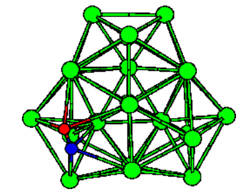
Vorlesung für Masterstudentinnen und –studenten
Modul Nr. 17 W



Prof. Dieter Bauer, Quantentheorie und Vielteilchenphysik
Prof. Karl-Heinz Meiwes-Broer, Cluster und Nanostrukturen
Homepage Dieter Bauer: /qtmps teaching WS 11/12 AC

<u>Atome</u>:
Atomare Struktur, Atom-Feld-Wechselwirkung, magnetische und optische Fallen, Bose-Einstein-Kondensate, kalte Fermionen, Atome in starken Feldern, Ionisation, Erzeugung Hoher Harmonischer, Teilchen-beschleunigung mit Lasern, Innerschalen-Effekte, Elektronen-korrelationen, relativistische Laser-Atom-Wechsel-wirkung, QED-Effekte

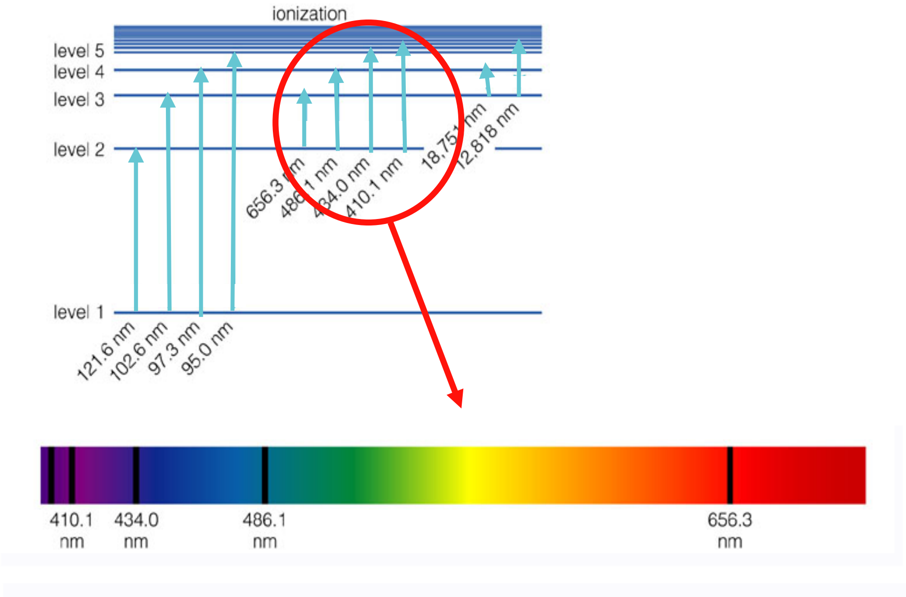
<u>Cluster</u>:
Bindungen, Erzeugung, Schalenmodell, Jellium-Näherung, elektro-nische Struktur, Fullerene, Nichtmetall-Metall-Übergang, Dichtefunk-tionalbeschreibung, Polarisierbarkeit, lineare Antworttheorie, Summenregeln, Resonanzen, Spektroskopie, optische Eigenschaften, Spinordnung, Cluster in He-Tröpfchen, an Oberflächen, in starken Feldern, Nanoplasmen

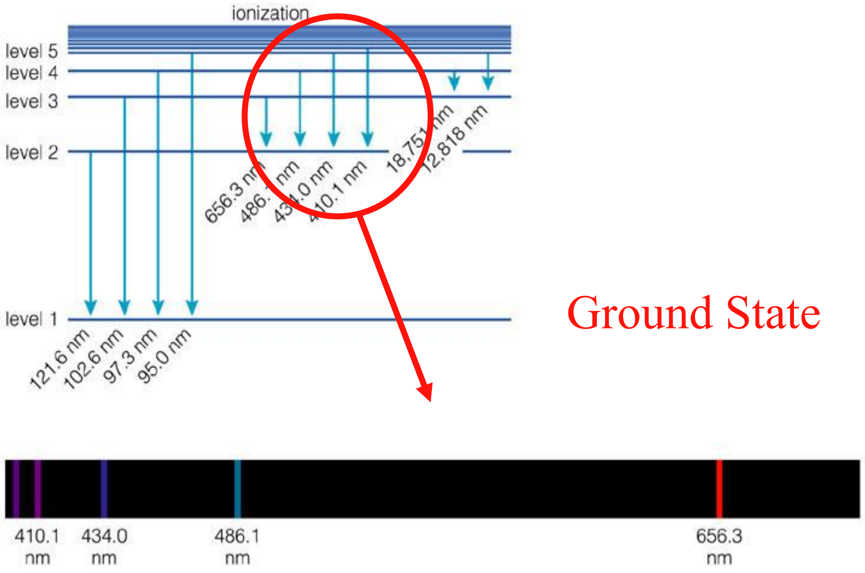
Theorie	Experiment
	Einf. Atom- und Clusterphysik
Atom-Feld-WW Materie im EM Feld	Präp.methoden Atomstrahl
Lichtkräfte auf Teilchen gedresste Atome	Laserkühlung
BEC	E + M Fallen
Starkfeld-Physik	Koinzidenztechniken, COLTRIMS
Starkfeld-Physik II	
Anregung mit hohen Frequenzen	FEL: Funktionsweisen
Innerschalen, Augerkaskaden	Einzelschuss-Diffraktion
	weitere FEL-Experimente
relativistische Laser-Atom-WW, QED	
	Cluster Einf., Bindungstypen
MO-Theorie	Erzeugungstechniken
Dichtefunktionaltheorie	PES, elektr. Eigenschaften
Jelliummodell für Cluster- und Kernphysik	
optische Eigensch.: Summenregel, Mie	Photofragmentspektroskopie, opt. Eigenschaften
zeitabh. Dichtefunktionaltheorie	Starkfeldanregung
	Magnetismus

programme for today:

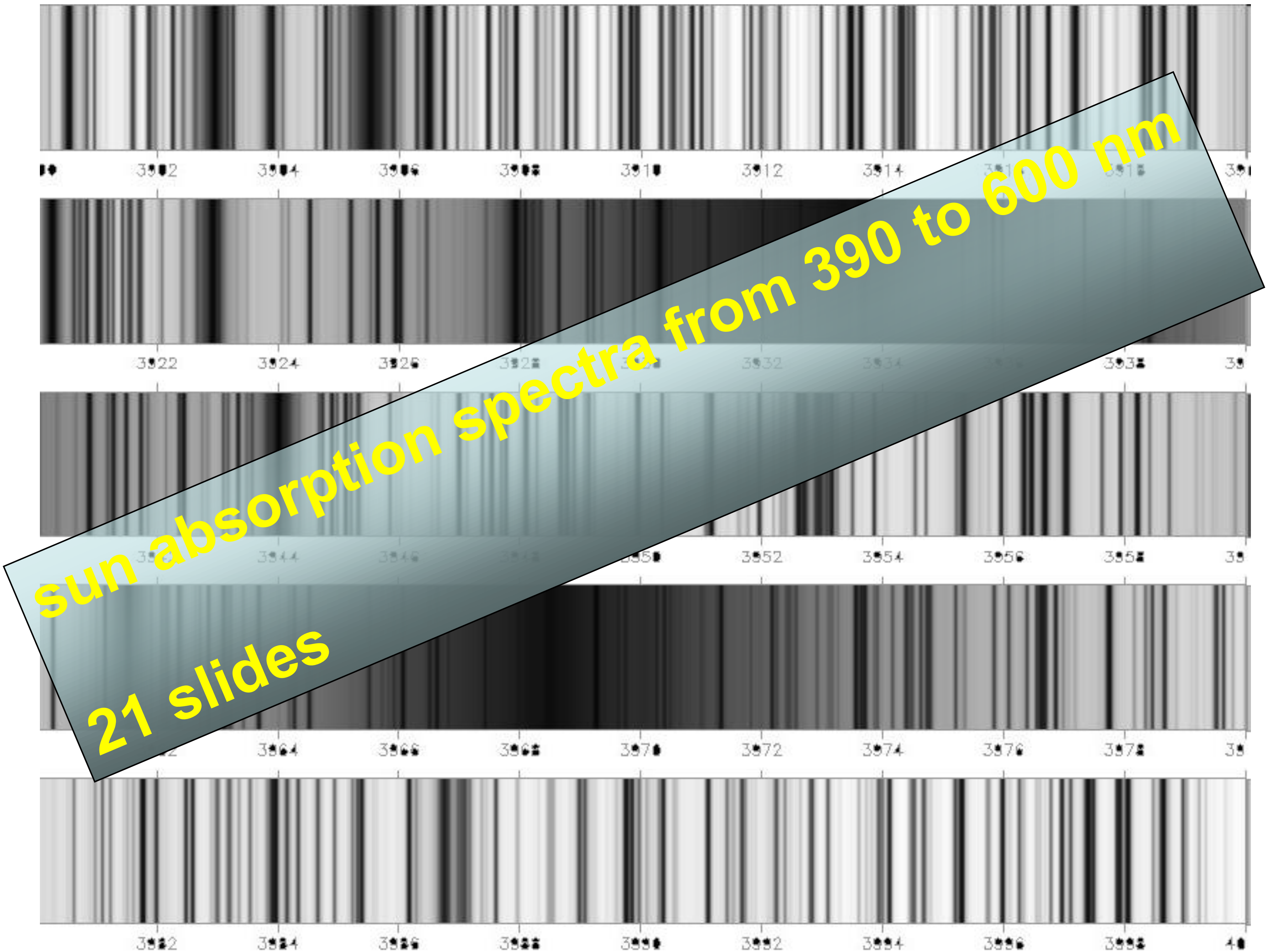
1. **relevance of atomic physics**
2. **introduction cluster physics**

absorption and emission

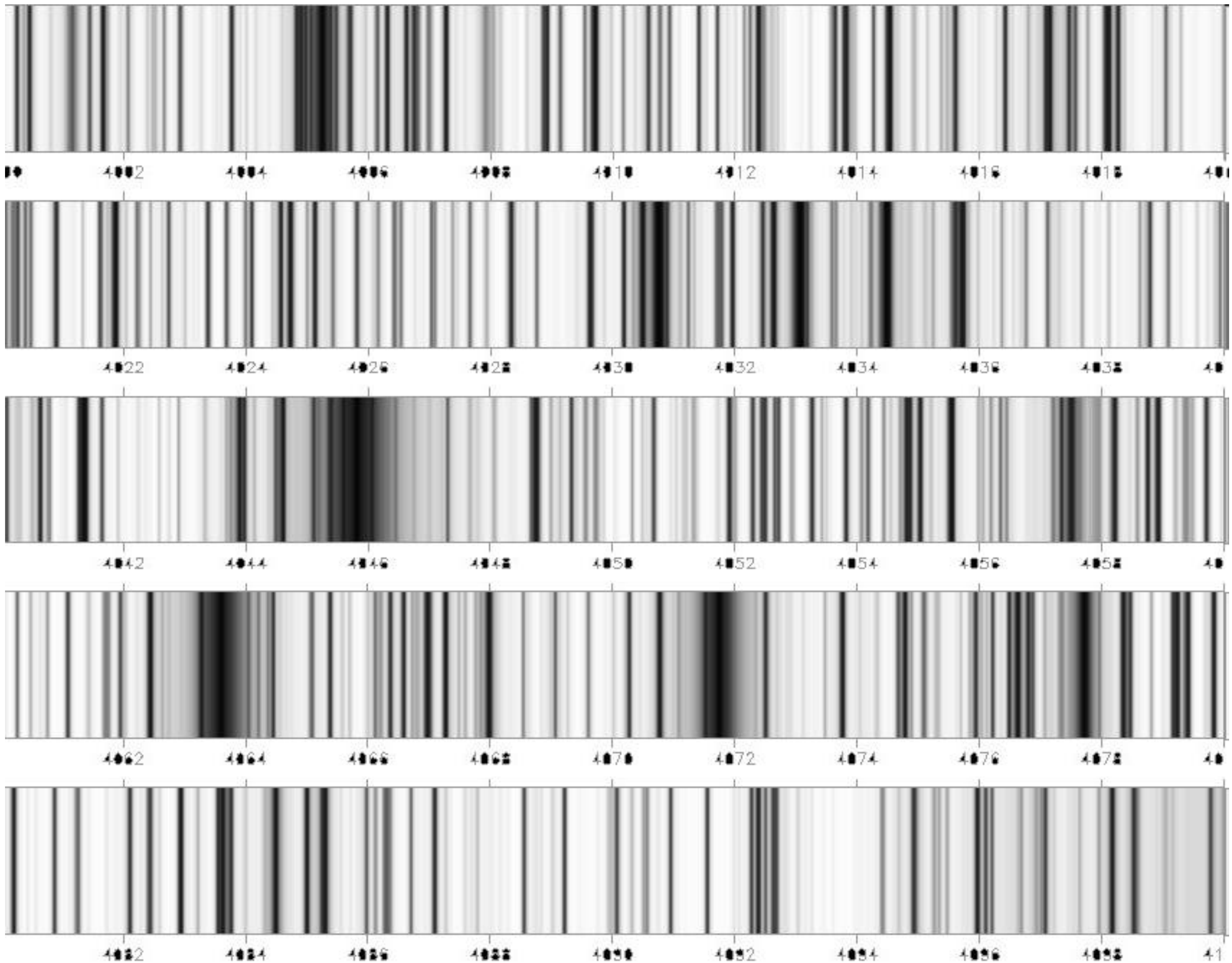


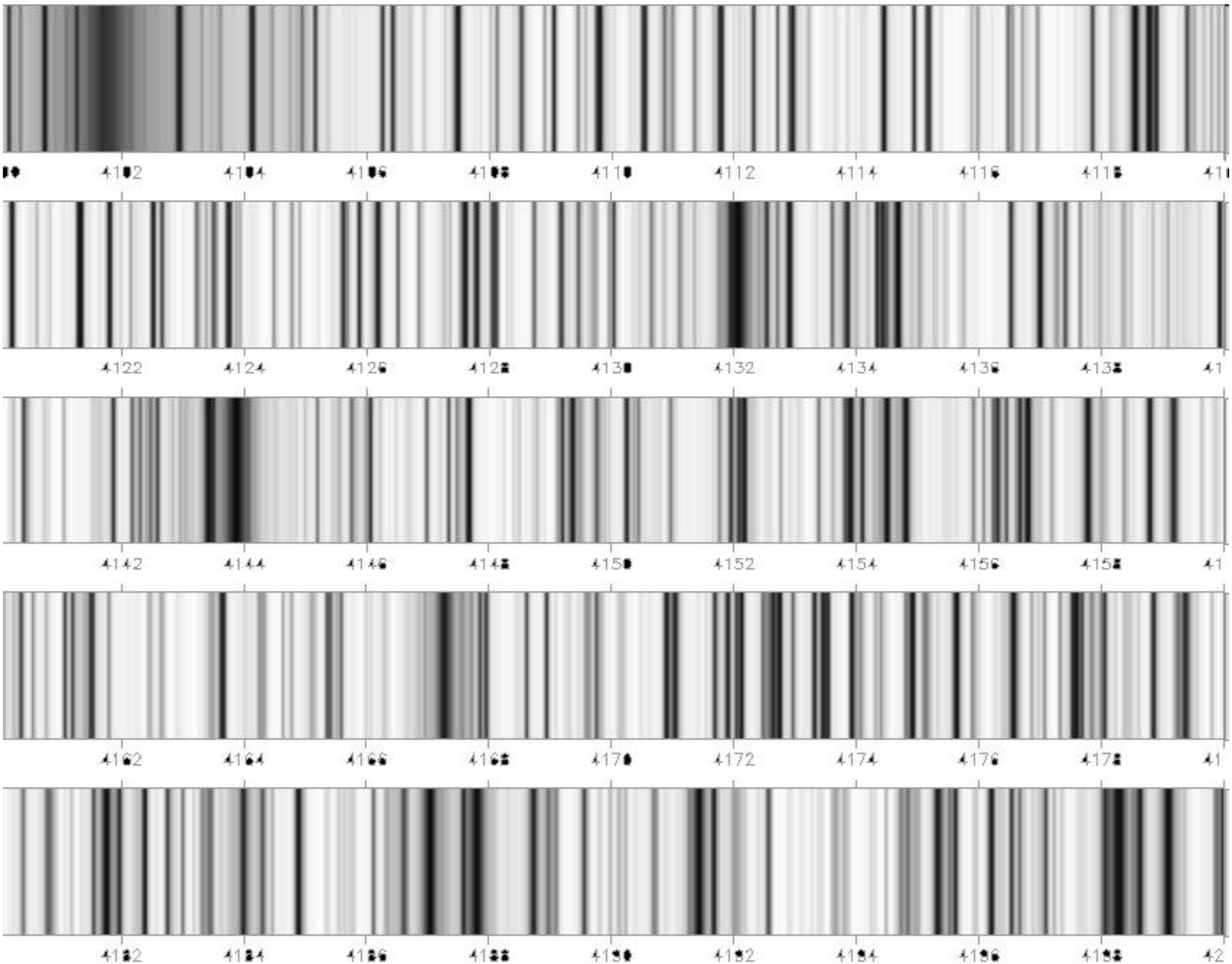


Ground State



Sonnenspektrum 390 nm bis 600 nm

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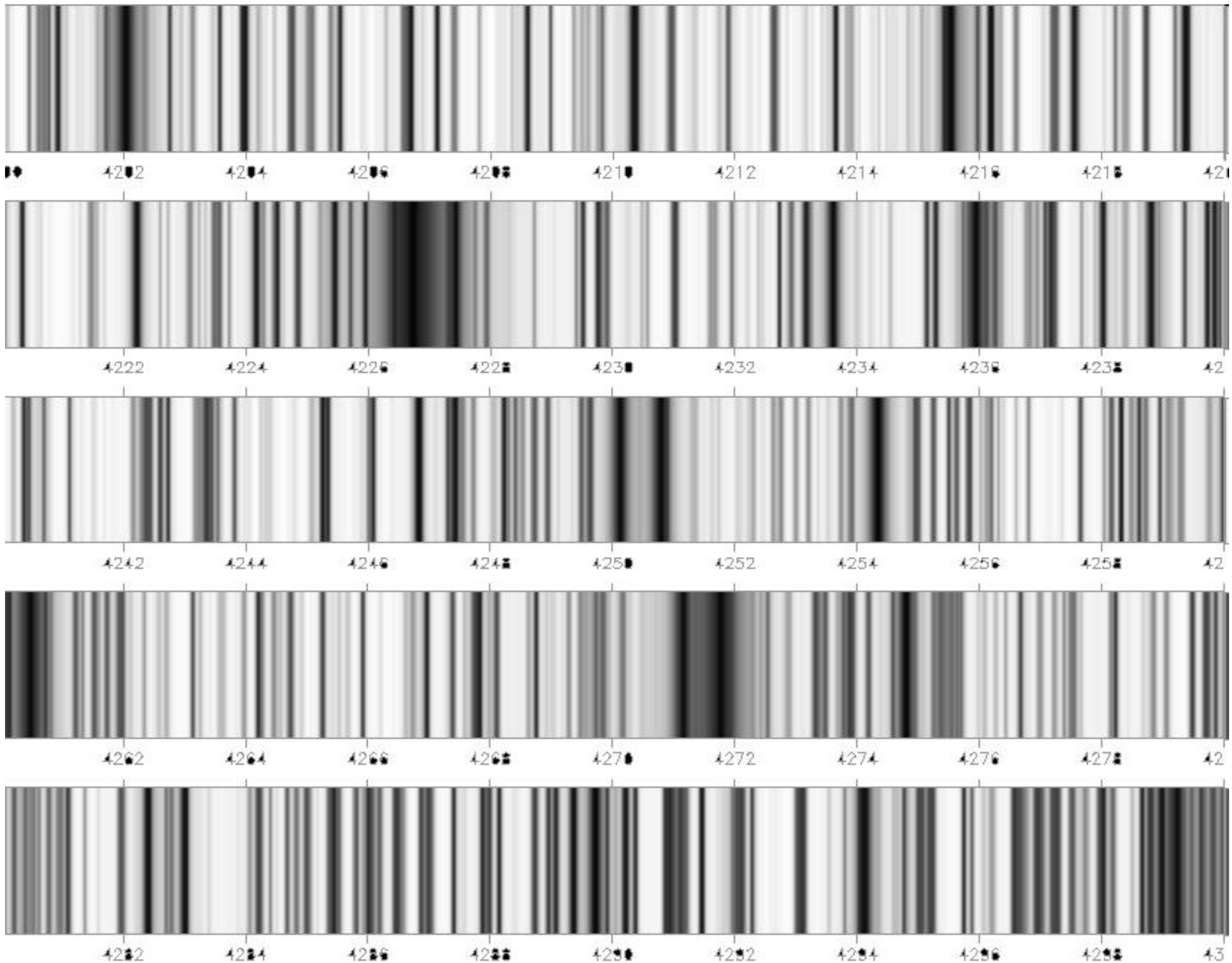
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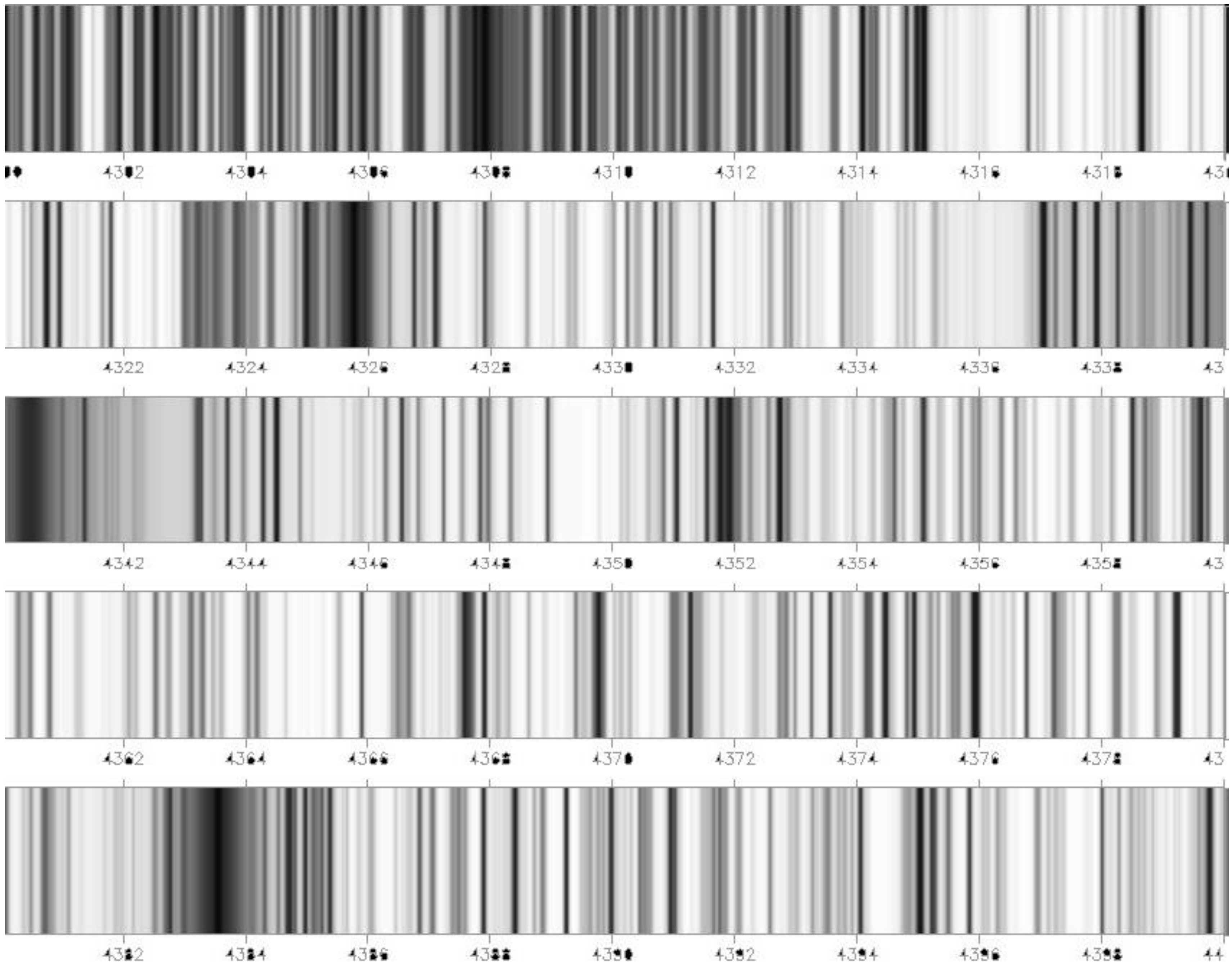
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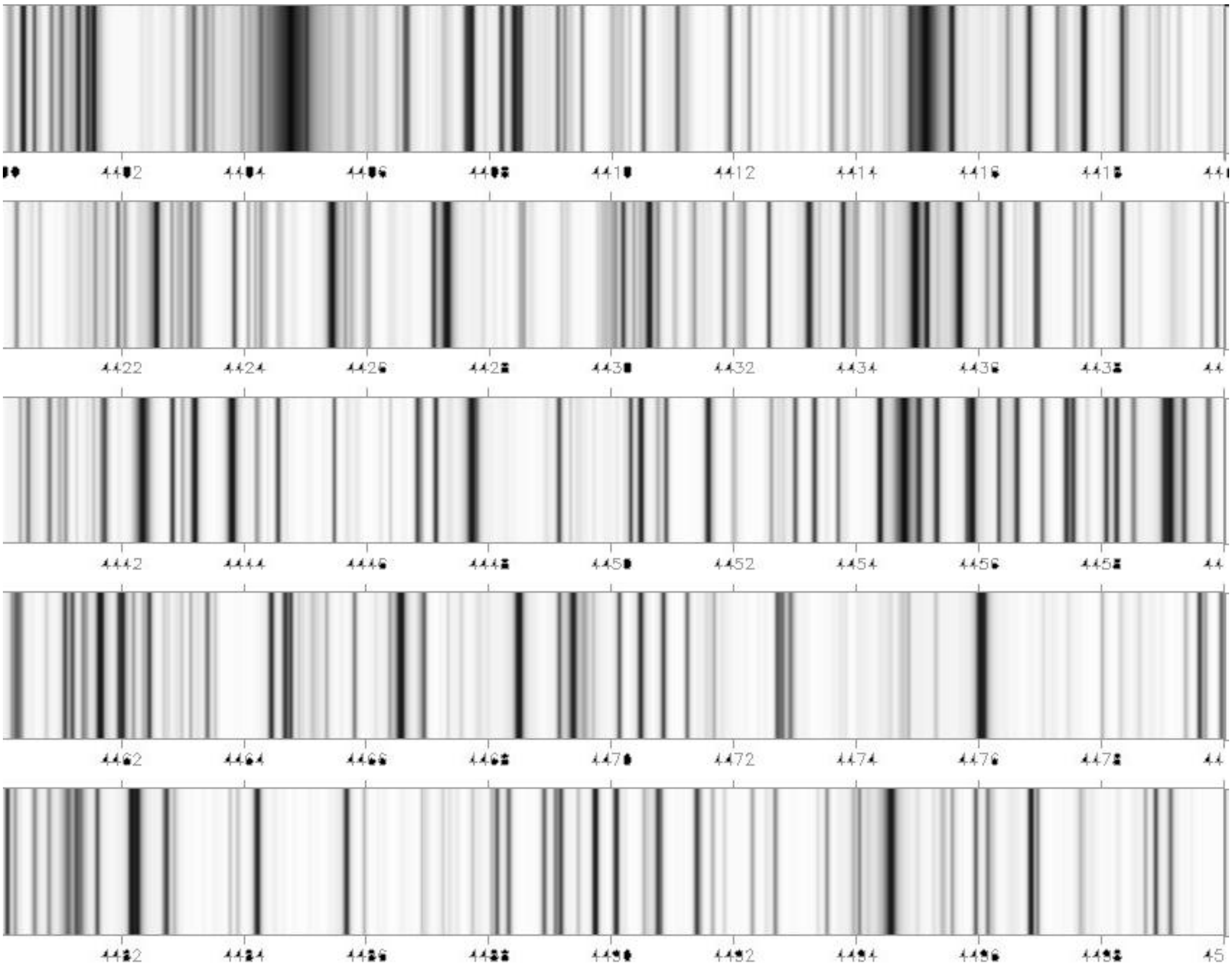
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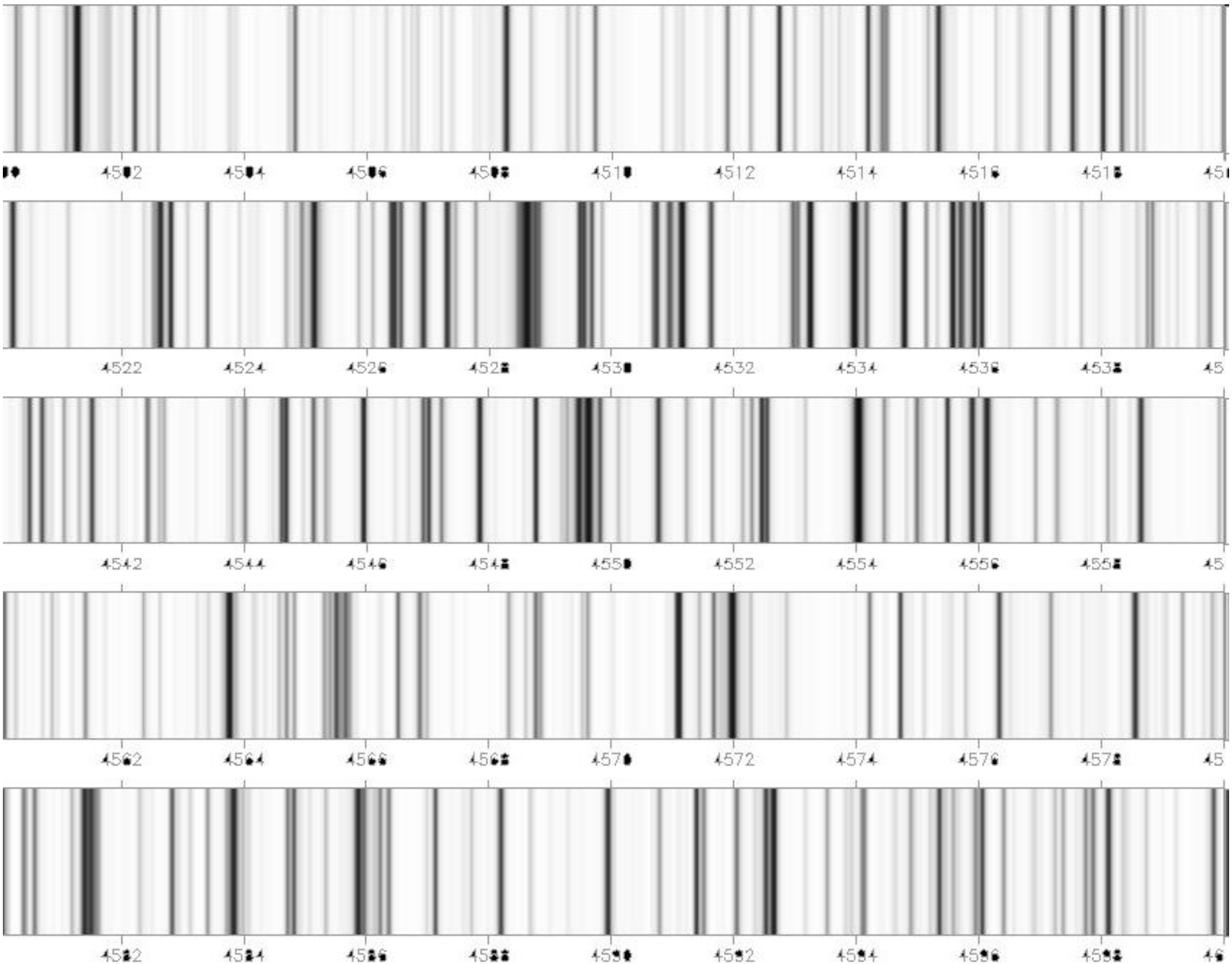
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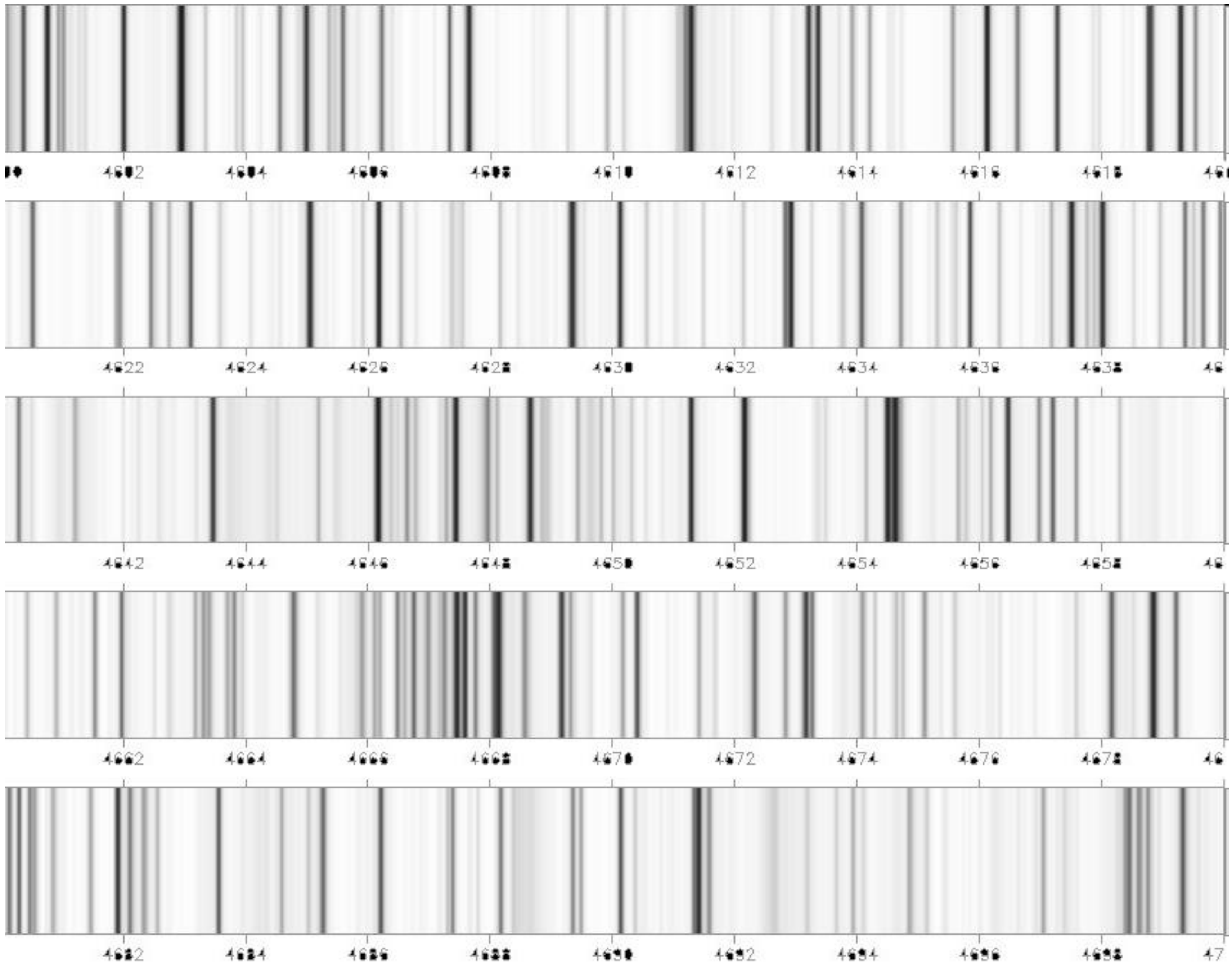

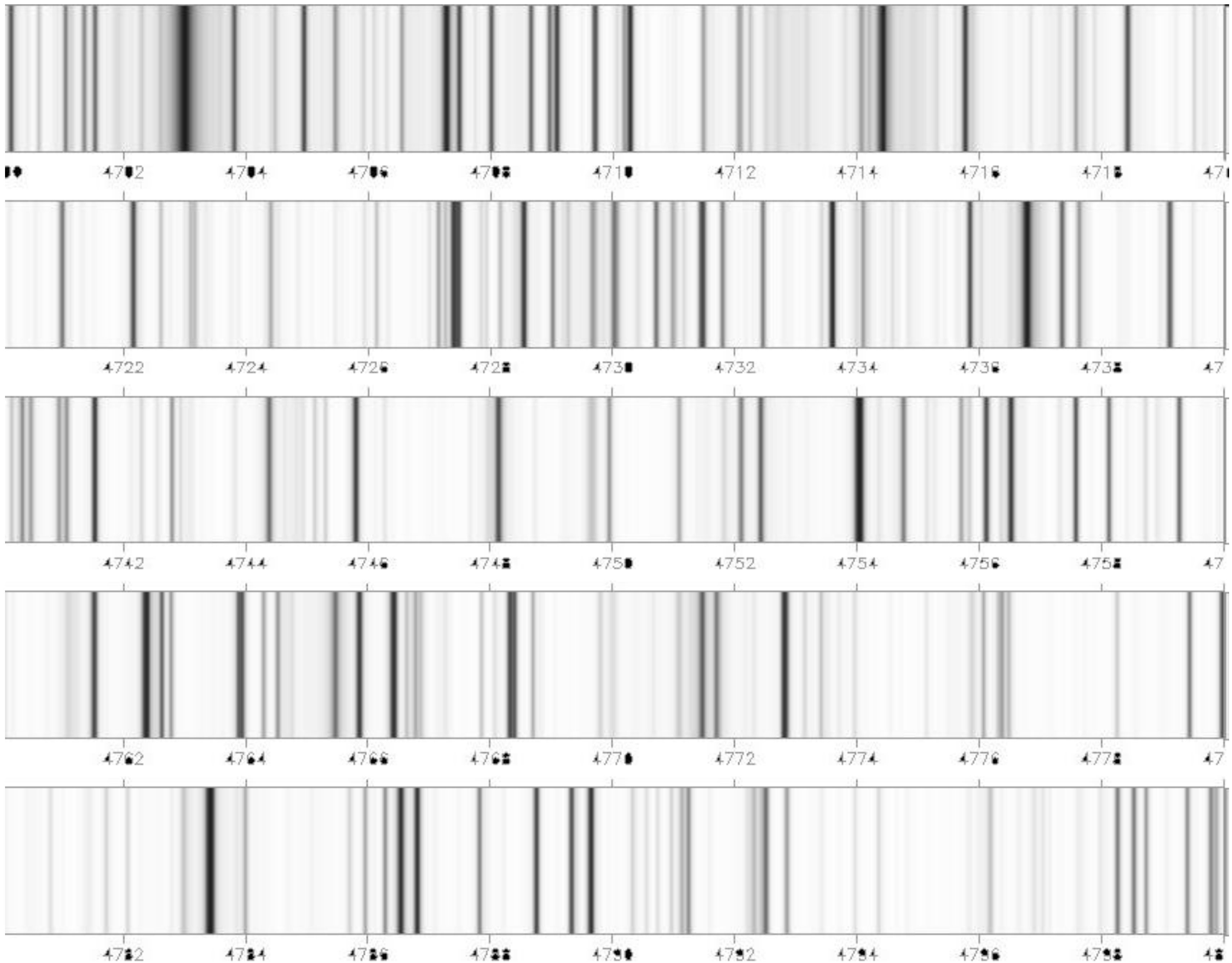
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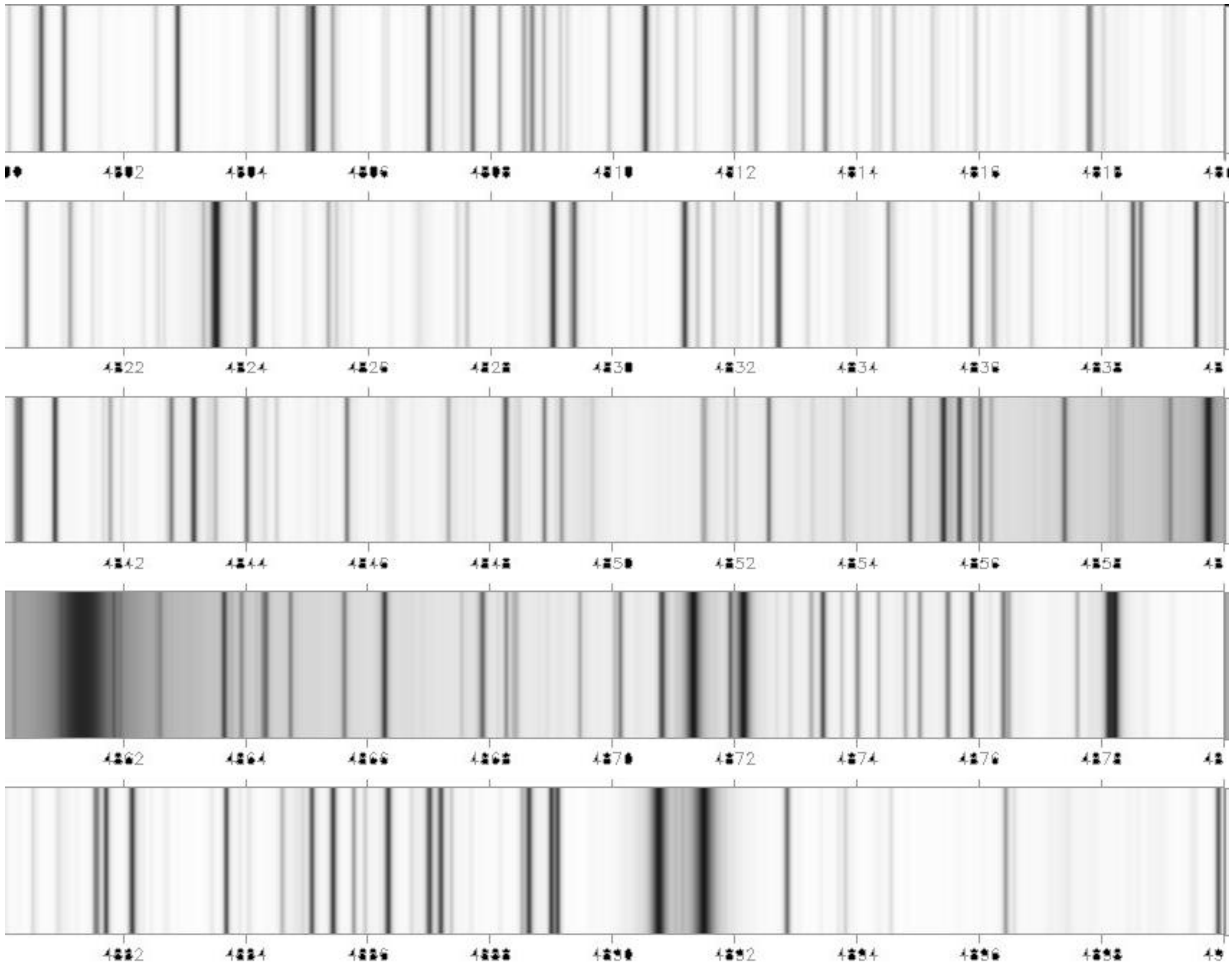

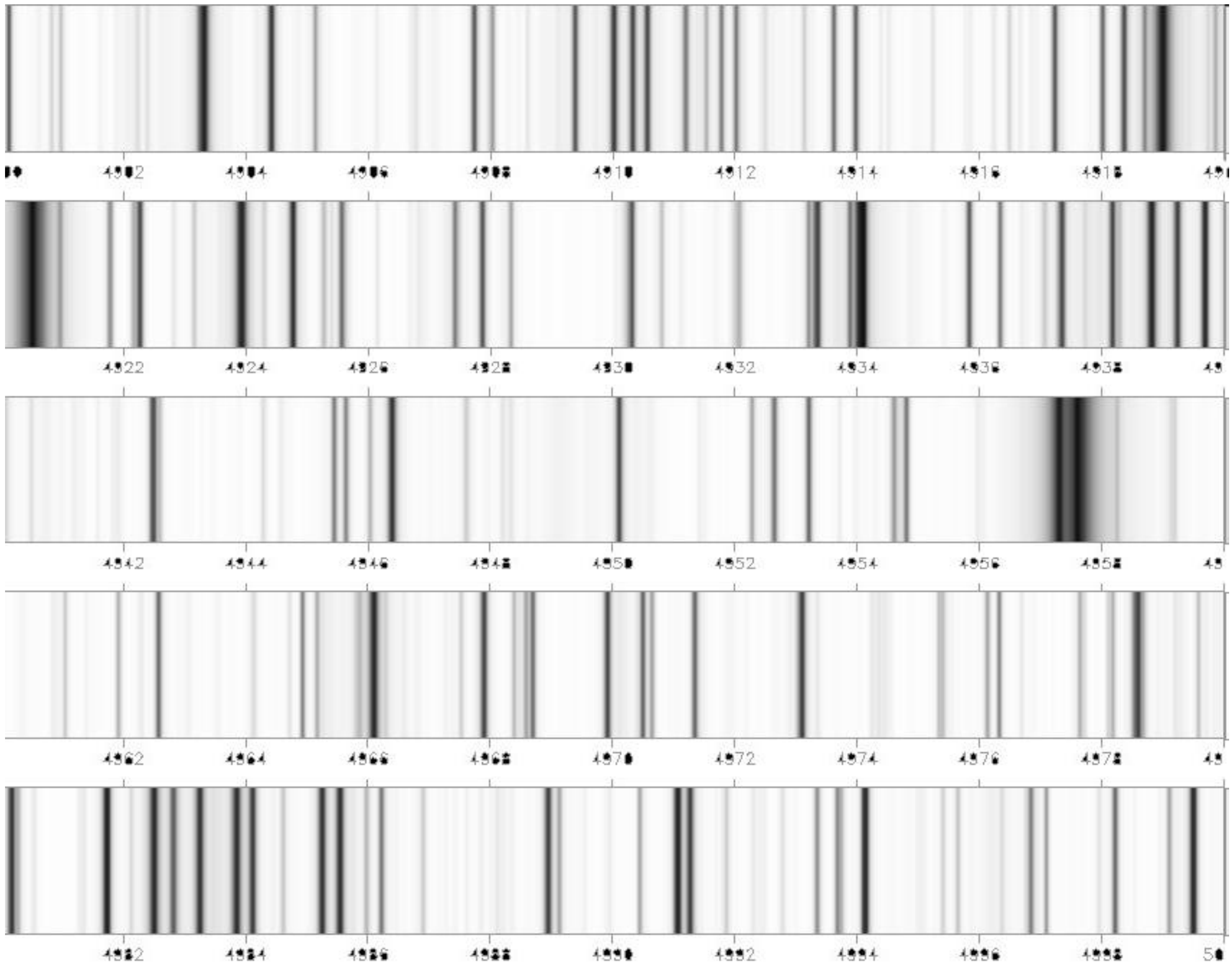

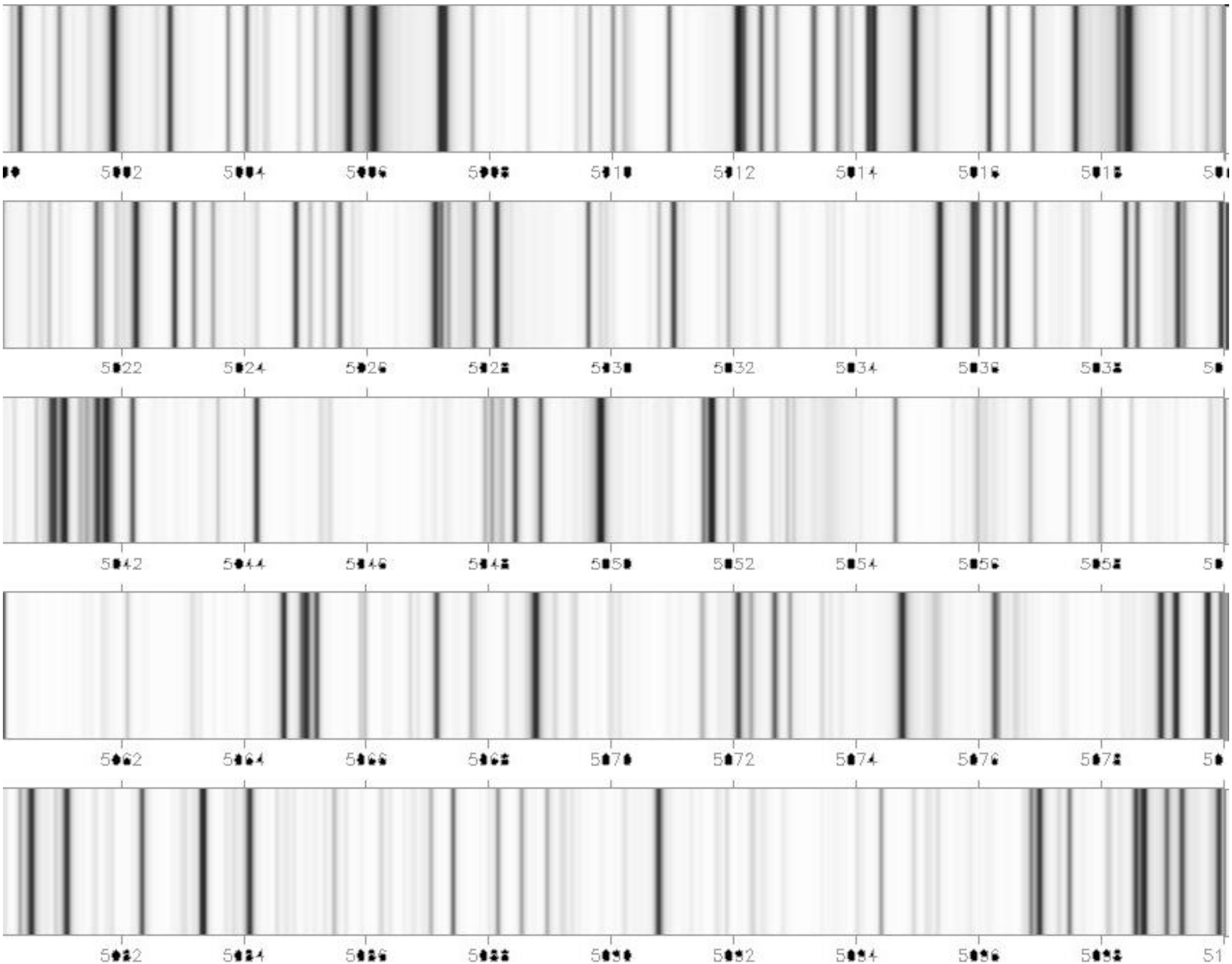

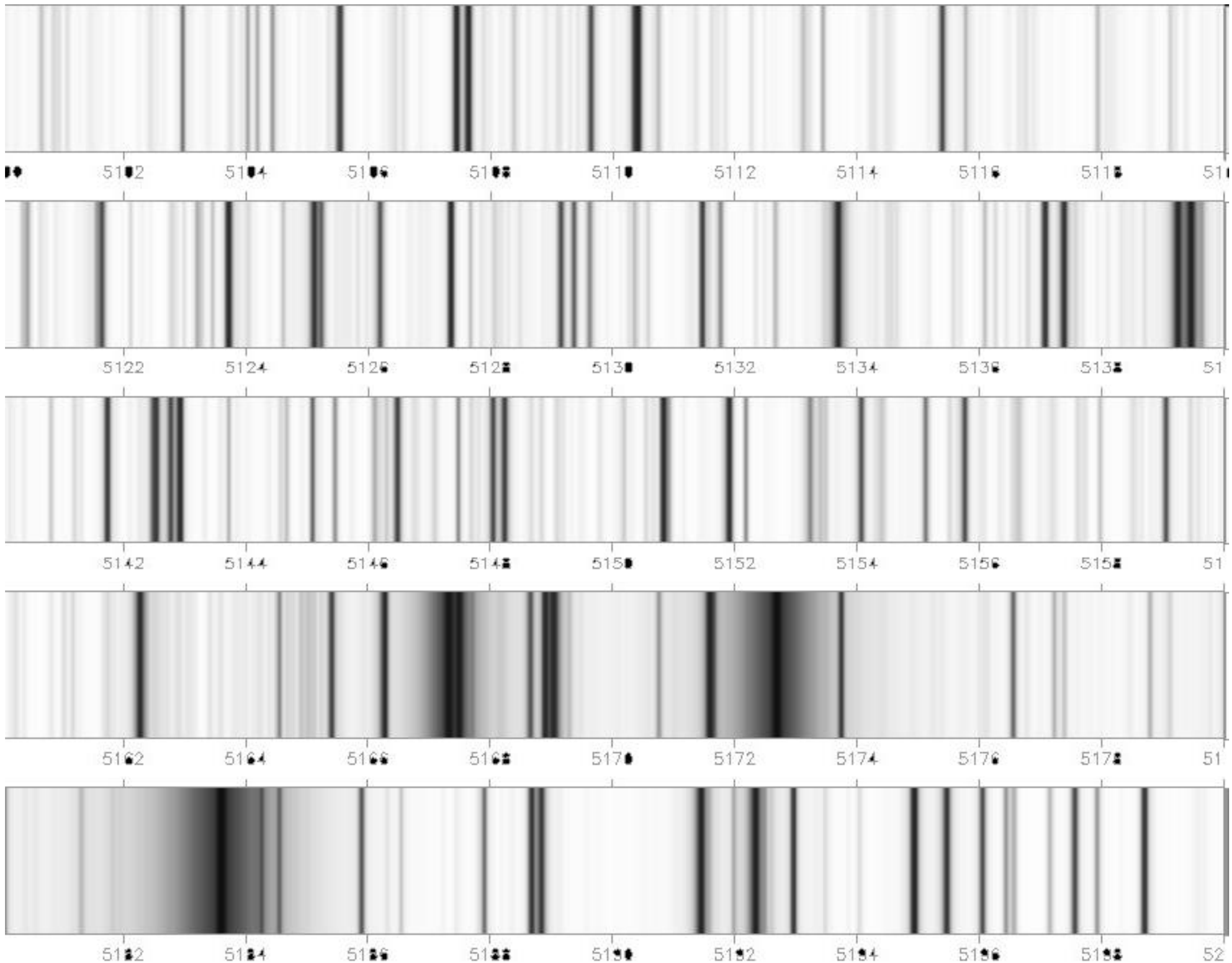
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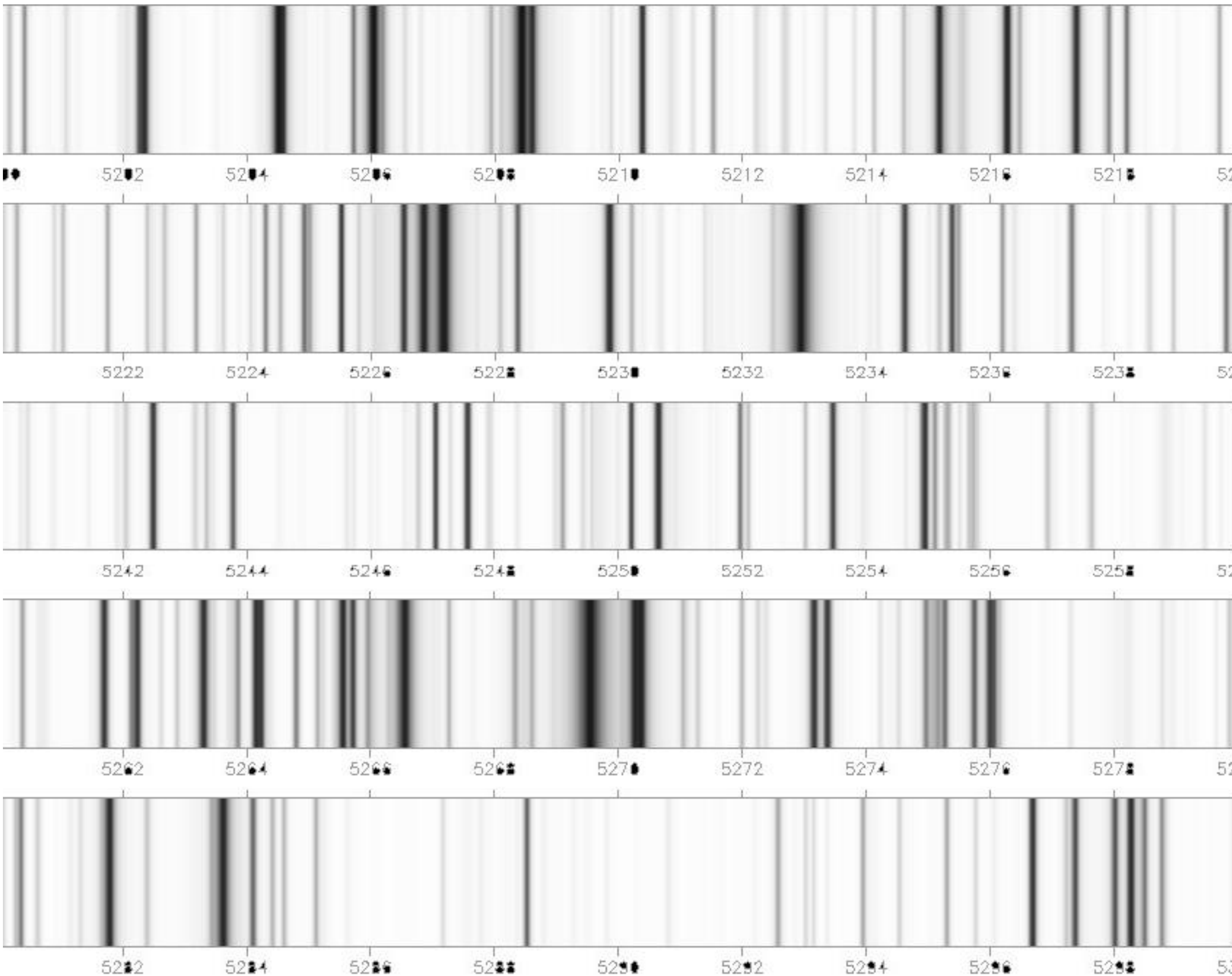

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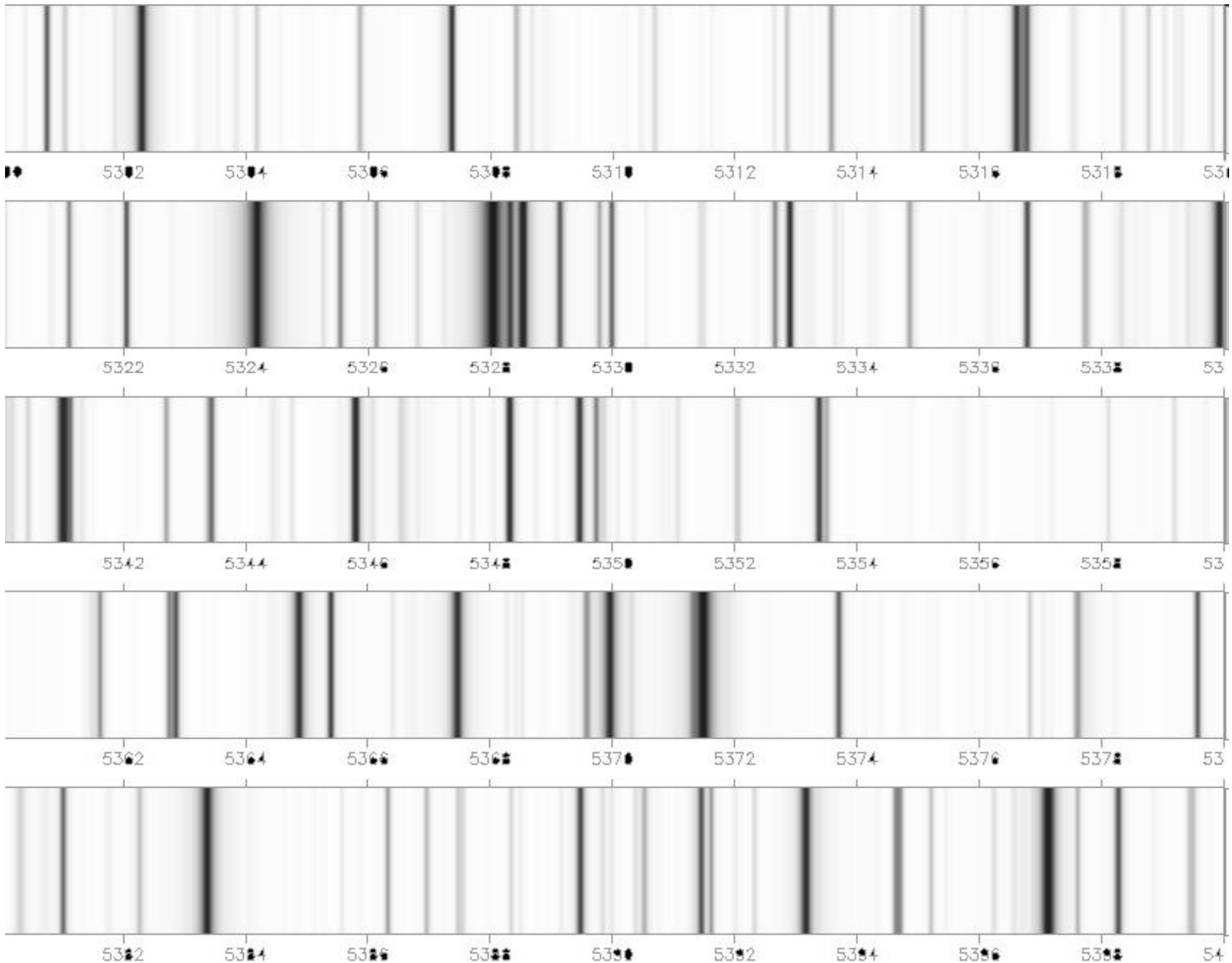
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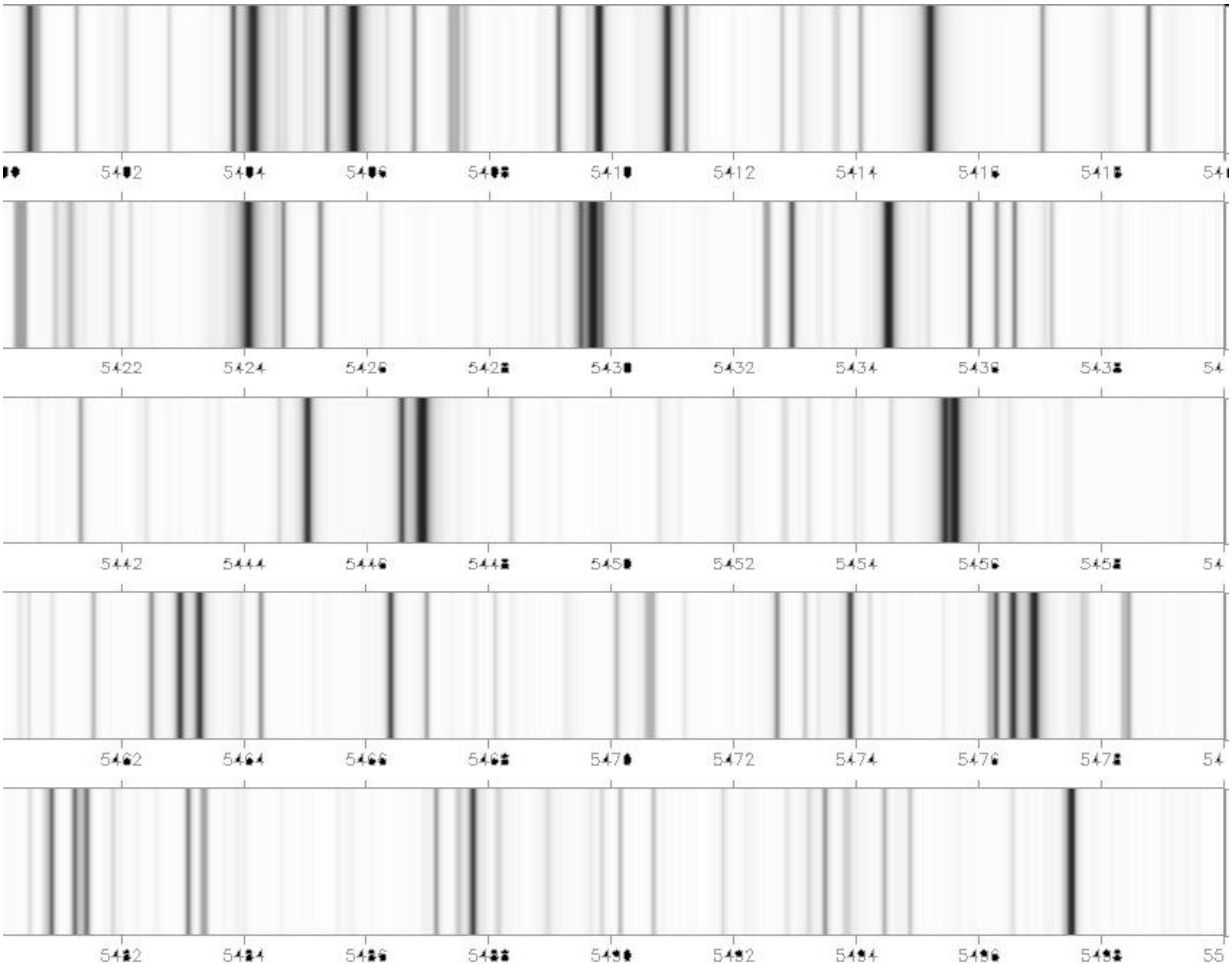
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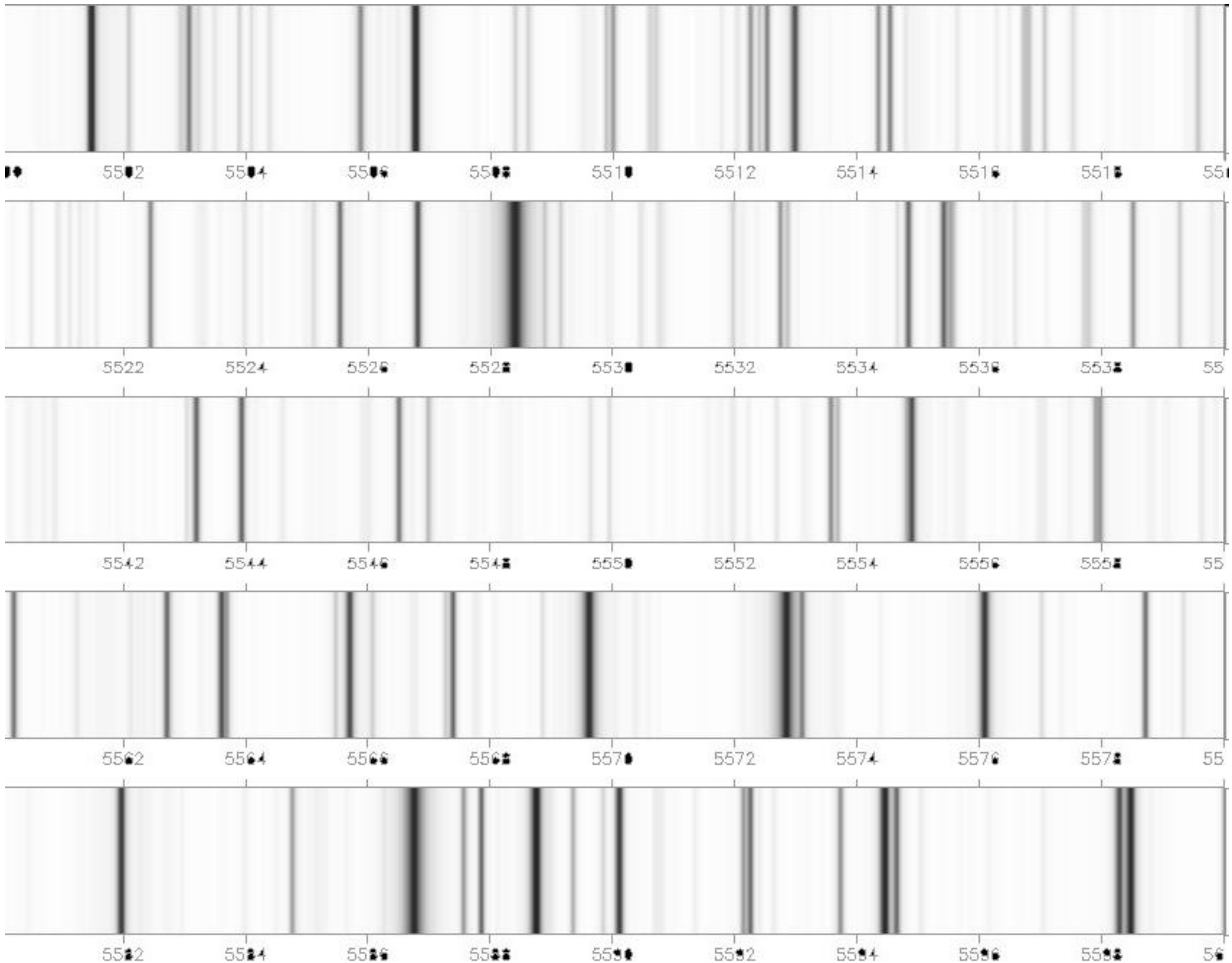
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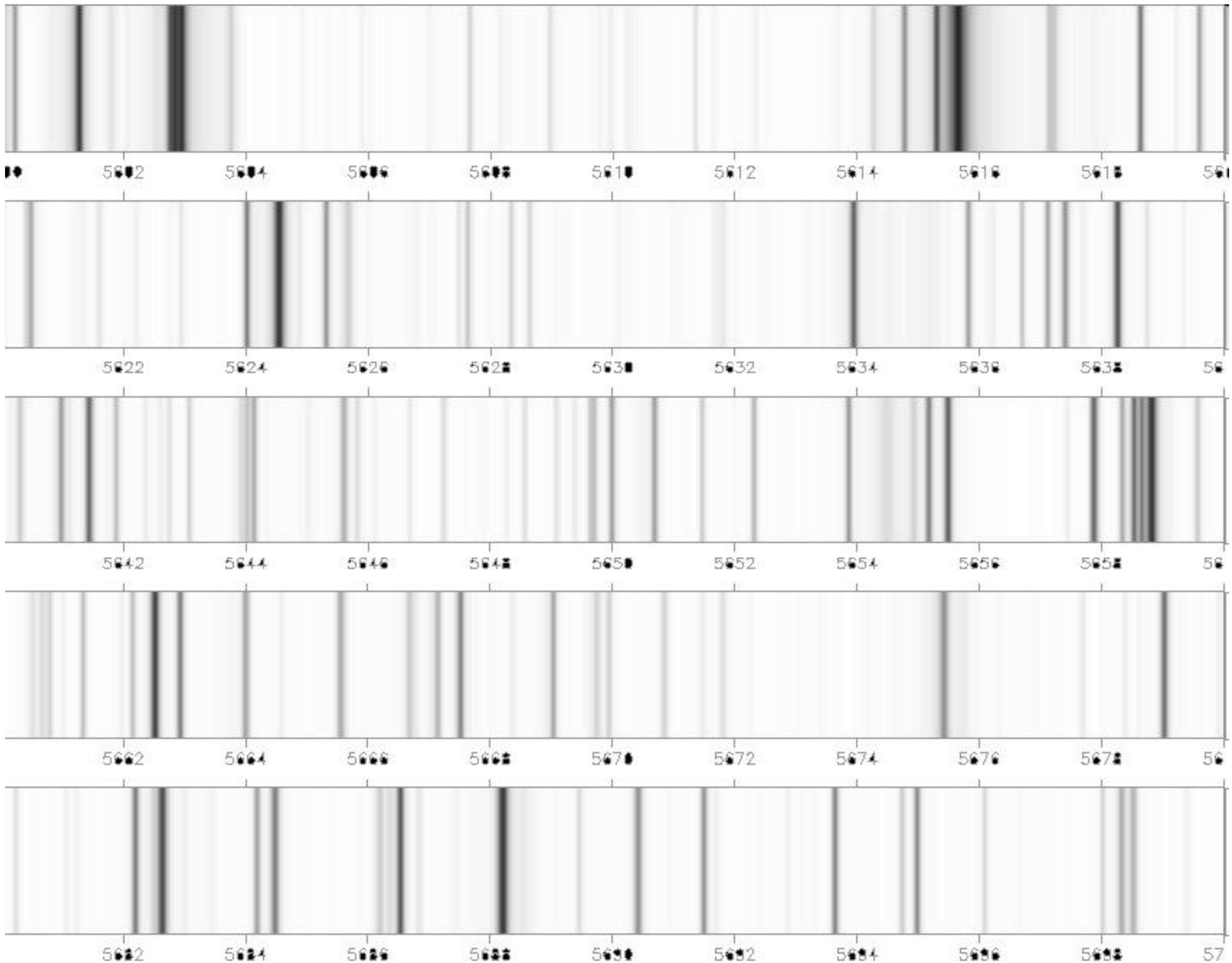
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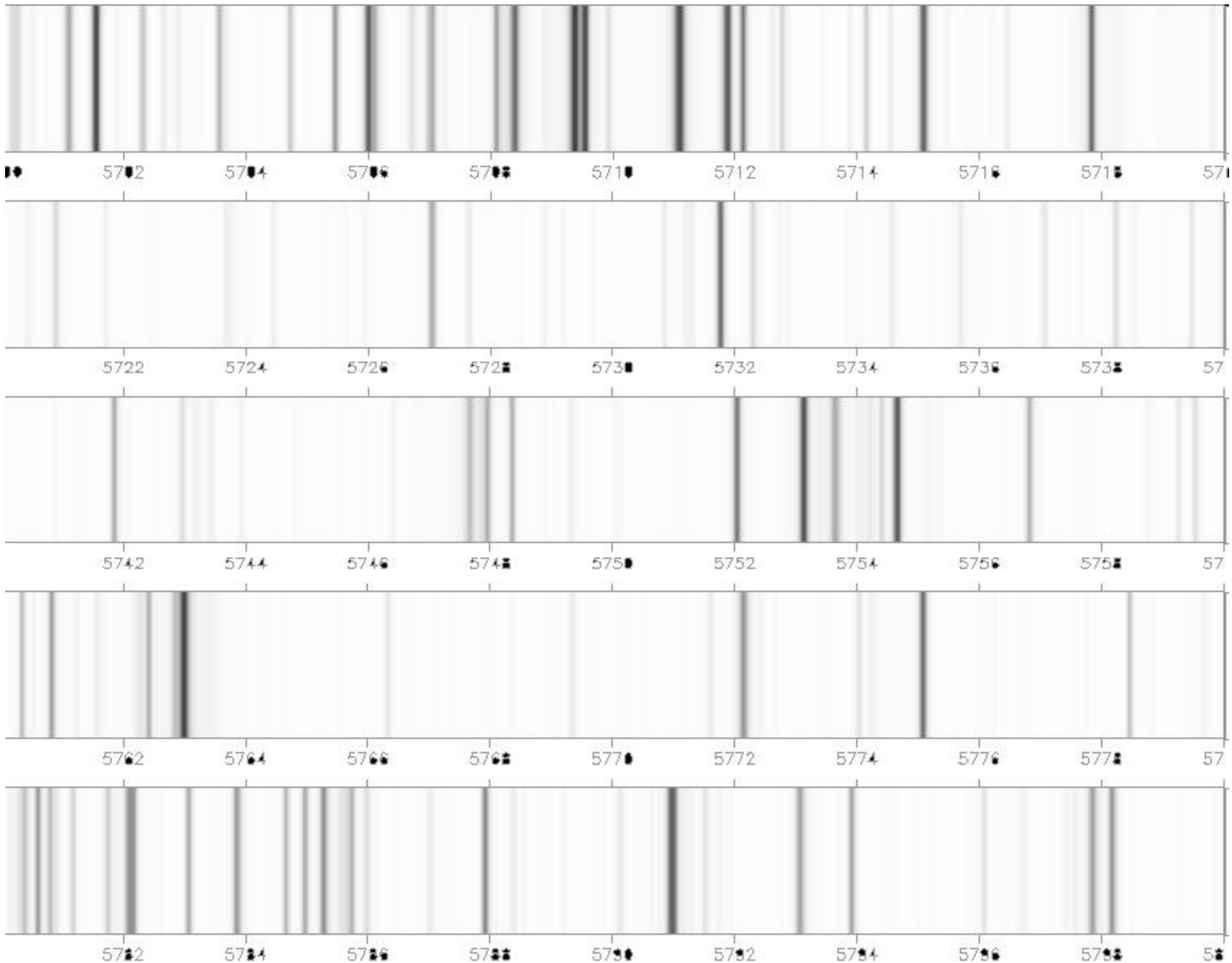
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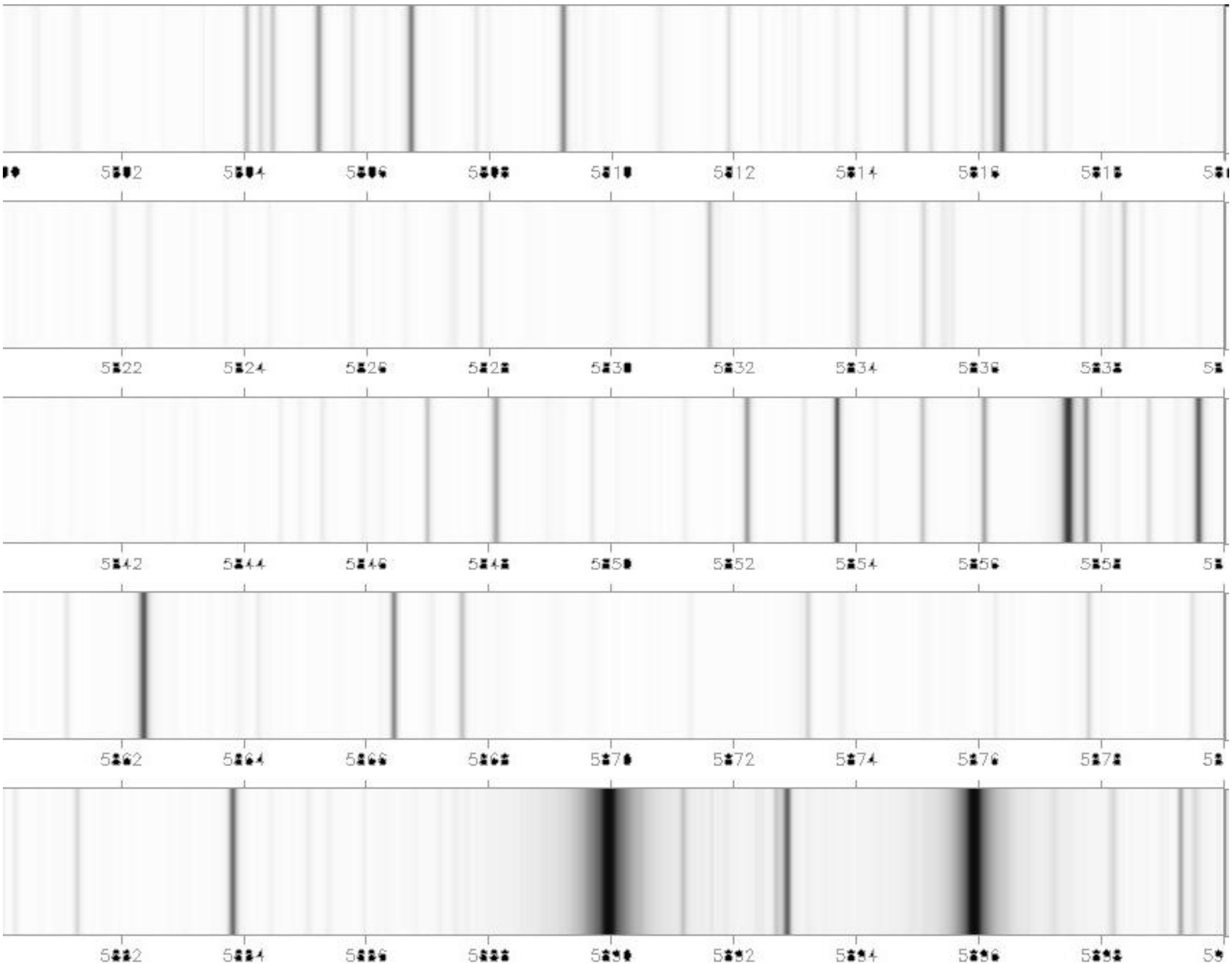
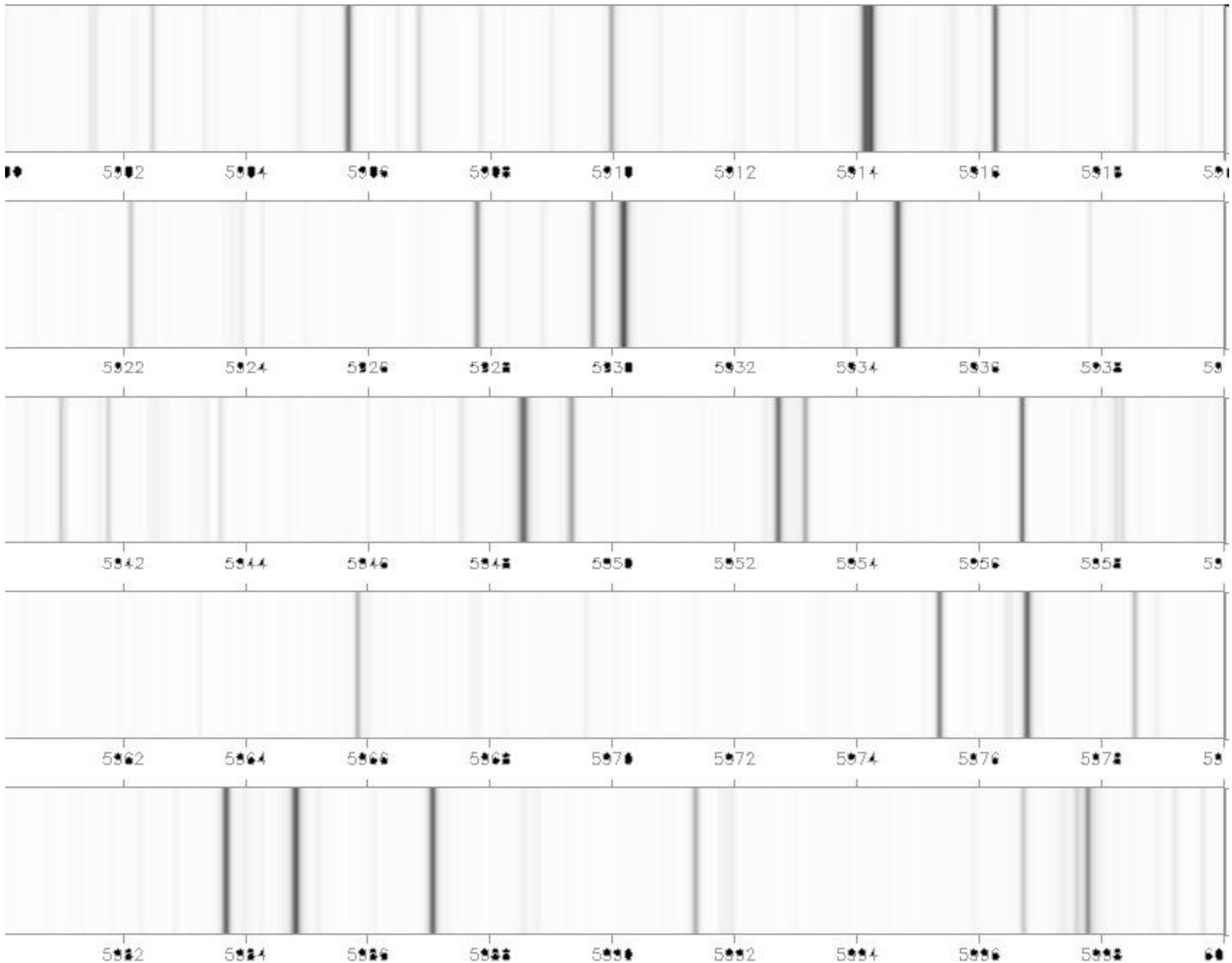
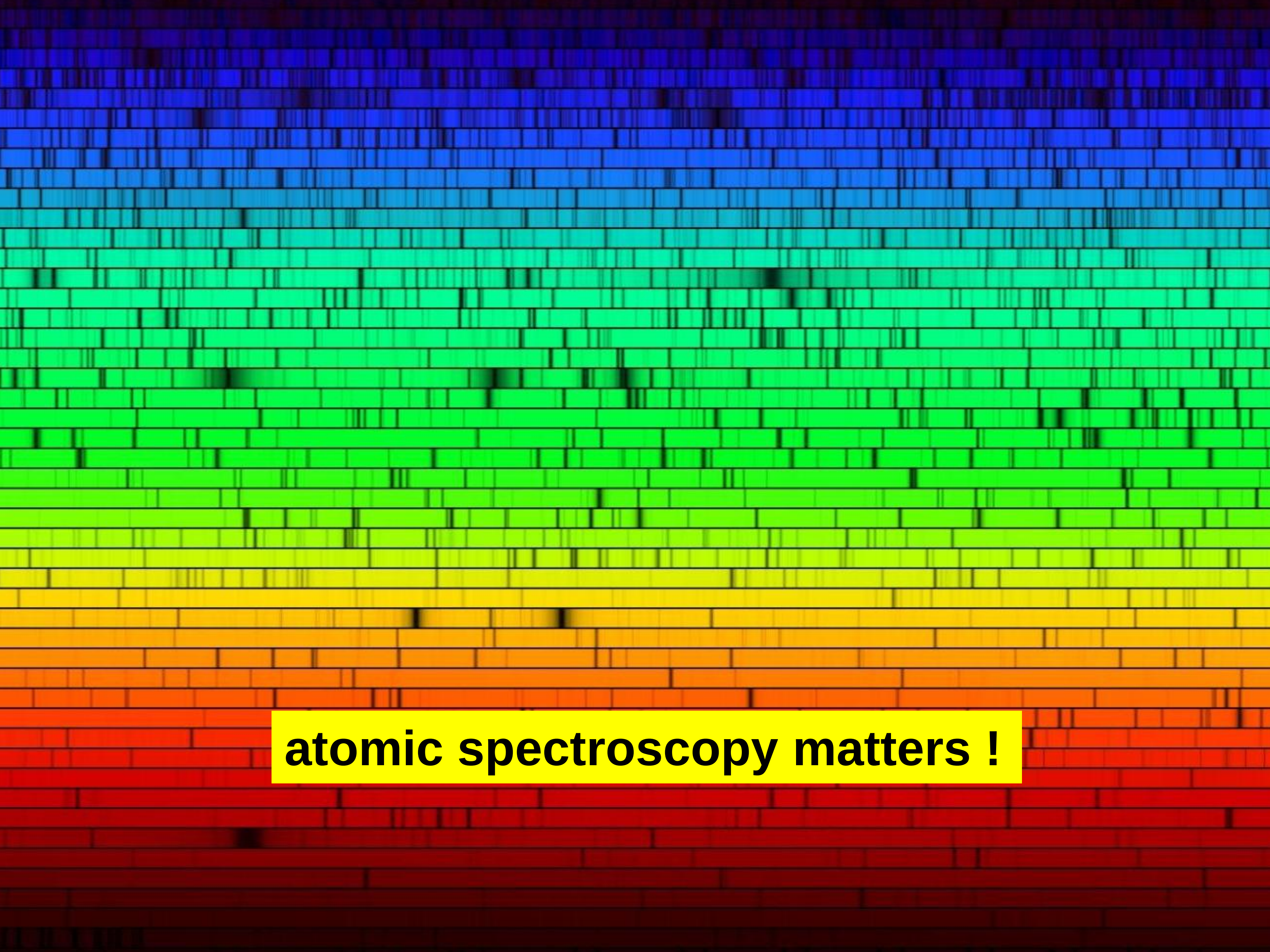
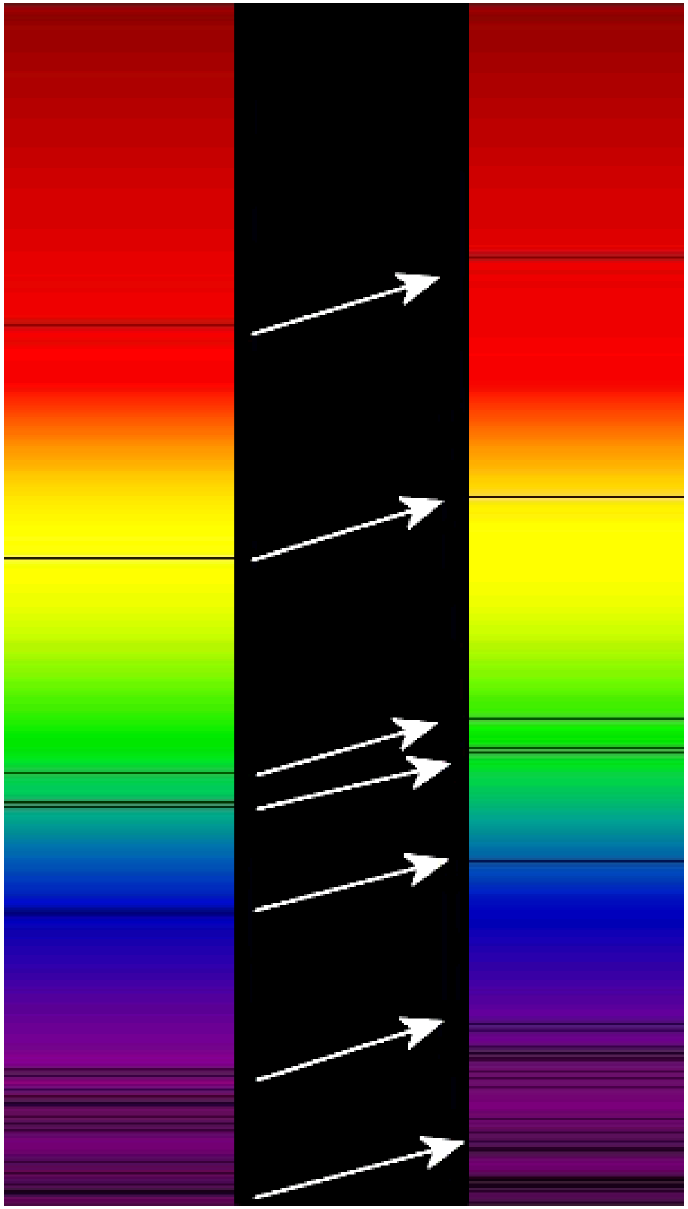




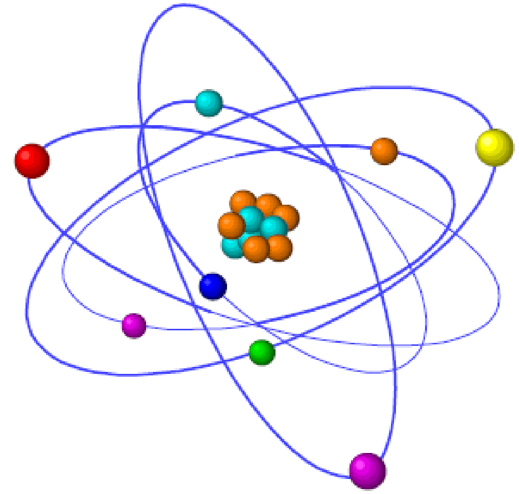

atomic spectroscopy matters !

Astronomie ohne Atomphysik undenkbar!

Absorptionslinien
Sonne



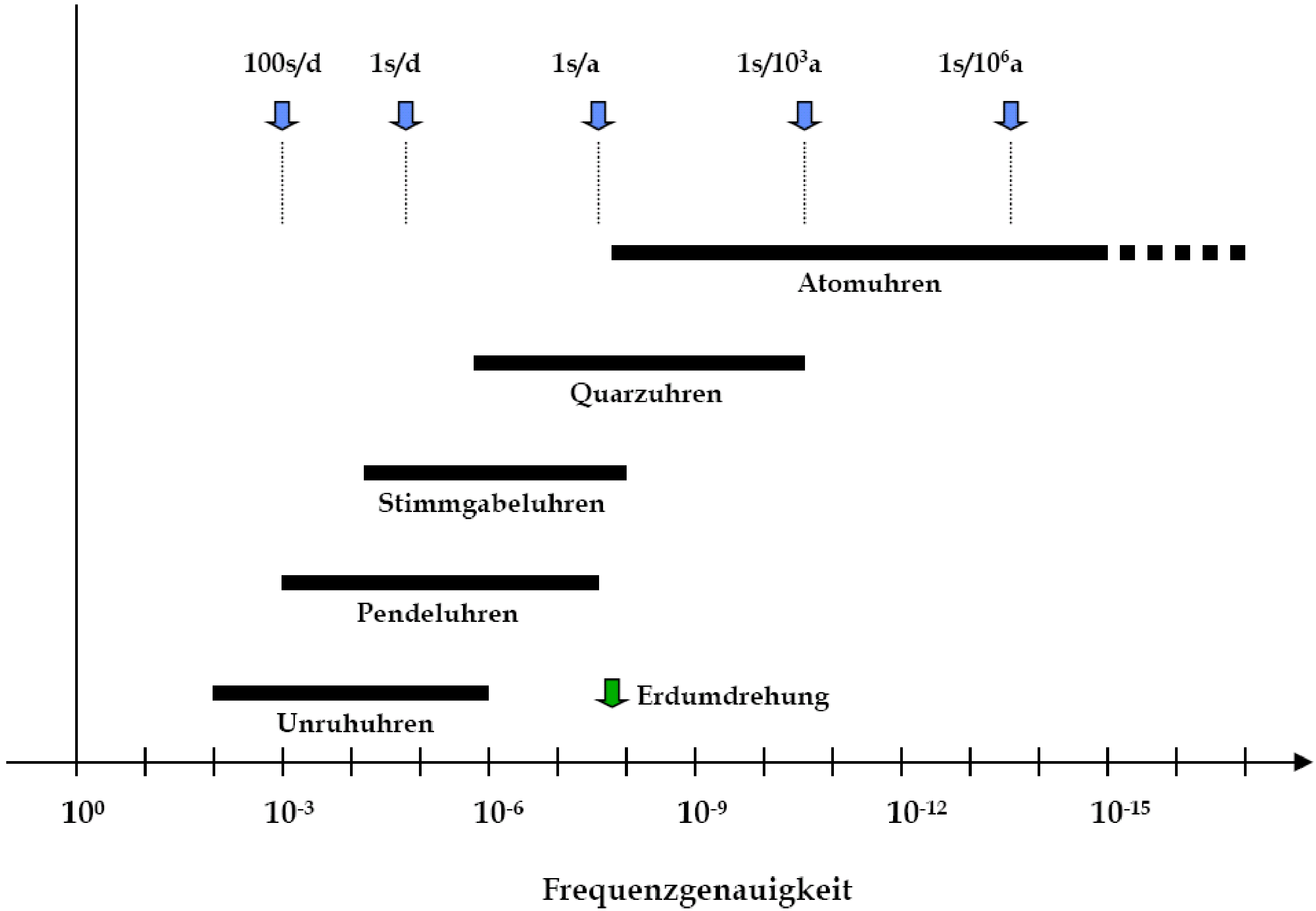
Absorptionslinien
Galaxieenhaufen BAS11



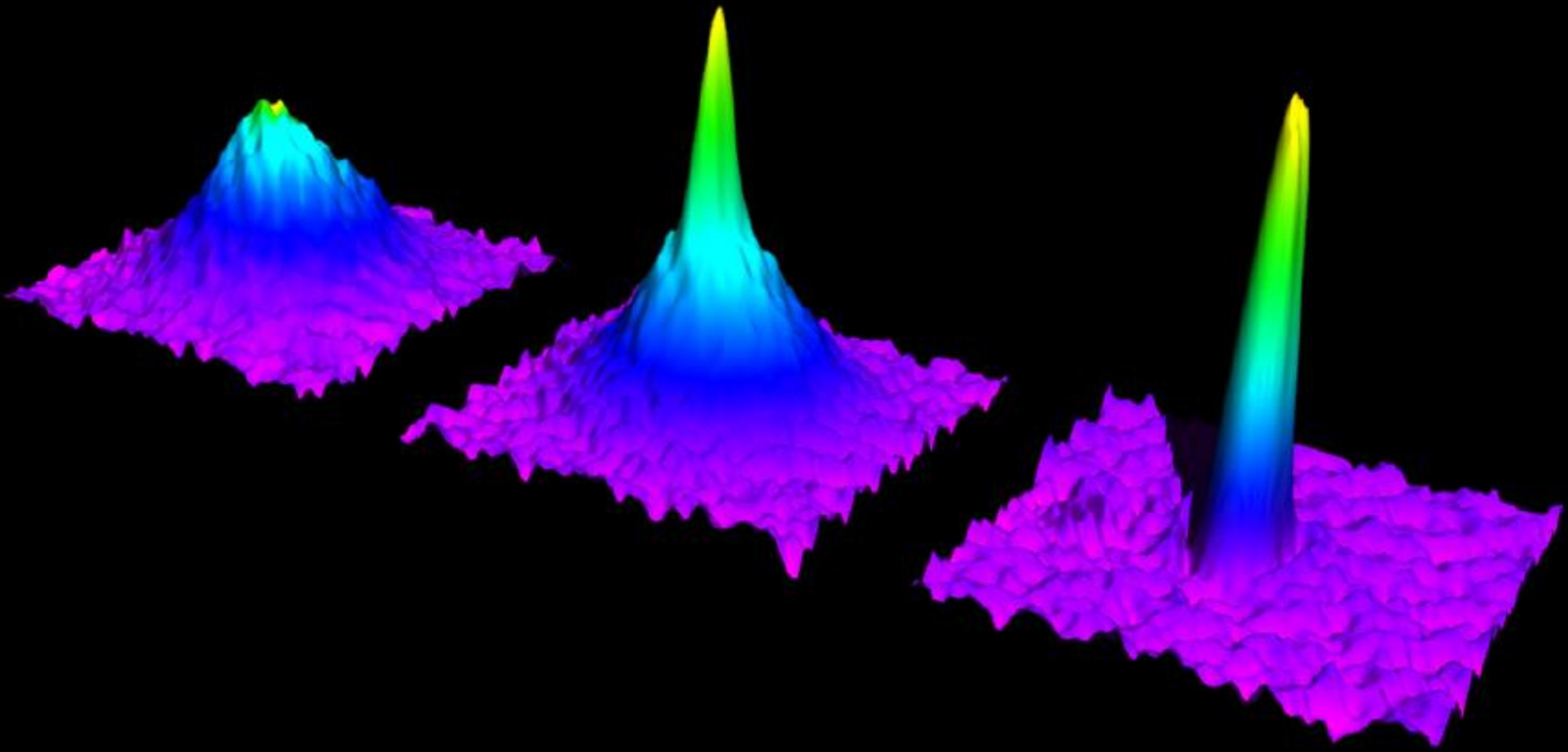
Die Atomsekunde -

Das Ende der mech. Räderuhr als Zeitstandard

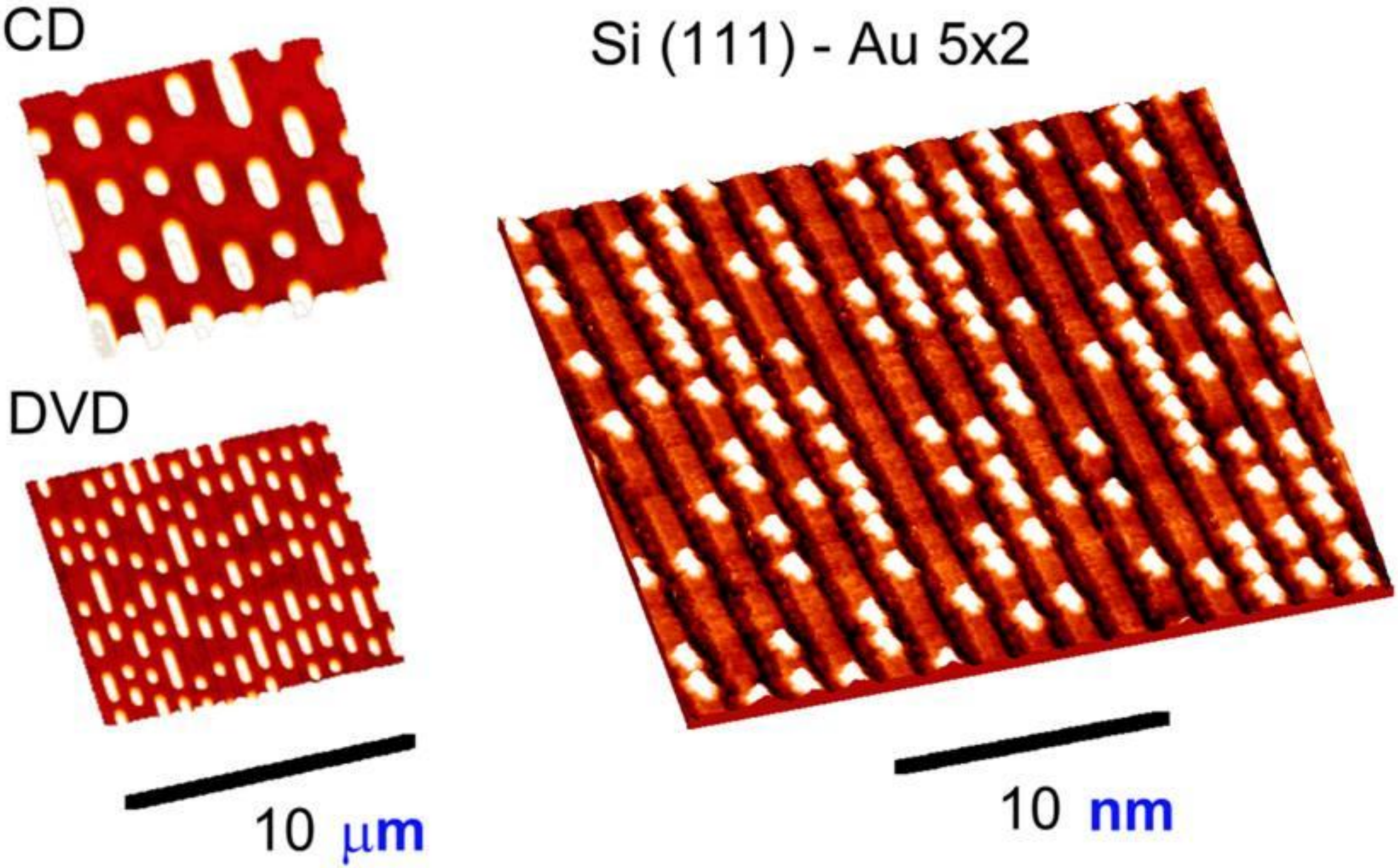
Gangunsicherheit im Vergleich



Bose-Einstein Kondensation



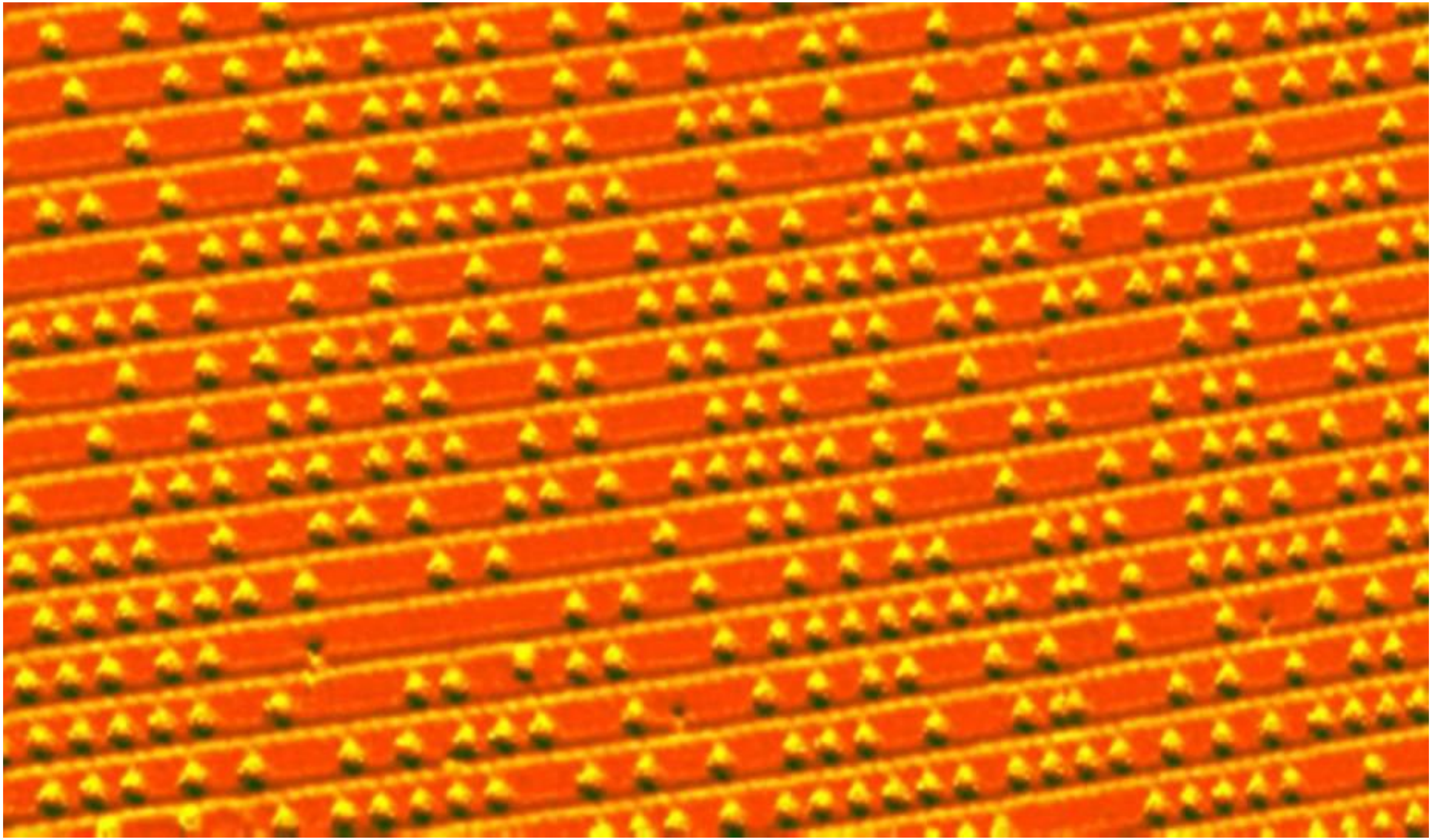
The ultimate storage medium: 1 bit = 1 atom



Increase in density by 10^6 !

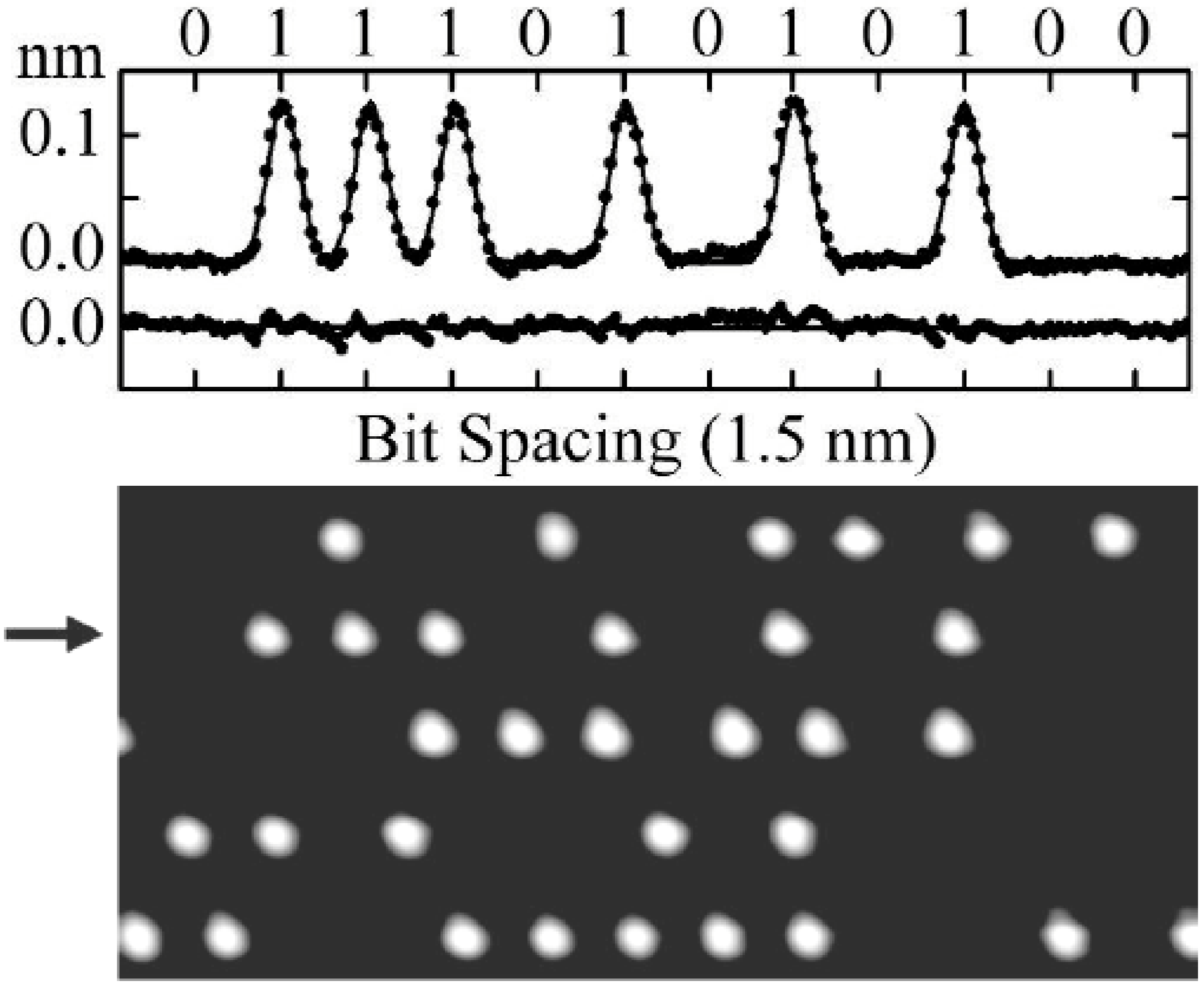
Barke (Rostock),
Himpsel (Madison)

Au on Si (111)



STM image Au auf Si(111)

Readout



Identical signals at well-defined locations

Hard Disk: S/N $\approx$ 240 = $2/\pi \cdot$ Width $\cdot$ Spacing / Jitter^2 (10^{-8} Error Rate)

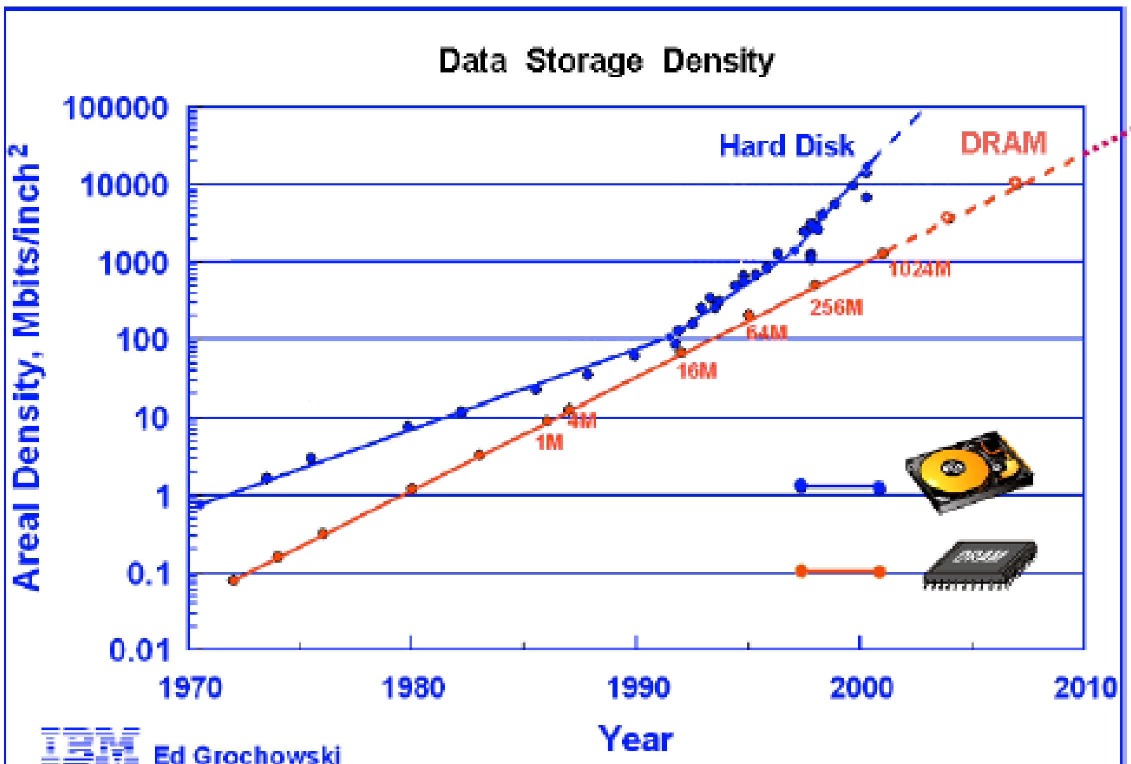
Si Atoms : S/N $\approx$ 2400 10x better, but different type of signal

When will we be down to atoms ?

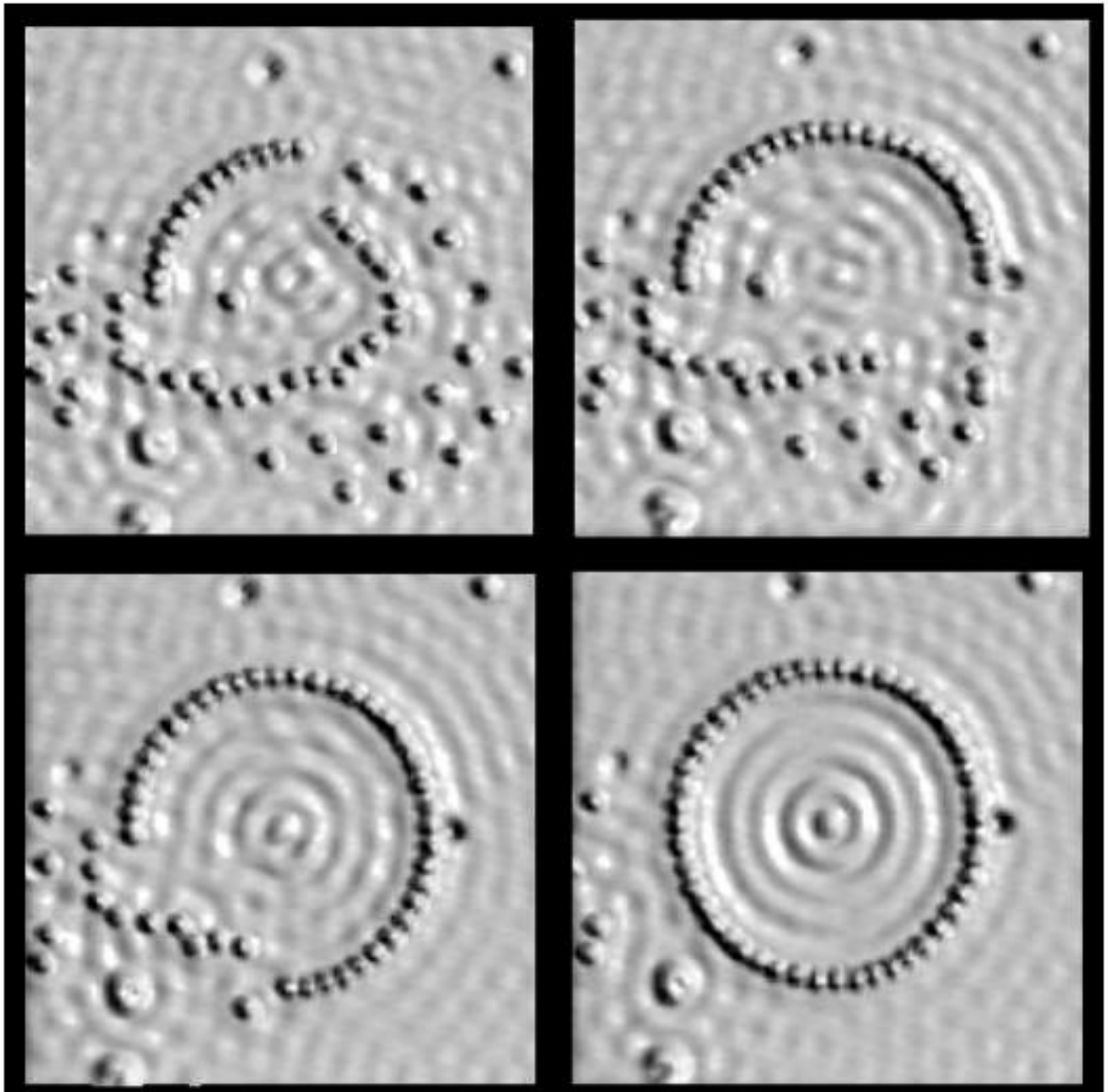
Using Moore's Law ...

250 Terabit/inch^2

Year 2038

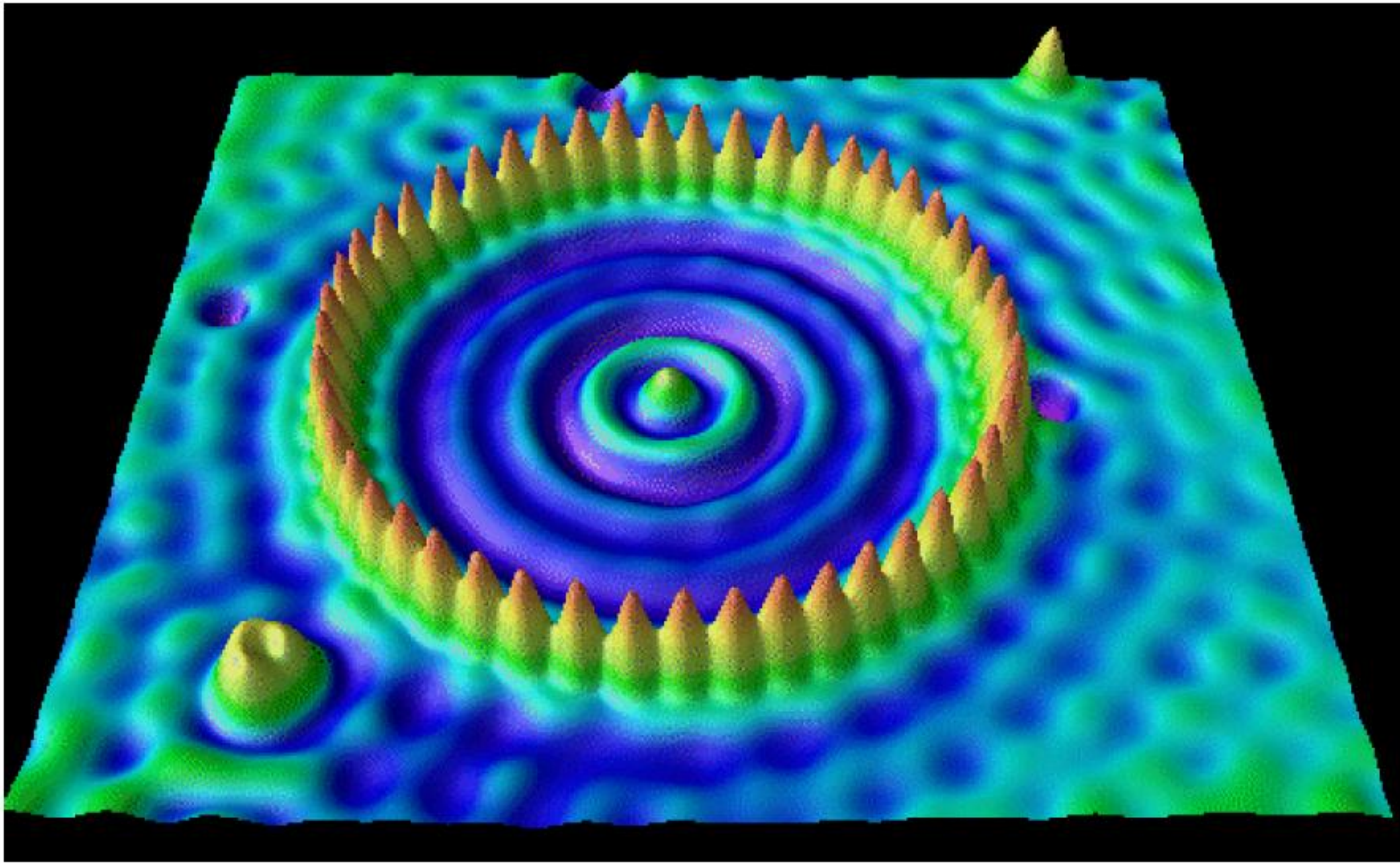


Building a Quantum Corral for Manipulating Electron Wavefunctions



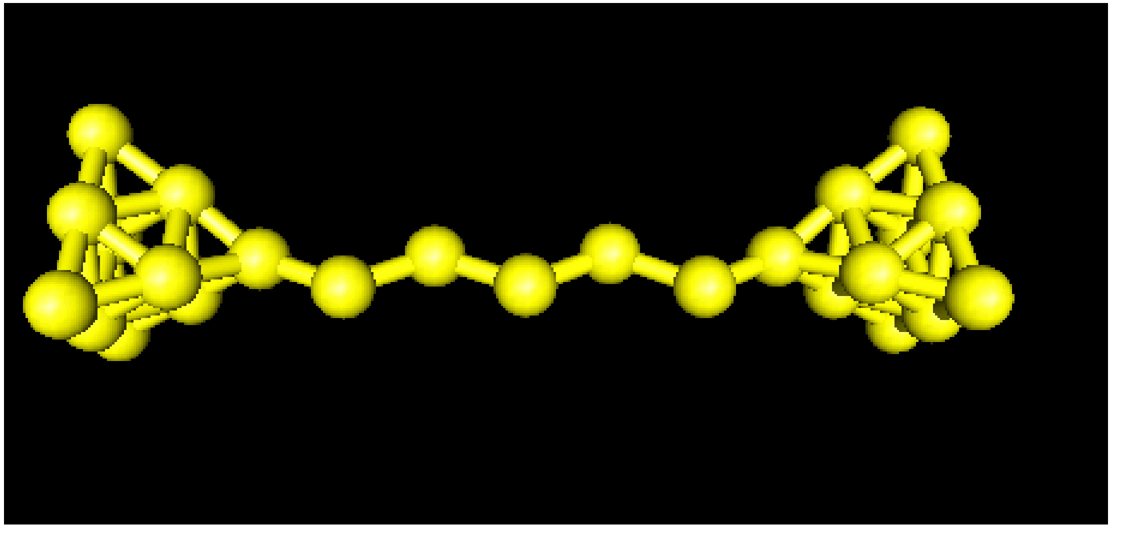
Crommie, Eigler

Rastersonden-Lithografie: Co atoms on copper



F.C. Crommie, et al., *Science* 263, 218 (1999)

atomic Au nanowire (calculated)



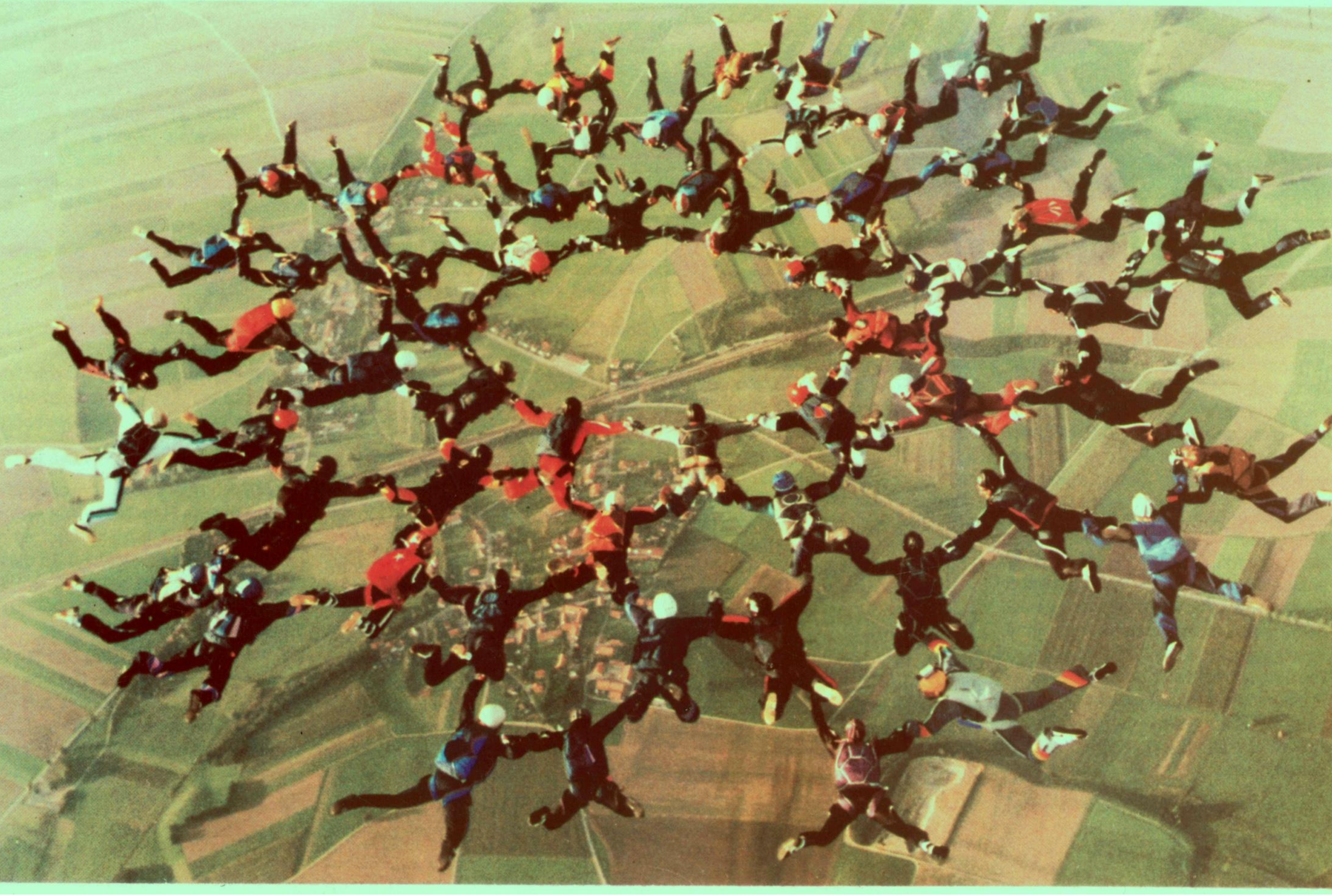
atomic physics plays an important role:

- **Astrophysik**
- **Laserentwicklung**
- **Prozesse in der oberen Atmosphäre**
- **Stoßprozesse bei der Kernfusion**
- **Laser-induzierte Elektronenbeschleunigung**
- **Quantenchemie**
- **Korrelationsprozesse in starken Feldern (Laser, Magnet)**
- **Prinzipielle physikalische Fragestellungen wie QED**
- **Exotische Systeme: Myonium, Positronium,**
- **...**

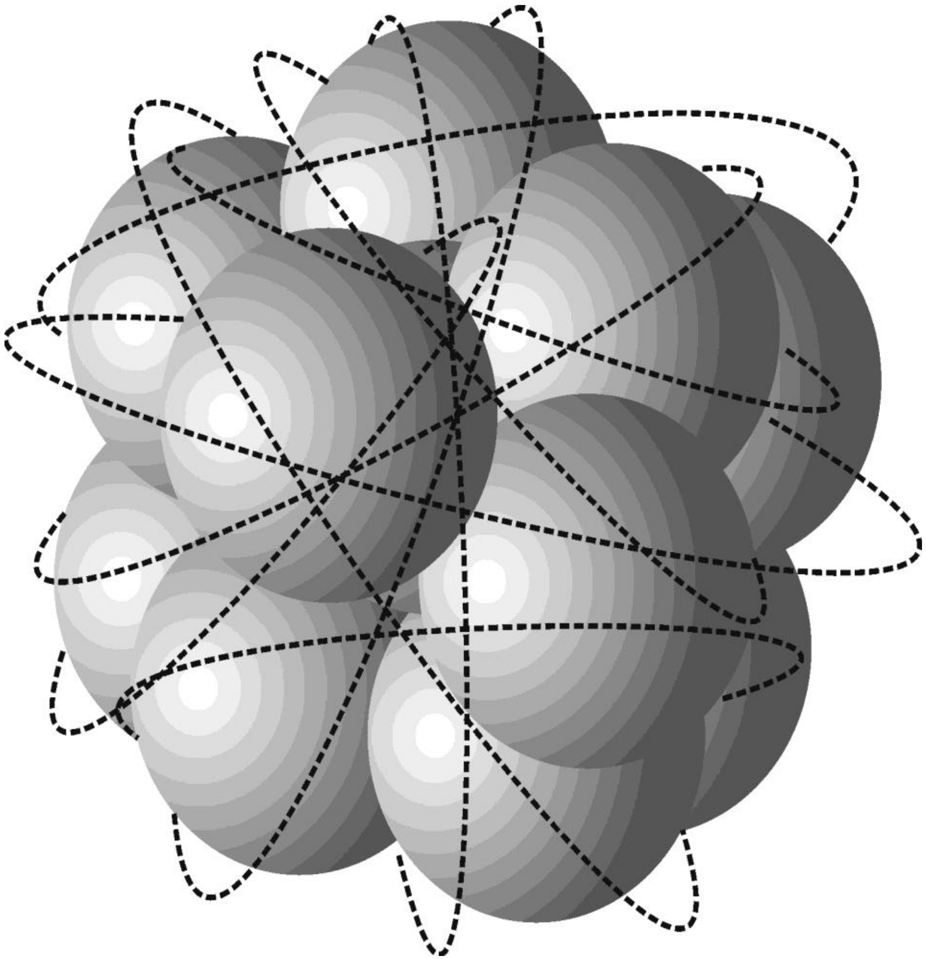
Atomic clusters

or

Physics on the 1-nm scale



A cluster of simple metal atoms can be considered as a metallic quantum dot. In the corresponding bulk materials the electrons need much more space.



Literature

- Sugano/Koizumi *Microcluster Physics* Springer 1998
- Haberland *Clusters of Atoms and Molecules* Springer 1995
- Ekardt *Metal Clusters (Theory)* Wiley 1999
- Kreibig/Vollmer *Optical Properties of Metal Clusters* Springer 1995
- Meiwes-Broer *Metal Clusters at Surfaces* Springer 2000
- Bergmann/Schaefer, Band 5, *Vielteilchensysteme*, S. 549ff

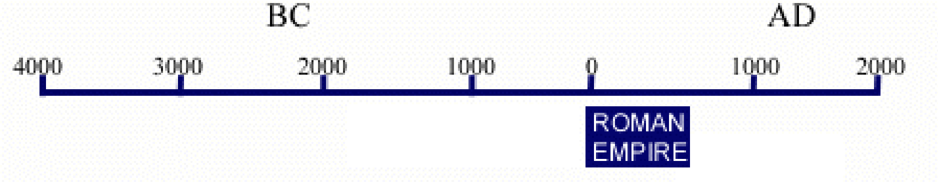
Nano-particles

Since long ago man has used the properties of particulate materials in an empirical manner

In the VIIIth century the Chinese discovered the « black powder », which later gave birth to fireworks, then to military uses about the year 1000, well before it was understood that the speed of the combustion was inversely proportional to the grain size.

Man created hand stencils by blowing pigments onto a hand against the wall, which has survived to the ages.(30000 years ago, grotte Chauvet)

Lycurgus-Becher



27 BC bis 5. Jht. AD

British Museum London

The Cup is surrounded by a frieze showing the myth of King Lycurgus. He is seen here being dragged into the underworld by Ambrosia, who has been turned into a vine.

Rubinglas mit eingebetteten Gold- und Silberteilchen lt. Röntgenanalyse

Stained-glass for cathedrals

St Nicolas de Port

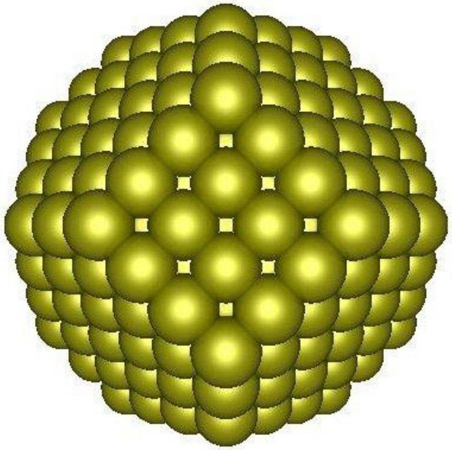
The origin of these colours, due to pigmented grains which are insoluble in their surroundings, was invoked by Michael Faraday (1791-1867) in 1853.

In 1907 Gustav Mie (1868-1957) explained the colours by showing how light in medium gets scattered by particles.

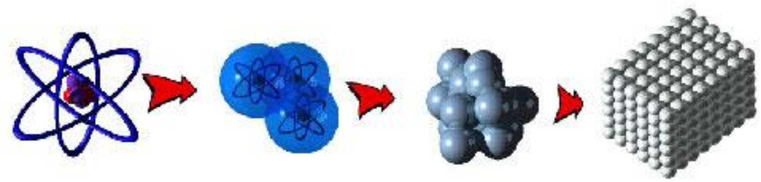

Nano-grains (of carbon) exist in interstellar medium
Horse-head nebula in Orion cloud.
Anglo-Australian observatory

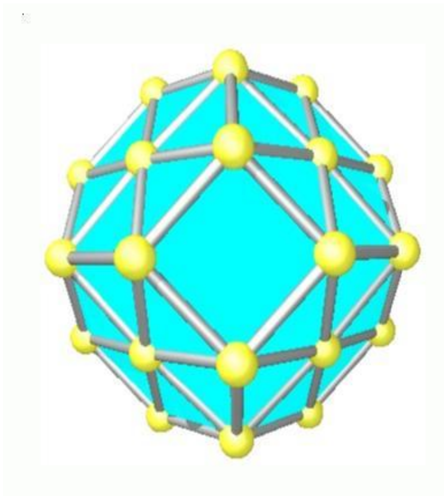
Introduction – What is a cluster ?

Clusters – Intermediate range between atoms and bulk matter



Aggregates of **2–10^n** particles
($n \rightarrow 6$ or 7)



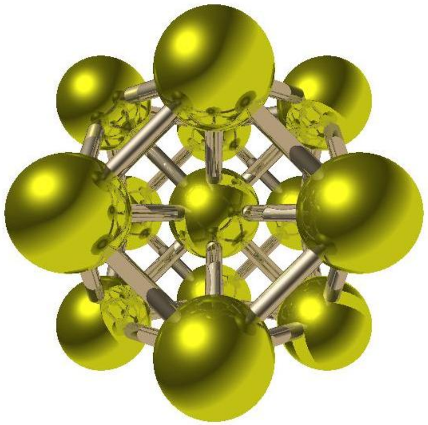


Cluster Size	N	Diameter / nm (Na_N)
Small	$\leq 10^2$	≤ 1.9
Medium	10^2–10^4	1.9–8.6
Large	$> 10^4$	> 8.6

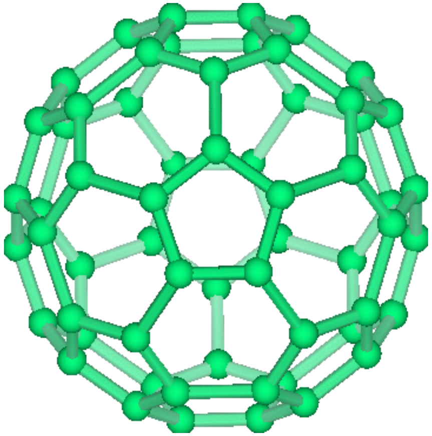
Types of Clusters - 1

Based on the type of constituent particles & type of bonding

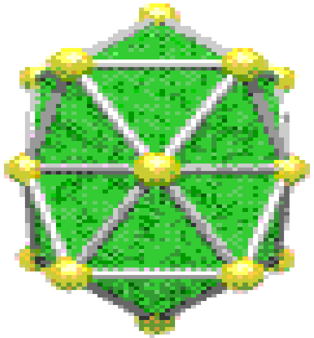
Metal Clusters | **Semiconductor Clusters** | **Rare gas Clusters**



S block – Metallic bond
(e.g. alkali & alkaline earth)
SP metals – Covalent bond
(e.g. Al)



Bonding – **Covalent**
e.g. C, Si & Ge

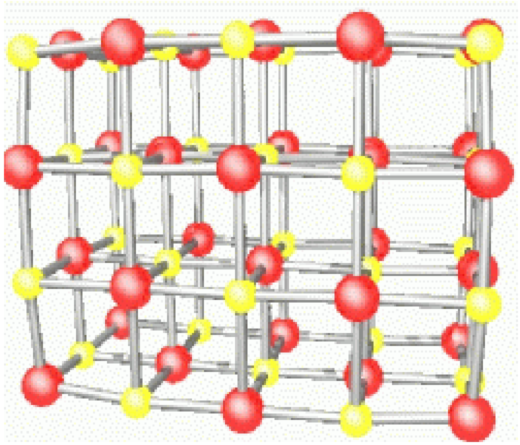


Bonding **-Van der Waals**
Inter-atomic attraction increases with increasing atomic mass (**He→Rn**).

http://www.tc.bham.ac.uk/~roy/Teaching/CHM3T1

Types of Clusters - 2

Ionic Clusters

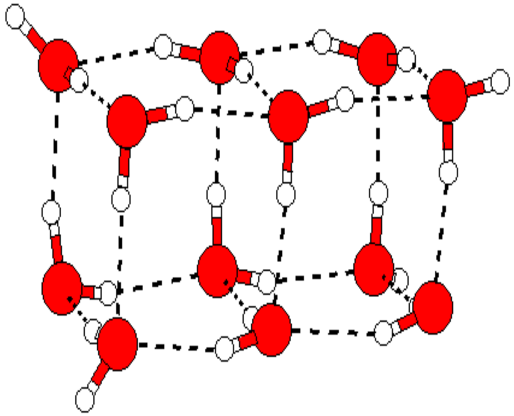


atoms with large difference in electronegativity

Bonding – **Ionic**

e.g. $(NaCl)_n$, $[Mg_xO_y]^{2(x-y)+}$

Molecular Clusters

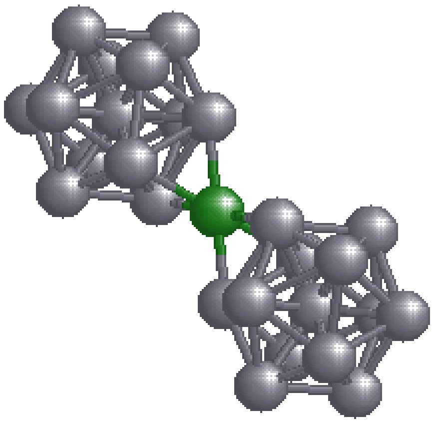


van der Waals,

dipole-dipole interactions, and hydrogen bonding

e.g. $(N_2)_n$, $(C_6H_6)_n$, $(H_2O)_n$

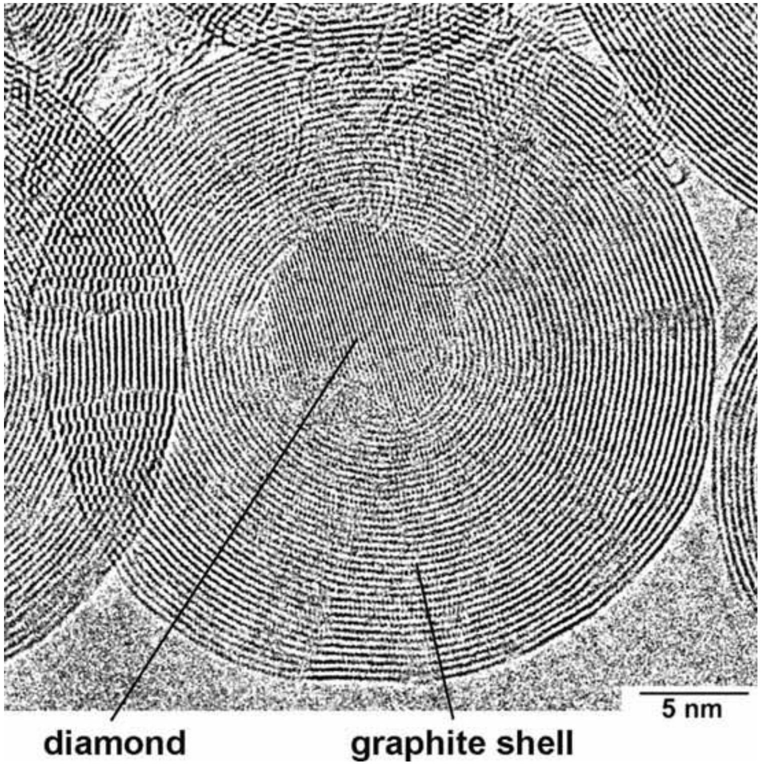
Cluster molecules



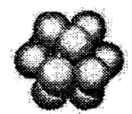
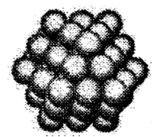
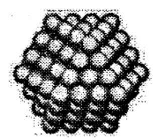
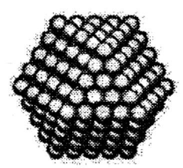
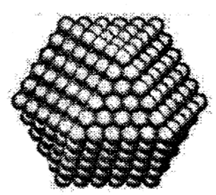
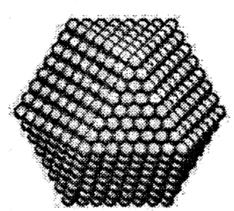
thermodynamically and/or kinetically stable with respect to coalescence

e.g. $Al_{13}MgAl_{13}$

Exotic clusters:
e.g., Carbon nano-onion with enclosed diamond



size-dependence

Full-shell Clusters		Total Number of Atoms	Surface Atoms (%)
1 Shell		13	92
2 Shells		55	76
3 Shells		147	63
4 Shells		309	52
5 Shells		561	45
7 Shells		1415	35

Size effects : number of atoms/molecules on the surface

Spherical cluster approximation / Hard atomic spheres

Volume of a building block (atomic sphere) : V_a

Volume of cluster : $V_c = \mathrm{n} V_a$ (rough approximation, no filling factor)

Radii of cluster and atom : $$\frac{4\pi}{3} R_c^3 = \mathrm{n} \frac{4\pi}{3} R_a^3$$

$$\boxed{R_c = \mathrm{n}^{1/3} R_a}$$

better: R_c equals the Wigner-Seitz radius

Number of atoms on the surface : $$\mathrm{n}_s = \frac{4\pi R_c^2}{\pi R_a^2} = 4\mathrm{n}^{2/3}$$

(divide the surface of the cluster sphere by the cross section of an atom)

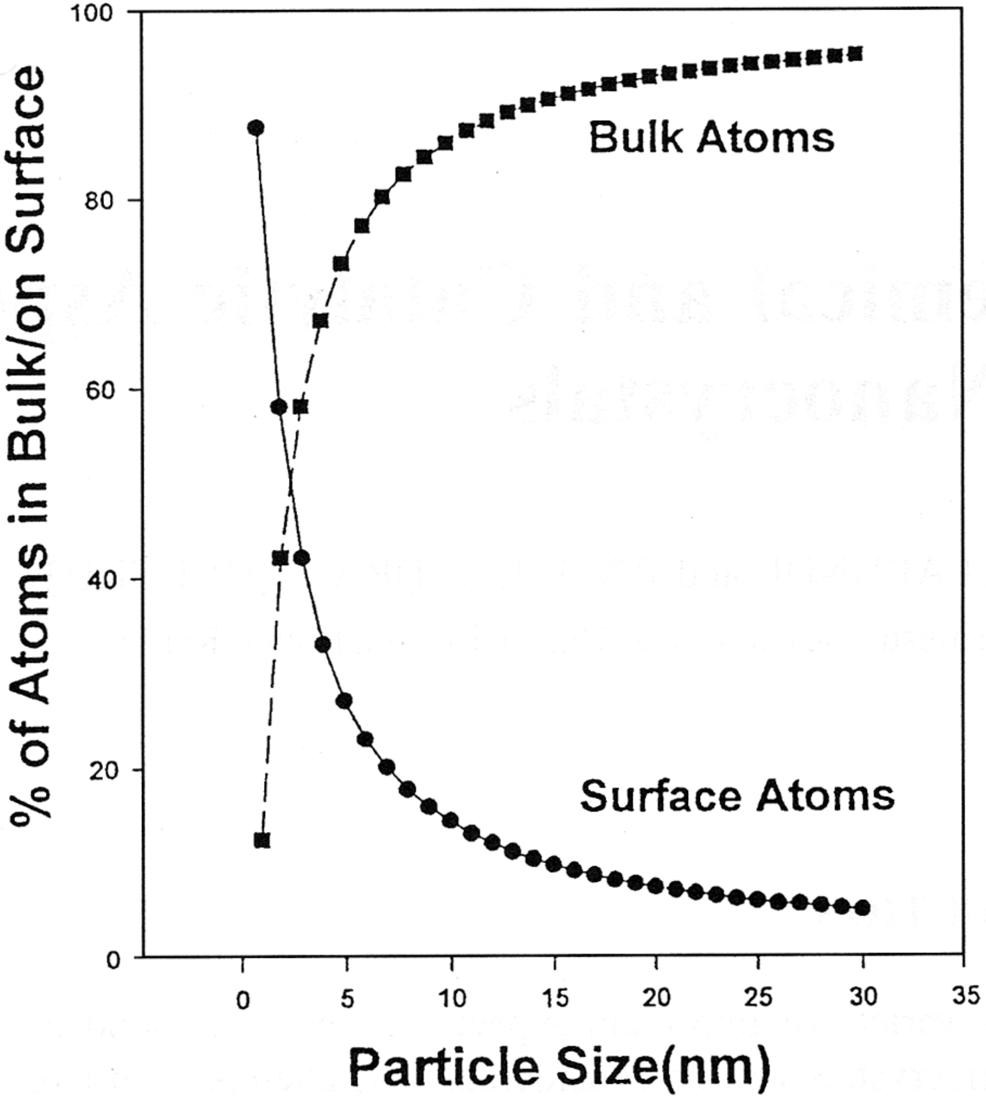
Fraction of atoms on the surface :

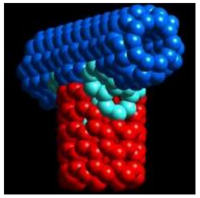
$$\boxed{F_s = 4\mathrm{n}^{-1/3}}$$

Surface to bulk atom ratio

- Spherical iron nanocrystals

- J. Phys. Chem. 1996, Vol. 100, p. 12142





Example : Sodium clusters
(average radius of the atomic sphere in the bulk = 0.2 nm)

Small Na clusters : diameter less than 1.9 nm
(**86%** of atoms on surface)

Large Na clusters : diameter larger than 8.6 nm
(**19%** of atoms on surface)

Need to have more than 64 million atoms for 1% of atoms on surface