Planetary atmosphere modelling and other activities at LMD, IPSL

François Forget and the LMD « Planetogy » team

CNRS, Institut Pierre Simon Laplace, Laboratoire de Météorologie Dynamique, Paris

Planetary Science in « Laboratoire de Météorologie Dynamique » (LMD) within Institut Pierre Simon Laplace (IPSL) In the Paris aera, France

• **LMD** = « **Laboratory for Dynamic Meteorology** : A department (~200 persons)
⇨ ***Atmospheric Sciences: theories, modeling and observations***

•**IPSL** = « **Institut Pierre Simon Laplace** »
= A federation of 7 « laboratories including » LMD (~1200 persons) in the Paris aera
⇨ ***Environmental Sciences: ocean, biosphere, atmosphere, chemistry, paleoclimates, planetary sciences***

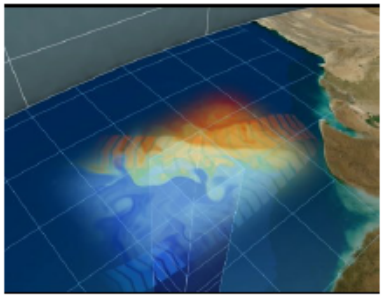
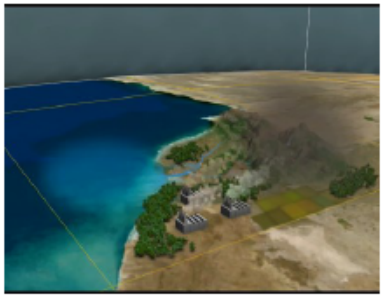
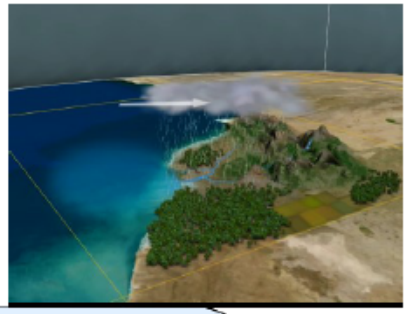
• **CNRS** = The big National administration which coordinate french research and pays civil-servant scientist salaries (unless they are professor in Universities)

• **UPMC =** University Pierre & Marie Curie: The Big University where our offices are and which pays Professors like Aymeric Spiga.

Institut Pierre Simon Laplace
Sciences de l'environnement

Numerical modelling of Earth climate at LMD and IPSL

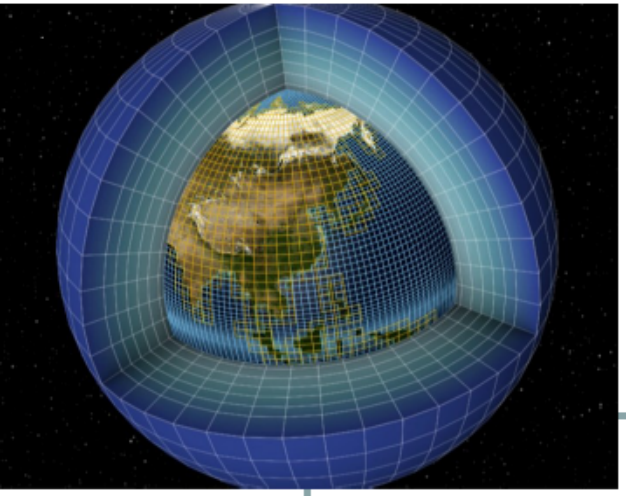
The IPSL-CM5 Earth System Model

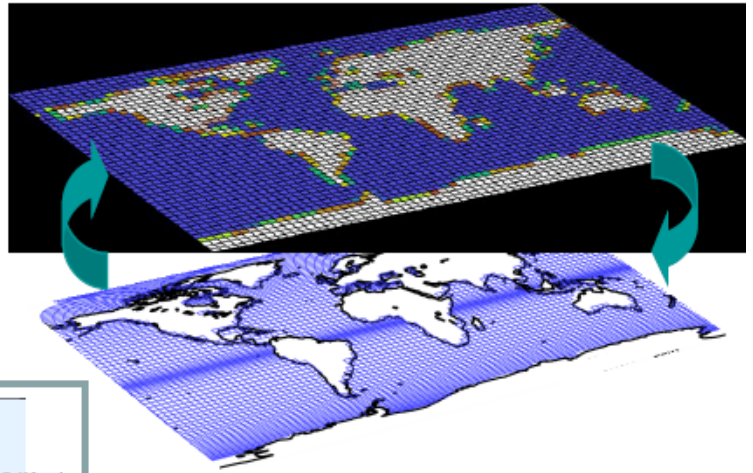
INCA / REPROBUS
(chimie atmosphérique)
(aérosol)

LMDZ
(atmosphère)

ORCHIDEE
(surfaces continentales)
(végétation)



OASIS
(coupleur)



OPA
(océan)

LIM
(glace de mer)

PISCES
(biogéochimie marine)

NEMO

***All models are developed at IPSL**, except the coupler*

Institut Pierre Simon Laplace
Sciences de l'environnement

Planetary Sciences at IPSL The « Solar System Center »

- ~80 permanent scientists and engineers et ~60 contractors (post-doc, students, engineers) working on Planetary Sciences

- **3 main topics** :

1. Climate and Meteorology on other planets
2. Interaction Sun – Planets - Earth
3. Origins of Planets and Life.

Institut Pierre Simon Laplace
Sciences de l'environnement

Topic #1 : Climate & [illegible] anets
Space-ba[illegible] delling

Mars Express: See talk by François Forget on Wednesday afternoon

Insight & Exomars: See talk by A. Spiga on Thursday

Venus Express: See talk by Sebastien Lebonnois on Thursday

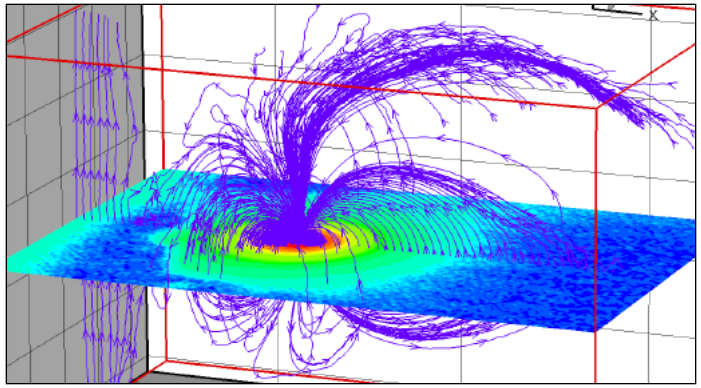
- **Mars**
  - ***Space Mission*** : Mars Express (instrument SPICAM, « IDS », Co-Is) : *LATMOS + LMD* [illegible] *A Exomars, Insight (2016, 201[illegible]*
  - ***Mod*** [illegible] imulator », méso/micro-scale: *LATM*
- **Venus**
  - ***Space Mission*** : Venus Express (instrument SPICAV-SOIR (LATMOS), Co-Is) : *LATMOS + LMD*
  - ***Modelling*** : GCM Venus: *LATMOS + LMD*
- **Titan**
  - ***Space Mission***: Cassini Huygens (PI, coIs)
  - ***Modelling*** : "IPSL" Titan GCM (*LMD + GSMA*)
- **Exoplanets** *& past atmospheres*
  - ***Modelling:*** « Generic » GCM (*LMD, LATMOS)*

⇨ *Space telescope Echo (ESA, preselected)*

Topic #2 :
Interaction Sun – Planets – Earth

- Interaction solar wind - exosphere - atmospheres
  ⇨ Atmospheric Escape
- Heliosphere and solar wind studies

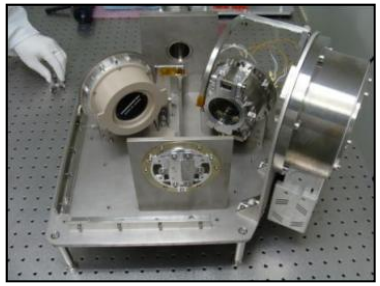
Numerical Simulations

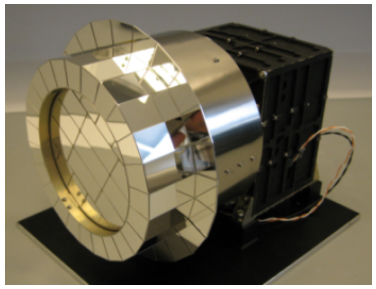


Modelling exospheres & interactions with solar wind

- Earth
- Mars (⇨ Mars Express; Maven)
- Mercury (⇨ Bepi Colombo)
- Ganymede (⇨ JUICE)

Space Obs.: UV and Mass spectrometers





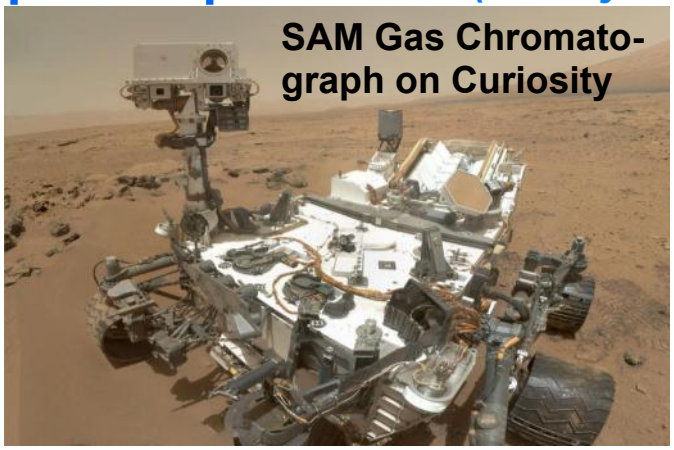
Ex: - **SOHO/SWAN** (Sun)
- Cassini: around Saturn (and Titan) since 2004
- Rosetta (launch: 2004: Comet in 2014). See below.

-Bepi-Colombo : Mercury (launch 2015) (LATMOS)
PI UV spectrometer *PHEBUS* (UV spectro & **co-PI *PICAM***
- **MAVEN** (Mars, launched 2013) : see below
- **TARANIS** (Earth): see below (2015)
- **JUICE** (Jupiter 2022): Mass Spectro ***NIMEIS*** , LATMOS (F. Leblanc) on instrument sutie JUMMP (Pi: Coates)

Topic #3 :
Origins of Planets and Life.

- To understand solid body formation by studying comets, asteroids and interplanetary dust.
- To study extraterrestrial organic matters and its evolution. (e.g. Mars, Titan).

Space experiments *(mostly in-situ)*



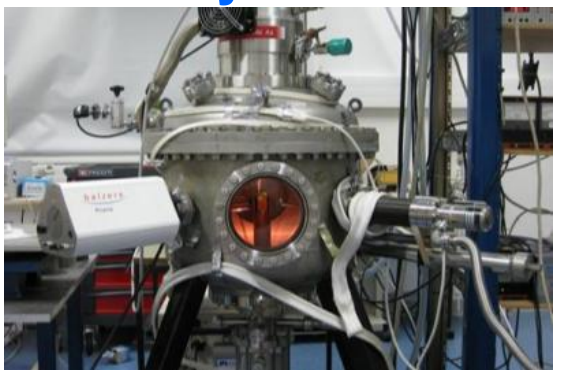
• **In-situ Analysis (LATMOS-LISA)**

-***Gas Chromatograph:*** SAM (Curiosity), GAP (Phobos-Grünt 2011) , COSAC (Rosetta, Comet) MOMA (Exomars Rover 2018) + COSIMA (dust analyser, Rosetta)

-**Radar (LATMOS):**

- Consert + Permitivity probe (Rosetta)
- Wisdom (Exomars Rover2018)

Laboratory simulations



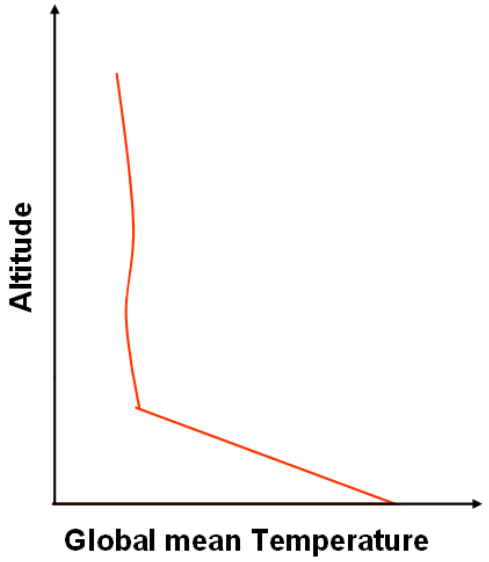
• **Simulating photochemistry on Titan and organic aerosols.**
Experiments PAMPRE (LATMOS), PLASMA, SETUP (LISA), SMARD (LATMOS,+LISA)

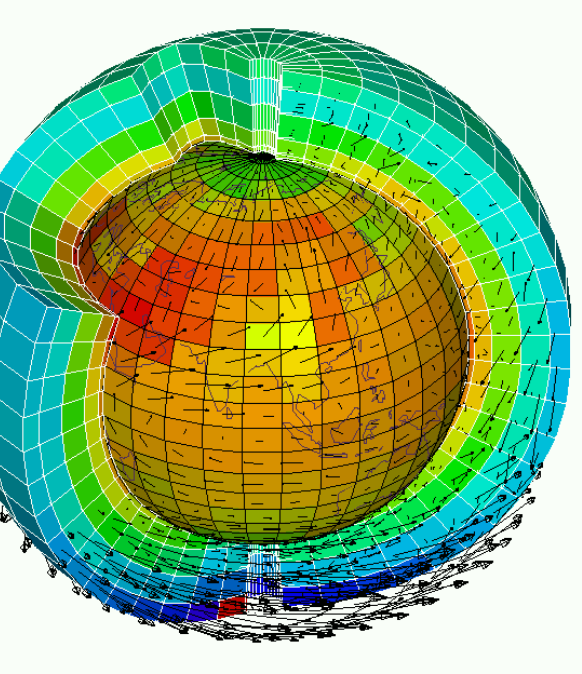
• **Physic of space ices :** experiments OREGOC (LISA), SPICES (LPMAA)

• **Physico-chemistry of Mars surface**
ExperimentsMOMIE (LISA+ LATMOS)

Modelling of Planetary Climates at LMD and IPSL

A hierarchy of models for planetary climatology





1. 1D global radiative convective models

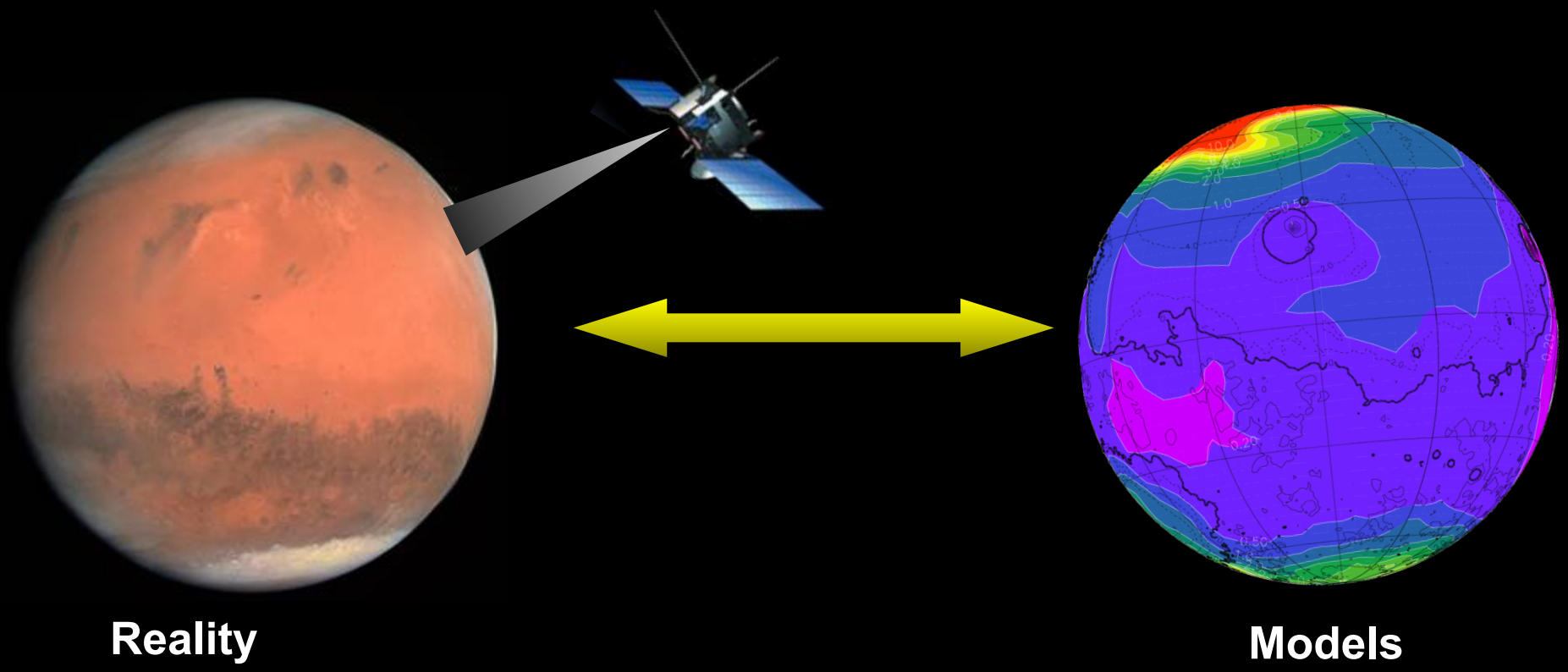
⇨ Great to explore a wide range of possible climates; *(e.g. Kasting et al. 1993)*

2. 2D Energy balance models…

3. Theoretical 3D General Circulation model with simplified forcing: used to explore and analyse the possible atmospheric circulation regime (*see Read 2011, Heng et al. 2011Showman et al. 2013, etc)*

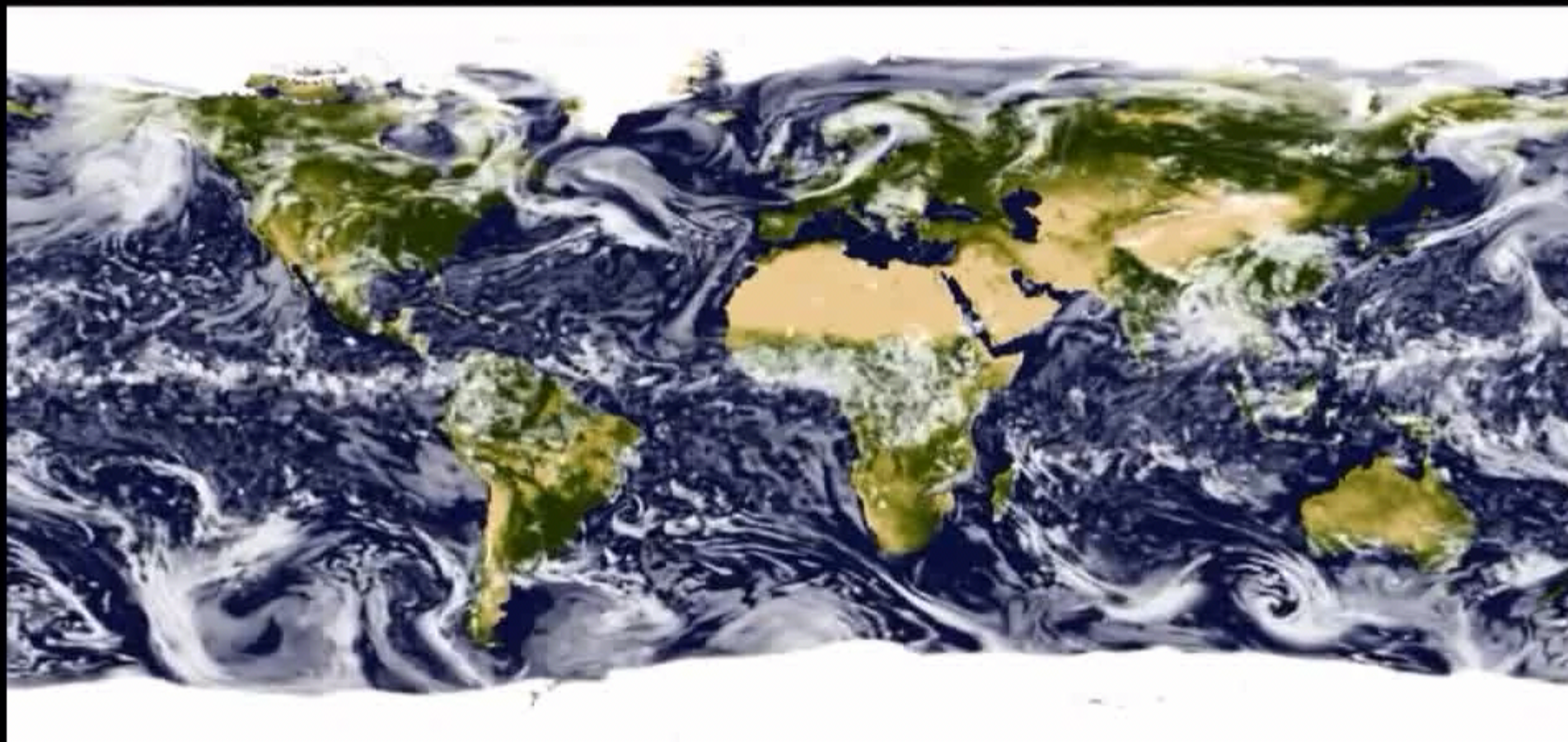
4. Full Global Climate Models aiming at building “virtual” planets.

Ambitious Global Climate models : Building “virtual” planets behaving like the real ones, on the basis of universal equations



How to build a full Global Climate Simulator ?

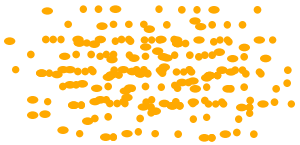
Earth System Model (CESM),:



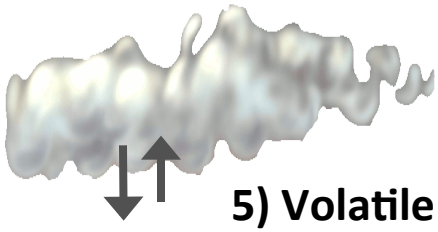
How to build a full Global Climate Model :

1) Dynamical Core to compute large scale atmospheric motions and transport

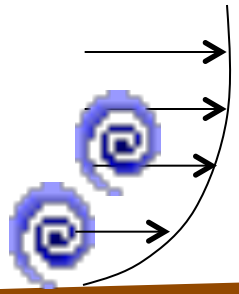
2) Radiative transfer through gas and aerosols



6) Photochemical hazes & mineral dust



5) Volatile condensation on the surface and in the atmosphere



3) Turbulence and convection in the boundary layer

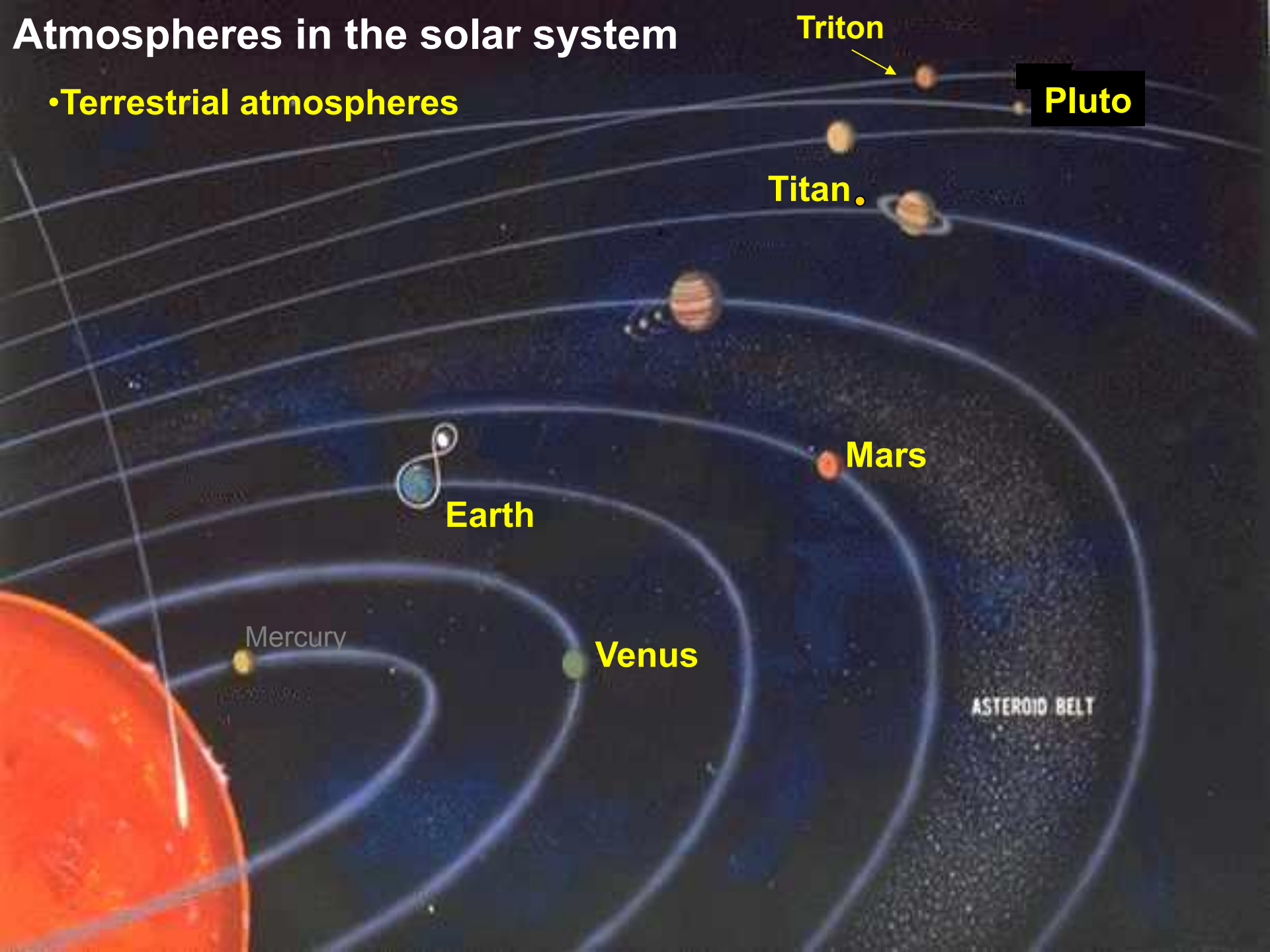
4) Surface and subsurface thermal balance

Forget and Lebonnois (2013) In "ComparativeClimatology of Terrestrial Planets" book, Univ of Arizona press 2013.

How to build a Global Climate Model :

Atmospheres in the solar system

- Terrestrial atmospheres

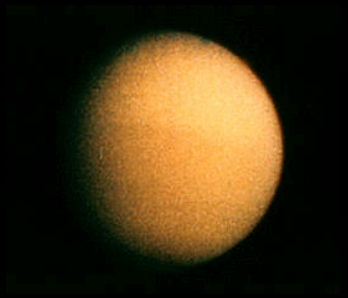


GCMs at LMD/IPSL

VENUS

EARTH

MARS

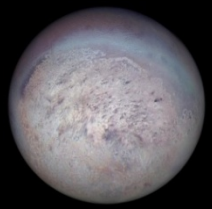


TITAN

Applications:
- Climatology
- **Climate projections**
- Paleoclimates
- chemistry
- Biosphere / hydrosphere cryosphere / oceans coupling
- Many other applications

Coupled cycles:
- CO_2 cycle
- dust cycle
- water cycle
- Photochemistry
- thermosphere and ionosphere
- isotopes cycles
- etc…

Applications:
Dynamics, assimilation; paleoclimates, etc…

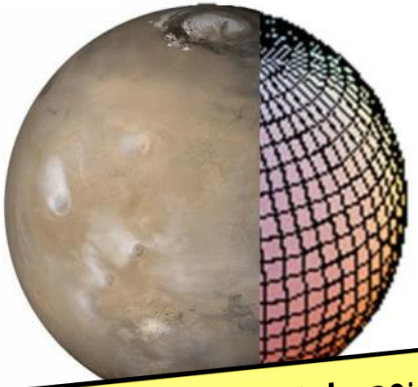


TRITON

PLUTO

T Mars system simulator »

Mars: See talk by François Forget on Tuesday morning



Mars Climate Database: See talk by Ehouarn Millour on Thursday

Atmospheric Dynamics

Exosphere Atm. Escape *(Latmos, LMD)*

CO_2 Cycle *(LMD, Latmos IDES)*

Mars GCM

Thermosphere Ionosphere *(IAA, LMD, Latmos)*

Mesoscale Model / LES

Dust cycle *(Oxford U., LMD, LISA, Latmos)*

Mesoscale models: See talk by Aymeric Spiga on Tuesday

Photo-Chemistry *(Latmos, IAA)*

Water Cycle *(LMD, Latmos)*

Radon Cycle

Climate variations & paleoclimates *(LMD, Brown U, IDES.)*

Volcanic eruption simulations (with Brown University)

HDO cycle *(Latmos, Lesia)*

Ancient Mars
(- 3 à -4 Gyr
(avec Harvard University Obs. Royal de Belgique)

Mars Climate database »

- Reference tool for the Scientific and Space Engineer community
- Version « pro » on DVD-ROM ordered par ~250 teams from ~20 countries
- Interactive website

d'Andalousie)

GCMs at LMD/IPSL

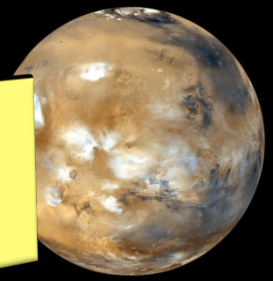
VENUS

Coupling dynamic & radiative transfer + cloud physics + photochemistry

Venus & Titan: See talk by Sebastien Lebonnois on Wednesday morning

EARTH

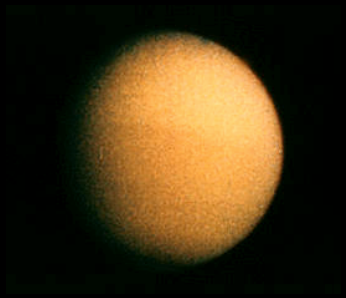
Applications:
- Climatology
- Climate projections
- Paleoclimates
- chemistry
- Biosphere / hydrosphere cryosphere / oceans coupling



MARS

Coupled cycles:
- CO2 cycle
- dust cycle
- water cycle
- Photochemistry
- thermosphere and ionosphere
- isotopes cycles
- etc…

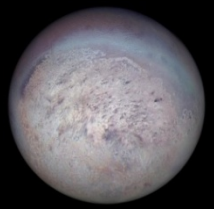
Applications:
Dynamics, assimilation; paleoclimates, etc…



TITAN

Coupling dynamic & radiative transfer +

Coupled cycles:
- Aerosols
- Photochemistry
- Clouds
- Paleoclimates



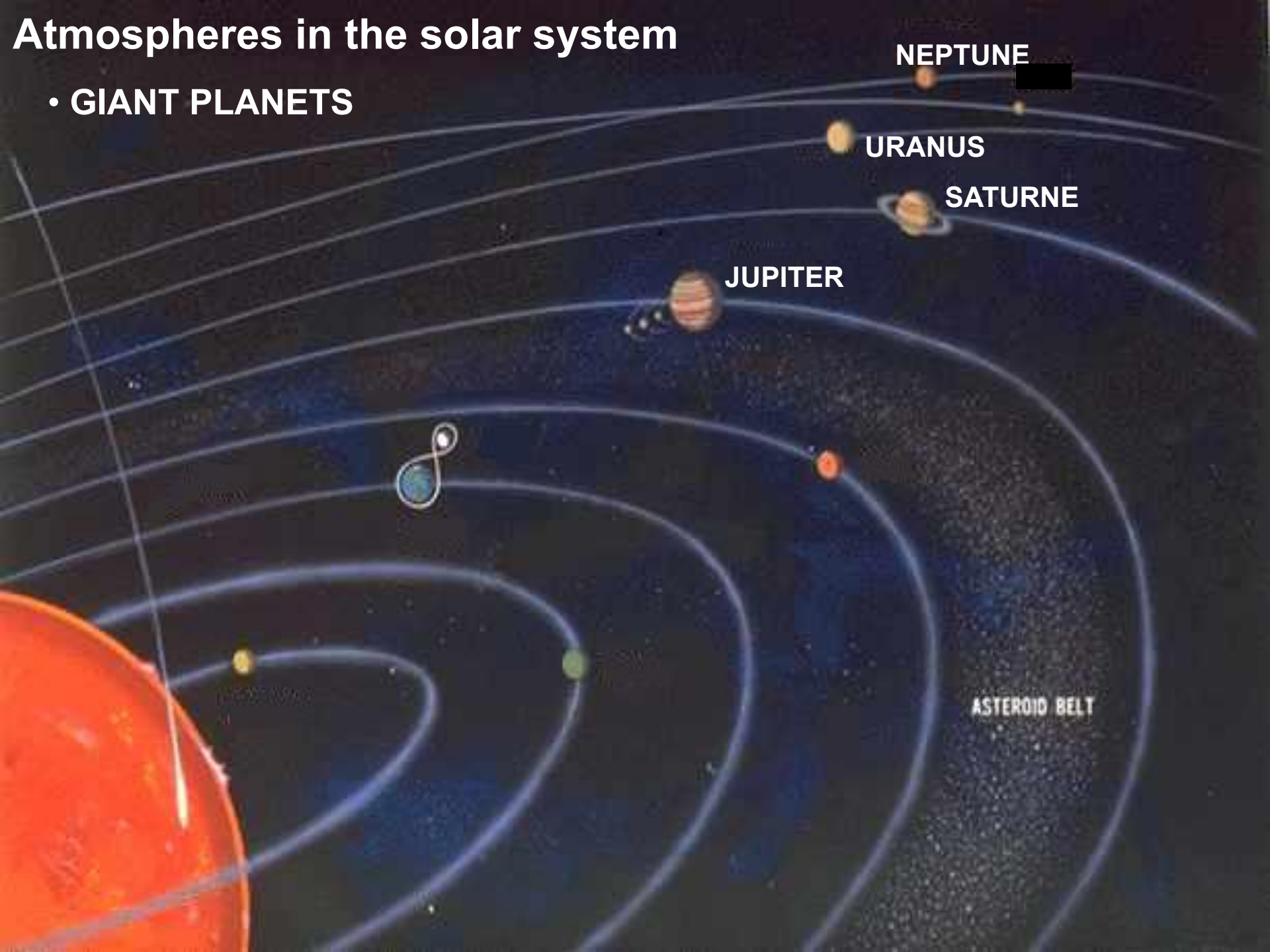
TRITON
GCM

PLUTO
GCM

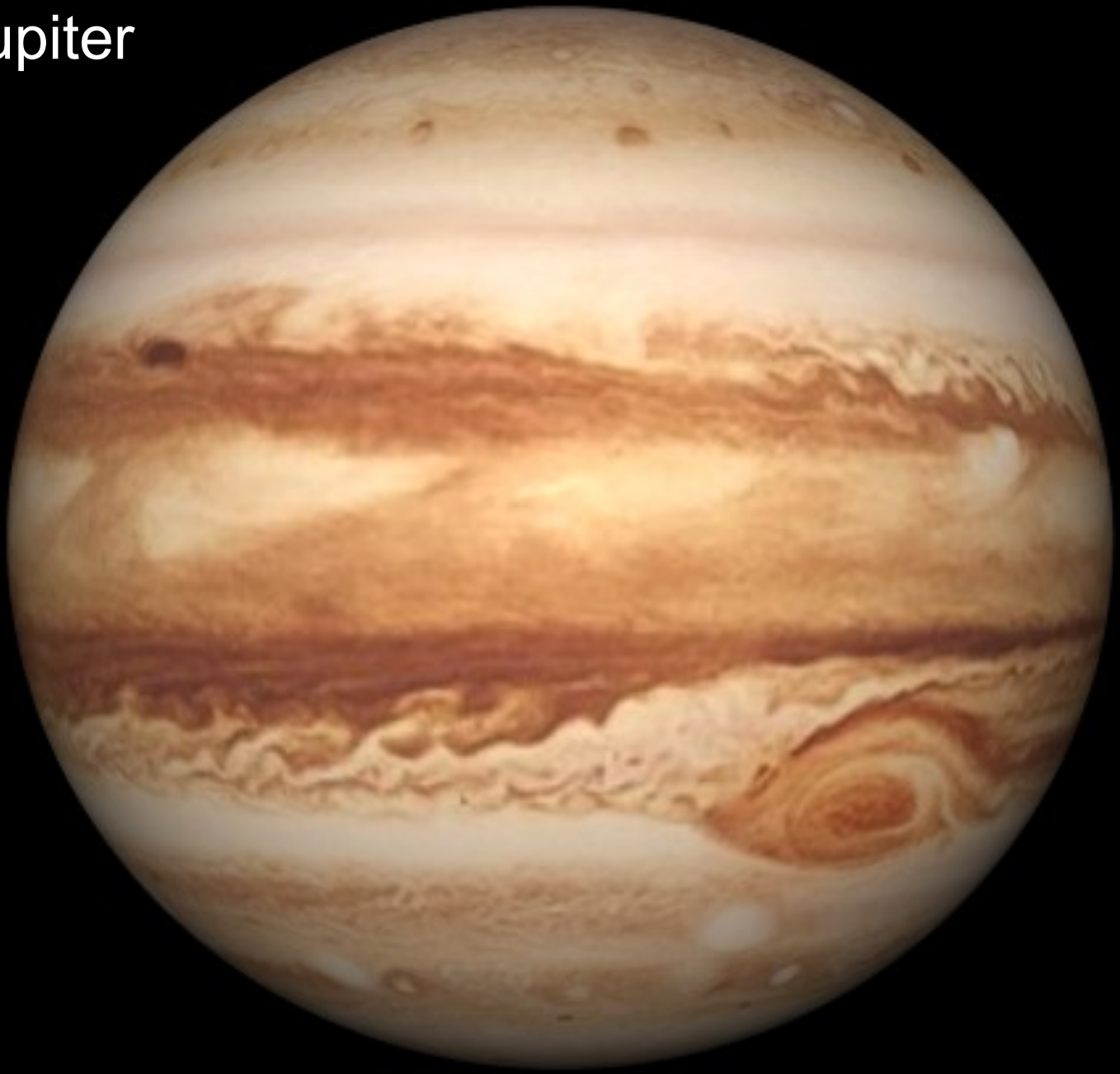
Pluto & Triton: See talk by François Forget on Friday

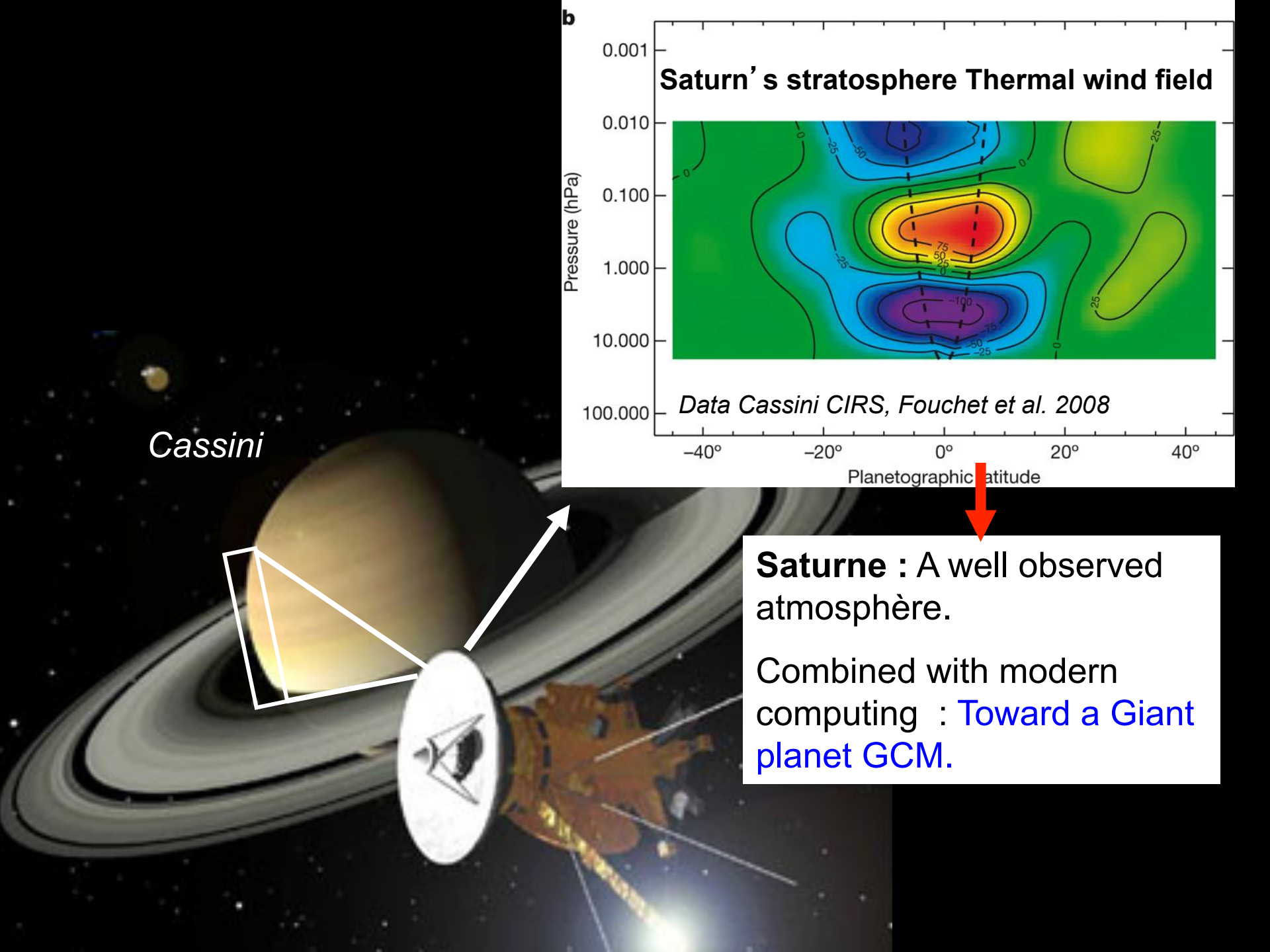
Atmospheres in the solar system

- GIANT PLANETS



Jupiter





Saturne : A well observed atmosphère.

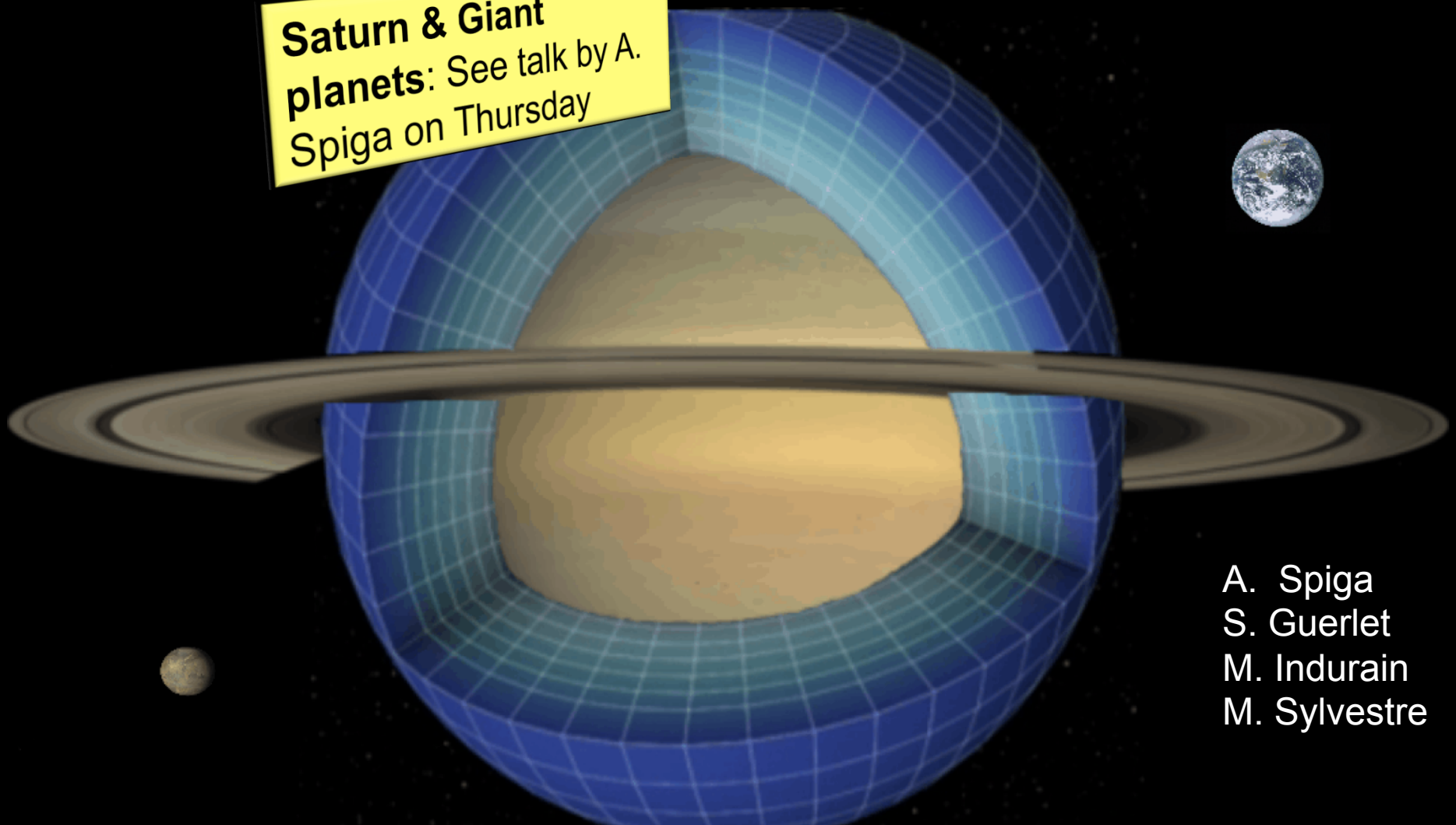
Combined with modern computing : Toward a Giant planet GCM.

A GCM for Saturn

Project « Emergiants » at LMD

Challenge: - Resolutions
- Long runs
- Boundary conditions

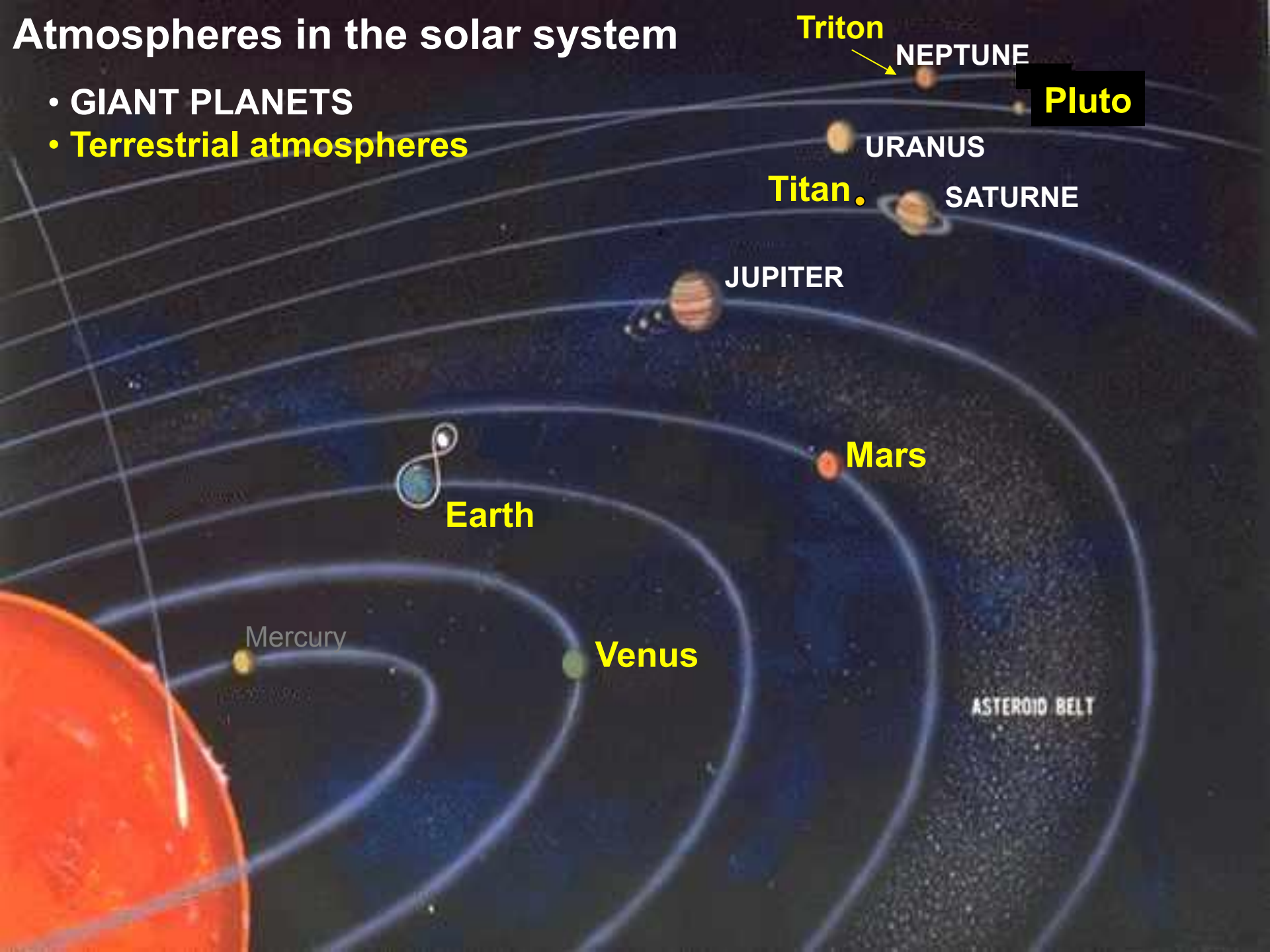
Saturn & Giant planets: See talk by A. Spiga on Thursday

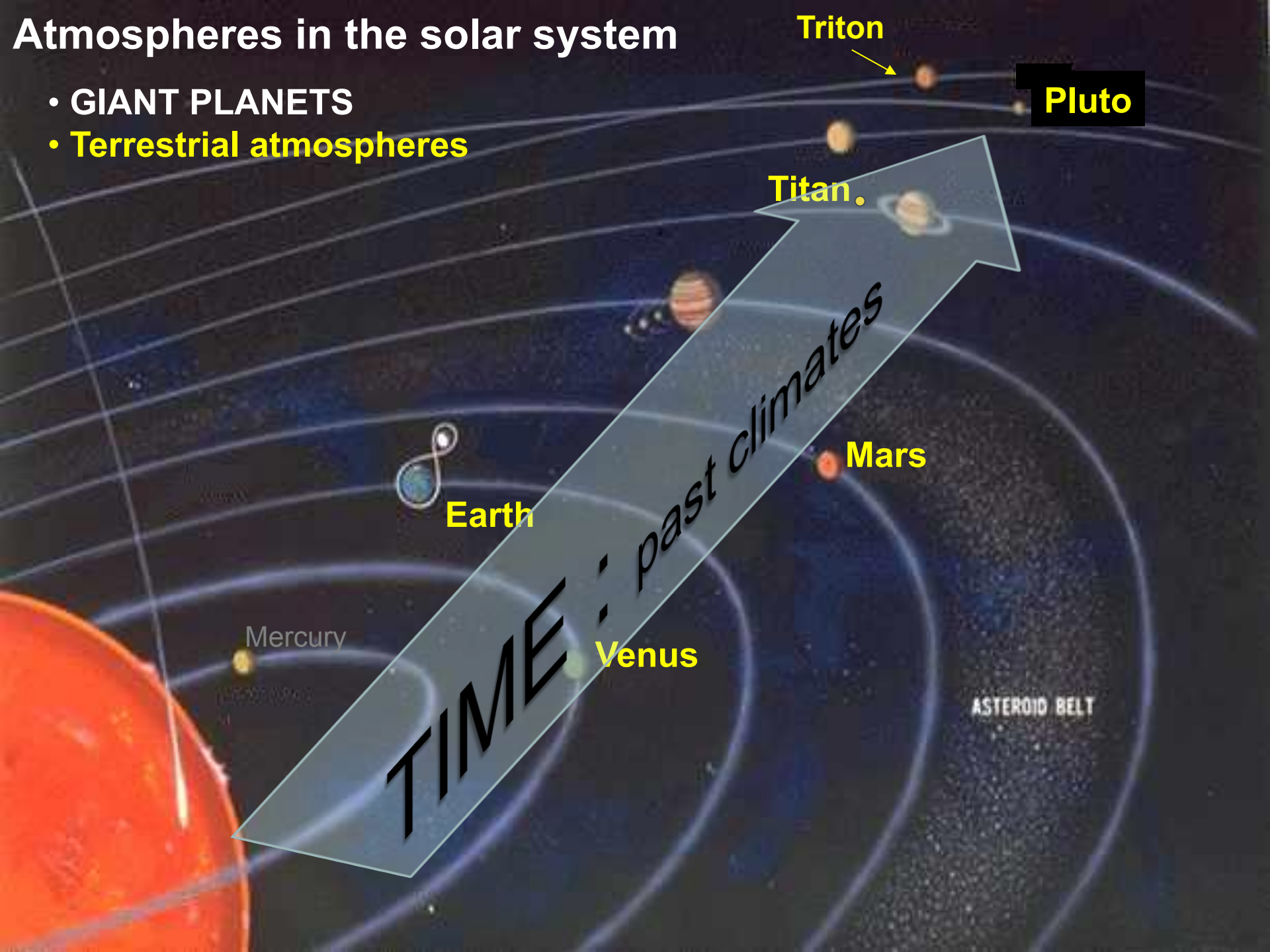


A. Spiga
S. Guerlet
M. Indurain
M. Sylvestre

Atmospheres in the solar system

- GIANT PLANETS
- Terrestrial atmospheres




Atmospheres in the solar system
• GIANT PLANETS
• Terrestrial atmospheres
Triton
Pluto
Titan
TIME : past climates
Mars
Earth
Mercury
Venus
ASTEROID BELT

Atmospheres in the solar system

- GIANT PLANETS
- Terrestrial atmospheres

Triton

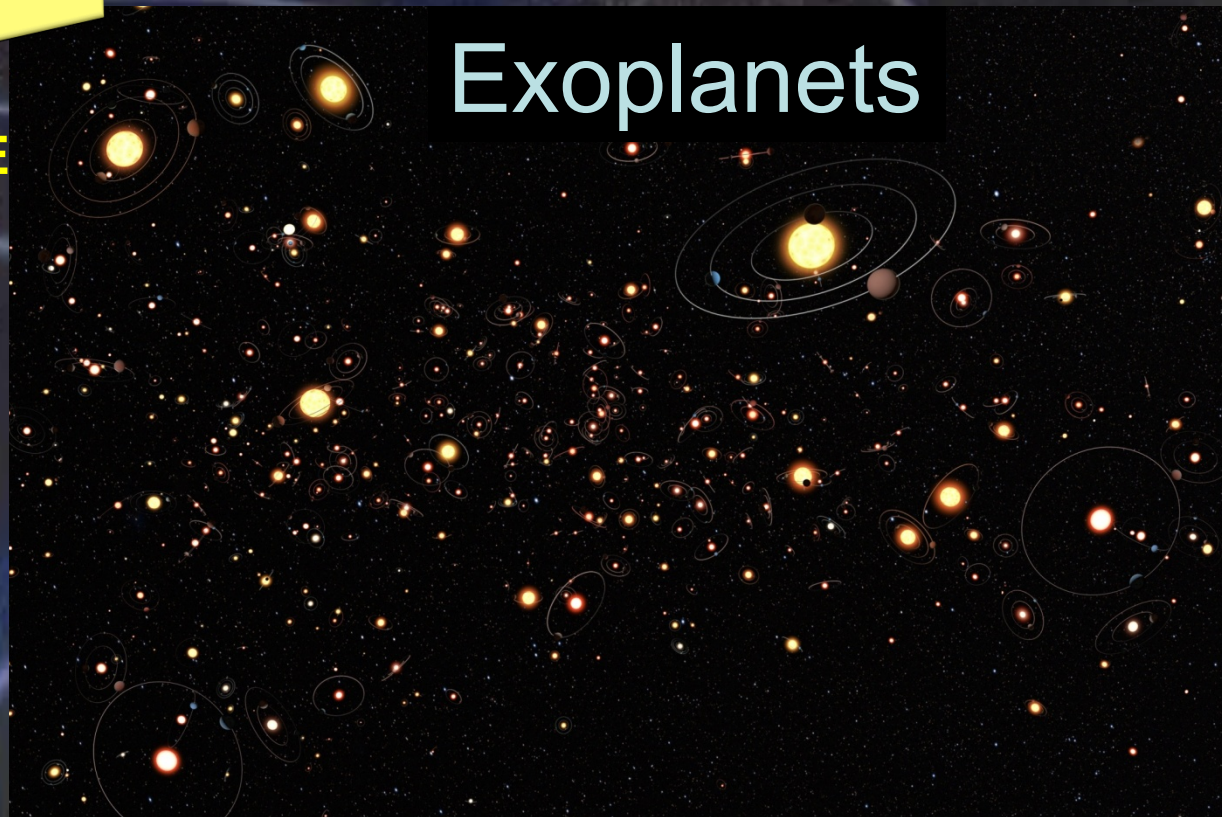
Pluto

Titan

Exoplanets & past climates: See talk by François Forget on Friday

E

Mercury



Why are we here today ?

- To collaborate and exchange ideas on modelling & planetary exploration…

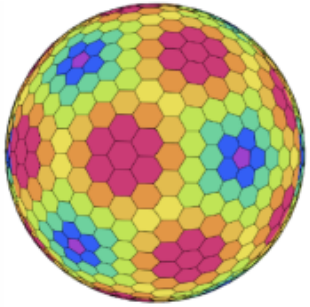
In particular:

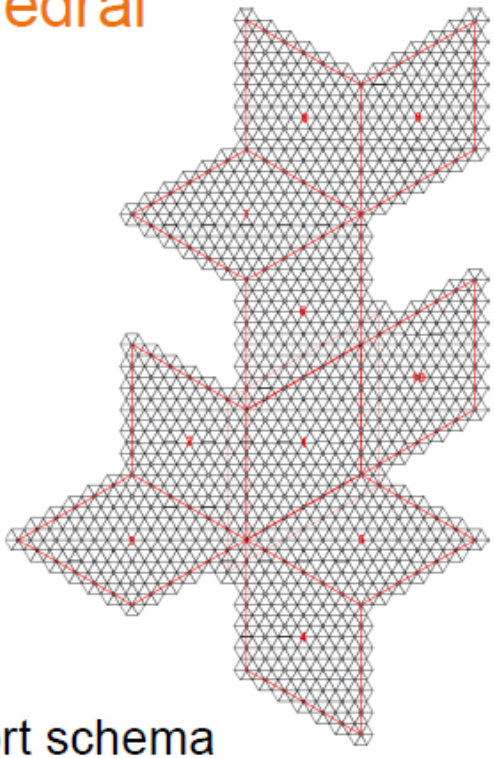
⇨ ***Brainstorm with you on the future of planetary climate modelling***

The future of planetary climate modelling: Some ideas

- **Improved dynamical cores & high parallelism**
  ⇨Toward very high resolution for global models

DYNAMICO: new dynamical core, icosahedral

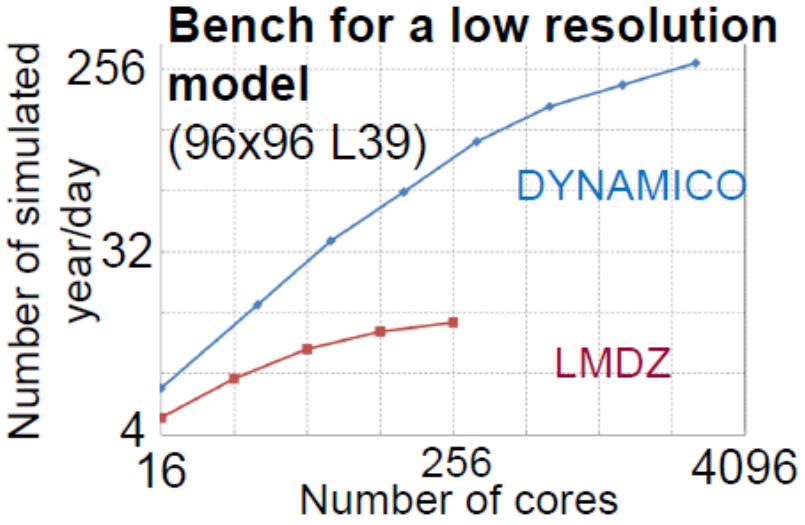




Present:

- New transport schema
- Quasi-uniform mesh
- Energy conserving

Participation to the ICOMEX project
Collaborations with applied mathematic
Collaboration with IIT Delhi (OP Sharma)



Bench with different resolutions

degrees	nb cores	year/day
3	320	**100**
1	1 280	**20**
½	11 520	***17***
¼	81 920	***14***

Plans:

- Stretched grid
- Non hydrostatic
- In the IPSL-CM model
- Deep atmospheres (planets)

The future of planetary climate modelling: Some ideas

- **Improved dynamical cores & high parallelism**
  ⇨Toward very high resolution for global models
- **Improved « parameterization » of climate processes**
  - More universal physics, less assumptions…
  - Design of Parameterizations + careful independant tuning using dedicated state of the art models (e.g. microphysics, LES, etc…)
  - Introducing stochastic events in global modelling
- **Toward a scientific methodology to tune Climate models..**

- Merci.
- Let’s have a great week !