Monitoring of northern lights using all-sky camera networks

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Structure

- Introduction
- MIRACLE
  - Image classification
  - Time series analysis
- ALIS
  - Image classification
  - Tomography
- GAIA
- Resources

Simple explanation for aurora

The earth's magnetic field captures some of the particles streaming by in the solar wind. Once captured, these particles spiral down along magnetic field lines toward the polar regions of earth, gaining speed (and energy) in the process. When these particles collide with certain gases in the earth's atmosphere, some of the energy is converted to light. The color of the light produced is dependent on the type of molecule involved.

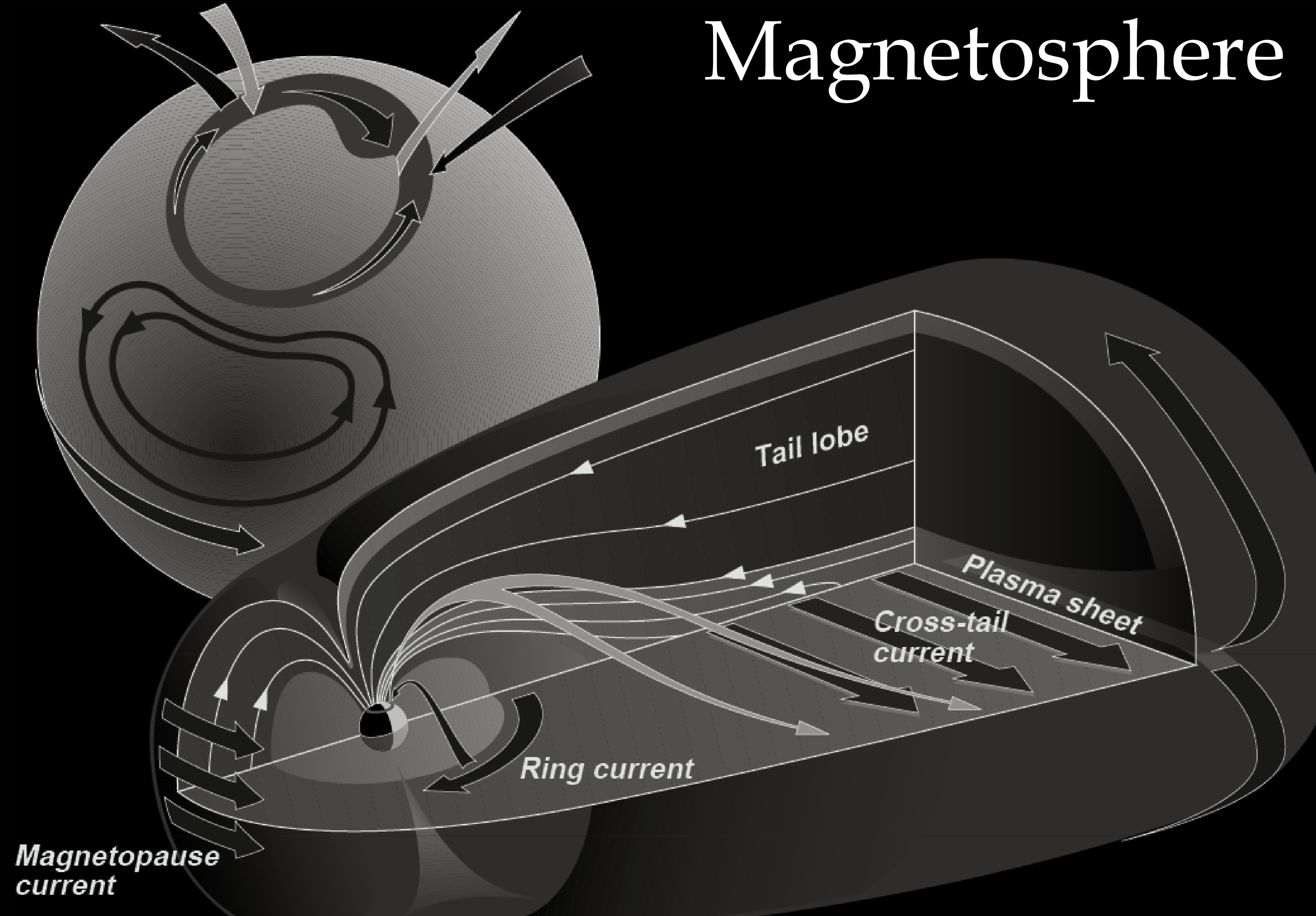
http://www.aurorasentry.net/

Another explanation for aurora

Geomagnetic field lines can guide energetic electrons and protons from magnetosphere or magnetosheath down to Earth's atmosphere. Precipitating particles loose their energy via collisions with the neutral particles and ionize them at approximately the same altitude range as solar UV radiation when creating the ionosphere. In addition, some of the atmospheric constituents are excited to higher energy levels: this can lead to emission of auroral light. Most of this activity occurs within the auroral oval (the major exceptions being the sun-aligned arcs and low-latitude aurorae).

http://www.oulu.fi/~spaceweb/textbook/auroras.html

Magnetosphere



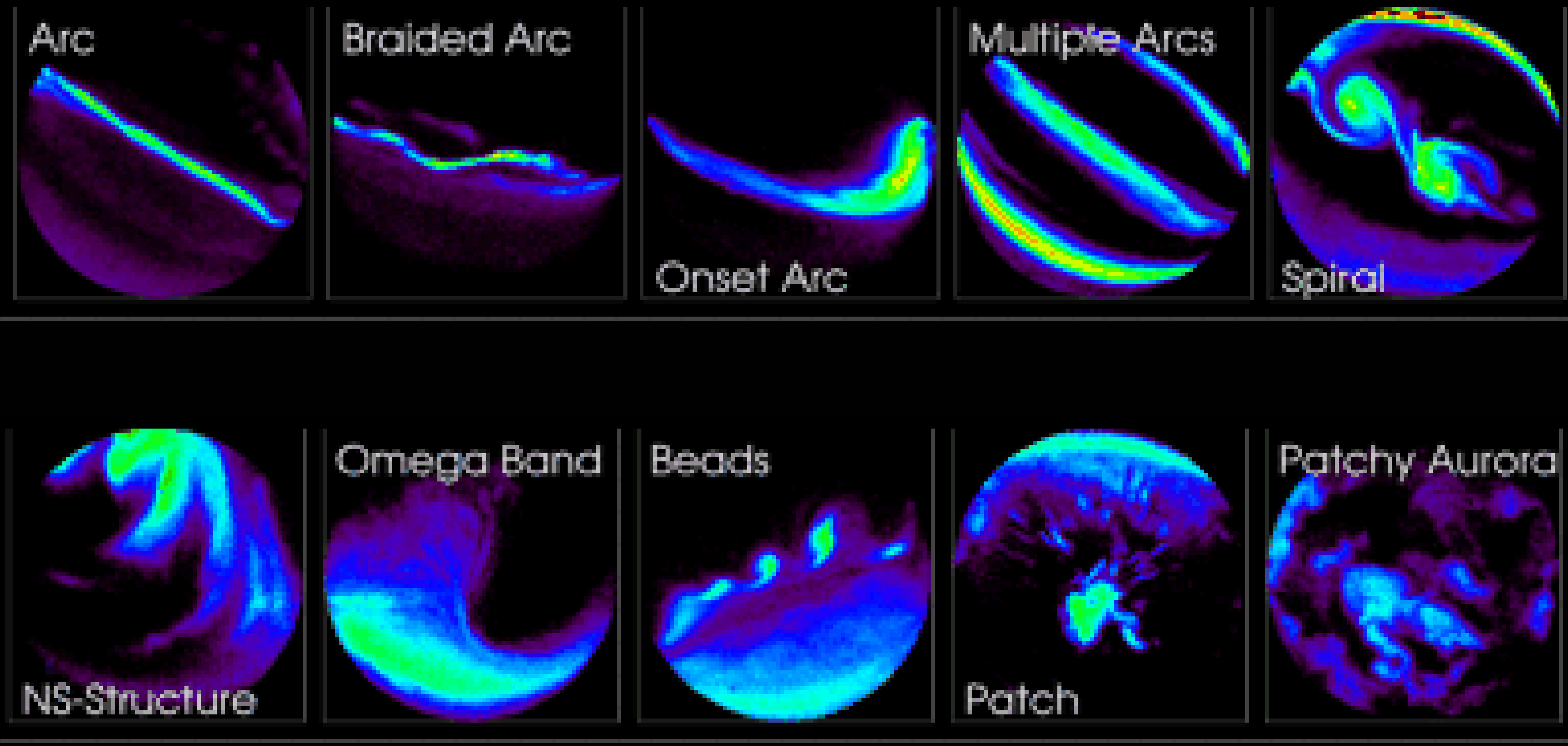
http://www.ava.fmi.fi/MIRACLE/ASC/asc-96.pdf

Discrete Auroras

- Discrete auroras are the most intense auroral types where field-aligned acceleration play an important role
- More pronounced premidnight than postmidnight
- Reflect the dynamics of the Earth's magnetotail
- Located on the poleward part of the auroral oval

http://www.oulu.fi/~spaceweb/textbook/auroras.html

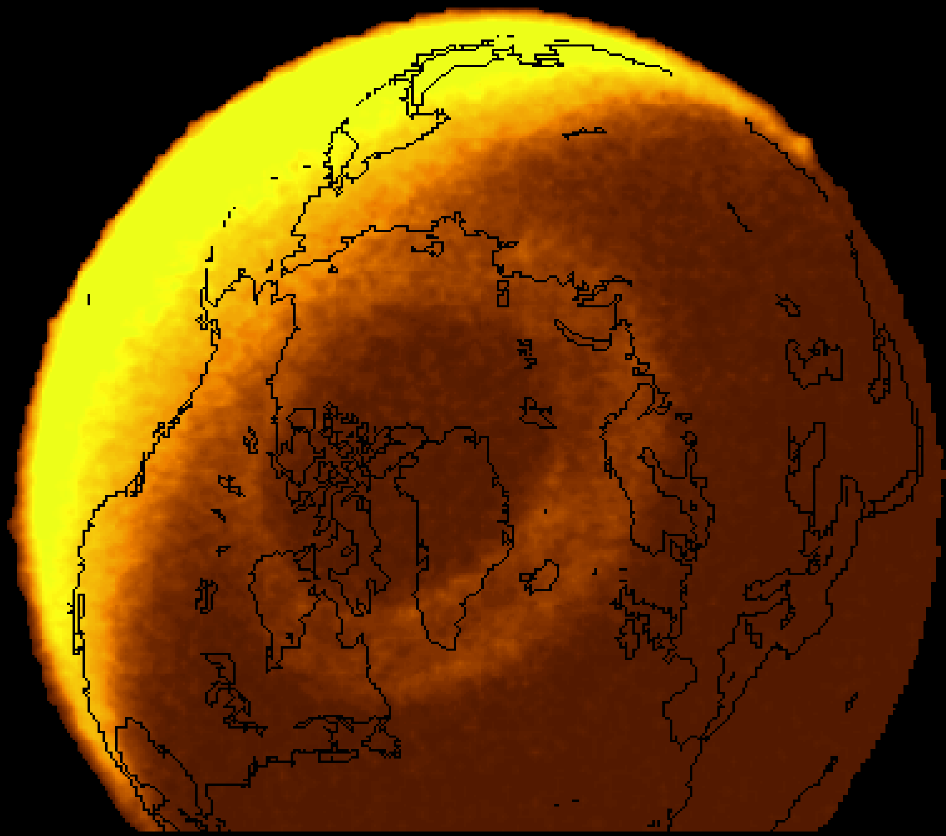
Discrete Aurora Shapes



http://aurora.phys.ucalgary.ca/norstar/asi/asi.html

Diffuse Auroras

- Not visible by naked eye
- Associated with electrons leaking out of the magnetotail instead of acceleration by electric currents
- First space observations by Lui and Anger (1973)
- Not without discrete structures; they are just too weak and difficult to observe
- Found on the equatorward part of auroral oval; often extends around entire auroral oval



http://www.oulu.fi/~spaceweb/textbook/auroras.html

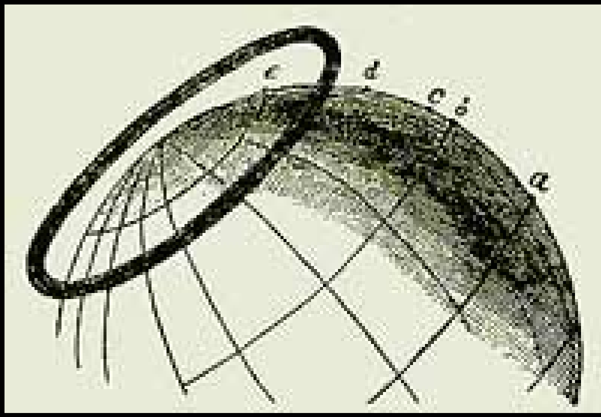
Early History

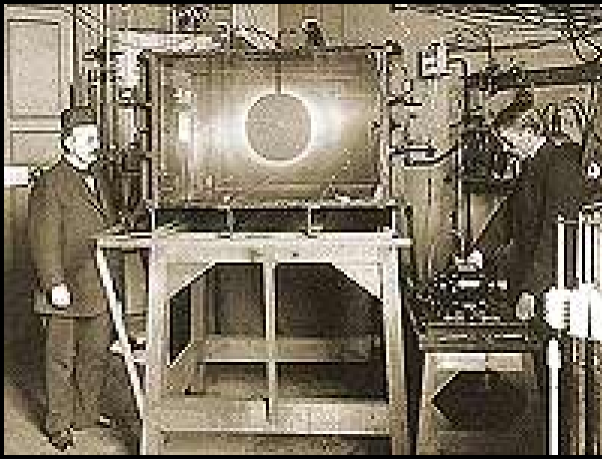
- First realistic description is found in the Norwegian chronicle the King's Mirror from about 1230 AD.
- 1700s
  - Through trans-Atlantic correspondence, established as a global phenomenon
  - Anders Celsius & Olof Hiorter: correlation with magnetic fluctiations
  - Erich Pontopidan: aurora are electric phenomena
  - Johann Wilke: auroral rays are parallel with direction of magnetic field
- 1800s
  - No trace of polarization: not reflections from other light sources

http://www.northern-lights.no/

Early History

- Sophus Tromholt (1851 - 1896): correlation with sunspot cycle, first auroral oval description
- Kristian Birkeland (1867 - 1917): terella experiments; artificial auroras; east-west current flow
- Carl Størmer (1874 - 1957): first auroral cameras, height distributions of auroras





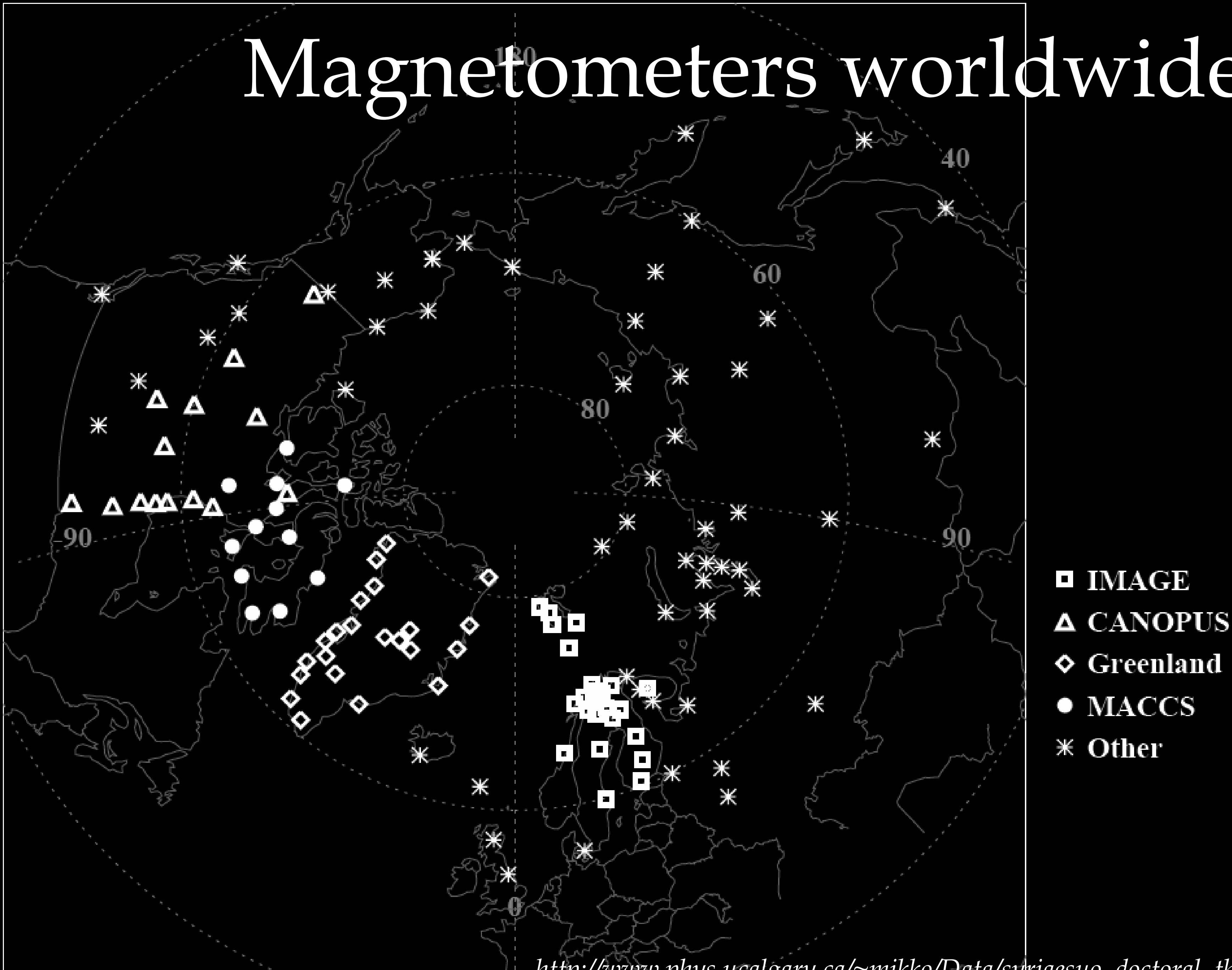
http://www.northern-lights.no/

Terminology

- Magnetometer
  - Measures magnetic field strength, used to monitor magnetospheric activity.
- Riometer
  - Relative ionospheric opacity meter. Measures the intensity of cosmic radio noise at the surface of the Earth.
- All-sky camera
  - Camera with a 180° field of view

http://www.oulu.fi/~spaceweb/textbook/instrumentation.html

Magnetometers worldwide



http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

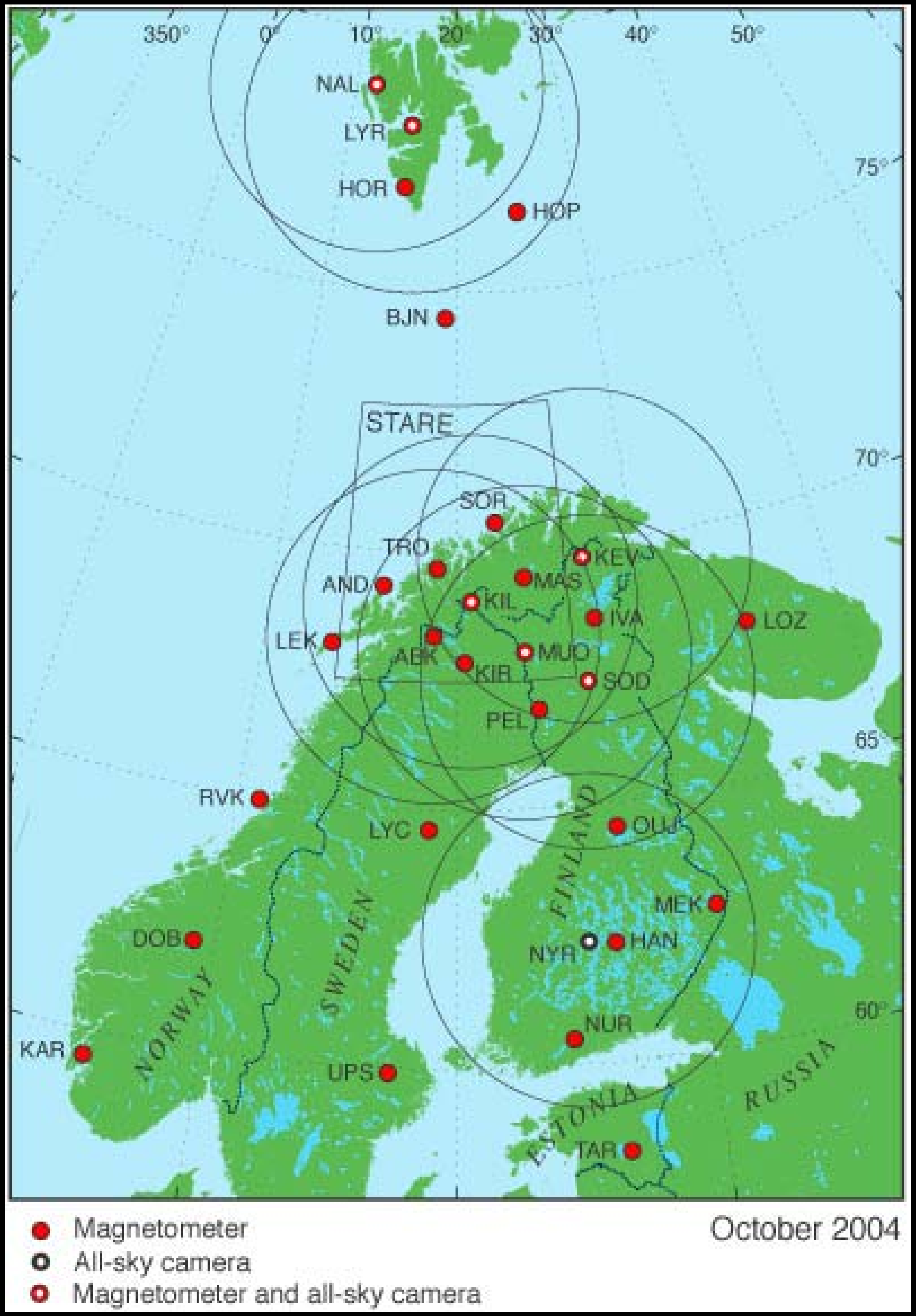
MIRACLE

- The Magnetometers - Ionospheric Radars - All-sky Cameras Large Experiment (MIRACLE)
- Two-dimensional instrument network constructed for mesoscale studies of auroral electrodynamics
- Maintained and operated as international collaboration under the leadership of the Geophysical Research Division of the Finnish Meteorological Institute.
- The various instruments have different spatial resolutions, but basically the network is designed for studies in the spatial scales from a few tens of km upward.
- In standard operation mode the time resolution of magnetic observations is 10s, while the sampling rate of STARE and all-sky cameras is 20s.

http://www.ava.fmi.fi/MIRACLE/whatis.html

MIRACLE

- Covers an area from subauroral to polar cap latitudes over a longitude range of about two hours of local time.
- The International Monitor for Auroral Geomagnetic Effects (IMAGE)
  - 29 magnetometer stations
  - most widely used part of MIRACLE both in FMI and internationally



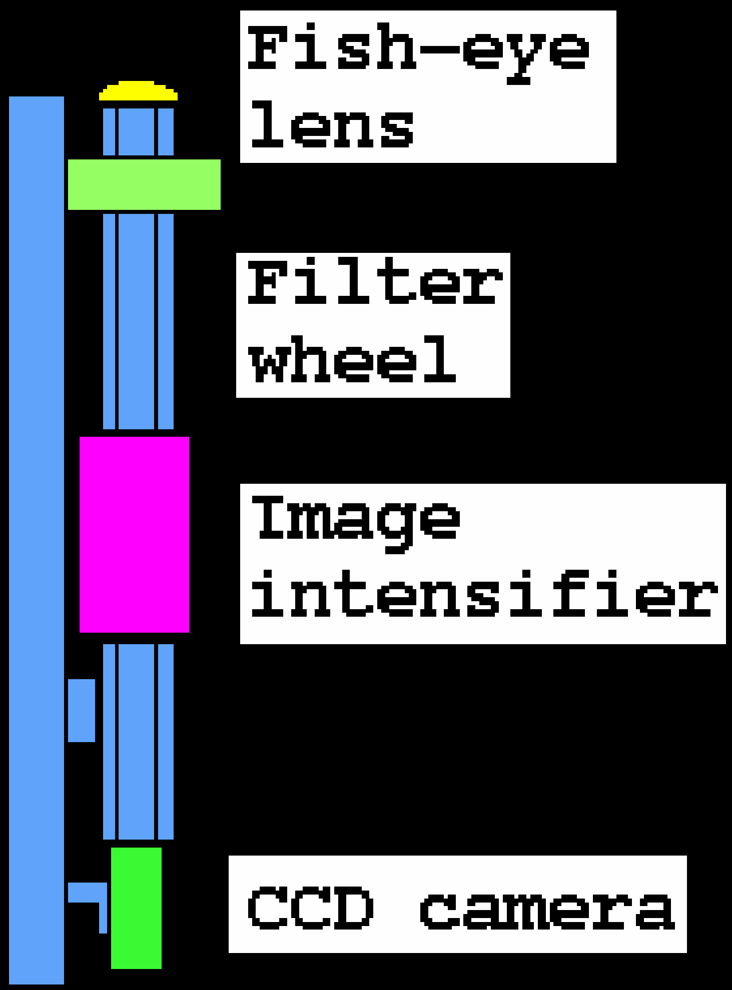
http://www.ava.fmi.fi/MIRACLE/sci_gen.html

MIRACLE ASCs

- All-sky cameras (ASCs) use special optical elements such as fish-eye lenses or spherical mirrors to acquire an image of the whole sky in one shot (hence the name).
- One ASC image covers a circular area with a diameter of about 600 km at 110 km altitude.
- The Geophysical Research Division of Finnish Meteorological Institute operates several all-sky cameras in wintertime
- Main scientific interests are in long-term auroral observations in Finland.

http://www.ava.fmi.fi/MIRACLE/ASC/

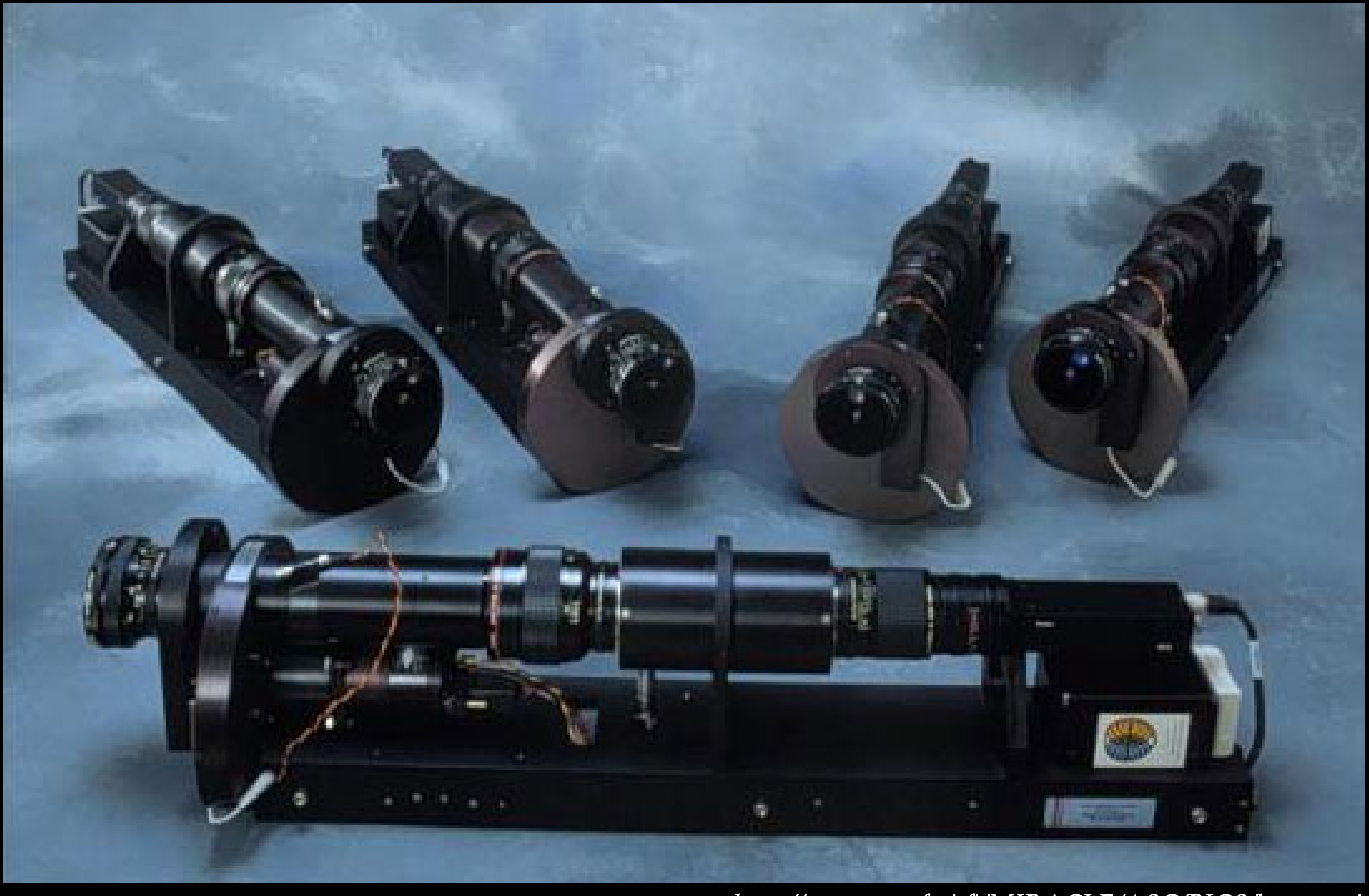
MIRACLE ASCs



- The all-sky imagers that are used in the new Finnish all-sky cameras are manufactured by KEO Consultants. Each imager has telecentric and non-vignetting optics, and the field of view of the fish-eye lens is 180 degrees.
- The filter wheel can accomodate seven narrow bandwidth interference filters. In normal operation one filter holder is left "free" to be able to acquire nonfiltered images. Every station has three filters: green, blue, and red.
- The faint images are intensified before the final image is acquired by the CCD camera (B&W) and digitised by the frame grabber card of the station computer. This intensification allows shorter exposure times with less expensive CCD cameras, and typically an exposure takes 500ms.

http://www.ava.fmi.fi/MIRACLE/ASC/asc_tech_00.shtml

MIRACLE ASCs



http://www.ava.fmi.fi/MIRACLE/ASC/PICS/kamerat.jpg

MIRACLE ASCs

http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

MIRACLE ASCs

Fish-eye lens	Canon 15mm/F2.8
Additional optics	Telecentric lens elements
Filter wheel	7-position filter wheel for 2" filters
Filters	Interference filters, 557.7nm, 427.8nm, and 630.0nm (BW 2.0nm)
Intensifier lens	Canon 85mm/F1.2
Image intensifier	Varo 25mm MCP Gen II model 3603
Reimaging optics	Canon 100mm/F2
CCD camera lens	Fujinon 25mm/F0.85
CCD camera	Pulnix 765E, 756(H)x581(V)

http://www.ava.fmi.fi/MIRACLE/ASC/asc_tech_00.shtml

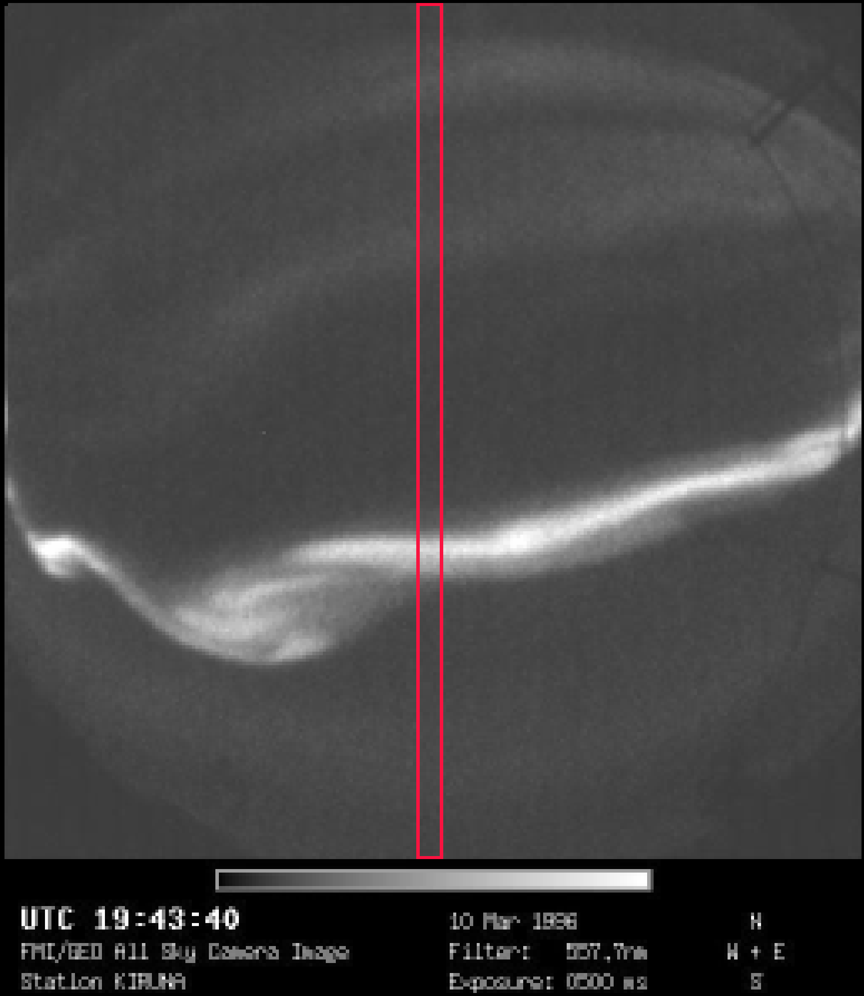
MIRACLE ASCs

- Have been used to study e.g. auroral streamers, arcs, and spirals
- Advanced machine vision methods have been utilized in the automated search routines for detecting auroral periods from the huge ASC image data base
- An inversion method adjusted for multiwavelength data from several cameras have been developed to facilitate the quantitative analysis of the acquired auroral intensities

http://www.ava.fmi.fi/MIRACLE/sci_gen.html

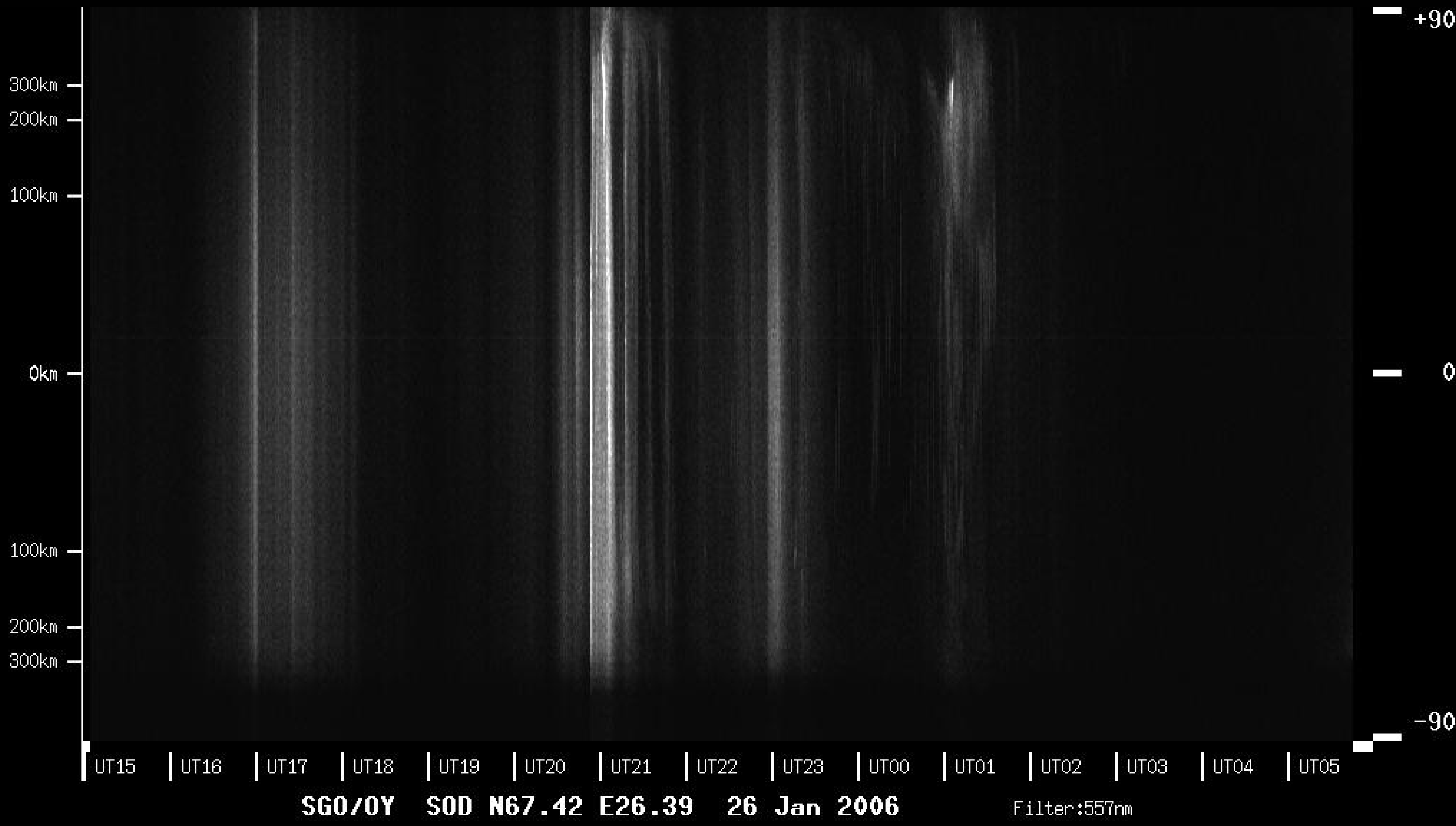
ASCs – Keograms

- Used in analysing auroral phenomena
- Created by extracting vertical pixel columns from individual all-sky images and putting the columns side by side. The horizontal axis is the time and the vertical axis is the geographical latitude.
- The name keogram comes from *keoitt* - an old Eskimoan word which means aurora borealis.



http://www.ava.fmi.fi/MIRACLE/ASC/asc_keo_00.shtml

ASCs – Keograms



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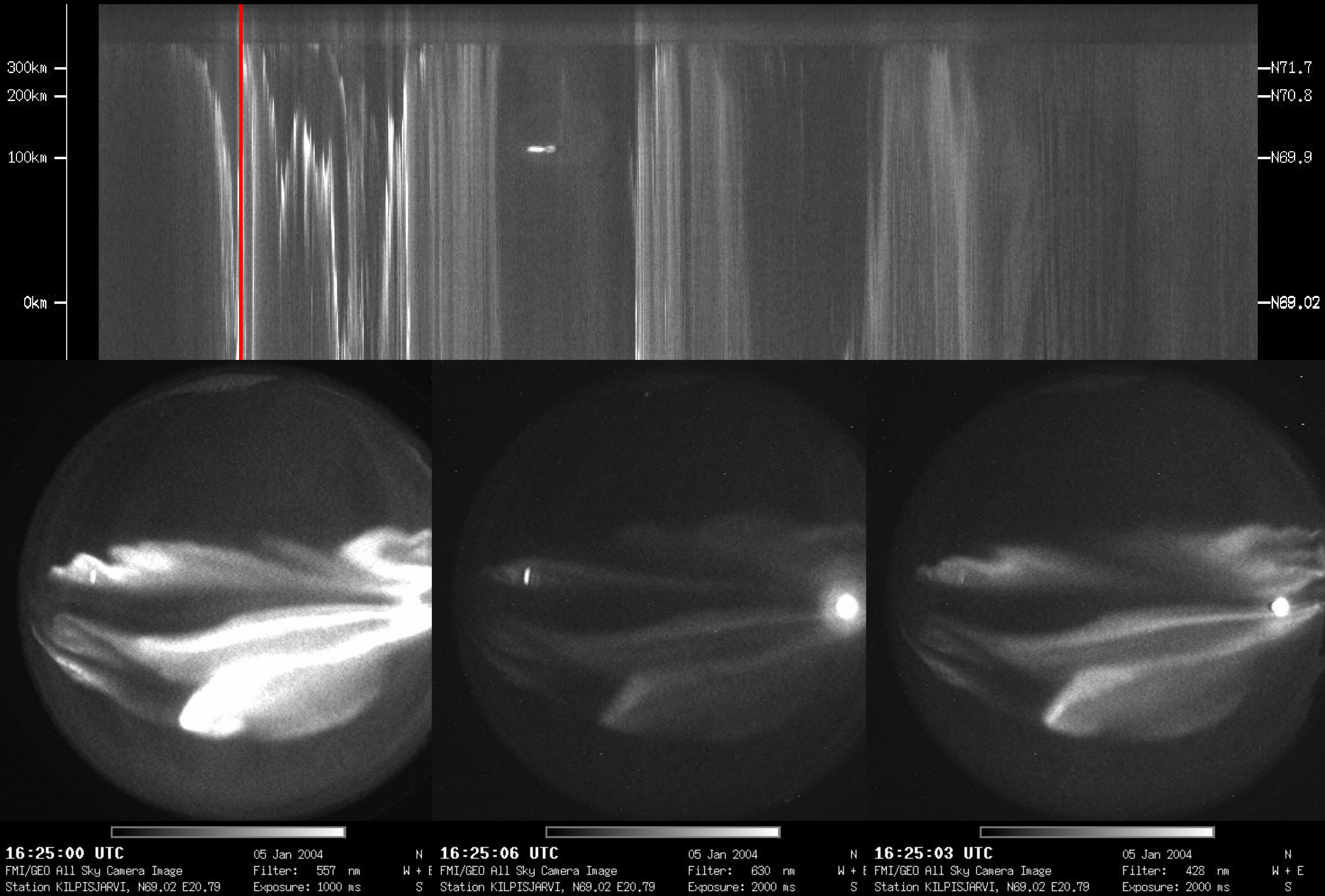
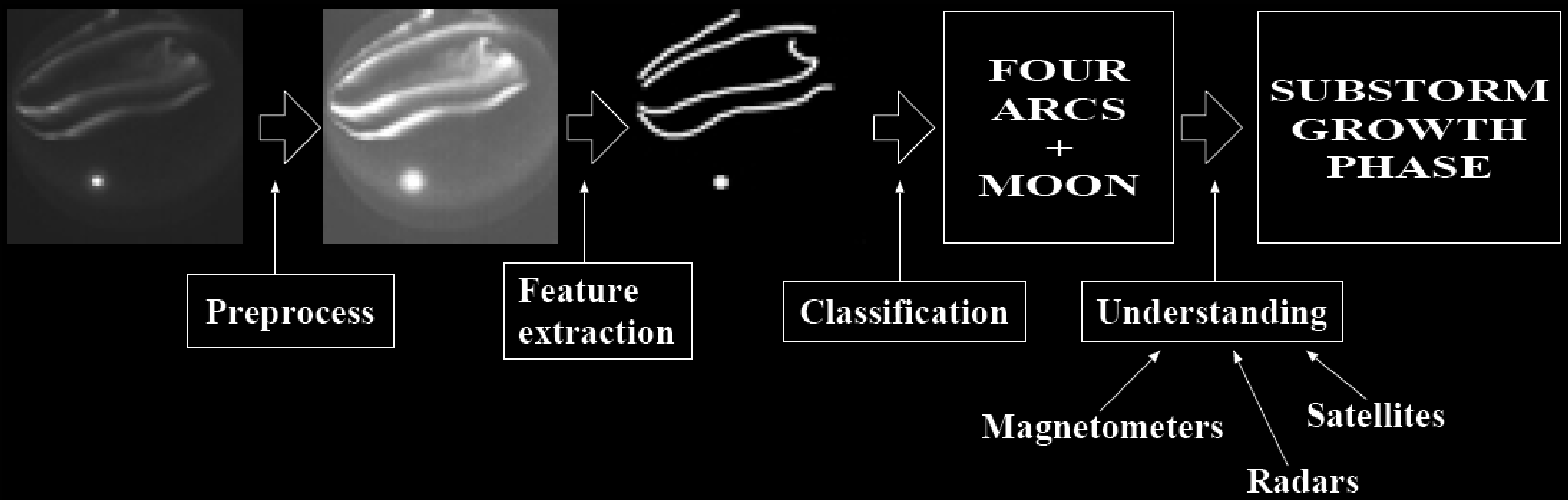


http://www.ava.fmi.fi/MIRACLE/ASC/asc_browse.html

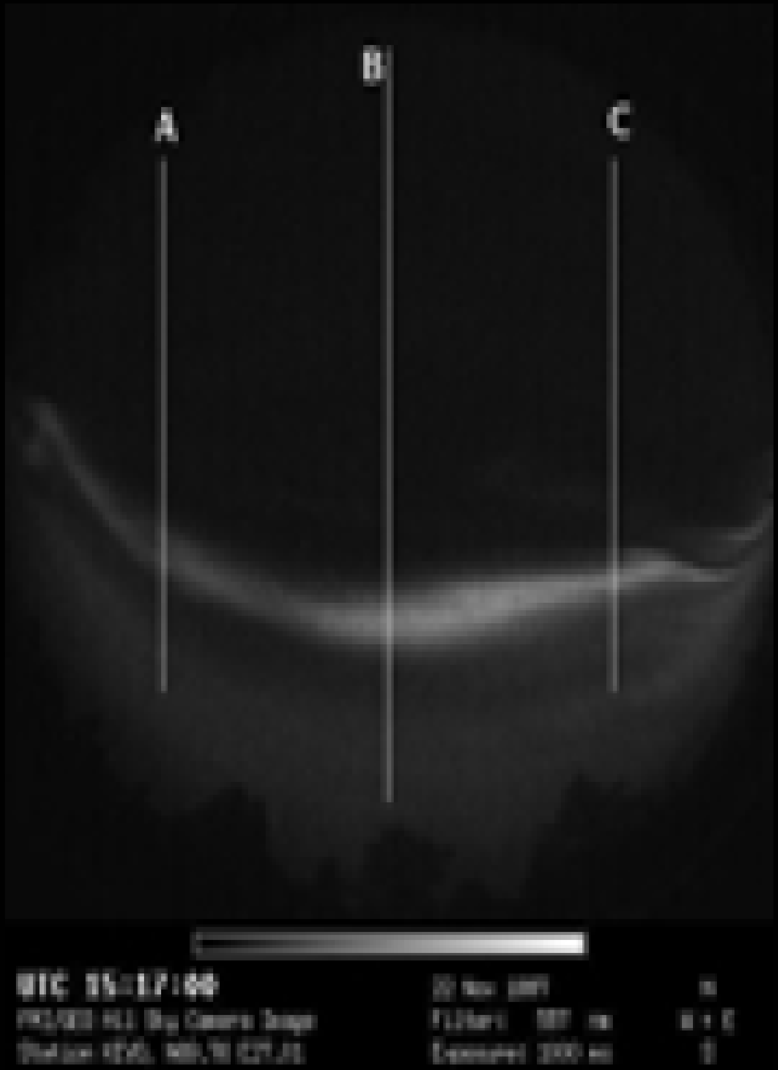
ASC Image Processing



http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

MIRACLE Image Classification

- Using brightness profiles
  - Coarse sorting to "aurora" and "no aurora" categories
  - Determined from two image features:
    - Maximum gradient calculated from a smoothed intensity profile
    - Maximum correlation of three north-south intensity profiles to a template auroral arc
  - Performs well in testing against a human expert



http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

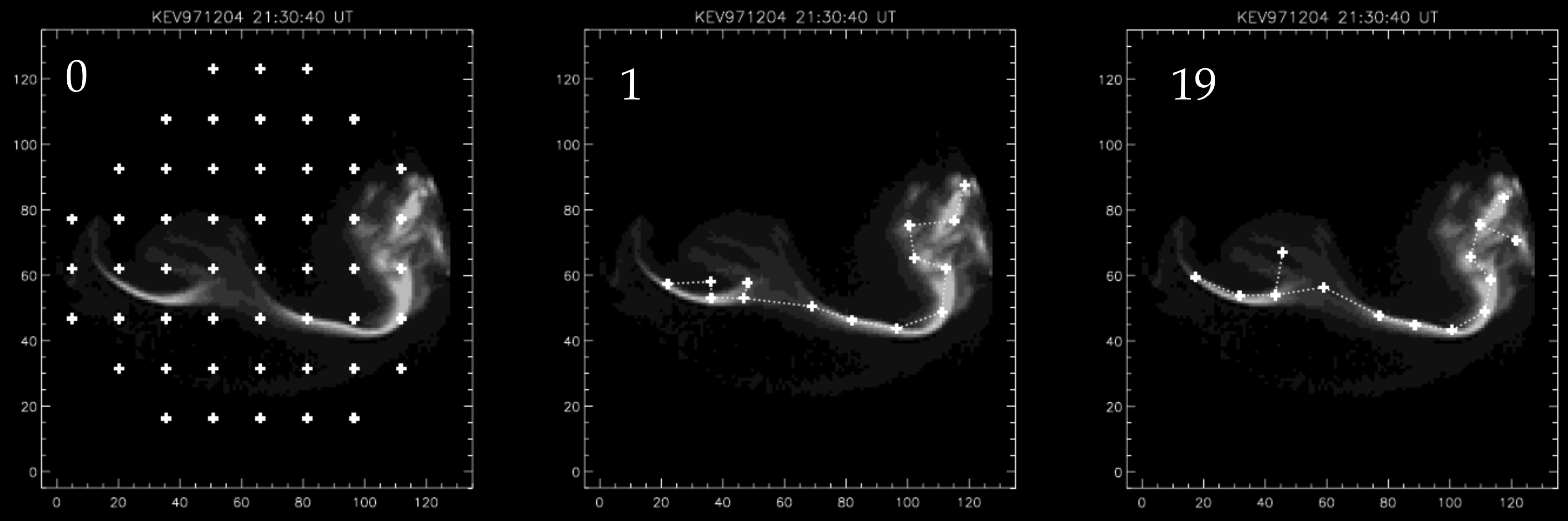
MIRACLE Aurora Skeletons

- Image classification by aurora shape
- Extraction of information from noisy image data
- Algorithm uses a batch mode minimum-spanning-tree self-organising map (MST SOM)

http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

MIRACLE Aurora Skeletons

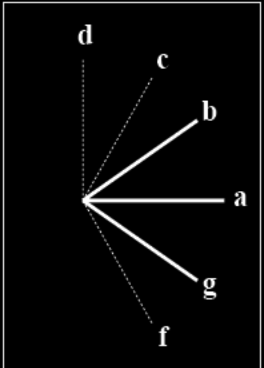
1. Preprocess data (subsampling & contrast enhancement)
2. Initialise a grid of skeleton nodes over the auroral image
3. Partition image data into Voronoi regions around nodes
4. Calculate the center of brightness of each region
5. Update nodes towards the centroid of the region
6. Iterate steps 3-5
7. Delete weak nodes & form MST between nodes



http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

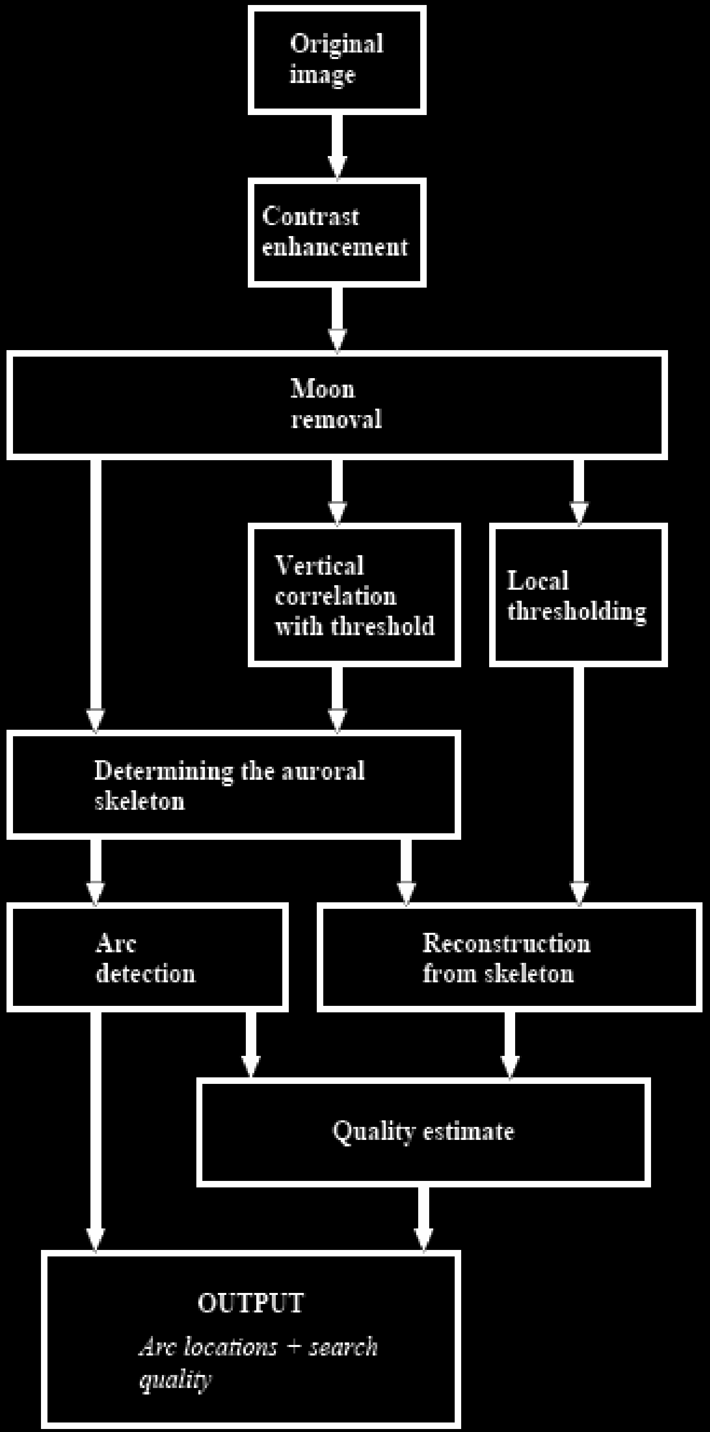
MIRACLE Aurora Skeletons

- Weighing for MST favours east-west direction due to prevalence of such arcs
- Improvement: fusing edge detected image data with the preprocessed image data
  - Need to finalise skeleton without edge data so as not to distort it towards the edges
- Arc grammar: decompose MST by direction to classify & locate arcs



Node connection directions

http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf



MIRACLE Aurora Skeletons

- Moon removed by replacing known location with square of background pixels
- Quality estimate from comparison of skeletonised aurora to optimally thresholded aurora

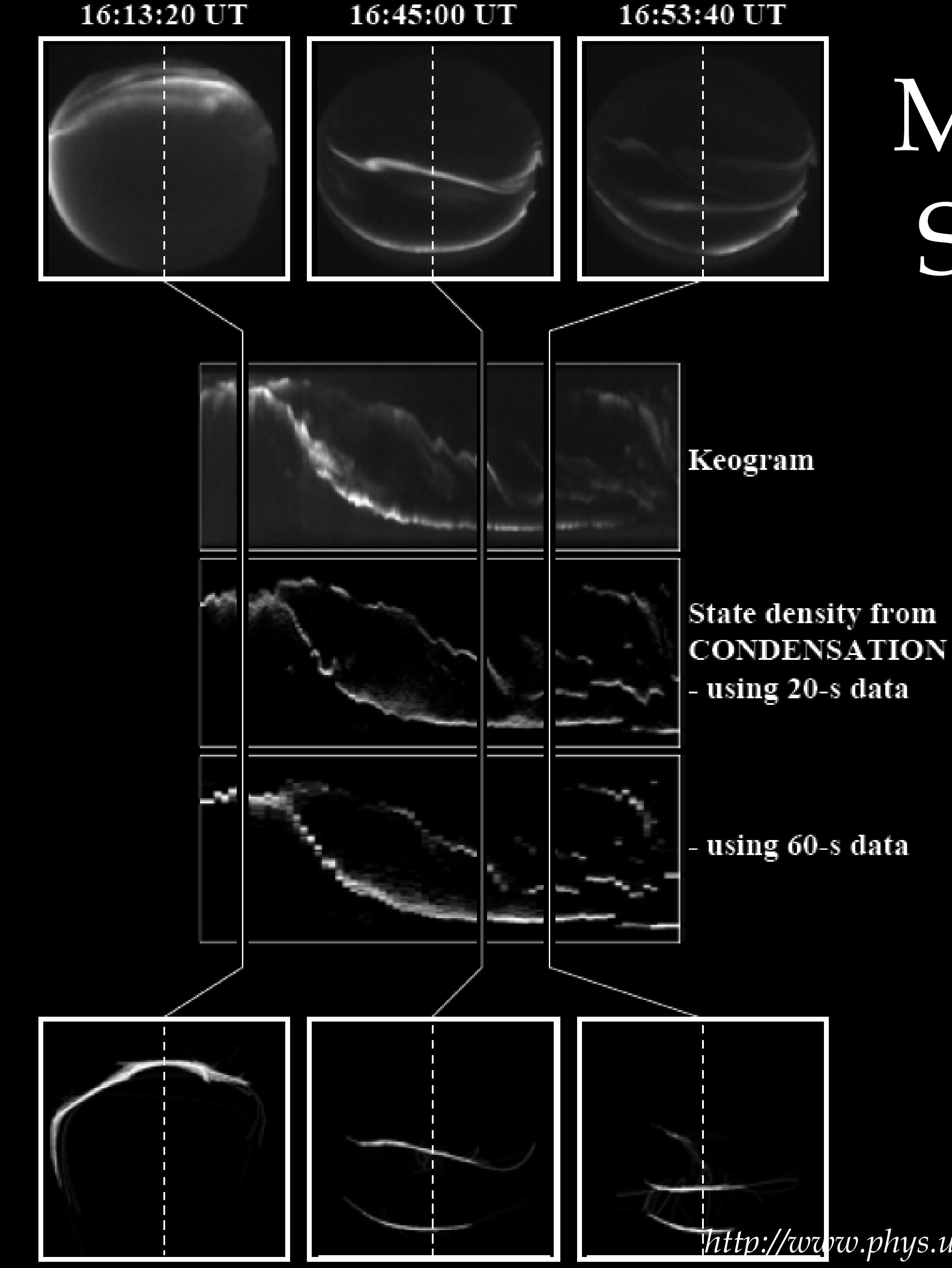
http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

MIRACLE Time Series Analysis

- Conditional Density Propagation tracker – stochastic tracker using random sampling techniques with shape and motion model for tracking objects in a noisy/cluttered scene
- Arcs represented in 6-dimensional shape space (from principal component analysis on 6-point B-splines)
- Brownian motion model, with a tendency to drift equatorward

http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

MIRACLE Time Series Analysis



- Accuracy sufficient for georgaphical location & drift velocity estimation
- Possibility to track multiple arcs simultaneously

http://www.phys.ucalgary.ca/~mikko/Data/syrjaesuo_doctoral_thesis.pdf

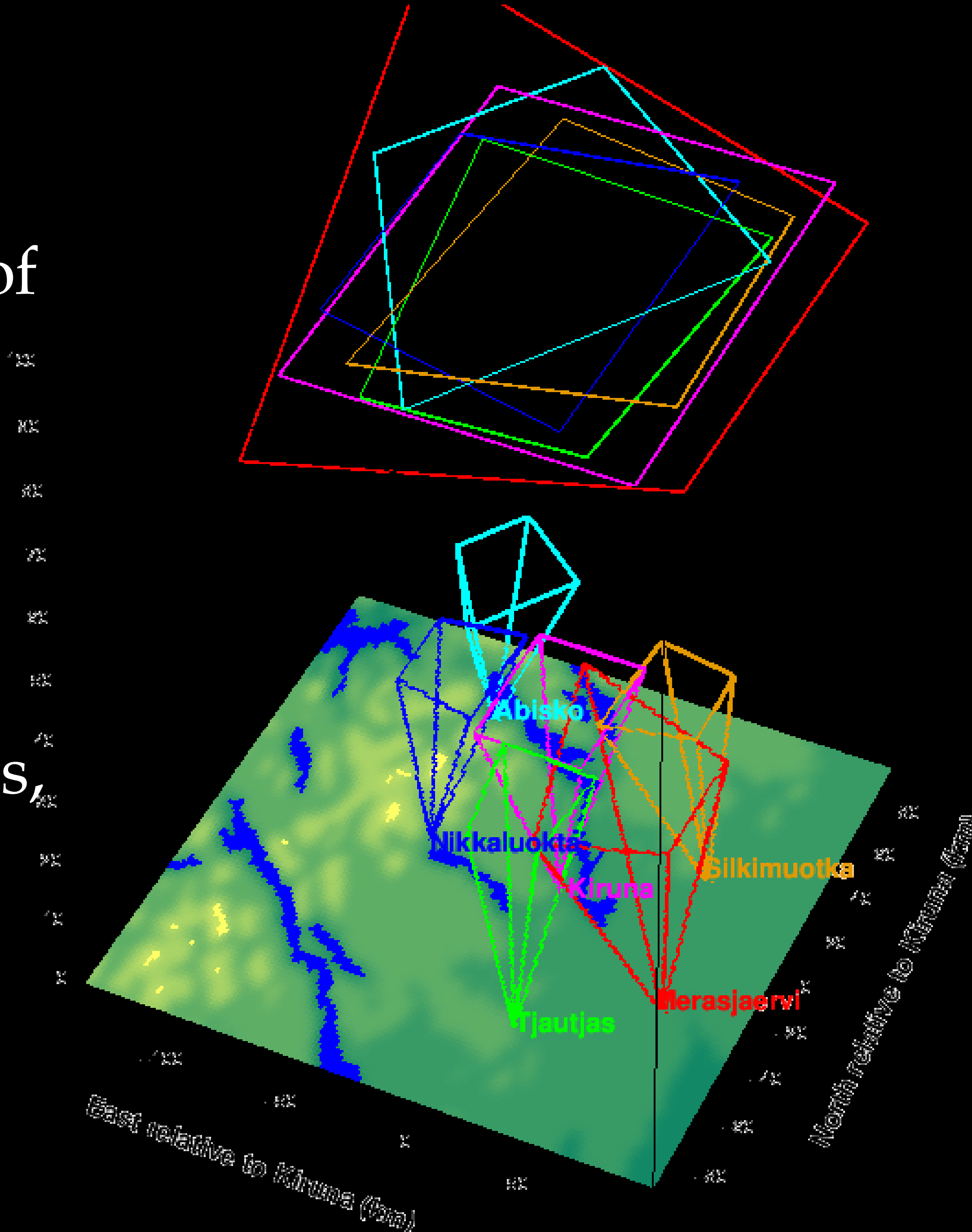
ALIS

- Auroral Large Imaging System
- Part of the research programme on Solar Terrestrial Physics at the Swedish Institute of Space Physics
- Grid of 6 unmanned CCD imager stations in Northern Sweden
- FOV 70°-90°

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

ALIS

- 3D reconstruction of auroral forms is a primary scientific objective
- Also used for studying polar stratospheric clouds, meteors & other atmospheric phenomena



http://www.irf.se/~bjorn/thesis/thesis.html

ALIS Image Classification

- Initially: a program for manual classification
  - By Petrus Hyvönen & Mats Luspa
  - Useful, but time-consuming
  - Quality dependent on operator; abandoned

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

ALIS Image Classification

Main morphological feature	Secondary morphological feature		Temporal feature	Vortex feature
Auroral arc one dimension is significantly larger than the other	Non-diffuse Multiple (2,3,...) Striated Dark aurora Partly clouds	Diffuse Rayed Corona Enhanced Intensity	Active Quiet Pulsating	Spiral (e.g. WTS, omega, torch) Fold Curl
Fragmented auroral structure	Non-diffuse Multiple (2,3,...) Striated Dark aurora Partly clouds	Diffuse Rayed Corona Enhanced Intensity	Active Quiet Pulsating	Fold Curl
Diffuse aurora covering a larger region	Dark aurora Partly cloudy Intensity		Pulsating	
Unidentified aurora				

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

ALIS Image Classification

- Pulse Coupled Neural Networks
  - 1997 exploratory study
  - Biologically inspired from visual cortex of small mammals; successfully used in mammography
  - Three-step process
    1. Use a PCNN for image segmentation
    2. Post-process the resulting data, either by using Singular Value Decomposition or by applying a second PCNN for feature extraction
    3. Carry out the actual classification using a traditional NN

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

ALIS Image Classification

- Improved NN by Peter Rydesäter in 1997
  - Finding arcs and their locations in images
  - Enhanced algorithm with Radial Basis Neural Network
  - "gave a robust detection of auroral arcs and their direction" in preliminary tests
- Analysis of isolines of auroral luminosity shapes
  - By Pudovkin in 1998
  - Confidently retrieves ellipses, spirals & folds

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

ALIS Tomography

- Simulation study by Gustavsson, 1998: "it is possible to achieve feasible reconstructions with the modified Multiplicative Algebraic Reconstruction Technique (MART)"
- 2000: "The result of the tomographic inversion cannot retrieve fine scale internal structures. However, estimates of the spatial distribution of ionospheric emissions which, in general, have a comparatively simple shape, can be accurately obtained."

http://www.alis.irf.se/~urban/avh/irfsr279-2.pdf

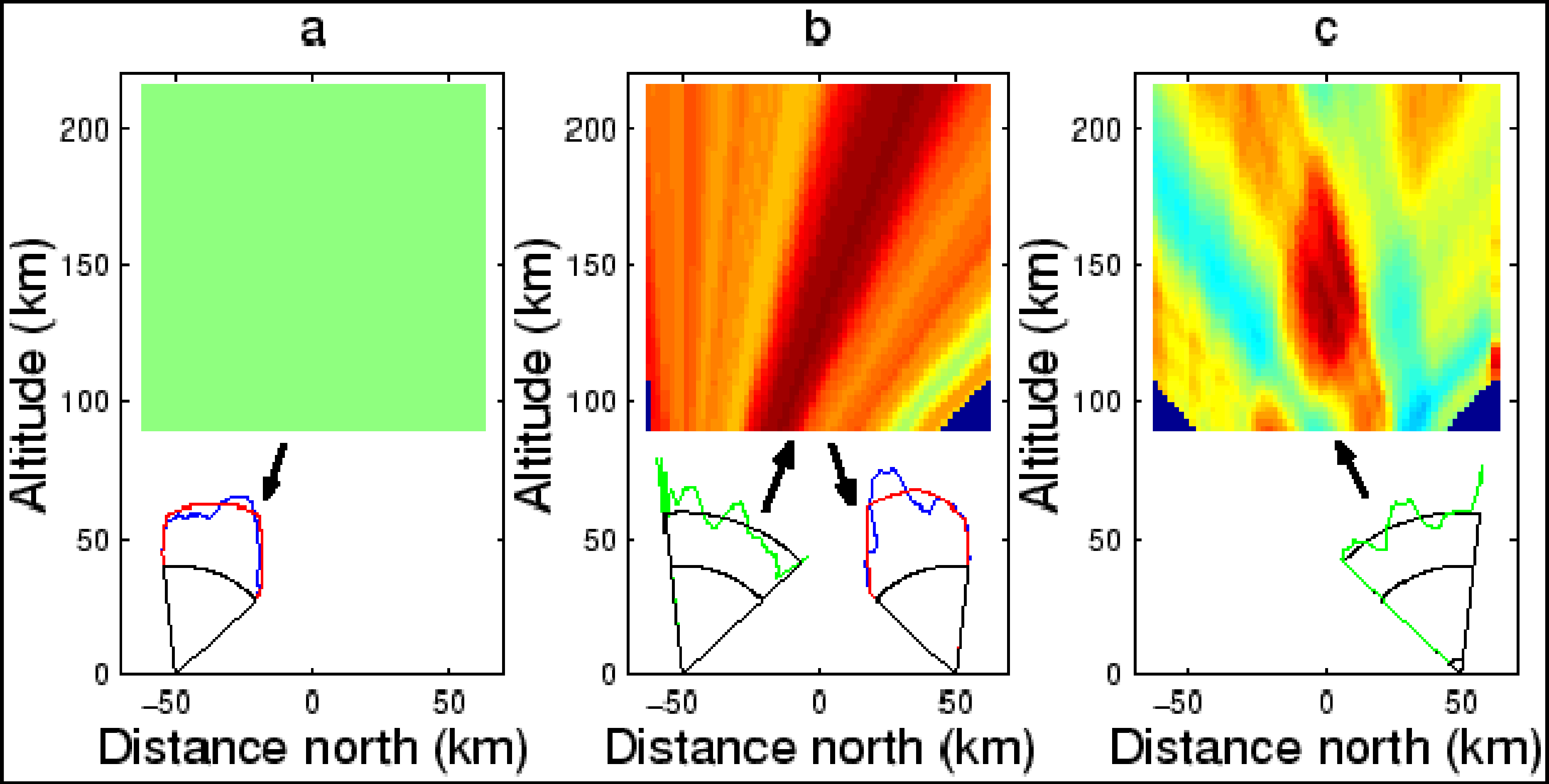
ALIS Tomography

- Algebraic Reconstruction Technique (ART)
  1. A constant initial guess is projected down onto one image
  2. The ratio between the measured image and the projection of the start guess is calculated and projected out into the solution
  3. In this way the voxel values along a pixel line-of-sight is increased if the measure image value is larger than the projection from the start guess and vice-versa
  4. This iteration is proceeded over all stations in random order until a stopping criteria is encountered
  - converges fast but is sensitive to noise in the images

http://www.irf.se/~bjorn/thesis/thesis.html

ALIS Tomography

- Algebraic Reconstruction Technique (ART)



http://www.irf.se/~bjorn/thesis/thesis.html

ALIS Tomography

- Simultaneous Iterative Reconstruction Technique (SIRT)
  - Modified form of ART in which the current guess/solution is projected down to all stations at once and the voxel intensity in the reconstruction is updated with the average ratio of pixels from all stations
- Can also incorporate a priori knowledge about auroral structures; filter to reduce noise; use more advanced iterative schemes

http://www.irf.se/~bjorn/thesis/thesis.html

GAIA

- The Global Auroral Imaging Access (GAIA) Project is a network-based set of tools for browsing summary data from All-Sky Imagers (ASIs), Meridian Scanning Photometers (MSPs), and riometers worldwide, and that provides indexes for direct access to data at PI institutes.
- A virtual auroral observatory for dealing with data from geospace optical and riometer systems
- There is increasing interest in the development of virtual observatories due to burgeoning data sets from arrays of different instrument types around the world.

http://www.agu.org/meetings/fm05/fm05-sessions/fm05_SM33D.html

GAIA

- Features
  - ease of use
  - credit to data providers
  - ability for data providers to monitor usage
  - reliance on software rather than hardware
- A summary data set consisting of
  - keograms
  - time series
  - thumbnail images
  - a fully peer to peer data access system
  - a relational data base that allows for easy grouping of and linkages between data

http://www.agu.org/meetings/fm05/fm05-sessions/fm05_SM33D.html

Why are we interested in this?

UNIVERSITY OF CALGARY

By 2007

- **we will** be running 35 ASIs
- **we will** be producing 10TB of image data per year
- **we are** operating 13 riometers
- **we are** operating 4 MSPs
- **we are** a partner in other riometer, MSP, and ASI projects
- **we have** past optical data sets- Wilbur, POCA, ISIS, Viking, Freja, Interball, etc.

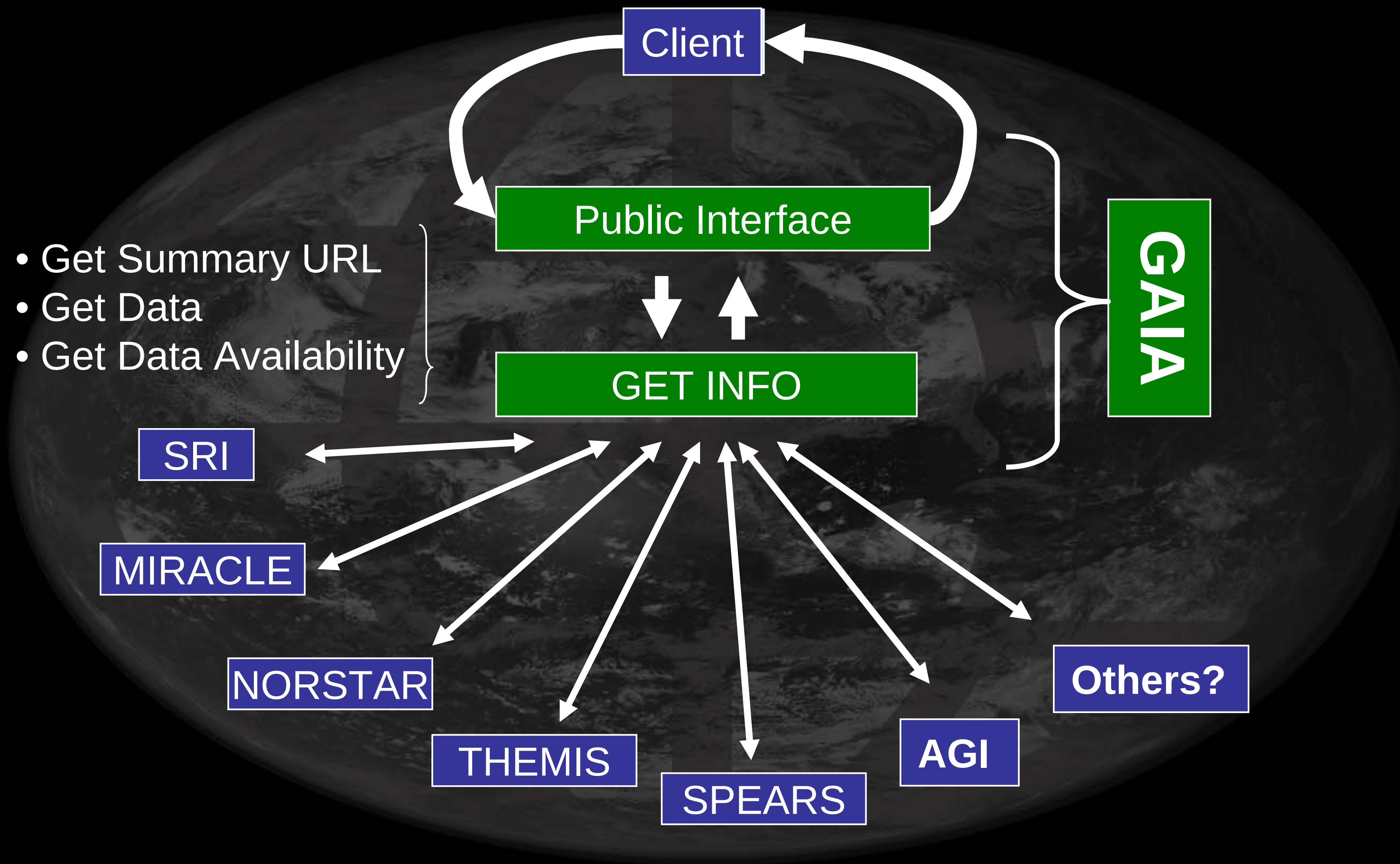
There is no existing way available for us to manage our data

We are going to solve our problem

We want to do this in a way that is scalable – so in principle our solution could be the kernel of a solution to the global problem.

We have an "unfunded mandate" – we can do whatever we want

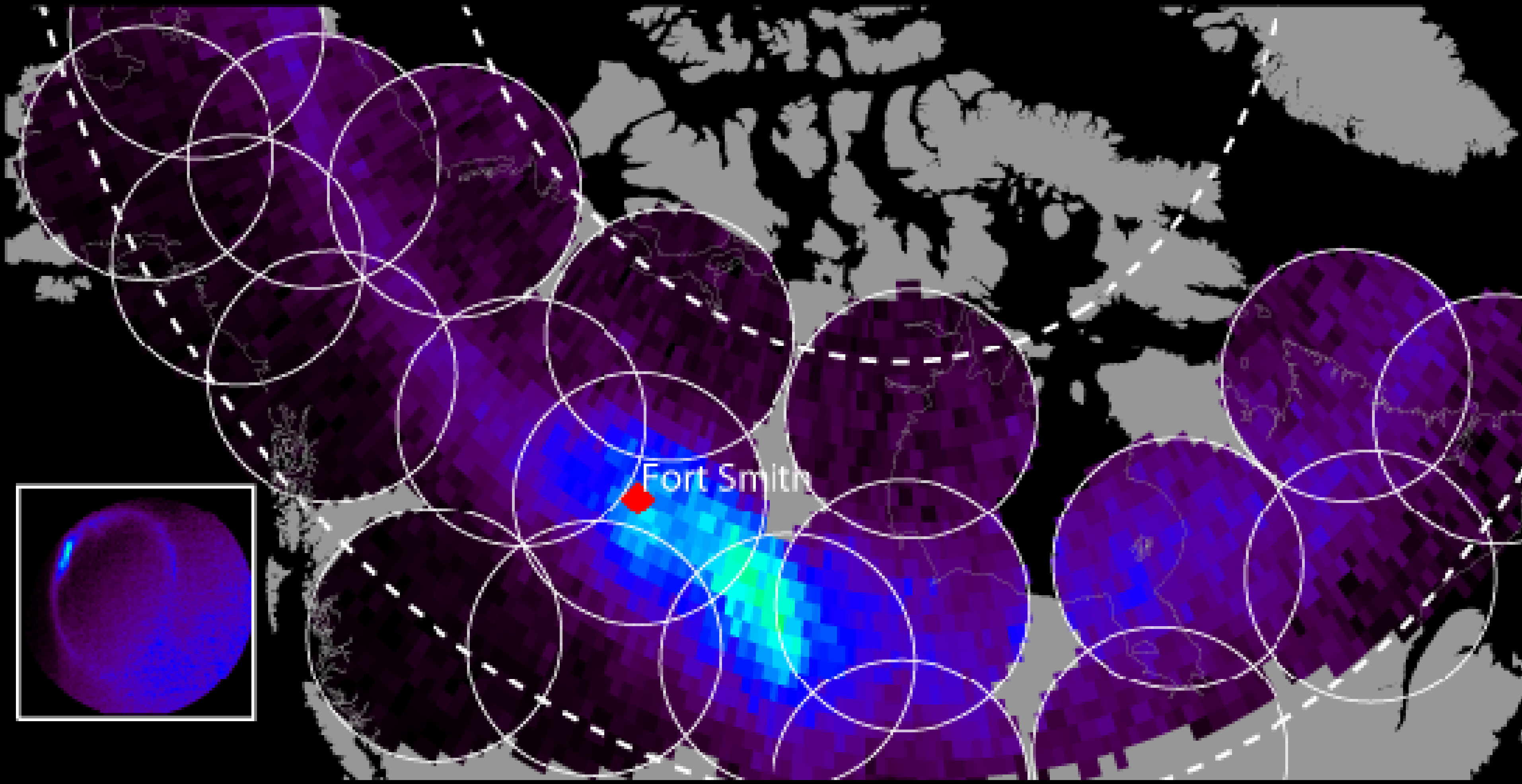
What is GAIA ???



GAIA will be a public interface (set of tools), to browse summary data, data availability, and retrieve data from a worldwide network of ASIs, MSPs, and Riometers.

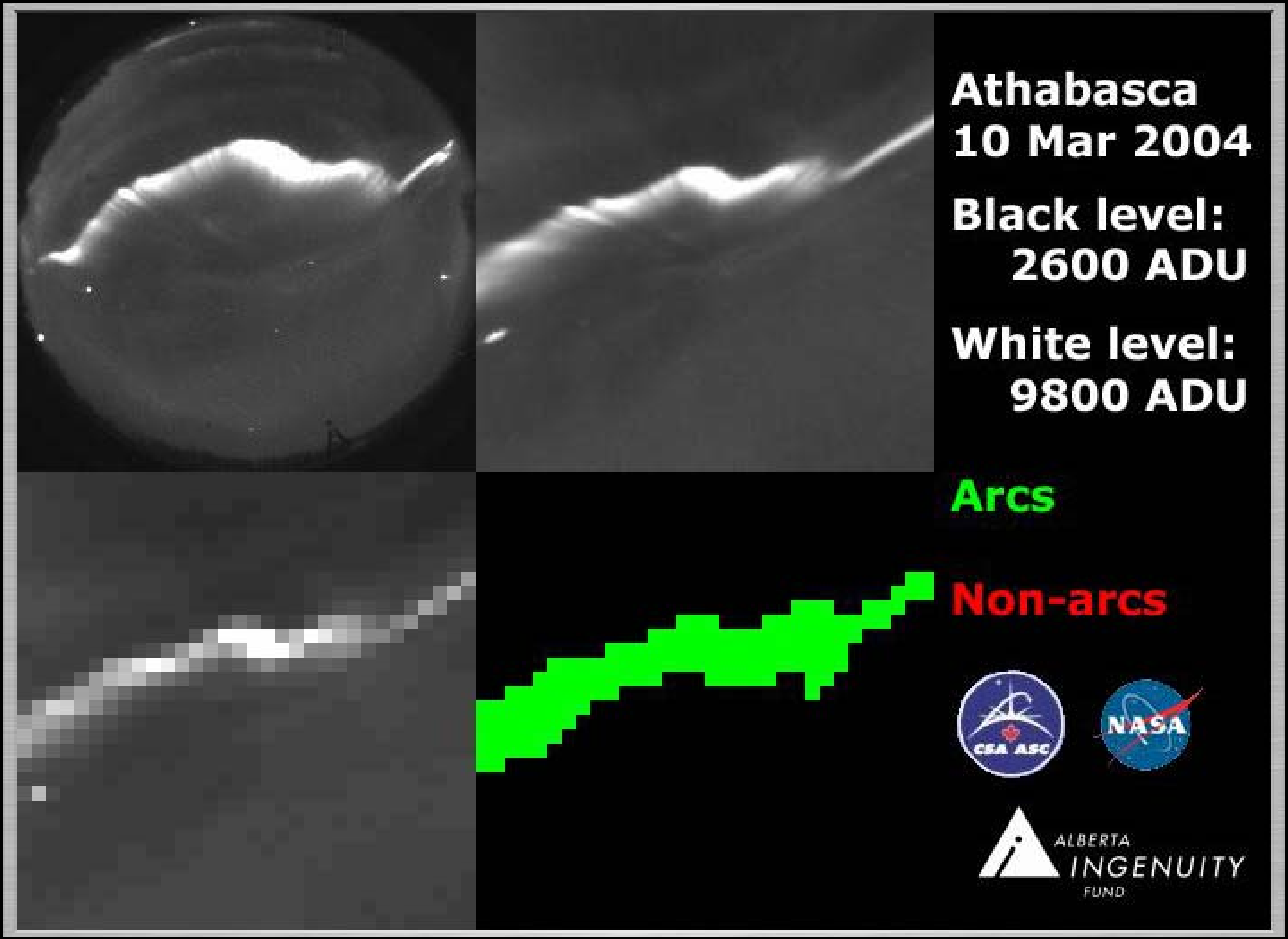
http://gaia-vxo.org/index.html

GAIA Granularity



http://gaia-vxo.org/index.html

GAIA Granularity

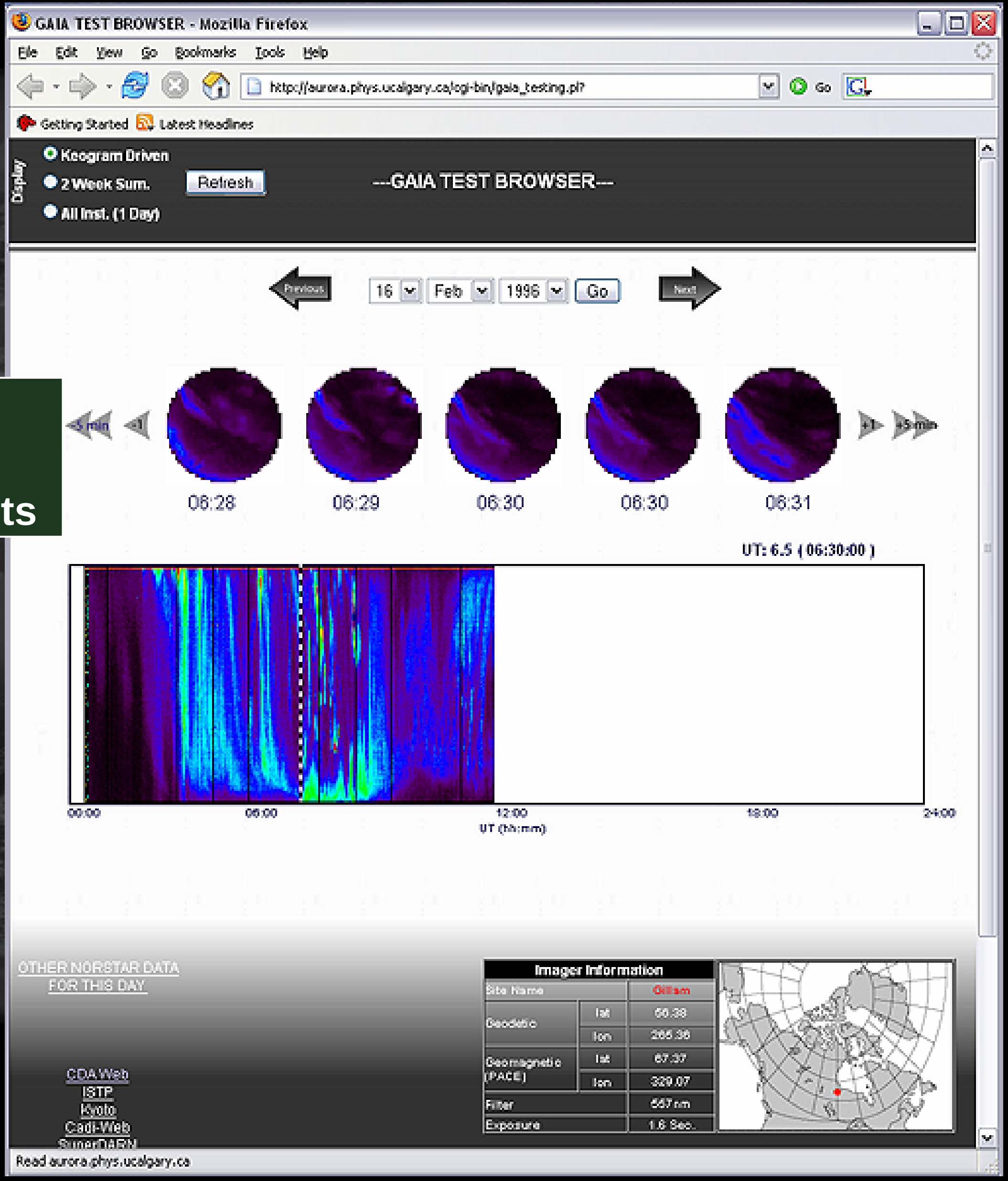


http://gaia-vxo.org/index.html

What GAIA Should Do

GAIA V1.0

Summary Data = 1 minute thumbnails
24 hour keograms
2 week summary plots



http://gaia-vxo.org/index.html

All-sky Camera Networks

- MIRACLE, Finland. http://www.space.fmi.fi/MIRACLE/
- ALIS, Sweden. http://www.alis.irf.se/ALIS/
- NORSTAR, Canada. http://aurora.phys.ucalgary.ca/norstar/index.html
- THEMIS (under construction), Canada. http://aurora.phys.ucalgary.ca/themis/themis_main.html

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