The Birth of Stars and Planets

a Vision of our Cosmic origin

Glenn White, University of Kent, UK

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Cosmic Vision 2015 - 2025
Paris September 2004

Narration – previous slide

- Stars are the fundamental objects of astronomy and understanding their evolution, effects on their environment, and their life cycle is a central theme of modern astrophysics. Since the discovery of extra solar planets, the prospect of studying exo-planet formation and the possibility to explain a number of major differences between what has been observed and our solar system has lead to great growth in the study of star formation, the associated chemistry and the gas dynamics

- Our Vision is to study the early phases of star formation, to determine how they collapse to form stars and planets. The protostellar cores are typically dense (≥ 105 cm-3) and cold (≤ 20K) and have more than the Jeans mass needed for collapse. The actual distribution of material, thermal balance and chemical composition are unknown and little studied due to extensive molecular depletion at mm/submm wavelengths and optical depth limitations at mid-infrared and shorter wavelengths

The next slide contains an animation that can be downloaded from:

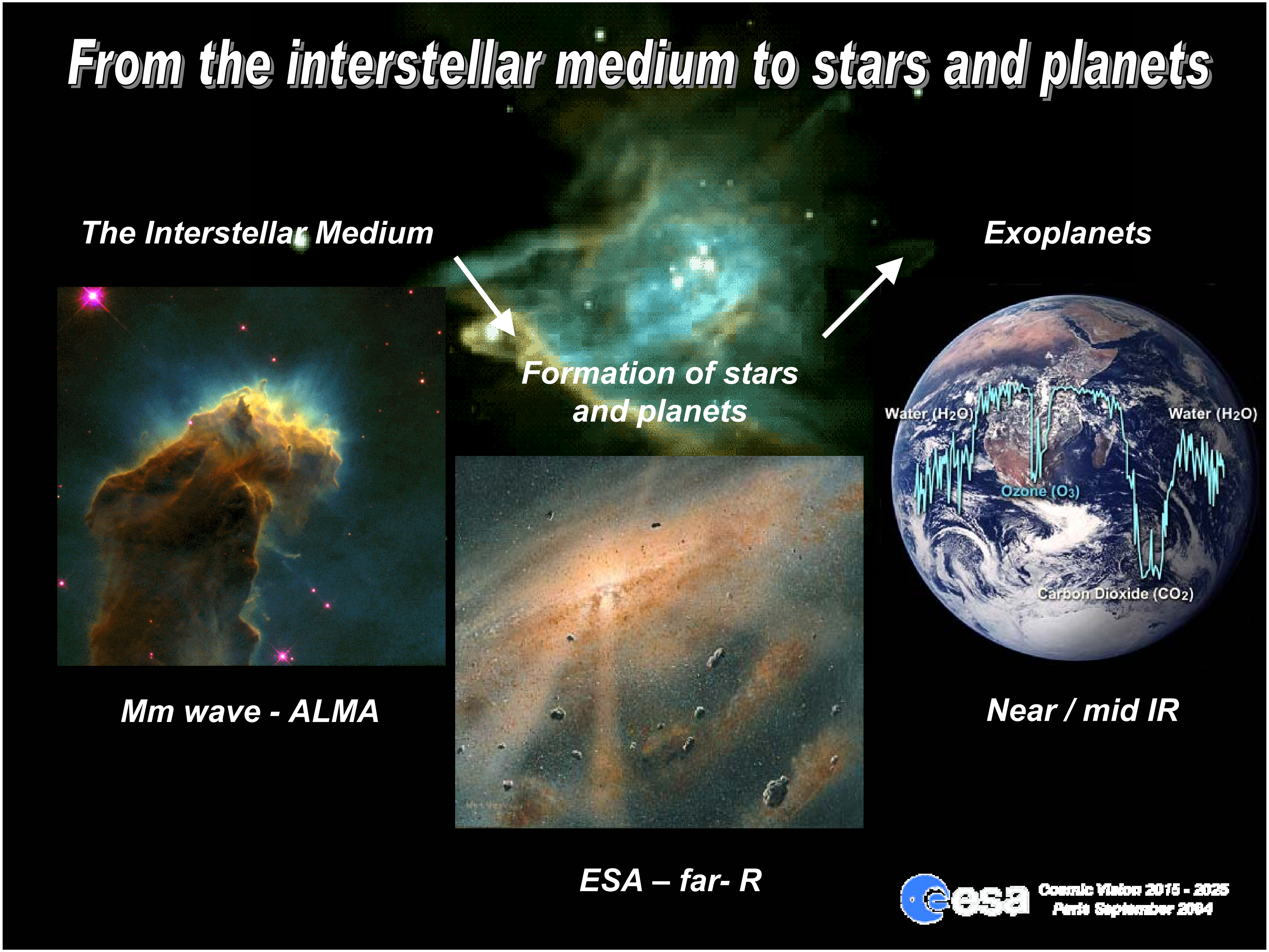
http://vis.sdsc.edu/research/orion.html

Narration over the animation:

Stars are the fundamental objects of astronomy – understanding their evolution, and their influence on theis environment is a central theme of modern astrophysics

Since the discovery of extrasolar planets, the prospect of studying exoplanet formation to explain the major differences between our own spolar system and those of the majority of other stars known to have their own systems, has led to detailed studies of star formation, chemistry and the dynamics of the gas and dust in protostellar disks

These disks are dense and cold. The distribution of material, and its thermal balance and chemical compositions are relativeley unknown, and difficult to study from the ground, due to depletion at mm and submm wavelengths, and optical depth problems in the near-IR and visible parts of the spectrum. The far-IR is a natural spectral region in which to study the Birth of Stars and Planets


From the interstellar medium to stars and planets
The Interstellar Medium
Formation of stars and planets
Exoplanets
Water (H_2O)
Ozone (O_3)
Water (H_2O)
Carbon Dioxide (CO_2)
Mm wave - ALMA
Near / mid IR
ESA – far- R
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The next slide contains an animation that can be downloaded from:

http://www.astronomy.swin.edu.au/

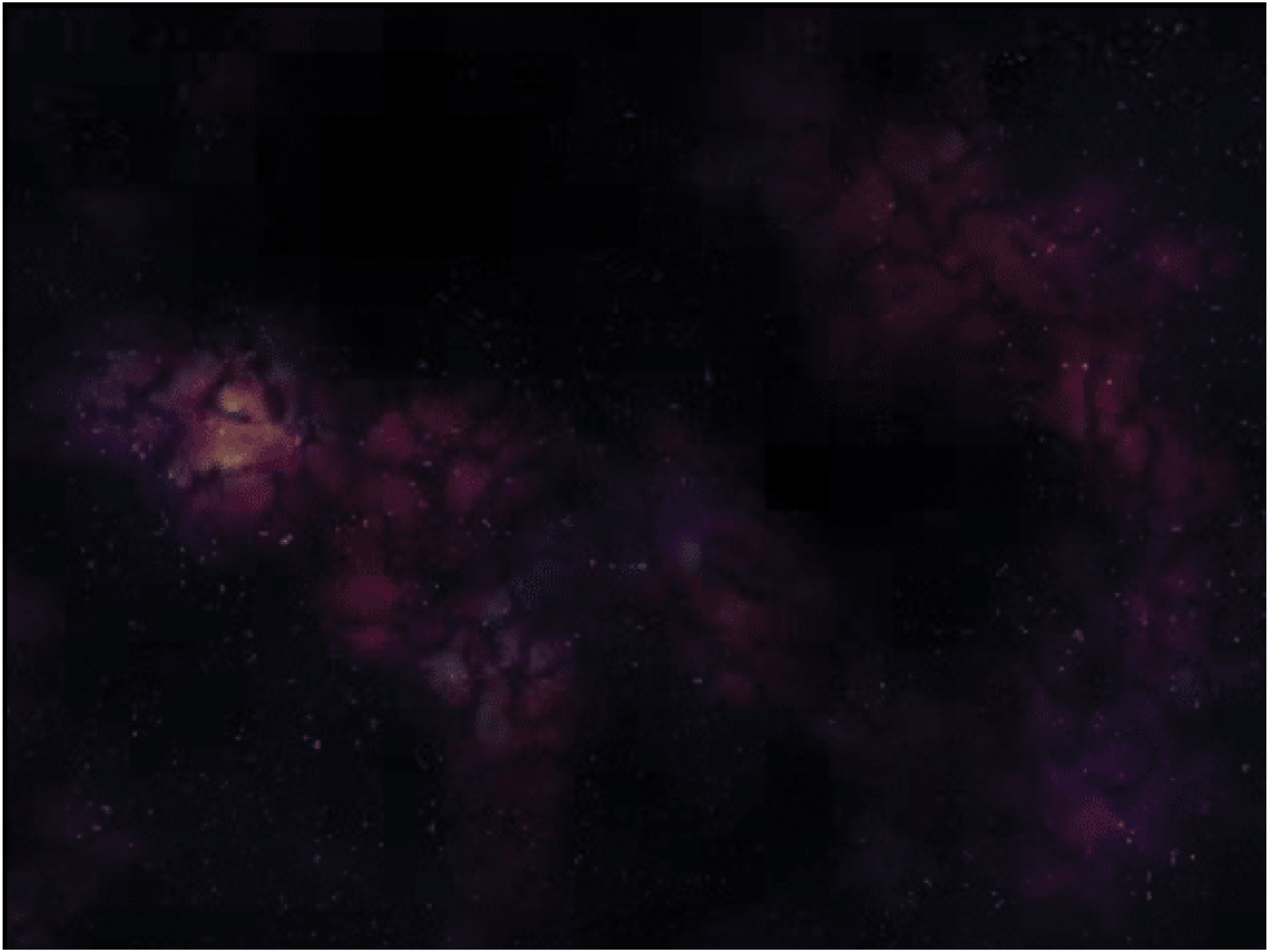
Narration over the animation:

- Protostellar disks are formed as material is accreted from the interstellar medium, merging to assemble planitesimals. Spectroscopic observations of the gas can trace this collapse, and the formation of protostars and protoplanets

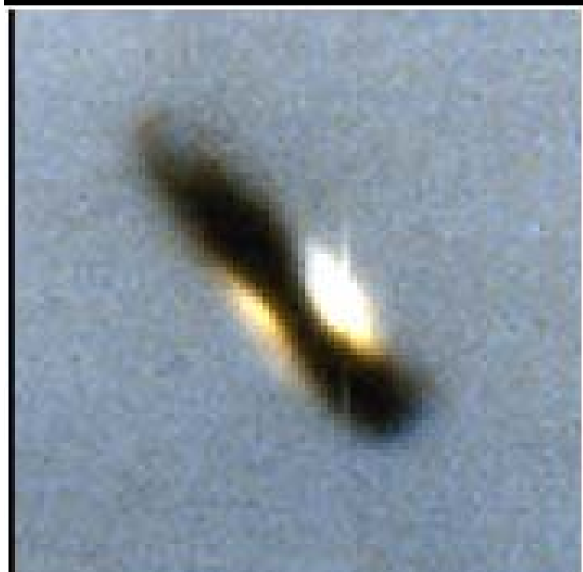
- Material Coalesces together over a few million years to assemble the stars and planets

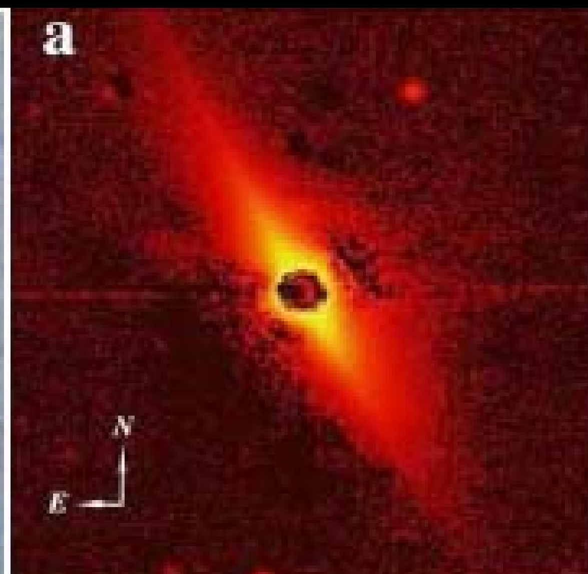
- The gas can be traced using molecular, atomic and ionsied spectral lines that are uniquely available at far-IR wavelengths, such as water, OH, molecular hydrogen and the carbon and oxygen fine structure lines

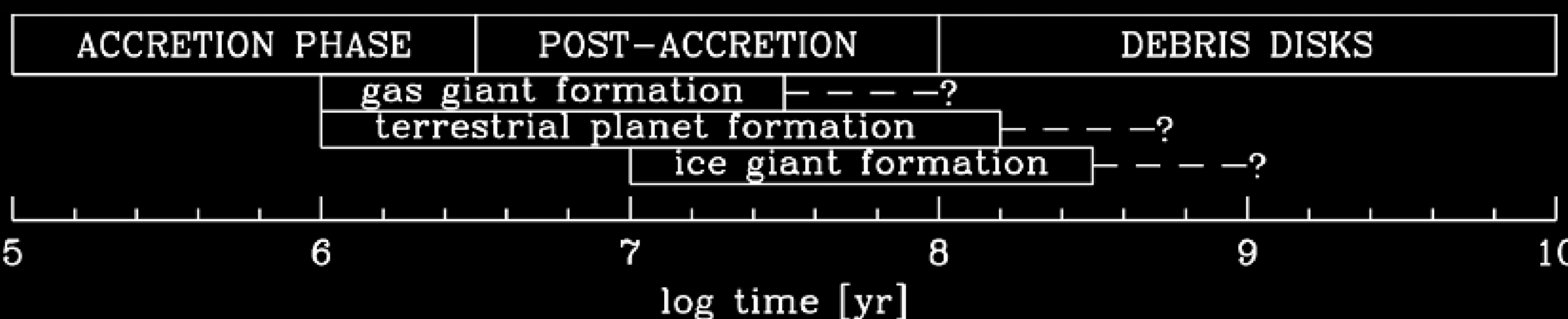
- Eventually the remnant disk is dispersed, leaving behind the central protostar, and its retinue of planets, minor bodies, dust and debris



The rocky road from Disks to planets







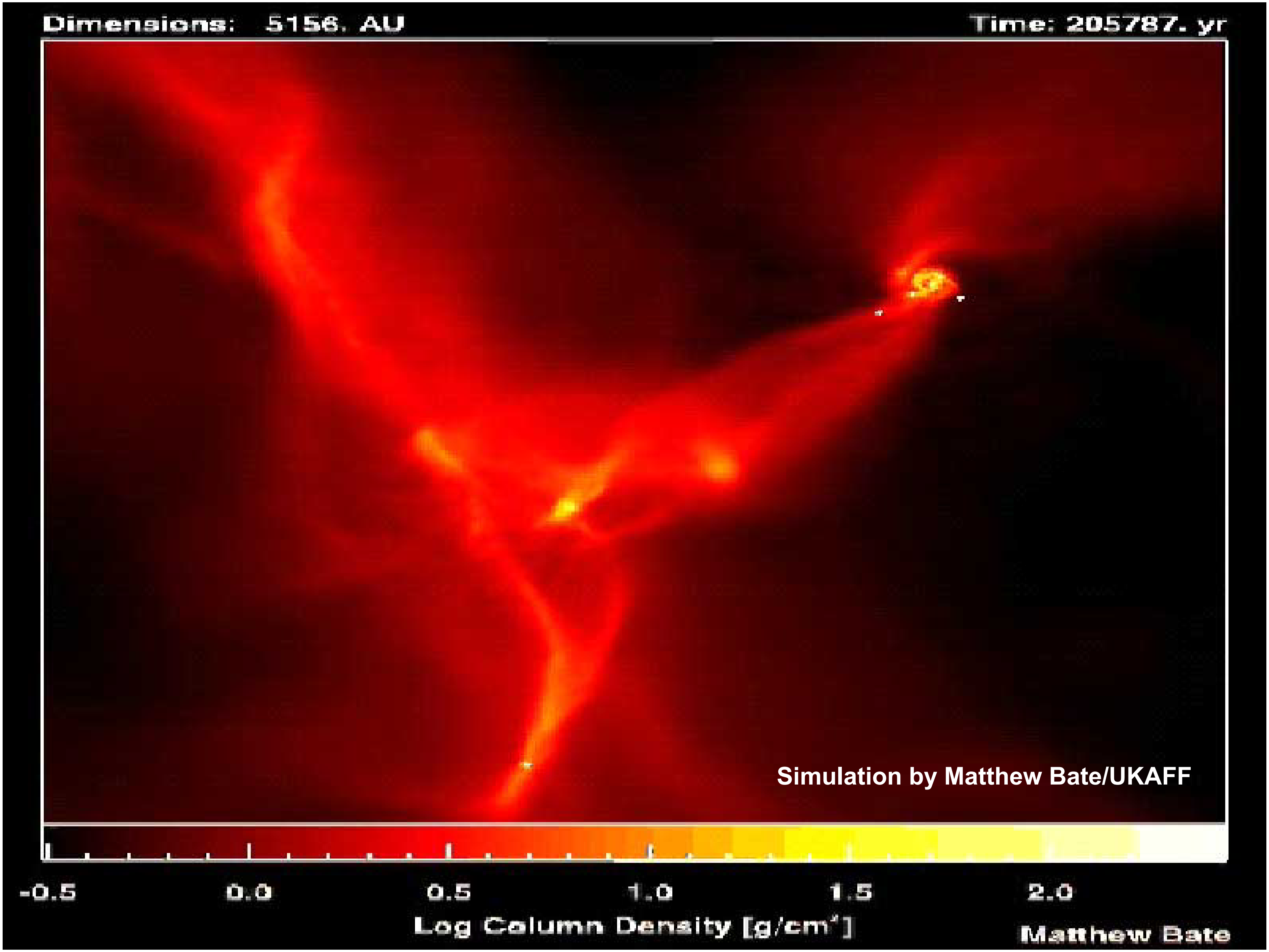
The next slide contains an animation that can be downloaded from:

http://www.ukaff.ac.uk/starcluster/

Narration over the animation:

The questions we seek to answer include:

- **How do stars form from the interstellar medium ?**
- **How are stars assembled inside dusty and gaseous nebulae ?**
- **How do circumstellar disks form ?**
- **What is the fate of these circumstellar disks ?**
- **Could they produce the chemical complexity that led to conditions similar to the early Earth ?**
- **The answers to these can be found from high angular resolution observations at far-IR wavelengths of the major FIR cooling lines; from species such as H_2O that are impossible to observe from the ground, and of the mineralogy of the solid material - dust – to understand how planetesimals are assembled.**


Dimensions: 5156. AU
Time: 205787. yr
Simulation by Matthew Bate/UKAFF
-0.5
0.0
0.5
1.0
1.5
2.0
Log Column Density [g/cm²]
Matthew Bate

The next slide contains an animation that can be downloaded from:

http://www.solarviews.com/cap/ds/vhh30.htm

Narration over movie in central panel:

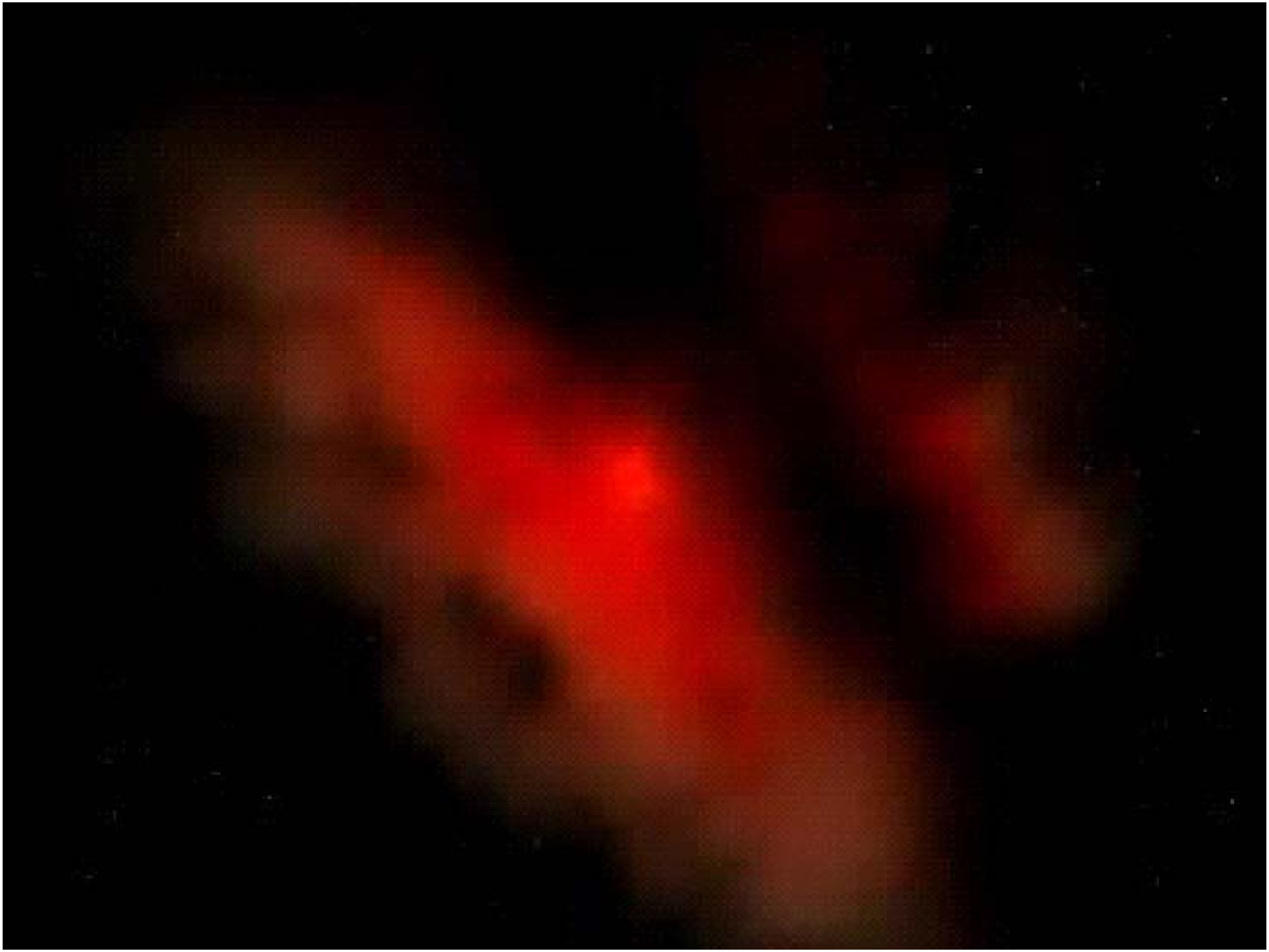
- **Material that avoids either falling into a forming star or being ejected in outflows can form stars and planets . The characteristic fingerprints of star formation are seen at mid/far-infrared wavelengths. Star-forming regions are highly obscured; the dust absorbs a significant fraction of all light shortward of the near-infrared and re-radiates this energy in the far-infrared**

- **The gas reservoirs cool through an extensive network of atomic, ionic and molecular cooling lines, which include the fine-structure lines of carbon and oxygen, ionic lines of neon and sulphur as well as many rotational transitions of molecules such as water and carbon monoxide. The lines can be very strong, emitting a fraction of the total far-infrared bolometric luminosity, and are generally not accessible to ground based telescopes**

- **Observations of combinations of lines will allow us characterise the physical properties that parameterise star-formation such as the nature and strength of the interstellar radiation fields, chemical abundances, local physical temperatures and gas densities. These powerful diagnostics can be used to study star-formation both very locally, and in the very distant Universe**

- **Observations of the solid material make it is possible to study the detailed mineralogy and compositions of the solid material – exocomets, zodi-disks, exoplanets**

- **The newly formed stars quickly couple to the galactic environment by injecting mass and radiation, exerting a profound influence on the chemical and dynamical evolution of the Galaxy**



The next slide contains an animation which can be downloaded from:

http://www.solarviews.com/cap/ds/vhh30.htm

Narration over the animation

- **Observations of the gas and dust in these regions can measure unique signatures of the formation Birth and formation of stars and planets Water is the major coolant of the envelope, and will be a much better diagnostic than molecules typically used from the ground. The lowest ortho/para transitions can be observed at very high spectral resolution in the far-infrared. Observations of the gas, using lines such as water and molecular hydrogen and far-IR lines of HD, will reveal the way that gas selfassembles the protostars – the high spectral resolution allowing details of the kinematics of the gas are accessible. Atomic limes, such as C+ will for the first time probe the detailed thermodynamics of the collapse process**

- **Water and other molecules can be studied close to the central object(s) to examine the gas flows, collapse, outflow etc; where the gas phase water in forming protostars resides; the heating rate of the central object. If there are compressive hot spots in the forming disk water will be a good indicator of these. When the disk remains cold, H_2D^+ will allow the dynamics to be directly observed. H_2D^+ has been observed in its higher energy symmetry in protostars, however the coldest, mid-plane regions of the outer disk will require observation of the ground state transition in the far-infrared**

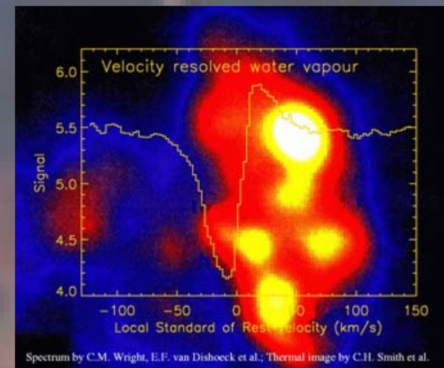
- **Observations of the solid material allow us to probe the structures of dust grains, the assembly mechanisms where grains coagulate together, eventually forming planitesimals, and the mineralogy of the planitesimals**

Structure of disks and star forming regions:

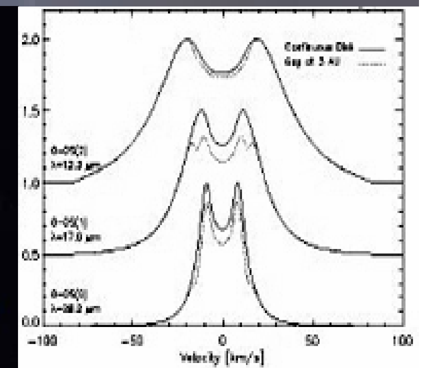
High resolution far IR spectroscopy:

Ions, hydrides, molecules

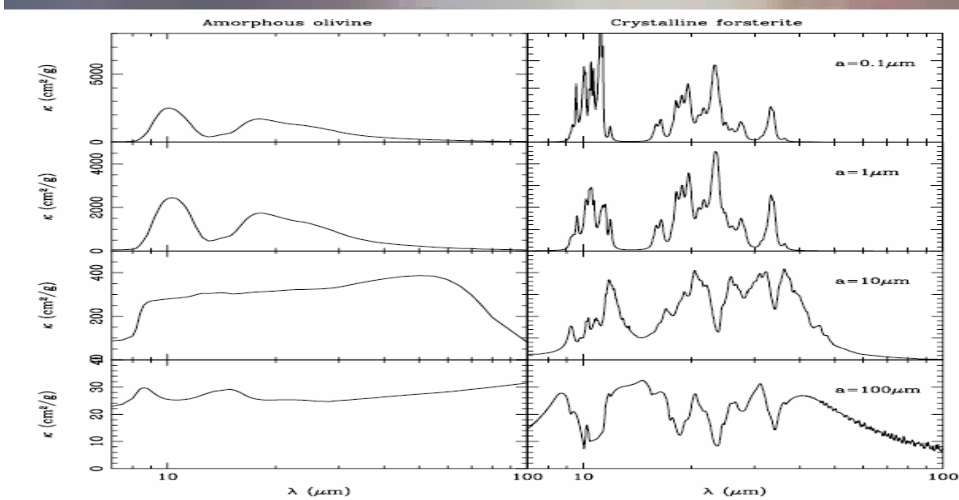
→ physical conditions in star forming cores and planet assembly regions



Traces water / ice



Main gas reservoir



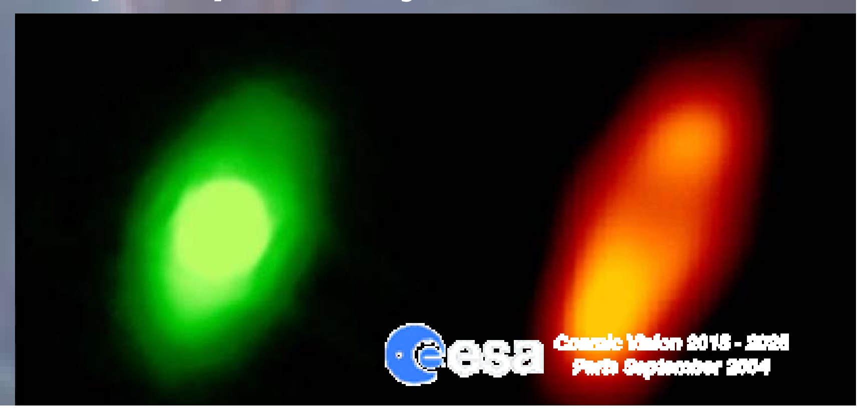
Low resolution far IR spectroscopy:

Water and organic ices, crystalline silicates, forsterite, calcite …

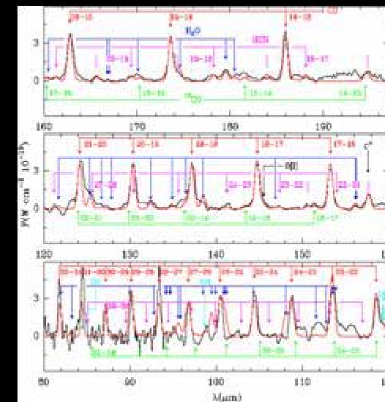
→ growth and evolution of solid state material in forming protoplanetary disks

High angular resolution far IR imaging

→ resolve assembly scales: discs, planetary systems, clusters, magnetic fields – dissipation, brown dwarfs, planets ?



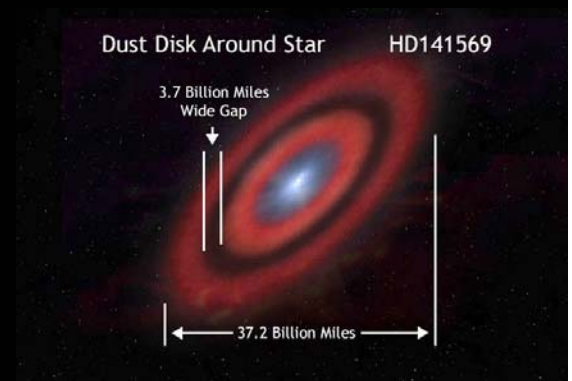
Top Level Science Objectives



Directly observe the formation of stars and planets

→ gas and dust formation in protoplanetary environments

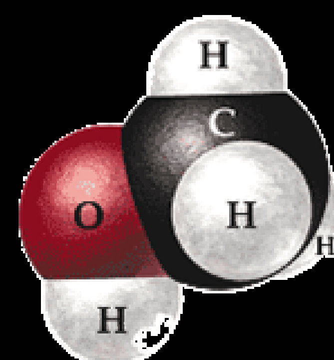
What planetary system architectures are present



→ what time scales do they evolve on ?

→ rotation, hot spots in the disk structure ?

What conclusions regarding habitability may be drawn from the observations of the molecular gas ?



→ formation of complex molecules - how ?

→ questions of great scientific and philosophical importance

Key Science objectives

- *Flow of gas and in cold dark pre-stellar clouds*

  → **accretion stages, outflows, shocks**

- *Abundance of gas around evolving protostars*

  → **planet assembly process, gaps, radiation**

- *Kinematics & chemistry of protostar / disk interaction*

  → **Planet formation and disk dynamics?**

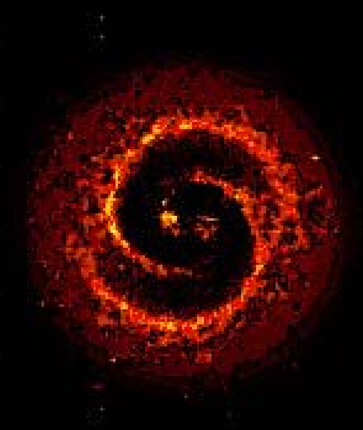
- *How is water,CO, OH and H_2 distributed in the envelope ?*

  → **ices → gas → planetesimals → dust assembly in C/O rich environments**

- *Magnetic fields and turbulence ?*

- *Implications for the formation of comets and asteroids/chondrites?*

- *Initial conditions and stellar mass that favour life ?*



Scientific Requirements

High angular resolution far IR spectroscopic observations

- **Actively cooled telescopes 20 ⟶ 200 μm → H_2 → C^+**
- **Angular resolution ⟶ 0.01 arcsec ⟶ 1 AU at Taurus**
- **High and low resolution spectroscopy ⟶ 1 km s^{-1}**
- **Baselines to ~ 1 km ⟶ unique gas and dust tracers in far IR ⟶ main gas reservoirs ⟶ mineralogy of planetesemal assembly**

  → First high angular resolution far-IR observatory

Cryogenic detectors limited by the natural background:

- **Large format arrays 10 – 100x more sensitive than current**
- **Heterodyne detectors for high velocity resolution**

  ⟶ New generation of sensitive detectors

Capability to develop detectors already exists in Europe

Help to maintain the European lead in FIR instrument technology

esa

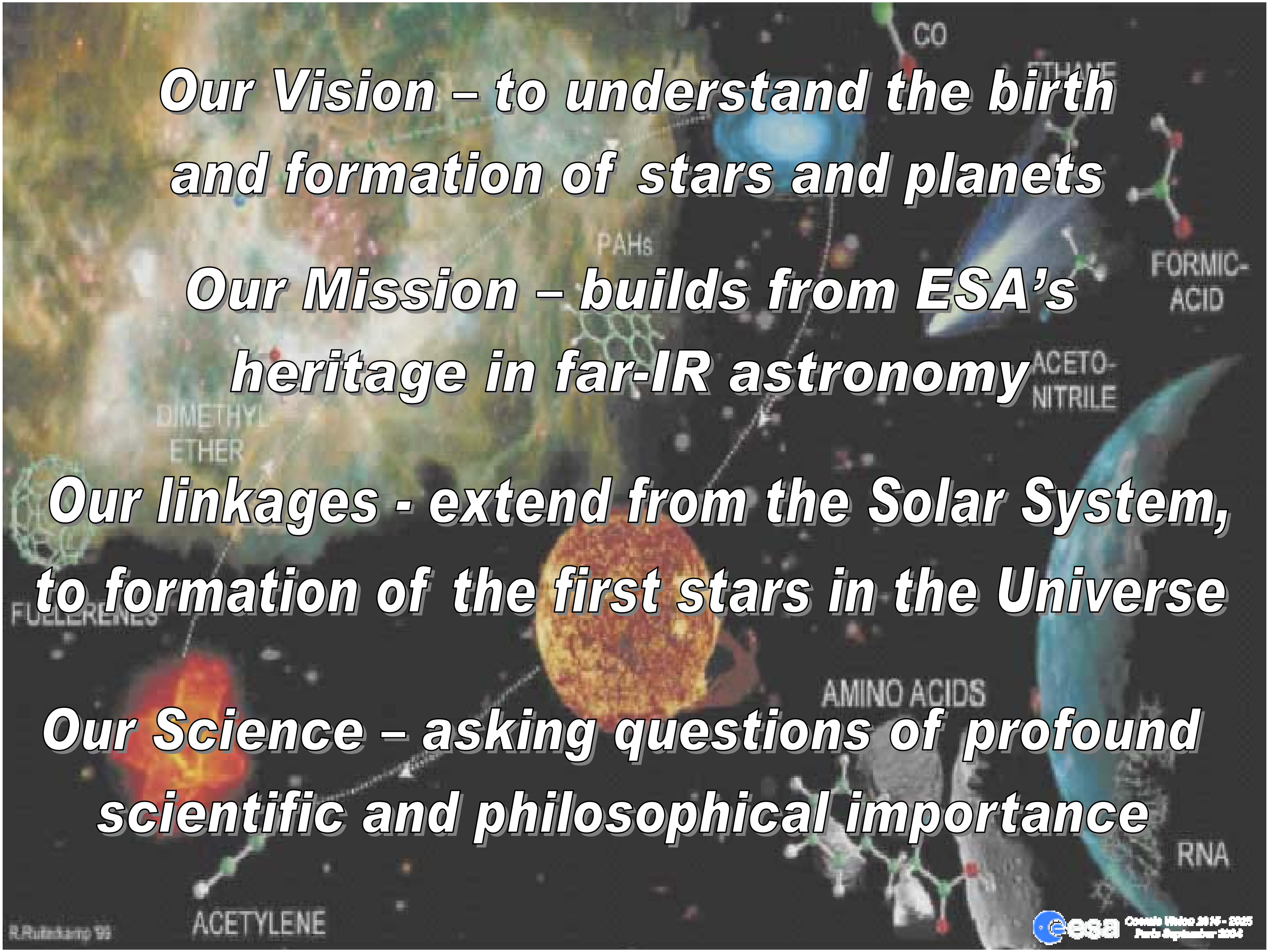

A multidisciplinary activity of great interest to the Public
Interdisciplinary
A collaborative programme
Public responsibility
Spin off
Maintain European lead
Builds on ESA heritage
esa
Cosmic Vision 2015 - 2025
Paris September 2004

Our Vision – to understand the birth and formation of stars and planets

Our Mission – builds from ESA's heritage in far-IR astronomy

Our linkages - extend from the Solar System, to formation of the first stars in the Universe

Our Science – asking questions of profound scientific and philosophical importance



This presentation used a number of animations and slides to summarise current understanding of the formation and properties of protostellar disks. Credit to the images (where not explicitly contained on the slides or in the links includes:

Slide 4 centre panel: Mark Garlick www.space-art.co.uk, and Hayden Planetarium http://vis.sdsc.edu/research/orion.html

Slide 6 http://www.astronomy.swin.edu.au/

Slide 9 Matthew Bate: http://www.ukaff.ac.uk/starcluster/

Slide 11 http://www.solarviews.com/cap/ds/vhh30.htm

Slide 13 http://www.solarviews.com/cap/ds/vhh30.htm

Slide 14 H_2 simulaution – University of Toronto, Water image C Wright, E van Dishoeck, C Smith

Slide 15 Methanol molecule: E van Dishoeck Leiden University website

Slide 19 Rene Ruiterkemp, published in Ehrenfreud and Charnely ARAA 2000, 38, 427

I would also like to acknowledge the contributions of many colleagues who contributed ideas for the science themes in this proposal, especially Bruce Swinyard, Matt Griffin, Thijs de Graauw, Ewine van Dishoeck, Frank Helmich, Jose Cernicharo, and the ESPRIT Workshop held in Utrecht September 2004