Auroral Phenomenon Localization, Classification, and Temporal Evolution Tracking

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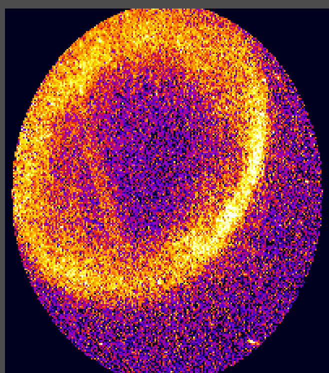
General Goal: Support Study of Aurora

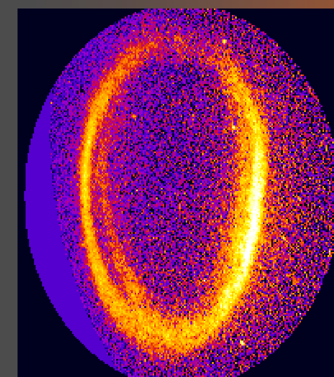
- UVI Polar Datasets
  - 9M+ images!
    - Exploitation Challenge
  - OST (Germany Talk @ AISR05)
    - Queries based on:
      - Sensor Location
      - Some Image Features:
        - Integrated Intensity
        - Boundary Position
        - Image Quality
    - Popular:
      - 1000/100

- UVI OST Link

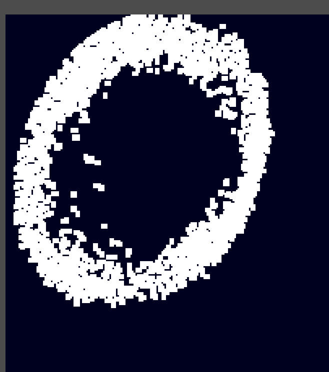
A Problem: Finding Auroral Oval

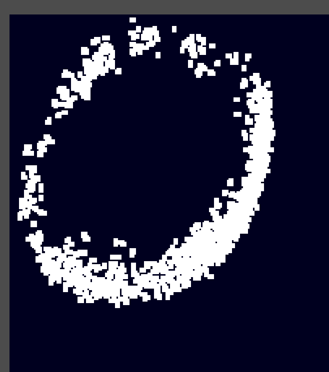

UVI image

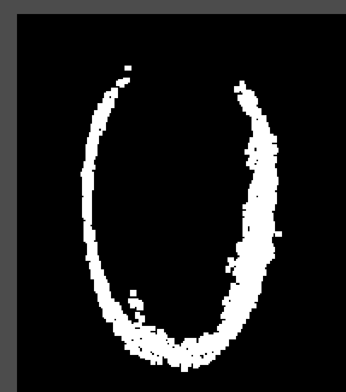

PCNN


UVI image


PCNN


HKM


AMET


HKM


AMET

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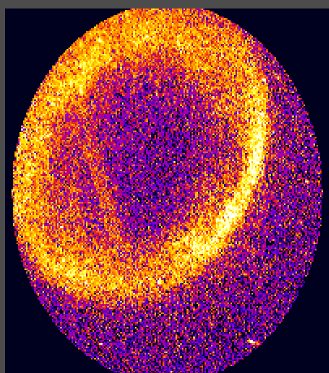
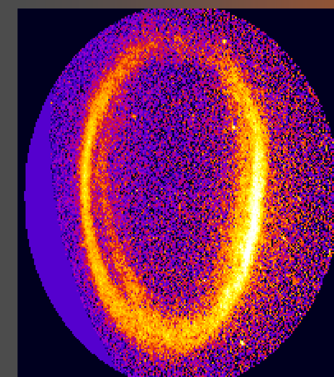


UVI image

PCNN

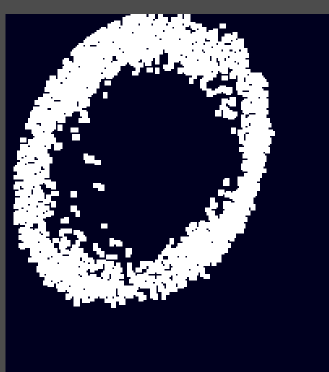


UVI image

PCNN

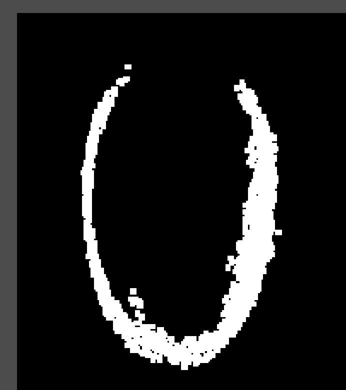
Inconsistent

Incomplete

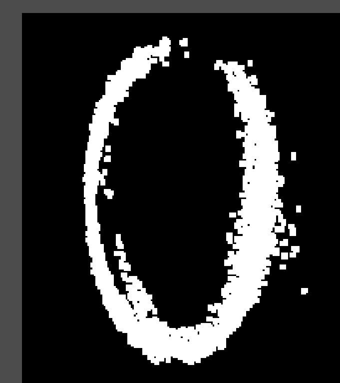


HKM

AMET



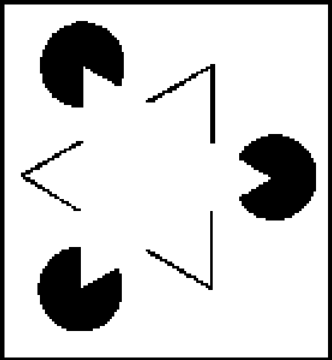
HKM



AMET

Visual Perception I

- What do you see?

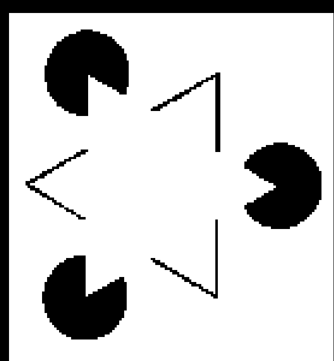


from Torrans 99 (GMU)

from Schiffman's *Sensation and Perception*, 2000, as presented by Loken et al., Macalester Coll.

Visual Perception I

- What do you see?



from Torrans 99 (GMU)

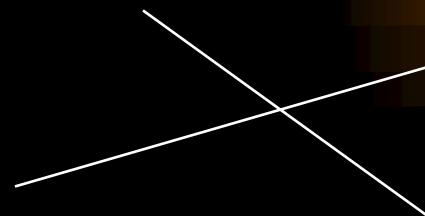
from Schiffman's *Sensation and Perception*, 2000, as presented by Loken et al., Macalester Coll.

Gestalt = Form, a unit of perception

Note: Avoid strict Gestaltism!

Visual Perception II: Some Gestalt

- Continuity



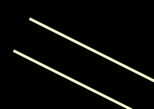
- Closure

H ppy Birthday

- Proximity

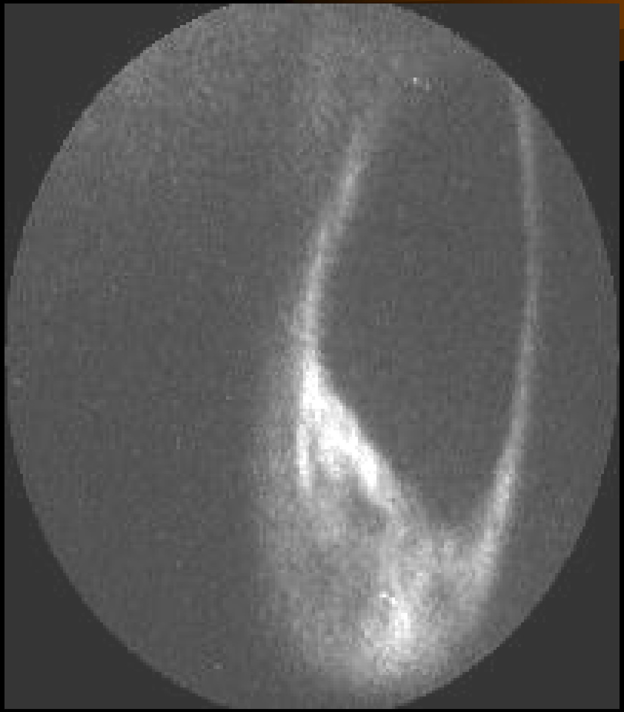
EEEEEEEEEEEFEEEEEEEEEEE

- Similarity



Toward a Better Solution?

- Exploit:
  - Continuity
  - Closure
  - Proximity
  - Similarity



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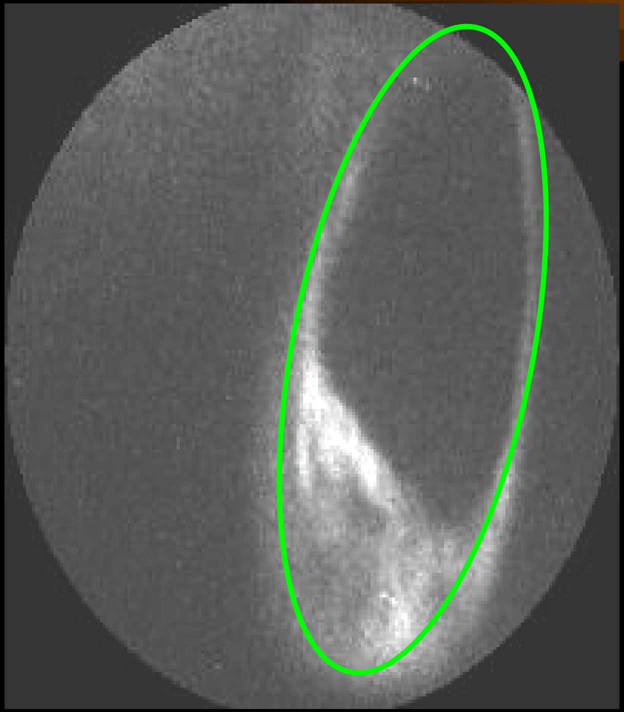


Specific Goal: Effective Retrieval

- UVI OST: Mining Pre-Processing
  - Removes Non-Auroral Features
  - Extracts Auroral Oval
    - Inefficient
    - Often fails
- Support Auroral Feature Search
  - **Shape-Based Processing** to Localize Oval
  - Better-support Auroral Feature Retrieval

Shape Recovery

- Our prior work:
  - Spheres
  - Cylinders
  - Cones
  - Ellipsoids
  - Paraboloids
  - Hyperboloids
  - Compound Structures

Exploiting Shape I

- Exploiting Shape: Preliminaries
  - What Shape?
  - Shape Invariant Descriptors

$$Ax^2 + By^2 + Cxy + Dx + Ey = 1$$

$$\Delta = \begin{vmatrix} A & C/2 & D/2 \\ C/2 & B & E/2 \\ D/2 & E/2 & F \end{vmatrix} \qquad J = \begin{vmatrix} A & C/2 \\ C/2 & B \end{vmatrix} \qquad I = A + B$$

$$\Delta \neq 0, J > 0, \frac{\Delta}{I} < 0: \text{ ellipse}$$

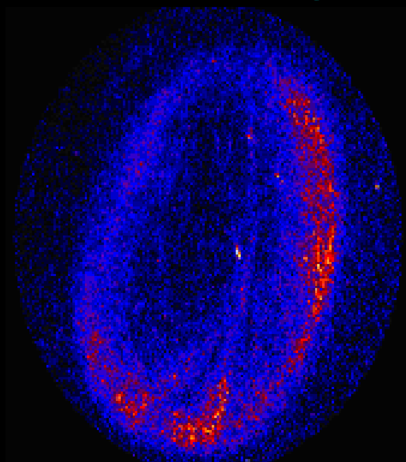
Exploiting Shape II: Experiments

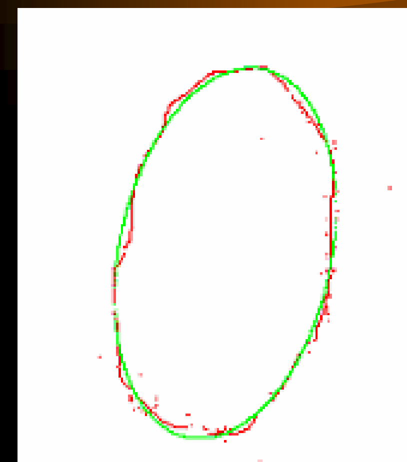
- Shape Testing
  - Manual Tracing
  - Linear Least Squares Fitting
  - Shape Invariant Extraction

Some Fitting Results

Colorized Image **Manually traced boundary** **Fittings** **Invar.**

97/011/053422





Δ = 2E-10
J = 1E-9
I = -8E-5
$\Delta / I < 0$

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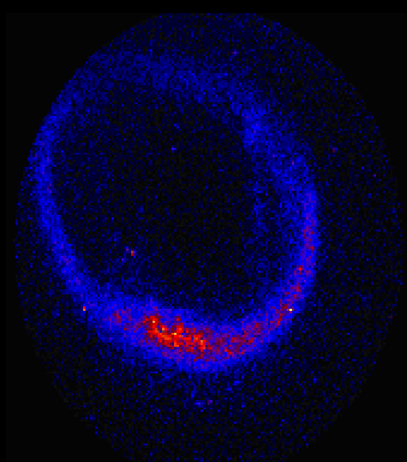
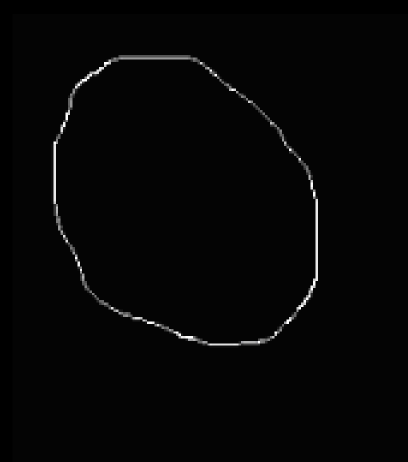
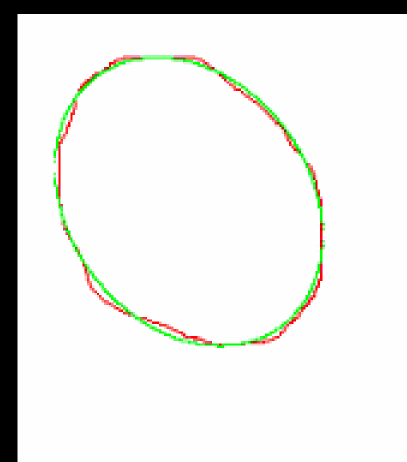


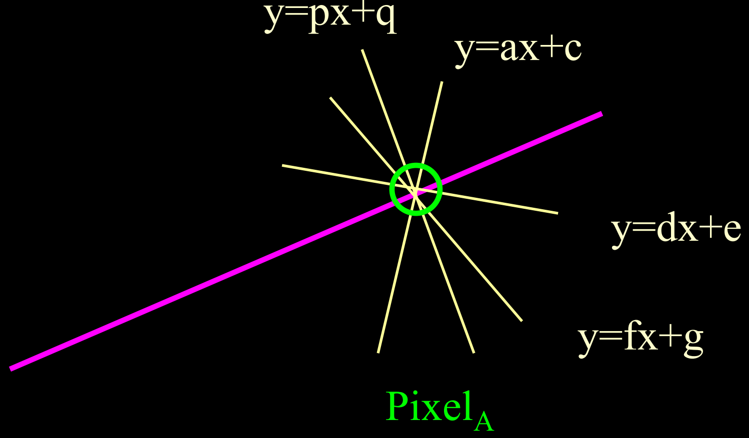




Δ = 9E-9
J = 2E-8
I = -3E-4
$\Delta / I < 0$

Initial Work: Localization

- Hough-Based Processing
  - Democratic:
    - Pixels Vote
  - Example
    - $y = mx + b$



Shape-based Detection

- Mod. Randomized Hough Transf. (MRHT) for ellipse:
  - Randomly Select Edgels
  - Fit General Quadratic
  - Determine Shape
  - Ellipse Parameter Recovery (next page)
  - Parameter Space Decomposition
    - 2D accumulate array for center
    - 2D accumulate array for axes
    - 1D accumulate array for orientation

Shape-based Detection (cont.)

- MRHT for ellipse
  - Recover: $Ax^2 + By^2 + Cxy + Dx + Ey = 1$

center $(x_0, y_0) = (\frac{2BD - CE}{C^2 - 4AB}, \frac{2AE - CD}{C^2 - 4AB})$

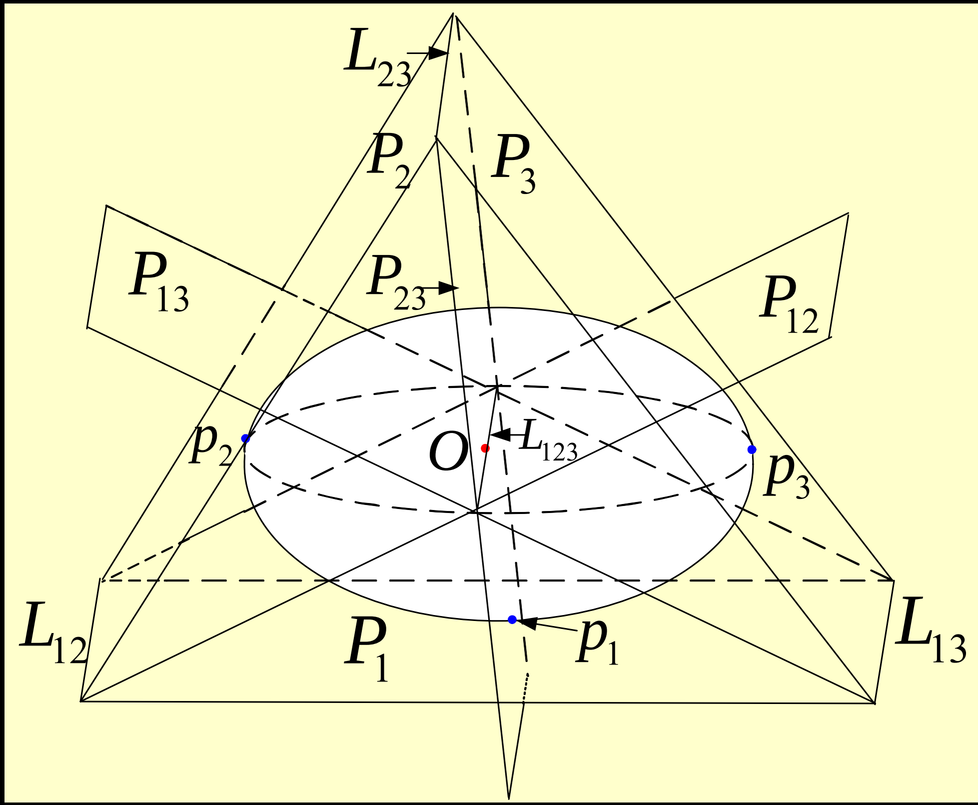
orientation $\theta = \arctan(\sqrt{\left(\frac{B-A}{C}\right)^2 + 1} + \frac{B-A}{C})$

axes $(a, b) = (\sqrt{\frac{|\Delta|}{|J r_1|}}, \sqrt{\frac{|\Delta|}{|J r_2|}})$

where
$$r_1 = \frac{1}{2}(A + B + \sqrt{(B-A)^2 + C^2}),$$
$$r_2 = \frac{1}{2}(A + B - \sqrt{(B-A)^2 + C^2}).$$

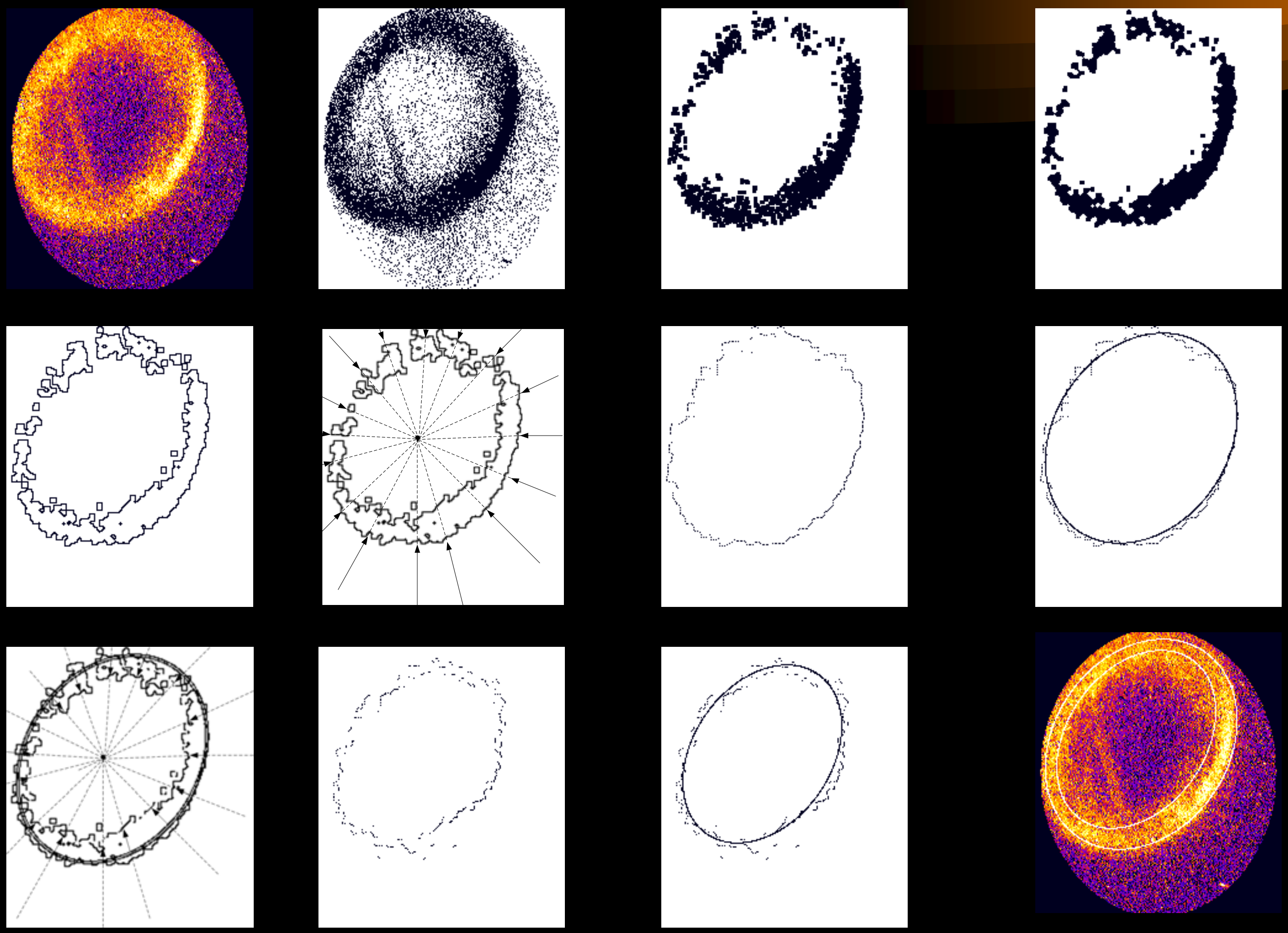
Spin-Off : MRHT for Ellipsoids

- Two Stages:
  - Center detection
  - Axes and orientation detection
    - Linear least-squares
    - Eigen analysis
- Multiple ellipsoids OK



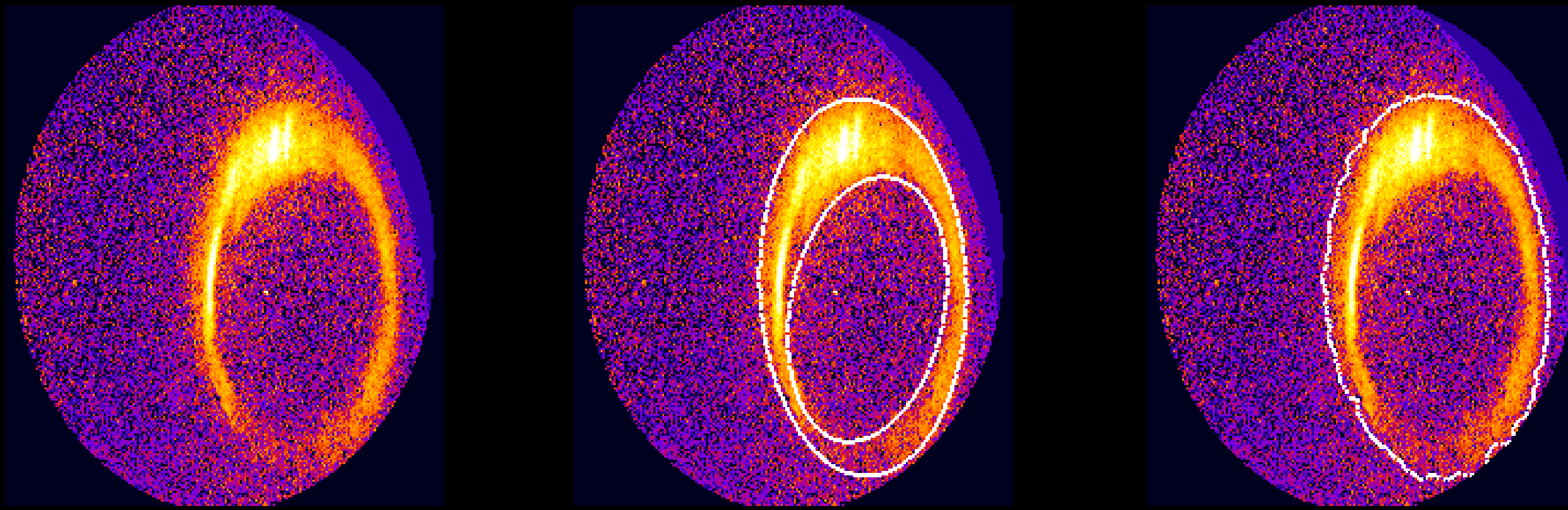
* ICPR 06 paper

Shape-based Detection Illustrated



Ongoing Work I: Improvements

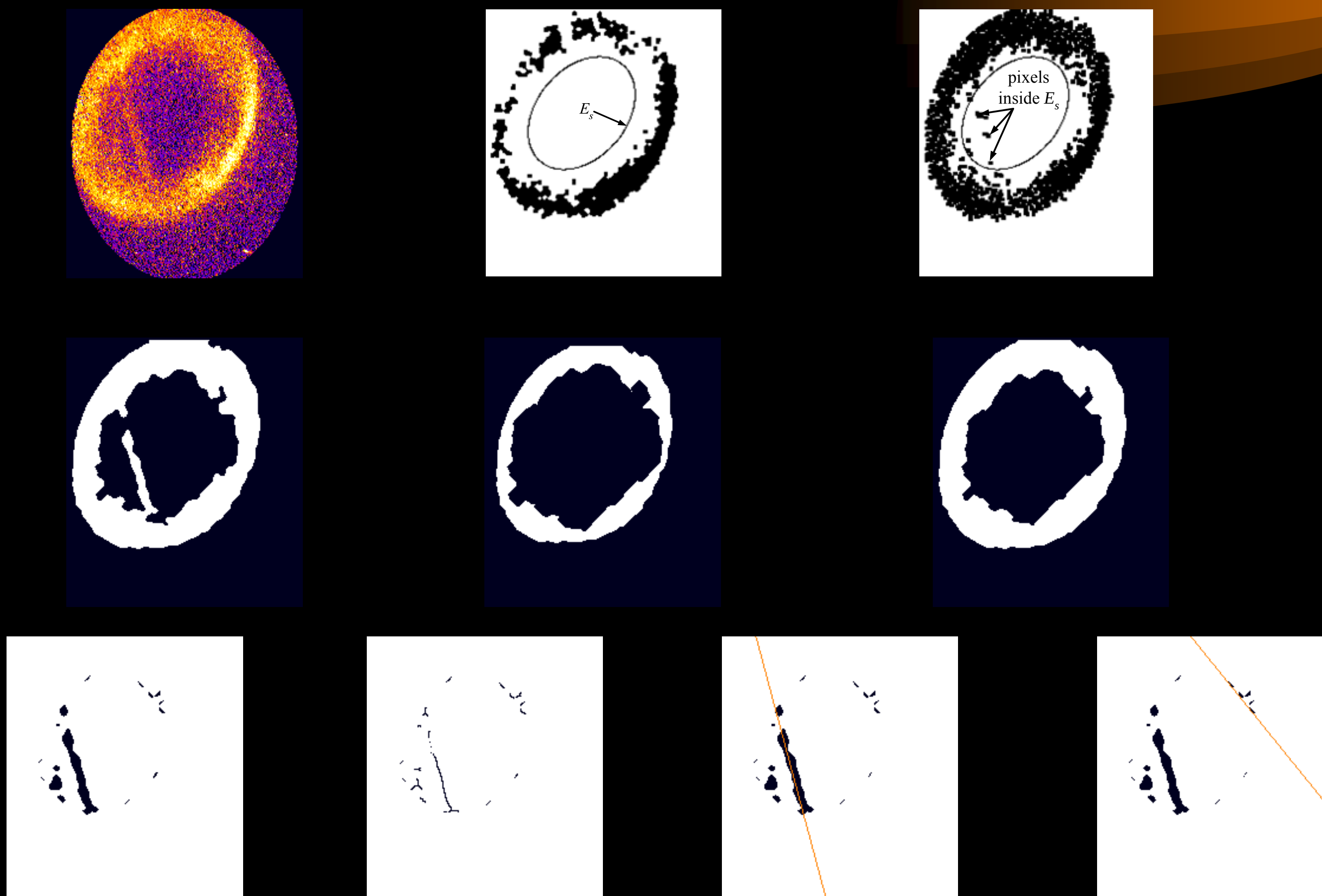
- Improve Auroral Oval Detection
  - Deformable Contour



Ongoing Work II: Auroral Classification A

- θ–aurora
  - Exploit θ Characteristics
- Steps:
  1. Transpolar activities exist? If none, stop; no θ-aurora
  2. Apply PCNN-based method for aurora oval detection
  3. Extract transpolar arcs and thin them
  4. Detect a line using Hough transformation (HT)
  5. Determine whether the transpolar arc belongs to a θ–aurora
  6. Determine if there exists more than one transpolar arc
  7. Determine if the aurora a candidate θ-aurora
  8. After examining all the images, determine whether the candidate θ–aurorae are real θ–aurorae

Ongoing Work II: Auroral Classification B



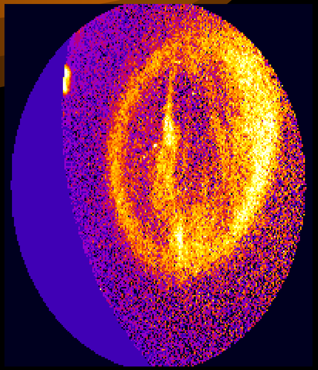
Ongoing Work II: Auroral Classification Results

- Experiment data set:
  - 6 days in years 1997 and 1999
  - 1206 images: 507 transpolar arc, 699 no transpolar arc
    - θ–aurorae: 79, Standard aurorae: 799, Dayglow: 267

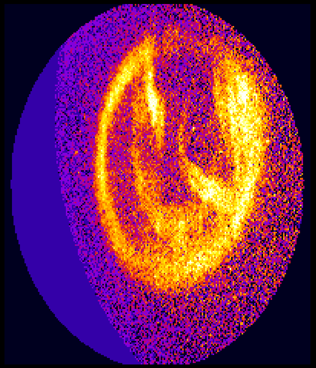
	Relevant Images	False Alarms	Missed Images	Precision	Recall
θ–aurorae	65	8	14	89%	82.3%
Standard Aurorae	761	70	38	91.6%	95.2%

Work Goals

- Better-Localized Auroral Oval
- Upcoming:
  - Additional Classification
  - Temporal Evolution Tracking
    - Substorms
  - Extend to FUV



Horse Collar



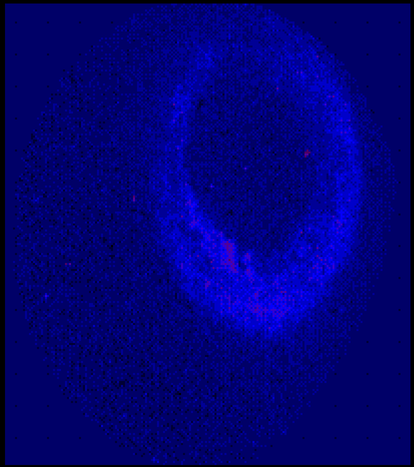
Bent Transpolar Arc

Conclusion

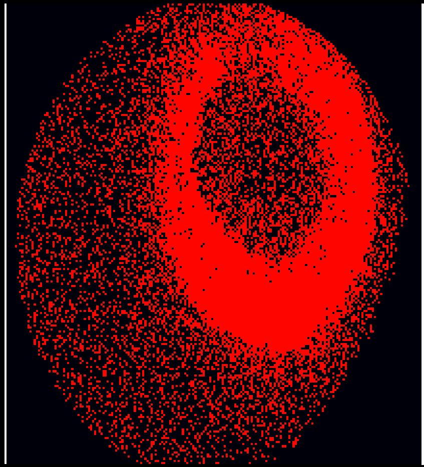
- Exploited Shape for:
  - More Robust Auroral Oval Detection
    - Comparative Study of Performance (Pub. Upcoming)
  - θ-Aurora Detection (Data Mining / Apps. pub.)
- Better OST
- Spin-off: Ellipsoids (ICPR pub.)

Approx. Auroral Oval Boundary

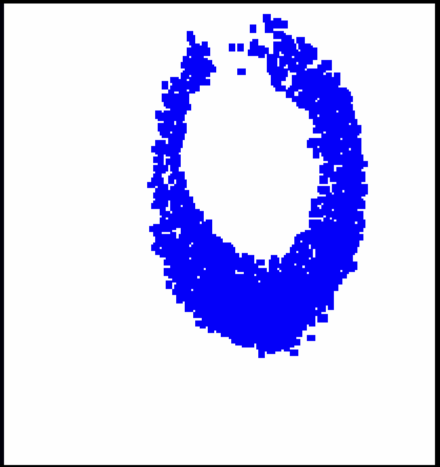
- Thresholding with density examination
  - Thresholding value: μ (mean of the pixel intensities)
- LoG edge detection



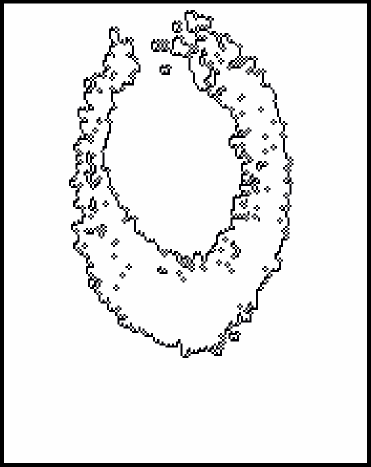
99/006/093006



Thresholded image



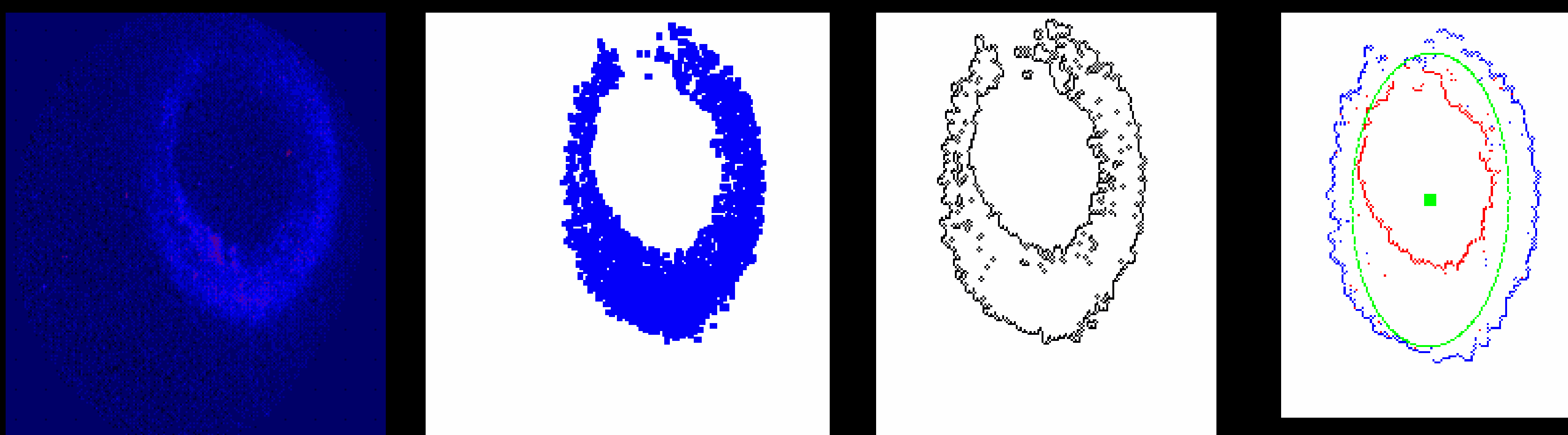
Dense part



Boundary

Shape-based Detection (cont.)

- Separation of inner and outer boundary
  - Based on distance to center of detected ellipse from boundary pixels

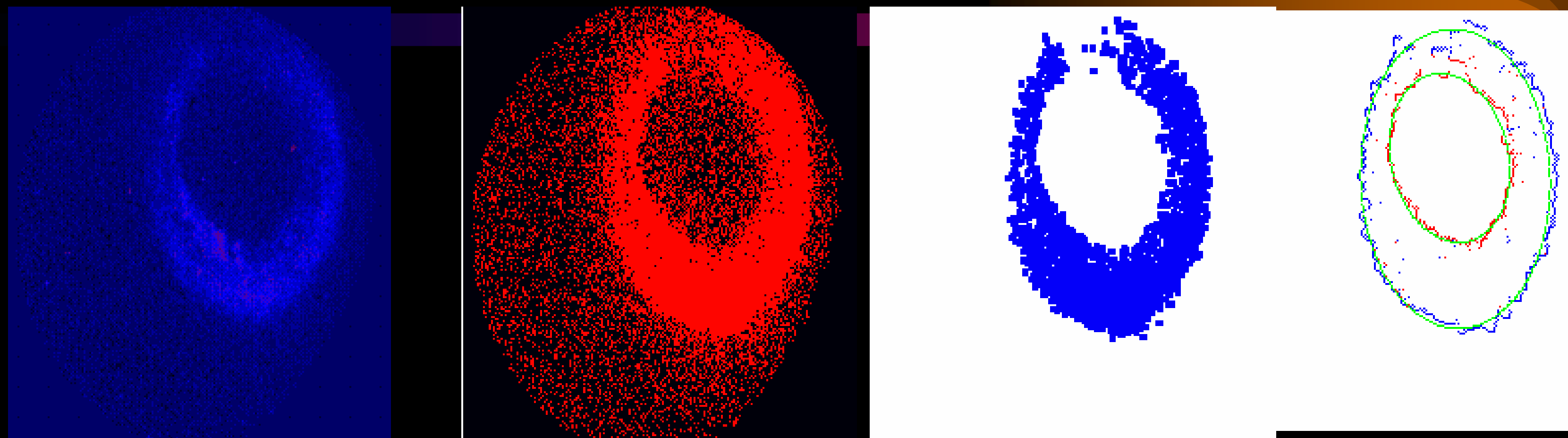


99/006/093006

Green = detected ellipse from boundary pixels. Red = inner boundary. Blue = outer boundary

Shape-based Detection (cont.)

- Shape detection of inner and outer boundary.



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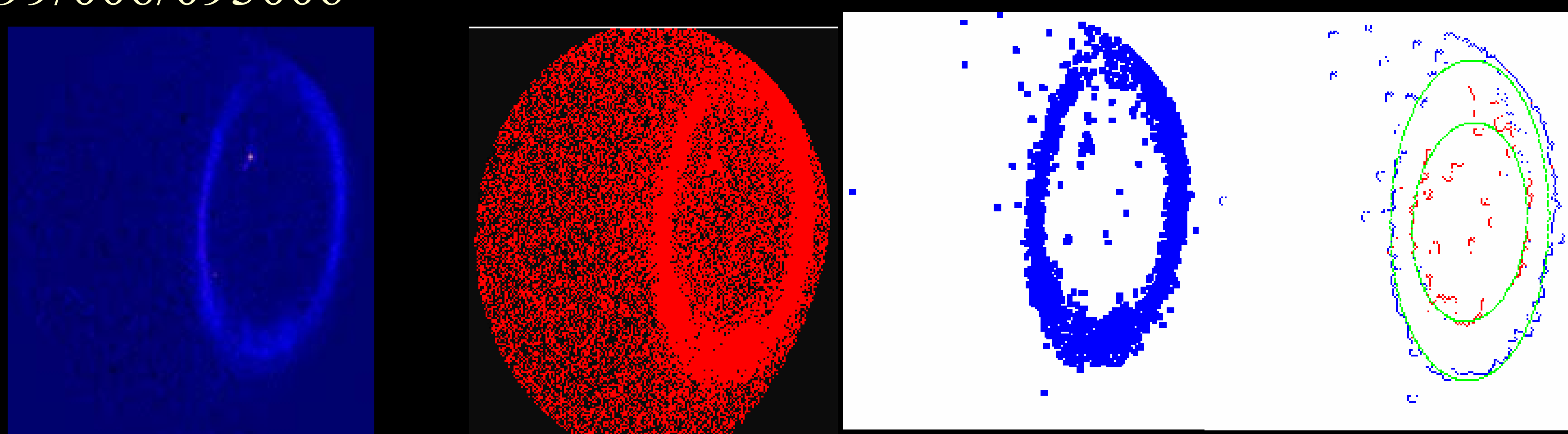

99/006/070027

Green = RHT ellipses. Red = Inner.
Blue= outer boundaries of the aurora arc.

Experimental Configuration

- Machine:
  - CPU: 2.3 GHz
  - Memory: 512 MB
  - OS: Windows XP
- Run time (wall clock)
  - 3 MRHT runs each with 100,000 fittings
    - One run for center estimation, two runs for inner and outer boundary detection
  - ≈ 45 seconds for each image