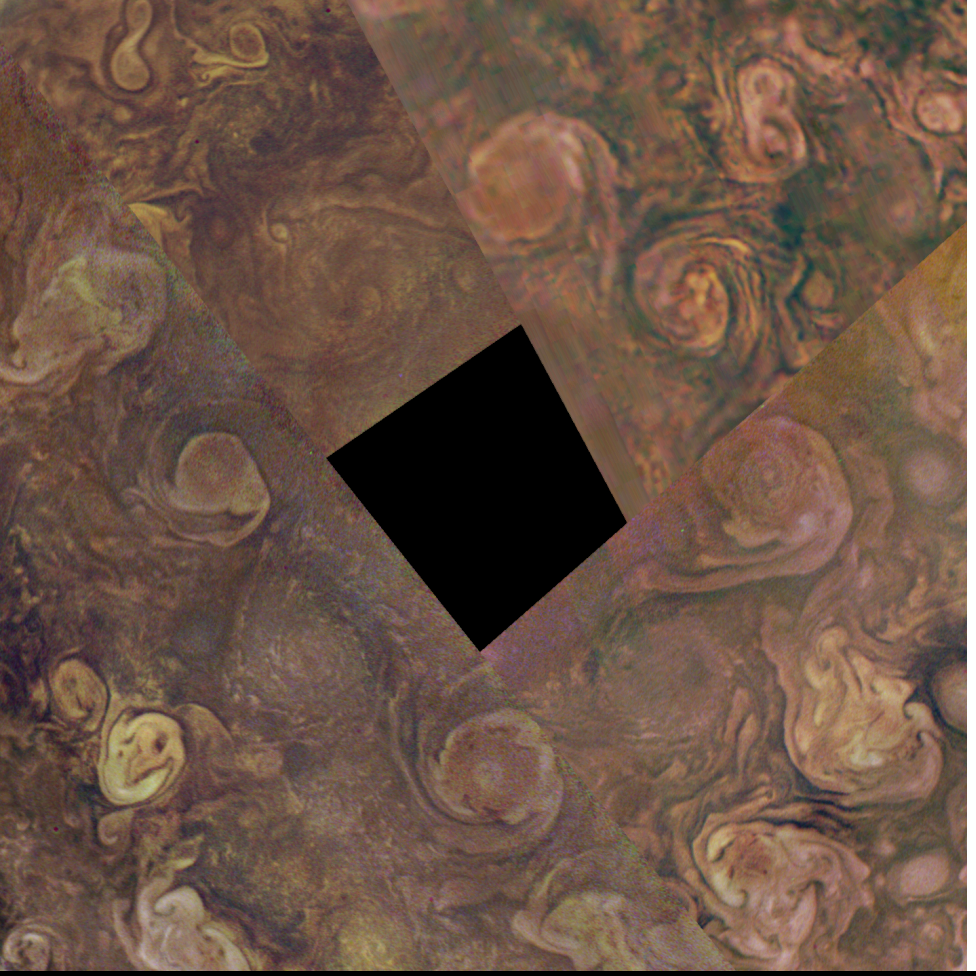

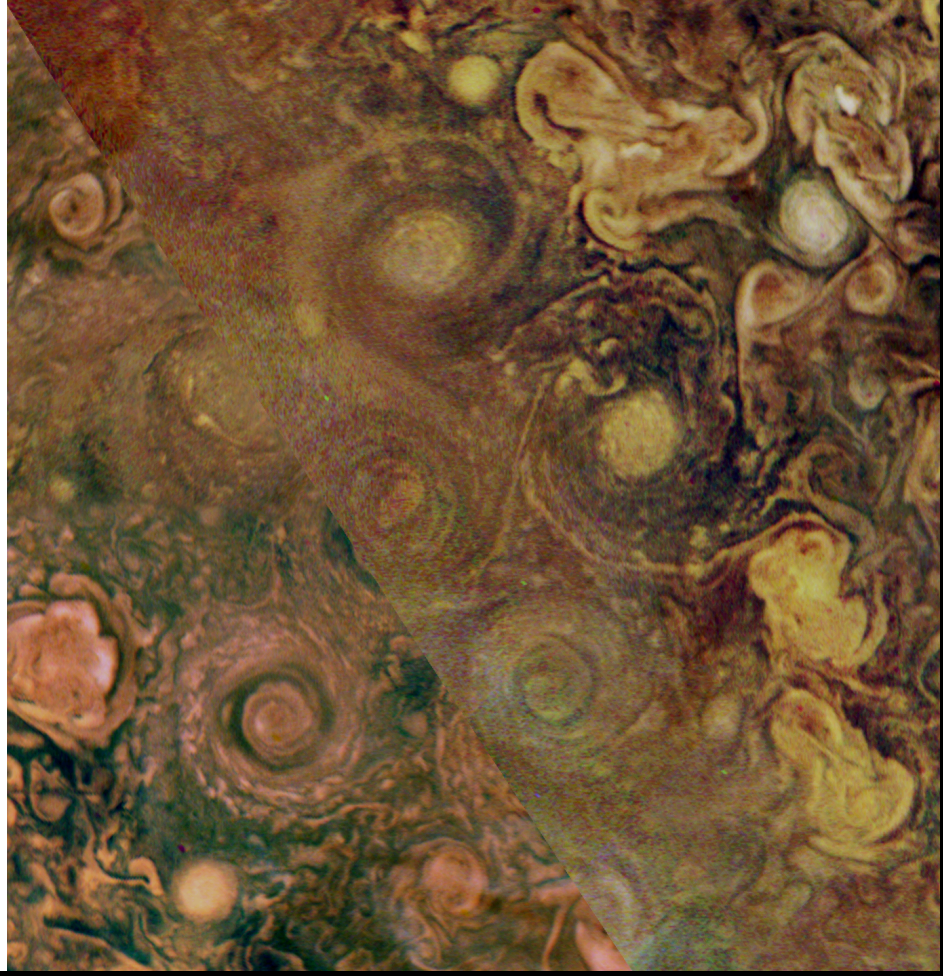

Stability and Evolution of the Jovian Circumpolar Cyclones

Fachreddin Tabataba-Vakili[1], J.H. Rogers[2], G. Eichstädt[3], G.S. Orton[1], C.J. Hansen[2], T.W. Momary[1], J.A. Sinclair[1], R.S. Giles[1], M.A. Caplinger[5], M.A. Ravine[5], A Mura[6], A Adriani[6] S.J. Bolton[7]

1: Jet Propulsion Laboratory, California Institute of Technology 2: British Astronomical Association 3: Independent scholar

4: Planetary Science Institute 5: Malin Space Science Systems 6: IAPS-INAF

7:Southwest Research Institute, San Antonio, Texas, USA

JUNO

Jet Propulsion Laboratory
California Institute of Technology

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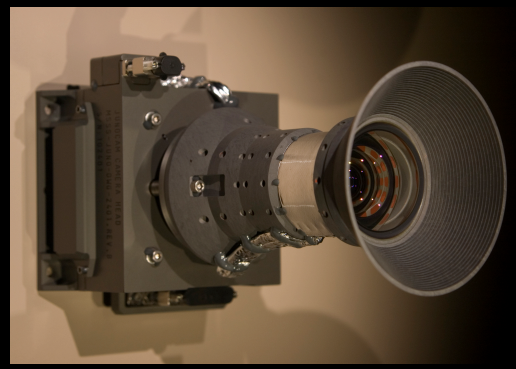
JunoCam

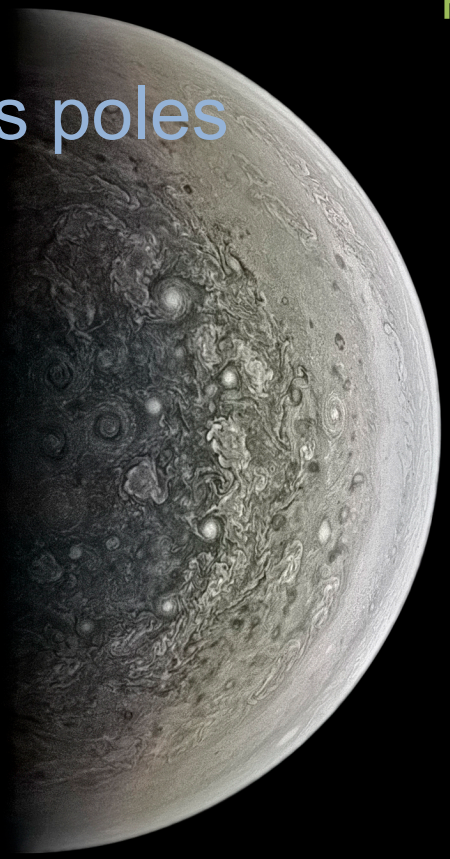
JunoCam is on the Juno payload to give the public an opportunity to participate in a planetary mission

Unique views of Jupiter's poles

Drove the camera design



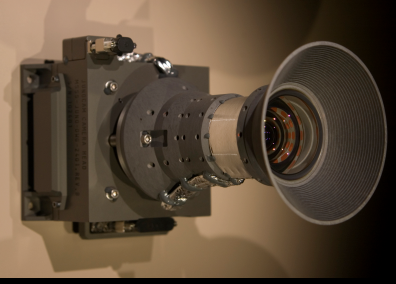
PJ1



South Pole

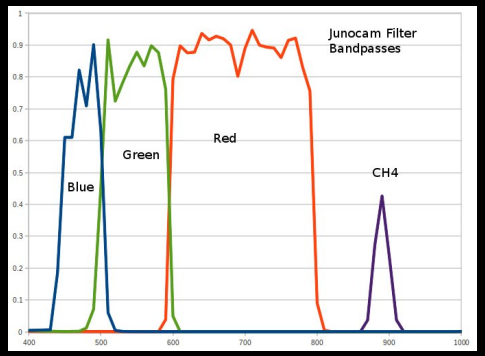
North Pole

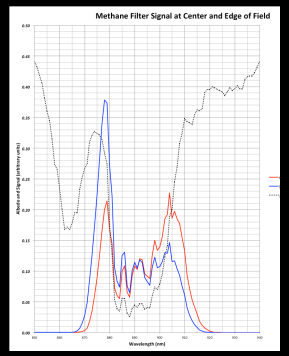
NASA / JPL / MSSS / Roman Tkachenko



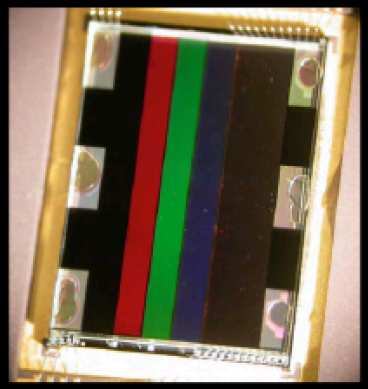
JunoCam Description

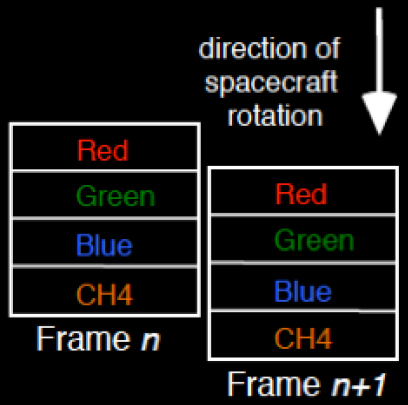
- JunoCam is a fixed-mounted, fixed field of view push-frame visible camera that images in four color bands
  - Broadband blue, green and red
  - Narrow methane band filter centered at 889 nm





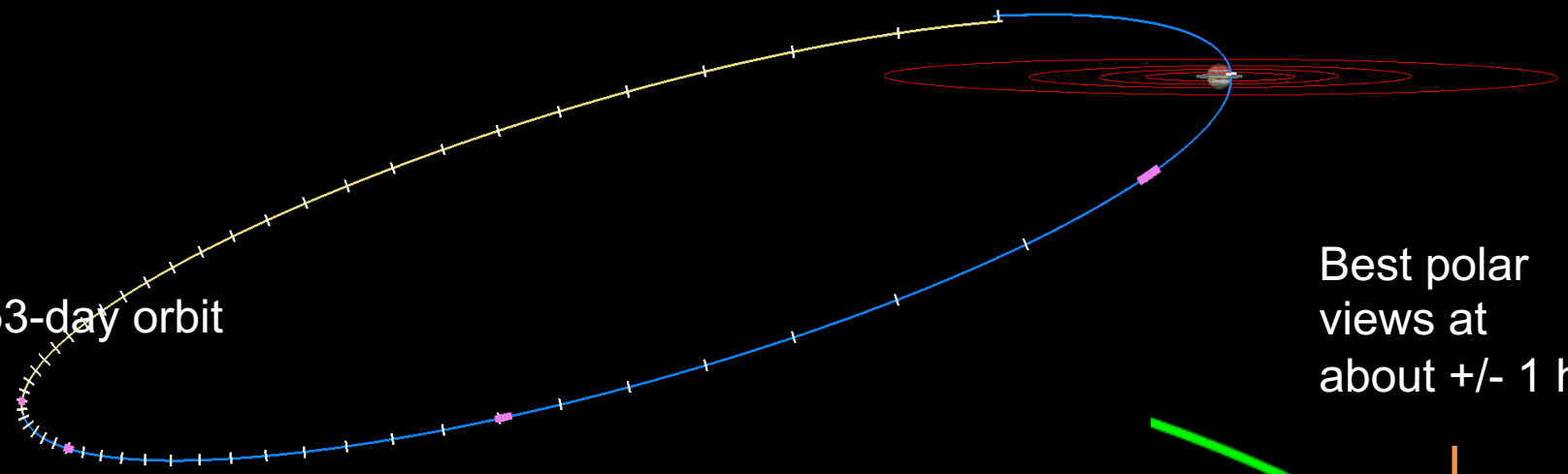
- *A JunoCam image is acquired as S/C rotation sweeps the 1600 pixel, 58° wide FOV across Jupiter*



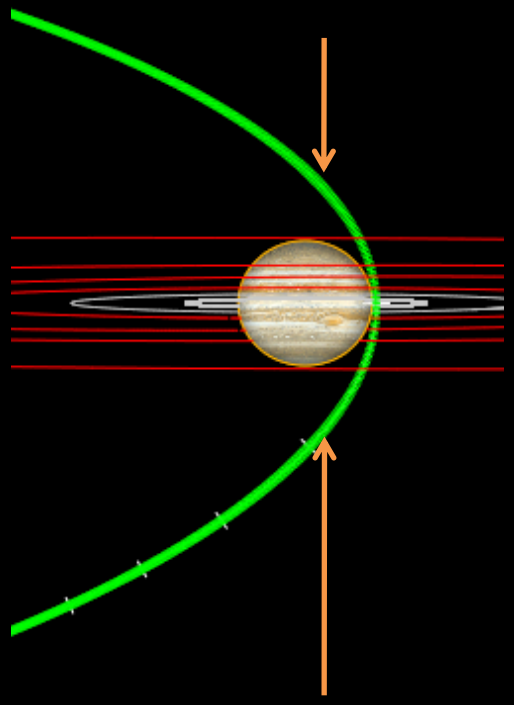


- Time-delayed integration (TDI) used to build up SNR
- Built and operated by Malin Space Science Systems

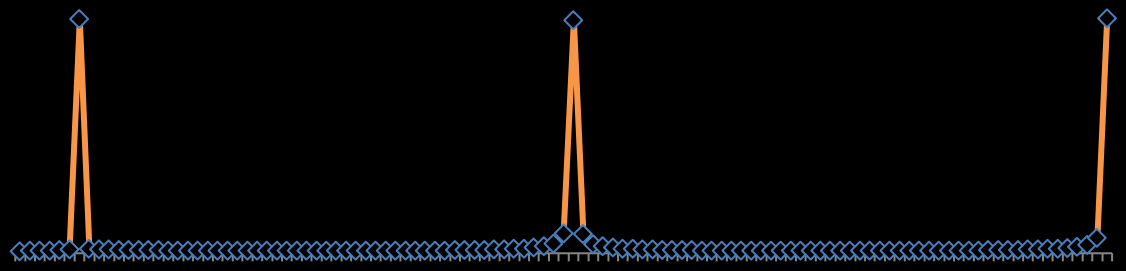
Juno's Elliptical Polar Orbit



Best polar views at about +/- 1 hr

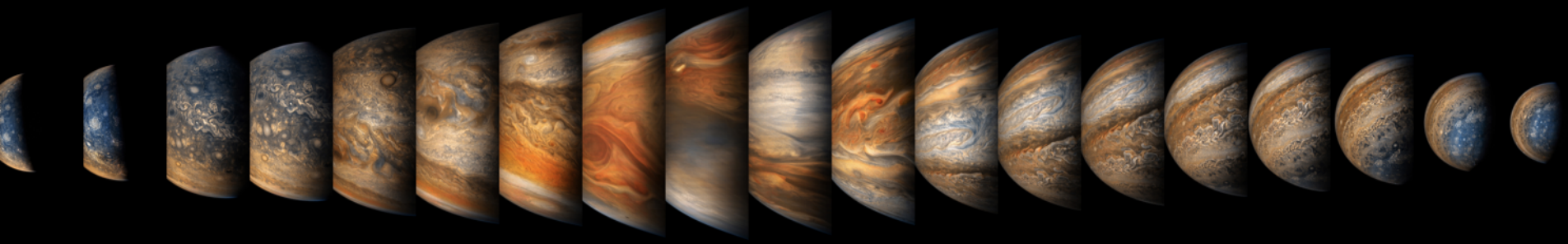


Jupiter is <50 pixels for most of Juno's orbit

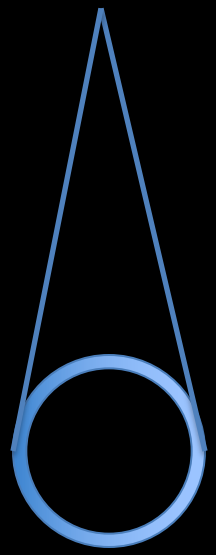


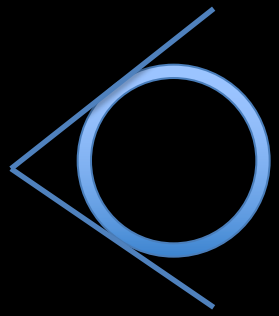
- Perijove swath begins ~1 hr before closest approach
- ~2h from north pole at minimum emission angle to south pole at minimum emission angle

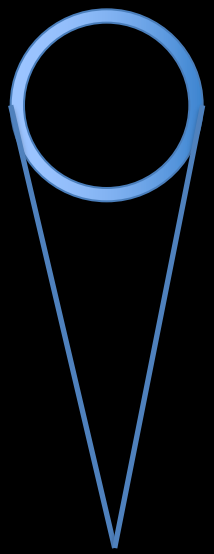
PJ8 Perijove Pass



NASA / JPL / MSSS / Gerald Eichstädt / Sean Doran





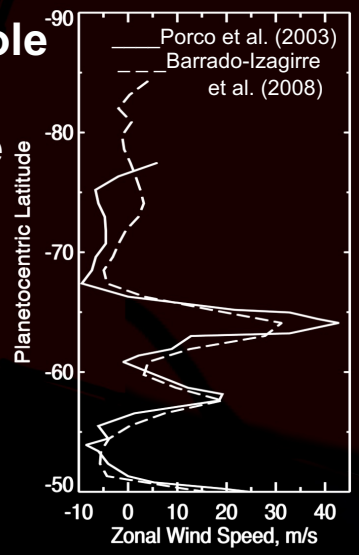


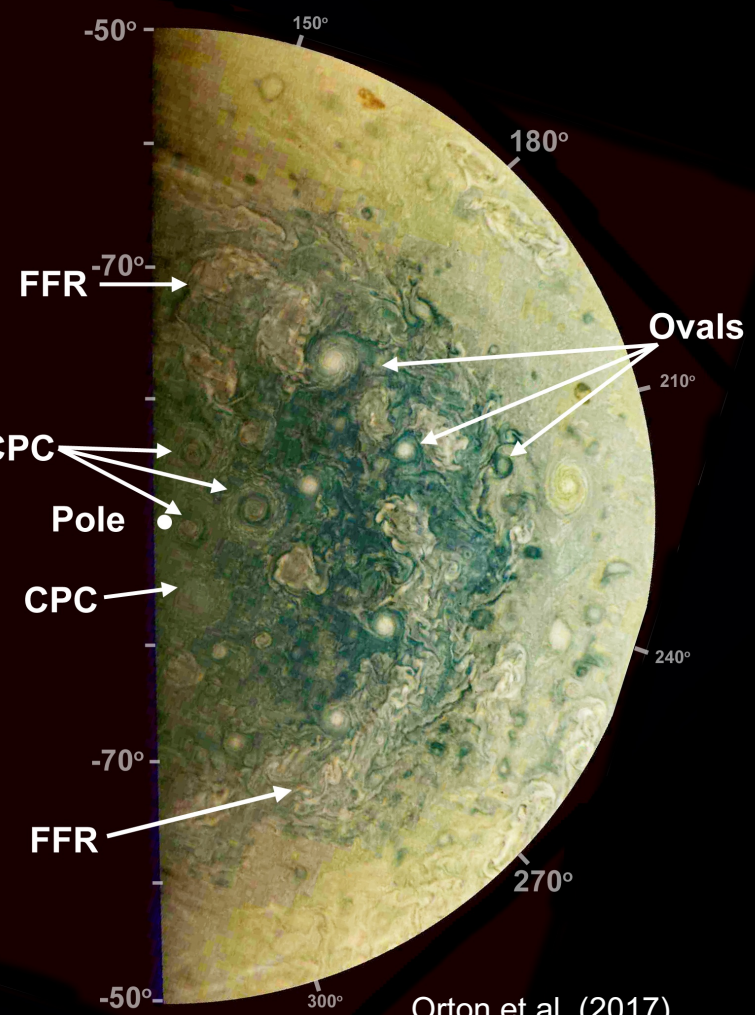
Polar Observations with Juno

JunoCam: South Pole

Perijove 1 (PJ1)

- FFR: Folded Filamentary Regions
  - Longest reaches across 10000 km
  - Colocated with eastward jet near 65°S
- Oval vortices
  - Largest is anticyclonic
- **CPC: Circum-polar Cyclones**
  - **Cyclonic vortices**
  - **Clustered around the pole**
  - **Central cyclone is slightly offset from pole**



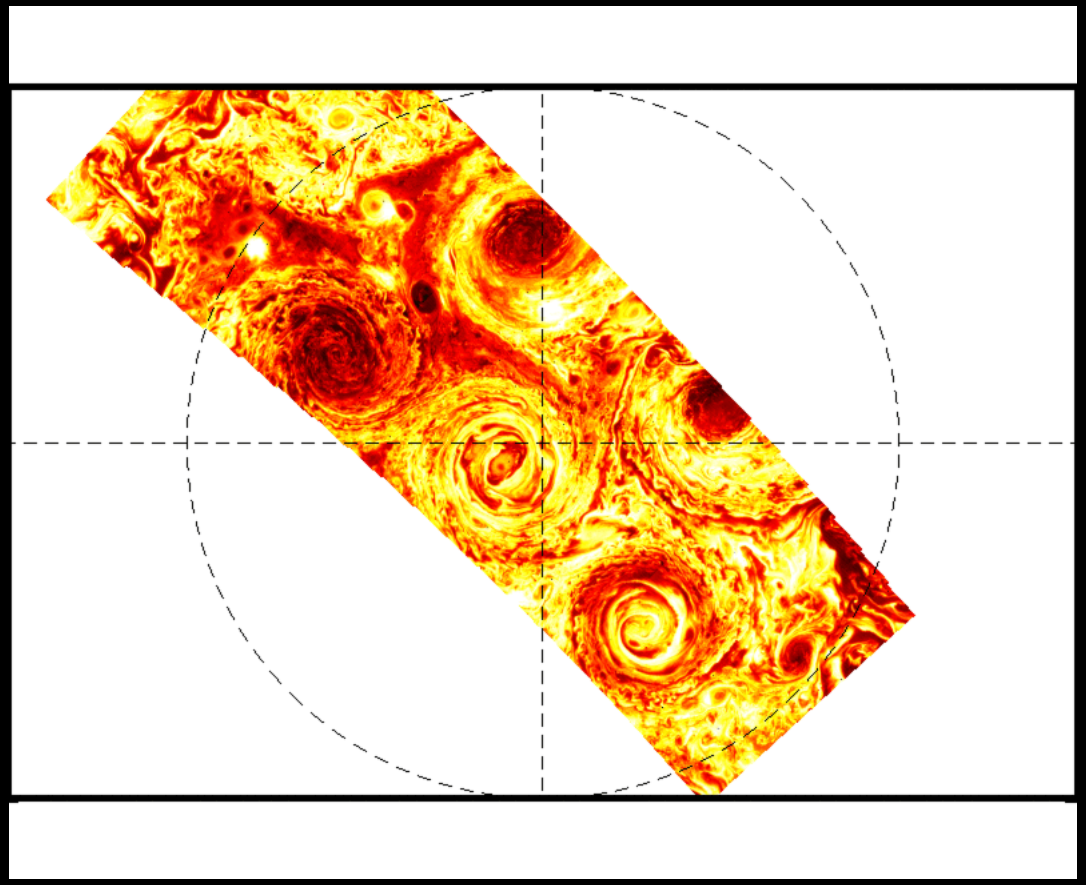


Orton et al. (2017)

Polar Observations with Juno

JIRAM (Jovian Infrared Auroral Mapper)

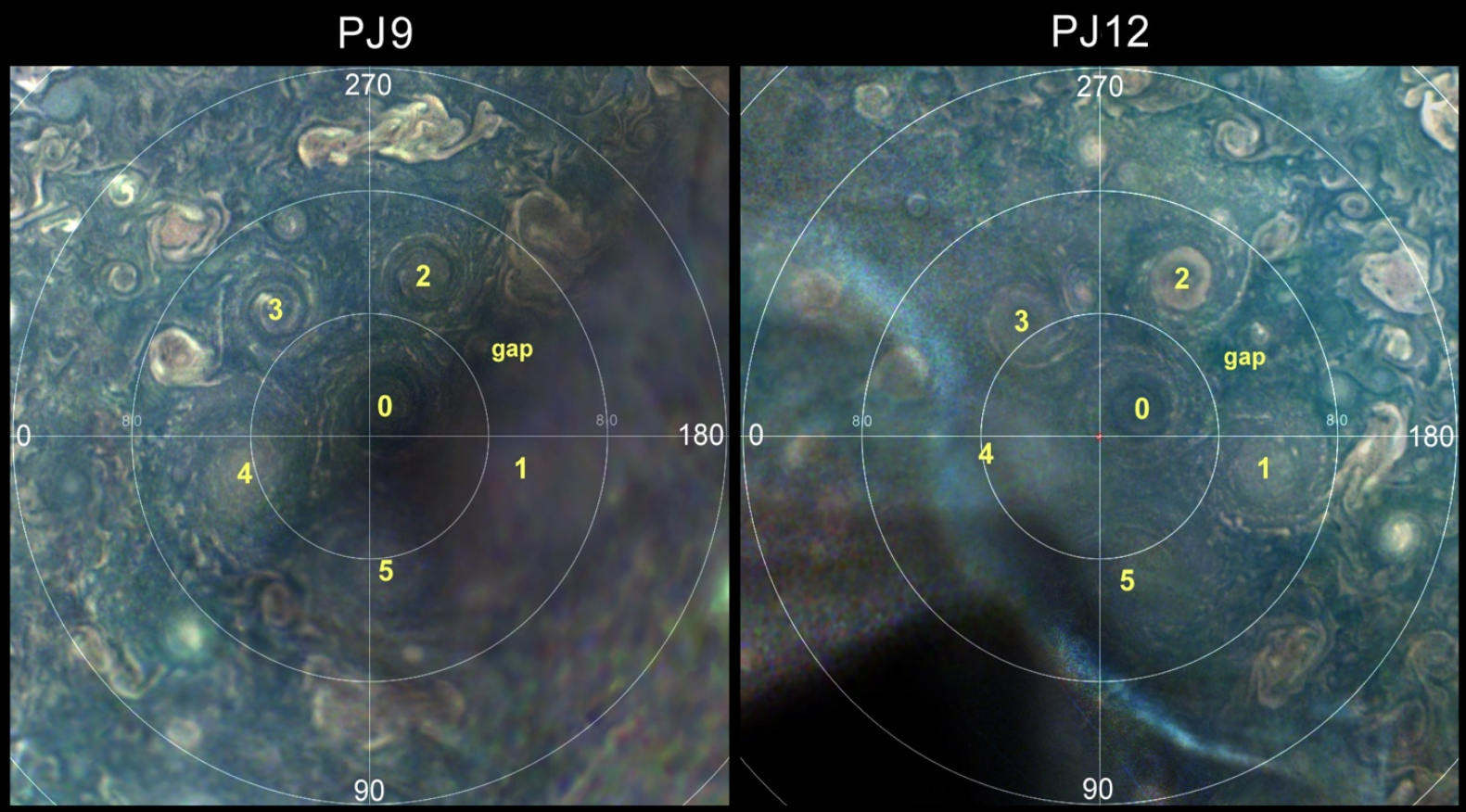
- Perijove 4
- South pole



Adriani et al. 2018

Polar Observations with Juno

South Pole: Cyclone Structure



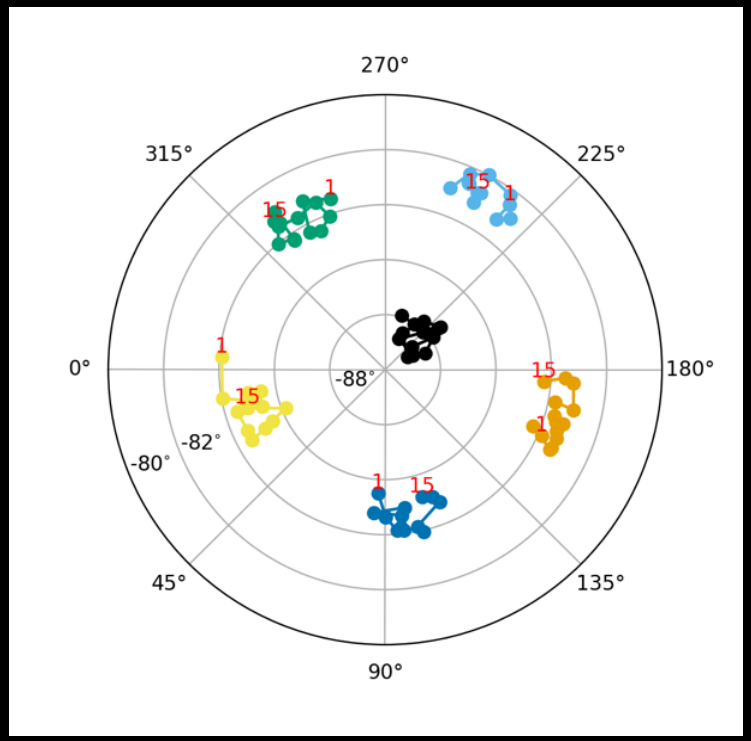
Tabataba-Vakili et al. (2020)

Polar Observations with Juno

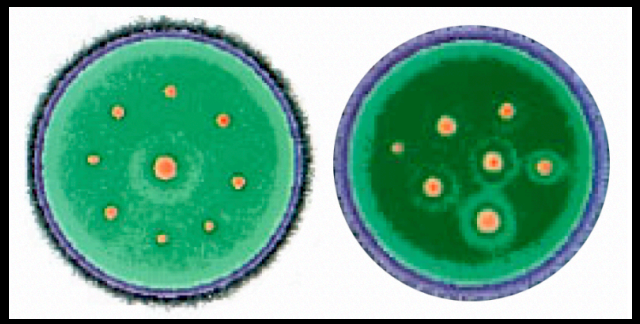
South Pole: Cyclone Structure

- Pentagonal structure of cyclones rotates westward with 1.5+/-0.2 degrees per perijove or 0.04 m/s
- Central cyclone has a circular motion with a period of 8 PJs
- Gap between CPCs 1 and 2 about 100 degrees, other CPCs distance ~65deg
- Overall stable state in 5+1 symmetry

- Good similarity with 2d vortex crystal theory

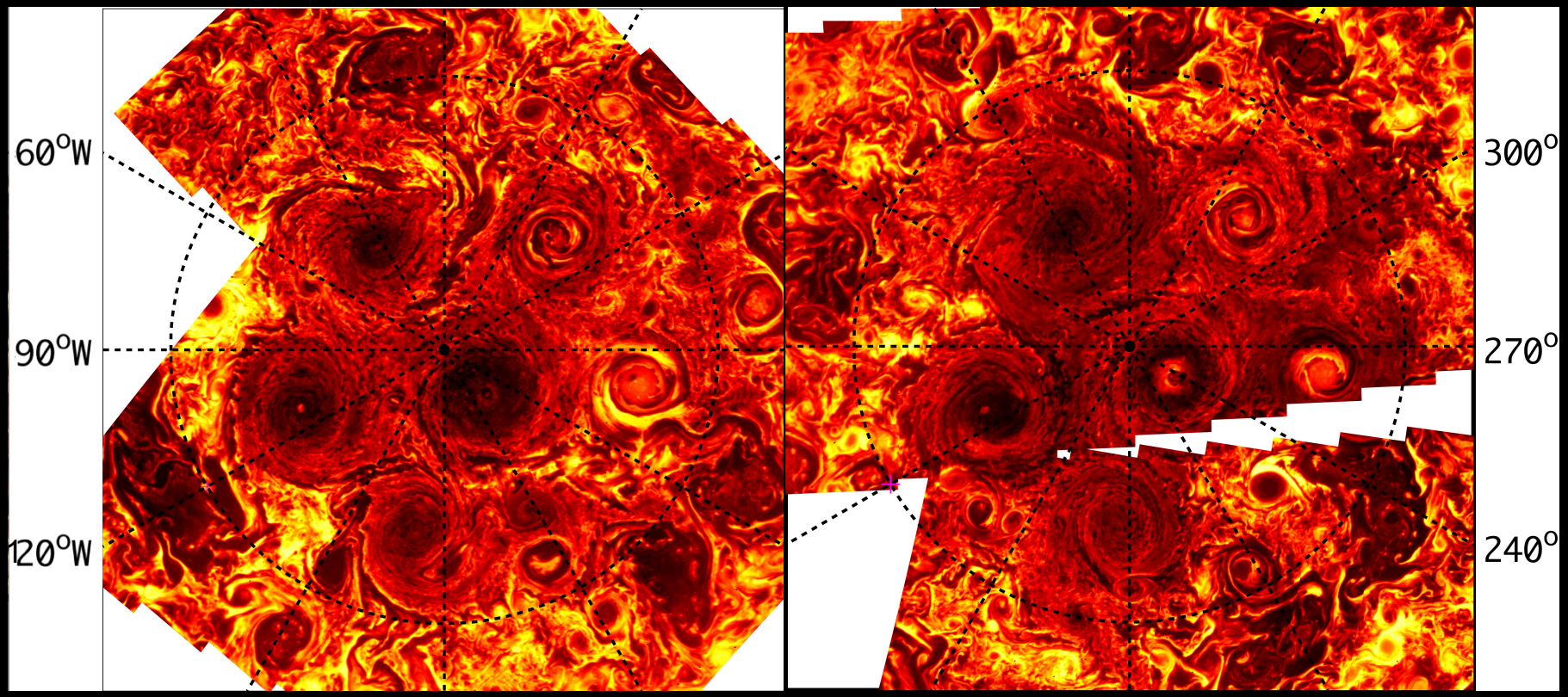


Tabataba-Vakili et al. (2020)

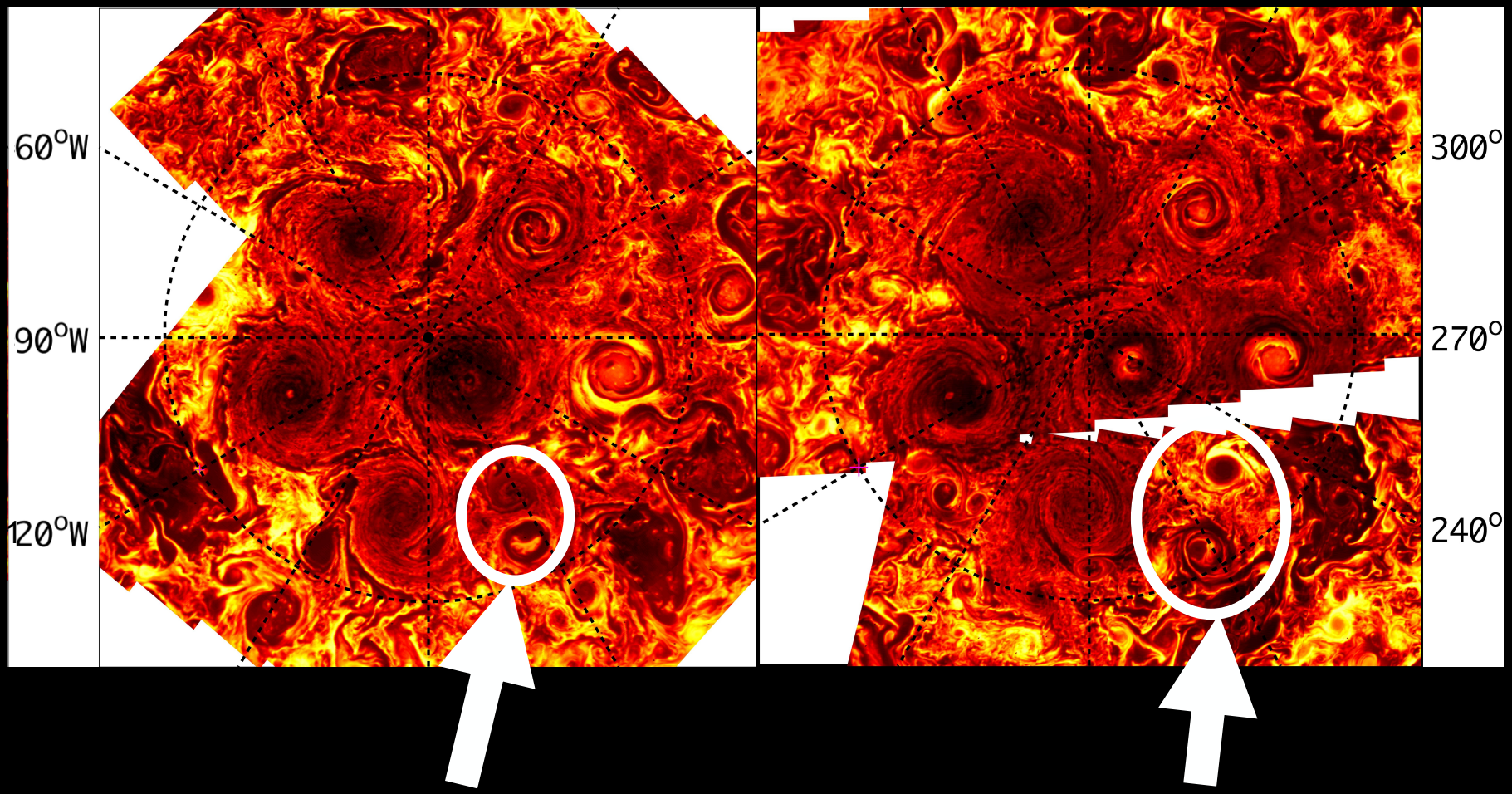


Fine et al. (1995)

South Pole
PJ18 vs PJ19
JIRAM



South Pole
PJ18 vs PJ19
JIRAM

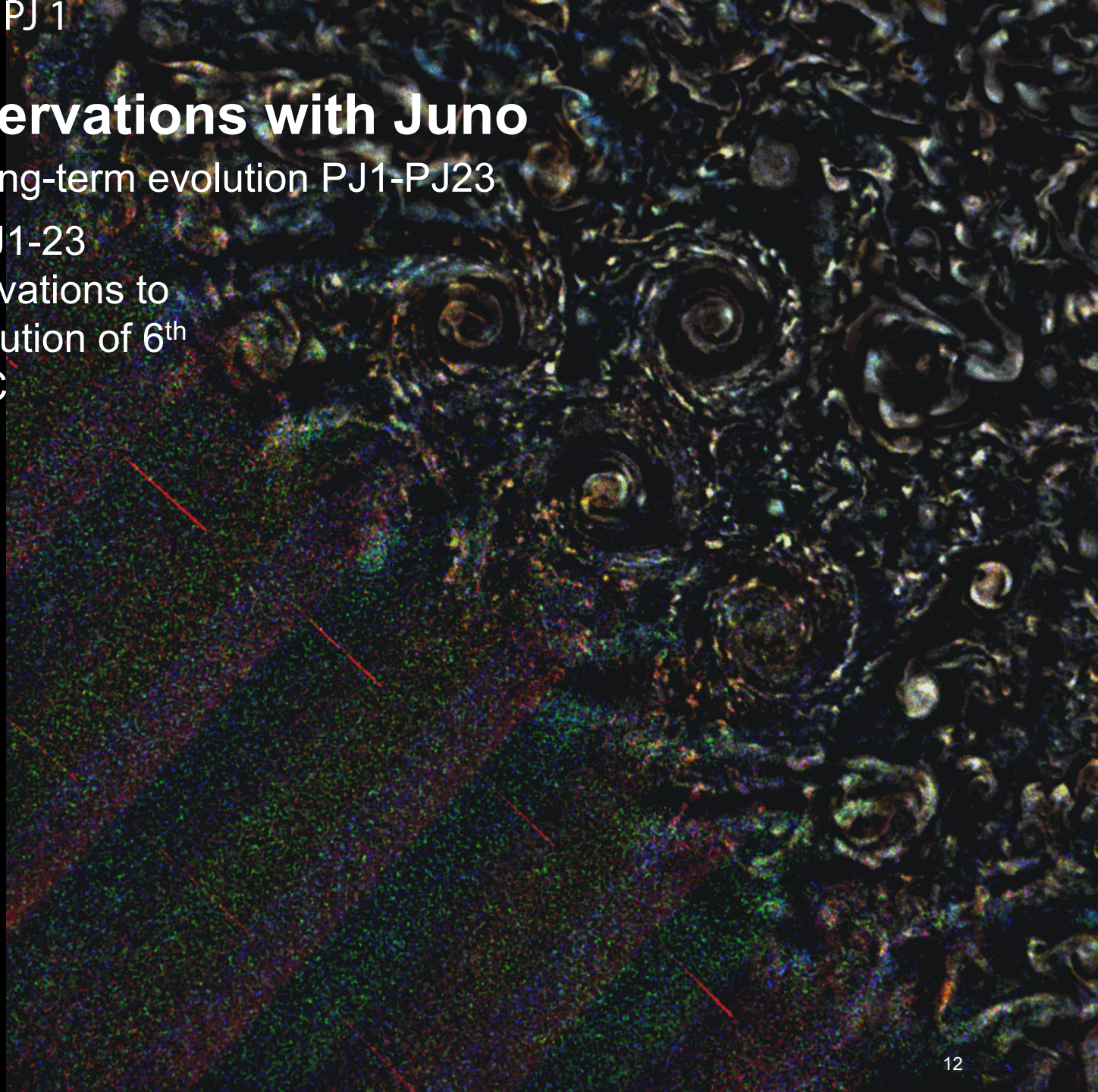


PJ 1

Polar Observations with Juno

South Pole: Long-term evolution PJ1-PJ23

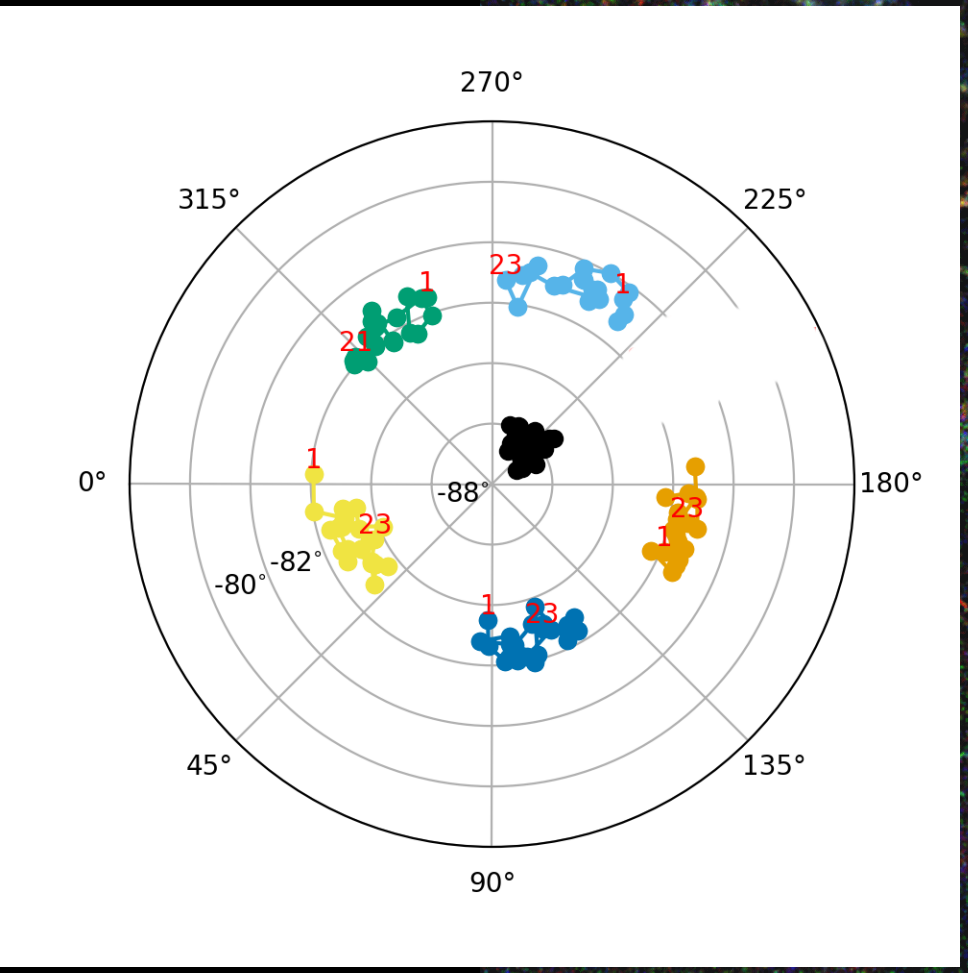
- Look through PJ1-23 JunoCam observations to understand evolution of 6th south polar CPC



PJ 1

Polar Observations with Juno

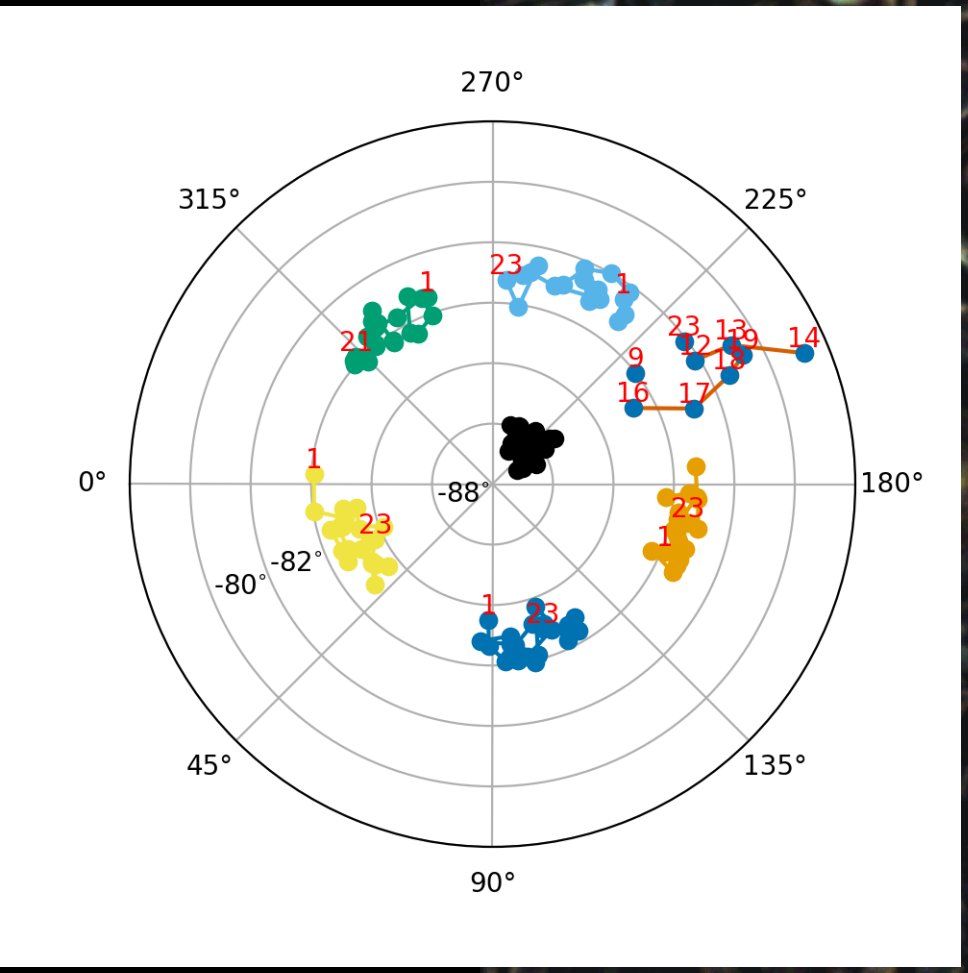
South Pole: Long-term evolution PJ1-PJ23



PJ 9

Polar Observations with Juno

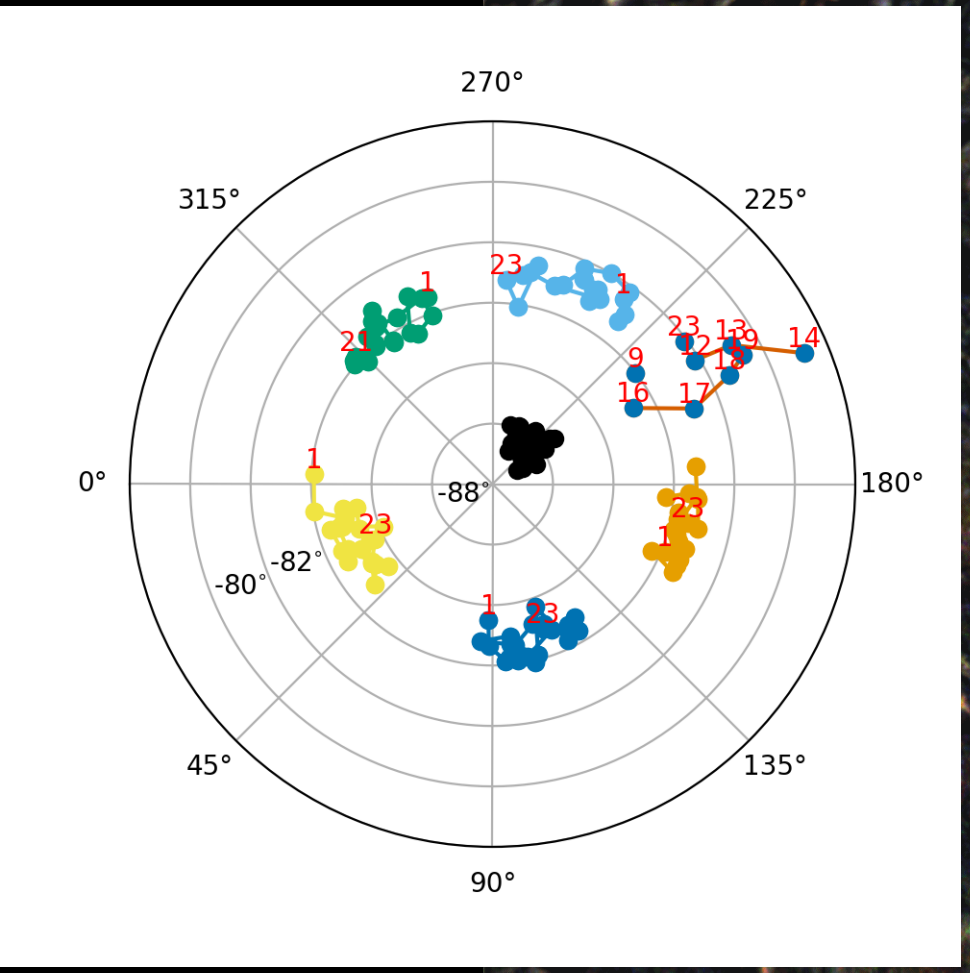
South Pole: Long-term evolution PJ9-PJ14



PJ 16

Polar Observations with Juno

South Pole: Long-term evolution PJ16-PJ19

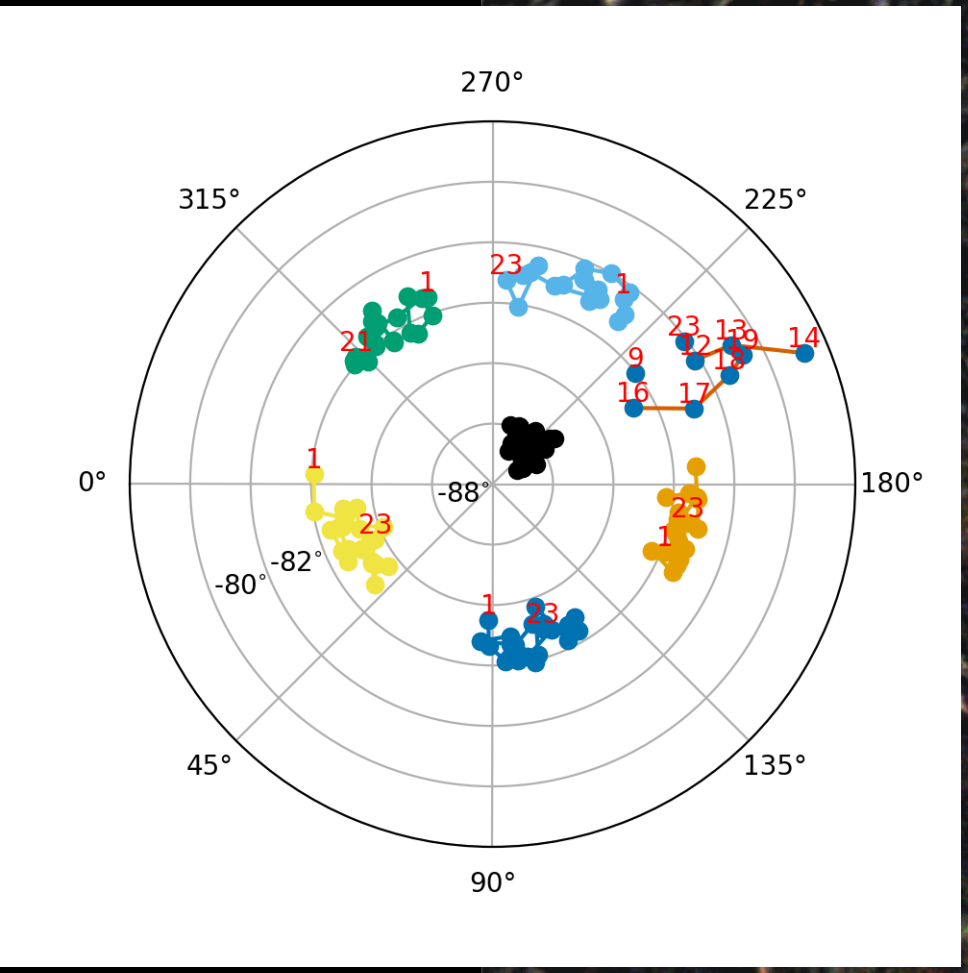


- CPC6 starts small in the gap, then moves outward with increasing size

PJ 16

Polar Observations with Juno

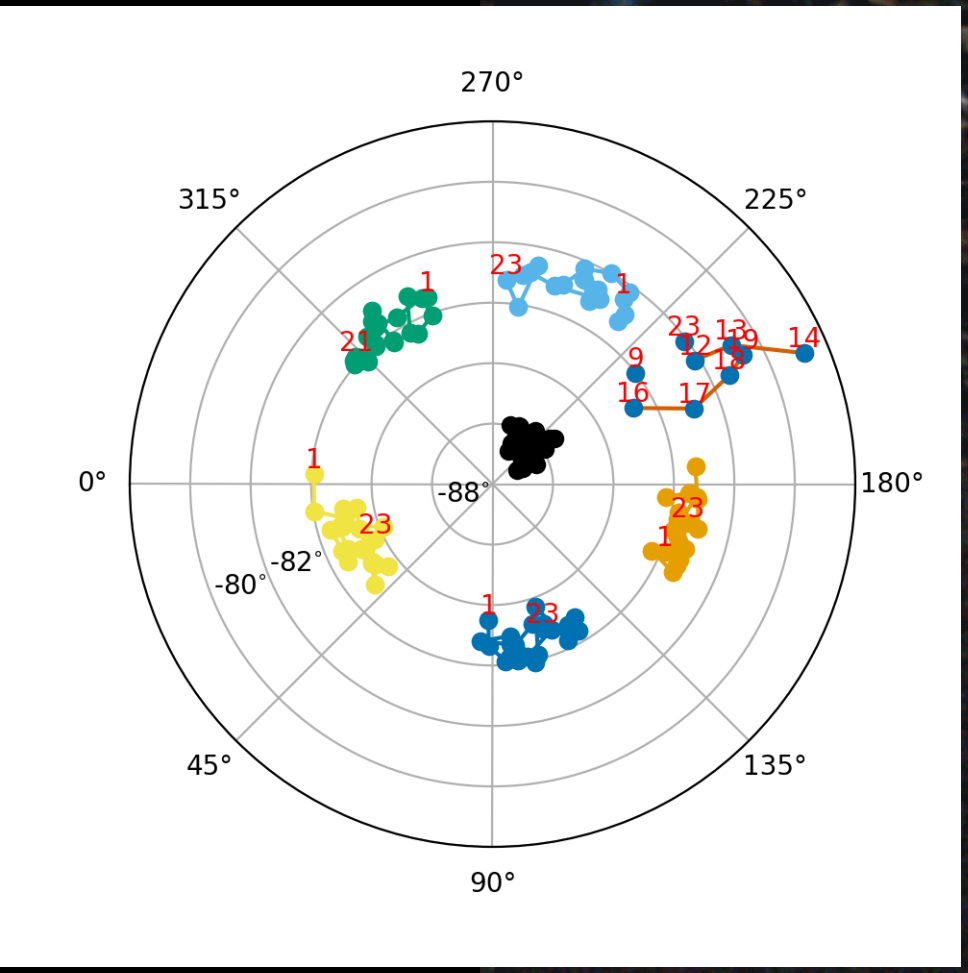
South Pole: Long-term evolution PJ16-PJ23



- Gap not visible during PJ20-22

Polar Observations with Juno

South Pole: Long-term evolution PJ23

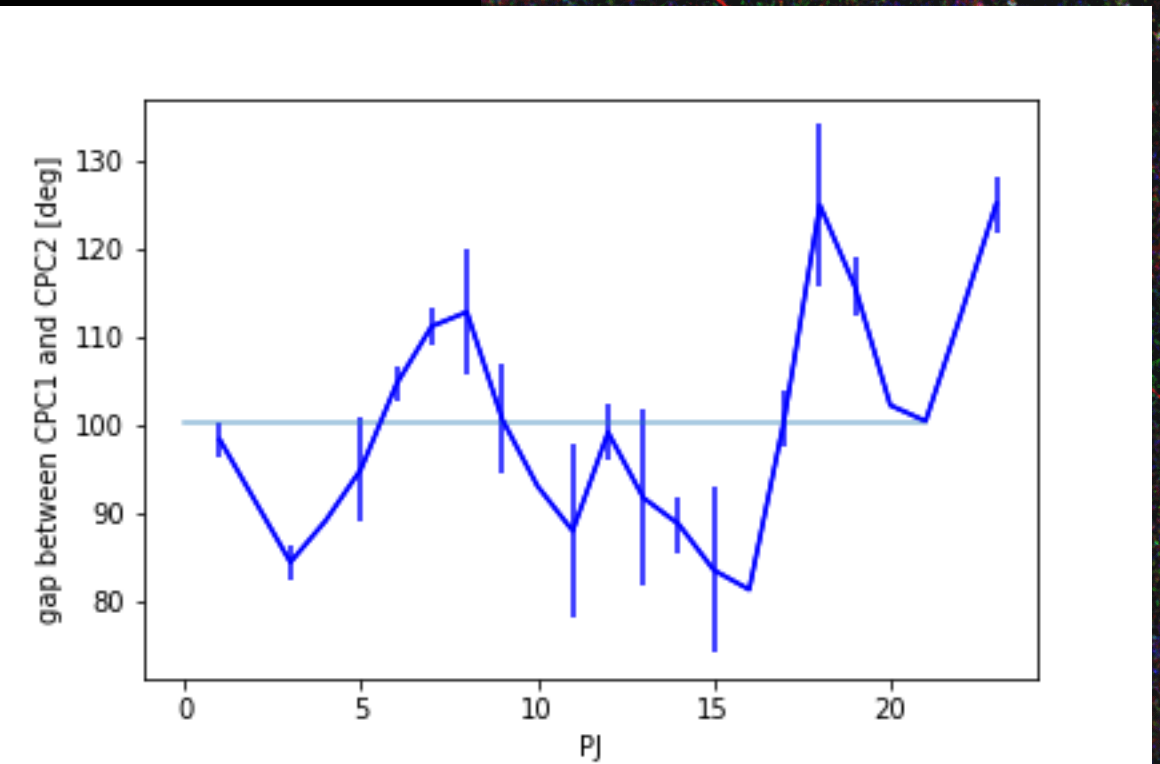


- Latest data (PJ23) has CPC6 firmly in the gap

PJ 1

Polar Observations with Juno

South Pole: Long-term evolution PJ1-PJ23

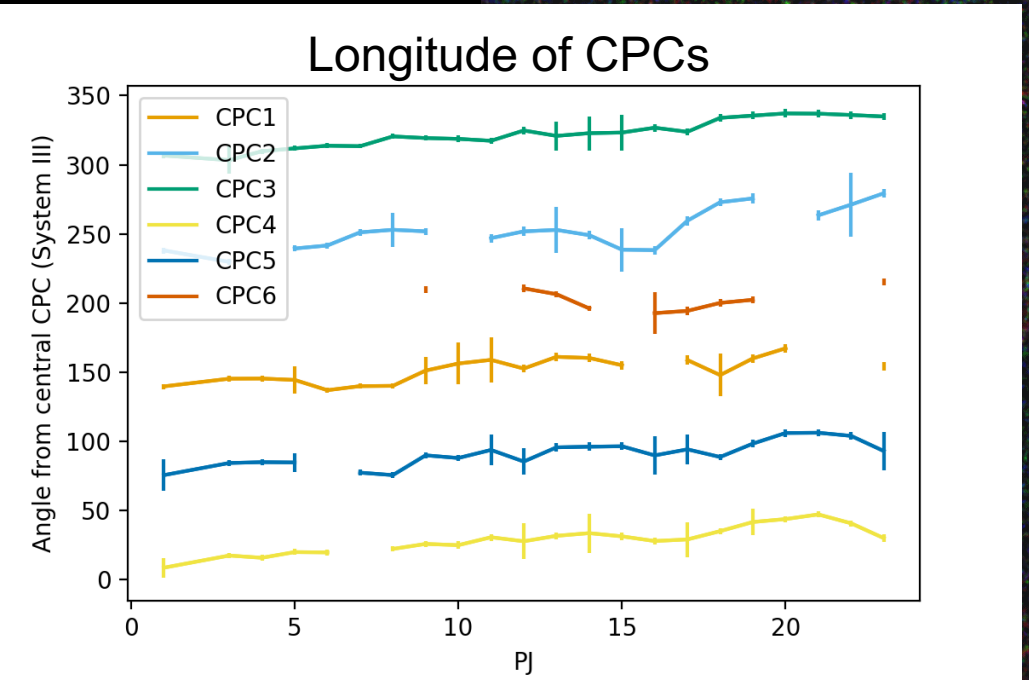


PJ 1

Polar Observations with Juno

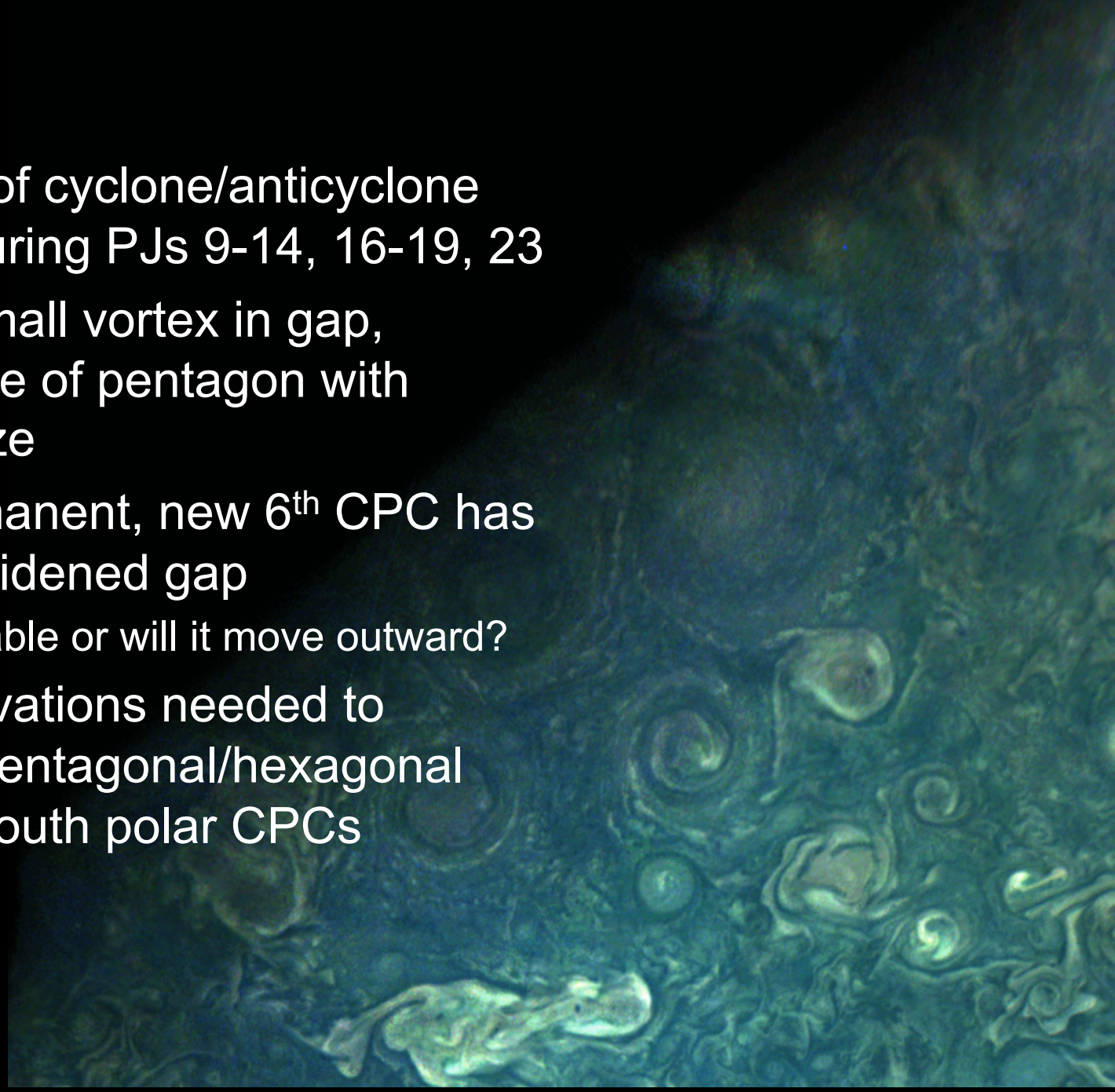
South Pole: Long-term evolution PJ1-PJ23

- CPCs1-5 remain stable and we can track their positions
- CPC6 has successfully moved into the gap during PJ 23
- Future observations will tell if this hexagonal setup remains stable

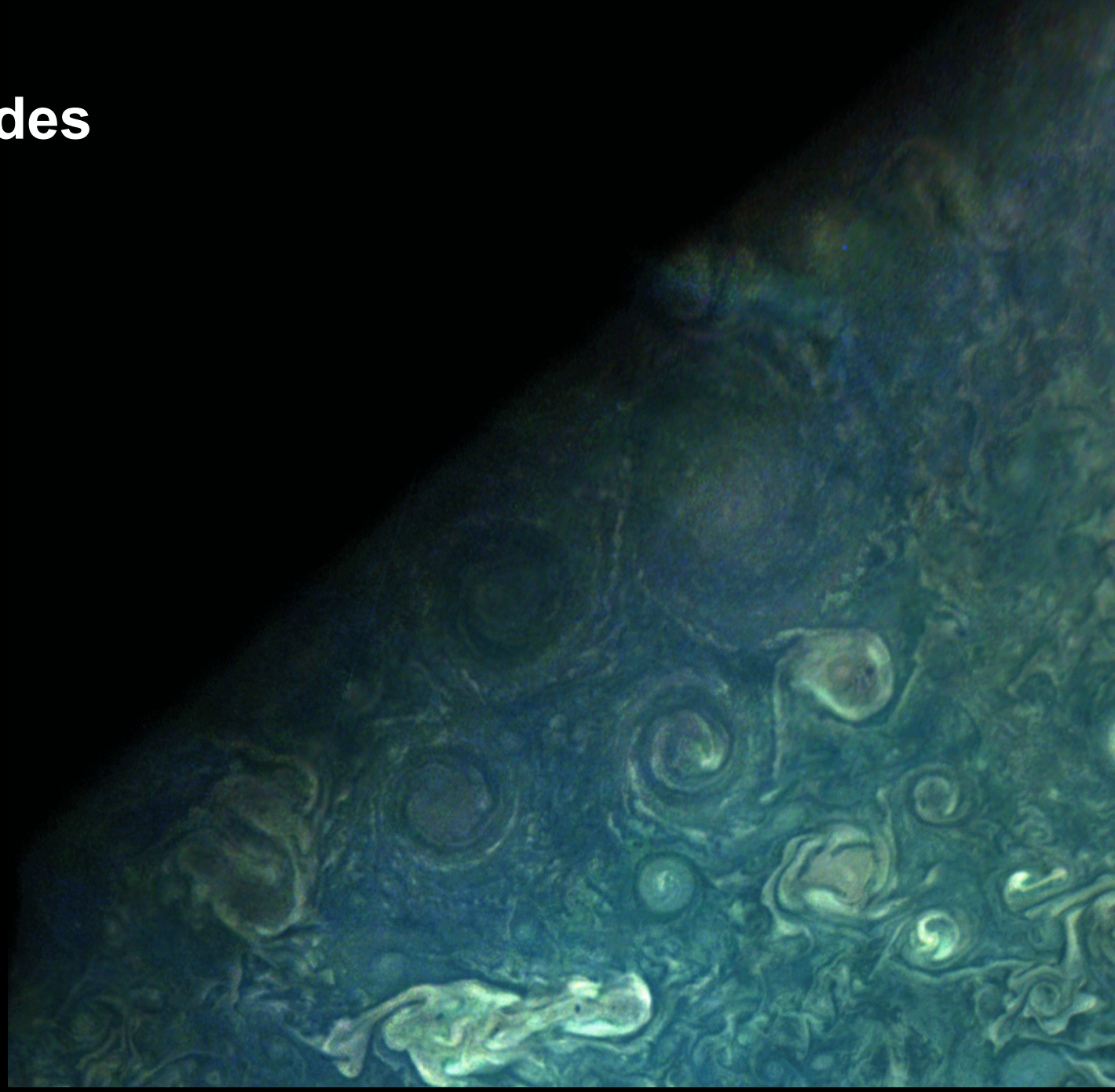


Summary

- Observation of cyclone/anticyclone pair in gap during PJs 9-14, 16-19, 23
- Starts with small vortex in gap, moves outside of pentagon with increasing size
- 5 CPCs permanent, new 6th CPC has moved into widened gap
  - Is CPC 6 stable or will it move outward?
- Future observations needed to understand pentagonal/hexagonal structure of south polar CPCs



Backup slides

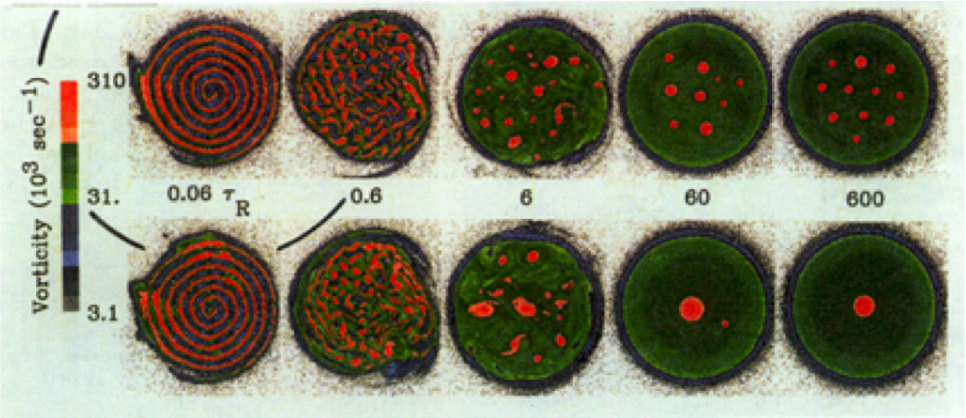


Comparison with Theory

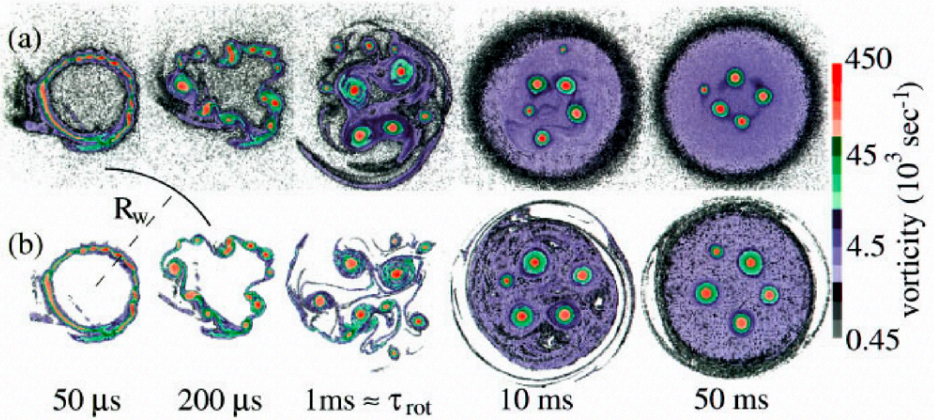
Vortex Crystals

- Constellations of vortices as rare stable solution for initial turbulence.
- Observed in magnetized plasma columns and rotating superfluids to represent 2d turbulence.
- Effect is described by 2d Euler equations.
  - No friction
  - Only positive vorticity
- Formation to achieve maximum entropy.
- In lab and models: stable for around 400 rotations, after which minute frictional effects cause dissipation.

Several stable configurations of vortex crystals. (Fine et al. 2005)



The evolution of two vortex experiments with slightly different viscosities. (Fine et al. 2005)

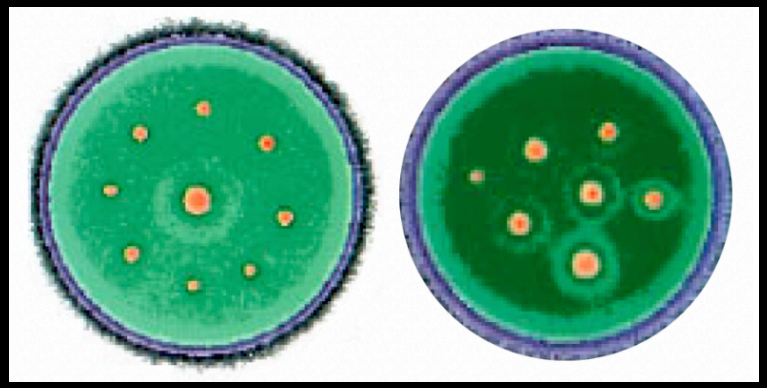


Experiment (a) and simulation (b) of vortex crystal evolution with the same initial conditions. (Schecter et al. 1999)

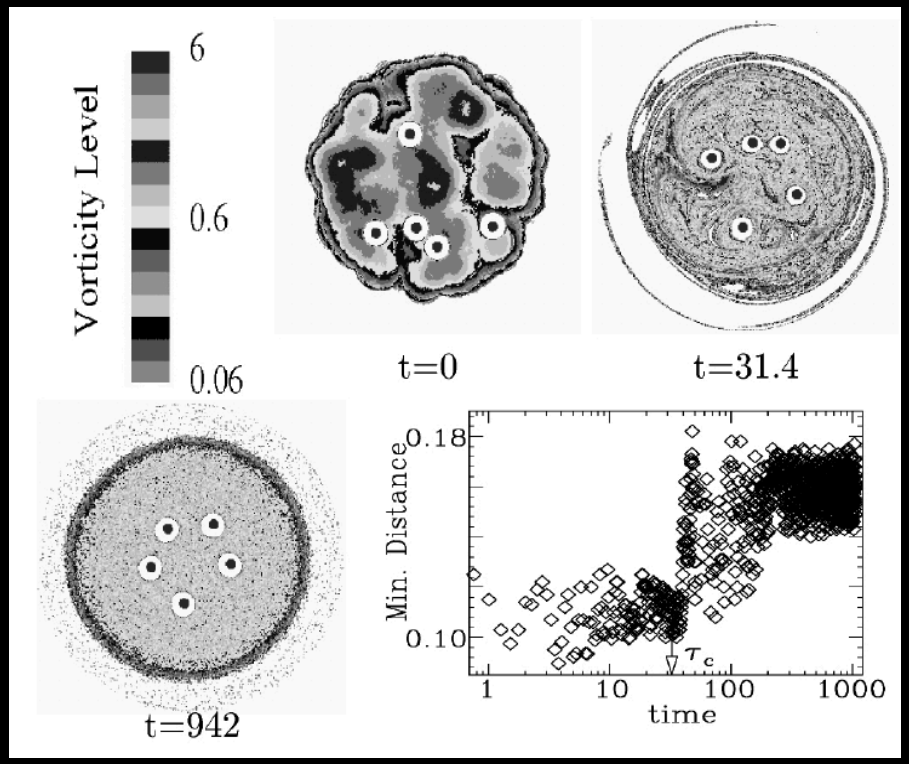
Comparison with Theory

Vortex Crystals

- CPCs and Vortex Crystals compare well in terms of
  - Shape
  - Time evolution



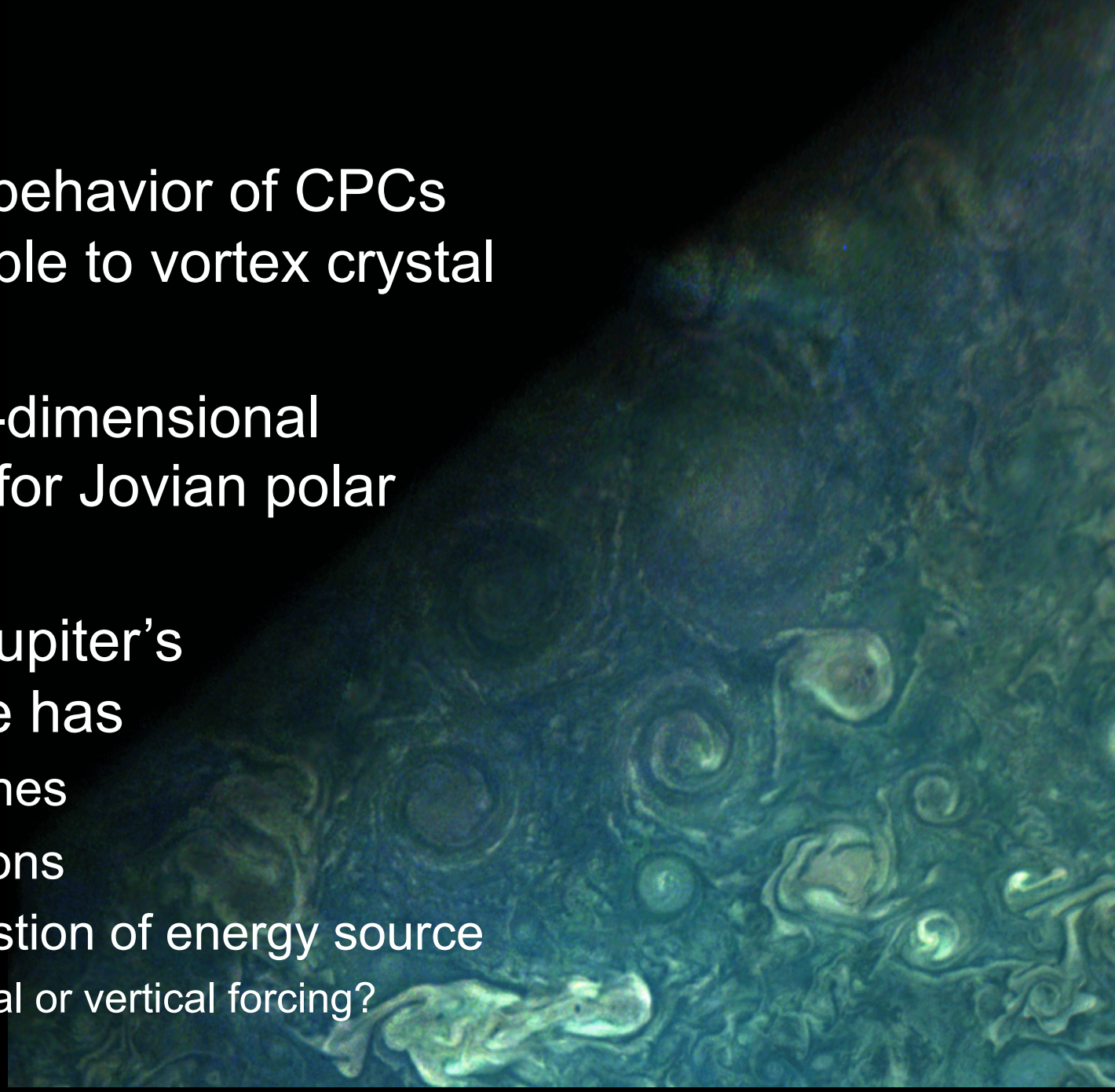
Fine et al. (1995)



Jin and Dubin (2000)

Summary

- Long-term behavior of CPCs is comparable to vortex crystal theory
- Supports 2-dimensional turbulence for Jovian polar region
- However, Jupiter's atmosphere has
  - Anti-cyclones
  - 3 dimensions
  - Open question of energy source
    - Horizontal or vertical forcing?

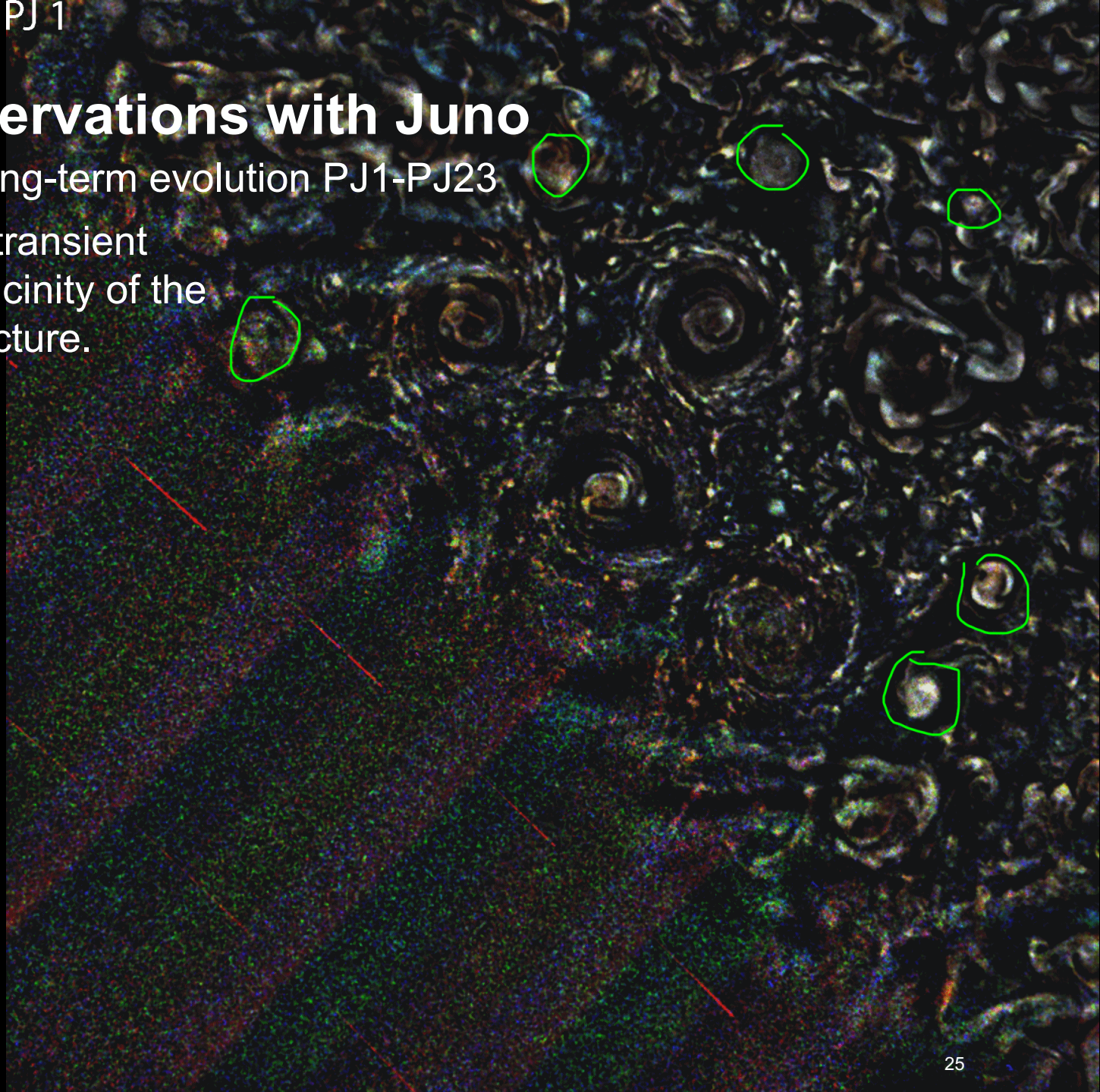


PJ 1

Polar Observations with Juno

South Pole: Long-term evolution PJ1-PJ23

- We see a lot of transient vortices in the vicinity of the pentagonal structure.

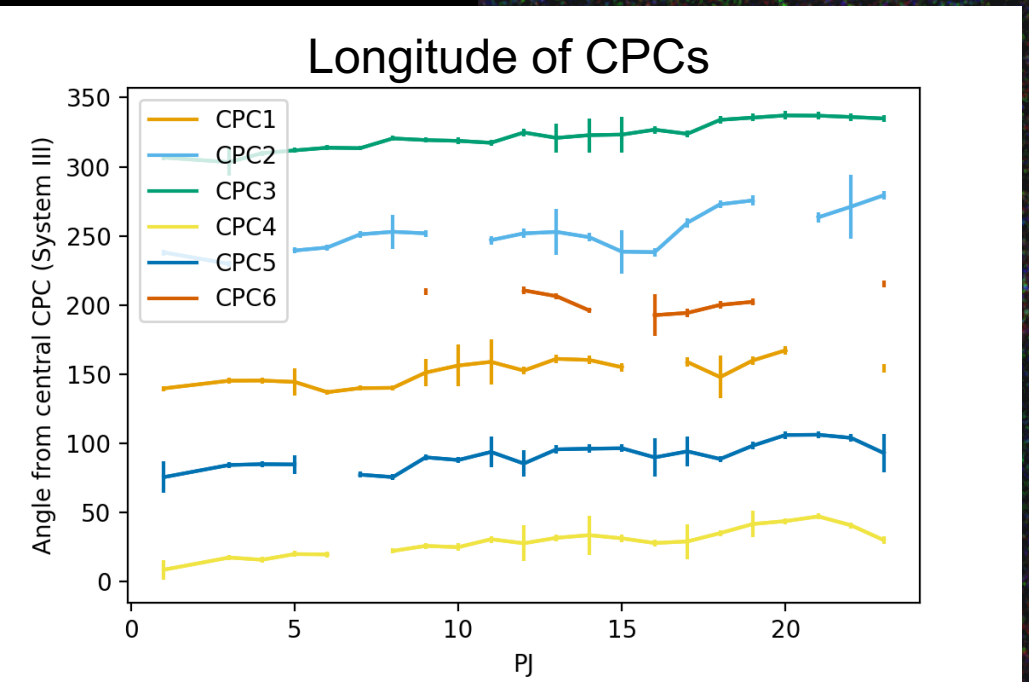


PJ 1

Polar Observations with Juno

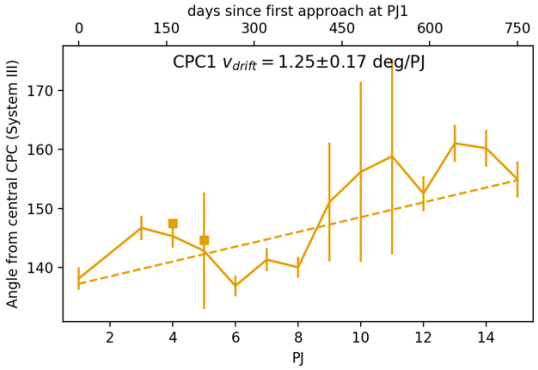
South Pole: Long-term evolution PJ1-PJ23

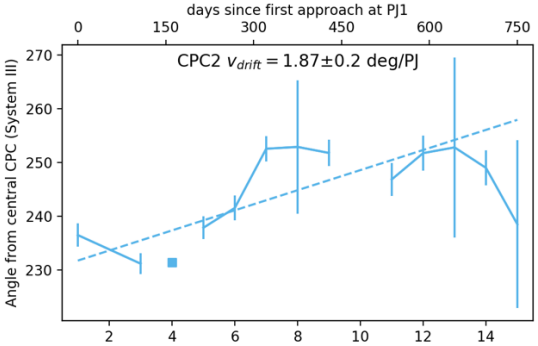
- We see a lot of transient vortices in the vicinity of the pentagonal structure.
- However, the positions of the CPCs are largely unaffected and the pentagonal structure remains.

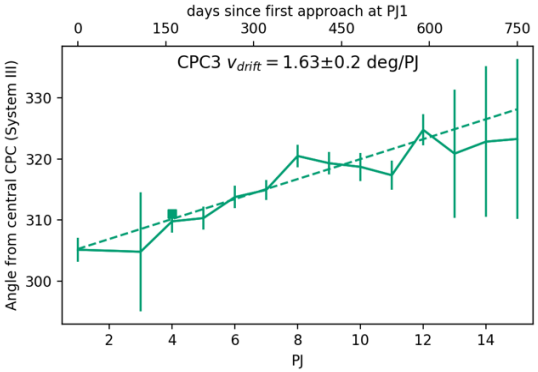


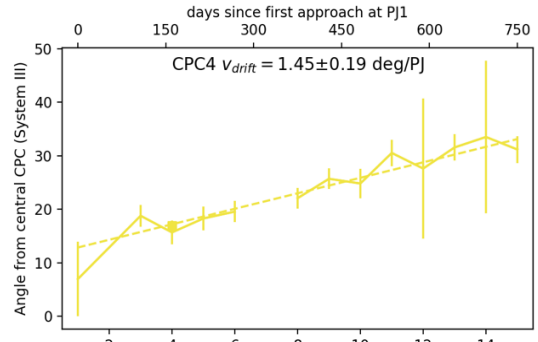
Polar Observations with Juno

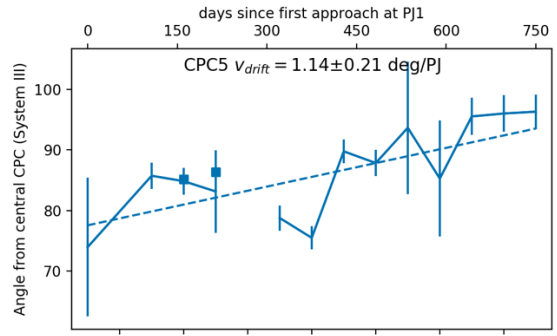
South Pole: Long-term evolution

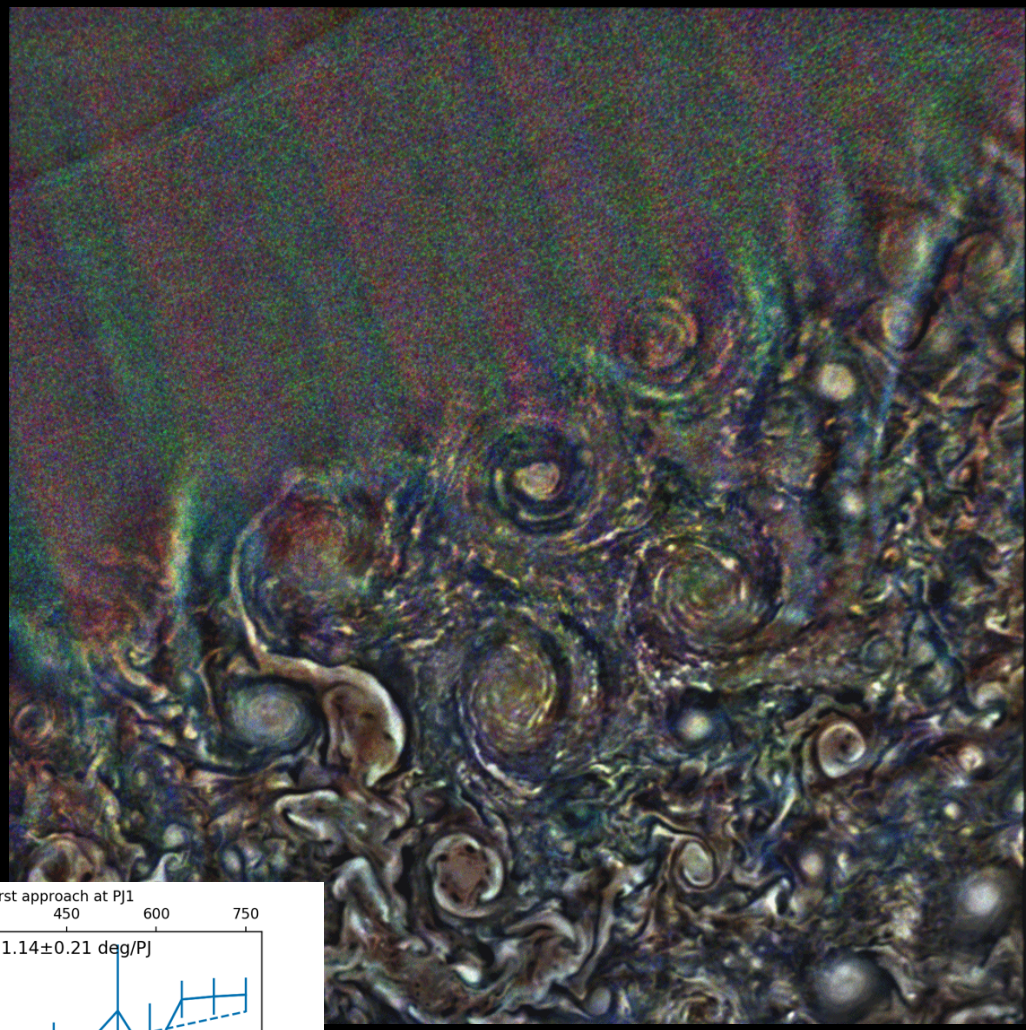










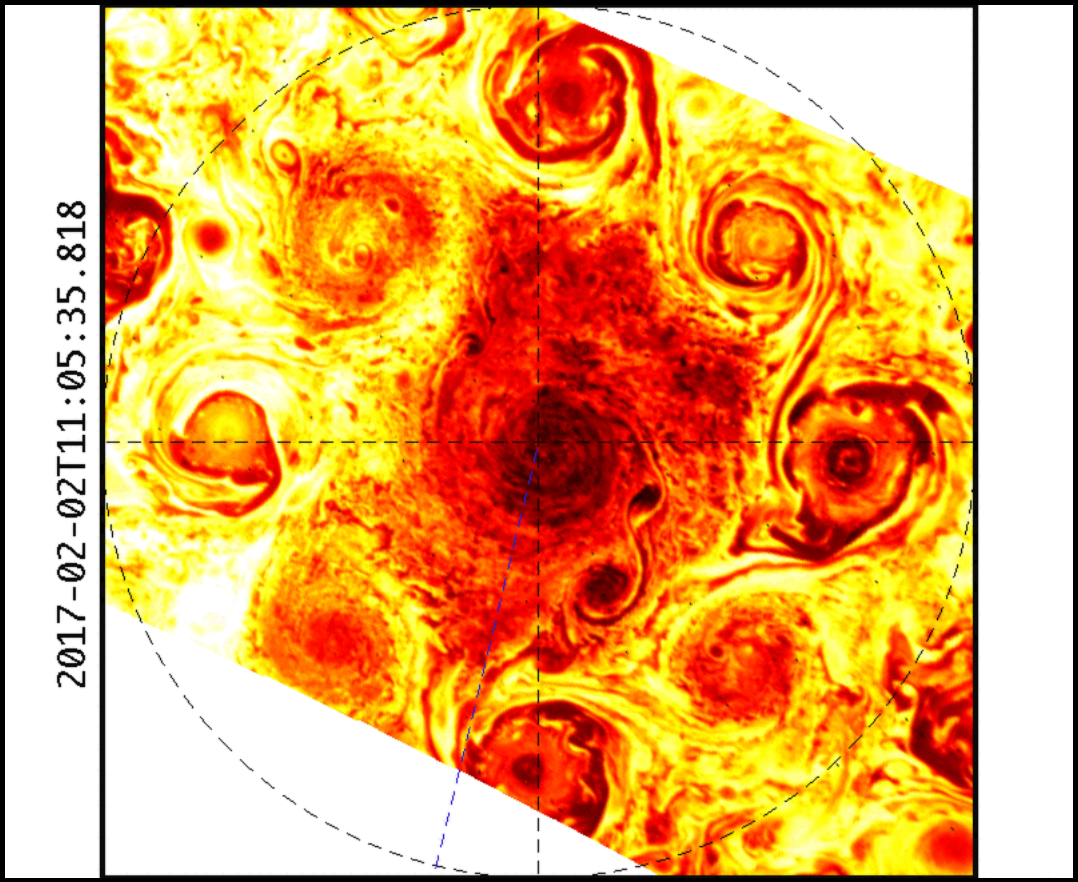


Tabataba-Vakili et al. (2020)

Polar Observations with Juno

JIRAM (Jovian Infrared Auroral Mapper)

- Perijove 4
- North pole

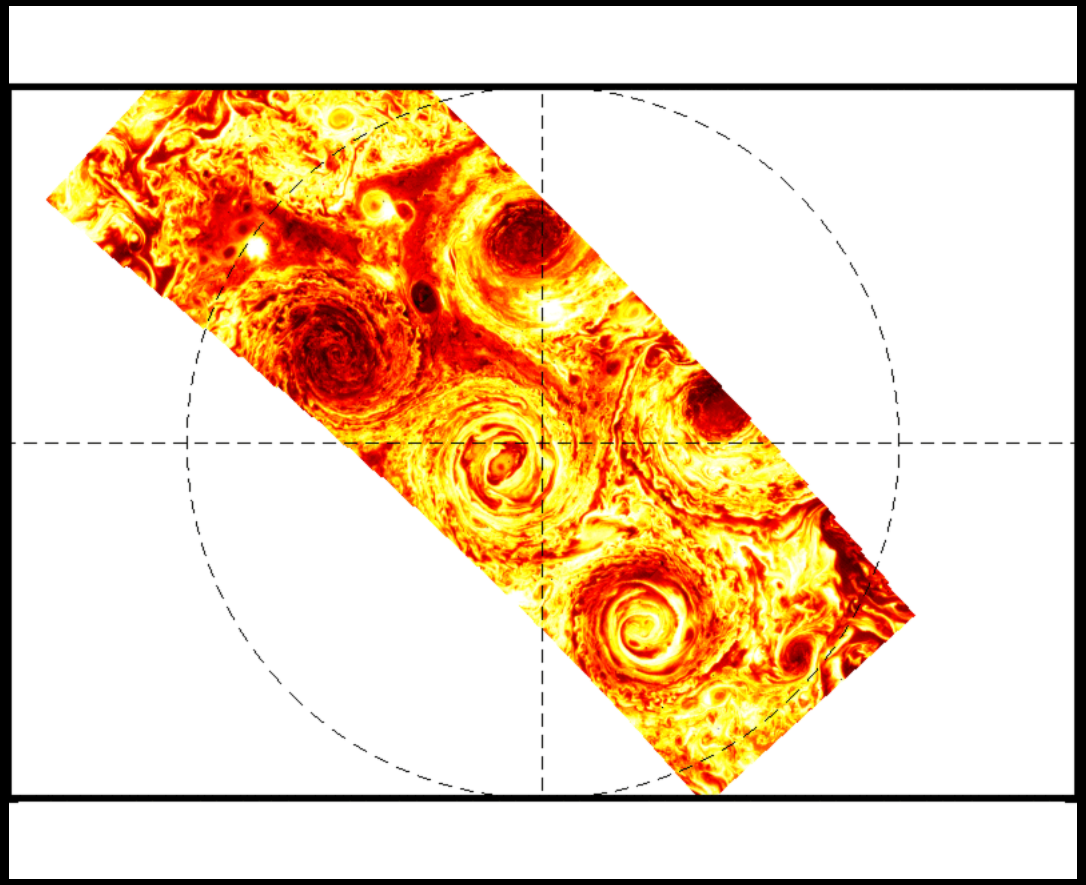


Adriani et al. 2018

Polar Observations with Juno

JIRAM (Jovian Infrared Auroral Mapper)

- Perijove 4
- South pole



Adriani et al. 2018

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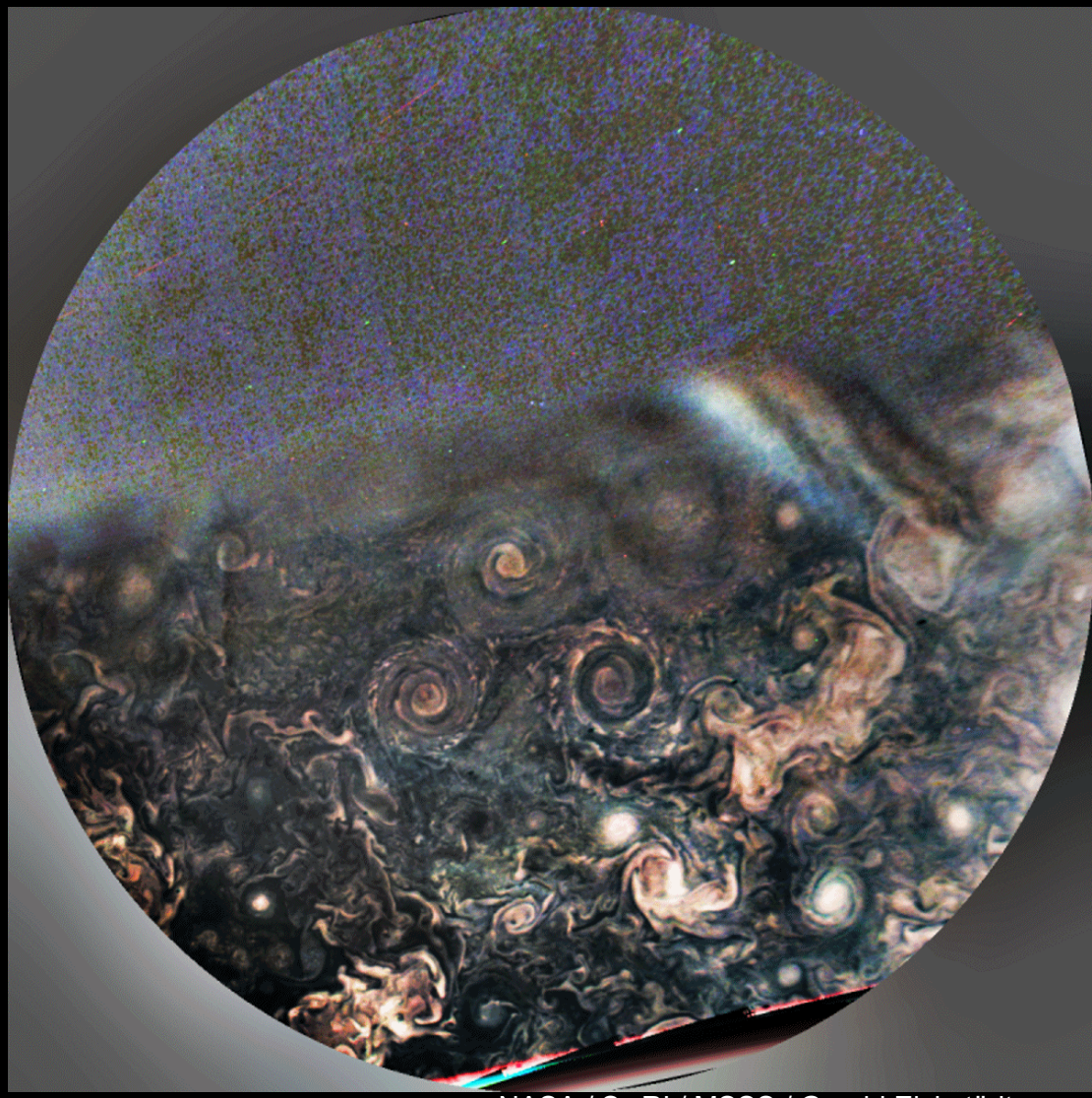
South Pole: Animations

- Perijove 5



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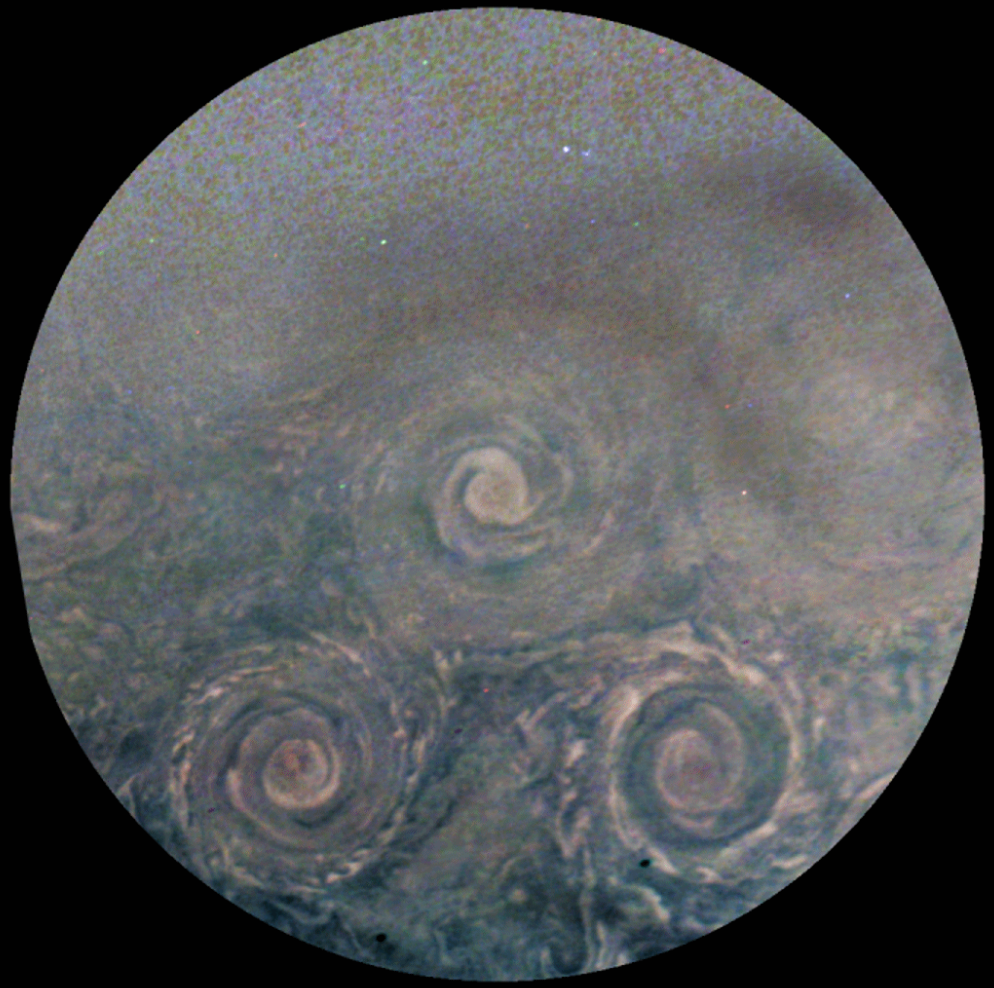
Polar Observations with Juno

South Pole: Animations

- Perijove 5



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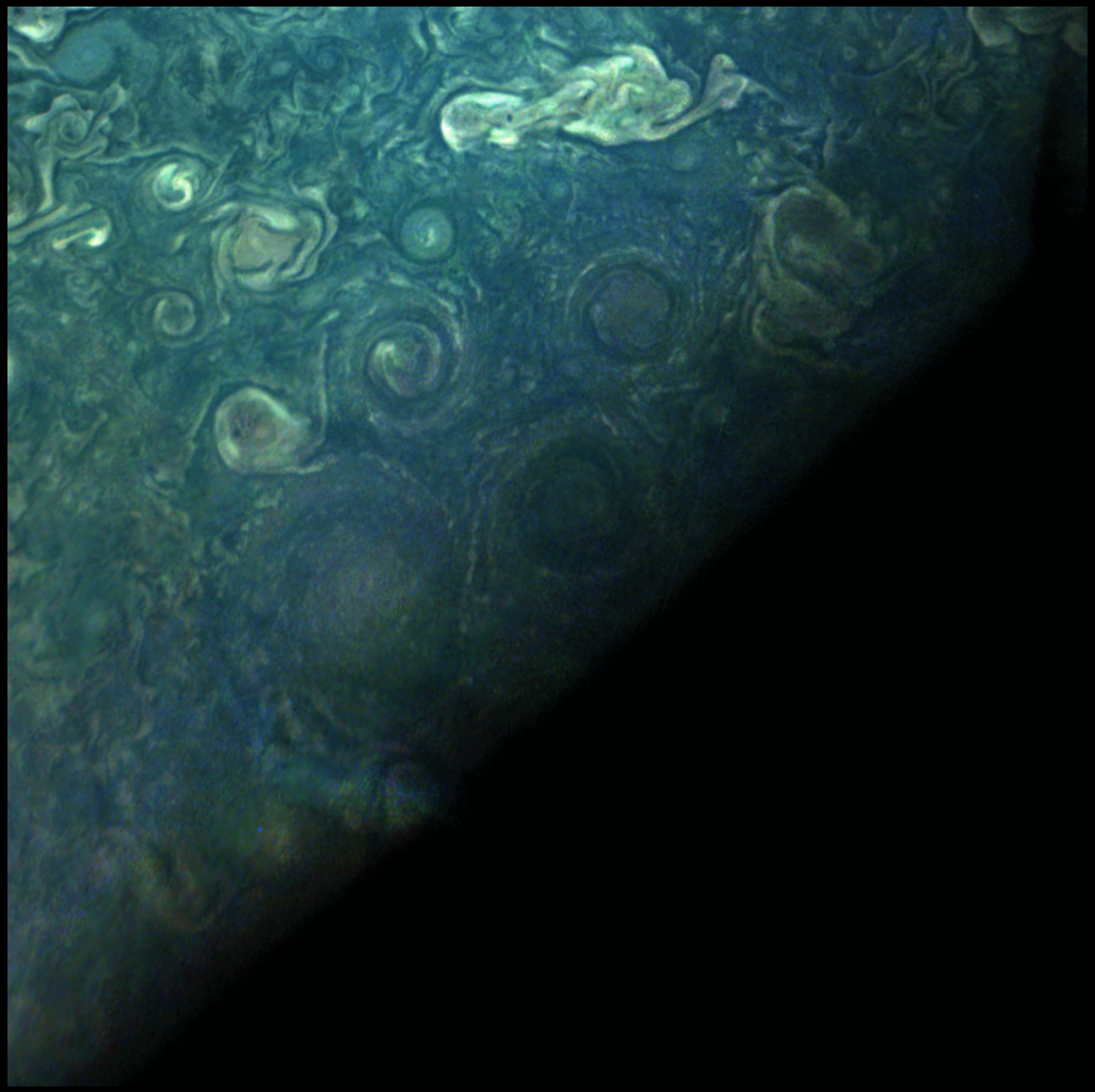
Polar Observations with Juno

South Pole: Animations

- Perijove 9



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