Measuring IPv6 Adoption

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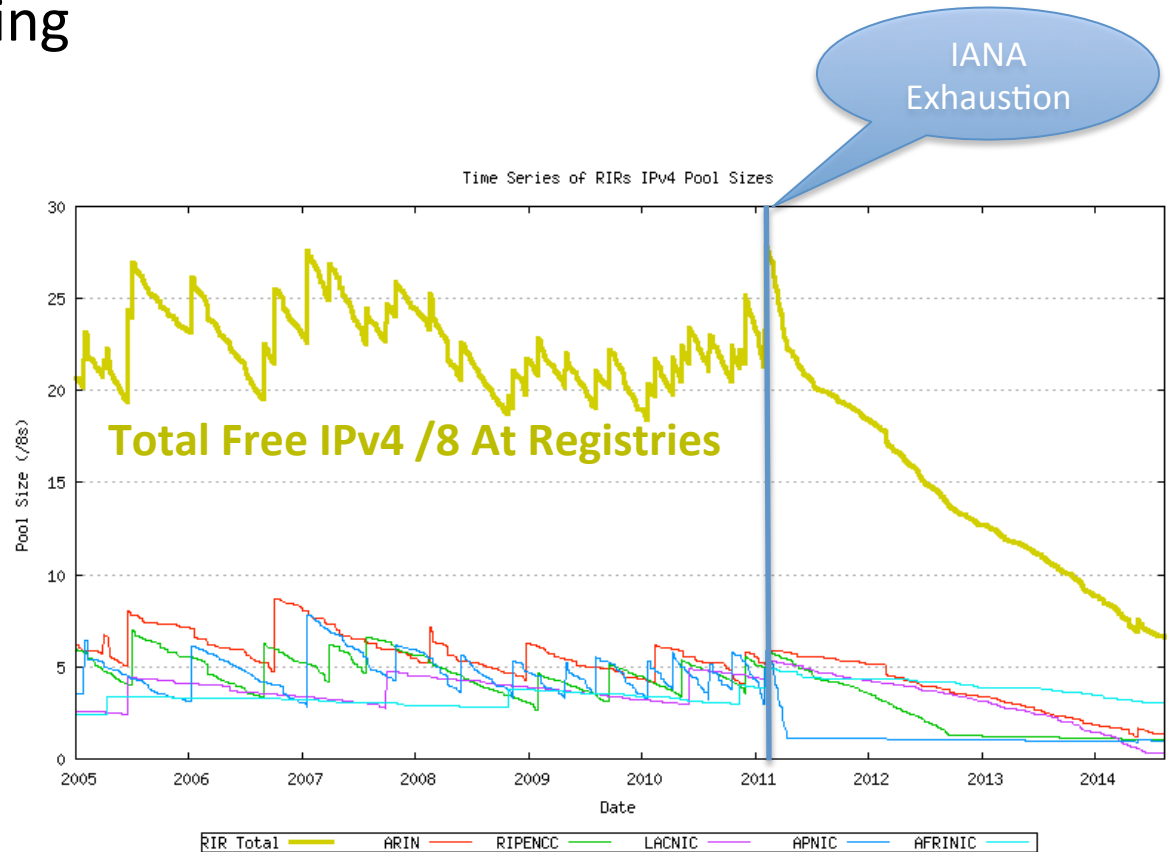
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Why Study IPv6 Adoption Now?

- Internet continues growing

- IPv4 space shrinking...

- IPv4 exhaustion events:
  - **IANA: February 2011**
  - Asia/Pacific: April 2011
  - Europe: September 2012
  - Latin America: June 2014

- IPv6 Community Flag Days
  - 2011 & 2012

(Image source: Geoff Huston, http://www.potaroo.net/tools/ipv4)

Our Study

- **Goal:** a systemic "big picture" of IPv6 adoption
  - Trading off depth for breadth
  - Are there cross-perspective insights?
- **Multi-perspective**: 10 datasets
- **Multi-year**: 2-10 years
- **Multi-aspect**: 12 metrics
- **Findings: IPv6 adoption**
  - varies by where you measure (region)
  - varies by what you measure
  - recently made a qualitative jump

Data Analyzed

- **Existing/Public Datasets**:
  - RIR allocation
  - Route Views BGP, RIPE-RIS BGP
  - Google.com clients,
  - Verisign zone files,
  - CAIDA Ark RTT

- **New Datasets**:
  - **Traffic**: Arbor Networks global traffic
  - **Naming**: Verisign .com/.net queries via IPv4, via IPv6
  - **Content**: Testing data of Alexa top-10K sites

Metrics

Prerequisite IP Functions

- Address Allocation
- Address Advertisement
- Topology
- DNS Name servers
- DNS Resolvers
- DNS Queries
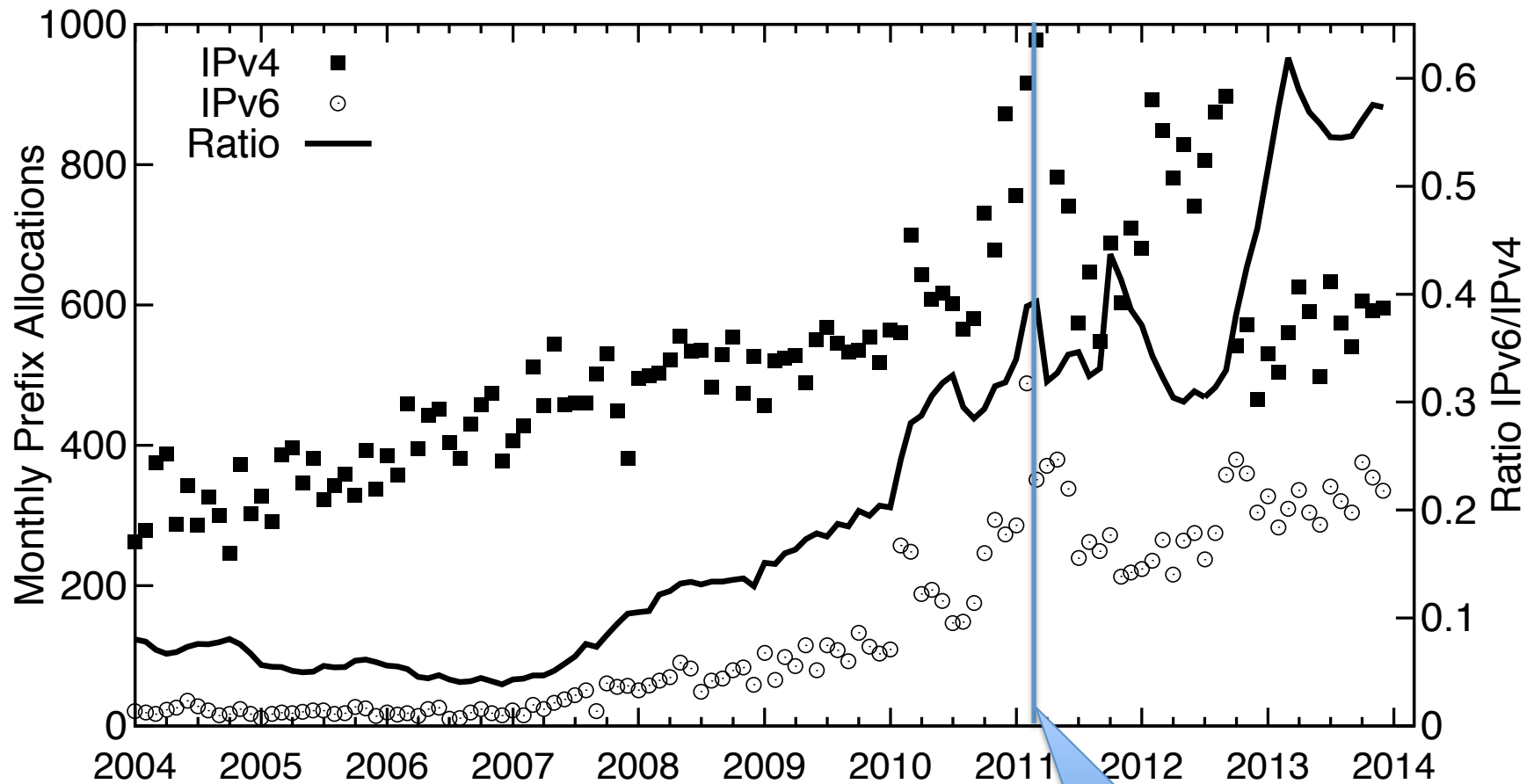- Server Readiness
- Client Readiness

Operational Characteristics

- Traffic Volume
- Application Mix
- Transition Technologies
- Performance (RTT)

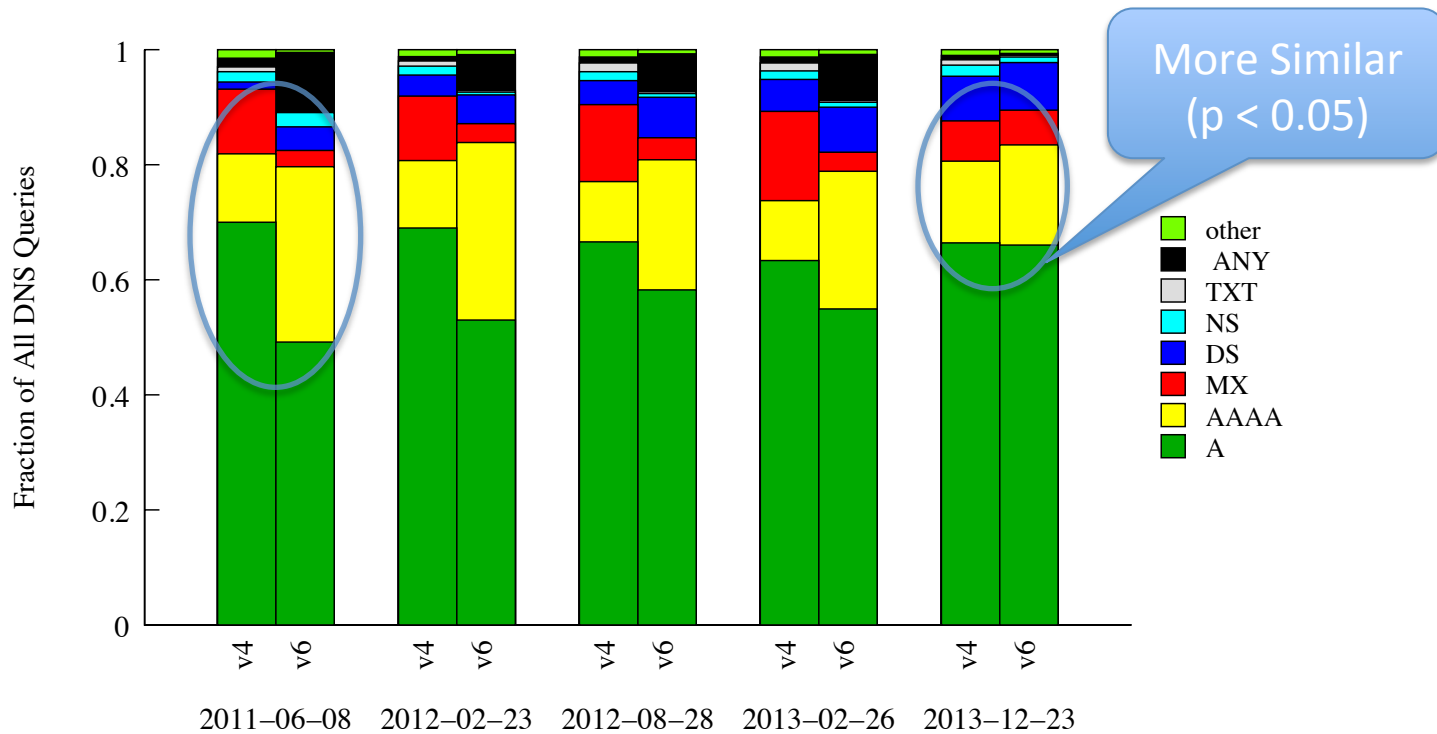"IPv6 adoption" = level relative to IPv4

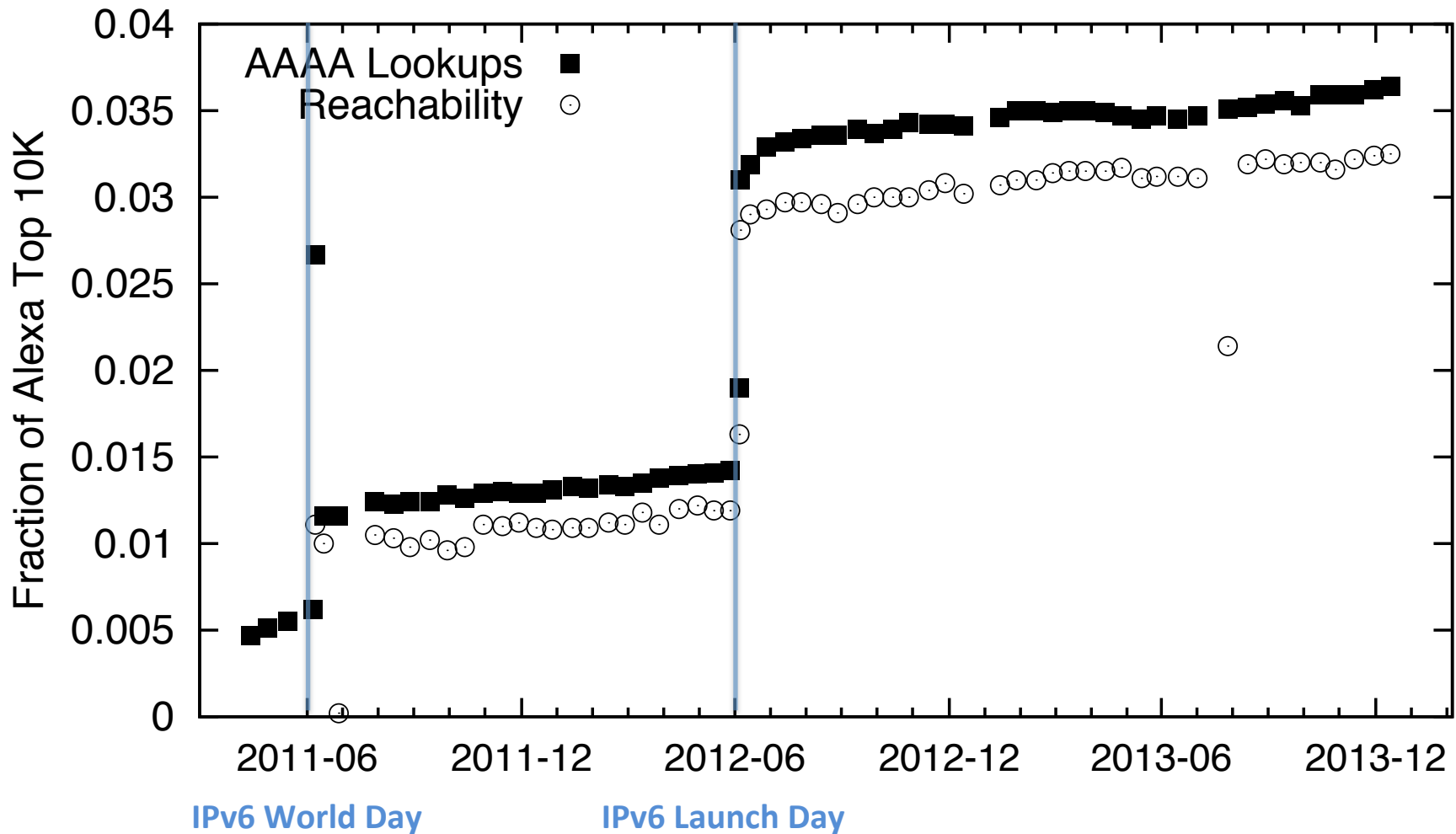# METRICS (PREREQUISITE)

Prefix Allocation

Naming: Domains & Record Types

- Queries from .com/.net; IPv4 & IPv6 name servers
  - Five day-long packet samples over 2.5 years
  - IPv6 DNS users query similar **domains** as IPv4
  - Query **types** are converging over this time period:

More Similar
(p < 0.05)

Legend:
- other
- ANY
- TXT
- NS
- DS
- MX
- AAAA
- A

X-axis dates: 2011–06–08 2012–02–23 2012–08–28 2013–02–26 2013–12–23

Y-axis: Fraction of All DNS Queries

Server Readiness:
Alexa Top Domain Reachability

Measuring IPv6 Adoption – Czyz et al.

Client Readiness:
visitors to google.com

(Data method in Colitti et al., 2010)

+43%

−7%

+61%

+147%

+151%

Fraction Clients Using IPv6

0.025
0.02
0.015
0.01
0.005
0

2009   2010   2011   2012   2013   2014

METRICS (OPERATIONAL)
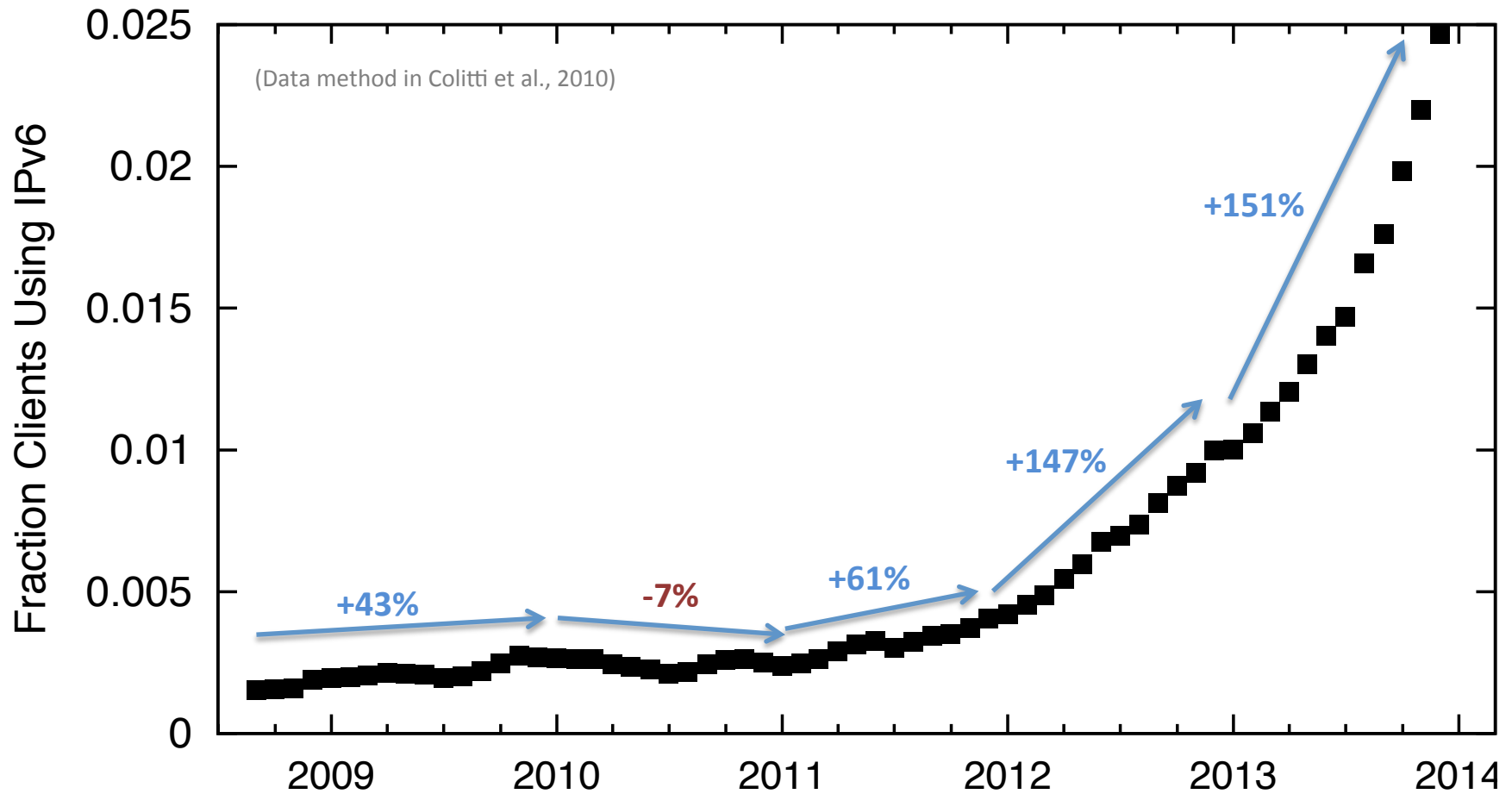
Measuring IPv6 Adoption – Czyz et al.

Global Traffic

- Arbor Networks global provider netflow data
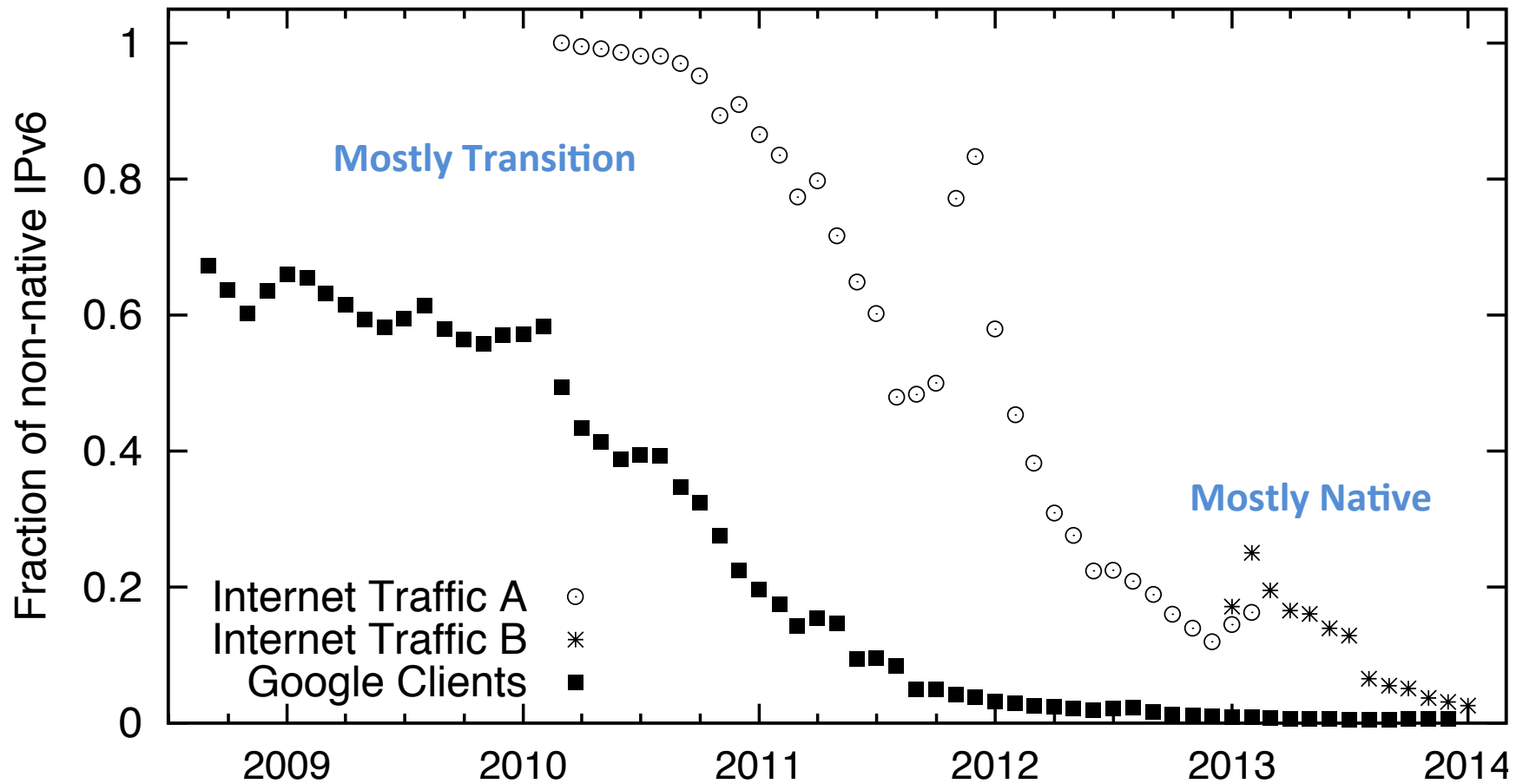 - 260 service providers (Dataset B) ~ 1/3 – 1/2 of all inter-AS traffic
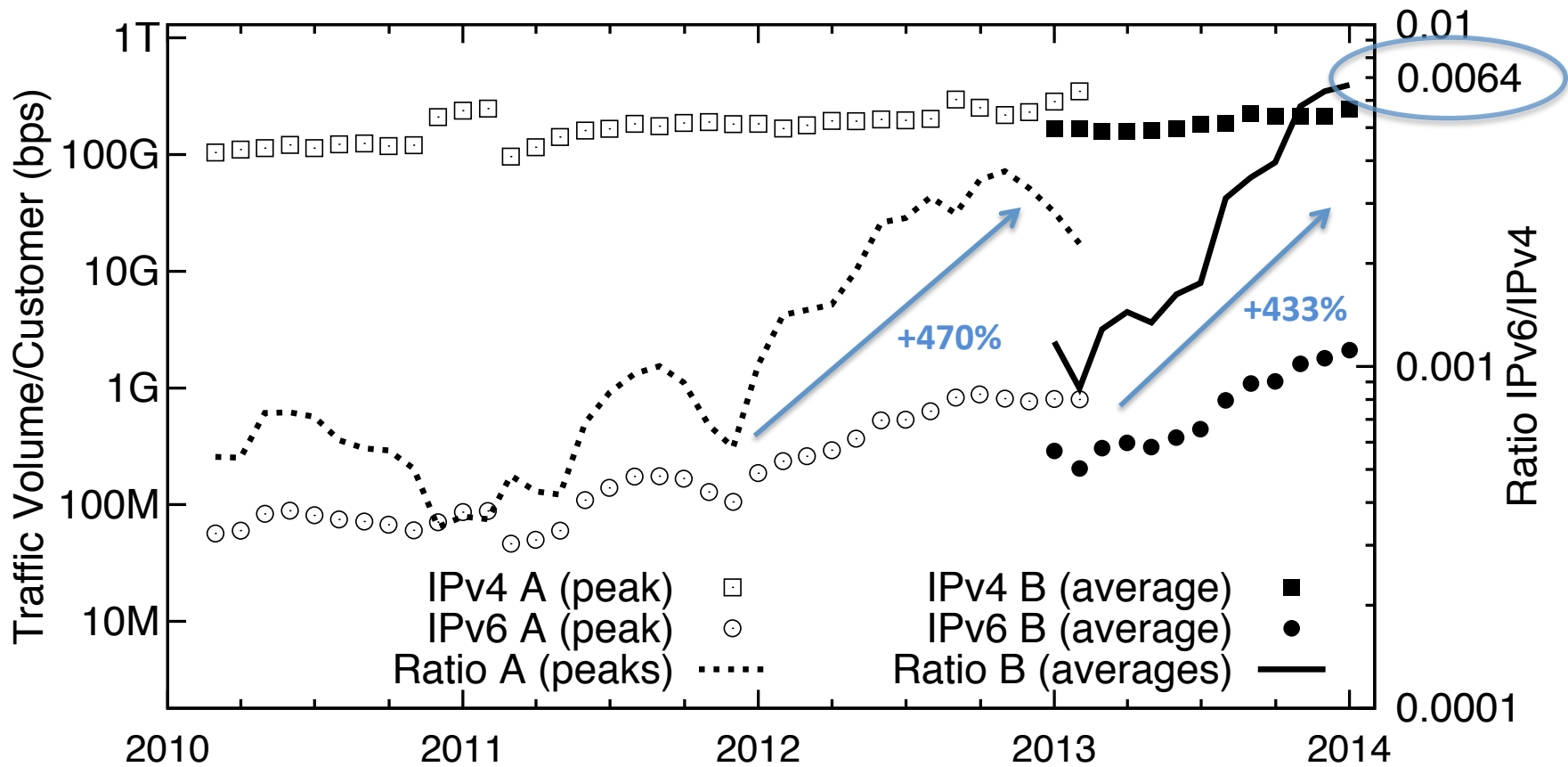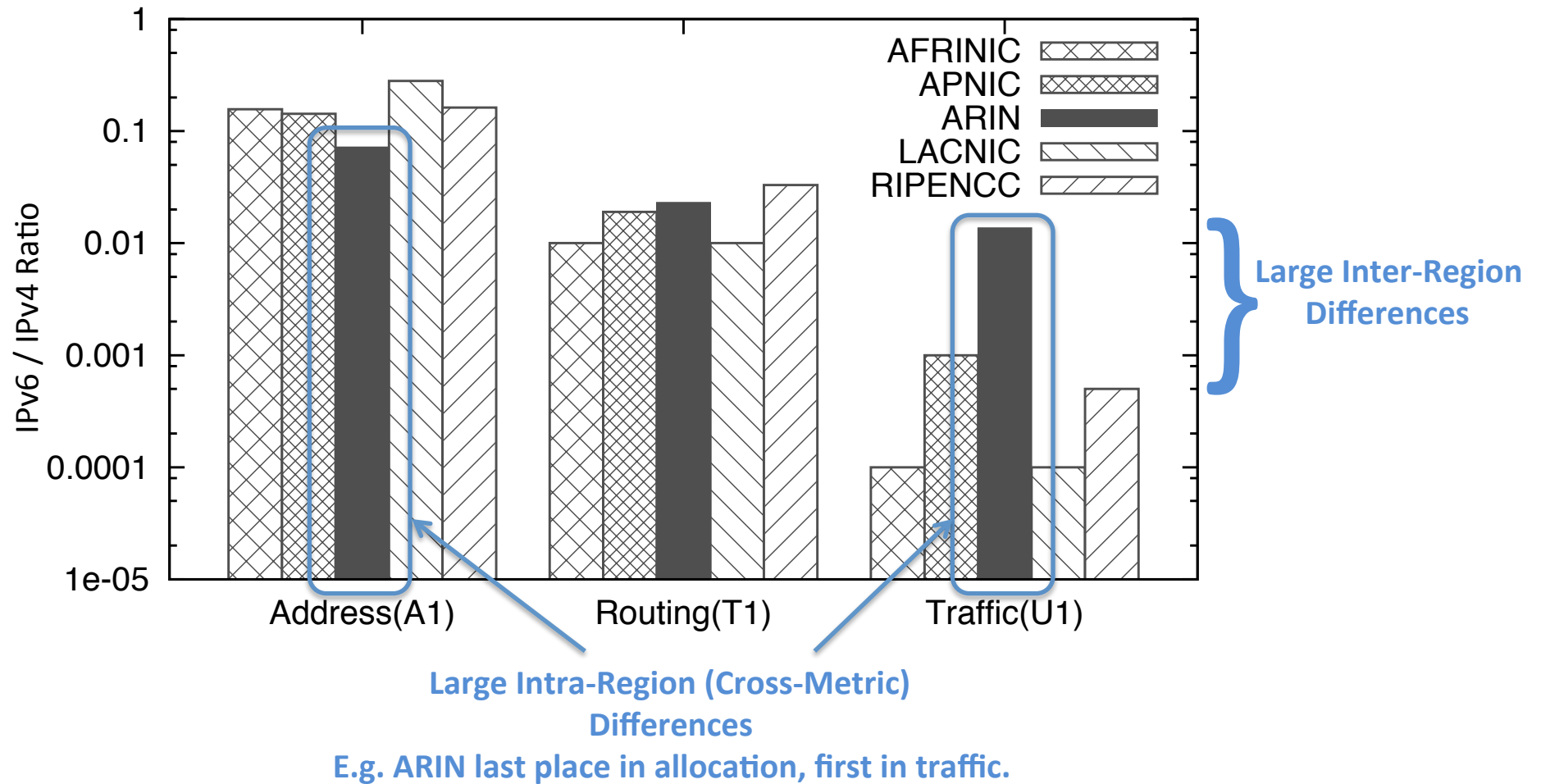
Application Mix
(% of IPv6)

User content {

| Application | Dec 2010 | Apr–Dec 2013 | |
	IPv6	IPv6	IPv4
HTTP	5.61	82.56	60.61
HTTPS	0.15	12.66	8.59
DNS	4.75	0.33	0.22
SSH	0.56	0.27	0.20
Rsync	20.78	0.13	0.00
NNTP	27.65	0.00	0.25
RTMP	0.00	0.00	2.74
Other TCP	*	1.66	4.08
Other UDP	*	0.27	2.82
Non-TCP/UDP	*	2.11	20.21

IPv6 Transition Technologies
(Teredo + 6to4)

CONCLUSIONS

Conclusion 1: Regions Differ

Large Inter-Region Differences

Large Intra-Region (Cross-Metric) Differences
E.g. ARIN last place in allocation, first in traffic.

Conclusion 2: Perspective Matters

IPv6 / IPv4 Ratio

- P1 (performance)
- A1 (allocation - monthly)
- A1 (allocation - cumulative)
- A2 (advertisement)
- T1 (topology)
- R2 (Google clients)
- N1 (.com NS)
- U1 (traffic - A.peaks)
- U1 (traffic - B.averages)

2-3 order of magnitude difference
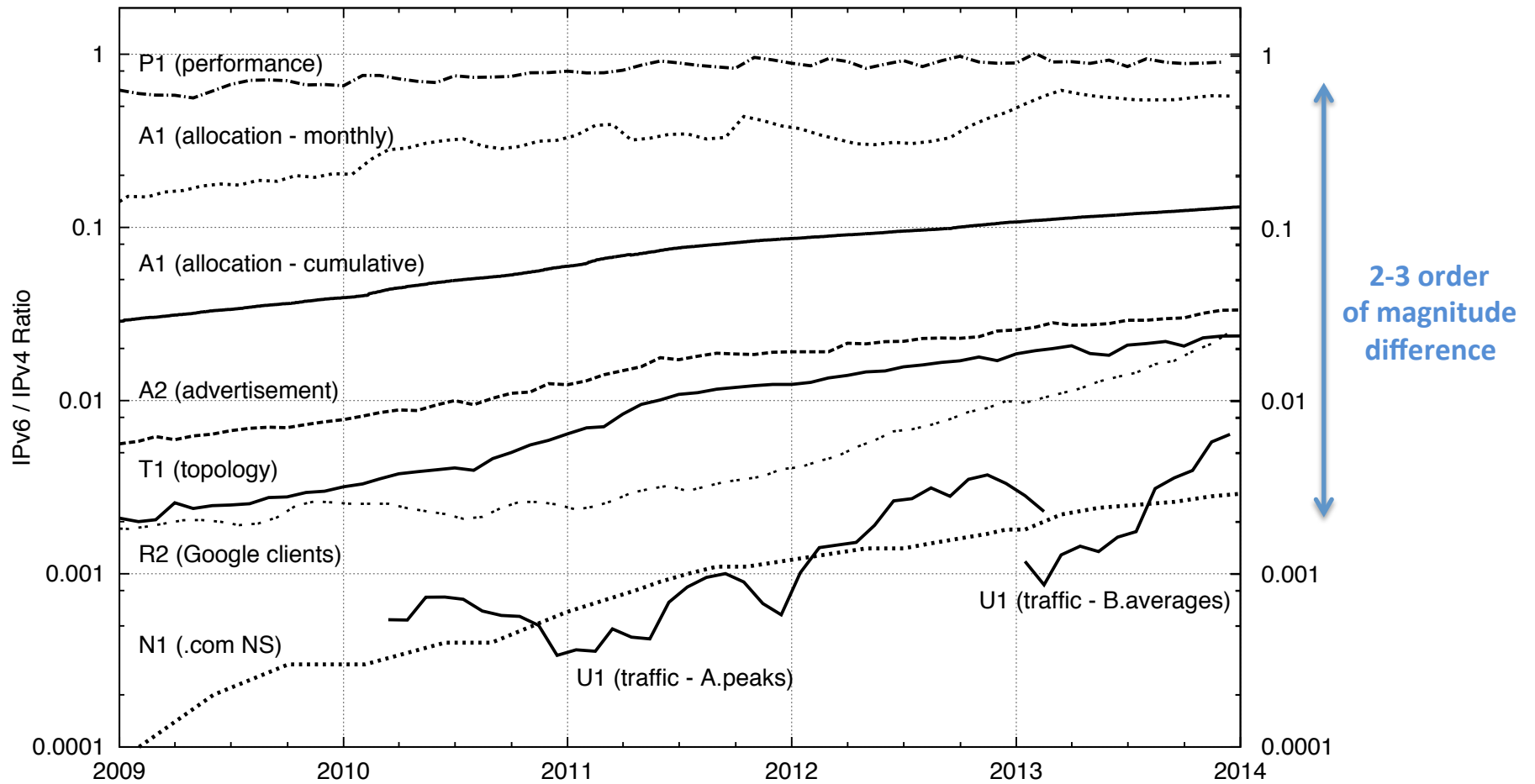
Conclusion 3: IPv6 is Real!

Operational Aspect Measured	IPv6 Status at End of:	
	2010	2013
IPv6 Percent of Internet Traffic	0.03%	0.64%
1-yr. Growth vs. IPv4 (*Mar-2010 – Mar-2011)	−12%*	+433%
Content's Portion of Traffic (HTTP+HTTPS)	6%	95%
Native IPv6 Packets vs. All IPv6	9%	97%
Native IPv6 Google Clients	78%	99%
Performance: 10-hop RTT^{-1} vs. IPv4	75%	95%

← **20x growth!**

← **15x growth!**

← **Traffic Flipped**

← **Nearly on-par**

Thank You!

Questions?

BACKUP SLIDES

Internet Devices and Users Continue to Increase

Billions of Devices

11% CAGR 2013–2018

Other Portable Devices (5.2%, 4.1%)
Tablets (2.3%, 5.0%)
PCs (12.2%, 7.0%)
TVs (10.0%, 12.8%)
Non-Smartphones (37.6%, 16.8%)
Smartphones (14.1%, 19.1%)
M2M (18.6%, 35.2%)
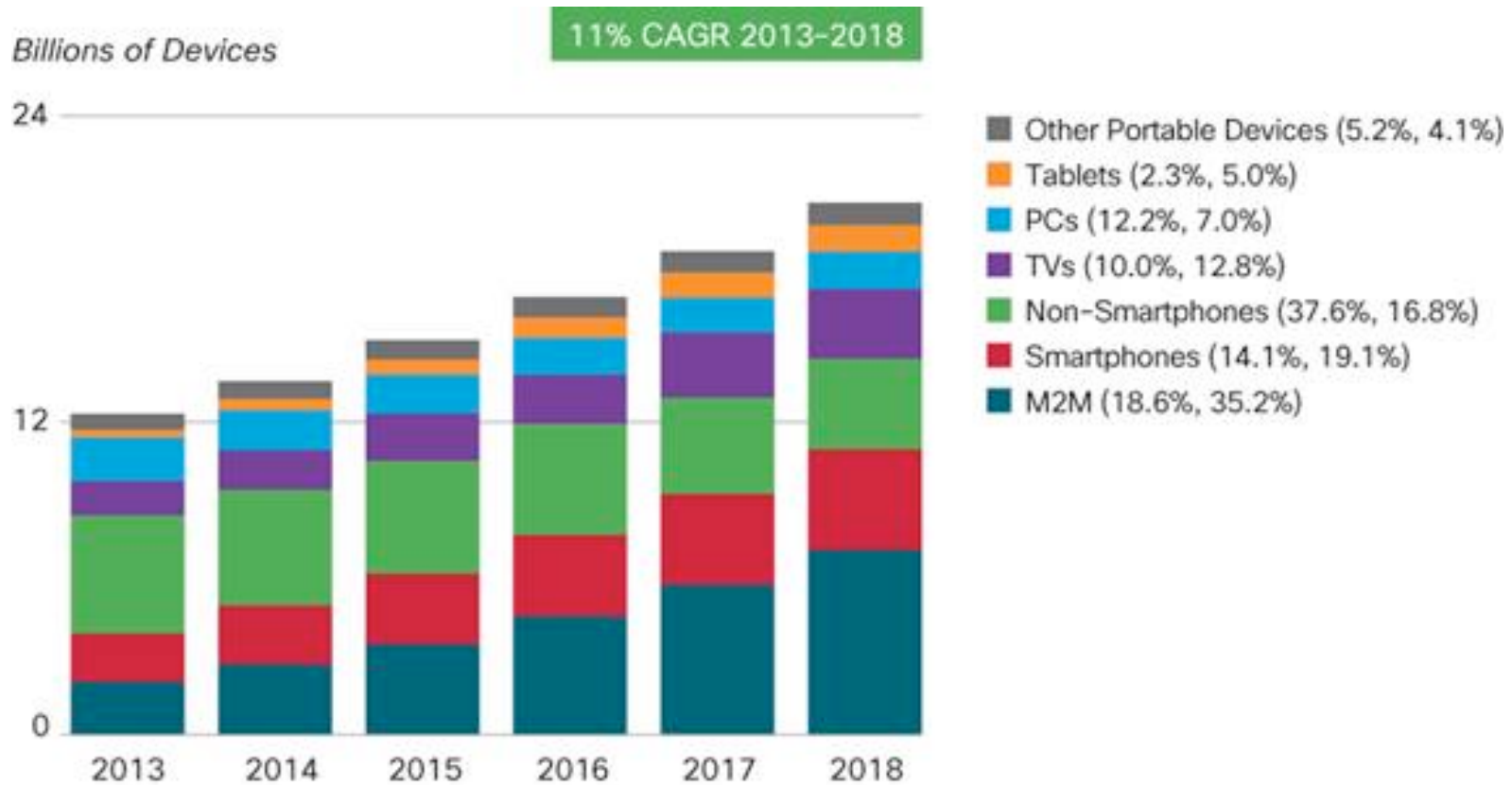
Source: Cisco VNI, 2014
The percentages in parentheses next to the legend denote the device share for the years 2013 and 2018, respectively.

Dataset Summary

| Dataset	Metrics	Time Period	Recent Scale
RIR Address Allocations	A1	Jan 2004 – Jan 2014	≈18K allocation snapshots (5 daily)
Routing: Route Views	A2, T1	Jan 2004 – Jan 2014	45,271 BGP table snapshots
Routing: RIPE	A2, T1	Jan 2004 – Jan 2014	
Google IPv6 Client Adoption	R2, U3	Sep 2008 – Dec 2013	millions of daily global samples
Verisign TLD Zone Files	N1	Apr 2007 – Jan 2014	daily snapshots of ≈2.5 million A+AAAA glue records (.com & .net)
CAIDA Ark Performance Data	P1	Dec 2008 – Dec 2013	≈10 million IPs probed daily
Arbor Networks ISP Traffic Data	U1, U2, U3	Mar 2010 – Dec 2013	≈33-50% of global Internet traffic; 2013 daily median: 50 terabits/sec (avg.)
Verisign TLD Packets: IPv4	N2, N3	Jun 2011 – Dec 2013	4 global sites, 5 of 13 gTLD NS letters (.com/.net), ≈4.5Bn queries /day
Verisign TLD Packets: IPv6	N2, N3	Jun 2011 – Dec 2013	15 global sites, both gTLD NS letters (.com/.net) w/IPv6, 647M queries/day
Alexa Top Host Probing	R1	Apr 2011 – Dec 2013	10,000 servers probed twice/month

Prefix Advertisement
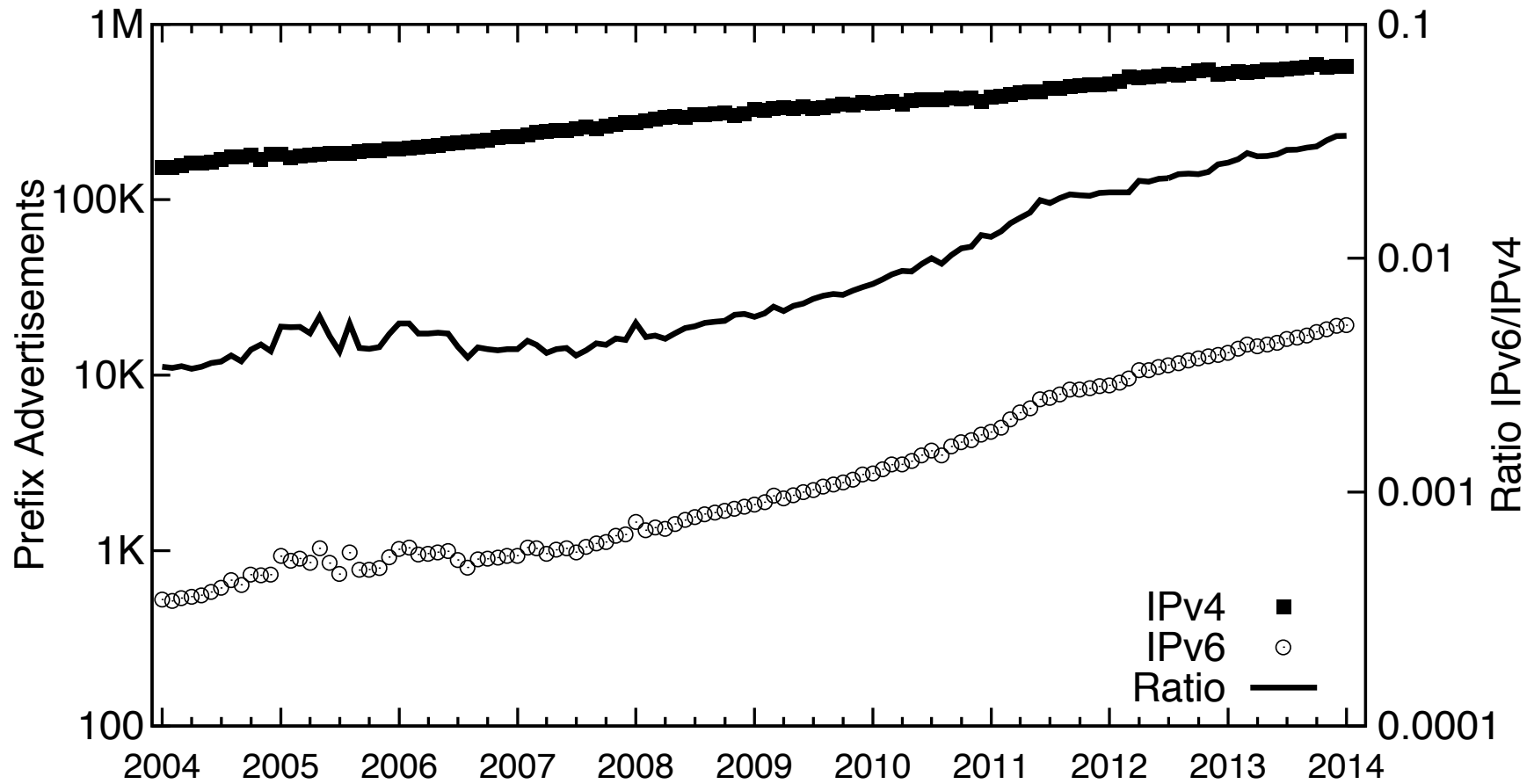
AS Centrality
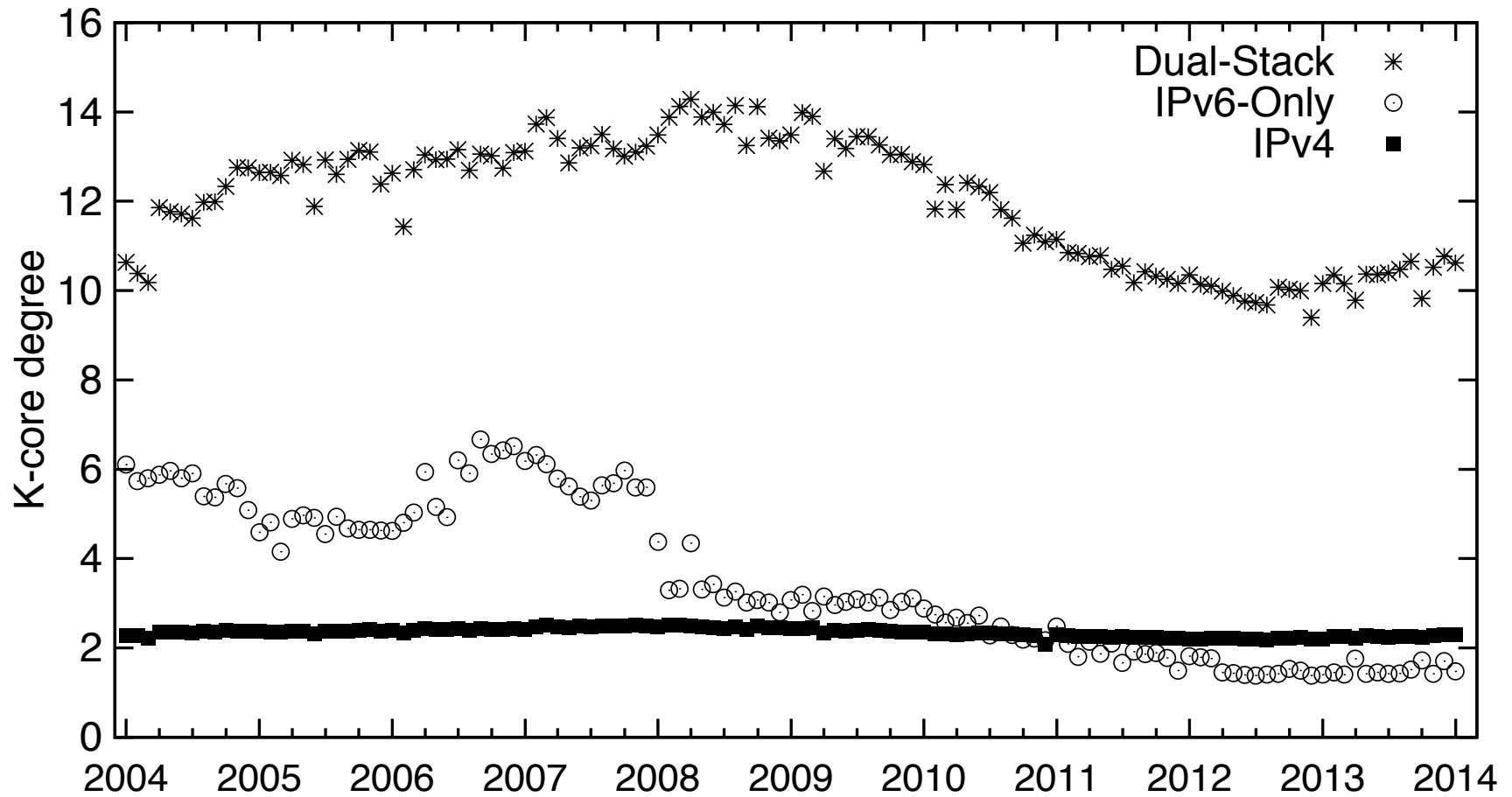
DNS: .com & .net Zones
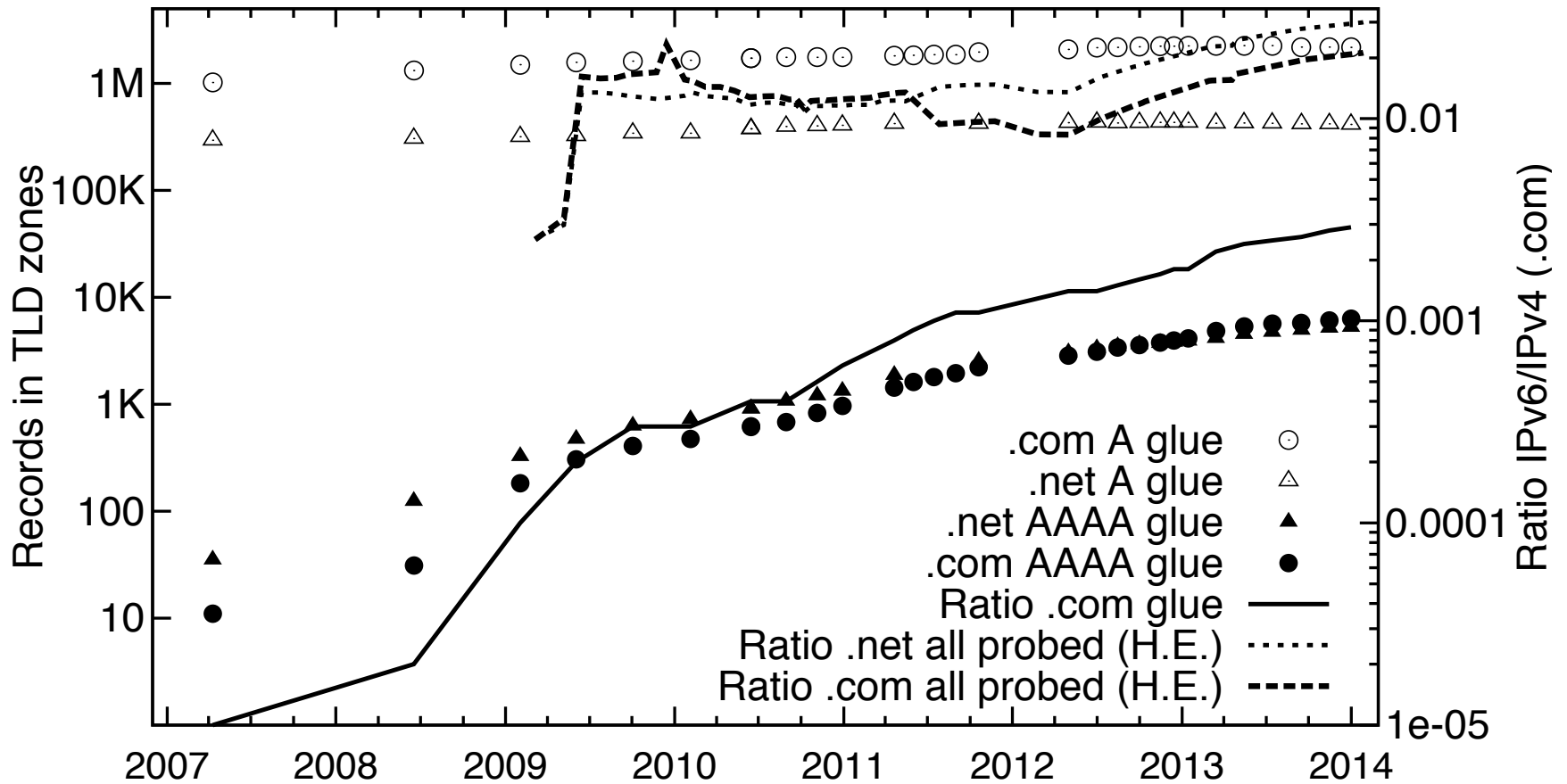
IPv4 .com/.net TLD A and AAAA Query Rank Correlation (Spearman's ρ)

Domain Lists	2011-06-08	2012-02-23	2012-08-28	2013-02-26	2013-12-23
4.A : 6.A	0.65	0.73	0.70	0.70	0.57
4.AAAA : 6.AAAA	0.69	0.80	0.82	0.74	0.68
4.A : 4.AAAA	0.32	0.32	0.35	0.34	0.42
6.A : 6.AAAA	0.29	0.23	0.20	0.26	0.32

Within type: **Strong**

Across type: Weak

Naming: Domains

- Queries from .com/.net; IPv4 & IPv6 name servers
  - Five day-long samples over 2.5 years
- Four sets of top 100k domains:
  - For both IPv4 and IPv6 packets (user populations)
  - Within each, for domains queried by A and AAAA
- Finding: IPv4 to IPv6 populations correlate strongly for the same query type {A,AAAA}
  - e.g. Spearman's ρ of 0.7 for IPv4 A versus IPv6 A
- So, IPv6 DNS users query similar domains as IPv4

Performance
(using 10- and 20-hop RTT)

Projections

A1 (allocation - cumulative)

U1 (traffic - A.peaks)

Polynomial Proj. (A1:R_2^2 = 0.996; U1:R_2^2 = 0.838)
Exponential Proj. (A1:R^2 = 0.984; U1:R^2 = 0.892)