05.07 Deep Uranus cloud structure and Methane Mixing Ratio as Constrained by Keck AO Imaging Observations.

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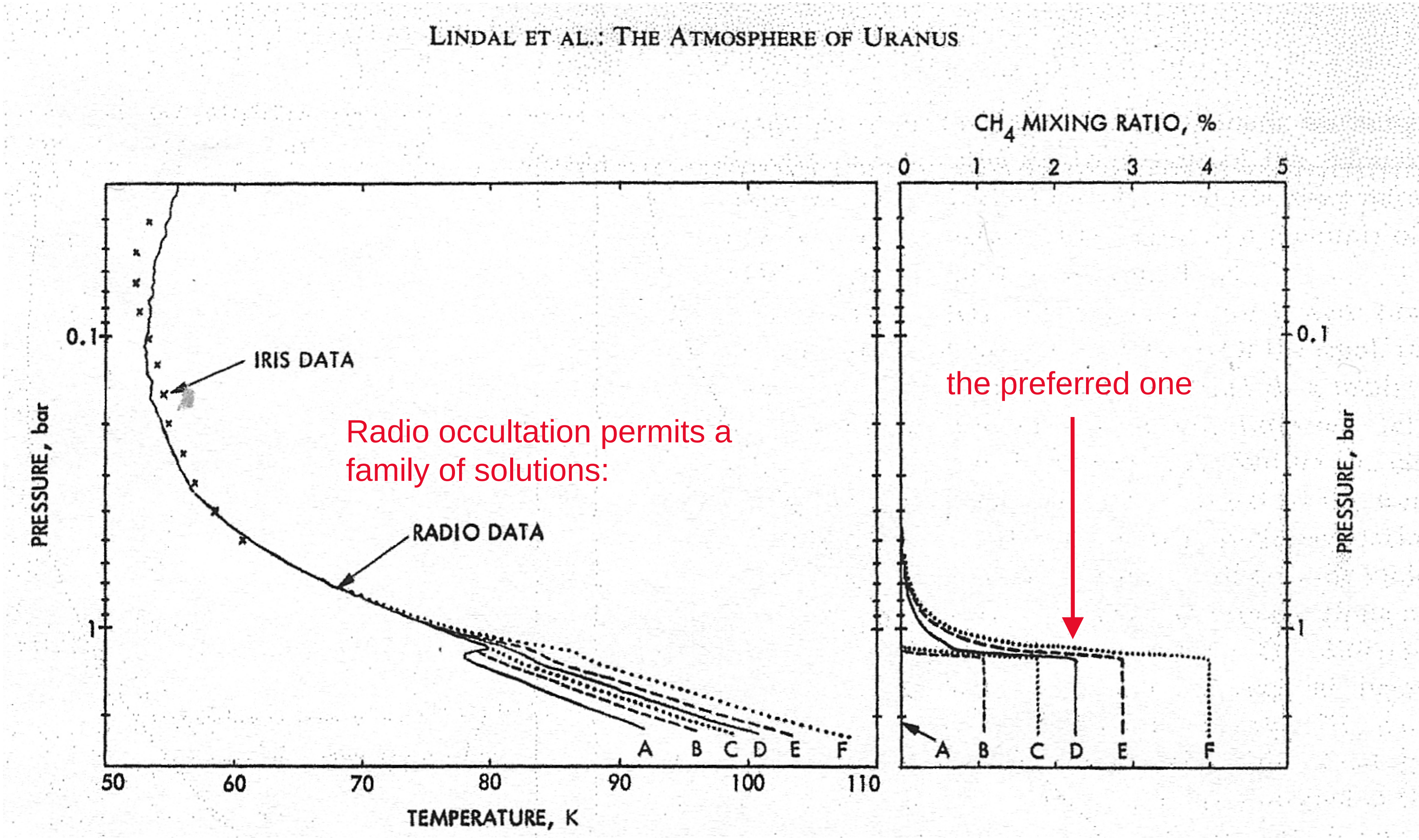
BACKGROUND

Voyager-2 radio occultation results for CH_4 and temperature (JGR 82, 1987):



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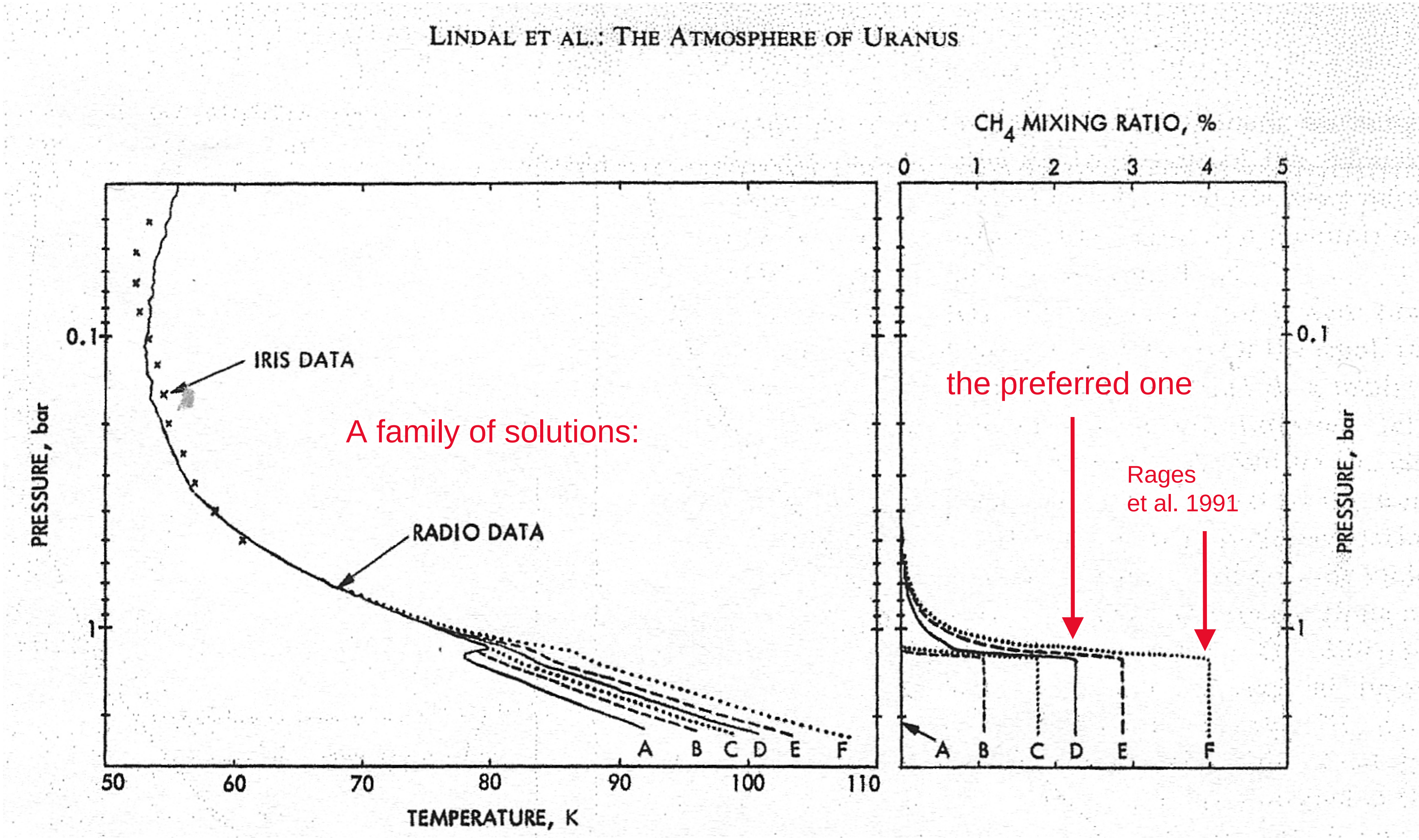

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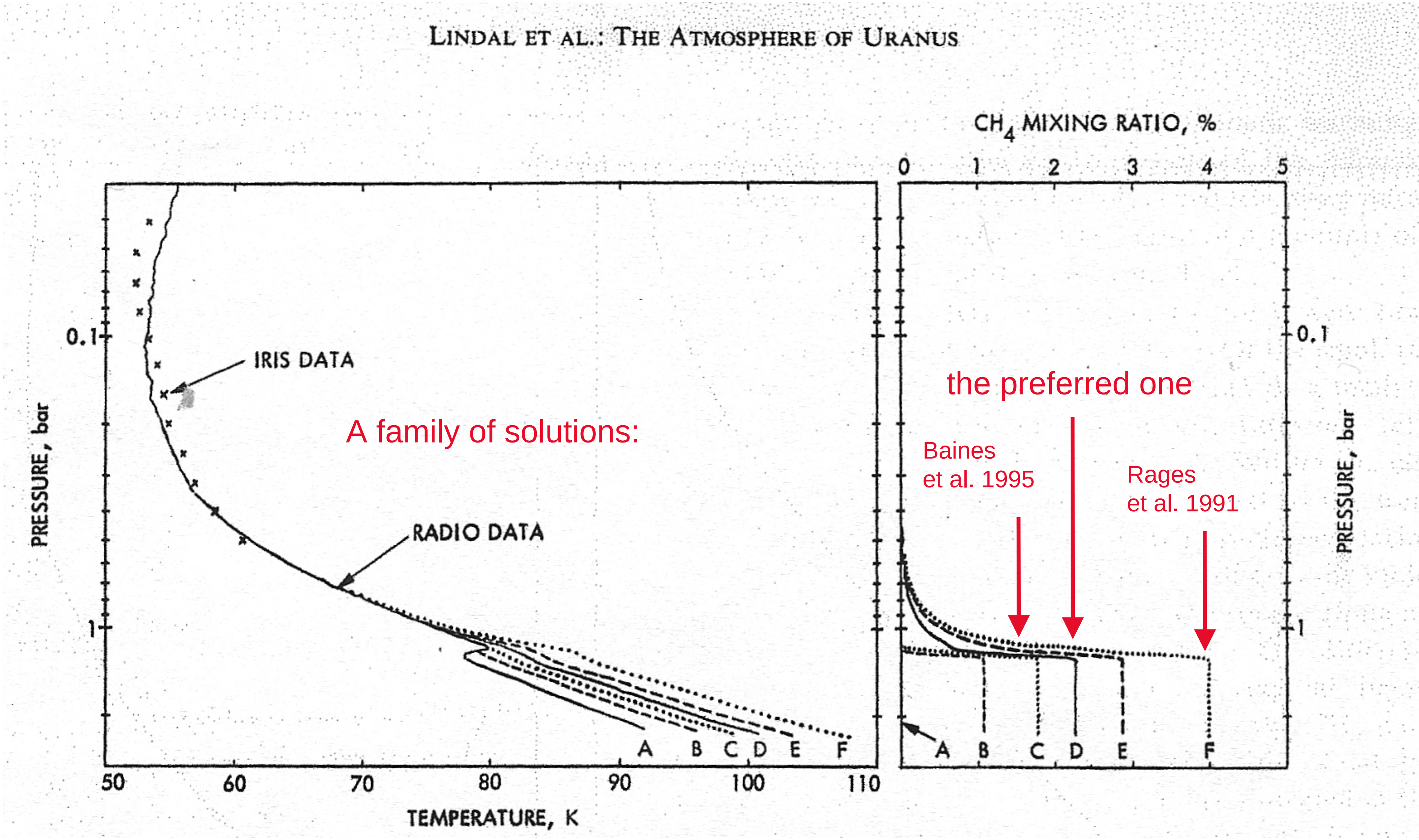


Ground-based spectroscopic analysis of Baines et al. (1995, Icarus 114).

Observations:

(1) 1981 full-disk, medium spectral res. obs. (Neff et al. 1984)

(2) 1980 full-disk high spectral res. obs. of 681.89-nm CH_4 line (Baines et al. 1983).

(3) 1981 full-disk, high spectral res. obs. of H_2 4-0 S(1) and S(0) lines (Trauger and Bergstralh 1981).

Assumptions:

(1) Upper cloud controlled by CH_4 condensation.

(2) Lower cloud is semi-infinite.

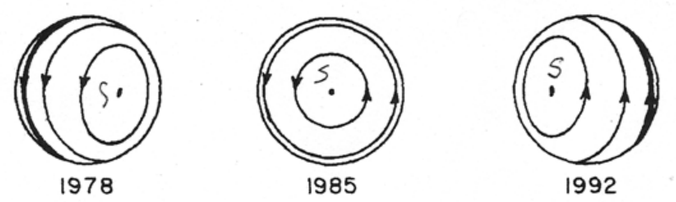
(3) All clouds have Rages et al. (1991) phase function.

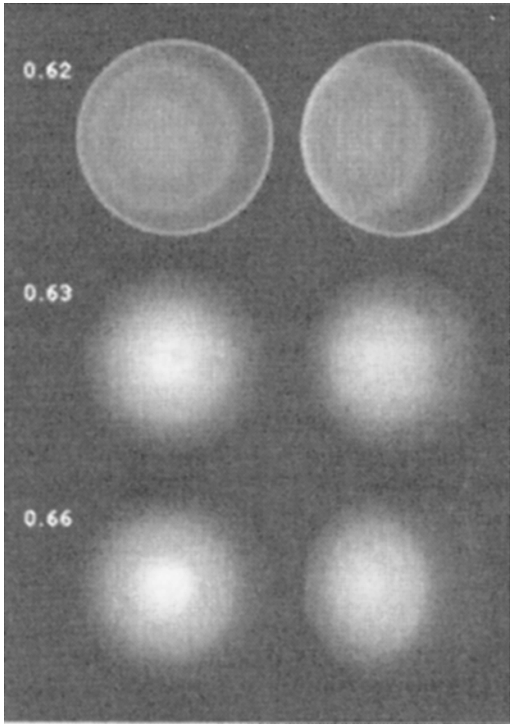
(4) Lindal et al. (1987) model D thermal profile.

(5) Methane saturated above cloud top.

Results:

CH_4 vmr = 1.1-2.3 %, lower cloud P = 2.9-4.2 bars





Karkoschka (2001, Icarus) albedo model.

Why new near-IR observations might improve constraints on deep clouds and the CH_4 mixing ratio:

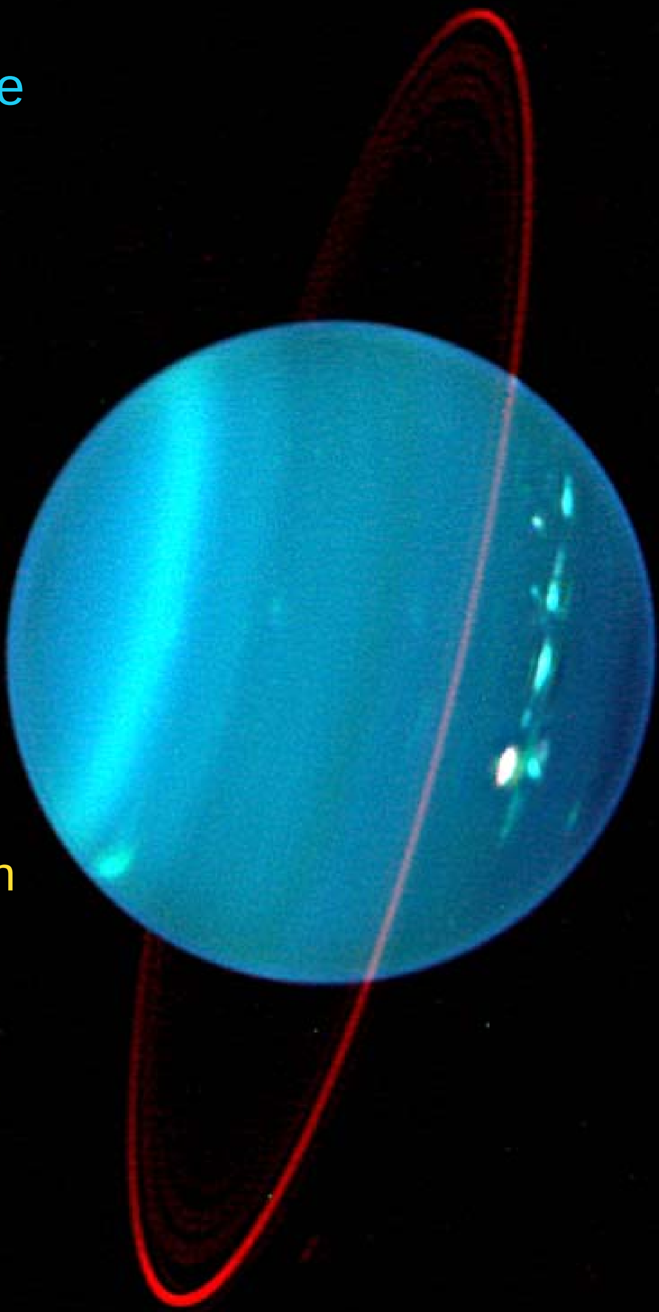
Rayleigh optical depth is reduced relative to aerosol optical depth, providing increased visibility and contrast of aerosol effects.

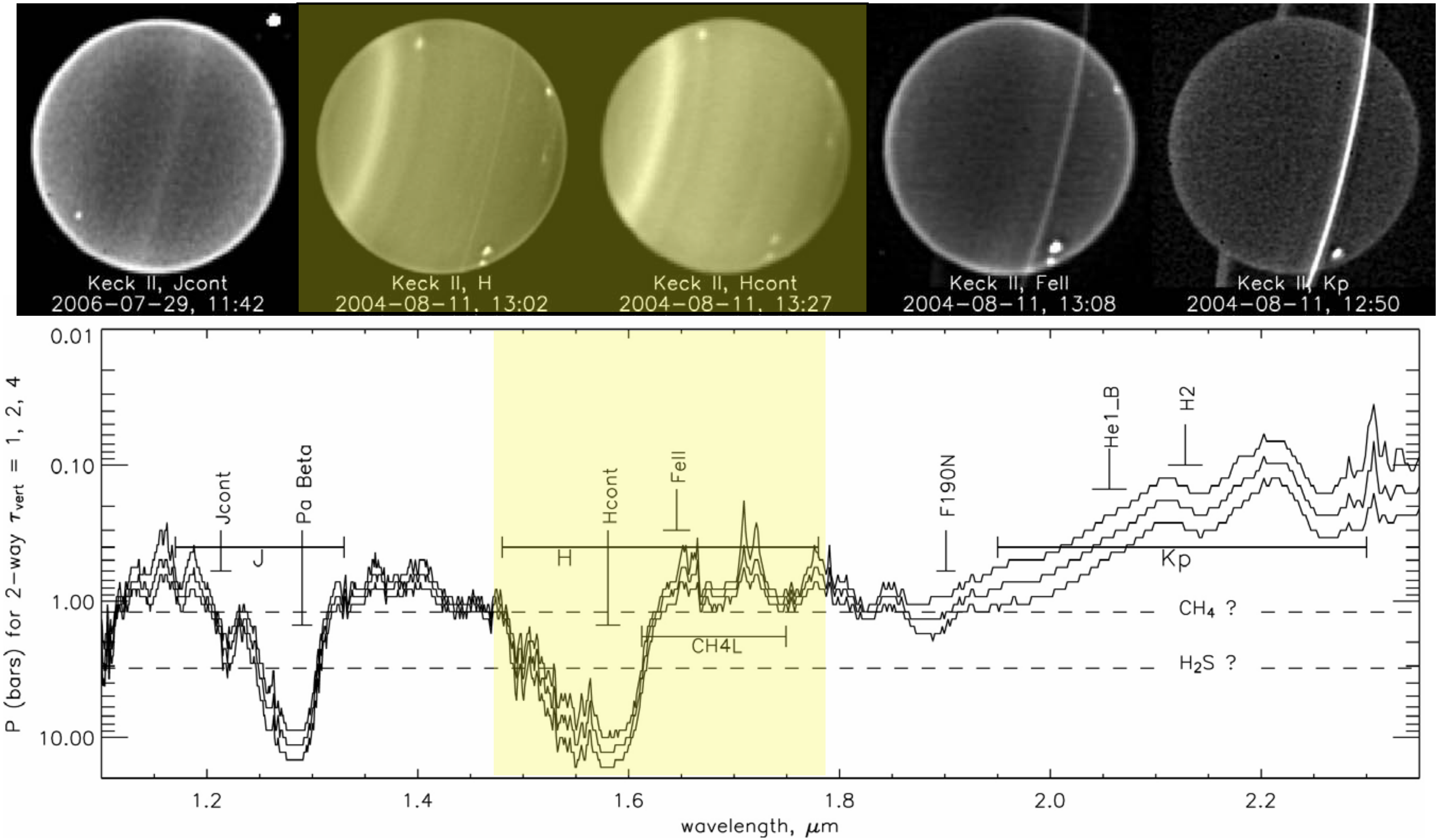
Reduced contribution of small-particle upper hazes and upper cloud in the window channels.

Good views of low latitudes (with less upper cloud obscuration) as Uranus approaches 2007 equinox.

Deconvolved Keck Adaptive Optics imagery can provide accurate center-to-limb profiles.

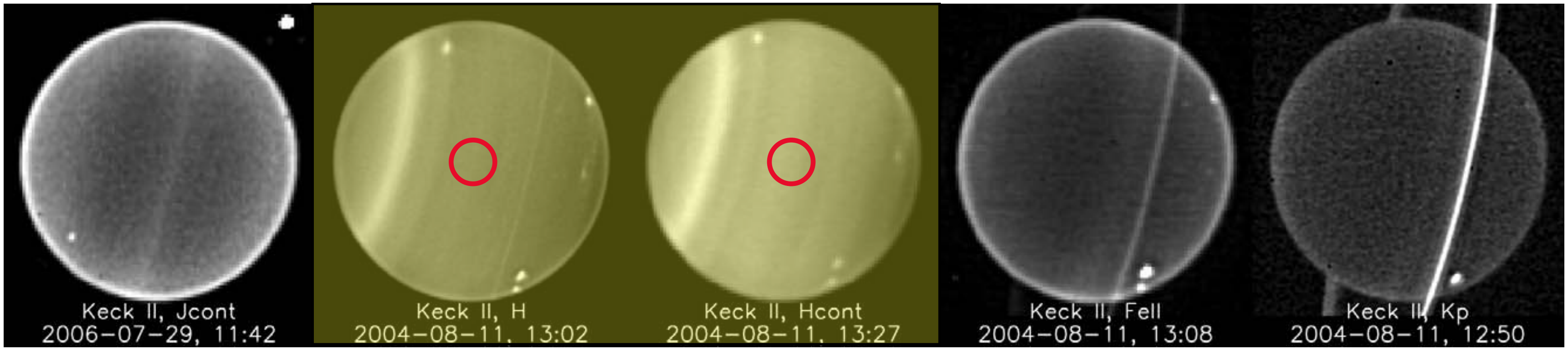
Improved models of CH_4 absorption can better account for low temperatures and weak absorptions (Irwin et al. 2006, Sromovsky et al. 2006).





We chose H and Hcont filters to constrain deep CH_4 and cloud properties because…:

They have nearly the same effective wavelength.
They have different relative sensitivities to CH_4 and H_2 CIA.
They can sense to near the 10-bar level in a clear atmosphere.

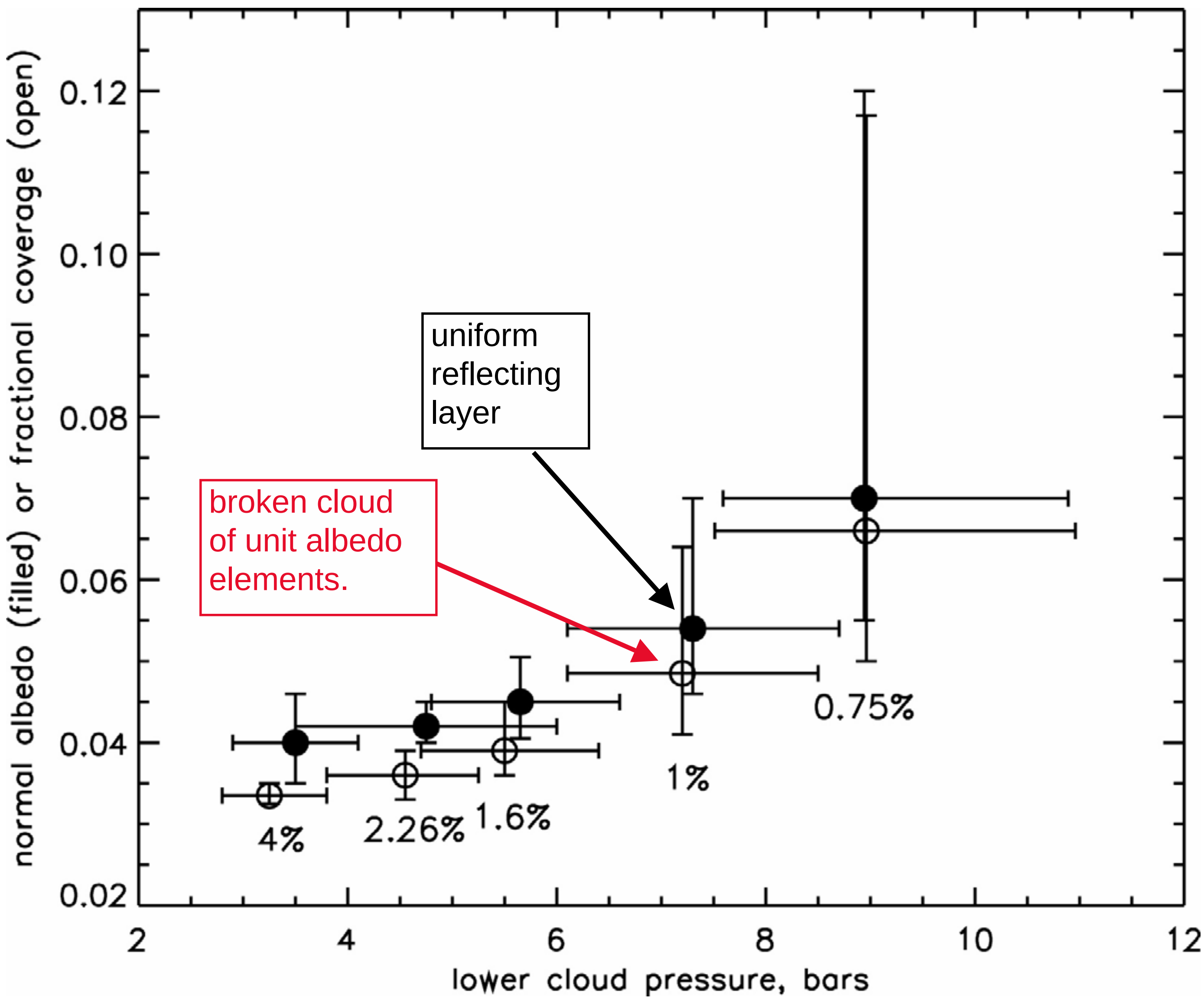


Two equations (for central-disk H and Hcont I/F values)

solved for two unknowns (lower cloud p and reflectivity)

for 5 different CH_4 mixing ratios (0.75% - 4 %)

for two cloud types (broken bright elements, uniform dark opaque)

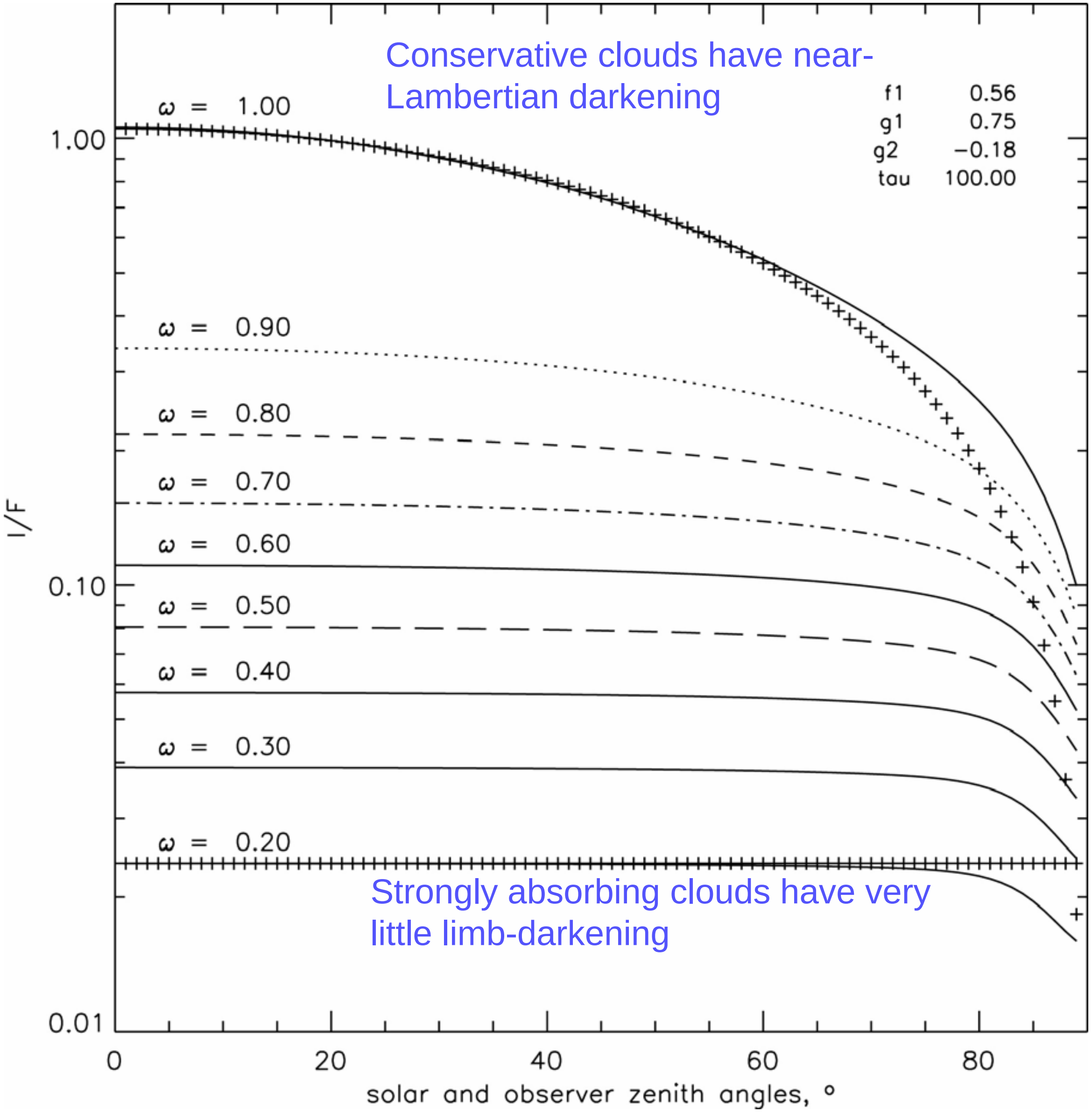


Deeper, more reflective cloud required at lower CH_4 mixing ratios.

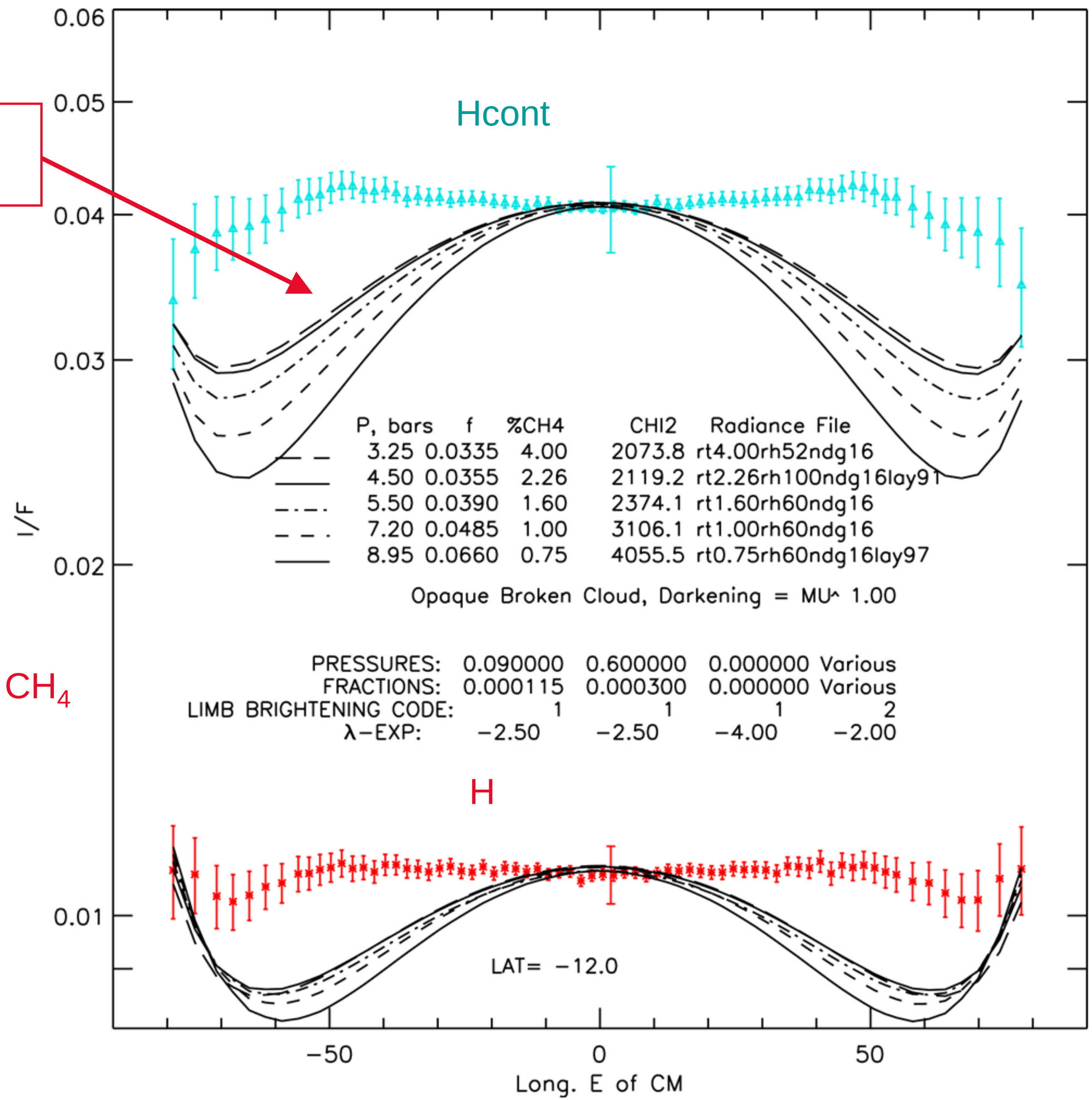
We now have one constraint relating cloud properties to the CH_4 mixing ratio.

Next we use center-to-limb behavior to obtain a second independent constraint on CH_4:

Center-to-limb response characteristics of opaque clouds (=100)

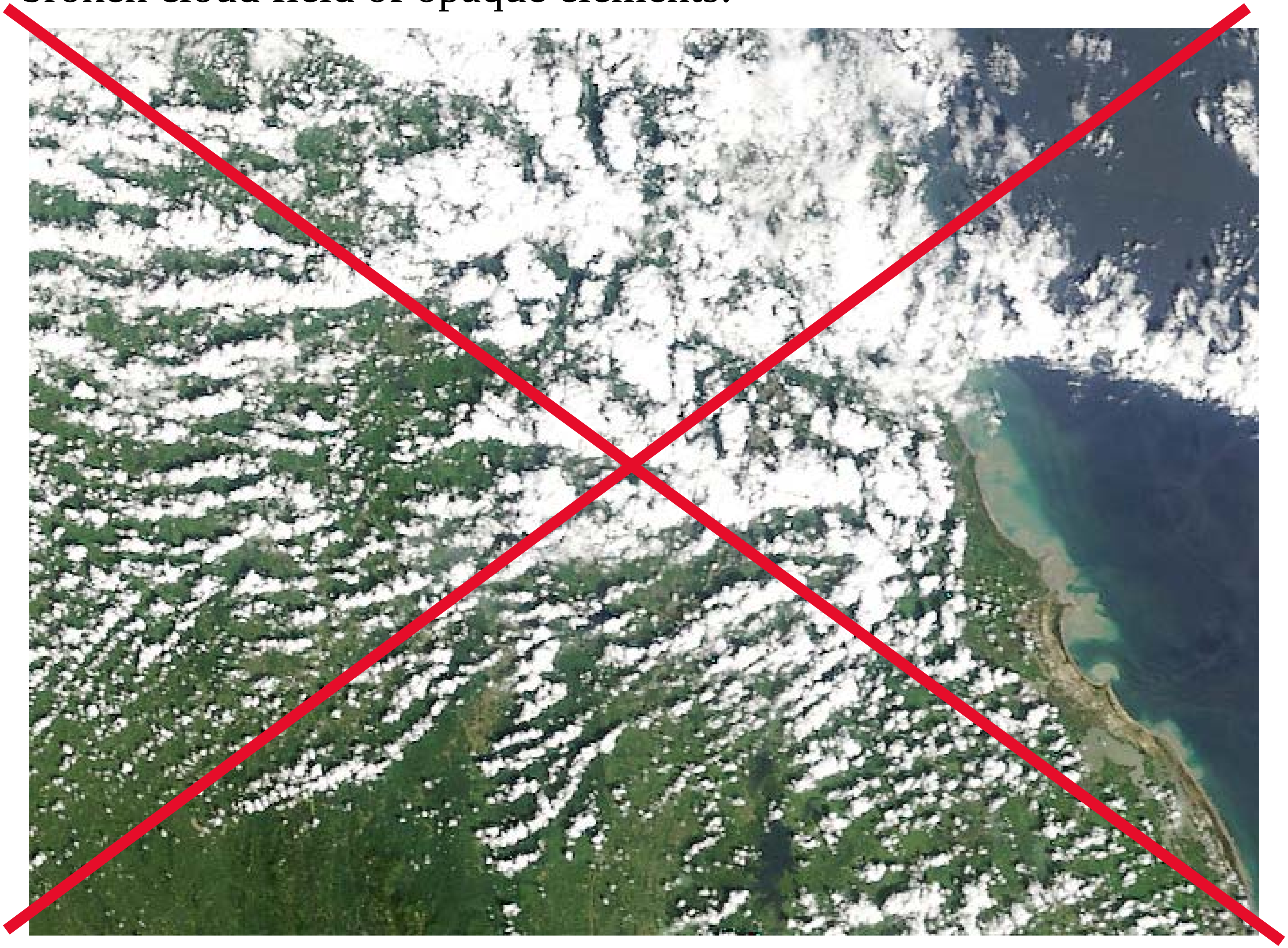


Broken clouds of bright opaque elements…



… cannot match observations for any CH_4 mixing ratio.

broken cloud field of opaque elements:

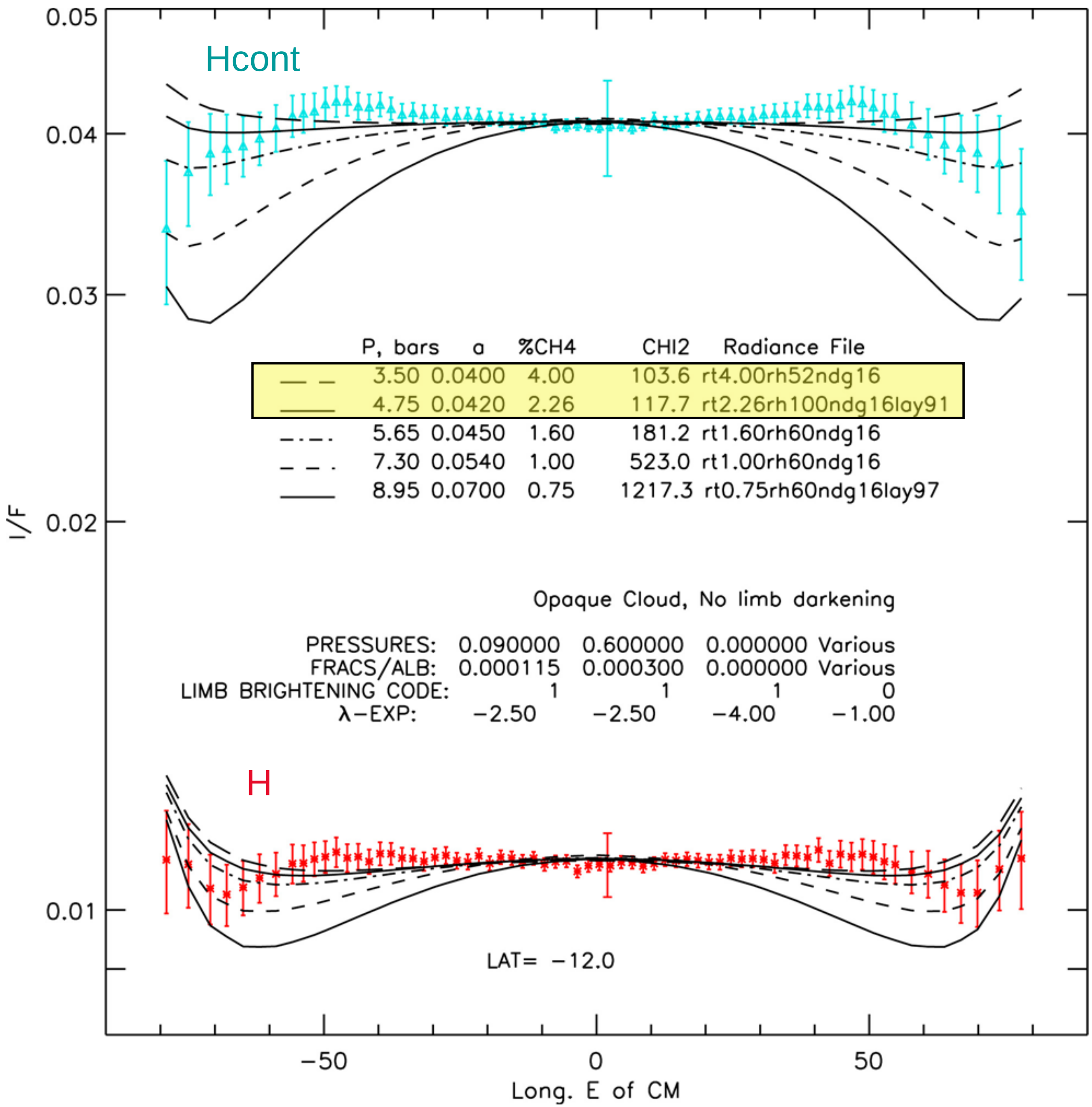


A uniform dark reflecting layer…

fits observations better with 2-4% CH_4,

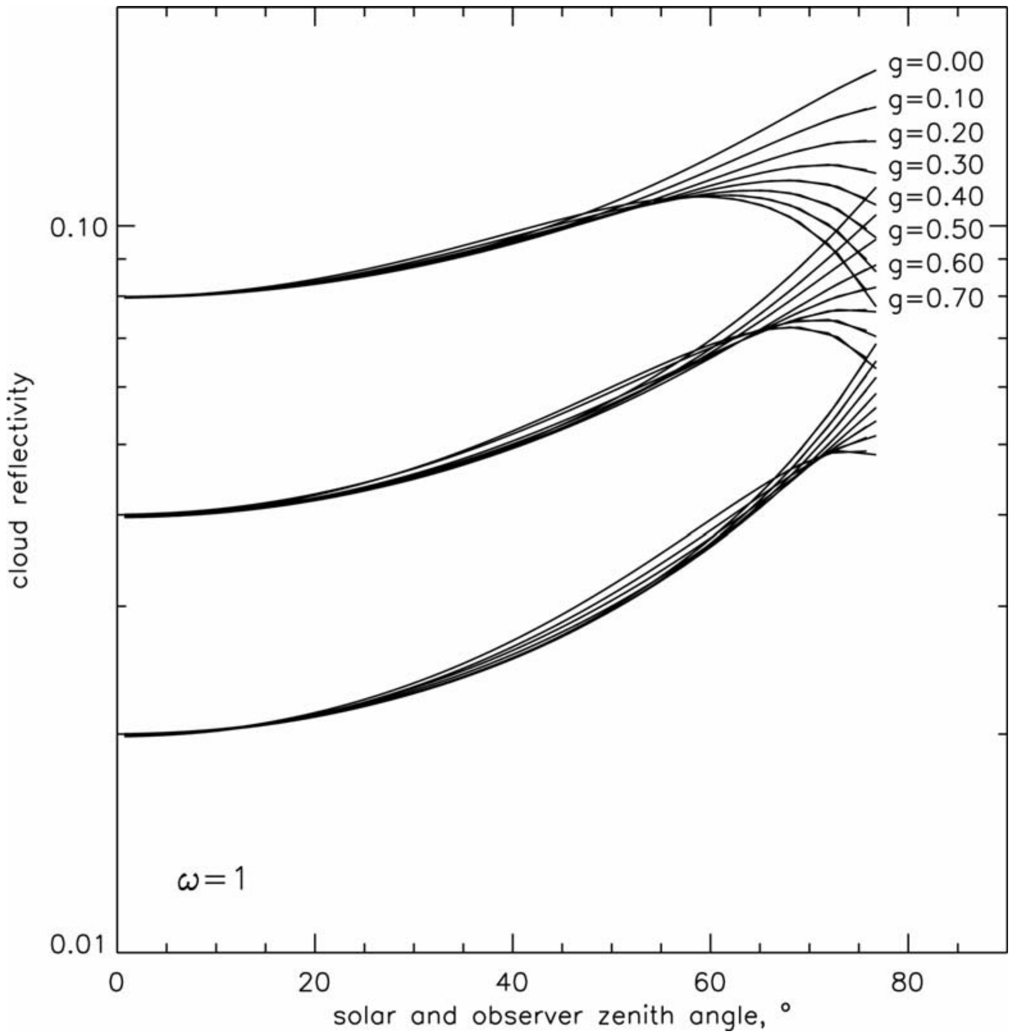
but misses key features of center-to-limb profile.

The lower cloud needs to have some limb brightening!



Optically thin layers are needed to produce limb brightening.

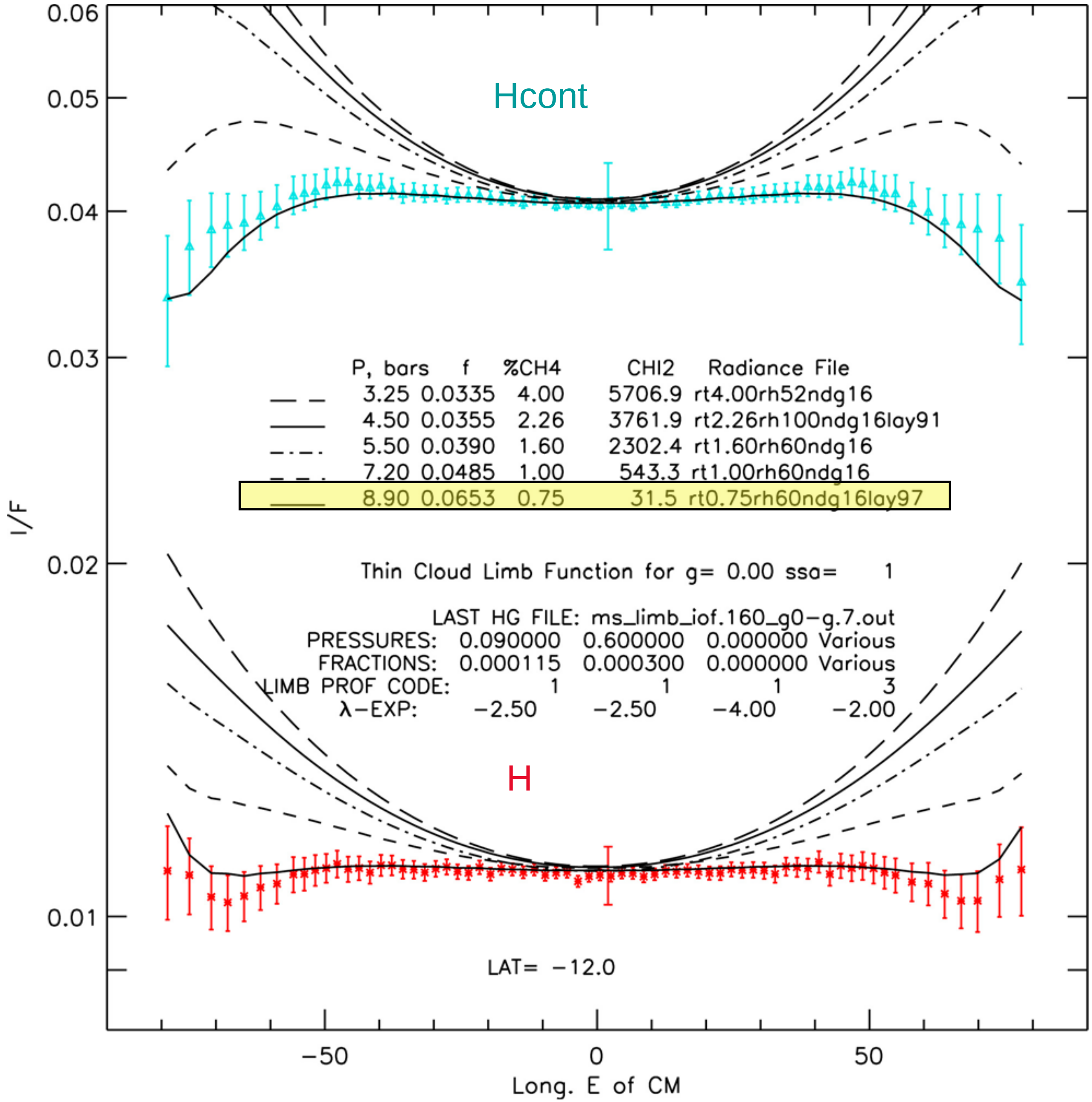
Conservative Henyey-Greenstein particles provide both needed reflectivity and limb-brightening that varies with asymmetry parameter (g).



A thin conservative layer fits observations well (^{2} = 31.5), but only with a low methane mixing ratio (~0.75%), and low asymmetry parameter (g~0-0.2).

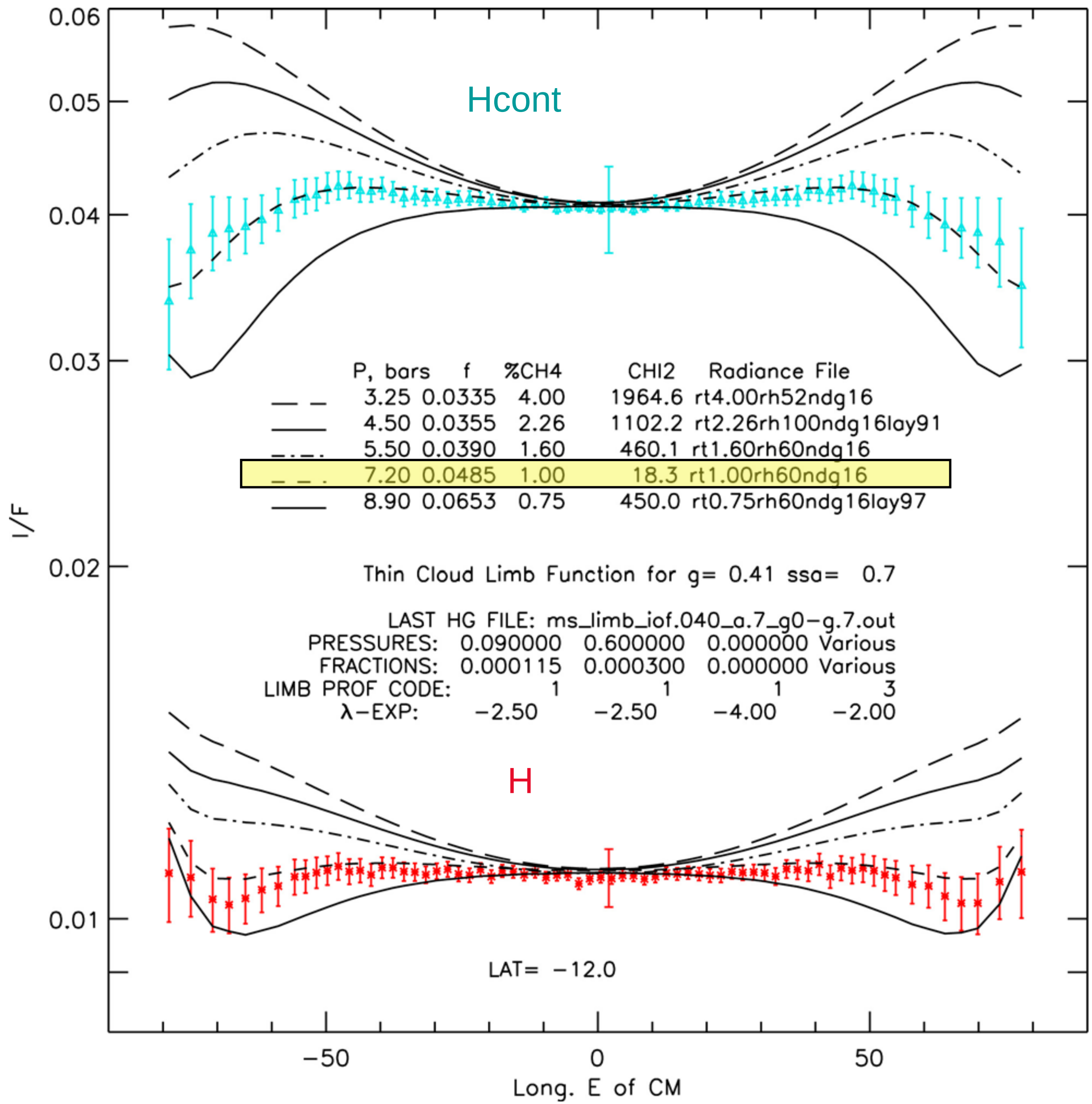
Nearly conservative scattering is expected if particles are pure NH_3 or pure H_2S.

To make models fit at higher CH4 vmr requires less limb-brightening with a less reflective cloud layer, which is not possible with



Adding absorption to the thin layer particles allows fitting observations well with most plausible CH_4 mixing ratios.

We obtained a best fit with 1% CH_4 (^{2} = 18.3), with =0.7 and g=0.41, but other fits are not significantly worse.



SUMMARY:

Is the lower cloud composed of optically thick sub-units of high albedo but low fractional coverage? Absolutely not.

Is the lower cloud composed of an optically thick cloud of strongly absorbing particles? Not likely.

Is the lower cloud optically thin (0.2 - 2 optical depths)? Very probably.

Could the lower cloud be a conservative and the CH_4 mixing ratio <1%? Maybe

Could the CH_4 mixing ratio be as high as 4%? Maybe

Could the lower cloud be moderately absorbing and the CH_4 mixing ratio In the 1-2% range? Probably.

Do assumptions about cloud properties affect conclusions about gas mixing ratios? Absolutely.

Do we need probes make direct measurements? Of course.

Are we likely to get them? You have to investigate the solar system with the NASA you have, not the NASA you might wish to have.

CONCLUSIONS:

No upper cloud other than the hydrocarbon haze is needed to explain I/F of strongly absorbing channels.

Window channel I/F values require a deep cloud pressure from 9 bars to 3 bars as the assumed CH_4 mixing is increased from 0.75% to 4%.

The window-channel H and Hcont center-to-limb profiles strongly suggest that the lower cloud is optically thin (less ~3 optical depths, possibly 0.2-0.3) rather than opaque, and definitely rules out a cloud of broken opaque conservative cloud sub elements.

If the lower cloud is a pure H_2S or NH_3 cloud, the implied high single-scattering albedo yields a best-fit methane mixing ratio of 1% or less, but non-conservative cloud particles are easier to fit in the shorter wavelength window.

If the lower cloud single-scattering albedo is reduced significantly by contaminants, or has stronger than expected absorption for some other reason, the methane mixing ratio is weakly constrained by these data, and good fits can be found with more than 2.3% methane.

Assumptions about cloud properties affect conclusions about gas mixing ratios.   We need more probes.