日本天文学会2020年春季年会

Z214c

初期宇宙の銀河星間環境を特徴付けるダストの性質の理解

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概要

低金属量で非常に活発な大質量星形成の兆候を示すSuper Star Cluster (SSC)を有するblue compact dwarf (BCD)銀河は、初期宇宙の低金属量の環境すなわち星形成のサイクルが歴史的に浅い系における星間ダストの特徴を探る上で、極めて重要な研究対象である。天の川銀河のように十分に星形成のサイクルが繰り返され年齢を経た系では、AGB星などに起源を持つ星間ダストが星間物質を特徴付けることができるが、遠方の銀河の星間物質は主として大質量星を起源とする星間ダストによって特徴付けられると考えられる。しかしながら、終焉期の大質量星を起源とするダストの化学組成や物性の観測的な理解は依然として乏しい。このため、JWSTを用いた超新星によるダストの形成および破壊の過程を探る観測や系内のWolf-Rayet星によるダスト形成過程を探る観測を通じた新たな知識の集積が期待される。一方で、SPICAの中間赤外線から遠赤外線波長域にかけてのより長い波長域の分光観測能力は、星周環境を離れ星間空間に到達する過程における幅広い温度帯域でのダストの放射の分光学的特徴を調べる上で有用であり、低金属量のBCD銀河内のSSCにおける中間赤外線ー遠赤外線放射、さらには、遠方の銀河の星間物質の赤外放射を、大質量星を起源とするダストが、如何に特徴付けるかを解釈する上で鍵となる。本講演では、SPICA サイエンス検討会の「近傍銀河・銀河系」班で検討しているサイエンスのうち、特に宇宙初期の銀河環境を特徴付けるダストの性質を探ることを目的とし、(1)「大質量星を起源とするダストの分光学上の特徴を探る試み」と(2)「低金属量のBCD内のSSCの赤外放射に大質量星を起源とするダストの痕跡を探る試み」のtwo-tieredで実施する観測の検討に焦点をあて報告する。

Background

- The dominant channels of dust production throughout cosmic time are still unclear.
- Sub-mm observations of galaxies at z=6 have uncovered the presence of copious amount of dust in galaxies where low- to intermediate-mass stars have not yet evolved to eject nucleo-synthesized elements
- Supernova (SN) dust (not yet fully characterized by observations)
  - IR photometry and spectroscopy in 18—200 um

    → aiming to decompose SN dust/circumstellar dust/interstellar dust
    in view of the dust temperatures and chemical compositions
    (medium-R ~1000 is required to avoid blending with ionic lines)
- Pre-existing circumstellar dust at SN explosion

  ~ Dust produced by Wolf-Rayet stars
- How the massive stars characterize the dusty ISM conditions in low-metallicity/high-redshift galaxies must be answered

Science Goal

- To demonstrate the process of dust enrichment in the ISM in the early Universe

via two-tired approaches

Tier-2: to attain clear knowledge on the chemical composition and properties of SN dust and WR dust

Tier-1: to demonstrate the compositions and properties of dust in super star clusters in low-metallicity blue-compact dwarf galaxies and examine how massive stars characterized the ISM conditions at high-z galaxies

[Tier2](1) Dust Formation by SNe

- Observational Evidence for the dust formation in SN ejecta:
  - Type II SN2003gd; 0.02 Msun (Sugerman et al. 2006) -> 4×10^{-5} Msun (Meikle et al. 2007)
  - Type II SN1987A; 7.5×10^{-4} Msun (Ercolano et al.2007) -> ~0.5 Msun (Matsuura et al. 2011, 2015)
  - Cas A ; 0.02--0.054 Msun (Rho et al. 2004), 0.08 Msun (Barlow et al. 2010)
- SN dust Science with JWST (by Eli Dwek):

  ”Are Core-Collapse SNe net producers or destroyers of interstellar dust?”

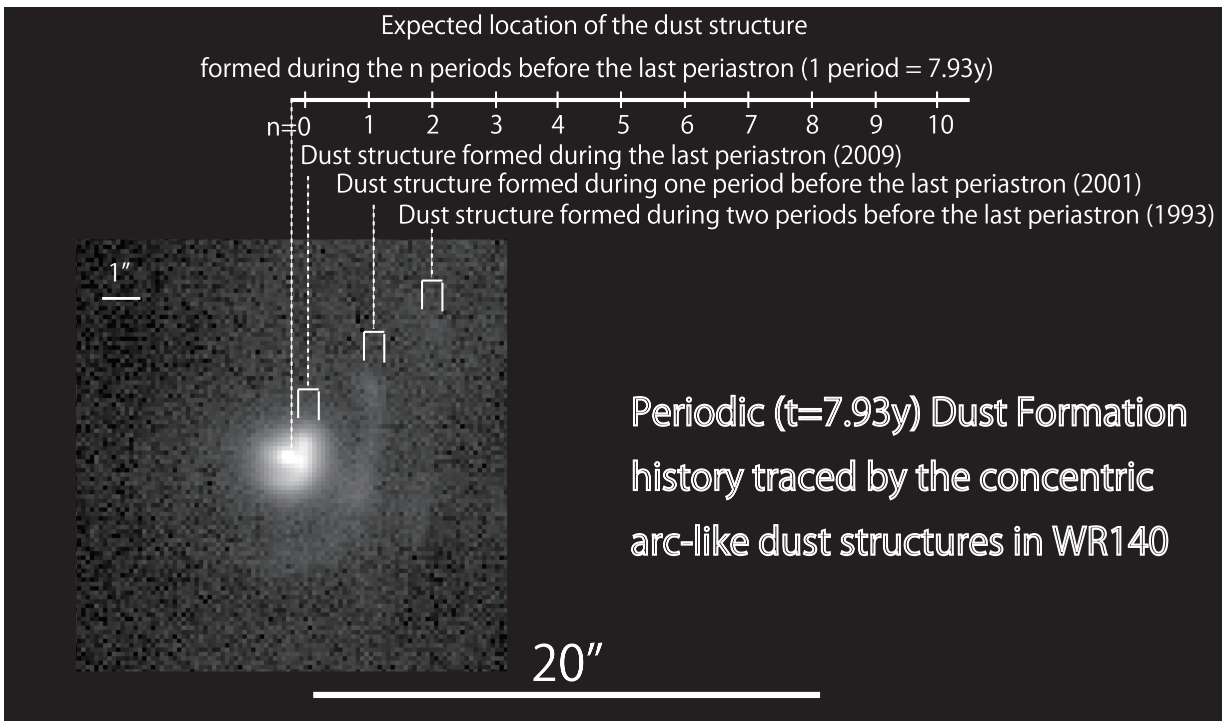
  1. Observations of SN 1987A
     - Grain destruction by reverse shock
     - Nature of dust, silicates of carbon, in the ejecta
  2. Observations of SNRs
     - Cas A: mass and composition of unshocked dust
     - Crab Nebula: mid-IR mapping, spectroscopy?
     - yield of dust that survives the reverse shock
  3. Observations of young dust-forming SNe
     - looking at SNe that exploded within the last ~ 3 yrs
     - initial dust yield from Core-collapse SNe

[Tier2](1) Dust Formation by SNe

- ISSUES TO BE SOLVED with SPICA: “How the SN dust survive and characterize the dusty ISM properties in low-metallicity galaxies, i.e., in the early universe”
- Obs. Method: collecting spectroscopic data of SN dust emission in 18-200μm, which should be fed in the SED analyses of dust emission in SSCs in BCDs via chemical composition diagnostics
  - **Extremely Nearby SNe (<10Mpc) within a few – a few tens years from the explosion**: identification of chemical composition, demonstrating dust mass evolution [80h]
    - SMI MRS spectroscopy (R~1000 required to remove ionic lines), SAFARI spectroscopy (spectral decomposition among SN dust/ circumstellar dust/interstellar dust of M_{dust} >10^{-4} M_{sun} with T~100-150 K)
    - Number of targets: 10 (observing time per target; 4h[SMI/MRS], 4h[SAFARI])
  - **Nearby SNe (<10Mpc) within a few – a few tens years from the explosion:** demonstrating dust mass evolution [160h]
    - SMI LRS (degraded to R~5), SAFARI spectroscopy (degraded to R~20) (spectral decomposition among SN dust/ circumstellar dust/interstellar dust of M_{dust} ~10^{-1} M_{sun} with T<100 K)
    - Number of targets: 20 (observing time per target; 4h[SMI/LRS], 4h[SAFARI])

[Tier2](2)Dust Formation by WR Stars

- JWST ERS “Establishing Extreme Dynamic Range with JWST: Decoding Smoke Signals in the Glare of a Wolf-Rayet Binary” (PI: Ryan Lau)
  - JWST/MIRI and NIRIS observations of the archetypal colliding-wind binary WR 140 to study its dust composition, abundance, and formation mechanisms



Subaru/COMICS 11.7um band image of WR140 observed 29 months after the binary periastron event in 2009

SPICA resolution (~20”) corresponds to ~8 periods ~ 60 yrs.

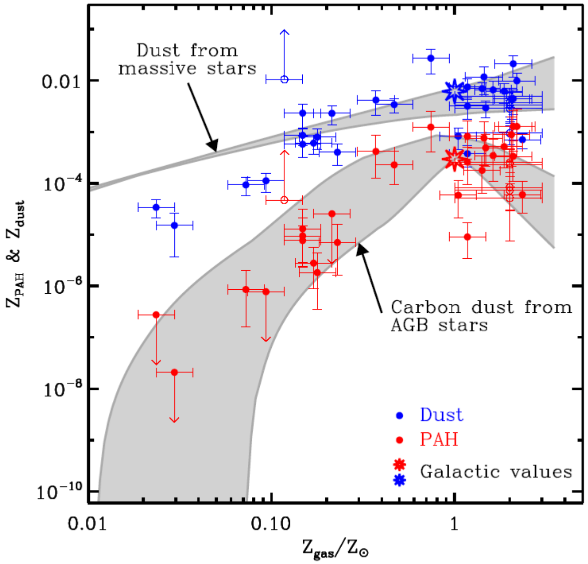
[Tier2](2)Dust Formation by WR Stars

- ISSUES TO BE SOLVED with SPICA: “How the WR dust forms in the circumstellar environment of SN progenitor”
  - The follow-up spectroscopic mapping of dusty structures around nearby WR stars on 20” spatial scale with SPICA/SMI and SAFARI will demonstrate the several tens to a hundred years’ evolution history of dust provided by evolved massive stars
- Obs. Method: : collecting spectroscopic data of WR dust emission in 18-200μm, which should be fed in the SED analyses of dust emission in SNe or in SSCs in BCDs via chemical composition diagnostics
  - **Galactic dusty WR (WC7+O systems), LBVs within several kpc:**

  20”x20” spectral mapping is required to cover the 100years’ of dust evolution history for targets at a few kpc) [160h]
    - SMI MRS spectroscopy (IFU preferred, R~1000 required to remove ionic lines), SAFARI spectroscopy
    - identification of chemical composition, demonstrating mass evolution of dust at <100K)
    - Number of targets: 20 (observing time per target; 4h[SMI/MRS; Slit Mapping] 4h[SAFARI])

[Tier1] Dust in SSCs in BCDs

- Deficiency of PAH emission in low-metallicity galaxies (Madden et al. 2006; Engelbracht et al. 2005)
  - destruction of PAHs by hard UV photons? (Madden et al. 2006)
  - more efficient destruction of PAHs by interstellar shocks? (O'Halloran et al. 2006)
  - ***the delayed injection of PAHs and carbon dust into the ISM by AGB stars*** in their final phase of their evolution? (Dwek et al. 2008)



(Dwek et al. 2008)

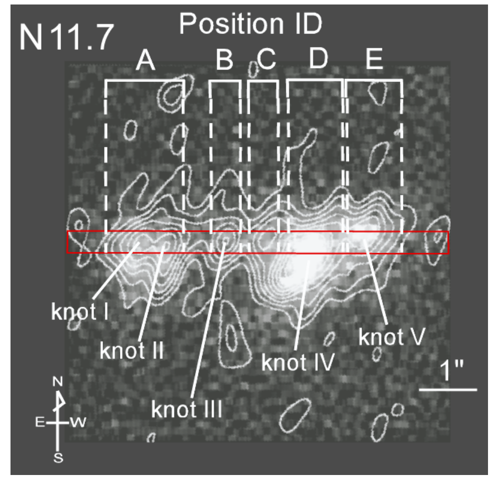
- Super Star Clusters (SSCs) in Blue Compact Dwarfs (BCDs)
  - BCDs: young metal-poor system with many massive stars and not old enough to have low- to intermediate mass AGB stars.
  - a unique laboratory for ISM dust from massive stars

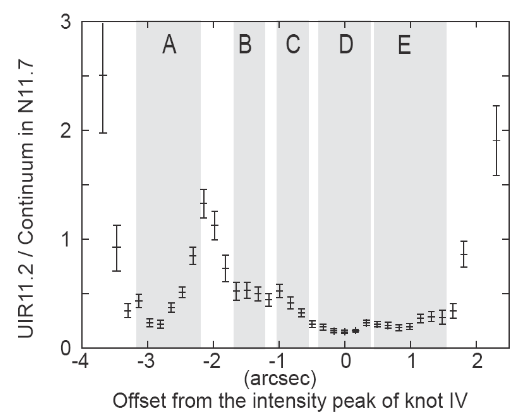
[Tier1] Dust in SSCs in BCDs

Henize 2-10 (Vacca & Conti 1992)

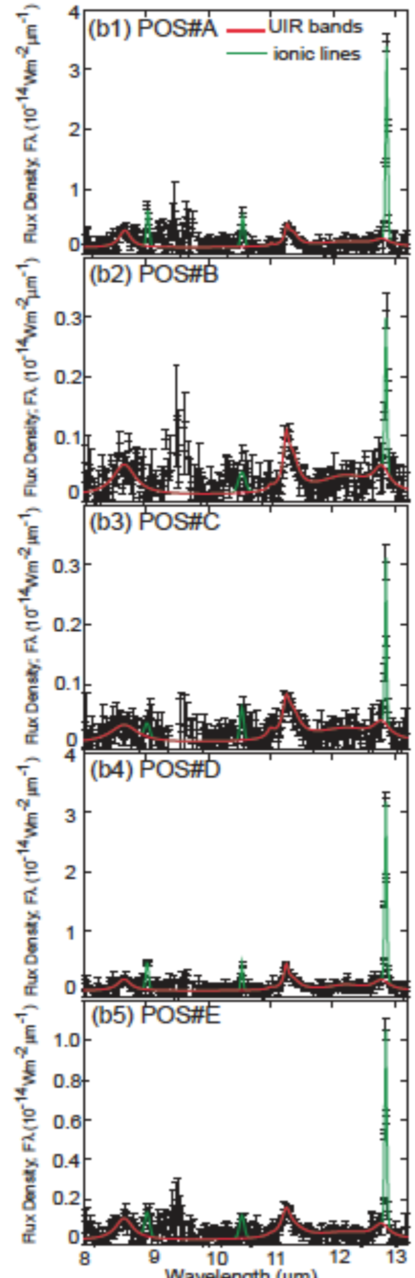
- a BCD galaxy at 9Mpc
- ~ solar metallicity
- contains embedded SSCs

  (Kobulnicky and Johnson 1999)
- Each SSC contains >1000 O-type stars
- young (a few Myr) and massive (10^4-$10^7 M_{\odot}$)
- absent from optical images and seen in radio & mid-infrared
- PAH features are relatively weaker in SSC positions (A~E) relative to the continuum dust emission.





PAH/continuum



continuum subtracted spectra

[Tier1] Dust in SSCs in BCDs

- ISSUES TO BE SOLVED with SPICA: “To demonstrate the properties and the origins of dust in SSCs in BCD galaxies”
- Obs. Method: Finding spectral features characteristic of SN dust/WR dust in the infrared dusty emission in SSCs in BCD galaxies
  - **Low-metallicity Blue compact dwarf galaxies** [160h]
    - SMI MRS slit mapping (or MRS/IFU preferred if available), SAFARI spectroscopy

      (spectral decomposition among SN dust/WR dust/interstellar dust via chemical composition diagnostics and SED analyses)
    - Number of targets: 20 (observing time per target; 4h[SMI/MRS Slit Mapping] 4h[SAFARI])

Appendix

Object	RA (J2000.0)	Dec. (J2000.0)	g, B	M_g, M_B	Redshift	12+logO/H	Comments
HS 0021+1347	00 24 25.9	+14 04 10	15.86	−17.81	0.014 23	8.39[a]	BCD
J0115−0051	01 15 33.8	−00 51 31	16.51	−14.85	0.005 59	8.37[a]	H II region in spiral galaxy
UM 311	01 15 34.4	−00 51 46	17.90	−13.46	0.005 59	8.33[a]	H II region in spiral galaxy
SHOC 137	02 48 15.8	−08 17 24	16.29	−14.04	0.004 69	7.97[a]	BCD
Mrk 600	02 51 04.6	+04 27 14	15.45[b]	−14.73	0.003 36	7.79[c]	BCD
Mrk 1089	05 01 37.7	−04 15 28	13.40[b]	−20.32	0.013 41	8.00[c]	interacting galaxies
Mrk 94	08 37 43.5	+51 38 30	16.90	−13.50	0.002 44	8.08[a]	H II region in spiral galaxy
I Zw 18	09 34 02.0	+55 14 28	16.08[b]	−14.39	0.002 51	7.24[a]	BCD
CGCG 007−025	09 44 01.9	−00 38 32	16.05	−15.91	0.004 83	7.77[a]	BCD
J1038+5330	10 38 44.8	+53 30 05	13.15	−17.82	0.003 20	8.30[a]	H II region in spiral galaxy
Haro 3	10 45 22.4	+55 57 37	13.25[b]	−17.67	0.003 15	8.35[d]	BCD
Mrk 36	11 04 58.3	+29 08 23	15.70[b]	−14.87	0.002 16	7.83[a]	BCD
Mrk 162	11 05 08.1	+44 44 47	14.93	−19.92	0.021 54	8.22[a]	BCD
Mrk 1450	11 38 35.7	+57 52 27	15.29	−15.61	0.00316	8.11[c]	BCD
Mrk 193	11 55 28.3	+57 39 52	16.40	−17.94	0.017 20	7.93[a]	BCD
Mrk 1315	12 15 18.6	+20 38 27	16.27	−14.75	0.002 83	8.33[a]	H II region in spiral galaxy
SBS 1222+614	12 25 05.4	+61 09 11	14.72	−15.58	0.002 36	8.01[a]	BCD
Mrk 209	12 26 15.9	+48 29 37	15.13	−13.96	0.000 94	7.88[a]	BCD
Mrk 1329	12 37 03.0	+06 55 36	14.40[b]	−17.76	0.005 44	8.34[a]	BCD
Mrk 450	13 14 48.3	+34 52 51	14.30[b]	−16.59	0.002 88	8.16[a]	BCD
Mrk 259	13 28 44.0	+43 55 51	16.27	−19.13	0.027 95	8.11[a]	BCD
SBS 1415+437	14 17 01.4	+43 30 05	15.68[b]	−14.42	0.002 03	7.57[c]	BCD
Mrk 475	14 39 05.4	+36 48 22	15.46[b]	−14.57	0.001 95	7.93[a]	BCD
Mrk 487	15 37 04.2	+55 15 48	15.45[b]	−14.50	0.002 22	8.06[a]	BCD

Izotov and Thuan (2016)