Global Ionospheric Scintillation Model: current status and further development strategies

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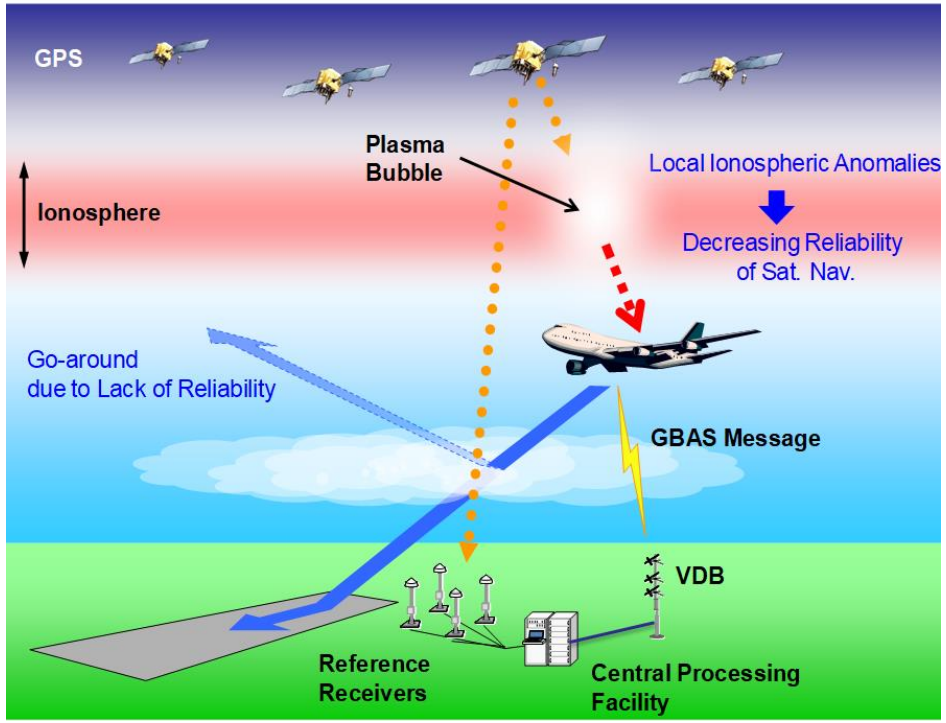
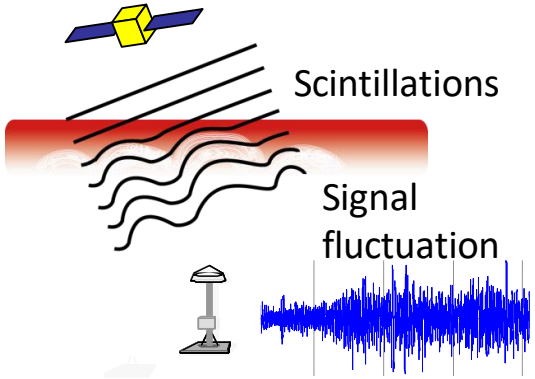
Motivation

Impact of Ionospheric Irregularities on GNSS Applications

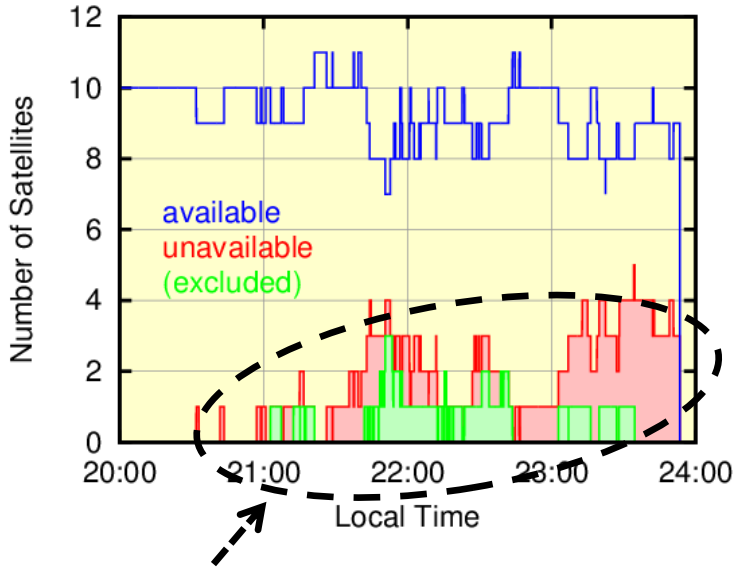
Airport Precision Approach



Plasma Bubble degrades availability of GNSS Precision Approach



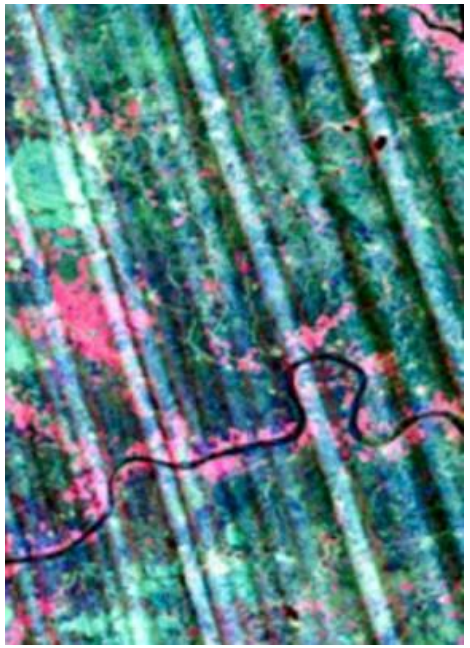
GNSS Signal is disturbed by ionospheric irregularities (plasma bubble) and may be lost in severe case.



Maximum 5 Sats. were Unavailable

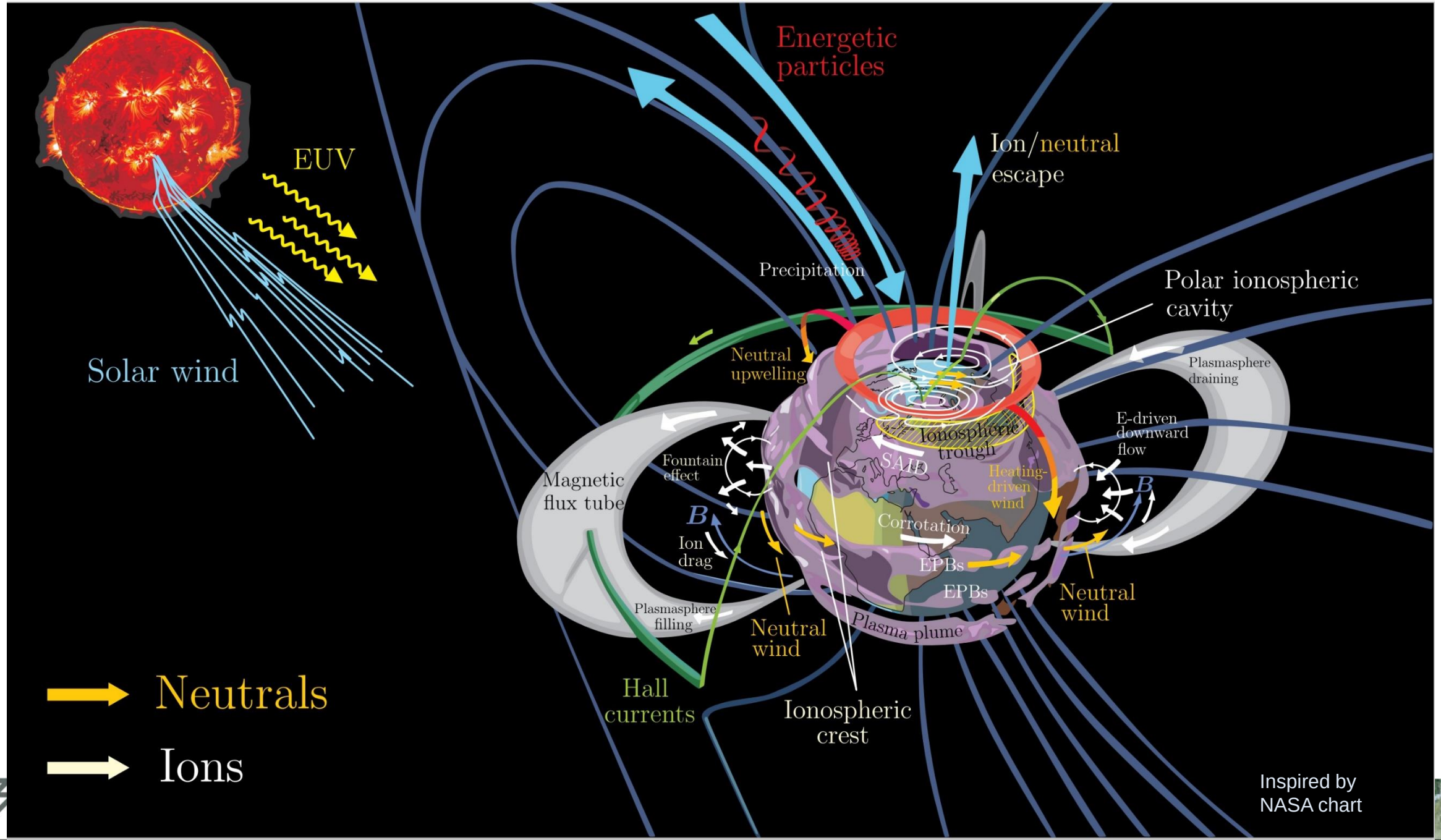
Impact on radar applications

Defocusing
Phase instability
Azimuthal streaking

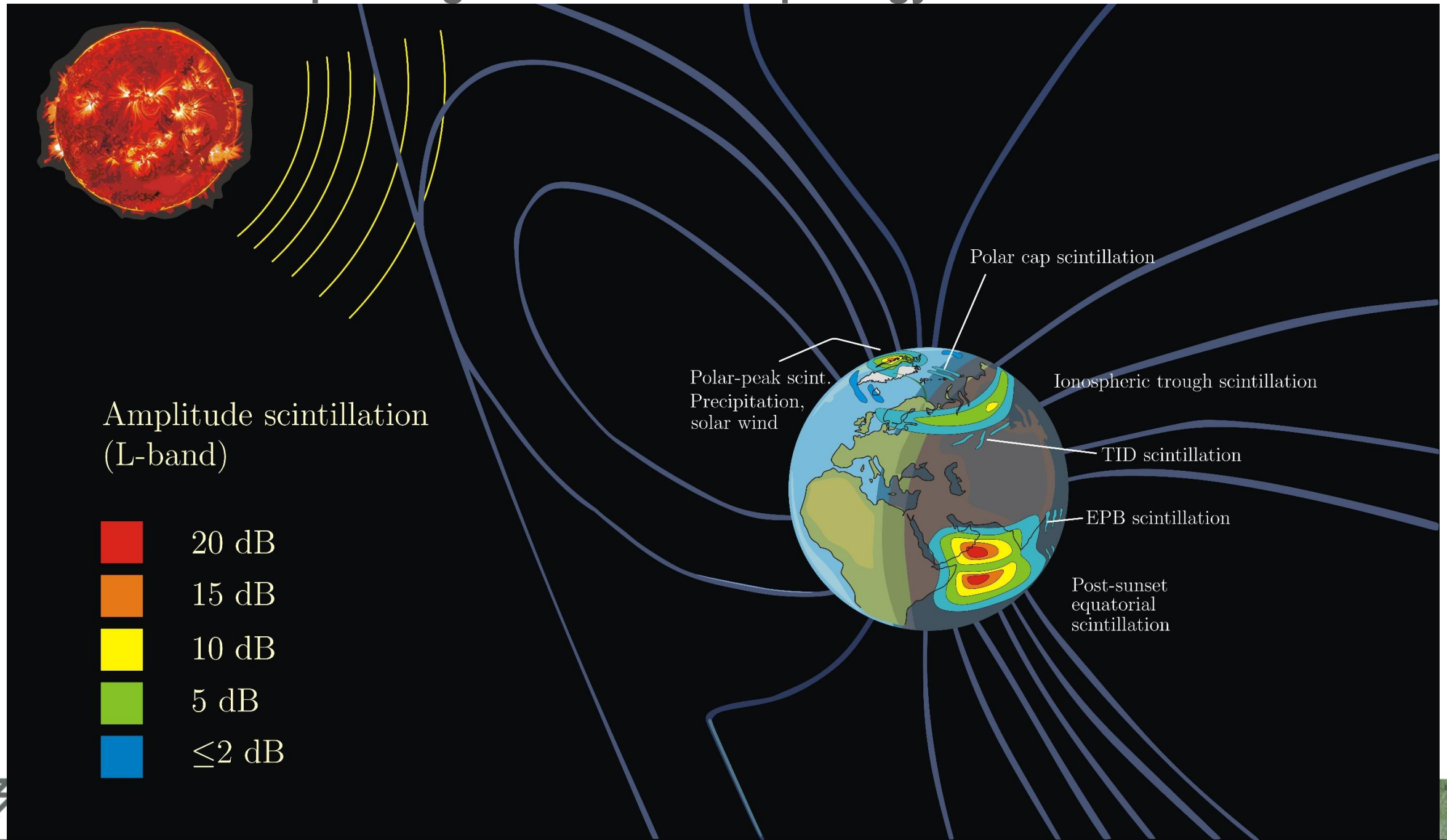


Radio Sci., 53, 1187

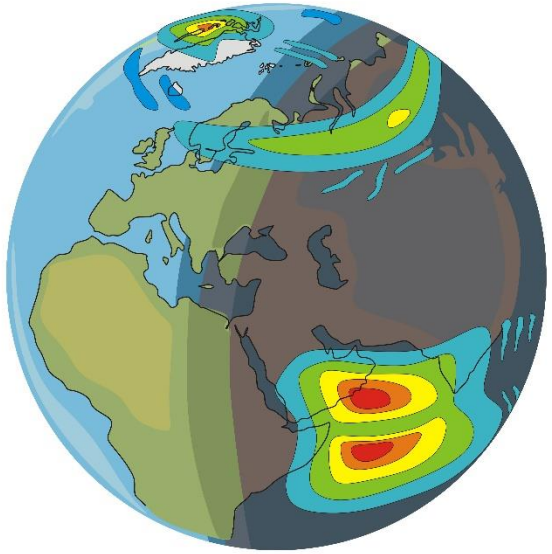
Processes related to scintillation occurrence…



… and the corresponding scintillation morphology



Overview of the existing scintillation models:



Analytical models

Global climatological models

Based on sat. in situ data

GNSS scintillation models

Tatarskii, Booker, Briggs & Spencer, Singleton — 1973

Fremouw & Rino — 1976

Basu et al., equatorial — 1979

WBMOD — 1981

Basu et al., high-lat. — 1985

Franke & Liu — 1999

Aarons model — 2006

GISM — 2007

Iyer et al. — 2009

Wernik et al. (WAM) — 2010

Cornell model — 2014

Retterer model — 2017

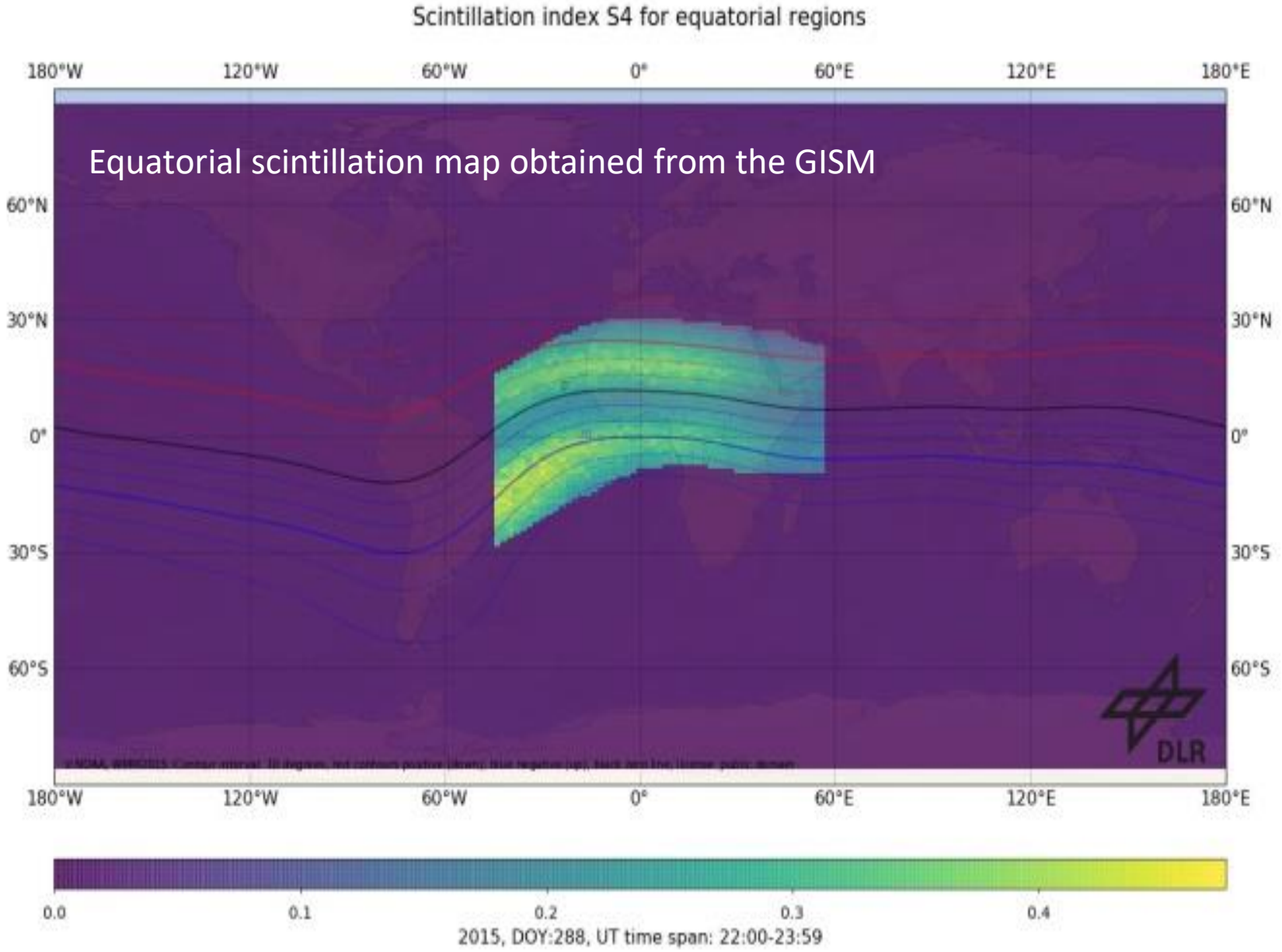
SIGMA — 2018

Rino's multifreq. model

SCINONAV

No claim that the chart is complete

Global Ionospheric Scintillation Model



GISM in a nutshell:

- Developed by Y. Bèniguel et al. (IEEA, France)

- Kindly handed over for further collaborative development to DLR by Y. Bèniguel (2019)

- Multiple phase screens (1D)

- NeQuick2 as ionosph. Model

- Ray tracing

- Arbitrary communication configuration

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Phase screen formalism

$$U \rightarrow U \exp(i\phi)$$

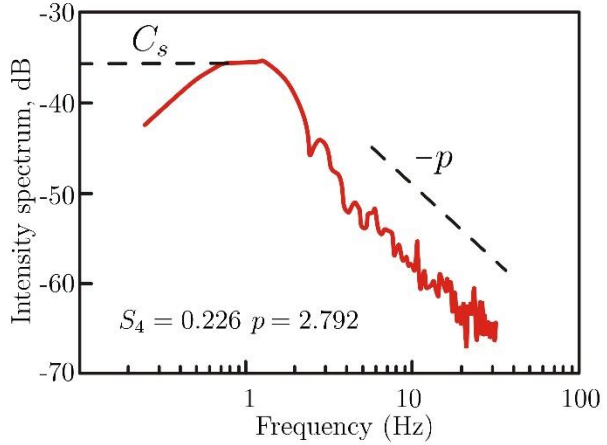
$$\phi \approx \delta N_e$$

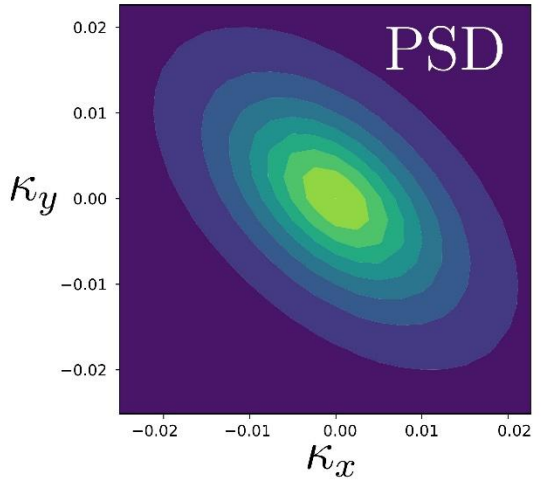
$$2ik\partial U/\partial z + \partial_\perp^2 U = 0$$

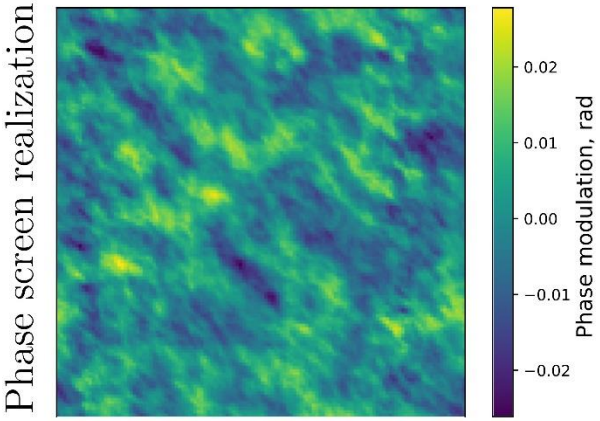
transmitted intensity

initial intensity

$N\times$ phase screens

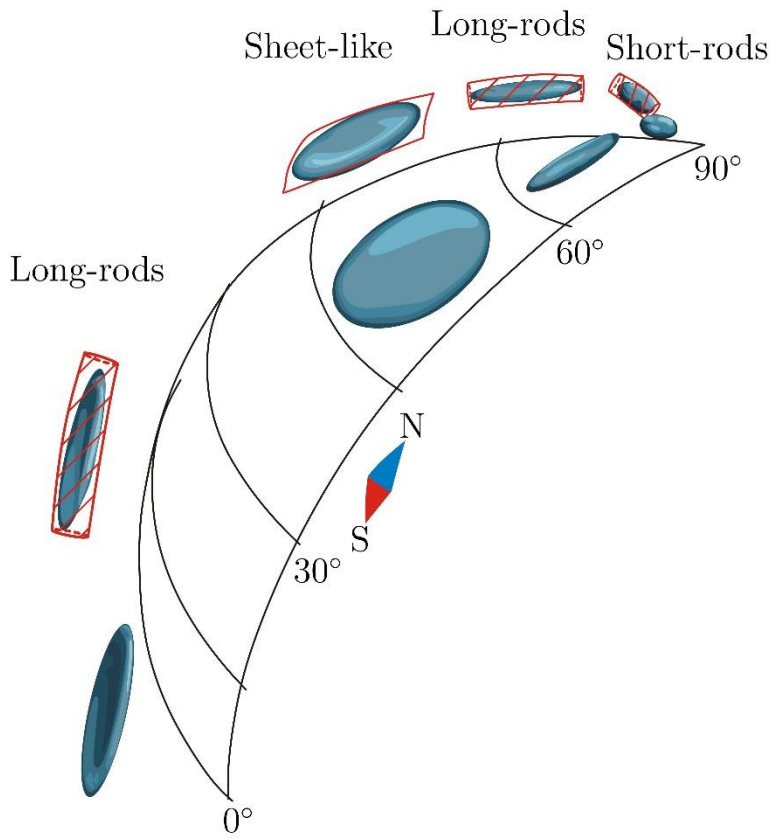






Modeling of the irregularity morphology

Simple model of irregularity shapes

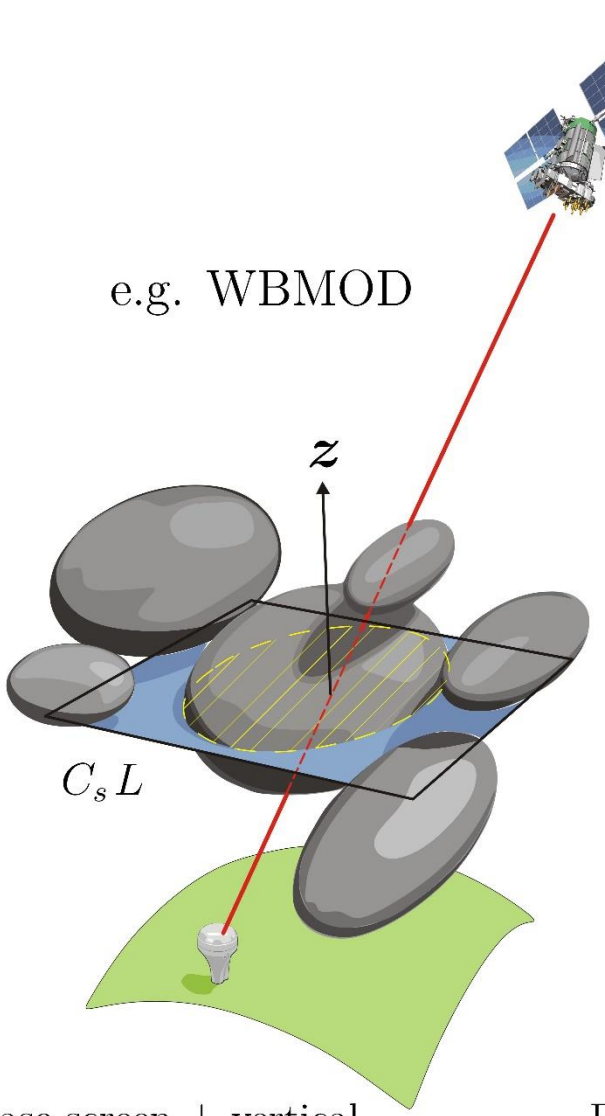


Important parameters:

- Structure constant C_s
- Spectral index p
- Axes ratios $a : b : 1$
- Drift velocity $\boldsymbol{v}_{drift}$

Approaches for incorporation of medium anisotropy

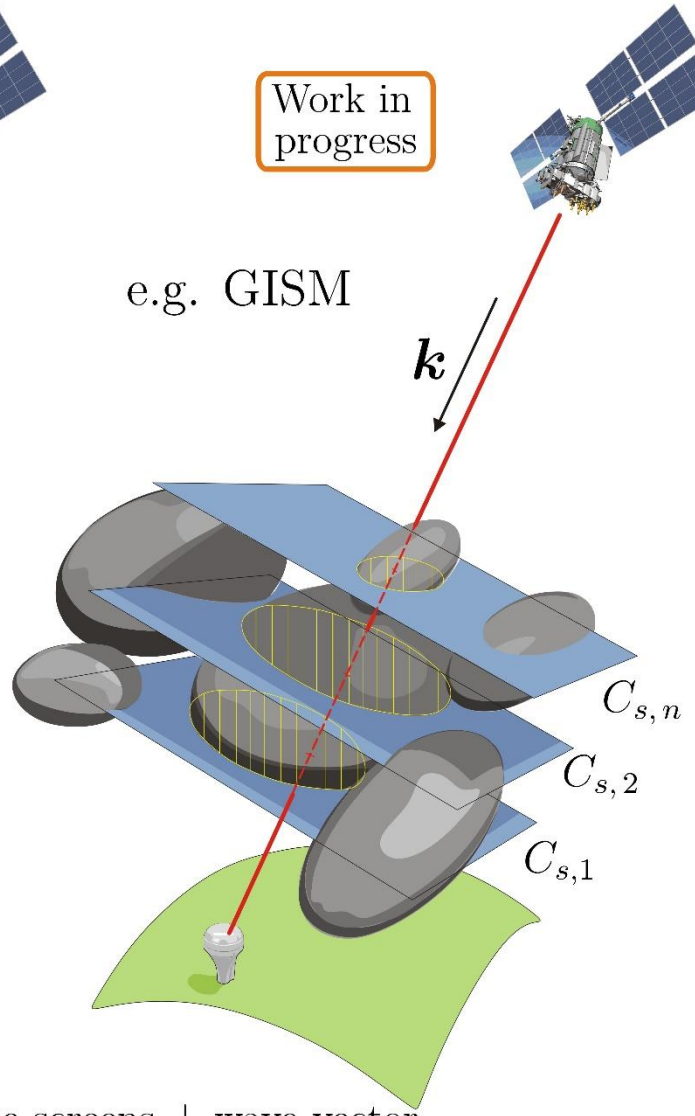
e.g. WBMOD



Phase screen ⊥ vertical

Work in progress

e.g. GISM



Phase screens ⊥ wave vector

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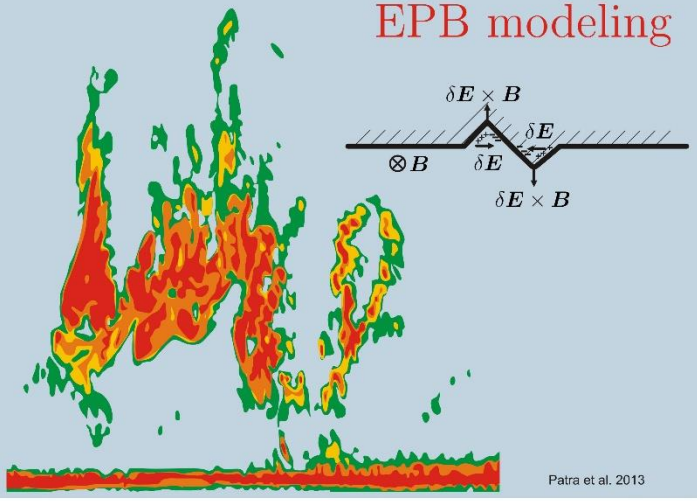
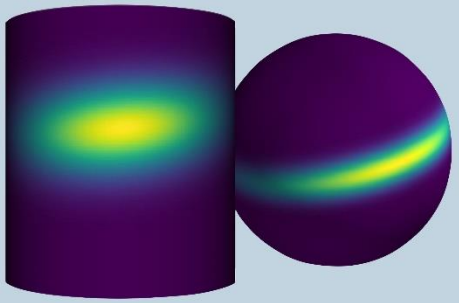
Another aspects of scintillation modeling to address:

EPB modeling



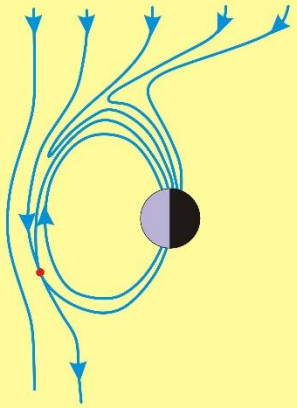


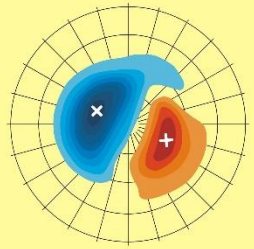
EPB: Statistical inference & probability of occurrence

Equator

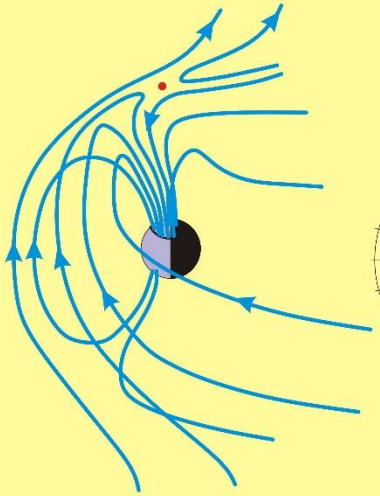
High-Latitudes

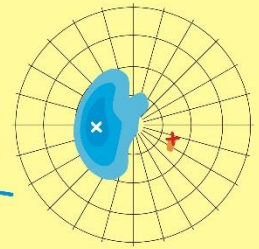
Topology of IMF



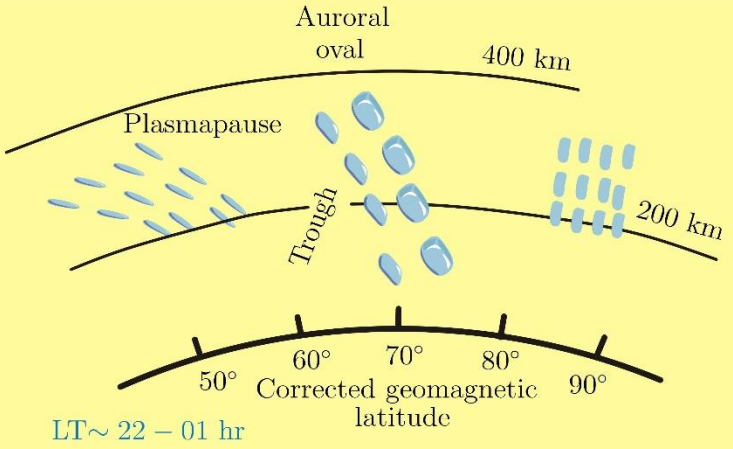


southward IMF

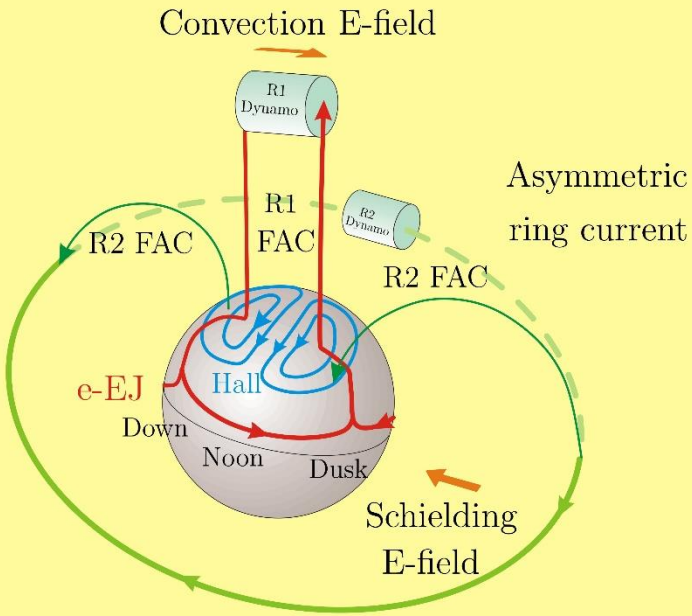




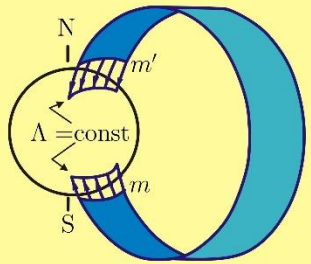
northward IMF

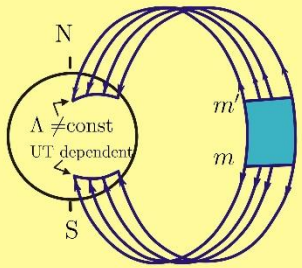


Geometry of irregularities



Transient events





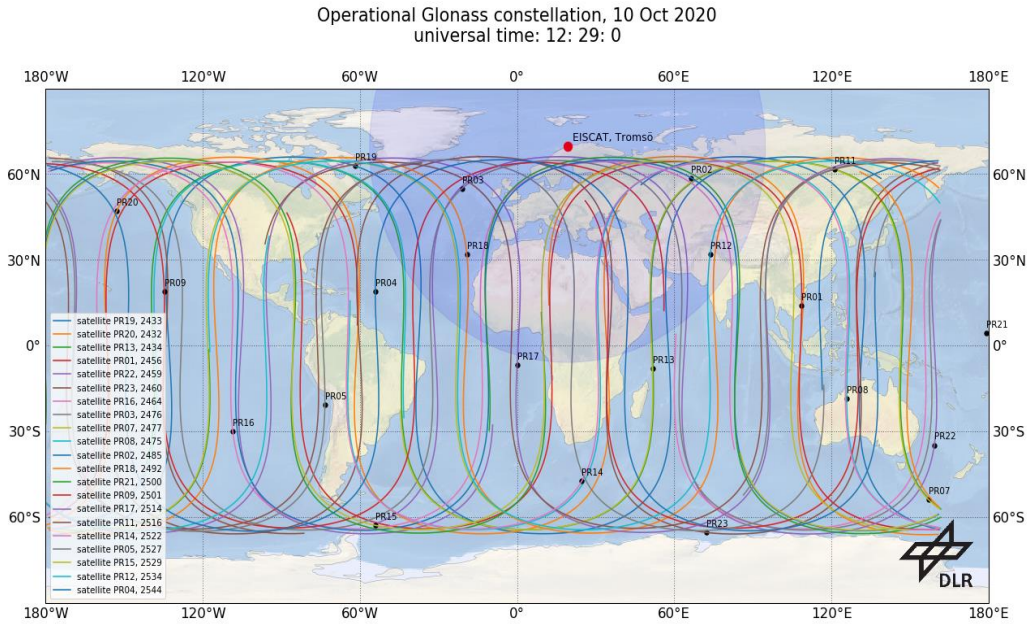
Particle precipitation

Future focus on the following user-cases:

GNSS applications

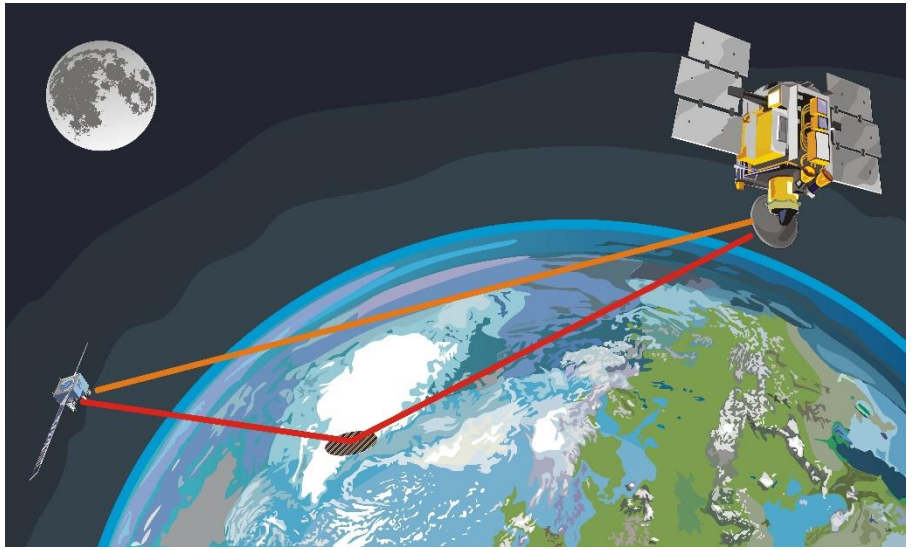
Constellations:

Galileo, GPS,
Glonass, Beidou



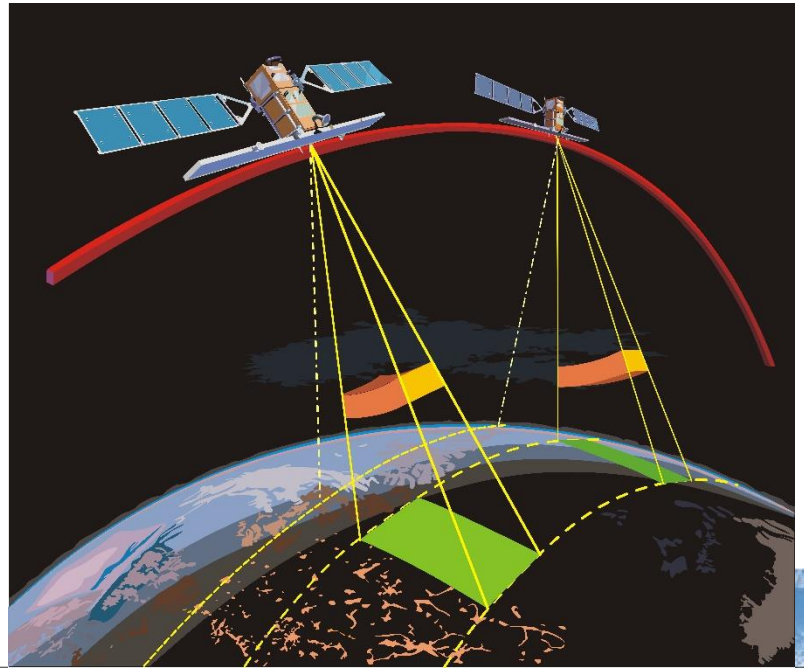
Remote sensing applications

Reflectometry, limb sounding



Radar applications

SAR missions



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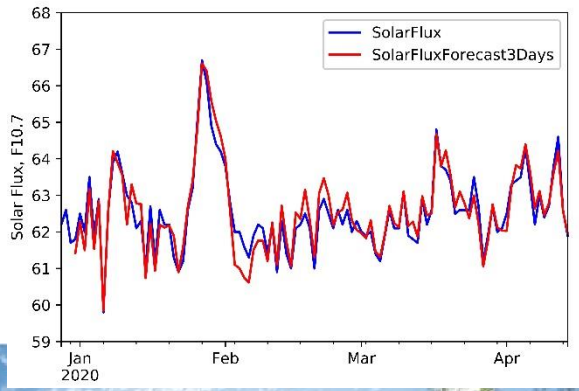
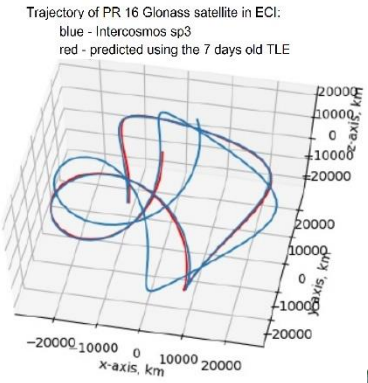
Forecast

GISM





Summary and outlook

GISM

- Extended capabilities of GISM:
  - 2D phase screens
  - Open for cooperation and inclusion of 3d iono models (NeQuick, NEDM, etc.)
  - Removed rigidity via OOP
  - Extended set of user-cases
- Work has to be done:
  - Irregularity geometry/spectral properties
  - EPB scintillation
  - High-latitude scintillation
  - Data-assimilation
  - Transient events
  - Forecasting

Scintillation modeling: glance in the future

- Properties of random medium inferred from measurements (radar, lidar, GNSS and microwave remote sensing). High spatial resolution of data.
- Optimization of phase screens placement.
- New methods in strong scintillation modeling (e.g. kinetic equation approach, phase approx. to Huygens Kirchhoff method).
- Parametric and non-parametric inference for modeling of scintillation occurrence.
- AI-assisted scintillation forecast.
- Aspire to have a scintillation forecast as good as synoptic forecasts.

Thank you!