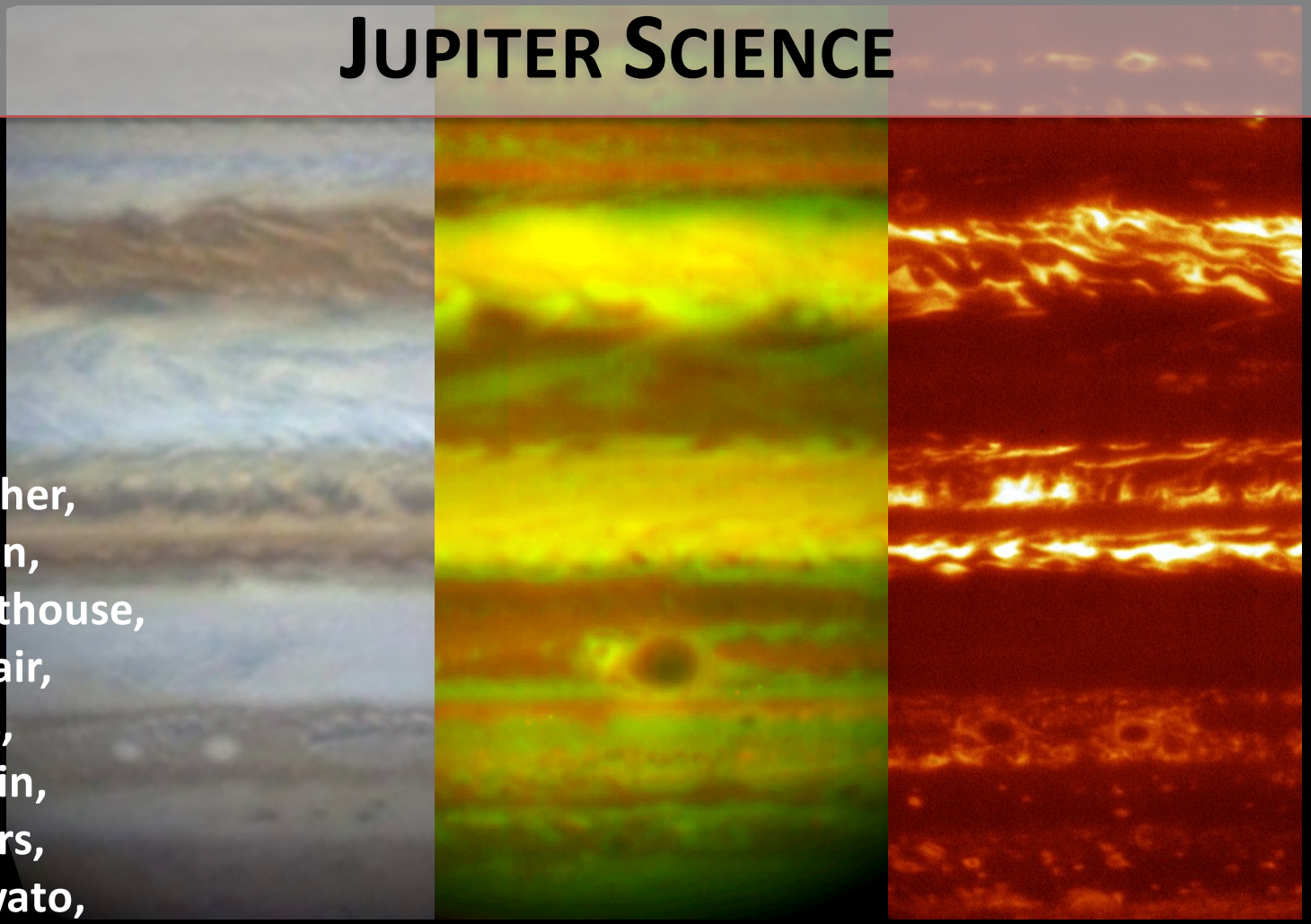
Pro-Am Collaborations for Thermal-IR Jupiter Science



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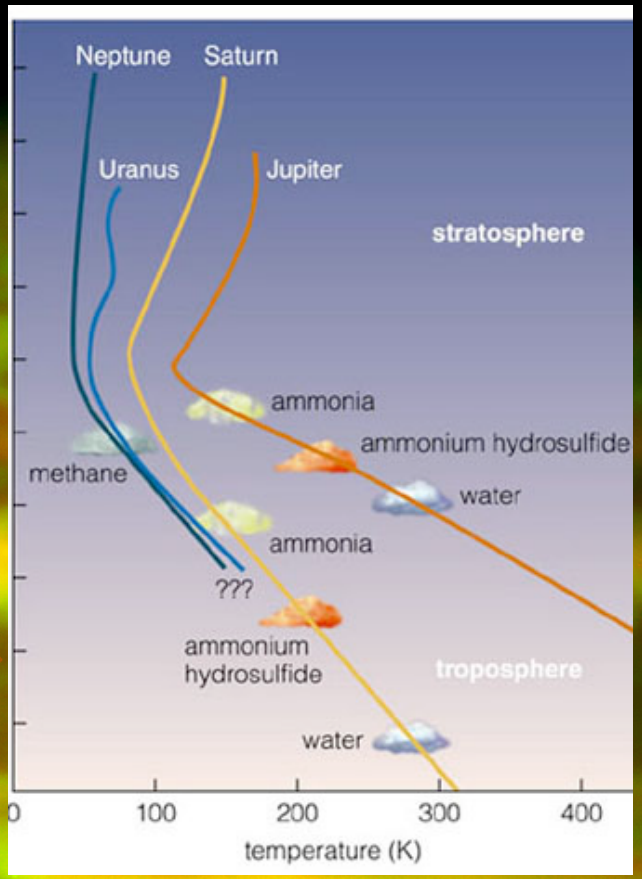
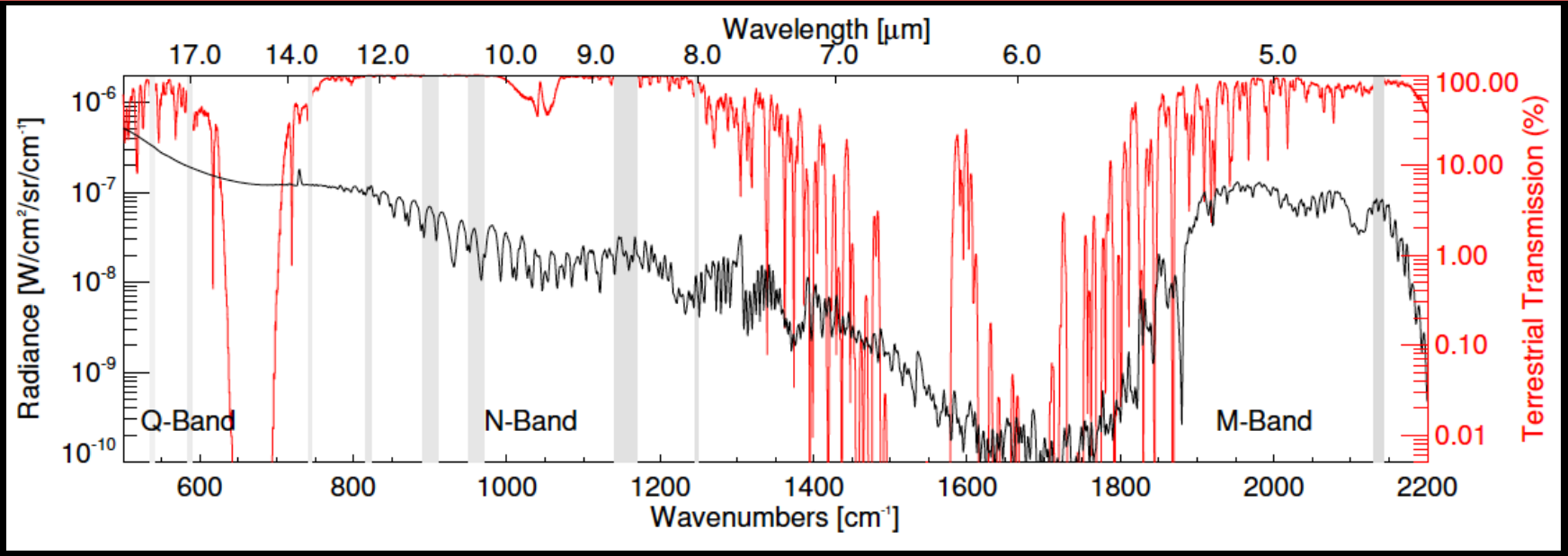
Why the Thermal-IR?

- ***Only* method of determining planetary climate associated with dynamic phenomena**:
  - 3D Temperature and wind structure;
  - Volatiles, disequilibrium species and photochemical products;
  - Aerosol/haze opacity;
- **…from the cloud-forming region into the middle-atmosphere.**
- Earth-based capabilities can now **match & surpass** those of visiting spacecraft (Galileo, Cassini).
  - Completely absent from Juno and JUICE.



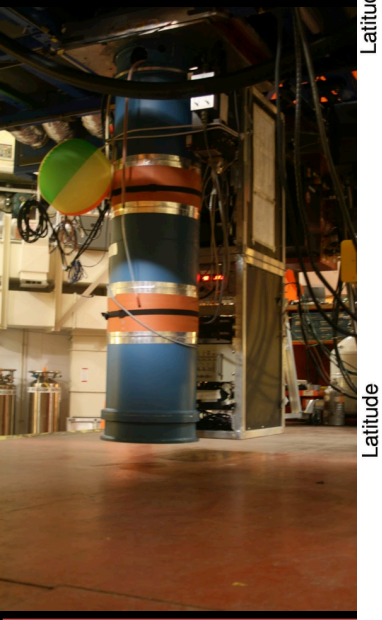
Goals of Thermal-IR Programme

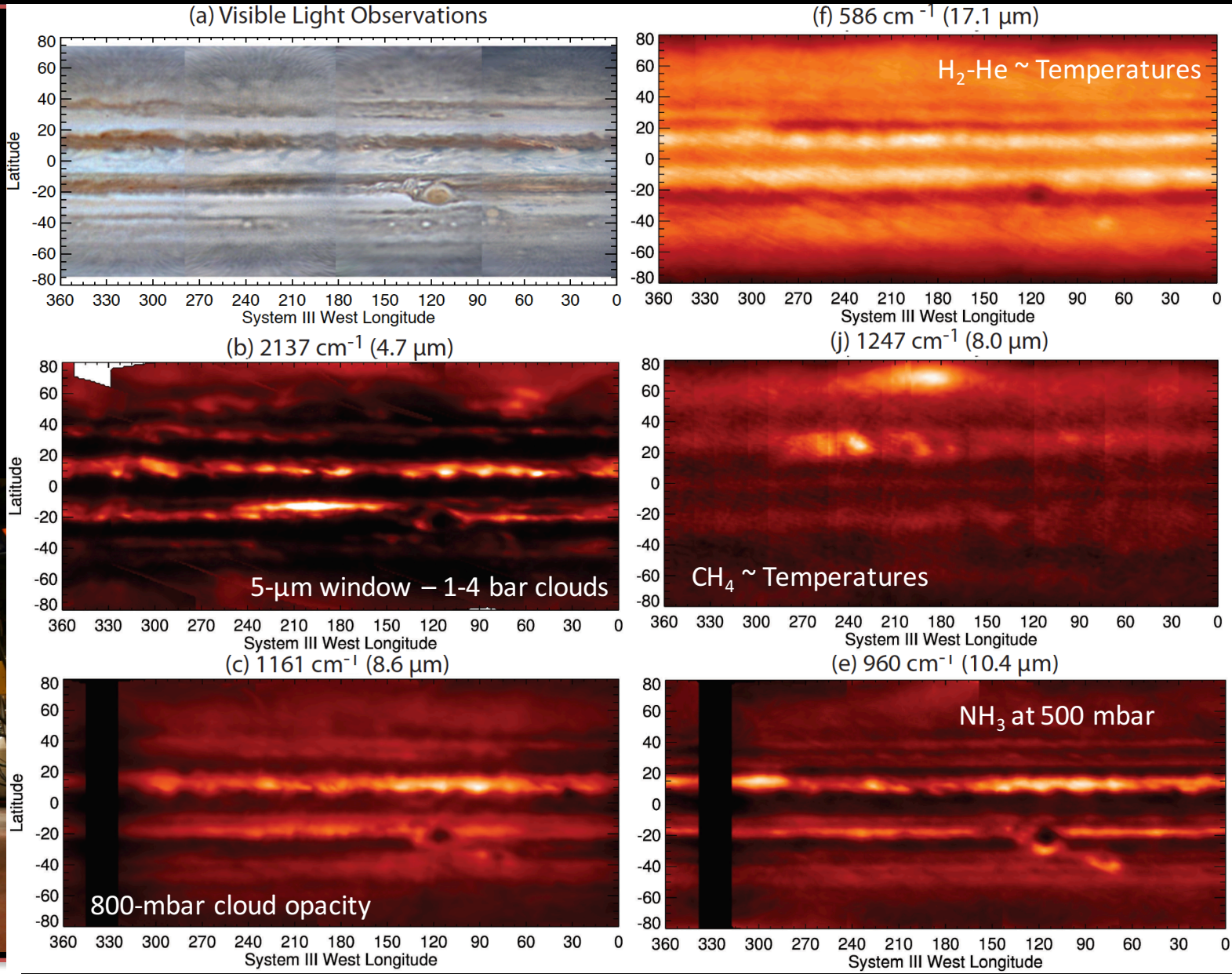


1. **Plug IR Gap in Juno remote sensing**
   - Temperatures, composition and cloud opacity from 70-800 mbar (troposphere) and 0.1-20 mbar (stratosphere).
2. **Spatial context for close-in perijoves.**
   - And exploit simultaneity with amateurs & other facilities
3. **Long-term temporal context for Juno science.**
   - IRTF Spectroscopic mapping since 2012.
   - Photometric imaging from 8-m observatories since 2006.
   - Long-term IRTF records since ~1980s.

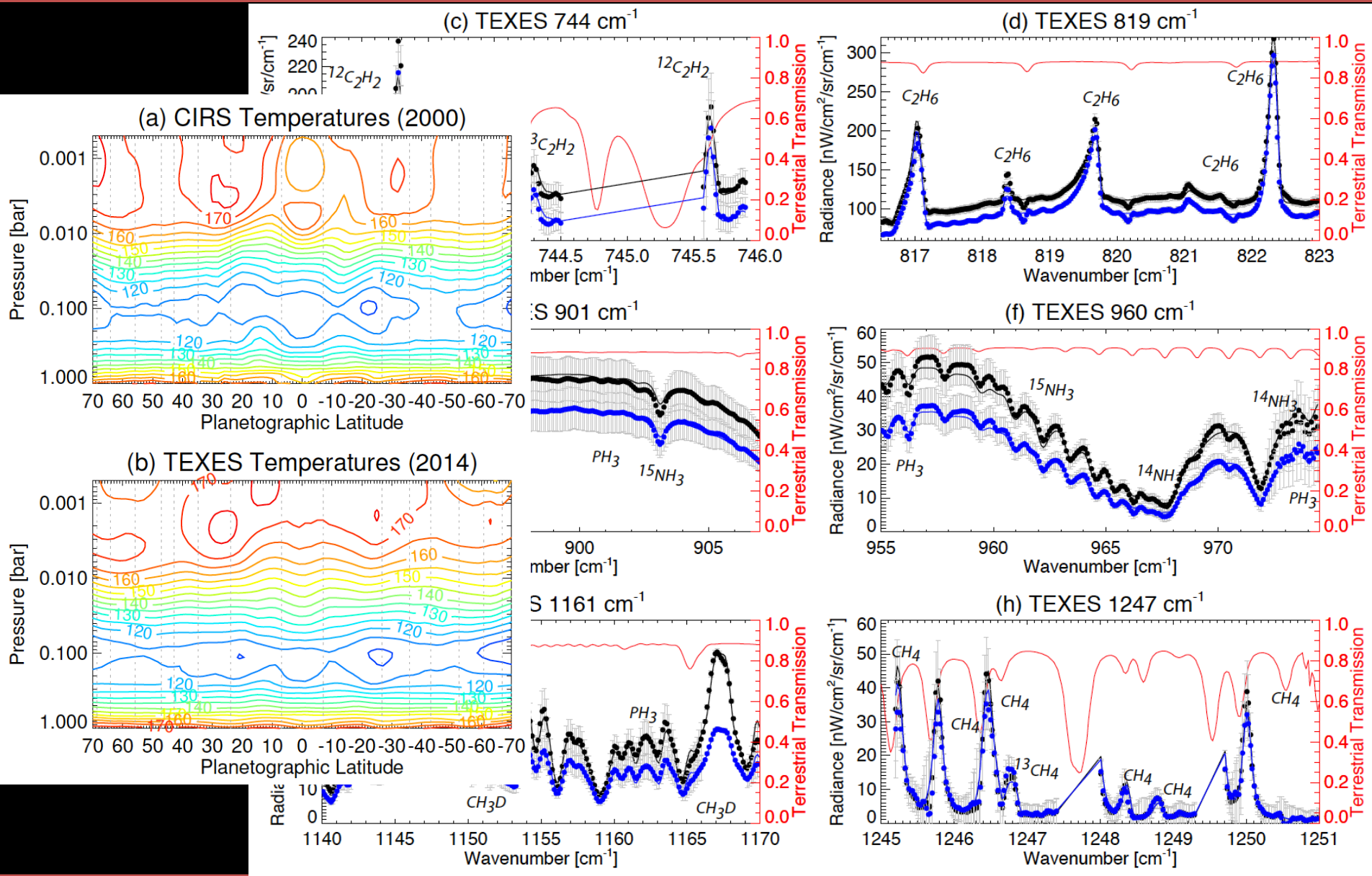
Obj1: Plug the IR Gap

- TEXES echelle spectro meter @IRTF. 5-25 µm
- R=2,000-80,000.



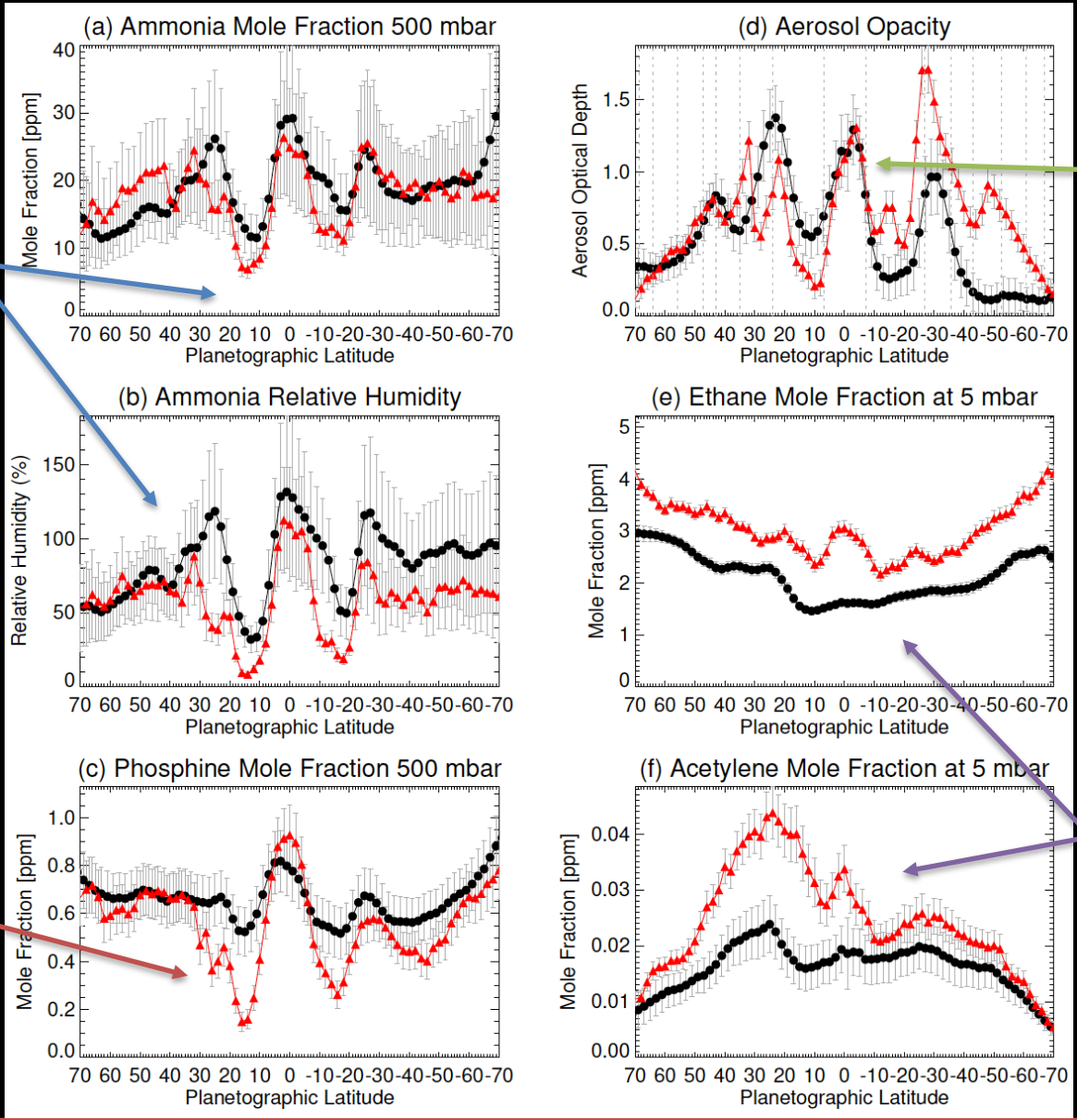


Obj1: Spectral Inversion & Temperature



Obj1: Gaseous Composition

Ammonia contrasts at 500 mbar set upper boundary for deeper microwave mapping by Juno/MWR



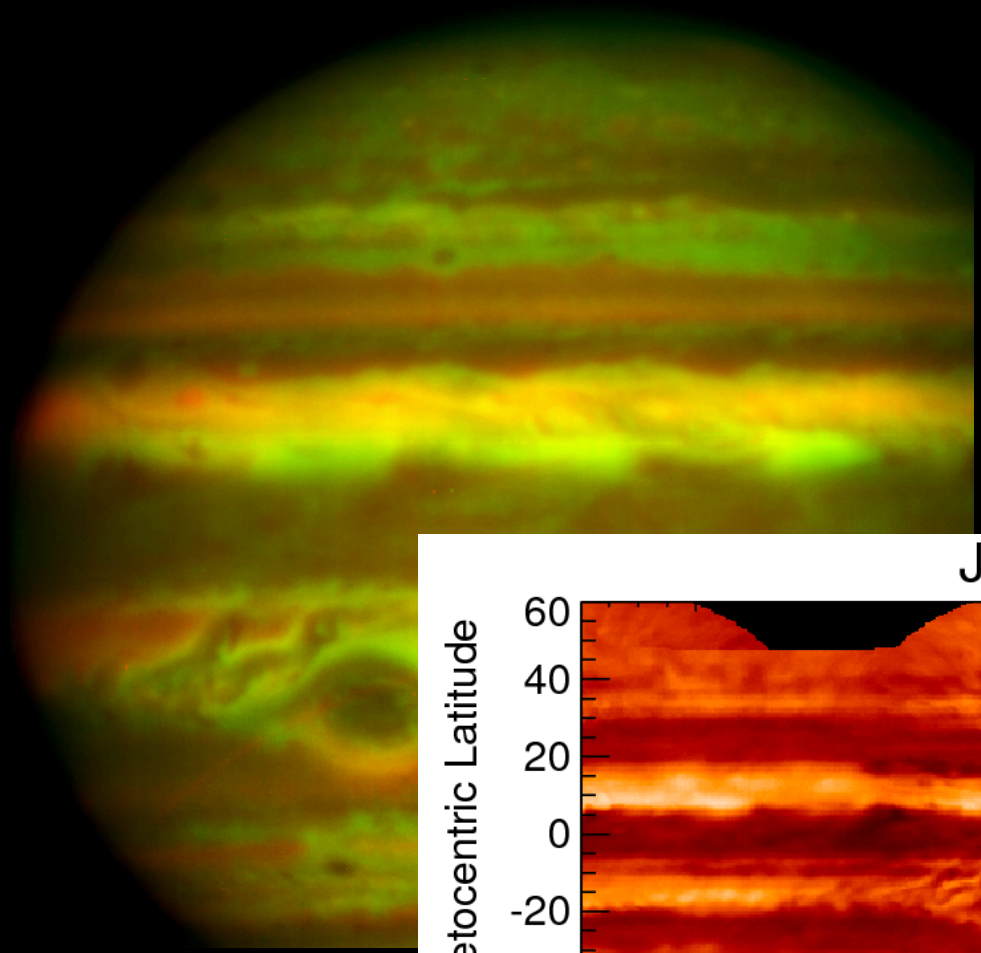
Infrared aerosol opacity contrasts with visible structure & colours from JunoCAM.

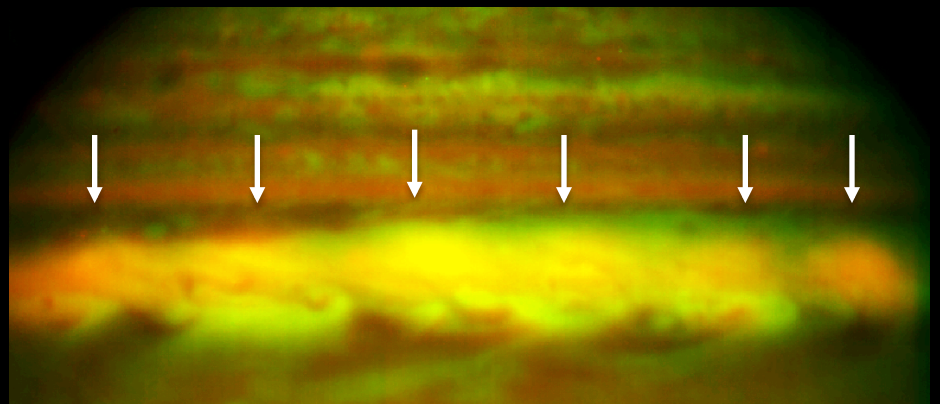
Phosphine traces tropospheric mixing, sets Juno/JIRAM spectra in global context.

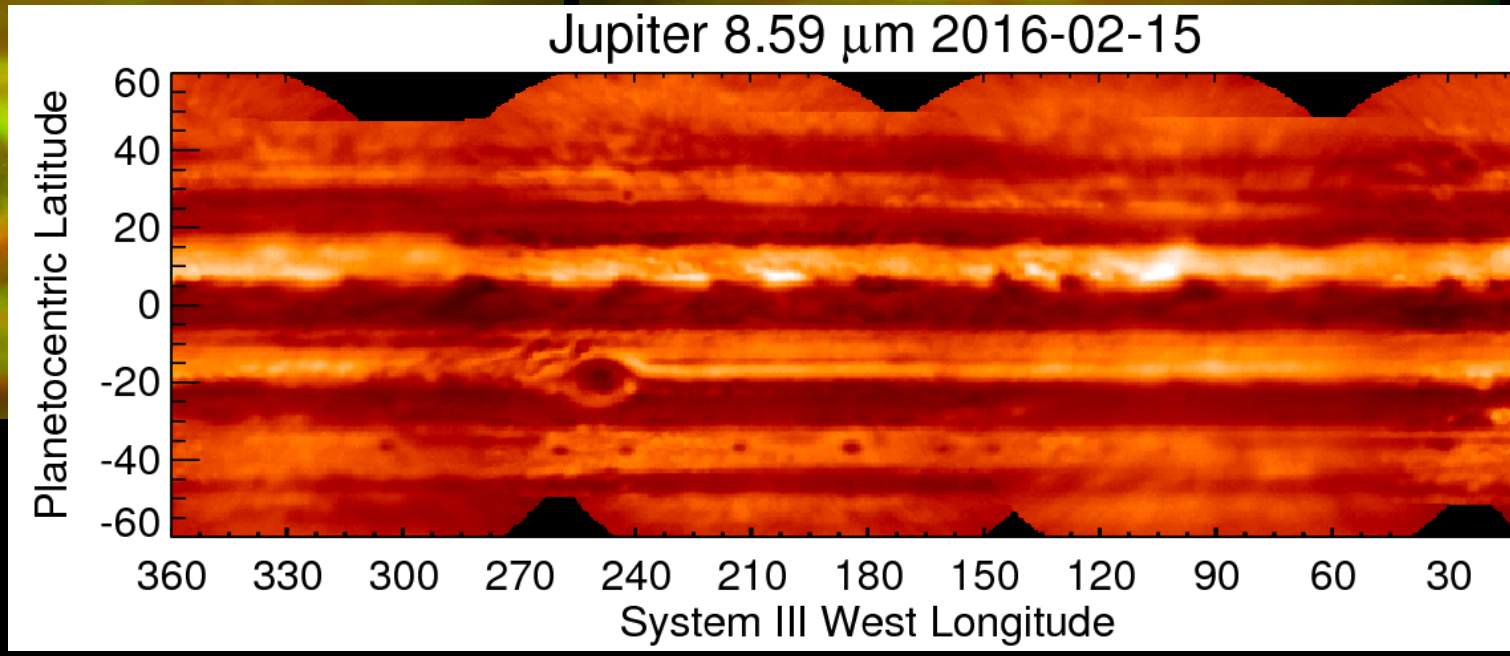
Ethane & acetylene trace stratospheric dynamics (waves, overturning), match to Juno/UVS hydrocarbon maps.

Obj2: Spatial Context for Juno

R=10.7 µm (temperatures and ammonia)
G=8.6 µm (cloud opacity)

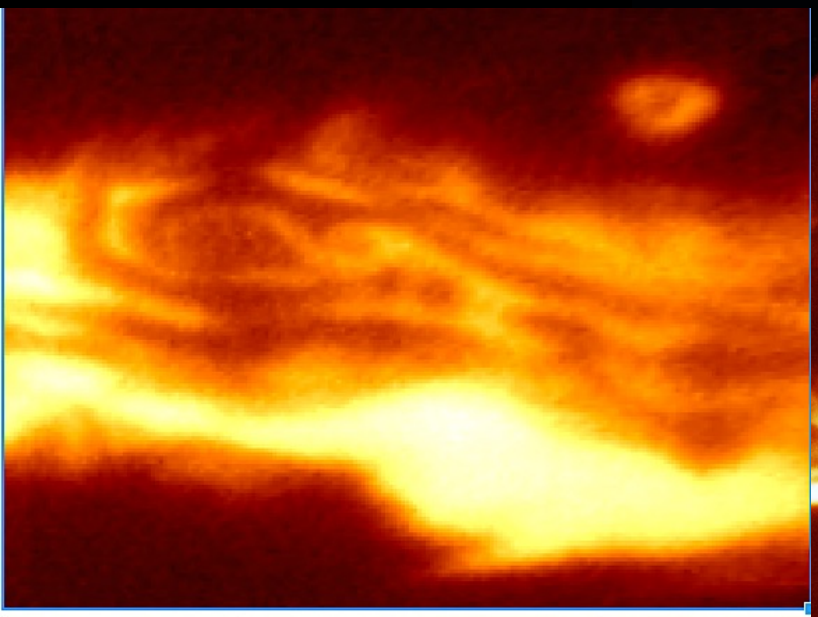


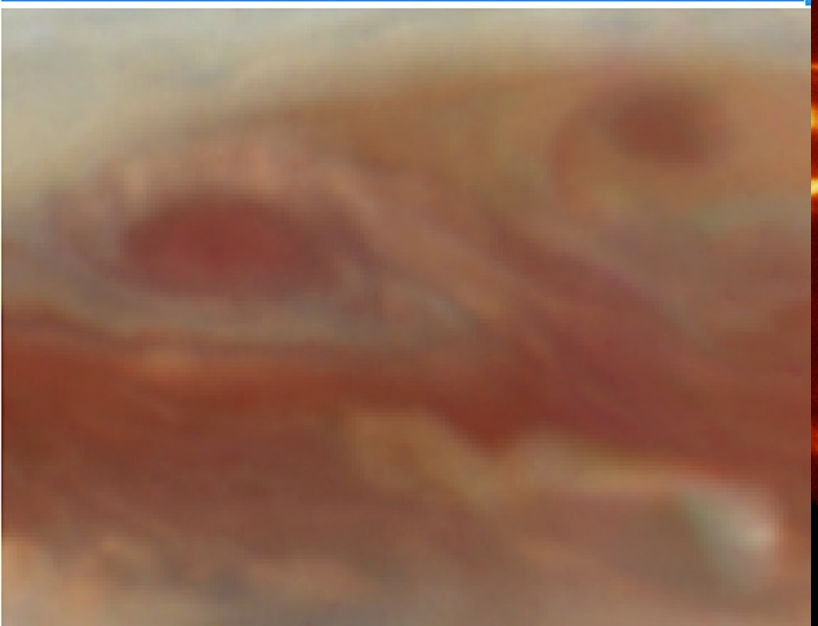


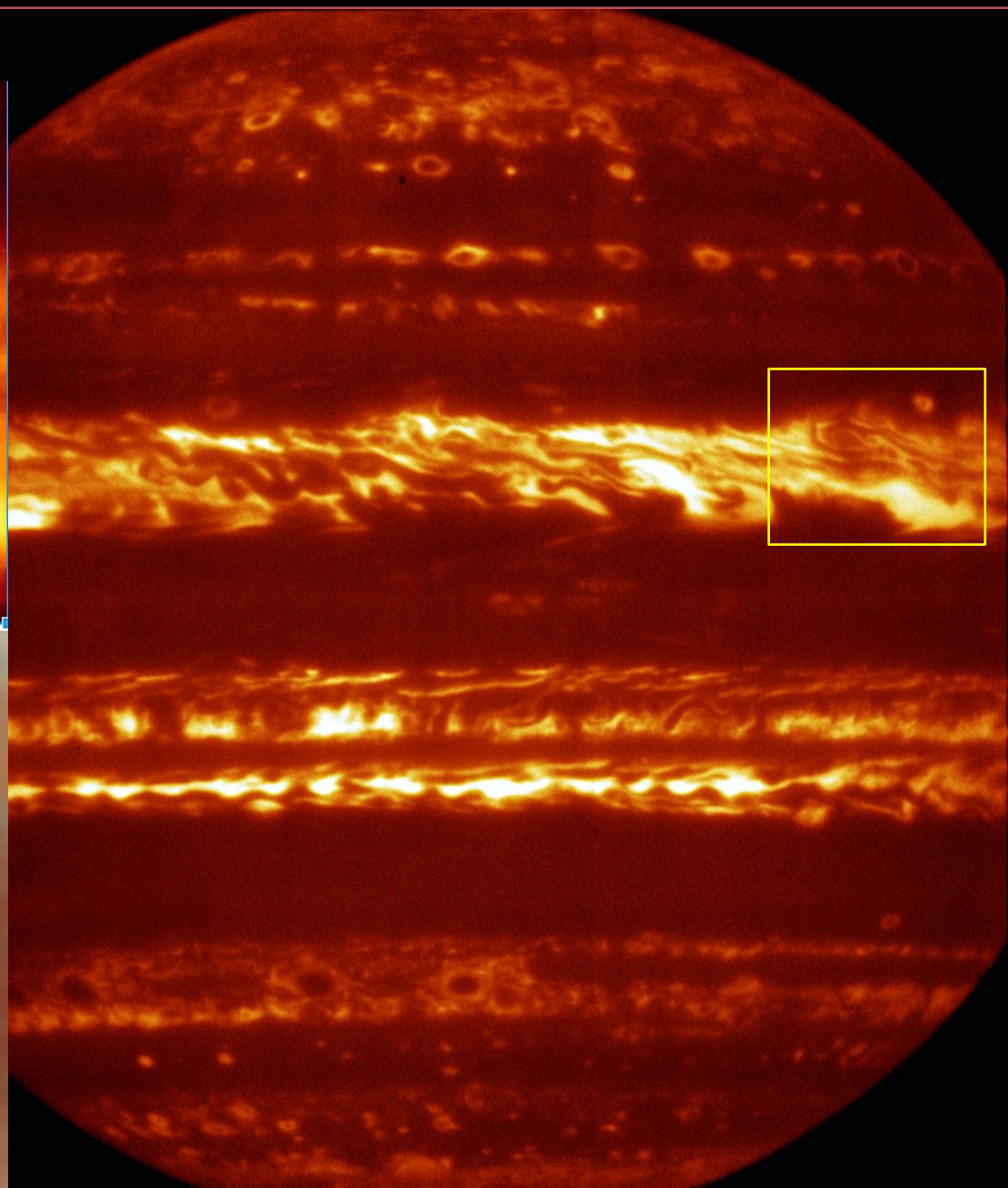


VLT/VISIR

Obj2: Lucky Imaging at 5 μm

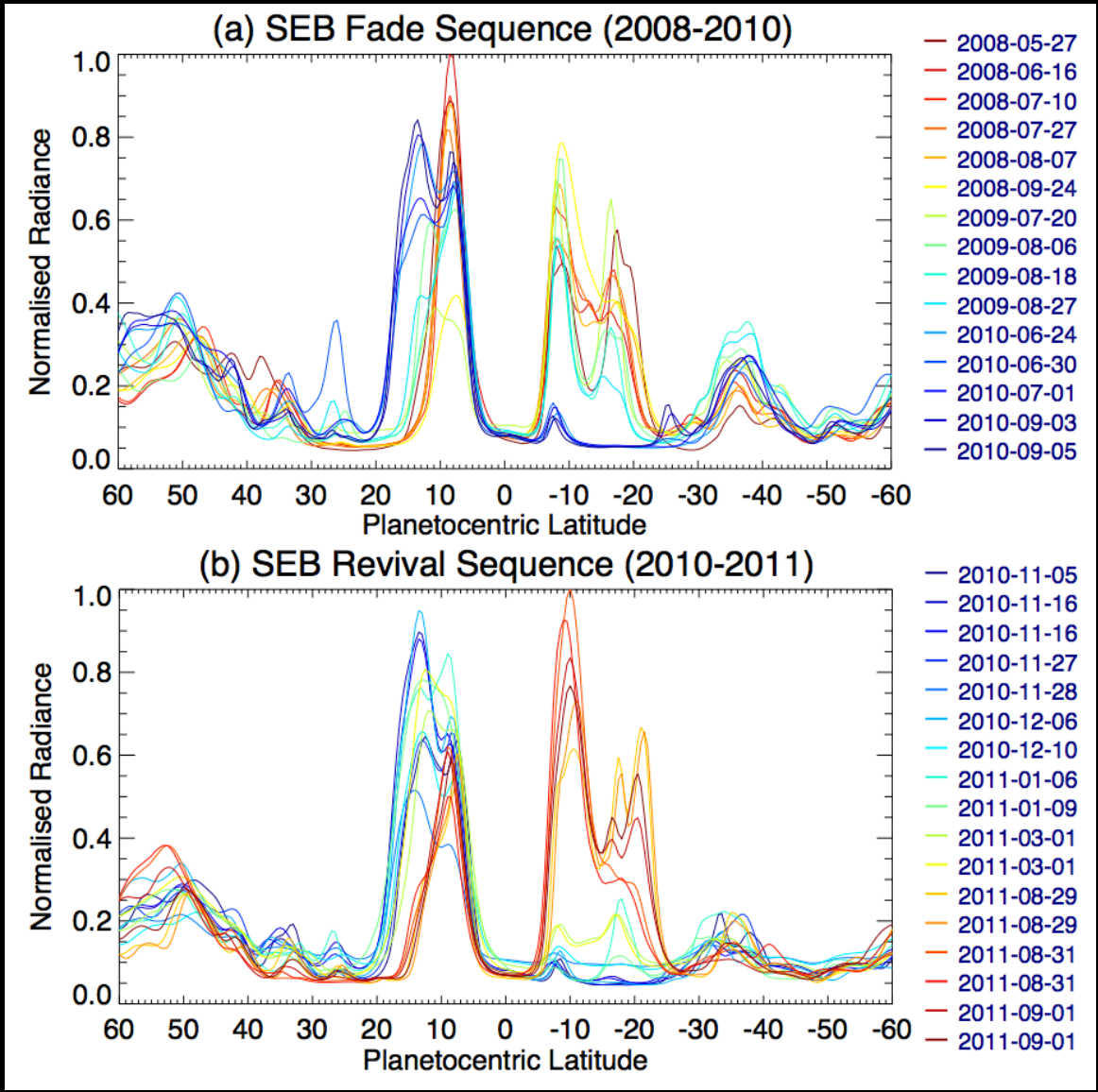






Obj3: Temporal Context - Upheavals

- Diagnosis of thermal conditions, circulation and chemistry during **belt/zone upheavals**:
  - SEB fade 2009-10 covered in 2011 paper (Fletcher et al., 2011)
  - Revival 2010-11 paper being drafted (w/help from Glenn, John, Marco).



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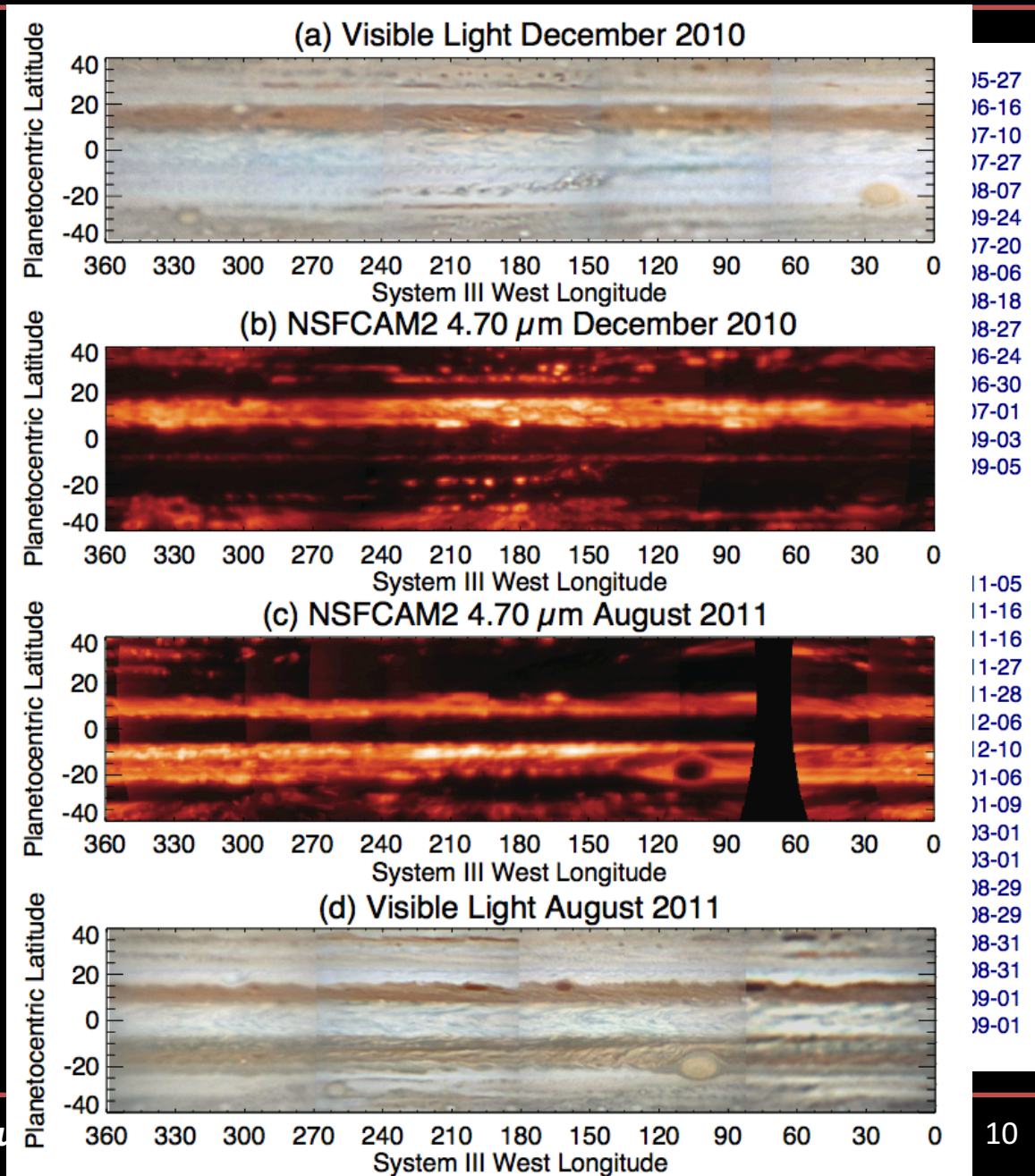
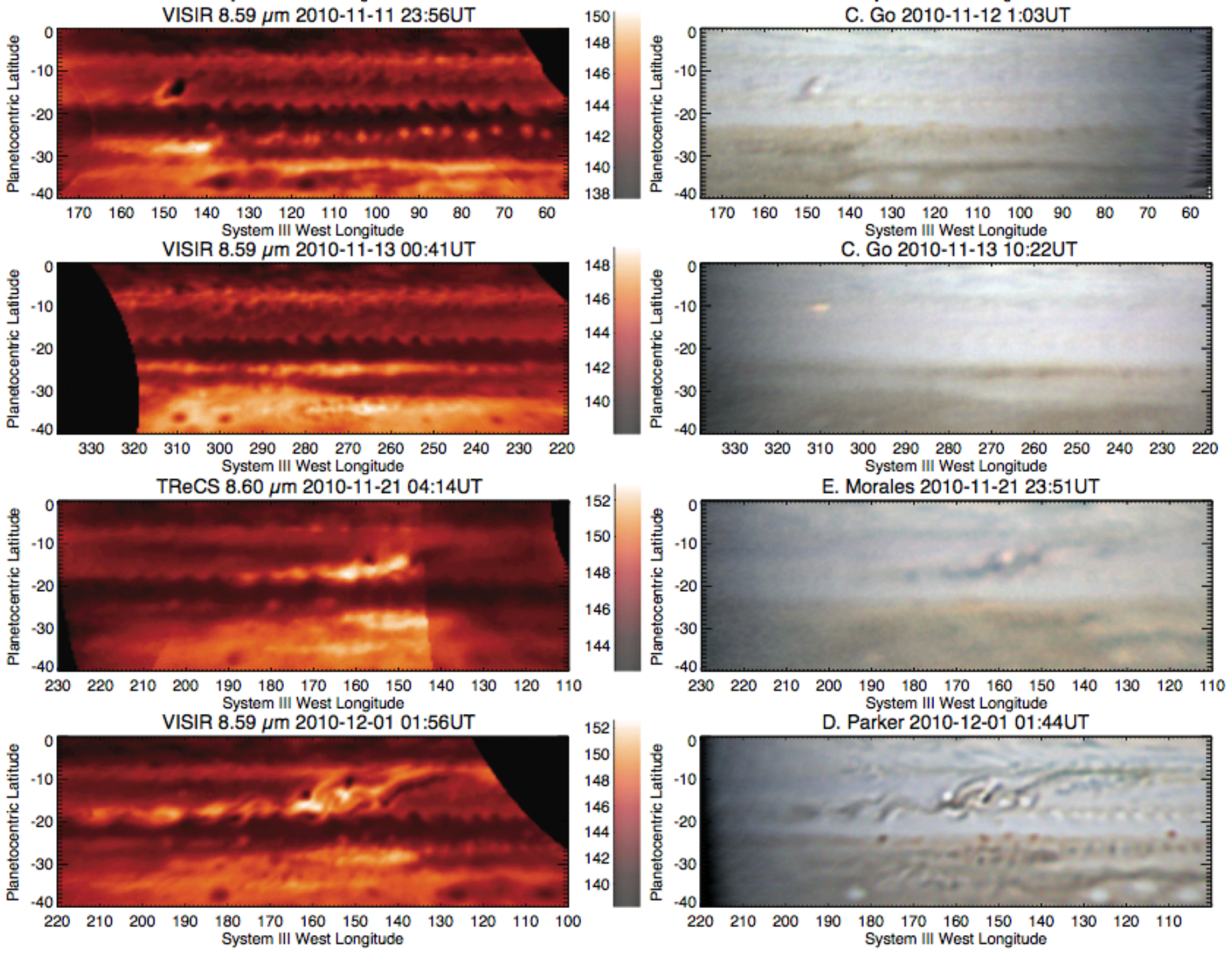
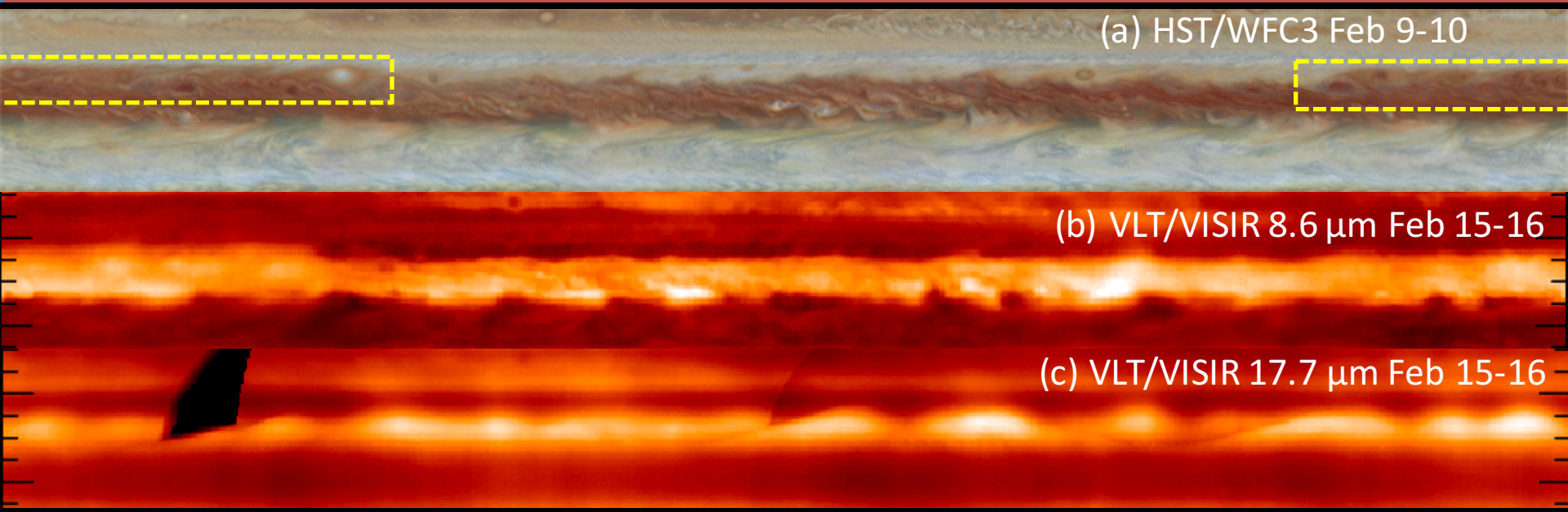



VISIR 8.59 μm 2010-11-11 23:56UT
C. Go 2010-11-12 1:03UT
VISIR 8.59 μm 2010-11-13 00:41UT
C. Go 2010-11-13 10:22UT
TReCS 8.60 μm 2010-11-21 04:14UT
E. Morales 2010-11-21 23:51UT
VISIR 8.59 μm 2010-12-01 01:56UT
D. Parker 2010-12-01 01:44UT
Planetocentric Latitude
System III West Longitude

Obj3: Temporal Context – NEB Today



- **NEB expansion events** at 3-5 year intervals since 1988.
  - 1987/88, 1993, 1996, 2000, 2004, 2009, 2012
- Suggestions from 2014/15 apparition of `ragged' northern edge.
- 2015/16 apparition shows expansion limited by White Oval Z near 280W and pair of red ovals near 50W.
- Thermal-IR shows expansion = clearing of 'white' cloud opacity.
- Tropospheric thermal wave and CH4-band wave at 10-15N, just like in 2000.

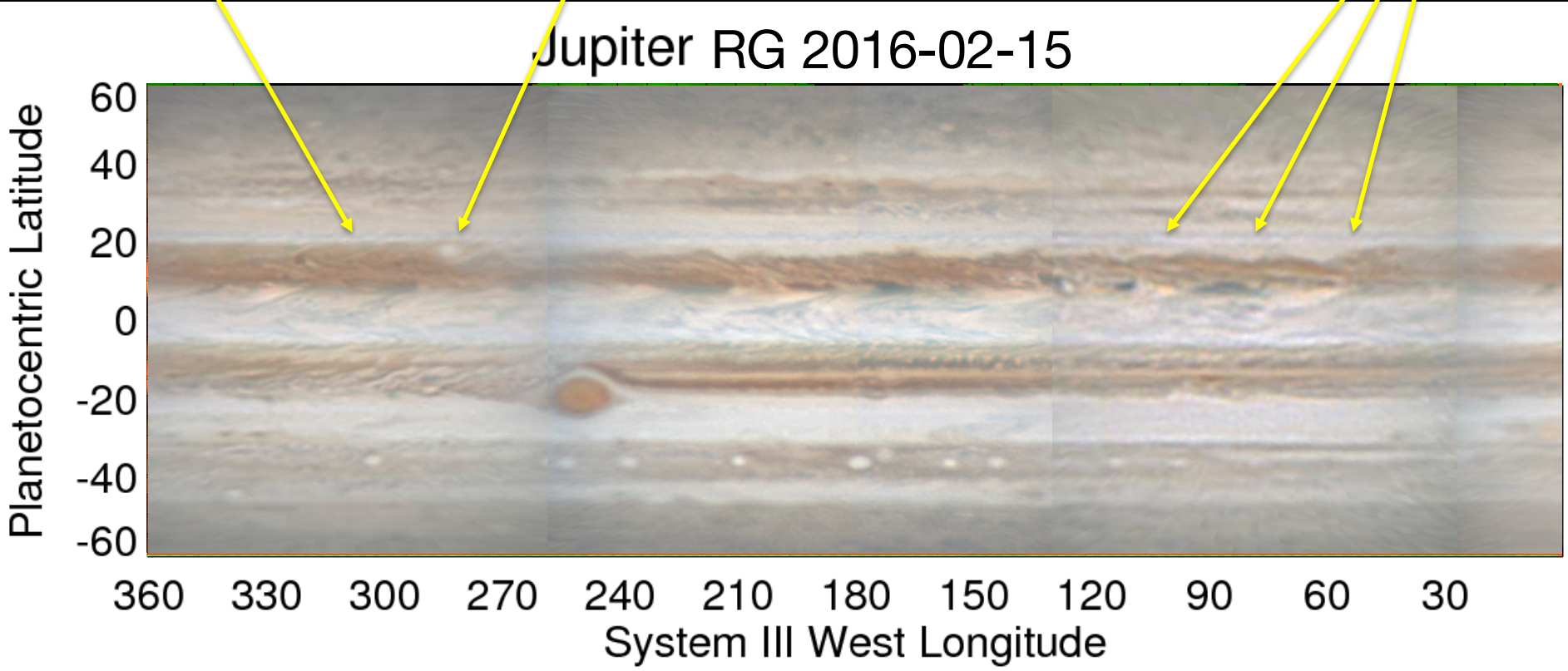
Aerosol clearing, but no T change?

Aerosol clearing with cool T shown by enhanced green

WSZ

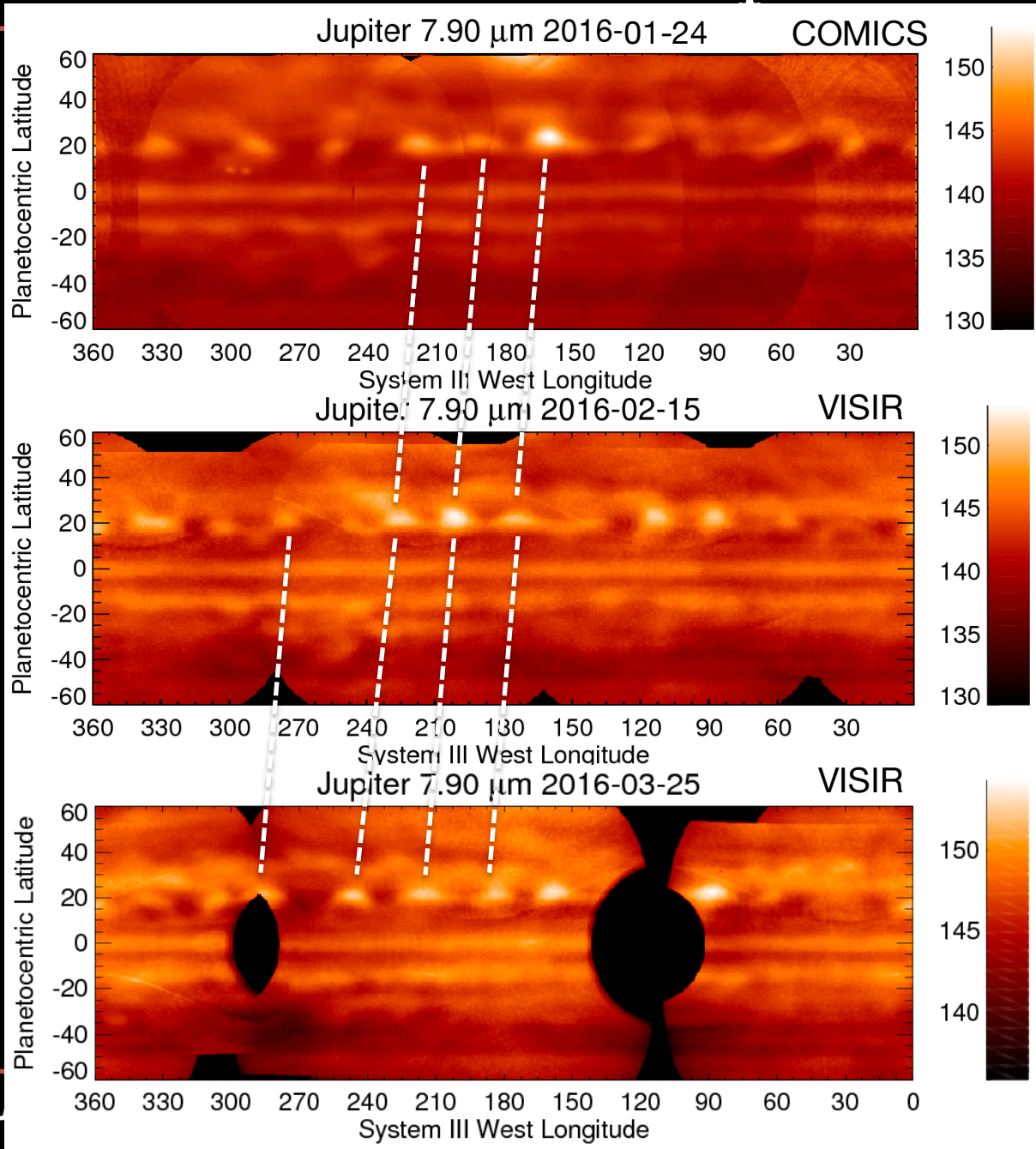
…aerosols filling in NTropZ? Different to an SEB revival

Wave pattern



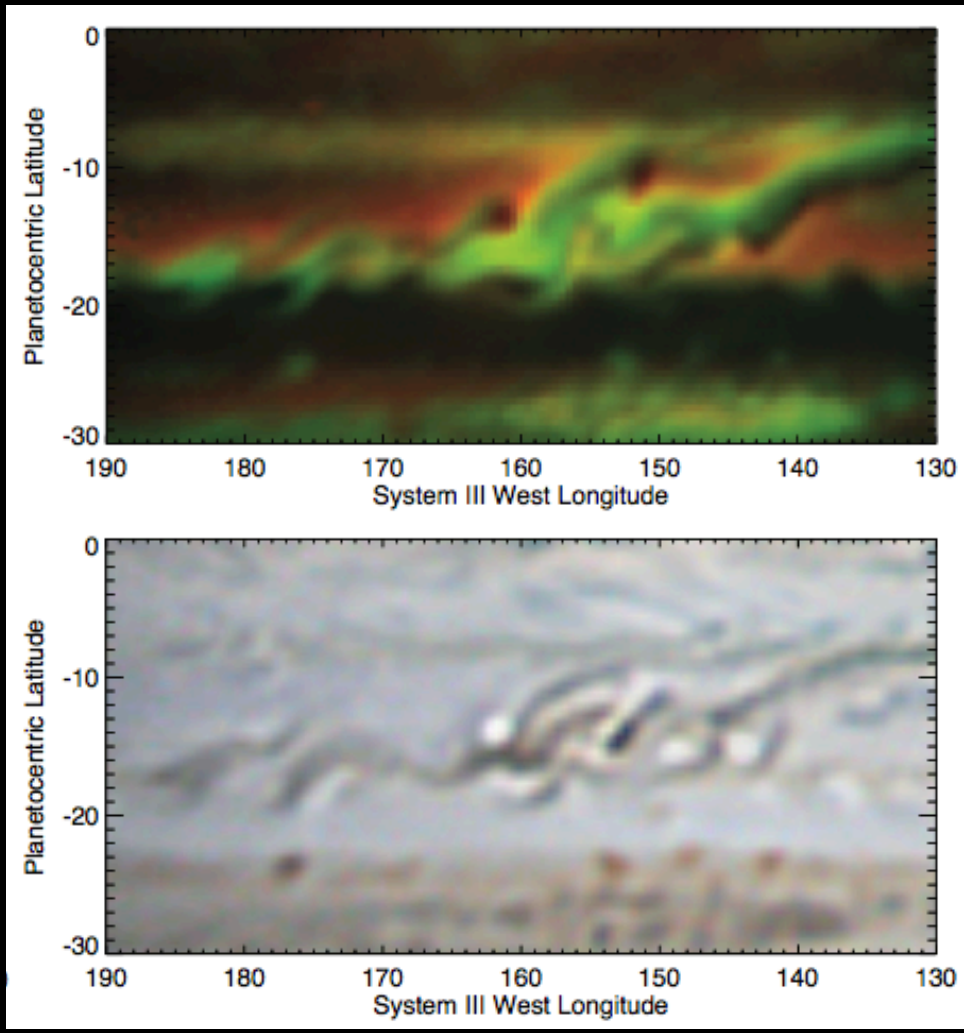
Obj3: Temporal Context - Stratosphere

- **Stratospheric wave activity** initiated by NEB expansion?
- Horizontal wavelength 30-40°, spans all longitudes.
- 22-38-day separation too large to determine phase speeds
  - Expect westward phase Rossby wave, ~12° over 40 days consistent with Cassini wave in 2000 (Li et al., 2006).



Future Plans: Thermal Imaging

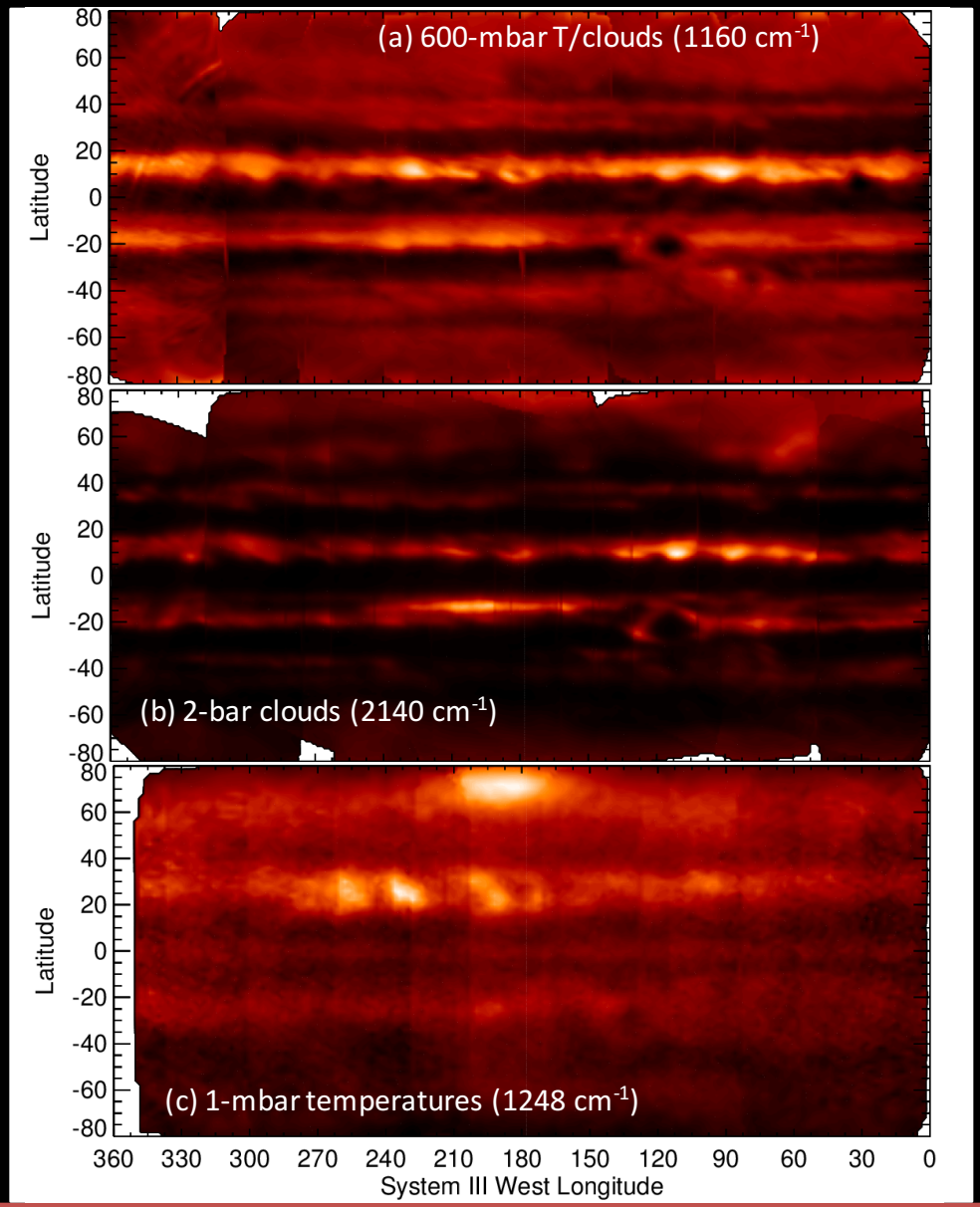
- **VLT/VISIR:** Global mapping in 10 filters (PI: Fletcher)
  - Service time executed in February and March 2016, time awarded for May and July 2016.
  - Time proposed for every perijove PJ6-PJ9, plus global map near 2017 opposition.
- **Subaru/COMICS:** Stratospheric imaging & slit spectroscopy (PI: Kasaba) in Jan'16.
  - Filtered imaging proposed for Jan'17 (PJ8).
- **UKIRT/MICHELLE:**
  - Moved from Gemini-N, proposed for 'some time in future' (PI: Orton)



SEB Revival from D. Parker and VLT/VISIR

Future Plans: Thermal Spectroscopy

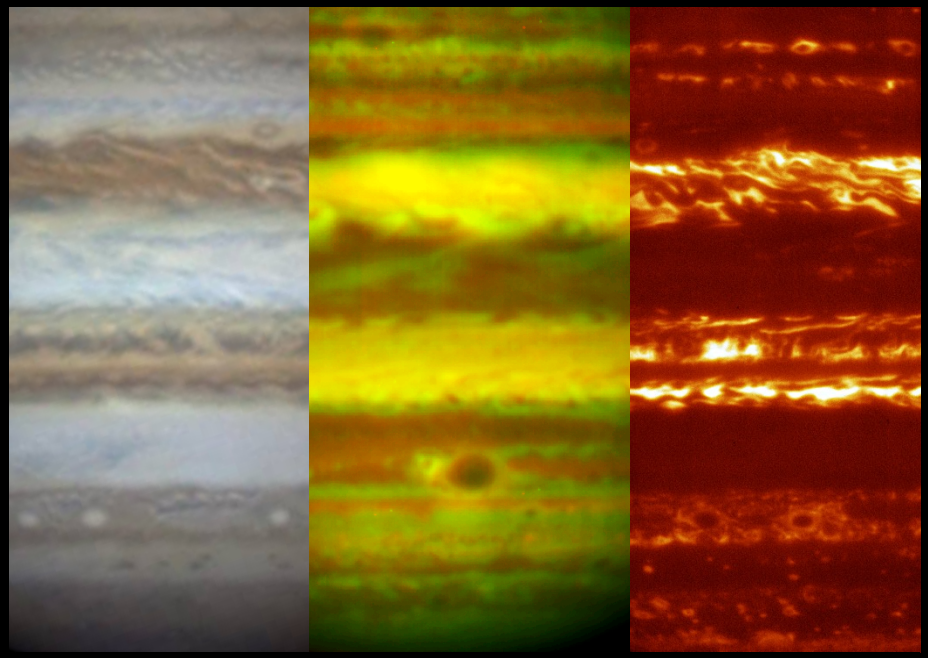
- **IRTF/TEXES:**
  - Scan mapping to generate spatial/spectral maps.
- Regular mapping in multiple 20-cm^{-1} wide channels to measure temperatures, clouds, composition.
  - Recent observations in Nov 2015, Jan & Apr 2016.
  - Proposed for more time in Dec 2016 and Jan 2017 (PIs: Greathouse, Fletcher, Sinclair, Encrenaz).



Summary & Future Plans

- **Mid-IR ground-based programme** to support Juno:
  - Connect temperature, composition & aerosols to Juno (i) deep sub-cloud dynamics and (ii) stratospheric composition.
- **Objectives:**
  1. Plug mid-infrared gap.
  2. Provide global spatial context.
  3. Temporal context.
- **Results:**
  - Inversion pipeline for analysis of TEXES spectroscopic maps revealed **temperature/composition contrasts to rival Cassini**.
  - Imaging campaigns have tracked **fade and revival** cycles for the NEB and SEB.

- **Future**: ~2 more global maps before Juno arrival; hemispheric imaging & spectra close to Juno perijoves 4-10 (hopefully).



Datasets and retrieved products will be made available to the community to aid interpretation and modelling of Juno data.