GNSS Network-RTK Today and in the Future Concepts and RTCM Standards

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GNSS Basic Principle

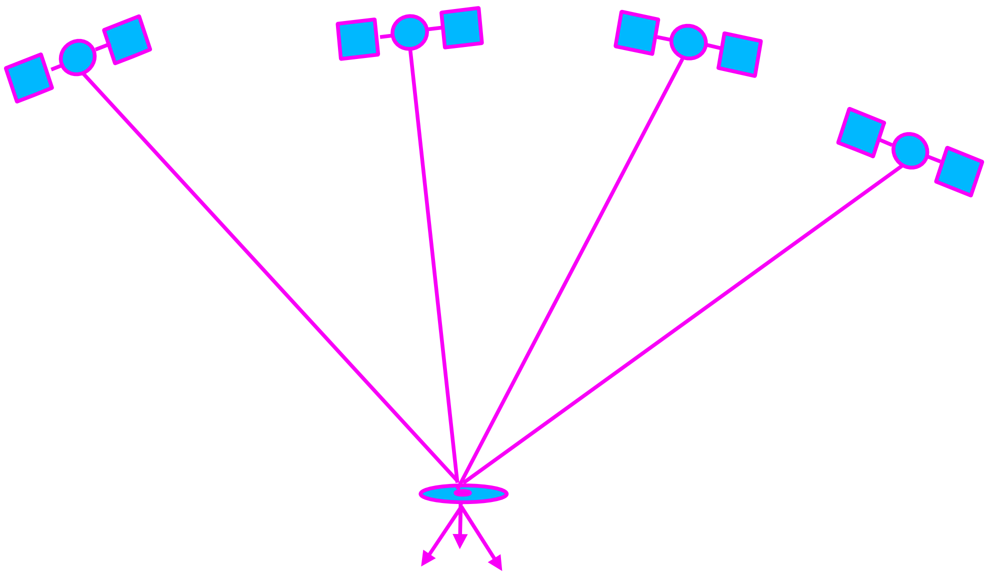
GNSS Basic Principle

- Position Determination of a single ("Stand-Alone") GNSS Antenna
- Determine Position and Receiver Clock from
  - 4 or more Pseudoranges

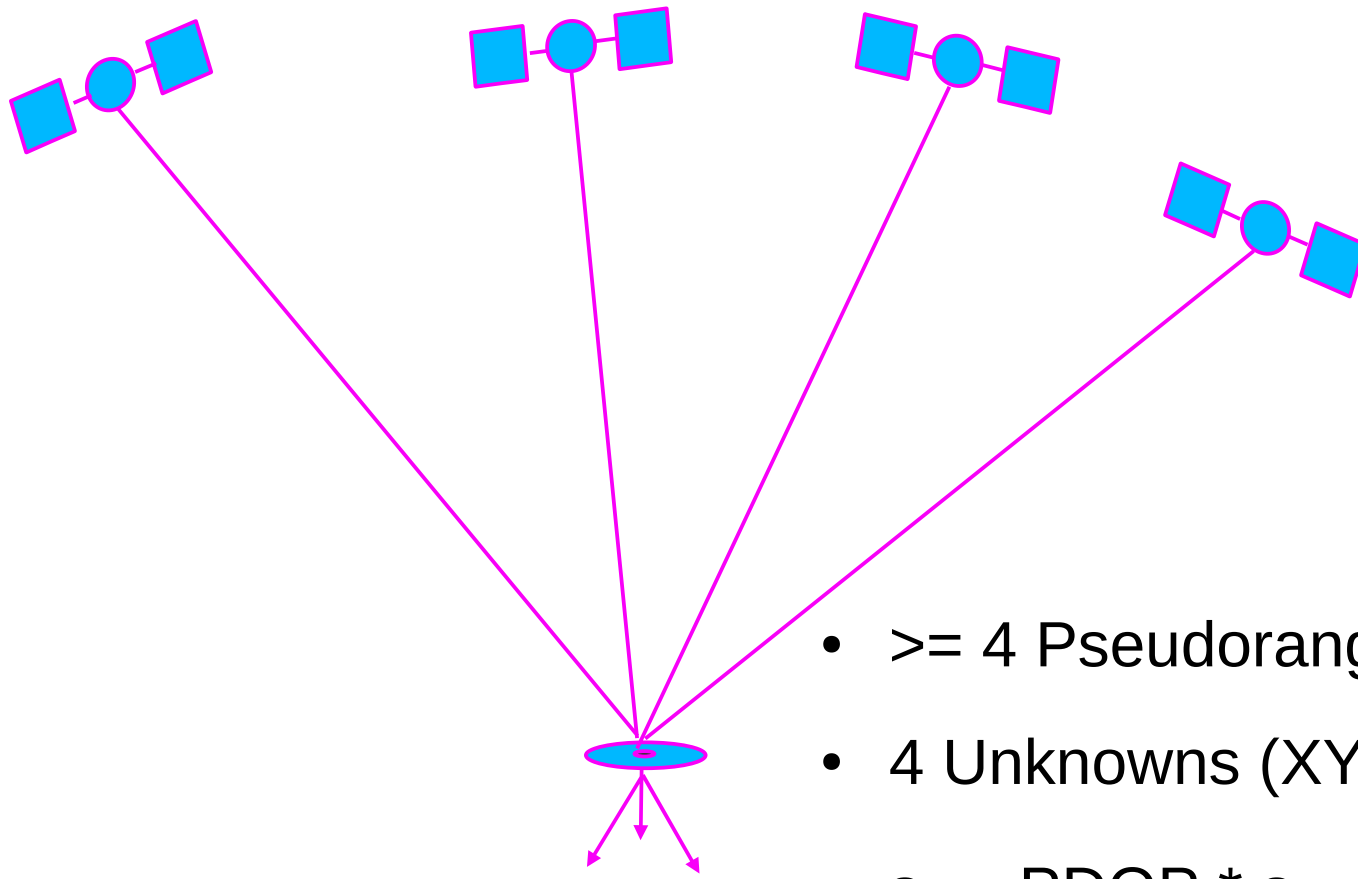
    or Carrier Phase Observables
- Position Accuracy

  = PDOP * Range Accuracy

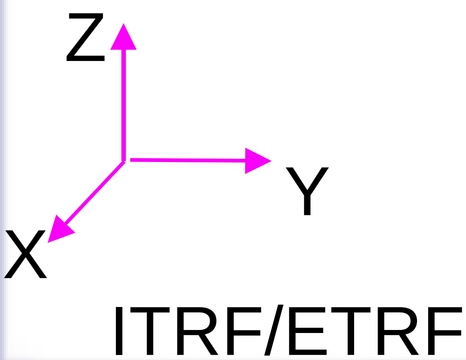
  $s_P = PDOP * s_R$
  - good PDOP = 1-2
- s_R contains all Error Influences
- cm or dm accurate Positioning requires
  - precise Observations (Code / Carrier phase)
  - precise Knowledge of all Error Influences



GNSS Basic Principle



- >= 4 Pseudoranges
- 4 Unknowns (XYZ,t)
- s_P = PDOP * s_R



GNSS Error Sources

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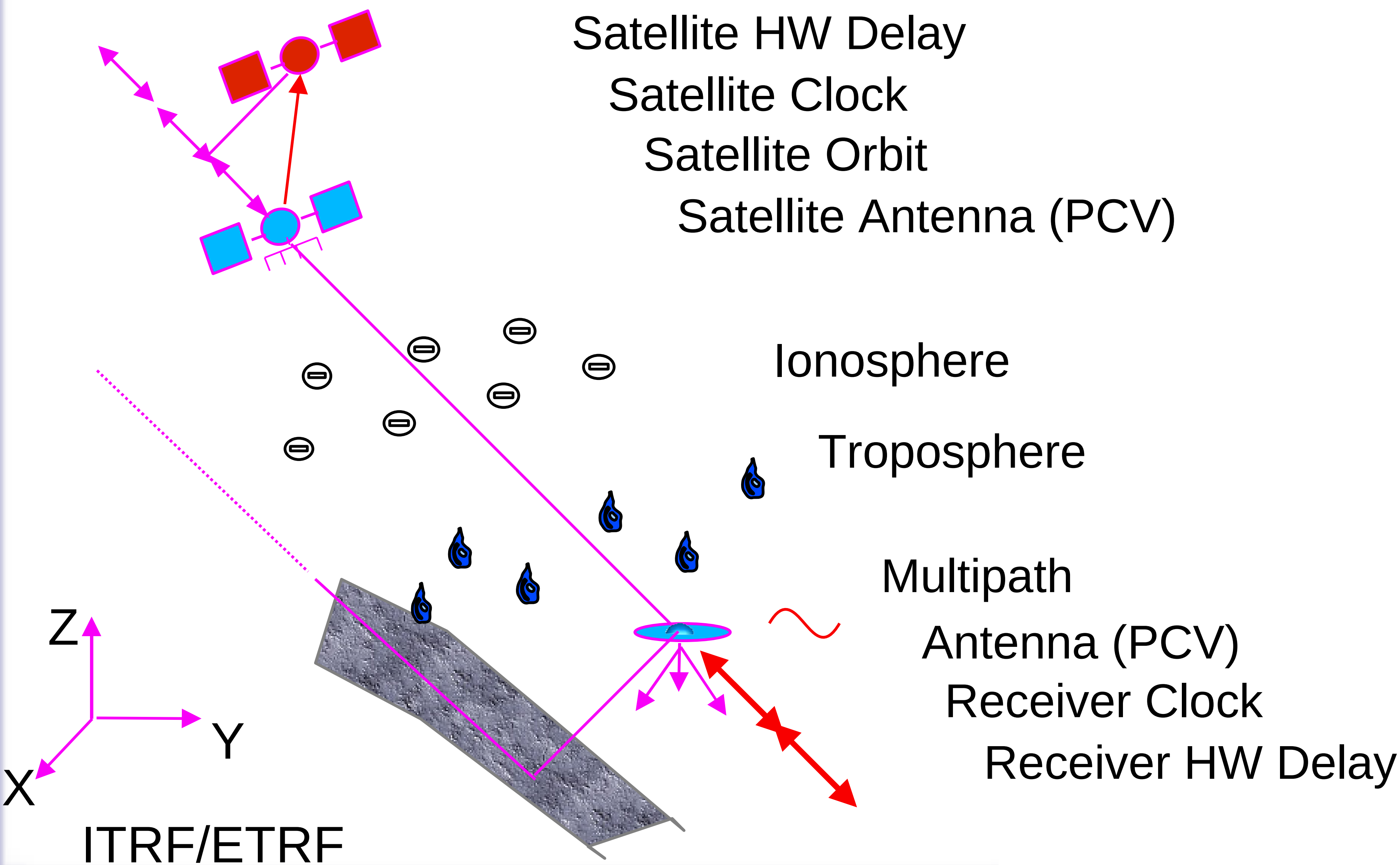

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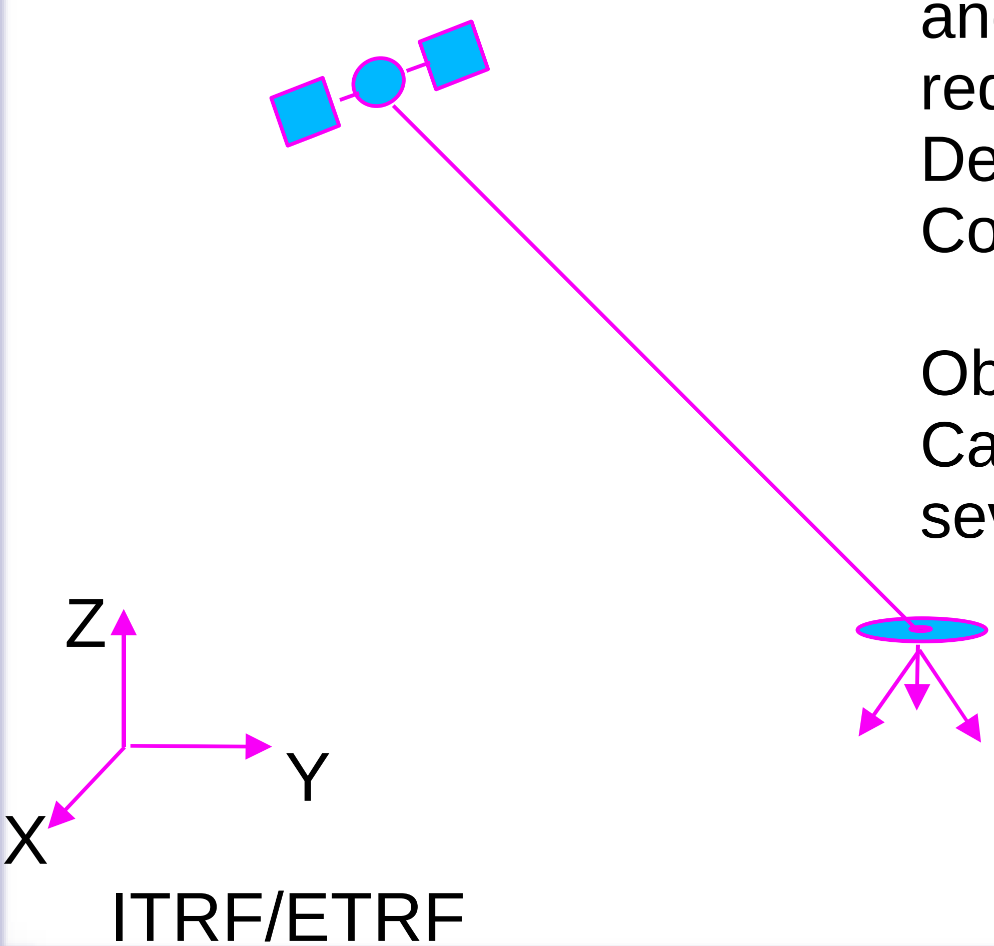
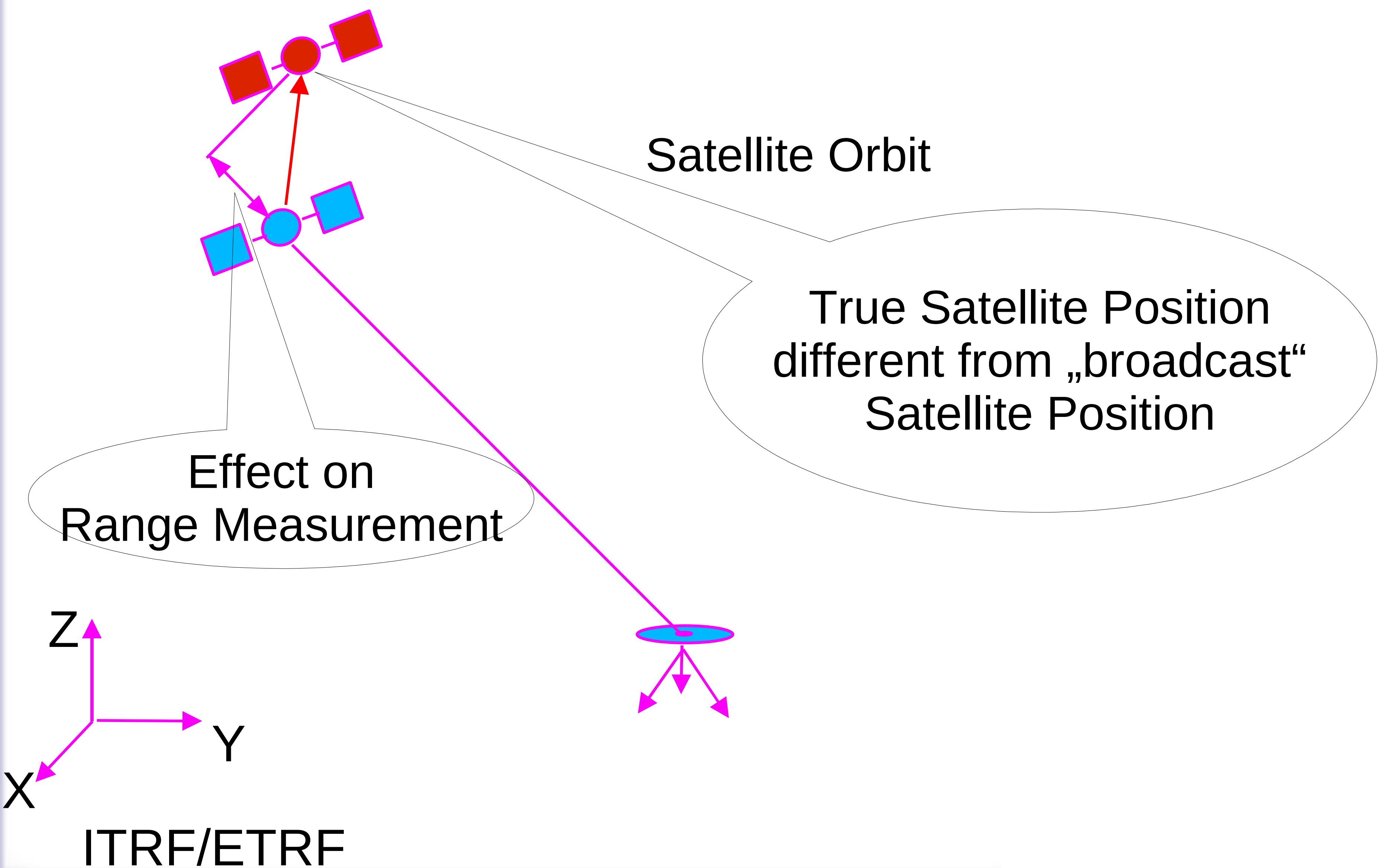


Geometric Distance between „Broadcast“ Satellite Position and Receiving Antenna required for Position Determination in a Global Coordinate Reference System.

Observed Pseudoranges and Carrier Phases are effected by several error components

GNSS Error Sources



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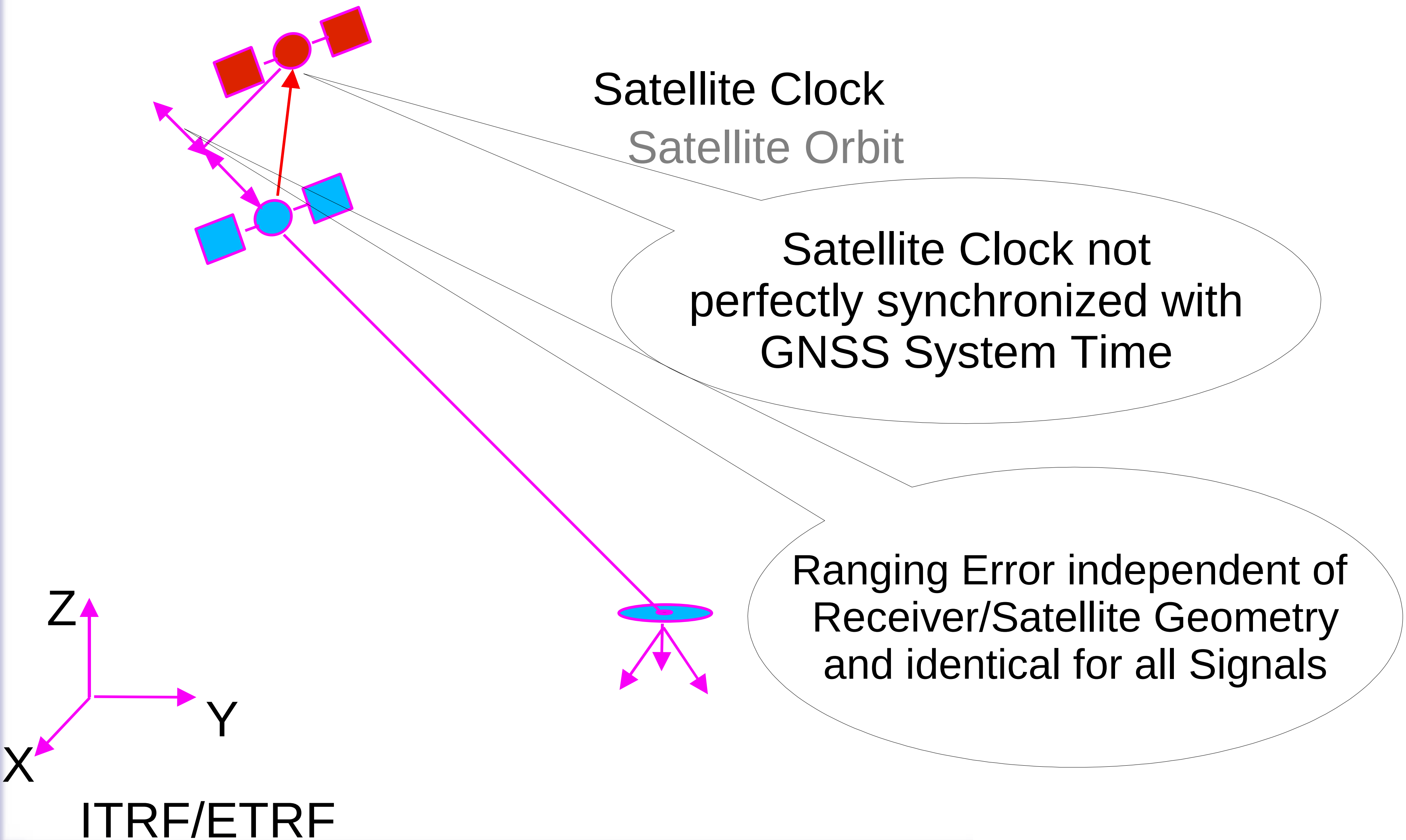
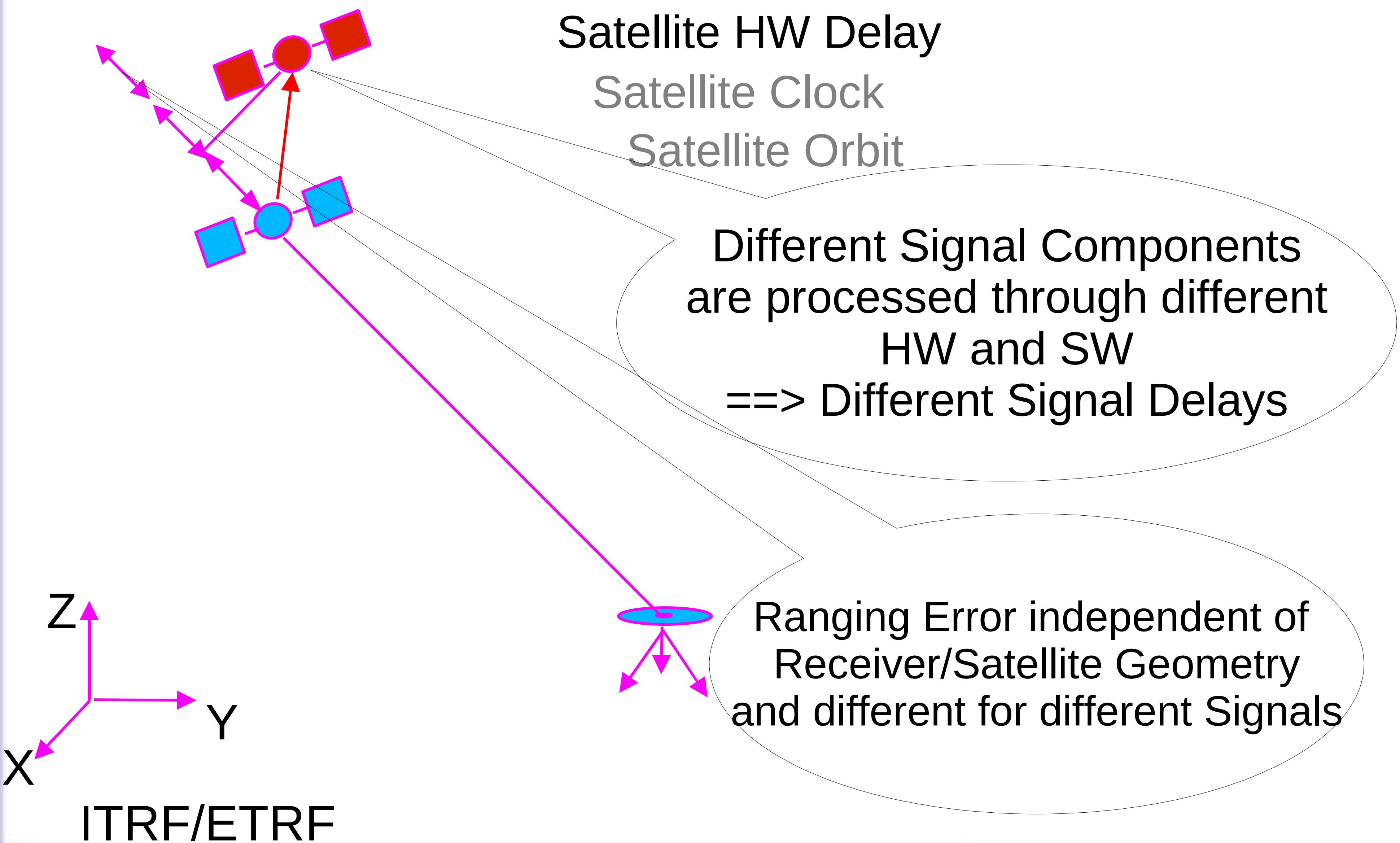


GNSS Error Sources



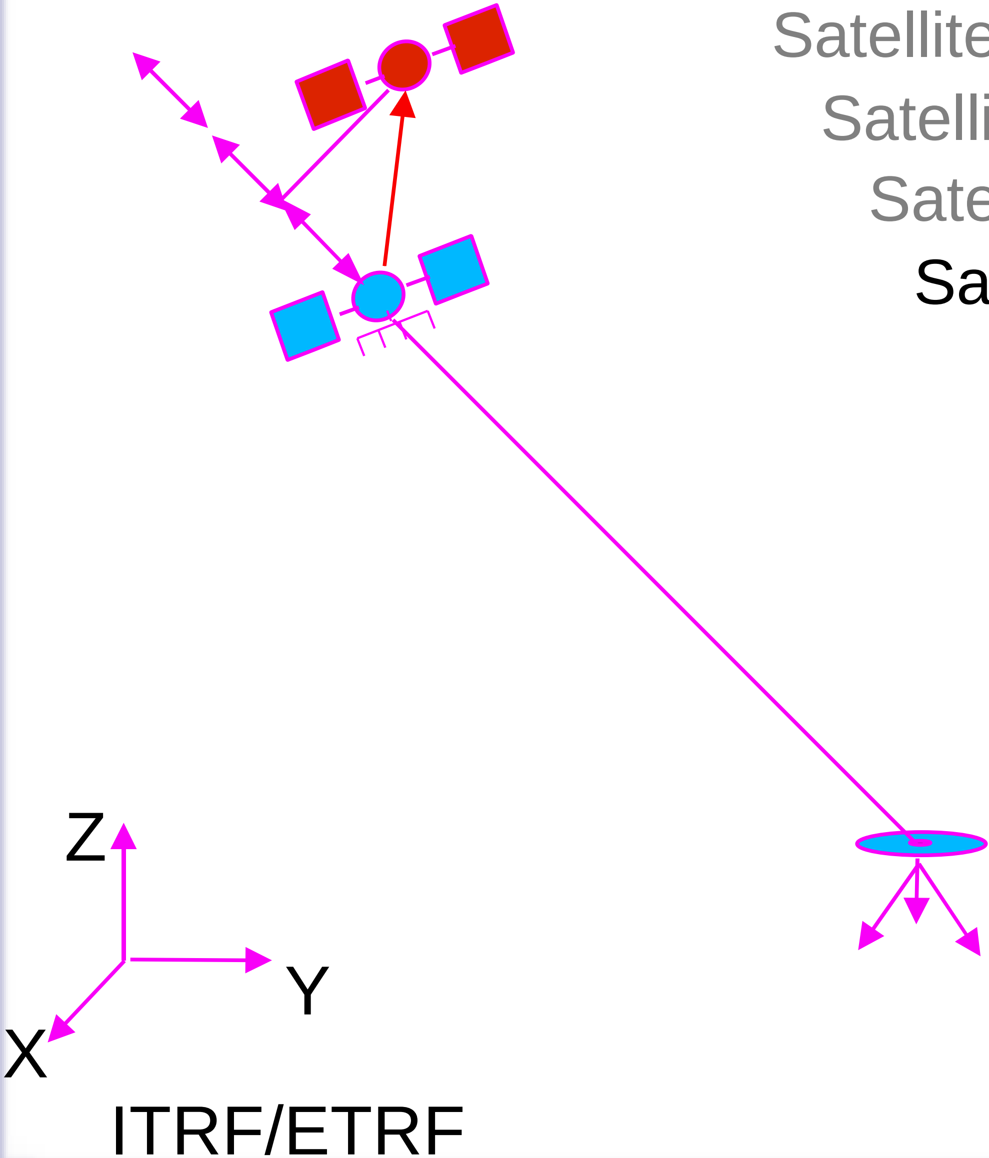
GNSS Error Sources

Satellite HW Delay

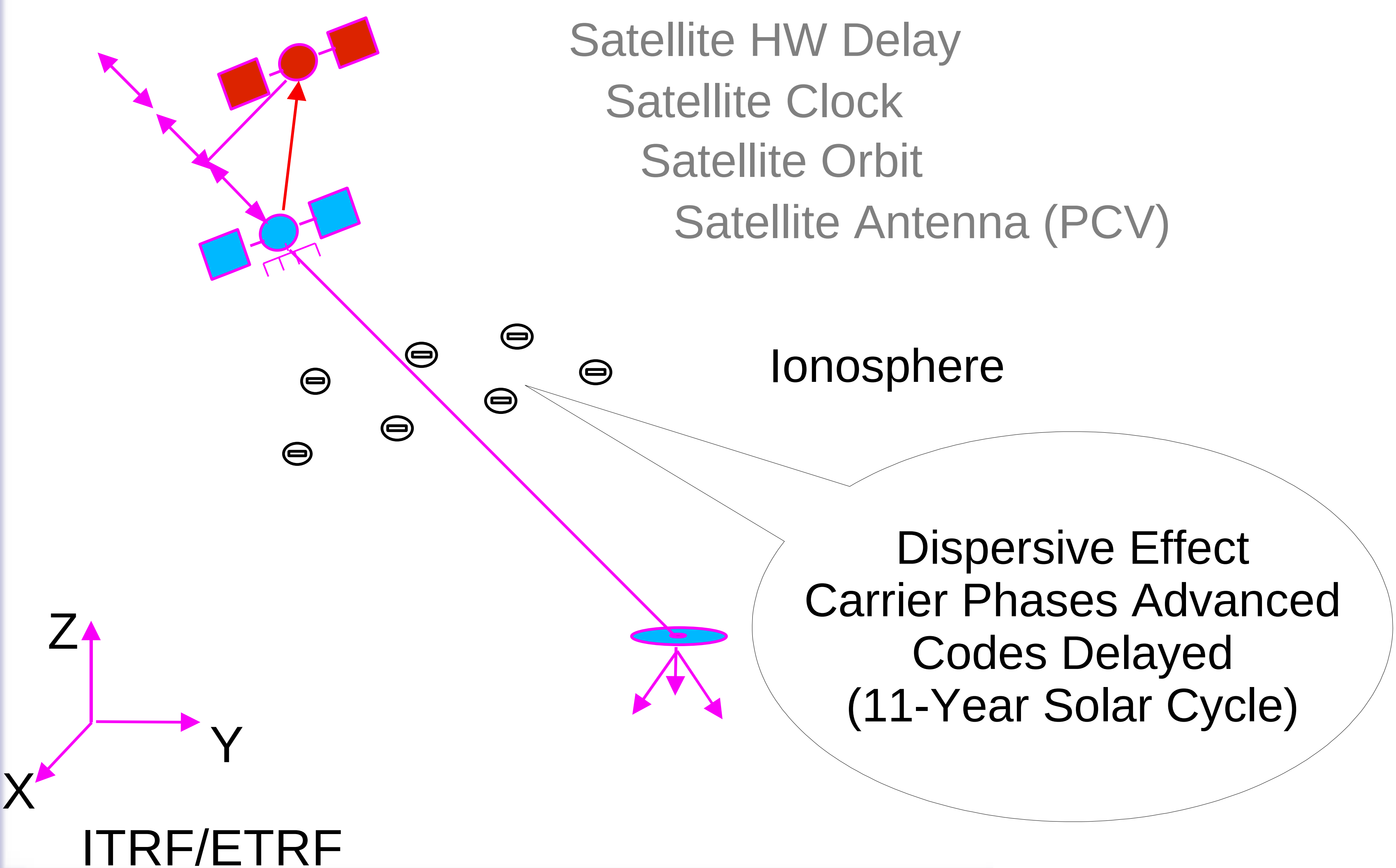
Satellite Clock

Satellite Orbit

Satellite Antenna (PCV)



GNSS Error Sources



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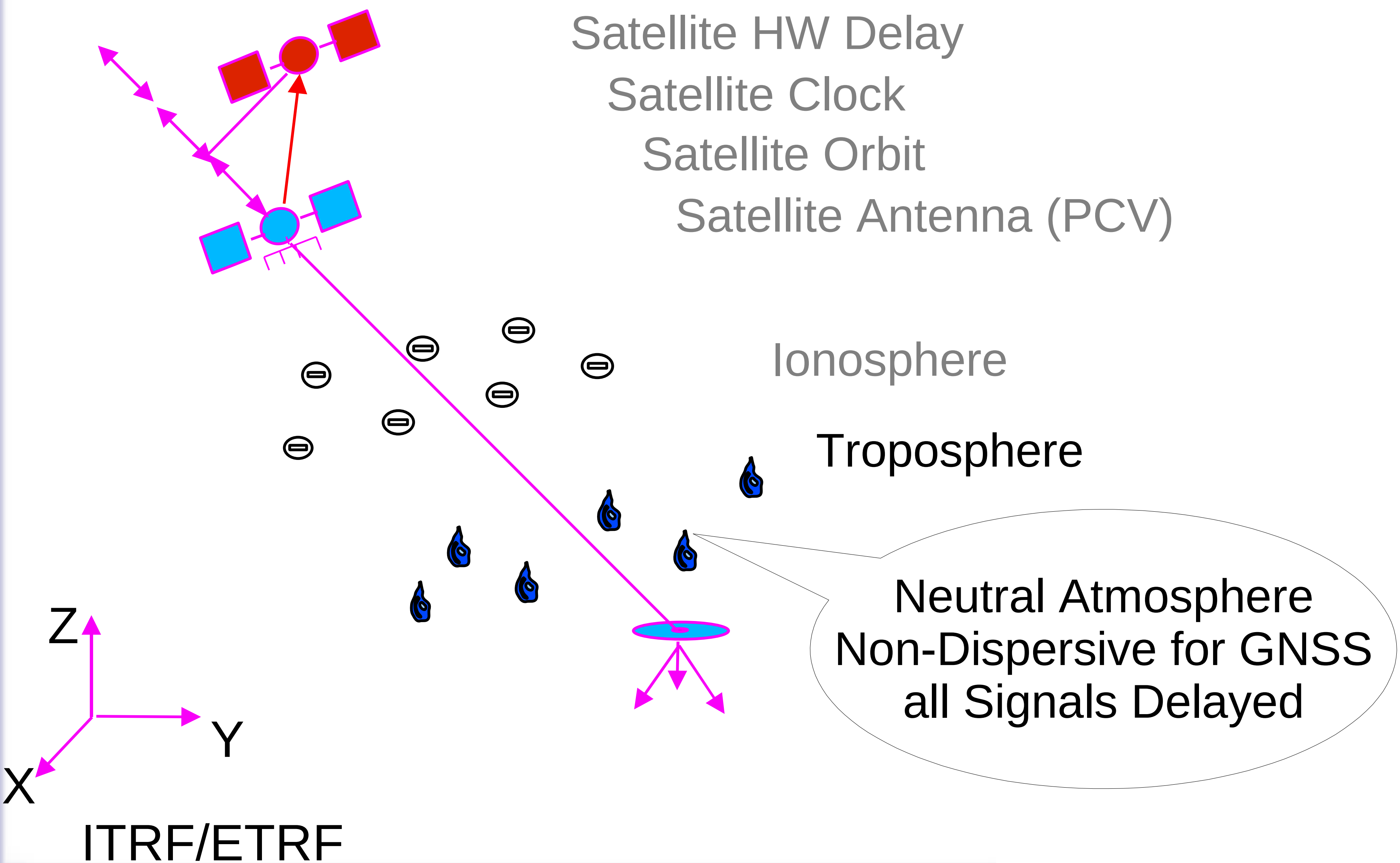
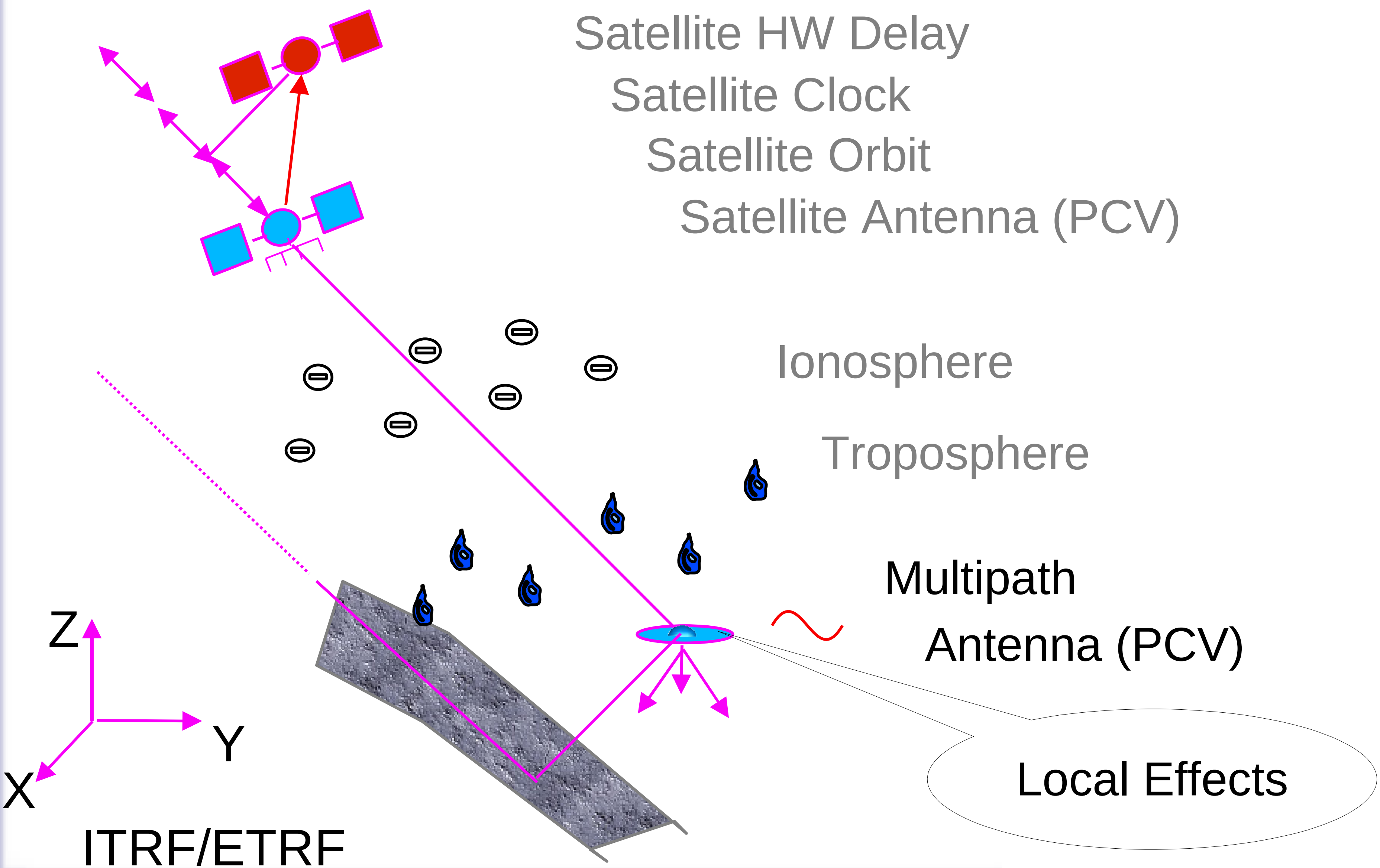
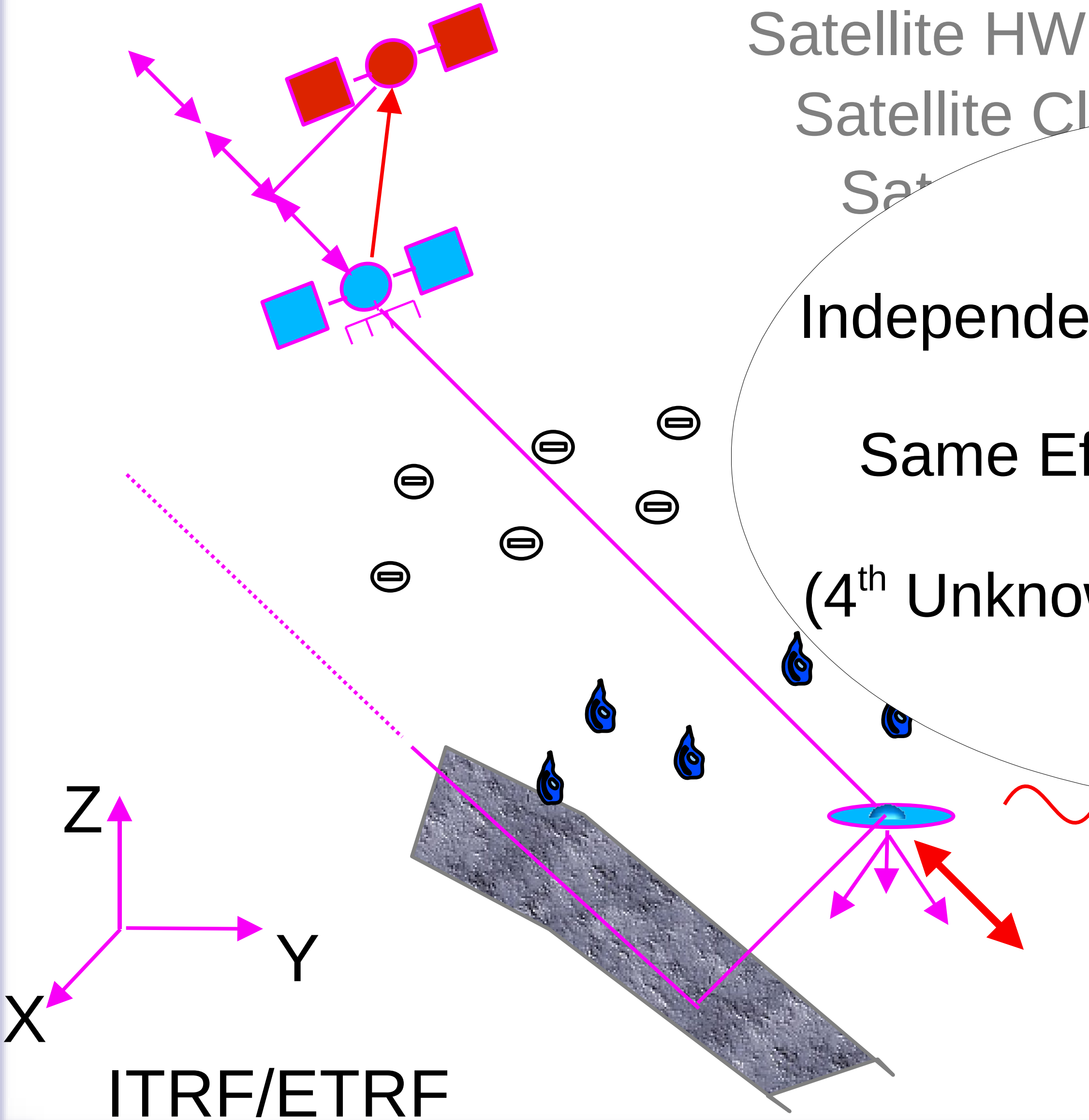


GNSS Error Sources



GNSS Error Sources



Satellite HW Delay

Satellite Clock

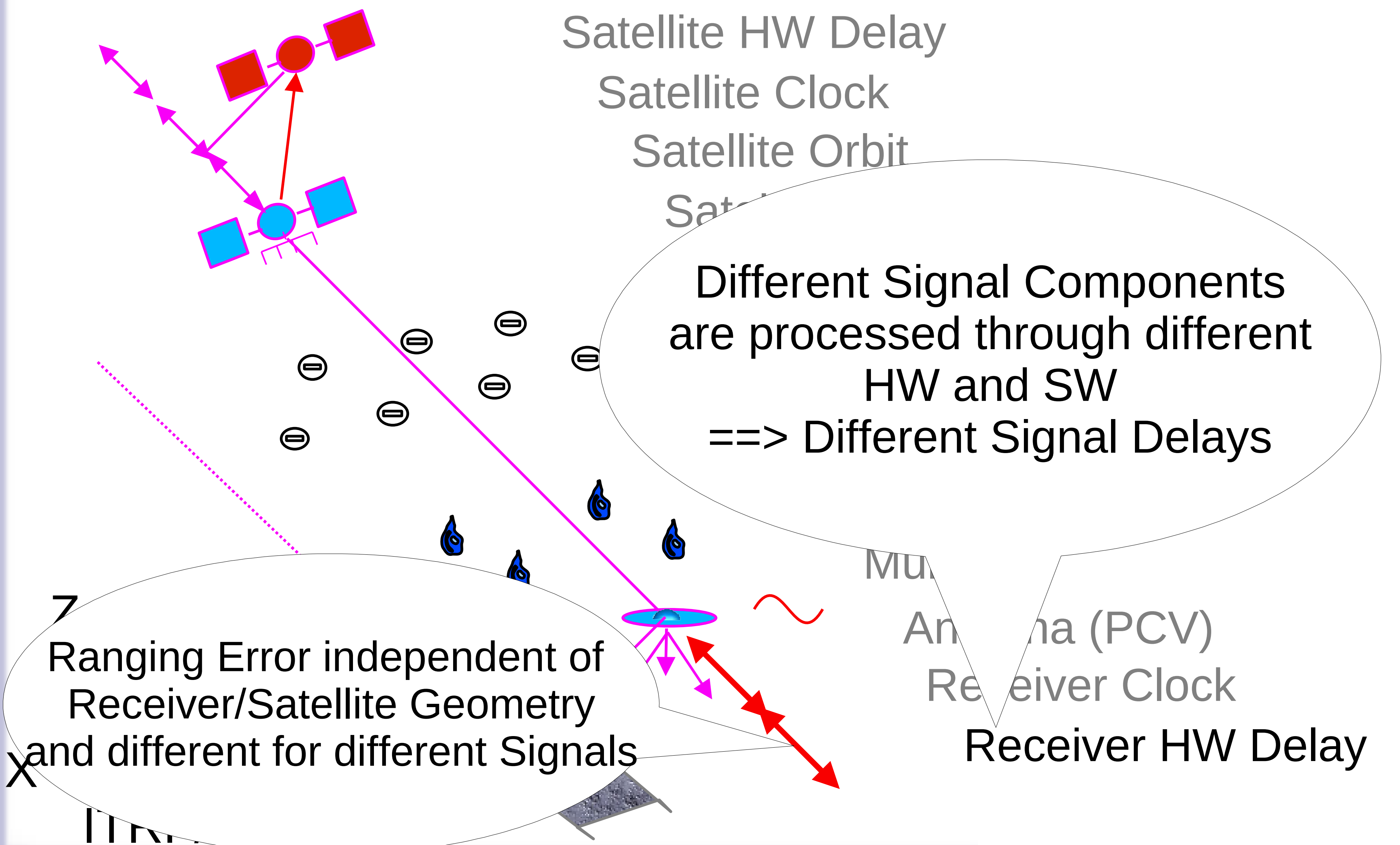
Sat

Independent of Receiver/Satellite Geometry
Same Effect for all Satellites and Signals
(4th Unknown in Basic Operation)

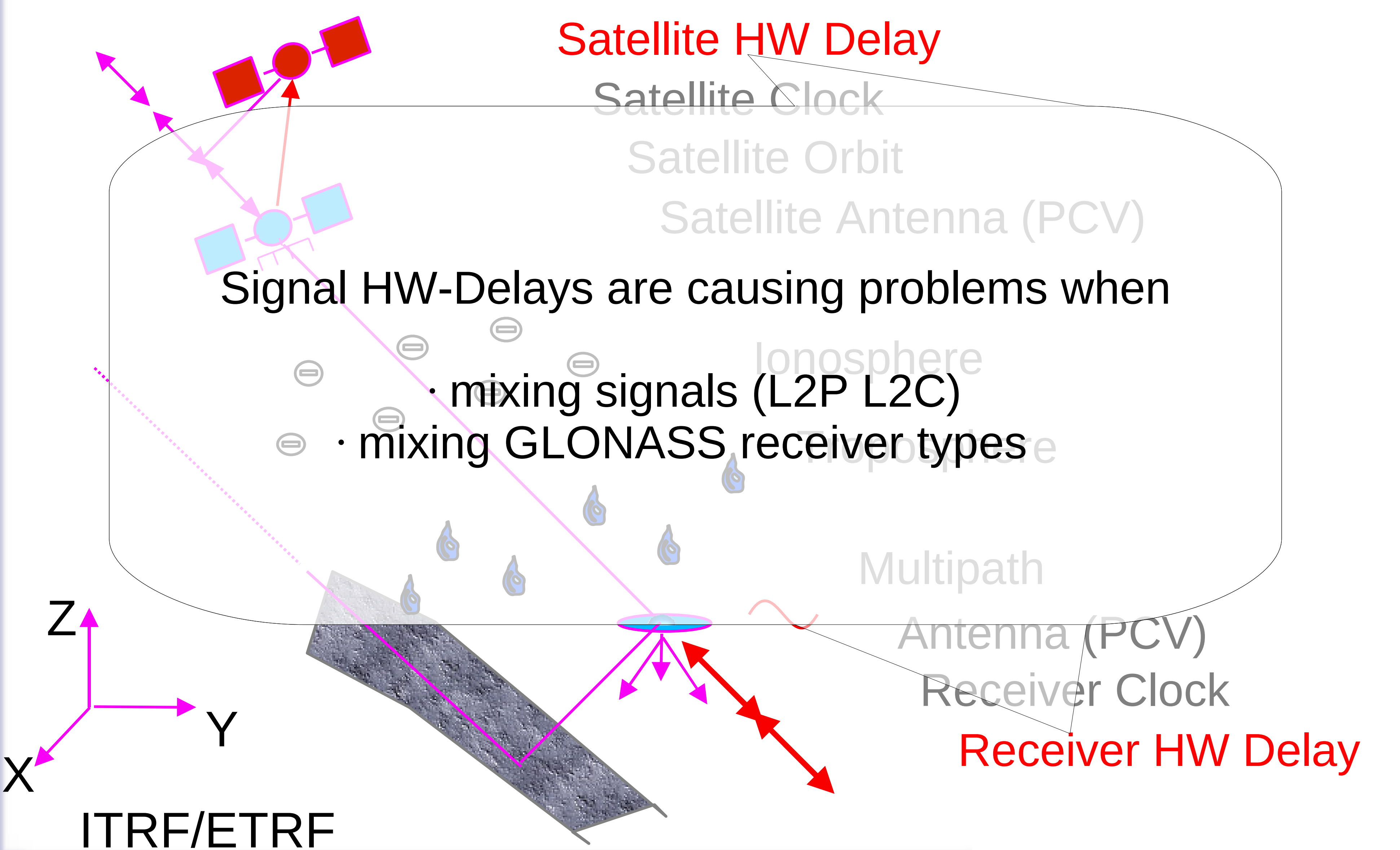
ntenna (PCV)

Receiver Clock

GNSS Error Sources



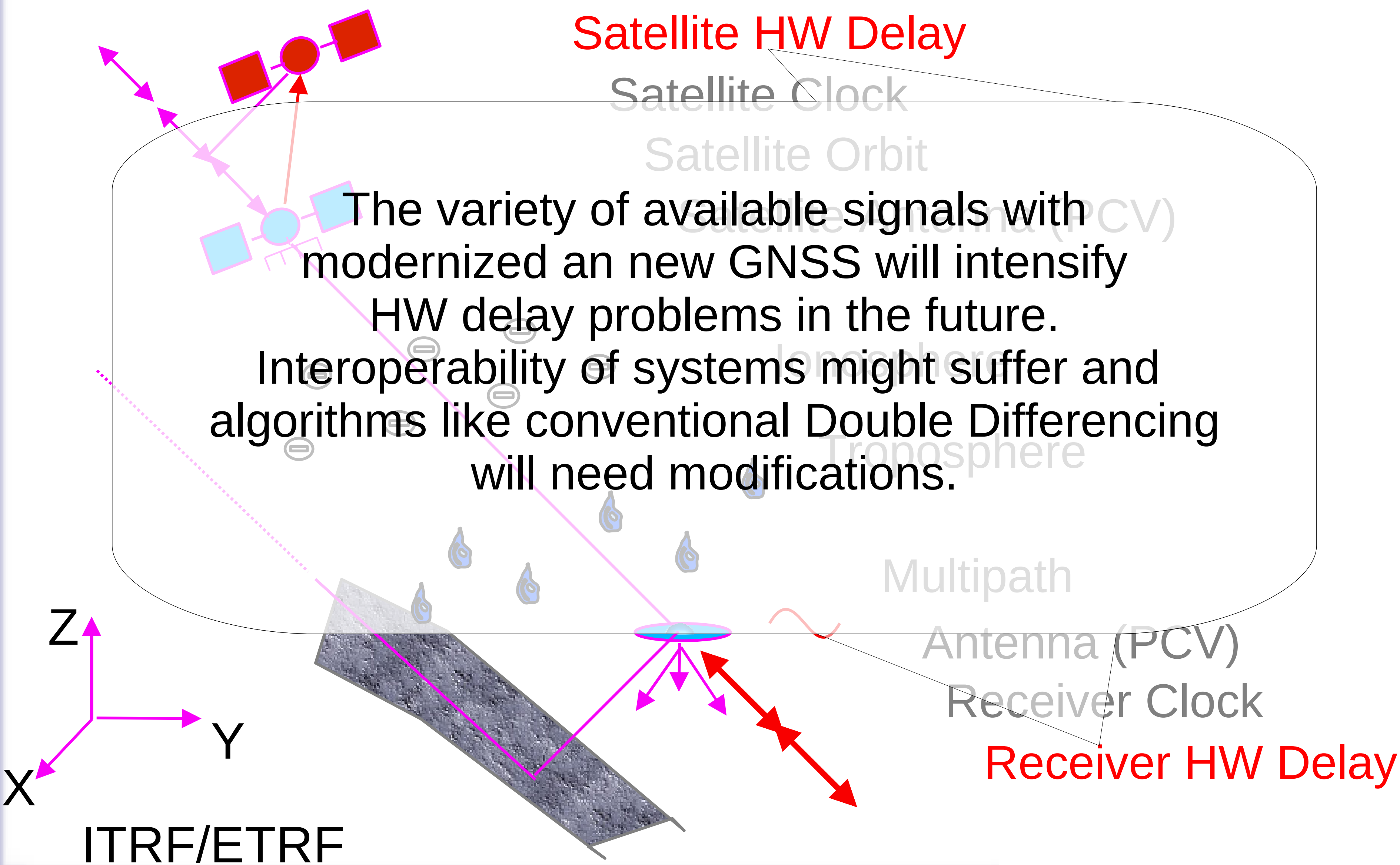
GNSS Error Sources (HW-Delays)



Signal HW-Delays are causing problems when

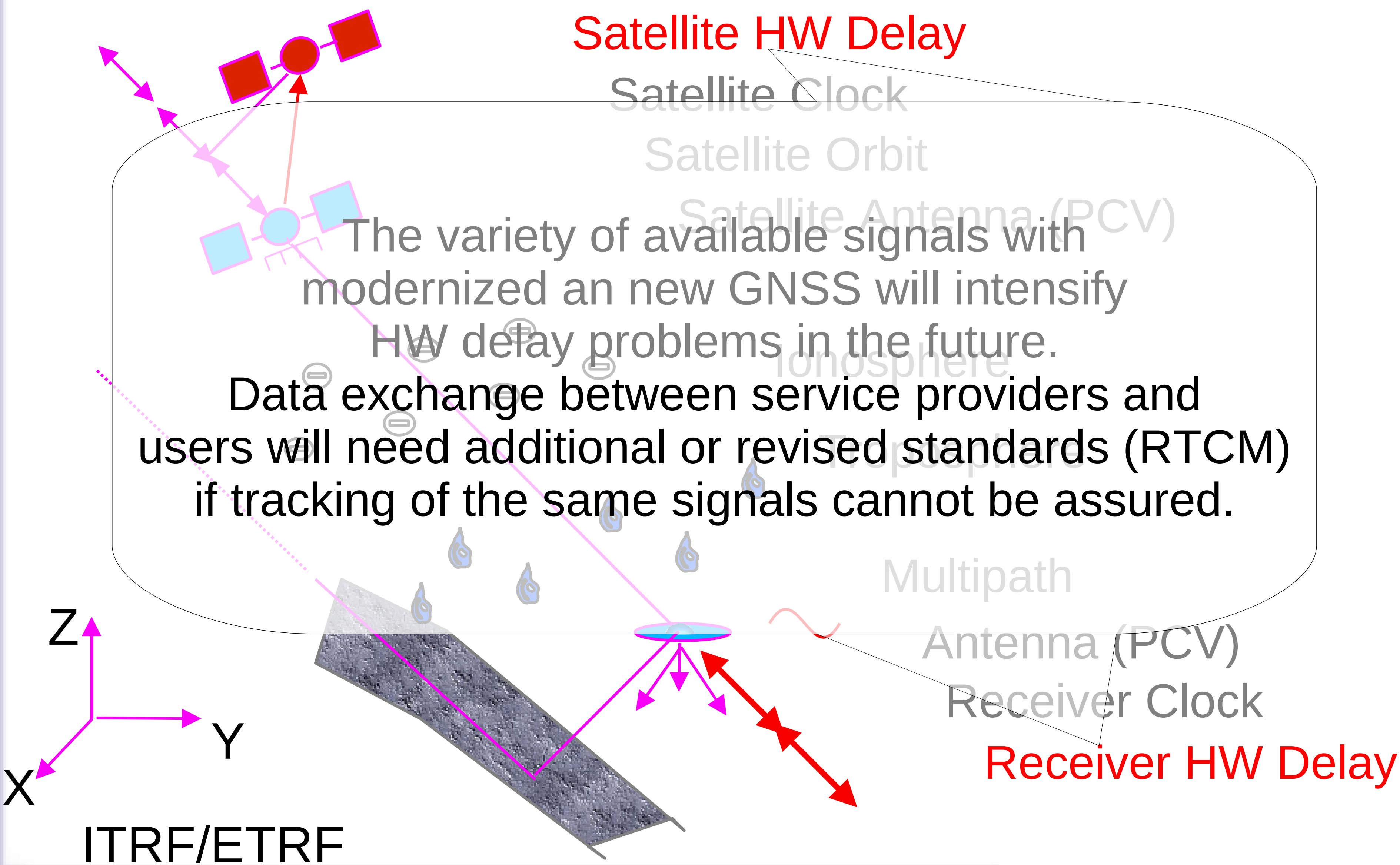
· mixing signals (L2P L2C)
· mixing GLONASS receiver types

GNSS Error Sources (HW-Delays)



The variety of available signals with modernized an new GNSS will intensify HW delay problems in the future. Interoperability of systems might suffer and algorithms like conventional Double Differencing will need modifications.

GNSS Error Sources (HW-Delays)



The variety of available signals with modernized an new GNSS will intensify HW delay problems in the future.

Data exchange between service providers and users will need additional or revised standards (RTCM) if tracking of the same signals cannot be assured.

Order of Magnitude of some GNSS Error Sources

Error Source	Absolute Influence
Satellite Orbit	2 ... 50m
Satellite Clock	2 ... 100m
Ionosphere	0.5 ... >100 m
Troposphere	0.01 ... 0.5 m
Multipath Code	m
Multipath Phase	mm ... cm
Antenna	mm ... cm

-> total: 5 ... 20 m

Precise Position Determination

- precise position determination requires knowledge of "Sum of all Errors"

  at the Rovers position with corresponding accuracy (s_P = PDOP * s_R)
- cm-accuracy requires cm accurate knowledge of "Sum of all Errors"
- Different solution techniques
  - Determination and representation of errors in Observation Space (OS)
    - describes effect of error sources in Range measurements
    - "Observation Space Representation" (OSR)
    - Technique used with current RTCM standards
  - Determination and representation of errors in State Space (SS)
    - Modelling of error source in a „State Space Model" (SSM) and
    - Representation as State Space Parameters
      - „State Space Representation" (SSR)
    - Technique used in Postprocessing "Precise Point Positioning" (PPP)
    - and Real-Time (SBAS (WAAS/Egnos), Geo++ GNSMART als PPP-RTK)

Differential GNSS

Differential („DGNSS“) Positioning

- Determine “Sum of Errors”

  at known reference station (XYZ) through

  Subtraction of „known“ Distance to satellites

  → „Corrections“

- transmit corrections

  to Rover

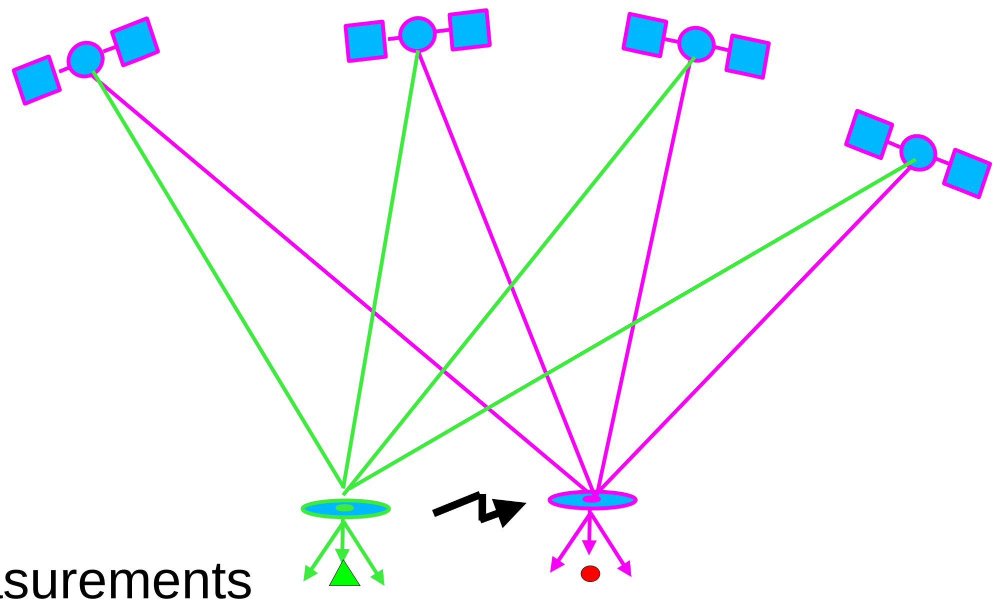
- Apply corrections at Rover

  → Reduction of error influences

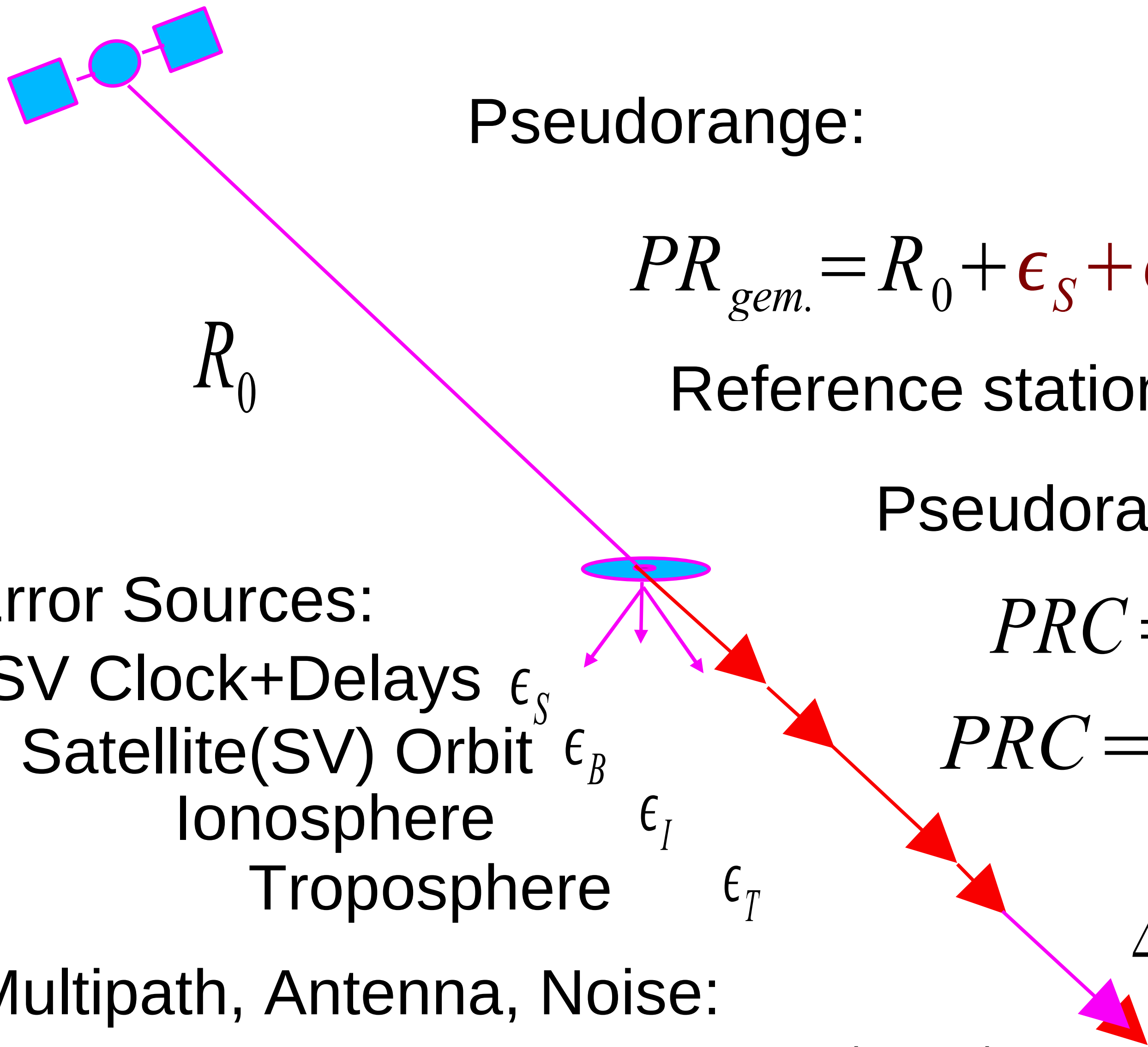
- Determine position from corrected measurements

  – with Codes („DGNSS“) or

  – with Carrier Phase („RTK“) (resolve Ambiguities)



Differential („DGNSS“) Positioning



Pseudorange:

$$PR_{gem.} = R_0 + \epsilon_S + \epsilon_B + \epsilon_I + \epsilon_T + \Delta t + \epsilon_L$$

R_0

Reference station => R_0 , Δt

Pseudorange-correction:

$$PRC = PR - R_0 - \Delta t$$

$$PRC = \epsilon_S + \epsilon_B + \epsilon_I + \epsilon_T + \epsilon_L$$

Error Sources:

SV Clock+Delays ϵ_S

Satellite(SV) Orbit ϵ_B

Ionosphere ϵ_I

Troposphere ϵ_T

Δt Receiver Clock + Delay(s)

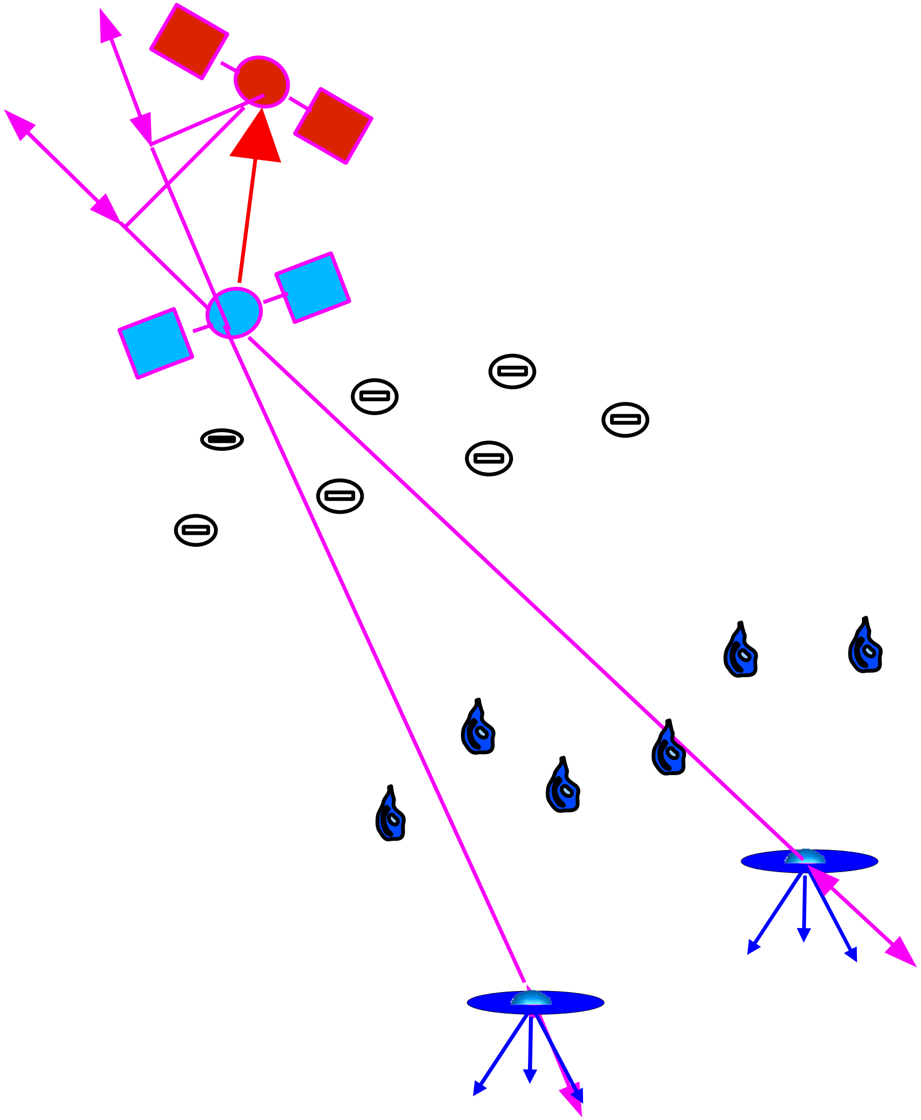
Multipath, Antenna, Noise:

$$\epsilon_L = \epsilon_M + \epsilon_A + \epsilon_\phi$$

Using Corrections or Raw Data for Single Rover Positioning

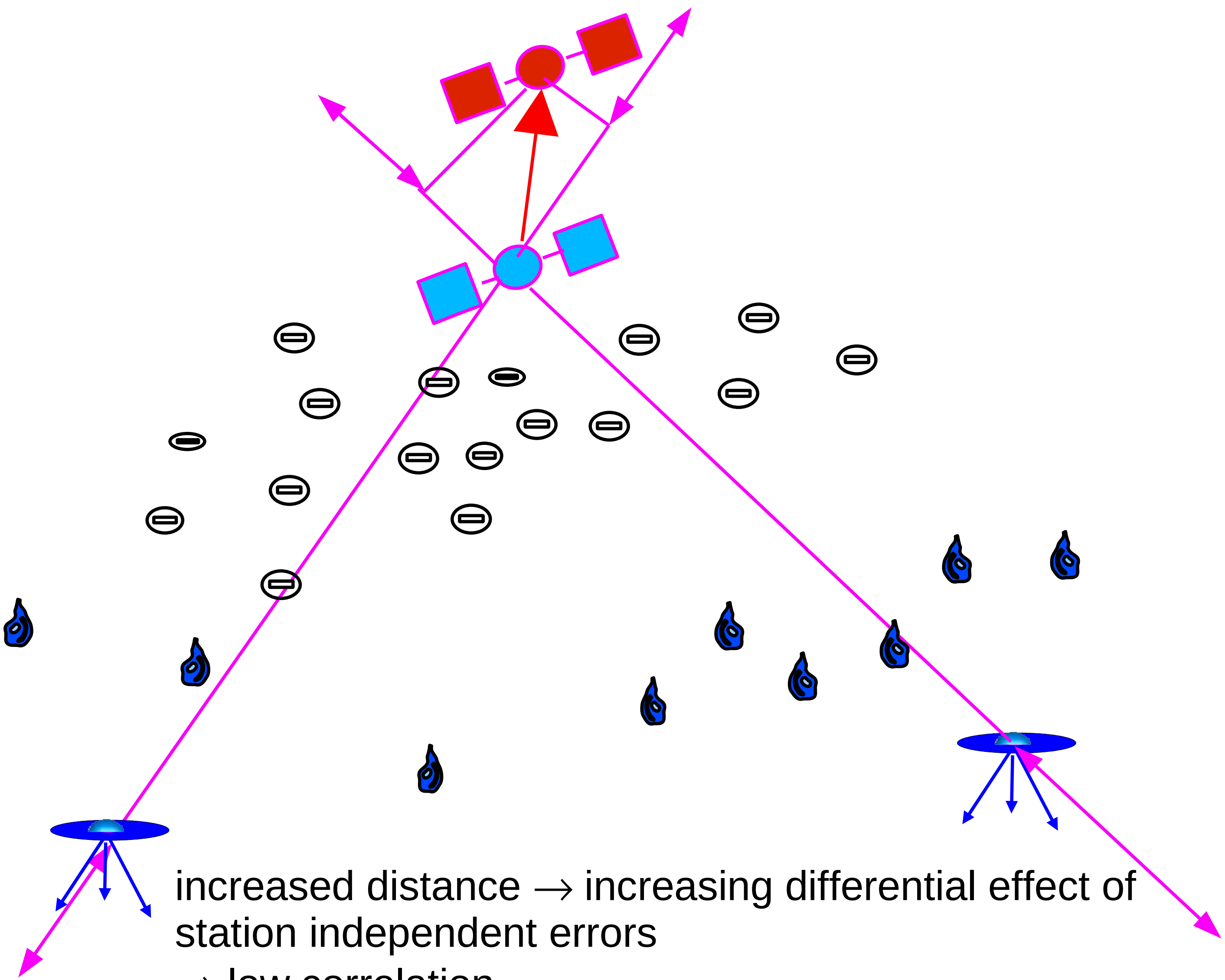
- Positioning of a single rover with GNSS can be done with
  - Corrections to observables (Codes and Carrier Phases) determined at the reference station
  - Baseline processing of raw data (Codes and Carrier Phases) using
    - undifferenced observables
    - single or double differenced observables
- All processing strategies in principle yield equivalent results
- Problem with Corrections and Differencing:
  - Same signal must be tracked by both receivers

DGNSS Error Sources – Spatial Variations



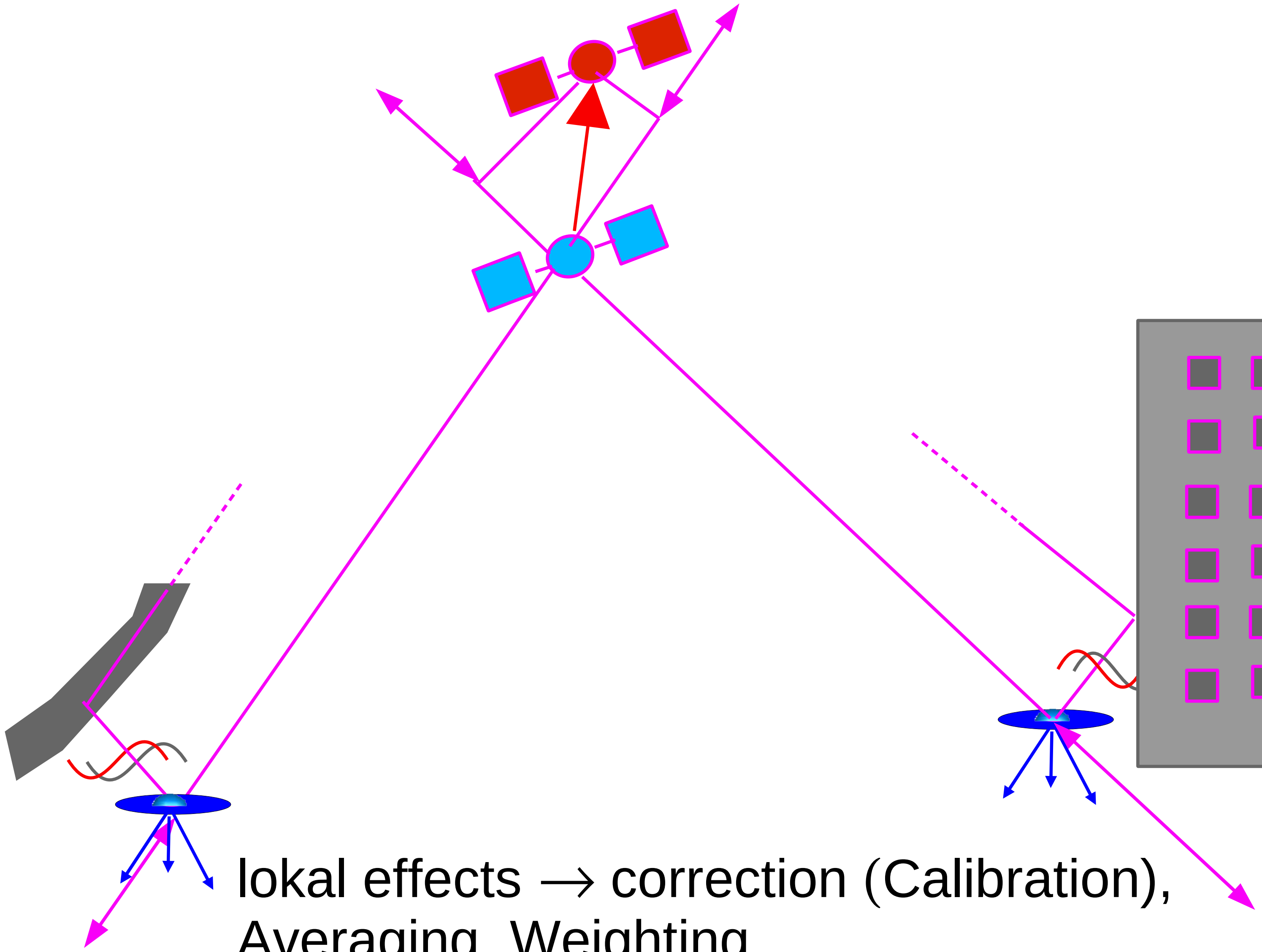
short distance → similar effect of station independent errors
→ high correlation

DGNSS Error Sources – Spatial Variations



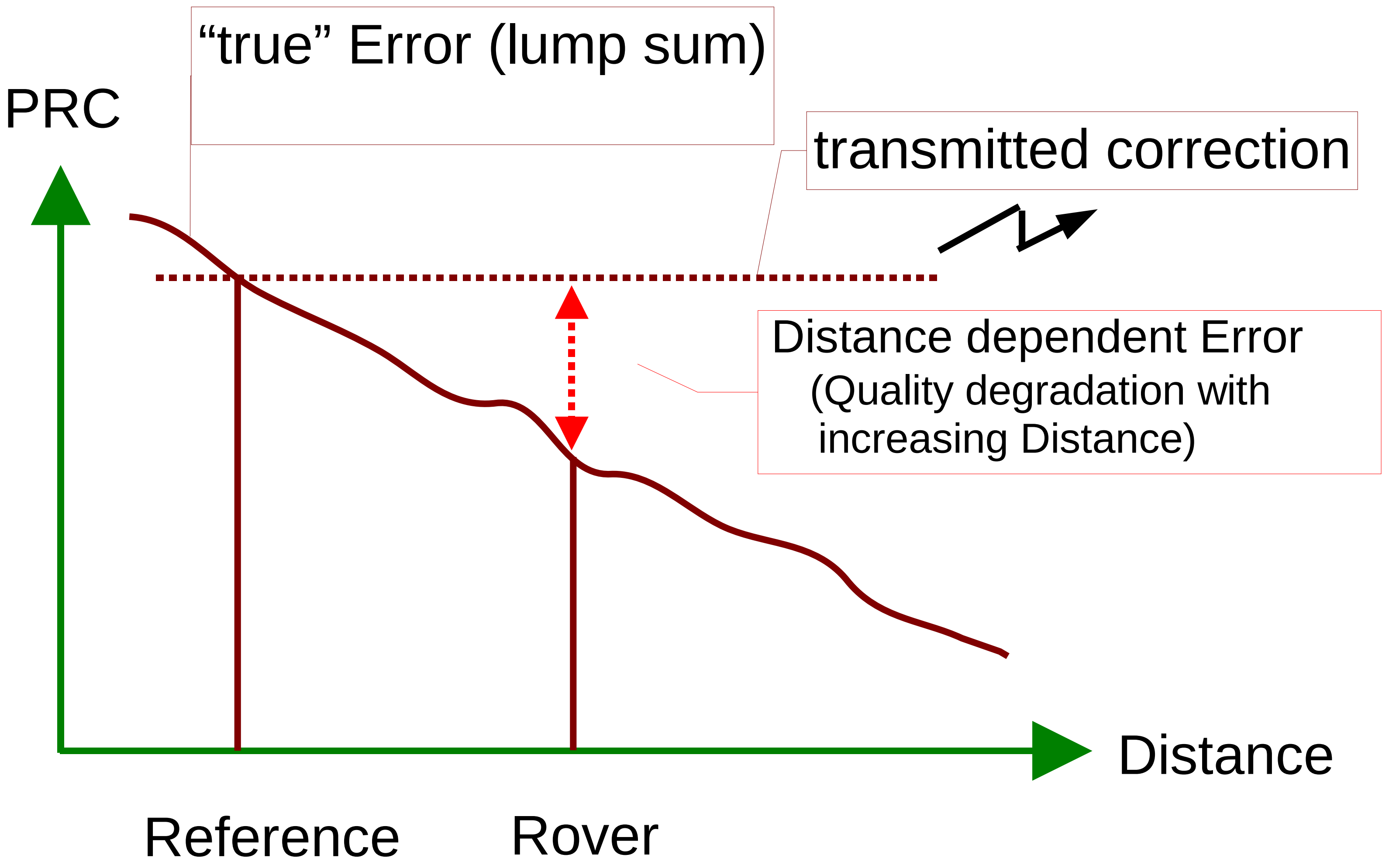
increased distance → increasing differential effect of station independent errors
→ low correlation

DGNSS Error Sources – Station Dependency



lokal effects → correction (Calibration),
Averaging, Weighting, ...
partially systematic influence!

DGNSS/RTK Distance Dependency



Order of Magnitude of some GNSS Errors

Error source	Absolute influence	Relative influence
Satellite Orbit	2 ... 50m	0.1 ... 2 ppm
Satellite Clock	2 ... 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

-> total: 1...2 cm + 1...20 ppm

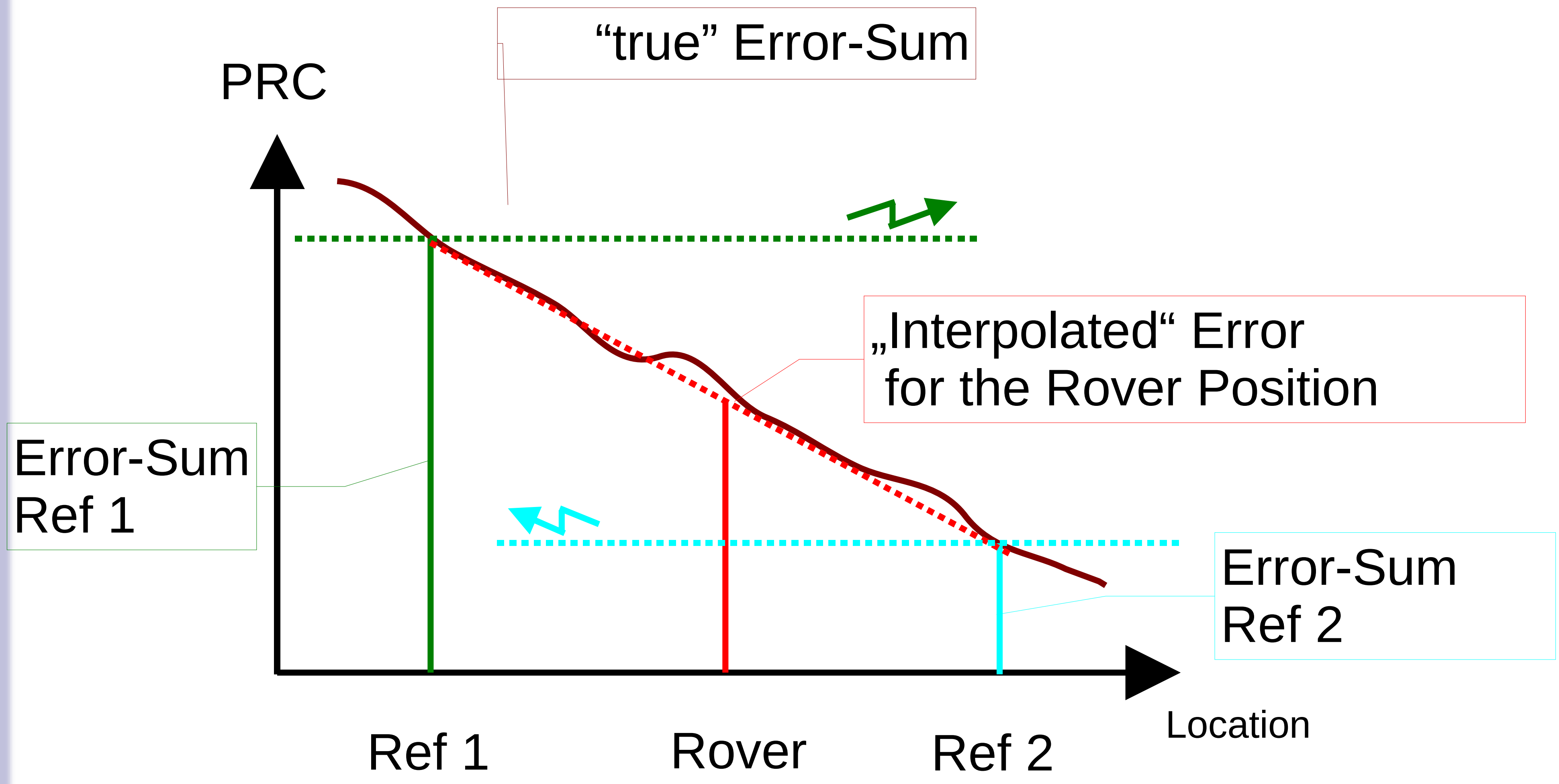
High spatial correlation (green) | Local (Calibration) (red)

RTK Networks

Network - RTK

- Principle:
  - Determination of Sum of Errors for Observations of Reference Stations for all observed Signals
  - Interpolation of Sum of Errors for Position of Rover
- Requirements for RTK:
  - Resolution of carrier phasen ambiguities between reference stations
- Implementations:
  - Initial: Simple Models for resolution of Ambiguities
  - sophisticated: complete state model for the determination of individual error components.

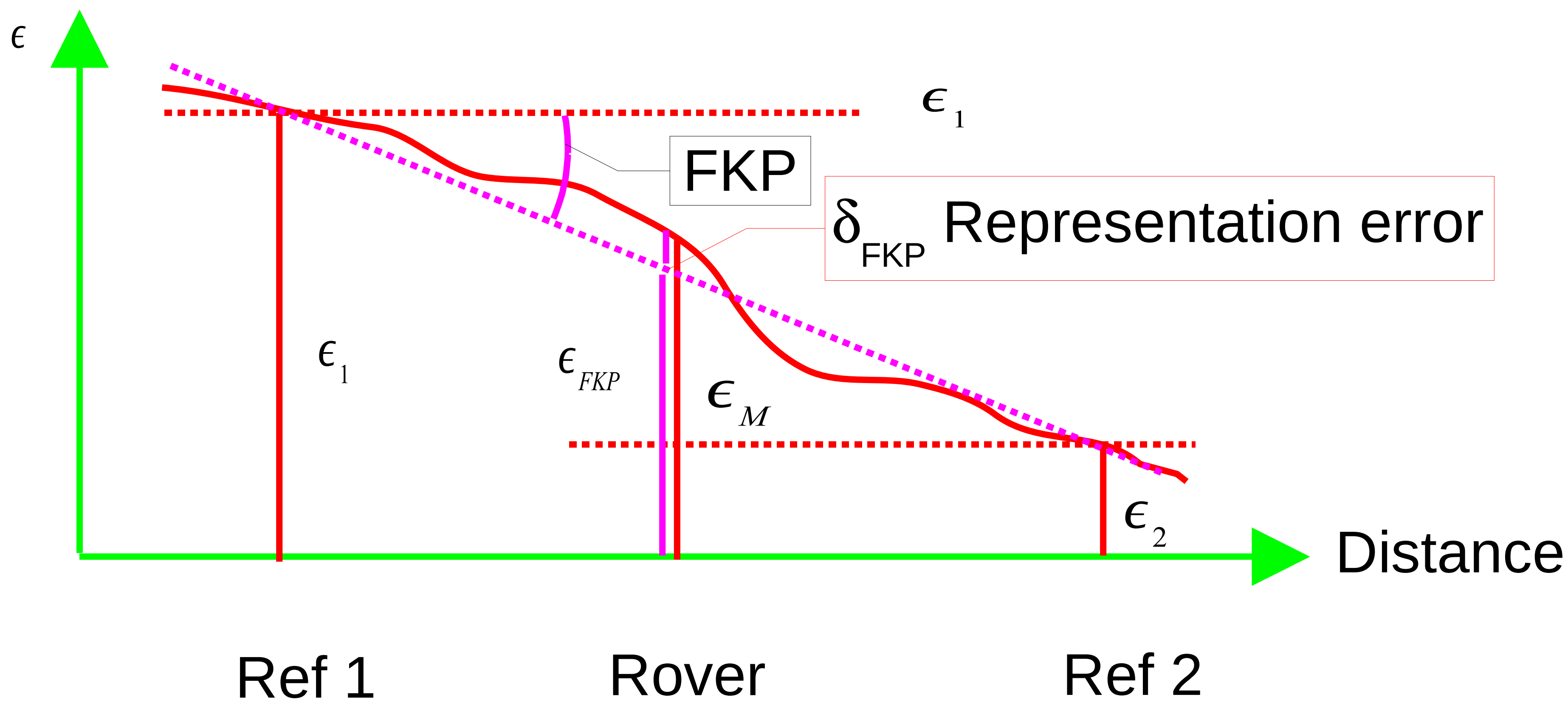
Determination of distance dependent Errors in RTK Networks



Network RTK Representation Techniques OSR

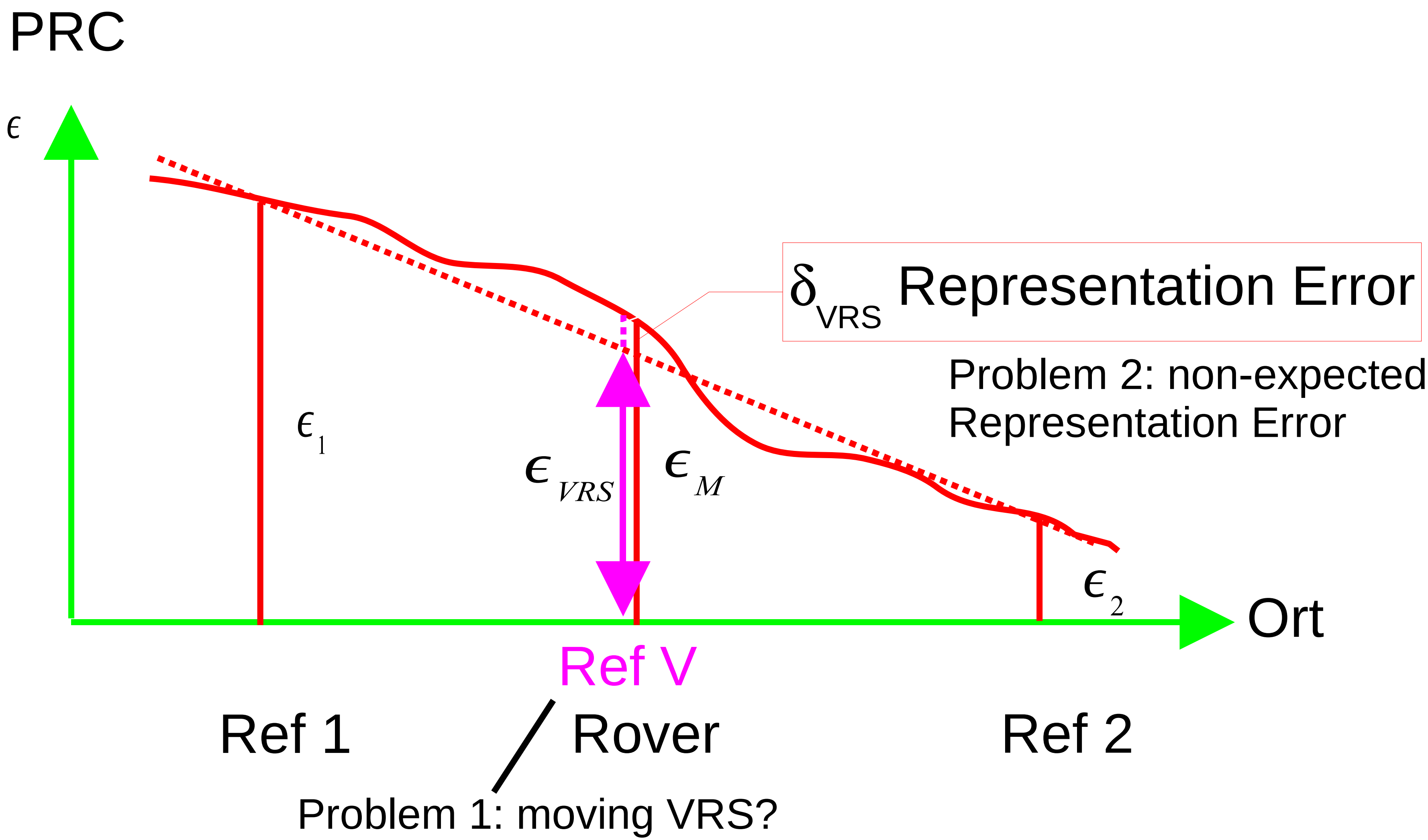
FKP Representation

PRC



Rover receives Raw Data/Corrections for Ref1 and FKP (Flächenkorrekturparameter)

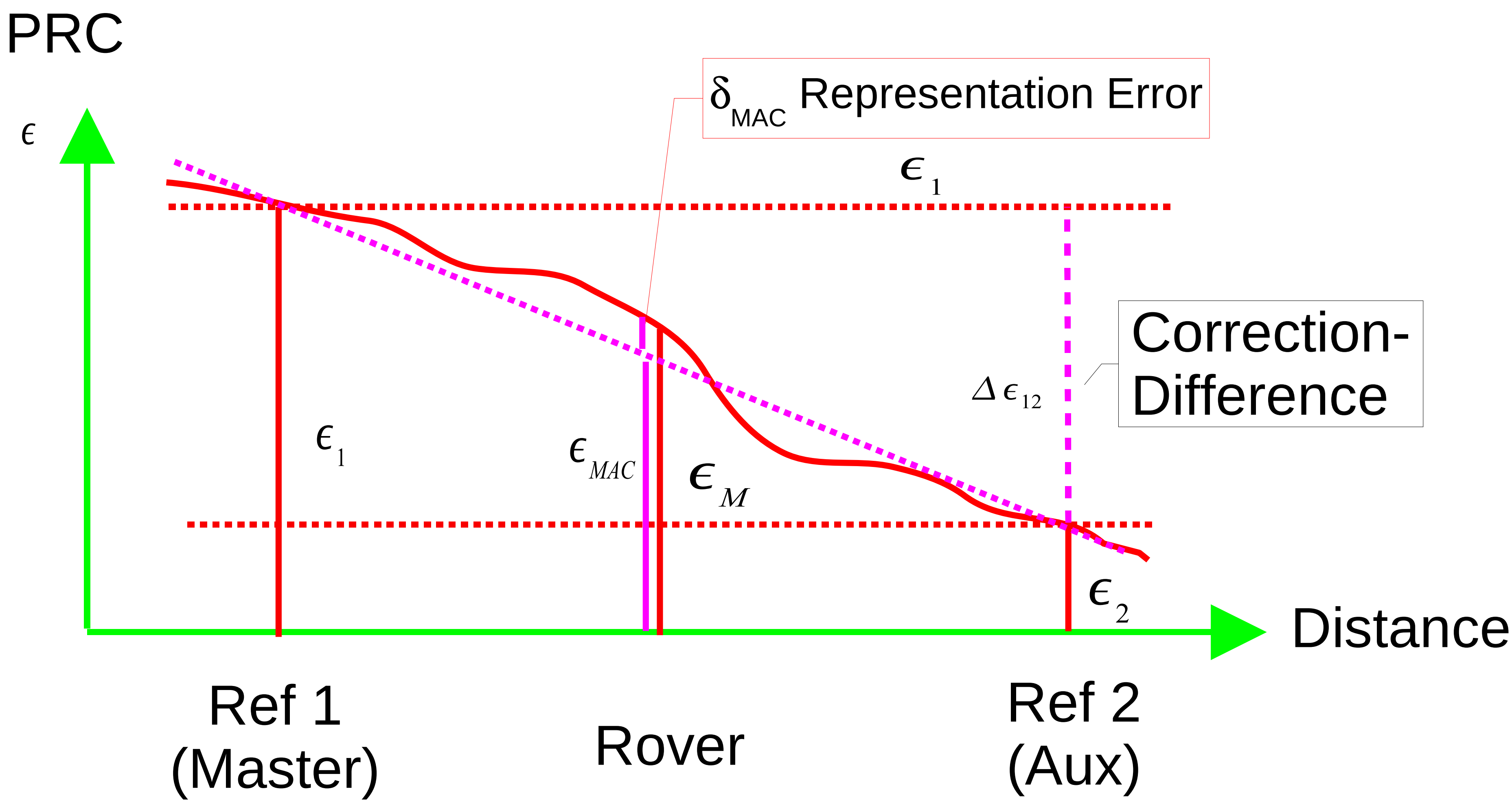
Virtual Reference Station (VRS)



Rover sends its own Position to Server und receives „Raw Data“/ “Corrections“ of the VRS

MAC Representation

Master Auxiliary Concept



Rover receives Raw Data of the Master Station and Correction-differences for the Aux-Stations (min. 2)

„State Space“ Representation

State Space Repräsentation

- OSR Dis-Advantages:
  - No Reduction of reference station dependent Errors (MP,Biases)
  - Only satellites and signals that are tracked at the „Master“-station are usable.
  - necessary update rate of corrections depent on the error component with highest dynamics (satellite clocks, ionosphere)
    - ==> bandwidth of communication link
  - Limited spatial validity of corrections
- Alternative concept: SSR
  - Tramission of individual error components to the rovers
  - Requirement: Determination of the complete state vector

„State Space“ Representation

- SSR Advantages:
  - Elimination or high reduction of reference station dependent errors (noise, MP, Biases) through high redundancy within the networks
  - better Modeling and Interpolation for individual errors (more realistic physical models)
  - independent from single reference stations, i.e.
    all satellites and signals are usable, which are tracked from a sufficient number of stations.
  - The data rate for corrections can be optimized for different state parameters. (i.e.. 10 seconds instead of 1 second)
    - Optimization of communication bandwidth
  - Broadcast of Parameters
  - Scalability of derived services
- SSR Disadvantages
  - Higher implementation efforts
  - Higher standardization efforts

Standardization

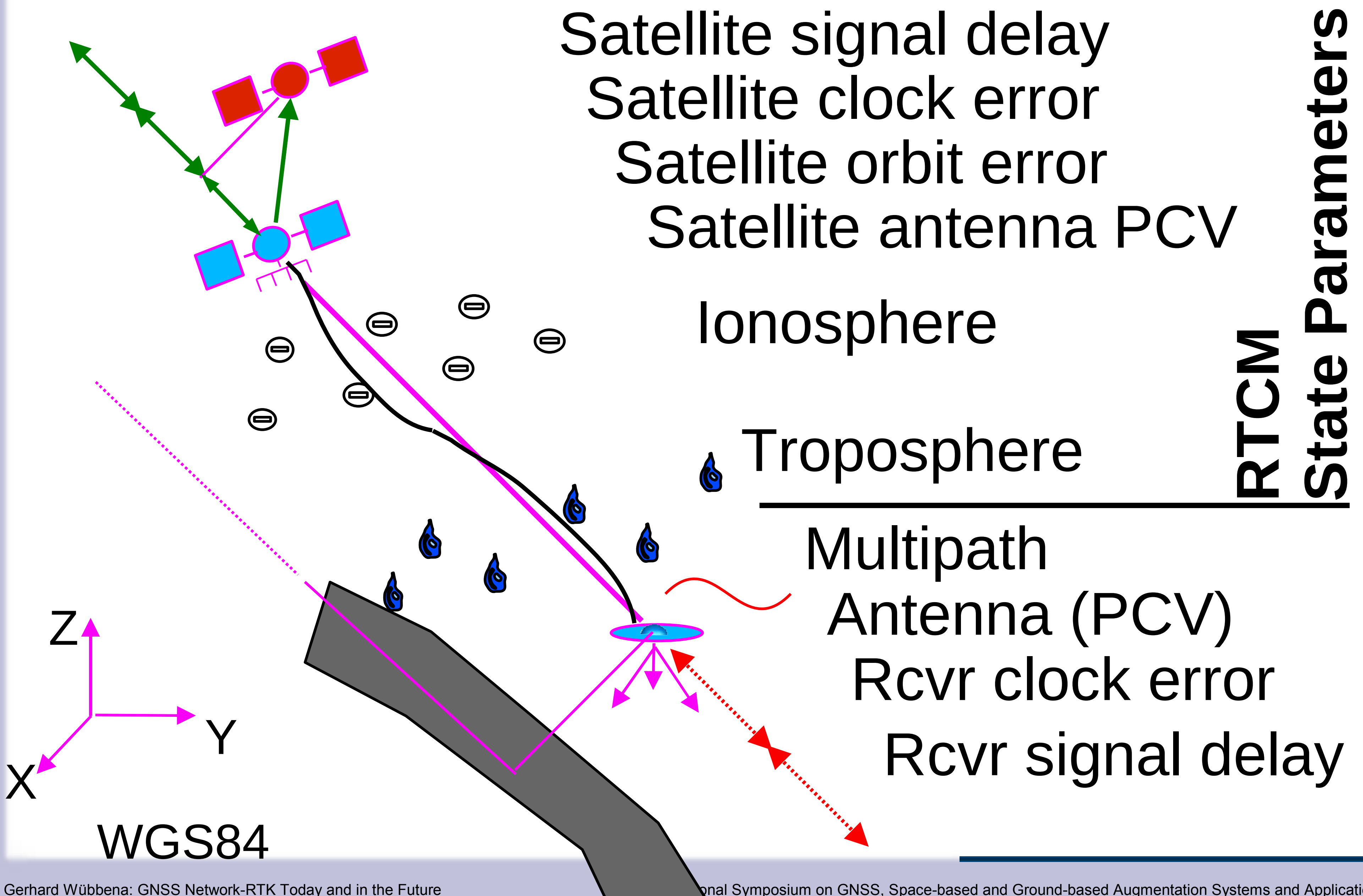
Standardization - RTCM

- RTCM SC104 stabdards for RTK Applications
  („Radio Technical Commission For Maritime Services“) :
- RTCM 2.0 – 1990 – DGPS
- RTCM 2.1 – 1994 – RTK Extension
- RTCM 2.2 – 1998 – DGLONASS + GLONASS RTK
- RTCM 2.3 – 2001 – Improvements: mm-Coordinates, Antenna-ARP,...
- RTCM-2.1+FKP-AdV – 2001 – 59-FKP Message („de facto“ Standard)
- RTCM 3.0 – 2004 – compressed Raw Data Format (Bandwidth) (RTK)
- RTCM 3.1 – 2006 – Network-RTK MAC (GPS only)
- RTCM 3.1 (Amendment 1) – 2007 – Transformation Messages
- RTCM 3.1 (Amendment 2) – 2007 – Network RTK Residual Messages, Non-Physical Reference Station (VRS)
- NTRIP 1.0 – 2004 – „Networked Transport of RTCM via Internet Protocol“

RTCM SC104

- Working Groups
  - Network-RTK: GLONASS MAC, FKP (Interoperability Testing)
  - „Version 3“: new Raw Data Messages for multiple GNSS Signals
  - GLONASS: Interoperability Problems, Biases
  - Galileo: Galileo Raw Data Messages
  - Private Services: Encryption (Interoperability Testing)
  - RSIM: Integrity of Single Reference Stations
  - Internet Protocol: NTRIP2.0 (UDP, full HTTP-Compatibility)
  - State Space: 1st Step: Satellite Clock/Orbit/Bias Messages (Interoperability Testing)

RTCM SC104 – State Space Parameter



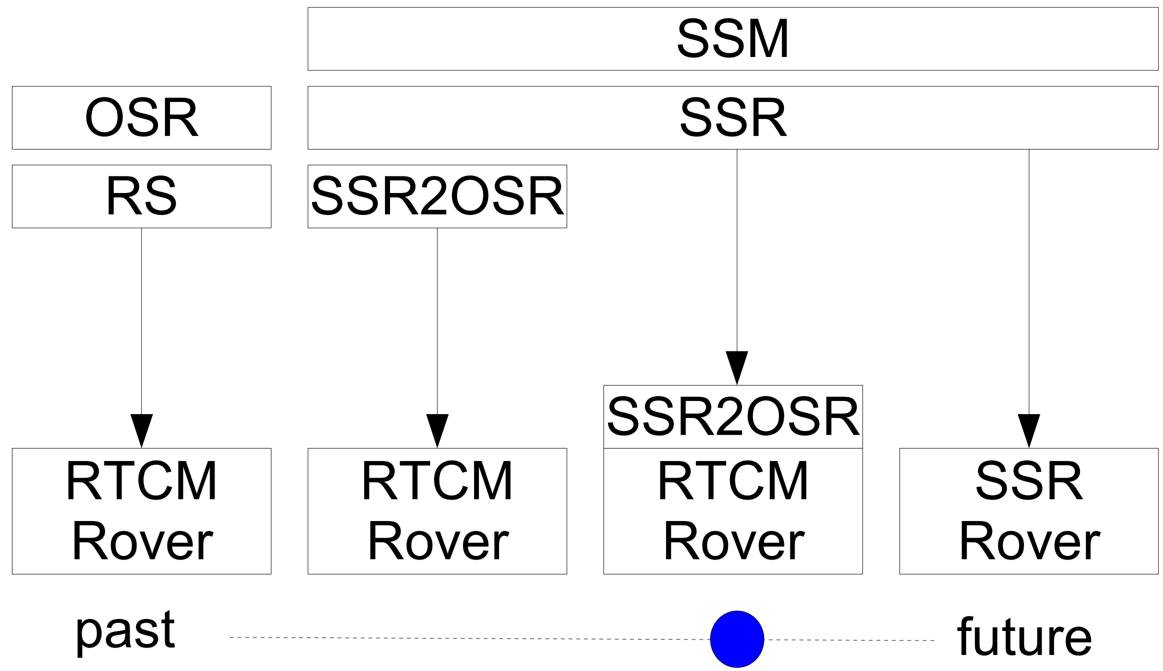
RTCM SC104 - State Space WG – Schedule

- Start May 2007 - Goal: Development of
  - Concepts and Messages for all Accuracies:
    - DGNSS and RTK (Single- and Multi-Frequency)
- Step 1: DF-RT-PPP („Dual Frequency – Real Time - PPP)
  - Message(s) for precise Satellite-Orbits and -Clock (incl. Biases)
- Step 2: SF-RT-PPP („Single Frequency – Real Time - PPP)
  - Messages for the vertical Ionospheric effect (VTEC)
- Stet 3: RTK-PPP („Real Time Kinematic - PPP)
  - Slant Ionospheric influence (STEC),
  - Troposphere, Satellite Phase-Delays,
  - Carrier Phasen Ambiguities („Integer Nature“)
- (PPP = Precise Point Positioning)

State Space Representation

Application/Transition

- conventional OSR with RTCM Rover
- SSR with conventional. **OSR Rover**
  - Conversion of SSR into standardized OSR format (RINEX, RTCM)
    - in Service Center
    - or at Rover
- Direct usage of SSR in **SSR rover**



- SSR concept operationally applied with Geo++ GNSMART

Reverse / Inverse
DGNSS
RTK

Reverse/Inverse DGNSS/RTK

- Principle:
  - Position Determination at Server instead of Rover
    - Rover sends Raw Data (Pseudoranges, Carrier Phases) to Server
    - Server computes DGNSS or RTK Position while using Information (SSR) from a RTK-Network
    - Server sends Position back to the Rover and/or other applications
- Requirements:
  - Duplex Communication
  - Reverse/Inverse Server
  - Rover with Reverse/Inverse Client Functionality (PDA, Mobile Phone,...)

Reverse/Inverse DGNSS/RTK

- Advantages:
  - Optimum „Performance“
    - Consistency of Algorithms with Netzworking Software
    - Rover-Receiver just a „Sensor“
      - No sophisticated algorithms required
        - Simple Single Frequency Receivers
        - „old“ Receivers (no firmware updates anymore)
        - Save Software Options
- Requeirements:
  - Duplex Communications
  - Reverse/Inverse Server
  - Rover with Reverse/Inverse Client Funktionality (PDA, Handy)

New GNSS and Modernization

- GPS: 3 Carrier-frequencies and new (civil) Codes (L2C, L5, L1C)
- GLONASS: „full Constellation“ in 2009/2010
- GLONASS: 5 Frequencies L3 (FDMA), $f_{L3}(i) = 94/125\ f_{L1}(i)$ and
  - GPS-L1 (CDMA) GPS-L5 (CDMA)
- Galileo: operational in 201?
- Galileo up to 5 Frequencies with different signals
- China: Compass GNSS 30(?) MEO's und 3 GEO's
- In total there will be 75-105 GNSS Satellites!
- RINEX 3.0 defines 40+ different Code Signals and Combinations on 7+ Carrier- Frequencies
- SBAS Systems with L1/L5 (Egnos,WAAS,MSAS,QZSS...)

Geo++® GNSMART

... artist view of Geo++® building in Garbsen