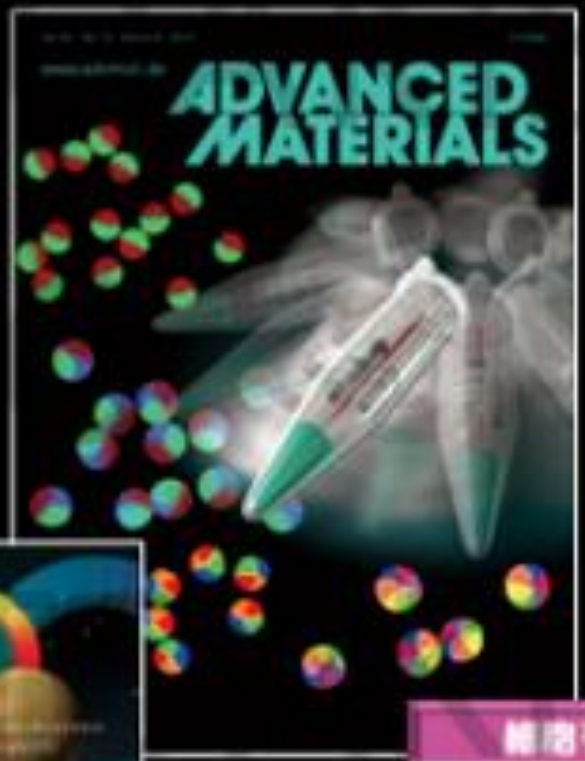
科学における
グラフィックデザインの役割

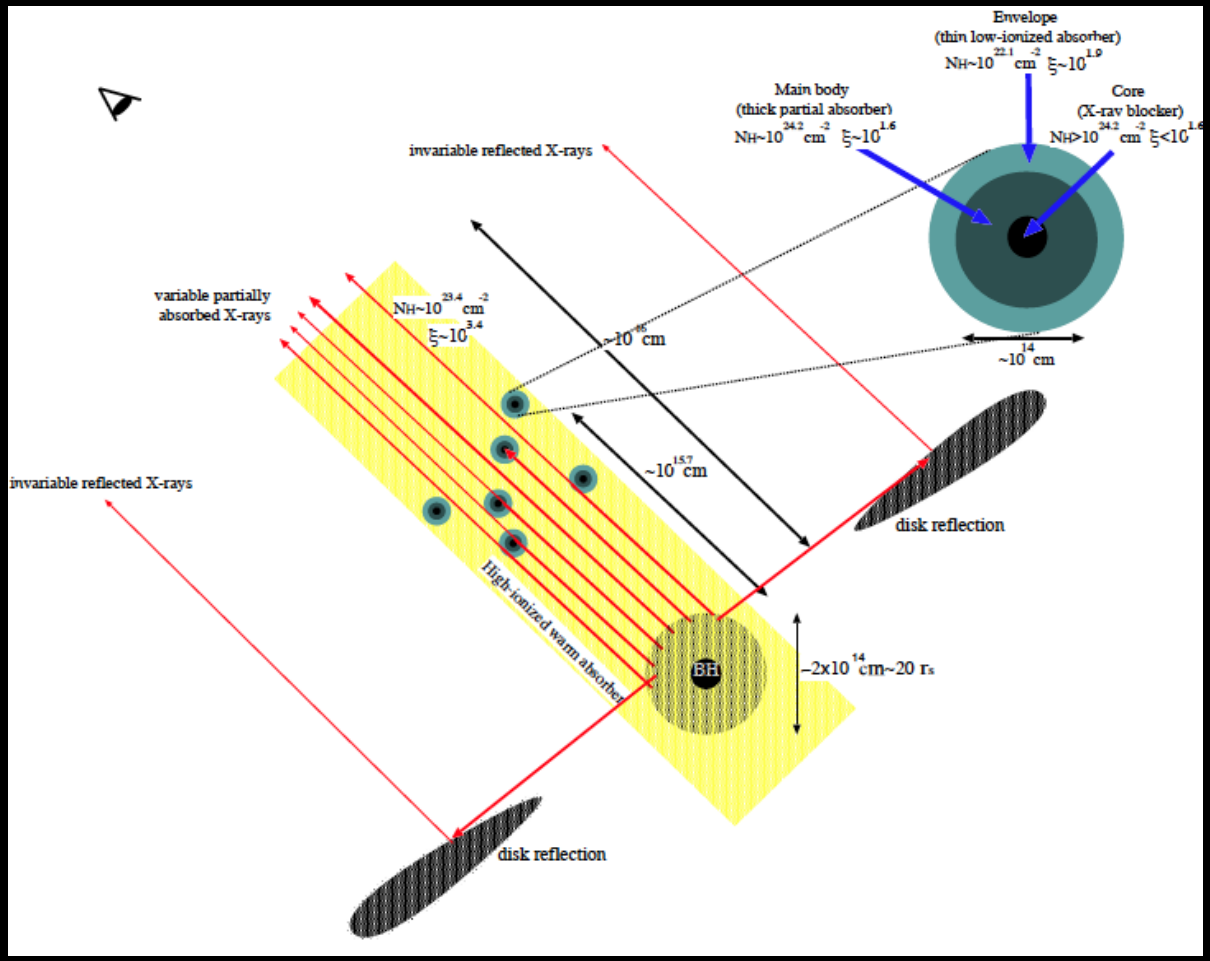
～ 宇宙から細胞まで ～

佐藤 暁子

東京大学 生産技術研究所 竹内昌治研究室

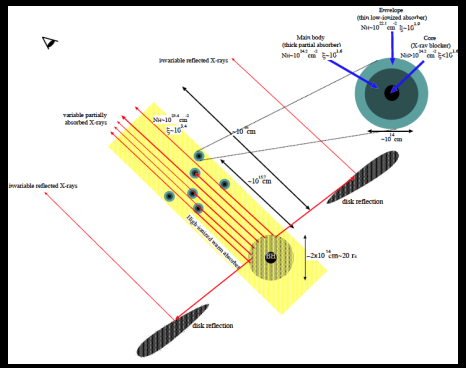


科学ビジュアルができるまで（宇宙編）



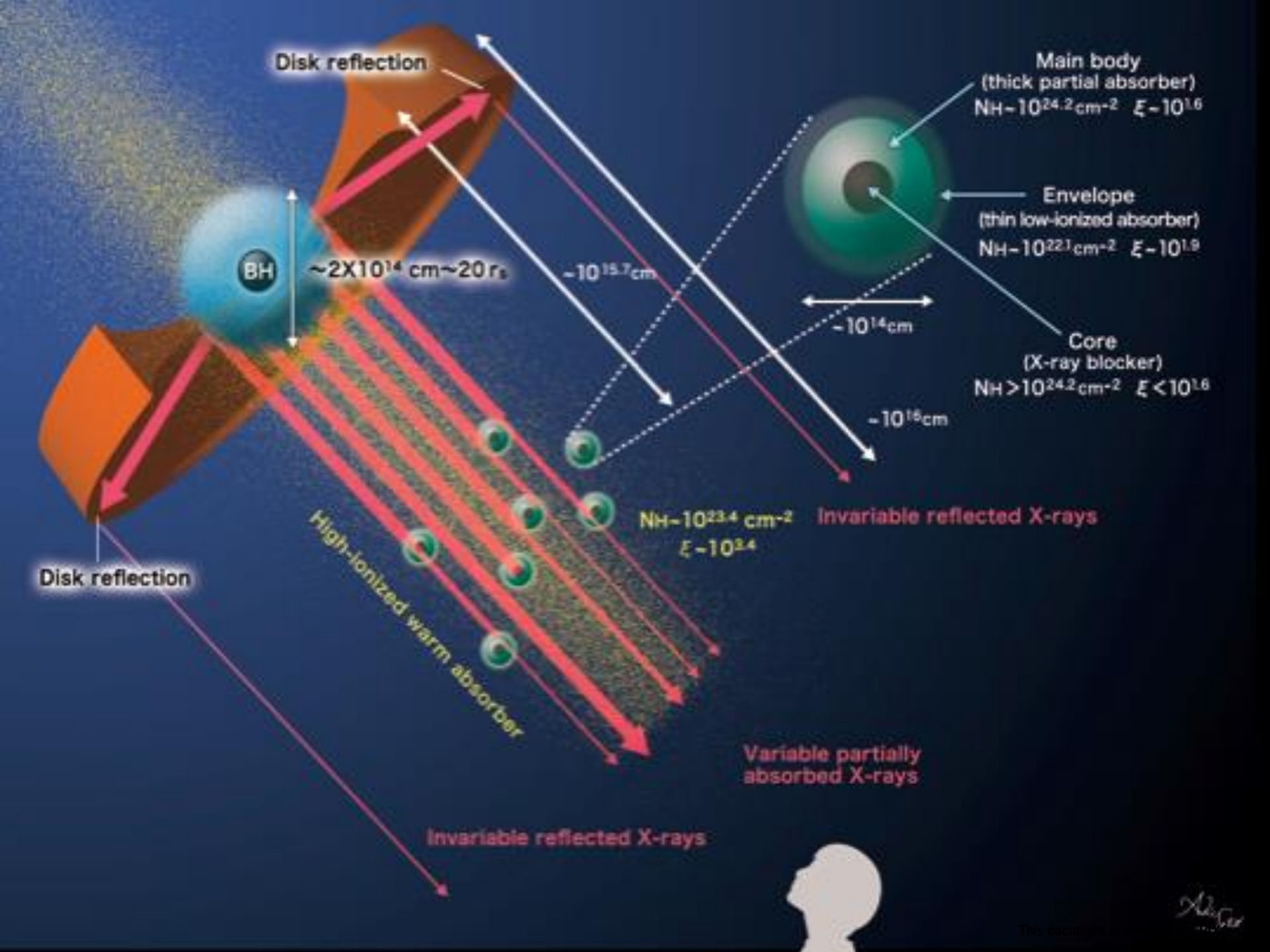
分からない点

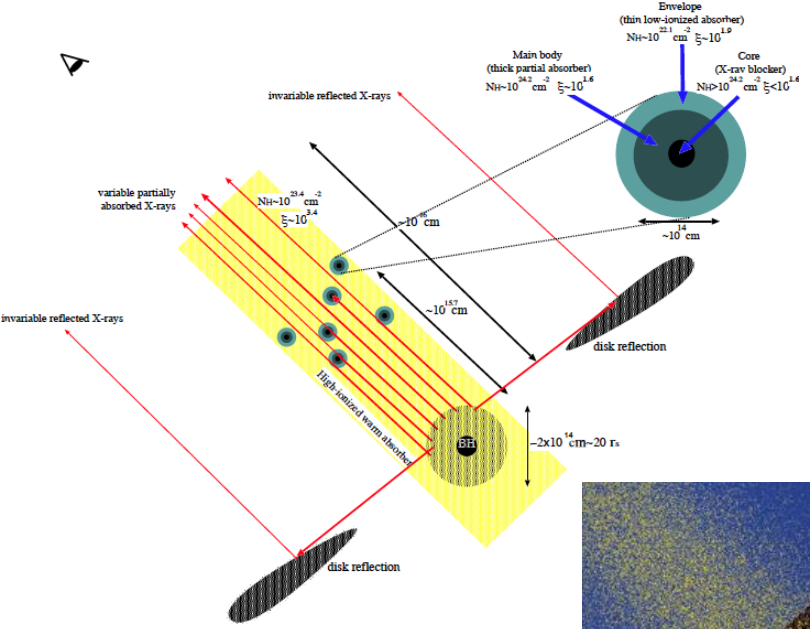
1. 見た事のない文字は何？大きさを示してる？
2. 緑の物質は、惑星みたいなもの？それともごつごつした岩みたいな感じ？想像だから分からない？
3. 黄色の部分は何？
4. 円盤によるX線の反射？？



その答え

1. ξ(グザイ)、これは「電離度」を表す電離パラメーター。
2. 内側(core)はX線を通さないほど厚くて低温で不透明なモノ。外層(envelope)は、高温で薄い炎みたいなもの。その間(main body)は半透明のイメージ
3. 高温のガスみたいなもの。
4. 円盤はドーナツのようにブラックホールを囲んでいて、それを輪切りにした様子。

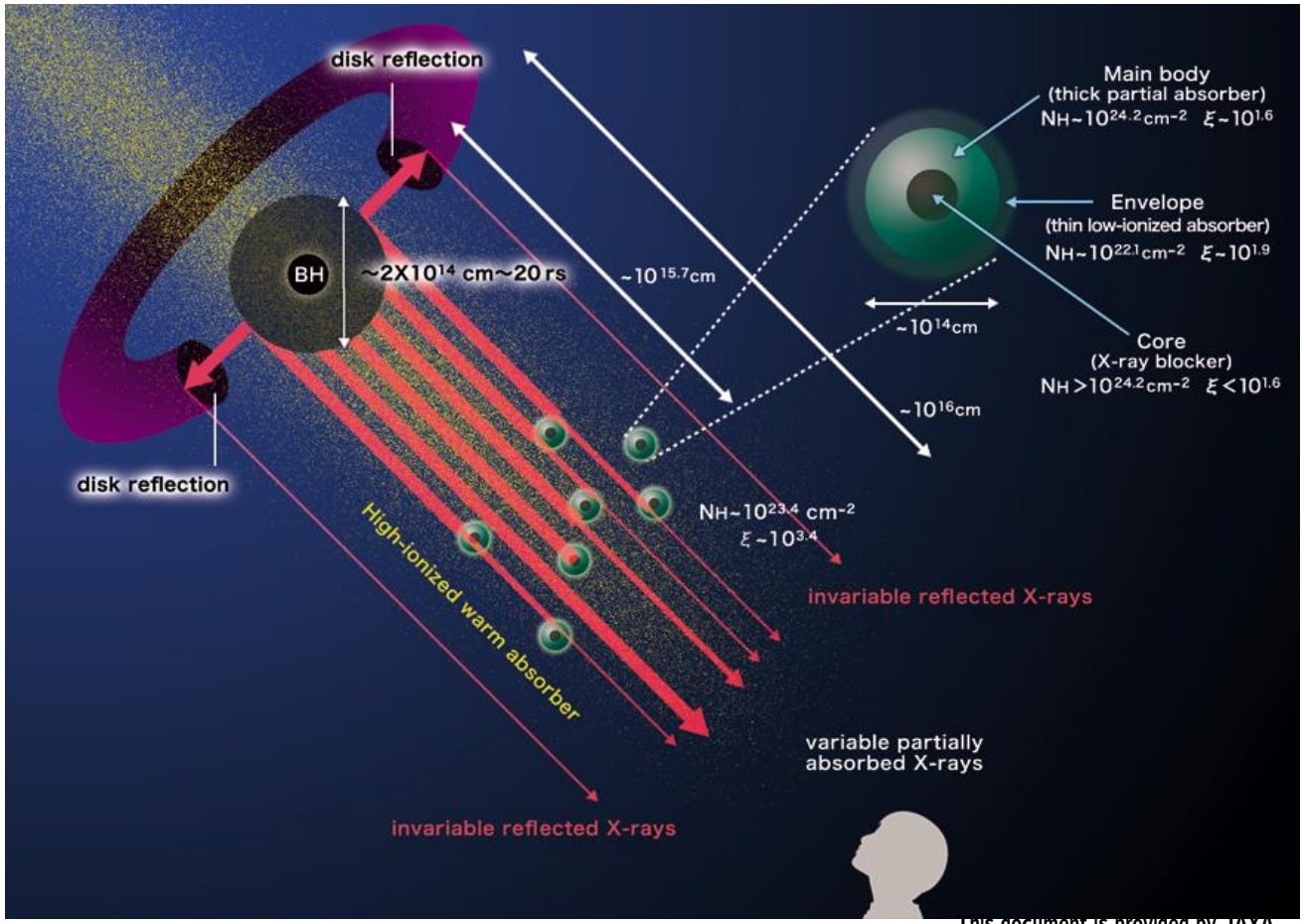

Disk reflection
Main body
(thick partial absorber)
NH~10^24.2cm^-2 ξ~10^1.6
Envelope
(thin low-ionized absorber)
NH~10^22.1cm^-2 ξ~10^1.9
BH
~2X10^14 cm~20 rs
~10^15.7cm
~10^14cm
Core
(X-ray blocker)
NH>10^24.2cm^-2 ξ<10^1.6
~10^16cm
NH~10^23.4 cm^-2
ξ~10^3.4
Invariable reflected X-rays
Disk reflection
High-ionized warm absorber
Variable partially
absorbed X-rays
Invariable reflected X-rays

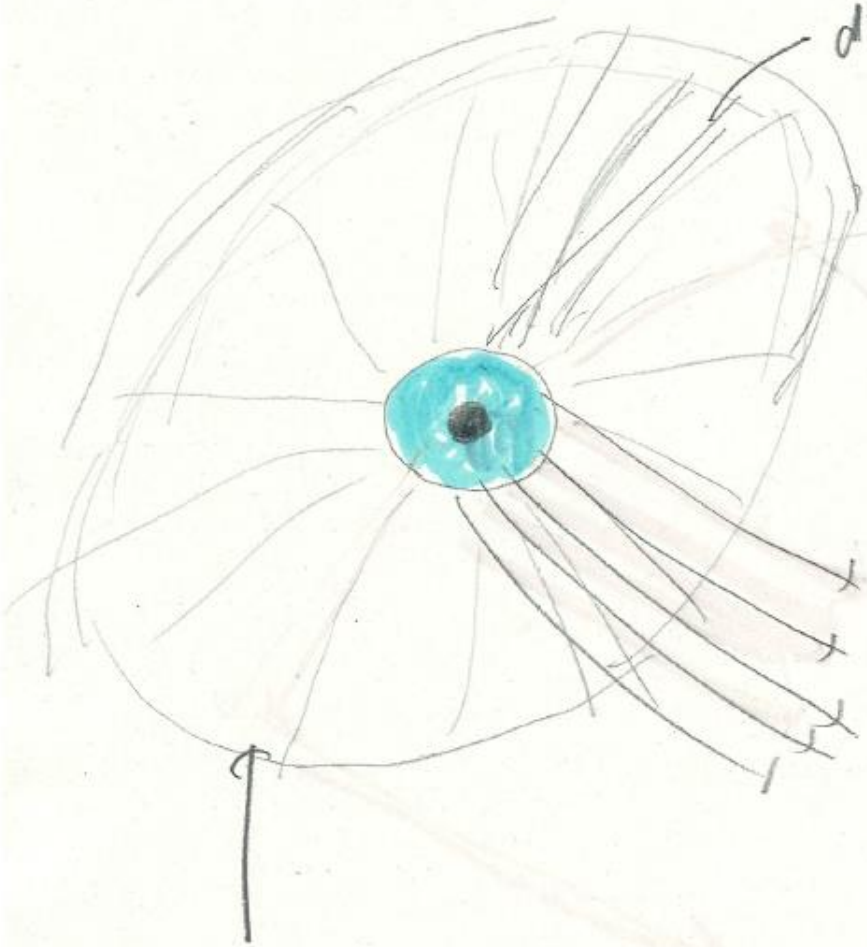


円盤によるX線の反射？？

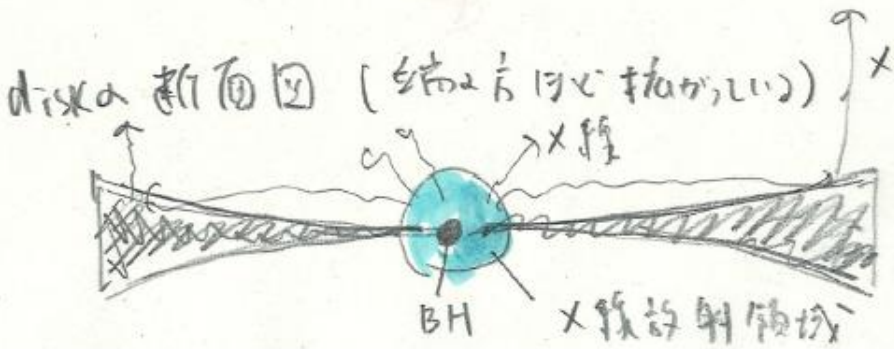
↓

円盤はドーナツのようにブラックホールを囲んでいて、それを輪切りにした様子

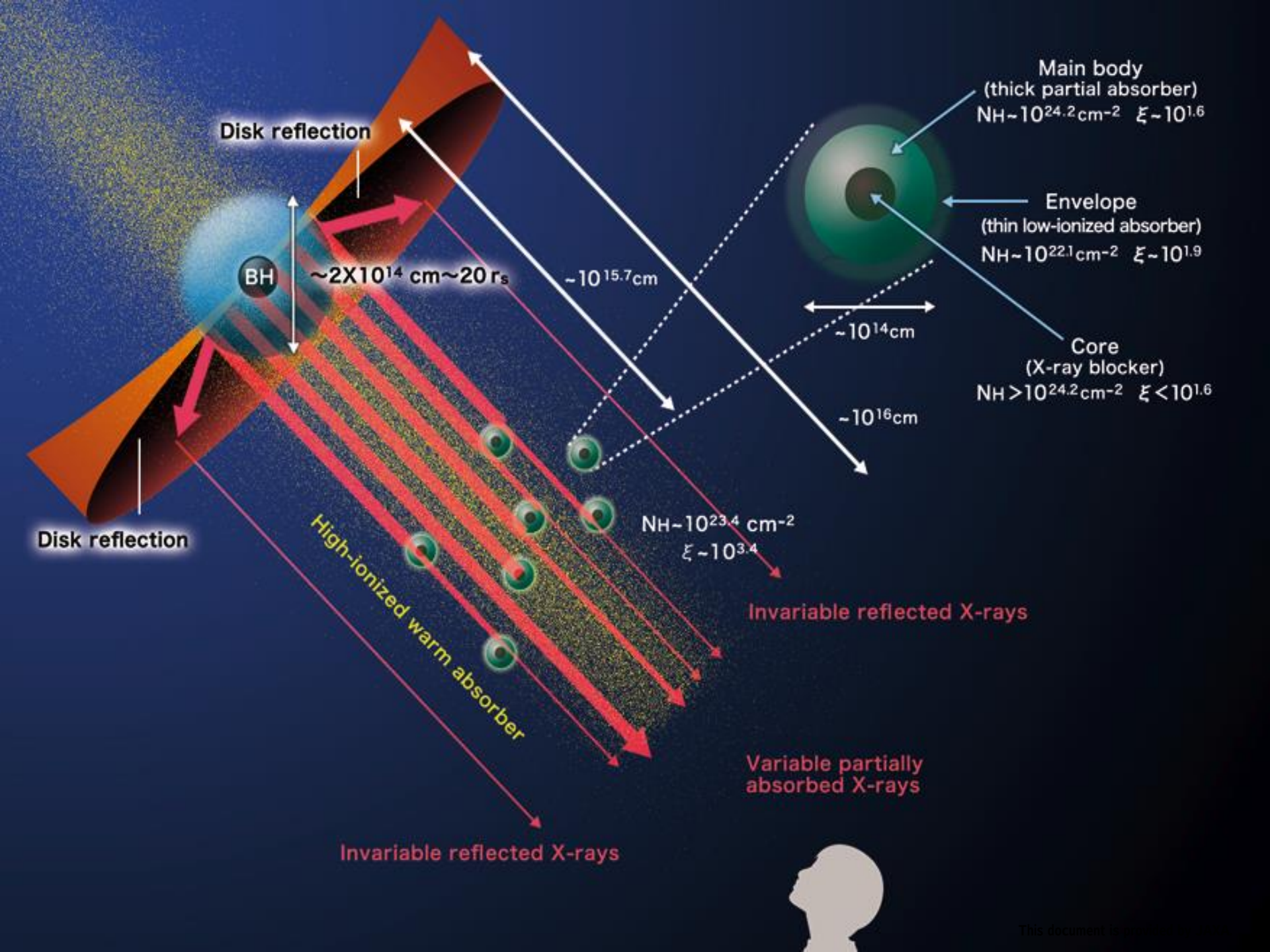


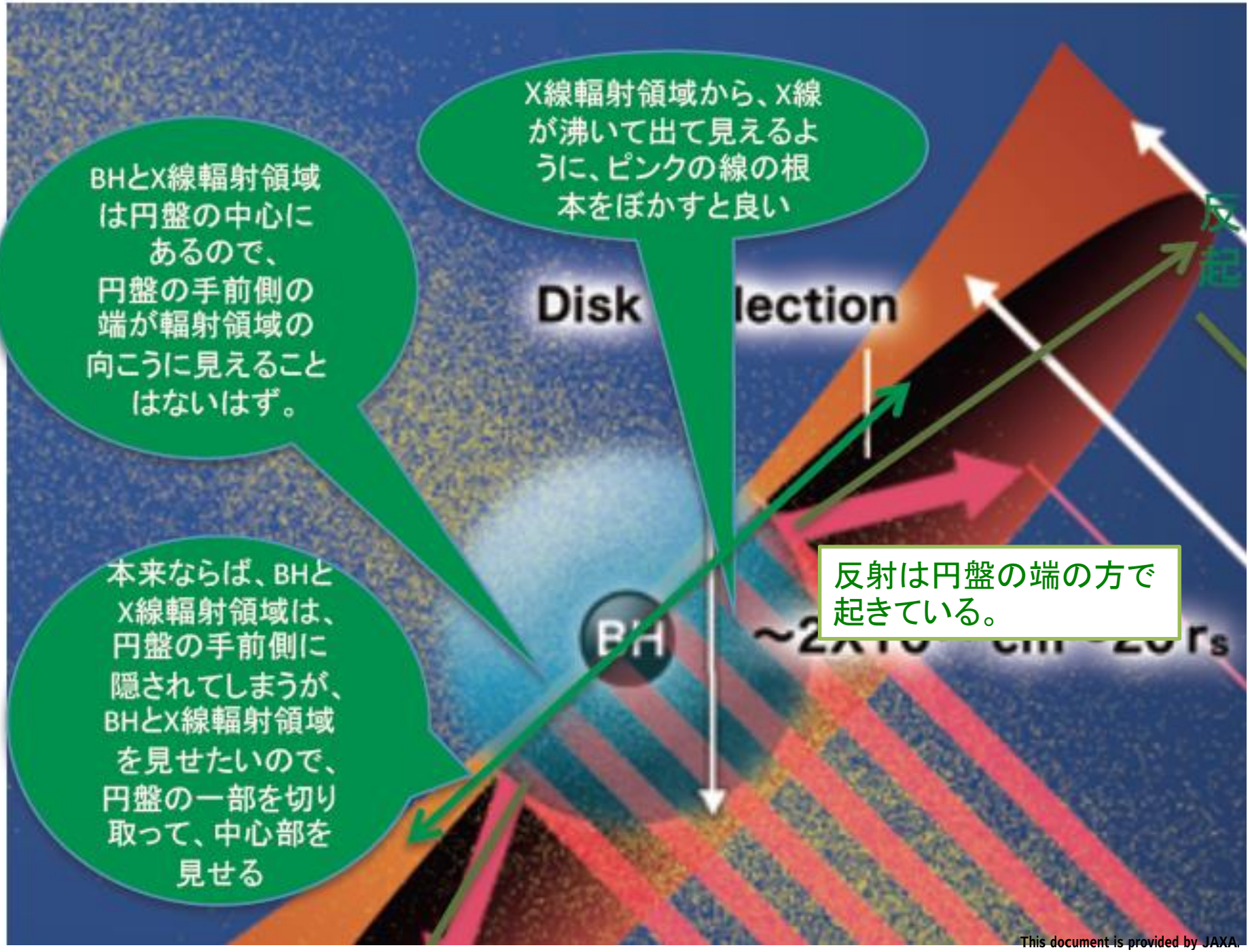


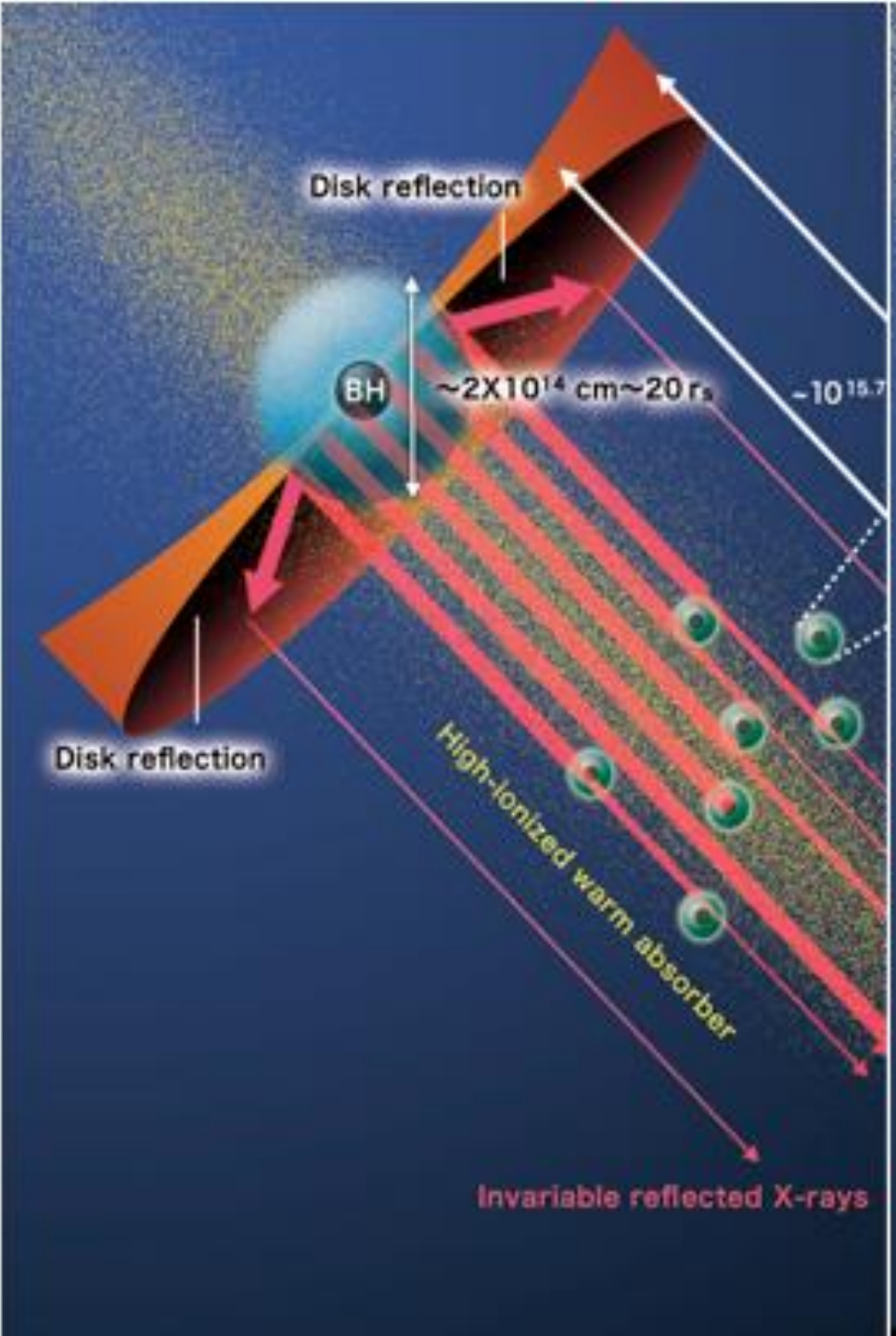
X線放射領域は
高温なので青い色
ガス　イメージ

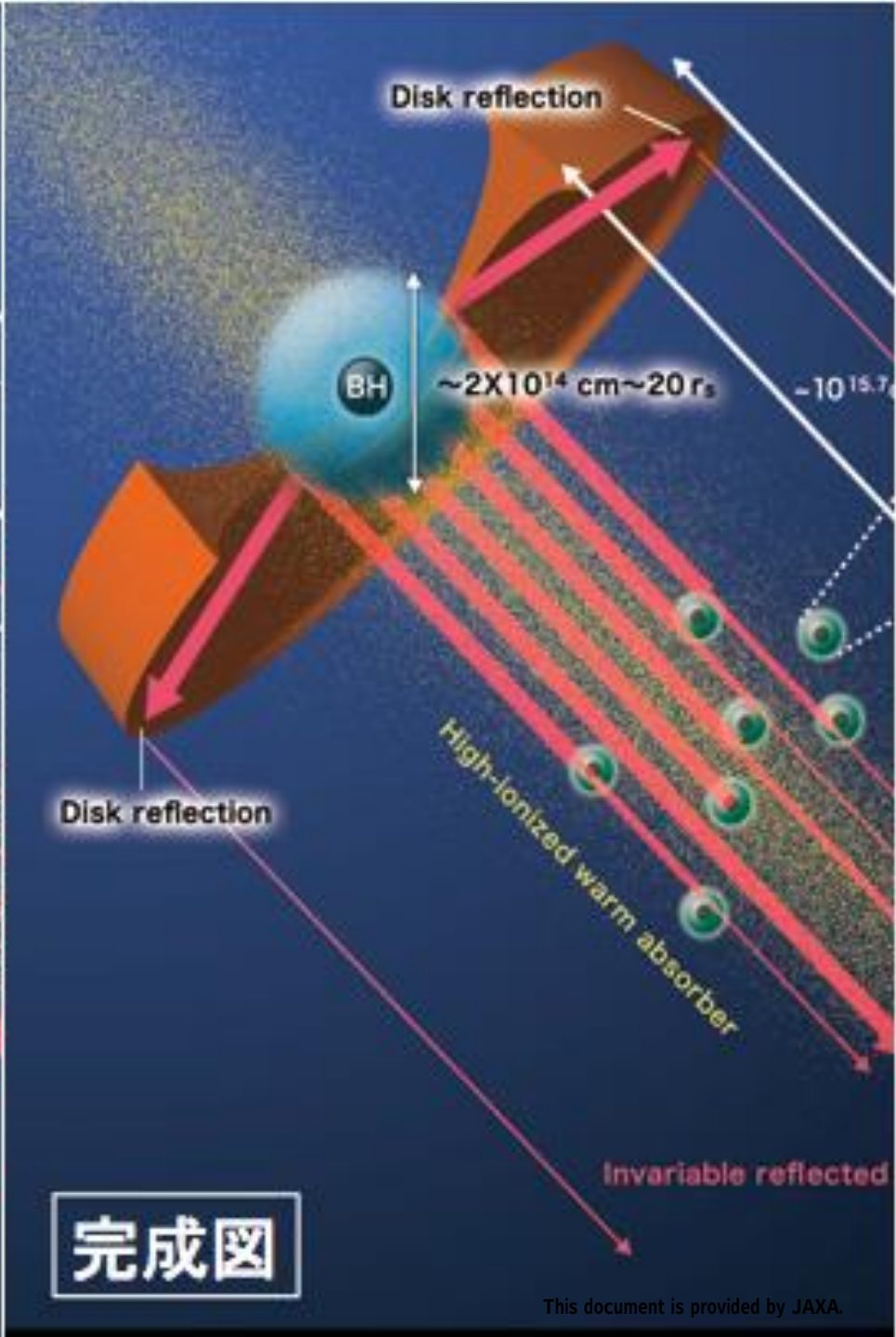


2012-4-3 Fukuyama


Disk reflection
BH
~2X10^14 cm~20 rs
~10^15.7cm
~10^14cm
~10^16cm
Main body
(thick partial absorber)
NH~10^24.2cm^-2 ξ~10^1.6
Envelope
(thin low-ionized absorber)
NH~10^22.1cm^-2 ξ~10^1.9
Core
(X-ray blocker)
NH>10^24.2cm^-2 ξ<10^1.6
Disk reflection
NH~10^23.4 cm^-2
ξ~10^3.4
High-ionized warm absorber
Invariable reflected X-rays
Variable partially
absorbed X-rays
Invariable reflected X-rays

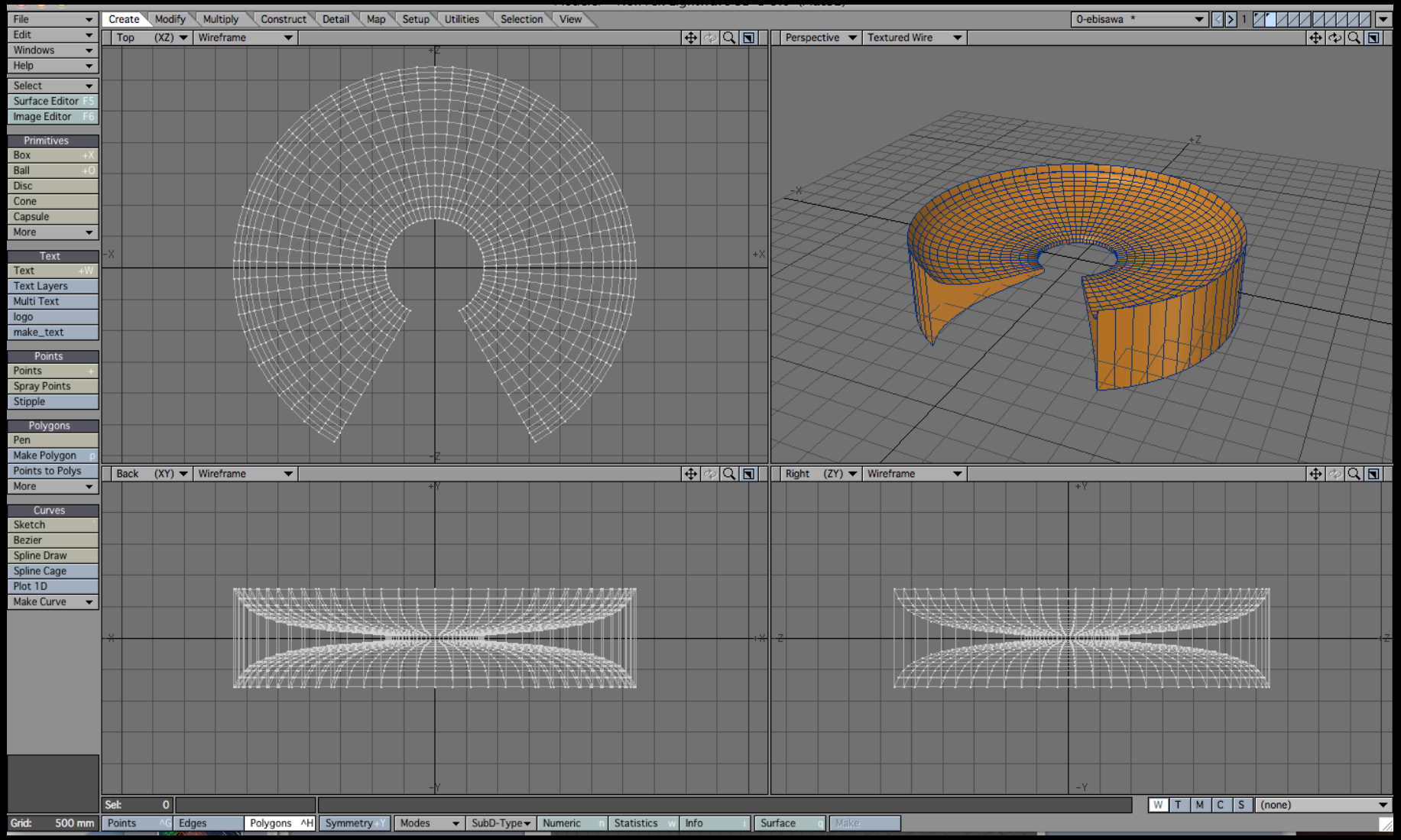




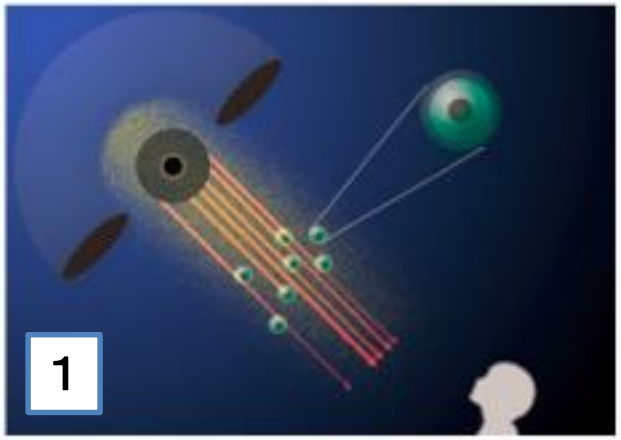


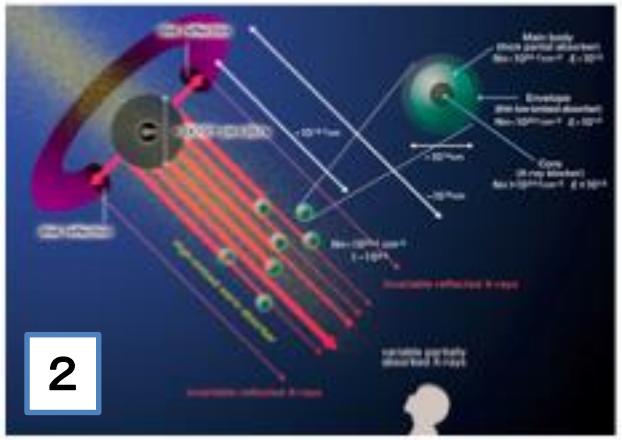
完成図

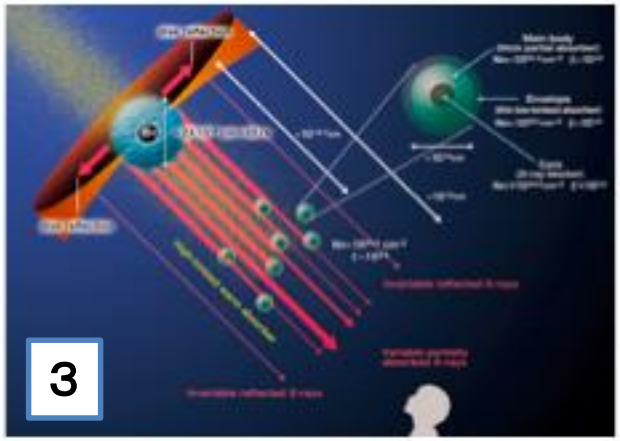
円盤の確認

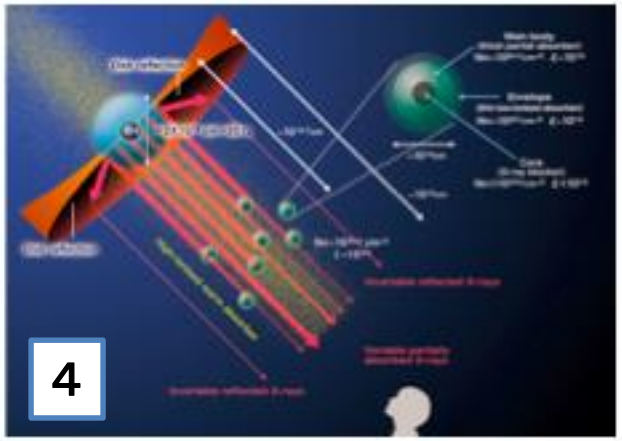

File
Edit
Windows
Help
Select
Surface Editor F5
Image Editor F6
Primitives
Box
Ball
Disc
Cone
Capsule
More
Text
Text
Text Layers
Multi Text
logo
make_text
Points
Points
Spray Points
Stipple
Polygons
Pen
Make Polygon
Points to Polys
More
Curves
Sketch
Bezier
Spline Draw
Spline Cage
Plot 1D
Make Curve
Create
Modify
Multiply
Construct
Detail
Map
Setup
Utilities
Selection
View
0-ebisawa *
Top (XZ) Wireframe
Perspective Textured Wire
Back (XY) Wireframe
Right (ZY) Wireframe
Sel: 0
Grid: 500 mm
Points
Edges
Polygons
Symmetry
Modes
SubD-Type
Numeric
Statistics
Info
Surface
Make
(none)

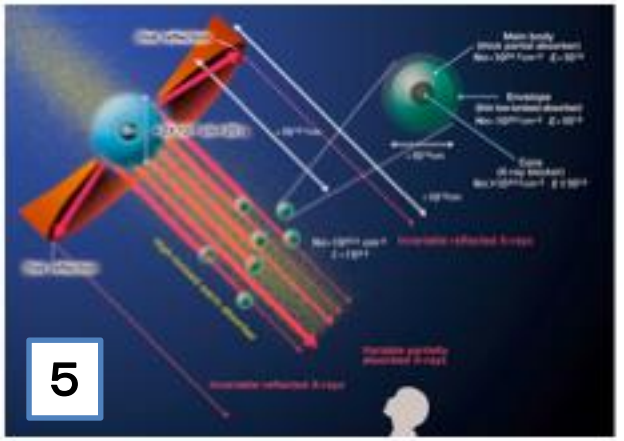
完成までの変化

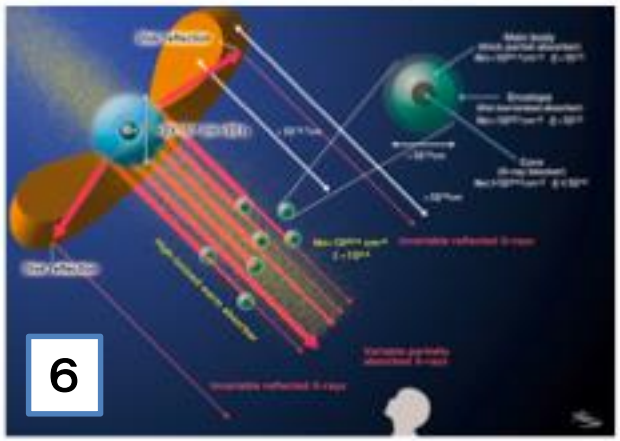


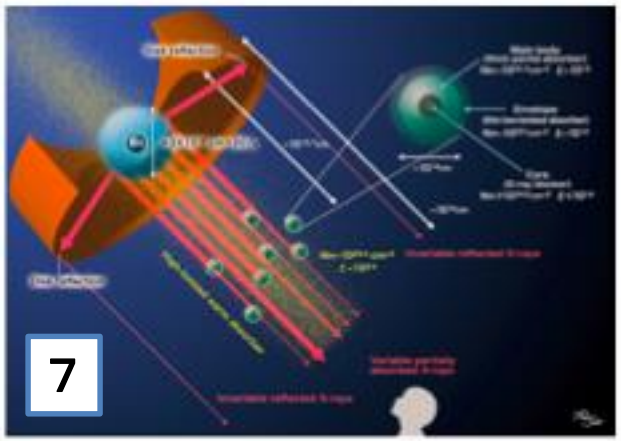


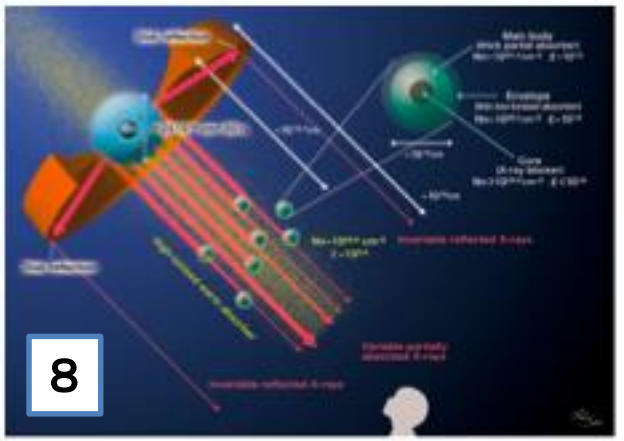




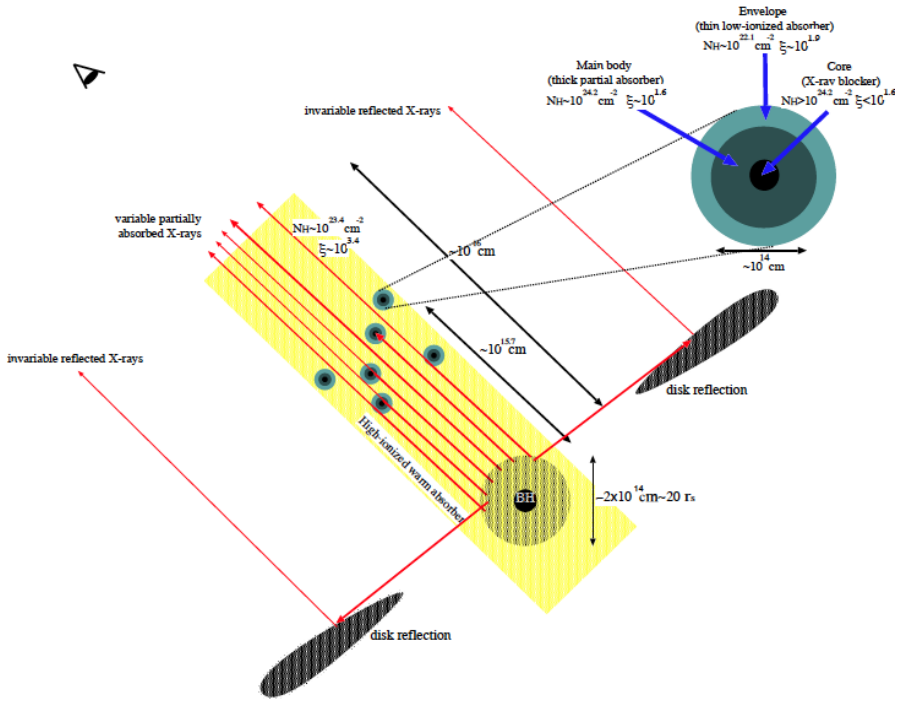




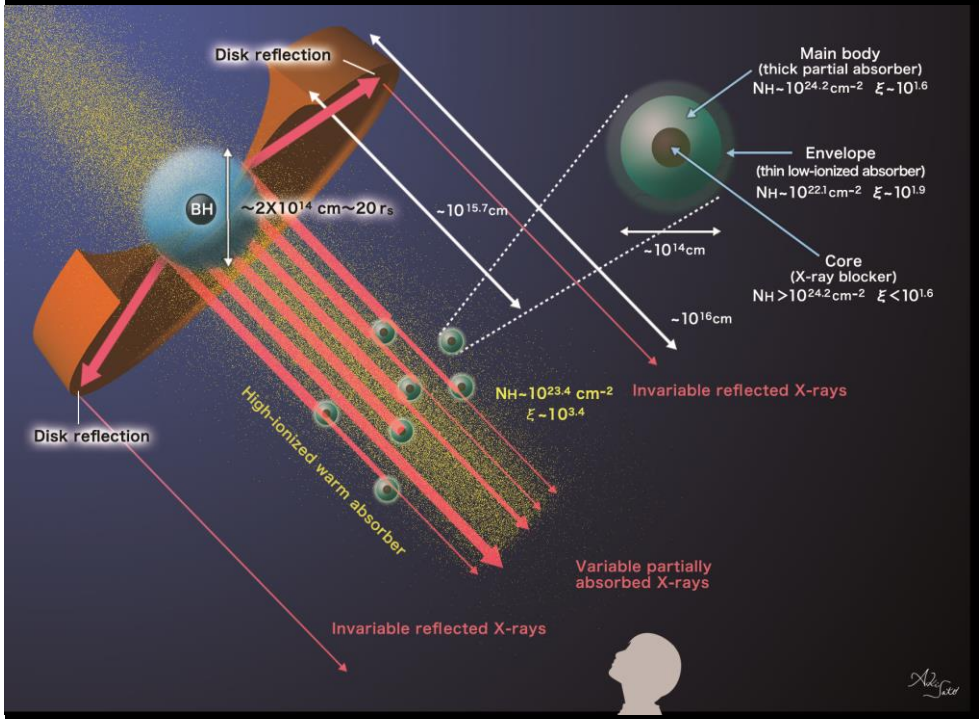




Before



After



科学ビジュアルができるまで（細胞編）

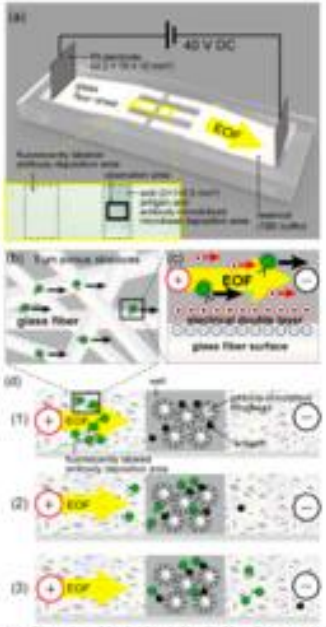


Fig. 1 (a) Illustration of the developed chip. (b) Glass fiber networks and a series of porous structures (mean pore size of 7 μm) in the glass fiber sheet. (c) EOF induced by an electrical double layer on the glass fiber. The EOF transports the molecules to the cathode. (d) Conceptual diagram of B/F (bound/free) separation by EOF.

Flash Red polystyrene fluorescent microspheres (7.3 μm in diameter, ex/em max= 660/690 nm, Bangs Labs, IN, USA) and tetramethyl rhodamine isothiocyanate bovine serum albumin (Sigma-Aldrich, MO, USA) were used for size-dependent filtration experiments.

For the glass fiber sheets, FUSION 5 sheets (thickness of 370 μm, mean pore size of 5 μm) were purchased from GE Healthcare.

Device fabrication

Fig. 1a represents an illustration of the developed chip. The chip is composed of a sheet of glass fiber and polymethylmethacrylate (PMMA) frames, as shown in Fig. 2a. A piece of glass fiber sheet was cut to the dimensions of the channel shape (width 2 mm) with a cutting machine (Craft ROBO PRO, GRAPHTEC, Yokohama, Japan). As the frames of the fiber sheet, PMMA plates (0.5 mm and 3 mm in thickness) were micromachined by a Mini Miller MM100 (Modia Systems, Saitama, Japan). At the middle of the glass fiber sheet channel, between the PMMA top and the main frames, a well (2×1×0.5 mm^3) was designed for the antigen and antibody-immobilized Sepharose beads (Fig.1a inset). Next to the well, an open cavity was hollowed out on the frame for introducing the fluorescently labeled antibody. The PMMA frames and the glass fiber sheet were thermally compressed and bonded at 140 °C for 5 min by a Single Thermostat (Rencasoft, NY, USA) (Fig. 2a).

Immunoassay procedure

A quantitative immunoassay was performed for CRP or insulin concentrations between 0 and 100 ng mL^{-1}. First, a sample solution of 2.5 μL was mixed with the antibody-immobilized Sepharose bead solution (2.5 μL) for 5 min and deposited in the sample well by pipetting. Then, the reservoirs (Fig.1a) were filled with a Tris-borate-EDTA (TBE) buffer (1×, pH 8.3), which was allowed to continuously soak into the channels by capillary force. Finally, 1 μL of 0.15 mg mL^{-1} fluorescently labeled antibody was deposited at the cavity area (Fig. 2b). For B/F separation, DC 40 V was applied between the reservoirs for 15 min with a pair of Pt electrodes at an interval of 42 mm (Fig.1a). The bubbles caused by the electrode reactions were negligible. For size-dependent filtration experiments, 1 μL of 1% Flash Red polystyrene microspheres or 1% tetramethyl rhodamine isothiocyanate bovine serum albumin were added to the area where the fluorescently labeled antibody was deposited.

Data acquisition and analysis

The fluorescence intensity of the beads at the observation area (Fig. 1a) was measured with a fluorescence microscope equipped with a 20× objective lens and a CCD camera (DS-7I with DP72, Olympus, Tokyo, Japan). The mean gray value of the observation area (the center area of the sample well) was estimated using image analysis software (ImageJ, National Institutes of Health, MD, USA).

For size-dependent filtration experiments, the samples were observed with a confocal laser scanning microscope (TCS SP5, Leica, Wetzlar, Germany).

Results and discussion

Principle of B/F separation with the chip

The chip makes use of EOF as the driving force of molecular migration. The glass fiber sheet is an unwoven fabric, as illustrated in Fig. 1b. Inside the sheet are glass fiber networks and a series of porous structures. The fiber surface is negatively charged due to silanol groups, which generate an electrical double layer on the fiber surface. Electrical forces on ions in the electrical double layer induce EOF under an electric field (Fig. 1c). It is expected that the porous structure produces a higher charge density and an efficient EOF.[21] We observed that the EOF steadily transported fluorescently labeled antibody in the direction of the cathode with 0.4 μL min^{-1} at 10 V cm^{-1} (see also Fig. S1). Note that the EOF was dominant in the direction of molecular migration over the electrophoretic force, despite its negative net charge. We determined that this constant flow

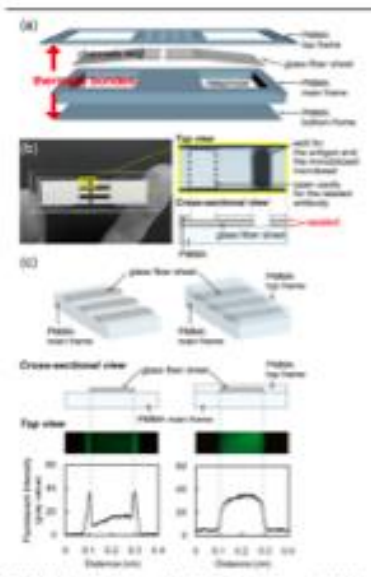


Fig. 2 (a) Assembly diagram of the chip. (b) Photo of the assembled chip and an enlarged view of the sampling well and the cavity for the labeled antibody. (c) The EOF is shaped through the glass fiber sheet directly onto the PMMA main frame (left), and the device is tightly sealed with these frames (right). Schematics, fluorescence microscopic images, and their line profiles are shown above.

permits B/F separation. The fluorescently labeled antibodies flow to the sample well and bind to the antigen, producing an antigen-antibody complex, while extraneous antibodies freely flow to the cathode (Fig. 1d). It is considered that the piled beads increase the surface area of the reaction sites and contribute to increase the fluorescence intensity and sensitivity.

Optimization of channel flow

To perform a quantitative assay with our chip, fluid flow must be precisely controlled for the B/F separation process. Preliminarily, we thermally bonded the channel-shape sheet directly onto the PMMA main frame without the top frame. However, the labeled antibody accumulated at the sheet/air interface in association with the EOF (Fig. 2c, left) because the fluid flow avoids obstacles, including the fiber matrix. To overcome this problem, previous studies used paper microfluidics to pattern the channel and wall by photolithography or a wax printing process, and these elements were used to control the fluid flow.[22] In this work, we sealed the fiber-sheet channels with PMMA frames to remove the sheet/air interfaces. Because of the thermoplastic characteristics

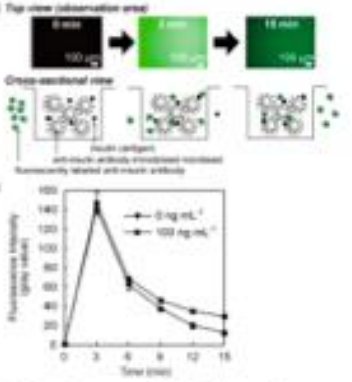


Fig. 3 B/F separation steps on the chip. (a) Time-course fluorescence microscopic images of the observation area at DC 40V and their conceptual diagrams. (b) Fluorescence intensity of the observation area estimated every 3 min. Insulin concentrations of 0 ng mL^{-1} and 100 ng mL^{-1} were used in the examples.

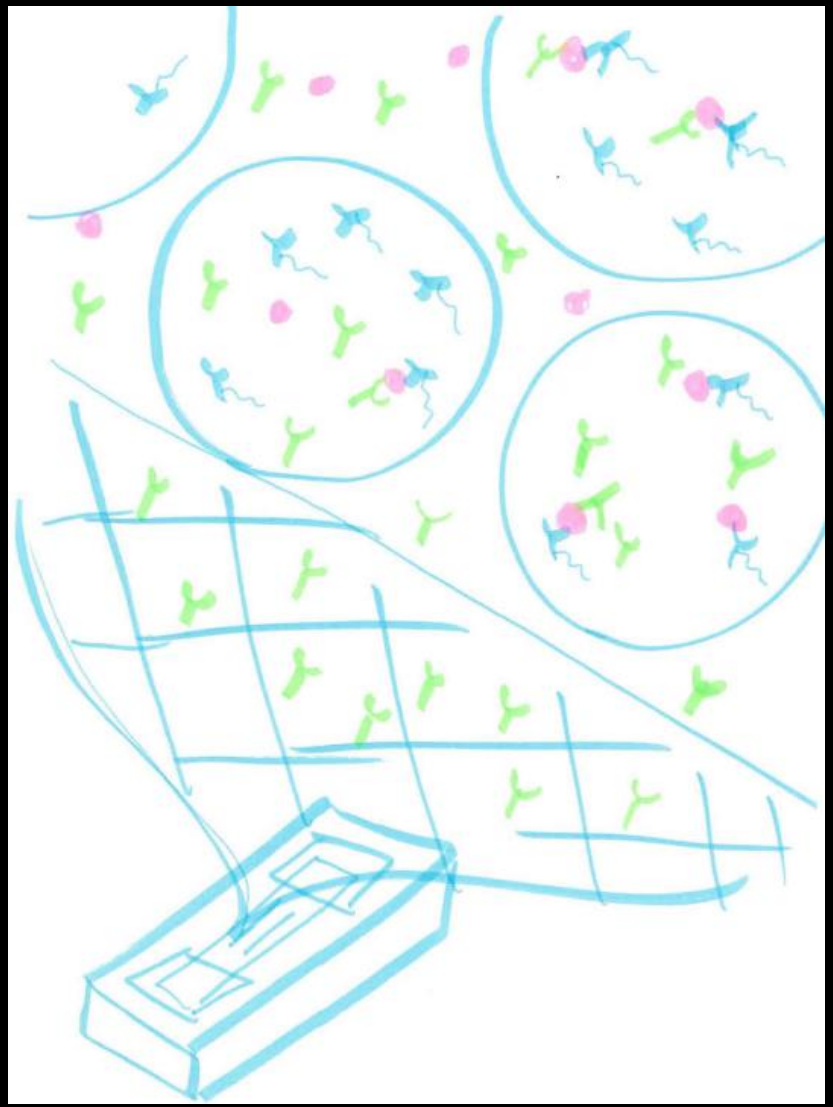
of PMMA, gapless bonds between the fiber and PMMA were easily formed by thermal bonding. As shown in Fig. 2c (right), the flow of labeled antibody significantly improved and became an ideal constant flow due to the tight seal formed by the PMMA walls.

EOF and B/F separation

We demonstrated B/F separation on the chip using the stable migration of labeled antibodies in an EOF. The sample analytes were 0 and 100 ng mL^{-1} of insulin. As described above, the analyte bound to the beads was deposited in the well and the labeled antibody was deposited at the fluorescently labeled antibody deposition area. A series of microscopic images and schematics in Fig. 3a show three characteristic states of the well during the B/F separation. At 3 min, the majority of the labeled antibodies had reached the sample well, representing the maximum fluorescence intensity. By the following buffer washing step, the intensity decreased because of the release of unbound antibody. The time-resolved fluorescence intensities are presented in Fig. 3b. The intensity difference between 0 ng mL^{-1} and 100 ng mL^{-1} insulin became larger with the application of a continuous EOF. The resulting difference corresponds to the signal at the defined concentration.

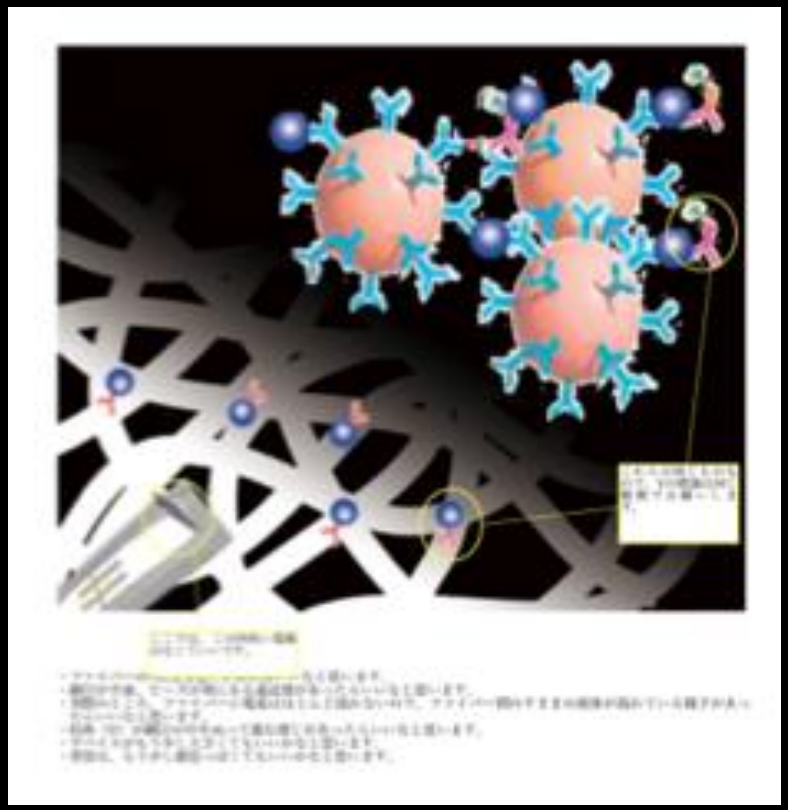
The applied DC voltage determines the EOF velocity; a higher voltage can shorten the time required for the B/F separation process, although the antigen-antibody reaction time is also reduced and may become insufficient. We found that separation at 40V for 15 min is the shortest sufficient condition for a quantitative immunoassay on the chip. Under this condition, the antibody-antigen reaction sufficiently proceeds and the B/F

研究者の描いたスケッチ



提案したラフ案

研究者からの要望



・ファイバーの3次元な感じがほしい。

・網目が手前、ビーズが奥にある遠近感があったらいい。

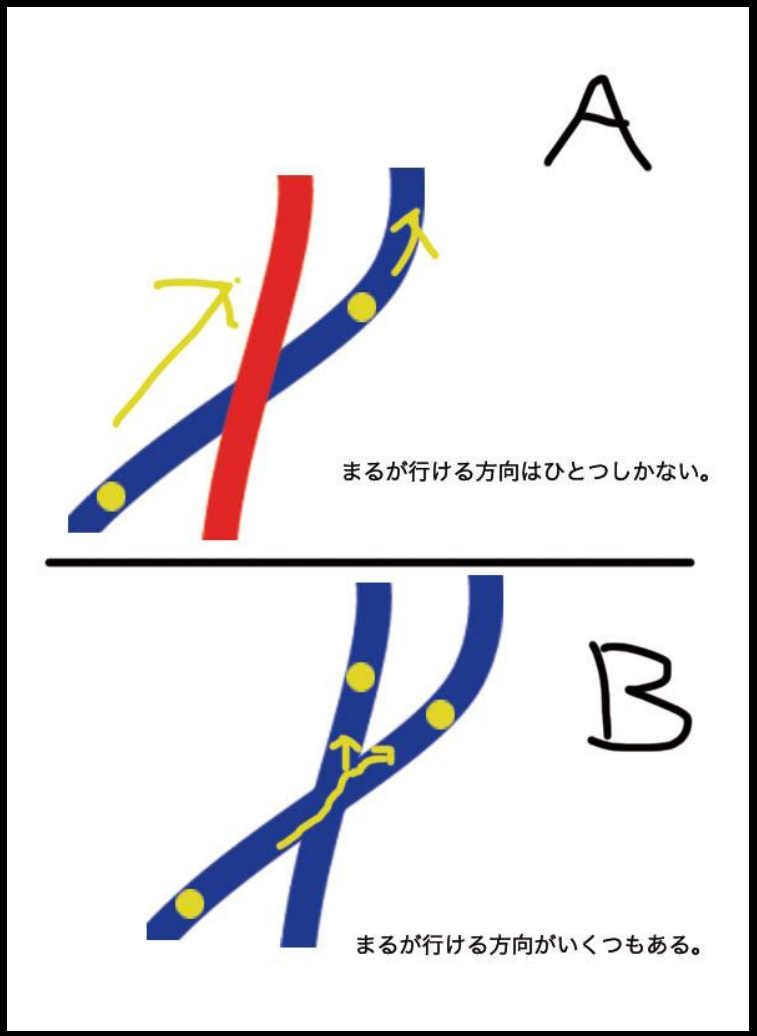
・実際のところ、ファイバーに電流はほとんど流れないので、ファイバー間のすきまの液体が流れている様子があったらいい。

・抗体（Y）が網目の中をぬって進む感じを出したい。

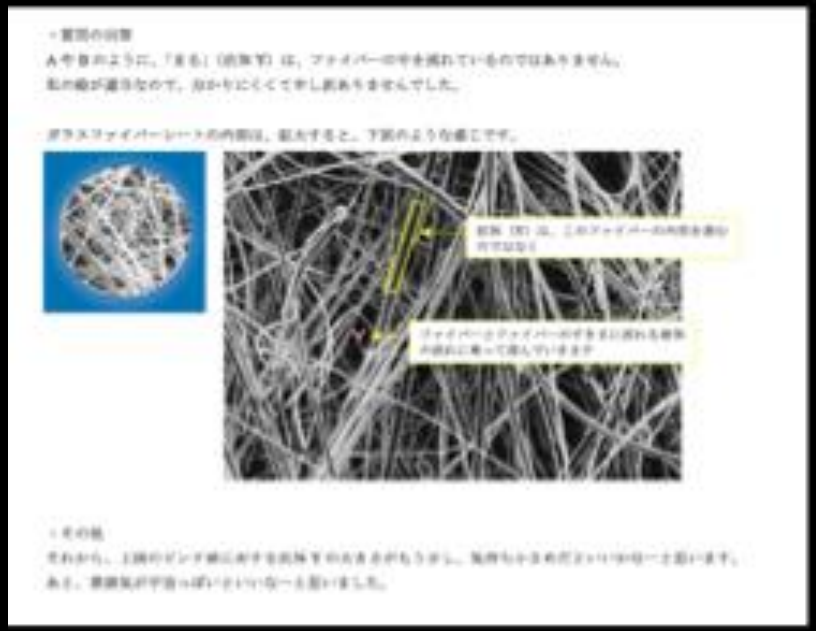
・デバイスがもう少し大きくてもいい。

・背景は、もう少し紺色っぽくてもいい。

図を描いて質問



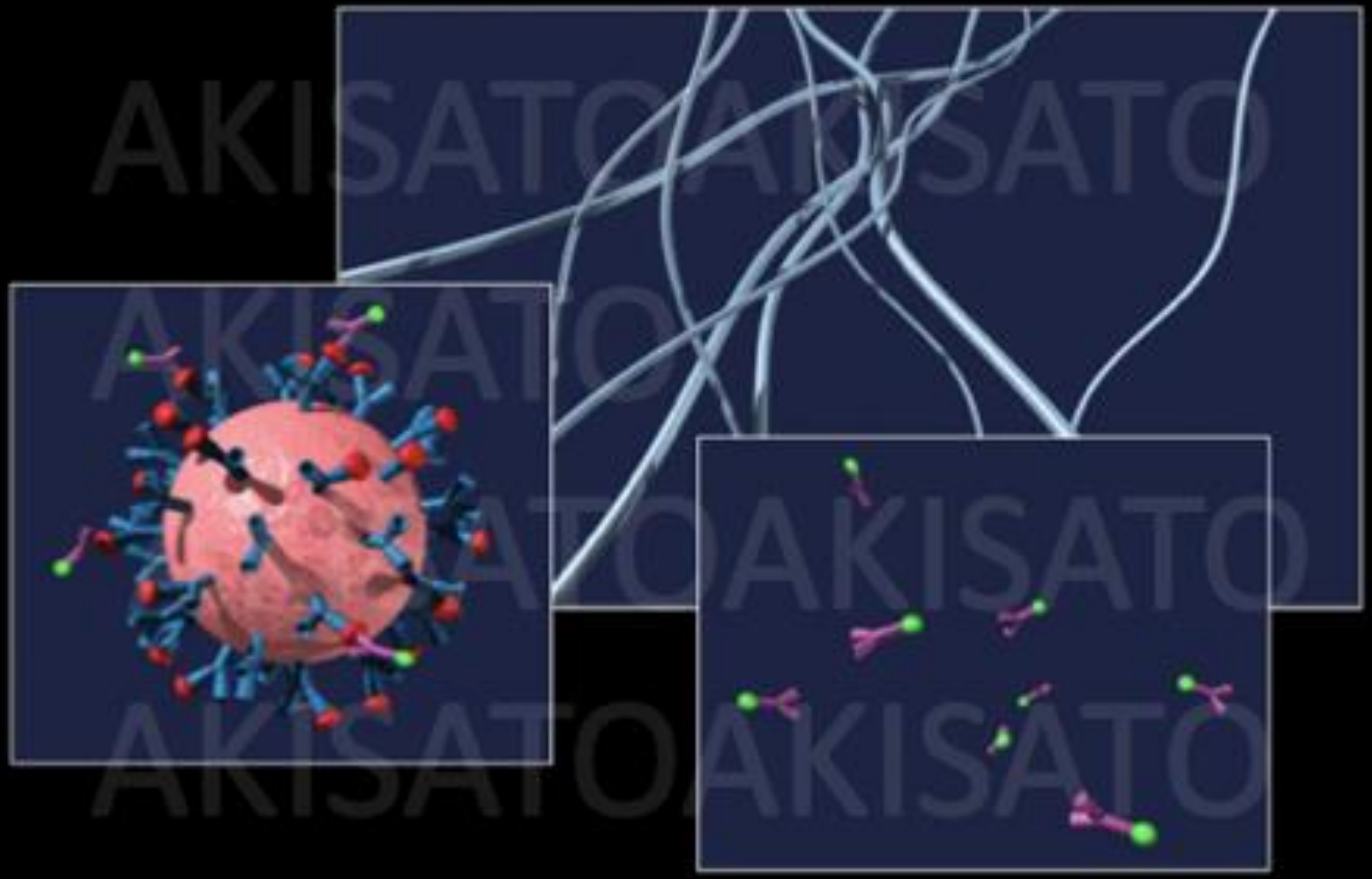
研究者からの回答



AやBのように、「まる」（抗体Y）は、ファイバーの中を流れているのではありません。

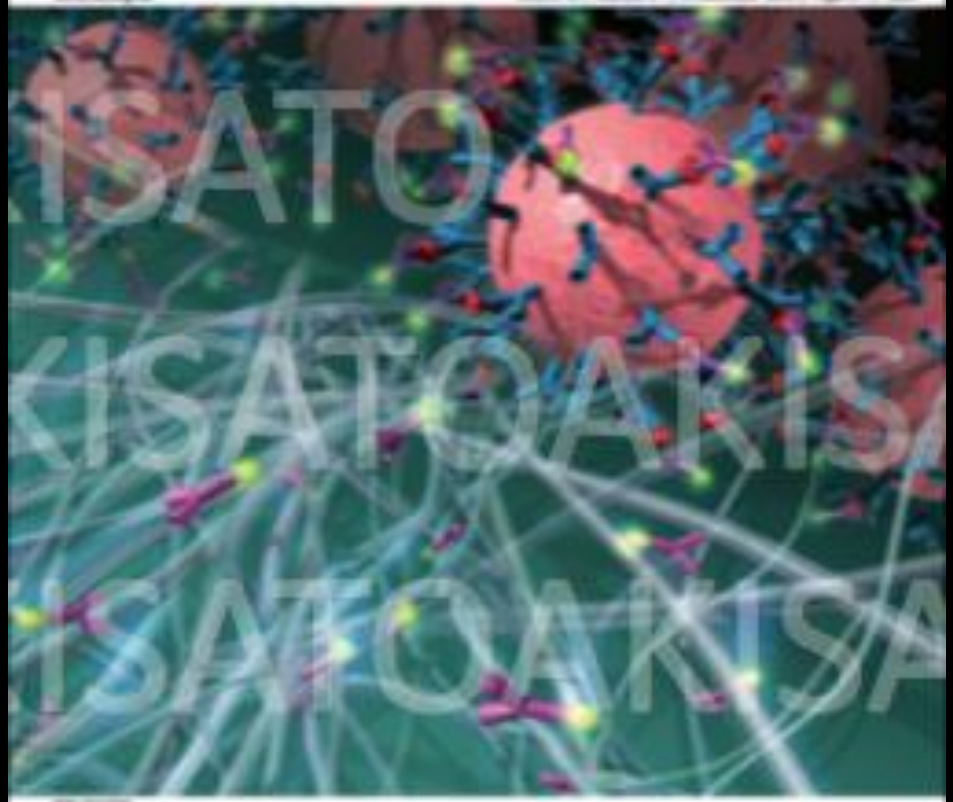
ファイバーとファイバーのすきまに流れる液体の流れに乗って進んでいきます

3Dで素材作り （使用ソフト：Light Wave3D）



Lab on a Chip

Miniaturisation for chemistry, physics, biology, materials science and bioengineering



RSC Publishing

コミュニケーション手段

- Face to Face
- メール
- Skype
- テレビ会議システム(POLYCOM vsx7000)

制作の流れ

- 研究内容を聞く。
- 分からない部分を投げかける。
- 返答をもらう。
- 研究者の要望を聞く。
- どの表現方法が適切か考える。
- ラフを提案する。（要望にそったもの＋α）
- ラフのフィードバックをもらう。
- 作り込み
- 完成！

制作環境

ハードウェア

- Mac Book Pro

  メモリ　4GB, 速度 : 1067 MHz , 種類 : DDR3

  プロセッサ　2.66GHz Intel Core i7

  グラフィックカード　NVIDIA GeForce GT 330M

ソフトウェア

- Adobe Illustrator
- Adobe Photoshop
- NewTek Light Wave

大事なことは、

研究者　×　デザイナー

コミュニケーション

お互い辛抱強く「伝える」「理解する」を重ねて最終的な形へ持っていく。

科学におけるグラフィックデザインの役割

- 研究の発展を図るためには、国民に研究開発の必要性を広く伝達し、理解を得ることが大切
- 高度な研究ほど専門外の人々がそれを理解することは困難である
- ことばだけでは分かりにくい内容も図にすることにより研究を身近に感じさせ、理解するための大きな手かがりとなると考える

謝　辞

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