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energy agency

the
abdus salam
international centre for theoretical physics

SMR/1328/15

School on the Physics of Equatorial Atmosphere

(24 September - 5 October 2001)

Imaging Science Instruments: Imagers and Spectrographs

M. Mendillo
(Boston University)

LECTURE 4.3: IMAGING SCIENCE INSTRUMENTS --- Imagers + Spectrographs (MENDILLO)

IMAGERS → Narrow field of view (FOV) ≈ degrees --- not useful for Equatorial Aeronomy
IMAGERS → Wide Angle ("All-sky") ≈ 180° FOV

- ROLES:
  - Spatial context for other diagnostics that provide line-of-site observations → Radars, LIDARS, Rockets + Satellites
  - Independent science for 2-D phenomena (e.g., gradients, waves, instabilities)

- TECHNIQUES:
  - All-sky camera with film as detector — developed for auroral research.

[Aside: "Naked-eye" detection requires λ-dependent brightness
e.g., AURORA → Green (5577 Å) ≈ 5-7 kR; Red (6300 Å) ≈ 15-20 kR } $\Delta t_{exposure} \lesssim 1$ sec

Equatorial Airglow typically ~ 50 - few kR
$\Delta t_{exp} \gtrsim$ 10's minutes]

  - All-sky camera with Video CCD — same comments as with film
  - All-sky camera with IMAGE INTENSIFIER.

Amplification of brightness by 3-5000 X ⇒ $\Delta t_{exposure} \lesssim$ minutes

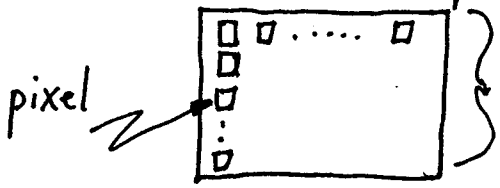
[Aside: Introduces noise ("speckle") in images.]

  - "Bare CCD" (i.e., non-intensified CCD, but very high Quantum Efficiency), with $\Delta t_{exp} \lesssim$ minutes

This is the "State-of-the-art" detector of choice.

IMAGING SCIENCE: Post-film era

- Detectors --- devices that record light.
  - Eye: person to person differences; no permanent record.
  - Film: chemical processes instigated by light ⇒ 2-Dimensional Images.
  - Electronic: Amount of light converted to an electrical signal --- a photo-meter, all light gathered by telescope.
  - Array:
    2-D (as with film), but chemicals replaced by tiny device that records photons



A Charge-Coupled-Device (CCD) --- A silicon chip with ~90% efficiency in recording light (eye ≈ 1%, film ≈ 10%)

... Incoming photons cause electric charge in each pixel. After exposure, computer "reads out" amount of charge, pixel-by-pixel ⟶ image stored as array of numbers.

IMPACT: CCDs can record very faint signals. The image is "quantitative" -- pixel-by-pixel numbers give brightness pattern very accurately.

- Other Aspects:
  - IMAGE PROCESSING: Quantitative images can be added + subtracted to enhance or isolate features.
  - Non-Visible Light: CCDs not limited to visible λs. - IR, UV applications
  - Costs: Very specialized CCD (e.g., for space mission) are expensive.
    Mass production for commercial use (CAM-recorders) make good CCDs readily available at low cost.

INTENSIFIED CAMERA SYSTEM

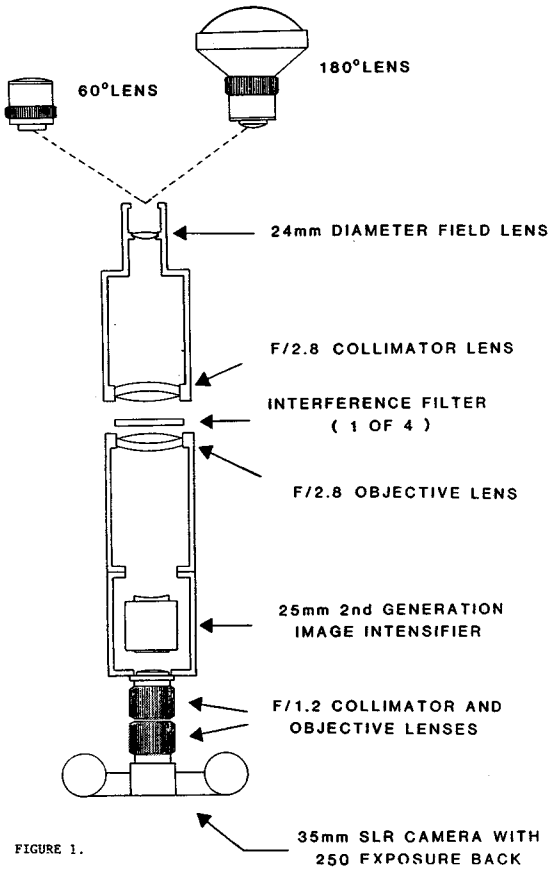
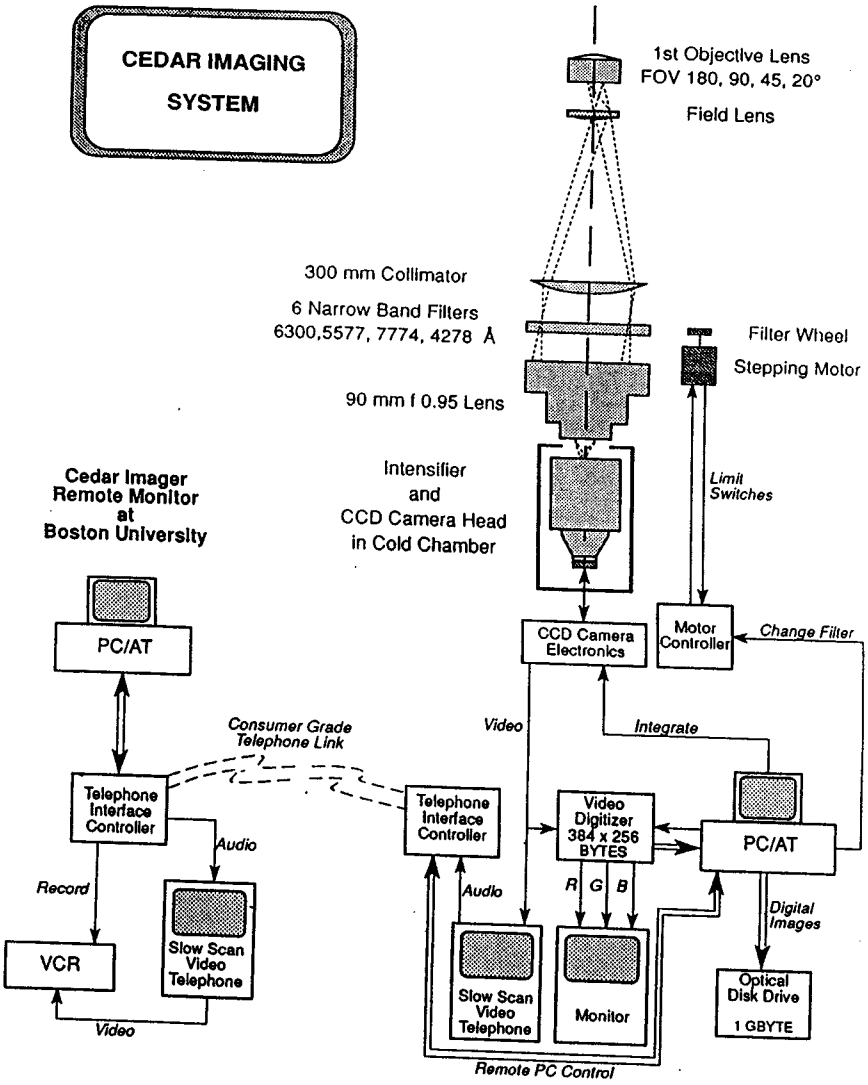
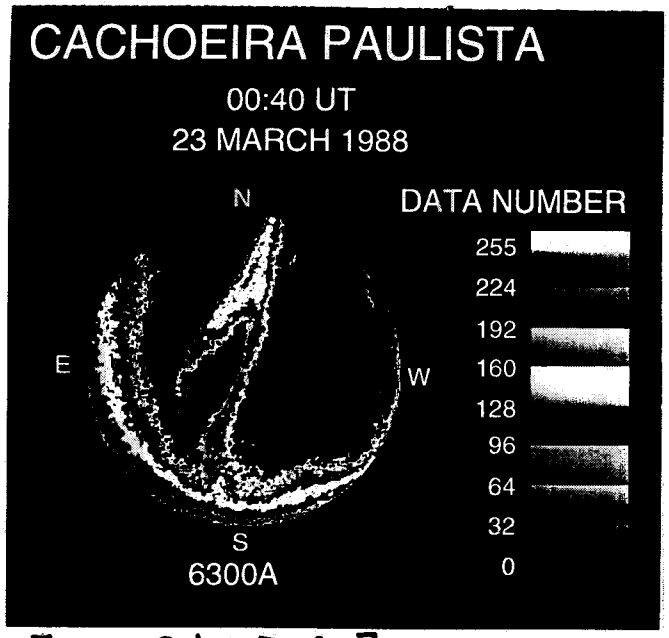


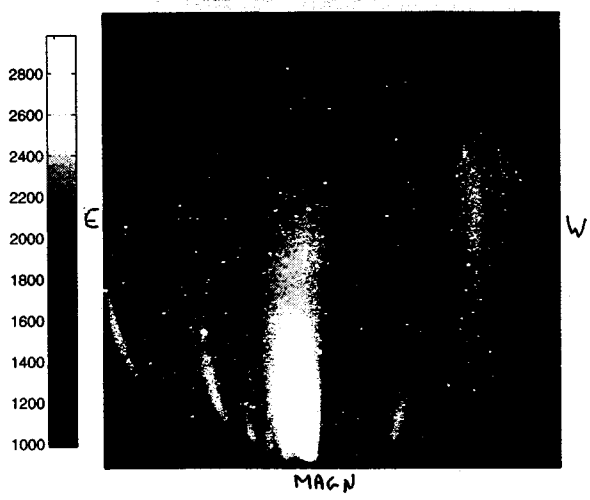
FIGURE 1.





[from Sahai: INPE]

CHRISTMAS ISLAND (630 nm)



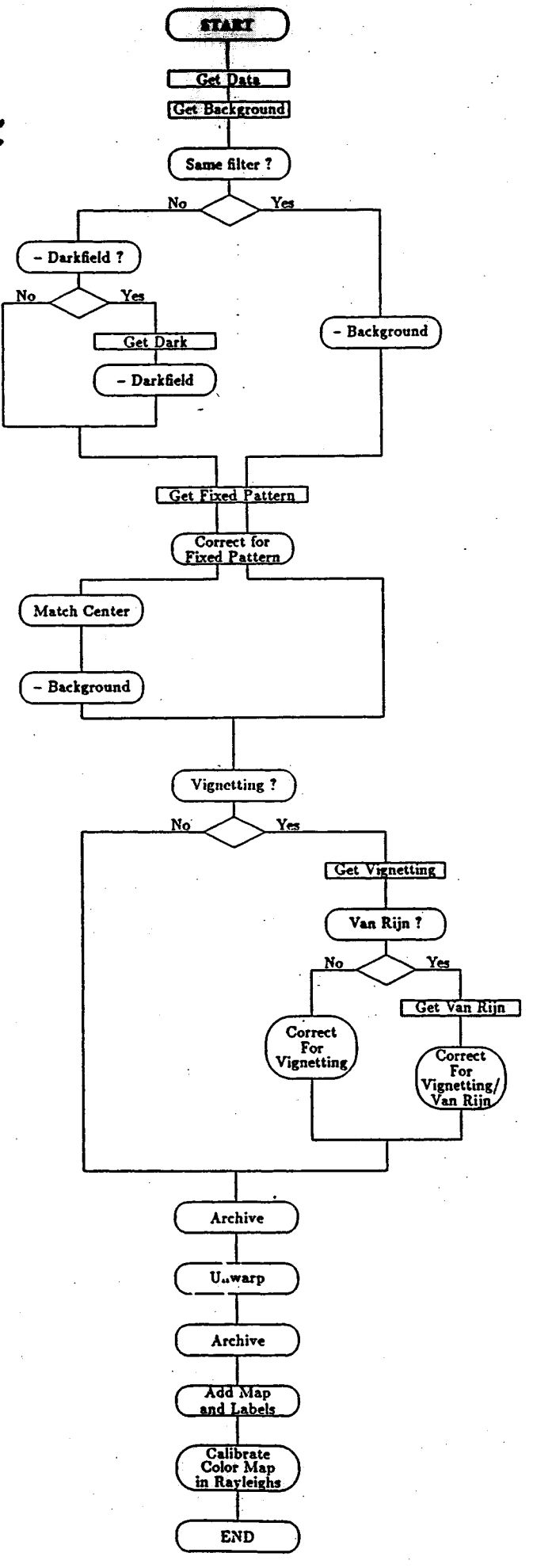
F-REGION DEPLETIONS

[TAYLOR: Utah State Univ]

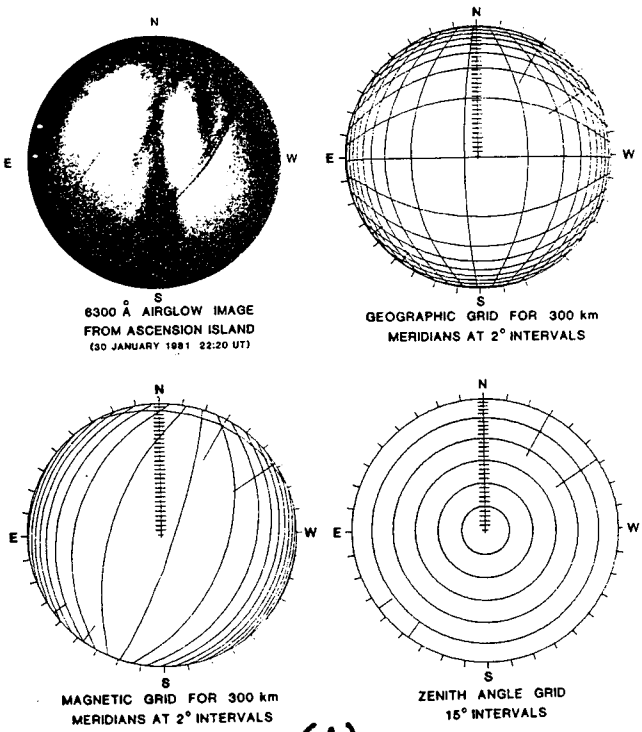
– Working with Digital Images:

Boston University Imaging System

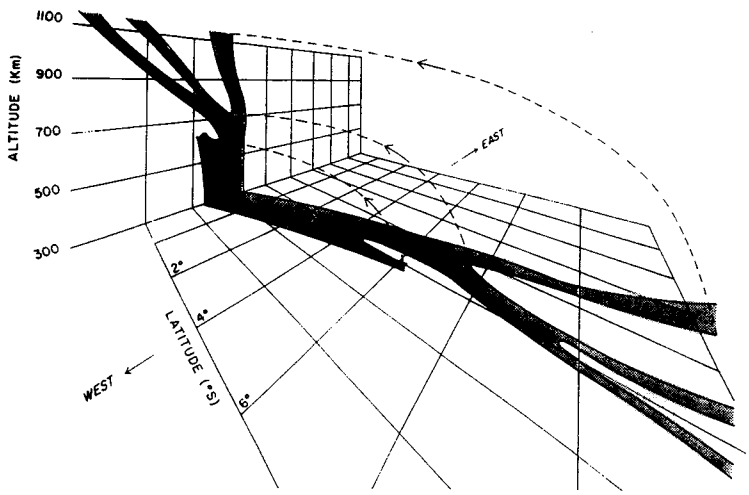
Image Processing Protocol



Airglow Imaging/Scanning Photometer Studies



(A)



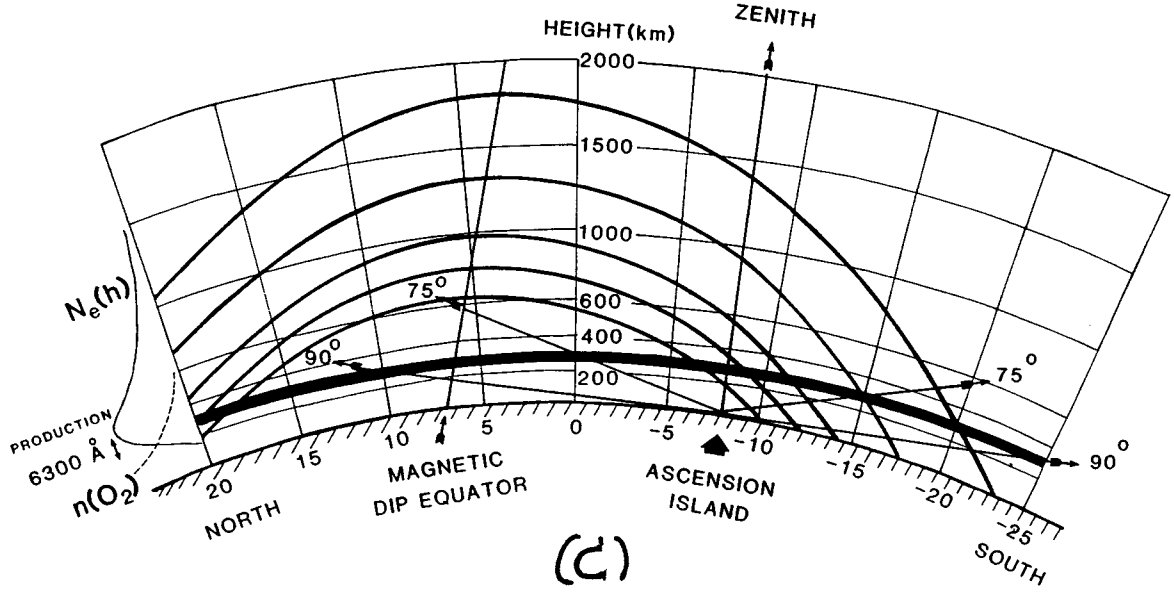
--- Determination of zonal velocity
[e.g., Mendillo and Baumgartner, 1983; Sobral et al., 1985]

--- Bubble morphology (e.g., wedge-shape)
[Rohrbaugh et al., 1989]

--- Maximum altitudes of bubbles
[Mendillo et al., 1993]

(B)

ASCENSION ISLAND MAGNETIC MERIDIAN
AIRGLOW VIEWING GEOMETRY



(C)

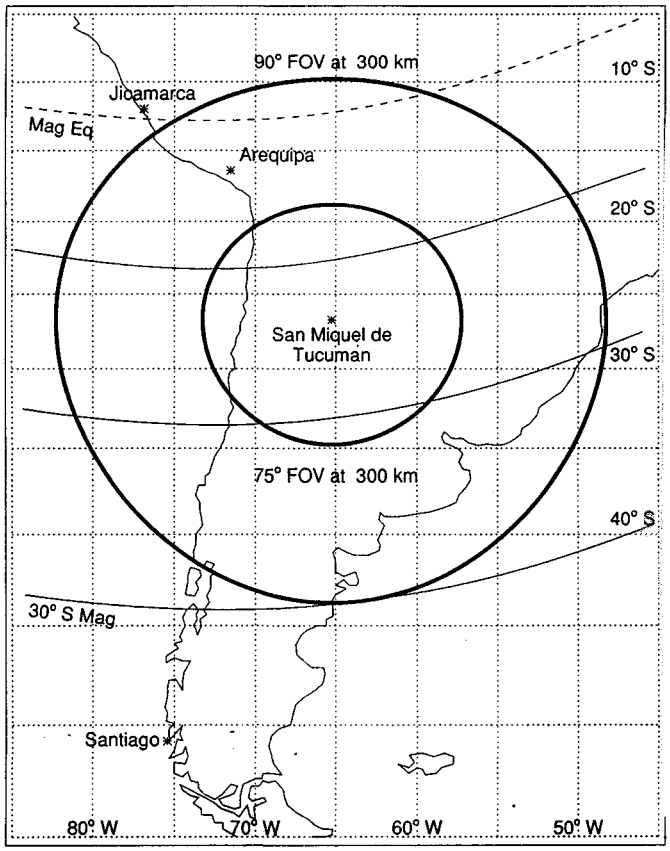
(A) Grids for an all-sky image

(B) Geomagnetic fieldline mapping ⇒ Apex Heights

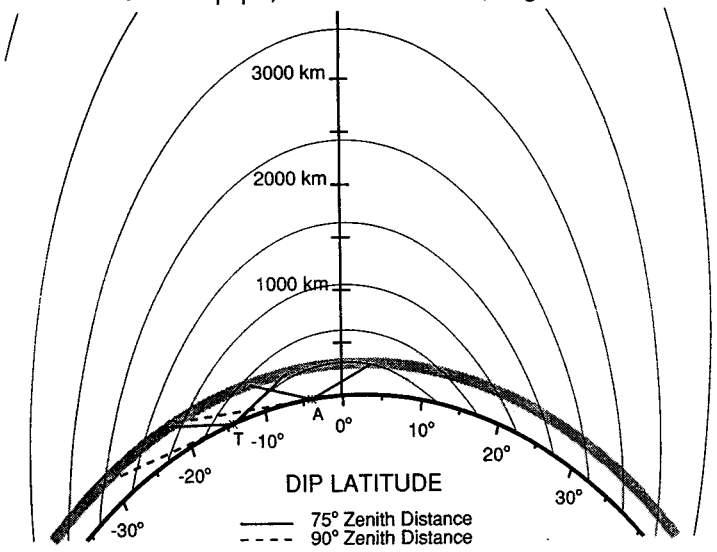
(C) Geometry for 6300Å Airglow layer + Apex mapping

Site-dependent Apex Mapping (6.)

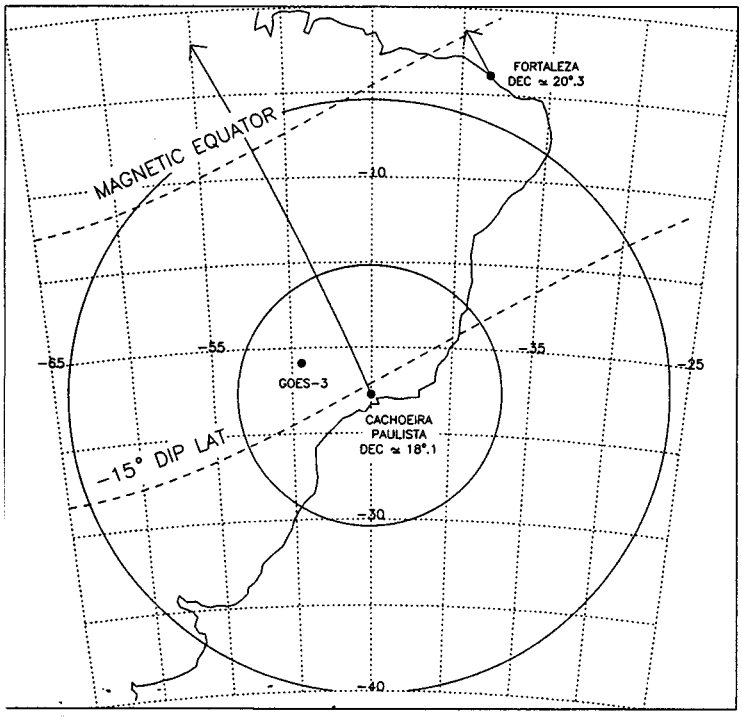
Field of View From
San Miquel de Tucuman

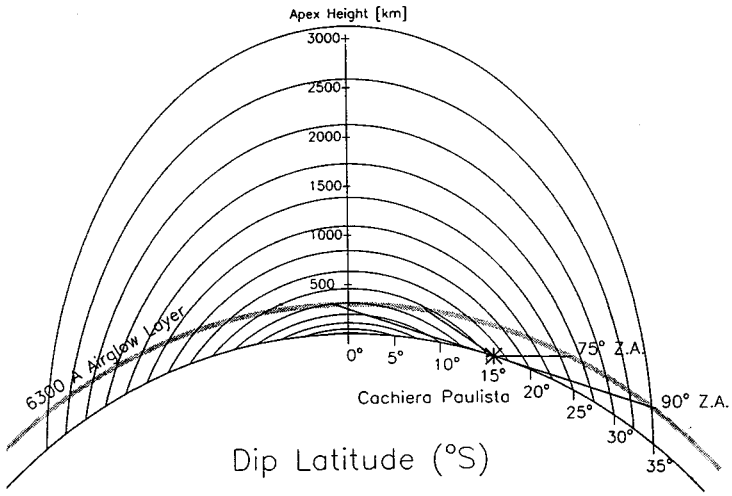


6300Å Airglow Viewing Geometry
from Arequipa, Peru & Tucuman, Argentina

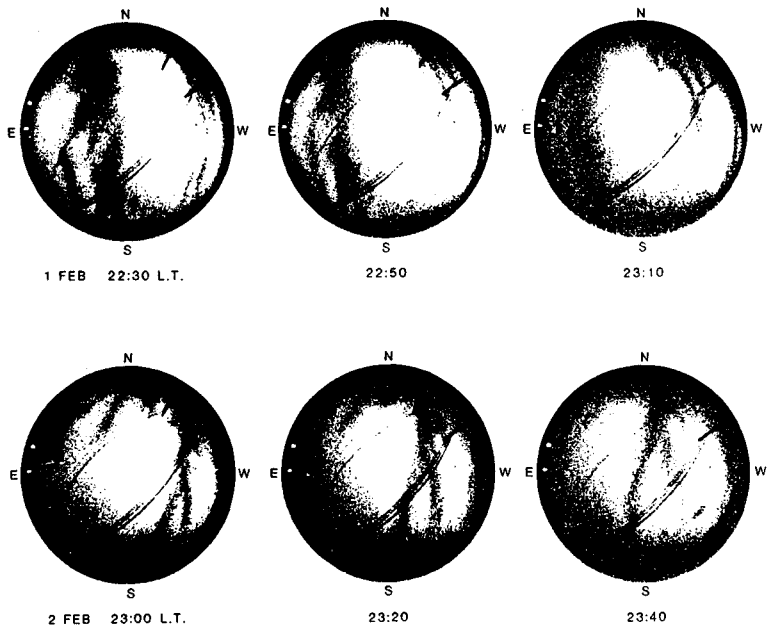


CIRCLES INDICATE THE
FIELD OF VIEW FOR 75° AND 90° ZENITH DISTANCES AT 300km

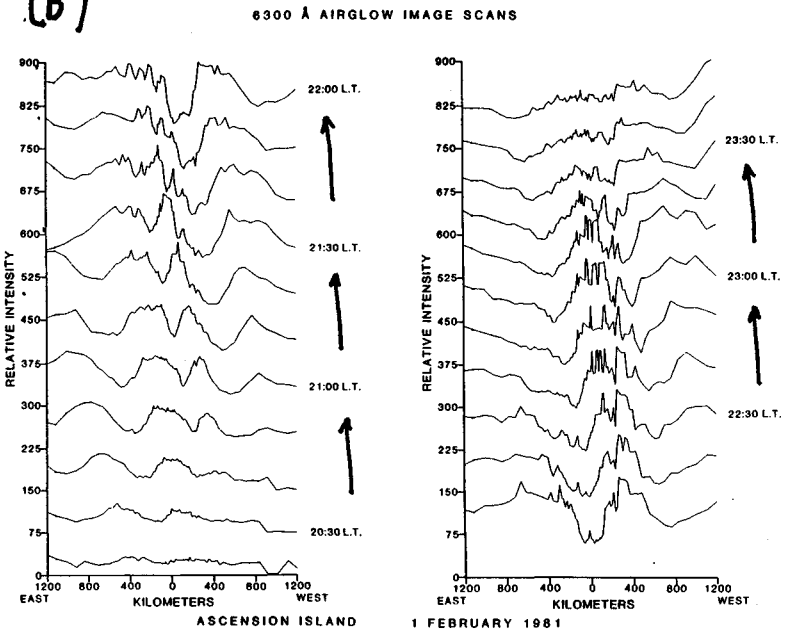




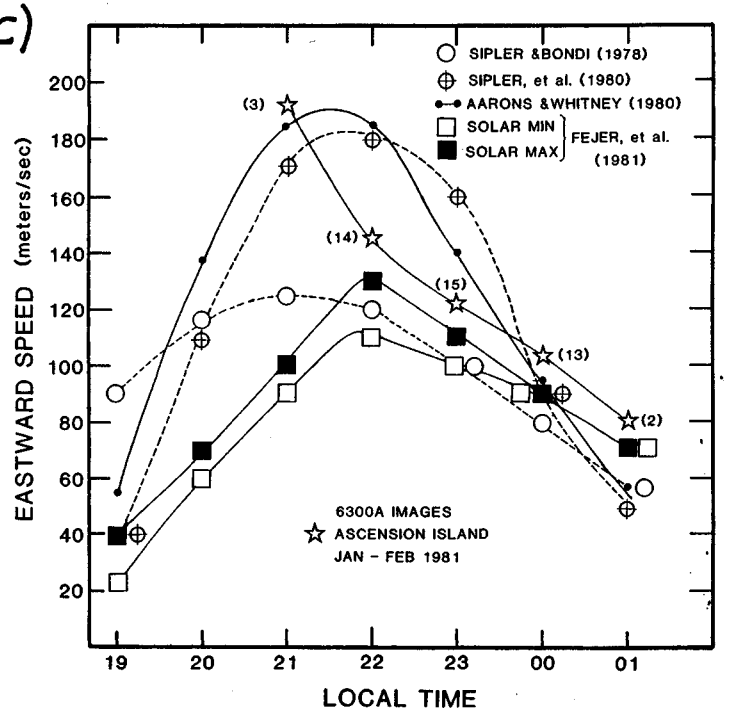
(A)



(B)



(C)



Example of deriving zonal Plasma Drifts from the motion of airglow depletions:

(A) Raw data

(B) "unwarped" (i.e., geographic map) scan of Brightness vs. Longitude

(C) Comparisons of multi-diagnostic methods for zonal plasma drift.

(4)

IMAGING WAVES IN THE MESOSPHERE [from Smith et al., JGR '00]

(8.)

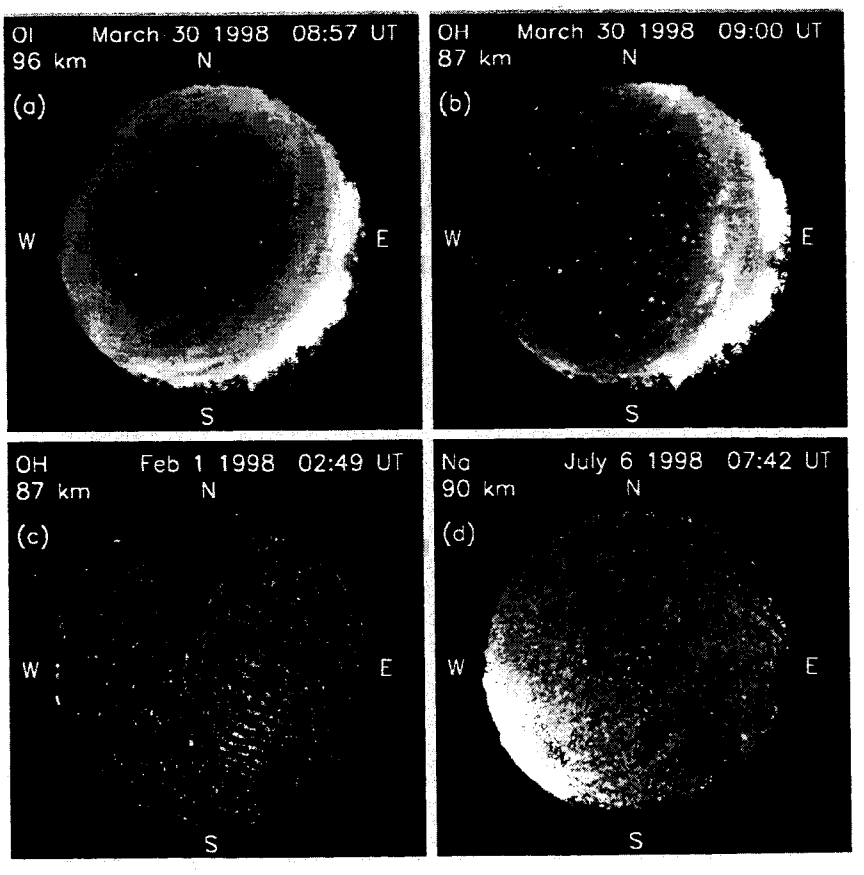


Figure 2. Emission images on March 30, 1998, showing extensive band structure for (a) raw OI and (b) raw OH. Time-difference image (see text) in OH emission taken on February 1, 1998, showing two ripple events together with a band event. (d) Time-difference image showing a band event in Na emission. This image has also been median-smoothed.

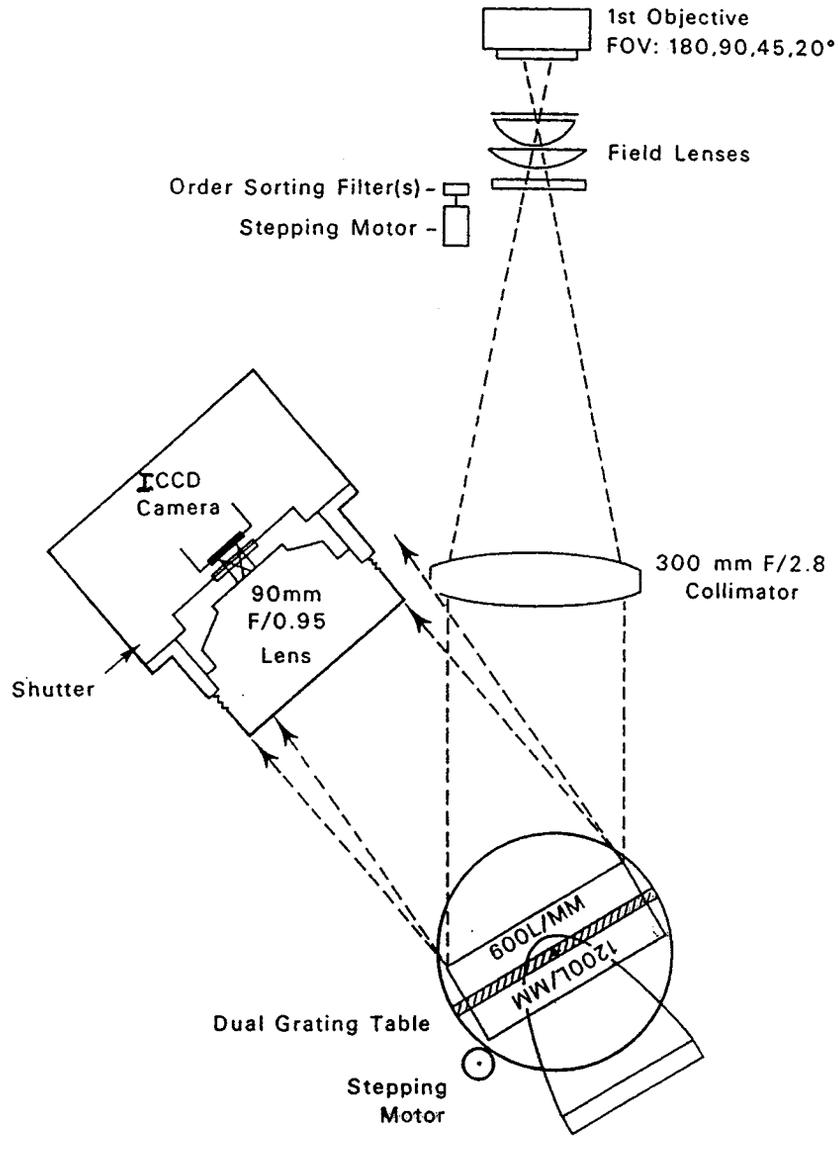
Table 3. A List of Several Previous Airglow Gravity Wave Imaging Studies of Band Events

Location	Geographic Latitude	Geomagnetic Latitude	c_{ob}, m s^{-1}	λ_h, km	τ_{ob}, min	λ_z, km	Reference
Culgoora	30.3°S	29.2°S	72	244	57	–	*Armstrong* [1982]
Alcantara	2.3°S	0.4°S	48	24	10	17	*Taylor et al.* [1997]
			(15)	(8)	(6)	(9)	
Maui	20.8°N	21.5°N	47	22	10	–	*Taylor et al.* [1995a]
			(17)	(10)	(7)	–	
			53	18	6	17	*Taylor et al.* [1995b]
			(11)	(7)	(4)	(13)	
			52	22	–	7–80	*Isler et al.* [1997]
			(16)	(9)	–	–	
Sacramento Peak	32.8°N	41.5°N	28	23	14	–	*Taylor et al.* [1991]
Nederland	40.0°N	49.0°N	24	35	32	–	*Taylor et al.* [1995d]
			(9)	(14)	(27)	–	
Millstone Hill	42.6°N	53.0°N	47	21	9	17	this study
			(20)	(7)	(5)	(4)	
Pic du Midi	42.9°N	37.8°N	5,17	30,70	–	–	*Moreels and Herse* [1977]
Cime de lat Bonette	44.3°N	39.0°N	15	45	–	–	
Gornergrat	46.0°N	40.9°N	38	26	11	15	*Taylor et al.* [1987]
Sondakyla	67.4°N	63.7°N	16	45	–	–	*Clairemidi et al.* [1985]
Mean values			33	32	12	18	
			(17)	(15)	(8)	(6)	

The computed (or published) mean values of several deduced parameters are listed together with the associated standard deviations in parentheses. In the case of only one or two parameter values, the computed range of values is given. The Culgoora results were not used in deriving the final mean values (see text).

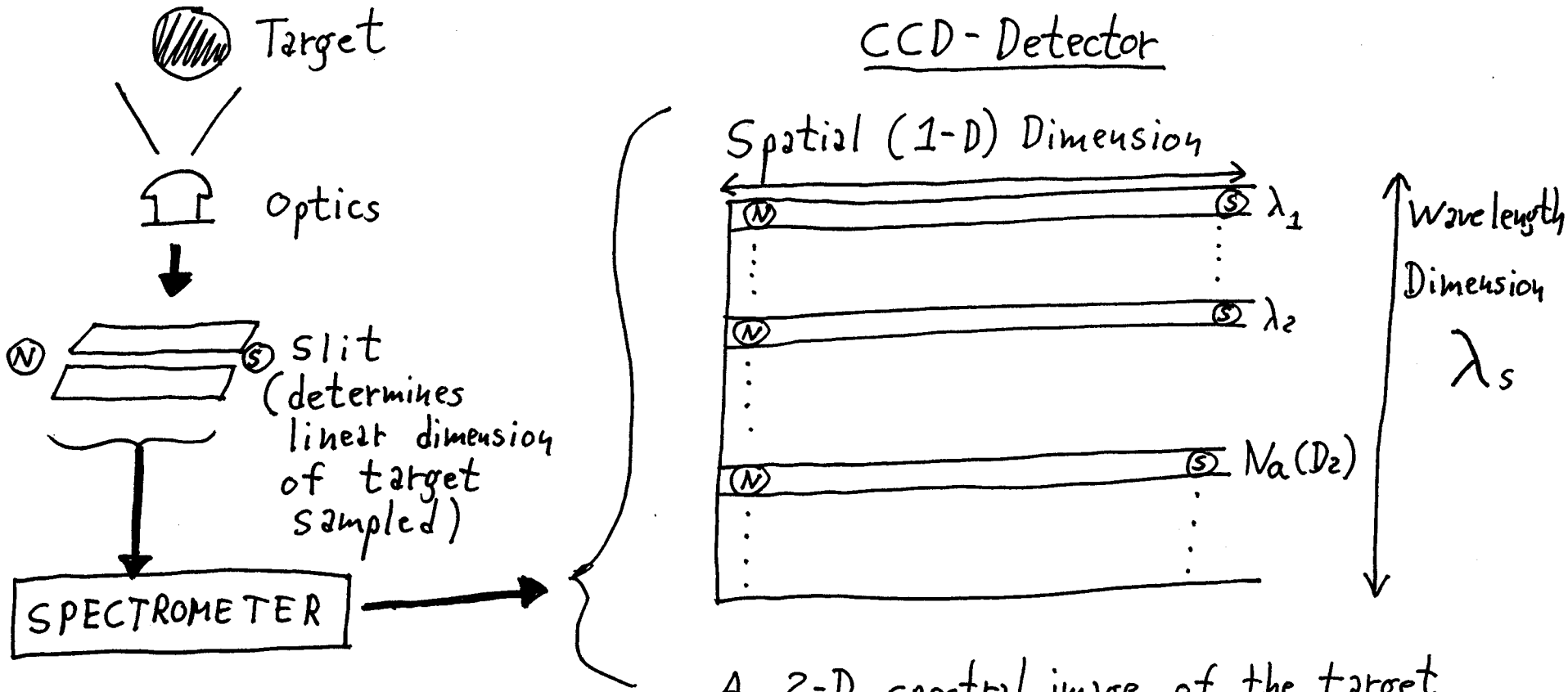
IMAGING SPECTROSCOPY:

MERIDIONAL SPECTROGRAPH SCHEMATIC



- CHARACTERISTICS
  - --- Simultaneous Observations at many λs → Broadens Science; → On/off bands
  - --- More certain calibration to Rayleighs
  - --- Spatial Coverage Reduced (usually 1-D).

How Does an Imaging Spectrograph Work?

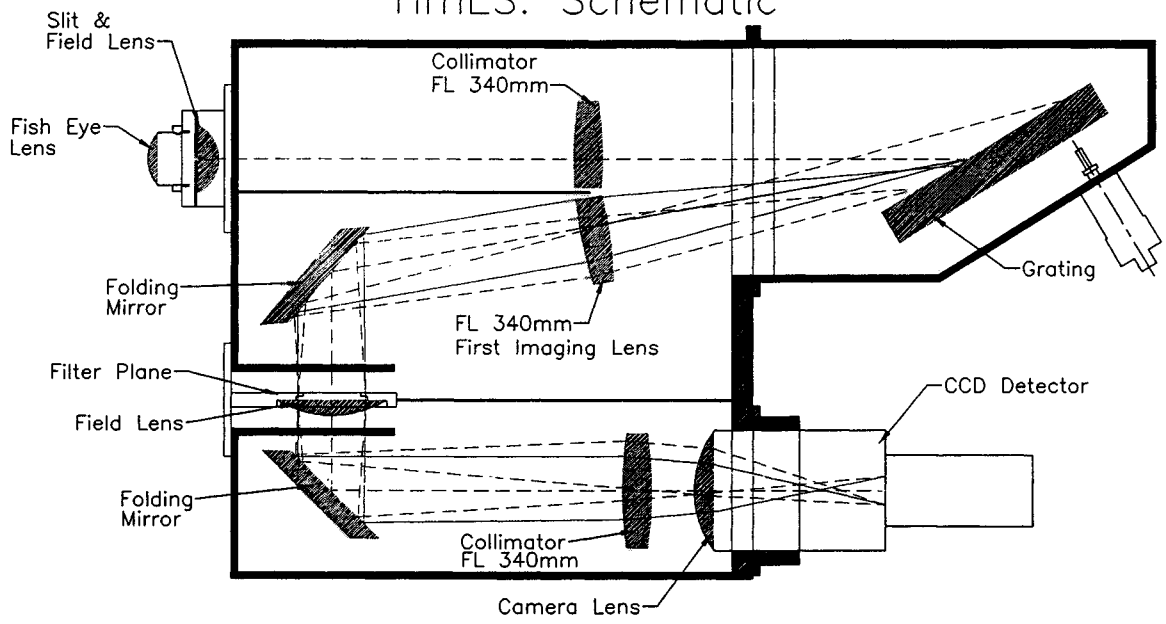


A 2-D spectral image of the target could be made by physically scanning the slit (i.e., in time) across the object.

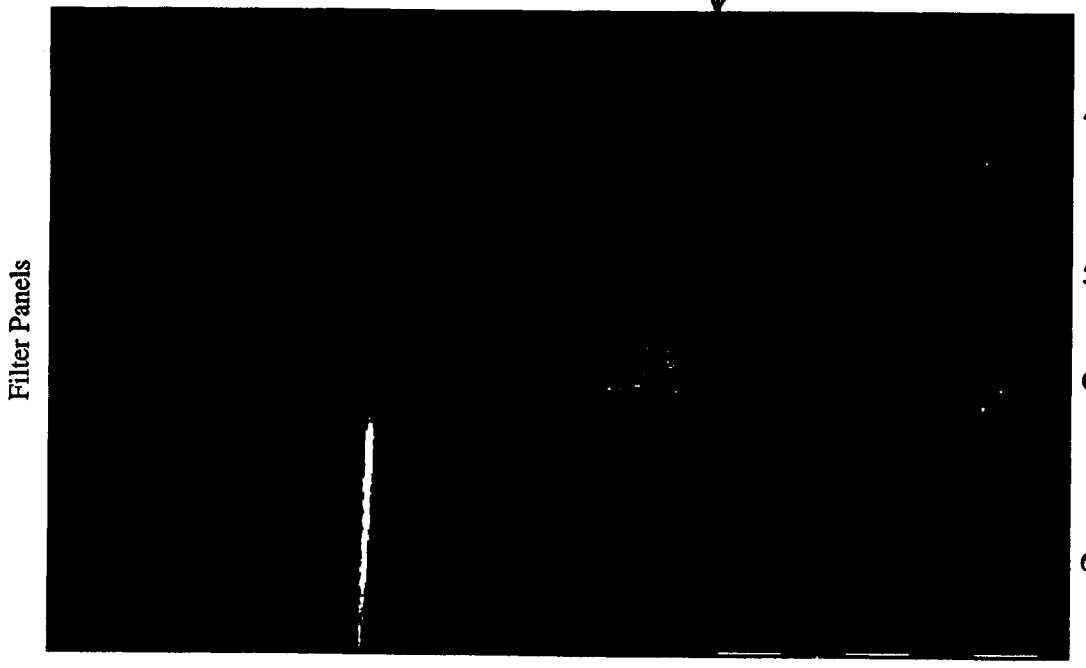
High-Throughput Imaging Echelle Spectrograph (HiTIES)

Spectral Resolution ≈ 1 Å

HITIES: Schematic



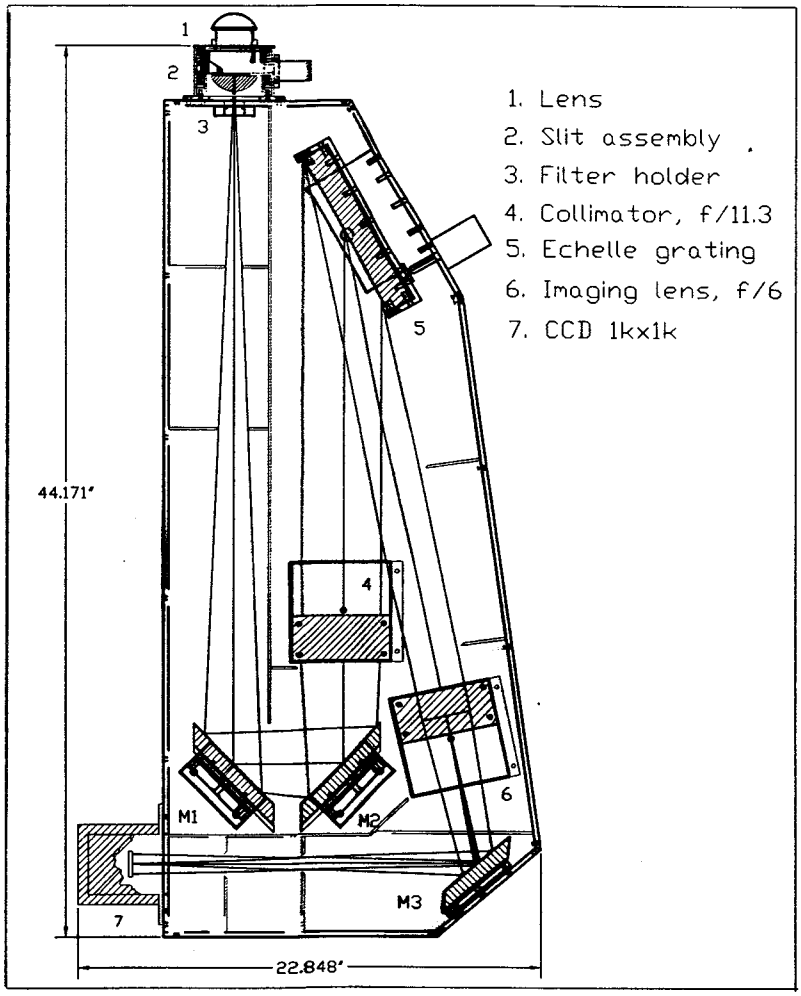
5577Å Line in 2nd Panel



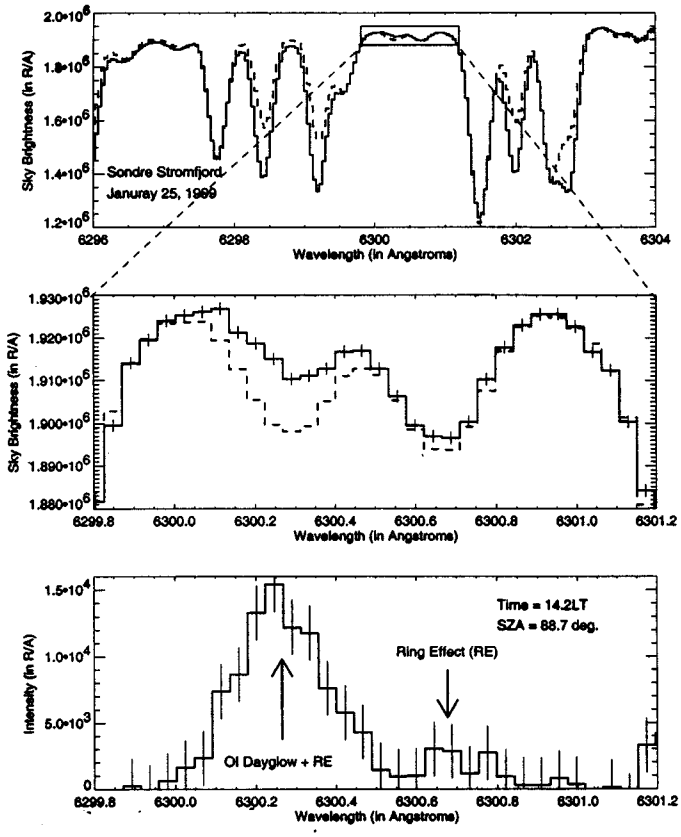
6300Å
"Line" in 4th panel

High Resolution Imaging Spectrograph Echelle (HIRISE)

HIRISE: Schematic

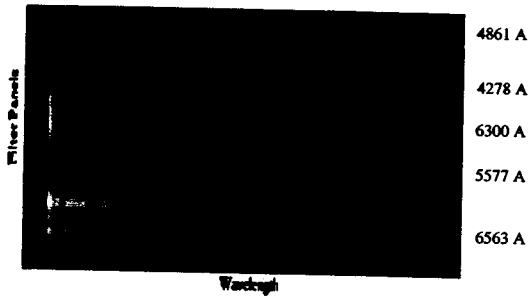


Spectral Resolution ≈ 0.12 Å

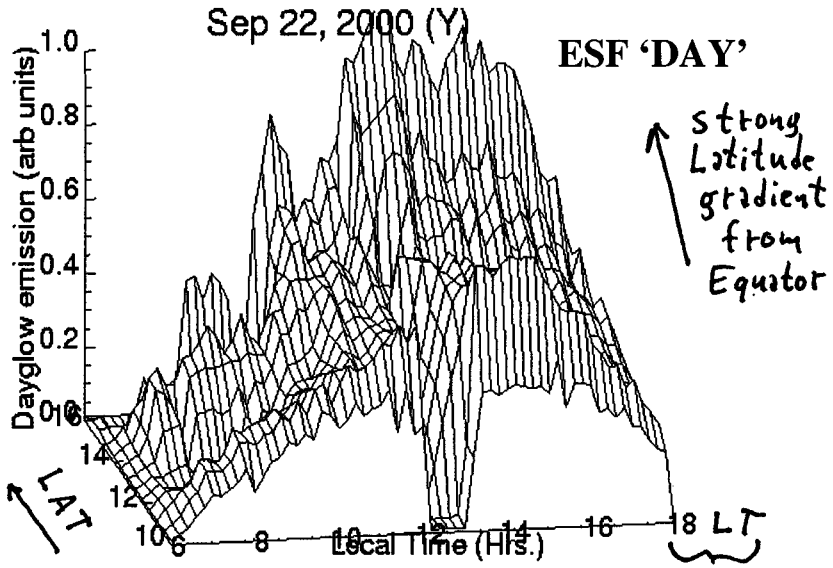


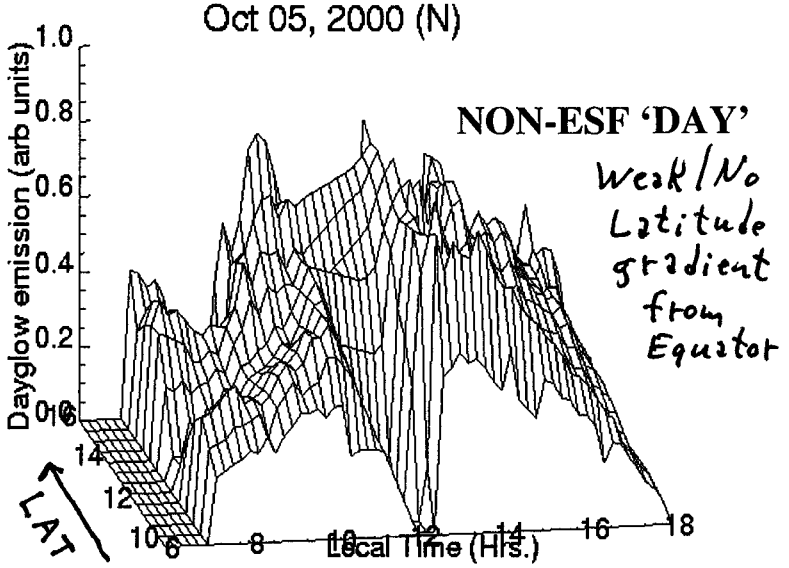
MOSAIC Filter

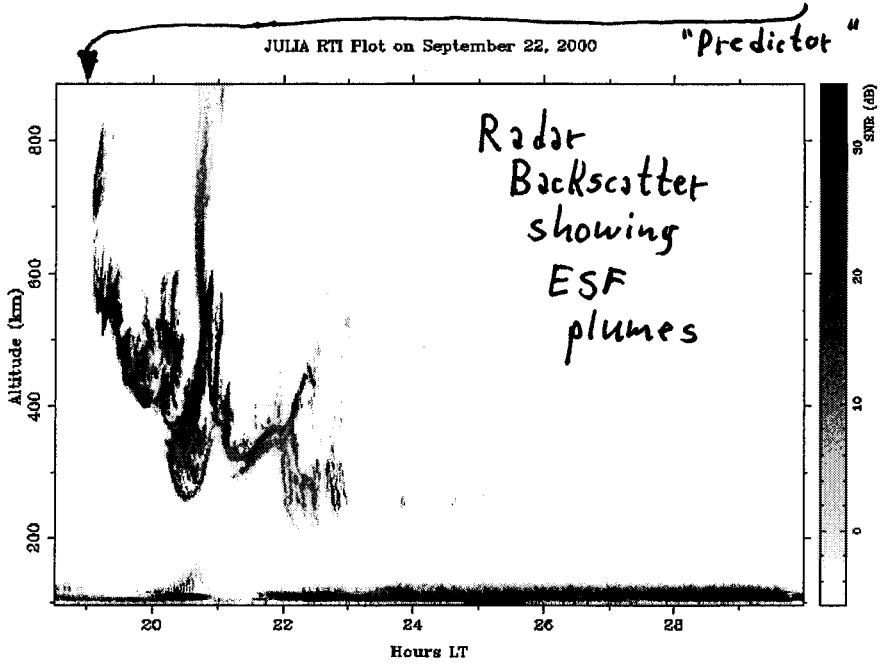
Image on the CCD

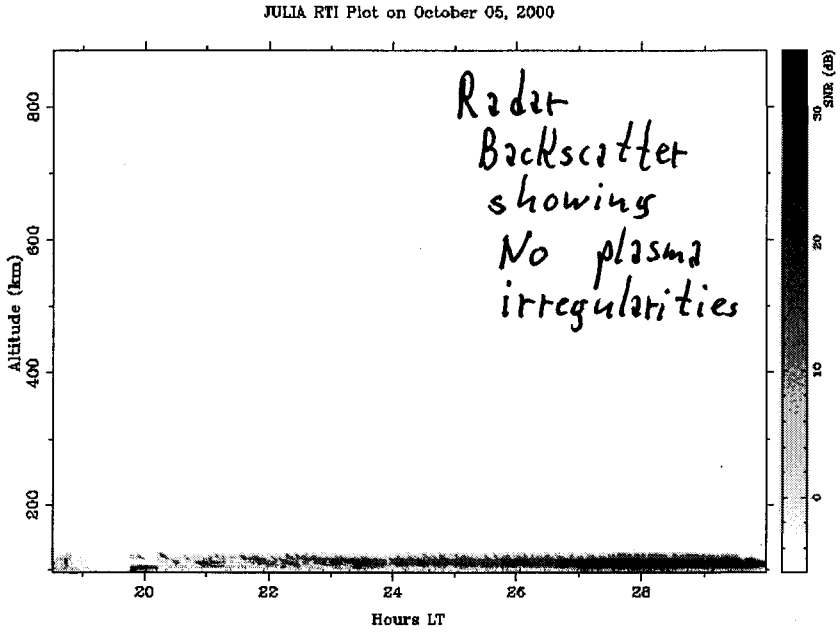


HIRISE Observations of OI 630.0nm Dayglow from Carmen Alto, Chile





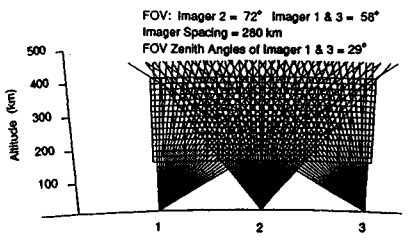




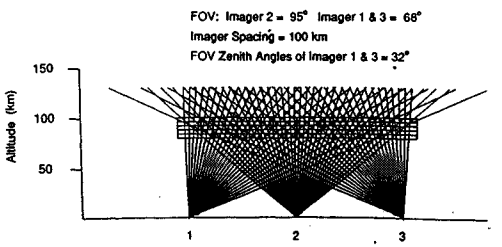
New Techniques:
— TOMOGRAPHY of sub-visual structures

OPTICAL TOMOGRAPHY OF AERONOMIC SYSTEMS

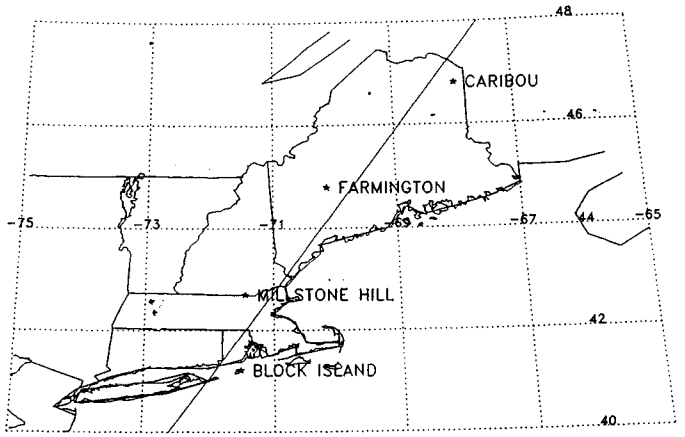
- Use state-of-art CEDAR Class-I Imager and Imaging Spectrographs
- Obtain meridional or zonal height profiles of volume emission rates (ε_{vol}) within context of an all-sky image
- ε_{vol} gives direct access to coupling processes between magnetosphere, ionosphere, and neutal atmosphere.

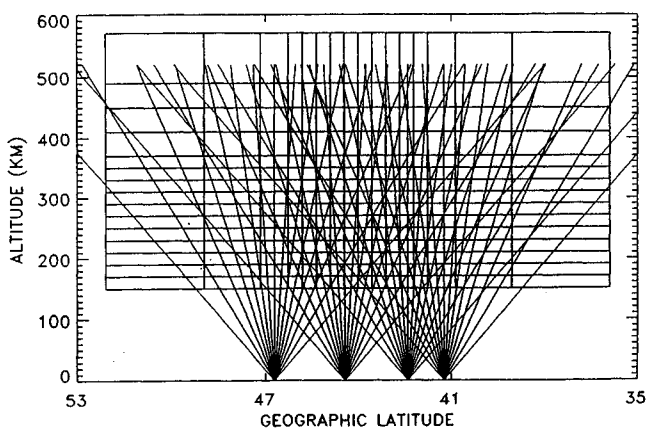


F-REGION EMISSIONS

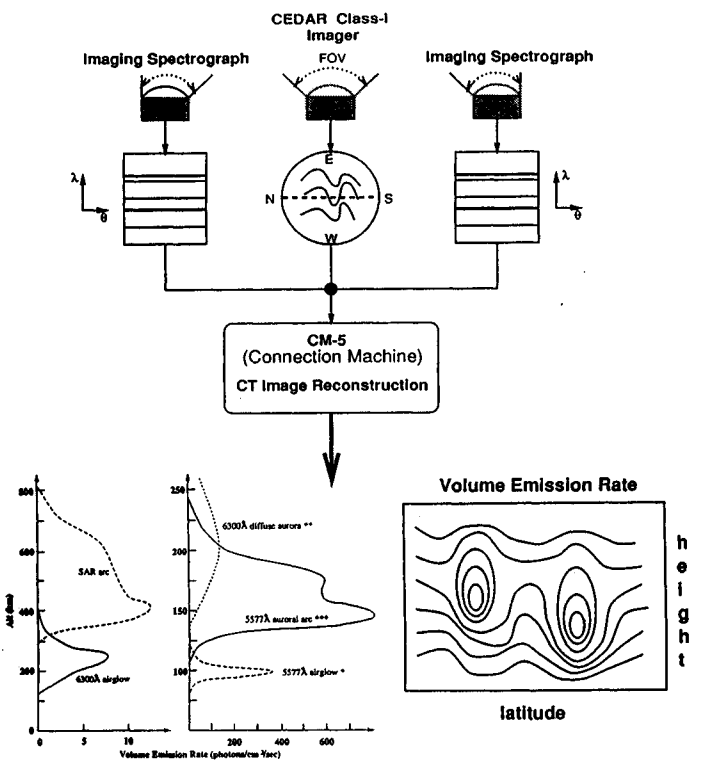


MESOSPHERE EMISSIONS





---Accessing the altitude-dependent volume emission rate physics---



OPTICAL TOMOGRAPHIC IMAGING SYSTEM

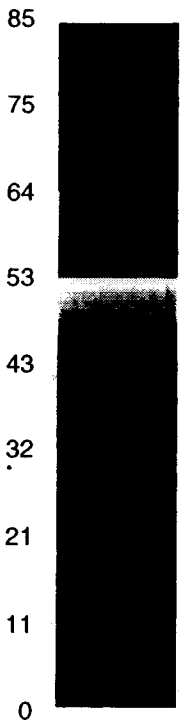
(14.)

EXAMPLE: Stable Auroral Red (SAR) Arc at Mid-Latitudes

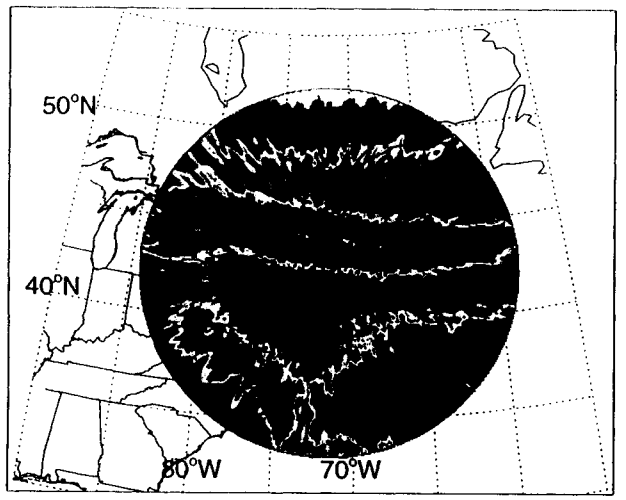
BOSTON UNIVERSITY
ALL-SKY IMAGIMG SYSTEM
MILLSTONE HILL

5 MARCH 1995
04:09:10 UT

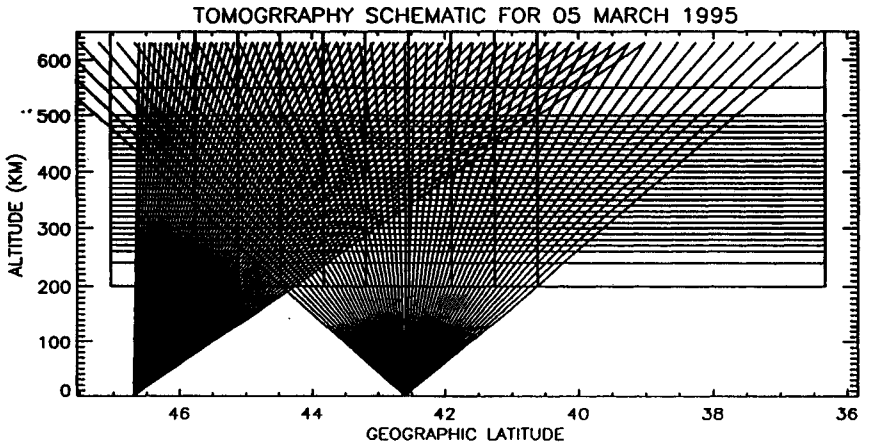
6300 A
RAYLEIGHS

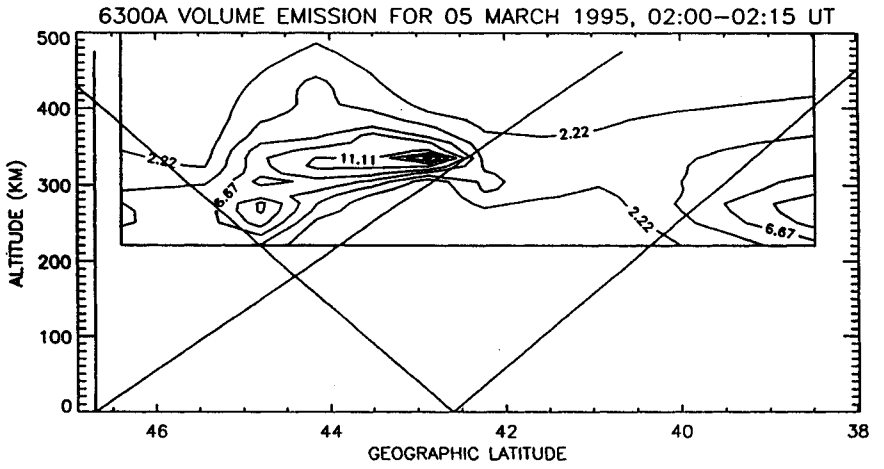


DIFFUSE AURORA, SAR ARC, and AIRGLOW



Optical Remote Sensing of Ionospheric Structure





Potential Uses at Equatorial + Low Latitudes:

--- Inter-tropical Arcs

--- ESF-related Airglow Depletions

(15.)

How Does an Image Slicer Work?