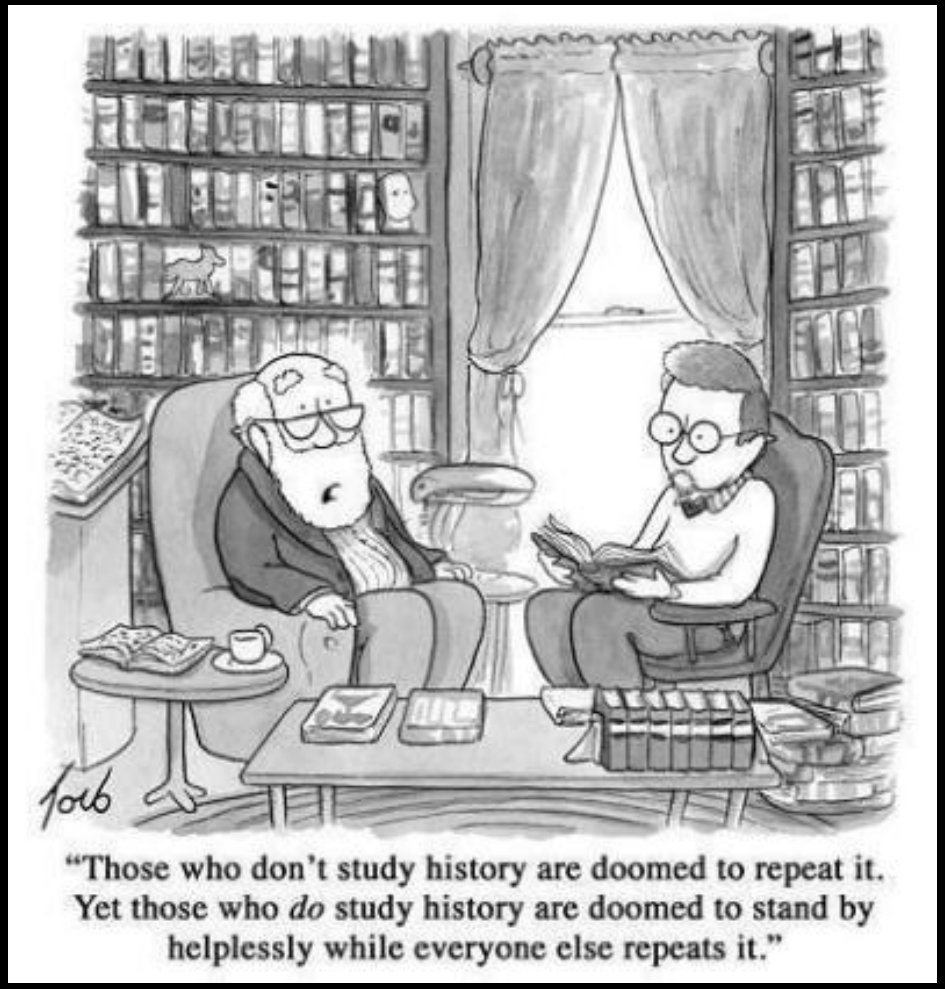
Those Who Do Not Study History…



C. Beichman, NASA Exoplanet Science Institute

January 3, 2015

1990 Decadal Review (Bahcall Report)

- Space Infrared Telescope Facility (SIRTF)→Spitzer
- Gemini-North/South
- SOFIA
- SIM---"The Astrometric Interferometric Mission (AIM) would permit definitive searches for planets around stars as far away as 500 light-years through the wobbles of the parent star"

1990 Decadal Review	
Large Initiatives	**Cost ($M)**
Space Infrared Telescope Facility (SIRTF)	1,300 (760)
Infrared-optimized 8-m telescope	80
Millimeter Array (MMA)	115
Southern 8-m telescope	55
Moderate Programs	
Adaptive optics	35
Spacecraft for FUSE	70
SOFIA	230
Delta-class Explorer acceleration	400
Optical and infrared interferometers	45
Several shared 4-m telescopes	30
Astrometric Interferometry Mission (AIM)	250
Cosmic ray telescope (Fly's Eve)	15
Large Earth-based Solar Telescope (LEST)	15
VLA extension	32
International collaborations on space instruments	100

2000 Decadal Review McKee Taylor Report

- James Webb Space Telescope (JWST)
- Terrestrial Planet Finder (TPF) technology
- Endorse SIRTF and SIM as part of on-going program
- Prominent mention of exoplanets

•The discovery of extrasolar planets in the past decade was one of the most remarkable achievements of the 20th century and represented the culmination of centuries of speculation about planets orbiting stars other than our Sun.

•We are witnessing the birth of a new observational science of planetary systems… The first step is to carry out a census of extrasolar planetary systems in order to answer the following questions: What fraction of stars have planetary systems? How many planets are there in a typical system, and what are their masses and distances from the central star? How do these characteristics depend on the mass of the star, its age, and whether it has a binary companion?

• The discovery of life on another planet is potentially one of the most important scientific advances of this century, let alone this decade, and it would have enormous philosophical implications.

2000 Decadal (Mckee-Taylor)

Large Initiatives			
Ground	Cost ($M)	Space	Cost ($M)
Giant Segmented Mirror Telescope (GSMT)	350	**Next Generation Space Telescope (NGST)**	**1,000**
Expanded Very Large Array (EVLA)	140	~~Constellation-X~~	~~800~~
Large Synoptic Survey Telescope (LSST)	170	Terrestrial Planet Finder (TPF) Tech	200
		Single Aperture Far IR Observatory	100
Moderate Initiatives			
Telescope System Instr. Program (TSIP)	50	Gamma-ray Large Area Space Telescope (GLAST) →FERMI	300
Advanced Solar Telescope (AST)	60	Laser Interferometer Space Antenna (LISA)	250
Square Kilometer Array (SKA)	22	Solar Dynamics Observatory (SDO)	300
Combined Array for Research in Millimeter-wave Astronomy (CARMA)	11	Energetic X-ray Imaging Survey	150

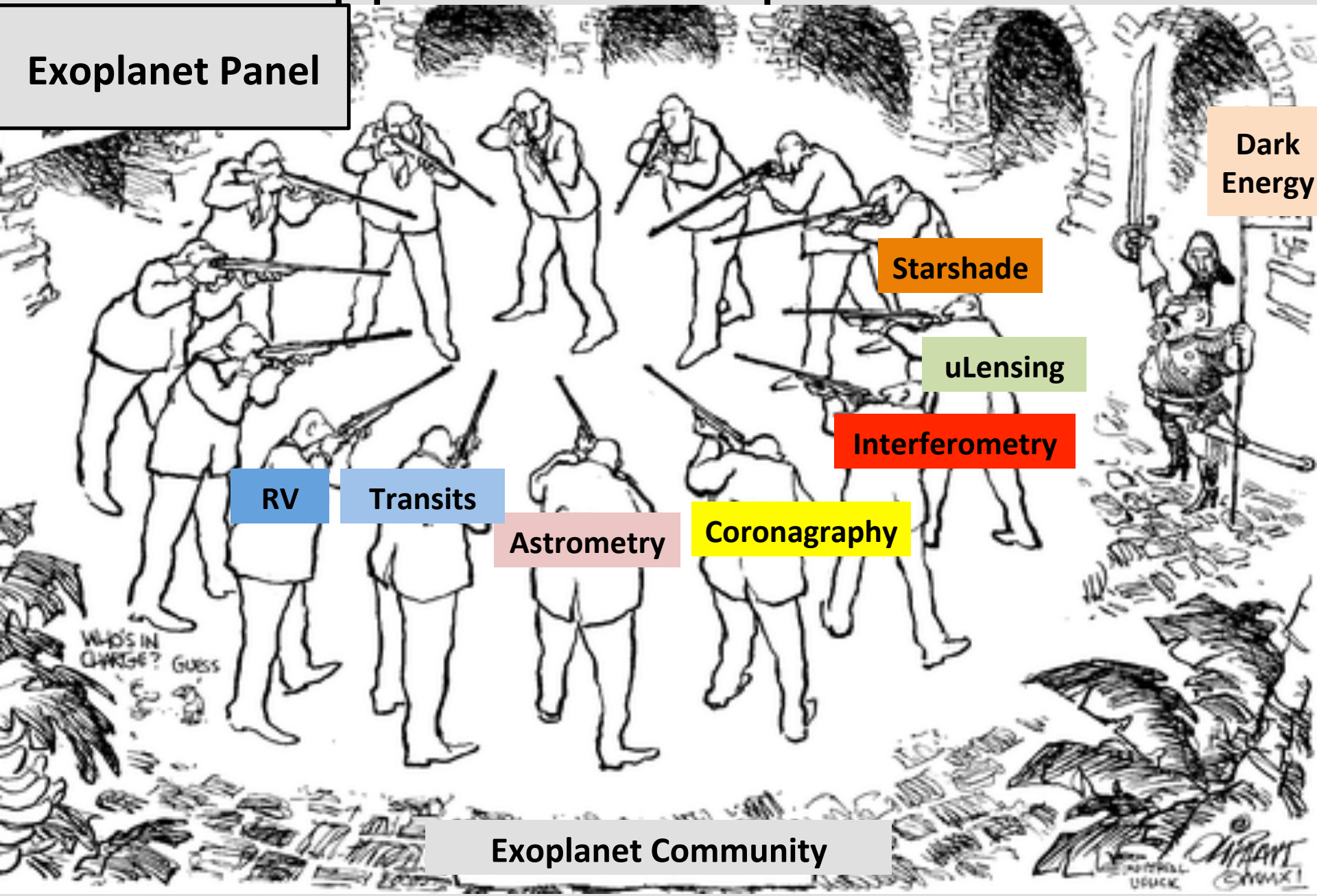
2010 Decadal Review

- Planets everywhere in the report but less prominent in recommendations!
- WFIRST for Dark Energy, microlensing census, surveys
- Technology for future New Worlds Telescope → WFIRST coronagraph!
- LSST for Time Domain Astronomy
- PRV initiative
- Space Interferometry Mission
  - *Overtaken by events: increased RV precision and GAIA*
  - Death by footnote--- *"SIM is not included in the recommended program for the decade"*

2010 Decadal Review

2010 Recommended Program			
Large Initiatives			
Ground	Cost ($M)	Space	Cost ($M)
LSST	465	WFIRST	1,600
MidScale Program	93-200M	Explorer Augmentation	463
GSMT	1,100/3,000	LISA	2,400/1,500
		IXO	5,000/3,100
Medium Initiatives			
CCAT		New Worlds Tech	100-200
Precision RV		CMB Tech	60-200

What Happened to Exoplanets in 2010?



What Happened to Exoplanets in 2010?

- Community was evolving extremely rapidly with progress in many areas (and all wanting piece of pie):
  - Transits and RV completing census
  - Technology for astrometry well advanced, but shrinking niche
  - Direct Imaging advances in science and technology
  - Direct detection from space split between coronagraphs, starshades, remnant interferometry. Technology and missions expected to be (very) expensive
- Community split between NASA goal of detection and spectroscopy of nearby Habitable Earths and more modest science goals of comparative exo-planetology
- Impossible to arrive at consensus

What Should 2020 Review Assume?

- Exoplanet Census (Mostly) Complete
  - Transit surveys maxed out (Kepler→K2→TESS→PLATO)
  - GAIA will (finally) demonstrate power of astrometry for Jupiters
  - PRV understanding of astrophysical limits: (0.1,0.5,1 m/s)
    - Do we reach nearest HZ Earths? Do we need astrometry?
  - Ground based →WFIRST microlensing census of snow-line
  - Imaging surveys of gas giants in outer solar system
  - Complete Exozodi survey of 50+ imaging targets
- Characterization of gas giants to Super Earths
  - JWST spectra of 100+ planets, few super Earths, no Earths
  - Direct imaging from ground with predictions for ELTs
  - Direct imaging with JWST identify/characterize young gas giants
- Technology development for internal coronagraphs will open path for detection of mature gas giants with WFIRST (Mid-Decadal endorsement critical)

What Programmatics Should 2020 Review Assume?

- JWST will have launched but sticker shock will remain
  - We have used the "Hubble Replacement" card
- Technology for UVOIR telescope beyond 4 m immature
  - Large UVOIR mission (8-16 m) more expensive than JWST (BIG +Cryo → VERY BIG+Pico) and will require launch vehicle beyond present capacity.
  - UV capability + extremely high contrast may be incompatible
  - Starshades offer significant advantages in IWA and throughput. Are they viable? Can they be demonstrated with WFIRST in L2? baselined with a 4m UVO telescope?

What Are The Key Science Questions for 2030?

- Are spectra of HZ Earths for biomarkers an astronomical priority? A NASA priority? A national priority? Very Expensive
  - Does the technology exist for 2030? 2040? Internal coronagraph vs. Starshade. Need demonstration of both by late 2020s
  - What will ELTs do for imaging/spectra of HZ Earths orbiting M stars?
  - Maximize PRV for census & masses for planets orbiting *closest* FGKM stars for potential HZ targets for imaging mission. Assess need for 2nd generation space astrometry
- Assess value of ~few 1000 spectra follow-on for TESS/PLATO planets, esp. long period planets of known age?
- What should the exoplanet community do? Develop a consensus program with a modest flagship plus modest "Probe" class options.