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# *Origin of dust and gas in the galaxies of the local group*

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# Topics

Test cases for gas and dust cycle

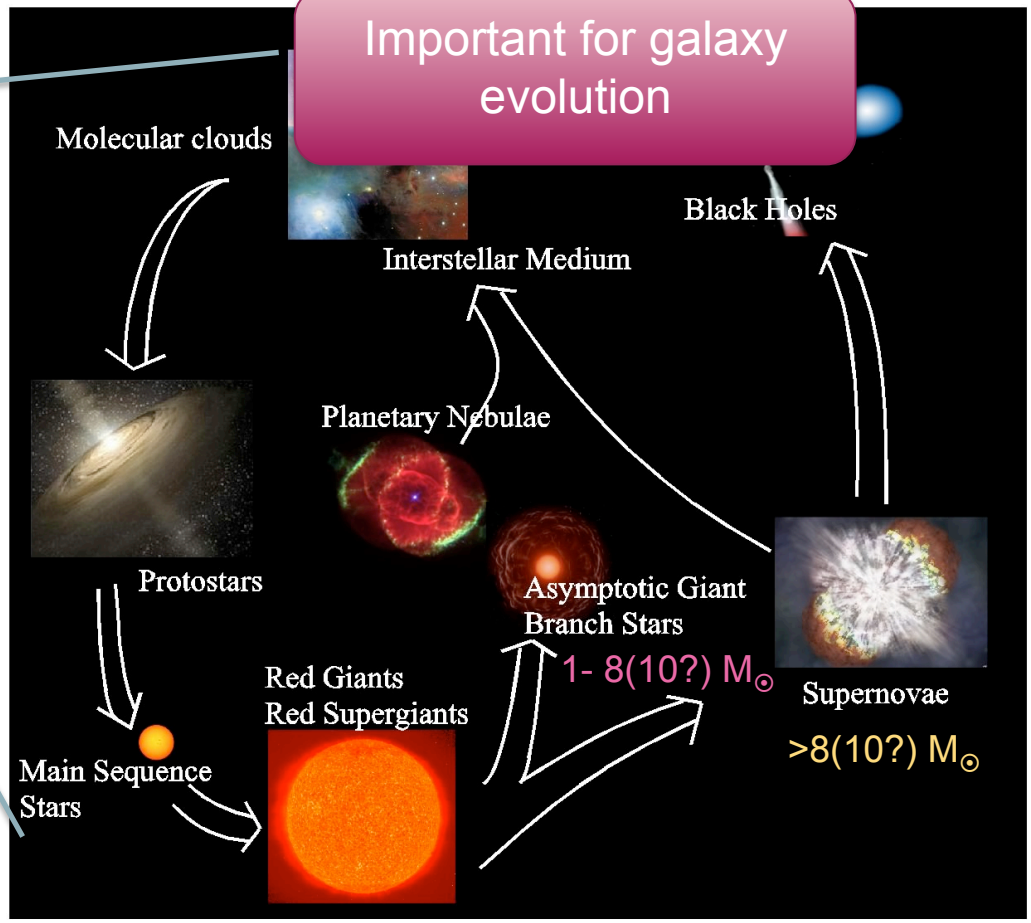
1. Gas and dust budget in the Large Magellanic Cloud based on observations

2. Dust in different environment: low-metallicity galaxies

# Cycle of matter (gas and dust) in galaxies

Concept of cycle of matter
Past: Theory/models
(population synthesis/chemical evolution models of galaxies)

Current: measurements




Important for galaxy evolution

Contents

1. Gas and dust budget in LMC
   1.1 Introduction
2. Dust in different environment: low-metallicity galaxies

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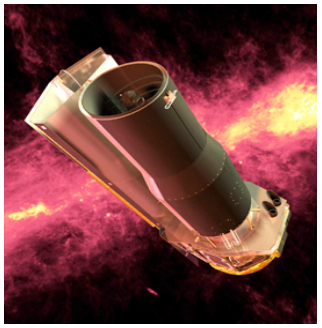
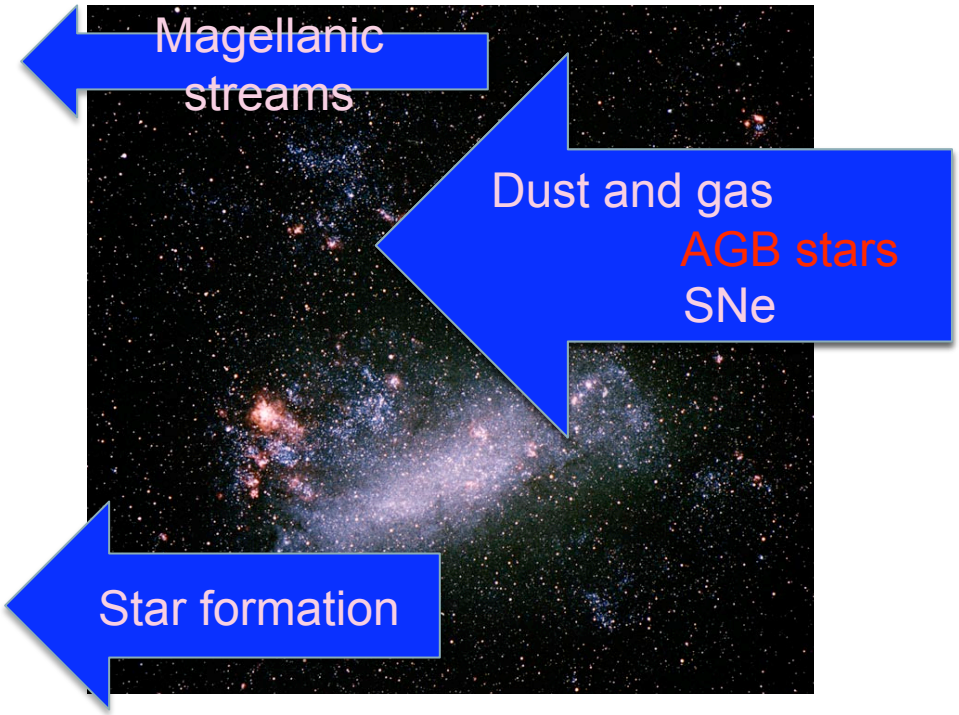
# Large Magellanic Cloud



- One of the nearest (50 kpc) galaxies
- Spitzer Space Telescope
  - Photometric survey (Meixner et al. 2006)
    - Complete census of asymptotic giant branch (AGB) stars
  - Spectroscopic survey (e.g. Zijlstra et al. 2006; Kemper et al. in preparation)
- First time to measure
  - the gas and dust budget within an entire galaxy scale
  - Based purely on observations

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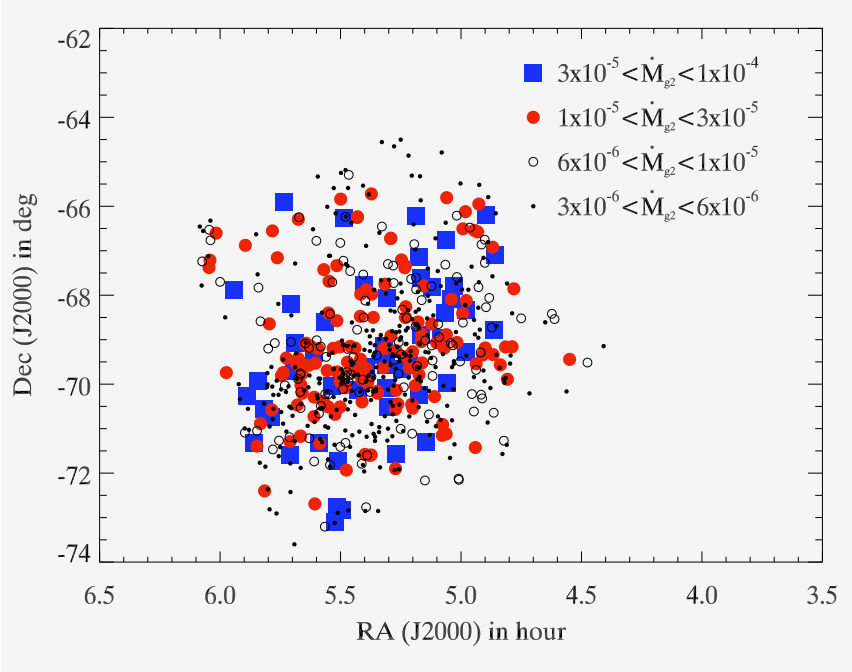
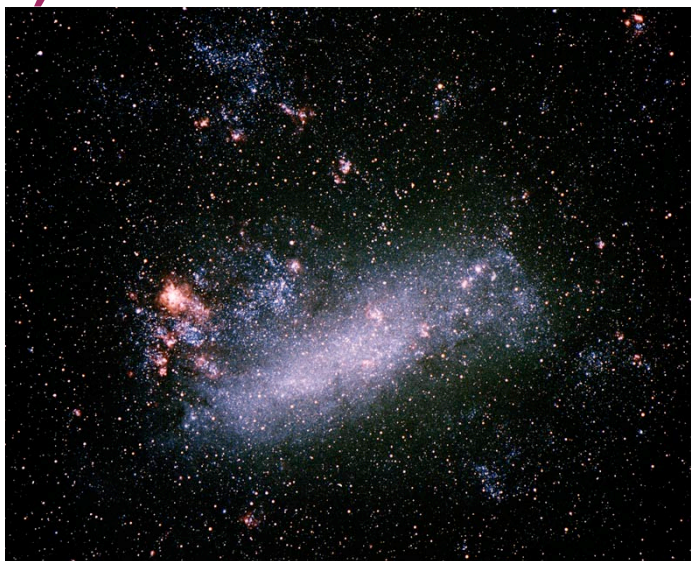
# Identified AGB stars + measured their mass-loss rate (gas and dust mass)



Detecting dust-embedded AGB stars using Spitzer

Matsuura et al. (2009, MNRAS, in press, astro-ph/09031123)

Contents

1. Gas and dust budget in LMC
   1.3 Analysis
2. Dust in different environment: low-metallicity galaxies

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# Gas feedback in the LMC

- Total AGB mass-loss rate: $2\text{-}4\times10^{-2}\ M_{\odot}\ yr^{-1}$
  - Oxygen-rich + carbon-rich AGB stars
- Type II SNe: $2\text{-}4\times10^{-2}\ M_{\odot}\ yr^{-1}$

- In the LMC, Type II SNe and AGB stars are both important gas sources


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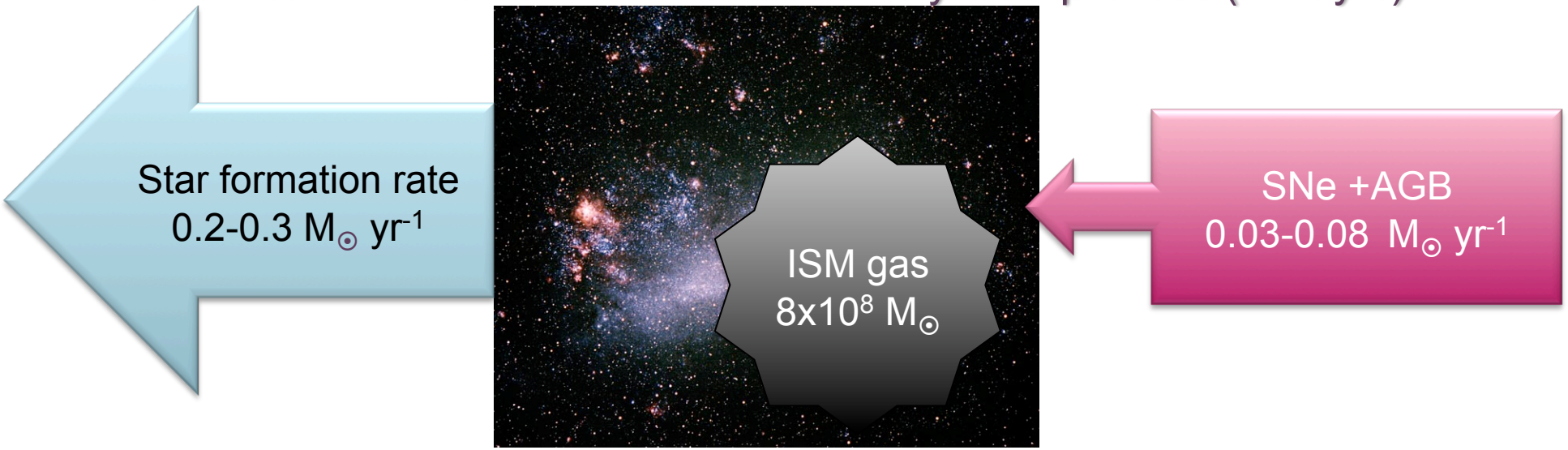
# Gas budget of the LMC

- Star formation rate (SFR) > Gas injection rate from SNe and AGB
- LMC star formation depends on the large reservoir of existing ISM gas
- The LMC is getting gas poorer. The SFR is likely to be declining with time.
- Chemical evolution of the LMC ISM is very slow process (~1 Gyrs)

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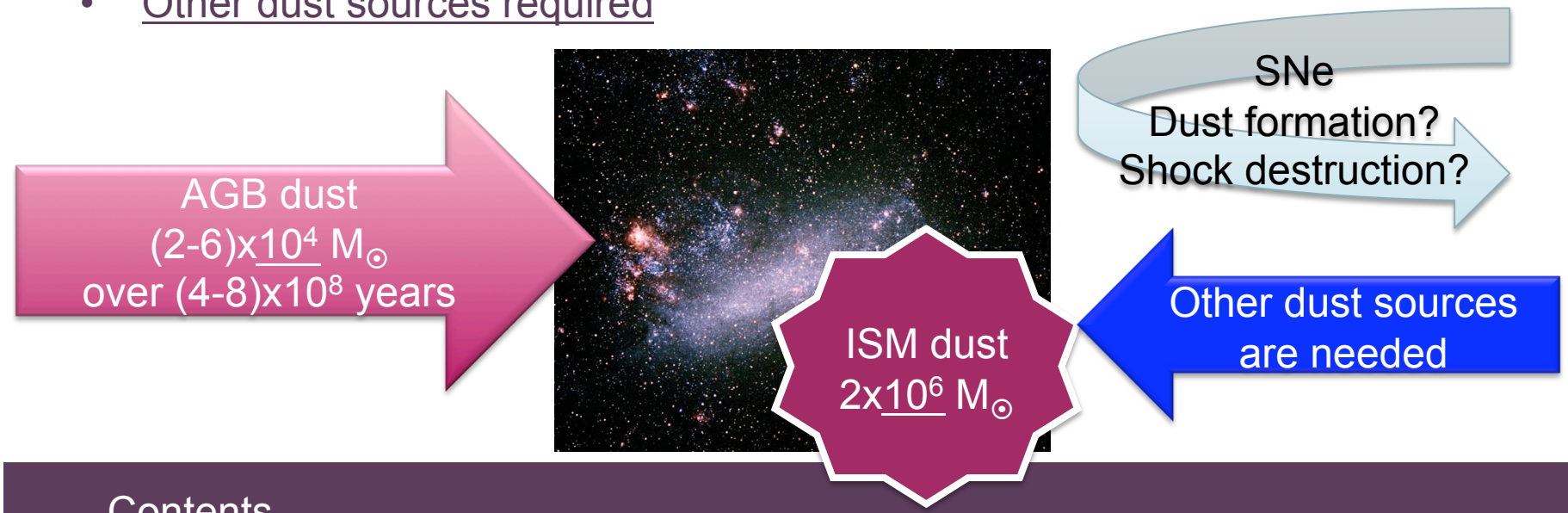
# Missing mass problem in dust budget

- Current LMC dust mass: $2 \times 10^6\ M_\odot$
  - HI+$H_2$ gas mass ($8 \times 10^8\ M_\odot$) x dust-to-gas ratio (0.0025)
- Dust injection rate from AGB stars: $4.3 \times 10^{-5}\ M_\odot\ yr^{-1}$ (up to $8 \times 10^{-5}\ M_\odot\ yr^{-1}$)
  - requires>20 Gyrs  Lifetime of the LMC (~15 Gyrs)
  - Dust lifetime was estimated to be $4\text{-}8 \times 10^8$ yrs (Jones et al. 1994)
- Dust deficit is short by a factor of 100
- Other dust sources required

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1. Gas and dust budget in LMC
   1.4 Results and discussion (3)
2. Dust in different environment: low-metallicity galaxies

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# Topics

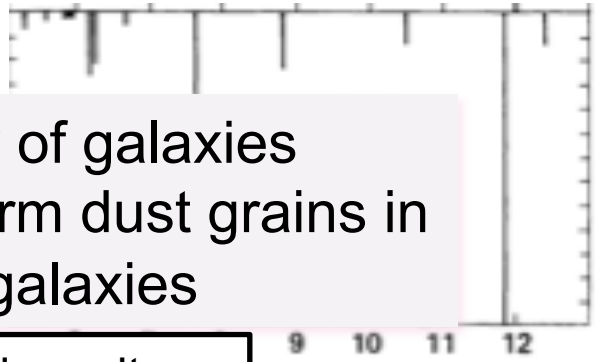
Test cases for gas and dust cycle

1. Gas and dust budget in the Large Magellanic Cloud based on observations

2. Dust in different environment: low-metallicity galaxies

# Can dust be formed at low metallicities? Dust needs (astronomical) metals!

- Oxides
  - Olivines : $Mg_{2x}Fe_{(2-2x)}SiO_4$
  - Pyroxenes : $Mg_xFe_{1-x}SiO_3$
- Carbonaceous dust
  - Graphite : C
  - Amorphous : C
  - Polycyclic aromatic hydrocarbons (PAHs)




Dust mass : as a function of metallicity of galaxies
It has been suggested that it is difficult to form dust grains in stars in low metallicity ($Z<0.1\ Z_\odot$) galaxies

But … we found unexpected results

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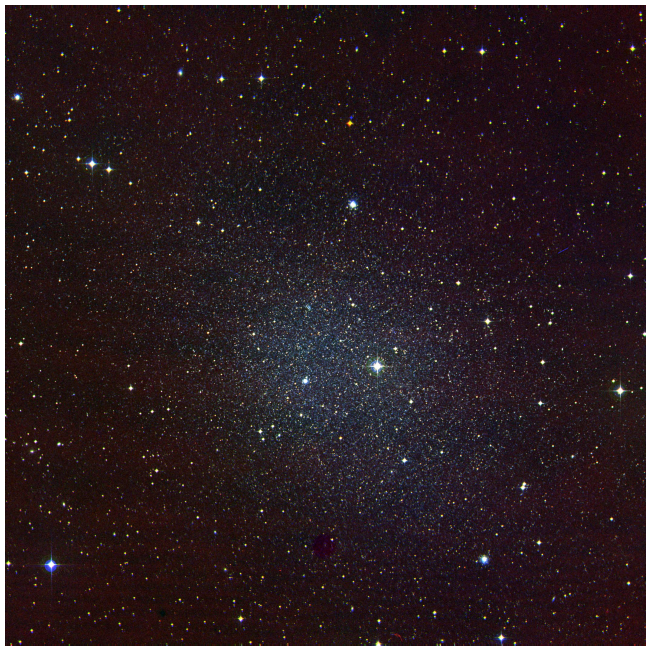
# The Galaxies of the Local Group

## Some galaxies have low metallicities

Sculptor dwarf spheroidal (dSph) galaxy
[Z/H]~-1.33



Fornax dwarf spheroidal galaxy
[Z/H]~-1.0

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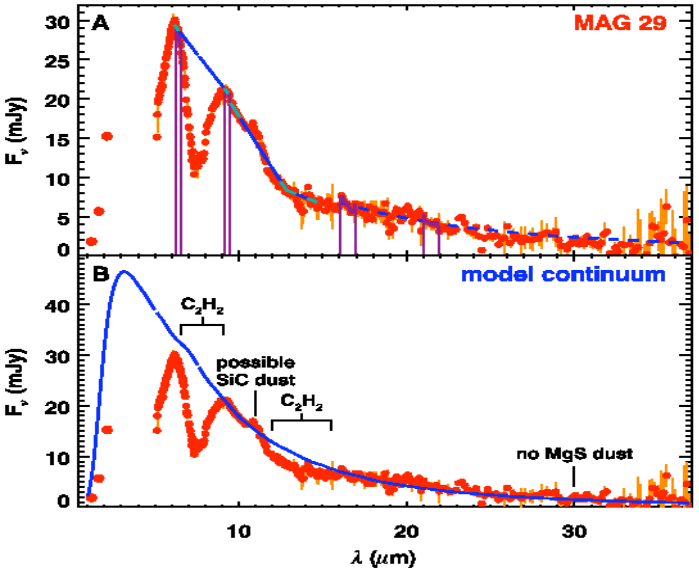
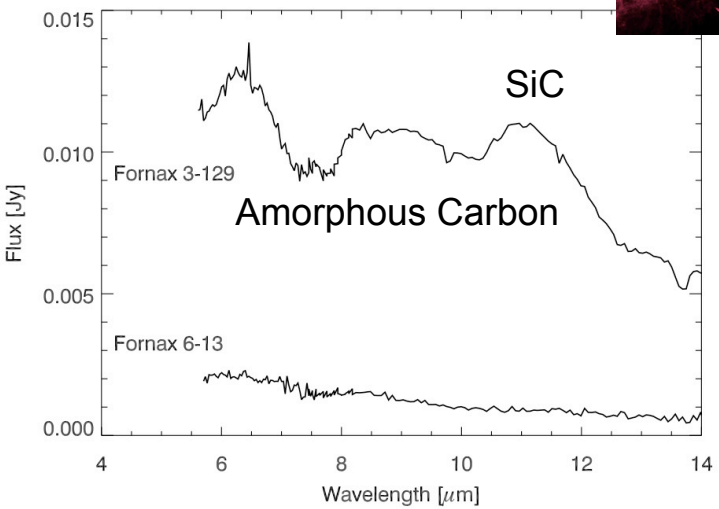
# Spitzer spectra




Sculptor dSph galaxy [Z/H]~-1.33
Sloan, Matsuura et al.
(2009, Science 323, 353)




Fornax dSph galaxy [Z/H]~-1.0
Matsuura et al. (2007, MNRAS 382, 1889)

Contrary to expectation, we detected dust at low metallicities

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1. Gas and dust budget in LMC
2. Dust in different environment: low-metallicity galaxies
   2.3 Results

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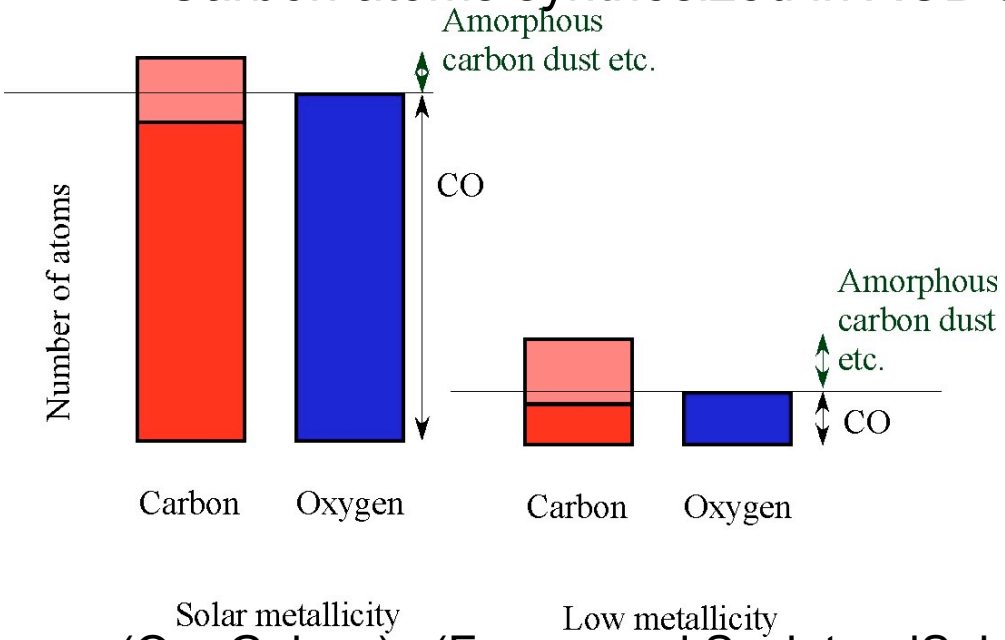
# Dust at low metallicity

AGB stars

- We detected amorphous (+SiC) dust
- Carbon atoms synthesized in AGB stars




- Dust formation process around stars is affected
  - not only by the metallicity of the parent galaxies
  - but also by elements formed inside stars, in particular, carbon

Matsuura et al. (2005 A&A 434, 691)

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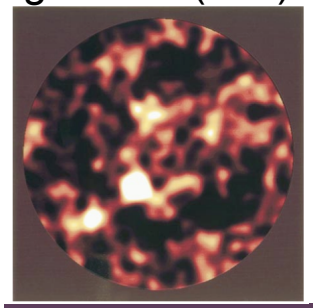
# Implications for high-z galaxies with dust

- Past explanation
  - AGB stars have two problems in producing dust
    - Age : Low and intermediate stars have not reached AGB phase (only after 1 Giga yrs)
      - Older than age of high-z galaxies (~0.3 Gyrs)
    - Low metallicity: It was difficult to form dust in AGB stars
  - Solely SNe could produce dust grains

- Current explanation Sloan, Matsuura et al. (2009, Science, 323, 353)
  - AGB stars can produce dust at high-z galaxies
    - AGB phase starts earlier than previously thought (about 0.28 Gyrs at 3 $M_{\odot}$; Z>8)
    - Dust can be formed in AGB stars even at low metallicity
  - Quantitative analysis is still waiting to be performed

Submm galaxies (z~6)



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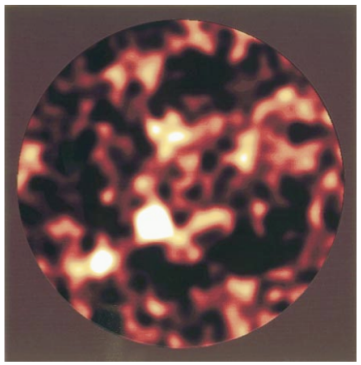
# Summary: life-cycle of dust

Gas and dust budget

- Both AGB stars and Type II SNe are important gas sources
- Missing dust mass problem



Dust at low metallicity

- Dust formation is affected by both
  - elements formed inside stars
  - elemental abundances of the parent galaxies
- Implications for high-z galaxies
  - AGB stars are present in high-z galaxies, and can produce dust

Future

- Quantitative analysis of the dust budget is still needed
  - Other galaxies of the local group
- Understanding dust input and destructions by SNe


Sloan, Matsuura et al. (2009, Science, 323, 353)

Matsuura et al. (2009, MNRAS in press)

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