The nature of the AS-level graph 1997 – 2009. And beyond?

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ENDS Seminar, 03-02-2009
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Introduction

- Routeviews.org stores archived BGP routing state, stretching back to 1997

  - Here, using data between 1997-11-08 and 2009-12-31
  - Only looking at relationships; not looking at prefixes

- The network continues to grow, but some properties or relationships do not seem to change

  - These invariants may be useful to evaluate models of future Internet graphs
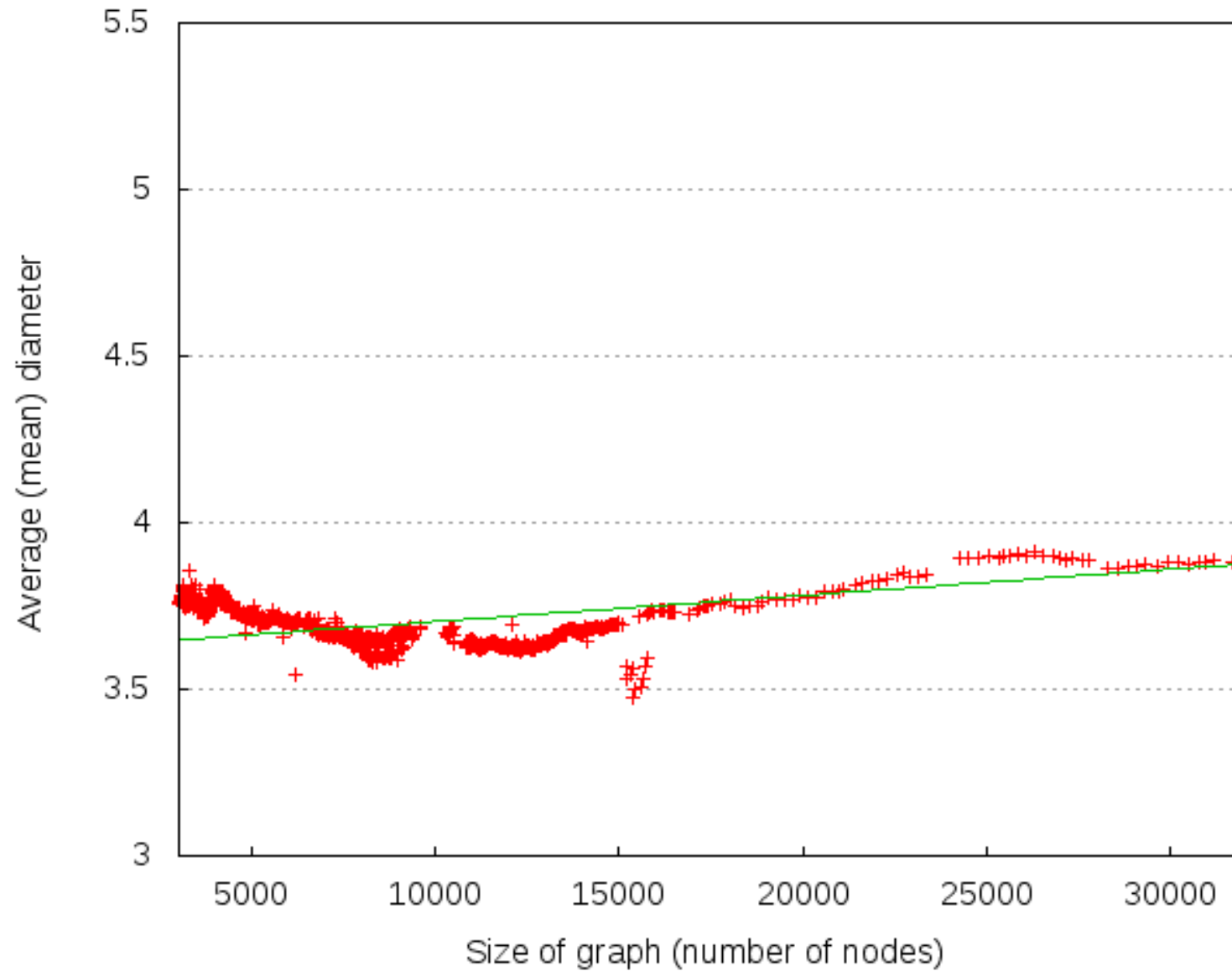
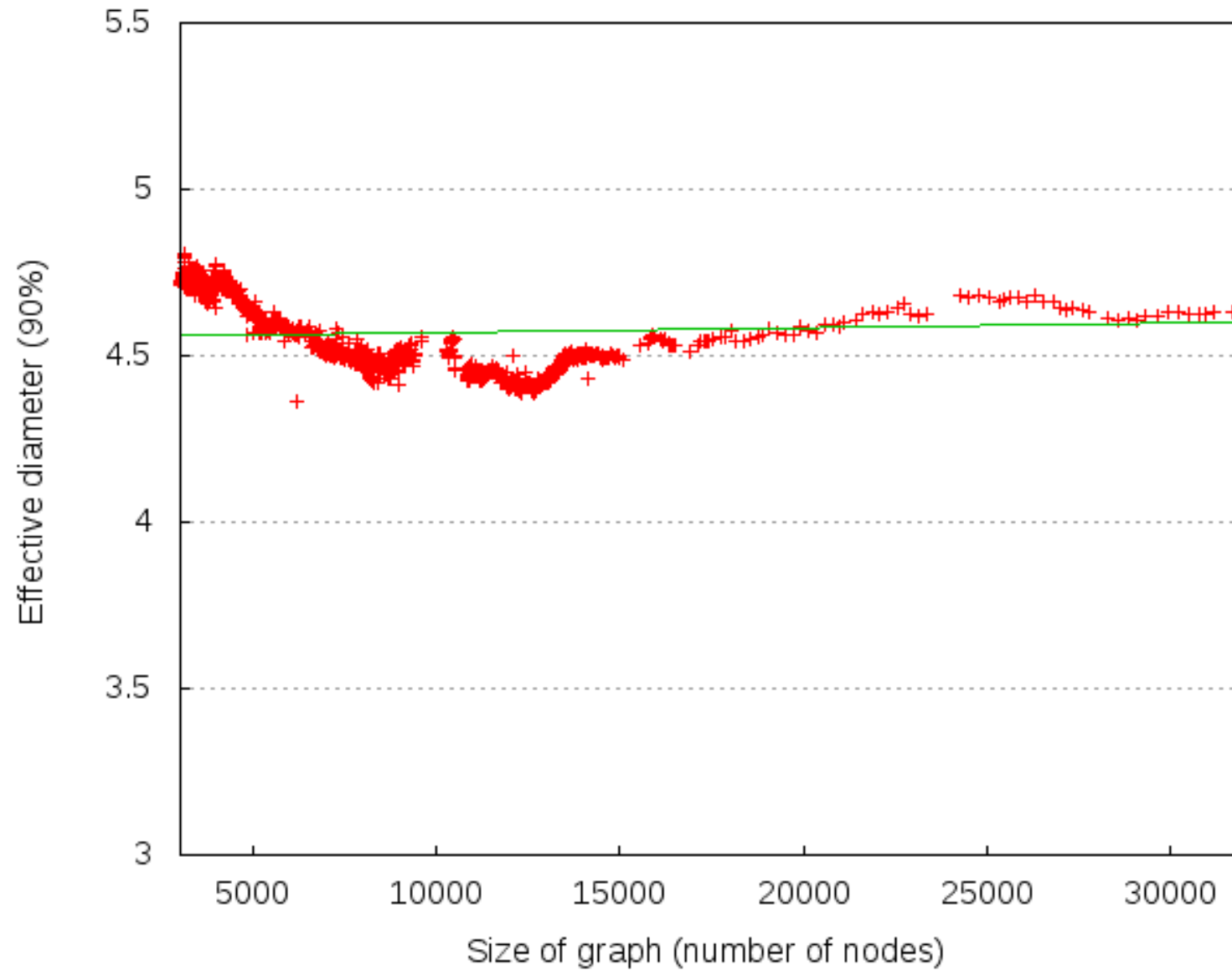# Network Growth

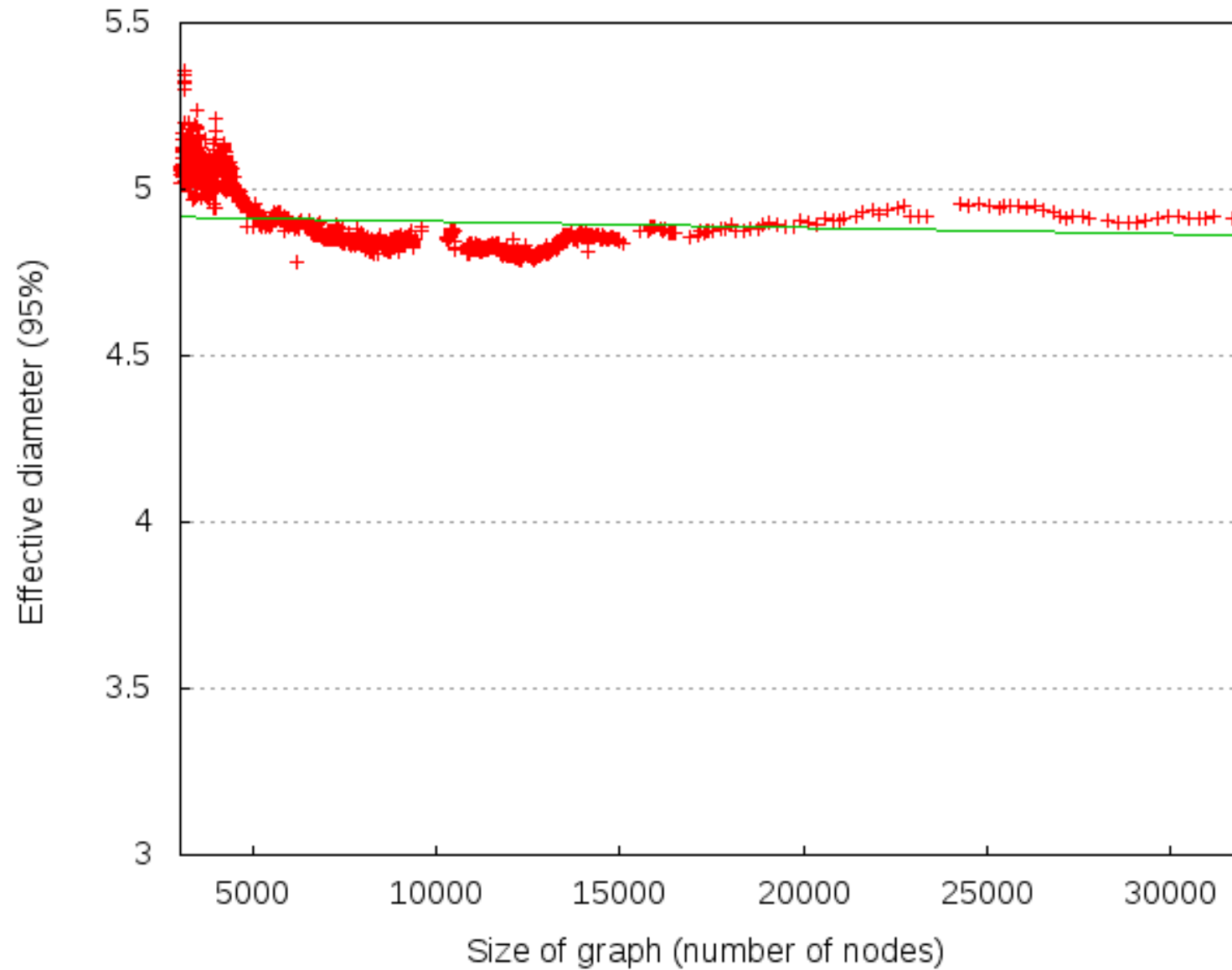# Network Growth
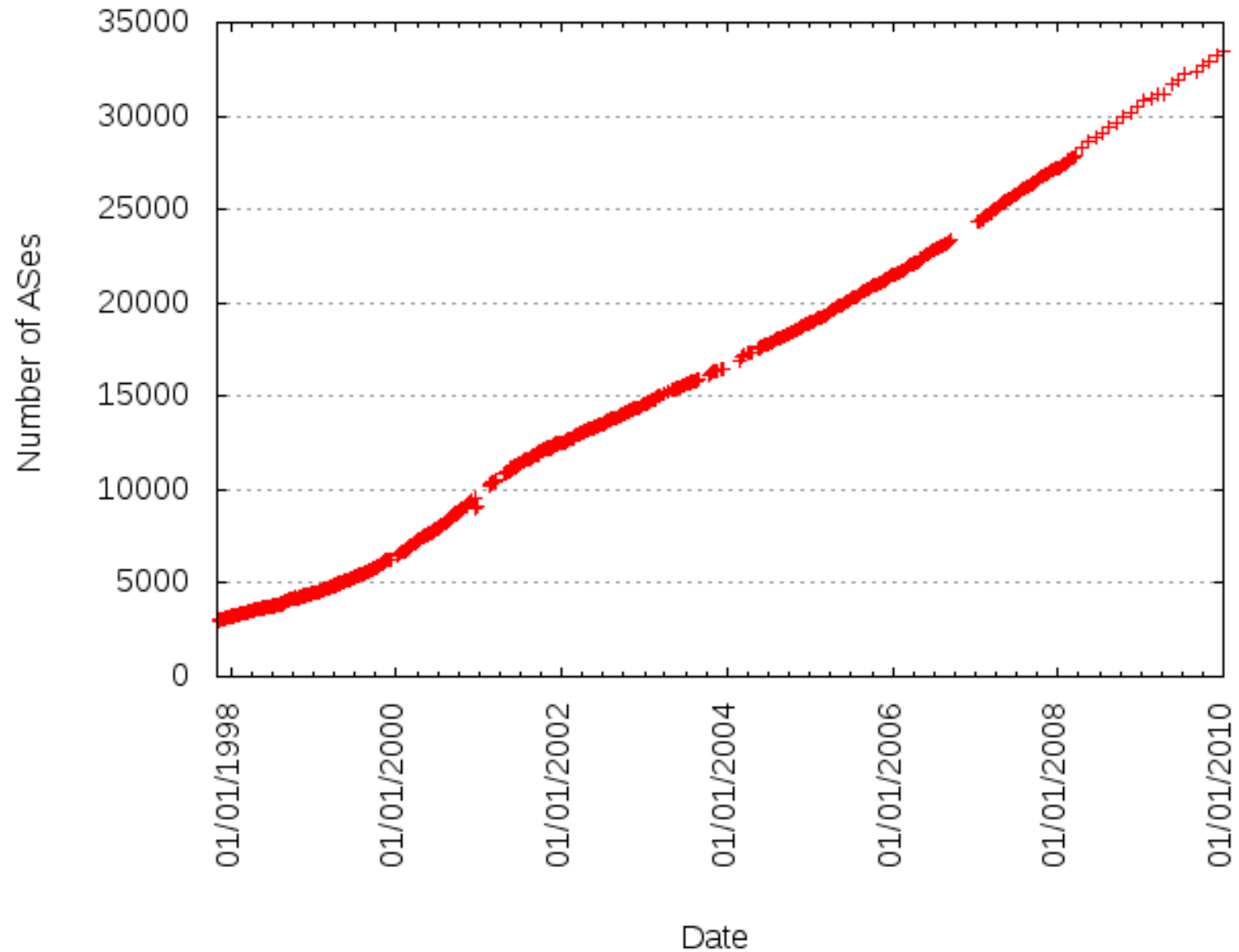
Network Growth
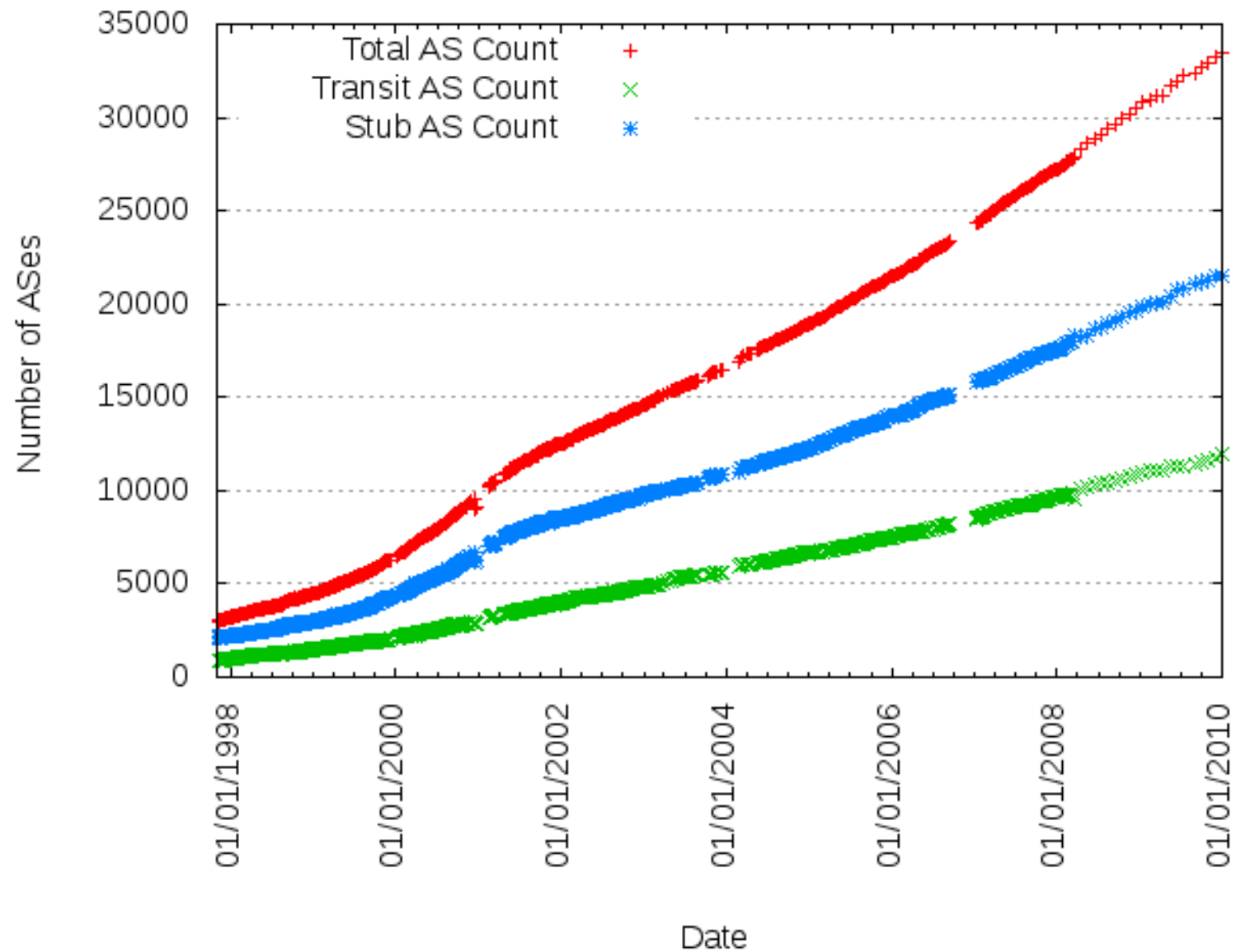
Network Width

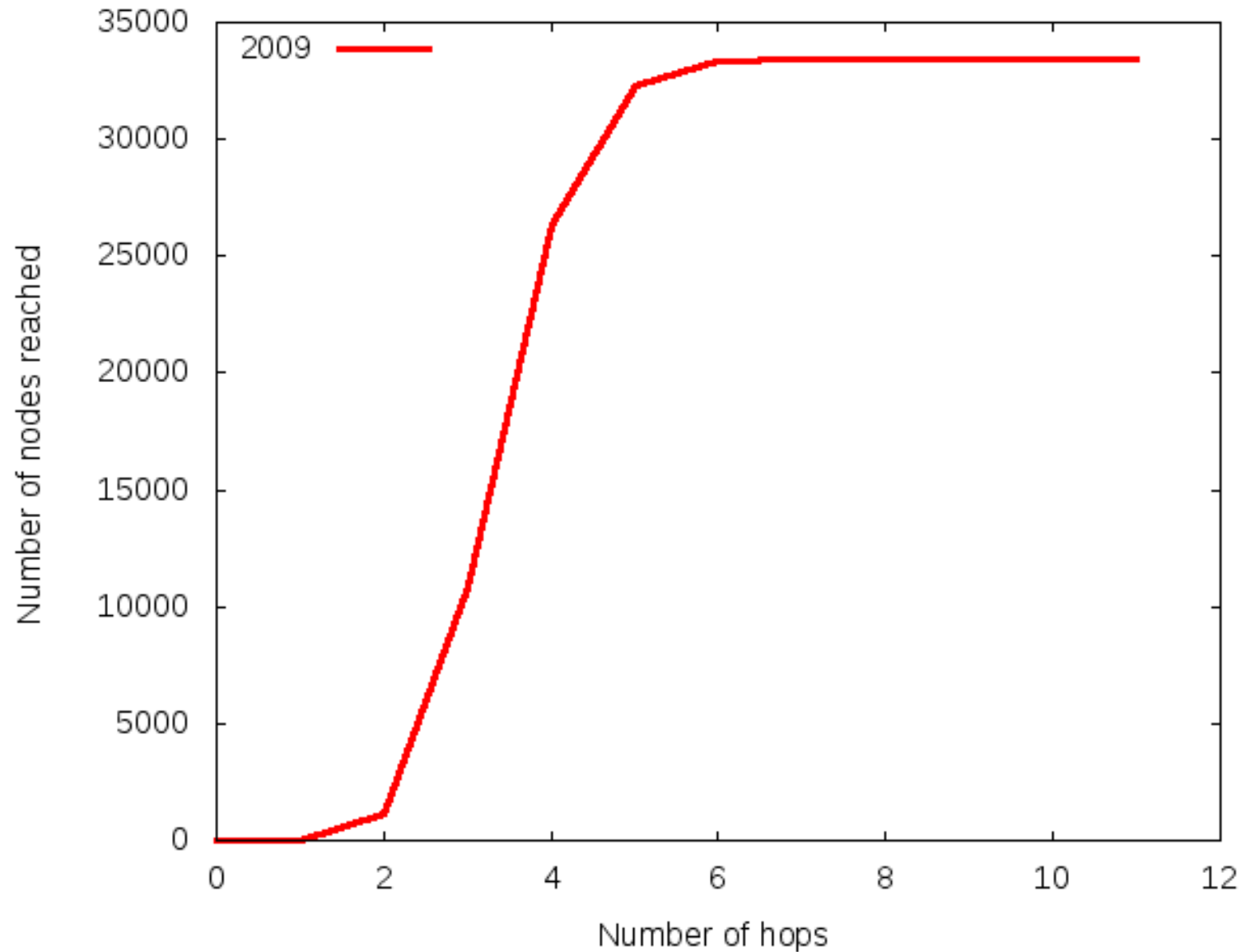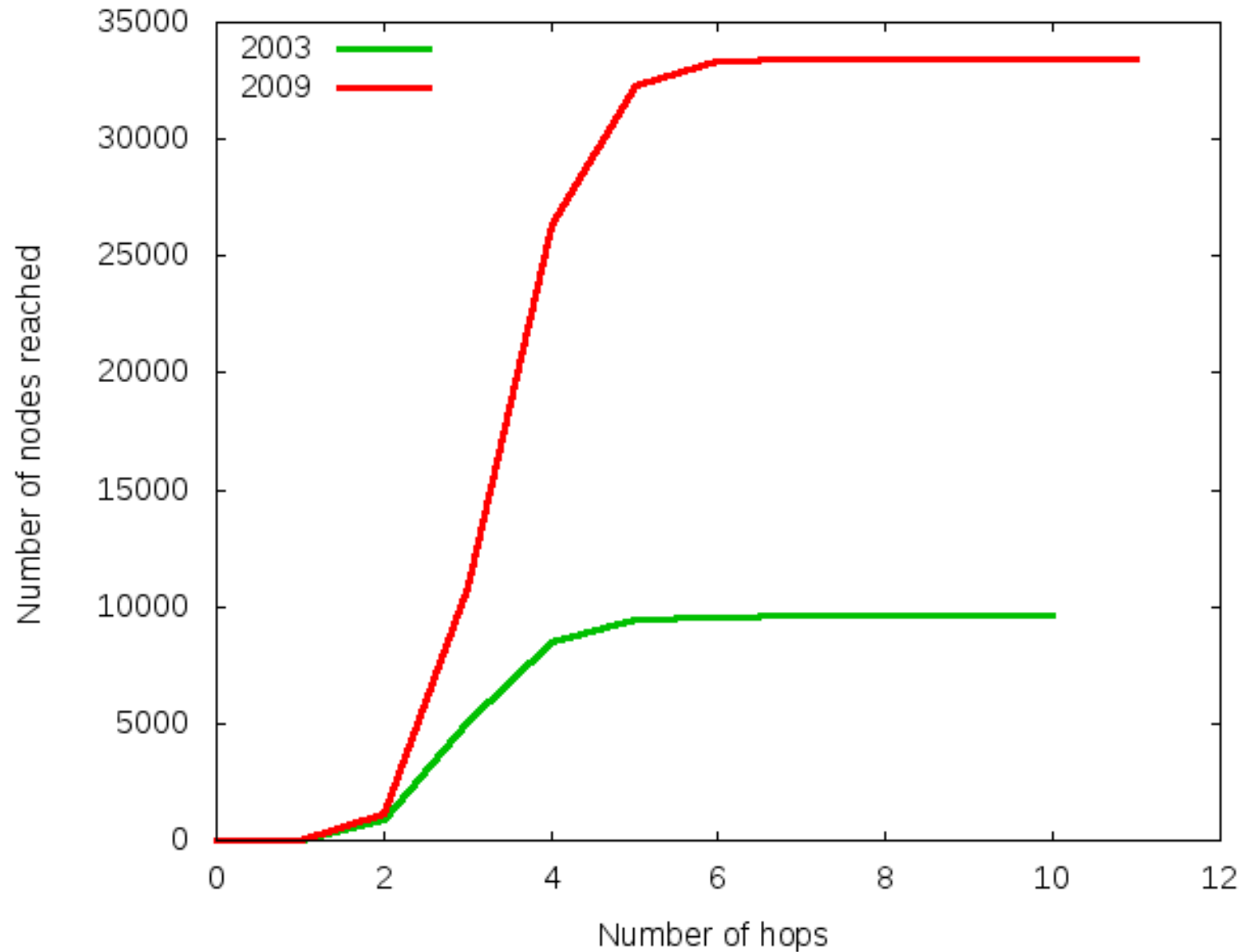# Network Width

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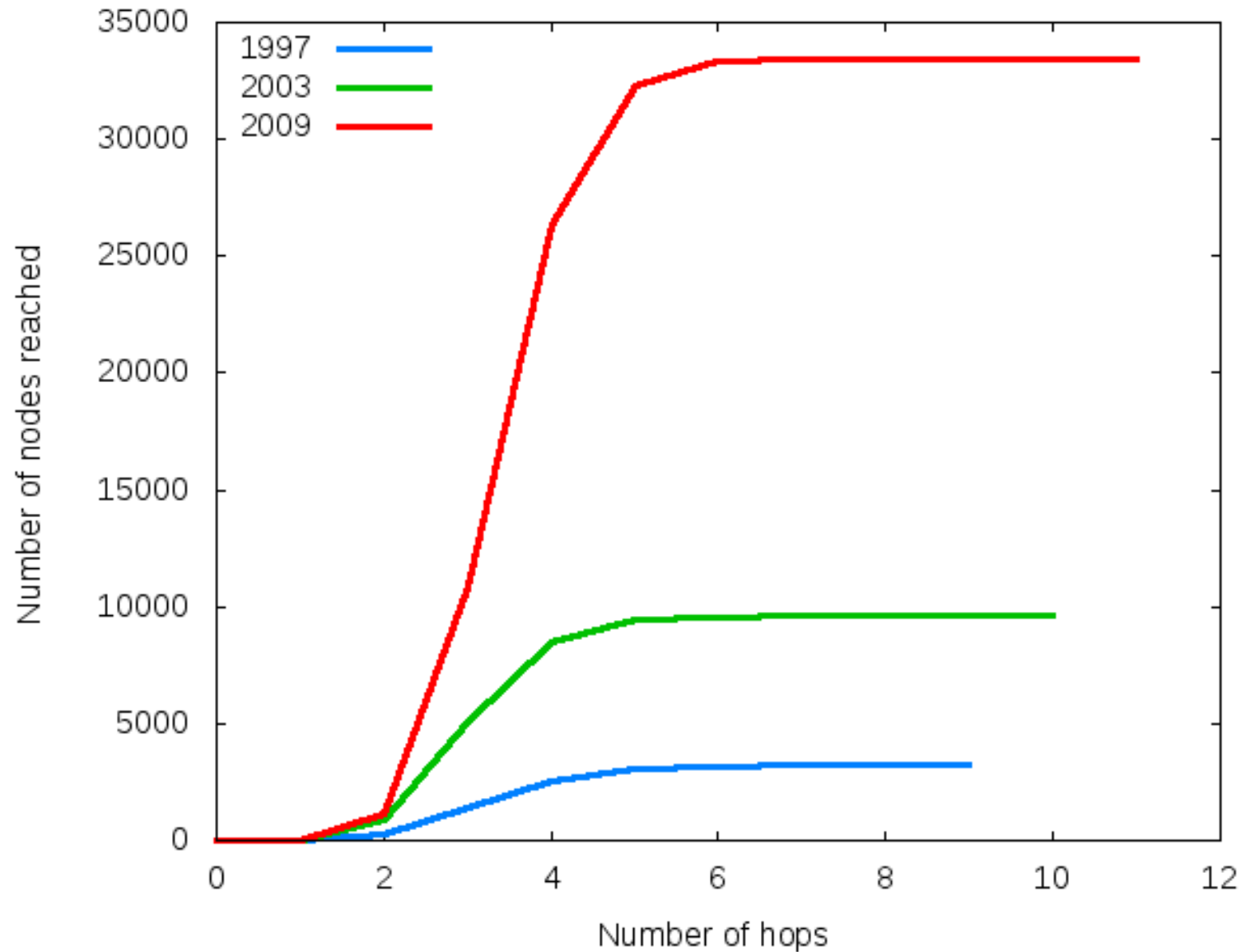# Network Width

Cumulative Node Reachability

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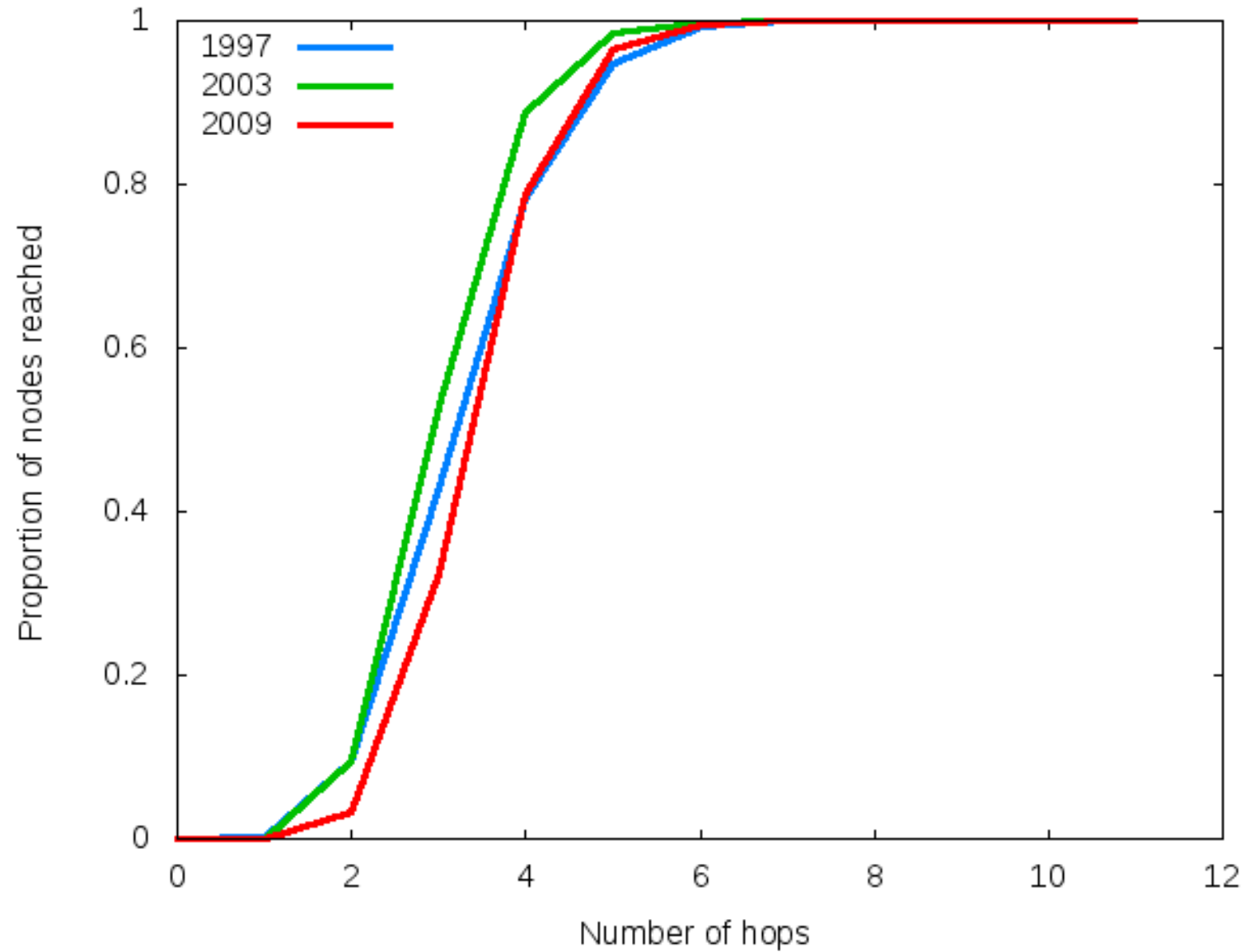
Cumulative Node Reachability

… Normalised.

Preferential Attachment

Preferential Attachment
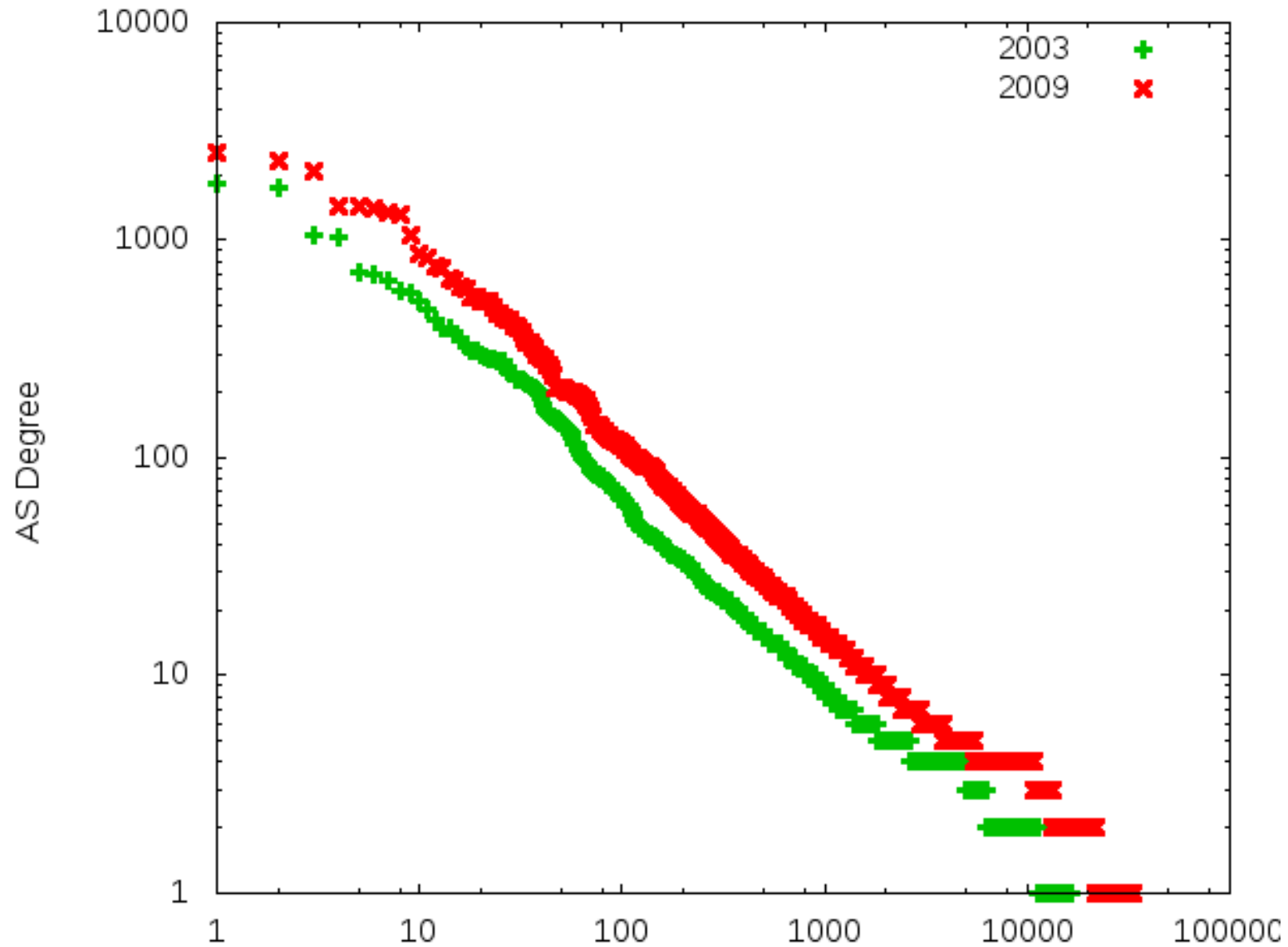
- "The better-connected get better-connected"?

- Arriving nodes tend to connect via well-connected nodess

  – Which helps maintain low hop counts

- Nodes then create additional links to other networks to increase network availability, bandwidth, reduce costs, etc

Degree distribution

Node Degree Distribution
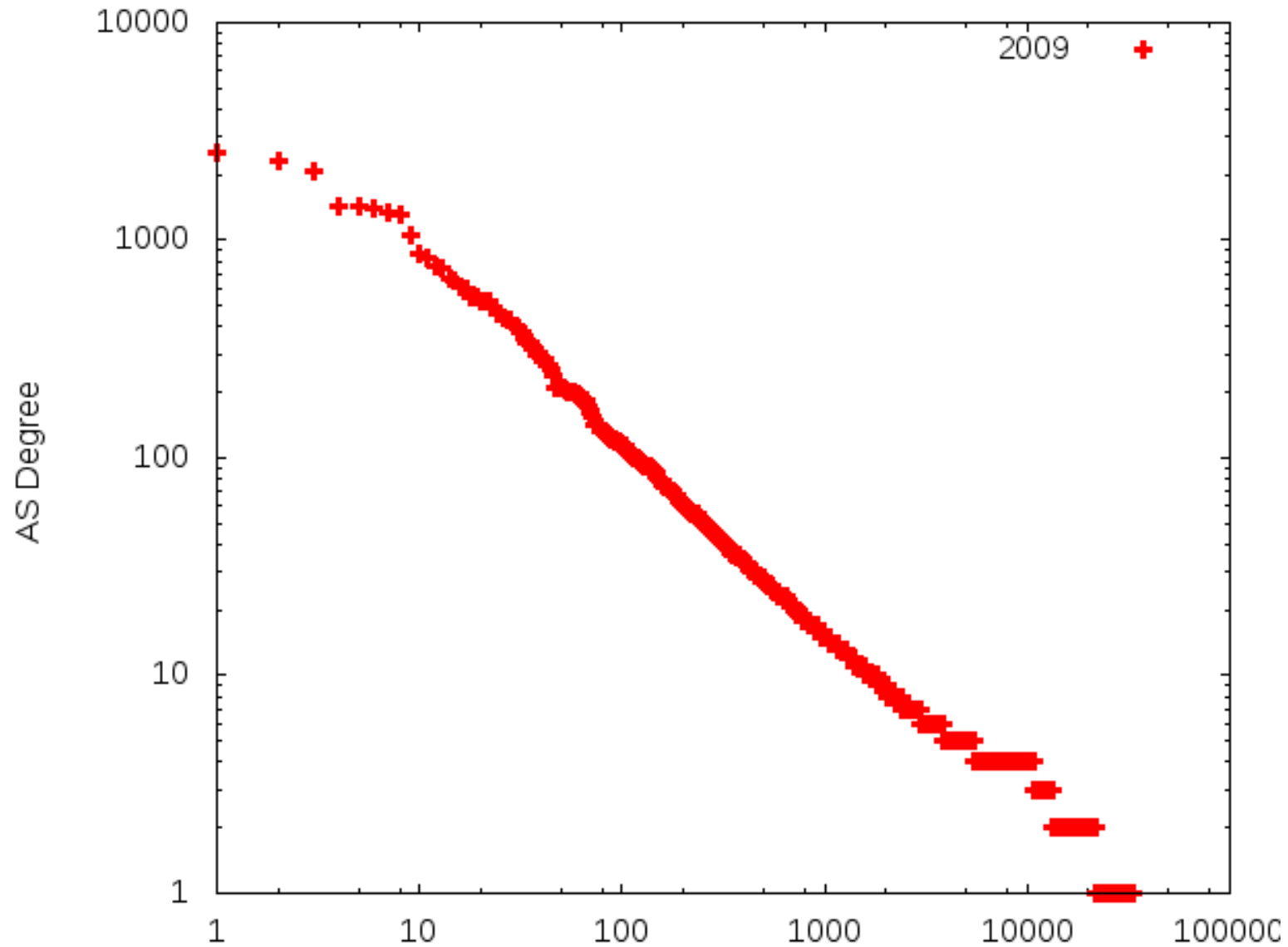
Node Degree Distribution

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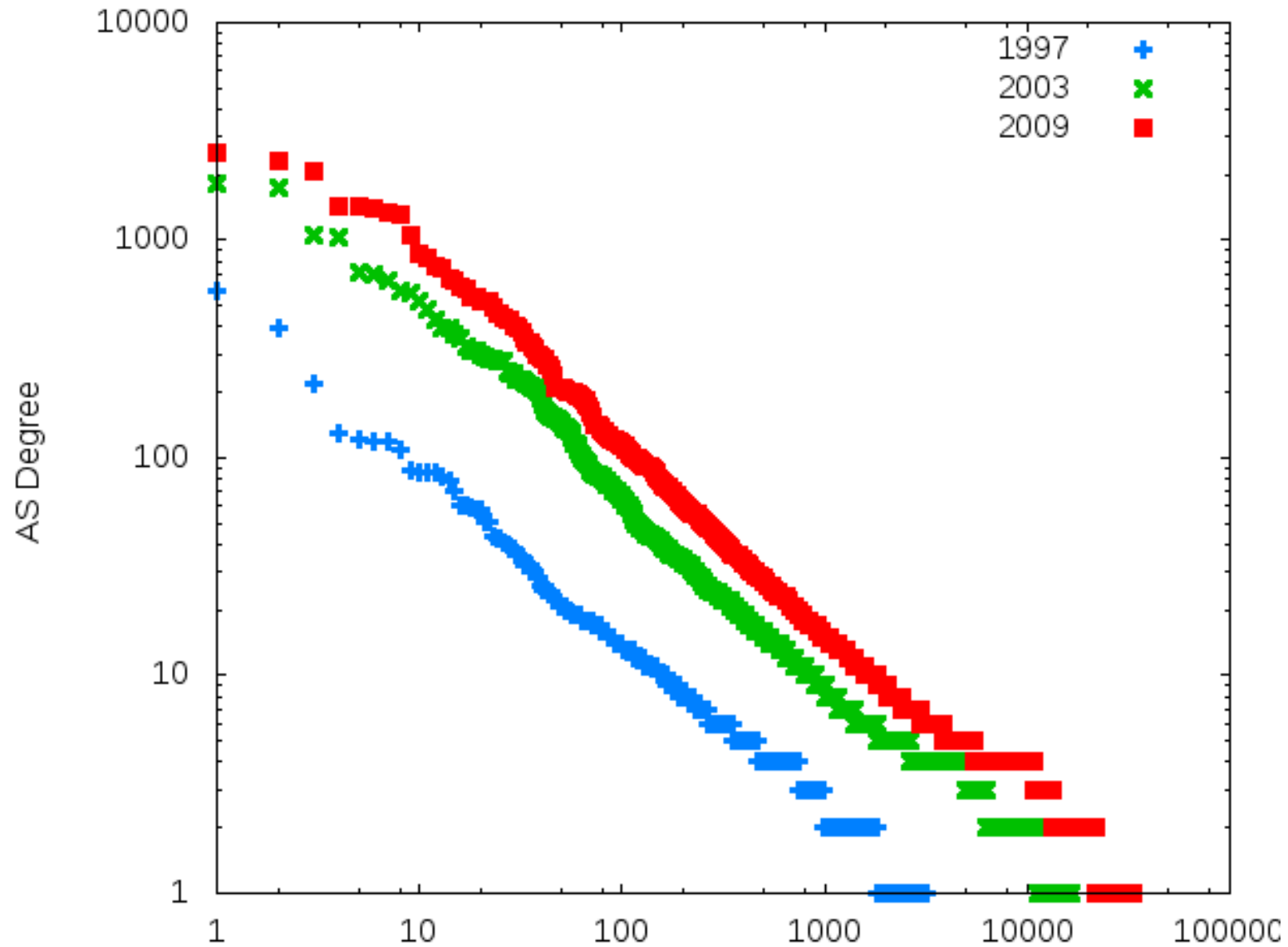
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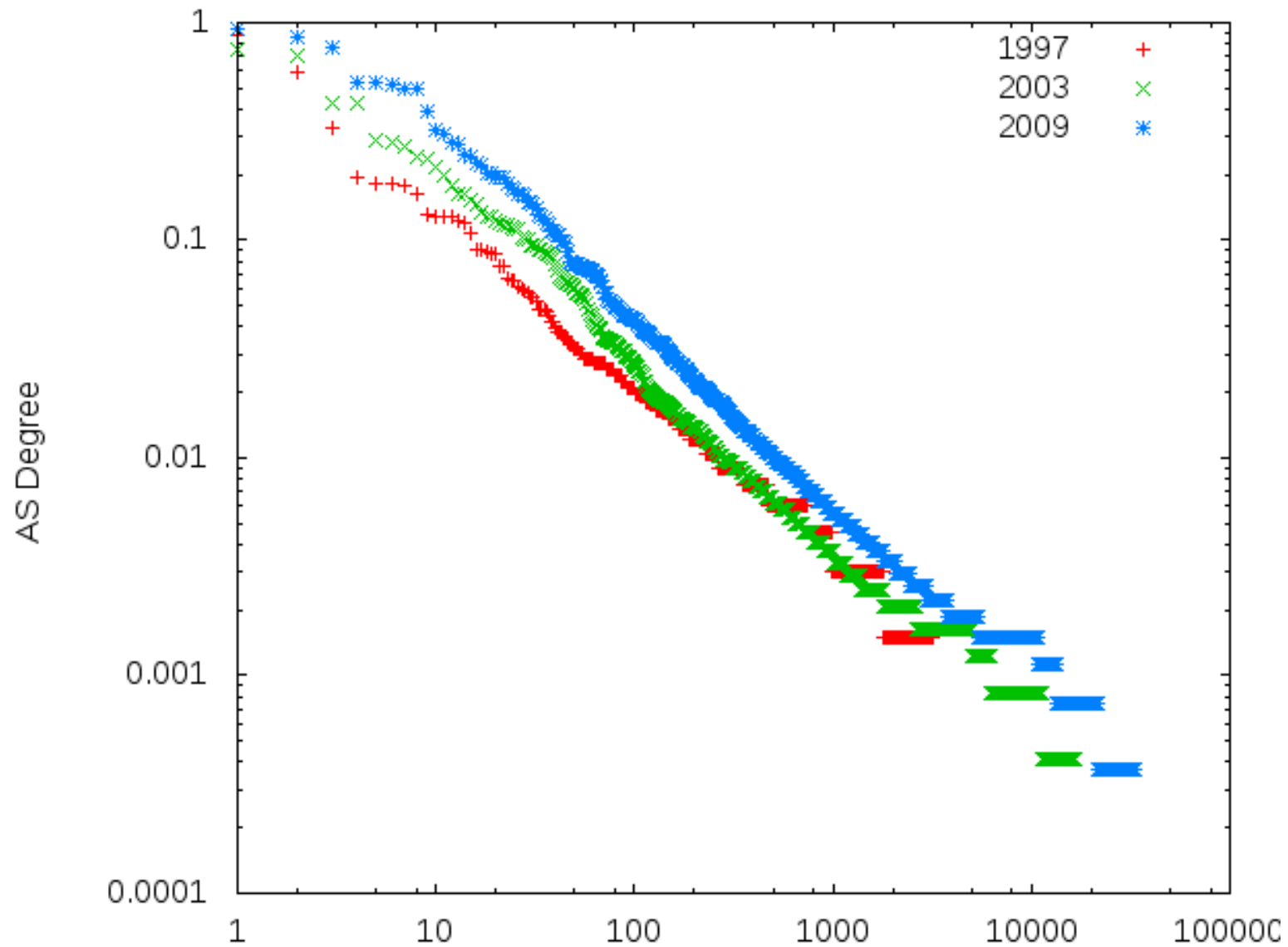
K-shell Decomposition

- Node degree alone is not a good indicator of connectivity with the rest of the network
  - Many connections to single-homed stubs inflate a simple degree measure

K-shell Decomposition

- Recursively remove nodes of increasing degree

  - Remove all nodes of degree 1

  - … then degree 2

  - … then degree 3

- Generates small, reasonably consistent sets of nodes

K-shell Decomposition
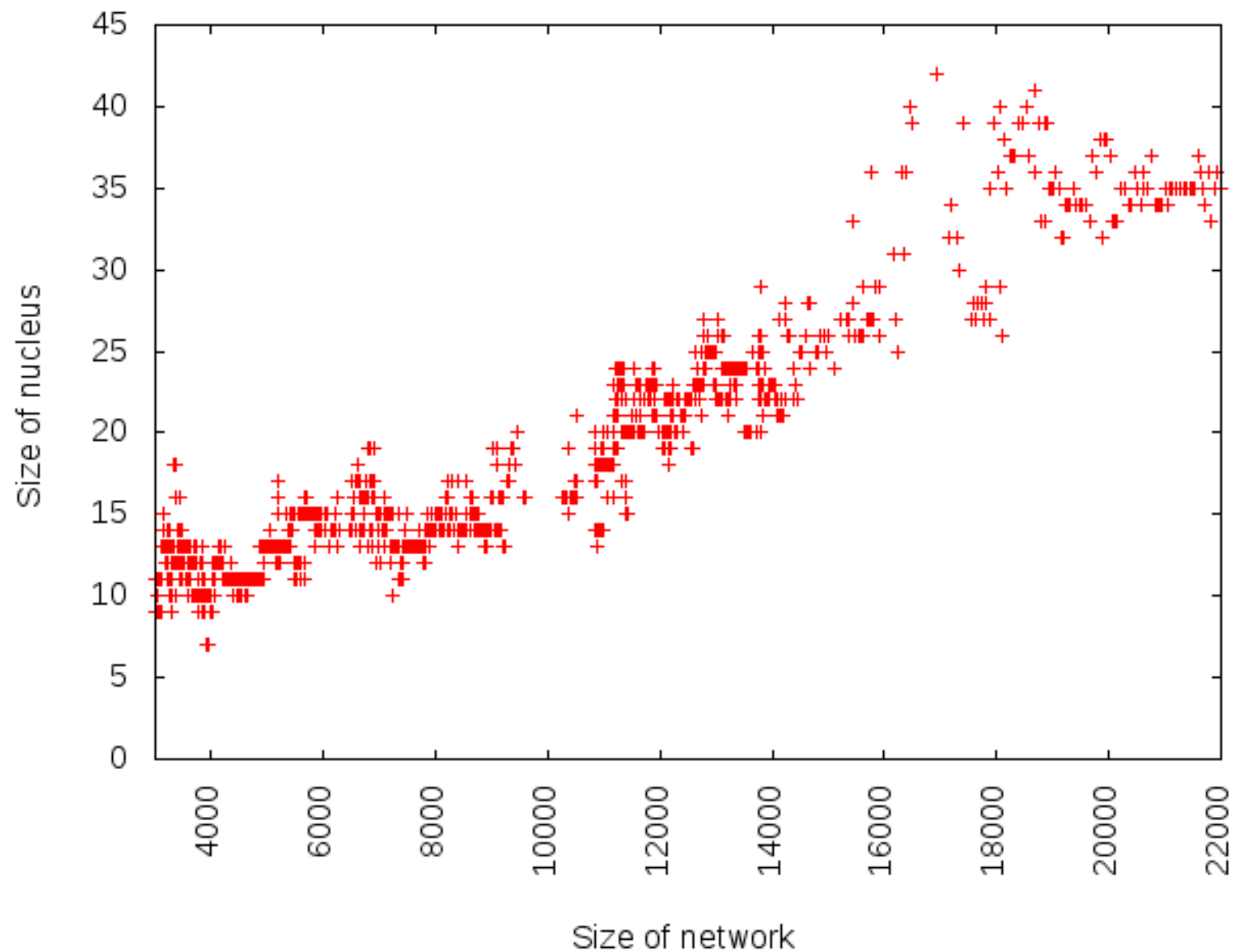
Consistency of k-shells

- Nucleus consists networks such as:
  - Cogent
  - Sprint
  - Level3
  - BT European backbone
  - Google, Microsoft (for low RTT and ease of content distribution, presumably)
  - Akamai (more content distribution)

Consistency of k-shells

- Requires more analysis, but...

- This seems to be a (reasonably) consistent set

  - Arbitrarily choosing the nucleus of a 2006 graph, 75% of it remains in 2009

"Growing" a Future Network?

- Modelling of the future...
  - Node arrivals, & likelihood of attachment point
  - Node removals
  - Rate of increase on node degree
  - Edge creation/destruction rates

Continued growth...

- Invariants provide tests for validity of model:

  - Diameter of network

  - Rate of nucleus growth

  - Degree distribution

- Potential additional metrics:

  - Global clustering coefficient

Conclusions

- Despite continued growth, many nodes connect via heavily-connected nodes, and grow from there
  - Nodes never become considerably more distant
- While the past can never be used to properly predict the future...
  - … it seems to offer some invariants which may be useful to "grow" and evaluate networks representing a future AS graph

Questions?

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