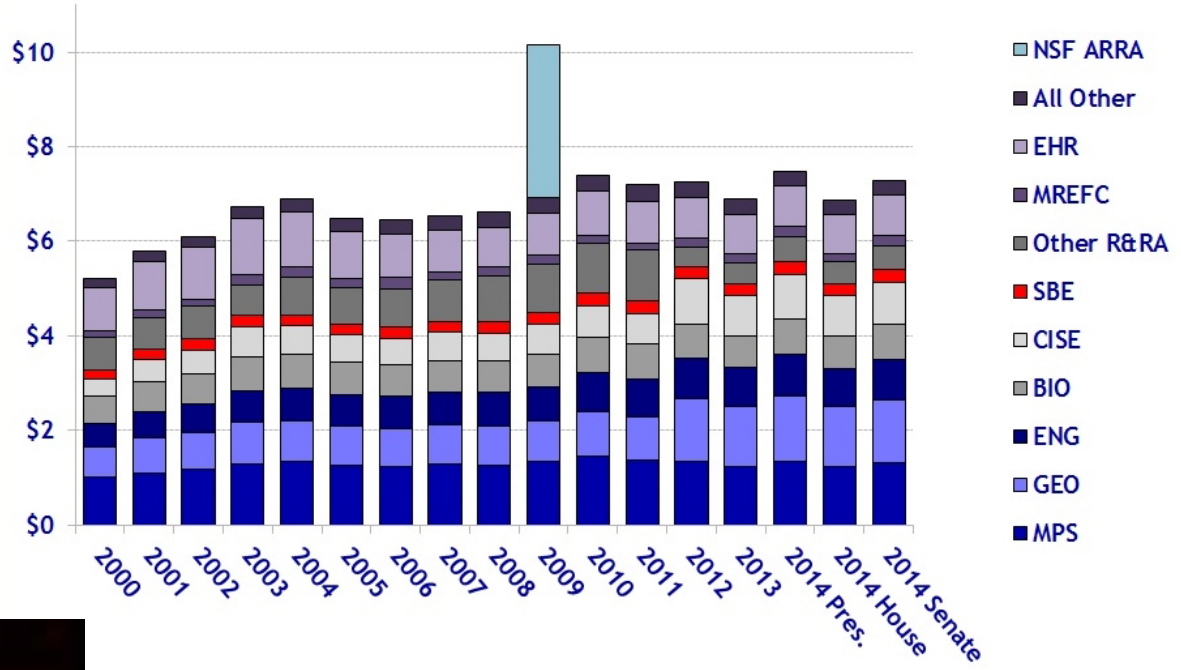
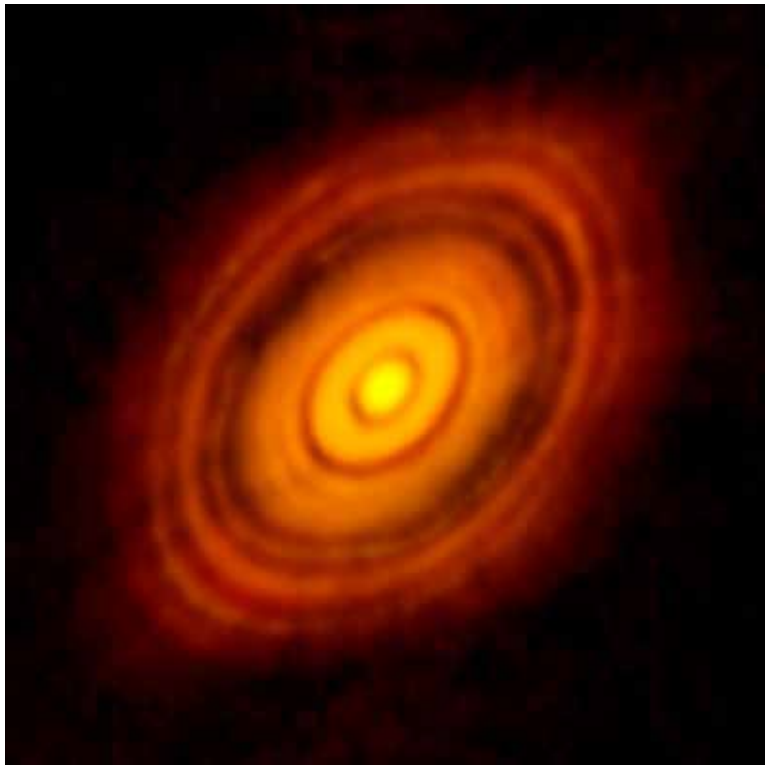




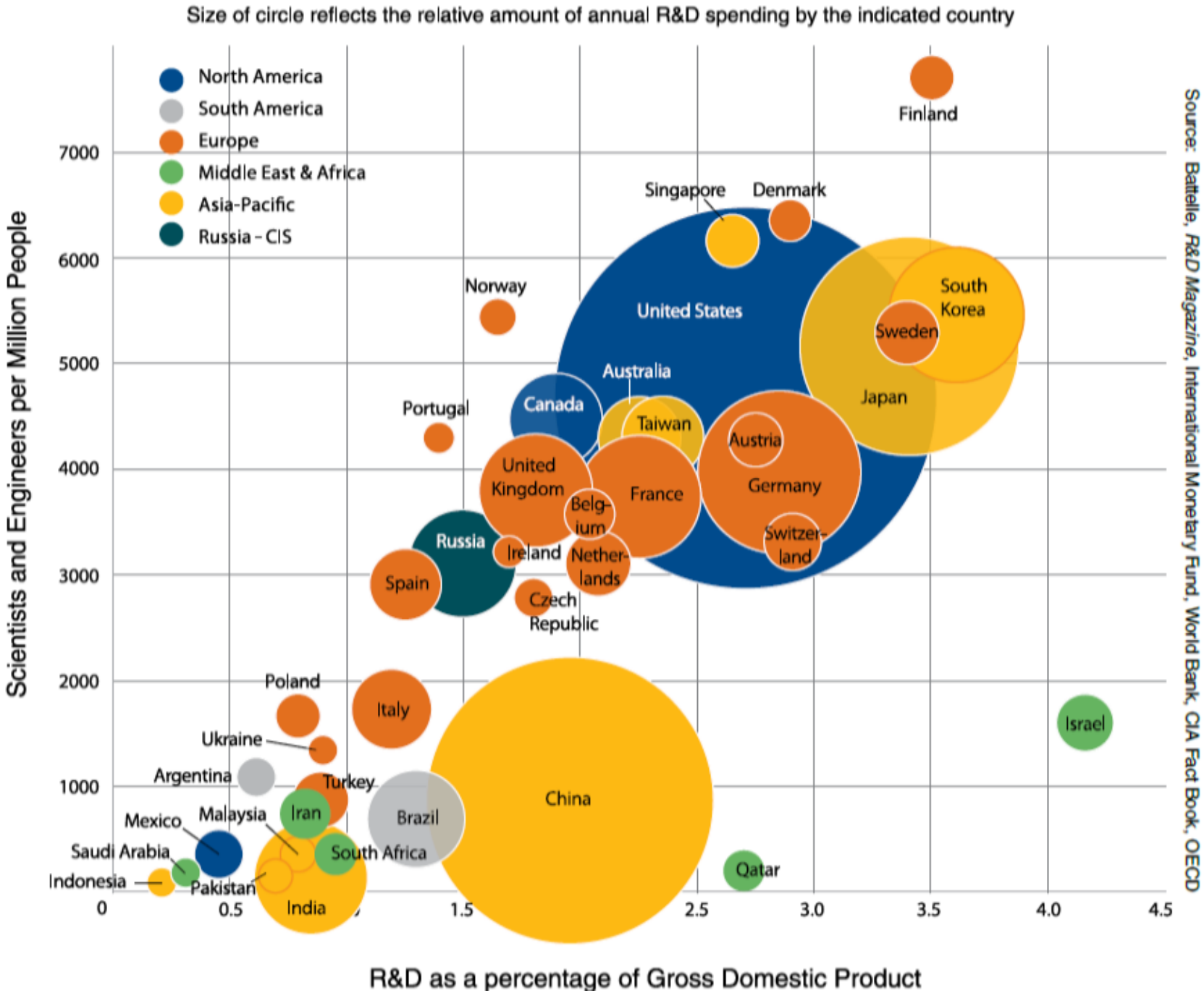
US Radio/Millimeter/Submm Interests in the 2020s

T. Beasley/NRAO

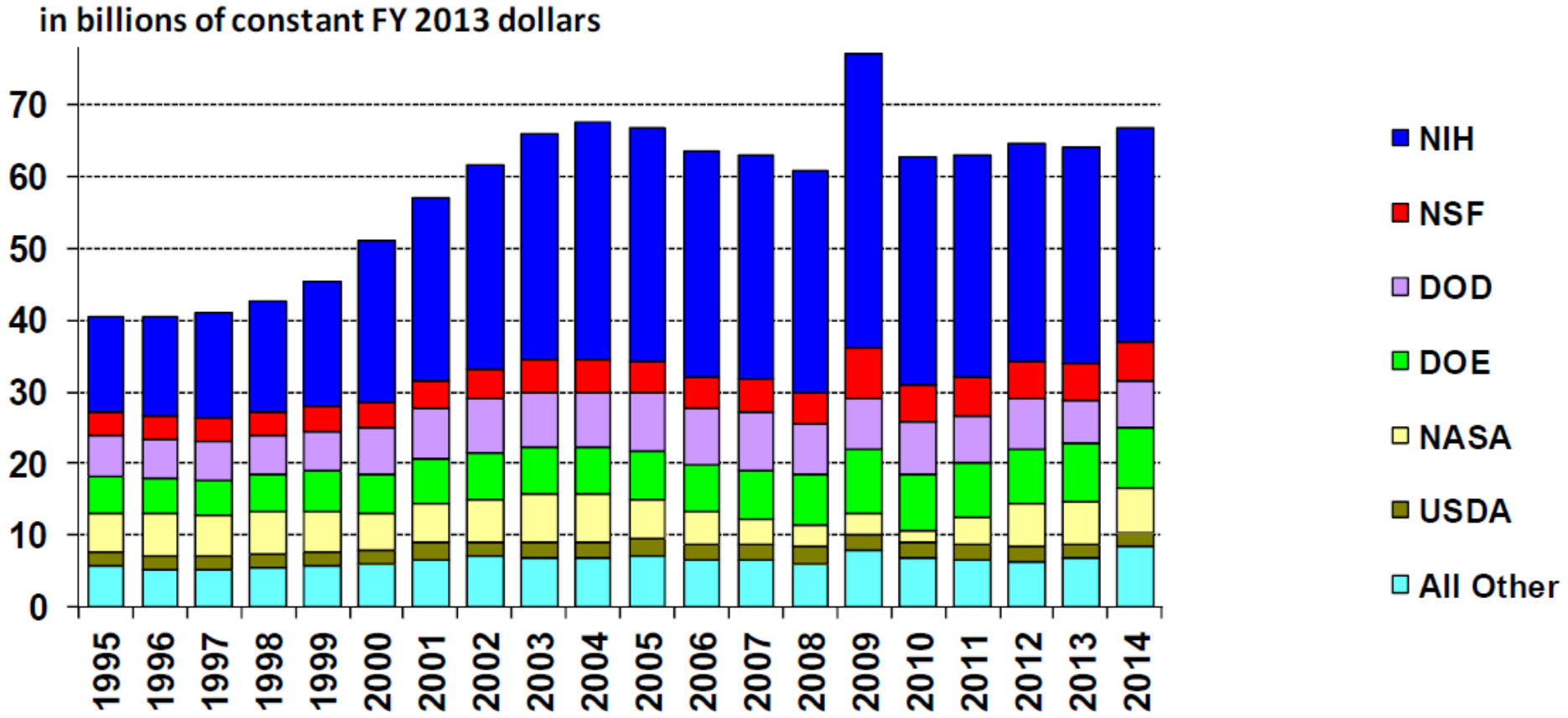
US RMS

- 1980s – VLA, VLBA, University Radio Observatories
- 1990s – GBT, ALMA development, SMA, LMT, ATA
- 2000s – ALMA, EVLA
- 2010s – End of UROs, no US SKA, GBT/VLBA divestment… L

- Radio astronomy – mainly Federally-funded (NSF) – signal?
- Overall economy – down (2008), weak (2010-2013), ok (2014+)
- R&D funding – fluctuates, but some growth

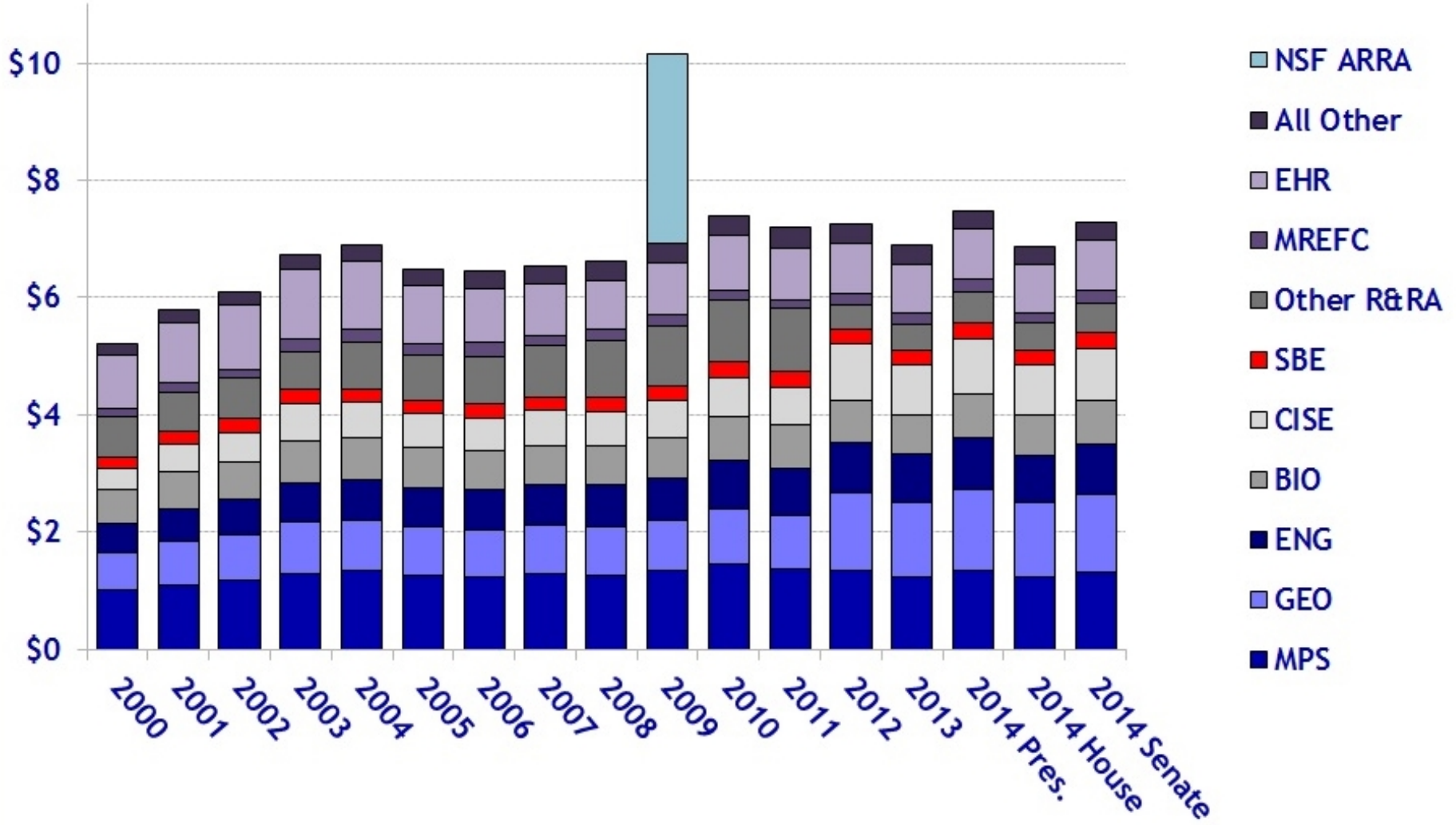

Size of circle reflects the relative amount of annual R&D spending by the indicated country
North America
South America
Europe
Middle East & Africa
Asia-Pacific
Russia – CIS
Scientists and Engineers per Million People
R&D as a percentage of Gross Domestic Product
Source: Battelle, R&D Magazine, International Monetary Fund, World Bank, CIA Fact Book, OECD
Finland
Singapore
Denmark
Norway
United States
South Korea
Sweden
Australia
Japan
Canada
Portugal
Taiwan
Austria
United Kingdom
France
Germany
Belg-ium
Russia
Switzer-land
Ireland
Nether-lands
Spain
Czech Republic
Poland
Italy
Israel
Ukraine
Argentina
Turkey
China
Brazil
Mexico
Malaysia
Iran
South Africa
Saudi Arabia
Qatar
Indonesia
Pakistan
India
0
0.5
1.5
2.5
3.0
3.5
4.0
4.5
1000
2000
3000
4000
5000
6000
7000

Federal Research by Agency, FY 1995-2014

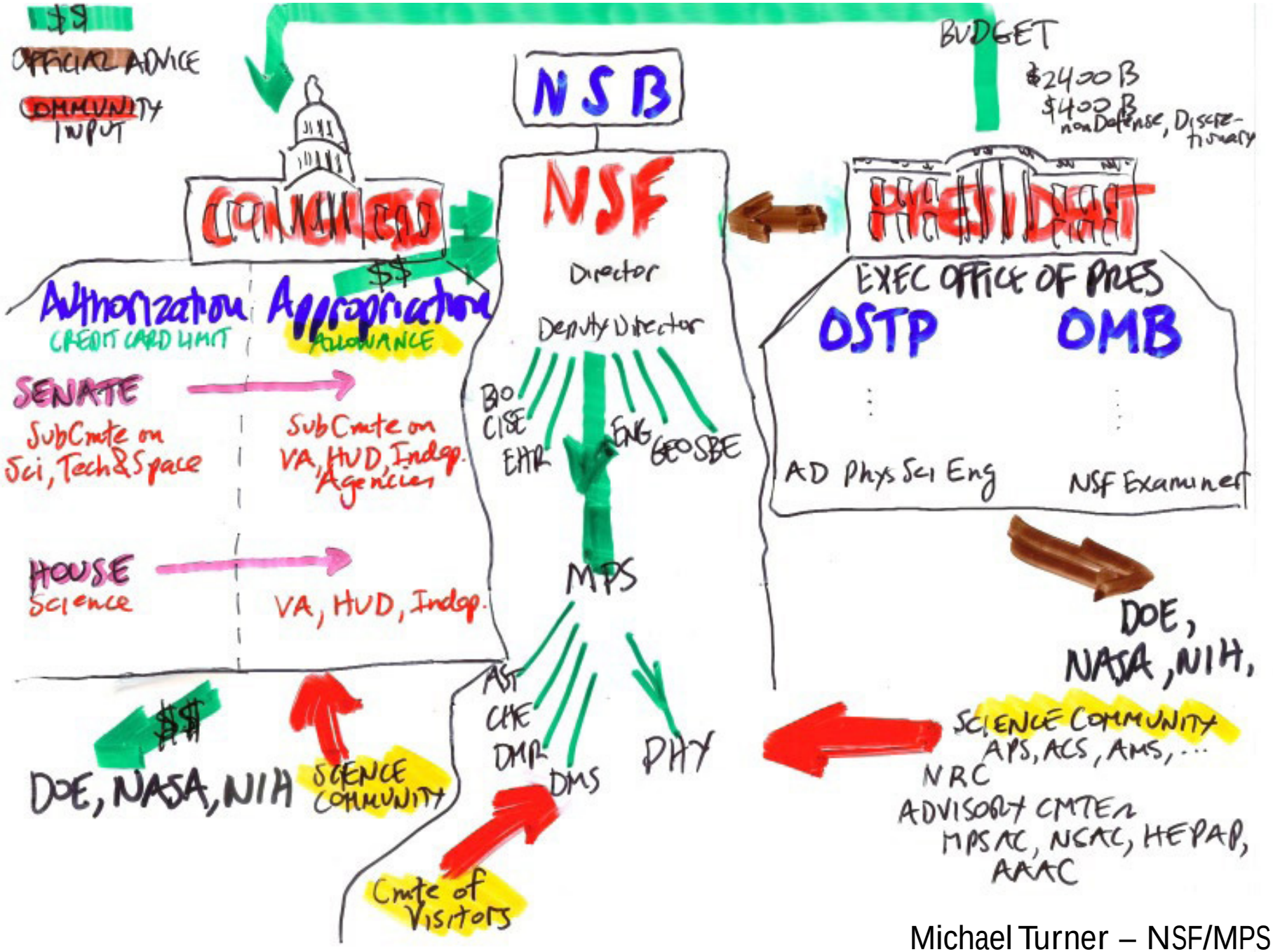


National Science Foundation Budget

Budget Authority in billions of constant FY 2013 dollars



Source: National Science Foundation budget requests and AAAS R&D report series. FY 2013 figures are latest estimates. NOTE: Several programs were recently shifted from standalone offices into directorates, reflected above beginning in FY 2012.



Michael Turner – NSF/MPS

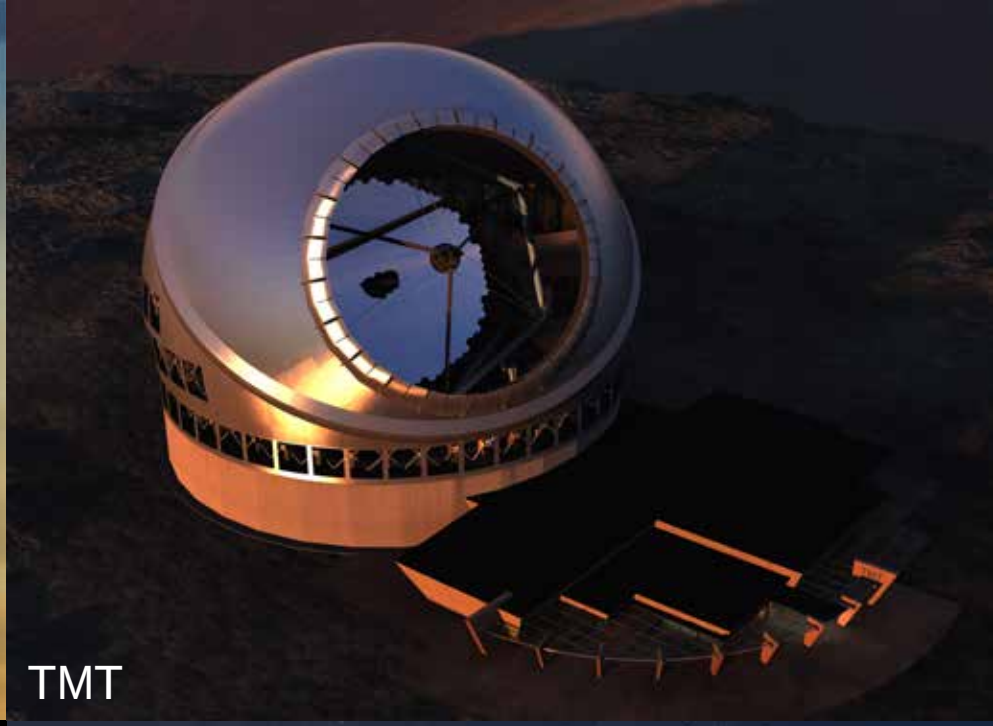
US RMS

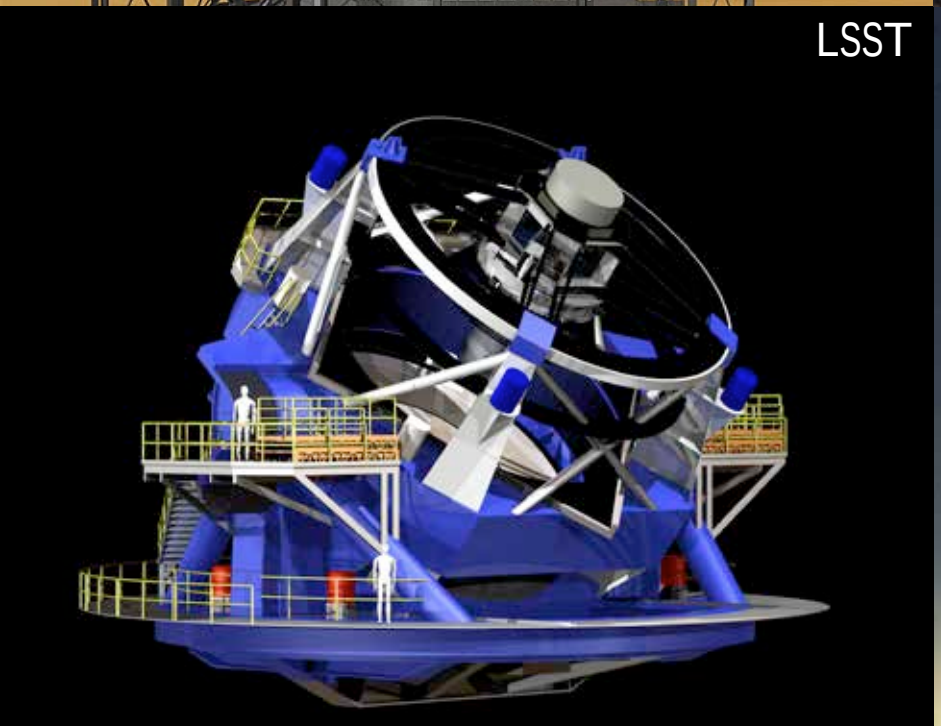
- 1980s – VLA, VLBA, University Radio Observatories
- 1990s – GBT, ALMA development, SMA, LMT, SPT, ATA
- 2000s – ALMA, EVLA
- 2010s – End of UROs, no US SKA, GBT/VLBA divestment… L

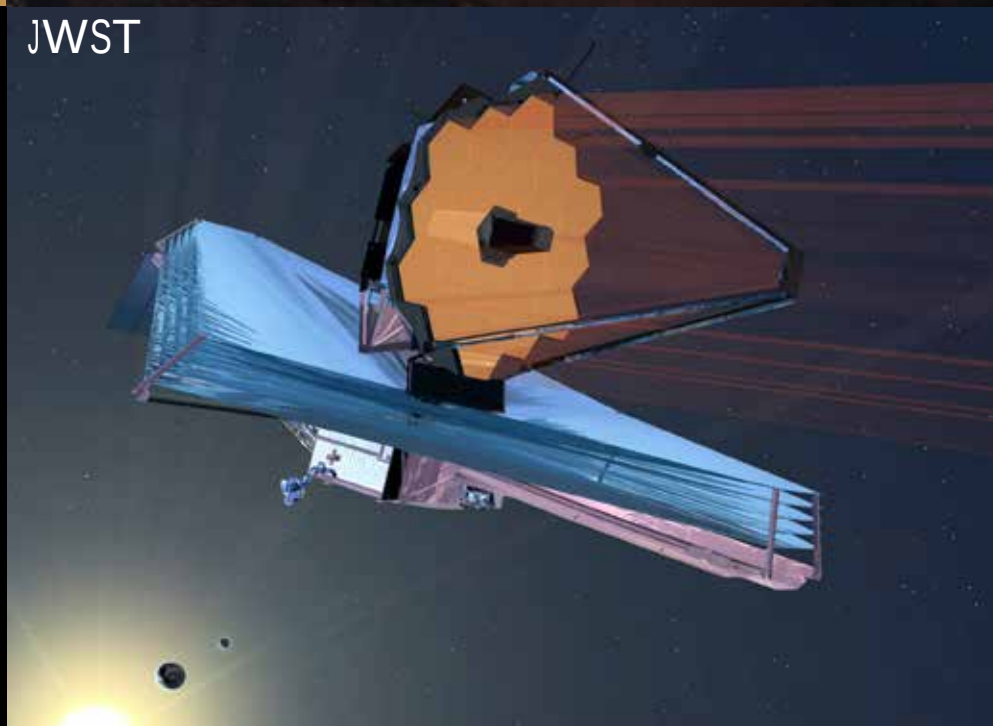
- Radio astronomy – mainly Federally-funded (NSF) – signal?
- Overall economy – down (2008), weak (2010-2013), ok (2014+)
- R&D funding – fluctuates, but some growth
- NSF funding – steady growth, bipartisan support

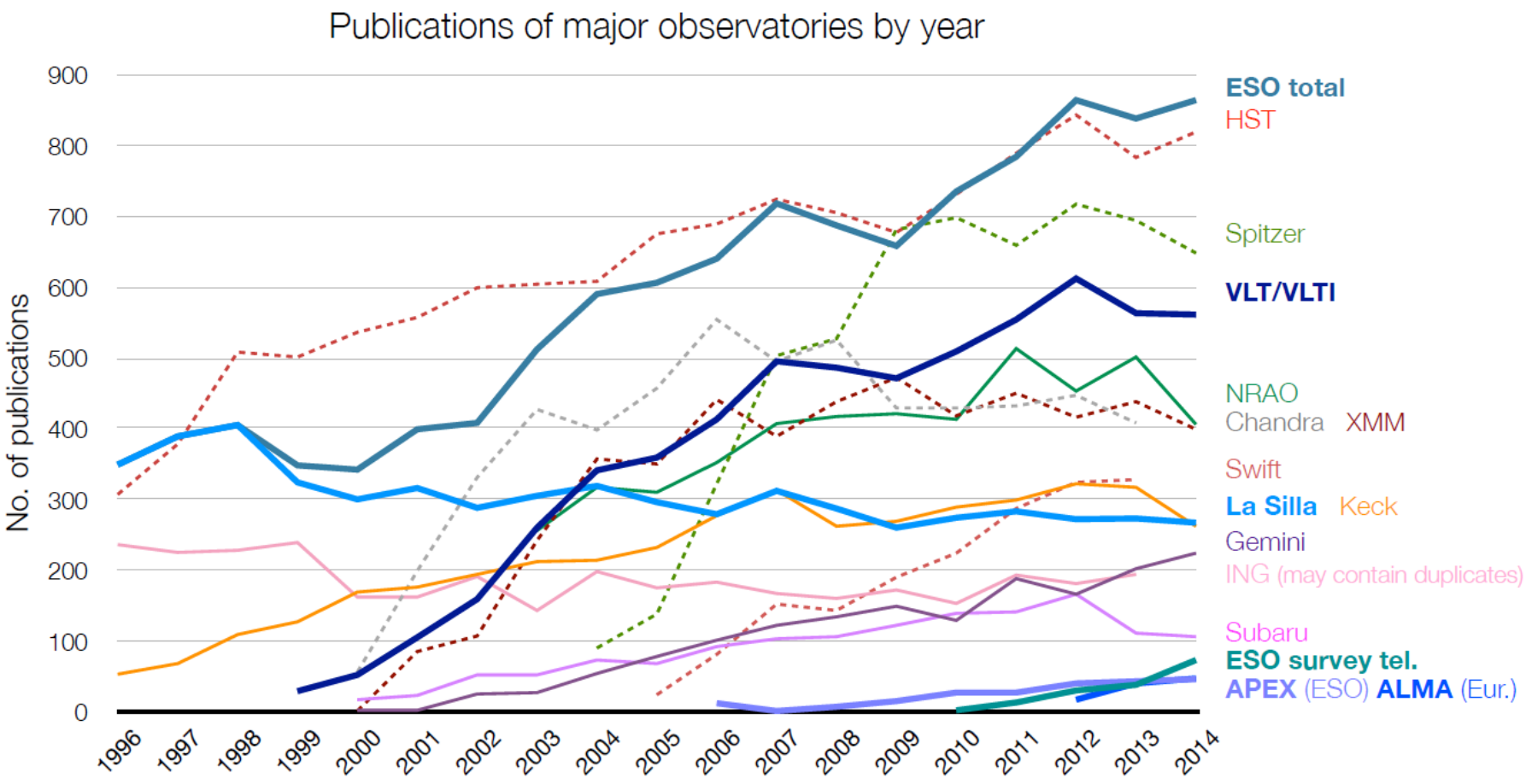
- Recent RMS fortune issues – unrelated to changes at national level?


GMT


TMT


LSST


JWST


Publications of major observatories by year
No. of publications
900
800
700
600
500
400
300
200
100
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
ESO total
HST
Spitzer
VLT/VLTI
NRAO
Chandra
XMM
Swift
La Silla
Keck
Gemini
ING (may contain duplicates)
Subaru
ESO survey tel.
APEX (ESO) ALMA (Eur.)

Issue: ASTRO2010

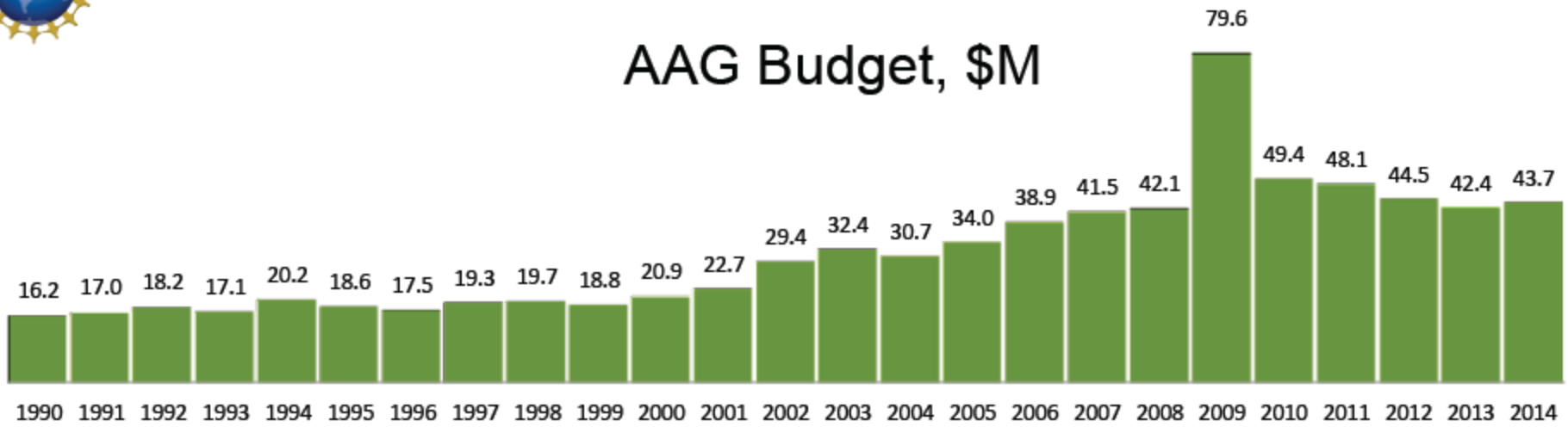
Decadal Survey Process

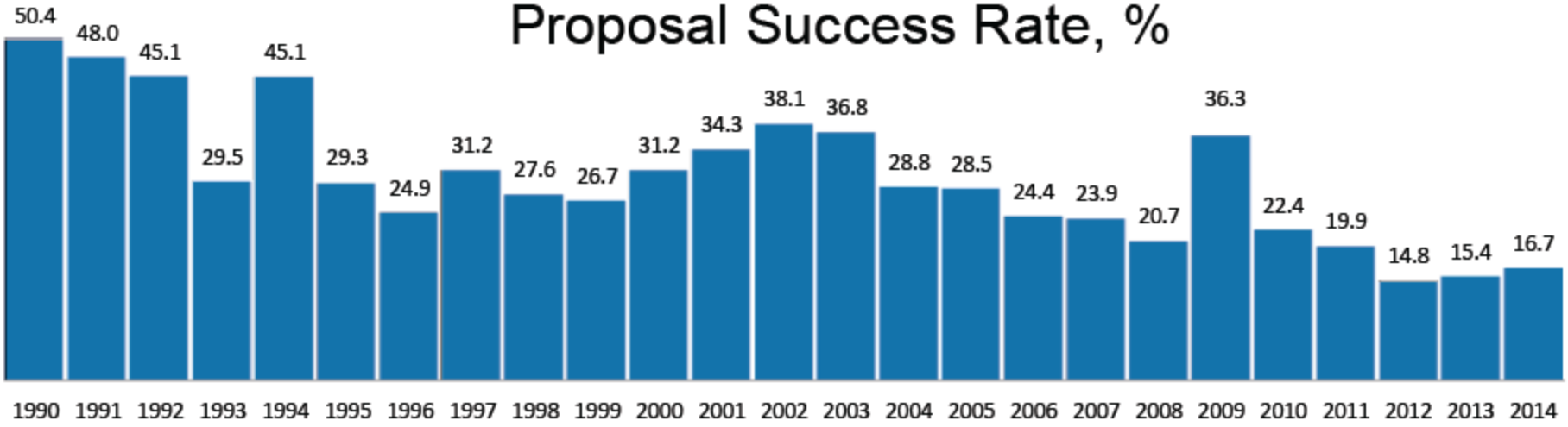
- Community-based review and prioritization of astronomy development
- 2010 (actually ~2008) – assumed incorrect budget growth model (housing bubble burst)
- Recommendations for different environment – limited use
- Added semi-quantitative independent review +/-
- Issues
  - Inflation of goals/costs in astronomy – small N
  - Project timescale >> decade
  - Politics (several types)
- Bar has been raised in US…

Example - SKA:

- *The panel believes that it is very important for the US to play a role in this international project.*
- *However, based on the information received from the projects and from independent analysis, none of the parts of this project have reached maturity sufficient to recommend construction at this time.*
- *Defining the way forward in this context requires a mix of technology development, demonstrator projects, and careful consideration of priorities.*
- *The panel recommends revisiting the SKA design costs in 5 years to assess end-of-decade feasibility.*

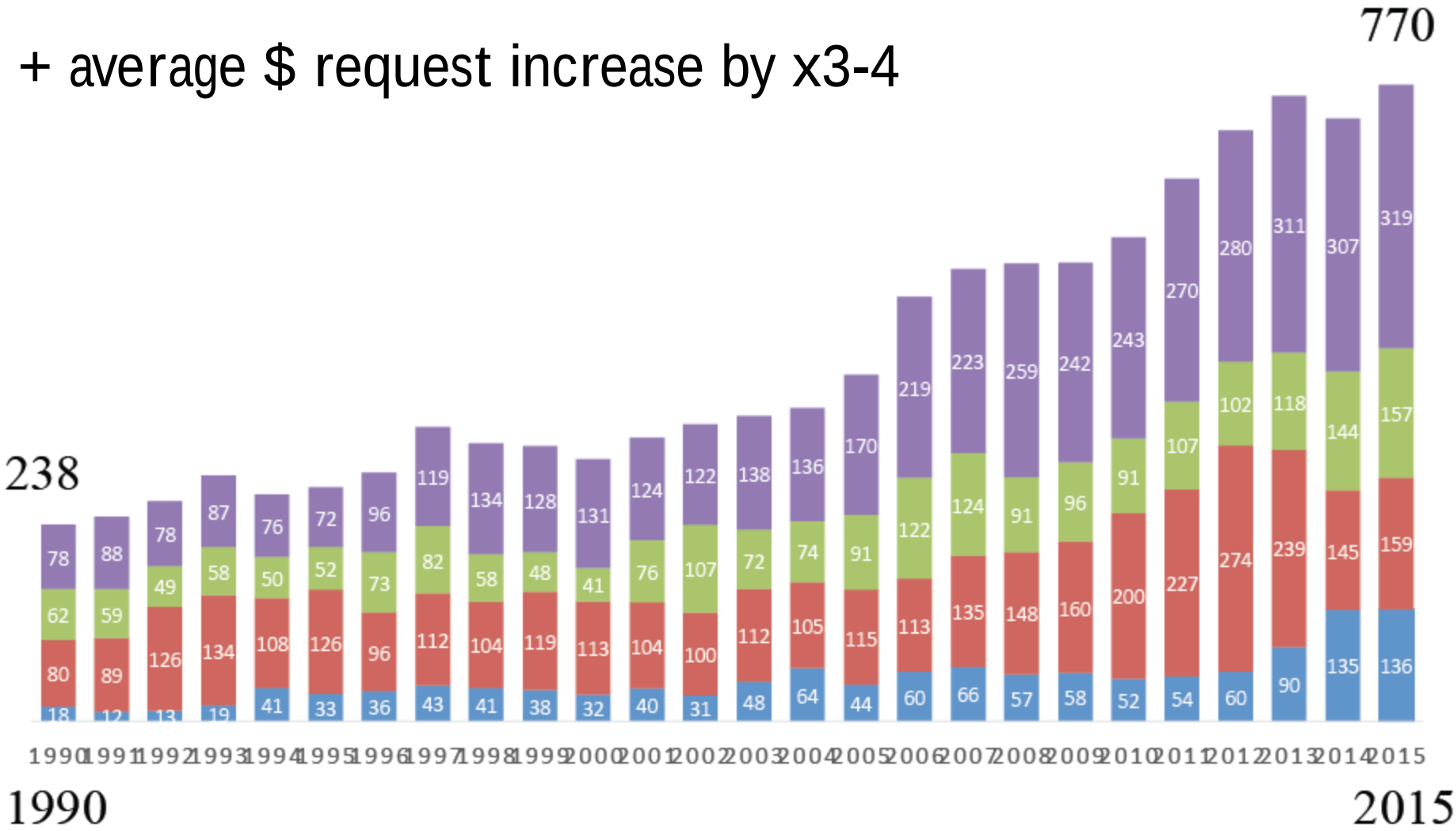
- Community planning process – some challenges, poor set of boundary conditions in 2010, rules changing
- NASA – dealing with it….
- NSF/AST (Ground-based astronomy)
  - Difficulties in 2000s (ALMA rebaselining, DKIST)
  - Changing customer base, flat funding


AAG Budget, $M
16.2
17.0
18.2
17.1
20.2
18.6
17.5
19.3
19.7
18.8
20.9
22.7
29.4
32.4
30.7
34.0
38.9
41.5
42.1
79.6
49.4
48.1
44.5
42.4
43.7
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

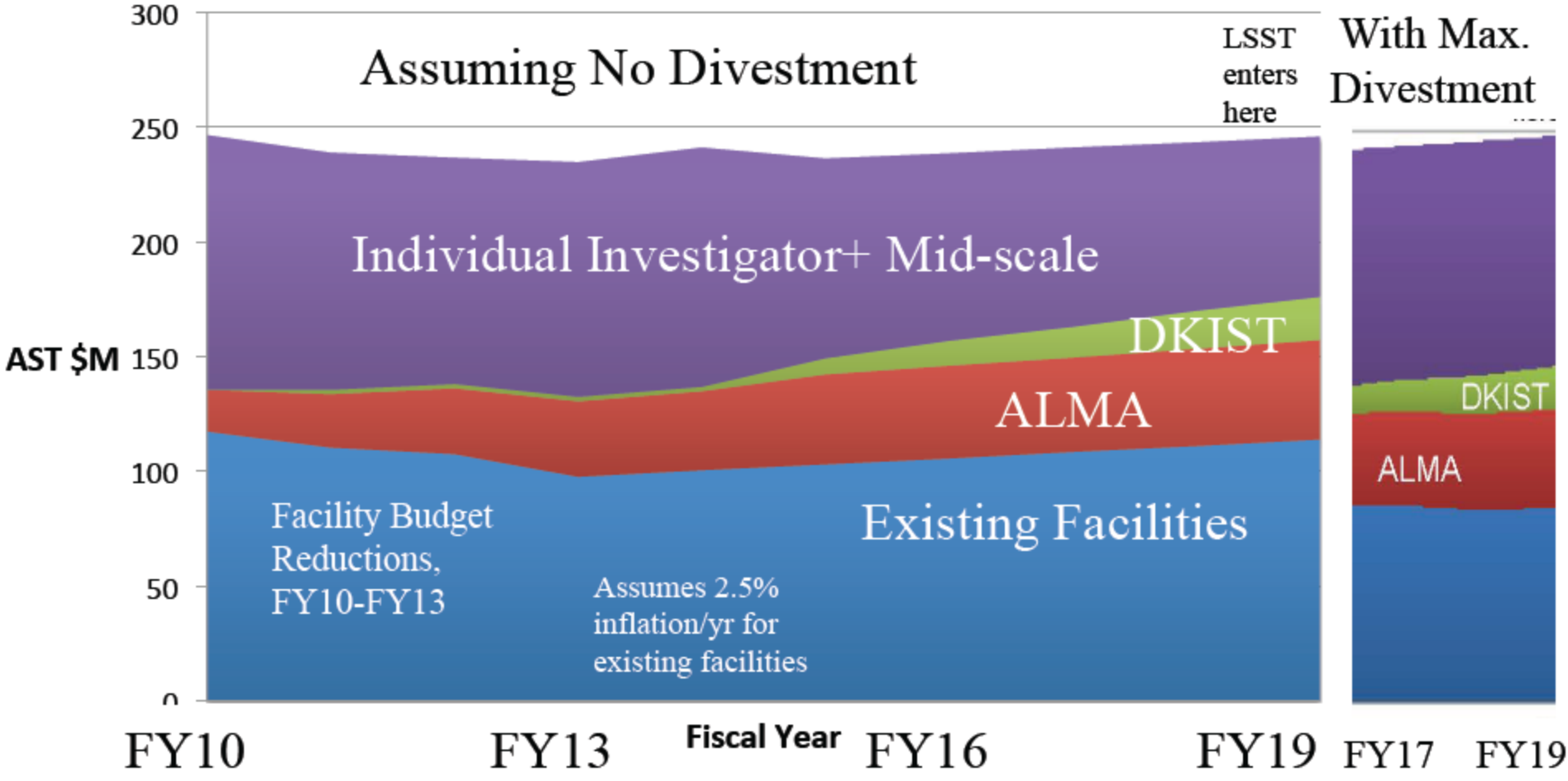

Proposal Success Rate, %
50.4
48.0
45.1
29.5
45.1
29.3
24.9
31.2
27.6
26.7
31.2
34.3
38.1
36.8
28.8
28.5
24.4
23.9
20.7
36.3
22.4
19.9
14.8
15.4
16.7
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

Proposals in AAG

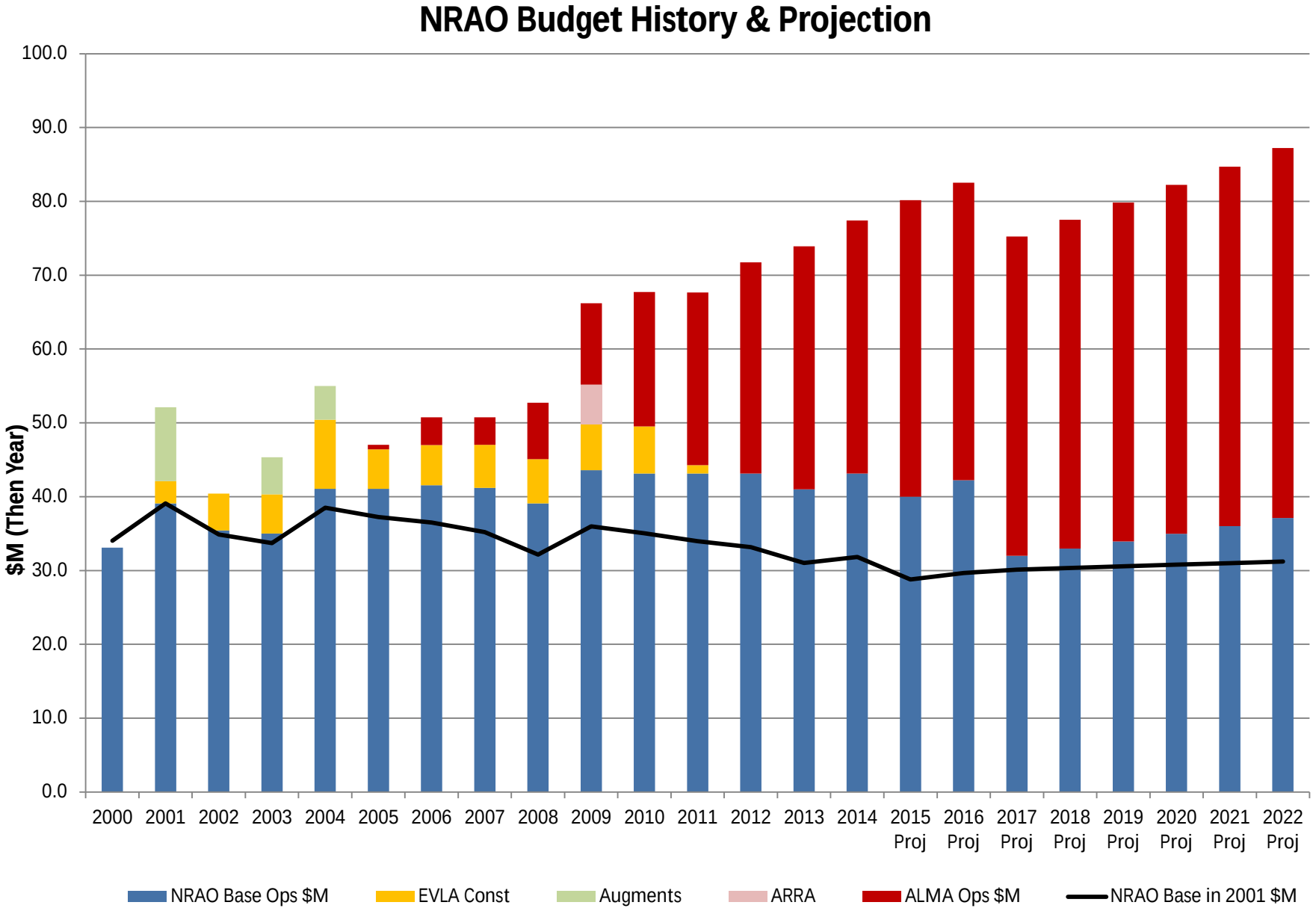
+ average $ request increase by x3-4



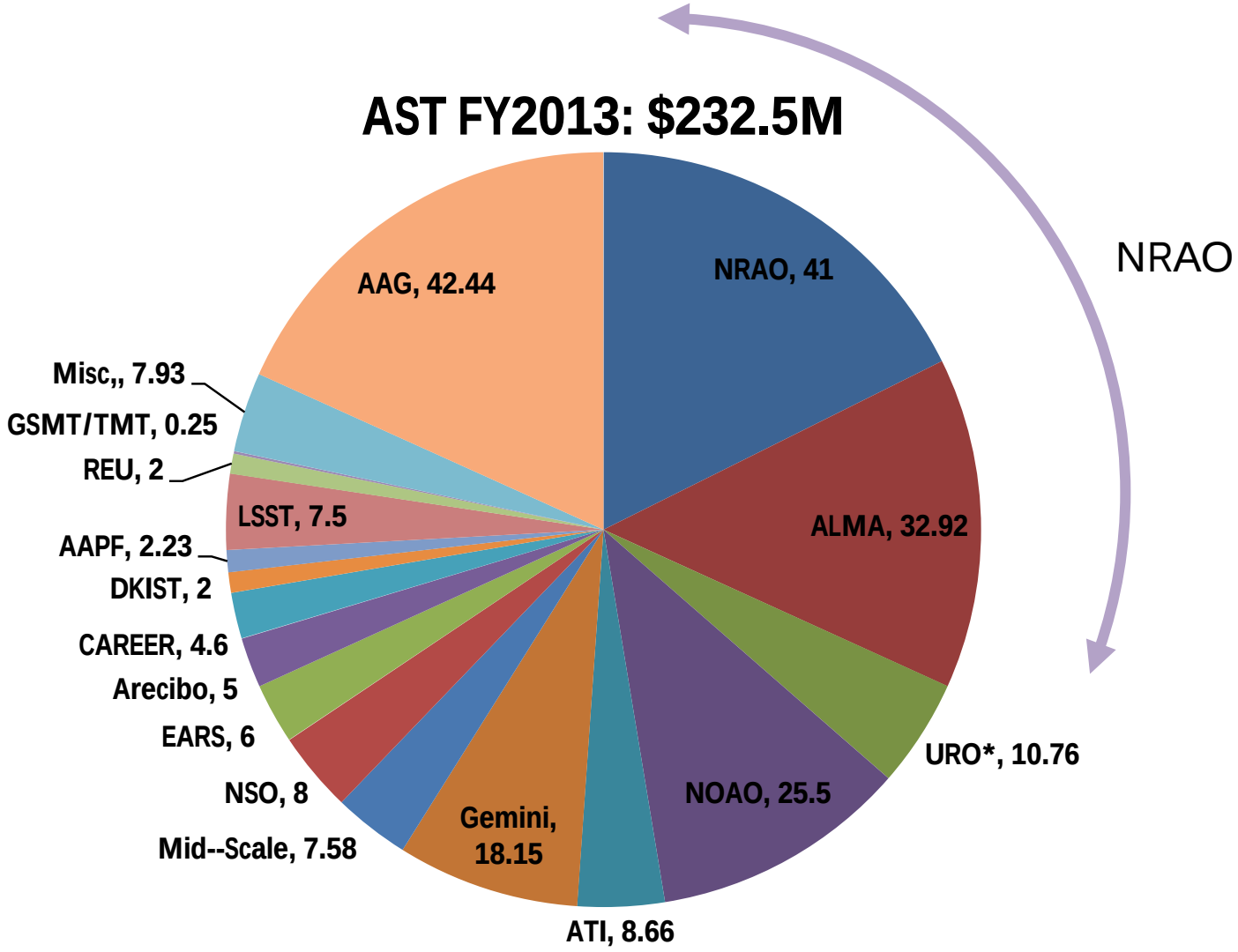
AST Portfolio Scenarios



AST budget assumption: FY15=Request, 1%/yr growth thereafter


NRAO Budget History & Projection
$M (Then Year)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015 Proj
2016 Proj
2017 Proj
2018 Proj
2019 Proj
2020 Proj
2021 Proj
2022 Proj
NRAO Base Ops $M
EVLA Const
Augments
ARRA
ALMA Ops $M
NRAO Base in 2001 $M

AST FY2013: $232.5M



- Community planning process – some challenges, poor set of boundary conditions in 2010, rules changing
- NASA – dealing with it….
- NSF/AST (Ground-based astronomy)
  - Difficulties in 2000s (ALMA rebaselining, DKIST)
  - Changing customer base, flat funding
  - Approach to facilities (construction: MREFC, operations: RRA) failing… while level of play (PM, SE) increasing
  - Hitting two fundamental limits:
    - Grants program – overpressured, 5% success rates
    - Facilities – science driving us to massive facilities + ops costs (6-10%)
- Recently: continued successes (both RMS + OIR) but no relief in sight… FYI: NRAO: GBT & VLBA – situation stable for now

RMS fortunes – disrupted planning + weak economic growth + conditions/decisions inside NSF

Moving Forward

- ASTRO2020 – approaching… (choices 2018, report 2020)
- NASA: JWST, 30-yr roadmap
- NSF: unresolved projects from ASTRO2010 (including "GSMT")
- Grants Program – something will change (?)
- Mid-scale Initiatives (RMS: HERA, EHT, CCAT, NANOgrav..) will continue to move (slow funding…)
- US Futures in RMS – Kavli Meetings
  - First meeting: Dec 15-17th Chicago (soon to be announced)
  - Bring RMS community together to explore Science opportunities, place into domestic/global context; explore options for 2020s; select projects to move forward to ASTRO2020
  - NRAO facilitating discussion; community decides

NASA 30-yr Roadmap

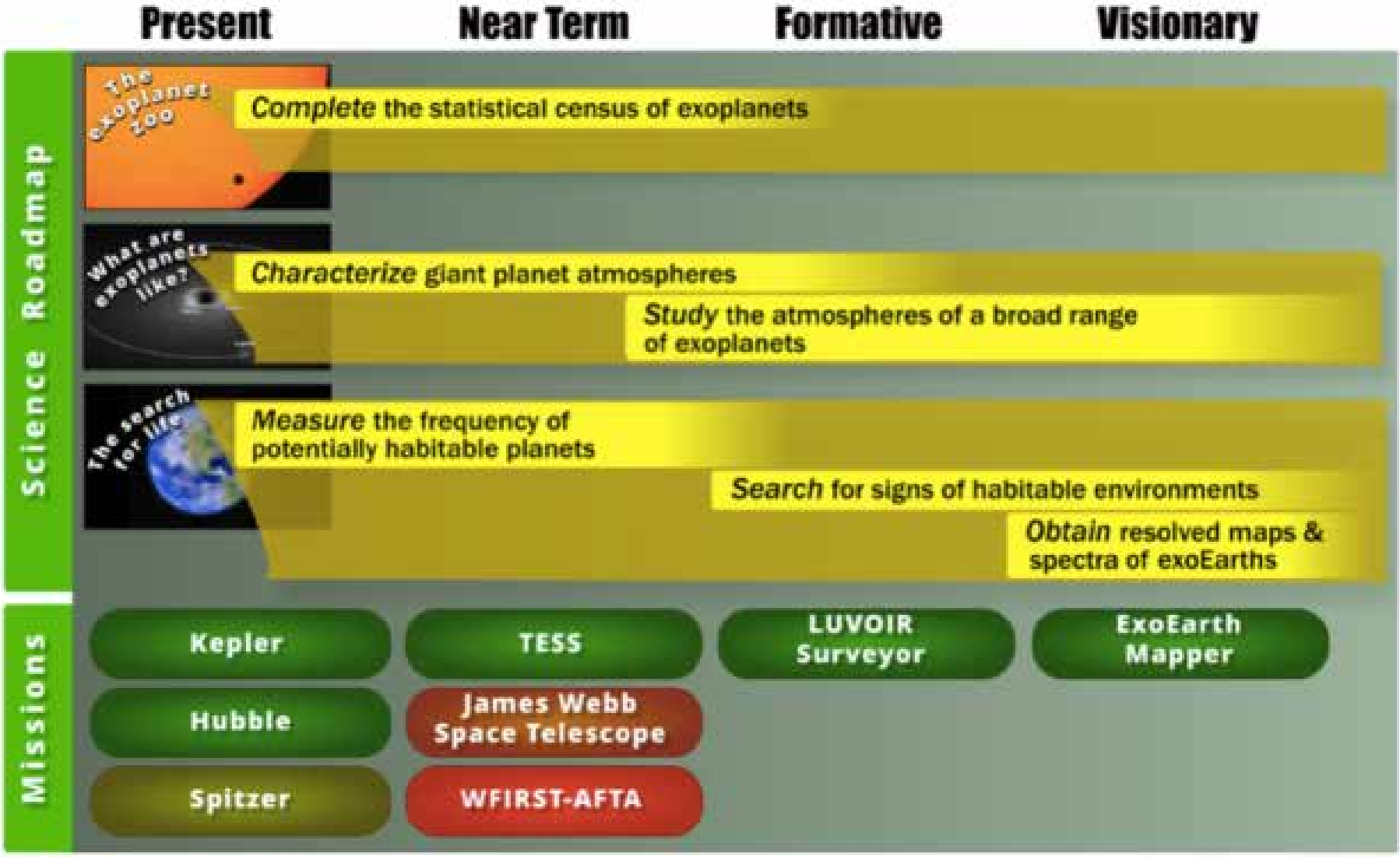


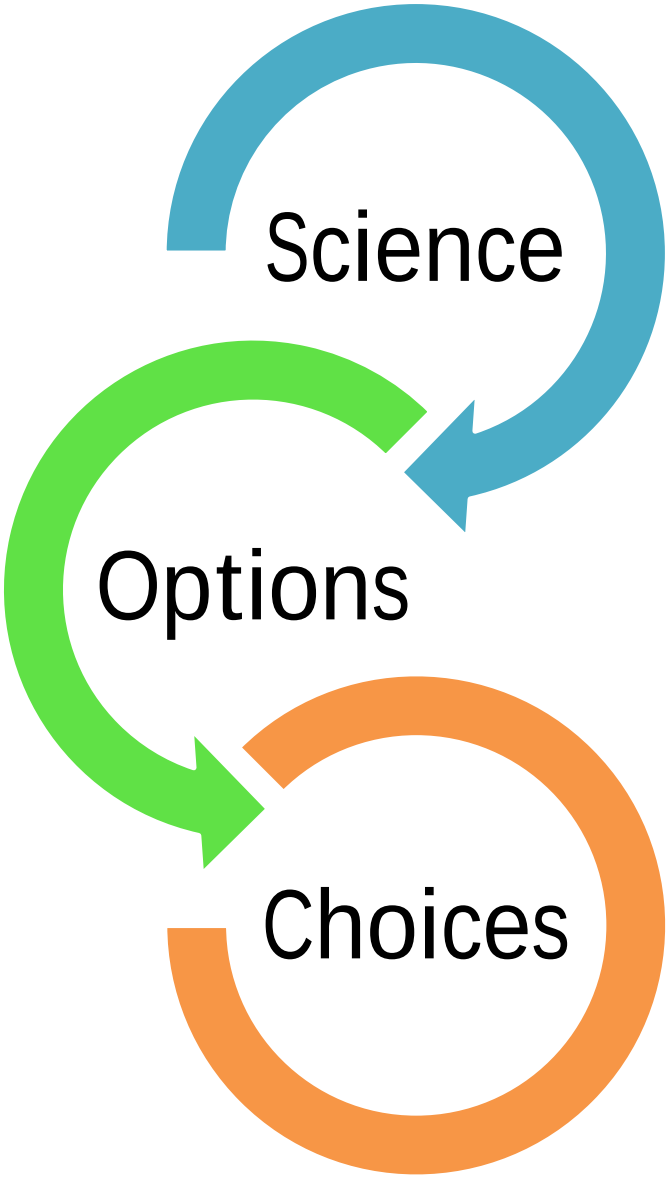
Figure 2.16 *Schematic of the Exoplanets Roadmap, with science themes along the top and a possible mission sequence across the bottom.* ***Credit: F. Reddy (NASA GSFC)***

US RMS Process

Kavli Community Meetings

Design/Prototype

Proposals



2015

2017

2020

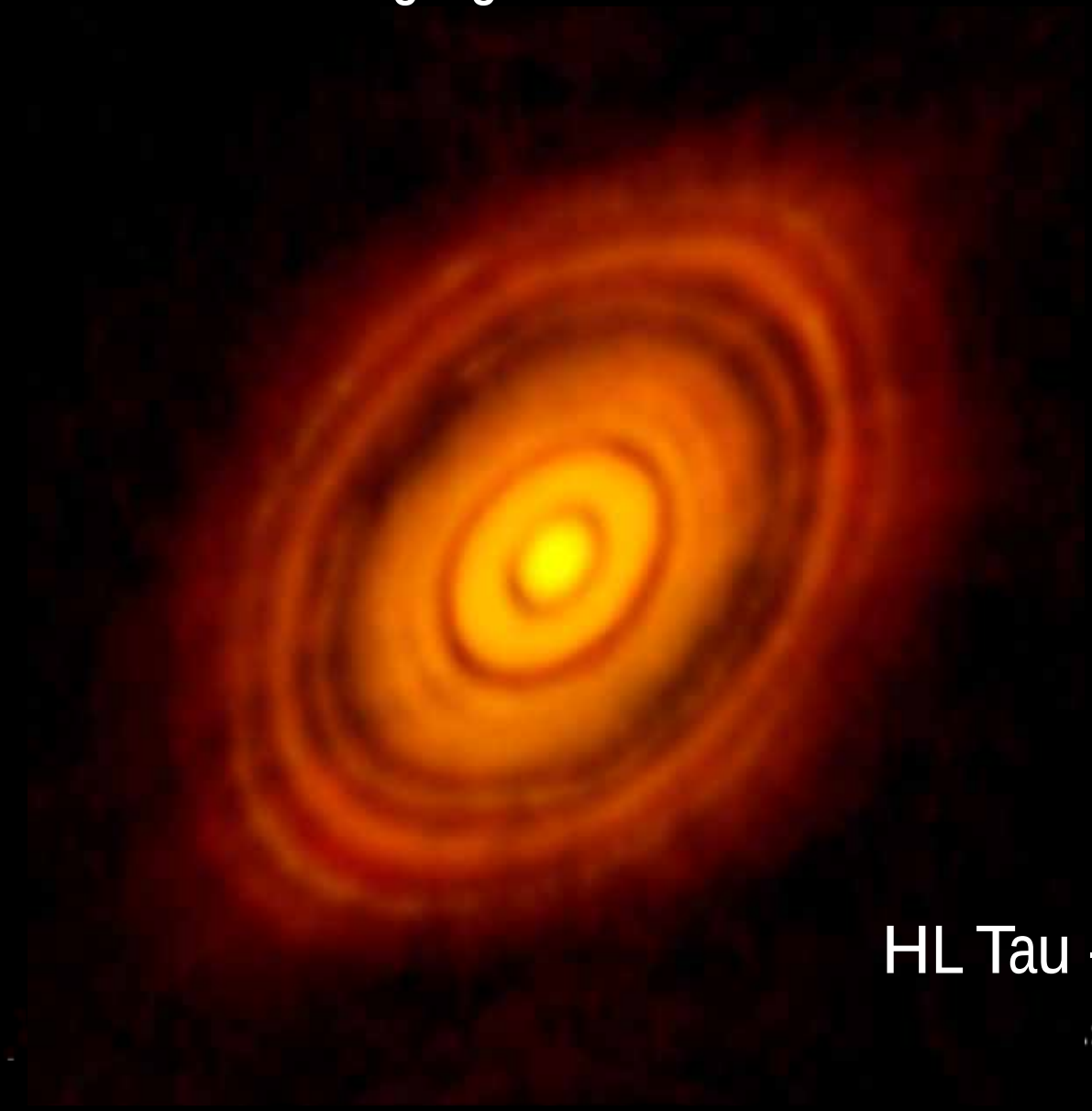
SKA & US

- No formal involvement (despite long history, current informal participation levels)
- Phase I – watching
- Phase II – scientific interest, entry route + funding unclear
- Several issues
  - Open Skies interactions
  - Broad vs deep science cases ($$)
  - Facilities vs experiments
  - Linkage to other capabilities (UVOIR)
- Discussions underway

- NRAO: internal discussions
  - Space: DARE, Far-infrared Interferometer
  - Low-frequency: SKA-L, HERA, US GW Observatory
  - Mid-frequency: SKA-Mid/High, Fast Transients, ngVLA
  - High-frequency: ALMA upgrade/expansion (2030s)

- Next-generation VLA
  - Thermal imaging on mas scales – bridge SKA & ALMA
  - 5-10x collecting area on few hundred km baselines around VLA, merge VLBA baselines
  - 1.2 – 116 GHz
  - (Northern Hemisphere Array)

NRAO – Thermal Imaging on Milliarcsecond Scales



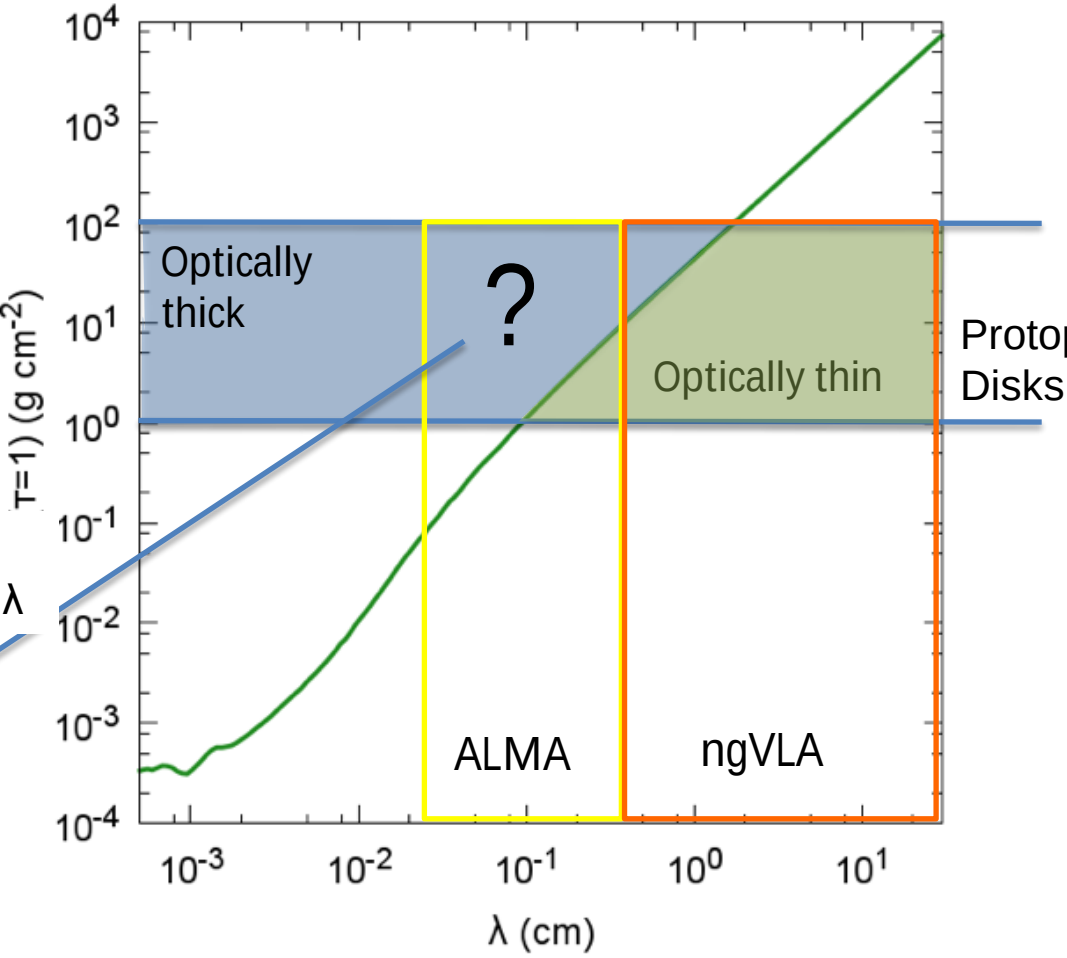
HL Tau – ALMA B6

What do these areas of interest have in common?

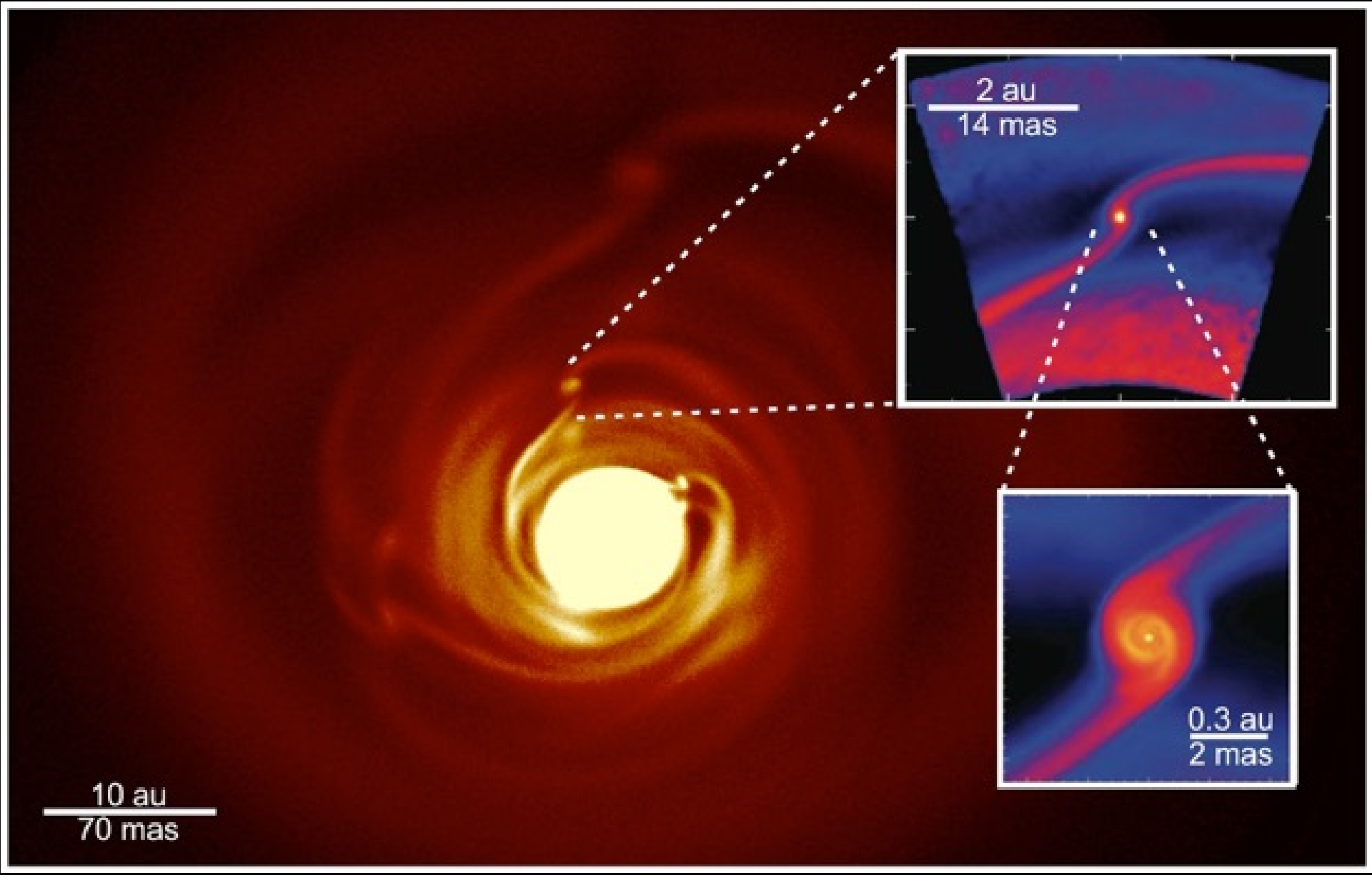
Amount of material needed to become optically thick

Terrestrial Planet forming region inaccessible for short λ

?

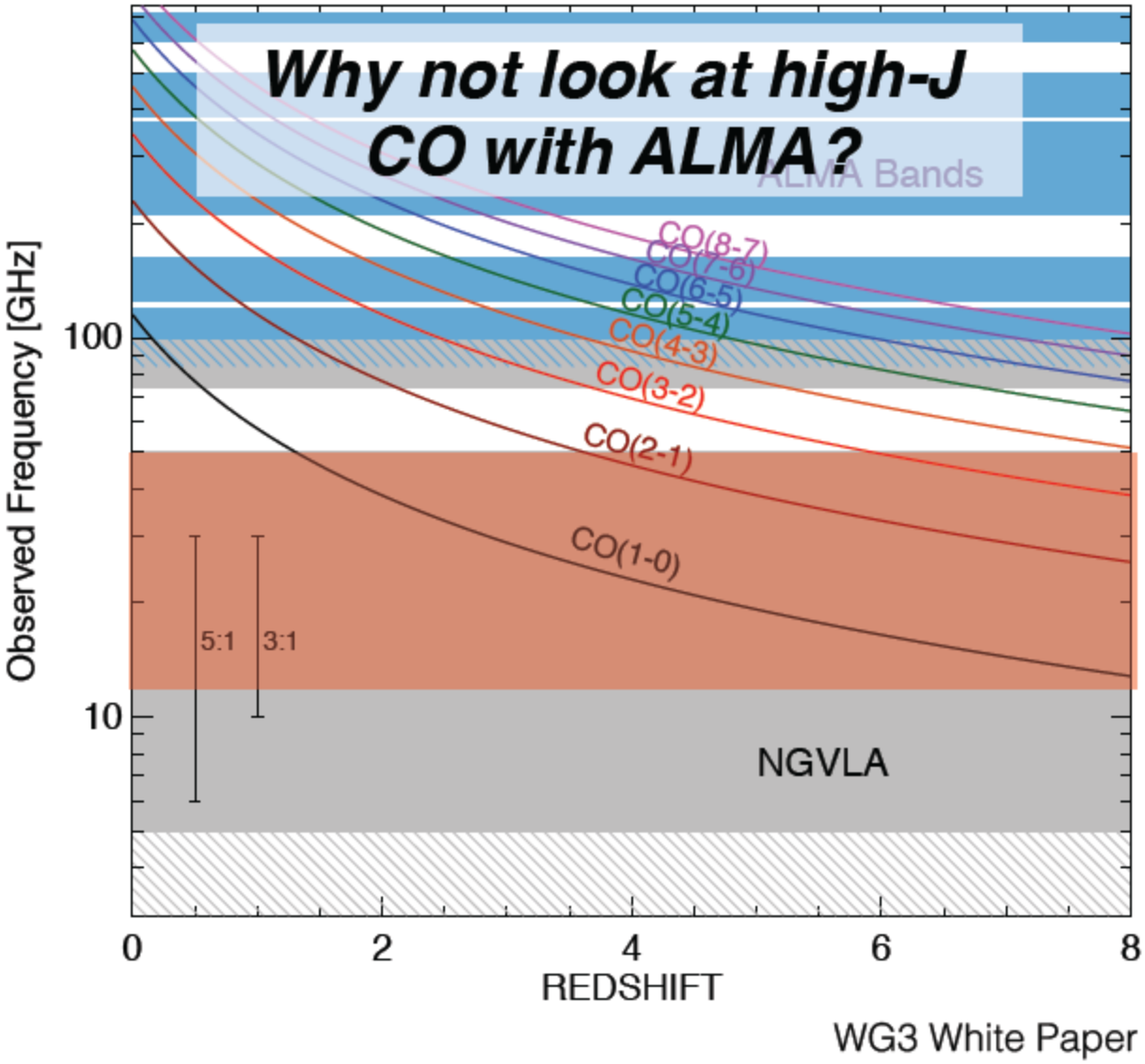


Planet Formation on Milliarcsecond scales



Kraus et al. 2014

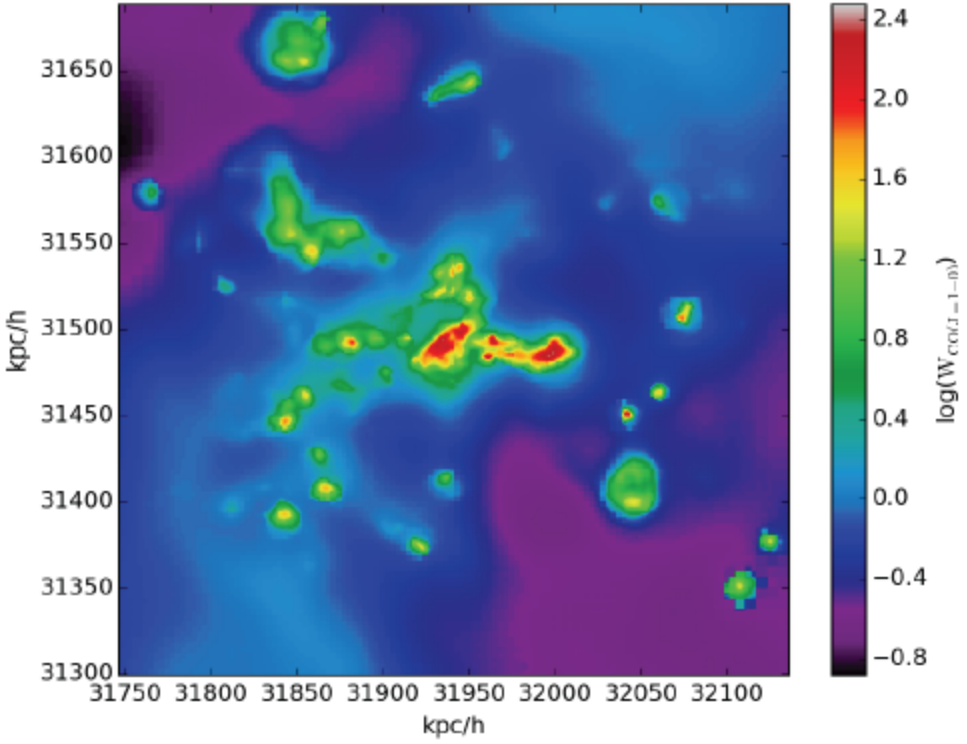
CO: probing H_2, star-forming gas



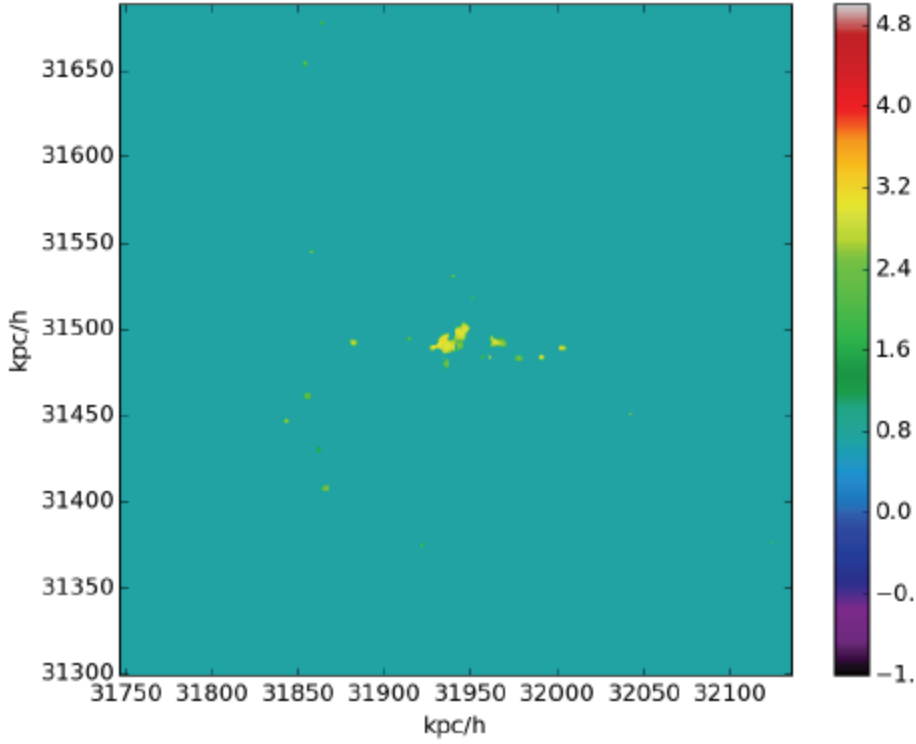
sweet spot

CO: probing H_2, star-forming gas

Simulations perspective:
(Narayanan Powderday RT code)



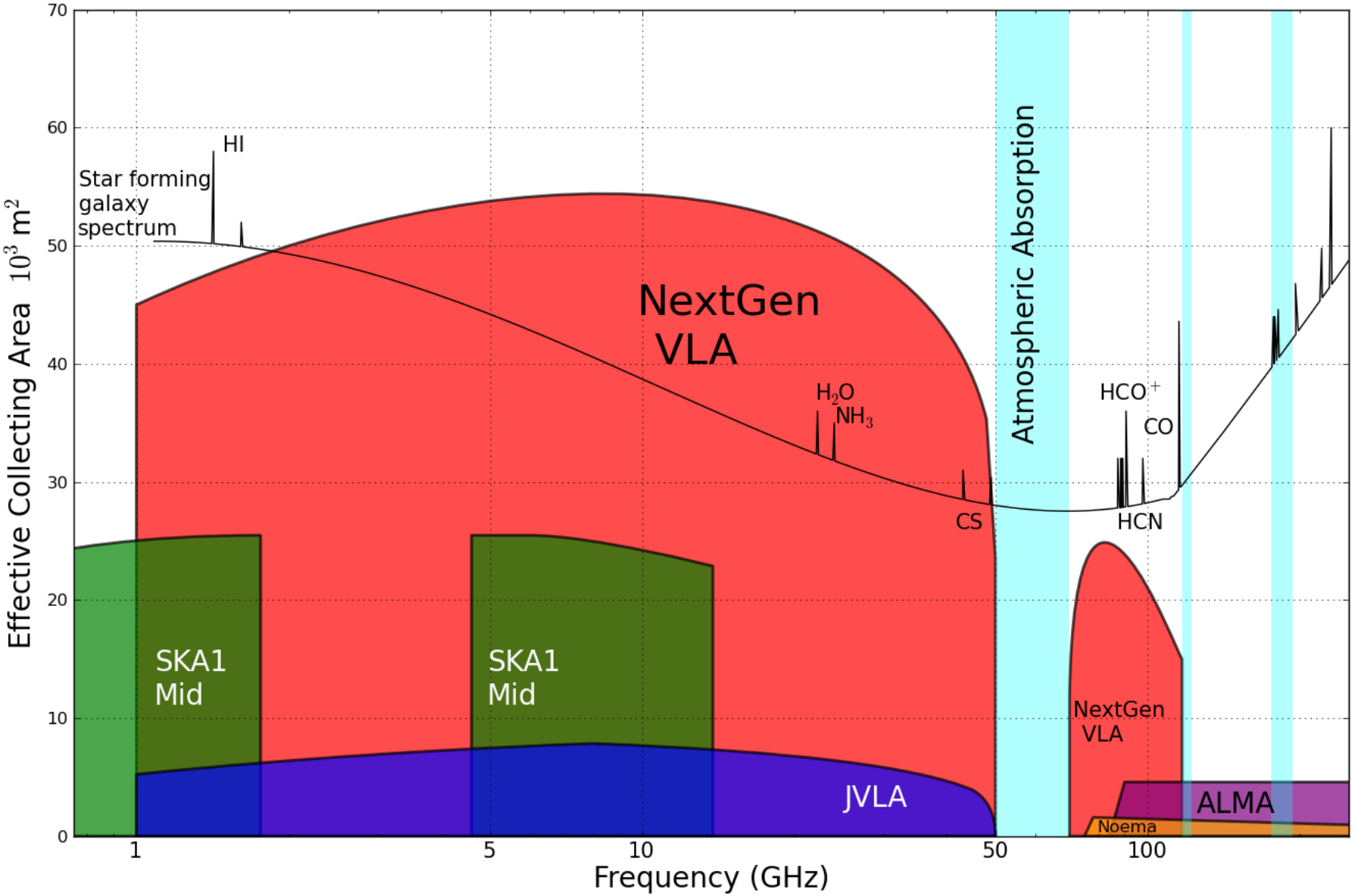
CO(1-0)



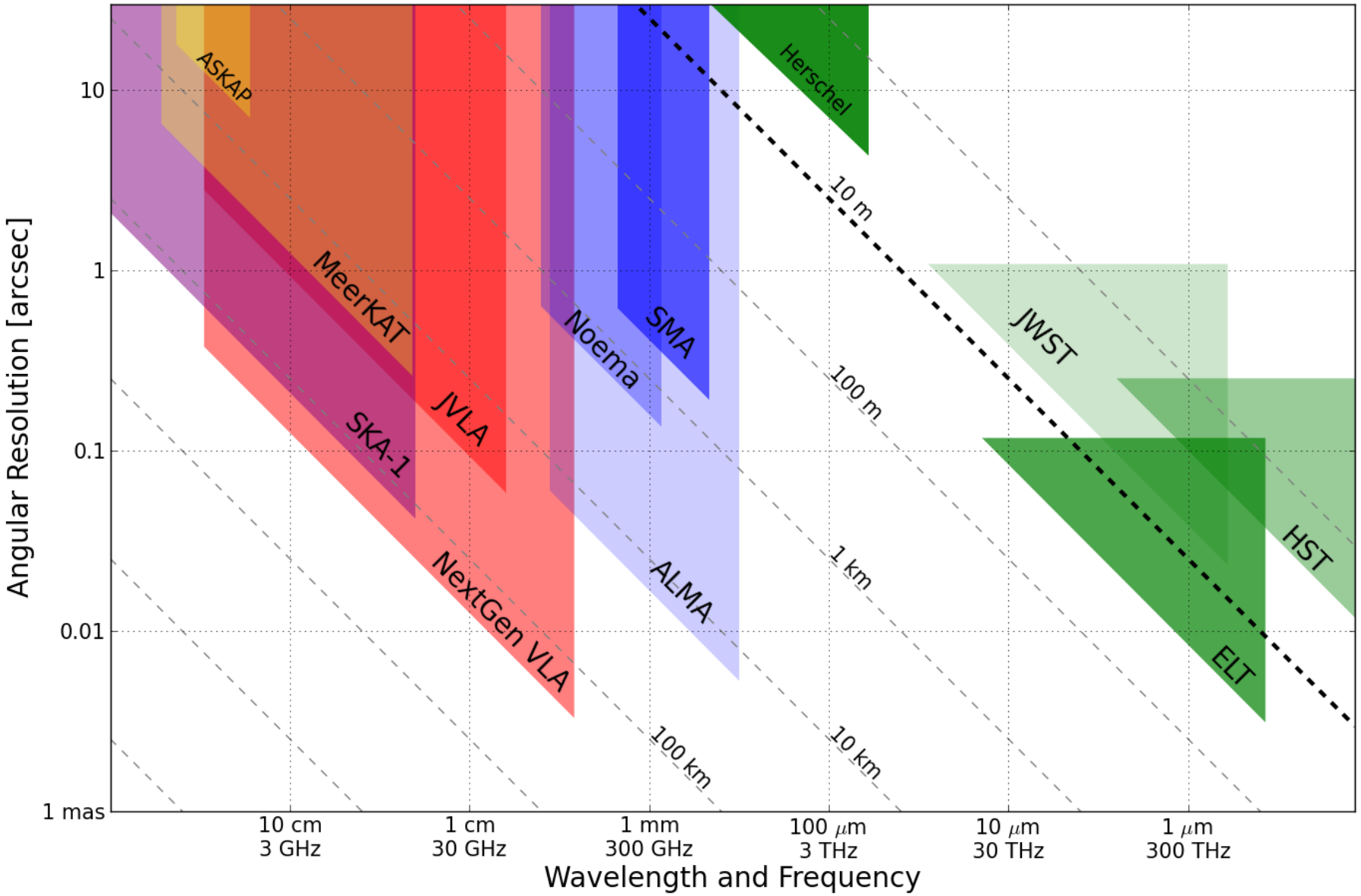
CO(3-2)

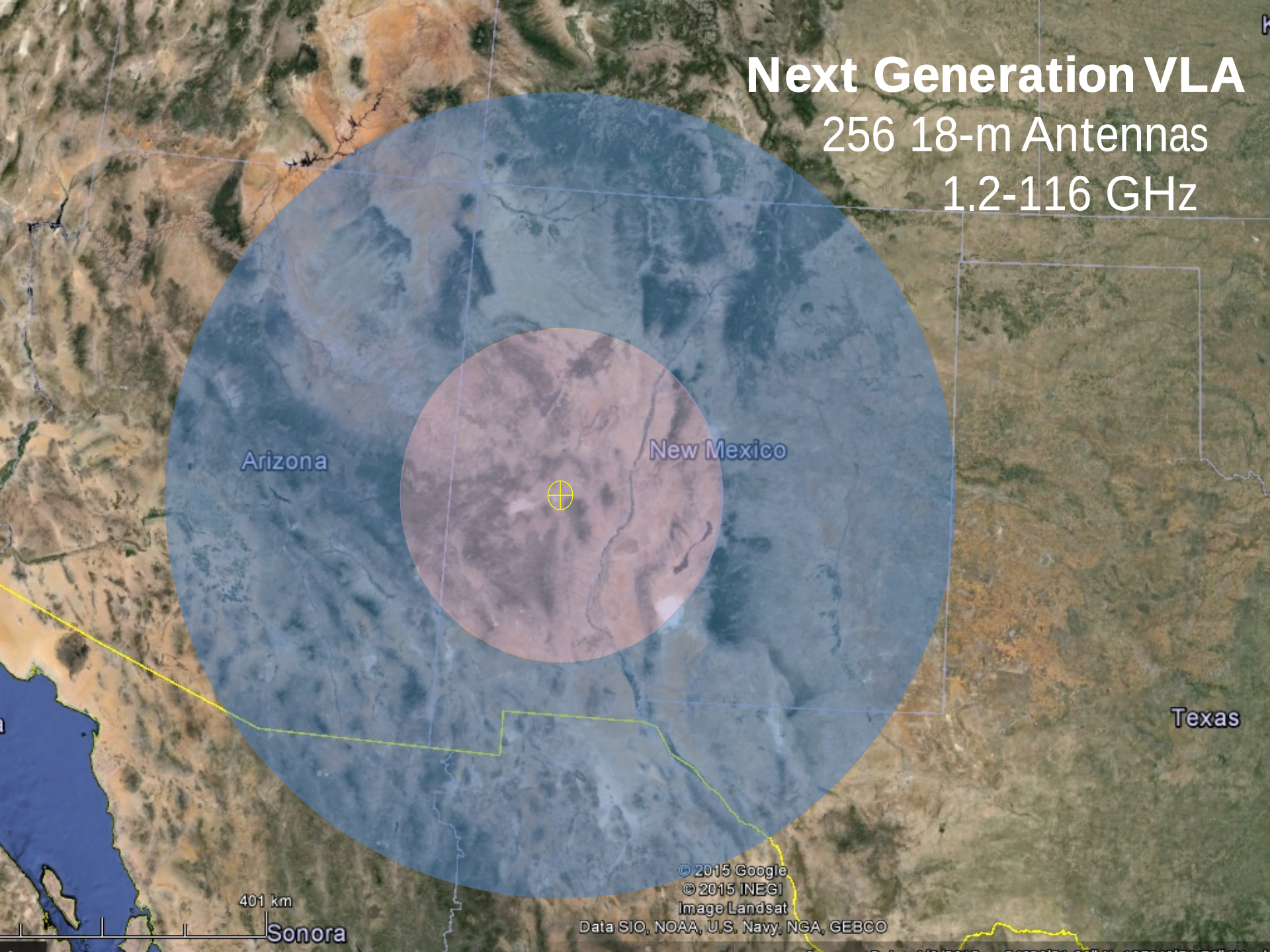
Galaxy variability & failure of high-J transitions to trace molecular gas => CO(1-0) key

ngVLA

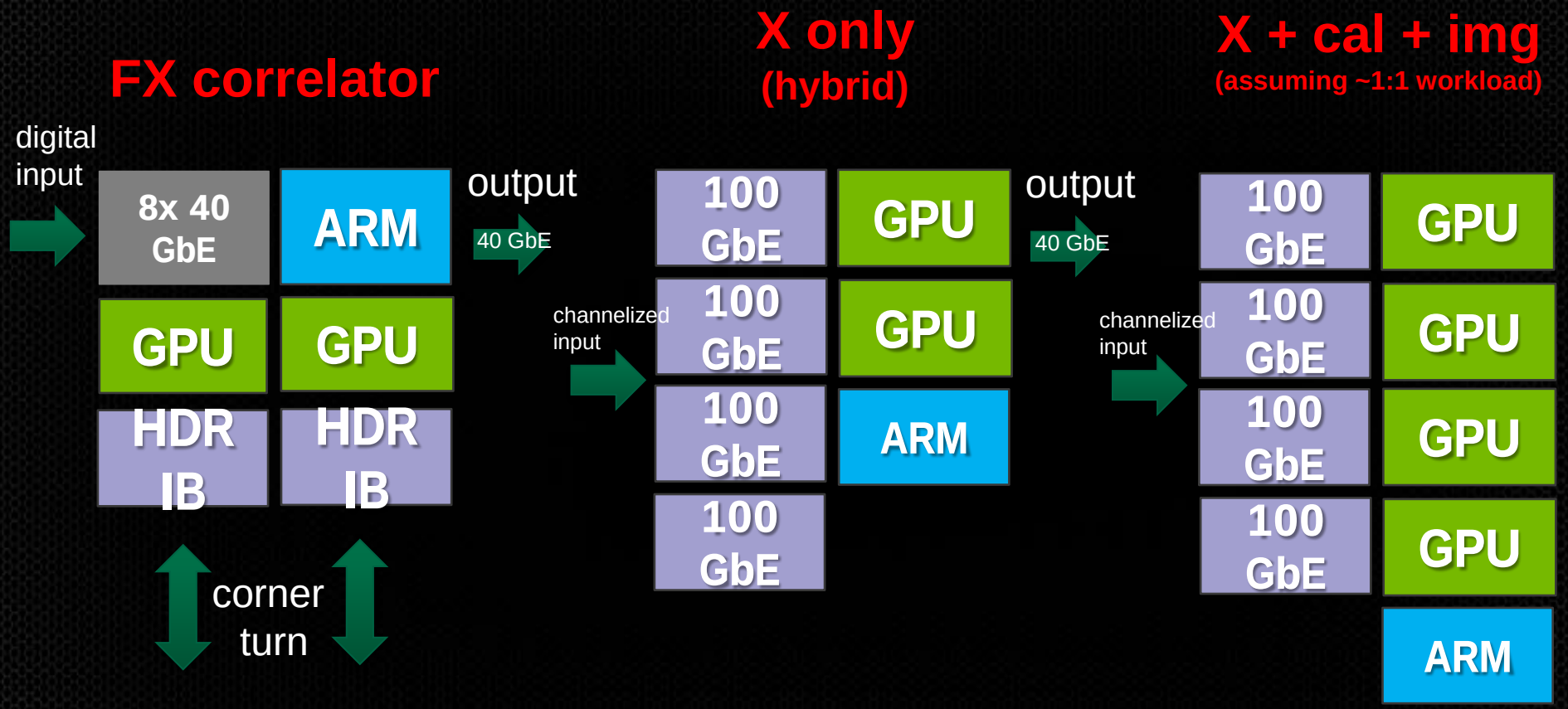

Effective Collecting Area 10^3 m^2
Frequency (GHz)
Star forming galaxy spectrum
HI
NextGen VLA
Atmospheric Absorption
H_2O
NH_3
CS
HCO^+
CO
HCN
SKA1 Mid
SKA1 Mid
JVLA
NextGen VLA
ALMA
Noema

ngVLA


ASKAP
MeerKAT
SKA-1
JVLA
NextGen VLA
Noema
SMA
ALMA
Herschel
JWST
HST
ELT
10 m
100 m
1 km
10 km
100 km
Angular Resolution [arcsec]
10
1
0.1
0.01
1 mas
10 cm
3 GHz
1 cm
30 GHz
1 mm
300 GHz
100 μm
3 THz
10 μm
30 THz
1 μm
300 THz
Wavelength and Frequency


Next Generation VLA
256 18-m Antennas
1.2-116 GHz
Arizona
New Mexico
Texas
Sonora
401 km
© 2015 Google
© 2015 INEGI
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

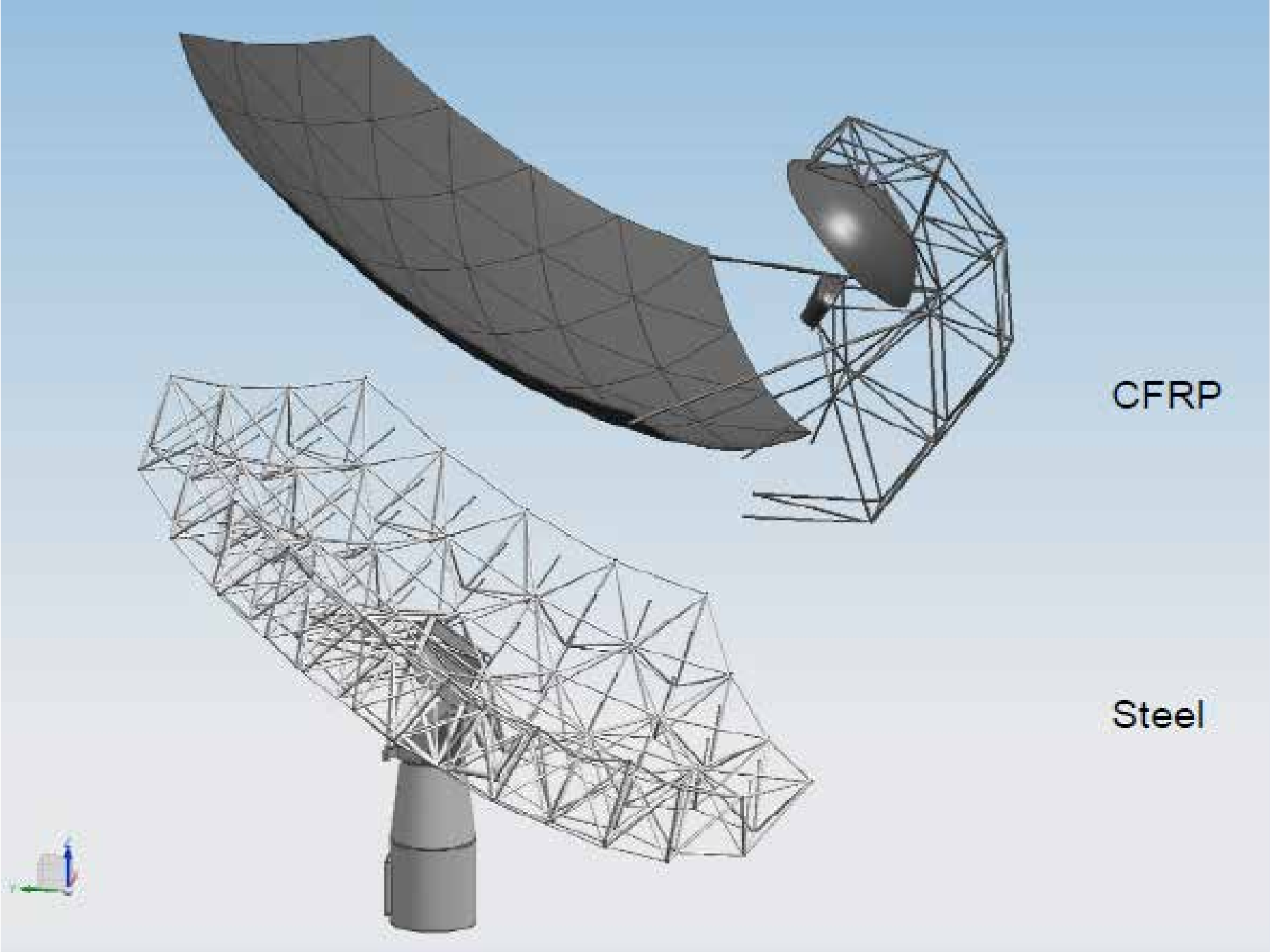
Possible configurations circa 2019



x 512 nodes = 13 racks
$19K per node
$10 M total
185 kW total

x 384 nodes = 10 racks
$15K per node
$5.8 M total
166 kW total (excluding F)

x 384 nodes = 10 racks
$25K per node
$9.6 M total
282 kW total (excluding


CFRP
Steel

ngVLA

- ngVLA – exploring technical/partnership opportunities, benefiting from SKA development (recent meeting @ Caltech)
- Technically – reasonable step beyond current frontier…
- Scientifically – nicely aligned with US community interests
- Strategically – may provide a route for US to join SKA Phase II

- NRAO: explore science/technologies as part of core business
- ngVLA & SKA – complement, not competition
- One option to be considered as part of Kavli meeting process

US RMS Interests in 2020s

- Building on incredible successes past 15+ years…
- Begin US ASTRO2020 process – explore opportunities
- Significant new funding is hard (Construction easier than Ops)
- Global RMS community – continue technology development, student/staff exchanges, joint programs
- SKA - hoping to arrive late to the battle…
- Proud to participate/collaborate scientifically e.g. JIVE/ERIC

- 2030s – upgrading ALMA (FOV, correlator, baselines..)

- Great science opportunities ahead… US will be there.

SURVIVAL

When you are in deep trouble,
say nothing, and try to look like
you know what you're doing.

www.nrao.edu
science.nrao.edu

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