Rotational Effects on Convection

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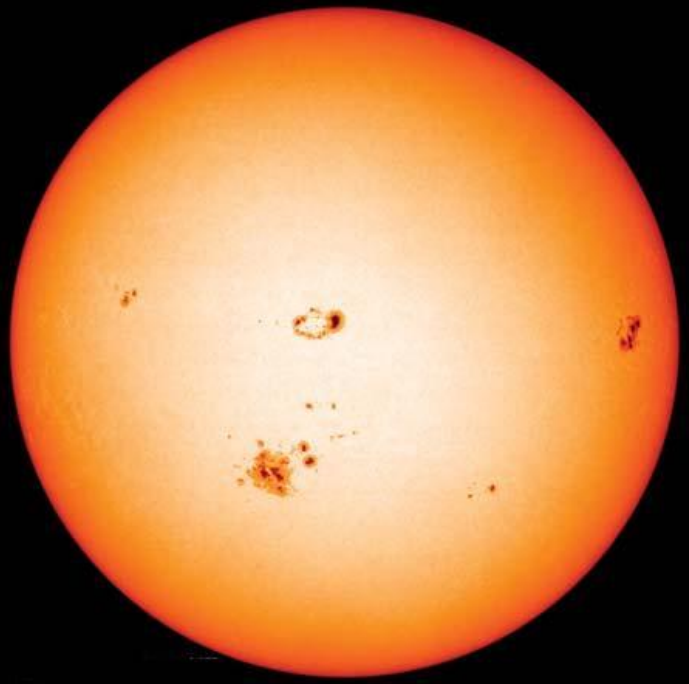
Conference on Differential Rotation and Magnetism across the HR Diagram

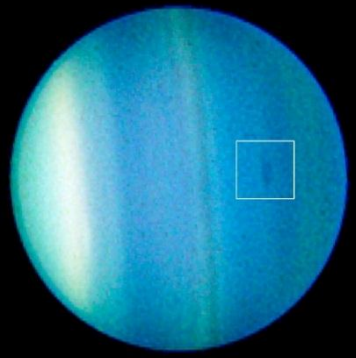
Great Red Spot of Jupiter NASA

Saturn spots Cassini/NASA

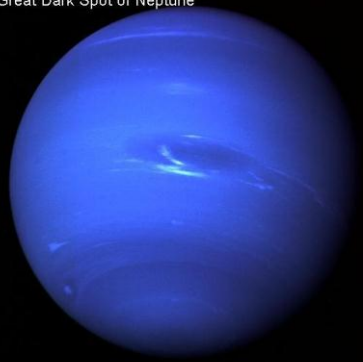
Solar Image by SOHO



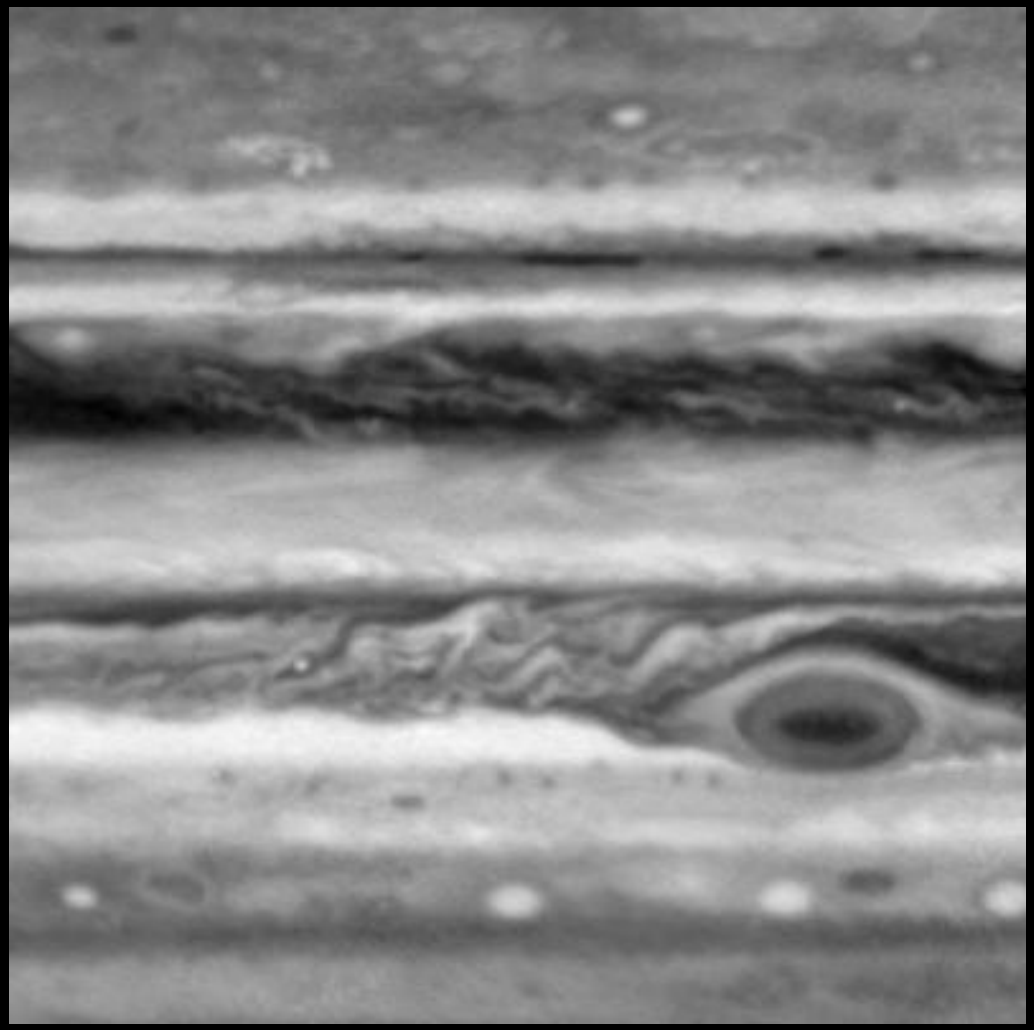
Uranus Dark Spot *Hubble Space Telescope*



Great Dark Spot of Neptune



Two Big Puzzles: Jets and Spots



Credit: Cassini/NASA

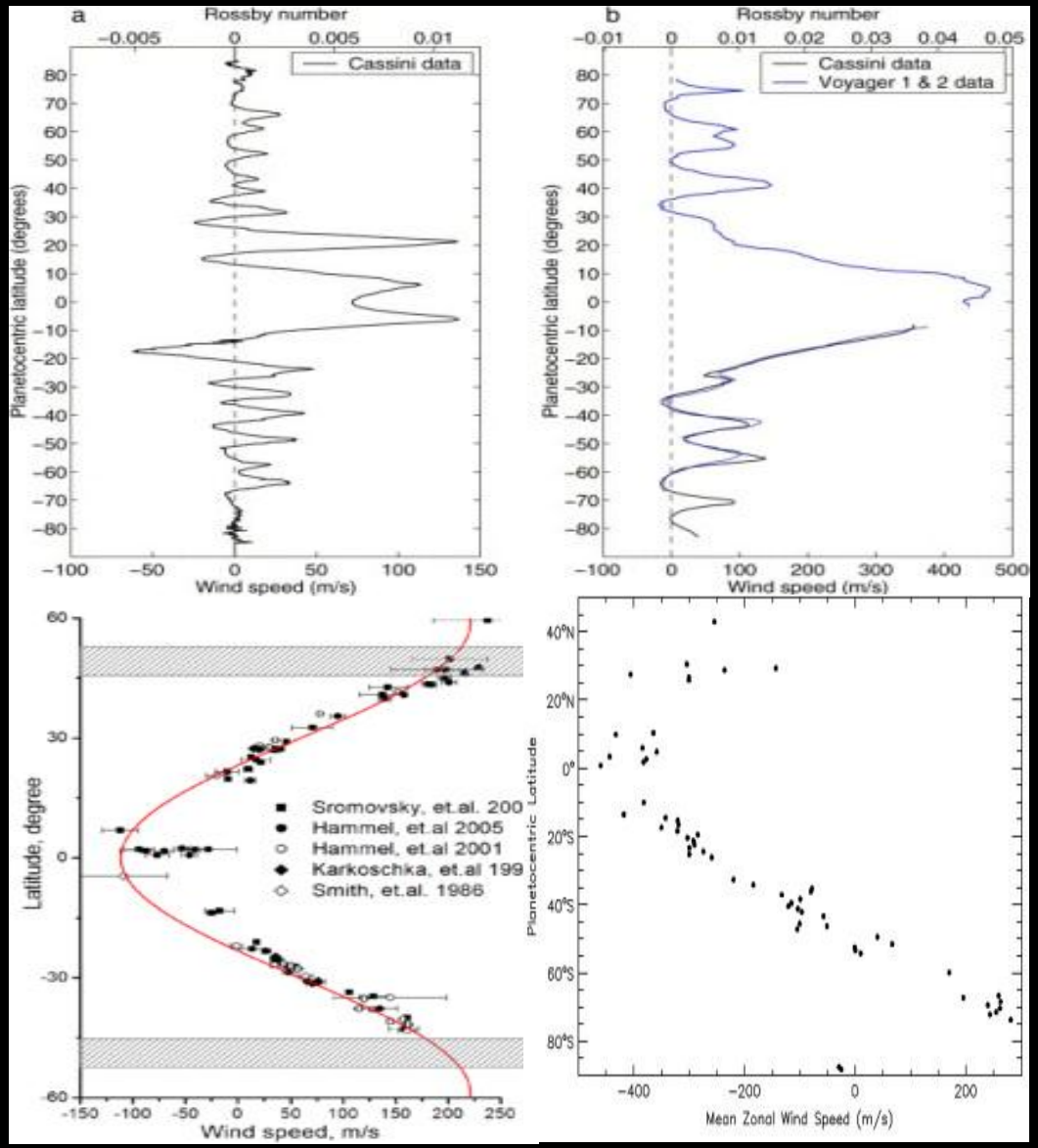
Mean Zonal Winds

Jupiter

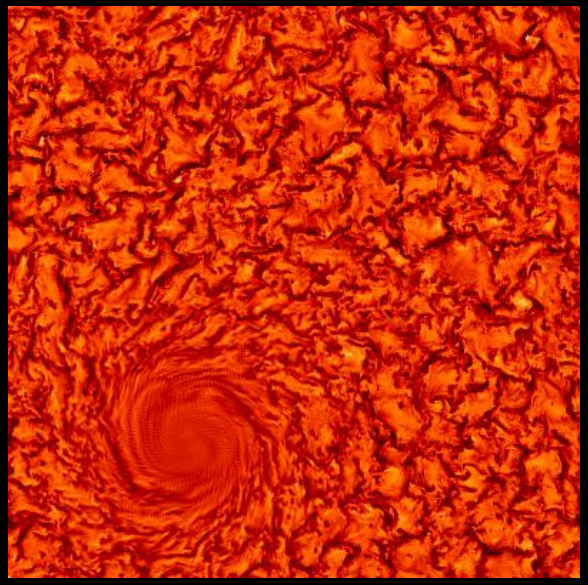
Saturn

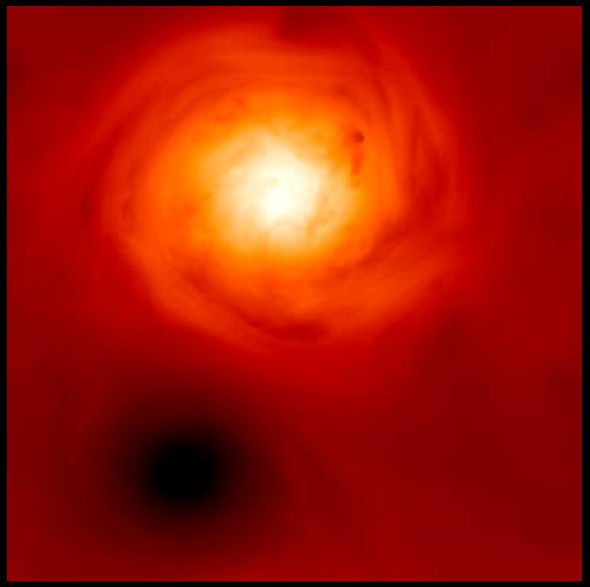
Uranus

Neptune



Long-lived Vortices





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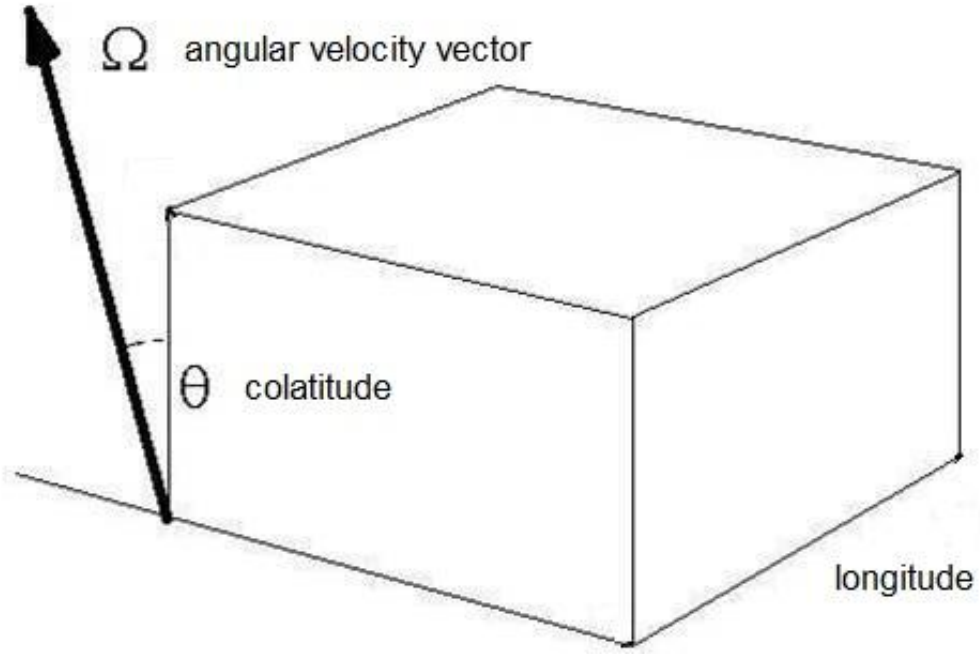
3D LES of Turbulent Compressible Convection in a f-Box

$$\partial_t \rho = -\nabla \cdot (\rho \boldsymbol{v})$$

$$\partial_t (\rho \boldsymbol{v}) = -\nabla \cdot (\rho \boldsymbol{v}\boldsymbol{v}) - \nabla p + \nabla \cdot \boldsymbol{\Sigma} + \rho \boldsymbol{g} + 2\rho \boldsymbol{v} \times \boldsymbol{\Omega}$$

$$\partial_t E = -\nabla \cdot \{(E + p)\boldsymbol{v} - \boldsymbol{v} \cdot \boldsymbol{\Sigma} + \boldsymbol{f}\} + \rho \boldsymbol{v} \cdot \boldsymbol{g}$$



Model Description

- Constant angular velocity vector
- Depth ~ 4 pressure scale heights; aspect ratio = 4; $\gamma = 5/3$
- Heat flux = 0.03125 pressure x Cs; Cs= isothermal sound speed at top
- Units: length = d, time = d/Cs, thermal quantities = values at top
- Latitude = 67.5, 22.5; $\Omega = 0.375, 0.75, 1.5, 3.$
- Conservative finite-difference scheme; 540x540x80 grids
- Re ~ $2 \times 10^3 - 10^4$; Ta ~ $2 \times 10^8 - 10^{10}$

Three ways to define the Coriolis number:

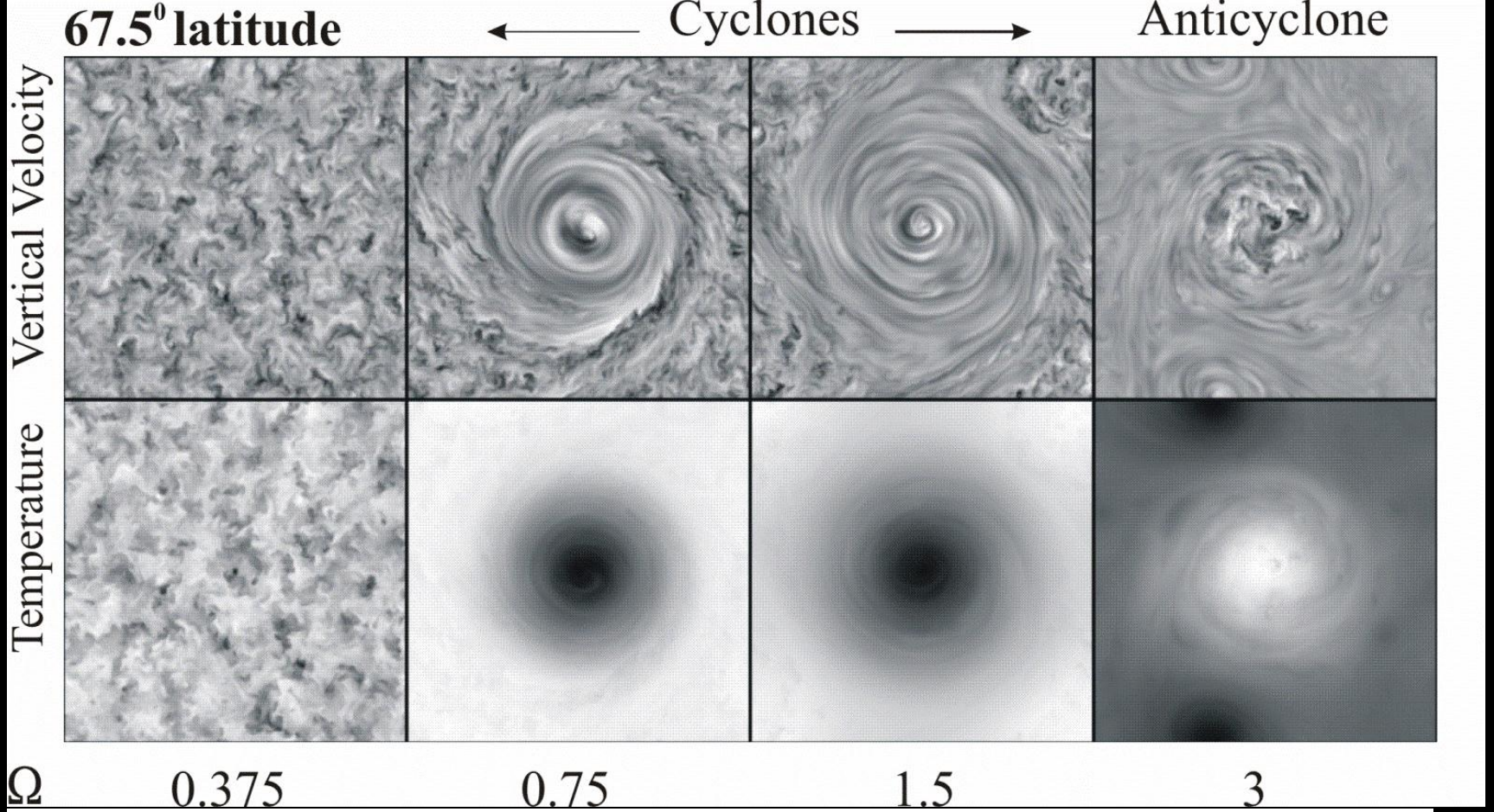
Co1 = f_0 d/V V = rms velocity, $f_0 = 2\Omega$

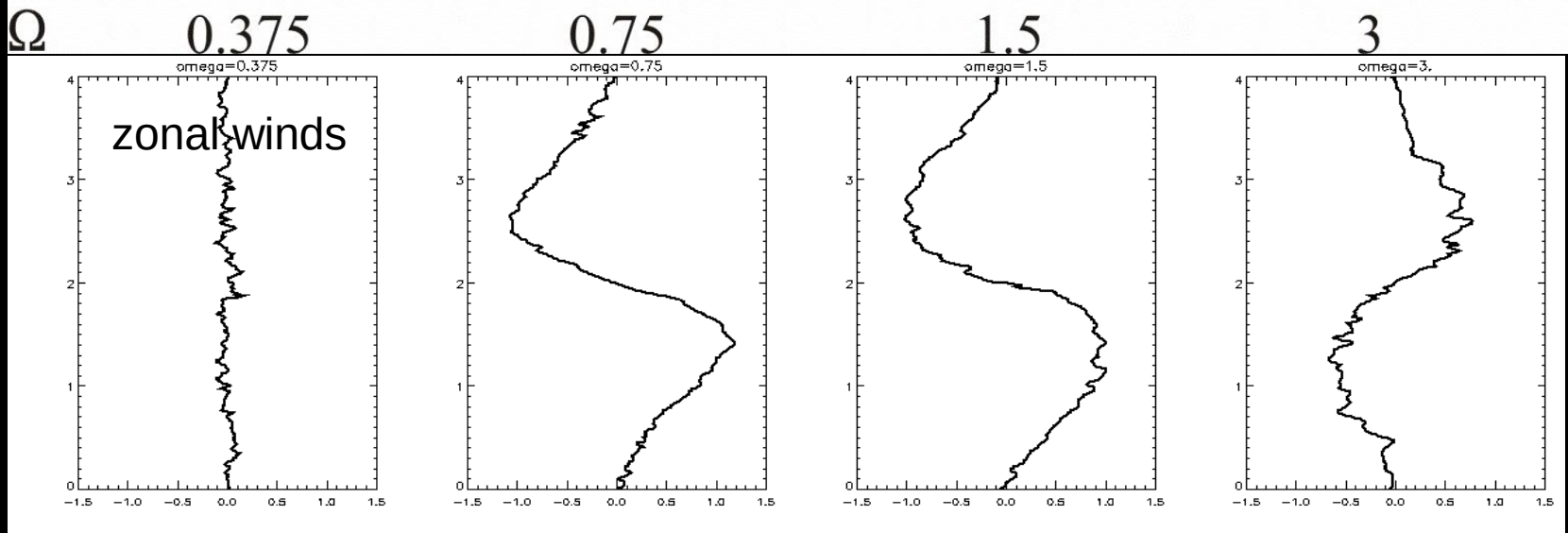
Co2 = f_0 d/V_0 V_0 = V of the non-rotating case

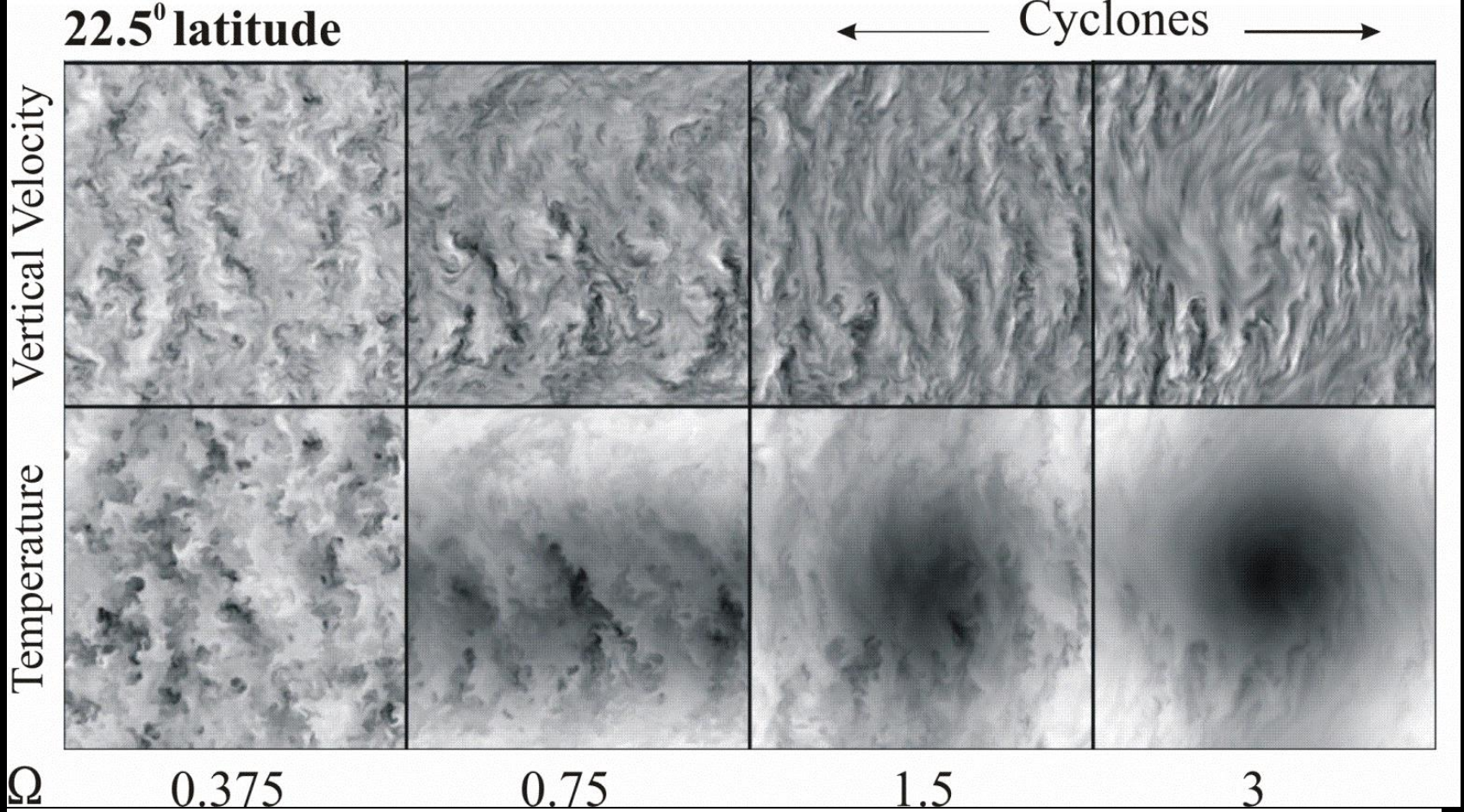
Co3 = f d/V_0 f = 2Ω cos(colatitude)

Case Set 1

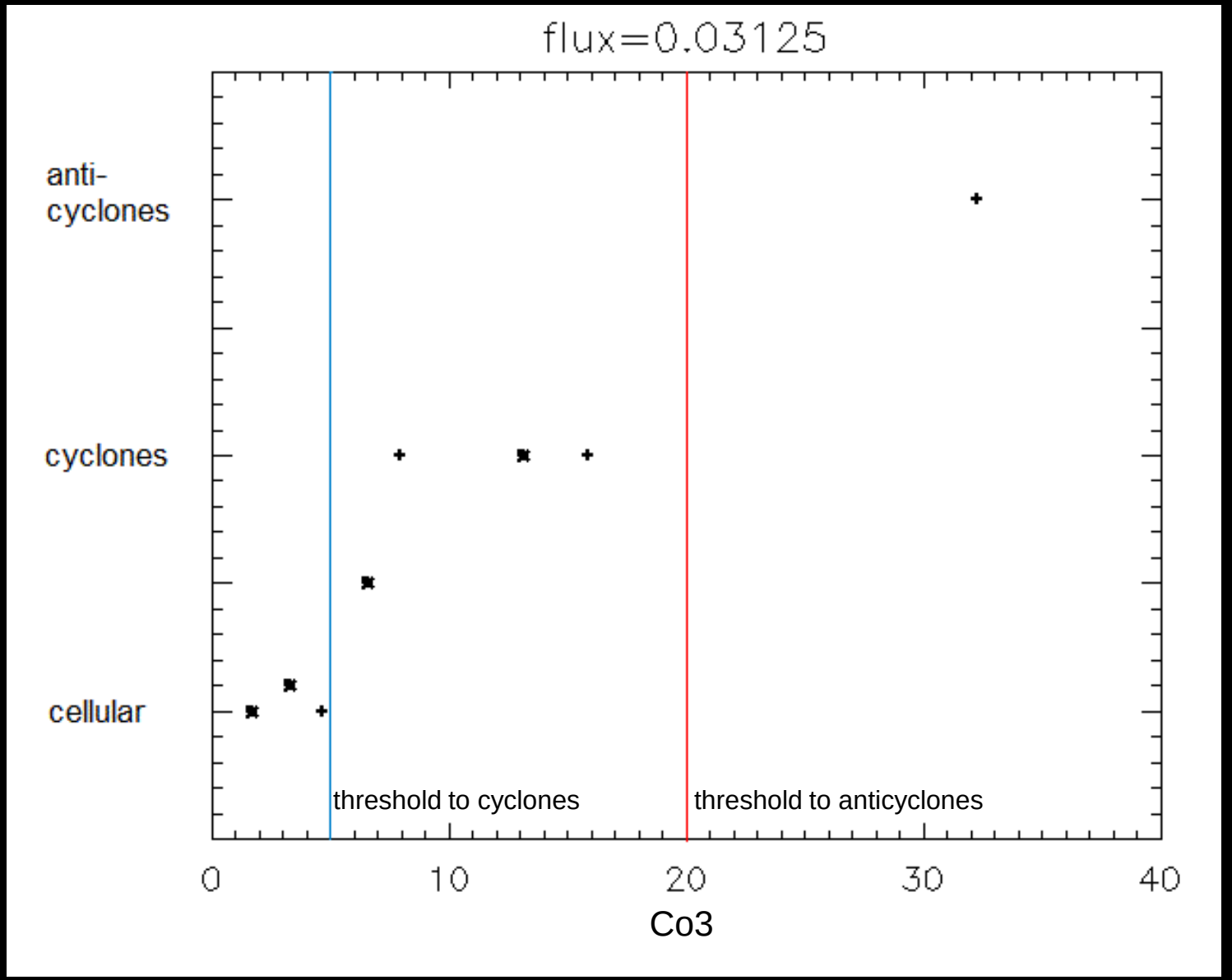
Case	λ	Ω	V	Co1 $f_0 d/V$	Co2 $f_0 d/V_0$	Co3 $f d/V_0$
0			0.136			
1	67.5	0.375	0.103	6.02	4.31	3.98
2	67.5	0.75	0.526	2.28	8.62	7.94
3	67.5	1.5	0.582	4.17	17.2	15.9
4	67.5	3.0	0.354	13.7	34.5	32.3
5	22.5	0.375	0.118	5.03	4.31	1.65
6	22.5	0.75	0.230	5.24	8.62	3.30
7	22.5	1.5	0.198	12.0	17.2	6.58
8	22.5	3.0	0.285	17.2	34.5	13.2


67.5⁰ latitude
Cyclones
Anticyclone
Vertical Velocity
Temperature

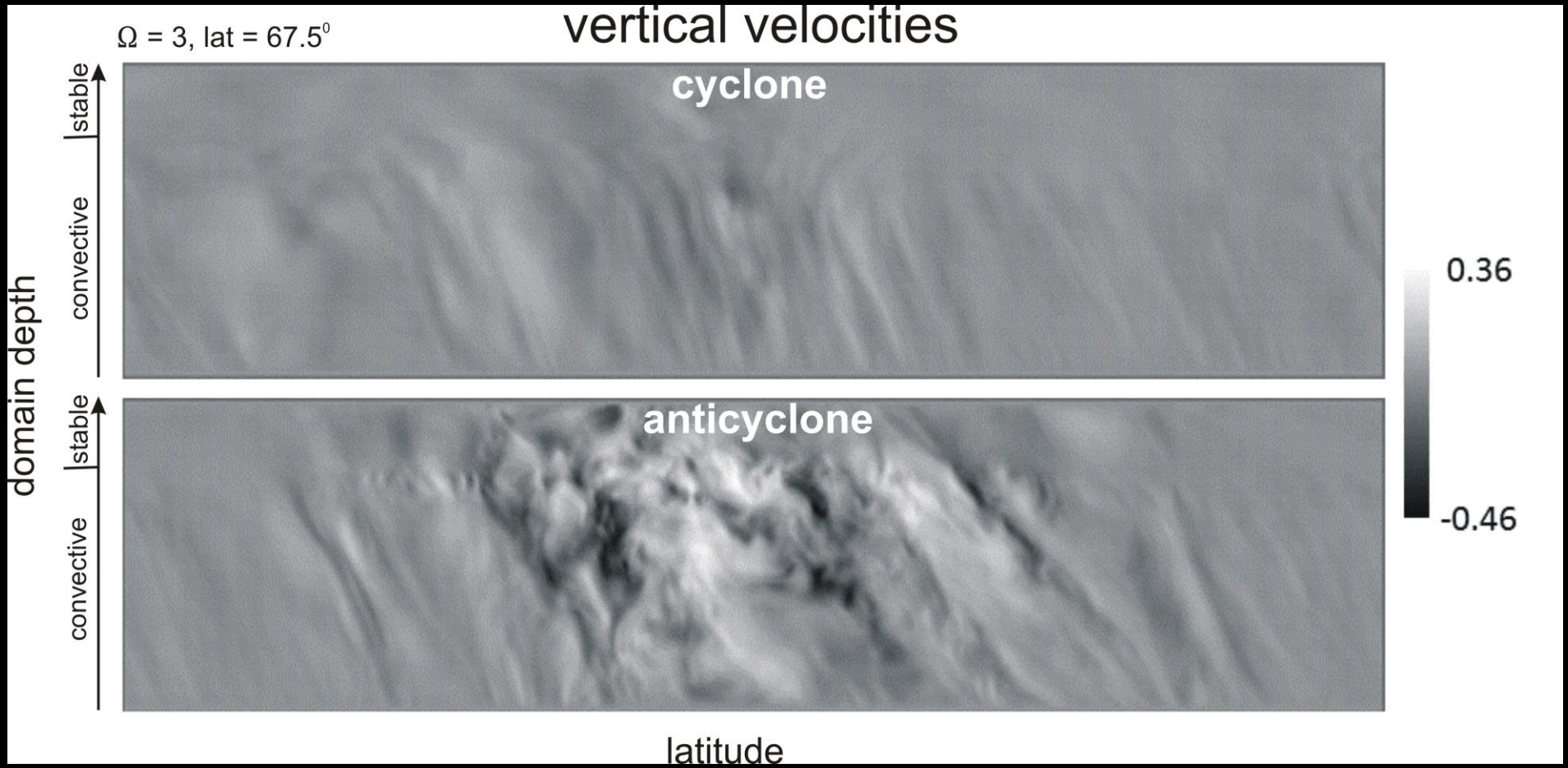

Ω
0.375
0.75
1.5
3
omega=0.375
omega=0.75
omega=1.5
omega=3.
zonal winds


22.5⁰ latitude
Cyclones
Vertical Velocity
Temperature
Ω
0.375
0.75
1.5
3
omega=0.375
omega=0.75
omega=1.5
omega=3.
zonal winds

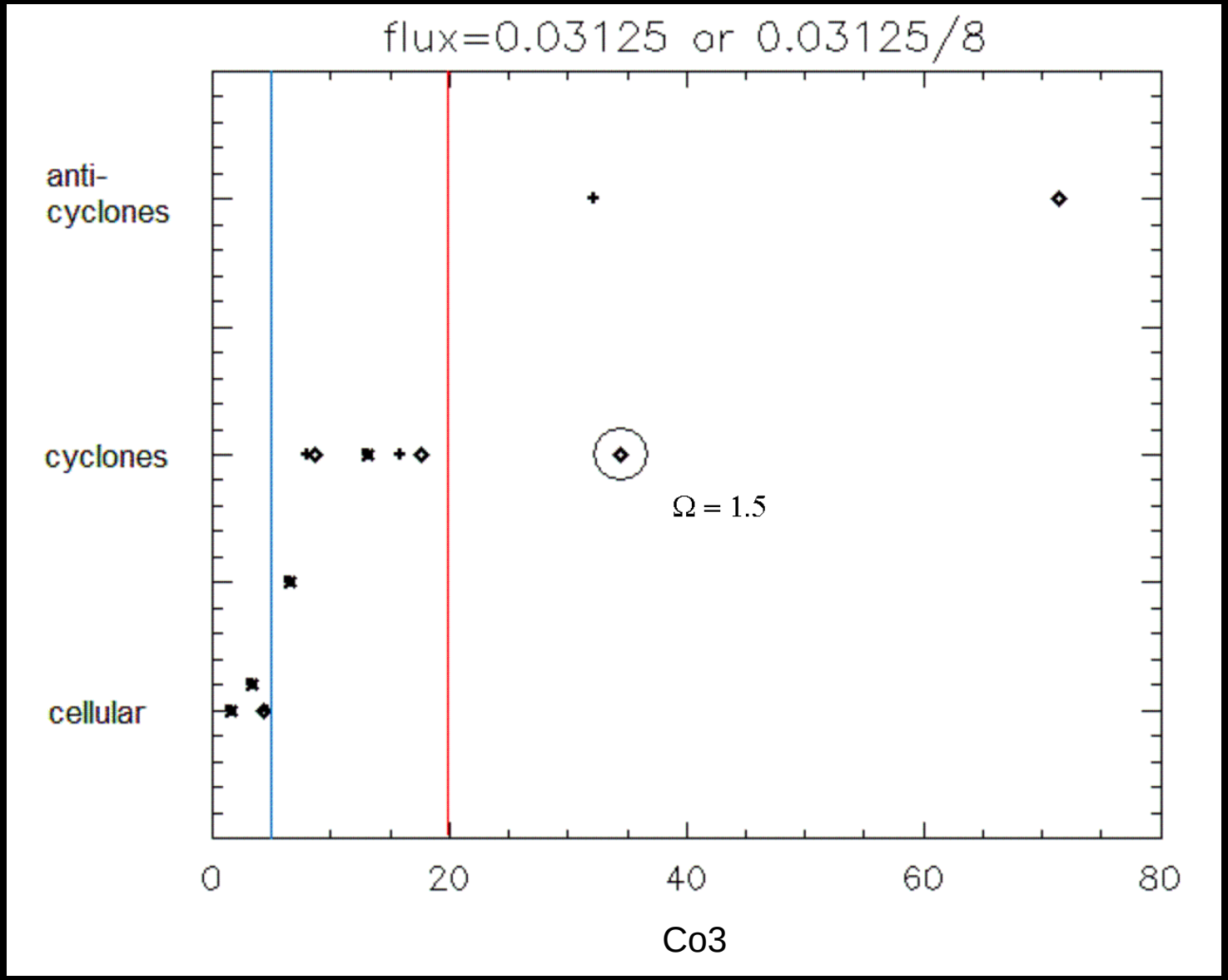
Regime Diagram



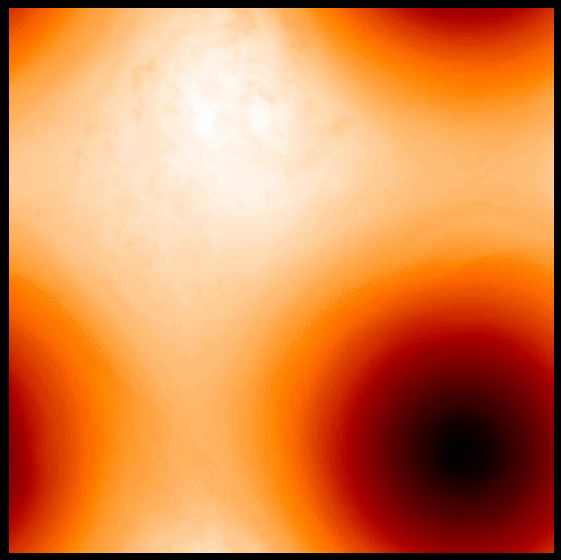
Vertical Cuts of Velocity Fields through Centers of Cyclone and Anticyclone

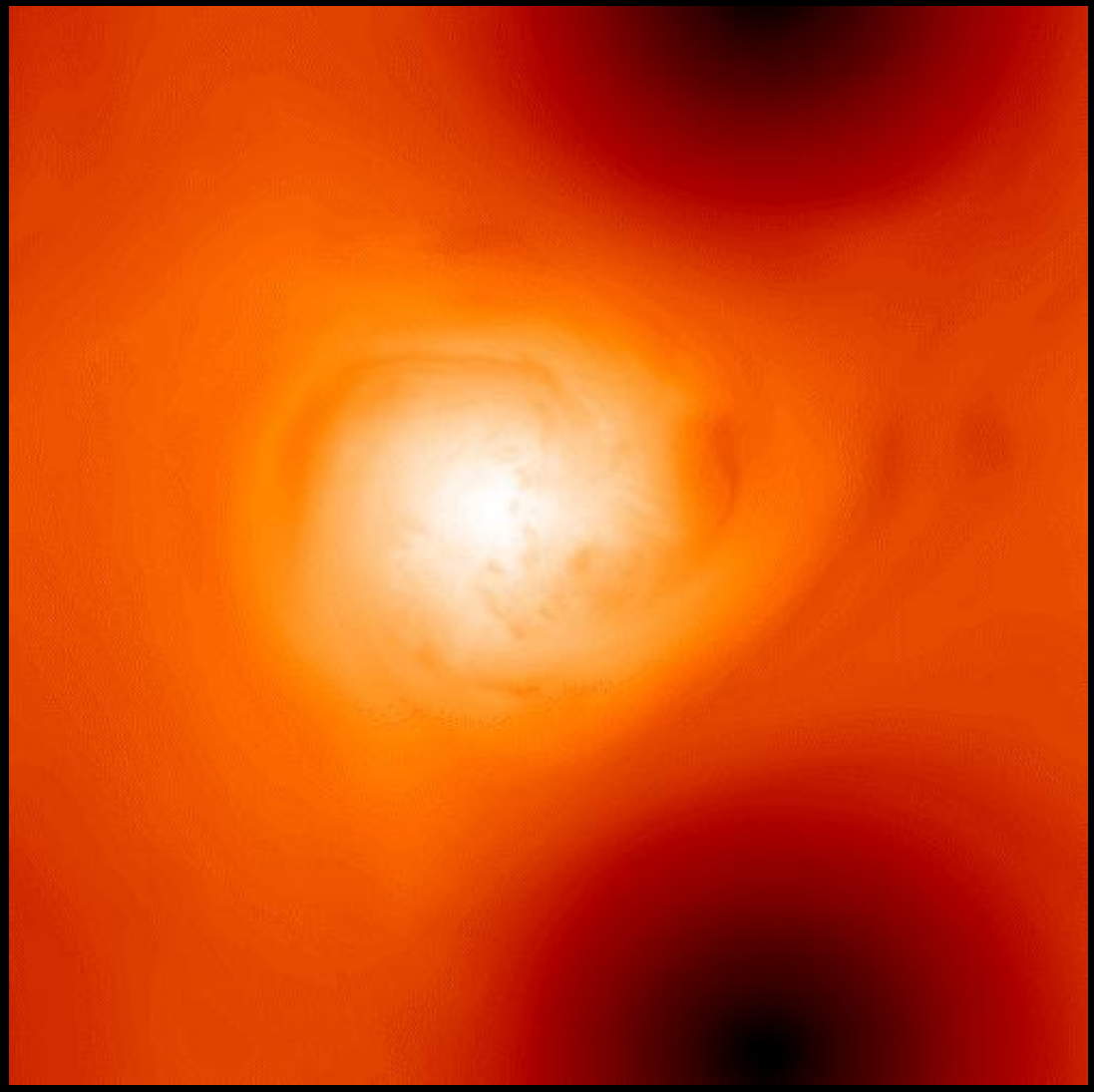


Regime Diagram (more cases)

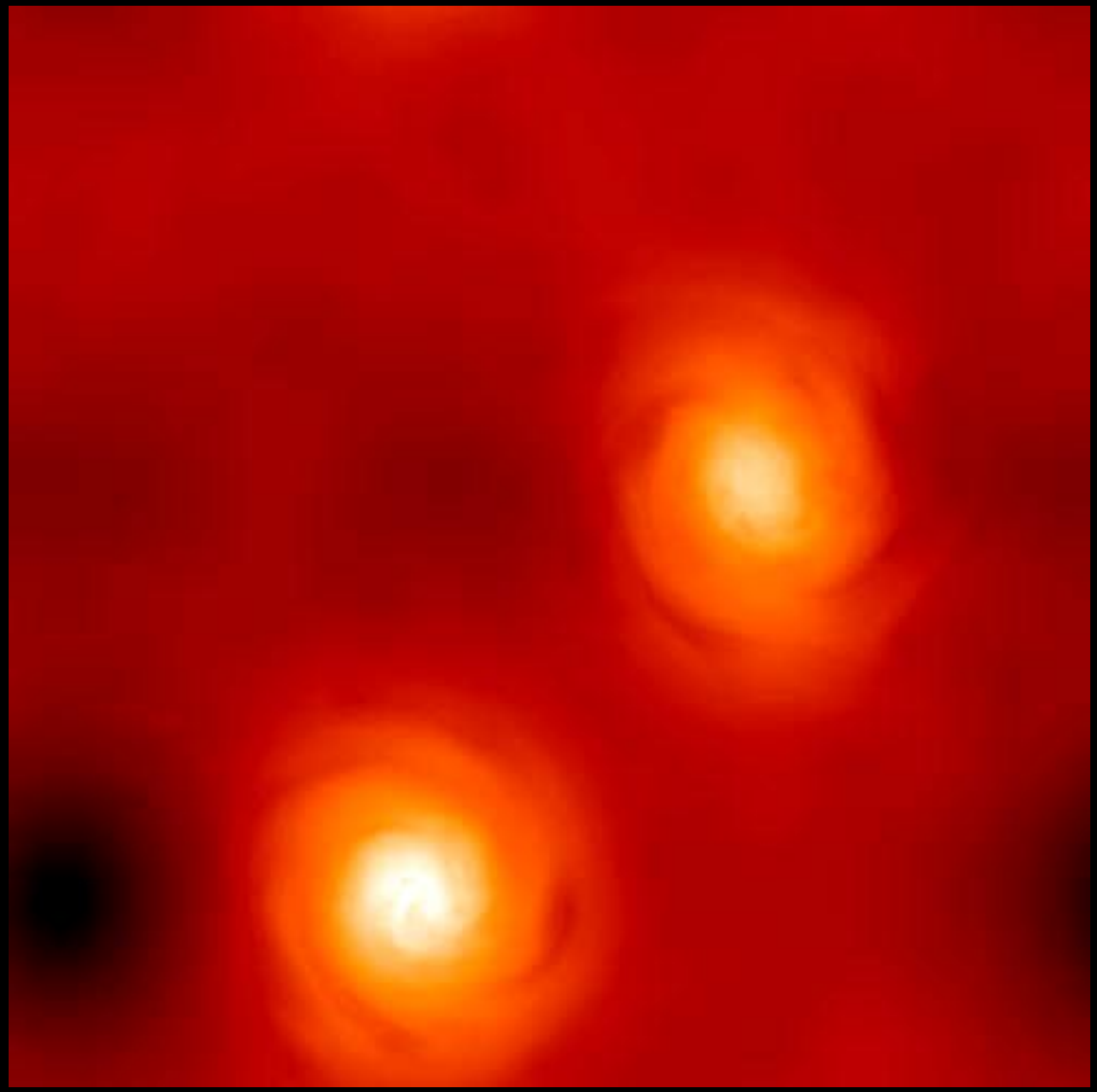


f = 0.0375/8, Ω = 1.5; aspect ratio = 4 & 8



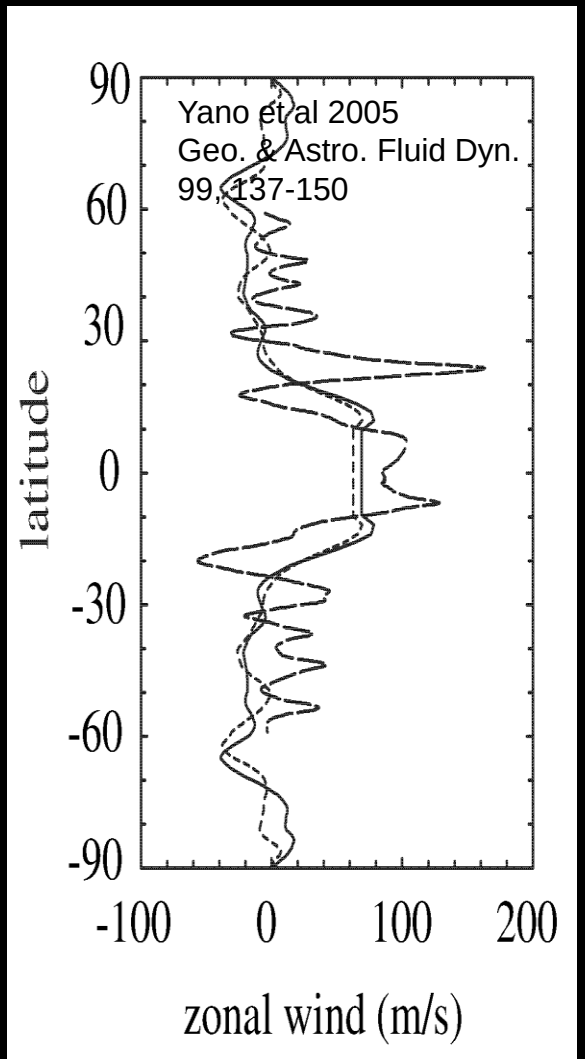


f = 0.0375/8, Ω = 3; aspect ratio = 8

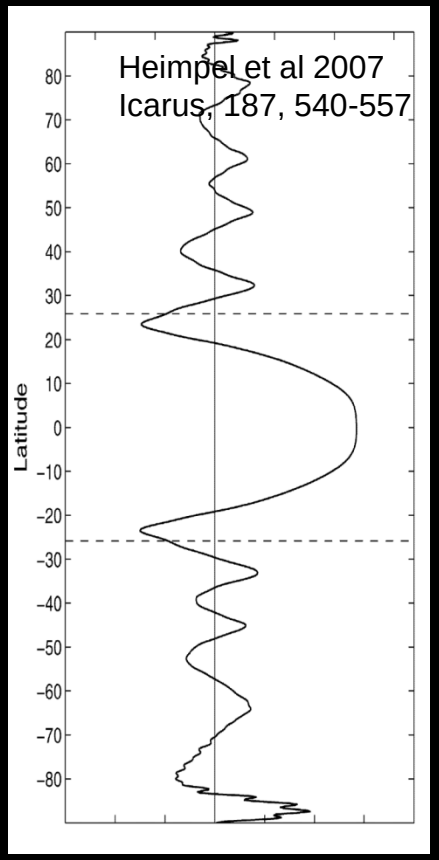


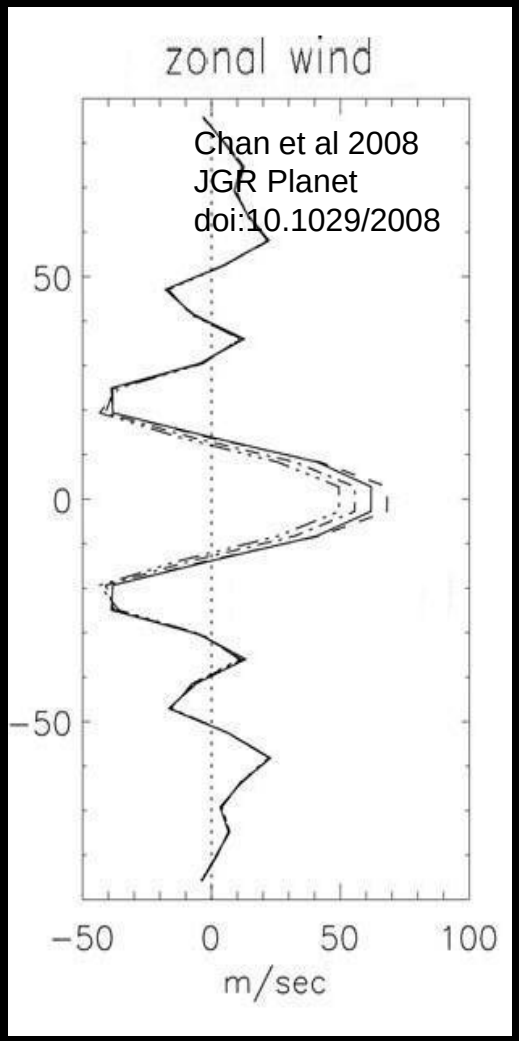
Zonal Wind Bands

2D turbulence models

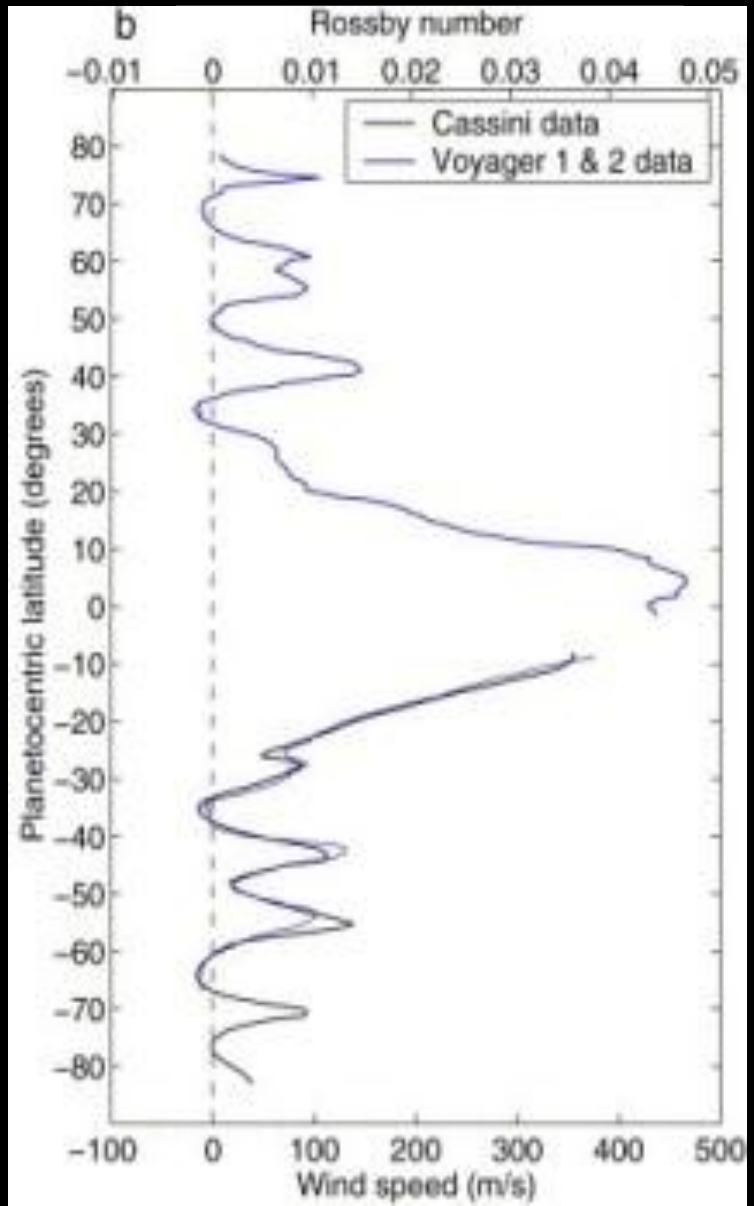


3D convection models

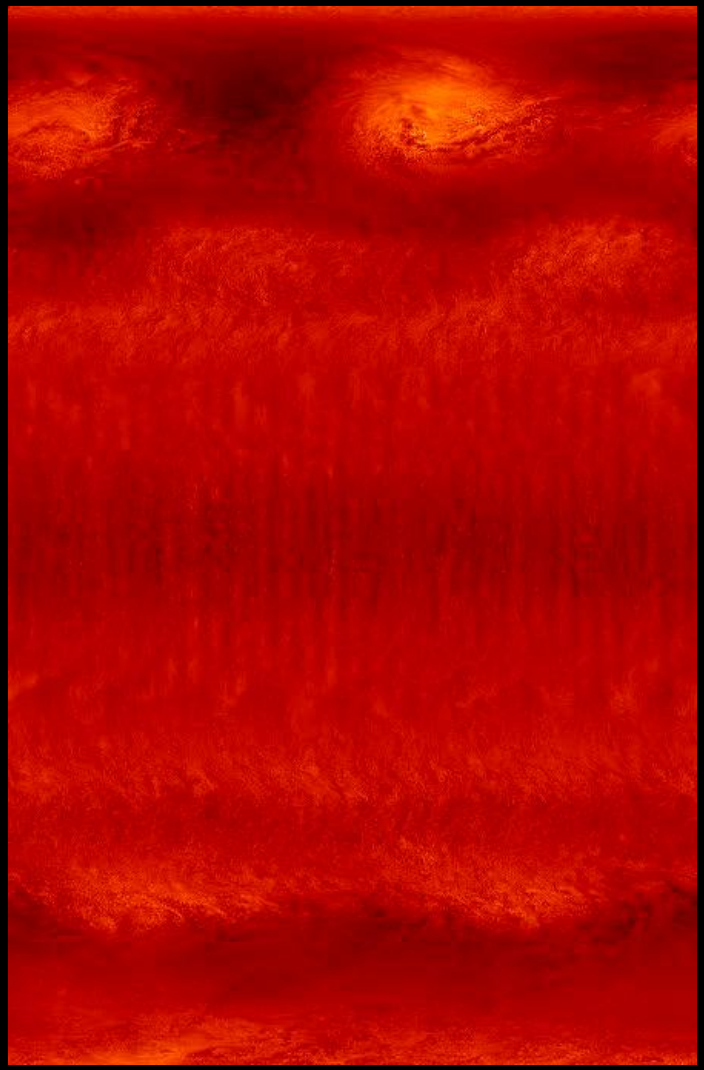




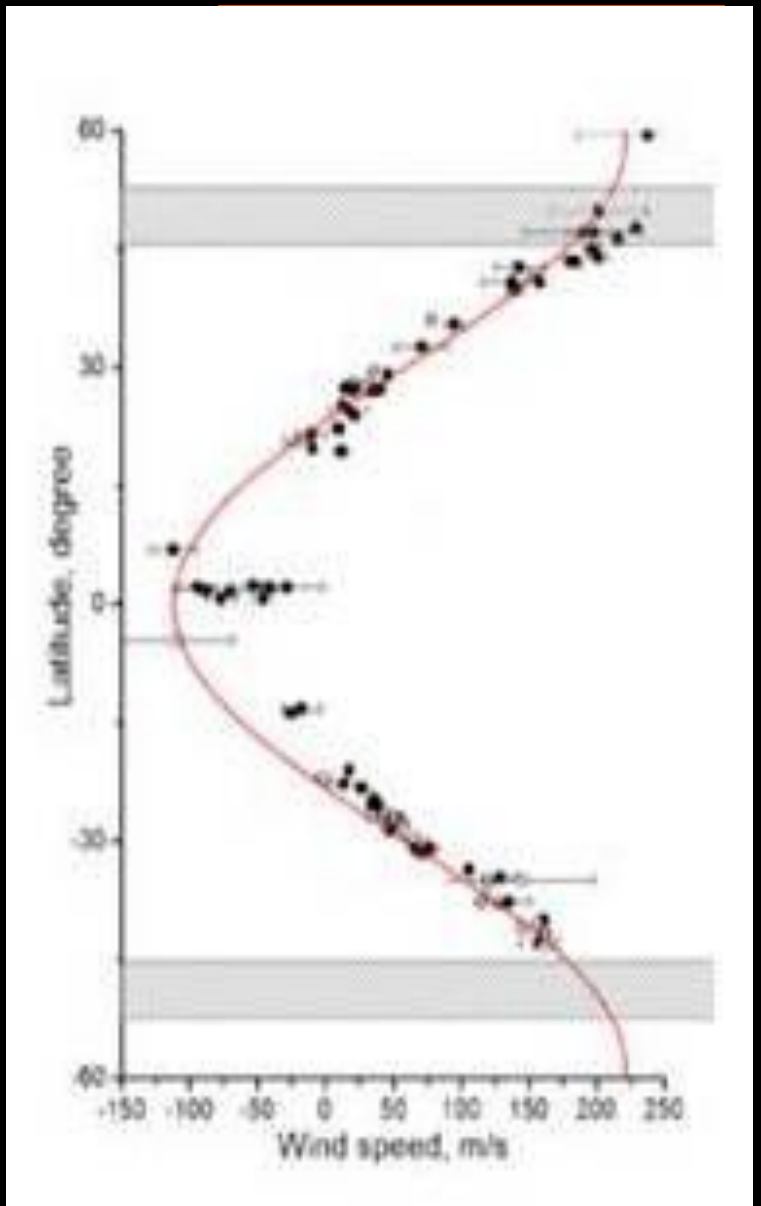
Multiple jets with prograde equatorial wind



Horizontal cut of temperature



Broad Retrograde Equatorial Wind



Horizontal cut of temperature

Summary

- Long-lived cyclones and anticyclones can be generated in a rotating convection zone
- As Co increases, cyclones appear first
- Multiple zonal wind bands can be generated in a rotating convection shell
- Prograde (or retrograde) equatorial wind depends on Co.
- Long-lived vortices can be generated in co-existence with the zonal wind bands

Thank You!