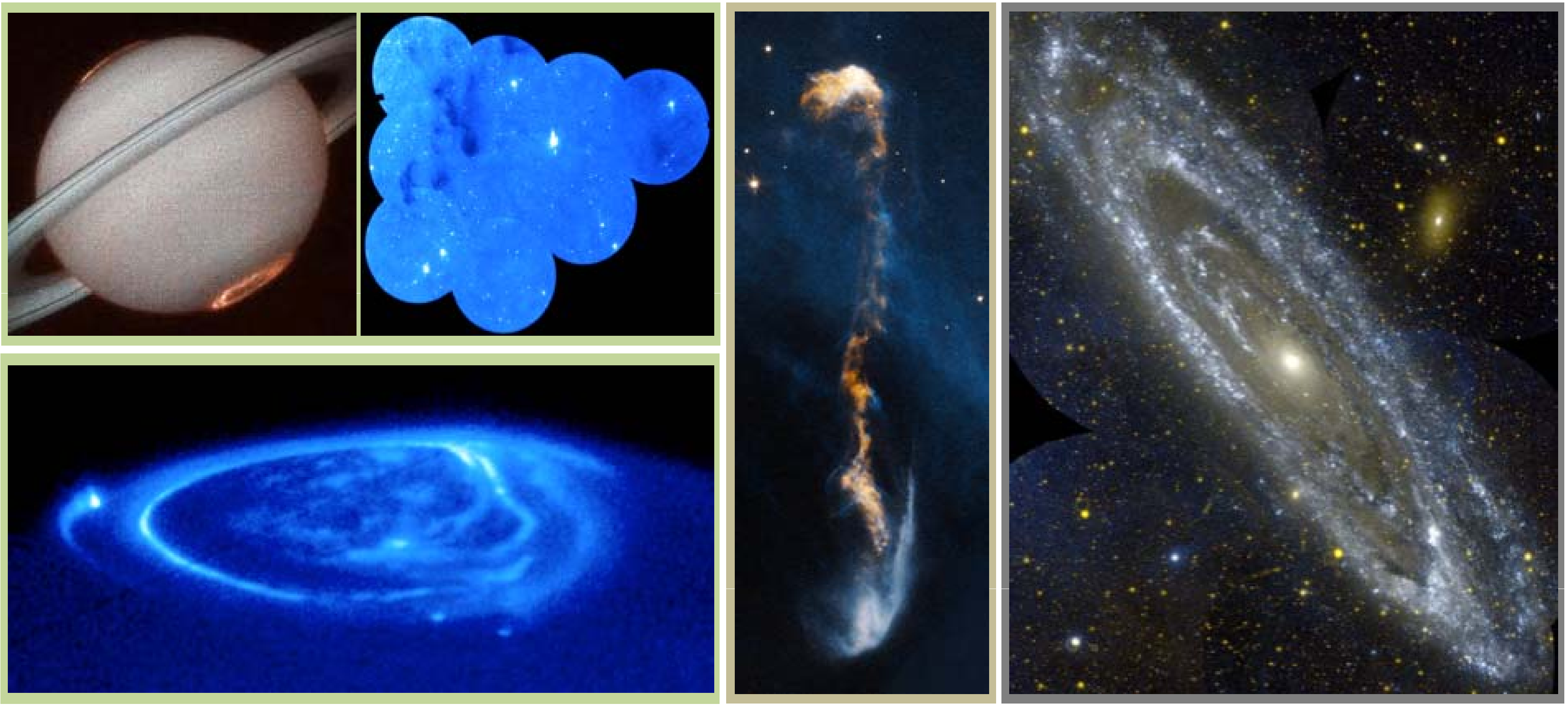


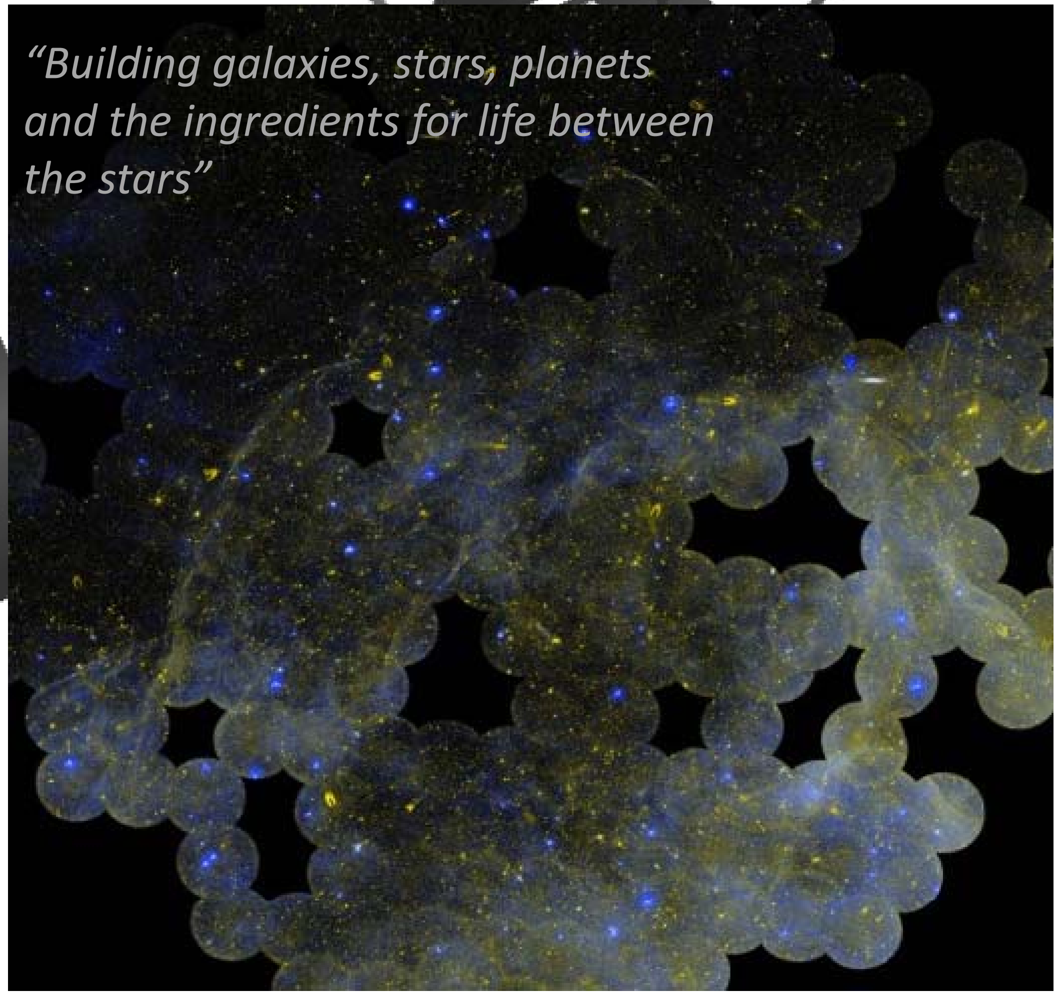
ESA COSMIC VISION – "THE FOUR THEMES"

Planets and Life - The Solar System - Fundamental laws - The Universe

EUVO

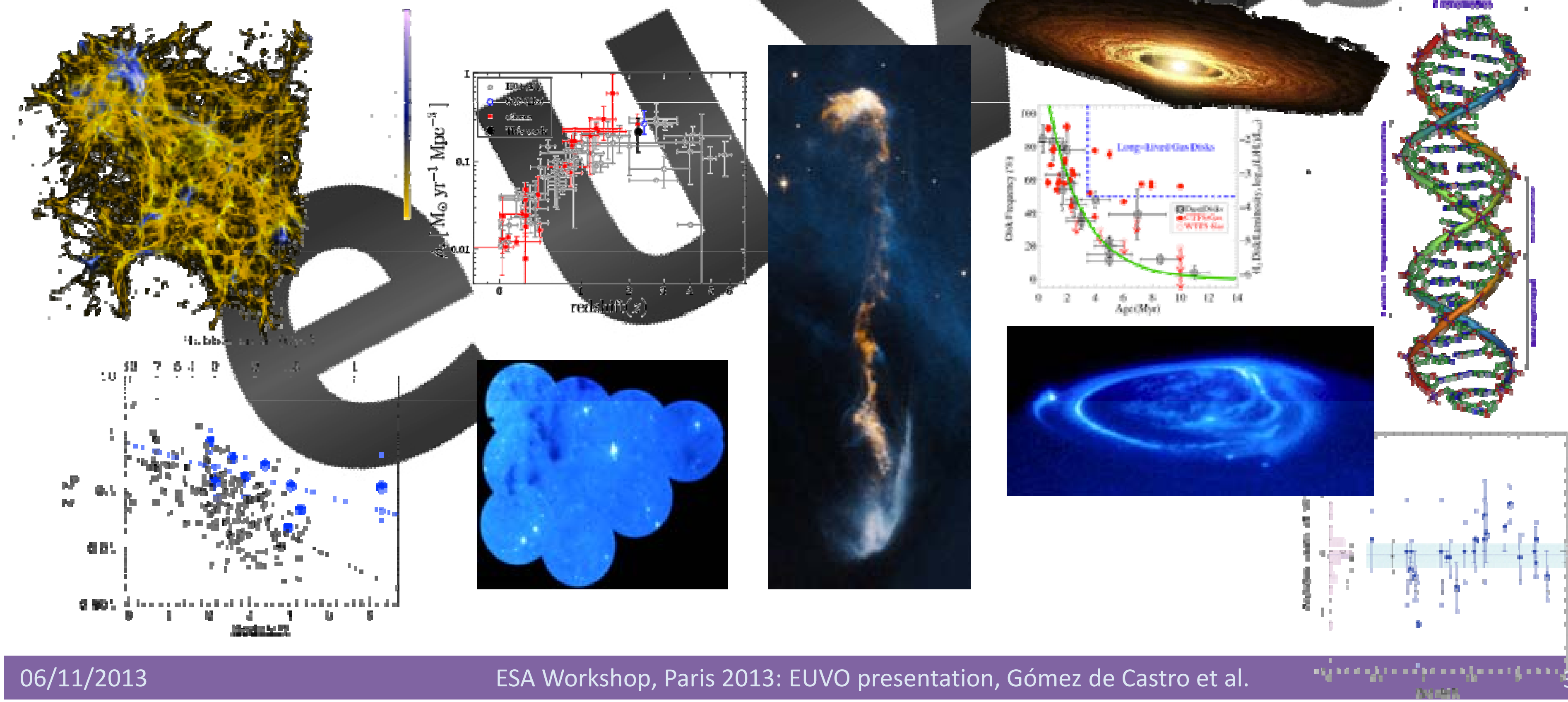
EUROPEAN ULTRAVIOLET-VISIBLE OBSERVATORY

Thierry Appourchaux – IAS France; Martin Barstow – University of Leicester UK; Mathieu Barthelemy - IPAG, France; Fréderic Baudin – IAS, France; Stefano Benetti – OAPD- INAF, Italy; Pere Blay - Universidad de Valencia, Spain; Noah Brosch - Tel Aviv University, Israel; Enma Bunce - University of Leicester, UK; Domitilla de Martino – OAC-INAF, Italy; **Ana Ines Gomez de Castro – Universidad Complutense de Madrid, Spain**; Jean-Michel Deharveng – Observatoire Astronomique Marseille-Provence, France; Roger Ferlet - Institute d'Astrophysique de Paris, France; Kevin France - University of Colorado, USA; Miriam García – IAC, Spain; Boris Gaensicke -University of Warwick, UK; Cecile Gry - Observatoire Astronomique Marseille-Provence, France; Lynne Hillenbrand – Caltech, USA; Eric Josselin - University of Montpellier, France; Carolina Kehrig – Instituto de Astrofísica de Andalucía, Spain; Laurent Lamy - LESIA, France; Jon Lapington – University of Leicester, UK; Alain Lecavelier des Etangs – Institute d'Astrophysique de Paris, France; Frank LePetit – Observatoire Paris-Meudom, France; Javier Lopez Santiago - Universidad Complutense de Madrid, Spain; Bruno Milliard- Observatoire Astronomique Marseille-Provence, France; Richard Monier - Université de Nice, France; Giampiero Naletto – University of Padova, Italy;Yael Nazé - Liège University, Belgium; Coralie Neiner - LESIA, France; Jonathan Nichols – University of Leicester, UK Marina Orio – OAPD-INAF, Italy; Isabella Pagano – OACT-INAF, Italy; Céline Peroux – Observatoire Astronomique Marseille-Provence, France; Gregor Rauw – University of Liège, Belgium; Steven Shore – University of Pisa, Italy ; Marco Spaans - Kaptein Astronomical Institute, The Netherlands ; Gagik Tovmassian - Instit. Astr. Sede Ensenada-UNAM, Mexico; Asif ud-Doula - Penn State University, USA; José Vilchez – Instituto de Astrofísica de Andalucía, Spain **and www.nuva.eu**



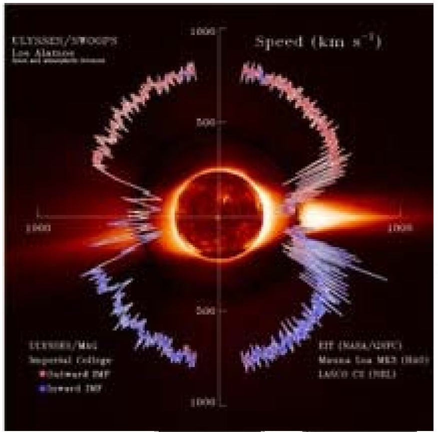
KEY SCIENCE TO BE ADDRESSED WITH euvo

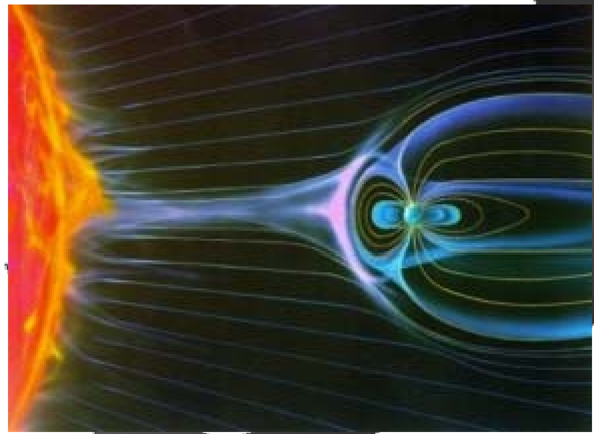
- transport processes in the intergalactic medium over 80% of the universe lifetime
- the interstellar medium (ISM)
- planet formation and the emergence of life
- the solar system
- stellar physics
- fundamental physics – testing the variation of the fine structure constant at $z<2$



THE EARTH CONNECTION

- **Earth's atmosphere is in constant interaction with the interplanetary medium and the solar UV radiation field**. Observation of planets, interplanetary medium, stellar magnetic activity provides the phenomenological baseline to understand the Earth atmosphere in context.





- A 50-100 times improvement in sensitivity would enable the observation of the key atmospheric ingredients of Earth-like exoplanets (carbon, oxygen, ozone), providing crucial inputs for models of biologically active worlds outside the solar system.

- Solar system planetary research is fundamental for **understanding atmospheres as global systems, including the Earth**.

PLANETARY SCIENCE: THE SOLAR SYSTEM IN CONTEXT

- An holistic understanding of ***all solar system bodies*** is required
- A UV telescope uniquely allows the exploration and comparative study of the ***entire population*** of the solar system as temporally and spatially resolved targets

Object	Diameter (“)
Mercury	4.6–12.5
Venus	10–60
Moon	1.865
Mars	14–24
Largest asteroids	Up to 0.8
Asteroids D > 50 km	>0.05
Jupiter	47
Io	1.2
Ganymede	1.7
Saturn + rings	19.5
Titan	0.8
Tethys & Rhea	0.17–0.25
Uranus	4.0
Oberon & Titania	0.12
Neptune	2.4
Triton	0.15
Pluto	0.1
Charon	0.055
Sedna	0.037
P/Halley	0.015
Hale-Bopp	0.075

All larger than the 0.015” angular resolution at Lyman α for a 2m UV telescope

Aperture diameter (m)	0.5	1.0	2.0	4.0	8.0
Angular resolution at Ly-α (“)	0.061	0.031	0.015	0.007	0.004

≈ Infrared JWST at 2μm

Time-domain spectro-imaging observations of atmospheres

Global circulation and local atmospheric dynamics.

Source, loss and transport processes, cold traps and cryovolcanism.

Atmosphere evolution, includi… ocean loss.

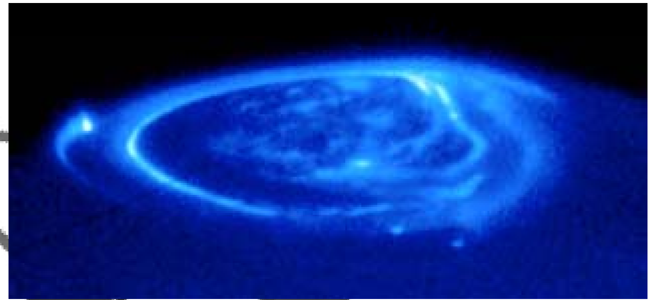
Composition, … temperat…

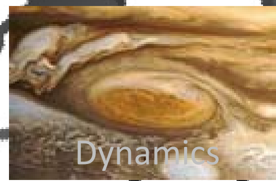
Ther… crises, … magnet…

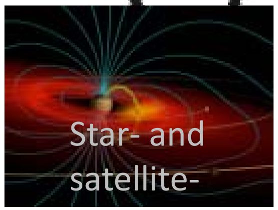
Magnetic … of planets with … …llites and rings, and oth… …es.

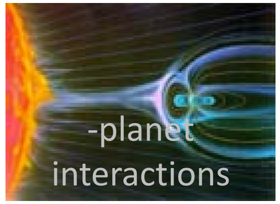
Comparison with exoplanet studies.

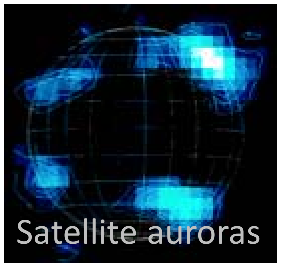
Time-varying UV auroras reveal magnetosph… proce…

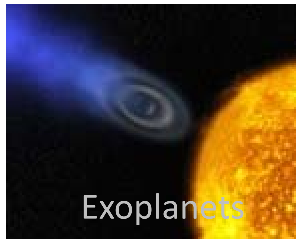












Time-domain spectro-imaging observations of surfaces and small bodies

Spatially-resolved albedo maps and characterization of regolith properties for all objects larger than 50 km.

Mineralogy, organics, geochemical provinces on planetary surfaces.

Origin of comet-like activity.

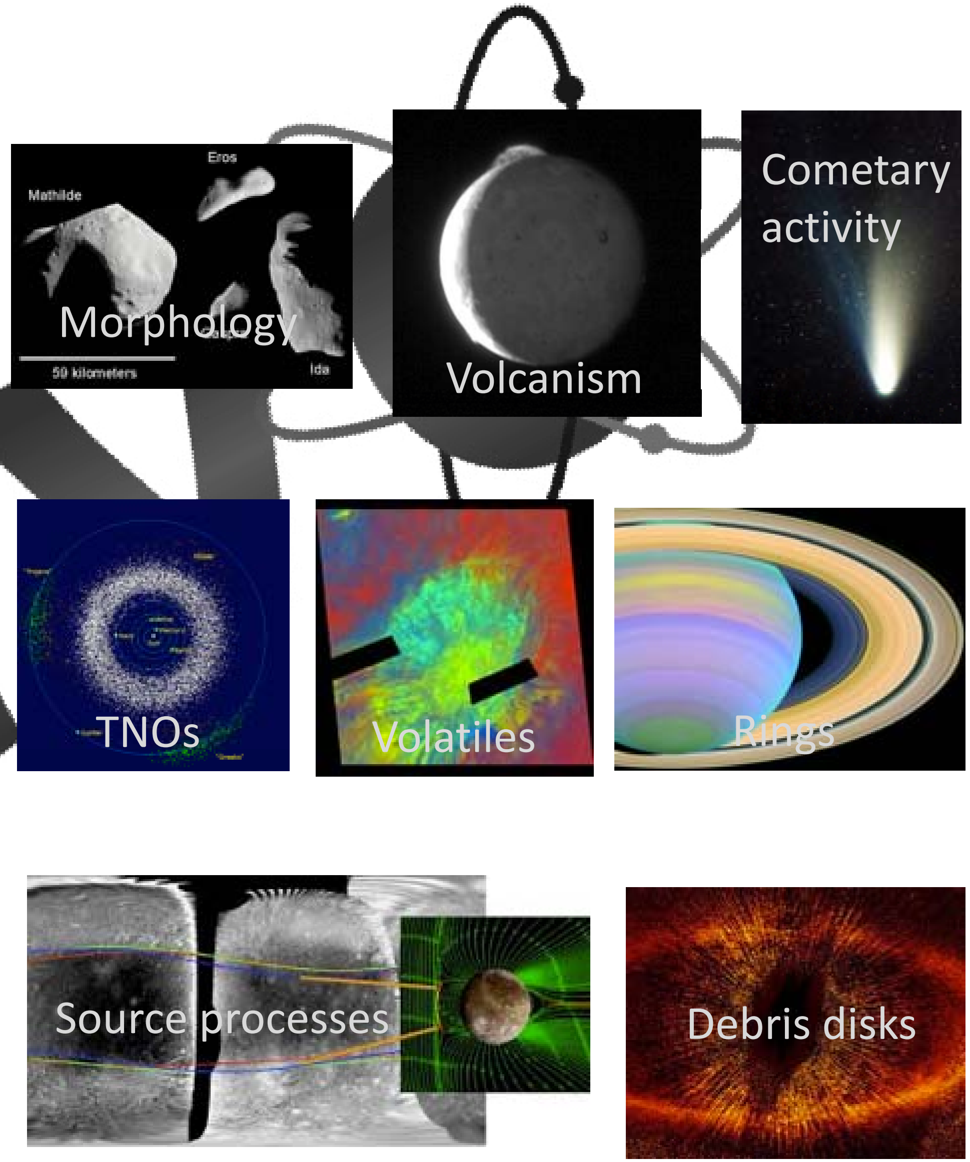
Volatile transport processes.

Origin, composition and evolution of planetary rings.

Shape, rotation and collisional history.

Spatial and size distribution, and chemical composition of comets and 1000s of TNOs.

Comparison with debris disk studies.



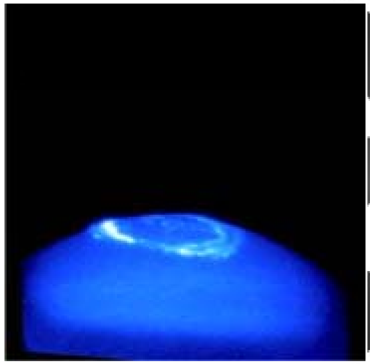
What hardware do we need?

For temporal solar system phenomena the key feature is observing time, such that L2 or HEO orbits are ideal

However, a 4m, or larger, telescope would enable all solar system bodies to be spatially resolved

Uranus, Neptune and satellites, and TNOS are EUVO discovery space

HST: Jupiter
4m EUVO: Saturn
8m EUVO: Uranus



4m EUVO ←

Saturn
Uranus

4m EUVO ←

Uranus

← 8m EUVO

HST ACS-SBC field of view

EXOPLANETS IN THE UV

Observations in the UV and visible wavelength are powerful diagnostics of the structural, thermal, and dynamical properties of planets, be they Solar System or extrasolar.

The most recent estimate:

GAIA will discover some hundred transiting Hot Jupiters (P <5 d) to G <14, and a few thousand to G <16. These will be prime targets for detecting atmospheric constituents through absorption spectroscopy, thereby characterizing the chemical and physical properties of the atmosphere.

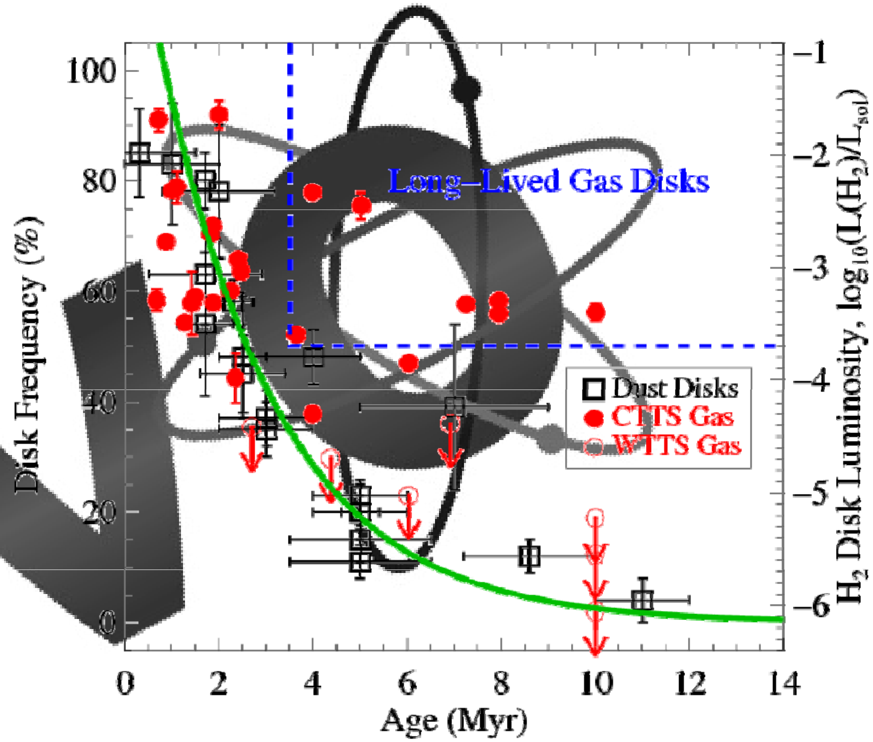
A sensitivity of $F=10^{-17}$ ergs/s/cm^2/A in 10^4s with R=100,000 will allow studying the dynamics of mass loss in hot Jupiters

A high sensitivity, moderate spectral resolution instrument in the near-UV would allow us to observe the Rayleigh scattering of H_2, haze and possibly CO_2 and N_2 atmospheres

Evolution disk → planets

- The **dust disc clearing timescale is expected to be 2-4 Myr**, however recent results indicate that inner molecular discs can persist to ages ~10 Myr in Classical TTSs.

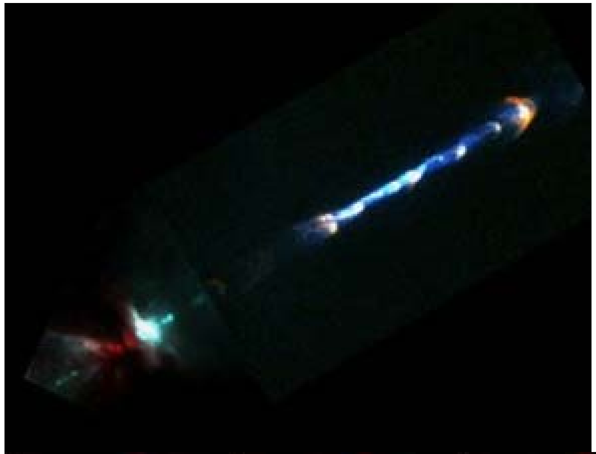
- H_2 probes gas column densities $<10^{-6}$ g cm^{-2}, making them the **most sensitive tracer of tenuous gas in the protoplanetary environment**.

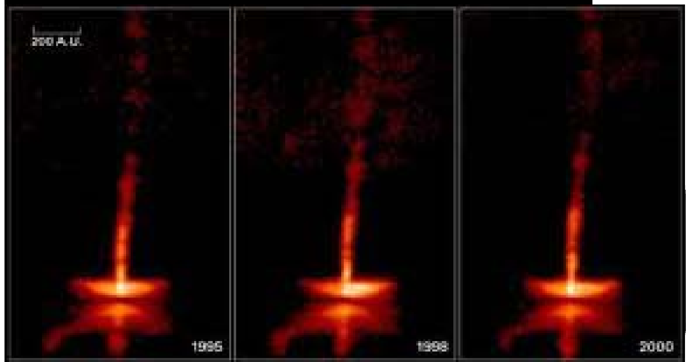


from Ingleby et al 2011, ApJ,743, 1051;
France et al 2012, ApJ, 756, 17

A far-UV survey of H_2 and CO disks (R=3000, F=10^{-16} erg/s/cm^2/A in 10^3s) will allow studying disk evolution (e.g. Orion (1Myr) -> Tucana (30 Myr))

UV IRRADIATED ENVIRONMENTS IN LIFE EMERGENCE, EVOLUTION AND STABILITY





During the formation of planetary systems, UV radiation is produced in the accretion engine. How does the variable UV radiation field affect

- the evolution of the disk?
- the formation of Earth-like planets?
- the chemistry of the disk?
- the formation of pre-biotic molecules?

How is magnetic energy build-up and released?

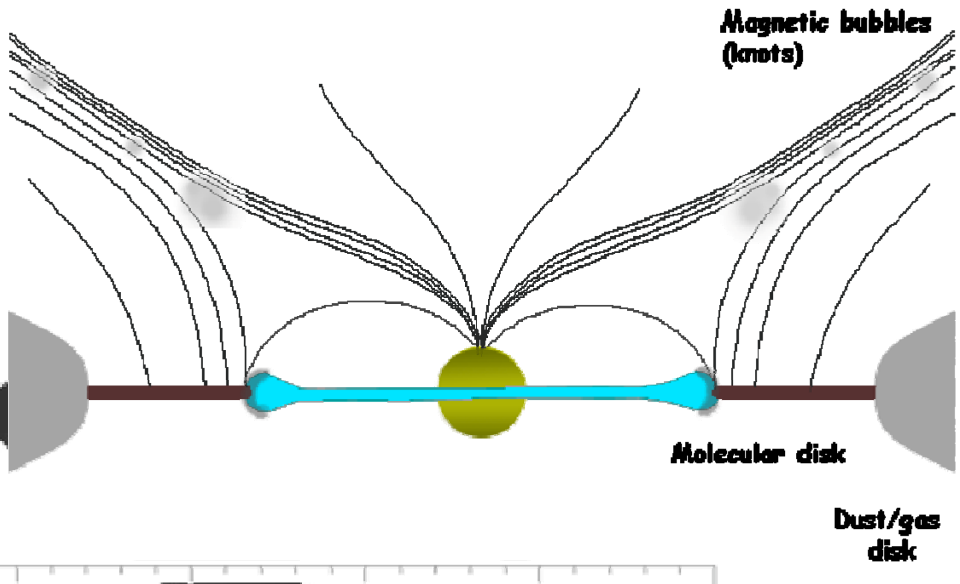
In the hard environment where terrestrial planets form and reside,

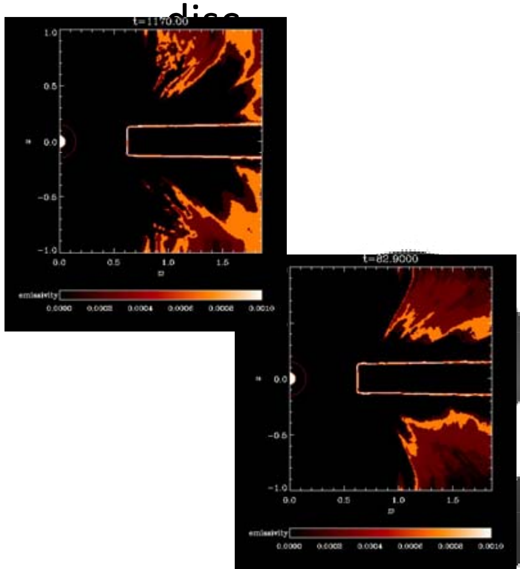
- how planetary atmospheres are formed?
- how do they evolve?
- which are the conditions for stability?

Star-disk interaction: the gravito-magnetic engine

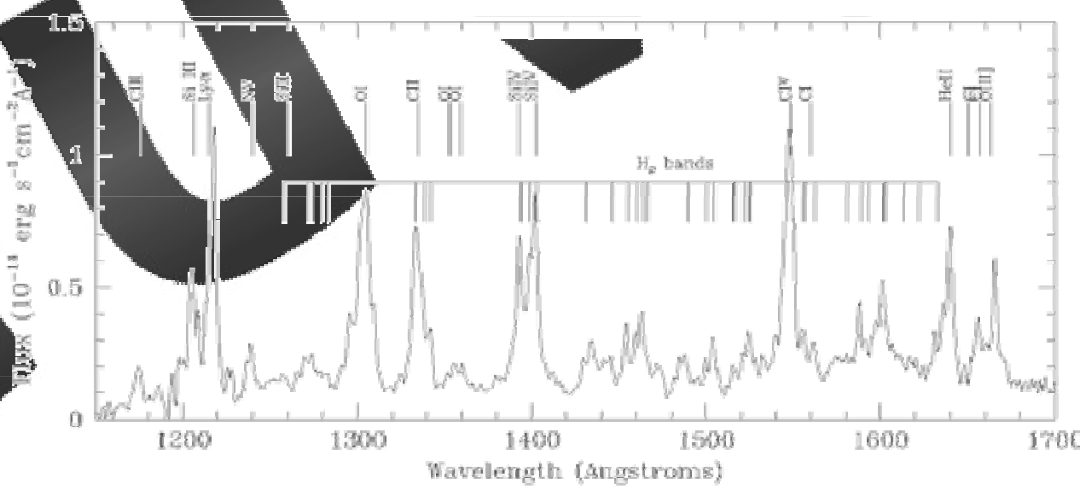
Star-disc interaction physics still poorly understood.

The role of stellar radiation and magnetic field on the engine performance the evolution of the disc.





from Gomez de Castro & von Rekowski 2011, MNRAS, 411, 849

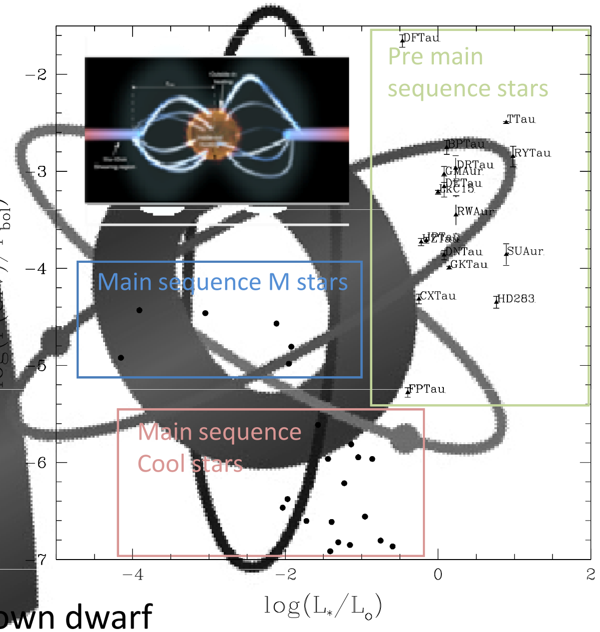


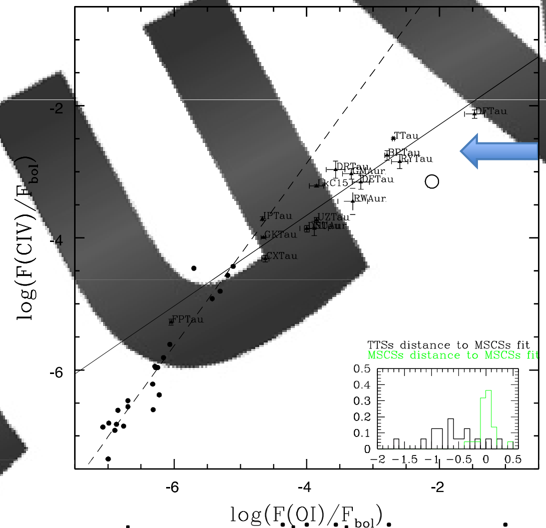
A single spectrum in the UV range contains information about all the physical components - atmosphere, magnetosphere, outflows (Solar-like winds, jets), accretion flow, inner disc structure, residual gas in the young planetary system – and their evolution into exoplanetary systems

Engine Evolution and habitability

- The **"habitability" of planets depends** on the **central star magnetic activity**, which strongly influences the chemical (and possibly biochemical) processes at the surface of the planet.

- **Engine physics** seems to extend smoothly **into substellar scales**:





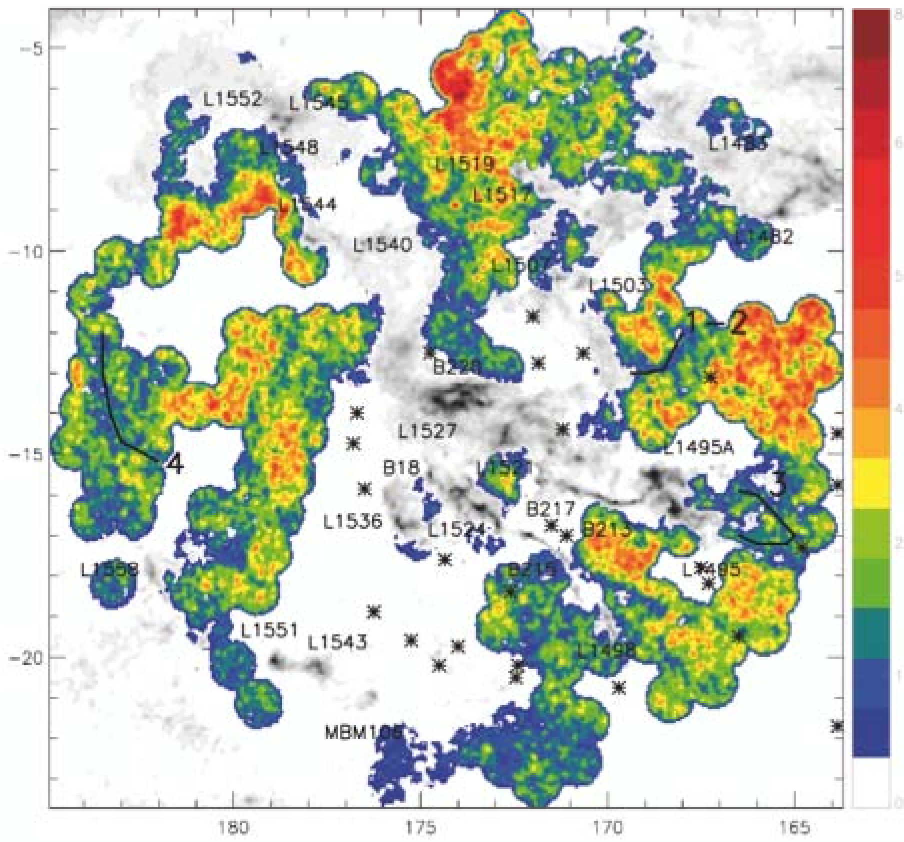
Brown dwarf

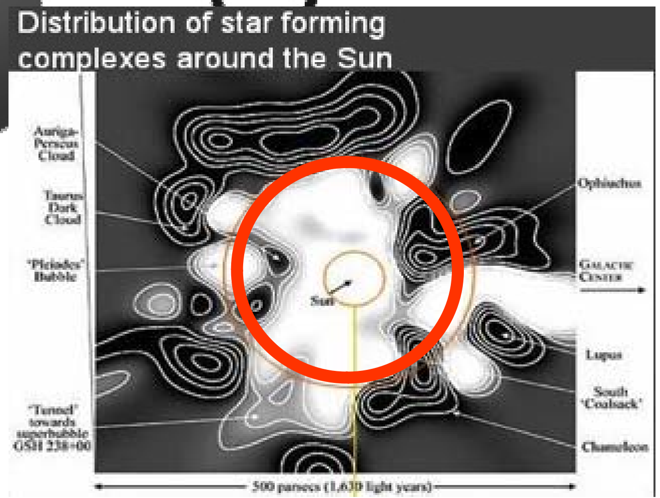
from Gómez de Castro and Marcos-Arenal 2012

At least, a factor of 10 improvement on sensitivity is required (reaching 10^{-17} erg/s/cm^2/A with R≈20,000) to observe the faintest components of the engine in a sample large enough. This represents a factor of ten improvement over current facilities (HST).

Engine evolution → Habitability

- Reaching NUV=22.3 mag will enable detecting active brown dwarfs to 150 pc
- A high sensitivity, low background equivalent flux level (10^{-18} erg/s/cm^2/A in 10^4s) equipped with photon counting detectors would enable a survey exoplanetary host M-stars within 50 pc (and K-dwarfs to 200 pc).



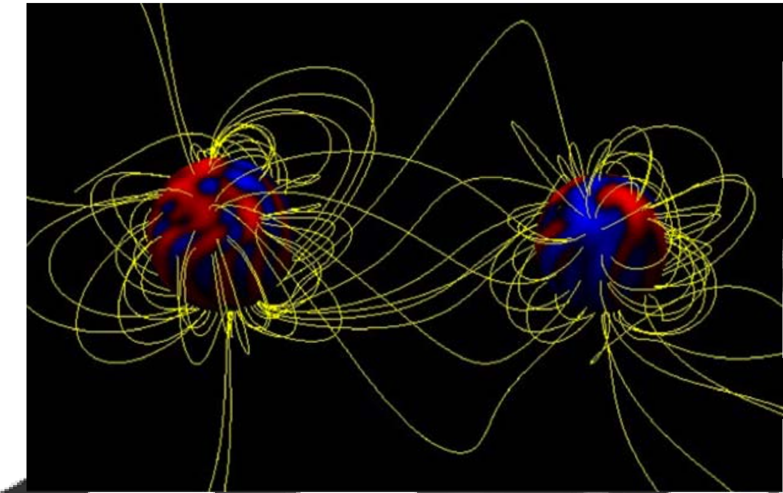


V=13-15 to reach the ***Star Formation Belt*** with R>20,000 and integration times < 300 s for key low mas stars

STELLAR PHYSICS

- **Open questions**:

- Fossil vs dynamo origin of magnetic field
- Mass loss, outbursts, flares
- Wind coupling
- Stellar evolution
- Rotational evolution
- Tidal interaction
- Accretion physics
  - Interacting binaries
  - Compact binaries
- White dwarfs
- Supernovae



All fields of stellar physics would benefit from EUVO:

- All types of main sequence stars
- Binary stars (compact binaries, Be-X-ray binaries,...)
- Pre-main sequence stars (T Tauri, Herbig stars...)
- Evolved stars (white dwarfs, neutron stars, magnetars...)

Need: hig. ...ical

- optical pr
- UV probes
- polarimetry ... ucture,

With UV+optical s... ...rimetric time series at high resolution, we can reconstruct the full system star + environment ... the interactions.

INTERSTELLAR MEDIUM

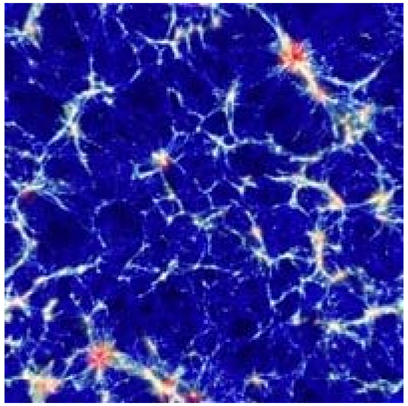
Unprecedented sensitivity permits to:

- Extend ISM studies to other galaxies.
- Cover a wide range of environments.
- Study the very diffuse gas.
- Study depletion and fractionation in denser molecular cores.

Unprecedented spectral coverage from near UV to far UV permits to:

- Cover all phases of the ISM by observing many different species from molecules H_2, CO and neutral atoms CI to high-ionization species CIV, NV, OVI.
- Get simultaneous access to the HI Lyman series and the H_2 Lyman and Werner bands → abundances, gas-to-dust ratios, molecular fraction.
- Couple dust and gas studies of the same sightlines.

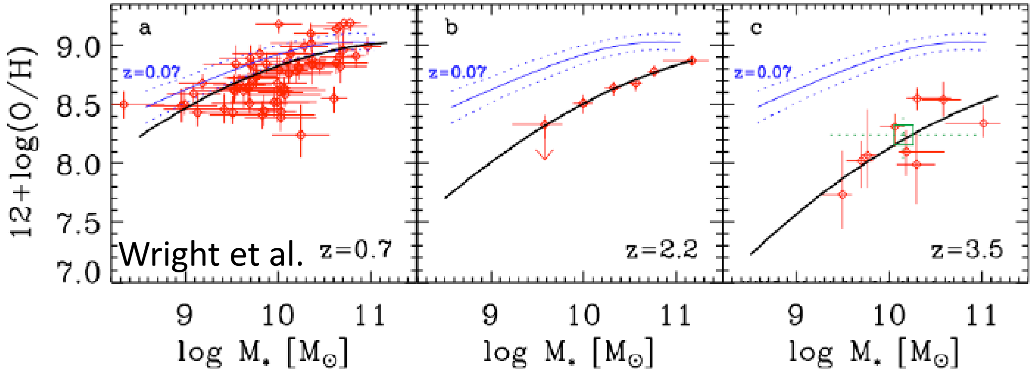
BARYONIC MATTER IN THE COSMIC WEB



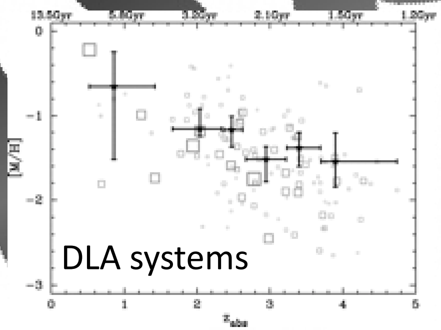
300 Mpc

What is the nature of the IGM, what are its origins, how does it evolve?

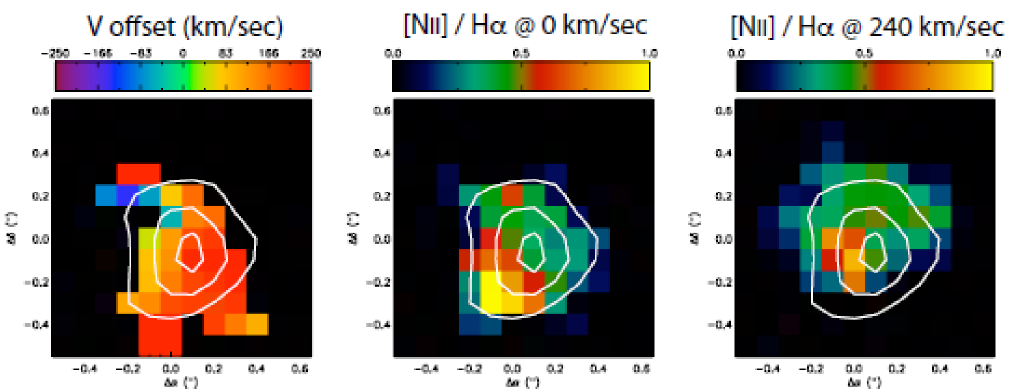
Metal enrichment with mass and redshift



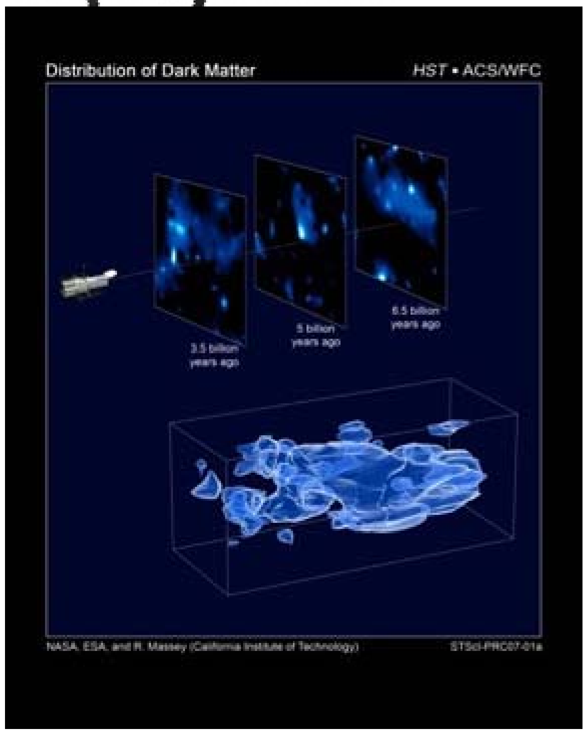
Low-mass galaxies at high-z? Does the relation still hold?



z = 1.527 Galaxy's [NII] dynamics and nebular ratio maps

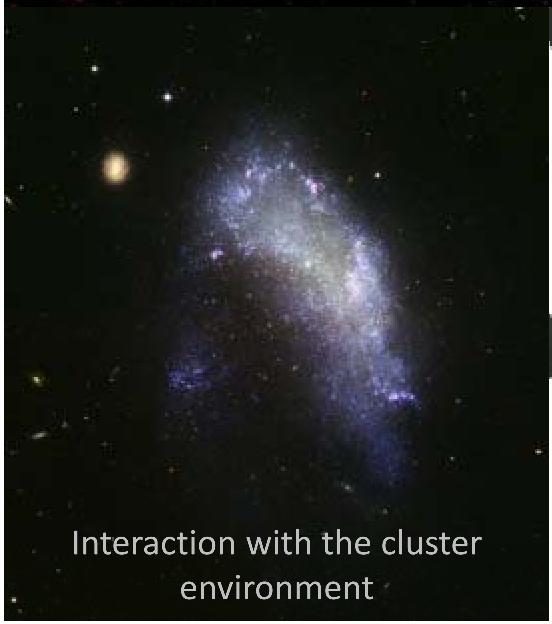


v([NII])-v(Hα)



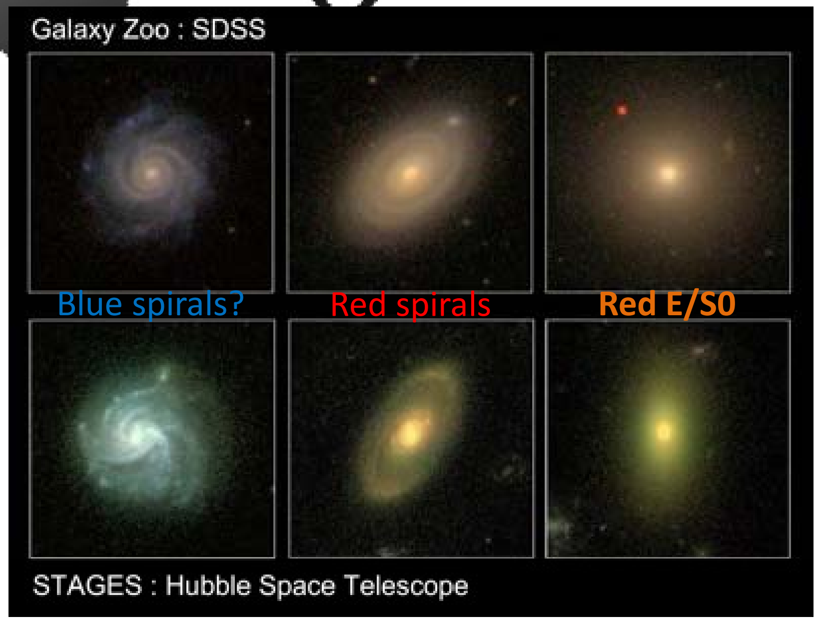
"Nature" vs "nurture" in galaxy evolution

How much of the morphological diversity of galaxies is decided upon formation and how much is modified later?

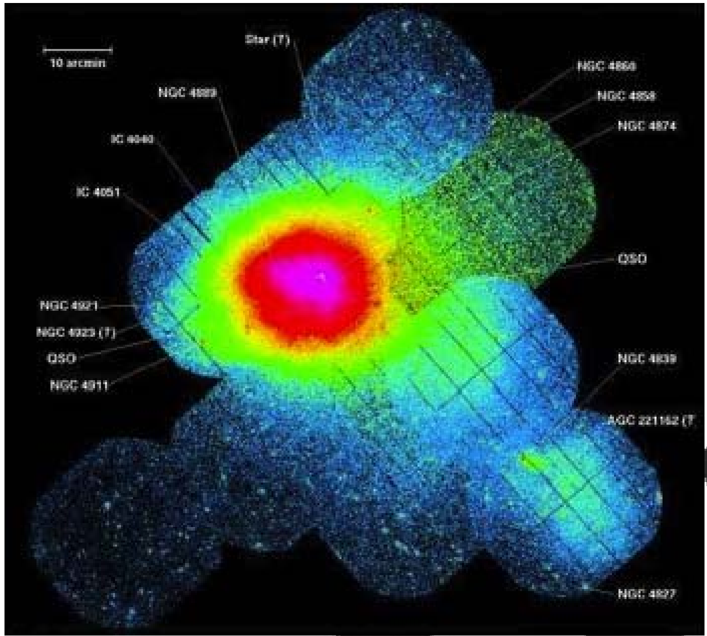


NGC 1427A shredding by in-fall into the Fornax cluster

NGC 300 (GALEX) shows strong star formation



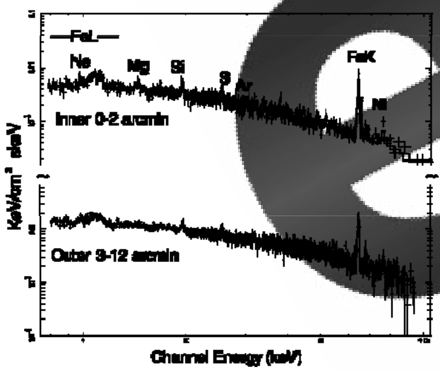
Metals in the intergalactic space



Hot gas in the Coma Cluster (XMM-Newton)

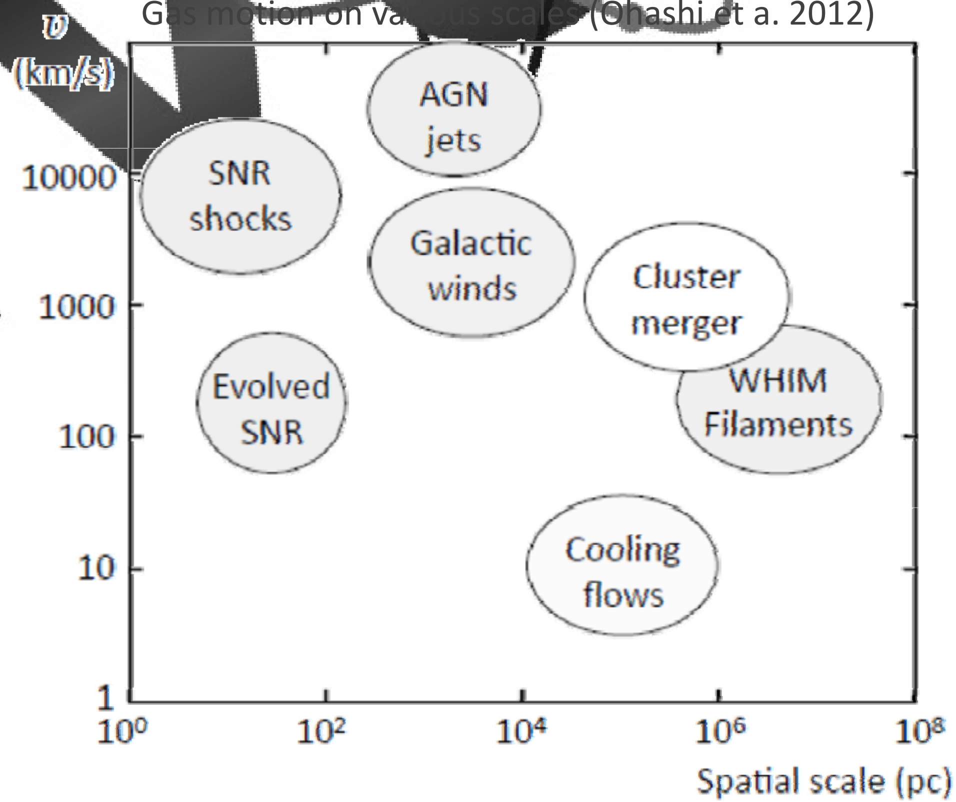
What is the origin of the hot gas in clusters?

How much of it is material processed in galaxies?

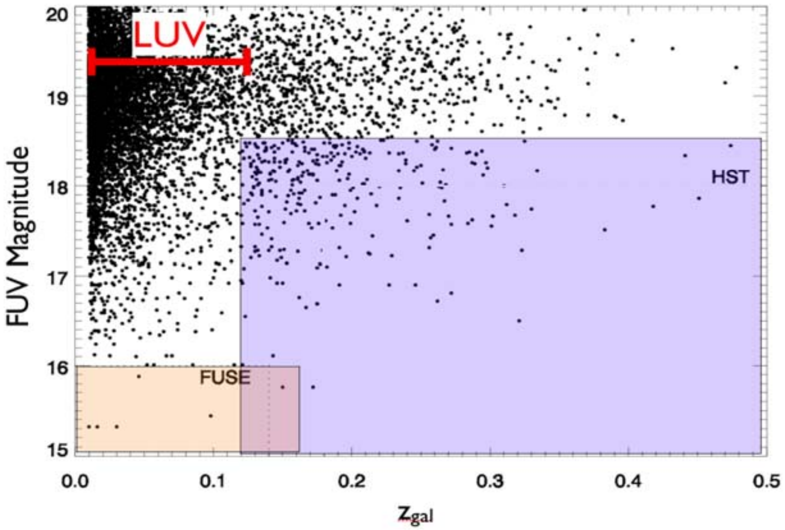


ASCA spectrum of Abell 496: reduced metallicity in the cluster outskirts

Gas motion on various scales (Ohashi et a. 2012)



Metals in the intergalactic space



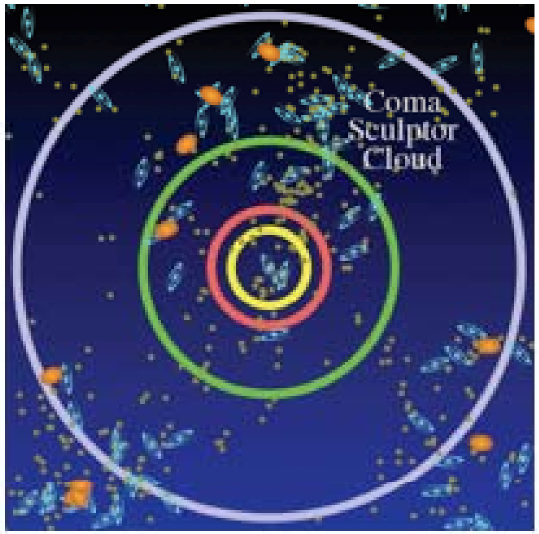
FUV accessibility to OVI
a key tracer to circumgalactic gas

Images from Tumlinson et al. 2013 (arXiv1209.3272v1)

An 8m telescope could observe more than 10 QSOs behind every galaxy out to 10 Mpc

At 0.2 < z < 2.0, lines of Ne VIII, Na IX, Mg X, and Si XII fall in the 900—3200 Å band. Ions with ionization potentials comparable to the X-ray absorbing gas detected in bright, local AGN.

A UV spectrograph with R~20,000 and a throughput of 5x COS would enable the detailed kinematical study of these species in hundreds of AGN at z > 0.2 more sensitively than any proposed X-ray telescope.



UV ASTRONOMY MISSIONS

THE MISSION (Orbit: HEO or L2; Lifetime: 15 – 20 years; Range: 900-7000 A)
International collaboration: US-Russia-India-Canada-Mexico-China

		IMAGING		INTEGRAL FIELD SPECTROSCOPY			SPECTROSCOPY		4m	8m
		FoV (arcmin)	Angular Res. (arcsec)	FoV (arcmin)	Angular Res. (arcsec)	R	R	Pol.		
Cosmic Web	IGM Star Formation	10	<0.01	10	<0.01	20,000	20,000			10 Mpc
Stars-to-Planets	Engine Disks Habitability	3	<0.01	10 10	1 1	1000 3000	20,000 30,000	*	Hya/Tau Orion	Tau/Orion M@50pc
Exo-planets	Detection Characterization •Atmosphere •Magnetosphere						100,00 0			50pc (K type)
Solar System	Atmospheres Magnetosphere	10” 1”-2”	<1” <0.01”		0.1	3000	100,00 0	*	Saturn	Uranus
Stars	Envelopes Magnetic Binaries Supernovae	10	<0.01	10		500-1000	100,00 0 100,00 020,00 0	* *		
Cosmo-logy	α measure						50,000		Z~0.8	Z=2

Instrument technology development

Enhanced optical coatings

- Spectral coverage: Lyman limit to NIR
- Net factor 2-3 gain in overall efficiency of telescope plus spectrographs (2-3 reflections in each subsystem)

Enhanced detector performance

- Raise QE to 80-90%, µs timing, high dynamic range (no bright limits), long term stability
- MCPs and photocathode coatings
- CCD/CMOS chip developments

Key European technology companies

- Carl Zeiss, gratings and optics
- Photonis, MCPs and photocathodes
- e2v, CCDs and CMOS
- HORIBA Jobin Yvon, gratings and coatings

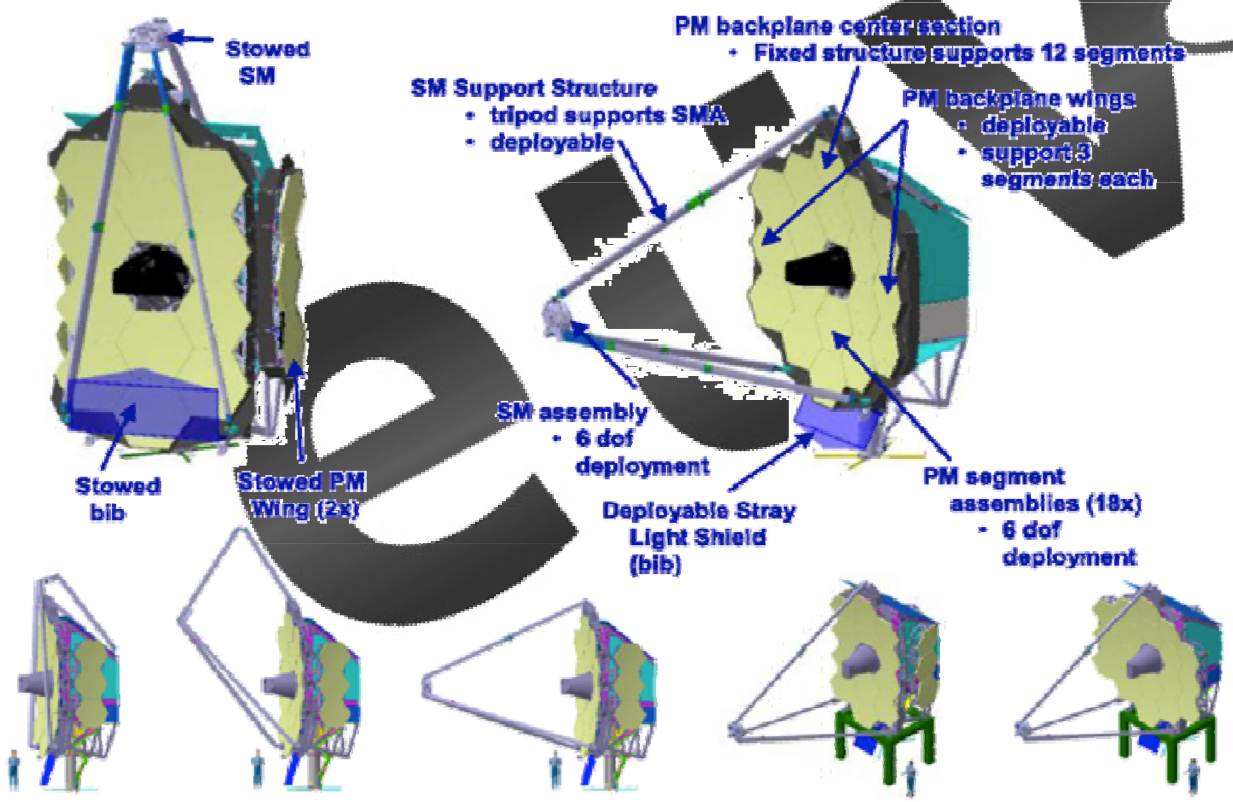
Telescope Concept

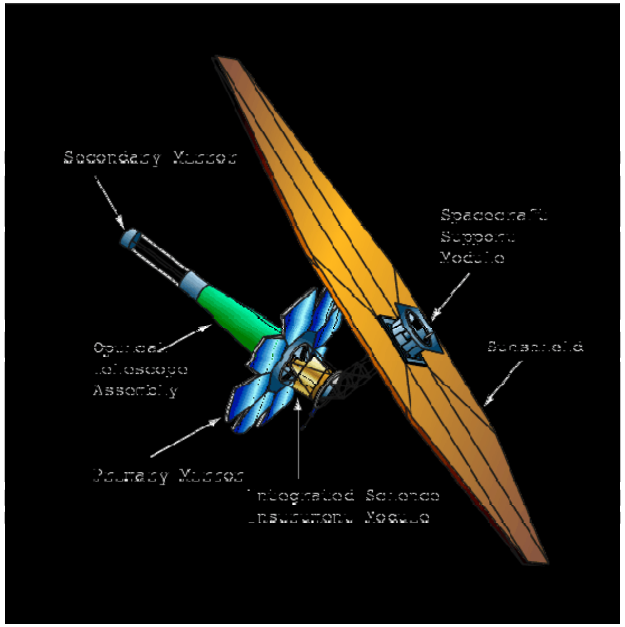
Ariane V fairing limit is 4m monolithic mirror

Deployable systems required for 8m

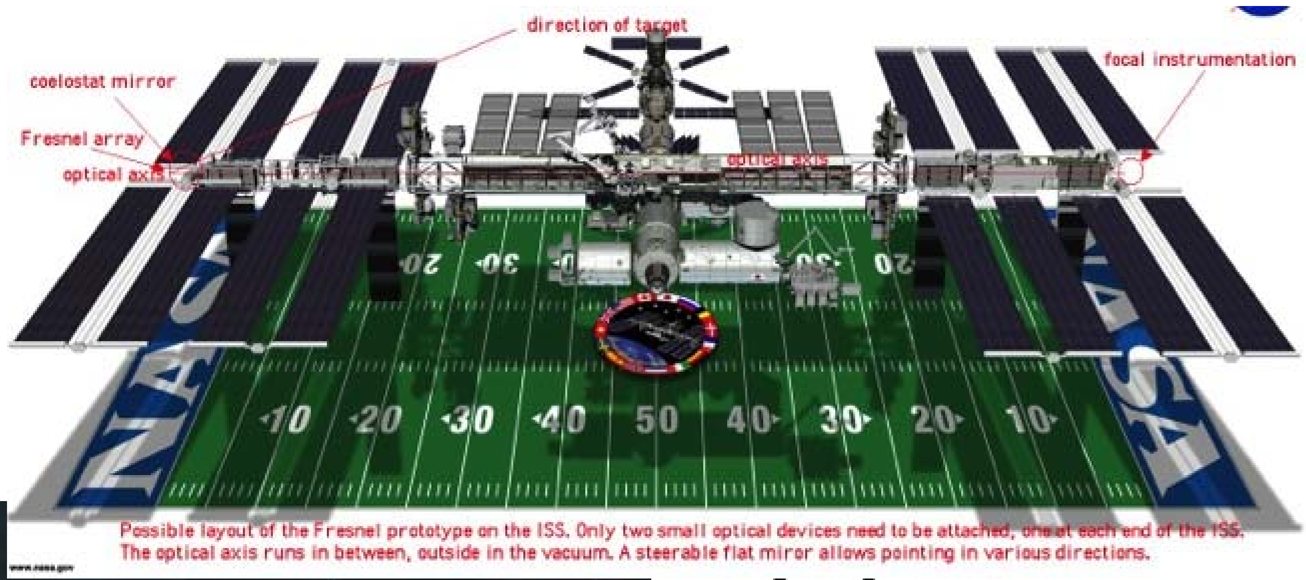
- James Webb concept to fly in 2018

  Refinements needed for UV accuracy requirements (cf. infra-red) and larger aperture
- Off-axis elliptical mirror to the largest size acceptable by the fairing deployable secondary





…and even more challenging Telescope concepts…



euvo

EUROPEAN ULTRAVIOLET-VISIBLE OBSERVATORY

THANK YOU

“Building galaxies, stars, planets and the ingredients for life between the stars”

Pictures Credits *(each slide images numbered from left to right - top to bottom)*

Slide 1 . 1: Saturn Aurora- HST-STIS – PRC98-05-ST Sc OPO – Jan.1998 – J. Trauger , JPL and NASA
2: WSO-UV Project
3: HH-47 J. Morse/STScI, and NASA/ESA
4: WSO-UV Project
5:Jupiter Aurora . NASA & John T. Clarke (U. Michigan)

Slide 2. 1: GALEX

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2: Hayes et al. 2010, A&A 509, L5
3: HH-47 J. Morse/STScI, and NASA/ESA
4: Ingleby et al. 2011, ApJ 743,1051; France et al. 2012, apJ, 756, 17
5: http://agaudi.files.wordpress.com/2008/09/dna_overview_es.png
6: Savaglio S. et al., 2006, American Astronomical Society Meeting 207
7: Gómez de Castro et al. 2013 (submited)
8: Jupiter Aurora NASA & John T. Clarke (U. Michigan)
9: http://www.eso.org/public/images/eso0407a/

Slide 4. 1: http://reinep.wordpress.com/2012/11/08/scientists-earths-protective-shield-is-now- failing/
2: Illustration of solar wind impact on Earth's magnetosphere : NASA
3: Aurora Borealis - author: United States Air Force photo by Senior Airman Joshua Strang

Slide 5. 1: Our solar system http://solarsystem.nasa.gov/planets/

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Slide 6. 1**:** Image of Jupiter's auroras observed in UV light by the Hubble Space Telescope. NASA and JT Clarke

2: WTP: Jupiter: Red Spot Turbulence, pds.jpl.nasa.gov

3: Transport of water vapour in the Martian atmosphere. ESA/AOES Medialab

4: Schematic of the Jovian magnetosphere showing the Io Plasma Torus (in red), the Neutral Sodium immediately surrounding Io (in yellow), the Io flux tube (in green), and magnetic field lines (in blue). Graphic created by John Spencer - http://www.boulder.swri.edu/~spencer/jupmag5na.jpg

5: Illustration of solar wind impact on Earth's magnetosphere . NASA

6: Fountains of Enceladus - NASA Photojournal, Jet blue, http://photojournal.jpl.nasa.gov/catalog/PIA08386

7:Provided by Matthieu Barthelemy & Jonathan Nichols

8: Provided by Matthieu Barthelemy & Jonathan Nichols.

9: Artist conception of the elongated, rugby ball shape of the outer layers of the extended upper atmosphere of HD 209458b, and of its escaping, comet like tail. Hubble ESA Information Centre, Garching, Germany

Slide 7. 1: Composite of five asteroids that have been imaged by spacecraft, to scale. (Mathilde, Eros, Gaspra, Ida and Dactyl, labelled), www.galaxypix.com

2: Discovering plumes on Io, taken in March of 1979 by *Voyager 1*. NASA, www.nasaimages.org

3: Image of comet C/1995 O1 (Hale-Bopp), taken on 1997 April 04, E. Kolmhofer, H. Raab; Johannes-Kepler-Observatory, Linz, Austria

4: The inner Solar System, from the Sun to Jupiter. This image is based on data found in the en:JPL DE-405 ephemeris, and the en:Minor Planet Center database of asteroids (etc) published 2006 Jul 6. The image is looking down on the en:ecliptic plane as would have been seen on 2006 August 14. It was rendered by custom software written for Wikipedia.

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6: simulated image of Saturn's rings, author NASA/JPL

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9: Coronagraph of star Fomalhaut showing disk ring and location of extrasolar planet b. NASA, ESA, P. Kalas, J. Graham, E. Chiang, E. Kite (Univ. of California, Berkeley), M. Clampin (NASA Goddard Space Flight Center), M. Fitzgerald (Lawrence Livermore National Laboratory), and K. Stapelfeldt and J. Krist (NASA Jet Propulsion Laboratory)

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2: Auroral formation on Saturn. Jonathan Nichols, NASA, ESA, University of Leicester
3: Bands and a new dark spot in Uranus' atmosphere. NASA/Space Telescope Science Institute

Slide 9 .1: Artist conception of the elongated, rugby ball shape of the outer layers of the extended upper atmosphere of HD 209458b, and of Its escaping, comet like tail. Hubble ESA Information Centre, Garching, Germany

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2: The dinamyc HH 30 disk and jet, HST-WFPC2. Credit: NASA and A.Watson (instituto de Astronomía, UNAM, Mexico) – STSCI
3: NASA
4: Sun magnetic fields. NASA

Slide 12.1: WSO-UV Project
2,3: Gómez de Castro & von Rekowski 2011, MNRAS, 411, 849
4: Provided by Ana I. Gómez de Castro

Slide 13.1, 2: Gómez de Castro and Marcos-Arenal, 2012, ApJ, 749, Issue 2, art.id. 190

Slide 14.1:Gómez de Castro et al. , ApJ, 2013 (submitted)
2:Provided by Ana I. Gómez de Castro

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2,4: Wright et al. 2012. Submitted to the 2010 Astronomy & Astrophysics Decadal Survey
3: Provided by N.Brosch
5: Distribution of dark matter. NASA, ESA, and R. Massey (California Institute of Technology)

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5: http://photojournal.jpl.nasa.gov/catalog/PIA04234
6: http://www.wso-uv.es/index.php/galeria-imagenes.html

Slide 24.1: James Webb Space Telescope: large deployable cryogenic telescope in space, Lightset et al. Opt. Eng. 51(1), 011003 (Feb 03, 2012). doi: 10.1117/1.OE.51.1.011003
2: JPL-NASA

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