

GNSS-SMART better than 1 centimeter

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GNSS-SMART

GNSS:

Global **N**avigation **S**atellite **S**ystem
(GPS, GLONASS)

SMART:

State **M**onitoring **A**nd **R**epresentation **T**echnique

User Requirements for a Positioning Service / System

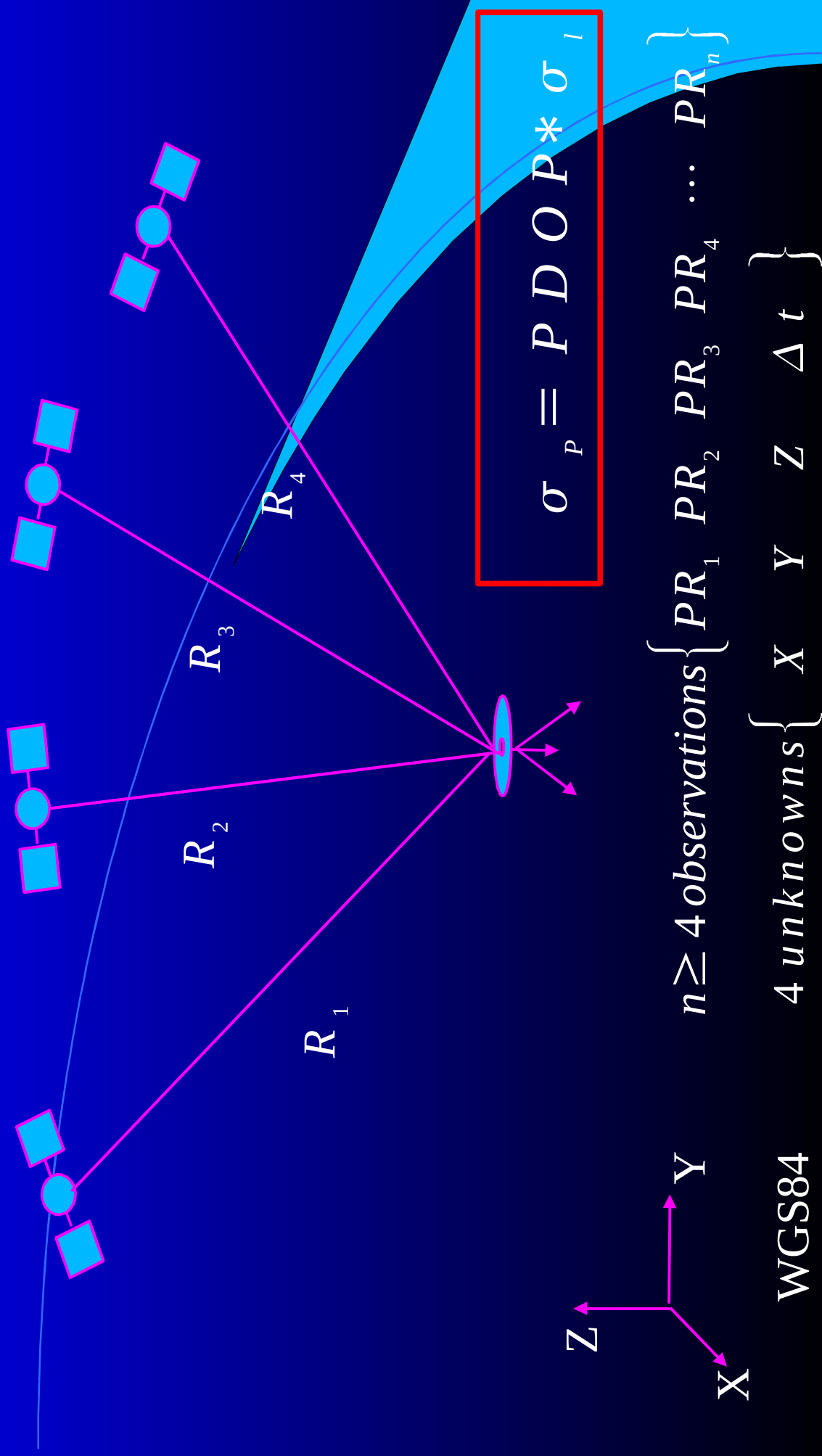
- Position determination
 - with high **Accuracy** (1–2 cm and better)
 - with high **Reliability** (99,9%)
 - with high **Availability** (99,9%)
 - **temporal** availability (time for initialization, real time)
 - **spatial** availability (obstructions, number of satellites)
 - in homogenous **Reference Frame** (ETRF, WGS)
 - transformation into **user system** (determined once)
 - with international **standardized user interface**
 - **cost effective**

GPS and GLONASS

Characteristics

- active satellite space segment
- one way signals (arbitrary number of users)
- position determination
 - **everytime** (temporal availability)
 - **everywhere** (obstructions, spatial availability)
 - **weather independent**
- in (quasi-) real time (temporal availability)
- (quasi-) **instantaneous** (no integration, 1 meas. epoch)
- accuracy: 10m–100m
- problem: **no cm accuracy !**

GNSS basic principle



GNSS Accuracy

$$\sigma_p = PDOP * \sigma_l$$

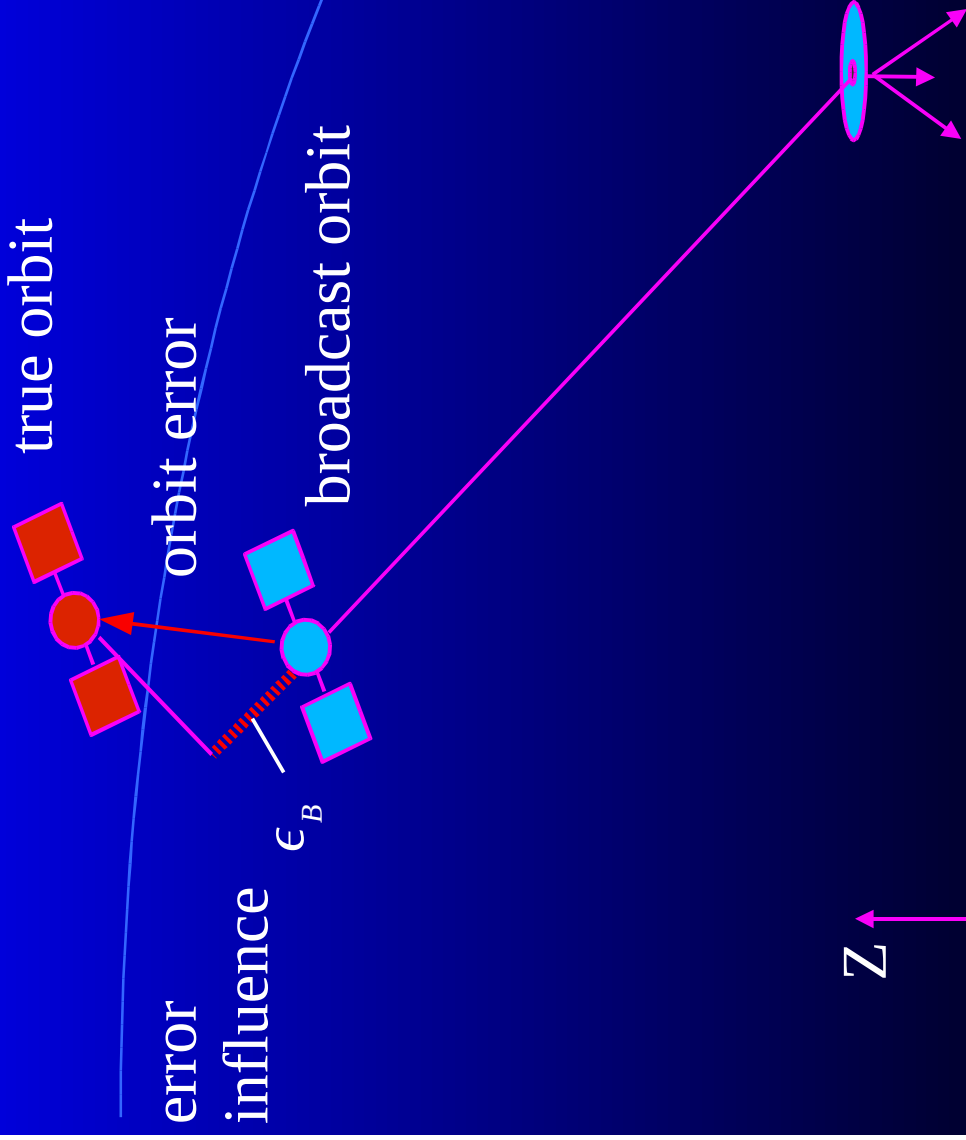
- σ_p – mean point error
- σ_l – standard deviation of pseudo range
 - total sum of all errors !
- $PDOP$ – Position Dilution Of Precision

GNSS Accuracy

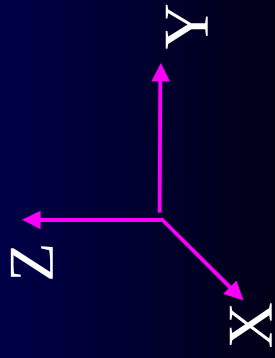
$$\sigma_p = PDOP * \sigma_l$$

- good geometry: PDOP = 2 – 3
accuracy of position: 2 – 3 cm
⇒ accuracy of pseudo range: 1 cm
⇒ only with **carrier phase measurements**
- **but: systematic errors**

GNSS Error Sources



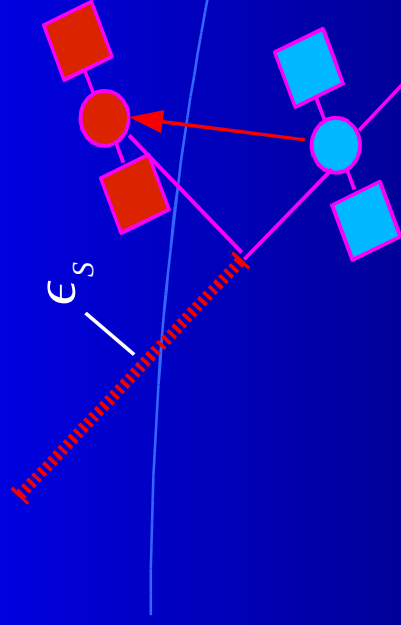
Satellite orbit error



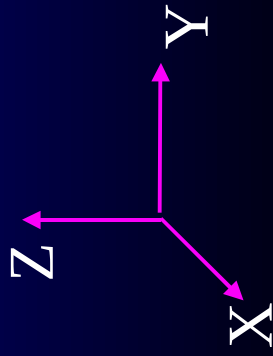
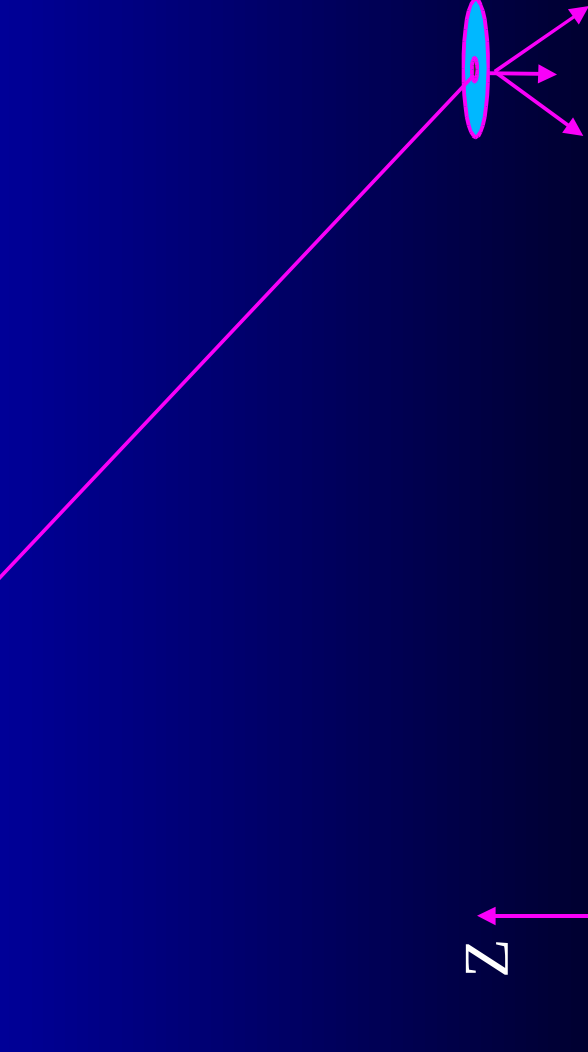
WGS84

GNSS Error Sources

error influence

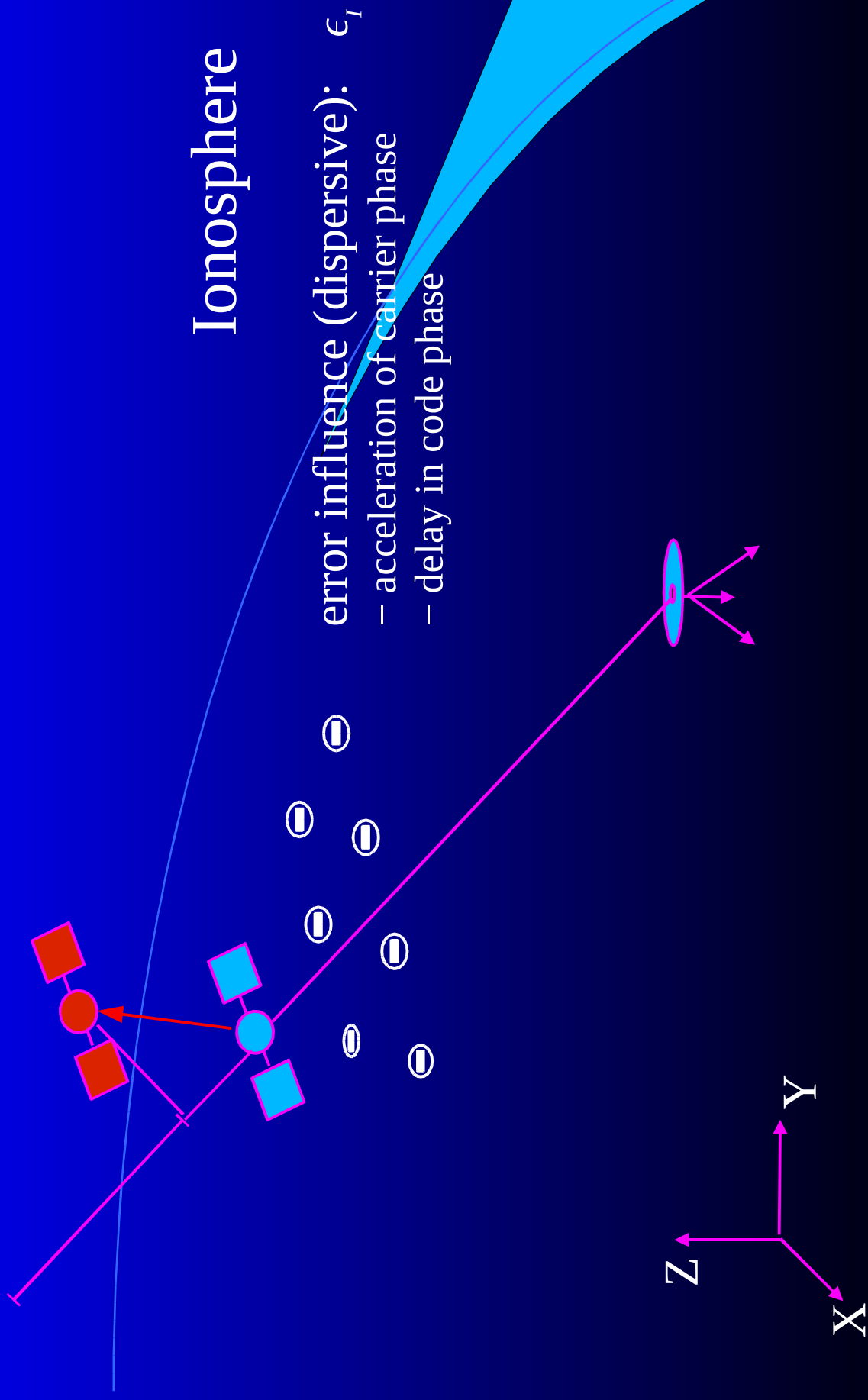


Satellite clock error



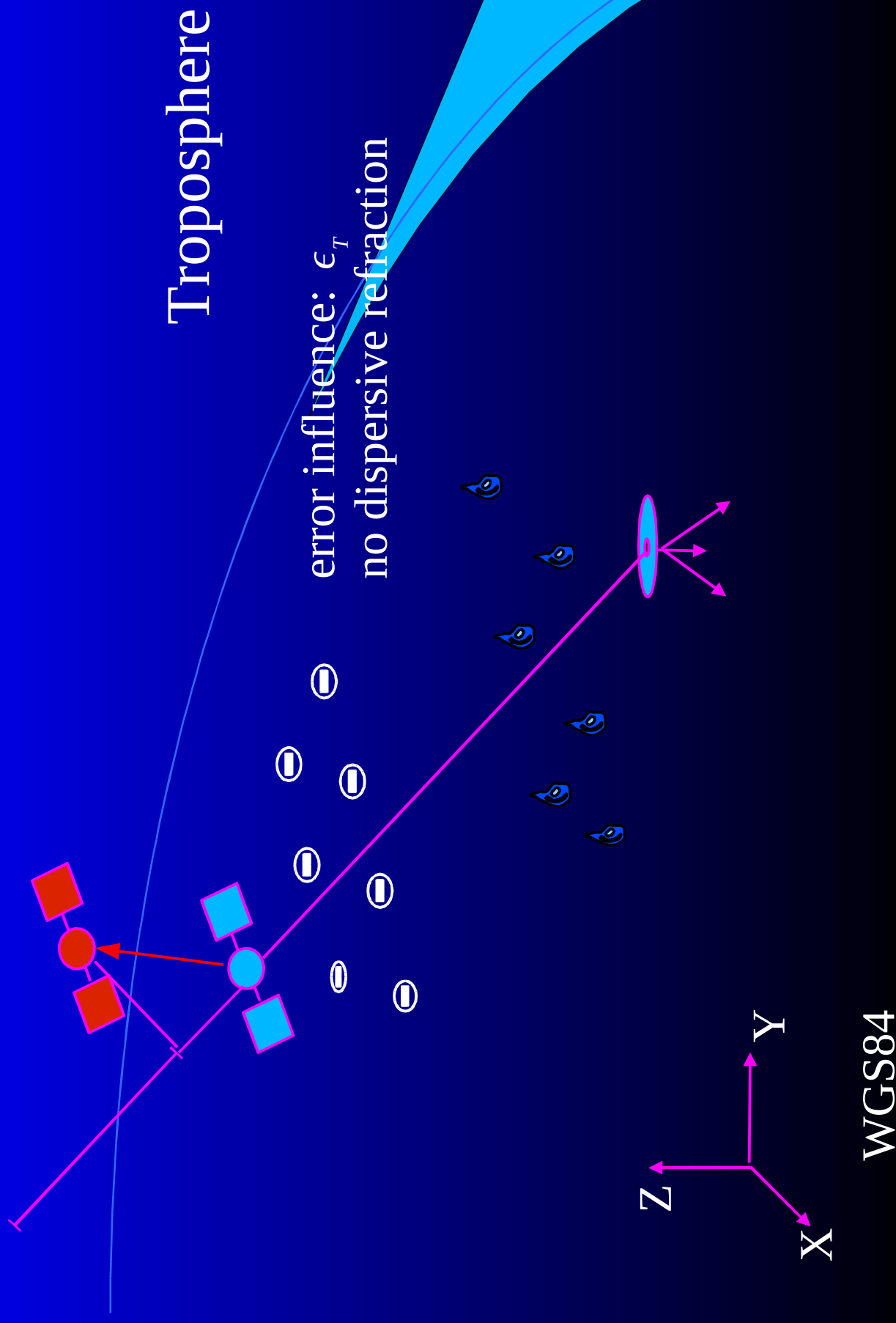
WGS84

GNSS Error Sources

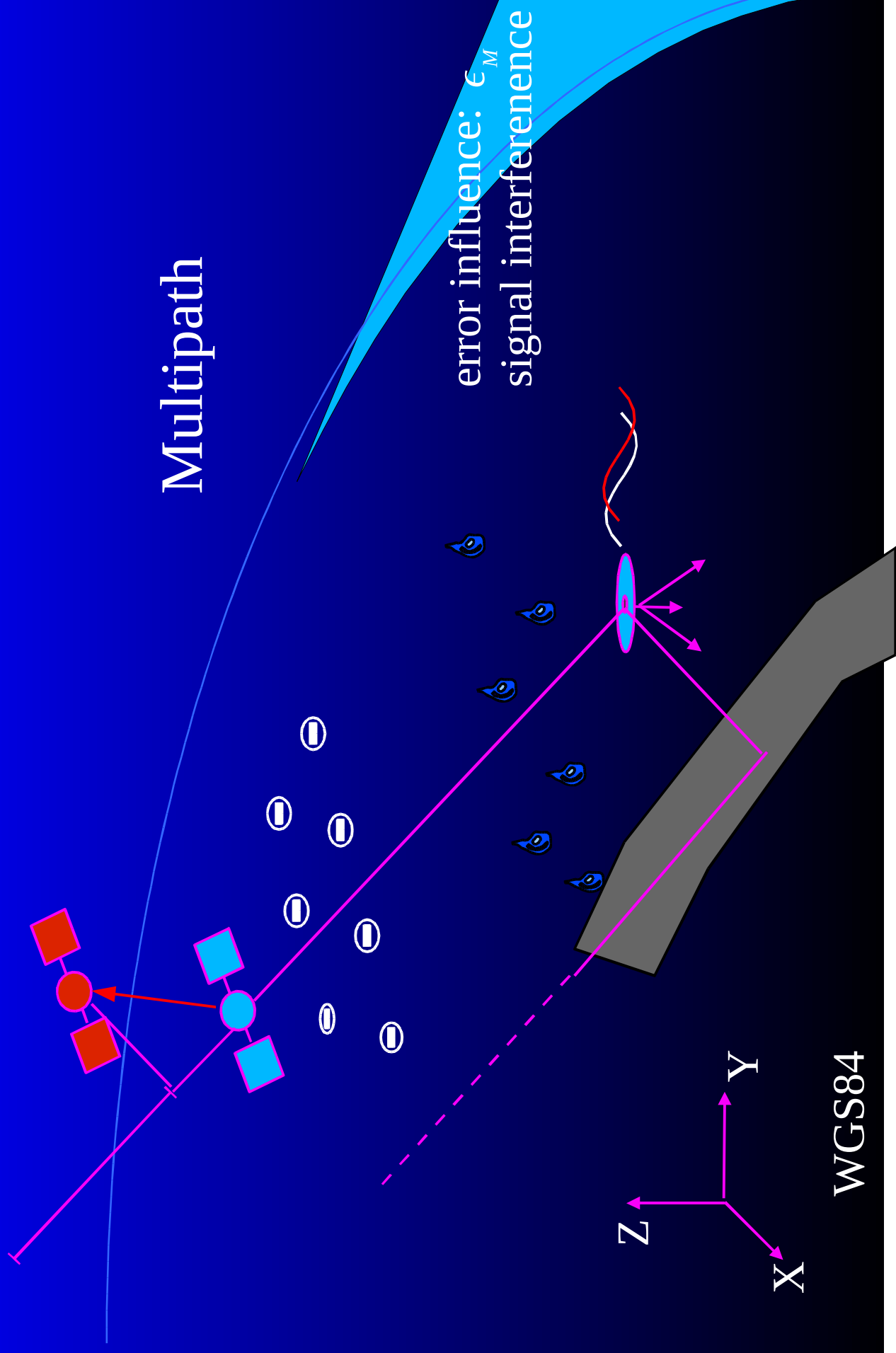


WGS84

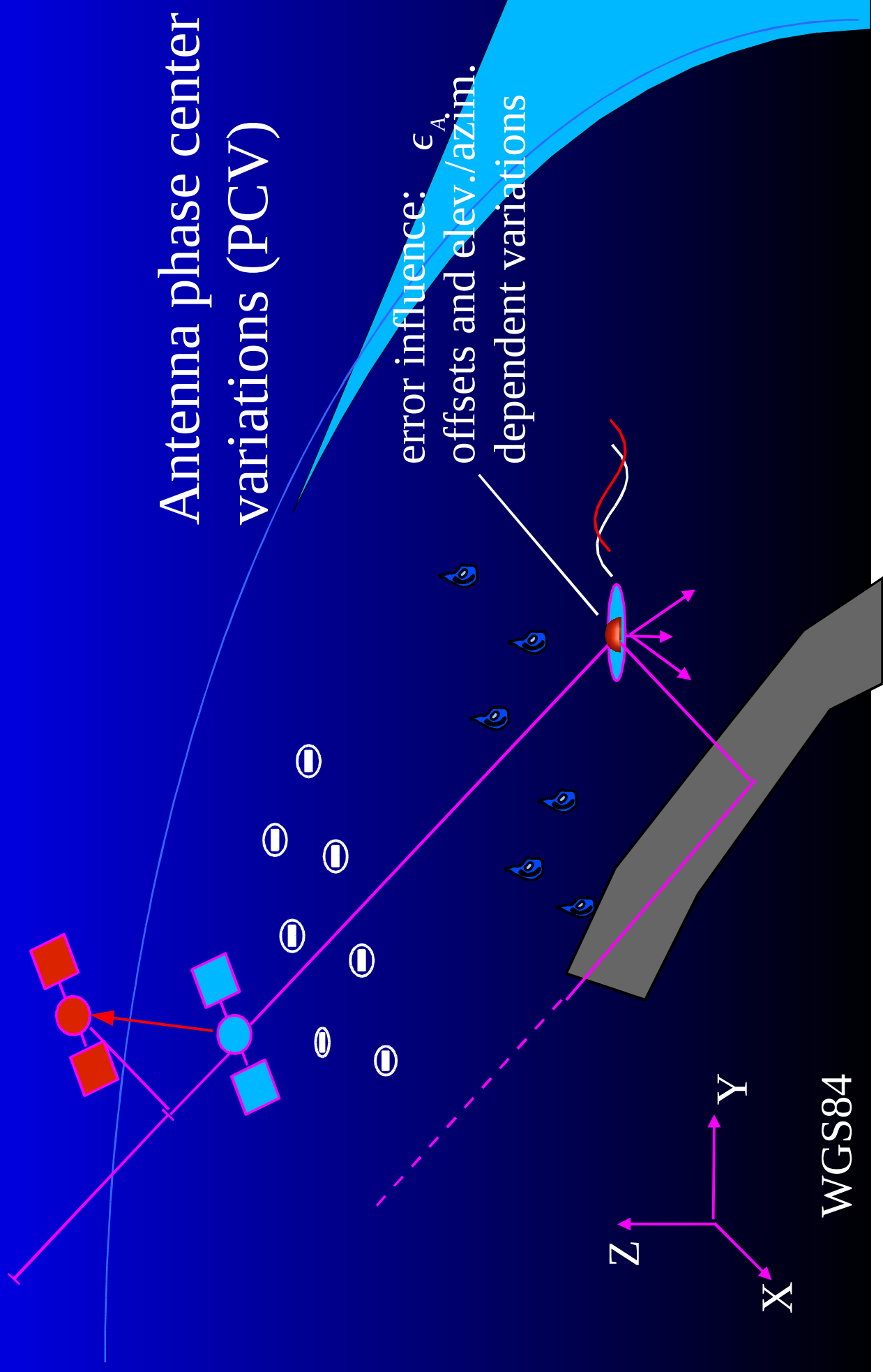
GNSS Error Sources



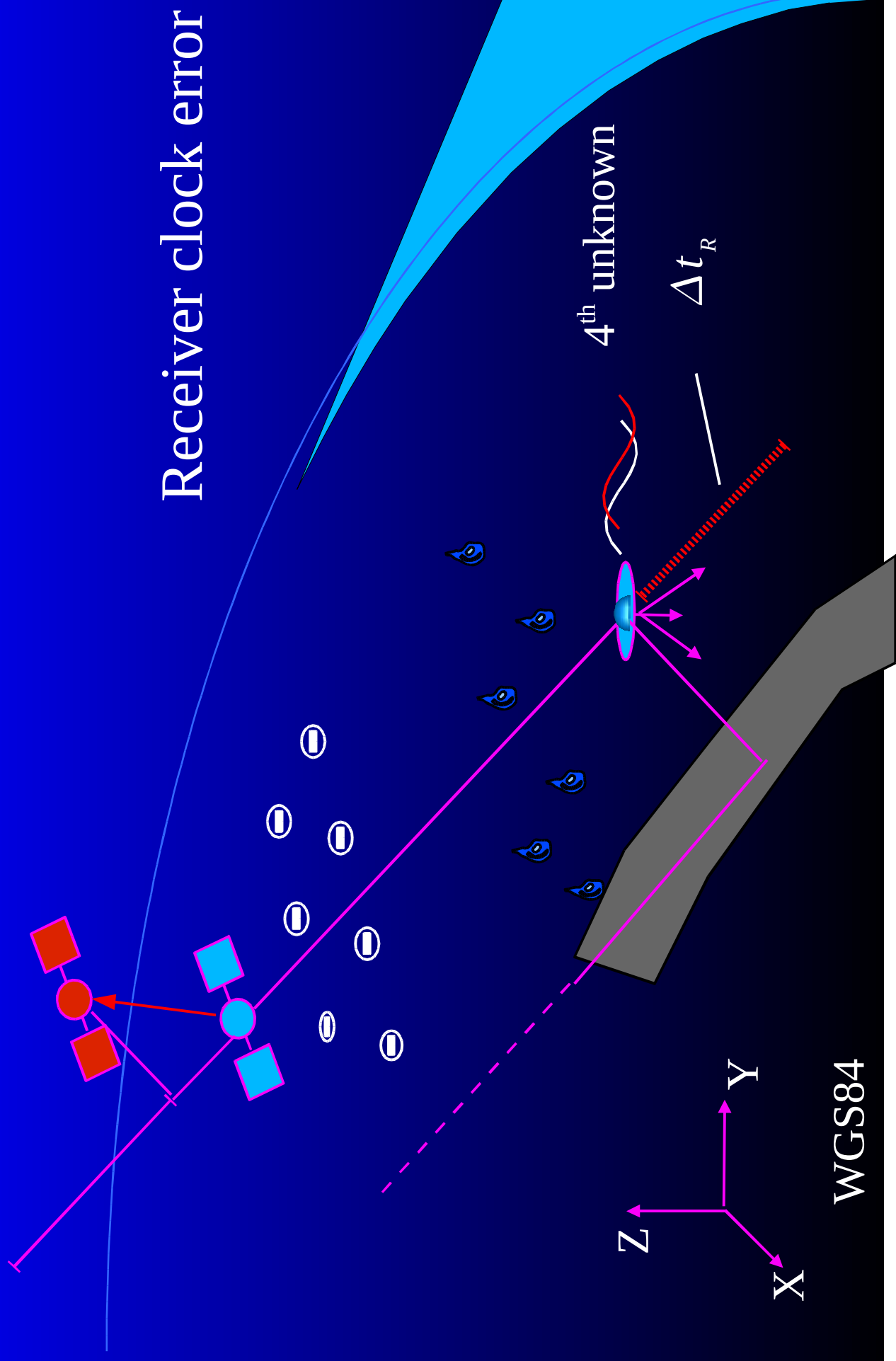
GNSS Error Sources



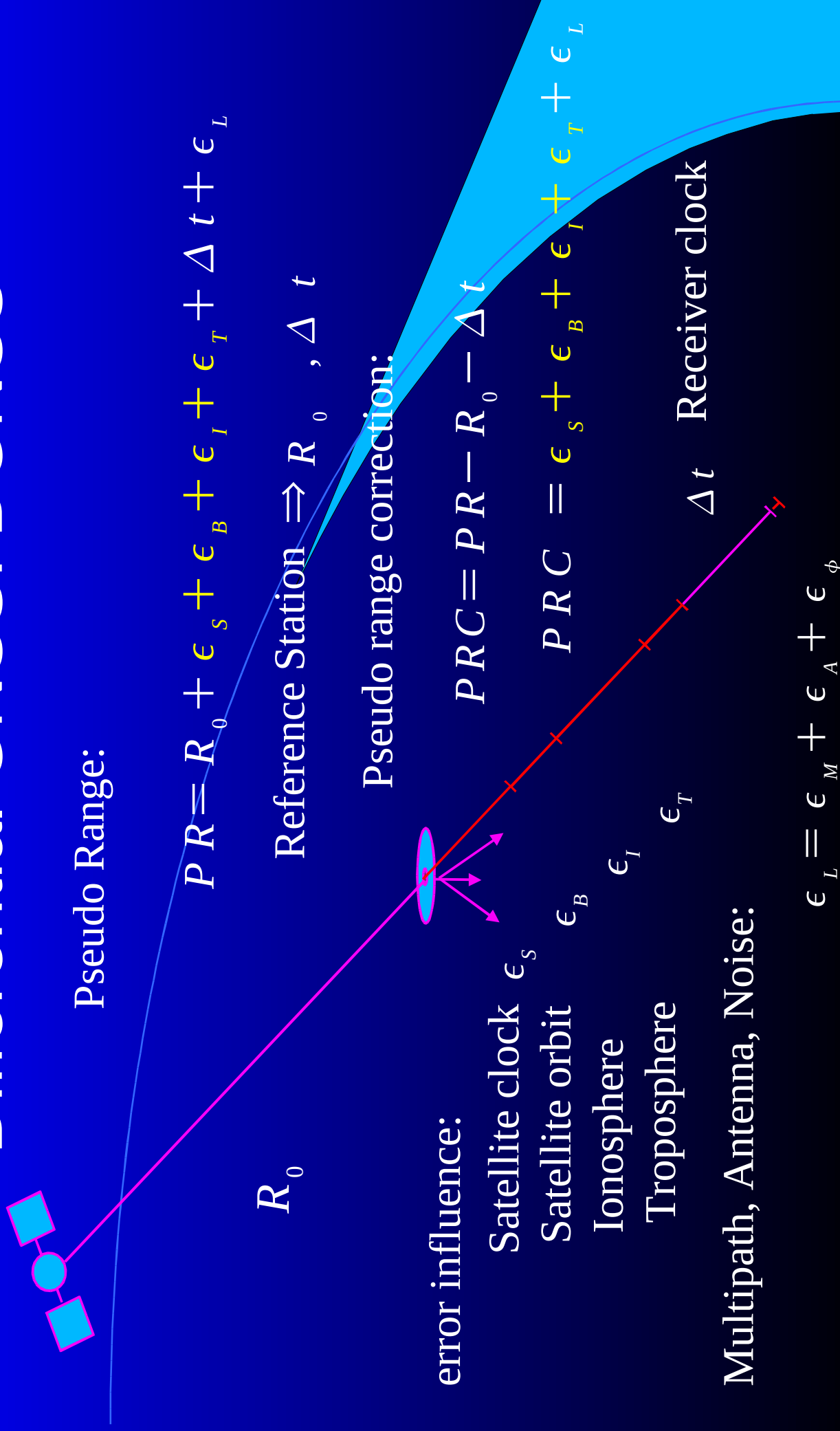
GNSS Error Sources



GNSS Error Sources



Differential GNSS: DGNSS



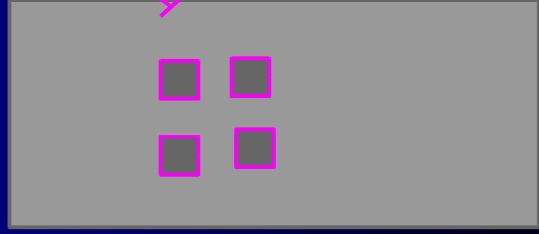
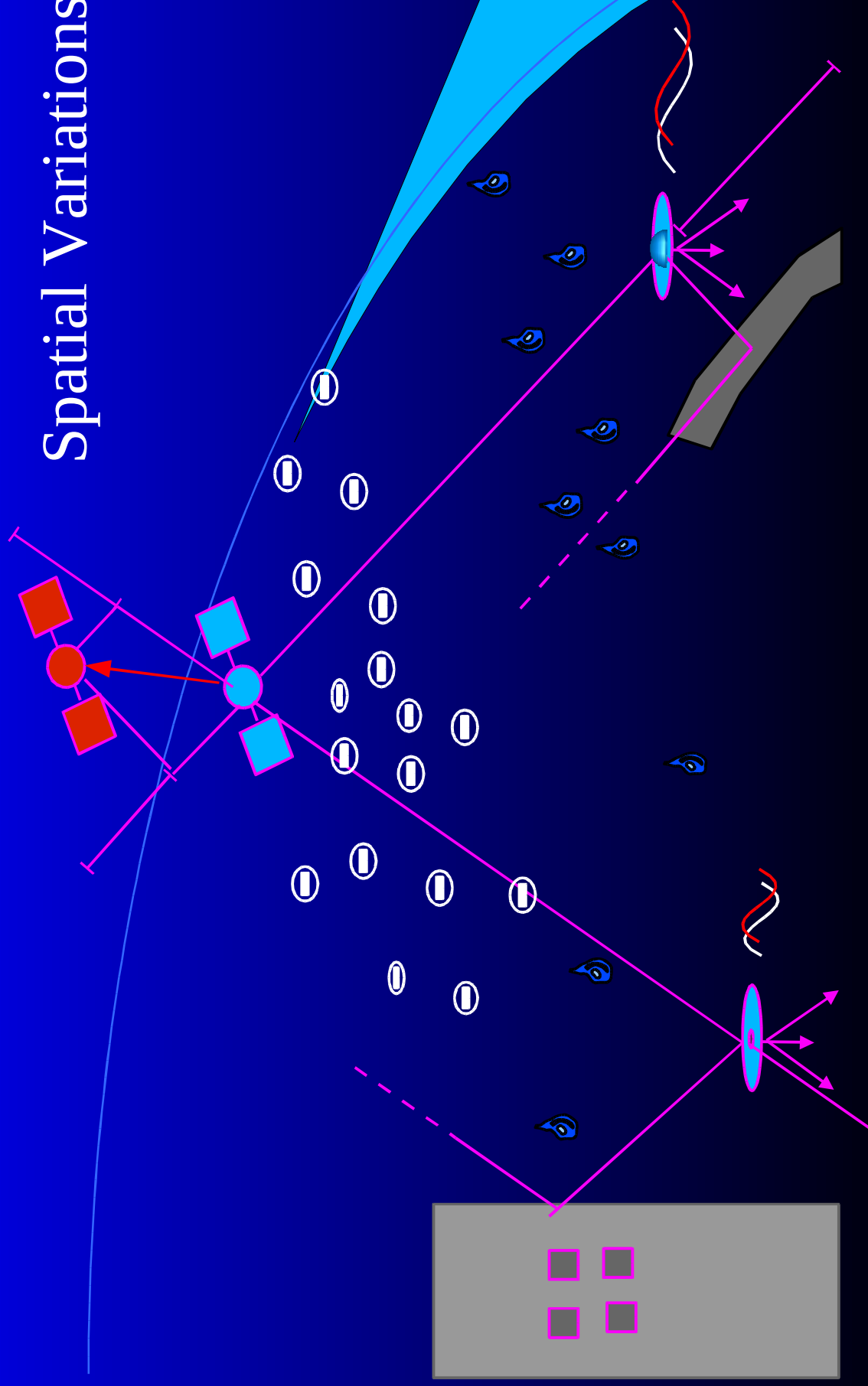
GNSS Accuracy

$$\sigma_p = PDOP * \sigma_l$$

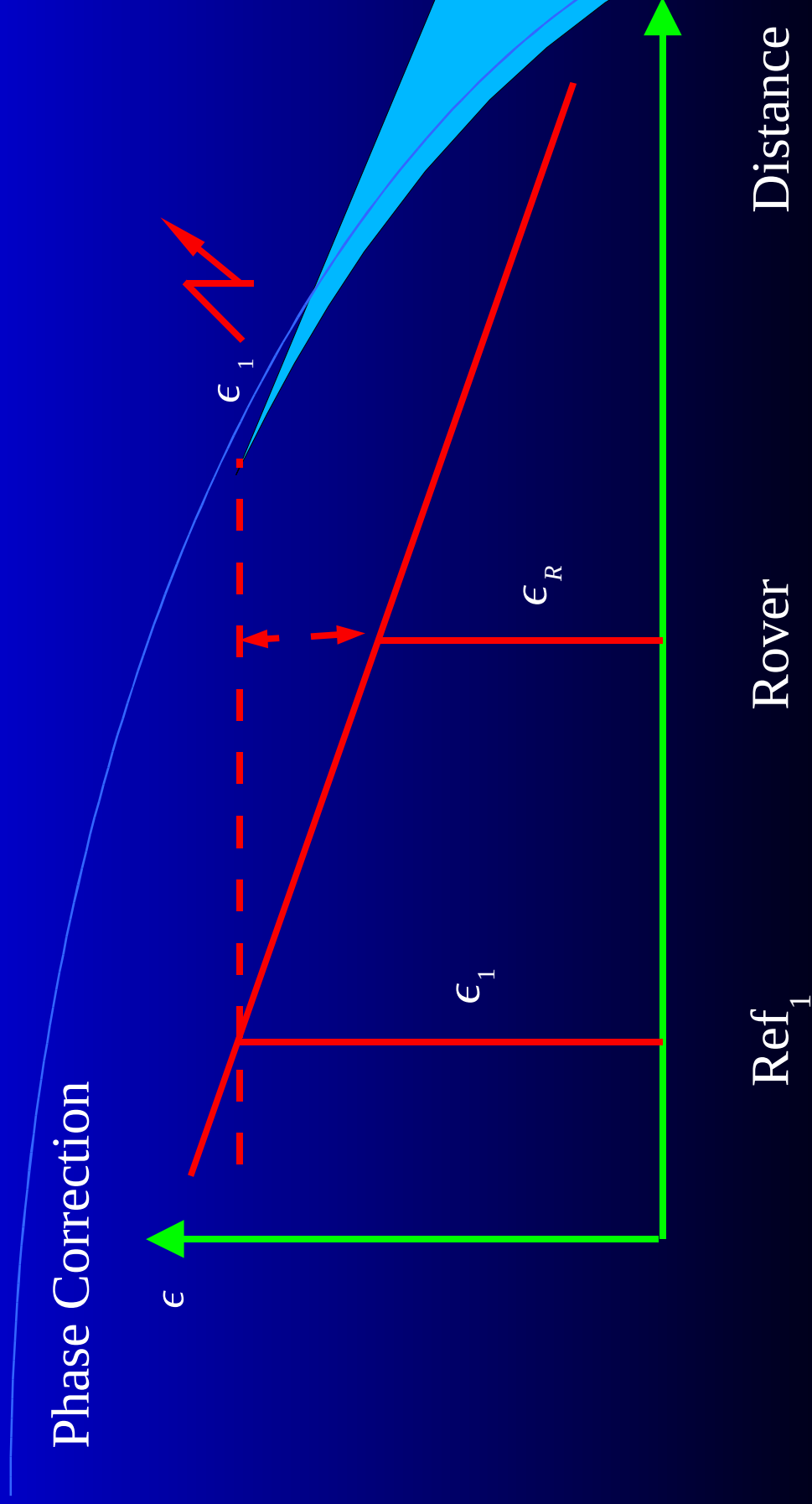
- PDOP = 2 – 3
- position accuracy (RTK): 2–3 cm
- the **Sum of all errors** must be determined with statistical accuracy of 1 cm !
- Problem: **distance dependency** !

GNSS Error Sources

Spatial Variations



Distance Dependency



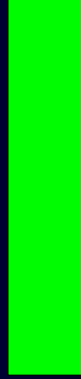
GNSS Error Budget

$$\sigma_p = PDOP * \sigma_l$$

- relative error influence: 1 ppm
⇒ relative pseudo range error: 1 cm / 10 km
- PDOP = 2 – 3
- Position error of 2–3 cm/10 km
⇒ accuracy of adjacent points: 3–5 cm / 10 km
- 2 independent measurements in 10 km distance to reference station yield to an accuracy of adjacent points of 3–5 cm!

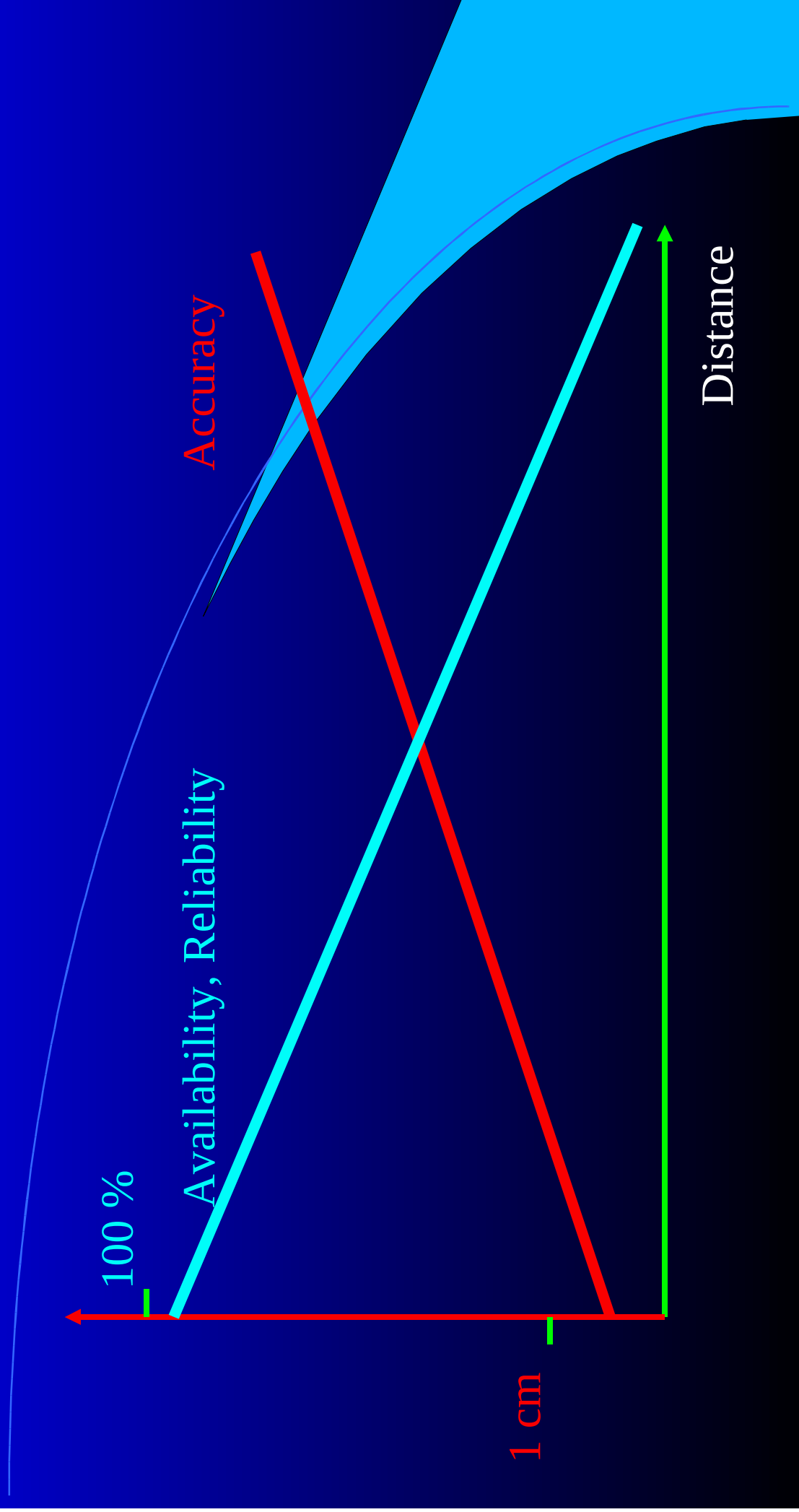
Error Sources Magnitude

Error source	Absolute influence	Relative influence
Satellite Orbit	5 ... 50m	0.2 ... 2 ppm
Satellite Clock	5 ... 100m	0.0 ppm
Ionosphere	0.5 ... >100 m	1 ... 50 ppm
Troposphere	0.01 ... 0.5 m	0 ... 3 ppm
Multipath Code	m	m
Multipath Phase	mm ... cm	mm ... cm
Antenna	mm ... cm	mm ... cm

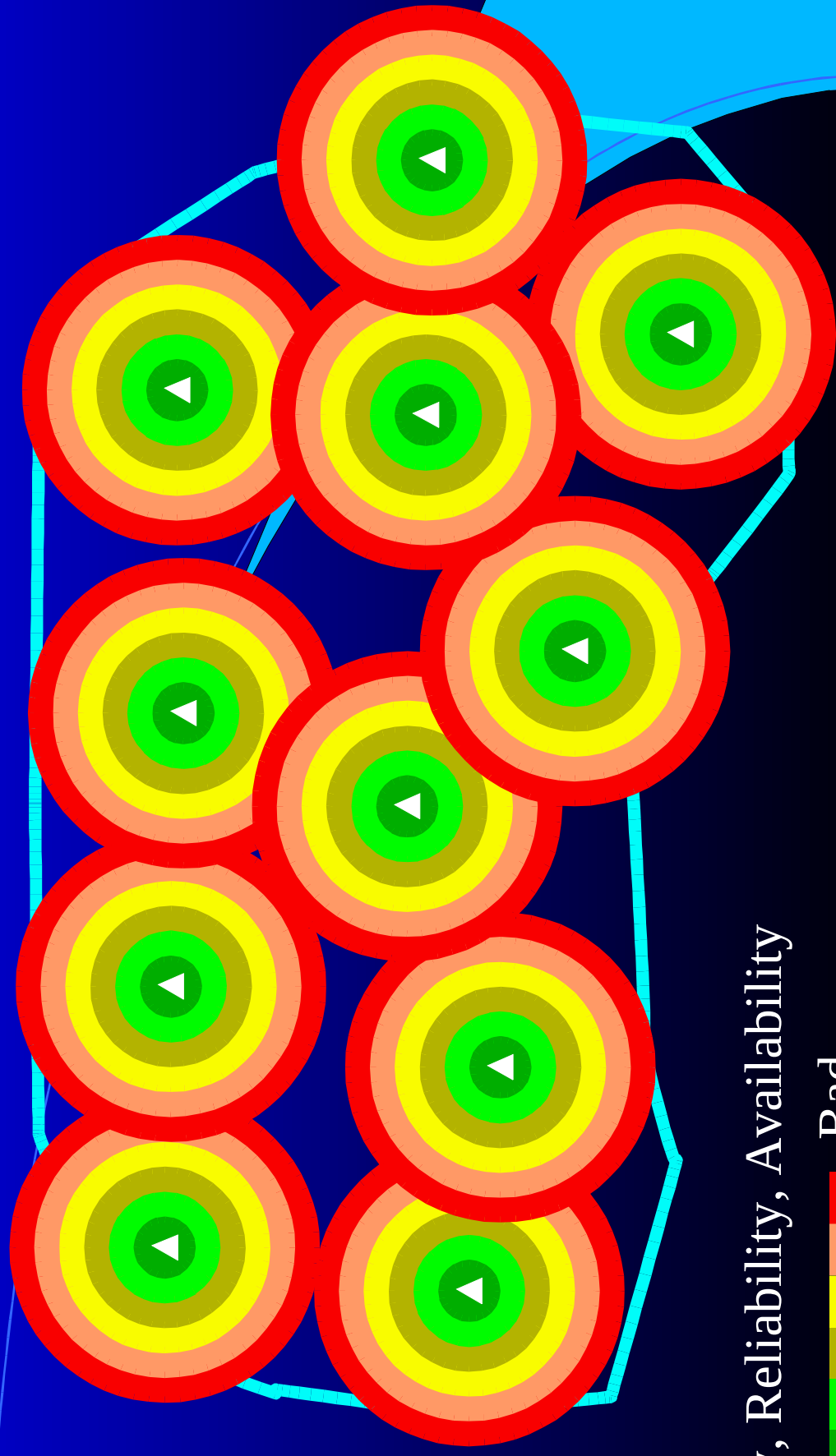
 Determined by GNSS-SMART

 Determined by Calibration rsp. avoid them

RTK: Accuracy, Reliability, Availability



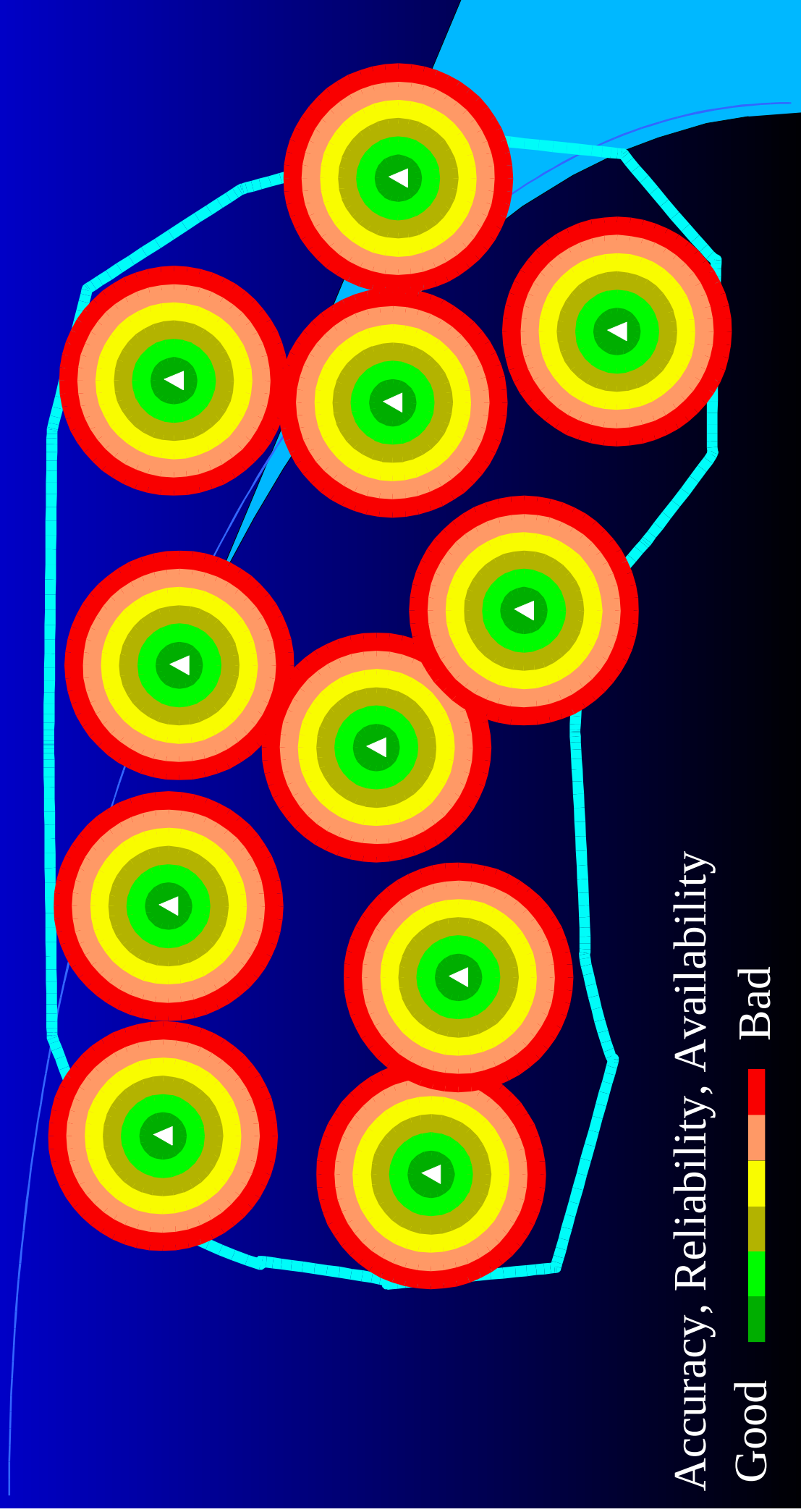
Stand Alone Reference Stations



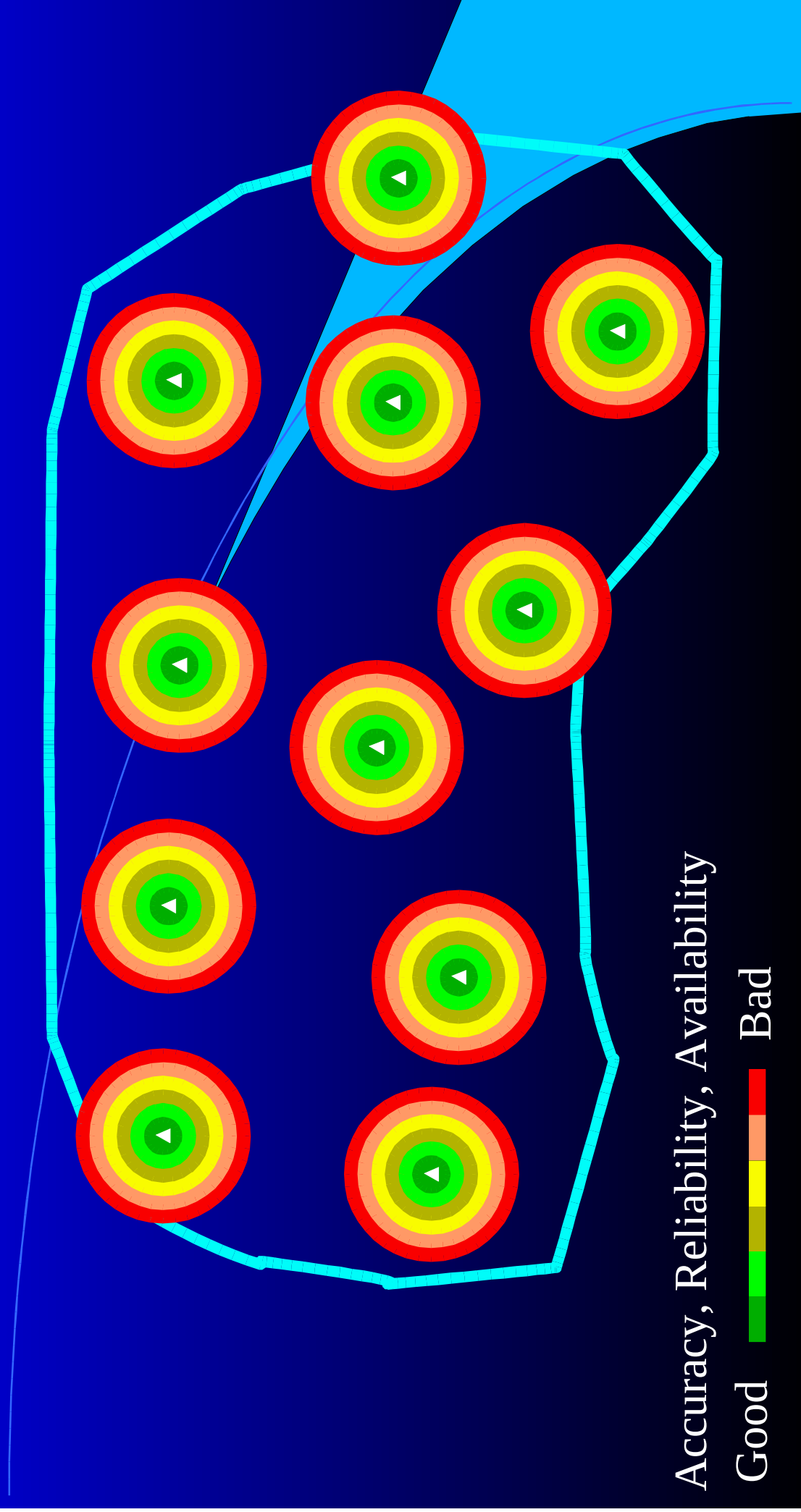
Accuracy, Reliability, Availability

Good    Bad

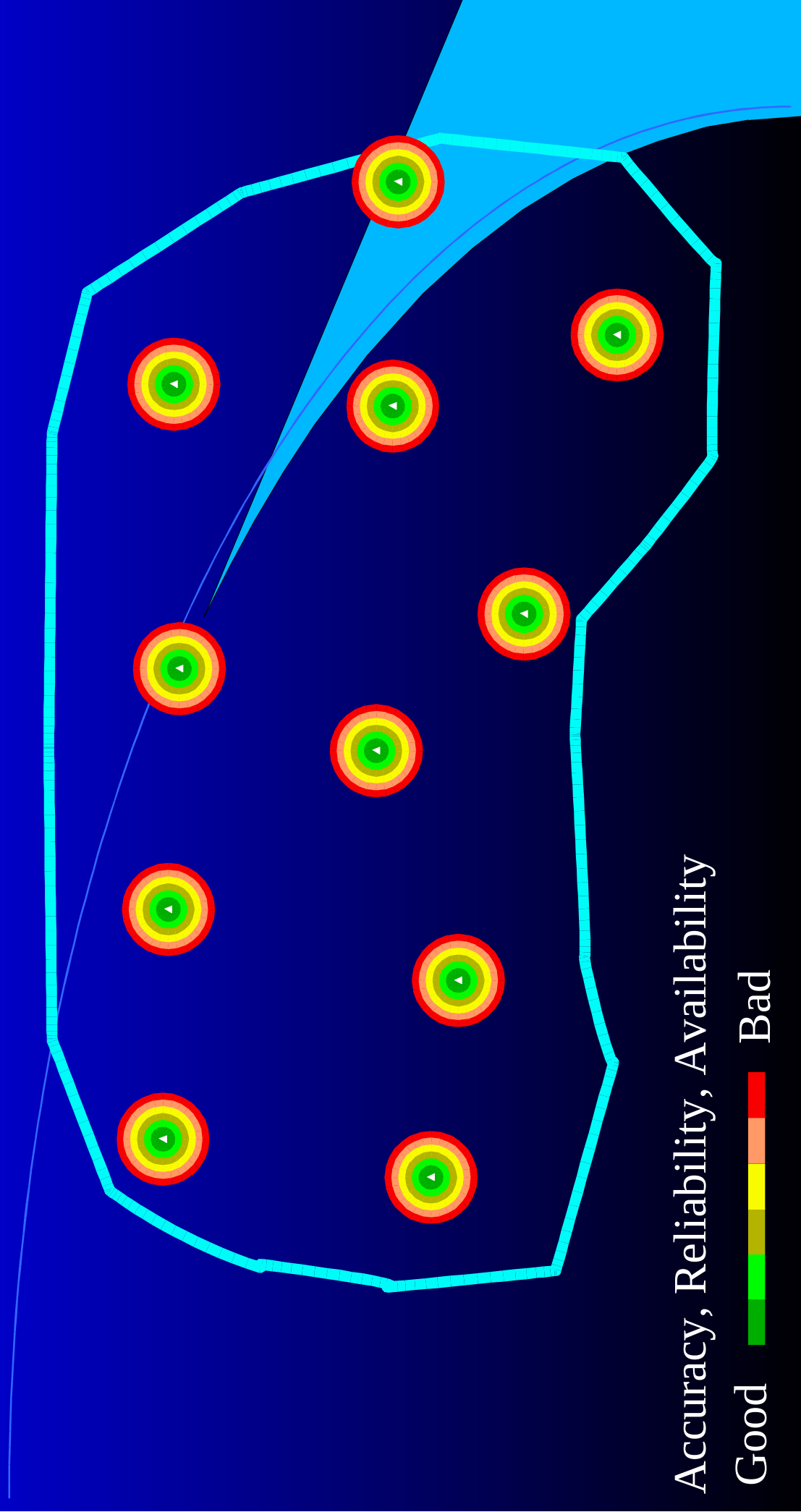
Stand Alone Reference Stations



Stand Alone Reference Stations



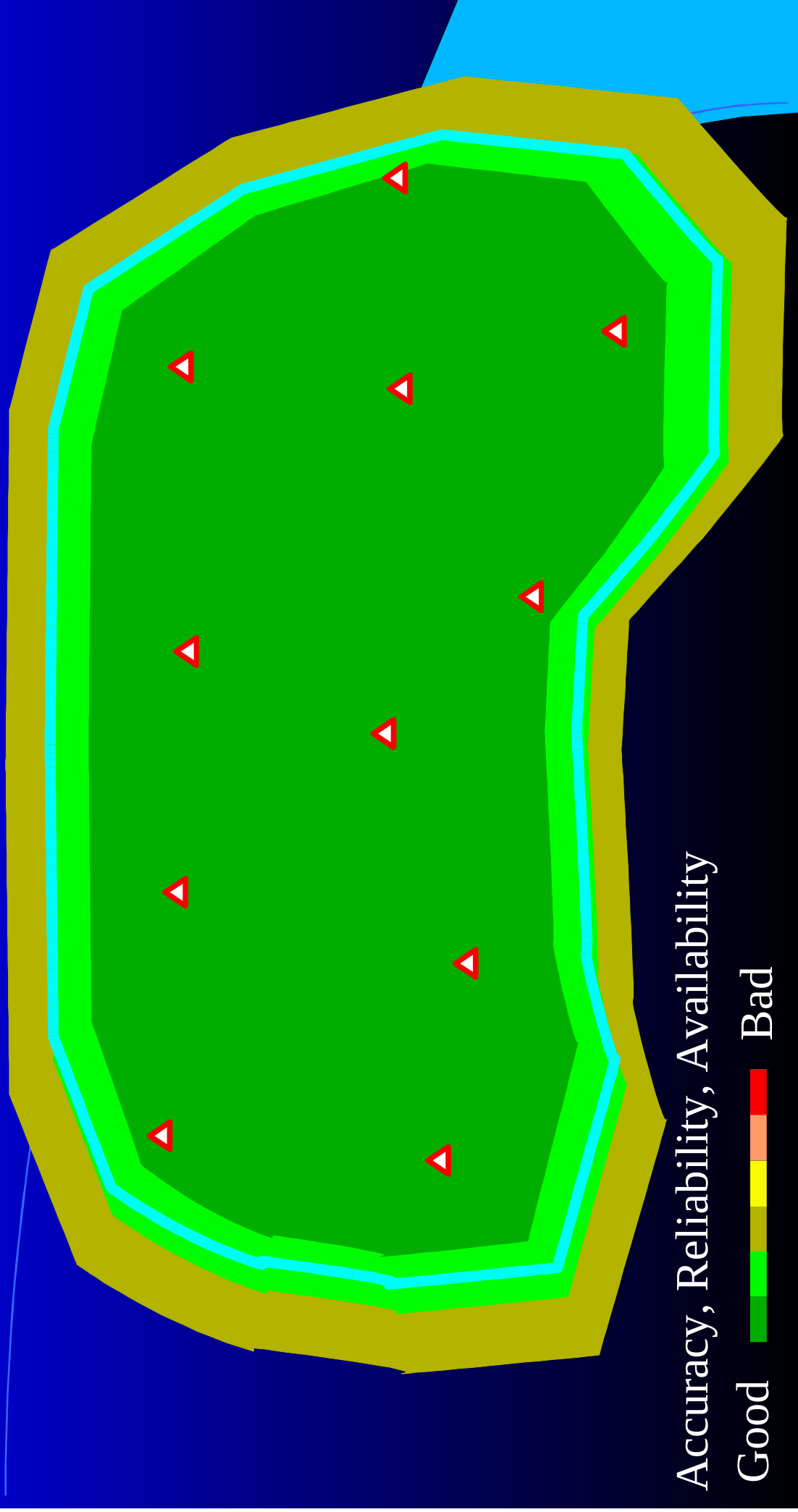
Stand Alone Reference Stations



GNSS-SMART

- **Goal:** RTK with
- everywhere **homogenous** and **high**
 - **Availability**,
 - **Accuracy** and
 - **Reliability**
- **Conditions:**
 - **Determining**,
 - **Modelling** and
 - **Representation**of the distance dependent systematic error sources
- Solution: **GNSS-SMART**

GNSS-SMART Network



GNSS-SMART Components

Sensors

(Reference Stations, Monitor Stations)

Communication

Modelling, State Estimation
(Ambiguity Determination)

State Representation (FKP)

Communication base-rover (RTCM++)

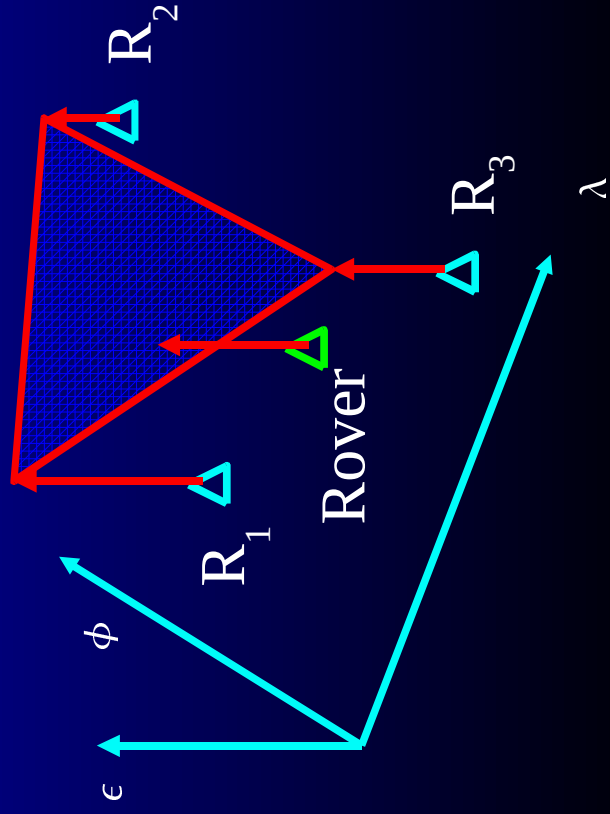
Convert into Standard Format (Decoder)
(RTCM 2.1, Virtual Reference Station)

Modelling, State Estimation

- **Requirement:** reliable and fast ambiguity determination over long distances
 - ⇒ **Multi Station Solution** in real time
- undifferenced observations
- Filter Model (Kalman Filtering)
- **complete dynamic modelling** of system state especially:
 - **satellite orbit**
 - **ionosphere**
 - **troposphere**
- correction of all antennas (PCV calibration)
- optimized Ambiguity Search Algorithms

State Representation

- simple State Model:
- generation of geometric and ionospheric error components (L0, Li)
- representation as plane polynomial (FKP, linear)
- update rate: 10 – 30 seconds
- optimized for low bandwidth

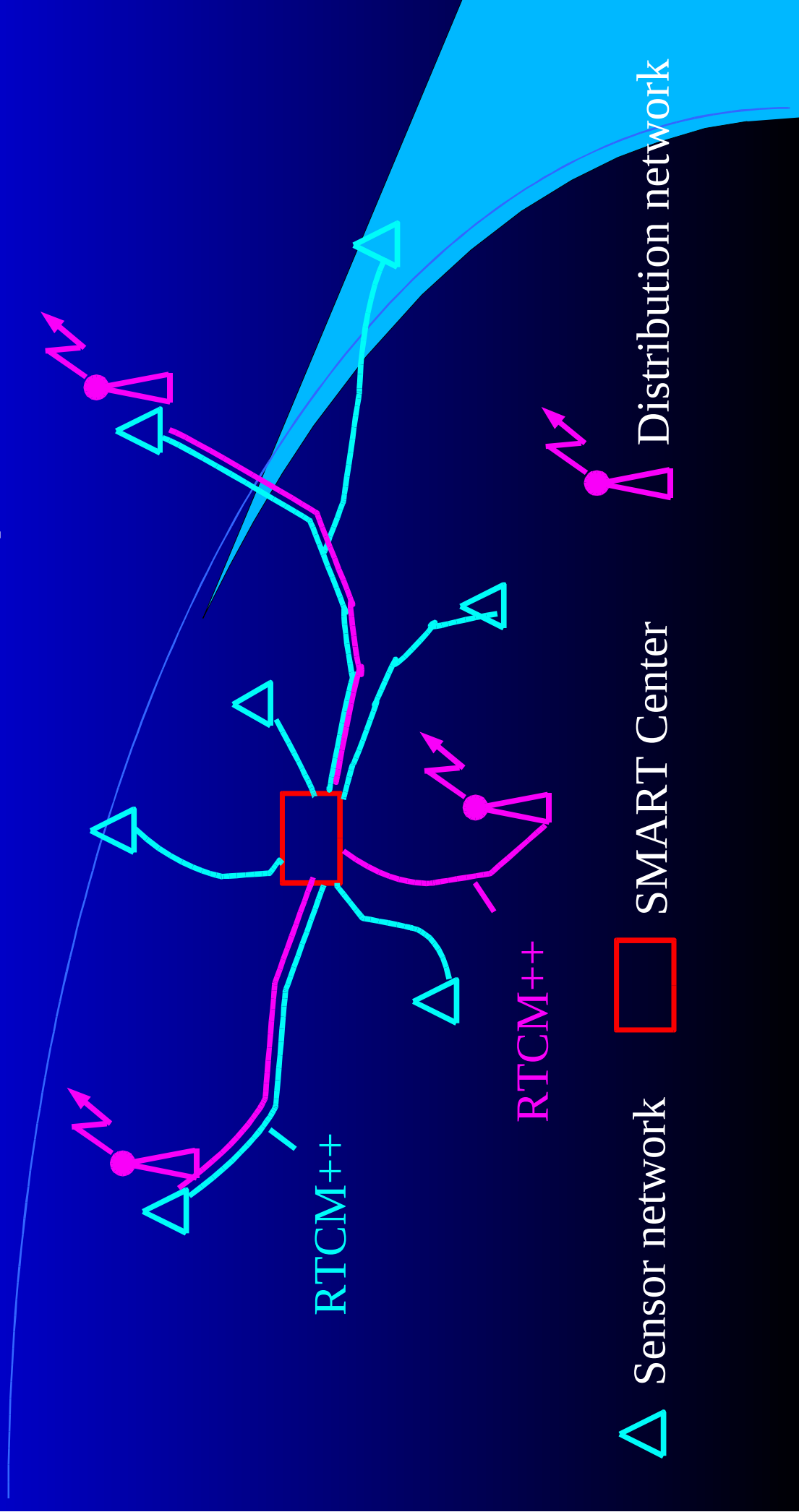


GNSS-SMART Data Format

- **Requirements**
 - medium: bandwidth
 - model: phase corrections (not raw observations)
 - user: international standard
- **RTCM++**
 - corrections
 - compression
 - encryption
 - FKP
- **RTCM-2.1**
 - international standard
 - phase/code corrections (message type 20/21)

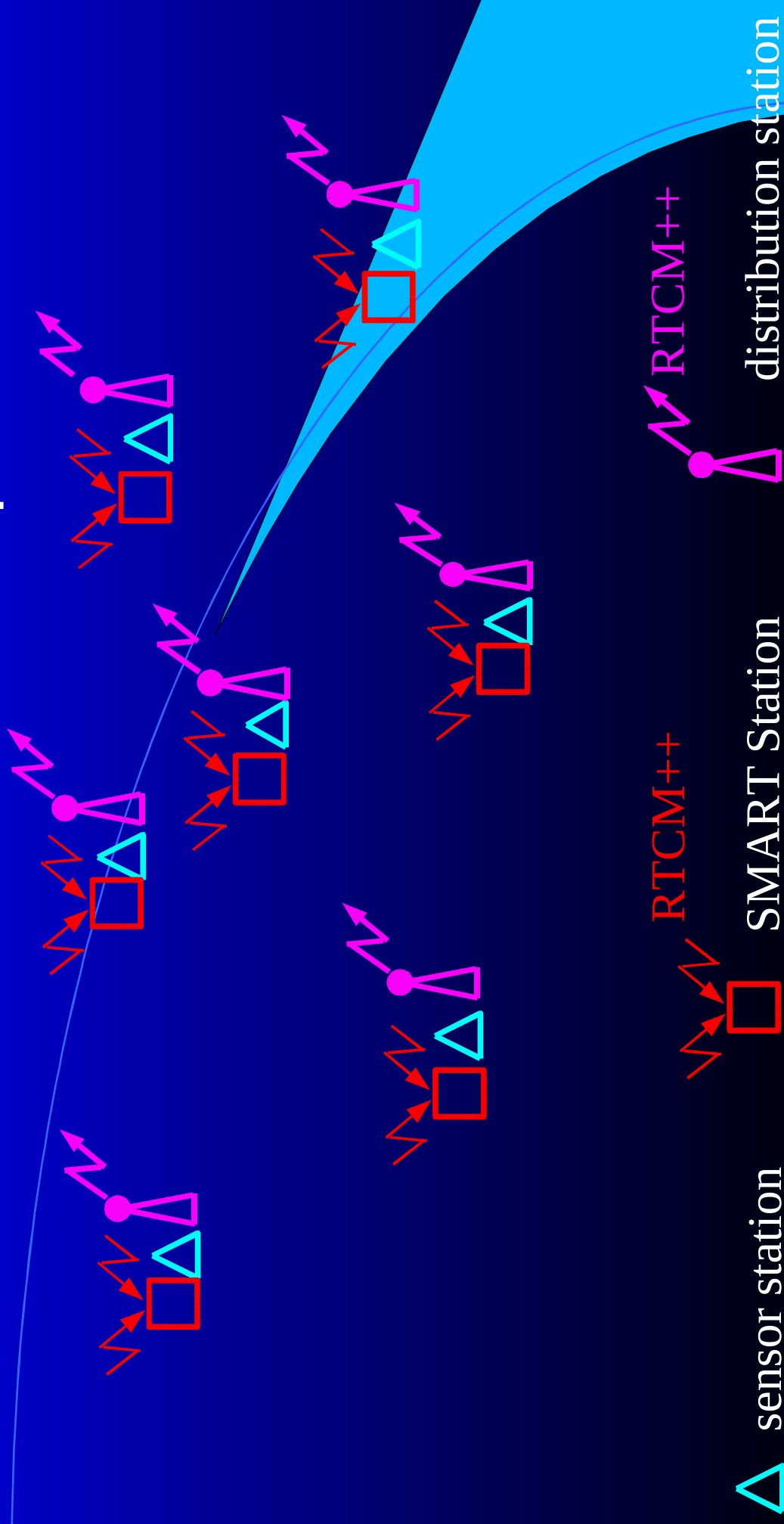
GNSS-SMART System Design

Central Concept



GNSS-SMART System Design

Decentral Concept



GNSS-SMART User View

