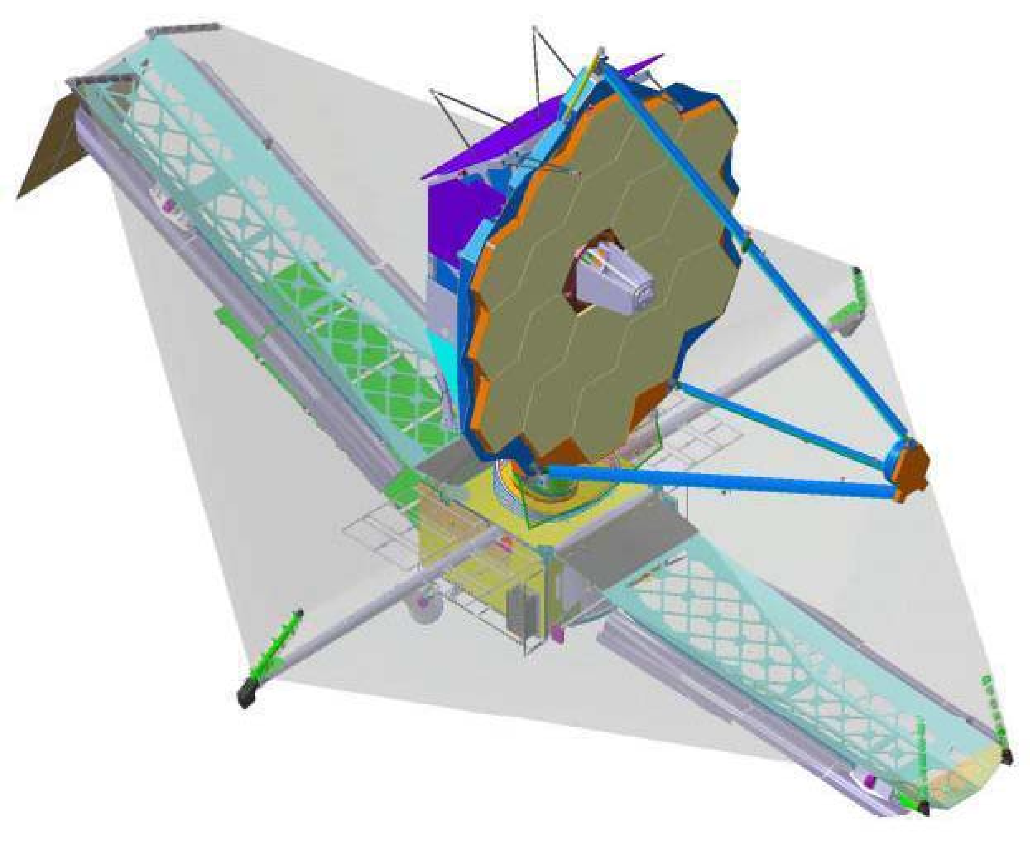
Astronomy with the James Webb Space Telescope

John Mather, NASA's GSFC

Sept 29, 2009



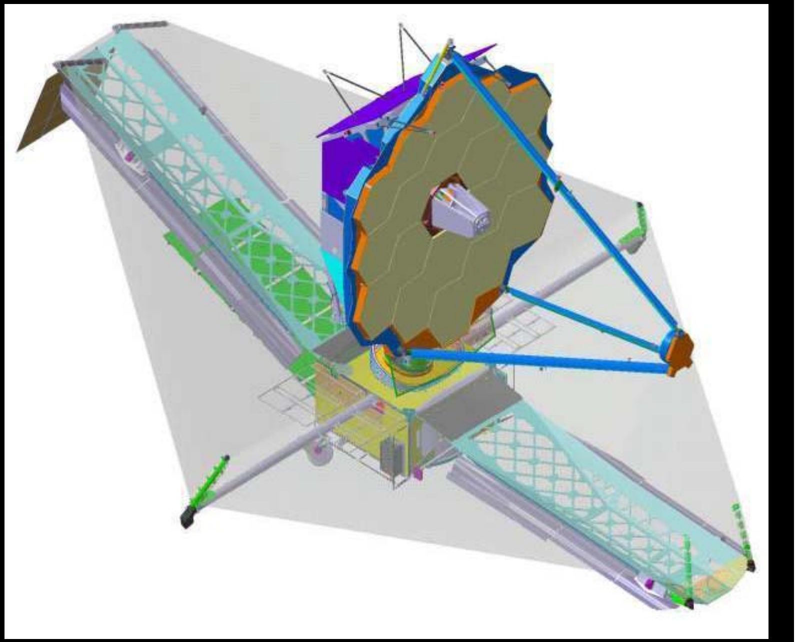
JWST Science Working Group (#4)

- 6 Interdisciplinary Scientists: H. Hammel, S. Lilly, J. Lunine, M. McCaughrean, M. Stiavelli, R. Windhorst
- Instrument Team Lead/ Science Representative: M. Rieke (NIRCam), G. Rieke and G. Wright (MIRI), Rene Doyon (FGS), & rotating scientist member, NIRSpec
- Telescope Scientist: M. Mountain (also STScI Director)
- Ex Officio: J. Mather (Chair), J. Gardner, M. Clampin, M. Greenhouse, K. Flanagan, G. Sonneborn, P. Jakobsen, J. Hutchings

JWST Mission "At a Glance"

Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime: Northrop Grumman Aerospace Systems (NGAS)
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA
- Operations: Space Telescope Science Institute



Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch 2014 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

JWST Science Themes

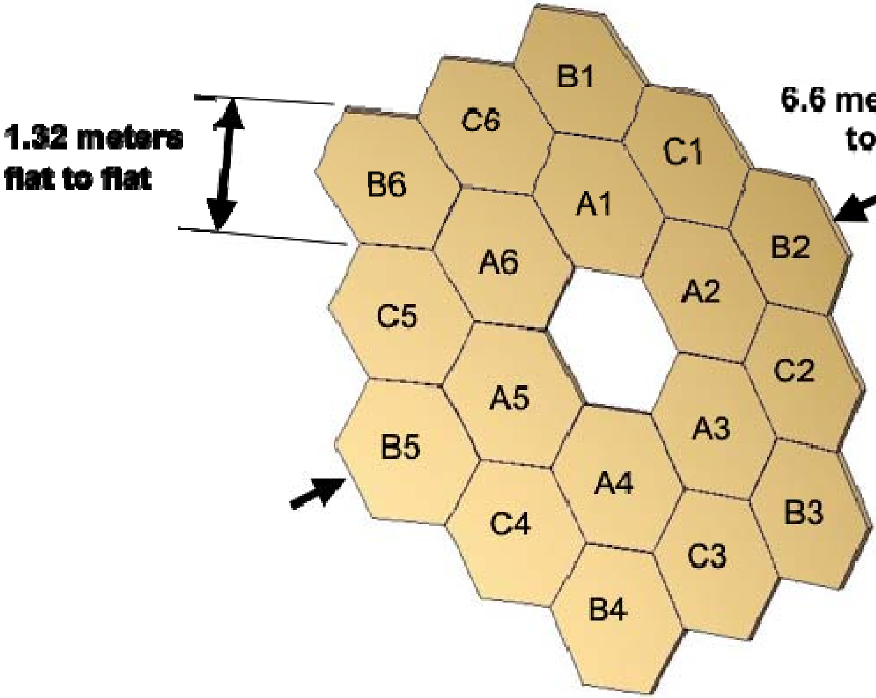
End of the dark ages: First light and reionization

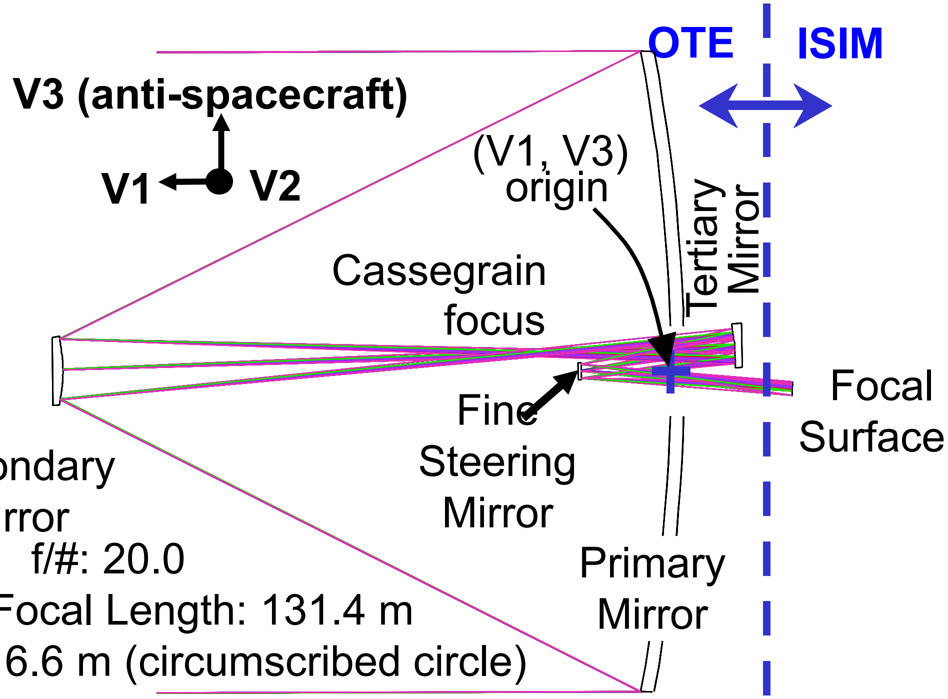
The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

Three Mirror Anastigmat Optical Design Provides a Wide Field-of-View



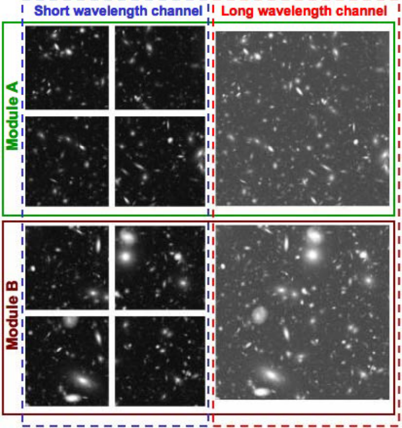


f/#: 20.0

Effective Focal Length: 131.4 m

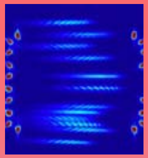
PM diameter = 6.6 m (circumscribed circle)

JWST Instruments

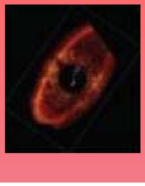


Deep, wide field broadband-imaging

Wavefront Sensing & Control (WFSC)

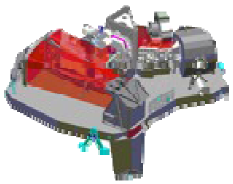


Coronagraphic Imaging

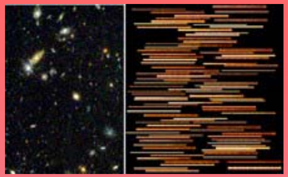


NIRCam

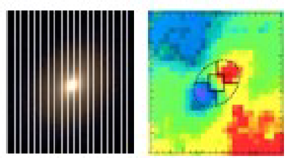
NIRSpec



Multi-Object, IR spectroscopy

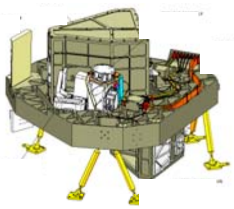


IFU spectroscopy

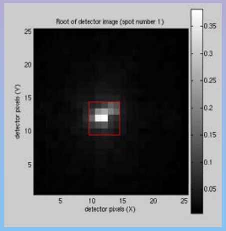


Long Slit spectroscopy

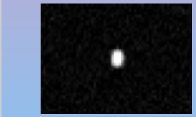
FGS/TF



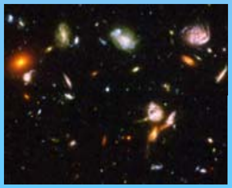
Fine Guidance Sensor



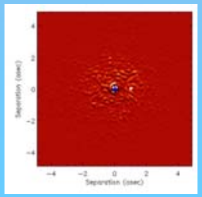
Moving Target Support



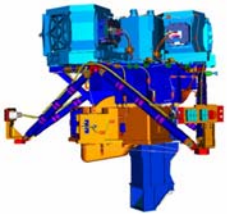
R=100 Narrowband Imaging



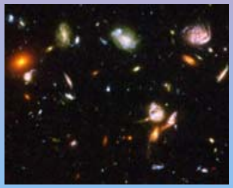
Coronagraphic Imaging R~100



MIRI

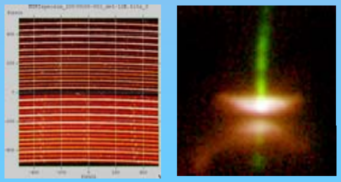


Mid-Infrared, wide field Imaging

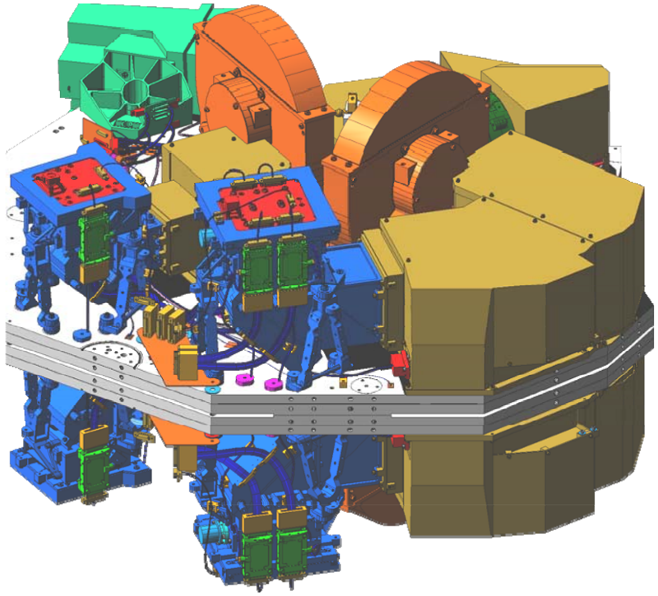


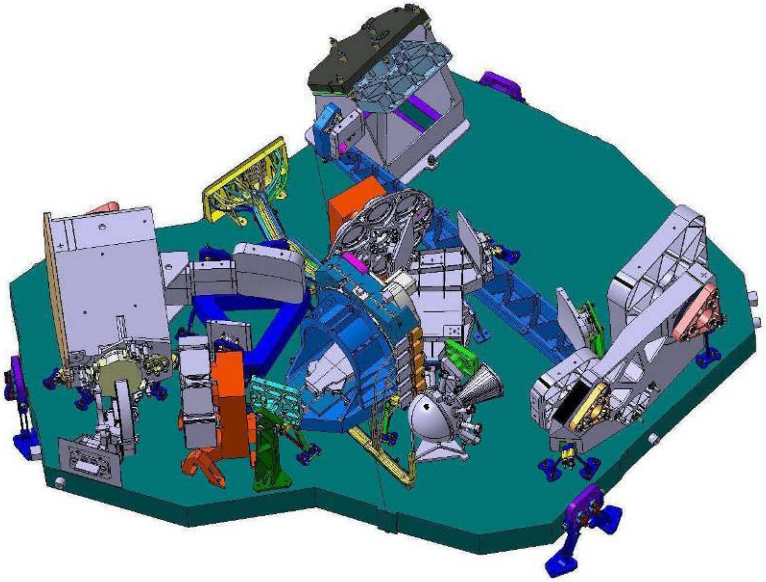
Mid-IR Coronagraphic Imaging

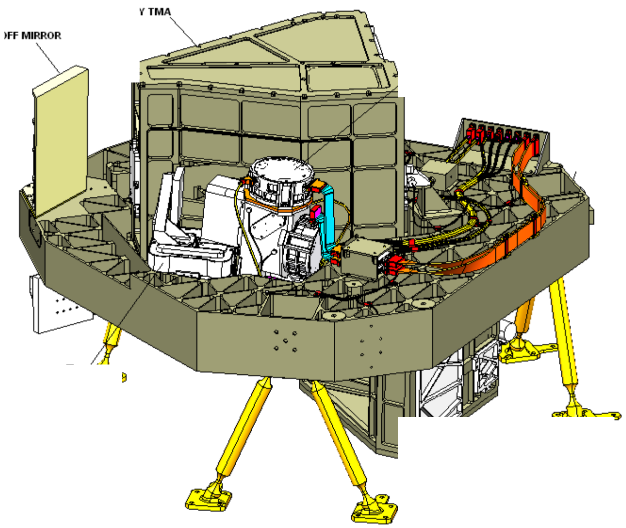
IFU spectroscopy

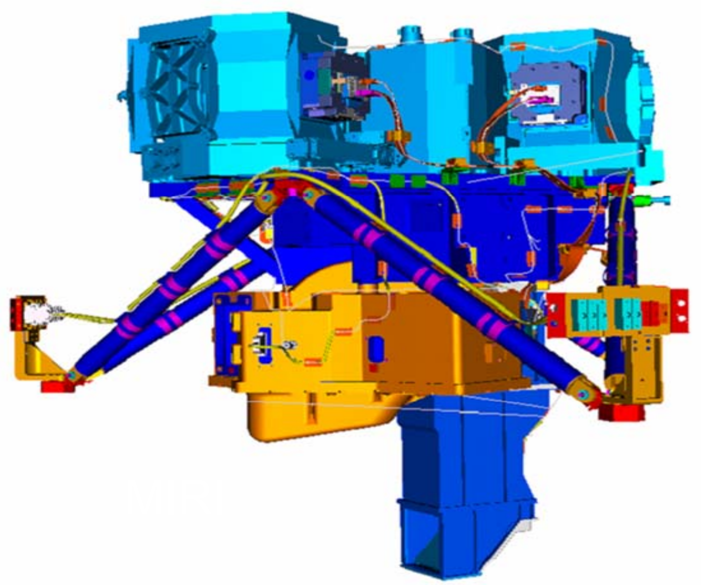


Four science instruments enable imagery and spectroscopy over the 0.6 – 29 micron spectrum



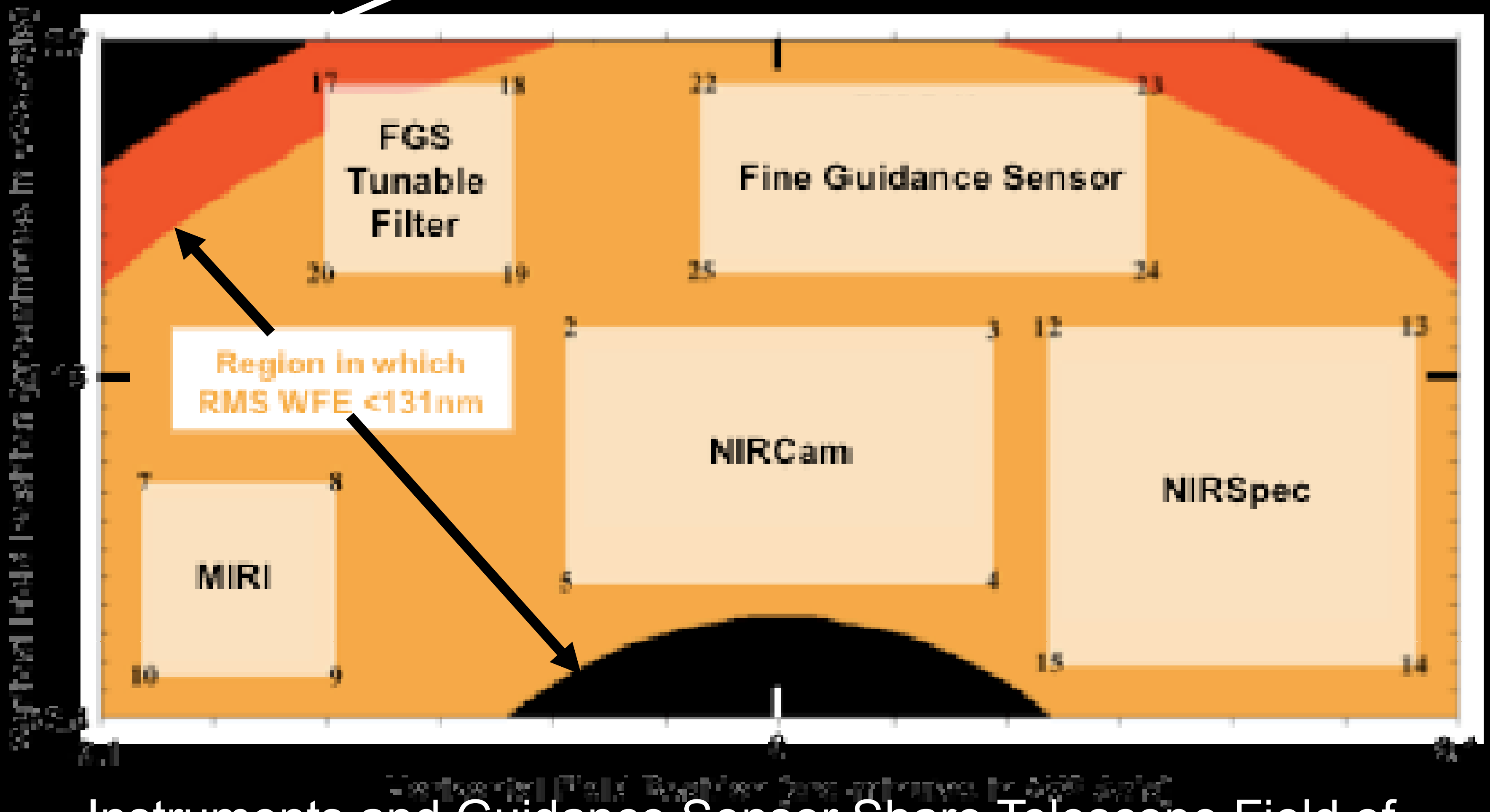






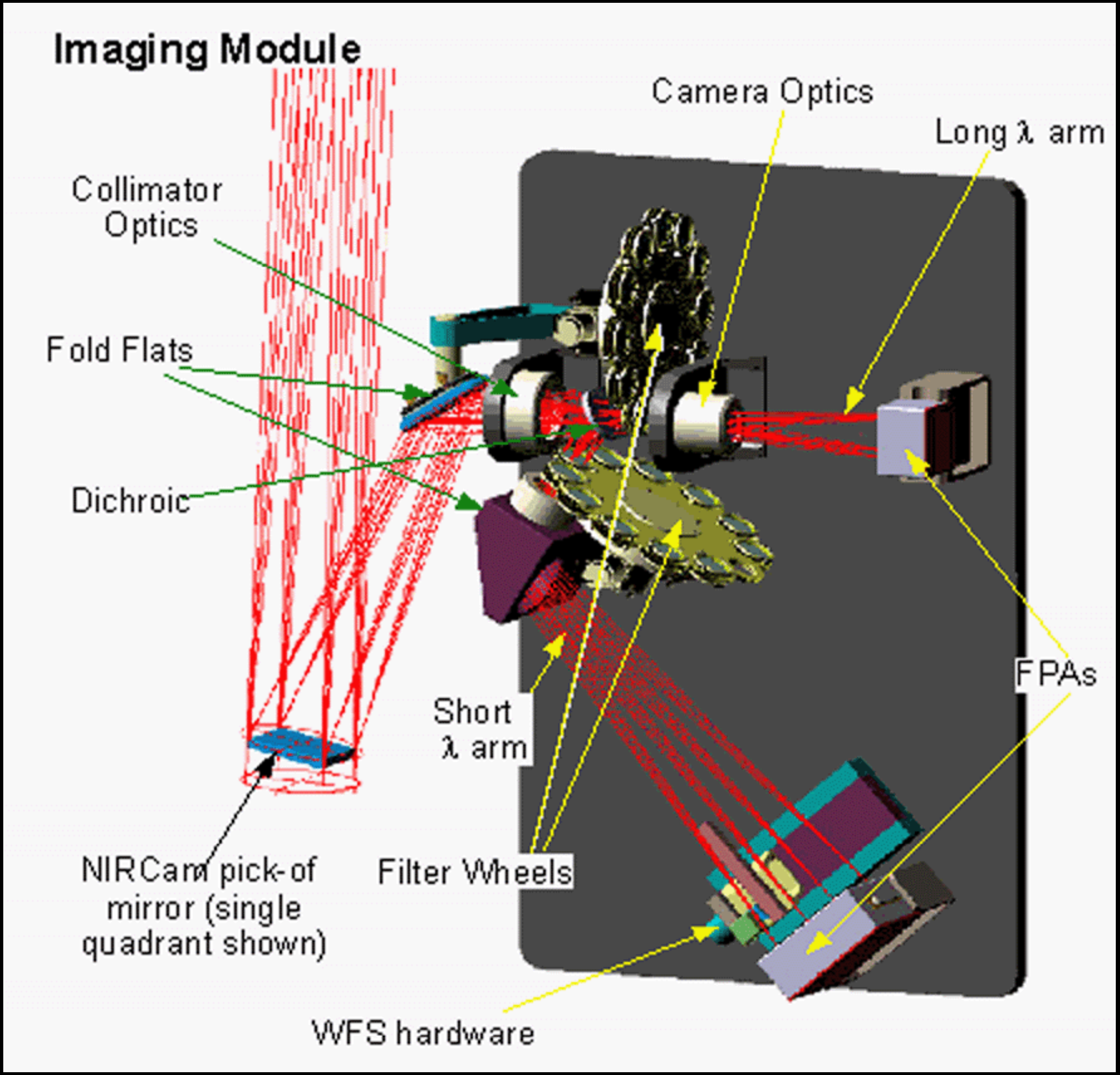
Field Position of Science Instruments

Boundary of Unvignetted field



Instruments and Guidance Sensor Share Telescope Field of View

A NIRCam Imaging Module

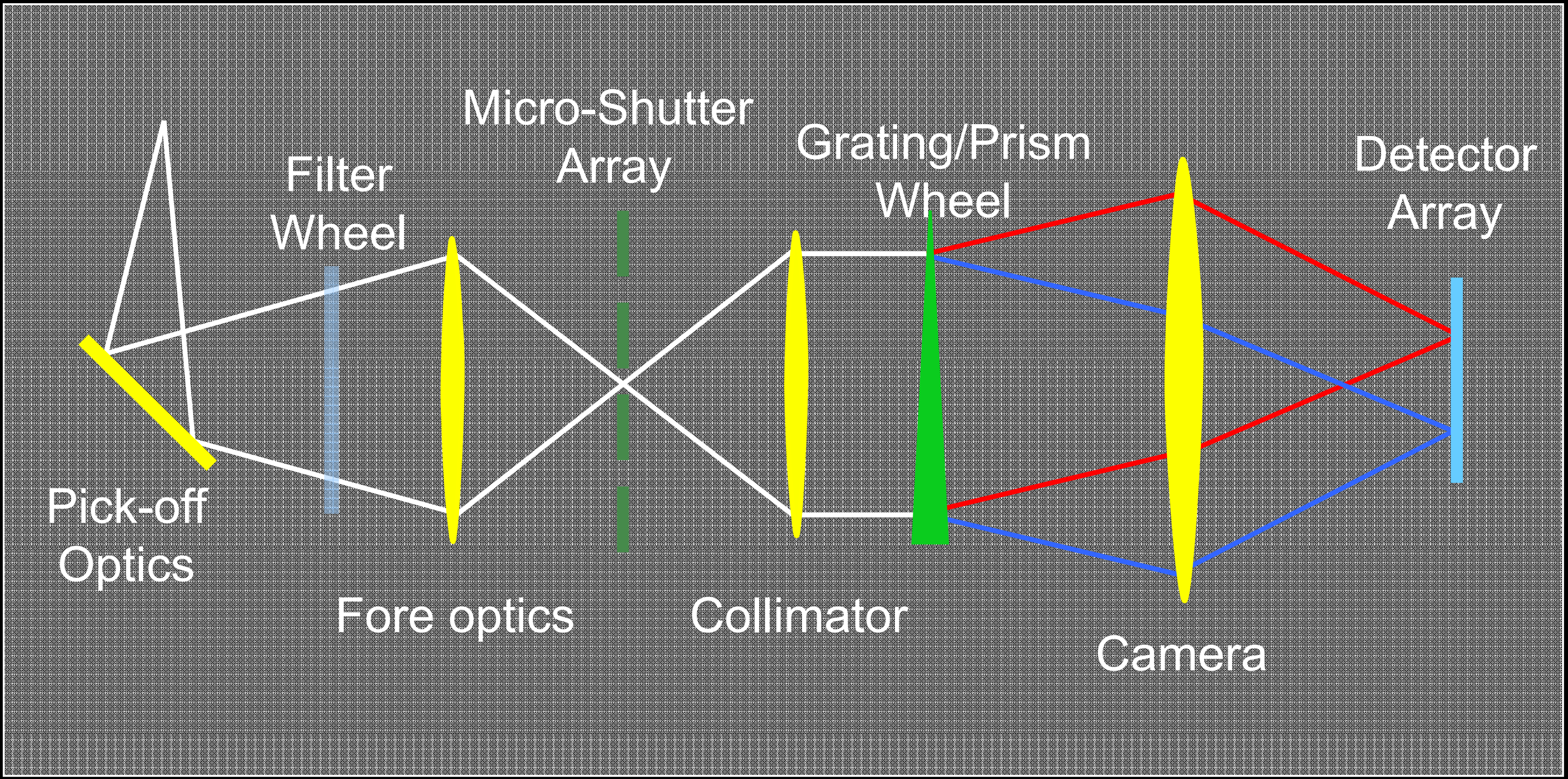


A dichroic allows simultaneous observing at two wavelengths.

This module’s dual filter wheels include pupils for wavefront sensing.

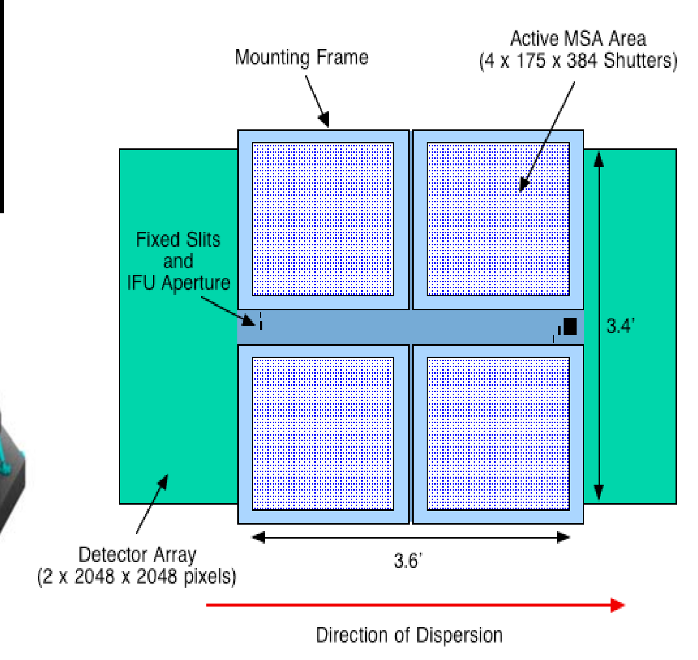
The two tunable filter modules for the FGS are similar but require no dichroics or wavefront sensing hardware.

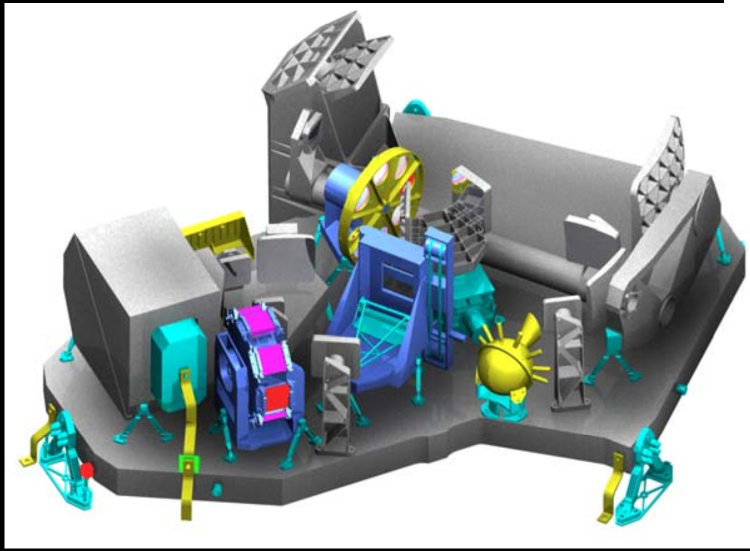
NIRSpec Schematic



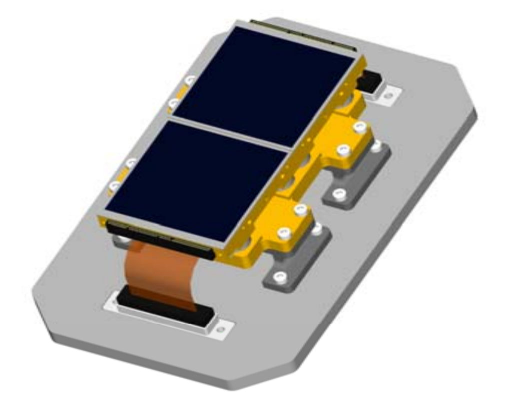
NIRSpec: ESA & Astrium

- > 100 Objects Simultaneously
- 9 square arcminute FOV



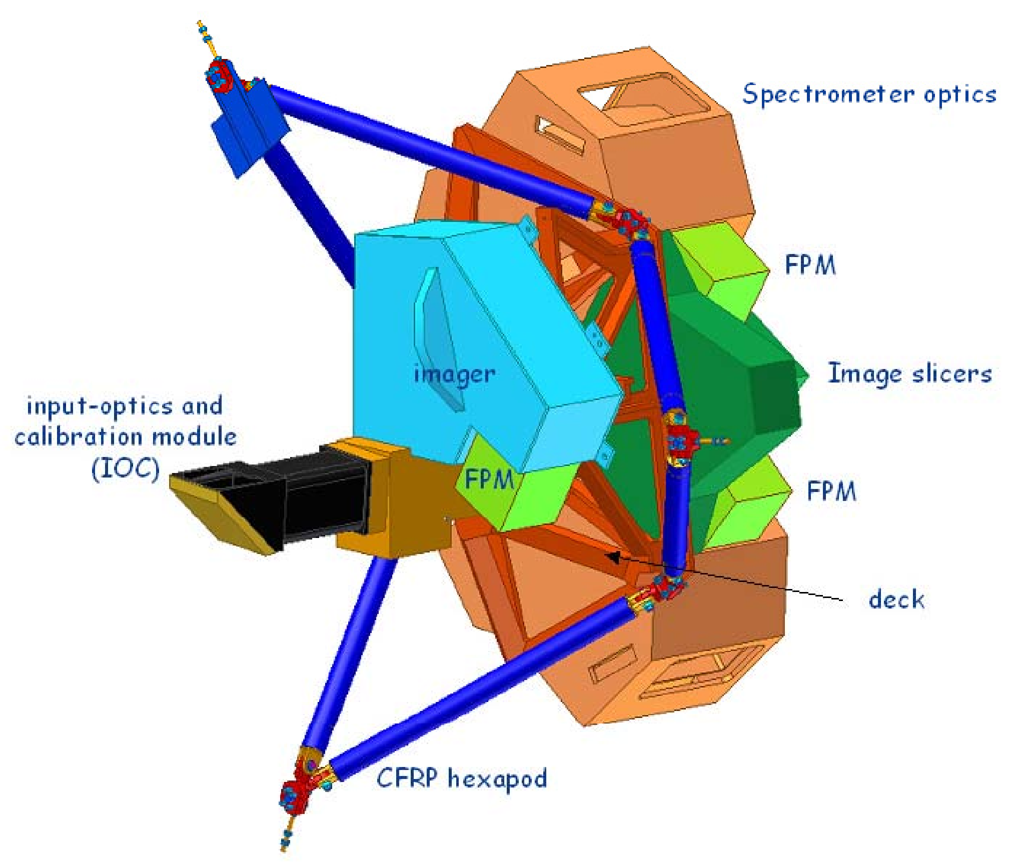


- **Implementation:**
  - 3.5' Large FOV Imaging Spectrograph
  - 4 x 175 x 384 element Micro-Shutter Array
  - 2 x 2k x 2k Detector Array
  - Fixed slits and IFU for backup, contrast
  - SiC optical bench & optics



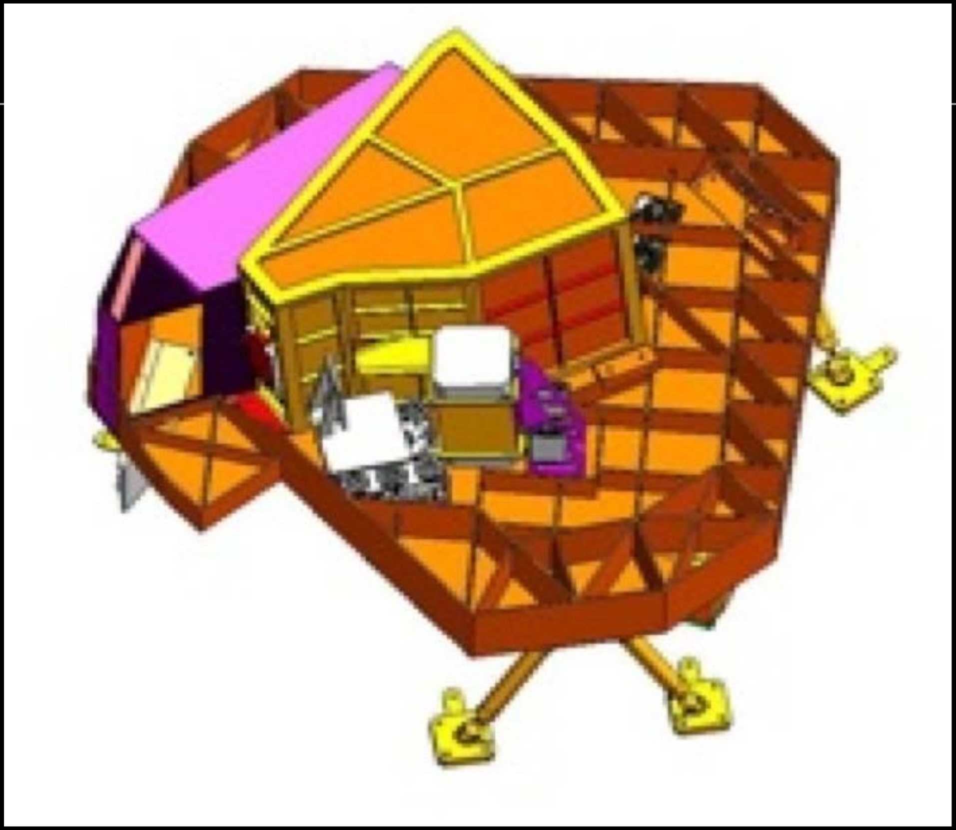
Mid-Infrared Instrument (MIRI)

- **Science team G. Rieke (lead), G.Wright (co-lead)**
- **European Consortium sponsored by ESA in partnership with NASA/JPL**
- **Science Goals include**
  - **Search for the origins of galaxies**
  - **Birth of stars and planets**
  - **Evolution of planetary systems**
- **Imaging**
  - **λ=5-29 μm wavelength range**
  - **Diffraction limited imaging with 0.1” pixels**
  - **~1.7’ field of view**
  - **Able to image sources as bright as 4 mJy at λ=10μm**
  - **≥12 bandpass filters**
  - **Low resolution spectrograph (R~100; λ=5-10 μm) for single, compact sources**
  - **Simple coronagraph**
- **Spectroscopy**
  - **λ=5-29 μm wavelength range, reach λ= 28.3 μm**
  - **Integral field spectroscopy with > 3” field of view**
  - **R~2000-3700 from λ=5-29 μm**



Optics Module concept developed by European Consortium

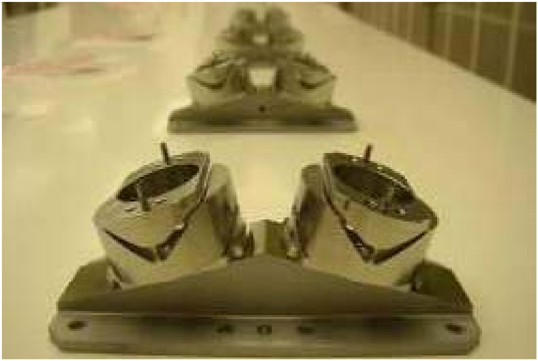
Fine Guidance Sensor (FGS)



- Guide star availability with >95% probability at any point in the sky
- Wide open bandpass for guiding (0.5 μm - 5.0 μm)
- Includes Tunable Filter Imager with R = 70 - 150, 1.7 μm - 4.8 μm
- Coronagraph

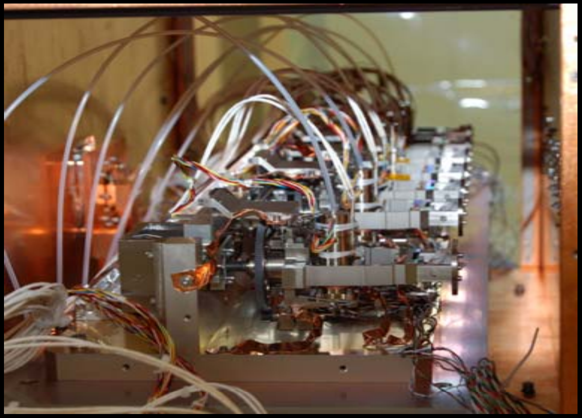
Primary Mirror Segment Assembly Flight Hardware Production Well Underway

Launch Restraint Flexures



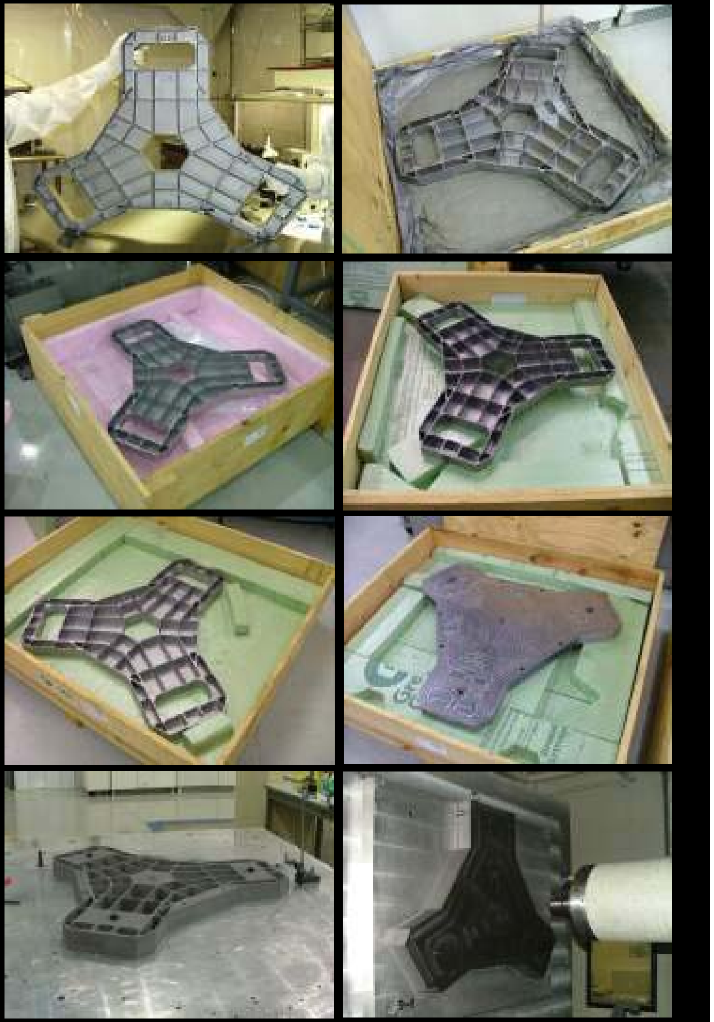
PM Bipod Mounting Brackets

Strongback Struts



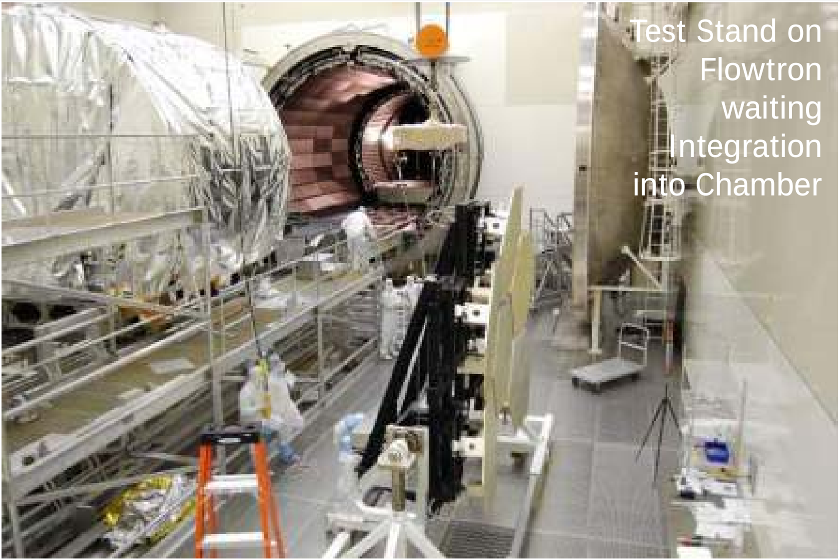
Flight actuators under test

PM Whiffle Assemblies



PM Delta Frames 1-8

Installation of Test Stand with Mass Simulators into MSFC XRCF Test Chamber Complete



Test Stand on Flowtron waiting Integration into Chamber

Craning Test Stand in Place

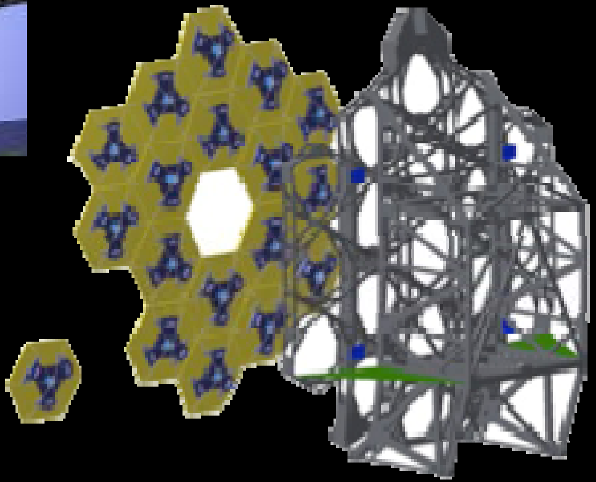
Installing Test Stand into Chamber

Test Stand in Chamber waiting installation of final helium shroud

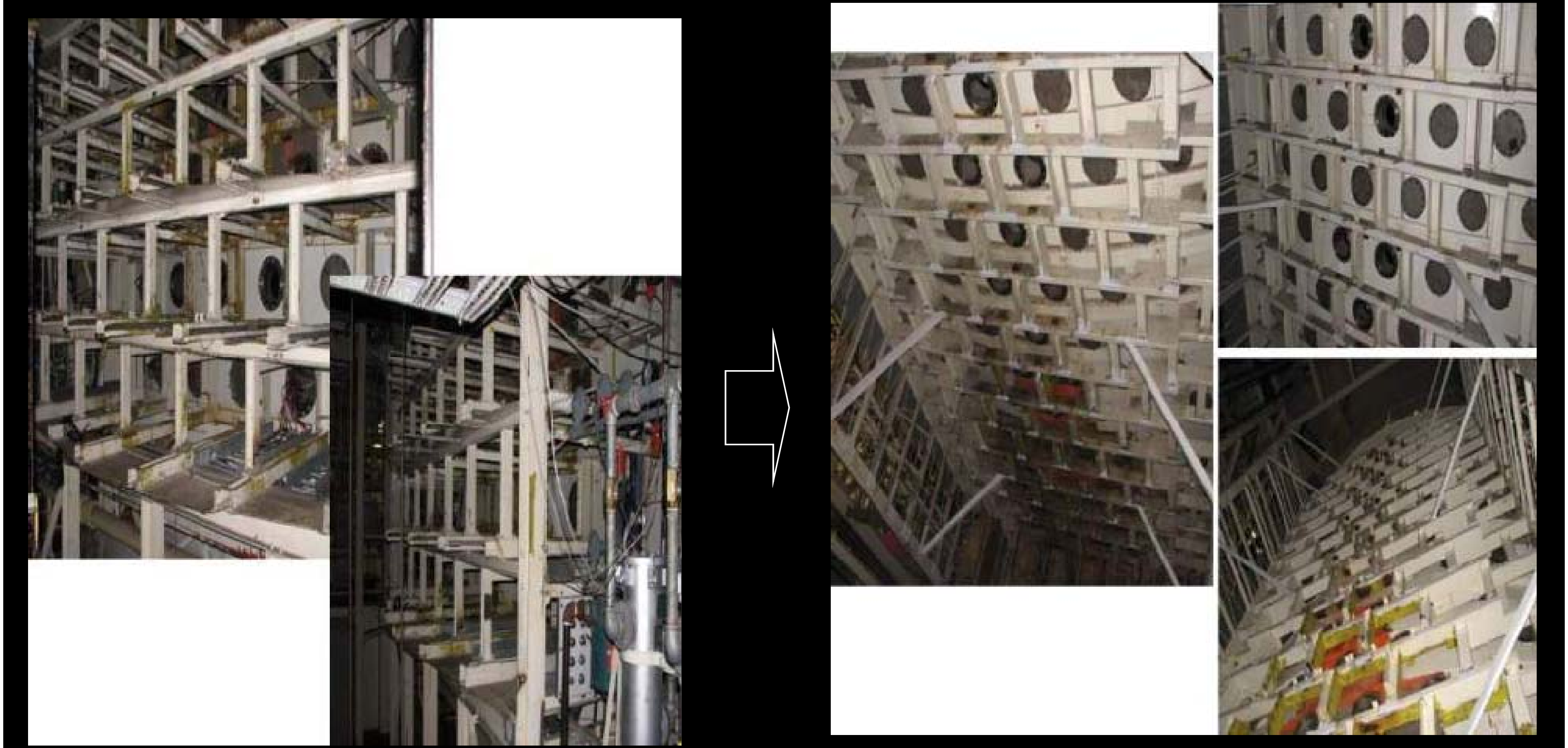
A1 and EDU at the XRCF

Sept. 29, 2009

Flight Backplane Started

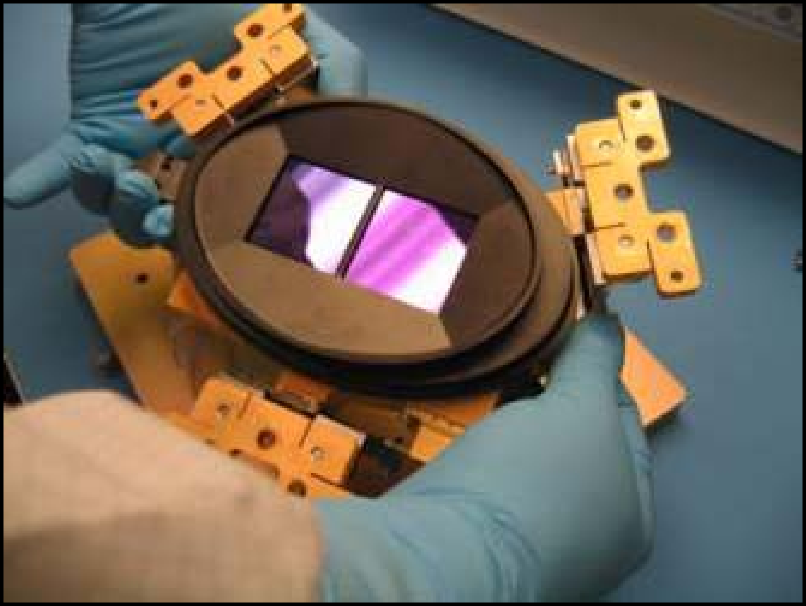


JSC Chamber A Modification Progress



External chamber modifications – removal of solar simulator structures

ETU Hardware Queuing Up for Instrument I&T



NIRSpec Focal Plane Assembly

NIRCam Pupil Imaging Lens Mechanism

NIRCam Shortwave Camera Triplet & Beamsplitter

NIRSpec Fore Optics

Integrated Science Instrument Module structure arrives at GSFC

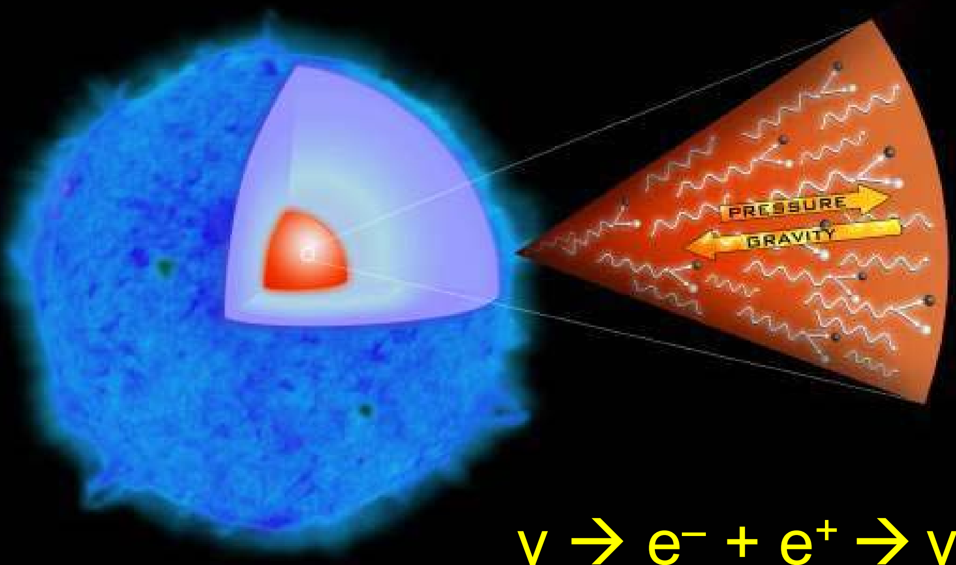
End of the dark ages:
first light and reionization

… to identify the first luminous sources to form and to determine the ionization history of the early universe.

Hubble Ultra Deep Field

SN 2006 gy – brightest supernova

- Could be the first observation of a pair-production instability, from the death of a very massive star.
  - Stars are normally held up by the balance of light pressure and gravity
  - Gamma rays producing electron/positron pairs scatters light, reducing pressure. Instability creates runaway collapse.
- A nearby analog for the first stars in the Universe.

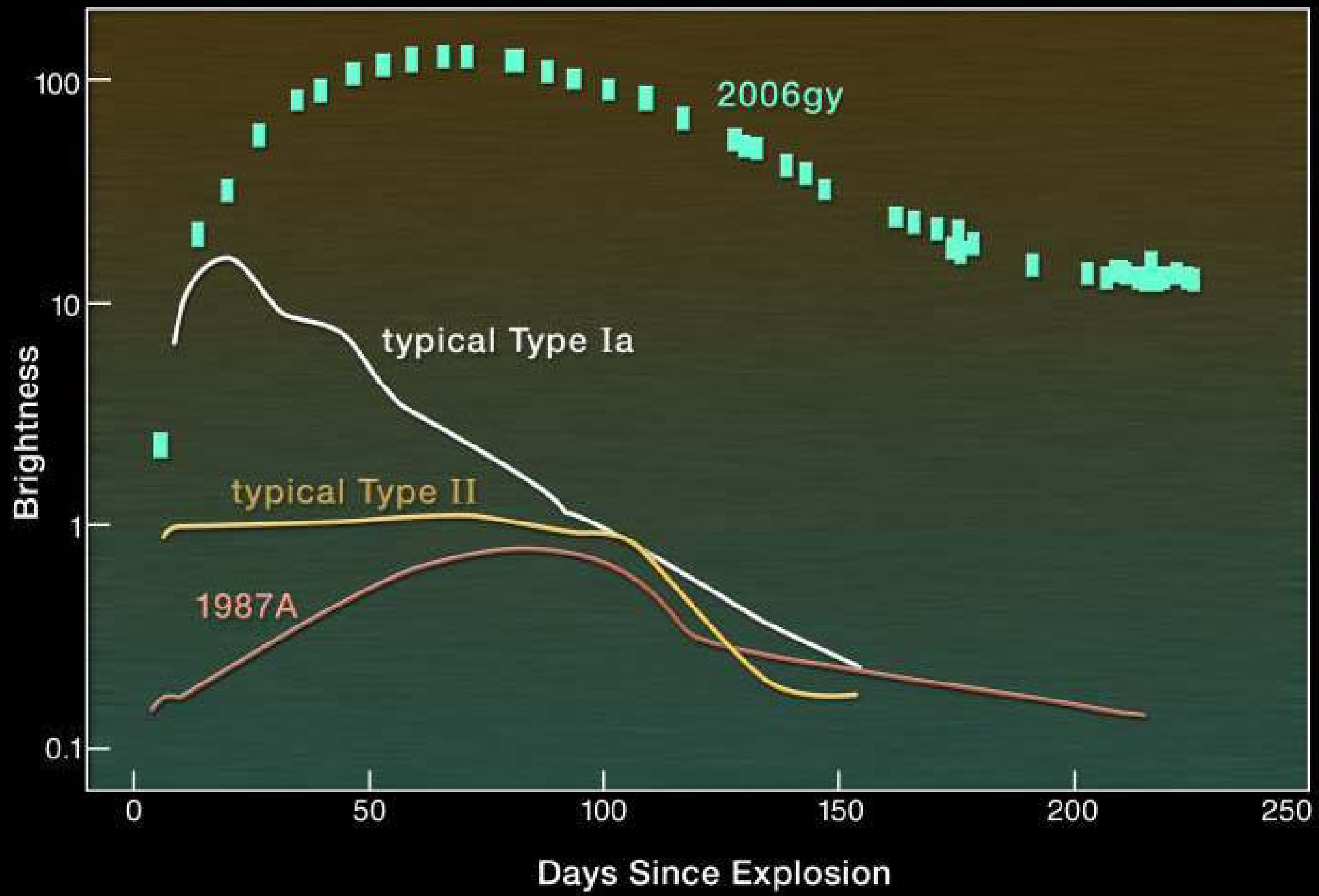


$$\gamma \rightarrow e^- + e^+ \rightarrow \gamma$$

- Progenitor was similar to Eta Carina.

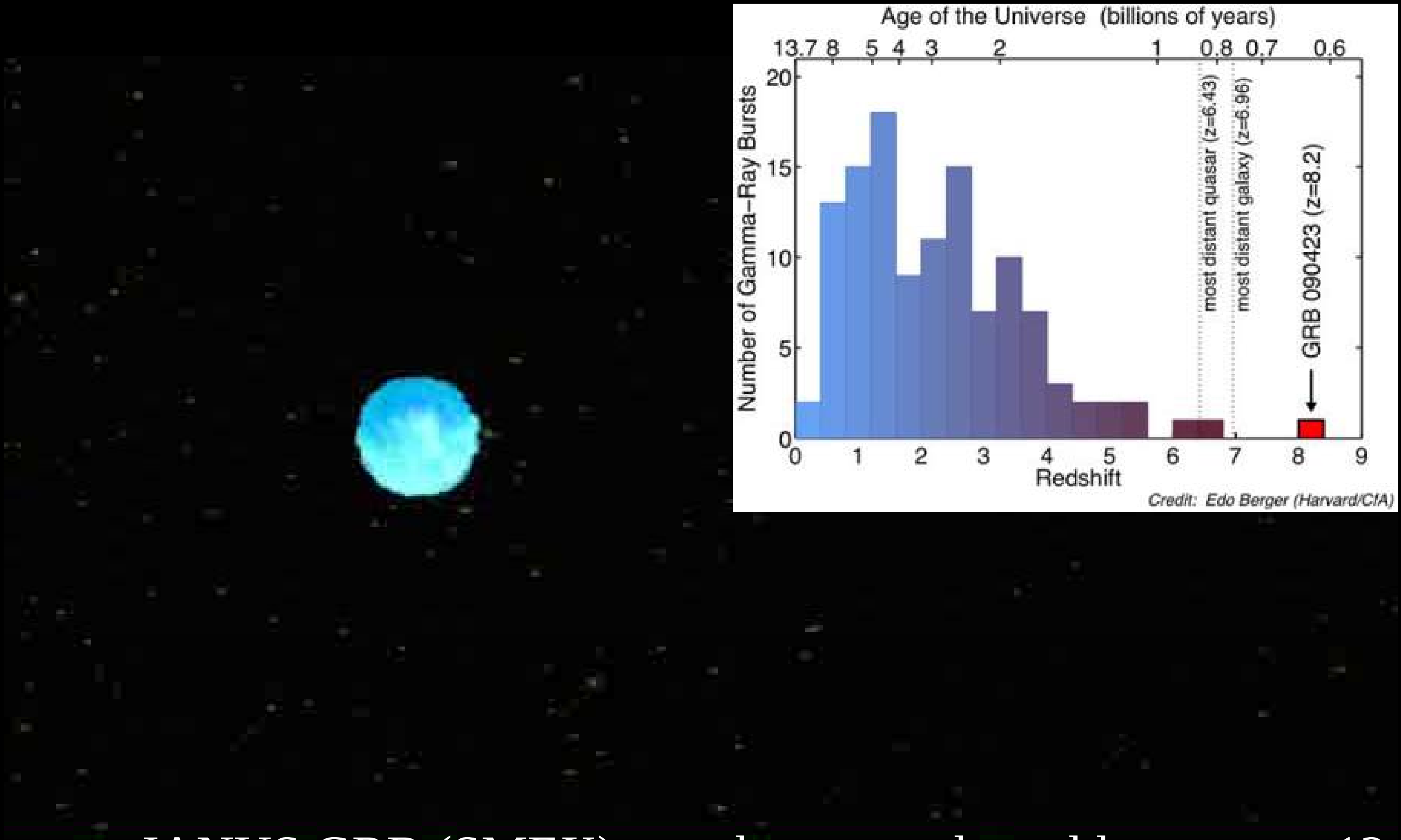
Hubble Image of Eta Carina

Pair-production SNe as First Stars



- Good news: JWST can easily detect these when stars first formed (but not as transients).
- Interesting news: pair-production instability doesn’t necessarily require primordial composition.

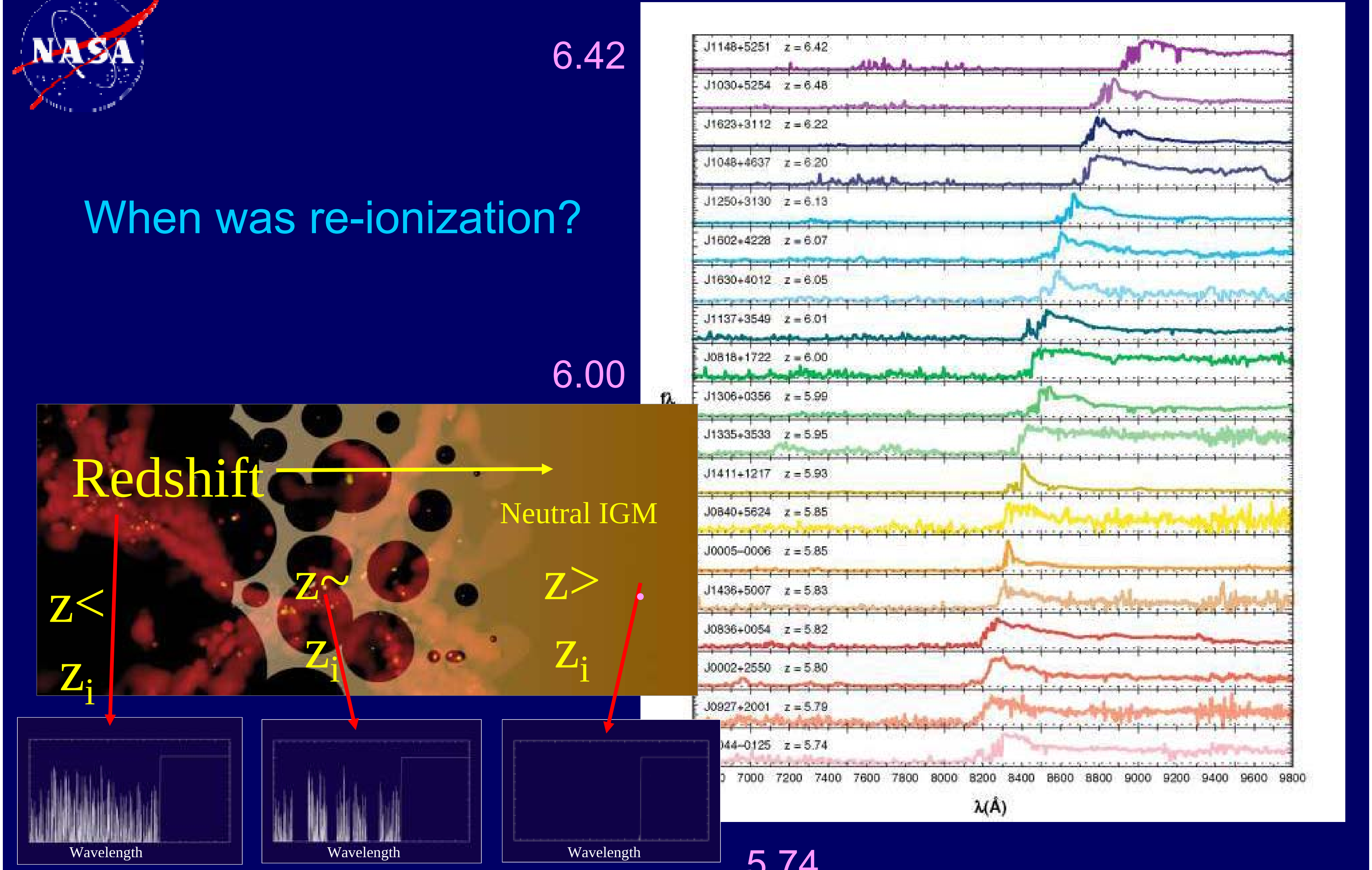
Gamma Ray Burst 4/23/09 was most distant object yet found (z = 8.2) – supernova jet aimed at us!



Credit: Edo Berger (Harvard/CfA)

JANUS GRB (SMEX) search proposed, could see to z = 12

When was re-ionization?



Lyman Forest Absorption

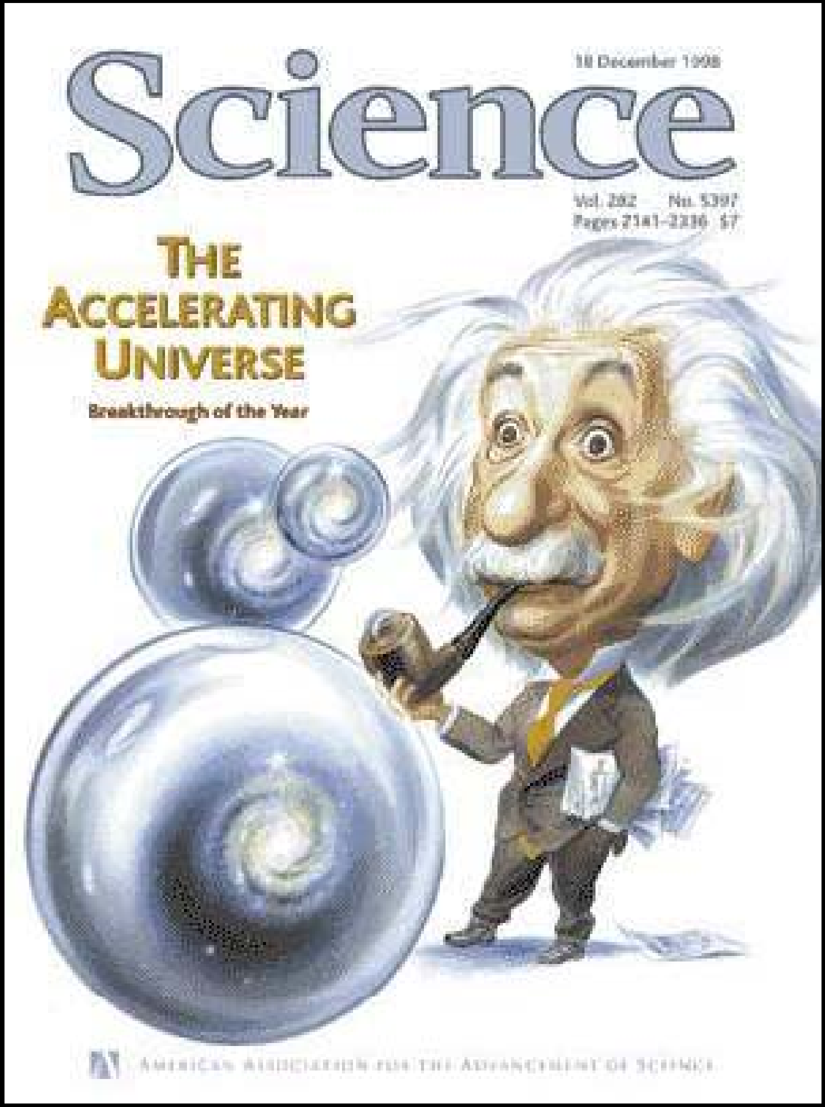
Patchy Absorption

Black Gunn-Peterson trough

Fan, Carilli & Keating 2006, ARAA, 44, 415

Dark Energy!

MacArthur Fellow
2008 - Adam Riess



Science

18 December 1998

Vol. 282 No. 5397
Pages 2141–2336 $7

THE ACCELERATING UNIVERSE

Breakthrough of the Year

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

S. Perlmutter, A. Riess, B. Schmidt

JWST, Dark Energy, Dark Matter

- JDEM/IDECS Science Coordinating Group report (Neil Gehrels, GSFC), http://jdem.gsfc.nasa.gov/docs/SCG_Report_final.pdf
- Problem: determine acceleration parameter now and in the past
- Multiple techniques required due to likely systematic errors
- JDEM/IDECS wide-field surveys will find targets for JWST
- JWST contributes by
  - Measuring very distant supernovae (standard candles?)
  - Measuring effects of dark matter too (distorted images of distant objects, masses of galaxies and clusters out to high redshift, rotation curves, etc.)
  - Cosmic archeology at high redshift (prior to acceleration, formation of galaxies and clusters)

How does environment affect star-formation and vice-versa?

What is the sub-stellar initial mass function?

- Massive stars produce winds and radiation
  - Either disrupt star formation, or causes it.
- The boundary between the smallest brown dwarf stars and planets is unknown
  - Different processes? Or continuum?
- Observations:
  - Survey dark clouds, “elephant trunks” and star-forming regions

The Eagle Nebula
as seen in the infrared

Exoplanets

- Potential Nobel Prize: Google "globe mail lost world" for story of Canadians' failed attempt: ""Gordon Walker and Bruce Campbell were the real true pioneers," says Alan Boss"
- As of 26 Sept, 374 total:
  - Radial velocity: 347 planets, 35 multiple planet systems
  - Transiting: 62 planets, 2 multiples (most good JWST targets)
  - Microlensing: 8 planets, 1 multiple system
  - Imaging: 11 planets, 1 system (a triple) (all good JWST targets)
  - Timing: 7 planets, 2 multiple planet systems
  - + predictions from dust disk structures
- Kepler launched Mar. 6, 2009, will monitor ~ 100,000 stars, find handful of Earths, thousands of others
- TESS (Transiting Exoplanet Survey Satellite**)**, proposed SMEX, would survey nearest stars, best candidates for detailed follow-up with JWST
- JWST Transits Working Group established – M. Clampin

Fomalhaut

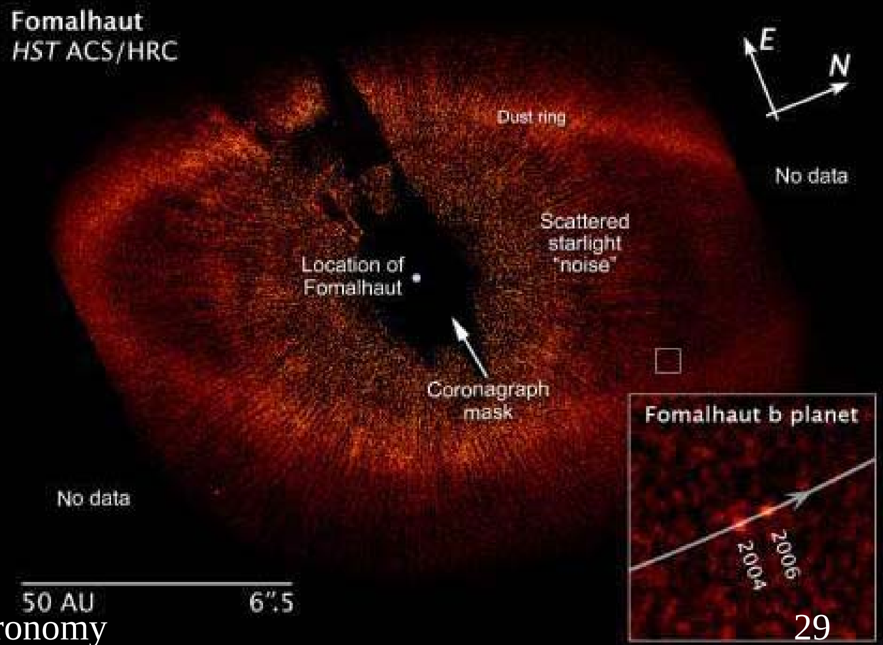
- HST Advanced Camera for Surveys achieved the optical detection of an exoplanet around a star 25 light years from Earth.
  - First optical detection of a massive planet since Neptune in 1846.
  - Like the discovery of Neptune the existence of Fomalhaut b was predicted in advance by theory.
- Planet’s mass lies between that of Neptune and Jupiter
  - Constrained by disk dynamics
- Too bright for just a planet
  - Probably has rings or dust disk

ScienceNews

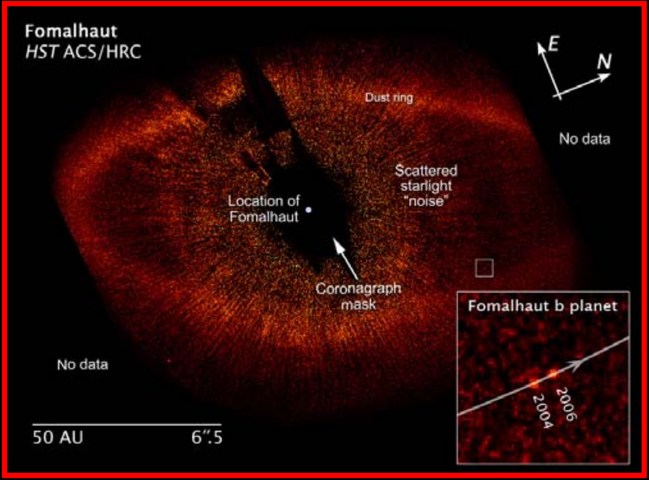
Exposed

Astronomers get an eyeful of extrasolar planets

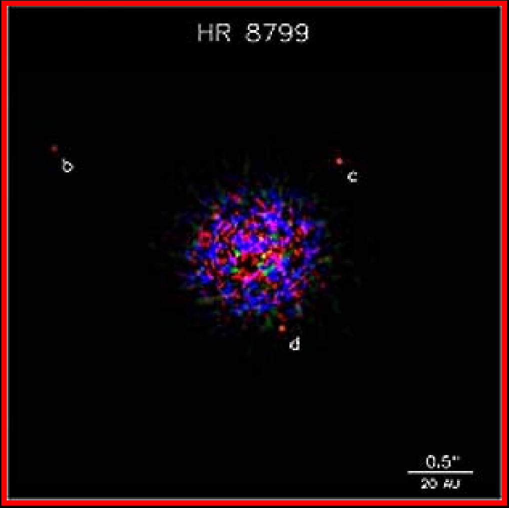
Named #2 Science Discovery of 2008



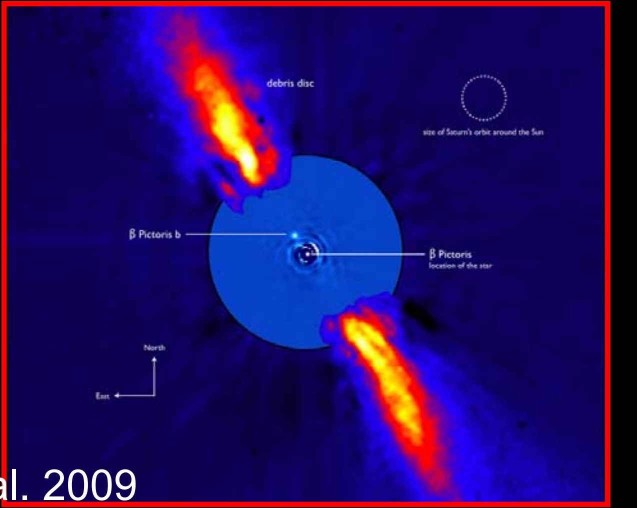
Crop of Recent Detections!



Fomalhaut B
Kalas et al. 2008

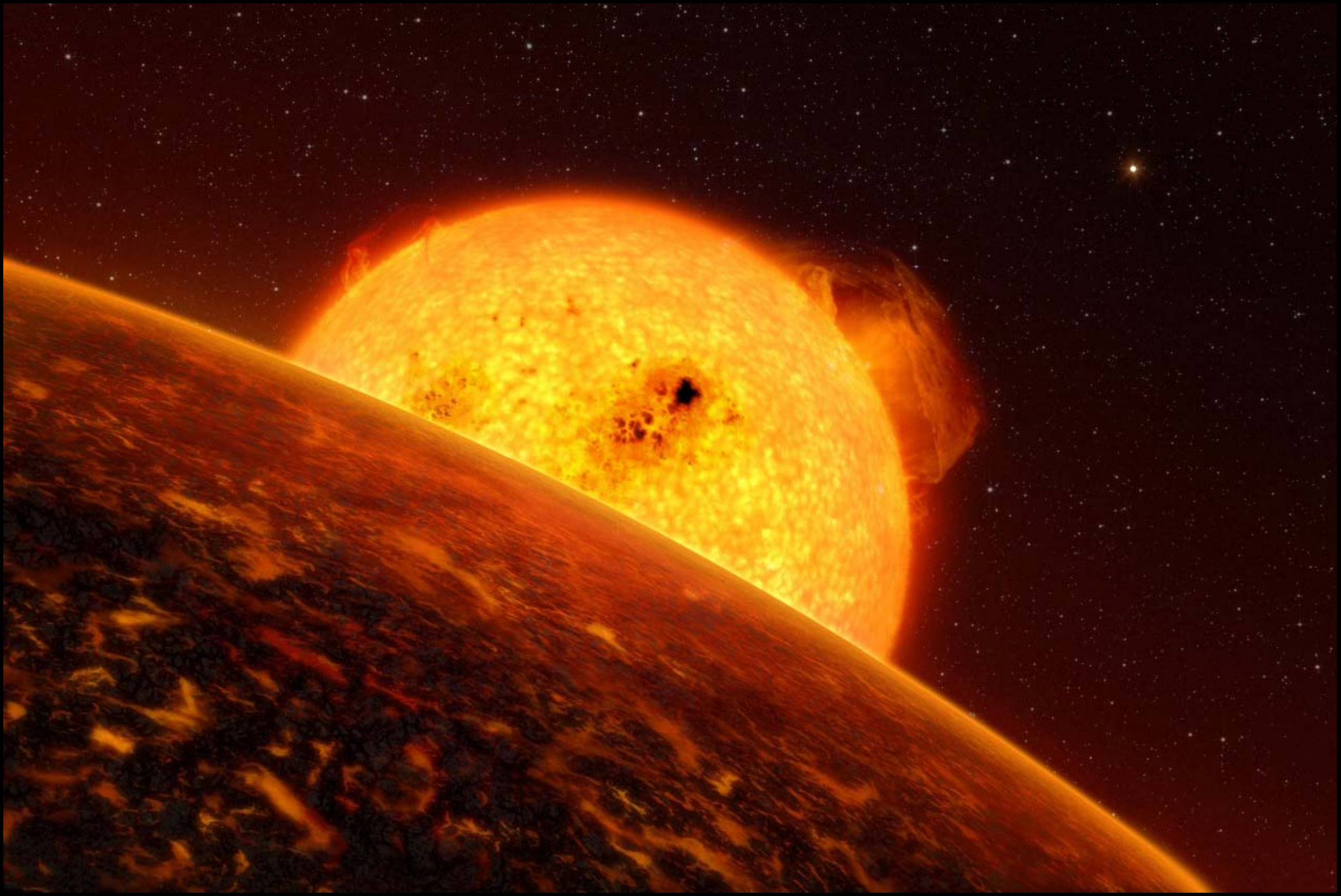


HR 8799
Marois et al. 2008



β Pictoris
A. M. Lagrange et al. 2009

Corot-7 b,c: 2 Super-Earths



JWST can observe Exoplanets

- Direct imaging and spectroscopy – block glare of star
  - Cameras have coronagraphic systems
  - TFI has special interferometric mode
  - NIRSpec has simple slit as well as multiples
  - Study debris disks as well as planets
- Transit studies
  - Planet blocks starlight, or vice versa
  - Need to know in advance where & when to look
  - Can get physical properties of planet

Imaging/Spectroscopy Modes

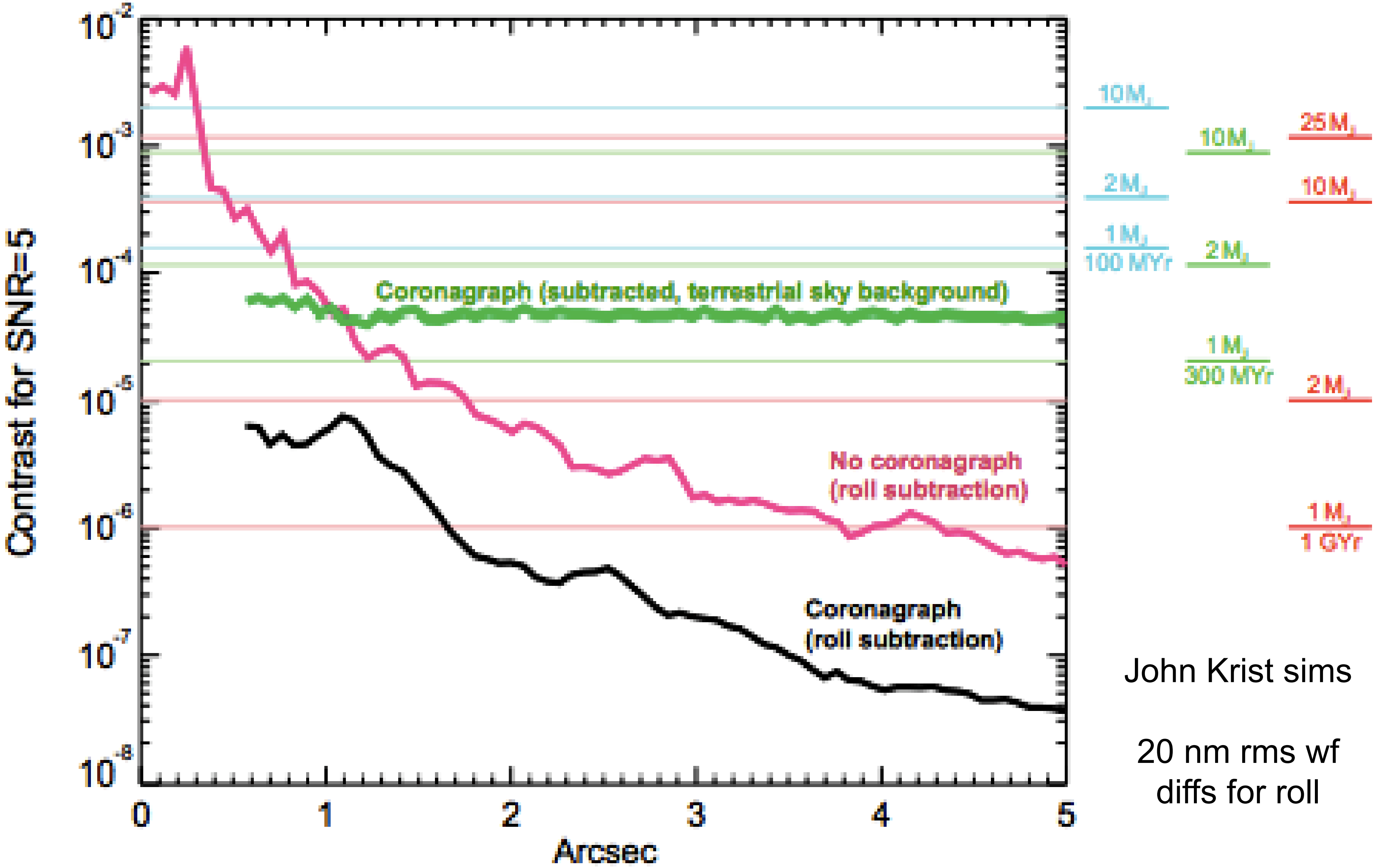
Instrument	Channel/Mode	λ (μm)	R (λ/δλ)
NIRCam	Short λ Lyot Coronagraph	0.6 - 2.3	4, 10, 100
NIRCam	Long λ Lyot Corongagraph	2.4 - 5.0	4, 10, 100
TFI	Multi-λ coronagraph	1.6 - 2.5	100
TFI	Multi-λ coronagraph	3.2 - 4.9	100
TFI	Non-redundant mask	1.6 - 2.5	100
TFI	Non-redundant mask	3.2 - 4.9	100
MIRI	Quadrant Phase Coronagraph	10.65	20
MIRI	Quadrant Phase Coronagraph	11.4	20
MIRI	Quadrant Phase Coronagraph	15.5	20
MIRI	Lyot Coronagraph	23	5

High Contrast Imaging

MIRI	Integral field spectrograph	5.86 - 7.74	3000
MIRI	Integral field spectrograph	7.43 - 11.84	3000
MIRI	Integral field spectrograph	11.44 - 18.20	3000
MIRI	Integral field spectrograph	17.53 - 28.75	2250
NIRSpec	Integral field spectrograph	0.7 - 5.0	2700

Integral Field Spectroscopy

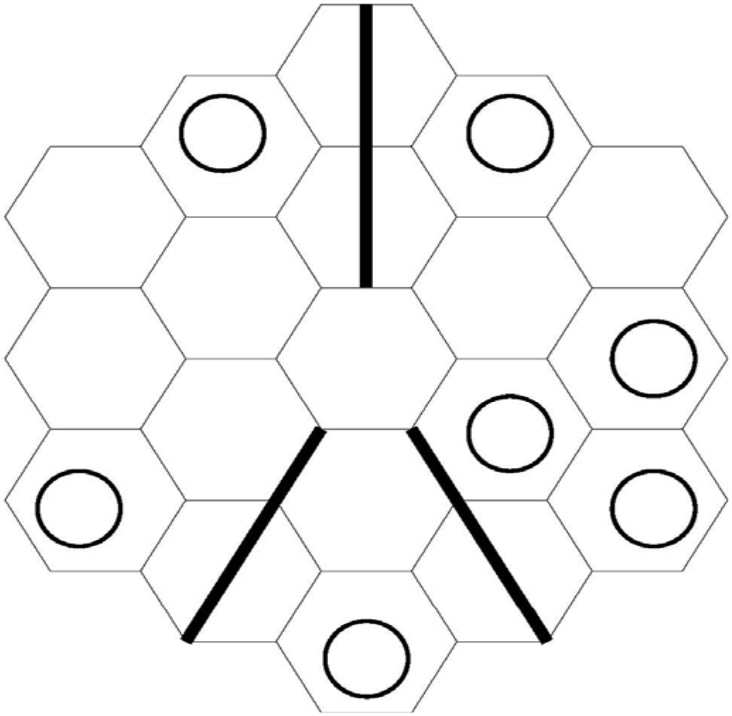
NIRCam: M0V Star at 4 pc (F460M)



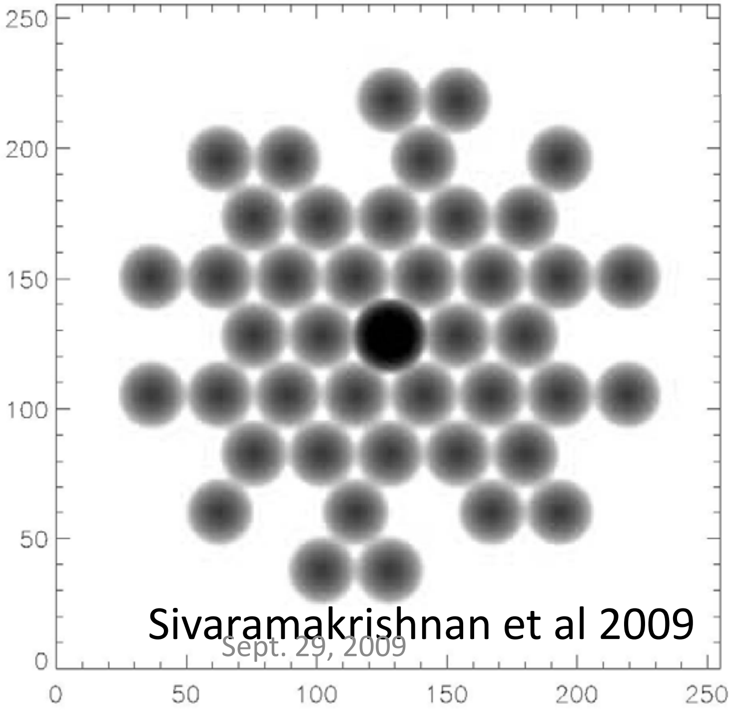
John Krist sims

20 nm rms wf
diffs for roll

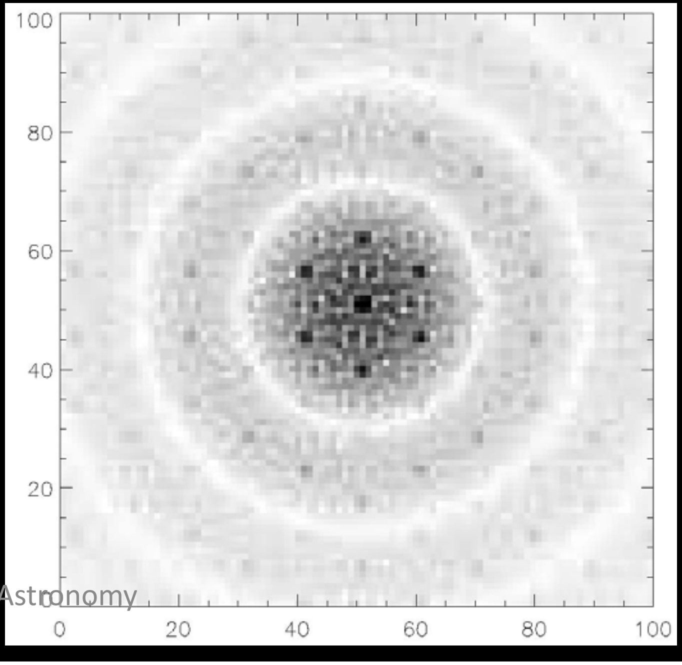
Non-Redundant Mask Imaging



- New mode for FGS/TFI utilizes “interferometric” mask producing 21 baselines and a narrow PSF (0.5λ/D)
- Ground-based contrast limits ~5 mag, in space > 10 mag possible at small IWA
- Flat fielding issues may be problem (>>Photon noise) for bright stars

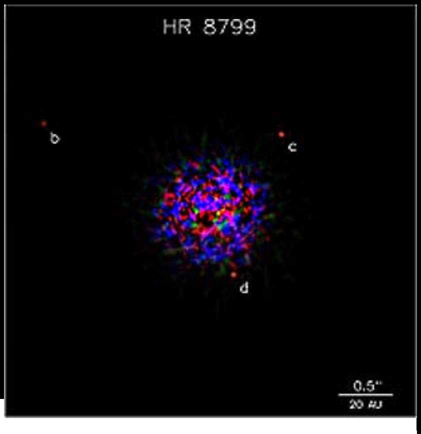


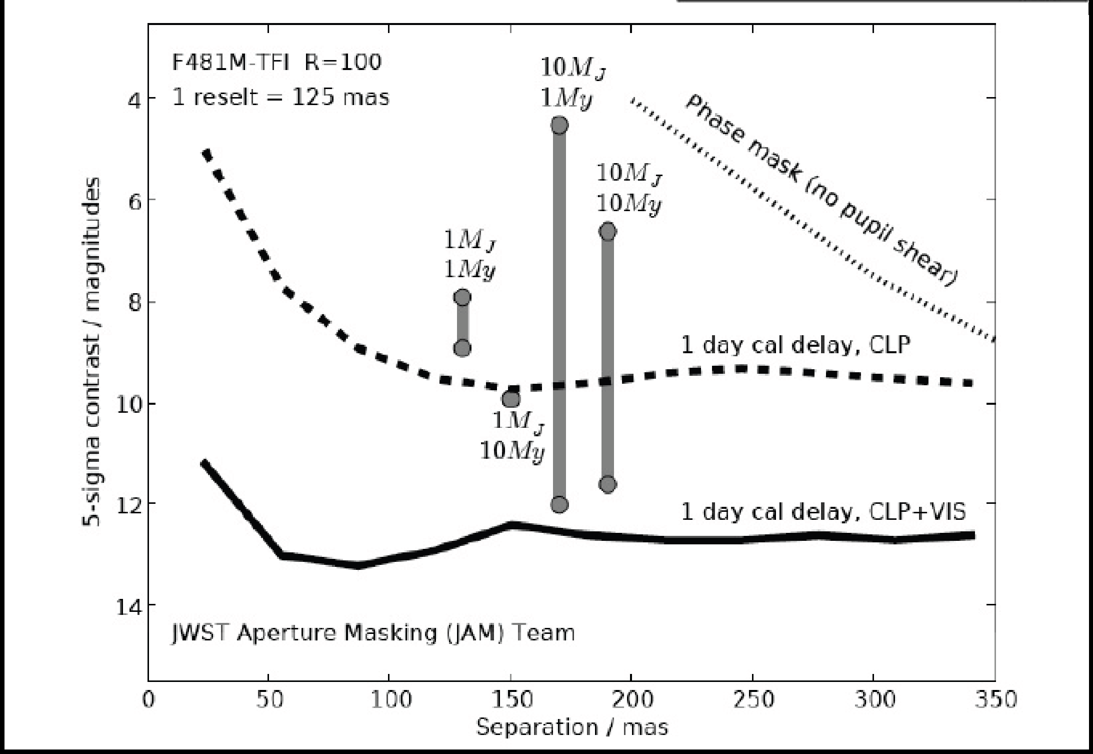
Sivaramakrishnan et al 2009



Tunable Filter Imager Coronagraph

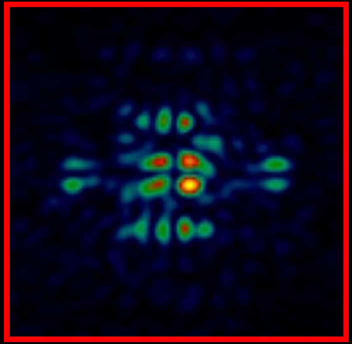
- **TFI Coronagraphic Capability Summary**
  - **Wavelength range:** 1.5-2.5, 3.1-5.0 µm
  - **Field of view:** 20”x20”
  - **Coronagraph**: Differential Speckle Imaging
  - **Contrast** gain of ~10x versus NIRCam
  - **Inner working angle: 4 λ/D**
  - Technique employed on HR8799 (Marois et al. 2008)
- **Non-redundant Mask**
  - **Wavelength range:** 1.5-2.5, 3.1-5.0 µm
  - **Coronagraph**: Closure Phase Imaging
  - **Trades inner working angle: 0.5 λ/D against contrast**



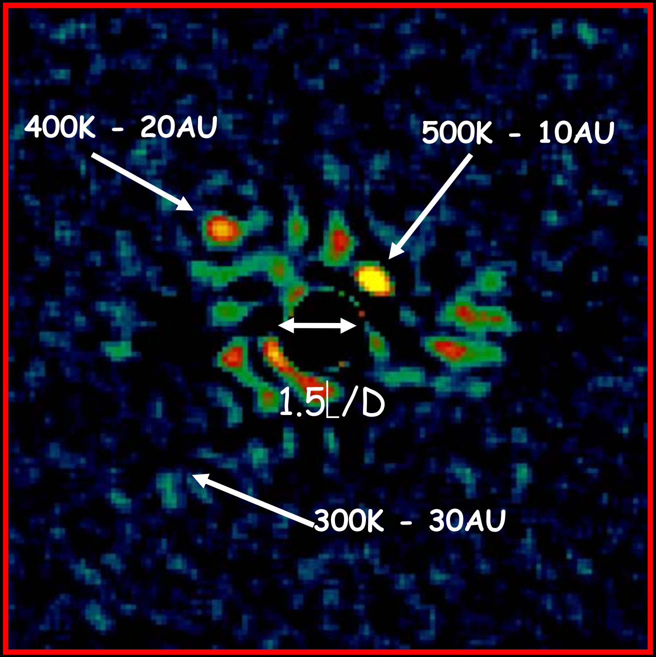


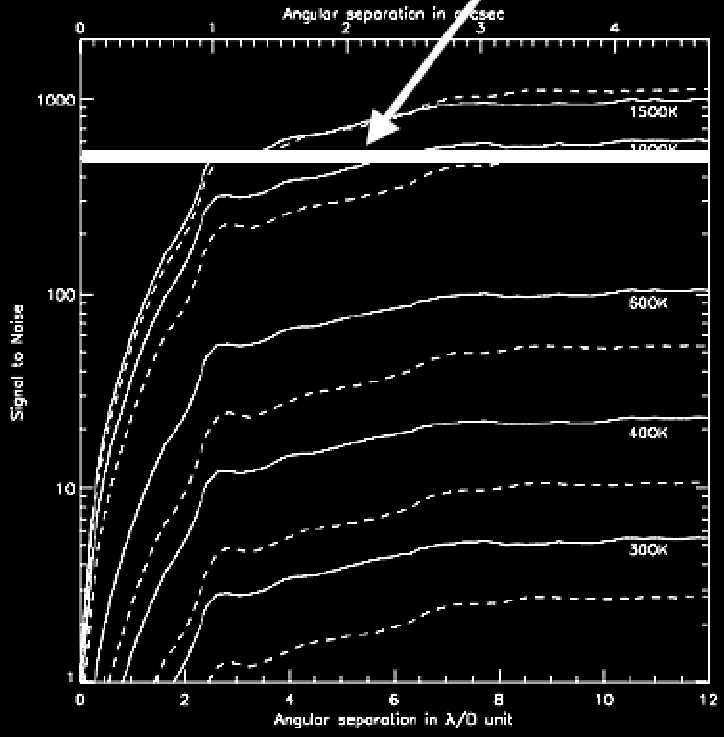
MIRI Exoplanet Detection Limits

Boccaletti et al.



M2V, 10pc



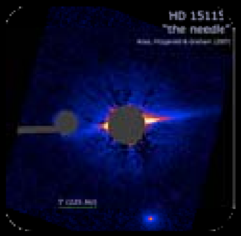


Detection limit (5-σ) with 30-m groundbased telescope

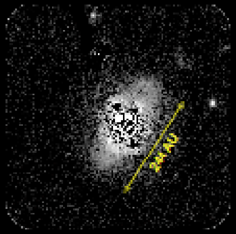
Signal to noise ratio of EGPs at 11μm as a function of the radial separation assuming a system located at 10 pc around an M2V star. The dotted and solid lines correspond respectively to the signal to noise ratio in the first and the second filters (ammonia absorption)

Debris Disks: HST's Legacy

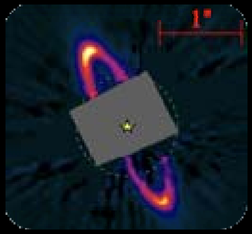
HD 107146
Ardila et al. 2005



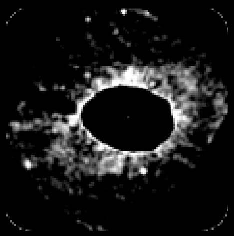
HD 15115
Kalas et al. 2005



HD 92945
Clampin et al. 2006



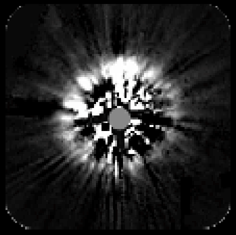
HR 4796
Schneider et al. 1999



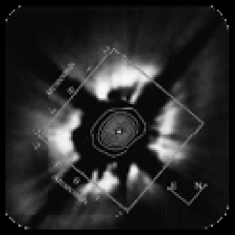
HD 207129
Stapelfeldt et al. 2007

HD 139644
Kalas et al. 2006

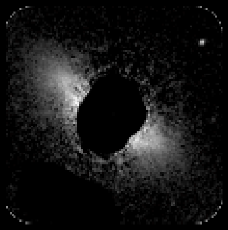
HD 51543
Kalas et al. 2006



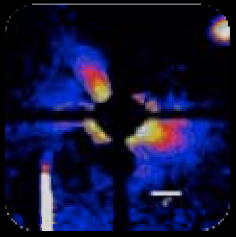
HD 181327
Schneider et al. 2006



HD 141569A
Weinberger et al. 1999

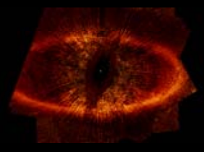


HD 10647
Stapelfeldt et al. 2007

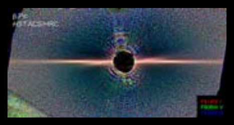


HD 32297
Schneider et al. 2006

AU Mic
Krist et al. 2005



Fomalhaut
Kalas et al. 2005

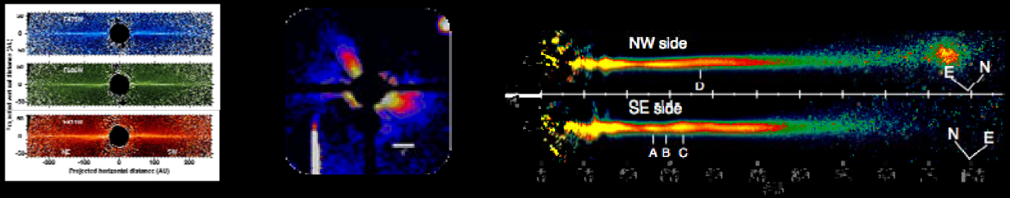


® **Pictoris**
Golimowski et al. 2005

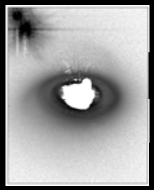
HD 202917
Clampin et al. 2007

Debris Disks: Evidence for Planets

- **Warps**

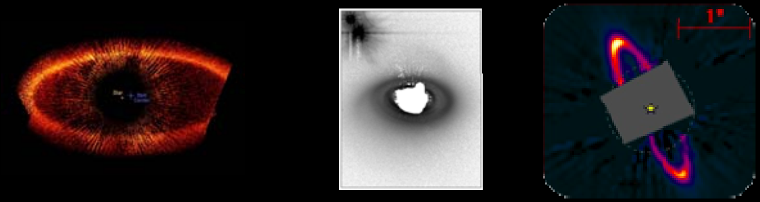


- **Spirals**

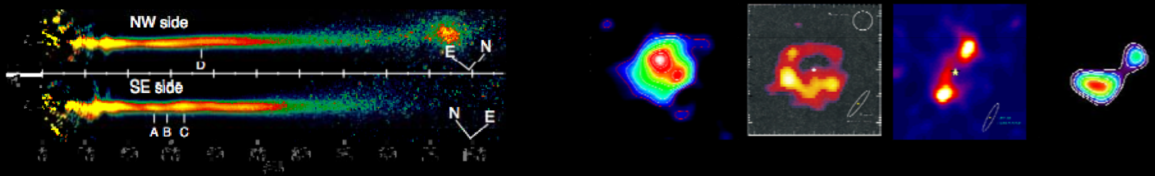


- **Brightness Asymmetries**

- **Offsets**



- **Clumps**



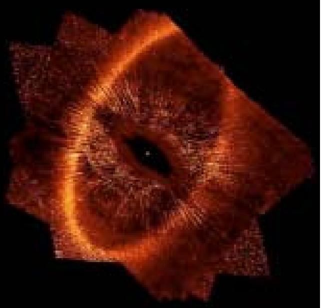
MIRI: Disk Characterization

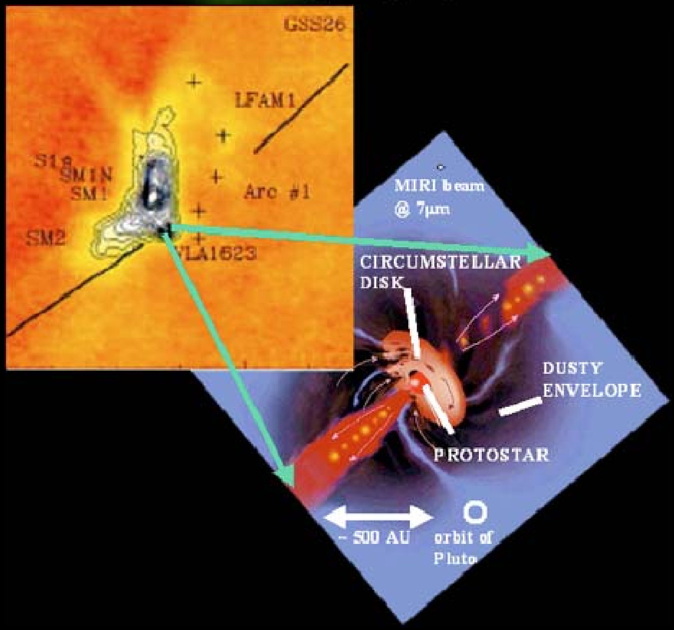
- Disk shape: scattered light & emission
- Disk mineralogy

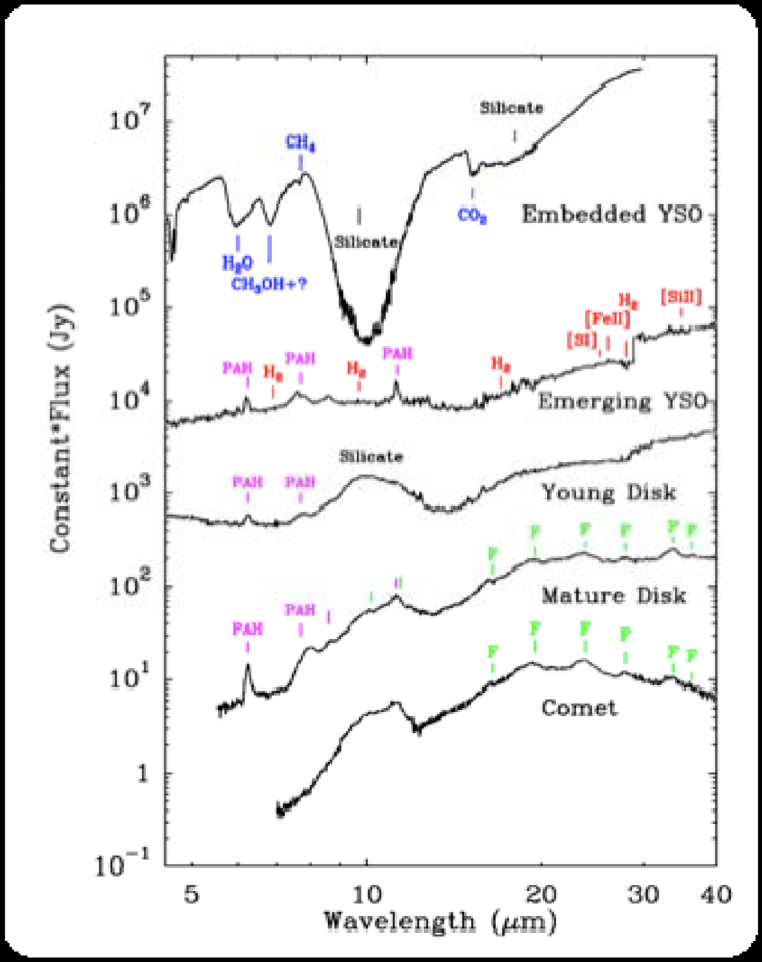
JWST 20 microns

Spitzer 24 microns

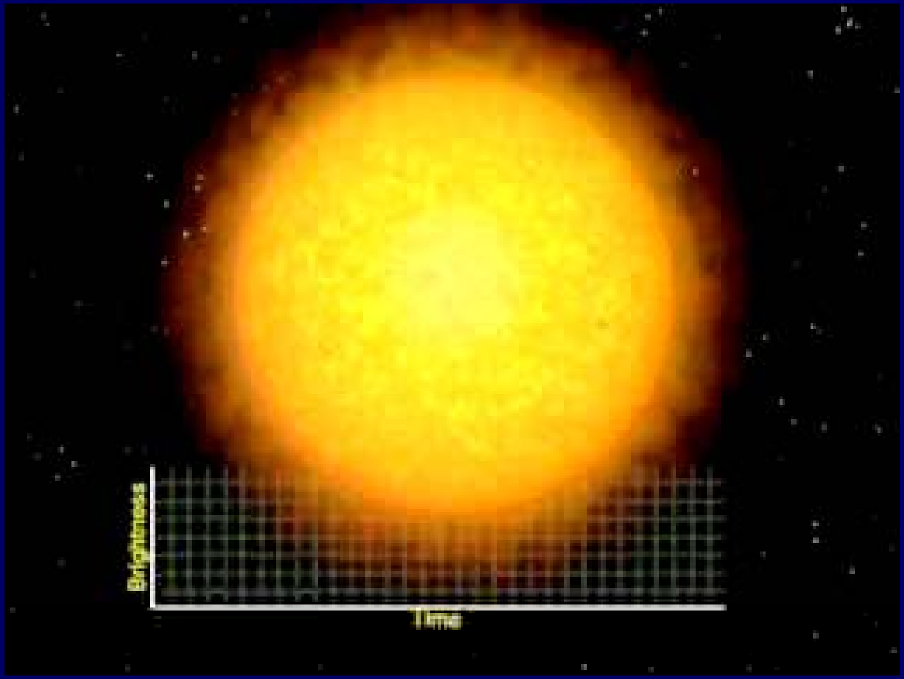
Visible (HST)





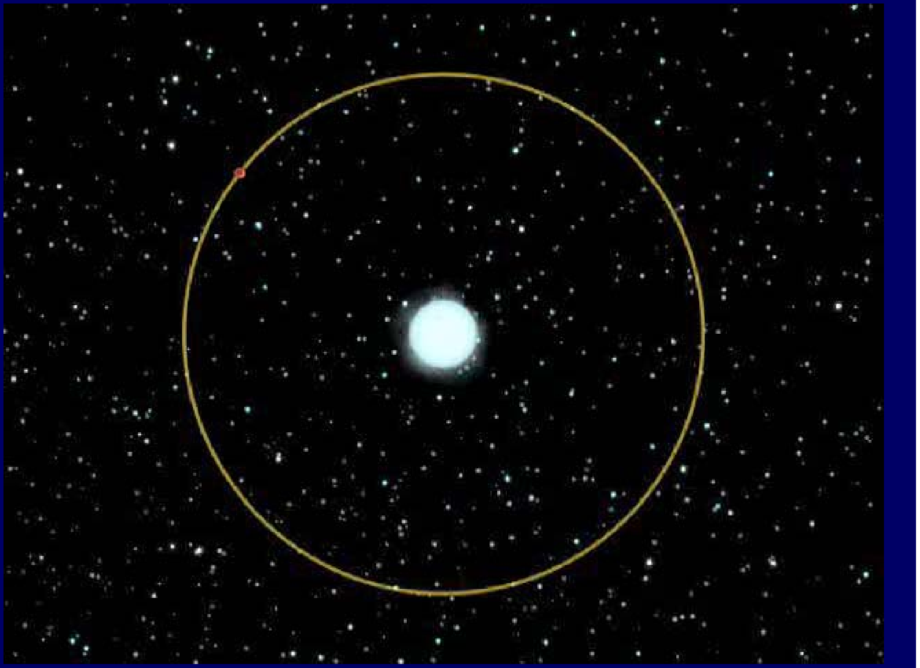


Primary



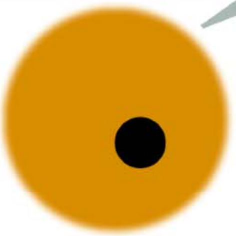
- Planet blocks light from star
- Visible/NIR light (Hubble/JWST)
- Radius of planet/star
- Absorption spectroscopy of planet’s atmosphere
- JWST: Look for moons (by timing), constituents of atmosphere, Earth-like planets with water, weather

Secondary



- Star blocks light from planet
- Mid-Infrared light (Spitzer/JWST)
- Direct detection of photons from planet
- Temperature of planet
- Emission from surface
- JWST: Atmospheric characteristics, constituents of atmosphere, map planets

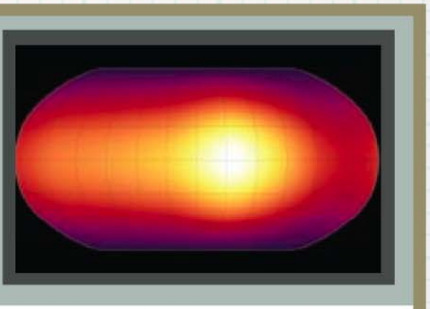
TESS provides targets for JWST

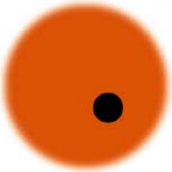


WEATHER ON HOT JUPITERS

1000+ TESS-provided sample

- Compare hot (~0.05AU) and cooler (0.1-0.2AU) systems
- Determine radiation time scales
- Measure temperature with altitude





FORMATION AND MIGRATION OF NEPTUNES

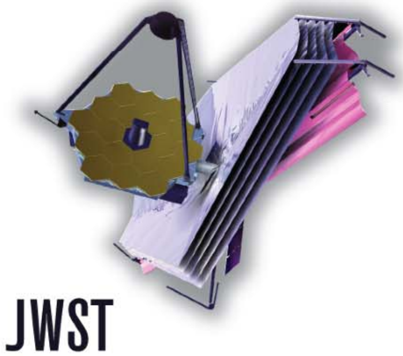
700+ TESS-provided sample

- Evaluate gas fraction vs. remnant core
- Differentiate atmospheric composition based on migration models

WET SUPER EARTHS

100+ TESS-provided sample

- Compare hot Super Earth's around the late type K stars and cooler Super Earths around mid-late M stars
- Investigate signs of habitability



TESS & JWST

TESS provides WHERE to look	**1. Star Location on sky**
TESS provides HOW to look	**2. Star Brightness**
TESS provides WHEN to look	**3. Planet Transit Time**

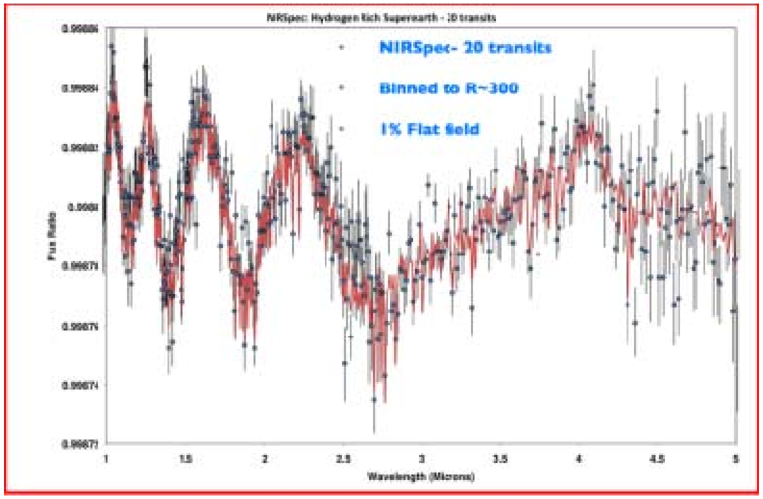
G. Ricker (MIT)
090107

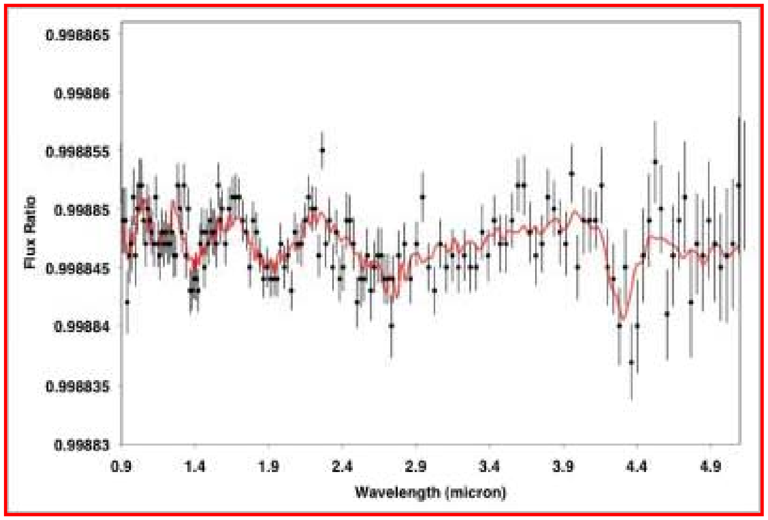
Transit Science Instrument Modes

SI	λ (μm)	Spectral Resolution (λ/δλ)	FOV	Mode	Comments	Application
NIRCam	0.6 - 2.3 2.4 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2’ x 2.2’) 2 x (2.2’ x 2.2’)	Imaging Imaging	Photometric Imaging	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of primary or secondary eclipses.
NIRCam	0.6 – 2.3	4, 10, 100	2 x (2.2’ x 2.2’)	Phase diversity imaging	Defocusing of images to 57 or 114 pixel diameters	High precision light curves of transits associated with bright objects which need to be defocused to avoid saturation within the minimum integration time
NIRCam	2.4 – 5.0	2000	2 x (2.2’ x 2.2’)	Long-λ Grism	Backup capability for WFSC. Used with F277W, F322W, F356W, F410M or F444W	Emission spectroscopy of hot gas giant transiting planets
NIRSpec	1.0 – 5.0	100, 1000, 2700	0.1” x 2.0”, 0.2” x 3.5”, 0.4”x 4.0”	Spectroscopy	Fixed long slits	Low and intermediate resolution transmission and emission spectroscopy of transiting planets.
NIRSpec	0.7 - 5.0	2700	3” x 3”	Spectroscopy	Integral Field Unit	Intermediate resolution, transmission and emission spectroscopy of transiting planets.
MIRI	5 – 29	4-6	1.9’ x 1.4’	Imaging	Photometric Imaging	
MIRI	5 - 11	100	5” x 0.2”	Spectroscopy	Fixed Slit or Slitless	Light curves of transits from photometry of point source images.
MIRI	5.9 – 7.7 7.4 – 11.8 11.4 – 18.2 17.5 – 28.8	3000 3000 3000 3000	3.7” x 3.7“ 4.7” x 4.5” 6.2”x 6.1” 7.1”x7.7”	Spectroscopy	Integral field unit	Intermediate resolution, emission spectroscopy of transiting planets.
TFI	1.6 – 2.5	100	2.2’ x 2.2’	Imaging	Selectable central λ	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of primary eclipses.
TFI	3.2 – 4.9	100	2.2’ x 2.2’	Imaging	Selectable central λ	High precision light curves of transits from photometry of point source images. Wavelength coverage permits photometric monitoring of secondary eclipses.

Transit Observations of Super-Earths

- Simulations of NIRSpec Observations of Super-Earths
- Spectra provided by E. Miller-Ricci and S. Seager (Miller-Ricci et al. 2009)





-- 20 Transit observation

-Hydrogen rich atmosphere

- Deep H_2O feature detected

- 100 Transit observation

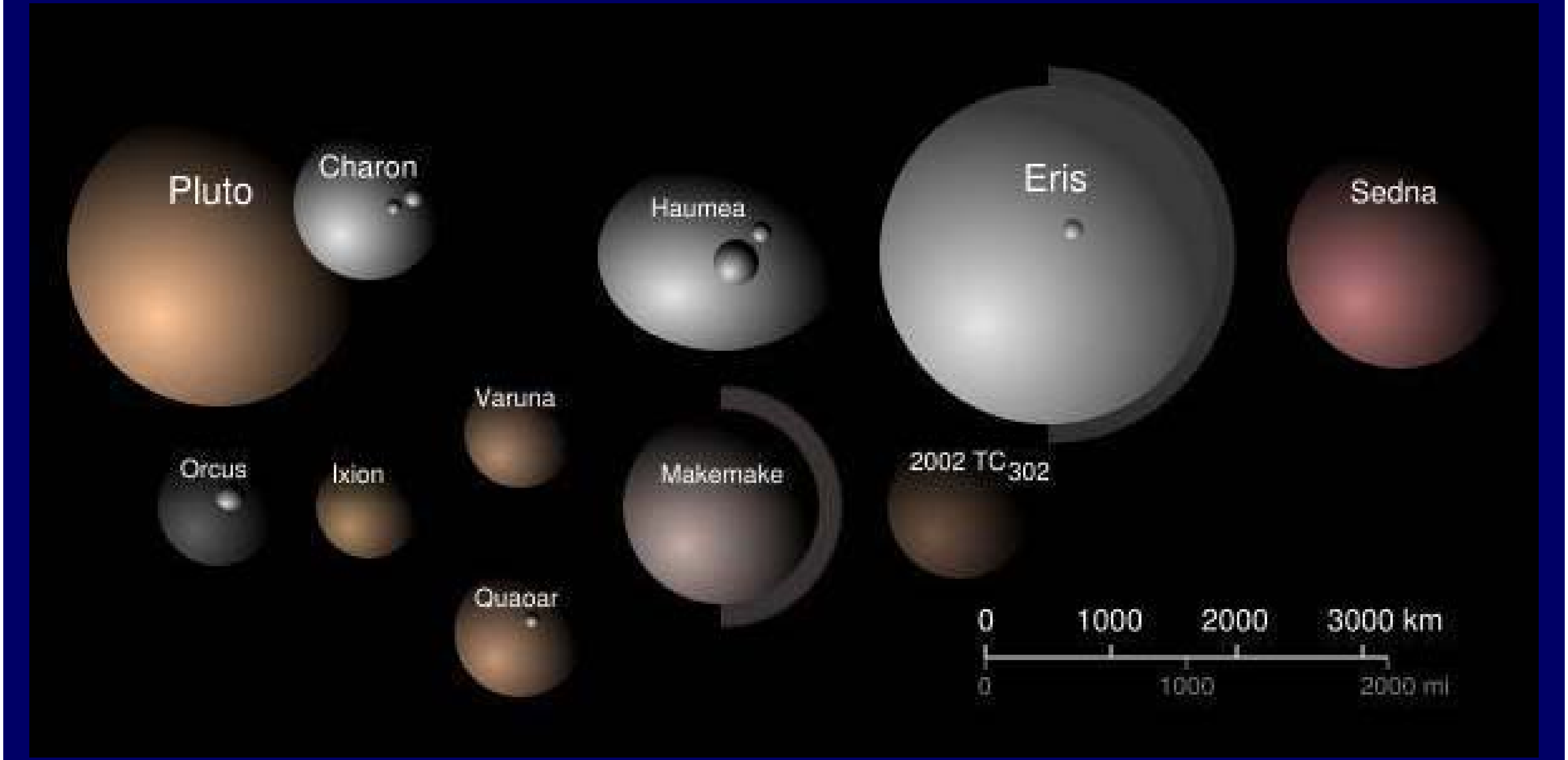
- intermediate atmosphere

- 4.3 μm CO_2 feature detected

Pluto?

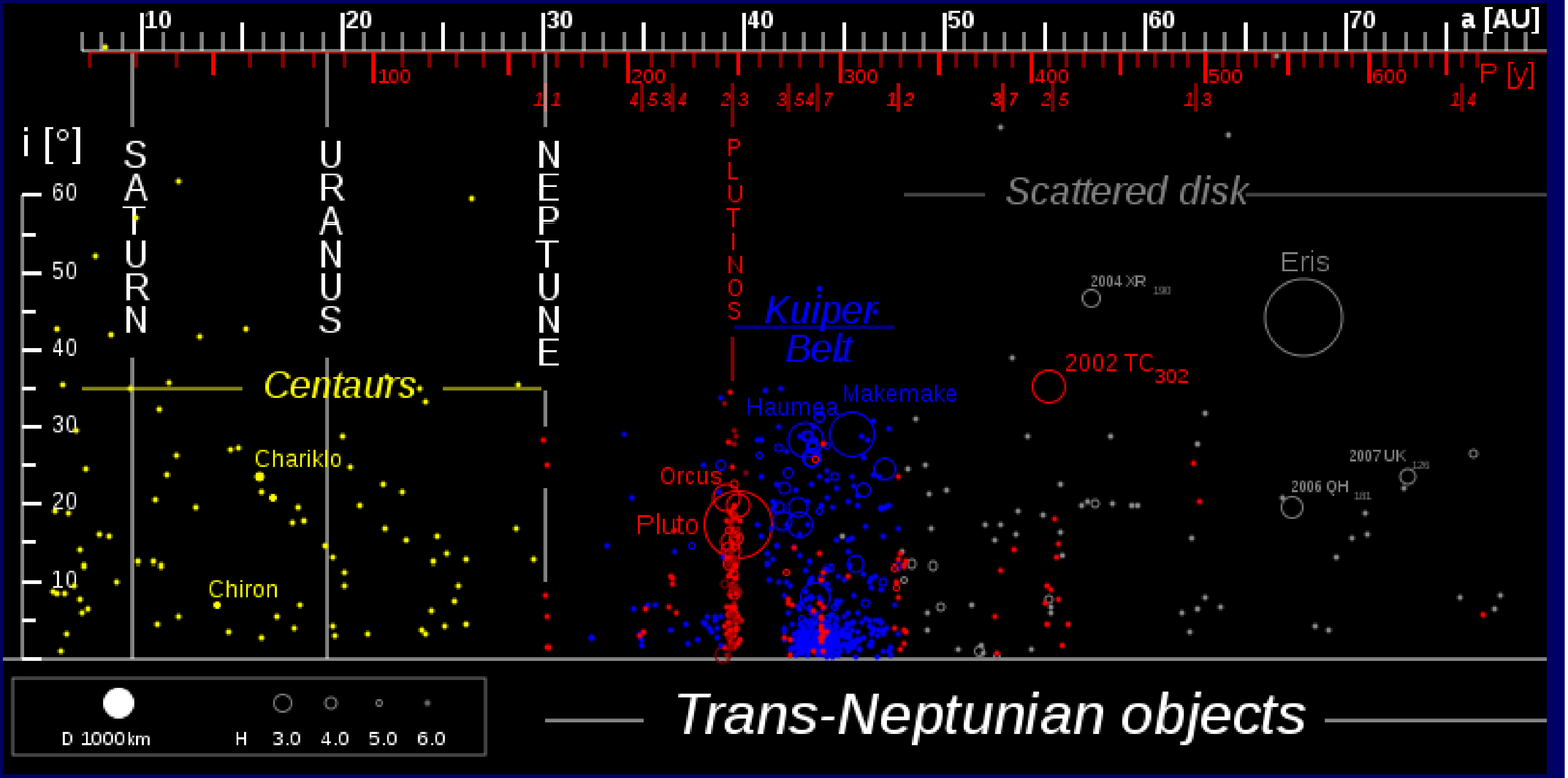
BREEN San Diego Union-Tribune© Copley News Service
I CAN'T BELIEVE I HAVE TO SIT AT THE "LITTLE PLANETS" TABLE...
PLUTO

Dwarf Planets and Plutoids



May be 2000 more when whole sky is surveyed
With moving object tracking JWST is perfect tool

Where they are



NORTHROP GRUMMAN

NEW WORLDS OBSERVER

Seeking Earth-like Planets in Our Solar Neighborhood

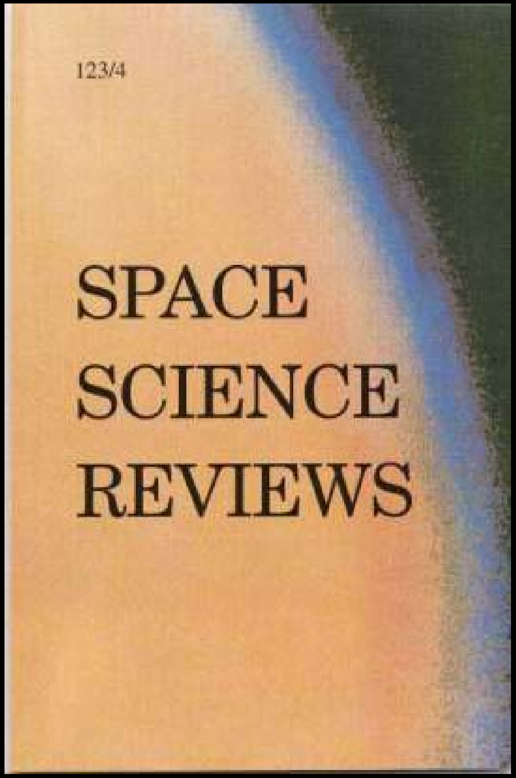
Summary

- JWST is on track for 2014 launch – a major accomplishment!
- Predicted performance for exoplanet transits is very good (limited by systematic errors and unknown stability)
- 3 coronagraphs provided but segmented aperture not optimal
- Small changes made for better photometric stability (NIRSpec) and better inner working angle (TFI non-redundant mask)
- External occulter proposed as complement to JWST (or future general UV-optical telescope)

More Info

- 600 MB tutorial: Decadal Survey White Papers (Google "2010 decadal survey"): http://sites.nationalacademies.org/bpa/BPA_050603
- 7 JWST White Papers submitted:
  - The Scientific Capabilities of the James Webb Space Telescope – Jon Gardner
  - Comparative Planetology: Transiting Exoplanet Science with JWST – Mark Clampin
  - Planetary Systems and Star Formation with JWST – George Rieke
  - Study of Planetary Systems and Solar System Objects with JWST – George Sonneborn
  - Stellar Populations with JWST: the Beginning and the End – Margaret Meixner
  - Galaxies Across Cosmic Time with JWST – Rogier Windhorst
  - First light and reionization : open questions in the post-JWST era – Massimo Stiavelli

More Info: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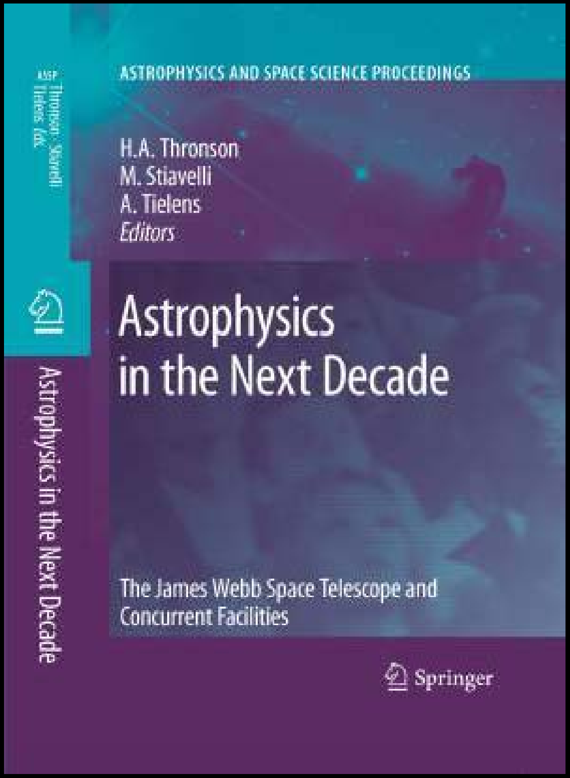
SPACE SCIENCE REVIEWS


ASSP Thronson · Stiavelli Tielens *Eds.*

Astrophysics in the Next Decade

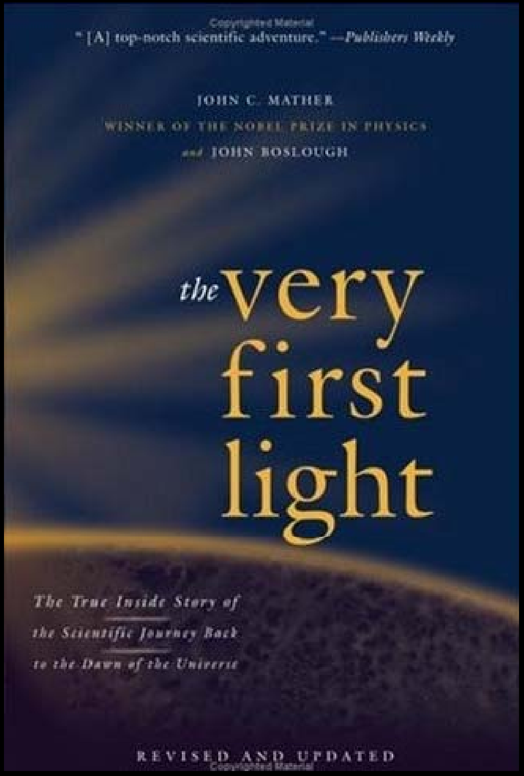
ASTROPHYSICS AND SPACE SCIENCE PROCEEDINGS

H.A. Thronson
M. Stiavelli
A. Tielens
Editors

Astrophysics in the Next Decade

The James Webb Space Telescope and Concurrent Facilities

Springer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and JOHN BOSLOUGH

the very first light

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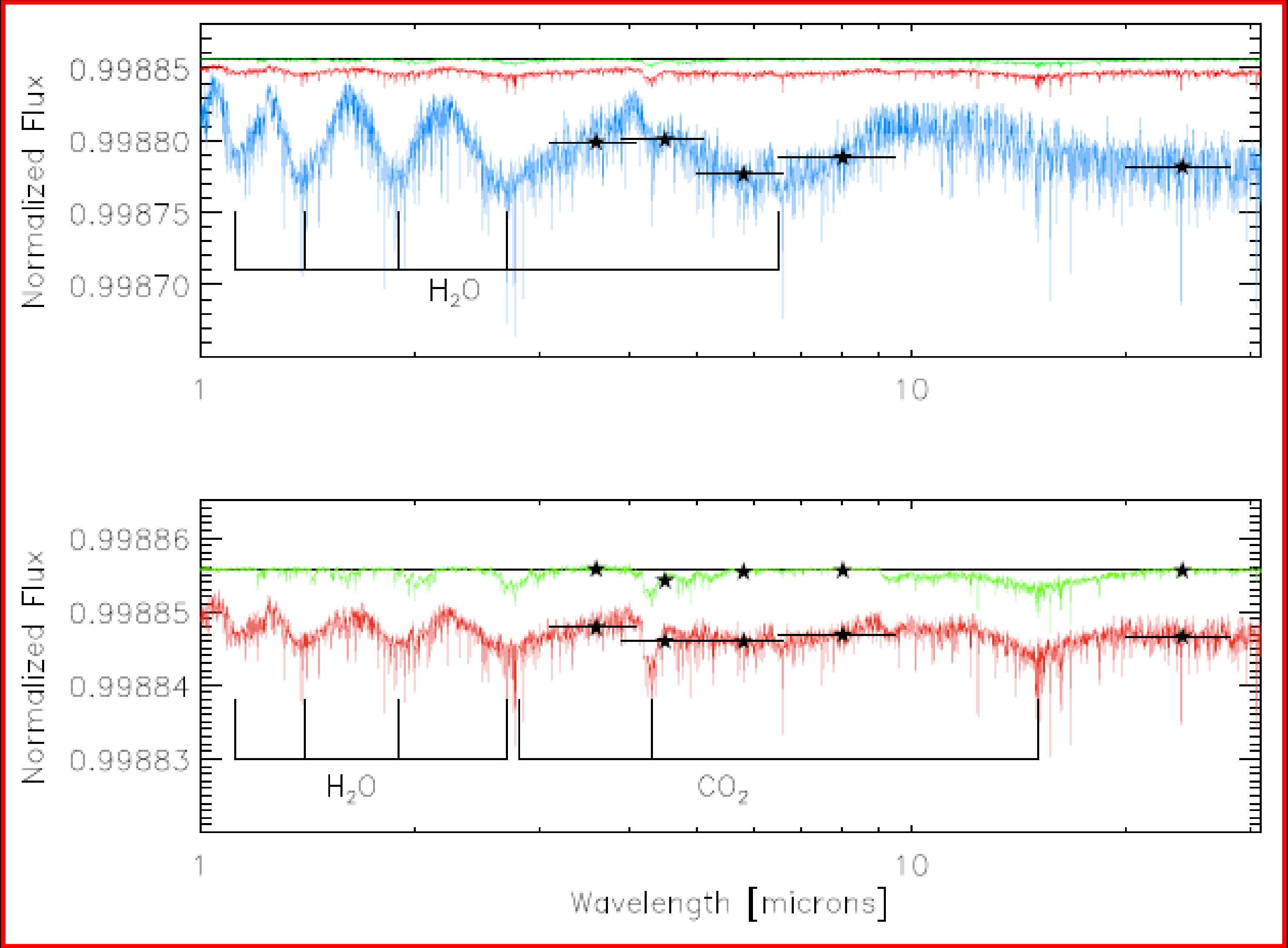
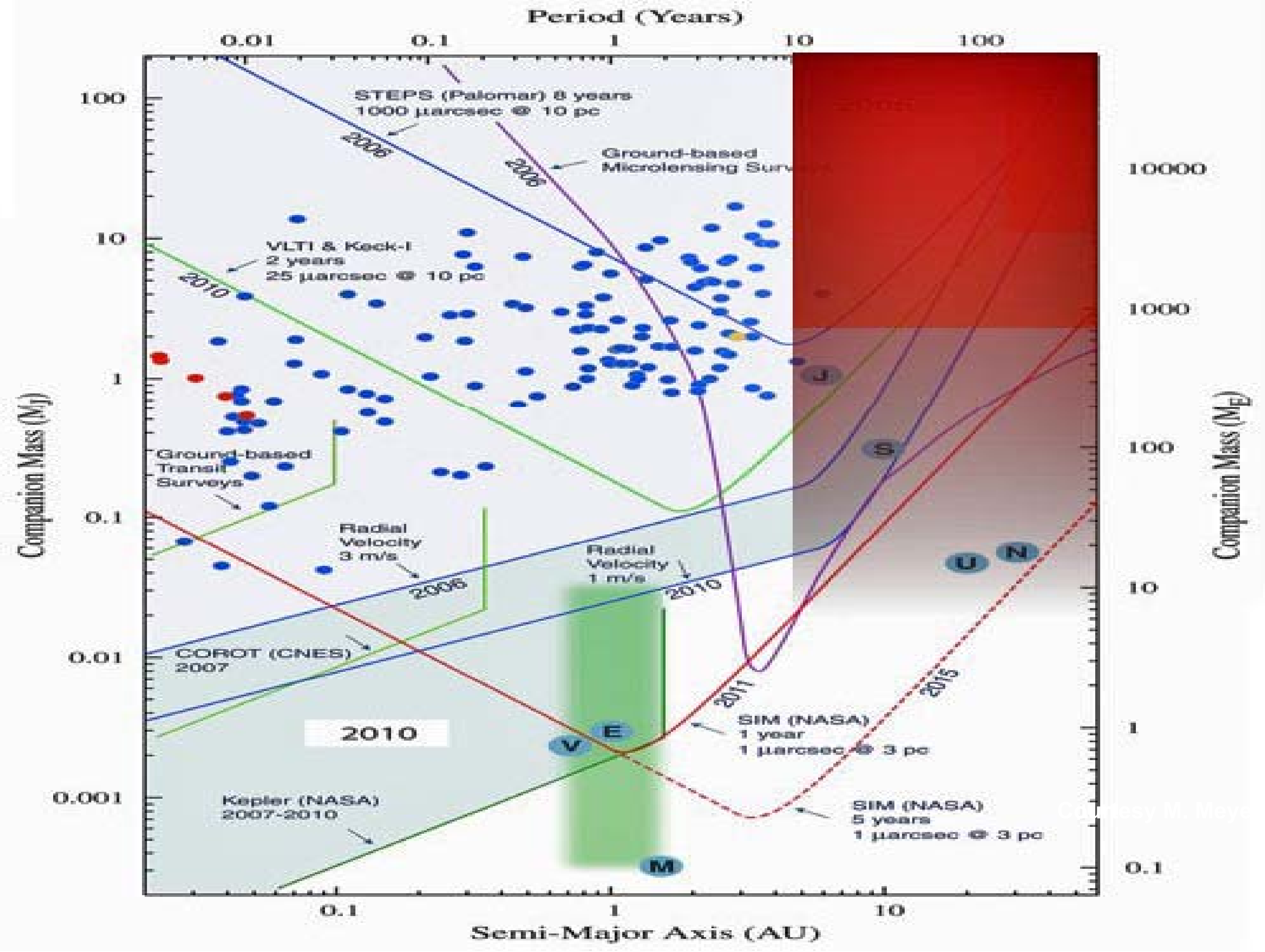
The End

- **The Atmospheric Signatures of Super-Earths: How to Distinguish Between Hydrogen-Rich and Hydrogen-Poor Atmospheres,** Eliza Miller-Ricci, Sara Seager & Dimitar Sasselov, 2008arXiv0808.1902M

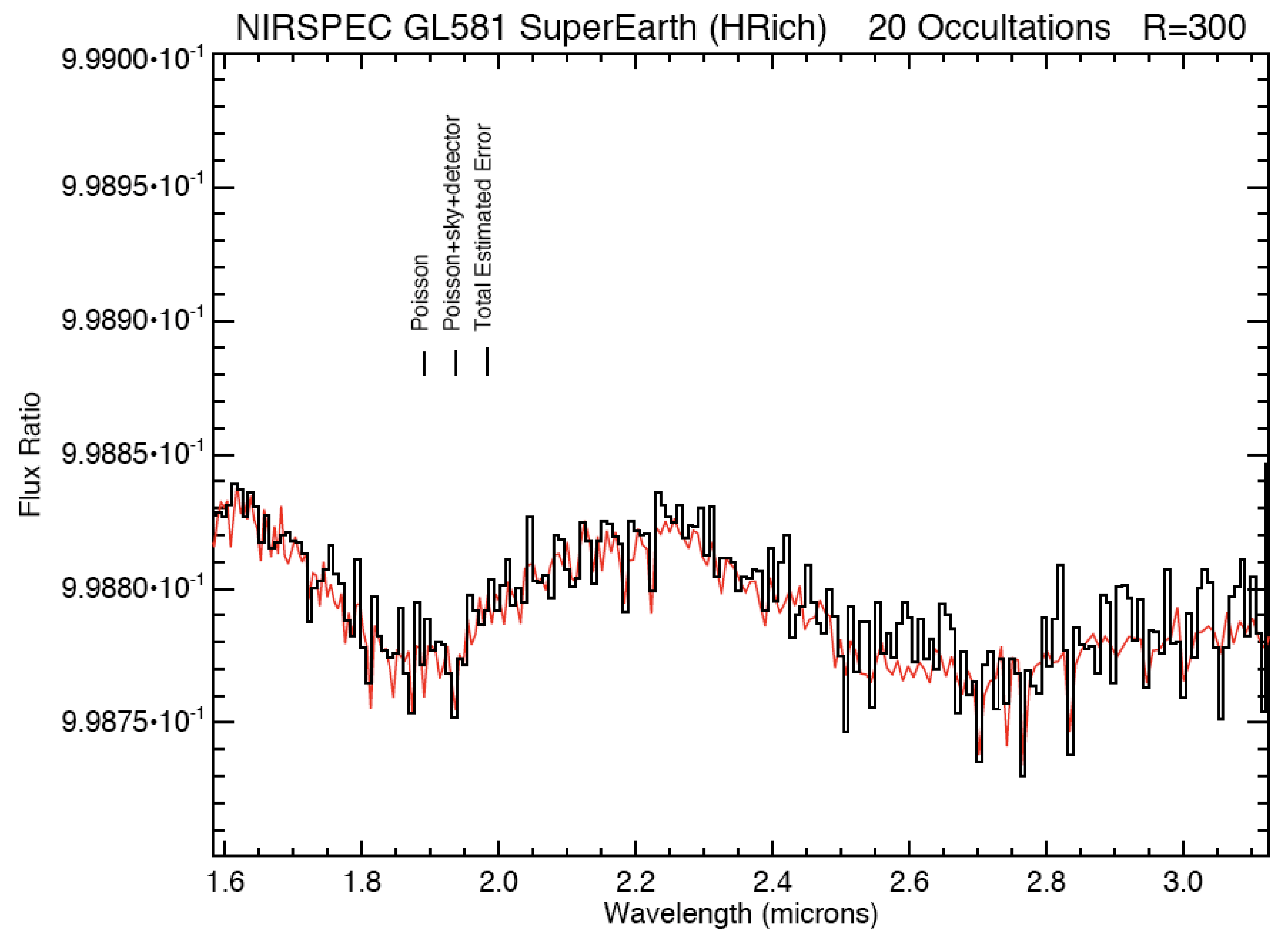




Courtesy M. Meye

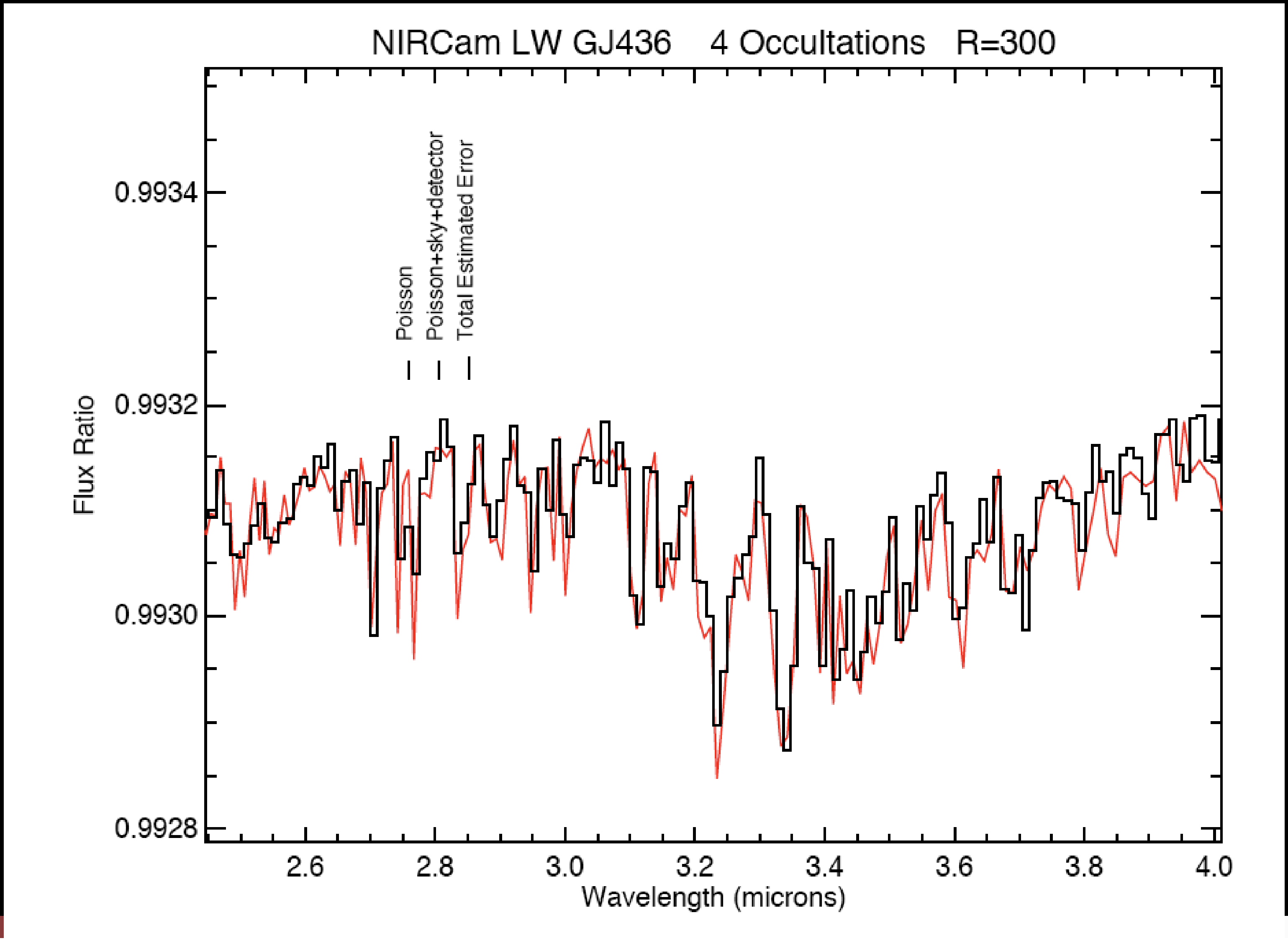
GL 581 - H_{rich} Superearth

- NIRSpec - 20 transits, binned to R~300



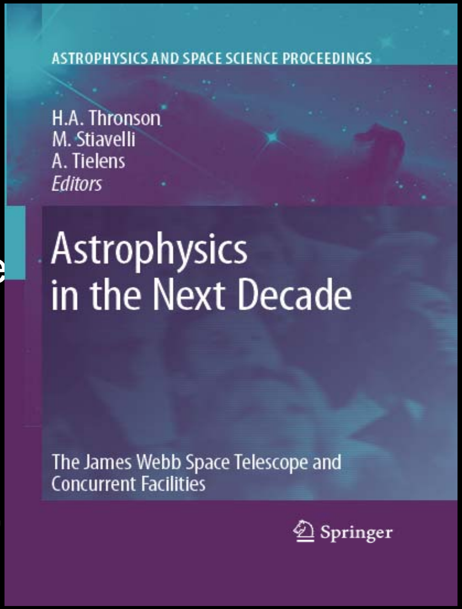
GJ436 _ Transmission

- **NIRSpec - 4 transits, binned to R~300**



2009 Major Events

- Sunshield Membrane Management System Preliminary Design Review, February
- ISIM Critical Design Review, March
- Assembly & Testing of NIRCam Engineering Test Unit, June
- Observatory Flight Software Build 1 Critical Design, June
- Microshutter device delivered from GSFC to NIRSpec, June
- NIRCam Flight Instrument build commences, August
- Electro-optical tests of ETU FGS at operating conditions, October
- MIRI Flight Instrument testing commences



ASTROPHYSICS AND SPACE SCIENCE PROCEEDINGS

H.A. Thronson
M. Stiavelli
A. Tielens
Editors

Astrophysics
in the Next Decade

The James Webb Space Telescope and
Concurrent Facilities

Springer

2007 Tucson conference proceedings published

NIRCam Team Transit Science

- R~1700 over entire LW channel, λ = 3 - 5 μm simultaneously (but limited by filters in series)
- No slit losses w/good sampling (0.065” vs NIRSpec 0.1”)
  - Precise transit spectrophotometry
  - Especially important for eclipse mapping

- Defocused imaging for transit photometry
  - Sub-arrays available for defocused imaging
  - 4λ, 8λ, 12λ waves of defocus

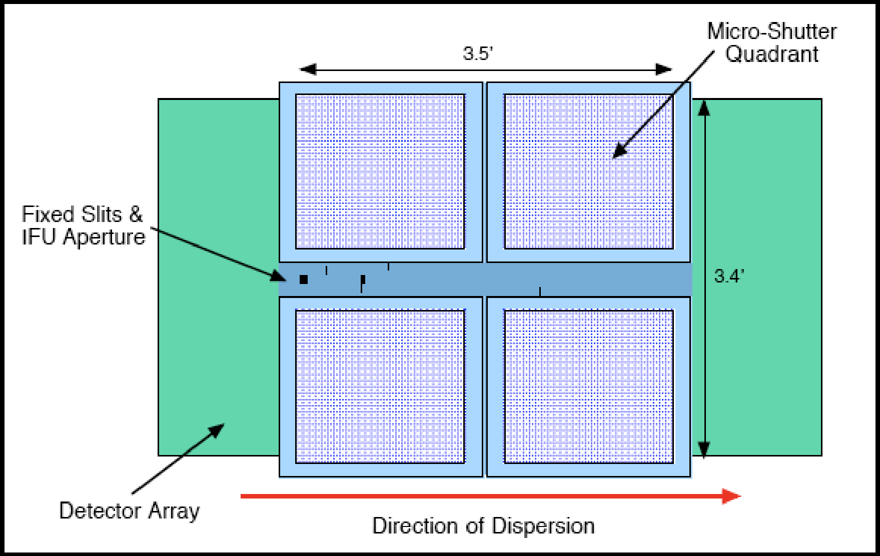
NIRCam Performance

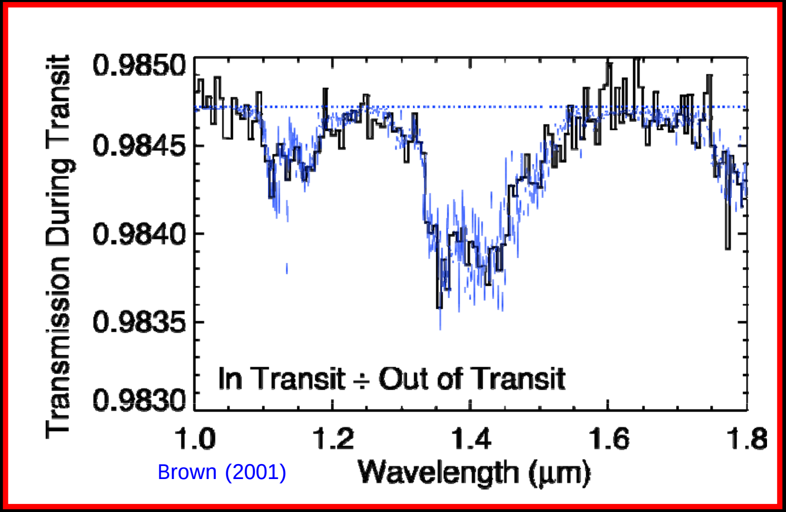
- Secondary eclipses of a hot Jupiter around bright G2V stars realistic to detect in R≤500 spectra.
- Hot Earths cannot be detected around G2V stars in R=500 secondary eclipse spectra
- High S/N R=500 spectra of a Jupiter around M2-3V stars can be observed via secondary eclipse.
- Secondary transits of Hot Earths around M5V stars could be detected at low SNR in R~50 spectra in ~10^4 sec

MIRI Team Science

- Imager can observe bright sources with good sampling
- MIRI imager should detect even small (1-2 $R_\oplus$) planets when transiting bright GKM stars
- LRS may be best to characterize the spectra of hot giant planets with high S/N and at R<=100 spectral resolution
  - Hot giant features detectable in a single transit @ R~50!
- MRS will be useful for R = 100 – 2000 spectra
  - 3 settings required to cover any broad spectral range

NIRSpec Team Science

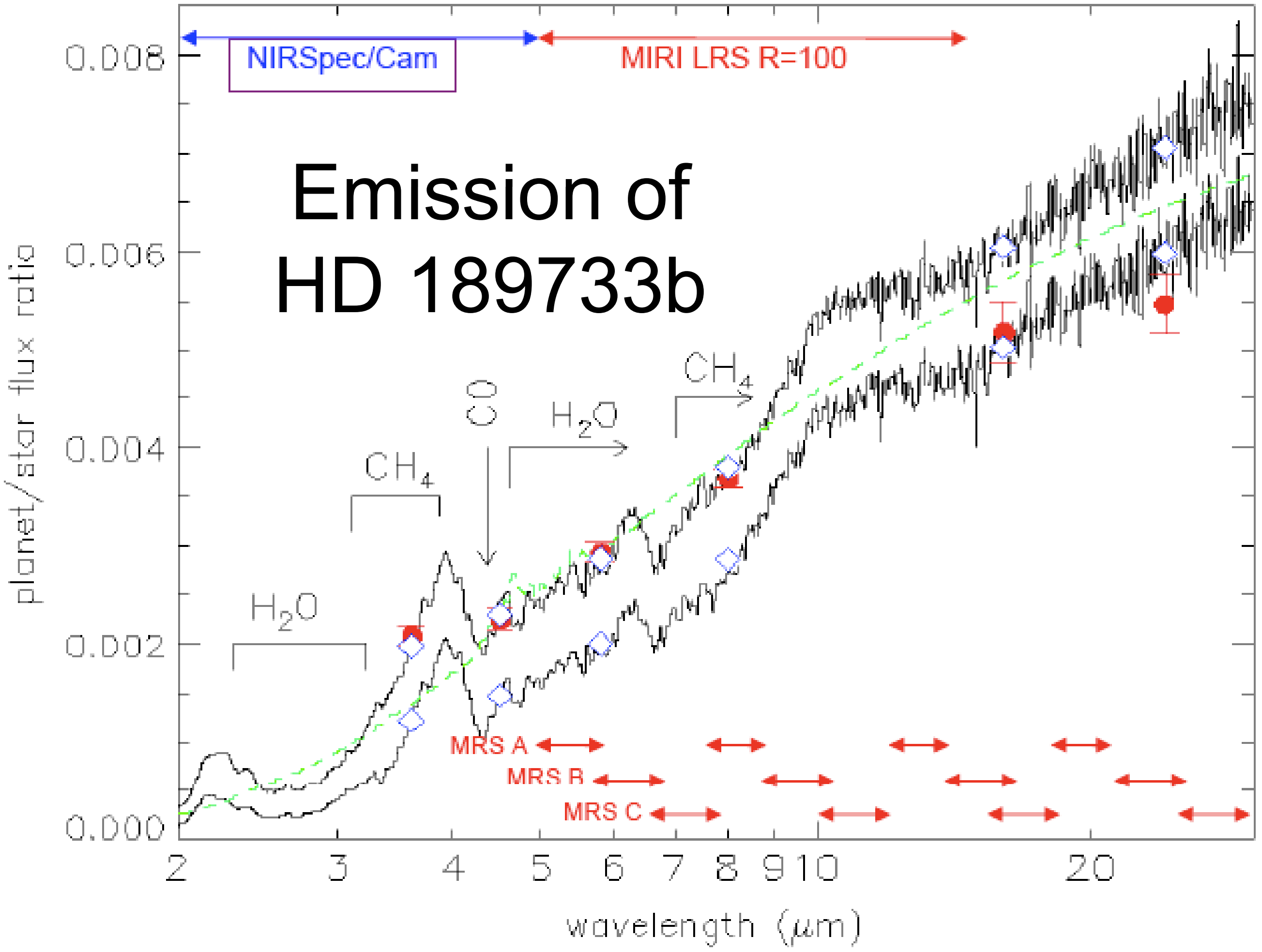




NIRSpec Transit Spectrum for HD 209458 at K=12

- NIRSpec designed for multi-object
- Recently added 1.6’x1.6” slit for transit spectroscopy
- Undersampled pixels remain a concern wrt systematics

NIRCam · MIRI



Emission of HD 189733b

CH4, CO, H2O constrain temperature and C abundance

Red symbols are measurements;

Top curve has fluz absorbed on day side only; bottom has uniform energy redistribution

Dashed line is BB

Charbonneau, Knutson, Barman, Allen, Mayor, Megeath, Queloz, & Udry (2008)

The NASA Astrobiology Roadmap

- Goal 1 — Understand the nature and distribution of habitable environments in the universe. Determine the potential for habitable planets beyond the Solar System, and characterize those that are observable.
- GOAL 7 — Determine how to recognize signatures of life on other worlds and on early Earth. Identify biosignatures that can reveal and characterize past or present life in ancient samples from Earth, extraterrestrial samples measured in situ or returned to Earth, and remotely measured planetary atmospheres and surfaces. Identify biosignatures of distant technologies.

Documentation

- Astrobiology Whitepaper: Lunine & Seager
  - (Google “jwst white paper”)
- JWST Coronography Whitepaper
- JWST Transit Science Whitepaper
- Space Science Reviews

Astrobiology Themes

- High contrast imaging and spectroscopy of Brown Dwarfs and Extrasolar Giant Planets
- Formation of planetary systems: tracing evolution of planetary systems from dust clouds to debris disks
- Studies of water and prebiotic organics in comets;
- Characterize organic and inorganic matter needed to create habitable environments
- Characterization of exoplanets via transit imaging

2008 Progress

- General
  - JWST successfully completed Non-Advocate Review and Confirmation Review and is approved to begin Implementation Phase
  - All observatory components, except for the spacecraft and membrane management system of the sunshield, have successfully completed their preliminary design reviews
  - All science instruments successfully completed critical design reviews
  - HQ approved moving object tracking requirement
- Telescope and Mirrors
  - All flight primary, secondary and tertiary mirrors completed machining and are in stages of rough polishing, smooth out and figure grinding
  - Mirror “Manufacturing Percentage” progressed from 41% to 55%
- Observatory
  - Sunshield Preliminary Design Review held in February 2008
  - Observatory Integration & Test control room opened at NGAS
- Ground Segment
  - Delivered all Science Instrument Integrated Test Sets (SITSs) and Science Instrument Development Units (SIDUs) to SI teams in the US, Canada and Europe

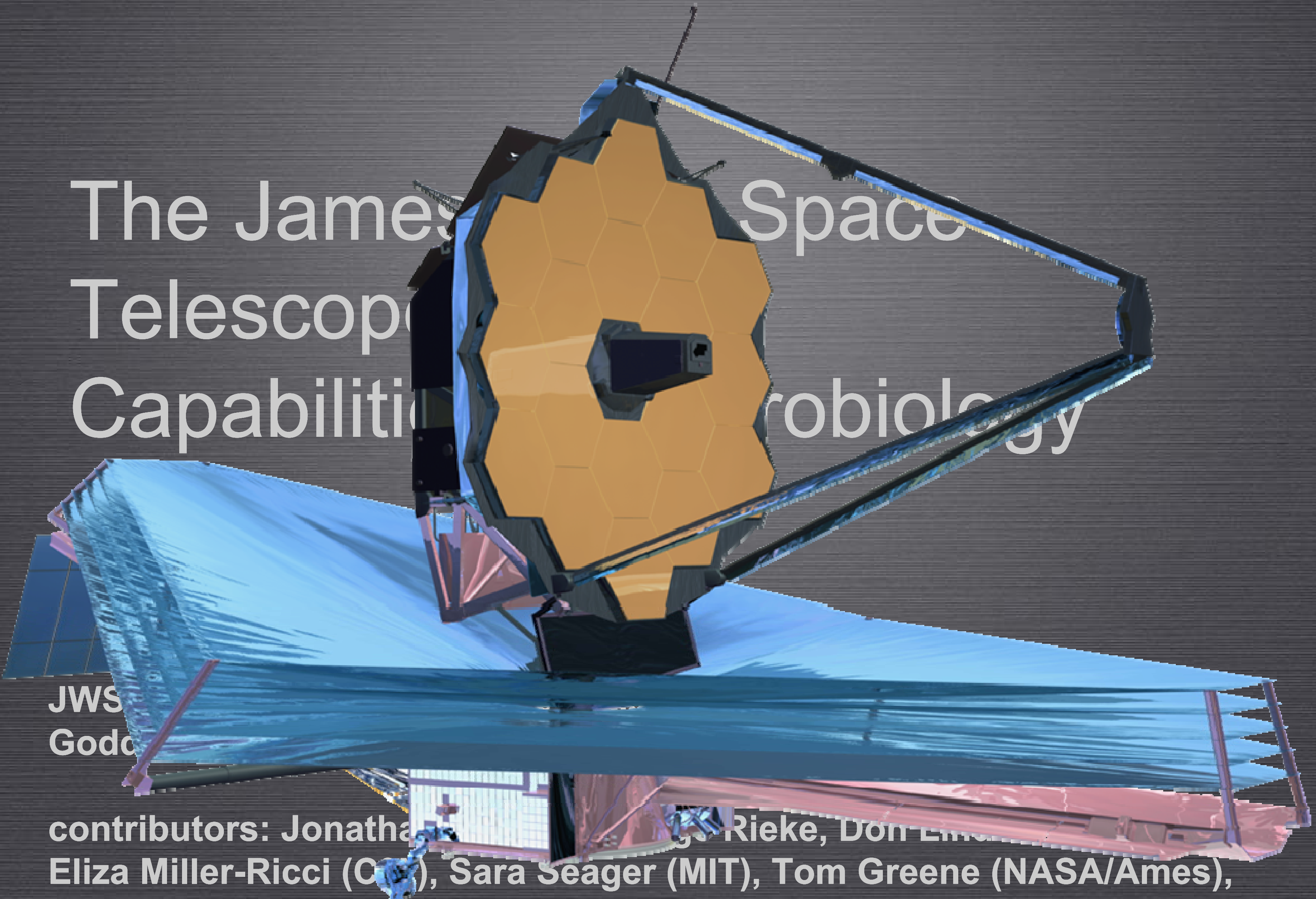
2008 Progress continued

- Integrated Science Instrument Module (ISIM)
  - MIRI
    - MIRI Verification Model (VM) completed, tested and achieved 6.2K operating temperature and first light!
    - Selected flight detectors for MIRI
  - NIRSpec
    - Delivered Engineering Test Unit detector subsystem to Astrium
    - Selection of flight detectors agreed to by NASA & ESA
    - ESA approved larger (1.6 arcsec square) aperture for NIRSpec for transits
  - NIRCam
    - Selected ALL flight detectors and filters for NIRCam
    - Completed bonding and vibration testing of the NIRCam ETU Optical Bench
  - FGS
    - Held FGS System CDR at COM DEV
    - Engineering Test Unit assembly begun, tunable filter etalon tested at cryo
    - CSA added Non-Redundant Masking to their Tunable Filter Imager
  - Structure
    - Completed bonding 5 of 13 Flight Hardware Decks

Sept. 29, 2009

Coronography (Dressler summary)

- NIRCam coronagraph (Krist 2007; Greene et al 2006)
  - Inner Working angle $\geq 4\lambda/D$ (500-750 mas at 3-5 μm)
  - Outer Working Angle ±10”
  - Dynamic range 10^5 (12.5mag) - 10^6 (15 mag) far from star
- TFI/Non Redundant Mask (Sivaramakrishnan et al)
  - Inner Working angle ~ $0.5\lambda/D$ (75 mas at 5 μm)
  - Outer Working Angle 0.5”
  - Dynamic range 10^4 (10 mag) possibly up to 10^6 (12.5 mag) with careful calibration, flat fielding
  - MIRI classic Lyot and 4-quadrant phase plate
  - Mostly disks but also planets on distant orbits (Fomalhaut-b)

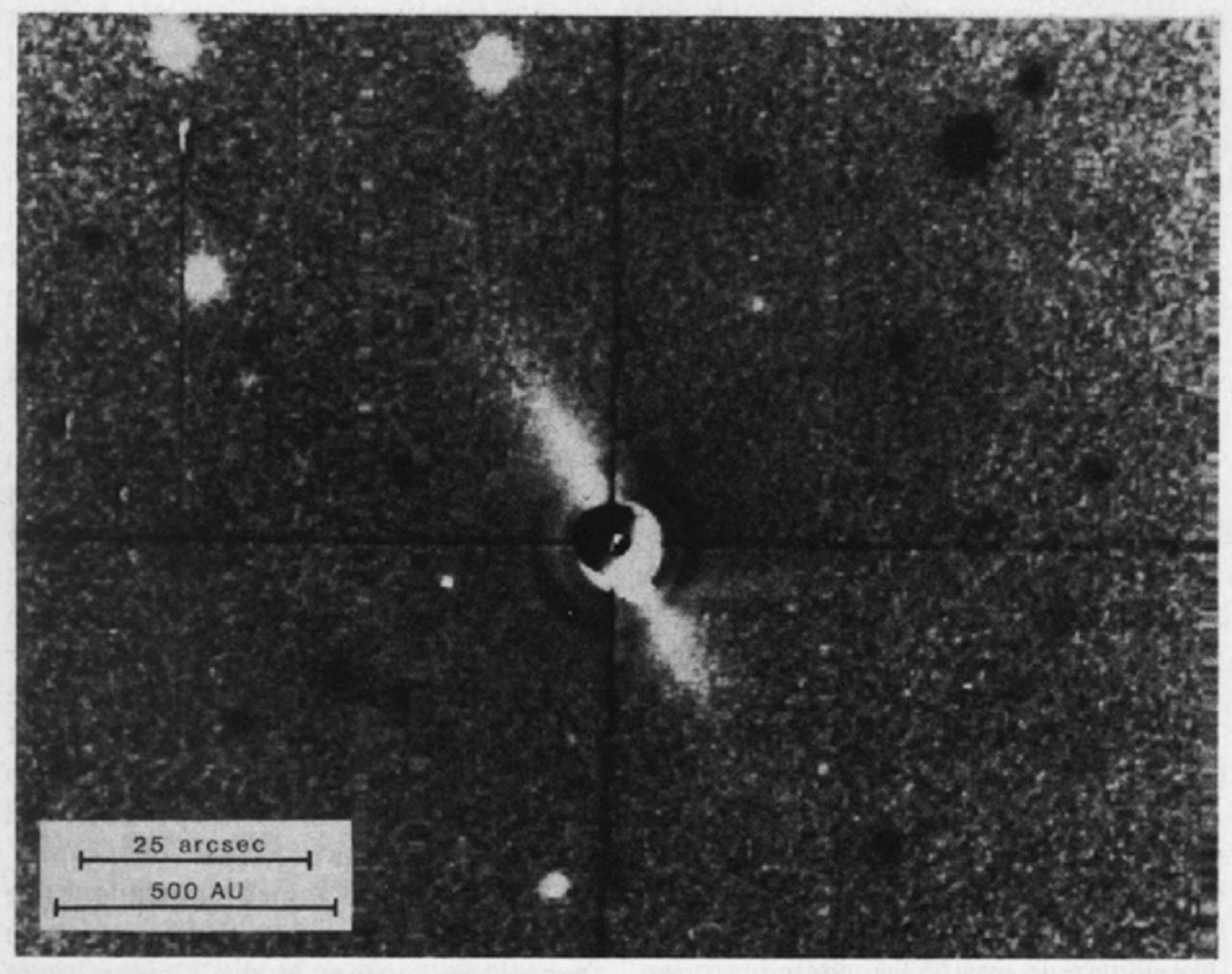


The James Space Telescope Capabiliti robiology

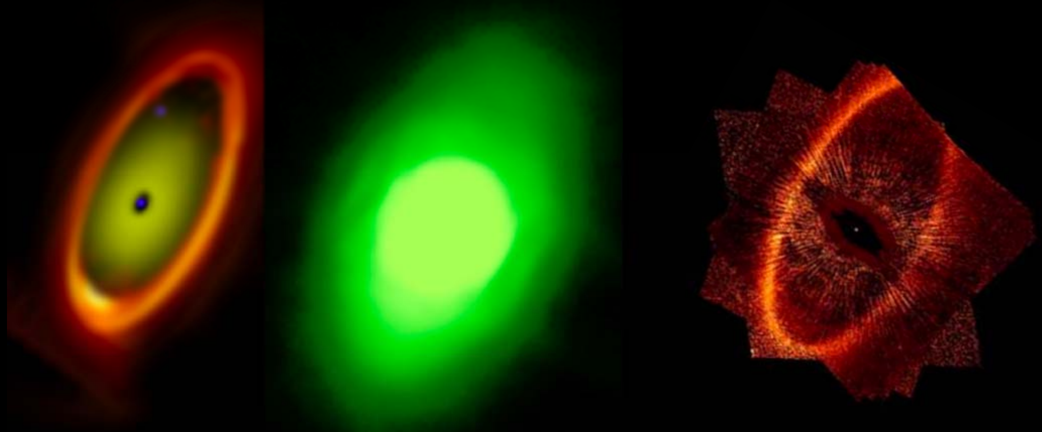
JWS
Godd

contributors: Jonatha Rieke, Don
Eliza Miller-Ricci (C), Sara Seager (MIT), Tom Greene (NASA/Ames),
Drake Deming (GSFC), and JWST SWG and SI Teams

Debris Disks: β Pictoris

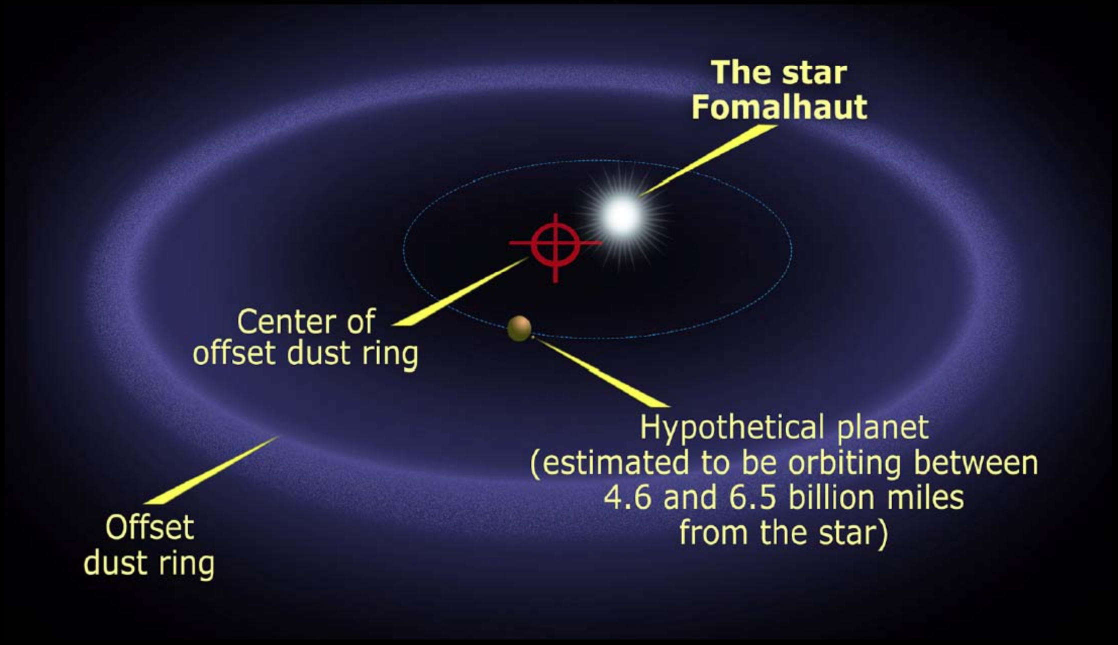


JWST Observations of Fomalhaut

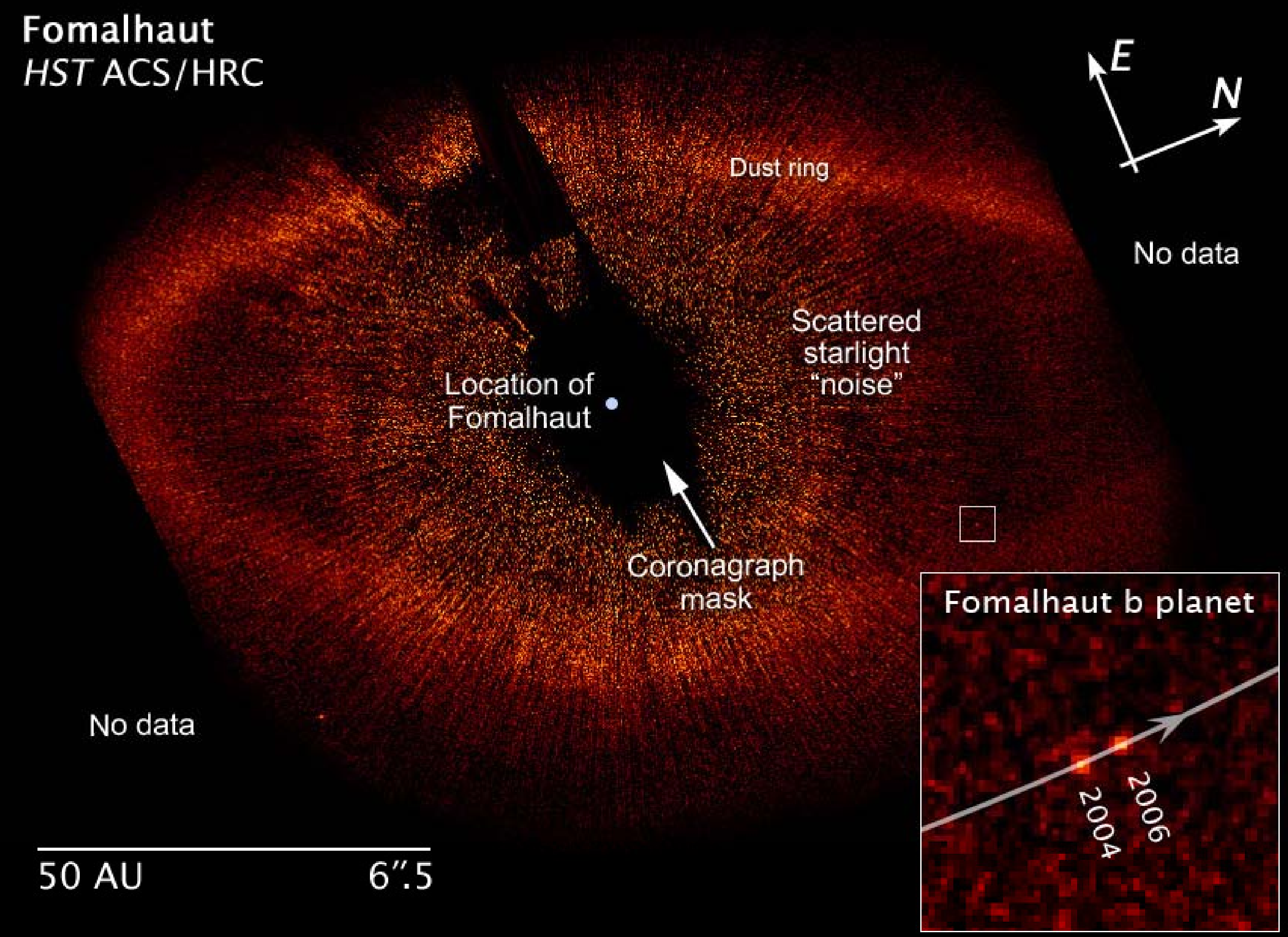


JWST (20 µm) Spitzer (24 µm) Visible (HST)

Fomalhaut



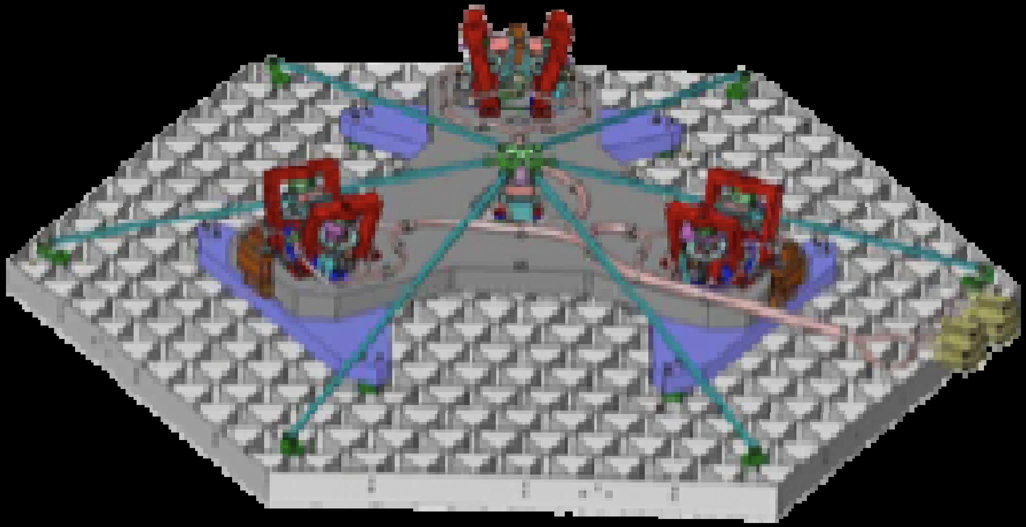
Direct Detection



- Mark McCaughrean, a JWST SWG member and astrophysicist at the University of Exeter quoted by BBC
- "It's like a London bus - you've been waiting for one for ages and suddenly four come along at once."

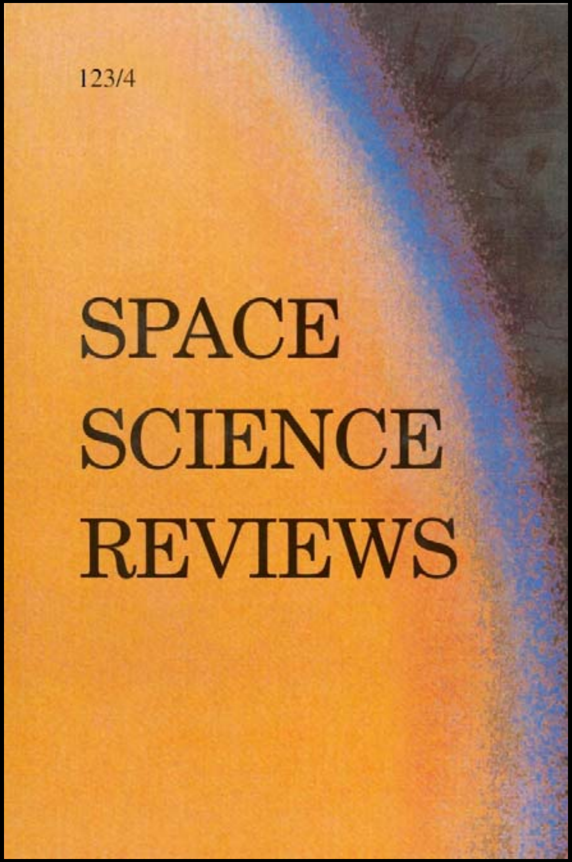
- and more to come!

Flight Mirror A1



Project Summary Document

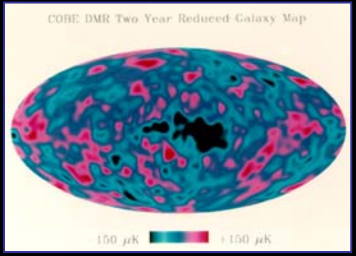
- Gardner et al. 2006, Space Science Reviews, 123/4, 485 http://jwst.gsfc.nasa.gov/scientists.html


123/4

SPACE SCIENCE REVIEWS

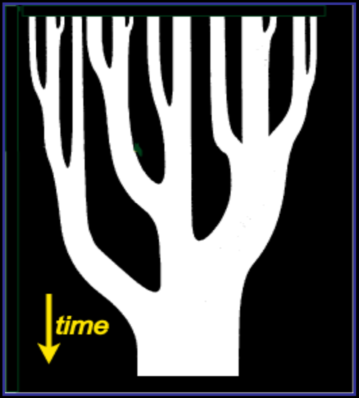
Early History of the Universe

Big
Bang
seen by
COBE &
WMAP



?

Galaxy
assembly



?

Galaxies,
stars,
planets,
life

- Horrendous Space Kablooey - exponential expansion, primordial fluctuations, matter/antimatter, dark matter, dark energy, 13.7 ± 0.2 billion years ago
- Annihilation of antiparticles, 1 part per billion matter remaining
- Formation of Helium nuclei, 3 minutes, redshift $z = 10^9$
  - [1+z = size of universe now / size then]
- Formation of neutral gas “recombination”, 389,000 yrs, z=1089
- Population III supermassive stars, super-supernovae, and black holes, z=17 (age ~ 200 Myr)
- Galaxy formation in small parts, star formation, merging and clustering of galaxy parts, until

Possible Early History of Earth

- Sun and first solid bodies in Solar System 4.567 billion years ago
- Mars-sized body hits Earth, melting everything, dispersing volatiles like C and H; debris forms Moon, 90 MY AF (after formation)
- Cool early Earth, possibly with water
- Jupiter, Saturn orbits switch twice, clear debris from solar system, cause “late heavy bombardment”, “Hadean” geologic period, many craters, new water and carbon delivery to Earth, 400 - 700 MY AF
- Life forms shortly after
- Sun gets steadily brighter with time, warming Earth

Continents Floating and Moving

- Huge volcanic effects on atmospheric composition (CO_2, H_2S, etc. fluctuate)
- Vaalbara, 3.3-3.6 billion years ago
- Rodinia, 1100 – 750 million years ago, split into proto-Laurasia, proto-Gondwana, and Congo Craton
- Pangaea, 250 MY ago
- Atlantic Ocean opens, ~ 100 MY ago

Ice Ages, Civilization, & Future Heat

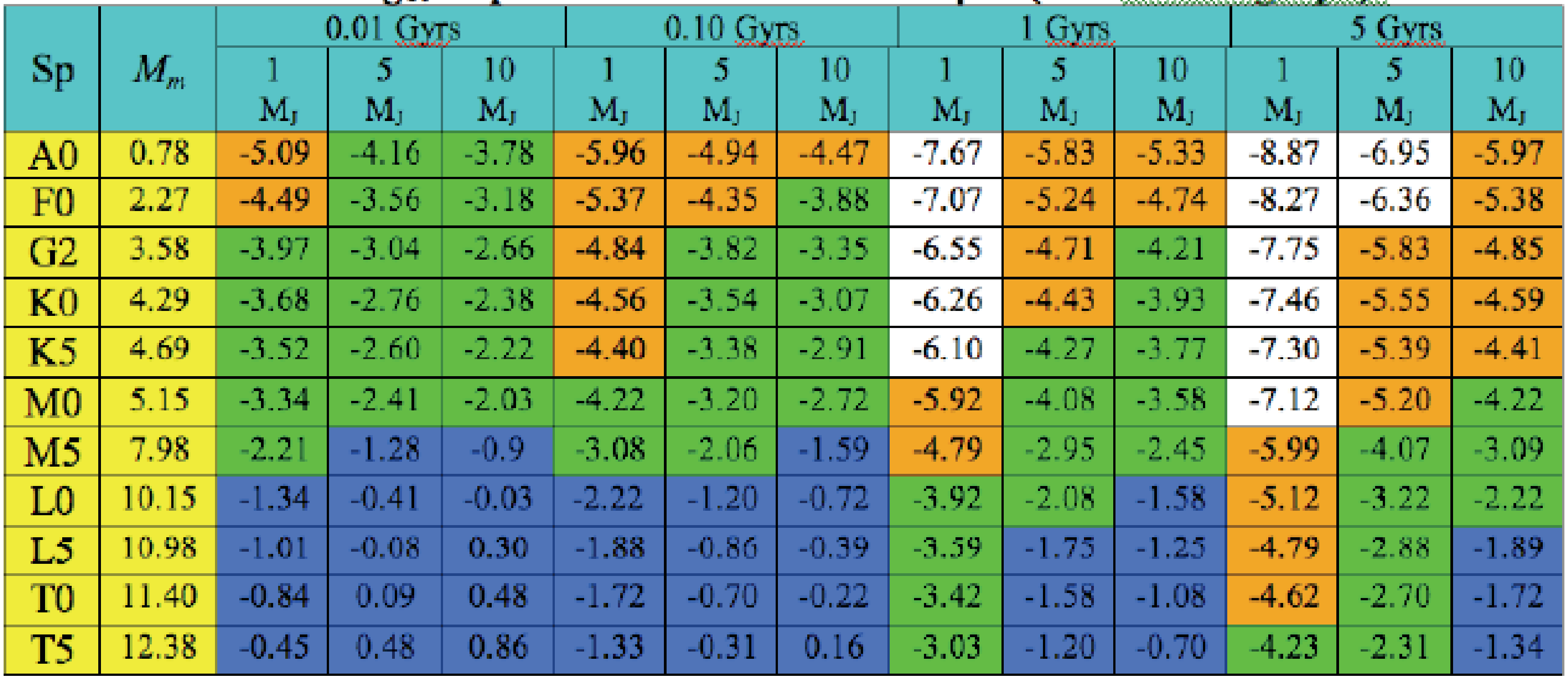
- Early Sun much weaker than present (25%) but CO_2 kept us warm?
- Huronian Ice Age, 2.7 – 2.3 BYA
- Cryogenian, 850 – 630 MYA, possible “snowball Earth”
- Volcanism releases CO_2, enables Cambrian explosion of life
- Andean-Saharan Ice Age, 460 – 430 MYA
- Current Antarctic ice sheet grows, 20 MYA
- Current Ice Age, 2.58 MYA, ending 10,000 YA
  - Riss, 180,000 – 130,000 YA (when Homo Sapiens developed?)
  - Wurm, 70,000 – 10,000 YA (begin modern civilization)
- Galileo’s telescope 1609 (International Year of Astronomy)

Sensitivity & Resolution

- Cameras and R ~ 100 spectroscopy background limited at all wavelengths
  - 6.5 m mirror much larger than HST, Spitzer - big gains
  - Background dominated by zodi light, and at > 12 µm from thermal emission from sunshield
  - Other stray light from galaxy, sometimes Earth or Moon
- NIRSpec sensitivity detector limited at R ~ 1000
- Image quality
  - Diffraction limited (λ/14 rms wavefront) at 2 µm (~ ground AO)
  - 0.034 arcsec pixels in NIRCam short band (Nyquist @ 2 µm)
  - 0.068 arcsec in NIRCam long band and Fine Guider
  - 0.2 x 0.45 arcsec shutters for NIRSpec
  - 0.11 arcsec pixels for MIRI camera
  - 0.19 - 0.28 arcsec pixels for MIRI image slicer integral field unit

Performance of the Non-redundant phase mask

Table 1 – Log_{10} of planet/star contrast at 4.6 μm (TFI Coronagraph)[1]



Sp	M_m	0.01 Gyrs			0.10 Gyrs			1 Gyrs			5 Gyrs		
		1 M_J	5 M_J	10 M_J	1 M_J	5 M_J	10 M_J	1 M_J	5 M_J	10 M_J	1 M_J	5 M_J	10 M_J
A0	0.78	-5.09	-4.16	-3.78	-5.96	-4.94	-4.47	-7.67	-5.83	-5.33	-8.87	-6.95	-5.97
F0	2.27	-4.49	-3.56	-3.18	-5.37	-4.35	-3.88	-7.07	-5.24	-4.74	-8.27	-6.36	-5.38
G2	3.58	-3.97	-3.04	-2.66	-4.84	-3.82	-3.35	-6.55	-4.71	-4.21	-7.75	-5.83	-4.85
K0	4.29	-3.68	-2.76	-2.38	-4.56	-3.54	-3.07	-6.26	-4.43	-3.93	-7.46	-5.55	-4.59
K5	4.69	-3.52	-2.60	-2.22	-4.40	-3.38	-2.91	-6.10	-4.27	-3.77	-7.30	-5.39	-4.41
M0	5.15	-3.34	-2.41	-2.03	-4.22	-3.20	-2.72	-5.92	-4.08	-3.58	-7.12	-5.20	-4.22
M5	7.98	-2.21	-1.28	-0.9	-3.08	-2.06	-1.59	-4.79	-2.95	-2.45	-5.99	-4.07	-3.09
L0	10.15	-1.34	-0.41	-0.03	-2.22	-1.20	-0.72	-3.92	-2.08	-1.58	-5.12	-3.22	-2.22
L5	10.98	-1.01	-0.08	0.30	-1.88	-0.86	-0.39	-3.59	-1.75	-1.25	-4.79	-2.88	-1.89
T0	11.40	-0.84	0.09	0.48	-1.72	-0.70	-0.22	-3.42	-1.58	-1.08	-4.62	-2.70	-1.72
T5	12.38	-0.45	0.48	0.86	-1.33	-0.31	0.16	-3.03	-1.20	-0.70	-4.23	-2.31	-1.34

🟩	Contrast exceeds the 10σ sensitivity beyond 1”. [2]
🟧	Contrast exceeds the 10σ sensitivity beyond 5”. [2]
🟦	Contrast exceeds the 10σ sensitivity beyond 1” *without* coronagraph and no PSF calibration.

[1] Evolutionary models from Barraffe *et al* 2003.

[2] Contrast threshold assuming the 2" (FWHM) occulting spot and a speckle noise attenuation factor ~10x

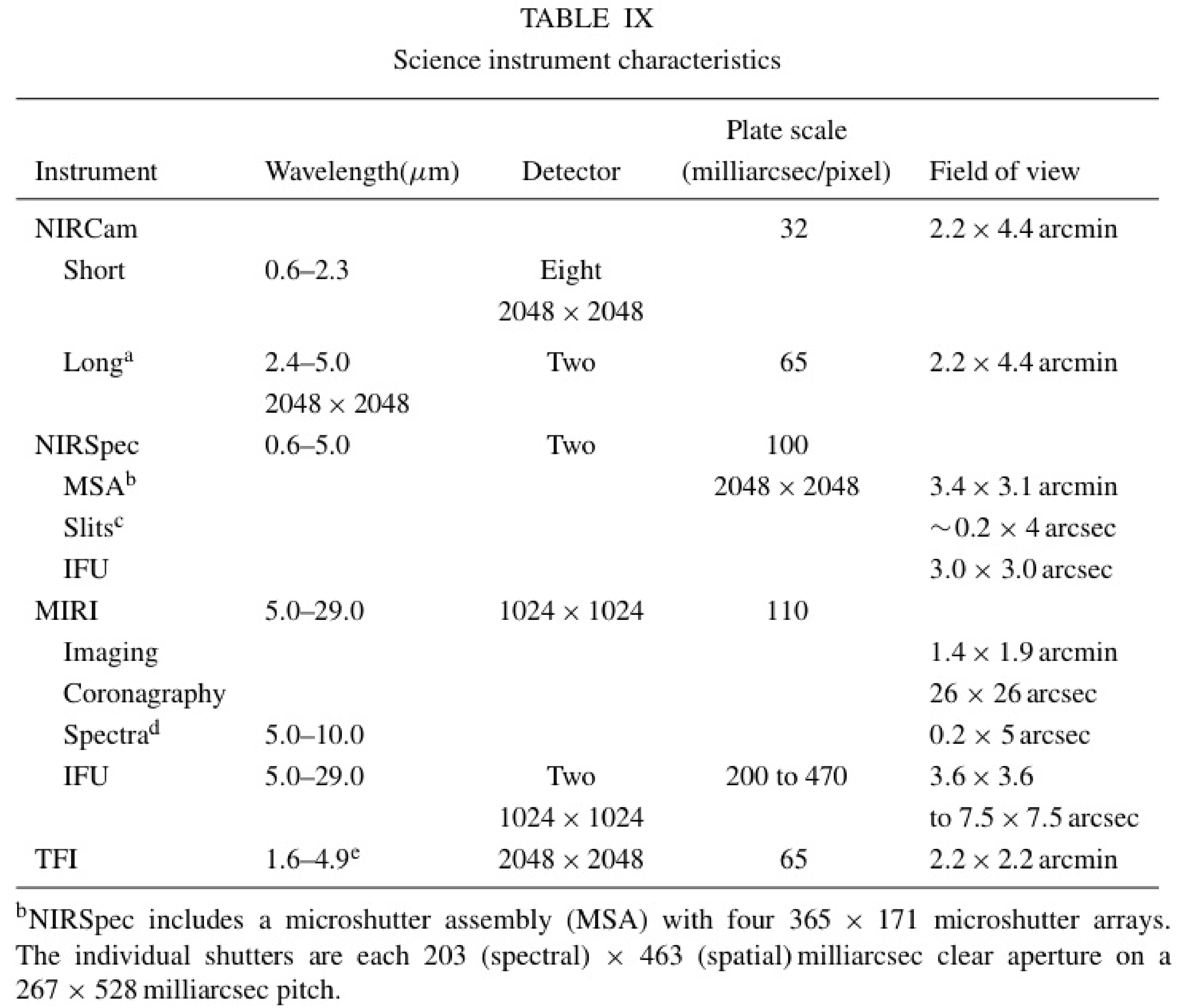


TABLE IX

Science instrument characteristics

Instrument	Wavelength(μm)	Detector	Plate scale (milliarcsec/pixel)	Field of view
NIRCam			32	2.2 × 4.4 arcmin
Short	0.6–2.3	Eight 2048 × 2048		
Long[a]	2.4–5.0 2048 × 2048	Two	65	2.2 × 4.4 arcmin
NIRSpec	0.6–5.0	Two	100	
MSA[b]			2048 × 2048	3.4 × 3.1 arcmin
Slits[c]				~0.2 × 4 arcsec
IFU				3.0 × 3.0 arcsec
MIRI	5.0–29.0	1024 × 1024	110	
Imaging				1.4 × 1.9 arcmin
Coronagraphy				26 × 26 arcsec
Spectra[d]	5.0–10.0			0.2 × 5 arcsec
IFU	5.0–29.0	Two 1024 × 1024	200 to 470	3.6 × 3.6 to 7.5 × 7.5 arcsec
TFI	1.6–4.9[e]	2048 × 2048	65	2.2 × 2.2 arcmin

[b] NIRSpec includes a microshutter assembly (MSA) with four 365 × 171 microshutter arrays. The individual shutters are each 203 (spectral) × 463 (spatial) milliarcsec clear aperture on a 267 × 528 milliarcsec pitch.

JWST Sensitivities

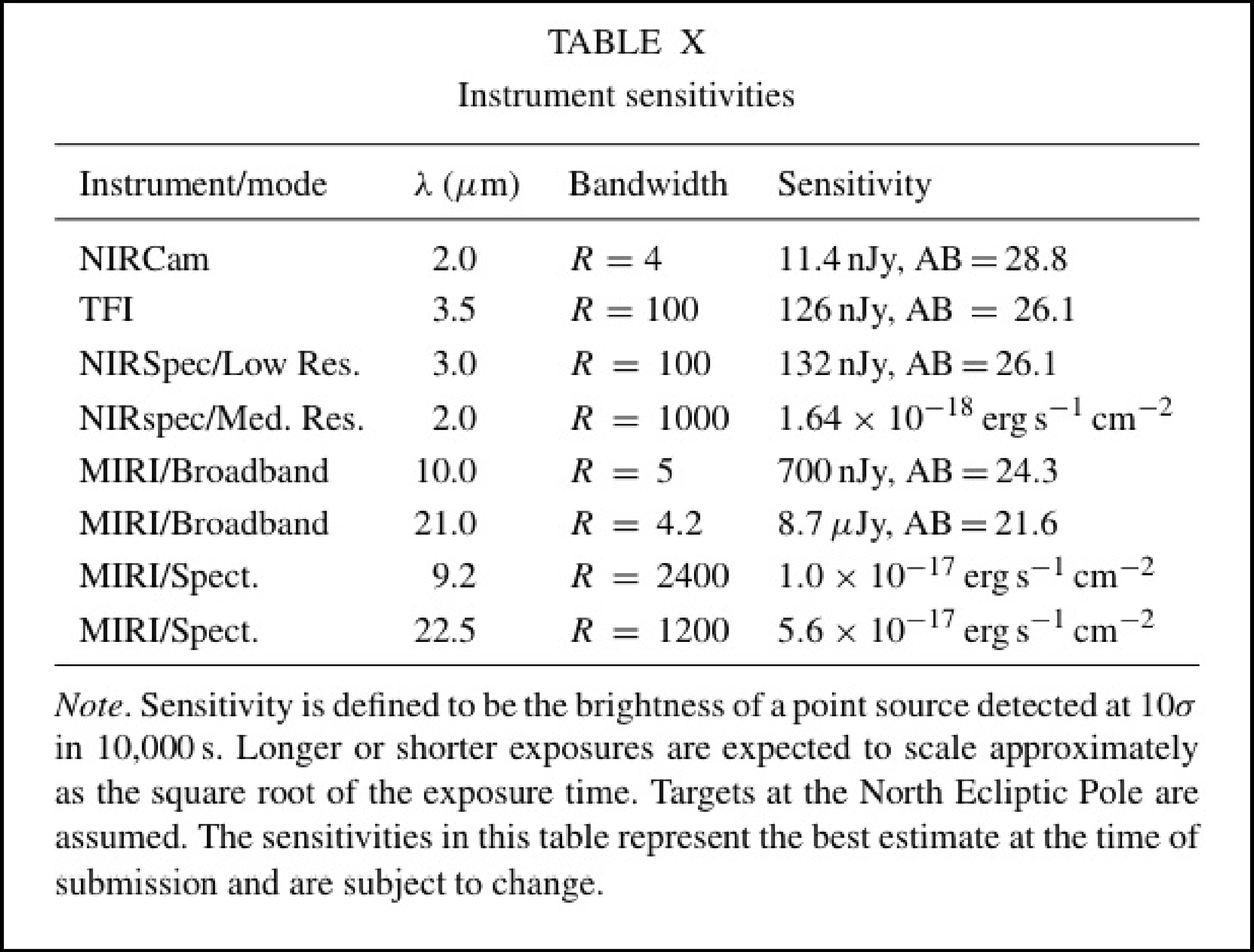


TABLE X

Instrument sensitivities

Instrument/mode	λ (μm)	Bandwidth	Sensitivity
NIRCam	2.0	$R = 4$	11.4 nJy, AB = 28.8
TFI	3.5	$R = 100$	126 nJy, AB = 26.1
NIRSpec/Low Res.	3.0	$R = 100$	132 nJy, AB = 26.1
NIRspec/Med. Res.	2.0	$R = 1000$	1.64×10^{-18} erg s^{-1} cm^{-2}
MIRI/Broadband	10.0	$R = 5$	700 nJy, AB = 24.3
MIRI/Broadband	21.0	$R = 4.2$	8.7 μJy, AB = 21.6
MIRI/Spect.	9.2	$R = 2400$	1.0×10^{-17} erg s^{-1} cm^{-2}
MIRI/Spect.	22.5	$R = 1200$	5.6×10^{-17} erg s^{-1} cm^{-2}

Note. Sensitivity is defined to be the brightness of a point source detected at 10σ in 10,000 s. Longer or shorter exposures are expected to scale approximately as the square root of the exposure time. Targets at the North Ecliptic Pole are assumed. The sensitivities in this table represent the best estimate at the time of submission and are subject to change.

Observing the "First" Light

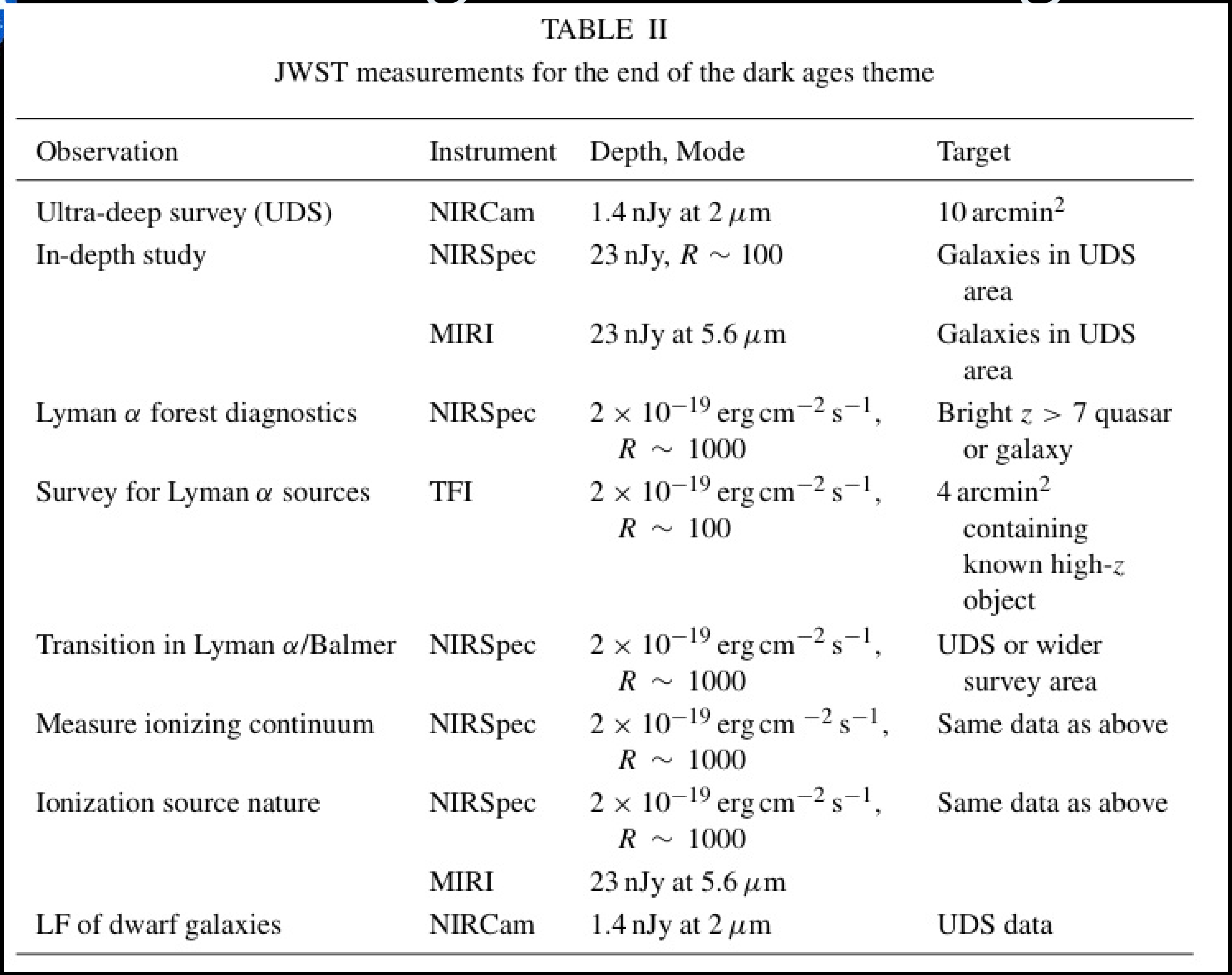


TABLE II

JWST measurements for the end of the dark ages theme

Observation	Instrument	Depth, Mode	Target
Ultra-deep survey (UDS)	NIRCam	1.4 nJy at 2 μm	10 arcmin^2
In-depth study	NIRSpec	23 nJy, $R \sim 100$	Galaxies in UDS area
	MIRI	23 nJy at 5.6 μm	Galaxies in UDS area
Lyman α forest diagnostics	NIRSpec	$2 \times 10^{-19}\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$, $R \sim 1000$	Bright $z > 7$ quasar or galaxy
Survey for Lyman α sources	TFI	$2 \times 10^{-19}\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$, $R \sim 100$	4 arcmin^2 containing known high-z object
Transition in Lyman α/Balmer	NIRSpec	$2 \times 10^{-19}\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$, $R \sim 1000$	UDS or wider survey area
Measure ionizing continuum	NIRSpec	$2 \times 10^{-19}\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$, $R \sim 1000$	Same data as above
Ionization source nature	NIRSpec	$2 \times 10^{-19}\,\text{erg}\,\text{cm}^{-2}\,\text{s}^{-1}$, $R \sim 1000$	Same data as above
	MIRI	23 nJy at 5.6 μm	
LF of dwarf galaxies	NIRCam	1.4 nJy at 2 μm	UDS data

Assembly of Galaxies

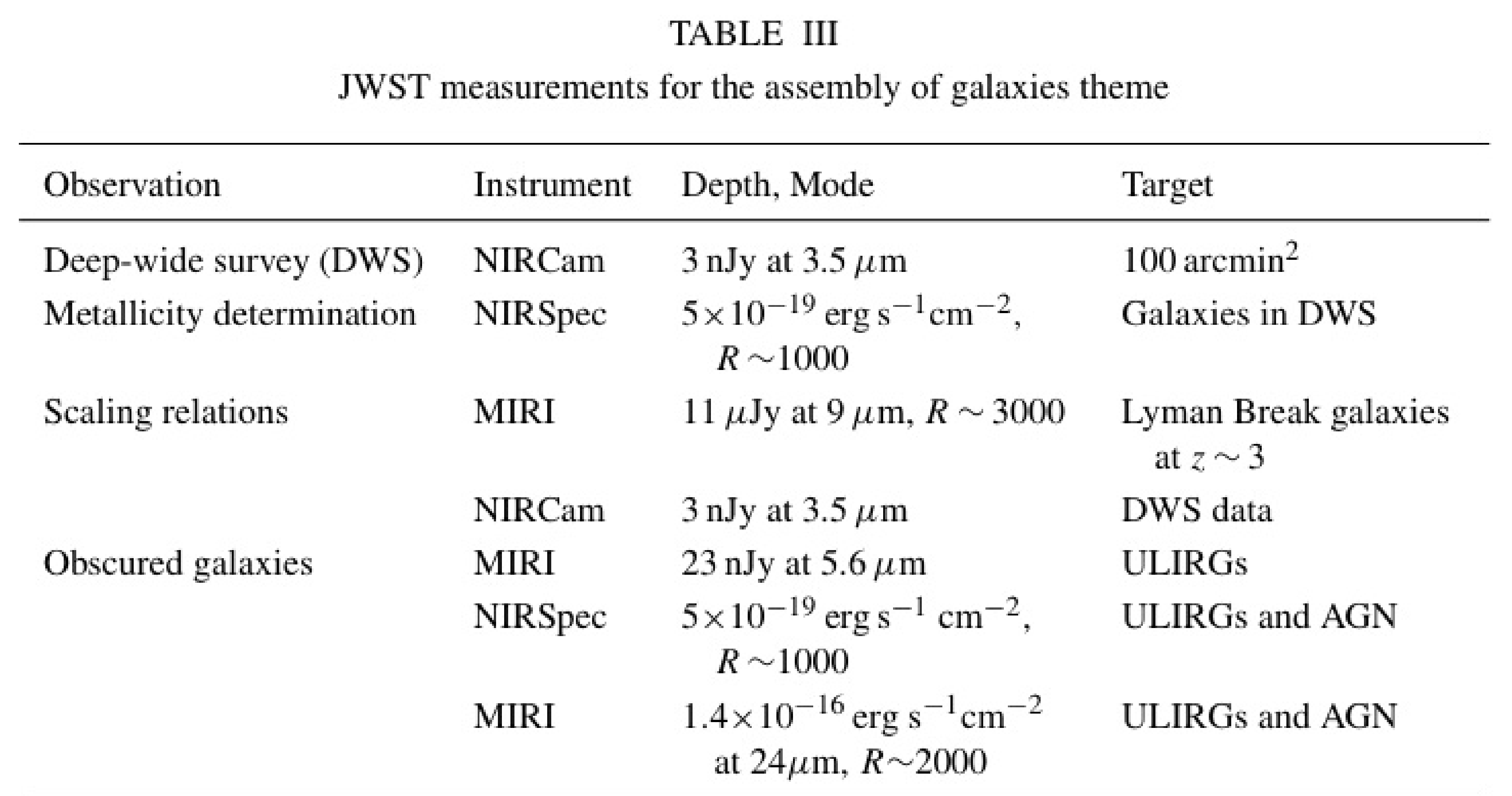


TABLE III

JWST measurements for the assembly of galaxies theme

Observation	Instrument	Depth, Mode	Target
Deep-wide survey (DWS)	NIRCam	3 nJy at 3.5 μm	100 arcmin^2
Metallicity determination	NIRSpec	5×10^{-19} erg s^{-1}cm^{-2}, $R\sim1000$	Galaxies in DWS
Scaling relations	MIRI	11 μJy at 9 μm, $R\sim3000$	Lyman Break galaxies at $z\sim3$
	NIRCam	3 nJy at 3.5 μm	DWS data
Obscured galaxies	MIRI	23 nJy at 5.6 μm	ULIRGs
	NIRSpec	5×10^{-19} erg s^{-1} cm^{-2}, $R\sim1000$	ULIRGs and AGN
	MIRI	1.4×10^{-16} erg s^{-1}cm^{-2} at 24μm, $R\sim2000$	ULIRGs and AGN