Comets: What do they tell us about the early Solar System

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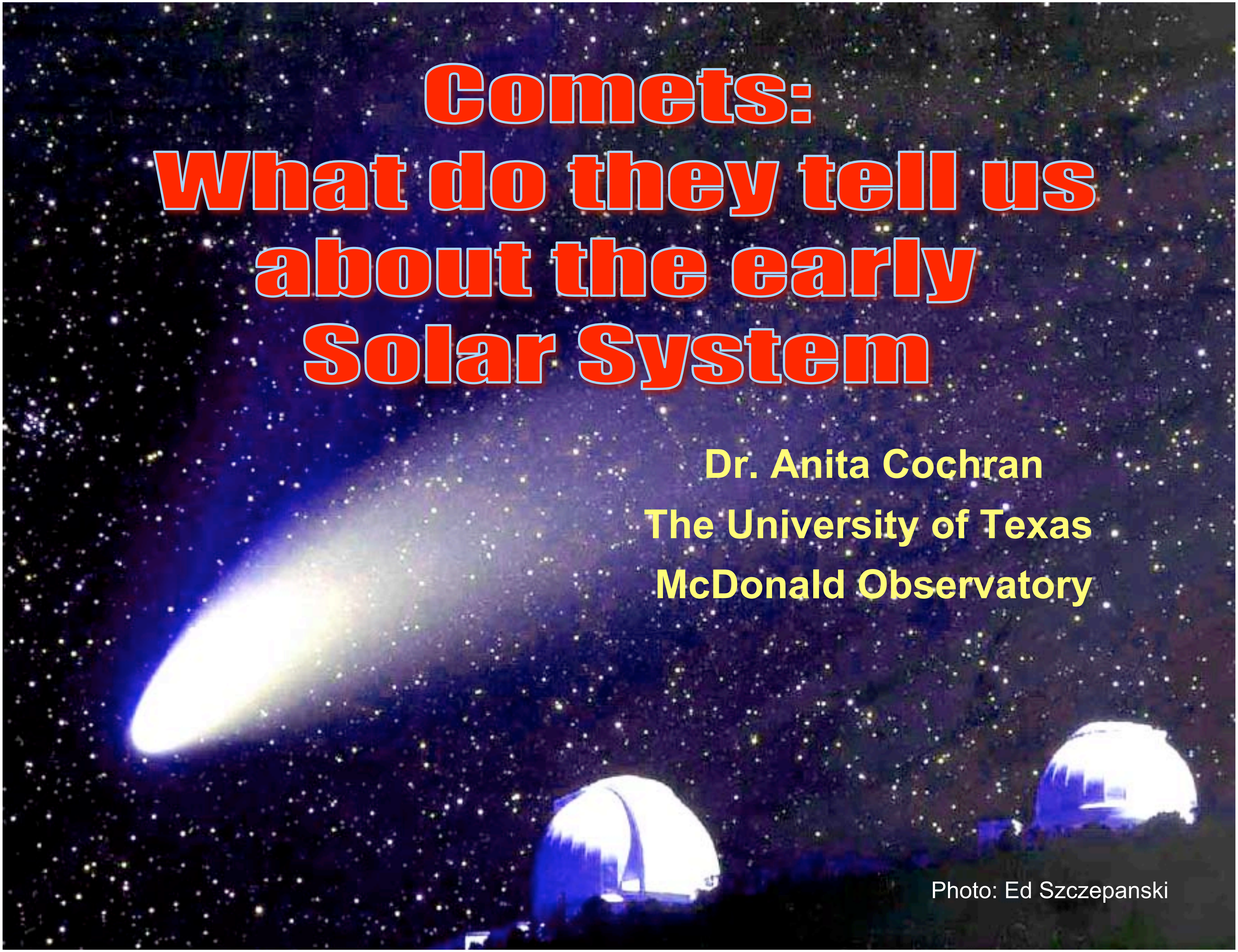
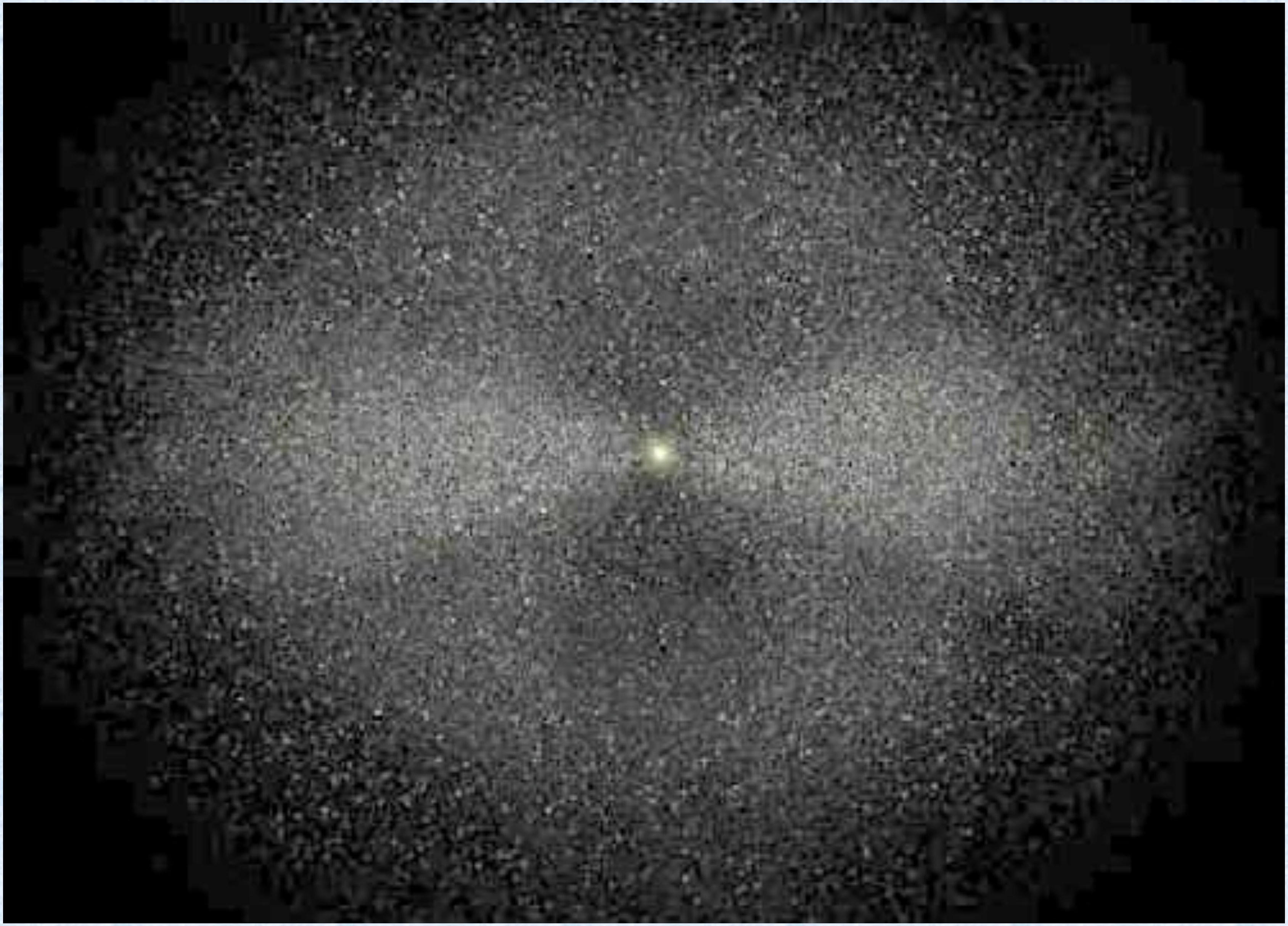


Photo: Ed Szczepanski

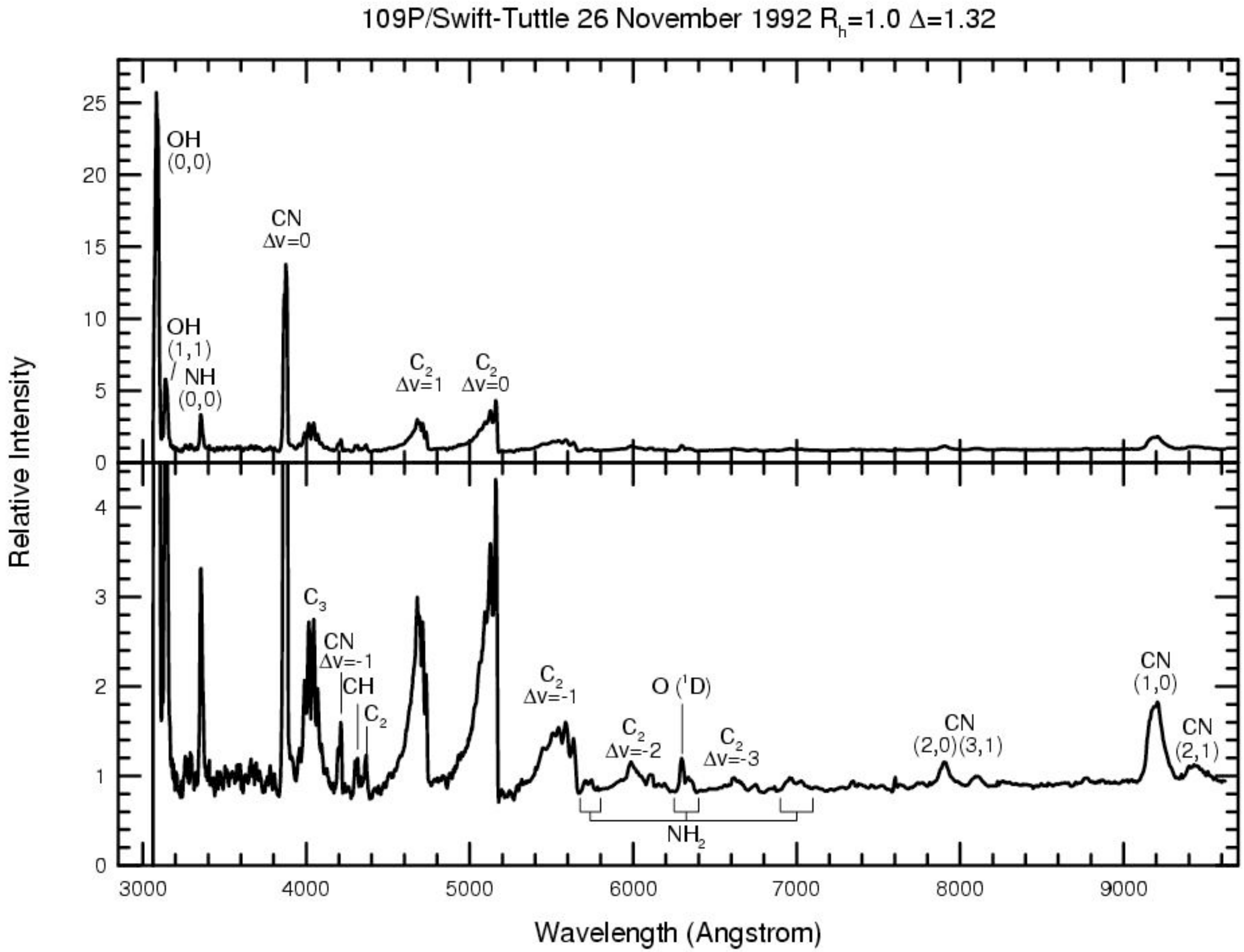
Why Study Comets?

- Comets are the least altered objects left over from the formation of the Solar System and were the building blocks of planets in the outer part of the Solar System.
- Comets we see today in the inner Solar System come from one of two reservoirs:
  - The **Kuiper belt** – a disk-like region located from Neptune outwards and mostly primordial
  - The **Oort cloud** – a spherical halo of comets out to about 10^5 AU; these objects were formed in the region of the giant planets



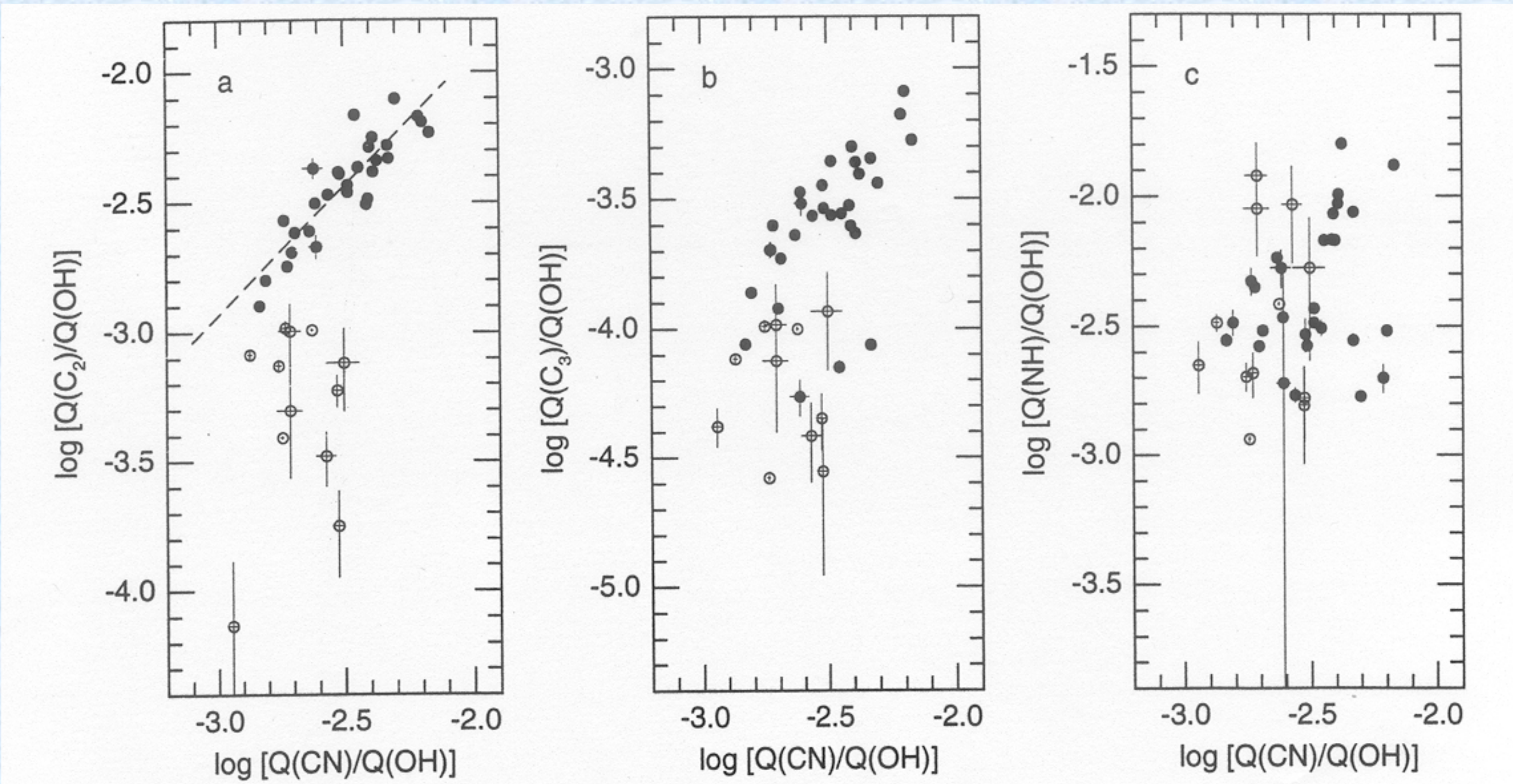
Composition

- The spectrum of a comet is mostly **molecular gas emission**, with a continuum formed from sunlight reflecting off the dust.
- Most of the spectral lines are formed via **resonance fluorescence**.
- Comets have high <u>**excitation**</u> temperature but not high physical temperatures.
- The presence of lines and their ratios <u>*do not*</u> indicate the density of the material. They are an indicator of the parent species


109P/Swift-Tuttle 26 November 1992 R_h=1.0 Δ=1.32
Relative Intensity
Wavelength (Angstrom)
OH (0,0)
OH (1,1)
NH (0,0)
CN Δv=0
C2 Δv=1
C2 Δv=0
C3
CN Δv=-1
CH
C2
C2 Δv=-1
C2 Δv=-2
O (1D)
C2 Δv=-3
NH2
CN (2,0)(3,1)
CN (1,0)
CN (2,1)
0
5
10
15
20
25
1
2
3
4
3000
4000
5000
6000
7000
8000
9000

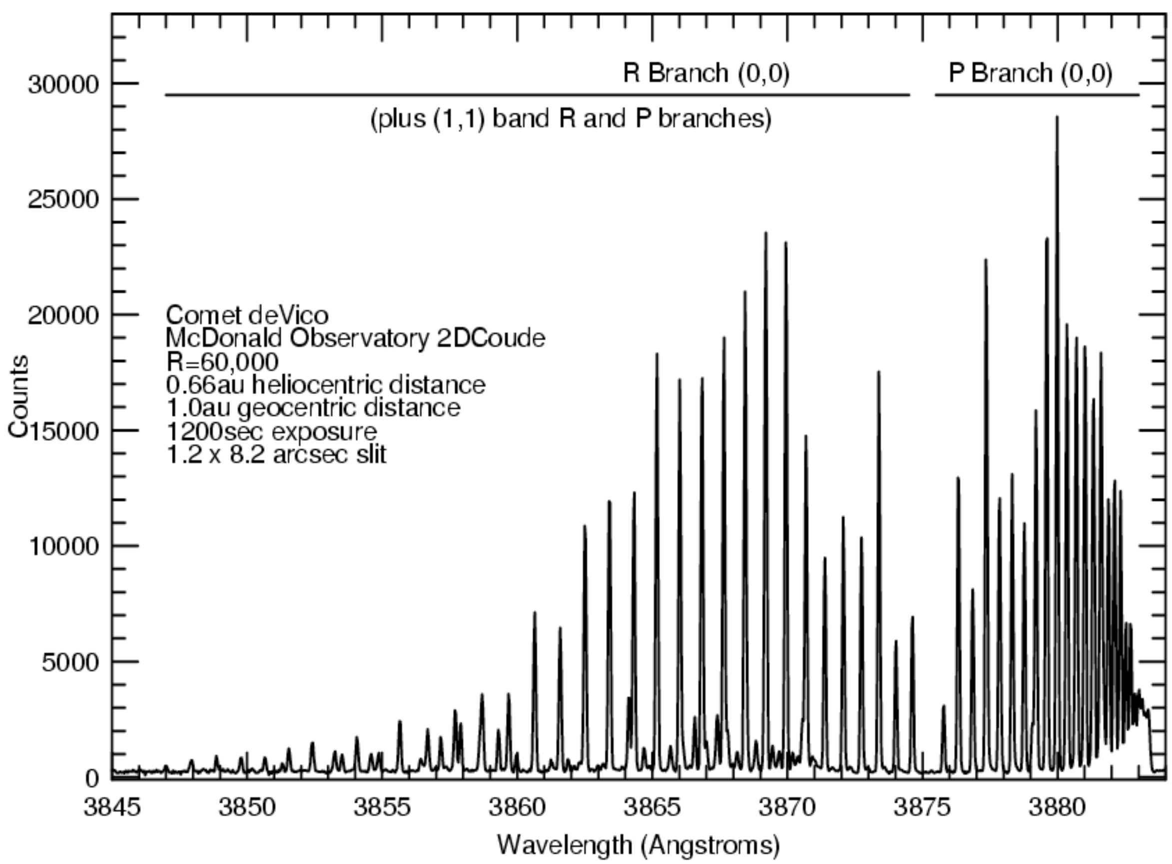
Are All Comets Chemically Similar?

- The vast majority of comets have similar composition
- There is a sub-group (generally Jupiter family comets) which have *different* spectral characteristics.



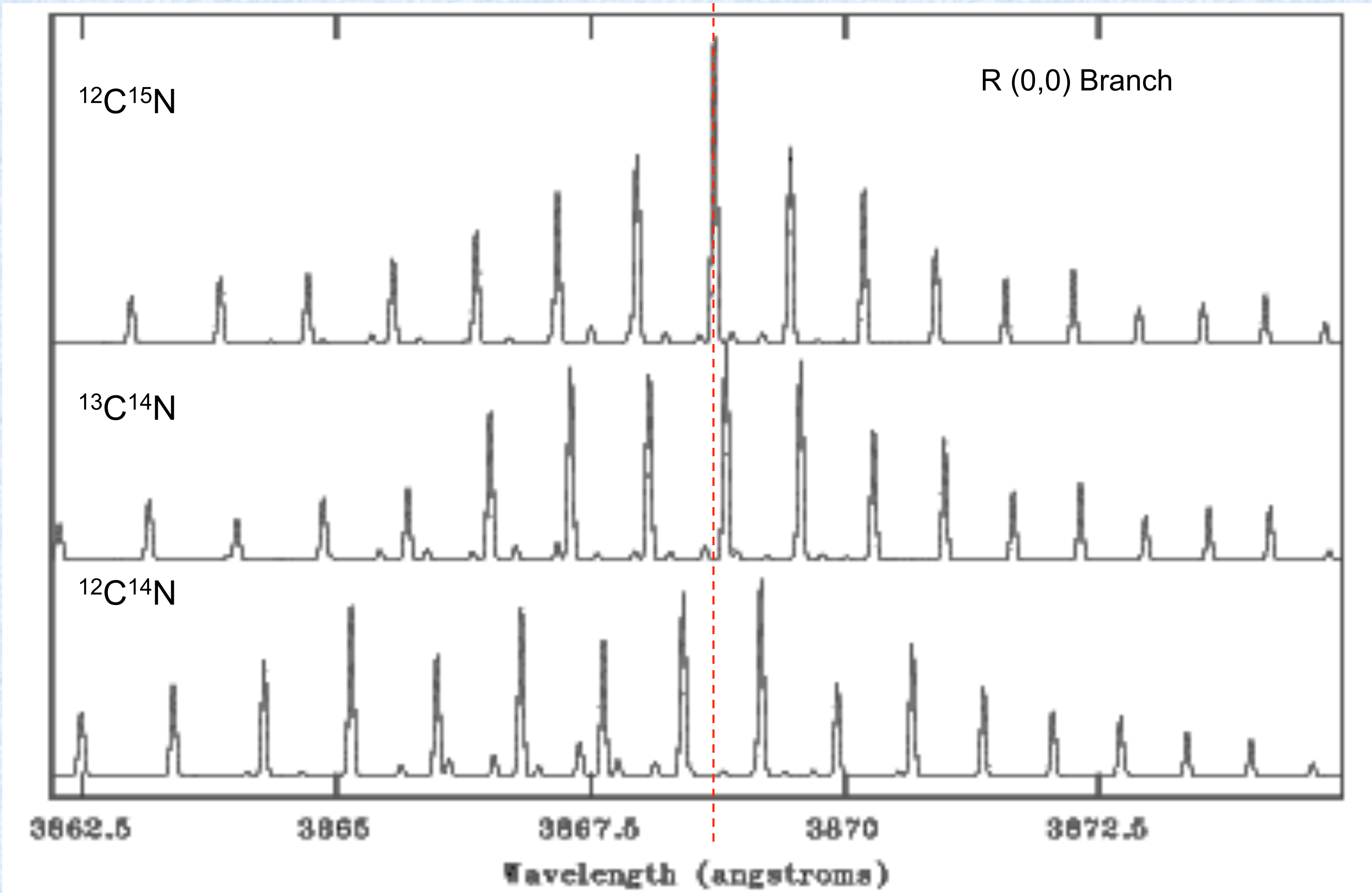
Measuring Isotope Ratios

- Isotope ratios yield information on the fractionation history of the gas.
- This is a function of temperature, density and pressure.
- We need to know the isotope ratios as a function of formational distance.



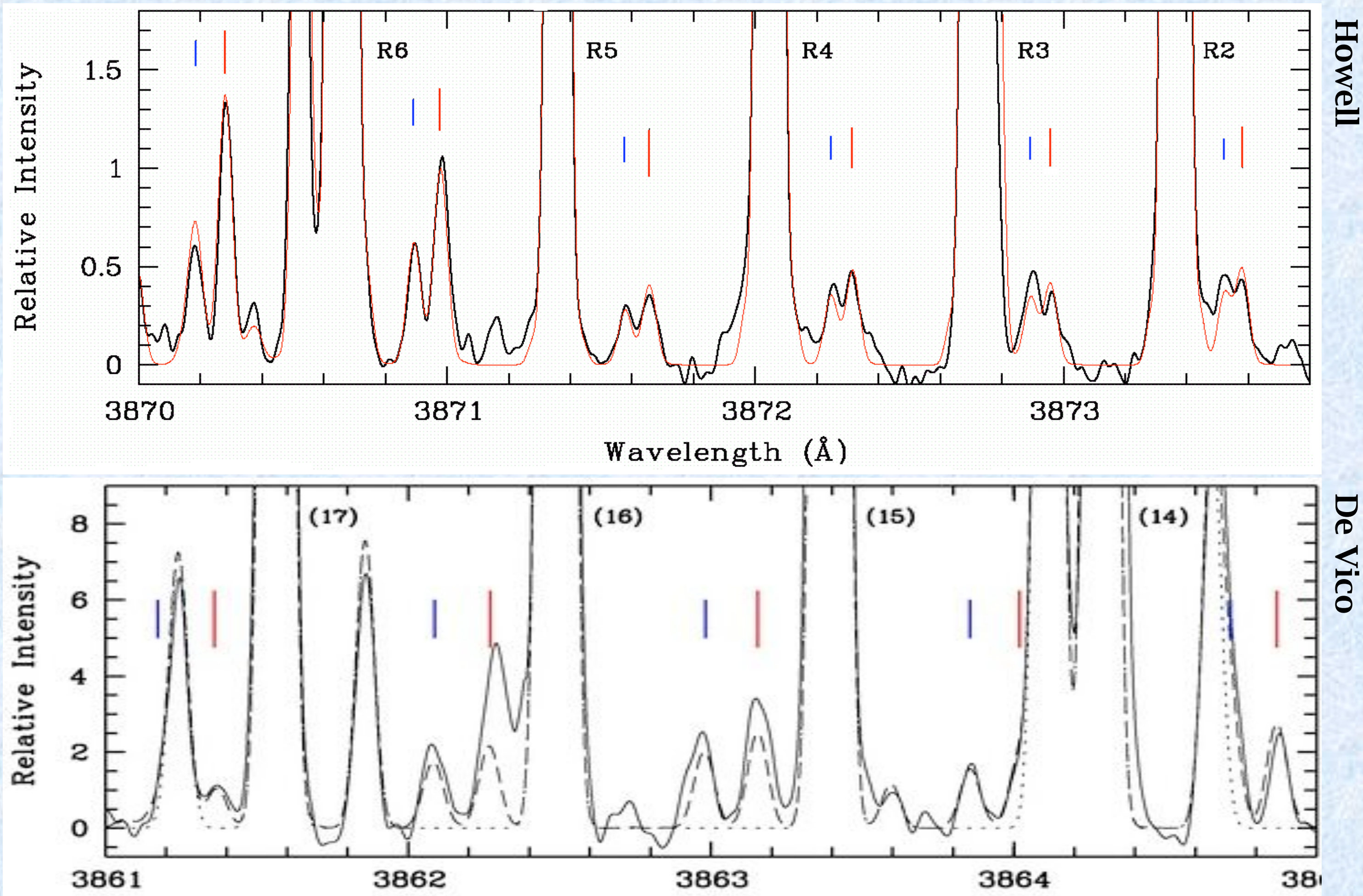
The B-X band of CN is a Σ – Σ transition so it has no Q-branch. The strongest lines are of the (0,0) band. There is also evidence of the P- and R-branch lines of the (1,1) band within the (0,0) R-branch lines, with a bandhead at 3871Å.

The isotopes are determined with synthetic spectra to model the isotopomers



Note the isotope shifts and different relative intensities.

Examples



Tickmarks

$^{12}C/^{15}N$

$^{13}C/^{14}N$

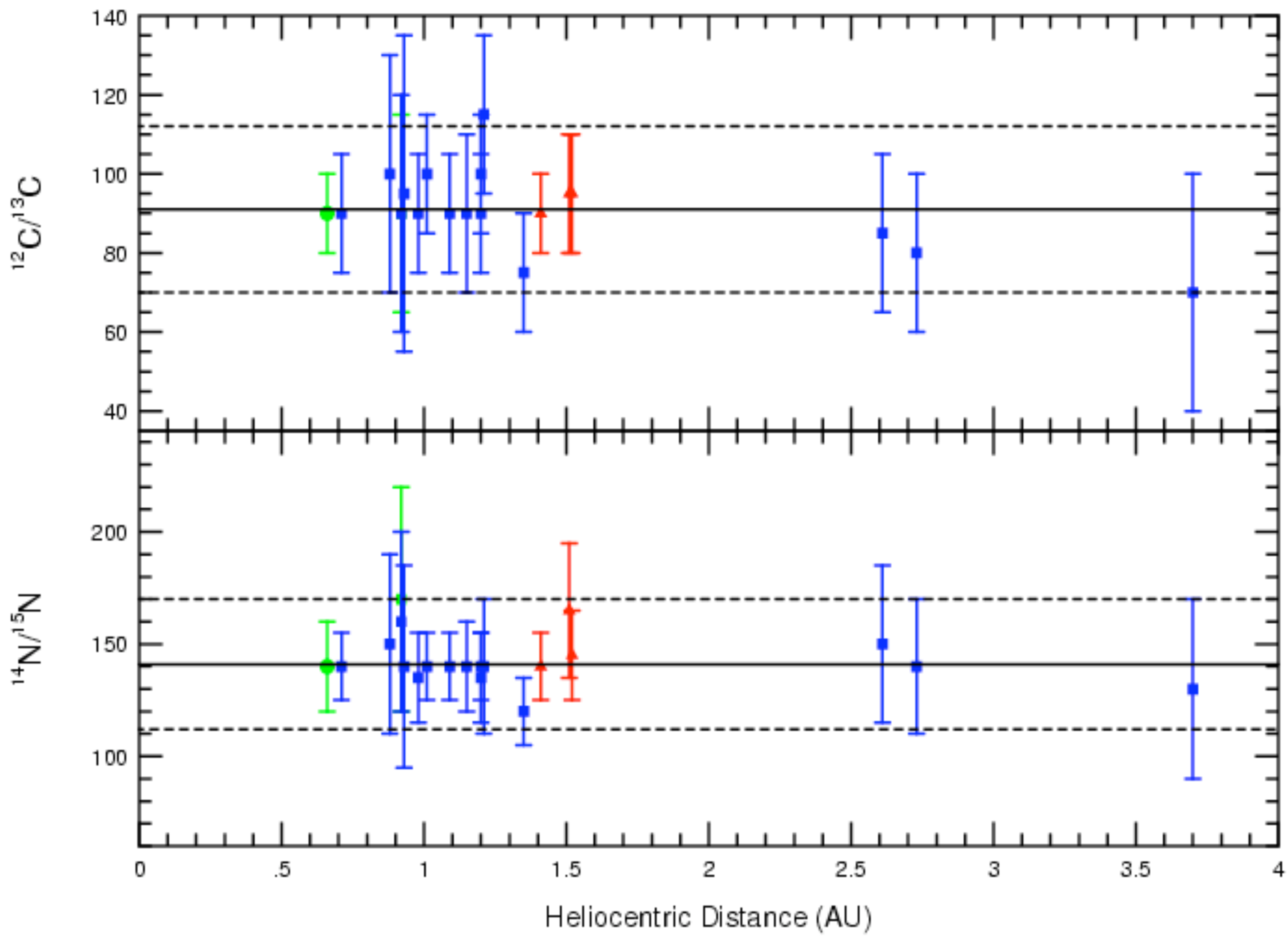
Solid line is data

Dotted line model without isotopes

Dashed line model with isotopes

$^{12}C/^{13}C$: Howell 90±10 ; de Vico 90±10 $^{14}N/^{15}N$: Howell 140±20; de Vico 140±15

Work of A. Cochran (Texas), E. Jehin (ESO), J. Manfroid, D. Hutsemakers, C. Arpigny (Liege), J.-M. Zucconi (Besancon), J. Stuwe (Leiden) and R. Schulz (ESA) – various publications

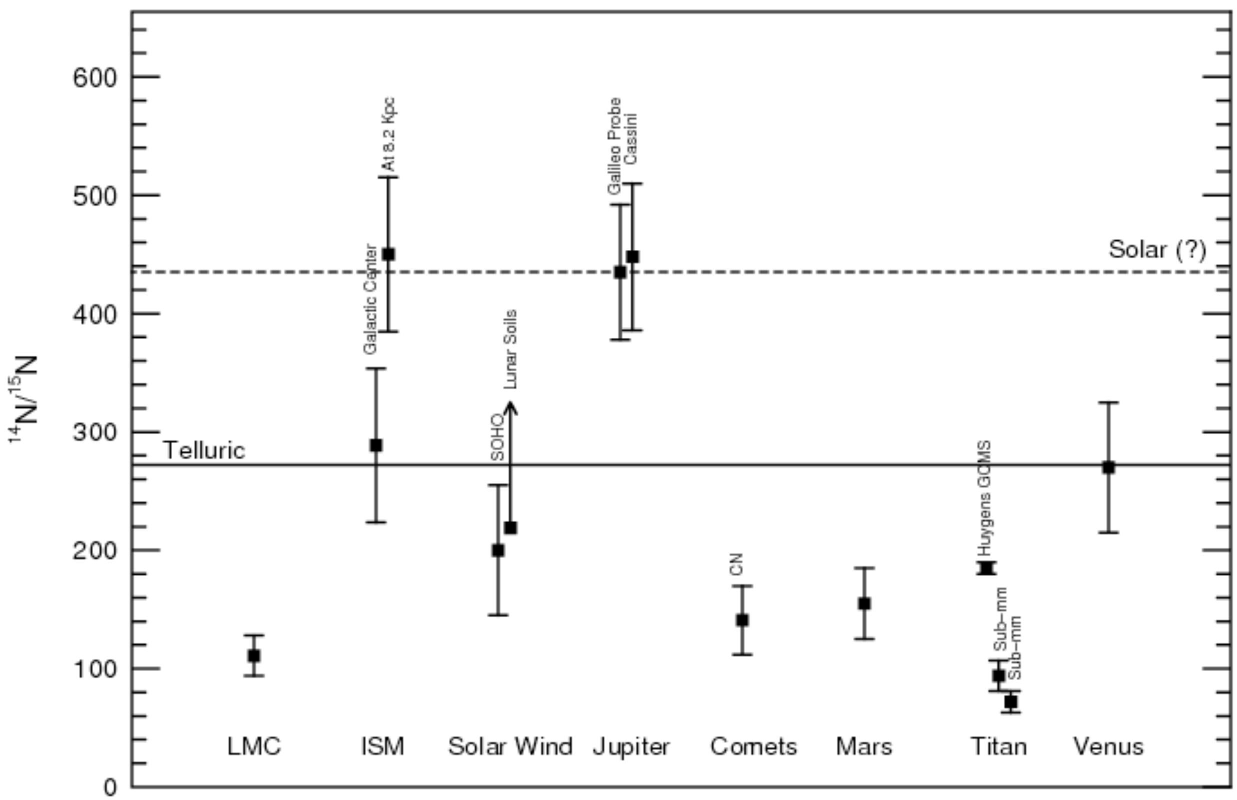


Halley Type comets are denoted with **green circles**; Oort cloud comets are denoted with **blue squares**; Jupiter family comets are denoted with **red triangles**.

Common Values for the Ratios

- C and N isotope ratios measured in 13 comets
  - 2 Halley Type comets, 2 Jupiter Family comets and 9 Oort Cloud comets
- All of these comets have the same $^{12}C/^{13}C$ ratio
  - $^{12}C/^{13}C = 91 \pm 21$
  - The same as the Solar System and terrestrial value
- All of these comets also have the same $^{14}N/^{15}N$ ratio.
  - $^{14}N/^{15}N = 141 \pm 29$
  - Solar System value assumed to be the terrestrial value of 272 (Anders and Grevasse 1989)
  - Our team was the first to measure this ratio in the optical

Nitrogen Isotopes Elsewhere



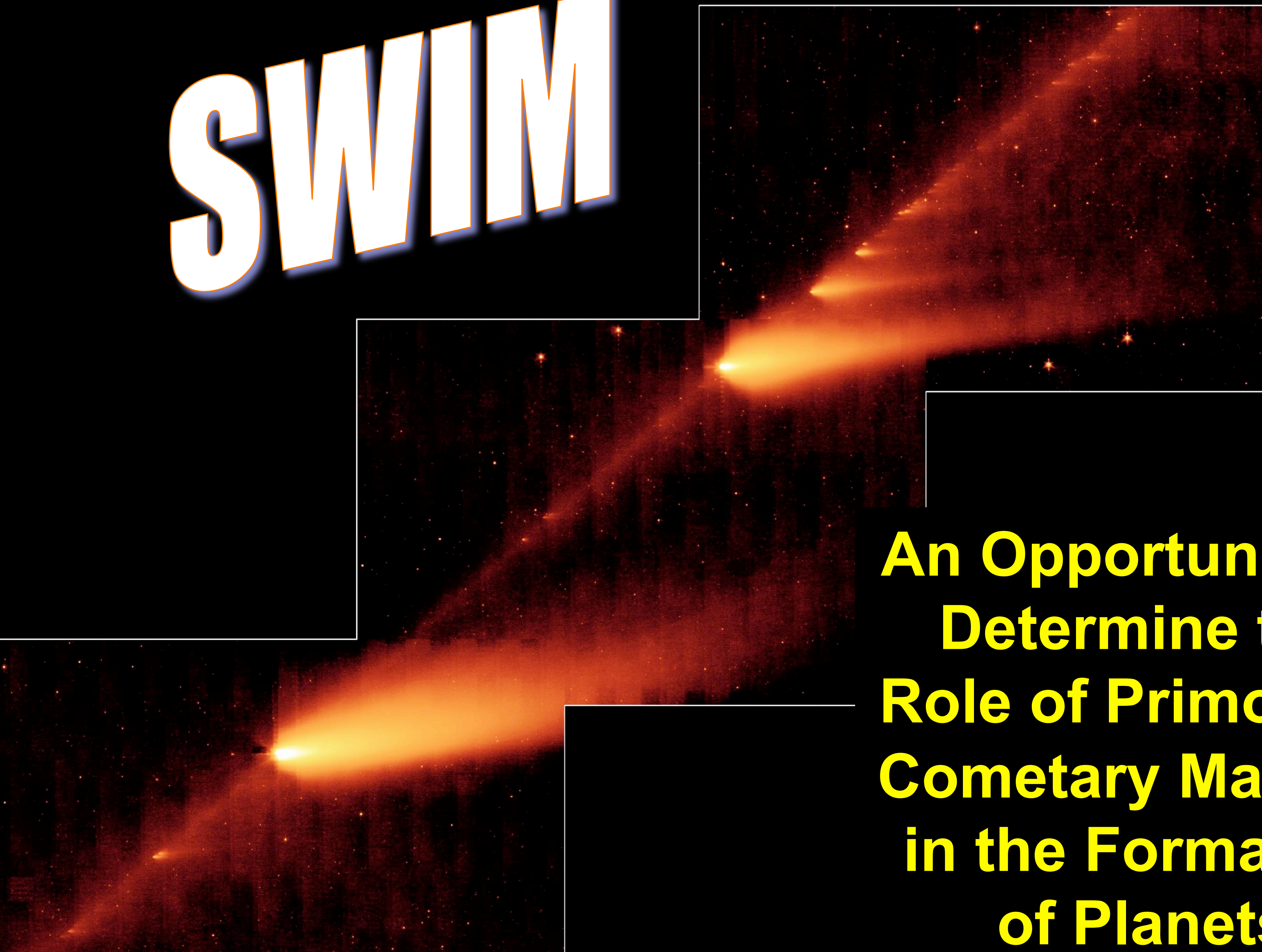
LMC = Large Magellanic Cloud $HC^{15}N$ [4]; ISM=Interstellar Medium HCN [6]; Solar wind from SOHO [14] and upper layers of lunar soils [16]; Jupiter from Galileo Probe [19] and Cassini/CIRS [1]; Comets CN, Mars[18], Titan Huygens GCMS [17], Sub-mm HCN [8], Venus [9]

Implications

- Owen et al. (2001) argue that the value of $^{14}N/^{15}N$ for Jupiter represents the solar value of this ratio since other isotope ratios (Carbon, Xenon) measured in Jupiter's atmosphere are the same as the Sun
  - The Local Interstellar Medium value (LISM, the ISM point at 8.2Kpc) agrees with the Jupiter value
  - The value measured for the solar wind from SOHO disagrees with the Jupiter value by a factor of two
- If the Solar value <u>is</u> ~400 but we measure ~140 from CN
  - Must be an additional parent for CN
  - That parent must have a $^{14}N/^{15}N$ much lower than the normal solar nebula value
  - Might point to large scale inhomogeneity in the solar nebula

Future Direction

SWIM



An Opportunity to Determine the Role of Primordial Cometary Material in the Formation of Planets