Study of chemical composition of cosmic ray nuclei with GRAINE experiments

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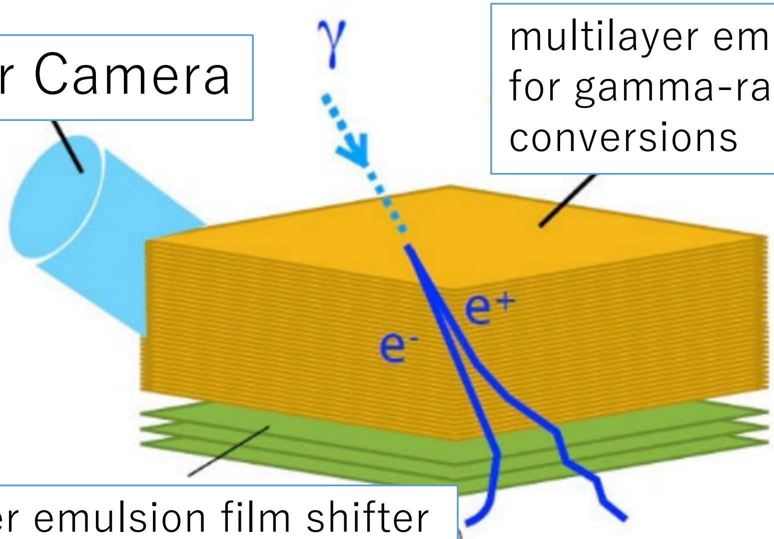
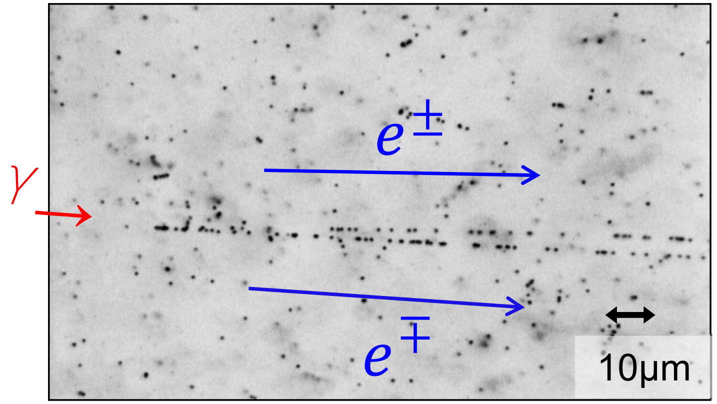
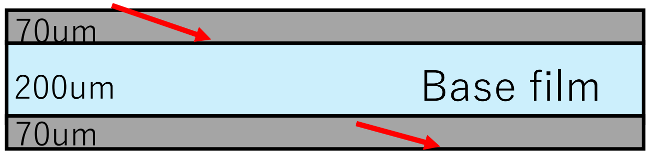
GRAINE project (Gamma Ray Astro-Imager with Nuclear Emulsion)

●**Concept of Balloon borne emulsion gamma ray telescope**



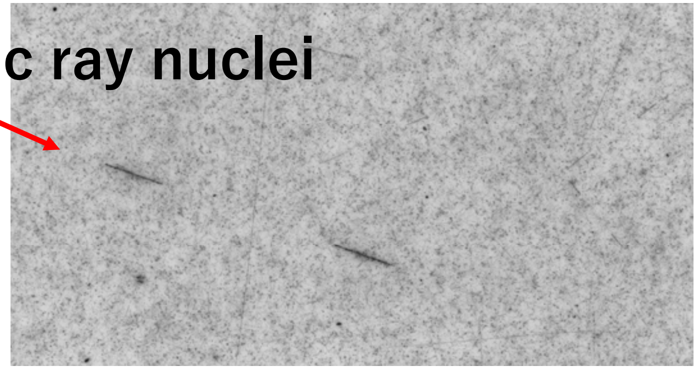


Coated on double side with gelatin within AgBr crystals



●**Main Purpose：**

Imaging of cosmic gamma ray objects with high angular resolutions of nuclear emulsion films



Composite image of two emulsion layers(1300um×685um) A1-P-3 杉君

●Balloon Flight

2011 Hokkaido

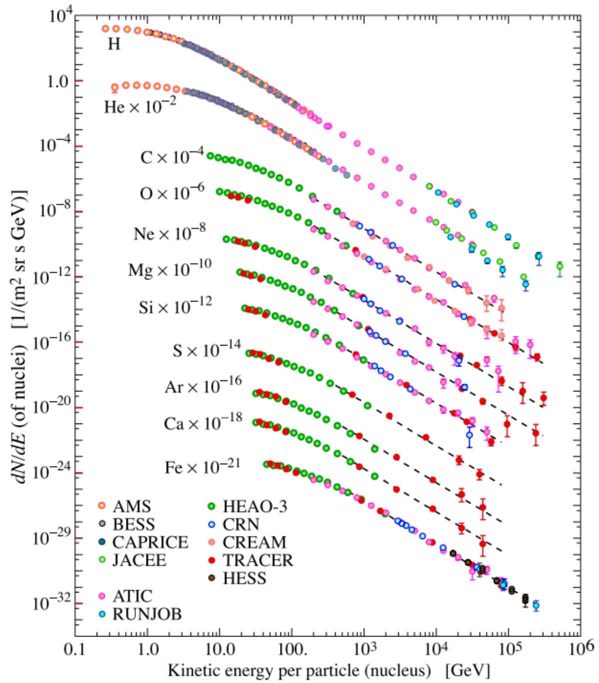
2015 2nd balloon flight @ Australia

2018 April balloon flight @ Australia 17.4hour, 0.38m^2

2023 April-May @ Australia 24hour 2.5m^2

- Energy spectra and chemical composition measurements
  - JACEE/RUNJOB utilized ECC type detectors to measure primary energies in calorimeters because interaction length and absorption length were needed above TeV energies.
- The recent progress of Nuclear Emulsion Technologies including HTS
  - Allows to carry out general scanning of nuclear emulsion films with wide angular acceptance.

➡Direct measurement of cosmic ray nuclei above the GeV energies is the one of the next aim in the GRAINE project to study the chemical composition of cosmic ray nuclei because of it large aperture area.



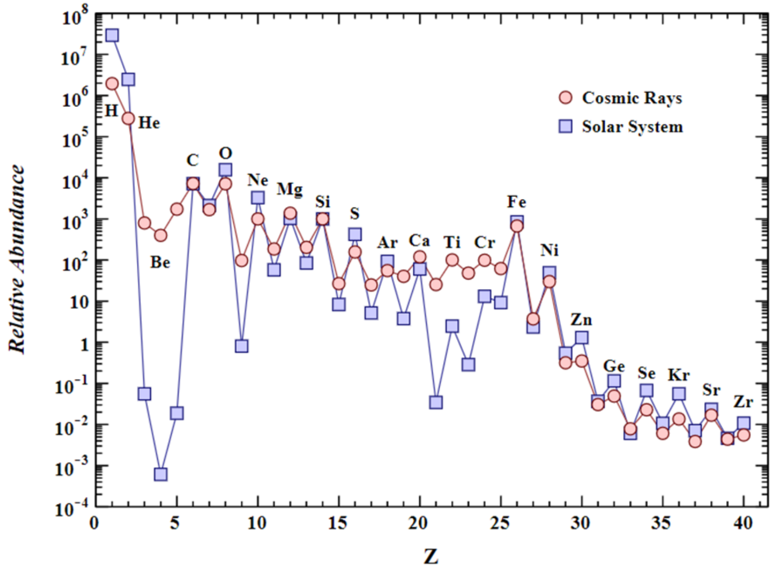


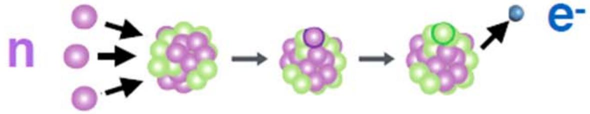
Figure 30.2: Cosmic ray elemental abundances compared to abundances in present-day solar system material. Abundances are normalised to Si=10^3. Cosmic ray abundances are from AMS-02 (H,He) [3,17], ACE/CRIS (Li-Ni) [18,19], and TIGER/SuperTIGER (Cu-Zr) [20,21]. Solar system abundances are from Table 6 of Ref. [22].

D.Siegel(2008)

The r-process and s-process

Burbidge, Burbidge, Fowler, Hoyle (1957), Cameron (1957):

The heavy elements (A > 62) are formed by neutron capture onto seed nuclei



Burbidge, Burbidge, Fowler, Hoyle ("B^2FH")

REVIEWS OF

MODERN PHYSICS

VOLUME 29, NUMBER 4 OCTOBER, 1957

Synthesis of the Elements in Stars*

E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

Kellogg Radiation Laboratory, California Institute of Technology, and Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

"It is the stars, The stars above us, govern our conditions";
(*King Lear*, Act IV, Scene 3)

but perhaps

"The fault, dear Brutus, is not in our stars, But in ourselves,"
(*Julius Caesar*, Act I, Scene 2)

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1957 February THE ASTRONOMICAL JOURNAL 9

and aggregates. The 21-cm absorption spectra will be investigated for accessible discrete radio sources. Studies relating to the spiral structure of our galaxy will be limited largely to regional surveys for small sections of the sky; we shall stress in these studies at all times the close interconnection that exists between radio and optical phenomena. Following Heeschen's successful detection of 21-cm emission from the Coma cluster of galaxies, we shall attempt to study further 21-cm radiation from beyond our own galactic system, but in these studies we shall be limited to some extent by our electronic equipment, which was designed especially for high-resolution work in our own galaxy.

The new equipment is described in some detail in *Sky and Telescope* for July 1956, and an article is in press in *Nature*.

Harvard College Observatory, Cambridge, Mass.

in the 1100Å to 1340Å detector which included the Lyman α line of hydrogen, 1216Å. The 1220Å to 1340Å tube detected discrete celestial sources. Of the region scanned by this tube the most significant responses were obtained in the Puppis-Vela region.

Naval Research Laboratory, Washington, D. C.

Cameron, A. G. W. On the origin of the heavy elements.

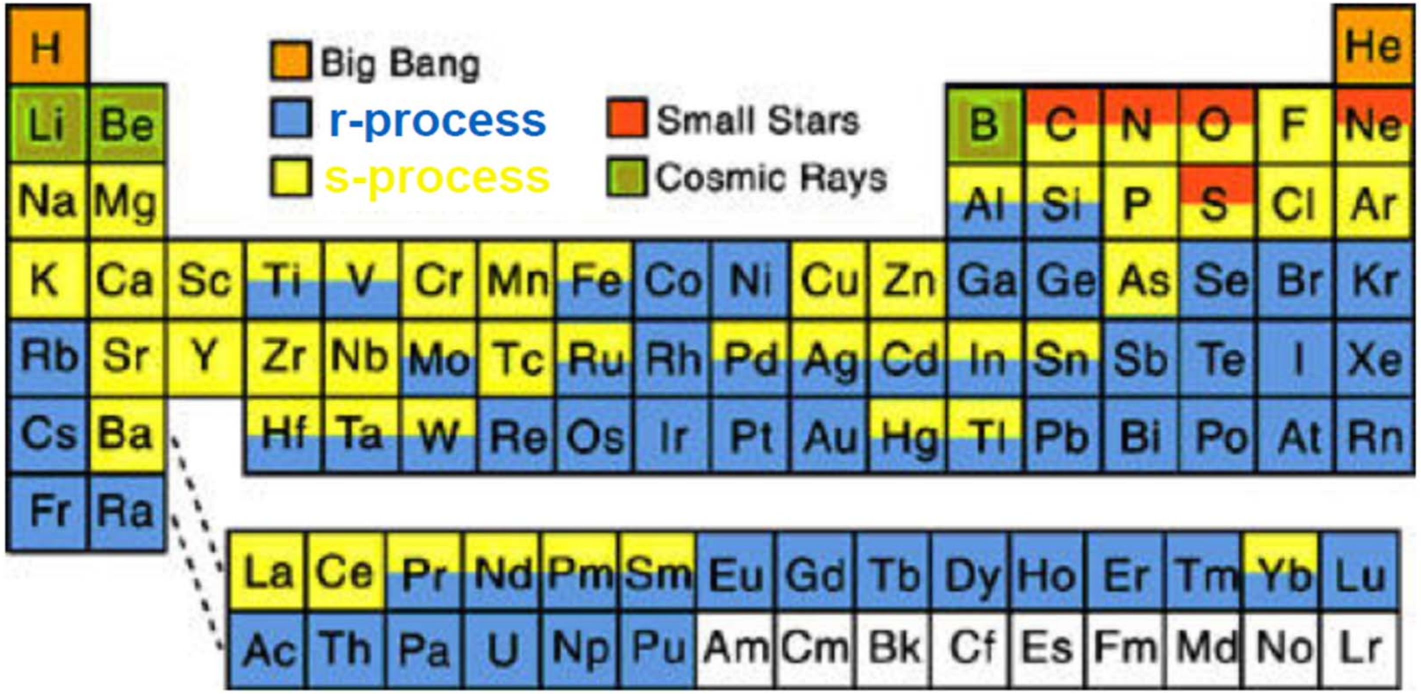
The inverse correlation between the metal abundances and the ages of stars suggests that the elements have been formed in stellar interiors. An analysis of the cosmic abundances of nuclear isobars, and calculations relating to the growth of nuclide abundances by neutron capture, show that the following three mechanisms are necessary, and probably sufficient, to produce the observed cosmic abundances of the nuclides with mass number greater than 70.

Cameron

speculated that r-process requires explosive environment of supernovae

The origin of the elements

D.Siegel(2008)

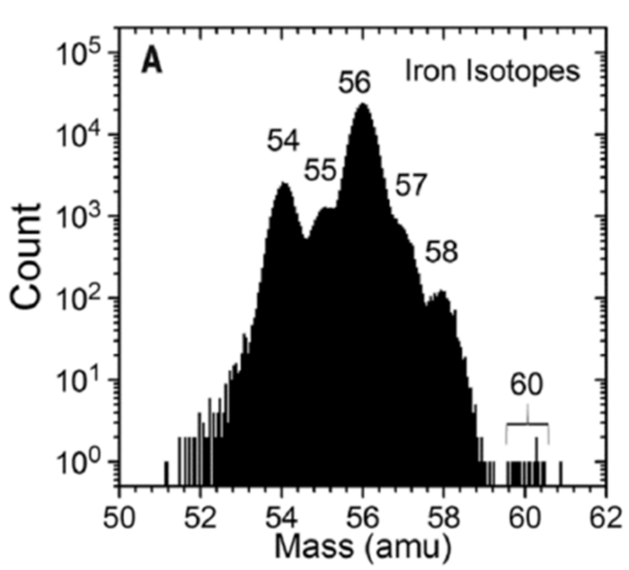


How are the heavy elements formed?

18 Source of heavy r-process nuclei: SNe VS BNSM

- Recent measurement of $_{60}$Fe (radioactive with half-life 2.6 Myr) by the ACE-CRIS experiment is the first conclusive evidence that there is a recently synthesized component in the cosmic rays
- The $_{60}$Fe almost certainly comes from SNe from nearby Sco-Cen OB associations

W. R. Binns et al., Science 10.1126 (2016)



- ○ If SNe synthesize and accelerate all of the r-process nuclei
  - expect to see significant numbers of the short lived $_{94}$Pu and $_{96}$Cm
- ○ If binary neutron star mergers (BNSM) are the source of the heavy r-process nuclei
  - expect to see little or no $_{94}$Pu and $_{96}$Cm since BNSM in the vicinity of the solar system are much less frequent than SNe and the short lived $_{94}$Pu and $_{96}$Cm should have mostly decayed

Short lived
Pu(Z=94,A=244)
Cm(Z=96,A=247)

Predictions:
SNe->significant number
BNSM->little or no

Cosmic ray nuclei measurements in GRAINE2023

- The Goal of this study:
  - To measure cosmic ray nuclei(CRN) in conventional eye-scan method in order to collect training data for machine learning of track recognition.

    => **100 CRN tracks**
- Test scanning data:
  - Image data in 3cm x 3cm region of one GRAINE2023 flight film obtained by HTS2.

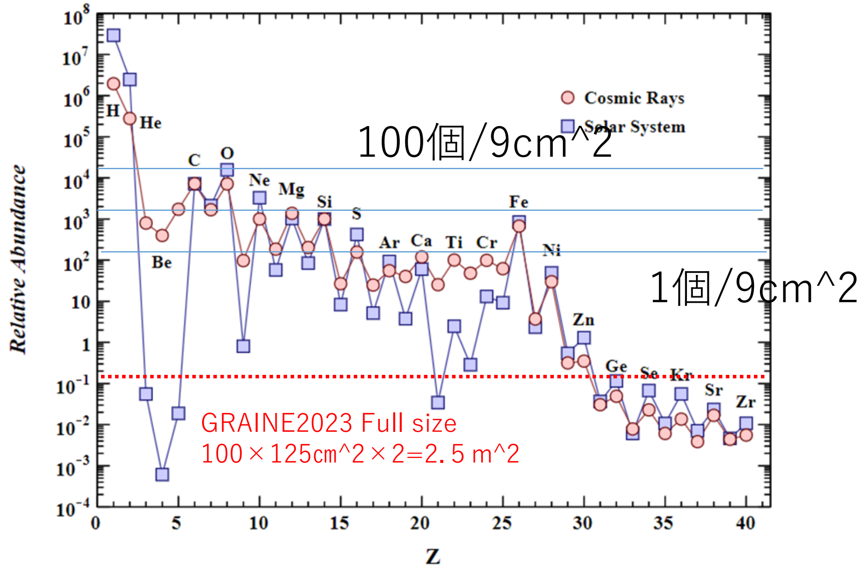


Figure 30.2: Cosmic ray elemental abundances compared to abundances in present-day solar system material. Abundances are normalised to Si=10^3. Cosmic ray abundances are from AMS-02 (H,He) [3,17], ACE/CRIS (Li-Ni) [18,19], and TIGER/SuperTIGER (Cu-Zr) [20,21]. Solar system abundances are from Table 6 of Ref. [22].

GRAINE2023 9cm^2スキャン	H	He	Li	Be	B	C	N	24時間・2sr 3cm×3cmスキャン
10~100GeV	16500	2625	16.5	6.6	21	66	21	
100~1TevV	367.5	57.75	0.375	0.15	0.45	1.425	0.45	

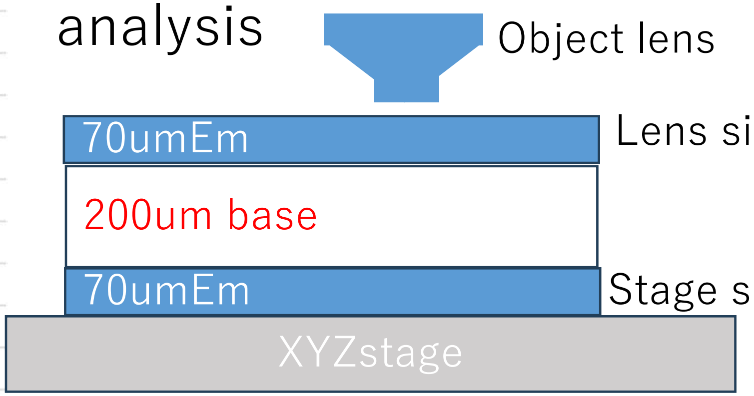
Nuclear emulsion film Images obtained by HTS2 system

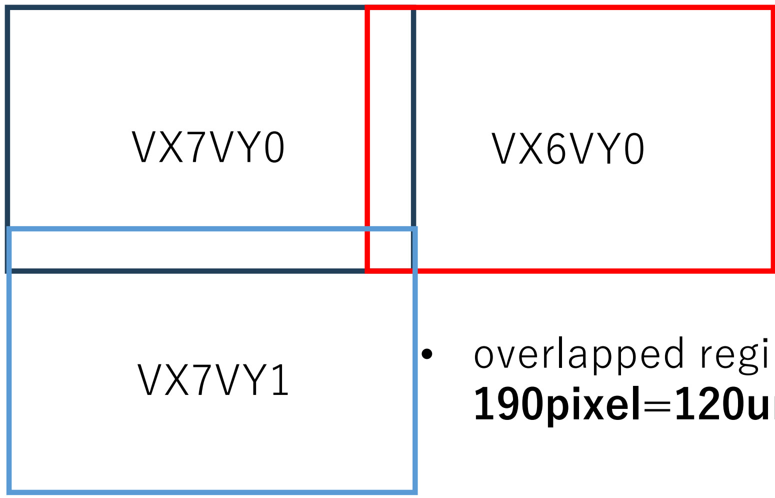
						VX ←						
(26,0)	(25,0)	(24,0)	(23,0)					(3,0)	(2,0)	(1,0)	(0,0)	
(26,1)	(25,1)	(24,1)							(2,1)	(1,1)	(0,1)	
(26,2)	(25,2)									(1,2)	(0,2)	
(26,3)											(0,3)	
(26,51)											(0,51)	
(26,52)	(25,52)									(1,52)	(0,52)	
(26,53)	(25,53)	(24,53)							(2(53)	(1,53)	(0,53)	↓
(26,54)	(25,54)	(24,54)	(23,54)					(3,51)	(2,54)	(1,54)	(0,54)	VY

- Scan region : 3 ｃｍ× 3 ｃｍ
- Image area label: VX： 0～2 6 VY: 0～5 4
- Number of area : 27×55 =1485

- One single image scanned by HTS2
  - Width:2048 pixel Height：1088 pixel
  - Real image size：1290um×685um
  - Image format: gray scale (png format)
  - Image area non overlapped ：VX＝1170um VY=560um
  - Z gap＝4um ->24 slices/emulsion layer
  - Pixel resolution :
    - 1290um／2048pixel ＝ 685um／1088pixel＝0.63um

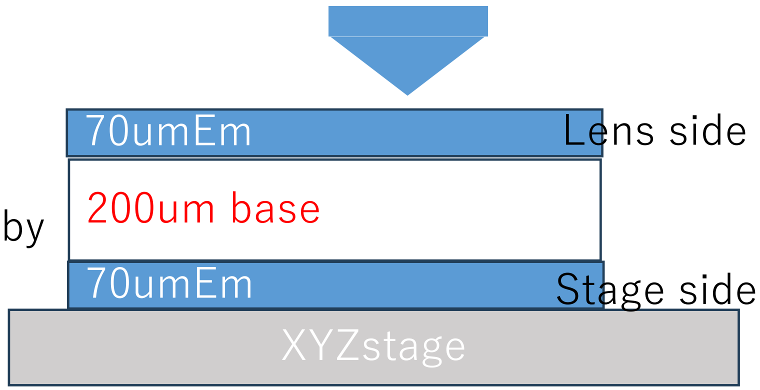
Region and areas of emulsion images in this analysis





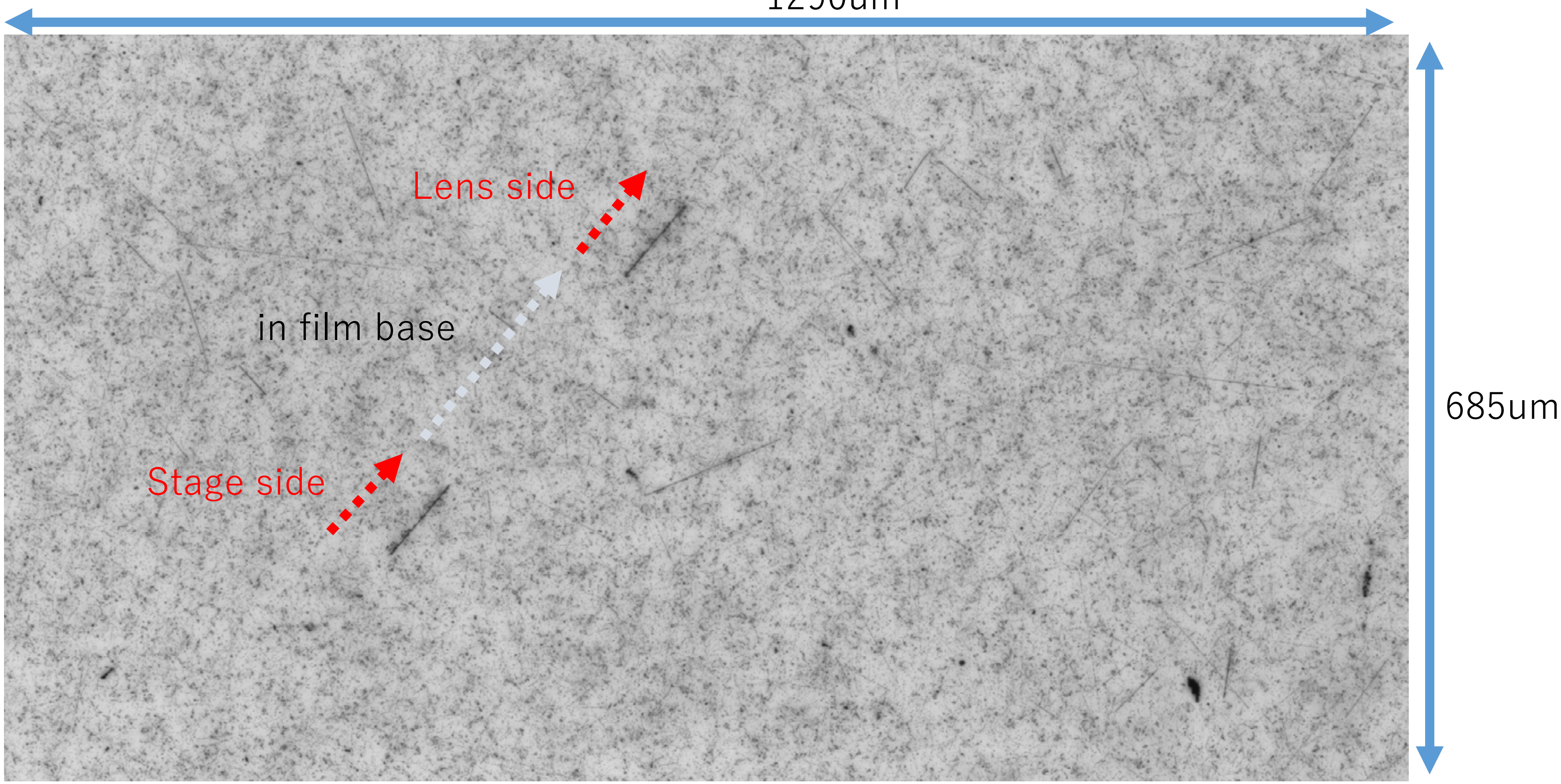
- overlapped regin
  190pixel=120um

Method of conventional eye-scan

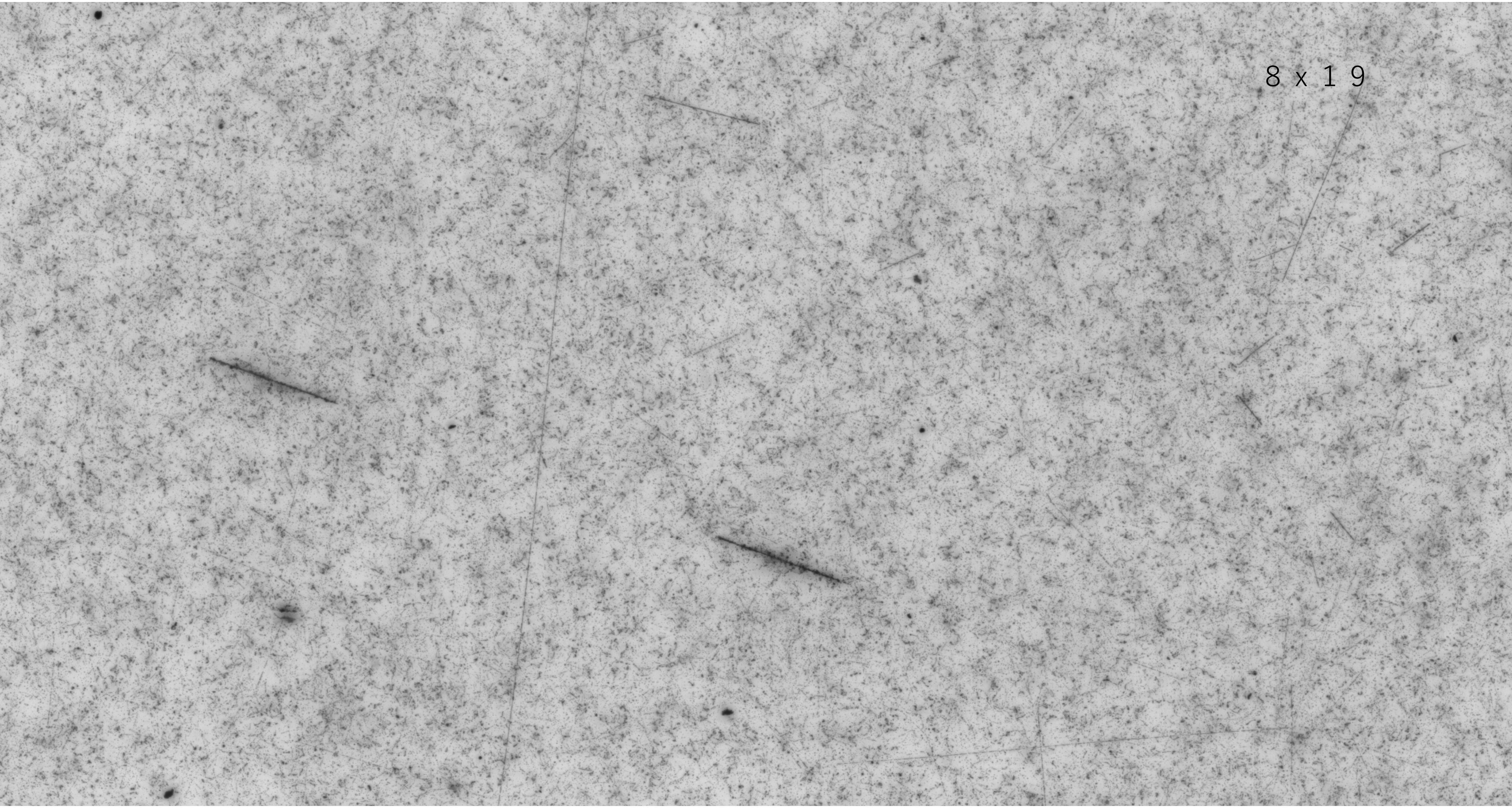


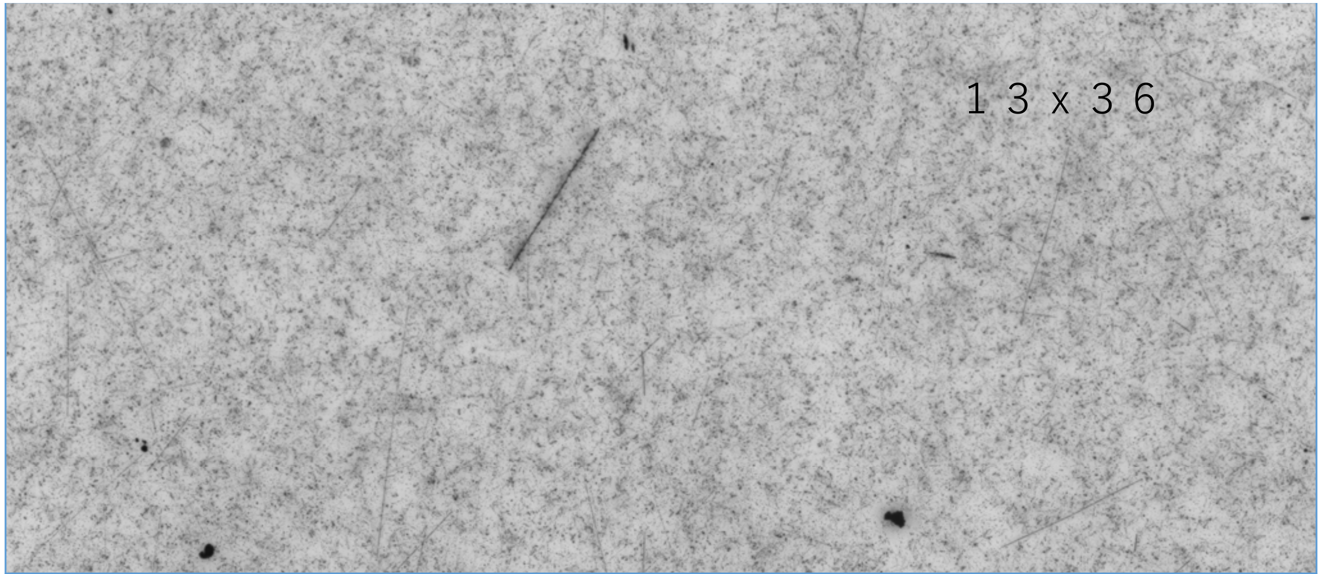
- Raw images for both side emulsion layers : 24 slices x 2 =48
- Composite images in both layer (24 slices x 2) at each area are created by means of multifocal imaging algorithm (poster presented by Sugi-kun). The depth information of grains is stored in the other images.

Example of composite image.



Other 20 examples are shown in the following slides.


8 x 19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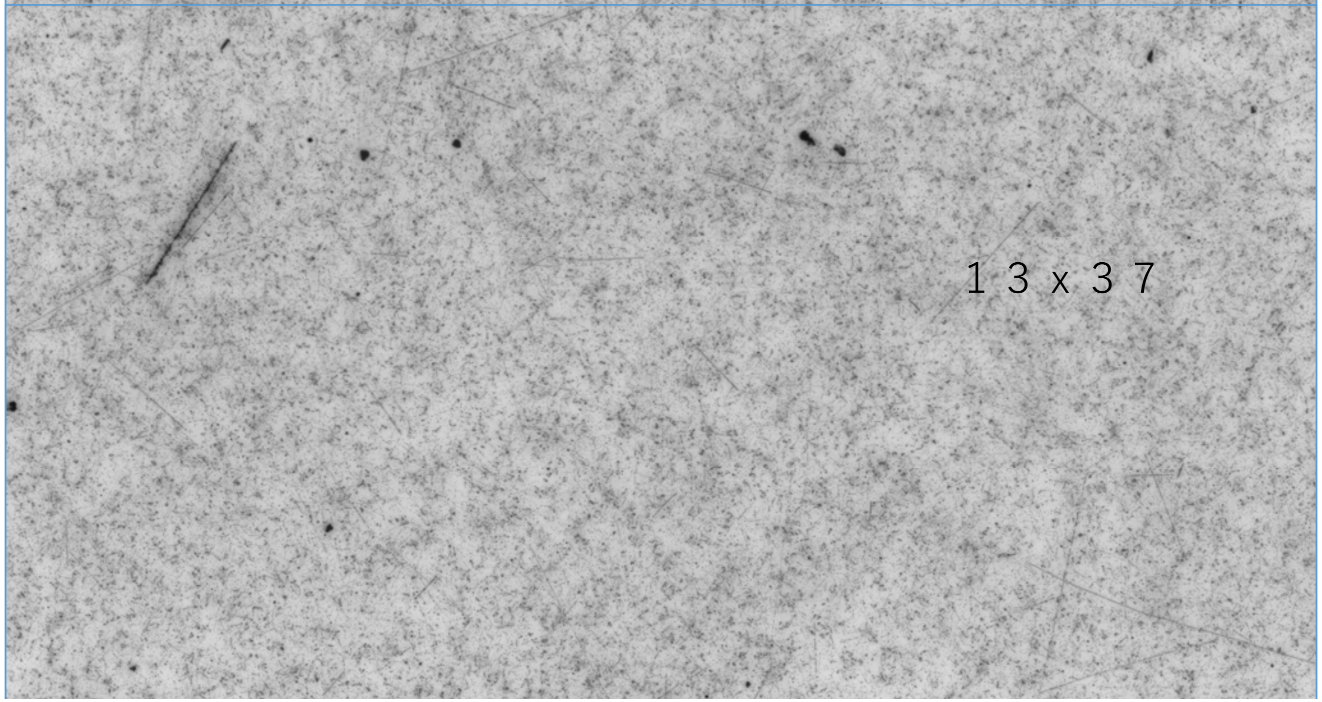
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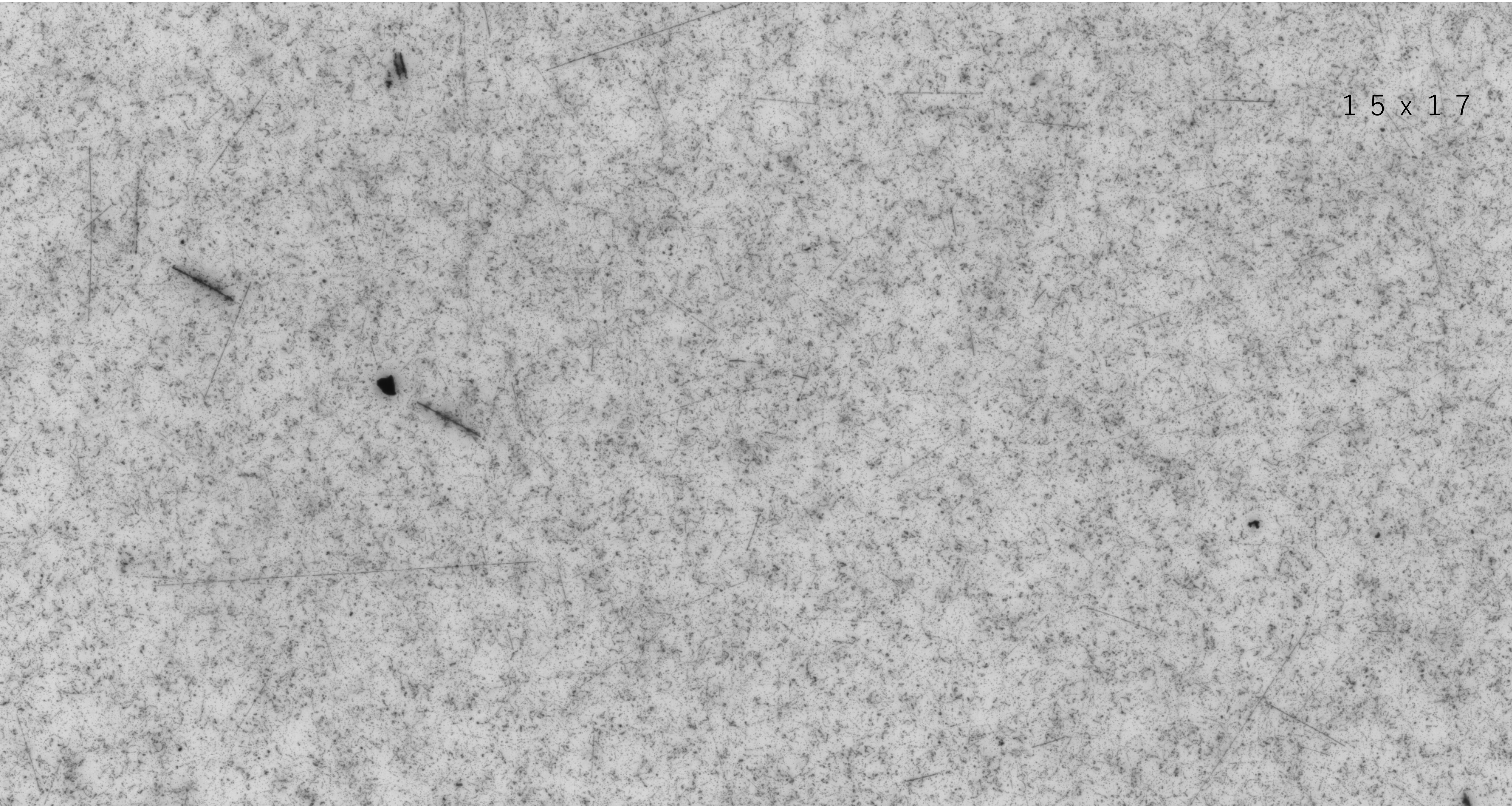
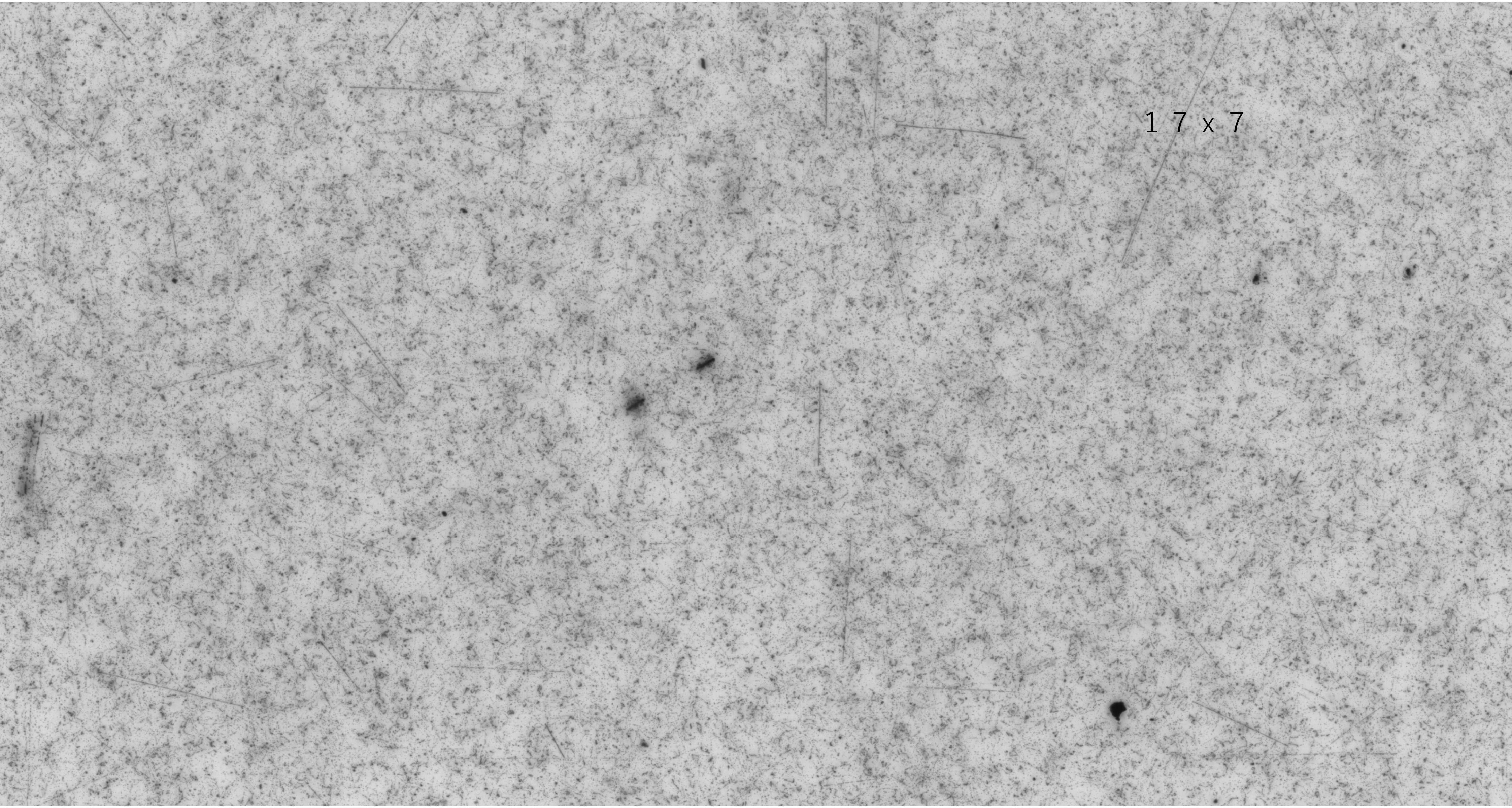
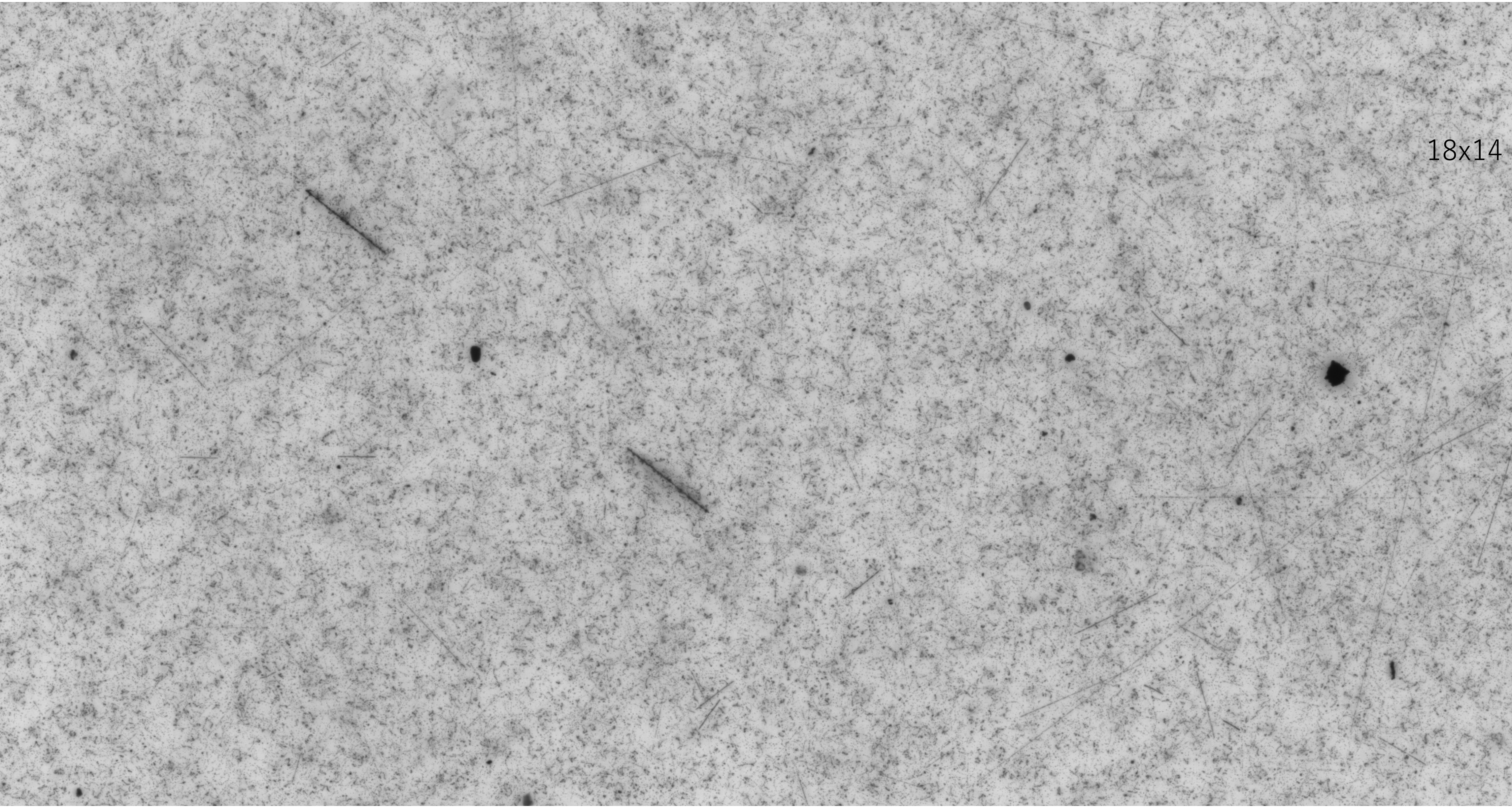
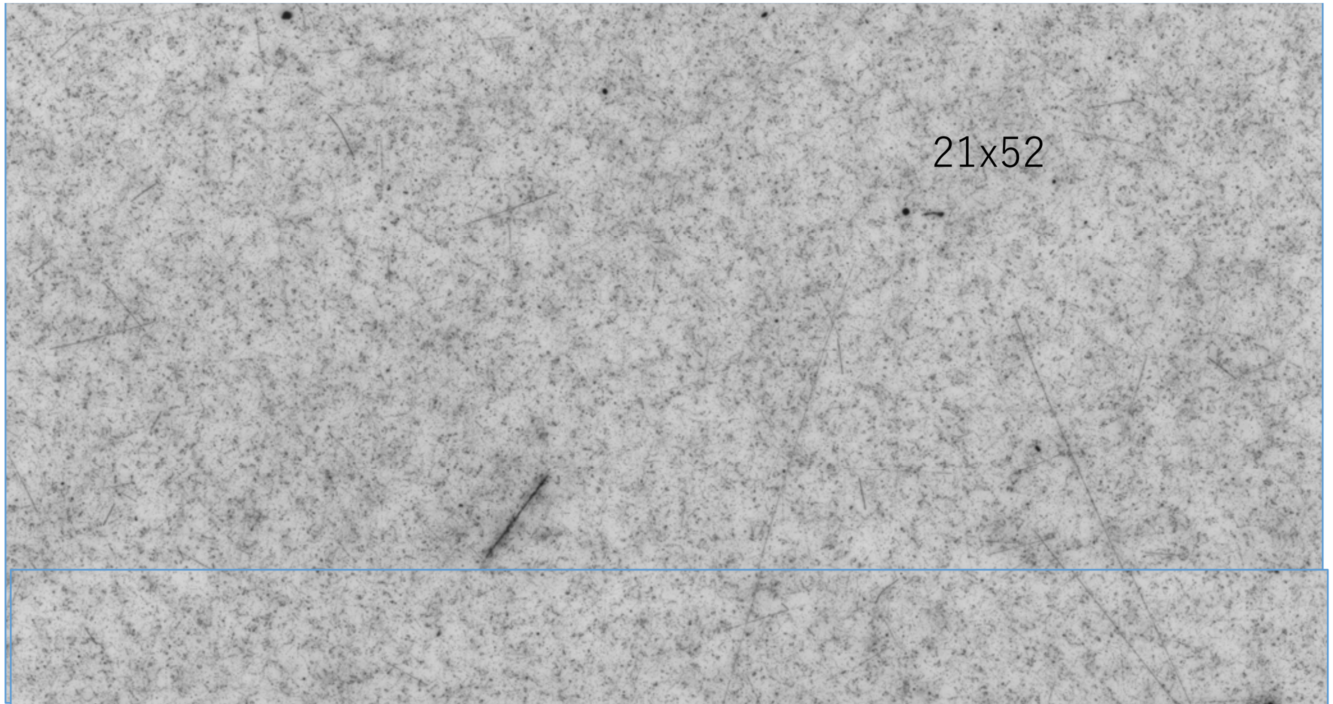
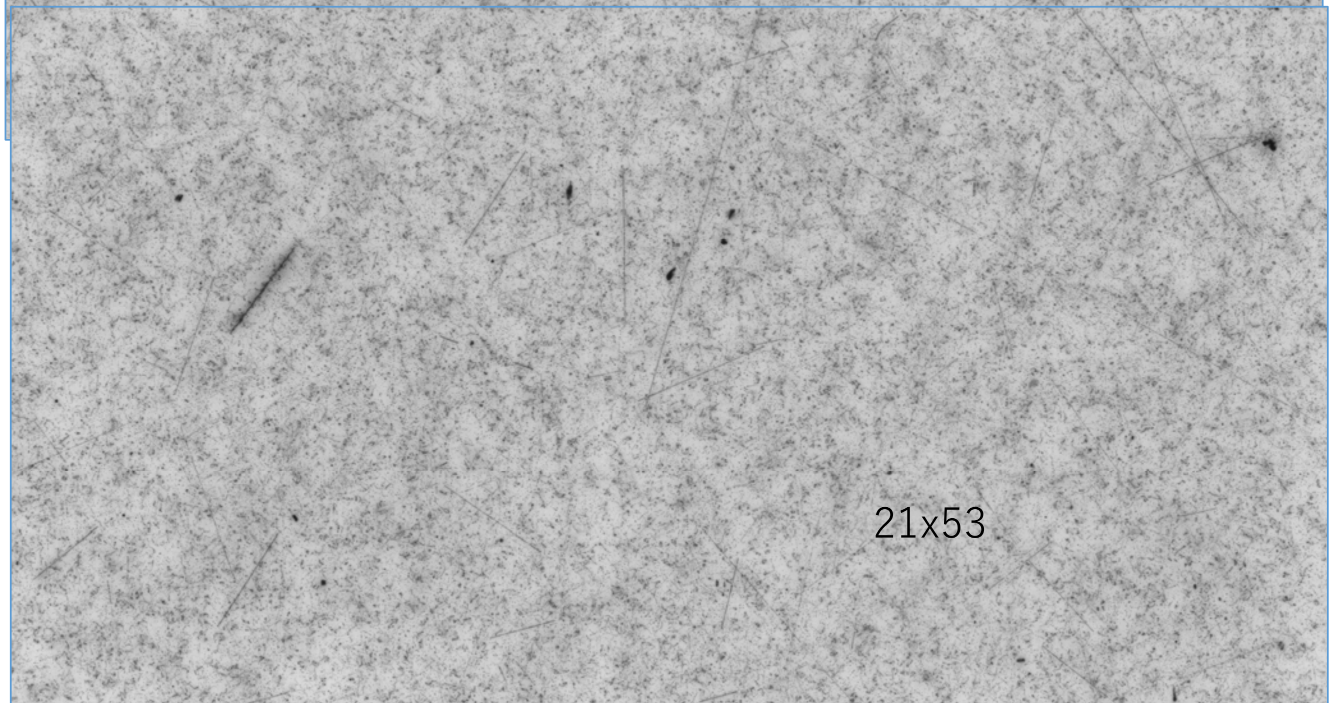

1 5 x 1 7


1 7 x 7


18x14


21x52


21x53

Summary

- We are going to analyze GRINE2023 emulsion images in order to obtain tracks of cosmic ray nuclei.

- In this eye-scan, 283/500 CRN tracks could be found in 3cm x3cm region. Feature measurements of each track such as track width, PHV etc., are on-going now.

- These CRN images are used for training data of machine learning algorithm to automatically recognize CRN tracks in emulsion images.

- We are going to extend image region from 3cmx 3cm to 10cm x 10cm for this image analysis. ~1TB