# Analysis Strategies And Software For Geodetic VLBI

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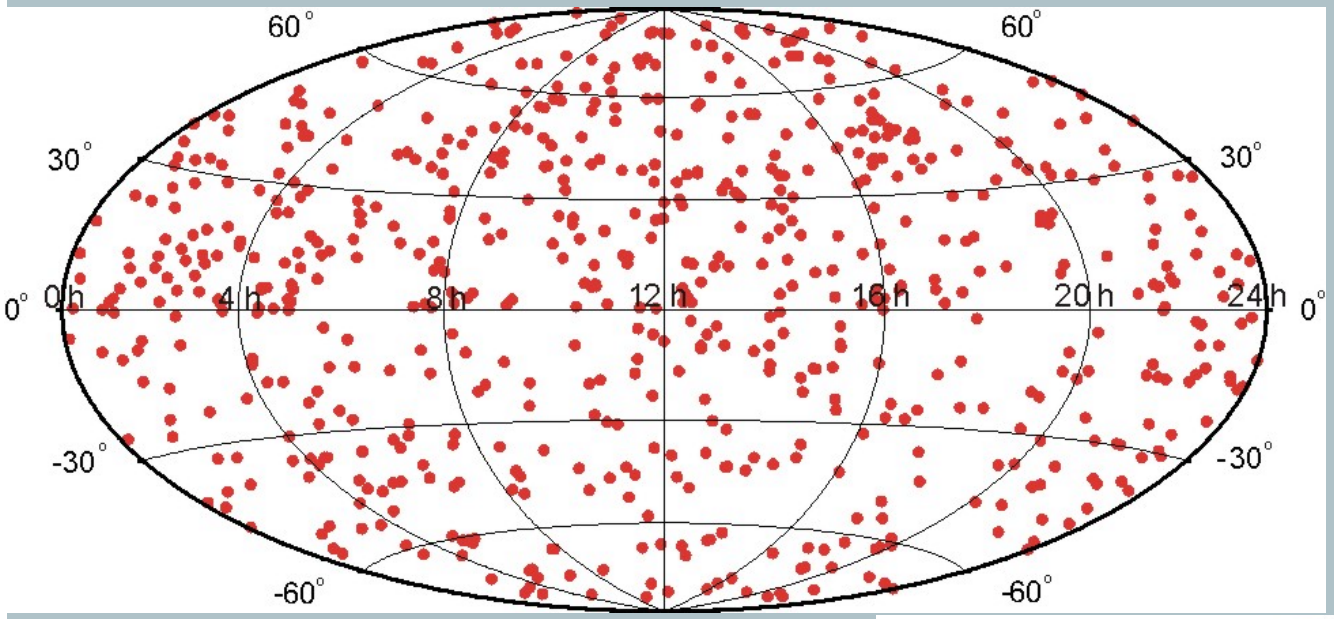
Presentation at the 7th EVN Symposium, Toledo, 2004

# Outline:

- Observing stategies and observables
- Data analysis strategies
- Data analysis software and data modeling
- Scientific goals today and in the future
- Necessary improvements today and in the near future

# Observing strategies and observables:

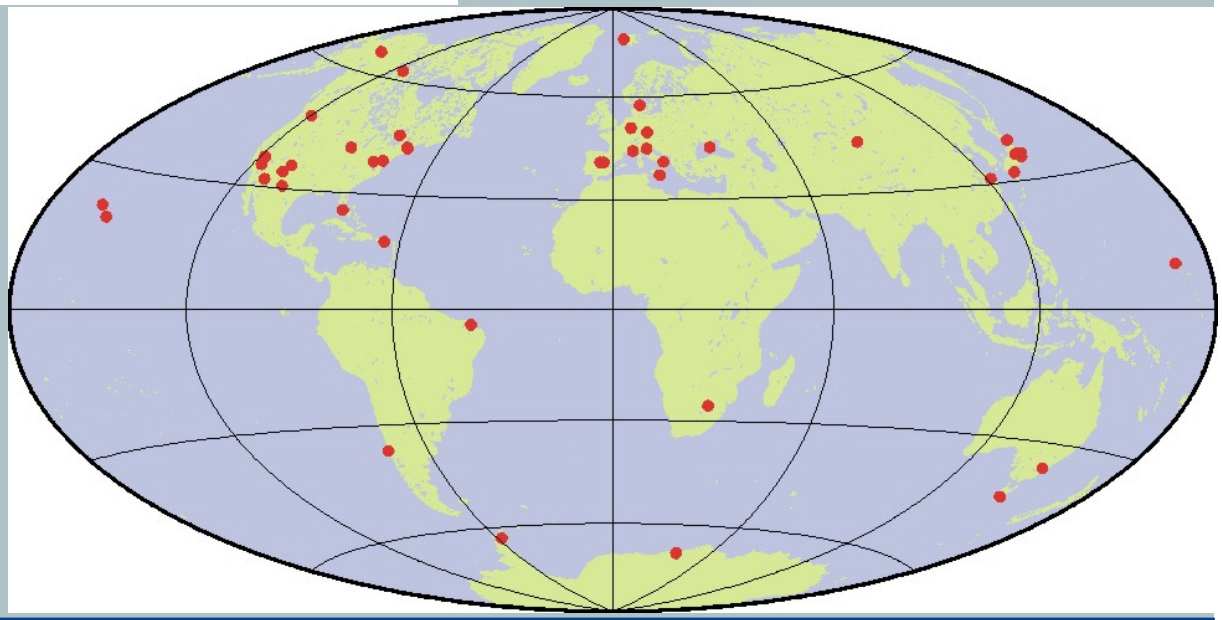
- Global geodetic VLBI observing schedule coordinated by the International VLBI Service for Geodesy and Astrometry (IVS)
- Main objectives:
  - => maintenance of reference frames
  - => relations betwwen reference frames
  - => investigation of geodynamic processes
- Geodetic VLBI observables at X- and S-band



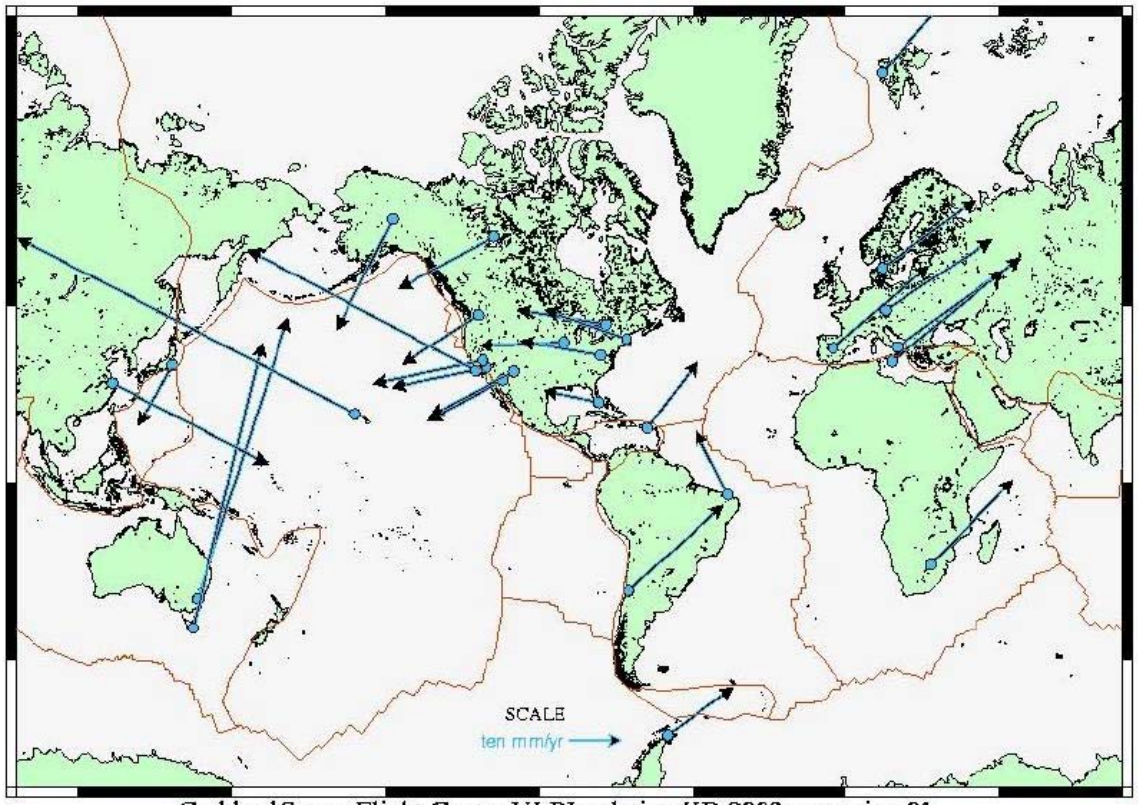

Celestial
<=== Reference
Frame (ICRF)

Terrestrial
Reference
Frame (ITRF)

===>



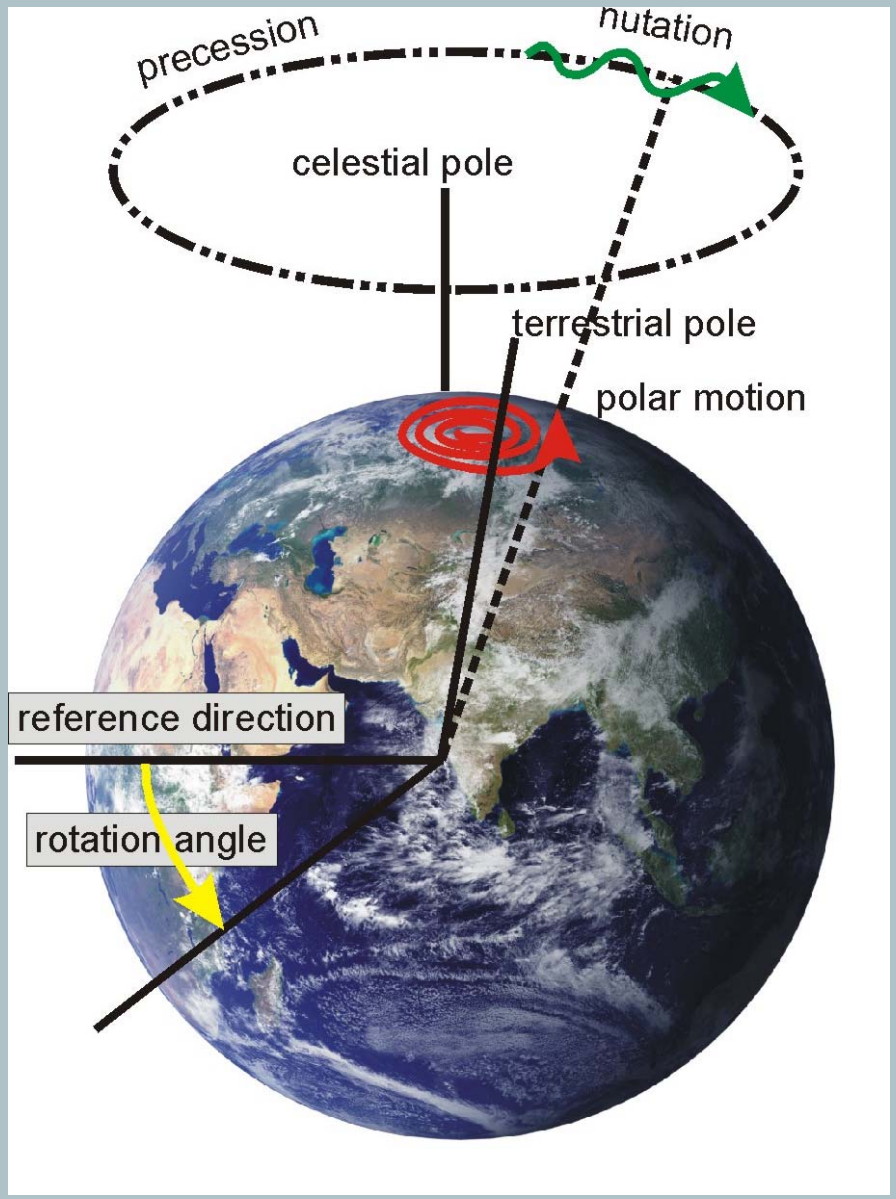
Corresponding ITRF velocities ===>



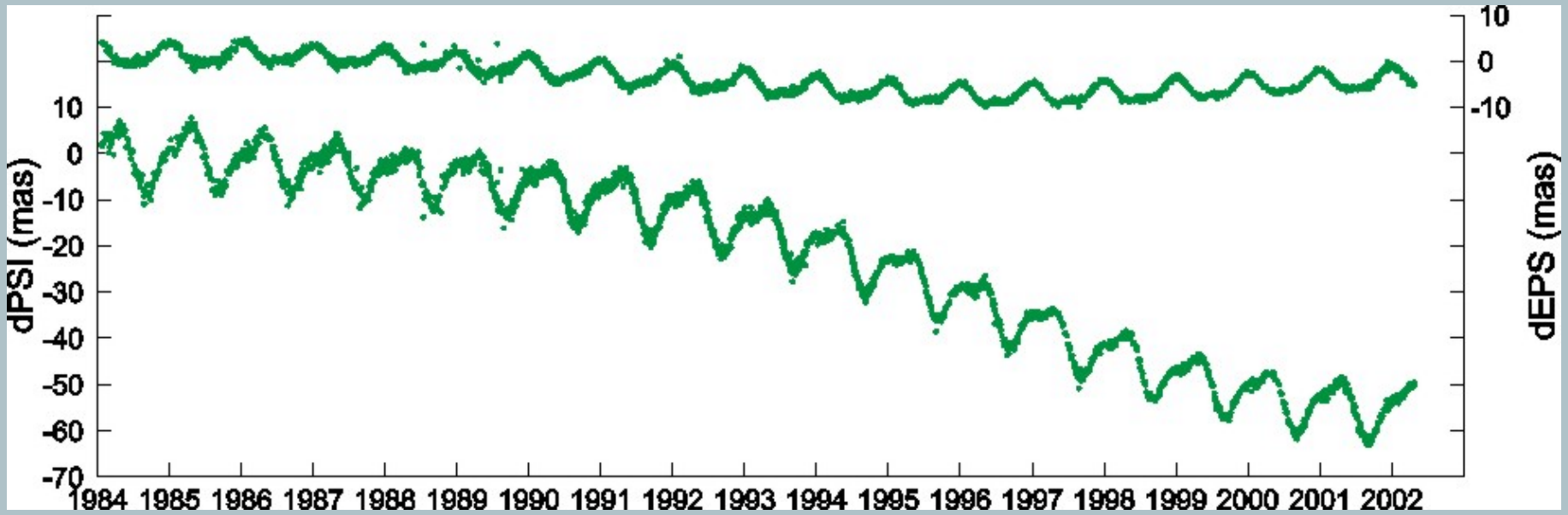

Goddard Space Flight Center VLBI solution KB 2003cn version 01
NUVEL1A-NNR reference frame.

Relation between
the reference frames:

===> Earth orientation
and rotation



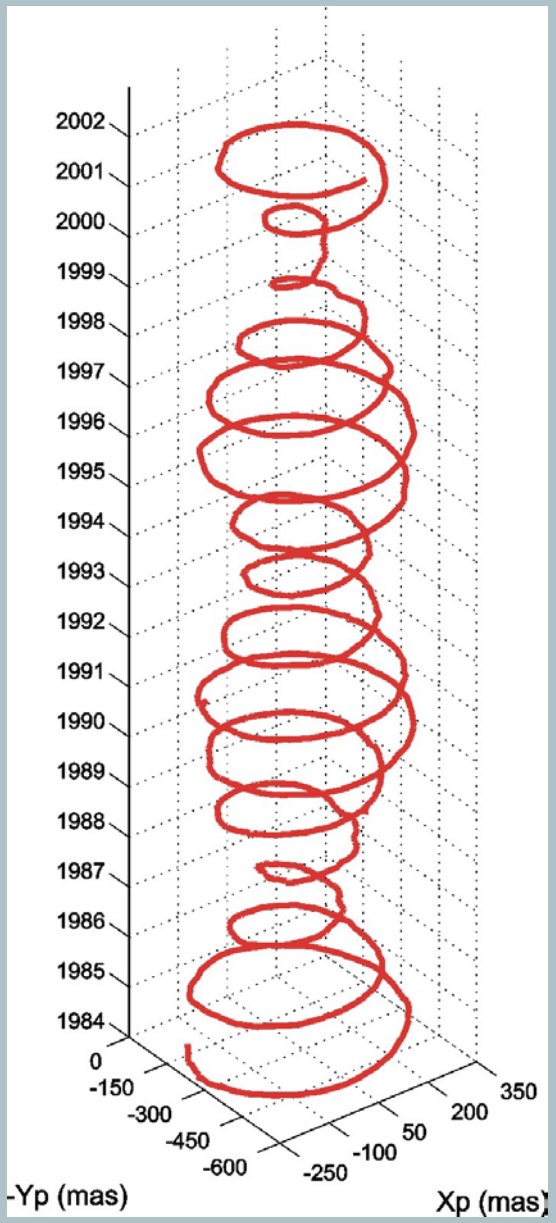
Example:
VLBI corrections to the IAU1980 nutation model.



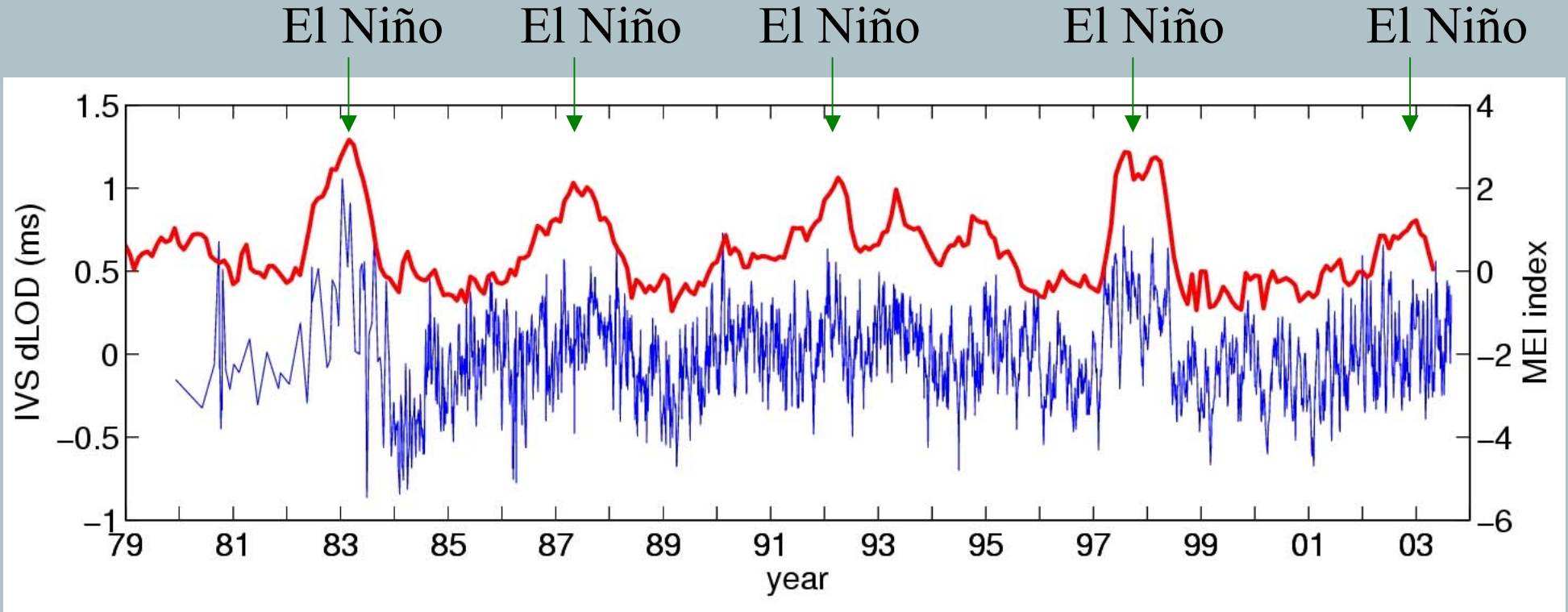

==> The new IAU2000 nutation model has been developed, based on theory and geodetic VLBI results.

Example:
Polar motion results.

==> Mainly superposition of
annual component and
Chandler component

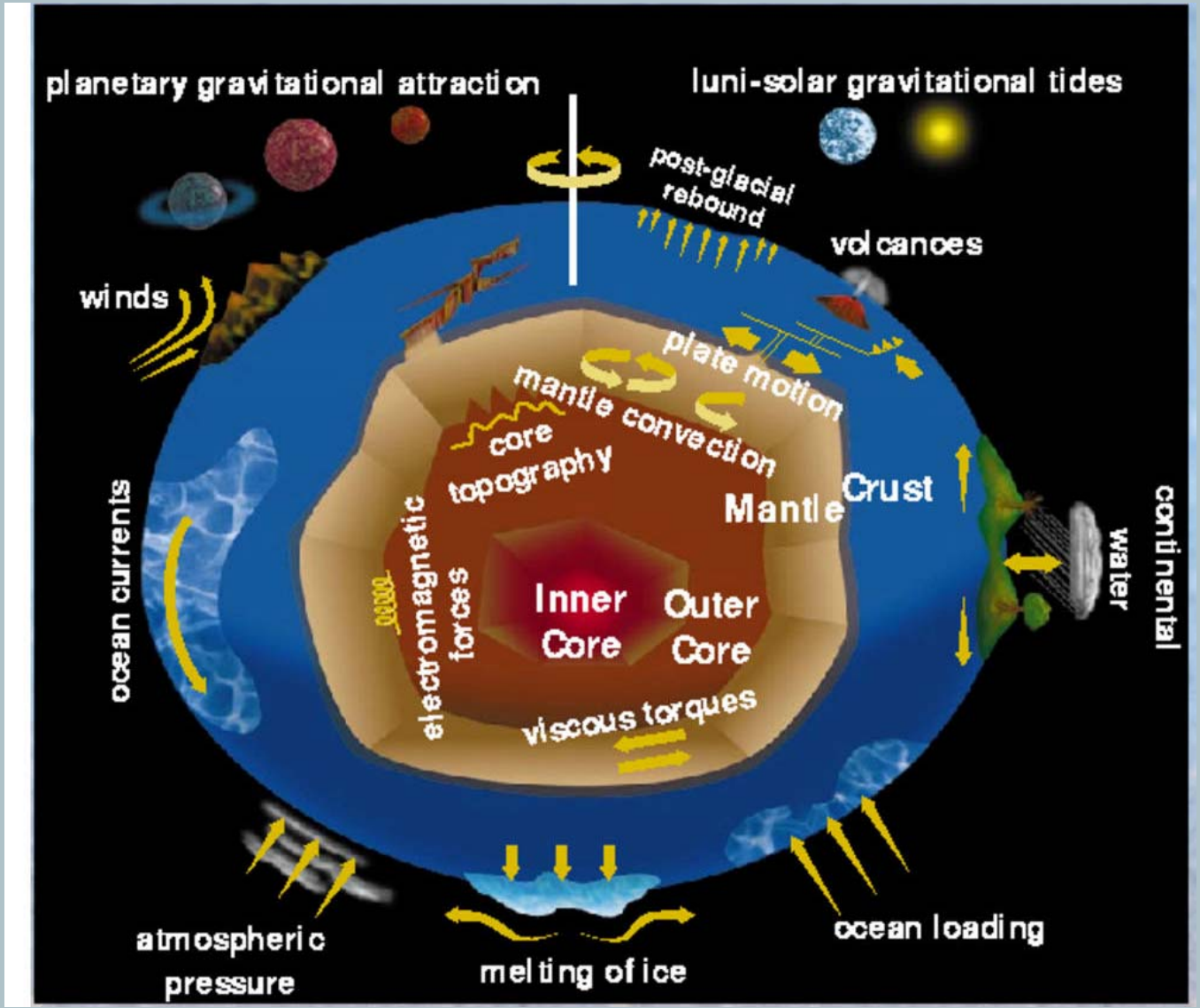


# Example:
# Earth rotation in terms of length-of-day (lod) changes




=> El-Niño/Southern Oscillation (ENSO) effects detectable

# Geodynamic processes:



# Observing strategies and observables (cont.):

Dedicated IVS observing series today:

- Multi-station 24h EOP sessions twice a week
- Two-station 2h UT1 sessions 6 times a week
- Multi-station TRF sessions 3-4 times per year
- Multi-station CRF sessions 6 times per year
- R&D-sessions a couple of times per year

# Observing strategies and observables (cont.):

- Schedules optimized for sky coverage, i.e. observing widest possible distribution of radio sources per time interval
- Consequences: large slewing ranges, phase coherence between succeeding scans gets lost
- => geodetic VLBI observable: group delay $\tau$
- Precision today on the level of 10 pico-seconds, (not high enough for the goal to have reference fames on 1 mm level)

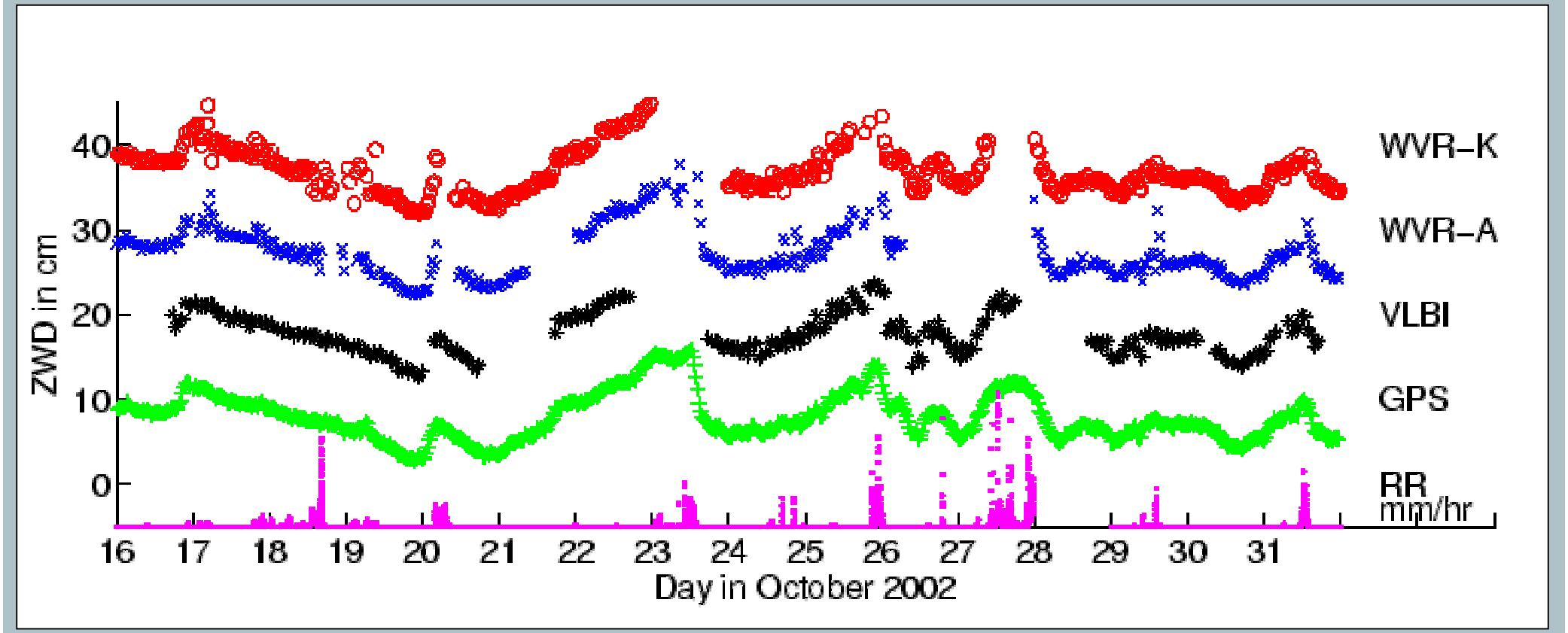
# Data analysis strategies:

- Two type of parameters: ”arc” and ”global”
- Arc-parameters are valid only for one session, e.g. polar motion, tropospheric parameters
- Global-parameters are valid for more than one observing session, e.g. radio source position, station positions and velocities, relativistic parameters

# Data analysis strategies (cont.):

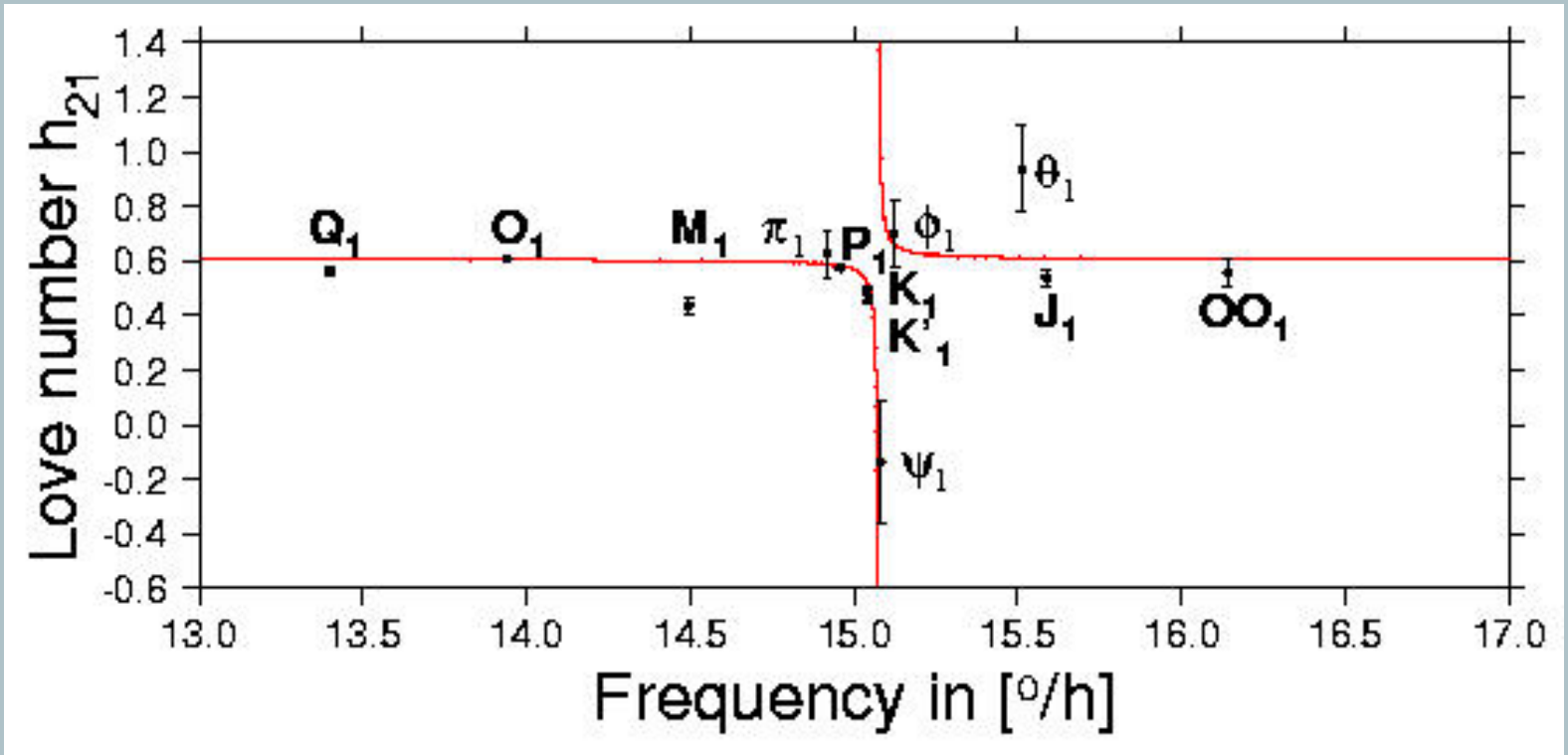
- Single-session analysis (SSA): one session (usually 24h) analysed, only arc-parameters can be determined
- Global analysis(GA): many sessions are analysed together; global parameters: solved based on accumulation of reduced normal equations; arc-parameters are determined by back-substitution of the estimated global parameters

# Data analysis strategies (cont.):




Example SSA: Zenith wet delay ( ZWD) at Onsala during CONT02.

# Data analysis strategies (cont.):




Example GA: Love number h derived from global VLBI analysis.

# Data analysis software and modelling:

Analysis methods used today:

- Least-Squares (LSQ)
- Least-Squares Collocation (LSQC)
- Kalman Filter (KF)
- Square-Root Information Filter (SRIF)

# Data analysis software and modelling (cont.):

- CALC/SOLVE (LSQ), 7 IVS-AC, (SOLVE => HP-UX)
- OCCAM (LSQ/KF/LSQC), 4 IVS-AC
- MODEST (SRIF), 2 IVS-AC
- SOLVK (KF), 1 IVS-AC
- STEELE-BREEZE (SRIF), 1 IVS-AC
- GLORIA (LSQ), 1 IVS-AC
- VLBEST (LSQ), 1 IVS-AC, real-time software (!)
- GEOSAT (KF), 1 IVS-AC, multi-technique software
- VORIN (LSQ)
- ERA (LSQ)
- GINS (LSQ), multi-technique software
- QUASAR (LSQC)

# Data analysis software and modeling (cont.):

- Data modeling following the IERS Conventions
- Transition IERS Conv. 1996 => 2003
- Includes state-of-the art relativistic modeling, tidal modeling, precession-nutation, S/X based ionospheric corrections, etc.
- Data input in binary format (VLBI data bases) or ASCII format (NGS-cards)
- IVS-PIVEX-project ongoing: goal to establish a platform independent exchange format

# Data analysis software and modeling (cont.):

Restrictions today:

- RFI problems in particular in S-band (move to K-band ?)
- Atmospheric modeling limitations (ray-tracing through numerical weather models, turbulence models ?)
- Source structure effects at S/X
- Loading models (atmosphere, hydrology)
- Thermal deformation of telescopes
- Modeling of stochastic parameters and handling of covariances

# Scientific goals today and in the future:

- Reference frames on the 1 mm accuracy level
- TRF: Improved treatment of periodic and aperiodic effects
- CRF: densification of CRF catalogue, observation of weaker sources
- Connection to dynamical reference frames (observing satellite signals, e.g. GNSS)

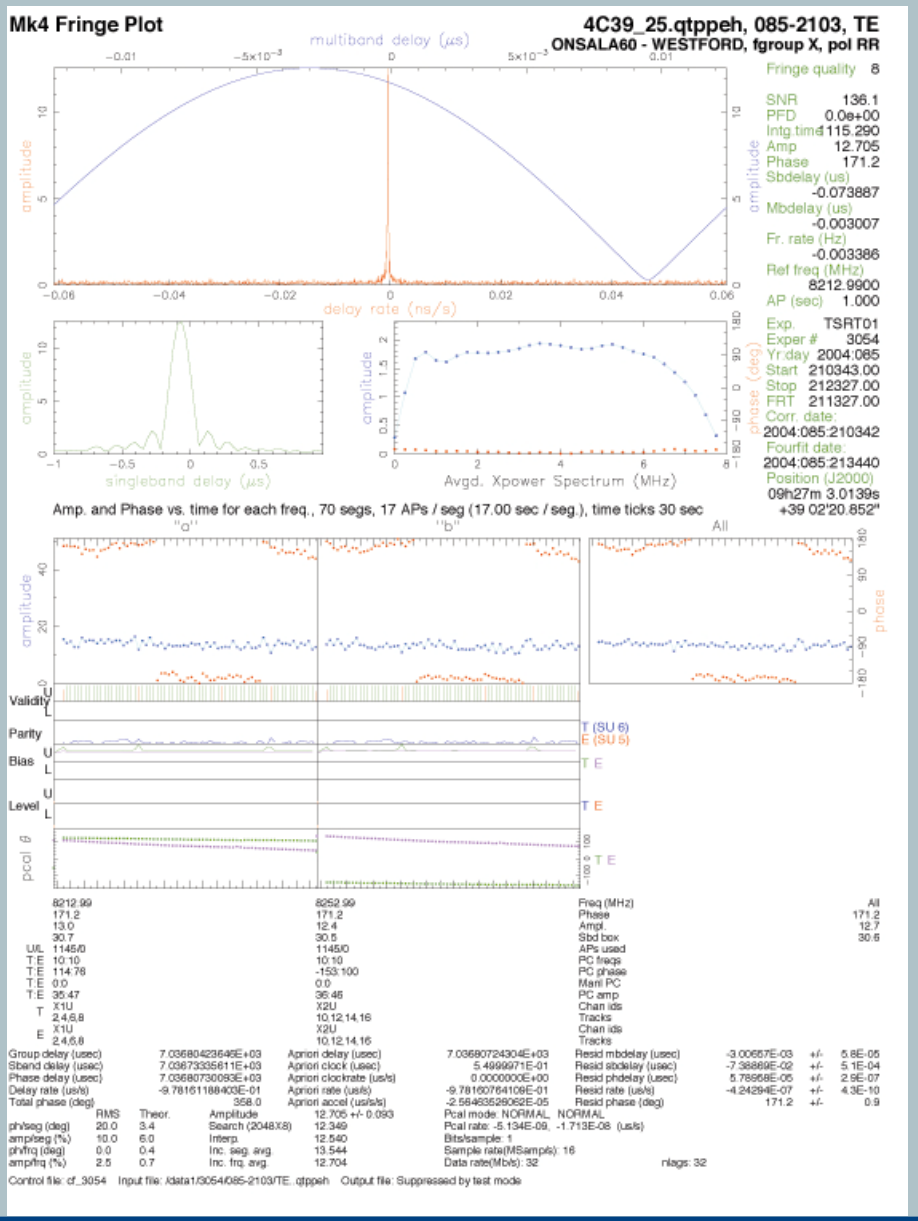
# Scientific goals today and in the future (cont.):

- Sub-diurnal EOP with high resolution
- Detection of transient geodynamical effects
- Processes in the earth's interior, e.g. Free Inner Core Nutation (FICN)
- Free oscillations of the earth

- Use of phase-delays
- Exploiting real-time e-VLBI

2004,March 25:
First inter-continental
real-time fringes
Onsala-Westford

1968:
First inter-continental
VLBI fringes
Onsala-Westford



# Why real-time eVLBI for geodesy?

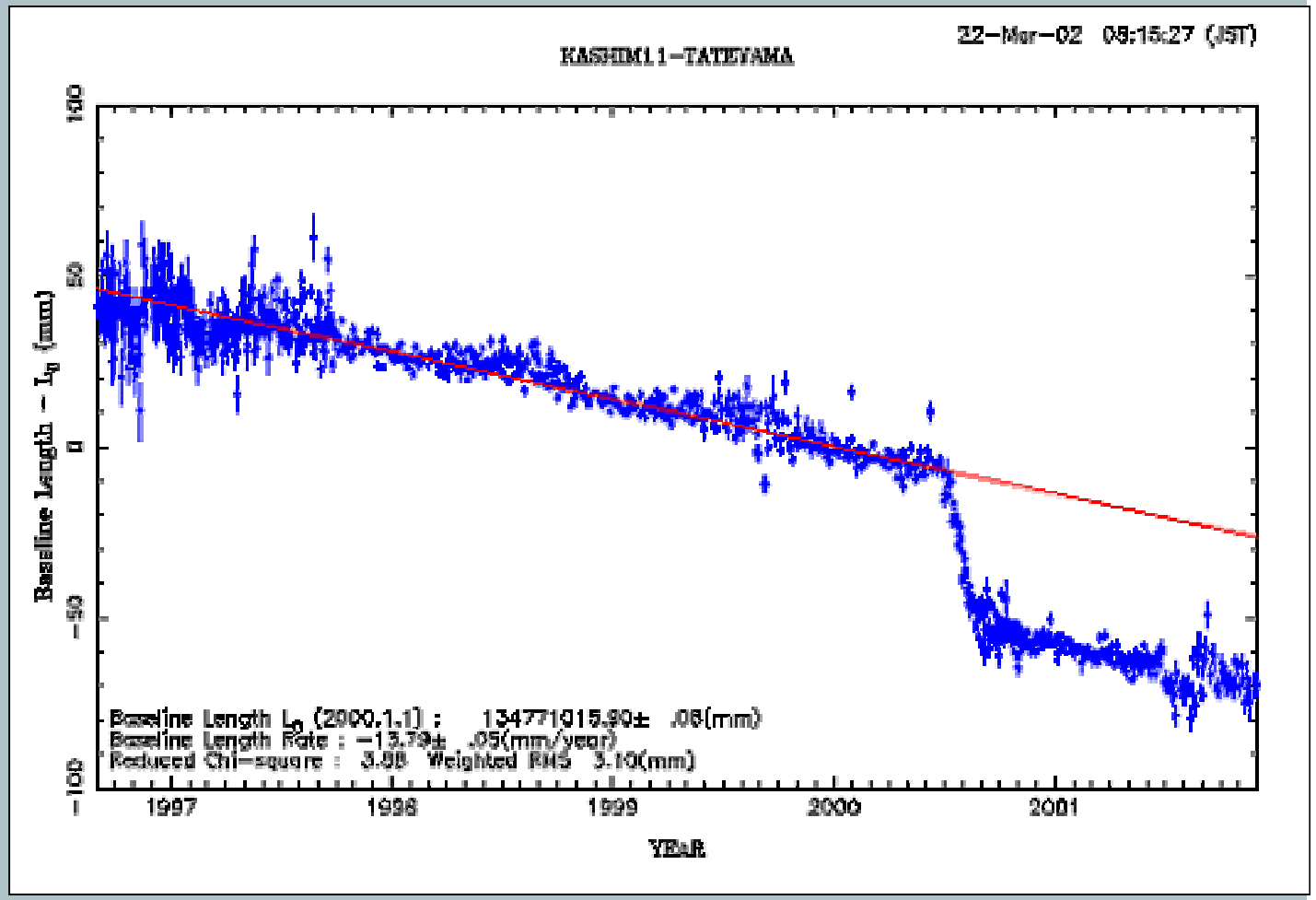
- Earth rotation investigations, in particular UT1
- Service for GNSS
- Space navigation (e.g. NASA Mars lander needed near-real-time UT1)
- Offers flexibility for investigation of transient geophysical effects, e.g. earth-quakes, co-seismic and post-seismic deformations, volcanic erruptions, etc.

Example HF-EOP:

Detection of 8h period in CONT02 polar motion.

Example transient effects:

Crustal motion in Japan, Keystone project



# Necessary improvements today and in the near future:

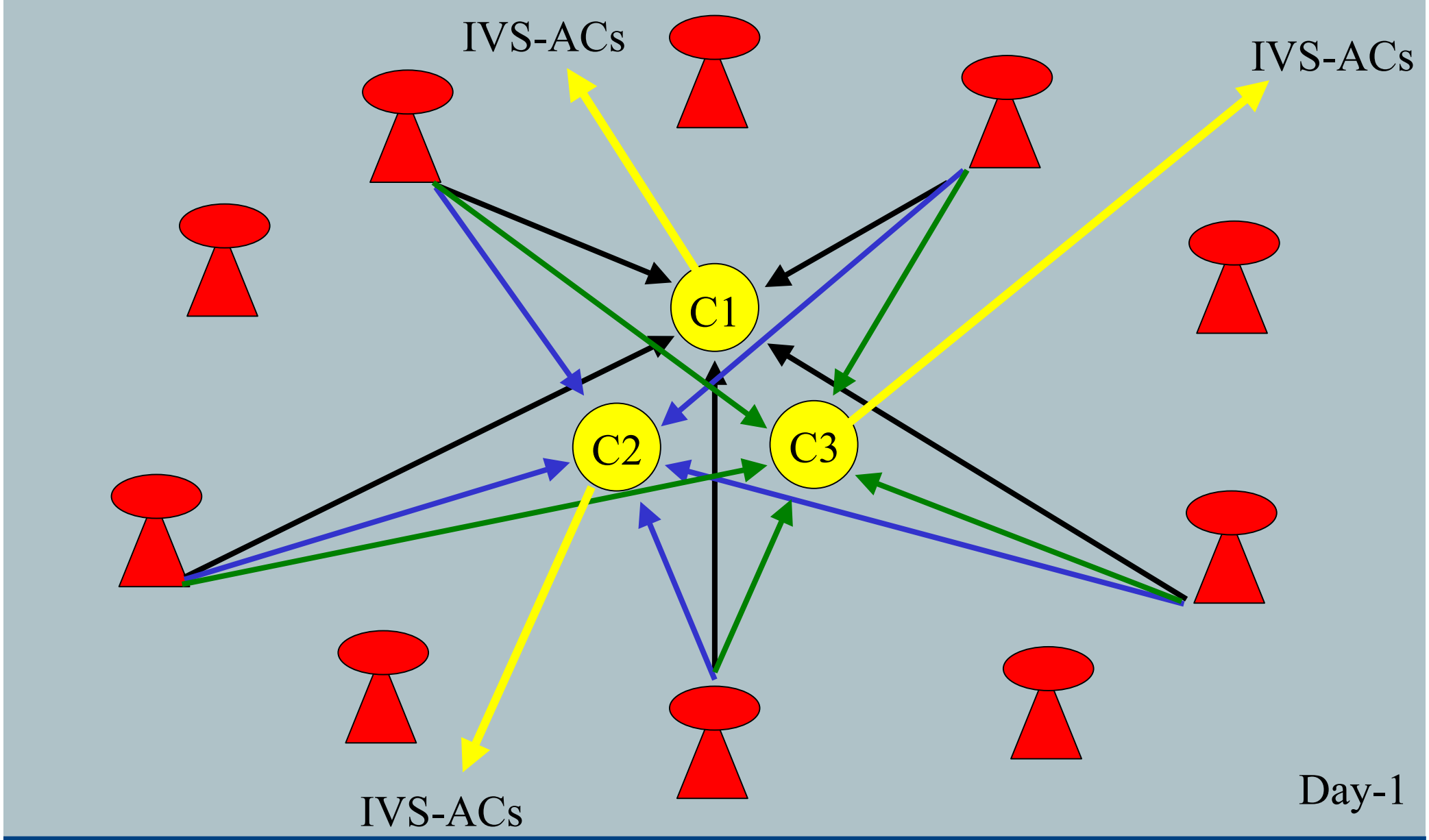
Technical improvements:

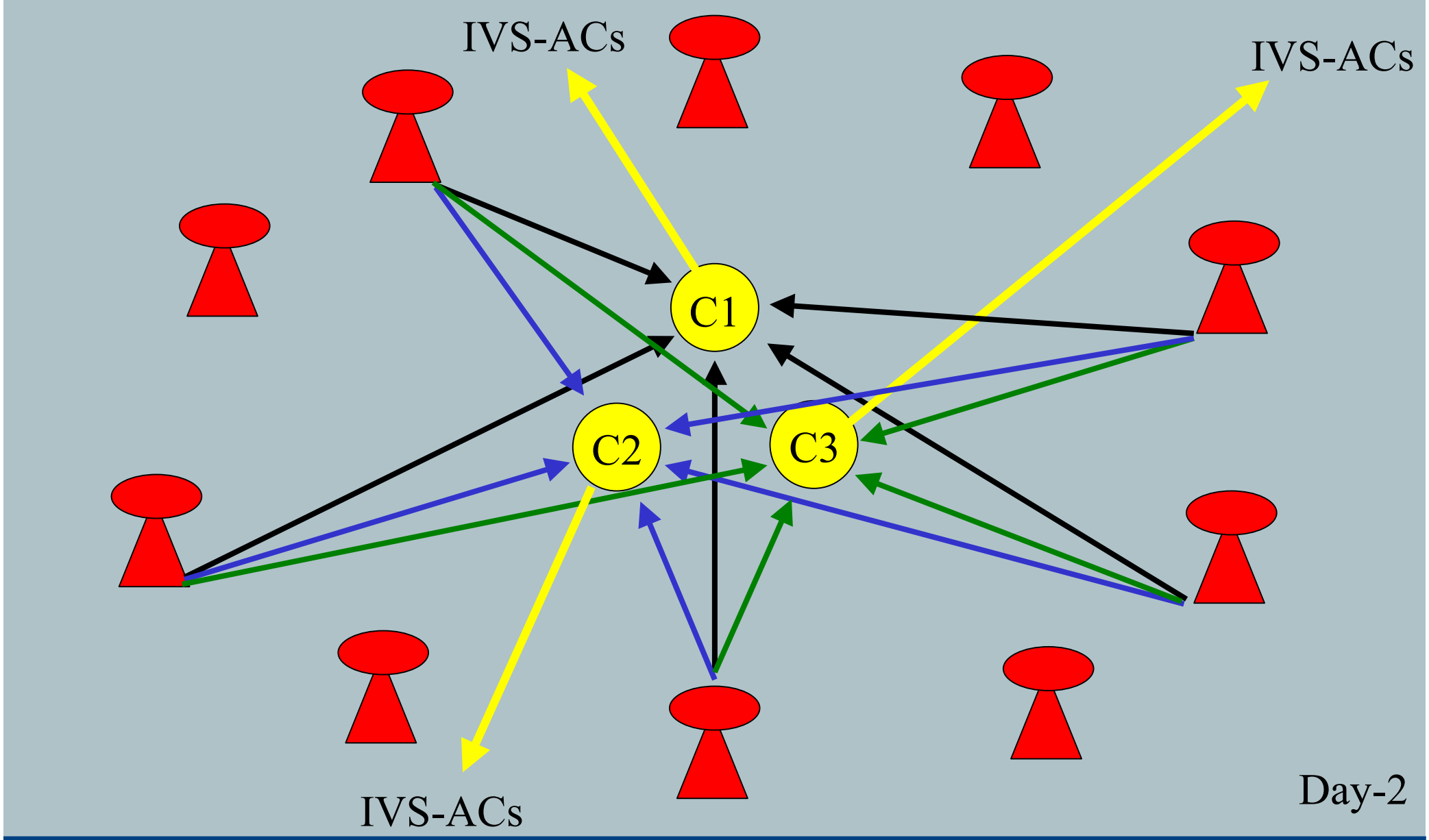
- Additional observing frequencies (L-to K-band ?)
- Telescopes as line-of-sight WVR's (?)
- Establishment of new telescopes
- Approaches to make possible the use of phase-delays for geodesy (e.g. 2 telescopes per site)
- Monitoring of local deformations (e.g. thermal)

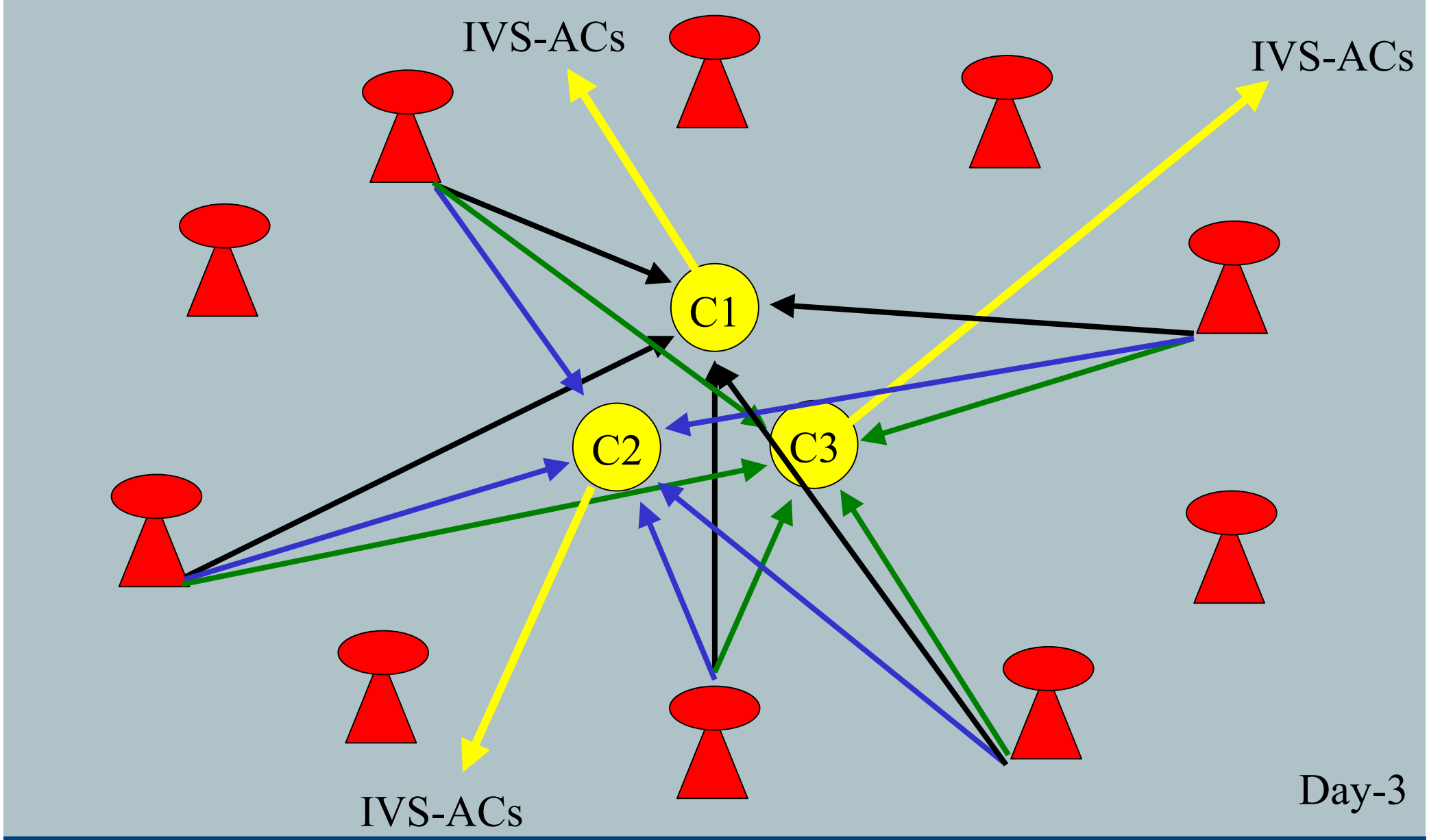
# Necessary improvements today and in the near future (cont.):

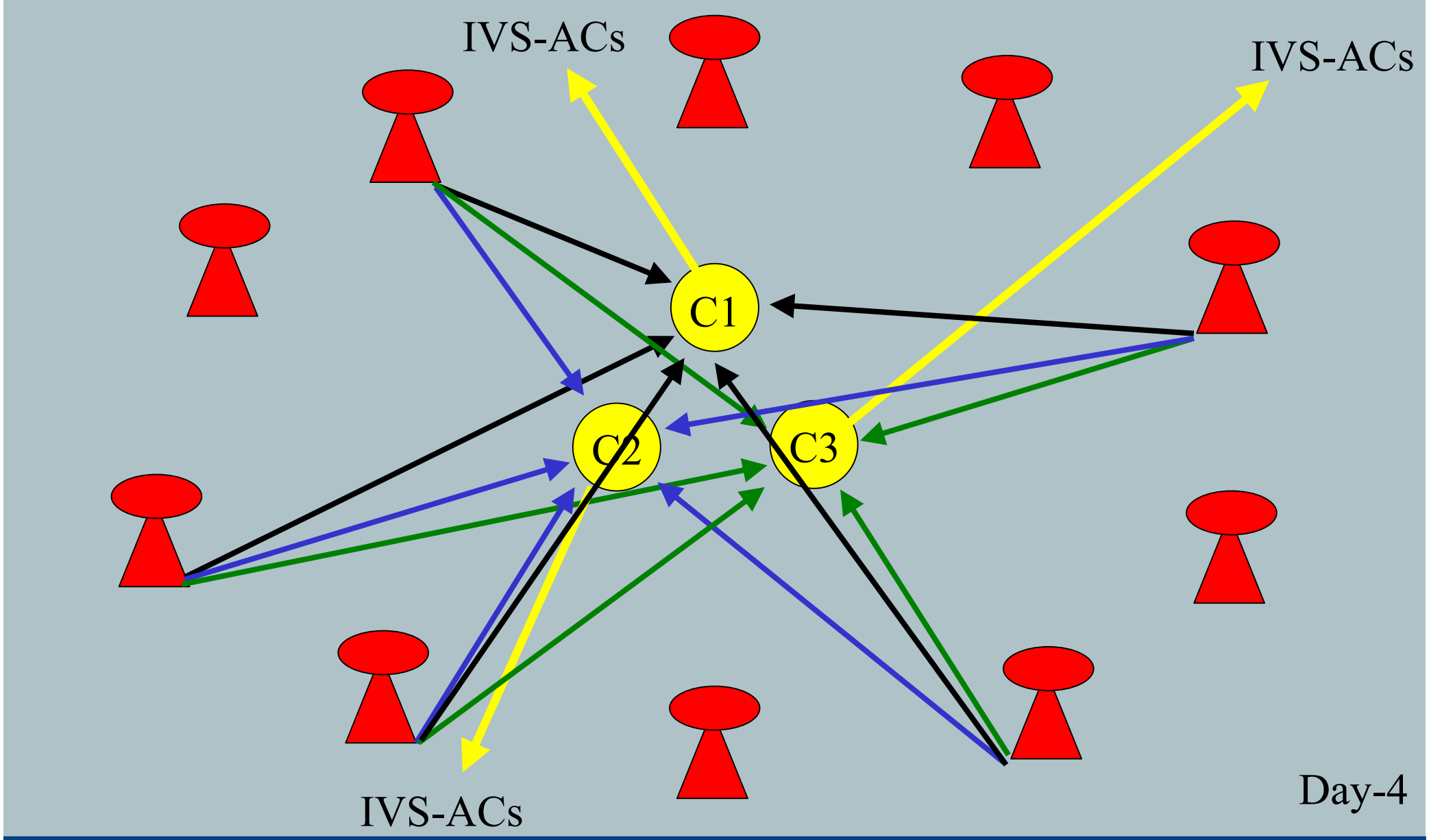
Observing and analysis improvments:

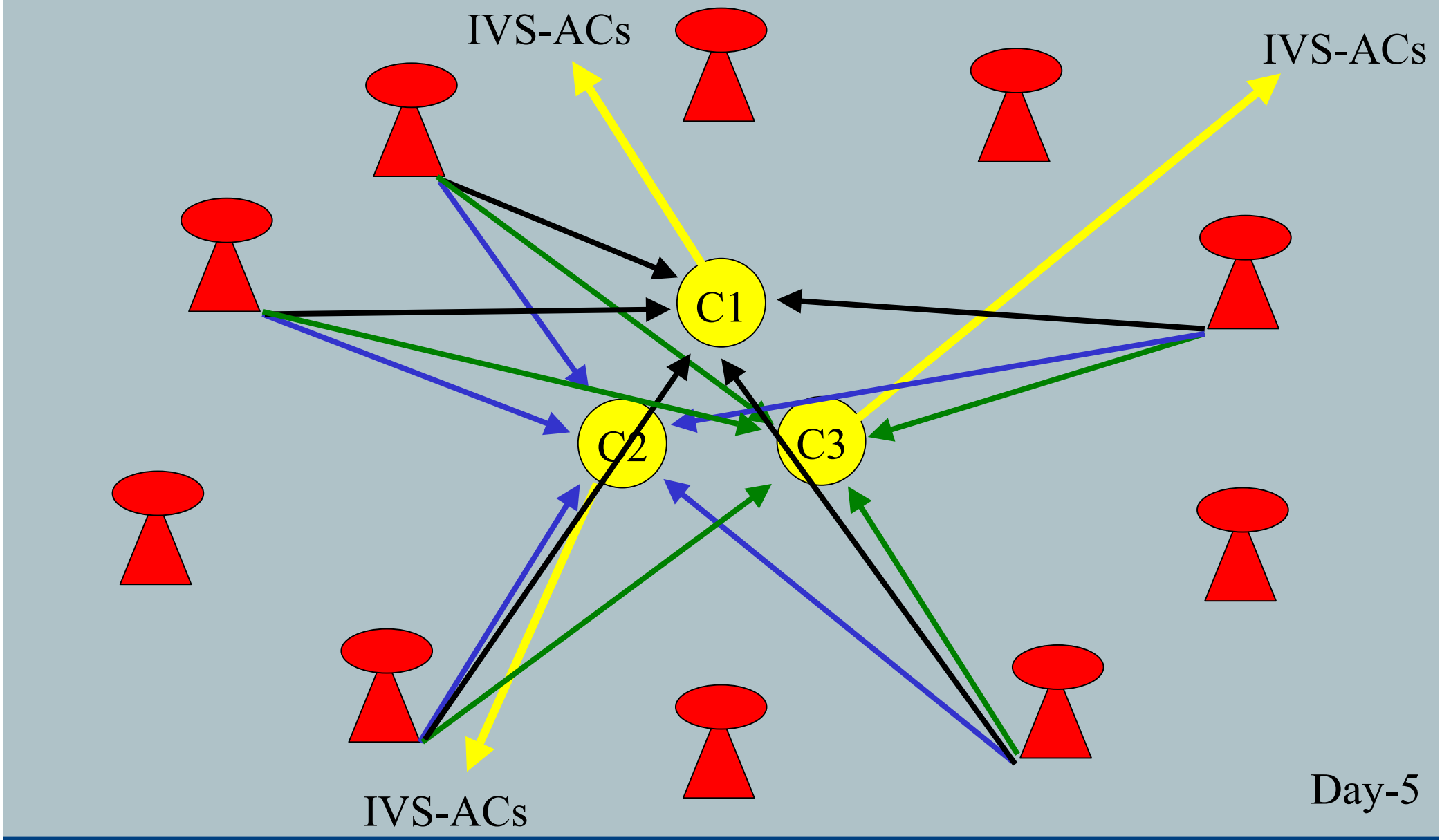
- Holistic approach to observing strategy and data analysis strategy, i.e. not strictly seperating into reference frames and geodynamics
- Continuous geodetic VLBI with changing networks using real-time e-VLBI
- Analysis software has to reflect these developments
- Ability to handle more frequencies than S/X
- Ability for real-time automated analysis

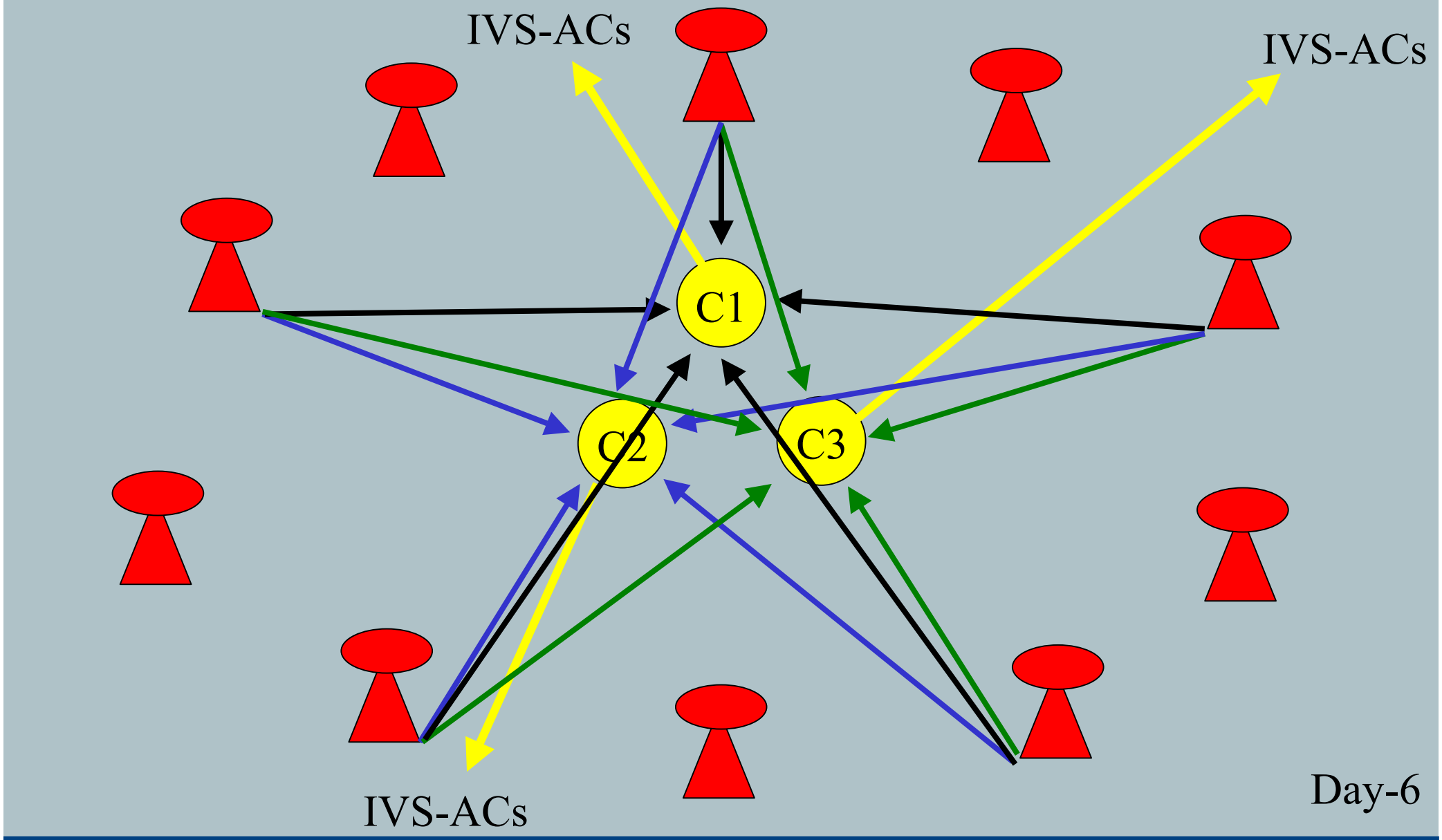

IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-1

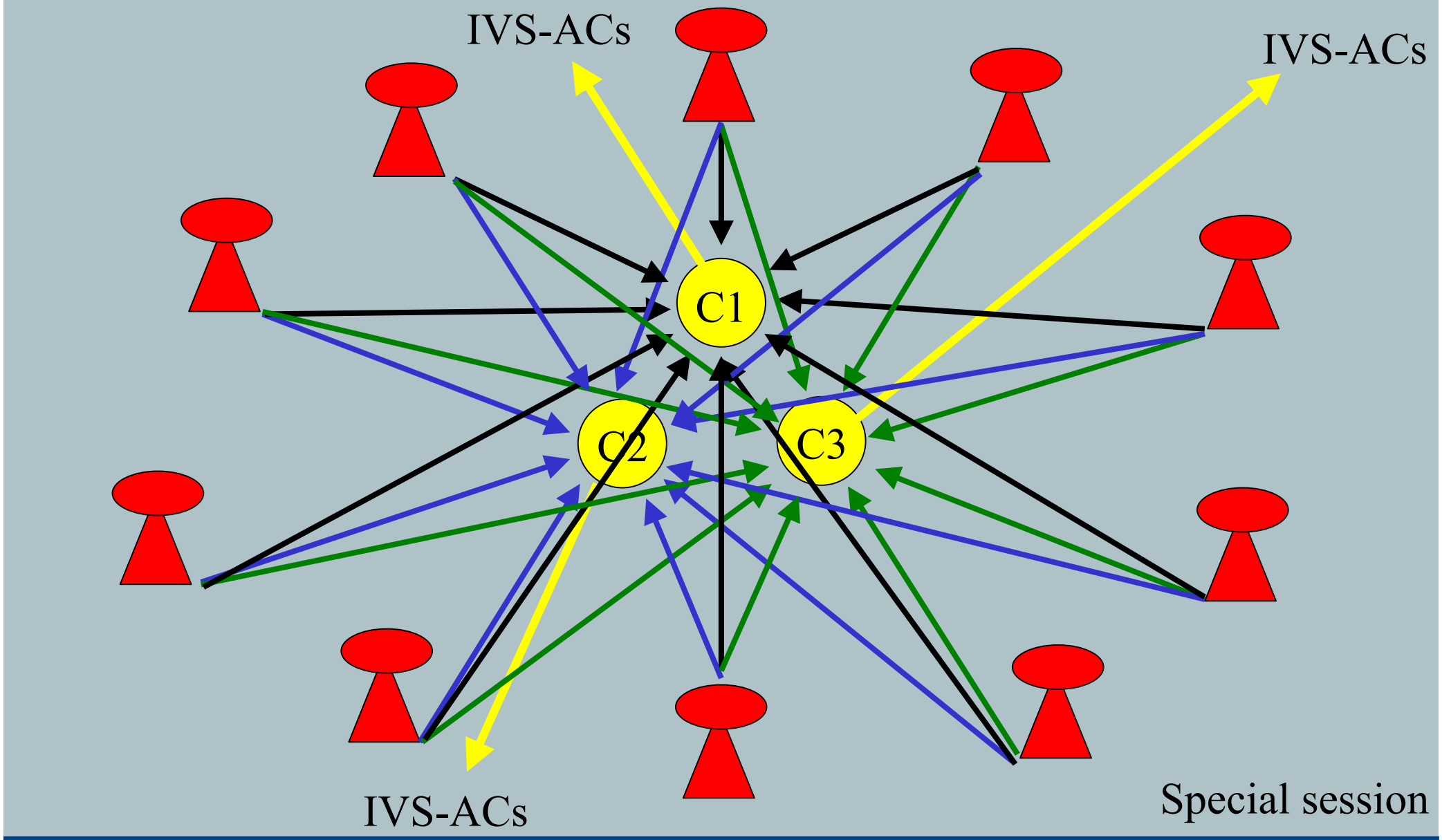

IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-2


IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-3


IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-4


IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-5


IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Day-6


IVS-ACs
IVS-ACs
C1
C2
C3
IVS-ACs
Special session

Programme starts in September

Closing date for applications is February 15

# Study Space Techniques in Sweden

For a final programme please see www.oso.chalmers.se/int-masters-prog


Odin. A Swedish millimetre wave astronomical and remote sensing satellite built in collaboration with France, Finland and Canada. The programme course topics are displayed in the figure.

International Master's Programme

## Advanced Techniques in Radio Astronomy and Space Science

The radome enclosed, 20m diameter millimetre telescope at Onsala Space Observatory, located less than an hours drive from the centre of Göteborg.

The programme provides directed systems training at Masters level with applications and training that will also fit the graduate for an industrial career in the communications and space industries. Today's space research and radio astronomy – especially the environmental research carried out at Chalmers – involve microwave and millimetre-wave devices just as does the communications industry. The course fills a niche in astronomy, space research, and microwave remote sensing, as well as in the areas of communications engineering systems and antennas.

Artist impression of ALMA – the Atacama Large Millimeter Array which is a large radio-astronomical project involving Europe, USA and Japan. ALMA will consist of 64 12m antennas in the northern Chilean Atacama desert.

**International Master's programme**

- Microwave and millimetre-wave systems
- Correlation techniques and interferometers
- Information and image techniques
- Astronomy and astrophysics
- Earth-system science
- Environmental measurements from Space
- Radiative Processes

**Master's thesis**

The thesis work provides an opportunity for students to work with a research scientist in the University, in local industry or with one of our collaborating groups, internationally.

**Entry requirements**

The programme is intended for students having a Bachelor's degree in either electrical engineering or engineering physics, or any other relevant discipline. Full details available on www.chalmers.se/masters.html

**Onsala Space Observatory**

is a National Facility responsible for the two radio telescopes at Onsala and a submillimetre-wave telescope at the European Southern Observatory in Chile. Research and development embraces high sensitivity microwave and millimetre-wave receivers and instrumentation of satellites for astronomy and atmospheric research.

Research is in many aspects of astrophysics from stellar evolution to accretion discs around black holes in Active Galactic Nuclei. In addition, the Observatory is involved in research into space-based applications of radio technology. One example is the recently launched Odin satellite, where we have developed a radiometer for both astronomical measurements and environmental measurements of the Earth's atmosphere. Other projects are in the use of synthetic aperture radar (SAR), and the global positioning system (GPS).

The Observatory is representing Sweden in the APEX and ALMA projects which involves constructing and operating high frequency telescopes in Chile.

French PhD student Christophe Risacher testing his new 4 GHz low noise HEMT amplifier, which has record-breaking sensitivity.

**Further information**

**Information on the Internet**
www.oso.chalmers.se/int-masters-prog

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# Onsala Space Observatory

<== Chalmers International Master's Programme:

Advanced Techniques in Radio Astronomy and Space Science (RAMAS)

Courses e.g.:

"Interferometry in Astronomy and Geodesy"

| | |
|---|---|
| Applications | Nov. 15-Feb. 15, 2005 |
| Start | Sep. 01, 2005 |

– No student fees!
– Taught in English

Chalmers University of Technology