



Institut national de physique nucléaire
et de physique des particules



Présentation du projet Einstein Telescope



ET-France meets industry

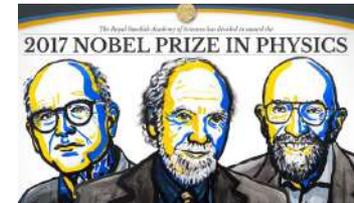
APC Paris, 23 Mars 2023

Patrice Verdier (IP2I Lyon – IN2P3) – patrice.verdier@in2p3.fr

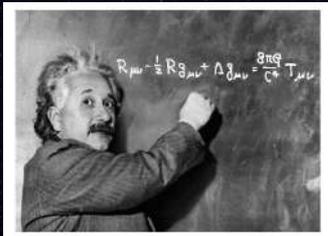
100 ans après leur prédiction dans le cadre de la théorie de la relativité générale d'Einstein, la découverte des ondes gravitationnelles ouvre une nouvelle voie d'exploration et d'étude de l'univers !



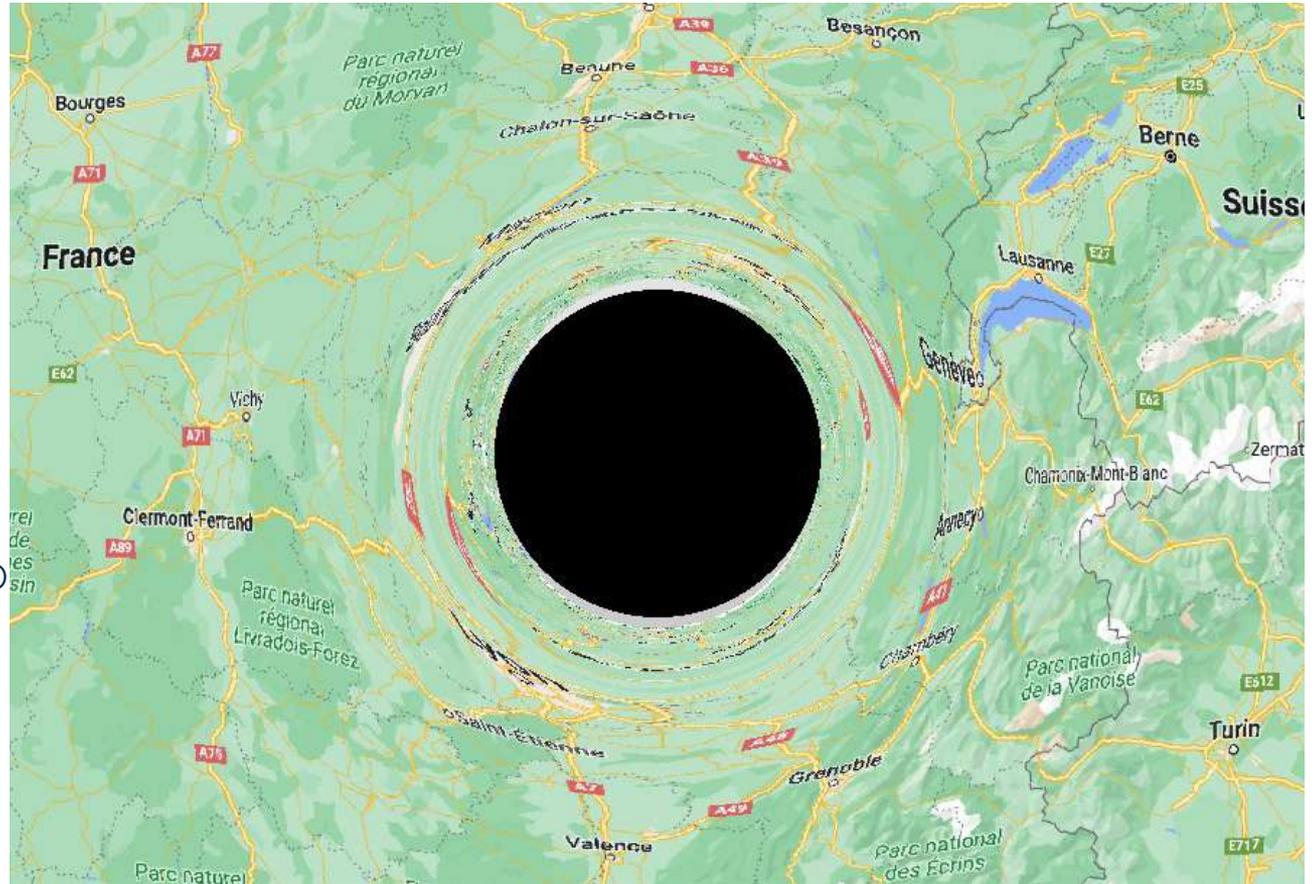
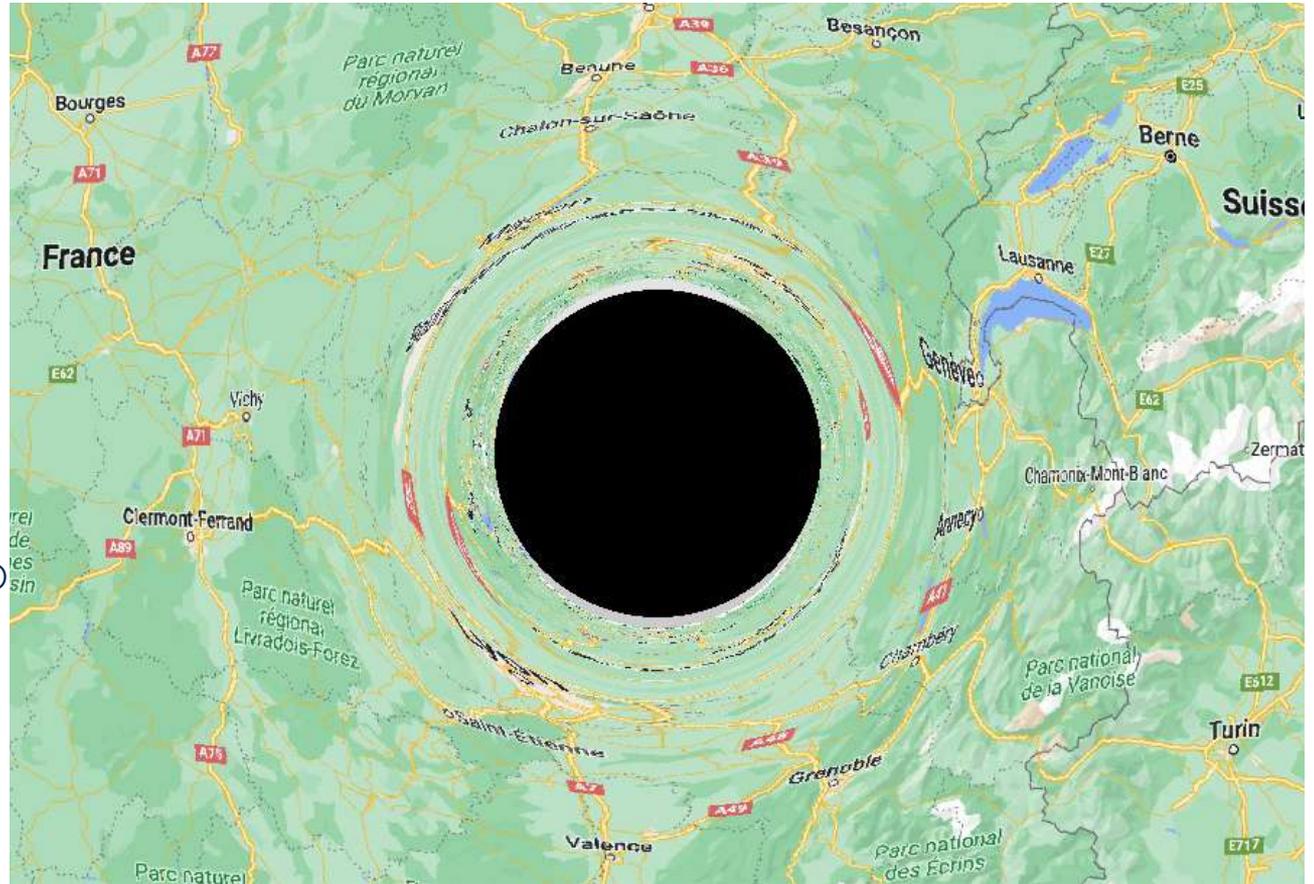
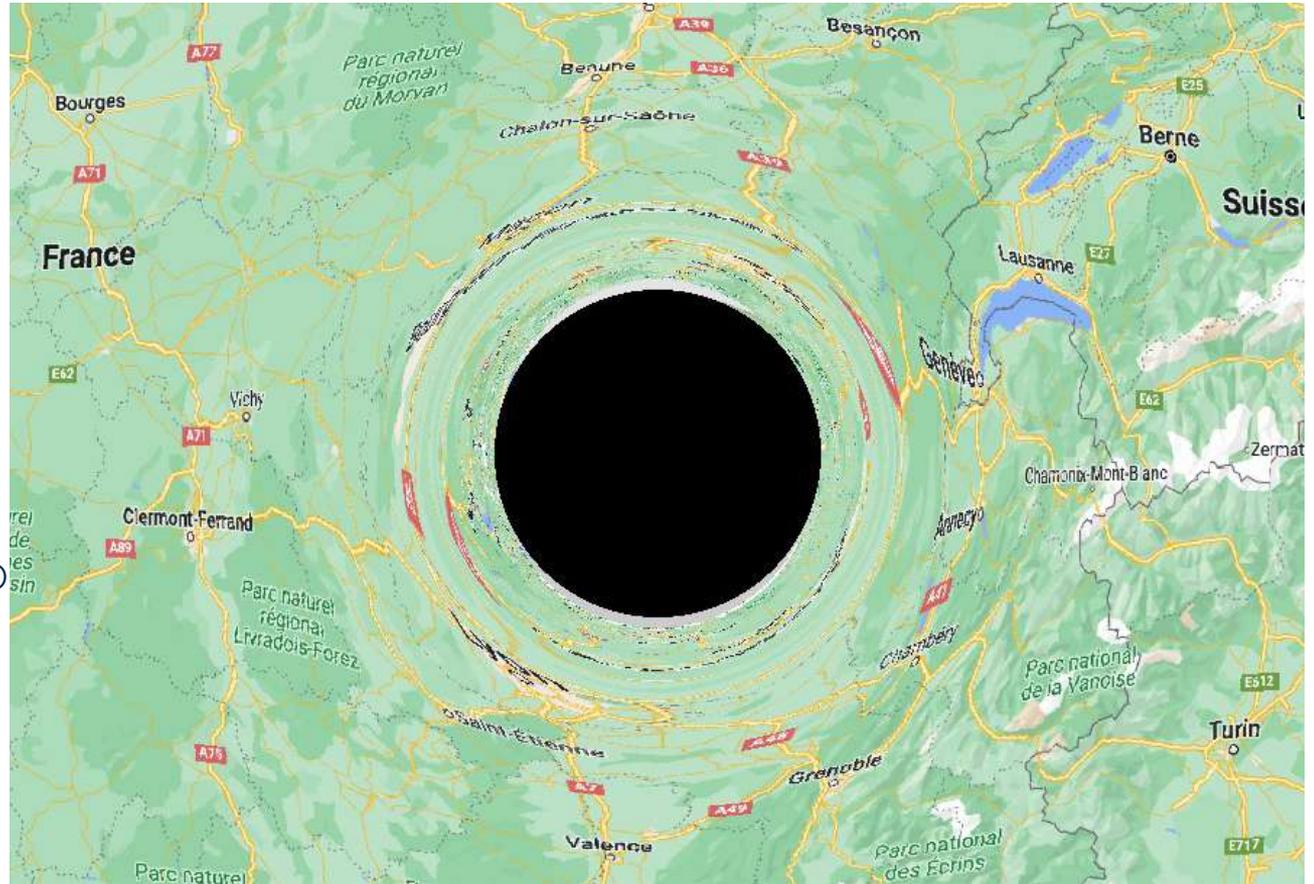
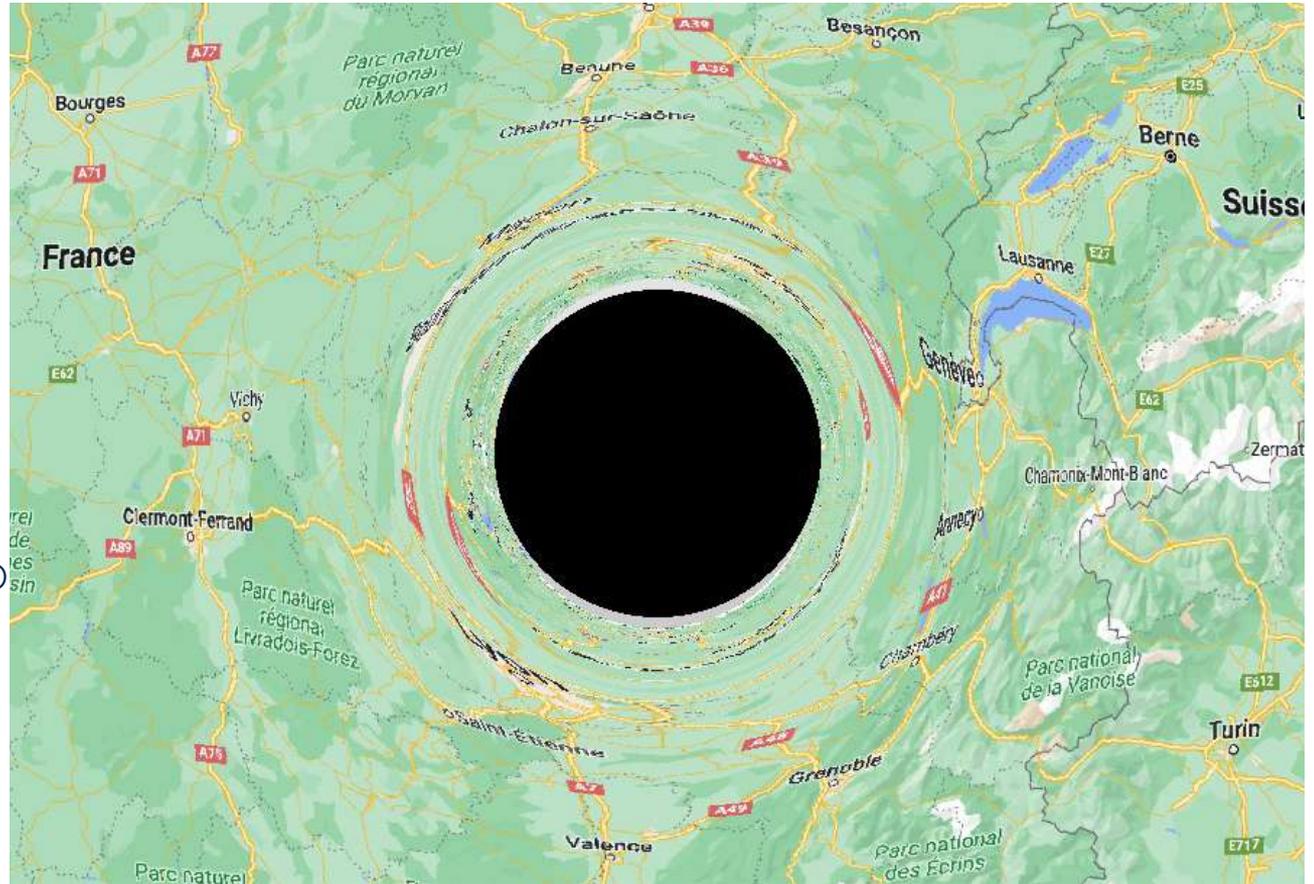
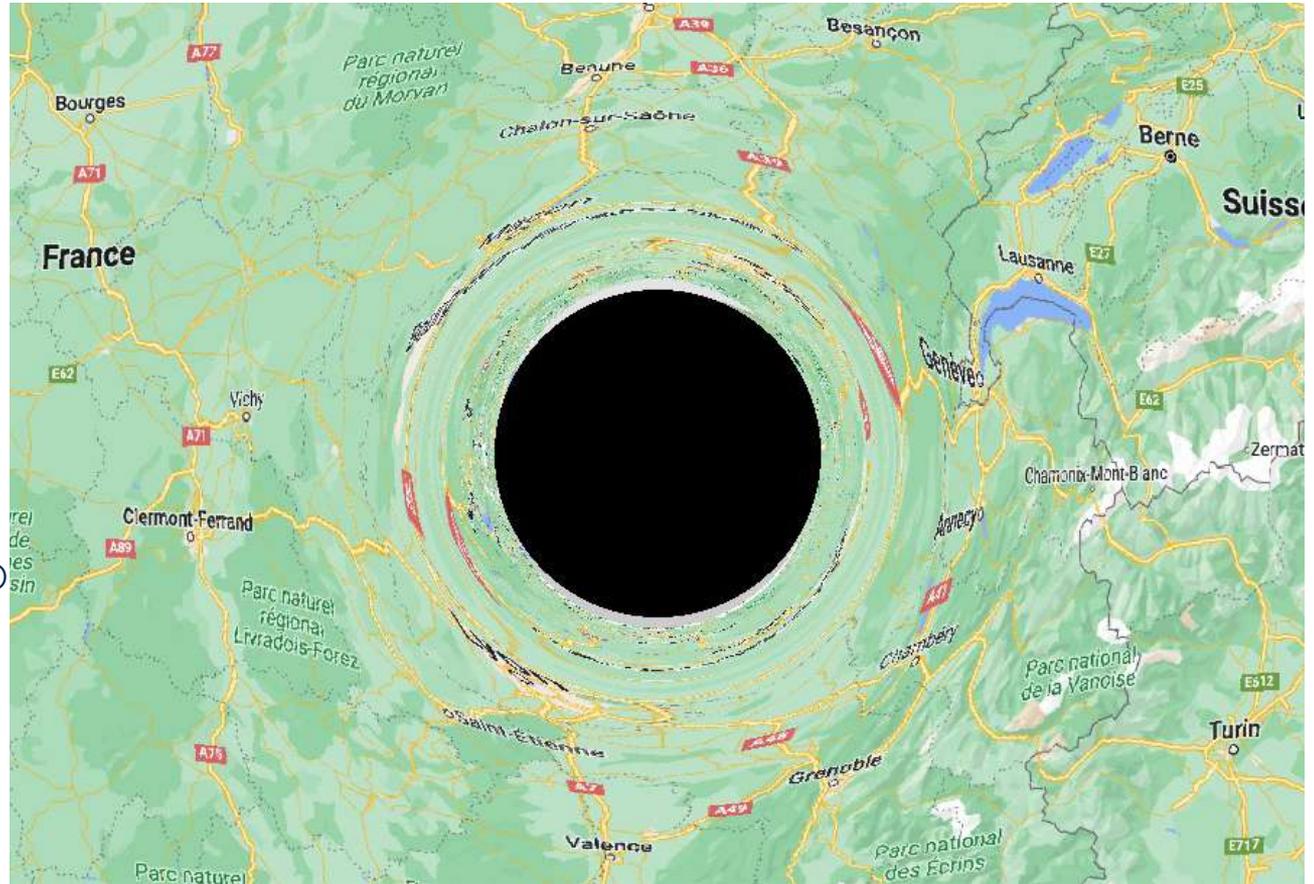
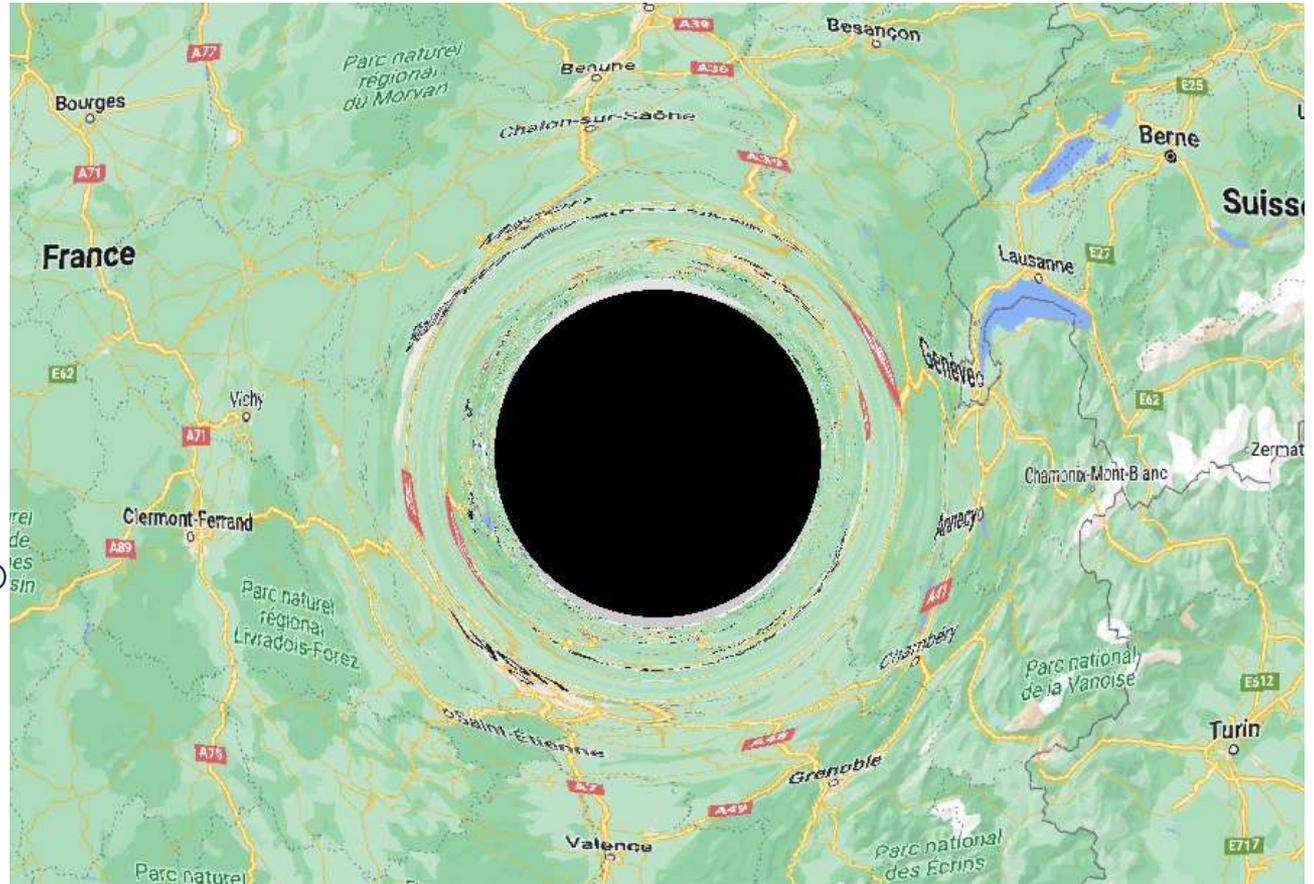
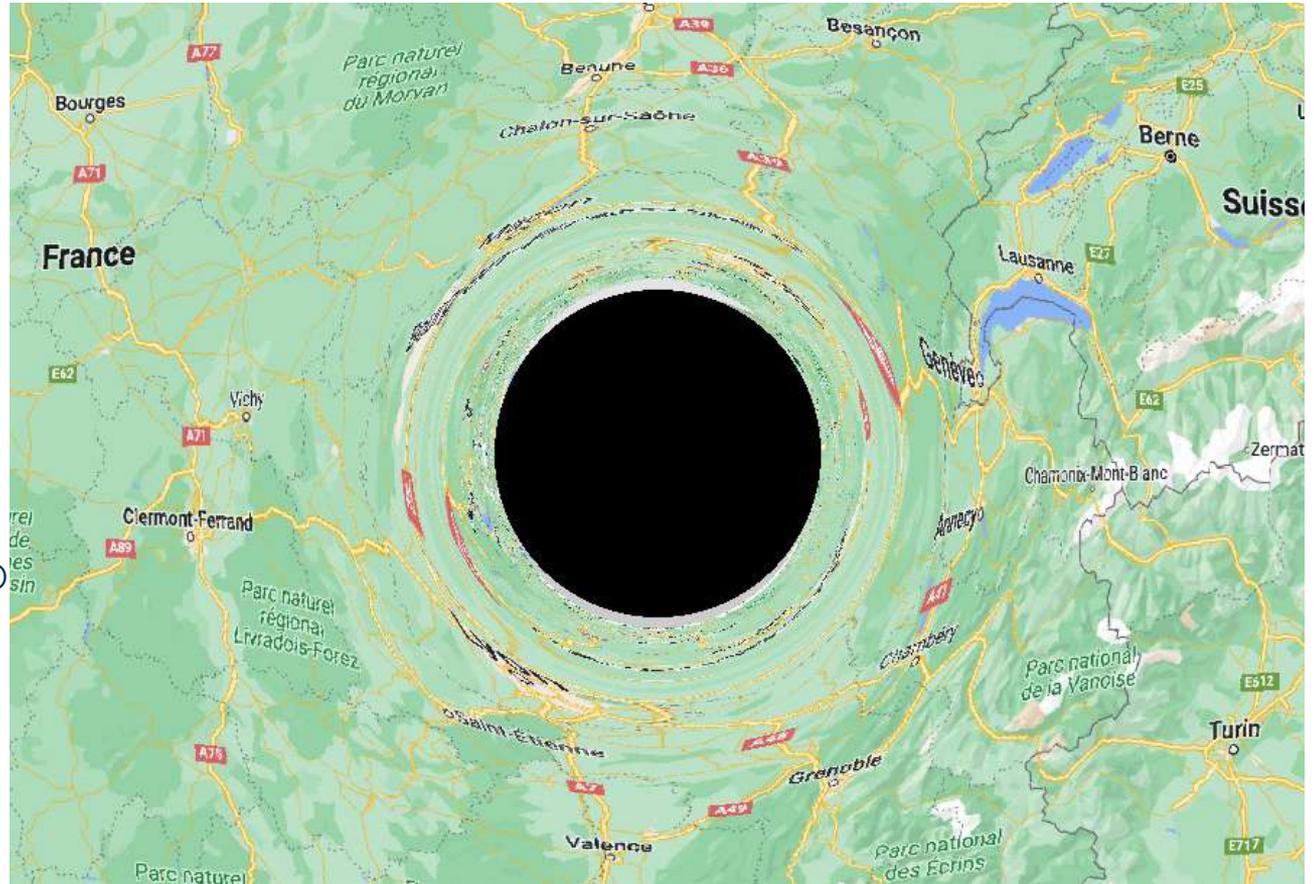
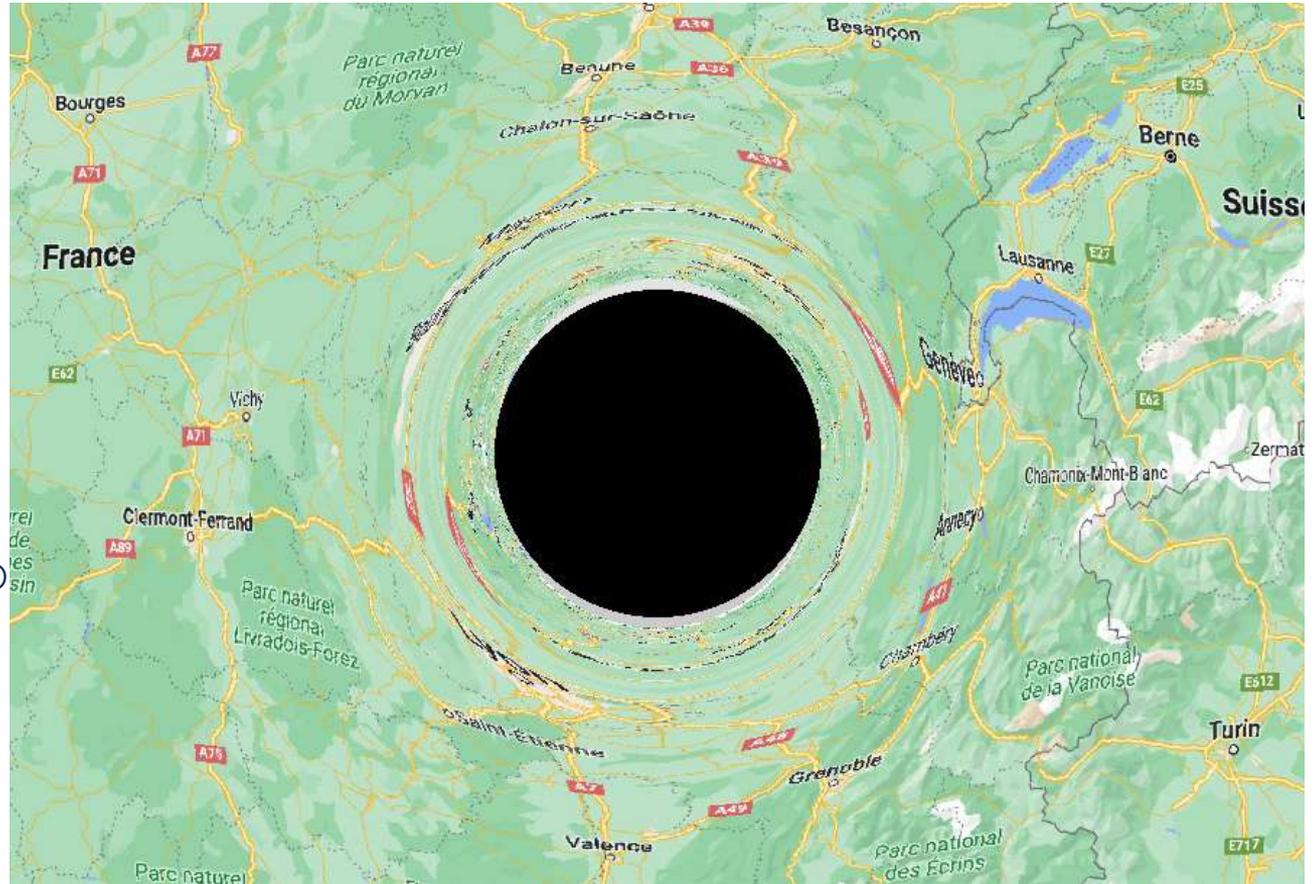
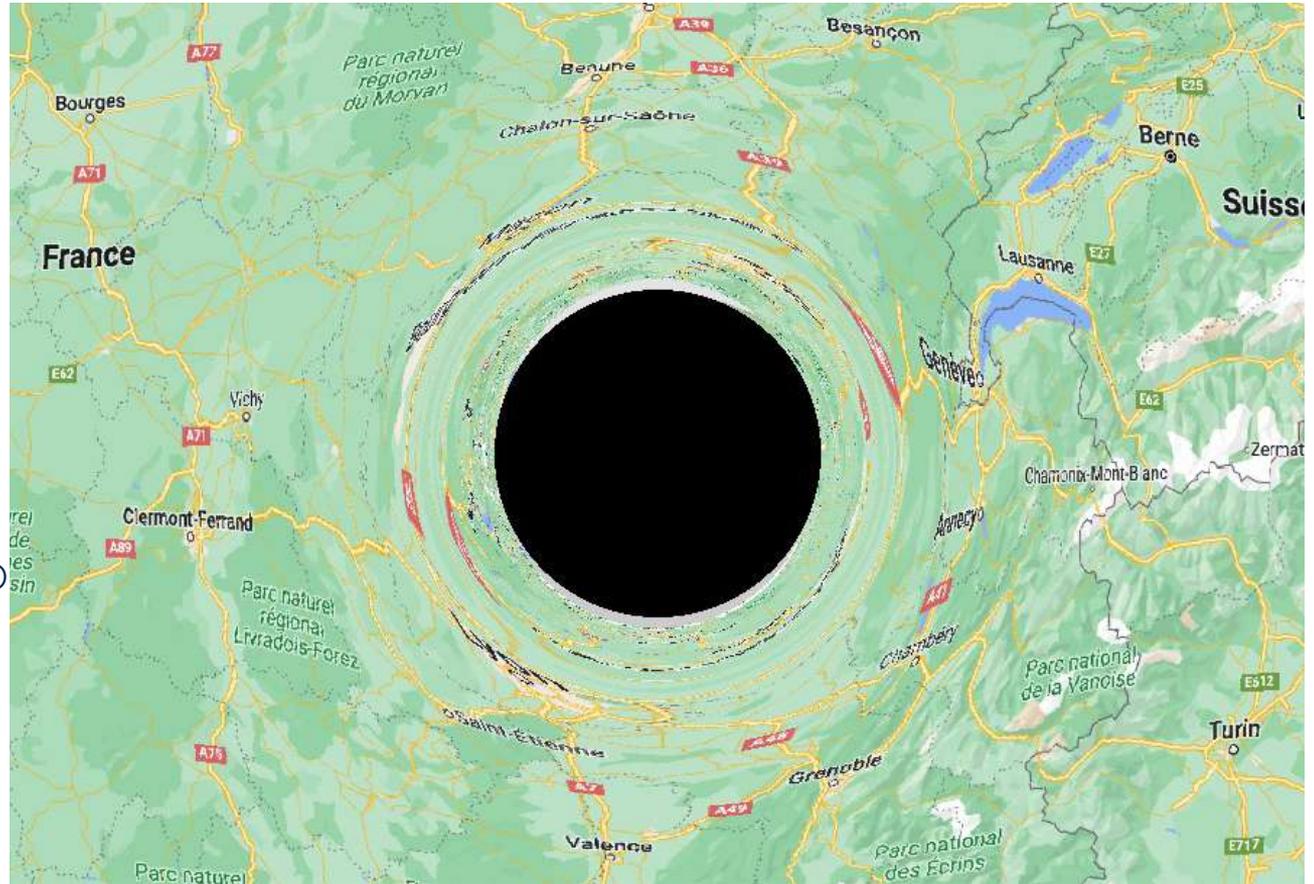
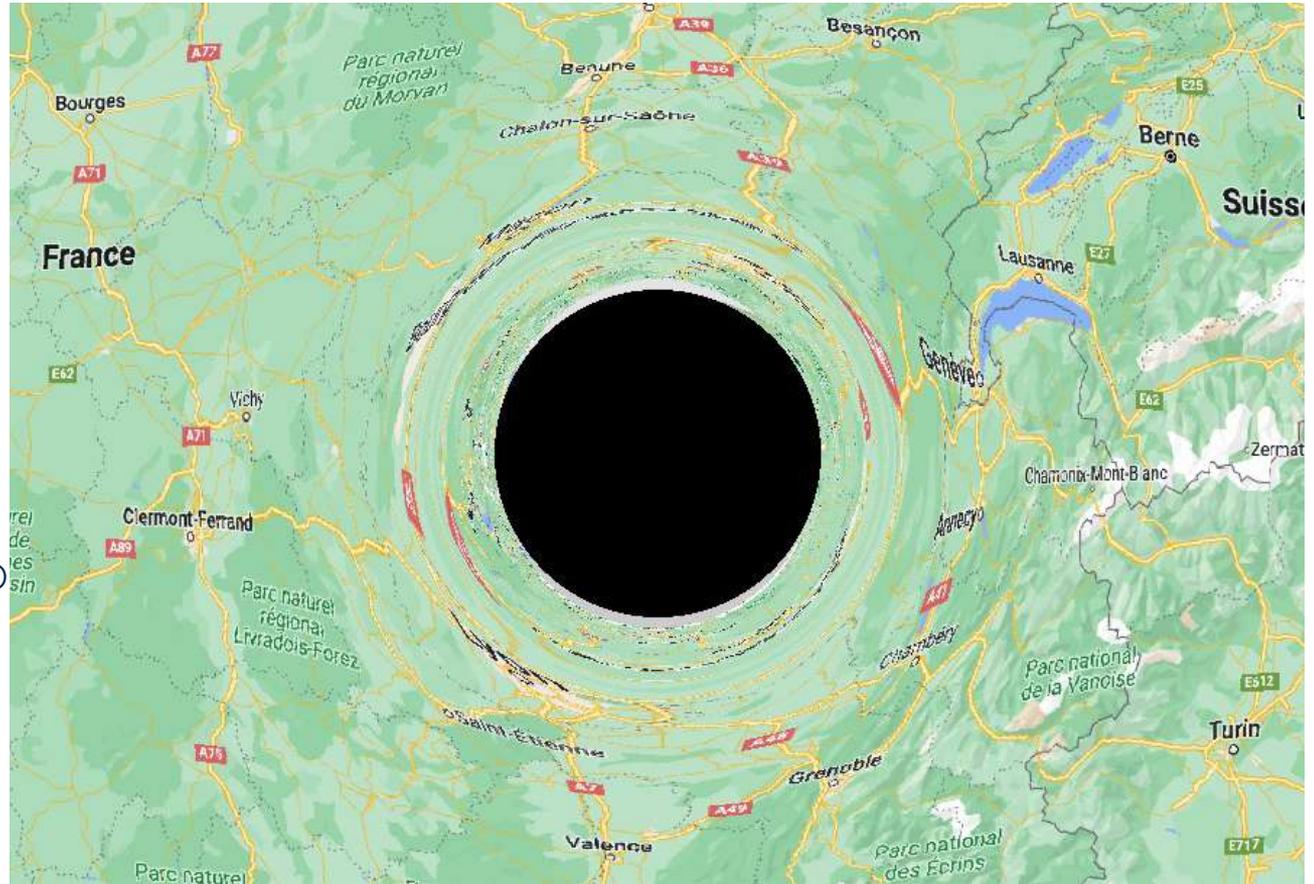
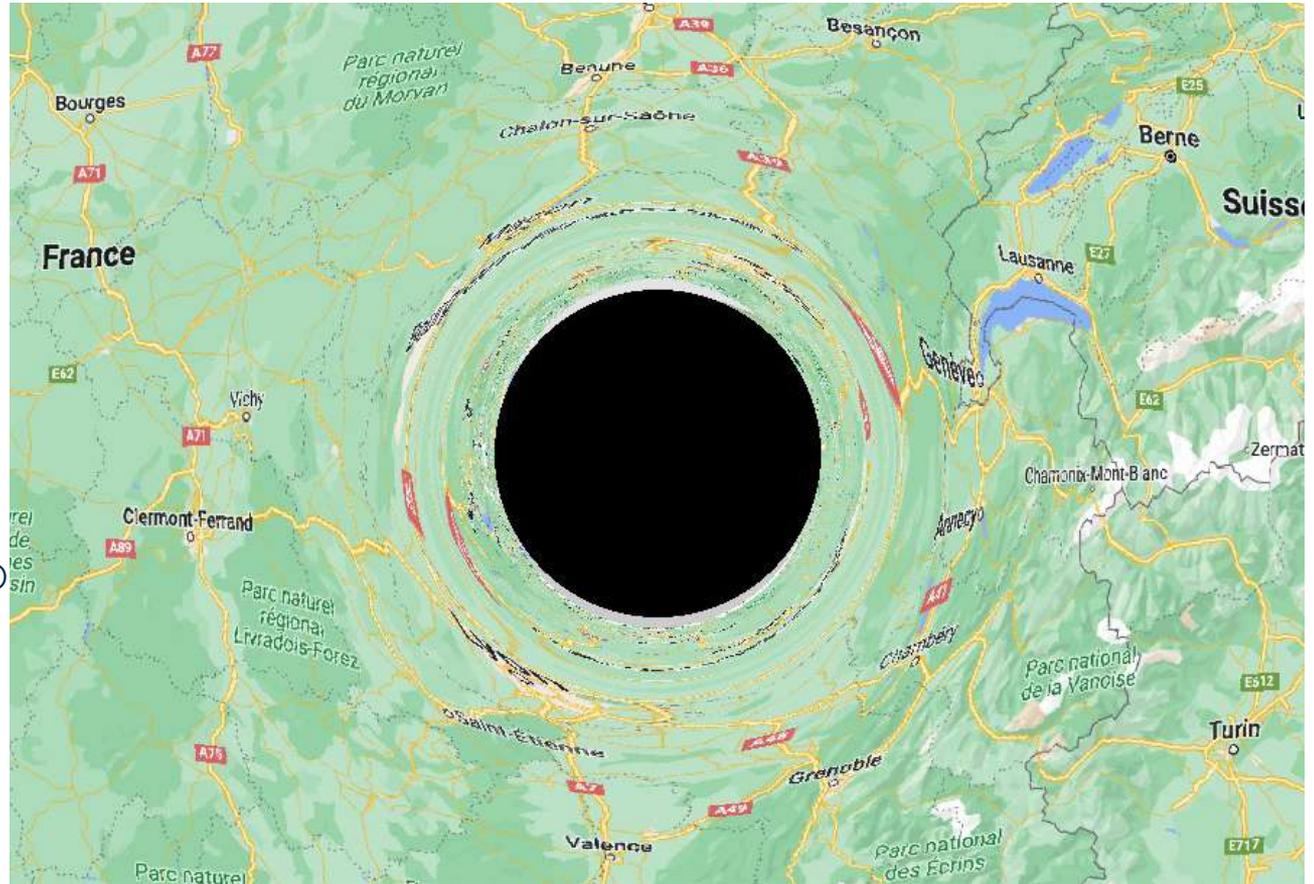
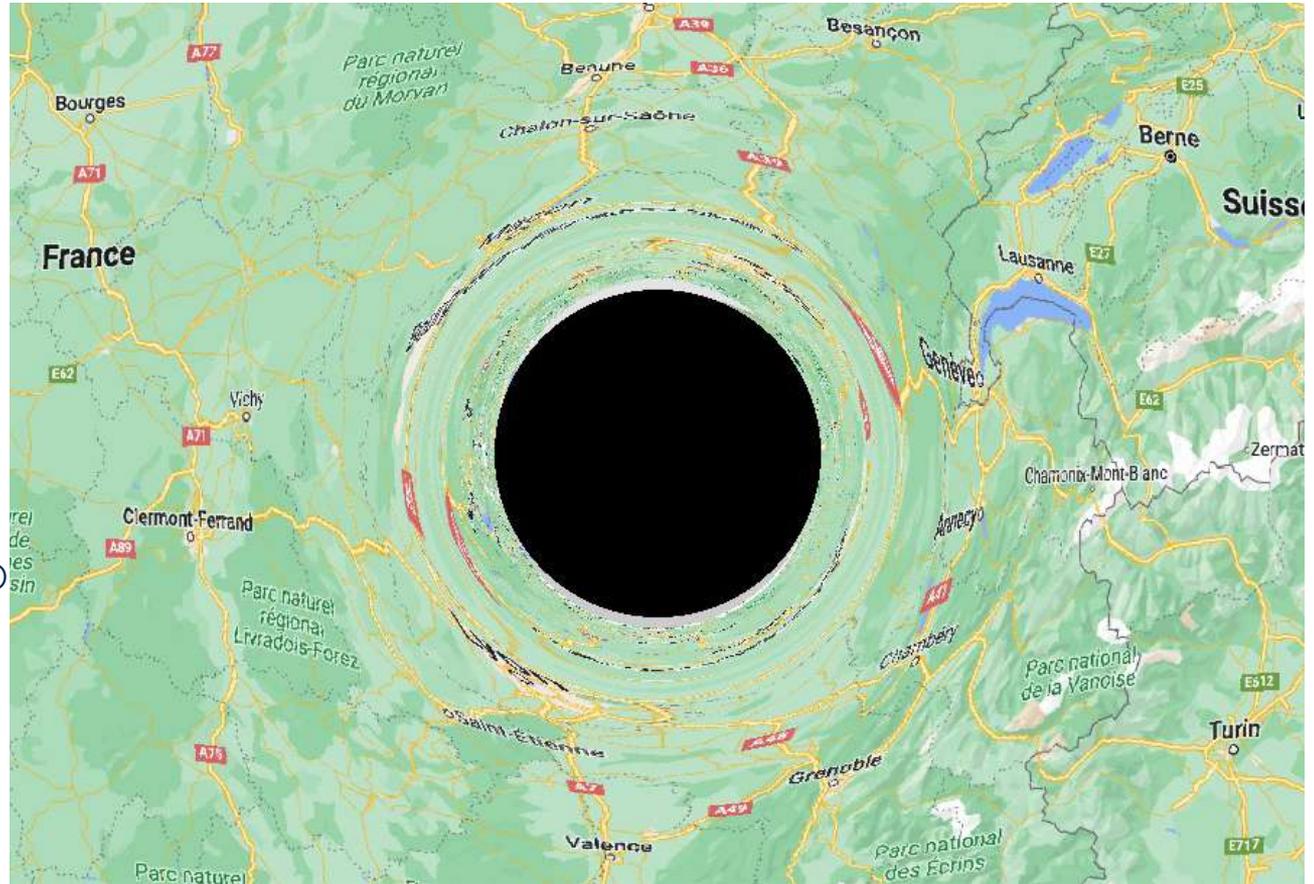
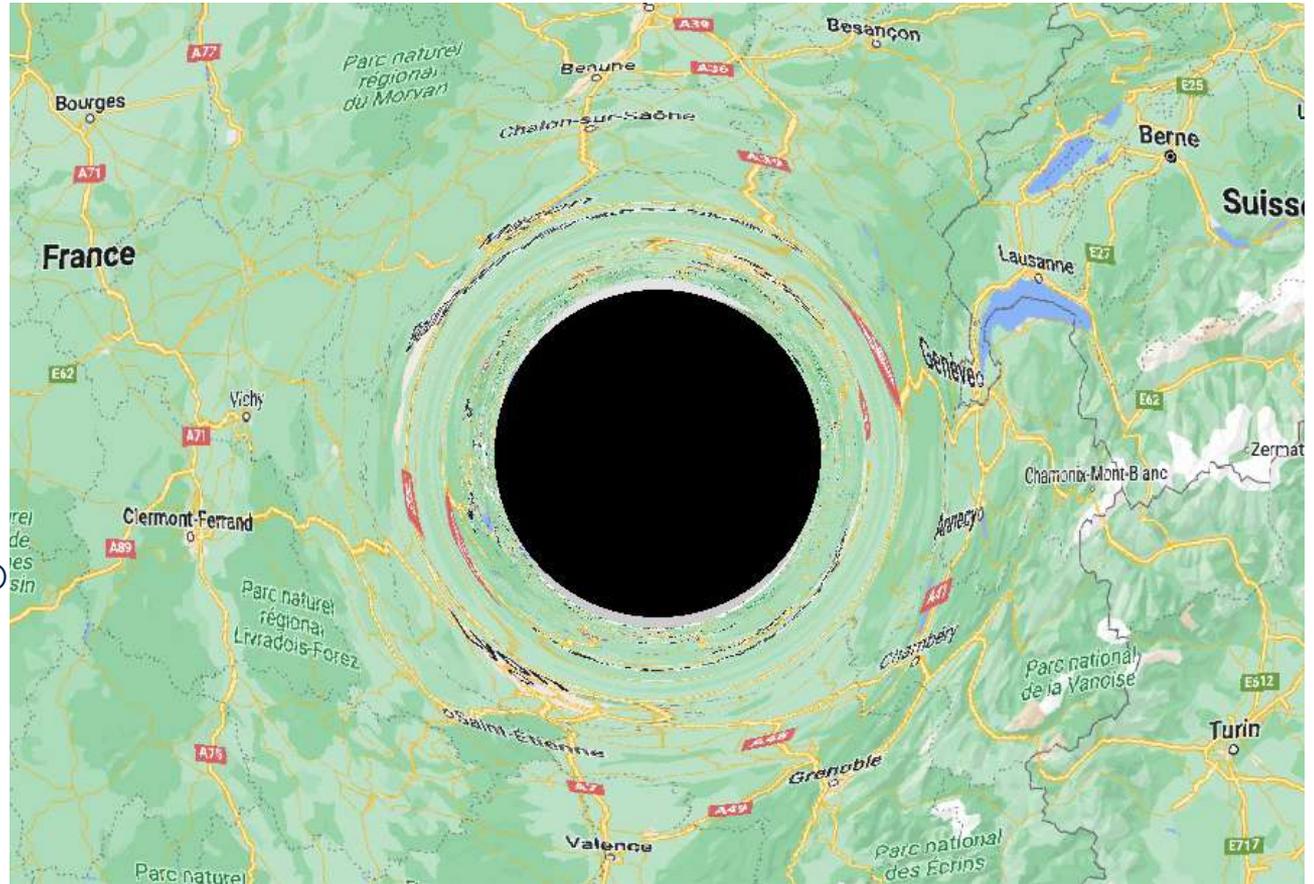
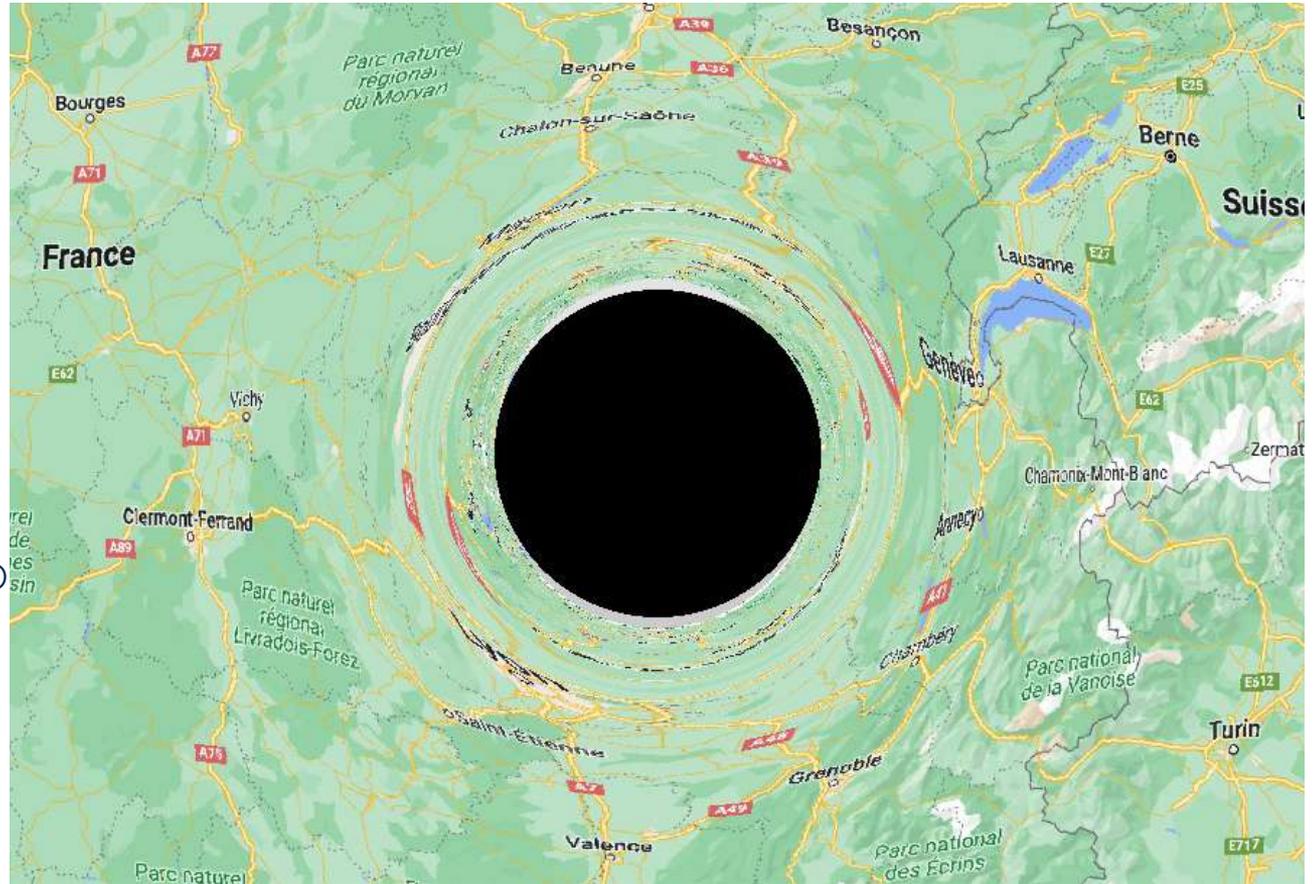
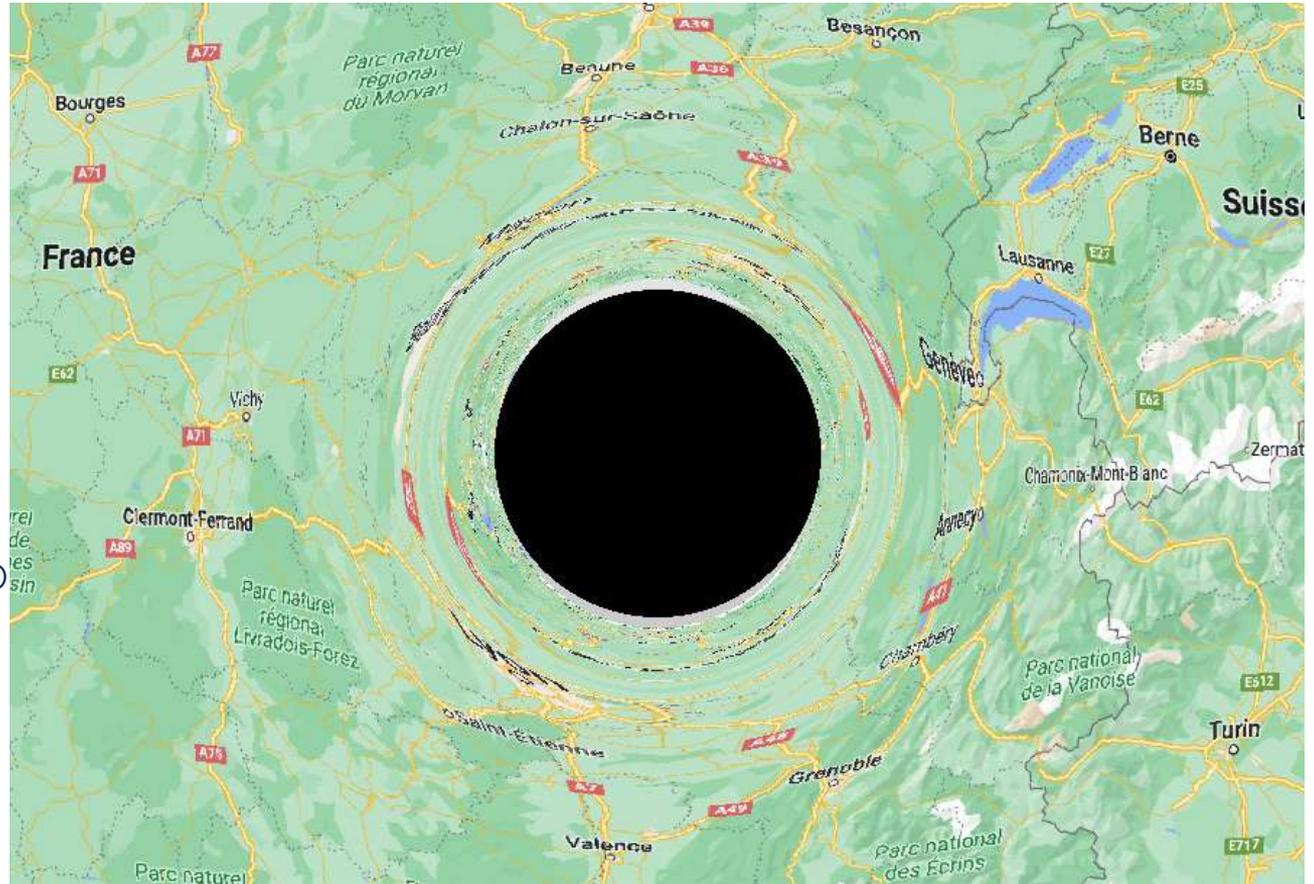
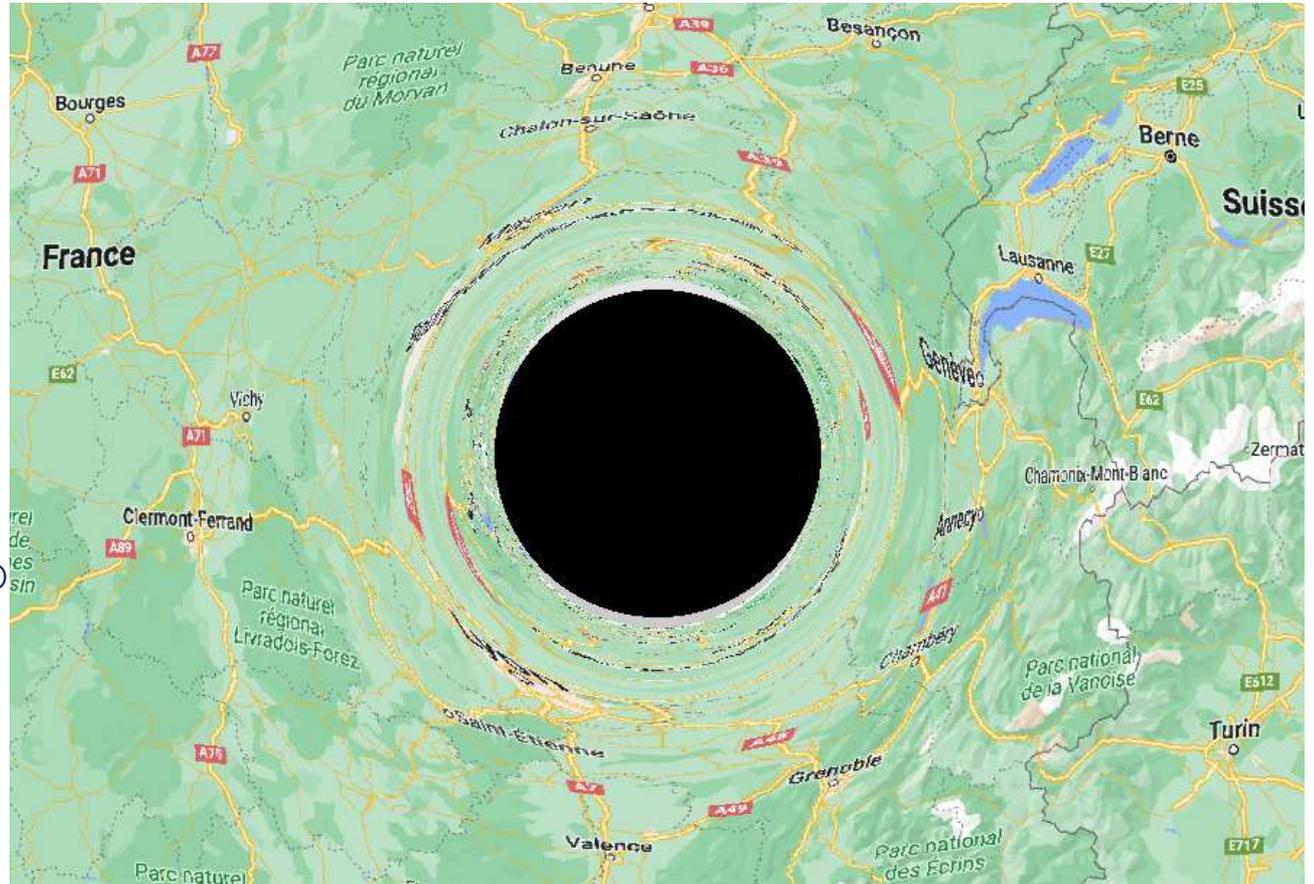
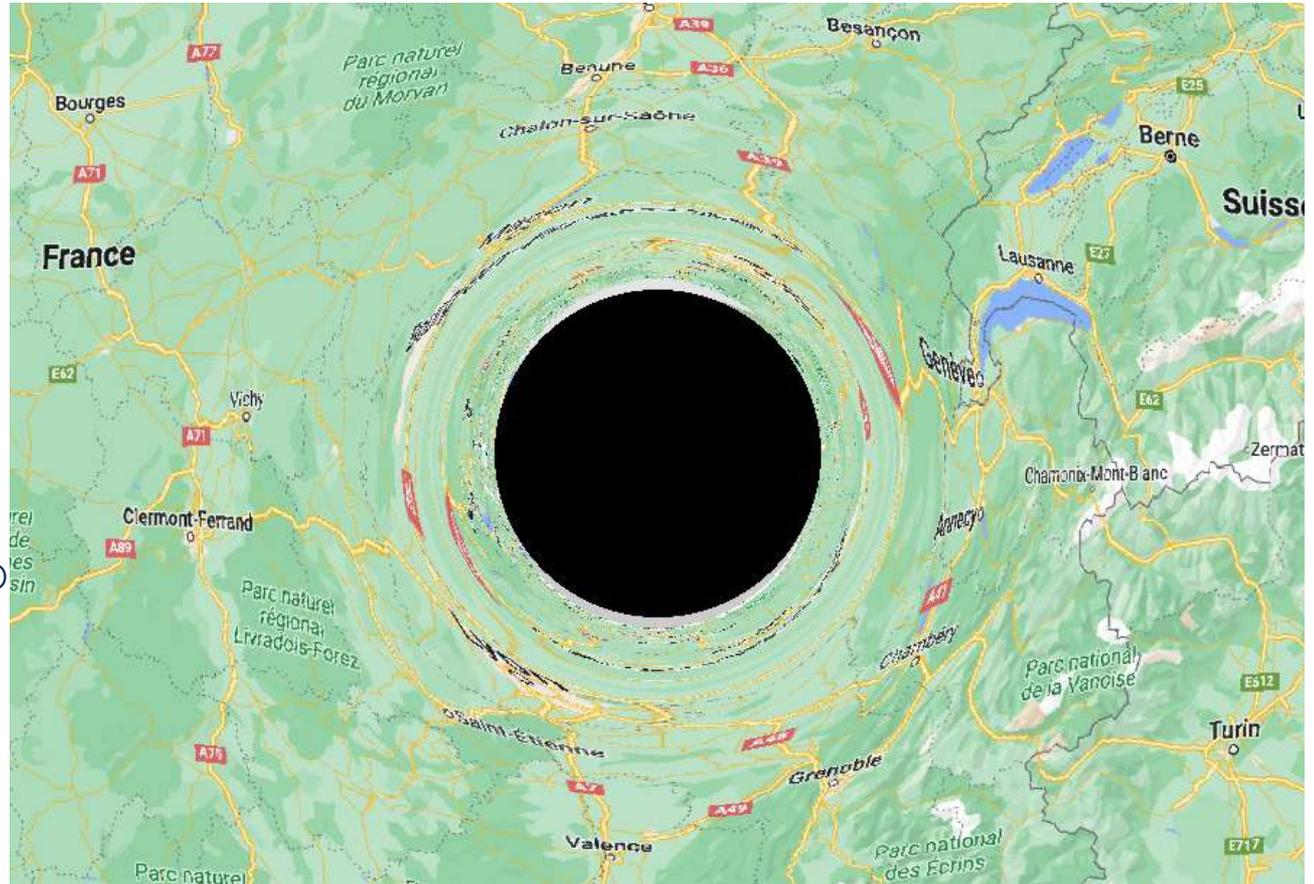
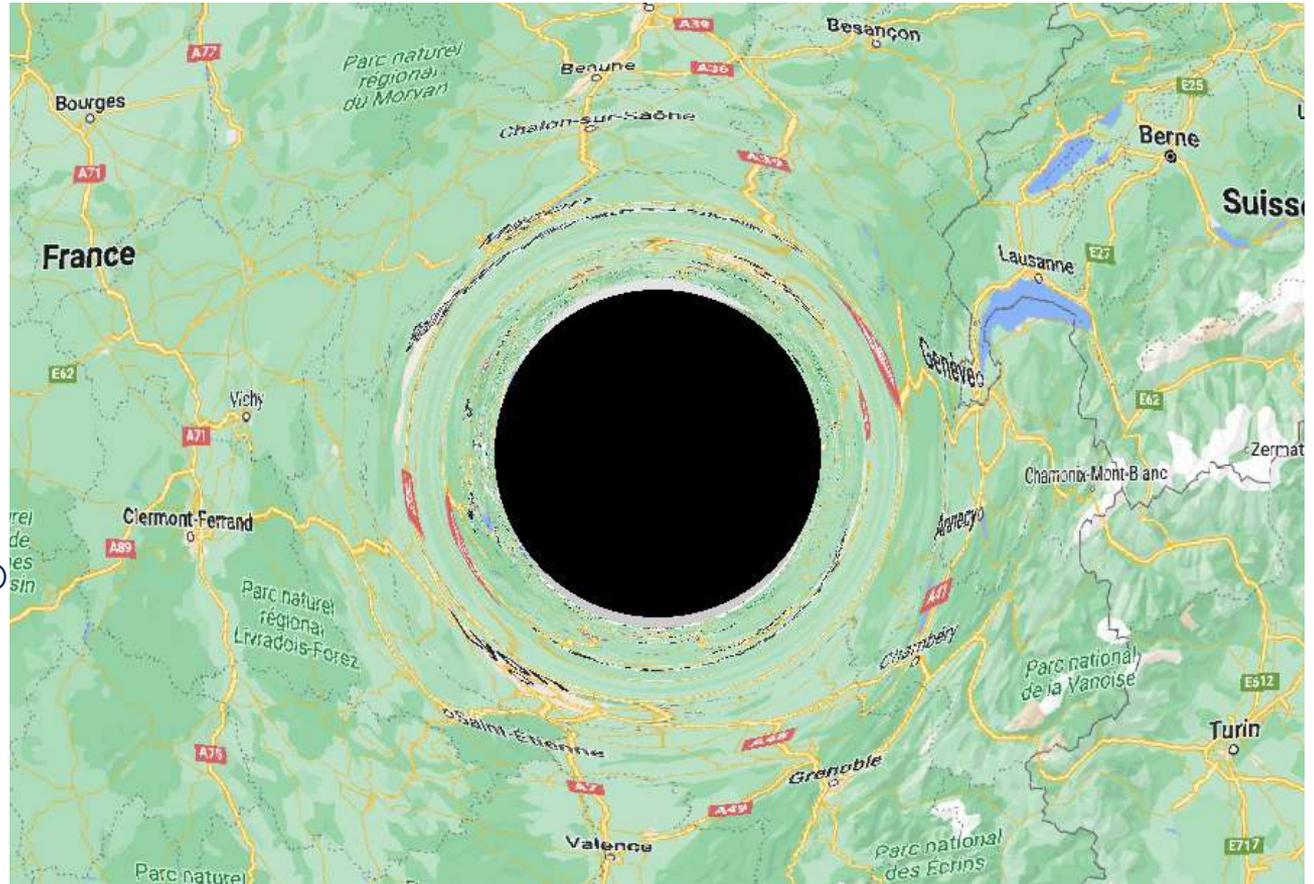
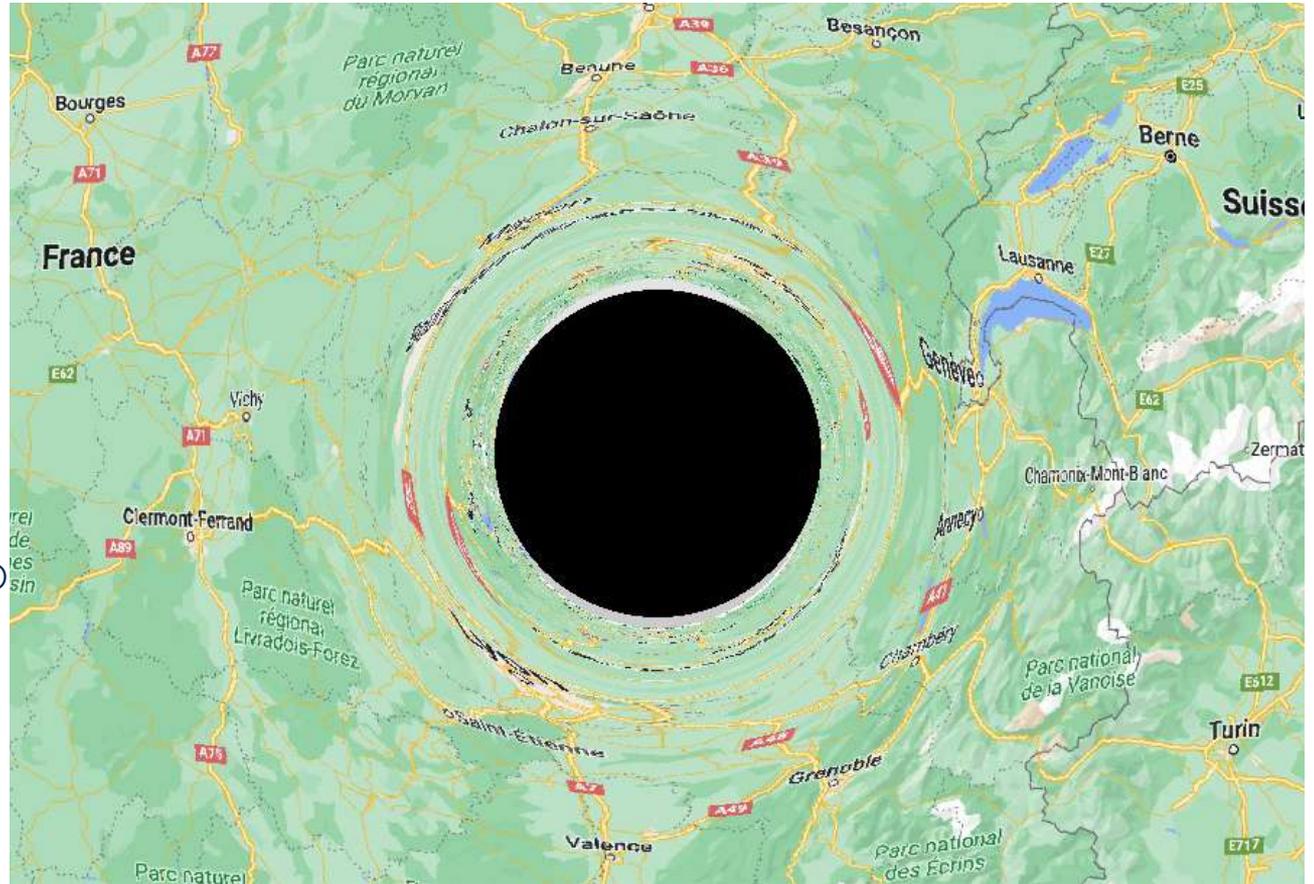
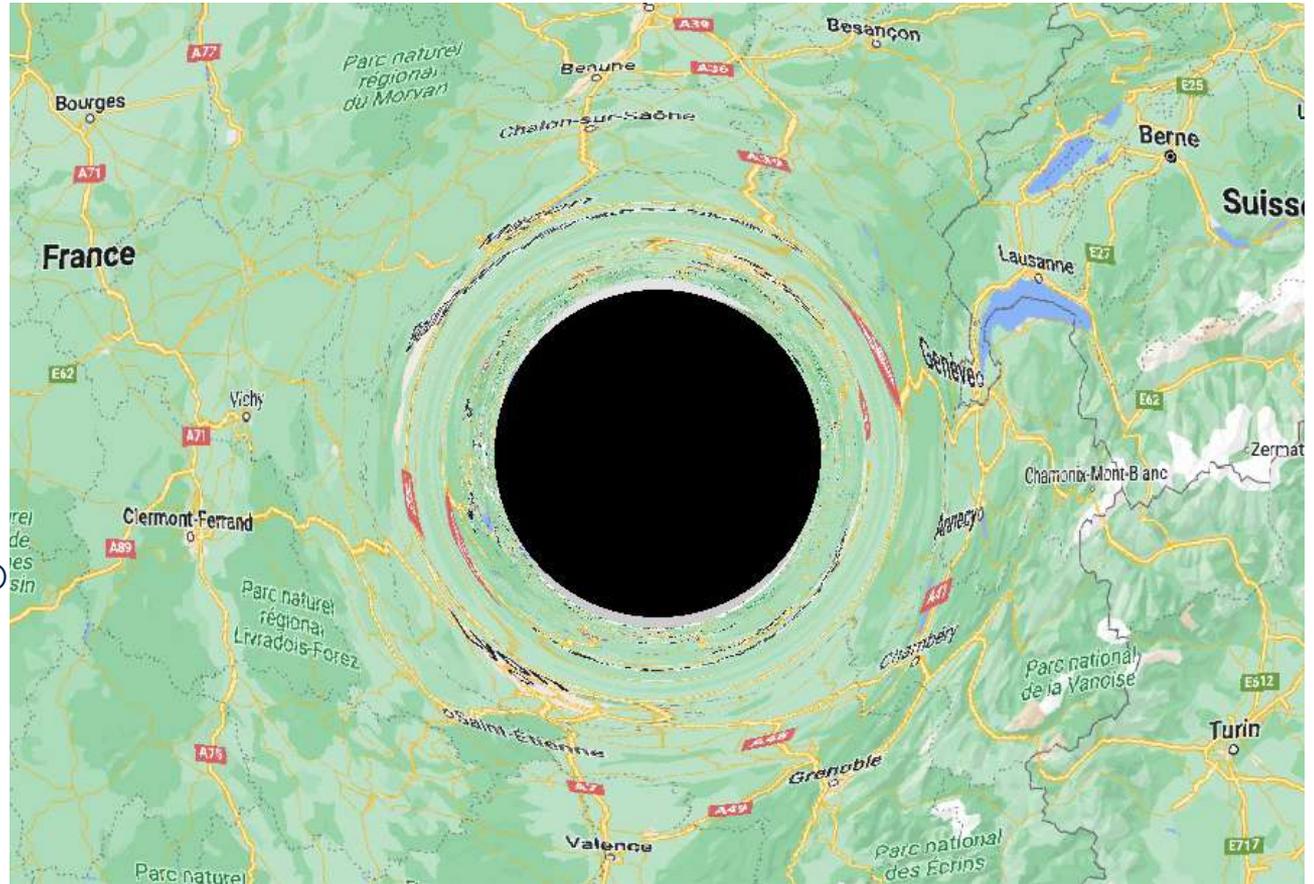
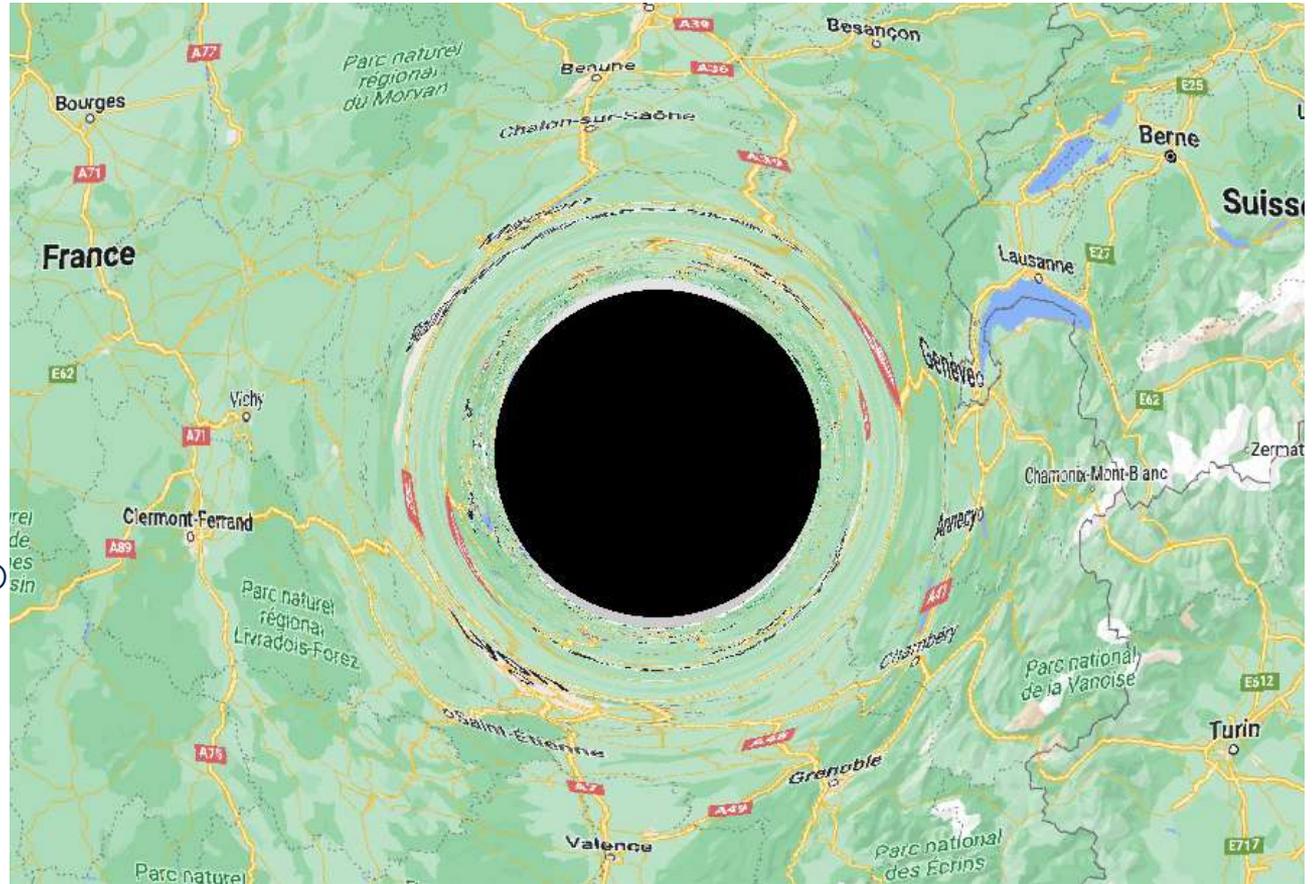
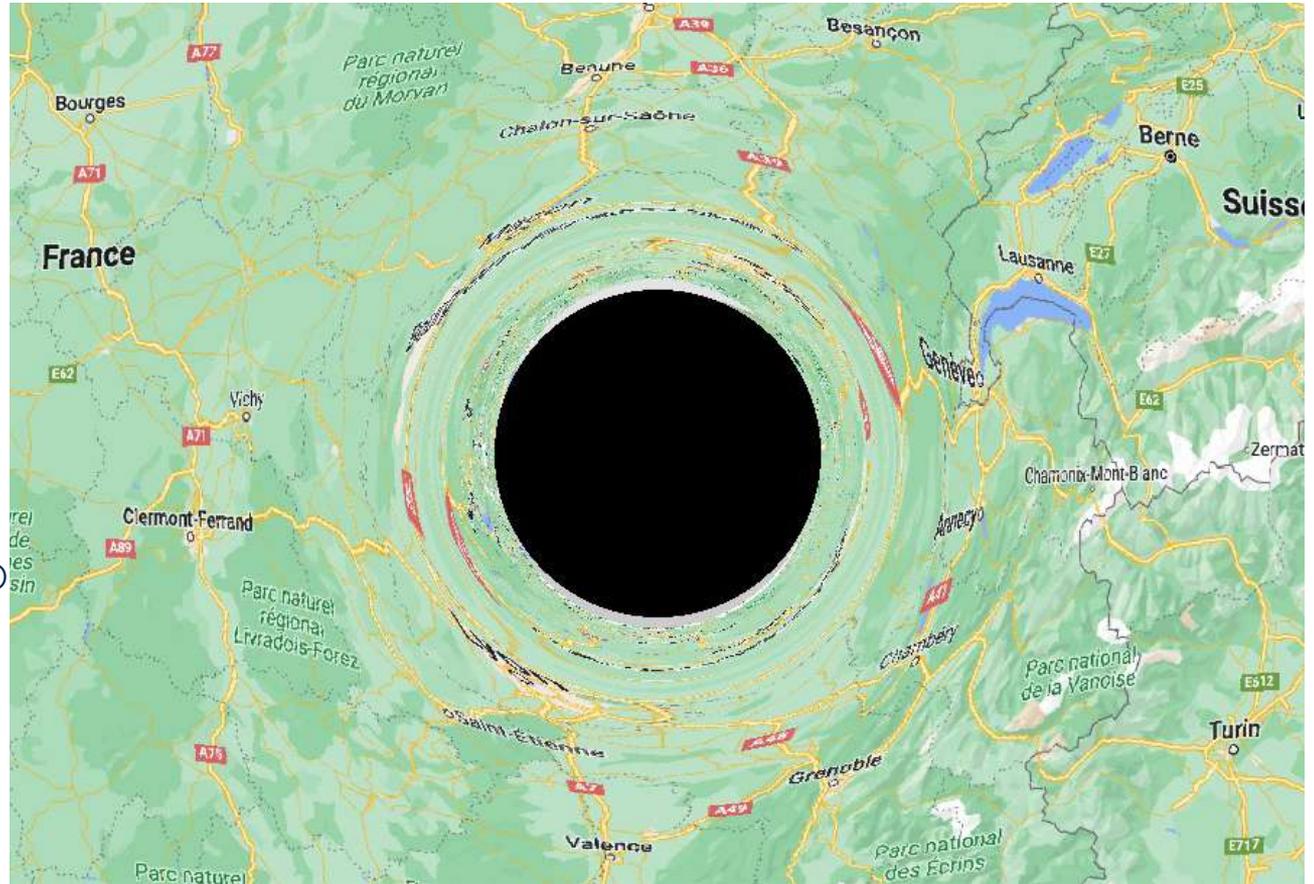
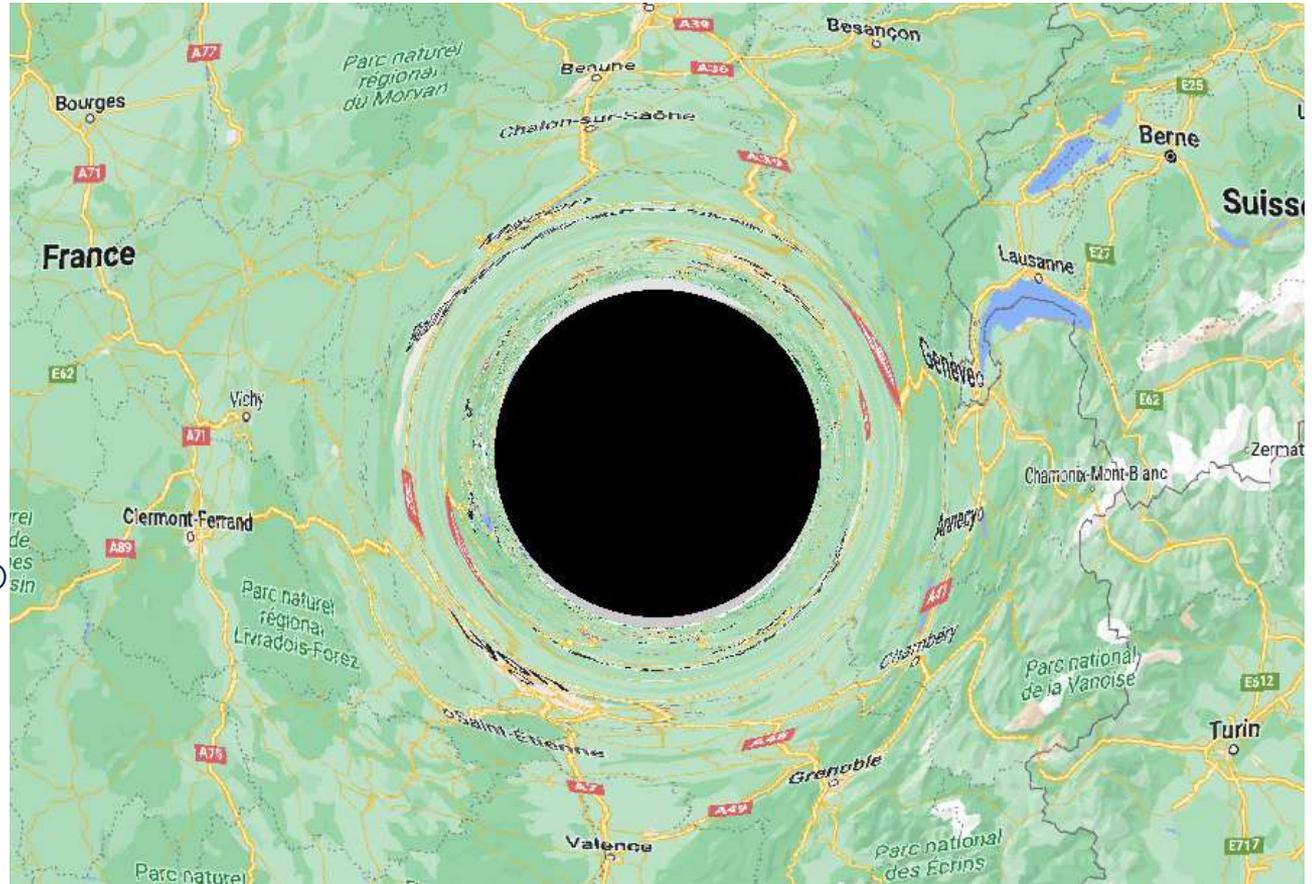
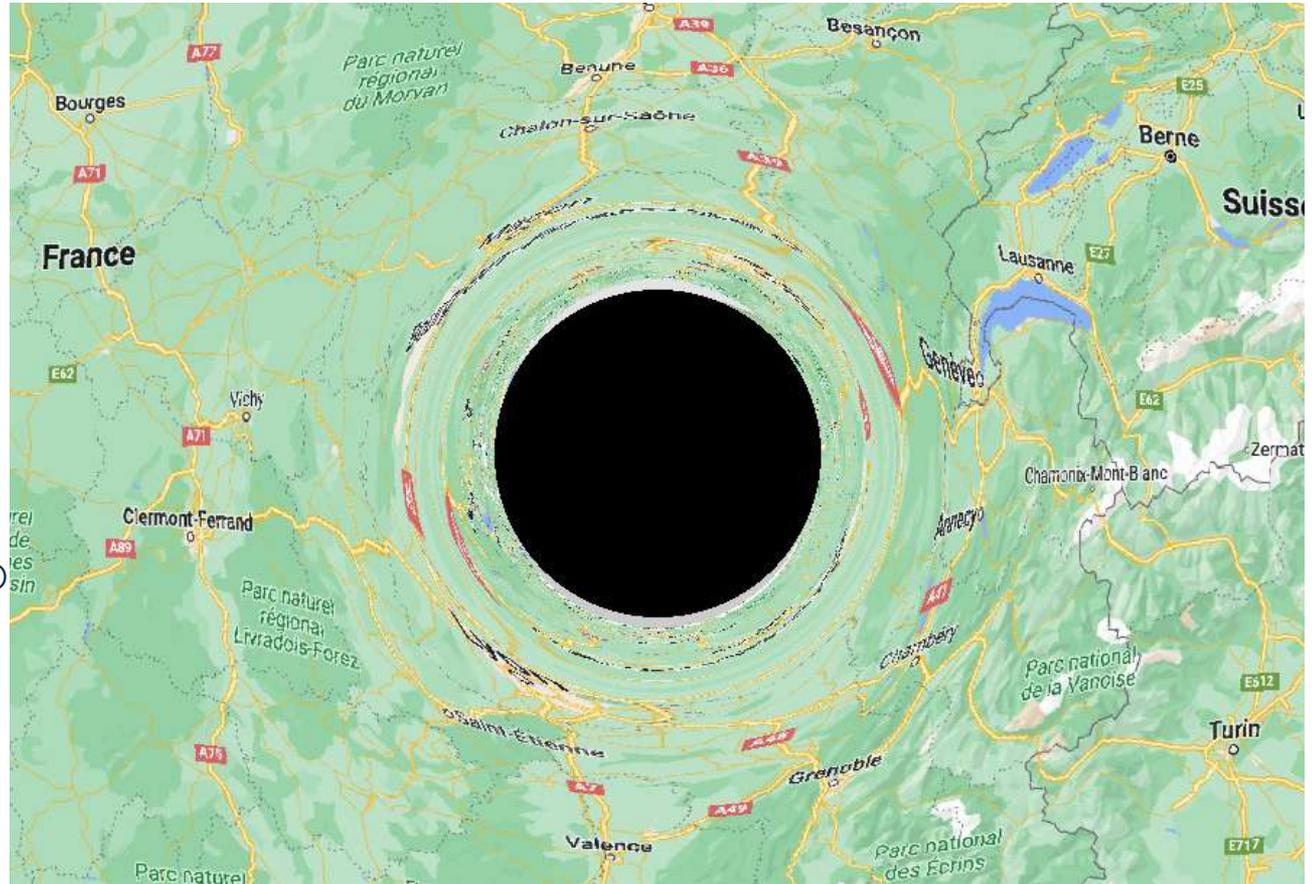
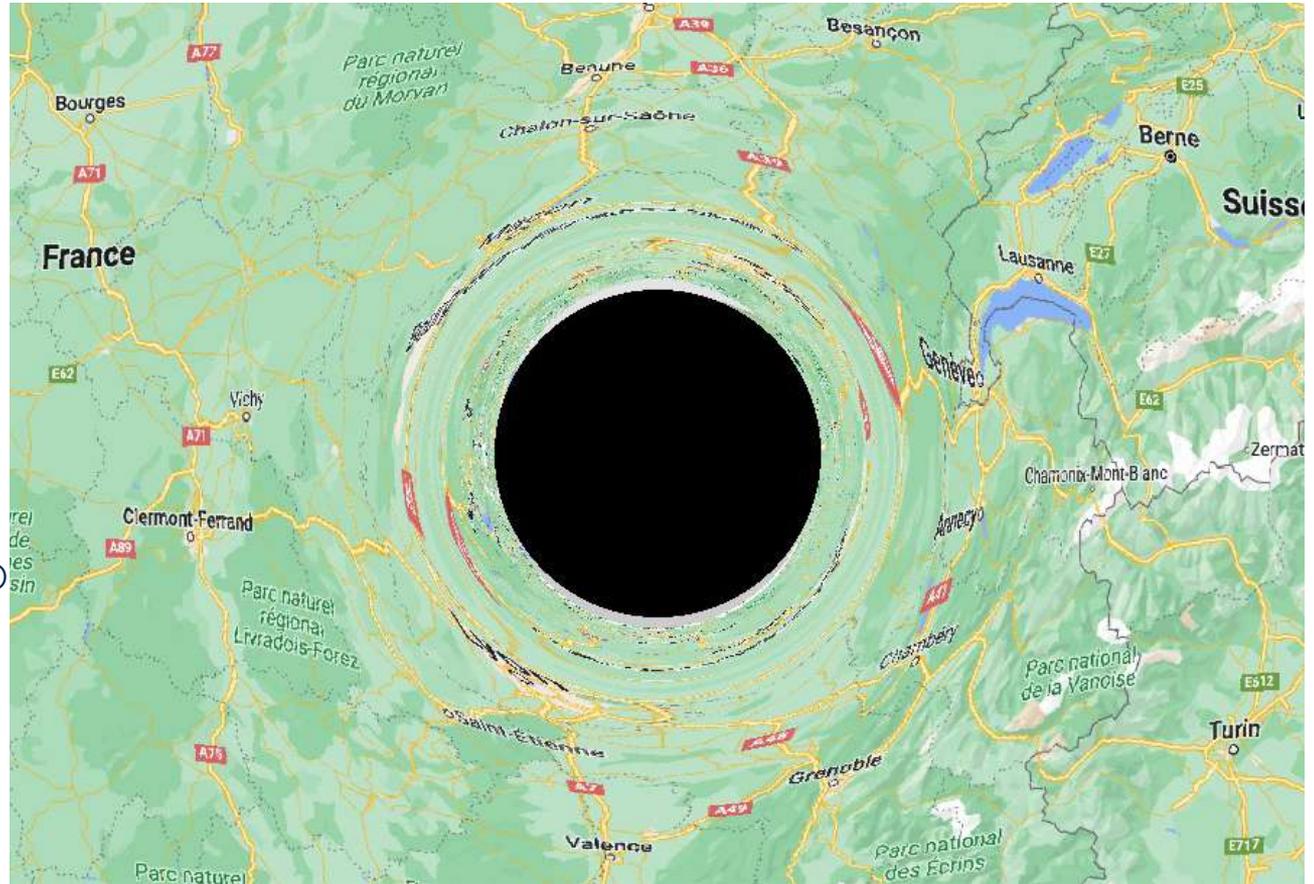
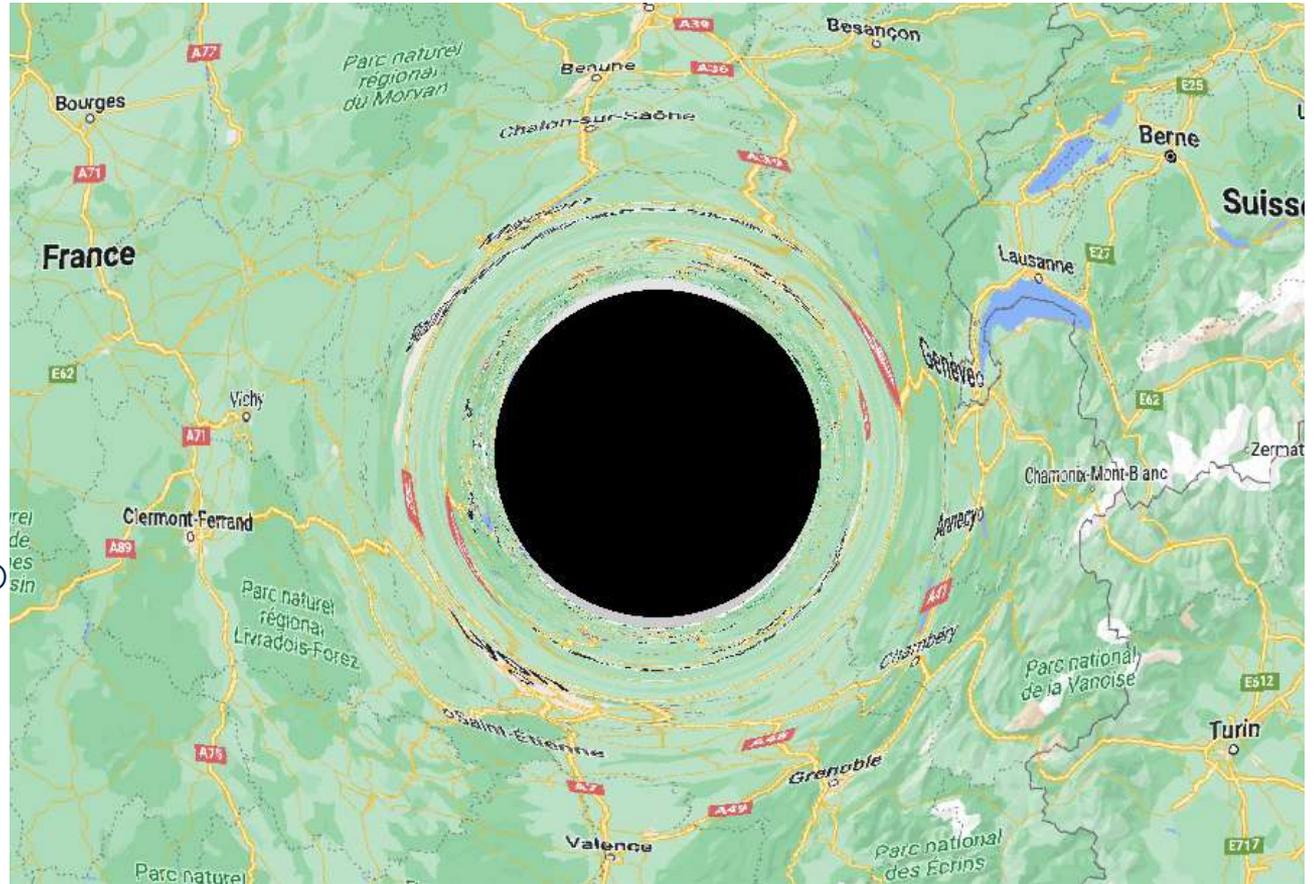
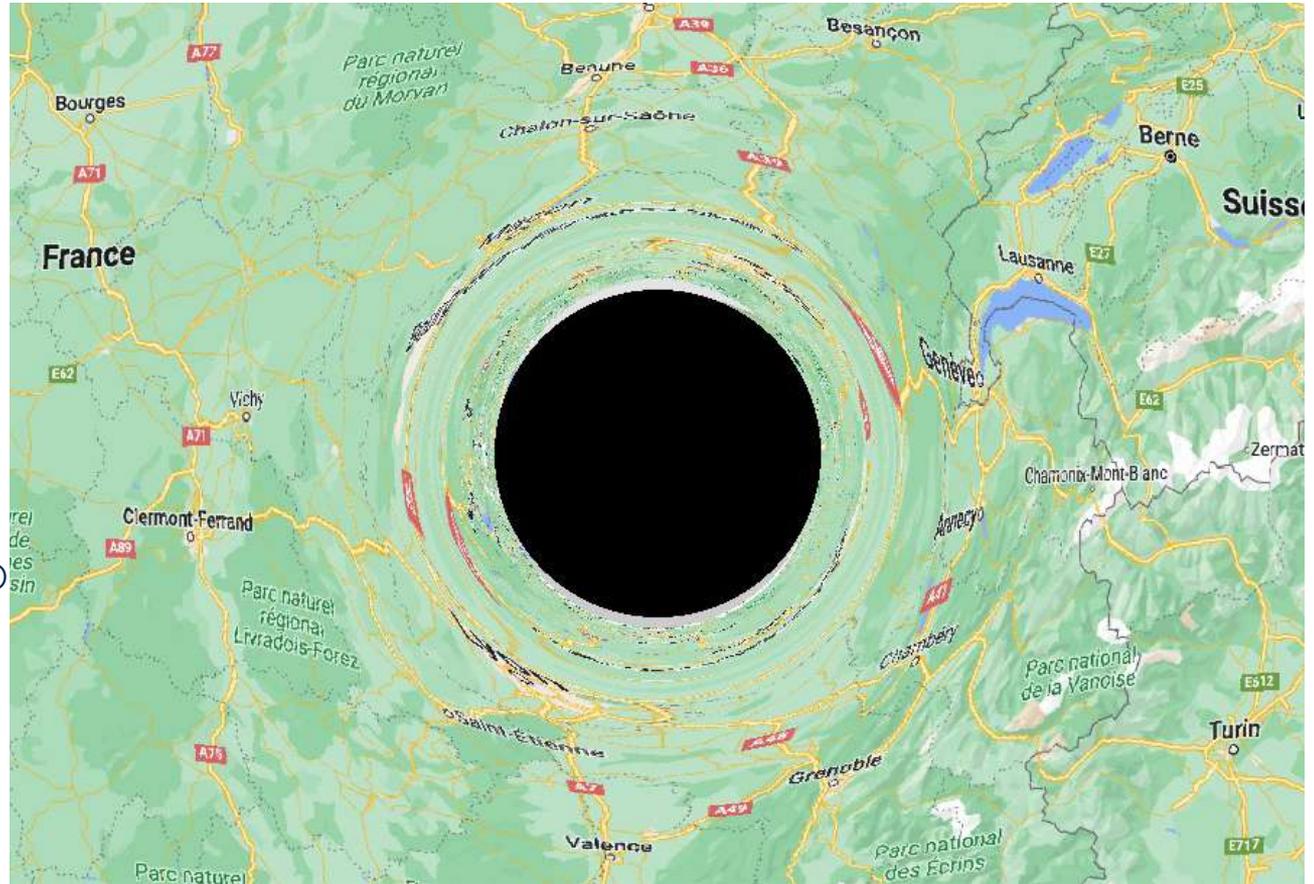
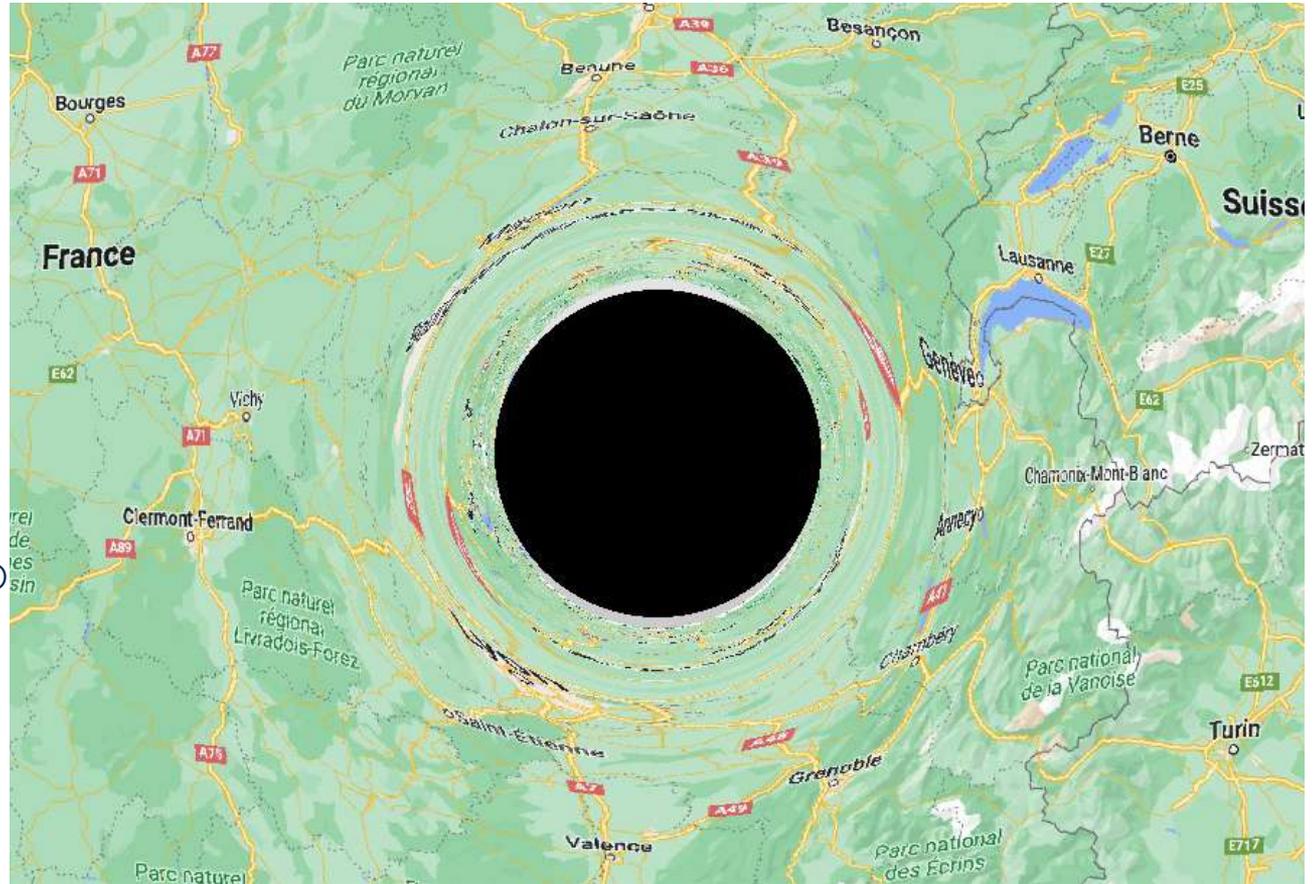
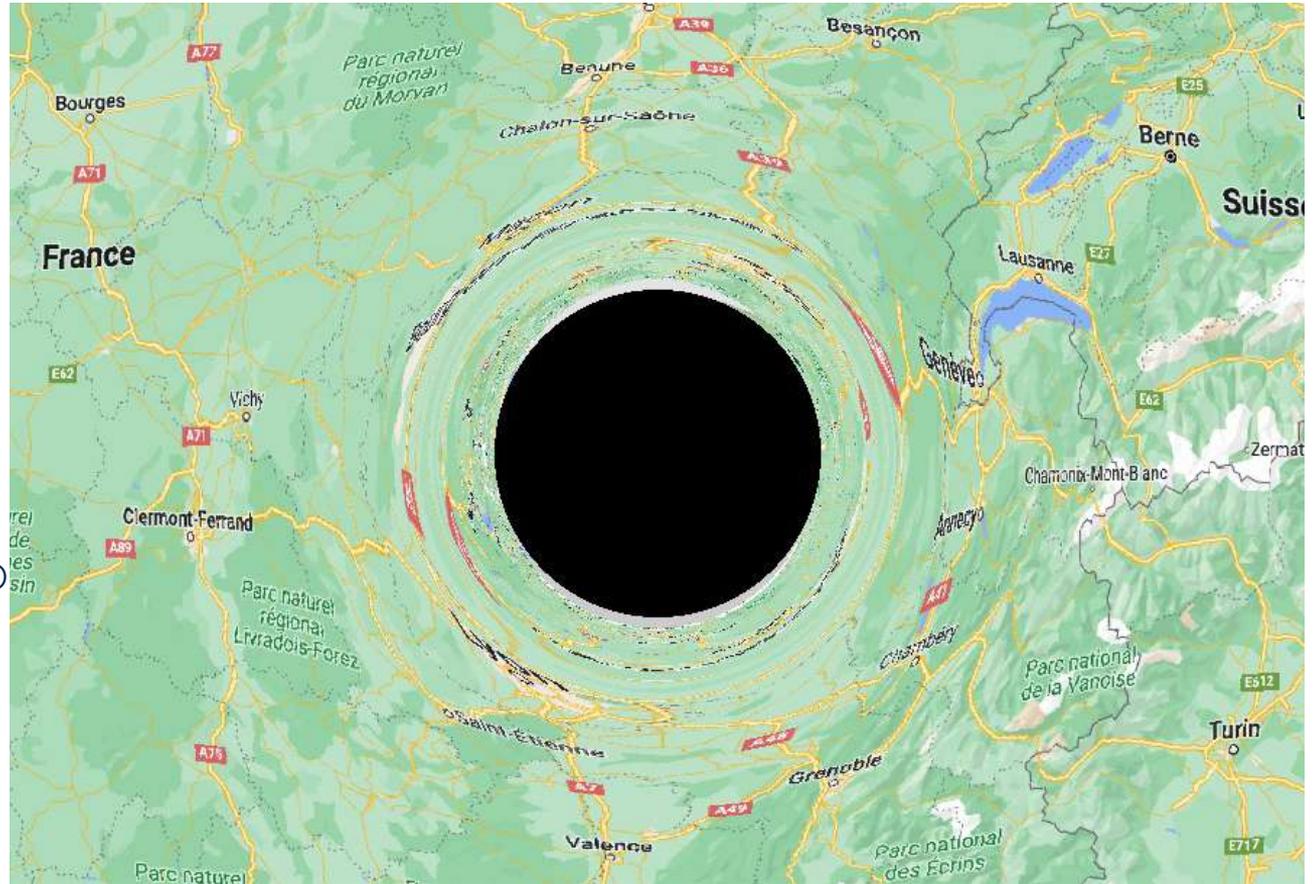
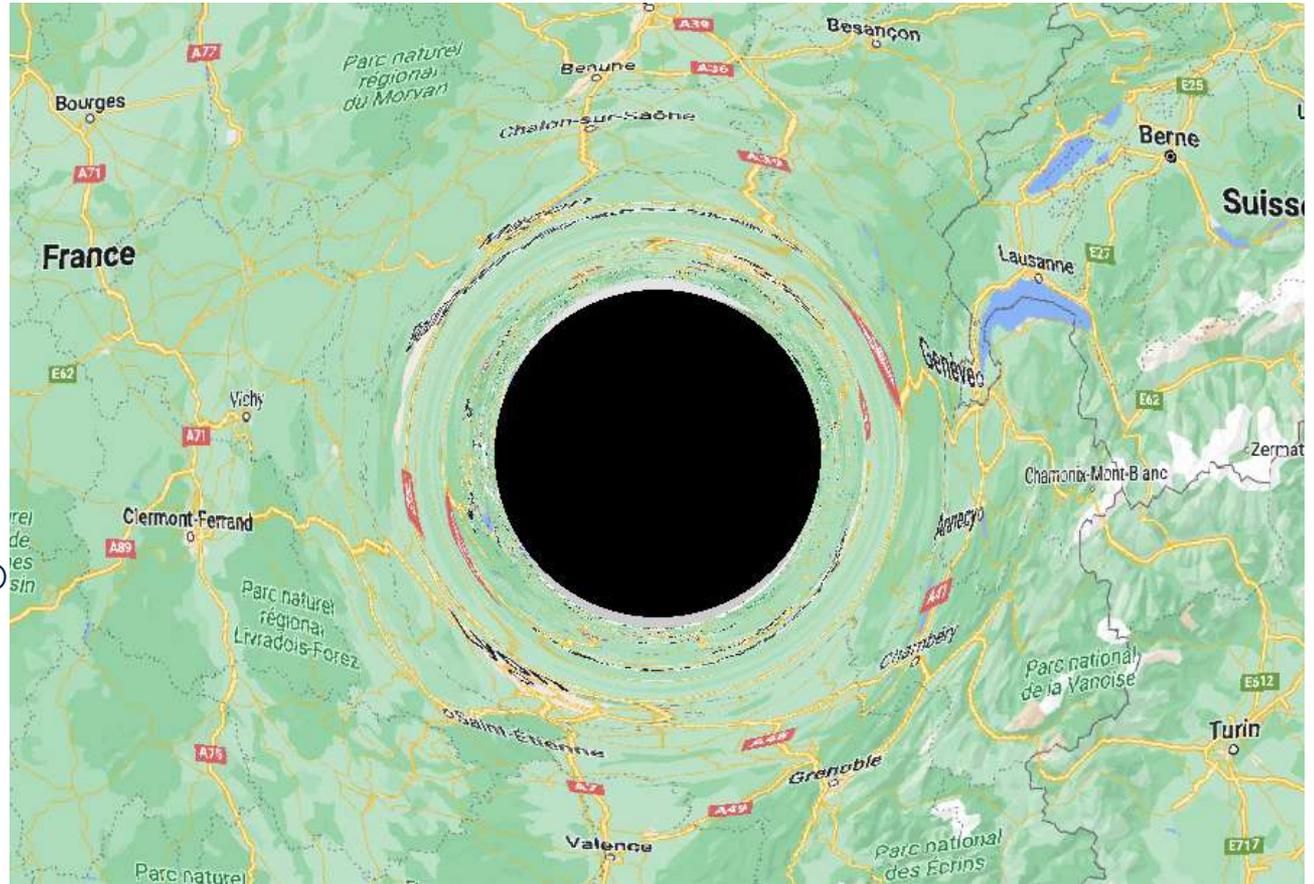
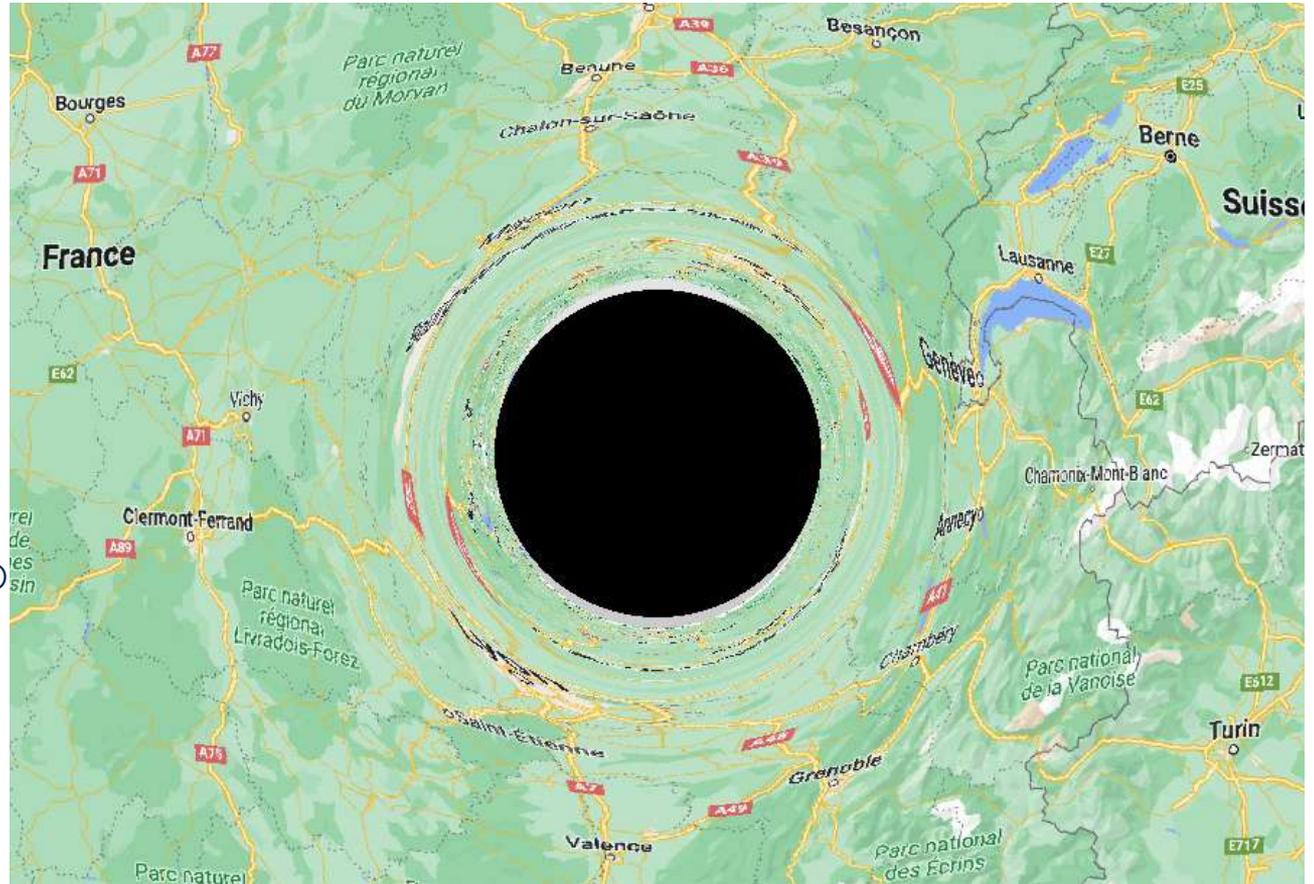
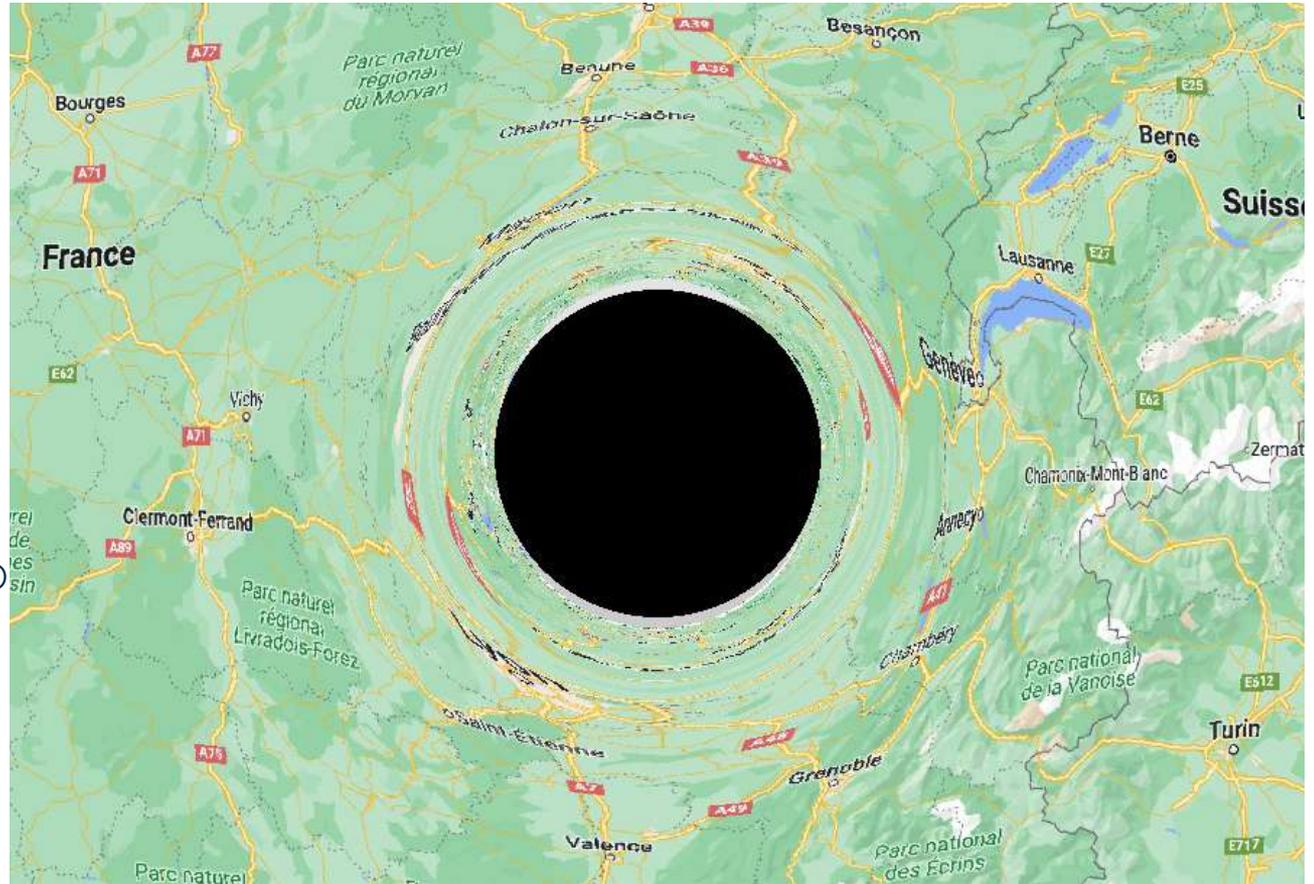
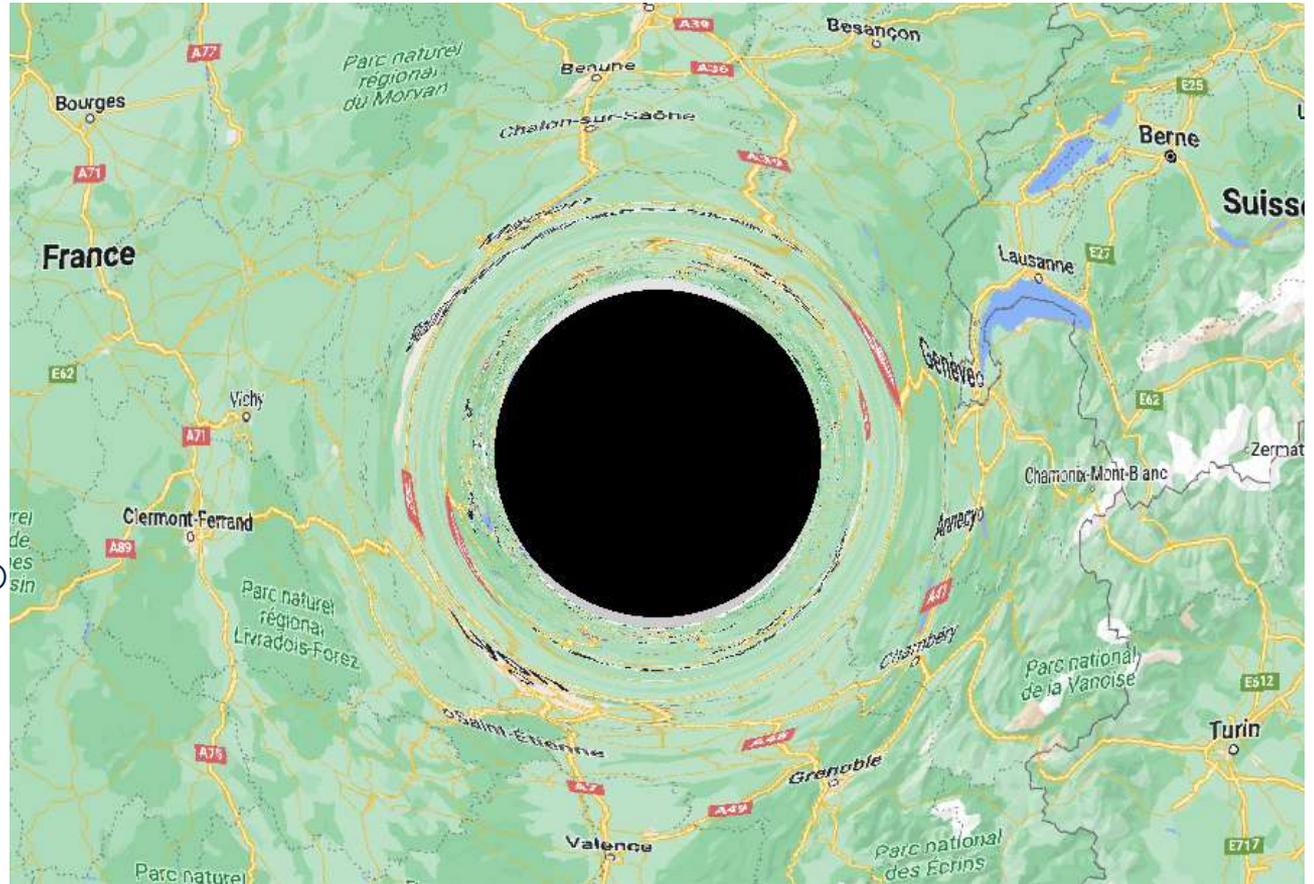
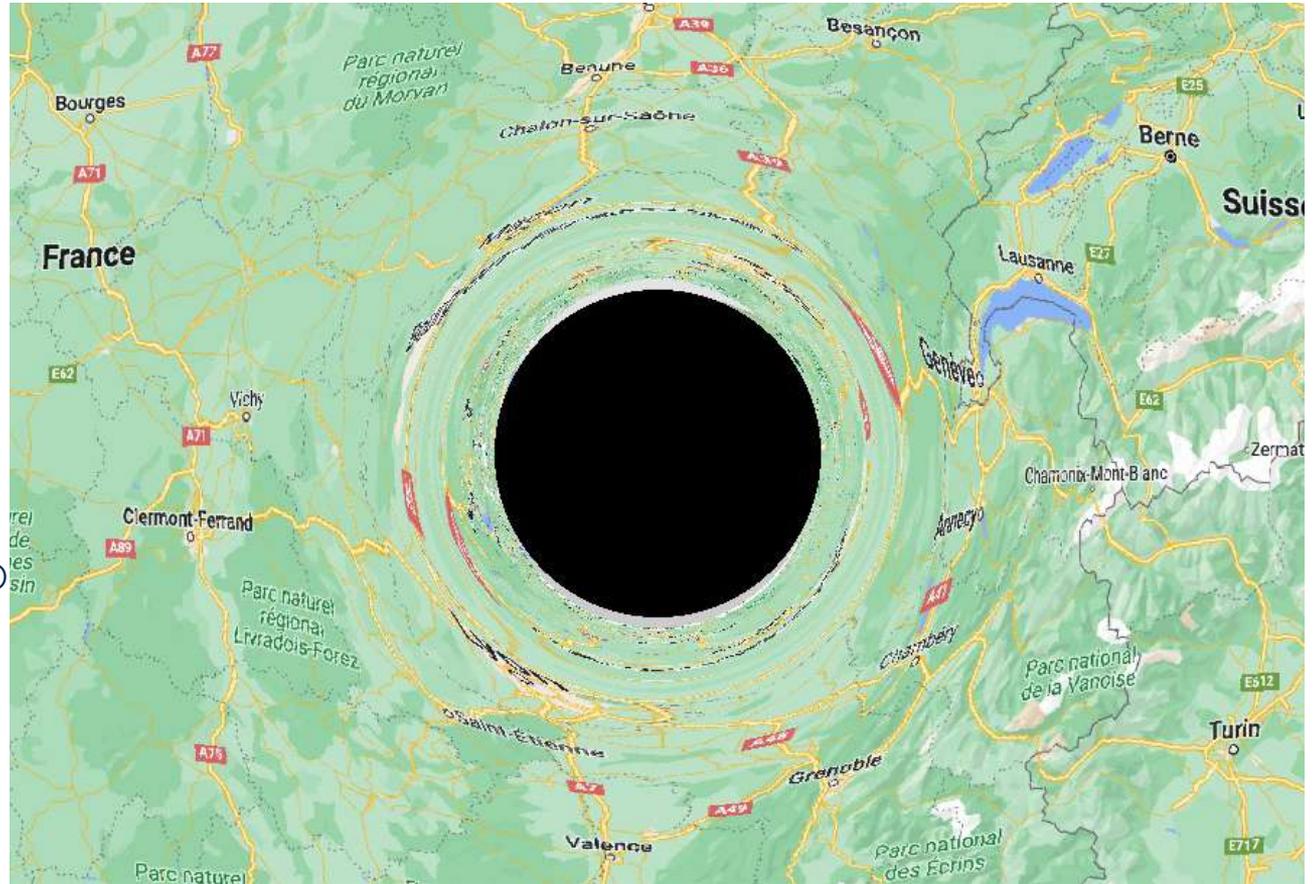
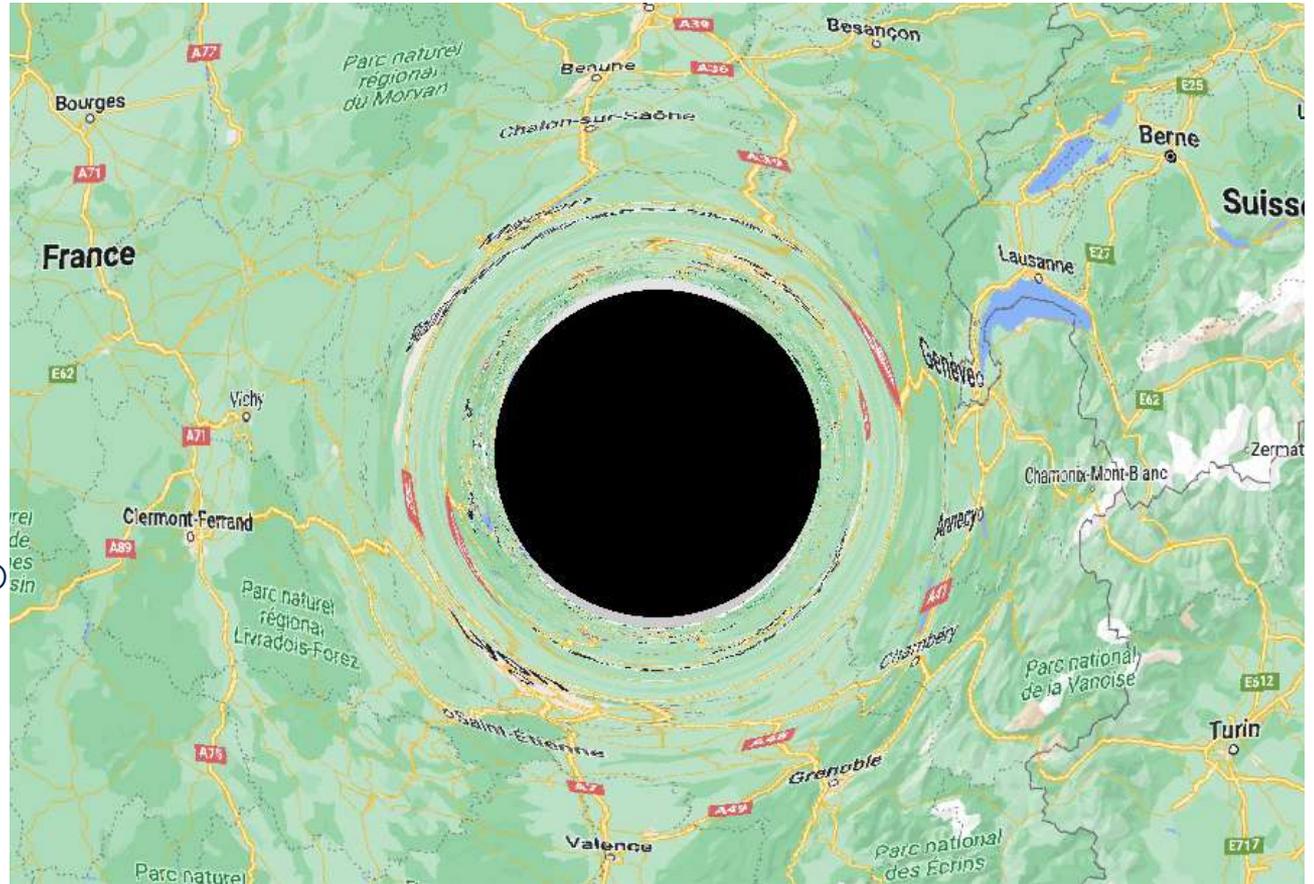
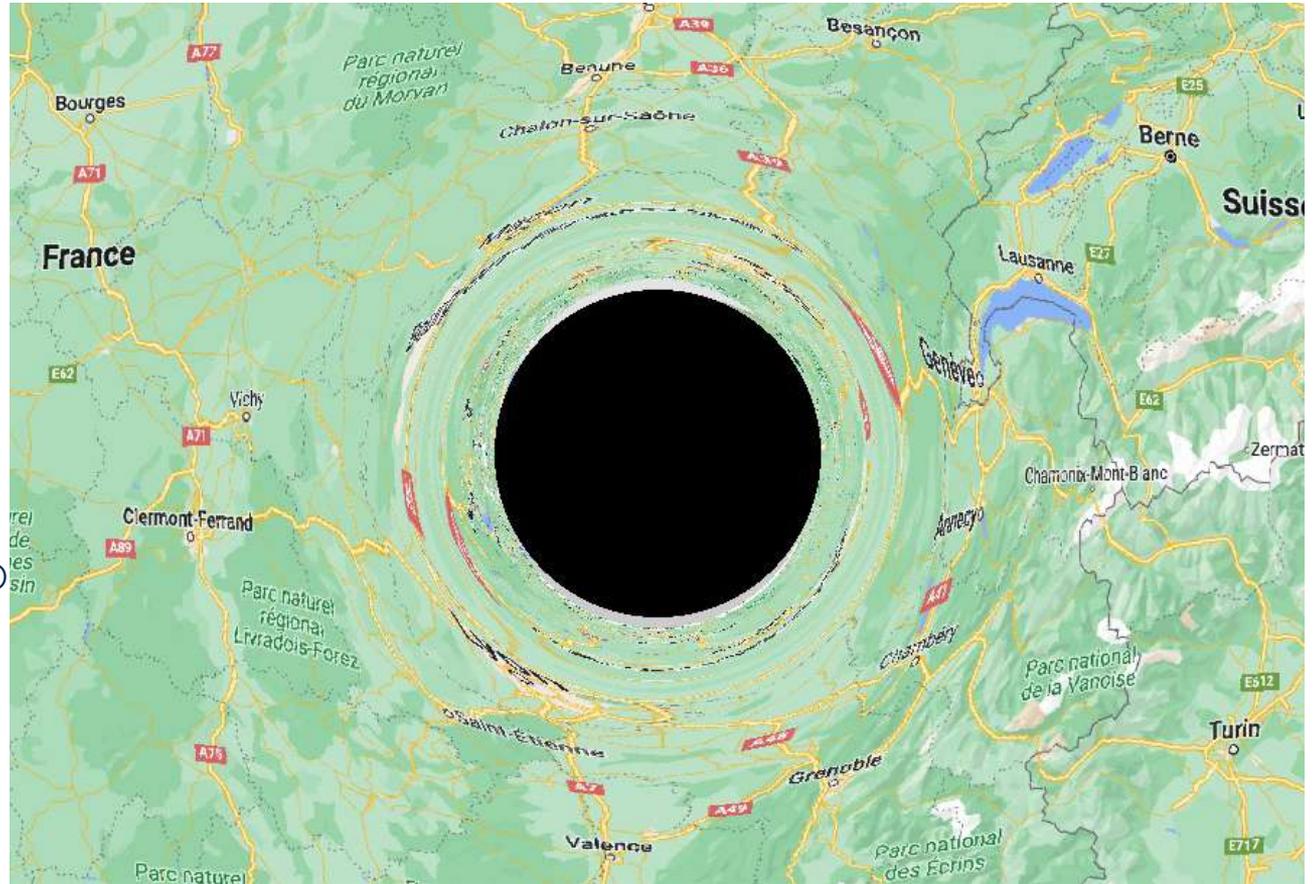
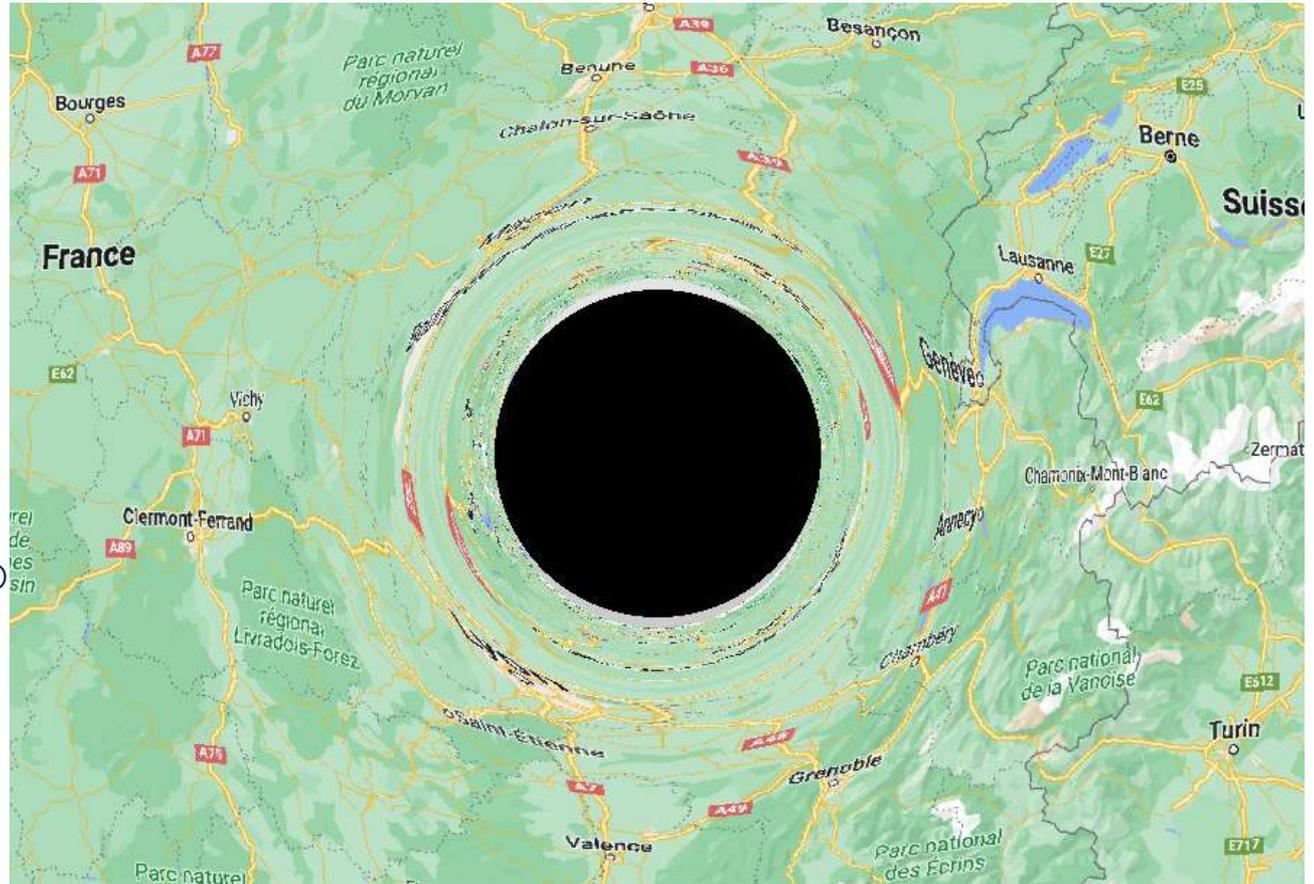
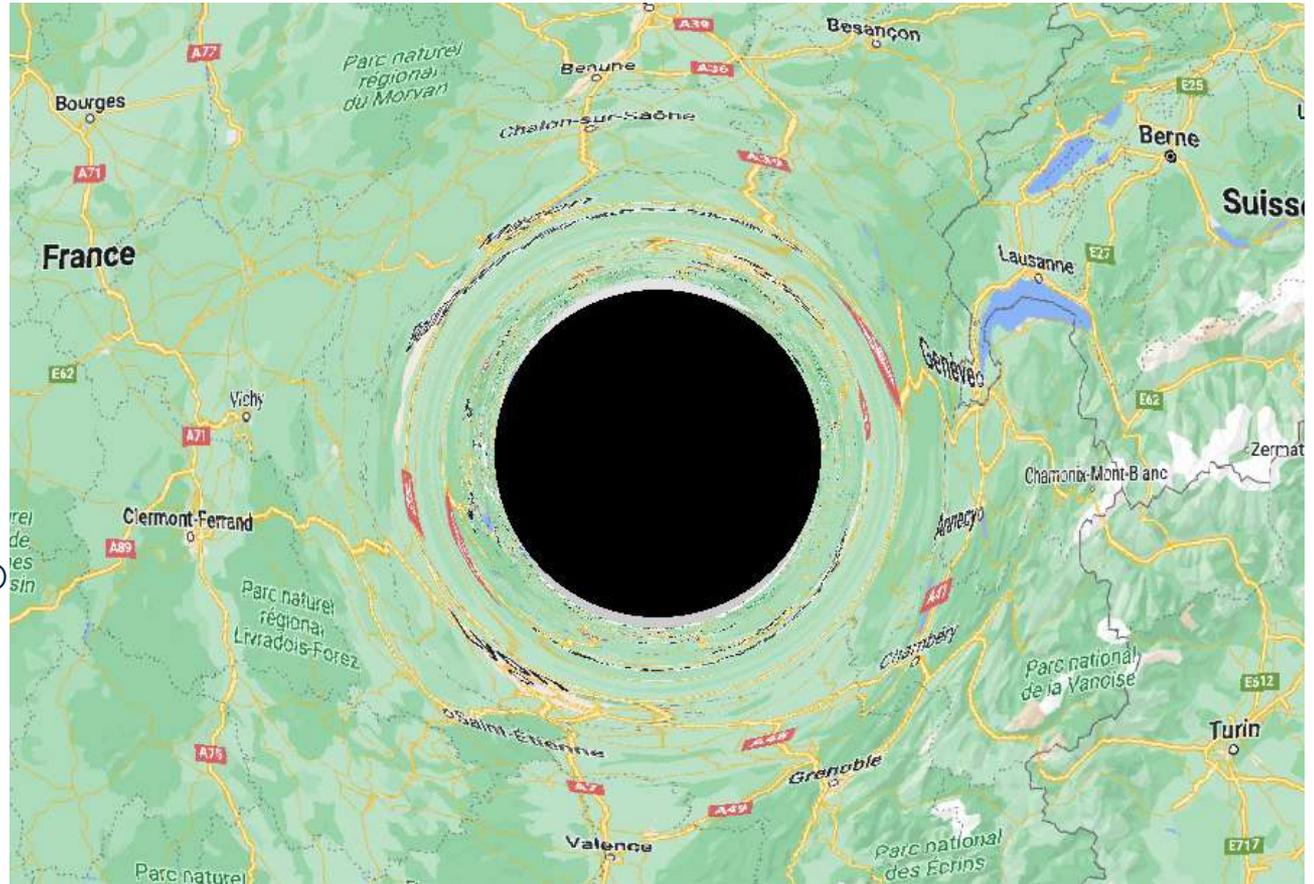
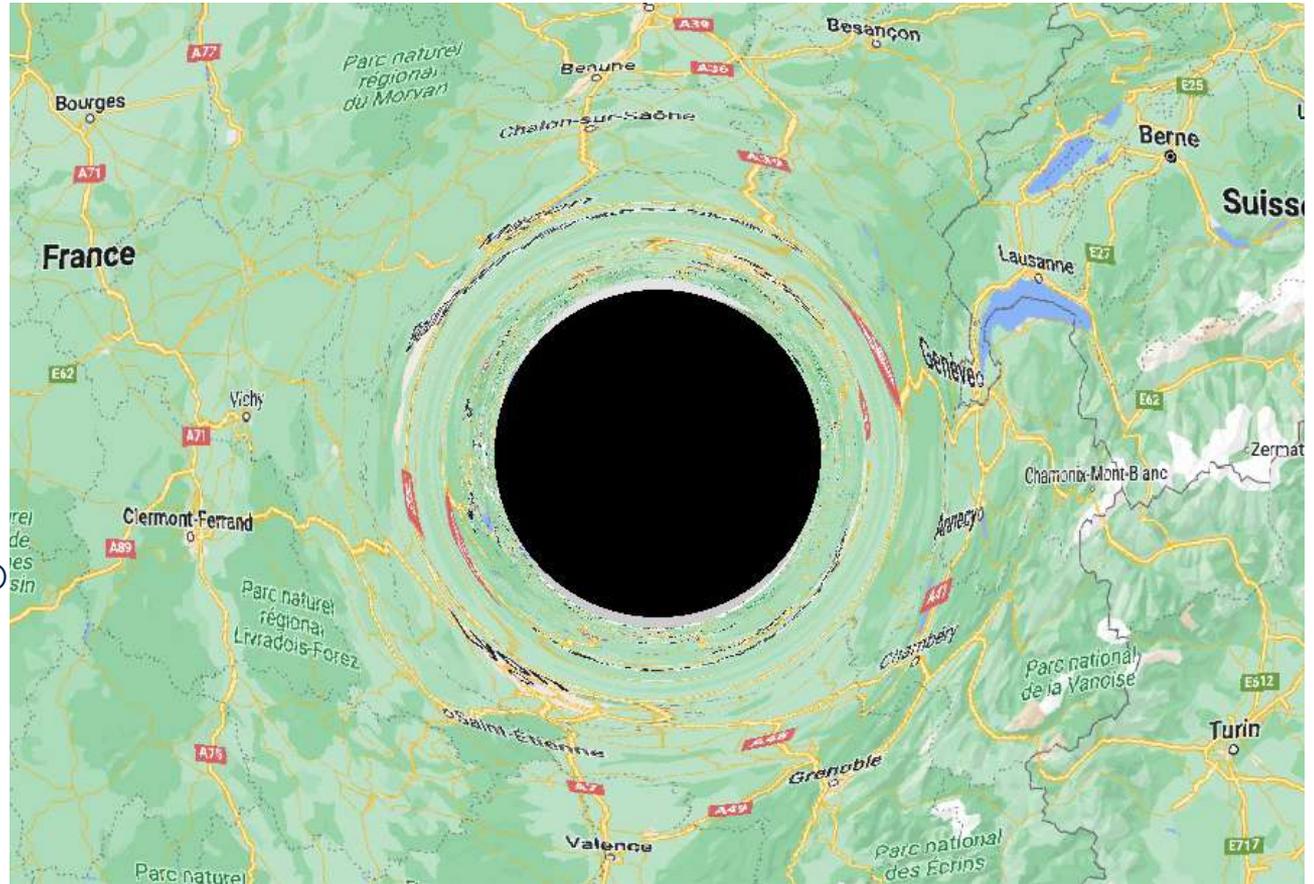
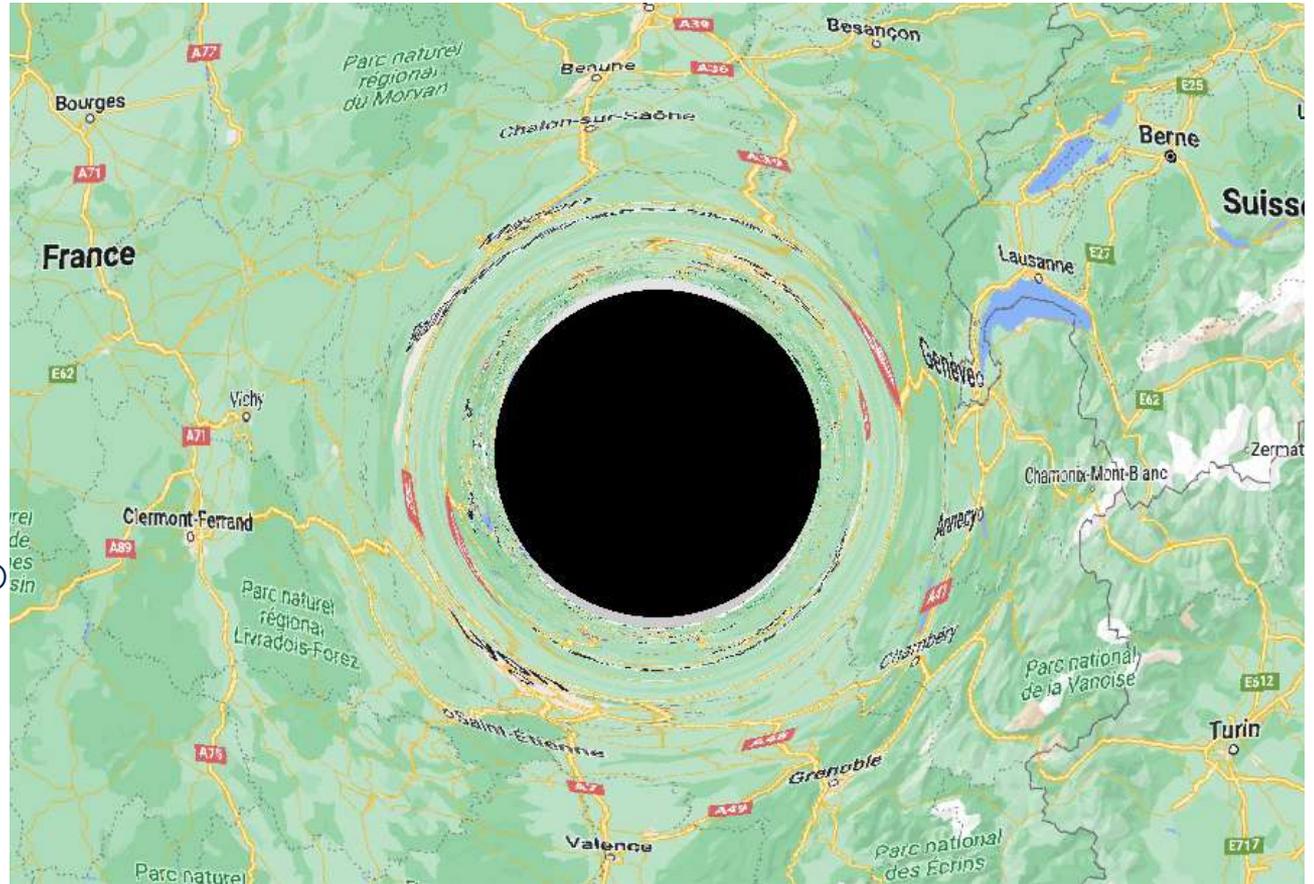
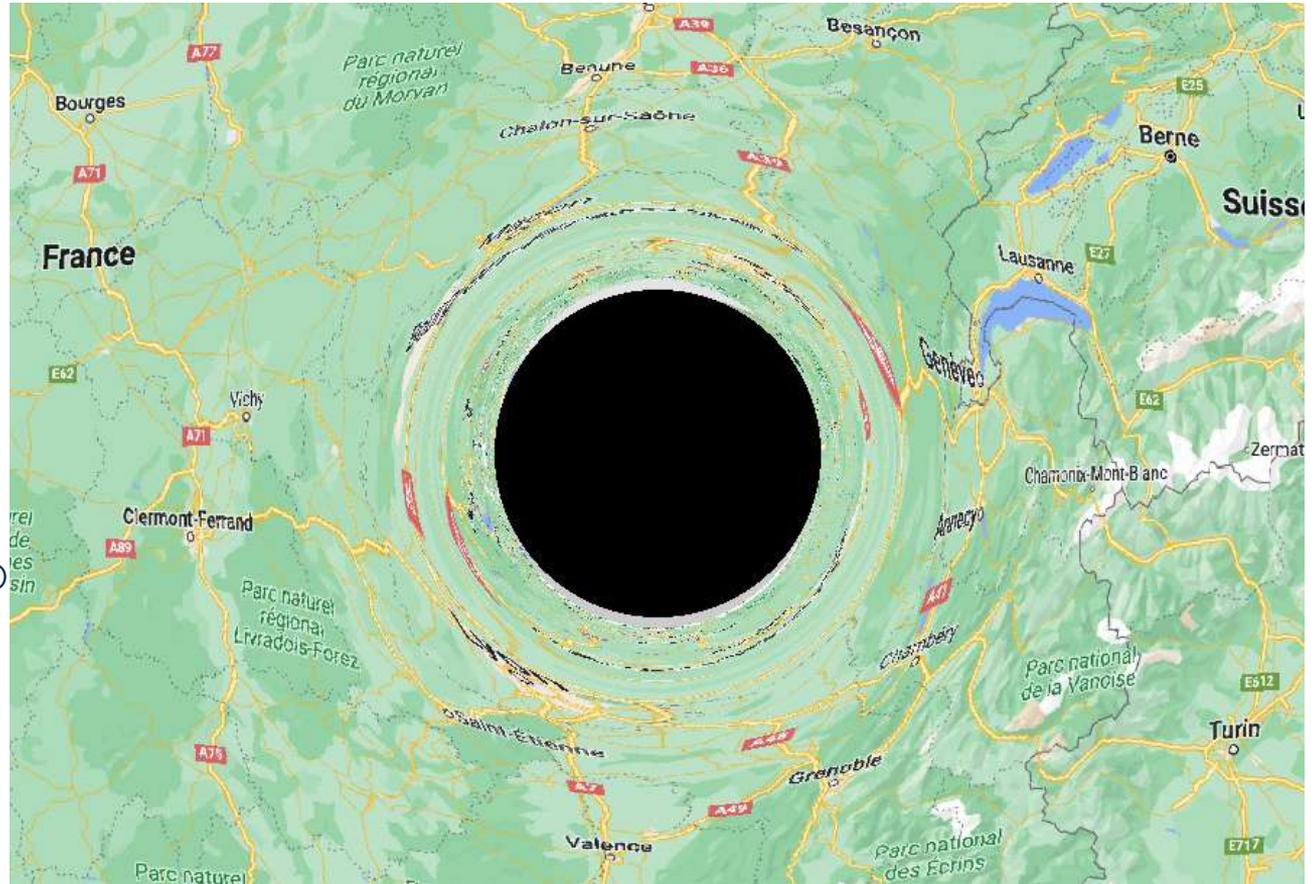
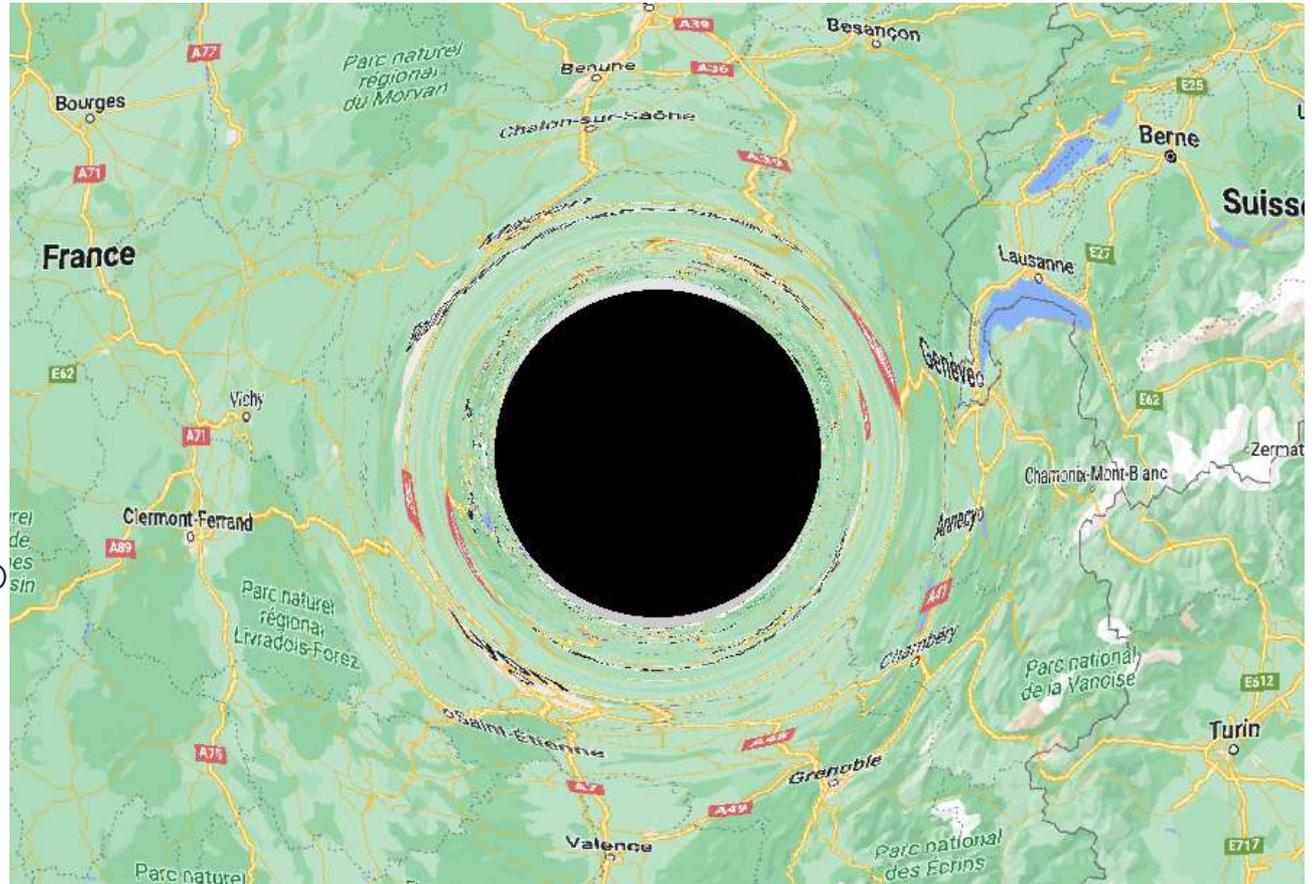
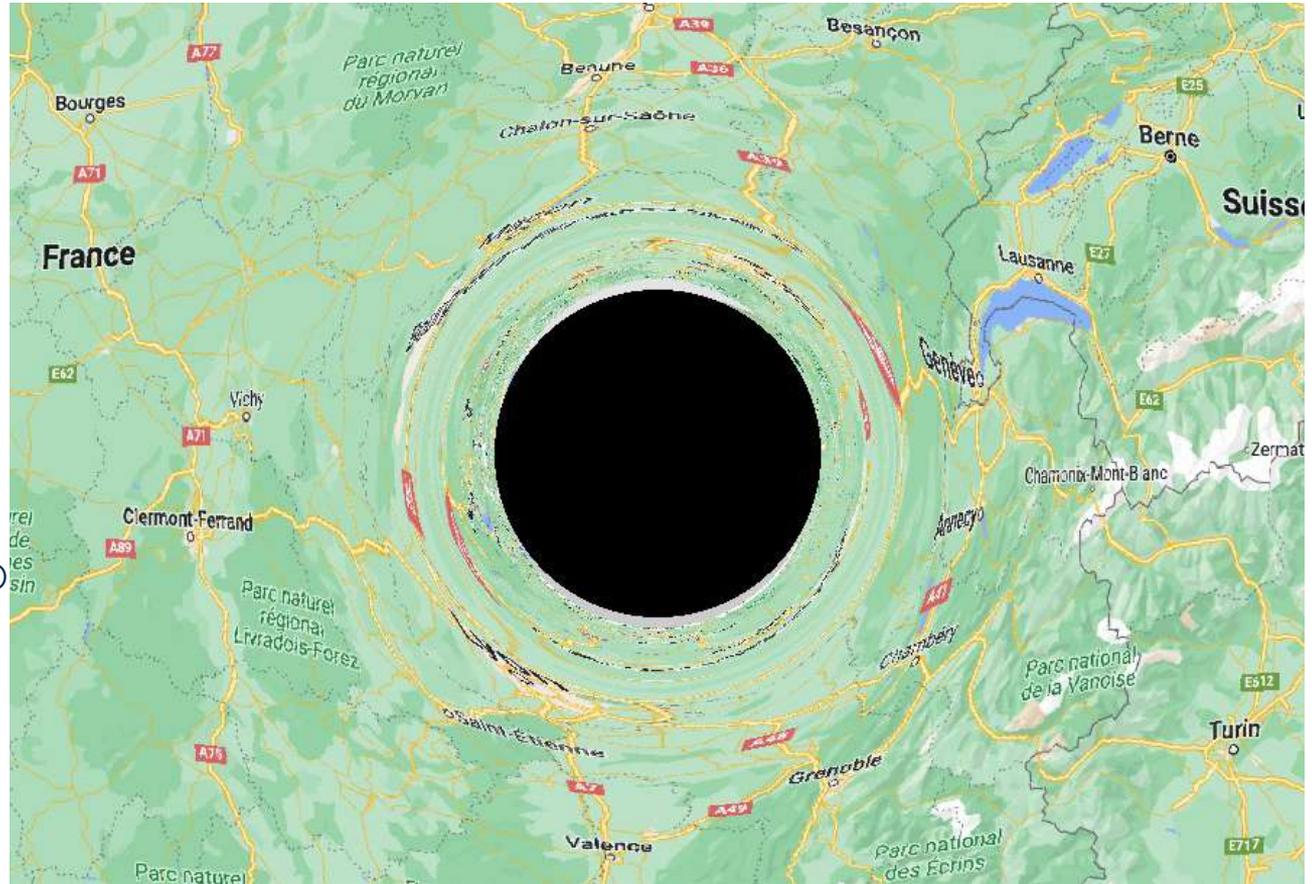
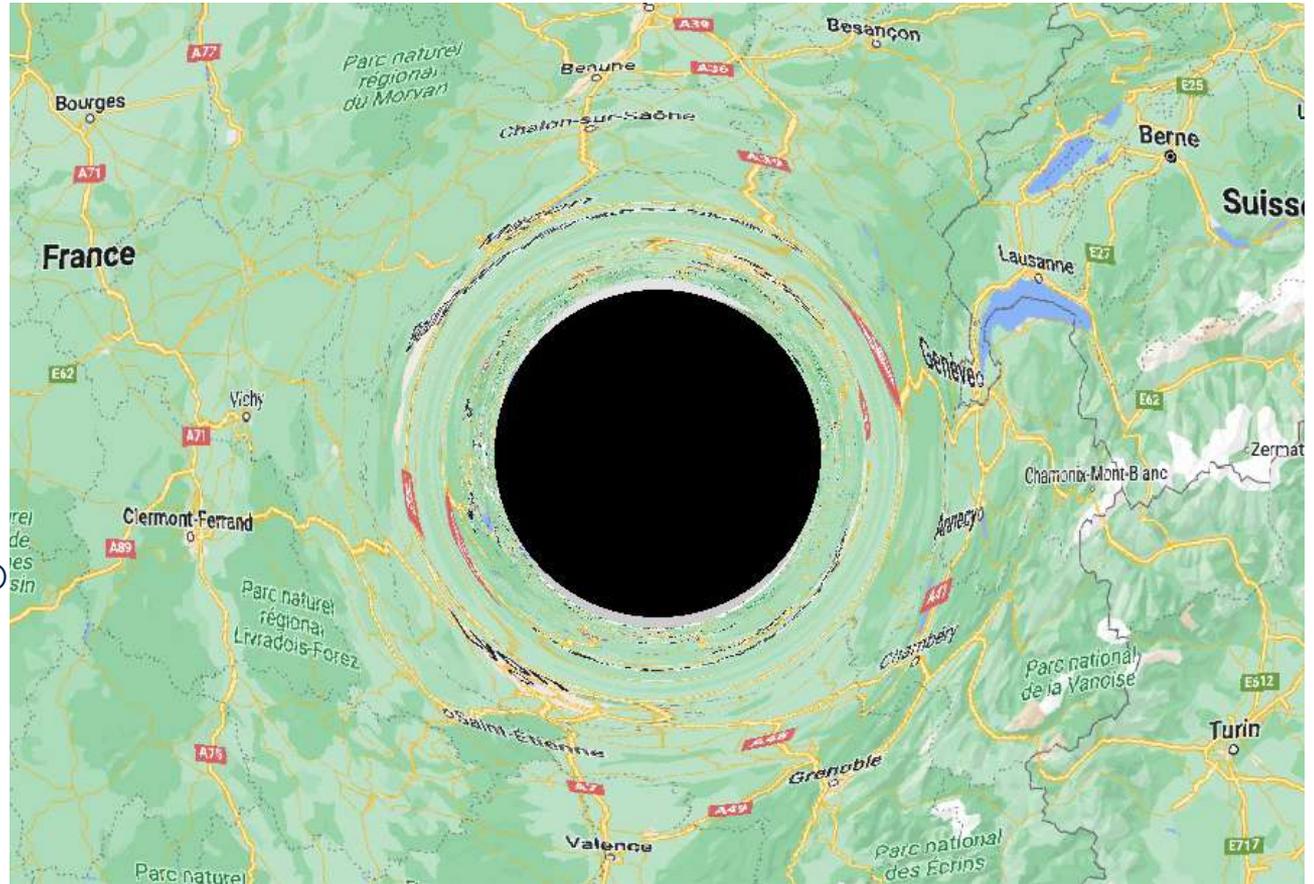
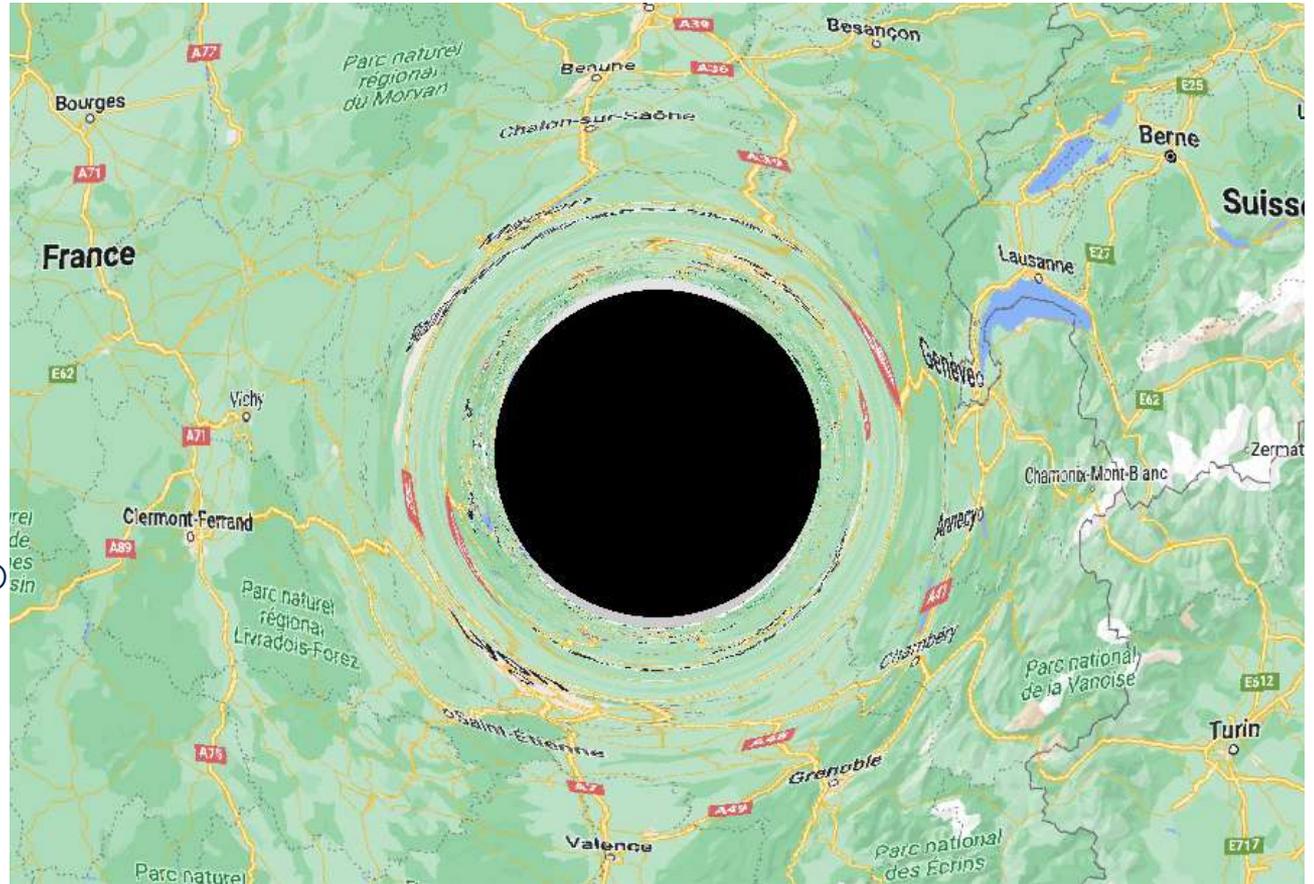
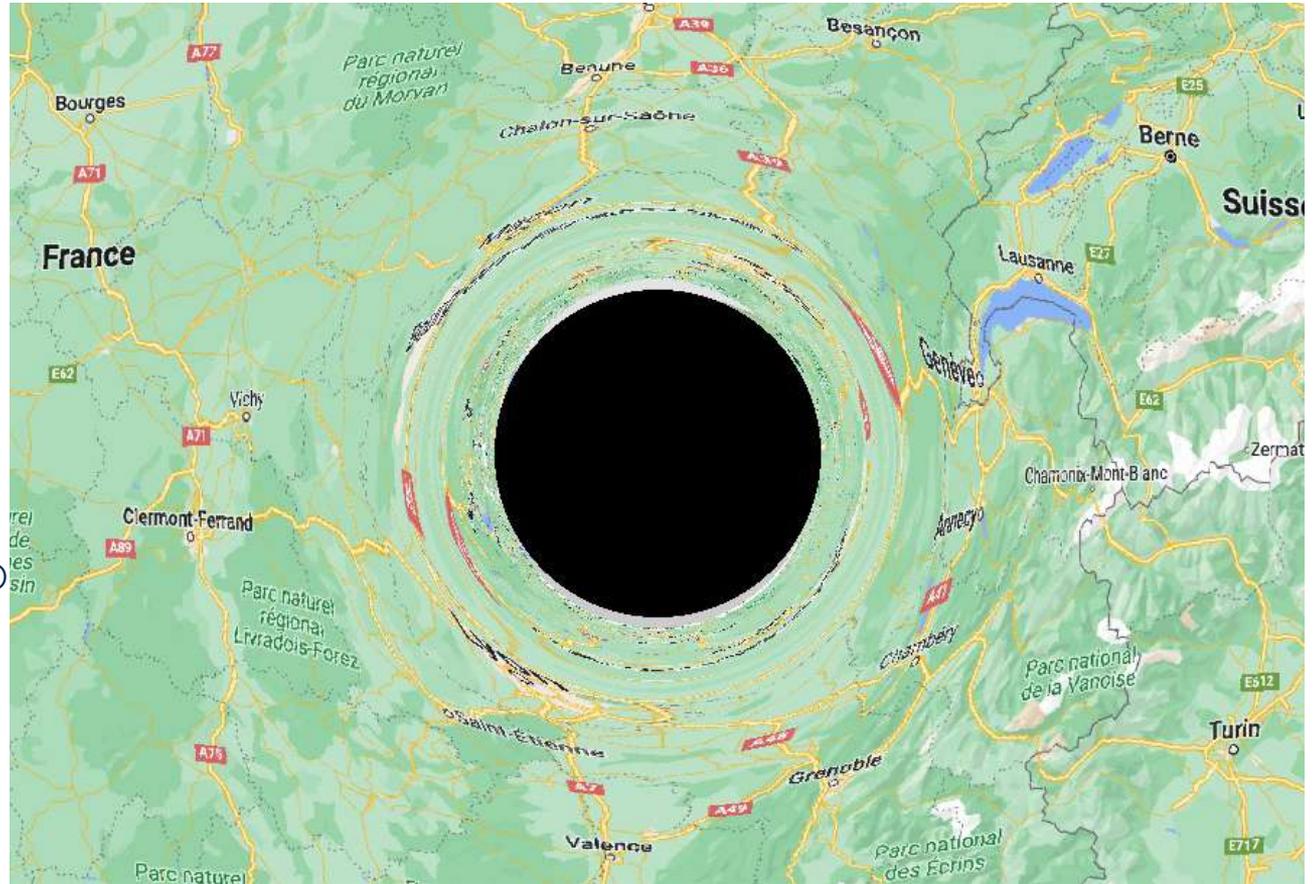
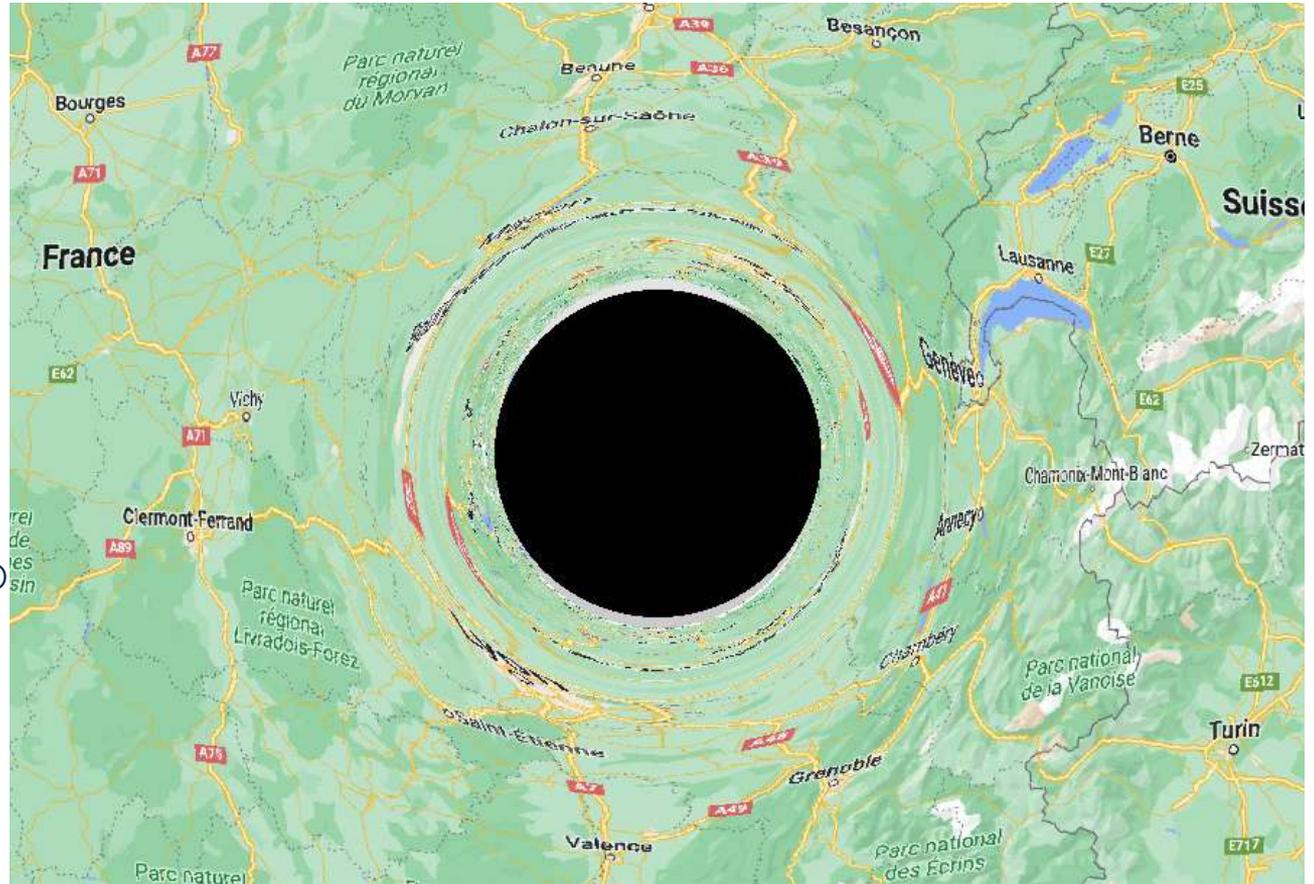
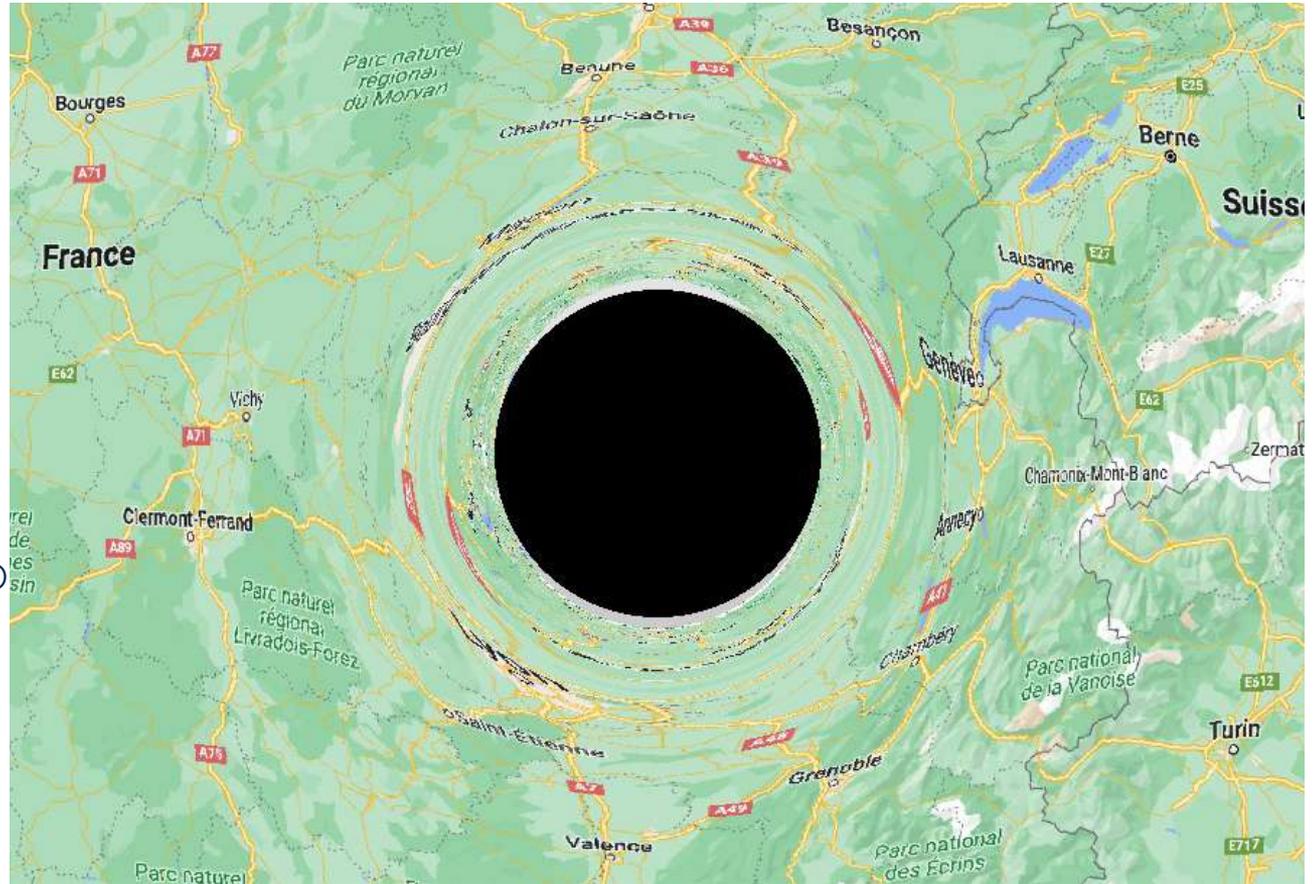
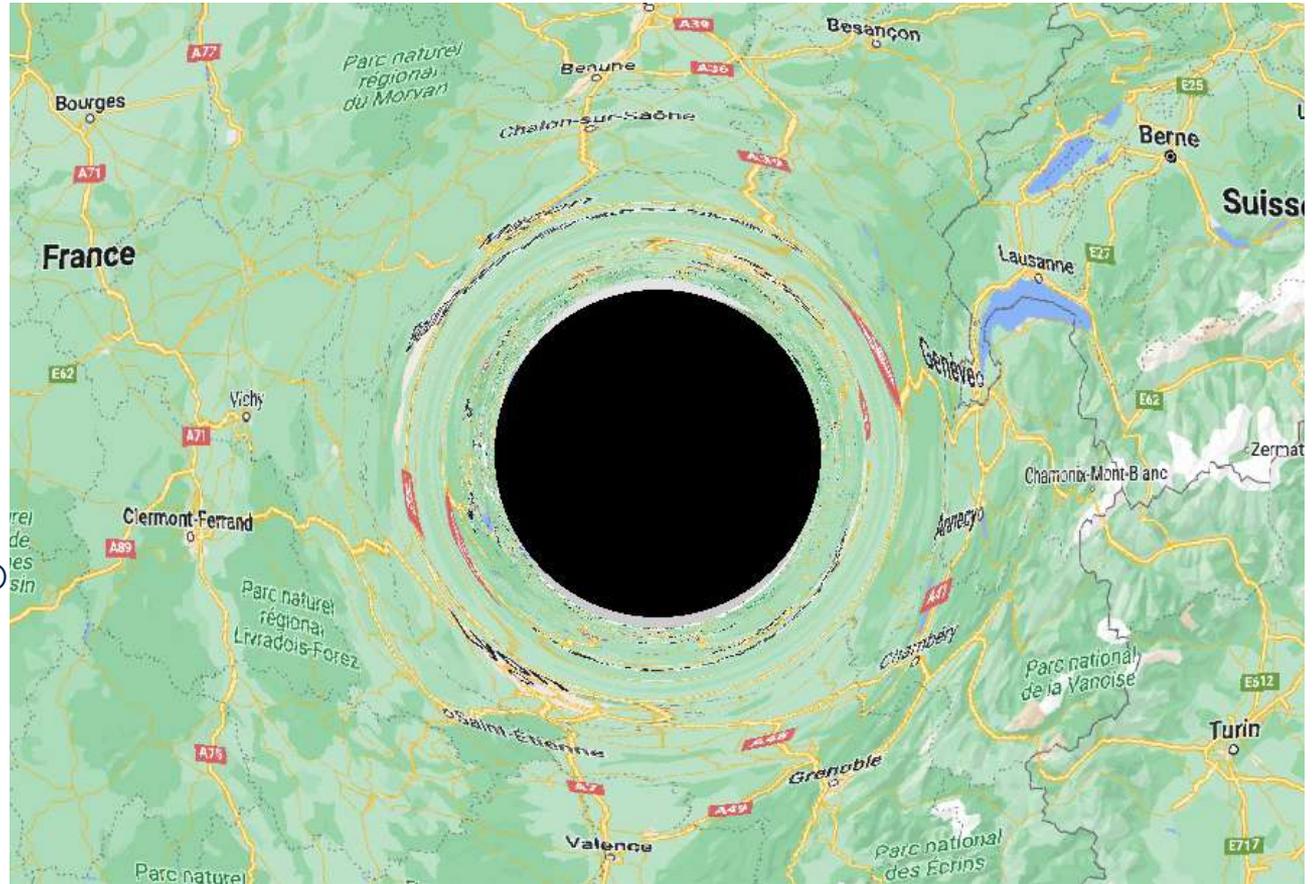
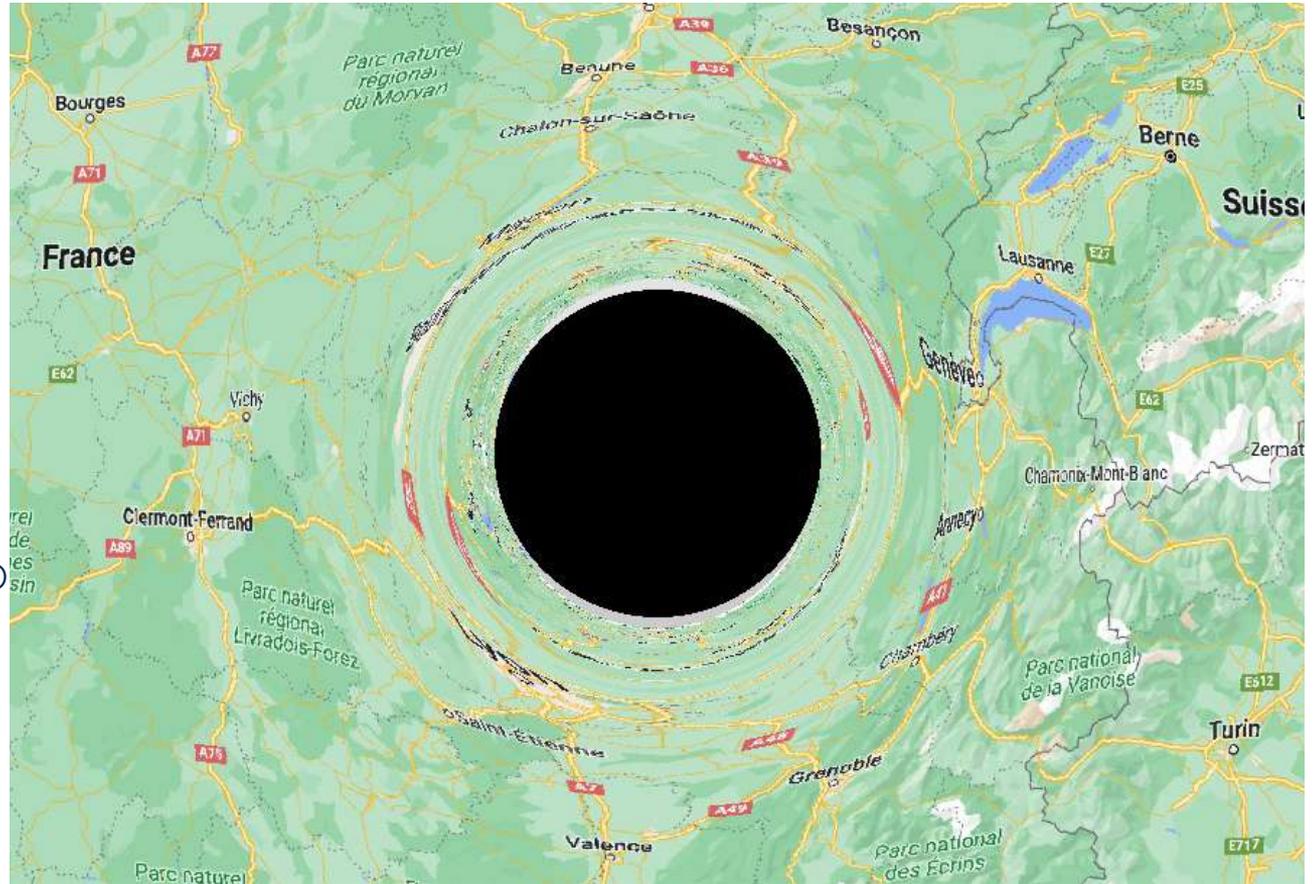
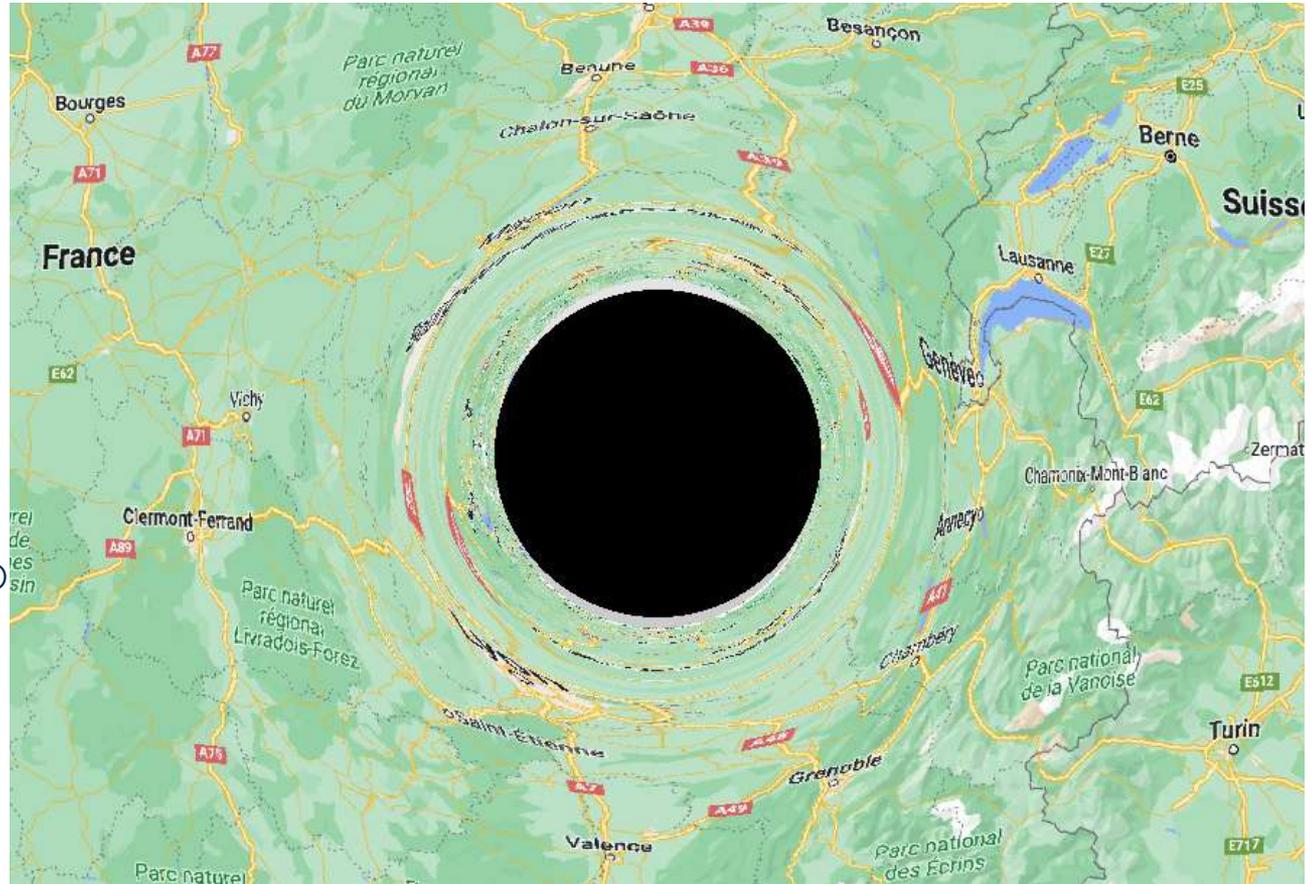
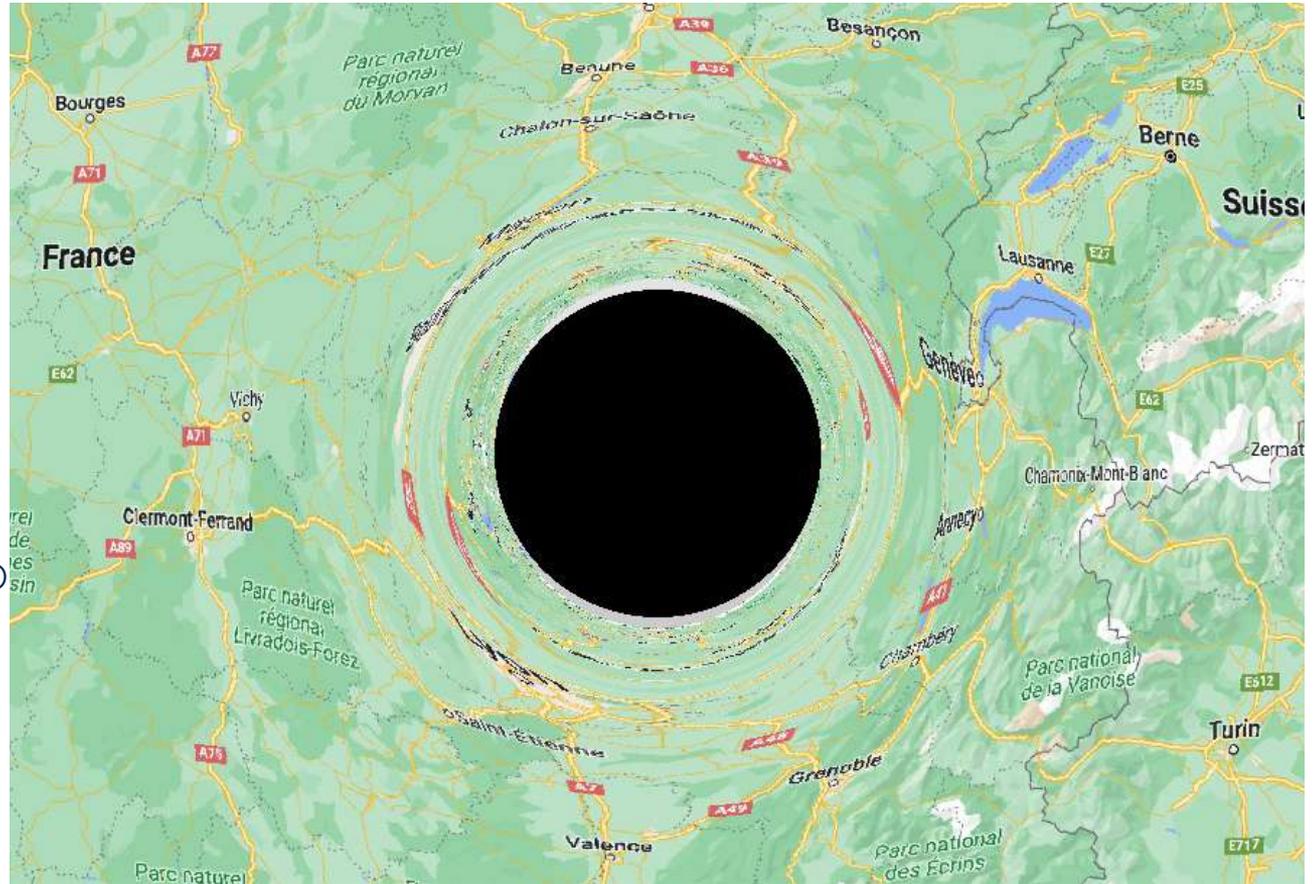
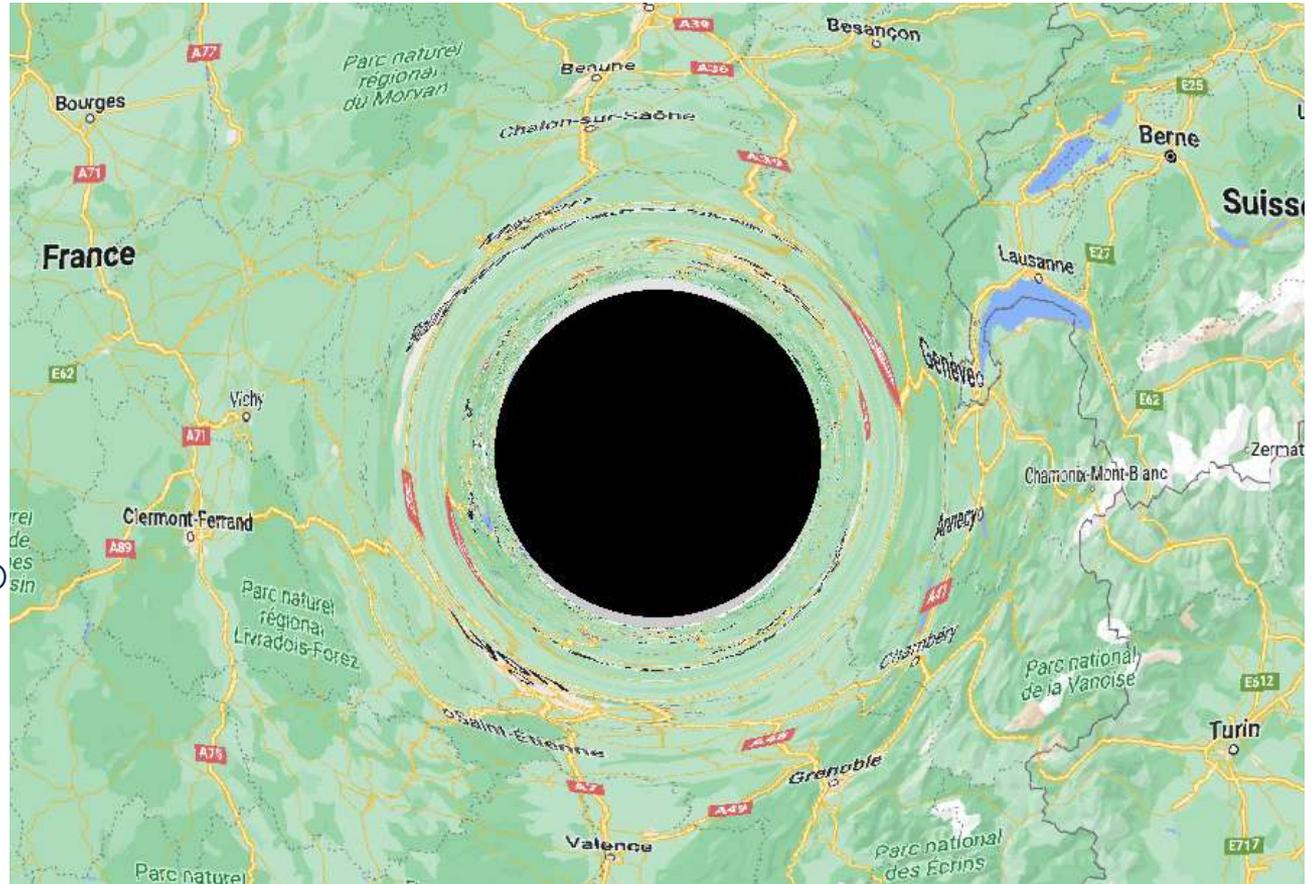
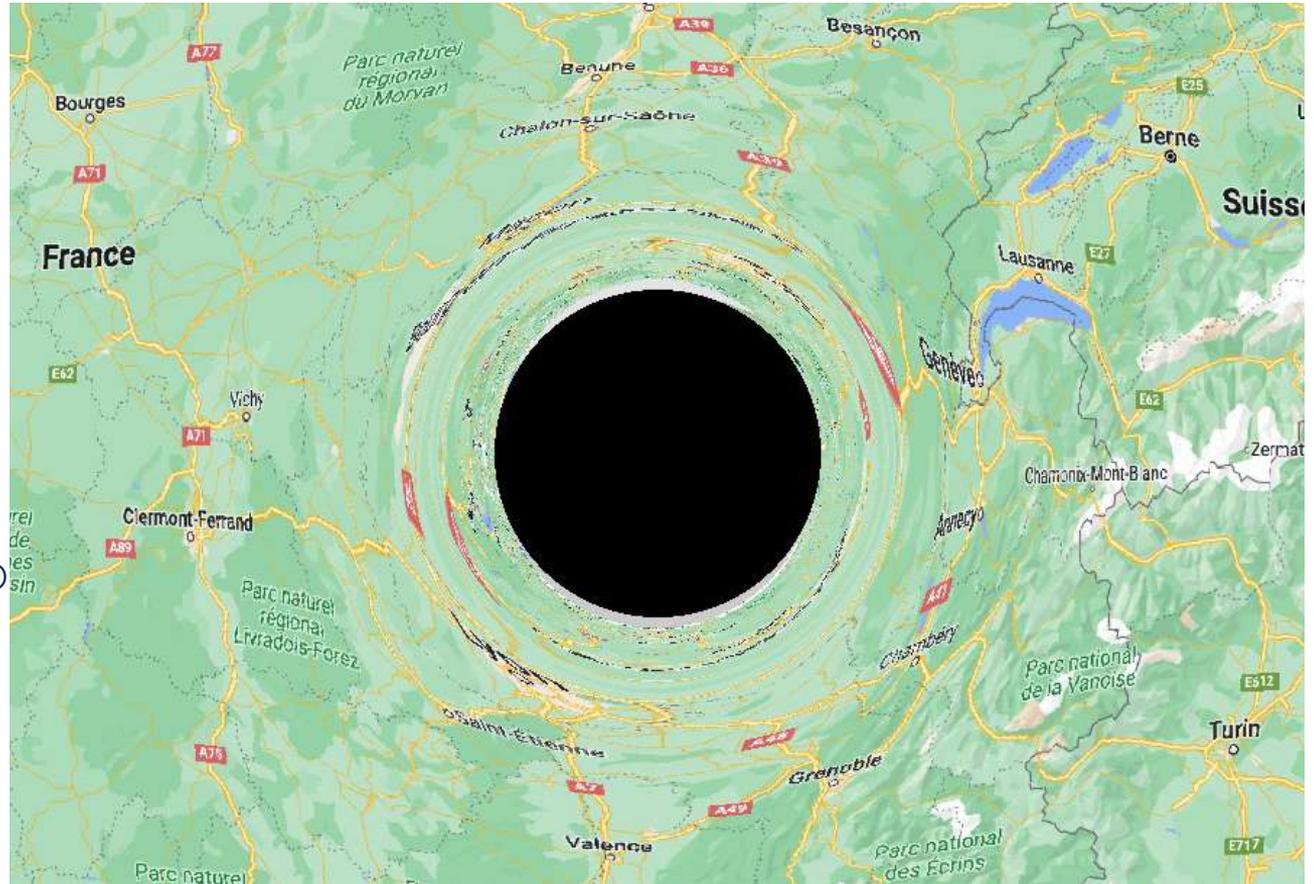
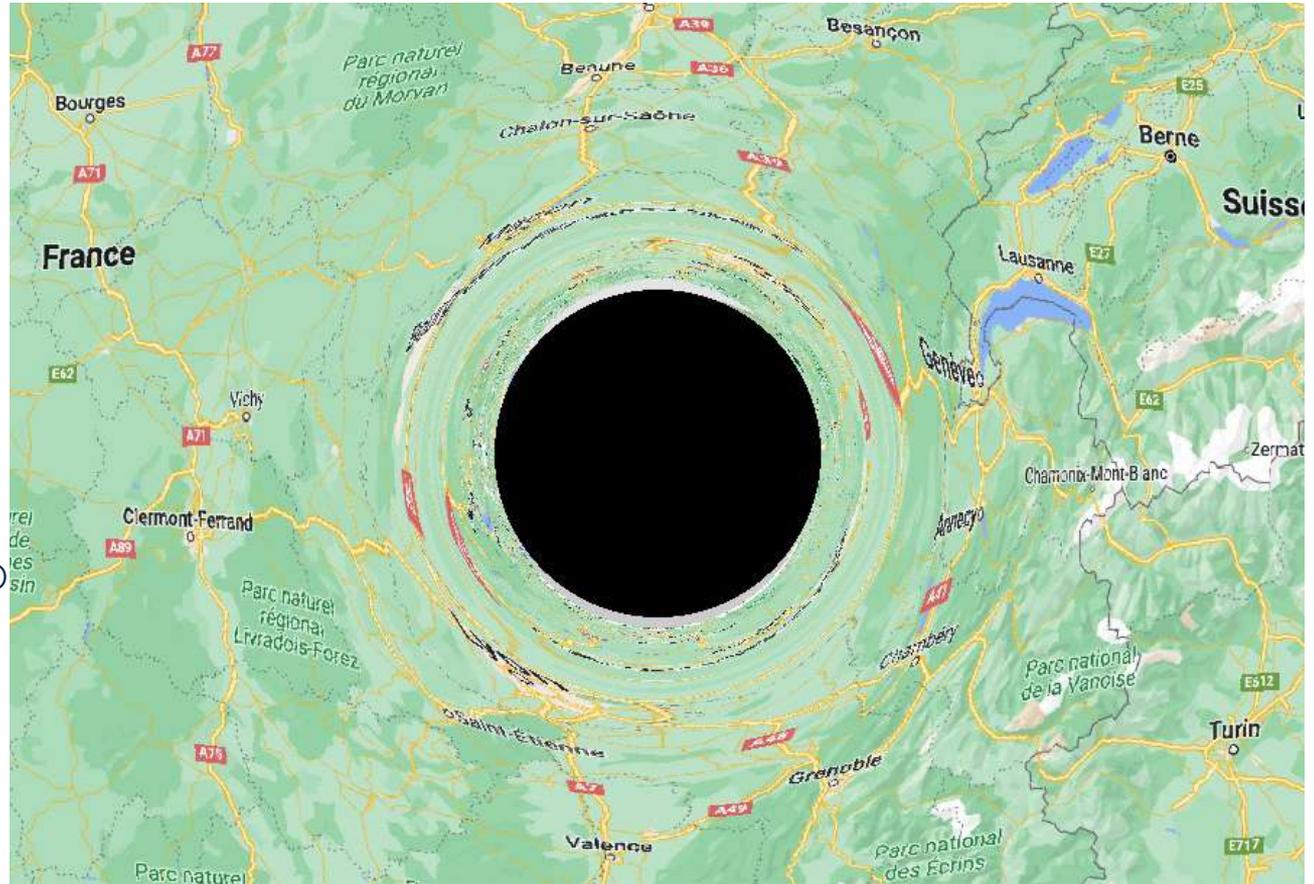
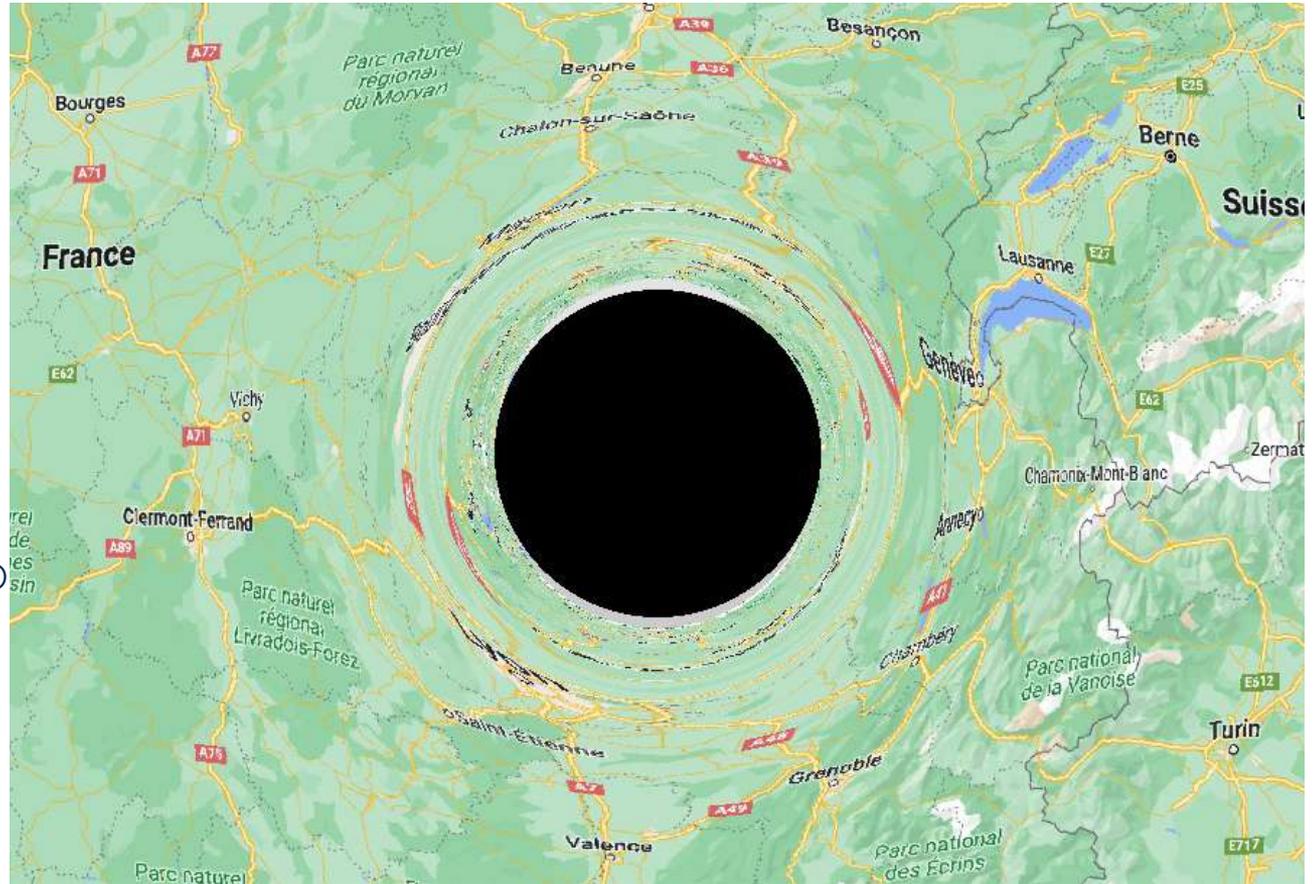
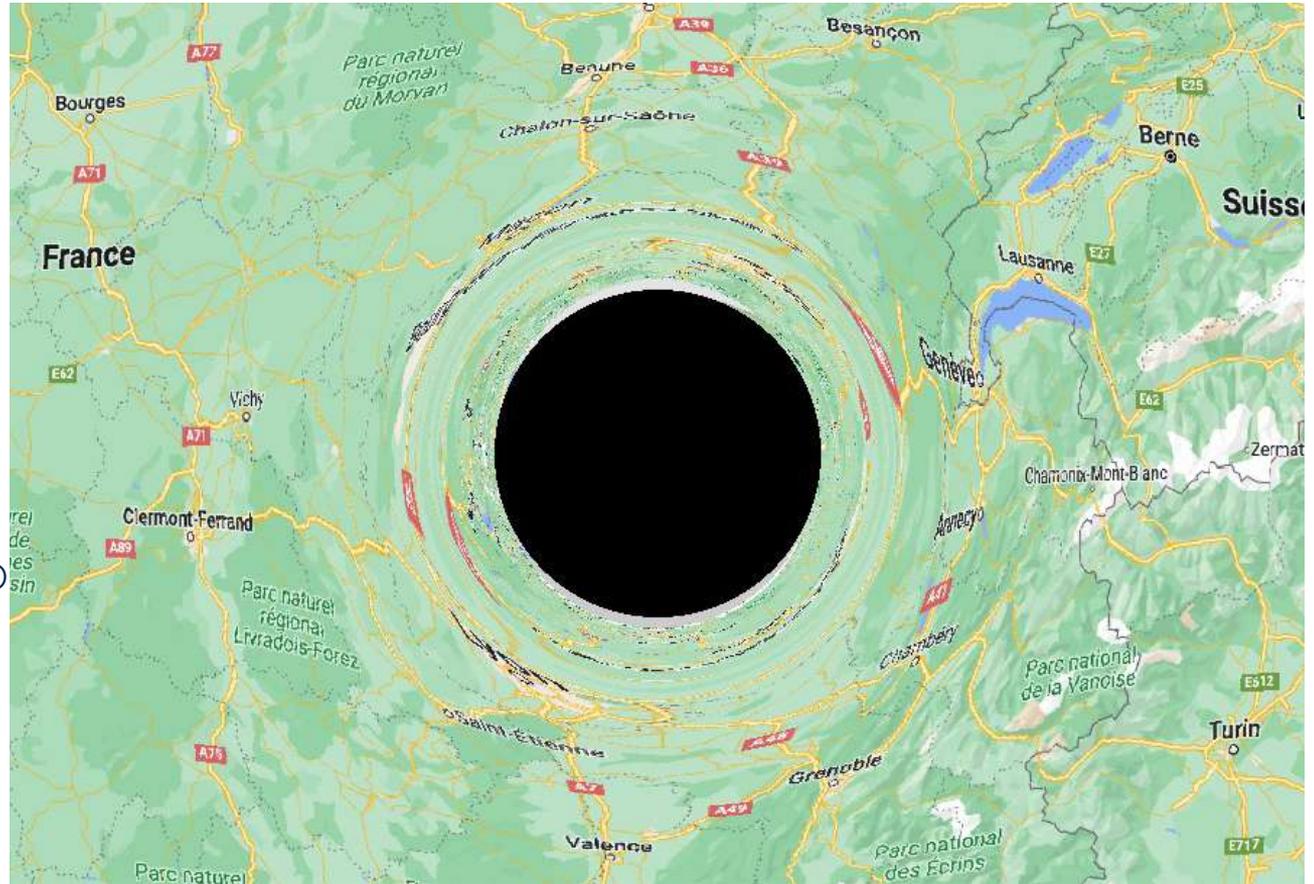
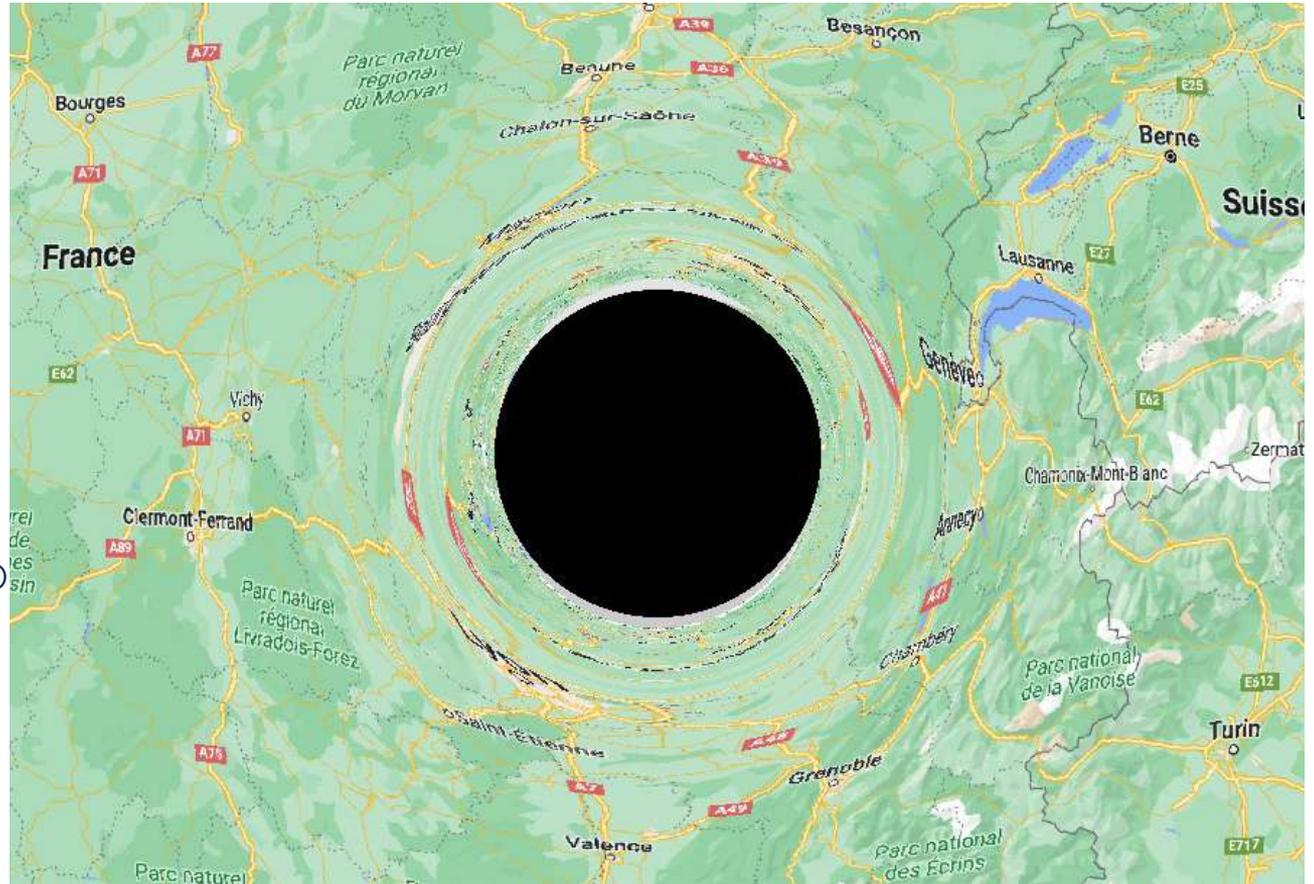
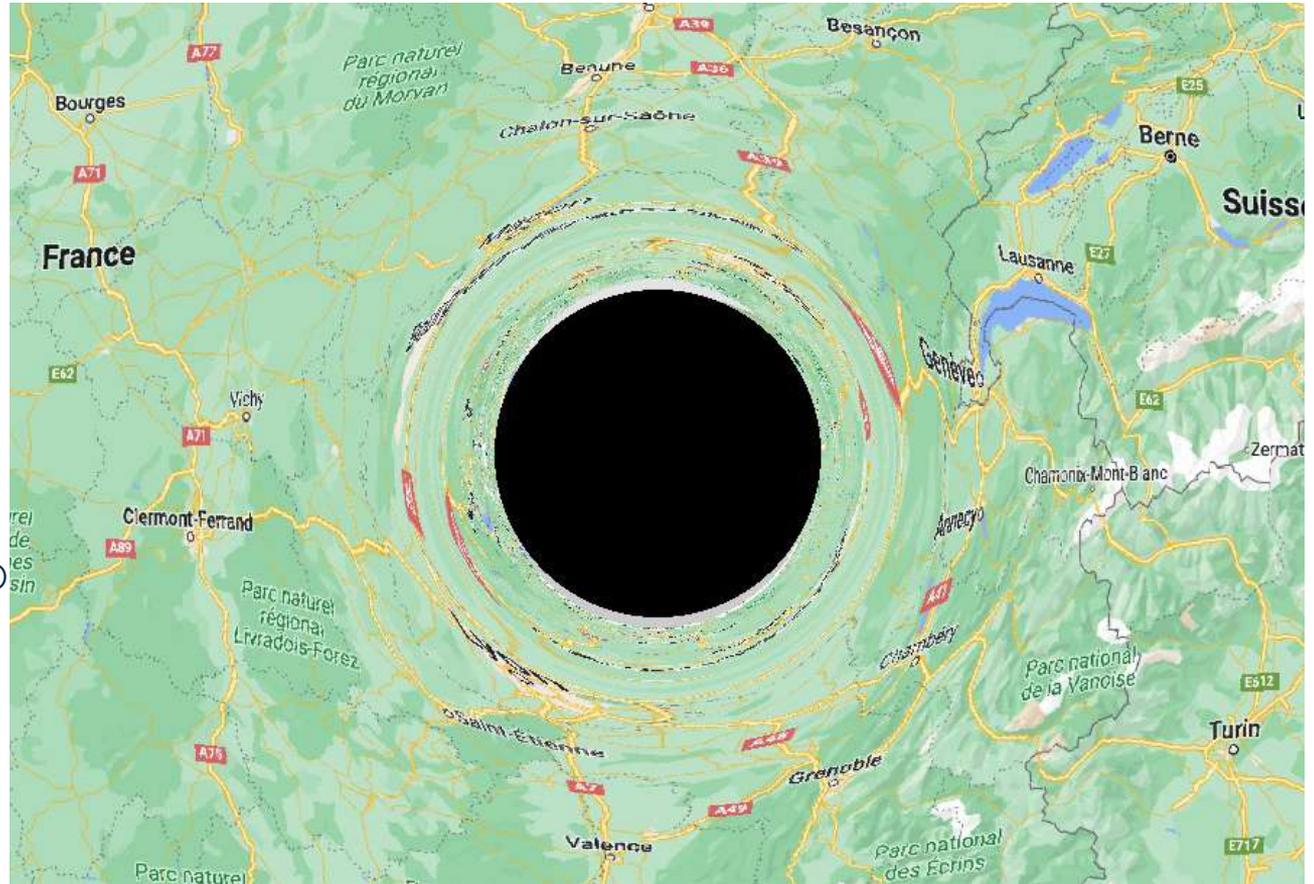
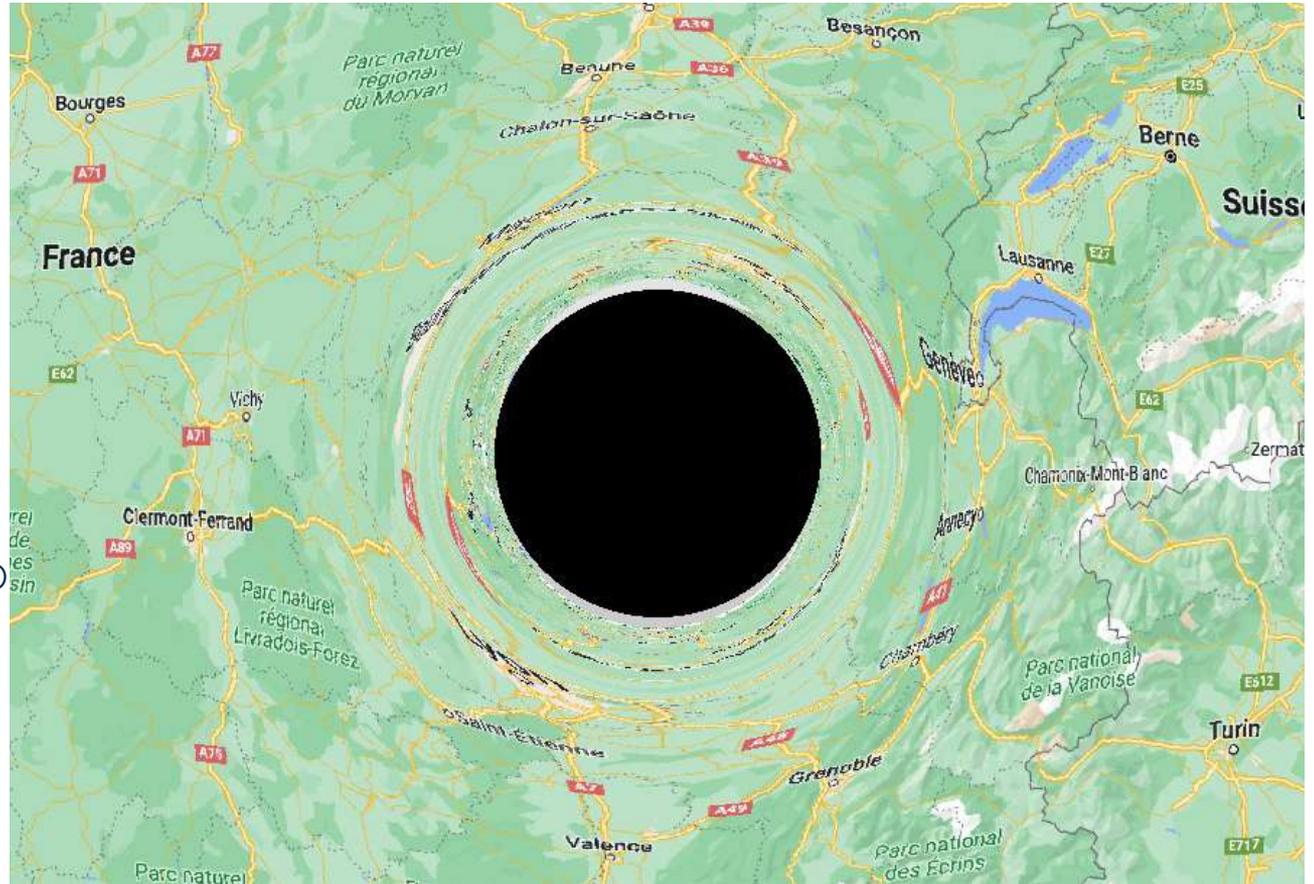
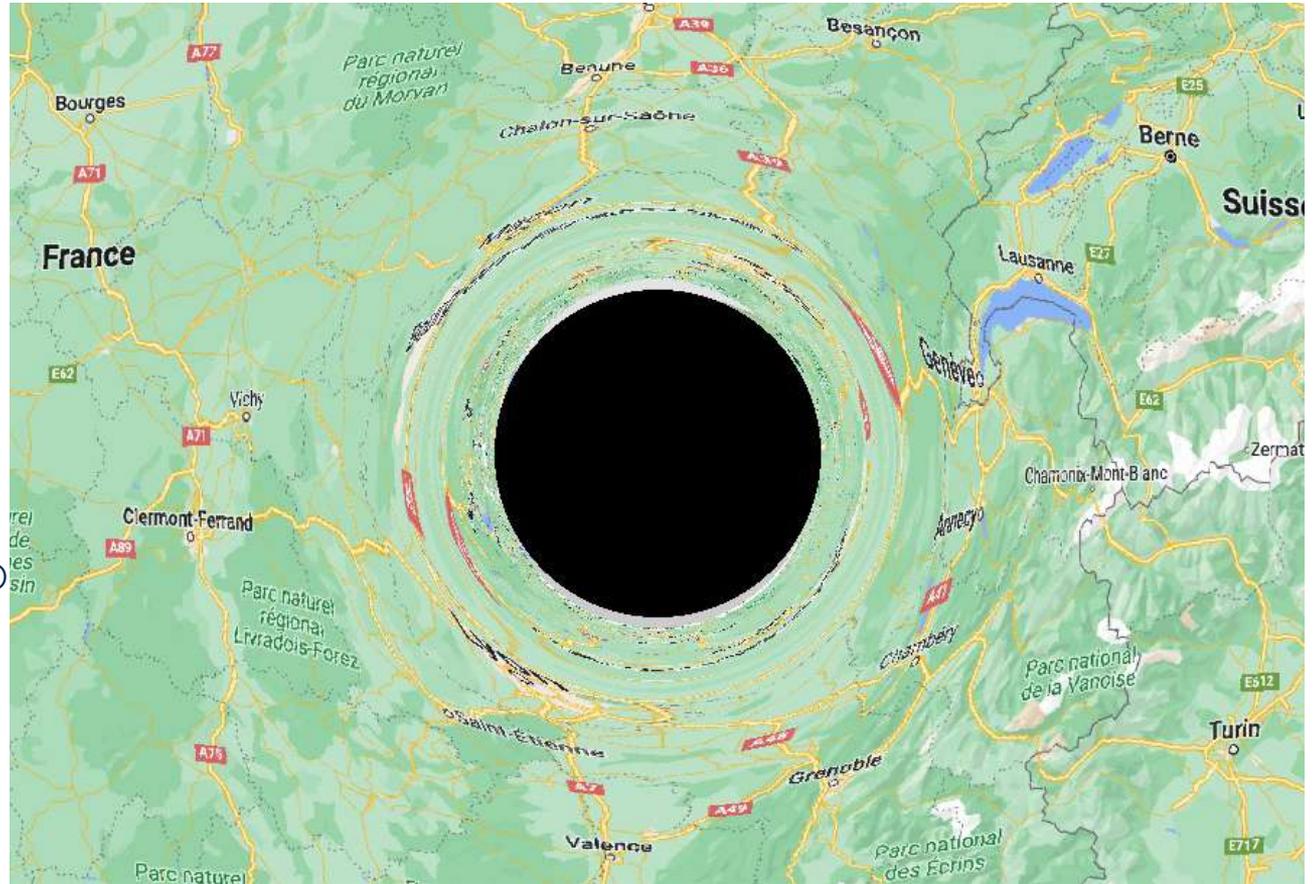
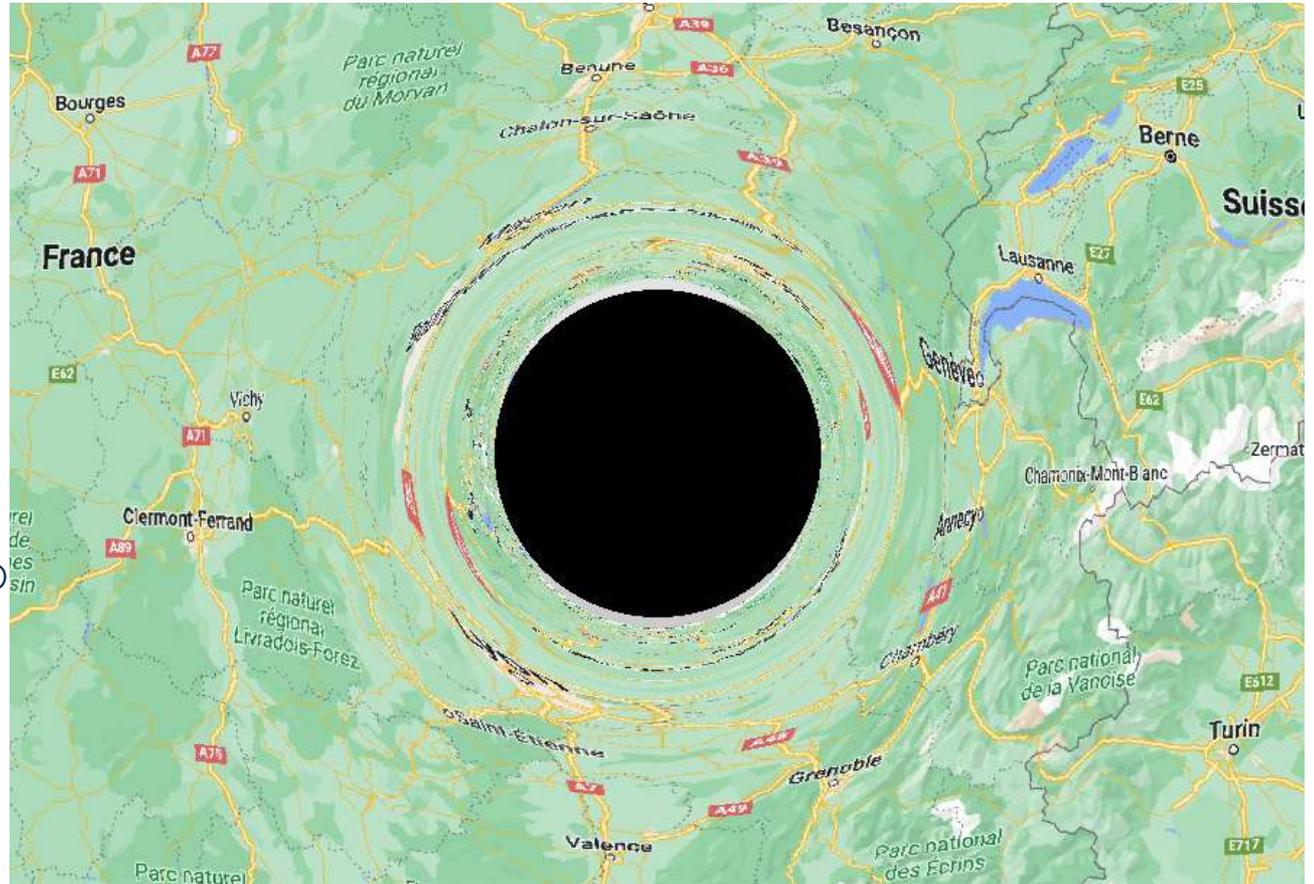
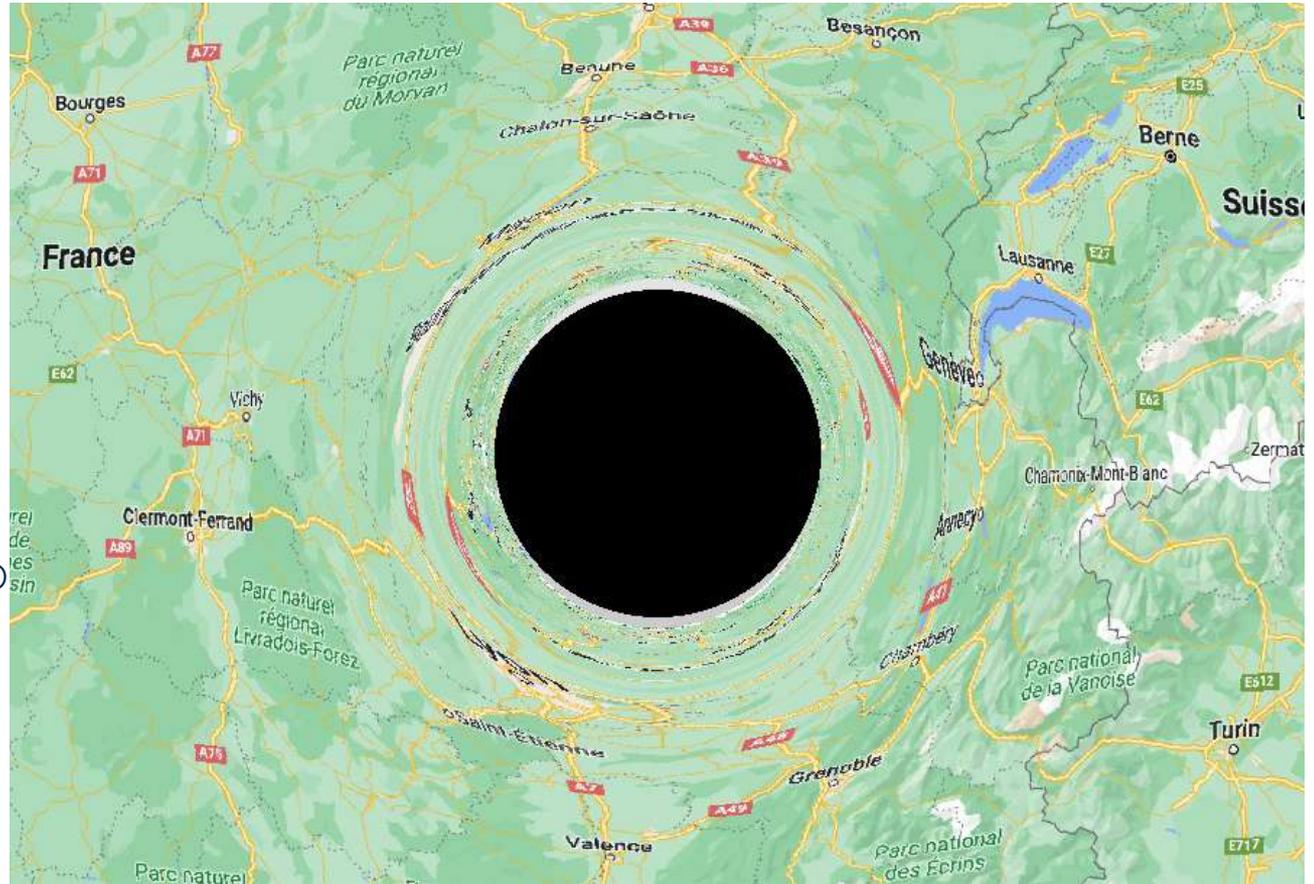
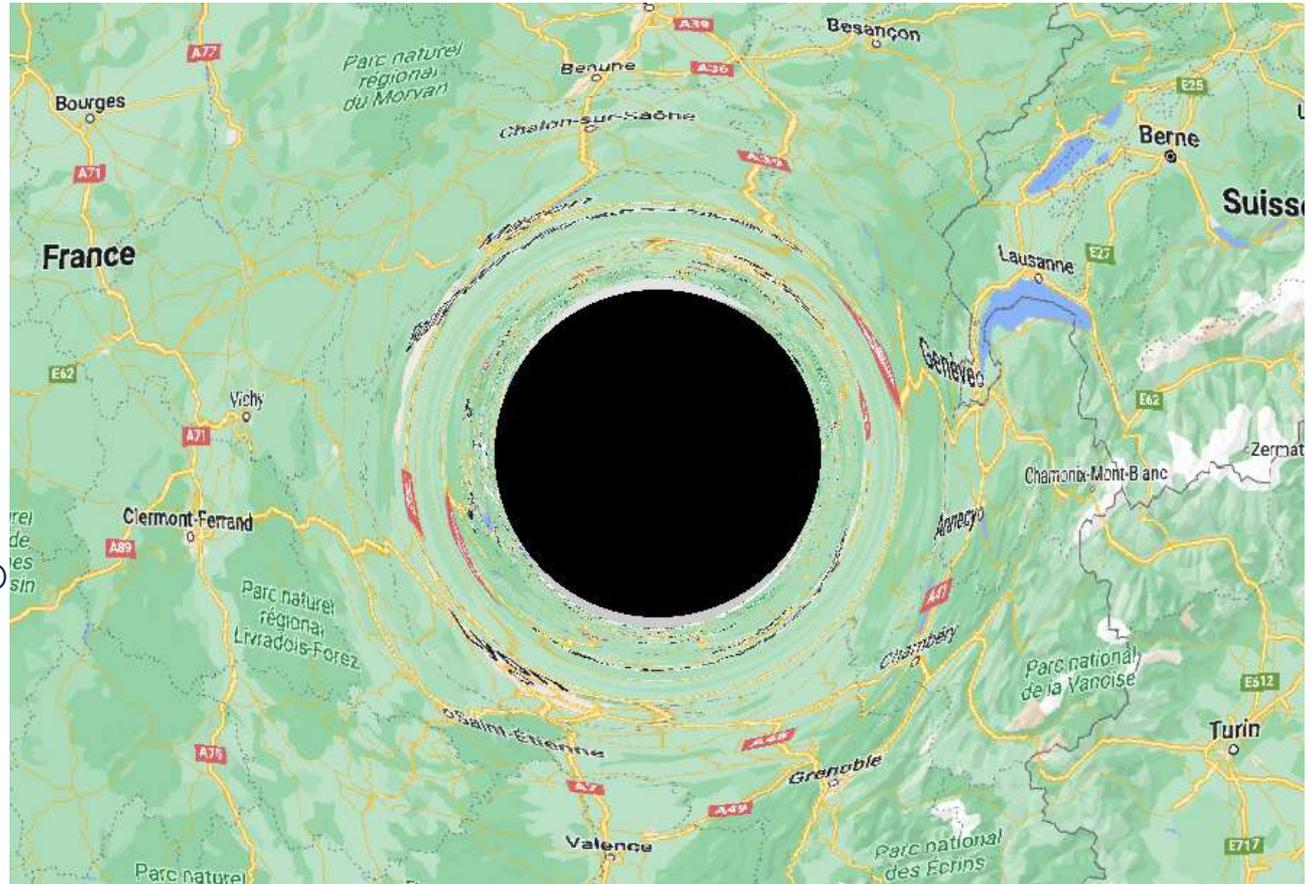
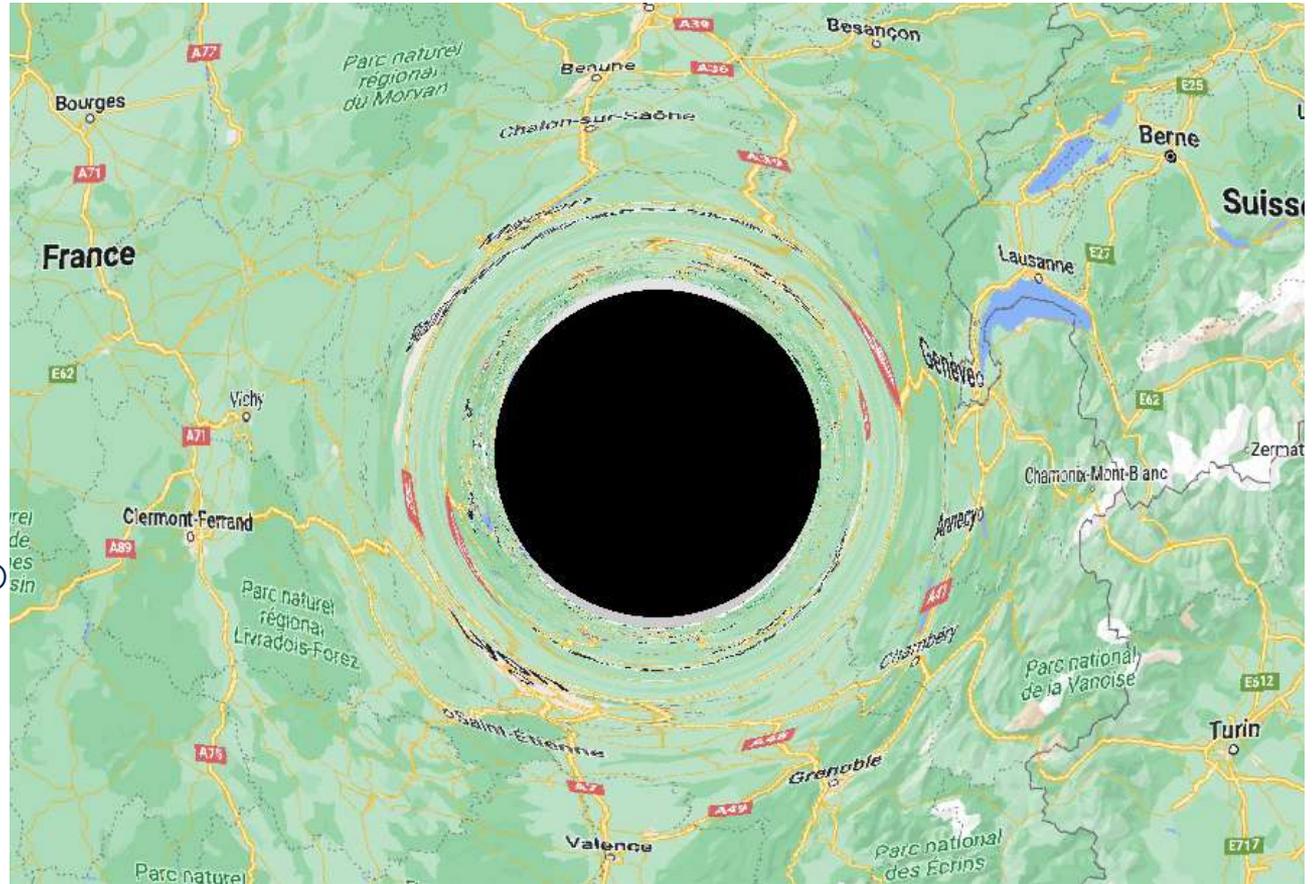
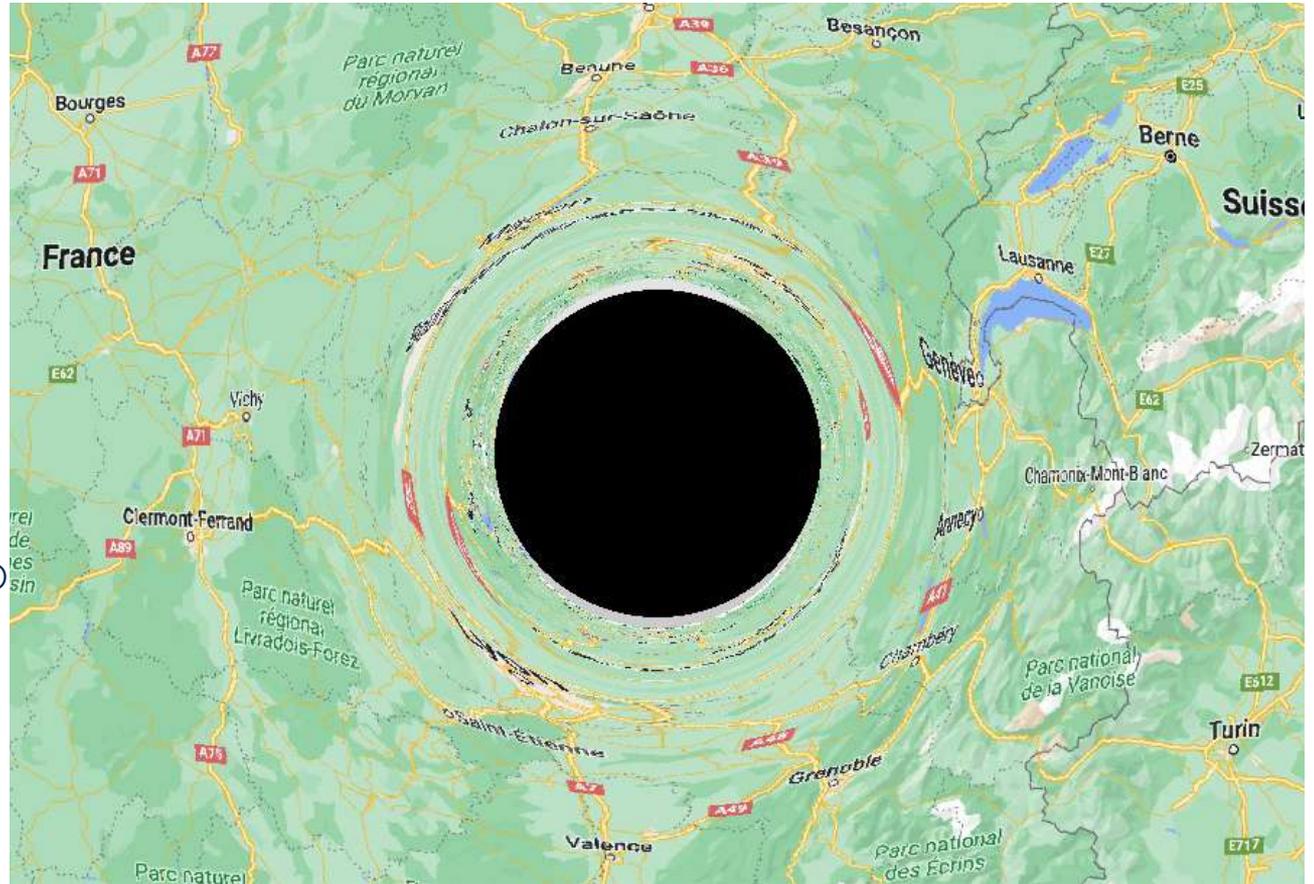
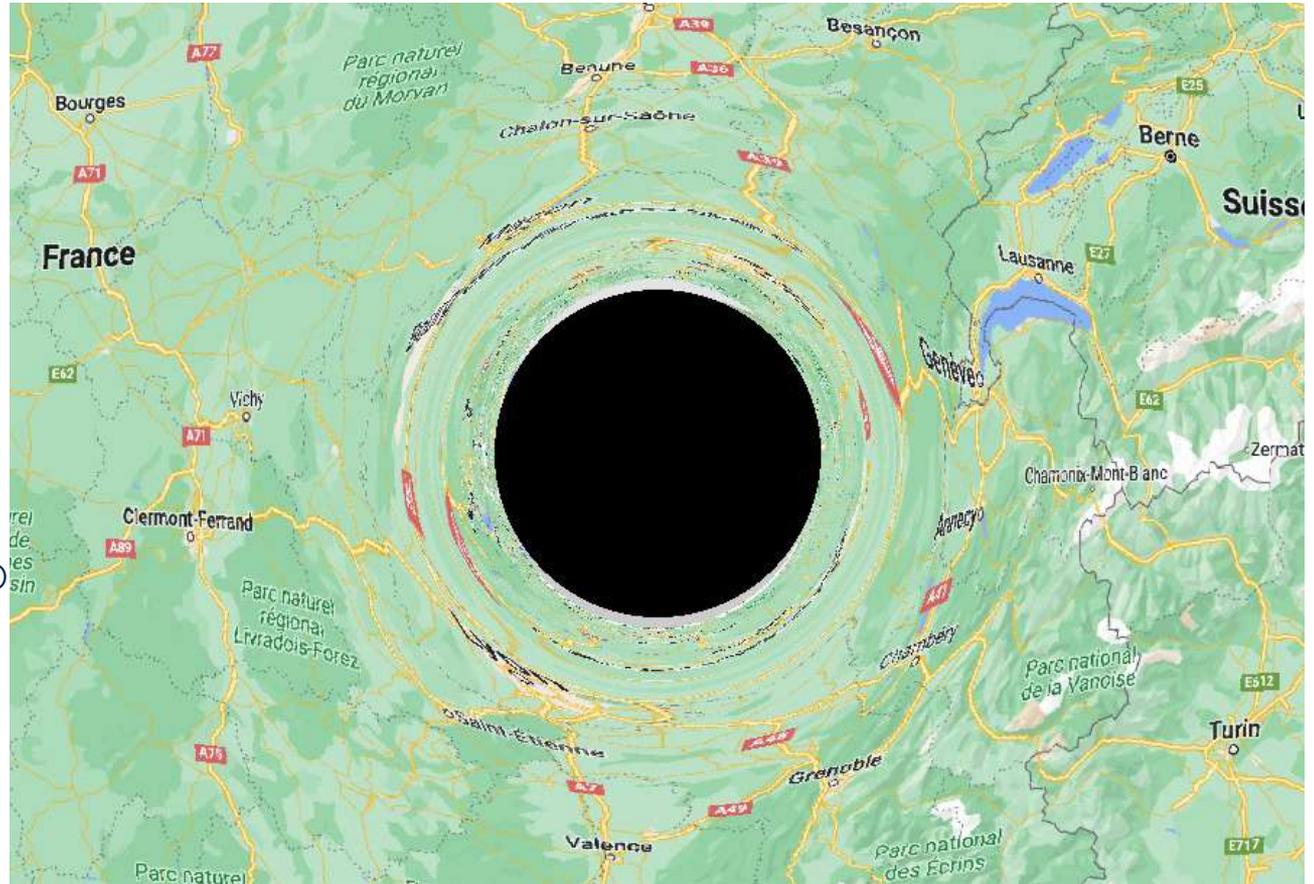
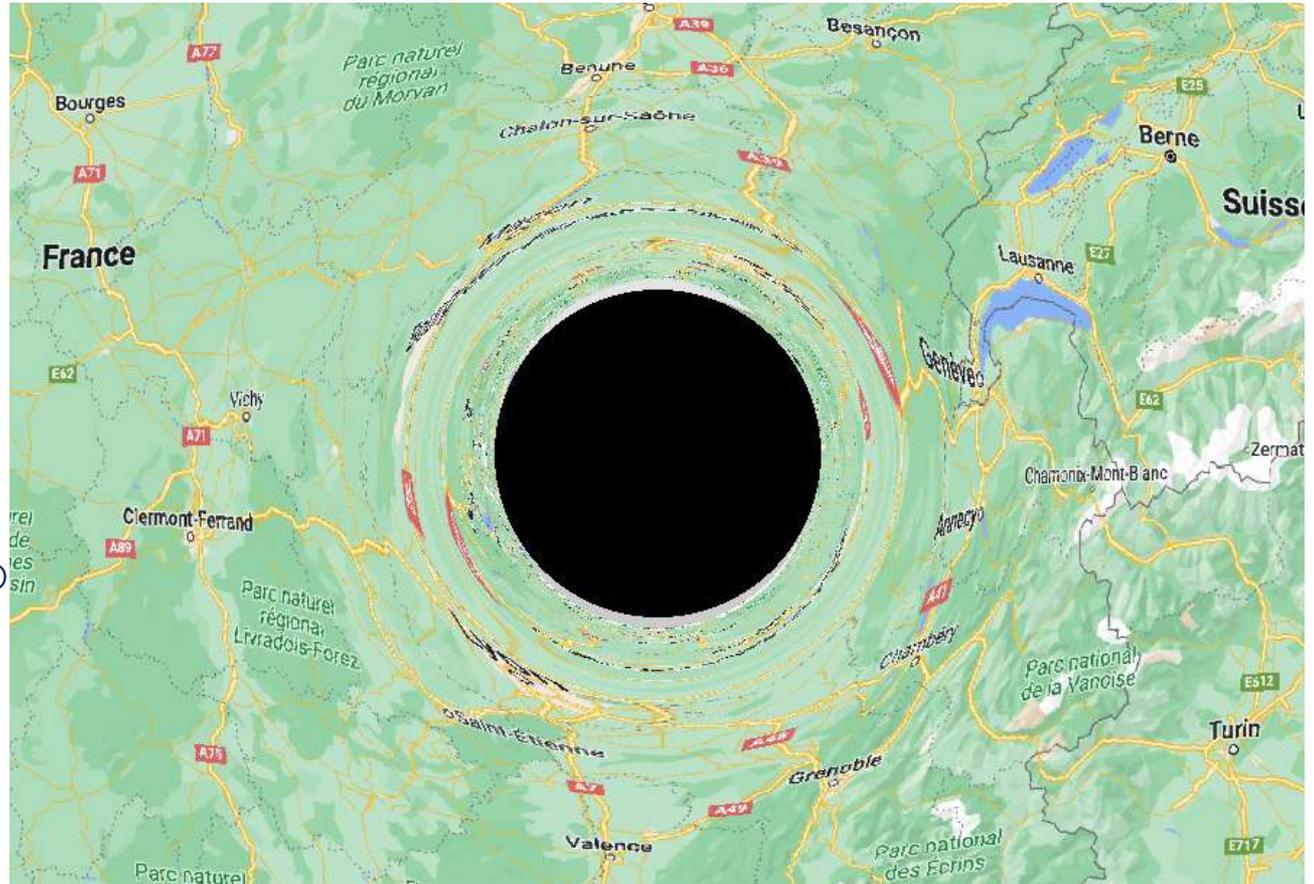
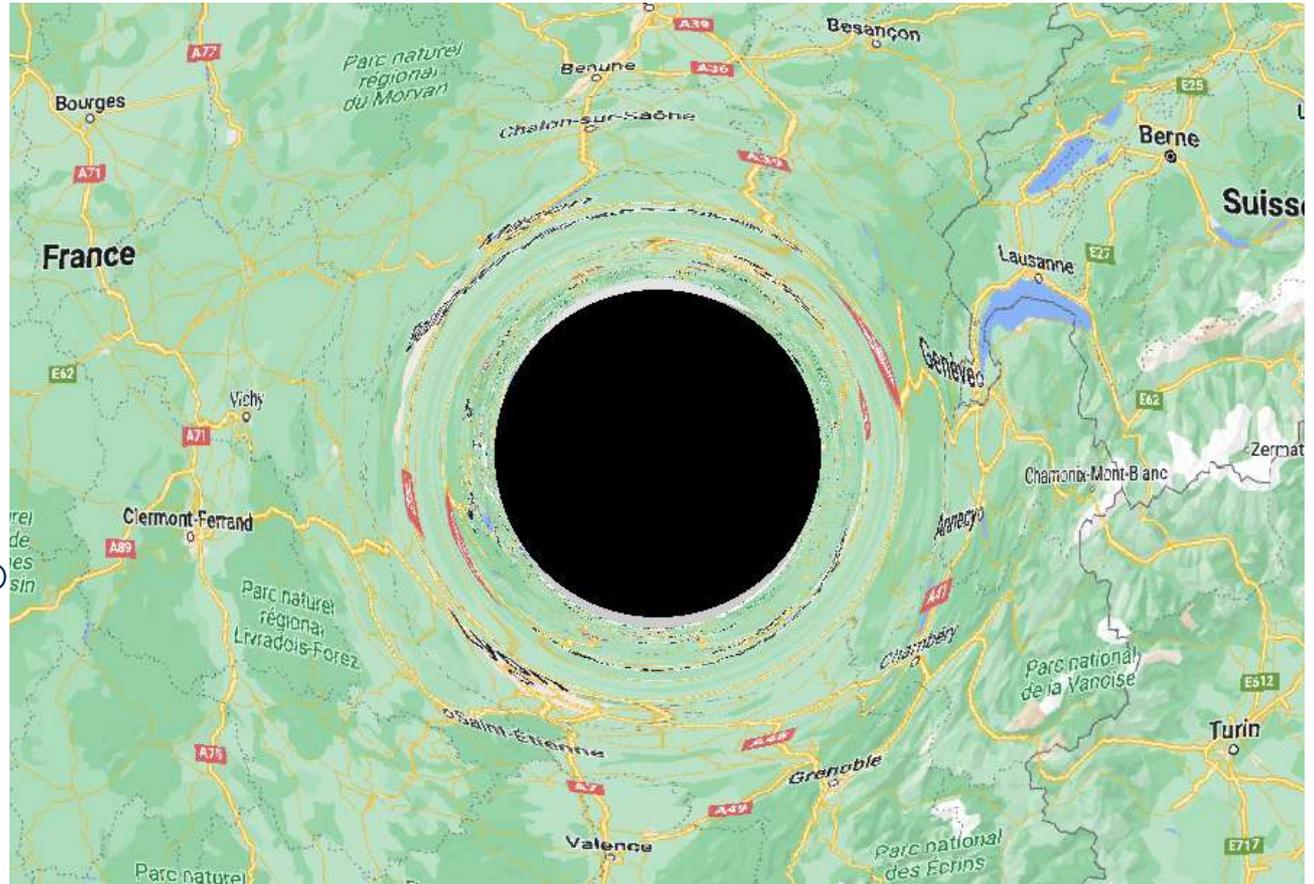
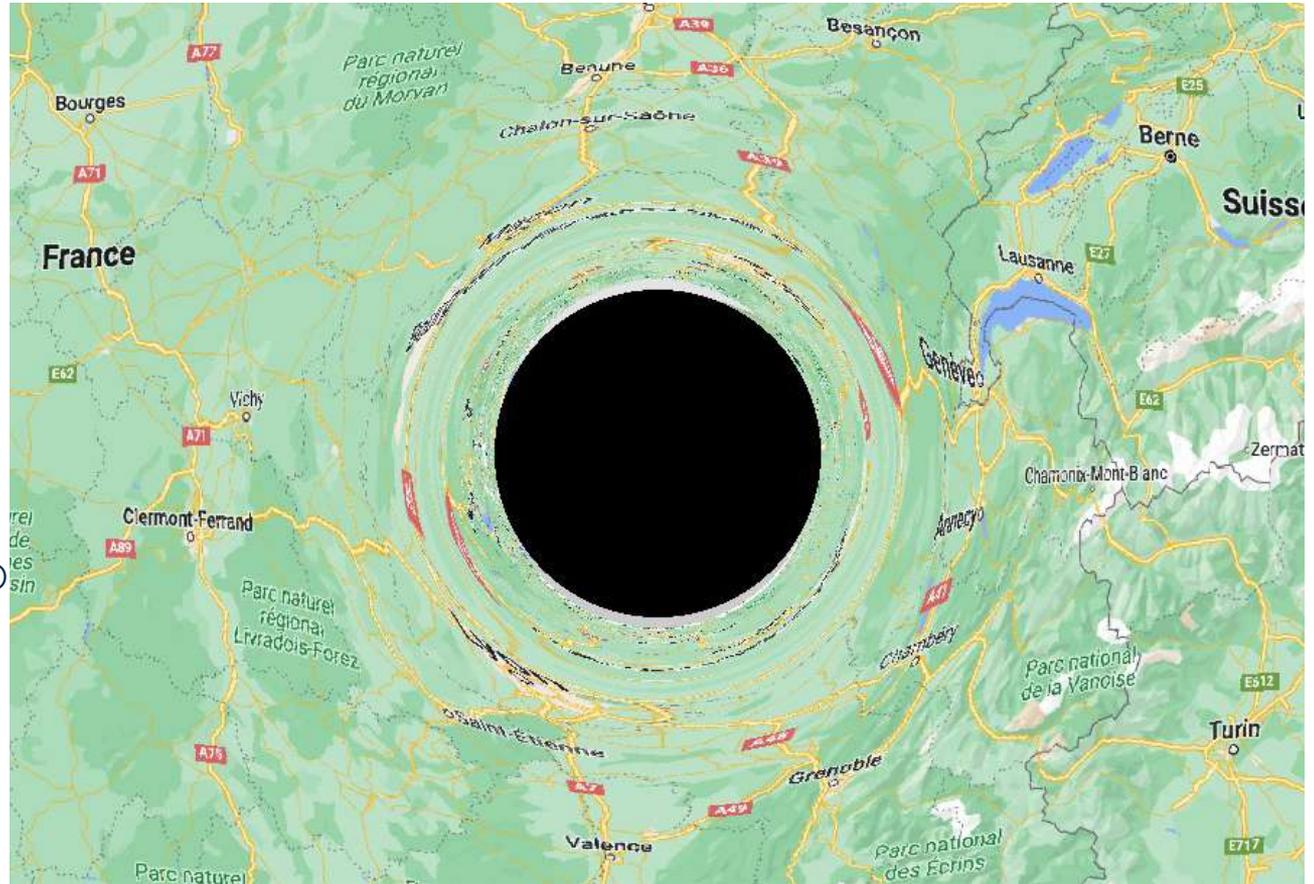
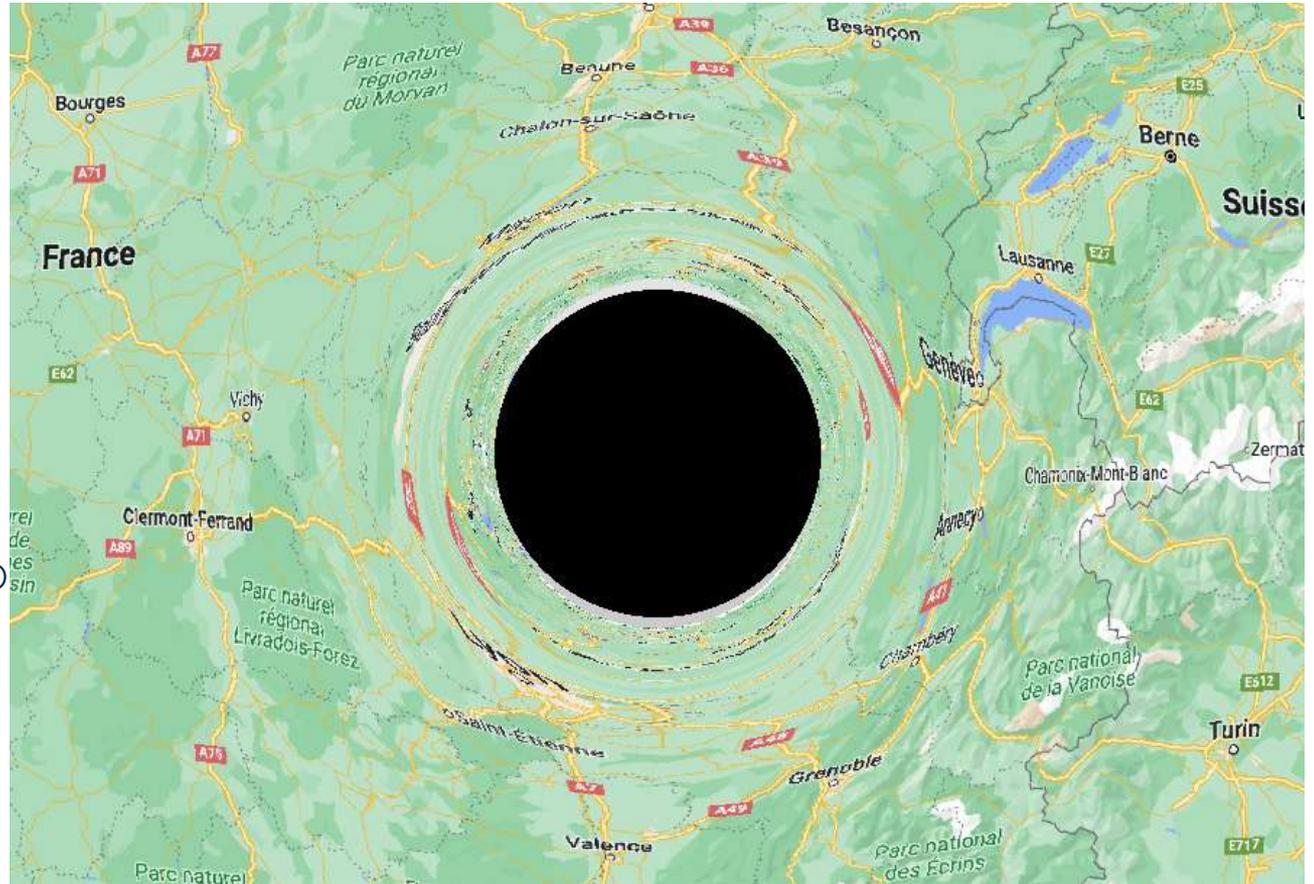
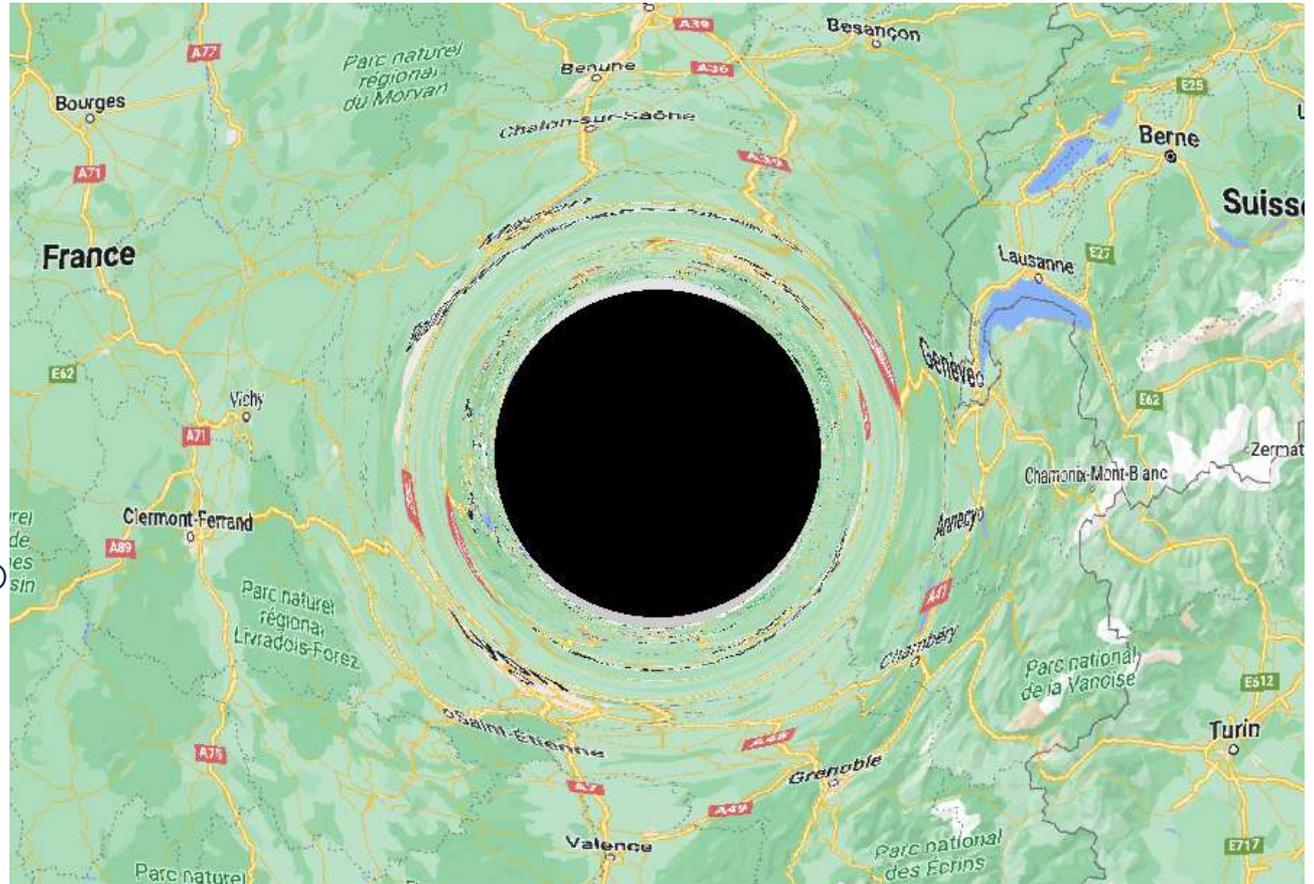
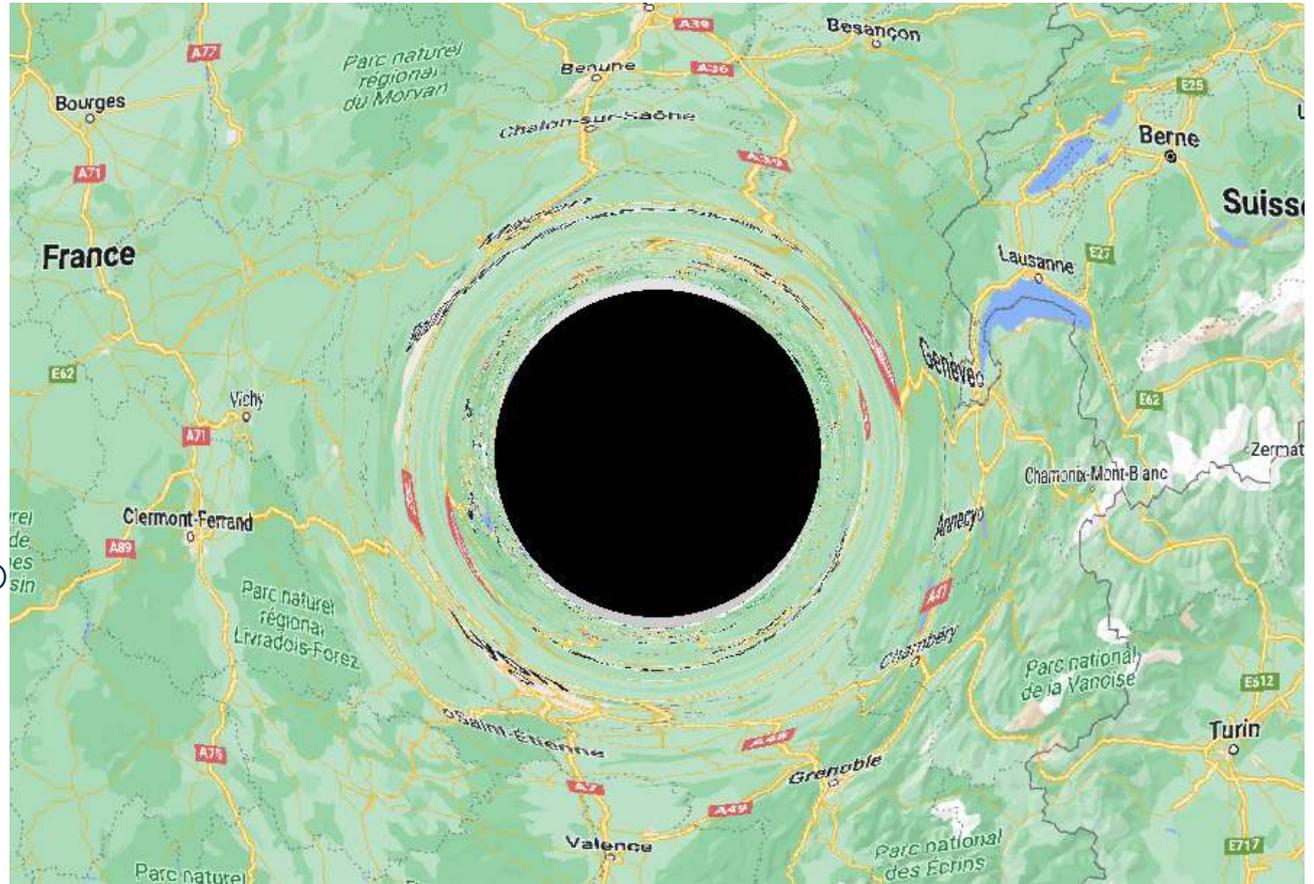
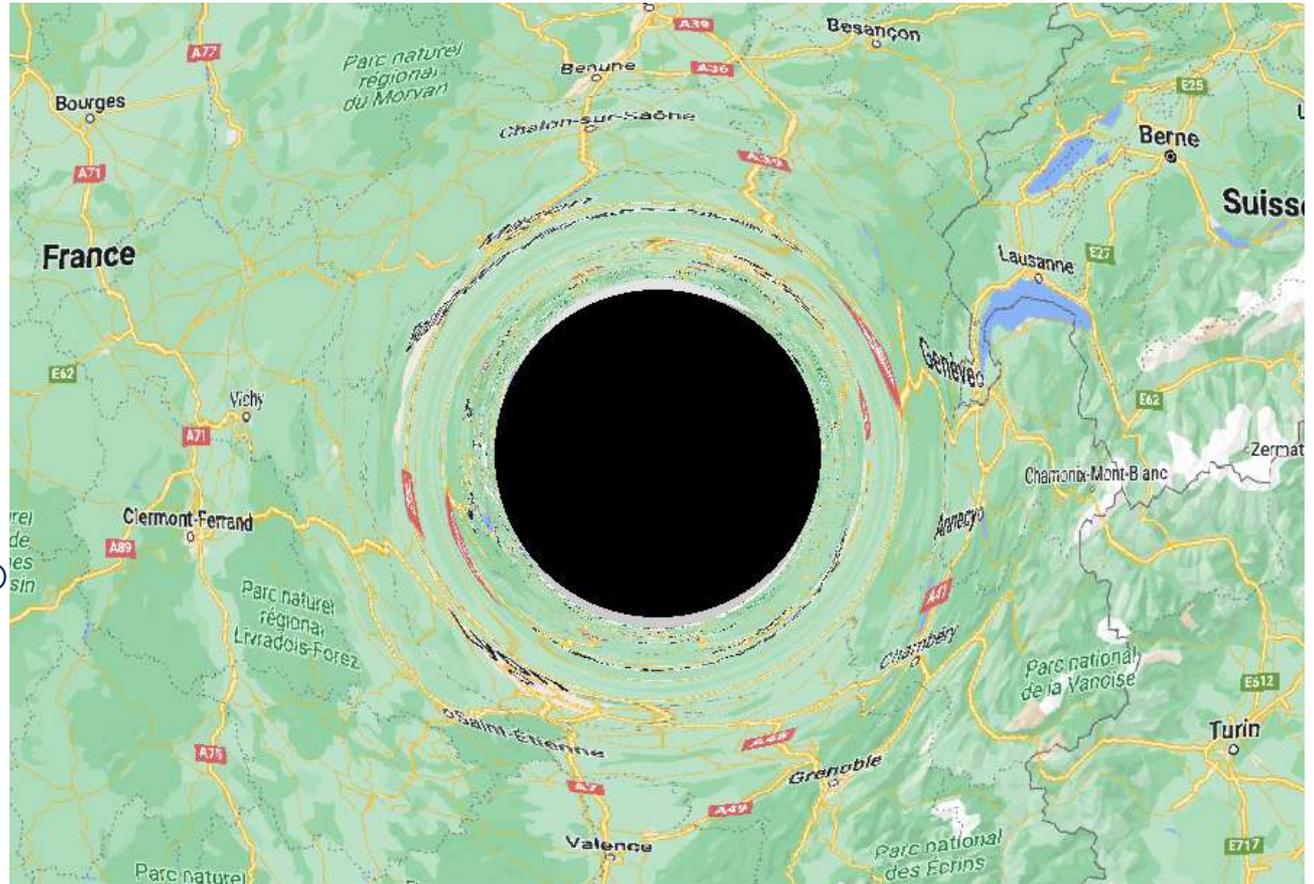
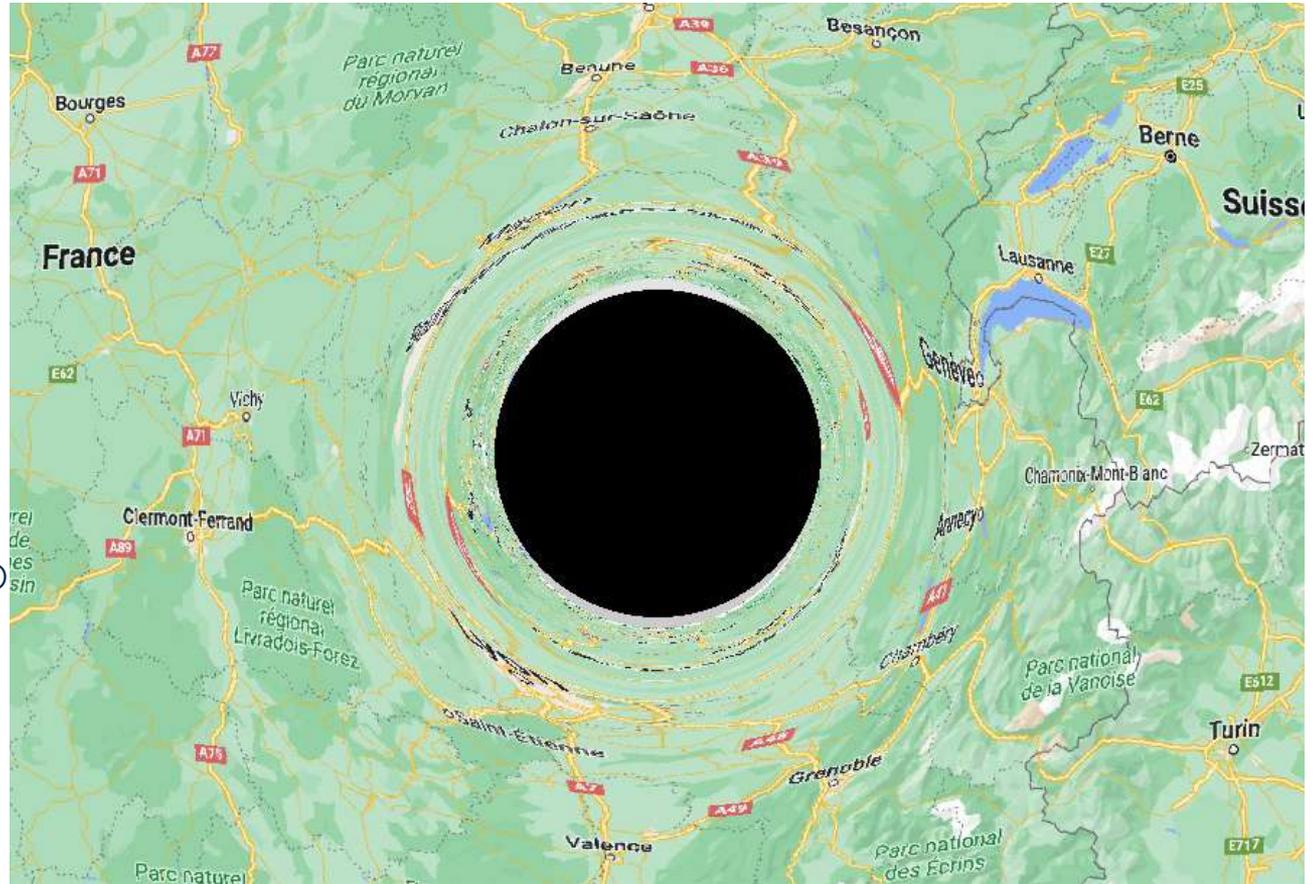
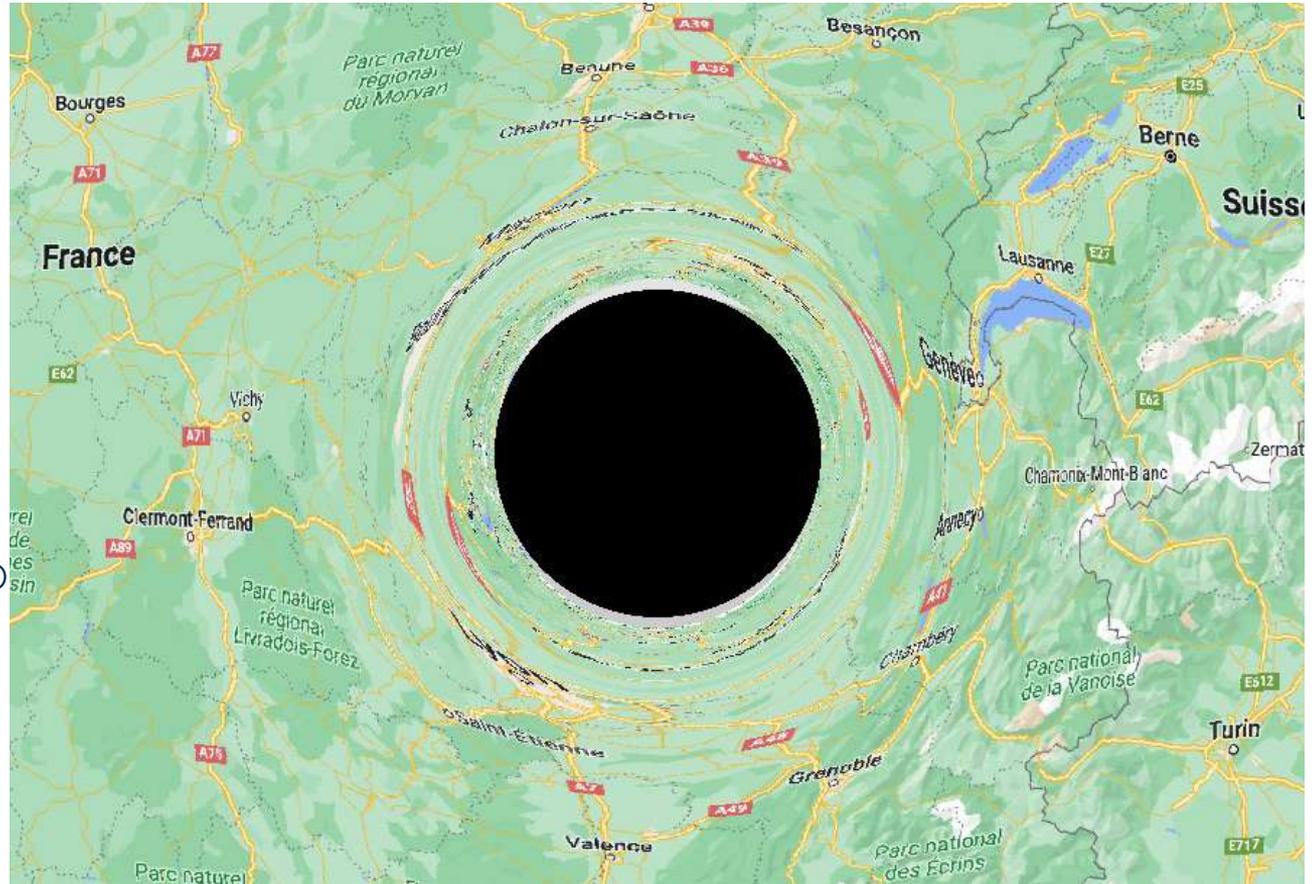
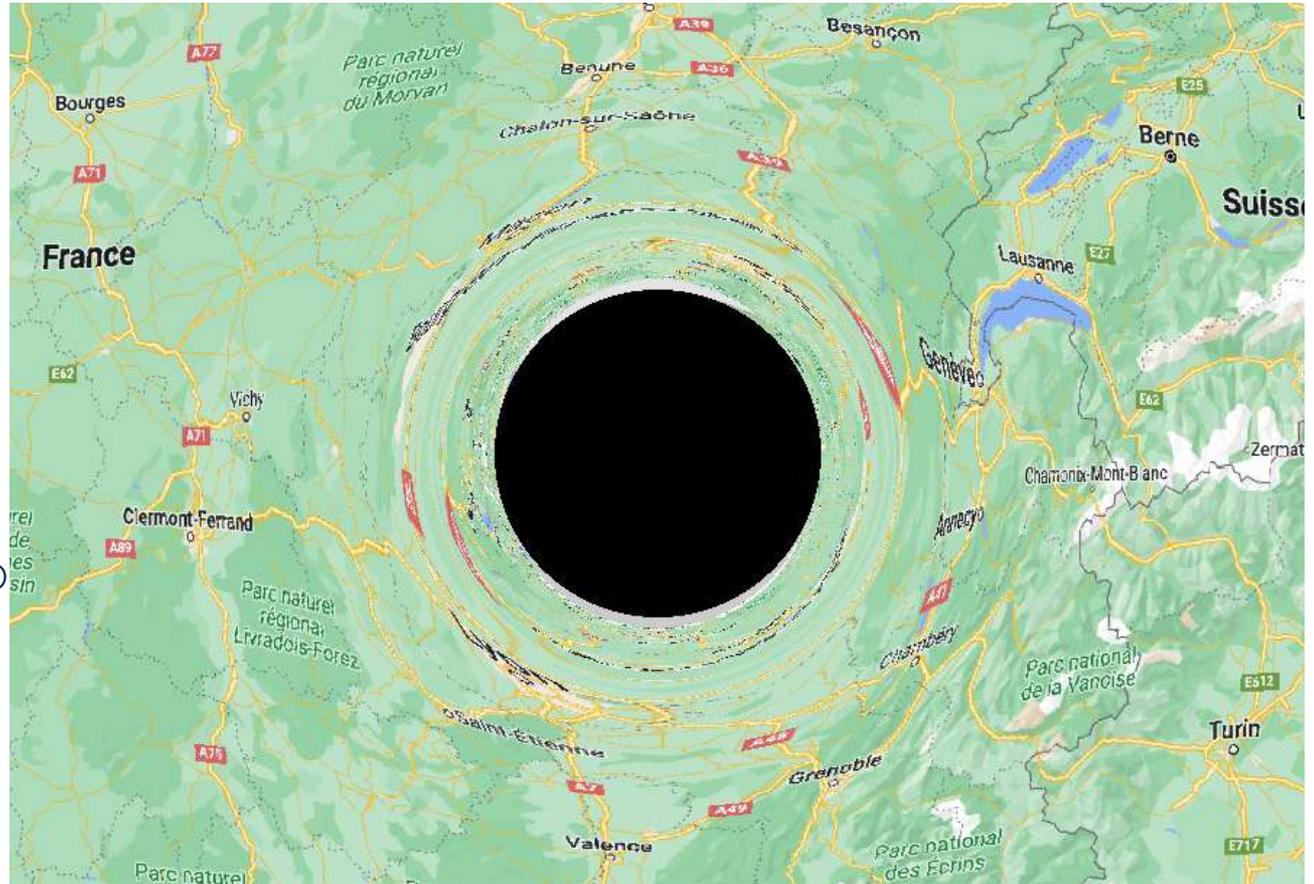
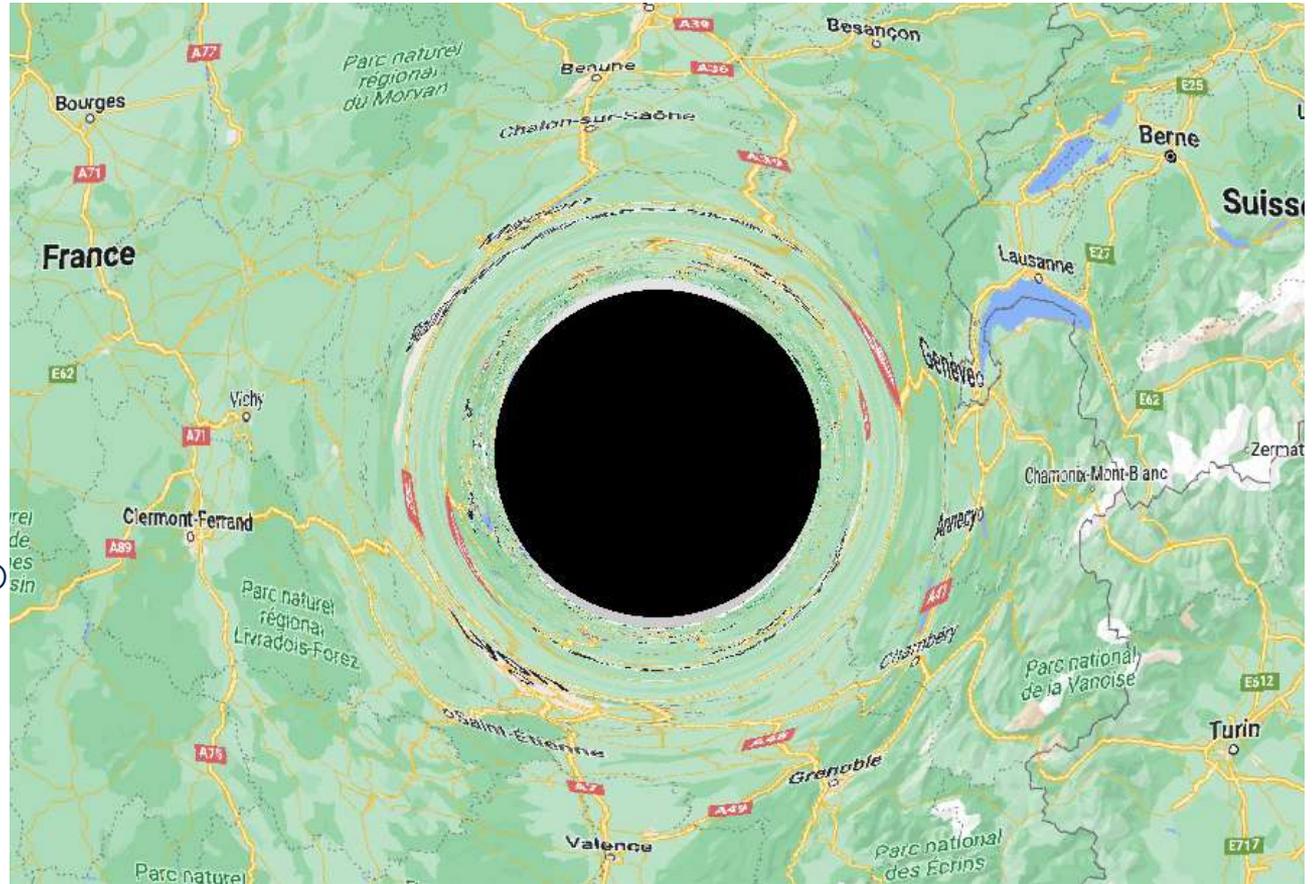
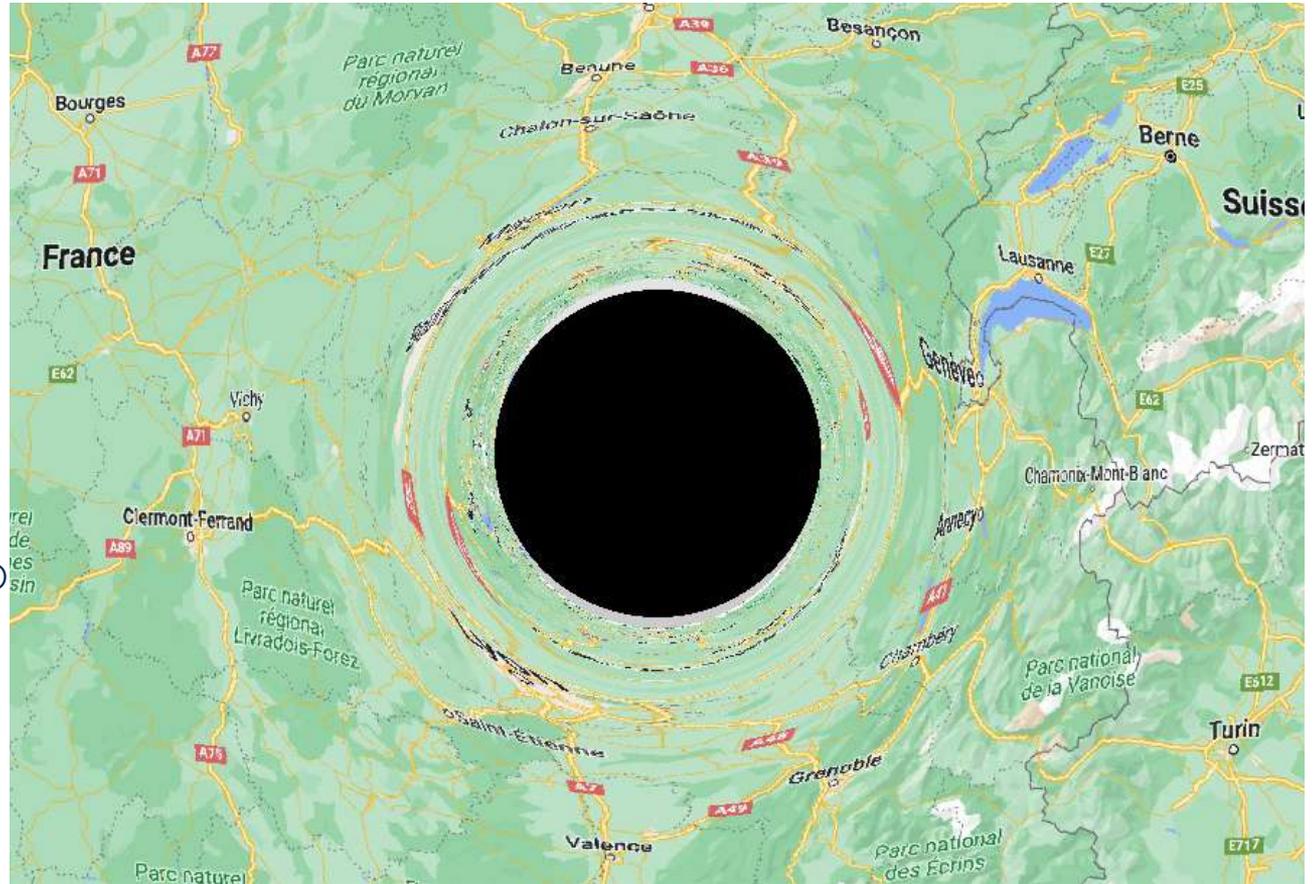
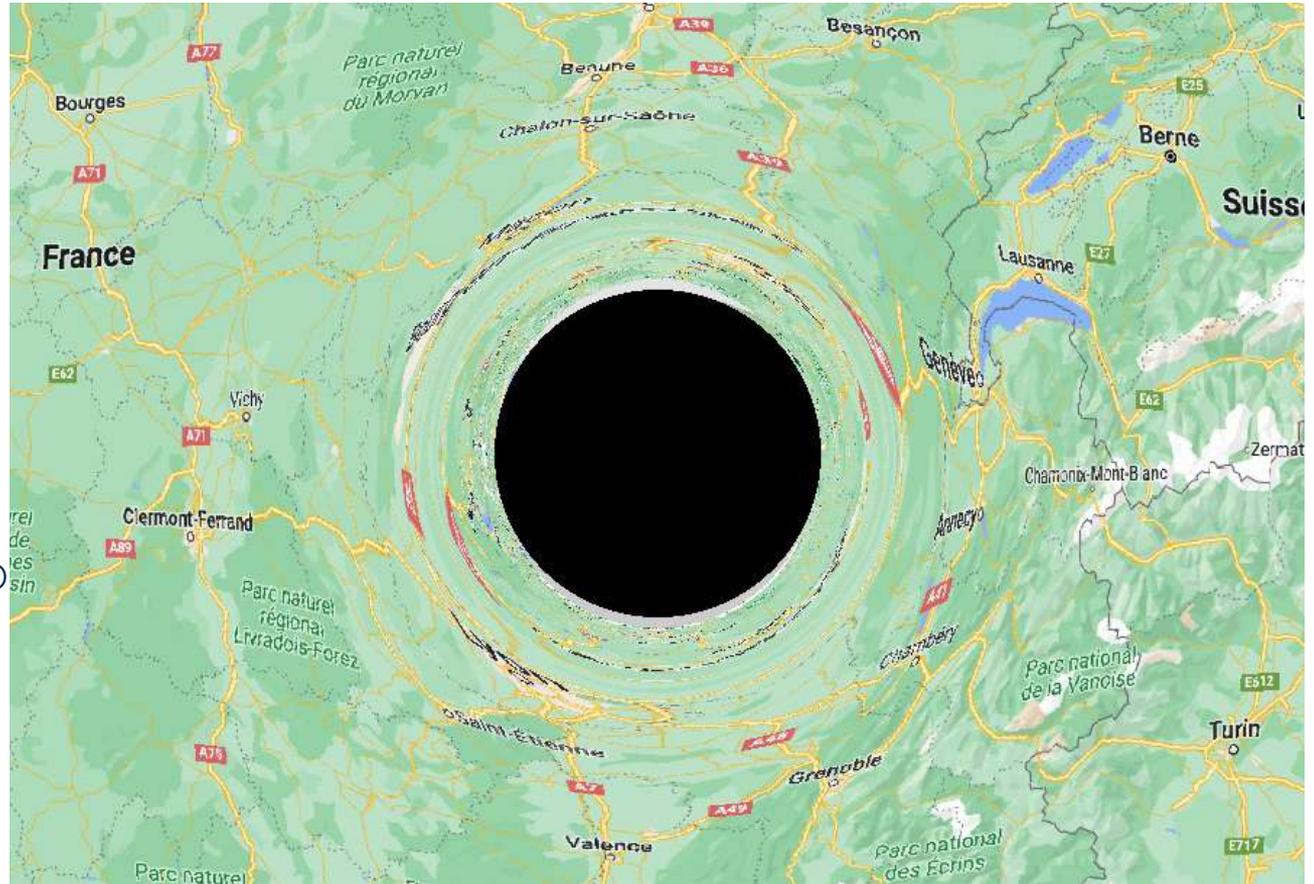
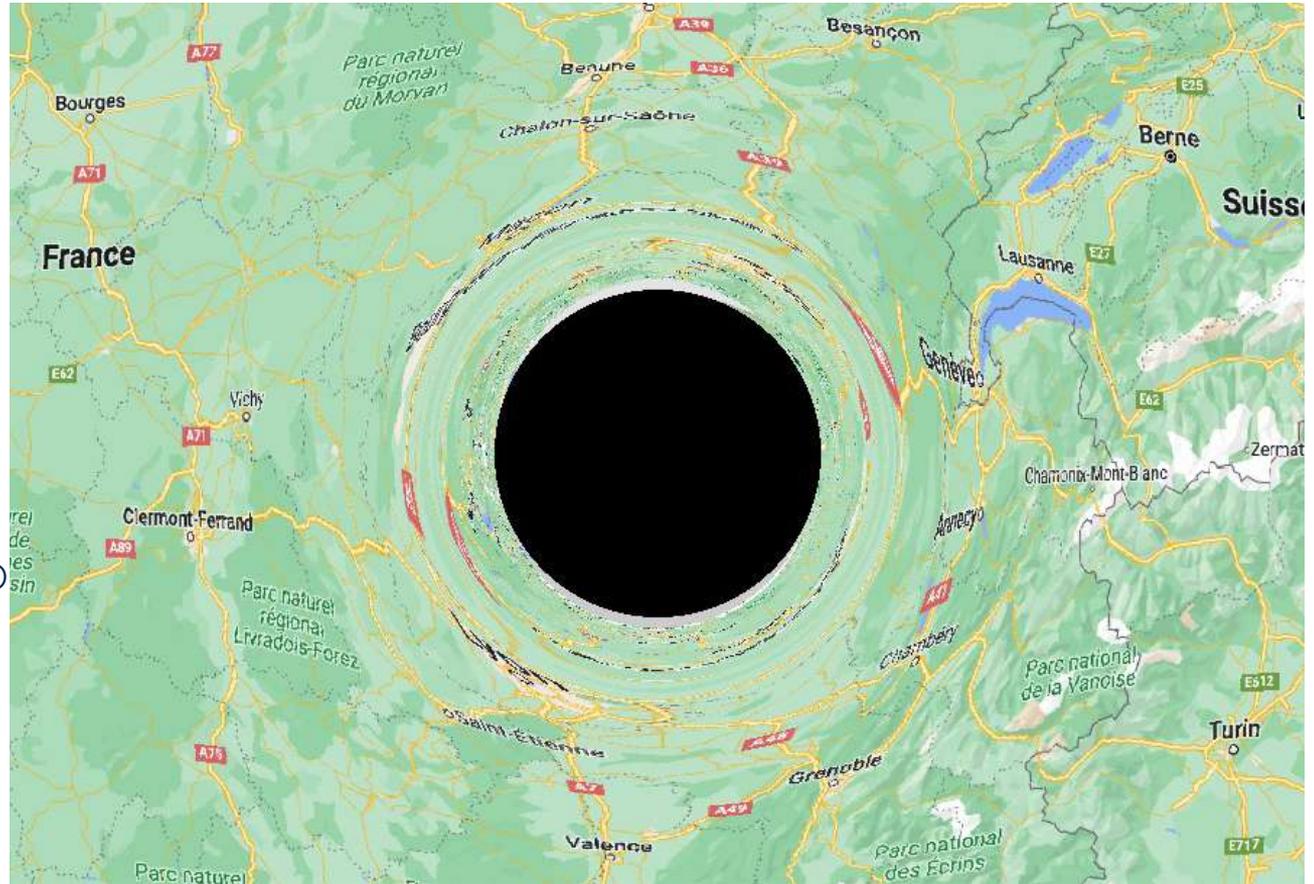
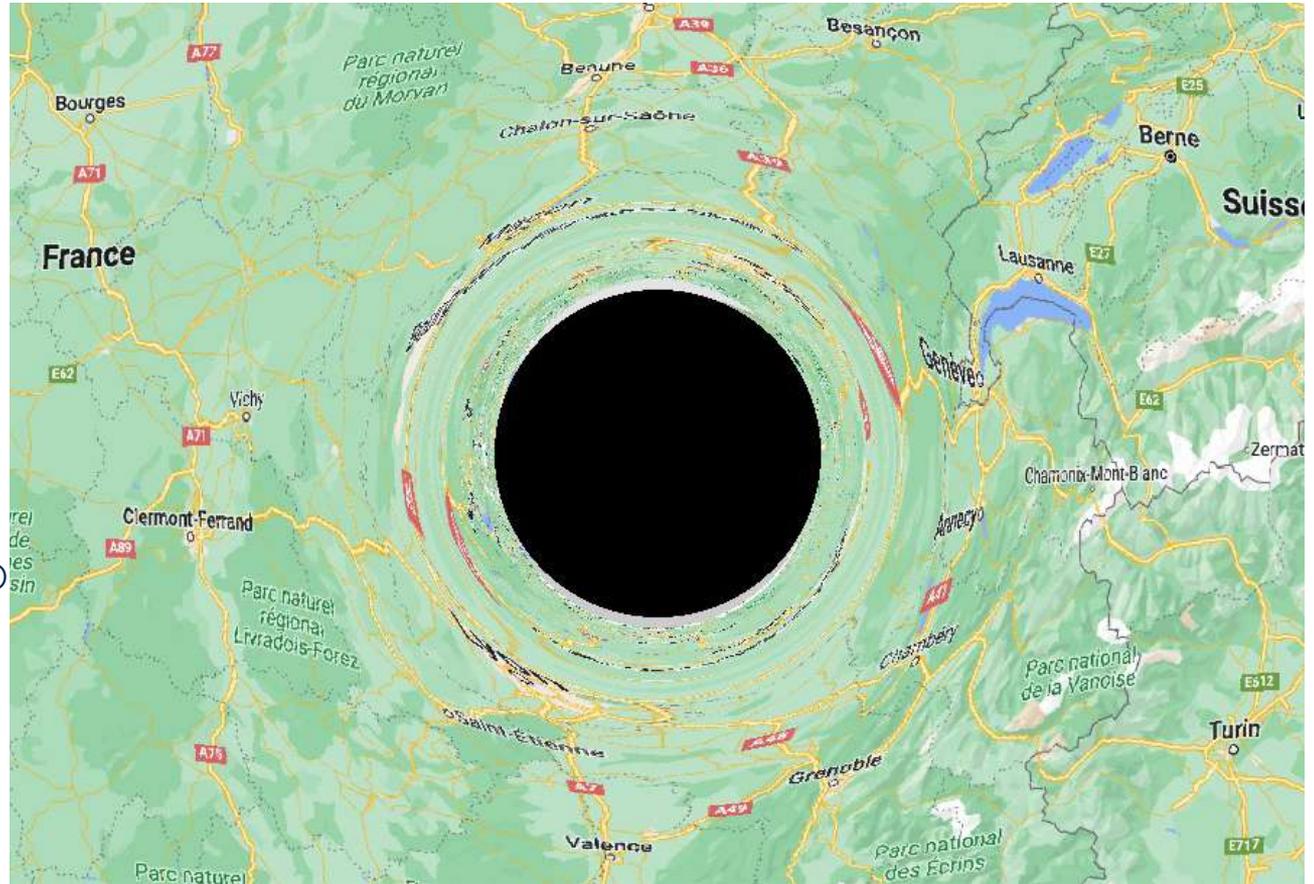
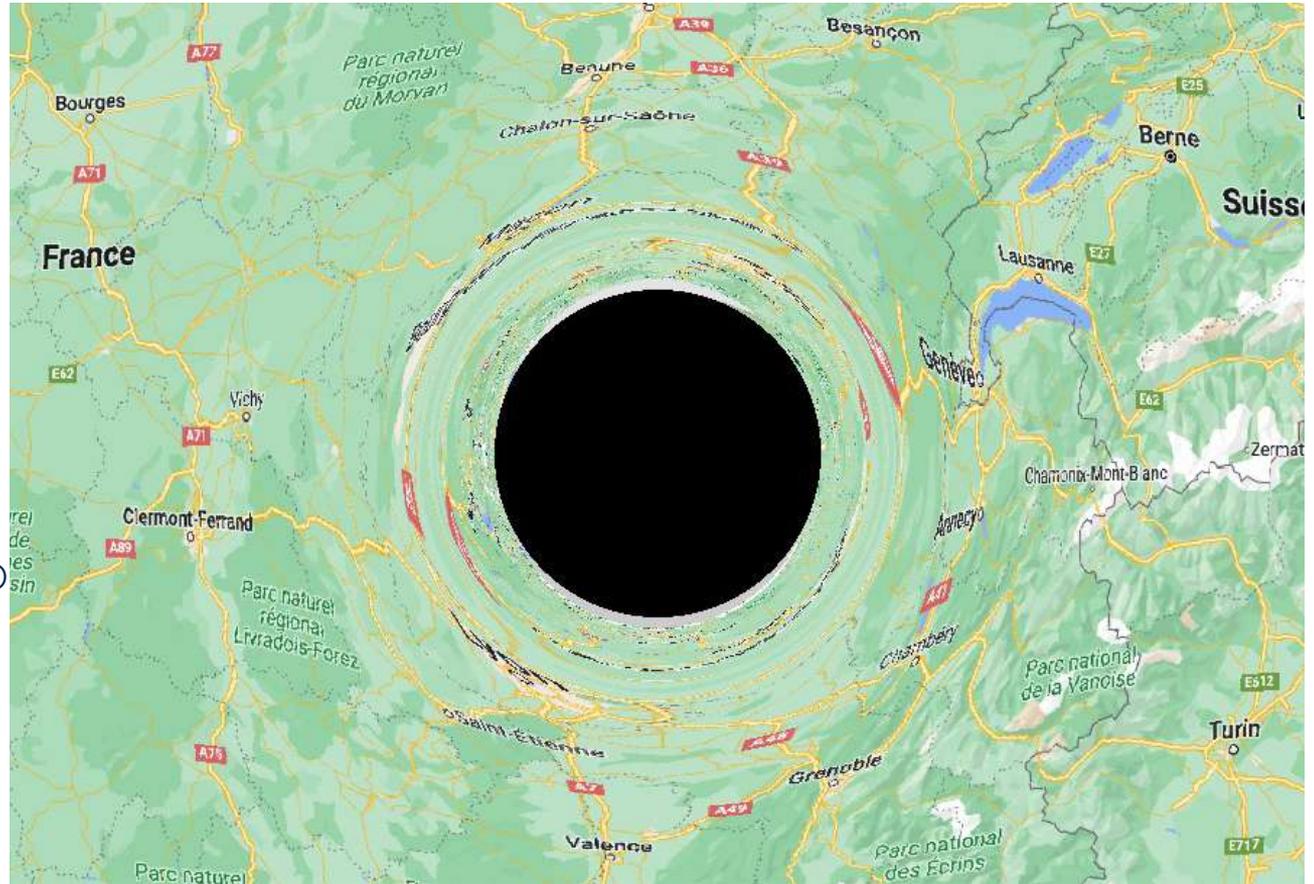
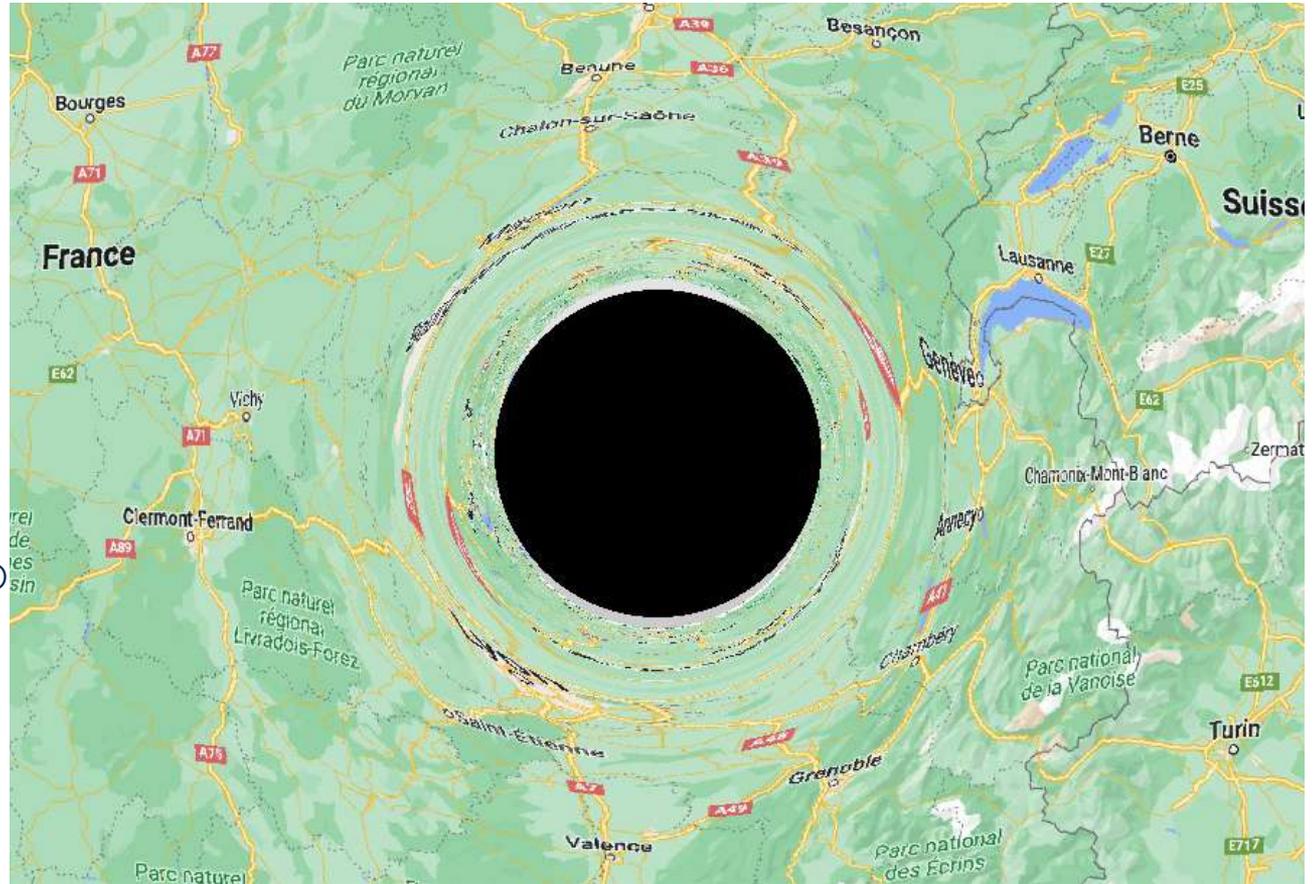
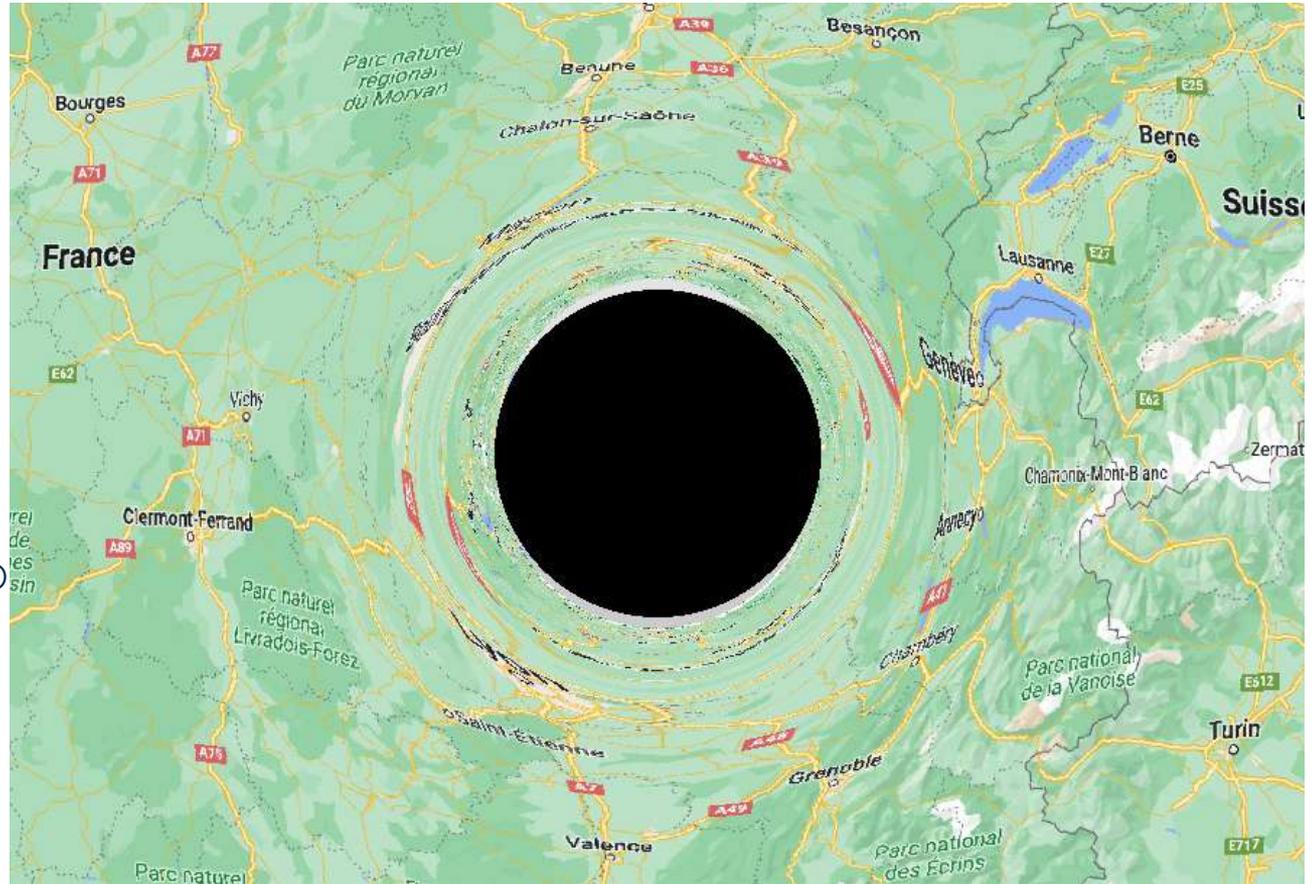
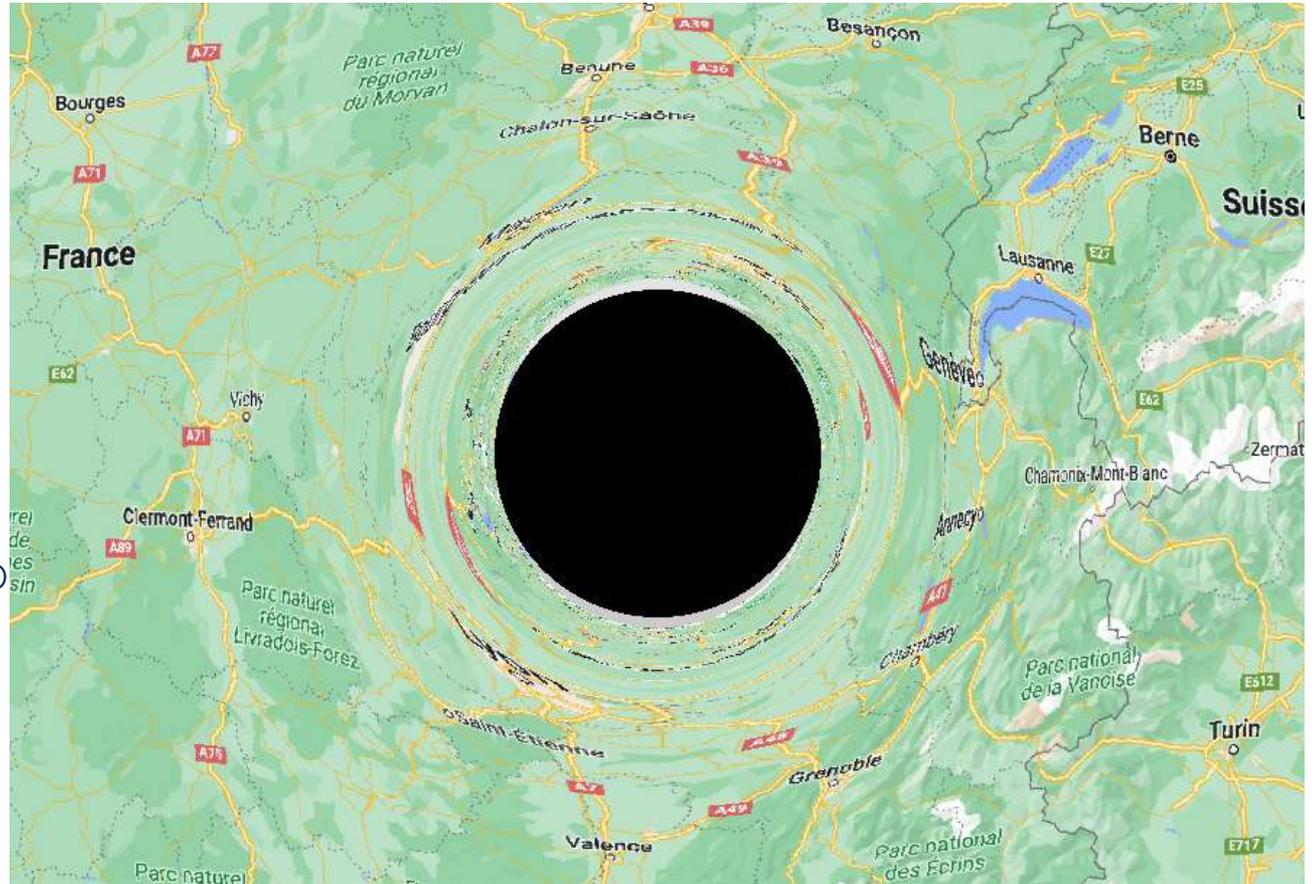
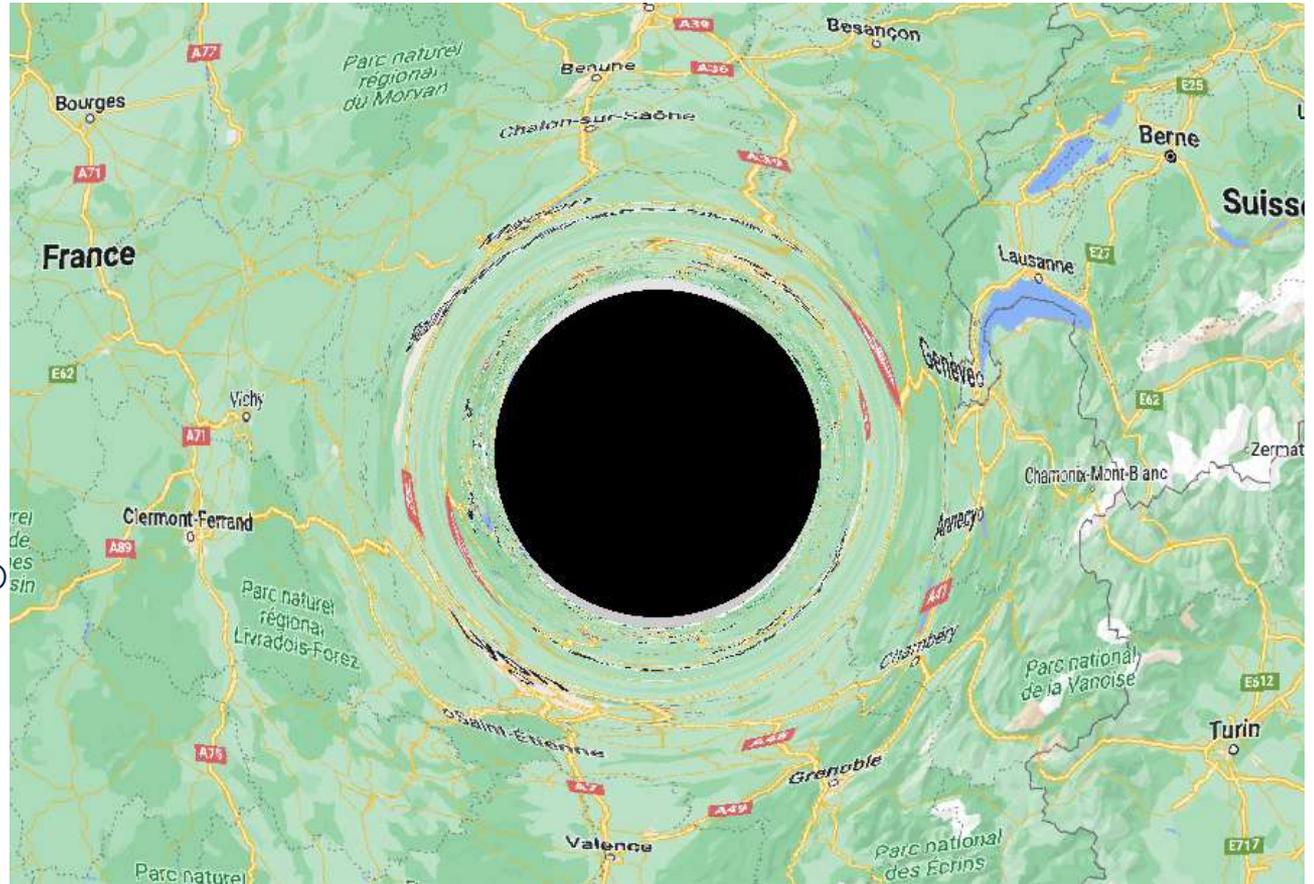
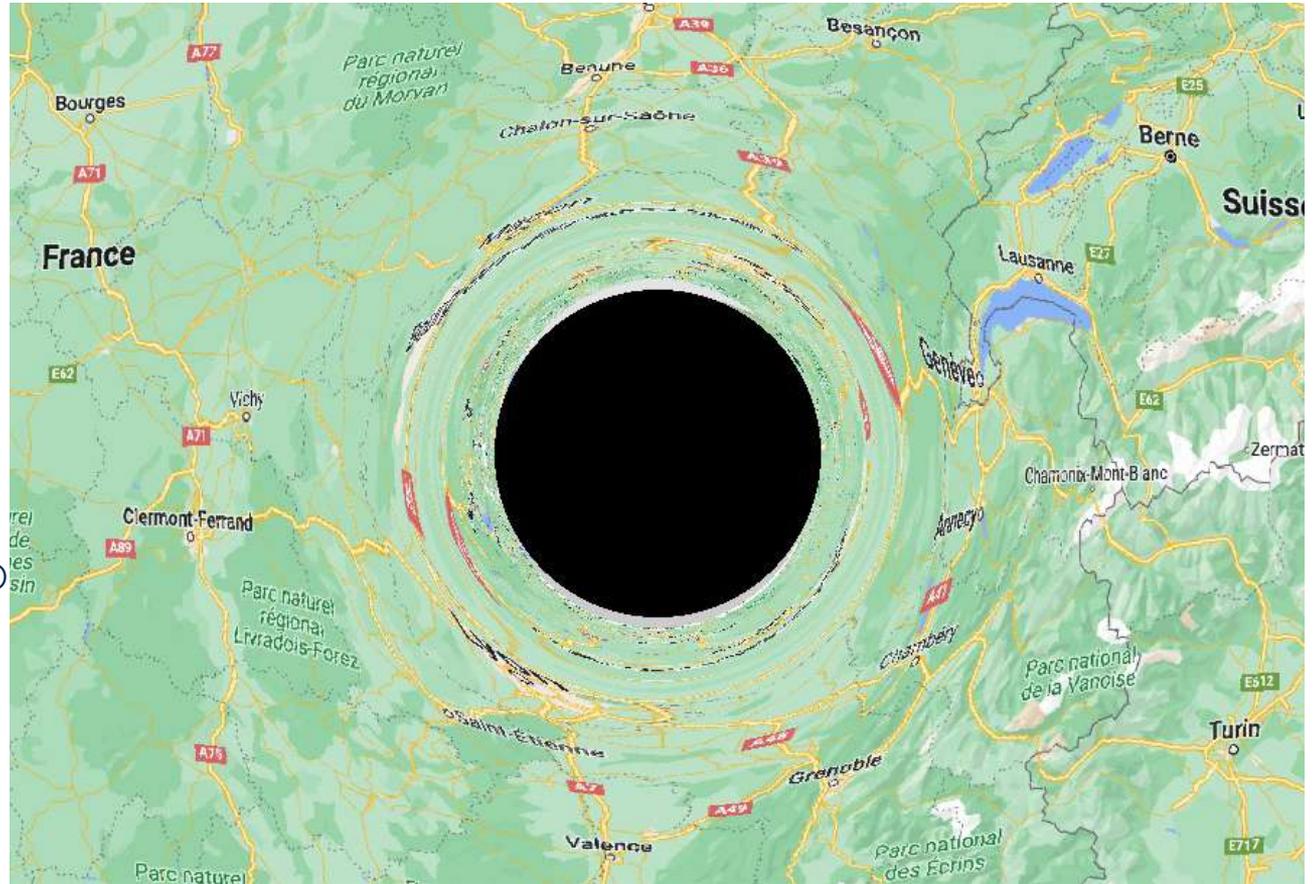
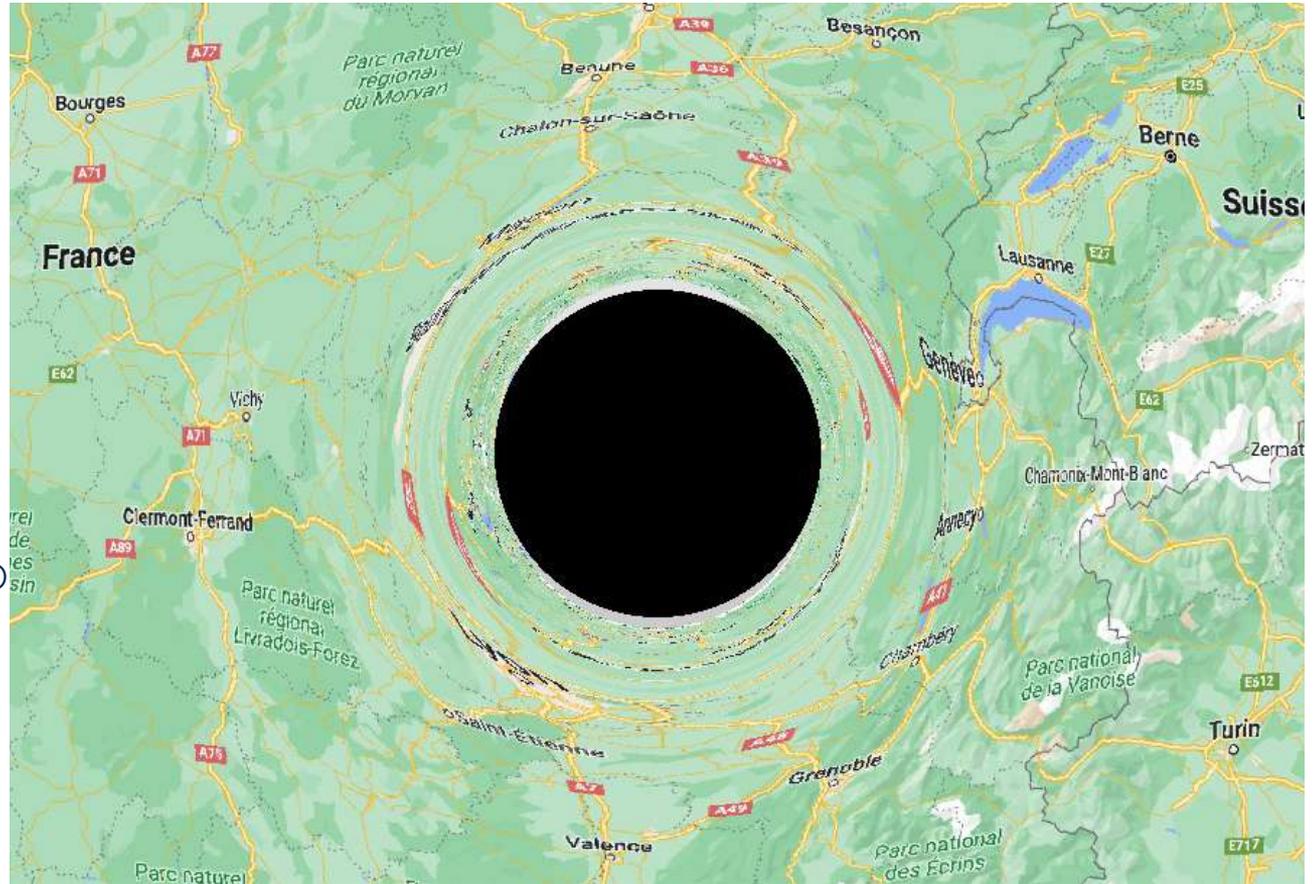
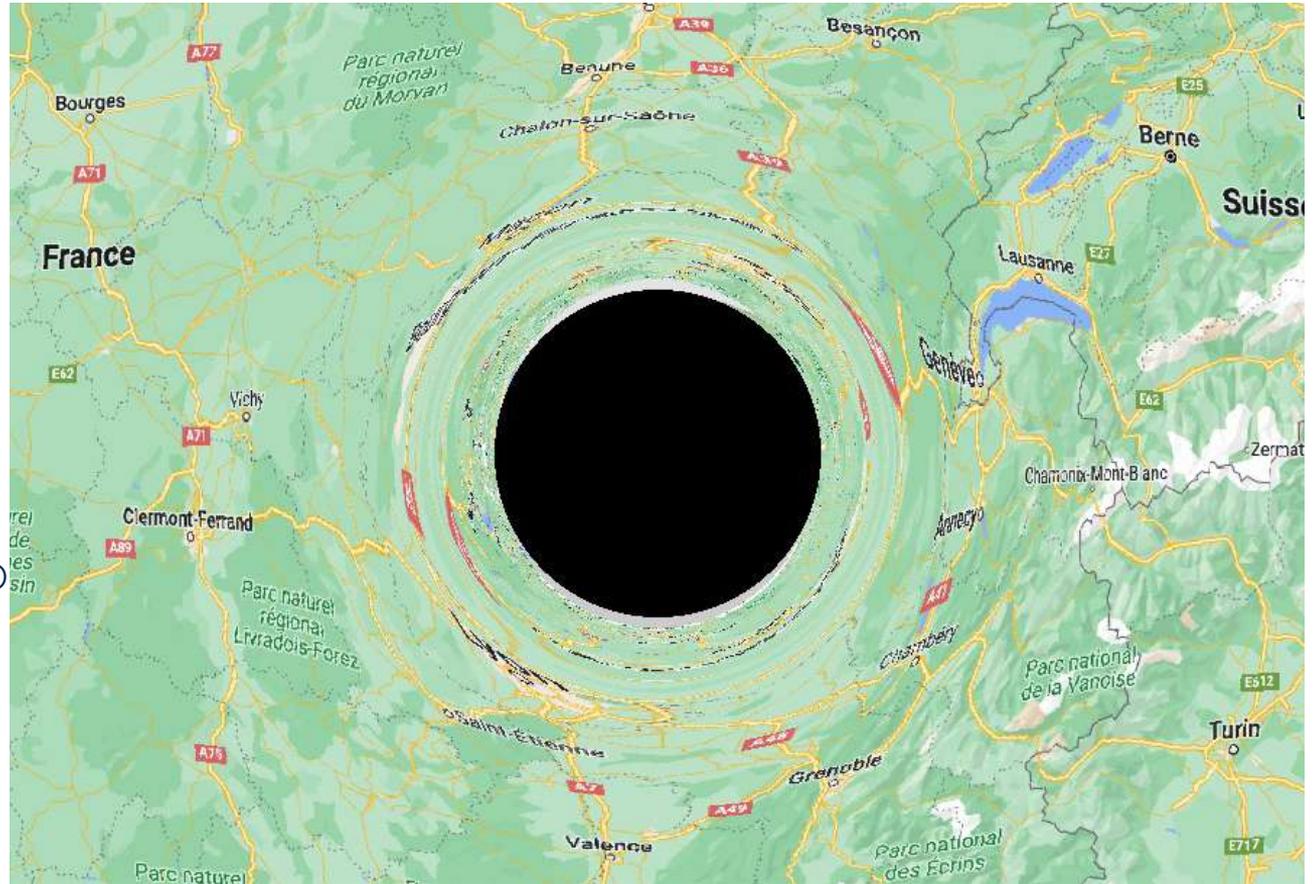
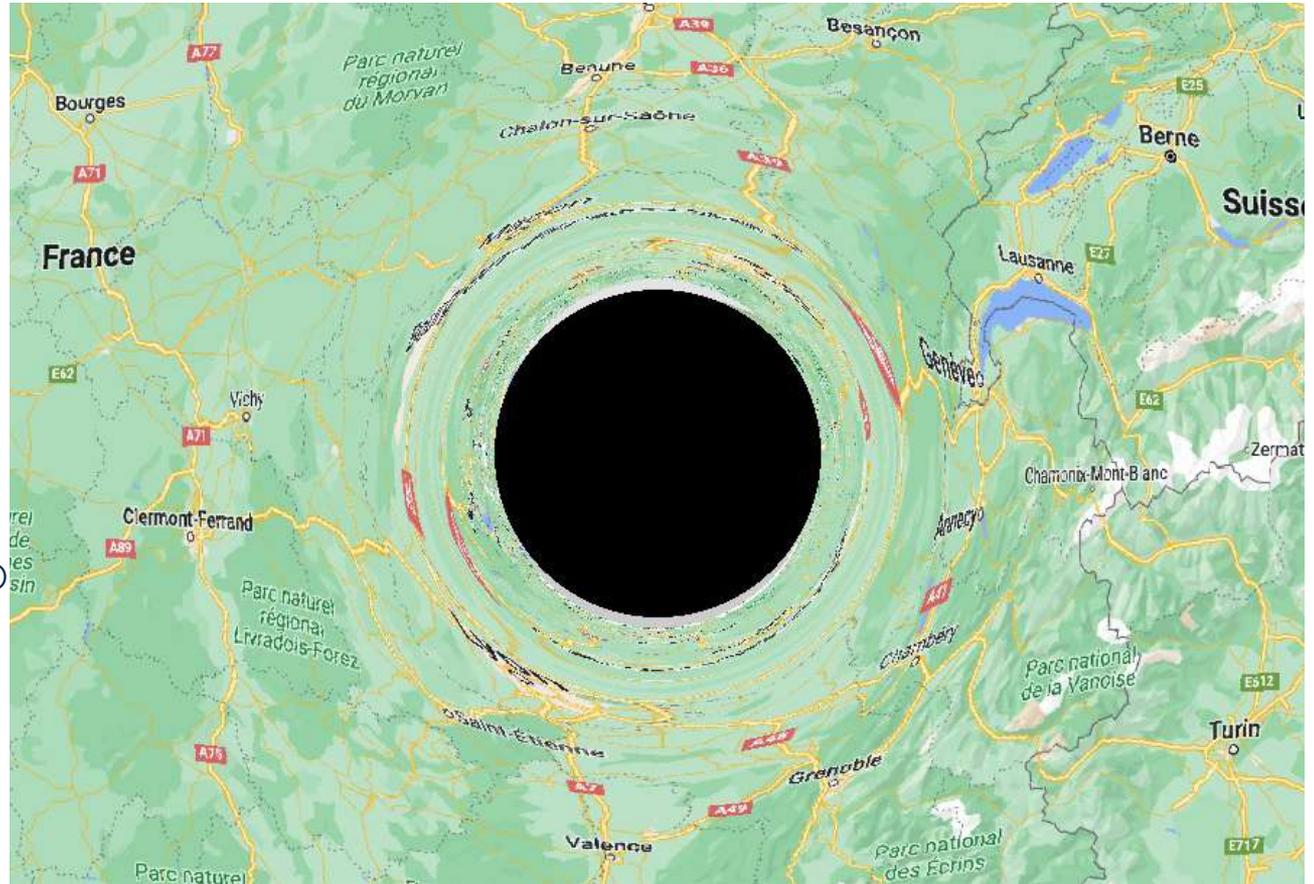
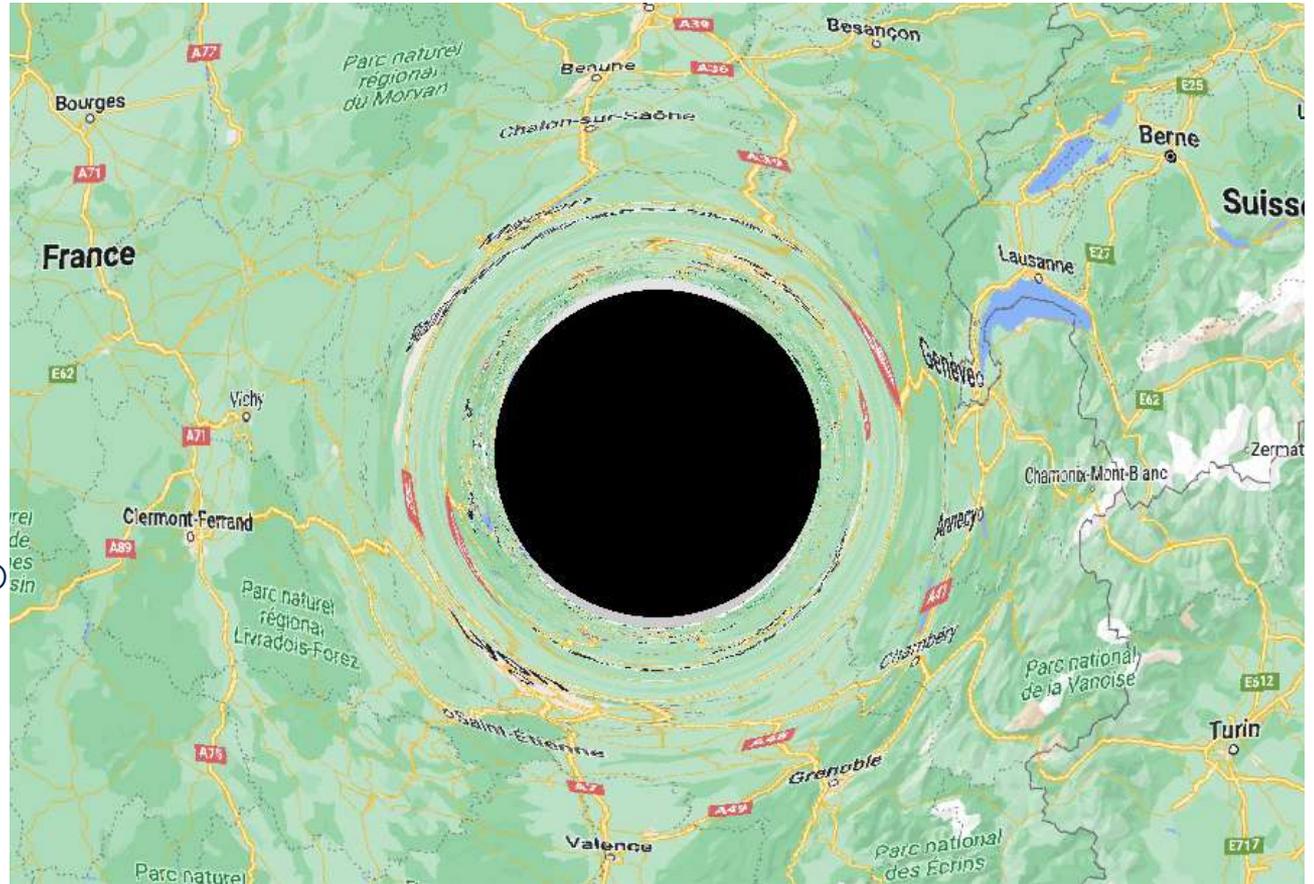
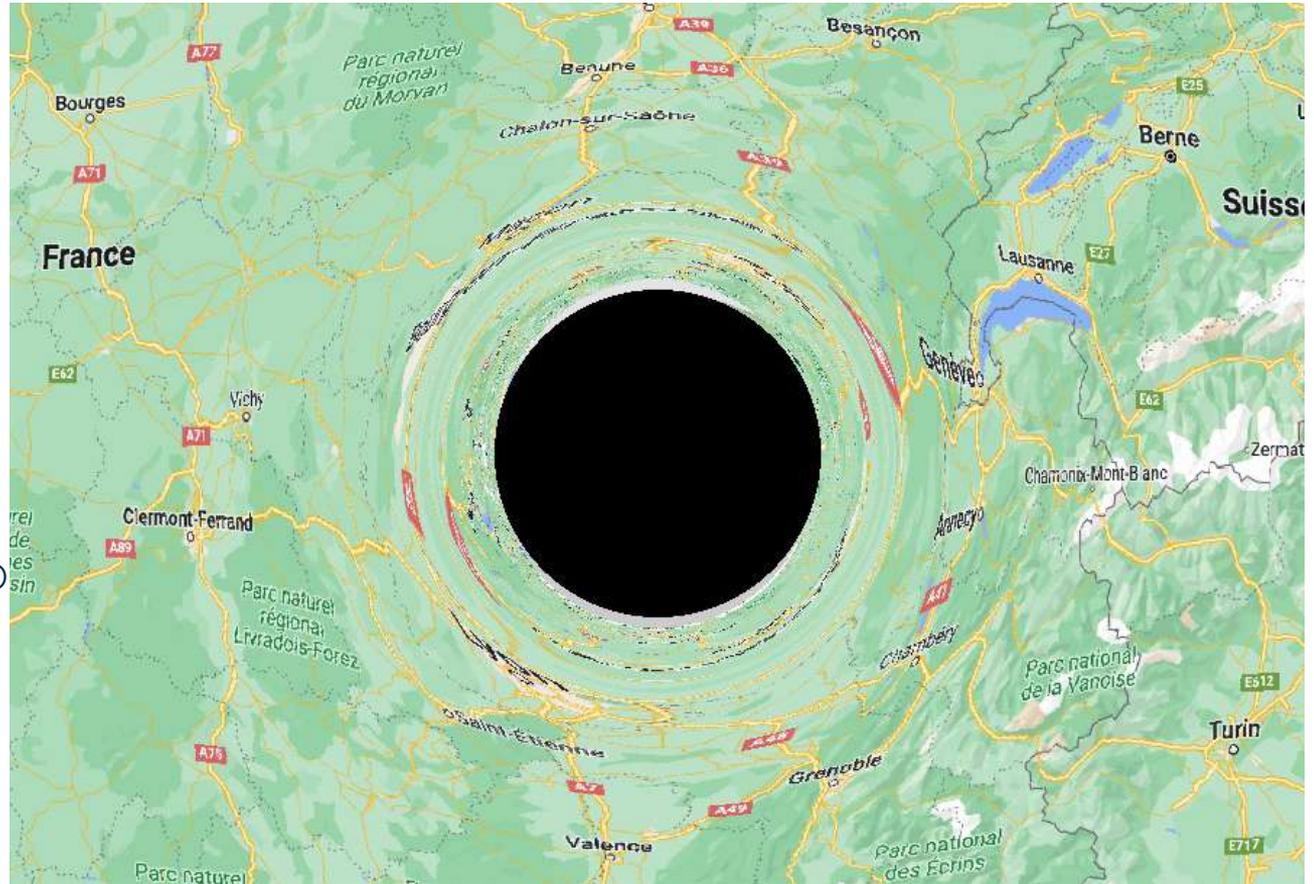
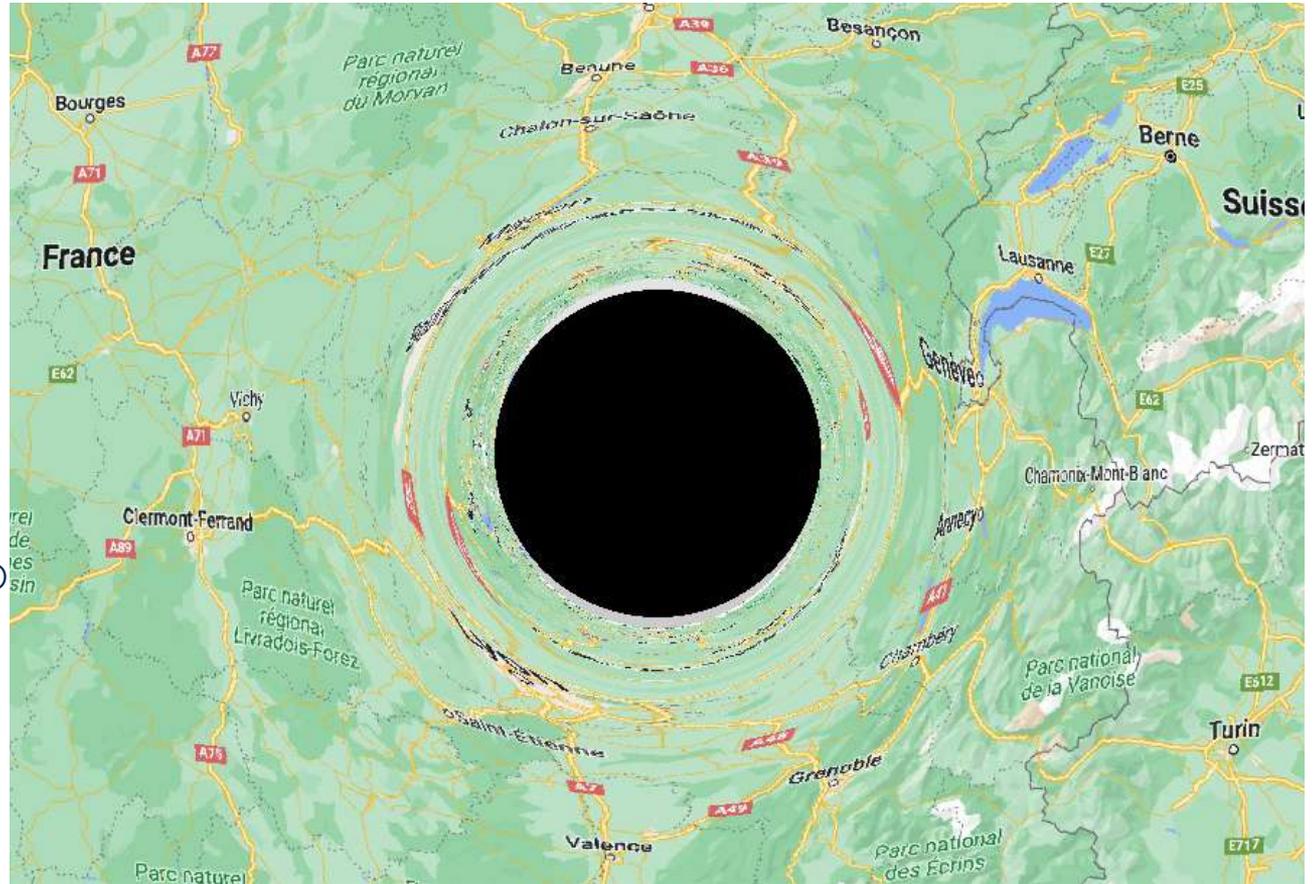
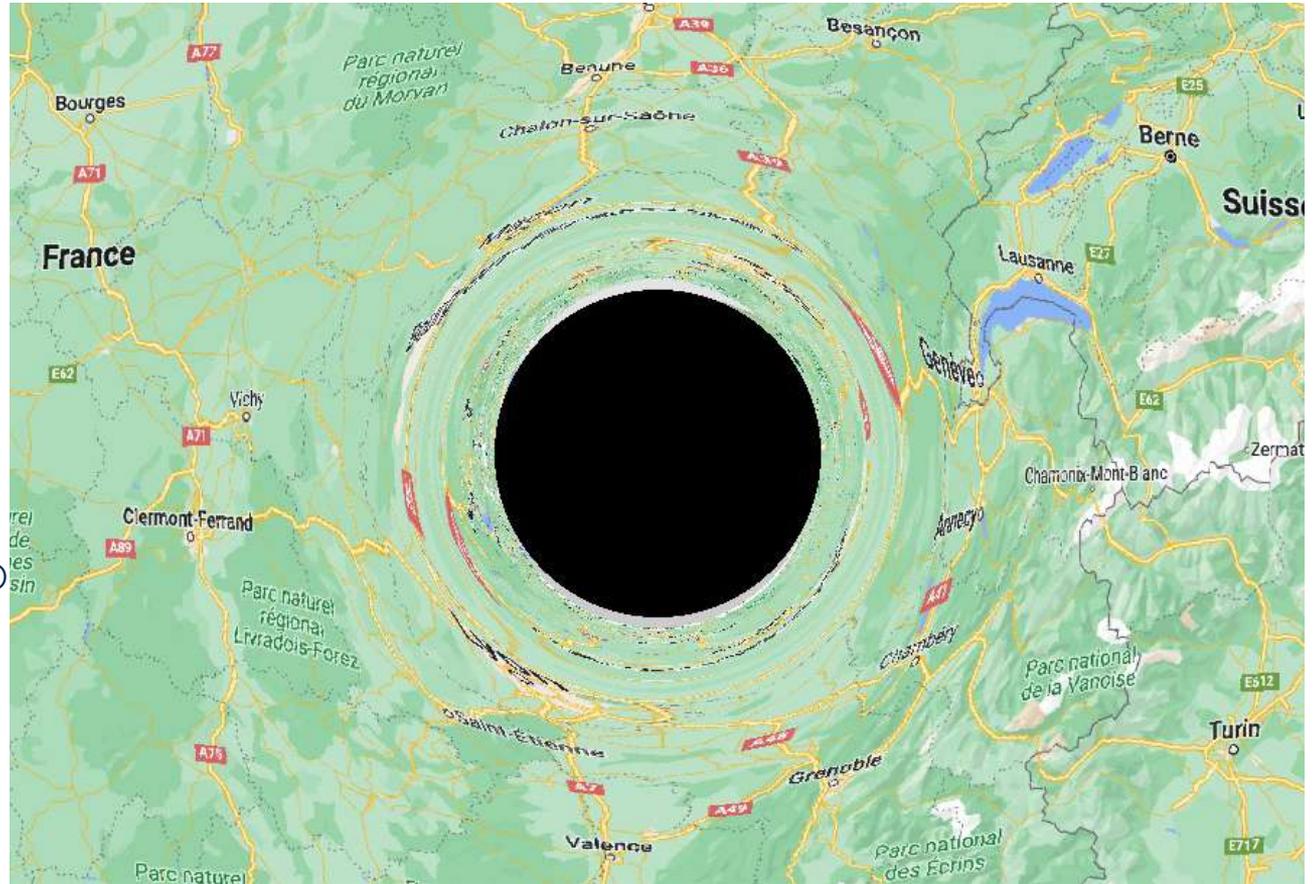
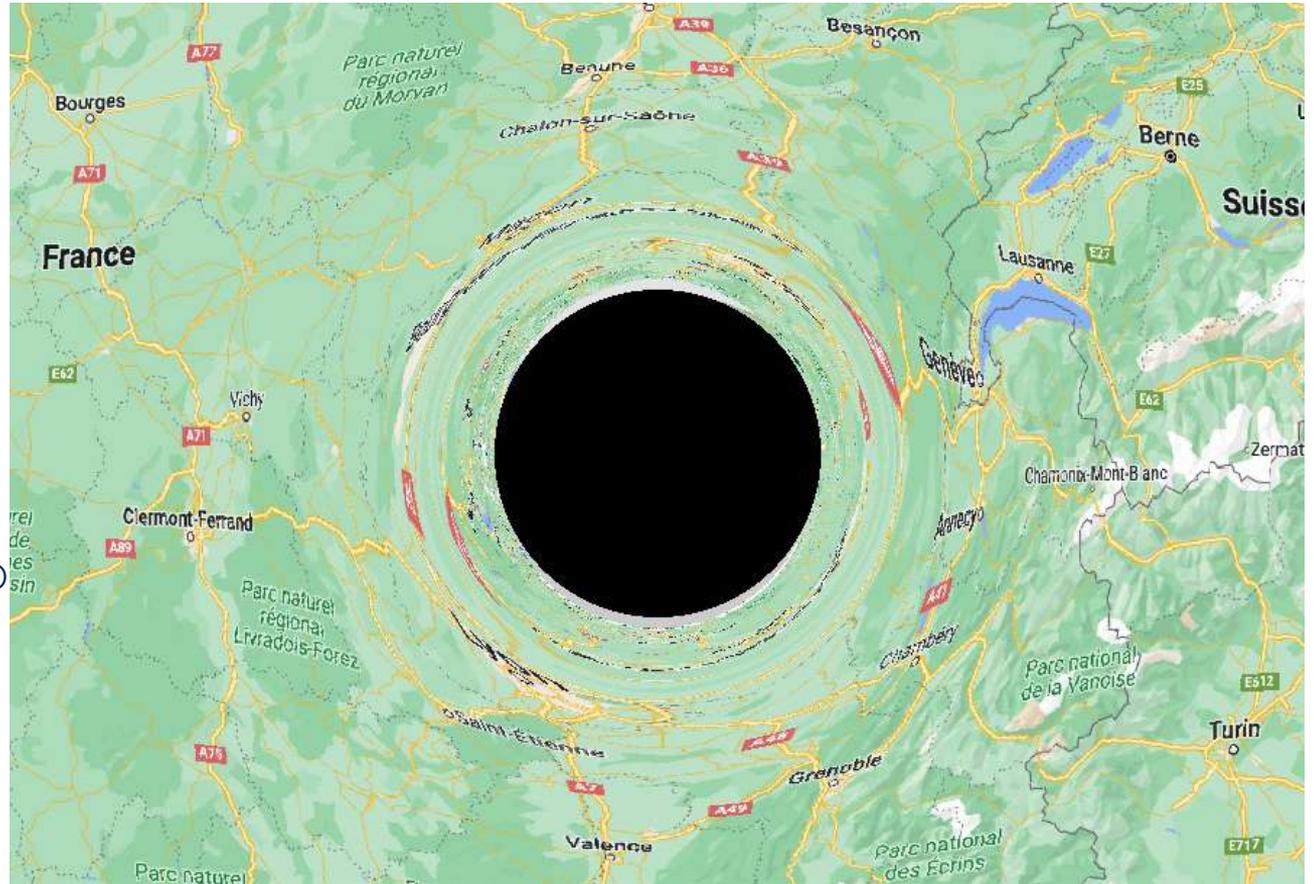
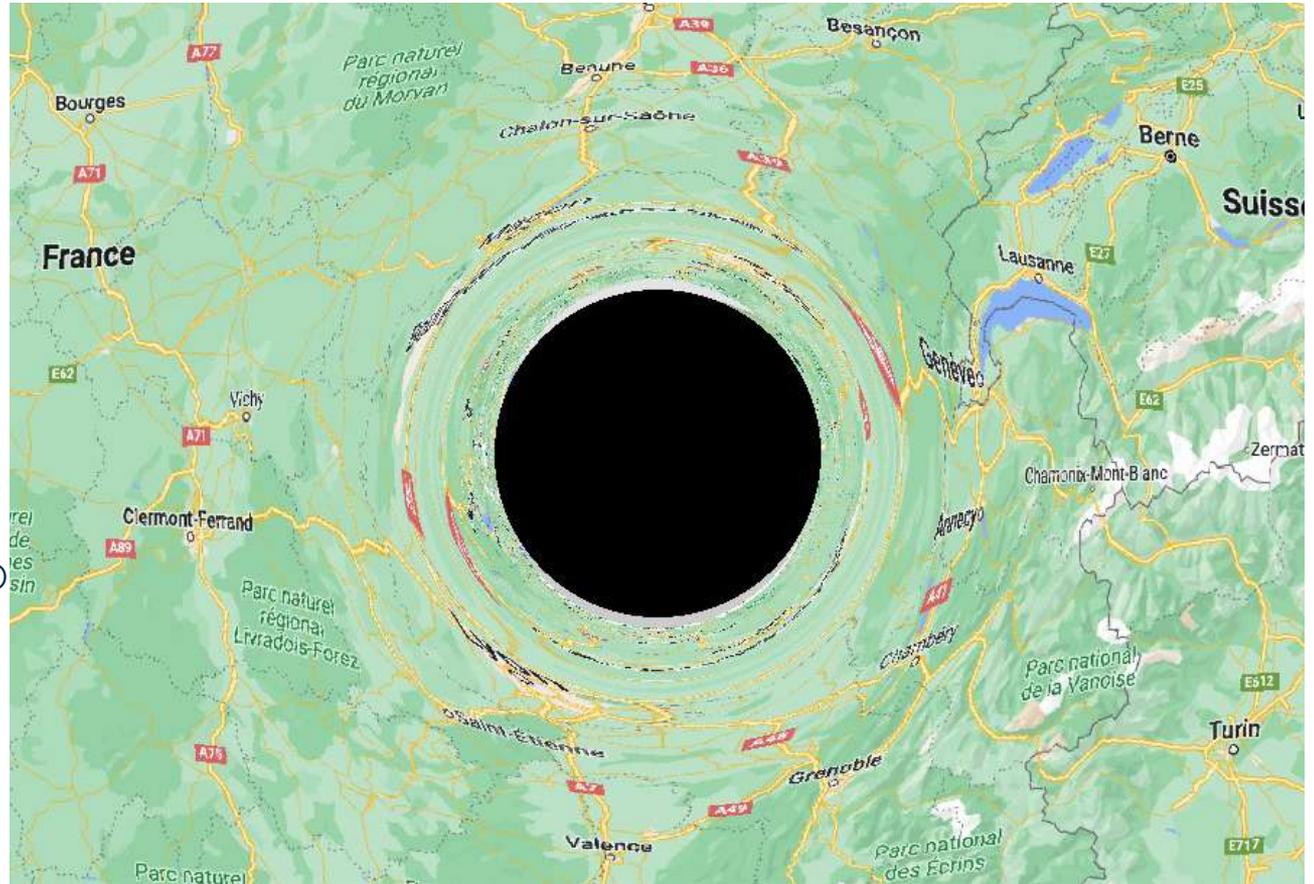
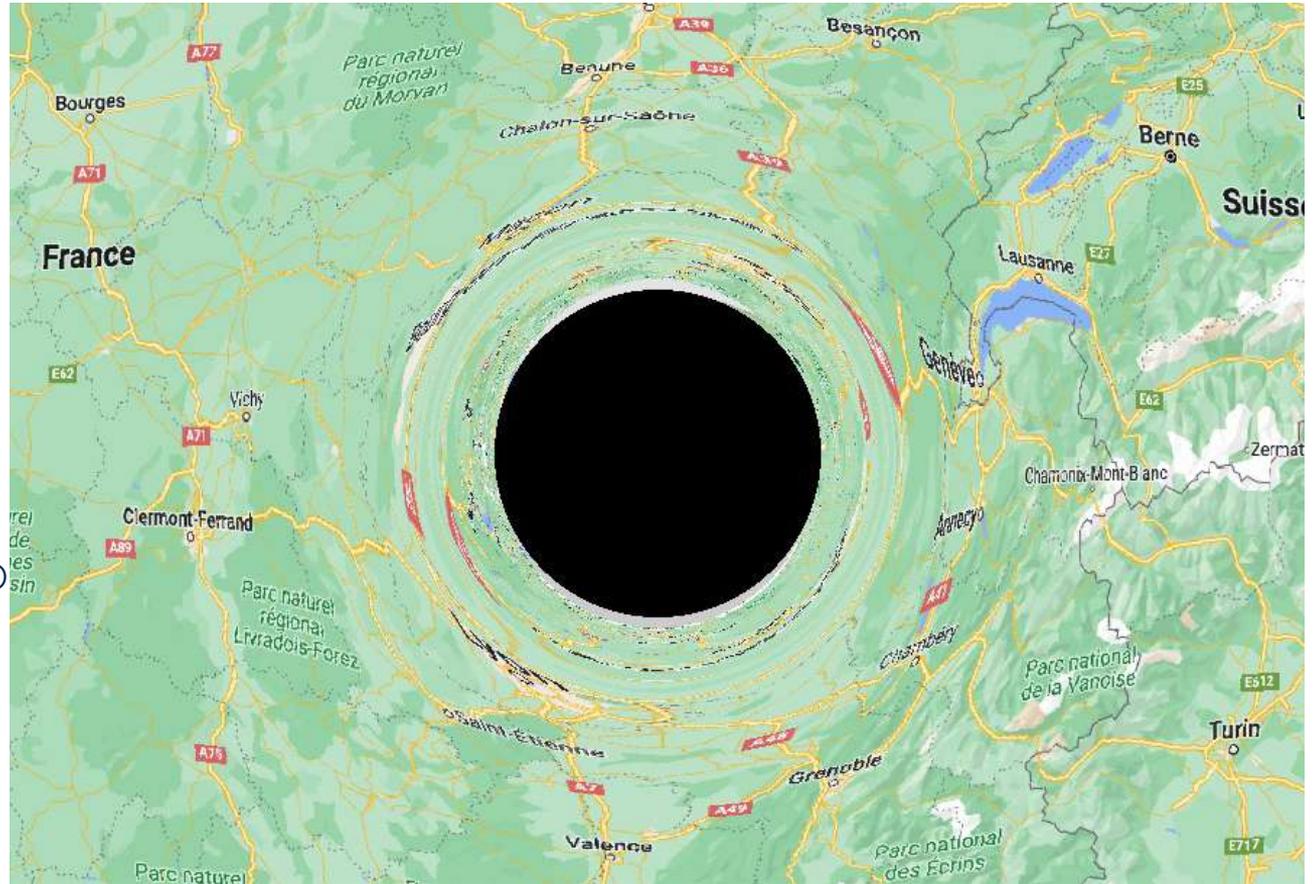
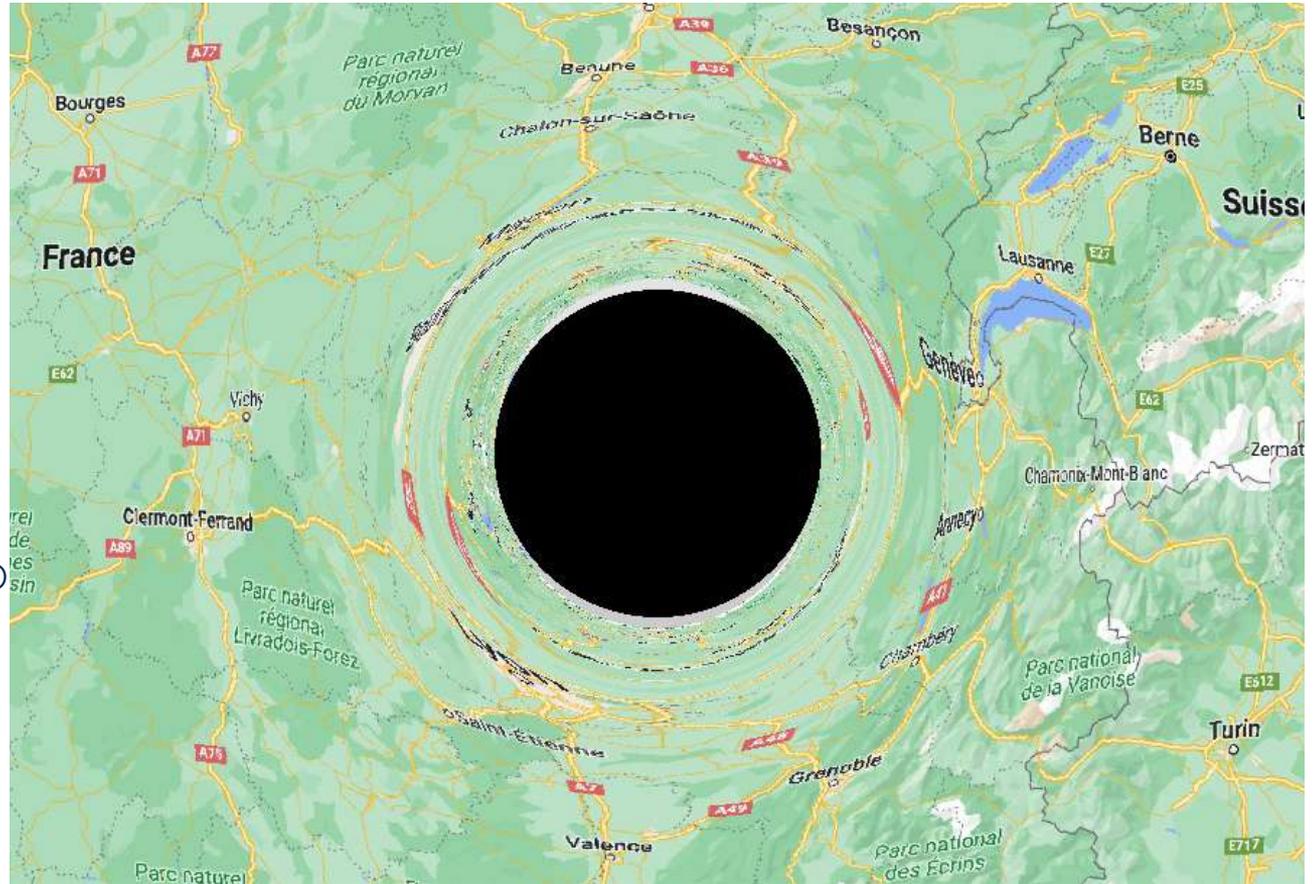
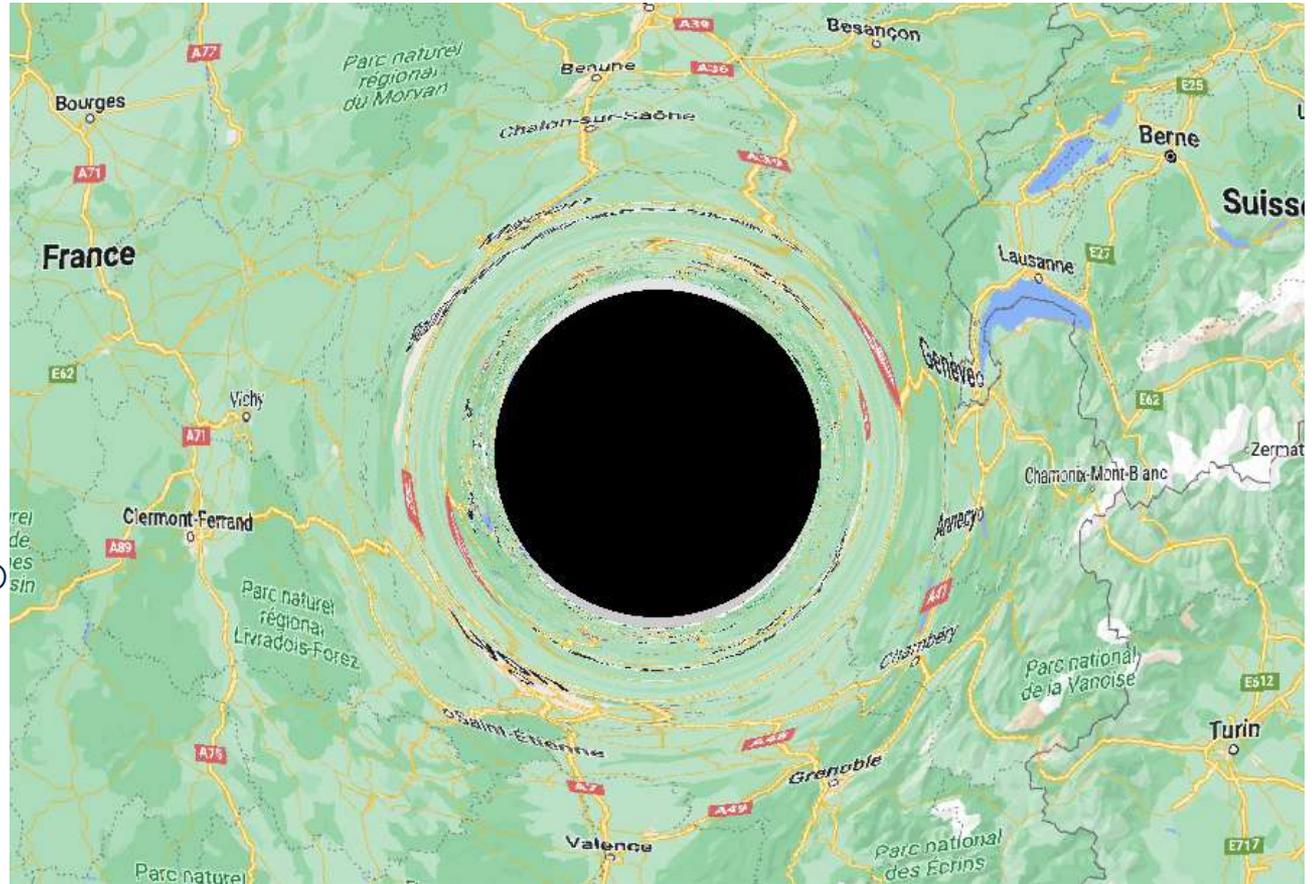
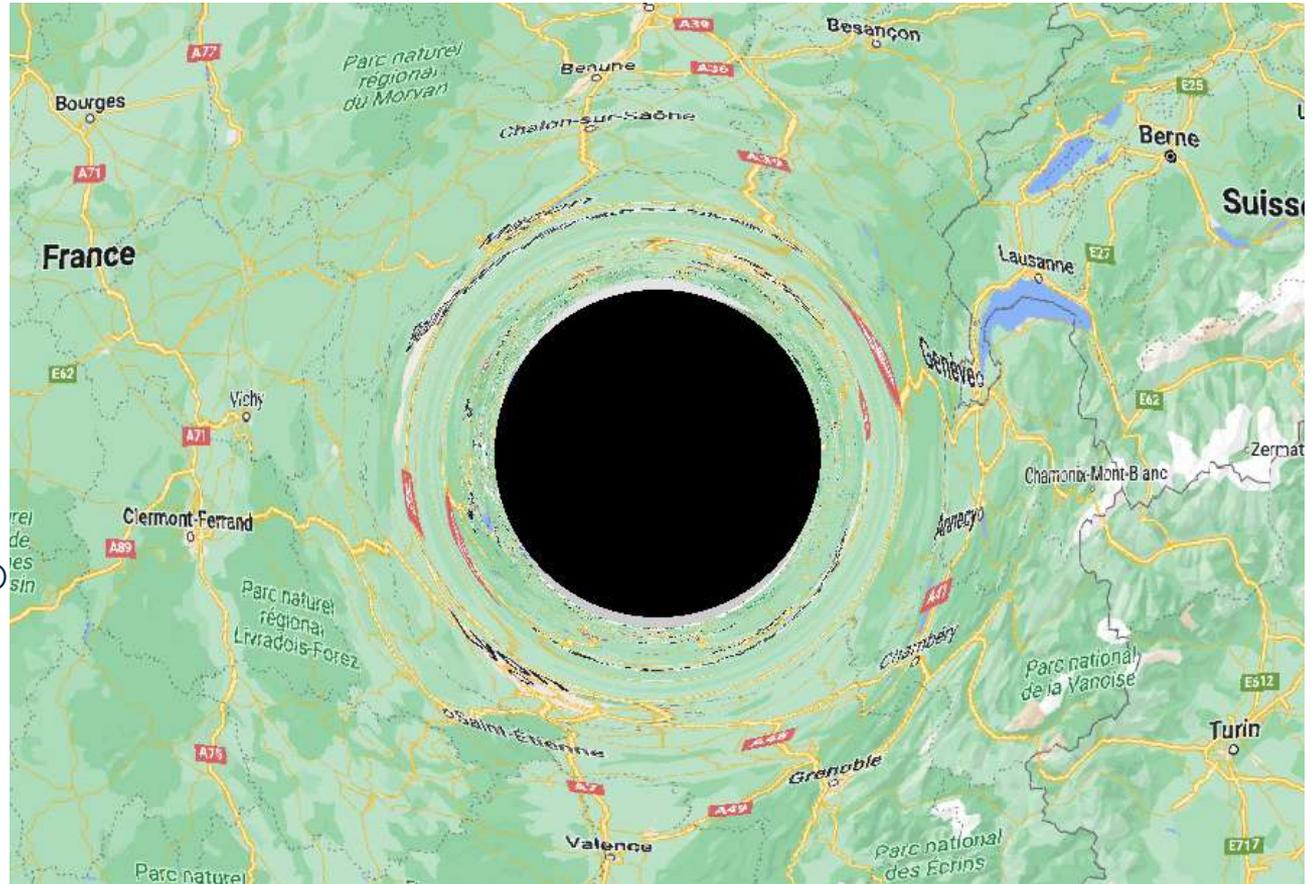
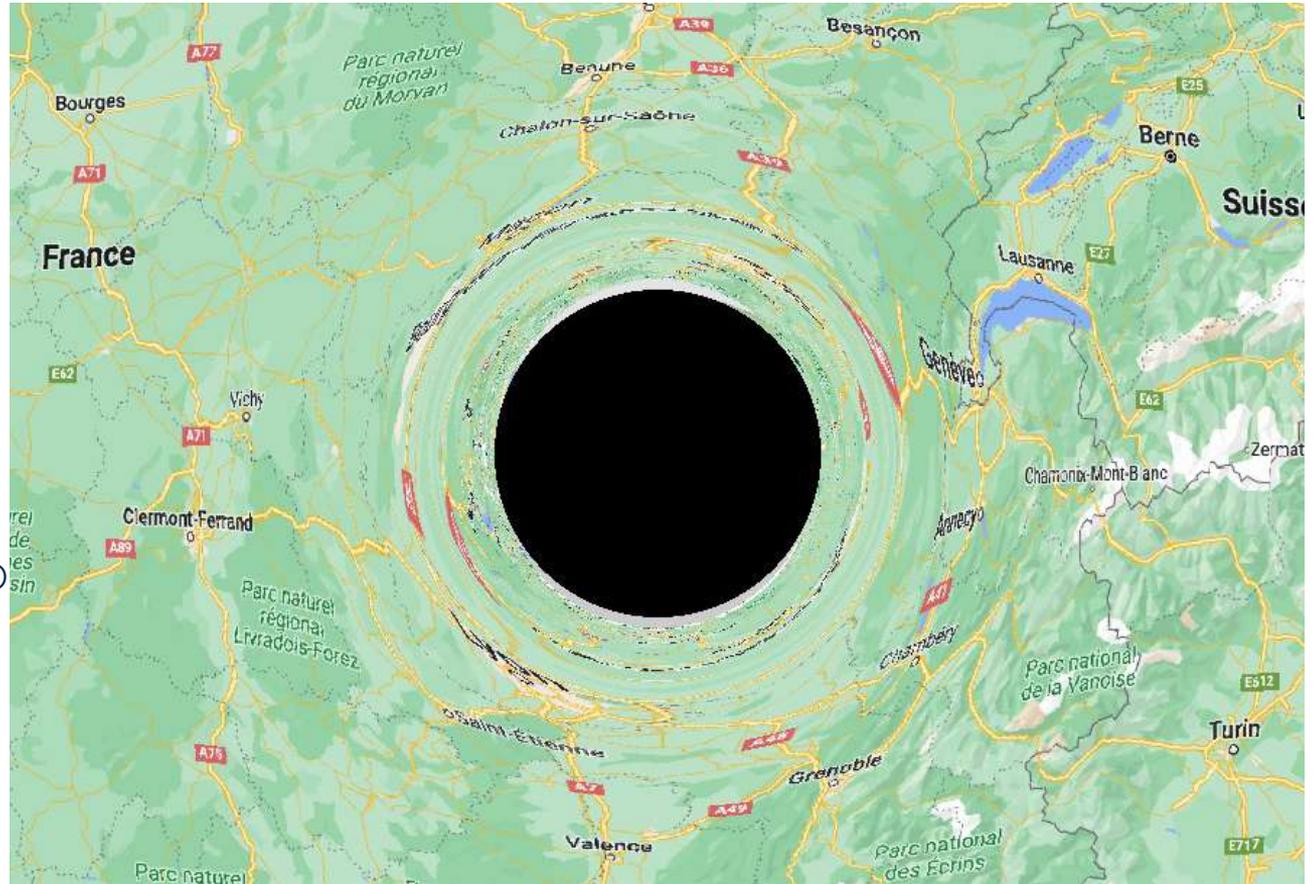
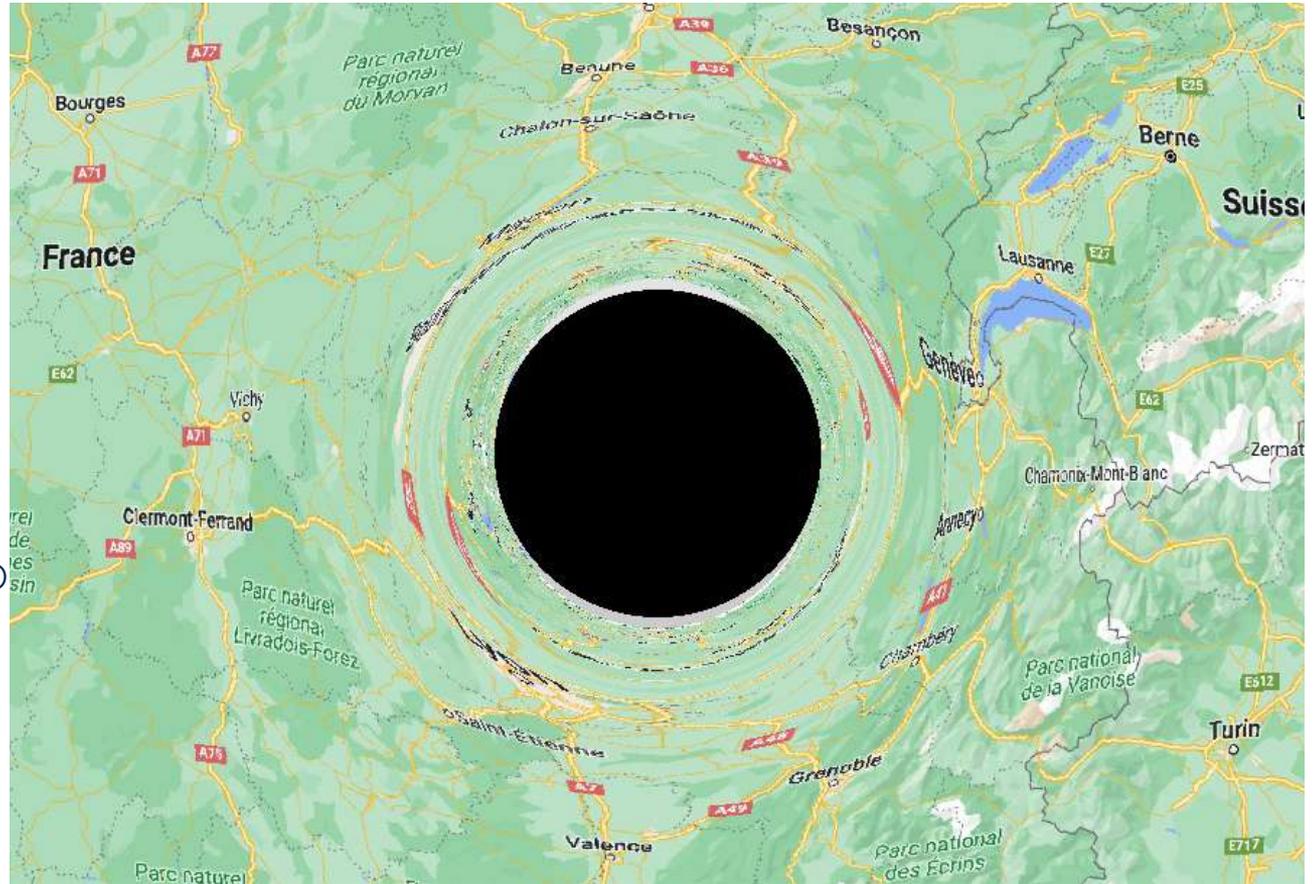
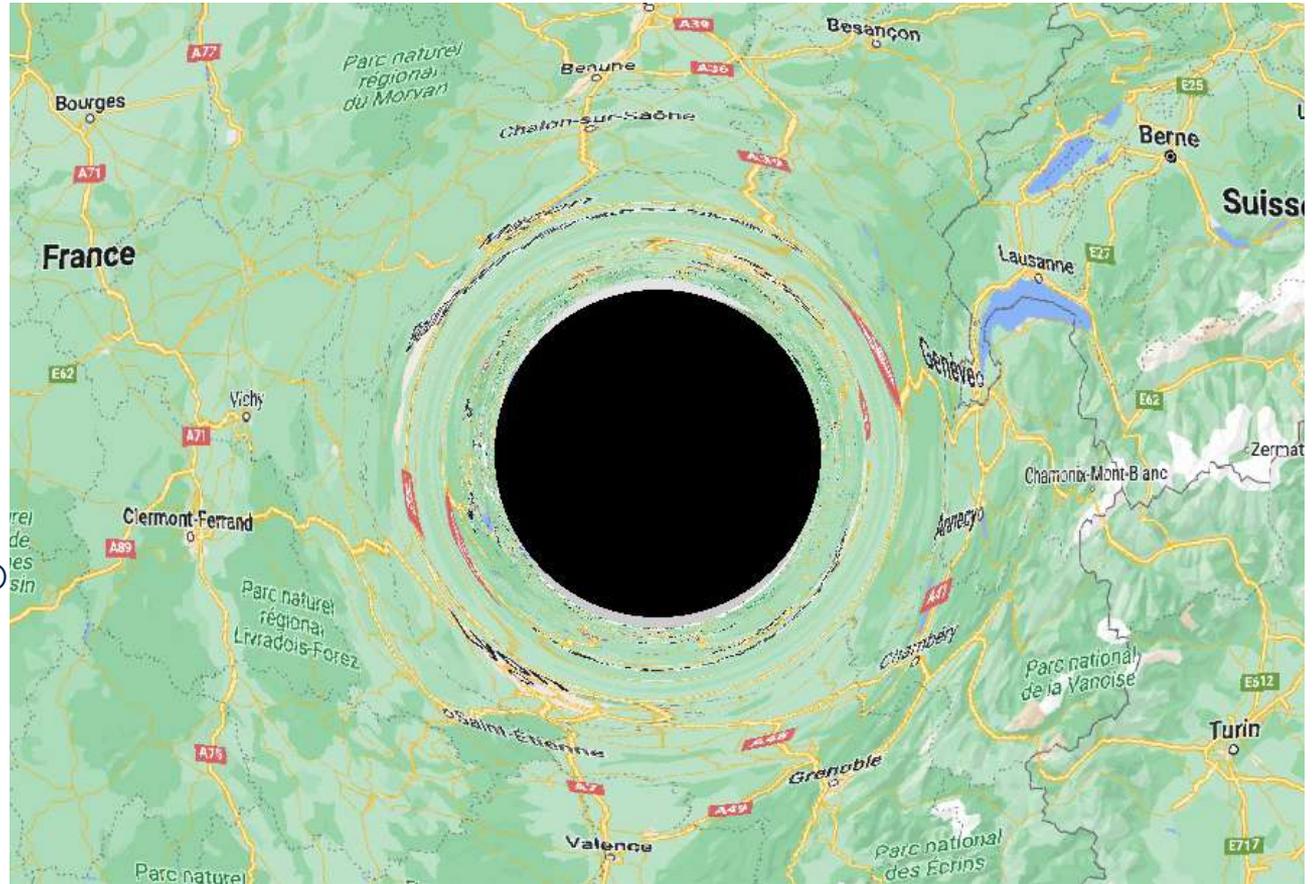
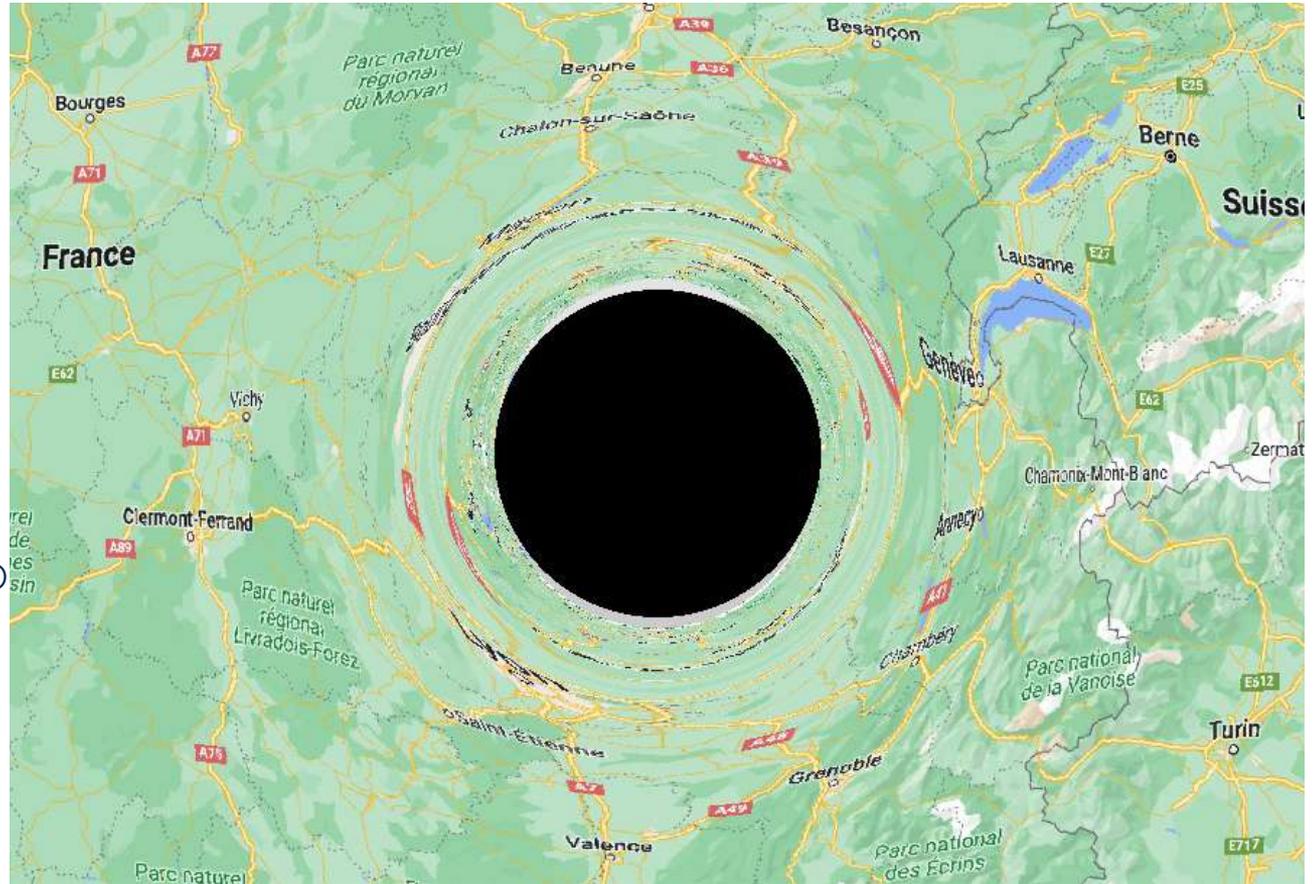
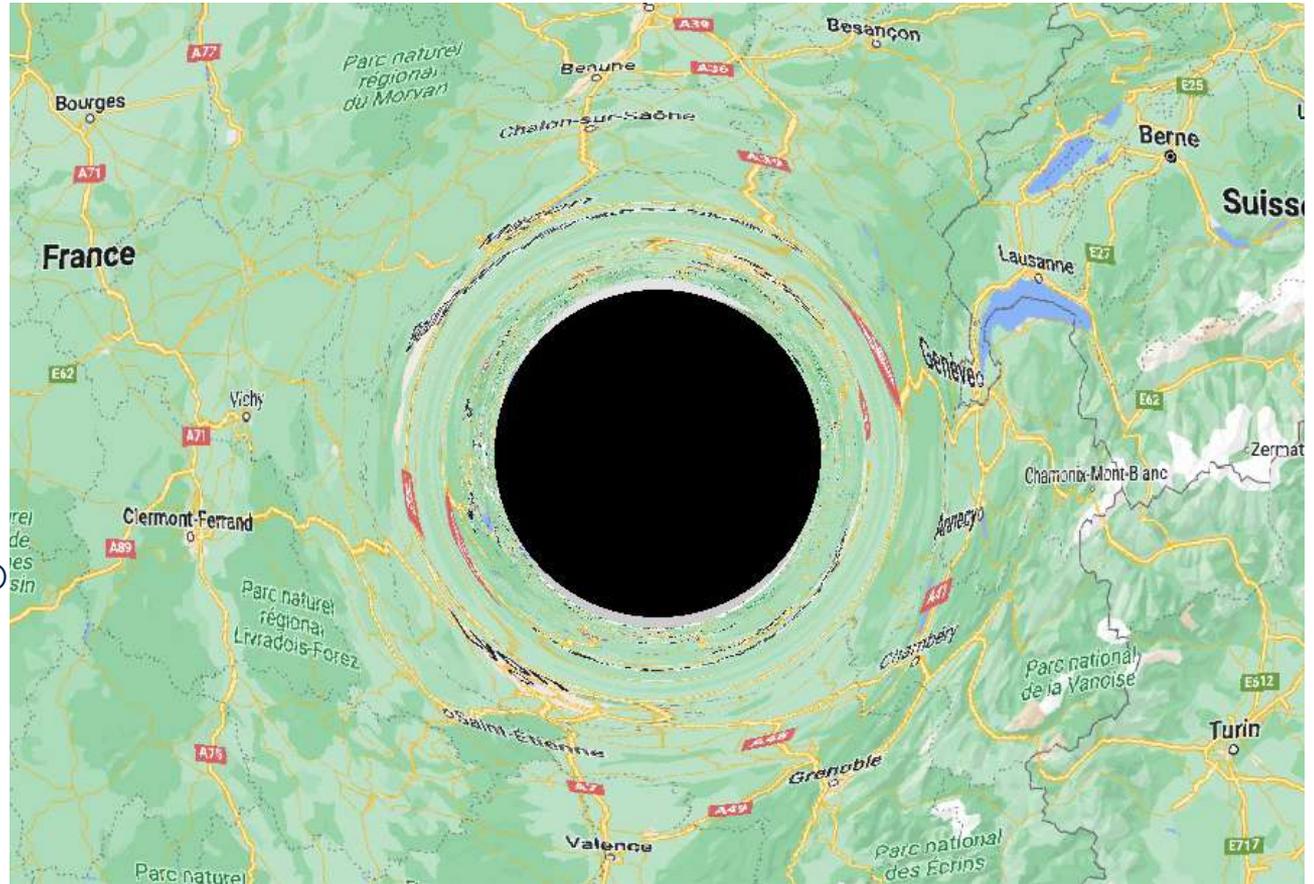
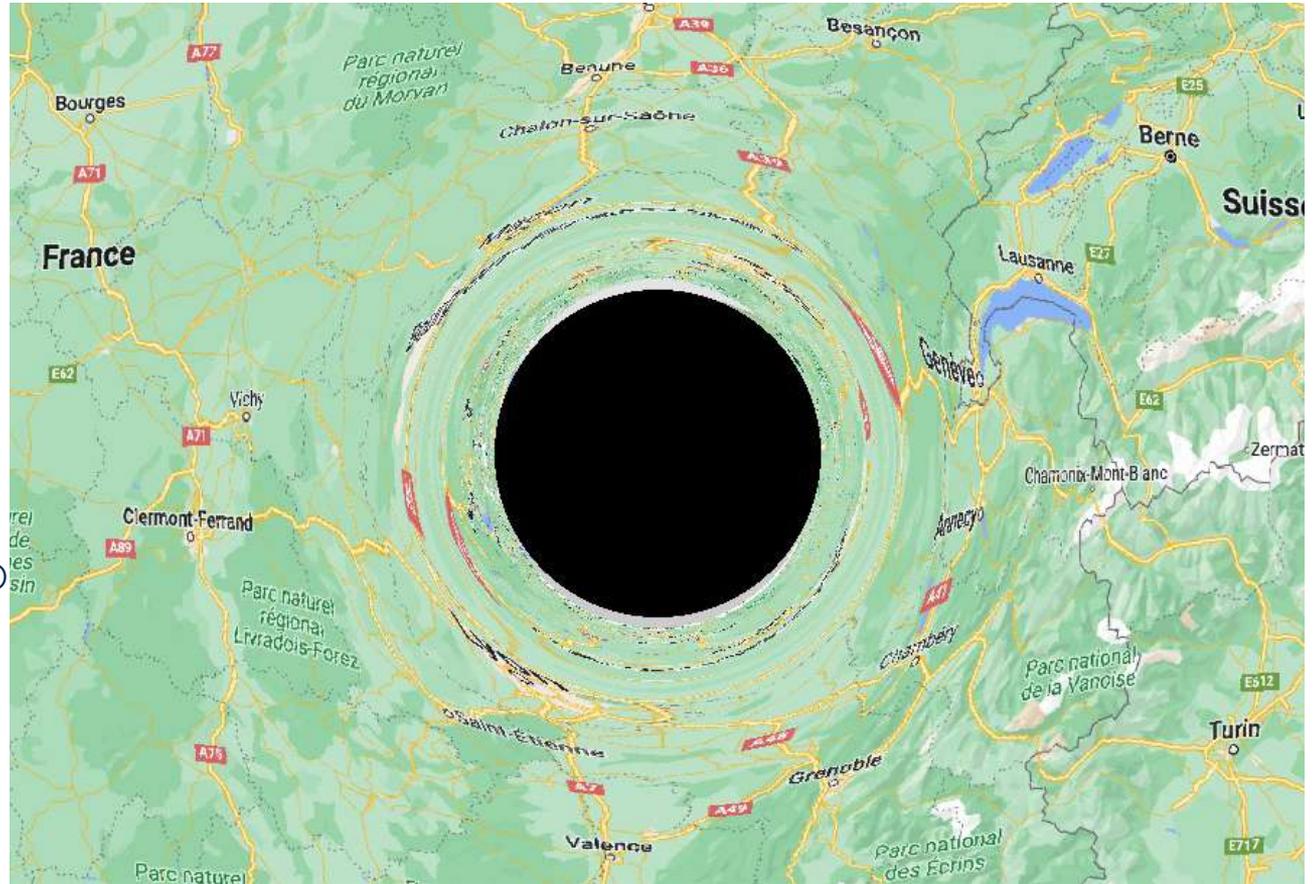
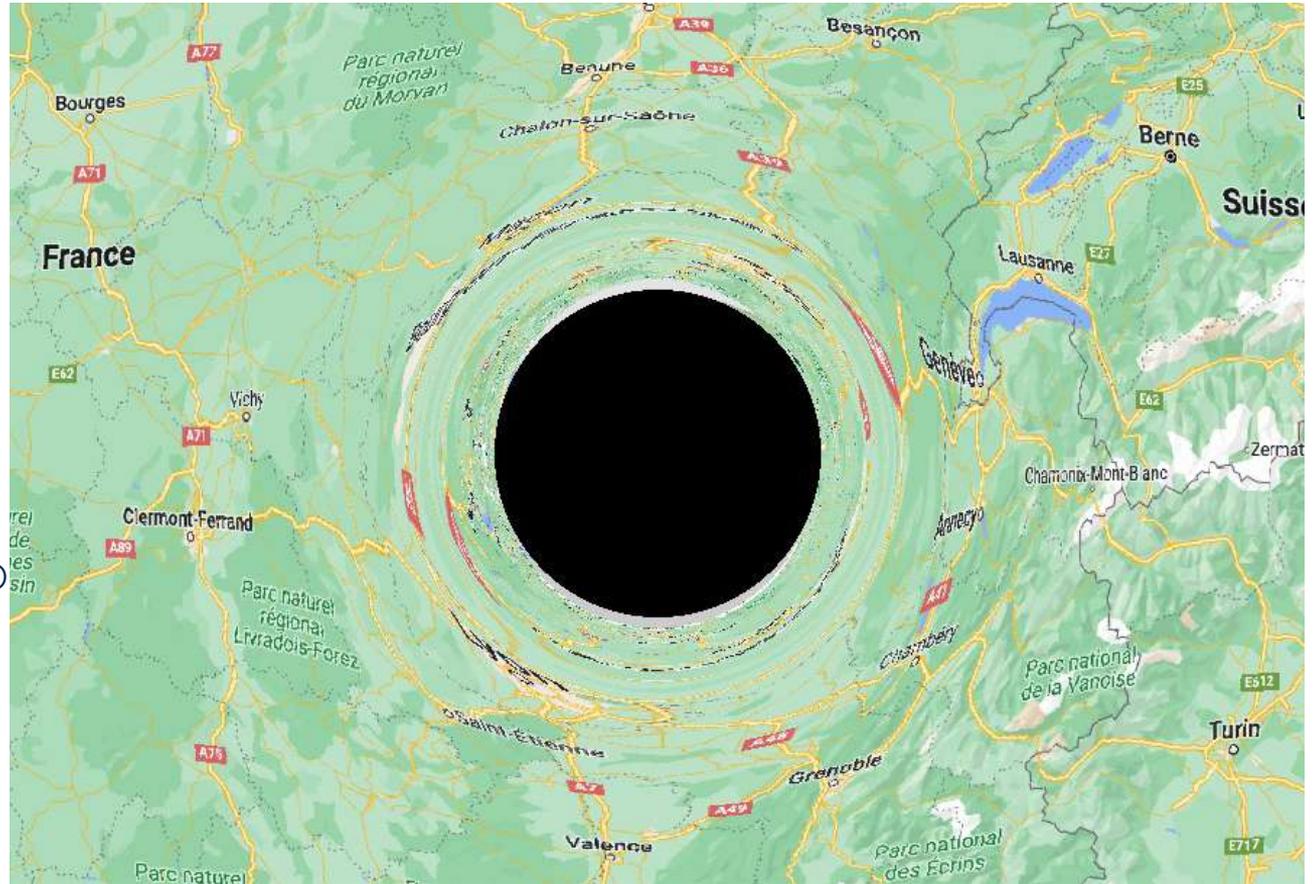
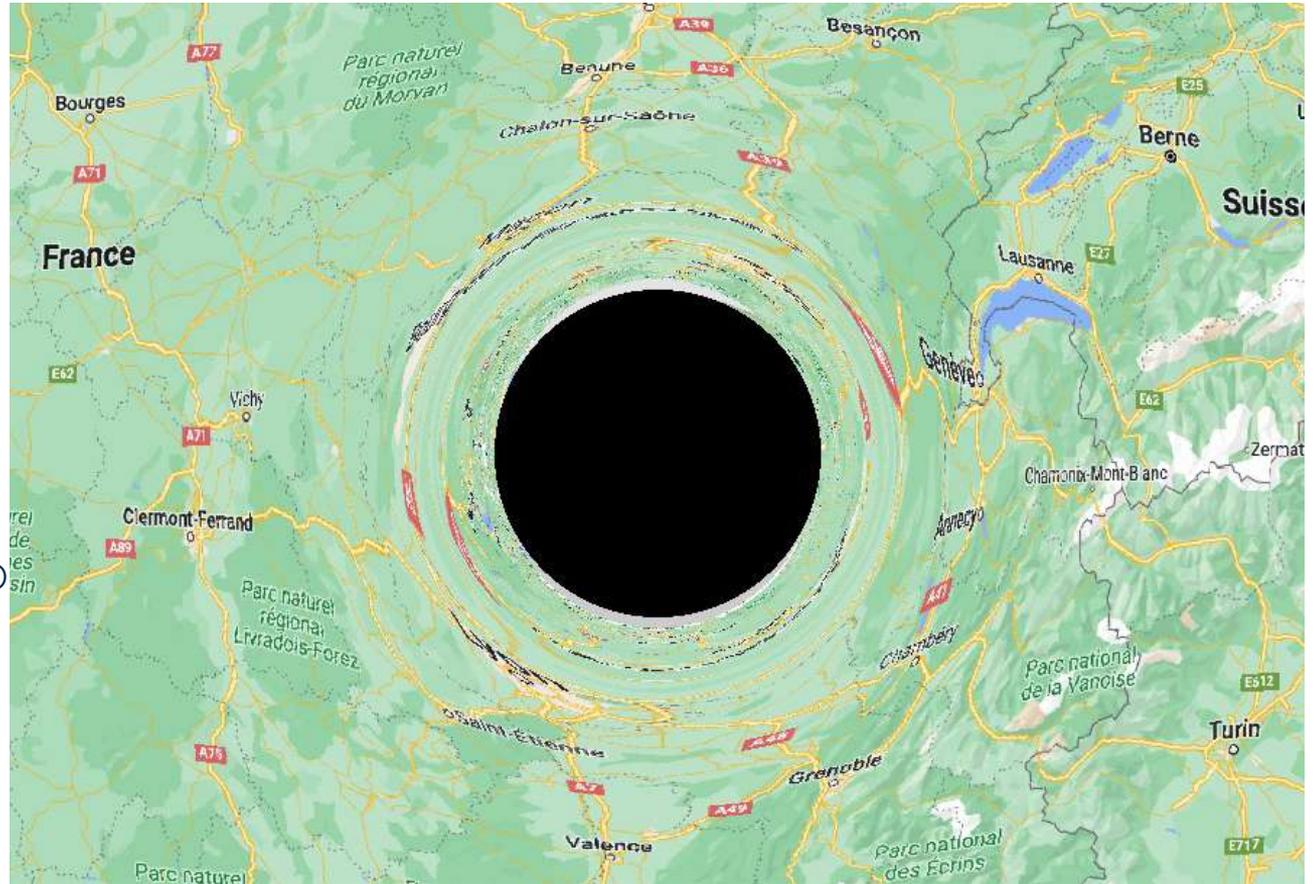
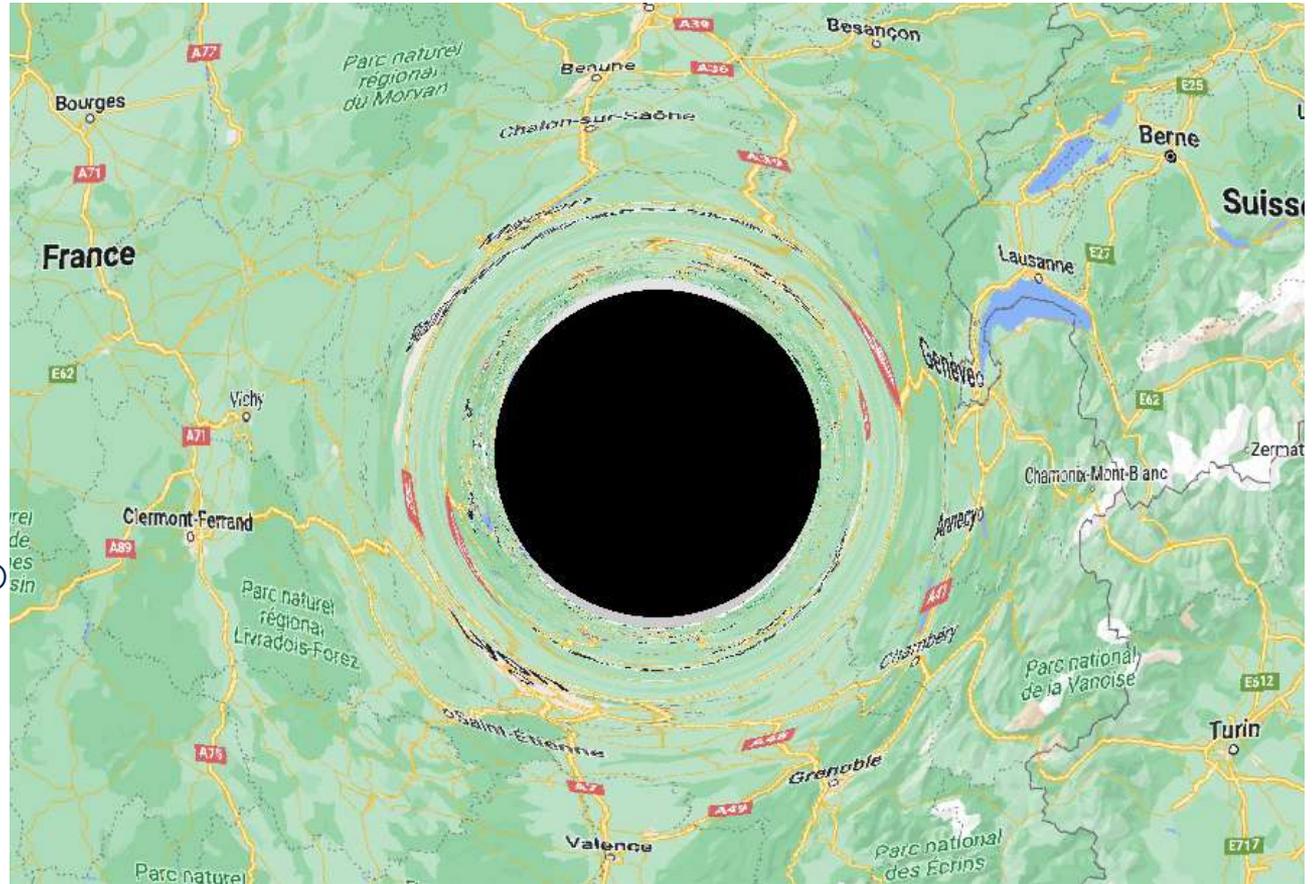
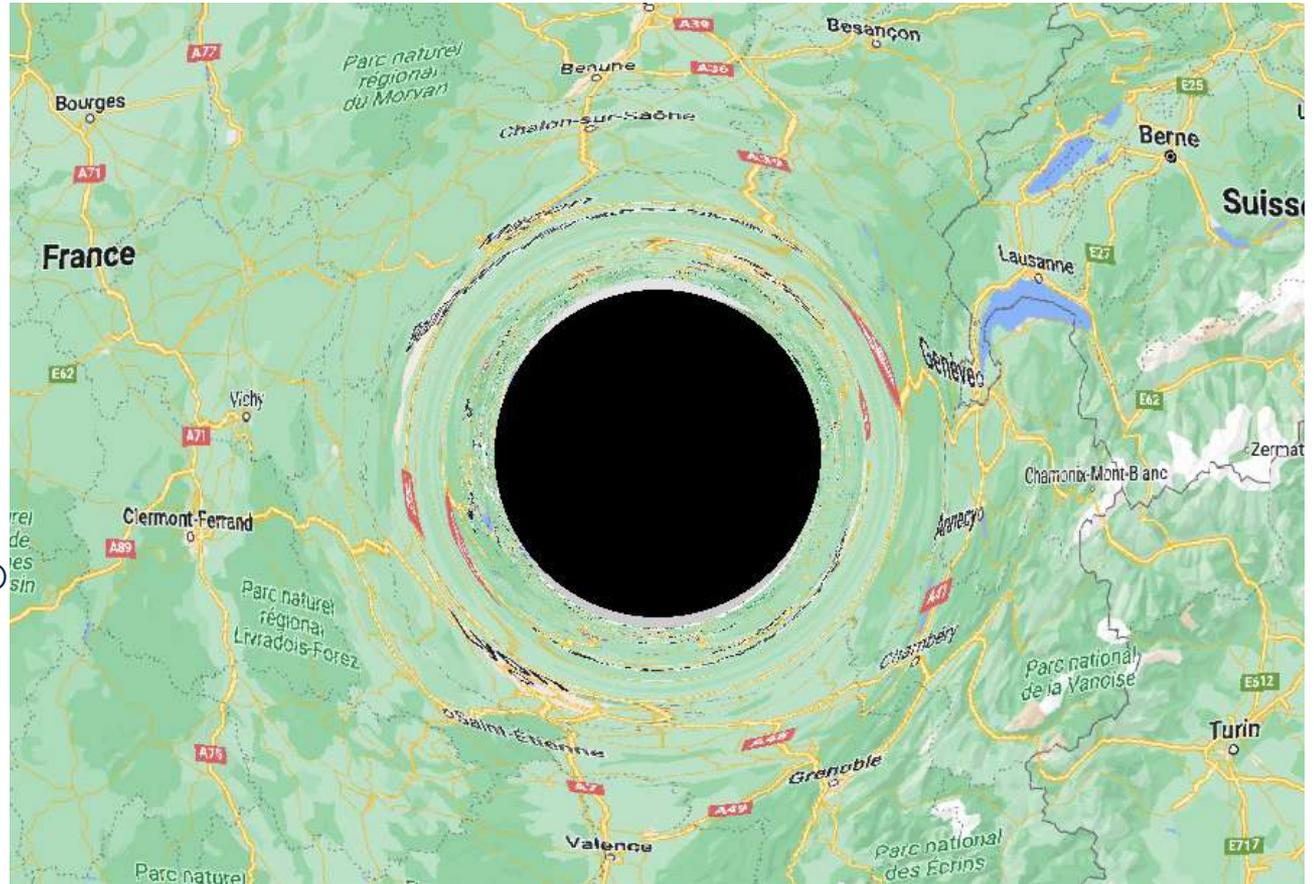
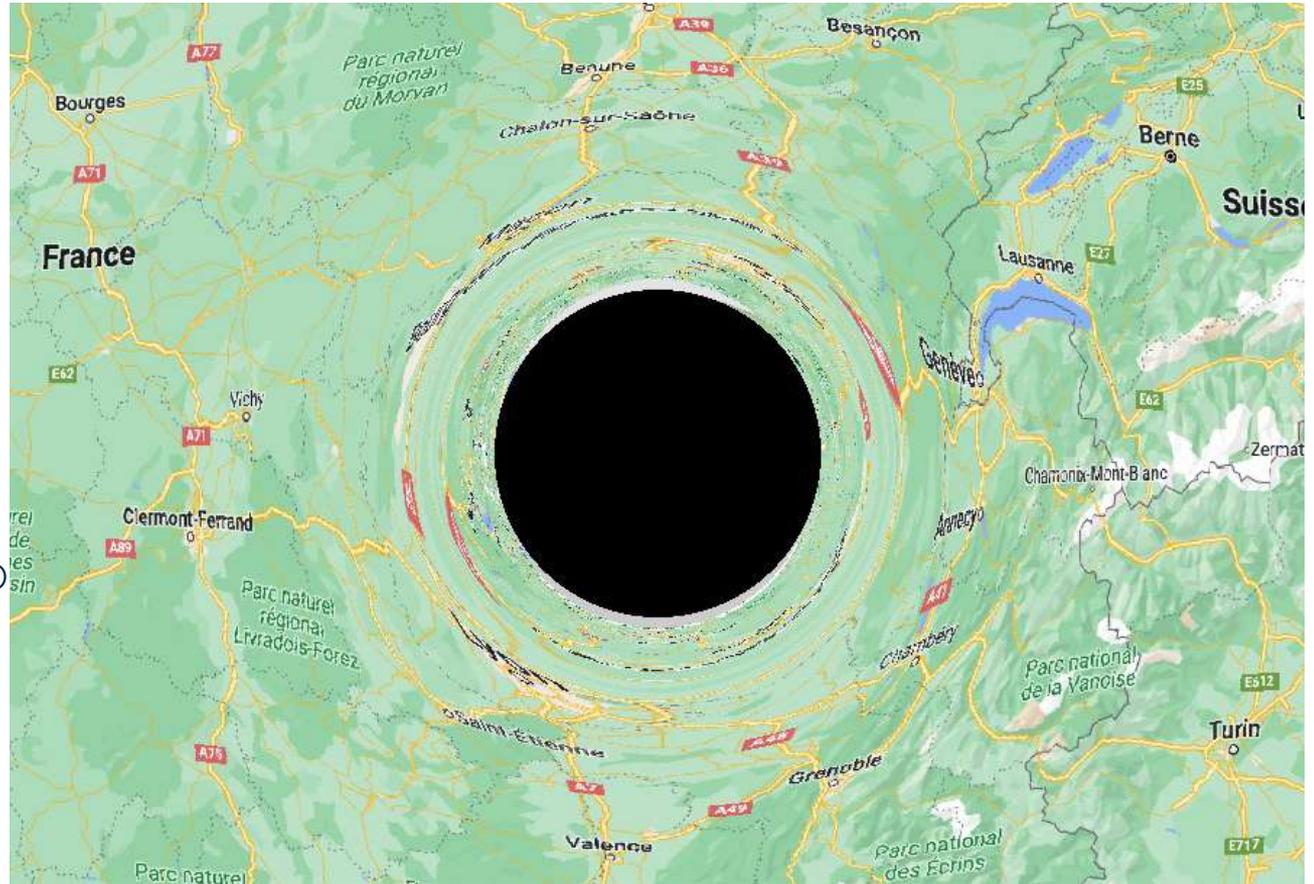
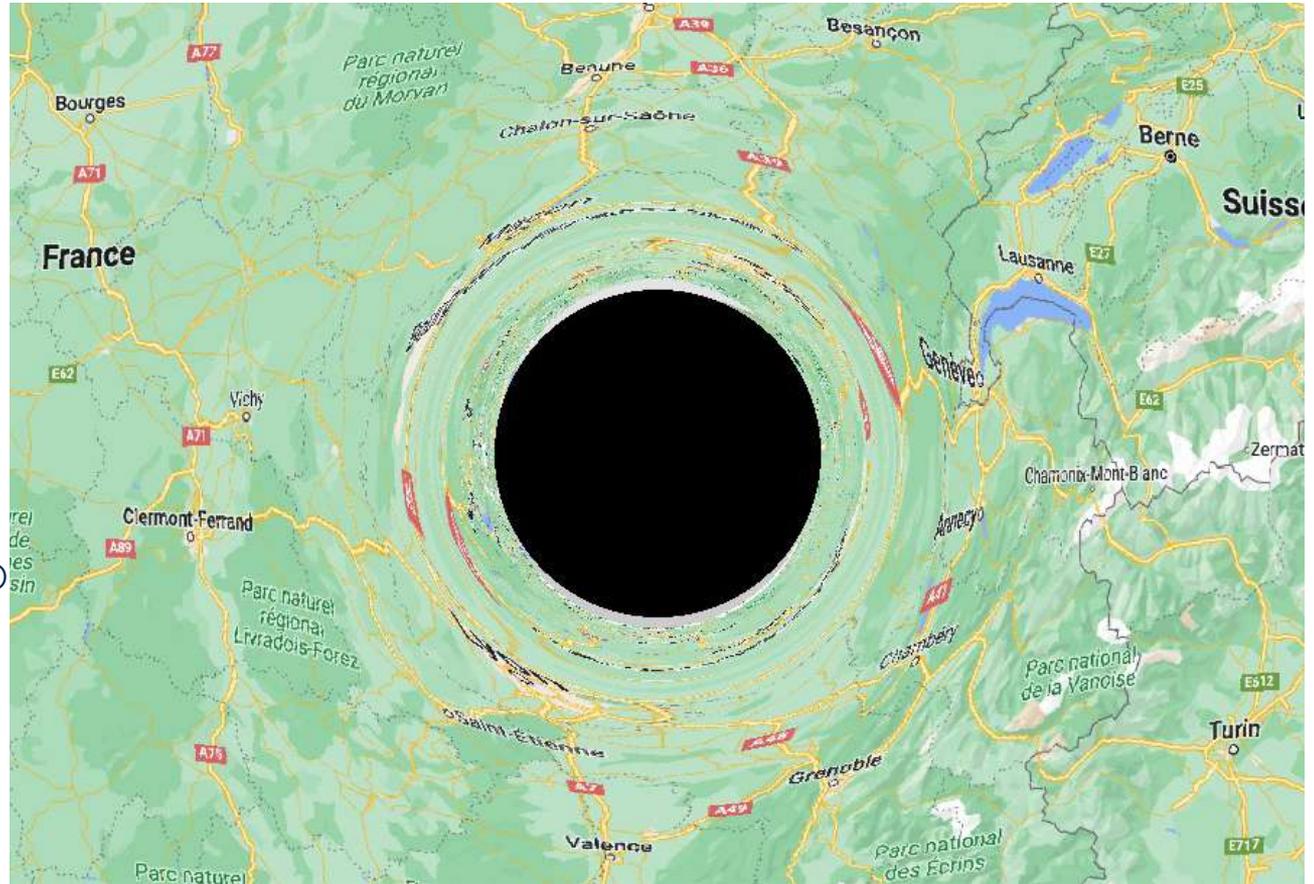
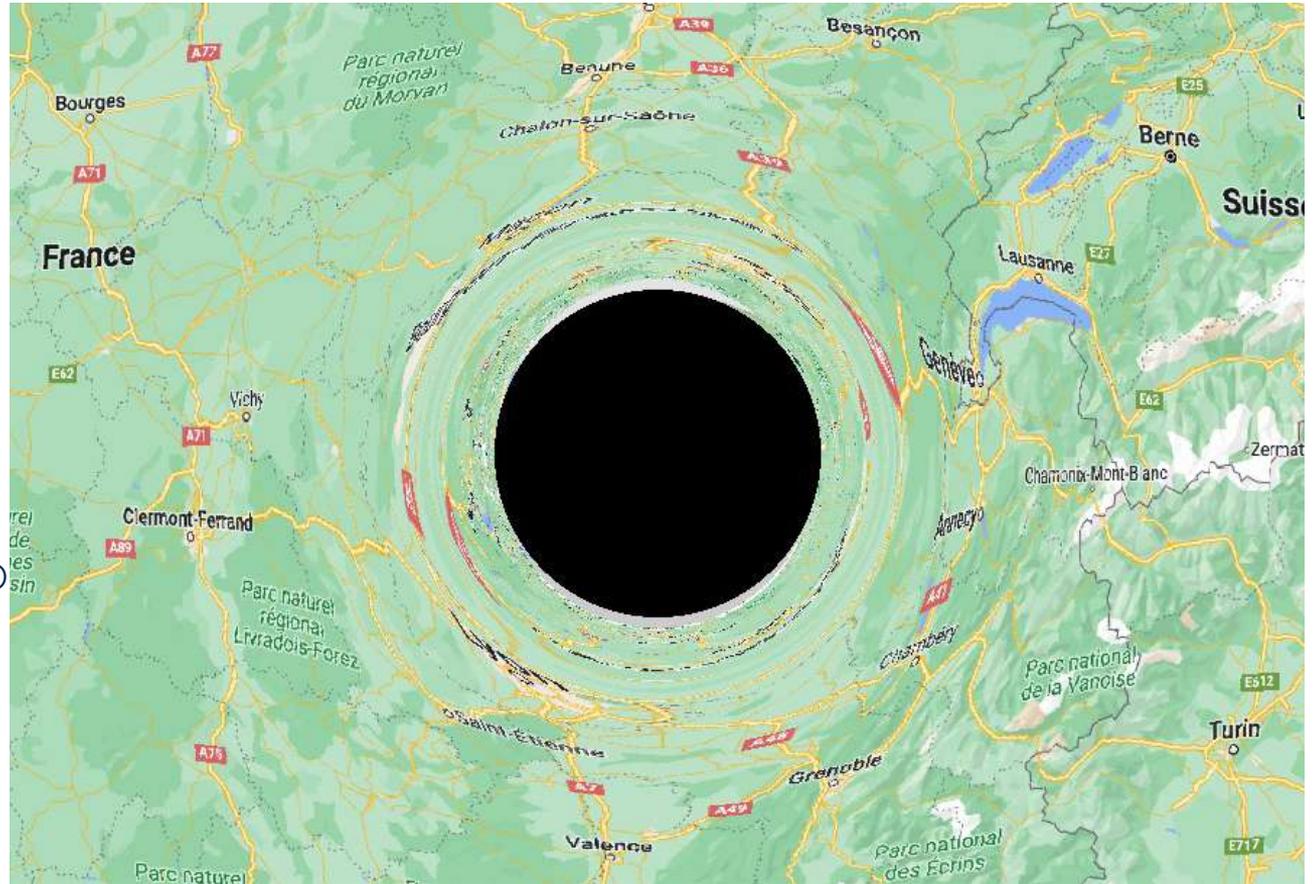
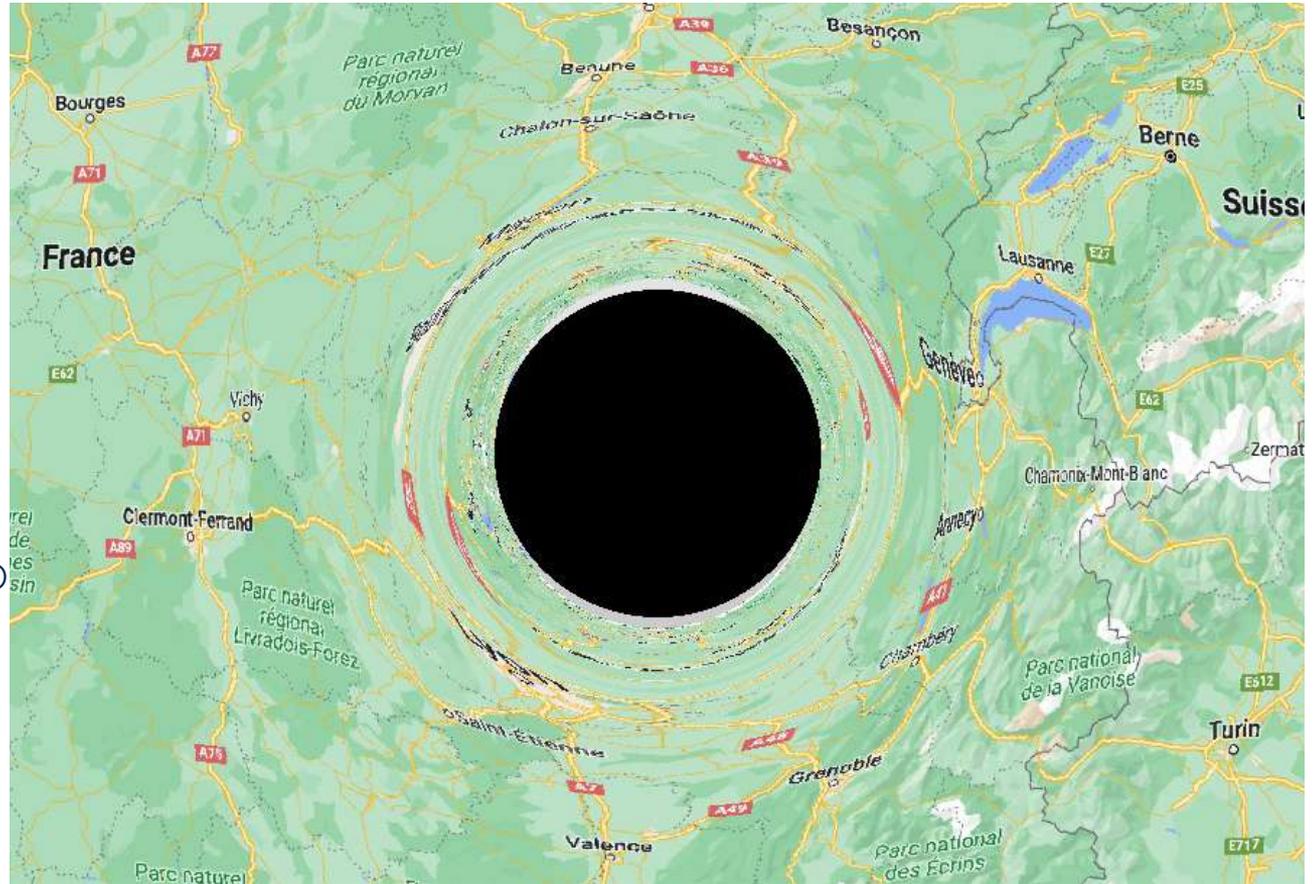
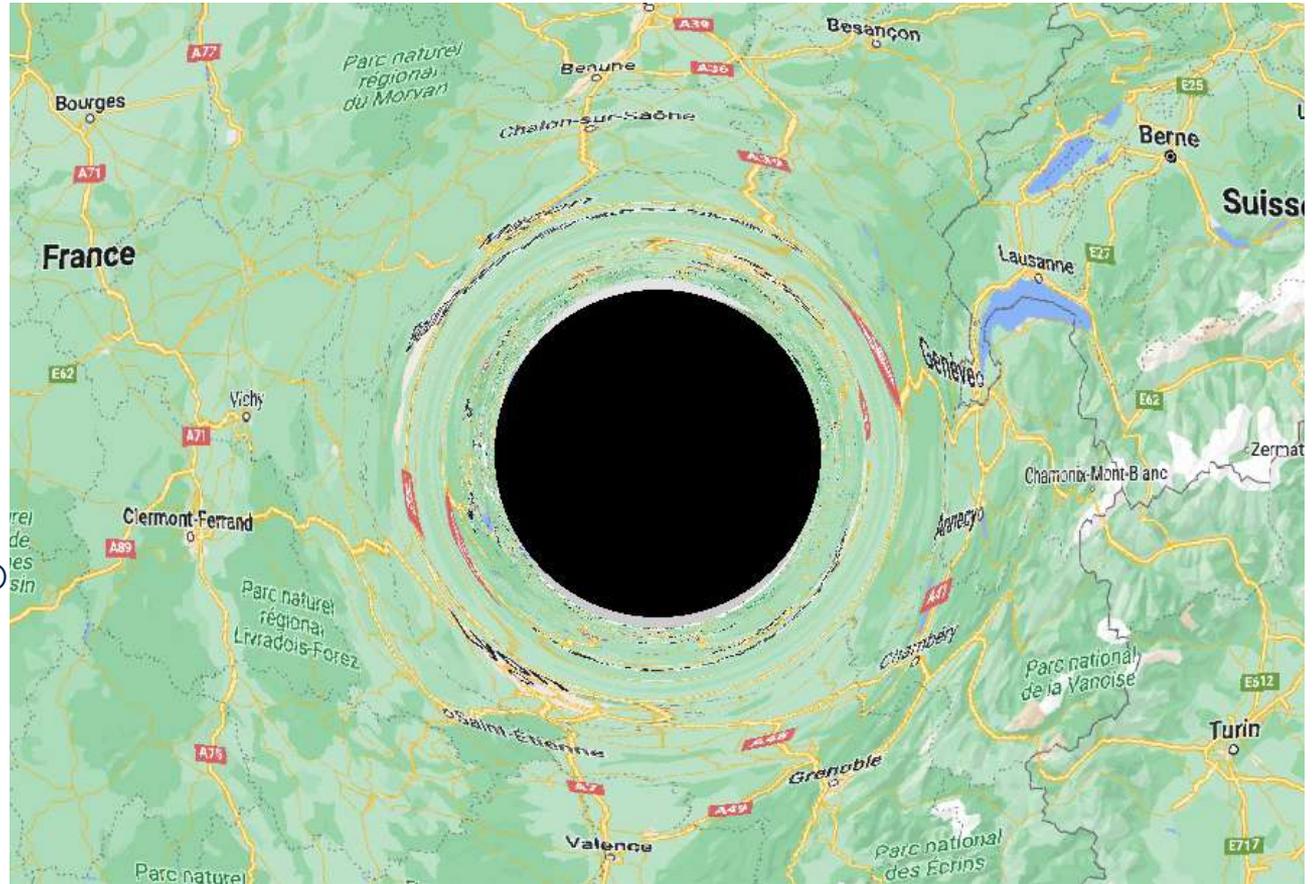
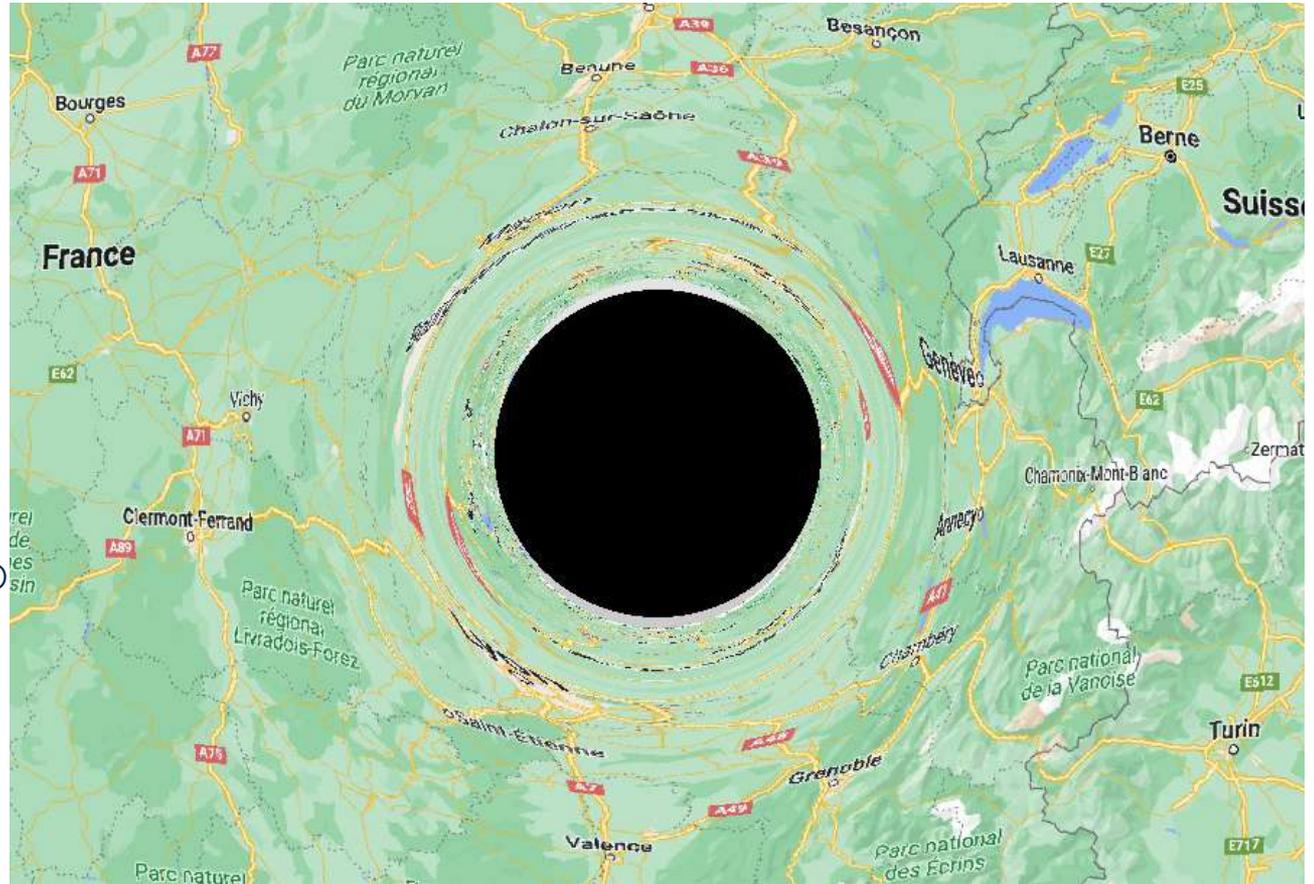
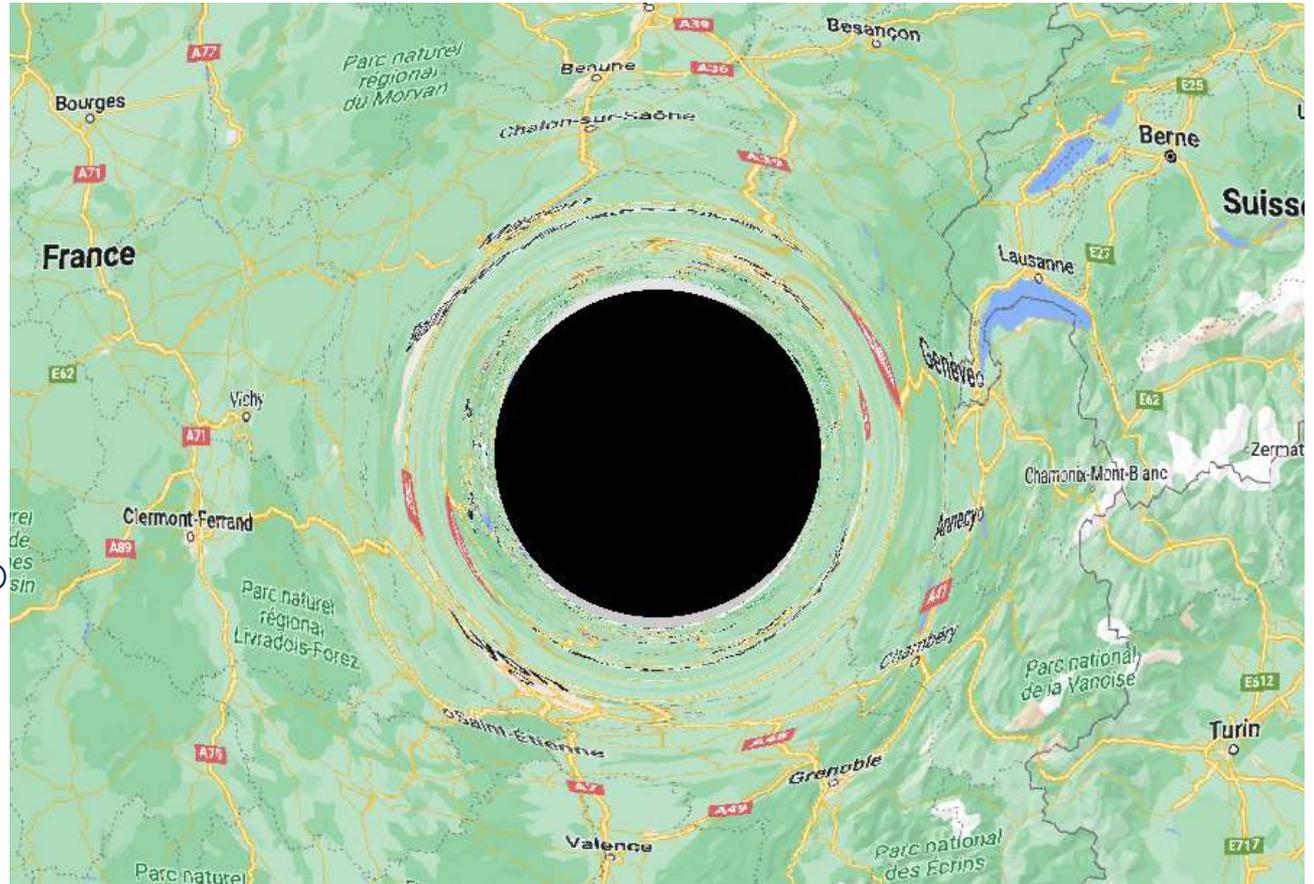
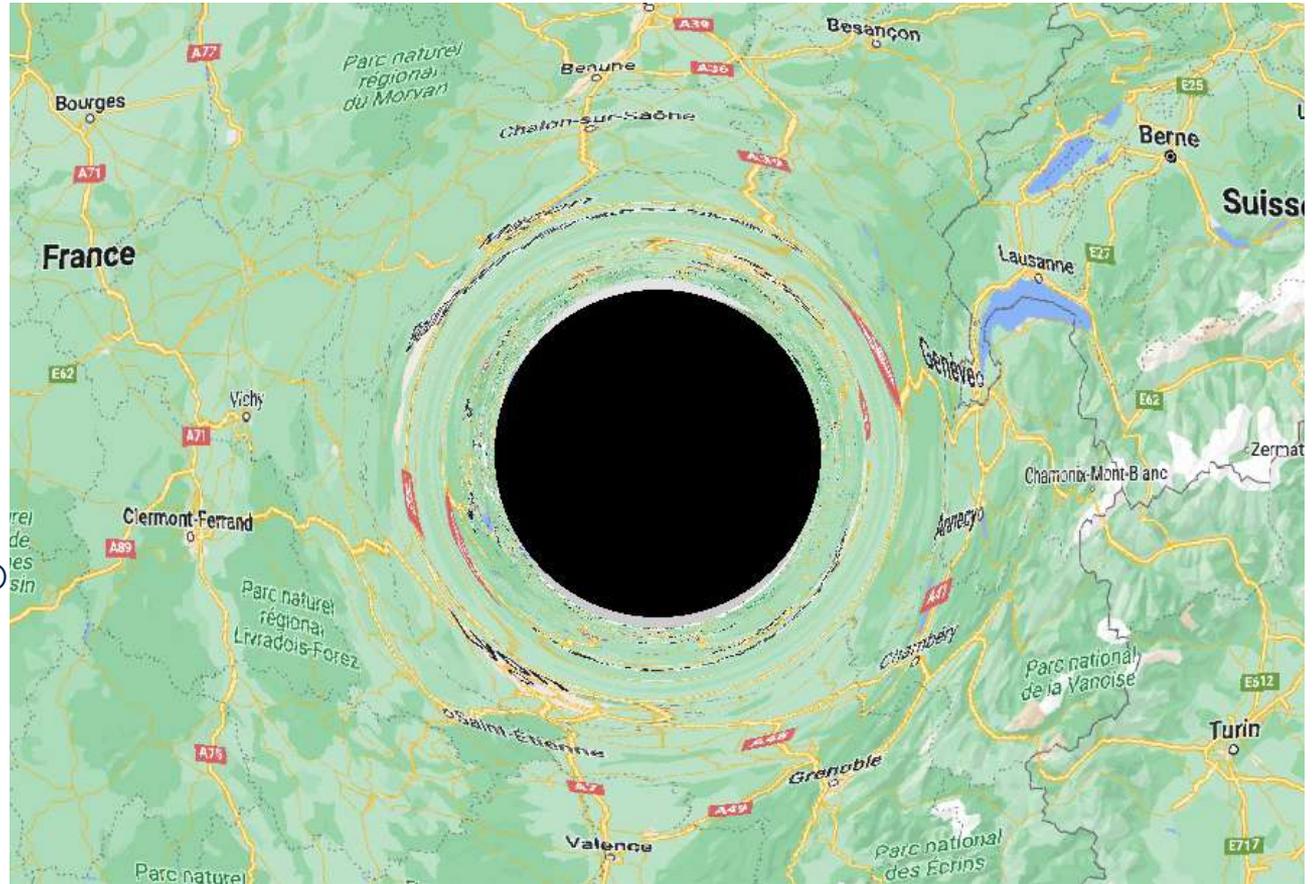
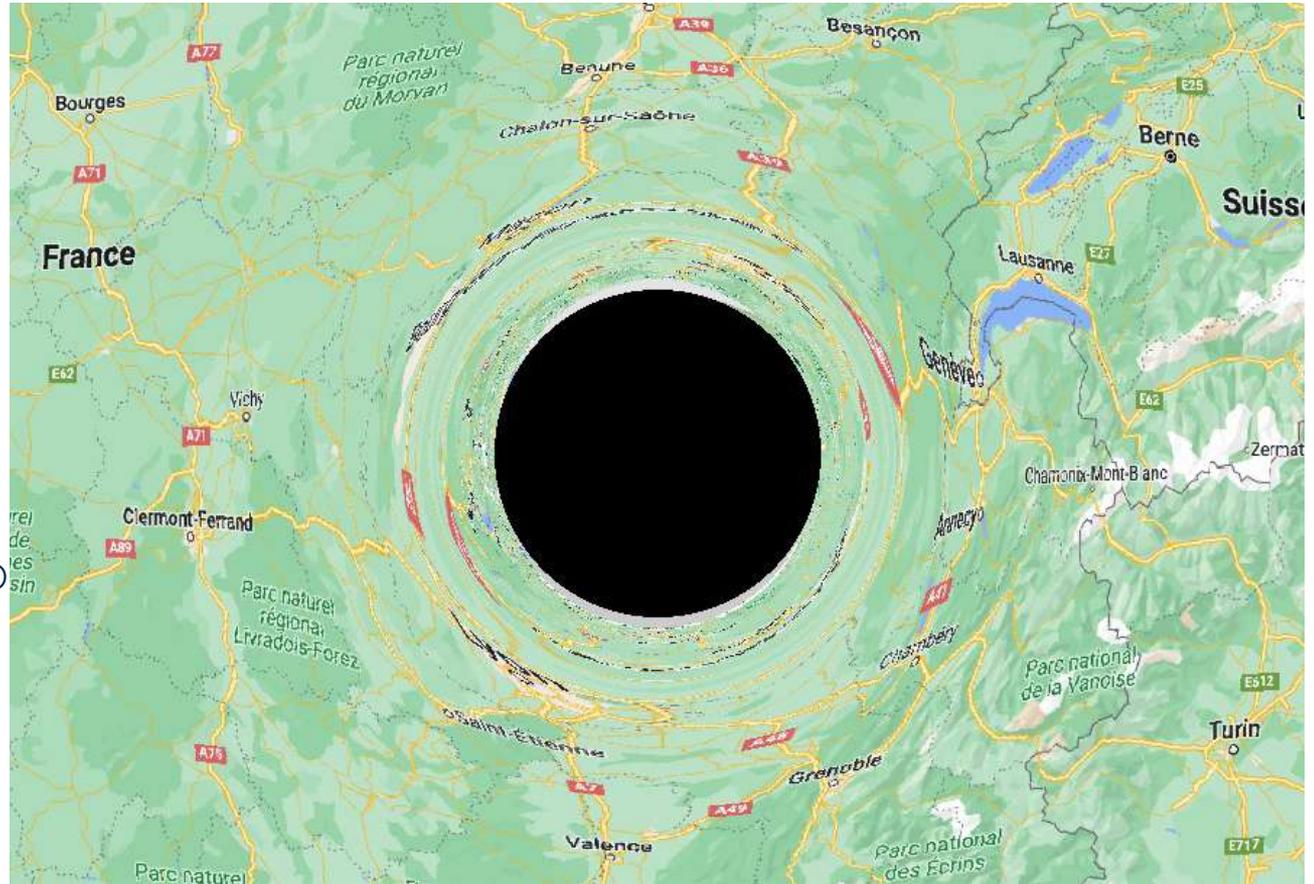
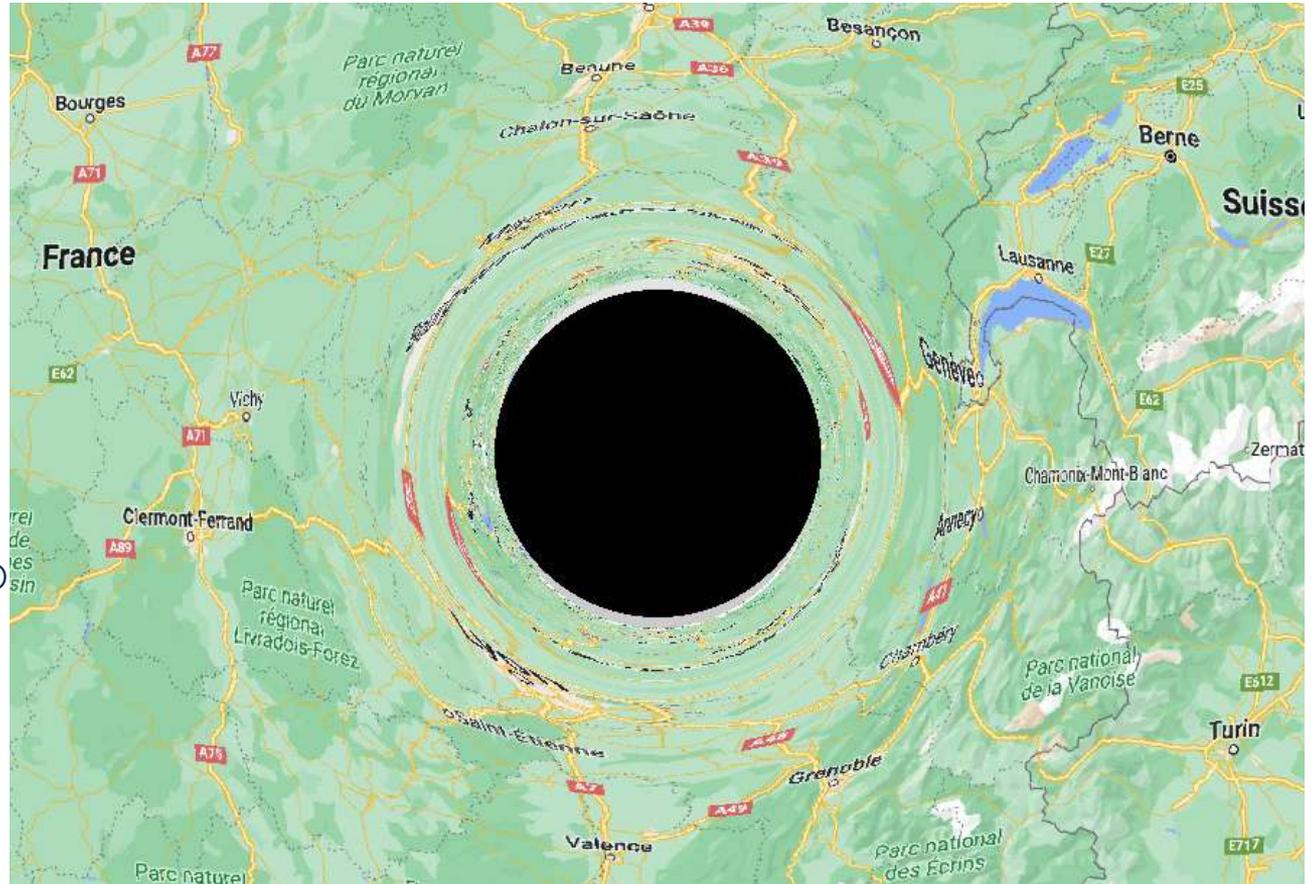
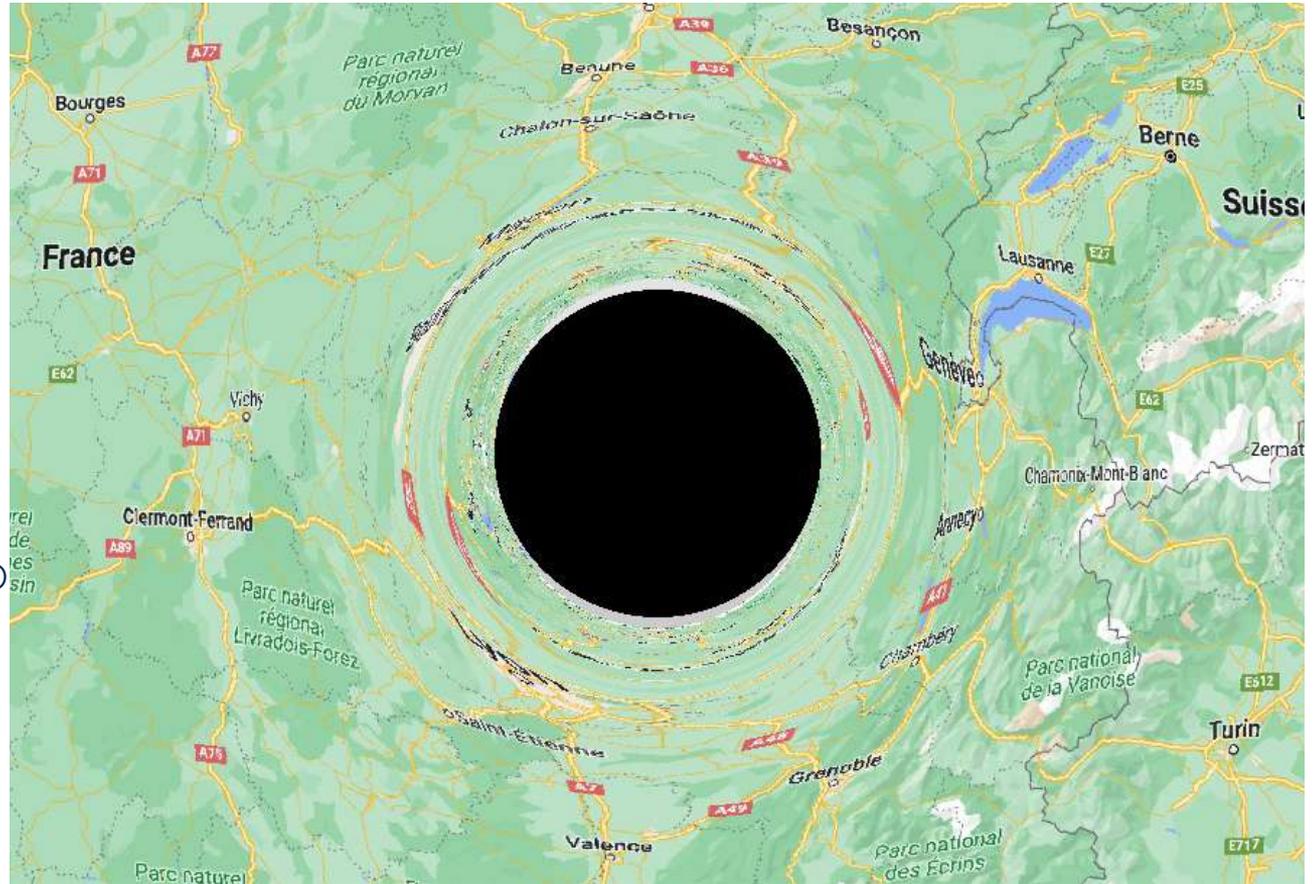
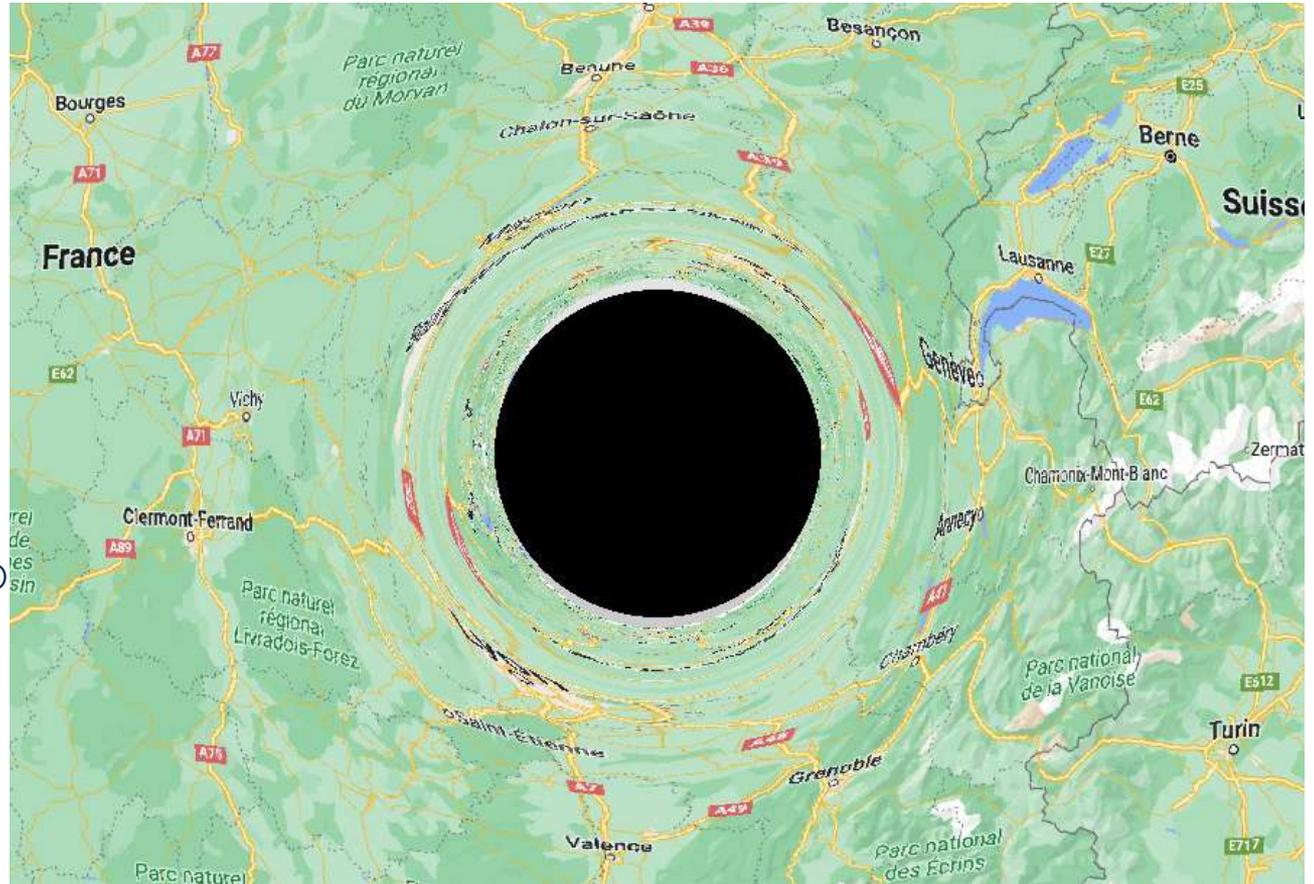
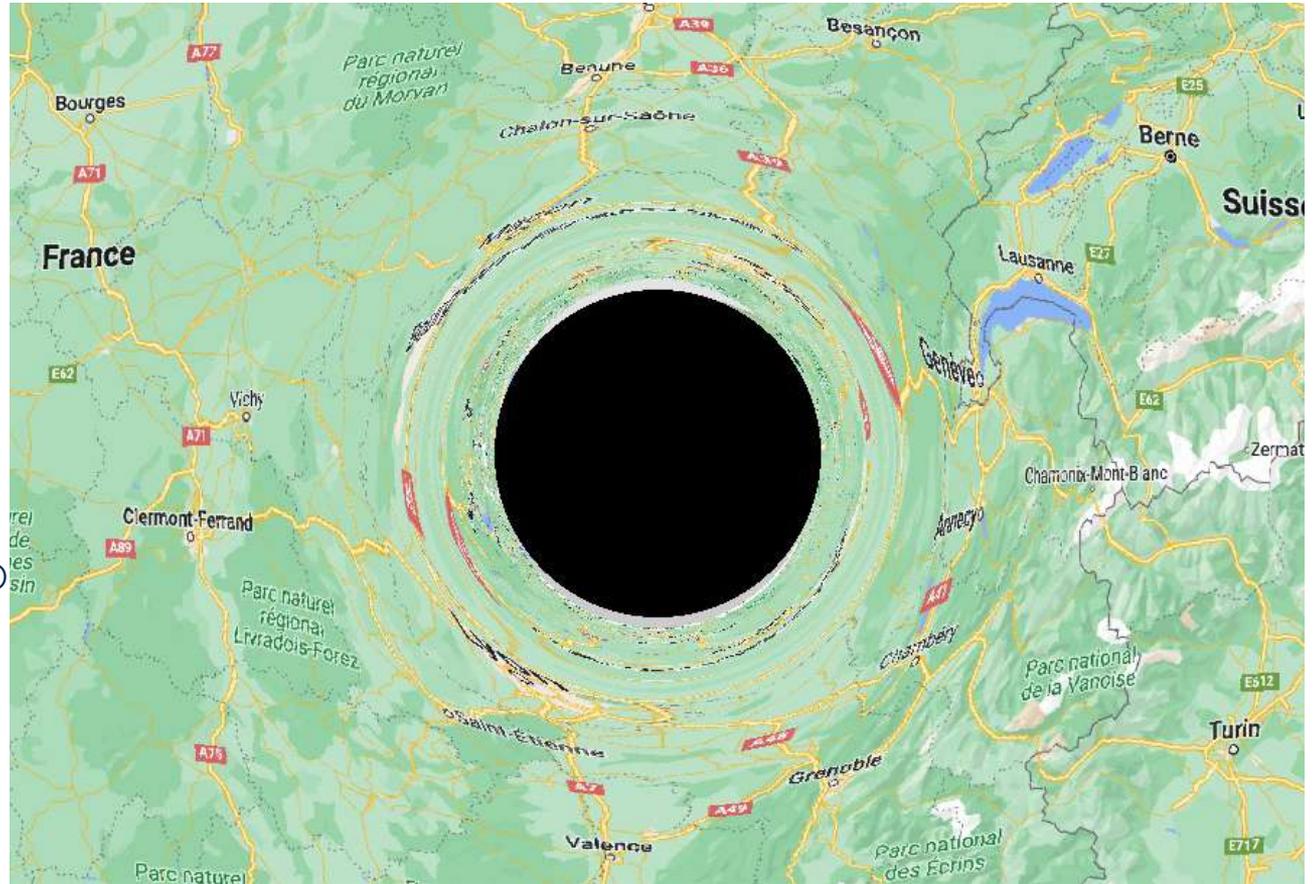
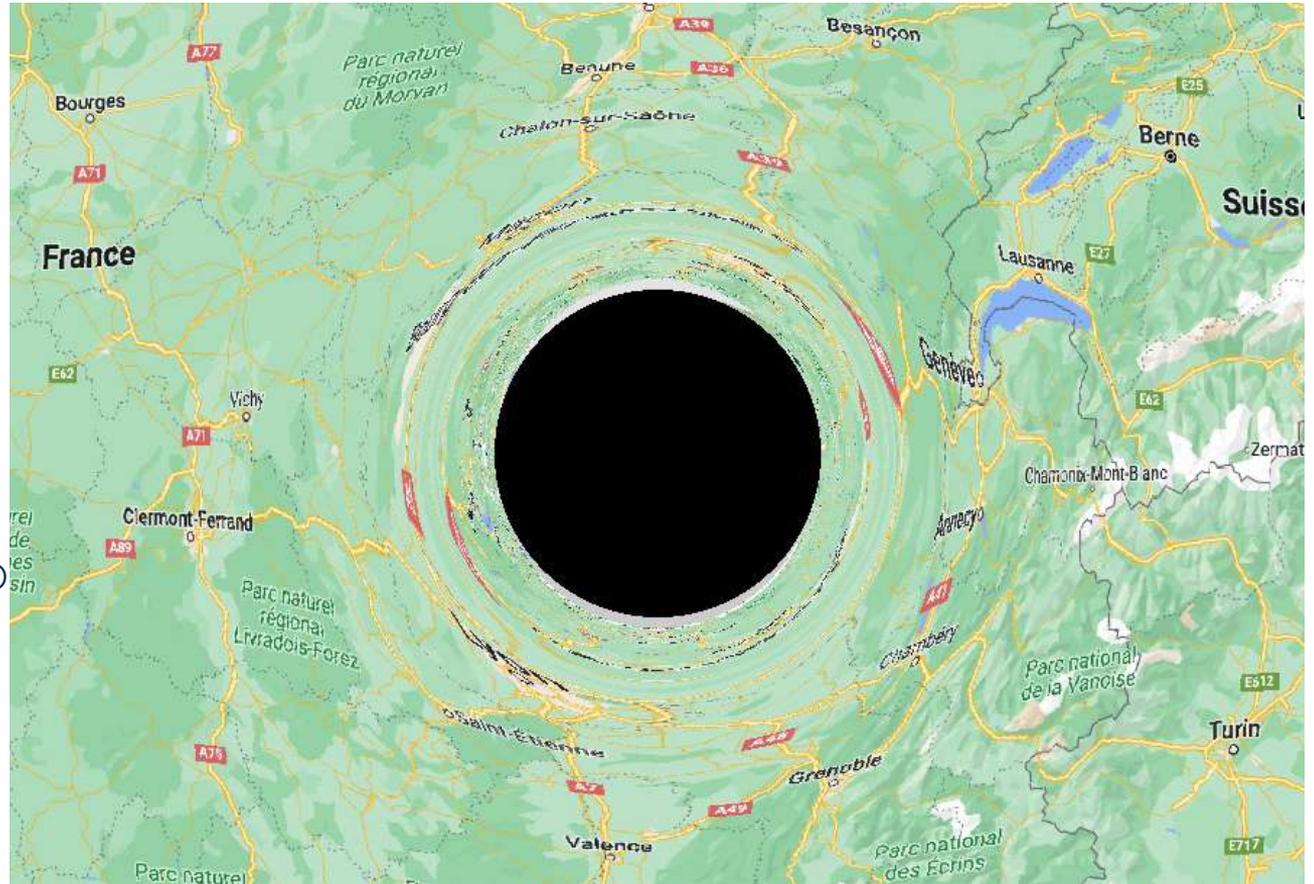
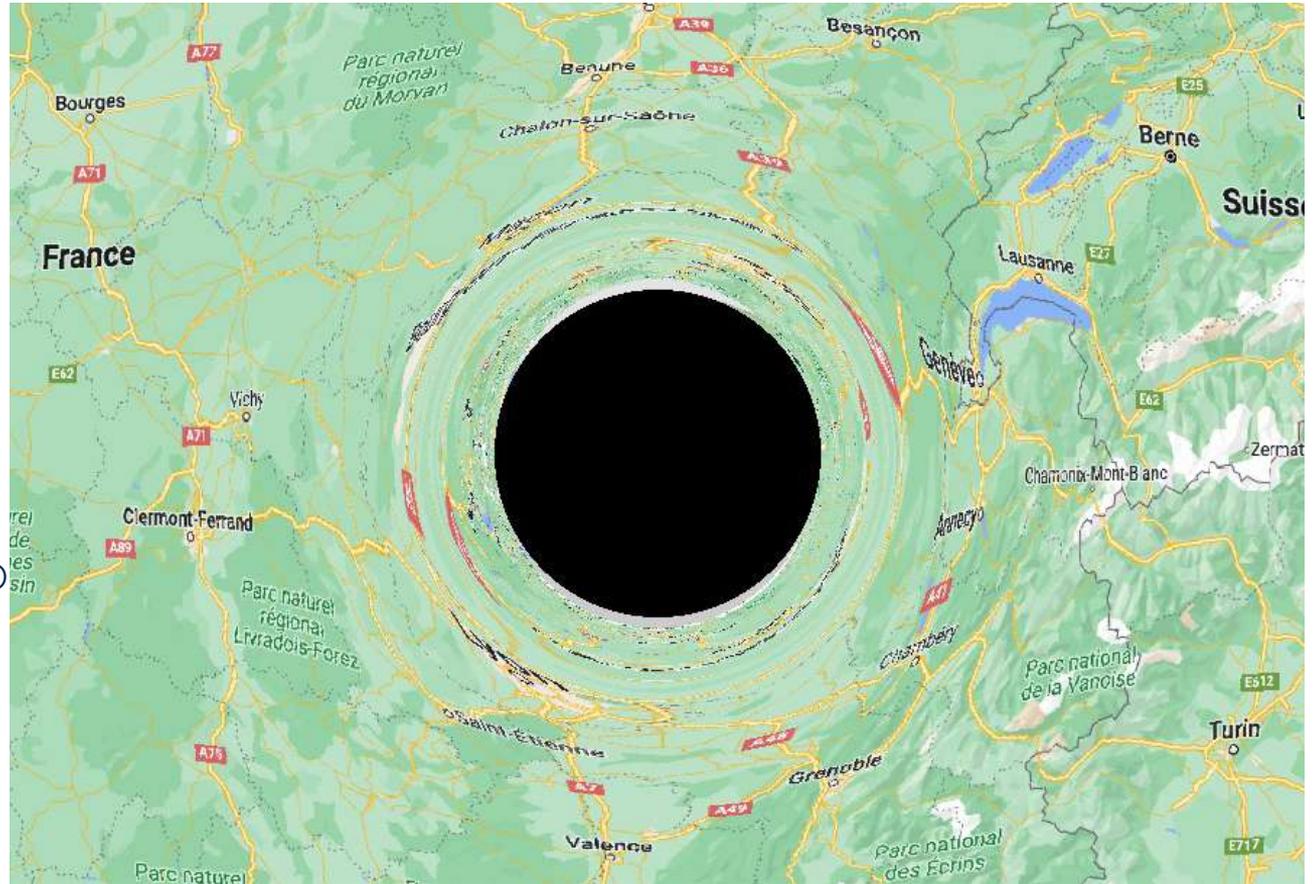
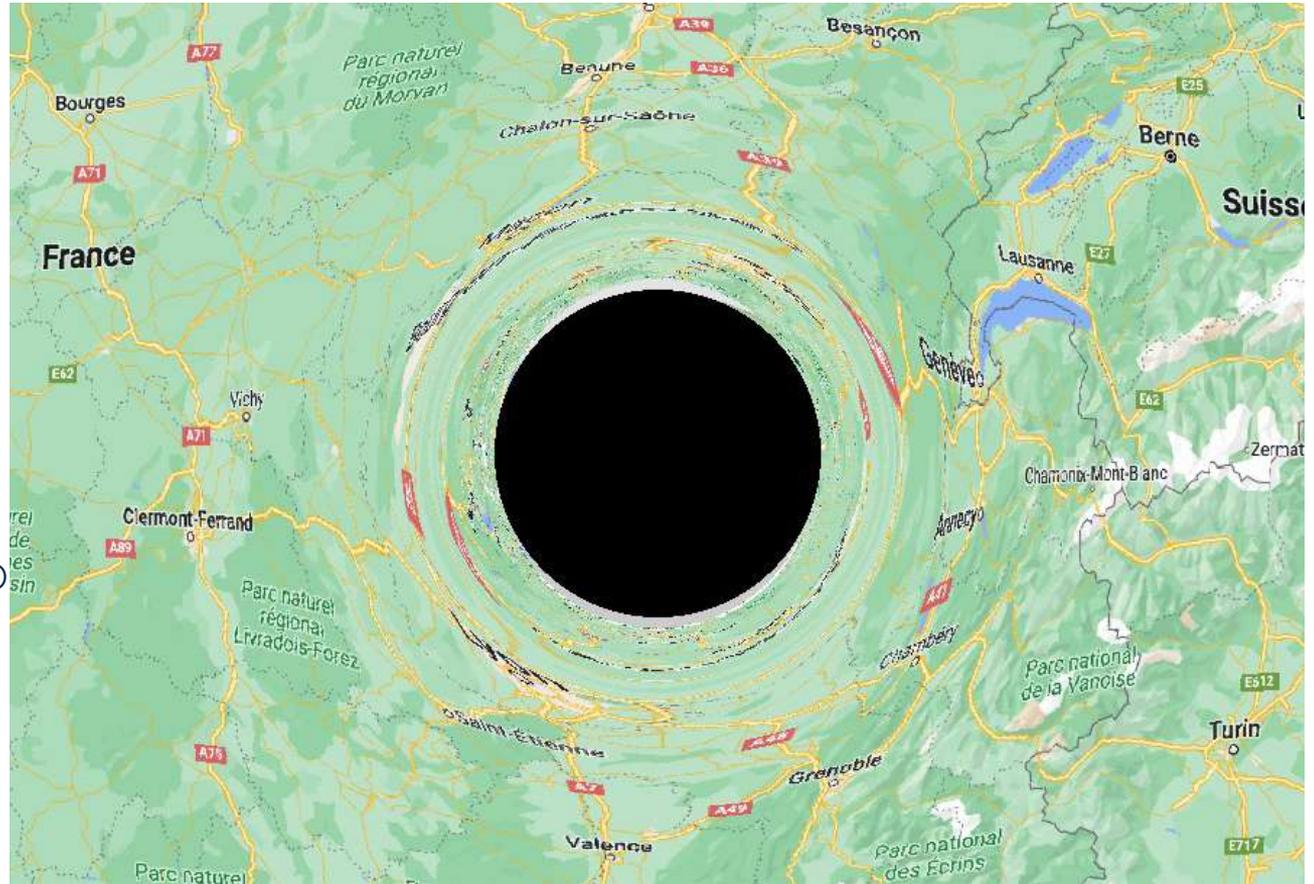
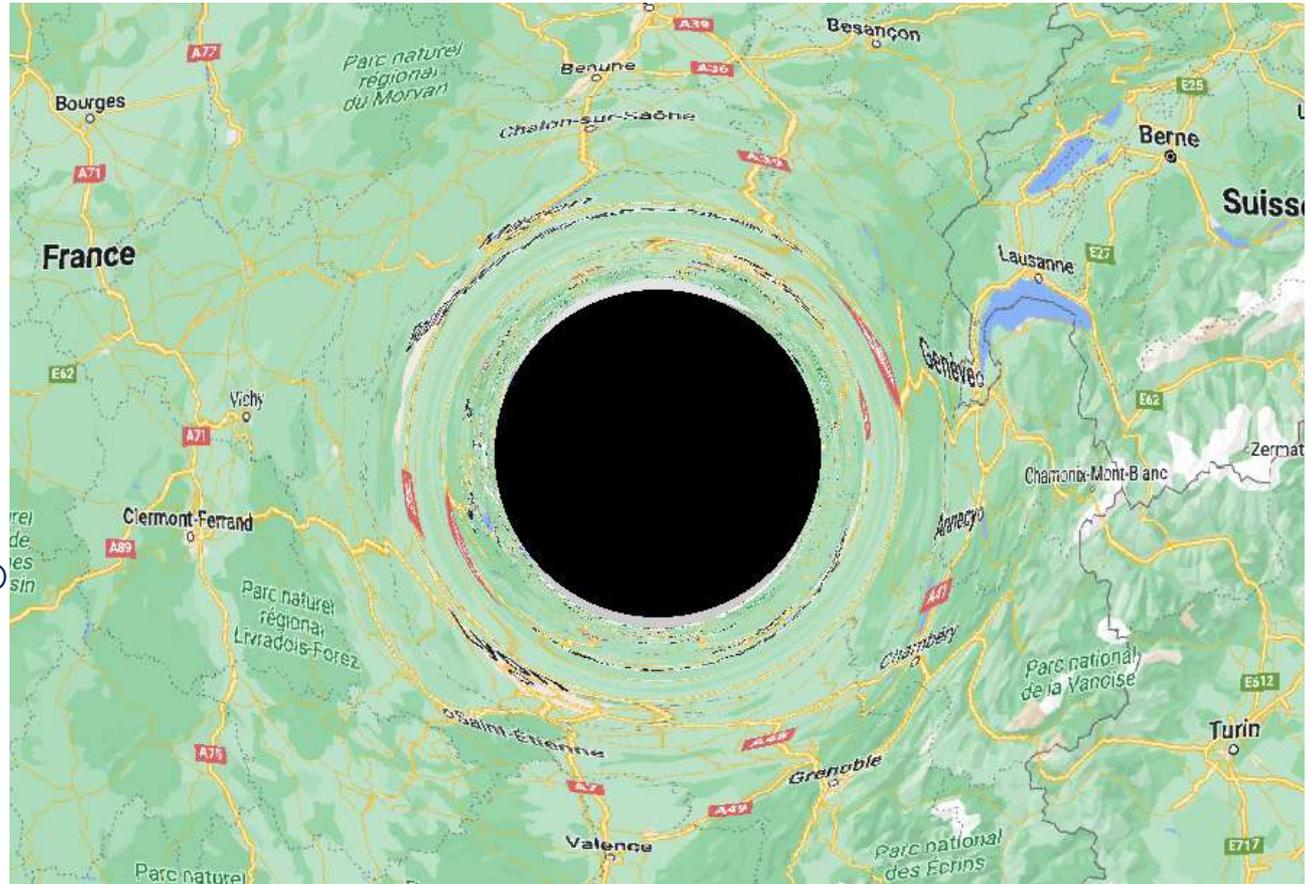
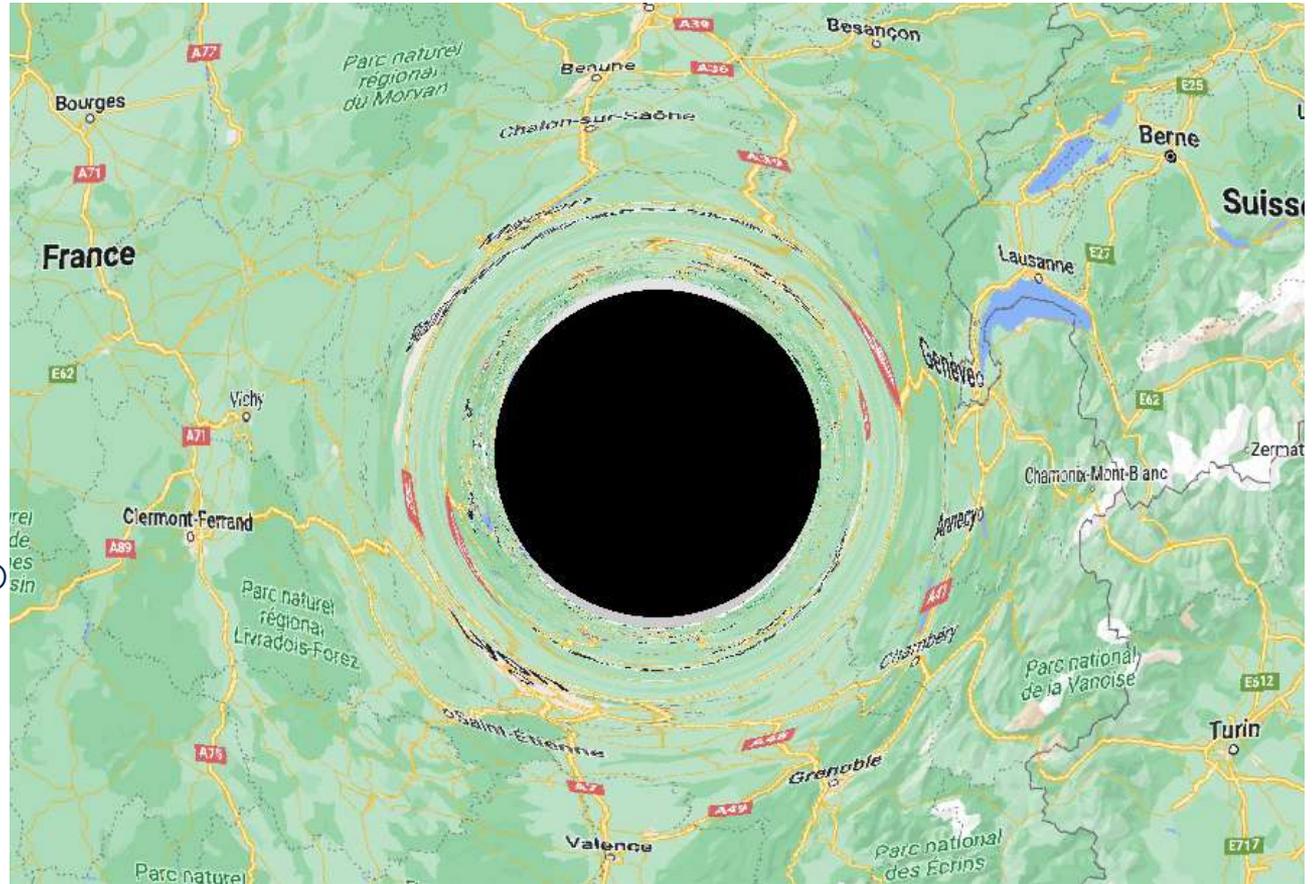
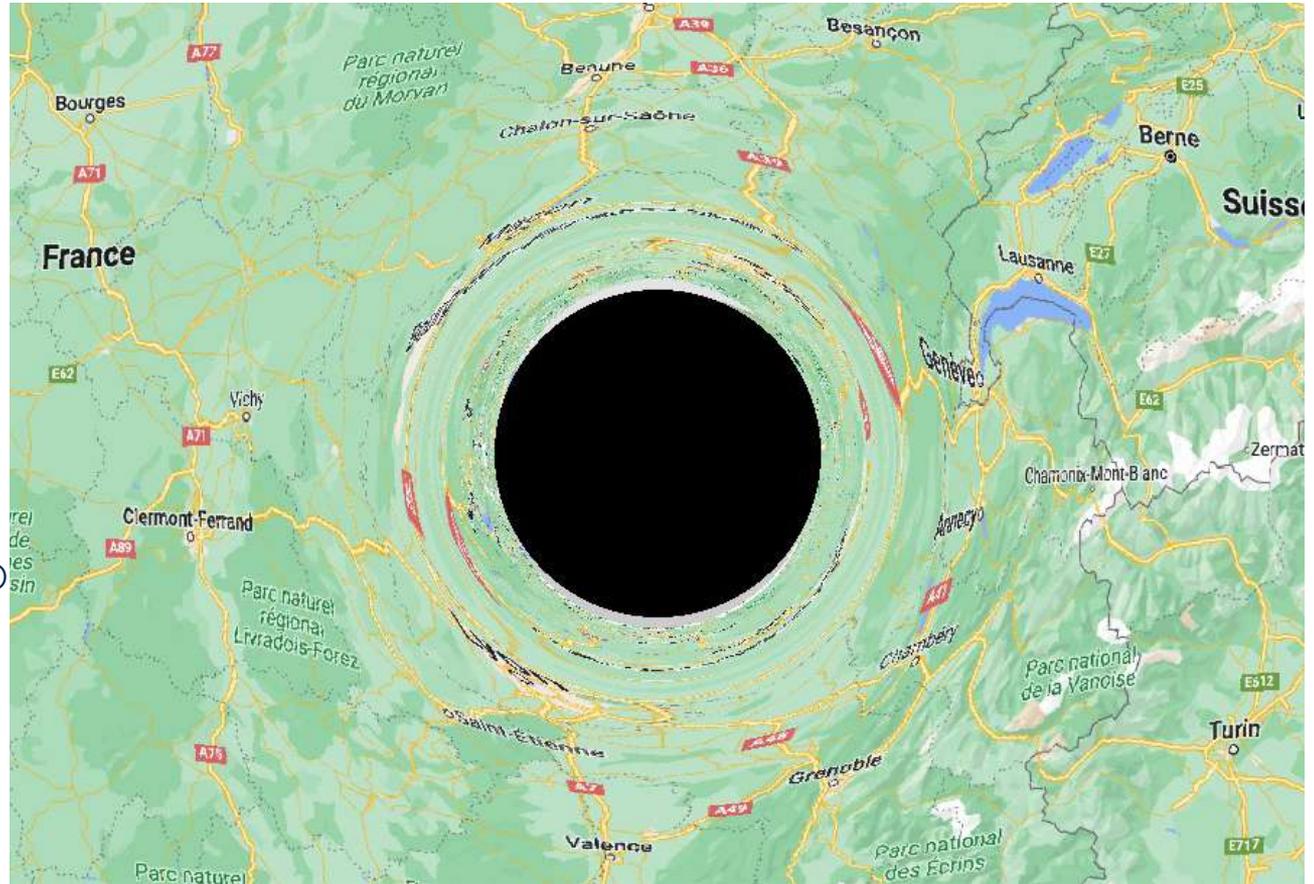
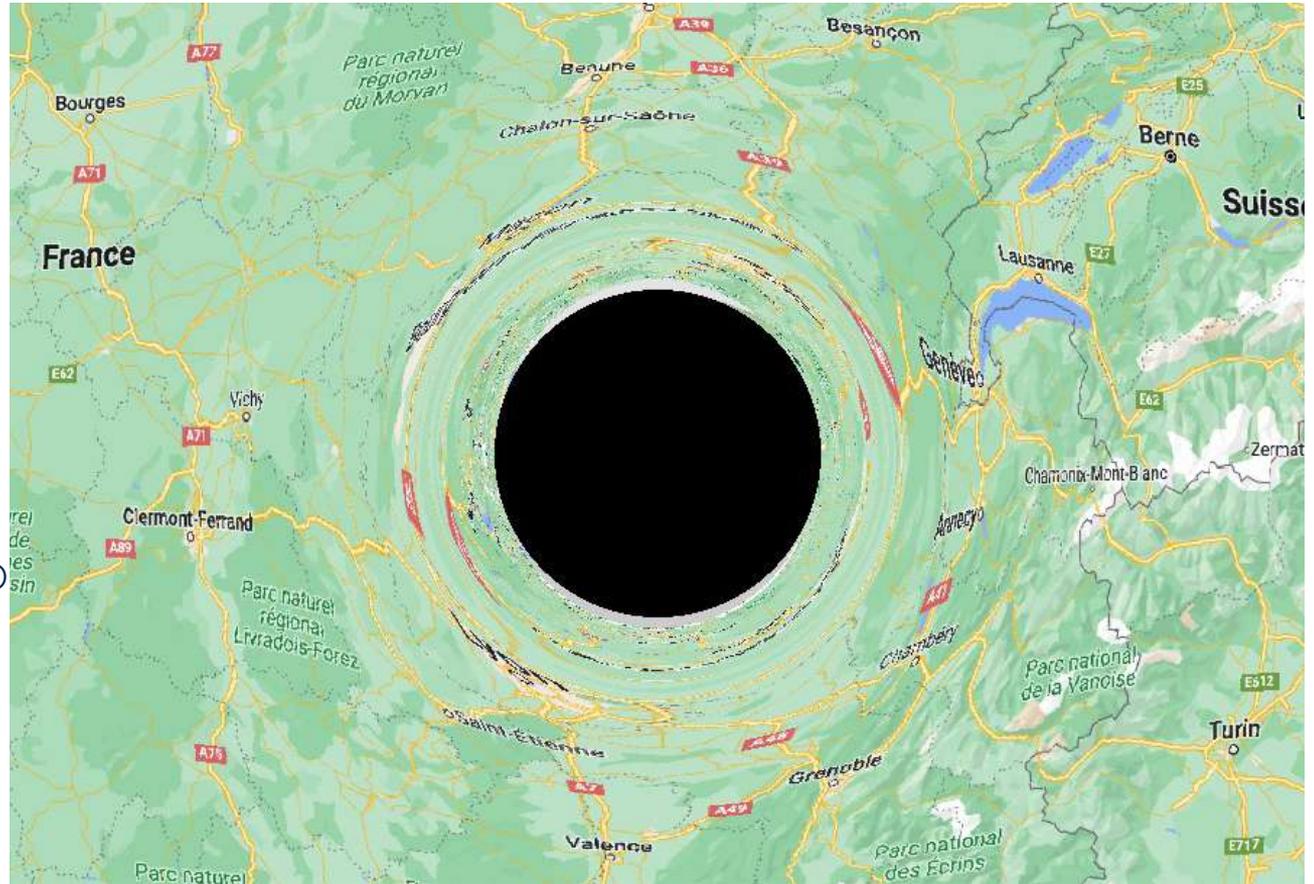
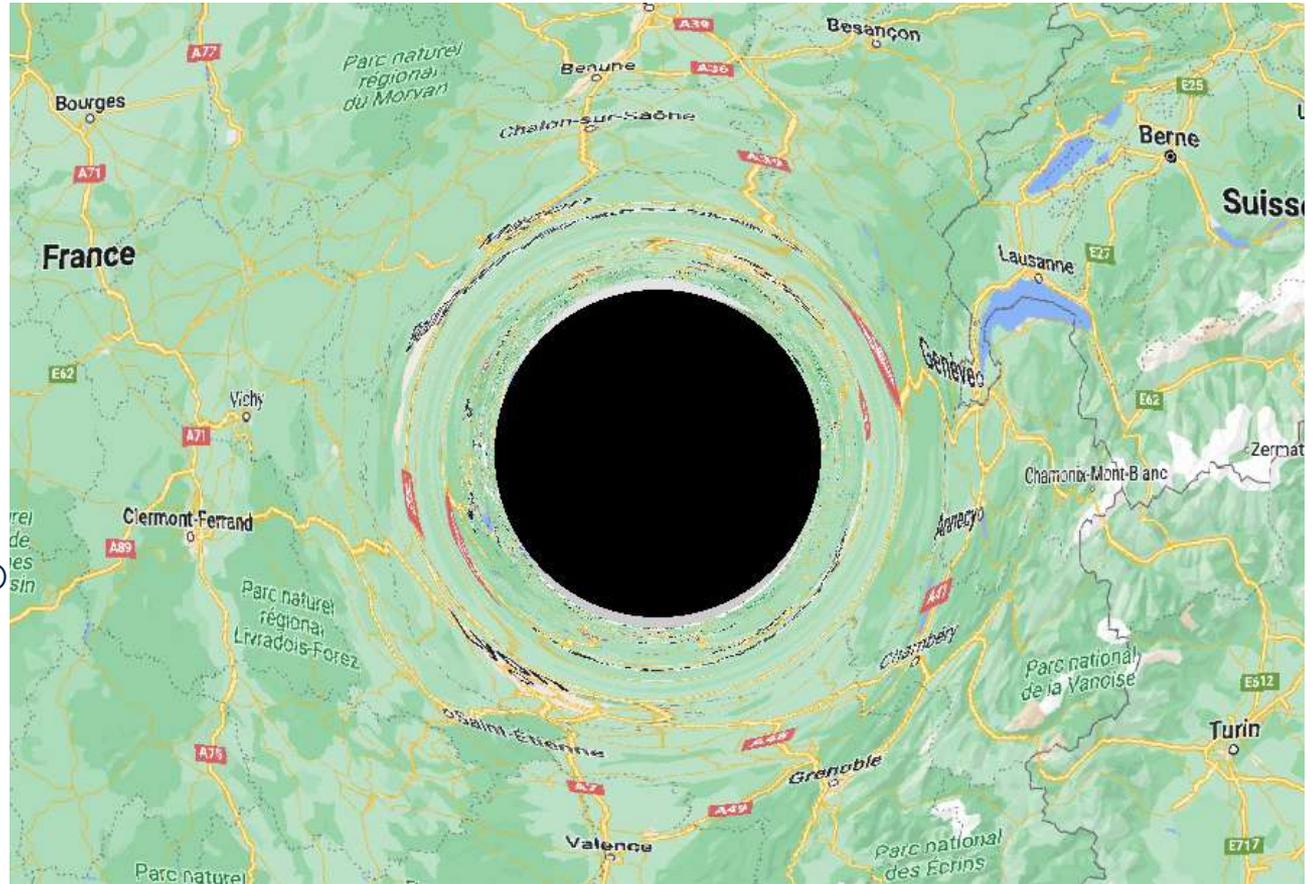
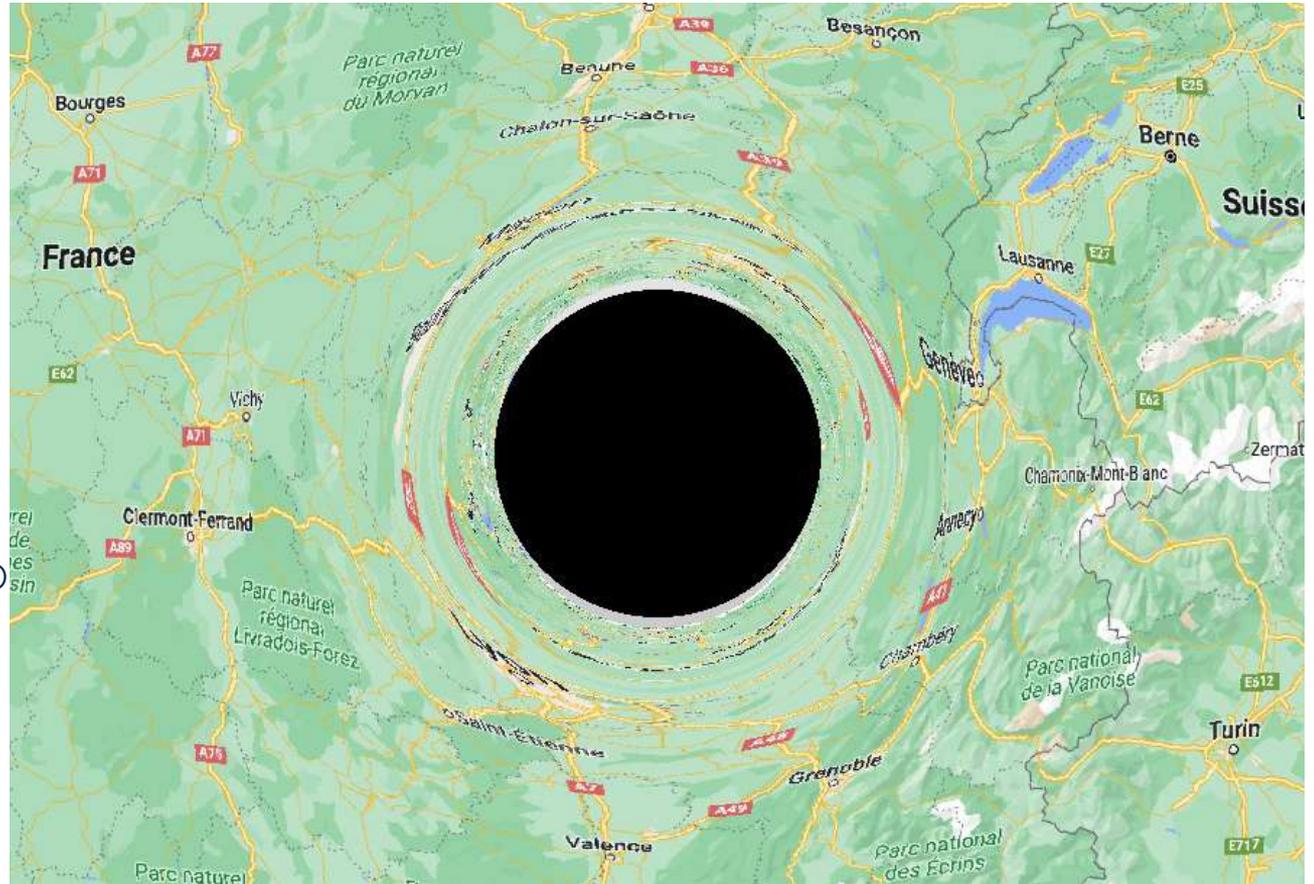
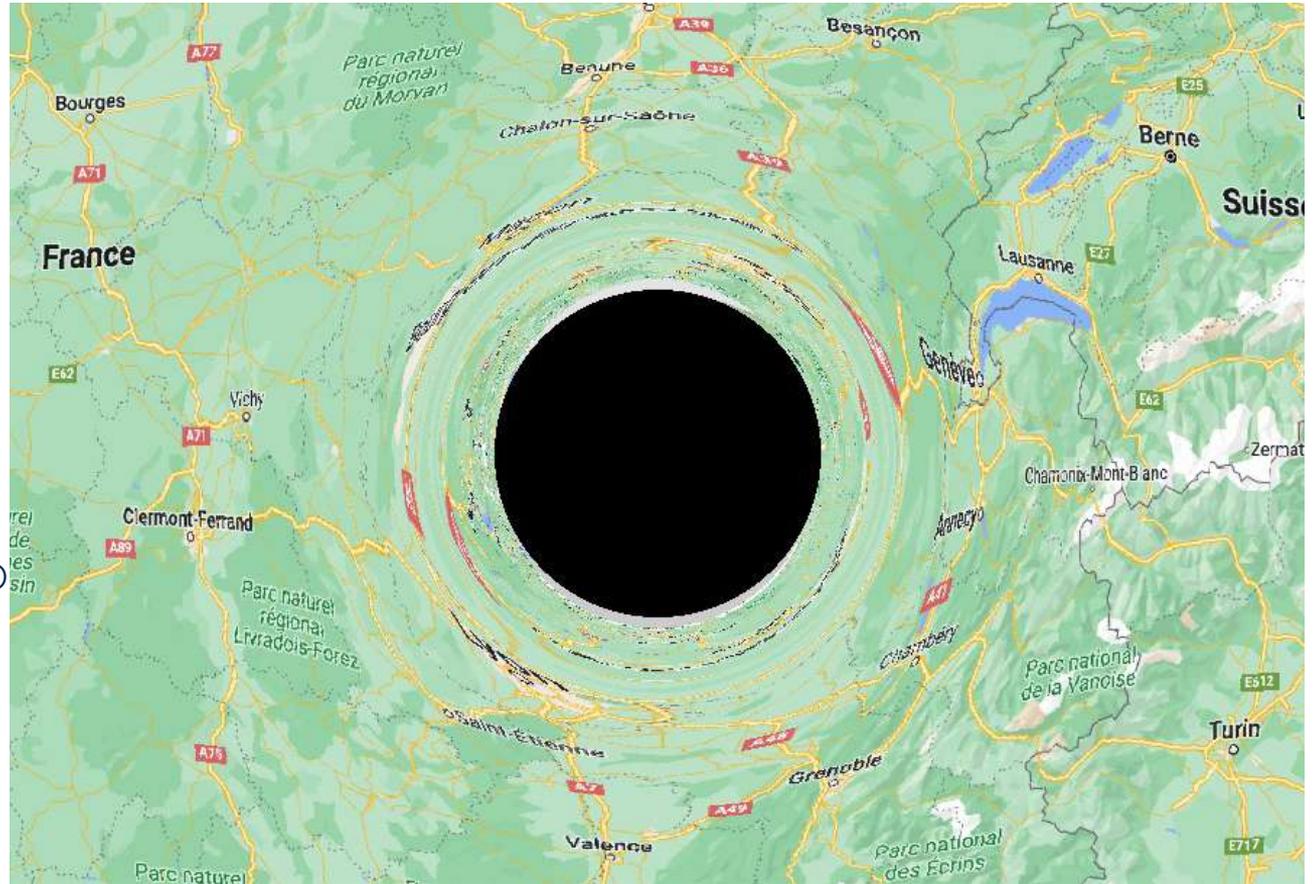
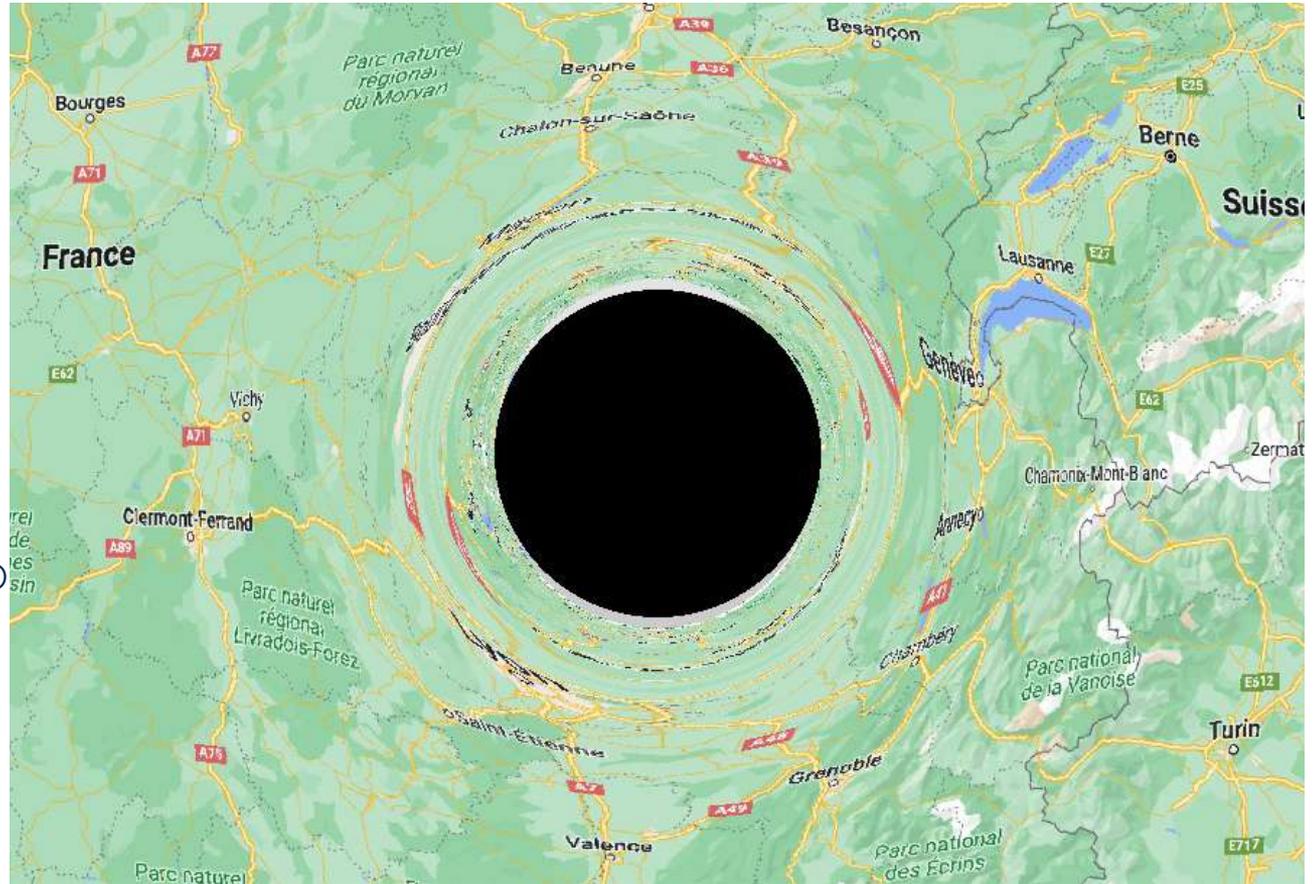
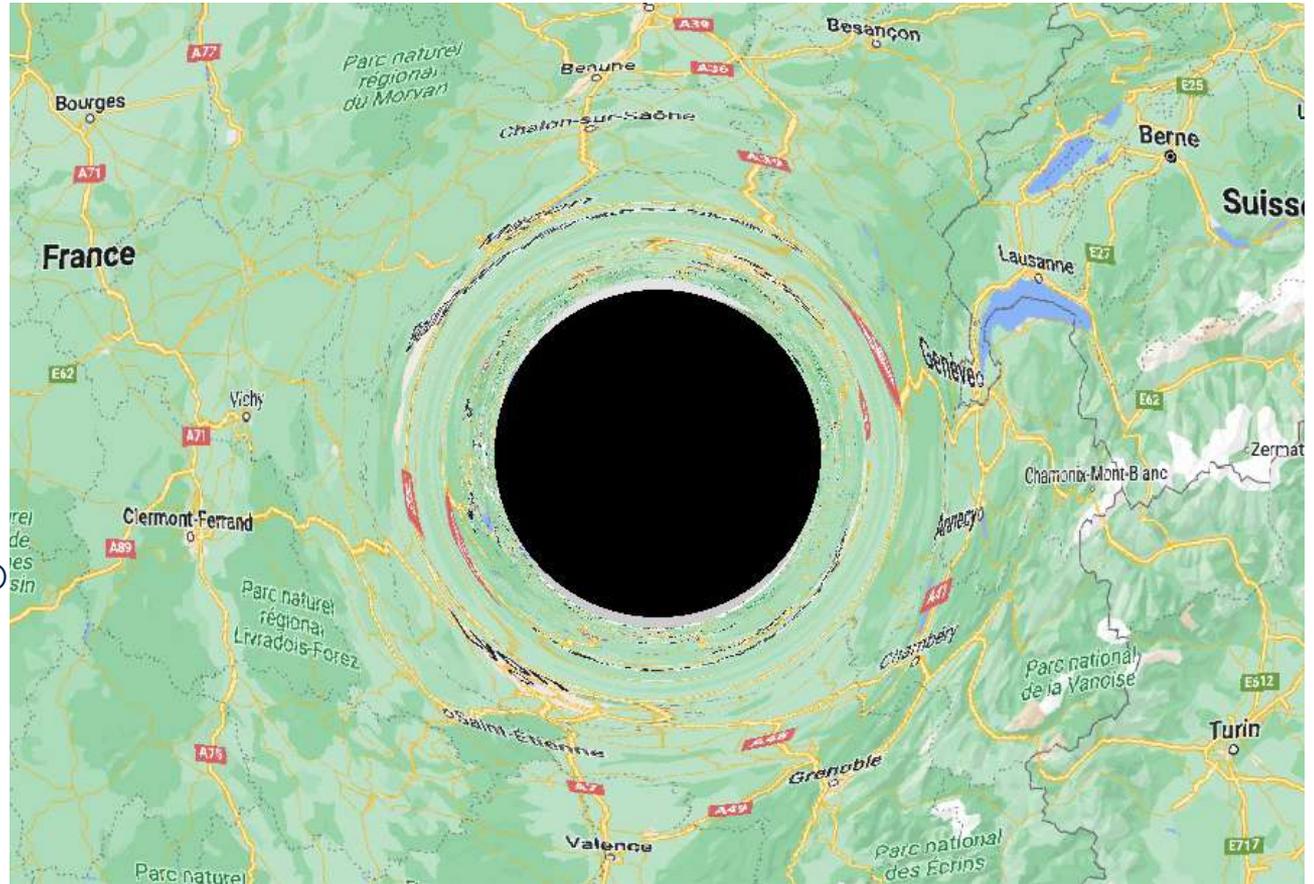
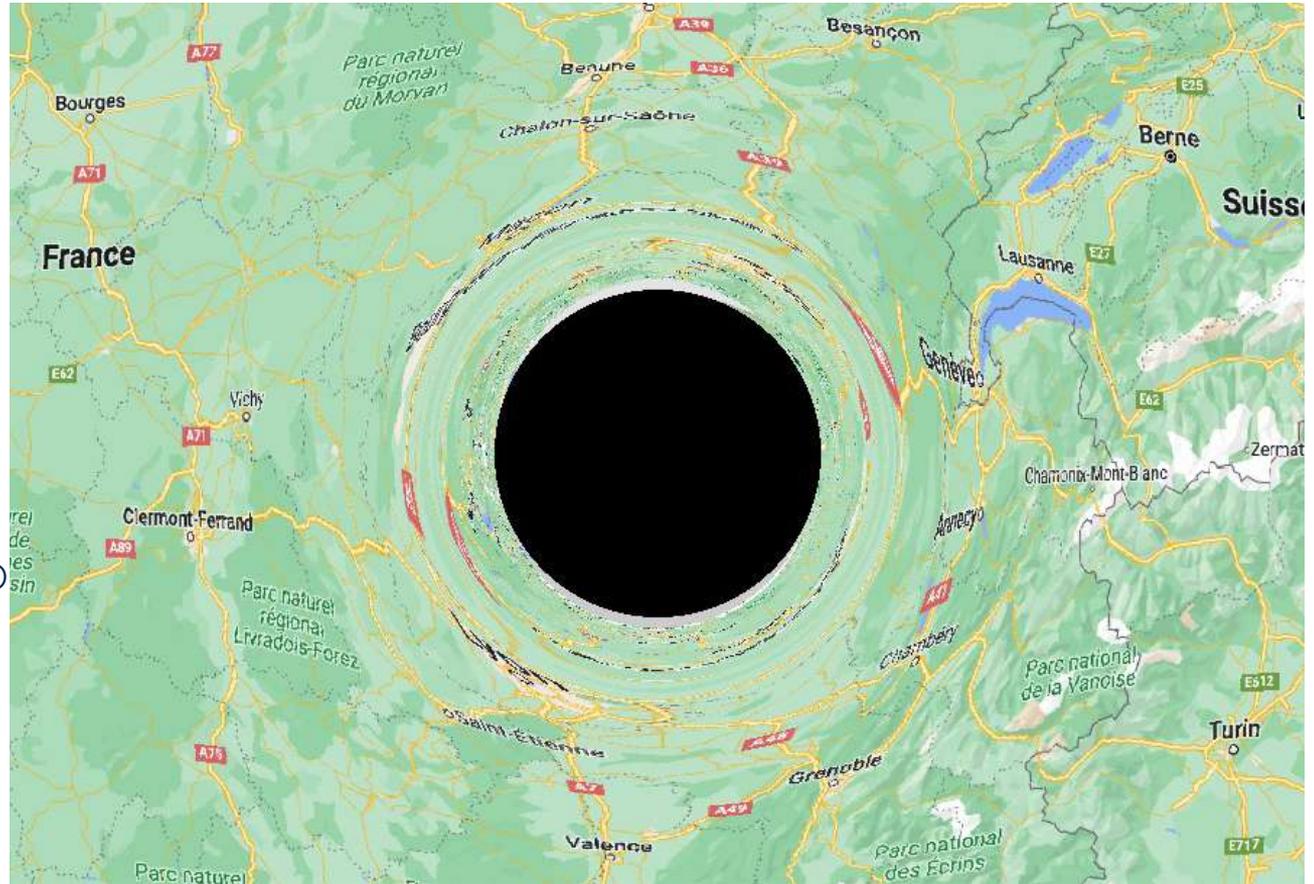
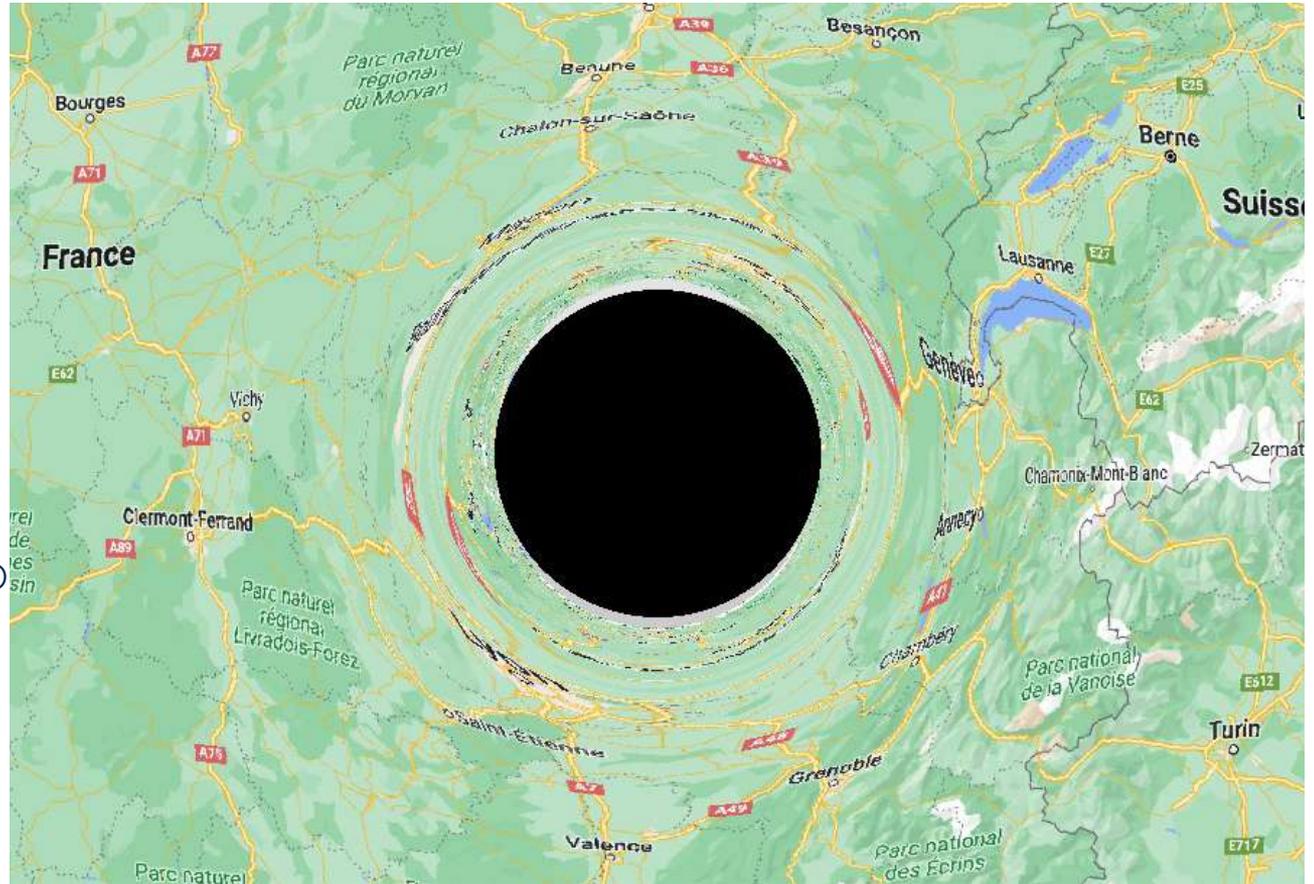
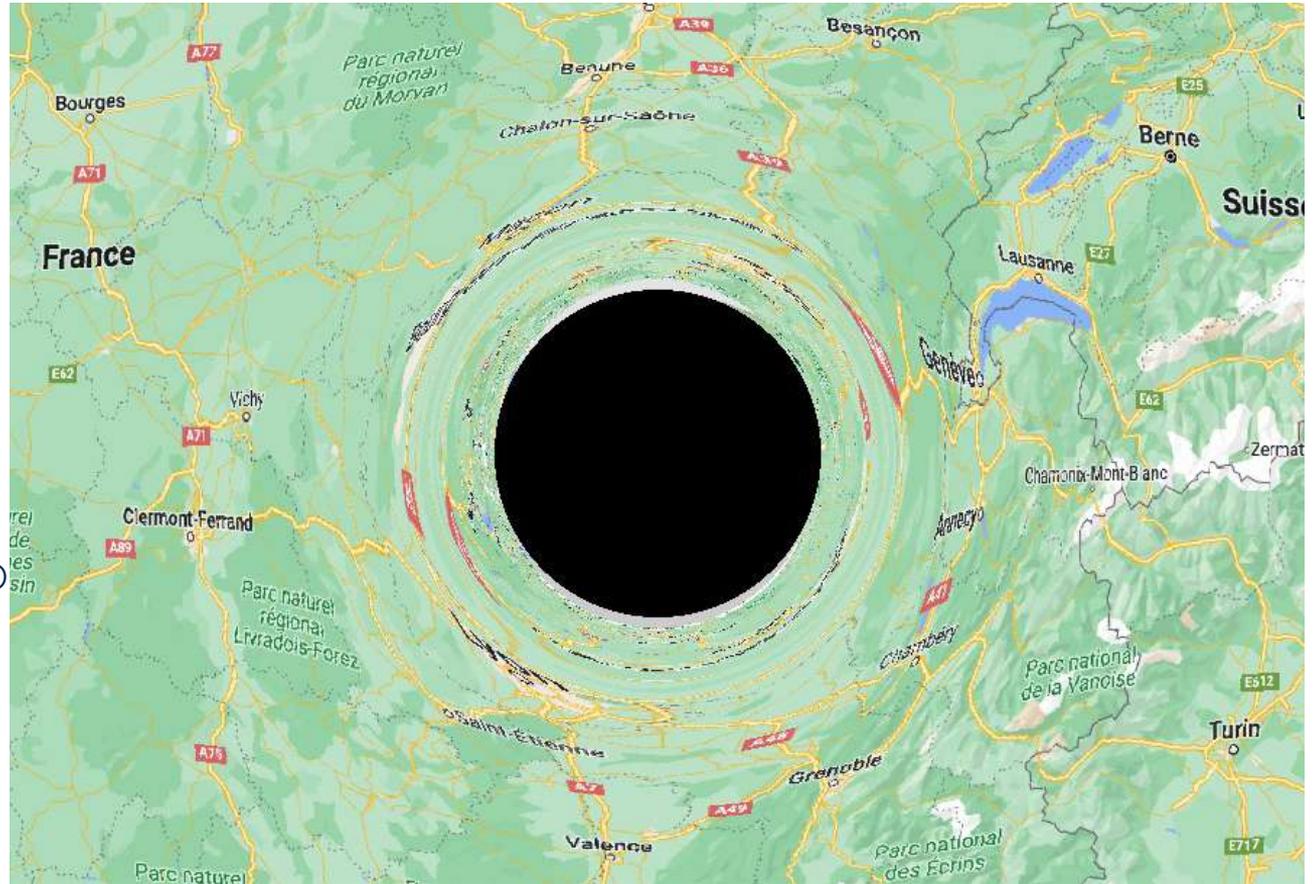
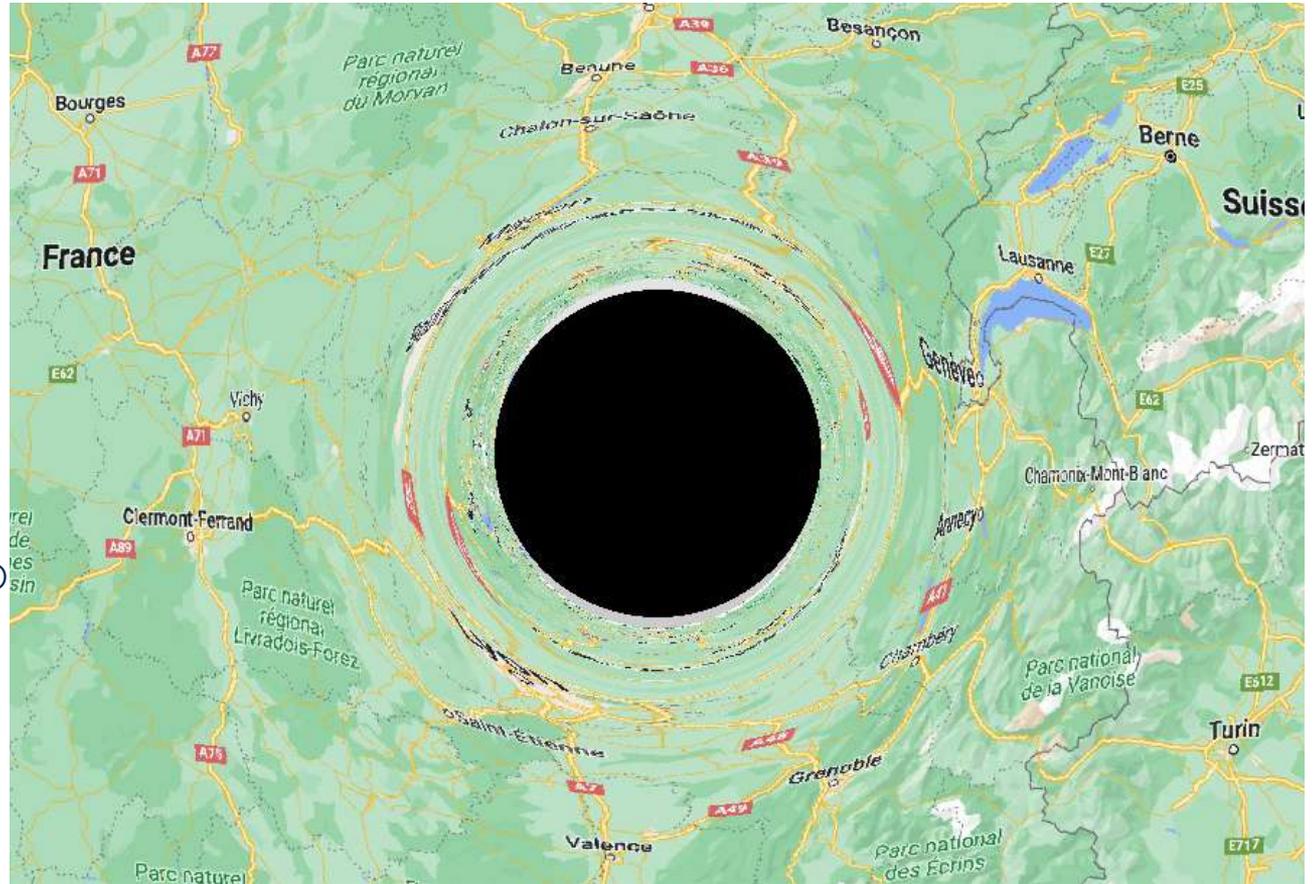
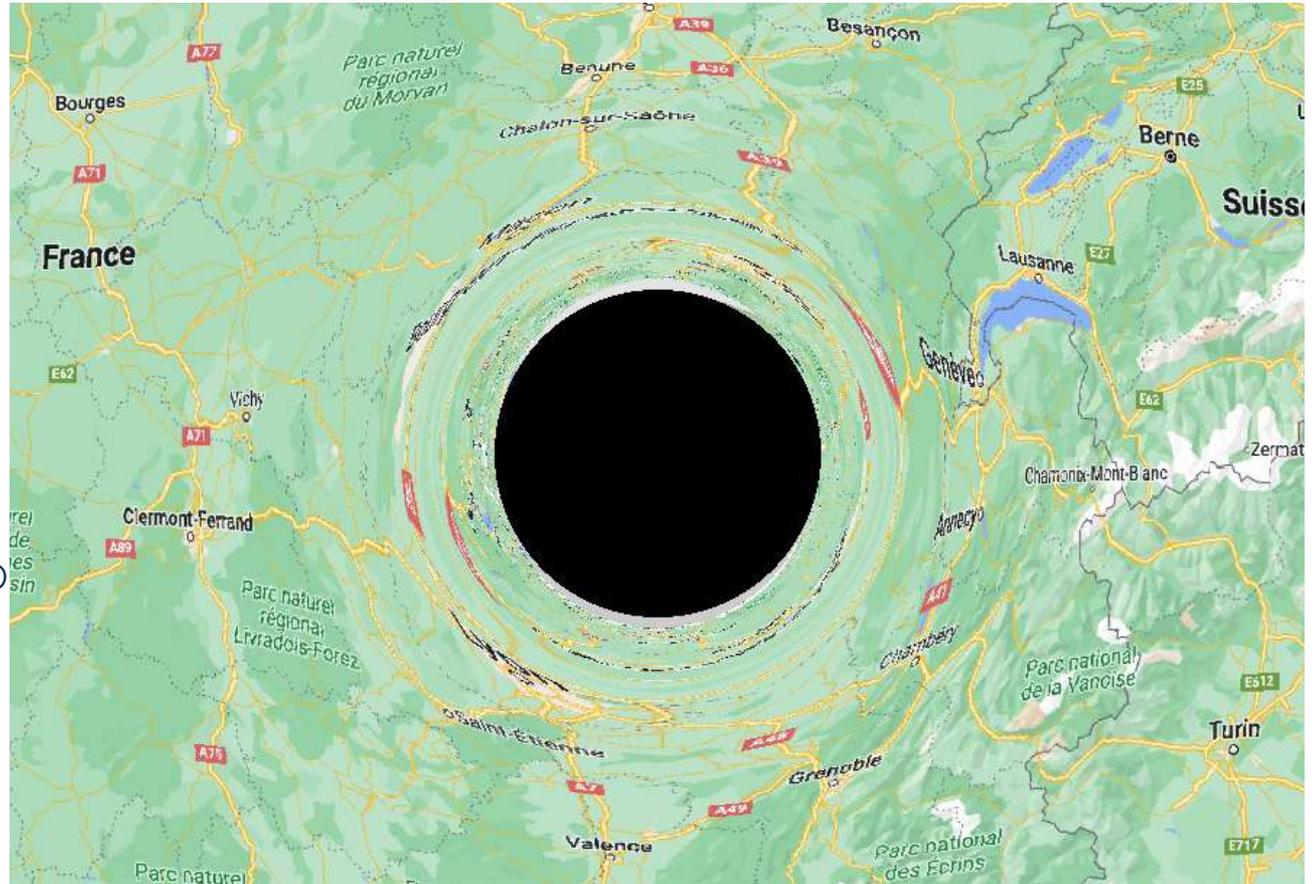
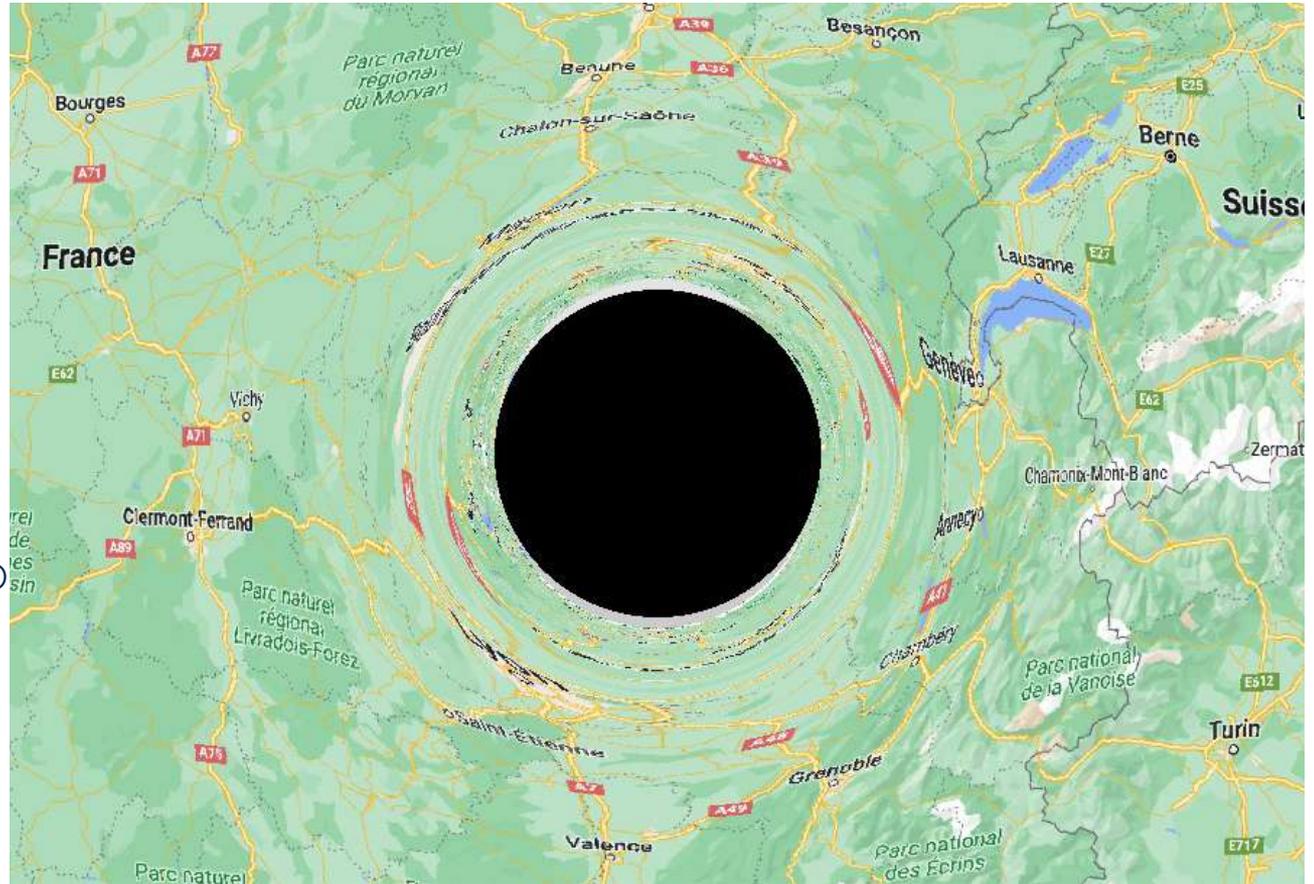
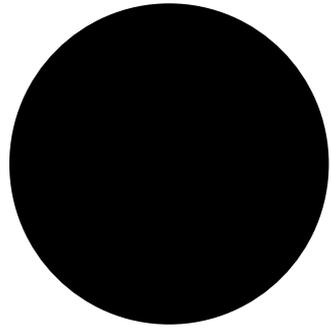
Prix Nobel de Physique 2017



Ce domaine de recherche est actuellement en pleine expansion

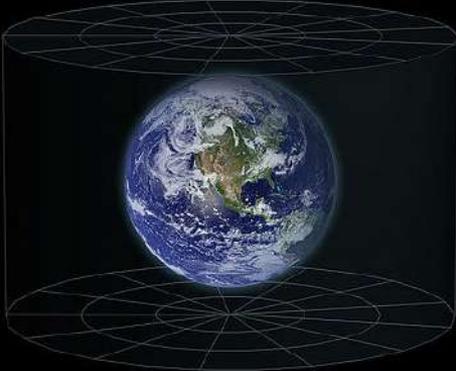


Trou noir de $15 M_{\odot}$

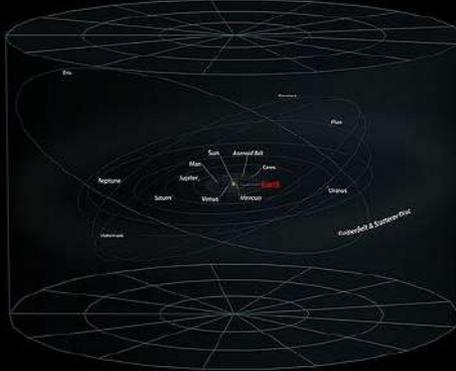


Introduction

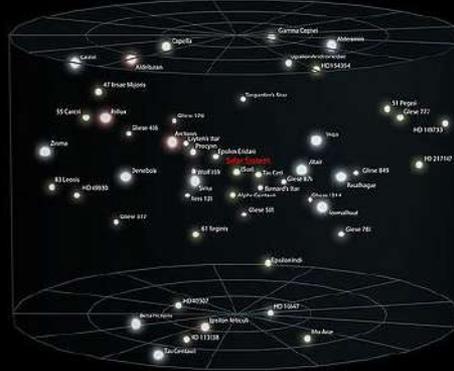
EARTH



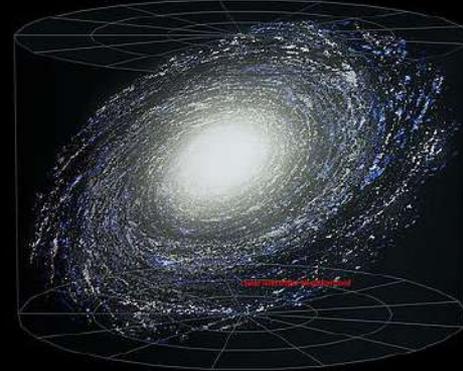
SOLAR SYSTEM



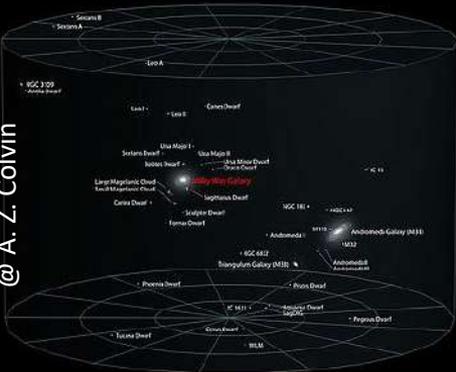
INTERSTELLAR NEIGHBORHOOD



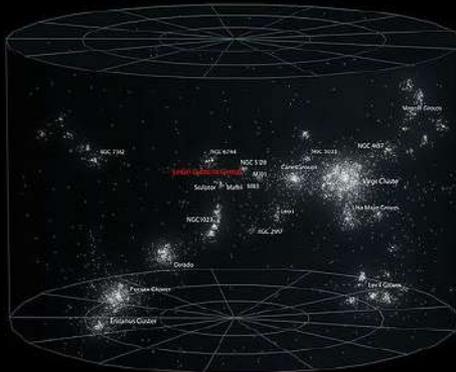
MILKY WAY GALAXY



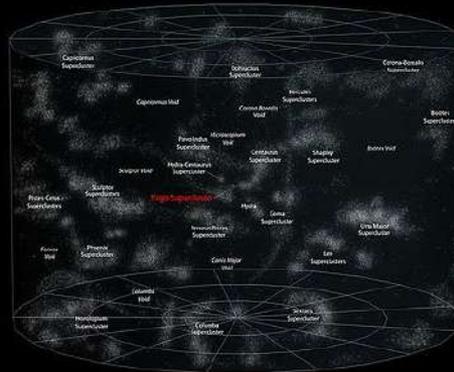
LOCAL GALACTIC GROUP



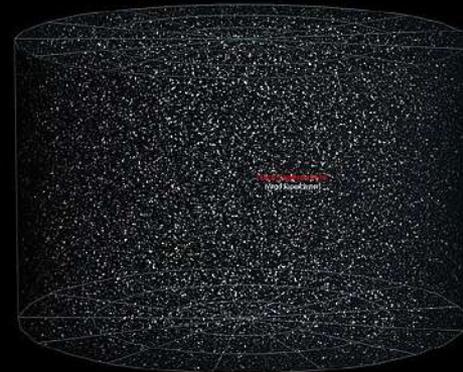
VIRGO SUPERCLUSTER



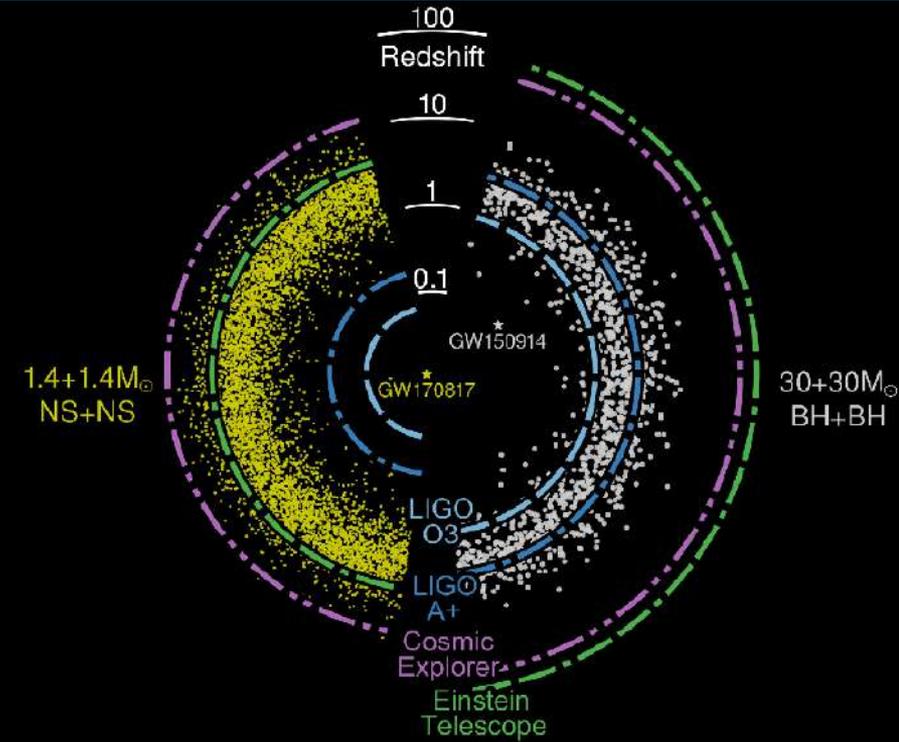
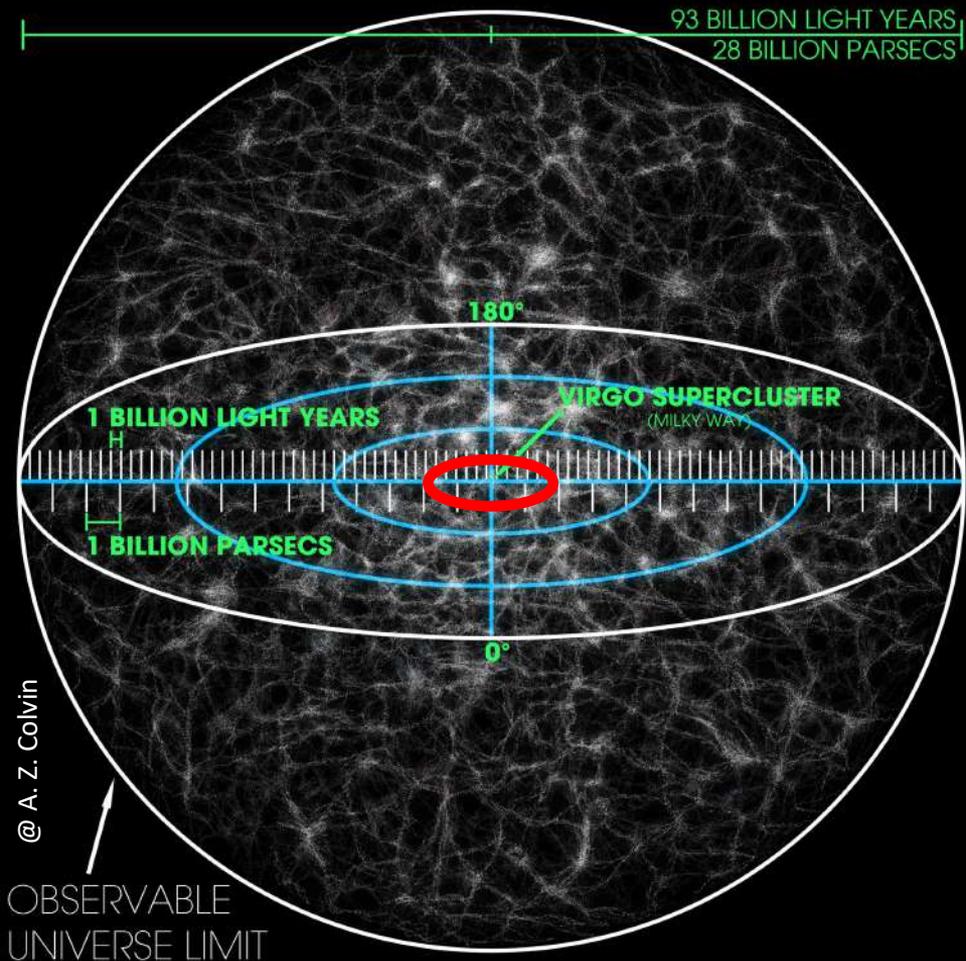
LOCAL SUPERCLUSTERS



OBSERVABLE UNIVERSE



Introduction



Einstein Telescope a pour objectif d'étudier la majeure partie de l'univers observable

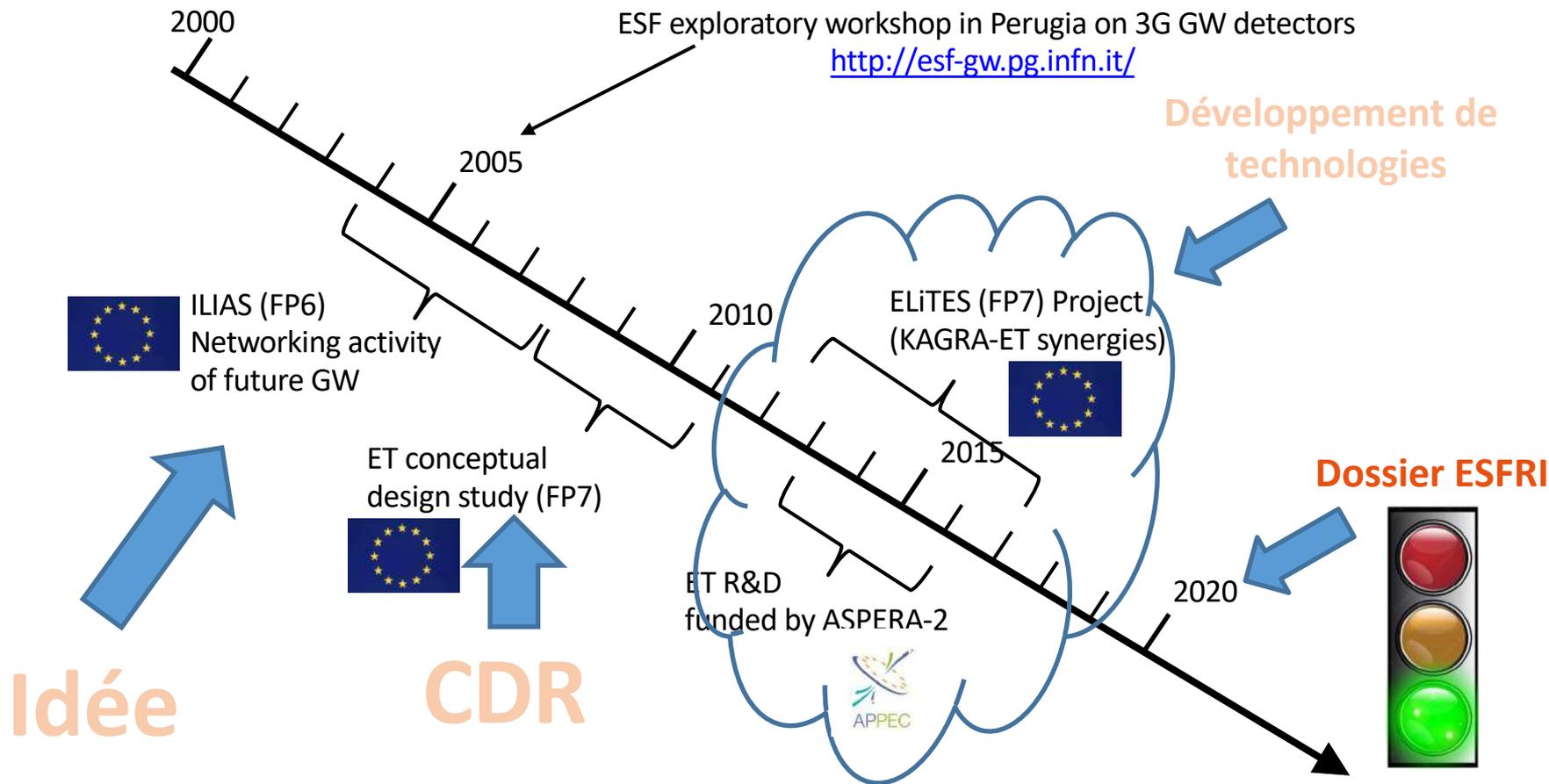
≥ 10km

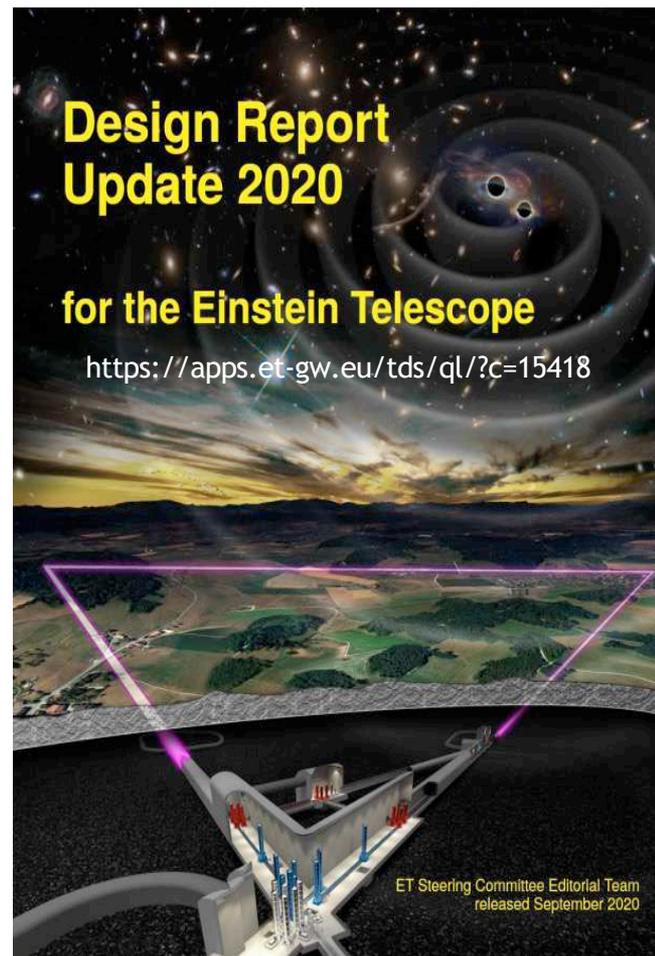
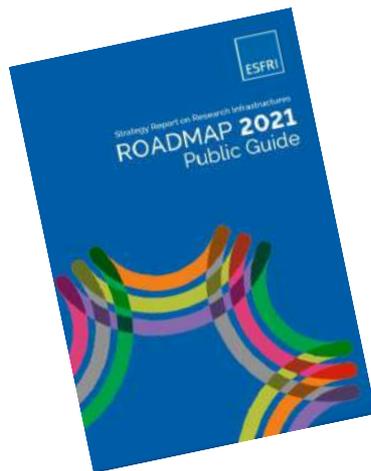
Profondeur:
200m

ET a lancé l'idée d'un observatoire d'OG de 3e génération :

- Une nouvelle infrastructure capable d'héberger de futures mises à niveau pendant des décennies sans limiter les capacités d'observation
- Une sensibilité au moins 10 fois meilleure que les détecteurs actuels (nominaux) sur une grande partie de la bande de fréquence
- Une amélioration spectaculaire de la sensibilité dans la plage des basses fréquences (quelques Hz à 10 Hz)
- Haute fiabilité et capacité d'observation améliorée

La genèse d'Einstein Telescope

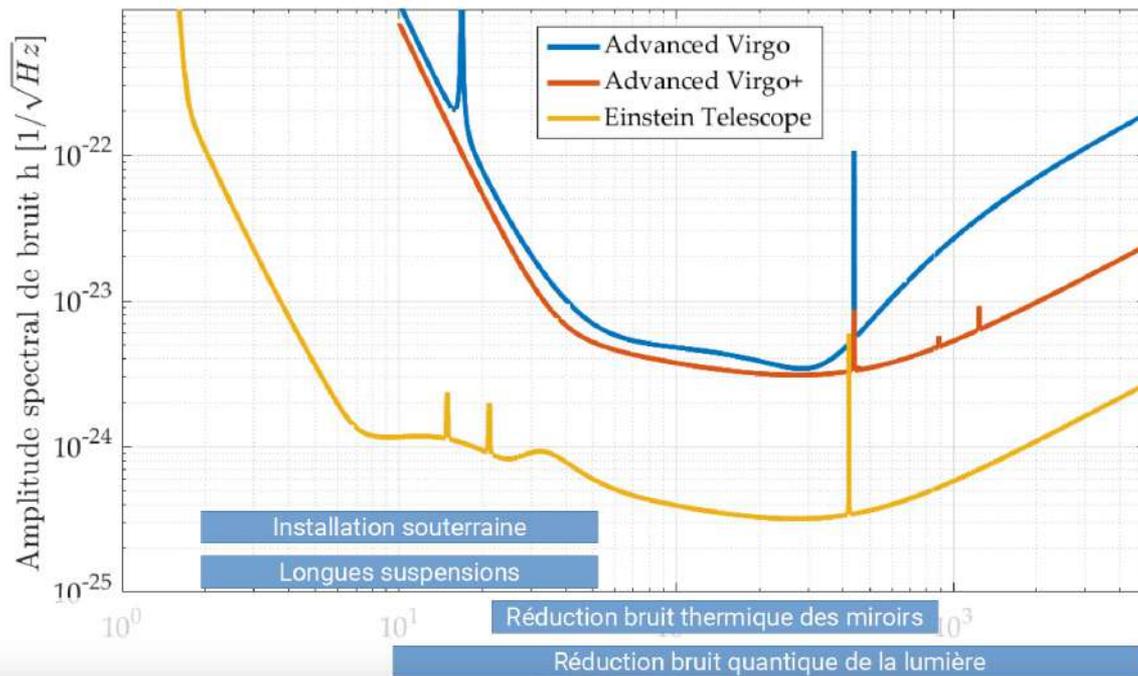




But de ET: être 10 fois plus sensible

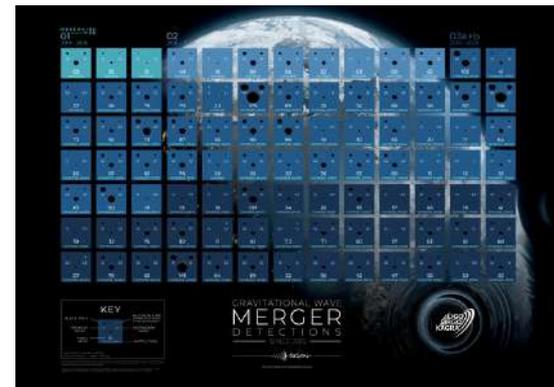
que la seconde génération de LIGO-Virgo (Advanced Virgo/LIGO)

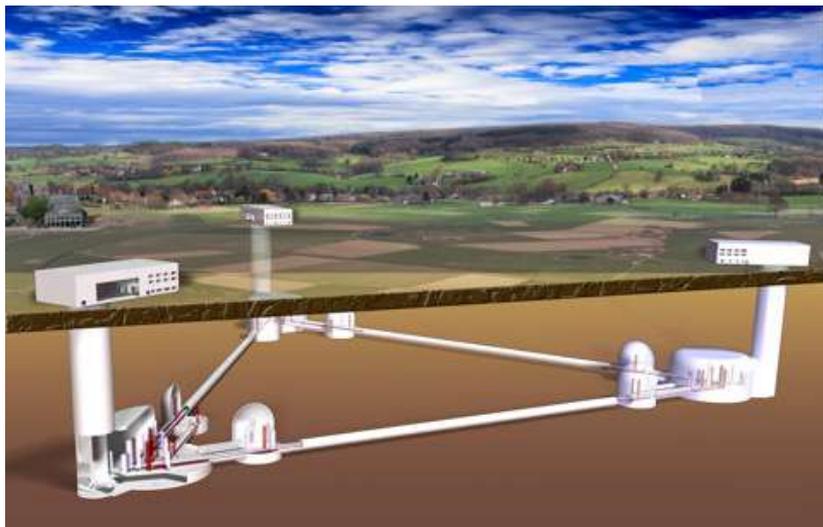
@J. Degallaix



Détecter 10^5 - 10^6 coalescences
de trous noirs et d'étoiles à
neutrons par an

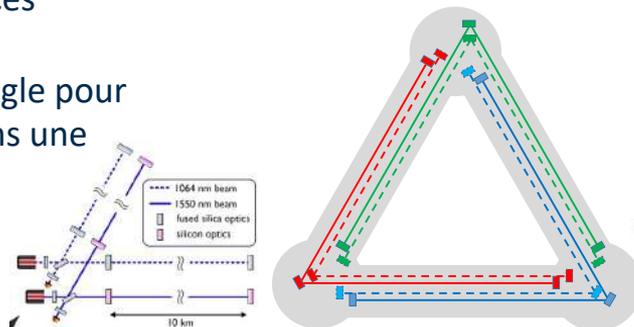
[Run 03-04 de Virgo-LIGO:
90 détections]





Xylophone: 2 interféromètres sensibles
à différentes fréquences

Configuration en triangle pour
avoir 3 détecteurs dans une
même infrastructure

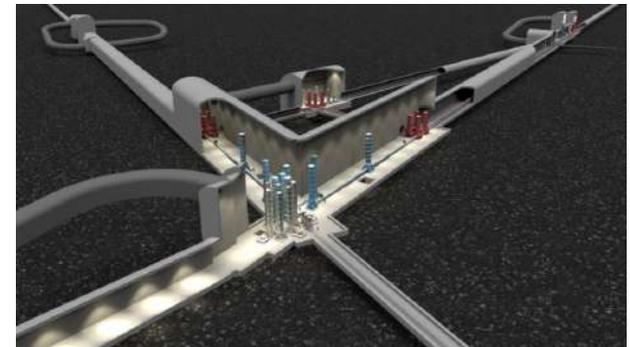
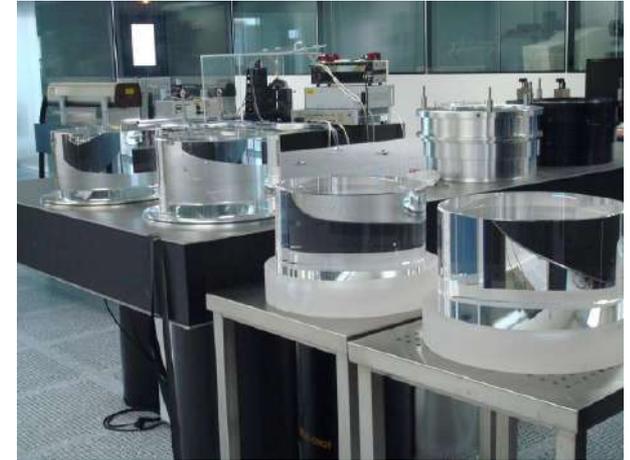


Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×300 m	2×1.0 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	TEM ₀₀	TEM ₀₀
Beam radius	12.0 cm	9 cm
Scatter loss per surface	37 ppm	37 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10} \text{ m}/f^2$	$5 \cdot 10^{-10} \text{ m}/f^2$
Gravity gradient subtraction	none	factor of a few

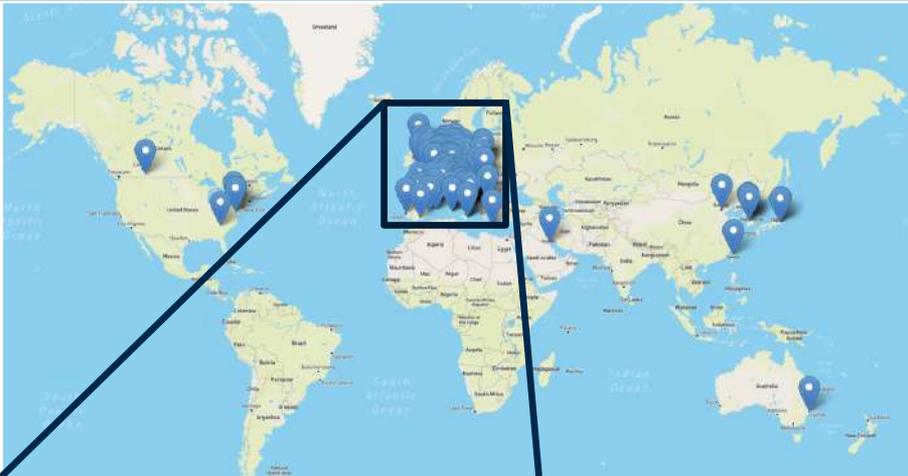
- Extrapolation des technologies actuelles ou prévues pour Virgo et LIGO
 - Squeezing (états quantiques de lumière)
 - Lasers haute puissance
 - Des miroirs plus grands
 - Nouvelles couches minces pour les miroirs
 - Techniques de compensation thermique
 - Systèmes de suspension parasismique
- Technologies non testées dans Virgo et LIGO (prototypes et/ou R&D en cours)
 - Cryogénie (également dans KAGRA)
 - Nouveaux matériaux cryogéniques
 - Nouvelles longueurs d'onde laser

c.f. Christelle's talk

Leadership français sur les miroirs (LMA)
Virgo-LIGO-Kagra



⇒ Mise en place de programmes de R&D



1370 collaborateurs de 202 instituts dans 23 pays dans le monde
ET en France: 17 laboratoires et 116 members

ARTEMIS (Nice)
IF-ILM (Marseille-Lyon)
IP2I-LMA (Lyon)
LAPP (Annecy)

APC (Paris) avec Subatech
IJCLab (Orsay) avec LKB
IPHC-L2IT (Strasbourg-Toulouse)
PARIS-CAEN LPC Caen, LUTH, IAP, GANIL, SYRTE, GEPI

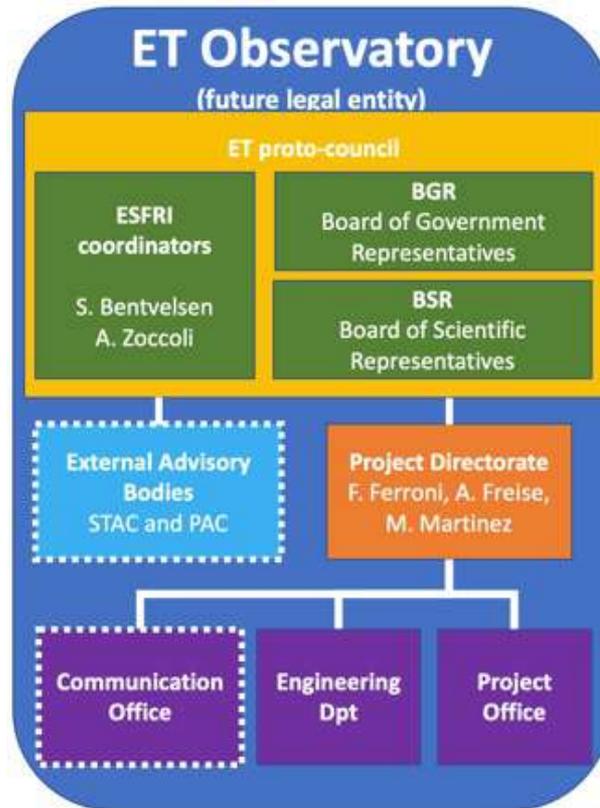
En France:

- Coordination CNRS avec la direction de l'IN2P3 qui rapporte au MESR les avancées du projet
- Revue en 2020 par le Haut-Conseil des TGIR
- Mise en place d'une organisation projet (janvier 2023), synergies maximales avec EGO/Virgo

L'UE soutien la création de l'infrastructure ET (ETO) via le financement d'un projet Infradev:

Einstein Telescope Preparatory Phase (ET-PP)

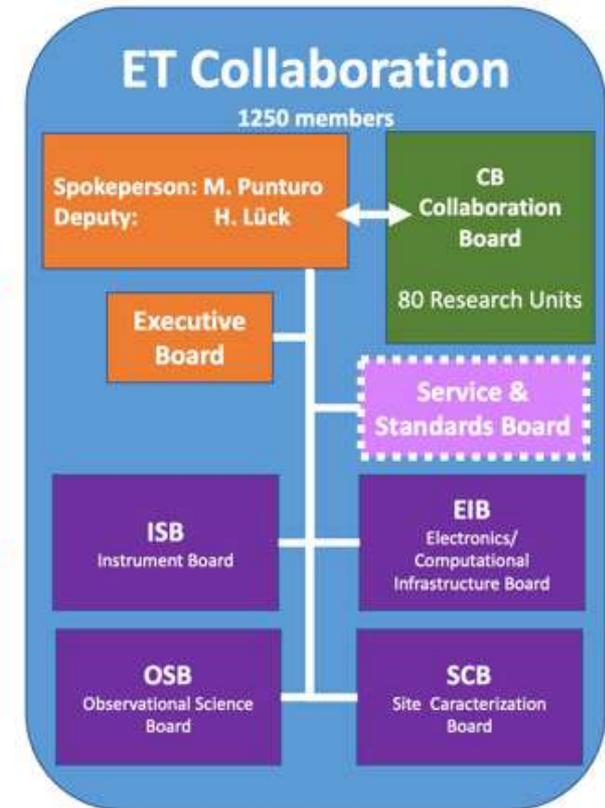
Forte contribution CNRS



Projects

Infradev ET-PP
Implementation plan of ET Observatory
M. Martinez (Managed by Project Directorate)

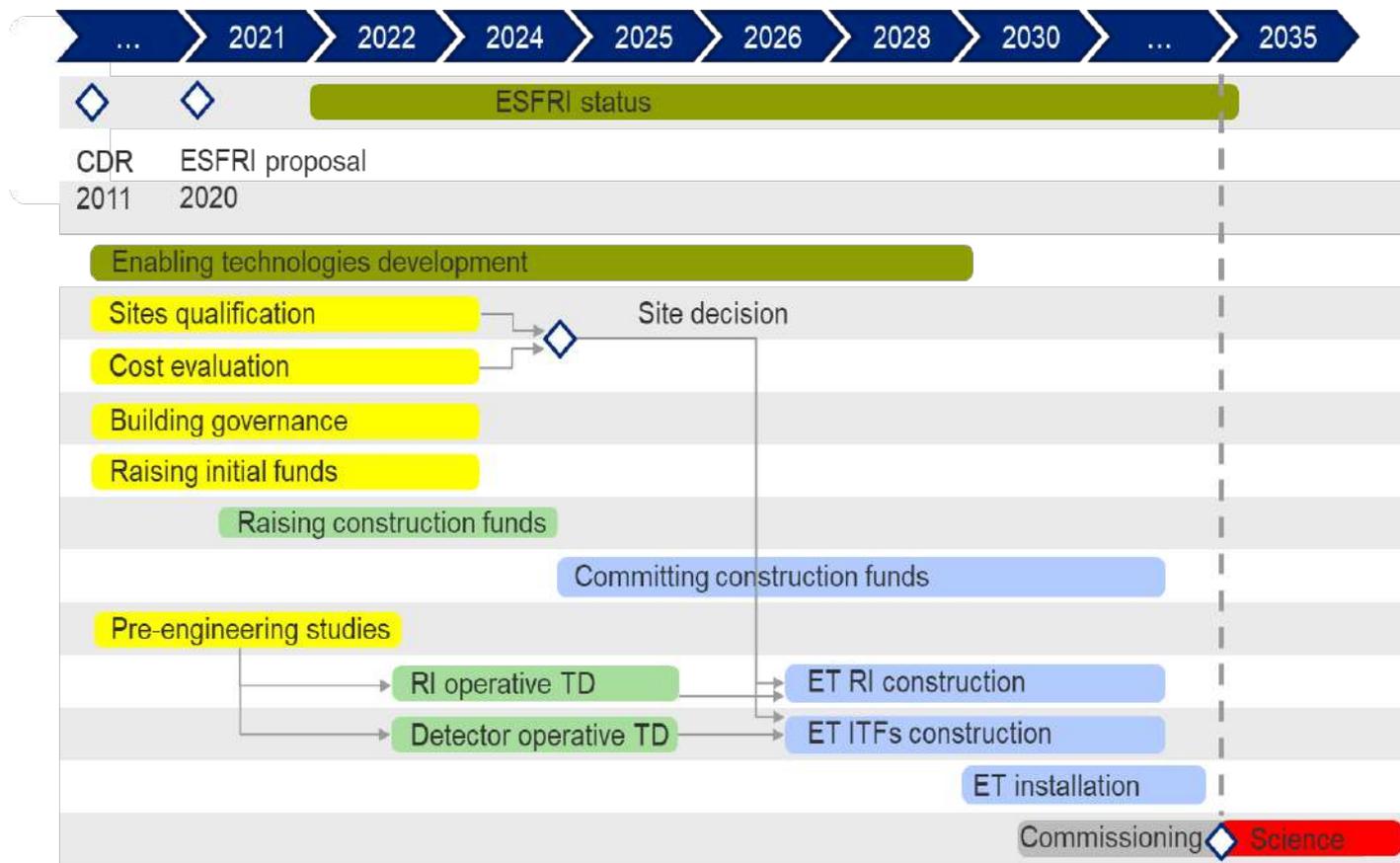
Design of ET Vacuum Pipe
P. Chiggiato (CERN coordination)



Depuis l'été 2022, le projet Einstein Telescope se structure rapidement

Calendrier

* Tentative schedule



ESFRI Phases: Design Preparatory Implementation Operation

Il existe actuellement deux sites, en Europe, candidats pour héberger ET :

- Le site de Sardaigne, à proximité de la mine de Sos Enattos
- Le site EU Regio Rhin-Meuse, à proximité de la frontière NL-B-D
- Une troisième option en Saxe (Allemagne) est en discussion

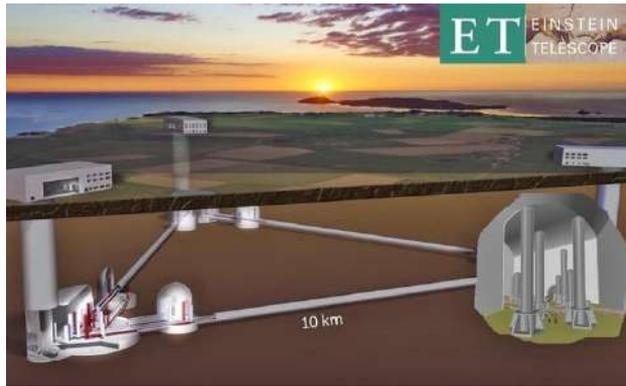
Les sites sont étudiés à travers

- mesures de bruit sismique en surface, en forage et en mine (Sardaigne)
- Mesures des bruits magnétiques et ambiants
- Caractérisations géophysiques et géotechniques
- ...

Des fonds importants sont nécessaires pour élaborer et proposer une candidature de site



Sardaigne – Italie

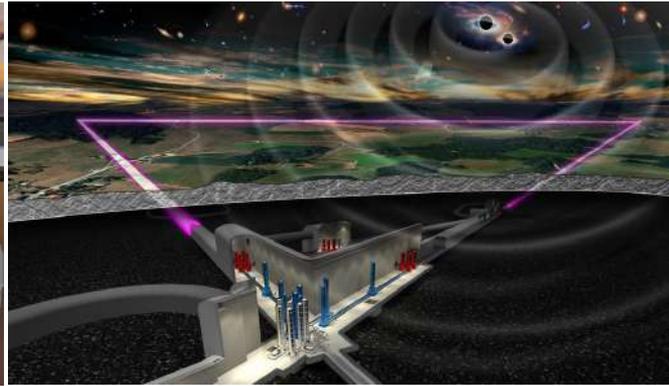


50 M€ pour les R&D et des travaux préparatoires

ETIC en Italie

Einstein Telescope Infrastructure Consortium
Financement « multi-100 M€ »
si le site d'ET est en Sardaigne

Euregio Meuse-Rhin – Pays-Bas



42 M€ pour les R&D et des travaux préparatoires

ET-Pathfinder à Maastricht

Financement « multi-100 M€ »
si le site d'ET est en Euregio
Meuse-Rhin

Saxe – Allemagne

The German Centre for Astrophysics

2 locations for research,
technology, digitalisation



Nouveau laboratoire DZA (2022)
170 M€/an sur 10 ans

3 piliers: astrophysique, sciences
des données, technologies

ET-PATHFINDER

- New facility for testing ET-LF technology in a low-noise, full-interferometer setup
- Key aspects: **Silicon mirrors** (3 to 100+kg), **cryogenics** cryogenic liquids and sorption coolers, water/ice management), “**new**” **wavelengths** (1550 and 2090nm), coatings etc
- Start with 2 FPMI, one initially at 120K and one 15K (2022+)
- >20 partners from NL/B/G/FR/SP/UK
- Initial capital funding of 14.5 MEuro
- Detailed **Design Report** available at apps.et-gw.eu/tds/?content=3&r=17177
- **Open for everyone interested to join**
- For more information please see: www.etpathfinder.eu

CREDIT: S. Hild



Interreg
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling



Vacuum System of 130 cubic meters.
Vacuum system EU tender completed.
Vessels in production now.
First tower acceptance test (10-9mbar) in July
First tower delivery scheduled for 4. August 2021

Un des axes du projet ETIC est le développement d'un labo cryo à Rome



3G Gravitational-Wave Lab



With ARC funds, we are preparing a lab for low temperature tests on a real size prototype of an ET LF-Payload

Pulse Tube Cooling Station

Cryogenic Tests Area:

Test Cryostat for a full size LF-Payload, cooled by two PT (~ \varnothing 3 m x 3.5 m):

- 2 thermal shields in insulation vacuum
- 1 experimental chamber with separated vacuum

Payload Development and Test Area (LF Payload – Real size)

The Rome1 ET Group:

From Virgo:

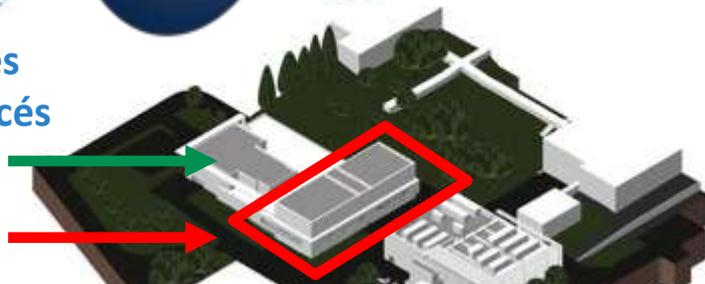
Sibilla	Di Pace	(Post Doc Researcher)
Ettore	Majorana	(Full Professor)
Valentina	Mangano	(Post Doc Researcher)
Luca	Naticchioni	(INFN Researcher)
Maurizio	Perciballi	(INFN Technician)
Paola	Puppo	(INFN Researcher)
Piero	Rapagnani	(Associate Professor)
Fulvio	Ricci	(Full Professor)

From CUORE:

Angelo	Cruciani	(INFN Researcher)
Antonio	D'Addabbo	(Post Doc Researcher LNGS)
Stefano	Pirro	(INFN Researcher)

From EGO:

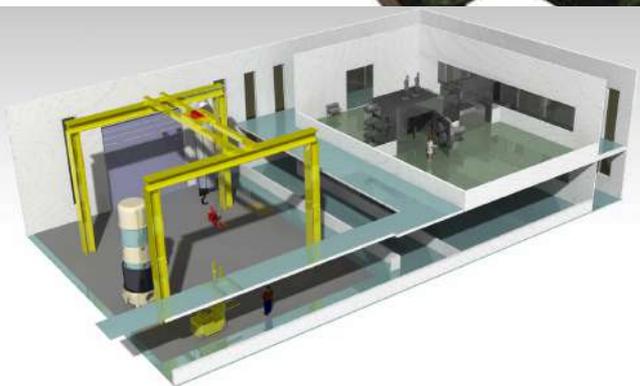
Paolo Ruggi	(EGO Researcher)
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Laboratoire des
Matériaux Avancés

Actuel

Extension



Les miroirs les plus parfaits au monde sont fabriqués à Lyon au LMA

Contrat de Plan
Etat-Région
2021-2027



Un investissement de **12 M€** pour:

- l'extension du bâtiment du LMA
- la construction d'un nouveau bâti permettant le dépôt de couches minces sur de très grands substrats (\varnothing 1,6 m, 600 kg)
- les outils optiques et de métrologie associés

Le LMA est une infrastructure de recherche unique au monde

- Développer les technologies pour les expériences du futur (Ex. : Einstein Telescope)
- Conserver le leadership international du LMA pour les 20 prochaines années

Infrastructure

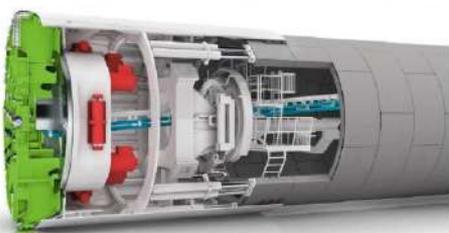
@J. Degallaix



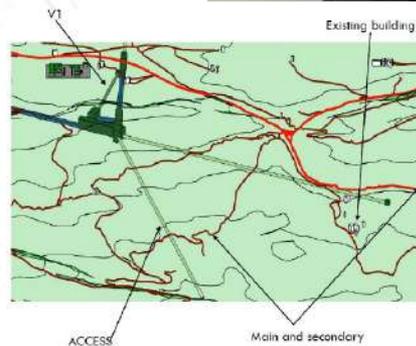
- stratégie pour la construction des tunnels et cavernes
- gestion infrastructure souterraine
- intégration dans l'environnement local



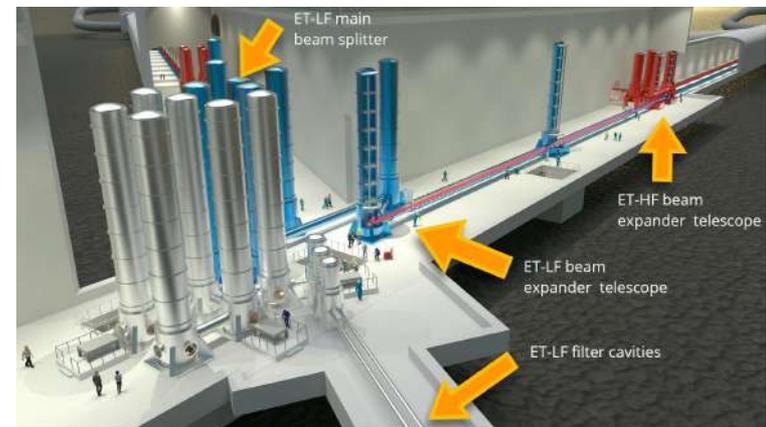
Taille, forme des cavernes ?



Méthode d'excavation ?



Installations existantes ?



+ Etudes pour la caractérisations des sites candidats en cours: forages, bruits ambiants (sismiques, éoliennes, magnétique ...)

Les systèmes à vide prévus pour les détecteurs 3G seront probablement les plus grands systèmes UHV construits

- Le tube de faisceau est son composant le plus important ($\sim 1/2$ du coût du système)
- 120 km de tubes UHV de 1 m de diamètre, volume total $\sim 10^5$ m³
- Exigences de vide : facteur > 5 plus strict que Virgo :
 - 10^{-10} mbar pour H₂
 - 10^{-11} mbar pour N₂
 - $< 10^{-14}$ mbar pour les hydrocarbures
- Durée de vie: 50 ans
- Coût estimé préliminaire ~ 560 M€

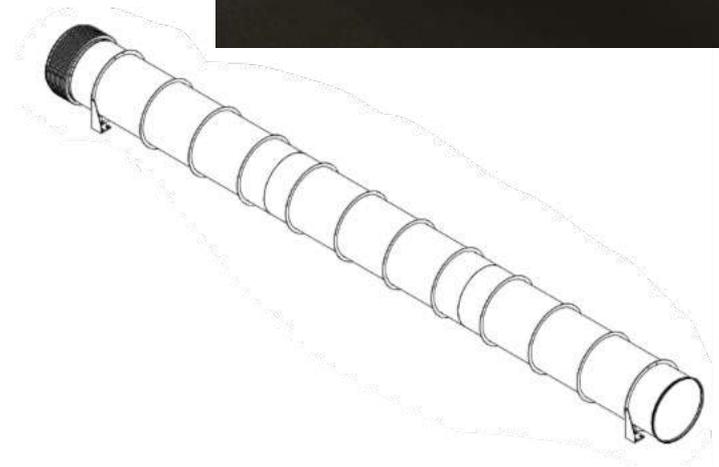
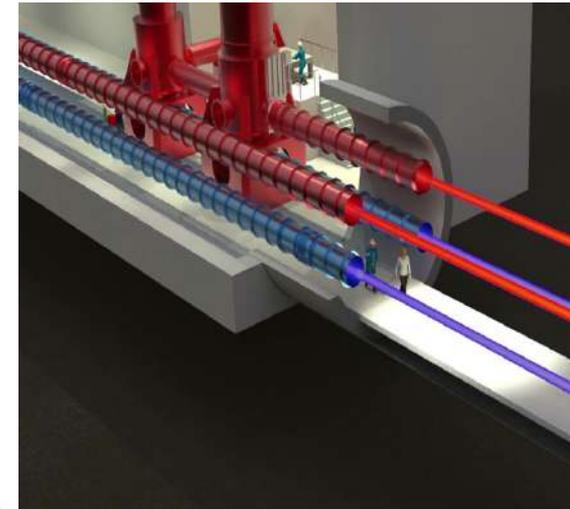
Développement conjoint avec le CERN impliquant Einstein Telescope et Cosmic Explorer (Projet US)



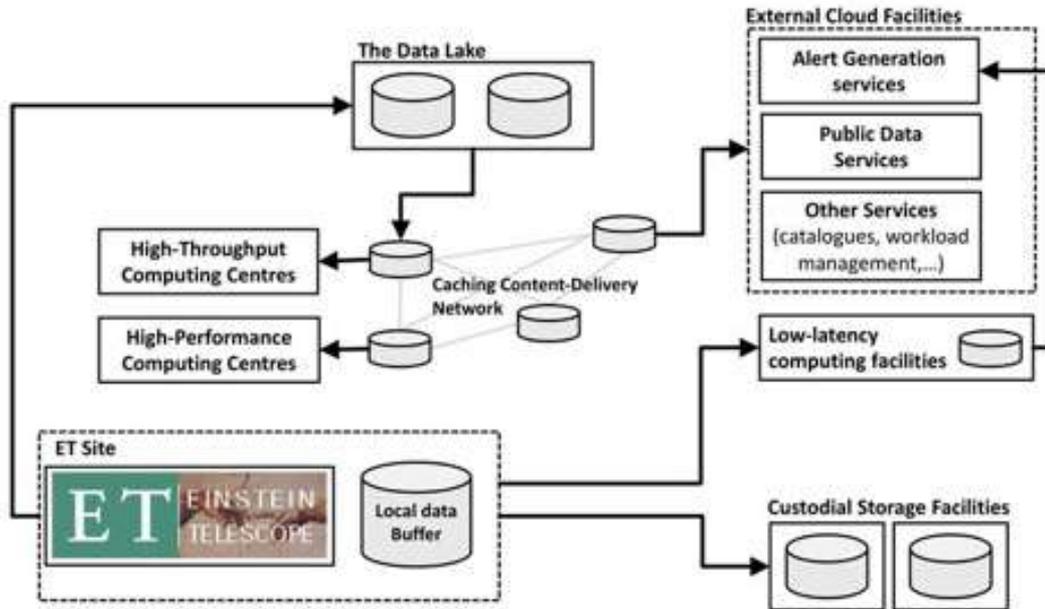
En supposant une approche à la Virgo et ~ 3 ans pour la production:

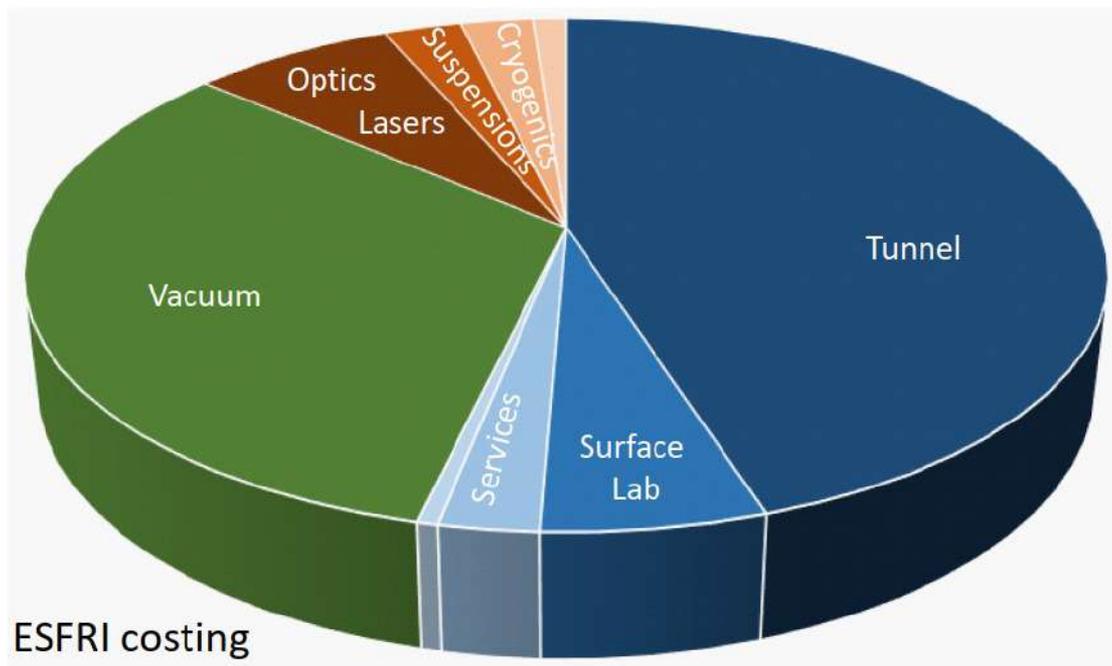
- 13000 t d'acier brut
- 8000 modules de 15 m de long (y compris le soufflet de dilatation thermique)
- Production de 8 modules/jour (y compris les contrôles de fuite et de contrôle qualité poussés)
- 240 stations de pompage (5000 l/s efficace, ionique, getter, turbo moléculaire auxiliaire)
- 720 vannes (250 mm)
- ajouter des brides tous les 250 m ?
- Vannes 48/72 (diamètre 1 m)
- 10 fours (chacun pour 4 modules à la fois) fonctionnant environ 3 ans 24h/24 et 7j/7 pour la cuisson à l'air
- 4 systèmes de nettoyage

En extrapolant les coûts de Virgo à ET: 560 M€



ET utilisera une **infrastructure informatique distribuée en Europe**, basée en grande partie sur les infrastructures existantes comme le **CC-IN2P3** en France (ET = $\sim 10\%$ d'une exp. LHC au CERN).
Utilisation croissante de calcul parallèle haute performance (HPC) vs calcul HTC.
Utilisation des outils et services développés dans le cadre de **'European Open Science Cloud** et des projets Européens comme ESCAPE pour la **physique multi-messagers**





ESFRI costing
2021

Tunnel	781 M€
Surface Lab	98 M€
Underground Services	44 M€
Direction	9 M€
	932 M€
Vacuum Systems	566 M€
	566 M€
Optics & Lasers	125 M€
Suspensions	48 M€
Cryogenics	45 M€
Installation	20 M€
	238 M€

Einstein Telescope est un projet très ambitieux nécessitant:

- ❖ Le développement de nouvelles technologies (next talk !)
- ❖ Une grande collaboration scientifique structurée et organisée
- ❖ Des partenariats solides entre les acteurs de la recherche académique et du secteur industriel pour:
 - Des programmes amonts de R&D
 - La construction de l'infrastructure et des instruments

<https://et-france.in2p3.fr>



The screenshot shows the website for Einstein Telescope France. At the top left is the logo for 'EINSTEIN Telescope France'. To the right are navigation links: 'ACCUEIL', 'EINSTEIN TELESCOPE', 'OBJECTIFS SCIENTIFIQUES', 'EINSTEIN TELESCOPE EN FRANCE', and 'ACTUALITÉ'. The main content area is titled 'à propos EINSTEIN TELESCOPE'. Below the title is a paragraph of text: 'Einstein Telescope (ET) est le projet Européen d'infrastructure de recherche souterraine pour héberger d'ici la fin des années 2030 un observatoire d'ondes gravitationnelles de 3ème génération. Il s'appuie sur le succès des détecteurs interférométriques Laser de 2ème génération, Advanced Virgo et Advanced LIGO, dont les découvertes sur les fusions de trous noirs et d'étoiles à neutrons ont révolutionné nos connaissances sur l'Univers et notre manière de l'étudier. Einstein Telescope améliorera la sensibilité en augmentant la taille de l'interféromètre avec des bras de 10km de long, comparé à 3km pour Virgo, et en mettant en œuvre toute une série de nouvelles technologies actuellement en développement.' To the right of the text is a large image showing a 3D rendering of the Einstein Telescope's L-shaped interferometer structure in a landscape. Below the main content area are three smaller images in a row: the first shows two black holes merging, the second shows a person in a blue protective suit working on equipment, and the third is the European Union flag.