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高赤方偏移クェーサー母銀河の星間ダスト進化と減光曲線
(Evolution of interstellar dust and extinction curve in the host galaxies of high-z quasars)

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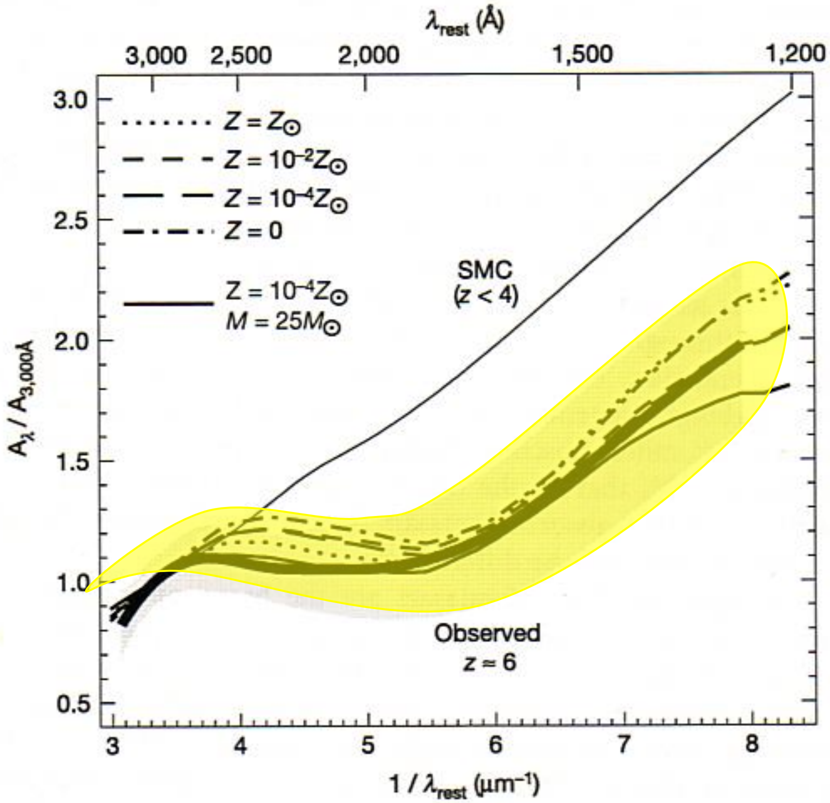
Reference:

Nozawa, Asano, Hirashita, Takeuchi (2014, submitted to MNRAS Letter)

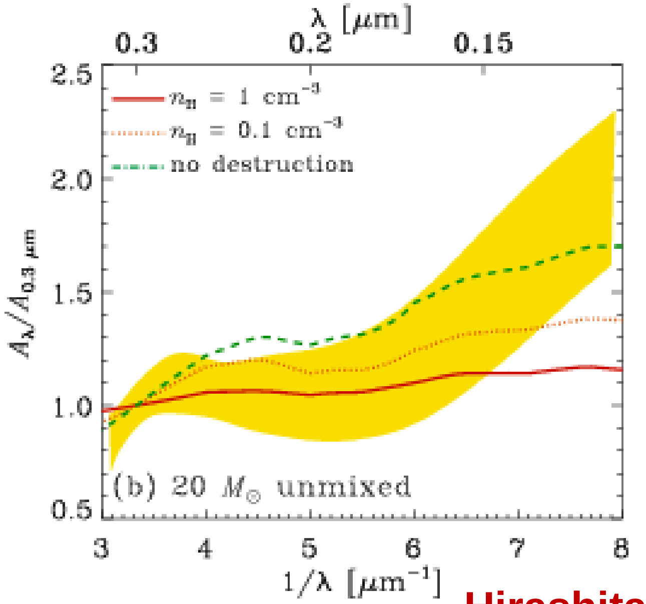
1-1. Extinction curves in high-z quasars

SDSS J1048+4637 at z=6.2

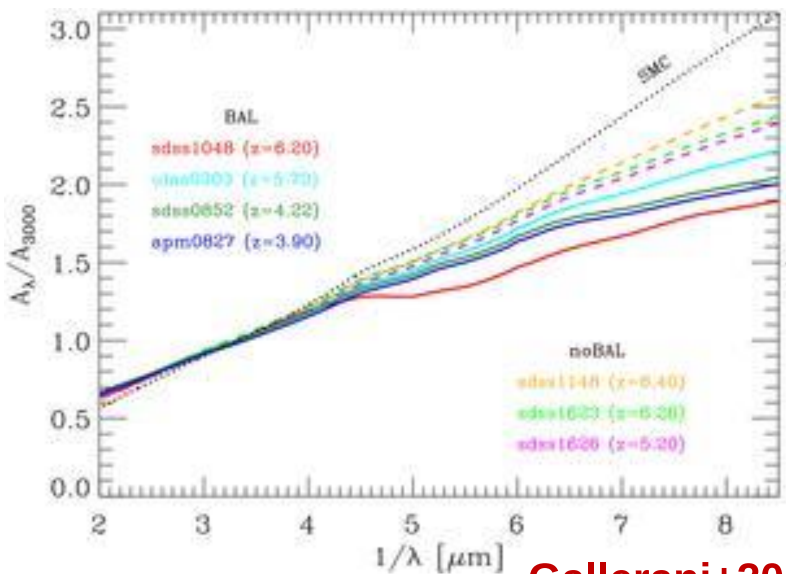
broad absorption line (BAL) quasars



Maiolino+2004, Nature, 431, 533



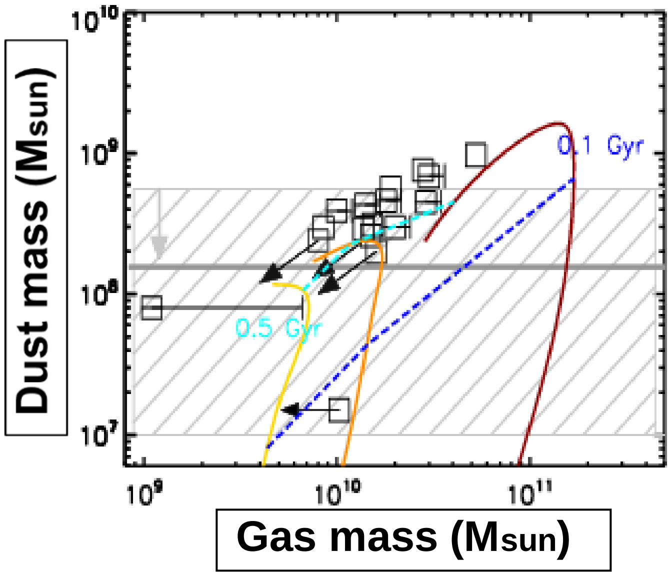
Hirashita+2008

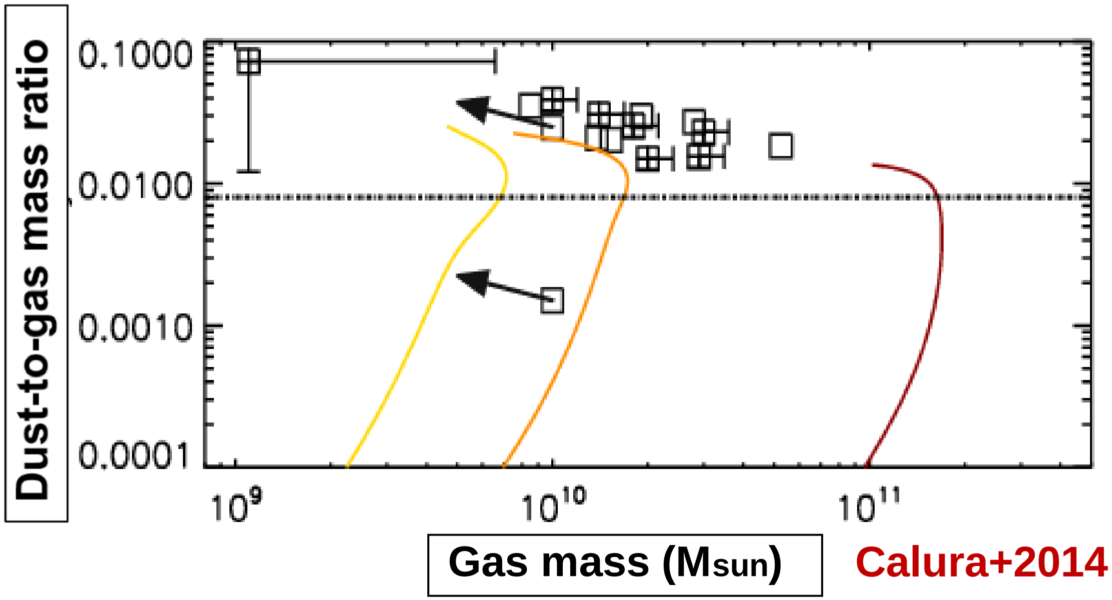


Gallerani+2010

➔ interstellar dust in the early universe is SN origin?

1-2. A large amount of dust in high-z quasars





Calura+2014

- **Huge amounts of dust grains (>10^8 Msun, D/G>0.01) are observed for the host galaxies of quasars at z > 5**

➜ **Grain growth in molecular clouds may be needed to account for such massive dust contents**

(Michalowski+2010; Mattsson 2011; Valiante+2011; Kuo & Hirashita 2012)

it seems only the contribution of dust from SNe II cannot explain
the observed amount of dust grains in high-z quasars

➜ 1 Msun of dust per SN and/or top-heavy IMF are required

1-3. Aim of our study

How can we explain the massive dust and unusual extinction curves observed for high-z quasars in a self-consistent way?

In previous works, we construct the evolution model of grain size distribution by considering the following dust processes:

- **production of dust in SNe II and AGB stars**
- **destruction of dust by interstellar shocks**
- **grain growth due to metal accretion in molecular clouds**
- **shattering and coagulation due to grain-grain collisions**

(Asano, Takeuchi, Hirashita, TN 2013)

We apply this dust evolution model to investigate the evolution of grain size distribution and the expected extinction curves in high-z dusty galaxies

2-1. Dust evolution model in a galaxy (1)

- one-zone closed-box model (no inflow and no outflow)

- $SFR(t) = M_{gas}(t)/\tau_{SF}$ (Schmidt law with n = 1)

- Salpeter IMF: $\varphi(m) = m^{-q}$ with $q=2.35$ for M_{star} = 0.1-100 M_{sun}

- dust processes
  - production of dust in SNe II and AGB stars
  - destruction of dust by interstellar shocks
  - grain growth due to metal accretion in molecular clouds
  - shattering and coagulation due to grain-grain collisions

- two dust species:
  - graphite (carbonaceous grains)
  - silicate (grains species other than carbonaceous grains)

- multi-phase ISM
  - WNM (warm neutral medium): T = 6000 K, n = 0.3 cm^{-3}
  - CNM (cold neutral medium): T = 100 K, n = 30 cm^{-3}
  - MC (molecular cloud): T = 25 K, n = 300 cm^{-3}

2-2. Dust evolution model in a galaxy (2)

- evolution of dust mass *ΔMd(a,t)* with radii between *a* and *a+da*

xSFR(t), astration

$$\frac{\mathrm{d}\Delta M_{\mathrm{d}}(a,t)}{\mathrm{d}t} = -\frac{\Delta M_{\mathrm{d}}(a,t)}{M_{\mathrm{ISM}}(t)} + \Delta Y_{\mathrm{d}}(a,t)$$

dust production by SNe II and AGB stars

$$-\frac{M_{\mathrm{swept}}}{M_{\mathrm{ISM}}(t)}\gamma_{\mathrm{SN}}(t)\left[\Delta M_{\mathrm{d}}(a,t) - m(a)\int_0^{\infty}\xi(a,a')\Delta a f(a',t)\mathrm{d}a'\right]$$

shock destruction

$$+\eta_{\mathrm{CNM}}\left[m(a)\Delta a\frac{\partial[f(a,t)]}{\partial t}\right]$$

grain growth

$$+\eta_{\mathrm{WNM}}\left[\frac{\mathrm{d}\Delta M_{\mathrm{d}}(a,t)}{\mathrm{d}t}\right]_{\mathrm{shat,WNM}} + \eta_{\mathrm{CNM}}\left[\frac{\mathrm{d}\Delta M_{\mathrm{d}}(a,t)}{\mathrm{d}t}\right]_{\mathrm{shat,CNM}}$$

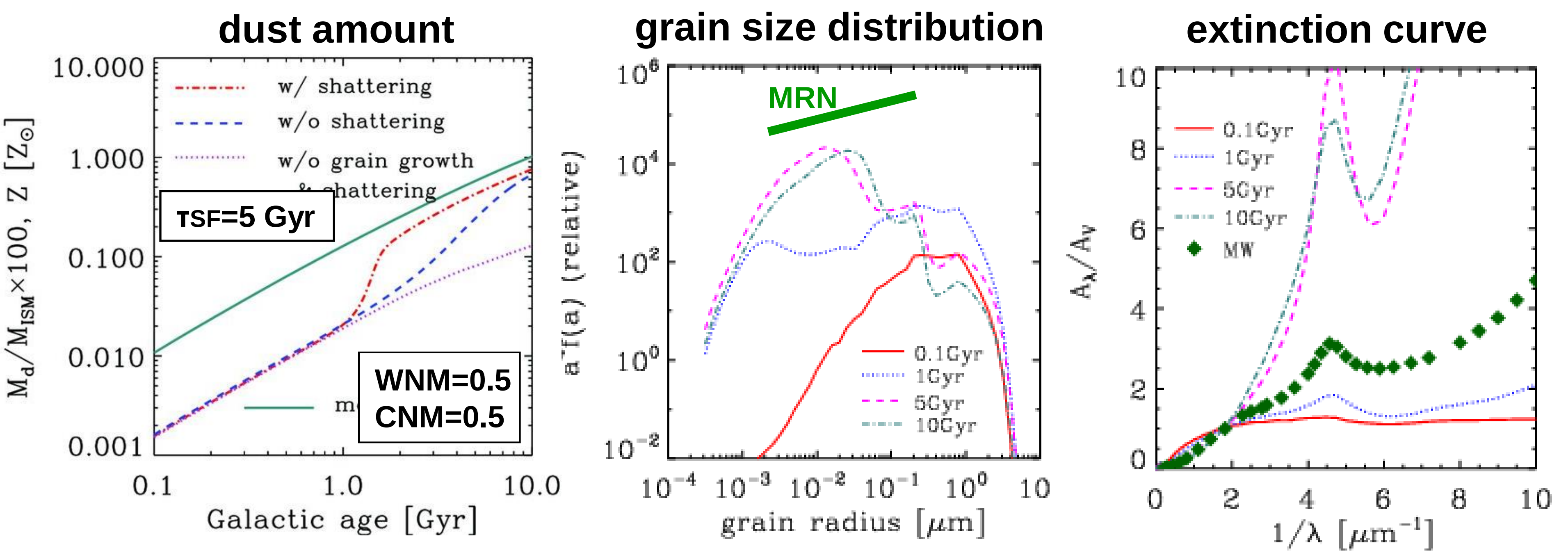
shattering

$$+\eta_{\mathrm{WNM}}\left[\frac{\mathrm{d}\Delta M_{\mathrm{d}}(a,t)}{\mathrm{d}t}\right]_{\mathrm{coag,WNM}} + \eta_{\mathrm{CNM}}\left[\frac{\mathrm{d}\Delta M_{\mathrm{d}}(a,t)}{\mathrm{d}t}\right]_{\mathrm{coag,CNM}},$$

coagulation

$$\Delta Y_{\mathrm{d}}(a,t) = \int_{m_{\mathrm{cut}}(t)}^{100\ \mathrm{M}_{\odot}} \Delta m_{\mathrm{d}}(m, Z(t-\tau_m), a)\phi(m)\mathrm{SFR}(t-\tau_m)\mathrm{d}m,$$

2-3. Evolution of extinction curves in galaxies



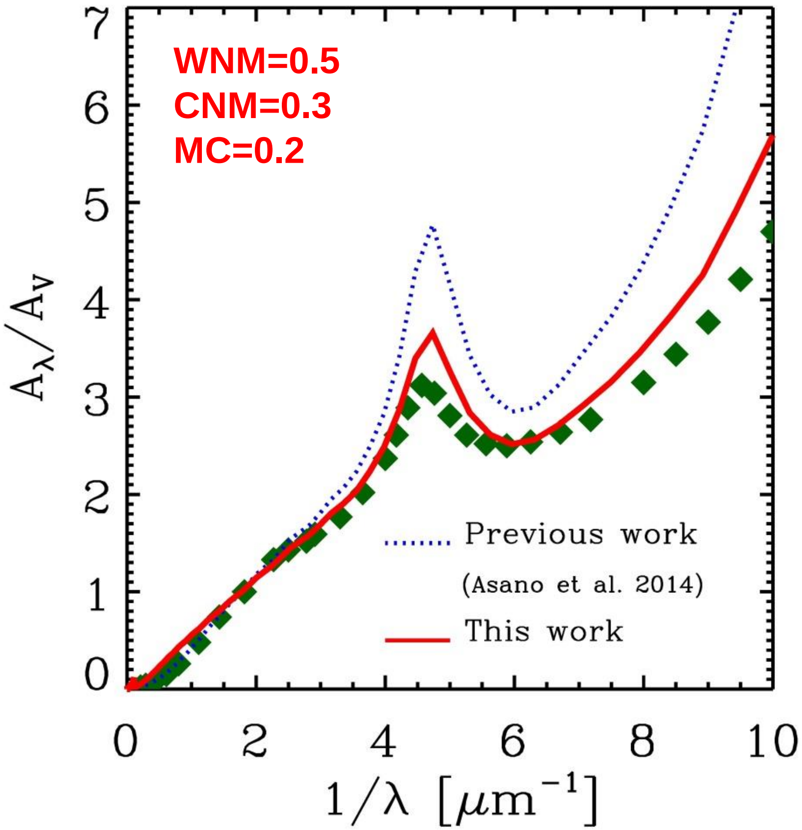
Asano, Takeuchi, Hirashita, TN+2013, 2014

- **early phase** : formation of dust in SNe II and AGB stars
  ➔ large grains (>0.1 μm) are dominant ➔ flat extinction curve
- **middle phase** : shattering, grain growth due to accretion of gas metal
  ➔ small grains (< 0.03 μm) are produced ➔ steep extinction curve
- **late phase** : coagulation of small grains
  ➔ shift of peak of size distribution ➔ making extinction curve flatter

2-4. Reproducing the MW extinction curve

- two-phase ISM
  - WNM (T = 6000 K, n = 0.3 cm^{-3})
  - CNM (T = 100 K, n = 30 cm^{-3})

- three-phase ISM
  - WNM (T = 6000 K, n = 0.3 cm^{-3})
  - CNM (T = 100 K, n = 30 cm^{-3})
  - MC (molecular clouds)
    ➜ T = 25 K, n = 300 cm^{-3}



Nozawa+2014, submitted

- three-phase ISM model including the MC phase can reproduce the average extinction curve in the MW
- ISM phase is one of the important quantities in constructing the evolution model of interstellar dust

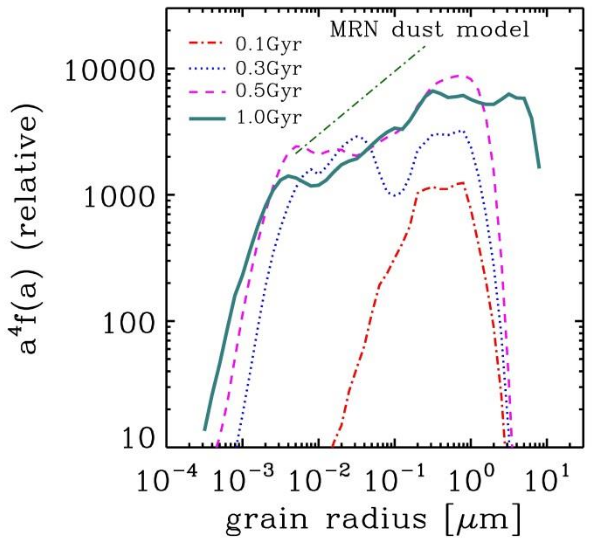
3-1. Explaining massive dust in high-z quasars

high-z quasar host: starburst galaxies

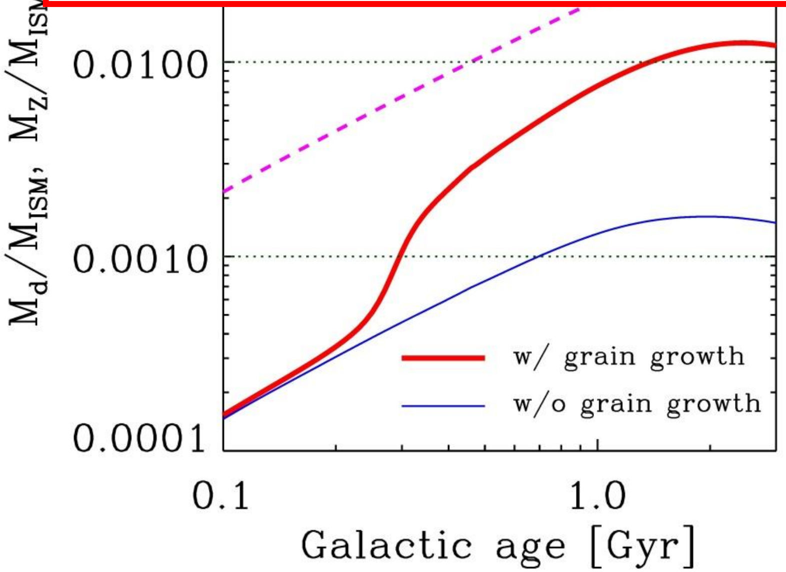
➜ indicating a high fraction of MC

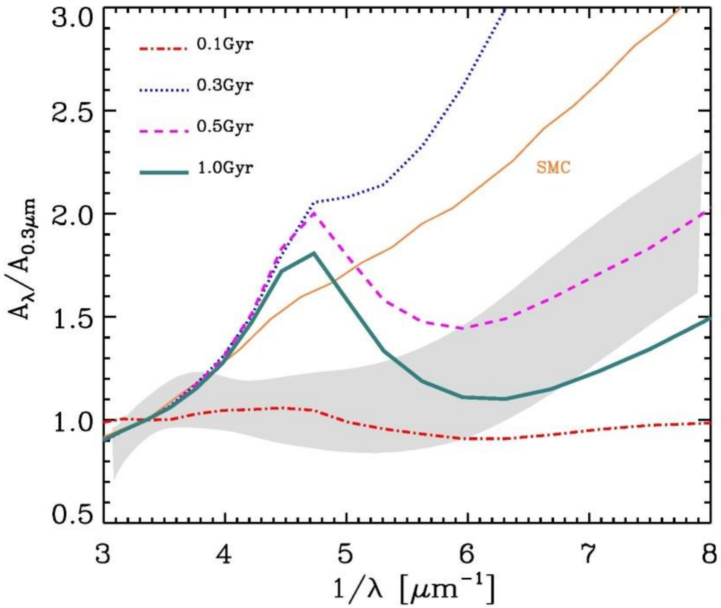
$M_{H2}/M_{H,total}$ ~ 0.7-0.97 (Calura+2014)

- **two-phase ISM:**
  WNM=0.3 and MC=0.7
- **τ_{SF} = 0.5 Gyr**



Grain growth is necessary to achieve the observed high D/G





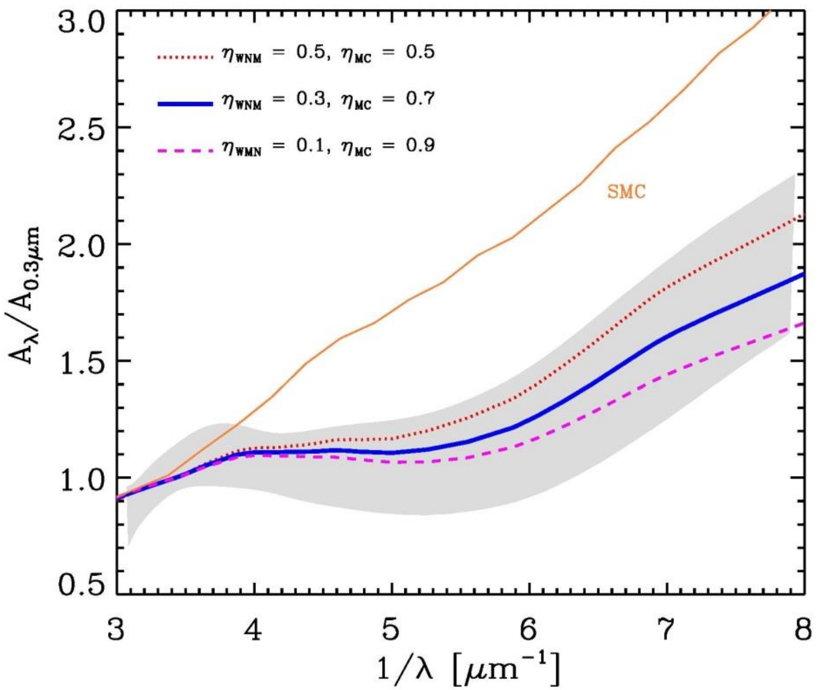
Nozawa+2014 submitted

3-2. Explaining the high-z extinction curves

The presence/absence of 2175 A bump may be related to the dust composition of dust rather than the dust evolution model

- **graphite and silicate**

- **amorphous carbon & silicate**
  ➜ **the derived extinction curve well match the observed high-z extinction curve**



Nozawa+2014 submitted

The origin of the 2175 A bump is still unclear
➜ **small size (<0.02 μm) of graphite?** (e.g., Draine & Lee 1984)
➜ **PAHs (polycyclic aromatic hydrocarbon?)** (e.g., Joblin+1992)

・ **formation site of PAHs**
- **AGB stars? (bottom-up scenario)** (e.g., Cherchneff+1993)
- **shattering of C grains? (up-down scenario)** (e.g., Seok+2014)

4. Summary

We investigate the evolutions of grain size distribution and the extinction curves in high-z dusty galaxies

- **our dust evolution model can reproduce the average extinction curve in the MW by considering**
  - **three-phase ISM (WNM=0.5, CNM ~ MC ~ 0.25)**
  - **graphite & silicate**

- **a large amount of dust grains and the unusual extinction curve observed for high-z quasars can be explained by considering**
  - **a large mass fraction of MC (>0.5) in the ISM**
    ➜ efficient growth and coagulation of dust grains
  - **amorphous carbon & silicate**
    ➜ different properties of carbonaceous grains

It is possible that the quasar extinction curves reflect the properties
of dust in circumnuclear (AGN) torus, not those of interstellar dust