The Crisis in Astrophysics:

Commercial Space
&
Prudent Program Design Principles
will let us Escape

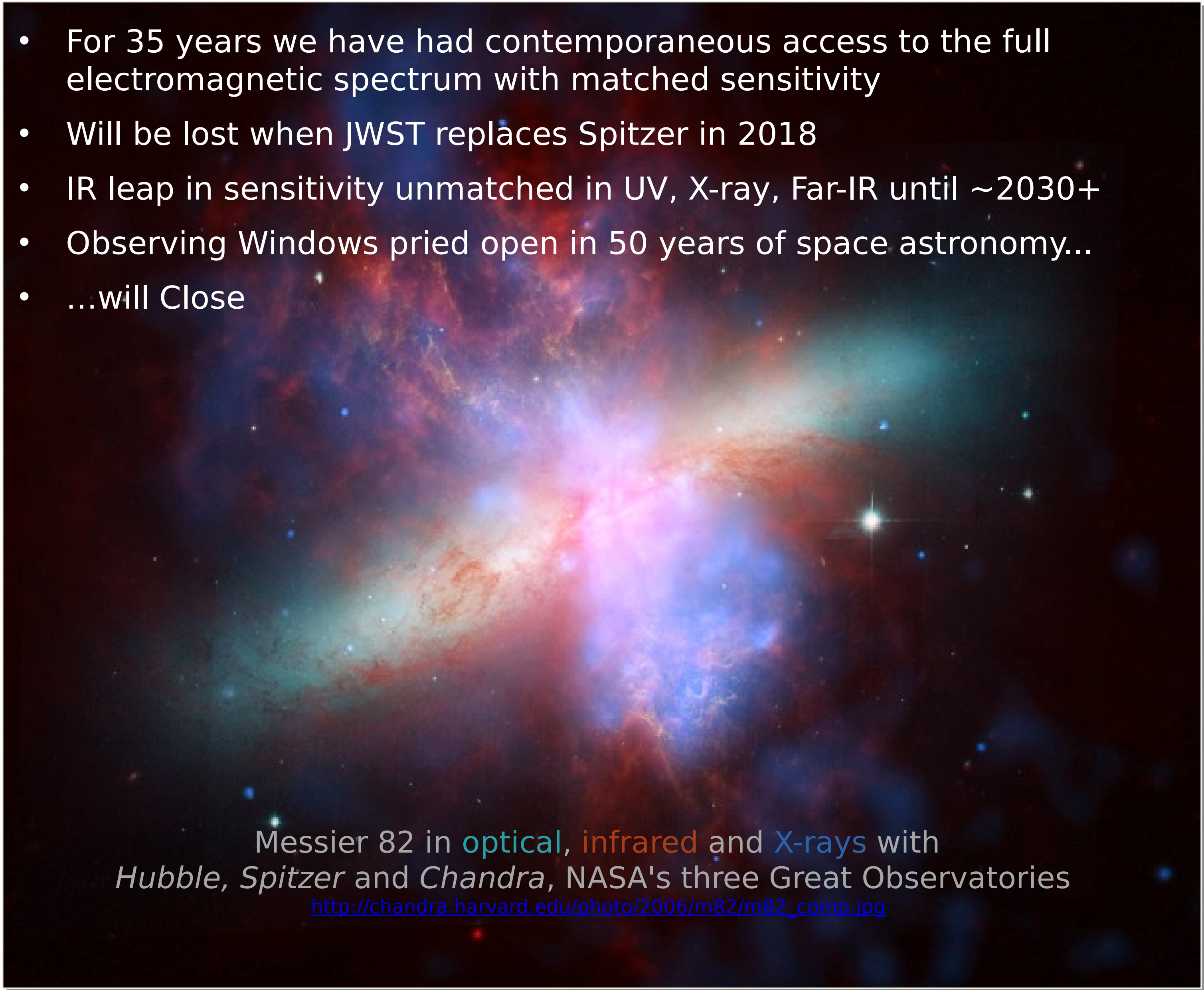
Martin Elvis
Harvard-Smithsonian Center for Astrophysics

Space Policy, in press. arXiv:1608.01004
Frontiers of Research in Astrophysics, PoS 2016, in press. arXiv: *soon*
HDST critique: arXiv:1509.07798
Vigorous Explorer program (arXiv:0911.3383)

What Crisis?

Pan-Spectral Coverage is Integral to 21st Century Astrophysics

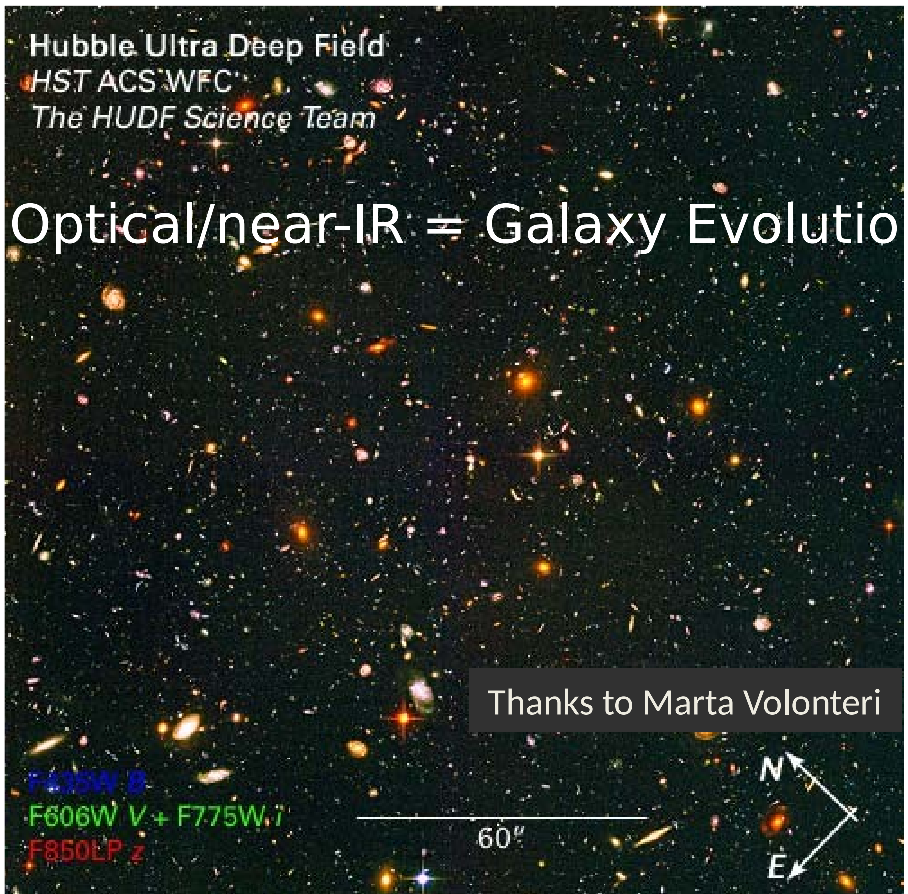
- For 35 years we have had contemporaneous access to the full electromagnetic spectrum with matched sensitivity
- Will be lost when JWST replaces Spitzer in 2018
- IR leap in sensitivity unmatched in UV, X-ray, Far-IR until ~2030+
- Observing Windows pried open in 50 years of space astronomy...
- ...will Close

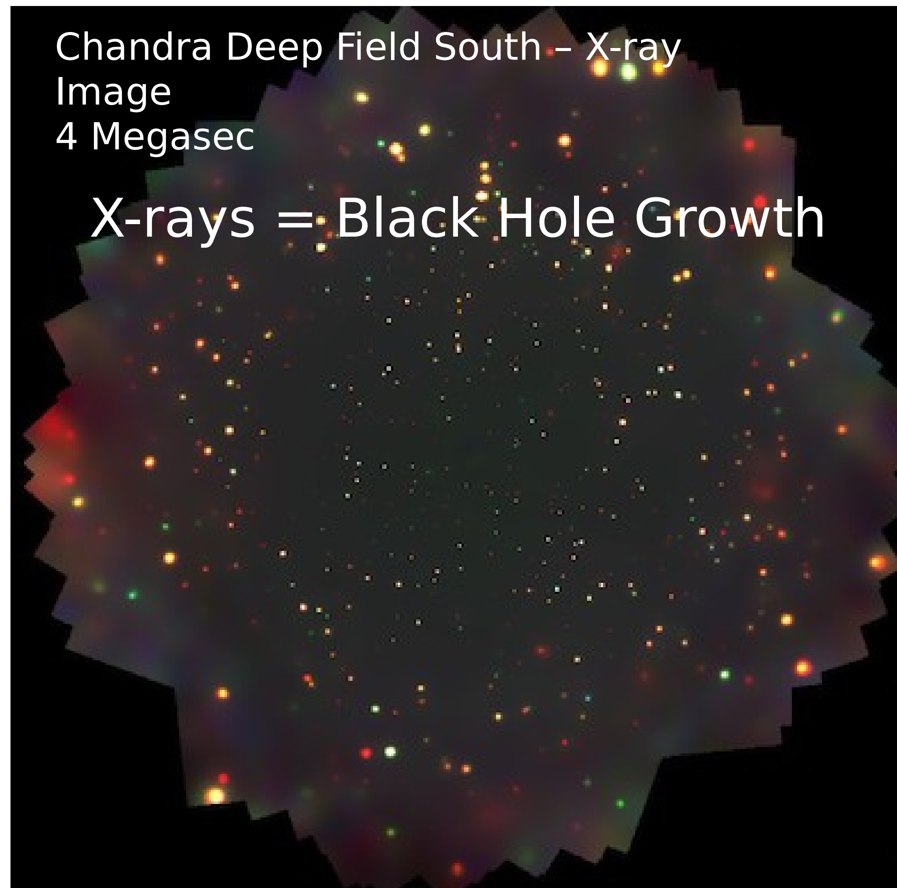


Messier 82 in optical, infrared and X-rays with
Hubble, Spitzer and *Chandra*, NASA's three Great Observatories
http://chandra.harvard.edu/photo/2006/m82/m82_comp.jpg

Even JWST Science will be in limbo without X-rays

- What are those z=10-20 blobs in JWST Deep Fields?
- The first stars in the first galaxies?
- Or adolescent black holes having a growth spurt?
- Without matched X-ray Deep Surveys how will you tell?



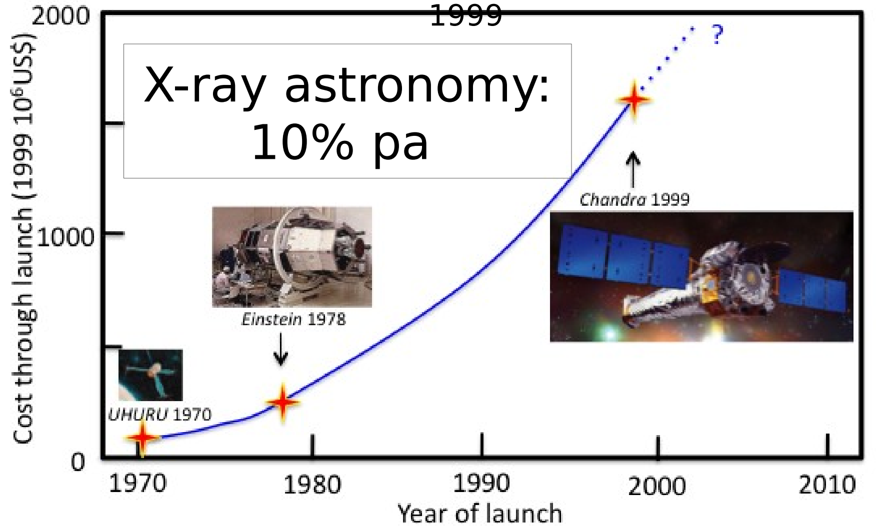


Martin Elvis, melvis@cfa.harvard.edu

Cost growth has cut the number of large missions to 1

- Economy grows at 2% - 3% a year
- Space mission costs grow far faster
- Unsustainable: the "funding wall"

Cost growth of leading X-ray astronomy missions 1970 - 1999



At ~$9B, JWST cannot be our model

Details:
Cost in constant 1999 US dollars:
$20M for *Uhuru* (1970$);
$100M for *Einstein* (1978$);
$1.6B for *Chandra* (1999$),. H Tananbaum, private communication.
(Inflation corrections from US Bureau of Labor Statistics;
URL: http://www.bls.gov/data/inflation_calculator.htm)

We have to get the cost down, …or the party's over

lwf.org

 Martin Elvis, melvis@cfa.harvard.edu

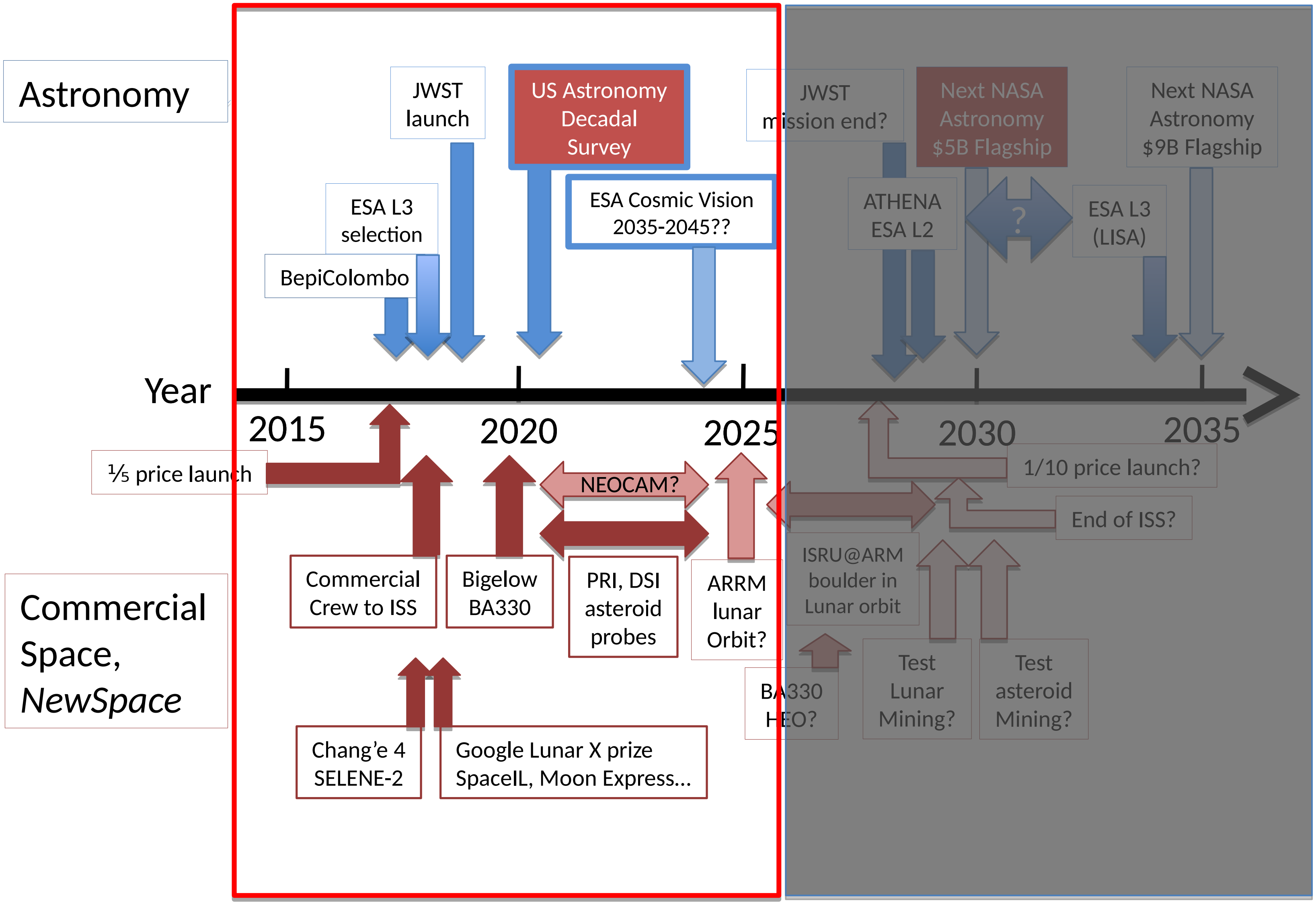
Two Responses

1. Harness Commercial Space

2. Adopt Prudent Principles for Program Design

1. Harness Commercial Space

Commercial Space will be very different for the 2020 decadal

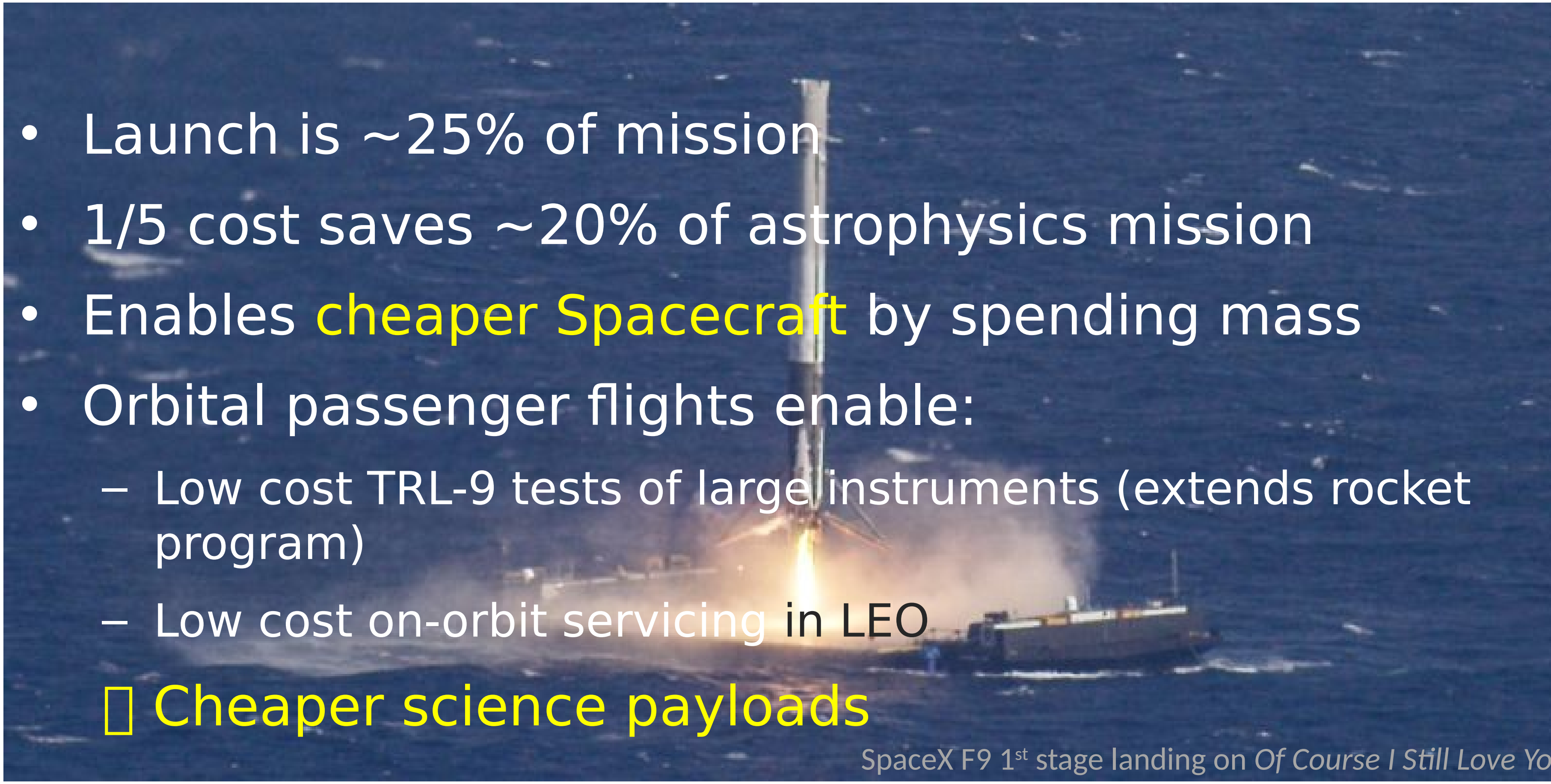


Commercial Space Will Cut Mission Costs by 2025

- $10 k/kg to LEO for decades
- SpaceX F-9: $3 k/kg *Now*
- ~2k/kg with 1st stage reuse
- **1/5 of traditional launch cost**

SpaceX Falcon 9 1st soft landing, 21 Dec 2015
(source: Space.com; wikimedia commons)

Cheaper Launch Now



- Launch is ~25% of mission
- 1/5 cost saves ~20% of astrophysics mission
- Enables cheaper Spacecraft by spending mass
- Orbital passenger flights enable:
  - Low cost TRL-9 tests of large instruments (extends rocket program)
  - Low cost on-orbit servicing in LEO

Cheaper science payloads

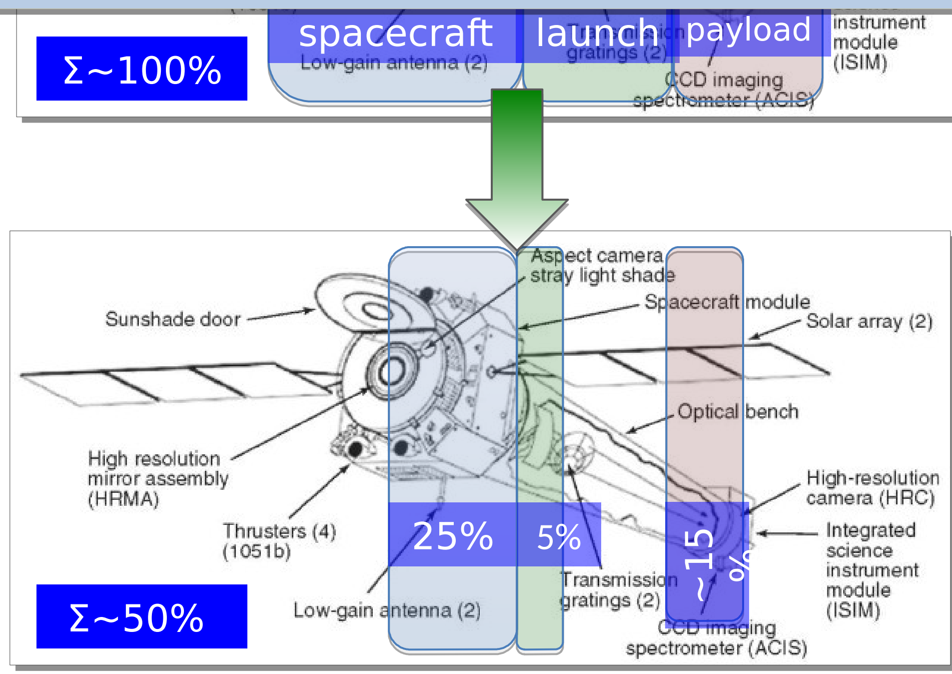
SpaceX F9 1st stage landing on *Of Course I Still Love You*

Martin Elvis, melvis@cfa.harvard.edu

Cut Flagship Mission Costs in Half by 2025?

- These are near-term changes
- 2020 Decadal Survey is for >2025 missions
- Cannot ignore commercial space

2025



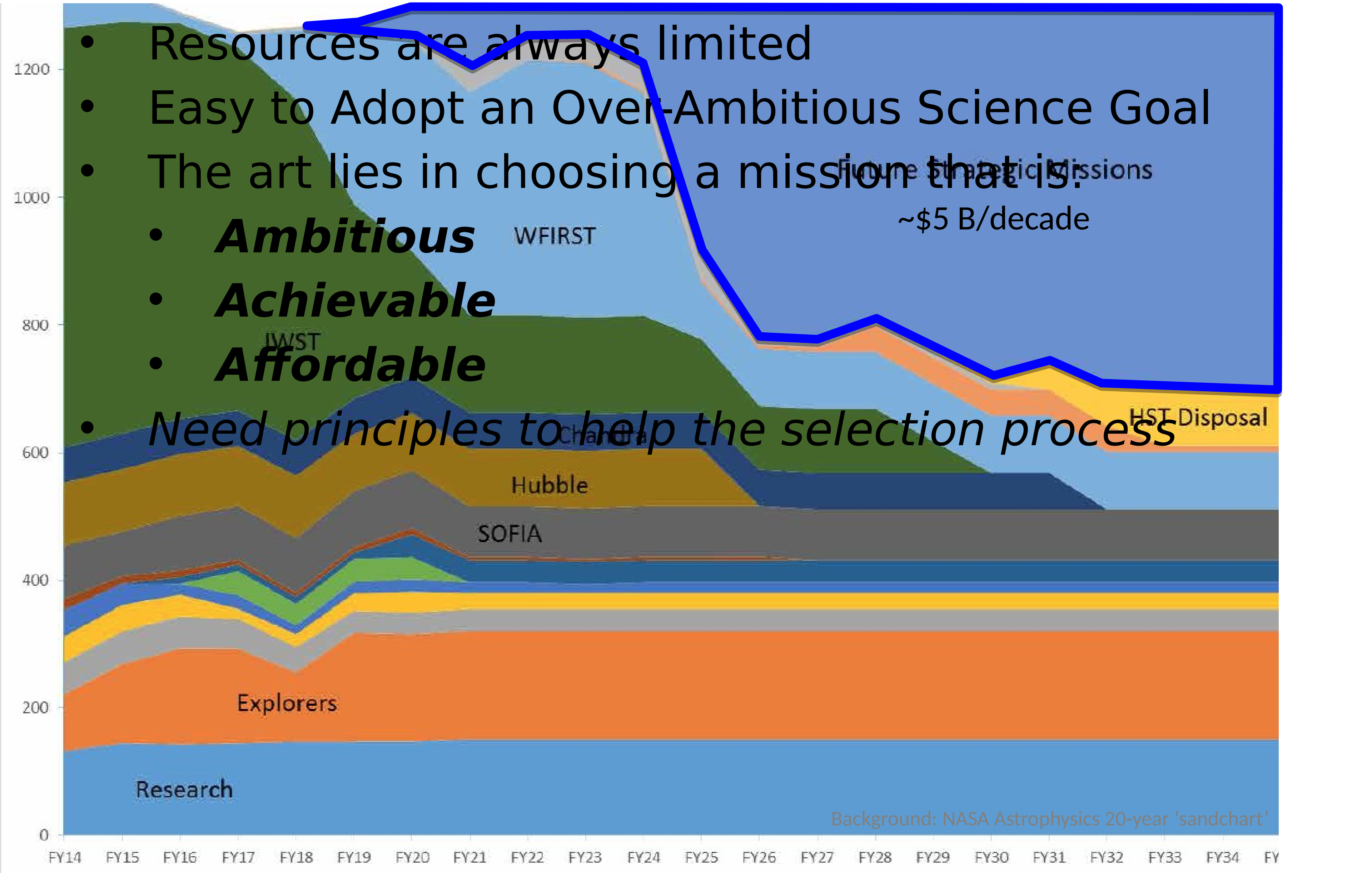
 Martin Elvis, melvis@cfa.harvard.edu

2. Adopt Prudent Principles for Program Design

Martin Elvis, melvis@cfa.harvard.edu

The Art in Choosing a Mission

- Resources are always limited
- Easy to Adopt an Over-Ambitious Science Goal
- The art lies in choosing a mission that is:
  - ***Ambitious***
  - ***Achievable***
  - ***Affordable***
- *Need principles to help the selection process*



Martin Elvis, melvis@cfa.harvard.edu

Prudent Principles for Program Design

- Missions require design principles to avoid failure
- Can adopt similar principles for entire *program*
- Without guiding principles temptation of drifting to “One Giant Mission” is strong
- Here are three guiding principles...

temptation

Martin Elvis, melvis@cfa.harvard.edu

#1: No Single Point Failure

- No large mission can have any component, sub-system, or system that is a *single point failure*:
  - i.e. mission ending
- Likewise,
- A science *program* should not have a single point failure
  - One Big Mission creates *program* vulnerability
  - *Program* lacks robustness

#2: Science Requirements

- Missions begin with science requirements
- These are then flowed down into mission requirements
- Are there **Science *Program* requirements**? *E.g*.
  1. Matched contemporaneous pan-spectrum coverage
     - Fleet of flagship missions
  2. Continuous Innovation
     - E.g. exo-planets: a major *Hubble, Spitzer* research area
       - Not pioneered on *Hubble, Spitzer*
       - Independent scientists took risks to pioneer field
     - Vigorous Explorer program (arXiv:0911.3383)

Martin Elvis, melvis@cfa.harvard.edu

#3: No Single Viewpoint Failure

- Dependence on a single Flagship telescope saps intellectual vitality of a program.
    - Lack of independent data to challenge results
    - Time and Money flow from one source
    - Fashions are unintentionally self-reinforcing
        - TACs have many previous winners
- *Program* needs multiple viewpoints:
    - Wavelength
    - Technique
    - Scale

Martin Elvis, melvis@cfa.harvard.edu

Implementation Issues

- Astro-sociological:
  - Giant missions get a large following
  - Speak louder than several less grandiose missions
  - Answer:
    - Hang together
    - Promote the "**Greater Observatories**"

- Agency, Government buy-in:
  - Agency:
    - Advocate for prudent *Program* principles
    - Cost Models are rightly hard to change
    - First try commercial pricing on probe-class mission
  - Government:
    - "*The* Best Mission" easier than a wish list
    - Promote "*The* Best *Program*" instead

Martin Elvis, melvis@cfa.harvard.edu

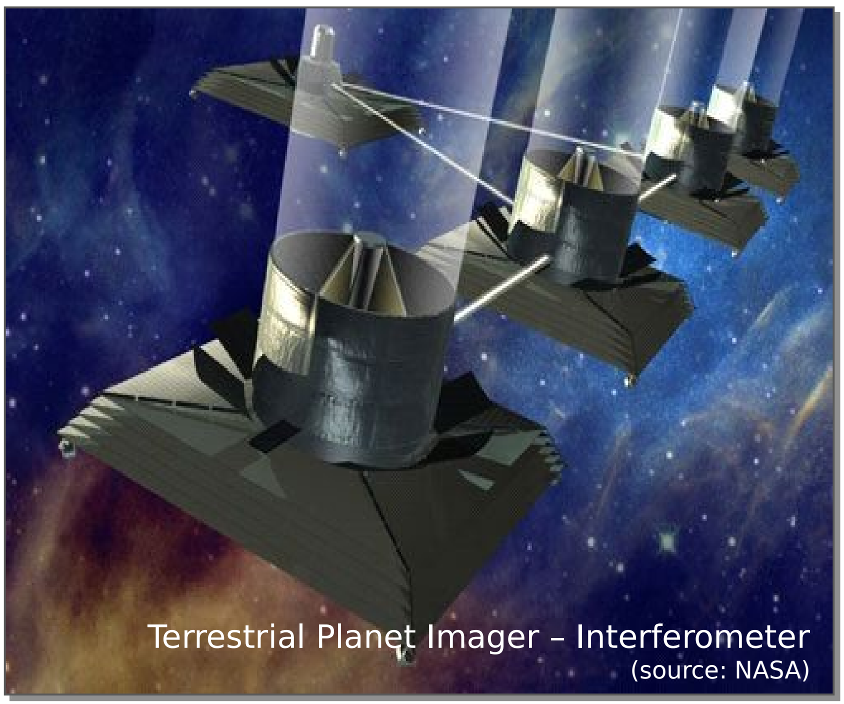
Summary: Escaping the Astronomy Funding Wall Crisis

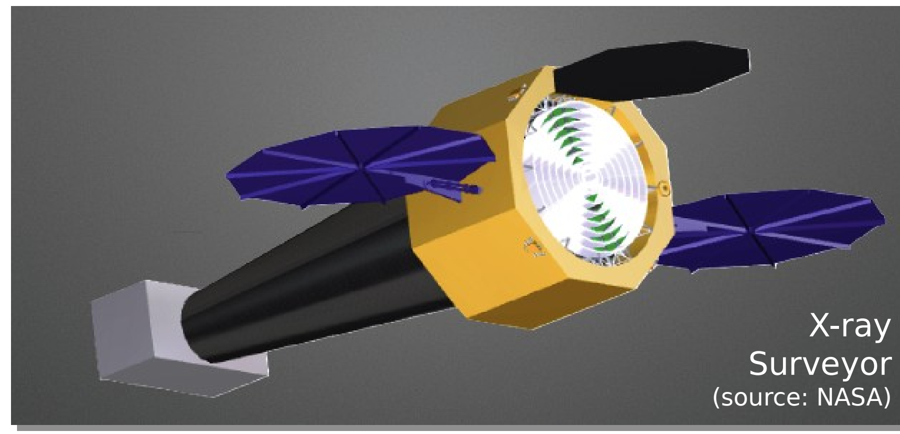
- **Mission costs rising far faster than economy grows**
  - ~10% p.a. vs. ~2% p.a. funding wall
- **Use Commercial Space to bring costs down**
  - Factors 2-3 plausible in next 5 – 10 years
  - i.e***. within decadal planning horizon***
  - Unwise to ignore
- **Use Prudent Design Principles for the Program**
  - As for a mission
    - No single point failure
    - Science Requirements, flowdown
    - No single Viewpoint failure
    - Constant Innovation
  - Restrain "One Big Mission" drift
  - Advocate The Best *Program*:
    - **The Greater Observatories**

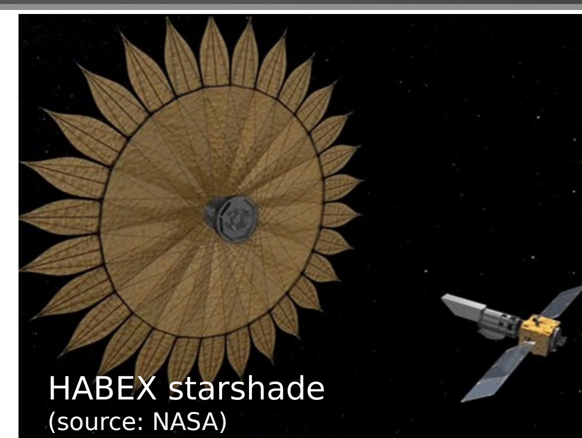
We have much to gain

Thank you

See more details in:
Frontiers of Research in Astrophysics, PoS 2016, in press. arXiv: *soon*
Space Policy, in press. arXiv:1608.01004
HDST critique: arXiv:1509.07798
Vigorous Explorer program (arXiv:0911.3383)

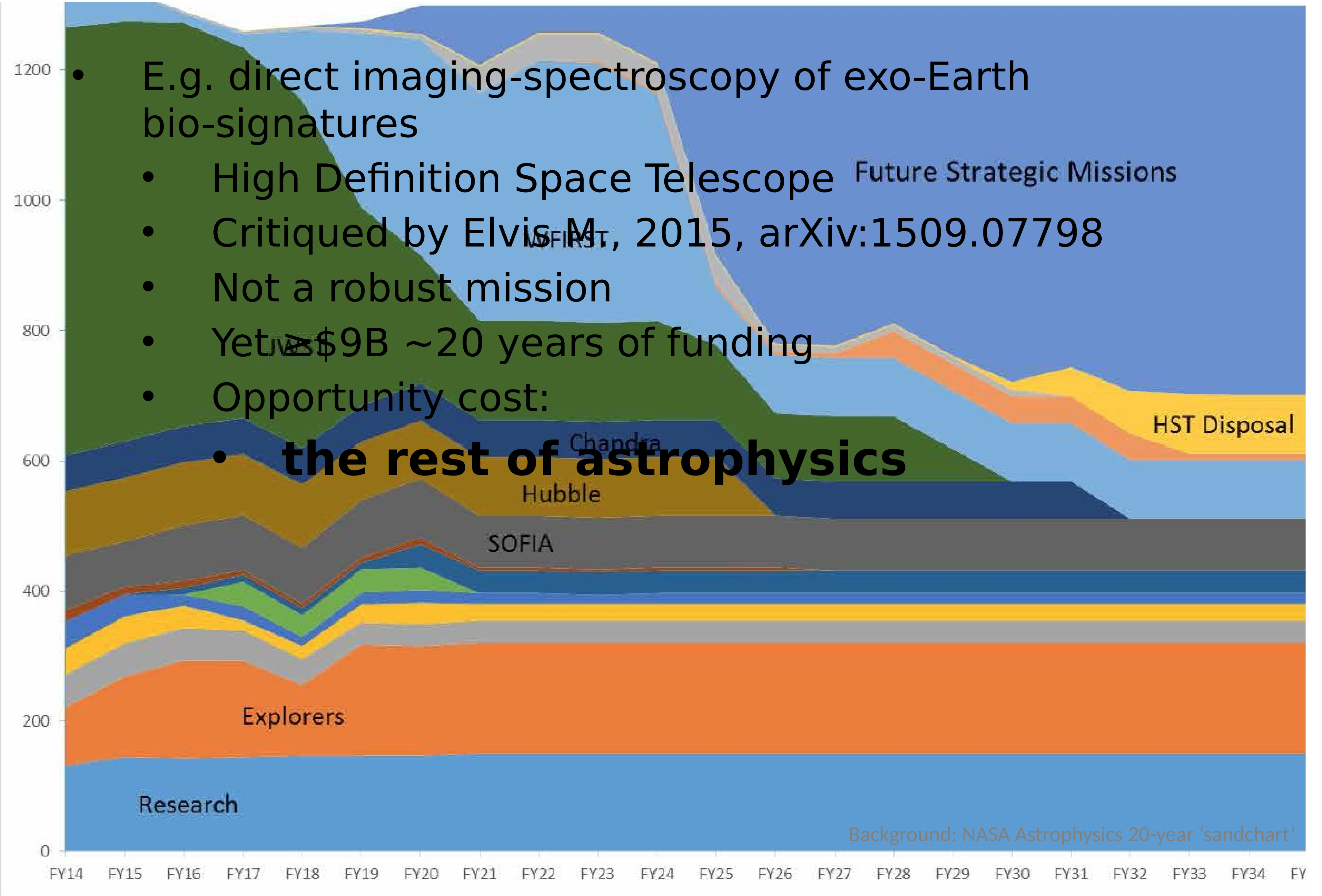

Terrestrial Planet Imager – Interferometer
(source: NASA)


X-ray Surveyor
(source: NASA)


HABEX starshade
(source: NASA)

Easy to Adopt an Over-Ambitious Science Goal

- E.g. direct imaging-spectroscopy of exo-Earth bio-signatures
  - High Definition Space Telescope
  - Critiqued by Elvis M., 2015, arXiv:1509.07798
  - Not a robust mission
  - Yet ≥$9B ~20 years of funding
  - Opportunity cost:
    - **the rest of astrophysics**



Martin Elvis, melvis@cfa.harvard.edu

Pie in the Sky?

Hopelessly optimistic?

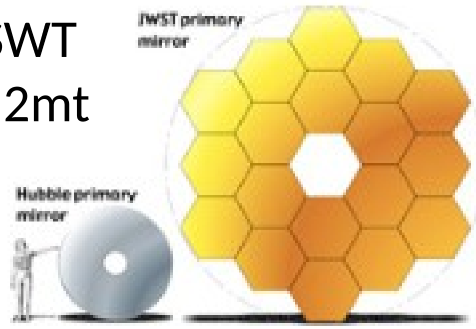
1. All space timelines “slide to the right”. Delays can be many years.
2. Savings require changing
   - Space Engineering practices,
   - Agency cost models.
3. To get more missions requires discipline from planners
   - Need guiding principles

http://wholeearthnatureschool.com

Martin Elvis, melvis@cfa.harvard.edu

Cheaper Spacecraft by 2025: The Real Saving

JSWT
6.2mt



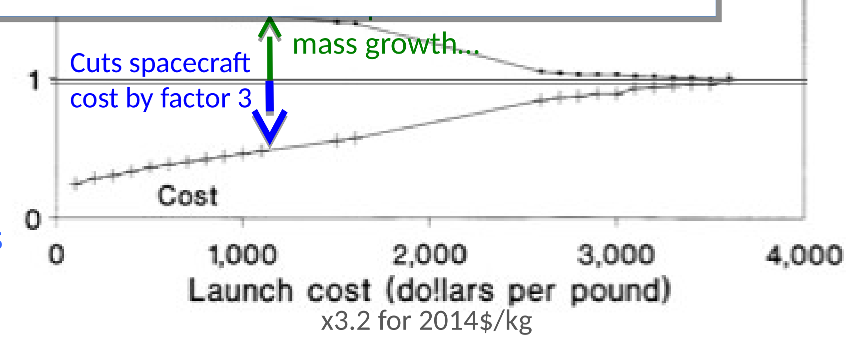
http://jwst.nasa.gov/mirrors.html

If the Hubble Space Telescope's 2.4 meter mirror were scaled to be large enough for Webb, it would be too heavy to launch into orbit. The Webb team had to find new ways to build the mirror so that it would be light enough - only one-tenth of the mass of Hubble's mirror per unit area - yet very strong.

 High Cost, Slow Implementation

10

- *Ma*
  →
  →
- *Nov much*
  - Robust structures: simpler design/testing
  - Larger solar panels: lots of power – cheaper electronics
  - Multiple redundancy: relaxed reliability requirements
  - Overcapable spacecraft batch production



- Much cheaper spacecraft
- Not a new idea: Morgan Report (1990)
  - 1/3 spacecraft cost for 50% mass growth
  - Needed launch cost reduction is now here
  - Time for a fresh study
    - E.g. “Deep Survey Telescope” Hearty & Stahl

University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Documents on Outer Space Law | Law, College of

1-1-1990

AFFORDABLE SPACECRAFT: Design and Launch Alternatives

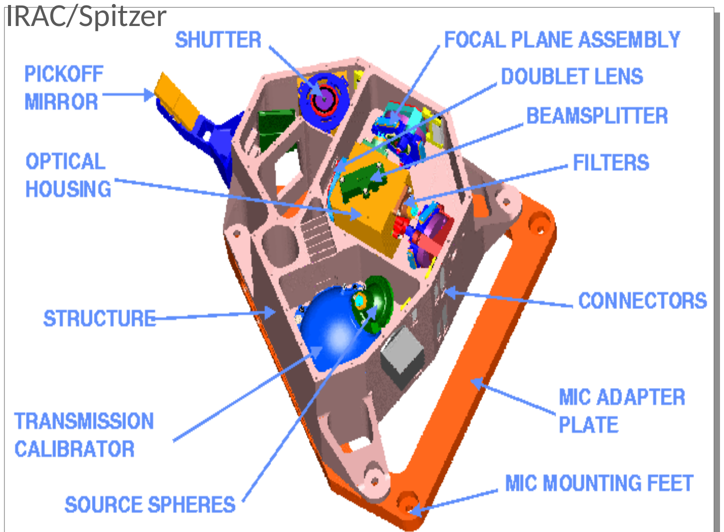
U.S. Congress, Office of Technology Assessment

Morgan report 1990

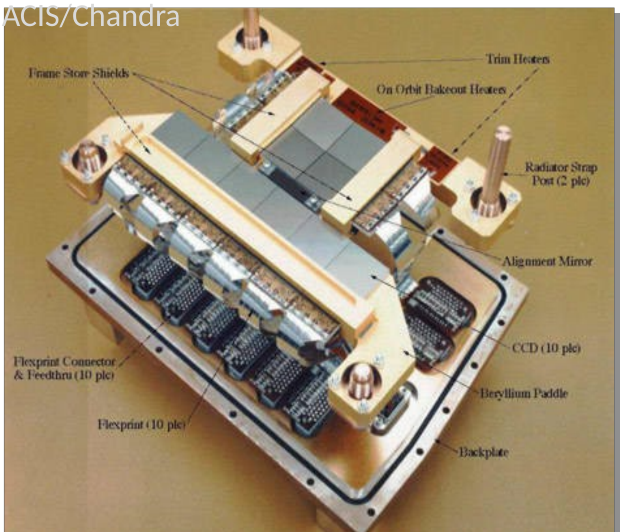
Cheaper Science Payloads

- Optics, sensors & pre-amp electronics stay expensive:
  - Essential to be state-of-the-art
- Other systems get cheaper
  - structure
  - thermal control
  - power supplies
  - post-amp electronics
  - data processing

IRAC/Spitzer



ACIS/Chandra



Commercial Passengers to LEO by 2025

2 companies offering rides to orbit >2020

- Addresses hi-tech parts of payload
- Cheap, quick TRL-9 instrument tests in Dragon trunk
  - shorter development cycles
  - cutting edge science payloads
- Affordable On-orbit Servicing in LEO
  - HST showed servicing is powerful
  - Too expensive – soon “cheap”
  - failure is a nuisance, not mission-ending
  - Can tolerate higher risk lower cost

Boeing. CST-100

SpaceX. Dragon 2

Martin Elvis, melvis@cfa.harvard.edu

Trend to Mega-projects, low innovation is Universal

Moviemaking has the same problem:

“It's an inherently conservative business because it's so expensive. And if you're not repeating something that's already a success then people are nervous.”

(Patricia Rozema, Director. NPR 2016)

Martin Elvis, melvis@cfa.harvard.edu

Resources are Always Limited