RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

Exoplanet Science of Nearby Stars on a UV/Visible Astrophysics Mission

Members of the ExoPAG community

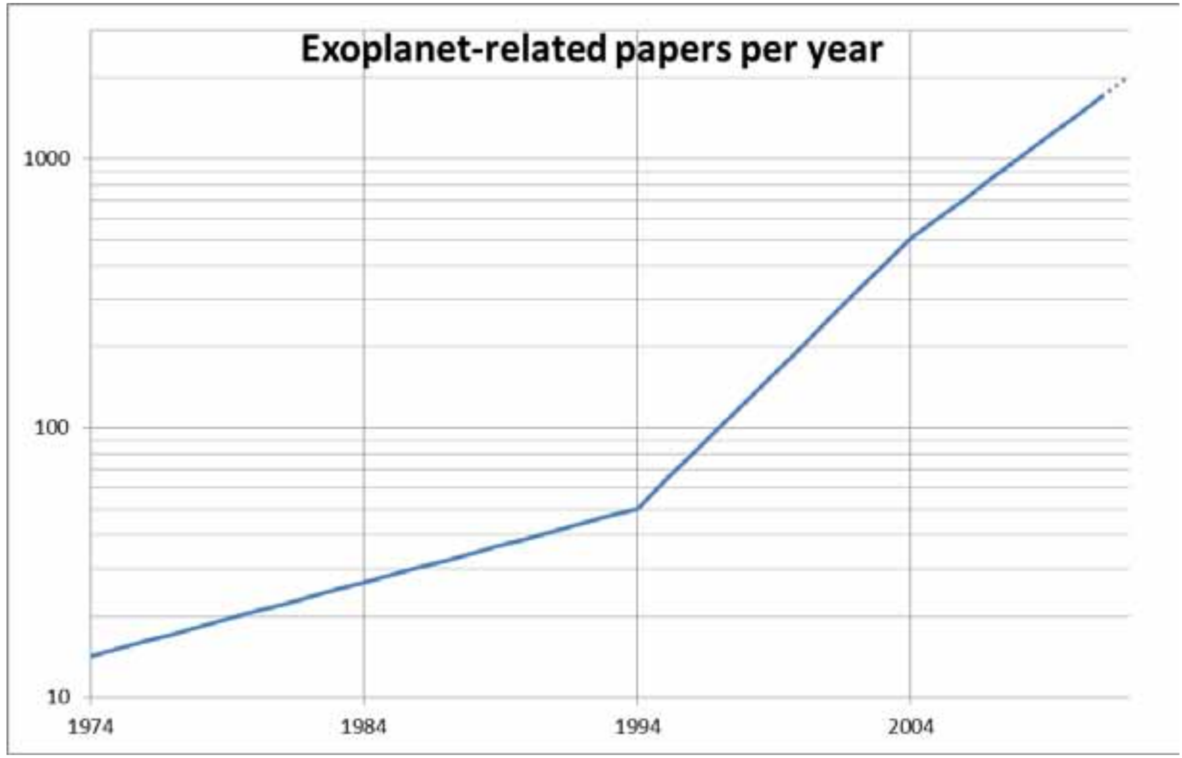
Charley Noecker

Jet Propulsion Laboratory

California Institute of Technology

Community and NASA interest in Exoplanet Science

- Publication rate
  - Doubling every 3-4 years
- A&A Decadal Survey
  - First priority for technology development
- NASA 2010 strategic plan
  - Astrophysics: "What are the characteristics of planetary systems orbiting other stars, and do they harbor life?"
  - COR: "What are the mechanisms by which stars and their planetary systems form?"
  - ExEP: "to advance our understanding of planets and planetary systems around other stars" and "to extend this exploration to the detection of habitable, Earth-like planets around other stars, to determine how common such planets are, and to search for indicators that they might harbor life"



Narrow scope of this discussion

- We consider the possibility of sharing a large UV-optical telescope
- That narrows our focus to just direct detection & characterization of rocky planets
- Other techniques of exoplanet science are just as important to the field, but do not require a large telescope in space
- That is why the white paper is nearly silent on those techniques

History of COPAG-ExoPAG collaboration

- Joint meeting at Space Telescope Science Institute (4/26/2011)
  - Topic: compatibility of the ExoPAG and COPAG mission concepts
  - http://exep.jpl.nasa.gov/exopag/exopagCopagJointMeeting/
  - http://cor.gsfc.nasa.gov/copag/mtgs/stsci_apr2011/
- Summary of that meeting given at the ExoPAG public meeting in June 2011 (Kasting)
  - http://exep.jpl.nasa.gov/files/exep/Kasting_Review%20of%20ExoPAG_COPAG.pdf in http://exep.jpl.nasa.gov/exopag/exopag4/agenda/
- Joint meeting of the full ExoPAG and COPAG at AAS January 2012
  - http://exep.jpl.nasa.gov/exopag/exopag5/agenda/ near the bottom
- The ExoPAG continues to share the COPAG's interest in a "flagship class" optical and UV telescope of 4m diameter and larger
  - Key tool in the effort for direct detection and characterization of planets down to Earth size orbiting nearby F, G, K stars
  - Internal coronagraph
  - External starshade

Exoplanet investigations that are compatible with a UV-optical astronomy space mission

1. Detection of individual exoplanets
   - semi-major axis, inclination, eccentricity
2. Spectral characterization of those exoplanets
   - Color → type of planet (gas giant, ice giant, terrestrial)
   - Estimate the mass, radius, and density via models based on brightness, orbit, and color, perhaps with intensive radial velocity measurements
   - Assess habitability (temperature, water abundance, solid surface)
   - Search for signs of life (oxygen, ozone, chlorophyll spectra)
3. Origin and ultimate fate of planetary systems
   - Presence, brightness, and distribution of debris disks
   - Long-term observations of position, photometry, and spectroscopy
   - Estimate of the state of the atmosphere (gas composition, clouds), and weather (variability of atmosphere)

➢ Unifying picture of the birth, evolution, and ultimate fate of planetary systems

Ultraviolet-Exoplanet Synergy

- L2 or drift-away orbits are advantageous to both
  - Stable environment, away from Earth and geocorona
- Unobscured (off-axis) telescopes are advantageous to both
- No strict requirements on size, although size determines what kinds of science we emphasize
  - 1-2 m diam → Giant planet spectroscopy and disk studies
  - 2-4 m diam → Terrestrial planets and their spectra → basic characteristics, habitability, and evidence of biology
  - 4-8 m diam → Sensitive higher-resolution spectroscopy of terrestrial planets to find stronger evidence of biology and begin to characterize it
- Possibility of long simultaneous UV and exoplanet observations in neighboring fields
- UV spectroscopy of planets

Telescope Characteristics and Drivers for Exoplanet Science

Preliminary features of our flagship telescope requirements:

- Wavelengths from 0.5 to 0.8 μm
  - Extra value for extending to 1 μm and toward the UV
- Aperture diameter of order 4 meters and larger
  - Could be smaller, with corresponding science descopes (see previous pg)
  - Could be larger, with some impact on telescope stability and substantial impact on cost
- Diffraction limited point spread function over a narrow FOV, roughly 1”×1”
  - Some options demand stringent optomechanical stability as well
- Obscurations and segmentation are compatible with some star-suppression options but not others;
  Technology readiness of those options will drive our decision at least as much as obscurations and segmentation.

Conclusions

- Exoplanet science is compatible with UV-optical astrophysics in
  - wavelength range – telescope size
  - wavefront quality – coatings
  - operations/scheduling
- Excellent opportunity to use one telescope to support both sets of science objectives

ExoPAG Executive Committee	ExoPAG community members	
Jim Kasting, former Chair, ex officio	Gerard van Belle	Marshall Perrin
David Bennett, Notre Dame, ex officio	JB Barentine	Joe Pitman
Jonathan Fortney, UCSC	Joseph Catanzarite	Lewis Roberts
Charley Noecker, JPL	Bill Danchi	Gene Serabyn
Peter Plavchan, Caltech/NexSci	Dawn Gelino	Arif Solmaz
Aki Roberge, GSFC	Tiffany Glassman	Zlatan Tsvetanov
Rémi Soummer, STScI	Tony Hull	Bob Vanderbei
Tom Greene, ARC	Jeremy Kasdin	Kaspar von Braun
Bruce Macintosh, LLNL, ex officio	Rick Lyon	Amir Vosteen
Wes Traub, ExEP Representative, ex officio	Bertrand Mennesson	

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

From Protoplanetary Disks to Extrasolar Planets :

Understanding the Lifecycle of Circumstellar Gas with Ultraviolet Spectroscopy

Disks → Planetary Systems

Kevin France

University of Colorado at Boulder

UV-Vis RFI Meeting; September 2012

CENTER FOR ASTROPHYSICS AND SPACE ASTRONOMY

Collaborators:

Kevin France[1*], Matthew Beasley[1], David R. Ardila[2], Edwin A. Bergin[3], Alexander Brown[1], Eric B. Burgh[1], Nuria Calvet[3], Eugene Chiang[4], Timothy A. Cook[5], Jean-Michel Désert[6], Dennis Ebbets[7], Cynthia S. Froning[1], James C. Green[1], Lynne A. Hillenbrand[2], Christopher M. Johns-Krull[8], Tommi T. Koskinen[9], Jeffrey L. Linsky[1], Seth Redfield[10], Aki Roberge[11], Eric R. Schindhelm[12], Paul A. Scowen[13], Karl R. Stapelfeldt[11], and Jason Tumlinson[14]

[1]University of Colorado, [2]Caltech, [3]University of Michigan, [4]University of California, Berkeley, [5]University of Massachusetts, Lowell, [6]Harvard/CfA, [7]Ball Aerospace, [8]Rice University, [9]University of Arizona, [10]Wesleyan University, [11]NASA/GSFC, [12]SwRI, [13]Arizona State University, [14]STScI

Collaborators, it takes a village:

Kevin France[1*], Matthew Beasley[1], David R. Ardila[2], Edwin A. Bergin[3], Alexander Brown[1], Eric B. Burgh[1], Nuria Calvet[3], Eugene Chiang[4], Timothy A. Cook[5], Jean-Michel Désert[6], Dennis Ebbets[7], Cynthia S. Froning[1], James C. Green[1], Lynne A. Hillenbrand[2], Christopher M. Johns-Krull[8], Tommi T. Koskinen[9], Jeffrey L. Linsky[1], Seth Redfield[10], Aki Roberge[11], Eric R. Schindhelm[12], Paul A. Scowen[13], Karl R. Stapelfeldt[11], and Jason Tumlinson[14]

[1]University of Colorado, [2]Caltech, [3]University of Michigan, [4]University of California, Berkeley, [5]University of Massachusetts, Lowell, [6]Harvard/CfA, [7]Ball Aerospace, [8]Rice University, [9]University of Arizona, [10]Wesleyan University, [11]NASA/GSFC, [12]SwRI, [13]Arizona State University, [14]STScI

= UV Observer

= Opt/IR Observer

= Theory + Opt/IR Observer

= UV Instrument

= Theory

= UV Instrument + UV Observer

Goal: From Disks to Planets

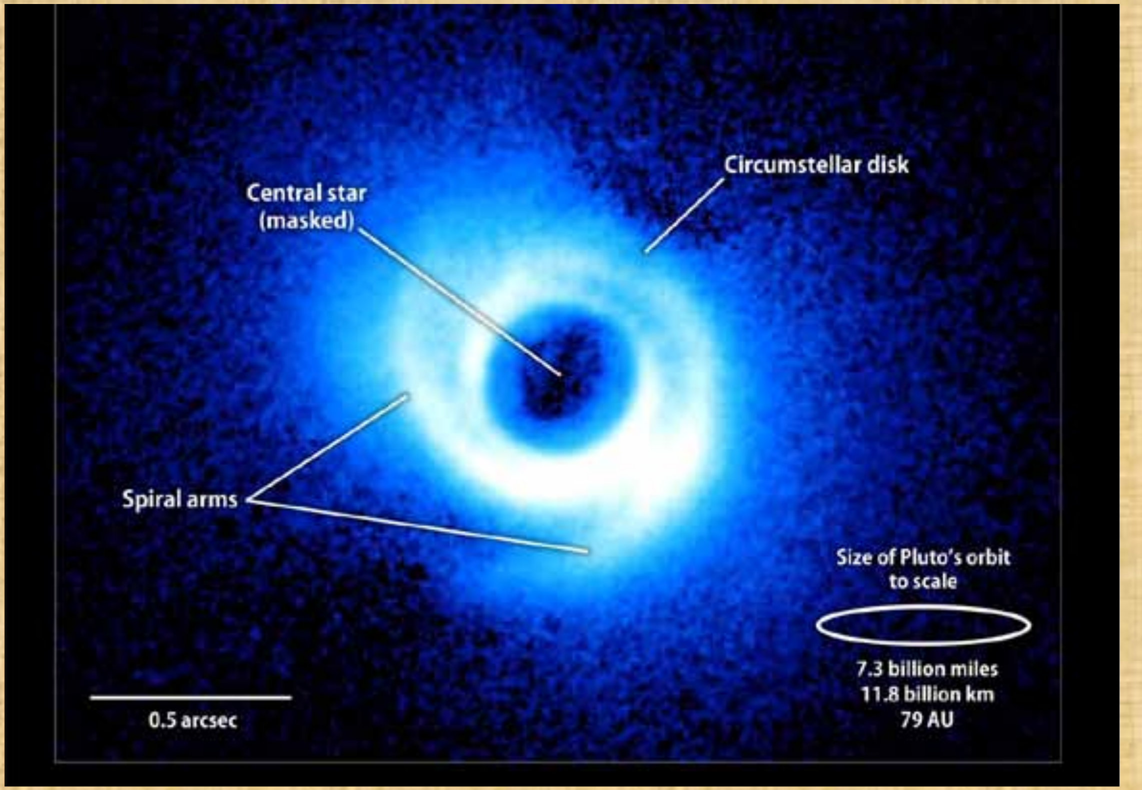
1. Inner Regions of Protoplanetary Disks (*r < 10 AU)* are the birthplaces of exoplanetary systems. Planet formation timescales (10^6 – 10^7 yrs) are about the same as characteristic lifetimes of gas-rich disks (T Tauri and Herbig Ae/Be Stars)

2. Gas disk lifetime and structure determine how planetary cores accrete a gas envelope, and how they migrate through their PPDs $\rightarrow$ Final architecture of exoplanetary systems

Gas & Dust Lifetimes : Giant Planet Formation and Migration

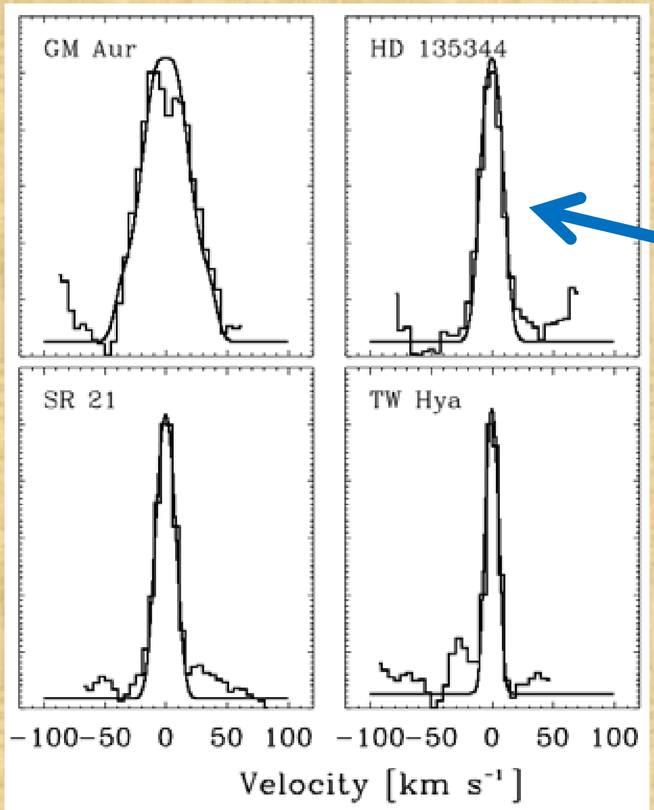
Dust properties have driven our understanding of disk dissipation,

$\tau_{dust} \leq 4$ Myr

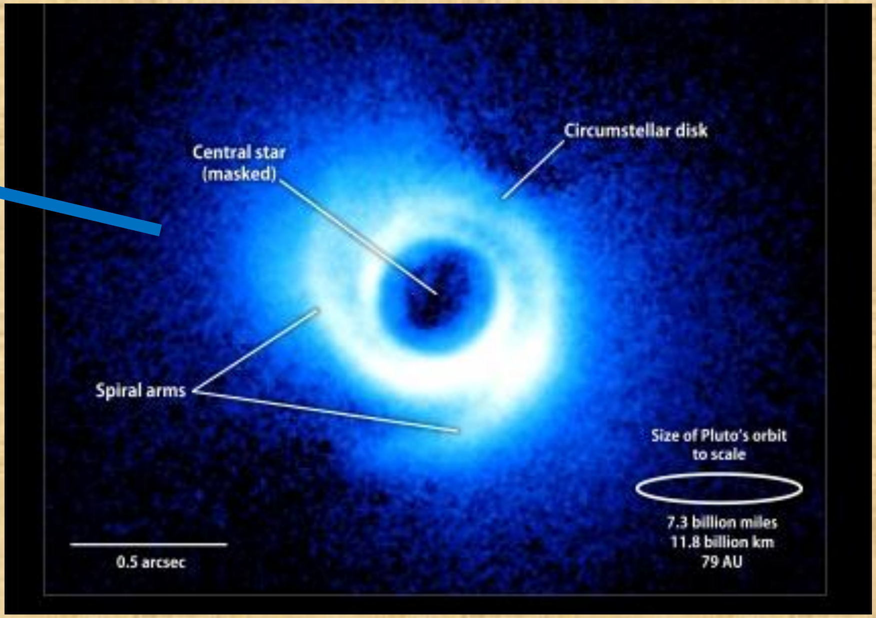


Muto et al. 2012

Molecules at *a* < 10 AU



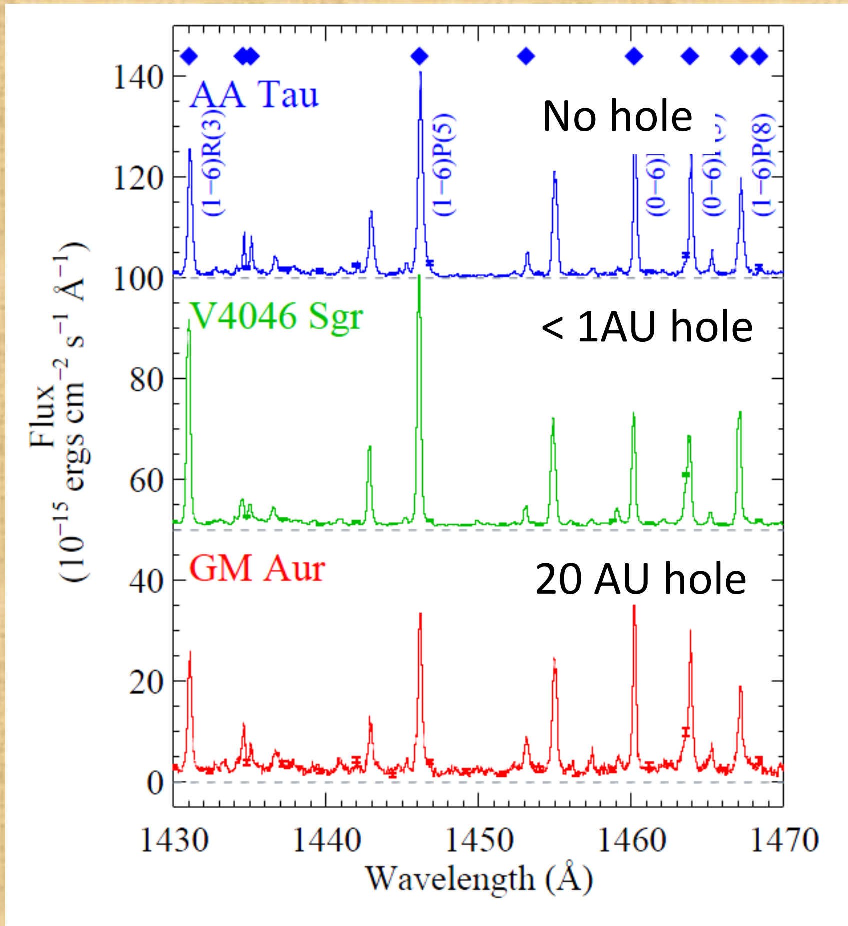
Salyk et al. 2009



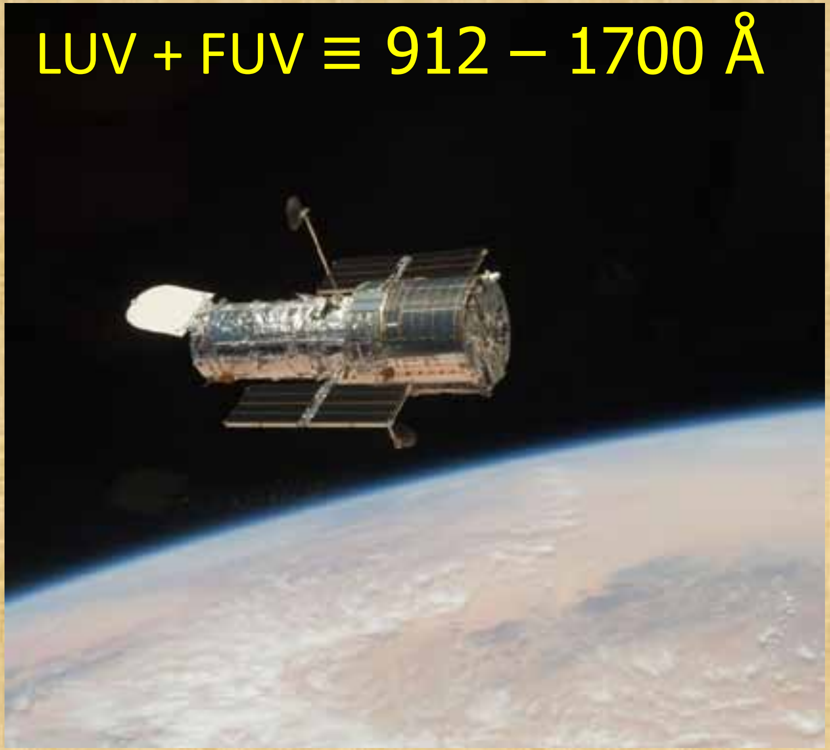
Collisionally and Photo-excited CO disks remain in systems older than 5 Myr with evolved inner dust disks

H_2 at *a* < 10 AU

- H_2 makes up 99% of the gas mass in protoplanetary disks
- Very hard from the ground



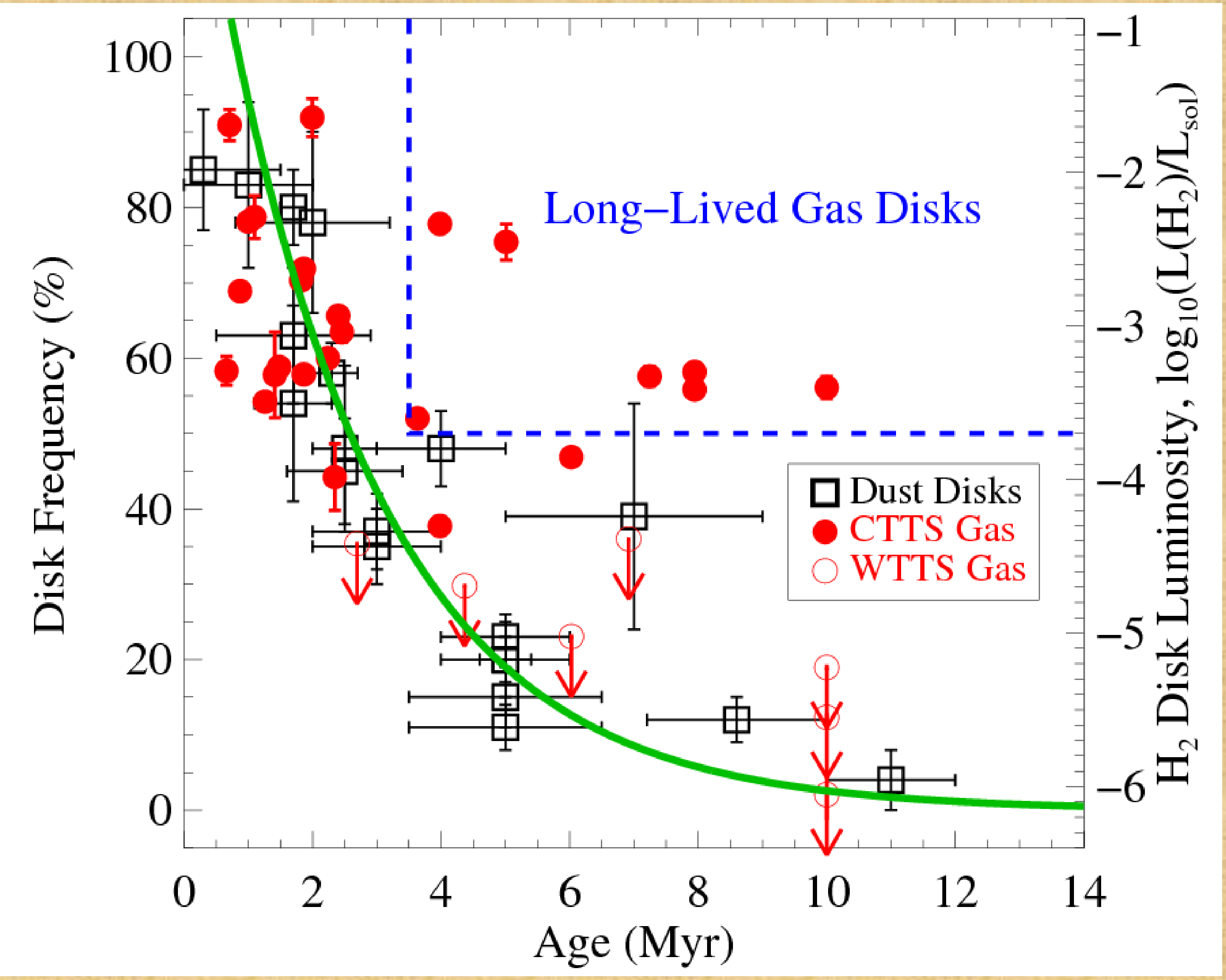
France et al. 2012c



Sensitive to

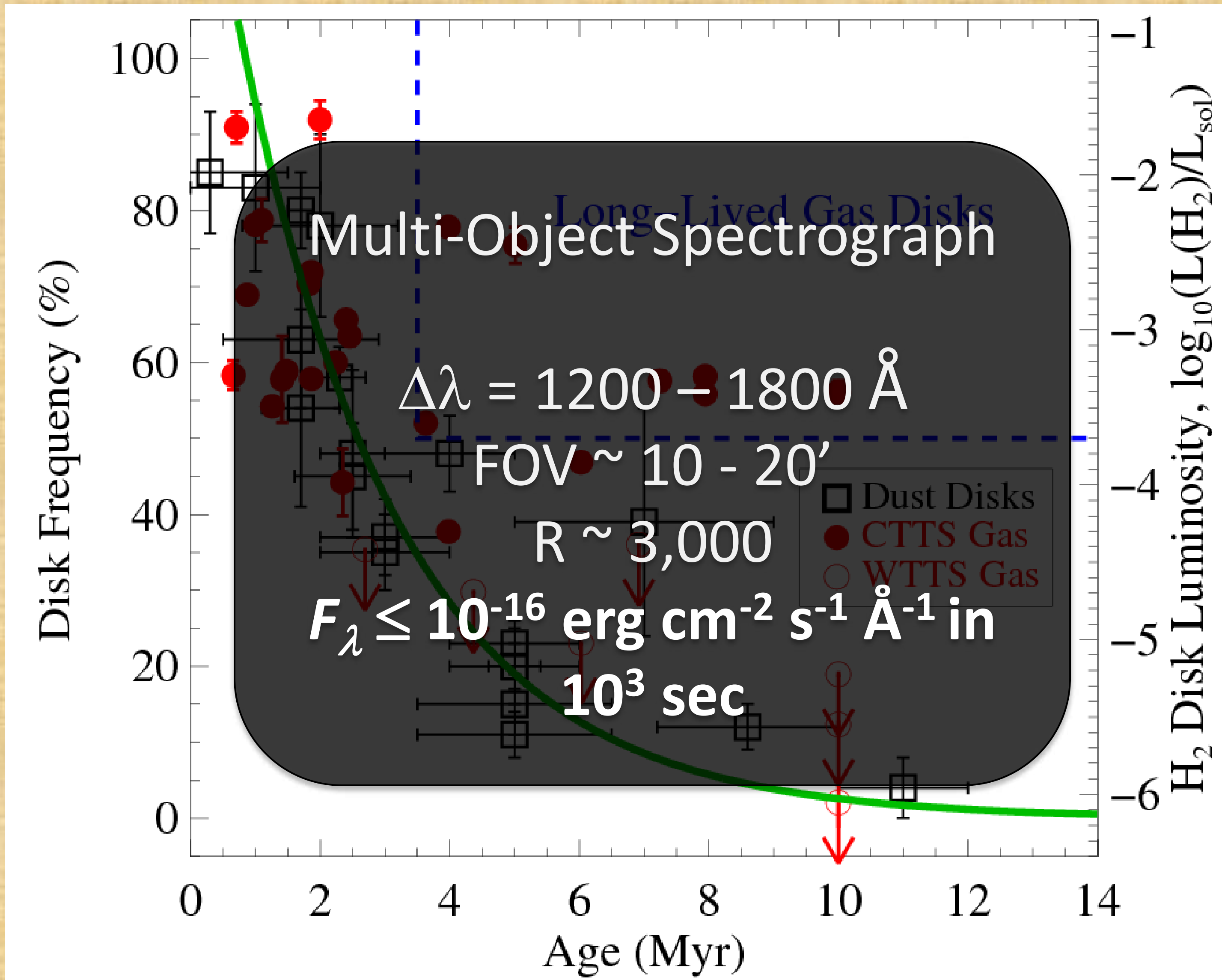
$\Sigma_{gas} < 10^{-6}$ g cm^{-2}

H_2 at a < 10 AU



Long–Lived Gas Disks
Dust Disks
CTTS Gas
WTTS Gas
Disk Frequency (%)
Age (Myr)
H2 Disk Luminosity, log10(L(H2)/Lsol)
100
80
60
40
20
0
2
4
6
8
10
12
14
−1
−2
−3
−4
−5
−6

H_2 at *a* < 10 AU



Multi-Object Spectrograph

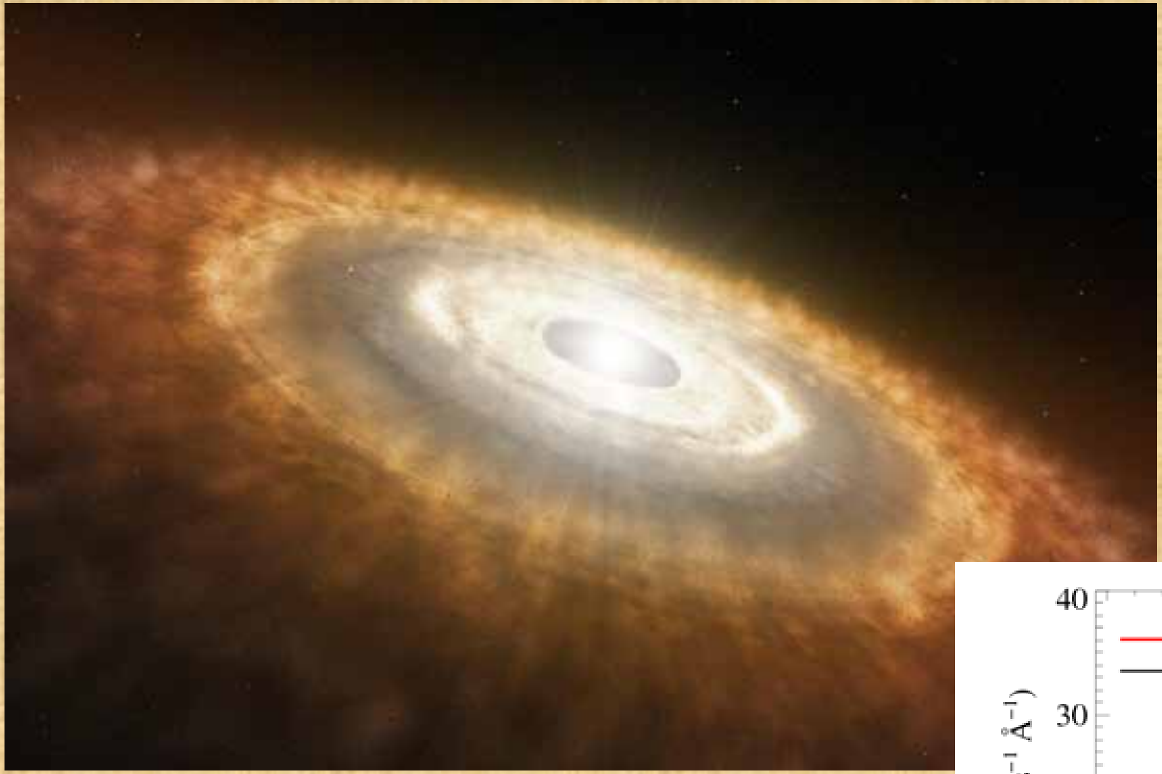
$\Delta\lambda$ = 1200 – 1800 Å

FOV ~ 10 - 20’

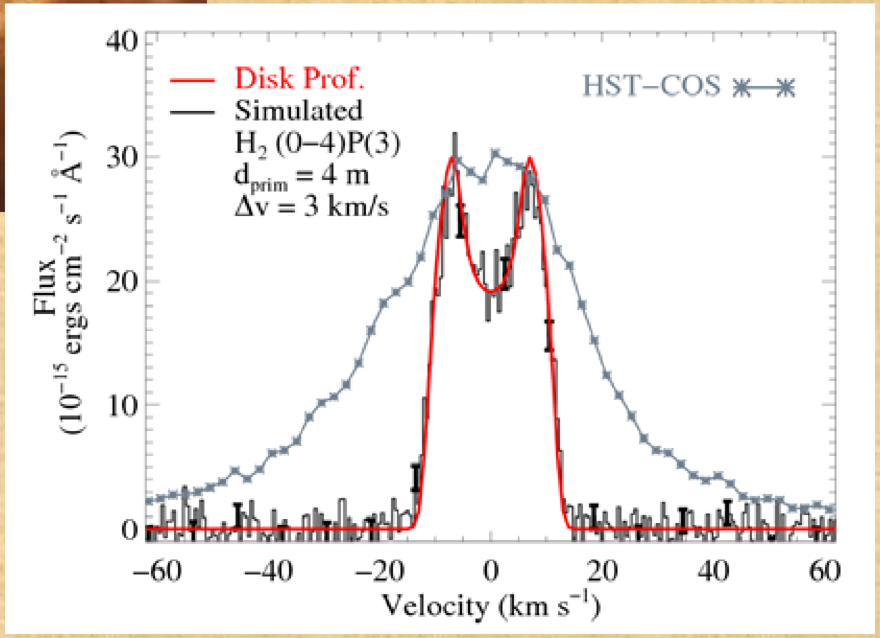
R ~ 3,000

$F_\lambda \leq 10^{-16}$ erg cm^{-2} s^{-1} Å^{-1} in 10^3 sec

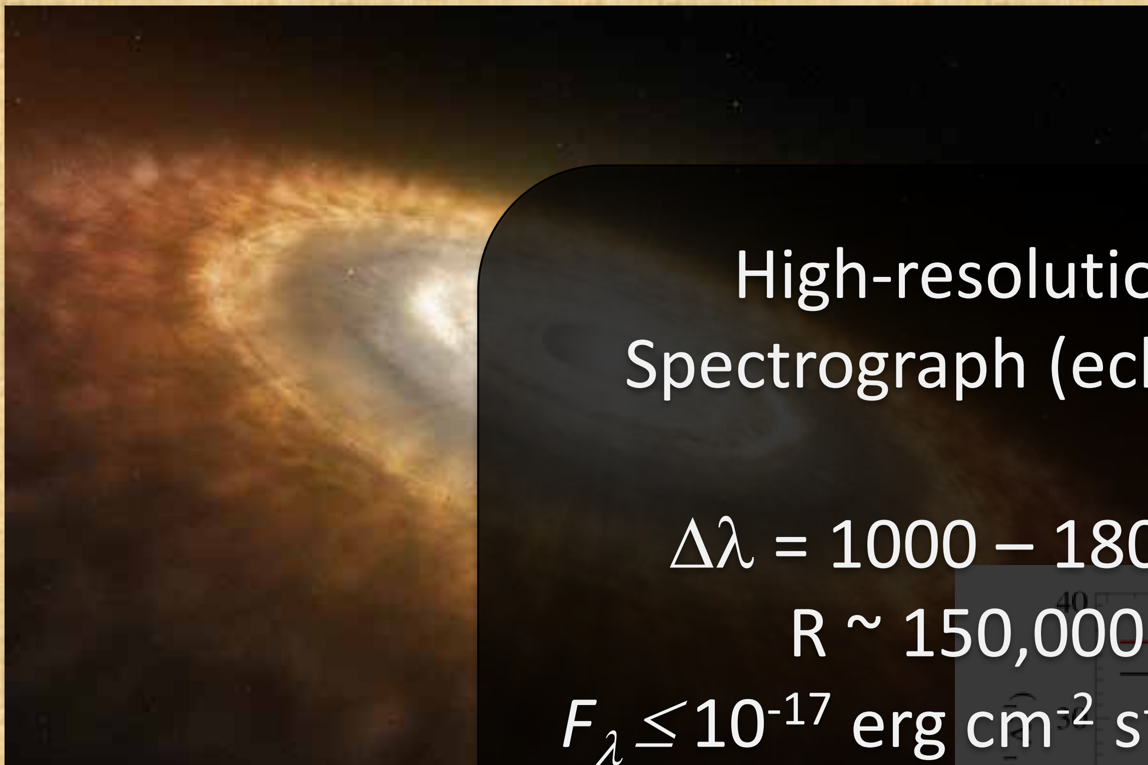
H_2 Disk Structure at *a* < 10 AU



For disks with known inclinations, high-resolution H_2 line profiles can be turned into gas disk rotation curves



H_2 Disk Structure at a < 10 AU



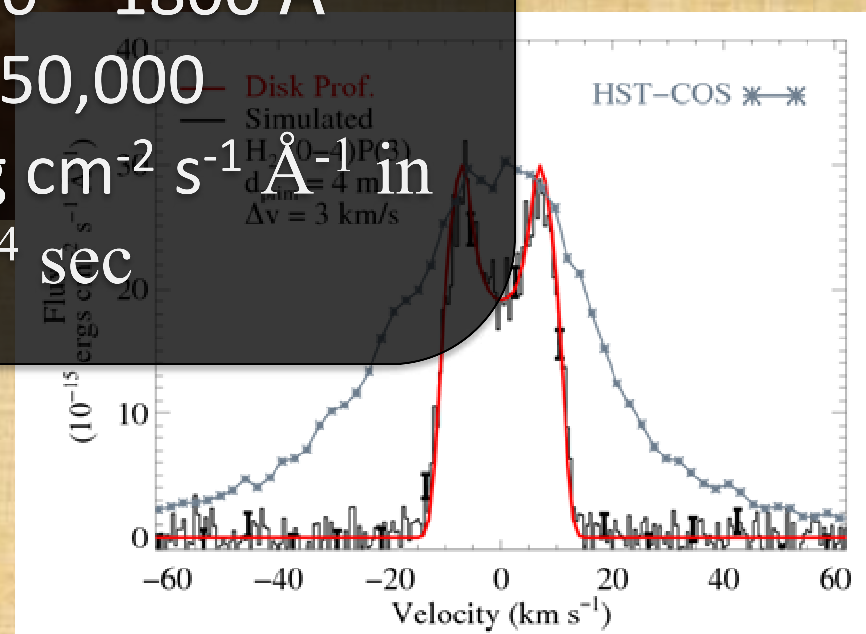
For disks with known inclinations, high-resolution H_2 line profiles can be turned into gas disk rotation curves

High-resolution Spectrograph (echelle)

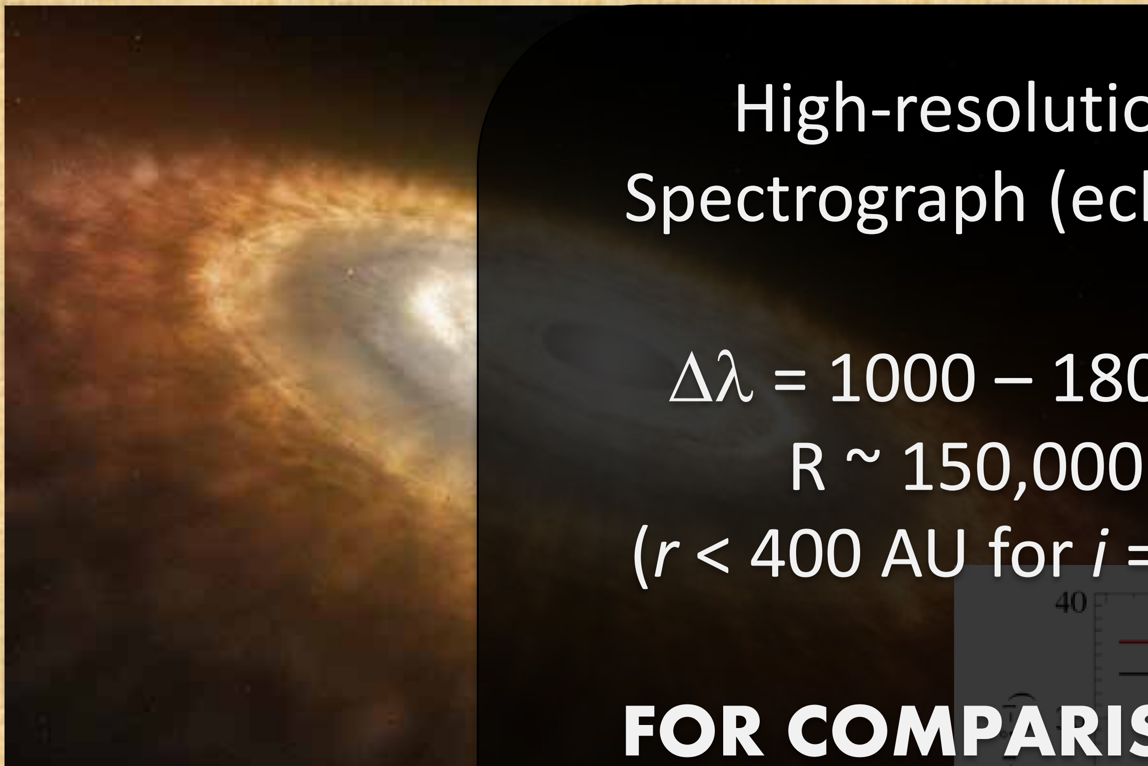
$\Delta\lambda$ = 1000 – 1800 Å

R ~ 150,000

$F_\lambda \leq 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1} in 10^4 sec



H_2 Disk Structure at a < 10 AU

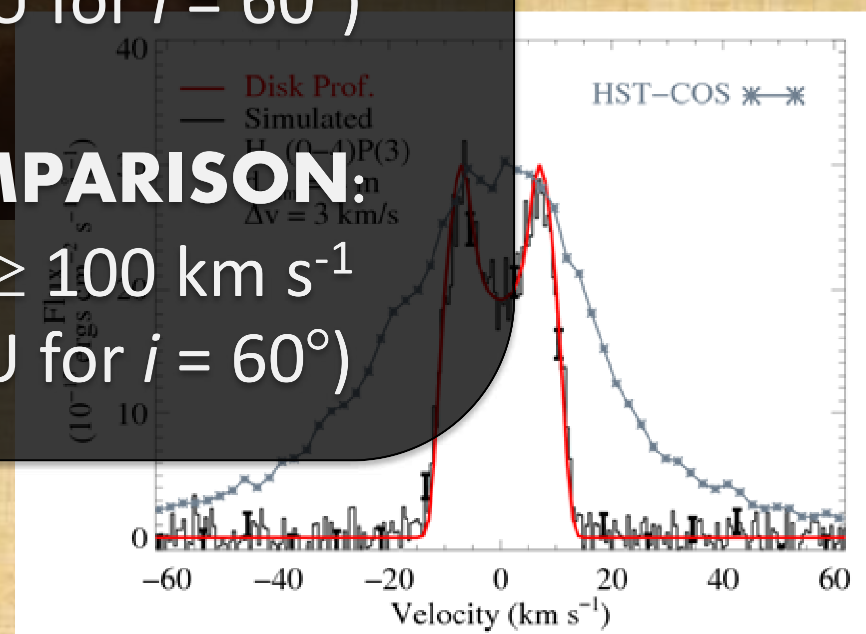


High-resolution Spectrograph (echelle)

$\Delta\lambda$ = 1000 – 1800 Å
R ~ 150,000
(r < 400 AU for i = 60°)

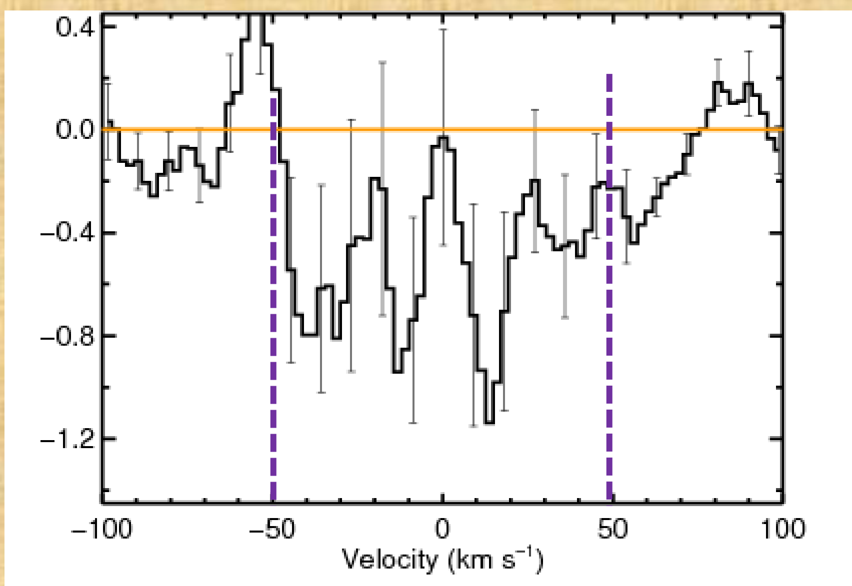
FOR COMPARISON:
JWST: $\Delta v \geq 100$ km s^{-1}
(r < 0.2 AU for i = 60°)

For disks with known inclinations, high-resolution H_2 line profiles can be turned into gas disk rotation curves



Exoplanet Atmospheres: Gas Giants

- Mass loss rates
- Atmospheric velocity structure
- **ONLY 3 planets!!!**



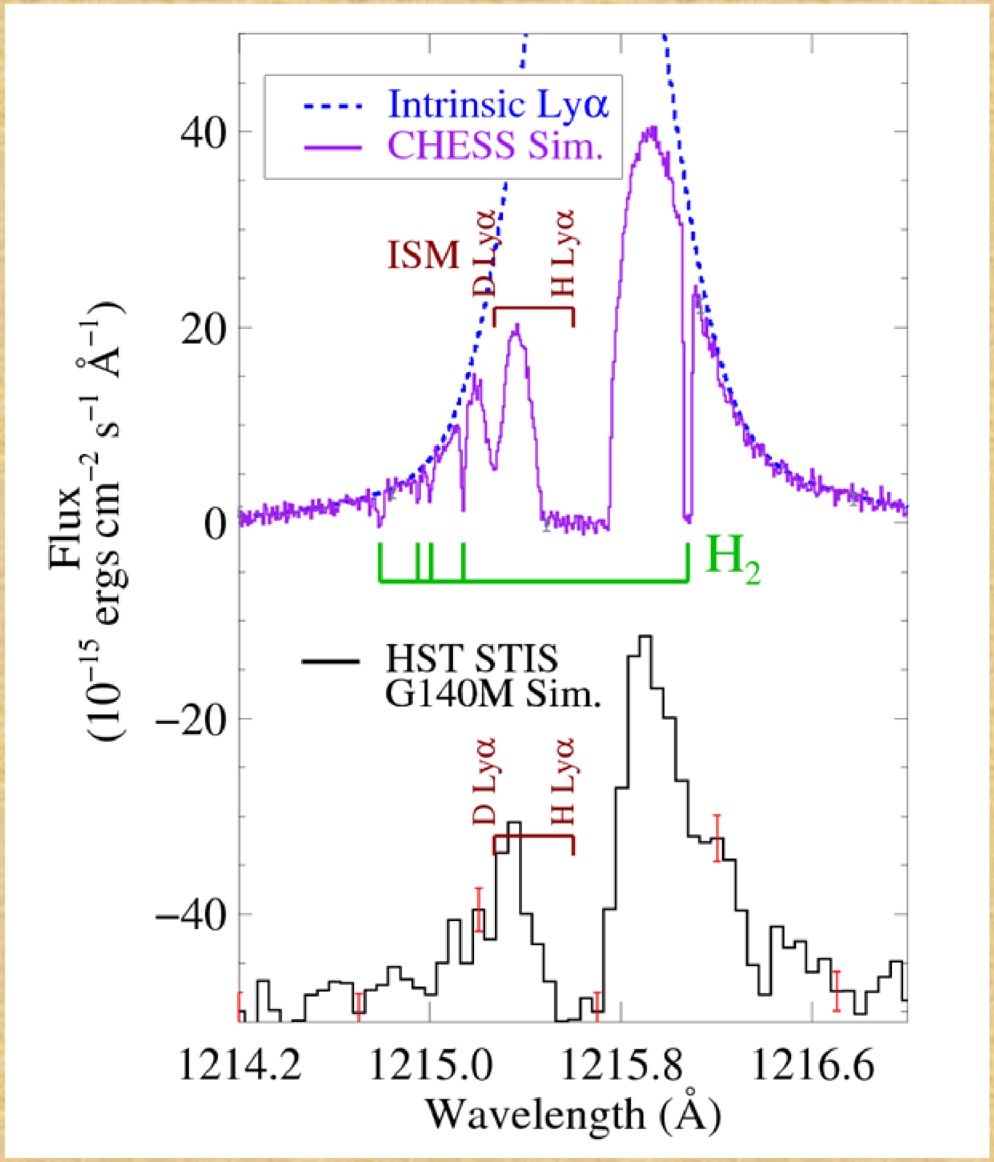
± 50 km/s

Linsky, Yang, France et al. 2010

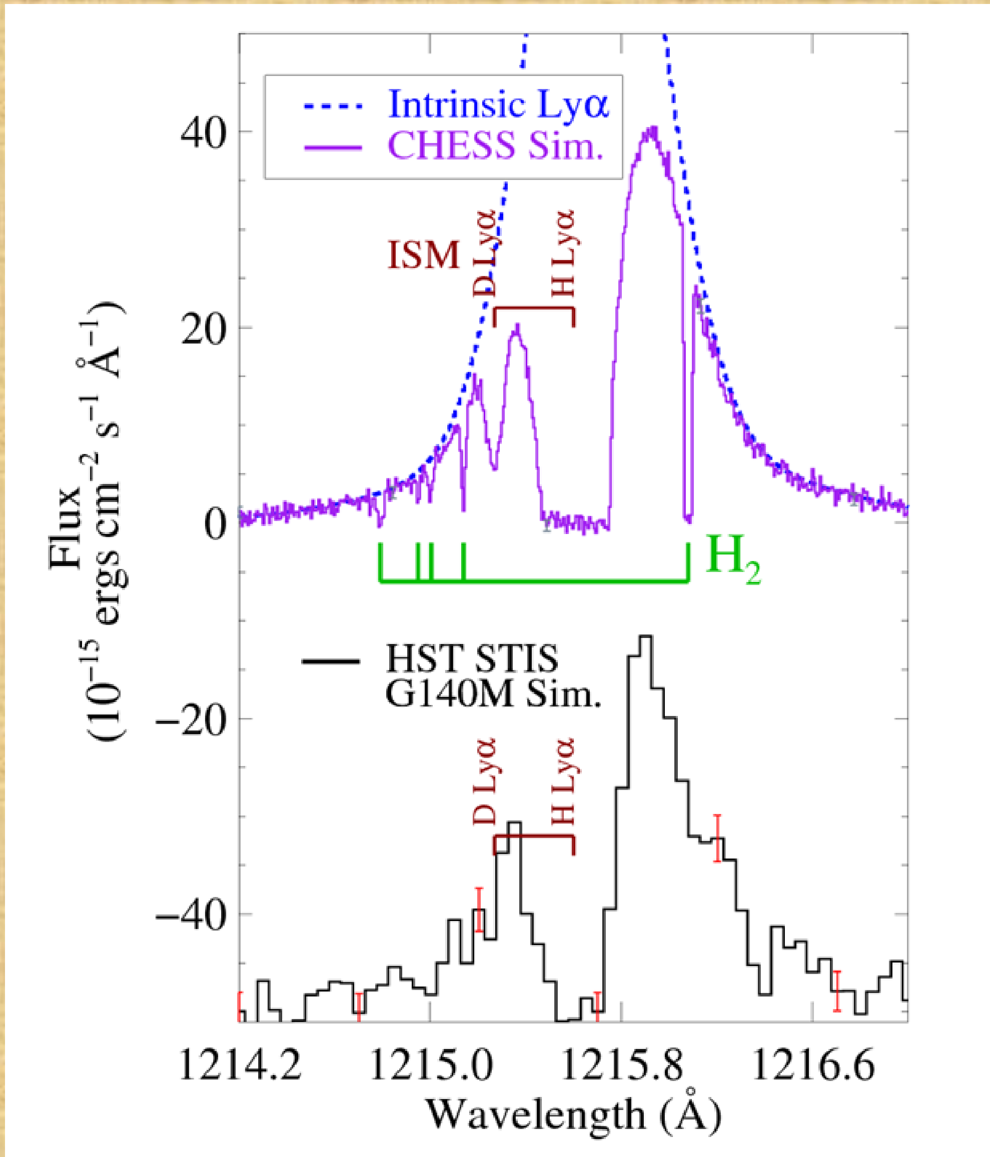
UV Spectroscopy on Late Night with Jimmy Fallon ?

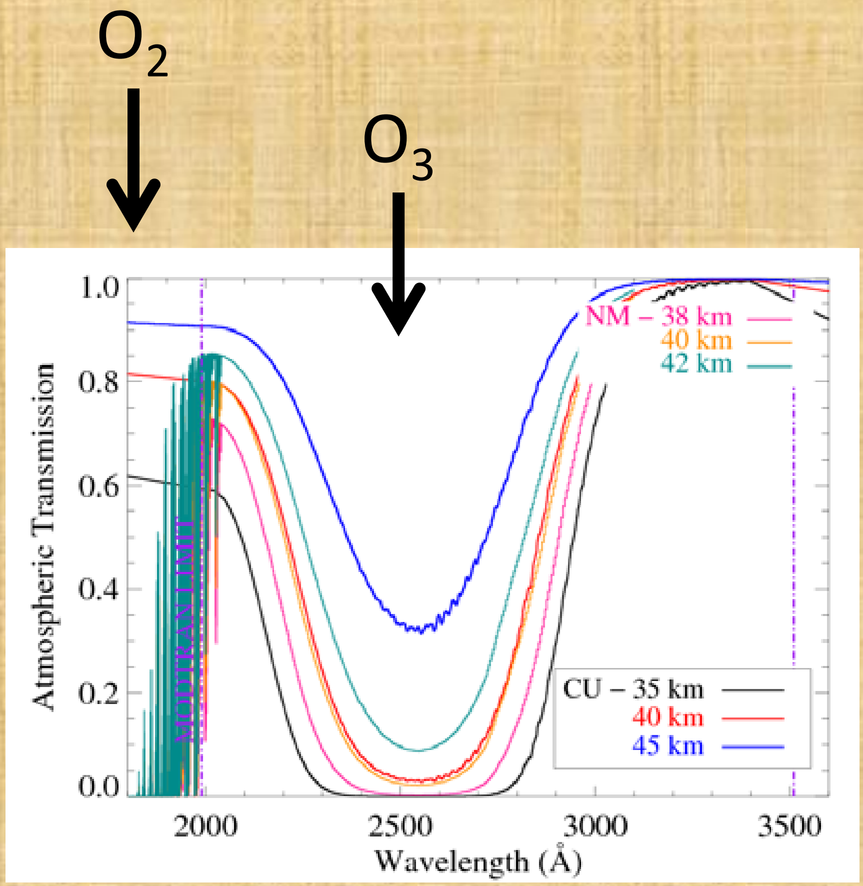
August 2010

Exoplanet Atmospheres: Future

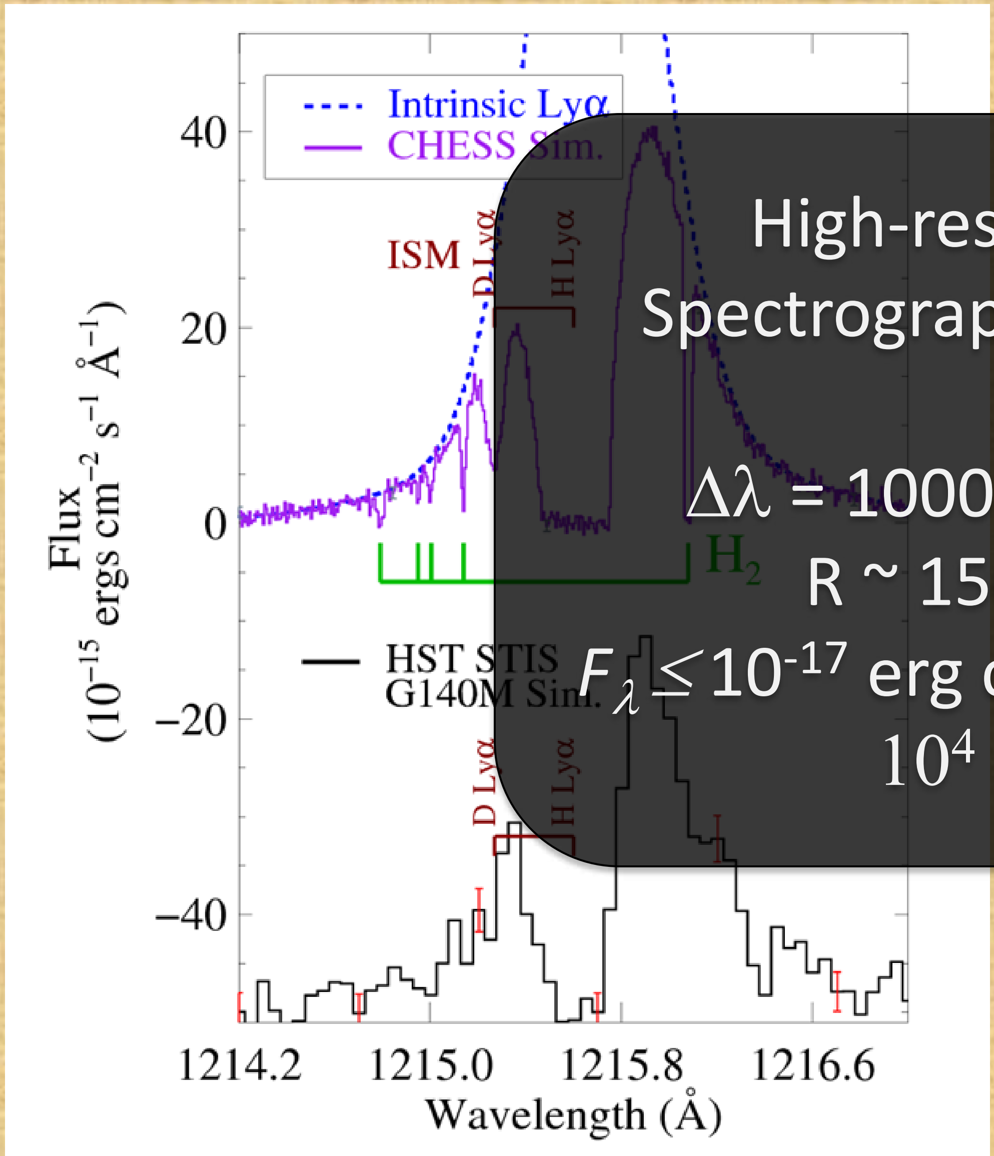


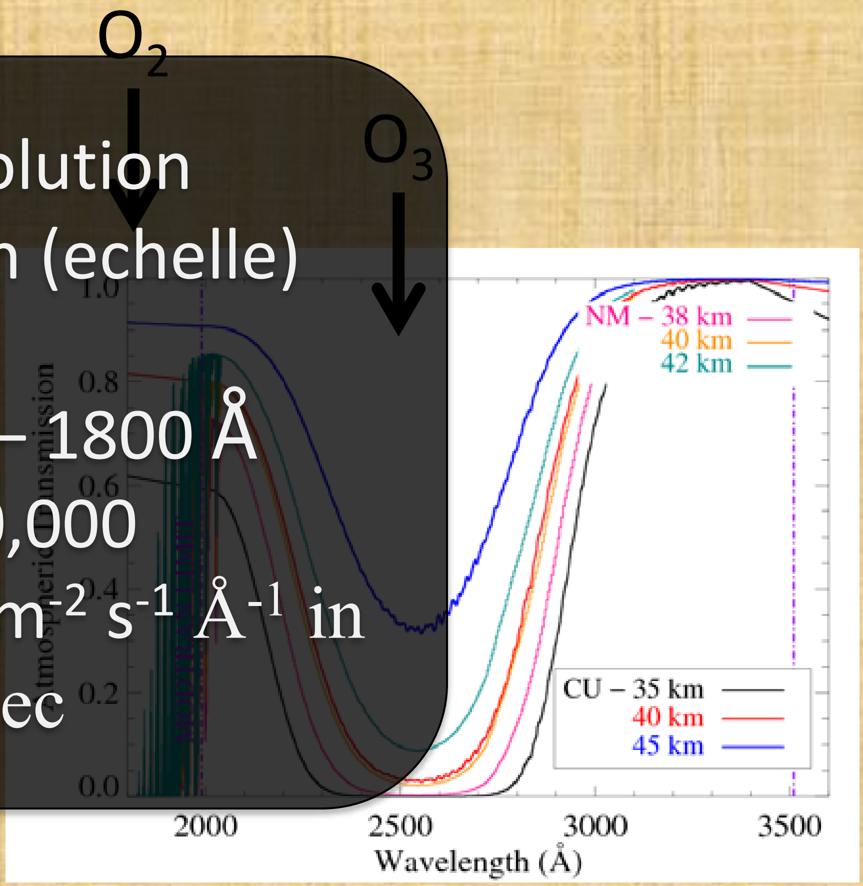
Exoplanet Atmospheres: Future





Exoplanet Atmospheres: Hot Jupiters





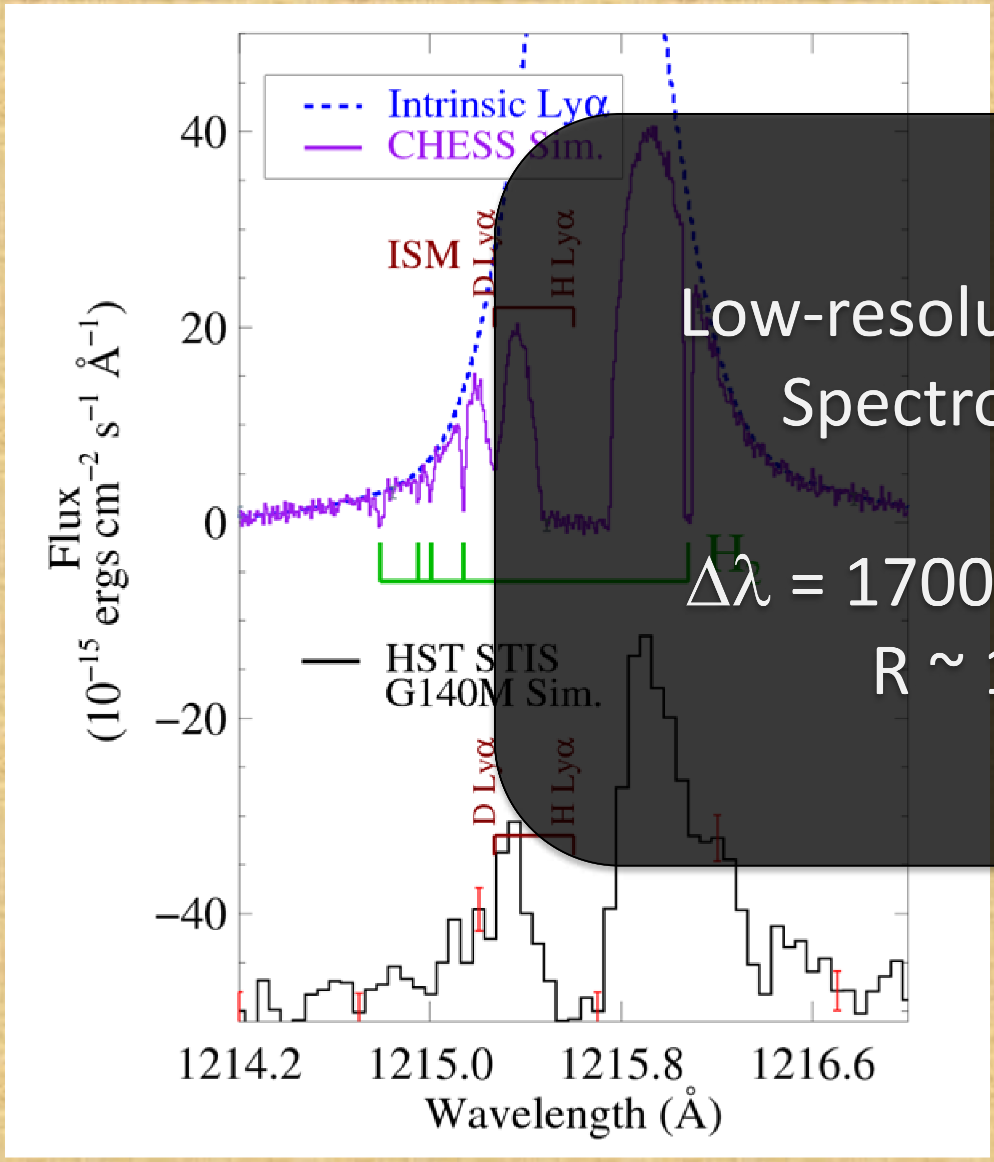
High-resolution Spectrograph (echelle)

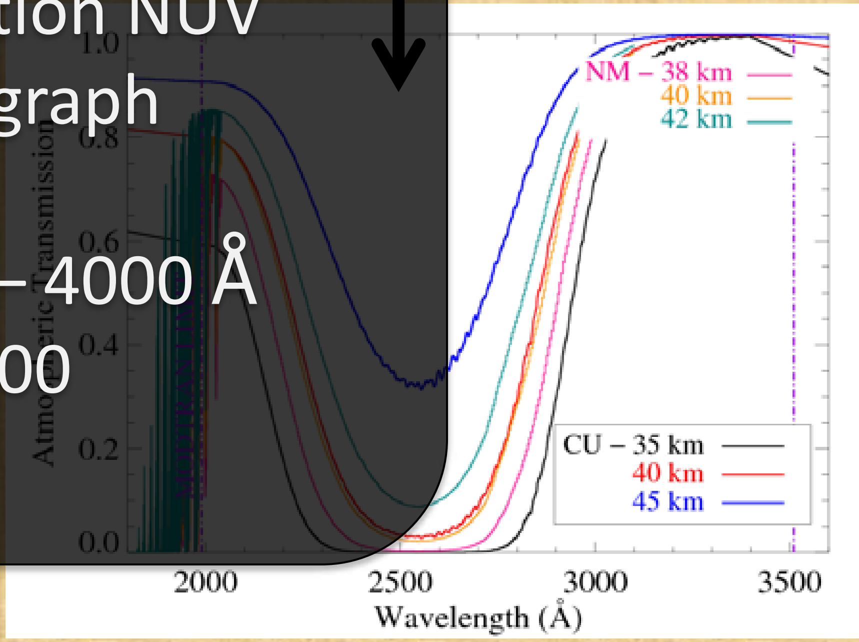
$\Delta\lambda$ = 1000 – 1800 Å

R ~ 150,000

$F_\lambda \leq 10^{-17}$ erg cm^{-2} s^{-1} $Å^{-1}$ in 10^4 sec

Exoplanet Atmospheres: exo-Earths





O_2

O_3

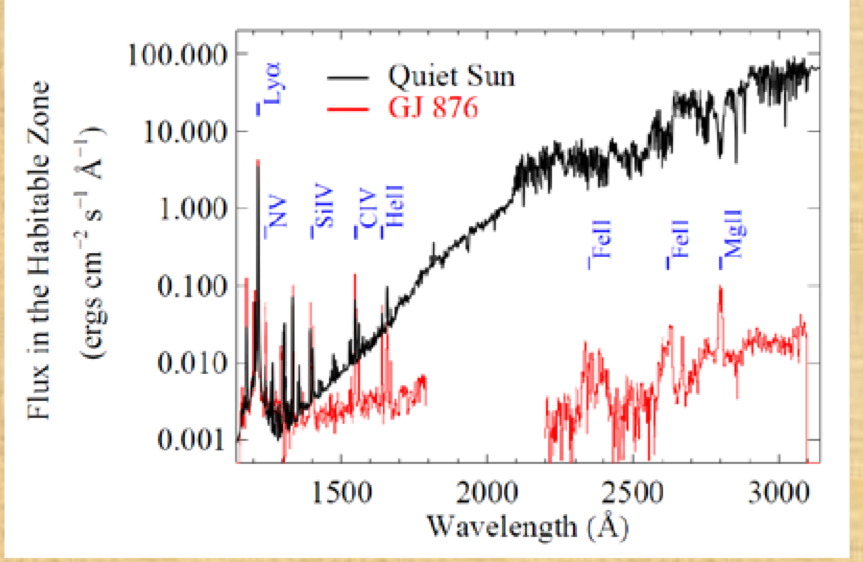
Low-resolution NUV Spectrograph

$\Delta\lambda$ = 1700 – 4000 Å

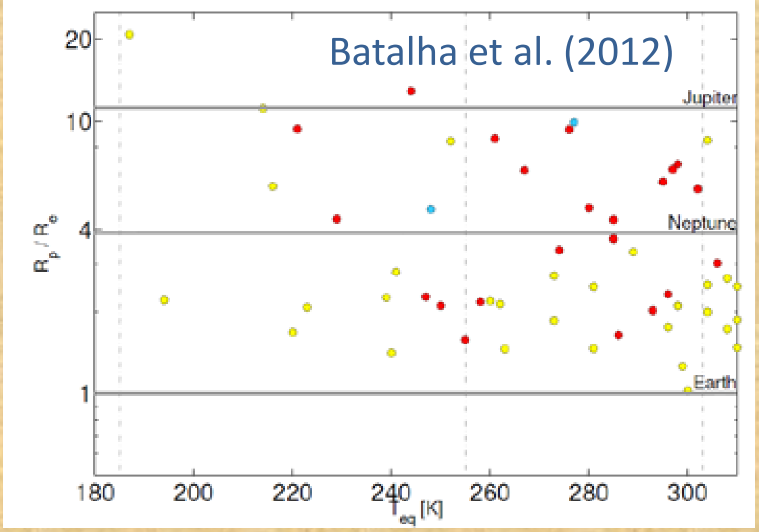
R ~ 100

Exoplanet Atmospheres: Exo-Earths

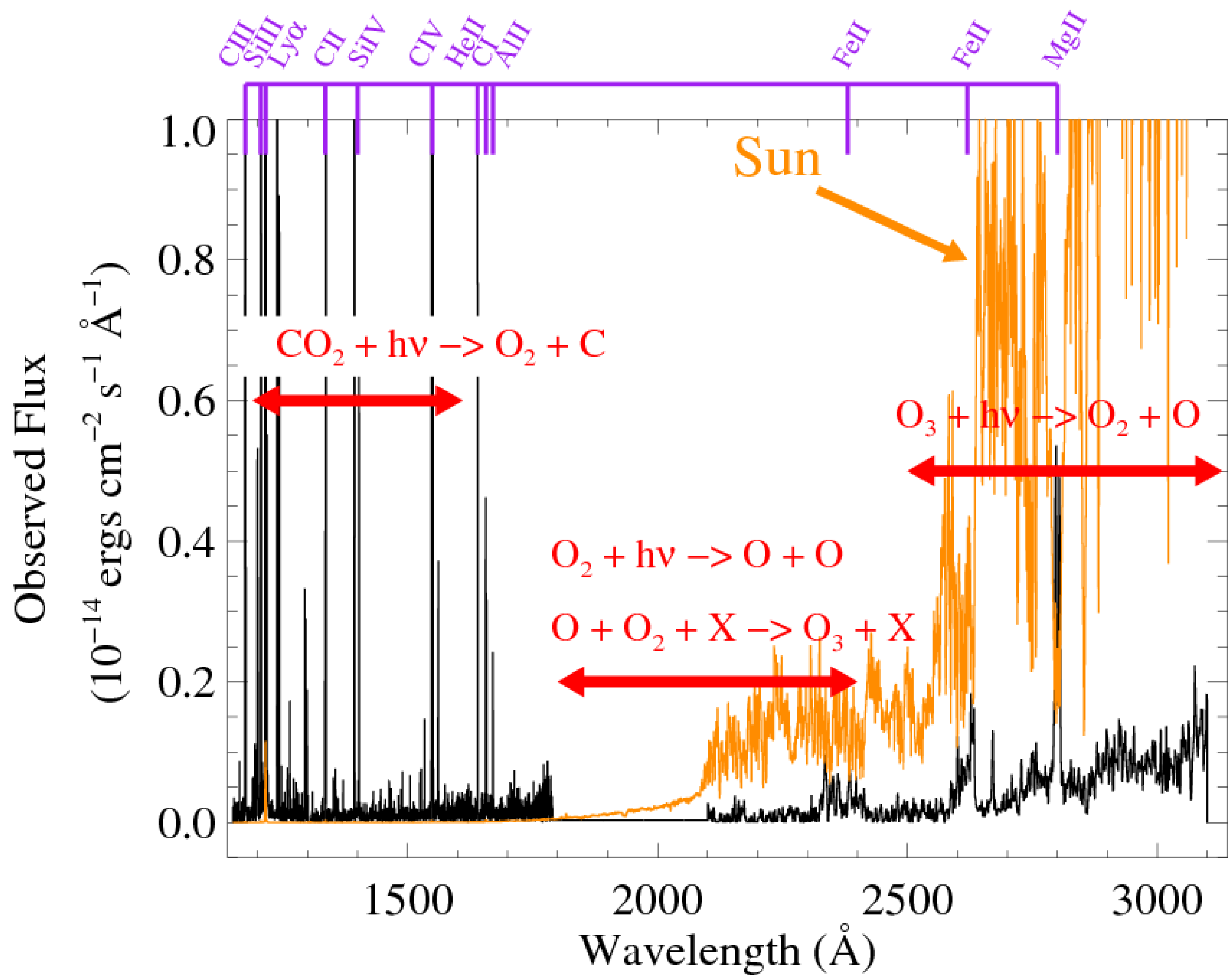
- Habitable planet candidates exist today
- The UV radiation fields of their host stars control the photochemical structure of their atmospheres – including formation of biomarkers
- But we know ***very*** little about chromospheric/coronal structure of average low-mass (M and late K) stars



France et al. (2012b)

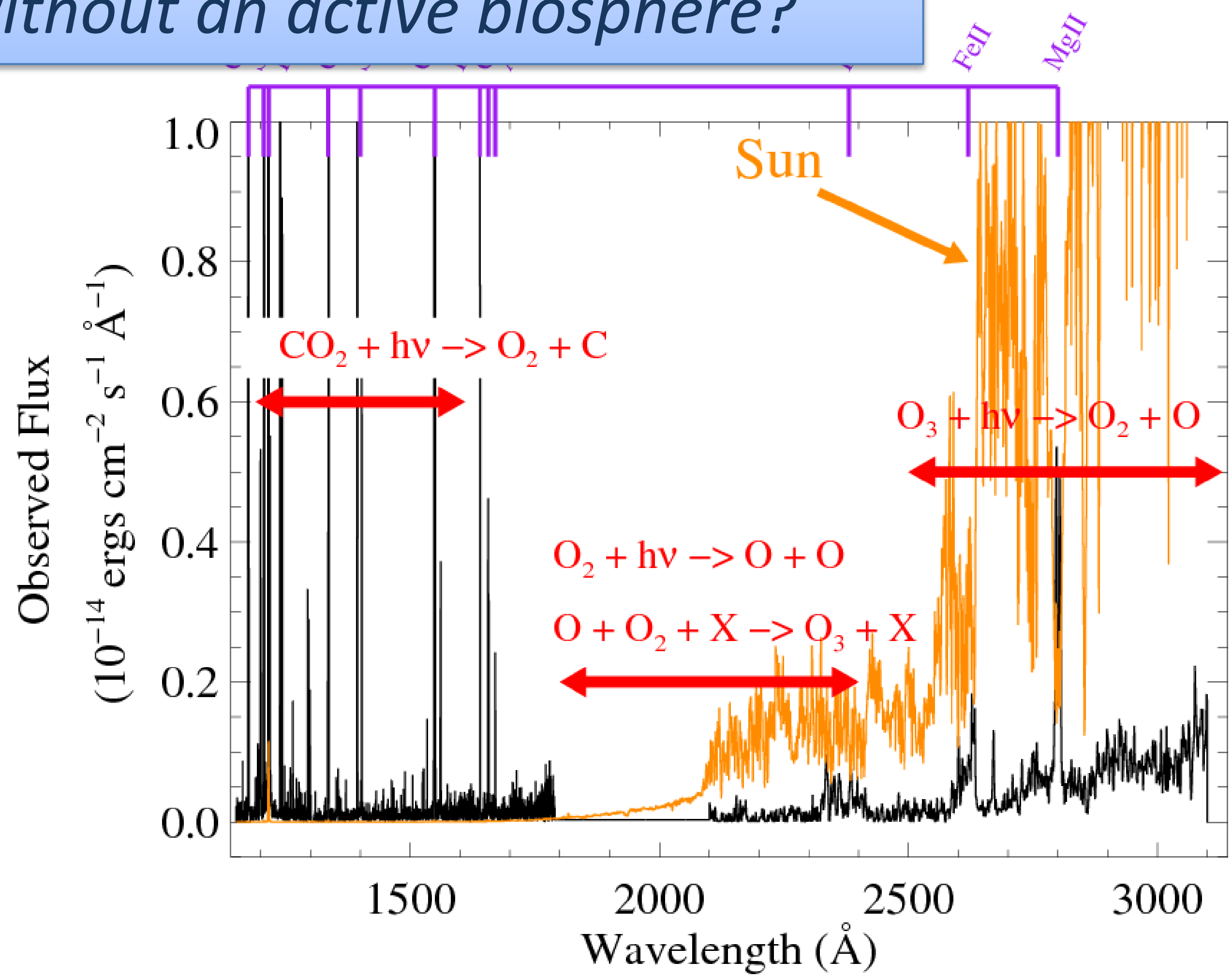


Exoplanet Atmospheres: Exo-Earths



M-dwarfs: Large FUV/NUV ratios.
Detectable Levels of O_2 and O_3
without an active biosphere?

: Exo-Earths



Tian, France, et al. – in prep.


Thank you
• kevin.france@colorado.edu
33

Kevin France: Protoplanetary Disks → Extrasolar Planets

UV Spectroscopy: 1) high-res and 2) multi-object

- UV Spectroscopy w/ photon-counting detectors (time res ≤ 1 sec)
  - 1) High-res = single object; 2) MOS 10 – 20’
- Angular resolution = 1 - 2”
  - Desired
- Spectral Resolution 1) High-res, $R = 1 - 1.5 \times 10^5$ ($\Delta v = 2 - 3$ km/s);
  2) MOS, $R = 3000$ ($\Delta v = 100$ km/s)
  - Desired
- Wavelength band(s) 1) High-res, 1000 – 1800 Å;
  2) MOS, 1200 – 1800 Å,
  - Required
- Sensitivity, 1) High-res: $F_\lambda \lesssim 10^{-17}$ erg cm^{-2} s^{-1} Å^{-1} in 10^4 sec;
  2) MOS: $F_\lambda \lesssim 10^{-16}$ erg cm^{-2} s^{-1} Å^{-1} in 10^3 sec
  - Required
- Dynamic Range: need to accommodate $F_\lambda \lesssim 10^{-18}$ erg cm^{-2} s^{-1} Å^{-1} without being swamped by Lyα airglow
  - Required
- Other requirement(s): one of these spectrographs should have a low-res (R ~ 1000) NUV capability (1700 – 4000 Å)
  - Required

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

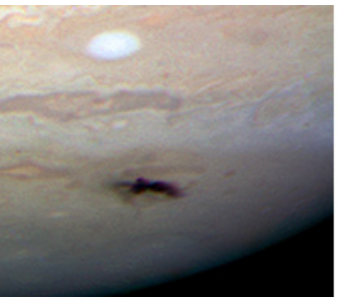
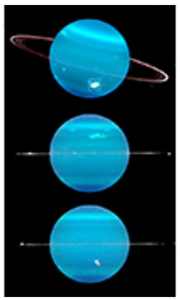
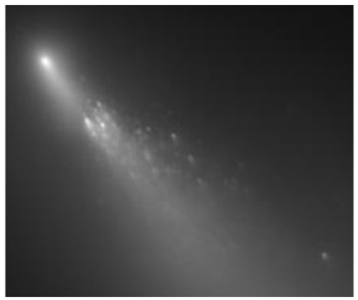
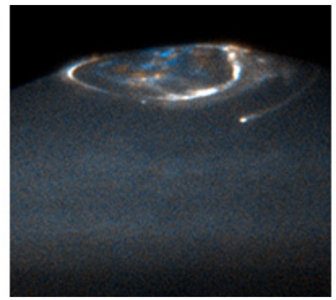
Mike Wong

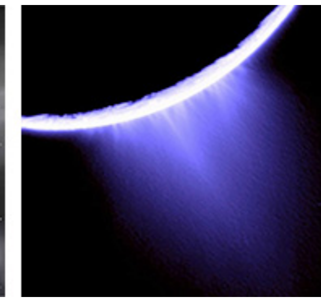
Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

Solar System Science Objectives with the Next UV/Optical Space Observatory



Michael H. Wong (UC Berkeley/Univ. Mich.), James F. Bell, John T. Clarke, Imke de Pater, Heidi B. Hammel, Walter Harris, Melissa A. Mcgrath, Kunio M. Sayanagi, Amy A. Simon-Miller

Solar System Science Context

- Solar System research provides a local reference point for origin/evolution of stars and planetary systems
  - origin: formation of planets, planetary systems, small body populations
  - evolution: chemical, compositional, atmospheric dynamics, orbital/collisional, internal structure, volcanism, magnetospheres
- Prior space telescopes have contributed
  - HST, Spitzer, FUSE, IUE, ISO, IRAS, WMAP, Herschel

Solar System Science from Space

- Advances in Solar System UV/O astronomy are currently enabled by HST
- Successor telescopes can also contribute:
  - need moving target tracking
  - can observe bright objects
  - FOV ~50 arcsec
- Remote observations often exploit time-variable processes
  - giant planet winds and storms, occultations, aurorae, volcanism/cryovolcanism, comet evolution

Science Requirements for Time-Domain Solar System Science

Investigation	Category	Data type (wavelength regime)	Sampling scales	Campaign duration	Resolution: R = spectral θ = spatial
Giant planet zonal winds and vortices	Atmospheres	Imaging (O)	Hours, single target rotation period	Years	θ ≤ 0.05"
Cloud/storm evolution and variability	Atmospheres	Imaging, spectroscopy (O, IR)	Hours, days	Days, years	R ≥ 2500 θ ≤ 0.05"
Occultations	Atmospheres	Photometry, spectroscopy (UV, O, IR)	Milliseconds	Hours	R ≥ 100–1000
Aurorae, magnetospheres	Atmospheres/ space science	Imaging, spectroscopy (UV)	Minutes, hours	Years, hours	R ≥ 500 θ ≤ 0.05"
Volcanic trace gases	Atmospheres/ geology/ astrobiology	Spectroscopy, imaging (UV, O, IR)	Days	Years	R ≥ 500–10000
Volcanic plumes	Geology	Imaging, spectroscopy (O, IR)	Days, hours	Years	R ≥ 2500 θ ≤ 0.025"
Cryovolcanism	Geology/ astrobiology	Imaging, spectroscopy (UV, O, IR)	Days	Years	R ≥ 2500 θ ≤ 0.025"
Mutual events, lightcurves	Small bodies	Photometry (O)	Milliseconds, minutes	Hours, months	R ≥ 5 θ > 10"
Cometary evolution	Small bodies	Imaging, spectroscopy (UV, O, IR)	Hours	Days	R ≥ 5 θ ≤ 0.05"

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

UNIVERSIDAD COMPLUTENSE DE MADRID

SEEKING BEHIND THE ANTHROPIC PRINCIPLE

Ana I Gómez de Castro and members of the European Network for UV Astronomy (NUVA) and the Imaging and Slitless Spectroscopy Instrument for Surveys (ISSIS*) science team

* ISSIS will be boarded in the WSO-UV Space Telescope

The emergence and eventual evolution of life

- The Universe in the range z=0-2
  1. Metallic evolution of the Intergalactic Medium.
  2. The physics and content of galactic haloes. Disk-halo connection.
  3. The evolution of UV irradiated environments involved in life emergence.

- Limited studies based on HST, GALEX and FUSE
  1. Few lines of sight observed. Inefficient spectroscopic methods.
  2. UV imaging with spatial resolution 2-3 arcsec and low sensitivity.
  3. Good spectroscopic information in the 115-320 nm range with HST/COS. Very scarce information at shorter wavelengths. Very scarce information on temporal scales.

Specific Science Investigation

- What cannot be done now?
  - High sensitivity, narrow band UV imaging.
  - Imaging or spectroscopy below 1150 Angstroms to the He I resonance transitions.
  - High sensitivity, high resolution (<0.08 arcsec) imaging.
  - Mid-to-long term monitorings of targets in the ultraviolet

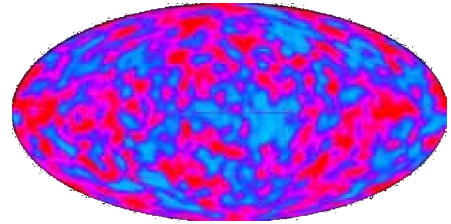
- What are next steps needed?
  - Larger collecting surfaces, efficient and large photon-counting detectors, technologies controlling light diffusion on nanometer scales (coatings), research on materials transparent to UV radiation and materials for UV optics (mirrors,gratings, coatings, grisms) less sensitive to the Earth environmental conditions to decrease the test and integration costs of UV instrumentation.
  - UV survey of the galactic plane
  - Accessible data base on molecular electronic transitions for space abundant and life associated molecules

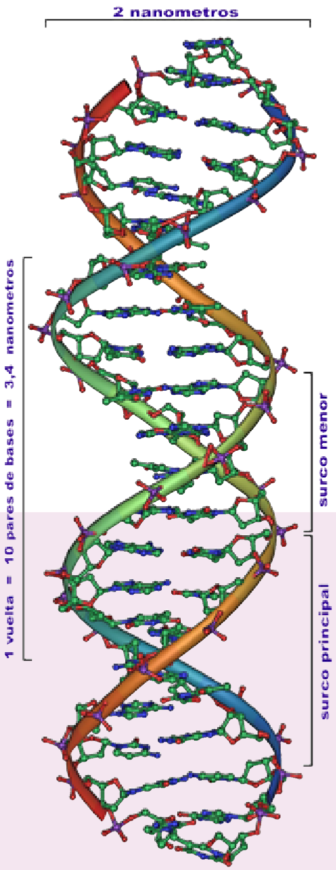
Science Requirements

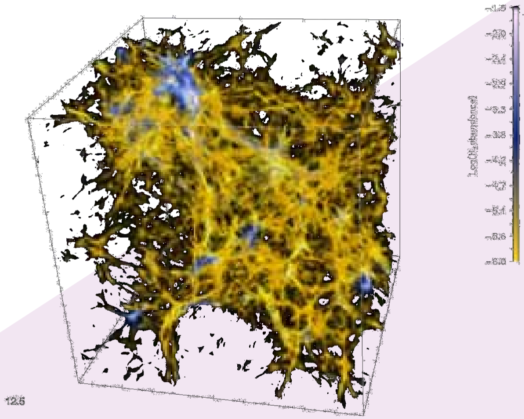
TOPIC	1. IGM	2. Galactic Halos & Winds	3. Environment for life emergence
Mode	Integral field Spectroscopy	High resolution imaging	High resolution imaging Mid Resolution Spectroscopy
FoV	Degrees	1-3 arcmin	1-3 arcmin
Angular Res.	1 arcsec	0.01 arcsec	0.05-0.001 arcsec
Spectral Res.	~ 1000	40 @ 1200	40 @1200 15,000
Spectral Range	900-3200 Angstroms	900-3200 Angstroms	500-3200 Angstroms
Sensitivity			1e-16 – 1e-18 erg/s/cm2/A
Dynamical Range	1e4-1e6	1e4	1e4-1e6

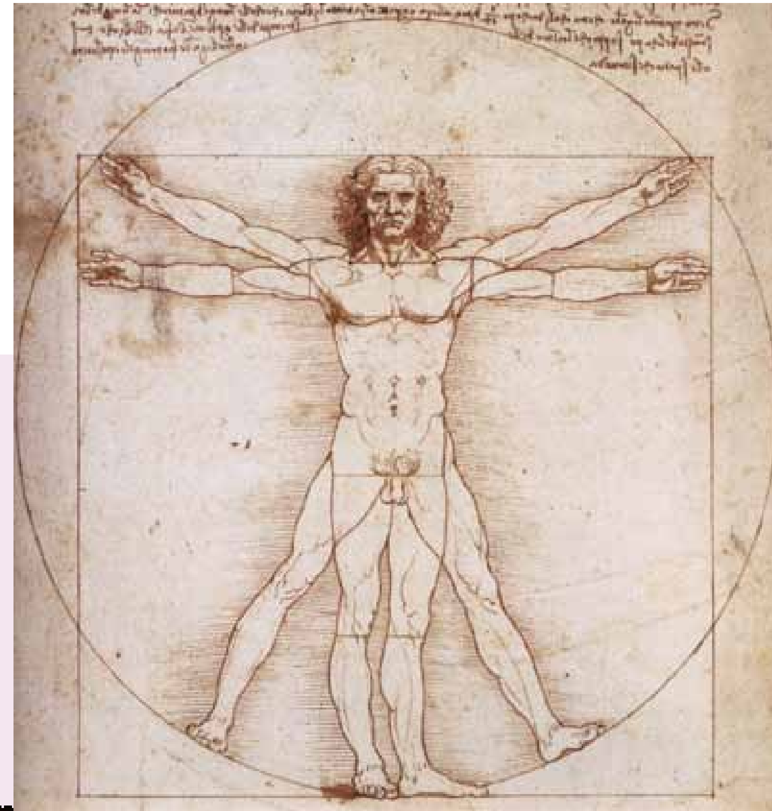
An efficient UV-Optical high resolution (50,000) spectrograph will allow to measure possible variations of the fine structure constant and the Lamb shift in the local Universe without the uncertainties imposed by the Atmospheric reflection index to the current studies.

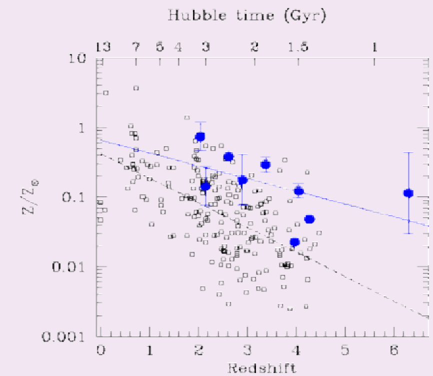
SEEKING INTO THE ANTHROPIC PRINCIPLE

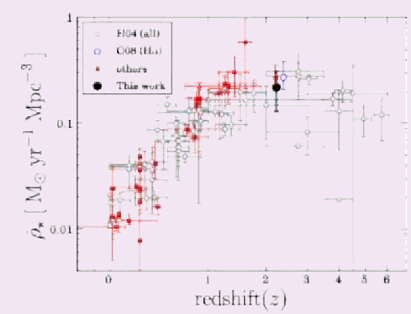


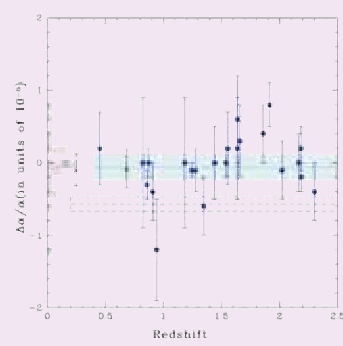












RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

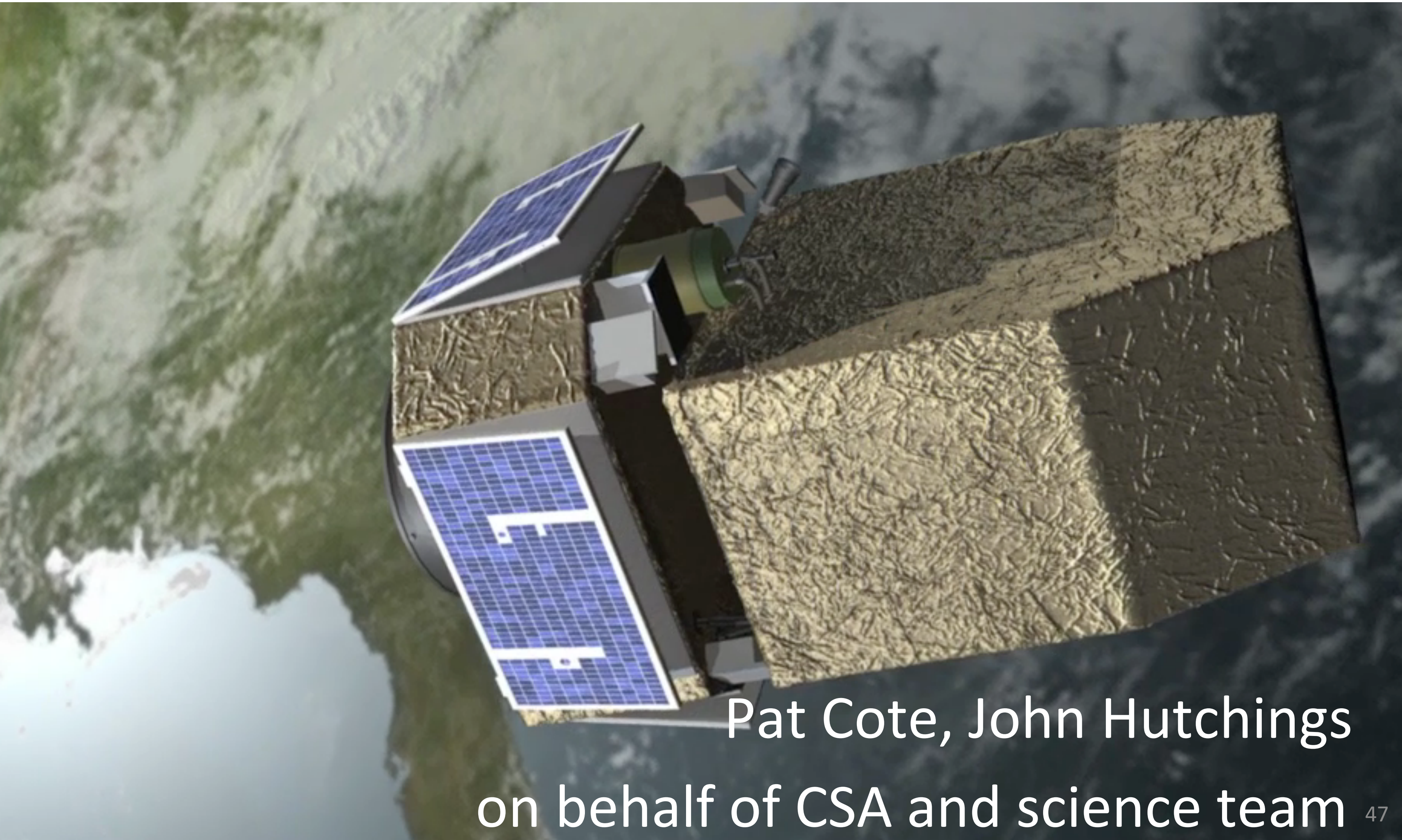
Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

Jason Tumlinson

CASTOR: A wide-field UV-optical survey telescope with 0.15" resolution



Pat Cote, John Hutchings
on behalf of CSA and science team

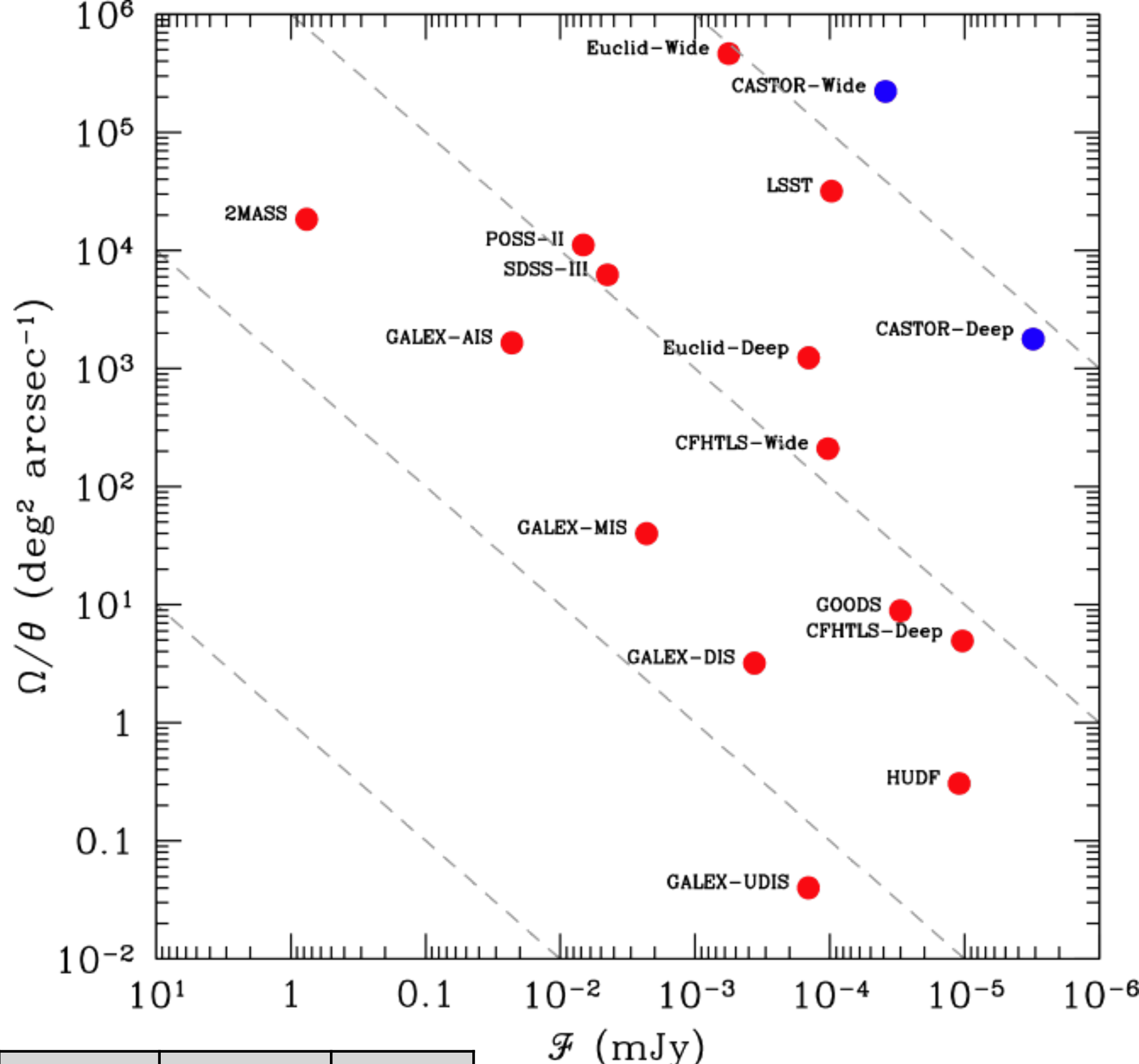
CASTOR - Science Context

- Big picture
  - Need for wide-field high-resolution surveys
  - Support DE/DM science: uniform high resolution
  - Some PI programs envisaged
  - Slitless spectra a simple option
- What has been done up to now?
  - Nothing in space; ground observing limited
  - GALEX and Astrosat .. but need better
  - Learned the value of a wide field imager in space

CASTOR Specific Science Investigation

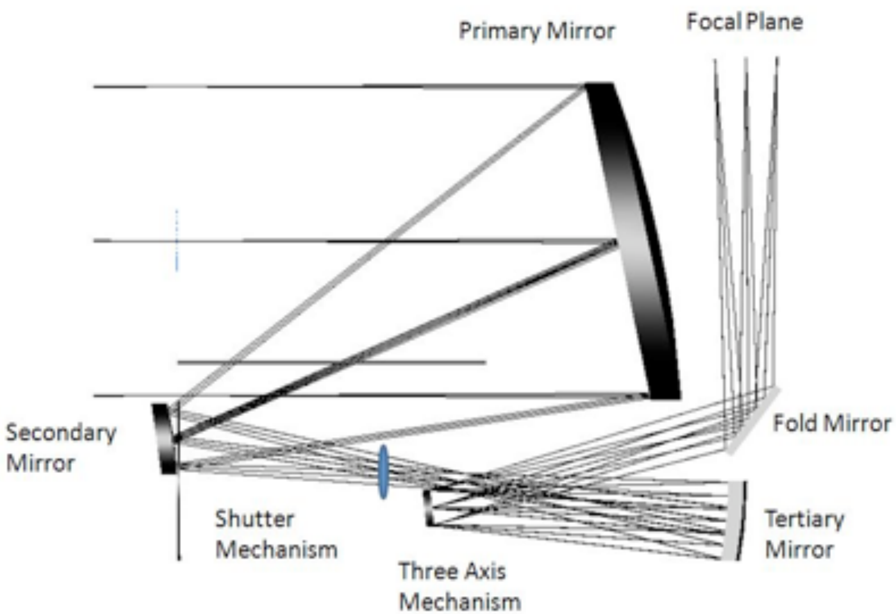
- What can be done now
  Technology exists for medium-cost mission
  – Risk retirement, design, cooler, ops need work
- What are next steps needed?
  – Phase A studies
  – Partnerships
  – Optical design for spectra

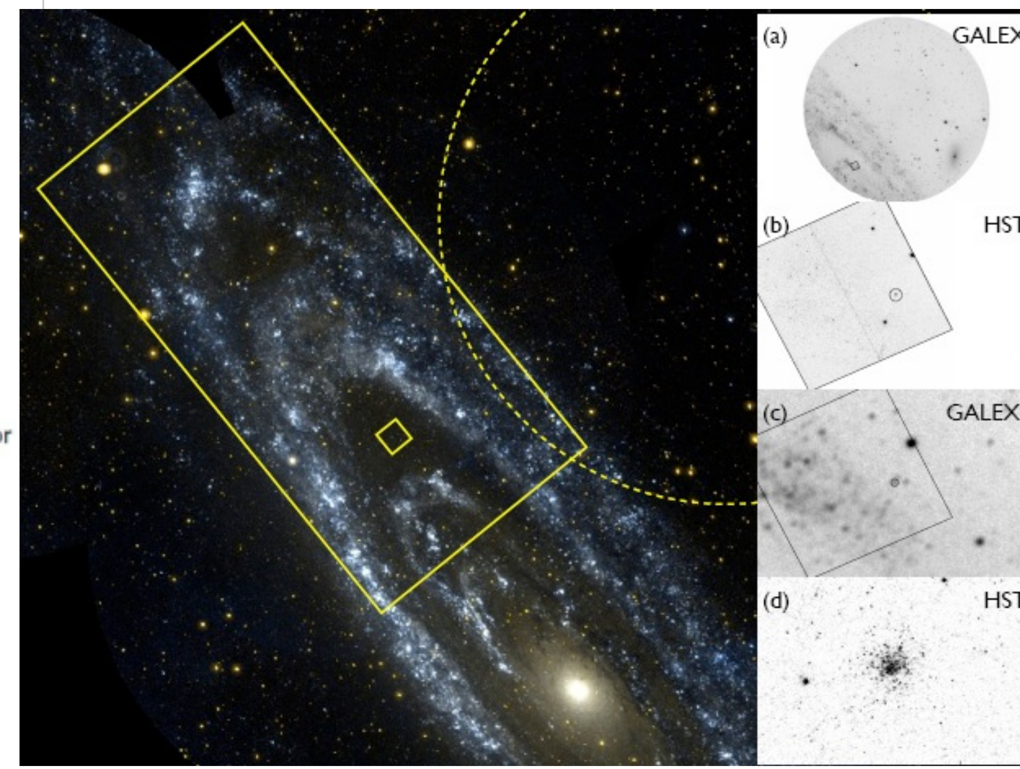
Survey strategies and comparisons

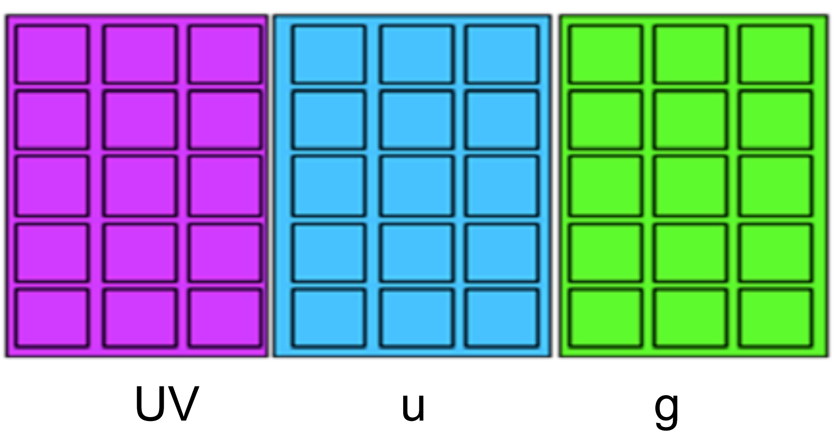


Survey	Area (deg^2)	Mode	UV_{lim} (mag)	u_{lim} (mag)	g_{lim} (mag)	T (years)
Wide	**5000**	**contiguous**	**25.79**	**27.10**	**27.78**	**1.8**
Deep	**40**	**contiguous**	**29.35**	**29.84**	**29.90**	**0.4**
Nearby Galaxies	**N ≈ 125**	**pointed**	**26.82**	**28.00**	**28.44**	**0.15**
Nearby Clusters	**150**	**contiguous**	**26.82**	**28.00**	**28.44**	**0.15**

Design and field of view







CASTOR Science Requirements

- Imaging / Spectroscopy / Time Domain All, in that order of priority
- Field(s) of View 2/3 square degrees (1.16 x .58)
- Physical / angular resolution(s) 0.15"
- Spectral resolution 100-700 full-field slitless
- Wavelength band(s) 150-550 nm in 3 bands
- Sensitivity NUV 26-29 mag point source for shallow/deep surveys
- Dynamic Range as per CCDs
- Other requirement(s) >700 Megapixels, ~170GB per day, 80% efficiency
- Design concept 1m aperture, single mechanism - imaging to spectra

Representative CASTOR Science

Dark Energy and Cosmology	Galaxy Evolution	Near-Field Cosmology	Stellar Astrophysics	The Outer Solar System

- What is the equation of state of the universe? How does dark energy evolve with redshift?
- What is the structure of dark matter halos?
- How did cosmic structures form and evolve as the universe expanded?
- When did star formation begin in the oldest galaxies?
- How did the subcomponents of galaxies arise, and when?
- How did supermassive black holes form and grow?
- What is the "mass function" of galaxies? How many faint galaxies are there?
- How common are central stellar nuclei in galaxies? Is there a connection to supermassive black holes?
- How important were mergers and accretions in the formation of the Milky Way and nearby galaxies?
- Where are the oldest and most metal-poor stars in the Galaxy?
- Where are the smallest galaxies in the local universe? How did they form?
- What is the three-dimensional structure of the local universe?
- How common are "intermediate-mass" black holes?
- What role do hot and massive stars play in the chemical enrichment of local galaxies?
- What were the formation channels of degenerate stars in star clusters?
- How many objects, including dwarf planets, exist in the far outer solar system? What is their distribution of sizes and masses?
- What is the surface chemistry of these small bodies? Is there evidence for organic ices? Has their chemistry changed with time?

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Charley Noecker

Kevin France

Mike Wong

Ana Gomez de Castro

John Hutchings (Côté)

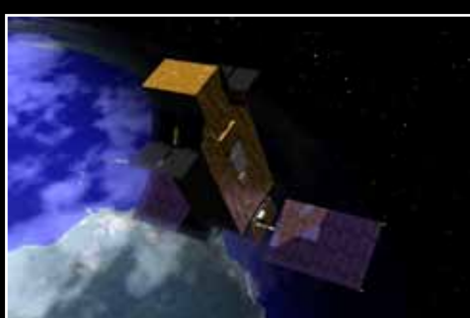
Jason Tumlinson

Unique Astrophysics in the Lyman Ultraviolet

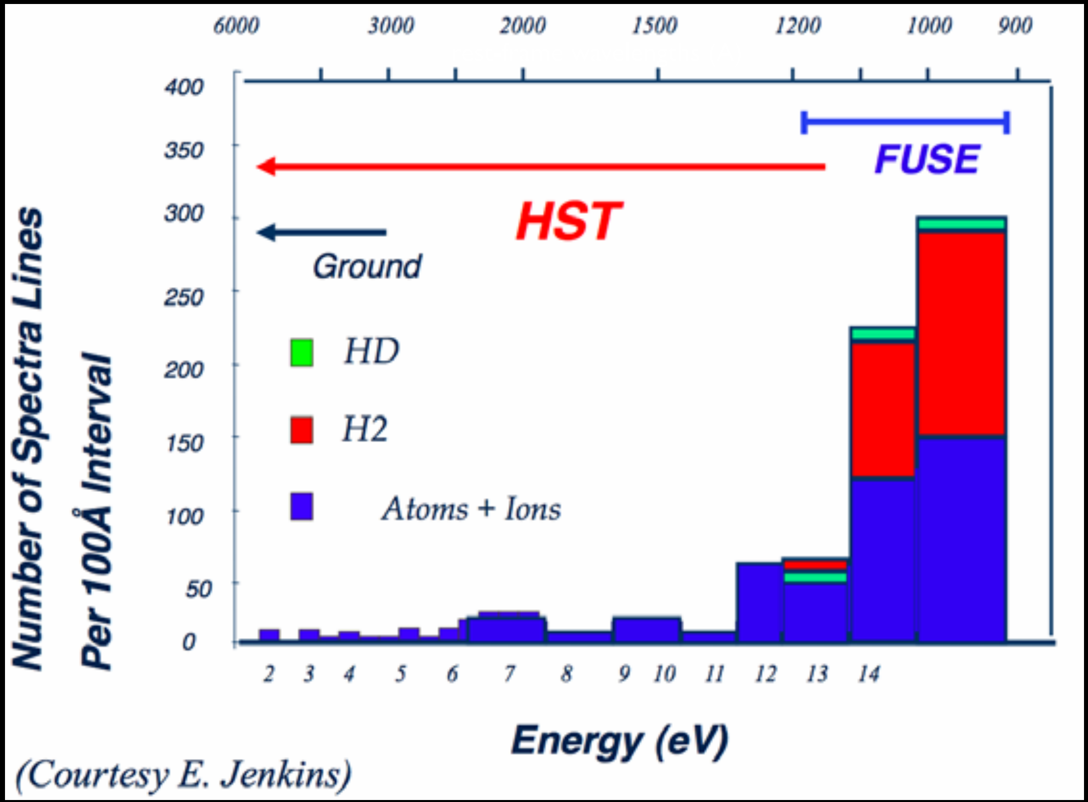
Jason Tumlinson (STScI)
for
Co-authors: Alessandra Aloisi, Jerry Kriss, Kevin France
Signers: Ken Sembach, Andrew Fox, Todd Tripp, Edward Jenkins, Matthew Beasley, Charles Danforth, Michael Shull, John Stocke, Nicolas Lehner, Christopher Howk, Cynthia Froning, James Green, Cristina Oliveira, Alex Fullerton, Bill Blair, Jeff Kruk, George Sonneborn, Steven Penton, Bart Wakker, Xavier Prochaska, John Vallerga, Paul Scowen

Short Version:

There is no astrophysical reason to break spectroscopic wavelength coverage anywhere between the atmospheric cutoff (3100 Å) and the Lyman limit (912 Å).

 +  = Awesome

A Band Rich in Physical Diagnostics



Mission		Lifetime	UV Coverage (Å)
Copernicus		1972 - 1981	900 - 3150
IUE		1978 - 1996	1150 - 3200
FUSE		1999 - 2007	900 - 1190
HST	FOS	1990 - 1997	1150 - 8000
	GHRS	1990 - 1997	1150 - 3200
	STIS	1997- now	1150 - 3200
	COS	2009 - now	Cyc 17-19: 1140 - 3200 Cyc 20+: 900 - 3200

FUSE needed to exist because the Hubble optics are coated with MgF_2, which has very poor reflectivity below 1150 Å.

The "Lyman Ultraviolet" between the Lyman limit (912 Å) and Lyman alpha (1216 Å) contains many astrophysical vital diagnostics of gas density, metallicity, and kinematics:

- molecular hydrogen (H2), in dense interstellar gas.
- O VI, in highly ionized, metal enriched ISM, CGM, or IGM.
- O I (neutral oxygen) lines that are sensitive metallcity indicators.
- the Lyman limit itself, which reveals the escape of ionizing radiation from galaxies.

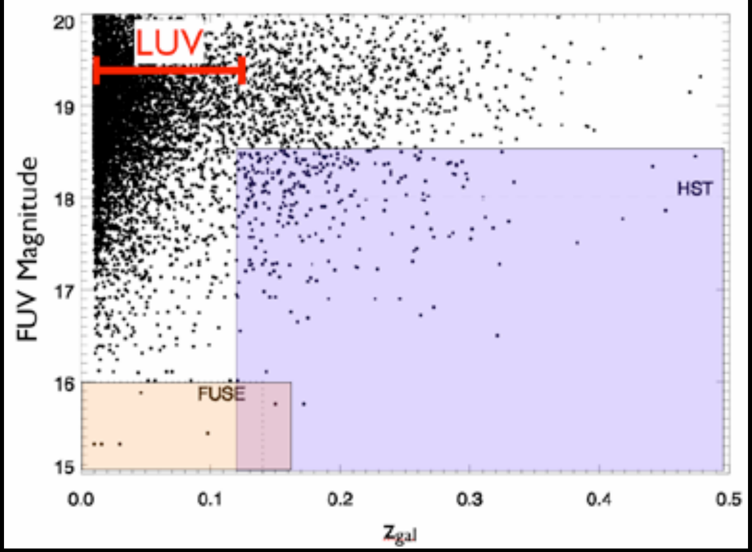
These lines can be observed with redshift, but that sacrifices their use in the all-important Local Universe.

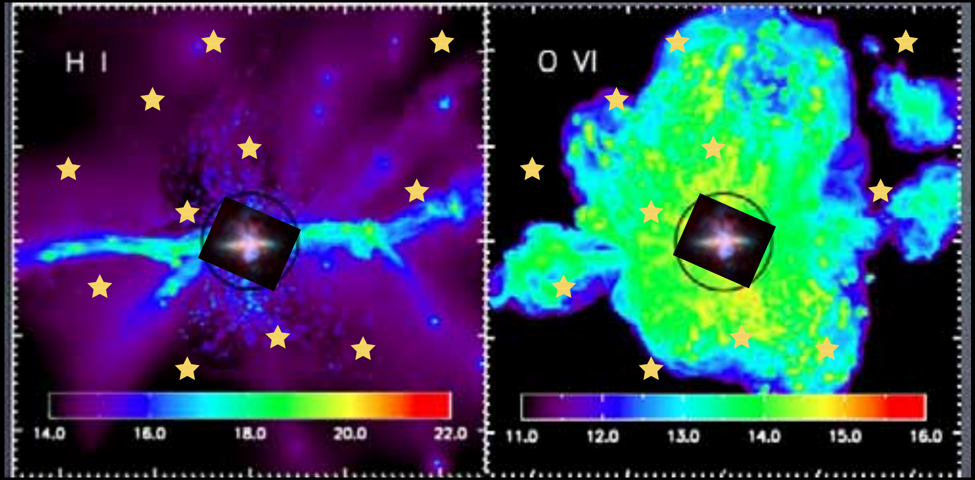
The Circumgalactic Medium (CGM) in High Fidelity

COS has been very successful at studying the CGM using LUV lines redshifted into the COS band at > 1150 Å.

The COS-Halos program has found that the CGM has as much metal content as the ISM, as traced by O VI λλ1032,1038 observed at z > 0.15.

But COS is severely limited in the number of galaxies it can probe with this technique: many more QSO/galaxy pairs are available at z < 0.1.





A new spectrograph on an 8 m telescope could observe HI and O VI with ~10 QSOs behind all of the galaxies in the local 10 Mpc volume.

Diverse Science Enabled by the LUV

Chemical Abundances in Star Forming Galaxies

- uses a range of weaker oxygen lines and Lyman series to nail down accurate H.
- 100x HST sensitivity means that OB star observed at S/N ~ 10 in ~ 50 HST orbits at 1 Mpc (Local Group), could be detected in **all** SFGs inside the 10 Mpc Local Volume.

A UV-band IFU or ~100-fold MOS capability would achieve a 1000-10,000 fold gain over HST that would allow us to map all the gas phases of the ISM at 100 pc scales in all star-forming galaxies within a 10 Mpc Volume.

Effect of UV Radiation on Exoplanet Biosignatures (and Habitibility)

- Abiotic O_2 production (via CO_2 dissociation) and the subsequent formation of O_3 depend on the LUV through NUV radiation of the host stars.
- FUV/LUV measurements of O VI and Fe XVIII are excellent tracers of the LUV AND X-ray flux incident on the upper atmospheres.

Without direct measurements of stellar UV emission, we will not be able to assess the potential of false positives for biomarkers that may be detected in the coming decade.

Reionization and the Escape of Ionizing Radiation

- Lyman continuum (LyC) is a major uncertainty in understanding reionization at $z \sim 6$.
- Sweet spot for direct measurements of LyC escape is at $z < 0.4$, in the LUV.

LyC escape and it spatial variation in resolved galaxies can be measured directly - informing all high-z studies of reionization, but only in the Local Universe and in the LUV.

Requirements and Recommendations

Resolving Power

$R = \Delta\lambda / \lambda = 30{,}000$ at minimum

50,000-100,000 is desired for resolving lines from cold gas.

Sensitivity / Effective Area

Minimum 10x better than HST/COS in the same time

$A_{eff} \gtrsim 20{,}000 \text{ cm}^{-2}$

Wavelength Coverage

from 912 Å to atmospheric cutoff

For the science in this RFI, LUV and FUV are more important than NUV (>2000 Å)

Multiplexing

Though not necessarily linked uniquely to the LUV, 10-100x MOS capability in the LUV/FUV would revolutionize studies of the ISM and star formation in the Local Universe.

Tradeoffs

1000 Å is often mentioned: this brings in H2 and OVI,

but not the higher Lyman series, C III, weak O I, or the LyC in the Local Universe.

Recommendations

1) Support development of optical coatings (LiF, thinner MgF2) than can cover the LUV.

2) Consider LUV wavelengths as part of any UV-focused mission concept. Don't leave out the LUV by default, or just because of history!

RFI Response Summaries

6 Rapid Science Summaries

Topic: Other Science

Open Discussion