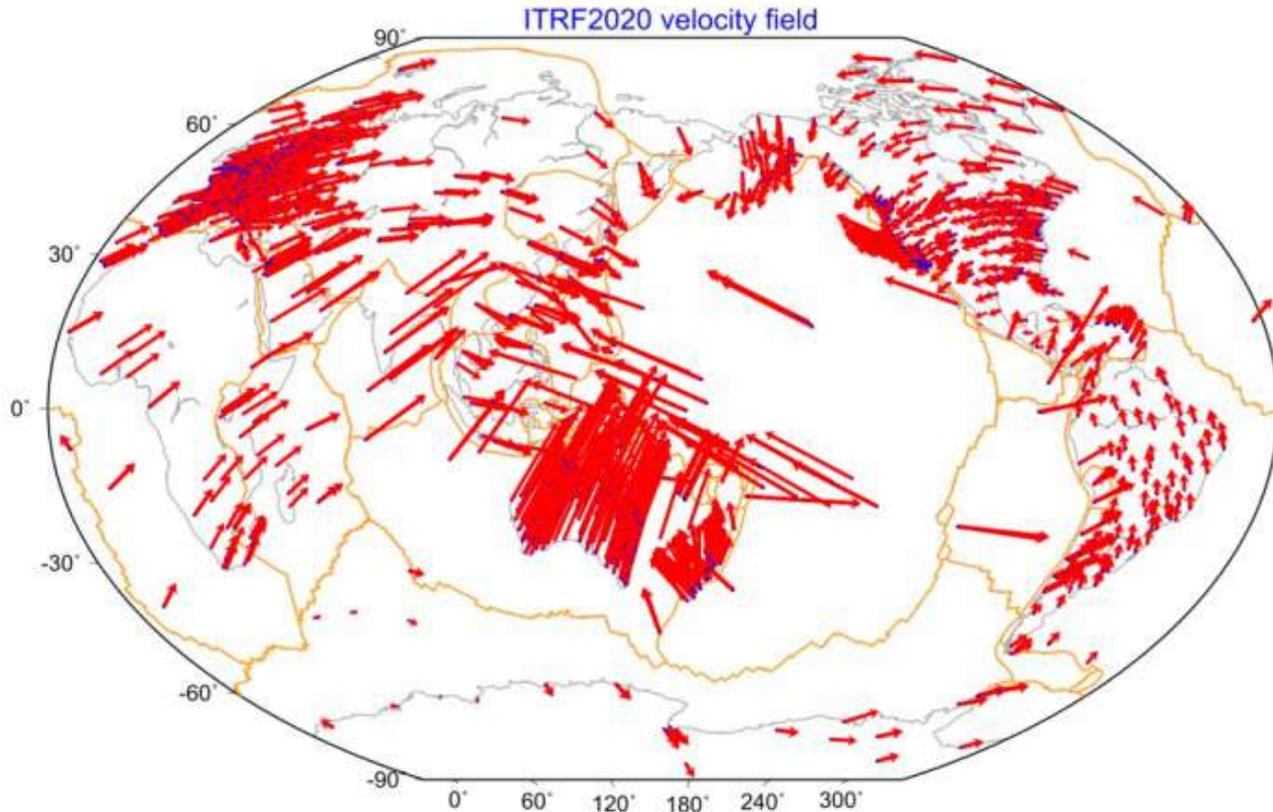


Vers une détermination automatique de la croisée des axes du télescope MEO par photogrammétrie

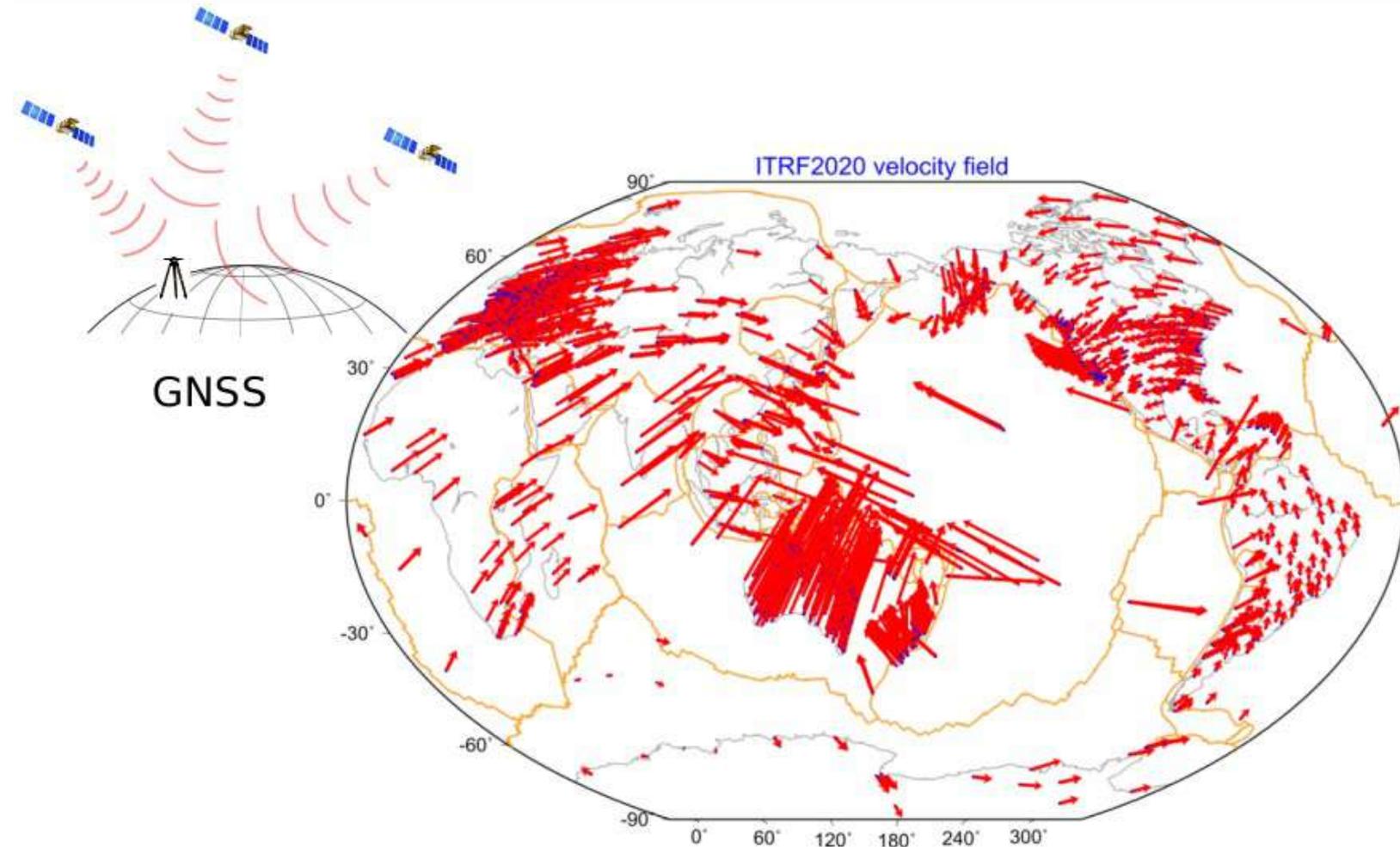
C. Bellon, Y. Meneroux et D. Pesce

20 mars 2025

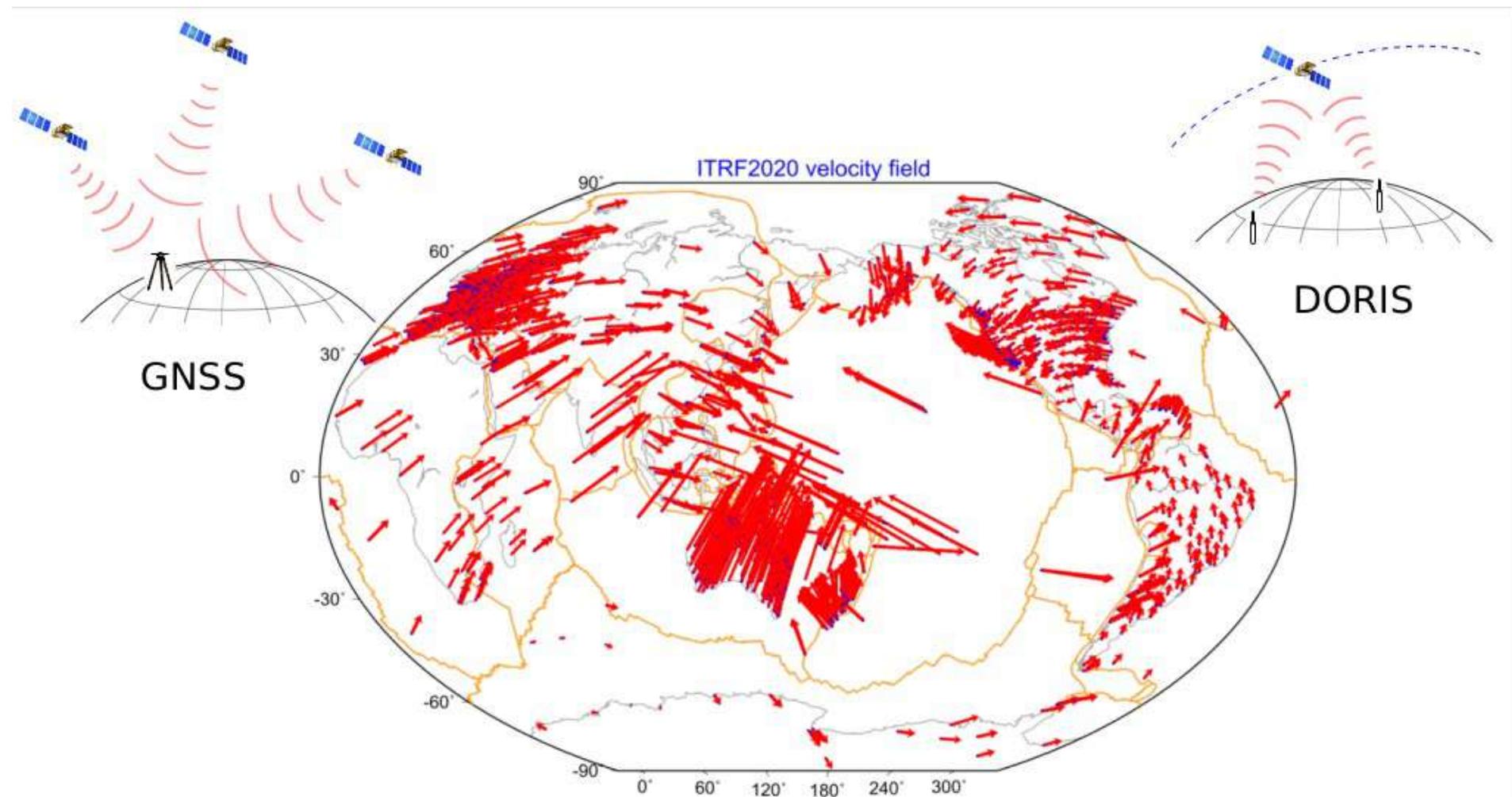
Contexte : Repère de référence terrestre international (ITRF)



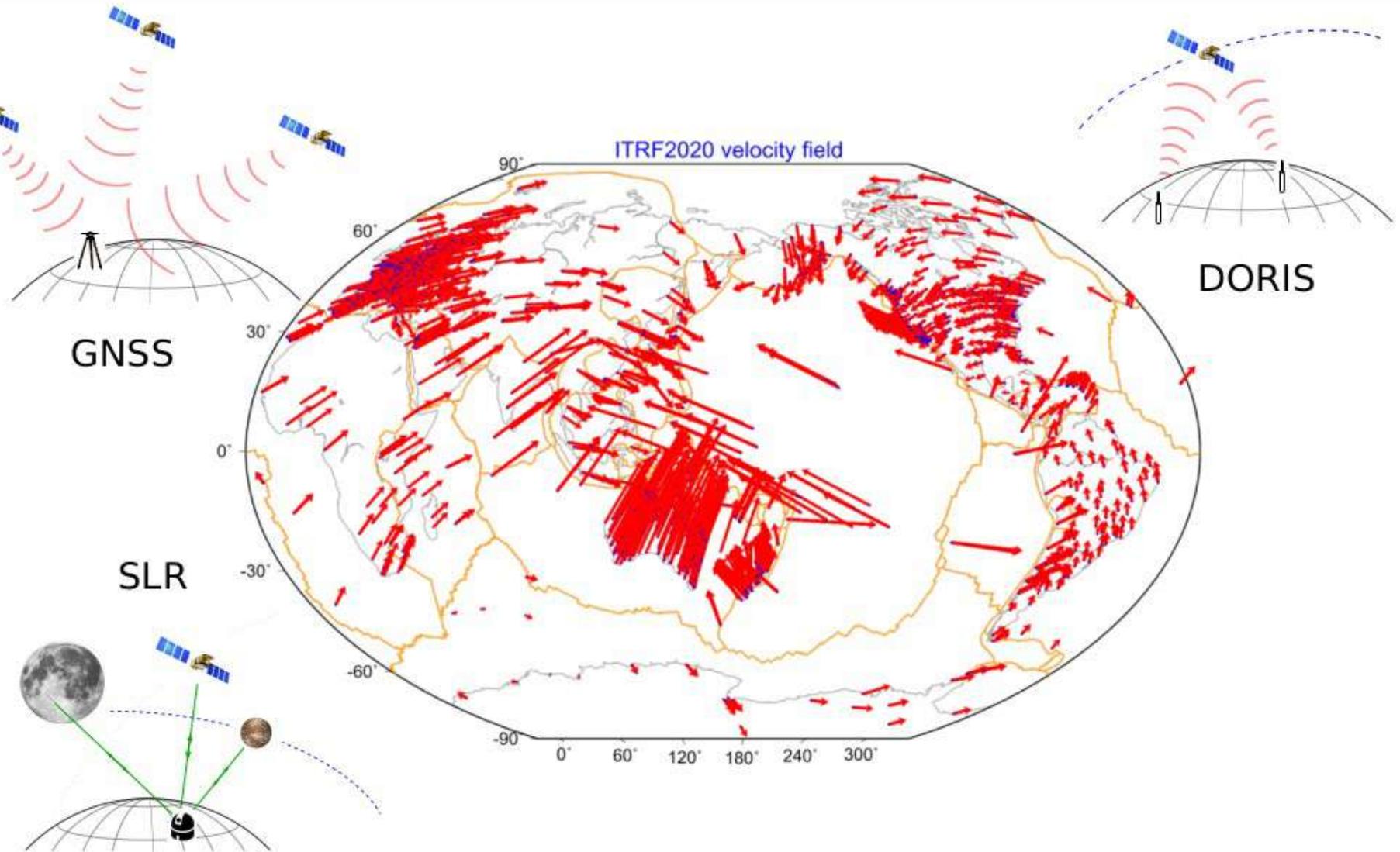
Contexte : Repère de référence terrestre international (ITRF)



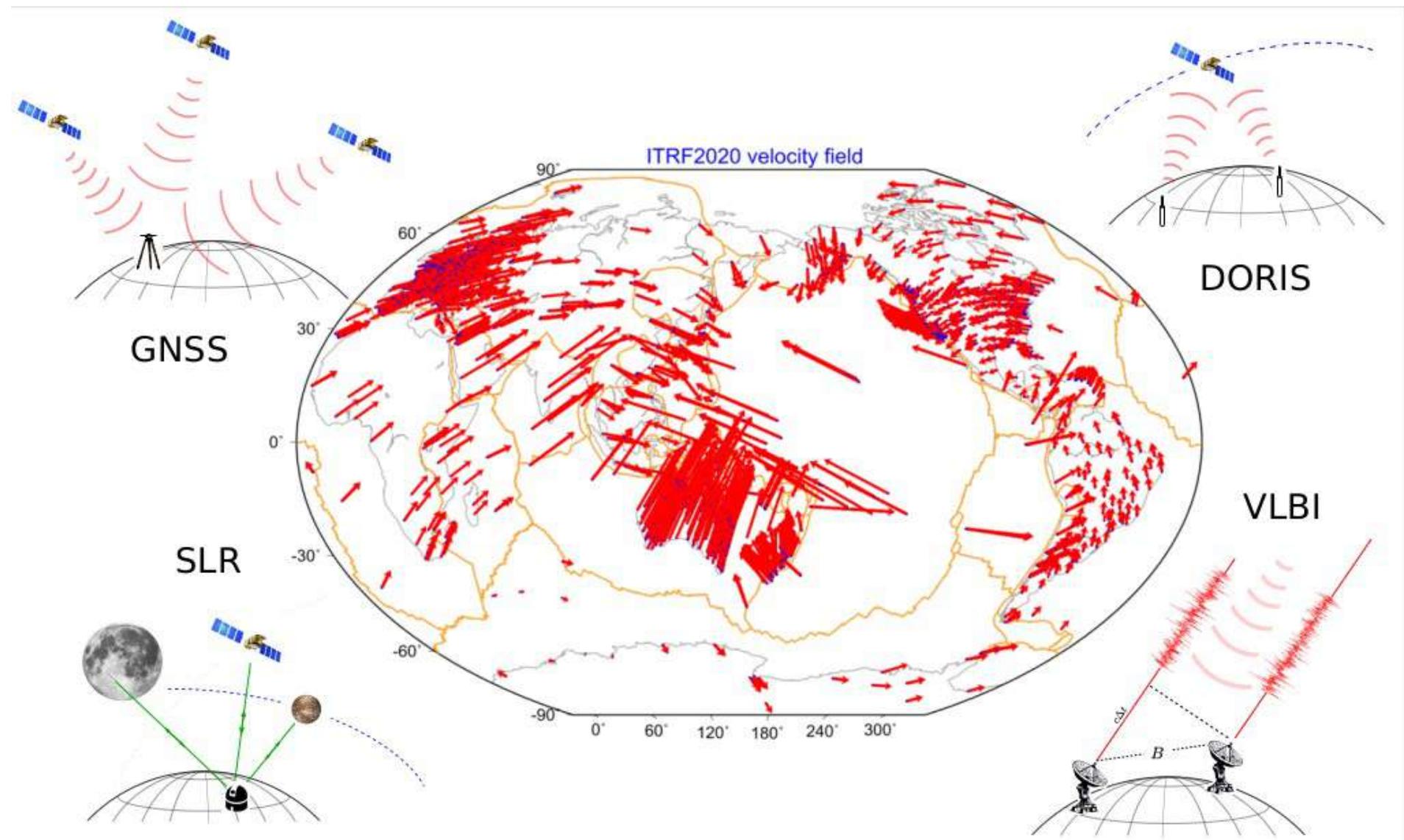
Contexte : Repère de référence terrestre international (ITRF)



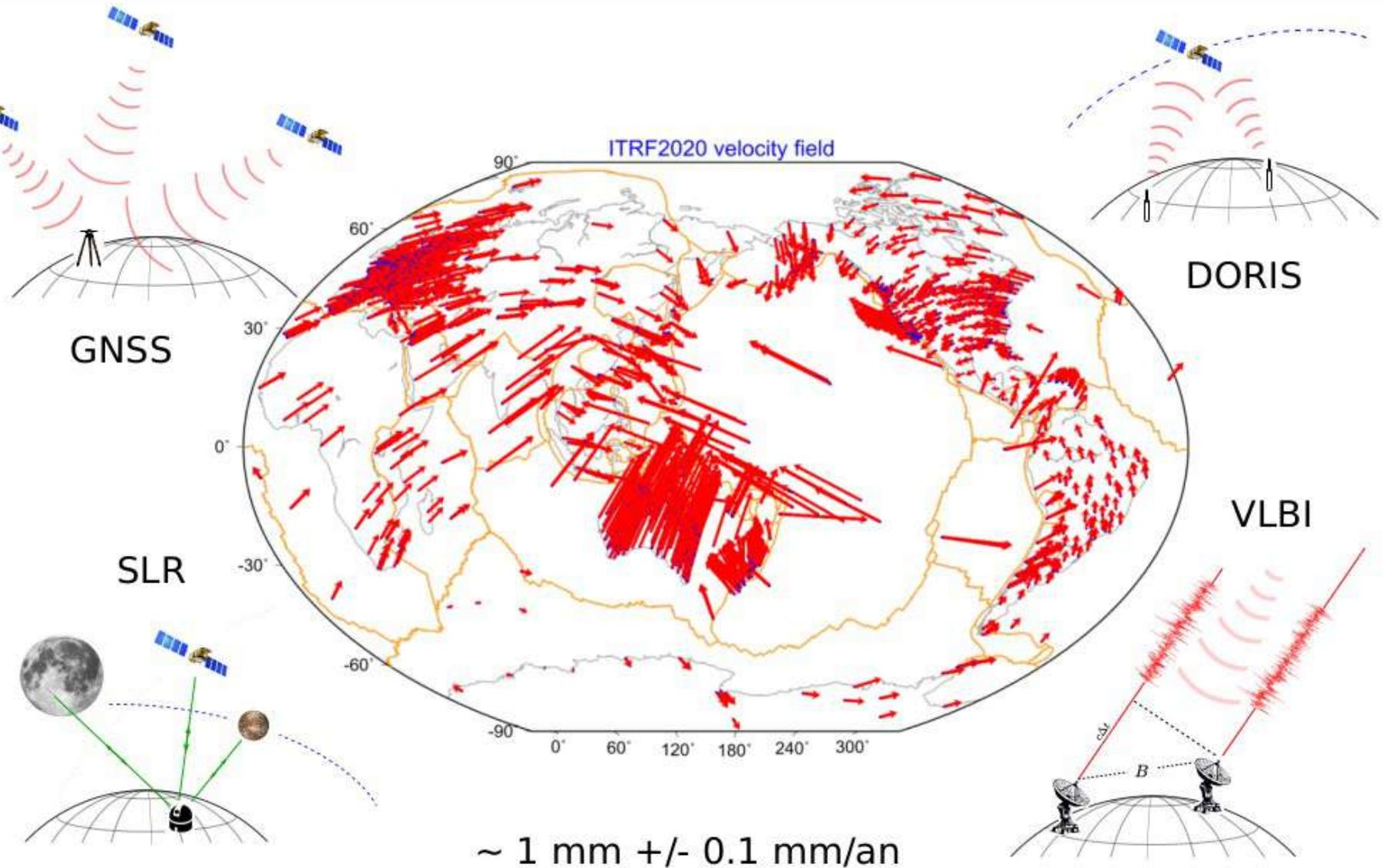
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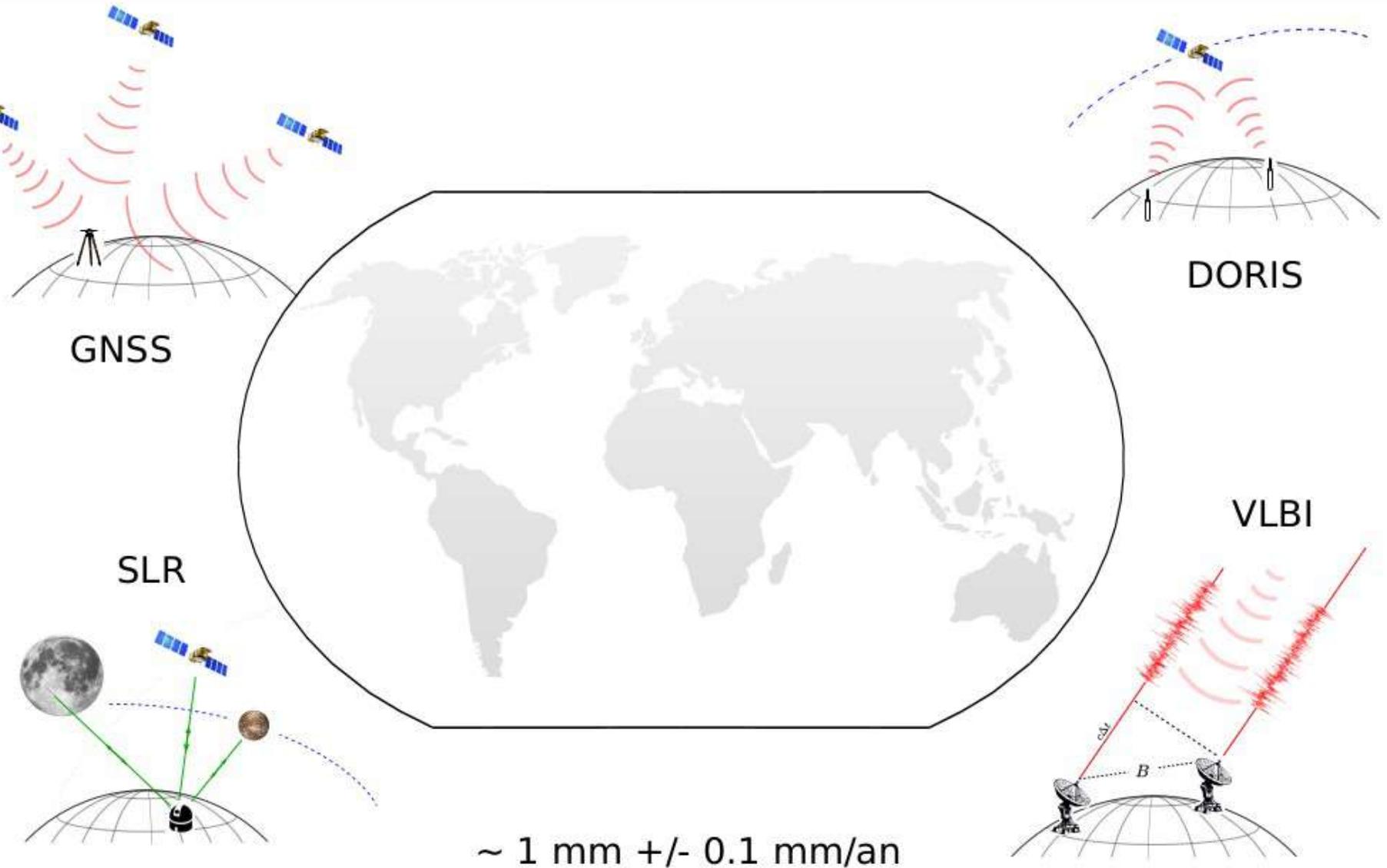
Contexte : Repère de référence terrestre international (ITRF)



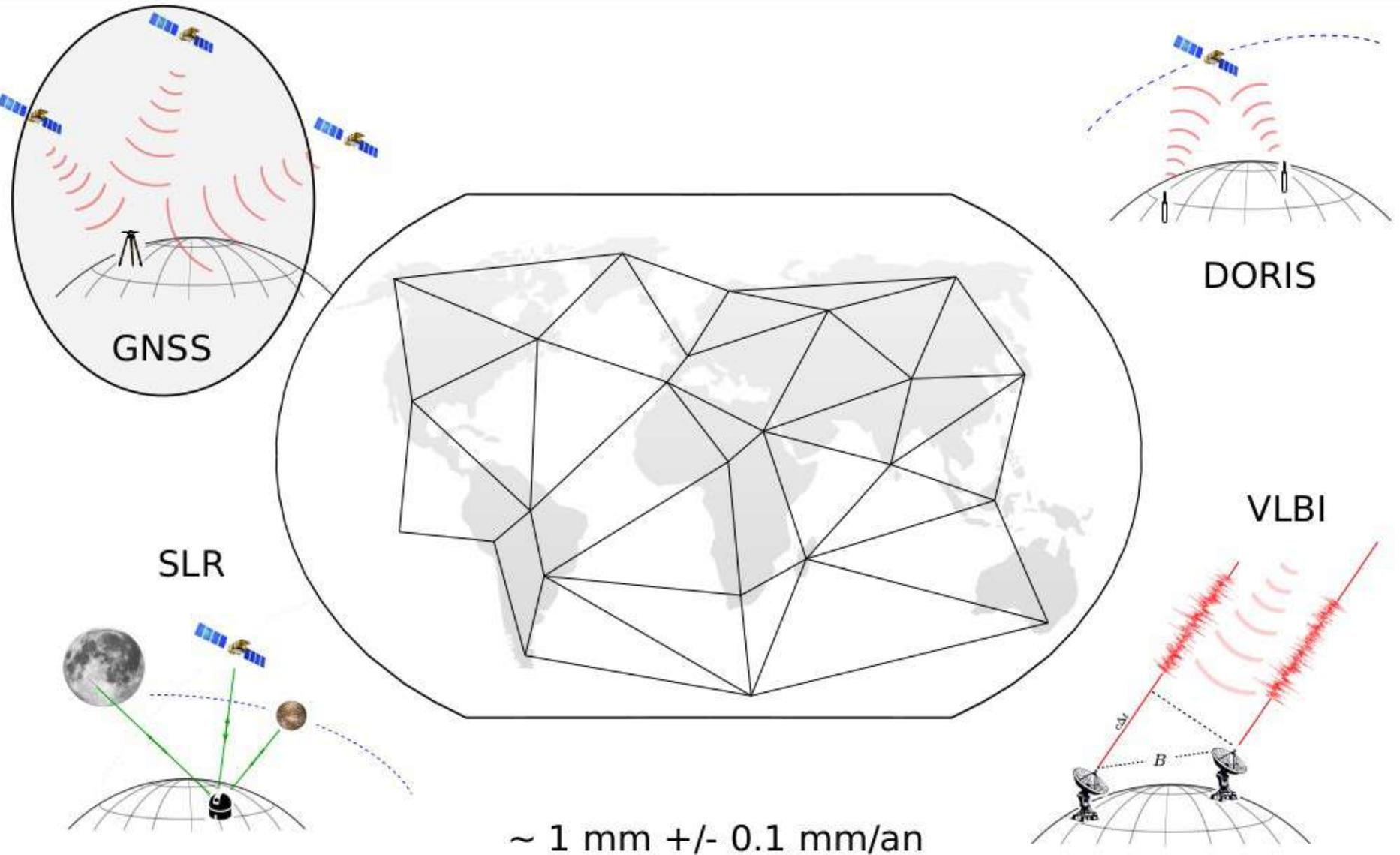
Contexte : Repère de référence terrestre international (ITRF)



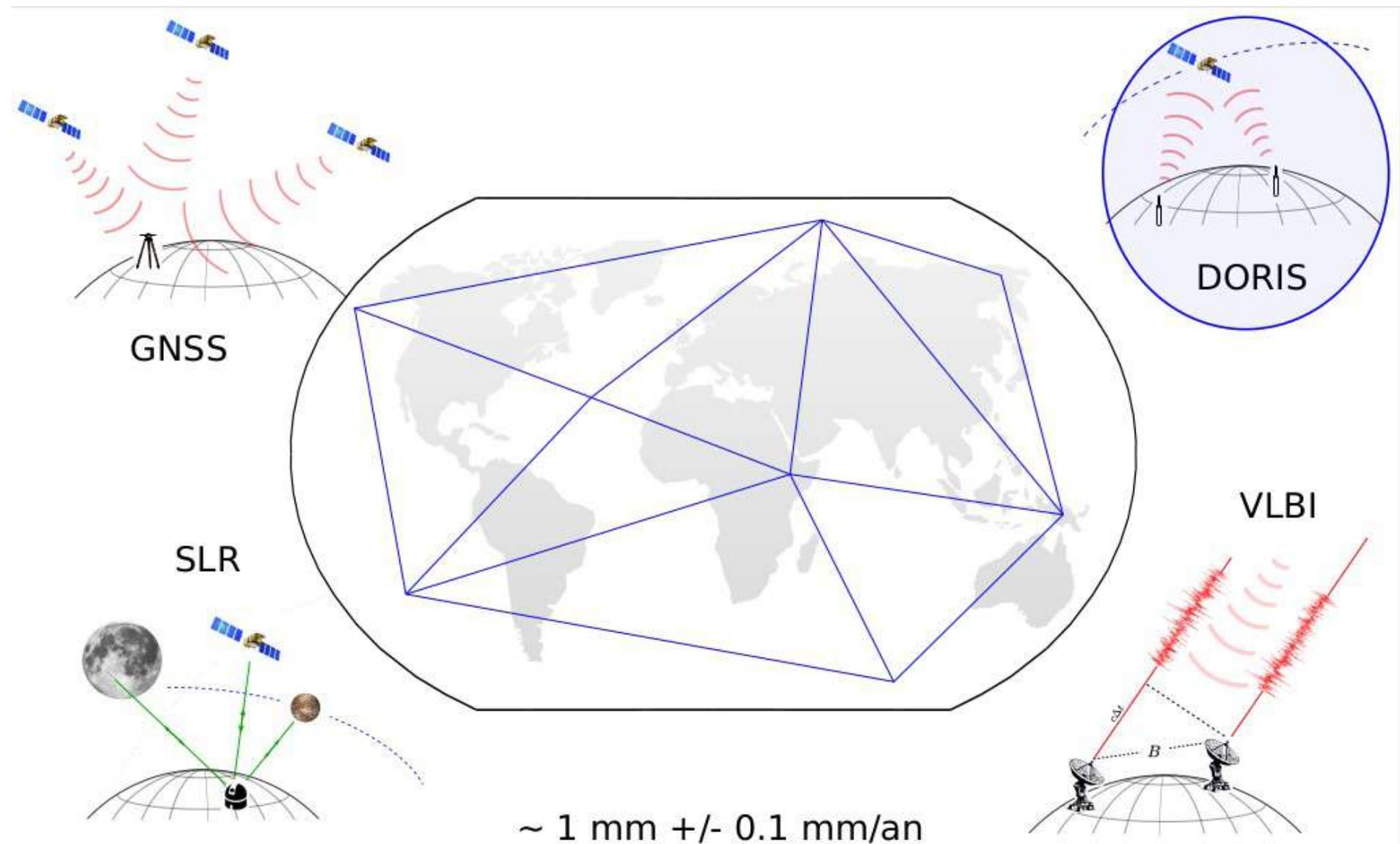
Contexte : Repère de référence terrestre international (ITRF)



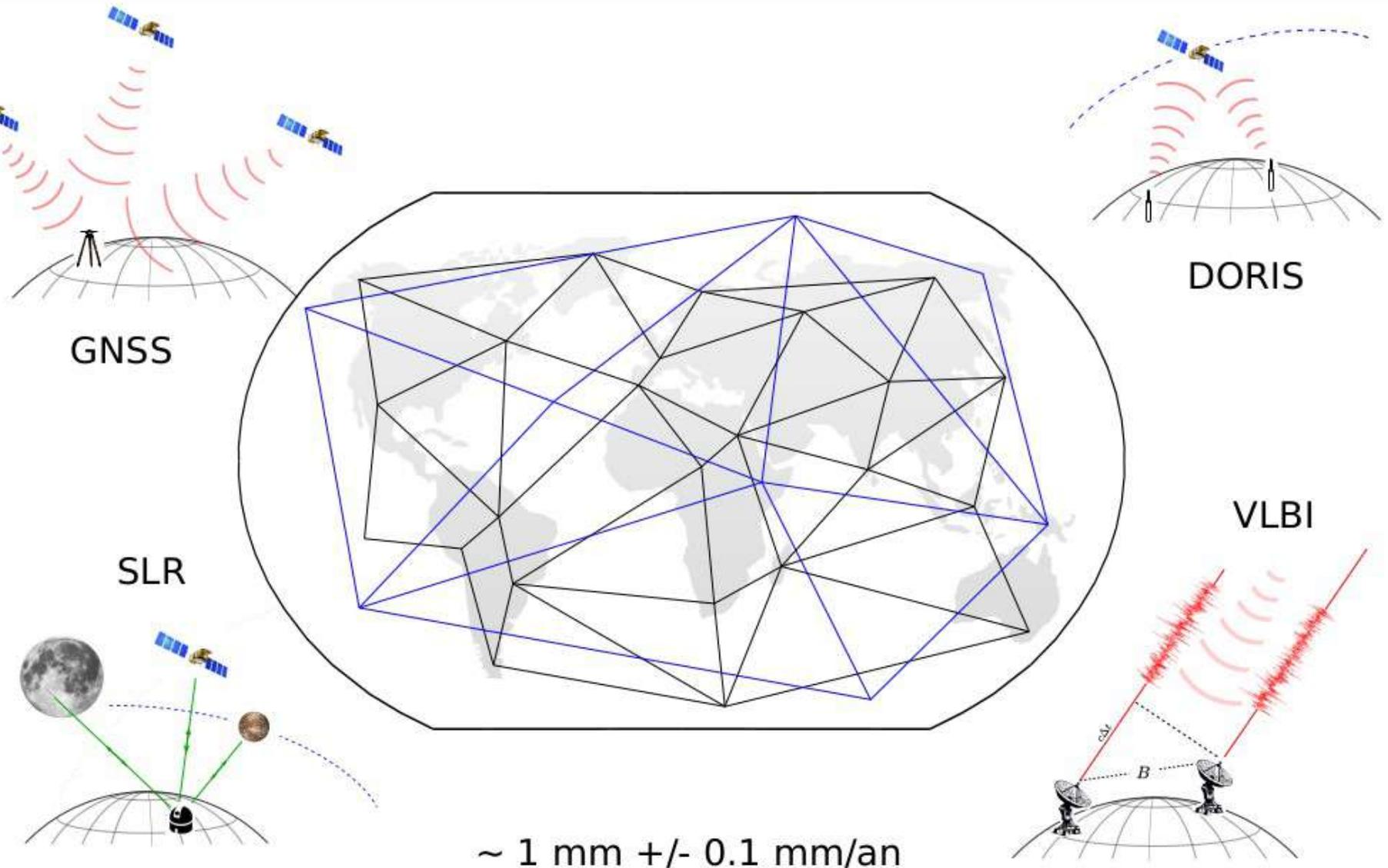
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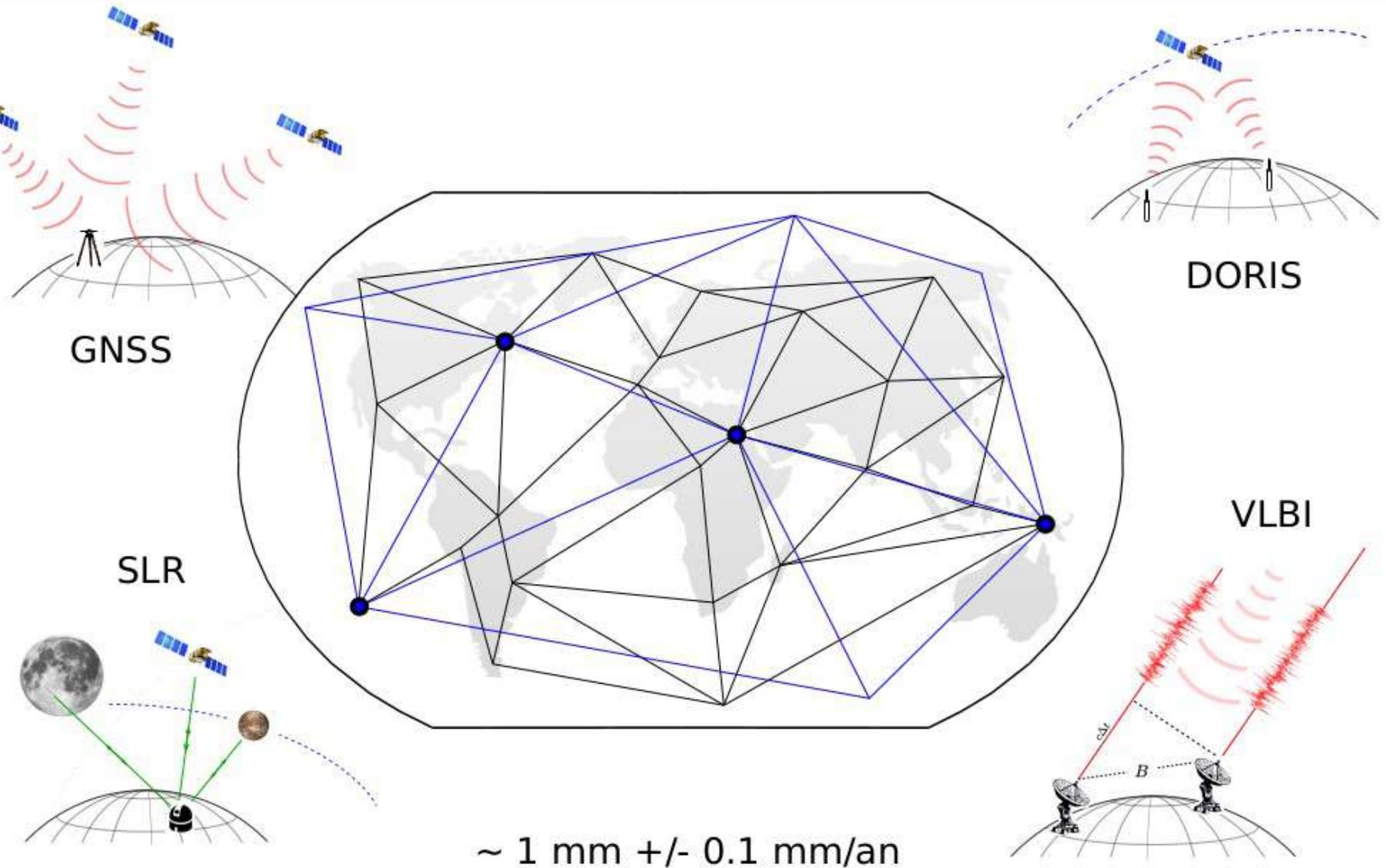
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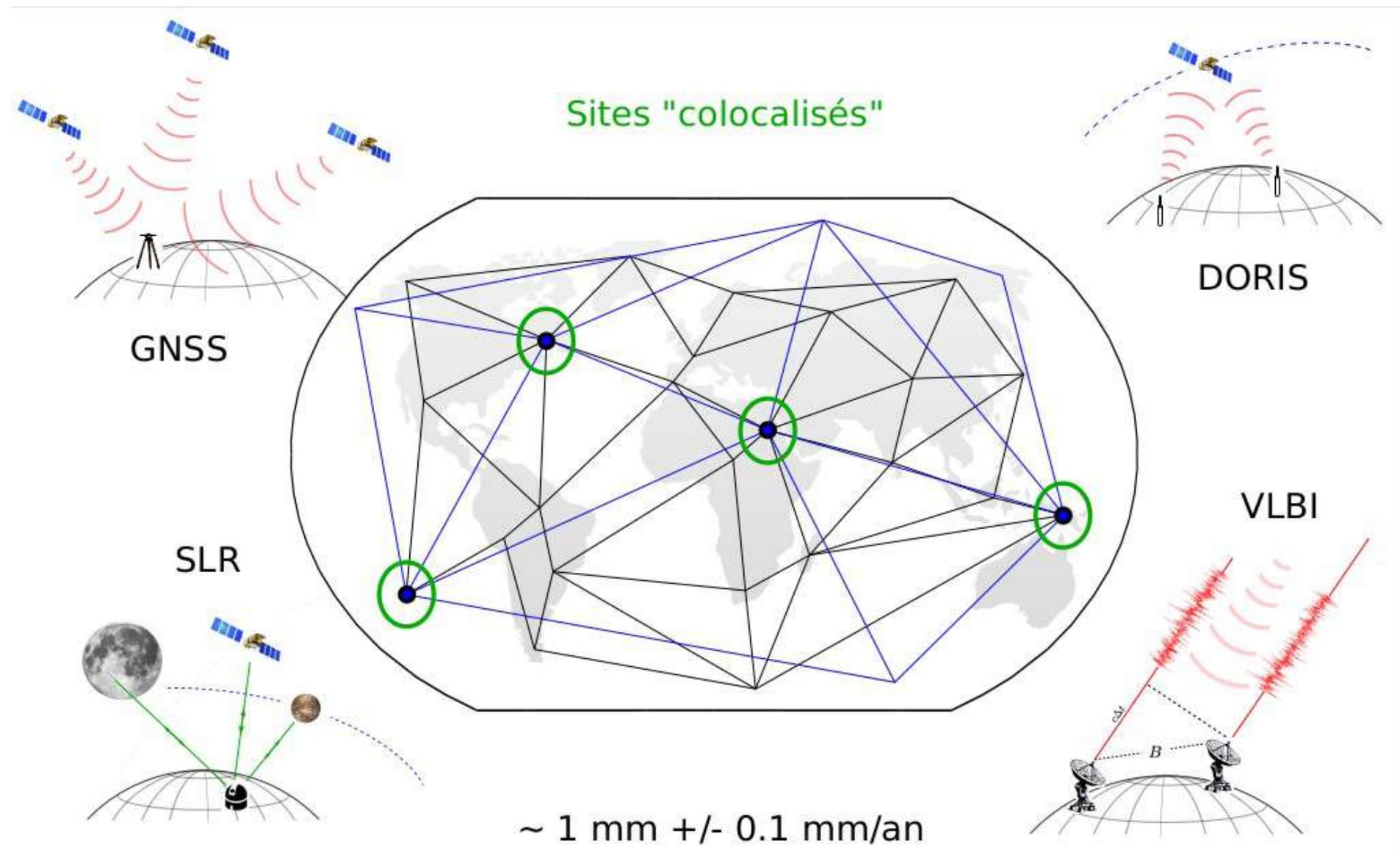
Contexte : Repère de référence terrestre international (ITRF)



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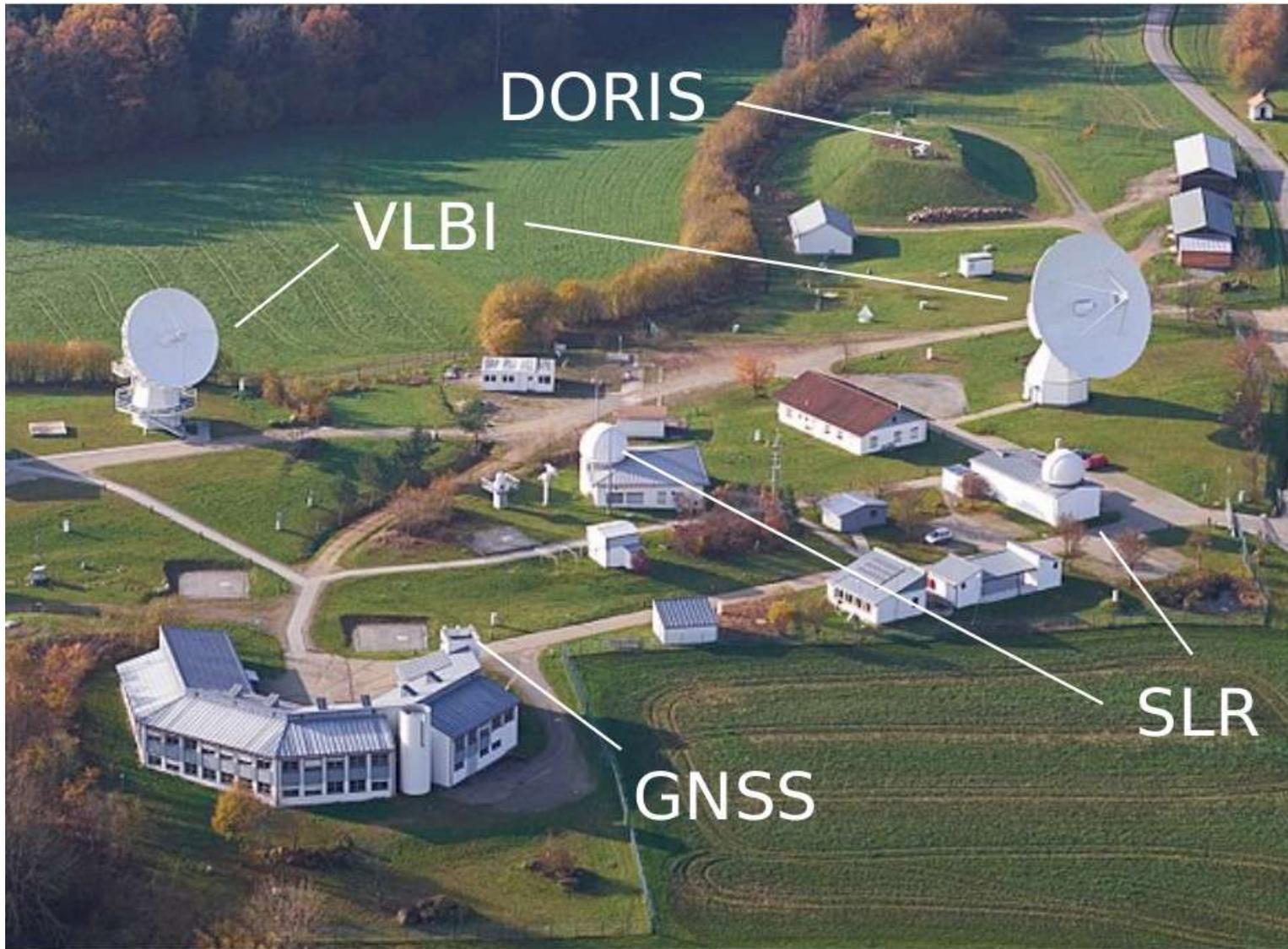


Rattachement

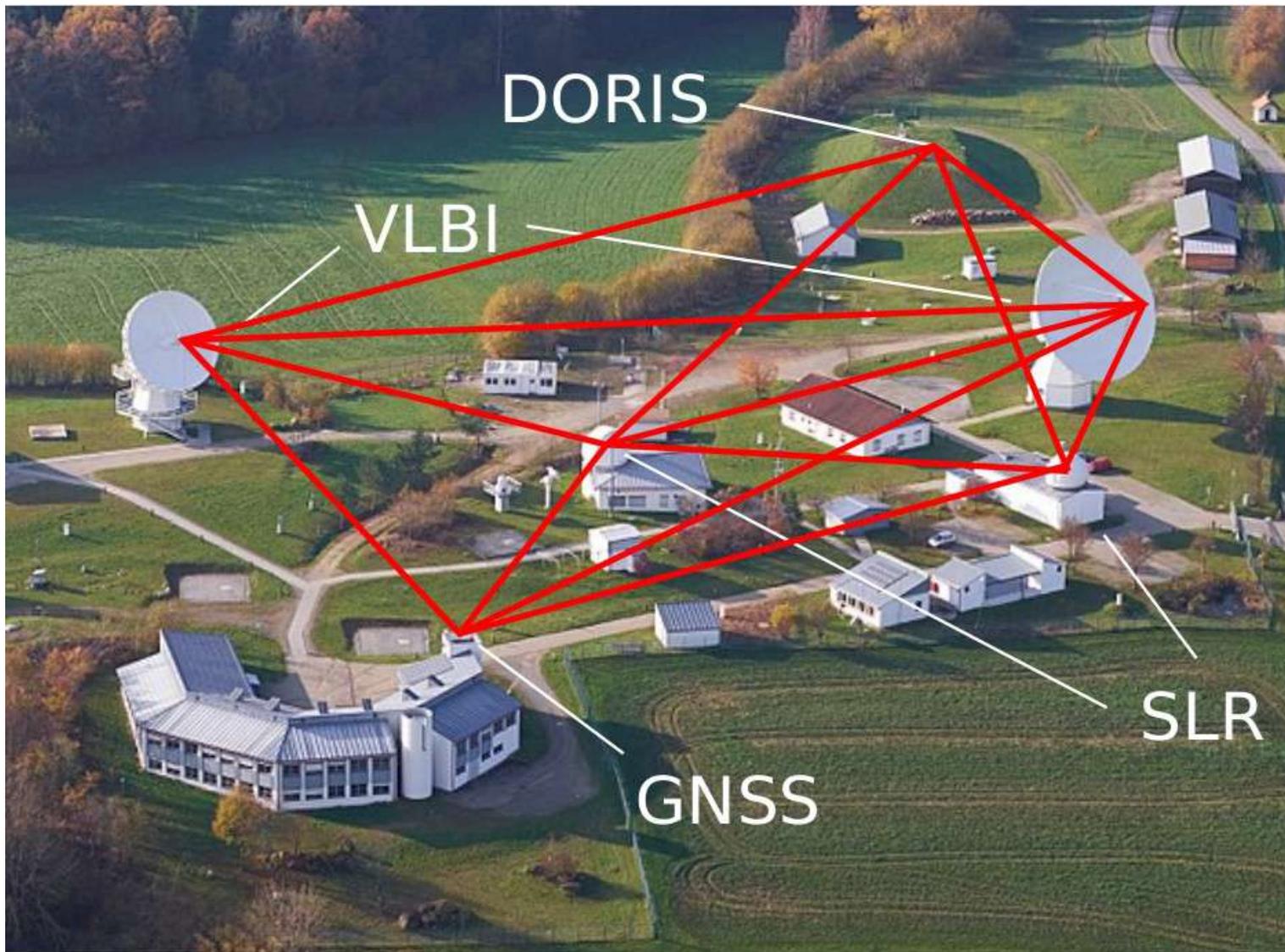


Wetzell Geodetic Observatory

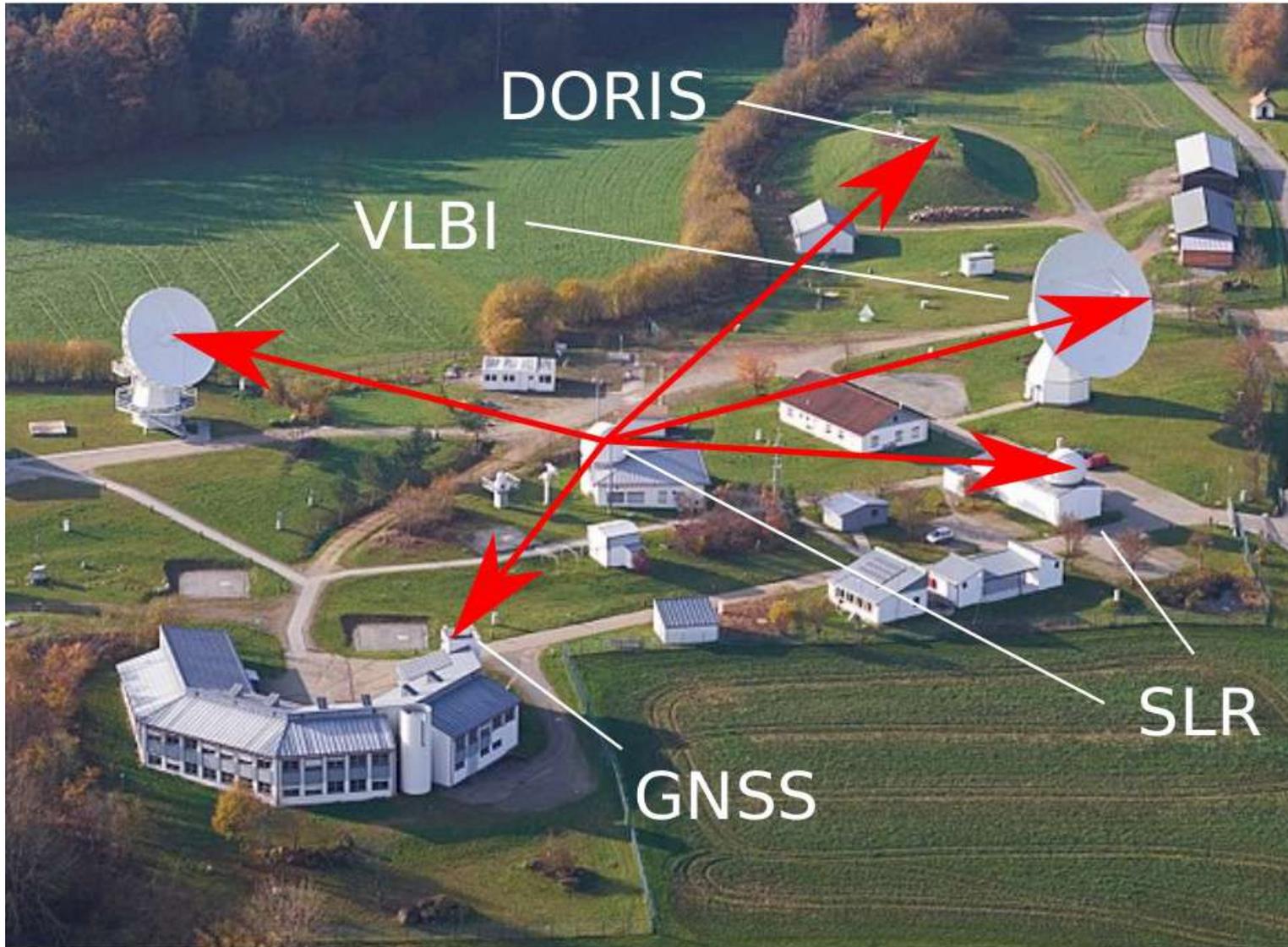
Rattachement



Rattachement



Rattachement – *Tie Vectors*



Problème de la détermination des centres



DORIS



GNSS



VLBI



SLR

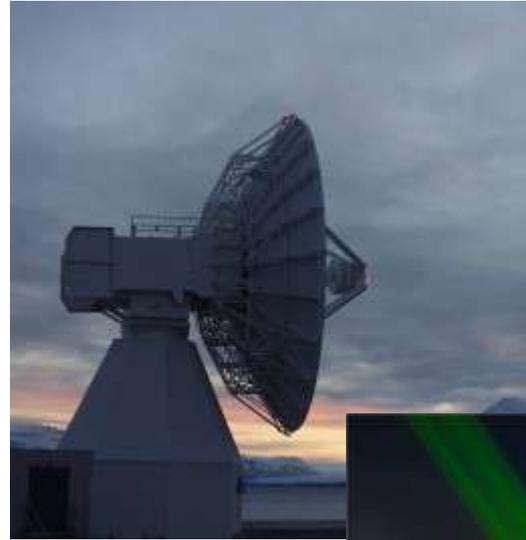
Problème de la détermination des centres



DORIS



GNSS



VLBI



SLR

Problème de la détermination des centres



DORIS



GNSS



VLBI



SLR

Problème de la détermination des centres



DORIS



GNSS



VLBI



SLR

ITRF 2020 :

65 % de résidus GNSS/**SLR** > 5 mm

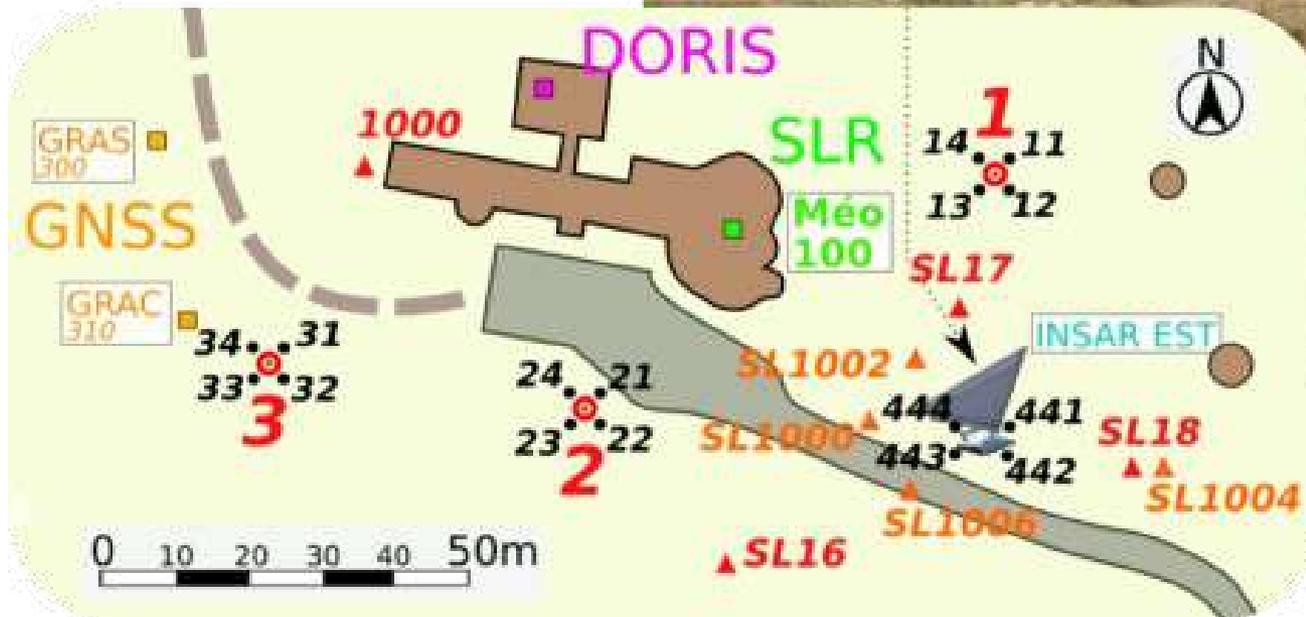
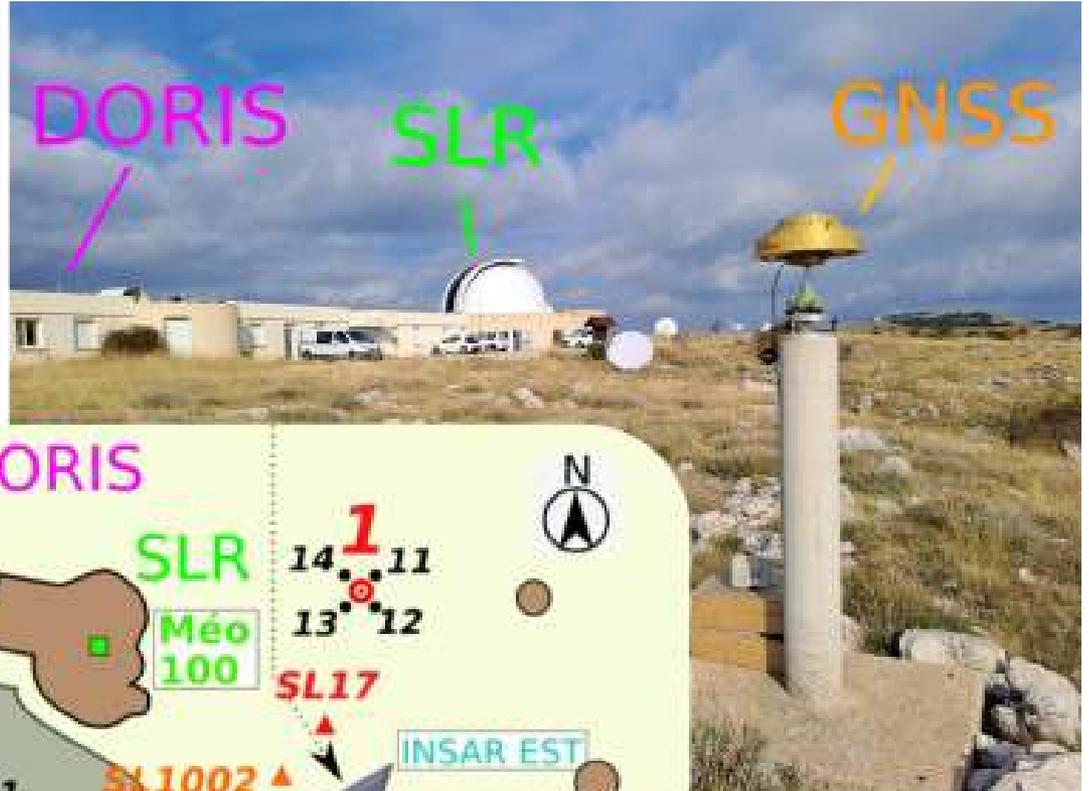
Site colocalisé de Calern (OCA)

■ Mission **rattachement ITRF** (09/2024)

■ 3 techniques

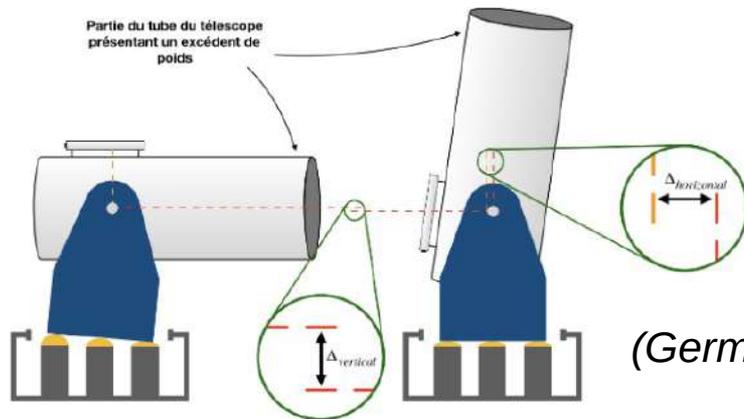
- GNSS
- DORIS
- SLR

+ instruments divers...

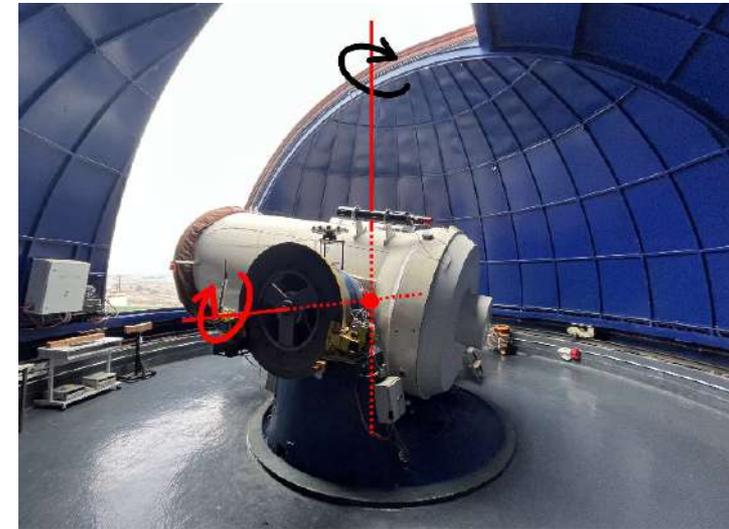


Configuration du chantier

- Coupole hémisphérique \varnothing 9 m
- Télescope à monture azimutale
- Centre défini par l'intersection des axes
 - d'azimut (-180 à $+180^\circ$)
 - d'élévation (-5 à 85°)
- Télescope désolidarisé du bâtiment
- Stabilité ?

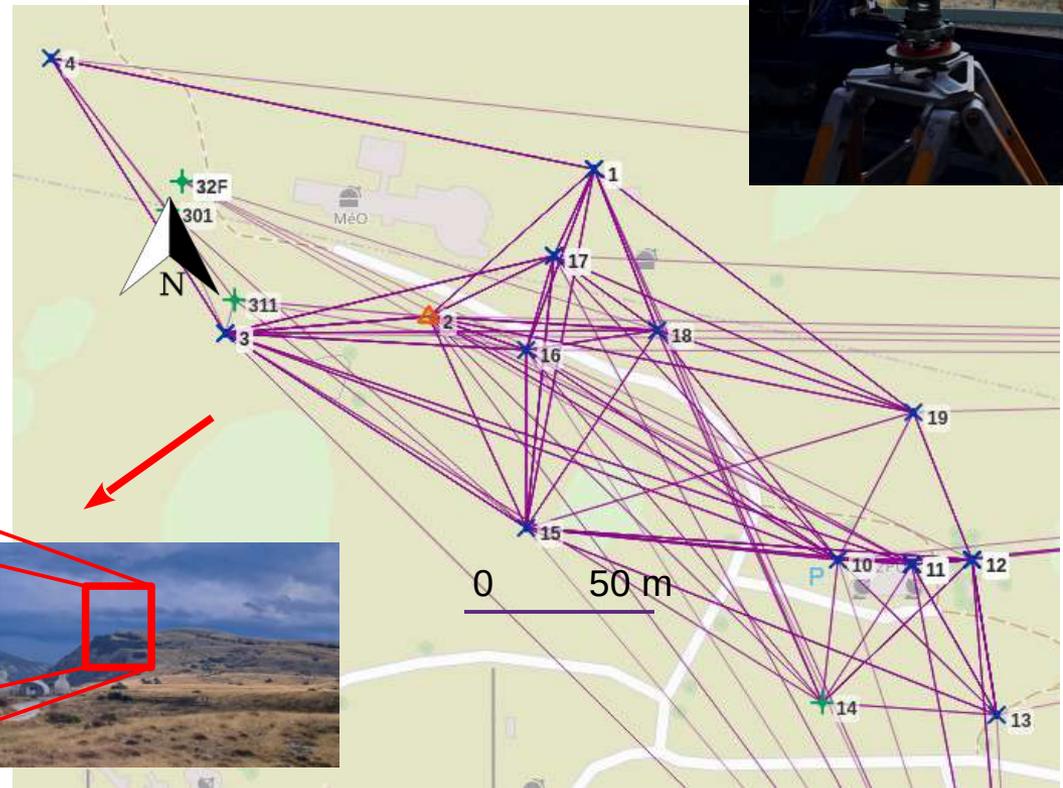


(Germerie, 2019)

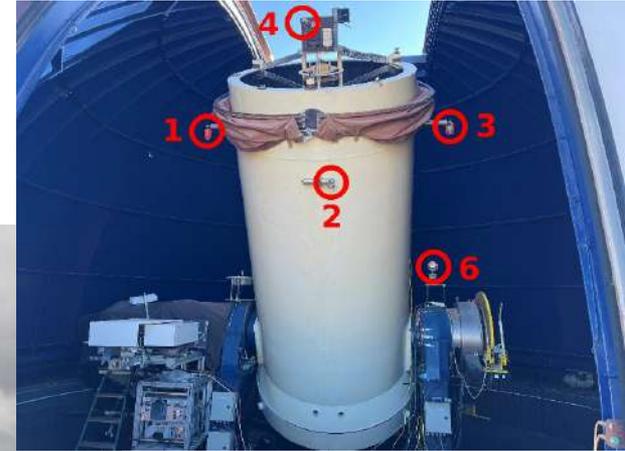


Configuration du chantier

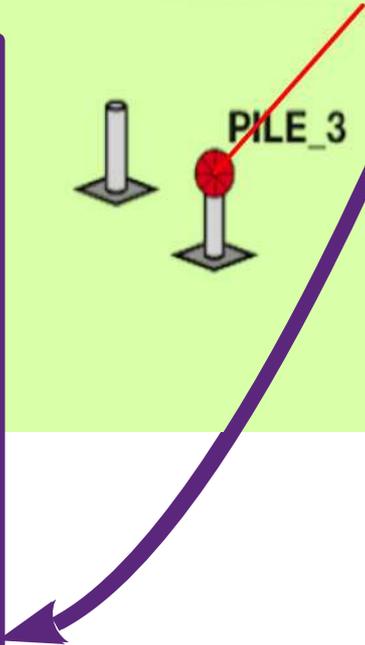
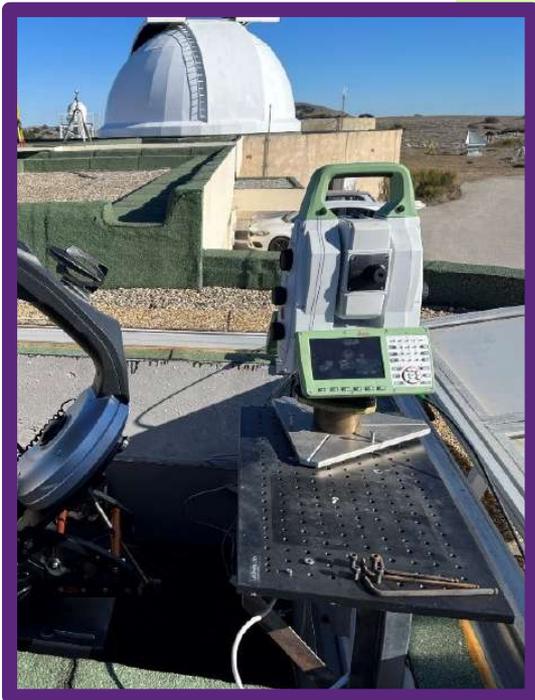
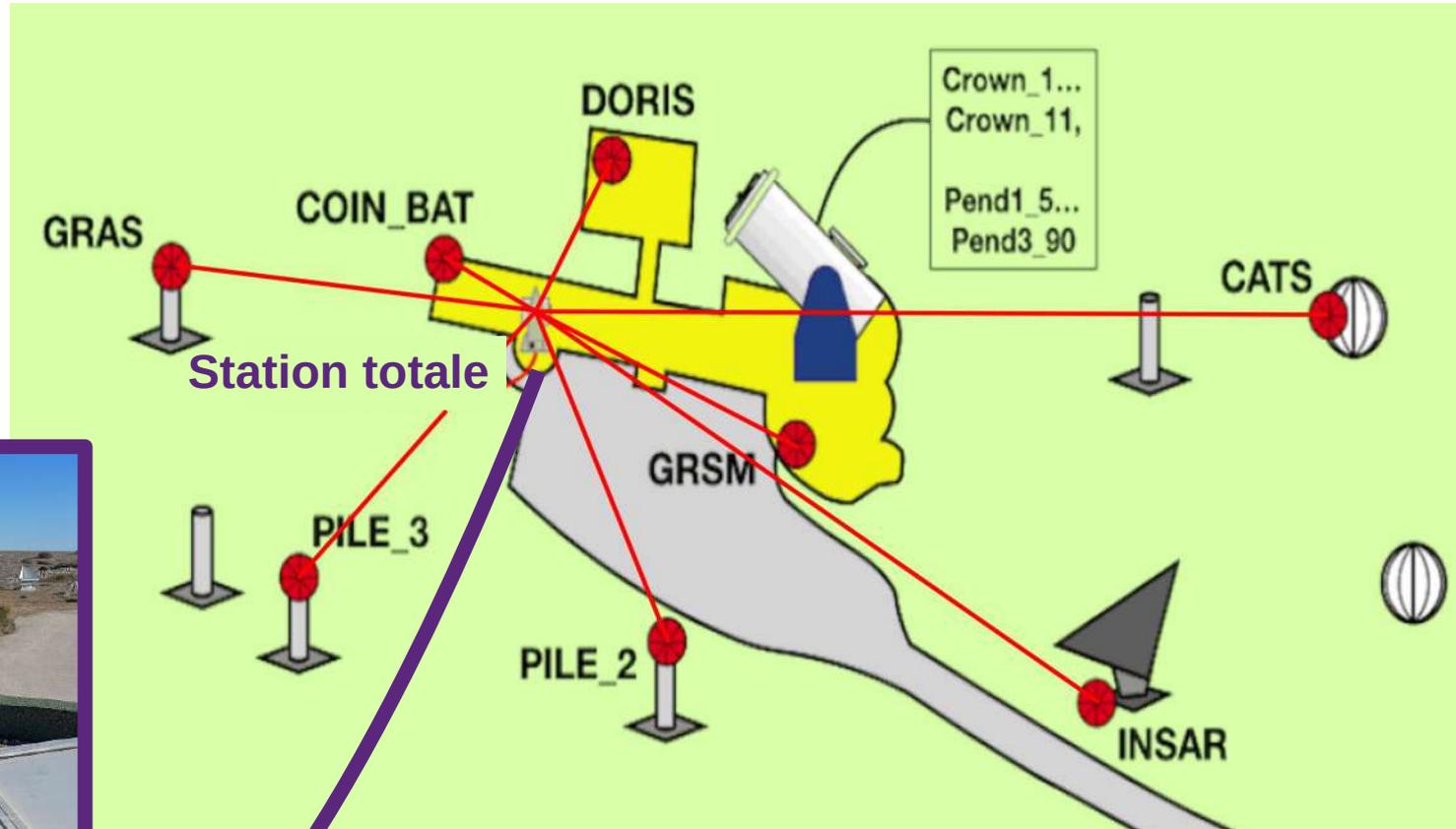
- Canevas topométrique / différents instruments & piliers géodésiques
- Précision relative : 0.5 mm
- Orientation absolue : 0.03°



Méthodes actuelles : approche directe (manuelle)

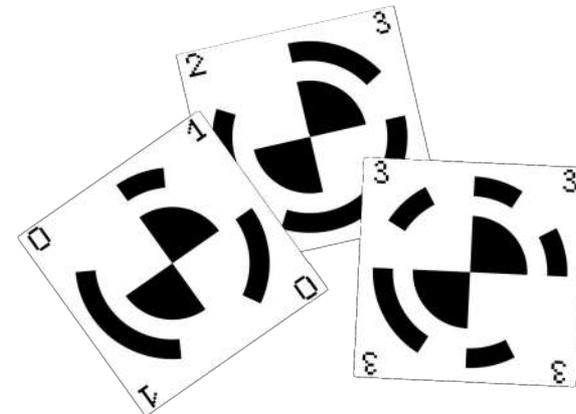


Méthodes actuelles : approche robotisée

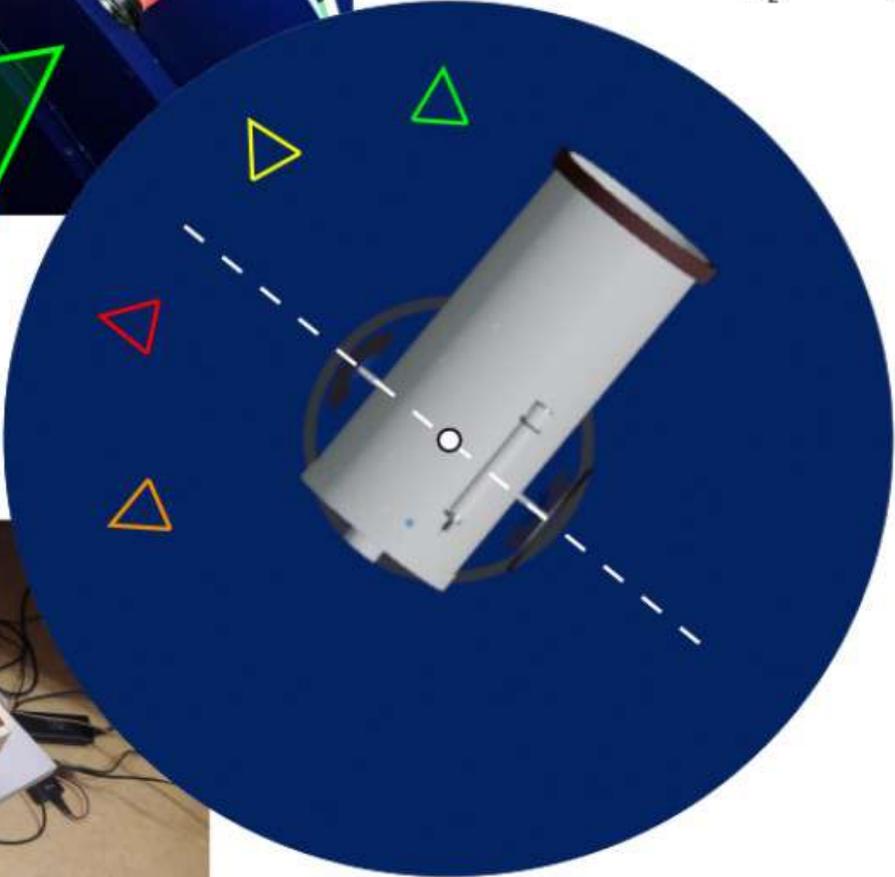
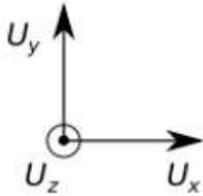
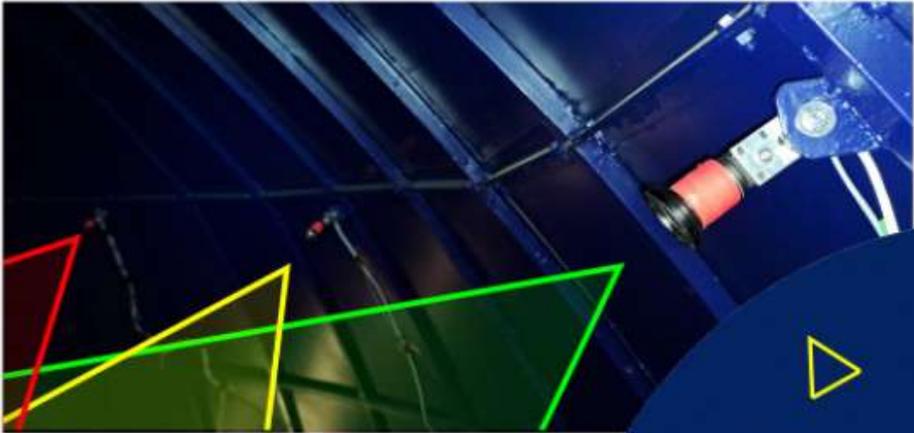


Approche photogrammétrique

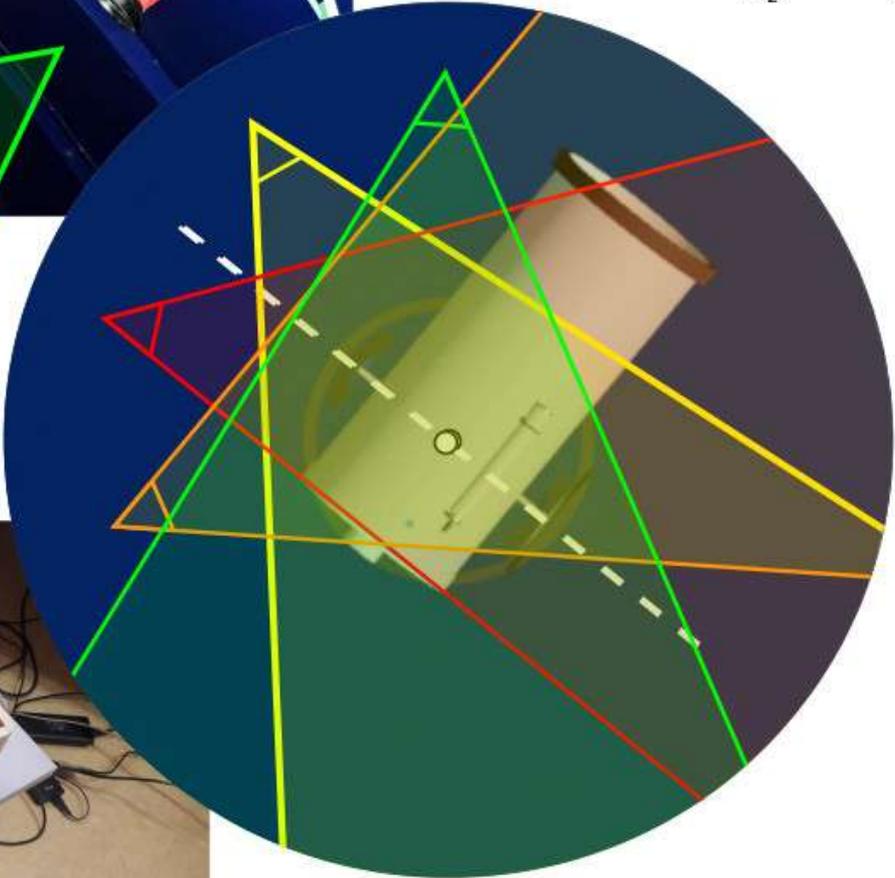
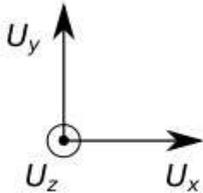
- **Objectif** : reconditionner le système développé pour le projet PRISSMA et tester son applicabilité à un autre problème
- **Principe** : caméras industrielles synchronisées et pré-calibrées dans la coupole
- « **Cahier des charges** »
 - Faible coût (~ k€)
 - Installation facile (~ 1 journée), sans « interférences » avec les équipements
 - Installation permanente
 - Précise (< 1 mm à chaque détermination)
 - Automatique & en continu et/ou rapide
 - Optionnel : temps réel



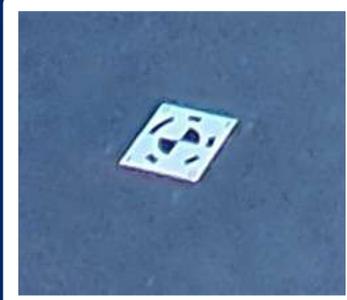
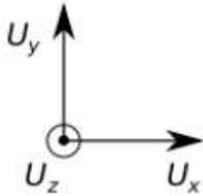
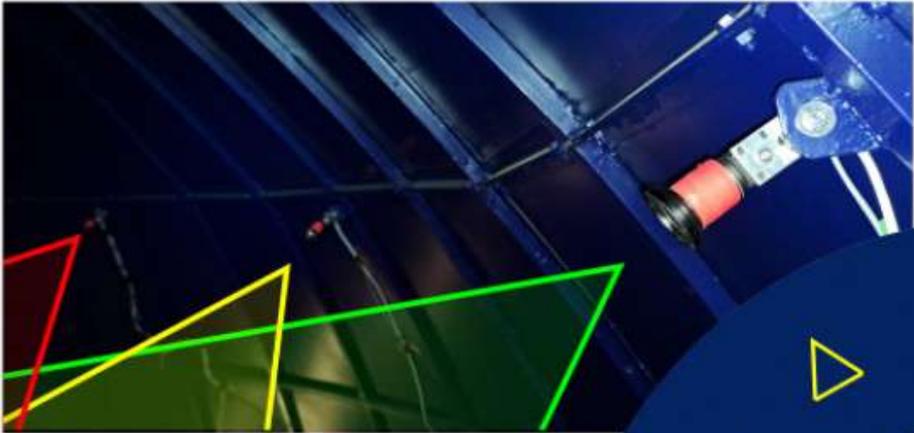
Approche photogrammétrique – Protocole



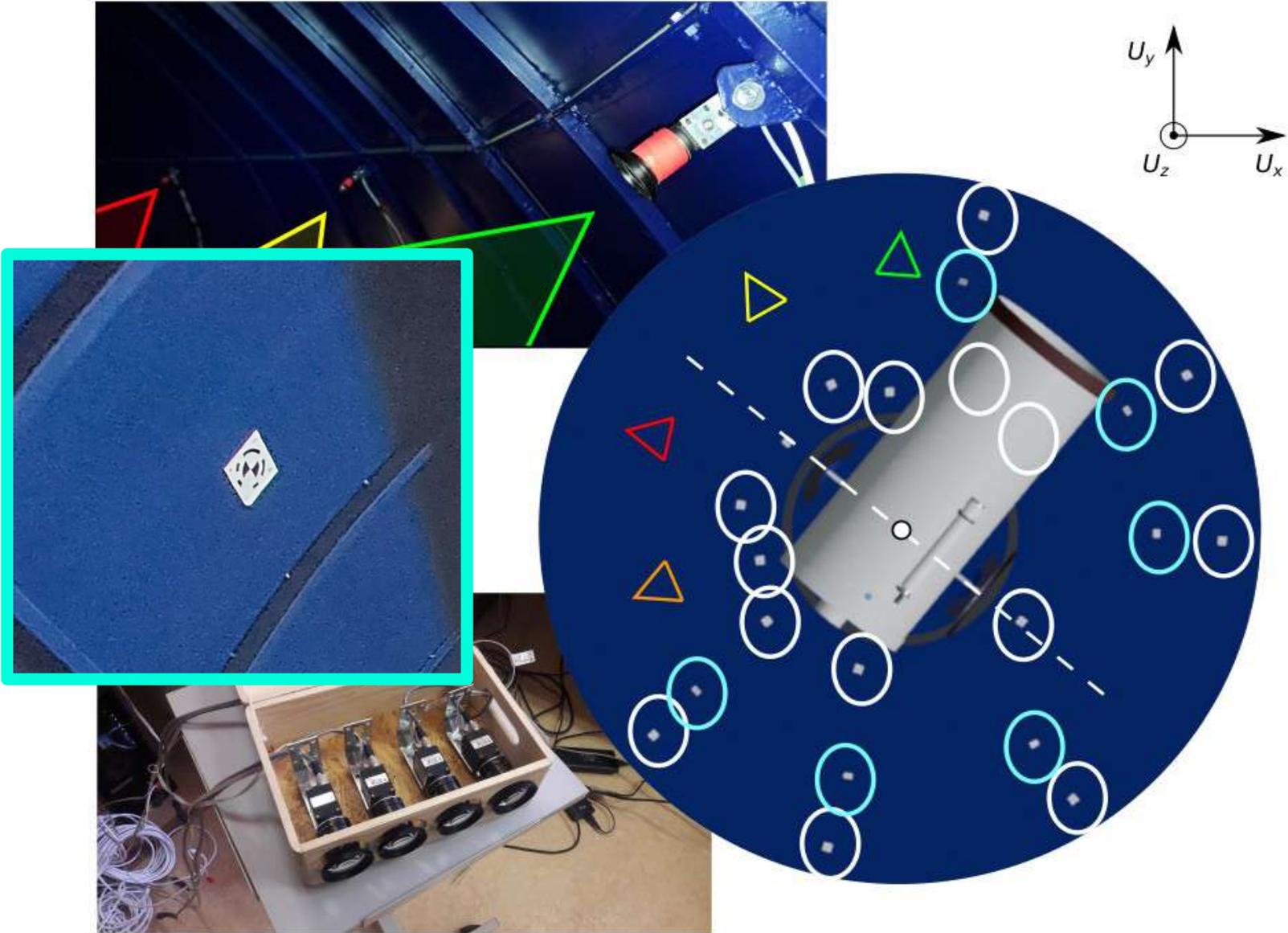
Approche photogrammétrique – Protocole



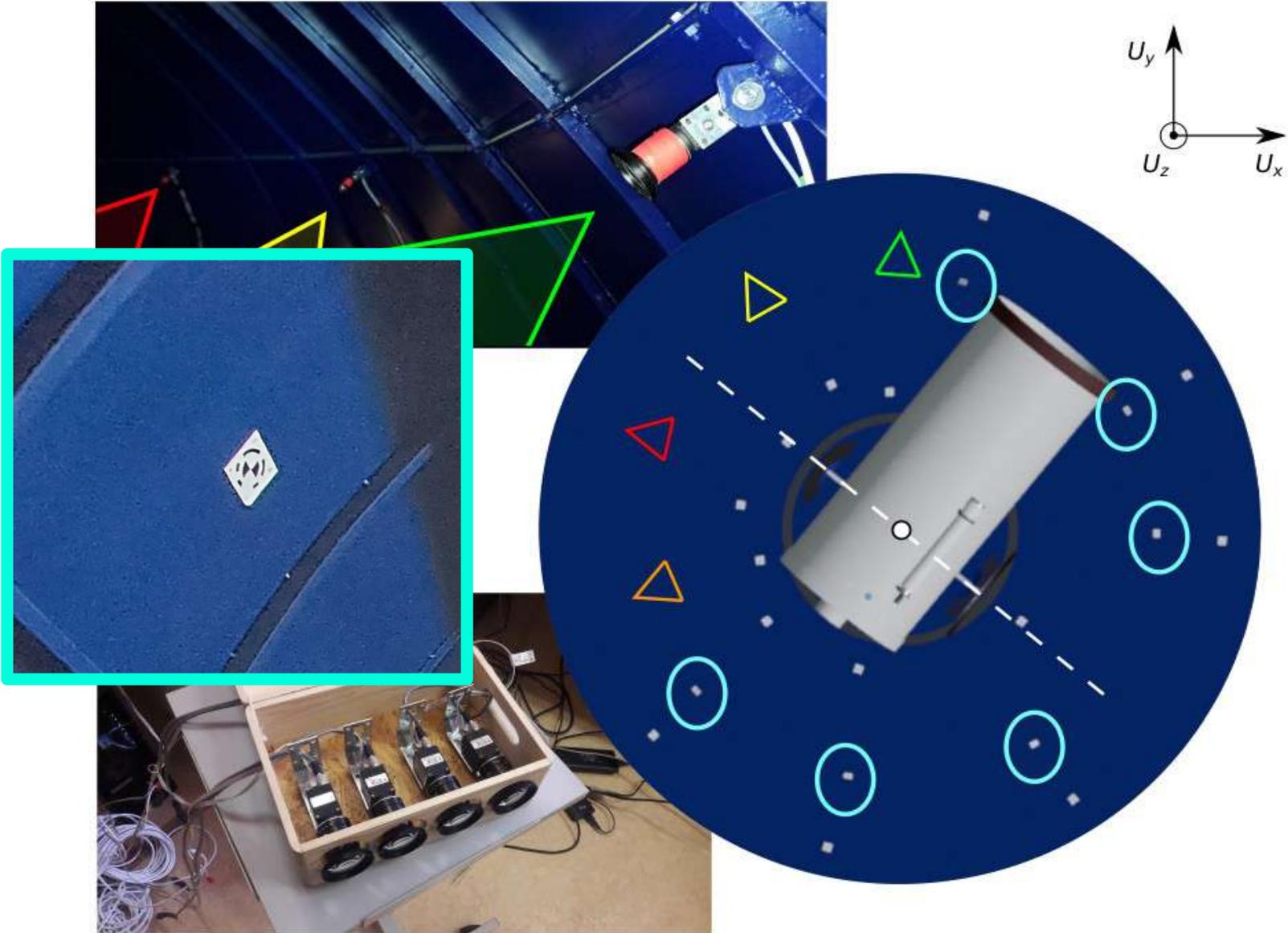
Approche photogrammétrique – Protocole



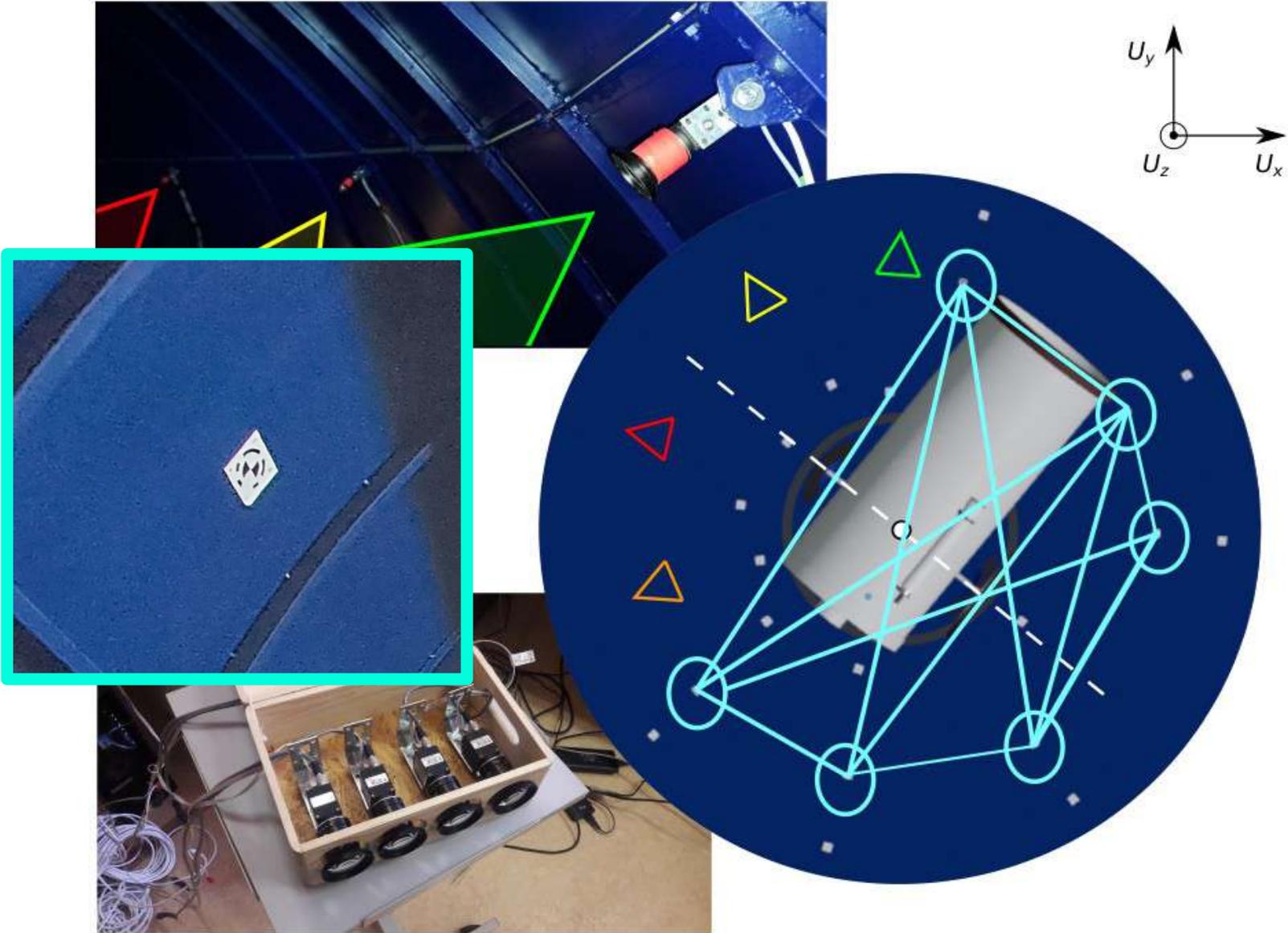
Approche photogrammétrique – Protocole



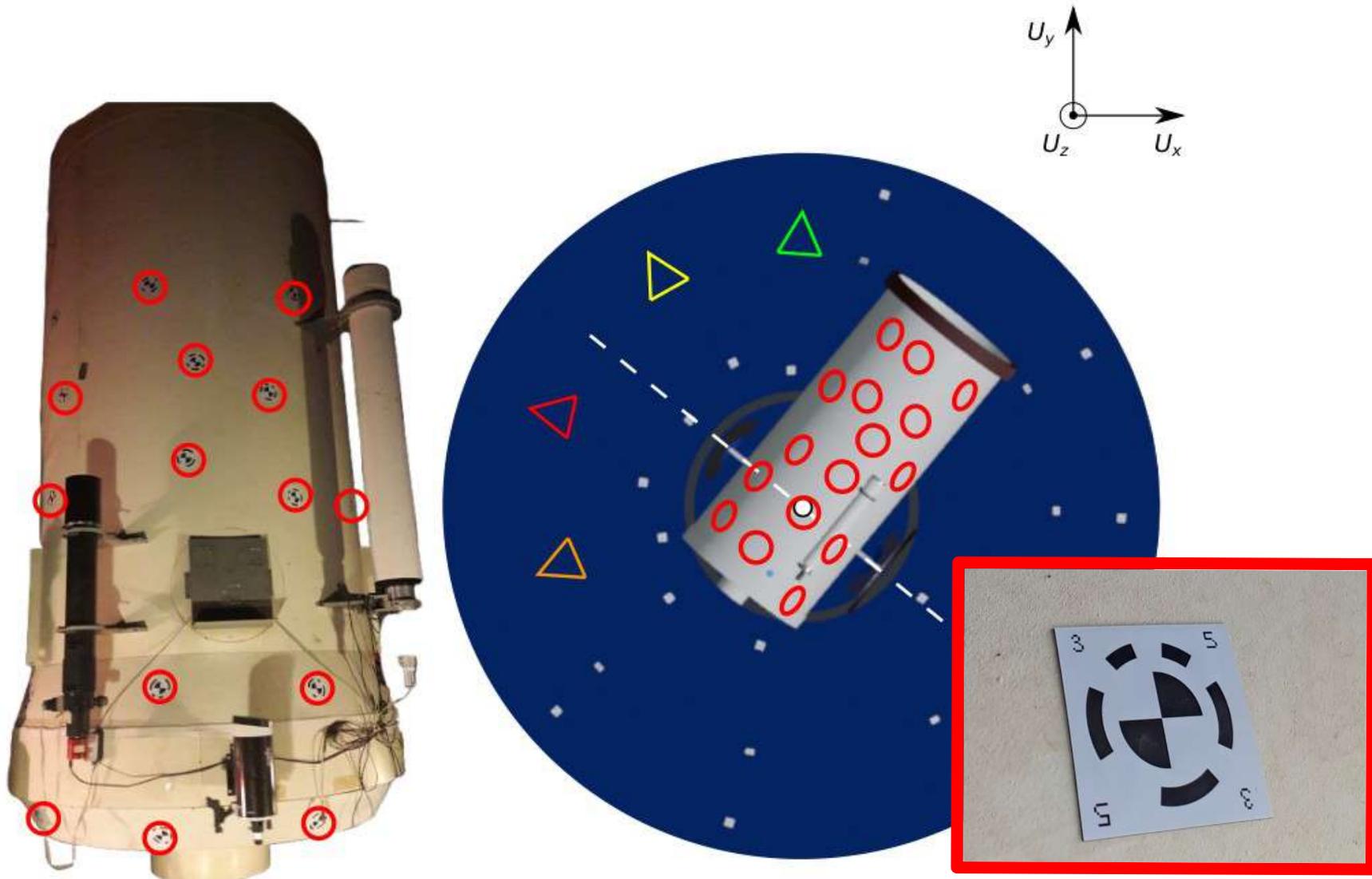
Approche photogrammétrique – Protocole



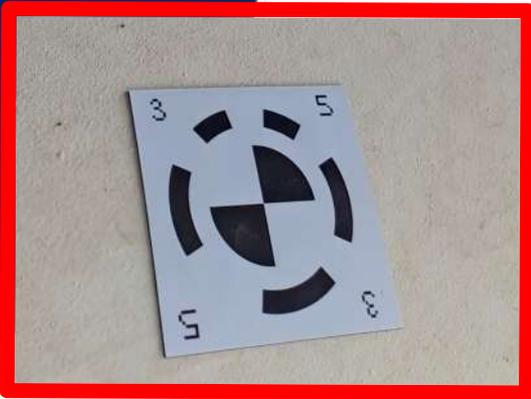
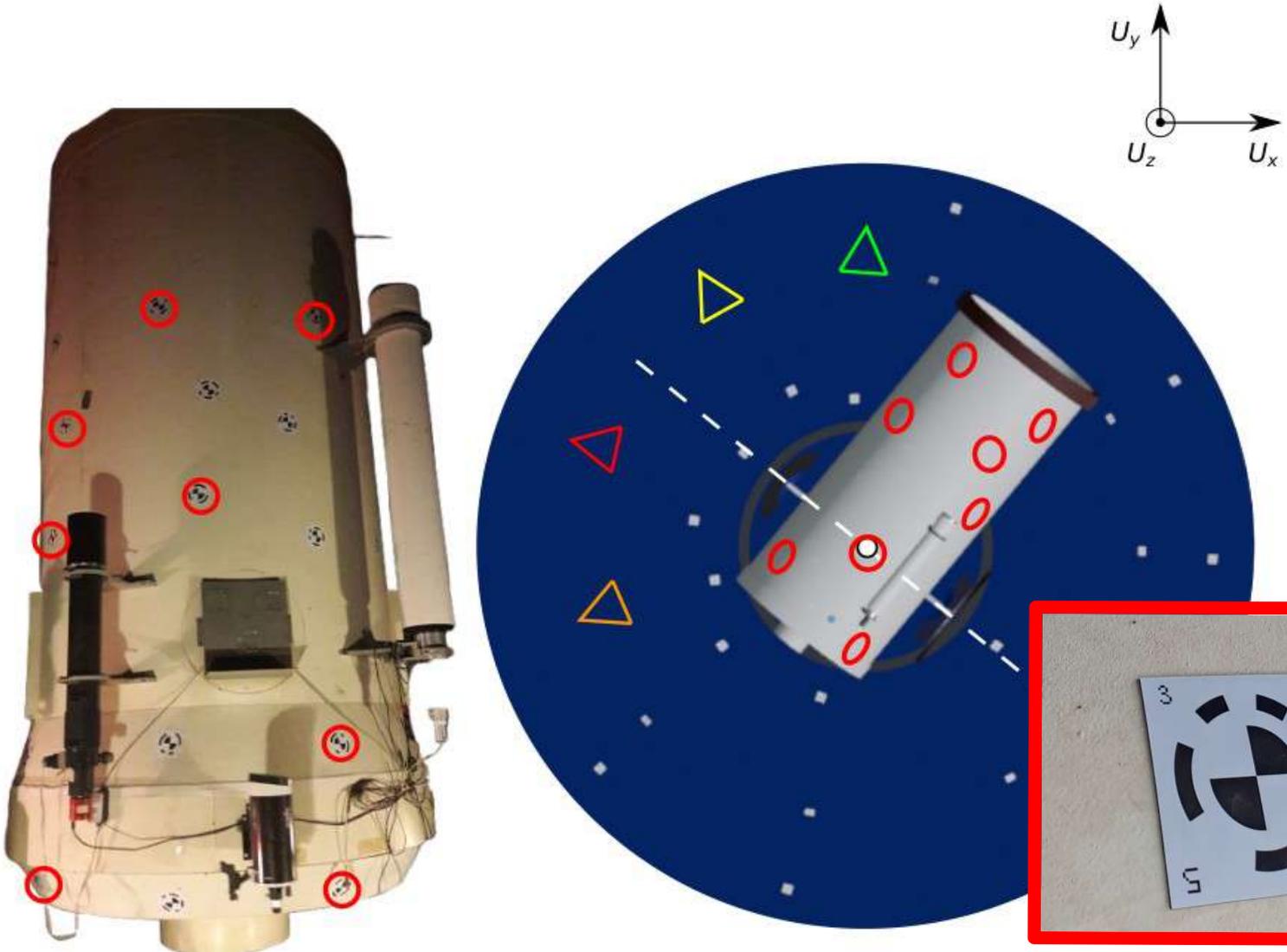
Approche photogrammétrique – Protocole



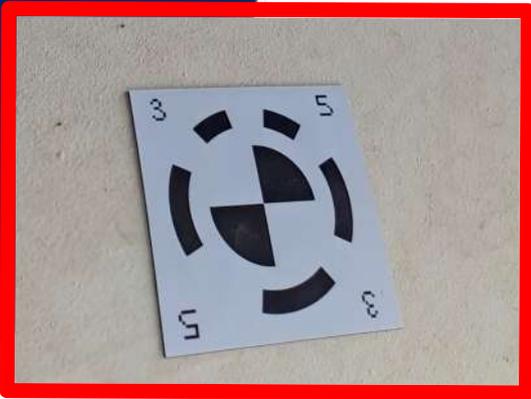
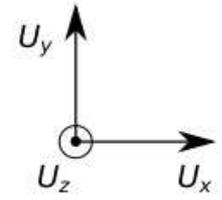
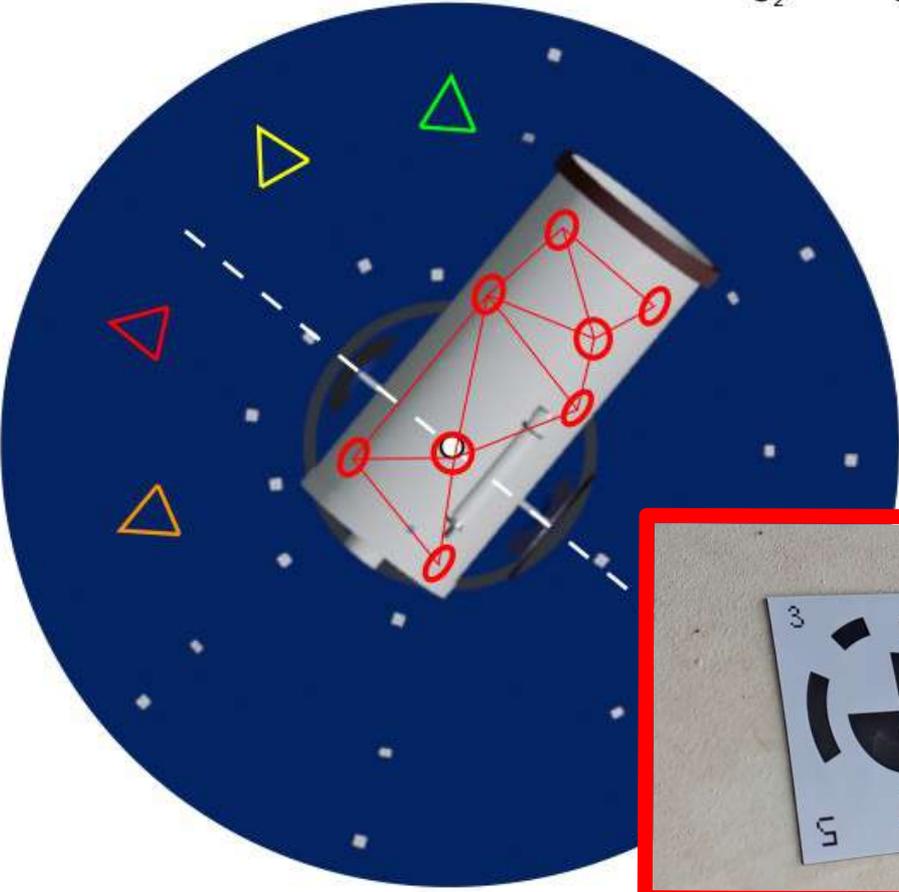
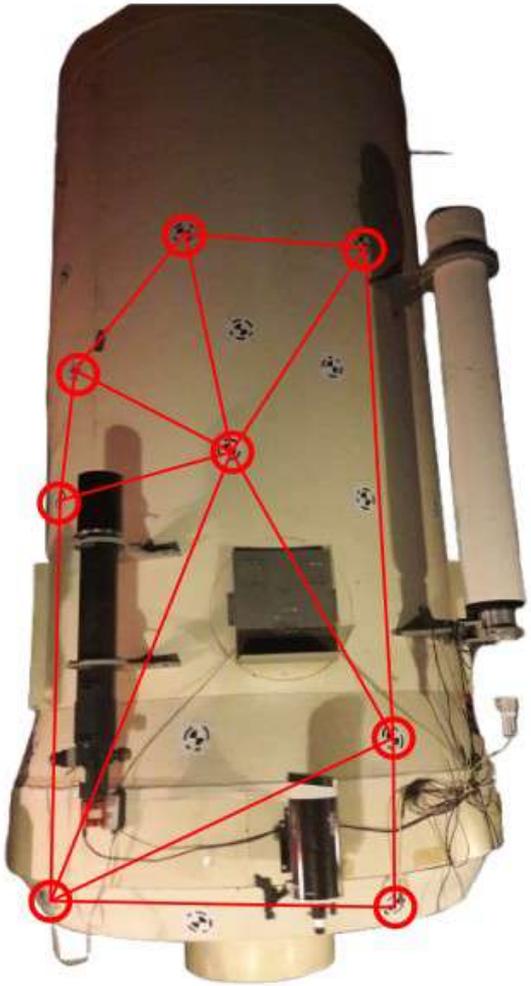
Approche photogrammétrique – Protocole



Approche photogrammétrique – Protocole



Approche photogrammétrique – Protocole



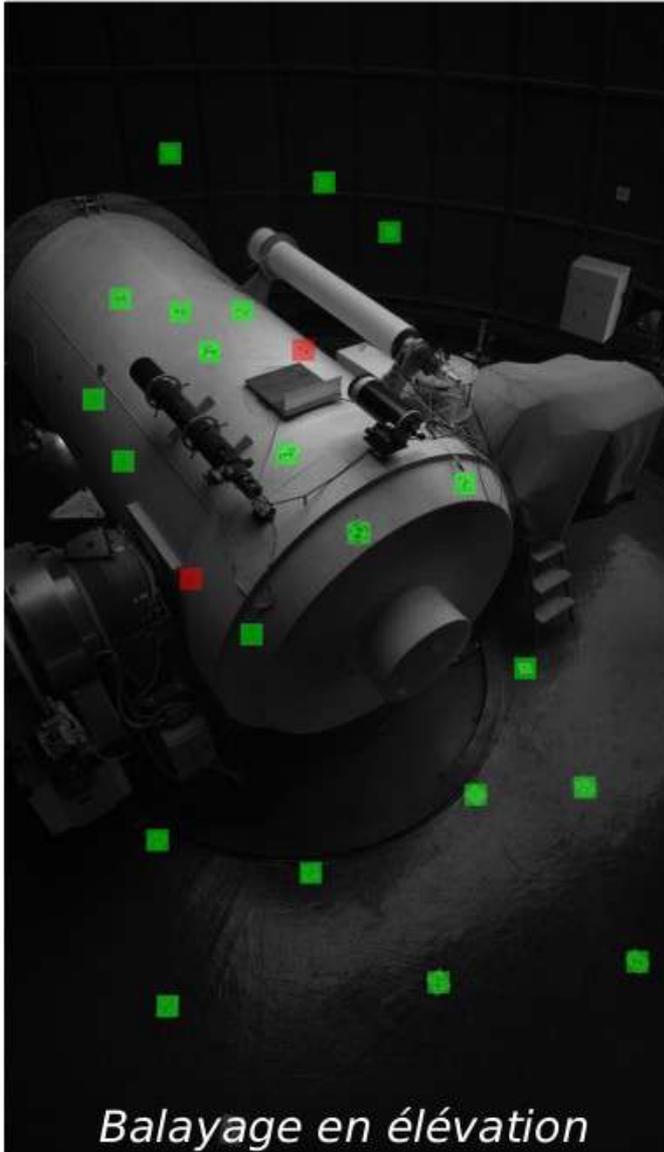
Approche photogrammétrique – Protocole



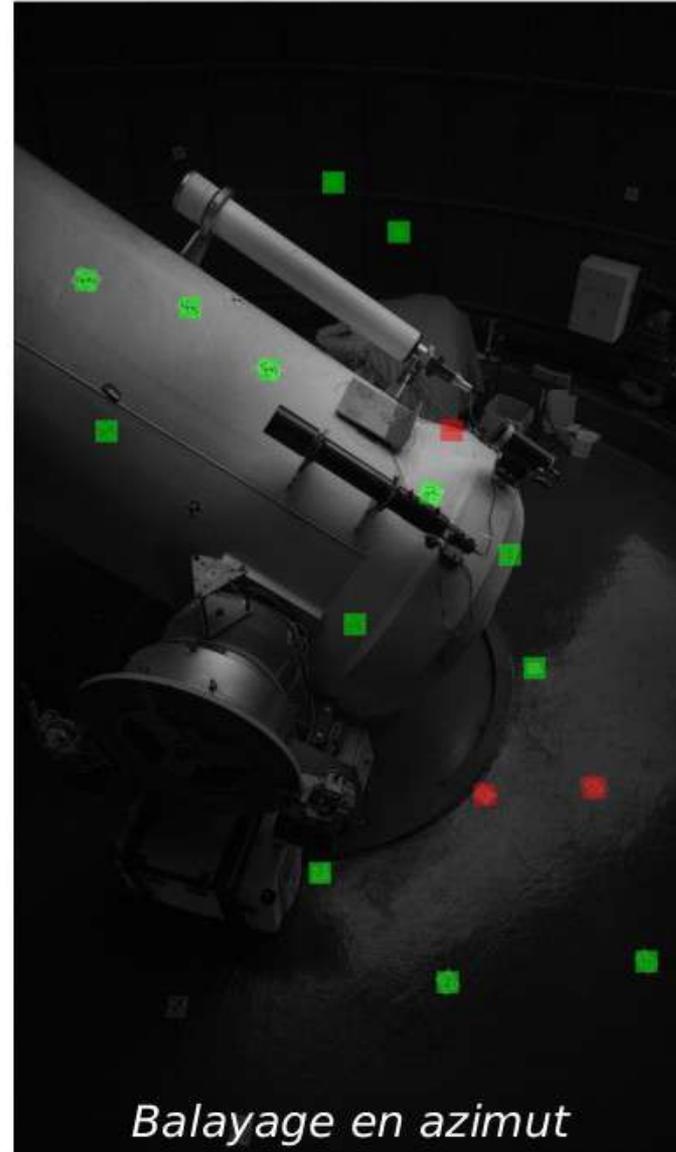
Approche photogrammétrique – Protocole



Approche photogrammétrique – Protocole

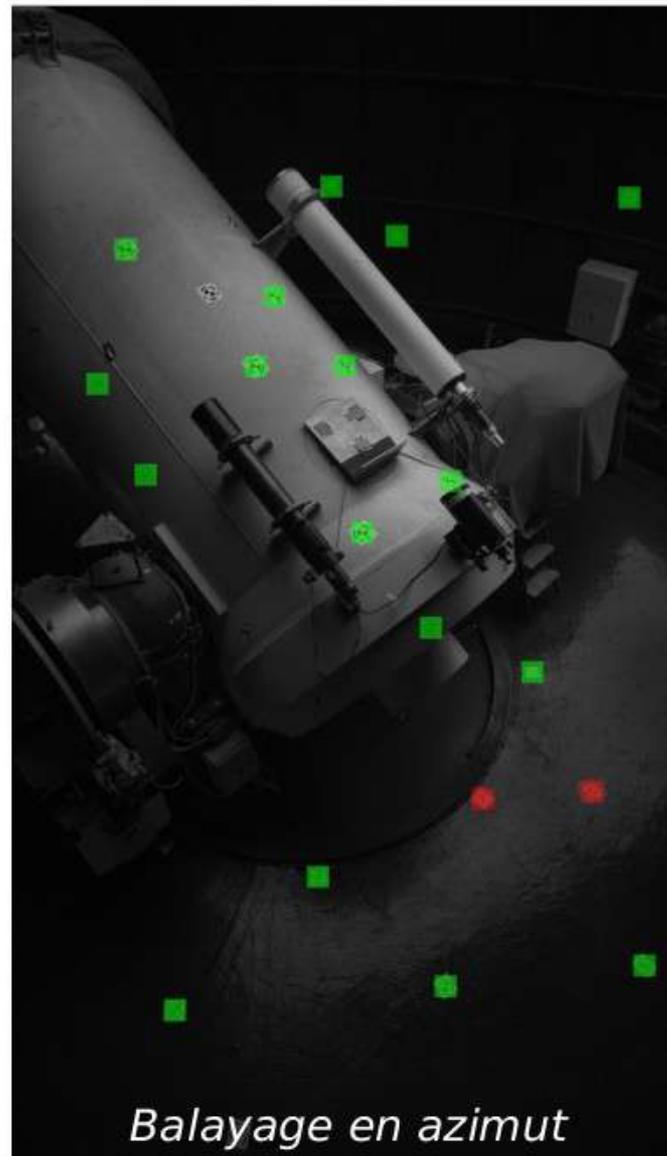
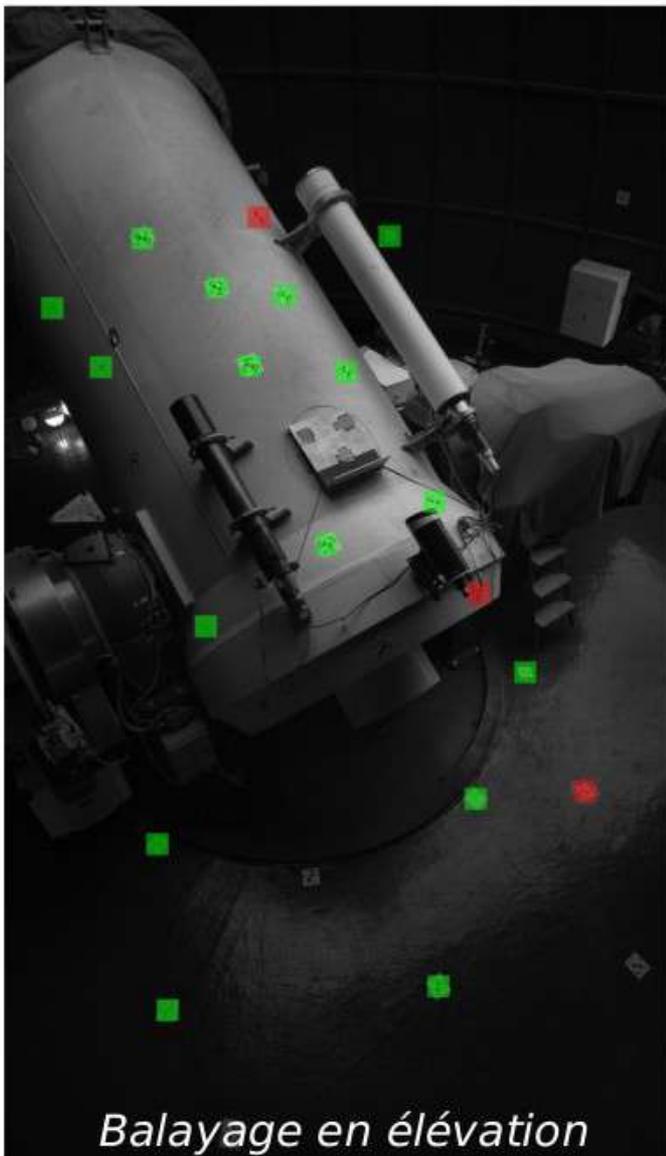


Balayage en élévation

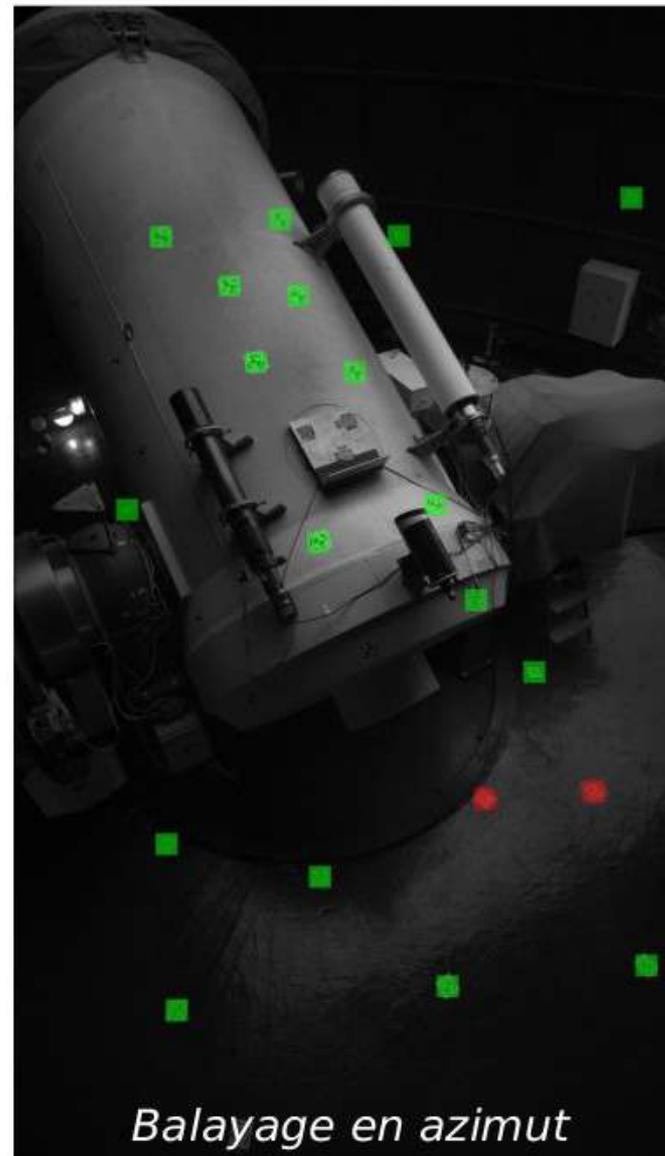
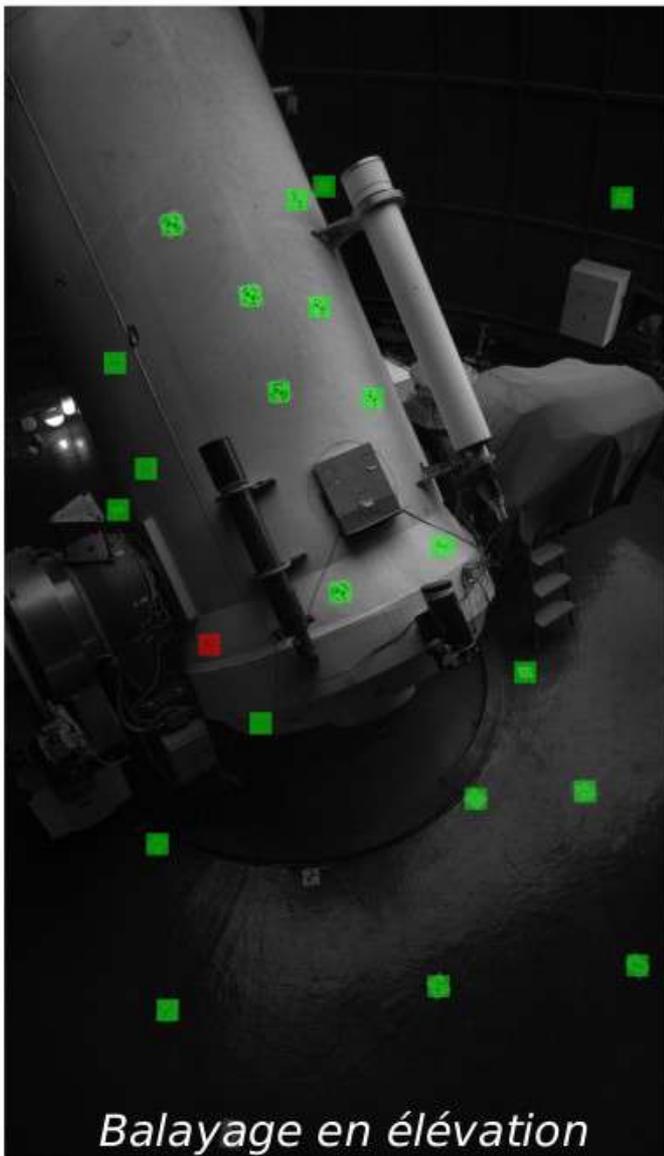


Balayage en azimut

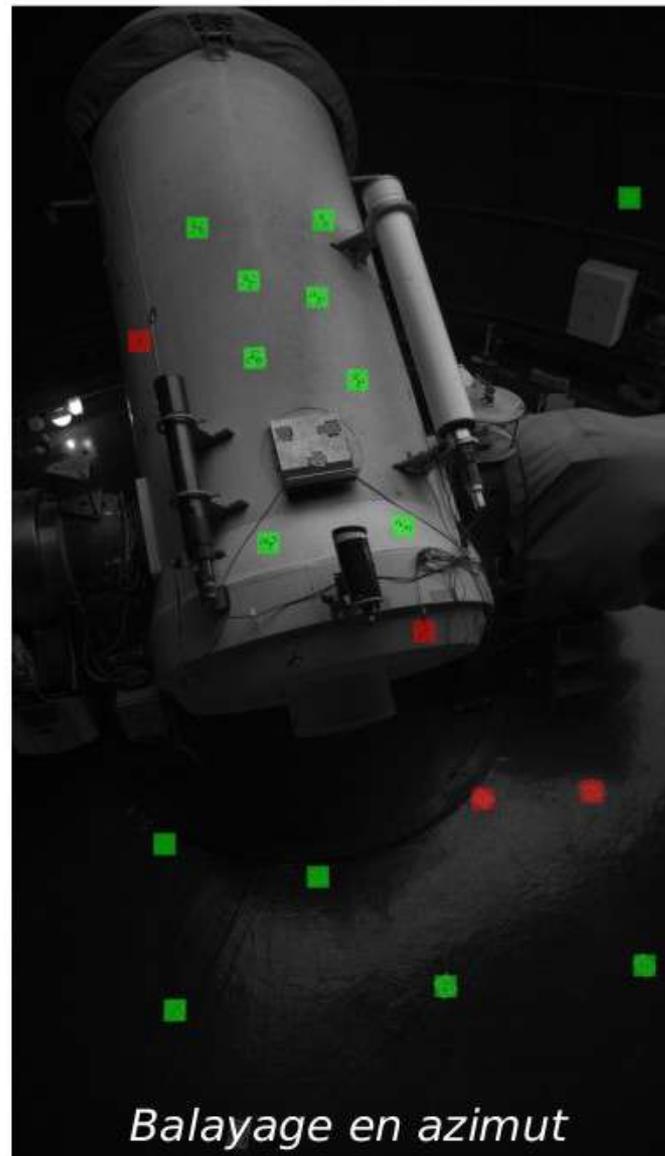
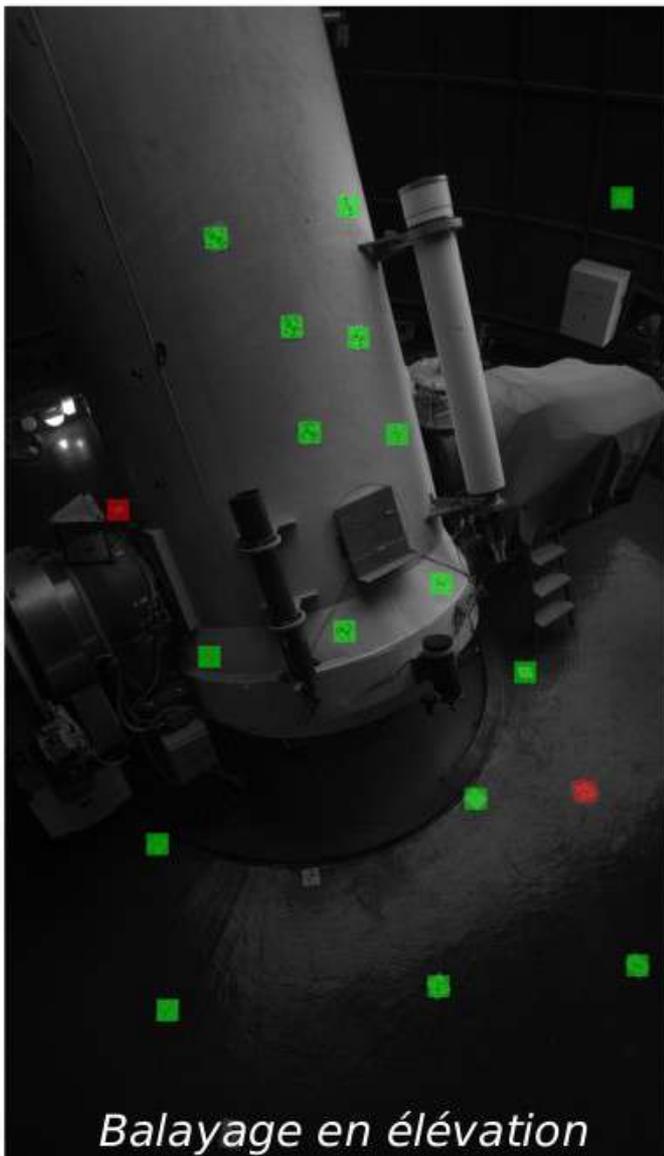
Approche photogrammétrique – Protocole



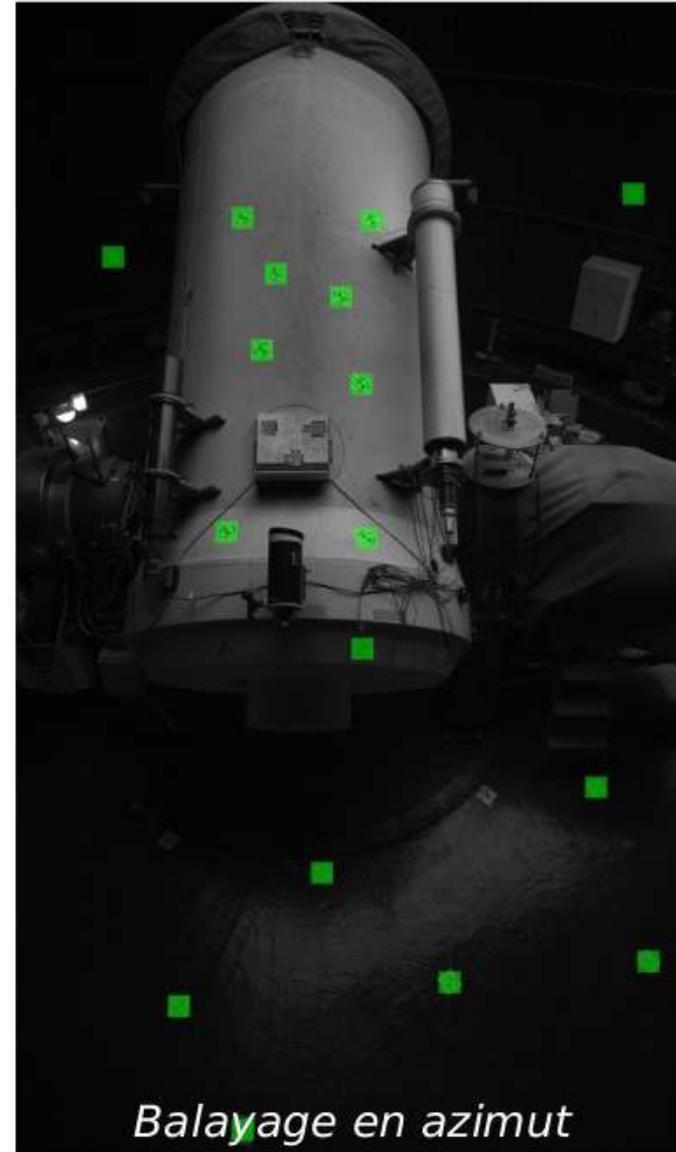
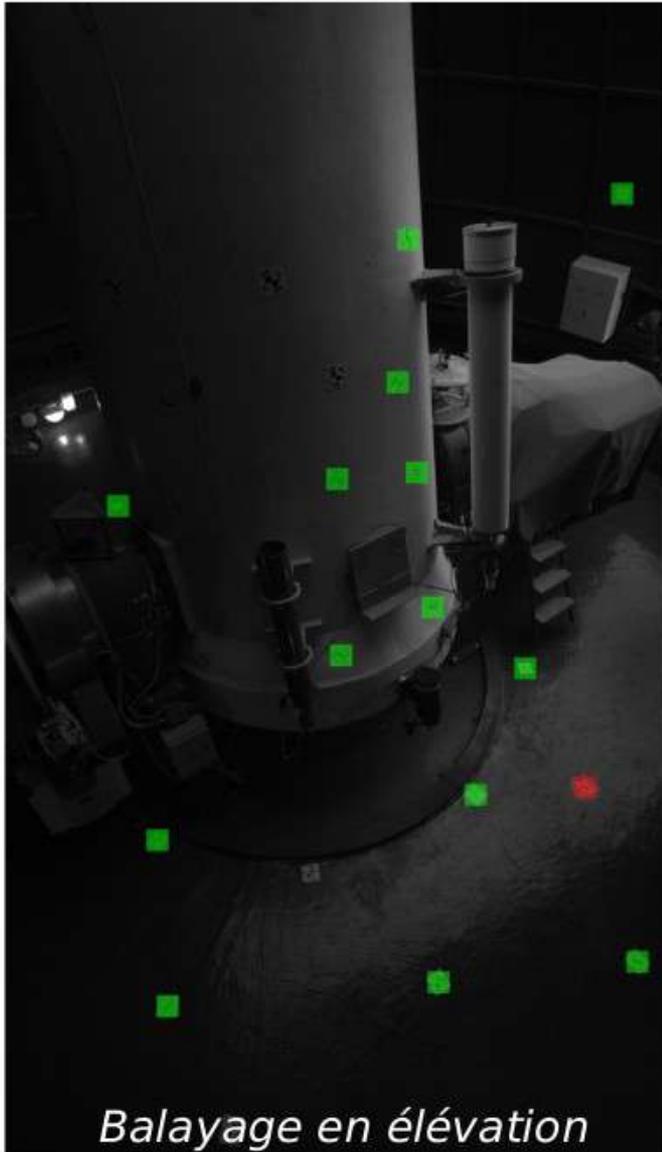
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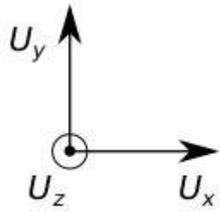
Approche photogrammétrique – Protocole



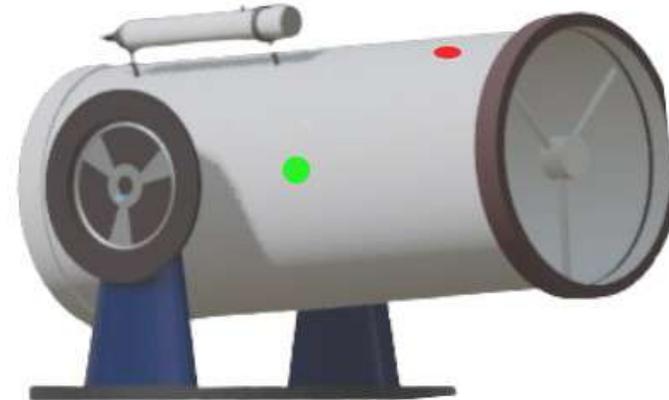
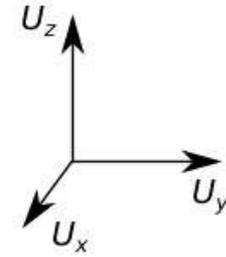
Approche photogrammétrique – Protocole



Approche photogrammétrique – Protocole

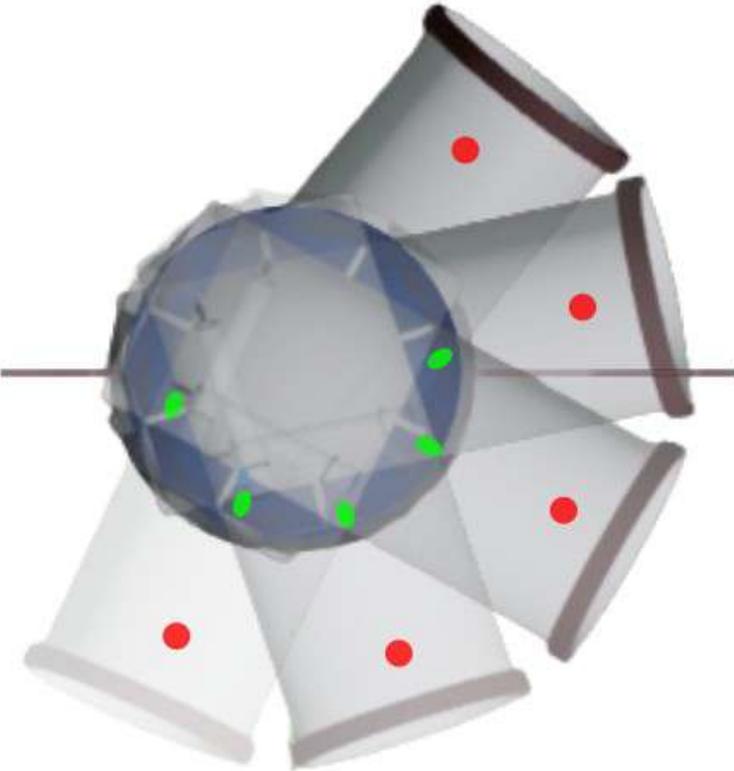
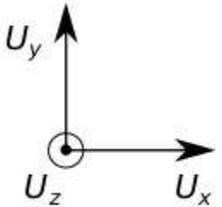


Azimut

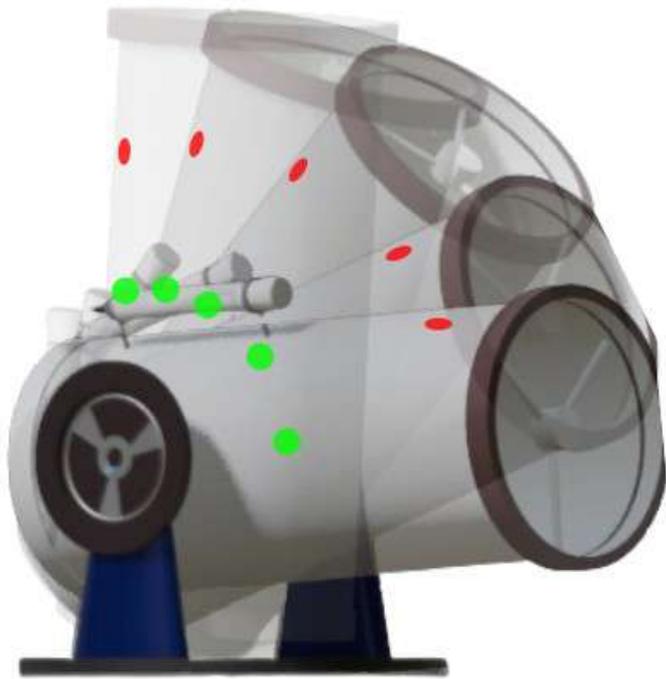
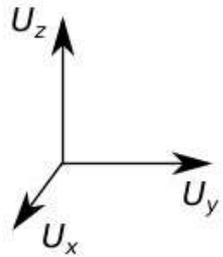


Élévation

Approche photogrammétrique – Protocole

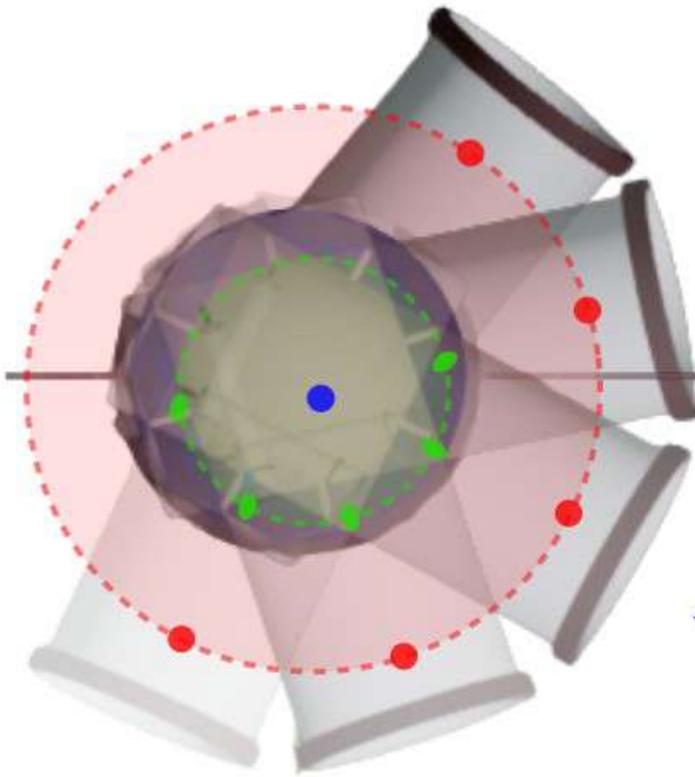
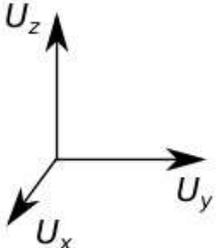
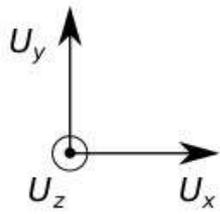


Azimut

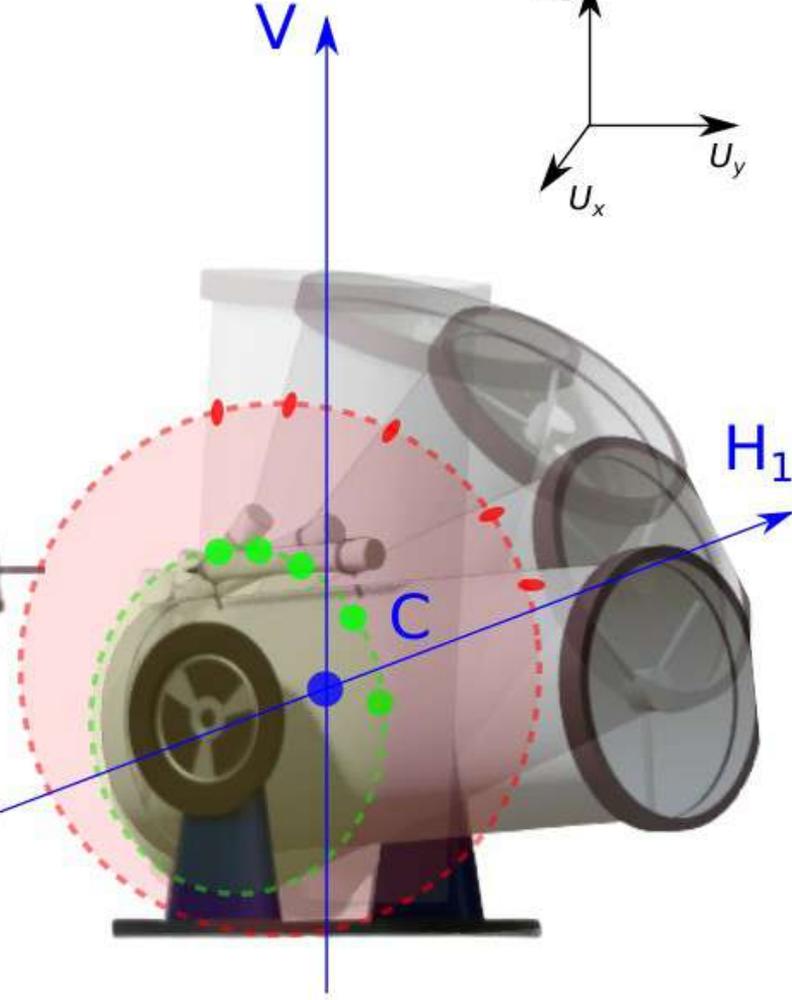


Elévation

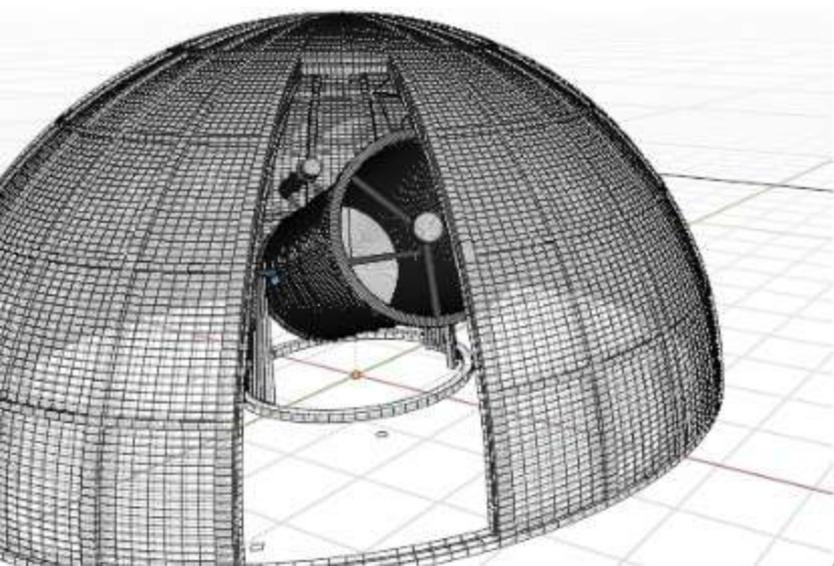
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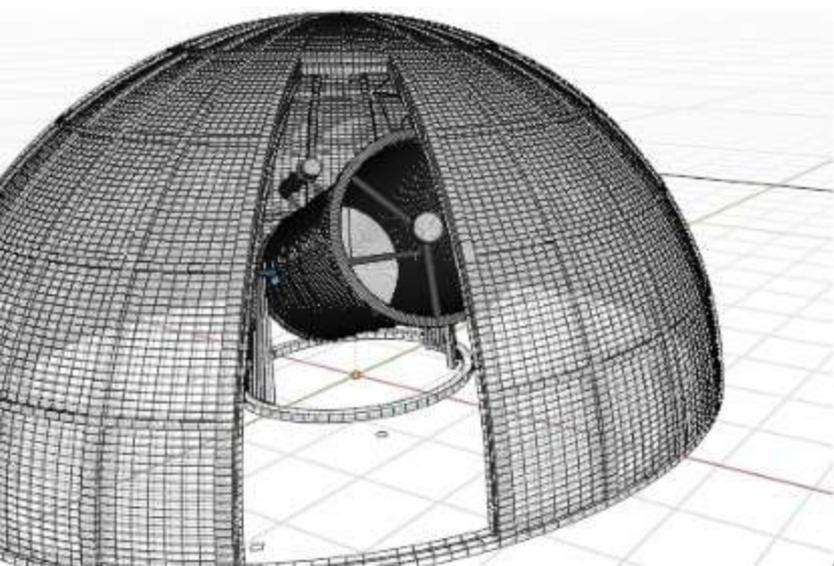


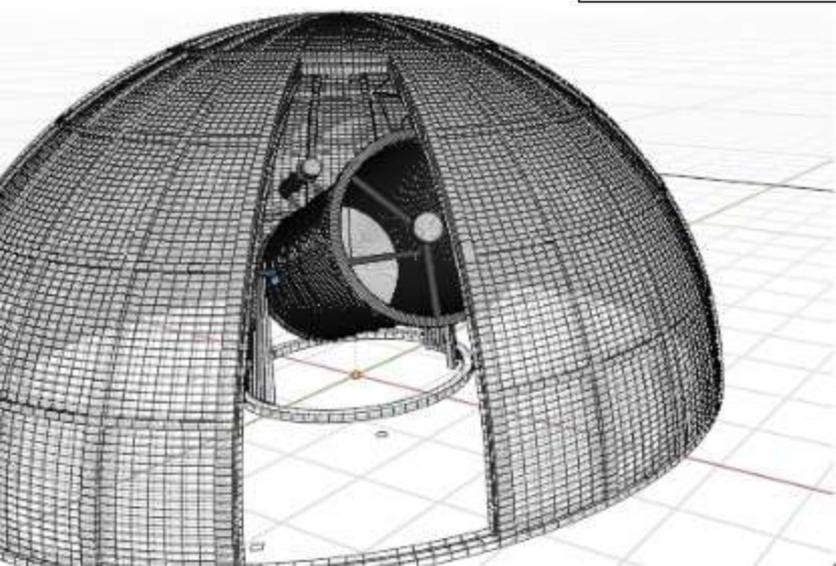
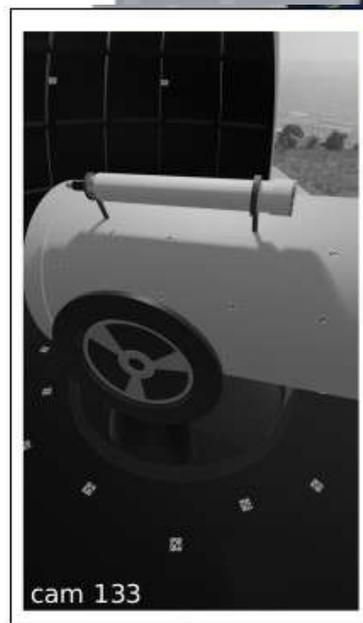
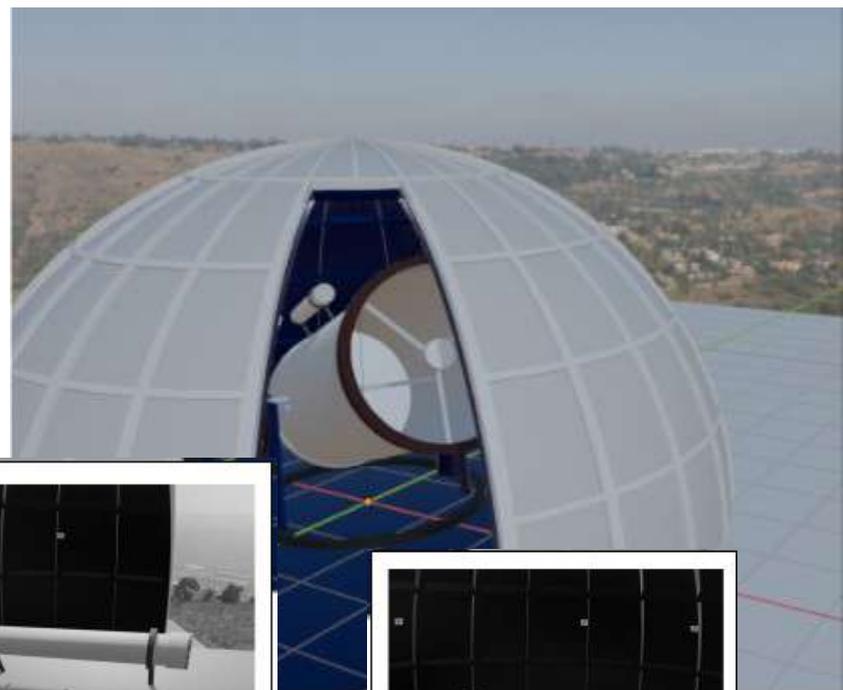
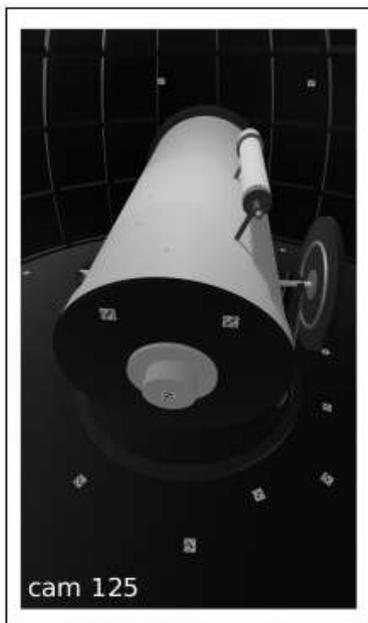
Azimut



Elévation







Approche photogrammétrique – Simulations



Acquisition

Simulation

Approche photogrammétrique – Résultats

- 8 séquences d'observations (~ 15 sec / séquence)

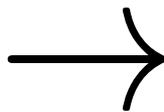
- 4 balayages $\Delta\varphi$ ($\theta = +5^\circ, +30^\circ, +55^\circ$ et $+80^\circ$)
- 4 balayages $\Delta\theta$ ($\varphi = 0^\circ, 45^\circ, 90^\circ$ et 135°)

- Vitesse de balayage $\omega = 1$ tr/min

- Fréquence d'acquisition : 0.33 image / sec

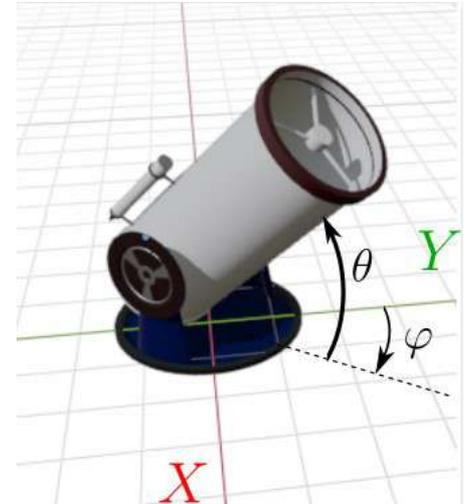
- 130 époques pour 4974 mesures de cibles (10 / cam / img)

- Export des mesures



- Compensation globale par moindres carrés avec Comp3D

- 7 715 paramètres à estimer, 17 234 équations
- 20 itérations (~ 10 minutes)
- σ_0 final = 0.66

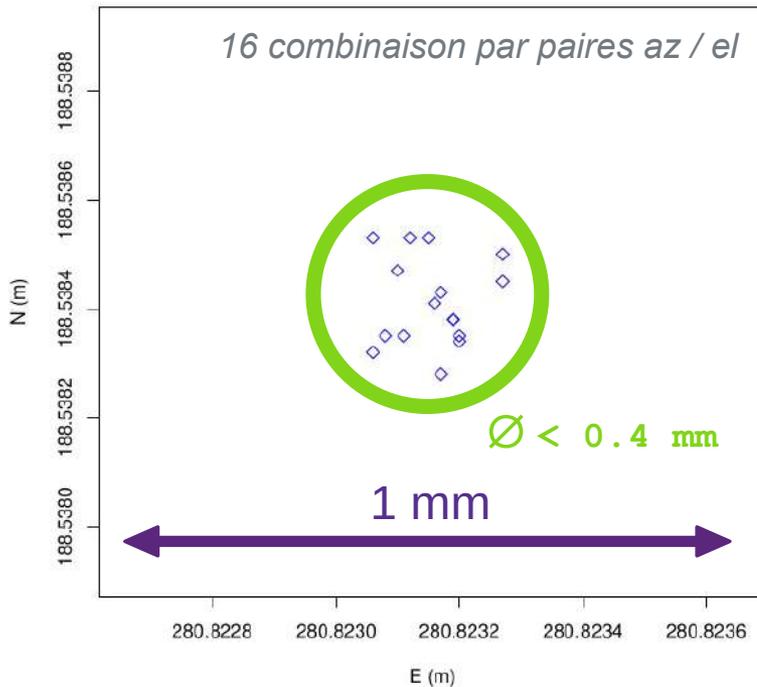
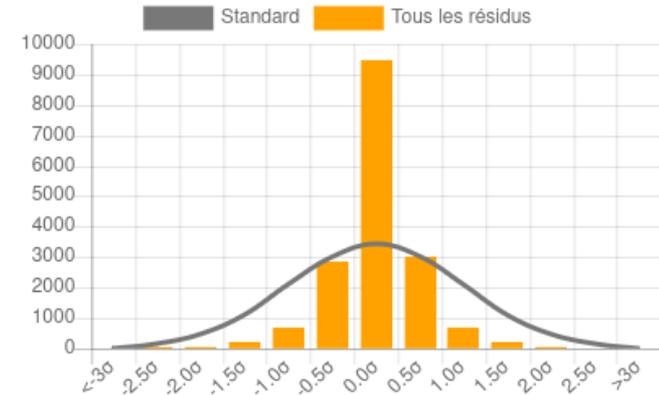


Approche photogrammétrique – Résultats

- Solution obtenue :

$E = 280.5977 \text{ m}$, $N = 188.3600 \text{ m}$, $U = 1323.3470 \text{ m}$

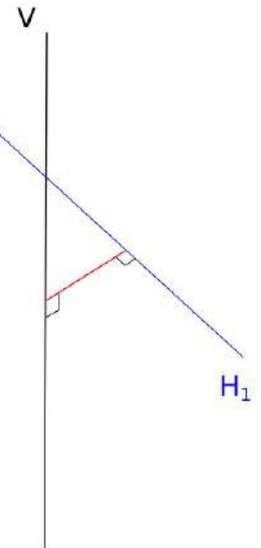
- Précision : **0.2 mm** sur chaque axe



- Précision caméras : **0.2 mm à 0.7 mm**

- Défaut de croisée des axes :

1.4 mm
± 0.6 mm

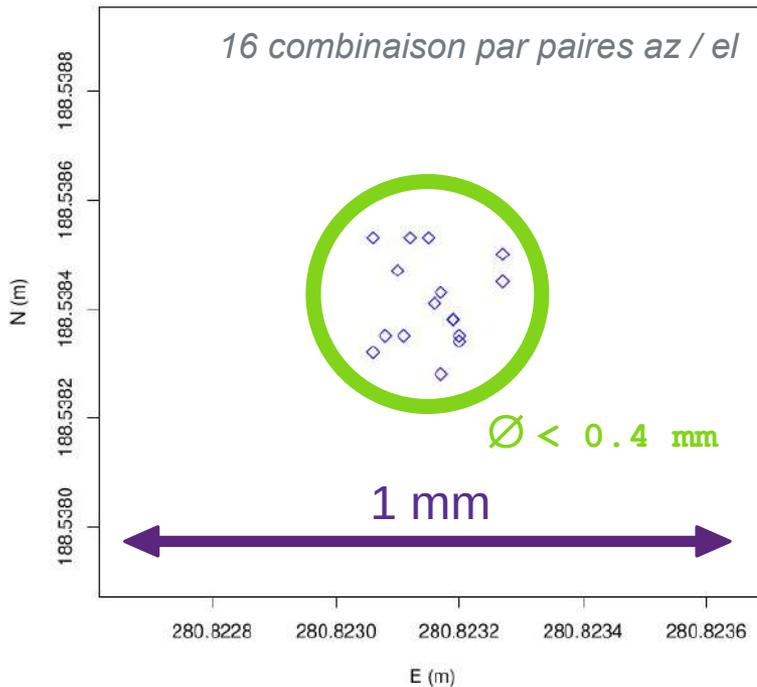
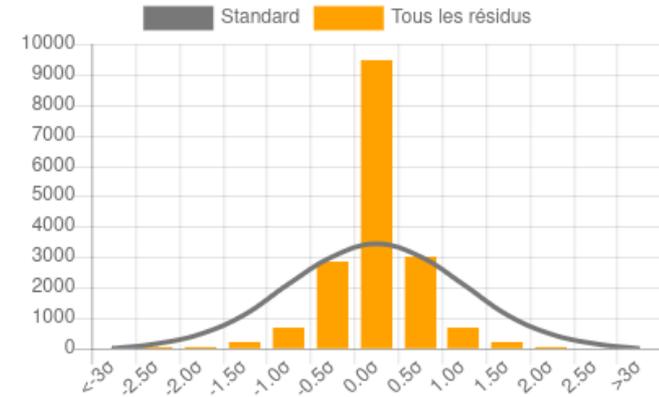


Approche photogrammétrique – Résultats

- Solution obtenue :

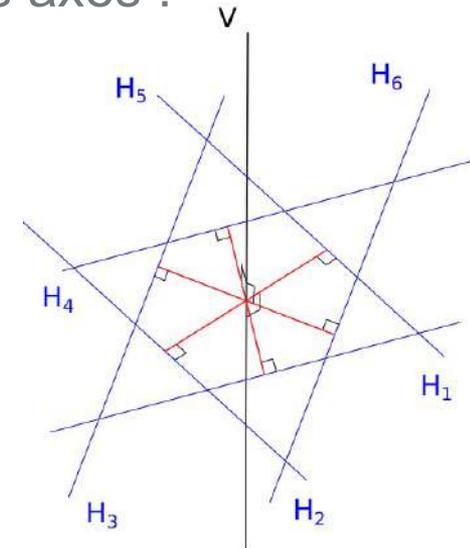
$E = 280.5977 \text{ m}$, $N = 188.3600 \text{ m}$, $U = 1323.3470 \text{ m}$

- Précision : **0.2 mm** sur chaque axe



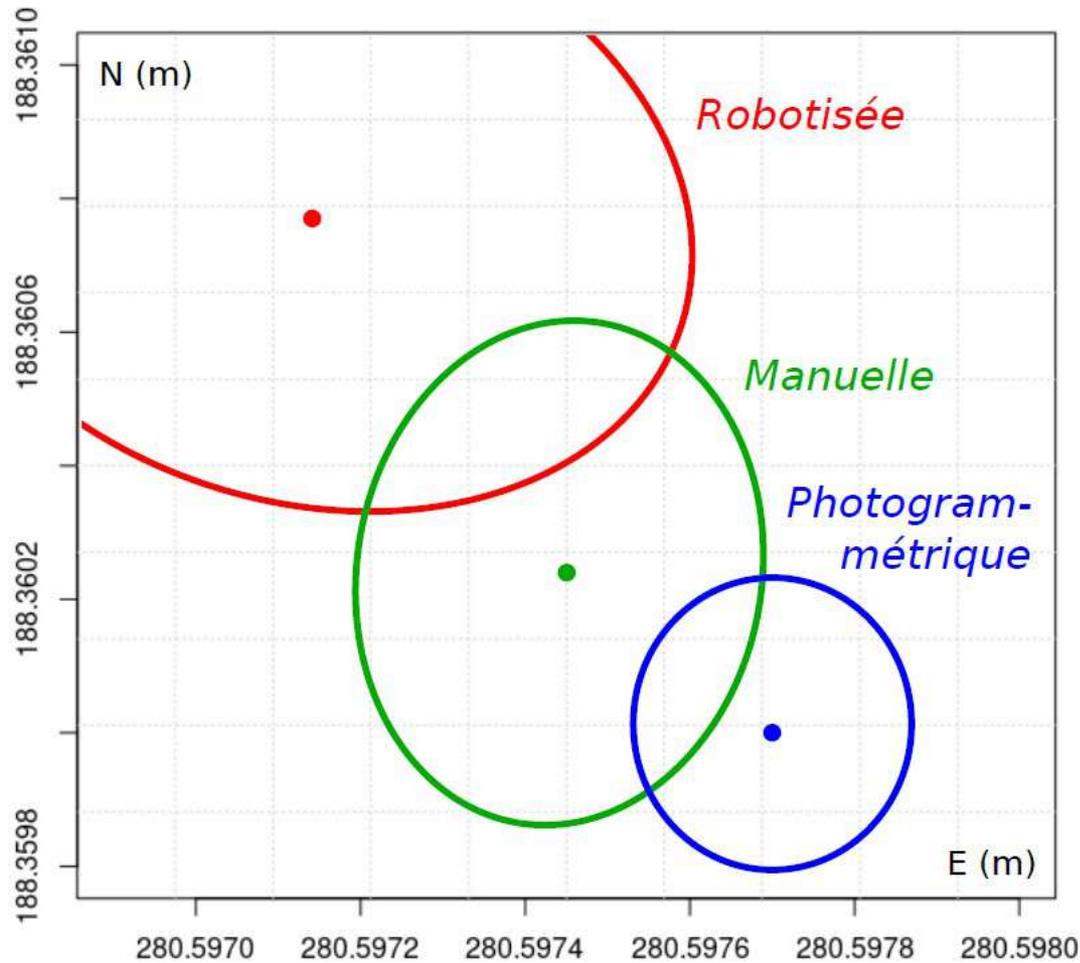
- Précision caméras : **0.2 mm à 0.7 mm**
- Défaut de croisée des axes :

1.4 mm
± 0.6 mm



Approche photogrammétrique – Résultats

- Comparaison avec les approches **manuelle** et **robotisée**



- Temps de calcul :
 - Manuelle : ~ 2h
 - Robotisée : 45'
 - Photogrammétrique : 6'20''

Vers un système « *low-cost* »

Cartes Raspberry + caméras HQ

- Objectif : ~ k€
- POC :
 - 2 balayages
 - 2 caméras
 - Sous-échantillonnage :
16 Mpx → 12 MPx
 - Bruit simulé
 - 6 cibles au sol
 - Pas de bloc rigide



- Résultats :

$\sigma = 0.7 \text{ mm}$ sur chaque axe (convergence en 20 sec...)

- À valider avec une expérimentation réelle...

Autres perspectives...

- Contrôle du référencement absolu



Autres perspectives...

- Extension aux radio-télescopes VLBI



A photograph showing the interior of a large, curved, blue structure, likely a tunnel or a large dome. The structure is supported by a network of steel ribs. In the center, a person wearing a blue hard hat and orange safety gear is standing on a platform, surrounded by surveying equipment, including tripods and a total station. To the right, a large, white, cylindrical object, possibly a piece of machinery or a container, is visible. The sky is visible through the opening at the top of the structure. The overall scene suggests a construction or maintenance project in a large-scale industrial or infrastructure setting.

Merci pour votre attention !