Space debris

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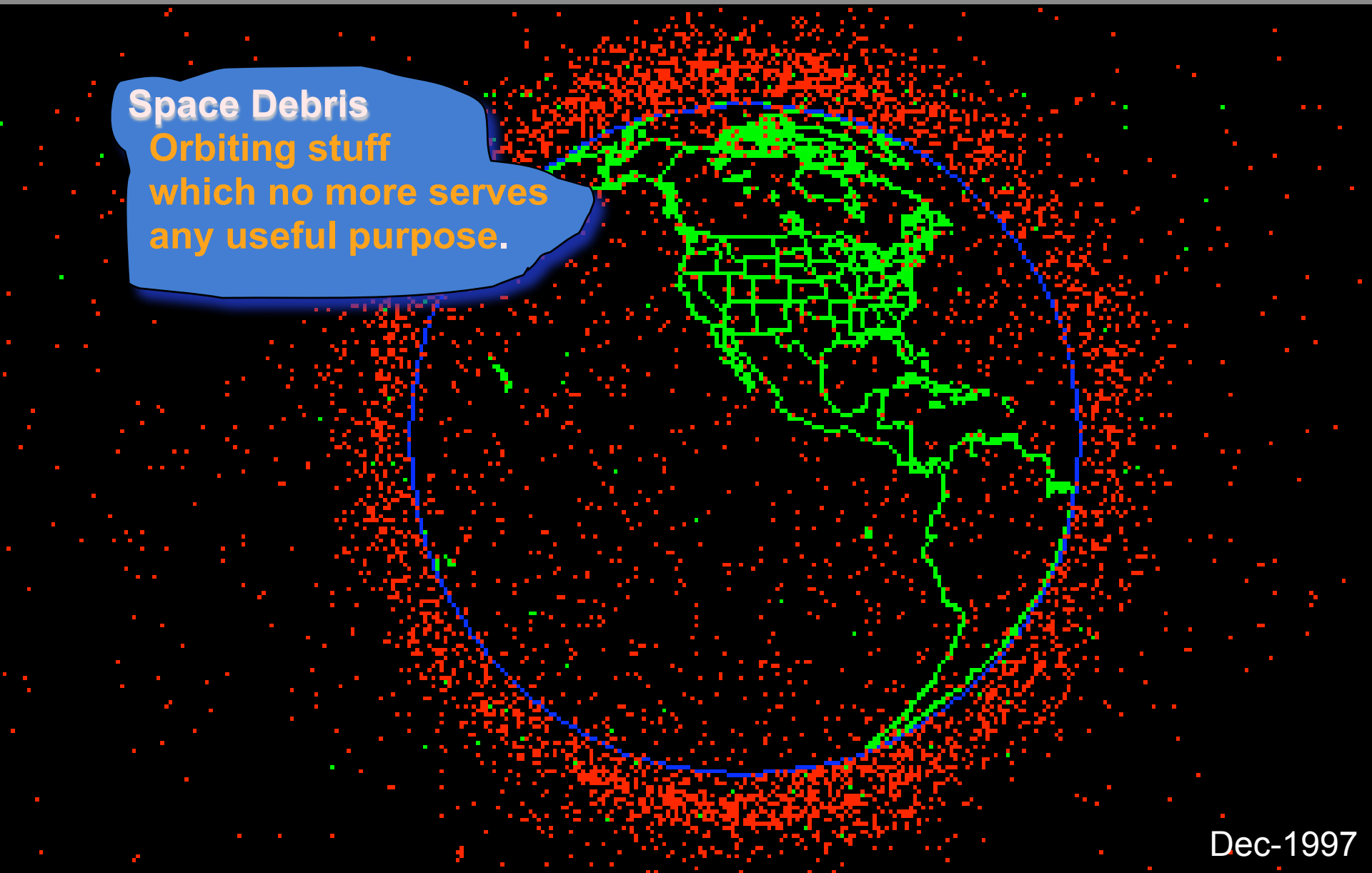
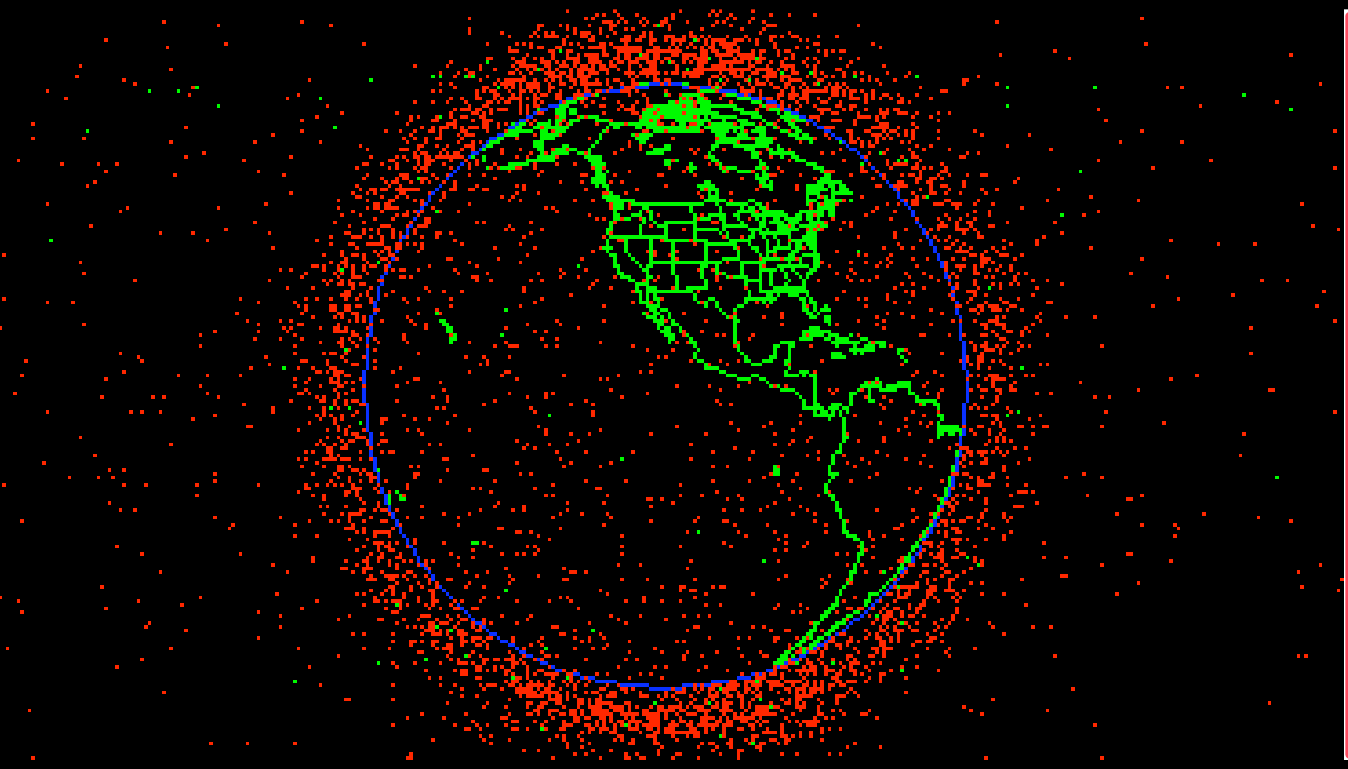
EISCAT RADAR SCHOOL, 1 Aug 2007

Space debris (orbital debris)



A global environmental problem …



GOOGLE

Nuclear Waste
25×10^6

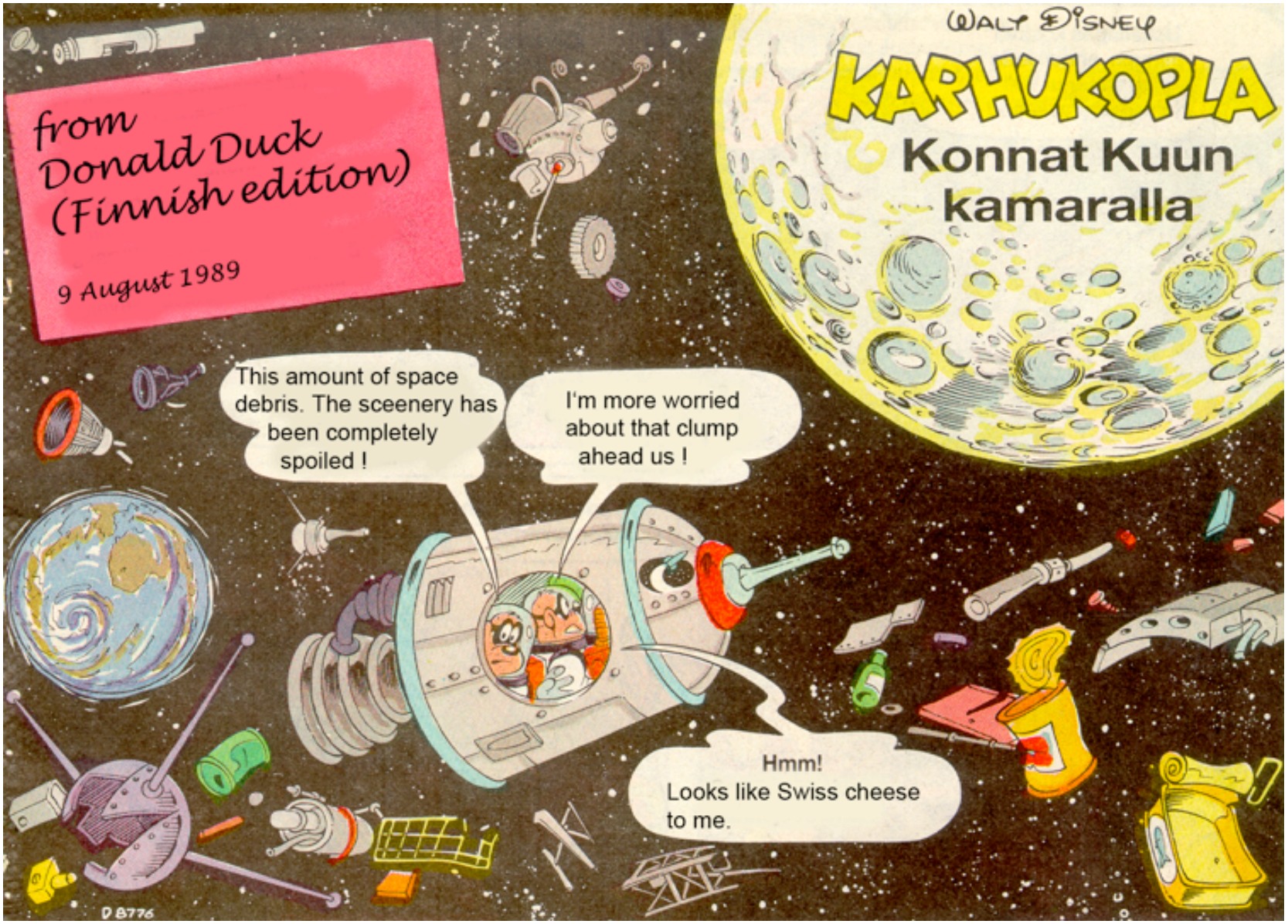
Space Debris
2×10^6

Ozone Hole
1.7×10^6

"Just 60 years ago there was nothing
but pristine, inky space ---
and now it's messier than a freshman's dorm room."

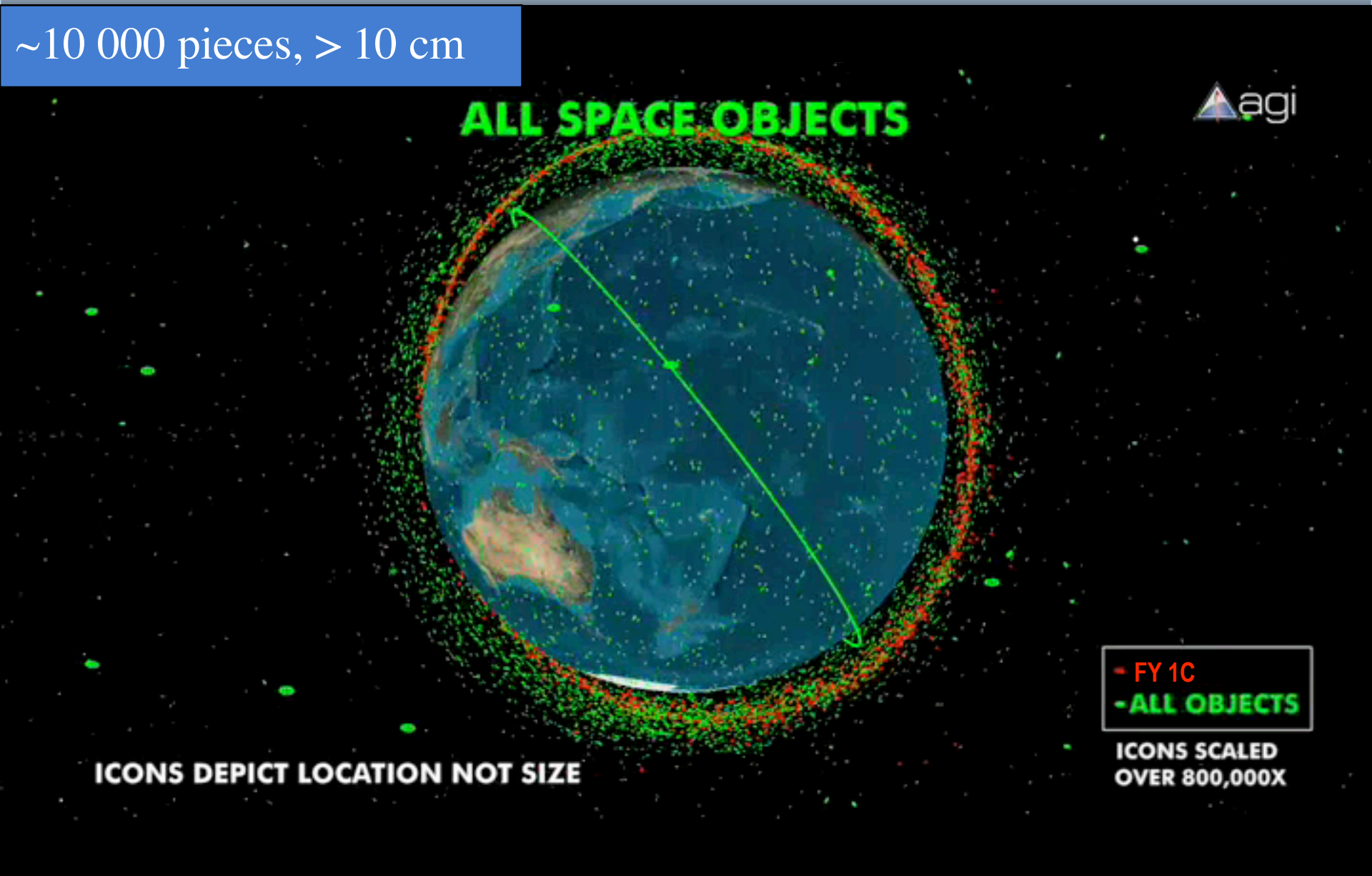
Chris Kemp, CityBeat, Jun 2001

… with widespread public interest

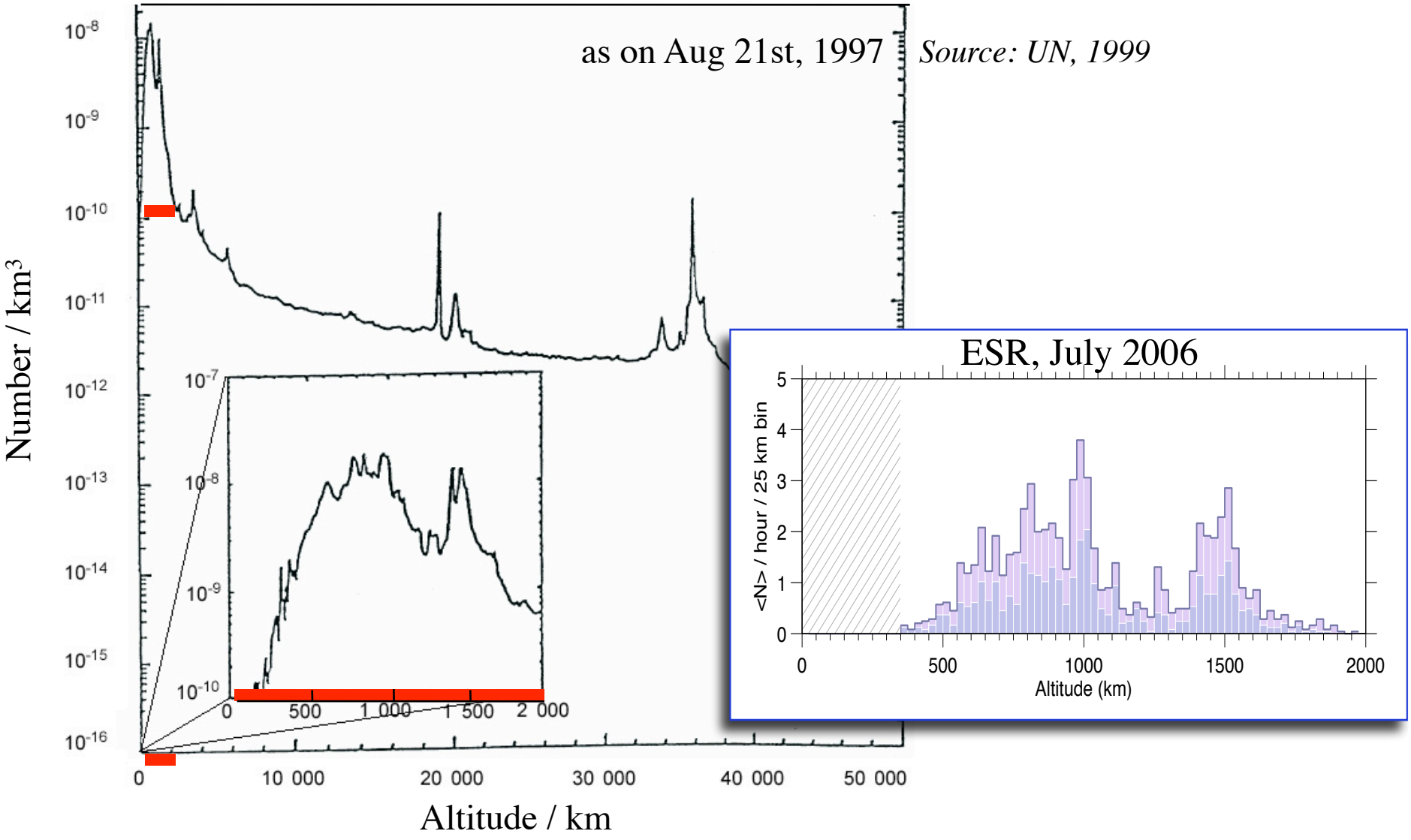


Catalogued objects, June 11, 2007

~10 000 pieces, > 10 cm

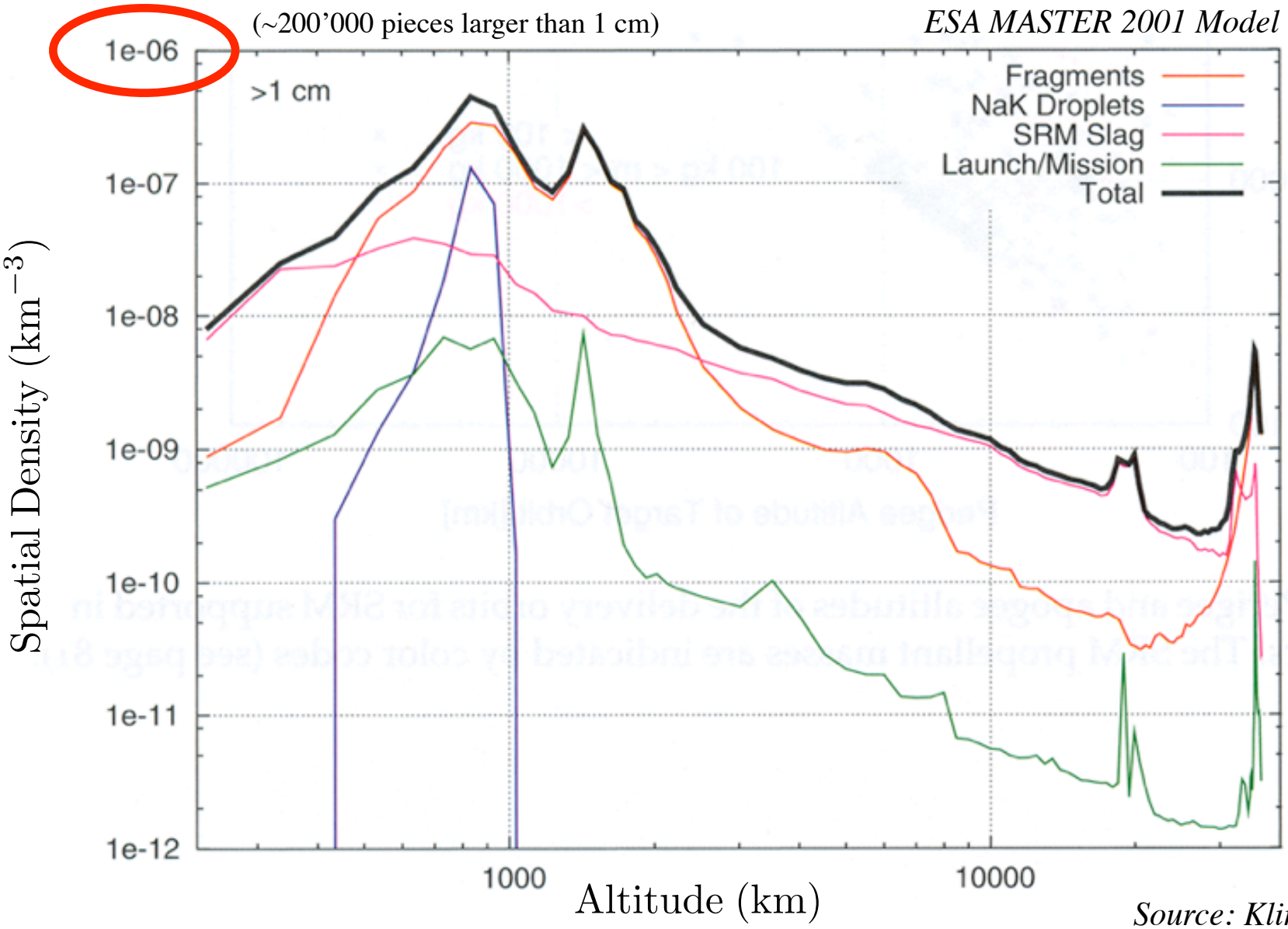


Altitude distribution of catalogued objects



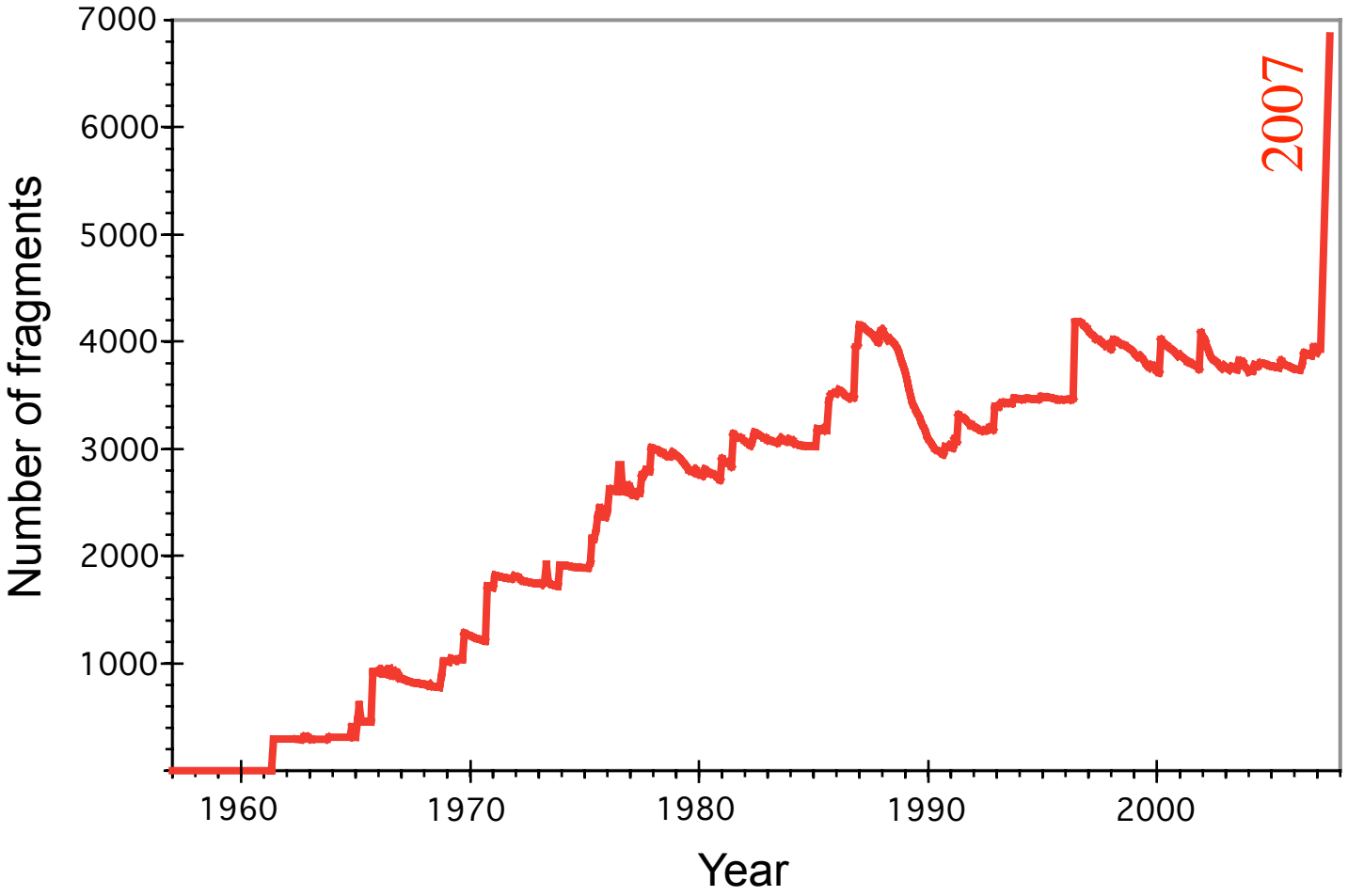
Space debris stuff

Mass of debris
$5 \cdot 10^6$ kg



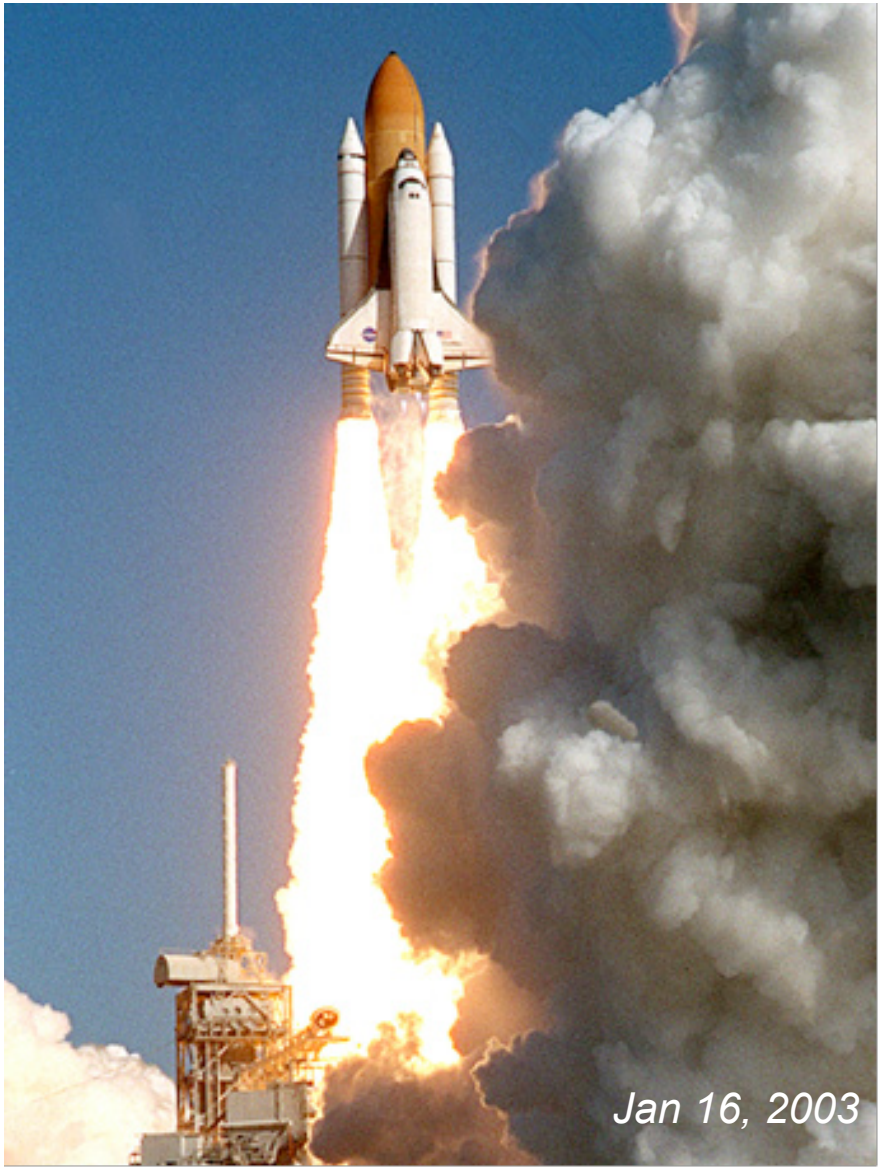
Source: Klinkrad, 2006

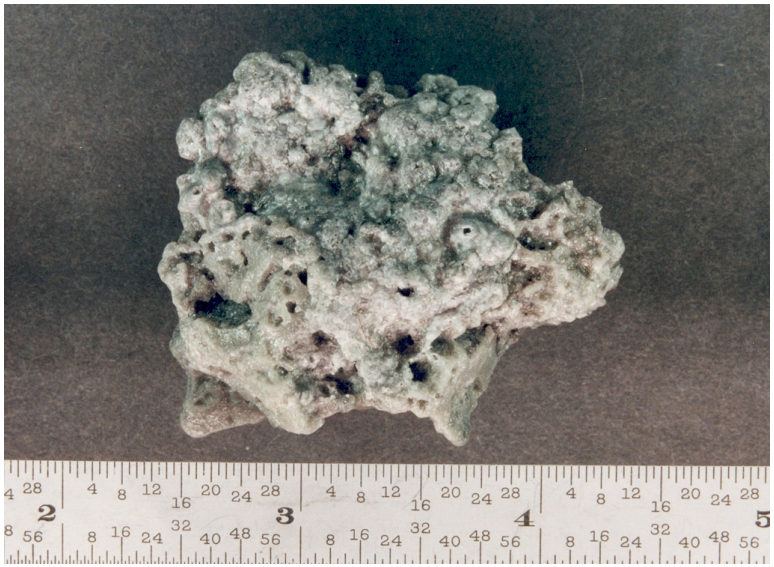
Number of catalogued fragmentation objects

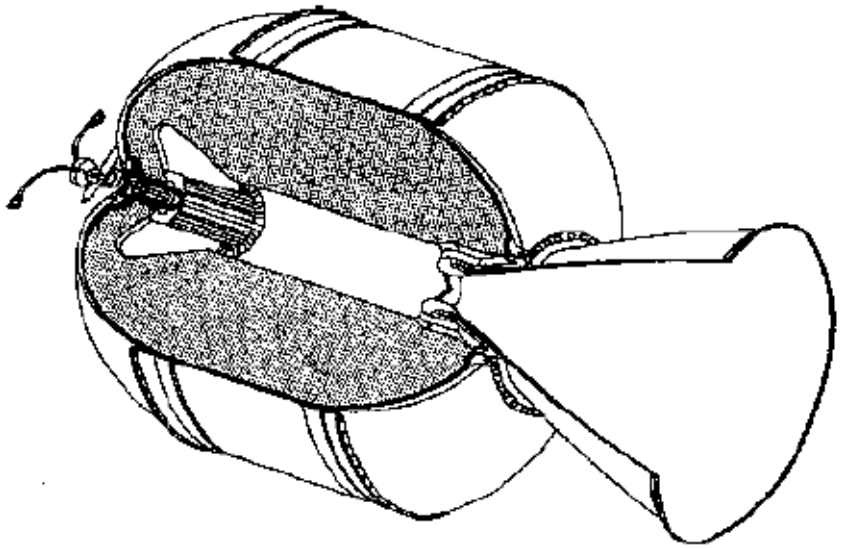


NASA ODQN, July 2007

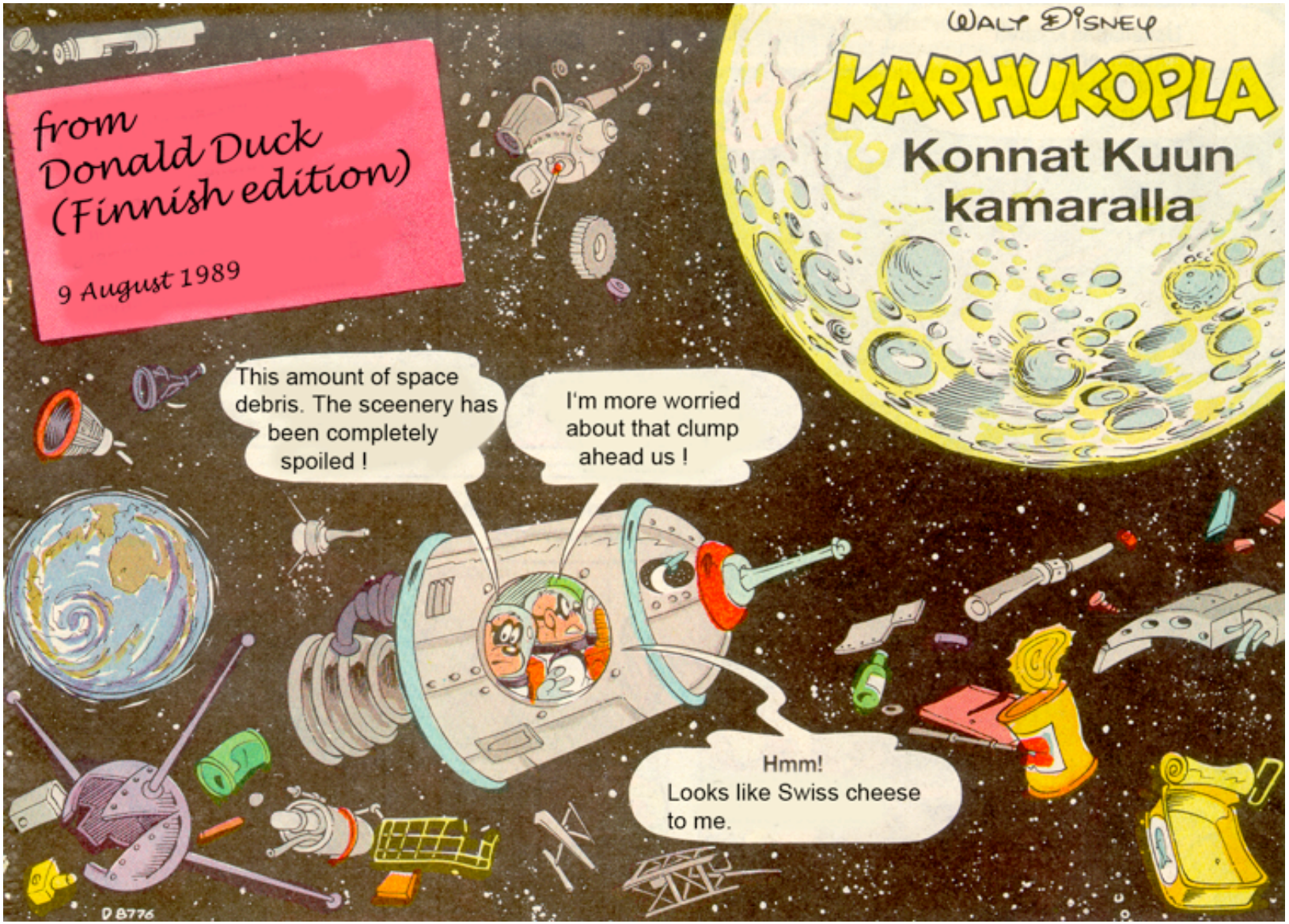
Solid rocket motor => dust and slag



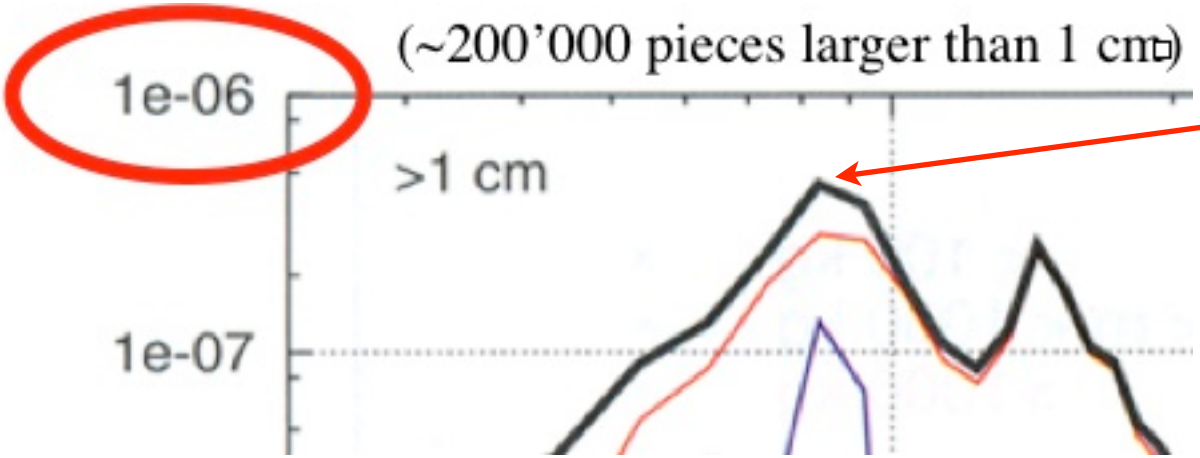




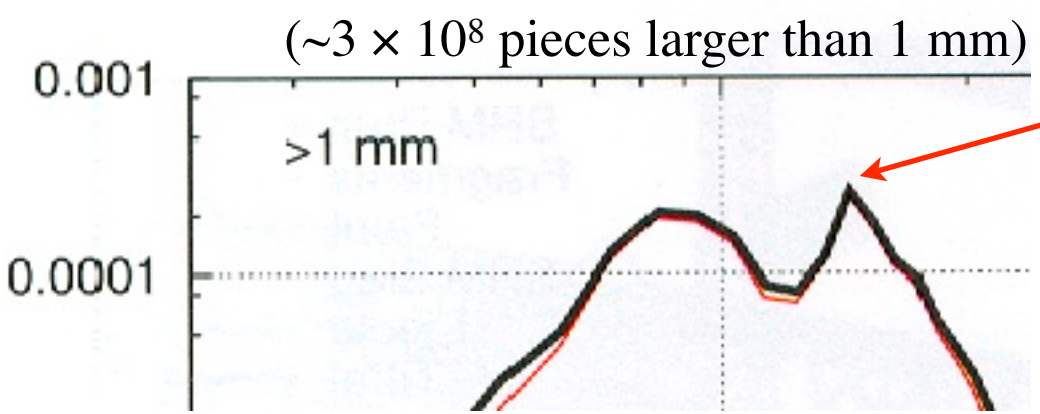
Mission related objects



Spatial density is not high



$< 1 / 10^6$ km^3



$< 1 / 10^3$ km^3

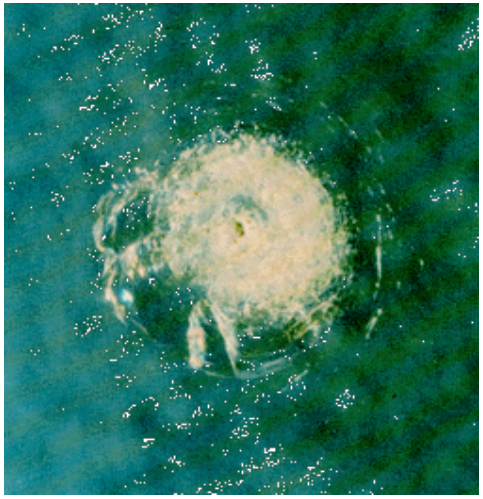
So .... What's the problem ?

Collisions typically at Mach 30

4 g, 10 km/s ⇒ 0.2 MJ

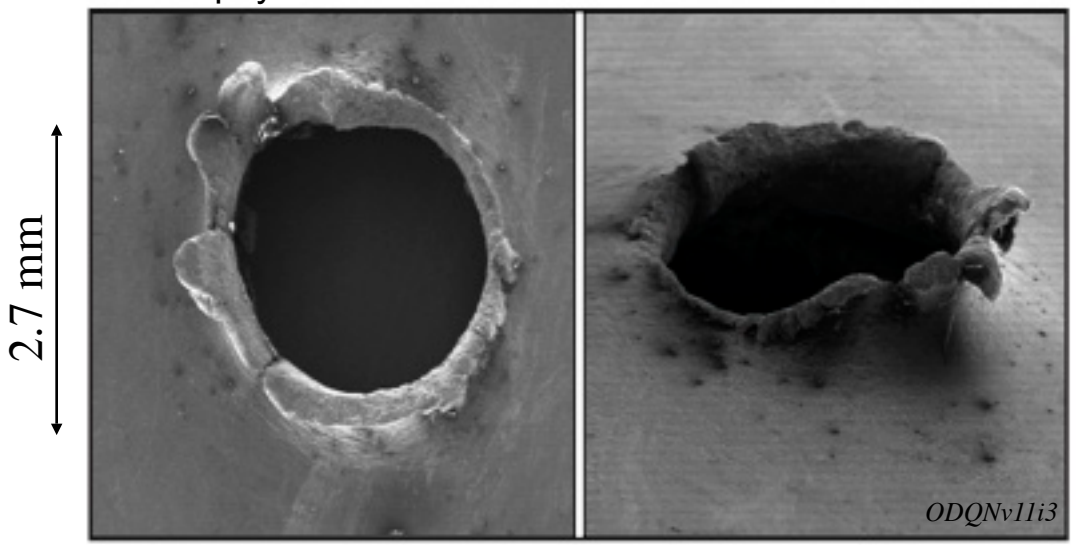
Collisions do occur

Shuttle window



Cause: paint flake

Shuttle payload door radiator



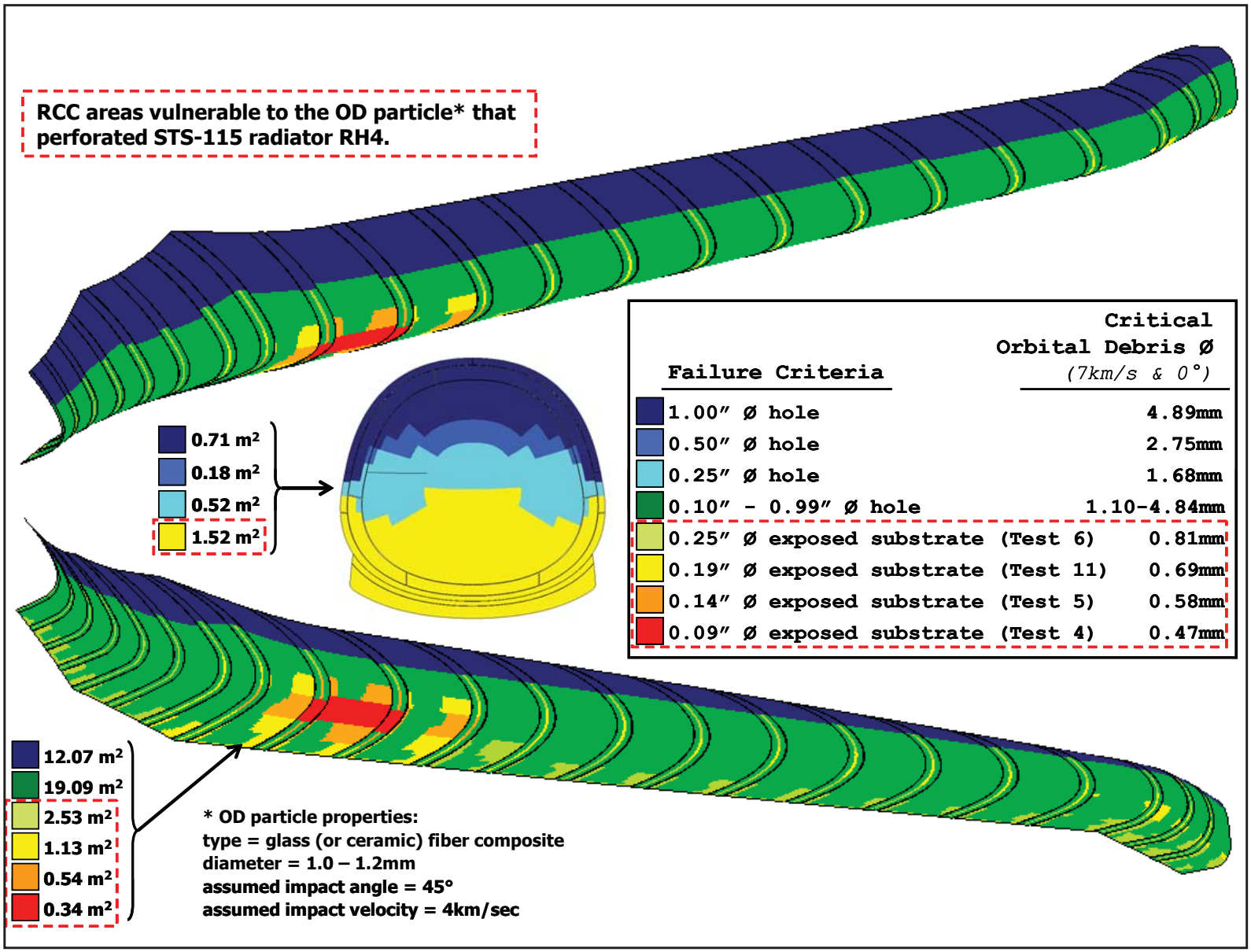
Cause: Grain of fiber glass, 1.2 mm, 2 mg, Mach 12.

Mean time between impacts on a sphere with 10 m^2 cross section

Height of circular orbit	*Objects 0.1-1.0 cm*	*Objects 1-10 cm*	*Objects >10 cm*
500 km	10-100 years	3,500-7,000 years	150,000 years
1,000 km	3-30 years	700-1,400 years	20,000 years
1,500 km	7-70 years	1,000-2,000 years	30,000 years

UN,1999

Debris and the space shuttle



Failure Criteria	Critical Orbital Debris Ø (7km/s & 0°)
1.00″ Ø hole	4.89mm
0.50″ Ø hole	2.75mm
0.25″ Ø hole	1.68mm
0.10″ - 0.99″ Ø hole	1.10-4.84mm
0.25″ Ø exposed substrate (Test 6)	0.81mm
0.19″ Ø exposed substrate (Test 11)	0.69mm
0.14″ Ø exposed substrate (Test 5)	0.58mm
0.09″ Ø exposed substrate (Test 4)	0.47mm

NASA ODQN
July 2007

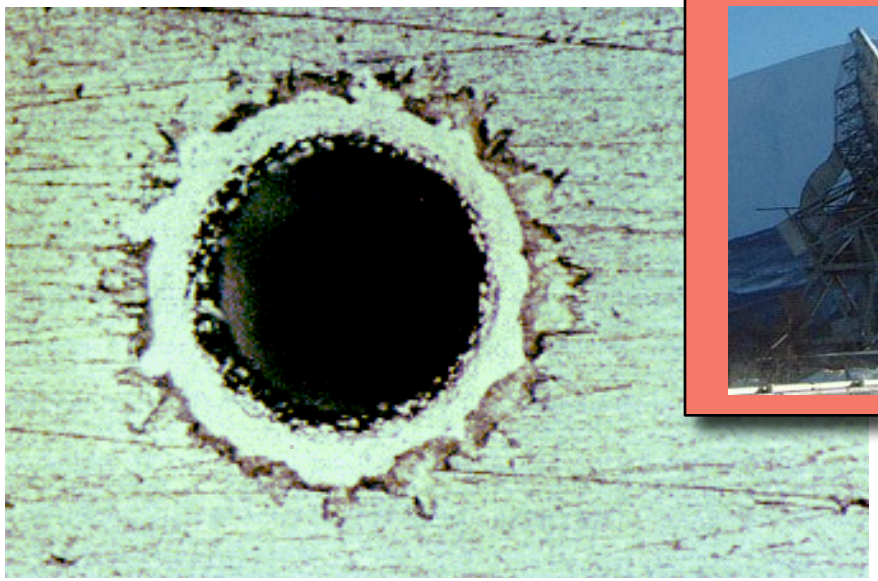
Measuring space debris

❖The LARGE

> 10 cm

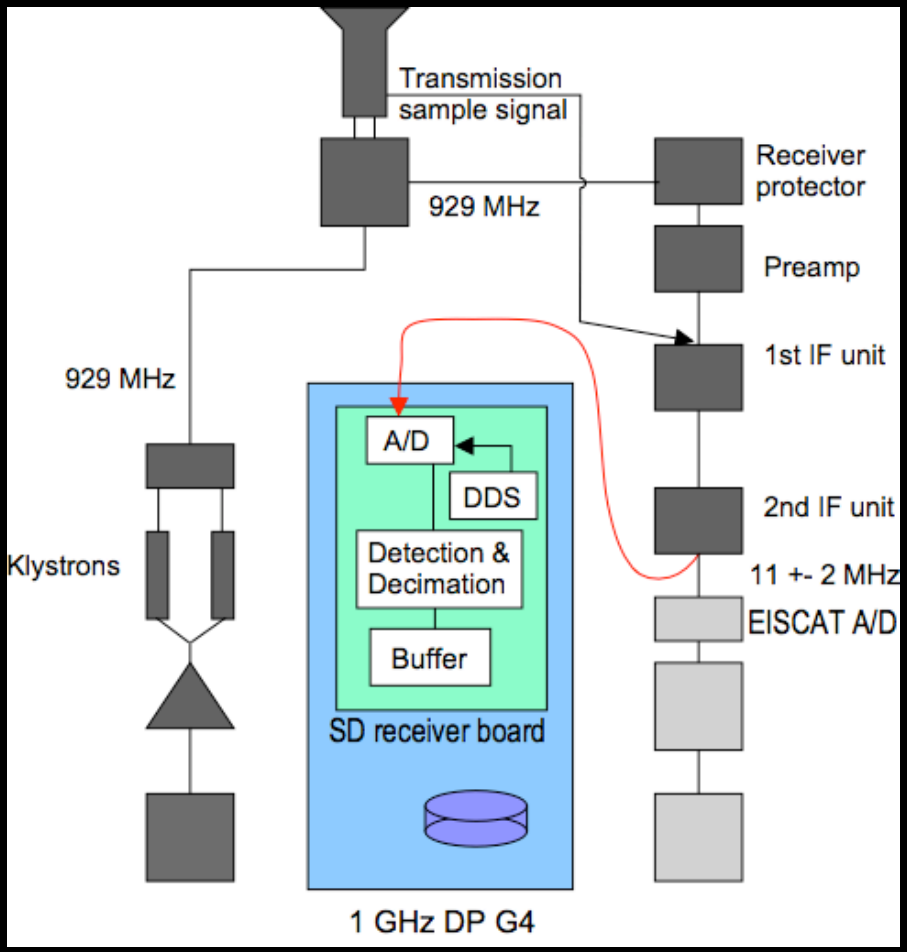
❖The SMALL

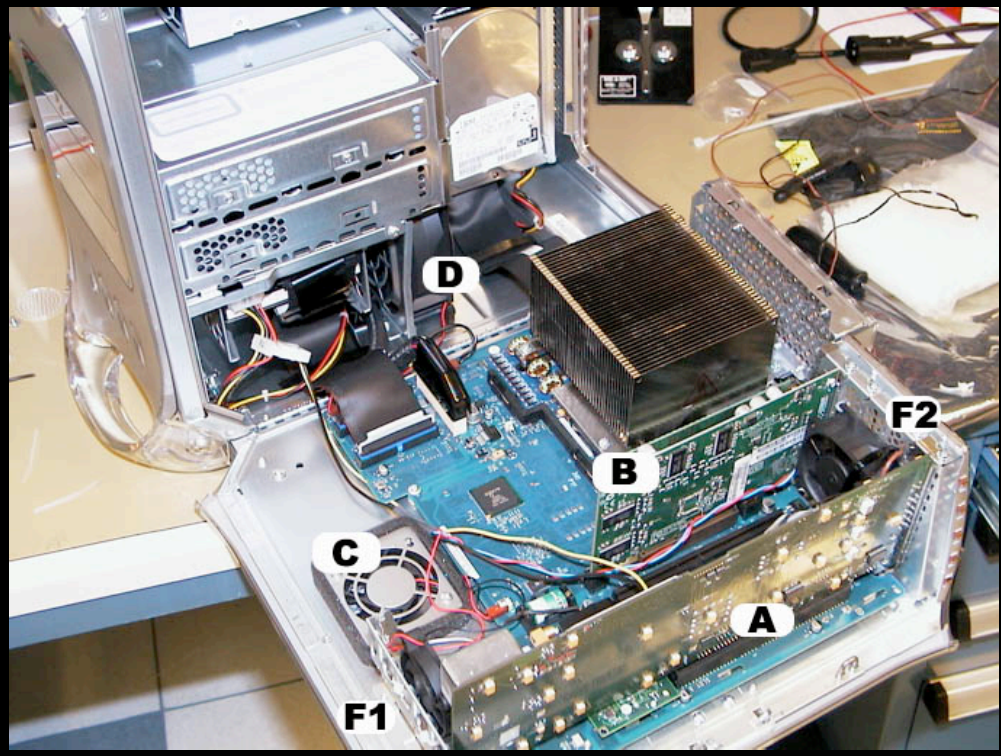
< 1 cm



The DIFFICULT

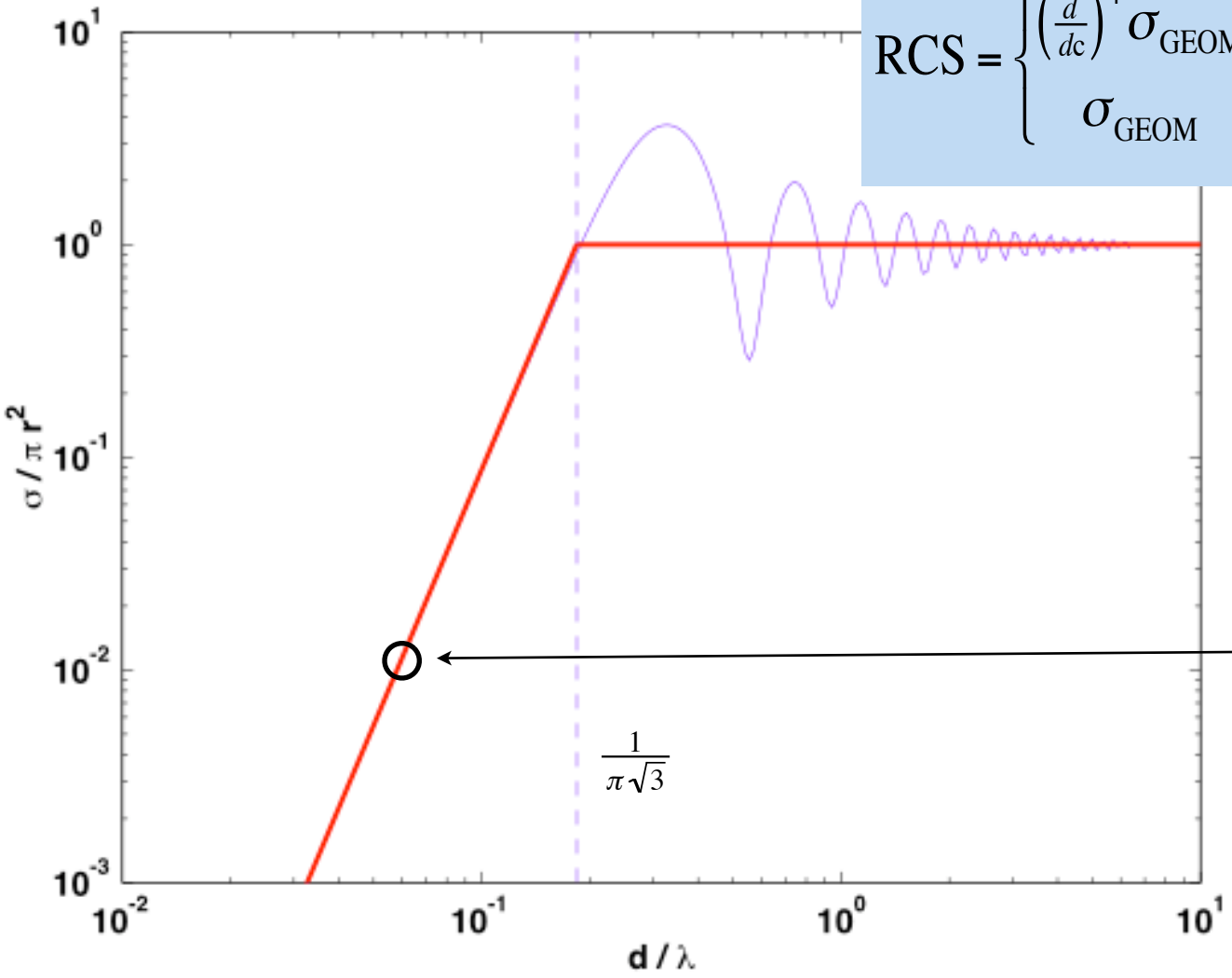
EISCAT space debris receiver





Sensitivity is “diffraction limited”

$$RCS = \begin{cases} \left(\frac{d}{dc}\right)^4 \sigma_{GEOM} & \text{when } d < d_c = \frac{\lambda}{\pi\sqrt{3}} \\ \sigma_{GEOM} & \text{when } d > d_c \end{cases}$$

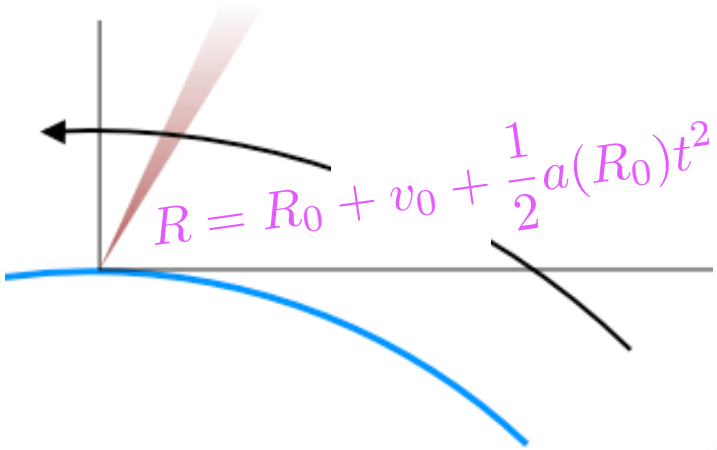


Radar	d_c
UHF	5.9 cm
VHF	26.6 cm
ESR	11.0 cm

@UHF

Use amplitude domain signal processing

Assume point target with a_r = const.



Get signal parameters by statistical inversion

$$(\widehat{A}, \widehat{R}, \widehat{v}) = \arg\max_{A,R,v} D_{\mathrm{p}}(\underbrace{A, R, v}|\mathbf{z})$$

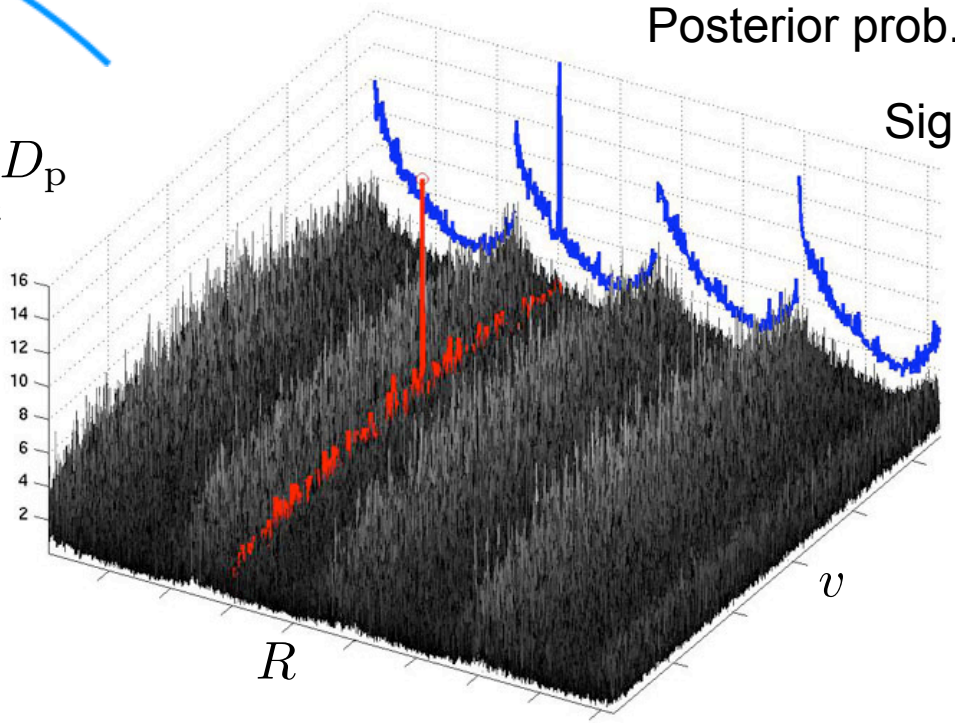
Posterior prob. density

Signal parameters

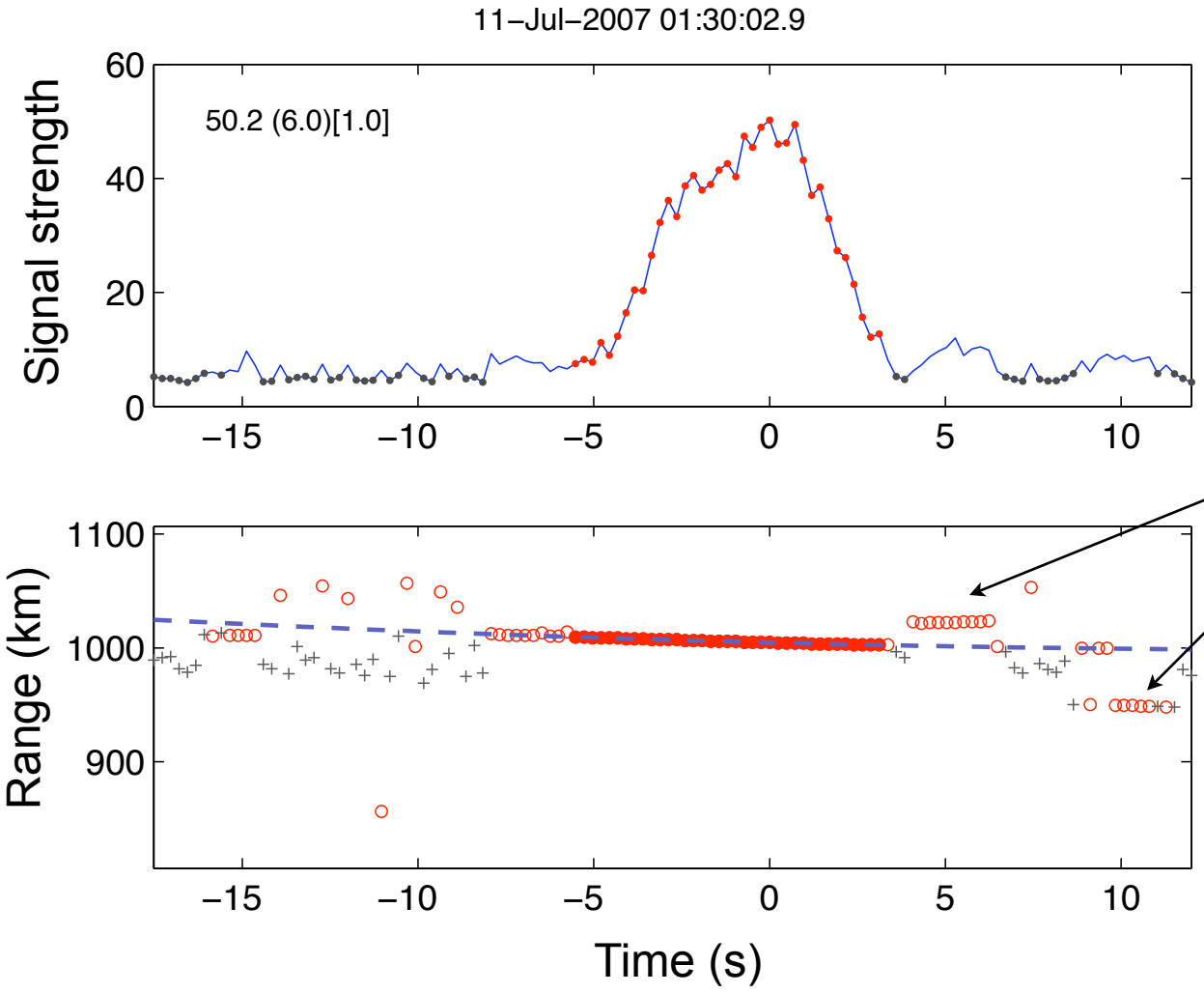
Measured signal on interval $[t_0, t_0 + \Delta]$

D_{p}

Radar ambiguity function



Fit to beam passage => event parameters



Multi-target analysis not attempted

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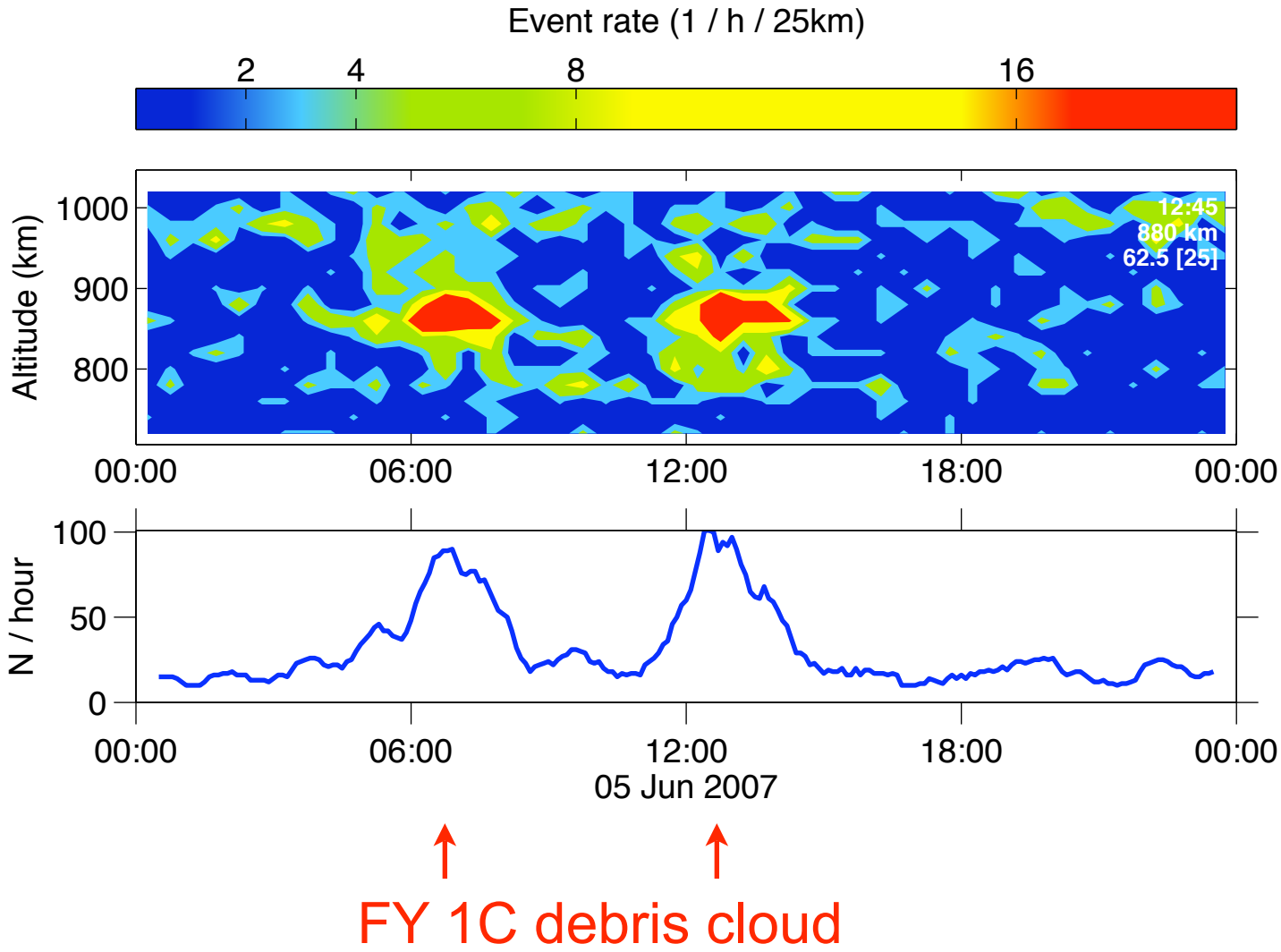
missed targets

IPY SD data summaries publicly available

http://www.sgo.fi/~jussi/spade/ipy/index.html



Getting rid of ?

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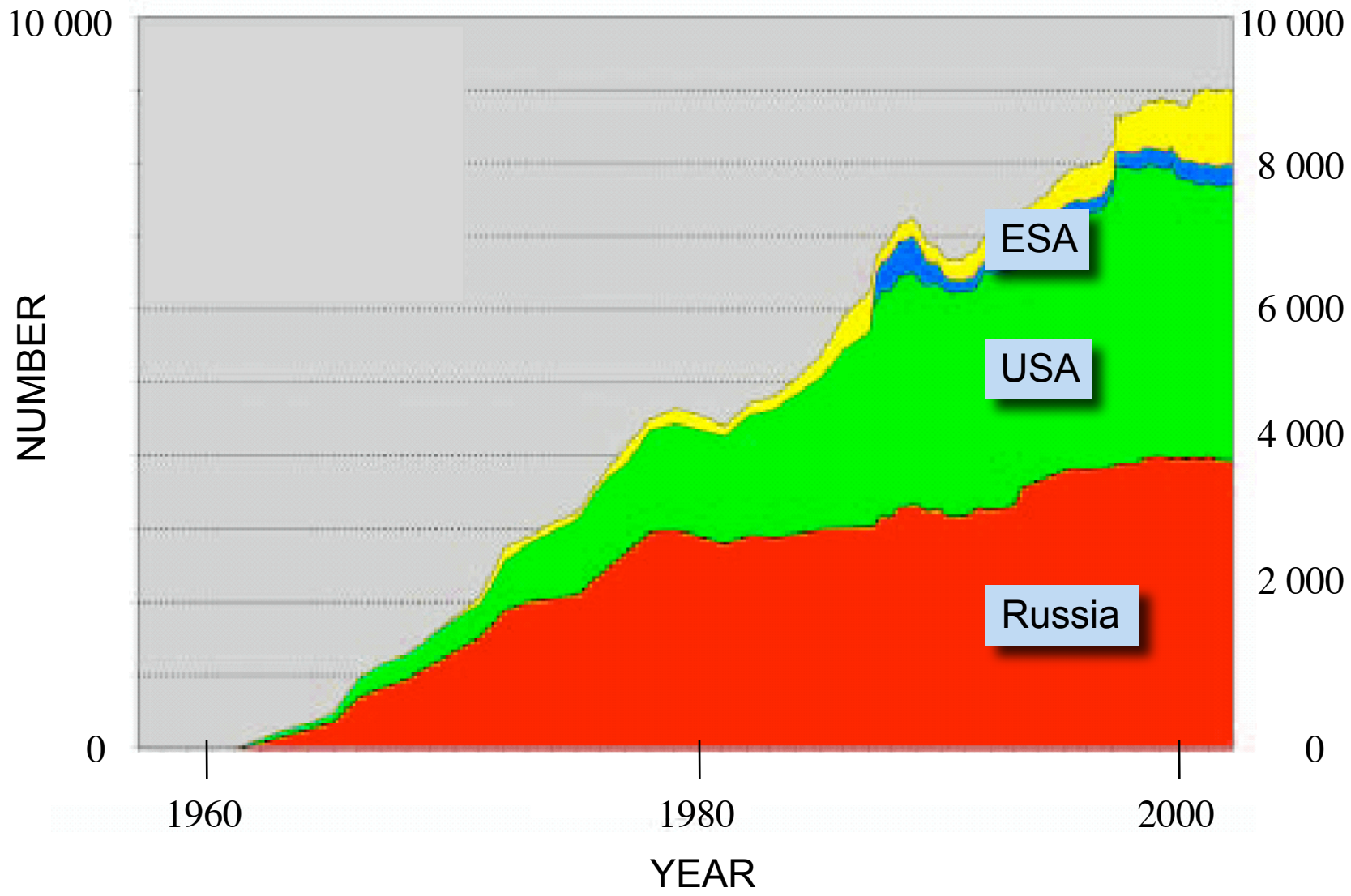


How long is long enough ?

A MODEL CALCULATION

Satellite breakup at 1000 km producing 300 catalogue-size fragments

Number density (km^{-3})

10^{-8}

10^{-9}

10^{-10}

10^{-11}

Initial distribution

400 years later

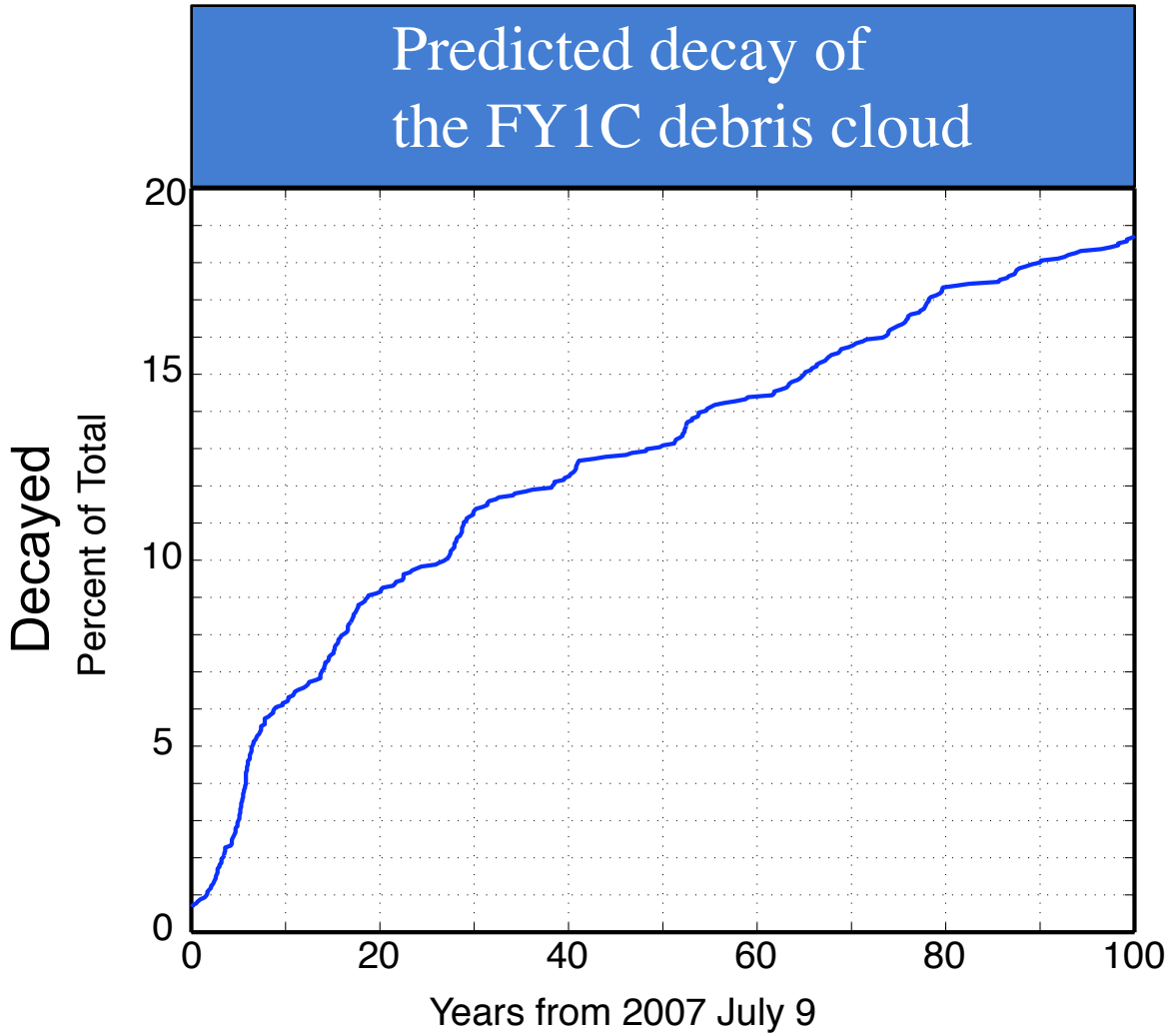
800 years later

0 500 1000 1500 2000

Altitude (km)

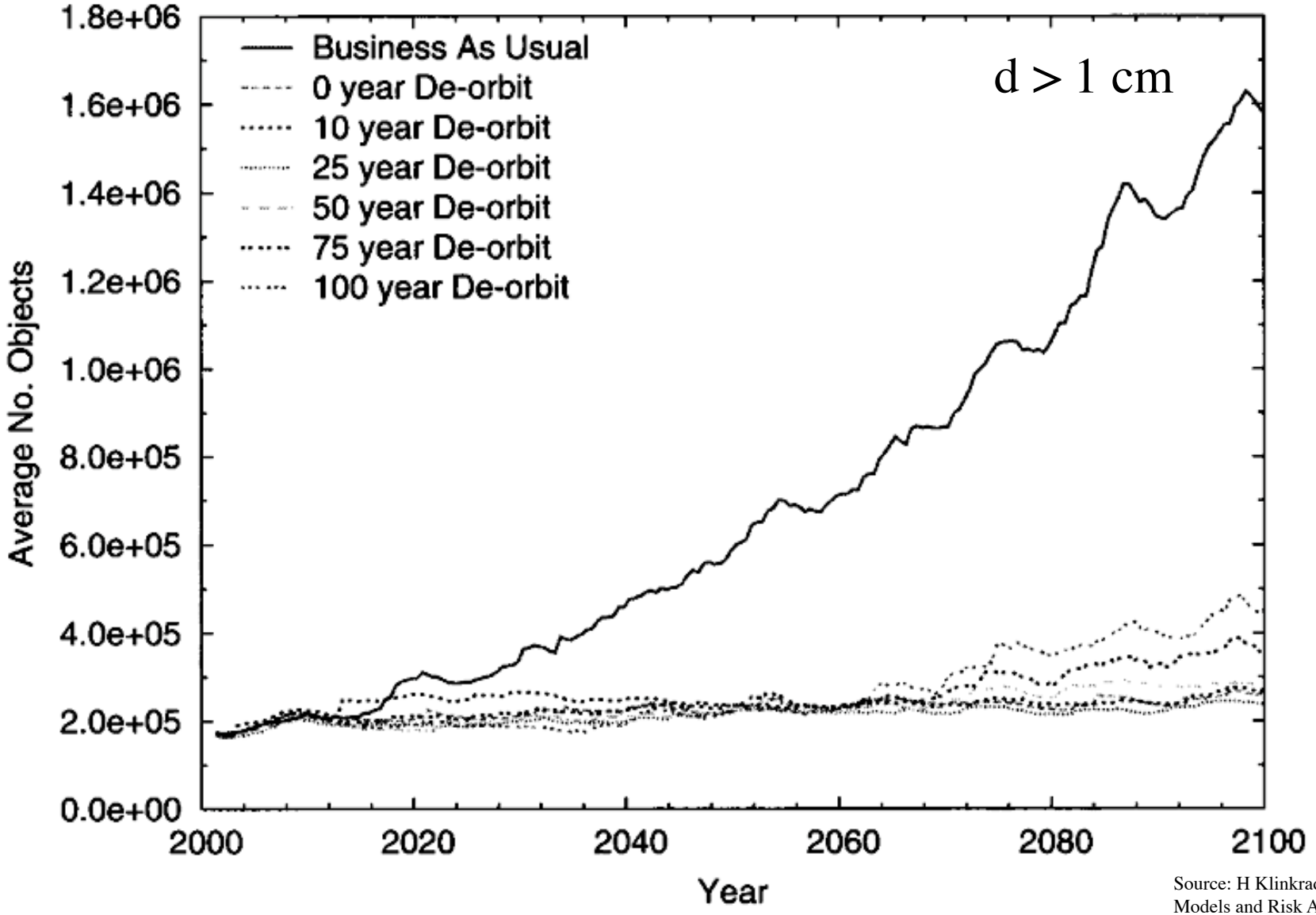
Kassler, 1991

How long is long enough ?



Source: CelesTrak/CSSI (http://celestrak.com/events/FY1C-Lifetime.pdf)

Predicted time development



Source: H Klinkrad, Space Debris, Models and Risk Analysis, p181.