均質核形成によるダスト生成実験と古典的核形成論

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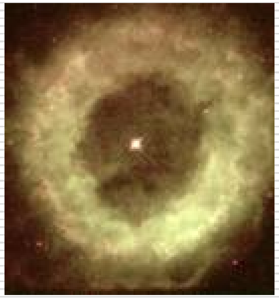
(77) GFWS/銀河のダスト研究会、神戸CPS、Sep. 2, 2010.

均質核形成によるダスト生成実験と古典的核形成論

Why nucleation?

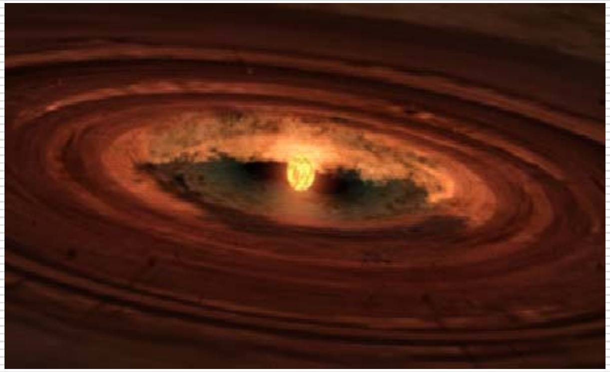
- Number
- Morphology
- Habit
- Size
- Size distribution



Evolved Star

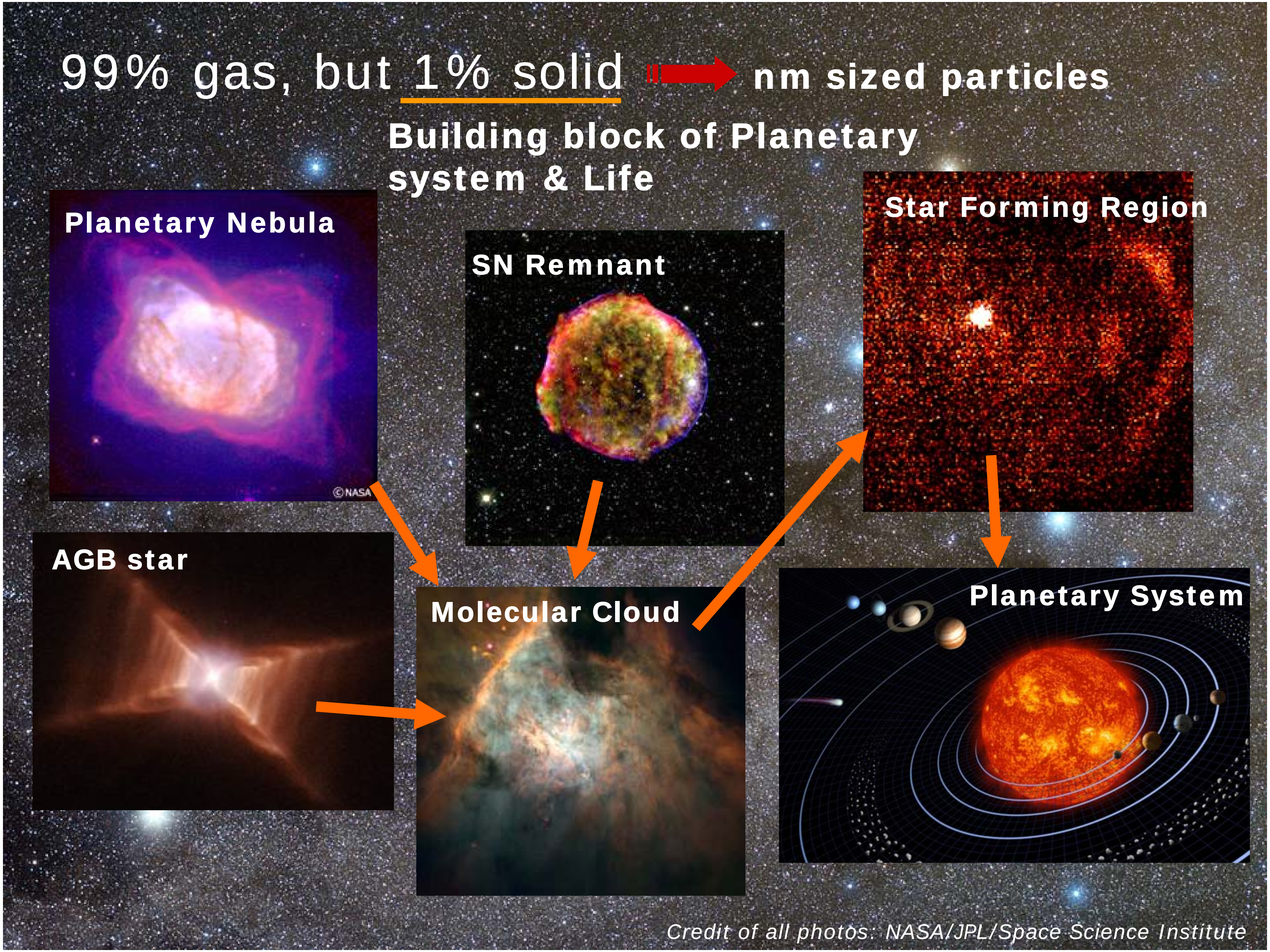
Not only industrially,

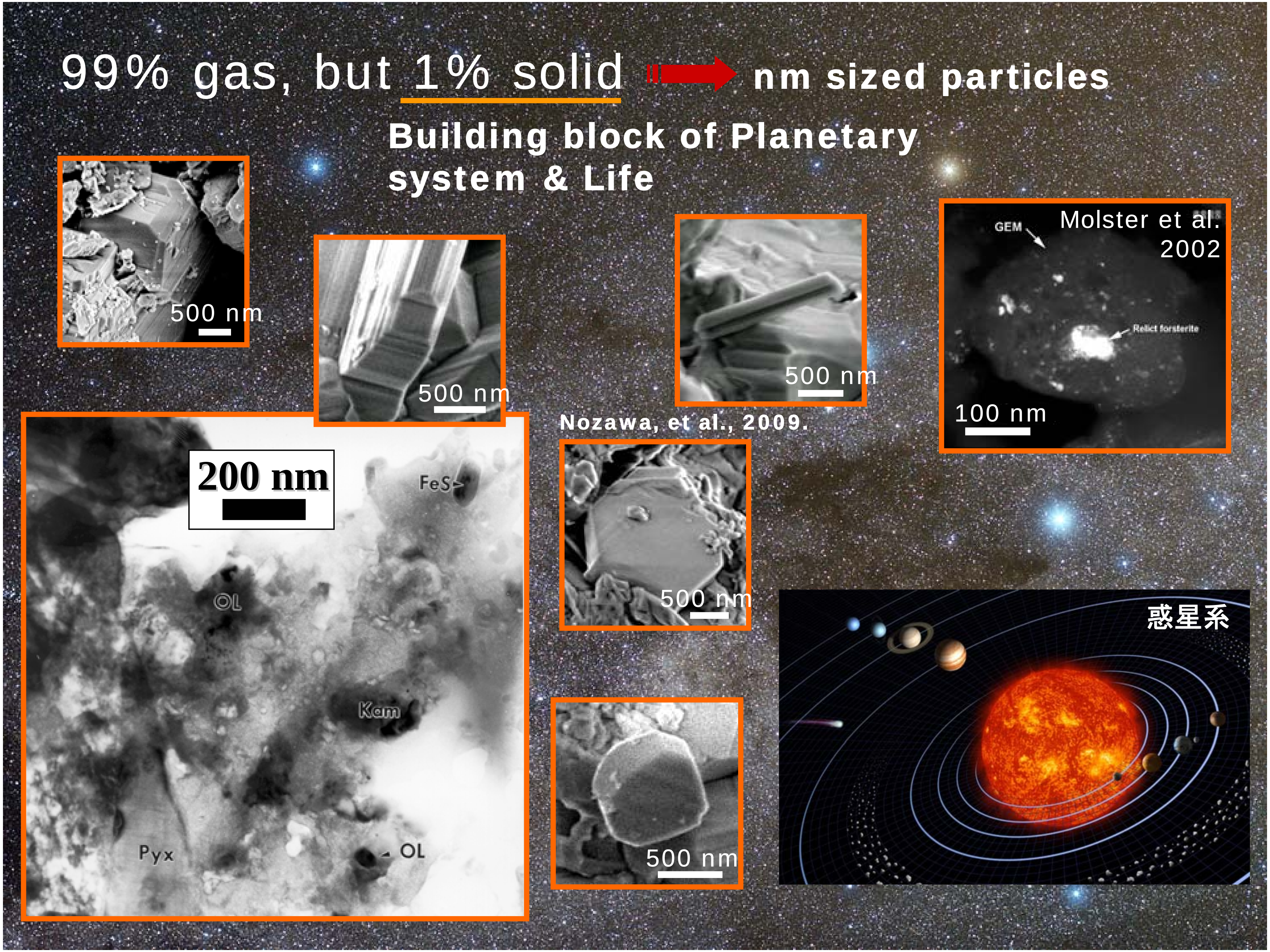
✓Nucleation is also important to know the formation process of Cosmic dust particles.



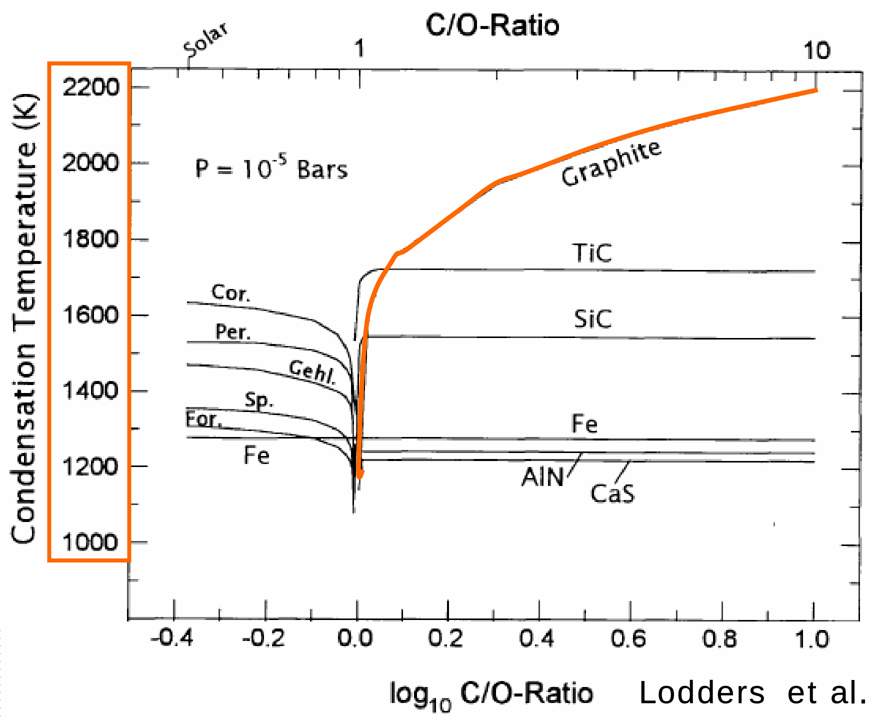
Planetary Nebula

We need understand Nucleation!


99% gas, but 1% solid
nm sized particles
Building block of Planetary system & Life
Planetary Nebula
©NASA
SN Remnant
Star Forming Region
AGB star
Molecular Cloud
Planetary System
Credit of all photos: NASA/JPL/Space Science Institute


99% gas, but 1% solid
nm sized particles
Building block of Planetary system & Life
500 nm
500 nm
500 nm
Molster et al. 2002
GEM
Relict forsterite
100 nm
Nozawa, et al., 2009.
200 nm
FeS
OL
Kam
Pyx
OL
500 nm
500 nm
惑星系

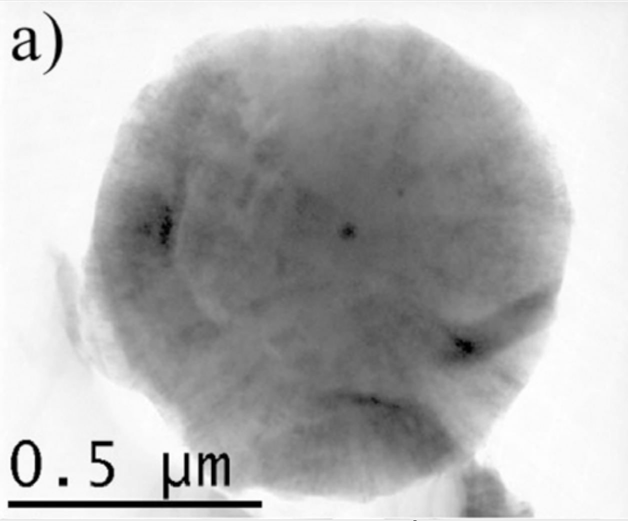
Condensation temperature of major elements as a function of C/O ratio.



Lodders et al. Meteoritics 30 (1995) 661.

ガスの温度が下がるにつれて
高融点物質から順に凝縮する。

Cor. Corundum, コランダム, Al_2O_3
Per. Periclase, ペリクレイス, MgO
Gehl. Gehlenite, ゲーレナイト, $Ca_2Al(AlSi)O_7$
Sp. Spinel, スピネル, $MgAl_2O_4$
For. Forsterite, フォルステライト, $(Fe,Mg)_2SiO_4$
Fe Iron, 鉄, Fe



Croat et al., 2004 LPS, 1353.

Constraints on the formation conditions and environment have been calculated.
(Lodders & Fegley 1995; Sharp & Wasserburg 1995; Chigai et al. 1999, 2002)

Condensation sequence

Sizes of core-mantle

→

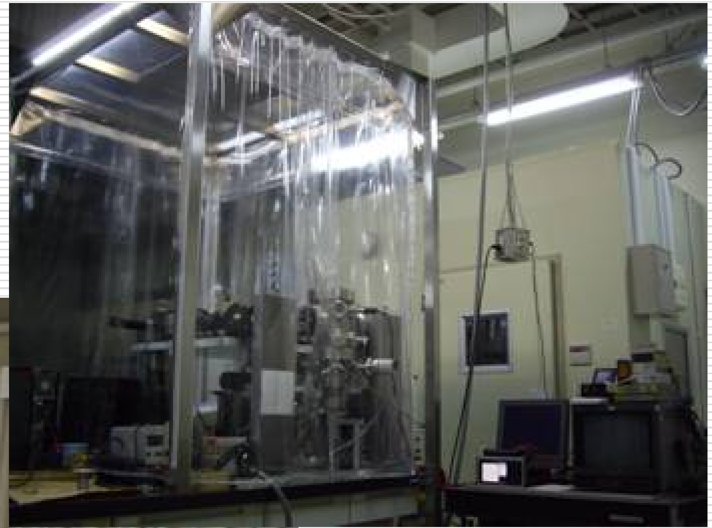
C/O abundance ratio
Total gas pressure
Gas outflow velocity
Stellar mass loss rate

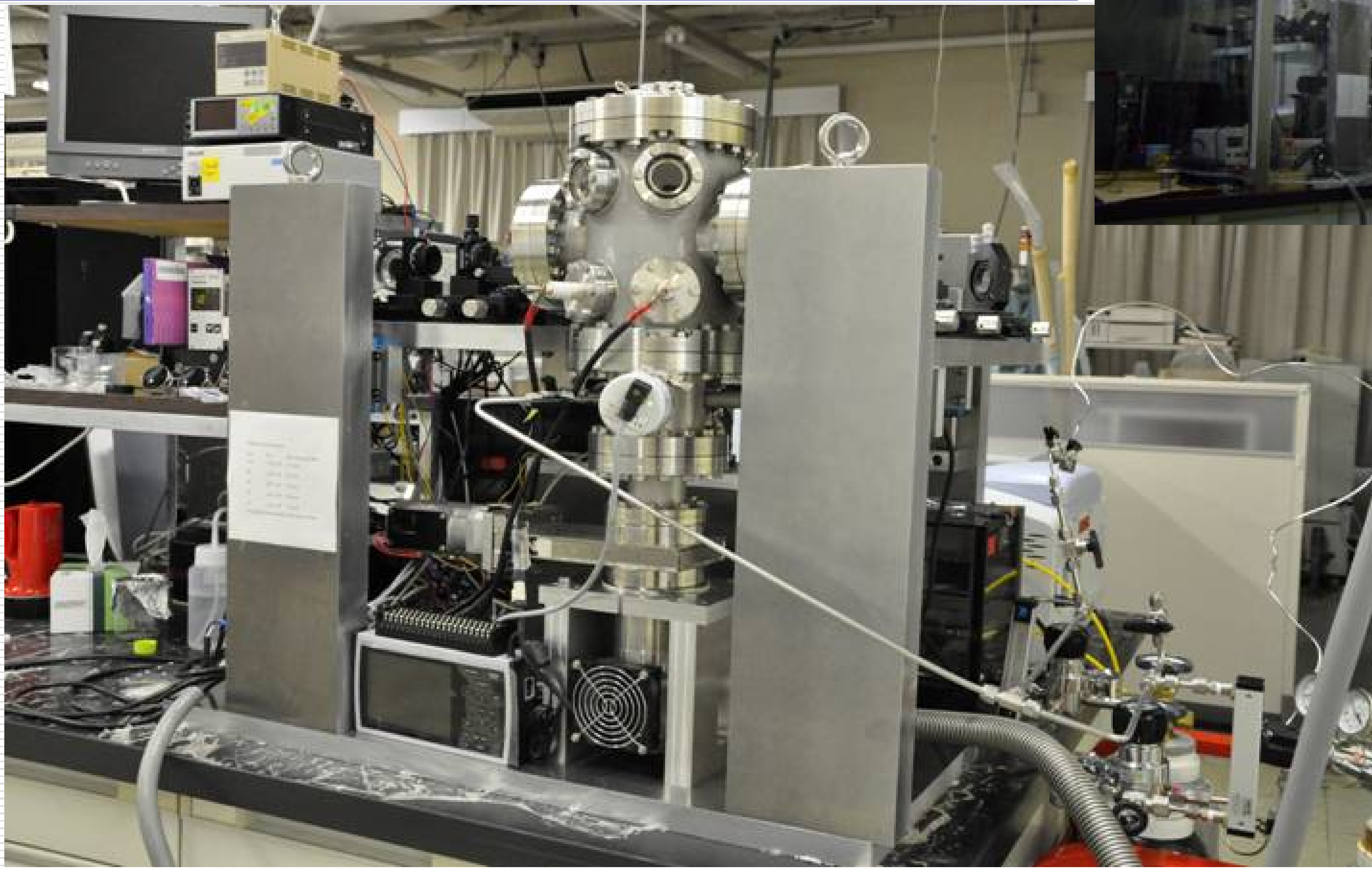
Smoke generator

Nickname is now wanted!

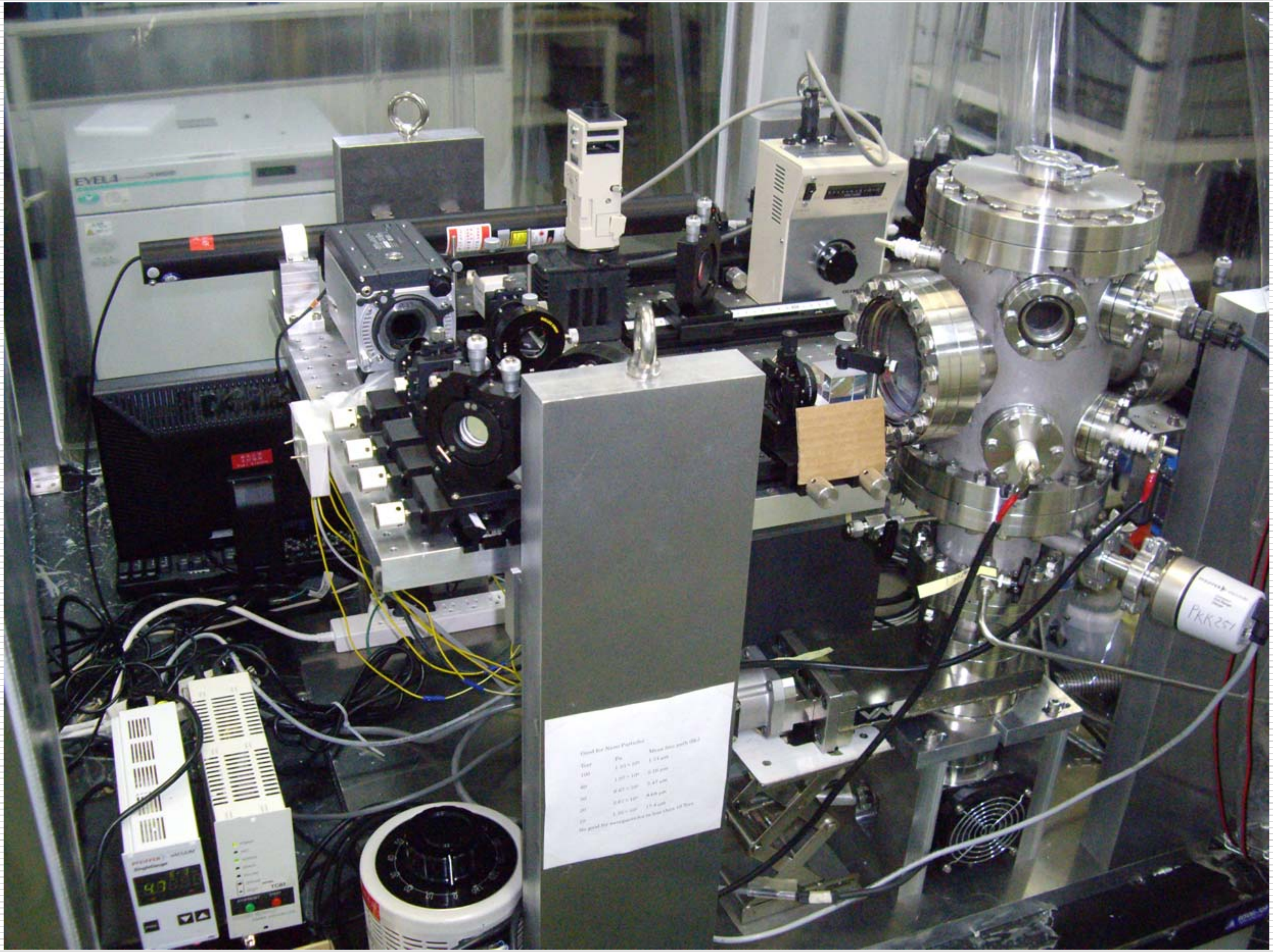
TASHIROS

The Absolute Smoke-generator and Hi-difinition Interferometric Rapid Observation System

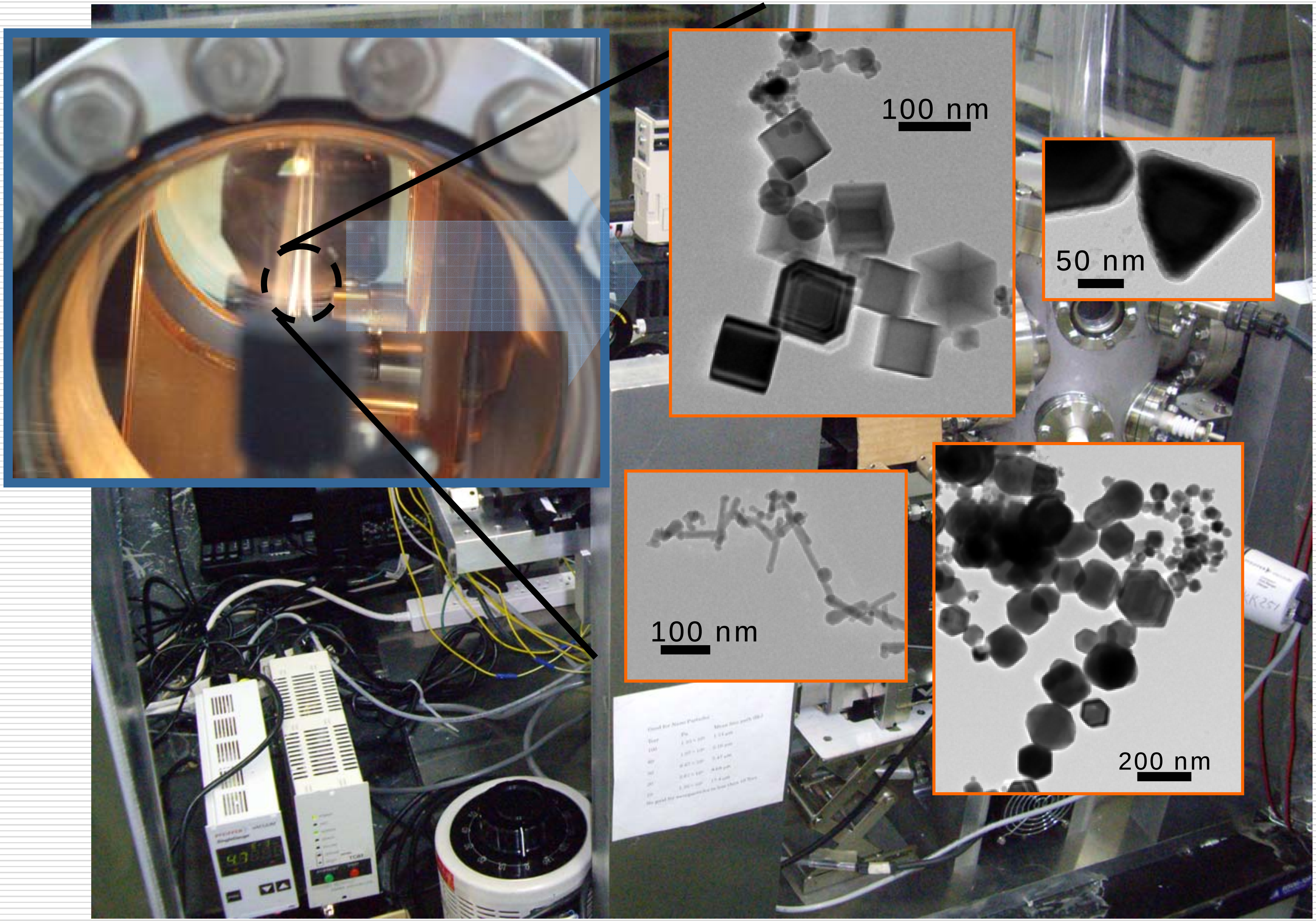


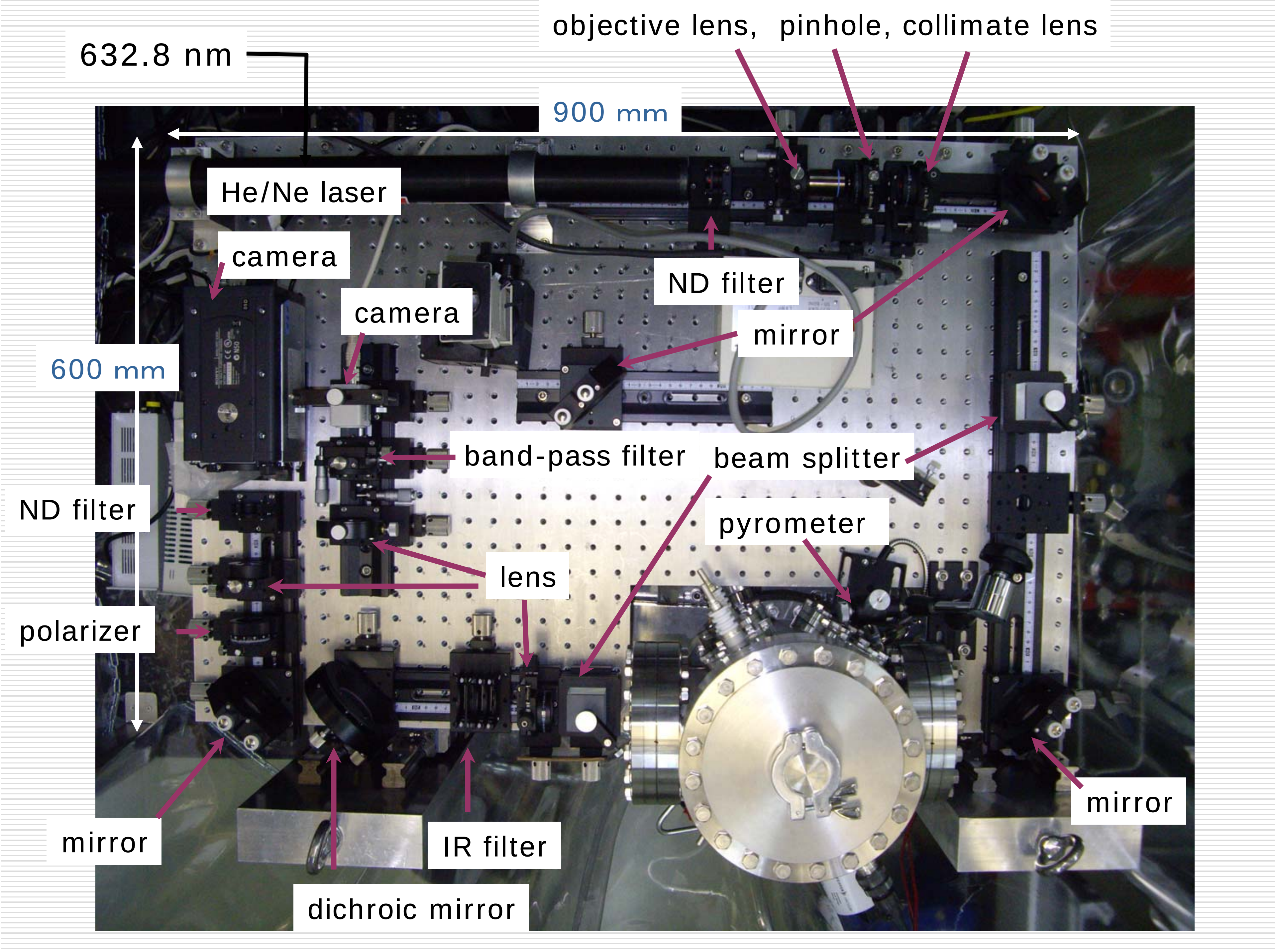


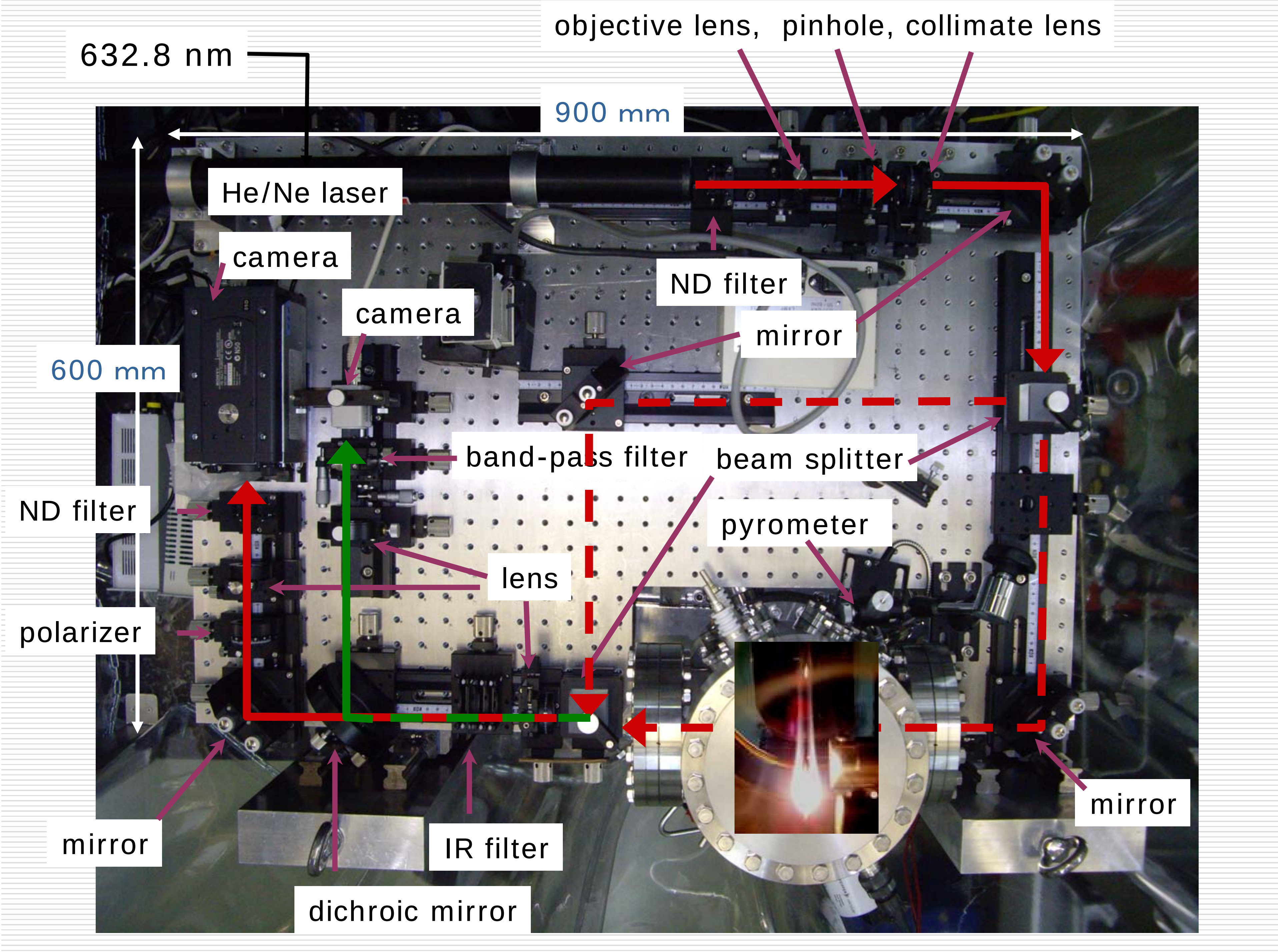
Smoke generator + Interferometer



Smoke generator + Interferometer




632.8 nm
objective lens, pinhole, collimate lens
900 mm
He/Ne laser
camera
camera
ND filter
mirror
600 mm
band-pass filter
beam splitter
ND filter
pyrometer
lens
polarizer
mirror
mirror
IR filter
dichroic mirror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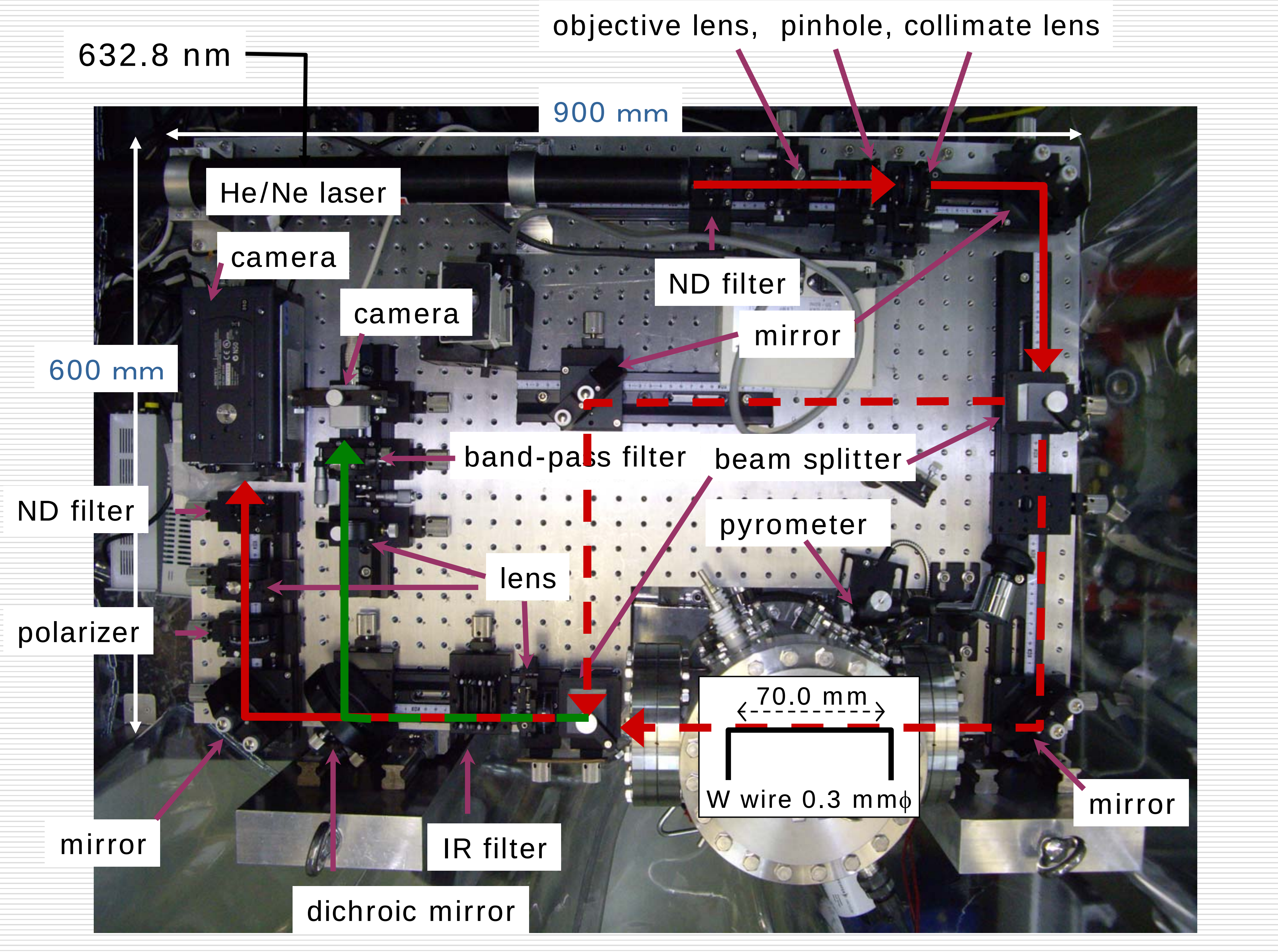

objective lens, pinhole, collimate lens
632.8 nm
900 mm
He/Ne laser
camera
ND filter
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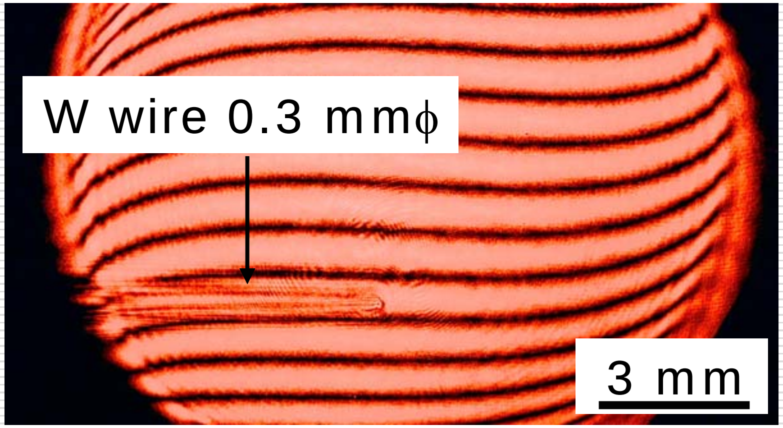
mirror
600 mm
band-pass filter
beam splitter
ND filter
pyrometer
lens
polarizer
70.0 mm
W wire 0.3 mmϕ
mirror
mirror
IR filter
dichroic mirror

Interferogram

Temperature: 298 K (25°C)
Gas: Ar 1×10^4 Pa
Refractive index: 1.00002714

Heating

Temperature: 323 K (50°C)
Gas: Ar 1×10^4 Pa
Refractive index: 1.00002503



Difference of refractive index is only 2×10^{-6}.

Interferogram

Temperature: 298 K (25°C)
Gas: Ar 1×10^4 Pa
Refractive index: 1.00002714

Heating

Temperature: 323 K (50°C)
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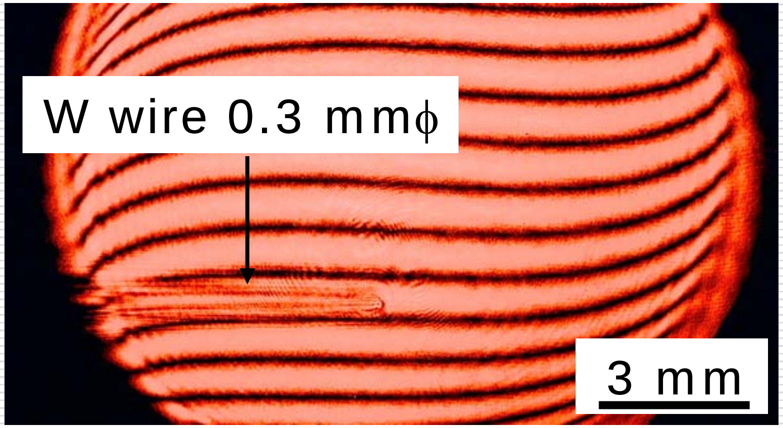
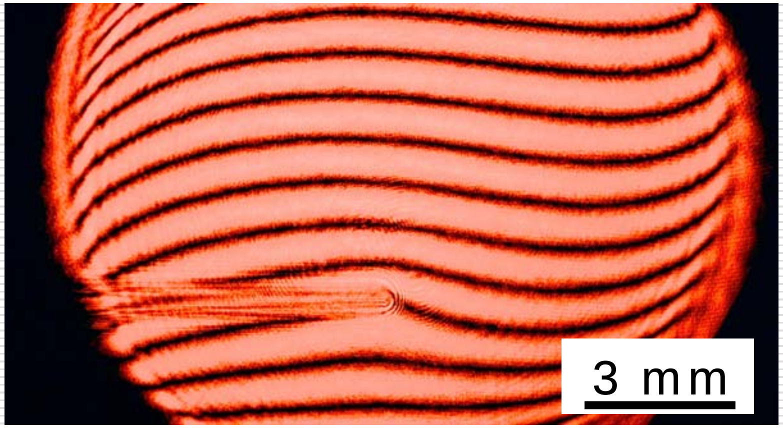
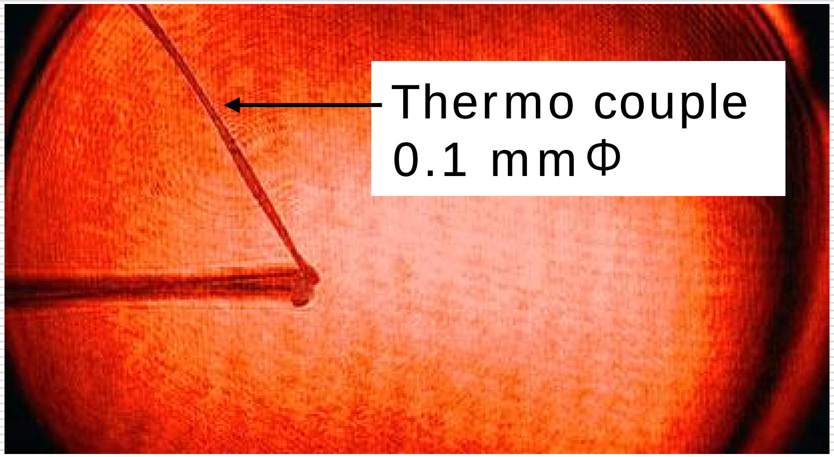
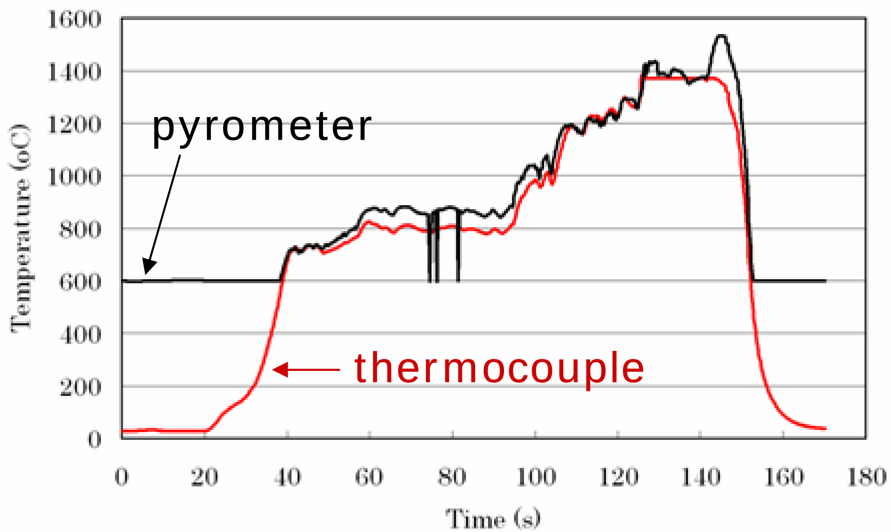




We can detect only a difference of 10^{-6}-10^{-7} orders!!



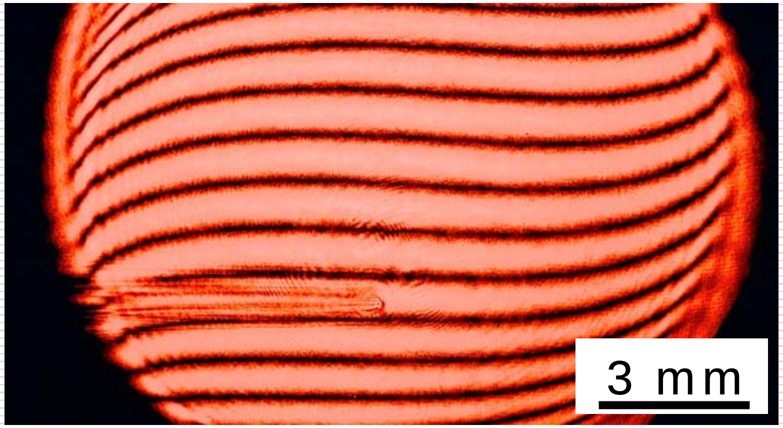


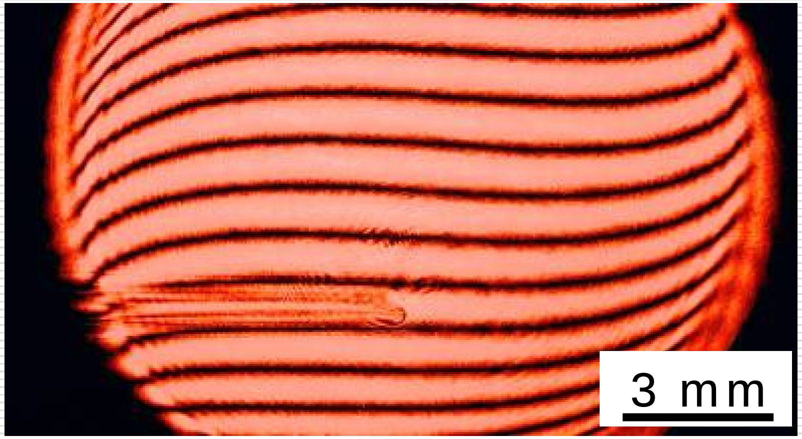
Interferogram

Temperature: 298 K (25°C)
Gas: Ar 1×10^4 Pa
Refractive index: 1.00002714

Oxygen

Temperature : 298 K (25°C)
Gas : Ar 9×10^3 Pa, O_2 1×10^3 Pa
Refractive index: 1.00002703





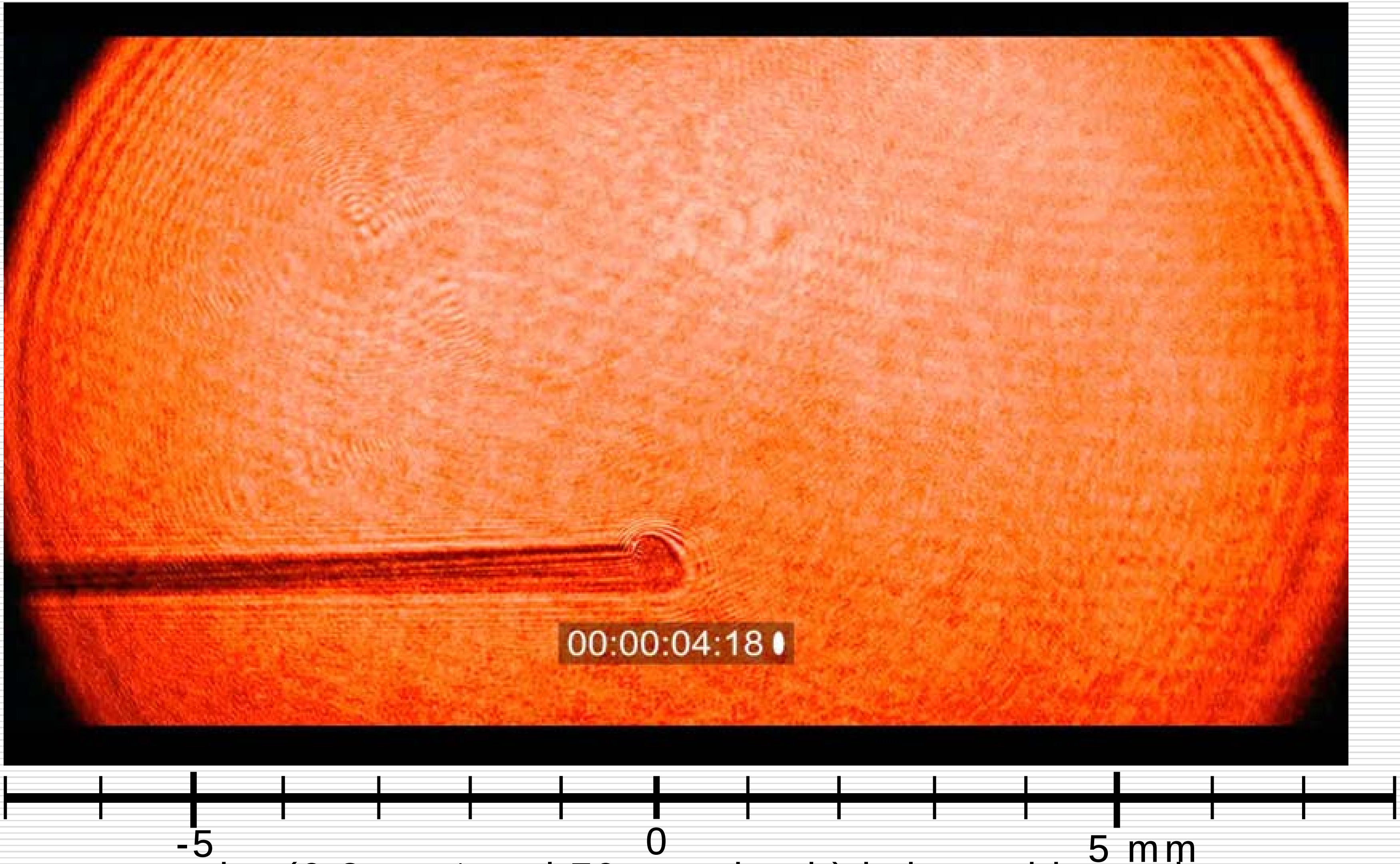
Heating
RT
↓
1570 K

Only Temperature

Temperature & concentration

Temperature information is subtracted by oxygen free experiment.

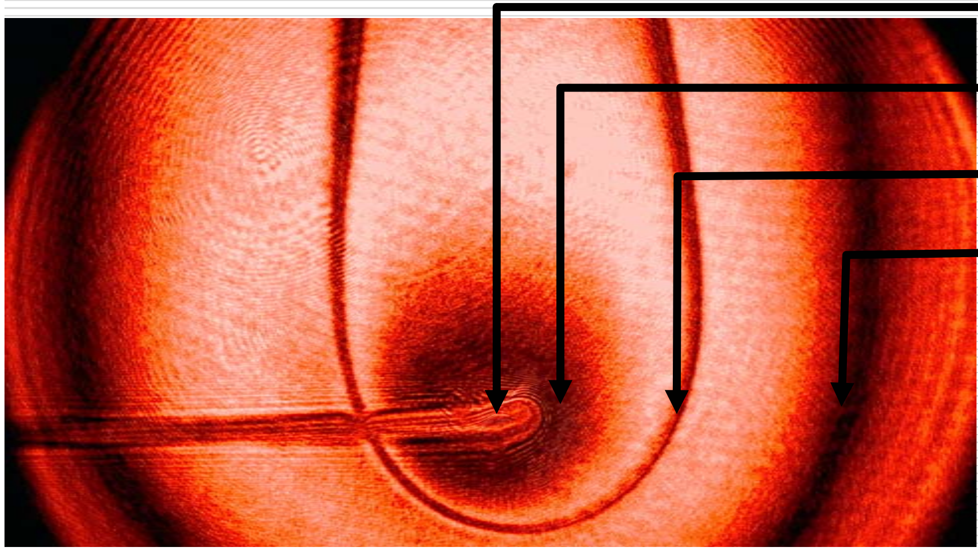
In-situ observation using interferometer



A tungsten wire (0.3 mmϕ and 70 mm depth) is heated in a mixture gas of Ar (9×10^3 Pa) and O_2 (1×10^3 Pa).

1st, 2nd and 3rd fringes correspond to 320, 500 and 1150 K, respectively.

In-situ observation using interferometer

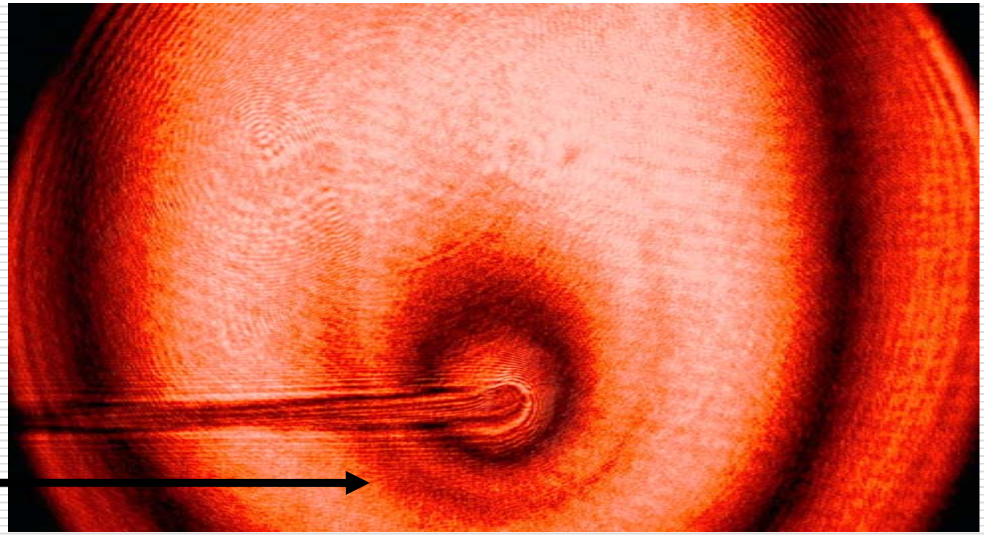


- WO_3 particles are condensed 700 K lower than equilibrium T due to homogeneous nucleation!

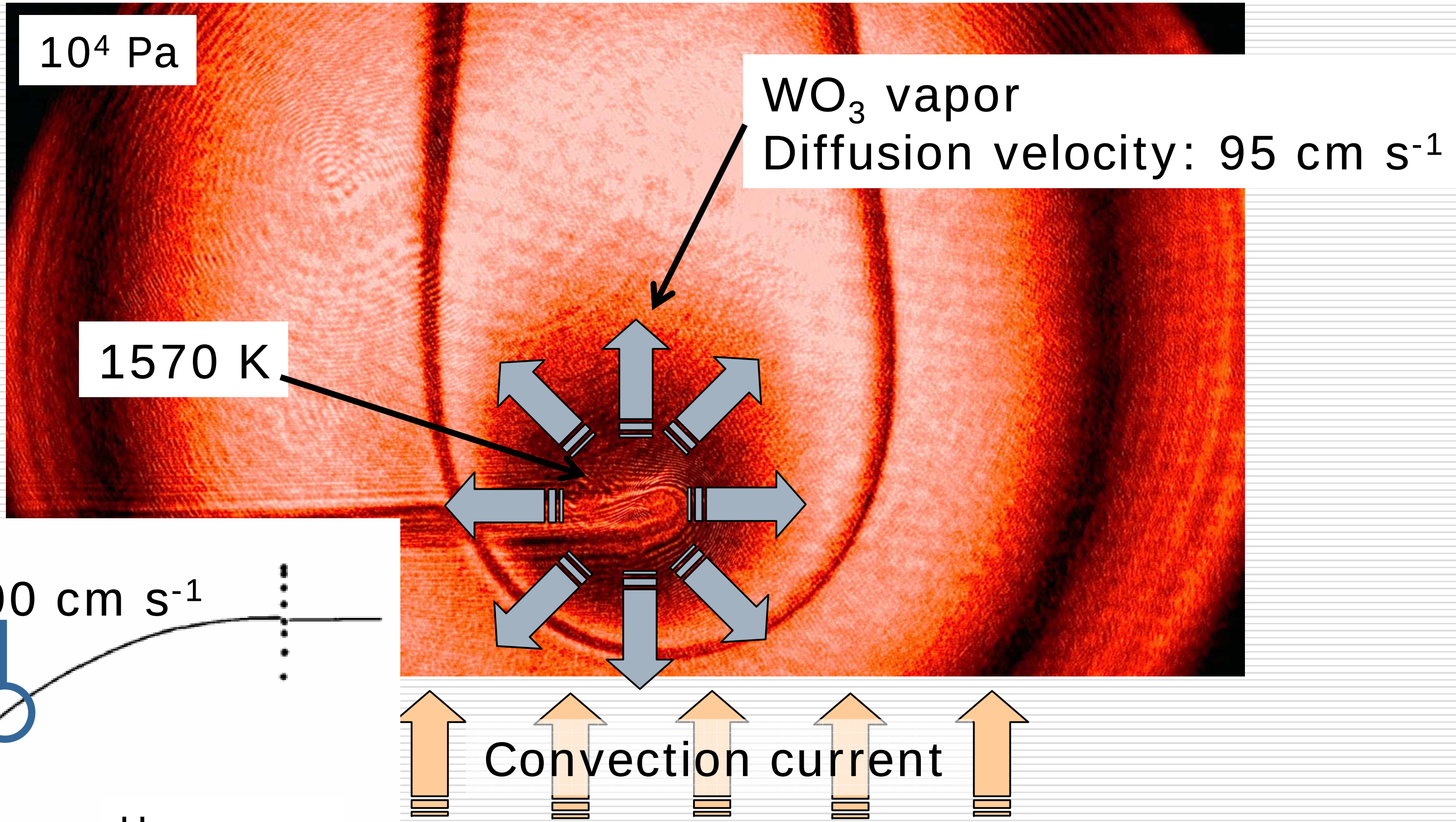
Evaporation Source
$P_e = 1.3 \times 10^3$ Pa at 1570 K
Position of Smoke
$P_e = \sim 10^{-9}$ Pa at 870 K

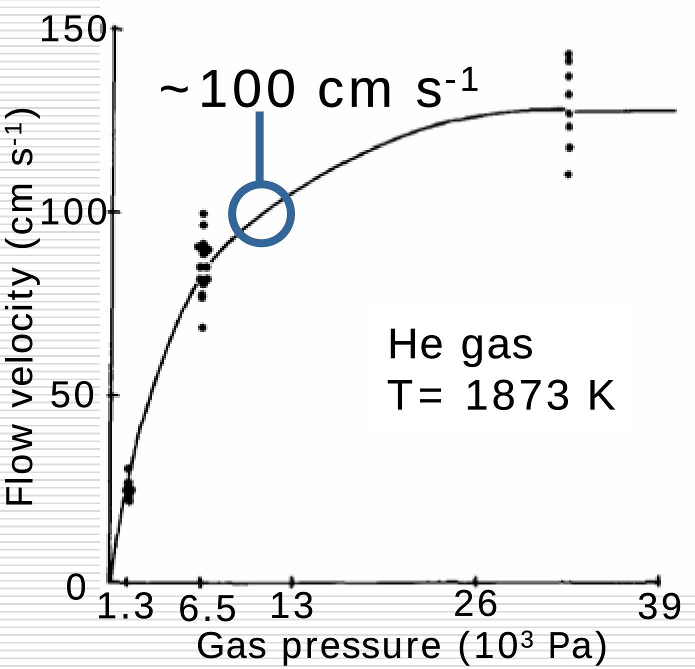
- Degree of supersaturation is at least 10^{11}!!

- Nucleation occurs below the evaporation source.



Convection current and Smoke

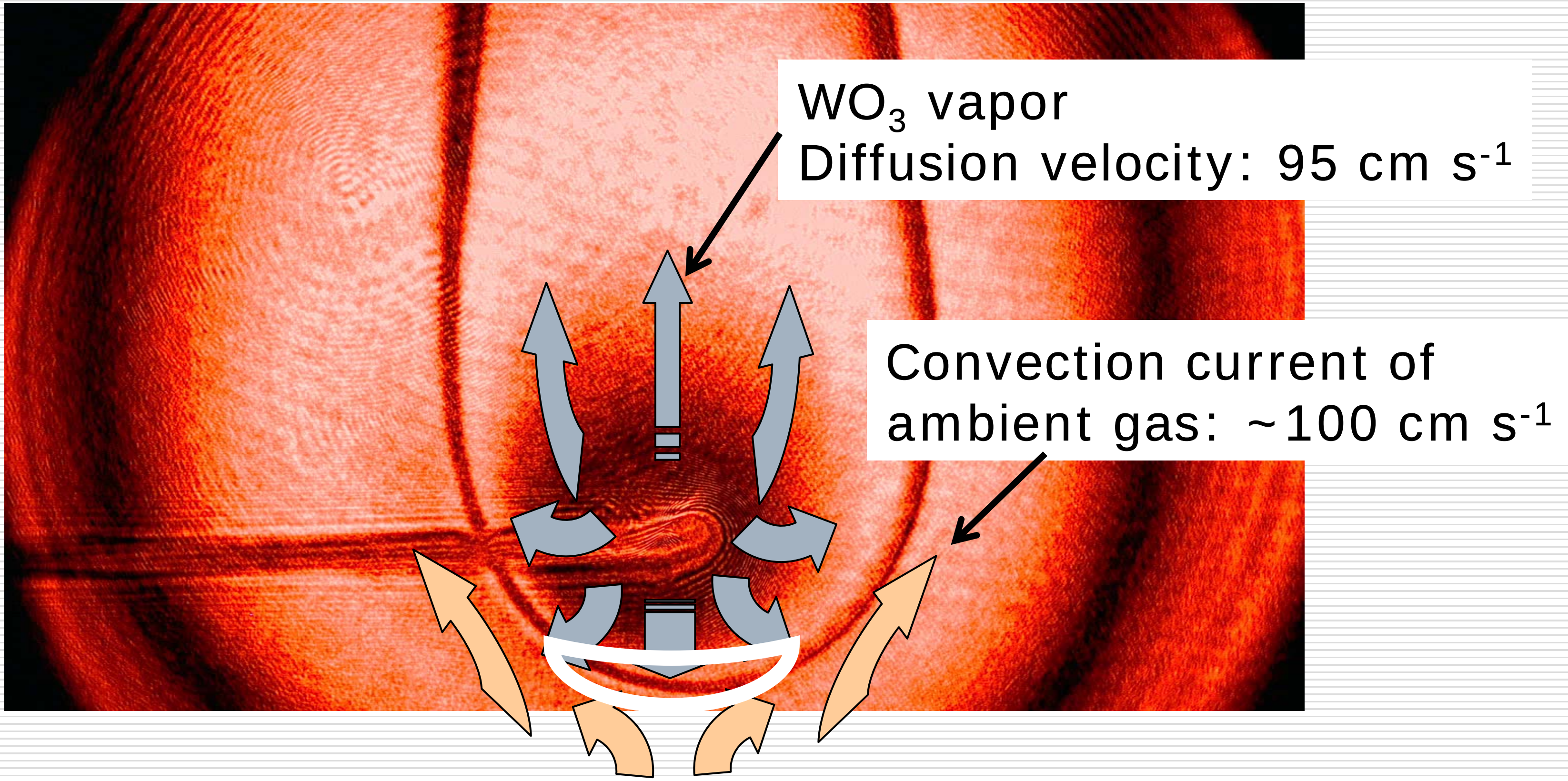




Yatsuya et al. J. Cry. Growth 70 (1984) 536.

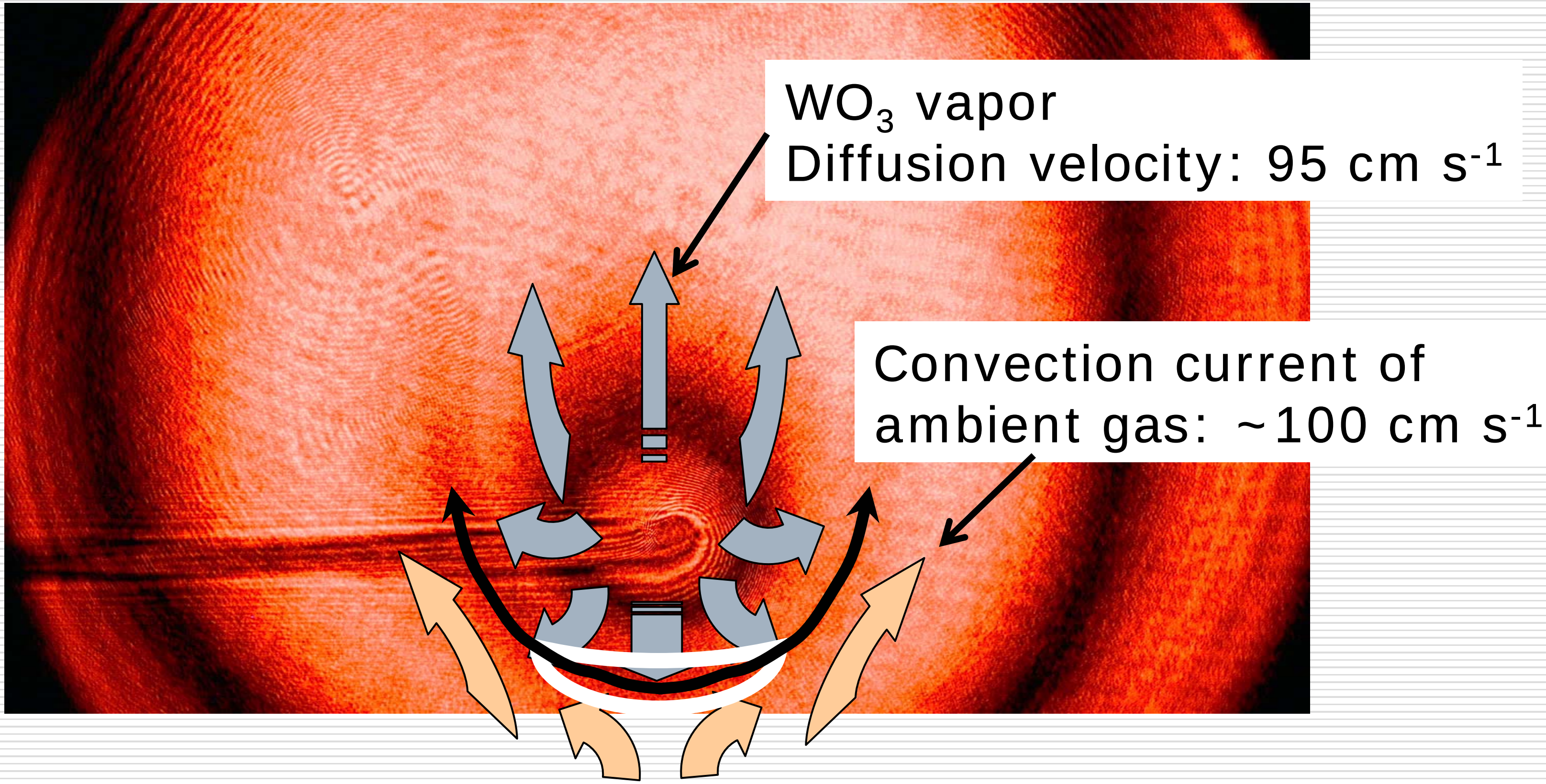
- The heated source generated a high-temperature atmosphere and convection currents (~100 cm s^{-1}).
- Evaporated WO_3 vapor diffuses in uniformly with 9.79 cm^2 s^{-1}.

Convection current and Smoke



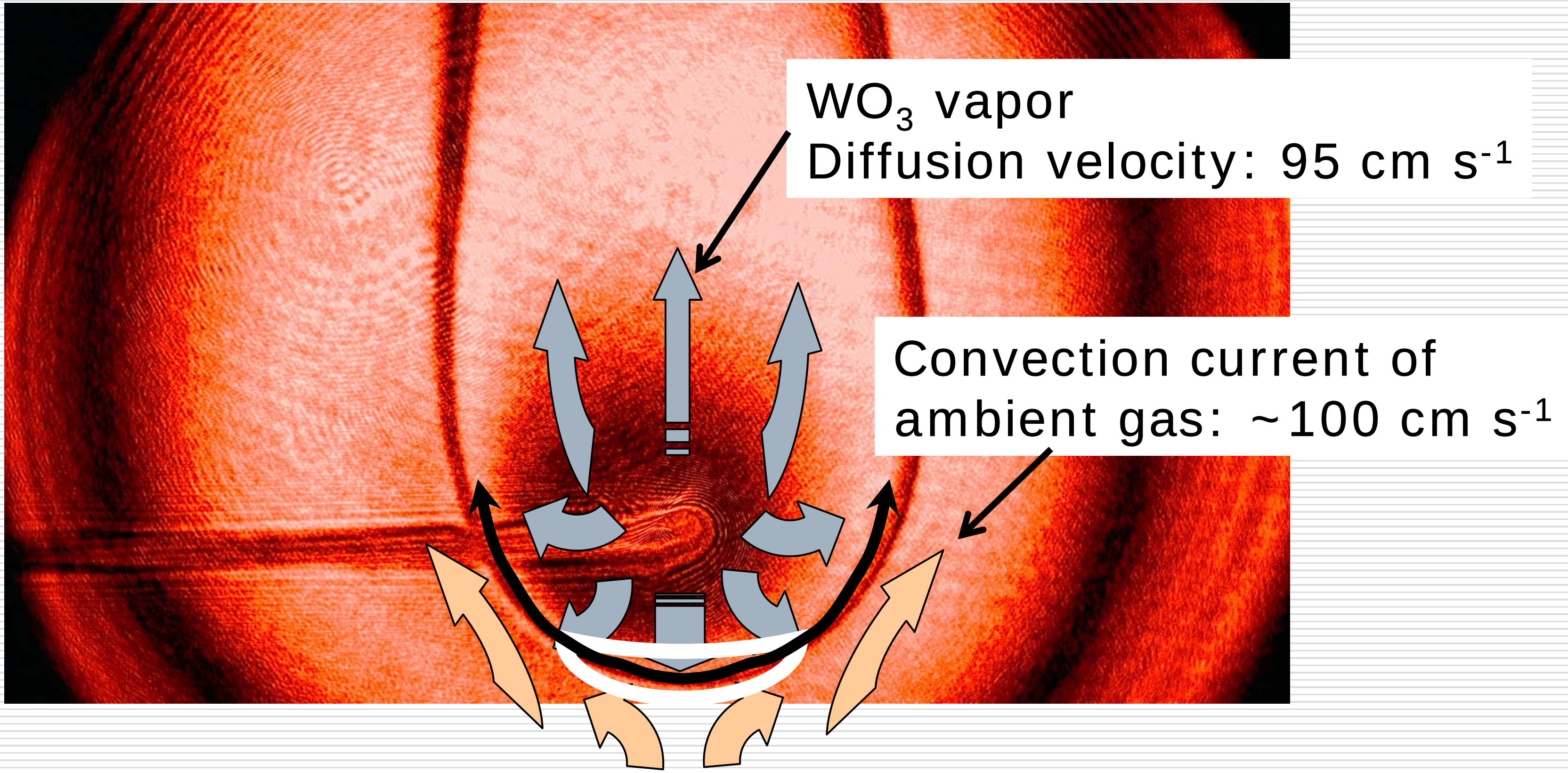
- Since there is a strong convection current, rising vapor is accelerated and down flow is restrained.
- As the result, concentration of WO_3 vapor is getting higher below the evaporation source.

Convection current and Smoke



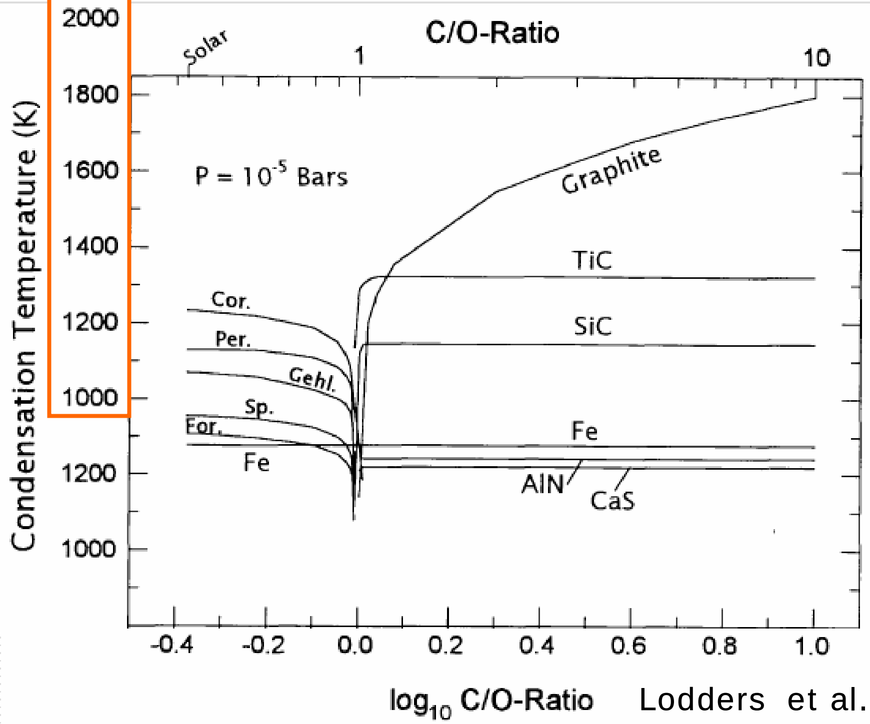
- Finally, nucleation occurs at the highest supersaturation environment between convection current of ambient gas and evaporated WO_3 vapor.
- Nuclei follow the convection current and grow to make nanoparticles in smoke.

Convection current and Smoke



- Finally, nucleation occurs at the highest supersaturation environment between convection current of ambient gas and evaporated WO_3 vapor.
- Nuclei follow the convection current and grow to make nanoparticles in smoke.
- **We can derive a lot of information from Interferogram.**

Condensation temperature of major elements as a function of C/O ratio.



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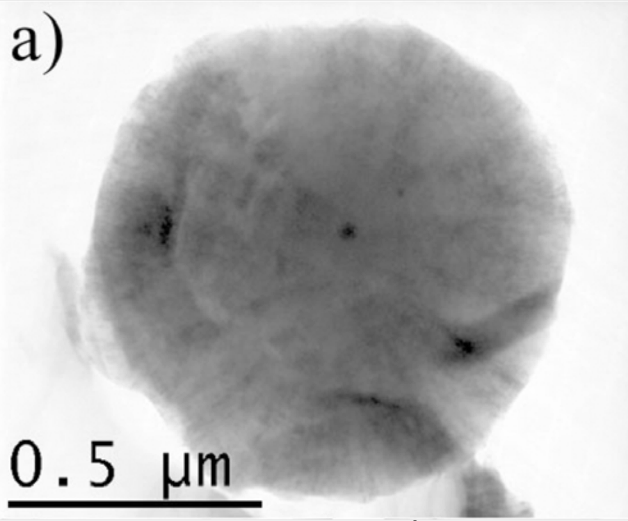
For. Forsterite, フォルステライト, $(Fe,Mg)_2SiO_4$
Fe Iron, 鉄, Fe



Croat et al., 2004 LPS, 1353.

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Condensation sequence

Sizes of core-mantle

C/O abundance ratio
Total gas pressure
Gas outflow velocity
Stellar mass loss rate

Conclusion

- Temperature and concentration can be measured in-situ during smoke experiment.
- Condensation occurs under very high supercooling ($\Delta T = \sim 400\text{-}700K$).
- Nucleation takes place below evaporation source in smoke experiment.
- Nucleation theory may be verified.