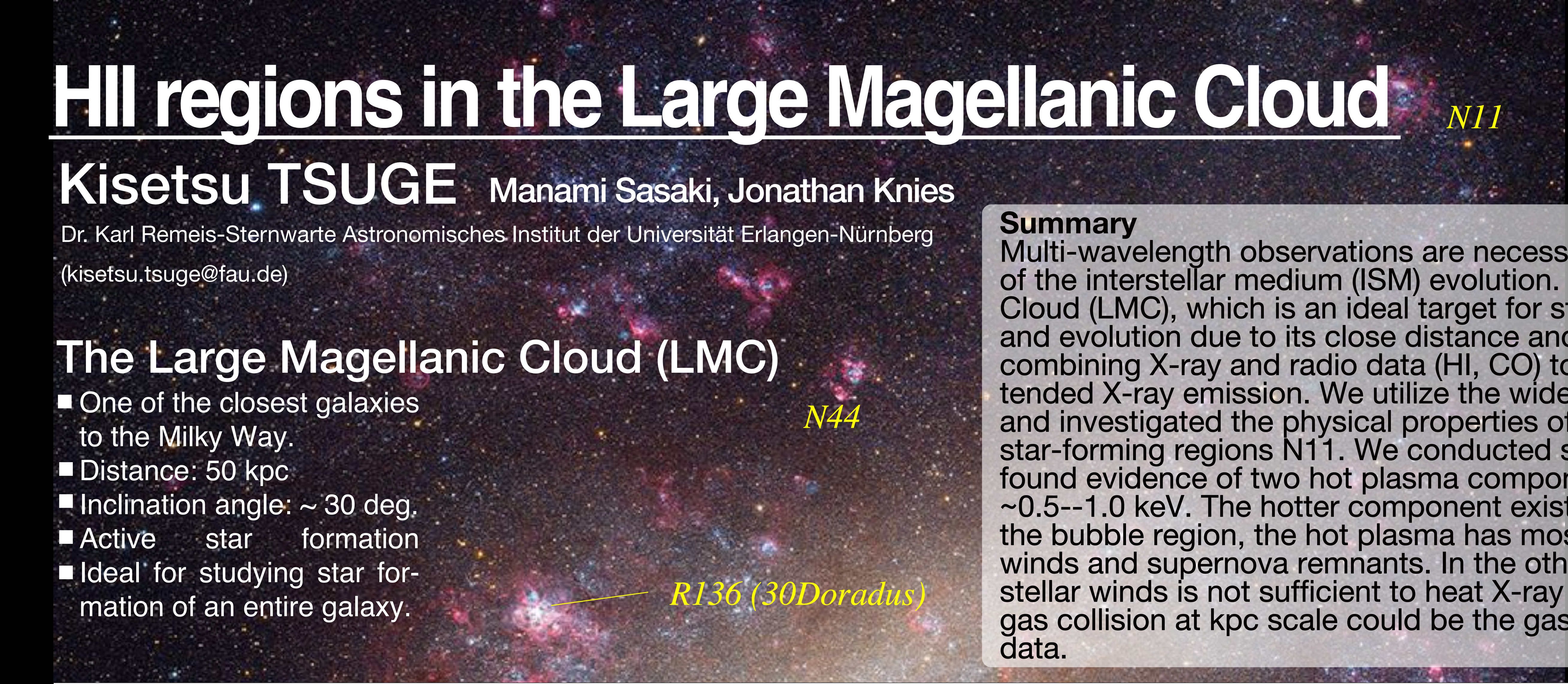

HII regions in the Large Magellanic Cloud

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The Large Magellanic Cloud (LMC)

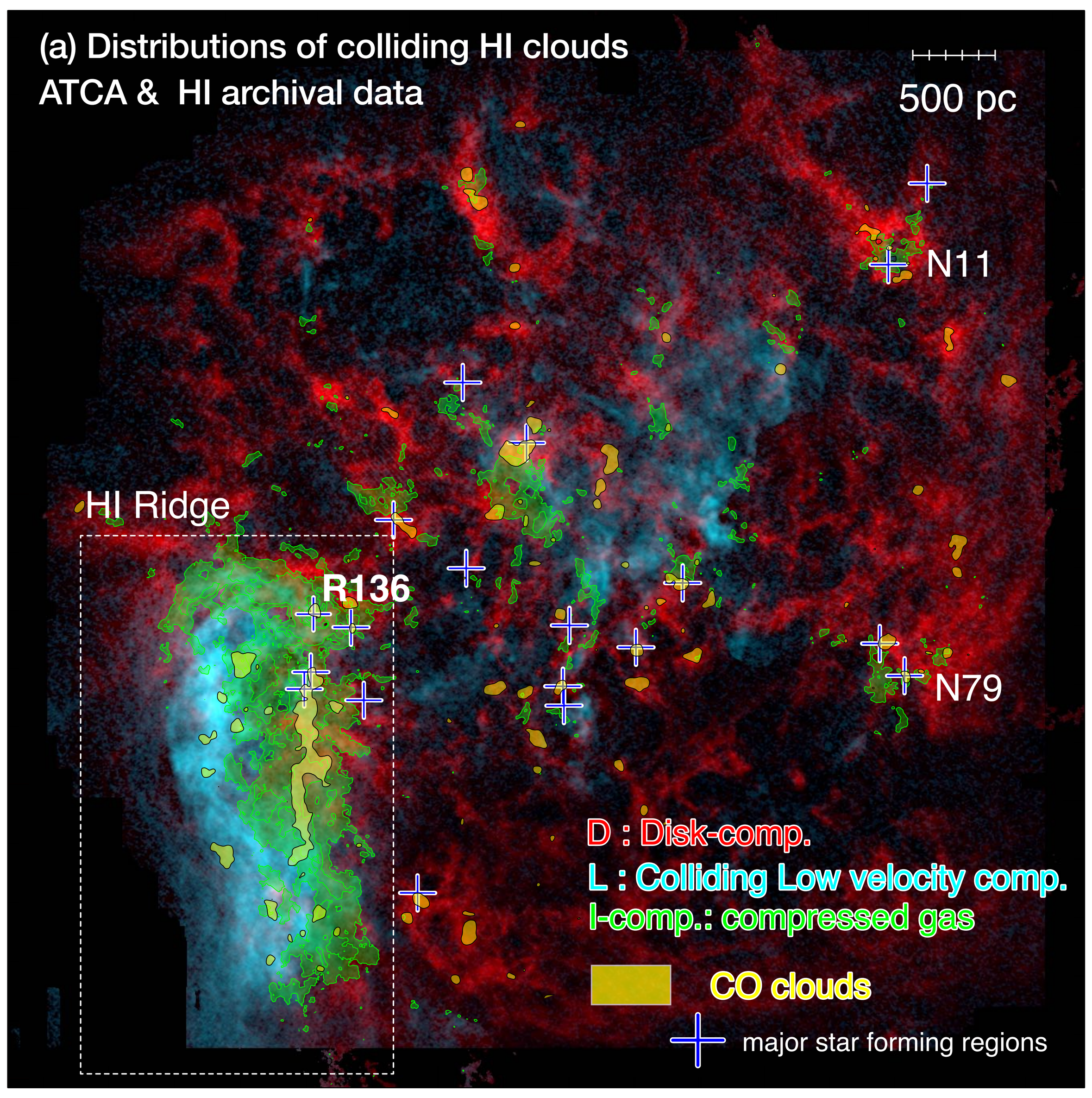
- One of the closest galaxies to the Milky Way.
- Distance: 50 kpc
- Inclination angle: ~ 30 deg.
- Active star formation
- Ideal for studying star formation of an entire galaxy.

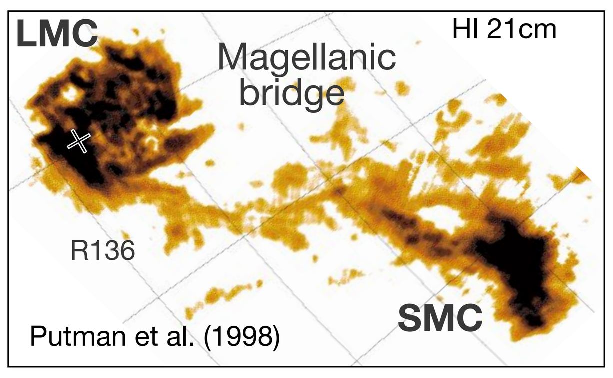
Summary

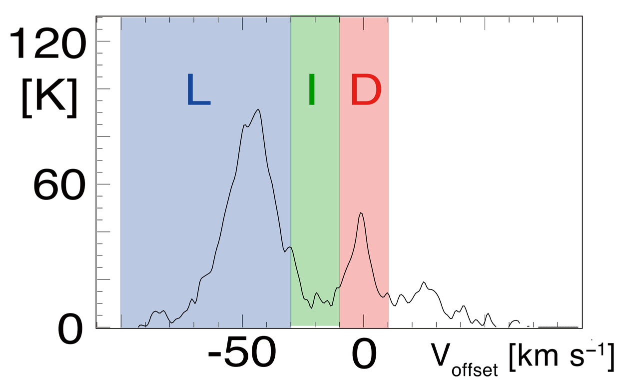
Multi-wavelength observations are necessary to obtain a comprehensive understanding of the interstellar medium (ISM) evolution. We focus our study on the Large Magellanic Cloud (LMC), which is an ideal target for studying galaxy-scale (~ kpc) ISM dynamics and evolution due to its close distance and almost face-on geometry. We analyzed by combining X-ray and radio data (HI, CO) to reveal the heating mechanism of diffuse extended X-ray emission. We utilize the wide field of view and high sensitivity of eROSITA and investigated the physical properties of diffuse X-ray in detail toward active star-forming regions N11. We conducted spectrum fitting toward four regions. We found evidence of two hot plasma components with temperatures of ~0.2 keV and ~0.5--1.0 keV. The hotter component exists much more near the superbubble of N11. In the bubble region, the hot plasma has most likely been heated by high-mass stellar winds and supernova remnants. In the other three regions, the energy of high-mass stellar winds is not sufficient to heat X-ray emissions. Instead, it is suggested that HI gas collision at kpc scale could be the gas heating mechanism by comparison with HI data.

Colliding HI gas flows triggers active star formation in the LMC

Fukui et al. 2017; Tsuge et al. 2019; Tsuge et al. 2021c







A typical spectrum of HI at (RA, Dec) = (5h46m43.54s, −69° 42′ 59.31s). The blue and red shaded ranges indicate the integration velocity ranges of L- and D-components, respectively.

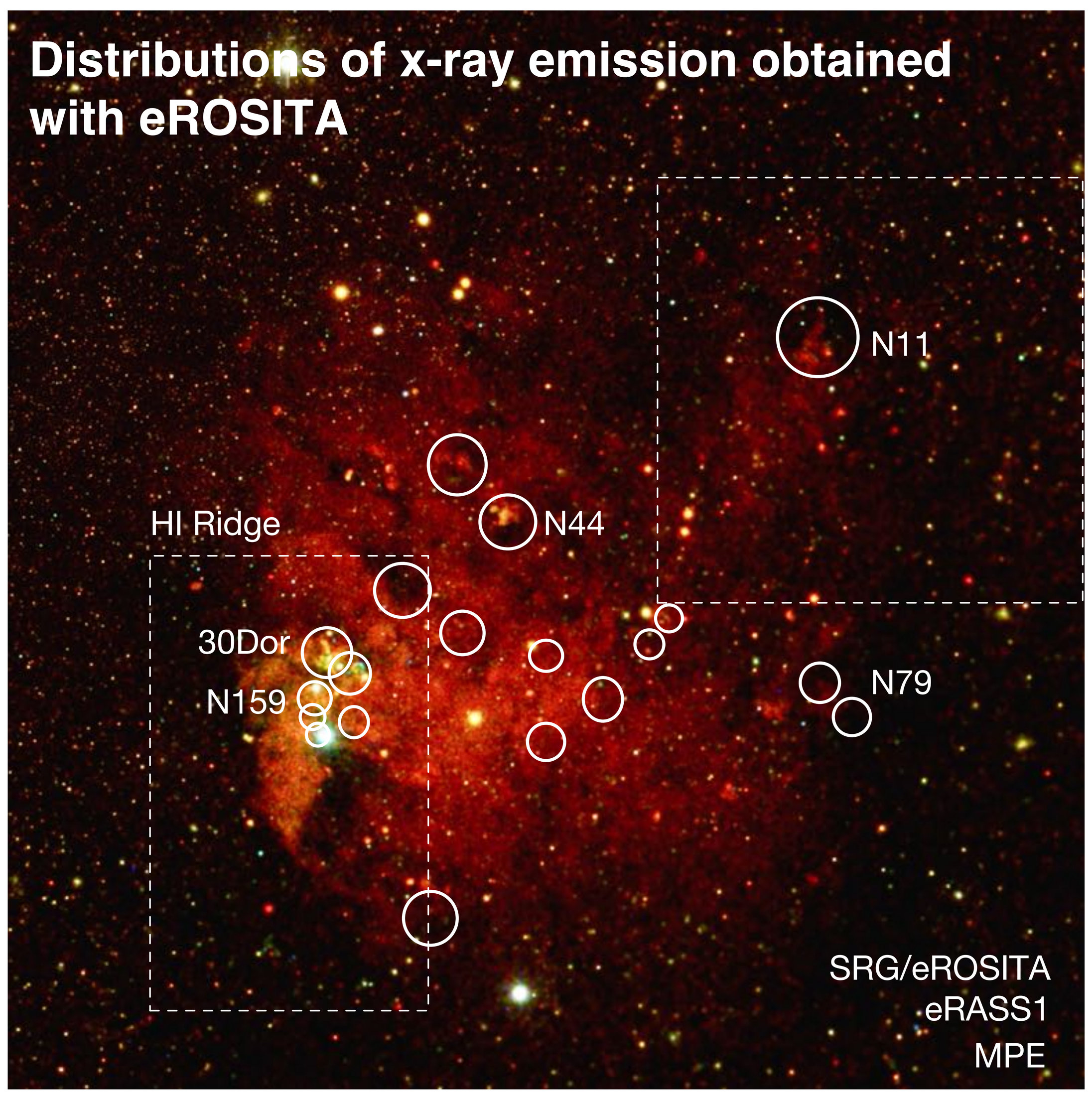
We define I-component as the intermediate velocity component of the L- and D-components.

- HI bridge between the LMC and SMC
- Formation of massive star cluster was possibly triggered by galactic tidal interaction (Fujimoto & Noguchi 1990)
  - LMC gas turbulence, Inflow of the SMC gas ; Bekki & Chiba (2007a, b)
- We analyzed HI data of the LMC
  - HI gas consists of two velocity components (L- and D-components) (Luks & Rolfs 1992)
  - We reveal the evidence of the collision toward the star-forming regions
    1. Complementary spatial distribution between the two components
    2. Bridge features connecting the L- and D-components
- The I-component is thought to be formed by deceleration of the gas due to the collision of the L- and D-components.
  →Observational trace of gas collisions
- The I-component coincides with the spatial distributions of the major star-forming regions (~70% of the total number; Tsuge et al. 2021c).

We propose that the collisions of HI gas were induced by the galactic tidal interaction between the LMC and the SMC and triggered high-mass star formation in the whole LMC.

Heating mechanism of ISM / Geometry of the HI collision

Tsuge et al. 2022 in prep.

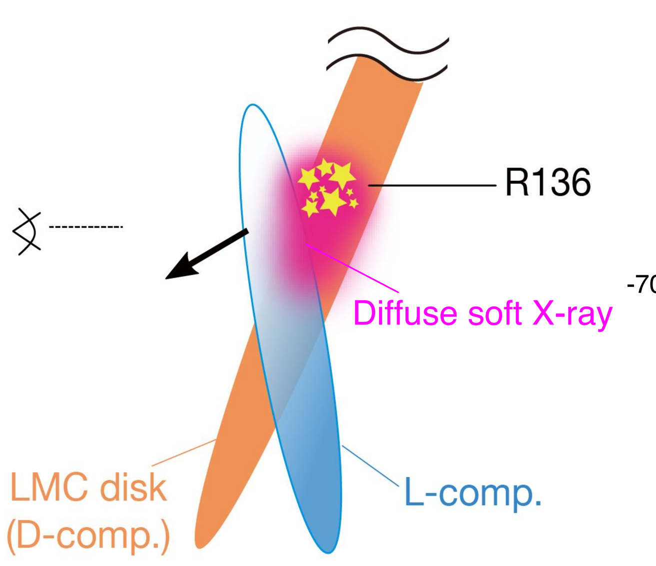


Gas heating by high-velocity collisions

- Two thermal components are required by spectrum fitting.
- North: heating by high-mass stellar winds
- South: No high-mass stars.

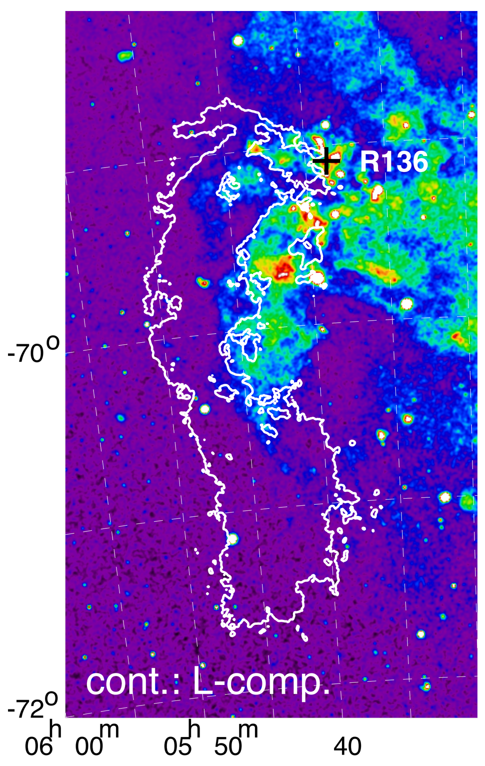
HI Ridge region (including 30 Dor)

Schematic view of collision



Knies et al. (2021)

Soft X-ray map



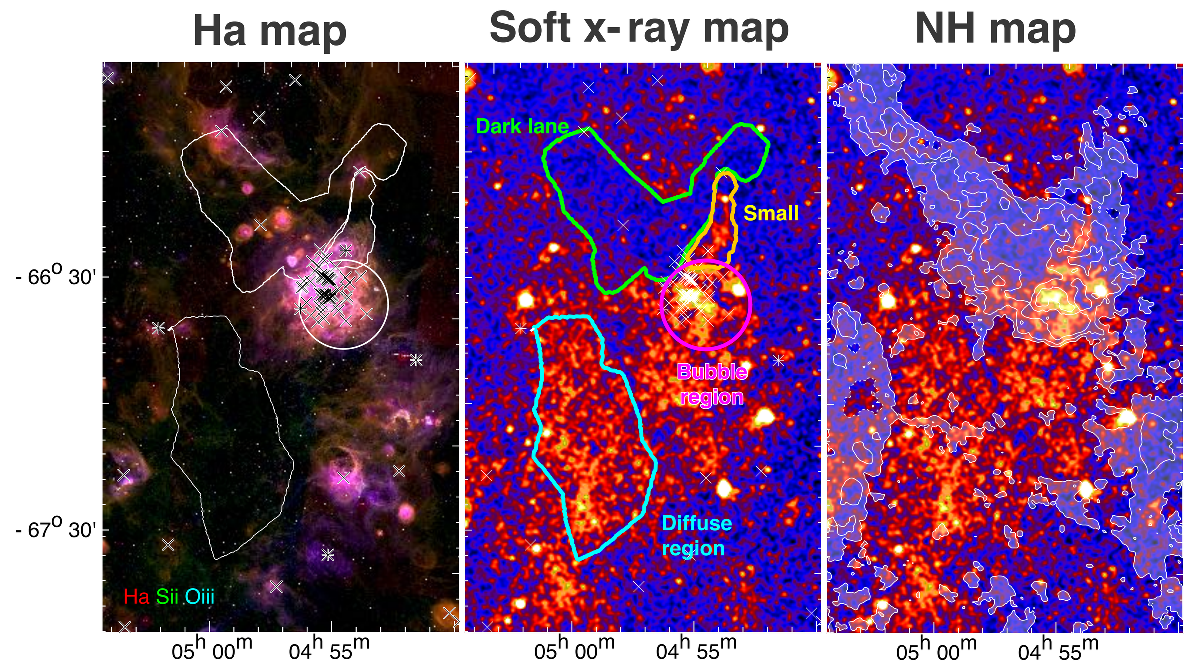
3D geometry of the collision

The L-comp. and soft X-ray are nicely anti-correlated.

→ The L-component is located in front of the D-component.

N11region (second largest HII region)

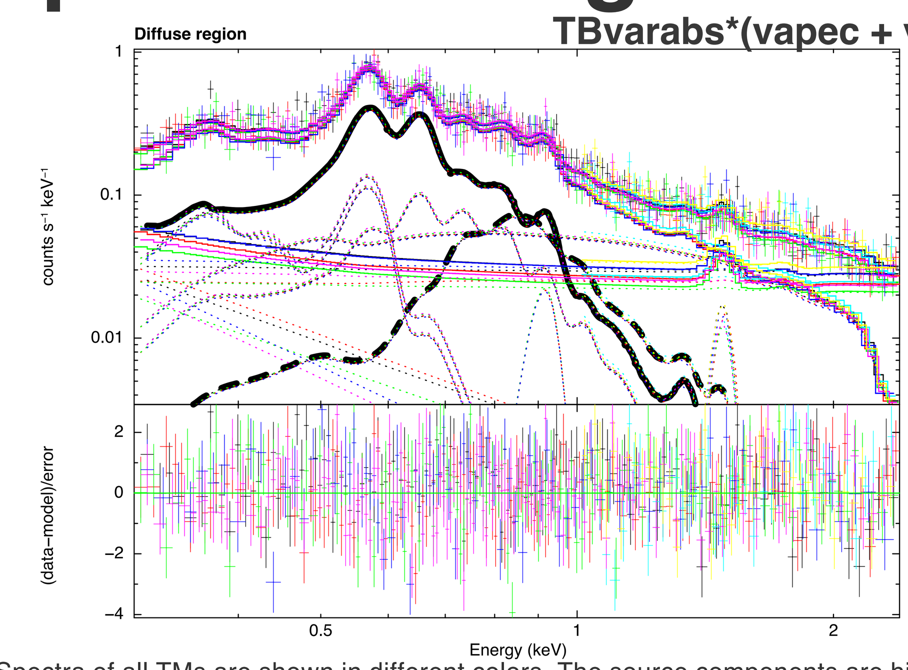
We selected four regions based on the morphology



Dark lane	: V-shaped morphology, Less intense than surroundings
Bubble	: Active star-forming region
Small	: Bright emission extending north of the bubble
Diffuse	: Diffuse emission extending north-south at kpc scale

NH and soft X-ray show nicely spatial anticorrelation toward Dark lane region

Spectral fitting



Spectra of all TMs are shown in different colors. The source components are highlighted with thick lines (solid: lower-temperature vapec1; dashed: higher-temperature vapec2

Region	kT_1 [keV]	norm1 [10^{-5} cm^{-5}]	kT_2 [keV]	norm2 [10^{-5} cm^{-5}]	N_H(X-ray) [10^{21}cm^{-2}]	red. χ^2 (d.o.f.)
Dark lane	$0.17^{+0.01}_{-0.01}$	$0.71^{+0.11}_{-0.28}$	$1.09^{+0.54}_{-0.27}$	$0.01^{+0.01}_{-0.01}$	$3.13^{+1.25}_{-0.66}$	0.99 (516)
Small	$0.21^{+0.01}_{-0.01}$	$1.70^{+0.96}_{-0.46}$	$0.70^{+0.59}_{-0.22}$	$0.14^{+0.05}_{-0.12}$	$4.07^{+1.89}_{-1.13}$	1.03 (102)
Bubble	$0.21^{+0.01}_{-0.01}$	$1.79^{+0.96}_{-0.46}$	$0.90^{+0.59}_{-0.22}$	$0.16^{+0.02}_{-0.02}$	$2.11^{+0.53}_{-0.73}$	1.03 (336)
Diffuse	$0.21^{+0.01}_{-0.01}$	$0.53^{+0.27}_{-0.95}$	$0.75^{+0.54}_{-0.27}$	$0.05^{+0.01}_{-0.01}$	$0.35^{+0.16}_{-0.18}$	1.06 (735)

Absorption column density

Region	N_H(X-ray) [10^{21}cm^{-2}]	N_H (radio) [10^{21} cm^{-2}]
Dark lane	$3.13^{+1.25}_{-0.88}$	2.80
Small	$4.07^{+1.89}_{-1.13}$	2.61
Bubble	$2.11^{+0.53}_{-0.73}$	3.47
Diffuse	$0.35^{+0.16}_{-0.18}$	0.90

- **Dark lane, Small**
  Diffuse X-ray is absorbed by cold ISM
  N_H (X-ray) ~ N_H (radio)
- **Bubble**
  ISM partially absorbed X-rays
  N_H (X-ray) < N_H (radio)
- **Diffuse**
  Absorption is weak.

Energy input by high-mass stars

Region	E_p [10^{51}] $f^{-0.5}$ erg	# of high-mass stars†	E_{star} [10^{51}] erg
Dark lane	$2.99^{+0.16}_{-0.66}$	4	~0.16
Small	$1.42^{+0.27}_{-0.18}$	2	~0.60
Bubble	$2.93^{+0.17}_{-0.66}$	28	~8
Diffuse	$2.44^{+0.18}_{-0.188}$	0	---

- **Bubble: E_p < E_{star}**
  Heating by stellar winds of high-mass stars. Stellar wind is enough to explain the E_p at ~20 % efficiency (Weaver et al. 1977).
- **Dark lane, Small, Diffuse**
  E_p > E_{star}
  Different heating mechanisms are needed
  --> **Shock heating by HI collision?**

Conclusions

We conducted the spectral fitting of the N11 region using eRASS 1-4 data

- Spectrum is fitted by 2apecs with absorption :TBvarabs *(vapec + vapec).
- **Absorption NH**
  Dark lane ~ Small > Bubble >> Diffuse
  Diffuse X-ray is absorbed by cold ISM
- **Heating mechanism of the diffuse X-ray**
  - Bubble: stellar wind
  - Dark lane, Small, Diffuse:
    Other mechanisms are needed.
    HI collision is one possibility

Future prospects

Heating mechanism of the diffuse X-ray
- Calculate the kinetic energy of the collision

Extend the study to the whole LMC
--> investigate universality and variety

Reference

• Fujimoto, M., & Noguchi, M. 1990, PASJ, 42, 505 • Bekki, K., & Chiba, M. 2007, PASA, 24, 21 • Fukui, Y., Tsuge, K., Sano, H., et al. 2017, PASJ, 69, L5 • Tsuge, K., Sano, H., Tachihara, K., et al. 2019, ApJ, 871, 44 • Tsuge, K., Sano, H., Tachihara, K., et al. 2021, arXiv:2010.08816 • Knies, J. R., Sasaki, M., Fukui, Y., et al. 2021, A&A, 648, A90 • Sasaki, M., Knies, J., Haberl, F., et al. 2022, 661, A &A, A37