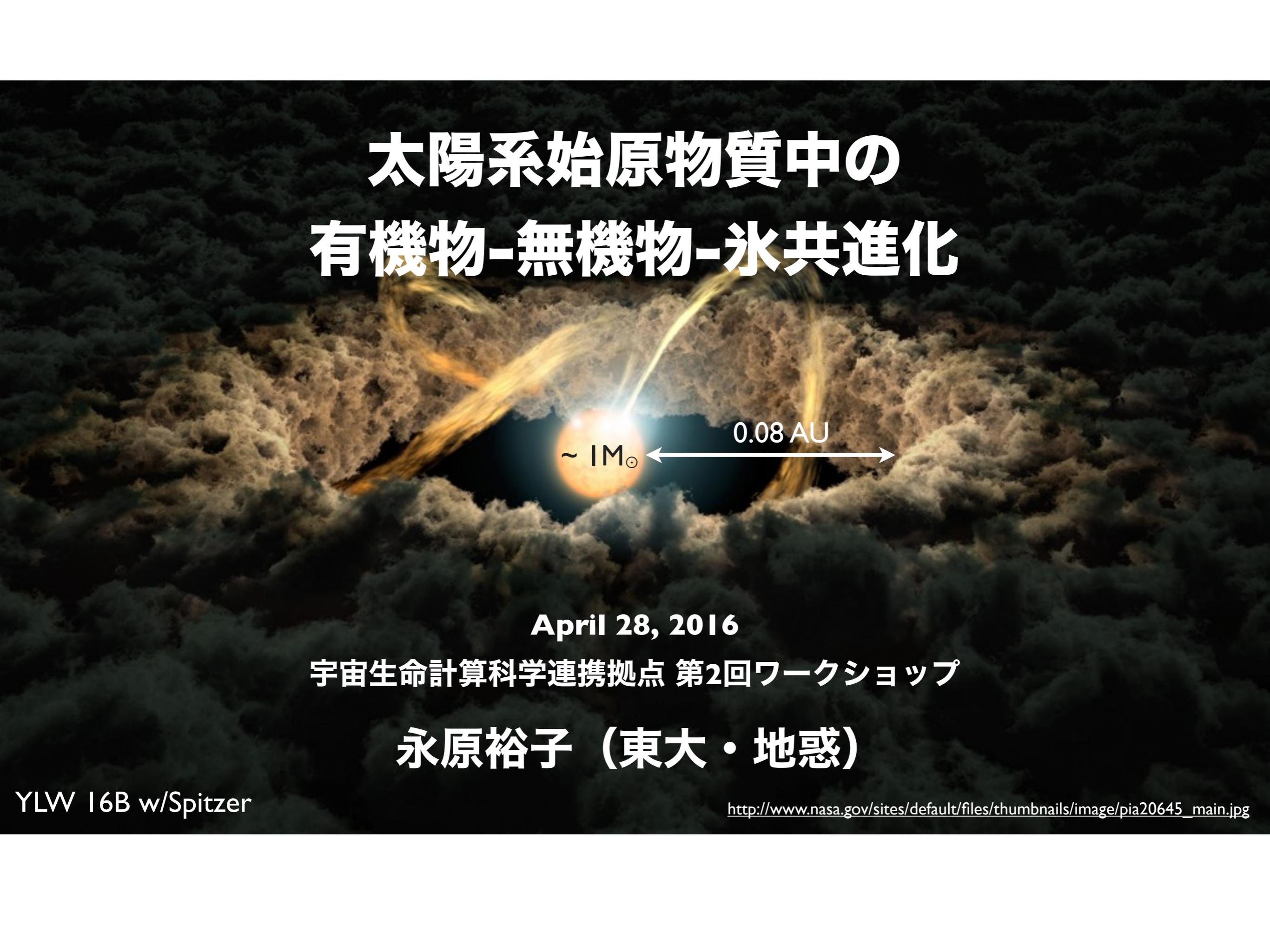


太陽系始原物質中の 有機物-無機物-氷共進化



~ $1 M_{\odot}$ ← 0.08 AU

April 28, 2016

宇宙生命計算科学連携拠点 第2回ワークショップ

永原裕子 (東大・地惑)

YLW 16B w/Spitzer

http://www.nasa.gov/sites/default/files-thumbnails/image/pia20645_main.jpg



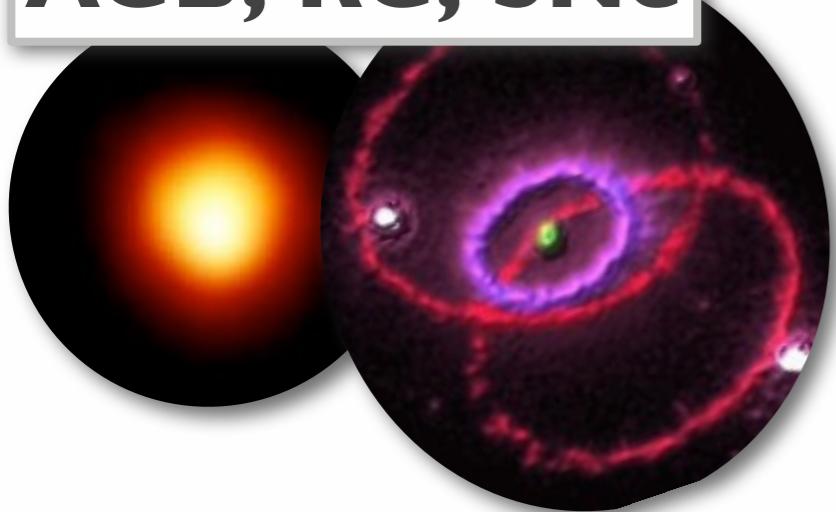
共同研究者

小澤 一仁 (東大・地惑) • 野口 高明 (九大・基幹教育院)
薮田 ひかる (阪大・宇宙地球) • 伊藤 正一 (京大・地惑)
岡崎 隆司 (九大・地惑) • 中村 智樹 (東北大・地球)
橘 省吾 (北大・自然史) • 寺田 健太郎 (阪大・宇宙地球)

http://www.nasa.gov/sites/default/files-thumbnails/image/pia20645_main.jpg

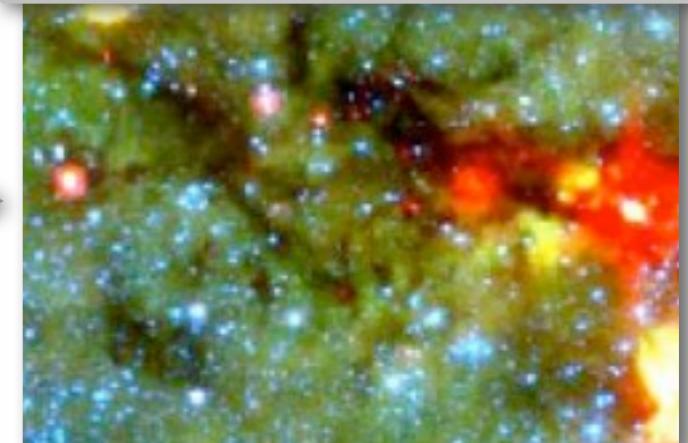
ダスト形成から微惑星へ

AGB, RG, SNe



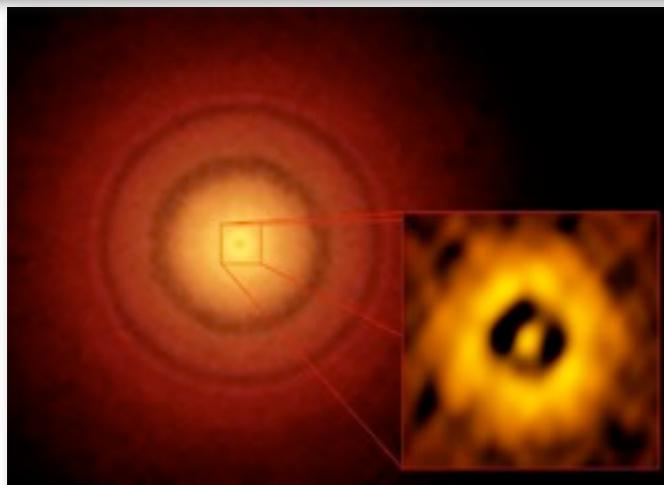
interstellar

prestellar core



物理と化学を統合的に理解する要

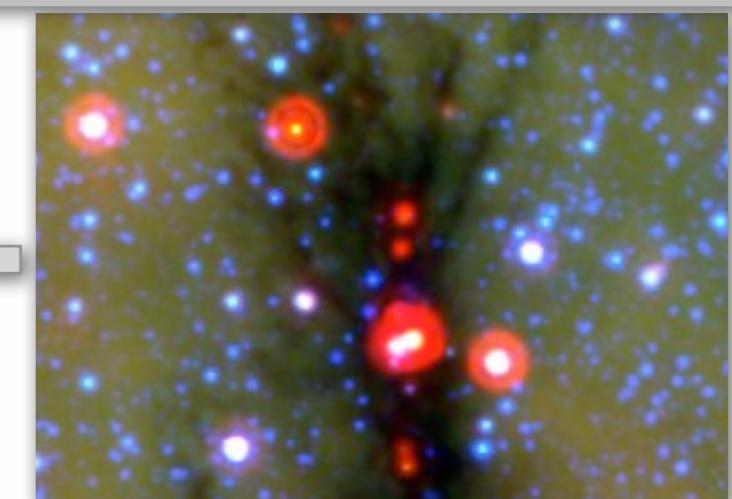
planet formation



PPD



protostellar core



Contents

- 始原的物質
- Cometary dust 情報
- 原始惑星系円盤とダスト移動・微惑星・彗星

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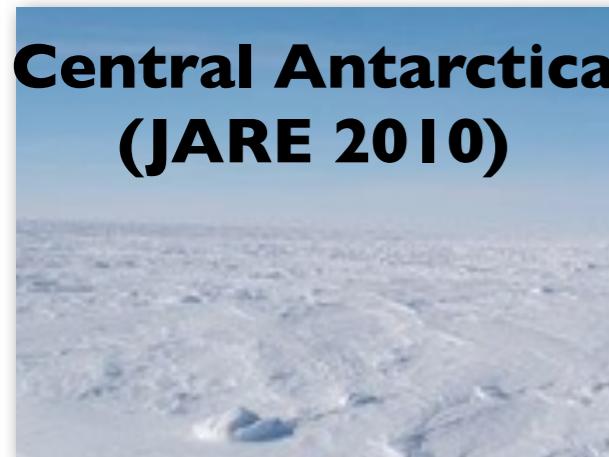
始原物質

- **隕石**：化学的には始原的。特に炭素質コンドライトには高温凝縮物、プレソーラーグレイン、有機物など含まれる。ただし、サイズ数10km以上の天体をなし、加熱・化学変化・水質変成・再結晶
- **IDP (interplanetary dust particle)**：成層圏で捕獲した彗星塵。捕獲時物理的・化学的变化
- **Stardust (Comet 81P/Wild2)**：Wild 2彗星コマから直接捕獲、これまでもっとも始原的物質、捕獲時加熱・エアロジェルとの化学反応
- **Cosmic dust / Micrometeorite**：地上に落下した彗星塵。多くは大気突入時に加熱・溶融、特定サイズのものは無反応で地上に落下
- **67P/Churyumov–Gerasimenko**：初めての直接探査、ただしリモートセンシングのみ

Contents

- 始原的物質
- **Cometary dust 情報**
- 原始惑星系円盤とダスト移動・微惑星・彗星

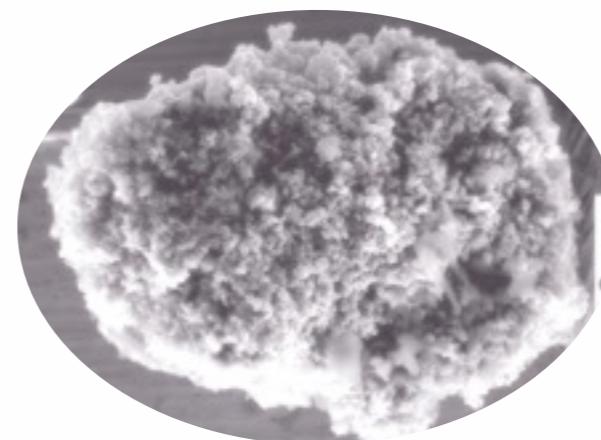
Antarctic Micrometeorites



~300 kg snow



**melting
filtering
picking
SEM**



**7 porous MMs
+ 1 compact MM**

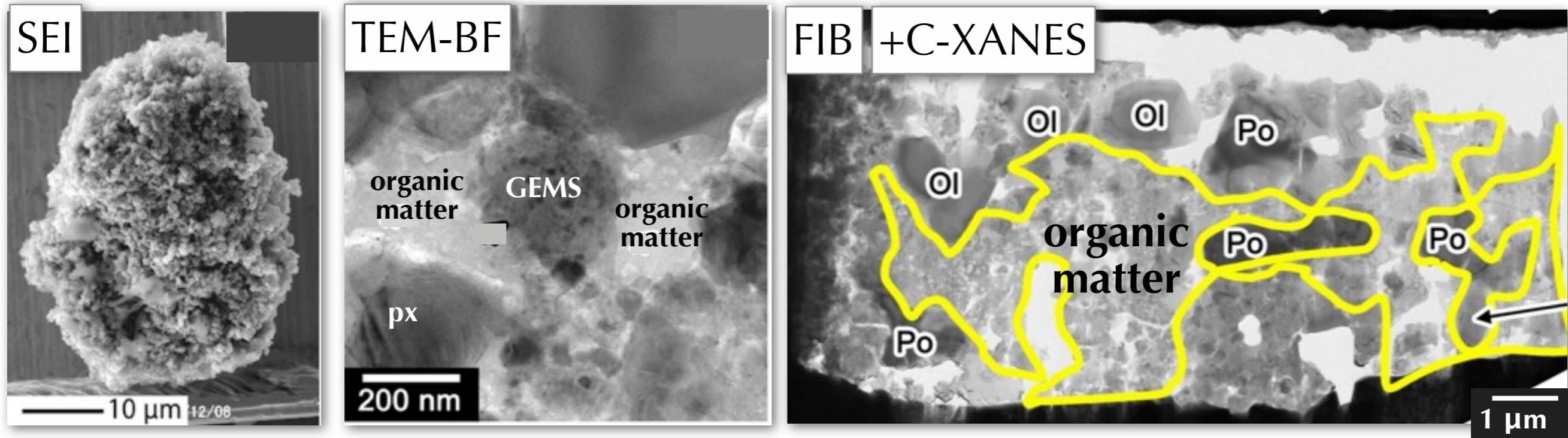


**pressed
into Au**

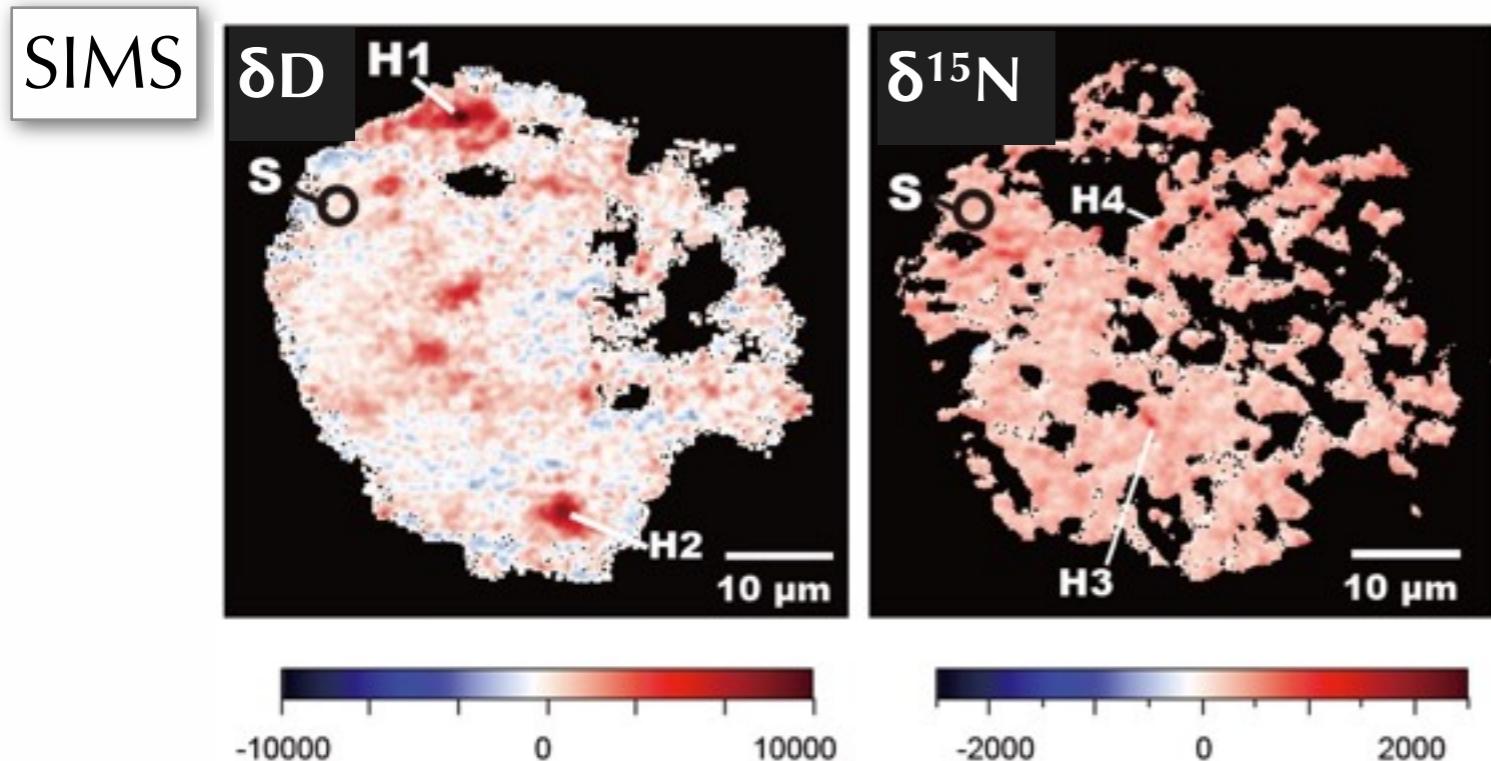
**FIB
sample**

- ✓ **SEM** (JEOL JIB-4501 FIB-SEM @ Ibaraki Univ.)
- ✓ **TEMs** (JEOL JEM-2100 @ Ibaraki Univ. and JEOL ARM-200F and FEI Tecnai 20F @ Kyushu Univ.)
- ✓ **C, N, and O-XANES analysis** (BL-5.3.2.2, ALS @ LBNL)
- ✓ **SIMS analysis** (Cameca ims-1270-E7 @ Hokkaido Univ.)

Stage 0 : DI0IB009 & 356



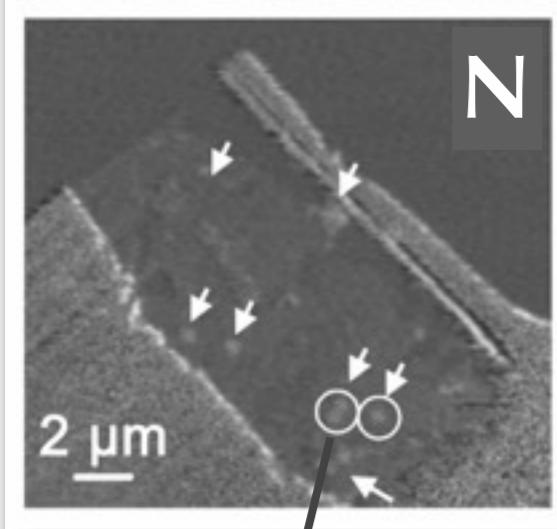
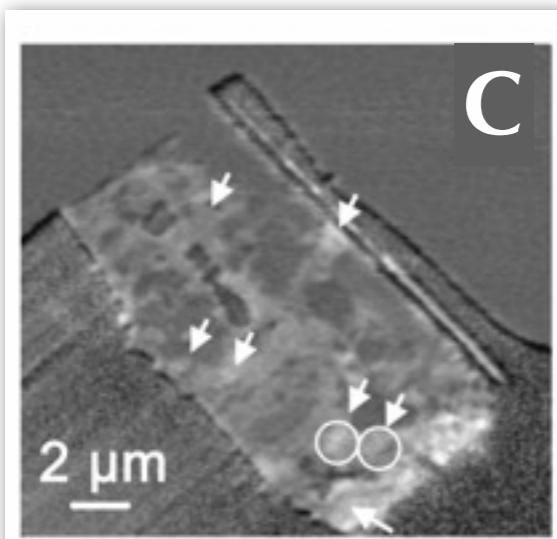
無水 silicates (高温起源) および 硫化物 が有機物中に散在
(海中の昆布に魚の卵 or 力エルの卵のよう)



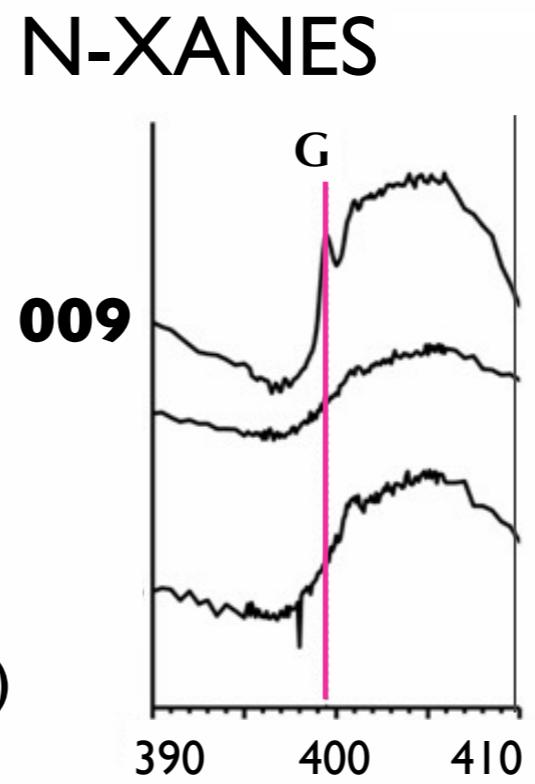
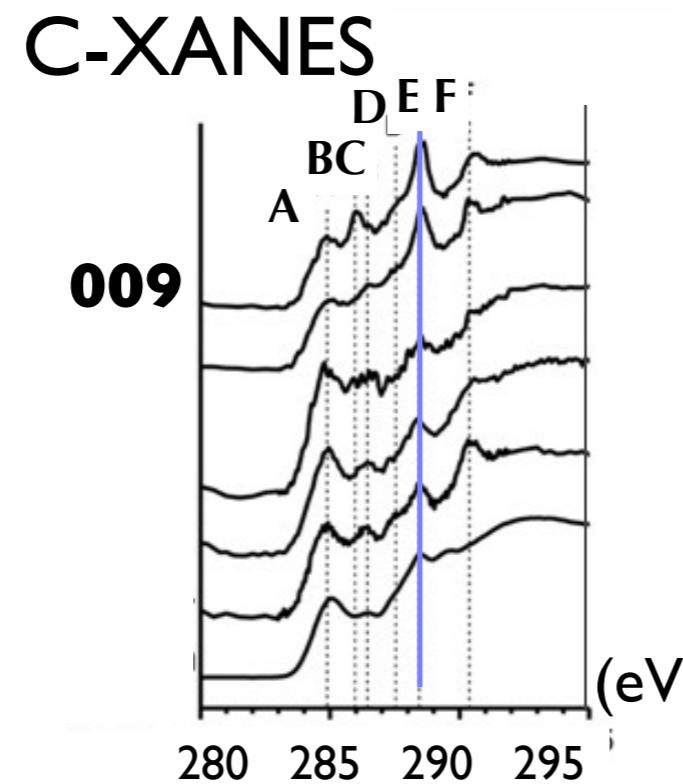
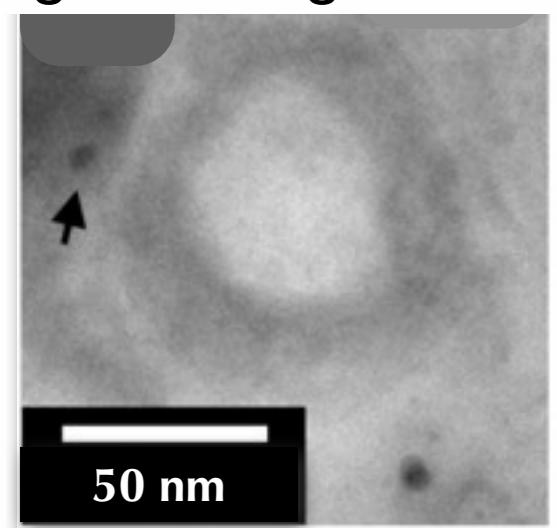
δD hot spot ~5000-10000‰
 $\delta^{15}\text{N}$ hot spot ~500-1000‰

有機物は極低温 (10- 30K) 起源

Stage 0 : 有機物



organic nanoglobule

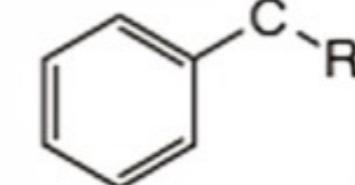
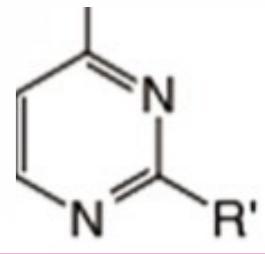


A : aromatic

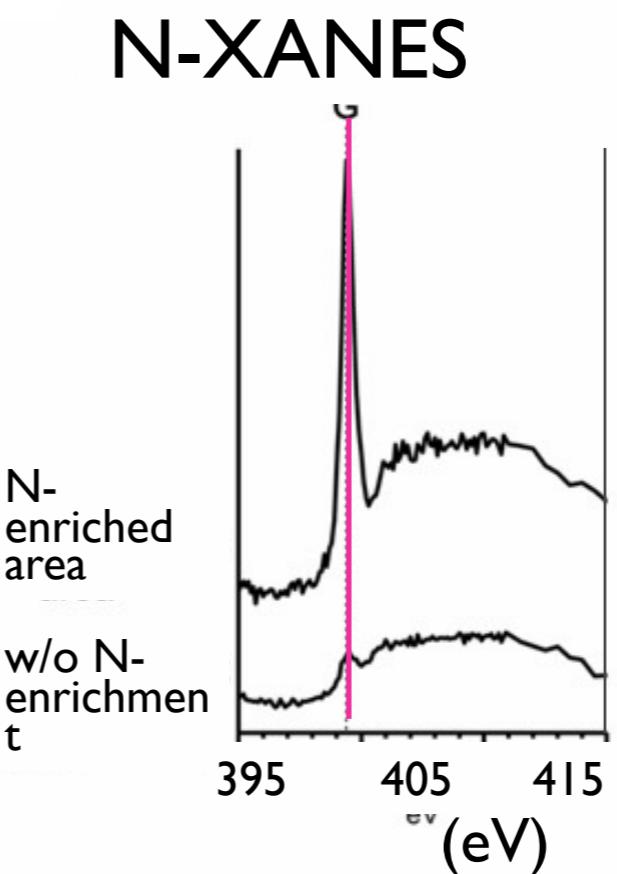
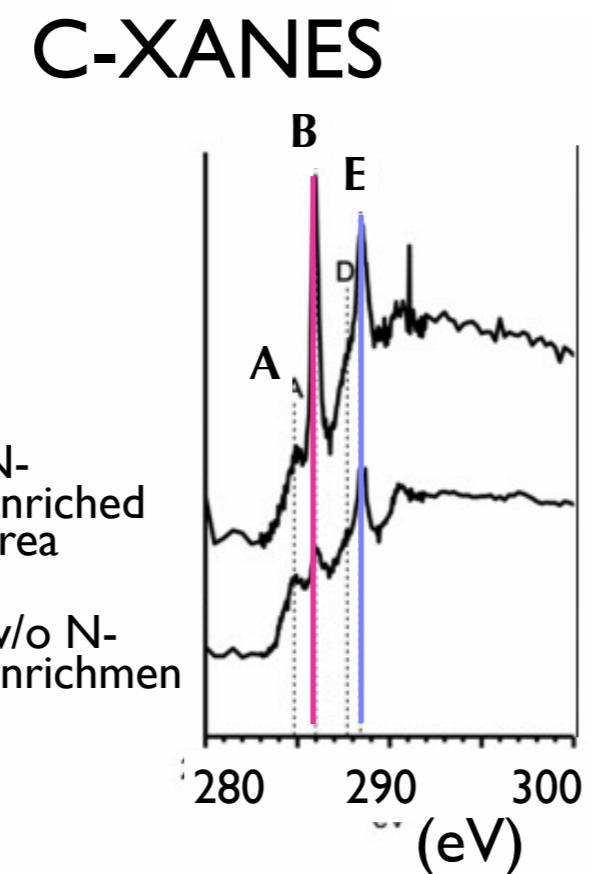


B & G : nitrile / N-heterocycle $\text{C}=\text{N}$ or

C : aromatic ketone

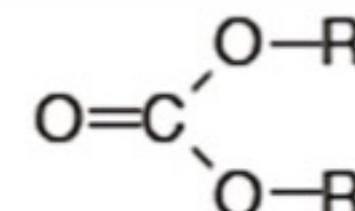


D : aliphatic $\text{R}-\text{CH}_x$

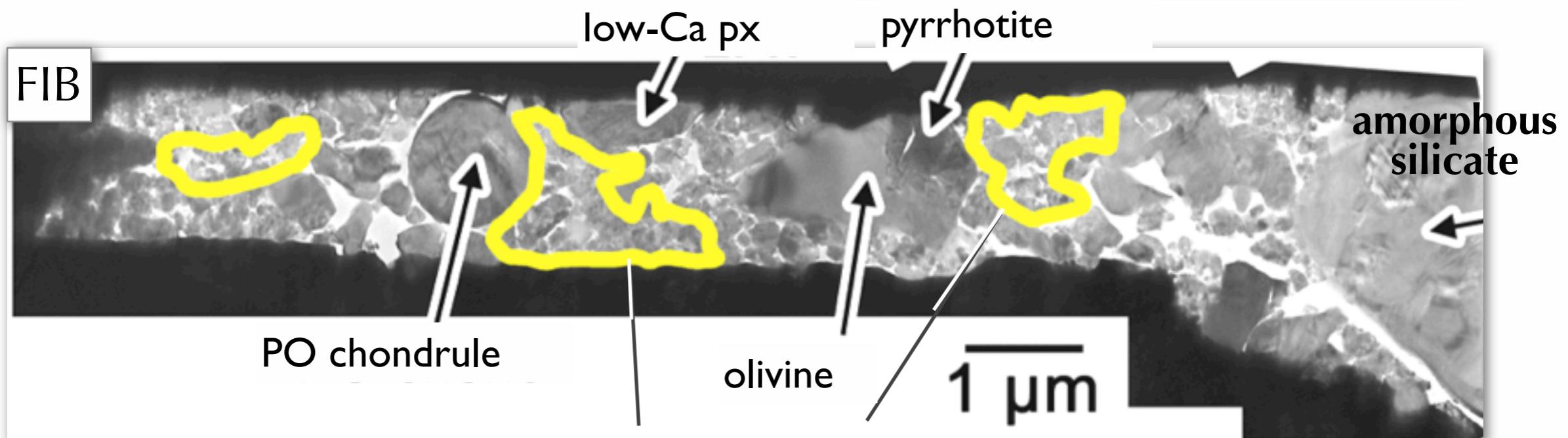
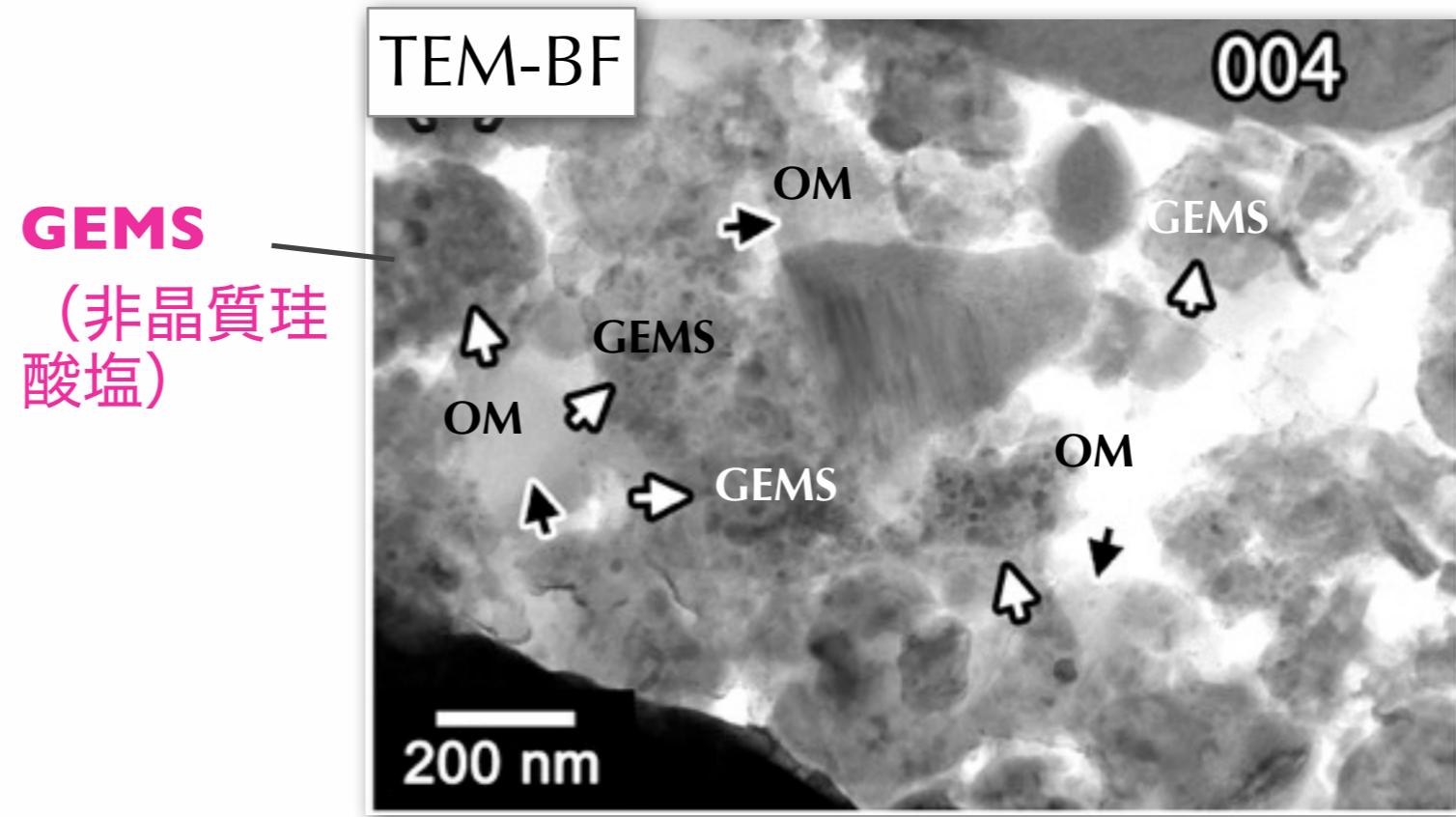
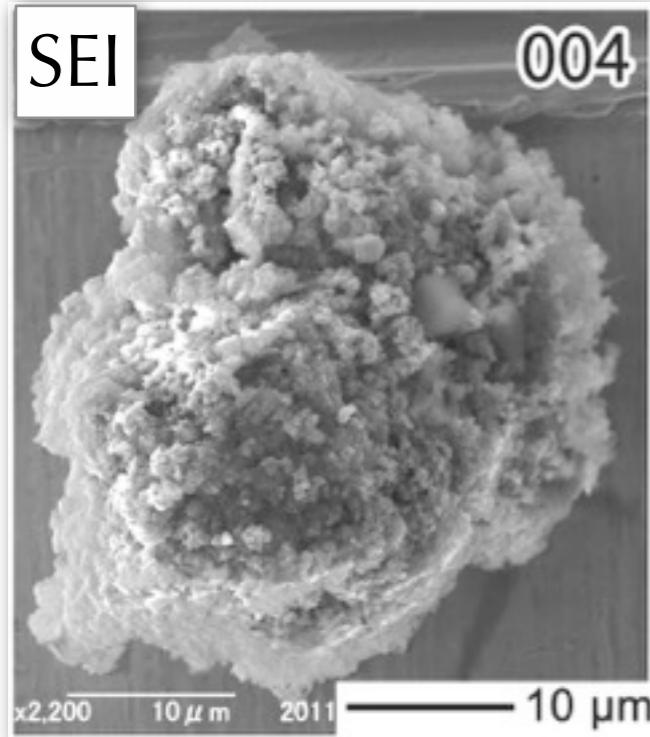


E : carboxyl / carbonyl $\text{R}-\text{COO}-\text{R}'$

F : carbonic acid/ester?

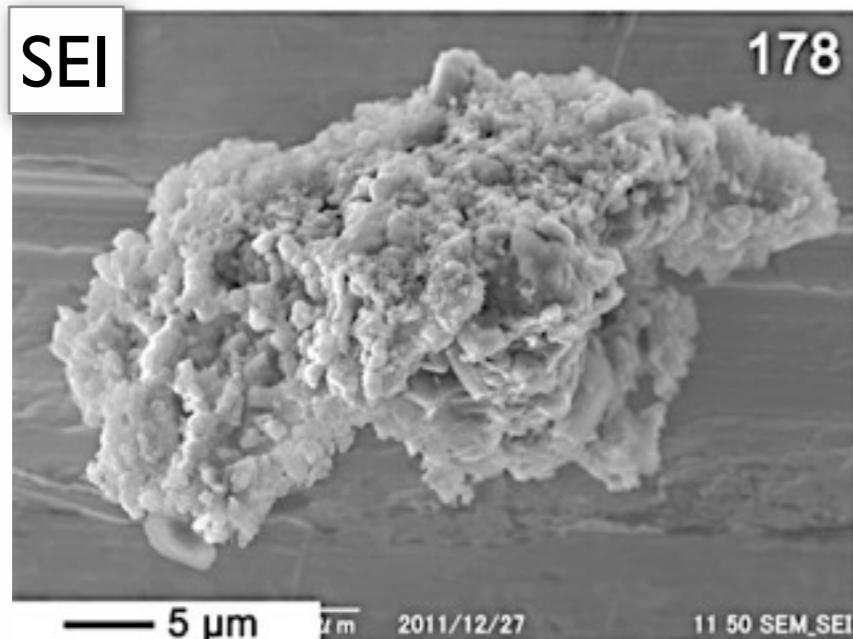


Stage I : DI0IB004 & 064



芳香族有機物, silicate などは Stage 0 と同じ

Stage II : DI0IB178 & 163



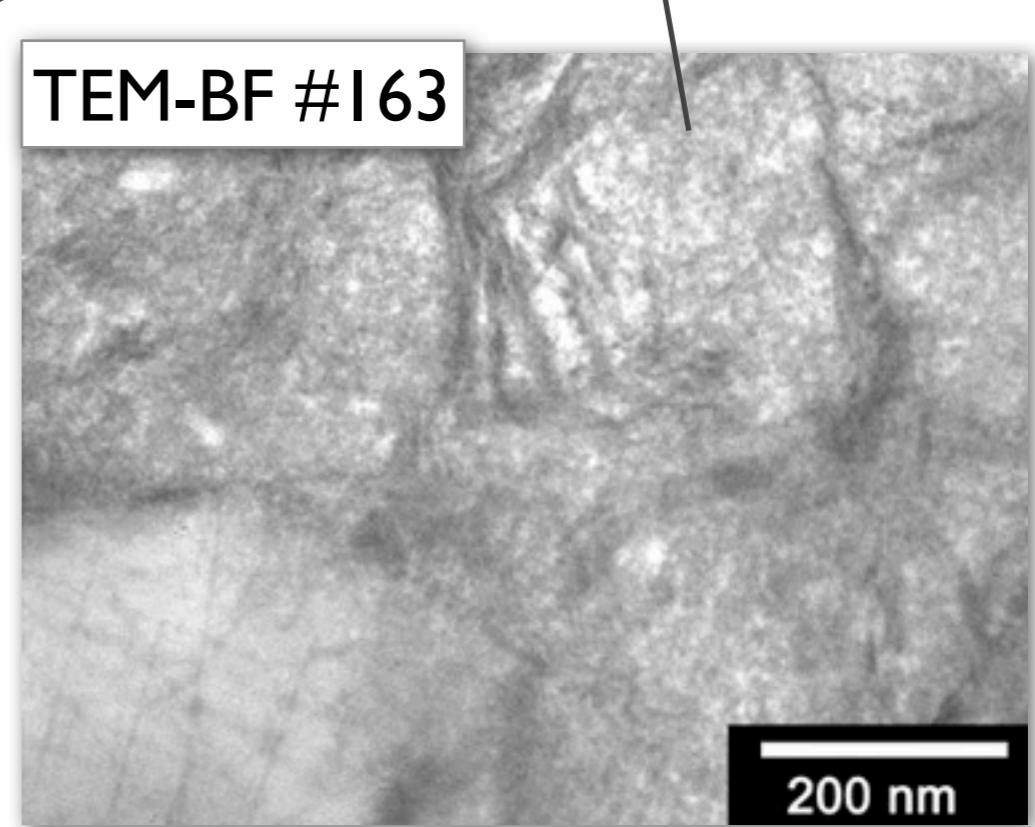
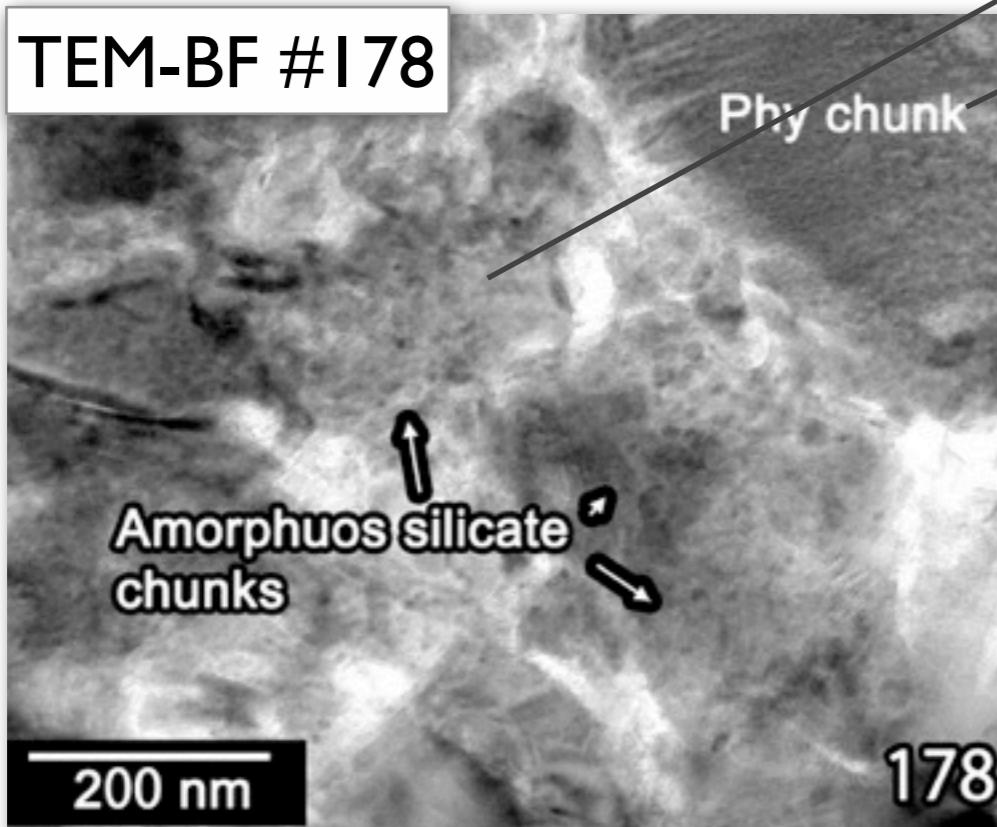
有機物量減少

GEMS (非晶質珪酸塩+Fe+FeS) 消滅

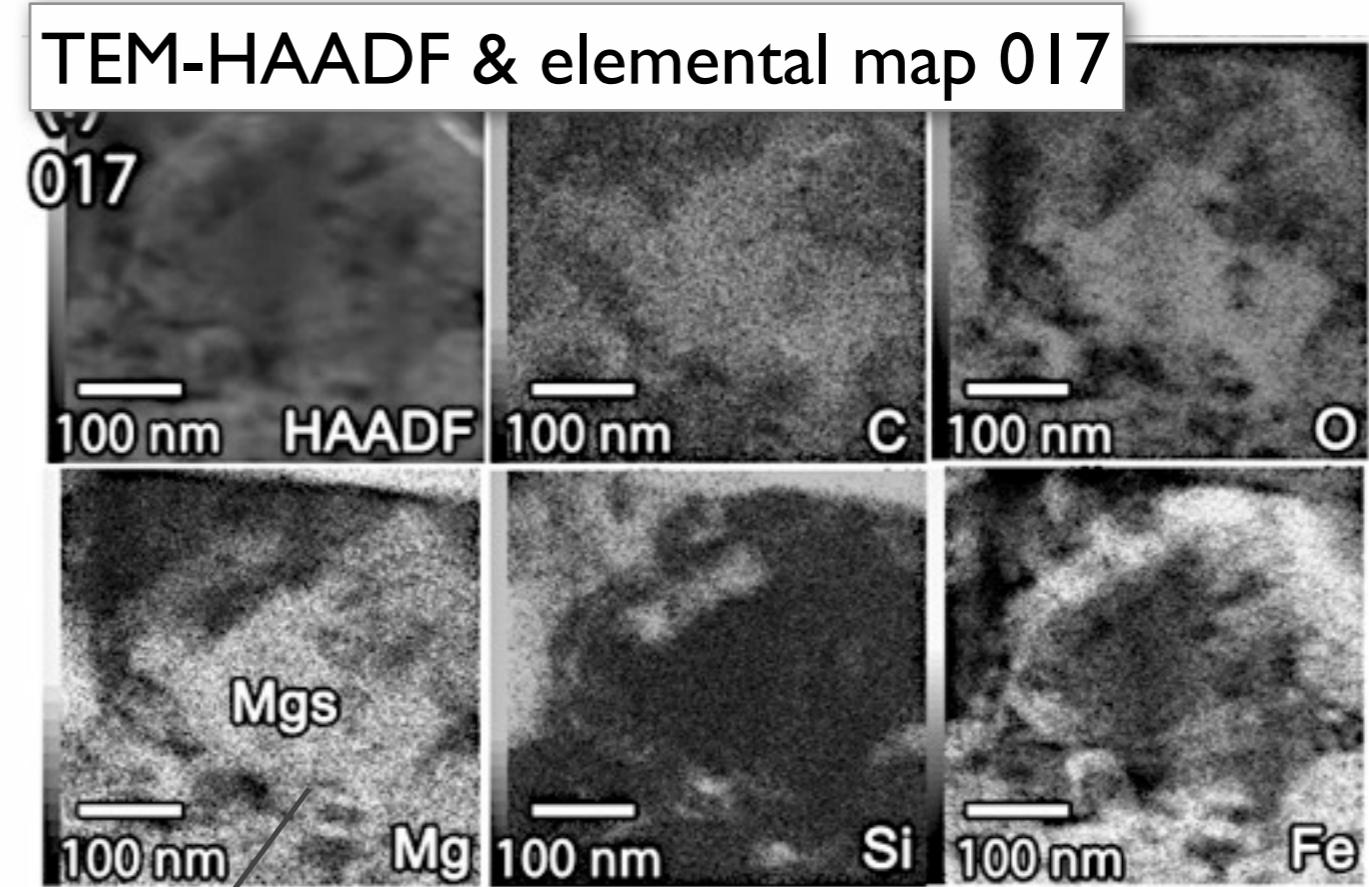
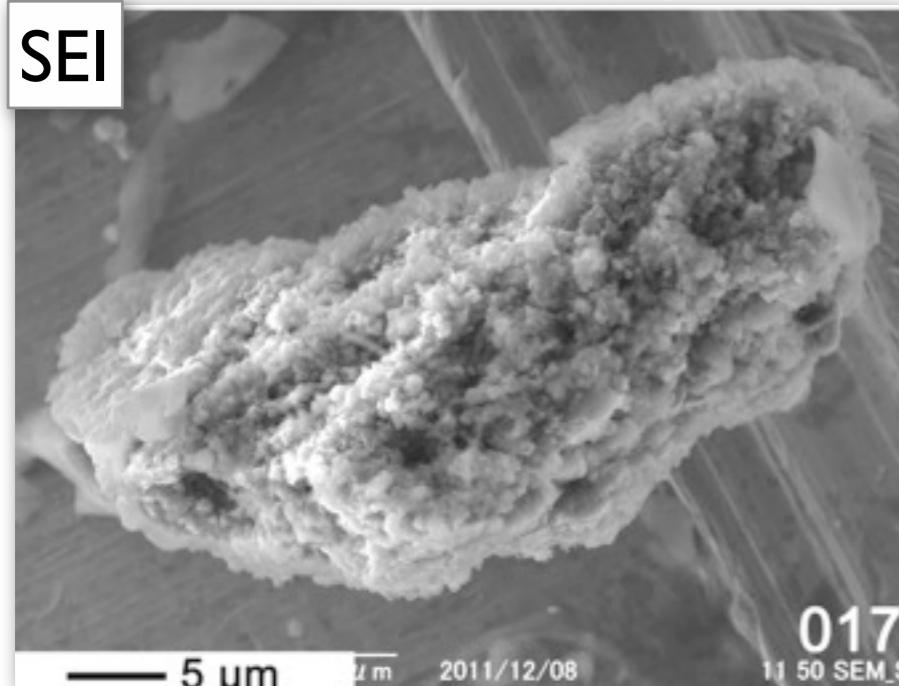
含水 silicate 出現

Fe-rich 非晶質 silicate

Fe-rich 粘土鉱物 (含水)



Stage III : D101B017 & 087

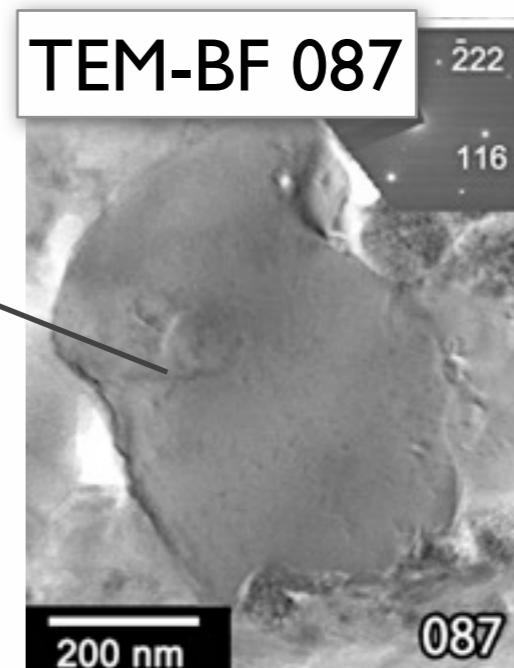


炭酸塩鉱物

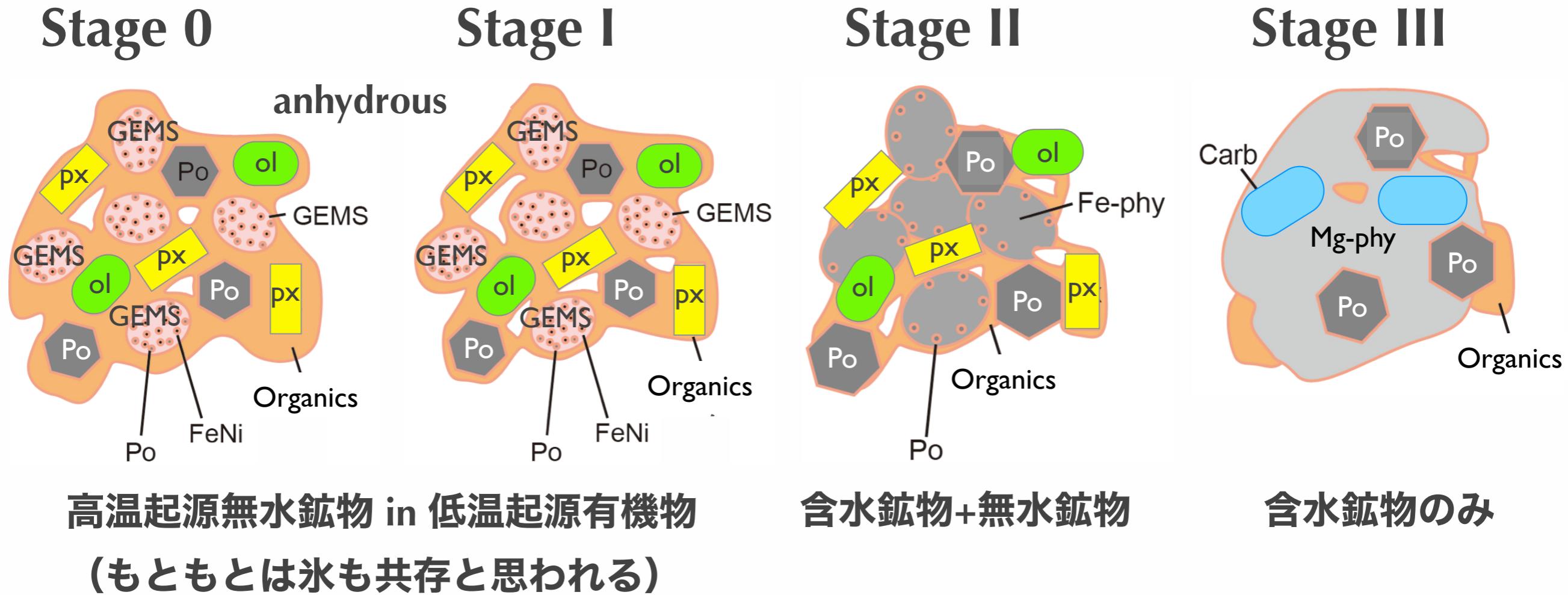
無水 silicate 鉱物消滅

Mg-rich 粘土鉱物 (含水) 出現

TEM-BF 087



初期物質と水質変成の進行



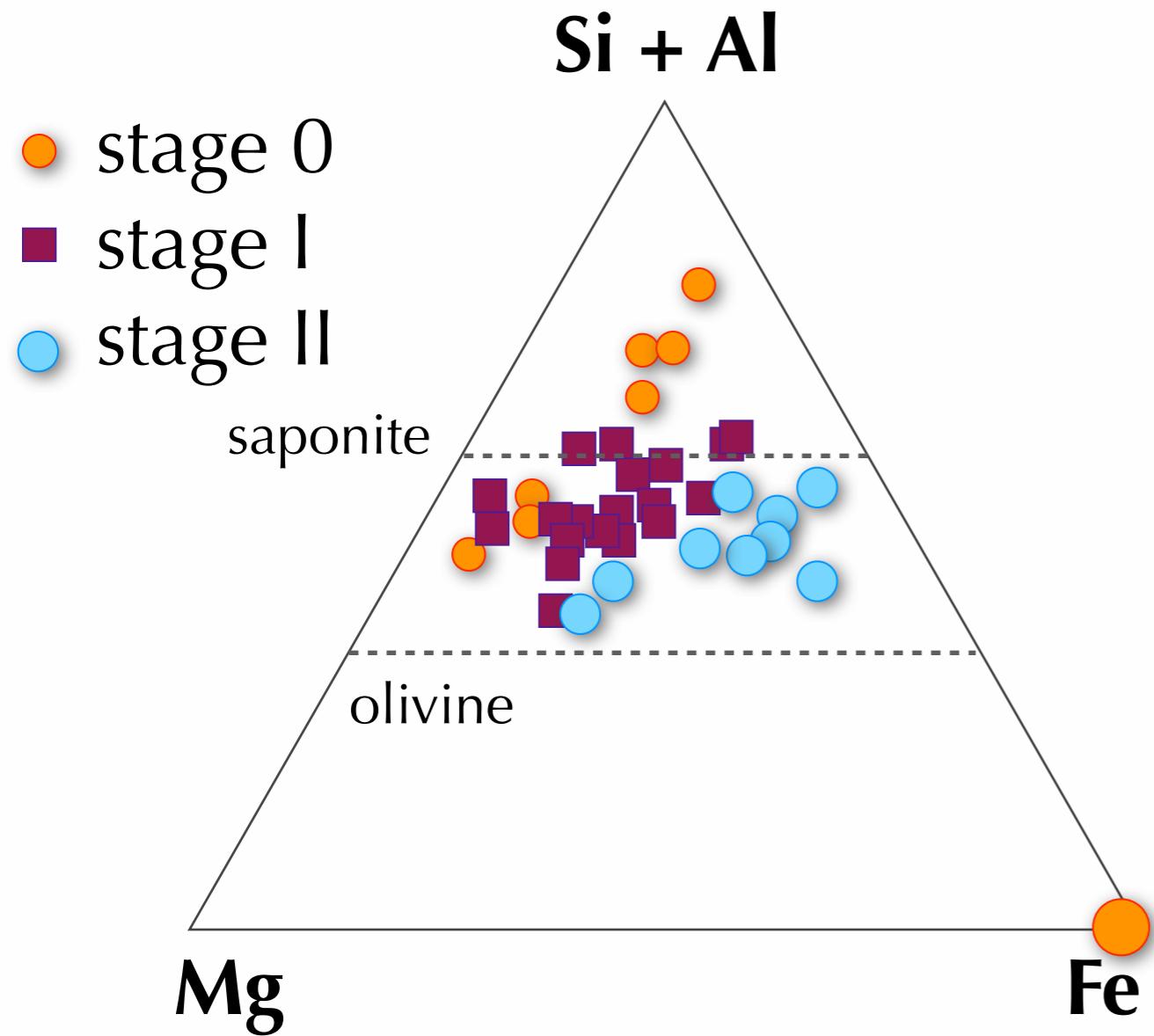
Stage 0 -> I organics carboxyl/carbonyl --> aromatic (in H₂O?)

Stage I -> II GEMS (amorphous-silicate + FeS) + H₂O --> Fe-phylllo + S²⁻

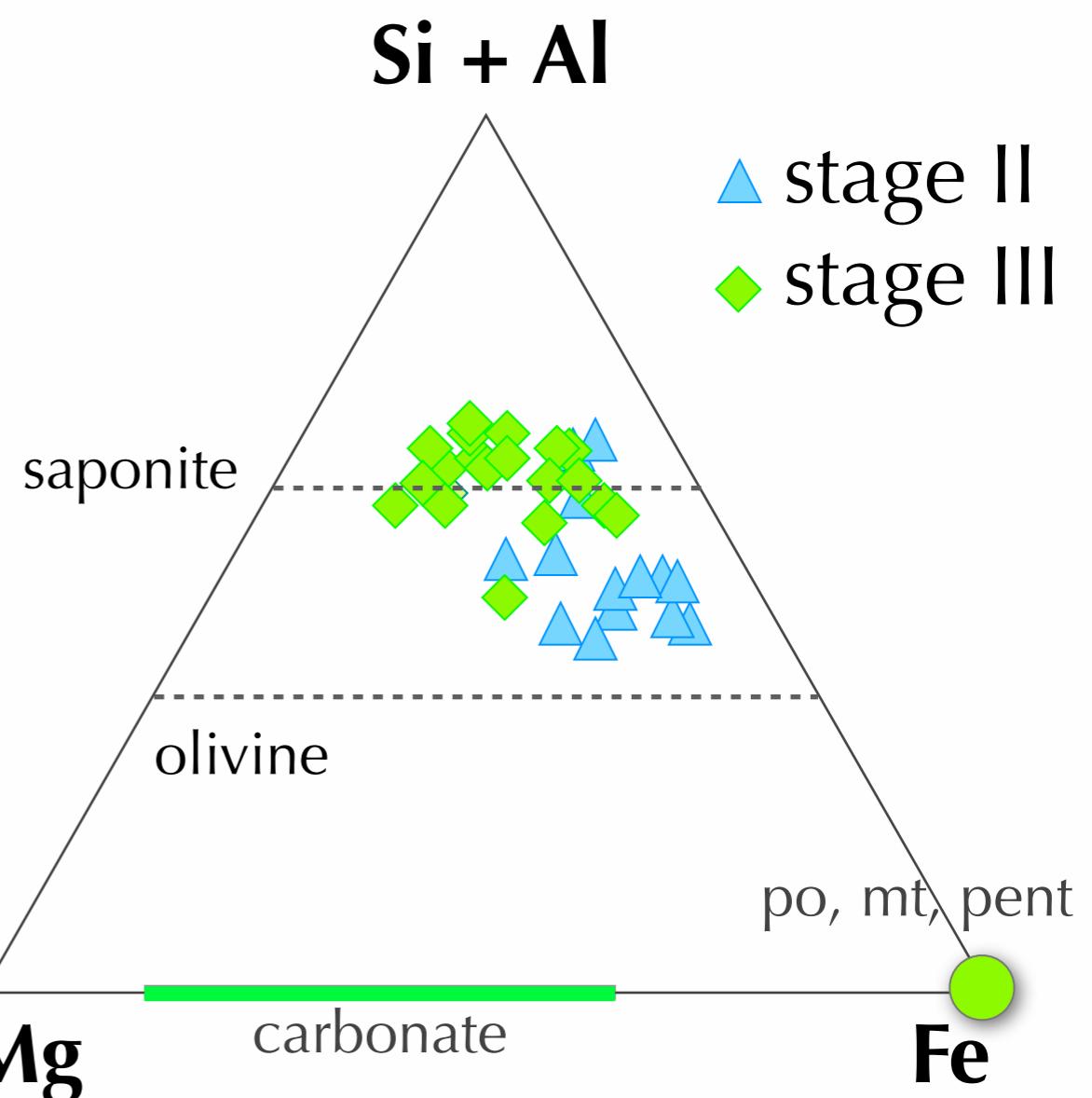
Stage II -> III Fe-phylllo + ol + px + H₂O + C --> Mg-phylllo + carbonate

珪酸塩物質化學組成變化

GEMS + amorphous silicate

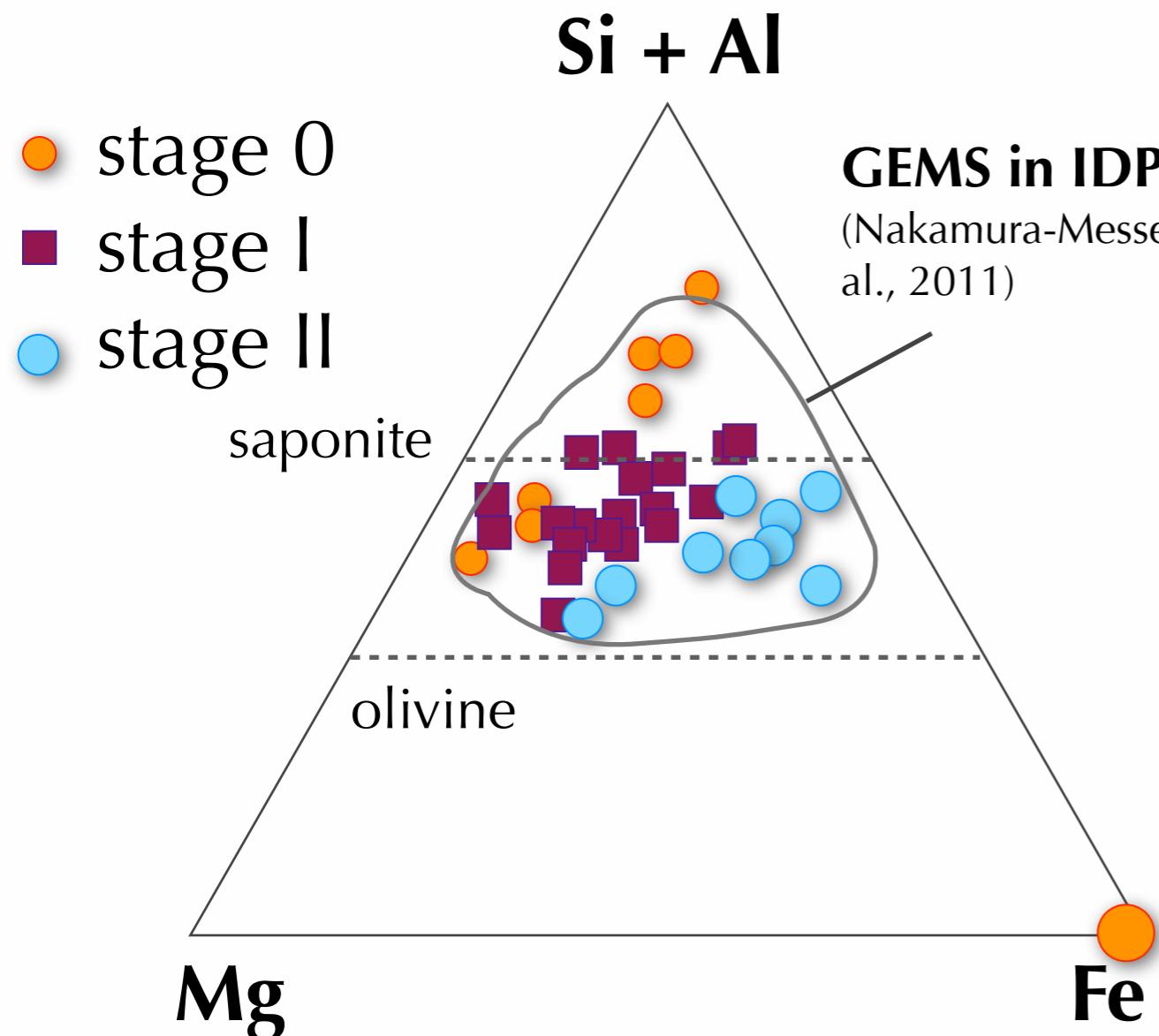


phylllosilicate

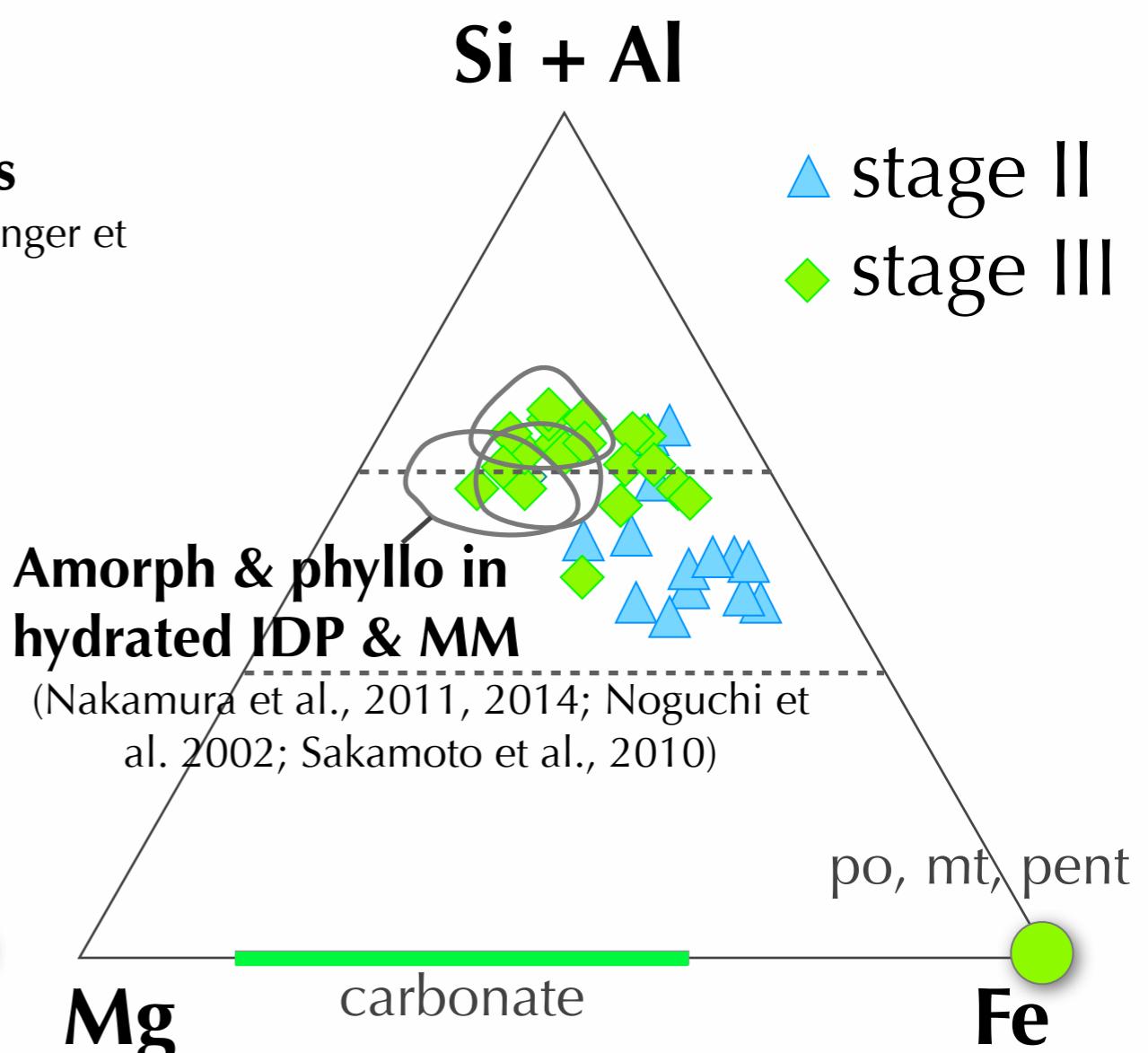


従来の彗星塵組成との比較

GEMS + amorphous silicate



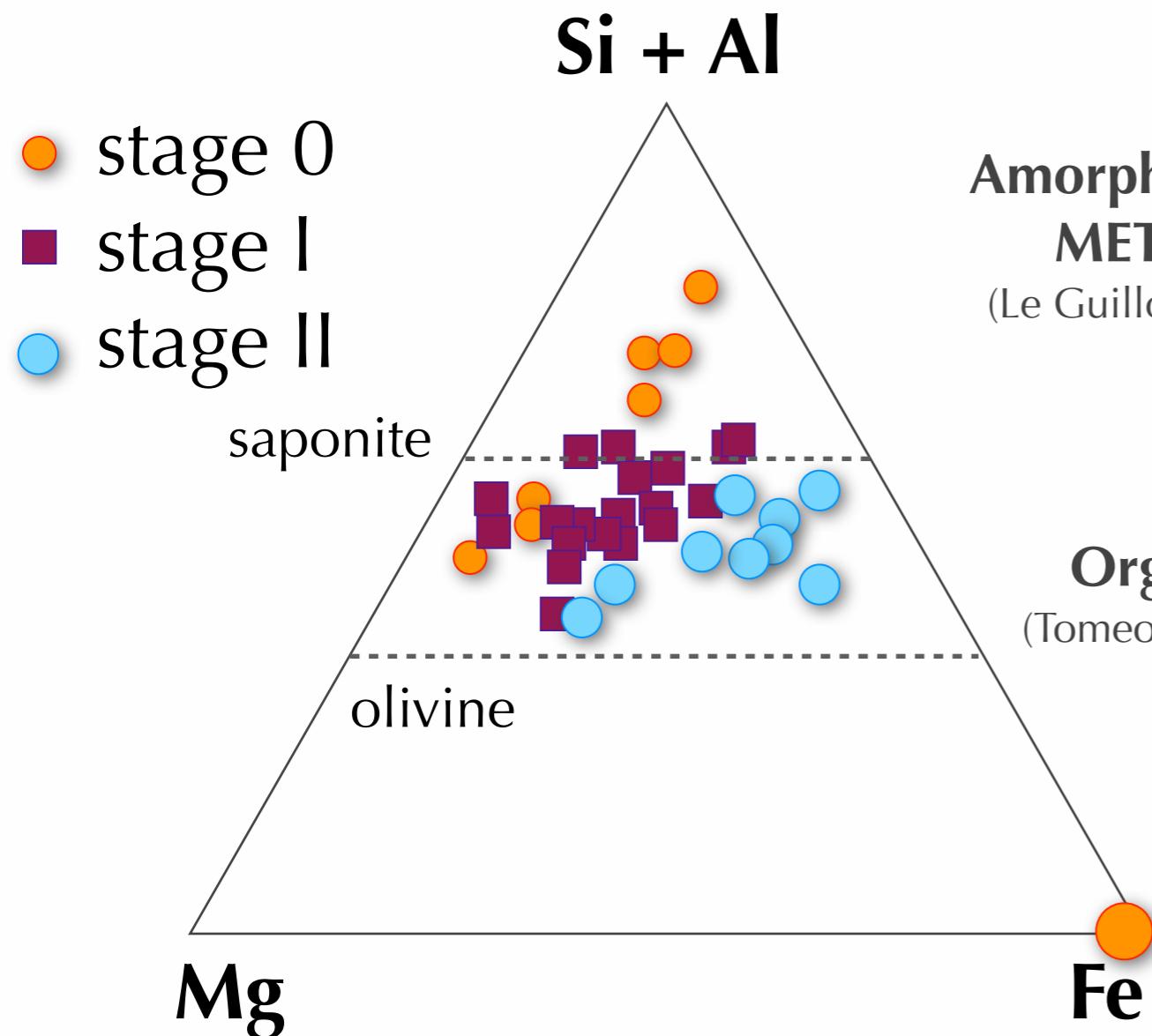
phylllosilicate



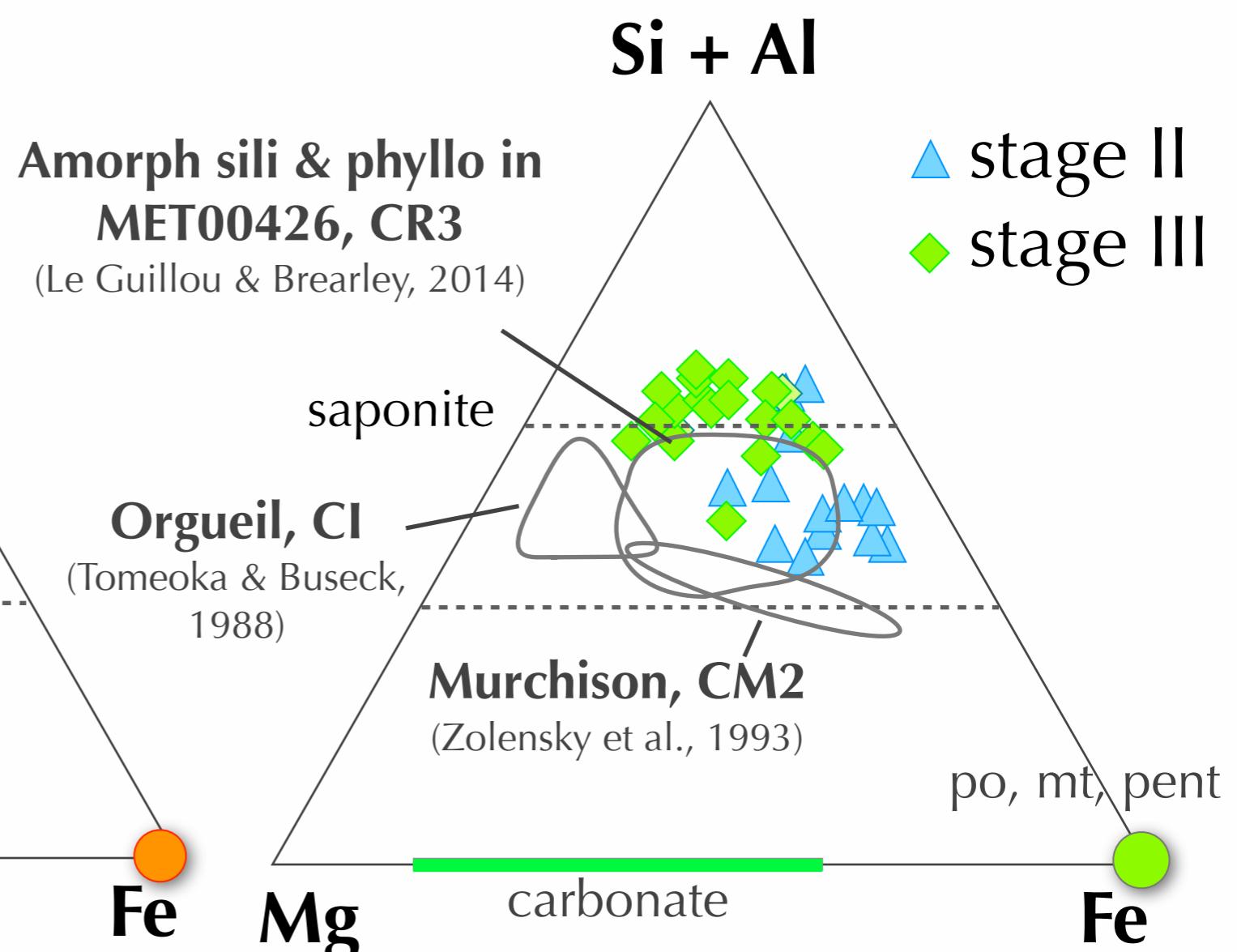
従来の IDP 中 GEMS の報告値：
様々な程度の水質変質のものを含む,
もっとも初生的なものは Fe に乏しい

炭素質コンドライトとの比較

GEMS + amorphous silicate



phylllosilicate



- comet の phylllosilicate : 炭素質コンドライトと異なる
- もともとの有機物の多さ -> 炭酸塩鉱物

micrometeorites まとめ

- 彗星塵：われわれが手にしうるもっとも始原的物質（微隕石）
- 構成物質：高温起源珪酸塩鉱物（結晶質・非晶質）+ Fe 微粒子 + FeS 微粒子 in 極低温起源有機物 (+ 氷)
- 水質変性：従来は彗星では水質変性は起きていないと考えられていたが、実はおきていた

67P/Churyumov–Gerasimenko

- $\rho = 0.4 \text{ g cm}^{-3}$, dust/ice = 0.4 - 2.6, porosity = 75 - 85 % [Kofman et al., 2015]
- low thermal inertia ($10 - 50 \text{ J K}^{-1} \text{ m}^{-2} \text{ s}^{-0.5}$) [Gulkis et al., 2015]
 - > 表面ダスト層 mm 程度 [von Allman et al., 2016]
- 表面有機物：高分子, 各種 C-H, O-H [Capaccioni et al., 2015], -CH₂- -O- [Wright et al., 2015], N-bearing species [Goesmann et al., 2015],
- H₂O, CO₂, CO : 異なる所から噴出 [Migliorini et al., 2016; Mall et al., 2016; Vincent et al., 2015]
- Ice-rich area, CO₂-rich area [Filacchione et al., 2016]
- D/H=(5.3+/-0.7)x10⁻⁴, ¹⁸O/¹⁶O=556+/-62, ¹⁷O/¹⁸O=2703+/-657 : 地球と同じ [Altwegg et al., 2015]
- N₂, Ar [Mousis et al., 2016]
- 23Na, 28Si, 39K, 40Ca : CI, CV と異なる [Wurz et al., 2015]
- 磁場 : 放出したH₂O+ とsolar wind の相互作用 [Aiho et al., 2016 ; Volwerk et al., 2016; Nilsson et al., 2016; Goetz et al., 2016; Koenders et al., 2015]

8 I P/wild 2

- 構成物質：最高溫起源珪酸塩鉱物 + chondrule 破片 + stardusts + organics
 - > 円盤内大規模物質輸送
- 同位体：太陽系

Contents

- 始原的物質
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考えるべきこと

- 構成物質：高温起源珪酸塩鉱物（結晶質、非晶質）+ Fe微粒子 + FeS 微粒子 in 極低温起源有機物 (+ 氷)
 - > 原始惑星系円盤内ダスト混合
- 水質変性：従来は彗星では水質変性は起きていないと考えられていたが、実はおきていた
 - > comet に液体の水が存在する条件

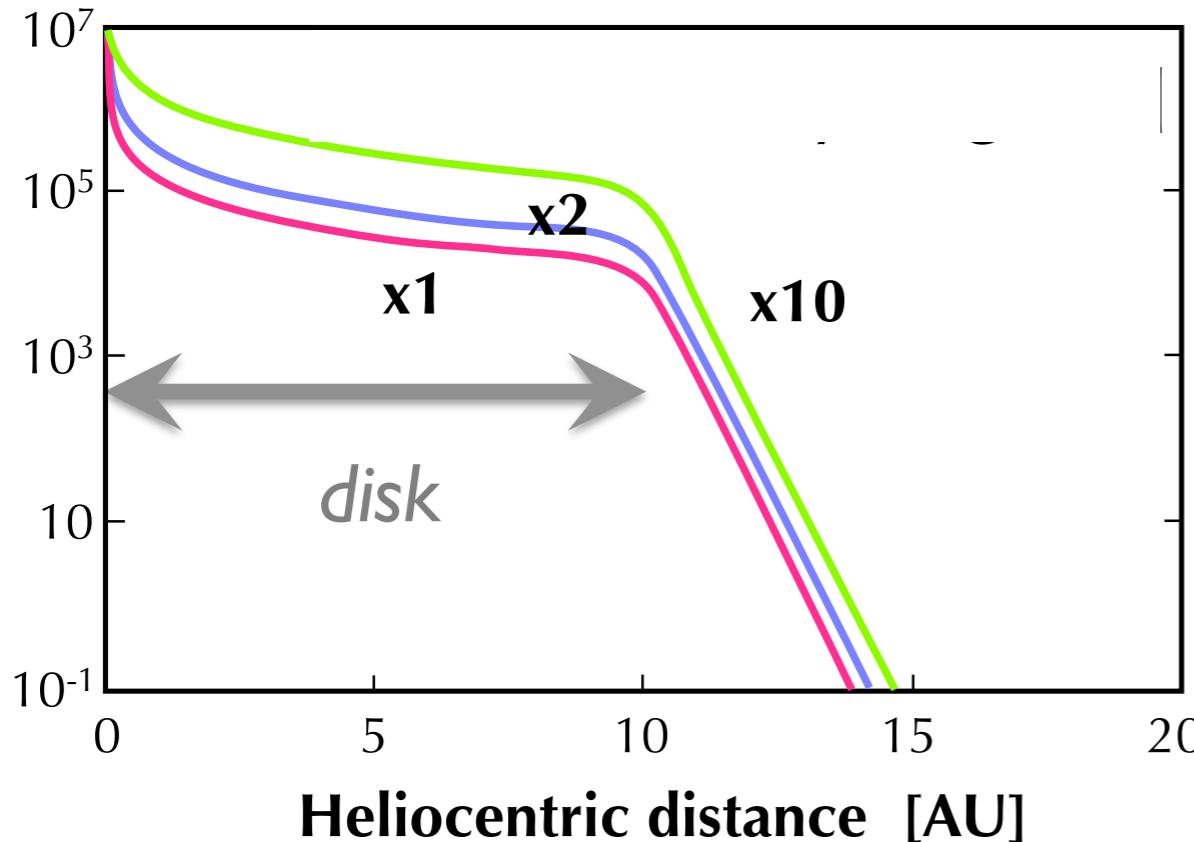
モデル

- Radial transportation of dusts with particle tracking model (Ciesla, 2010, 2011), where movement of individual dust particle is tracked through disk evolution
- Disk P (surface density) - T evolution
- H₂O ice sublimation limit (= conditions for coagulation of dusts to pebble or larger bodies)
- Evolution of radial mixing of dry and wet particles
- Conditions (when and where) for comet formation

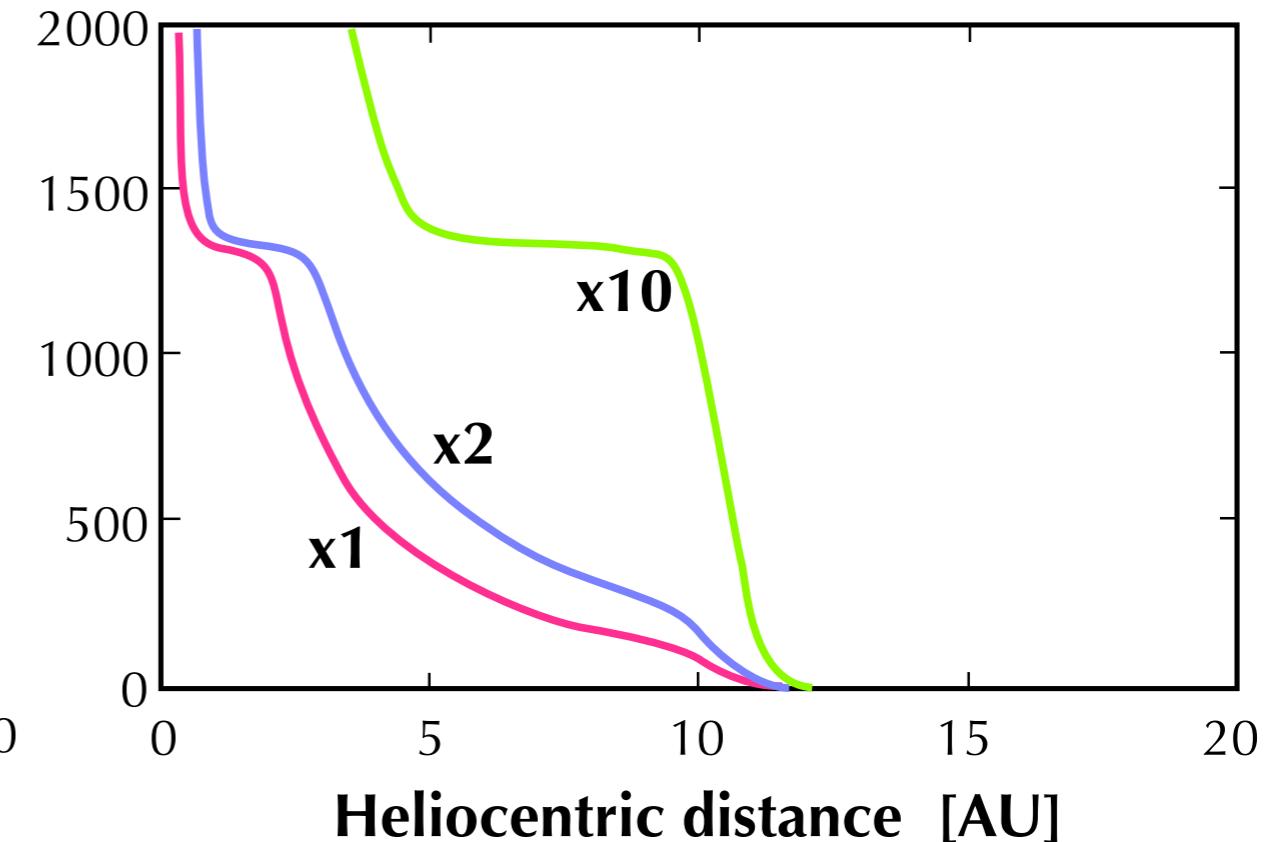
Disk model

- 1D
- α disk ($\alpha = 10^{-3}$)
- $M_{\text{disk}} = (1-10) \times M_{\odot}$ ($x1 = 0.1 M_{\odot}$)
- no disk accretion, no dust coagulation
- dust = 1 μm

Initial surface density



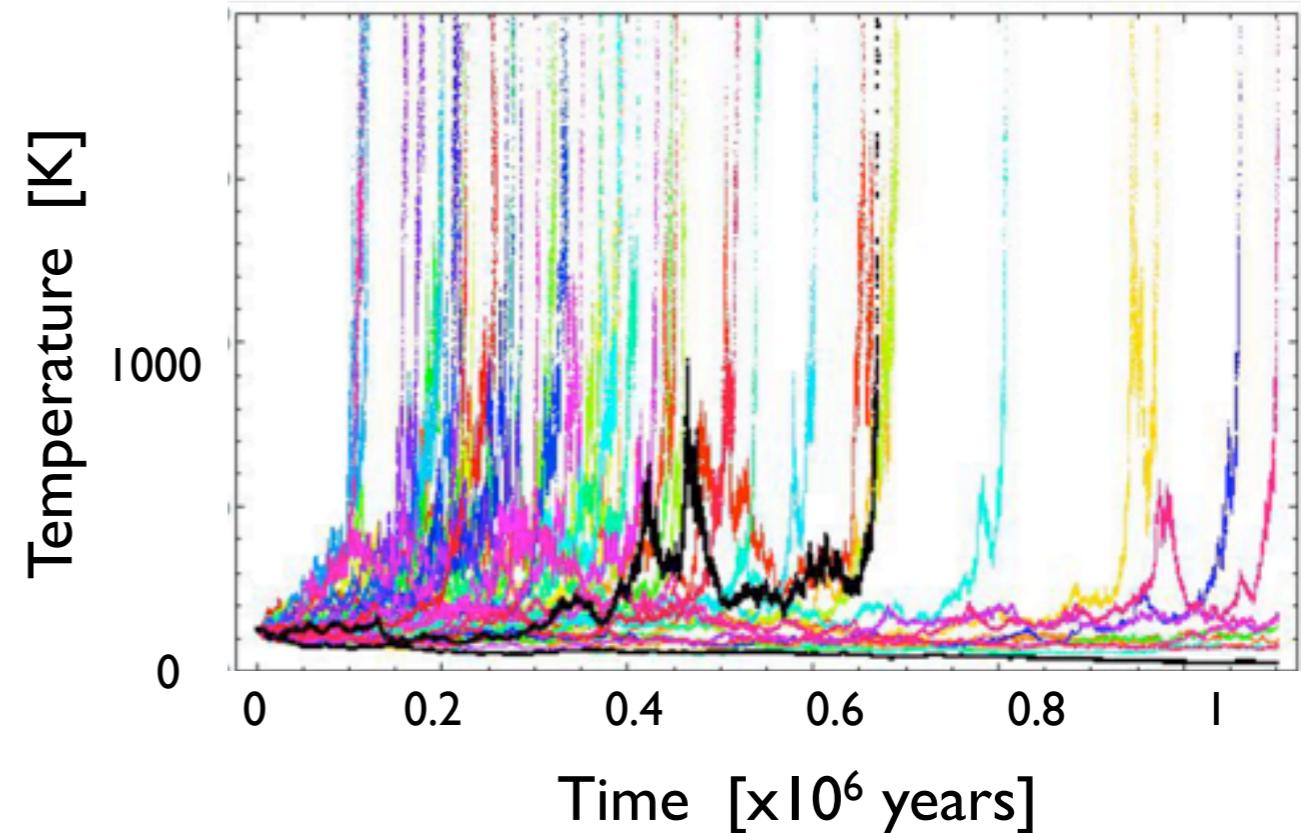
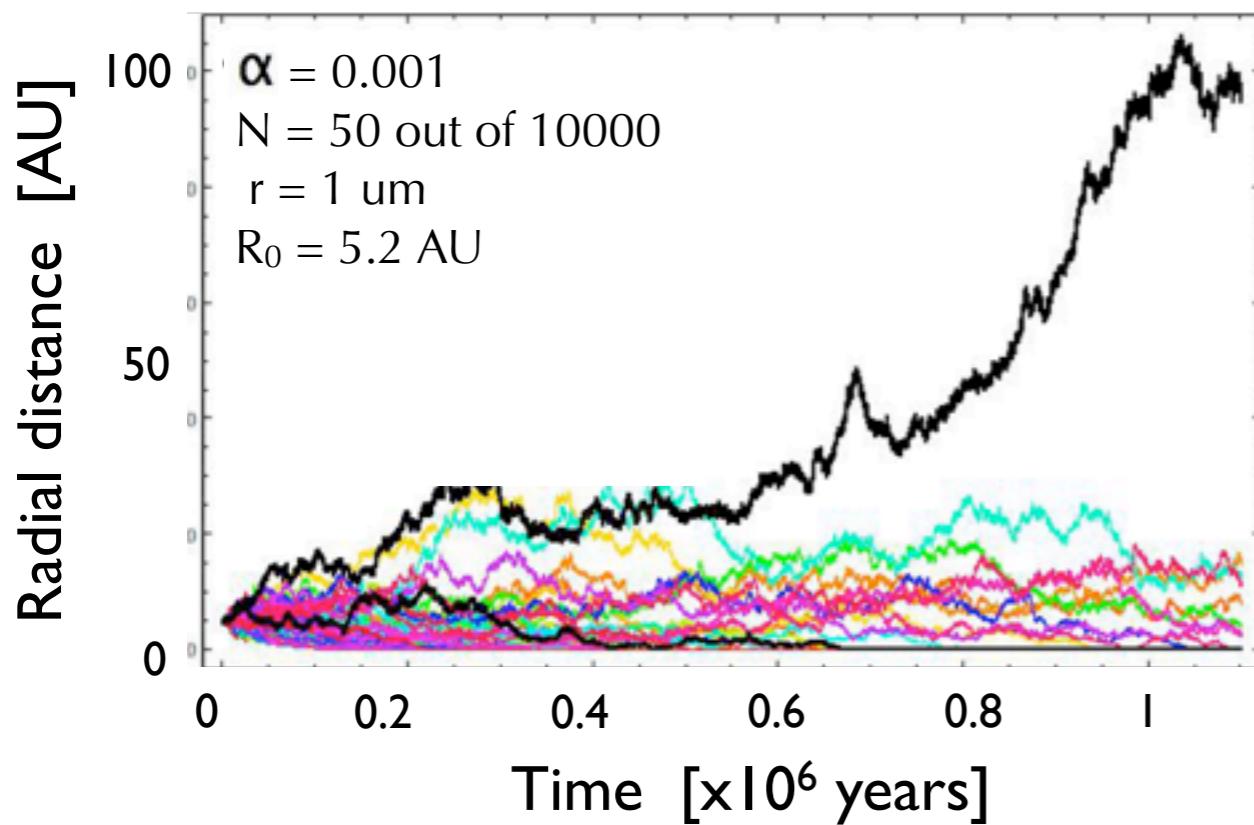
Initial temperature



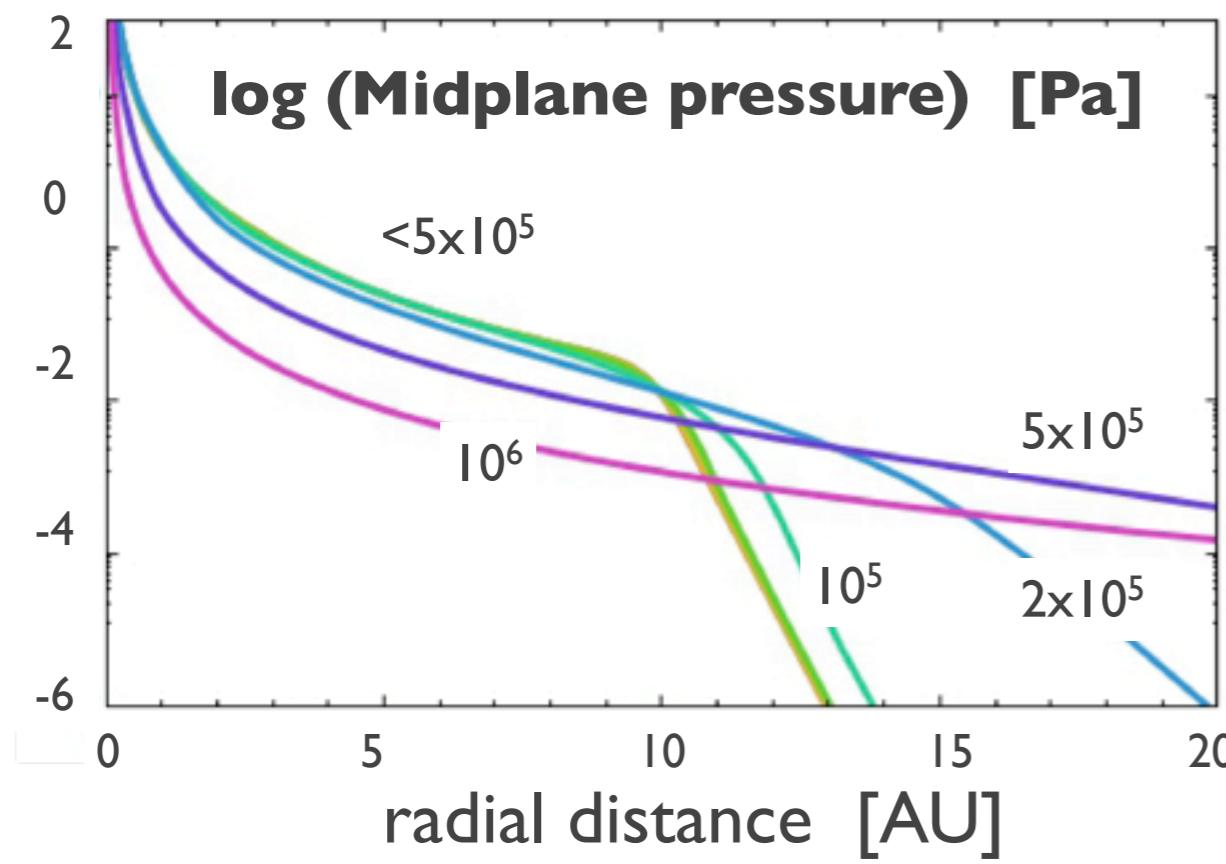
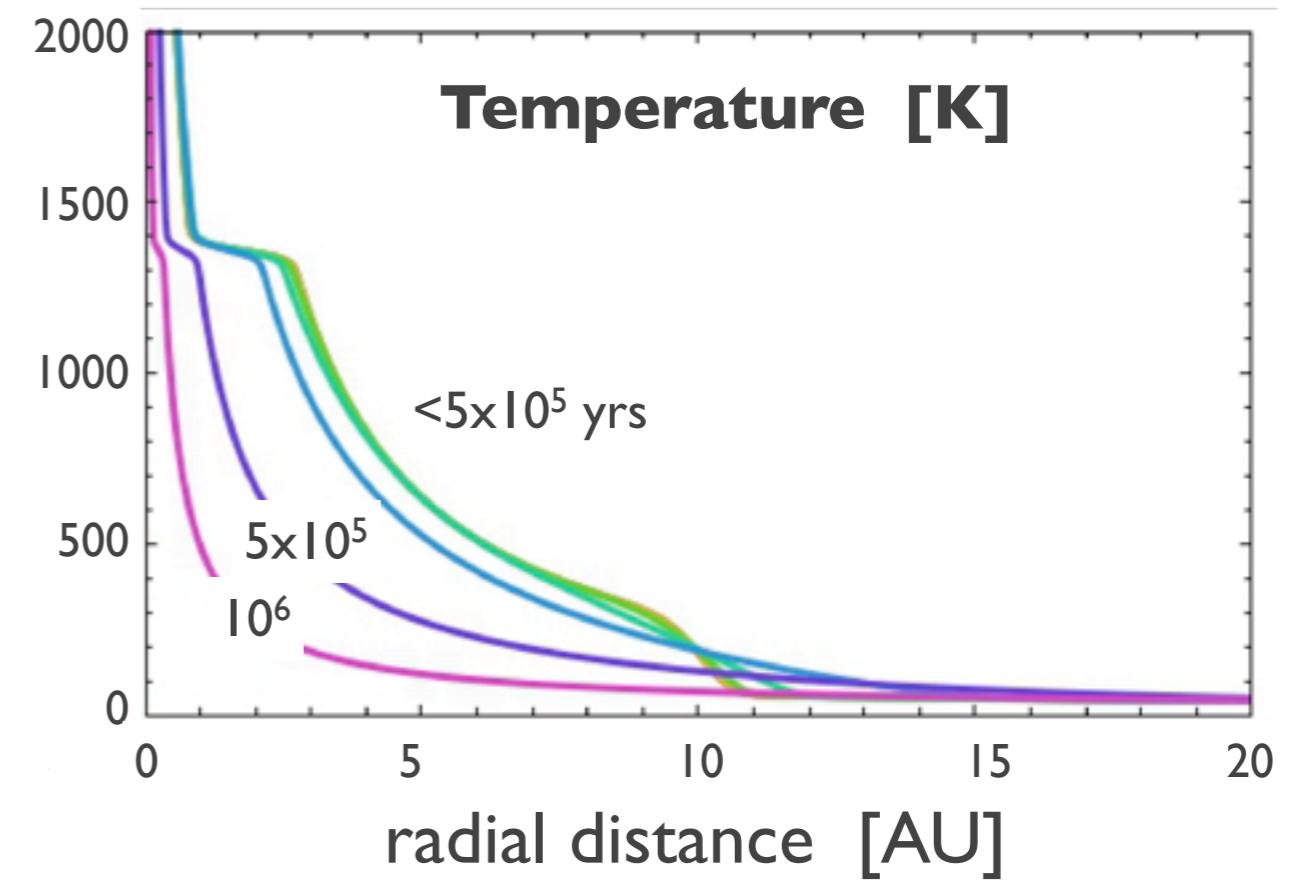
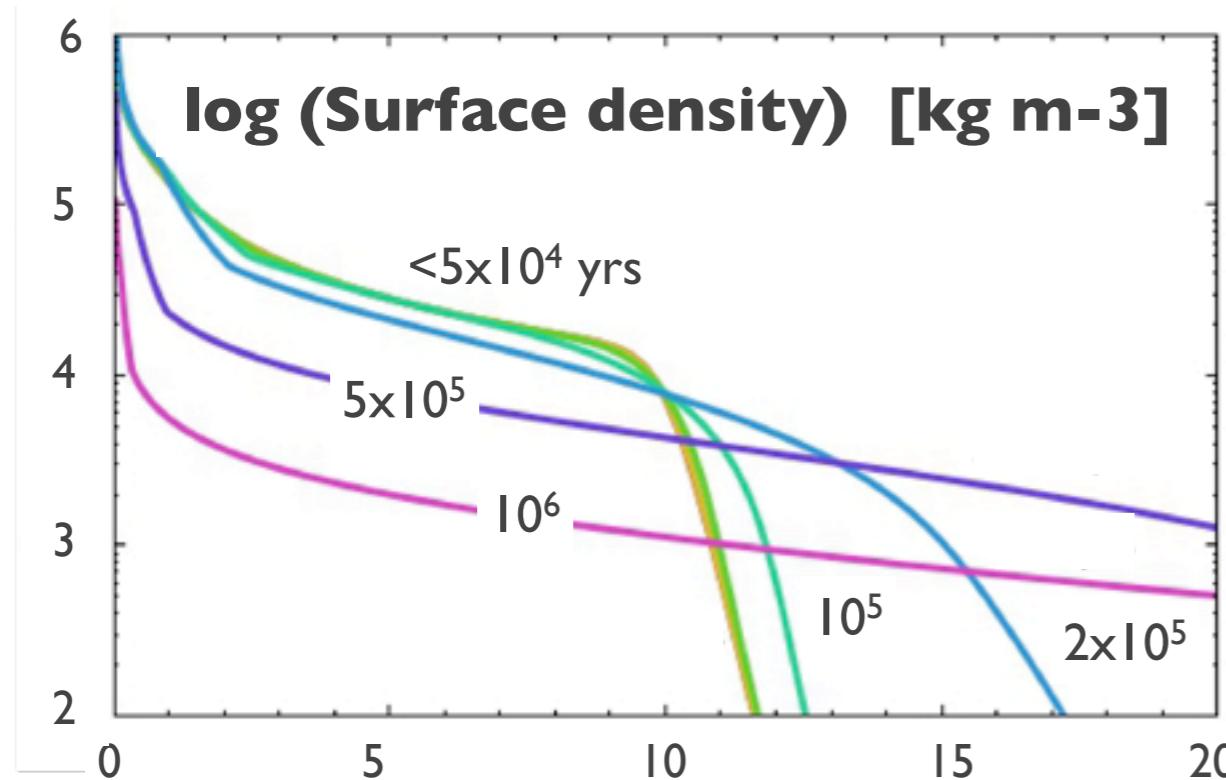
Particle Tracking

radial advection-diffusion equation with the Lagrangean specification to trace the trajectory of individual grains

track **R-T-P-t trajectory** of individual grains
(1,000,000 - 10,000,000 particles)



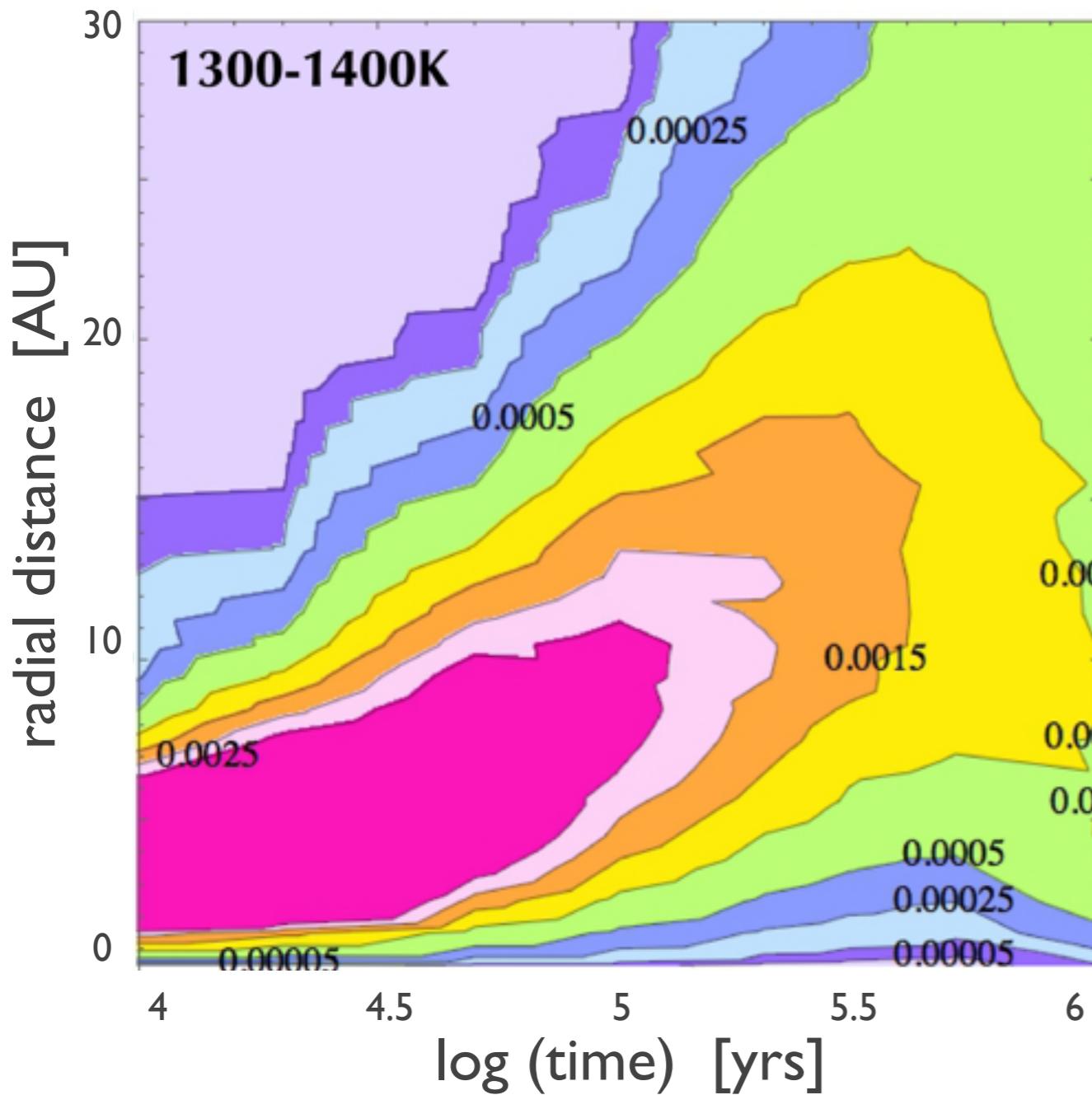
Disk Evolution



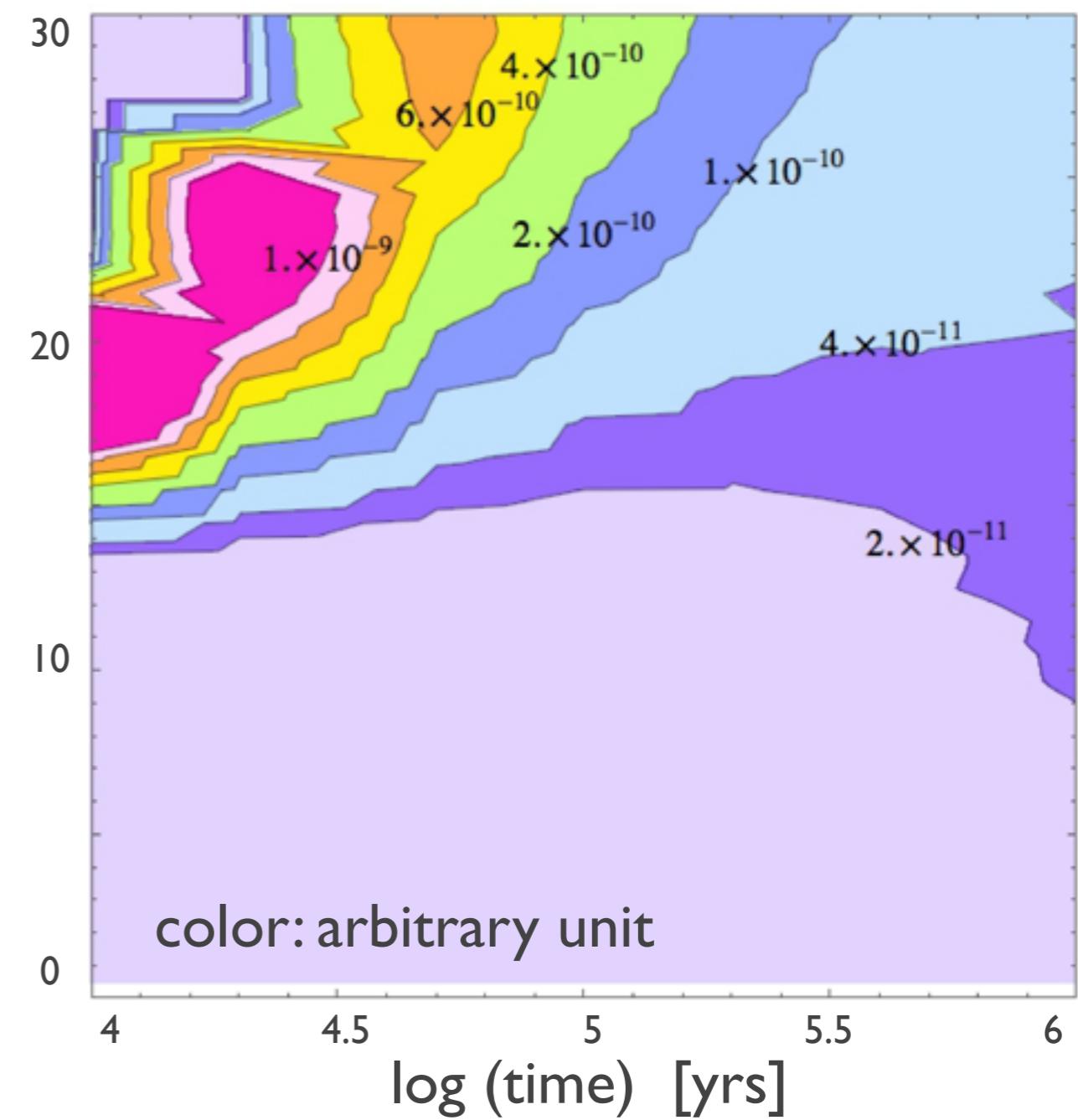
$M_{\text{disk}} = 0.1 M_{\odot}$, $\alpha = 10^{-3}$

High-T Silicates and Ice-bearing Dusts

High-T dusts

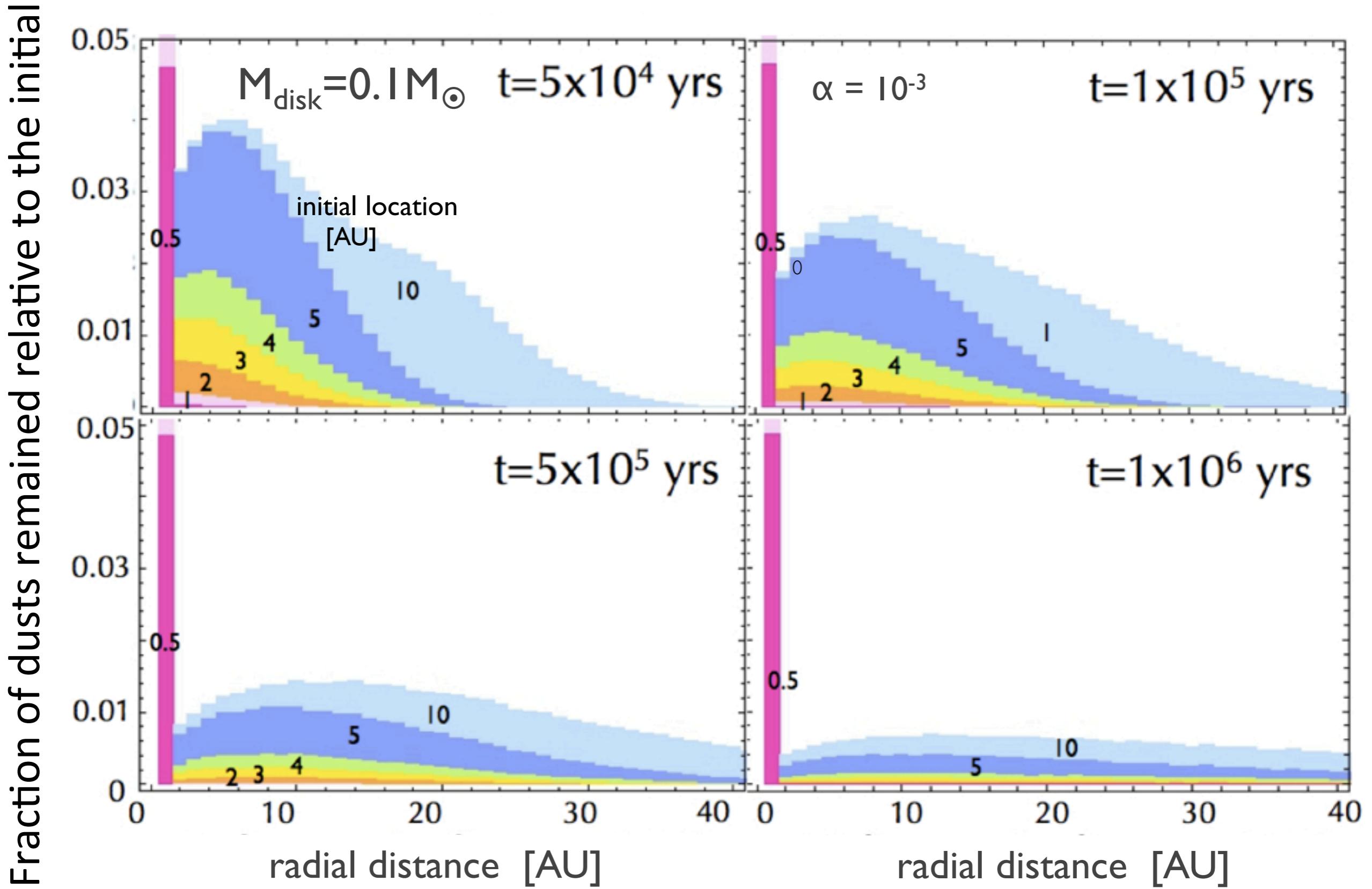


Ice-bearing dusts



Mixing of high-T and ice-bearing dusts : beyond ~ 20 AU before 10^5 yrs

Radial Mixing



Conditions for Comet Formation

✓ **Coagulation to pebble : $T < 160K$**

aqueous alteration needs liquid H₂O

sublimation of H₂O in proto-solar disk

$\sim 160 \text{ K} @ P_{\text{tot}} = 10^{-4} \text{ Pa}$

< stability of **liquid H₂O** (273K)

coagulation in the outer region of the disk

✓ **Aqueous alteration at Stages I and II :**
 $T \sim 0^\circ\text{C}$ for < a few days

very quick formation of phyllosilicates from GEMS

experimental work by Nakamura-Messenger et al, (2011)

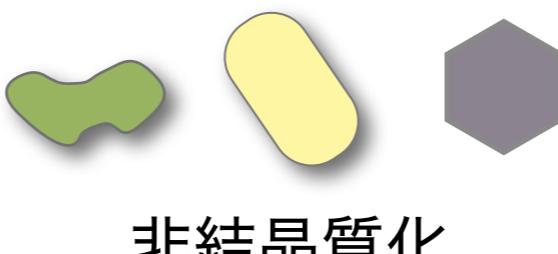
transient heating of porous pebble

まとめ

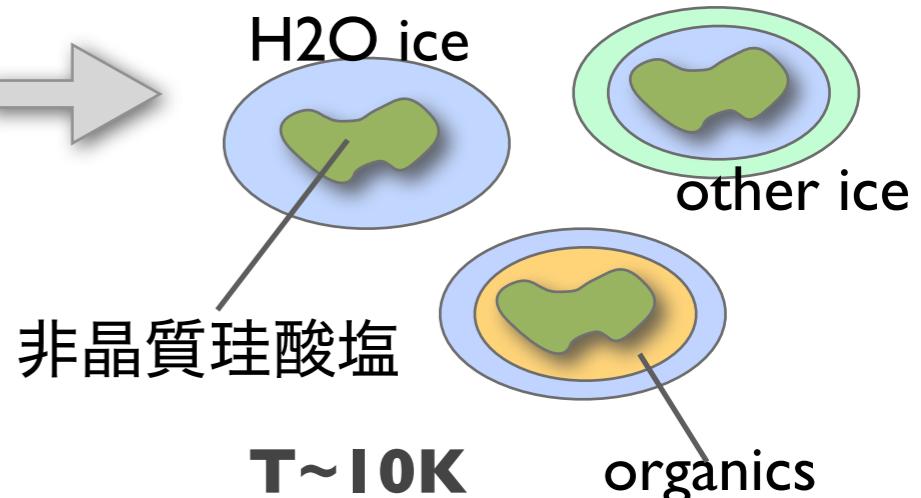
AGB, RG, SNe



interstellar



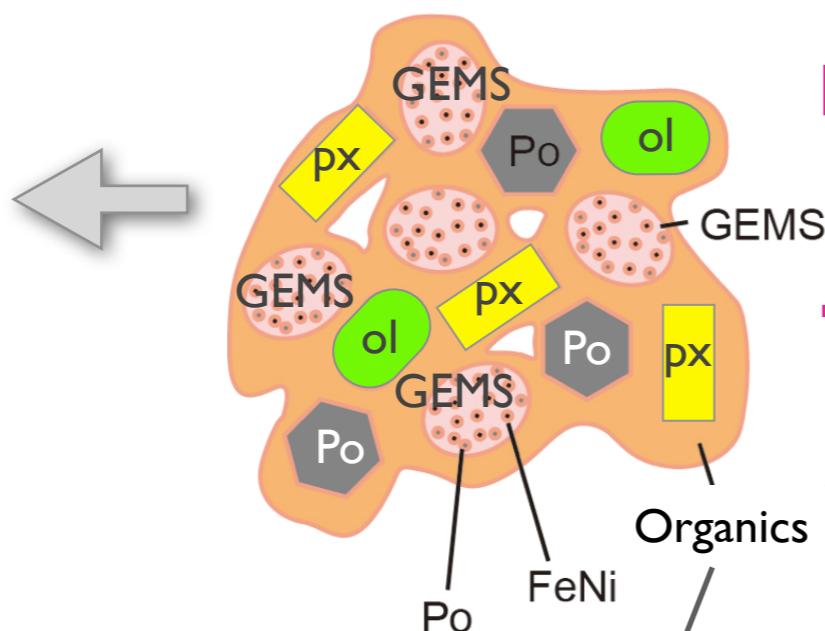
prestellar core



planet formation

PPD

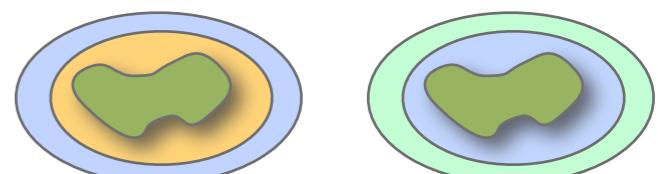
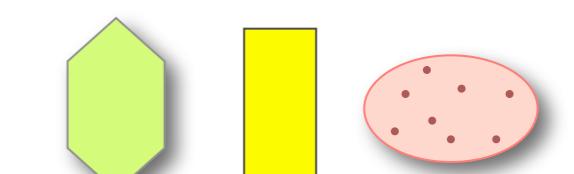
protostellar core



PPD内移動・混合

T < 160Kで集積
円盤早期 (< 10⁶ yr)

T~1300K T~1000K



Take Home Work



物質と円盤進化の統合

- ダスト合体成長・破壊の取り込み
- ダスト輸送
- **self-consistent** 温度構造
- 温度に応じた物質変化
- 酸素・水素同位体



いかに検証するのか

- **comets**
- **chondrites**
- 他には？