On the Discovery of Hot Water Vapour around CW Leonis by observations with the Herschel satellite

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LETTERS

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Warm water vapour in the sooty outflow from a luminous carbon star

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Technical Background: ESA's Herschel satellite

- Launched 17 months ago (May 2009)
- Expected lifetime: until 2013
- 1.5 Mio km away from the Earth
- Primary mirror: 3.5 m

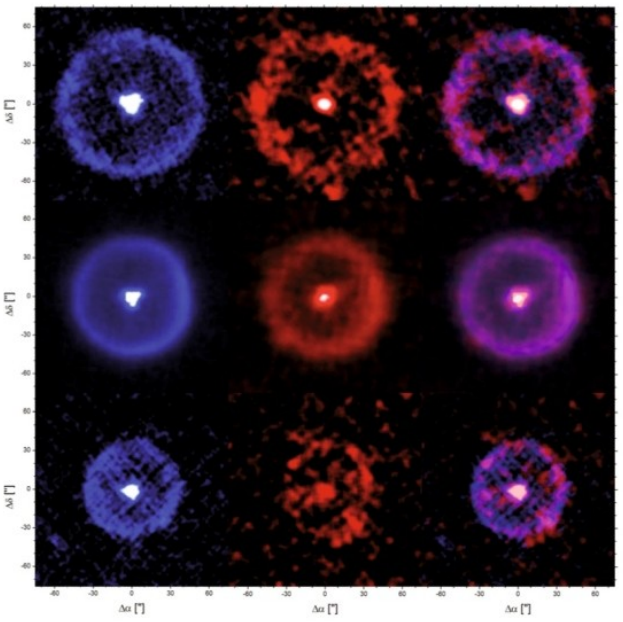


Fig. 1. *Herschel*-PACS scan maps (*left to right*: at 70 μm, 160 μm, two colour composite) of AQ And, U Ant, and TT Cyg (*top to bottom*).

Detectors:

HIFI: Radio receiver , 480-1910 GHz

SPIRE: Photometry and Spectroscopy, 200-670 µm

PACS: Photometry and Spectroscopy 55-210 µm

Some first results on AGB stars:

Detached shells of AQ And, U Ant, TT Cyg

(F. Kerschbaum et al., A&A 518, L 140)

Basic data on CW Leonis = IRC +10 216

- Position in the sky:
  ~ 5 degrees west of α Leo
- Distance: ~450 light years
- Carbon-rich AGB star
- B-magnitude ~11mag.
- K-magnitude ~1.2 mag.
- Massive dust shell
- Mass loss rate ~3 $\times 10^{-5} M_{o}$ /y
  (~10 Earth masses / year)
- Many molecule species found

CW Leo’s many faces

- Gas mass loss + dust mass loss
- Bow shock at transition to ISM (bottom left)
- Concentric shells scatter starlight
- Inner envelope has a clumpy structure
- Profiles of molecular and dust features: a wealth of information
- Dust: amorphous carbon, SiC, MgS

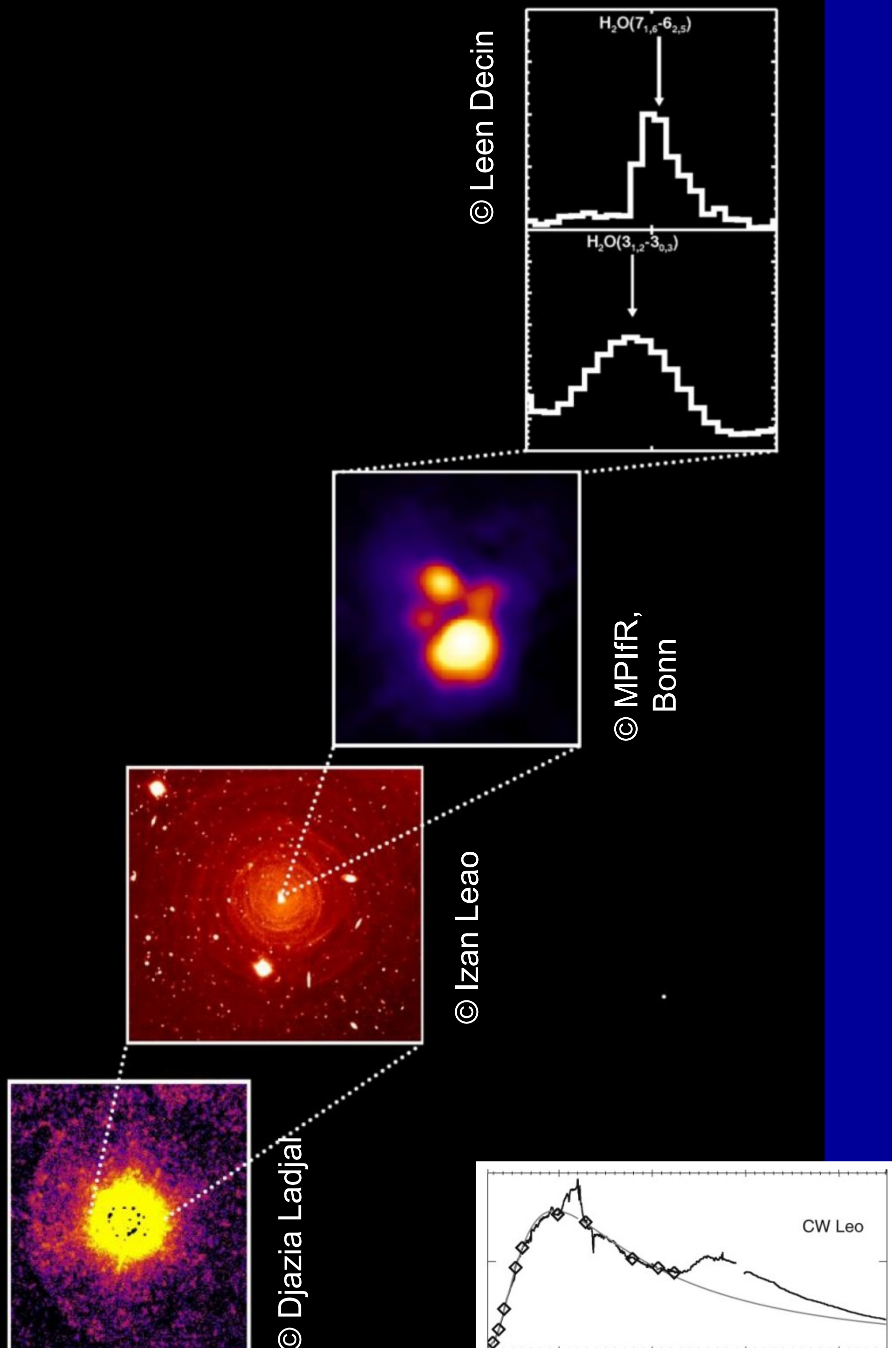
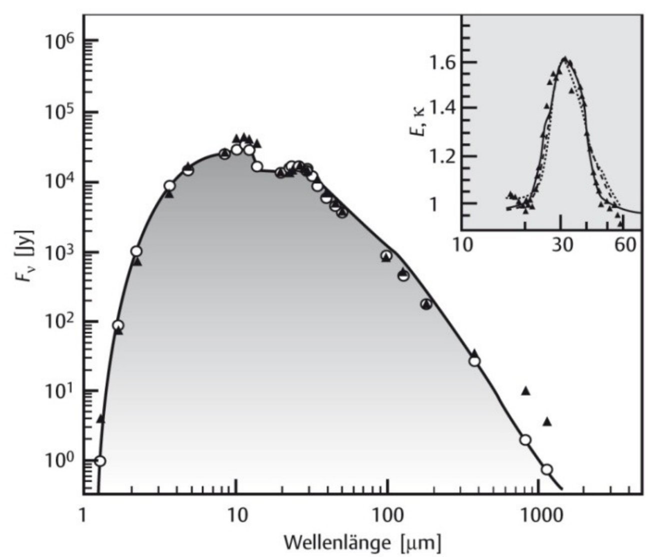
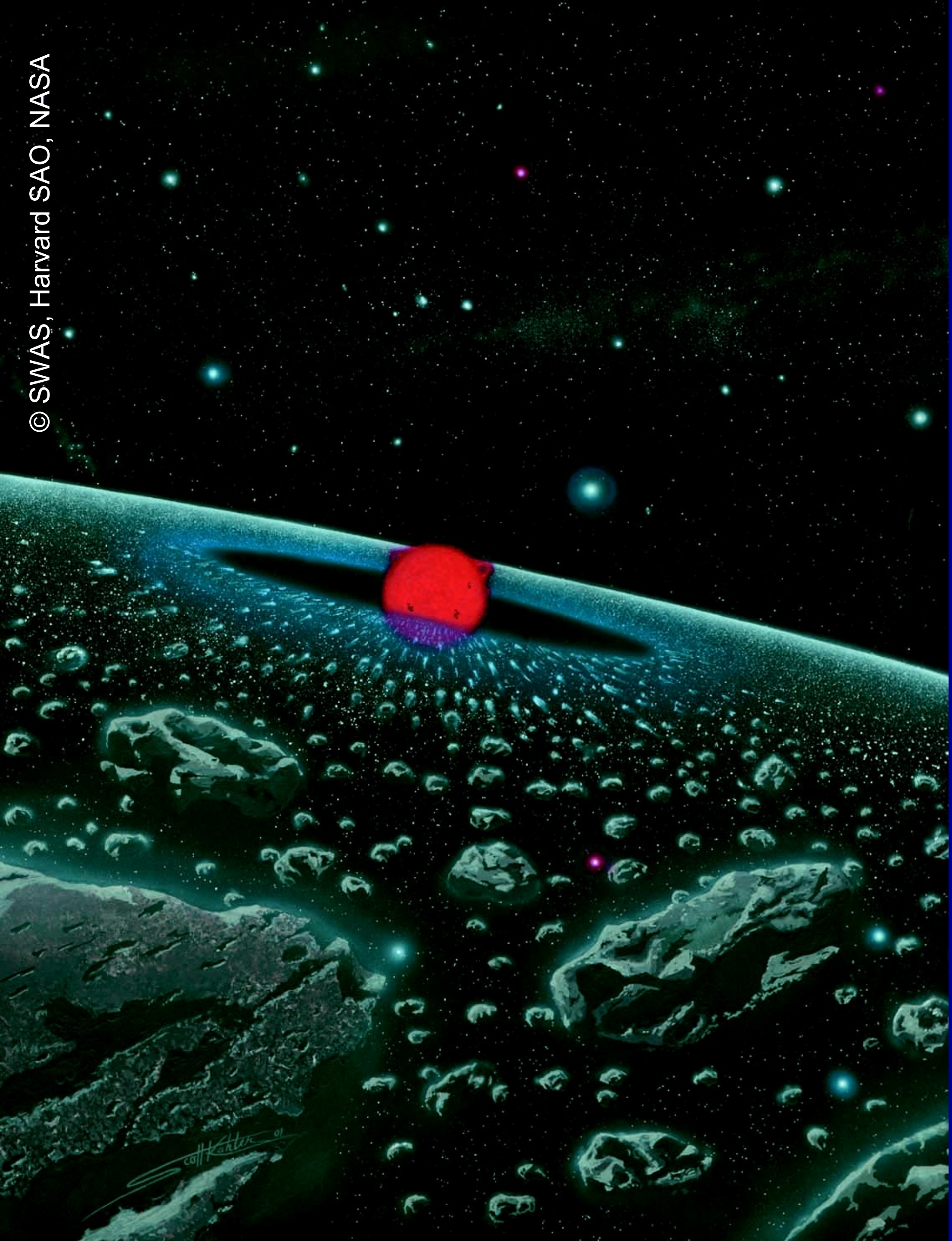


Abb. 7: Spektrum des Kohlenstoffsterns CW Leonis (IRC + 10 216). Die Punkte sind Beobachtungen, die durchgezogene Kurve das mit eigenen Daten berechnete Modell. Rechts oben: Darstellung des Profils der 30-µm-Bande der Quelle mit Labordaten der Mischsulfide $Mg_xFe_{1-x}S$ für x = 0.5...0.9. (Nach Begemann und Mitarb. 1994)



^ H. Mutschke, J. Dorschner, Sterne & Weltraum 6/1997, p. 551
< F. Molster et al. in Henning (ed.) 2010, Astromineralogy, p. 164



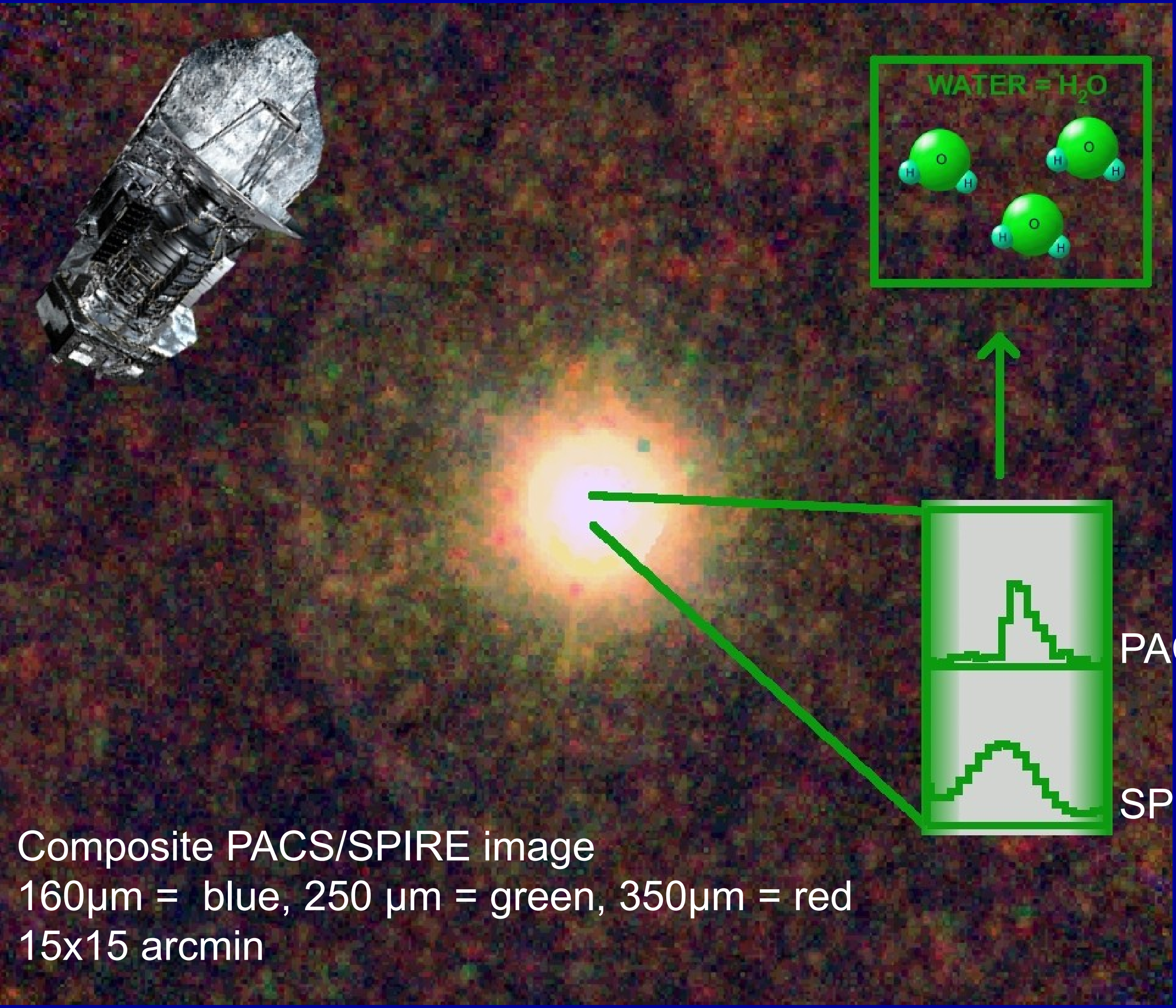
An important previous study on CW Leonis

- Melnick et al. 2001*: Evidence for H_2O vapour around CW Leo
- Assume a cloud of comets partly vaporized by the central star.
- Compare the comet cloud to the Kuiper belt
- Spectroscopic data were not sufficient to constrain the temperature and formation region of H_2O

* Reference:
Melnick, et al., Discovery of water vapour around IRC110216 as evidence for comets orbiting another star. Nature 412, 160–163 (2001).

Leen Decin et al.

observed CW Leo (Nov. 2009) with Herschel-PACS &SPIRE



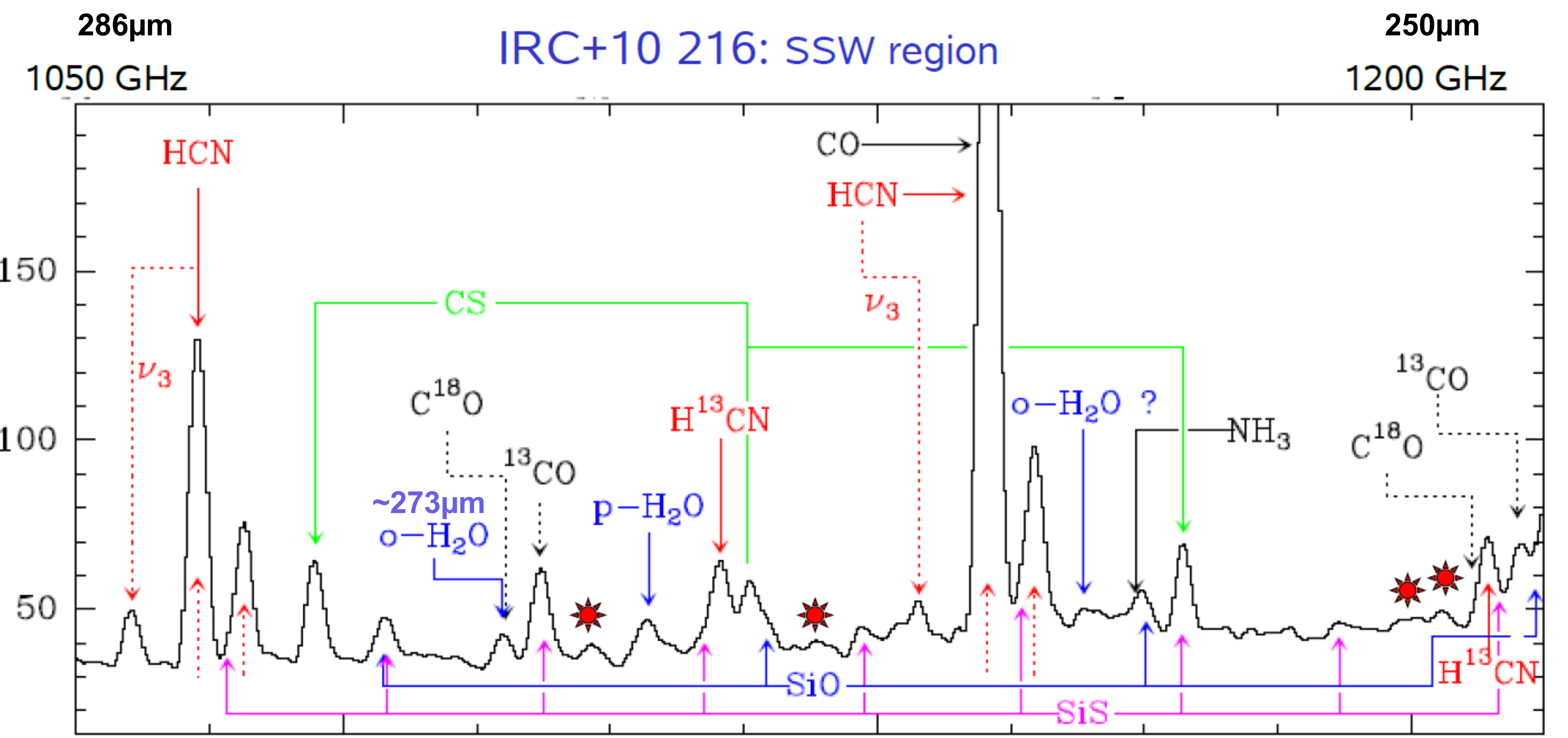
Composite PACS/SPIRE image
160μm = blue, 250 μm = green, 350μm = red
15x15 arcmin

...to check whether H_2O is indeed cold and primarily in outer envelope of CW Leo.

> 60 water lines detected in the PACS and SPIRE spectrum of CW Leo

A large 'zoo' of molecular lines:

The 250-286μm region of the CW Leo spectrum as seen by Herschel-SPIRE

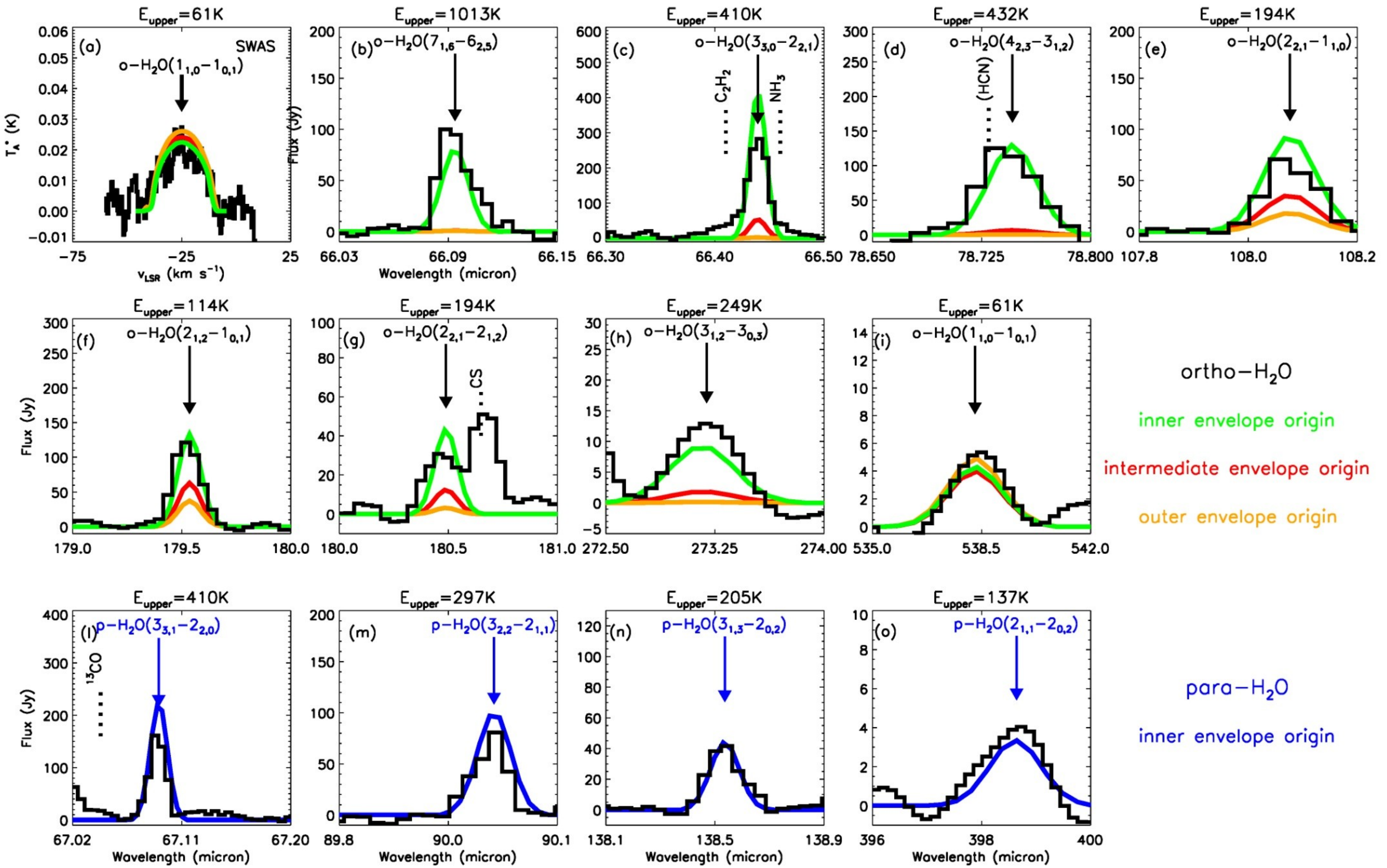


This is to show that the water lines are only minor contributions to the total spectrum.

But we shall look at them more closely.

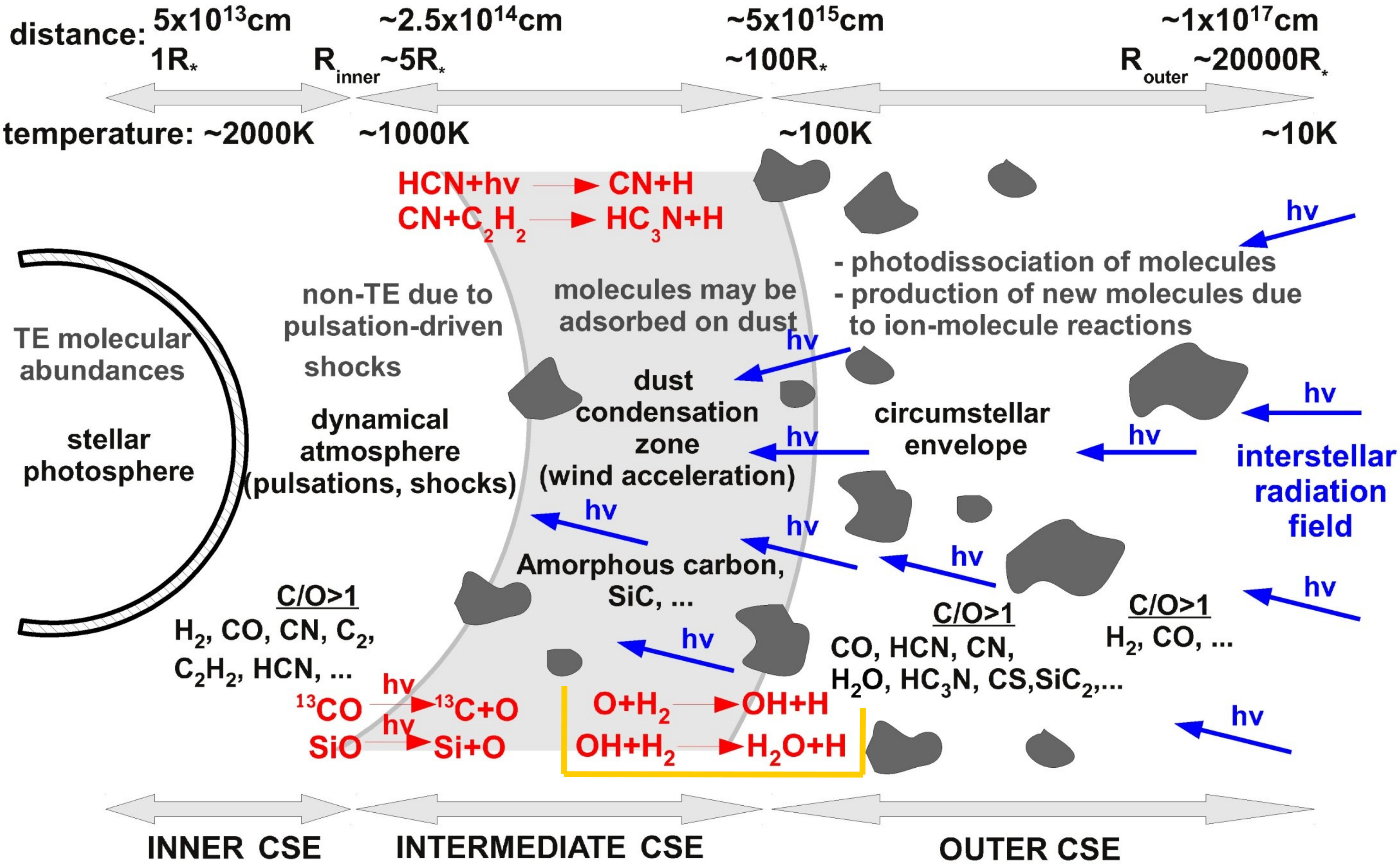
The decisive new spectra…

… showing that H_2O must be present in the inner envelope region (T_{excit} up to 1000K)



A possible scenario …

… explaining the presence of H_2O vapour in the inner envelope region



New view of hot water formation in CW Leo in a nutshell

- High excitation-temperature lines → Water must be formed at $r < 15 R_{star}$
- Clumpy structure → interstellar UV photons can penetrate into the inner circumstellar layers
- Water could be formed by photodissociation e.g. of ^{13}CO (→ liberation of atomic oxygen), which is then available for these reactions:
  $O + H_2 \rightarrow OH + H$
  $OH + H_2 \rightarrow H_2O + H$
- Deduced amount of water : 0.003 Earth masses
  (models assume *ortho*-$H_2O/H_2 = 2.5 \times 10^{-7}$, consistent with results from SWAS)
- Penetration of interstellar UV photons → formation of hydrides, in the inner envelope by successive hydrogenation reactions of N, C, and S
- Example: Ammonia (NH_3) – which is indeed observed in inner region

Consequences

• The discovery of high-excitation H_2O lines in the inner envelope of CW Leo changes our views of the envelope chemistry in C-rich stars

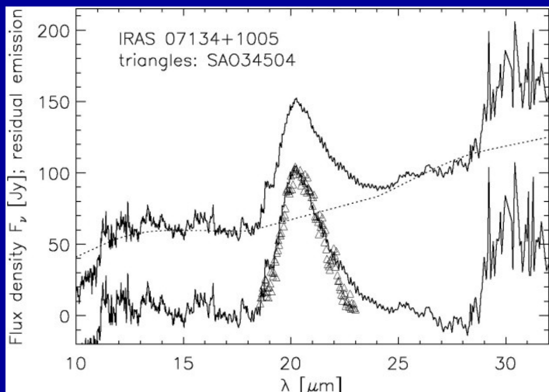
• It outlines the importance of UV-induced photochemistry in the CSEs of evolved stars

• For O-rich environments, the same mechanism predicts high abundances of carbon-rich species, such as HCN, CH_4 and CS (Agúndez et al., 2010, ApJ, submitted)

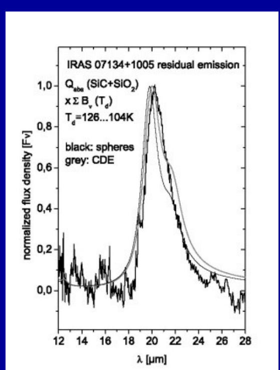
Evidence for analogue situation in other environments?

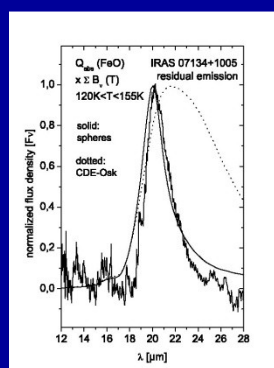
One of the most longstanding puzzles of astromineralogy is the “21”µm band.

Could it also be caused by oxidized material in carbon-rich stars?



Total and residual dust emission of IRAS 07134+1005 (ISO-SWS); “21”µm feature profile of SAO 34504

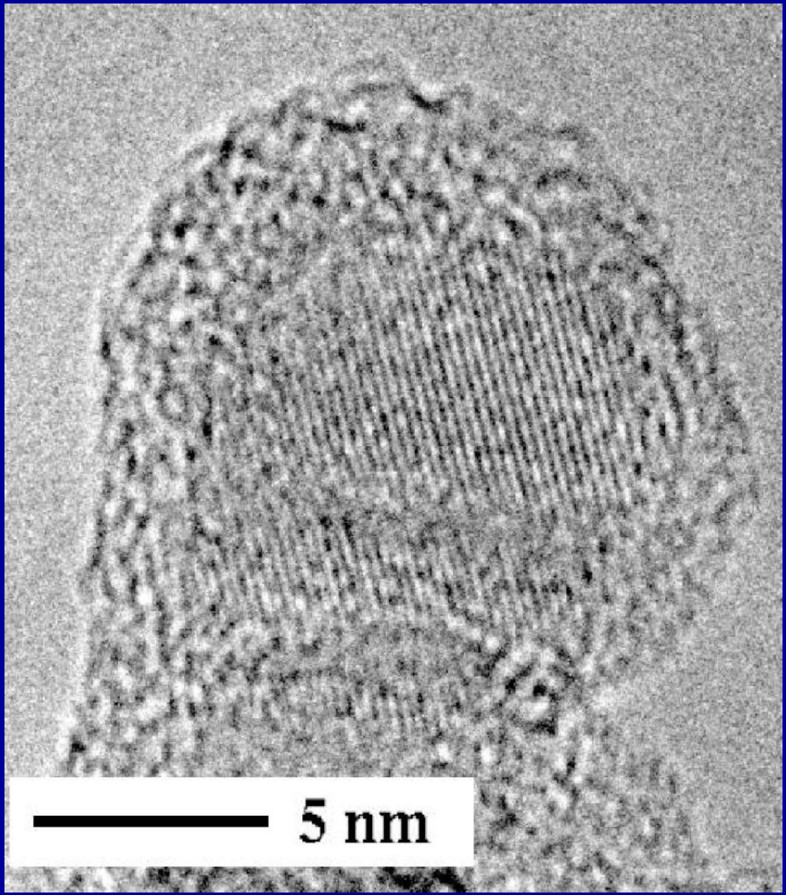




Figures from Posch et al. (2004)

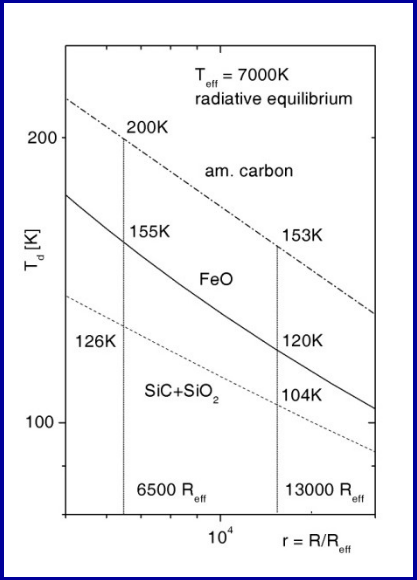
- Discovery: Kwok et al. (1989), IRAS-spectra of C-rich PPNe. Position: ~21µm
- Proposed carriers: SiS_2, carbonaceous macromolecules, diamond, PAHs, TiC, N-doped SiC, ...
- Seen only in emission, only for C/O ~ 1 (or larger), only for T_d < 250K
- Recently suggested carriers: cold FeO; Superficially oxidized SiC (“SiC+SiO_2”)
- Core-mantle-grain calculations provide good match with observed feature profile
- Details in Posch et al. (2004), ApJ 616, 1167

Some more notes on the "21" μm feature



Core-mantle particle consisting of SiC and amorphous SiO2. The silicon carbide core is identified by its characteristic lattice fringes.

1) Pure SiC nanoparticles are easily oxidized at their surfaces under the influence of the laboratory atmosphere (cf. left fig.)



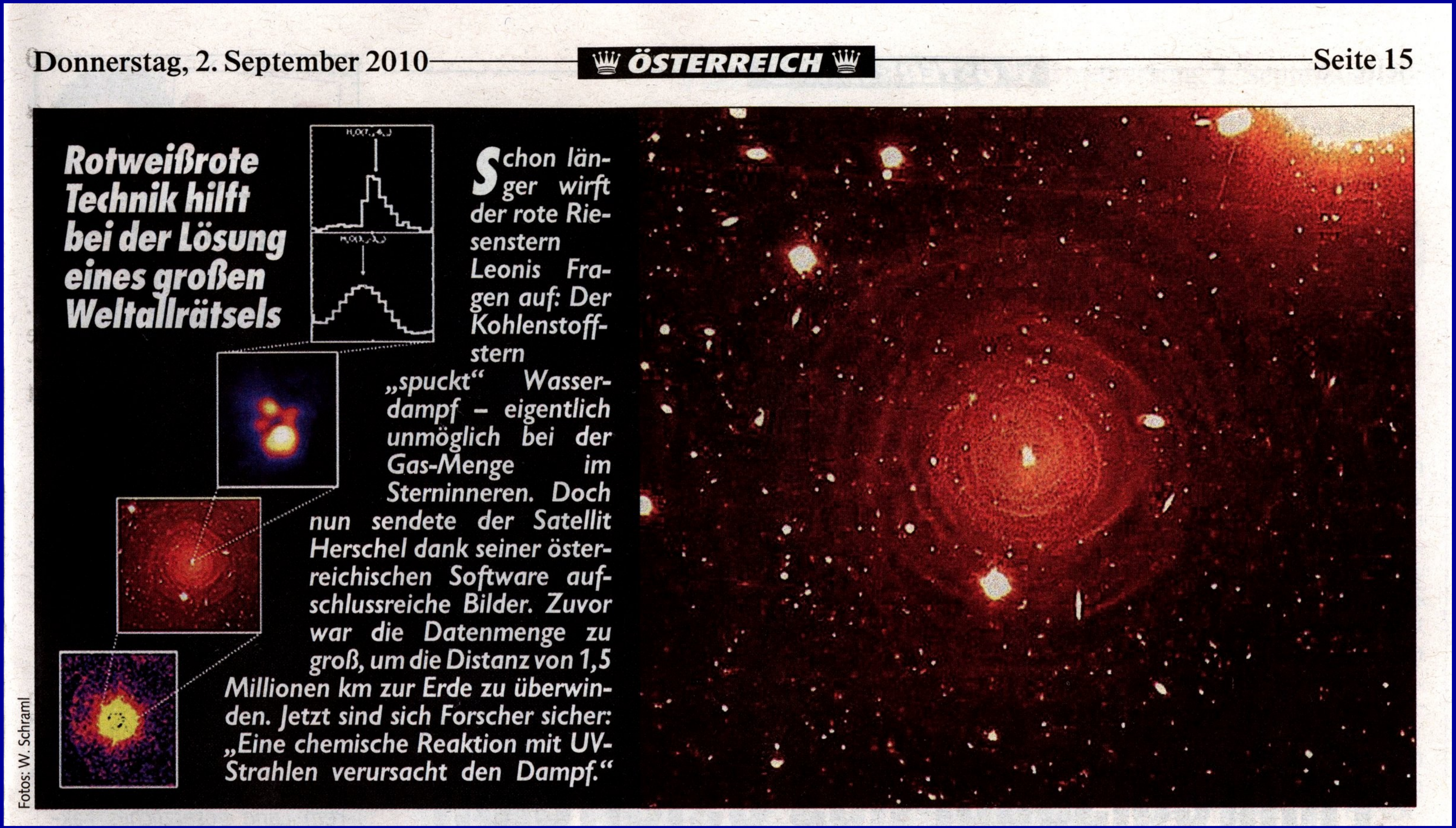
2) Radiative equilibrium temperatures vs. observational constraints:

$T_{i,obs.}$ = 165 … 220K

< Posch et al. 2004
<<< Clément et al. 2003

Appendix: How the press rephrased the hypothesis

“A great puzzle of the universe has been solved by means of Austrian technology”



Donnerstag, 2. September 2010 — ÖSTERREICH — Seite 15

Rotweißrote Technik hilft bei der Lösung eines großen Weltallrätsels

Schon länger wirft der rote Riesenstern Leonis Fragen auf: Der Kohlenstoffstern „spuckt“ Wasserdampf – eigentlich unmöglich bei der Gas-Menge im Sterninneren. Doch nun sendete der Satellit Herschel dank seiner österreichischen Software aufschlussreiche Bilder. Zuvor war die Datenmenge zu groß, um die Distanz von 1,5 Millionen km zur Erde zu überwinden. Jetzt sind sich Forscher sicher: „Eine chemische Reaktion mit UV-Strahlen verursacht den Dampf.“

Fotos: W. Schraml

Kronen-Zeitung , 2nd Sept. 2010