Seasonal variation of radial brightness contrast of Saturn's rings viewed in mid-infrared by COMICS

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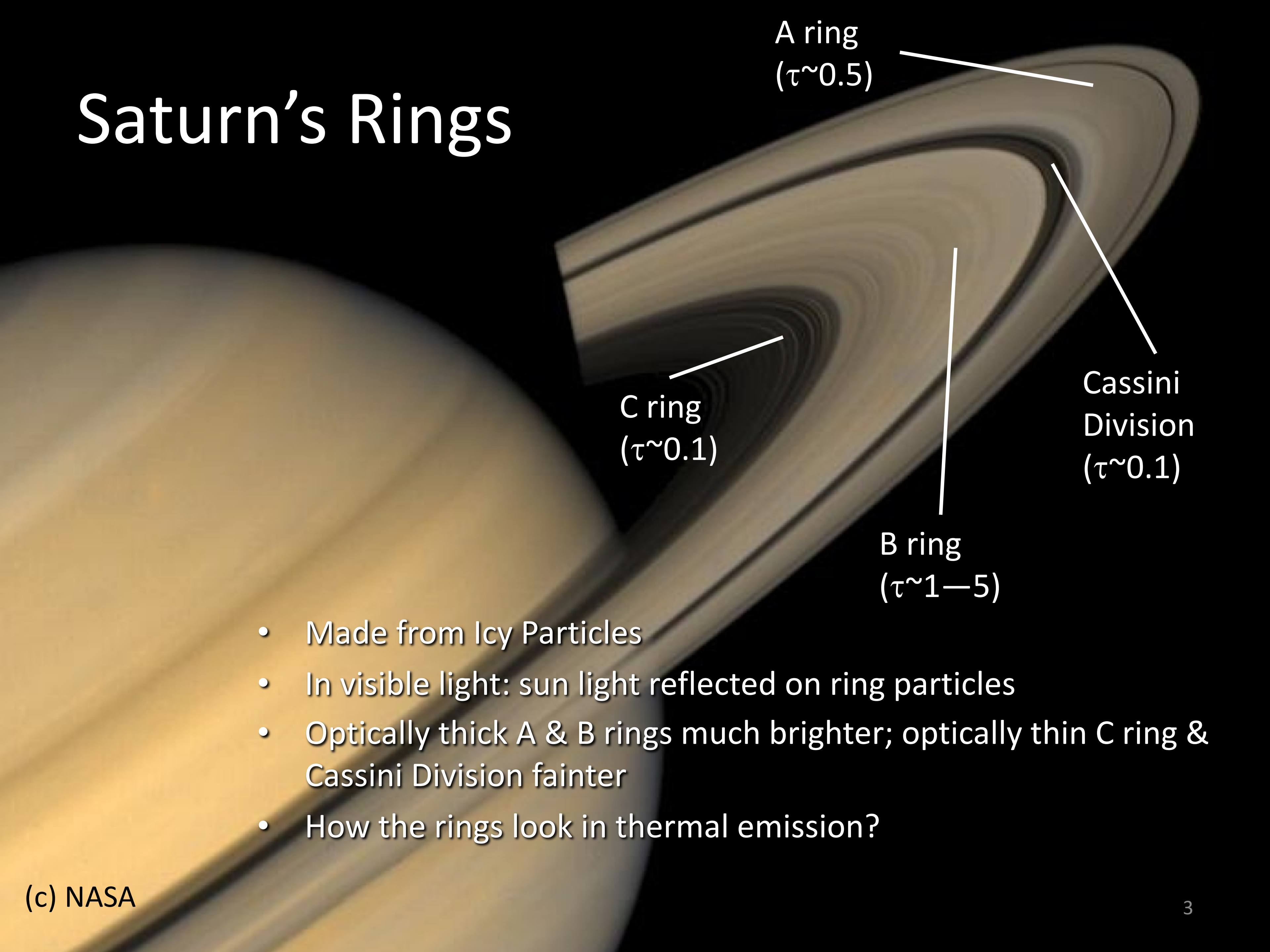
Planetary Rings:
Miniature of dusty debris disks?

- Disk structure by solid particles
- Gas-free or gas-less system
- Probably generated by collisions

Saturn's rings

Debris Disk HR 4796A
(Thalmann+ 2011)

Saturn’s Rings



- Made from Icy Particles
- In visible light: sun light reflected on ring particles
- Optically thick A & B rings much brighter; optically thin C ring & Cassini Division fainter
- How the rings look in thermal emission?

Data

- MIR Camera COMICS on Subaru Telescope with 8.2 m Primary Mirror on Maunakea
- Multi-wavelength Imaging at 8.8, 9.7, 10.5, 11.7, 12.5, 17.7, 18.8, 20.5, 24.5 μm
- Observed in 2008/1/23 by G. Orton, L. Fletcher et al. (unpublished)
- Almost edge-on rings to observer/Sun

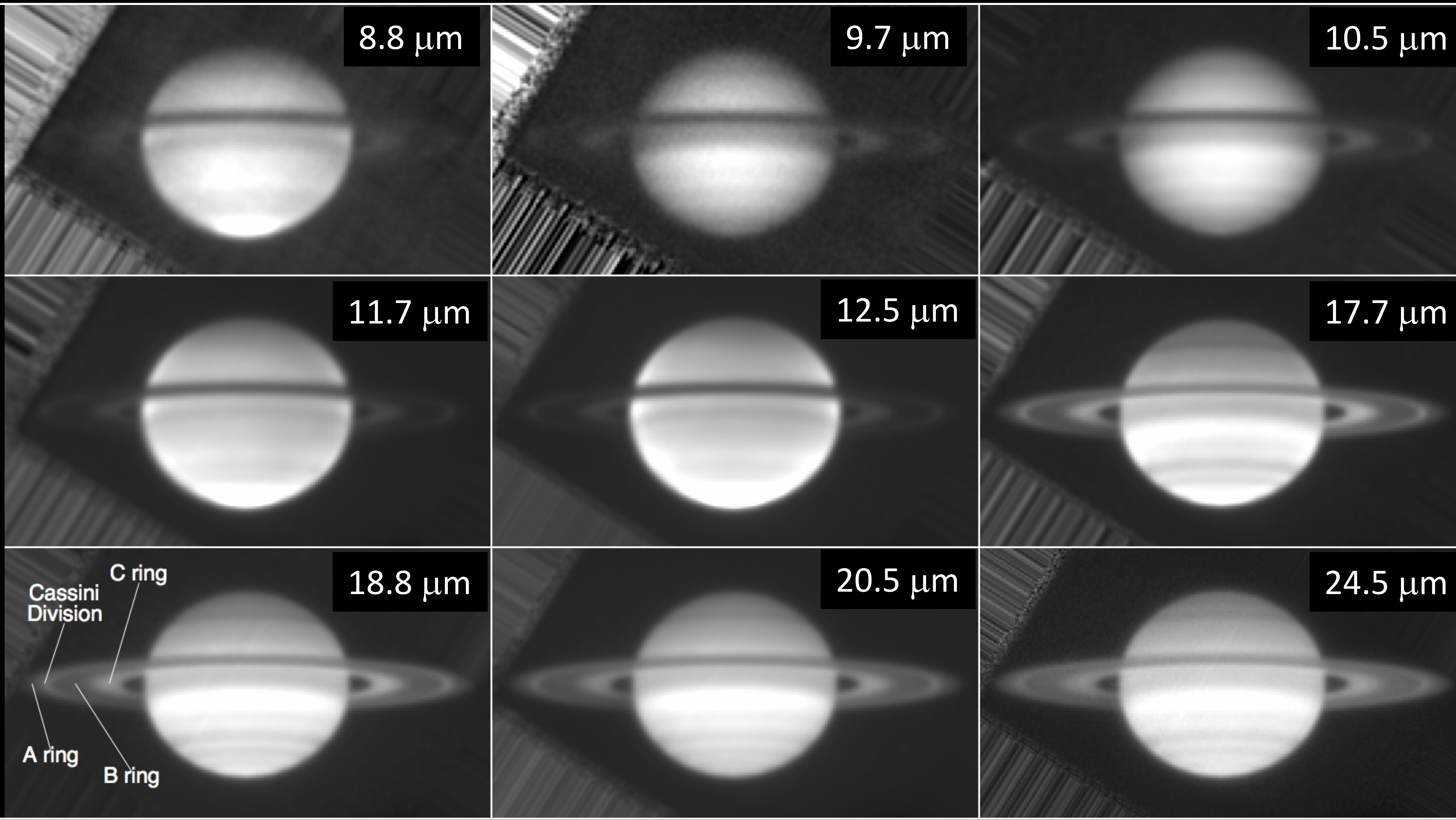
Astrometrical parameters

Epoch (UT)	r (au)	Δ (au)	B' (deg)	B (deg)	α (deg)
January 23, 2008	9.27	8.45	−8.7	−7.2	3.5

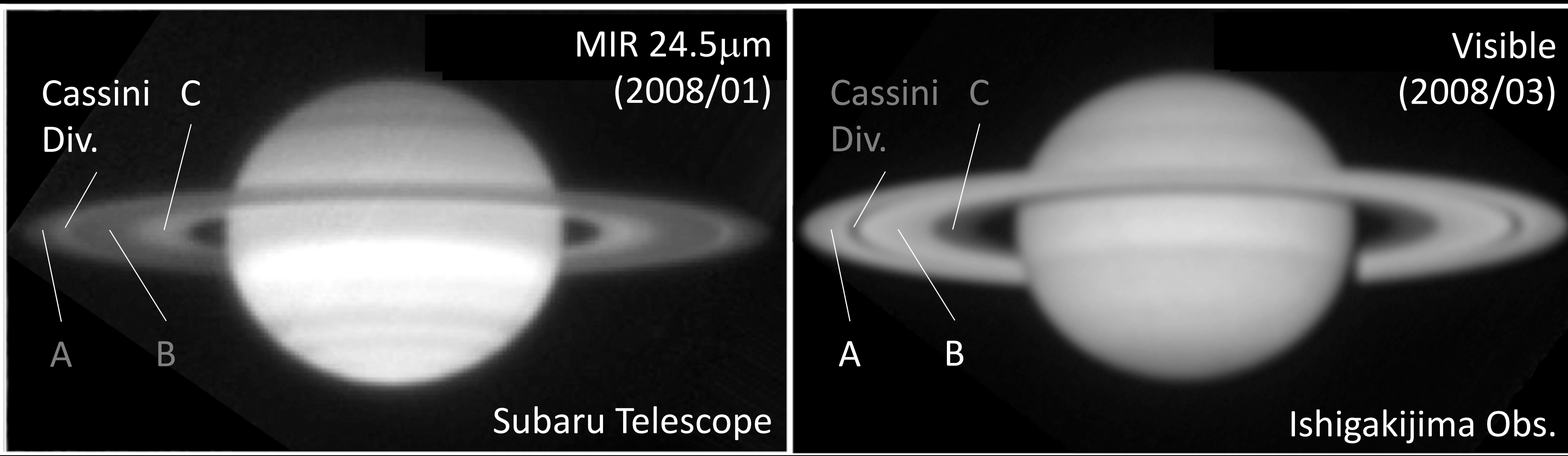
Sun-Saturn | Earth-Saturn | Solar El. (above ring plane) | Earth El. | Phase Ang.

Ring Brightness

Spatial Res: 0.38-0.67” = a few 1000 km
(**Highest-ever in MIR from ground**)



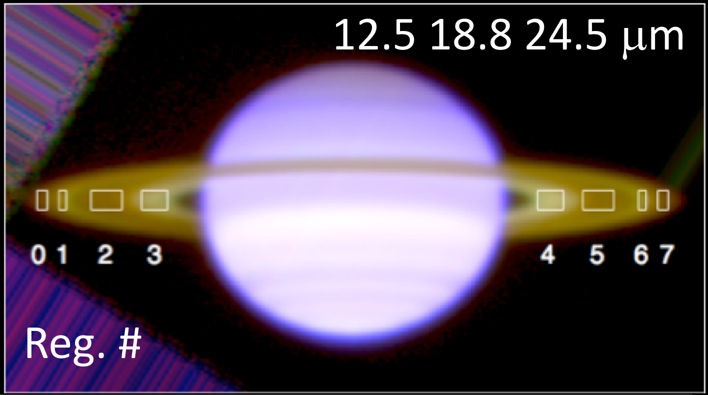
Comparison w/ visible image

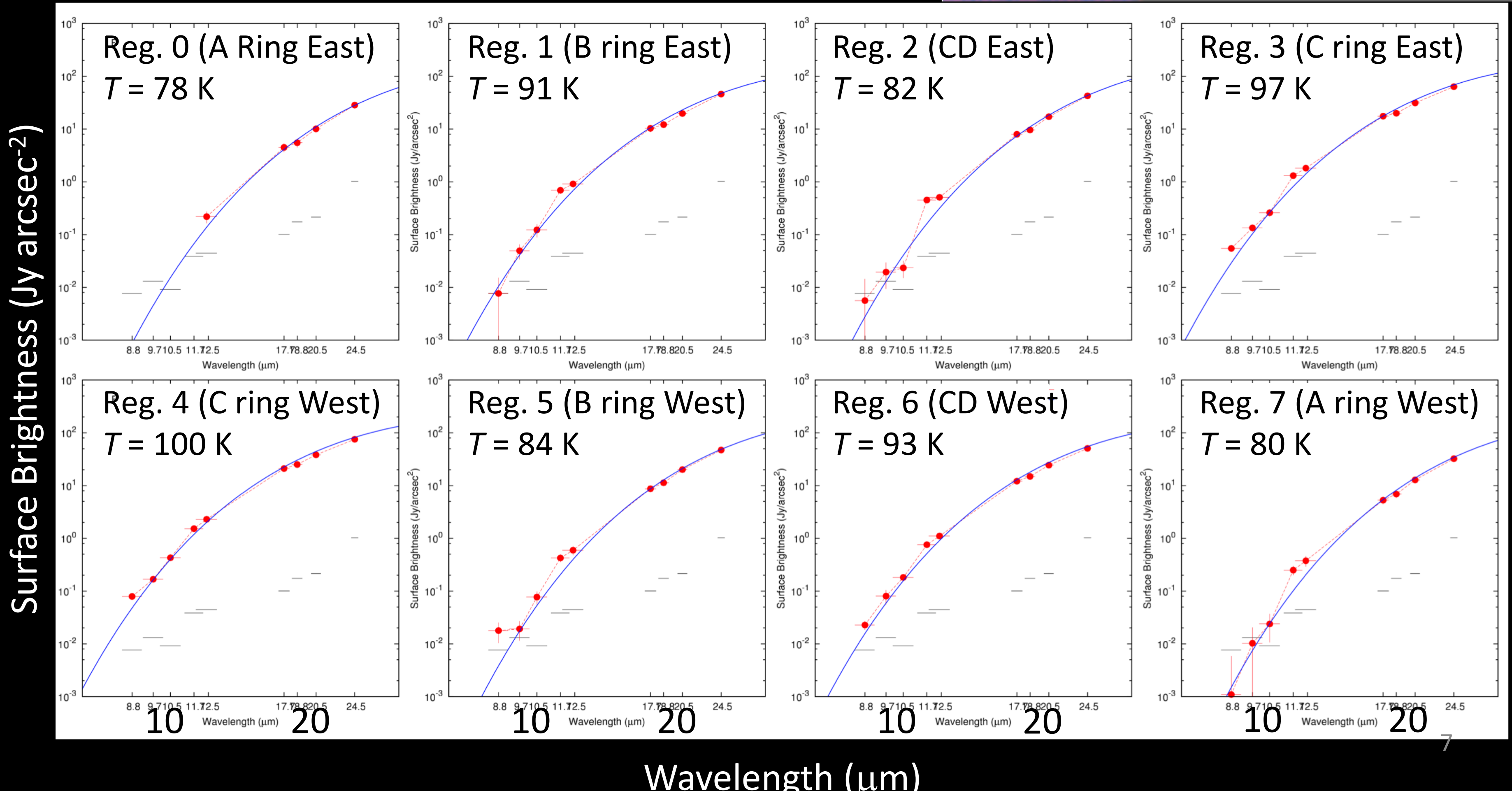


- Compared with visible image by Ishigakijima Obs.
- C ring and Cassini Div. are brighter than B and A rings in MIR while C rings and Cassini Div. are always fainter in visible
- Ring brightness contrasts in MIR and visible are reversed

SEDs of Rings

- Blackbody peaking at > 25 μm
- No significant dust features

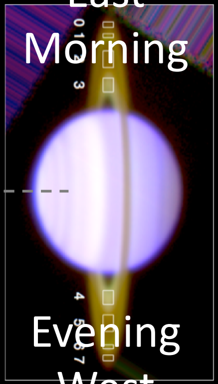




Ring Temperatures

- SED fit w/ BB (assuming τ, measured from stellar occultation)
  → Physical Temperature of Ring Particles
  - Brightness $I_\nu(\lambda) = \beta B_\nu(\lambda, T)$
  - Filling Factor $\beta = 1 - \exp(-\tau/|\sin B|)$

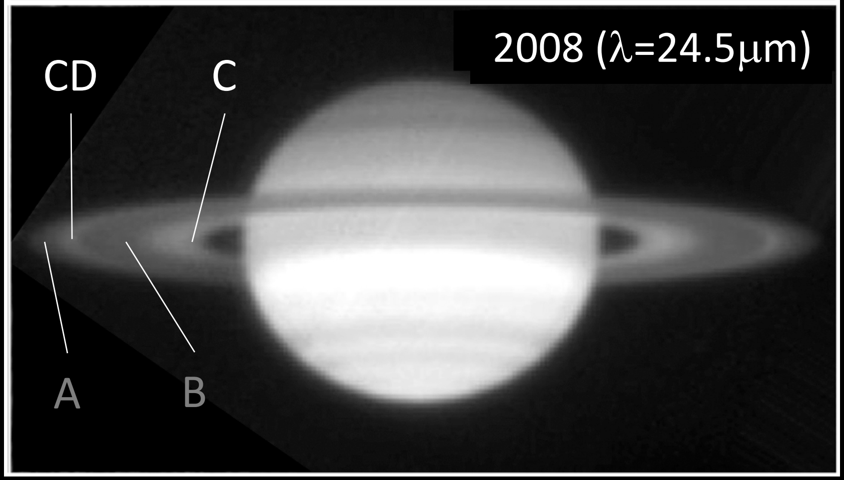
Region	Ring	*T* by COMICS (K)					
		τ = 0.05	0.1	0.2	0.5	1	2
0	A ring (East)	–	**–**	80	**78**	78	–
1	Cassini Division (East)	97	**91**	87	–	–	–
2	B ring (East)	–	**–**	–	82	**82**	82
3	C ring (East)	102	**97**	92	–	–	–
4	C ring (West)	105	**100**	95	–	–	–
5	B ring (West)	–	**–**	–	84	**84**	84
6	Cassini Division (West)	99	**93**	89	–	–	–
7	A ring (West)	–	**–**	82	**80**	80	–



- C ring & Cassini Div. warmer than B, A rings
- West side warmer than east side in each ring

Discussion

1. In the MIR, optically thin C ring and Cassini Div. were brighter than optically thick A & B rings in 2008
2. Temperatures in C ring and Cassini Div. were higher than A & B rings
3. West side is generally warmer than the east over the rings
   – Accounted for by eclipse cooling in Saturn's shadow (E=morning, W=evening)



- (1) & (2) related to each other
- Surface Brightness in Thermal Emission: $I_\nu(\lambda) = \beta B_\nu(\lambda,T)$
- Filling factors in C ring and CD were lower than A & B rings
- BUT, effect of higher temperatures in C & CD overcome lower filling factors

Variation from 2005 to 2008

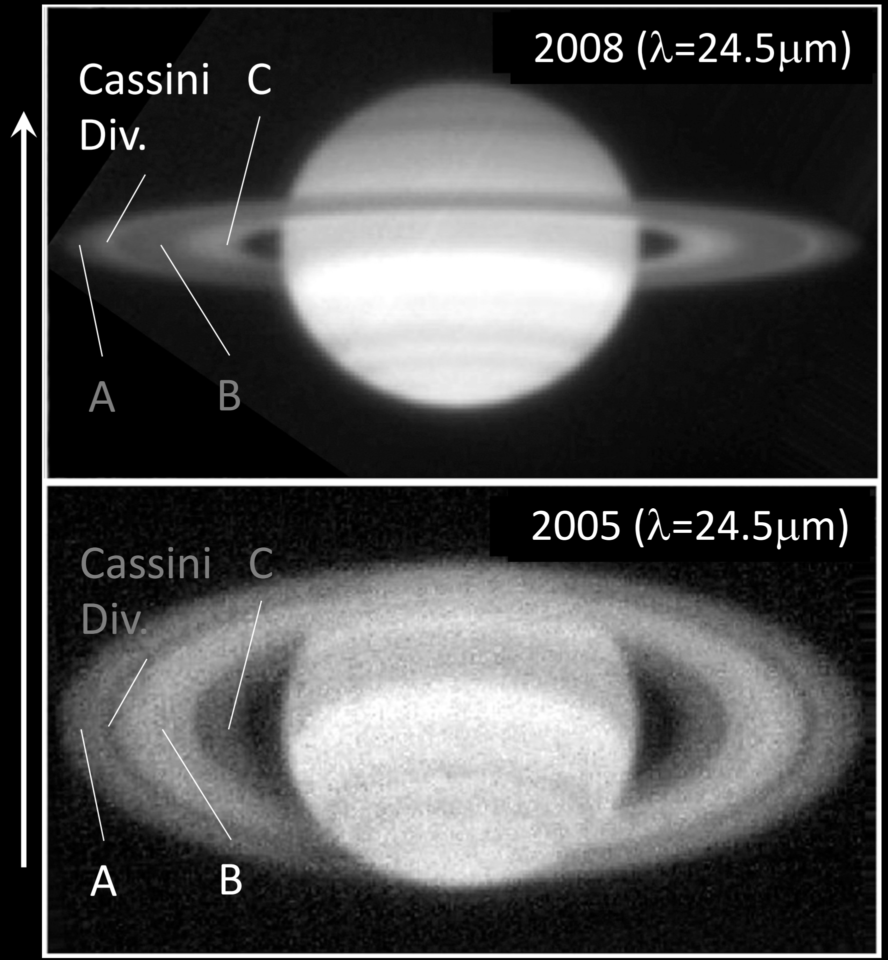
- Compared with data in 2005 April, when ring opening was larger

Epoch (UT)	r (au)	Δ (au)	B' (deg)	B (deg)	α (deg)
January 23, 2008	9.27	8.45	−8.7	−7.2	3.5
April 30, 2005	9.07	9.33	−21.9	−23.6	6.1

(above ring plane)

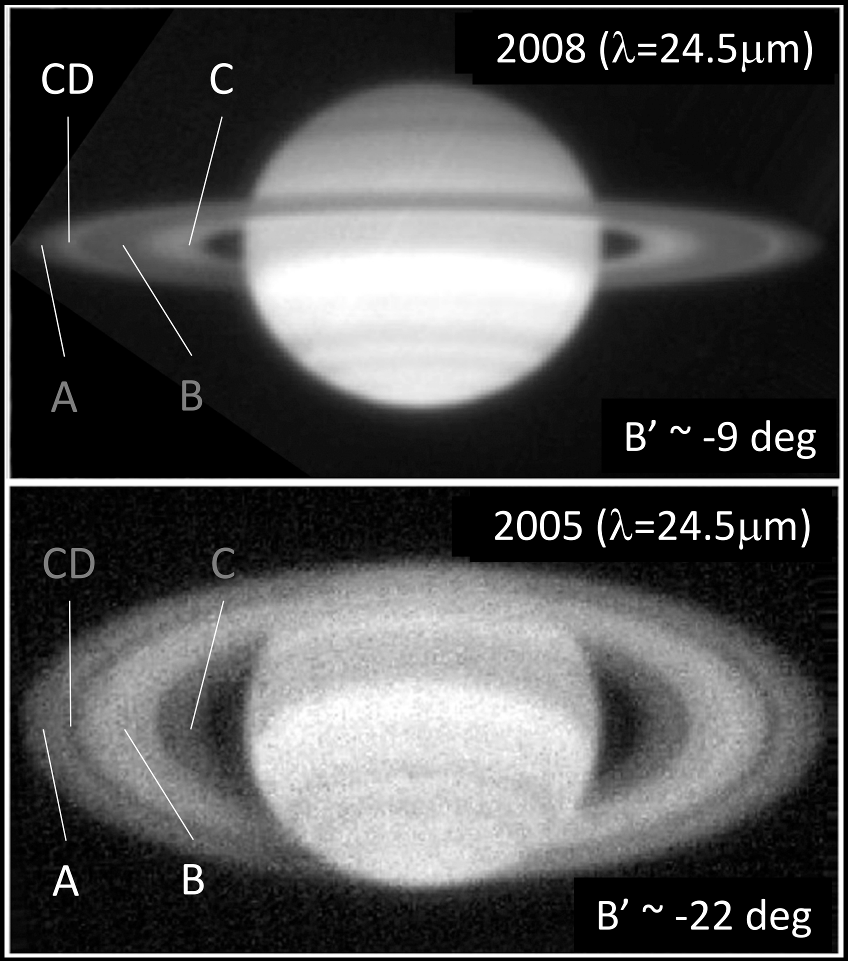
Solar El. Earth El.

- Contrast reversed in 2005-2008
- Could be explained by change in filling factors
- Larger opening angle makes larger contrast in optical depths
- C ring & CD fainter

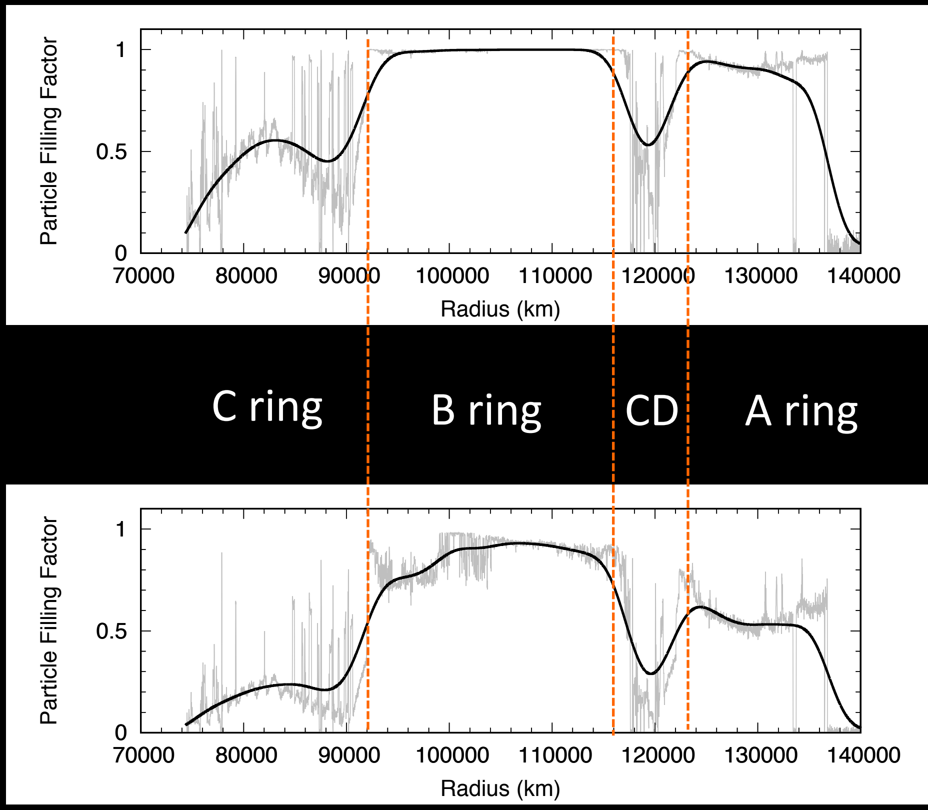


(See Fujiwara et al. 2017 A&A for quantitative discussion)

Temporal Variation in Filling Factors



Particle Filling Factors



- Larger ring opening angle makes larger contrast in filling factor

Summery

- MIR image of Saturn from Subaru/COMICS
- Measurement of Ring Brightness & Temperatures (Highest-ever spatial resolution from the ground)
  - C ring and Cassini Div. were warmer than B and A rings
- In 2008 C ring and Cassini Div. were brighter than B and A rings (opposite contrast to visible light)
- MIR Brightness Contrast became inverse from 2005 to 2008

- Observed temporal variation in the MIR brightness contrast is interpreted as a result of a seasonal effect with changing elevations of the Sun and observer above the ring plane